HF Radio Amplifier with Lowpass/Bandpass Filter

ECE 499

June 23rd, 2025



University of Victoria

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I Objectives

- Design and evaluate an HF Radio Amplifier, that has integrated lowpass and bandpass filters incorporated for signal clarity and harmonic suppression.
- Deliver a working amplifier prototype with functioning filters.
- Investigate the feasibility of amateur radio infrastructure as a low-cost emergency communication solution for rural areas through testing the amplifier at varying distances.

II 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 or 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, but at 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 our group's ECE 499 project, our team 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 amp 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 no attempt to develop a portable radio, or any other piece of HF radio equipment. Our group'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 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 networks 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 each of their communities during outages. This solution is also valuable to disaster relief organizations that are working in remote, forested, 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.

III Literature Survey & Specifications

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 our group 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 100W on a 5W 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 1 below.



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

The Xiegu XPA125B amplifier was the second amplifier analyzed. This unit produces an output power of 100W on a 5W 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 2 below.



Figure 2: *The Xiegu XPA125B Amplifier [15].*

The Elecraft KXP100 was the third amplifier surveyed. This amplifier also produces 100W on a 5W 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 heat sink, but has no fans [17]. Filtration is also included with this amplifier. A picture of the Elecraft KXPA100 can be viewed in Figure 3 below.



Figure 3: *The Elecraft KXPA100 Amplifier [17].*

Reviewing these amplifiers, it became apparent that there were some noticeable gaps in the market. While all the amps in the 3 price categories offered 100W 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 amp 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 amp, 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 our amp (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 4 below.

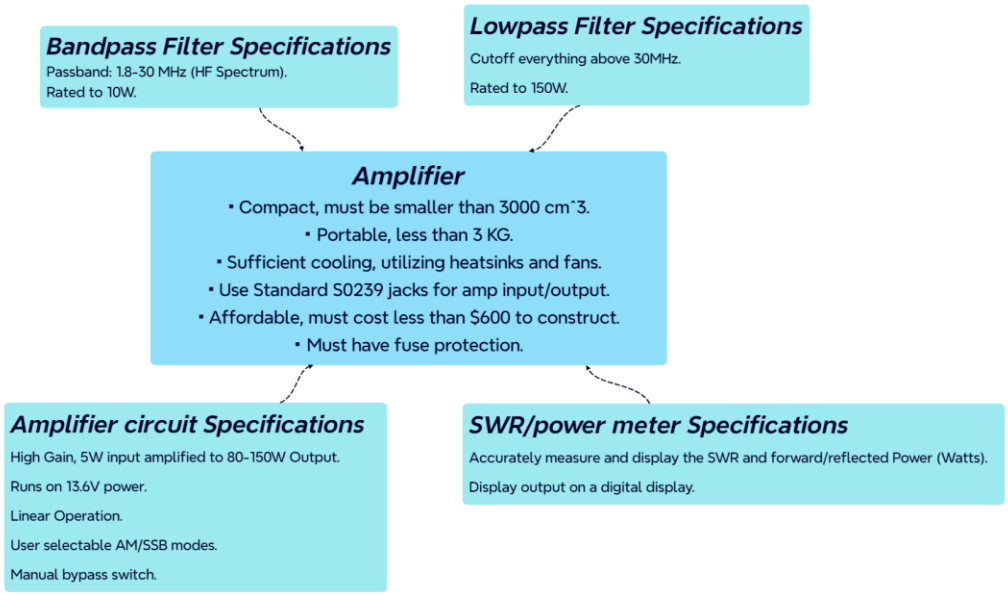
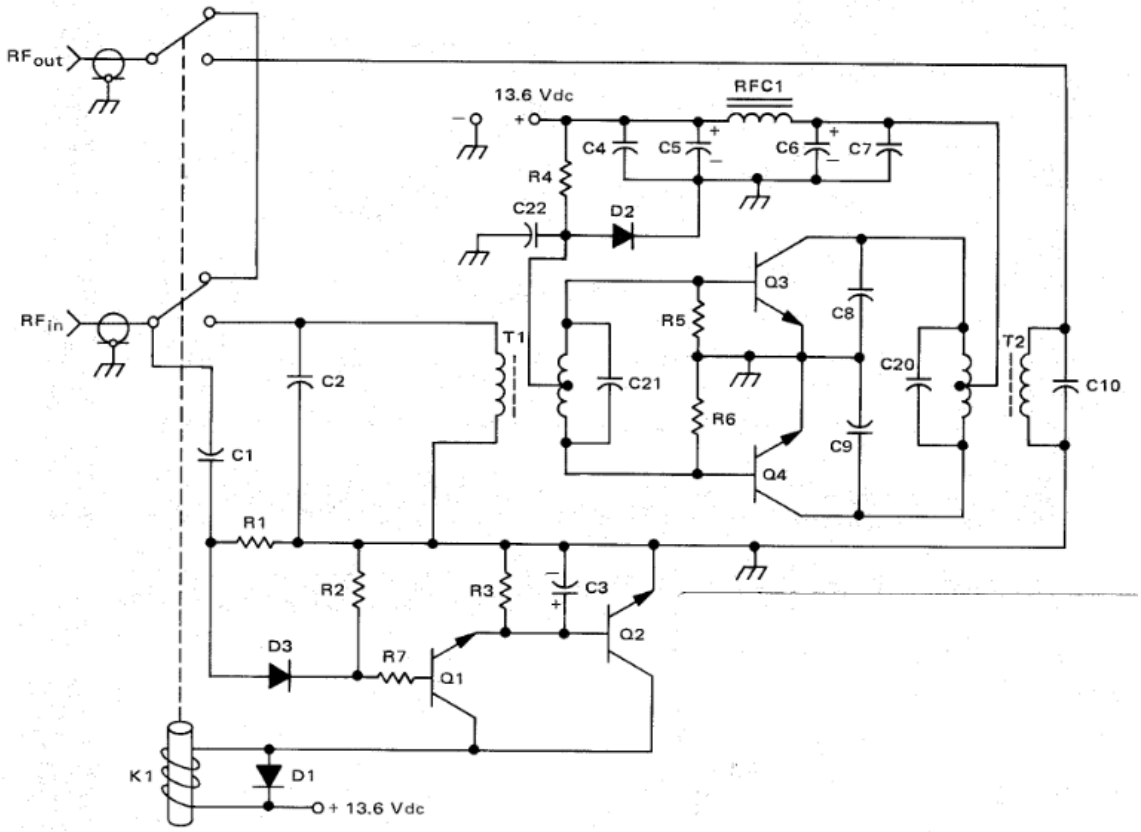


Figure 4: *A breakdown of the specification of the amplifier, and its 4 feature categories including the bandpass filter, the amplifier circuit, the lowpass filter and the SWR/power meter circuit.*

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]. Transistors on the other hand 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, our group 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 to focus on designing and implementing other features, as well as testing the prototype to ensure a working product come demonstration day. Producing an amplifier with the comprehensive feature set listed in Figure 4 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 5.



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

As can be viewed in Figure 5, 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 6 below, and the input vs output power of the EB63 amplifier circuit can be viewed in Figure 7 below.

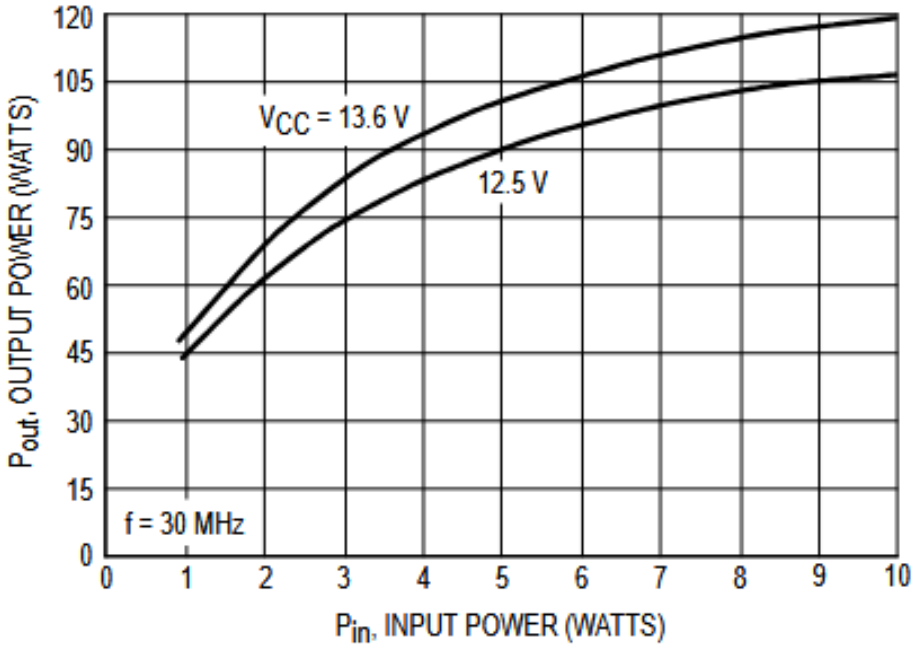


Figure 6: *The input vs output power of a single MRF454 transistor, with values recorded at a voltage of both 12.5VDC and 13.6VDC, frequency of 30 MHz [26].*

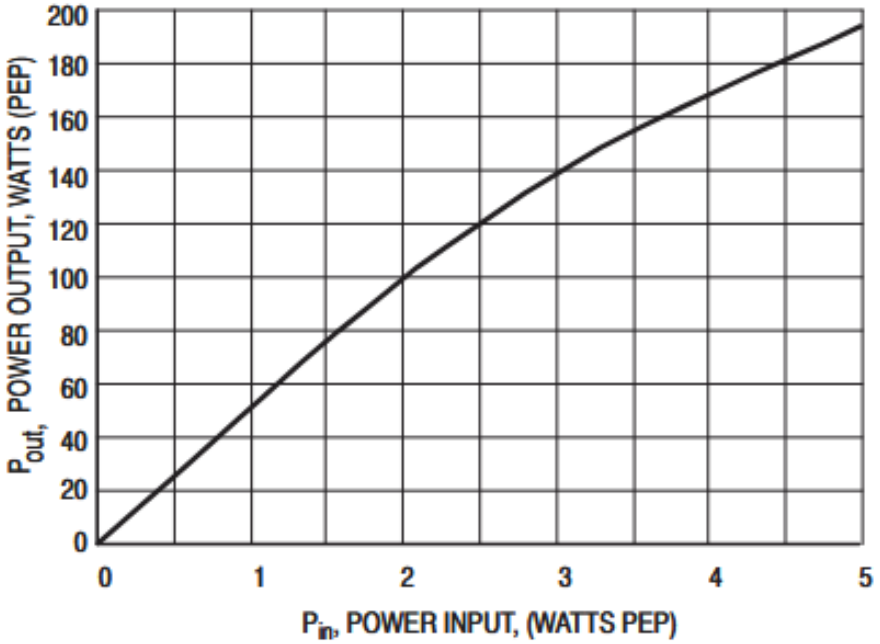
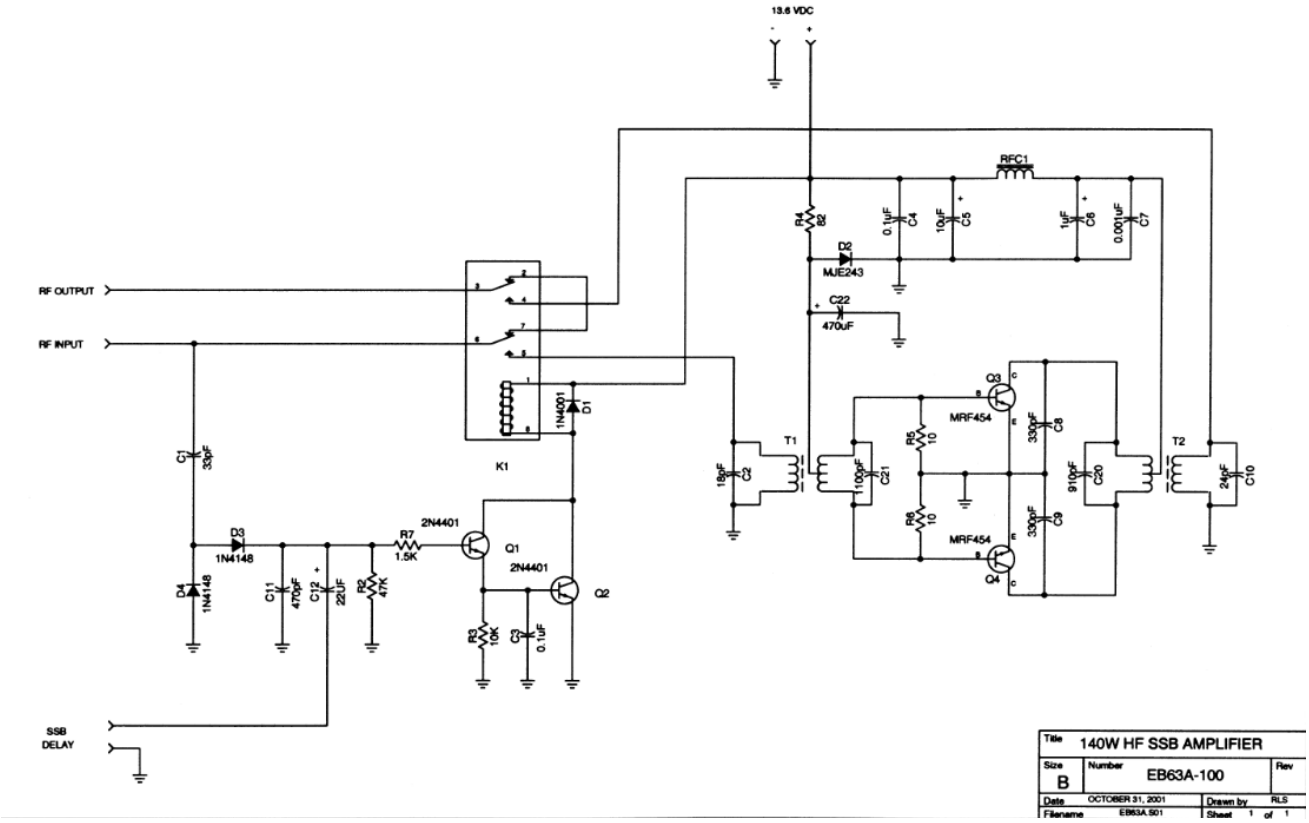


Figure 7: *The input vs output power of a single EB63 amplifier circuit, with values recorded at a voltage of 13.6VDC, frequency of 30 MHz. Note the high gain offered by this circuit [25].*

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 amp 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 amp to stay in transmit mode between spoken syllables during an SSB transmission [27]. With an AM signal, the carrier wave provides 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 8 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 8: *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 in consideration, the team selected the EB63A as the base circuit for our amplifier design because of the following features:

- Proven power output capability in the 2-30MHz 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 EB63. 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 EB63 in that it used a pair of MRF454 transistors in push pull-configuration, but it lacked several features of the EB63. 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 EB63 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 watts [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 watts, 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 nice, it was higher than what our specification required, and sacrificing the amp's versatility to work on fewer radios was viewed as not a worthy trade off. Furthermore, given our group's limited high-power electronics experience, a 300W amplifier was viewed as too much for us to handle at this moment, and such an amp could be investigated in the future after gaining more hands-on experience with smaller RF amplifiers like the EB63.

