HF Radio Amplifier with Lowpass/Bandpass Filter

ECE 499

August 1st, 2025

University of Victoria

- *Introducing:*

Squawker Talker

1.8 – 30 MHz

HF Radio Amplifier

Version 1.0



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Executive Summary

In recent BC history, forest fires within have ravaged rural communities. During these natural disasters, communication blackouts occur due to failure in the power grid and cellular networks. HF radio offers the potential for decentralized emergency communications, but affordable HF radios are low power, thereby limiting adoption. This project was conducted to create a portable HF amplifier designed to pair with low power, affordable transceivers to facilitate long range emergency communications.

To initiate this project, several current market amplifier offerings were analyzed, looking at the strengths and weaknesses of each to determine gaps in the market. After referencing these competitive offerings, the feature set of the amplifier was specified. The amplifier would need to offer high gain, run on 13.6 V power, have cooling features, in addition to being lightweight and affordable. The amplifier would have a manual bypass switch and mode select between AM and SSB. A 1.8 – 30 MHz bandpass filter was specified to be placed at the input of the amplifier, in order to filter out band noise prior to amplification. A 30 MHz lowpass filter was placed at the output of the amplifier, to remove any unwanted harmonics.

To design this amplifier, an in-depth literature review was completed, obtaining critical knowledge on amplifier circuits and filter layouts. From this research, the Motorola EB63 linear amplifier was selected as the base circuit of choice for the amplifier, offering a high gain output of 140 W-150 W. This circuit was modified to include mode selection and manual bypass features, as well as replacing obsolete components with modern alternatives. A pi-network constant k bandpass 1.8 – 30 MHz band pass filter was designed and simulated in LTSpice, along with a 30 MHz 9^{th} order T based Chebyshev filter. Other circuits, including a voltage regulator, mode select, and fuse circuit were also designed, with PCB schematics for all of the above circuits being created. Components were ordered, and a suitable enclosure using an extruded aluminum heatsink and laser cut/3D printed components were designed and produced.

The amplifier was assembled, first winding the LPF inductors using a custom tool, before soldering PCBs, assembling the filters, tapping the heatsink, and assembling the complete prototype. Each component of the prototype was fully tested, with the frequency response of the forward voltage gain for the BPF and LPF being measured, and observed, with filter layout being adjusted to achieve optimal performance, with minimum passband ripple and strong attenuation outside of the passband. The amplifier circuit's gain was tested, noted to be linear in nature, with only minor fluctuations due to transceiver related power output inconsistency. The specifications of the amplifier were almost all met or exceeded, with only the unit cost being above the specified $600.00 limit, and the amplifier volume being larger than the initial volume goal. The amplifier was field tested, demonstrating the potential for HF to be used as a portable, rapidly deployable emergency communication system.

In conclusion, Group 4 successfully designed a high gain, portable amplifier with input and output filtration for use in emergency communication. To complete this report, future development recommendations were included, from suggesting integrating an SWR/power meter, antenna tuner, and conducting additional tests on other HF bands.

I Introduction

Over the past decade, the forest fires in BC have decimated and terrorised rural communities [1]. Frequently, these rural communities face communication blackouts during these natural disasters, when the power grid or cellular/internet access fails [2]. These types of outages severely limit the coordination of first responders, government agencies, and the public, leading to slower rescue response times. This illustrates a clear need for a decentralized, cost effective, long range and reliable communication system that can remain operational in crisis scenarios. This gap in communication is filled by radio services. Traditional emergency radio communications operate in the very high or ultra high frequency (VHF & UHF) bands [3]. These bands have a very short range, which typically vary from common commercial handheld portable radios between 6.5-10km on flat ground, with the range decreasing based on the terrain of the area [4]. More powerful vehicle mounted radios are still distance limited, to a range of only 20km-30km depending on the terrain [4]. These radios rely on repeater networks to accept and retransmit their signals to extend their range [5]. While repeater networks have previously been used effectively, they are expensive to set up, requiring land, and a tower in addition to other expensive radio equipment [5]. Additionally, like cell networks, repeater infrastructure is also prone to damage during natural disasters, as well as general vandalism that can render the equipment inoperable when needed [6]. This makes VHF/UHF communication also impractical for emergency communications in BC's interior, as vast distances between communities will prevent these radios from being able to transmit to one another without repeaters, which are expensive to implement, and prone to damage. However, high frequency (HF) offers far better propagation characteristics than VHF/UHF radios. HF radio groundwaves can transmit 100km over land, and 300km over sea [7]. Furthermore, using HF skywaves refracting the radio waves off the ionosphere can increase an HF radio's range even further [7]. Additionally, unlike commercial networks, HF radio infrastructure can be powered by solar energy, deployed rapidly, and operated without dependence on ISPs or cellular towers [8].

However, HF radio has yet to be practically adopted by government agencies for natural disaster relief, despite being used to great effect by amateur radio operators in the disaster relief of events such as Hurricane Katrina, the Tōhoku earthquake and tsunami and the recent North Carolina Hurricane in the Fall of 2024 [9, 10]. This lack of adoption is in large part due to the cost of HF radios. High power HF radios are very expensive, starting at over $1500.00 CAD for quality entry level models [11]. This cost has made mass adoption of HF equipment cost prohibitive. Additionally, HF radios are often quite bulky, making portability a concern for rapid communication deployment [11]. However, affordable, reasonable quality low power HF radios from China have started to become readily available in recent years [12, 13]. These compact radios offer HF propagation and high portability, with a far more affordable price (less than $800.00 CAD). However, these radios have low power output, meaning that to achieve their maximum distance, they require a compact, external portable HF amplifier.

Therefore, for Group 4's ECE 499 project, the team members will design a high-power, compact, portable, linear HF amplifier that can be paired with these affordable HF radios.

By conducting a current market analysis, the required features and relevant specifications of the amplifier will be determined. Extensive research will be conducted to learn how to successfully implement the required features' specifications. A design will be created, and components will be sourced and assembled. Once the prototype is completed, extensive testing will be conducted. Testing will focus on testing the amplifier in a portable communication role, as well as testing the range of the HF radio when using the amplifier. It should be noted that the scope of this project is limited to the development of a portable HF amplifier, with an intended use in disaster communication relief efforts. There will be no attempt to develop a portable radio, or any other piece of HF radio equipment. Group 4's development will solely focus on producing an HF amplifier.
The main goals of this project are:

- Design and deliver a functional HF amplifier system that operates between 1.8-30 MHz.
- Develop theoretical hands-on experience in RF design, circuit simulation and PCB board design, component sourcing, and prototype construction.
- Observe the effectiveness of the amplifier in increasing signal range, and by extension, analyze the feasibility of the HF radio communication for disaster relief efforts.

This project has been selected because it gives the team members the opportunity to solve a real-world problem using a practical engineering design. As future electrical engineers and amateur radio enthusiasts, the team understands that there is a growing importance of developing reliable radio communication systems, given the high volume of natural disasters in the past decade that have been caused by extreme weather events [1, 2]. The need to have a low-cost, independent communication network in rural areas is not just technically rewarding but ethically and socially relevant. By making this amplifier modular, affordable, and easy to deploy, this project has the possibility to help end users such as local fire halls, medical clinics, and community groups maintain critical contact when commercial systems fail. In addition, licenced amateur radio operators can also utilize this system to provide critical backup communication within their communities during outages. This solution is also valuable to disaster relief organizations that are working in remote, forested, and isolated environments where cellular and internet services are unreliable/unavailable. This project is also essential for educational purposes, by offering schools a practical platform for teaching youth how to properly operate HF radio equipment during emergency situations.

The anticipated user base for the portable amplifier prototype during this project includes emergency responders in rural areas, local fire halls, search-and-rescue teams, off-grid medical units, and the amateur radio community. From Group 4's preliminary research, it was determined that these users require portable, resilient communication systems that function when traditional infrastructure collapses.

II Objectives

The project objectives set out by Group 4 to be completed through the development and construction of a portable HF amplifier are listed below:

- To design and evaluate a high-frequency (HF) radio amplifier operating from 1.8–30 MHz, with integrated lowpass and bandpass filters for harmonic suppression and signal clarity.
- To prototype, test and verify a functional, portable linear amplifier with cooling considerations and built-in filtration.
- To analyze and demonstrate the feasibility of HF communication infrastructure as a low-cost emergency communication solution for rural and disaster-affected regions.

III Design Specifications

To define the specifications for this project, the amplifier and three specified features were split up into four categories, the overall amplifier and its three critical subsystems, including the amplifier circuit, bandpass filter and lowpass filter. The design specifications for the amplifier and its critical subsystems are listed below:

Amplifier
- Compact, must be smaller than 3000 cm^3.
- Portable, less than 3 kg.
- Sufficient cooling, utilizing heatsinks and fans.
- Use standard SO239 jacks for amp input/output.
- Affordable, must cost less than $600 to construct.
- Must have fuse protection.

Amplifier Circuit Specifications
- High gain, 5 W input amplified to 80 W–150 W output.
- Runs on 13.6 V power.
- Linear operation.
- User-selectable AM/SSB modes.
- Manual bypass switch.

Bandpass Filter Specifications
- Passband: 1.8–30 MHz (HF Spectrum).
- Rated to 10 W.

Lowpass Filter Specifications
- Cutoff everything above 30 MHz.
- Rated to 150 W.

For the overall amplifier, the design was specified to have a volume smaller than 3000 cm^3 and a mass less than 3 kg, enabling the amplifier to be as portable as possible. SO239 coaxial cable jacks were specified to be the connectors for the amplifier's RF input and output. The SO239 is the most common coaxial cable connector used in HF radio stations. Additionally, the amplifier was set have inline fuse protection for the amplifier circuit, the cooling circuit and the SWR/power meter circuit, increasing the safety factor of the overall amplifier. Automotive fuses were selected as the fuse of choice for this system, as they are

available in a wide array of sizes. Additionally, they are commonly available in automotive stores, making finding replacements during emergency situations far easier than other fuse options. To provide sufficient cooling, the amp was specified to employ a combination of a heatsink and fans. More specifically, the amplifier PCB was directly mounted to the heatsink, to enable maximum heat transfer. A 120mm cooling fan would be bolted to the heatsink as well, forcing air through the heatsink's fins, thereby improving thermal transfer. Two 40mm fans would also be utilized to cool the amplifier, with one fan pulling cool air into the enclosure, and the other fan pushing warm air out of it. Note that since the amplifier was run on 13.6 V power and the cooling fans run on 12 V power, a voltage regulator circuit to step the 13.6 V down to 12 V was required. This was achieved by designing a LM317 based voltage regulator circuit that steps down from 13.6, utilizing the formula below to determine the component values to provide the desired output voltage [52].

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right)$$

Where:
V_{ref} = 1.25V
R_1 = 390Ω
R_2 = 3.3k Ω
V_{out} = approx. 12V

Note that the full calculation for this voltage regulator can be viewed in section VI of the report.

For the amplifier circuit, the amplifier was specified to require high gain, provided an output power of 80 W – 150 W output on a 5 W RF input. Additionally, linear operation was specified, running on 13.6 V, the standard voltage utilized in HF radio equipment. These specifications were completed by utilizing a modified EB63 amplifier circuit. The EB63 amplifier is a compact amplifier circuit, which utilises two MRF454 transistors to achieve its gain. Each of the MRF454 transistors was specified for the following [26]:

- Frequency Range: 1.8 – 30 MHz
- Voltage: 12.5 V to 13.6 V
- Output Power (Single Transistor): ~80 W @ 30 MHz
- Efficiency: ~50% @ 30 MHz

The developed amplifier circuit was configured for Class AB linear amplification, specified to deliver up to 140 W-150 W safely. This amplifier utilized an RF carrier operated relay (COR) circuit, employing a tuned capacitor to delay the switching of the relay on SSB mode. To allow for mode selection between AM and SSB, a single pull double throw (SPDT) was specified to allow the operator to select the desired operation mode by switching between the 10µF AM delay capacitor, and a 100 µF delay capacitor. For SSB mode, Group 4 members specified the use of a 100 µF delay capacitor to keep the relay open during modulation, preventing the relay from chattering [25,27]. A manual bypass switch was also specified, allowing the user to turn the amplification of the system "on" or "off" for testing, antenna tuning or for power saving purposes. The specifics of the amplifier circuit are discussed in detail within Section IV of this report.

The filter on the input of the amplifier was specified to be a 1.8 – 30 MHz bandpass filter. This filter was intended to attenuate any out of band noise from entering the amplifier when the radio is transmitting, or from entering the radio when it is receiving. The filter developed to meet this specification was a 2-stage pi-configuration constant-k LC bandpass filter [37, 8]. It is designed with cutoff frequencies of 1.5 MHz (low) and 31 MHz (high), to account for potential error in real-world components shifting the cutoff frequency into the passband. This feature was intended to prevent the noise from low quality HF transceivers from being amplified or remove out of band interference from impacting signal reception. The design for this filter was specified to have a 50 Ω characteristic impedance, matching the standard characteristic impedance of HF radio equipment. The filter is also specified to handle up to 10 W of RF power. This filter was designed using the following formulas to obtain the values for the inductors and capacitors [37, 38].

Highpass Formula:

$$L = \frac{Z_0}{4\pi f_c}$$

$$C = \frac{1}{4\pi f_c Z_0}$$

Where:

fc = 1.5 MHz
Z_o = 50 Ω

Lowpass Formula:

$$L = \frac{Z_0}{\pi f_c}$$

$$C = \frac{1}{\pi f_c Z_0}$$

Where:

fc = 1.5 MHz
Z_o = 50 Ω

Combining the above highpass and lowpass formula results into a single circuit, a two-stage pi configuration produced the specified bandpass 1.8 – 30 MHz filter. Note that the full calculations and LTSpice simulations for these filters can be viewed in Section VI of this report.

The filter on the output of the amplifier was a 30 MHz lowpass filter, intended to attenuate any higher order harmonics produced by the amplifier. The filter developed to meet this specification was a 9th order T-type Chebyshev lowpass filter [42]. This filter was designed to handle 200 W power handling, with a cutoff frequency of 31 MHz (to account for component variation). This filter was specified to display minimal passband ripple and strong attenuation of 2nd, 3rd, and 5th harmonics (discussed in detail in Section IV and VI

of this report). The inductors for this filter were custom hand-wound 1.8mm air core coils, and the capacitors were specified to all be silver mica, selected for their high voltage rating, low loss and excellent RF performance [54]. The formulas used to determine the component values of this Chebyshev filter are shown below [40].

Inductor Formulas (Series Elements):

$$L_i = \frac{Z_0 \cdot g_i}{2\pi f_c}$$

Capacitor Formulas (Shunt Elements):

$$C_i = \frac{g_i}{2\pi f_c Z_0}$$

$f_c = 31$ MHz
$Z_0 = 50\ \Omega$
g-values: g_1 to g_7 (from a normalized Chebyshev table, see Section VI of this report).

Note that the full calculations for circuit component values, and LTSpice simulations verifying the lowpass filter performance can be viewed in Section VI of this report.

A block diagram of the specified amplifier design can be viewed in Figure 1 below.

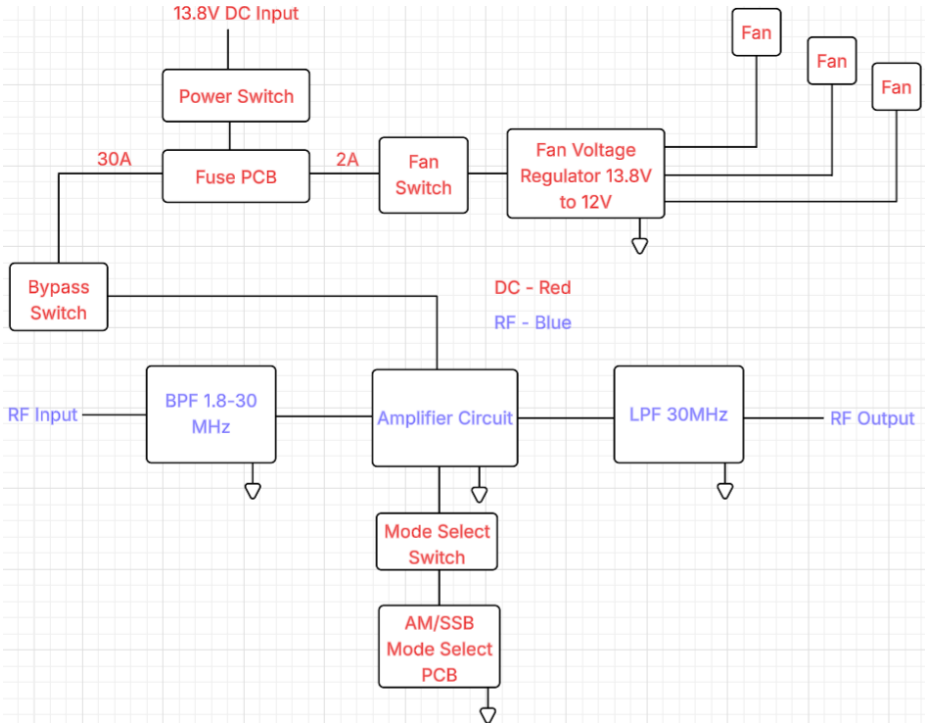


Figure 1: *A block diagram for the complete amplifier design, including all the specified technical features for the amplifier, and the three critical subsystems (amplifier circuit, BPF and LPF).*

These design specifications align with multiple EGBC principles, including:

- **Principle 1 – Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace:**
    - Proper filtering ensures regulatory compliance and avoids interference.
    - Cooling and fuse protection prevent overheating and electrical failure.
- **Principle 3 – Have regard for the common law and any applicable enactments, federal enactments, or enactments of another province:**
    - All design specs (e.g., max output power, frequency range) meet Industry Canada rules for amateur radio operation [18].
- **Principle 12 – Undertake work and documentation with due diligence and in accordance with any guidance developed to standardize professional documentation for the applicable profession:**
    - All component ratings, power limits, and thermal design decisions are justified using simulation, datasheets, and prior art.

IV Literature Survey

To start this project, before any technical literature was reviewed, this project was launched by conducting by a survey of current market offerings. In this survey, three of the most popular commercially available compact, portable amplifier design options were analyzed, looking at their prices, features and specifications. By overviewing alternative current market offerings, this research allowed Group 4 to observe if the market already filled the role that our amplifier intended to, or if there was a gap in the market that justified the development of our amplifier. The three currently available amplifier options surveyed included the following:

1. RM Italy Kl203P
2. Xiegu XPA125B
3. Elecraft KXPA100

The RM Italy Kl203P amplifier was the first amplifier that was surveyed. This unit produces an output of 100 W on a 5 W input, and is very compact (109*125*35mm) [14]. The mass of this unit was recorded as 325g [14]. It is also affordable, costing only $179.99 CAD [14]. However, this amplifier lacked filtration, which requires the user to acquire a lowpass filter to stay within Industry Canada compliance. It has a mode select feature to allow the user to choose between SSB and AM modes [14]. Additionally, the amplifier lacks cooling considerations, with only a small heatsink to dissipate the generated heat, and no fans being provided [14]. No SWR/power meter feature is present on the unit. A picture of the RM Italy kl203P can be viewed in Figure 2 below.



Figure 2: *The RM Italy KL203P Amplifier [1].*

The Xiegu XPA125B amplifier was the second amplifier analyzed. This unit produces an output power of 100 W on a 5 W input, and is compact, with a size of 260*150*100mm [15]. The mass of this unit was recorded as 2.66 kilograms [16]. It is expensive, costing $830.00 CAD [15]. It has a mode select feature to allow the user to pick between SSB and AM modes [15]. There are no cooling features, with no heatsink or cooling fans to dissipate the generated heat [16]. No filtration is present in the unit. There is a SWR/power meter with a digital display present, and also an automatic antenna tuner [16]. A picture of the Xiegu XPA125B can be viewed in Figure 3 below.



Figure 3: *The Xiegu XPA125B Amplifier [15].*

The Elecraft KXP100 was the third amplifier surveyed. This amplifier also produces 100 W on a 5 W input [17]. This unit is very expensive, costing $2272.33 CAD, and is relatively compact, at a size of (254*130.18*107.95 mm) [17]. The mass of this unit was recorded as 3.2 kilograms [17]. This unit offers mode select, a SWP/power meter with an LED display, an antenna tuner and a manual bypass switch [17]. It also offers a large convection-cooled heatsink but has no fans [17]. Filtration is also included with this amplifier. A picture of the Elecraft KXPA100 can be viewed in Figure 4 below.



Figure 4: *The Elecraft KXPA100 Amplifier [17].*

Reviewing these amplifiers, it became apparent that there were some noticeable gaps in the market. While all the amplifiers in the three price categories offered 100 W output power in a compact portable package, only the highly expensive Elecraft KXPA100 amplifier added a notable heatsink to prevent overheating, which is a critical consideration in compact, high wattage circuit designs. It is also the only amplifier to include a manual bypass switch, or filtration. This lack of filtration means that an operator would need to carry a lowpass filter to filter the output of the amplifier, in order to stay within Industry Canada compliance. This is another critical feature, that like the cooling, is missed by the less expensive options. Both the KXPA100 and Xiegu XPA125B have SWR/power meters, which is a useful feature that the more affordable RM Italy KL203P lacks. The KL203P amp also lacks an automatic tuner, a feature offered by the other two options. Therefore, it became clear that there is a gap in the market for an affordable, compact high power HF amplifier that includes a critical filtration feature, as well as cooling consideration. With this in mind, it was determined that developing such an amplifier is indeed justified, as it will fill a midrange roll, offering critical features lacked by the more affordable amplifier options, while costing far less that the premium Elecraft KPA100 amplifier.

From reviewing these commercially available amplifiers, the ideal features for our HF radio amplifier were split into four categories, including the following:

1. Amplifier circuit.
2. Lowpass filter circuit.
3. Bandpass filter circuit.
4. Standing Wave Ratio (SWR) and Power Meter circuit.

The first three features were viewed as critical features of the design that must be included in the final prototype. Of course, to build an amplifier, the amplifier circuit is the most critical component, so it could not be omitted. However, the filters were viewed to be just as critical, for two specific reasons. The first reason involves harmonics. Amplifier circuits for HF frequency very commonly produce higher order harmonics, sending unwanted signals into frequencies that are not permitted to be broadcast in [18]. Therefore, placing a lowpass filter at the output of the amplifier is critical to filter out these harmonics, keeping the amplifier within the spectral purity expectations and regulations set out by Industry Canada [18]. The second issue is noise. If a low-quality radio is connected to the amplifier and transmits out of band noise into the amplifier, the amp will also amplify the noise, distorting the desired message signal. Therefore, a bandpass filter mut be placed at the input of the amplifier, to attenuate any unwanted out of band noise prior to amplification [19].

The SWR and power meter feature was viewed as a stretch goal, and not a critical feature. Having a SWR and power meter implemented into our amplifier after the output of the amplifier and the lowpass filter circuits would be very useful, as it would display the amplifiers exact amplification and SWR, is assisting in the tuning of both the radio's input signal power, and the impedance matching between the radio transmitter and its antenna [20]. However, while this feature would be useful, lacking it would not impede the function of the amplifier, so therefore this feature was determined to be a stretch goal that would only be implemented once the other features were designed and tested. Note that an automatic antenna tuner was not considered as an additional feature for Group 4's amplifier (even though it was present in 2/3 market offerings), as this is a complex circuit that would

be tricky to implement, in addition to raising the overall project's cost. The benefit is also dubious, as an antenna tuner is not needed as long as the antenna used has been tuned to be resonant on the band being operated, which is usually the case (especially when used by professionals for the purpose of emergency radio communication operations) [21].

After setting out the feature categories for our amplifier, the required specifications for each feature subset, as well as the overall amplifier were determined. The required specifications of the overall amplifier design, and its four specific feature categories are highlighted in Figure 5 below.

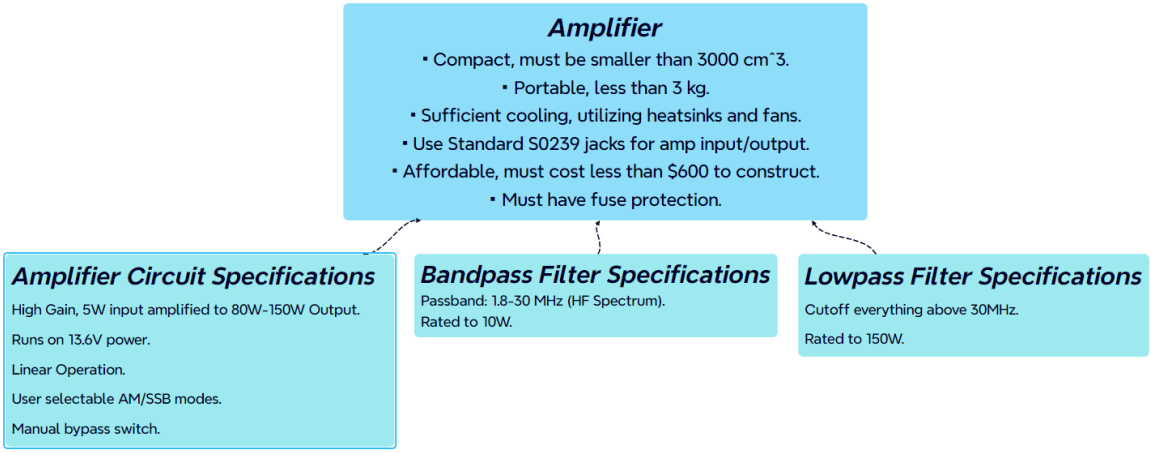


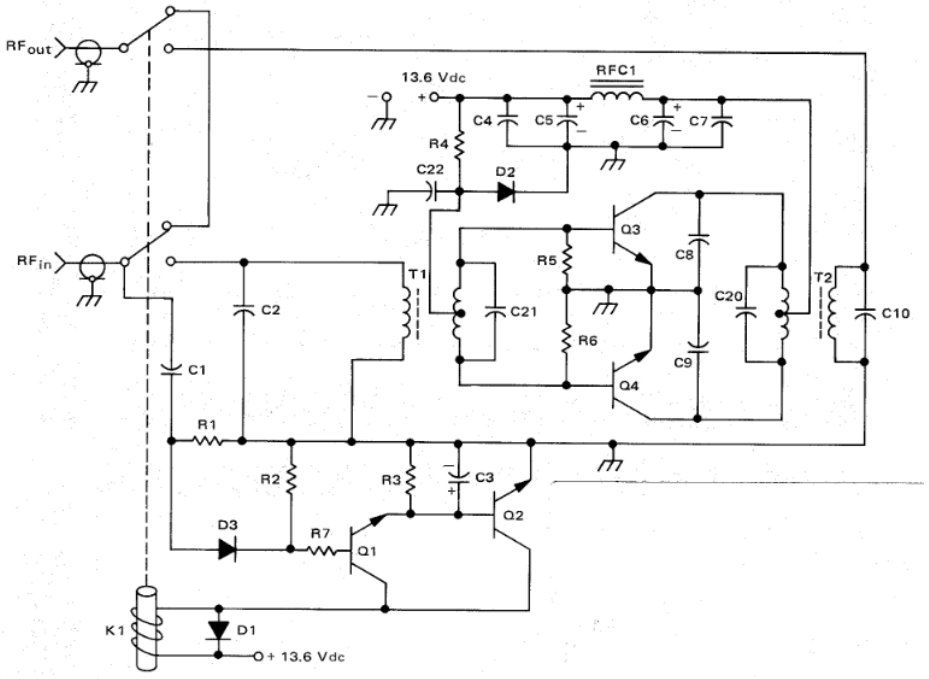
Figure 5: *A breakdown of the specification of the amplifier, and its 3 critical feature categories including the amplifier circuit, the bandpass filter and the lowpass filter.*

When reviewing the available literature to find an amplifier circuit design to base our radio amplifier design on, there was one initial decision that had to be made. This decision was whether to use vacuum tubes or transistors to achieve the desired HF signal amplification. Both components were found to offer unique advantages. Vacuum tubes were noted to be more durable, handle antenna mismatches better, and offer more watts per dollar than transistors [22]. However, they were noted to be large, far larger than equivalent gain transistors. Additionally, vacuum tubes were also difficult to source, with the most common examples used in current radio amplifier design being surplus components from old Soviet radio hardware [23]. On the other hand, transistors were found to be readily available and size efficient, power efficient with modern switching PSUs, while offering excellent linearity in a properly designed amplifier circuit [24]. These factors, combined with our group members' experience with transistor circuits (and lack of experience with vacuum tubes), led to our group selecting transistor-based amplifiers as the starting point for the design of this project.

It should be noted that for this project, Group 4 decided it was best to find a currently available design, and iterate upon it to complete this project, rather than design a new RF amplifier from scratch. This was decided upon for two primary reasons. The first reason was simply that the time allotted in ECE 499 is quite short, so development and testing time needed to be maximized. By starting with a tested core, it could allow for our group members to focus on designing and implementing other features, as well as testing the prototype to ensure a working product on demonstration day. Producing an amplifier with the comprehensive feature set listed in Figure 5 was determined to be the primary

focus of this project, instead of focusing on ensuring the amplification circuit was a completely original design. The second reason was safety. HF amplifiers draw a large amount of current, with our amplifier being set to draw an estimated 20 amps, which can be quite dangerous. Given all members' inexperience with both high power RF amplifiers, and high current DC circuits in general, starting with a tested base would help improve the safety factor of the project, limiting any potentially harmful mistakes made during the design process.

With that in mind, an investigation into various amplifier designs was conducted. After reviewing several amplifier circuit designs used in amateur HF radio construction, the Motorola EB63 linear amplifier was selected to be the core circuit of our radio design. The EB63 is a widely cited and compact RF amplifier circuit which is capable of delivering ~140 watts (PEP) of output power in the HF spectrum from 1.8 – 30 MHz [25]. The EB63 is a relatively simple design that can produce a high gain, which made it a very popular choice among amateur radio enthusiasts for home-built amplifier circuits in the 1990s [25, 28]. The original circuit diagram for the EB63 is displayed below in Figure 6.



C1	=	33 pF Dipped Mica	R7	=	100 Ω 1/4 W Resistor
C2	=	18 pF Dipped Mica	RFC1	=	9 Ferroxcube Beads on #18 AWG Wire
C3	=	10 μF 35 Vdc for AM operation, 100 μF 35 Vdc for SSB operation.	D1	=	1N4001
			D2	=	1N4997
C4	=	.1 μF Erie	D3	=	1N914
C5	=	10 μF 35 Vdc Electrolytic	Q1, Q2	=	2N4401
C6	=	1 μF Tantalum	Q3, 4	=	MRF454
C7	=	.001 μF Erie Disc	T1, T2	=	16:1 Transformers
C8, 9	=	330 pF Dipped Mica	C20	=	910 pF Dipped Mica
R1	=	100 kΩ 1/4 W Resistor	C21	=	1100 pF Dipped Mica
R2, 3	=	10 kΩ 1/4 W Resistor	C10	=	24 pF Dipped Mica
R4	=	33 Ω 5 W Wire Wound Resistor	C22	=	500 μF 3 Vdc Electrolytic
R5, 6	=	10 Ω 1/2 W Resistor	K1	=	Potter & Brumfield KT11A 12 Vdc Relay or Equivalent

Figure 6: *The original EB63 amplifier circuit diagram published by Motorola [25].*

As can be viewed in Figure 6, the circuit of this amplifier is relatively compact. In this circuit, the amplifier uses two MRF454 transistors in class AB push-pull amplifier configuration [25]. These HF specific NPN transistors are specified to produce an 80-watt power output with a 5-watt input drive at 30MHz, 12.5 VDC [26]. Additionally, at this frequency and voltage, the transistor's efficiency is 50% [26]. A graph of the input vs output power of an individual MRF 454 transistor can be viewed in Figure 7 below, and the input vs output power of the EB63 amplifier circuit can be viewed in Figure 8 below.

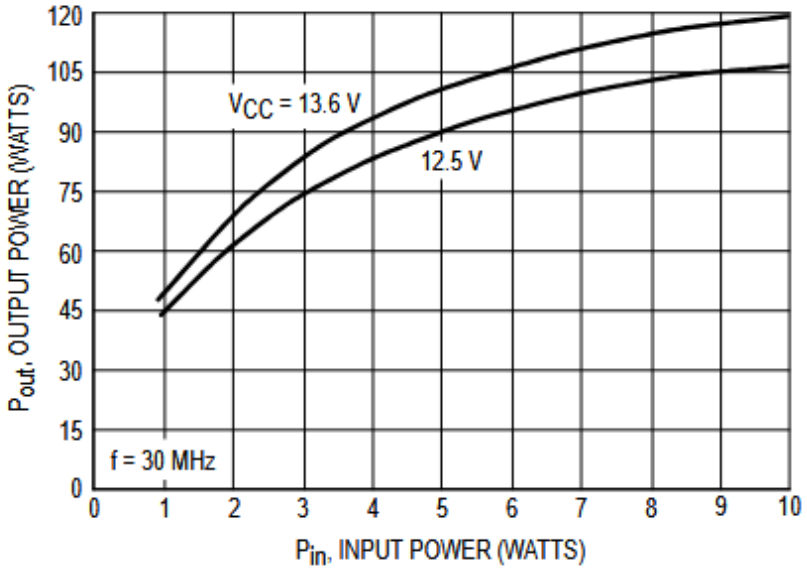


Figure 7: *The input vs output power of a single MRF454 transistor, with values recorded at a voltage of both 12.5VDC and 13.6VDC, frequency of 30 MHz [26].*

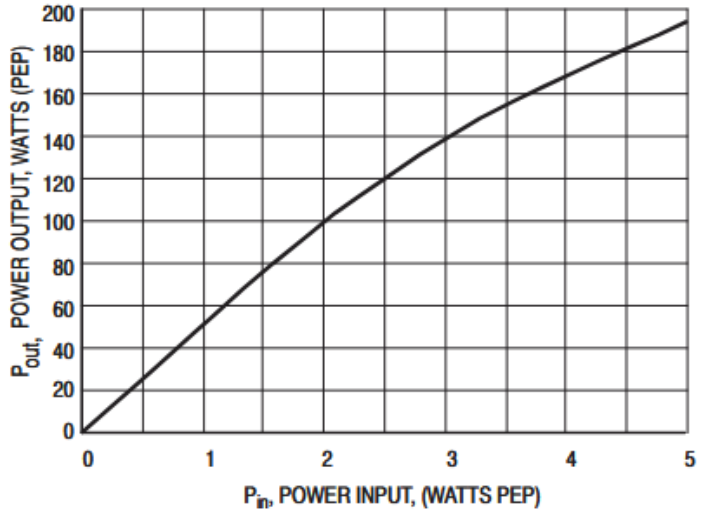
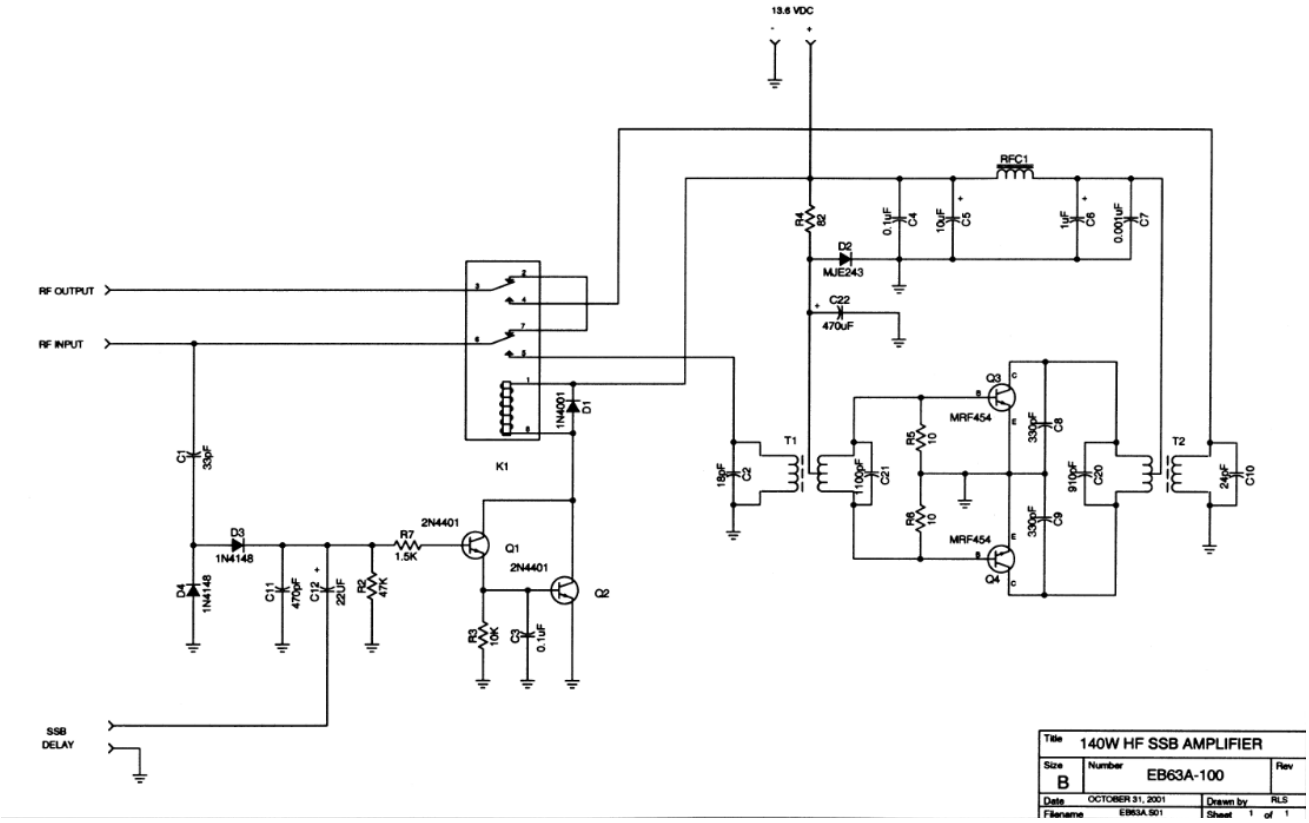


Figure 8: *The input vs output power of a single EB63 amplifier circuit, with values recorded at a voltage of 13.6VDC, frequency of 30 MHz. Note the high gain offered by this circuit [25].*

This amplifier will accept an AM or SSB signal, with the SSB delay being tuned by changing capacitor values [25]. However, it should be noted that no mode switching is offered, meaning that when the amplifier is assembled it is either tuned for AM or SSB use. SSB delay is critical on amplifiers such as the EB63 that have a carrier operated relay (COR) circuit [28]. The COR circuit employs an RF signal triggered transmit and receive relay (K1) to allow the amplifier to stay in transmit mode between spoken syllables during an SSB transmission [27]. With an AM signal, the carrier wave provides a signal to switch the amp to transmit [27]. Because an SSB signal has no carrier wave, without tuning to increase the SSB delay, the amp would turn on and off between transmit and receive when talking on SSB resulting in audible chatter [27]. A tuned SSB delay will hold the transmit relay on for a sufficient amount of time to remain in transmit mode [27]. Therefore, a capacitor value for C3 of 10μF is required for use with AM signals, whereas a capacitor value of 100μF is needed for SSB, to allow for a proper amount of SSB delay [25].

