Washington State University

School of Electrical Engineering and Computer Science

EE 352 Electrical Engineering Laboratory

Final Project Report

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Abstract

The goal of this project was to design, construct, and demonstrate an AM radio capable of modulating, transmitting, and demodulating a single tone AM-modulated signal s(t) for all single tone frequencies between 400 Hz and 4kHz. The transmitter circuit consisted of an oscillator to generate the carrier signal, a switching modulator to combine the signals from the oscillator and the input, a bandpass filter to choose only the needed frequencies to pass through, and then a power amplifier to increase the signal amplitude so it can be sent to the receiver. The receiver consisted of a peak detector to detect the peaks of the incoming signal and start the process of recovering the message signal, then the noise was filtered out of the signal using a band pass filter. Finally, the signals is sent through another power amplifier to be sent to a speaker. The simulated circuit yielded results that met the design requirements and the physical transmitter and receiver built in lab met the design requirements as well.

1.0 Introduction

The project was split into two parts, the transmitter and receiver. The transmitter purpose was to take in a message signal and output an AM signal. The transmitter circuit consisted of various smaller circuits such as an oscillator, switching modulator, and bandpass filter. These smaller circuits will be explained further in a later section.

Amplitude modulation (AM) is a process in which the amplitude of the carrier signal is varied linearly with the message signal. An amplitude-modulated wave can best be described as follows:

$$s(t) = A_c[1 + k_a m(t)]\, cos(2\pi f_c t) \quad (1)$$

Where *s(t)* is the modulated signal, k_a is a constant known as the amplitude sensitivity, A_c is the carrier amplitude, *m(t)* is the message signal, and f_c is the carrier frequency. It can be observed that s(t) and m(t) exhibit the same shape as long as the following conditions are satisfied: $k_a m(t) < 1$. This is to ensure that the phase never becomes reversed, & f_c must be much greater than the message bandwidth W, this is to ensure that the envelope can be visualized. It is shown in figure 2 when $k_a m(t) > 1$.

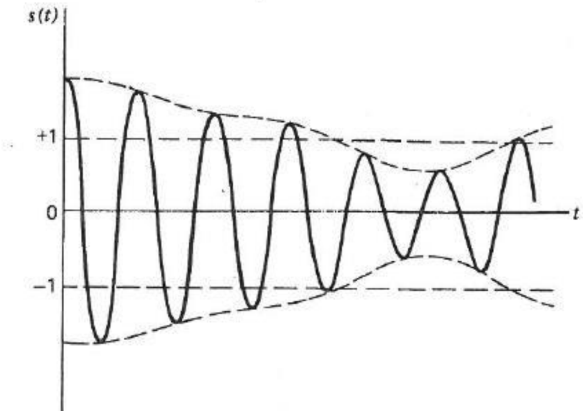

Figure 1. AM wave for $k_a m(t) < 1$ for all t

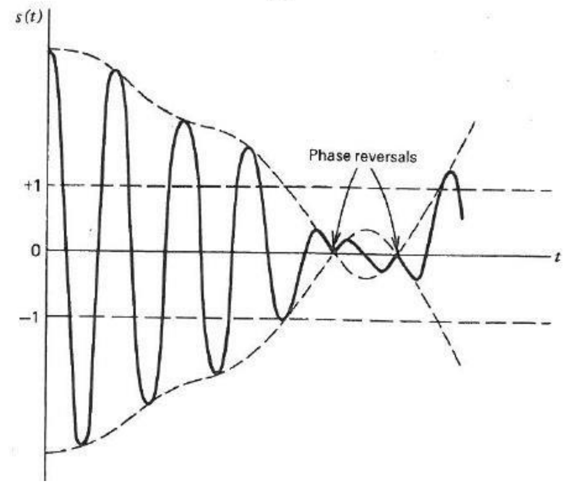

Figure 2. AM wave for $k_a m(t) > 1$ for some t

The time domain and frequency domain of the AM signal can be described as shown in figure 3 below.