The EB63 and EB63A amplifiers are not perfect designs, and there are flaws that must be remedied by our group. 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 signal passthrough 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 damaging components in case of current overdraw, and potentially preventing a failure that could harm the operator. However, the most significant issue with the EB63 amplifier is harmonics. As mentioned earlier, higher order harmonics are often an issue in HF amplifiers, and the EB63 is no exception. This can be viewed in Figure 9 below, where the harmonics of the EB63 can be observed with the amplifier operating at 30 MHz.

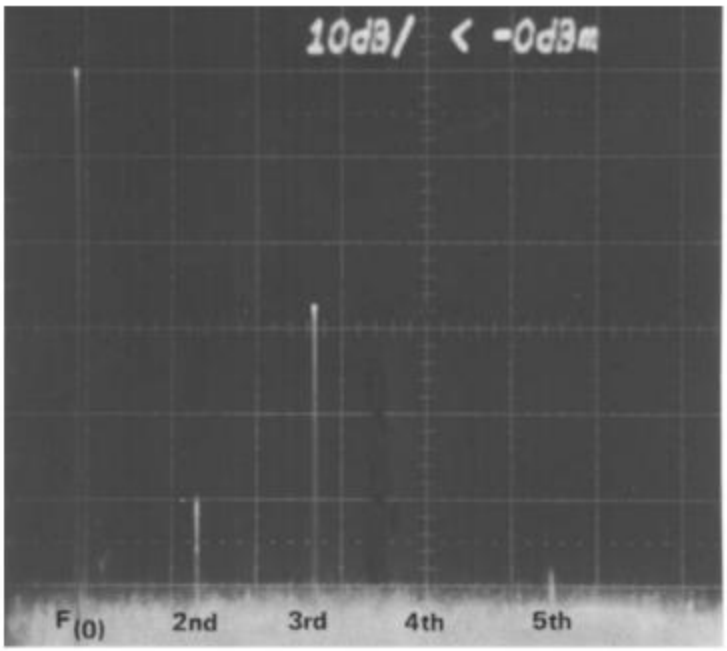


Figure 9: *The EB63 amplifier frequency spectrum, Frequency Spectrum, with $F_{(0)}$ = 30 MHz, with the 2nd, 3rd, and 5th harmonics are visible. Note that vertical resolution is 10 dB/div and the horizontal resolution is 20 MHz/div. [25].*

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 10 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 11 below [18].

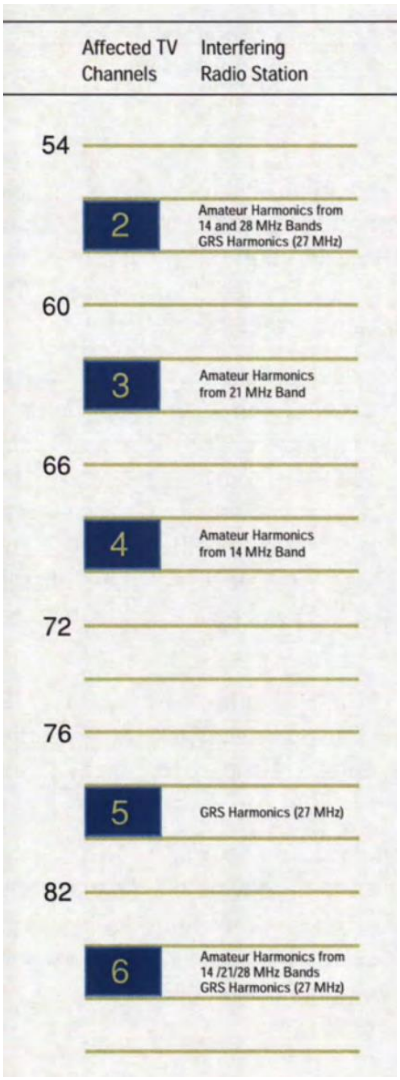


Figure 10: *A listing of TV channels, their relevant frequencies, and the interfering radio station frequencies that produce the harmful harmonics [18].*

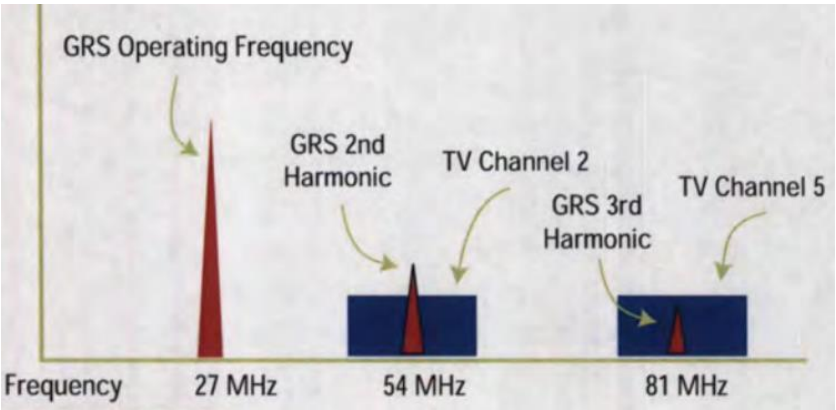


Figure 11: *An example diagram of the harmful harmonics produced by a GRS radio station, and the TV channels with which these harmonics interfere [18].*

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 amplifiers output, removing the risk of interference. Additionally, a bandpass filter with a pass band 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, 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 12 below.

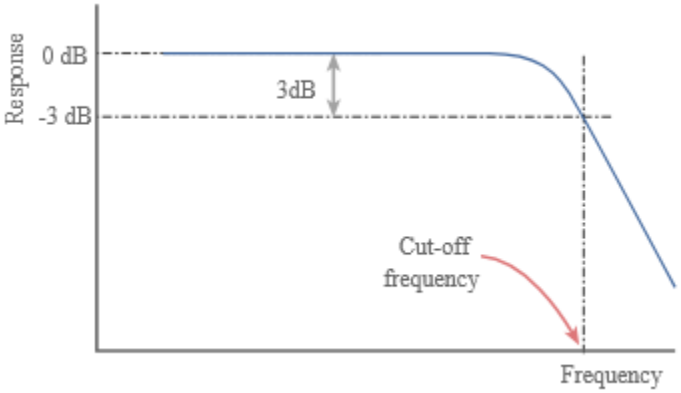


Figure 12: *The frequency response of a generic constant-k LC lowpass filter [36].*

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 13 below [40].

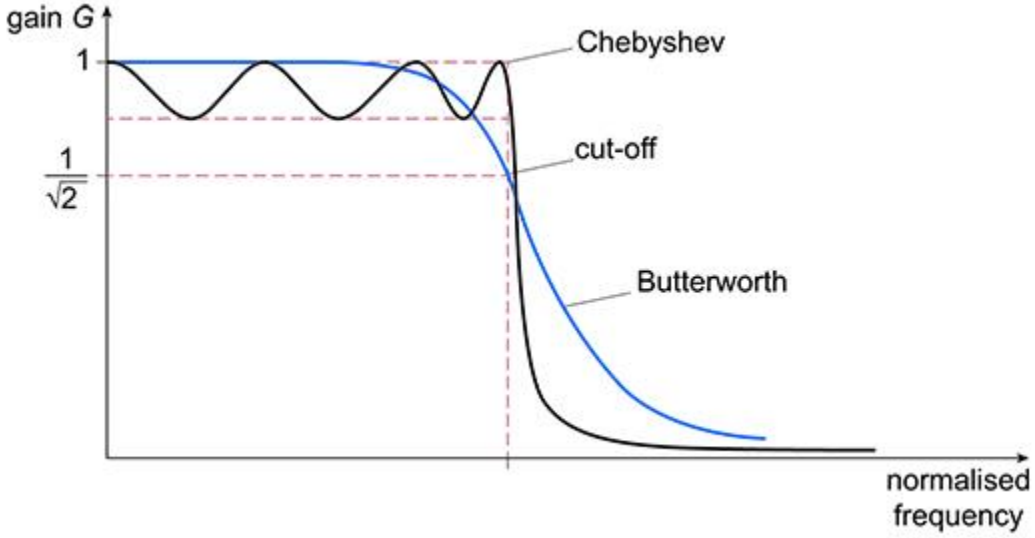


Figure 13: A *comparison of a seventh-order Butterworth and Chebyshev lowpass filter frequency response [40].*

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 filter 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 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 10W 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 14 below.

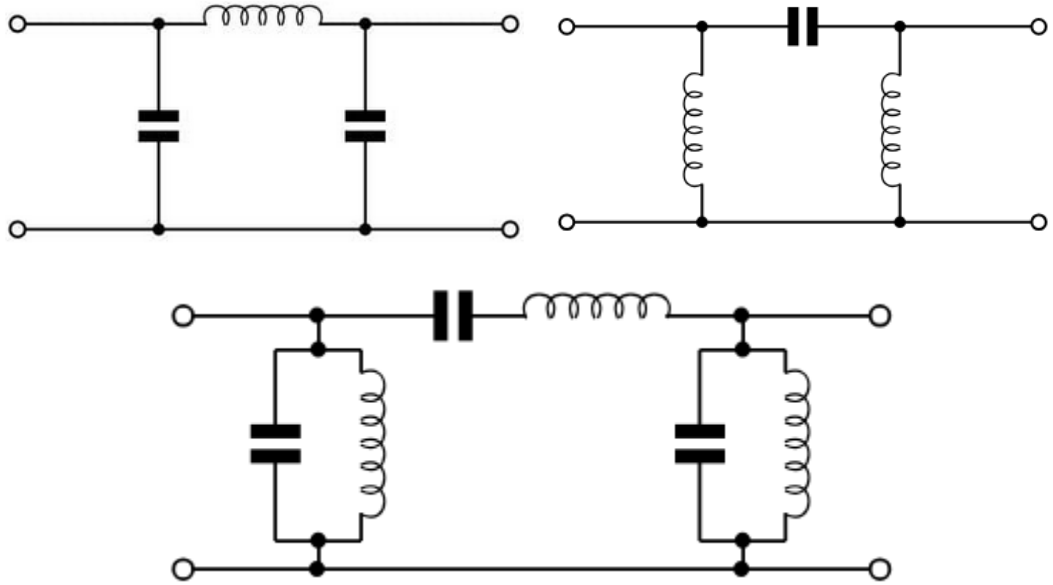


Figure 14: *The pi configuration constant-k filter topologies for a lowpass (top left) and highpass filter (top right), and a combined bandpass filter (bottom) [37, 38].*

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 150W, 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 too, 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 9^{th} order T base Chebyshev filter, and the filter's topology can be viewed in Figure 15 below.



Figure 15: *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 16 below.

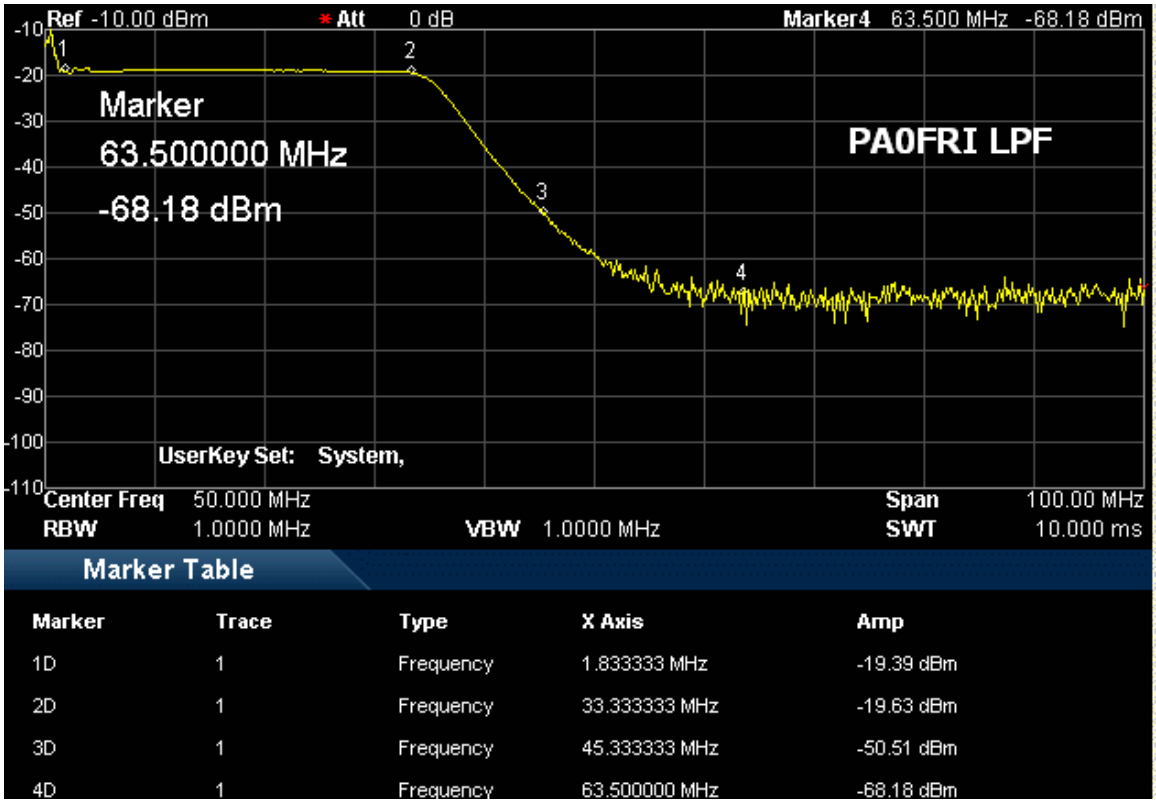


Figure 16: *The spectrum analyzer graph produced by the 200W 30MHz Chebyshev LPF, showing its frequency response [42].*

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 17 below.