Due to the age of the EB63, there are two components which are used in this amplifier that have become obsolete, which made the design fall out of favour after the turn of the century [28, 29]. These obsolete components include the KT11A 12V relay (K1) and the 1N4997 high voltage diode (D2), both of which are no longer in production, and are not readily available to purchase new in today's market [29].

While researching the obsolete components for the EB63 amplifier, an updated version of the amplifier, referred to as the EB63A amplifier was discovered. This amplifier offered a modernized version of the original EB63, replacing the obsolete KT11A relay with a modern Omron G2RL-24-DC12 relay, and the obsolete 1N4997 diode with an MJE243 NPN transistor operated in diode mode [30, 31]. Both these new components were reported to serve as effective alternatives to the original, obsolete components. Additionally, the EB63A's carrier operated relay (COR) circuit was updated, as the original design by Motorola was reported to perform poorly [28, 29]. It should be noted that the gain of both the amplifiers has been reported to be the same, since no changes to the configuration of the MRF454 transistor was made in the updated circuit. It should also be noted that the capacitor used to tune the delay has been changed to C12, as opposed to C3 in the original EB63 circuit [25, 29]. The updated EB63A design circuit diagram can be viewed in Figure 9 below.



EB63A PARTS LIST

C1	33 pF Dipped Mica	R1	Not Used
C2	18 pF Dipped Mica	R2	47K ohm ¼ W Resistor
C3	0.1 uF Ceramic Mono	R3	10K ohm ¼ W Resistor
C4	0.1 uF Ceramic Mono	R4	82 ohm 5 W Resistor
C5	10 uF 35 Vdc Electrolytic	R5, 6	10 ohm ½ W Resistor
C6	1 uF 35 Vdc Tantalum	R7	1.5K ¼ W Resistor
C7	0.001 uF Erie Disc Ceramic	RFC1	10 Ferroxcube Beads on #18 AWG Wire
C8, 9	330 pF Dipped Mica	D1	1N4001
C10	24 pF Dipped Mica	D2	MFJ243 Transistor
C11	470 pF Ceramic Disc	D3, 4	1N4148
C12	22 uF 25 Vdc Electrolytic	Q1, 2	2N4401
C20	910 pF Dipped Mica	Q3, 4	MRF454
C21	1100 pF dipped Mica	T1	16:1 RF400 Transformer
C22	470 uF 10 Vdc Electrolytic	T2	16:1 RF1000 Transformer
		K1	Omron G2RL-24-DC12 8 Amp

Figure 9: *The updated EB63A amplifier circuit diagram, which iterated on the original Motorola design by replacing obsolete components and improving the COR circuit [29].*

Taking everything mentioned above into consideration, Group 4's team selected the EB63A as the base circuit for the amplifier design because of the following features:

- Proven power output capability in the 2-30 MHz range [25].
- Relatively simple circuit topology, which is easier to prototype and debug.

- Compatibility with both AM and SSB, which is essential for flexible amateur operation [25].
- Support from the amateur radio community, including documentation and performance data [28, 29, 32].

It must be mentioned that other amplifier circuit designs were considered and reviewed before selecting the EB63A. The primary alternative circuit of interest that was analyzed was the AN762 [33]. This circuit was another Motorola design, the AN762 circuit was similar to the EB63A in that it used a pair of MRF454 transistors in push pull-configuration, but it lacked several features of the EB63A. Specifically, it lacked an RF signal carrier operated relay circuit. The lack of a COR circuit would in theory make SSB tricky to employ, as it is this relay that allows most radio amps to stay in transmit mode between spoken syllables during an SSB transmission [27]. Further investigation yielded no results as to how this unit could be tuned to have a proper SSB delay, and therefore, given the importance of having a reliable SSB mode to the core design of the amplifier, the EB63A amplifier design was selected over the AN762. Another notable alternative circuit was the EB27A. This circuit was interesting, as while it had the same compact size of the EB63, it had a maximum rated power output of 300 W [34]. This circuit was similar in design to the EB63 amplifier, but used a higher wattage transistor, the MRF422 [35]. However, the input power used to drive this amplifier was rated at 18-20 W, which is higher than many of the affordable HF radios available on the market. Therefore, this design was eliminated, as while the extra power would be beneficial, it was higher than what our specification required, and sacrificing the amplifier's versatility to work on fewer radios was viewed as not a worthy trade off. Furthermore, given Group 4's limited high-power electronics experience, a 300 W amplifier was viewed as too much for team members to handle at this time, and such an amplifier could be investigated in the future after gaining more hands-on experience with smaller RF amplifiers like the EB63A.

The EB63 and EB63A amplifiers are not perfect designs, and there are flaws that must be remedied by Group 4. The first flaw is the lack of mode switching. These designs require a capacitor value for either AM or SSB mode to be selected. Therefore, to enable mode section, the amp circuit will be modified to include a manual switch to switch between capacitance values, allowing for the selection of a specific mode. Additionally, no manual bypass functionality is offered by these circuits. A manual bypass switch allows a signal to pass through without amplification during testing, or when operating in low-noise environments where the extra power is not required. Therefore, the circuit will be modified to include a bypass switch. Additionally, the EB63 offers no fuse protection. Given the high current draw of this amplifier, adding a safety fuse is critical to prevent damage of components in case of current overdraw, and potentially preventing a failure that could harm the operator. However, the most significant issue with the EB63A amplifier is harmonics. As mentioned earlier, higher order harmonics are often an issue in HF amplifiers, and the EB63A is no exception. This can be viewed in Figure 10 below, where the harmonics of the EB63A can be observed with the amplifier operating at 30 MHz.

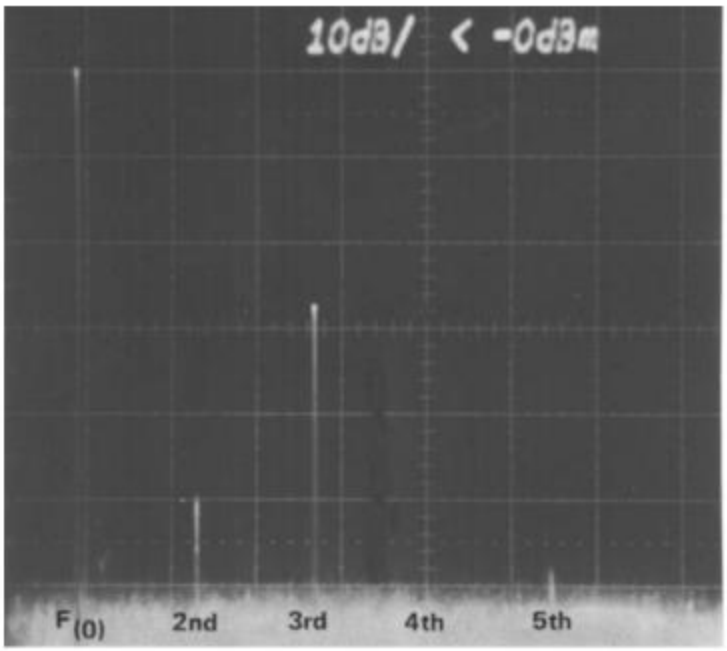


Figure 10: *The EB63 amplifier frequency spectrum, with $F_{(0)}$ = 30 MHz, with the 2nd, 3rd, and 5th harmonics are visible. Note that vertical resolution is 10 dB/div and the horizontal resolution is 20 MHz/div. [25].*

In this diagram, it should be noted that higher order harmonics, specifically the 2nd, 3rd, and 5th harmonics are present. These harmonics can cause interference in other bands. For example, shown below in Figure 11 is a chart showing TV channels (and frequencies) listed, and the amateur radio and general radio service (GRS, also known as CB) frequencies that cause harmonics in these TV channels [18]. Additionally, a diagram of the harmonics of the GRS service and the TV channels that these harmonics interfere with is listed in Figure 12 below [18].

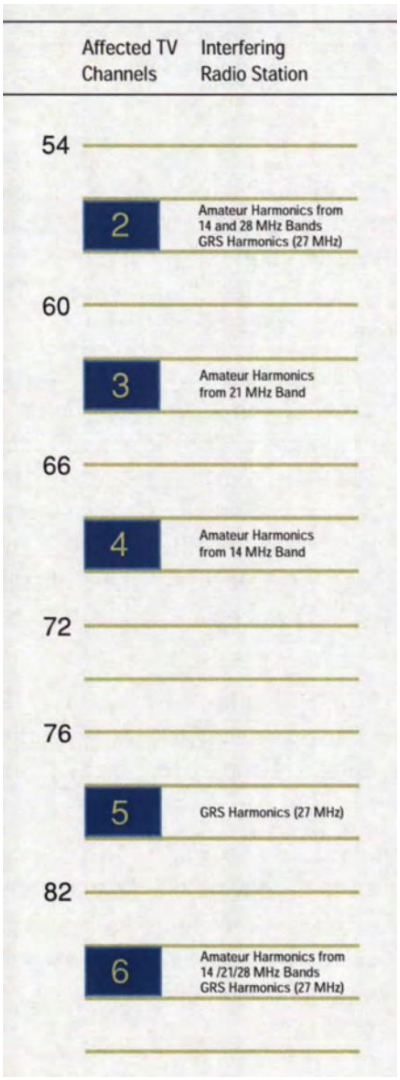


Figure 11: *A listing of TV channels, their relevant frequencies, and the interfering radio station frequencies that produce the harmful harmonics [18].*

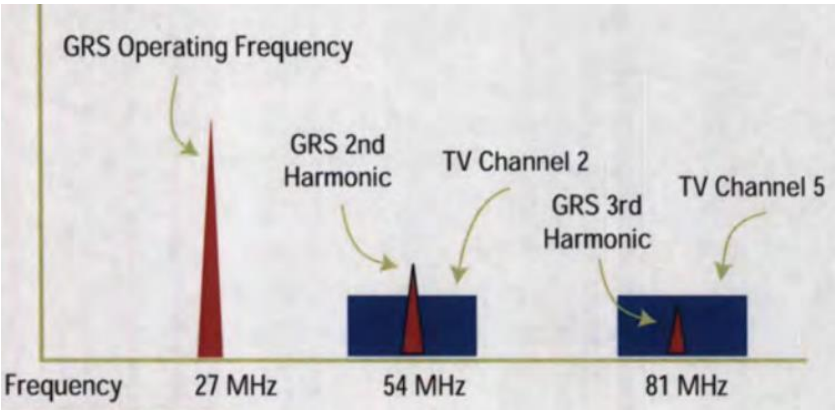


Figure 12: *An example diagram of the harmful harmonics produced by a GRS radio station, and the TV channels with which these harmonics interfere [18].*

Therefore, to account for these harmonic issues that the EB63/EB63A experiences, a lowpass filter with a cutoff frequency around 30 MHz would need to be installed at the output of the amplifier. This filter would serve to attenuate any unwanted harmonics from the amplifier's output, removing the risk of interference. Additionally, a bandpass filter with a passband of 1.8-30 MHz would be installed at the amplifier's input, to attenuate any out of band noise before it could enter the amplifier and distort the signal. There are three primary topologies that could be considered, these being Constant-k LC, Butterworth and Chebyshev. Constant-k filters are basic LC filter circuits that are built with repeating L and C sections, being simple to design, at the expense of a shallow frequency roll off [37, 38]. The frequency response of a constant-k LC filter network can be viewed in Figure 13 below.

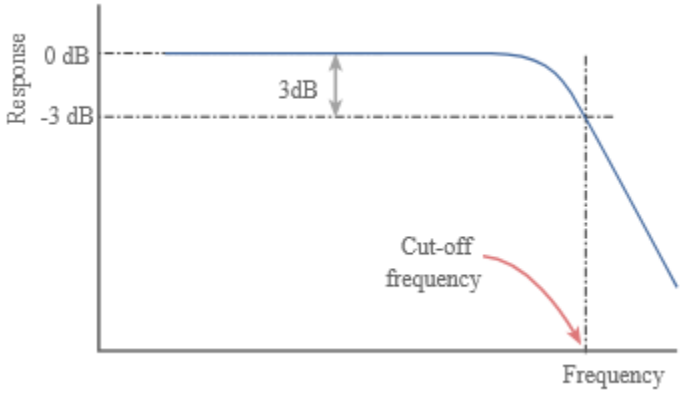


Figure 13: *The frequency response of a generic constant-k LC lowpass filter [36].*

Butterworth filters are characterized as smooth and stable in the passband, but have a slow cutoff, whereas Chebyshev filters have a faster cutoff at the expense of having a ripple in the passband [39]. A graph showing the frequency of both filters is shown in Figure 14 below [40].

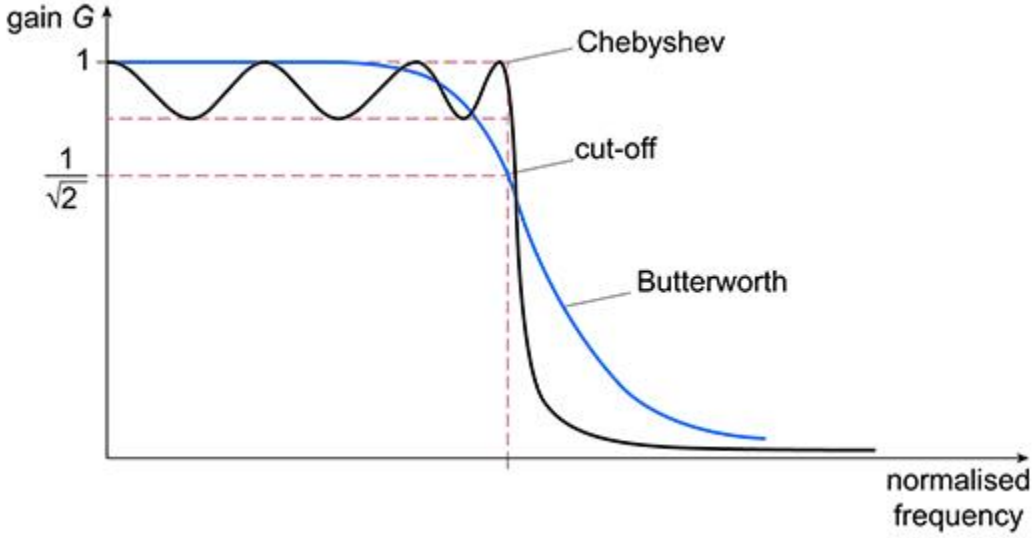


Figure 14: A *comparison of a seventh-order Butterworth and Chebyshev lowpass filter frequency response [40].*

Realistically, any of the listed filter topologies could work for the filter applications of this amplifier. This is because the harmonics and noise are far outside the passbands, so the steeper cutoff offered by the Chebyshev is not critical to the design. Additionally, given the high power of the amplifier, having a slight ripple in the passband would have a negligible impact on the performance of the amplifier, making the smoothness of the Butterworth filter not super critical either. All these filter designs have been used in the production of amateur radio equipment to great success. However, what is critical is component availability. The ability to obtain components that can operate in these filters is crucial. Therefore, developing filter designs with obtainable components was important to developing the filters.

It was decided that the amplifier input 1.8-30 MHz bandpass filter would be designed using simple pi configuration constant-k LC lowpass and highpass filters combined into one circuit. This topology was selected because it is relatively straight forward to calculate (having gained experience with these calculations in ECE 300), offered reliable performance, and could be adjusted to obtain a sharper frequency cutoff by adding more sections. Additionally, the filter is designed to a characteristic impedance of 50 ohms, which allows for excellent matching of the filter circuit to the characteristic impedance of the amateur radio equipment [37, 38]. It should also be noted that the relatively low maximum rated input power to the amplifier of 10 W also allows for a wide variety of filter components to be selected, as compared to the higher wattage lowpass filter on the amplifier output. The constant-k lowpass and highpass filters are calculated using the following equations [37, 38].

Lowpass filter equations –

$$L = \frac{Z_0}{\pi\, fc} \text{Henries}$$

$$C = \frac{1}{Z_o\, \pi\, f_c} \text{Farads}$$

$$fc = \frac{1}{\pi\sqrt{L\, C}}\ Hz$$

Highpass filter equations –

$$L = \frac{Z_0}{4\, \pi\, f_c} \text{ Henries}$$

$$C = \frac{1}{4\, Z_0\, \pi\, f_c} \text{ Farads}$$

$$Fc = \frac{1}{4\, \pi\, \sqrt{L\ C}} \text{ Hertz}$$

Where:

Z_0 = characteristic impedance in ohms
C = Capacitance in Farads
L = Inductance in Henries
f_c = Cutoff frequency in Hertz

Additionally, the topologies of a generic 3-pole pi configuration constant-k highpass, lowpass, and bandpass filters are displayed in Figure 15 below.

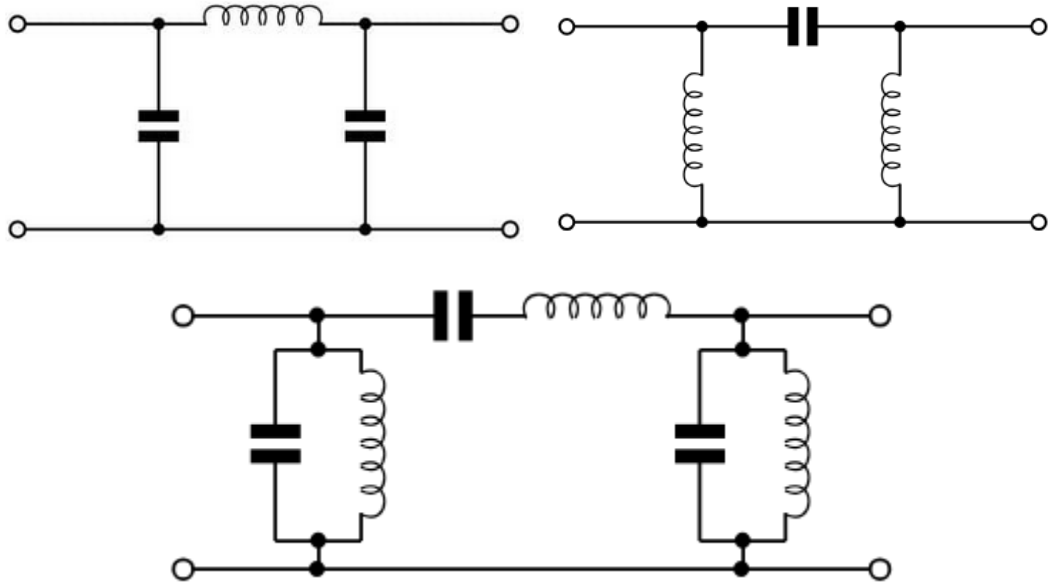


Figure 15: *The pi configuration constant-k filter topologies for a lowpass (top left) and highpass filter (top right), and a combined bandpass filter (bottom) [37, 38].*

For the lowpass filter at the output of the amplifier, the research into designing that filter was a bit trickier. While again reiterating any of the three previously discussed filter topologies would work sufficiently in this role, the bigger issue was the availability of high wattage rated inductors and capacitors. At a max rated output of 150 W, finding RF grade inductors and capacitors is a tricky proposition. Preliminary investigation highlighted potential capacitors that could fit this role (discussed later in Section 5 of this report). Finding inductors proved more difficult, as there were no RF rated inductors found for the high wattage rating that the amp would be pushing at its output. Therefore, it was determined that inductors must be custom produced. However, given the high wattage nature of this filter, group members were hesitant to start designing a filter from scratch with custom inductors, due to the danger from the high power this circuit would be subjected to, compounded with our inexperience in high power RF electronics. Therefore, research was conducted into currently available high power RF LPF designs, which included several alternative designs from the American Radio Relay League, as well as other open sources, observing how other amateur radio operators tackled this challenge [41]. However, after viewing all of the lowpass filter designs employed by other radio operators, a design by Danish ham radio operator of callsign PA0FRI was selected as the best base for our group's lowpass filter. This filter was a highly tuned 9th order T base Chebyshev filter, and the filter's topology can be viewed in Figure 16 below.



Figure 16: *The 9th order T base Chebyshev 30 MHz lowpass filter design filter, designed and open sourced by radio operator PA0FRI [42].*

This design was rated up to 200 W of output power, and offered dimensions for hand wrapping air-core inductors that would handle the high-power rating. It should also be mentioned that the reported performance of this Chebyshev filter was excellent, offering a relatively strong cutoff after 30 MHz, with a very minimal ripple for Chebyshev design, showing an extremely smooth passband [42]. The spectrum analyzer graph produced by this filter can be viewed in Figure 17 below.

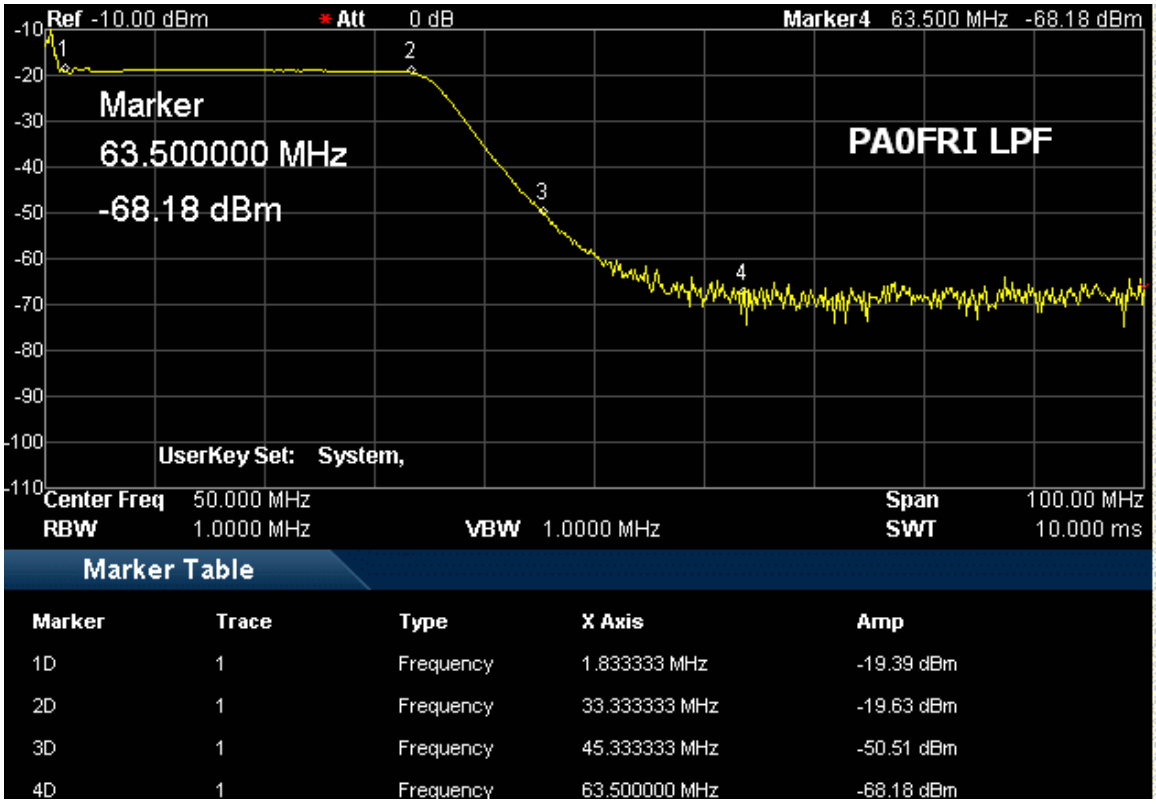


Figure 17: *The spectrum analyzer graph produced by the 200W 30MHz Chebyshev LPF, showing its frequency response [42].*

With the research into the amplifier circuit and filter design taken care of, as well as laying out the features and specifications of the amplifier, the only pieces of the design left to investigate were the SWR and power meter. While the implementation of this feature was a stretch goal for this project, it was one that the group actively wanted to do our best to implement. As such, an investigation into the literature around SWR and power meters was conducted.

Initially, the focus was on understanding theory around a SWR/power meter. While everyone in the group knew what these tools were used for, no one had ever learned how they functioned to obtain, process and display the information. To summarize our findings, an SWR meter measures the standing wave ratio in a transmission line. This reflects how well an antenna system is matched to the radio transceiver. A high SWR will lead to poor transmission efficiency and increased power loss [43]. Additionally, a high SWR can cause excessive power to be reflected into the transceiver, leading to overheating and equipment failure. By using a SWR/power meter, radio operators can identify issues that can potentially damage equipment, allowing for an impedance mismatch or poorly tuned antenna to be adjusted before equipment failure [42]. There are several styes of SWR meter designs that have been used to produce SWR meters, including Wheatstone bridges, capacitive dividers (commonly used in analog meters), as well as direct RF sampling using an analog to digital converter (ADC) to calculate the power/SWR using digital signal processing (DSP). However, in 21st century homebuilt SWR and power meter design, the directional coupler-based meter is the most commonly employed SWR meter [45]. A directional coupler measures the magnitude of the forward and reflected waves by individually testing each with a directional coupler, using these values to calculate the SWR and power [44, 45]. A circuit diagram of a simple directional SWR meter can be viewed in Figure 18 below.

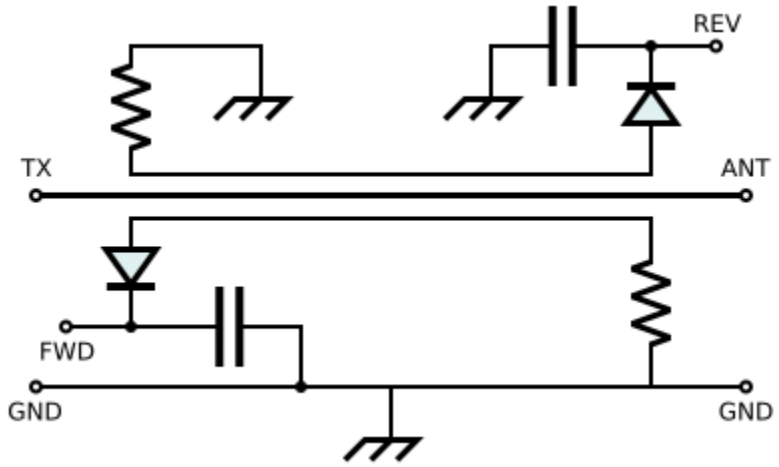


Figure 18: *A generic directional SWR meter circuit diagram [44].*

Viewing Figure 18 above, the transmitter (TX) and the antenna terminals (ANT) are connected through an internal transmission line. This transmission line is coupled to two smaller detection lines that serve as the directional couplers [44]. These lines are terminated with a resistor at one end, which match the characteristic impedance of the second line (50 Ω in the case of amateur radio equipment) [44]. A diode bridge is connected to the other end of the directional couplers, which is used to convert the magnitude of the forward and reverse waves to their corresponding DC voltages, which are smoothed by a capacitor. The SWR is then found by first using the forward and reflected voltages to determine the reflection coefficient Γ, which is then used to determine the SWR. The equations used to complete these calculations are displayed below [46].

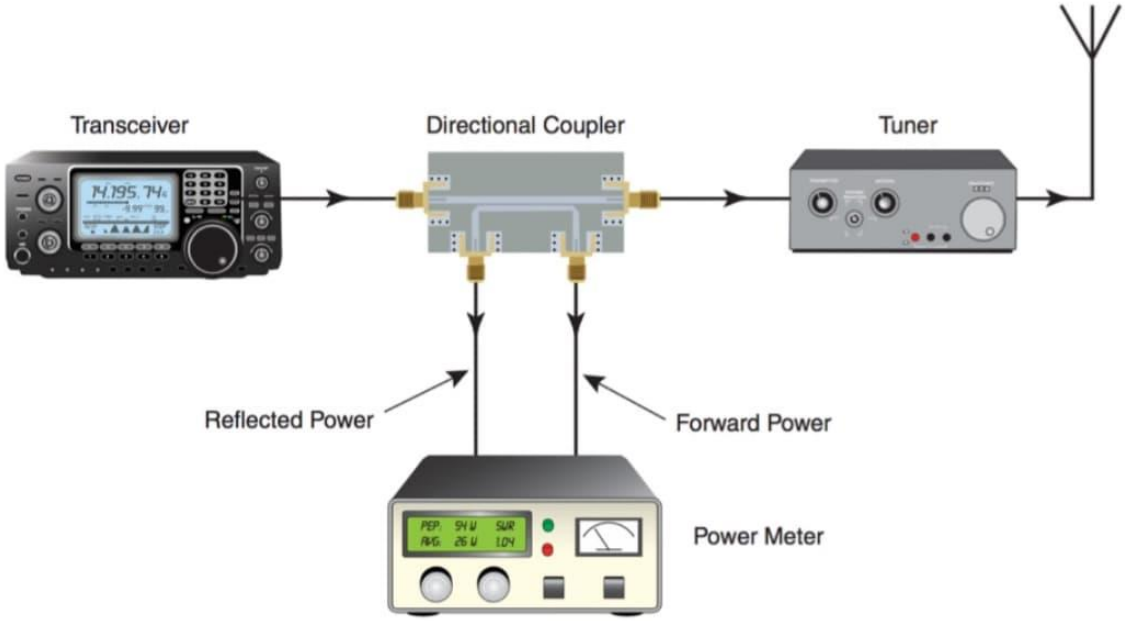
Reflection Coefficient Equation –

$$\Gamma = \frac{V_{\text{ref}}}{V_{\text{fwd}}}$$

SWR Equation –

$$\text{SWR} = \frac{1+\Gamma}{1-\Gamma}$$

The position of a directional SWR/power meter in a radio system setup is displayed in Figure 19 below.



b

Figure 19: *A directional SWR meter implemented into a radio system, placed between the transceiver, and an antenna tuner and antenna [20].*

With basic circuit theory in mind, the designs of various homebuilt SWR meters were overviewed, to observe if any were practically possible to construct and implement into Group 4's amplifier. The majority of designs initially surveyed were unserviceable, as they were set up to operate at too low a wattage. However, a 2011 ARRL article by radio operator, Bill Kaune (callsign W7IEQ), was found that overviewed how to construct a Power/SWR meter that could be rated up to 1 kW [20]. This unit used an LCD display to show the forward and reflected power, as well as the SWR. The circuit used a PIC16F876A and two AD8307 log detectors [20]. An AD8307 log detector is a logarithmic RF detector that converts an RF signal power into a DC voltage [50]. In this circuit, the AD8307's forward and reflected RF signals from a directional coupler are fed into the two AD8307 chips, with each outputting a voltage representing the logarithmic power (in dBm) [50]. The microcontroller then reads these voltages, and calculates the reflected and forward power, as well as the SWR [20]. This circuit uses lengths of shielded coax cable looped

through toroidal cores to sample RF voltage, which was processed by the AD8307 log detectors [20]. This design offers promising performance, and appears to be practical to complete in the time allotted for the ECE499 project. The circuit diagram for this RF sampling circuit of this SWR meter can be viewed in Figure 20 below.

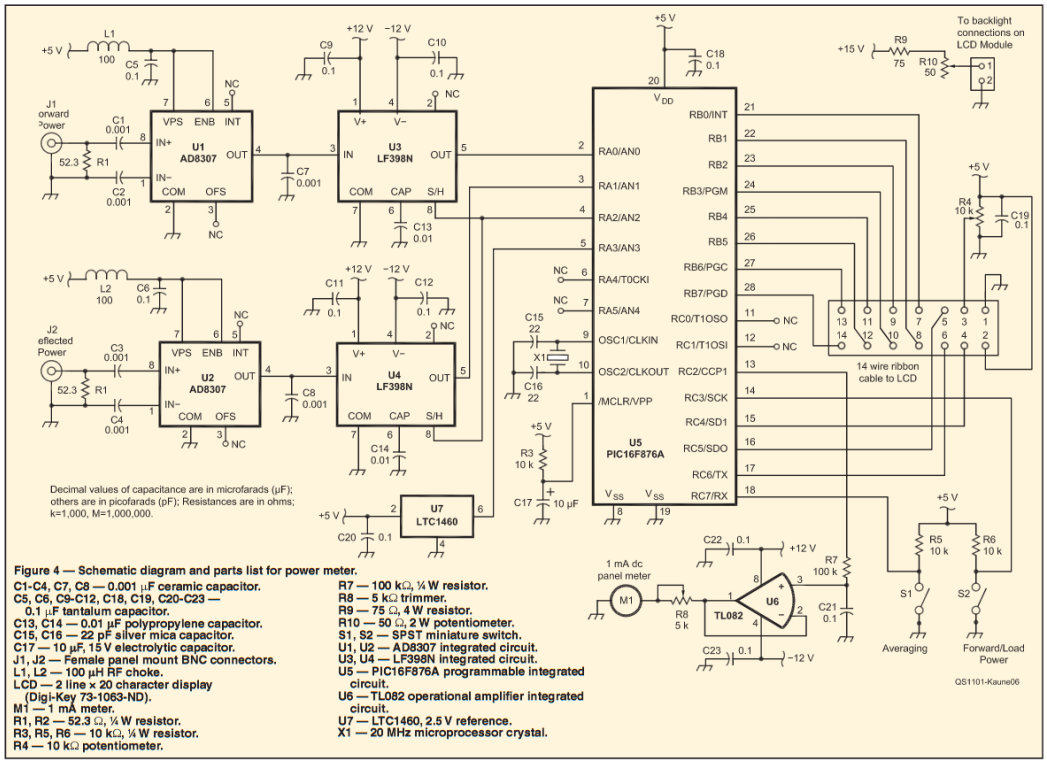


Figure 20: *The AD8307 log detector and a PIC16F876A microcontroller circuit that convert the voltages from the directional coupler into power and SWR meter measurements [20].*

While this design appeared promising, to be thorough, other SWR meter options were investigated. This inquisition resulted in our group finding a product improved version of the previously discussed directional coupler SWR meter. Designed by radio operator, JG. Holstien (callsign PD0LEW), this open-source design iterated upon the previous meter by upgrading the microcontroller to a Teensy 4.0 [47]. This lightening fast 600 MHz MCU was far more powerful than the previous PIC16F876A, enabling the SWR meter to use an attractive TFT LCD screen to display the power/SWR brightly [47]. The coupler and RF sampling circuits were also improved, by adding improved filtration to ensure signal quality before sampling, while retaining the powerful AD8307 log detectors [47, 48]. The circuit schematics for the coupler circuit, and the microcontroller circuit, are displayed in Figure 21 below [48].