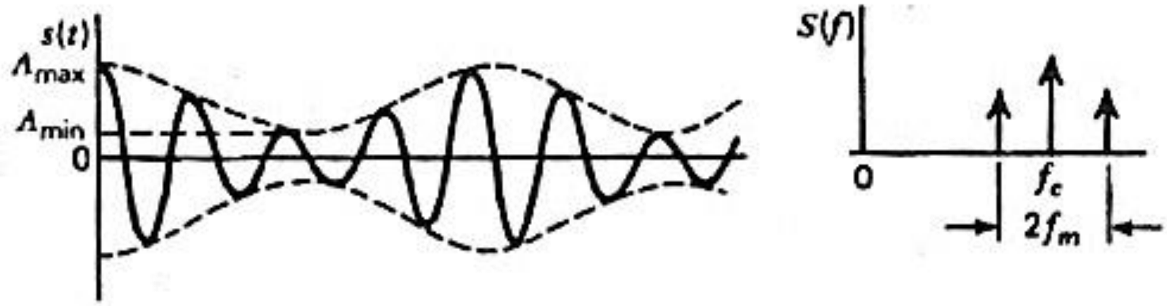

Figure 3. Time domain and Frequency domain (FFT) of the AM signal

Figure 4 below shows the block diagram of the transmitter portion of the AM radio. Moving from left to right, the first component of the transmitter circuit is the oscillator. The oscillator consists of an amplifier and a frequency selective network connected in a positive feedback loop, causing it to produce a constant oscillating frequency. The output of the oscillator becomes the carrier frequency c(t) and is combined with the message signal m(t) in the next component of the circuit, which is the switching modulator. The switching modulator consists of a summer and a half-wave rectifier to add the two signals together. The amplifier then takes in the combined signal and eliminates the unwanted frequencies, and the power amplifier finally amplifies the signal to be sent across the BNC cables to the receiver

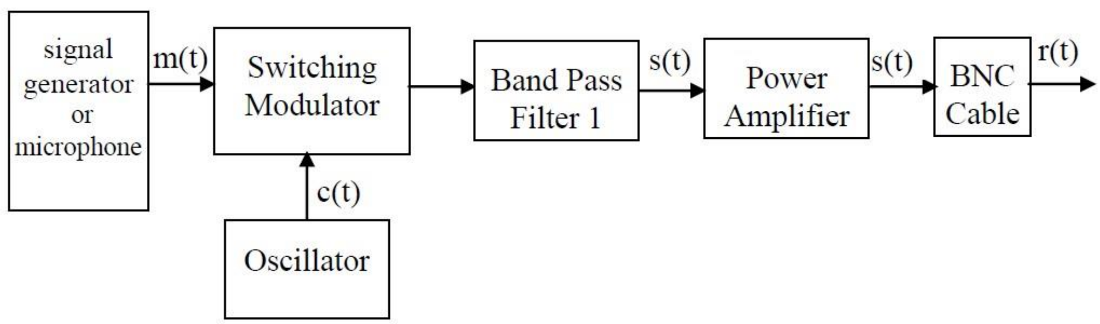

Figure 4. Block diagram of AM radio transmitter

The receiver demodulates the AM signal and sends the demodulated signal to a speaker. Shown in figure 5 the AM radio receiver takes the signal from the BNC cable into an Envelope detector, which detects the peaks of the signal to obtain the message signal. The message signal is then output from the Envelope detector into a bandpass filter to reject any unwanted frequencies. Next, a power amplifier is used to amplify the voltage to be sent to the speaker.

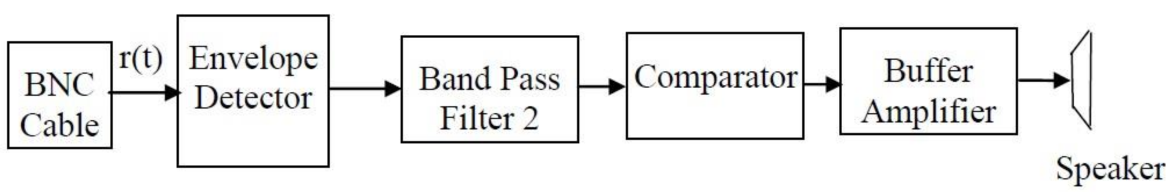

Figure 5: Block Diagram of Radio Receiver

Design Requirements

The components of the of the AM radio are restricted to the contents of the student analog parts kit. With the power supply set to +/- 12 Volts the radio must be able to transmit and receive a single tone message signal m(t) from 400Hz to 4kHz. The radio must demonstrate successful sine wave output at both 400Hz and 4kHz, as well as any frequency in between. The carrier frequency f_c of the carrier wave c(t) must be between 40kHz and 50kHz. The transmitter bandpass filer must have a lower stop band of -20dB when the frequency is less than 4kHz, and -10dB when the frequency is greater than 2 f_c. The difference of the magnitude of the bandpass filter at f_c – 4kHz and f_c + 4kHz must be between -1 dB and 1 dB.