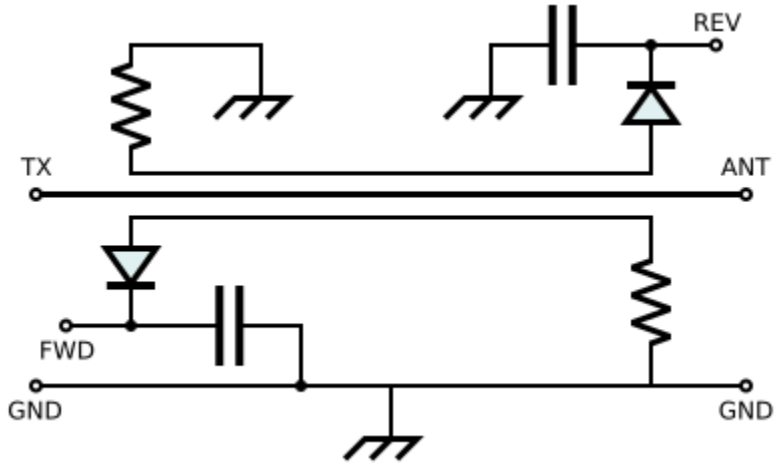


Figure 17: *A generic directional SWR meter circuit diagram [44].*

Viewing Figure 17 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 section 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].

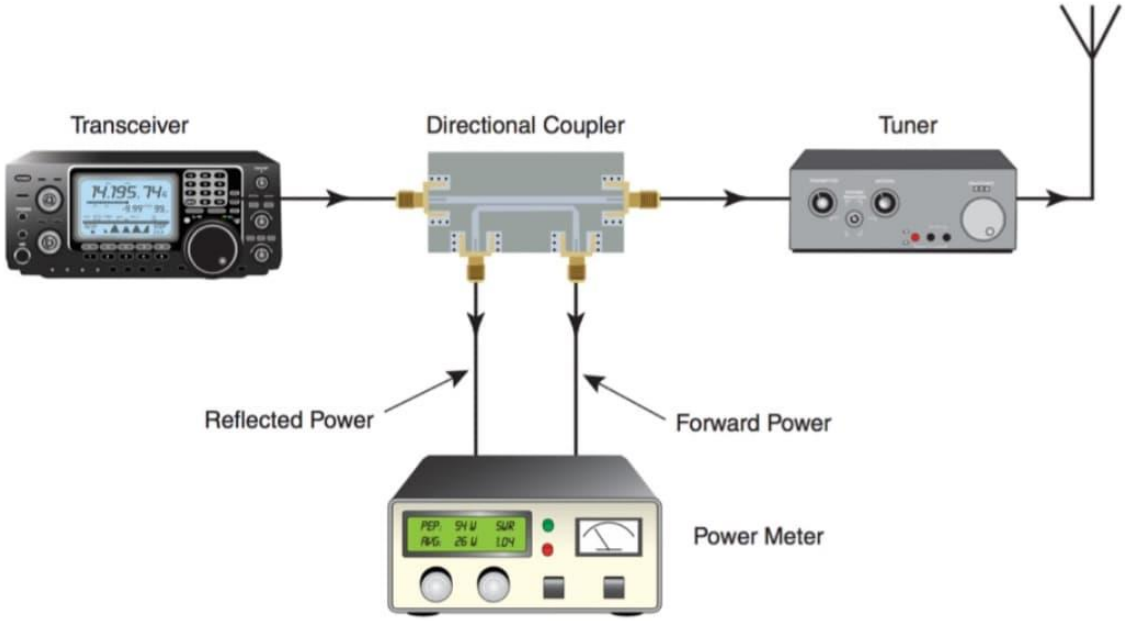
Reflection Coefficient Equation –

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

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 18 below.



b

Figure 18: *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 our 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 19 below.

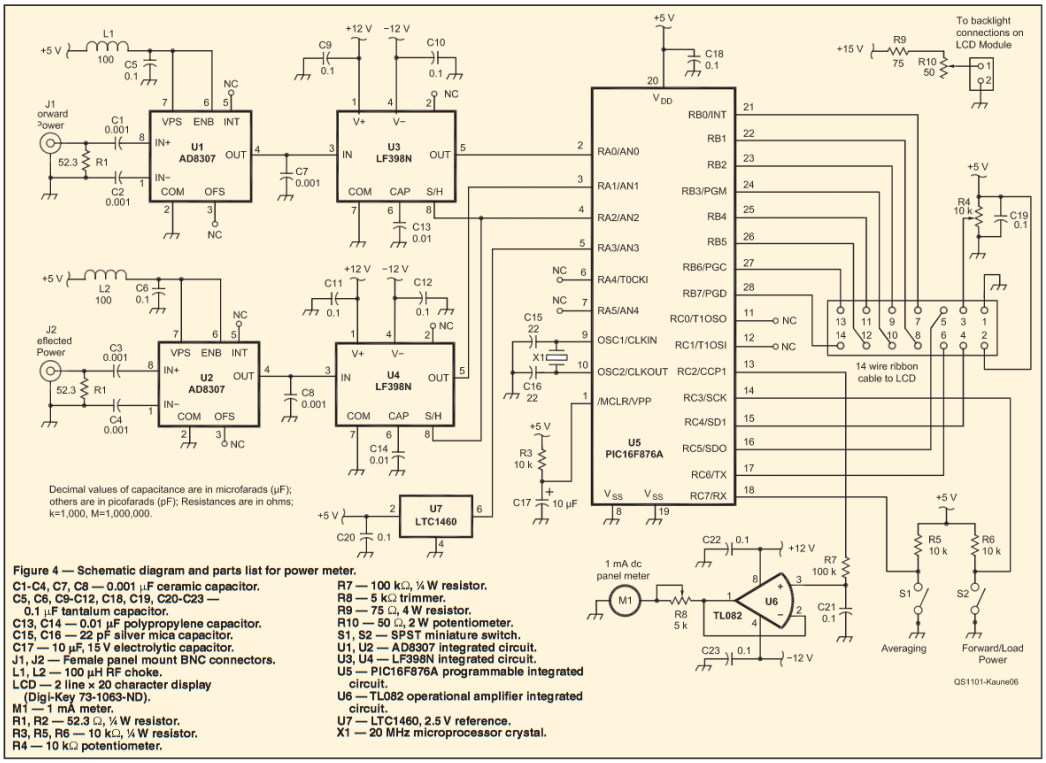


Figure 19: *The AD8307 log detector and a PIC16F876A microcontroller circuit that convert the voltages from the directional coupler into power and SWR meter measurements [20].*

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 20 below [48].

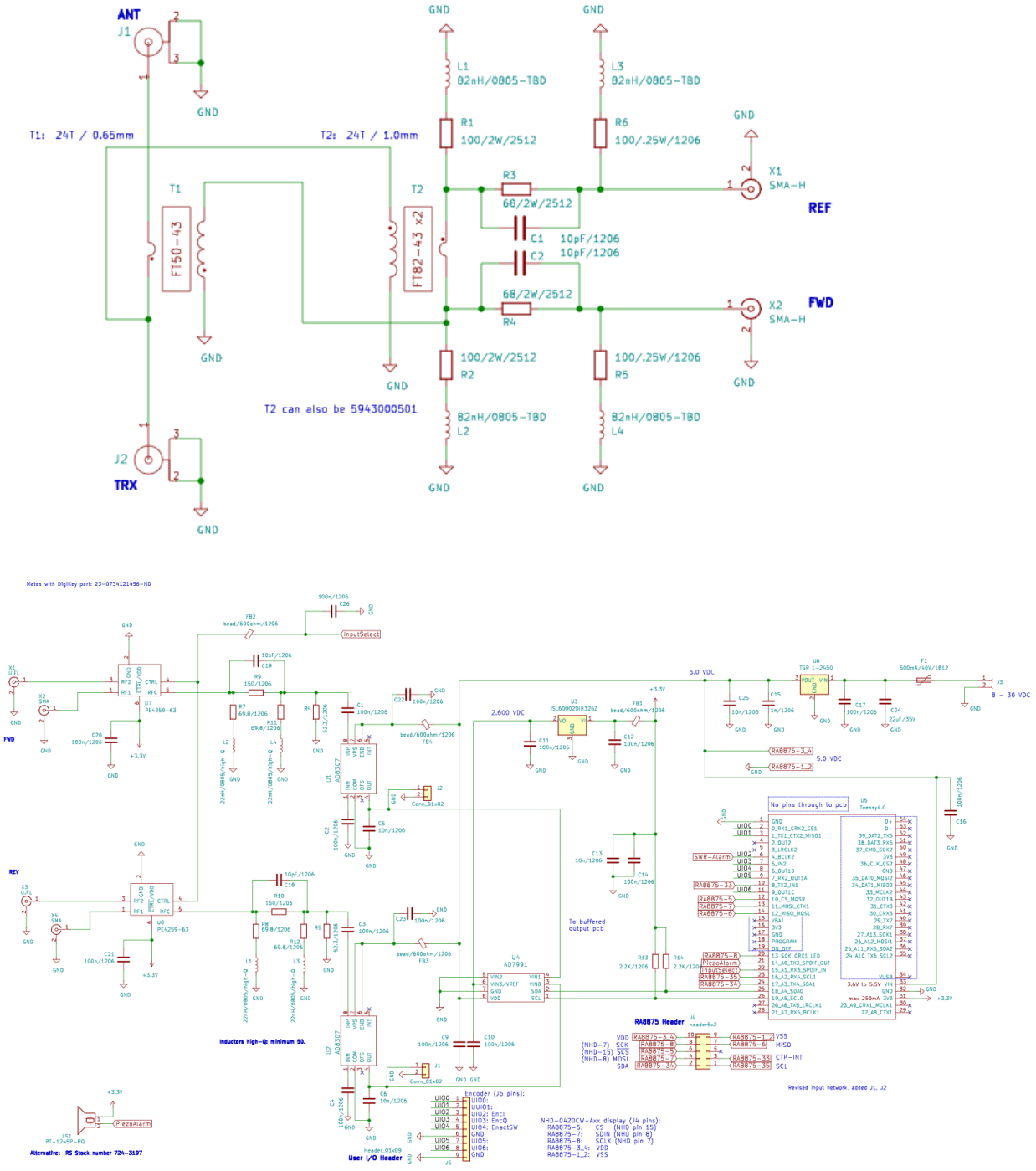


Figure 20: *The directional coupler schematic (Top,) and the AD8307 log detector and Teensy 4.0 microcontroller circuit that convert the voltages from the directional coupler into power and SWR meter measurements [48].*

From viewing the schematic of the directional coupler circuits in Figure 20 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 doesn't 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 the schematic review of Figure 20, it was determined that this SWR/power meter design is 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 140W 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 amp, 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 4 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 4 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.

IV 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	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,

	• Component Sourcing • Documentation • Demonstration of Prototype	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 PCB advisor, being a second pair of eyes to assist in determining any errors in the PCB designs prior to producing the boards.
Emil:	<u>Role –</u> PCB and Enclosure Design <u>Assigned Tasks -</u> • 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:	<u>Role –</u> Website Lead and Communication <u>Assigned Tasks -</u> • 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:	<u>Role –</u> Documentation and Supervisor Laision <u>Assigned Tasks -</u> • 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 Advanced 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]:

1. Principle #1 – Hold paramount the safety, health, and welfare of the public and the protection of the environment.

- 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.

2. Principle #3 – Provide an opinion only when it is founded upon adequate knowledge and honest conviction.

- 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.

4. Principle #6 – Conduct themselves with fairness, courtesy and good faith toward colleagues and others.

- 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!

5. 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.

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 our group. 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 21 below.