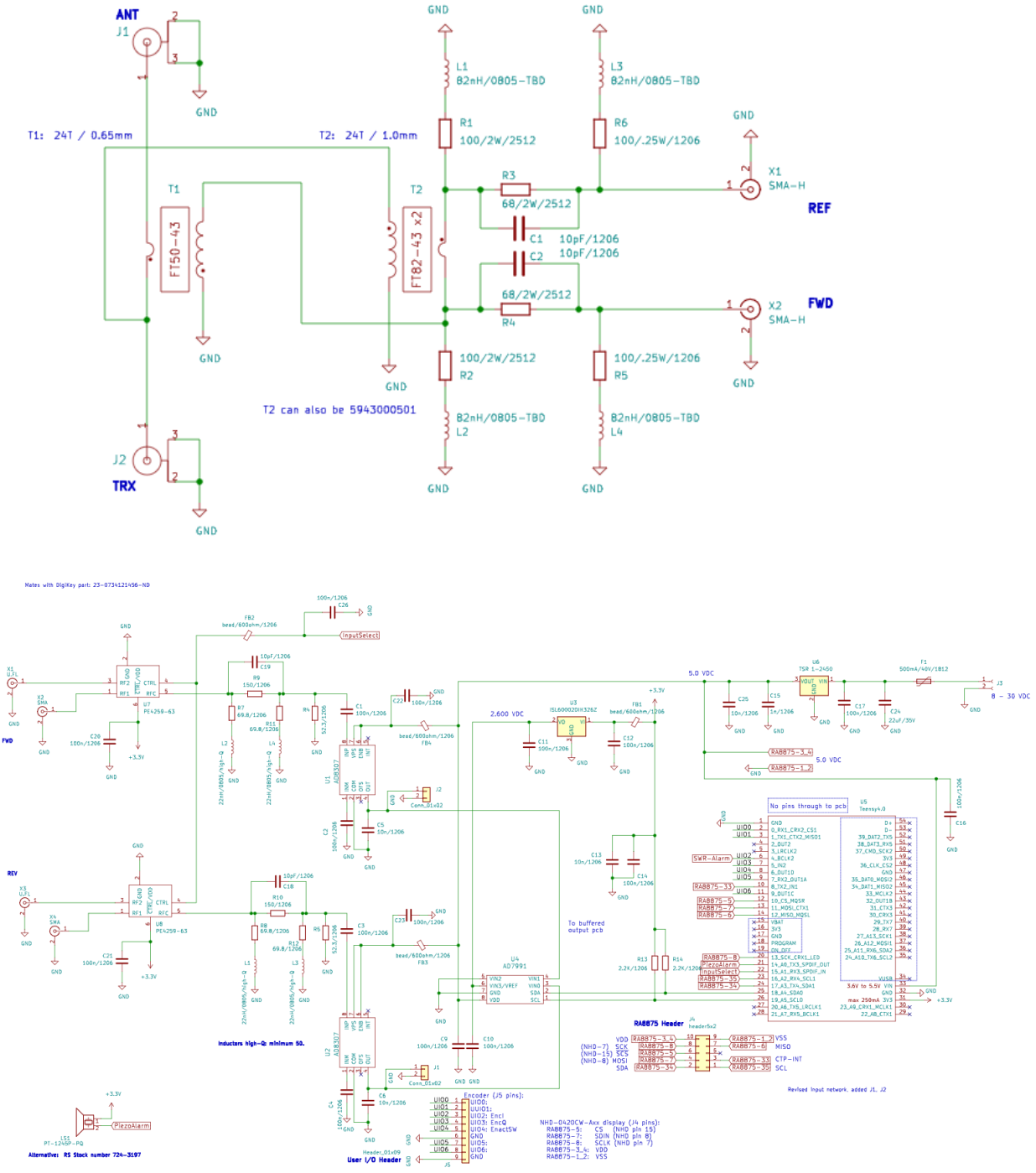


Figure 21: *The directional coupler schematic (top,) and the AD8307 log detector and Teensy 4.0 microcontroller circuit that convert the voltages from the directional coupler into power and SWR meter measurements(bottom) [48].*

From viewing the schematic of the directional coupler circuits in Figure 21 above, the operation of this SWR/power meter can be summarized as follows [20, 47]:

- The directional coupler uses toroidal transformers to pick up forward and reflected RF signals off the main feedline [20].
- It samples the signals inductively, so it does not interrupt or load the RF path [20].
- Resistor-capacitor networks tap a small portion of the signal for measurement [48].
- There are separate lines for forward and reflected power.
- RF switches (PE4259s) let the microcontroller select which signal goes to the detector [48].
- An AD8307 logarithmic amplifier converts the selected RF signal into a DC voltage [48].
- A Teensy 4.0 microcontroller reads those voltages and calculates power and SWR [47].
- The readings are displayed on a TFT display.
- If SWR gets too high, a buzzer goes off to warn the user [47].

From overviewing the schematic review of Figure 21, it was determined that this SWR/power meter design was possible to implement into our amplifier design within the allotted ECE 499 development time, and as such this design was selected as the base for our SWR/power meter feature moving forward in the development of our amplifier project.

Therefore, the proposed solution to creating an affordable, compact, portable HF amplifier would include an EB63 140 W amplifier as the core of the amplifier design. The input would be connected to a bandpass filter to filter out any band noise from the radio before entering the amplifier. The output would include a lowpass filter to remove higher order harmonics, and a SWR/power meter would be included to measure the power produced by the amplifier, and the SWR between the radio transceiver and the antenna. All further design choices would be made in accordance with the specified features highlighted in Figure 5 above.

This project directly supports several ethical principles that are outlined in the EGBC guide to the Code of Ethics (V2.0) [49]:

- **Principle 1: Hold paramount the safety, health, and welfare of the public** — The filtration implemented into the design minimizes interference with other users and public safety services [18]. Additionally, the specification for proper cooling shown in Figure 5 will prevent the amplifier from overheating, failing catastrophically and potentially injuring the operator.
- **Principle 3: Provide an opinion only when it is founded upon adequate knowledge and honest conviction** — An extremely detailed literature review was conducted to inform all design decisions. Additionally, the team has three licensed radio operators on it, two basic license holder and one advanced license holder, showing the group's strong theoretical background and understanding of RF principles.
- **Principle 4: Follow the law and professional regulations** — The amplifier adheres to Industry Canda limits for amateur radio operation power, and spectral purity [18].
- **Principle 6: Conduct themselves with fairness, honesty, and good faith** — Project documentation will be shared openly on a website, with a focus on

transparency and traceability. All referenced work is cited properly, giving credit to the original designers.

- **Principle 12: Undertake work with due diligence and appropriate preparation** — All phases of the design are scheduled, reviewed, and validated using electronics theory, literature review, simulation tools and real-world practical testing.

V Team Duties & Project Planning

Given the scope of this amplifier design, to assist in project planning, the project was broken down into various tasks. These tasks include the following:

- Supervising Professor Communication
- Group TA Communication
- Setting The Project Timeline
- Literature Review
- Theoretical Circuit Calculations and Design
- PCB Design
- Component Sourcing
- Enclosure Design
- Website Design
- Prototype Assembly
- Prototype Testing
- Documentation – Progress Report and Final Report
- Demonstration of Prototype

Each member has been assigned a role catering to their strengths. Furthermore, the tasks listed above were split up and assigned as individual responsibilities to each group member. The roles and task responsibilities of each member can be viewed in Table 1 below.

Table 1: *Team member roles, assigned task and responsibilities.*

Member Name:	Role & Assigned Tasks	Task Responsibilities
Hudson:	Role – Project Lead Assigned Tasks - • Setting The Project Timeline • Literature Review • Theoretical Circuit Calculations and Design • Component Sourcing • Documentation	Hudson initiated the project concept and took the lead from the start. He is responsible for conducting all the literature review, as well as theoretically designing and calculating all the circuits on paper, and assigning duties to other team members. As the team lead, he has ensured that the timelines set by the group have been followed and that the communication between team members has been effective. Hudson is responsible for component sourcing, creating a full parts list, and placing the parts orders to make sure we receive the components on time and ahead of schedule. Hudson has also been serving as a

	• Demonstration of Prototype	PCB advisor, being a second pair of eyes to assist in determining any errors in the PCB designs prior to producing the boards.
Emil:	Role – PCB and Enclosure Design Assigned Tasks - • PCB Design • Enclosure Design • Prototype Assembly • Documentation	Emil transformed Hudson's paper designs into Altium and has been ultimately responsible for laying out all the printed circuit boards (PCBs) that are required for this project. Emil has been working closely with Hudson to confirm component values and footprints. Emil has made sure all design elements are meeting project specifications. Together with Hudson, Emil has conducted schematic reviews and implemented revisions where necessary. Once the circuitry is designed, Emil will be in charge of designing a suitable enclosure to house the amplifier, design the enclosure based on the manufacturing tools that are available to our group. He will also be responsible for soldering the components to the PCBs to assist in prototype assembly.
Kevin:	Role – Website Lead and Communication Assigned Tasks - • Group TA Communication • Website Design • Prototype Assembly • Documentation	Kevin has been responsible for all external communications with our group's TA Maryam, and has taken the lead on developing the team's project website. After conducting comparative research, Kevin recommended using a modern website builder instead of manual HTML/CSS development. Wix was selected as the platform because of its efficiency and quality factors. Kevin used online instructional resources to learn Wix tools and implemented the site using a structured template that is suitable for an engineering design project. The website architecture includes the following key sections: Home (project overview), Features (system capabilities), Schematic Design, PCB Design, and Team. The foundational content has been added to each section. Once final documentation and test results are available, Kevin will update the site with technical specifications, design iterations, and test outcomes. Kevin has also been tasked with producing all of the project's digital figures,

		as well as assembling the prototype enclosure.
Huss:	Role – Documentation and Supervisor Laision Assigned Tasks - • Supervising Professor Communication • Prototype Assembly • Prototype Testing • Documentation – Progress Report and Final Report	Huss is in charge of preparing the progress report, final documentation and weekly progress reports. He is also the main point of contact for Dr. Sima, ensuring that updates and deliverables are communicated clearly to the faculty supervisor. Huss will also be responsible for assembling the prototype's internal wiring, utilizing his pre-engineering background as a red seal electrician to ensure that no errors in wiring are made. Huss will also complete the amplifier testing task, using his basic amateur radio license to transmit AM and SSB signals using the amplifier (not that team leader Hudson will assist in this testing too, using his Basic amateur radio license to respond to the signals transmitted through the amplifier).

The distribution of these team roles, and task responsibilities was completed in a manner to comply with the EGBC Code of Ethics, adhering to several EGBC principles. These principles include the following [49]:

- **Principle #1 – Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace:**
    - The task responsibilities were carefully assigned to each member based on their competence in. For example, PCB design was assigned to Emil, who has prior experience designing PCBs in a Co-op program. Hudson was responsible for component sourcing, as sourcing high grade, safe electrical components is a responsibility at his current Co-op as an electronics repair technician. Prototype wiring and assembly was tasked to Huss, given his experience as a red-seal electrician. By assigning each task to a member with prior experience the team is ensuring the project prototype will be completed in as safe a manner as possibility, protecting safety and health of the operator and the environment where the amplifier is operated.
- **Principle #7 – Provide professional opinions that distinguish between facts, assumptions, and opinions:**
    - Again, by splitting up tasks based upon prior experience, this planning technique is ensuring that each group member has been contributing where their prior knowledge will guarantee competence in whichever task was being completed by a given member.
- **Principle #9 – Report to their association or other appropriate agencies any hazardous, illegal or unethical professional decisions or practices:**

    - Our team took care to designate tasks to those able to complete them in a non-hazardous and legal manner. For example, the amplifier testing was assigned to Hudson and Huss only, as they are licensed radio operators, meaning they have permission from Industry Canada to operate on the amateur bands required to test the amplifier. Additionally, by keeping an open communication line with all members, as well as our group's TA and supervising Professor, Dr. Sima, it has allowed the opportunity to bring forward any illegal or unethical practices should they arise, and if not resolved, they can be reported on to the proper authorities.
- **Principle #13 – Conduct themselves with fairness, courtesy, and good faith towards clients, colleagues, and others, give credit where it is due and accept, as well as give, honest and fair professional comment:**
    - By clearly and evenly dividing the project tasks amongst the group members, this planning approach ensured that our group's assigned workload has been displaying fairness amongst all members, with no member feeling slighted by having to complete a larger share of the workload than another. Furthermore, by splitting some tasks into a collaborative effort (like testing the amplifier or reviewing the PCB designs) it ensured that group members could in good faith assist one another in the completion of critical tasks. This has been a great team building strategy!

Project Timeline - Critical Milestones and Dependencies:

In addition to the course required deliverables, this project also has several critical milestones that must be completed by Group 4. These are listed below:

1. **Completion of the Literature Review**
2. **Design of the Amplifier Circuit Diagrams**
3. **PCB Design & Component Sourcing**
4. **Enclosure Design**
5. **Amplifier Prototype Assembly**
6. **Amplifier Testing and Evaluation**

To properly complete these milestones, an ECE 499 Timeline was developed to schedule the completion of each milestone. To guarantee that each aspect of the project timeline will be completed on time, a Gantt chart was created to visualize the project schedule and progress during the time period allotted for ECE 499. This Gantt chart can be viewed in Figure 22 below.

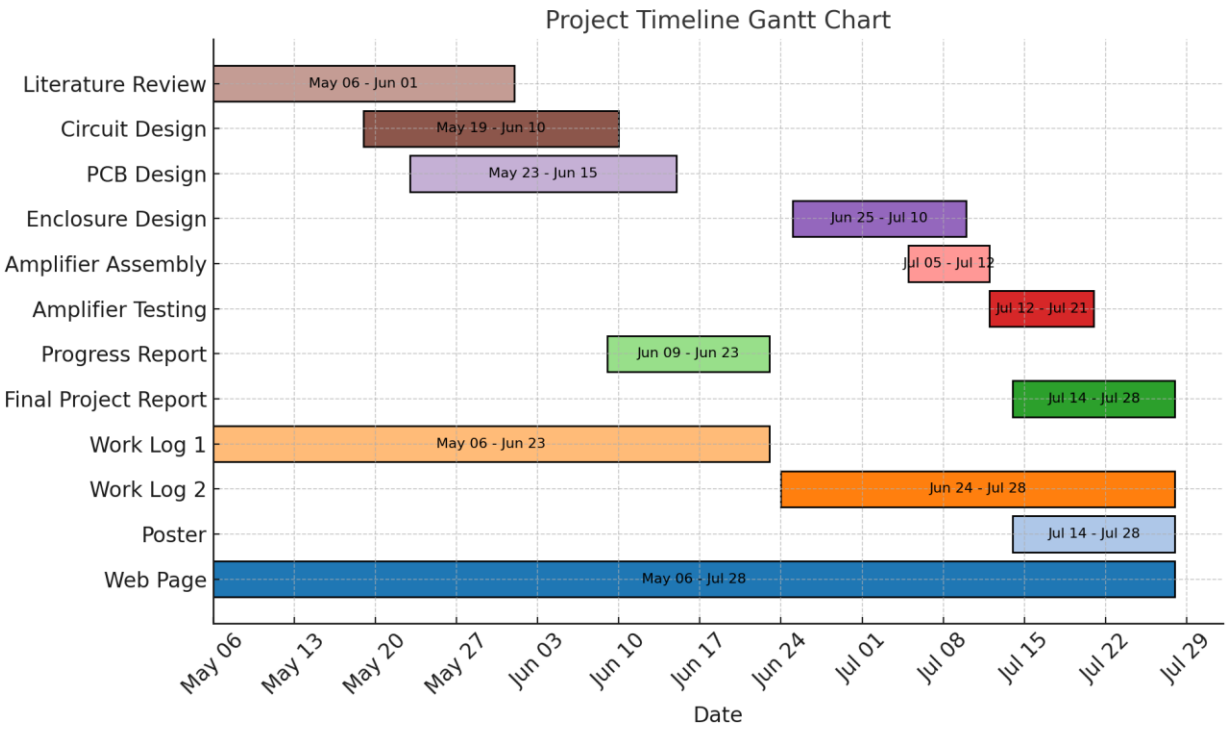


Figure 22: *The Gantt chart developed to plan and schedule the project milestones listed above, and the course deliverables.*

Viewing Figure 22 above, it should be discussed briefly that the milestones are dependent upon the completion of another milestone. For example, development of a circuit diagram design for an amplifier feature cannot be completed until the literature on that aspect of the amplifier has been conducted. Additionally, the PCBs cannot be developed until circuit diagrams are finished, and prototype assembly cannot be finished until all source components and PCBs are delivered, and an enclosure has been designed. Furthermore, the amplifier cannot be tested until all the other milestones have been completed, and the full amplifier prototype has been assembled. To mitigate these bottlenecks, Group 4 members have utilized this Gantt chart to streamline the development of these milestones, coordinating progress between members. For example, to speed PCB development, group member Hudson would conduct the literature review on a specific circuit, design a schematic, and hand it off to Emil for PCB development, rather than linearly complete the whole literature review at once. By using this strategy, it ensured that bottlenecks were not encountered during the completion of all six milestones, ensuring that the amplifier be completed before the ECE 499 demonstration.

To minimize risk of project incompletion, our team has developed fallback strategies for our two primary development concerns. The first primary development concern that was identified was major potential risk involved with the PCB fabrication process. Given that these boards must be ordered from overseas, there is a possibility the team may encounter manufacturing errors, order delays, or in the worse case scenario, a loss of the shipment due to negligence or theft. In case of any such manufacturing errors

or delays that could potentially occur, a contingency plan is in place. The team has secured access to a laser cutter, and will use this to manually fabricate PCB prototypes if needed. This process will allow for the continued hardware development without relying entirely on external vendors. Additionally, the second development concern that could potentially be encountered is that our group will be unable to fully implement, assemble and test all amplifier features prior to the demonstration of the amplifier. Therefore, as a fallback strategy, our group is prepared to not implement the SWR and power meter into the demonstration prototype if time spent constructing and testing the other features becomes too constrained for the remainder of the course time period. This will ensure that members have enough time to implement the critical amplifier features for the demonstration, while having the option to add in the stretch goal SWR/power meter in the future.

VI Design Methodology & Analysis

Upon completing the literature review, it was time to put our design methodologies to work, by designing and drawing diagrams of each of the required circuit subsystems. However, before any circuit diagrams were designed and recorded, it was first decided to draw a simple block diagram of the amplifier. This diagram would highlight the flow of the RF signal from the radio, through the four features of the amplifier, and out to the antenna. This sketched block diagram can be viewed in Figure 24 below.

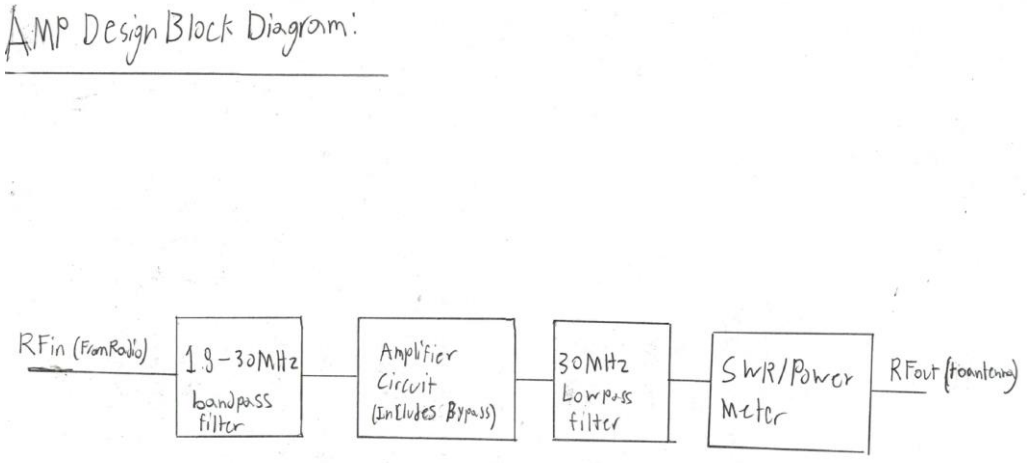
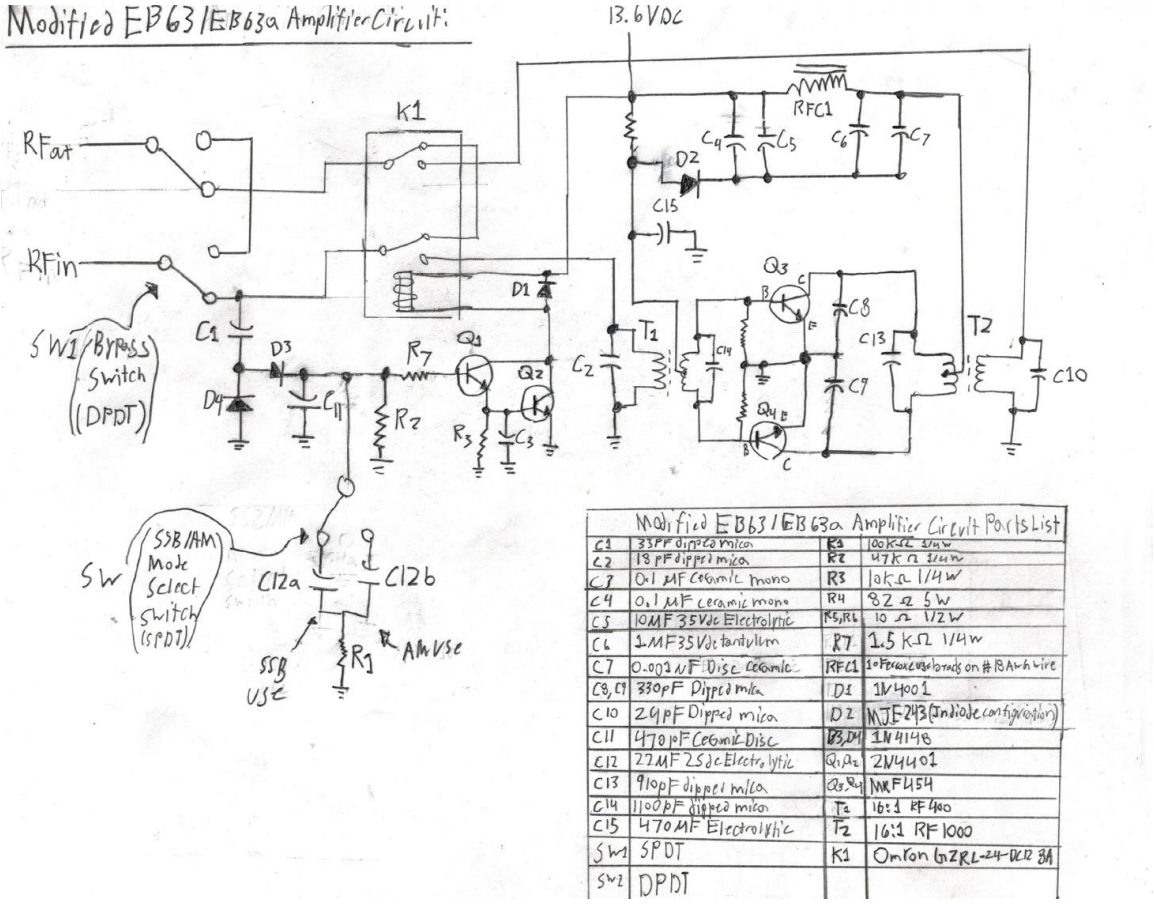


Figure 24: *A block diagram of the amplifier, showing the proper order in which the RF signal flows through each feature of the design.*

After sketching the amplifier block diagram, design focus shifted to circuit development. To begin, the core amplifier circuit was overviewed, noting that modifications were needed to bring the EB63A circuit up to the specifications set during the literature review. Specifically, the circuit needed to be modified to offer the user the ability to switch between AM and SSB modes, and the ability for the user to manually bypass the amplification circuit. These modifications to the amplifier circuit were implemented by adding switches into the circuit. More specifically, for the mode select feature, a switch was inserted at the point of the circuit where the SSB delay capacitor was located (C12 on the EB63A diagram). The type of switch determined was a single pull double throw switch (SPDT), which was chosen because it can take a single input, and switch it between two outputs

[51]. In this mode select modification design, the single C12 capacitor would be replaced. Instead, the input of the switch was placed where C12 was originally on the schematic, with the switches being placed between new capacitors, C12a and C12b. These capacitors will now enable the user to switch between operating modes by selecting a different capacitor with C12a being a 22µF capacitor tuned for AM, and a 100µF capacitor tuned for SSB delay. Using this setup, the user can now use the SPDT switch to select between modes, and bring the amplifier up to specification. The other modification to the circuit was the implementation of a manual bypass switch. This was done using double pull double throw switch (DPDT). This switch type controls two separate circuits, with each circuit having two connection paths [51]. By wiring the two inputs of the DPDT switch with the RF signal input and output ports, two of the switch output ports were modded to be wired to the amp circuit's input and output, and two switch output ports were modded to be connected directly to one other, bypassing the amplifier. That way, using this DPDT switch setup, the user can select whether he/she wants to operate the amplifier with amplification enabled, or bypass this amplification for testing purposes or when operating in low noise conditions. The modified EB63A circuit diagram with these two design modifications can be viewed in Figure 25 below.



Modified EB63/EB63a Amplifier Circuit Parts List			
C1	33PF dipped mica	R1	100KΩ 2W
C2	18 PF dipped mica	R2	47K Ω 2W
C7	0.1 MF Ceramic mono	R3	10kΩ 1/4W
C4	0.1 µF ceramic mono	R4	82 Ω 5W
C5	10MF 35Vdc Electrolytic	R5,R6	10 Ω 1/2W
C6	1MF35Vdc tantalum	R7	1.5 KΩ 1/4W
C7	0.002 MF Disc Ceramic	RFC1	10 Ferrous beads on #18 AWG wire
C8, C9	330pF Dipped mica	D1	1N4001
C10	20pF Dipped mica	D2	MJE243 (In diode configuration)
C11	470pF Ceramic Disc	D3,D4	1N4148
C12	22MF 25dc Electrolytic	Q1,Q2	2N4401
C13	910pF dipped mica	Q3,Q4	MRF454
C14	1100pF dipped mica	T1	16:1 RF400
C15	470MF Electrolytic	T2	16:1 RF1000
SW1	SPDT	K1	Omron G2RL-24-DC12 3A
SW2	DPDT		

Figure 25: *The modified EB63A circuit diagram with the updated design to match our amplifier circuit specifications. (Note the bypass DPDT switch added to the circuit to enable manual bypass of the amplifier, and the mode select SPDT switch added to enable*

the user to switch between AM and SSB mode by selecting a properly tuned delay capacitor for each mode).

The next step in the circuit design of the amplifier was designing the filters. There were specifically two filters of note, the 1.8 – 30 MHz bandpass, and the 30 MHz lowpass filter.

Starting with the bandpass filter, the pi configuration constant-k LC bandpass filter topology was selected in the literature review as the topology used to design this circuit. Firstly, the cutoff frequencies were defined at 1.5 and 31 MHz, instead of 1.8 and 30 MHz. The choice to "oversize" the cutoff frequencies of the passband was selected to ensure that in the electrical component variation, there would be buffer room so the variances would not cause the filter to cut into the passband. The hand calculations completed to design the 1.8-30 MHz filter can be viewed in Figure 26 below.

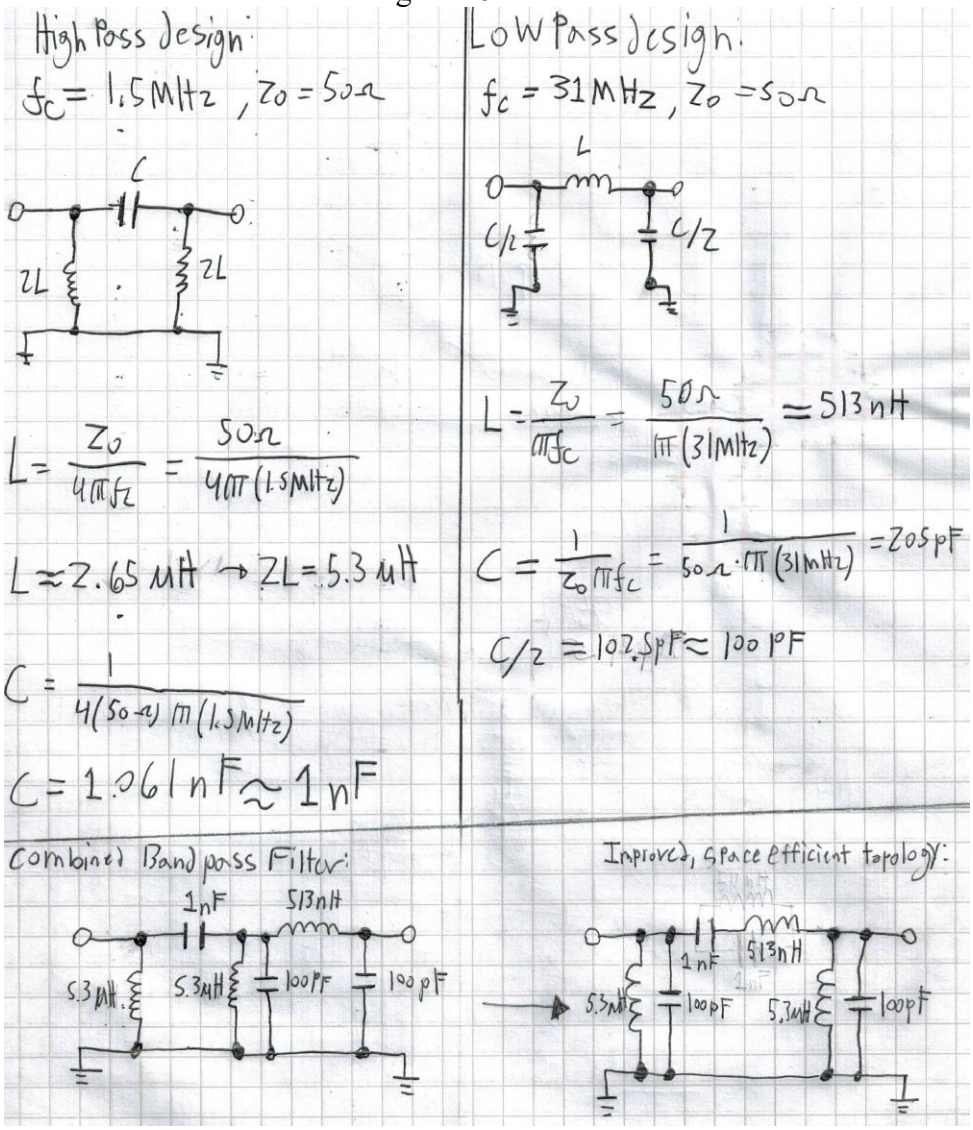


Figure 26: *The hand calculations completed to design the 1.8-30 MHz filter for the input of the amplifier.*

To verify the performance of this filter design, it was simulated in LTspice to evaluate its out of band attenuation performance. It should be noted that the inductor values were rounded from 5.3µH to 5µH, and 513nH to 500nH, to simulate the circuit with values of the closest available components. The results from this simulation are displayed in Figure 27 below.

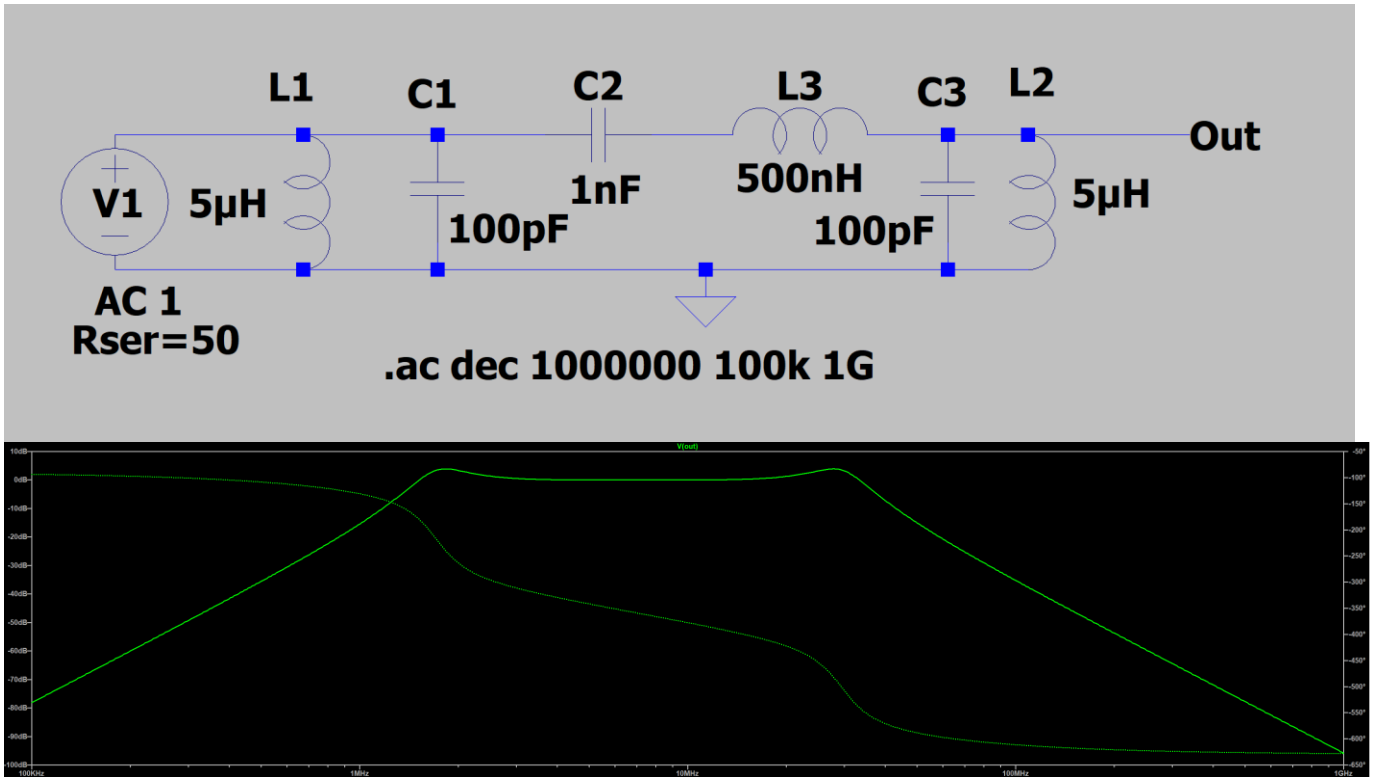


Figure 27: *The LTspice circuit (top) used to perform a simulation of the 1.8-30 MHz filter for the input of the amplifier, and the resulting performance graph (below). Note the rounded components simulating purchasable components as opposed to the theoretical values of the diagram in Figure 25 above.*

From viewing Figure 27 above, it can be observed that the filter performed its function adequately, with a passband centered in between ~1.8 – 30 MHz. The frequency cutoff was reasonably strong for a constant-k design. A slight ripple is present on both cutoff frequencies, indicating that despite being a constant-k LC designed filter, this design also exhibited Chebyshev filter properties. While the performance of this filter was reasonable, it was determined that a second stage would be added to the filter, as when a second stage is added to a constant-k LC filter, theoretically the frequency cutoff steepness would be improved. Therefore, a second stage was added to the simulated circuit, and the simulation was shown again, with the results highlighted in Figure 28 below.