2.0 Theory

The first component in the radio transmitter was the oscillator. Shown in figure 6 is the circuit diagram for the oscillator. The oscillator produces an oscillating output at a frequency determined by the values selected for the capacitors and resistors in the circuit. The oscillating output signal is used as the carrier signal in the transmitter circuit.

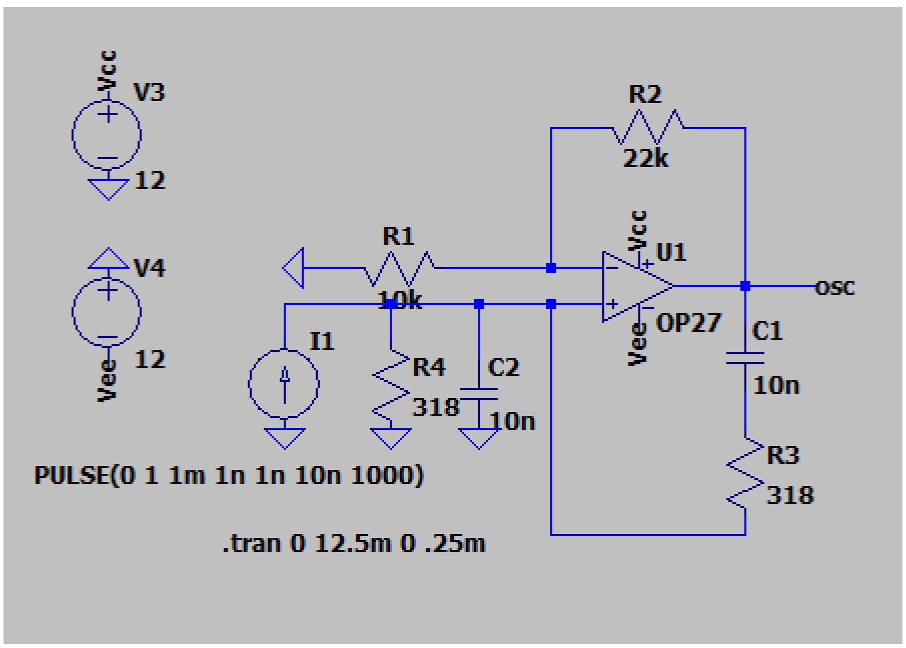

Figure 6: Oscillator Circuit in LTSPICE

The Wein Bridge Oscillator was used specifically in our design. This circuit produces a carrier signal f_c that oscillates between the op-amps saturation voltage values of +/- 12 V. It uses a positive feedback loop to produce an oscillating output at a certain frequency. The gain with the feedback is given by the equation below.

$$A_f = \frac{A(s)}{1-AB(s)} \quad (2)$$

Where A is the gain from the op-amp and B is the gain from the resistive network

$$AB(s) = L(s) = 1 \quad (3)$$

Where L(s) is the loop gain. From the circuit in figure 6 the following equations can be derived:

$$A(s) = 1 + \frac{R_2}{R_1} \quad (4)$$

$$B(s) = \frac{Z_p}{Z_p+Z_s} \quad (5)$$

Where Z_p is C2 and R4 in parallel, and Z_s is C1 and R3 in series. Since R3 and R4 theoretically have the same value, they are just referred to as R in the coming equations. The same case is for capacitors C1 and C2, so they will be referred to as C in the coming equations. By plugging in the equations 4 and 5 into equation 3 and substituting jw for s, we get the following equation for the loop gain

$$L(s) = \frac{1+\frac{R_2}{R_1}}{3+jwRC_1-\frac{j}{wRC}} \quad (6)$$

At the center frequency, the loop gain equals one. Setting the loop gain equation in equation 6 to one, we can derive the following equations:

$$w_0 = \frac{1}{RC} \quad (7)$$

$$\frac{R_2}{R_1} = 2 \quad (8)$$

The equations above were used to choose values for the components of the oscillator circuit. Those values were R = 318 Ω, R2 = 22kΩ, R1 = 10kΩ, & C = 10nF. At these values, the carrier frequency f_c was equal to 50kHz which was in the range of carrier frequencies specified in the design. The circuit was tested in LTspice and was confirmed that it met the requirements. A plot of the output of the oscillator in LTspice is shown below in figure 7.