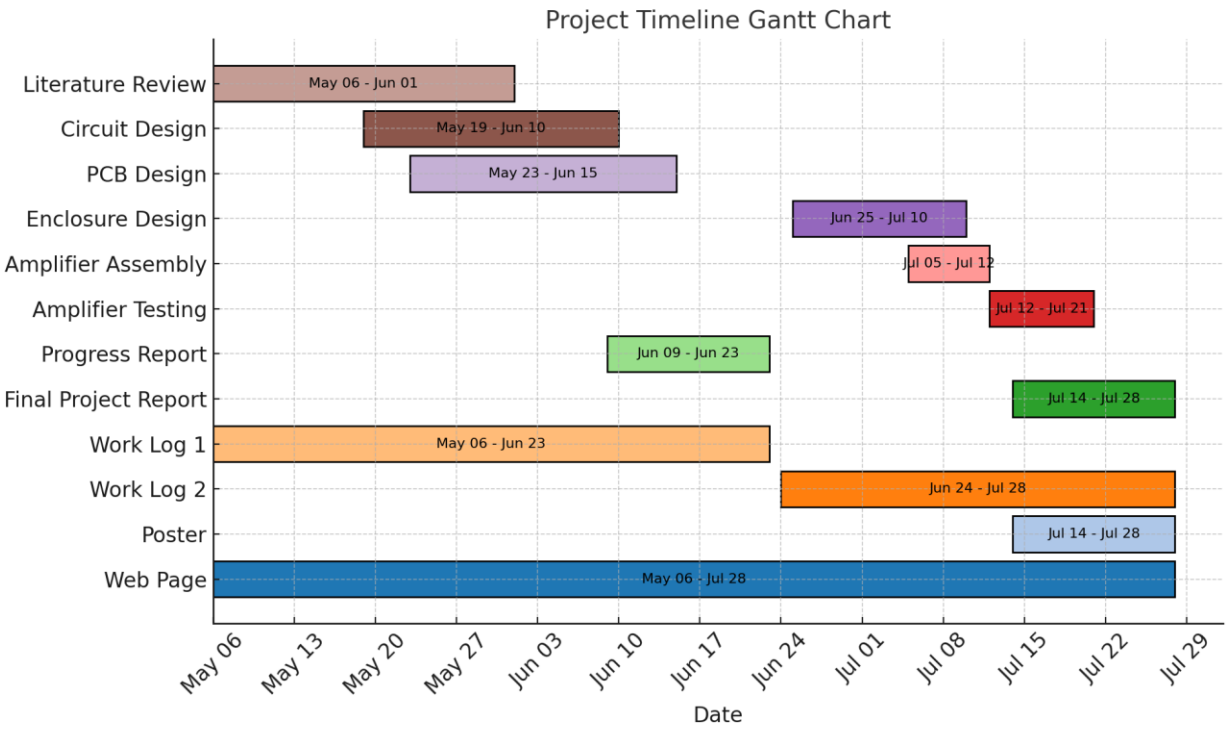


Figure 21: *The Gantt chart developed to plan and schedule the project milestones listed above, and the course deliverables.*

Viewing Figure 21 above, it should be discussed briefly that the milestones are dependent upon the completion of another milestone. For example, development of a circuit diagram designs 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, our group has 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 the first three milestones, and this tactic will be continued during the remainer of the ECE 499 project development time.

Fallback Strategies:

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 amp features for the demonstration, while having the option to add in the stretch goal SWR/power meter in the future.

V Milestone & Progress Made

Project Milestone Staging Approach:

Instead of using a traditional linear timeline with strict deadlines, this project follows a milestone-based development model with each major engineering phase organized as critical milestone, as displayed in the Gantt chart in Figure 21 above. For the sake of clarity, the six critical project milestones are relisted 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.**

As of June 23rd, the team members of this project have successfully completed Steps 1 through 3, and are currently preparing to begin milestone Step 4, which is the enclosure design stage. This step can commence once all of the necessary components have been delivered, and dimensions have been taken, to enable our group to determine what goes where. A summary mind map of the critical project milestones, and the necessary steps to complete each one is highlighted in Figure 22 below.

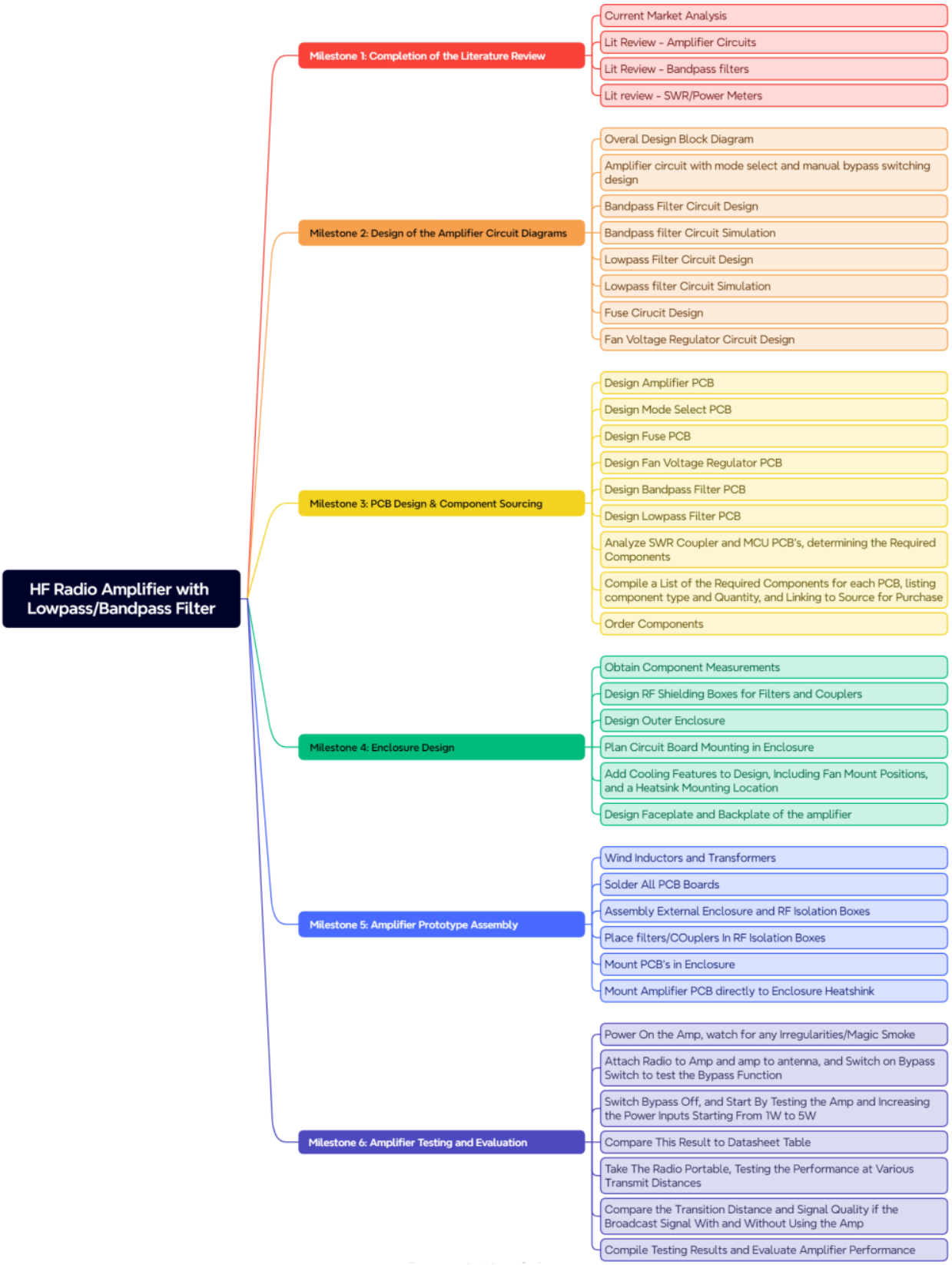


Figure 22: *The mind map developed to summarize each of the project's critical milestones, and the steps needed complete each one.*

Progress Made - Completed Milestones:

Milestone 1 – Completion of the Literature Review:
The steps taken to complete this milestone were covered in great detail in Section III of this report. However, the list displayed below briefly summarizes the steps taken to cover what was done to compete this literature review.

- Conducted a market analysis of 3 popular portable HF amplifiers.
    - Low-cost models lacked filtration and cooling; high-end models were too expensive.
    - Identified a gap for a compact, feature-rich amplifier under $600.00
- Defined the amplifier's feature set, including 3 core systems and one stretch goal:
    - Amplifier Circuit
        - Linear, 5W input to 80–150W output, 13.6V operation.
        - Includes user-selectable AM/SSB modes and manual bypass.
    - Input Bandpass Filter
        - Passband: 1.8–30 MHz, 10W rated.
    - Output Lowpass Filter
        - Cutoff above 30 MHz, rated for 150W.
    - SWR/Power Meter (Stretch Goal)
        - Digital display of forward/reflected power and SWR.
- Amplifier design based on EB63A circuit, chosen for its proven performance and modern component compatibility.
- Input bandpass filter designed using a pi-configured constant-k LC topology for ease of construction and good impedance matching.
- Output lowpass filter selected from a tested Chebyshev 9th-order design (PA0FRI), providing excellent harmonic suppression and 200W handling.
- Directional coupler-based SWR/power meter selected, using Teensy 4.0 and dual AD8307 detectors for accurate RF measurement and digital output.
- This integrated design balances performance, safety, and cost — enabling successful completion of a compact, portable HF amplifier within ECE 499-time constraints.

With Milestone 1 finished, it was time to use the knowledge gained during the literature review to design the required circuit diagrams.

Milestone 2 – Design of the Amplifier Circuit Diagrams
After completing the previous literature review, it was time to design and draw 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 23 below.

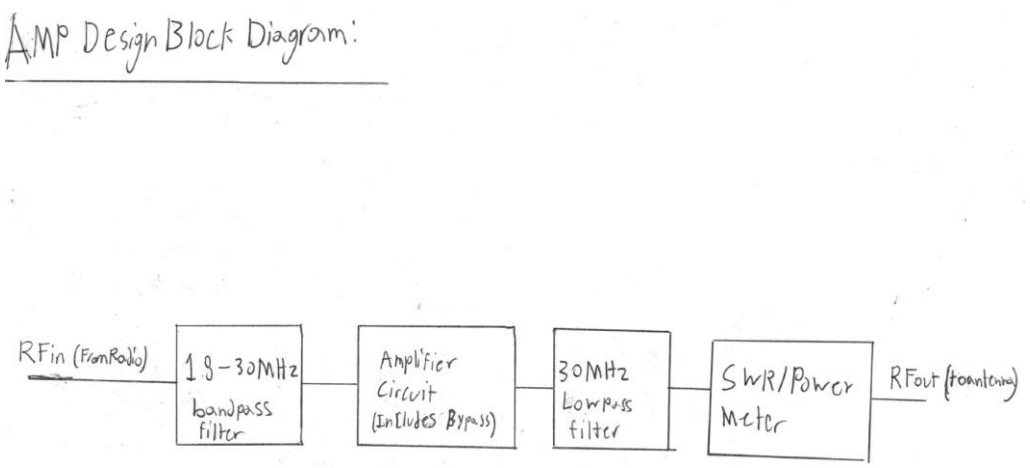
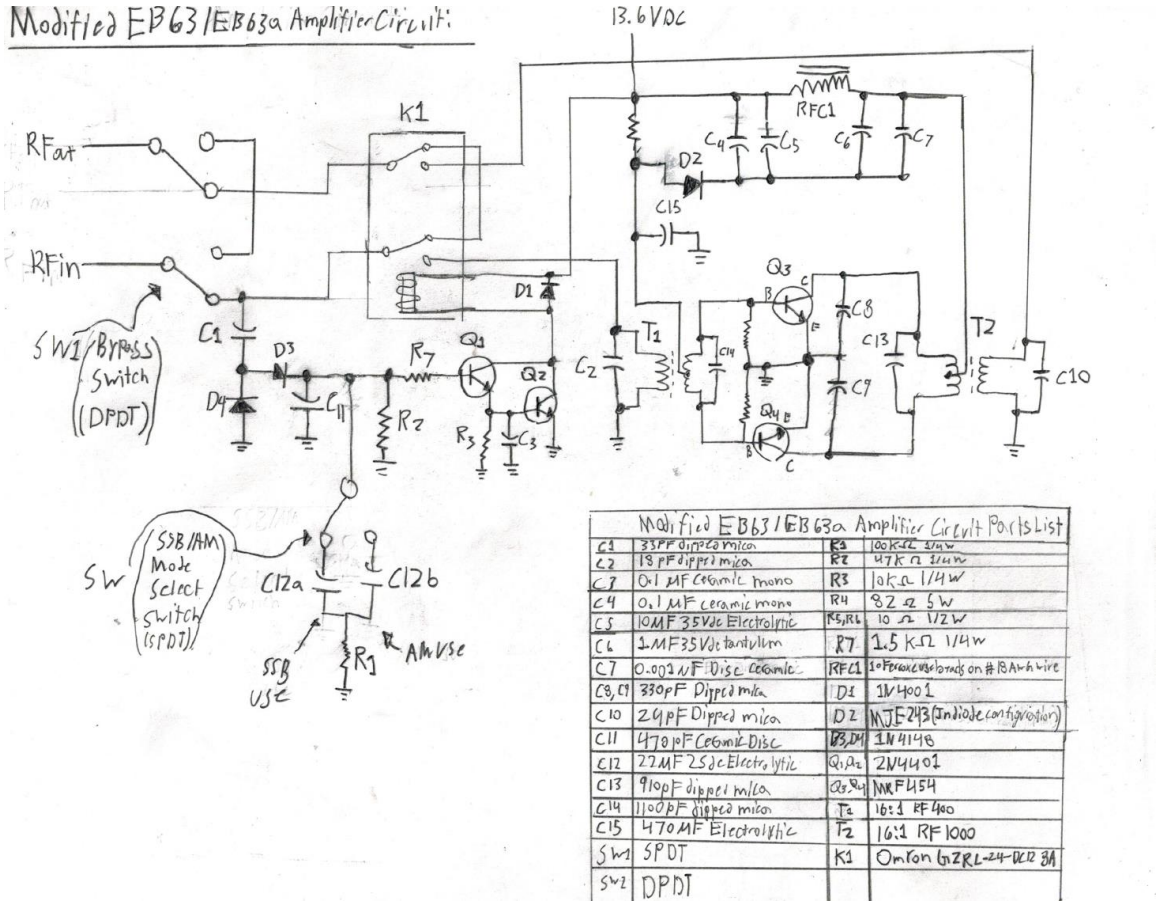


Figure 23: *A block diagram of the amplifier, showing the proper order in which the RF signal flows through each feature of the design.*

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 24 below.