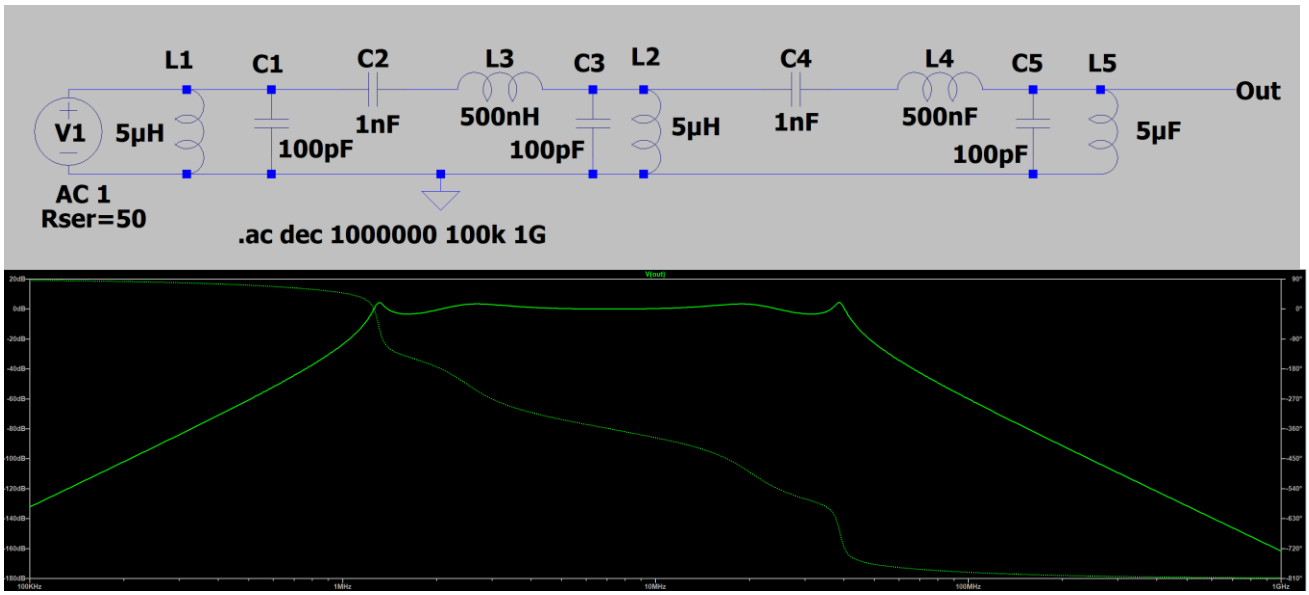


Figure 28: *The updated LTspice circuit (top) for the modified bandpass filter with an added second stage, and the resulting performance graph (below).*

From viewing the output graph in Figure 28 above, it appeared that adding a second stage to the filter gave it further Chebyshev characteristics, with a sharp ripple being present around both the cutoff frequencies. The passband was smooth and it could be observed that the frequency cutoff was steeper than the single stage design displayed previously. Therefore, given the improvements to the steepness of the frequency cutoff, Group 4 decided to select this filter configuration as our bandpass filter going forward.

Onto the lowpass filter, recall that during the literature review, our group made the decision to seek out a previously made design, and selected a 9th order T base Chebyshev 30 MHz filter. This was done to assure we could access high power inductors, as purchasing premade offerings is virtually impossible, and the design selected had detailed instructions for wrapping high wattage air core inductors. However, just because a design was selected did not mean our group was going to implement it without verifying its out of band attenuation performance. Therefore, the decision was made to calculate a 9th order T base Chebyshev filter at a cutoff frequency of 31 MHz for the same component variance buffer reasons listed for the bandpass filter. The passband ripple was estimated to be 0.01db, as in the spectrum analyzer output of the filter shown in Figure 17 above, no noticeable ripple. The calculation done to verify this filter can be viewed in Figure 29 below.

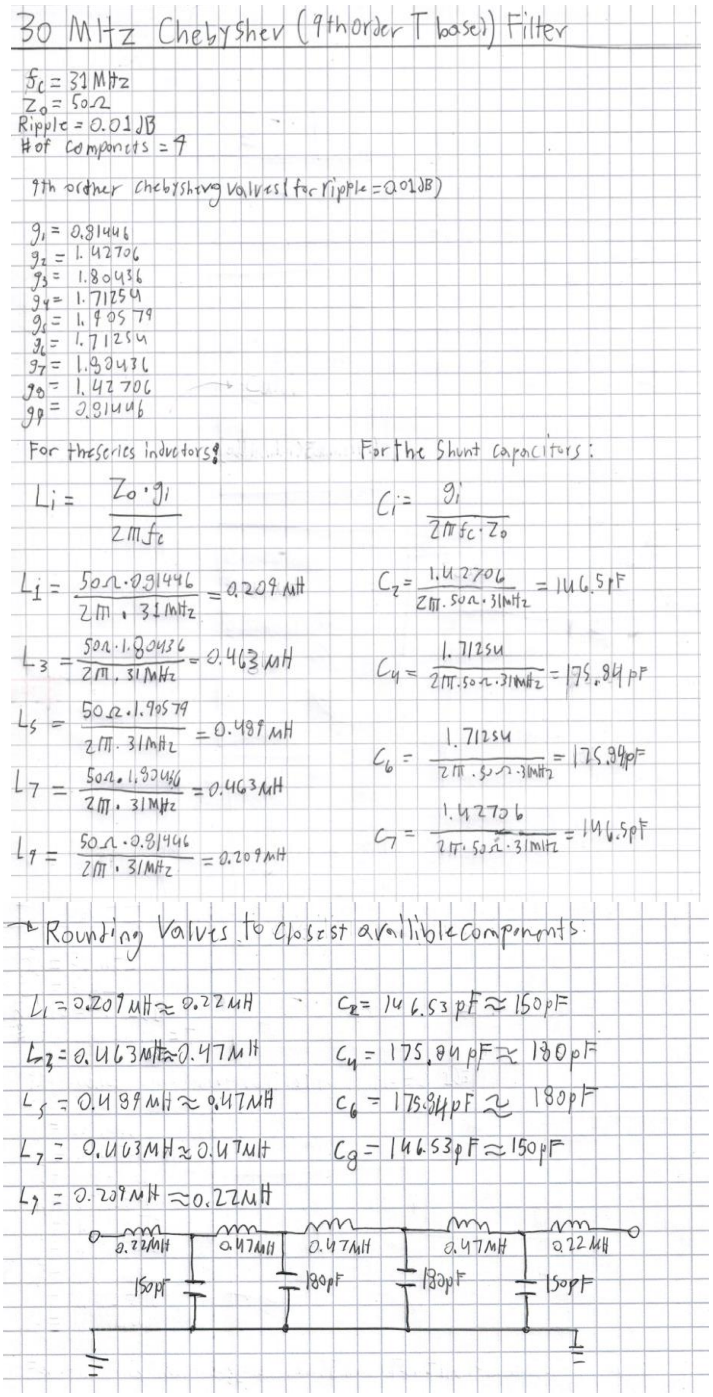


Figure 29: *The hand calculations completed to verify the 9th order T base Chebyshev 30MHz filter for the output of the amplifier.*

From the results calculated in Figure 29 above, the 9th order T base Chebyshev 30MHz filter was determined to have been properly theoretically designed by the original creator, with component values matching the theoretical calculations. To further test the performance of this filter, it was simulated in LTspice, with the results being shown in Figure 30 below.

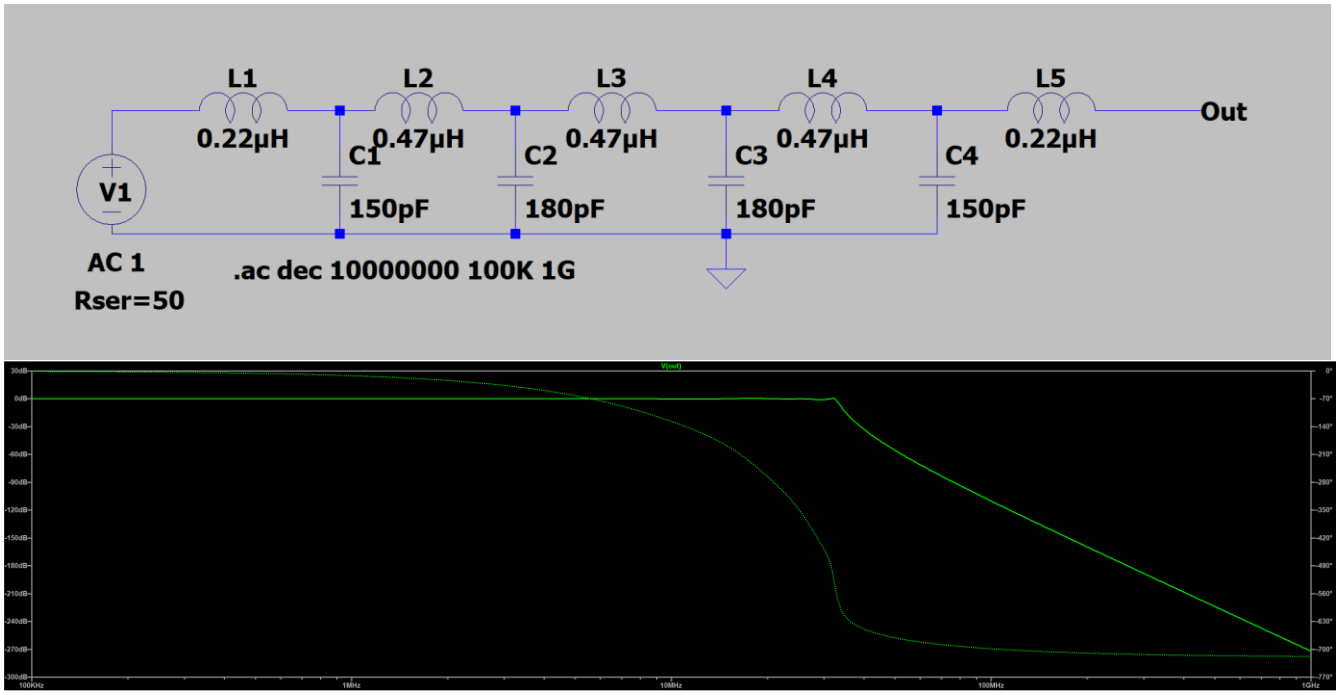


Figure 30: *The LTspice circuit (top) for the 9th order T base Chebyshev 30MHz filter, and the resulting performance graph (below).*

From viewing the simulation graph in Figure 30 above, it can be observed that similar to the spectrum analyzer output shown in Figure 17 above, this LPF design showed a steep frequency cutoff, starting at ~30 MHz with a very slight ripple. Therefore, given the excellent simulated performance, this LPF design was confirmed to be our 30 MHz LPF going forward in development. With both the filter designs tested and verified, the final designs were recorded in Figure 31 below.

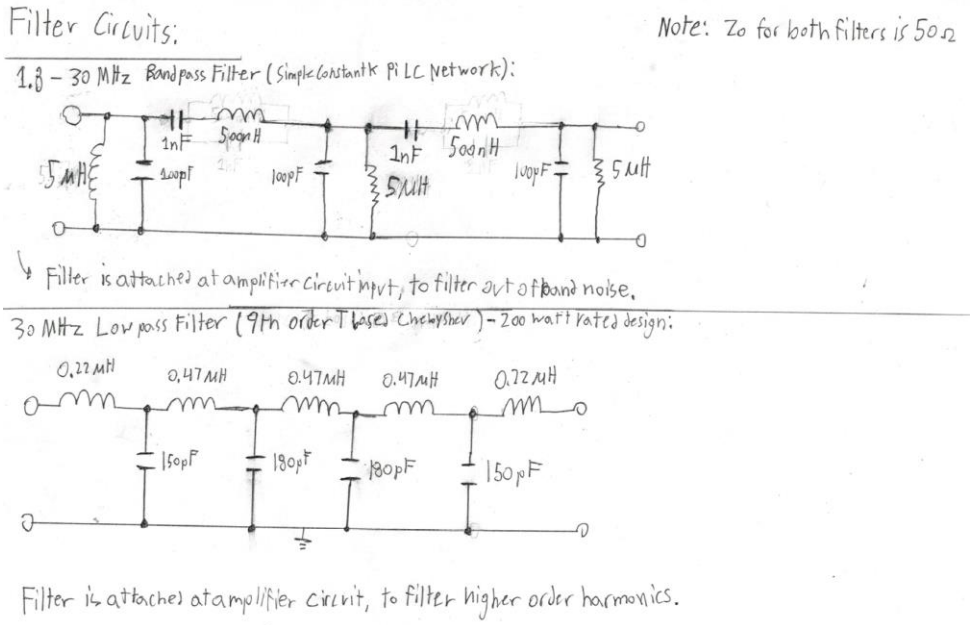


Figure 31: *The finalized bandpass and lowpass filter designs.*

To meet the requirements of two amplifier specifications, two more circuits were developed. The first of these circuits was a voltage regulator. This circuit was developed to power the cooling fans that were employed to cool the amplifier components, and establish a safe and reliable operation. These cooling fans require a constant 12VDC. Therefore, a LM317 voltage regulator integrated circuit was employed to step down the 13.6 V input voltage used to run the amplifier to a constant 12V, ensuring that the fans would have their correct operating voltage, and thereby increasing their longevity. Three fan connectors were connected in this circuit to allow for up to three cooling fans, increasing the cooling performance of the amplifier. The second circuit design was a simple fuse circuit. This circuit was set up to be connected to the power input of the amplifier, and split this input between three fuse outputs, one powering the amplifier, one powering the fan 12 V voltage regulator discussed above, and another to power the stretch goal SWR/power meter circuit. This fuse circuit was added to increase the safety level of the design, as this amplifier is an extremely high amperage piece of electronics, and as such, adding a fuse will increase the safety to the operator, ensuring that safe current thresholds are not overreached. The circuit diagram for the fan voltage regulator circuit (and the calculations used to determine the resistor ratio used to obtain a 12V output), and the simple fuse circuit, are highlighted in Figure 32 below.

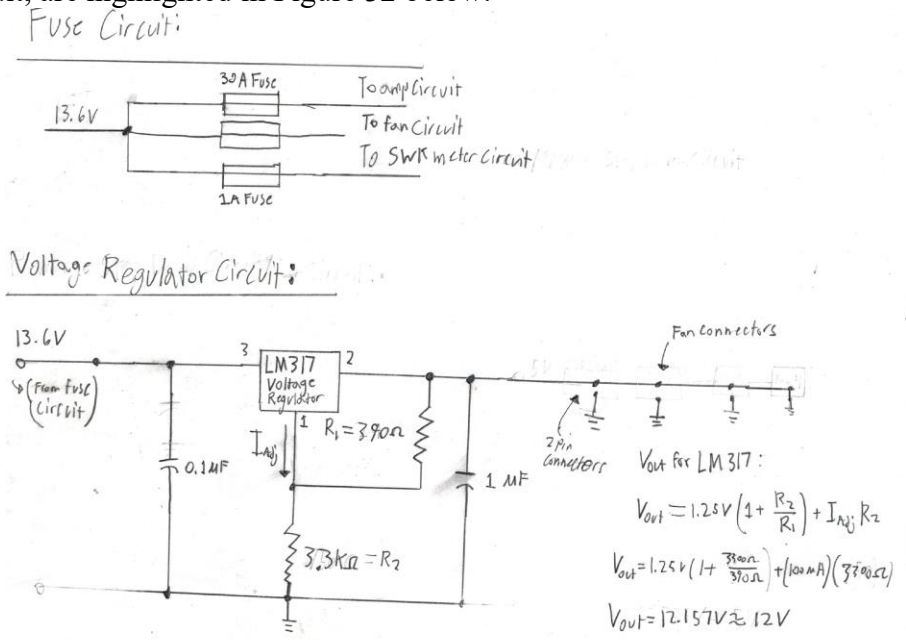


Figure 32: *The circuit diagrams for the fuse circuit and fan voltage regulator circuit. Note the calculations used to determine the resistor ratio used to obtain a 12V output [51].*

The voltage regulator circuit in Figure 32 above was also simulated in LTSpice, to verify that the resistor ratio that was calculated provided the proper output voltage value. This test resulted in a simulated voltage output of 12.182 V, very close to the calculated value of 12.157 V, indicating that this voltage regulator design produced an output well within the cooling fans safe operating range. The LTSpice circuit used to conduct this simulation, and the test results can be viewed in Figure 33 below.

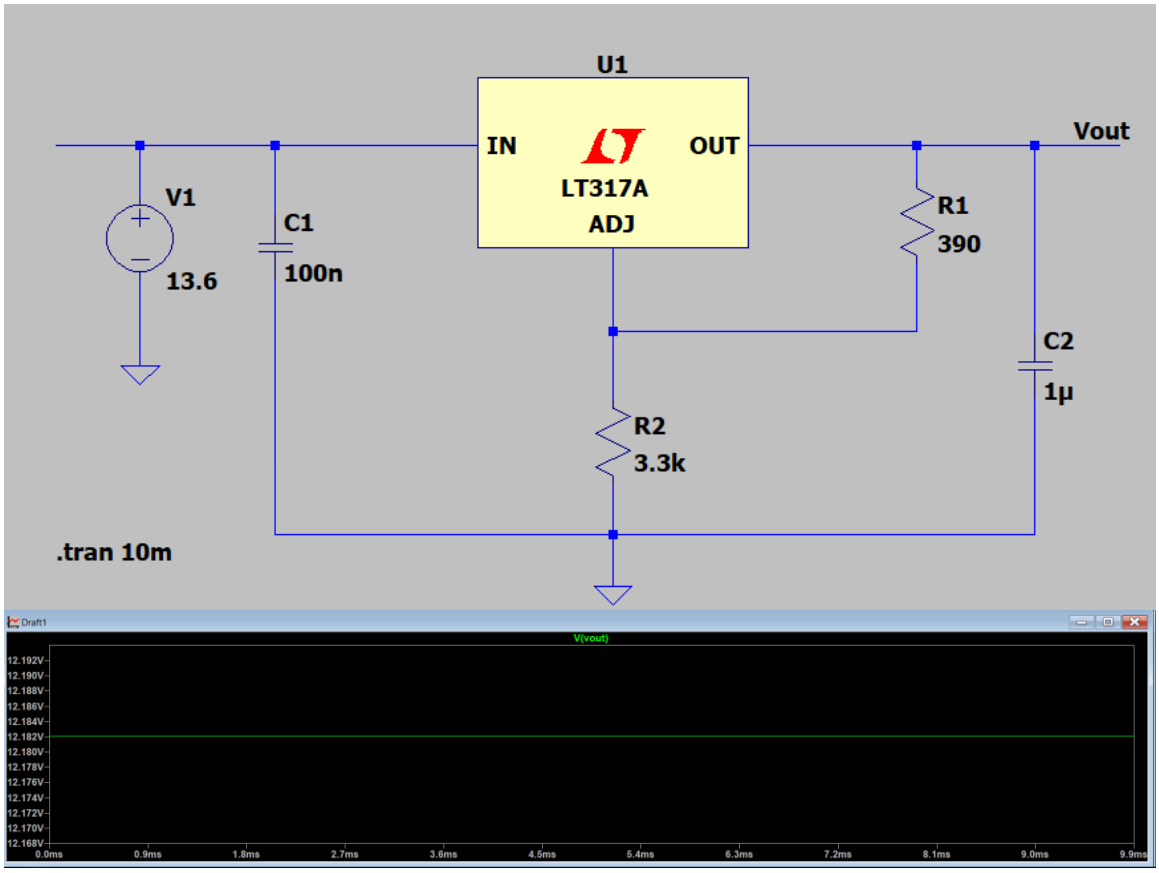


Figure 33: *The LTSpice circuit created to simulate the voltage regulator circuit (top), and the simulated circuits output voltage (bottom), showing an output of 12.182 V.*

With all of the circuit diagrams completed on paper, it was time to convert these schematics into PCBs. To initiate this, the amplifier circuit was attempted to be drawn in Altium. The Altium schematic produced when creating this PCB is shown in Figure 34 below.

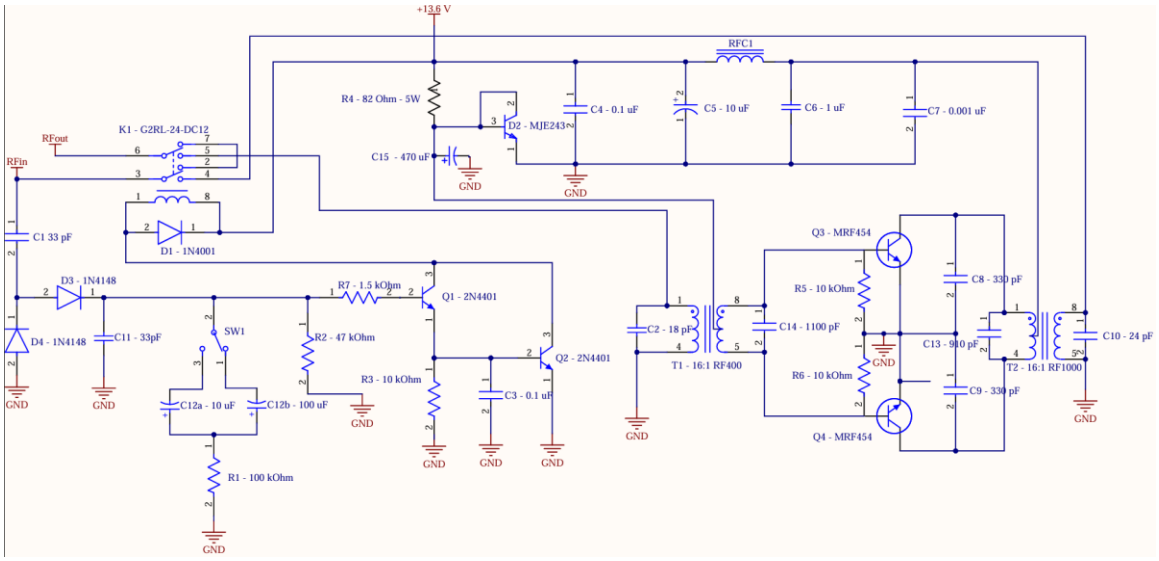


Figure 34: *The Altium PCB schematic drawn for the updated amplifier circuit.*

Note that in this circuit, there were some issues making a proper schematic. Several components, specifically the two MRF454 transistors, the RF choke, and the transformers did not have available footprints (although alternate models were inserted into the schematic to make it look more complete). Reviewing the literature on the EB63 amplifier revealed that because these amplifiers were designed long before professional PCB manufacturing became available to the general public, the boards for these amplifiers are intended to be hand-cut on a heavy 2 oz copper blank PCB using a Dremel tool (or a CNC milling machine for more accurate results). Board layout/cut paths pictures were actually provided in the original Motorola EB63 documents. These board layouts and cut paths can be viewed in Figure 35.

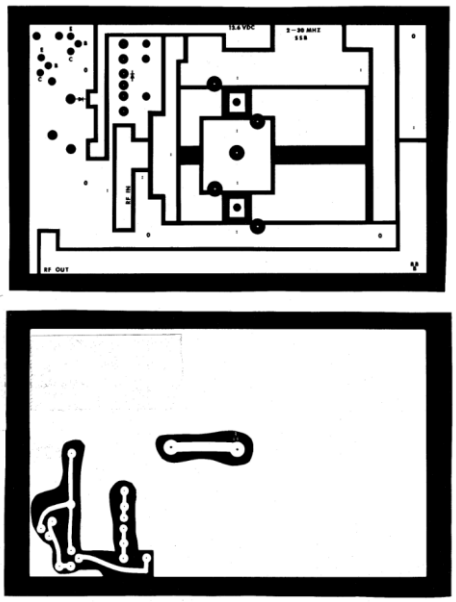


Figure 35: *The PCB board layout/cut path pictures provided to assist in the production of the EB63/EEB63A amplifier's PCB [25].*

Because the EB63's original components such as the RF400 and RF1000 transformers, as well as the MRF454 transistors are only used in the production of older, relatively obscure homebuilt amplifier designs, no PCB footprint for these components was ever released. Therefore, given the limited project development time, instead of attempting to estimate footprints for these components, Group 4 shifted its design methodology and decided it would be wise to have a proper EB63 style PCB CNC milled (as opposed to hand-milled with a Dremel tool, which has issues with precision errors). After conducting research into milling services (since no group member owns or has access to a mill), a company specializing in producing obsolete RF amplifiers was discovered, who offered PCB milling services for older amp designs like the EB63. As such, one of these boards was ordered, with an arrival time estimated for the end of June 2025.

Now, before the issues with the PCB footprints for the overall amp circuit started, it had already been decided that the SPDP switch AM/SSB mode select circuit would be developed on its own board, as opposed to being added to the main amplifier board This

was done because of the possibility that the SSB delay capacitors would need to be further tuned. While the value of 100µF for SSB was in theory correct, very often these capacitance values need to be adjusted to obtain optimum SSB performance. By splitting this part of the circuit to a separate PCB, it would allow for this board to be placed in an easier to access location than the main amplifier PCB, allowing for easier tuning of the capacitance values to obtain the perfect SSB delay. Therefore, this mode select circuit was developed on its own PCB, with the Altium PCB schematic and board being highlighted in Figure 36 below.

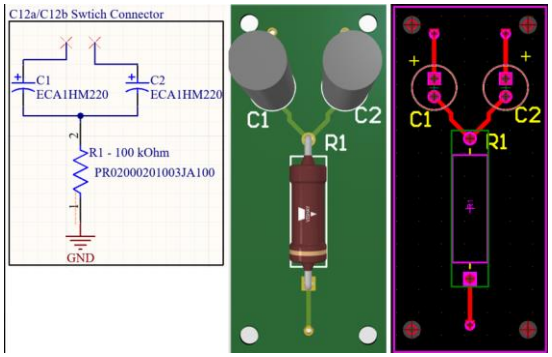


Figure 36: *The Altium PCB schematic (left), the 3D PCB view (middle) and the PCB layout (right) diagrams designed to implement the AM/SSB mode select circuit.*

Note that this board was designed as a single sided PCB. This was not an error, but rather an intentional design choice. This design methodology was selected to allow this PCB board to be produced on a laser engraver using acid etching and blank single sided FR4 PCB (already owned by group member Hudson) [53]. This was one of our group's fallback strategies in case issues in the supply chain causing a delay to obtain PCBs from overseas, as well as providing an excellent opportunity to gain hands on experience independently manufacturing prototype PCBs without relying on foreign manufacturing. This single sided PCB design philosophy was continued for the remaining PCBs designed by our group, for the same reasons listed for the mode select circuit.

The next PCB design involved the fuse PCB circuit. This design of this simple fuse PCB board can be viewed in Figure 37 below.

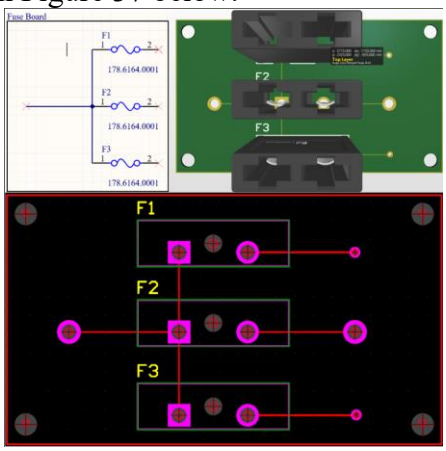


Figure 37: *The Altium PCB schematic (top left), the 3D PCB view (top right) and the PCB layout (bottom) diagrams designed to implement the fuse circuit.*

After designing the fuse circuit PCB, the PCB for cooling fan voltage regulator circuit was designed. This board included the fan clips to enable the three cooling fans to lock positively into the board, to ensure the fan wires will not fall out during transportation. Special attention was placed on the layout of this PCB to ensure space efficiency. The design of the cooling fan voltage regulator PCB can be viewed in Figure 38 below.

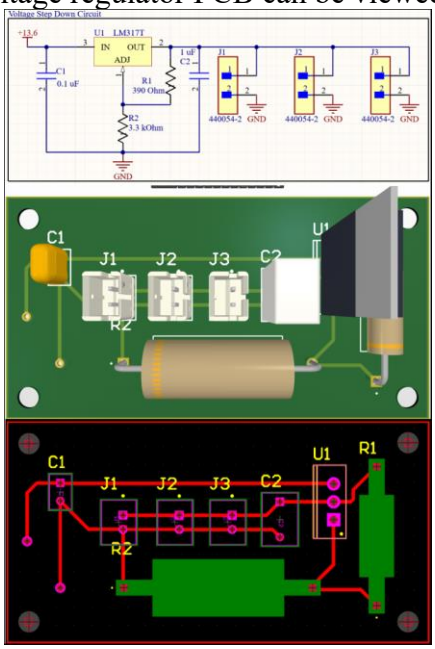


Figure 38: *The Altium PCB schematic, the 3D PCB View and the PCB Layout diagrams designed to implement the cooling fan voltage regulator circuit.*

The next PCB board designed was that of the 1.8 – 30 MHz bandpass filter. This circuit required the use of unique footprints for the unique RF 5µH and 500nH inductors used in the construction of this filter. Additionally, wider than standard RF signal input and output through holes were specified on this board, to enable a cable capable of handling the maximum 10 W input power. The design of the bandpass filter PCB can be viewed in Figure 39 below.

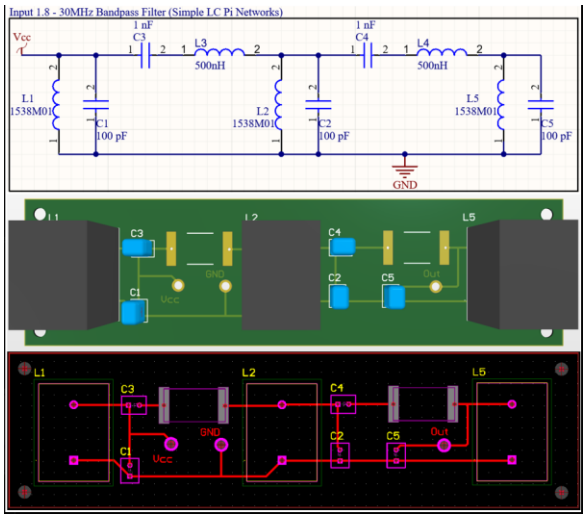


Figure 39: *The Altium PCB schematic, the 3D PCB view and the PCB layout diagrams designed to implement the bandpass filter circuit.*

After creating the bandpass filter circuit, a PCB for the lowpass filter circuit was developed. This board required a thicker trace width to handle the high wattage output signal produced by the amplifier. Additionally, this PCB required the use of custom length inductor footprints to ensure that the hand-wrapped air core inductors could properly fit in the PCB. Additionally, the component layout of the PCB was tinkered with to maximize the size efficiency of the board. The design of the lowpass filter PCB can be viewed in Figure 40 below.

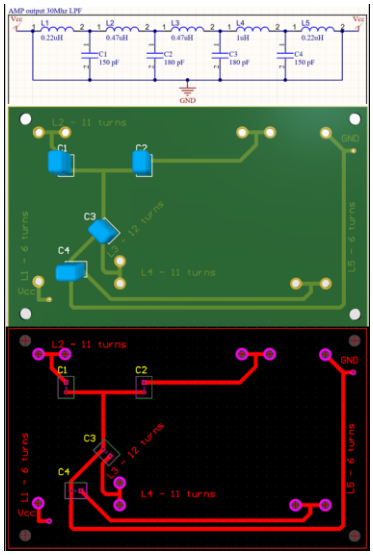


Figure 40: *The Altium PCB schematic (top), the 3D PCB view (middle) and the PCB layout (bottom) diagrams designed to implement the lowpass filter circuit.*

With the design of this PCB, all the custom PCB designs for the three core features of the amplifier were completed. However, there were two more PCBs for the stretch goal SWR/power meter that were overviewed, including the directional coupler and microcontroller PCBs [48]. The designs of these PCBs can be viewed in Figure 41 below.

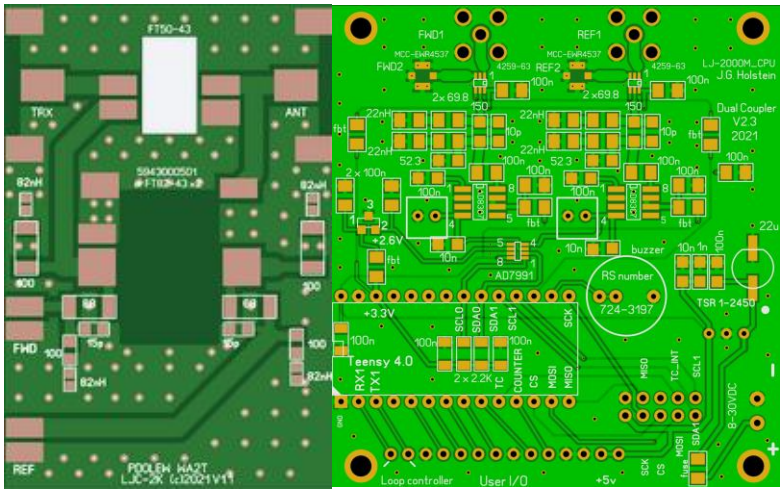


Figure 41: *The PCB designs required for the SWR/power meter, including the directional coupler PCB (left) and the microcontroller PCB (right) [48].*

These PCBs were analyzed carefully to determine the components that made up the circuits as there was no BOM provided with the open-sourced Gerber files. The results were compiled in a completed parts list for each PCB board. Note that these PCB designs were ordered as is, as the SWR/power meter was only a stretch goal circuit, so designing, verifying, assembling and testing the amplifier circuit, and bandpass lowpass filter critical features was viewed as more important than focusing development effort on the boards. Therefore, the open-sourced boards would utilized to implement the SWR meter into the Demonstration Day prototype (if time permits after finishing and testing the other amplifier features).

Note that while completing the PCBs, components for each PCB board were sourced simultaneously alongside the PCB development. This was done to ensure that the proper components' footprints were used to develop the boards, minimizing the potential for making a design error. The components for each PCB board were investigated, particularly focusing on finding low variance components whenever possible, to assure as close to a theoretically performance match as possible. There is too much information about the component selection process to mention here. However, there are several components that were sourced that warrant mentioning. The first components were the capacitors used in the filter construction. Finding RF grade capacitors capable of handling high power applications was a tricky proposition. After reviewing RF filter building manuals, a pattern with capacitor selection was noticed. The majority of filter designs surveyed in the literature review utilized silver mica capacitors in their construction. Silver mica capacitors have fallen out of popularity for other electronics applications in the 21st century due to their high cost. However, they have remained a mainstay in the production of RF equipment [54]. This is due to possessing particularly beneficial properties including the following [54]:

- High accuracy (variance of +/- 1%).
- Low levels of temperature coefficient.
- High Q.
- Low loss.
- Very low capacitance change with voltage.

- High voltage rating.

Therefore, given the listed advantages, silver mica capacitors were selected as the capacitor type for use in our group's lowpass and bandpass filters, with capacitors matching each of the values needed being sourced.

Another component worth mentioning when it comes to component sourcing was the high wattage RF grade inductor. As mentioned briefly in the literature review, these components are simply not available for purchase. Instead, they must be produced in a DIY fashion, wrapping winding wire to exact dimensions to ensure the correct result. However, given the high wattage nature of this filter, group members were hesitant to start designing a filter from scratch with custom inductors, due to the danger from the high power this circuit would be subjected to, compounded with our inexperience in high power RF electronics. As a result, the 9th order T base Chebyshev 30 MHz lowpass filter was selected, as this amplifier design provided dimensions for how to correctly wrap the high wattage air core inductors used to construct the lowpass filter. The instructions for winding these inductors can be viewed in Figure 42 below.

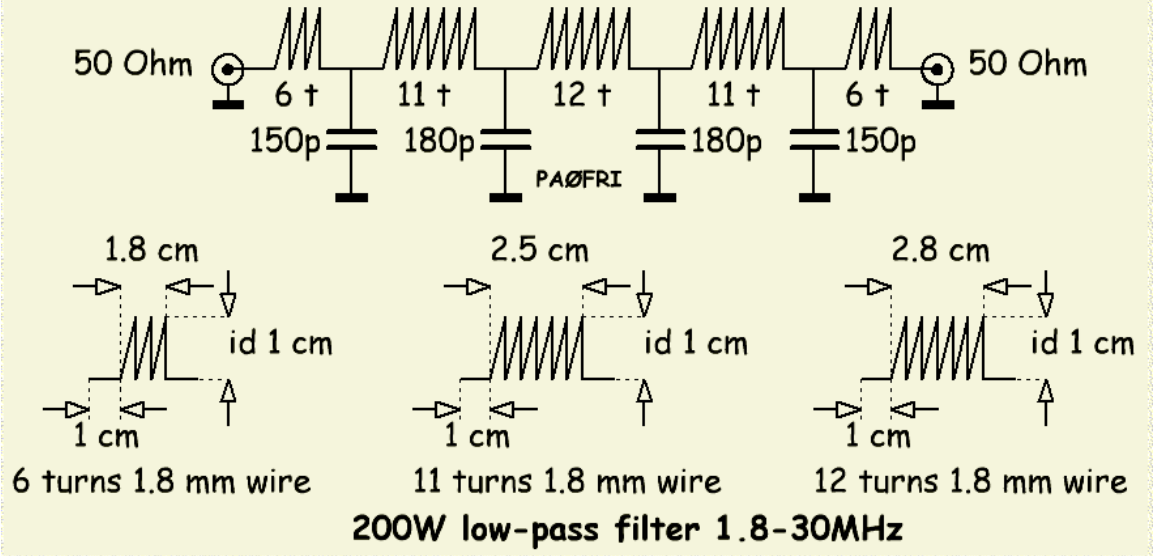


Figure 42: *The instructions provided to produce the inductors [42].*

Therefore, to produce the high wattage inductors, 1.8mm winding wire was acquired. Additionally, 1 cm diameter cylinders of lengths 1.8cm, 2.5cm and 2.8cm were designed, and 3D printed, to act as a coil winding jig, ensuring the coils would be wound to the correct internal diameter and length. The STL files of these inductor winding jigs can be viewed in Figure 43 below.