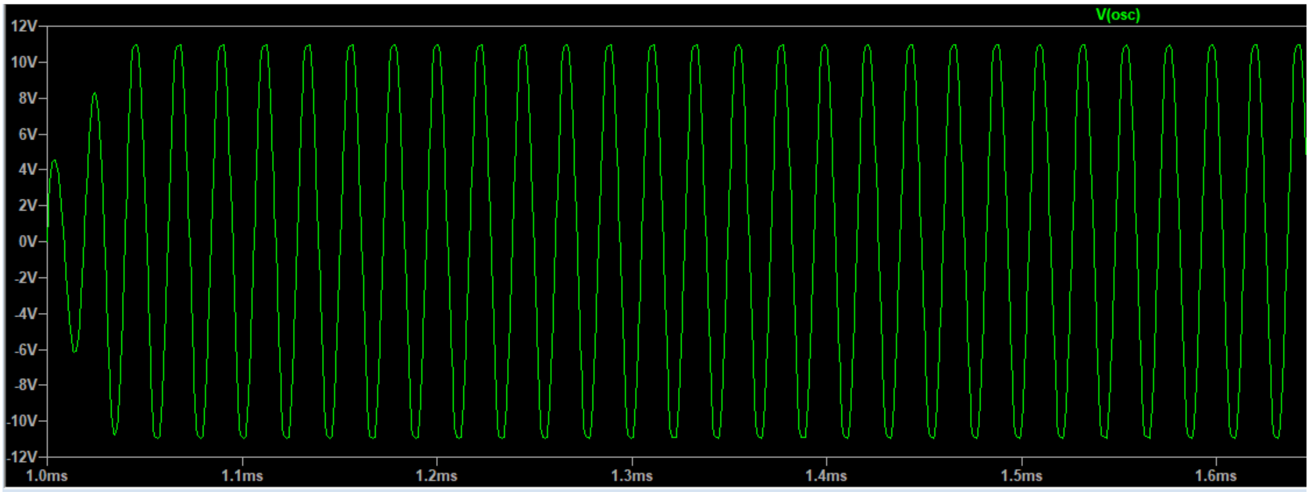

Figure 7: Wien Oscillator Output

The second component of the transmitter circuit is the switching modulator. The switching modulator is composed of a summing amplifier and a half wave rectifier. The circuit diagram for the switching modulator is shown in figure 8. The purpose of the switching modulator is to combine the carrier signal (the signal from the oscillator) with the message signal. Upon analyzing the switching modulator circuit, the equation for output voltage Vo was obtained.

$$V_o = \frac{R7}{R5} C(s) + \frac{R7}{R6} M(s) \quad (9)$$

Where C(s) is the carrier signal and M(s) is the message signal.