Modified EB63/EB63a Amplifier Circuit Parts List			
C1	33PF dipped mica	R1	100 KΩ 1/4W
C2	18 PF dipped mica	R2	47K Ω 1/4W
C3	0.1 MF Ceramic mono	R3	10K Ω 1/4W
C4	0.1 MF ceramic mono	R4	82 Ω 5W
C5	10MF 35Vdc Electrolytic	R5,R6	10 Ω 1/2W
C6	1MF35Vdc tantulum	R7	1.5 KΩ 1/4W
C7	0.002 MF Disc Ceramic	RFC1	30 Ferrite beads on #18 AWG wire
C8, C9	330pF Dipped mica	D1	1N4001
C10	24pF Dipped mica	D2	MJE243 (2 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 RF 400
C15	470MF Electrolytic	T2	16:1 RF 1000
SW1	SPDT	K1	Omron G2RL-24-DC12 3A
SW2	DPDT		

Figure 24: *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. First 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 25 below.

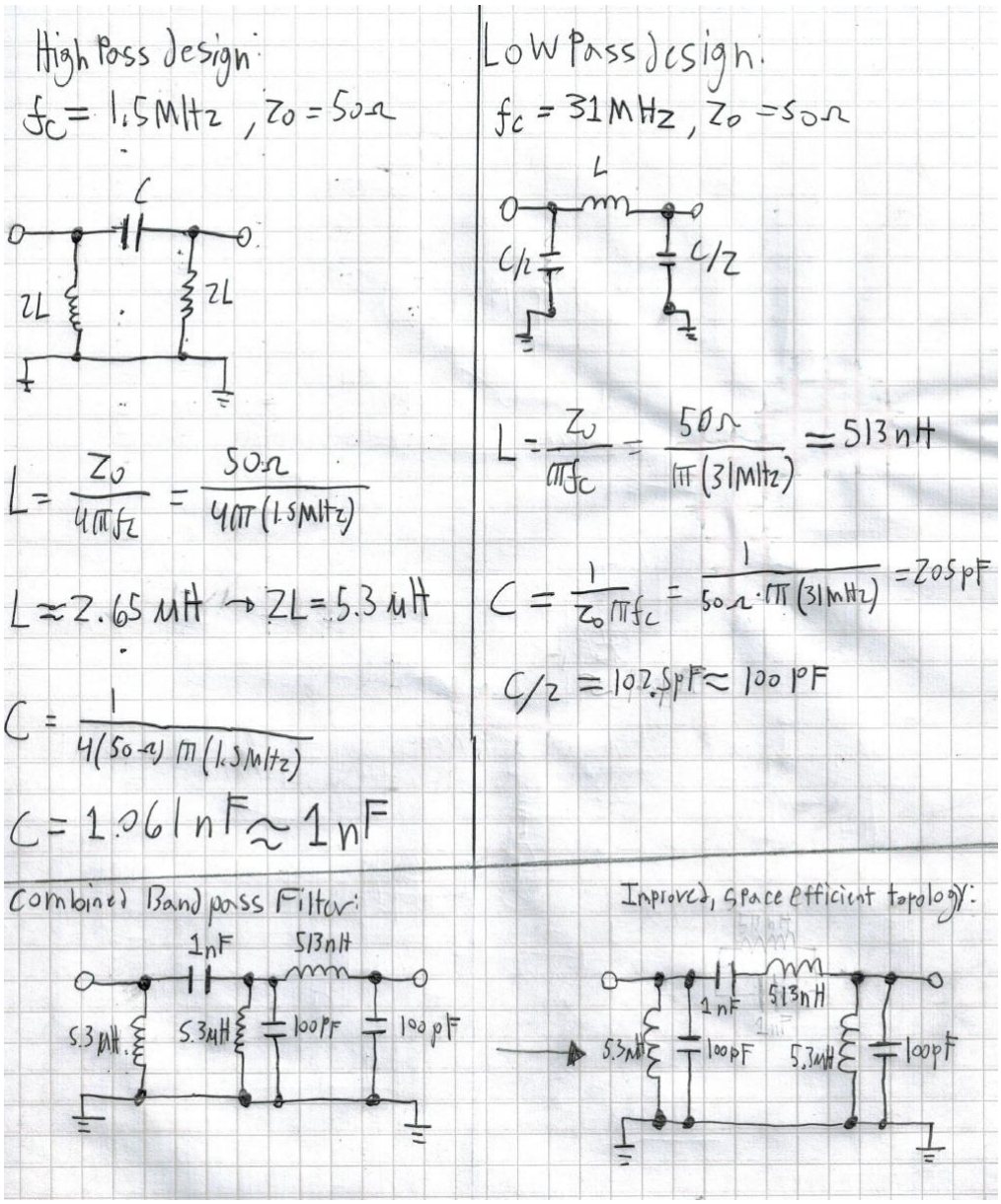


Figure 25: *The hand calculations completed to design the 1.8-30 MHz filter for the input of the amplifier.*

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 26 below.

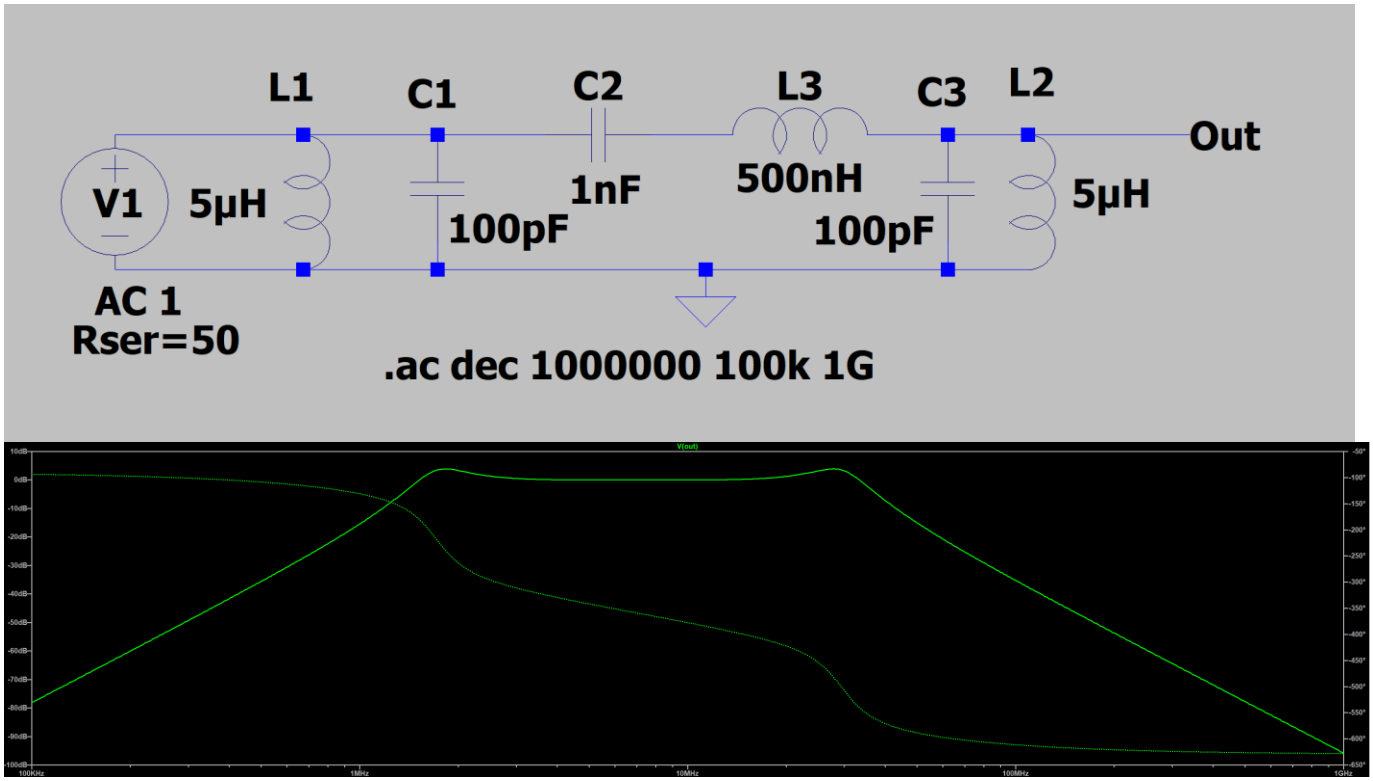


Figure 26: *The LTspice circuit (top) used to perform a simulation of the 1.8-30 MHz filter for the input of the amplifier, and the resulting performance graph (below). Note the rounded components simulating purchasable components as opposed to the theoretical values of the diagram in Figure 25 above.*

From viewing Figure 26 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 exhibits 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 27 below.

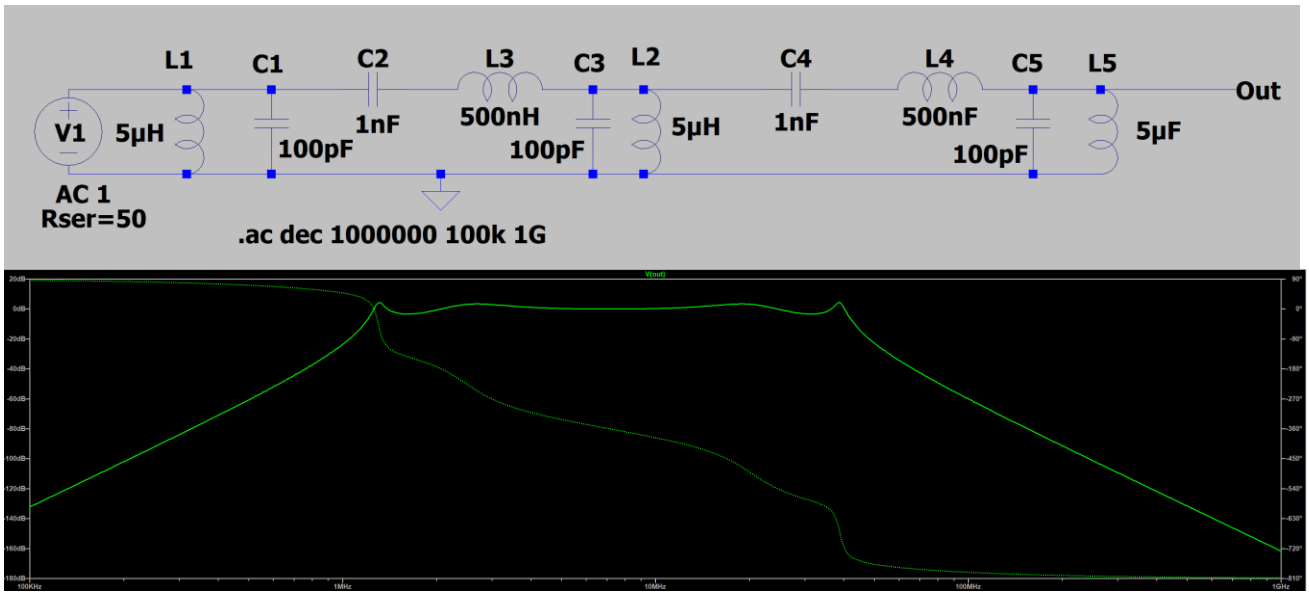


Figure 27: *The updated LTspice circuit (top) for the modified bandpass filter with an added second stage, and the resulting performance graph (below).*

From viewing the output graph in Figure 27 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, our group decided to select this filter configuration as our bandpass filter going forward.

Onto the low pass 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 does 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 16 above, no noticeable ripple. The calculation done to verify this filter can be viewed in Figure 28 below.

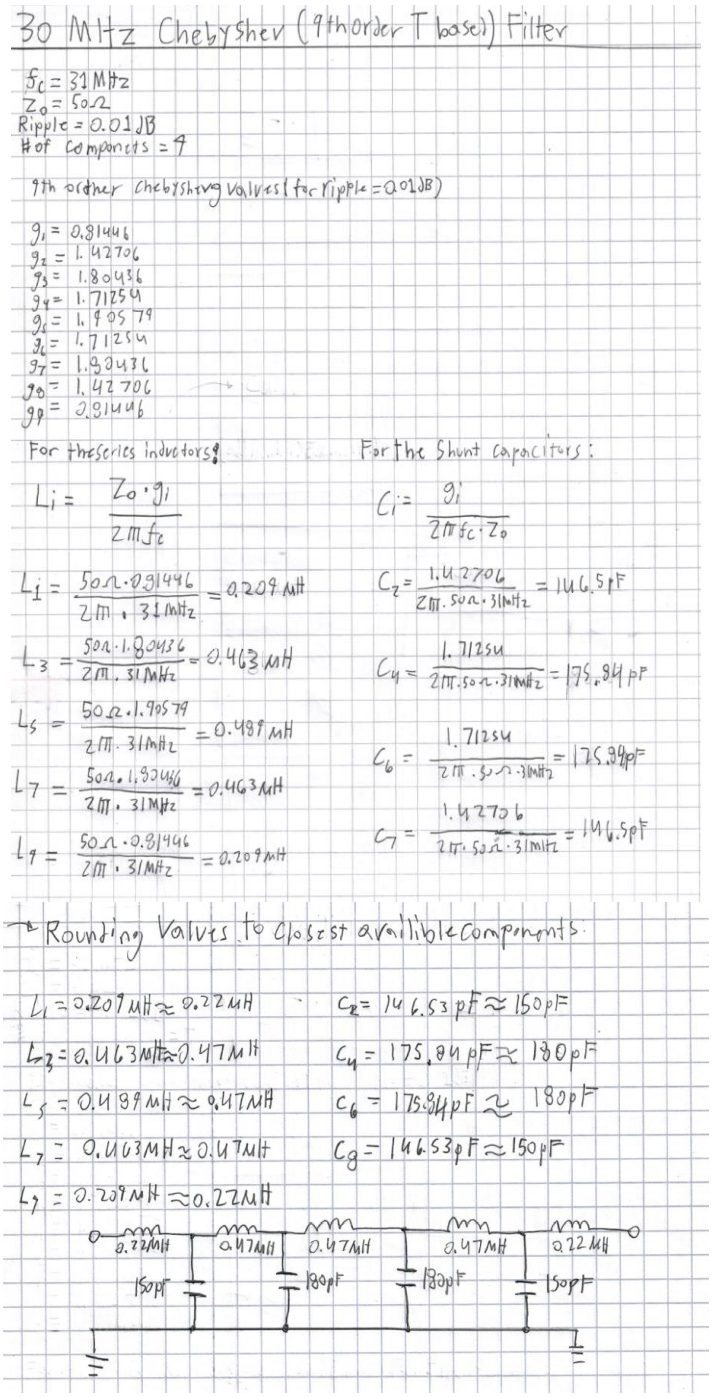


Figure 28: *The hand calculations completed to verify the 9th order T base Chebyshev 30MHz filter for the output of the amplifier.*

From the results calculated in Figure 28 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 29 below.