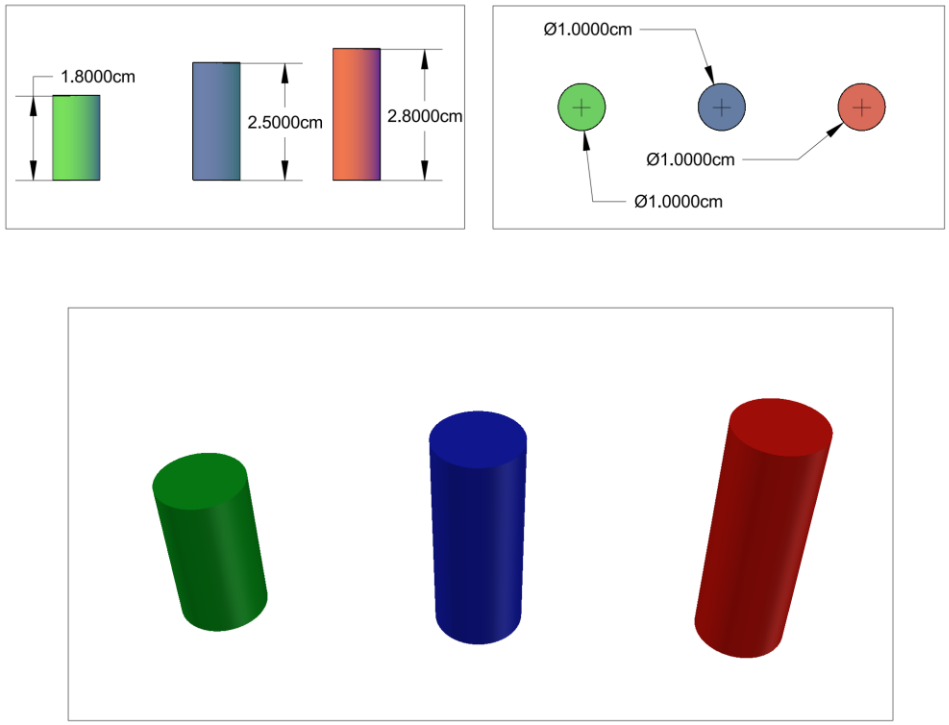


Figure 43: *The jigs designed to assist in winding the required inductors, with the jig lengths (top left) and the internal diameter (top right).*

Additionally, to route the signal between the various PCBs, RG-316 coaxial cable was also selected. Initially, the plan was just to use standard wire. However, upon further investigation, it was determined that even on short internal runs, the benefits of a shielded and impedance matched coaxial cable would greatly assist in noise protection and impedance matching, so our wiring design methodology was shifted to utilize coaxial cable. RG-316 coaxial cable was selected as the coaxial cable of choice for this amplifier because of several features. For example, RG-316 offers low loss at HF frequencies, has excellent shielding, matches the 50Ω characteristic impedance of the other radio equipment, and is both flexible and durable, making it the perfect choice for the internal wiring of this amplifier [55].

Once the PCB design and coaxial cable selection were completed, the team moved on to designing the enclosure for the amplifier. For this phase of the project, the design methodology for the enclosure focused on the ability to produce components in-house. This was because the team members did not know exactly how long it would take to assembly the PCBs, and how many enclosure layout adjustments would be required. Therefore, when designing the enclosure, Group 4 initially focused on the one part of the enclosure that we could not be self-fabricated, that being the amplifier heatsink. As no group member currently owns a CNC mill, the only options for acquiring a heatsink, that being to purchase a premade heatsink, or design a custom heatsink and have the UVIC machine shop mill it to our specifications. Both of the potential design methodologies were seriously investigated, with a purchased premade extruded aluminum heatsink offering lower cost, excellent surface finish and speedy acquisition through Amazon Prime. The milled heatsink option offered more customization, but at a higher cost and requiring longer manufacturing time. Given the limited assembly time, it was decided to purchase the

heatsink, and design the enclosure around it. As such, a 300mm x 140mm x 20mm extruded aluminum heatsink was acquired. This would require some minor metalworking, included tapping screw mounting points for the amplifier PCB, cooling fan and the enclosure.

With the heatsink confirmed, the remainder of the enclosure design revolved around accommodating that critical component. This design methodology was taken into account based on the manufacturing tools available to Group 4. These key tools included, an xTool S1 40 W diode laser cutter/engraver and a Bambu Lab X1C 3D printer. It was decided that as much of the enclosure as possible would be laser cut, with various accessories being designed and 3D printed to facilitate enclosure assembly. Laser cutting the main enclosure body was selected over 3D printing due to three primary factors, which included the following:

1. **Speed**: Cutting wood or acrylic is far faster than extruding plastic, allowing for rapid prototype adjustment.
2. **Material Cost**: To produce equivalent sized boxes cost less using laser cut material such as wood or acrylic as opposed to extruded plastic.
3. **Labelling:** The laser cutter's ability to engrave material to label the enclosure is something that a 3D printer can not replicate.

While the laser cutter beats the 3D printer in these areas, the 3D printer offers its own advantages, including the ability to create custom shapes not offered by the laser cutter's 2D manufacturing, as well as allowing for interesting types of plastics with different chemical properties to be printed. Therefore, the design methodology for the enclosure development focused on maximizing the potentials of both of these machines.

To create the main enclosure body, it was decided to make an open top box out of laser cut wood. The box's external dimensions were set to be 300mm x 140mm to match the heatsink, keeping the box's exterior flush with the heatsink. Wood was selected for this role because it is fast to produce, aesthetically pleasing and engraves very well.. This enclosure required a substantial amount of engraving, and as such, wood was the perfect choice to facilitate this marking. Wood is also light weight which was a factor in keeping the portable amplifier weight to a minimum. The finalized design for the external enclosure can be viewed in Figure 44 below.

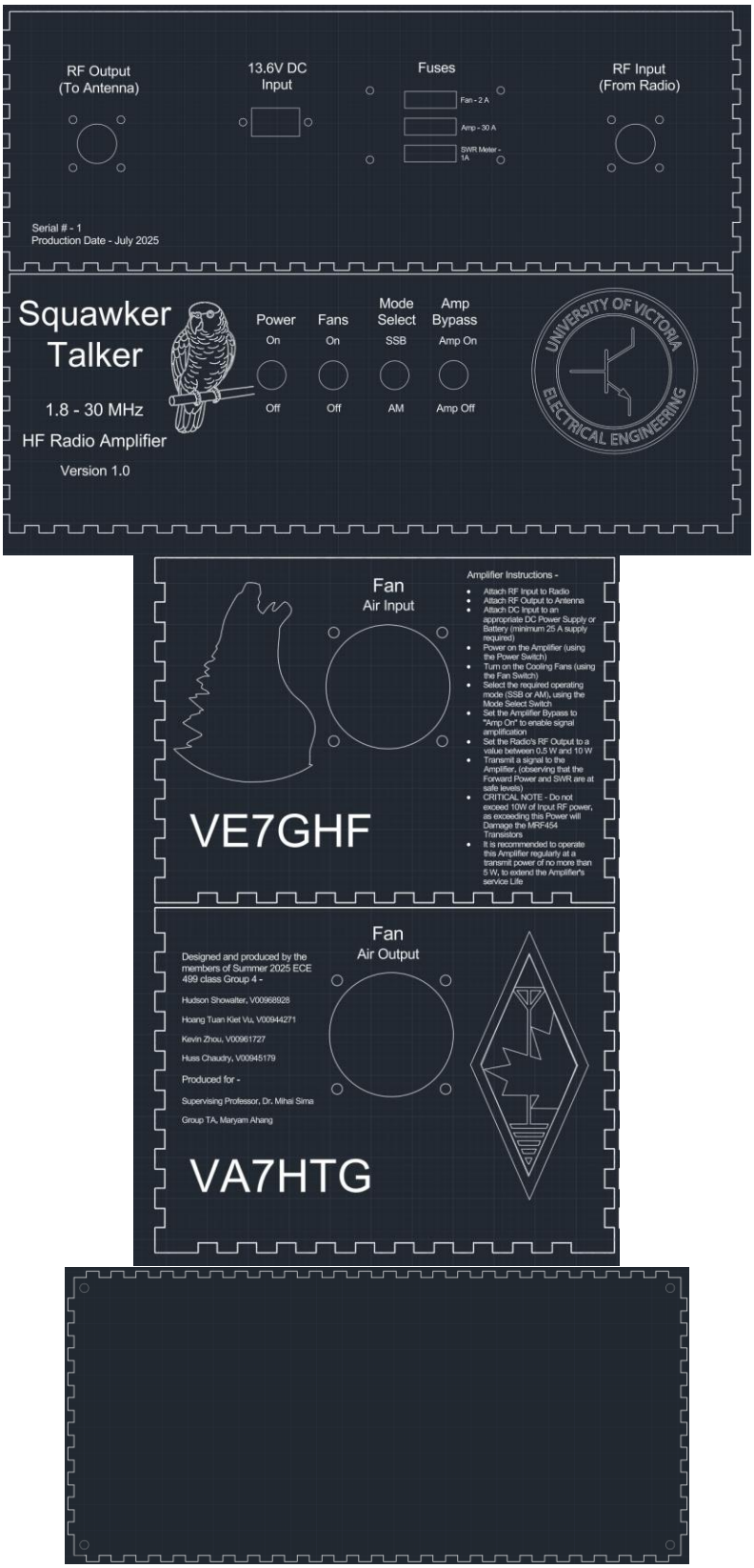


Figure 44: *Finalized design of the external enclosure box.*

This enclosure was created using AutoCAD. This design software was selected for 2D design as one group member has three levels Autodesk approved certification in AutoCAD and is very comfortable with the program. The enclosure was designed using interlocking 5mm fingers to hold the box together. The box was cut to mount and label various peripherals. These included the overall amplifier power, fan power, mode select and bypass switch on the front panel, as well as the amplifier name, its specification and version. On the sides, the input and output 40mm cooling fans were mounted to ensure cold airflow through the internals of the enclosure. Additionally, amplifier operation instructions were included to ensure that an emergency services member who is not well versed in radio operation could utilize this amplifier without requiring specialized training. Additionally, the call signs of two radio licensed group members, as well as the names and student numbers of each group member, the names of our supervising professor and group TA and an engraving of the Radio Amateurs of Canada logo was included. An outline of Godzilla was also engraved on the amplifier, to highlight the importance of natural disaster preparedness. On the rear of the amplifier, the RF input and output SO239 jacks, as well as the DC input and the fuse PCB were cut to be mounted, and appropriately labeled. Note that the design went through several iterations adjusting peripheral locations, fonts and enclosure height to ensure the prototype looked and performed as expected.

There are several specific design selections briefly overviewed in the enclosure design worth discussing further before proceeding to the 3D printed portions of the amplifier enclosure. The first would be the name and logo of the amplifier, being given the name Squawker Talker, with a parrot being engraved as the amplifier mascot. This was not a frivolous design choice, but in fact was added to pay homage to a key inspiration for the amplifier, that being group member Hudson's parrot Lulu. Lulu is a Yellow Headed Amazon parrot, who has an extremely loud voice in a small package! These were the exact characteristics required by a portable RF amplifier, and as such, Lulu was selected as the perfect mascot to represent this project, with a name being selected to pay homage to this inspiration, and an engraving of her being placed on the face of the amplifier. A picture of Lulu, the Squawker Talker mascot can be viewed in Figure 45 below.



Figure 45: *Lulu the Yellow Headed Amazon selected as the mascot of the amplifier due to her loud voice in a small package.*

Discussing the cooling fans for the enclosure, three cooling fans were to be required to facilitate sufficient cooling. These fans included, two 40mm cooling fans and one 120mm fan. This design methodology was selected to mimic the cooling of a desktop computer, a topic several of the group members were familiar with from previously building custom desktop gaming PCs. The two 40mm cooling fans were setup to have one pulling air into the enclosure from one side panel, with the other fan set up to push air out from the other side. This would ensure that cool air would be constantly pulled over the hot components, with the hot air being pushed out, enabling optimal thermal transfer. The 120mm fan was set to be mounted on top of the heatsink fins, pushing cold air down and through the fins, enabling the heatsink to remain as cool as possible while pushing the air through the fins, venting out either side of the heat sink. Custom fan grills were also 3D printed for each fan to ensure external debris would not damage the blades.

For the DC input, a modern design methodology was employed, specifically Anderson power poles. While relatively a new peripheral compared to more traditional DC connectors, Anderson power poles have become the go to DC connection method for radio operators, as well as gaining popularity in solar panel installations [57]. This is due to several factors, including durability, high amperage rating (30 A in the case of Group 4's project), and convenient connection, making these connectors the perfect DC power peripheral to use to power the amplifier. To mount these connectors, a mounting bracket was 3D printed. This bracket, as well as two power poles inserted within it, can be viewed in Figure 46 below.

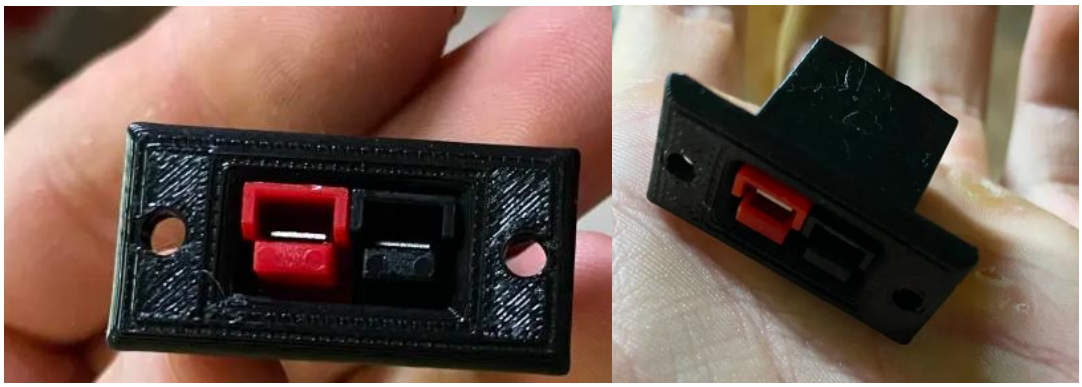


Figure 46: *The Anderson power pole mount printed to hold the power poles, allowing for a power cord to be inserted into the amp to power it. Note that two power poles can be viewed within the mount, showing a tight and strong fit with no wobble at all.*

To facilitate the mounting of PCBs to the enclosure required the design of several spacers. These spacers were required to offset the PCBs from the enclosure, making them evenly, and preventing solder joints from contacting the enclosure. Specifically, it was determined that three sizes of spacers were needed, which included 3mm inner diameter, 4mm outer diameter cylindrical spacers with varying lengths of 3mm, 6mm and 12mm. The inner diameter of 3mm was selected as this was the mounting hole diameter of all the PCBs. These spacers can be viewed in Figure 47 below.

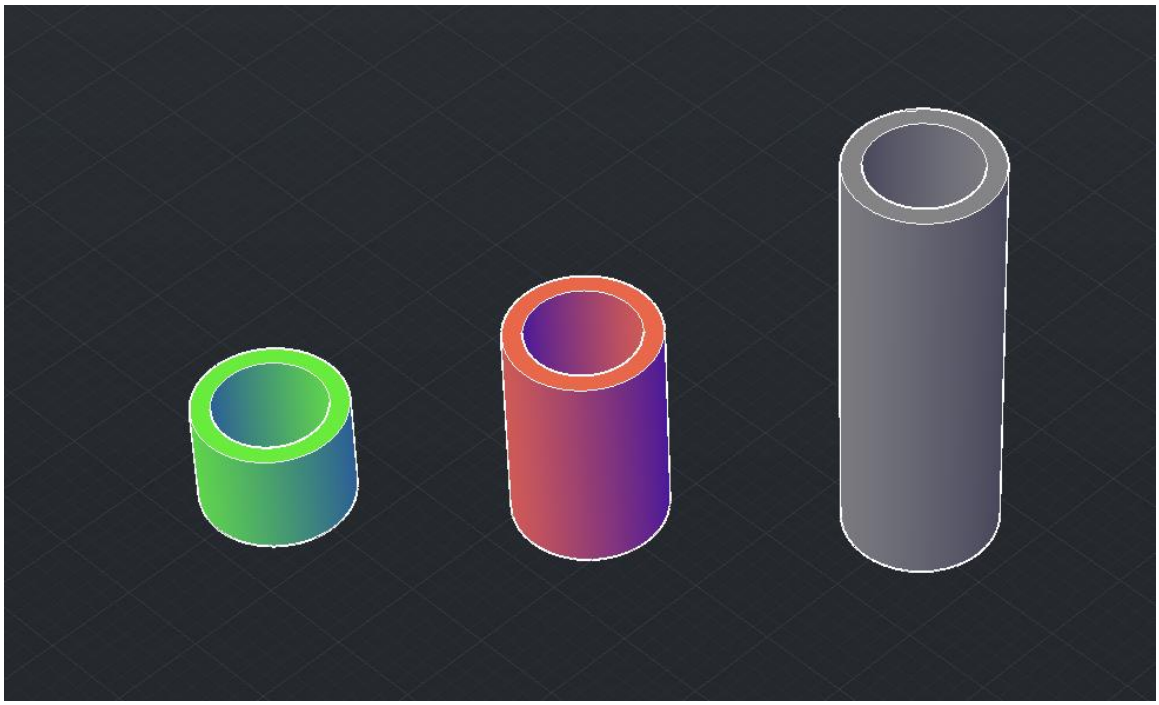


Figure 47: *The 3D printed spacers designed to enable the PCB boards to be mounted to the enclosure. Each has an inner diameter of 3mm, an outer diameter of 4mm. The lengths include 3mm, 6mm and 12mm.*

To allow the amplifier to sit evenly, a foot design was also drafted, which consisted of a 15mm x 15mm x 10mm box with a countersunk hole for an m3 screw. What was unique about this print was the material used to print it, that being thermoplastic polyurethane (TPU). All of the other printed components for the amplifier were produced using Polyethylene Terephthalate Glycol (PETG) filament, as this filament is strong and resistant to deformation when subjected to high temperature [58]. However, PETG is rigid and slippery. TPU on the other hand has rubber-like properties, making it slightly squishy and sticky [58]. This property of the printed enclosure feet was incorporated to prevent the amplifier from slipping if it was pushed or hit by accident. The TPU foot design can be viewed in Figure 48 below.

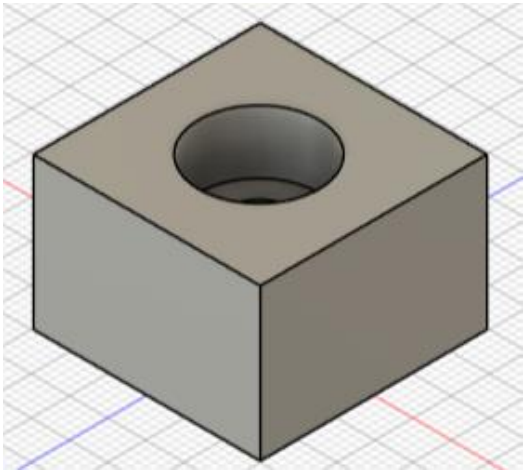


Figure 48: *The enclosure foot printed from TPU.*

To mount the heatsink to the enclosure body, a special 3D printed bracket (using PETG filament) was designed and produced. This bracket was a simple 10mm x 10mm rectangle of length 102mm, designed to fit flush in the enclosure box. However, on the bottom of each 10mm x 10mm face was a 3.72mm diameter hole designed to allow a heat set insert to be placed into the bracket. A heat set insert is a brass insert with threads (m3 in this case), that when heated and pressed into printed plastic, provides strong, durable and reusable threads for screws to attach to. A drawing of this enclosure and heatsink bracket mount can be viewed in Figure 49 below, and a 3D model of the bracket itself can be viewed in Figure 50 below.

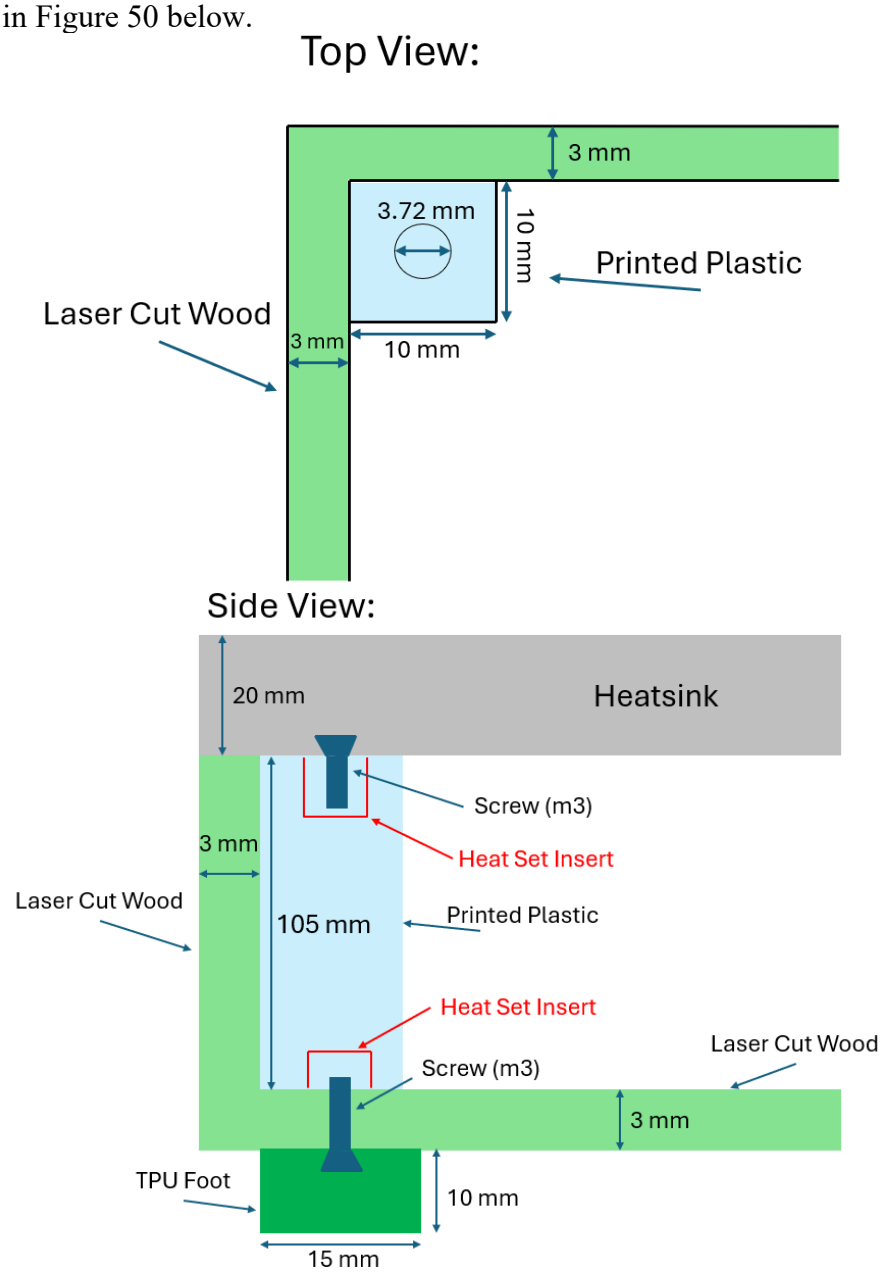


Figure 49: *The heating and enclosure mounting design, with the top view (top) showing the position of the heatsink mounting bracket relative to the enclosure walls, and the side*

view (bottom) showing how this bracket is used to mount the heat sink and TPU foot to the enclosure.

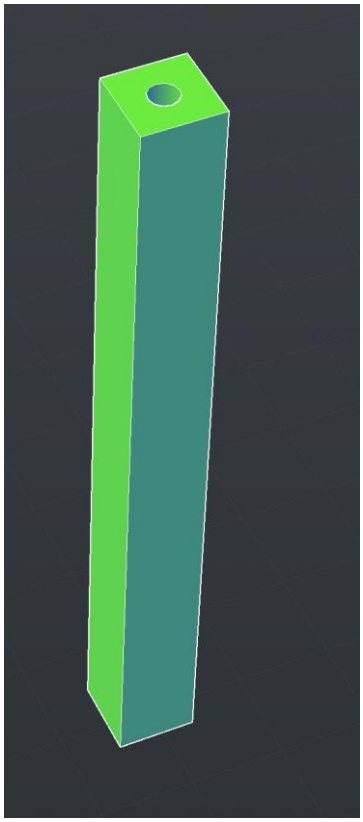


Figure 50: *The 3D printed bracket designed to mount the TPU feet and heatsink to the enclosure.*

To clarify, the design methodology used for developing the enclosure design, all of the 2D laser cut/engrave patterns were drafted using AutoCAD. However, the 3D printed part models were developed using two different CAD softwares, one again being AutoCAD, and the other being Fusion360. The reason for the variation in design software was based on group member choice, with each member selecting the software that he was most comfortable using.

The last step in the design of the enclosure that was required was to develop the isolation boxes for the filter circuits. In order to operate properly without experiencing interference from external noise, filters are placed in boxes that will isolate them from any electrical noise [42]. This isolation is typically achieved by utilizing a metal box, but as we had no access to metal fabrication equipment, a different design methodology was required to produce these critical enclosure components. After doing some further research, an interesting product, that being Faraday tape, was discovered. This tape is designed to be used for EMI/RF shielding, and was IEEE 299-2006 tested by Keystone Compliance Laboratory, with a top-rated shield effectiveness being reported [59]. Using this tape would remove the requirement for a metal box, as the Faraday tape would provide the shielding. However, a box was still required. Laser cut wood was again considered but was deemed a bit risky due to the high temperature experienced by the low pass filter. Looking at potential alternatives, black acrylic was determined to be the best option. This plastic is strong, thermally resistant, can stick to the Faraday tape effectively and can be cut on a

40W diode laser. As such, both designs for the band pass and low pass filters were drafted right away, this time utilizing a sliding lid design to facilitate smooth installation of the filter PCBs. The Faraday tape used to shield the boxes can be viewed in Figure 51 below, and the design for the band pass and low pass filter isolation boxes can be viewed in Figure 52 below.



Figure 51: *The Faraday tape used to shield the band pass and low pass filter circuits from EMI and RF interference.*

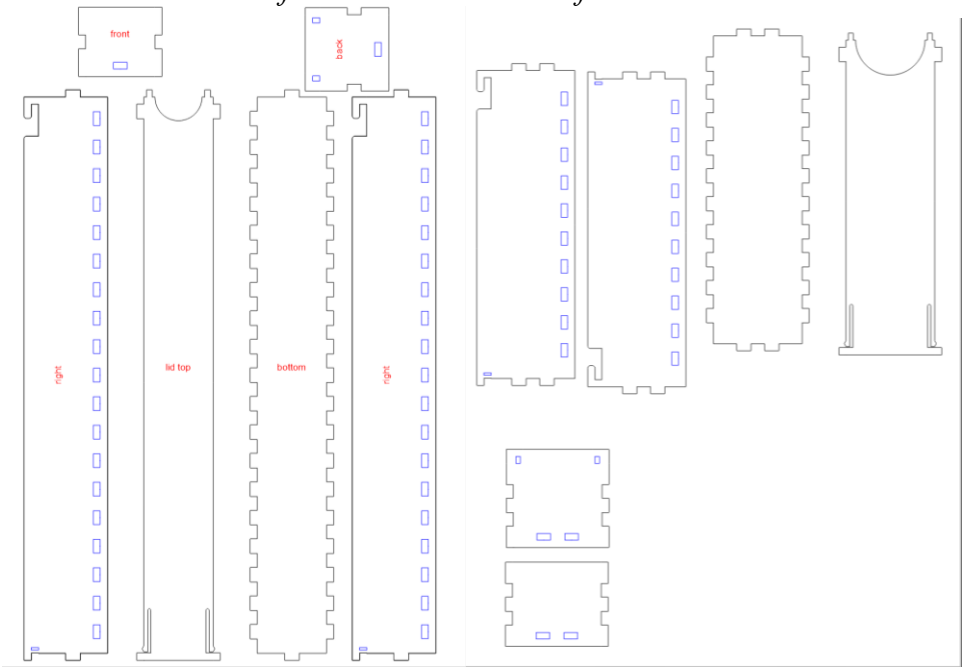


Figure 52: *The laser cut pattern design produced to create the isolation box for the low pass filter (left) and the band pass filter (right), cut from black acrylic plastic.*

During the completion of the design methodology and analysis, the EGBC code of ethics was top of mind, and every design methodology utilized by Group 4 was done to ensure that the amplifier design adhered to the stated principles. Some examples of compliance to these principles are highlighted below.

- **Principle #1 – Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the**
- **promotion of health and safety in the workplace:**
- The amplifier fuse circuit was designed to distribute power between the amplifier, fans, and SWR meter circuits to avoid a full system failure if a single subsystem failure occurred.
- The voltage regulator circuit was designed to keep fan voltage locked at 12V to prevent overheating.
- The amplifier cooling setup was designed with maximum heat dissipation in mind, with two 40mm fans on the sides, 120mm on top of the heatsink to ensure no overheating occurred.
- Every aspect of amplifier enclosure design was analyzed to ensure that the safest, most effective enclosure could be constructed.

- **Principle #7 – Provide professional opinions that distinguish between facts, assumptions and opinions:**
  - The filters were mathematically calculated by hand initially, then simulated using LTSpice to verify the hand calculated results.
  - The voltage regulator was simulated to ensure proper functioning, outputting 12.18V on a 13.6V input.
  - Inductor values in the filters were adjusted to match real-world parts, then re-simulated to confirm proper function.
  - Chebyshev low pass circuit component values were not taken at face value, and were recalculated and simulated to confirm the results.
  - Silver mica capacitors were researched and selected for their performance characteristics, as opposed to using more common but poorer performing capacitors in Group 4's filter designs.

- **Principle #10 – Present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded:**
  - Design schematics and PCB layouts were professionally labelled to allow all readers to understand them.
  - Enclosure panels engraved with instructions and safety markings to ensure the amplifier could be effectively utilized in the field.
  - Every step of the chosen design methodology was clearly and transparently presented in this report, to ensure that readers understood the rationale and methodology behind every design choice made in this project.

- **Principle #13 – conduct themselves with fairness, courtesy and good faith towards clients, colleagues and others, give credit where it is due and accept, as well as give, honest and fair professional comment:**
    - Tasks were divided between group members by skillset, to ensure that tasks were completed efficiently and effectively.
    - Group members were allowed to select their CAD of choice when designing 3D printed parts, enabling members to work with the software they were most comfortable with.
    - The mode select circuit was given its own PCB so SSB delay tuning could be completed in the future without having to tear into the main amplifier board, easing maintenance duties for colleagues.

VII Design & Prototype

Once the design methodologies were implemented, and all relevant PCBs were develop, the focus of the project shifted to ordering these electrical components so that the prototype could be assembled, tested and verified. This required ordering all of the components from various sources, primarily being Amazon, Dijikey, Mouser and JLC PCB. Once all components arrived, assembly was started immediately to ensure the prototype was assembled, tested and validated prior to the ECE 499 project demonstration.

The first task conducted in the assembly was the widening of the custom, high wattage inductors. Recall that this filter required five inductors, each with an internal diameter of 1 cm, using 1.8mm winding wire. This included two inductors with an internal diameter of 1cm, and length 1.8cm with six turns of wire. Two other inductors required a length of 2.5cm, with eleven turns of wire. The last inductor was slightly larger than the previous two, requiring a length of 2.8mm, using 12 turns of wire. Initially, winding the wire manually around the 3D printed inductor jigs was attempted. However, this method was not successful due to lack of ductility in the wire, making hand wrapping impossible. As such, to produce these inductors required thinking outside the box. Looking at various strategies for wrapping inductors, none were found that would work on that thick a winding wire. Therefore, a new strategy inductor winding strategy was developed. This winding technique involved creating a custom tool using a $7/16^{th}$ inch bolt and nut to wrap the inductor wire onto. This size of bolt was selected because the inner diameter of the threads is .95cm, the outer diameter of the threads is 1.1cm and the distance between the threads is approximately 1.6mm. By winding the inductor wire on the threads of the bolt, it would ensure that the coil would have even turns and a consistent, accurate inner diameter. This bolt was modified by drilling a hole through it at the base of the threads, allowing the winding wire to be initially inserted. To force the wire to wind onto the bolt's threads required the fabrication of a $7/16^{th}$ inch nut with a specialized notched lip that forced the inductor wire onto the threads. This nut was fabricated by using a grinder to remove the material to create the correct inductor winding notch. In Figure 53 below, the custom bolt and nut can be viewed closeup, and in Figure 54 below, the procedure for using the tool to produce the inductors is illustrated.



Figure 53: *The customized bolt (left) and nut (right) inductor winding tool that was fabricated to allow the inductors to be wound. Note the drilled hole in the bolt to allow the winding wire to be initially inserted, and the large notch ground into the bolt to enable the tool to shape the wire into an inductor coil.*



Figure 54: *Inductor winding steps, including the initial wire insertion (top left), the inductor winding (top right), the wrapped coil on the bolt (bottom left) and the finished inductor coil (bottom right).*

Viewing Figure 54 above, to use the inductor winding tool first required inserting the winding wire through the hole at the base of the threads, and then threading the winding nut onto the bolt, continuing to thread it until the point right before the inductor forming notched lip came into contact with the wire. This nut was gripped with a vice to ensure it remained motionless, and one group member held onto the winding wire to keep the feeding position constant. The other member, using a ratchet, turned the bolt, forcing the winding wire through the forming nut, wrapping it to the wire. The bolt was turned until the winding wire was wound into every thread on the bolt. Once this step was completed, the wire that was inserted through the hole in the bolt was pounded out using a hammer and punch. Then the coil was simply unscrewed off the bolt, resulting in a perfectly sized inductor coil that could be fabricated into any of the five required inductor lengths by bending the wire to the required number of turns and length. These inductors were tested with the 3D printed gauges to ensure proper coil length and the internal diameter was properly sized, and then the legs of each coil were bent to the proper size to fit on the PCB. This PCB inductor fit test can be viewed in Figure 55 below.

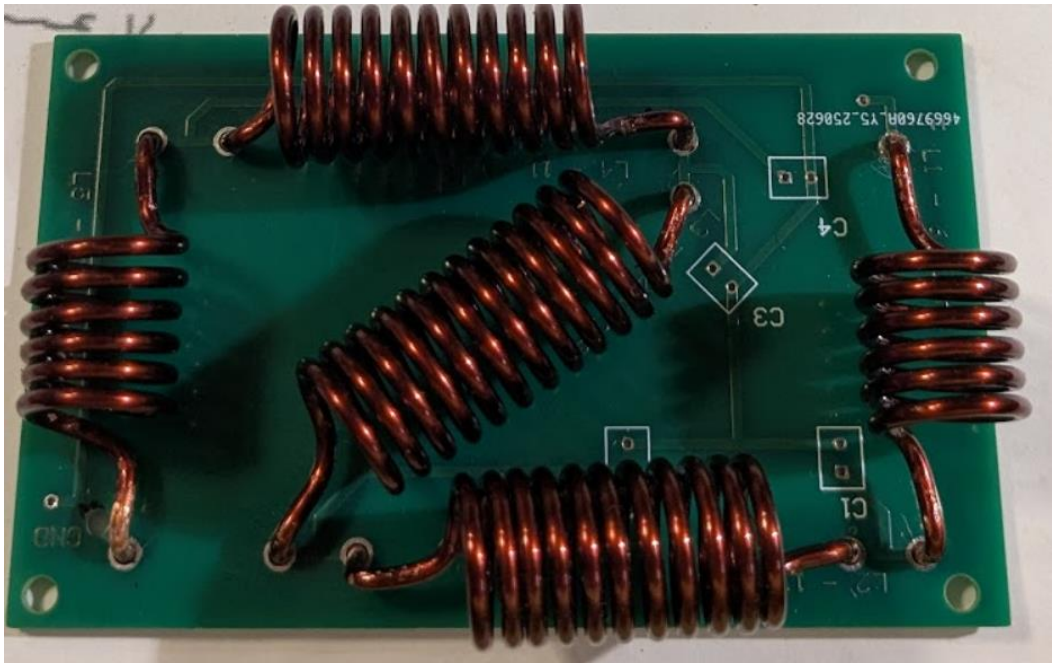


Figure 55: *Testing the fit of the inductor on the PCB.*

An interesting issue that was encountered when winding the coils was the roughness of the bolt's threads. This roughness was causing the wire coating on the internal diameter of the coil to peel off. While not likely to cause an issue, there was a concern that if the coil windings did touch directly without the insulation of the enamel coil, it would affect the inductance of the coil, and by extension the filter performance. Therefore, to resolve this issue, the bolt was put in a tumbler with steel pins for several hours. This tumbler forced the steel pins to rub over the bolt, deburring the bolt, smoothing all of the threads. It also removed the chrome coating of the bolt, which is why in Figure 53 the bolt is dark grey, but in Figure 54 the bolt is chromed, as the tumbler removed the chrome finish during the deburring process, smoothing the bolt. With this modification, the coils were wound without any damage to the wire coating.