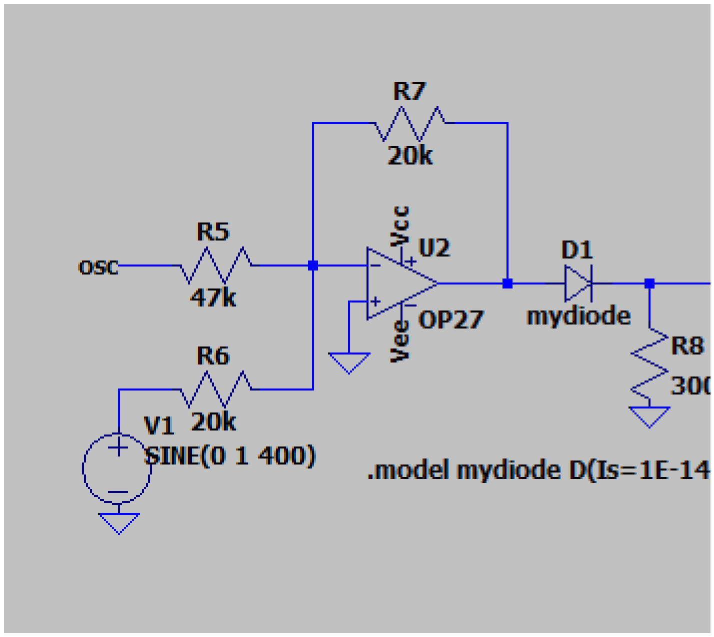

Figure 8: Switching Modulator Circuit PSPICE

For the switching modulator to always stay above zero the following values were chosen: The input resistor to the oscillator R5 was chosen to be 47kΩ, the feedback resistor R7 was chosen to be 20kΩ and the input resistor of the message signal R6 was chosen to be 20kΩ also. The load resistor after the diode was chosen to be 300Ω. The circuit was built and simulated using LTspice and a plot of the outputs for the summer as well as the whole switching modulator circuit are shown below. It can be observed from these plots that the output of the mixer is above zero when the message signal is at 400Hz and 4kHz. The designed circuit met the given design requirements.