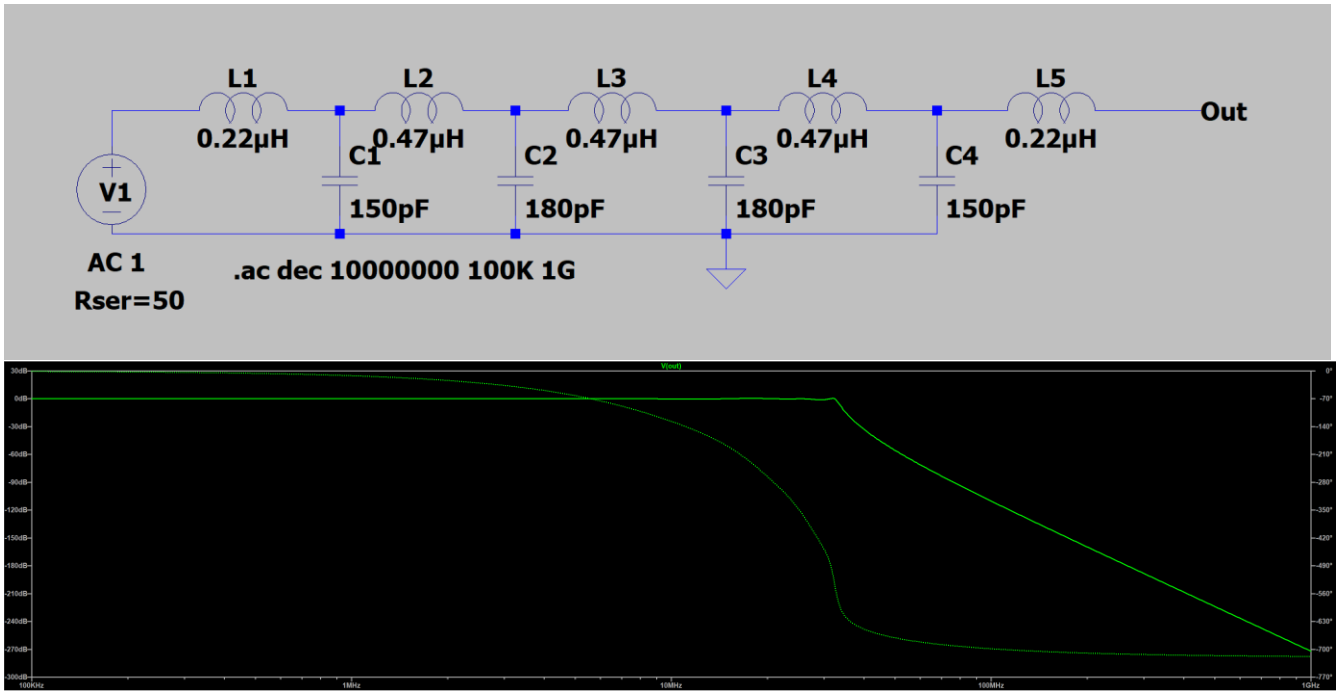


Figure 29: *The LTspice circuit (top) for the 9th order T base Chebyshev 30MHz filter, and the resulting performance graph (below).*

From viewing the simulation graph in Figure 29 above, it can be observed that similar to the spectrum analyzer output shown in Figure 16 above, this LPF design showed a steep frequency cutoff, starting at ~30 MHz and 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 30 below.

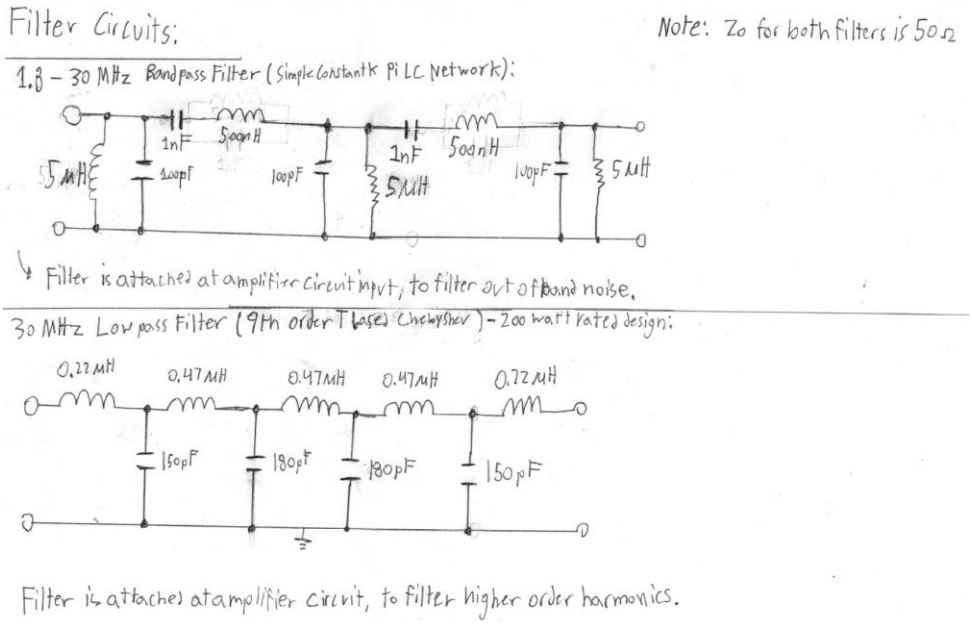


Figure 30: *The finalized bandpass and lowpass filter designs.*

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 will be 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 13.6VDC input voltage used to run the amplifier to a constant 12V, ensuring that the fans will 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 setup to be connected to the power input of the amplifier, and split this input between three fuse output, one powering the amplifier, one powering the fan 12V voltage regulator discussed above, and another to power 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 31 below.

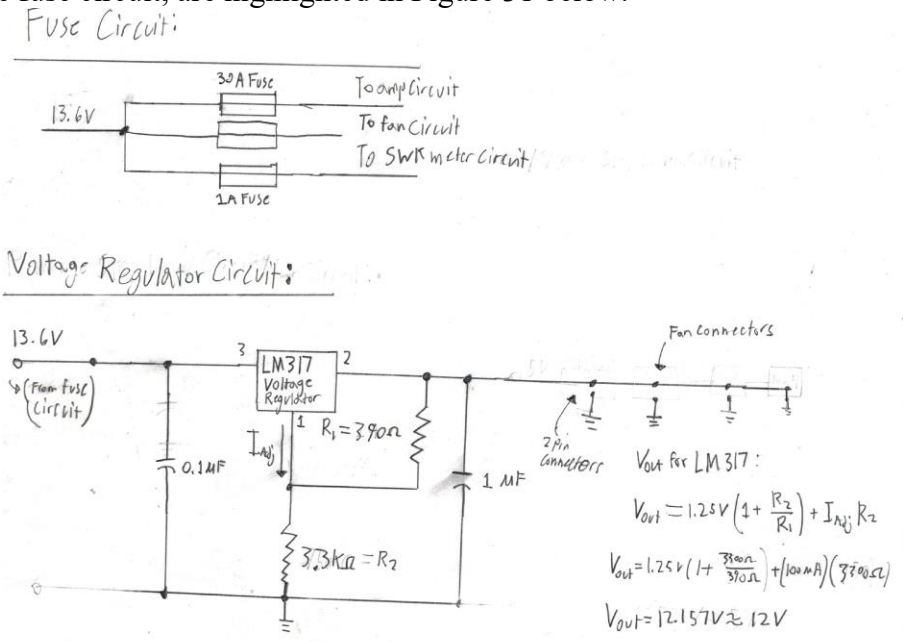


Figure 31: *The circuit diagrams for the fuse circuit and fan voltage regulator circuit. Note the calculations used to determine the resistor ratio used to obtain a 12V output [51*

With the circuit design portion of the design completed, Milestone 2 was completed, and the circuit diagrams were handed off to our groups PCB developer to be implemented into PCBs.

Milestone 3 - PCB Design & Component Sourcing:

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 32 below.

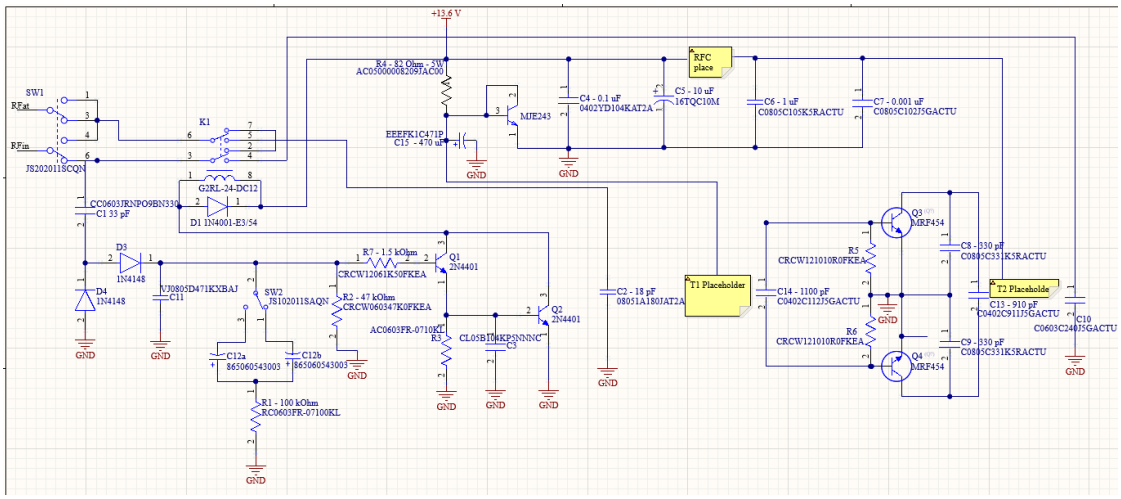


Figure 32: *The Altium PCB schematic drawn for the updated amplifier circuit.*

Note that in this circuit, there was some issues making a proper schematic. Several components, specifically the two MRF454 transistor, 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 33.

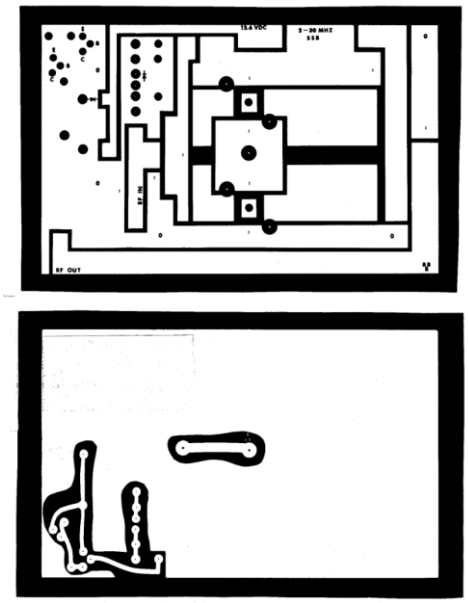


Figure 33: *The PCB board layout/cut path pictures provided to assist in the production of the EB63/EEB63A amplifier's PCB [25].*

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, our group collaborated and decided it would be wisest 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.

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 amp 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 34 below.

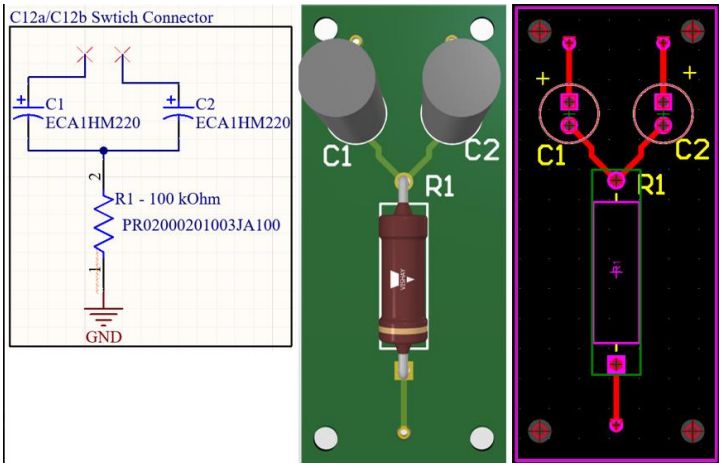


Figure 34: *The Altium PCB schematic (left), the 3D PCB View (middle) and the PCB Layout (right) diagrams designed to implement the AM/SSB mode select circuit.*

Note that this board was designed as a single sided PCB. This was not an error, but rather an intentional design choice. This was done 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 PCB's 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 35 below.