The next step of the construction process was to wind the coupling transformers for the SWR/power meter. This design required four transformers, each wound with twenty-four turns of winding wire. This wire was wound around ferrite cores. The process for winding these transformers can be viewed in Figure 56 below.

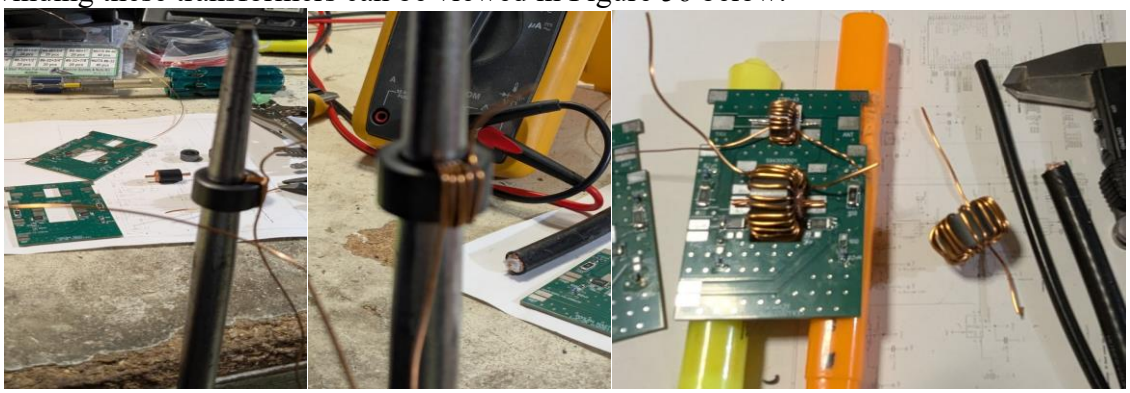


Figure 56: *The coupler transformer winding building process. This included placing the ferrite core on the end of a crowbar (right). Then, 24 turns of winding wire were wound around the core (middle). A custom length of RG174 cable was cut and inserted through the core, and the fit was tested on the coupler PCB (right.)*

Viewing Figure 56 above, to wind the transformers, first the ferrite core was placed on the end of a crowbar. Then, twenty-four turns of winding wire were wound around the core (middle). A custom length of RG174 cable was cut and inserted through the core, and the fit of the transformer was tested on the coupler PCB.

With all the wire winding completed for the project, the next step was to assemble all of the PCBs by soldering the required components to the boards. This task was initially started by soldering the simple PCBs, that being the mode select, voltage regulator and fuse PCB boards. The results of soldering the boards can be viewed in Figure 57 below.

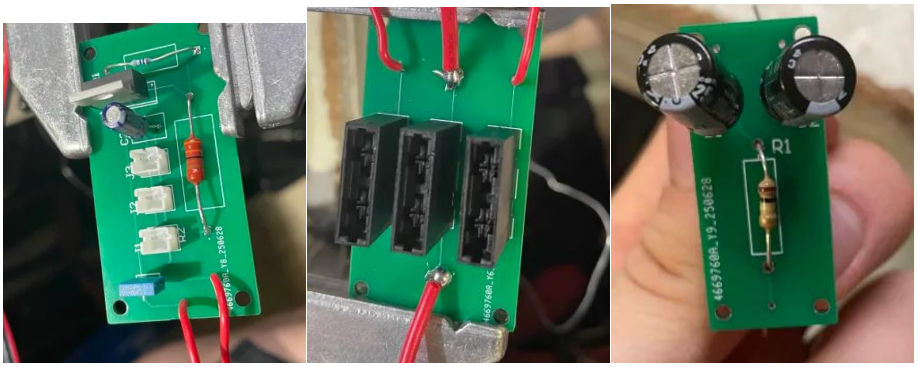


Figure 57: *The assembled voltage regulator (left), fuse (middle) and mode select (right) PCBs.*

The assembly of these boards was relatively straight forward, with no major hiccups encountered during the soldering process. However, a potential board design issue was noticed on the fuse PCB. The traces on the DC input and the amplifier circuit power feedlines were noticed to be very thin, too thin to handle a 25 A current draw required by the circuit. Therefore, to remedy this issue before failure, a 30 A rated wire was soldered to the base bottom of the PCB to ensure that the thin trace would not fail. This board repair can be viewed in Figure 58 below.

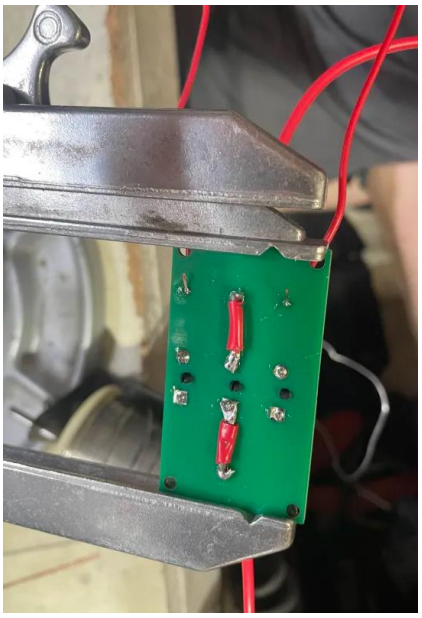


Figure 58: *The fuse PCB's repair, using high amperage wire jumpers to ensure that the high amperage draw through the tiny PCB traces would not cause board failure.*

The next PCB that was assembled was the bandpass filter PCB. This board went together relatively smoothly. Only one small issue was encountered. The through holes for the 1 nF capacitors (C3 and C4) were slightly too small, and the cap legs would not fit. This was quickly fixed by gently expanding the through hole with a .8mm micro drill bit, to allow the capacitor to fit without issue. The continuity of the through hole was tested to verify that this modification did not affect board function. The completed bandpass filter PCB can be viewed in Figure 59 below.



Figure 59: *The assembled bandpass filter PCB.*

The next filter that was assembled was the lowpass filter. Similar to the assembly of the bandpass filter, this lowpass filter was also assembled relatively smoothly. However, there was a layout issue with the capacitors. The design footprint used in Altium for the capacitors was too small for the silver mica capacitors. In order to fit, they had to be soldered to the bottom of the PCB. The assembled bandpass PCB can be viewed in Figure 60 below.

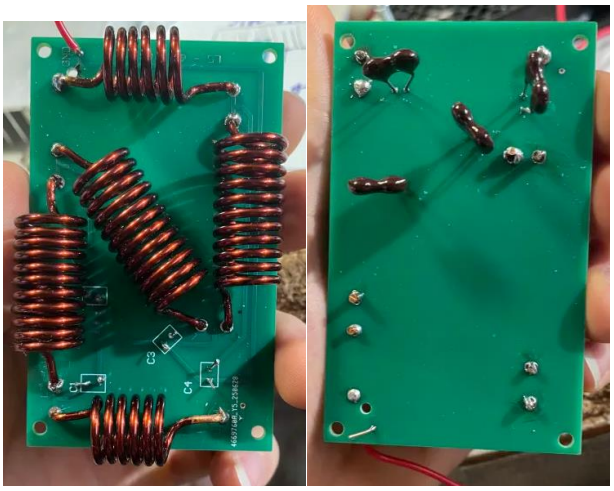


Figure 60: *The assembled lowpass filter PCB, with the coils mounted on top (left) and the capacitor mounted on the bottom (right).*

However, due to problems with the PCB layout, serious issues in the filter's frequency response were revealed during testing. This is discussed in detail in the next section of the report, but to fix the filter's performance required abandoning this PCB layout, with the coils being soldered directly to one another in a layout that would prevent the coil fields from interacting. This updated lowpass filter layout can be viewed in Figure 61 below.



Figure 61: *The updated lowpass filter, directly soldered one to one another (top), and this filter setup was epoxied into the acrylic board (bottom).*

The next board that was assembled was the amplifier PCB. This PCB was far tricker than the previous circuit boards, with a variety of unique component that made assembling this board a major challenge. This board was soldered in two stages. The first being up to the point where the MRF454 transistors were to be soldered. Figure 62 below shows several photos compiling the board construction progress up to this point.

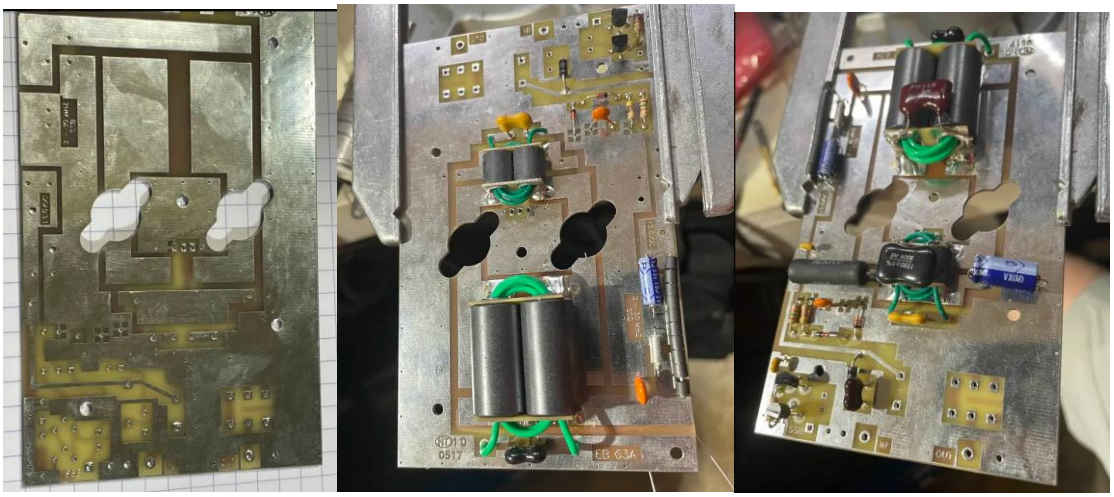


***Figure 62*:** The first stages of soldering the amplifier PCB, starting with a blank PCB (left*), assembling the COR circuit and the transformers, and the bias supply circuits (middle and left).*

At this stage of assembly, before installing the MRF454 transistors, a small test was conducted to ensure that bias supply was providing the correct voltage, as too large a bias voltage could damage the MRF454 transistor. Therefore, a 10 Ω resistor was temporally soldered across a transistor base pad and the ground plane, providing a small load to enable measuring the bias voltage. The bias voltage from one transistor was measured to be 0.691 V, and the other was measured at 0.6896 V. Both bias voltages were within the anticipated range of 0.66 to 0.74 V, indicating that this circuit was operating correctly. The set up used to conduct this intermediary test can be viewed in Figure 63 below.

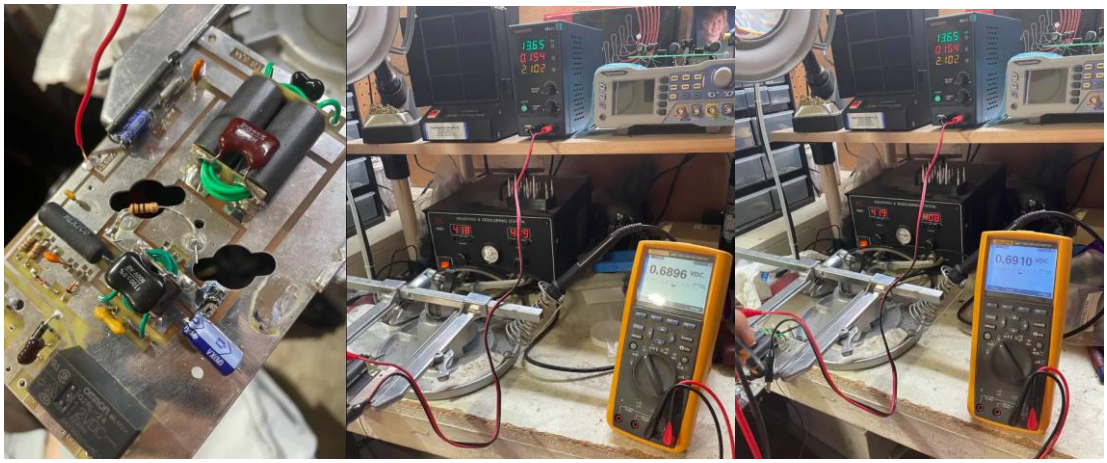


Figure 63: *The intermediary bias voltage test conducted to ensure that the bias voltage for the MRF454 transistors were within the correct operating range. Observe the resistor soldered across the transistor pad to simulate a load (left), and the values for bias voltage measured across each transistor (middle and right).*

After this test was passed, the remainder of the components were soldered to the amplifier board. The completed board can be viewed in Figure 64 below.

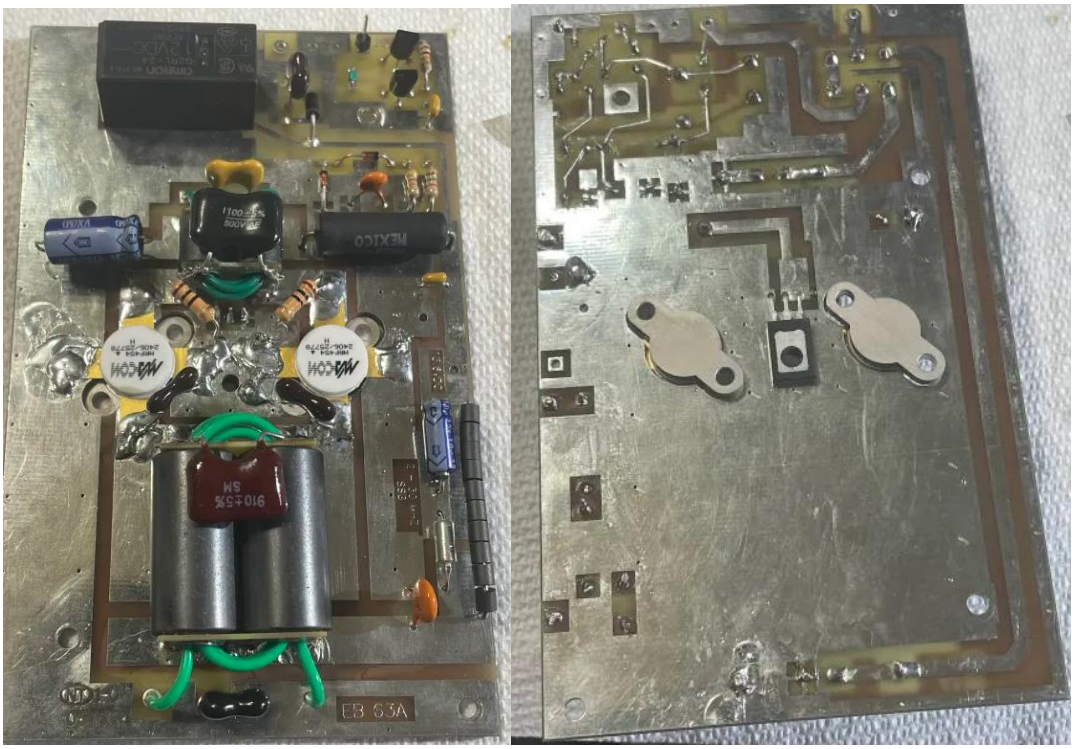


Figure 64: *The completed amplifier board, with the top of the board (left), and the bottom of the board (right).*

The next board that was soldered was the SWR meter microcontroller board. This board was very tricky to solder due to the high volume of very small SMDs. However, no issues were encounted in the assembly of this PCB, and the resuliting board can be viewed in Figure 65 below.



Figure 65: *The completed SWR meter microcontroller board, note the high volume of SMDs.*

At this stage of the development, it should be mentioned that Group 4 was forced to abandon the addition of the SWR/power meter feature into the prototype. This was due to an incompatibility issue between the acquired screen and the SWR microcontroller PCB.

This meter board required a 3.5” TFT LCD screen with an ILI9488 driver using serial peripheral interface (SPI) protocol. Our group ordered a 3.5” TFT LCD with the correct driver ILI9488 driver. However, unbeknownst to the group members, this screen that was ordered did not support SPI. After much troubleshooting, this incompatibility issue was discovered. At this point, there was insufficient time remaining before the demonstration to order a replacement LCD. Therefore, the fallback strategy of jettisoning the SWR/power meter feature was employed, putting this feature on the backburner to focus on delivering a prototype with all of the critical subsystems working as intended.

With all the PCBs assembled, the next step was to mount the amplifer board dirctly to the heatsink. It was decided to place the amplifier directly in the center of the heatsink bottom. The 120mm cooling fan was placed in the center, on the top of the heatsink to ensure that cool air was forced over the hottest part of the heatsink. Note that before the amplifier was installed, the blank PCB board was used to make the heatsink to prepare for tapping it. This marking can be viewed in Figure 66 below.

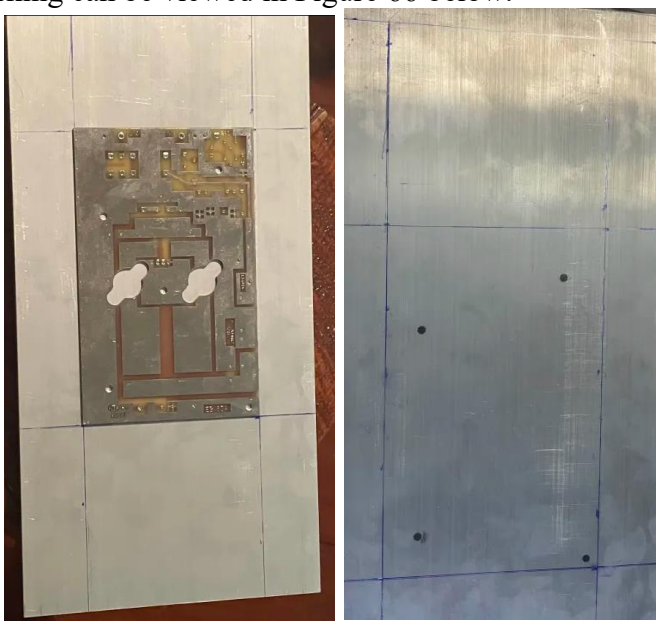


Figure 66: *Measuring and marking the heatsink to tap mounting holes for the PCB and fan, using the PCB as a stencil (left) and the resulting measurements and markings (right).*

The required holes were tapped, first by drilling a pilot hole, and then running through a #4-32 machine screw tap to create the threads. The same procedure was followed to tap the mounitng holes for the cooling fan, but using an #8-32 screw tap to create the threads.

To prep the amplifier for mounting to the heatsink, the bases of the transisters were each given a dap of thermal compound to facilitates proper heats transfer beteween the amplifier and the heatsink/ Arctix MX-5 thermal compound was used as this paste has an excellent repulation for use in PC CPU cooling (being used for the past 4 years in group member Hudson’s desktop). Note that an insulating mica washer was inserted between the MJE transistor and the heatsink, to prevent shoriting out the bia supply, with thermal compound being applied to both sides of the mica washer. The amplifier PCB was then mounted to the heatsink using the tappeed screwholes, with this board ready for implementation into the final prototype (after some individual testing which is discussed in the next section of

the report). The set up taken to mount the amplifier PCB to the heatsink can be viewed in Figure 67 below.

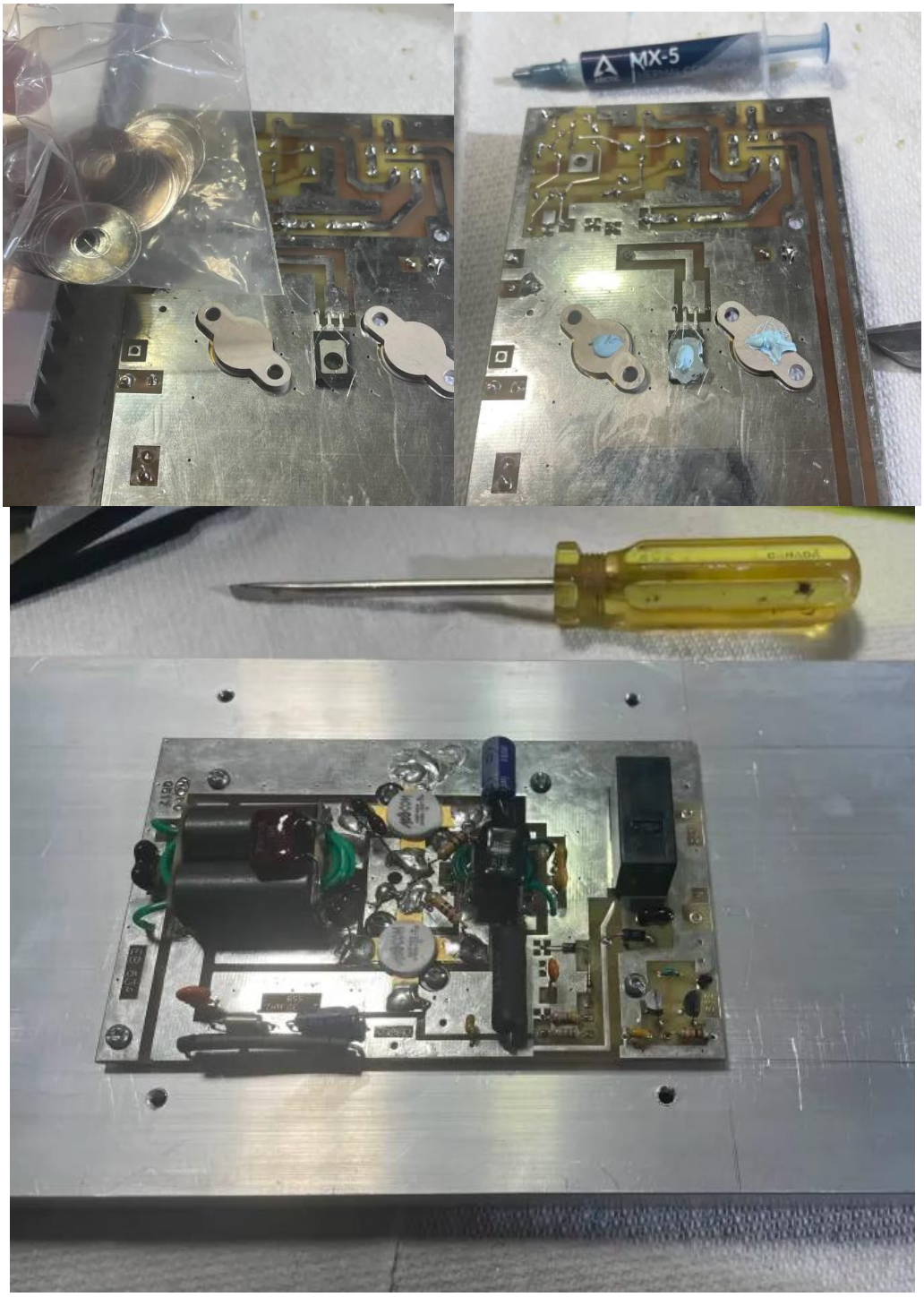


Figure 67: *Mounting the amplifier to the heatsink, using the insulating mica washer (top left) and thermal compound (top right), before screwing the PCB into the heatsink to secure in (bottom).*

At this point in assembly, the focus was shifted from the amplifier PCB to the creation of the filter isolation boxes. As discussed in the design methodology section, the intention was to create the boxes using black acrylic. However, given the limited supply of that material, prototypes of these boxes were cut from wood first before making the acrylic boxes. An example of a prototpye wood box to test the fit of the lowpass filter can be viewed in Figure 68 below.



Figure 68: *The prototype laser cut box used to test the fit of the LPF isolation box design.*

Each box was then cut from the acrylic, with the filters being mounted to the base of the filter box, before being wrapped in Faraday tape. Note that prior to wrapping the Faraday tape, shielded and terminated RG316 coaxial cables were installed to ensure the signal remained unaffected by noise. The procedure used to create these isolation boxes is highlighted in Figure 69 below.

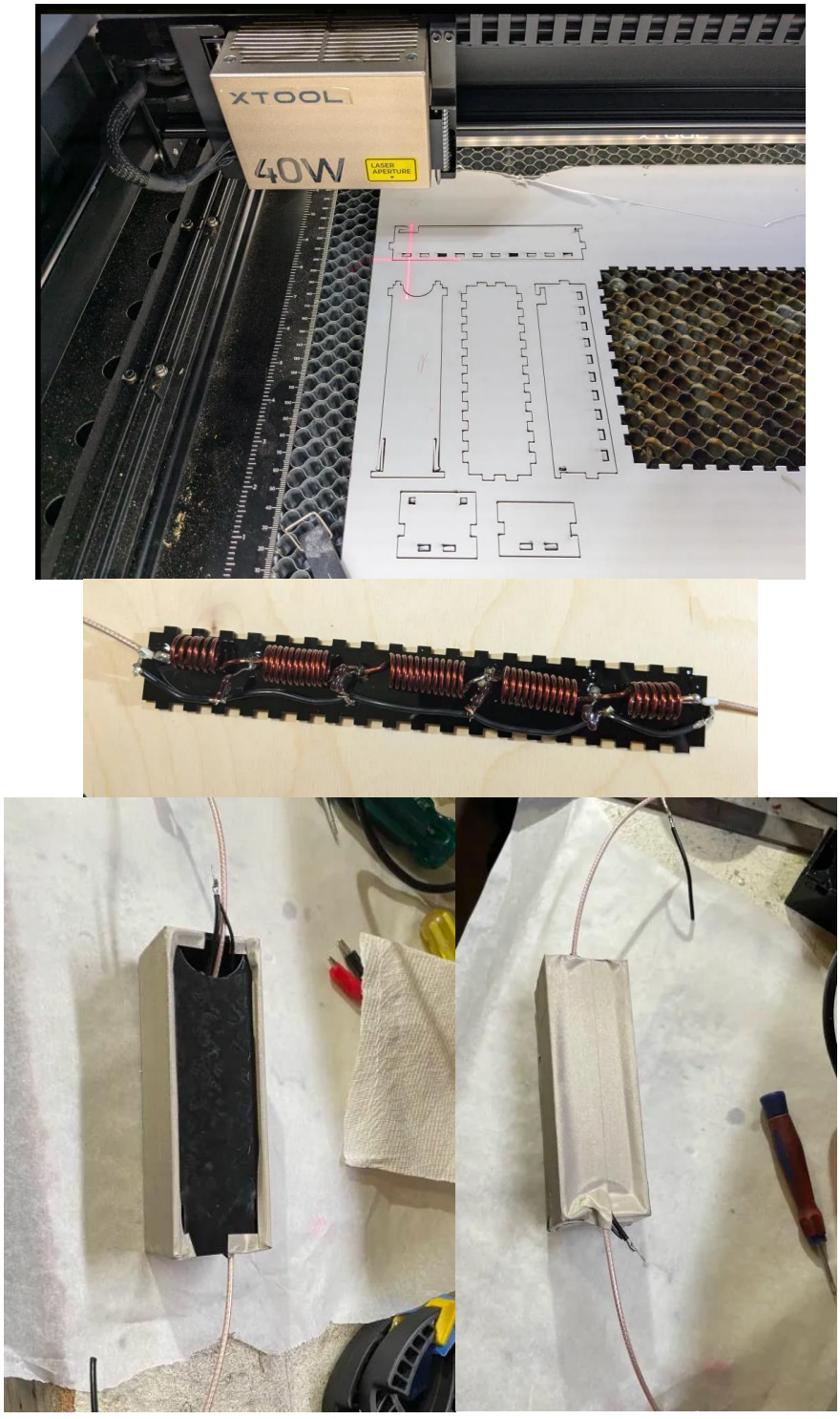


Figure 69: *The process of producing a filter isolation box, starting with cutting the acrylic with the laser (top), mounting the filter to the center of the box (middle) and assembling the box, as well as wrapping it with Faraday tape (bottom left and right).*

The next task was to print the required components, which involved taking the 3D models, which were drafted in the previous report section. These models were sliced using Bambu Studio to obtain G-code, and running the G-code on the Bambu Lab X1C printer to produce the parts. Figure 70 below displays the slicer settings used to generate the G-code for various printed components.

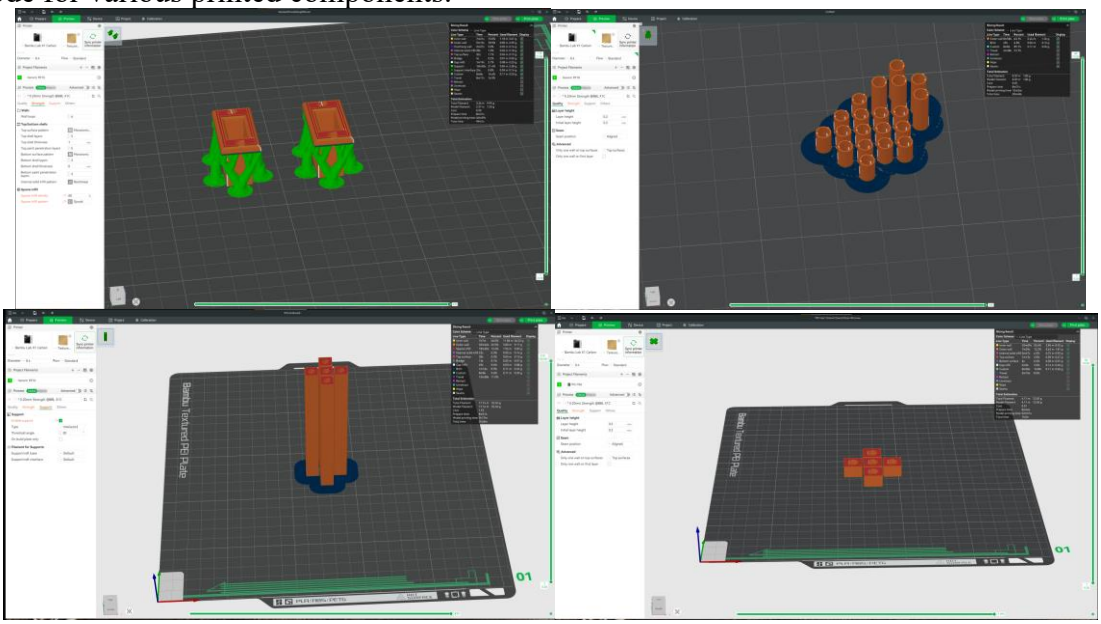


Figure 70: *The slicer results for various printed components including the Anderson power pole mounts (top left), PCB spacers (top right), heatsink mounting brackets (bottom left) and the TPU enclosure feet (bottom right), used to generate the G-code that was run on the printer to produce the components.*

Note that the heatsink mounting bracket required some further assembly post-print, inserting heat set inserts into the holes to give the model strong m3 threads. First, an insert was placed in the mounting location, namely a hole on the face of the bracket. Next, a heated soldering iron on a custom pressing tool was used to evenly press the heat insert into the plastic. Once inserted, the iron was removed, leaving a perfectly placed set of m3 threads embedded in the plastic. Figure 71 below illustrates the procedure utilized to install the heat set inserts.



Figure 71: *The procedure used to install the heat press insert, with first the insert being placed on the bracket hole in a position ready to be inserted into the model (top left), then the heated soldering iron was used to press the insert into the plastic (right), leaving strong threads embedded within the plastic (bottom).*

The last step of the enclosure fabrication step was to cut the main enclosure body. As discussed early, this was intended to be cut out of wood (specifically 3mm wood) to enable clear labeling of the amplifier's peripherals. To cut the wood, the AutoCAD files were converted to SVGs, then worked into cut and engraving paths for the laser to execute. One interesting trick that was employed was that the wood was covered in painter's tape prior to being cut, as this reduces the amount of excess burn around the engraving, keeping lettering sharp and easy to read. Figure 72 below shows the laser cutting a piece of the enclosure body, as well as the face of the amplifier before the painter's tape was removed.

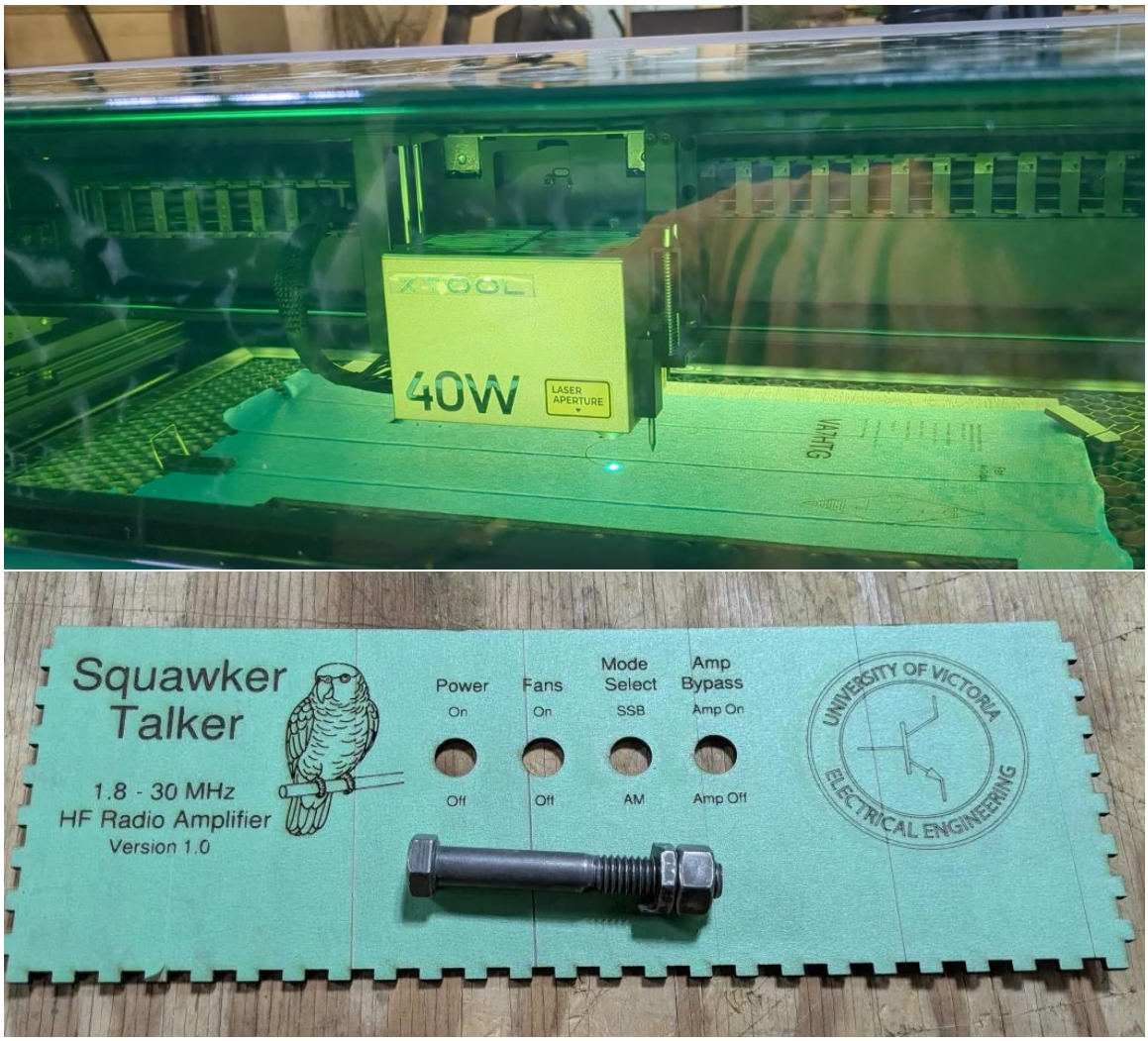


Figure 72: *The laser cutting the enclosure, specifically one of the side panels (top), and the fully cut and engraved front panel (bottom).*

With all the enclosure panels cut, and PCBs completed, it was time to assemble to completed prototype. This involved several steps, including gluing and assembling the enclosure body together, and installing the heatsink brackets, enclosure feet, PCBs and various amplifier peripherals (using m2 screws and nuts) and correctly wiring and grounding every piece of the amplifier together. Images from the amplifier construction can be observed in Figure 73 below.