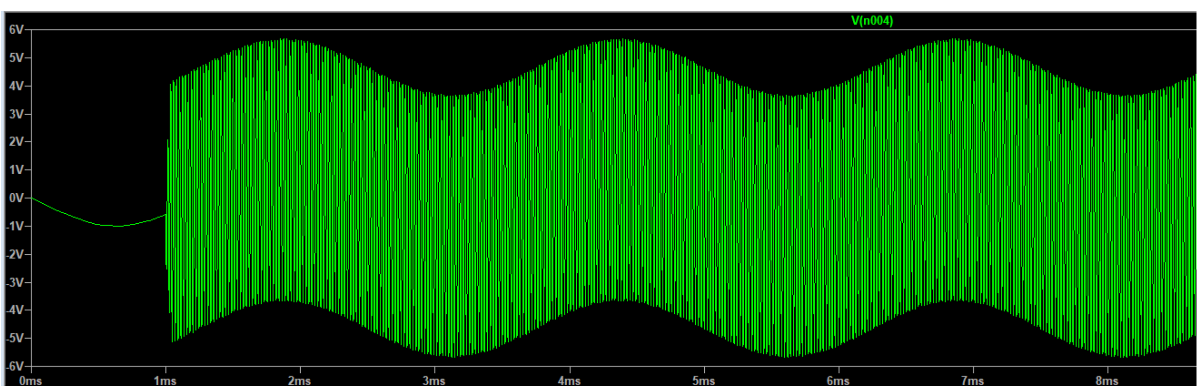

Figure 9: Summer Output at 400 Hz

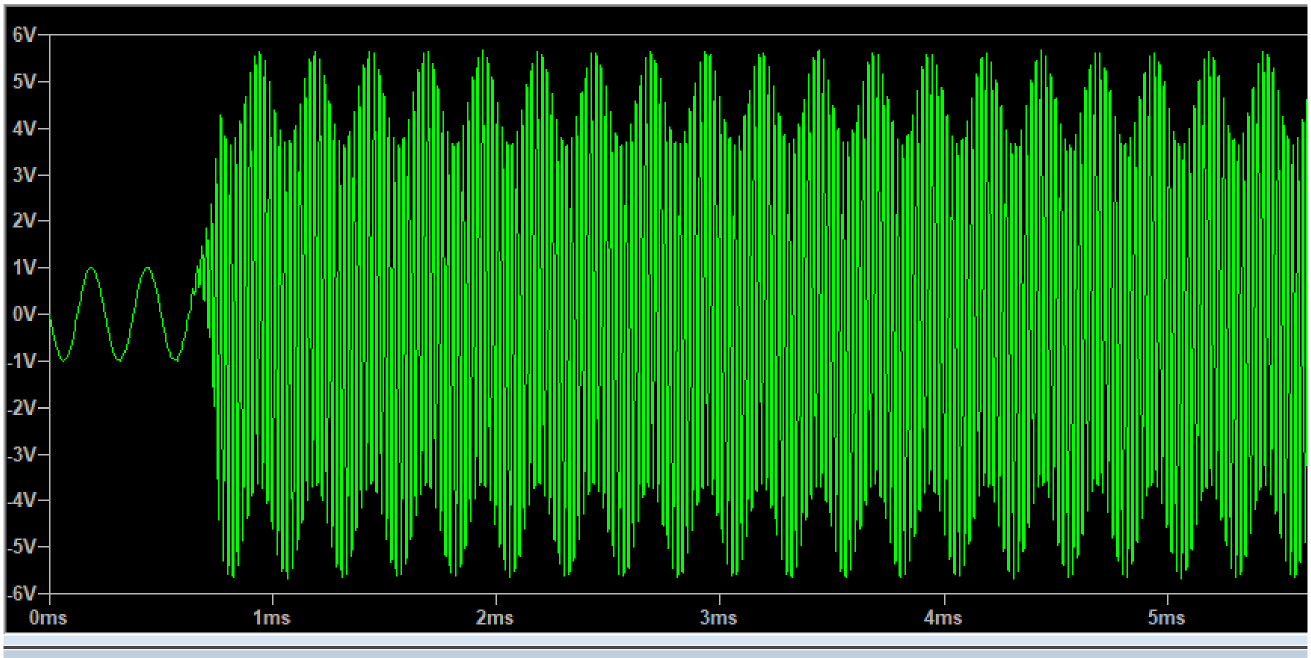

Figure 10: Summer Output at 4 kHz

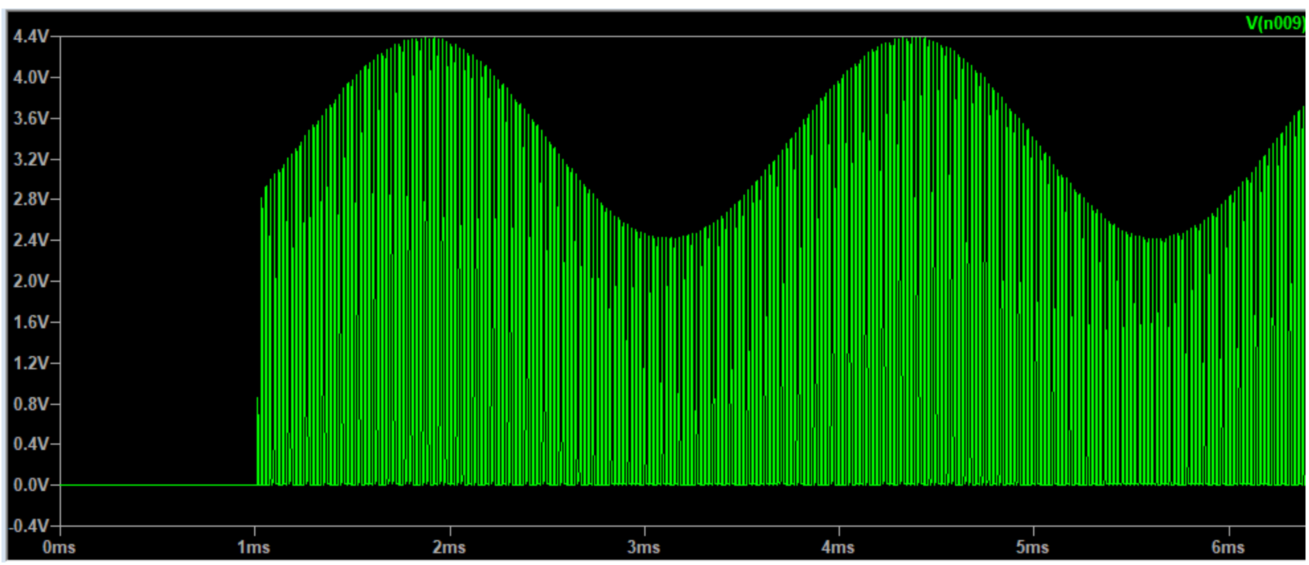

Figure 11: Switching Modulator Output at 400 Hz

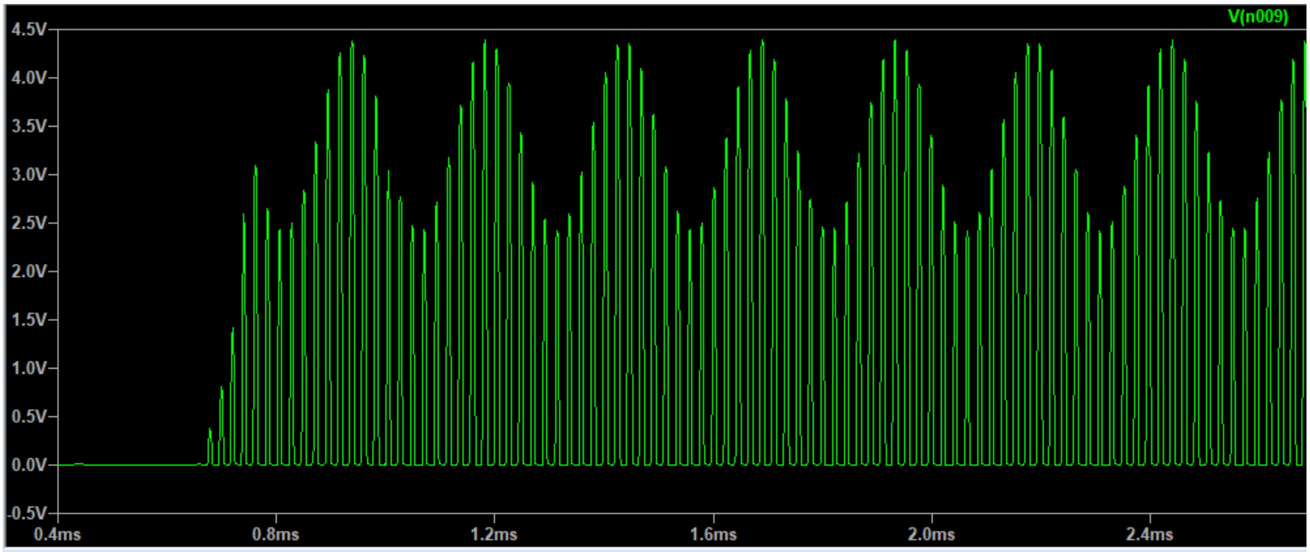

Figure 12: Switching Modulator Output at 4 kHz

The Final component before the power amplifier of the transmitter circuit was a bandpass filter. This bandpass filter was used to filter out the mirrored frequencies. The bandpass filter uses an op-amp to allow signals in between the cutoff frequencies to pass through easily while frequencies outside the cutoff frequencies will be rejected. The cutoff frequencies for the bandpass filter were determined by the resistor and capacitor values of the circuit. A circuit diagram of this bandpass filter can be found in figure 13 below.

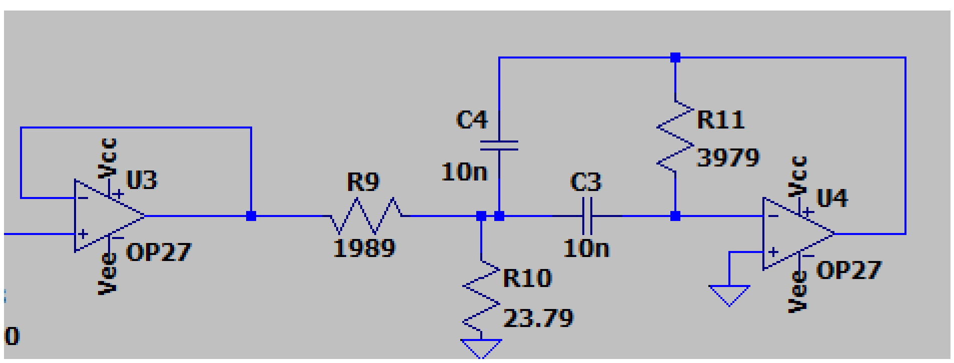

Figure 13: High Q Bandpass Filter in LTSPICE

The transfer function for this High Q Bandpass filter is as shown below

$$H(s) = \frac{-\frac{s}{R_9 C_4}}{s^2 + \frac{2}{R_{11} C_4} s + \frac{1}{R_{eq} R_{11} {C_4}^2}} \quad (10)$$

Where R_{eq} is R9 and R10 in parallel. Since the capacitors are the same they will be denoted as just C. The transfer function is shown in standard form below.

$$H(s) = \frac{-KBs}{s^2 + Bs + {w_0}^2} \quad (11)$$

Where B is the bandwidth of the filter, KB is the gain, and w_0 is the center frequency of the filter. The following equations can be used to describe these variables.

$$B = \frac{2}{R_{11} C} \quad (12)$$

$$KB = \frac{1}{R_9 C} \quad (13)$$

$${w_0}^2 = \frac{1}{R_{eq} R_{11} C^2} \quad (14)$$

Using these equations and choosing C to equal 10nF, the values for R9, R10 and R11 were able to be calculated. The values obtained from the calculations are R9 =1989Ω, R10 = 40Ω & R11 = 3979Ω. When the circuit was built physically, the bandpass filter appeared to need tuning to achieve the correct requirements. The value of R10 was tuned to 23.79Ω and the resulting bandpass filter met the requirements. Using these values, the circuit was built in LTspice and simulated for amplitude and phase of the frequency response. FFT graphs of before (fig.16) and after (fig.17) the bandpass filter is provided to show that the filter eliminates the unwanted harmonic frequencies. Figures 19 & 20 show the output of the bandpass filter. From the plots it can be seen that the bandpass filter meets the design requirements.