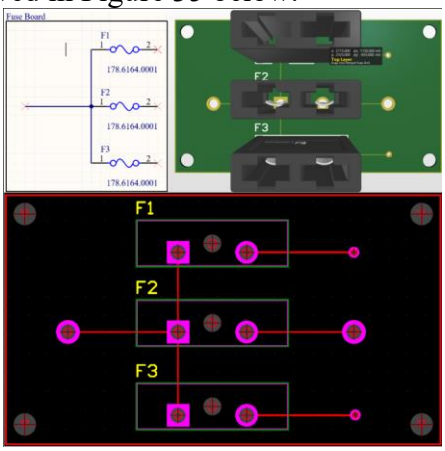


Figure 35: *The Altium PCB schematic (top left), the 3D PCB View (top right) and the PCB Layout (bottom) diagrams designed to implement the fuse circuit.*

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 36 below.

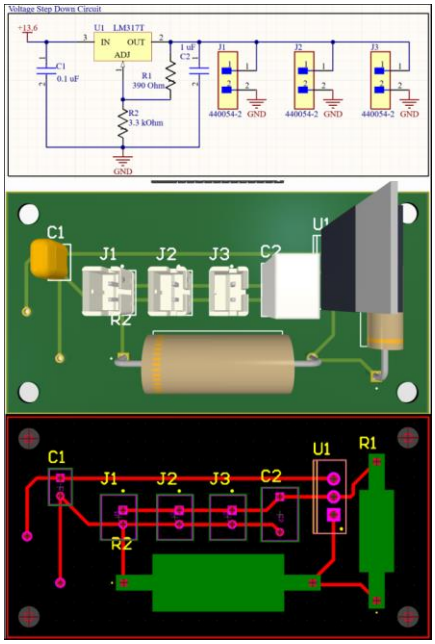


Figure 36: *The Altium PCB schematic, the 3D PCB View and the PCB Layout diagrams designed to implement the cooling fan voltage regulator circuit.*

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 inductor 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 10W input power. The design of the bandpass filter PCB can be viewed in Figure 37 below.

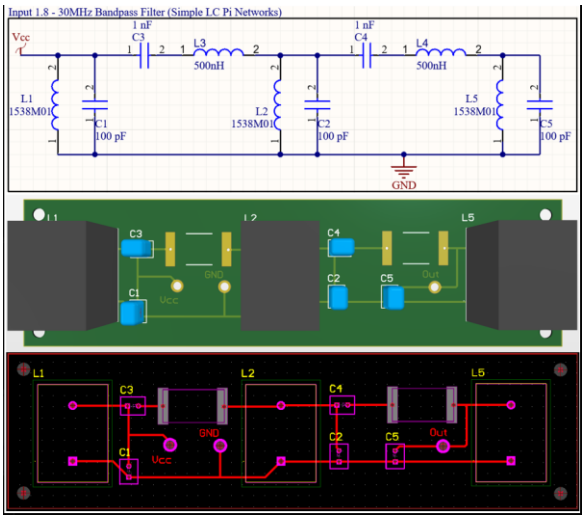


Figure 37: *The Altium PCB schematic, the 3D PCB View and the PCB Layout diagrams designed to implement the bandpass filter circuit.*

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 38 below.

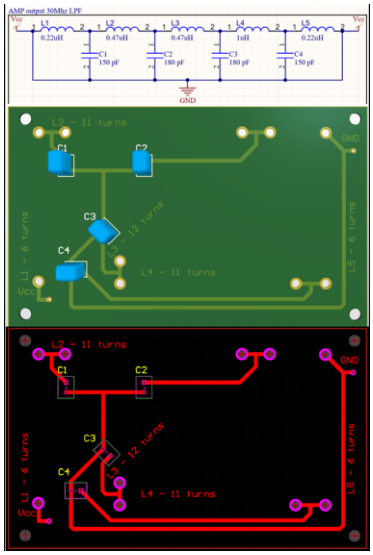


Figure 38: *The Altium PCB schematic (top), the 3D PCB View (middle) and the PCB Layout (bottom) diagrams designed to implement the lowpass filter circuit.*

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 39 below.

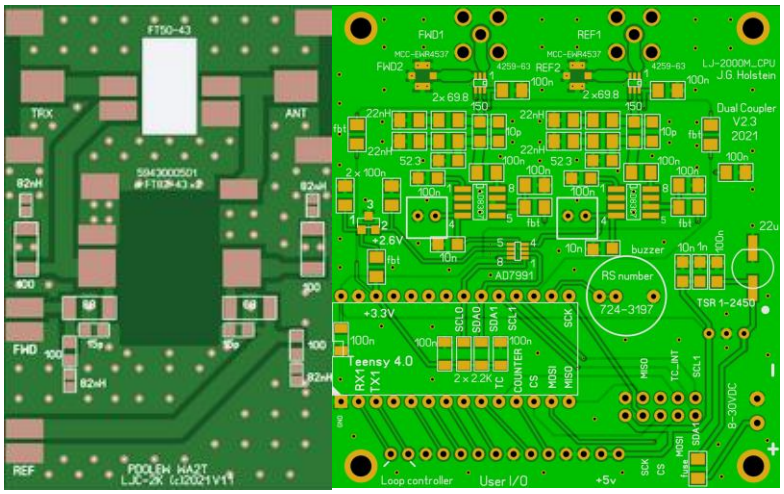


Figure 39: *The PCB designs required for the SWR/power meter, including the directional coupler PCB (left) and the microcontroller PCB (right) [48].*

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 will be 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 are 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 too, 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 40 below.

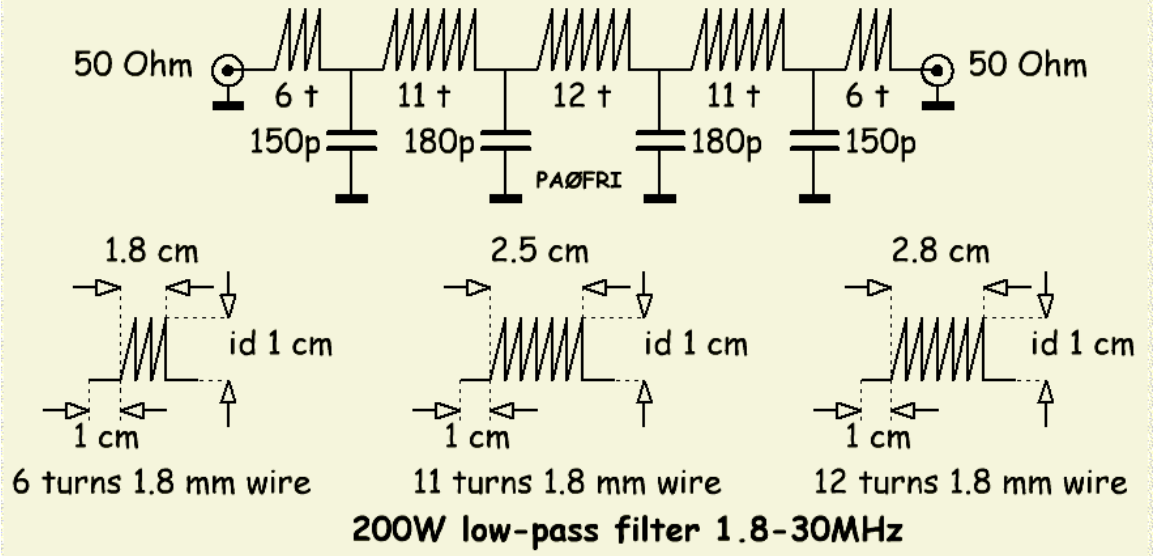


Figure 40: *The instructions provided to produce the inductors [42].*

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 will be wound to the correct internal diameter and length. The STL files of these inductor winding jigs can be viewed in Figure 41 below.

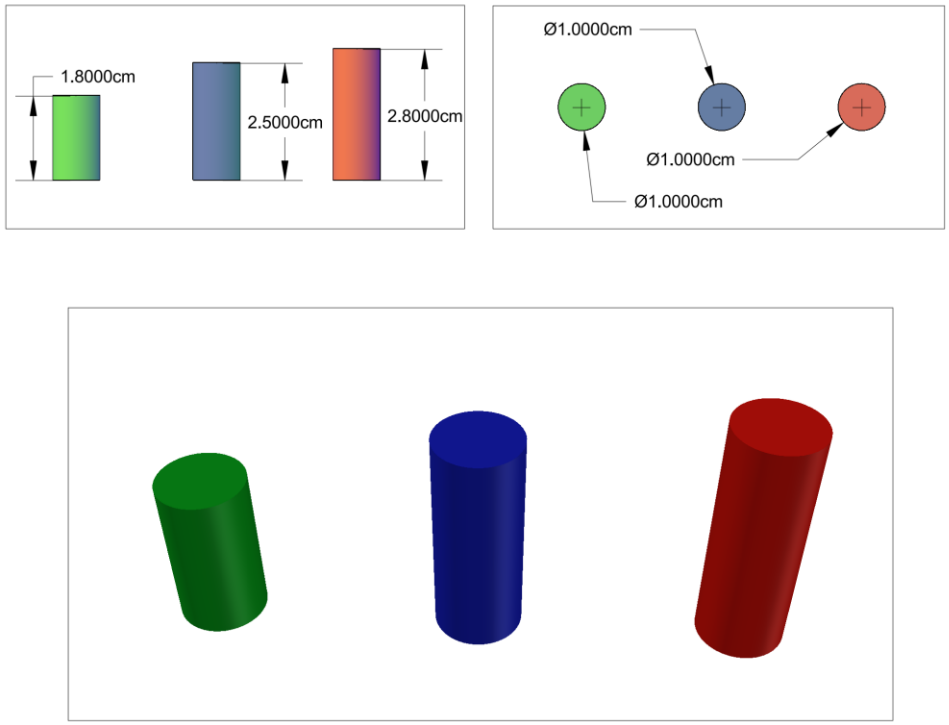


Figure 41: *The jigs designed to assist in winding the required inductors, with the jig lengths (top left) and the internal diameter (top right).*

In Table 2 below, the compiled list of the sourced components for each of the amplifier and mode select PCBs is listed, along with the quantity needed and the link to where each component can be purchased.

Table 2: *The sourced components for the amplifier & mode select circuit PCBs.*

Item	Qty	Link
MRF 454	2	https://www.digikey.ca/en/products/detail/macom-technology-solutions/MRF454/4429887?s=N4IgTCBcDaILYCcBmAWArCkBdAvkA
SO-239 chassis mount	2	https://www.dxengineering.com/parts/aml-83-1r-2
100 kΩ resistor	1	https://www.digikey.ca/en/products/detail/yageo/CFR-25JB-52-100K/245
10 µF	1	https://www.digikey.ca/en/products/detail/nichicon/UKL2A100KPD/2598556
100 µF	1	https://www.digikey.ca/en/products/detail/nichicon/UKL1E101KPD1TA/7702093
33pF mica	1	https://www.mouser.ca/ProductDetail/Cornell-Dubilier-CDE/CD5EC330GO3F?qs=FKrQhPEeH%252B6Fv5gb7uwbsA%3D%3D
18pF mica	1	https://www.mouser.ca/ProductDetail/Cornell-Dubilier-CDE/CD15CD180JO3?qs=%2F1dUQgrGUe%252BjRpY%2FrhBwpg%3D%3D
0.1 µF	2	https://www.mouser.ca/ProductDetail/Vishay-BC-Components/K104M20X7RH53L2?qs=SFC1ZZvMyCE87rbn3%2FQBJw%3D%3D

10 µF 35V	1	https://www.mouser.ca/ProductDetail/Panasonic/ECA-1VM100?qs=F80sRR%252BEZdBj42PTfvMN/Q%3D%3D&mgh=1
0.001 µF	1	https://www.mouser.ca/ProductDetail/Vishay-Cera-Mite/440LD10-R?qs=Ihd9YkxhV%2F1aEhVz1HY2Dw%3D%3D
330pF mica	1	https://www.digikey.ca/en/products/detail/cornell-dubilier-knowles/CDV16FF331JO3F/191865
24pF mica capacitor	1	https://www.mouser.ca/c/passive-components/capacitors/mica-capacitors/?product=Mica%20High-Reliability%20Dipped%20Capacitors&tolerance=5%20%25&voltage%20rating=500%20V
470pF disc capacitor	1	https://www.mouser.ca/ProductDetail/Vishay-BC-Components/D471K25X5FL63L6R?qs=sGAEpiMZZMsh%252B1woXyUXj9HV3trBt2tzxACsBCbv1EQ%3D
22 µF 25V	1	https://www.mouser.ca/ProductDetail/Vishay-BC-Components/MAL215253229E3?qs=sGAEpiMZZMvwFf0viD3Y3Yd5qvTVv7orqA6oynJdbOA%3D
910pF mica	1	https://www.mouser.ca/ProductDetail/Cornell-Dubilier-CDE/CD19FD911FO3?qs=0yhueWoPdxZvjYrtkwvzlA%3D%3D
1100pF mica	1	https://www.mouser.ca/ProductDetail/Cornell-Dubilier-CDE/CMR06F112JPDP?qs=m78fPdUw%2FC622vPMgdPHBg%3D%3D
470 µF 10V	1	https://www.mouser.ca/ProductDetail/Nichicon/UKL0J471KPD?qs=ZVaCMNtmgGtLYlZZF0T0YA%3D%3D
47 kΩ resistor	1	https://www.mouser.ca/ProductDetail/Vishay-Dale/RN60C4702BRE6?qs=sGAEpiMZZMtlubZbdhIBIK3X3PWD81tWJEVrcF4%252BYH8%3D
10 kΩ resistor	1	https://www.mouser.ca/ProductDetail/Vishay-Beyschlag/UXB02070F1002BR100?qs=sGAEpiMZZMtG0KNrPCHnjbzpkYId2j dB70F1sB11KFfDtaMoJWVxIw%3D%3D
82 Ω 5W resistor	1	https://www.mouser.ca/ProductDetail/Vishay-Dale/RS00582R00FB12?qs=sGAEpiMZZMtTURnxoZnJAO0hnOwCUI0sl2UFs mAo0v8%3D
10 Ω 1/2W resistor	1	https://www.mouser.ca/ProductDetail/Welwyn-Components-TT-Electronics/MFR4-10RFI?qs=sGAEpiMZZMtlubZbdhIBIGYFHJev72lv0Yu23ll%252BFcQ%3D
1.5 kΩ 1/4W resistor	1	https://www.mouser.ca/ProductDetail/KOA-Speer/CF1-4L152J?qs=sGAEpiMZZMtlubZbdhIBID%2F3ETw08syTXvqogapQg2U%3D
Ferrite beads	10	https://www.communication-concepts.com/56-590-65-3b/b
1N4001 diode	1	https://www.mouser.ca/ProductDetail/Diodes-Incorporated/1N4001-T?qs=e%2FRqmsgwm9i%2FVrrtazegeg%3D%3D
MJE243 transistor	1	https://www.communication-concepts.com/mje243/
1N4148 diode	2	https://www.digikey.ca/en/products/detail/onsemi/1N4148/458603