Figure 73: *Assembling the Squawker Talker amplifier including assembling the enclosure body (top), mounting the isolated filter boxes and the Fuse PCB and grounding the RF output SO239 jack (middle left and right) and installing the rear panel peripherals (bottom).*

With the enclosure assembled the Squawker Talker prototype amplifier design was completed, with every critical subsystem being integrated into the final product. The completed amplifier prototype can be viewed in Figures 74 and 75 below.



Figure 74: *The completed Squawker Talker amplifier prototype, showing the front panel (top), back panel (middle), side panels (bottom).*

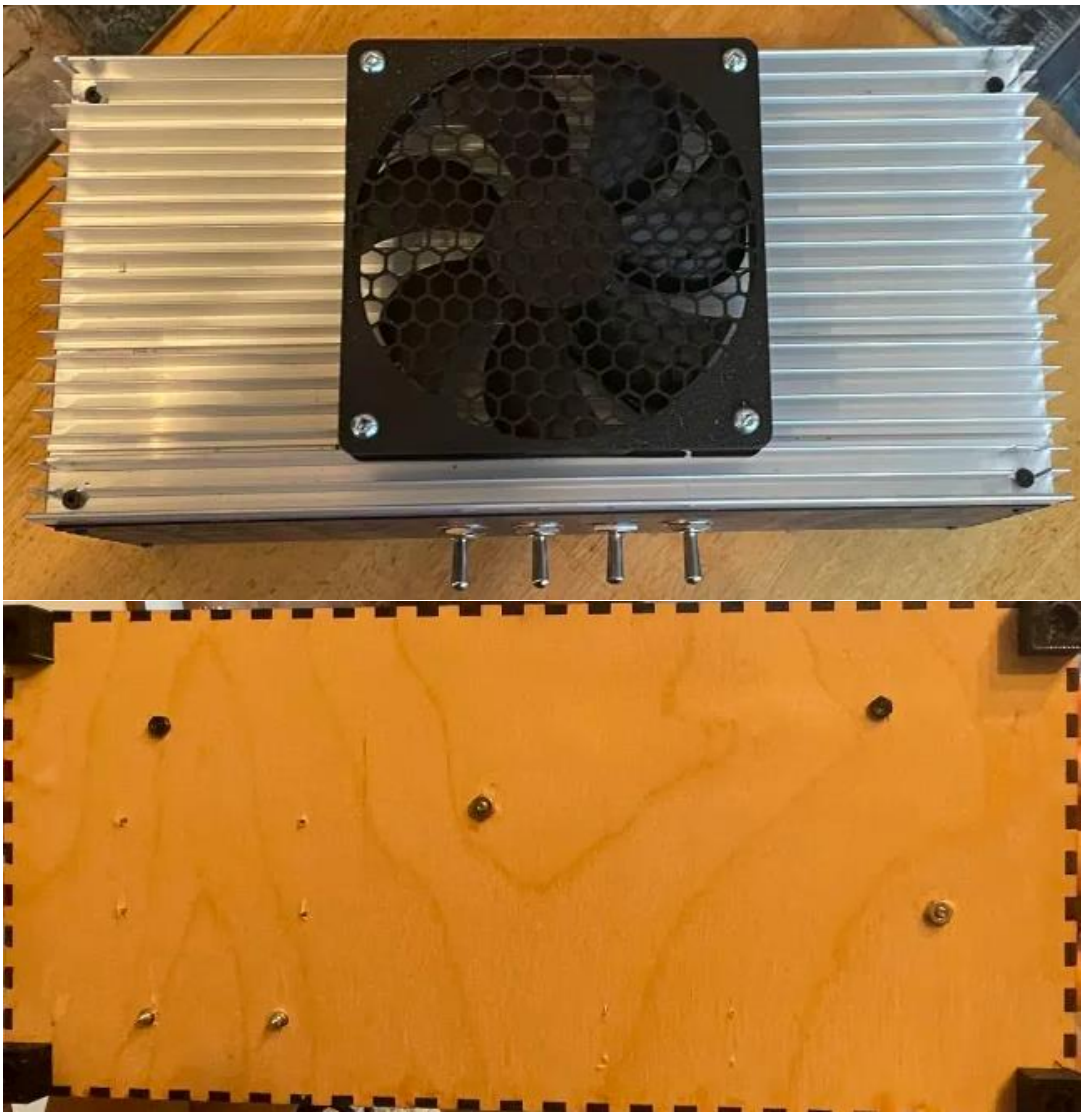


Figure 75: *The completed Squawker Talker amplifier prototype, showing the (top) and (bottom) of the design.*

Therefore, the final design of the Squawker Talker was assembled. Comparing the results of the final design to the specifications of the amplifier, the following specifications were met.

Amplifier

- Portable, less than 3 kg. ✓
- Compact, must be smaller than 3000 cm^3. ✗
- Sufficient cooling, utilizing heatsinks and fans. ✓
- Use standard SO239 jacks for amp input/output. ✓
- Affordable, must cost less than $600 to construct. ✗
- Must have fuse protection. ✓

Amplifier Circuit Specifications

- High Gain, 5 W input amplified to 80 W–150 W output. ✓
- Runs on 13.6 V power. ✓
- Linear operation. ✓
- User-selectable AM/SSB modes. ✓
- Manual bypass switch. ✓

Bandpass Filter Specifications

- Passband: 1.8–30 MHz (HF Spectrum). ✓
- Rated to 10W. ✓

Lowpass Filter Specifications

- Cutoff everything above 30 MHz. ✓
- Rated to 150W. ✓

Viewing the specifications above, it was determined that every specification of the critical subsystems was met or exceeded. The only two specifications not met were the cost and the volume of the prototype. However, not meeting these specifications had no impact on practical electronics performance of the amplifier (more detail on the specifications is overviewed in the Testing and Validation Section of the report).

This prototype was confirmed through testing and validation (covered in detail in the next report section) to meet all three of the objectives set out at the start of the project, including:

- To design and evaluate a high-frequency (HF) radio amplifier operating from 1.8–30 MHz, with integrated lowpass and bandpass filters for harmonic suppression and signal clarity.
- To prototype, test and verify a functional, portable linear amplifier with cooling considerations and built-in filtration.
- To analyze and demonstrate the feasibility of HF communication infrastructure as a low-cost emergency communication solution for rural and disaster-affected regions.

Through the completion of the design phase, Group 4 did in fact design and evaluate a 1.8 – 30 MHz amplifier design with built-in filtration, utilizing varying design methodologies to ensure every aspect of the design, from component selection to enclosure design and detailing was covered. The prototype was constructed, tested and verified, validating all of the technical amplifier specifications (see next section of the report for the testing results. During testing the feasibility of utilizing an HF amplifier for signal was also demonstrated (see next section of report for specifics), indicating that an amplifier such as the Squawker Talker has the potential to greatly improve emergency communications in natural disaster relief efforts.

VIII Testing & Validation

To complete the testing of the amplifier, each of the three primary subsystems, that being the LPF, BPF and amplifier PCB were tested, analyzed and adjusted prior to assembling the full prototype. As such, the discussion of the prototype testing will be broken up into specific discussions on each of the three subsystems.

To test the lowpass and bandpass filters required the use of a vector network analyzer (VNA). A VNA is a piece of testing equipment that measures the s-parameters of an electrical network [60]. In this project, the VNA utilized to test both the LPF and the BPF was a NanoVNA. The NanoVNA employed for this test can be viewed in Figure 76 below.

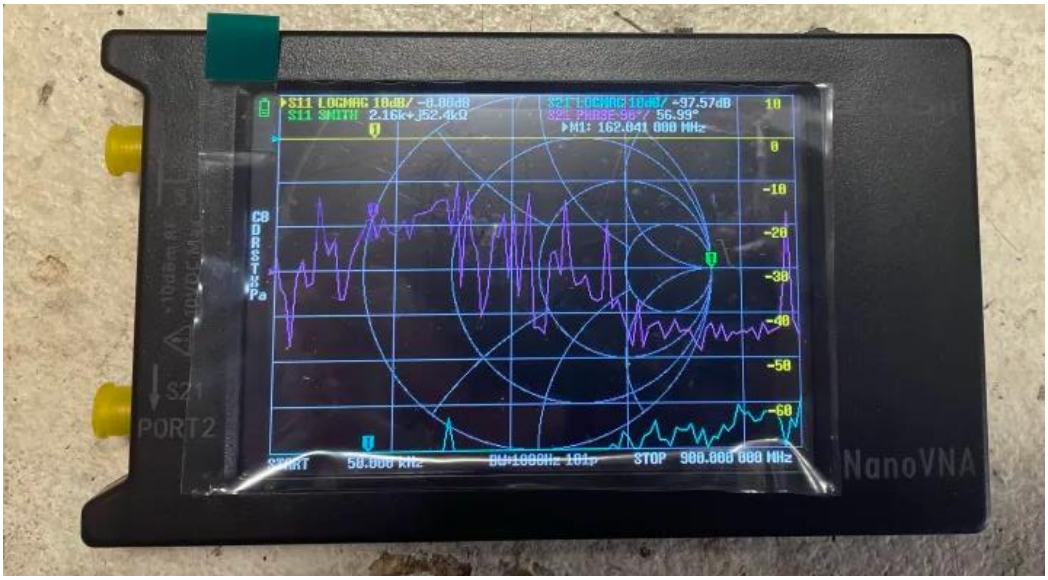


Figure 76: *The Nano VNA used to test both the bandpass and lowpass filters for the amplifier.*

As can be observed, the NanoVNA has two test ports, which enable it to measure four S-parameters, including S_{11}, S_{21}, S_{12}, and S_{22}. To test the filter, measuring the frequency response of the forward voltage gain, that being the S parameter S_{21} was required. To enable this test, a frequency sweep range of 100 kHz to 80 MHz was set, to highlight the performance before and after the cutoff frequency of the filter. The analyzer was calibrated to these test parameters, and the original lowpass filter PCB displayed in Figure 76 above was connected to the VNA. The resulting frequency response of the lowpass filter can be viewed in Figure 77 below.

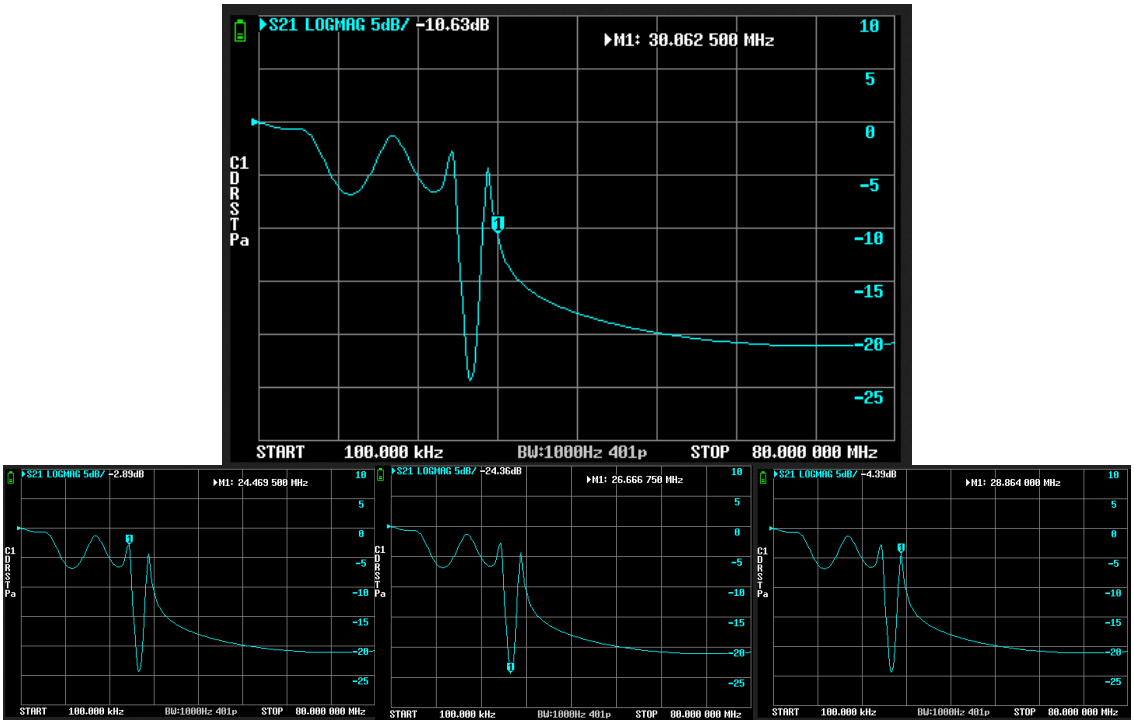


Figure 77: *The initial frequency response of the lowpass filter PCB, showing the cutoff frequency (top), and the beginning, end and lowest point of the attenuation spike (bottom left, right and middle respectively).*

Looking at the frequency responses in Figure 77 above, it can be observed that there were some issues with this filter. The cutoff frequency of 30 MHz was noted to be located at a point of -10.63dB, indicating that the frequency cutoff and corresponding filter attenuation was occurring earlier than it should. Specifically, there were clear, large ripples in the passband, with a large attenuation spike between 24.469 MHz and 28.864 MHz, with the peak of this attenuation occurring at 26.666 MHz, where the attenuation was -24.36dB. This attenuation spike was very poorly located, impacting both the 12m and 10m band performance. Not only are these two bands popular for general radio usage, 10m is the only band that our testing antenna was resonant on, meaning that preceding with this filter configuration would lead to serious performance issues. As such, the lowpass filter layout was experimented upon. Eventually, it was discovered that the layout of the PCB, specifically some of the capacitor traces under the inductors were causing parasitic capacitance. This parasitic capacitance affected the frequency response of the lowpass filter. Additionally, the proximity of the inductor coils to one another on the PCB was a notable concern. Given that these custom produced hand-wound inductors were unshielded, close proximity would likely cause interference between the magnetic fields, leading to adverse coupling. Due to the issues with the PCB layout and the corresponding poor filter performance, it was decided to rebuild the filter circuit in an improved configuration, with the coils spaced properly apart and no traces under the coils, as was shown and discussed in the previous report section (see Figure 77 above). This improved lowpass filter layout was retested with the NanoVNA, and the resulting forward voltage gain frequency response results can be viewed in Figure 78 below.

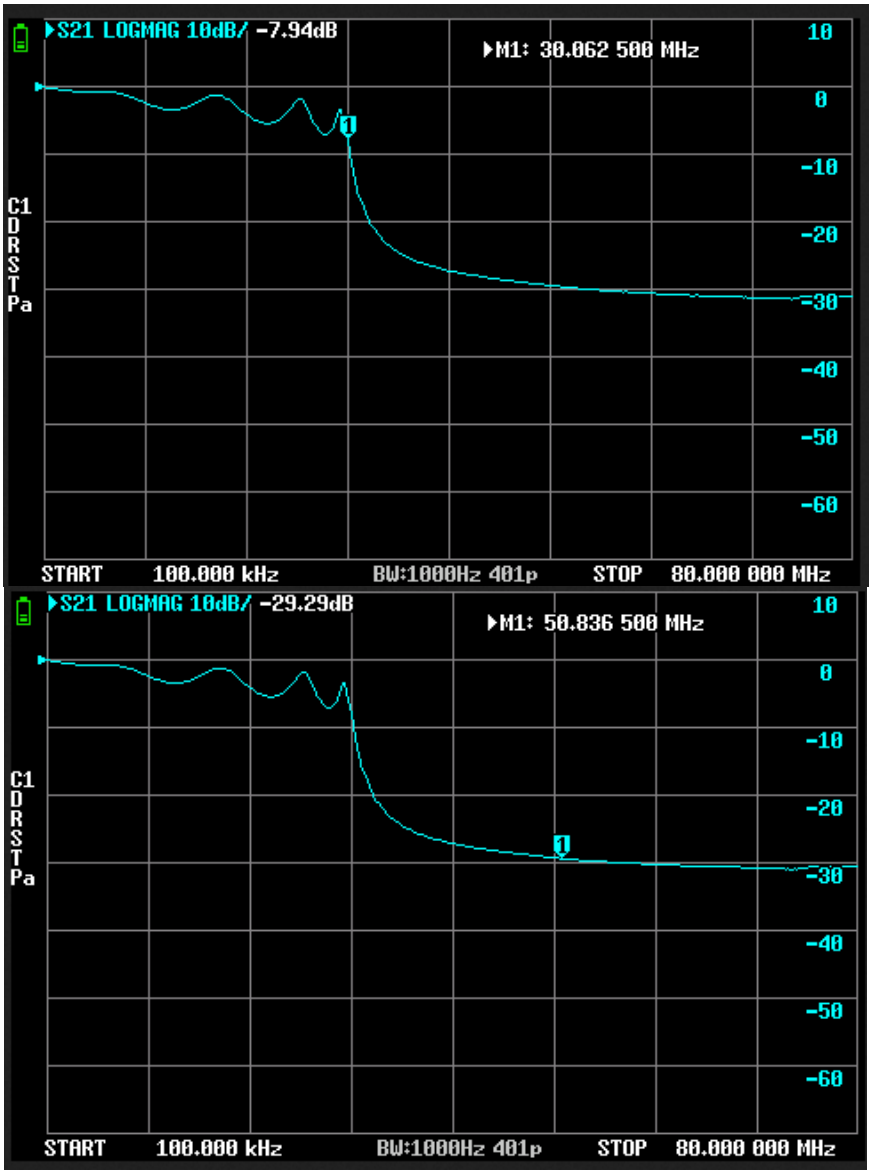


Figure 78: *The updated frequency response of the improved low pass filter layout, showing the cutoff frequency (top), and the attenuation at 50 MHz (bottom).*

As can be viewed in Figure 78 above, the adjustment of the LPF yielded excellent results. The cutoff frequency was located just at the start of the attenuation. The passband was far flatter, with the ripples displayed matching those expected on a theoretical Chebyshev filter. The attenuation displayed was strong, with an attenuation of –29.29 dB occurring at 50 MHz, ensuring any unwanted higher order harmonics produced by the amplifier circuit would be filtered out. Therefore, the lowpass filter with the updated layout was observed to perform as expected, and with the design validated, was determined to be ready for implementation into the overall amplifier.

To test the bandpass filter, a similar procedure with the VNA was employed, as the same forward voltage gain frequency response output figures were required to evaluate its performance. As such, the bandpass filter was connected to the VNA and the resulting

forward voltage gain frequency response results of the bandpass filter can be viewed in Figure 79 below.

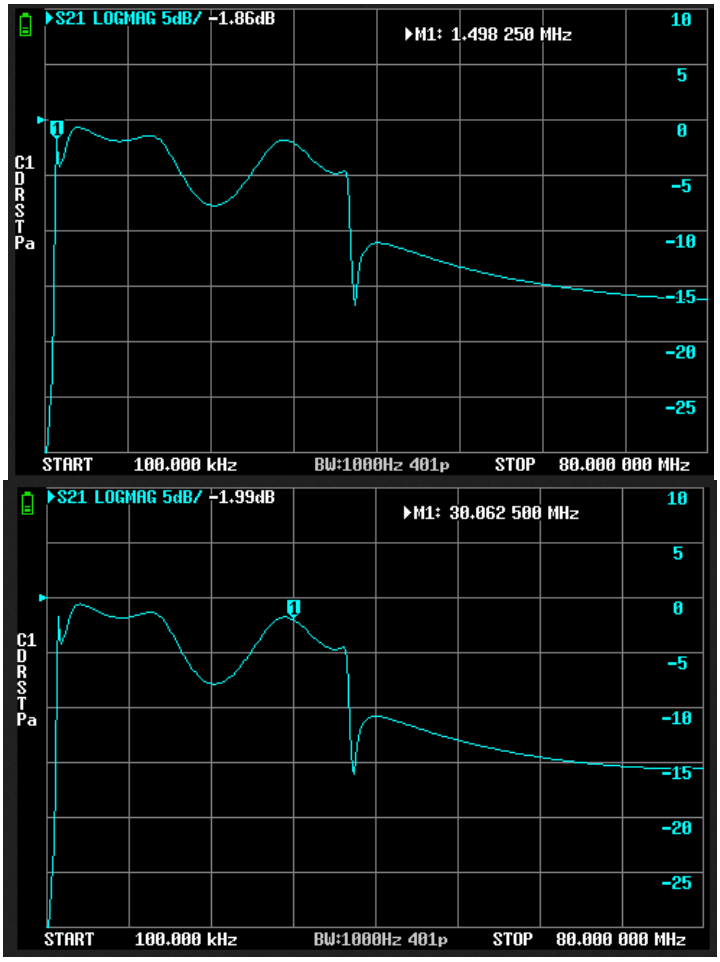


Figure 79: *The initial frequency response of the bandpass filter PCB, showing the highpass cutoff frequency (top), and lowpass cutoff frequency (bottom).*

Viewing Figure 79 above, the cutoff frequencies for the amplifier band pass filters showing 1.5 MHz for the high pass portion of the amplifier, and 30 MHz for the low pass portion of the filter can be observed. For the highpass side of the filter, the cutoff was extremely sharp, attenuating rapidly prior to the cutoff frequency. The lowpass side of the filter was less aggressive, with the attenuation between 30 and approximately 36 MHz being relatively anemic, after which attenuating in a sharper manner. However, a large ripple in the passband was concerning, as this approximately -9 dB ripple impacted the 15m and 17m amateur radio bands significantly. However, while conducting the testing, it was observed that when the VNA probes touched one another, the positions of these ripples would shift, indicating that perhaps the unshielded portion of the probes were introducing noise into the filter. To overcome this, shielded coaxial cable was installed to the input and output of the filter, with the probes being kept far away from one another and the filter PCB, in order to avoid any potential noise issues. The filter was retested with the VNA in this updated, shielded configuration, and the results can be viewed in Figure 80 below.

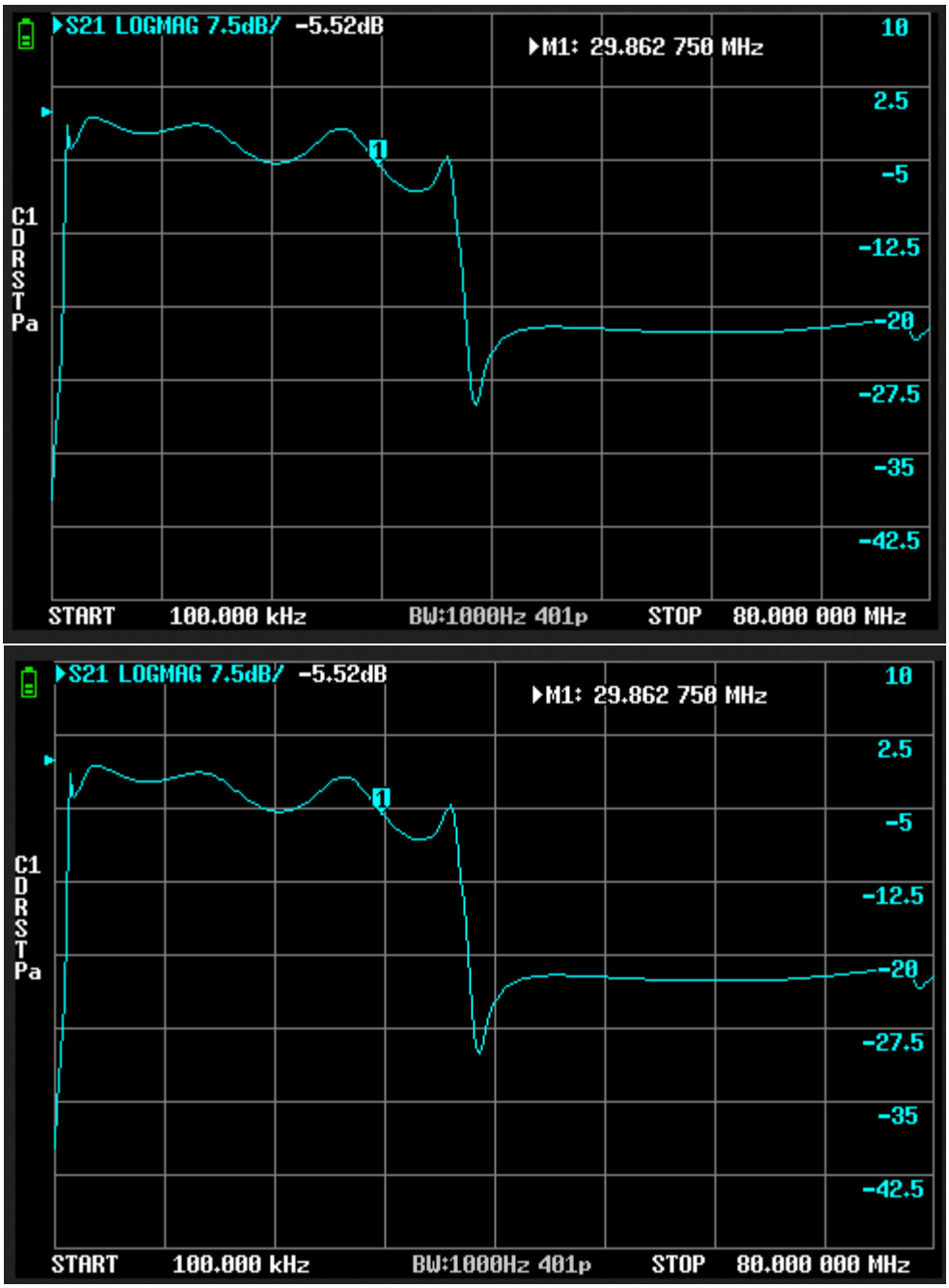


Figure 80: *The retested frequency response of the bandpass filter PCB, showing the highpass cutoff frequency (top), and lowpass cutoff frequency (bottom).*

As can be viewed in Figure 80 above, the frequency response of the bandpass filter was greatly improved by adding the shielded coaxial cable input and output to the BPF. The ripple in the passband dropped from approximately -9 dB to -5 dB, with the highpass attenuation continuing to remain sharp. The lowpass attenuation was sharper as well, with the attenuation being steeper between 30 - 36 MHz, and very sharp after this point before plateauing at approximately -21 dB. It should be noted that there is a ripple at 36 MHz, which while unwanted, does not impact the filter performance, which is expected to filter

out interference from AM/FM broadcast stations. These are known to introduce noise and impact the performance of lower cost Chinese-produced radios. Outside of those two ripples, the performance of the bandpass filter was excellent, performing close to the anticipated theoretical performance tested in LTSpice (see Figure 28 above). Therefore, given that the filter design was validated through observing its performance, the bandpass filter was determined to be ready for implementation into the Squawker Talker amplifier.

The last and arguably most important subsystem of the amplifier to test was the amplifier PCB itself. As mentioned above when discussing prototype assembly, the bias voltage across each of the MRF454 transistors was tested and validated prior to full board assembly, which was a promising indication of board performance. However, it was determined to be necessary to fully test the amplifier potential prior to complete assembly, so as to ensure any errors could be easily identified and corrected without having to take down the entire prototype. Therefore, to test the amplifier, the amplifier PCB was bolted to the heatsink, and was connected to the mode select circuit board and switch, as well as the bypass switch. This was connected to the radio on the amp input, and an SWR/power meter and antenna on an output using shielded RG316 coaxial cables and SO239 coax connectors. A 30 A, 13.8V DC power supply was used to power both the radio and the amplifier. It should be noted that a dummy load should typically be used to ensure that other radio operators are not affected during amplifier testing. However, since Group 4 did not have a dummy load, an antenna was used to dissipate the load, with the testing being conducted at 4:00 am on an unused frequency (specifically 28.4 MHz) to ensure testing was completed without impacting other radio operators. The transceiver specifically used for these tests was a Xiegu X6100, a low cost 0 – 10 W Chinese-produced transceiver that is a perfect representation of the style of affordable transceiver intended to be paired along side the Squawker Talker amplifier. The testing setup to test the amplifier PCB can be viewed in Figure 81 below.

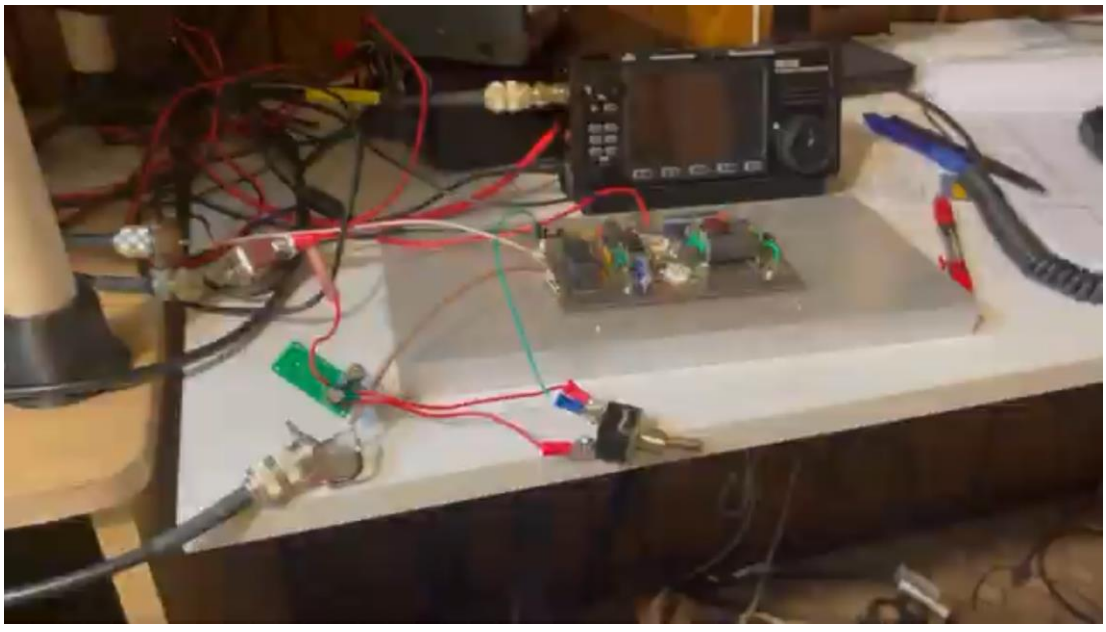


Figure 81: *The testing setup to test the amplifier PCB performance, including the amplifier's gain, as well as the mode select and bypass switching frequency. Note that the amplifier board is mounted to the heatsink, to ensure that the transistors do not overheat.*

Using the setup in Figure 81 above, the amplifier's PCB was tested. First the AM mode was tested, with the mode select switch set to the AM 10 µF delay capacitor, and the radio was set to a very modest 0.5 W output, to ensure that the amplifier prototype was not overdriven prior to learning its characteristics. Once verifying that this output power was sufficient, a full test of the input vs the output power was conducted, testing the amplifier at varying input power levels between 0 – 10 W, recording the forward and reflected power. The resulting input power vs output power recorded power curve can be viewed in Figure 82 below.

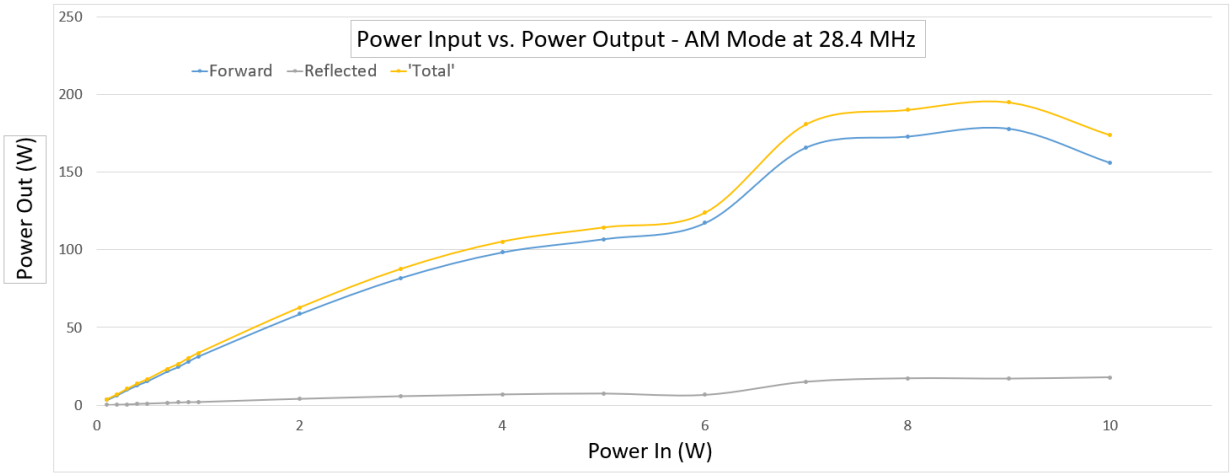


Figure 82: *The input power vs the output power (forward, reflected and total) produced by the amplifier when tested on AM mode.*

Using the values for total output power obtained in Figure 82 above, the gain of the amplifier was also calculated, and the input power vs the amplifier gain was plotted, which can be observed in Figure 83 below.

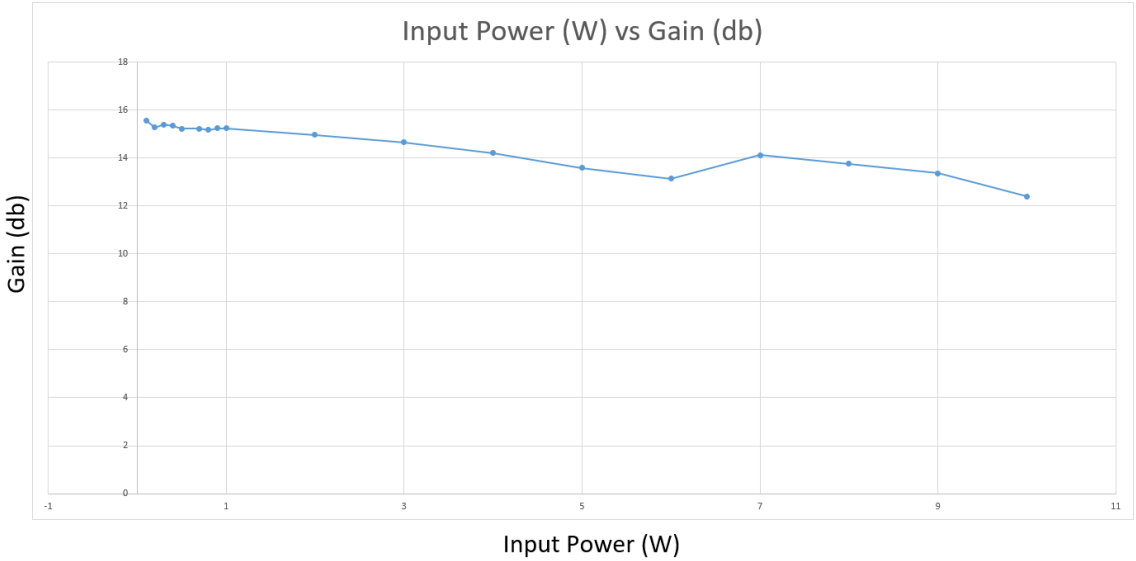


Figure 83: *The input power vs the gain dB produced by the amplifier when tested on AM mode.*

Observing Figure 82 and 83 above, it is highlighted that between an input power of 0 to 6 W, the amplifier circuit showed a consistent power output curve for both the forward and reflected power (and by extension the total power). The average gain between 0 to 6 W was recoded as 13.89 dB. Note, that between an input power of 1 W and 6 W, the gain fell from 15.24 dB (ratio of 33.43) to 13.14 dB (ratio of 20.165), with an average gain of 14.92 dB in this range. Between an input power of 6 to 7 W, the gain of the amplifier increased from 13.15 dB (ratio of 20.165) to 14.16 dB (ratio of 26.08). Between an input power of 7 to 9 W, an average gain of 13.74 dB was recorded. Also, at 10 W of output power, the gain fell to 12.43 dB (ratio of 17.5). The observed inconsistency in both the input vs output power curve in Figure 82, and the gain in Figure 83 at higher input transmit powers is likely due to the Xiegu X6100 transceiver used in testing. This transceiver is known to offer inconsistent higher wattage output powers, and has been observed by Group 4 to struggle to output a clean 10 W signal on the 10m band. Alternatively, at 10 W, the amplifier could be experiencing saturation, leading to a poor drive response. However, despite some slight transceiver related oddities, the amplifier circuit performed excellently, with an overall mean average gain of 14.60 dB between 0 to 10 W being recorded. In Figure 83, it can be observed that linear behaviour is displayed by the amplifier, with the gain almost constant for varying strengths of input signals, with only slight variations in the gain. These slight gain variations are likely due to inconsistent power transmission from the Xiegu transceiver, or an impedance mismatch in the HF station setup.

It should be noted that two issues were encountered during the testing of the amplifier PCB. The first issue had to do with the manual bypass switch. Initially, the amplifier had a bypass switch implemented using a double pull double throw switch, passing the RF signal directly though it to the amplifier, as well as the bypass cable (see the circuit diagram in Figure 25 above). Unfortunately, this setup proved to introduce audible noise to the radio. While difficult to quantify, qualitatively, it introduced audible noise into the radio, making signal reception harder to complete. After overviewing the setup, it was determined that while the shielded coaxial cables protected the signal going into the switch, the unshielded switch itself was where the unwanted noise was being introduced. To test the theory, the DPDT switch was removed from the circuit, with the noise disappearing along with it. However, still wanting a manual bypass switch, the circuit was analyzed to figure out an alternate solution. During this analysis, it was noticed that the carrier operated relay switched into bypass mode when the amplifier power was off, which would in theory allow the signal to bypass the amplifier if power was shut off. This was tested first using a multimeter continuity test to ensure that indeed the relay did bypass the signal. When this was proven, a 0.5 W input was passed through the turned off amplifier circuit to ensure that this theory functioned as expected. Viewing a power meter on the output illustrated that powering off the amplifier did in fact allow the signal to bypass the amplifier. Furthermore, because this amplifier circuit utilized transistors as opposed to vacuum tubes, the circuit did not require any warm-up time, and the amplifier could be turned on and off and operated at will by the user. Therefore, to resolve this bypass switch issue, a secondary power switch was placed into the circuit between the fuse PCB board and the amplifier PCB, allowing just the amplifier PCB's power to be manually turned on and off, enabling the user to bypass the amplifier circuit for testing or antenna tuning purposes.

The second issue encountered was with regard to the mode select feature. Initially, the AM mode was fully tested to ensure proper functionality. Then, the SSB mode was briefly tested to observe that it functioned properly as well, which it did. The circuit was then disconnected and moved to a safe resting place with the intention to fully test the SSB portion of the amplifier the following night (recall testing was completed very late between 4-5 am to not disturb other operators). When testing the SSB mode the following day, it was observed that now the carrier operated relay was chattering, causing the signal to not transmit properly. This indicated there was an issue with the mode select circuit, specifically with the 100 µF delay capacitor, which was odd given that it had been observed to be functioning correctly the previous night. However, all testing led towards the idea that either the relay had failed, or the capacitor delay needed to be increased. Not believing it to be a relay issue given the amplifier functioned perfectly on AM mode, the mode select PCB was experimented upon, testing increased values of capacitance, specifically increasing the delay cap from 220 µF to 470 µF to 1000 µF. However, none of these increased capacitances resolved the chattering relay. Investigating further, continuity tests were conducted on the mode select circuit. Specifically, the continuity between the amp board to the mode select switch and the mode select switch to the mode select PCB were tested, with perfect continuity being observed. However, when testing the ground of the delay capacitor to the ground of the amplifier circuit, it was noted that the ground connection was inconsistent, not providing a reliable continuity. Testing the continuity further, it was found that one of the mode select PCB traces had developed a microfracture at the ground output connection, causing the ground connection to be inconsistent. This caused the mode select circuit to be essentially removed from the amplifier altogether, causing the carrier operated relay to not properly stay open during SSB mode, leading to the chattering. Replacing this PCB with a spare and improving the durability of the ground connection fixed this problem perfectly, with the SSB mode (and the mode select switching circuit as a whole) being tested to be reliable following these improvements.

It should be noted that a power in vs power out plot for SSB was not recorded or provided, and the quantitative amplifier testing was conducted on AM mode. This is due to the operating characteristics of these two modes. AM mode operates with a constant carrier wave, making it an ideal, repeatable baseline for testing and plotting amplifier performance. SSB mode does not have a constant carrier, instead only transmitting during modulation. Simply put, SSB transmits only when someone speaks into the mic. This makes SSB unsuitable for steady measurements using a power meter, as the output will rapidly fluctuate with the fluctuations and inflections in the voice input, offering no reliable baseline for a quantitative comparison. However, the amp was tested on SSB, observing that the relay did not chatter as discussed above, and that the observed fluctuating output power was within the approximate expected fluctuation range for voice modulated SSB operation, indicating a proper amplifier response. Note that video testing footage of the amplifier PCB can be viewed on the project's website, see Appendix 2 for the website link.

It should be noted that prior to full prototype assembly, the voltage regulator PCB output was tested to verify it produced an approximate 12 V output voltage (it produced 11.89 V, well within the reasonable operating range of the selected cooling fans). The setup used to test the voltage regulator PCB can be viewed in Figure 84 below.

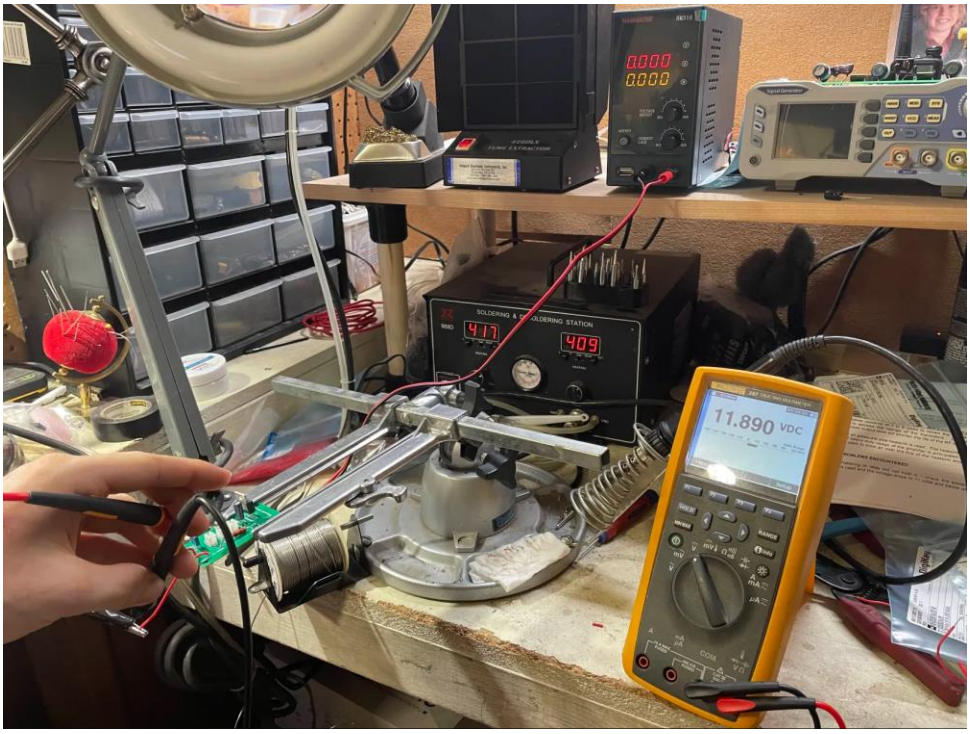


Figure 84: *The testing setup used to verify that the voltage regulator PCB would produce the approx. 12 V output voltage required to power the fans. The recorded voltage was 11.89 V, with the operating range of the fans. It should be noted that input voltage to the voltage regulator was set to 13.8 V, to match the voltage of the amplifier PCB's required voltage.*

With the three primary subsystems and the fan voltage regulator tested and validated individually, the prototype was fully assembled as shown in the previous section of this report. Once assembled, the prototype was again tested, verifying filter operation with the VNA and observing that amplifier gain matched what was produced previously. The bypass and mode select switches were again tested. Additionally, the overall amplifier power switch, as well as the fan operation were validated, yielding expected, proper performance. Signal reception was also carefully, qualitatively analyzed to listen for any noise, which was observed not to be present in the radio's reception. This indicated that all of the shielded coaxial cables were properly terminated, and the filter isolation boxes were keeping out unwanted noise as expected. Furthermore, the cooling fans were observed to keep the amplifier heatsink cool to the touch. This was an improvement from initial testing of just the amplifier PCB, where the amplifier heatsink was noted to get hot when used for extended durations. The 3-fan cooling combination kept the overall amplifier extremely cool during extended operation, meeting and exceeding the amplifier's cooling specification. Note that video testing footage of the completed amplifier prototype can be viewed on the project website, see Appendix 2 for the website link.

To summarize the amplifier specifications met by the completed prototype, the following list was compiled:

Amplifier

- *Compact, must be smaller than 3000 cm³.* - The only specification not fully met, the overall volume of the amplifier was 5670 cm^3.

- *Portable, less than 3 kg.* – The total mass of the final prototype was 1.504 kg, making the amplifier lightweight and portable.
- *Sufficient cooling, utilizing heatsinks and fans.* – The heating and 3 cooling fan setup kept all subsystems cool during extended service operation.
- *Use standard SO239 jacks for amp input/output.* – This was met using SO239 connector jacks, to allow for standard HF antennas and coaxial cables to be utilized easily.
- ***Affordable, must cost less than $600 to construct.* –** This specification was not met, as the total cost of the parts was approx. $804.48 pre-tax, which is above the $600.00 cost limit.
- *Must have fuse protection.* Fuses for each circuit are included, utilizing standard, commonly available automotive fuses.

Amplifier Circuit Specifications

- *High Gain, 5W input amplified to 80W–150W output.* – Amplifier circuit displayed high gain, exhibiting approx. 110 W of total power output on a 5 W input (on AM mode at 28.4 MHz).
- *Runs on 13.6V power.* – It does!
- *Linear operation.* - This modified EB63 amplifier circuit design is linear, exhibiting consistent, almost constant gain.
- *User-selectable AM/SSB modes.* – User selectable AM/SSB mode operation was integration, and the function validated.
- *Manual bypass switch.* The manual bypass feature was added and refined to ensure its operation without affecting signal clarity.

Band Pass Filter Specifications

- *Passband: 1.8–30 MHz (HF Spectrum).* – The filter's frequency response was shown to effectively pass signals in the designated passband.
- *Rated to 10 W.* – All of the utilized components are rated for this wattage, and performed during testing without failure.

Low Pass Filter Specifications

- *Cutoff everything above 30 MHz.* - The filter's frequency response was shown to effectively attenuate signals past the cutoff frequency.
- *Rated to 150 W.* - All of the utilized components are rated for up to 200 W and performed during testing without failure.

As can be observed, all but 2 specifications were fully met. The volume of the final product was larger than the specified 3000 cm^3. This was not a deal breaker as the low mass of the prototype offset this size increase for portability, and in future amplifier iterations, this size could be reduced. The cost of the amplifier components exceeded the $600.00 price specification. However, given that to create a second amplifier would not require the development costs, a second and third prototype would be far closer to the allotted unit cost. Therefore, given the large scope of the specifications, this technical performance of the Squawker Talker amplifier was deemed to be a great success, meeting and exceedingly almost all of Group 4's expectations.

Note that a further round of testing was conducted. This test was not to test any function of the amplifier's hardware, but rather to test the validity of using portable HF radio for natural disaster response. Strictly speaking, our group wanted to observe if we as a communication's team could rapidly deploy and utilize a complete HF radio station including a PSU, radio, our Squawker Talker amplifier, an SWR/power meter and an antenna. This was completed at the ECE 499 final project demo, where within a span of 10 minutes, our group set up the radio, amplifier and SWR meter, raised the antenna and connected it to the radio setup. This setup was able to repeatedly broadcast both an AM and SSB amplified system reliably for over three hours during the demonstration, offering consistent service with no malfunctions occurring. When the demonstration was over, the group was able to disable the setup in under 10 minutes again. Therefore, this proved that rapidly deployable HF radio is very possible, and our amplifier provided the compact, portable radio with extra transmission power to allow it to perform reliably during emergency situations. In Figure 85 below, the setup of this portable HF radio test demonstration can be viewed.



Figure 85: *The portable HF radio test demonstration setup, with the amplifier, radio PSU and SWR/power meter(top), and the 10m resonant antenna (bottom).*

Test Plan Summary

Therefore, to summarize the test plan of this amplifier, the repeatable testing steps are summarized as follows. Each main part of the amp was tested on its own before wiring it all together. All tests were done at 13.8 V (same voltage as the final system), with 50-ohm coaxial cables, indoors at room temperature, and using real-world conditions. Below is a breakdown of how our group tested the amplifier prototype:

- **Low Pass Filter (LPF)**
  - Connected to a NanoVNA.
  - Ran a sweep from 100 kHz to 80 MHz.
  - Checked the cutoff frequency was at ~30 MHz and that everything above that attenuated strongly.
- **Band Pass Filter (BPF)**
  - Same NanoVNA sweep used as the LPF.
  - Checked that the filter passed 1.8–30 MHz and attenuated signals outside of the passband.
  - Looked at passband ripple and verified it was acceptable and did not impact performance significantly.
- **Amplifier PCB**
  - Hooked up to the power supply and radio (Xiegu X6100), tested between 0.5–10 W input.
  - Measured output using an SWR/power meter.
  - Calculated gain for each RF input power on AM mode.
  - SSB was tested for general function but not plotted.
- **Bypass + Mode Select Switches**
  - Bypass tested by passing signal with Squawker Talker off.
  - Mode switch checked for relay delay on AM and SSB, making sure no chatter occurred on the latter mode.
- **Voltage Regulator Board**
  - Input voltage was set to 13.8 V.
  - Output voltage measured at ~11.9 V — within operating range for the fans.
- **Full System Test**
  - Assembled all boards into the enclosure.
  - Re-tested filters, amplifier, bypass, and mode select switching.
  - Verified system ran cool, and had no unwanted noise in the reception.
  - Operated for 3 hours during final demo without any issues.

EGBC Principles Applied During Testing

Even though this was a student design project, Group 4 still took its development very seriously, and as such we followed the core principles laid out by EGBC were strictly followed. Below are examples of how Group 4 adhered to these professional principles:

- **Principle #1 – Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace:**
  - Transmitting was only done on legal amateur bands by licensed operators (Hudson and Huss).
  - Tests were done late at night on an unused frequency (28.4 MHz at 4 a.m.) to avoid interfering with any other operators.
  - Filters were tested to make sure harmonics were attenuated well below legal limits.
  - Fuses were added to each board to prevent anything cooking itself or causing a fire.
- **Principle #5 – Maintain competence in relevant specializations, including advances in the regulated practice and relevant science:**
  - Even though this was a school project, we still did everything like it was a legitimate employed position — no steps being skipped or corners being cut.
- **Principle #7 – Provide professional opinions that distinguish between facts, assumptions, and opinions:**
  - Testing was done by group members who actually understood the gear and subsystems.
  - No assumptions were made — if something didn't make sense, it was rested.
  - All claims were numerically backed the results.
- **Principle #9 – Report to their association or other appropriate agencies any hazardous, illegal or unethical professional decisions or practices:**
  - All RF testing was done in compliance with Industry Canada regulations.
  - Any subsystem experiencing abnormal behavior during tested was analyzed and repaired quickly, catching these issues prior to full prototype assembly.
  - Regular communication between our group TA was conducted through the submission of weekly progress reports and in person meetings. Our supervising professor was kept informed of Group 4's project development through a detailed progress report.
- **Principle #13 – Conduct themselves with fairness, courtesy, and good faith towards clients, colleagues, and others, give credit where it is due and accept, as well as give, honest and fair professional comment:**
  - Test duties were split up evenly. Some parts required multiple members, so collaboration of team members was included.
  - Workload was distributed evenly, catering to the strengths of each member.
  - Continuous discussion among team members was utilized to overcome difficulties in design and testing.

IX Cost Analysis

In Table 2 below, the Squawker Talker's direct costs, (including all of the component and enclosure material costs), has been compiled, providing a total pre-tax and post-tax cost.

Table 2: *The direct costs expended to produce the Squawker Talker amplifier, including all the component and enclosure material costs.*

Direct Cost:	Before Tax	After Tax
Amplifier & Mode Select Circuit	$433.17	$485.15
Fuse Circuit	$35.02	$39.22
Voltage Regulator & Fan Circuit	$5.09	$5.71
Lowpass Filter	$59.66	$66.82
Bandpass Filter	$87.51	$98.01
Enclosure	$184.03	$206.11
Total Direct Costs:	**$804.48**	**$901.02**

As can be viewed in Table 2 above, the total material costs for the Squawker Talker were $804.48 CAD before tax, with the GST and PST sales taxes increasing the cost to 901.02. Note that in Appendix 3, the complete listing of all the amplifier components that were tabulated in this summary table can be viewed.

In Table 3 below, the indirect costs for developing the Squawker Talker can be observed.

Table 3: *The indirect costs expended to produce the Squawker Talker amplifier, including all the component and enclosure material costs.*

Indirect Cost:	Labour Hours	Rate	Total
Amplifier Prototype Design	~100	$22.50	$2,250.00
Amplifier Prototype Assembly & Testing	~100	$22.50	$2,250.00
Total Indirect Costs:	~200	$22.50	**$4,500.00**

As can be viewed in Table 3 above, the estimated indirect prototype development costs, including labour cost for designing, assembling and testing the amplifier, amounted to approximately $4500.00. Therefore, the grand total of Group 4's amplifier development cost, including both the direct and indirect cost was found to be:

Grand Total Amplifier Development Cost = $901.02 + $4500.00 = **$5401.02**

Note that for the indirect cost for labour, a rate of $22.50 per hour was specified. This rate was selected because it is a common wage for ungraduated engineering students on co-op, and therefore represent a fair gauge of what we should evaluate our per hour time to be worth.

It should be mentioned that because this project was proposed by the team members, there was no external funding offered by a third party who would be concerned with return on investment. Instead, this was a self-funded radio enthusiast project completed to expand out skill sets, produce a unique and useful prototype, and provide a blueprint for producing affordable and effective amplifiers for disaster relief. As such, because there is no external funding, there really is not a way to quantify the return on investment. However, it can be stated that our amplifier matched and even exceeded the gain of three competitive offerings analyzed during the literature, while coming in at a lower cost than the two premium offerings. Additionally, Group 4's amplifier offered far better cooling and filtration than the cheapest option surveyed. Therefore, our amplifier investment did produce an excellent product at a price undercutting several competitive offerings.

To cut down on the overall prototype cost, if Group 4 were to produce more amplifiers, the primary key would be to purchase components in larger quantities, thus taking advantage of economies of scale. By purchasing components at larger quantities, costs can be significantly reduced. For example, the MRF454 transistors cost $117.82 each to purchase when less than 20 are ordered. However, when 20 or more are ordered, this price falls to $91.12 each, reducing the overall amplifier cost by $53.40. Extending these economies of scale savings to all of the other components would result in a far less expensive amplifier without having to sacrifice performance. The next option would be to offshore the manufacturing of the amplifiers. While the first prototype had to be built by our team to learn the construction techniques required to assemble such a unit, future amplifiers do not need to be assembled by us. Instead, by utilizing external labour, especially if the production is offshored the assembly costs can be substantially reduced. For example, if produced in a Malaysian factory, the price for construction per hours can be significantly reduced, as according to Indeed, the average per hour wage of a Malaysian factory worker is $4.63 compared to the $22.50 Group 4's members skillset is evaluated at [56].

X Conclusion & Recommendations

Overall, it can be stated that the "Squawker Talker" amplifier prototype was a resounding success. To reiterate, the objectives set for this project included the following:

- To design and evaluate a high-frequency (HF) radio amplifier operating from 1.8–30 MHz, with integrated lowpass and bandpass filters for harmonic suppression and signal clarity.
- To prototype, test and verify a functional, portable linear amplifier with cooling considerations and built in filtration.
- To analyze and demonstrate the feasibility of HF communication infrastructure as a low-cost emergency communication solution for rural and disaster-affected regions.

All three of these objectives were completed in this project. The team members began the amplifier project by conducting an extensive literature review, analyzing prior use of HF radios in disaster relief, highlighting gaps in current amplifier design, and overviewing amplifier and filter theory and schematics to become familiar with RF amplifier and filter design techniques. Using this knowledge, Group's 4 design was developed to meet the specifications laid out for the amplifier and each of the three critical subsystems, including the amplifier, band pass filter and low pass filter. Schematics, PCBs and enclosure hardware designs were produced, with relevant components being ordered. Using these components, team members assembled, tested, iterated upon and tested again to verify that a fully functional prototype was produced. Overall, the amplifier prototype only missed the completion of two of the specifications laid out in the design phase. These included a final amplifier volume of 5670 cm^3 which exceeded the target specification of 3000 cm^3 and the overall direct cost of $600.00 being exceeded to a value of $804.48 (pre-tax). Every other original amplifier specification was met or exceeded. These include the following:

Amplifier

- Portable, less than 3 kg. ✓
- Sufficient cooling, utilizing heatsinks and fans. ✓
- Use standard SO239 jacks for amp input/output. ✓
- Must have fuse protection. ✓

Amplifier Circuit Specifications

- High Gain, 5 W input amplified to 80 W–150 W output [25, 29]. ✓
- Runs on 13.6 V power. ✓
- Linear operation [25, 29]. ✓
- User-selectable AM/SSB modes. ✓
- Manual bypass switch. ✓

Band pass Filter Specifications

- Passband: 1.8–30 MHz (HF Spectrum) [37, 38]. ✓
- Rated to 10W. ✓

Low pass Filter Specifications

- Cutoff everything above 30 MHz [42]. ✓
- Rated to 150W [42]. ✓

Furthermore, the concept of setting up a rapid, portable radio communications system for disaster relief was practically field tested, with quick assembly of an amplified HF station in under 10 minutes. This station was demonstrated to reliably broadcast amplified AM and SSB signals over a three hour period, and even received a signal from Washington state during this time period, demonstrating the effective HF radio at a distance. The station was disassembled in 10 minutes, further demonstrating the portability of this amplifier in disaster areas.

One further point of Group 4's amplifier development that should be mentioned is a direct performance comparison was conducted with one of the competitive offerings. While our group was not able to acquire an RM Italy KL203P or an Elecraft KXPA100 Amplifier, we actually did end up acquiring a Xiegu XPA125B amplifier when purchasing the Xiegu X6100 transceiver used in the amplifier testing. As such, this amplifier was also tested briefly to get a feel for operating it compared to Group 4's "Squawker Talker" amplifier. Quantitatively, the Xiegu amplifier offered a 100 W output on a 5 W input, so slightly lower than the Squawker Talker. However, it was noted from reading the manual that this amplifier is output limited, and will not output above 100 W when driven with more than 5 W (so we did not try). Additionally, this amplifier requires band data from the radio to have automatic band switching. We could not get this feature to work and were stuck using manual band switching, which was frustrating. Whether or not this was a user error, this is not an issue with the Squawker Talker amplifier, as it can be operated within any HF amateur band without the need for any switching. The XieguXPA125 included a built-in SWR meter and wattmeter which was appreciated. However, its reading was very inaccurate, outputting 76 W when two other calibrated meters measured an output of 100 W. This is a common issue with this Xiegu amplifier model that has been well documented [62]. While our amplifier lacked this convenient feature, it can be reasonably argued the Xiegu also lacked this feature given the inaccuracy of the power reading. In terms of volume, the Xiegu beat the Squawker Talker handily, coming in at 3900 cm^3. However, the Squawker Talker was far lighter, more than 1 kg less than the Xiegu's hefty mass of 2.66 kg. Where the Squawker Talker really moved ahead of the Xiegu was with regard to its cooling capability. The Xiegu has no cooling fans or heat sinks, and as a result, heats up very quickly. Compare this to the Squawker Talker, which was observed to stay cool to the touch over extended periods of operation. It should be noted that the Xiegu XPA125B had an excellent built in antenna tuner, something our amplifier lacked completely. The costs of the amplifier units were relatively similar, with the Xiegu being $830 pretax, and the Squawker Talker being closer to **$**804.48 pre-tax**,** and not counting labour. Overall, from Group 4's assessment, the Squawker Talker's reduced weight, improved cooling and ability to output higher gain considerably outweighs the XPA125B's smaller volume, excellent tuner circuit and less than excellent power/SWR meter. However, our group members are inherently biased to the Squawker Talker, as it is our brainchild. Interestingly, it should be mentioned that a different, neutral Xiegu XPA125B owner actually overviewed the Squawker Talker at the ECE 499 project demonstration, and found its performance to be very competitive with his Xiegu unit, Additionally, two other radio operators and a high ranking naval officer were very impressed with the performance of the Squawker Talker, suggesting that it could be commercialized , sold and deployed with little to no adjustment. Therefore, it can be stated that at the very least, HF amplifier users are impressed with this amplifier's performance, and there is potential for future development and production of Squawker Talker amplifiers moving forward. Professor Driessen's comments were also very encouraging following his review of the Squawker Talker's performance. He stated that the only aspect of Group 4's amplifier prototype that needed to be addressed was, how to get this amplifier to market.

To further iterate and improve upon Group 4's amplifier prototype, several suggestions are recommended. The first recommendation would be to reduce the volume of the enclosure to ensure that it meets the expected value of 3000 cm^3 laid out in the design

specifications. This would be completed by adjusting PCB board layouts, and testing minimized area board layouts to find a combination which reduces space without sacrificing performance. Additionally, the enclosure does have some unutilized surface area that could be removed upon a recut of the main enclosure body, further reducing the amplifier volume.

The next recommendation for amplifier improvement would be to finish implementing and integrating the SWR/power meter circuit within the amplifier. As discussed earlier, this feature was all but implemented into the prototype, apart from an incompatibility issue that arose between the PCB and the ordered screen. Therefore, it is recommended that a compatible screen be ordered, and that the amplifier prototype be modified to include this built-in SWR/power meter feature.

Another technical recommendation would be to design a new PCB for the low pass filter. Recall that the original PCB layout, while compact, exhibited a poor frequency response due to parasitic capacitance and inductor magnetic field interaction. This was resolved in the current prototype by removing the PCB board entirely, soldering the components directly to one another, and mounting them on a custom acrylic board. To fix this problem permanently, a new and improved PCB layout should be designed. Additionally, the layout of the bandpass filter should also be adjusted, tinkering with component placement to further flatten the passband. The last technical recommendation for further prototype development of this amplifier prototype would be to investigate the feasibility of adding an antenna tuning circuit. This feature was included on some of the competitive offerings. However, in order to keep the scope of this project realistic to a 3-month development and demonstration schedule, our group decided to omit this feature, as it is not necessary so long as the user has a resonant antenna, which Group 4 had. However, in the event of a natural disaster where access to a resonant antenna may be unavailable, having the ability to tune an impedance match between the amplifier and the antenna is a significant advantage, and as such, the final recommendation for further amplifier development would be to investigate how to implement this tuner feature.

In addition to technical recommendations, there are several testing procedures that should be conducted. First, the amplifier needs to be tested on more radio bands. The radio was only tested on the 10m radio band as this band was the only band that our antenna was perfectly resonant on, ensuring the max power transfer with the least reflection. However, to further gauge the amplifier, testing must be completed on the remaining HF bands, including the 160m, 80m, 60m, 40m 30m 20m, 17m, 15m and 12m [61]. It should be stated that EB63 based amplifier circuits are typically reported to perform more efficiently the lower one goes in frequency on the HF spectrum, so testing the amplifier at the upper end of the HF spectrum was ideal as the results would be amplifier's "worst case" [25, 29]. It was originally intended to test this amplifier on more bands, with a multiband HF antenna kit being purchased for that purpose. However, our group ran out of time to assemble it prior to the project demonstration and subsequent writing of this report.

Additionally, the Squawker Talker amplifier must be tested on more radios. It was primarily tested on a Xiegu X6100, which is an excellent test radio for this unit. Additionally, it was also tested at a 5 W input on a second radio, a Yaesu FTDX101D to observe if the output power matched (which it did). However, no other radios with an output below 5 W were securable prior to the demonstration, so only the Xiegu numbers could be included. Therefore, to further validate the results, additional testing with other

radios is recommended. The last test procedure that is recommended is to further field test the amplifier. While the amplifier was field tested during the demonstration where it showed promising results, it was in a non ideal area, with many buildings surrounding the antenna to limit signal propagation. Testing the amplifier in more ideal field conditions is recommended, to gain a more accurate understanding of the distance performance improvements offered by this amplifier.

To conclude this ECE 499 project, it must be stated that the development of the "Squawker Talker" amplifier was a ton of work, and a ton of fun. Thie project required our group to learn a plethora of new skills, ranging from fundamental RF filter design techniques, to operating new testing equipment such as a vector network analyzer, to practical hands-on electronic skills such as terminating coaxial cables. Overall, this course was an amazing experience, and we are confident the valuable skills gained during the completion of this project will serve all group members well as we transition from being students to going out into the field to work as engineers in training.

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Appendix

1. The EGBC Code of Ethics

The complete EGBC code of ethicss is listed below [63]:
A registrant must adhere to the following Code of Ethics:
Registrants must act at all times with fairness, courtesy and good faith toward all persons with whom the registrant has professional dealings, and in accordance with the public interest. Registrants must uphold the values of truth, honesty, and trustworthiness and safeguard human life and welfare and the environment. In keeping with these basic tenets, registrants must [63]:

1. Hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace;
2. Practice only in those fields where training and ability make the registrant professionally competent;
3. Have regard for the common law and any applicable enactments, federal enactments, or enactments of another province;
4. Have regard for applicable standards, policies, plans, and practices established by the government or Engineers and Geoscientists BC;
5. Maintain competence in relevant specializations, including advances in the regulated practice and relevant science;
6. Provide accurate information in respect of qualifications and experience;
7. Provide professional opinions that distinguish between facts, assumptions, and opinions;
8. Avoid situations and circumstances in which there is a real or perceived conflict of interest and ensure conflicts of interest, including perceived conflicts of interest, are properly disclosed and necessary measures are taken so a conflict of interest does not bias decisions or recommendations;
9. Report to Engineers and Geoscientists BC and, if applicable, any other appropriate authority, if the registrant, on reasonable and probable grounds, believes that:
    a. The continued practice of a regulated practice by another registrant or other person, including firms and employers, might pose a risk of significant harm to the environment or to the health or safety of the public or a group of people; or
    b. A registrant or another individual has made decisions or engaged in practices which may be illegal or unethical;
10. Present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded;
11. Clearly identify each registrant who has contributed professional work, including recommendations, reports, statements, or opinions;
12. Undertake work and documentation with due diligence and in accordance with any guidance developed to standardize professional documentation for the applicable profession; and

13. Conduct themselves with fairness, courtesy, and good faith towards clients, colleagues, and others, give credit where it is due and accept, as well as give, honest and fair professional comment.

2. Website Link and the Main Page Image

The link to the project website is listed below.

https://zhouqiwei48.wixsite.com/ece-499

In Figure 86 below, an image of the main web page is displayed.



Figure 86: *An image of the project website's main page.*

3. Details of data, test results, codes, etc., if applicable

Below is a raw power in vs power out data recorded during the amplifier test. Experimental data, and the complete listing of the components (and their cost) for all the materials used to construct the Squawker Talker.

Table 4: *The raw experimental data used to Produce the Power Input vs Power Output and Power Input Vs Gain plots located in the testing and validation section of the report.*

In (W)	Out (W)	Forward	Reflected	Total	Gain(db)
0.1		3.48	0.12	3.6	15.56303
0.2		6.42	0.33	6.75	15.28274
0.3		9.88	0.5	10.38	15.39076
0.4		12.88	0.84	13.72	15.35294
0.5		15.58	1.05	16.63	15.21922
0.7		21.89	1.47	23.36	15.23375
0.8		24.62	1.68	26.3	15.16866
0.9		28.09	1.96	30.05	15.23602
1		31.4	2.03	33.43	15.24136
2		58.68	4.06	62.74	14.96515
3		82	5.74	87.74	14.66076
4		98.5	6.86	105.36	14.20616
5		107	7.44	114.44	13.59608
6		117.33	6.55	123.88	13.1485
7		166.1	14.93	181.03	14.12653
8		173.1	17.12	190.22	13.76166
9		178.15	16.92	195.07	13.35948
10		156.1	17.77	173.87	12.40225

Table 5: *The cost for the voltage regulator components.*

Items	**Qty**	**Price (Total)**	**Price (Total)**
LM317 voltage regulator	1	$2.94	$2.94
0.1 uF	1	$0.33	$0.33
1 uF capacitor	1	$0.19	$0.19
390 Ω	1	$0.52	$0.52
3.3kΩ	1	$0.81	$0.81
1x2 connector	3	$0.10	$0.30
	Sub Total		$5.09
	GST	5%	$0.25
	PST	7%	$0.36
	Total		$5.71

Table 6: *The cost for the Fuse PCB components.*

Items	**Qty**	**Price (Total)**	**Price (Total)**
Fuse holder	3	$6.35	$19.05
Fuse (25\ A, 2A, 1A)	1	$15.97	$15.97
	Sub Total		$35.02
	GST	5%	$1.75

	PST	7%	$2.45
	Total		$39.22

Table 7: *The cost for the Amplifier and Mode Select PCB components.*

MRF454	2	$117.82	$235.64
SO-239 chassis mount	2	$23.44	$46.88
100 kΩ resistor	1	$0.10	$0.10
10 µF	1	$0.72	$0.72
100 µF	1	$0.92	$0.92
33pF mica	1	$15.11	$15.11
18pF mica	1	$3.38	$3.38
0.1 µF	2	$0.68	$1.36
10 µF 35V	1	$0.28	$0.28
0.001 µF	1	$2.23	$2.23
330pF mica	1	$5.97	$5.97
24pF mica capacitor	1	$8.80	$8.80
470pF disc capacitor	1	$0.68	$0.68
22 µF 25V	1	$3.29	$3.29
910pF mica	1	$11.50	$11.50
1100pF mica	1	$47.66	$47.66
470 µF 10V	1	$1.10	$1.10
47 kΩ resistor	1	$1.62	$1.62
10 kΩ resistor	1	$4.89	$4.89
82 Ω 5W resistor	1	$9.15	$9.15
10 Ω 1/2W resistor	1	$0.71	$0.71
1.5 kΩ 1/4W resistor	1	$0.89	$0.89
Ferrite beads	10	$0.20	$2.00
1N4001 diode	1	$0.31	$0.31
MJE243 transistor	1	$1.75	$1.75
1N4148 diode	2	$0.10	$0.20
2N4401 transistor	2	$0.74	$1.48
RF400 transformer	1	$7.90	$7.90
RF1000 transformer	1	$10.93	$10.93
Omron G2RL24-DC12 relay	1	$5.73	$5.73
	Sub Total		$433.17
	GST	5%	$21.66
	PST	7%	$30.32
	Total		$485.15

Table 8: *The cost for the lowpass filter components.*

Items	Qty	Price (Total)	Price (Total)
Inductor Wire	1	$26.62	$26.62
150 pF mica	2	$8.26	$16.52
180 pF mica	2	$8.26	$16.52
	Sub Total		$59.66
	GST	5%	$2.98
	PST	7%	$4.18
	Total		$66.82

Table 9: *The cost for the bandpass filter components.*

Items	Qty	Price (Total)	Price (Total)
1nf mica	2	$10.69	$21.38
100pf mica	3	$5.52	$16.56
5 microhenry	3	$14.33	$42.99
500 nh	2	$3.29	$6.58
	Sub Total		$87.51
	GST	5%	$4.38
	PST	7%	$6.13
	Total		$98.01

Table 10: *The cost for the amplifier enclosure materials.*

Items	Qty	Price (Total)	Price (Total)
PETG	50 Grams	$21.99/kg	$1.10
3mm Walnut Sheet	1	$65.99 for 12	$5.50
3mm Birch Sheet	1	$24.99 for 8	$3.13
Black Acrylic Sheet	1	$16.98 for 2	$8.49
M3 Heat Press	8	$9.19 for 100	$0.74
TPU	12 grams	$25.99/kg	$0.32

1" Thick Faraday Tape	2	$15.00	$30.00
PCB	25	$5.87 for 5	$29.35
Heat Sink	1	$25.00	$25.00
30 Amp Single Pole Switch	3	$8.95	$26.85
Single Pole Double Throw Switch	1	$11.62	$11.62
RG316 Coax Cable	2 Meters	$11.34	$22.68
AMP PCB	1	$19.24	$19.25
	Sub Total		$184.03
	GST	5%	$9.20
	PST	7%	$12.88
	Total		$206.11