2N4401 transistor	2	https://www.digikey.ca/en/products/detail/central-semiconductor-corp/2N4401-PBFREE/4806892
RF400 transformer	1	https://www.communication-concepts.com/rf-400-transformer/
RF1000 transformer	1	https://www.communication-concepts.com/rf-1000-transformer/
Omron G2RL-24-DC12 relay	1	https://www.digikey.ca/en/products/detail/omron-electronics-inc-emc-div/G2RL-24-DC12/307667

In Table 3 below, the compiled list of the sourced components for the fuse circuit PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 3: *The sourced components for the fuse circuit PCB.*

Item	Qty	Link
Fuse holder	3	https://www.mouser.ca/ProductDetail/Littelfuse/17861640002?qs=3tbmSRLcNVfzxIX36ez%2Fsg%3D%3D&mgh=1
Fuse (25\ A, 2A, 1A)	1	https://www.amazon.ca/130PCS-Standard-Assortment-SIM-NAT/dp/B07G33XCHM?source=ps-sl-shoppingads-lpcontext&ref_=fplfs&psc=1&smid=A2QLFR4HNCTTLU

In Table 4 below, the compiled list of the sourced components for the voltage regulator/fan circuit PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 4: *The sourced components for the Voltage Regulator / Fan Circuit PCB.*

Item	Qty	Link
LM317 voltage regulator	1	https://www.mouser.ca/ProductDetail/926-LM317AT-NOPB
0.1 uF	1	https://www.digikey.ca/en/products/detail/epcos-tdk-electronics/B32529C0104J289/1089744
1 uF capacitor	1	https://www.digikey.ca/en/products/detail/kemet/ESK105M100AC3FA/13176422
390 Ω	1	https://www.mouser.ca/ProductDetail/Vishay-BC-Components/MBA0204BC3900FCT00?qs=sGAEpiMZZMtlubZbdhIBIDf1ptYLsLpZklHWvJ04a8c%3D

3.3kΩ	1	https://www.mouser.ca/ProductDetail/Vishay-BC-Components/PR02000203301FA100?qs=sGAEpiMZZMtlubZbdhIBID%2Fk4zWMowBeD4dDpbV%2FILA%3D
1x2 connector	3	https://www.digikey.ca/en/products/detail/te-connectivity-amp-connectors/440054-2/2077939

In Table 5 below, the compiled list of the sourced components for the lowpass filter PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 5: *The sourced components for the lowpass filter PCB.*

Item	Qty	Link
Inductor Wire	1 spool	https://www.amazon.ca/gp/product/B0D1GBSBMV?smid=A1NR50YASSZD11&psc=1
150 pF mica	2	https://www.digikey.ca/en/products/detail/cornell-dubilier-knowles/CD15FD151FO3/2616871
180 pF mica	2	https://www.digikey.ca/en/products/detail/cornell-dubilier-knowles/CD15FD181FO3F/1917815

In Table 6 below, the compiled list of the sourced components for the bandpass filter PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 6: *The sourced components for the bandpass filter PCB.*

Item	**Qty**	**Link**
Inductor Wire	1 spool	https://www.amazon.ca/gp/product/B0D1GBSBMV?smid=A1NR50YASSZD11&psc=1
150 pF mica	2	https://www.digikey.ca/en/products/detail/cornell-dubilier-knowles/CD15FD151FO3/2616871
180 pF mica	2	https://www.digikey.ca/en/products/detail/cornell-dubilier-knowles/CD15FD181FO3F/1917815

In Table 7 below, the compiled list of the sourced components for the SWR/Power Meter - Coupler PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 7: *The sourced components for the SWR/Power Meter - Coupler Circuit PCB.*

Component	**Qty**	**Link**
Small Transformer	1	https://www.digikey.ca/en/products/detail/fair-rite-products-corp/5943001101/8593847
0.65 mm Winding Wire	1 role	https://www.amazon.ca/dp/B0CYPG2JYY

Large Transformer	2	https://www.digikey.ca/en/products/detail/fair-rite-products-corp/5943000501/8594082
1.0 mm Winding Wire	1 role	https://www.amazon.ca/dp/B0CYP7D6B8
100 Ω 1W	2	https://www.digikey.ca/en/products/detail/stackpole-electronics-inc/RMCF2512JT100R/1756924
100 Ω 0.25W	2	https://www.digikey.ca/en/products/detail/te-connectivity-passive-product/CRG1206F100K/2389961
68 Ω 2W	2	https://www.digikey.ca/en/products/detail/te-connectivity-passive-product/CRGP2512F68R/8577309
82 nH (0805)	4	https://www.mouser.ca/ProductDetail/Coilcraft/0805CS-820XGRC?qs=rQFj71Wb1eXev9ZkN5JlZA%3D%3D

In Table 8 below, the compiled list of the sourced components for the SWR/Power Meter - microcontroller PCB is listed, along with the quantity needed and the link to where each component can be purchased.

Table 8: *The sourced components for the SWR/Power Meter – Microcontroller PCB.*

Item	Qty	Link
Teensy 4.0 Board	1	https://ca.robotshop.com/products/teensy-usb-board-version-40-w-pins-soldered?pr_prod_strat=e5_desc&pr_rec_id=f0299e215&pr_rec_pid=7861864235159&pr_ref_pid=7728996024471&pr_seq=uniform
ILI9488 Display	1	https://www.amazon.ca/HiLetgo%C3%82%C2%B6%C3%82%C2%A9-HiLetgo-Display-ILI9486-Mega2560/dp/B073R7Q8FF
Fuse 500mA 1812	1	https://www.digikey.cn/en/products/detail/bourns-inc/MF-MSMF050-40X-2/12334068
TSR 1-2450	1	https://www.digikey.ca/en/products/detail/traco-power/TSR-1-2450/9383780
ISL60002 DIH326Z	1	https://www.digikey.ca/en/products/detail/renesas-electronics-corporation/ISL60002DIH326Z-TK/1915182
AD7991	1	https://www.digikey.ca/en/products/detail/analog-devices-inc/AD7991YRJZ-1500RL7/1805659
AD8307	2	https://www.digikey.ca/en/products/detail/analog-devices-inc/AD8307ARZ-REEL/3771264
PE4259-63	2	https://www.digikey.ca/en/products/detail/psemi/4259-63/2614473
PT-1245P-PQ Buzzer	1	https://www.digikey.ca/en/products/detail/mallory-sonalert-products-inc/PT-1245P-PQ/1957867
Terminal Block	1	https://www.mouser.ca/ProductDetail/Phoenix-Contact/1756993?qs=iCzJi/IZBF5Zal4EhCc1xA%3D%3D&mgh=1
5x2 Header	1	https://www.amazon.ca/Header-Lystaii-Pin-Connector-Electronic/dp/B06ZZN8L9S
1x2 Connector	2	https://www.digikey.ca/en/products/detail/te-connectivity-amp-connectors/440054-2/2077939?gad_campaignid=17336435733
Teensy Board Connector	2	https://www.amazon.ca/Pieces-2-54mm-Single-Female-Header/dp/B07WK5S2PL

22uF SMD	1	https://www.digikey.ca/en/products/detail/w%C3%BCrth-elektronik/865060543003/5728178
100nF 1206	15	https://www.mouser.ca/ProductDetail/TAIYO-YUDEN/MCJCU31LBB7104KTPA01?qs=tlsG%2FOw5FFgiqRcQEEePOw%3D%3D
1nF 1206	1	https://www.mouser.ca/ProductDetail/TAIYO-YUDEN/MCASS31QHB7102KTNA01?qs=tlsG%2FOw5FFjZlLRdDEBGgw%3D%3D
10nF 1206	3	https://www.mouser.ca/ProductDetail/TAIYO-YUDEN/MBASU105SB7103KFNA18?qs=tlsG%2FOw5FFi07WyLActvvg%3D%3D
150 Ω 1206	2	https://www.digikey.ca/en/products/detail/stackpole-electronics-inc/RMCF1206JG150R/1757480
10pF 1206	2	https://www.mouser.ca/ProductDetail/Vishay-Vitramon/VJ1206A100JXAAC?qs=WHlX%252B%252B9%2FRwCxjICwtDObrg%3D%3D
69.8 Ω 1206	4	https://www.digikey.ca/en/products/detail/yageo/RC1206FR-0769R8L/729068
22nH 0805 High Q	4	https://www.digikey.ca/en/products/detail/abracon-llc/AISC-0805HQ-22NJ-T/4259668
Bead 600Ω 1206	5	https://www.mouser.ca/ProductDetail/Murata-Electronics/BLM31KN601SH1L?qs=EU6FO9ffTwe9dq4ji0ZK9A%3D%3D
52.3 Ω 1206	2	https://www.digikey.in/en/products/detail/stackpole-electronics-inc/RMCF1206FT52R3/1754077
2.2 kΩ 1206	2	https://www.digikey.ca/en/products/detail/te-connectivity-passive-product/CRGCQ1206F2K2/8576416

Note that every component listed in Tables 2 – 8 has been ordered, with an estimated arrival time of late June to early July. Additionally, to route the signal between the various PCBs, RG-316 coaxial cable was also ordered. Initially, the plan was just to use standard wire. However, upon 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. 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].

In addition to technical design work related to completing the listed project milestones, other progress has been made in the course deliverable side of the project. Consistent entries into the project website have been made weekly, documenting development progress. Additionally, each member has completed an informal progress report weekly, which is submitted to our TA, explaining what each member completed that week, and the planned tasks for the following week. And of course, all members have participated in completing their official work logs, submitting Work Log 1, and completing this progress report. To summarize the progress made in our ECE 499 project thus far, the first three milestones, that being the literature review, circuit design as well as the PCB design and component sourcing have been fully completed, along with consistent weekly work being conducted toward completing course deliverables.

VI Summary & Future Work

To summarize this report, our group's ECE 499 project is to design, build, and test a high-power HF, portable amplifier. The development and testing of this amplifier is being completed with the intention to create a low-cost, decentralized piece of emergency communication system infrastructure for use in rural and disaster-prone areas during natural disaster and emergency situations. At the time of writing this report, our team has successfully completed the first three milestones, including a literature review, circuit designs and component sourcing/PCB designs. The project literature review that was conducted, analyzed current market offerings to identify the features and specifications needed for our amplifier prototype, as well as learning how to implement them successfully. For the primary amplification feature, a transistor-based push pull amplifier was chosen over the conventional vacuum tube alternatives because of its smaller footprint, availability and better efficiency. The specific core amplifier design selected was the 140-watt EB63A amplifier circuit. The EB63A was paired with two filtration features, a constant-k LC 1.8 – 30 MHz bandpass filter at the input to attenuate out of band noise, and a 30 MHz Chebyshev lowpass filter at the output to attenuate higher order harmonics. A stretch goal for implanting a directionally coupled SWR/power meter was investigated, and was determined to be possible to complete. All circuit designs have been completed, overviewed and finalized, with the filters simulated using LTspice. The required PCBs have been all designed, and a full bill of materials was compiled, with all the required parts having been ordered, and anticipated arrival dates being between late June through early July. Additionally, roles and tasks were assigned to each member at the start of the project, and critical milestones and deliverables were organized in a Gantt chart to ensure smooth project development. Milestone completion dependencies were identified, and fallback strategies have been employed to ensure for a successful amplifier completion and prototype demonstration. Consistent work on the project website has also been conducted regularly to ensure this deliverable is completed accurately and on time.

The next phase of the project development work is to complete the enclosure design, protype assembly, and testing/debugging of the amplifier. Our team is scheduled to begin completion of these milestones once the remainder of our electrical components arrive, expected to be in late June and early July. Future work for the project includes the following tasks:

- Design an enclosure to house the amplifier and keep components cool.
- Assemble the protype, including assembling all of the PCBs, constructing the enclosure, and wiring the amplifier.
- Conduct performance tests on factors such as output power, harmonic distortion, and thermal stability.
- Tuning and verifying the bandpass and lowpass filters.
- Optionally integrating the SWR/power meter circuit.
- Test the amplifier in the field, observing its performance at varying distances.
- Finalize technical documentation and poster content for project demonstration.
- Complete the ECE 499 Final Report, and the 2nd Work Log.

To close this ECE 499 project progress report, our group can confirm our ECE 499 project development remains on track for assembly, testing and completion prior to the demonstration during the last week of July.

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