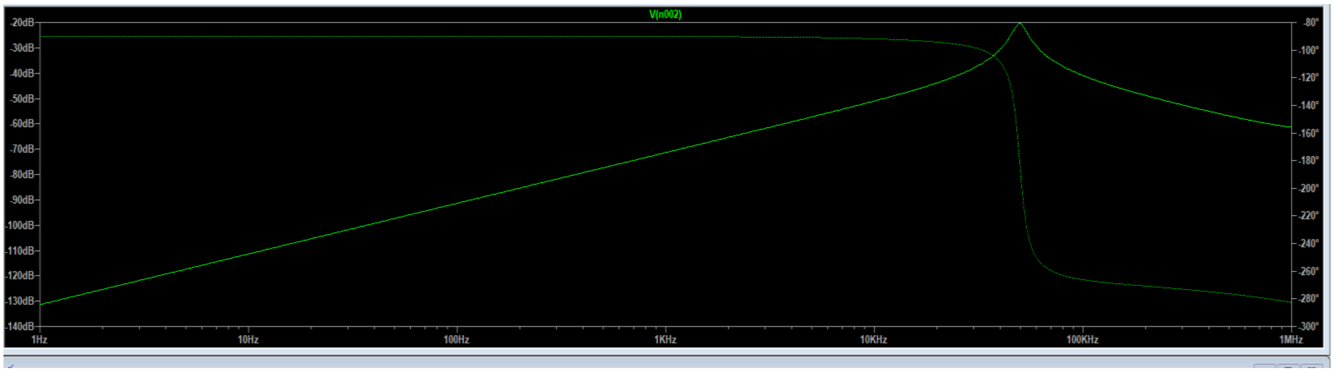

Figure 14: High Q Bandpass Filter Amplitude & Phase Response

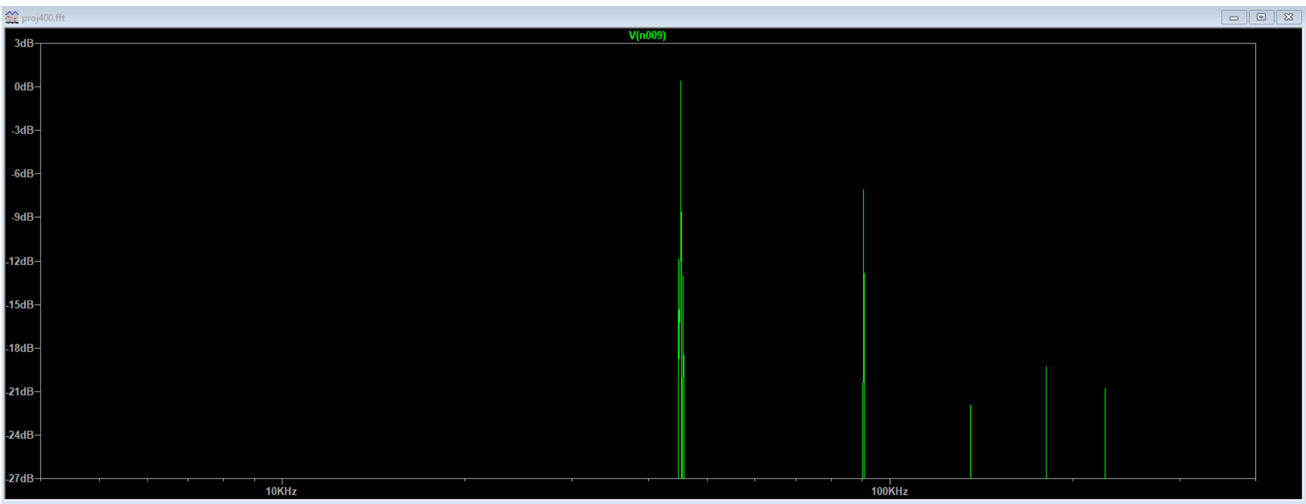

Figure 16: FFT Output of Switching Modulator

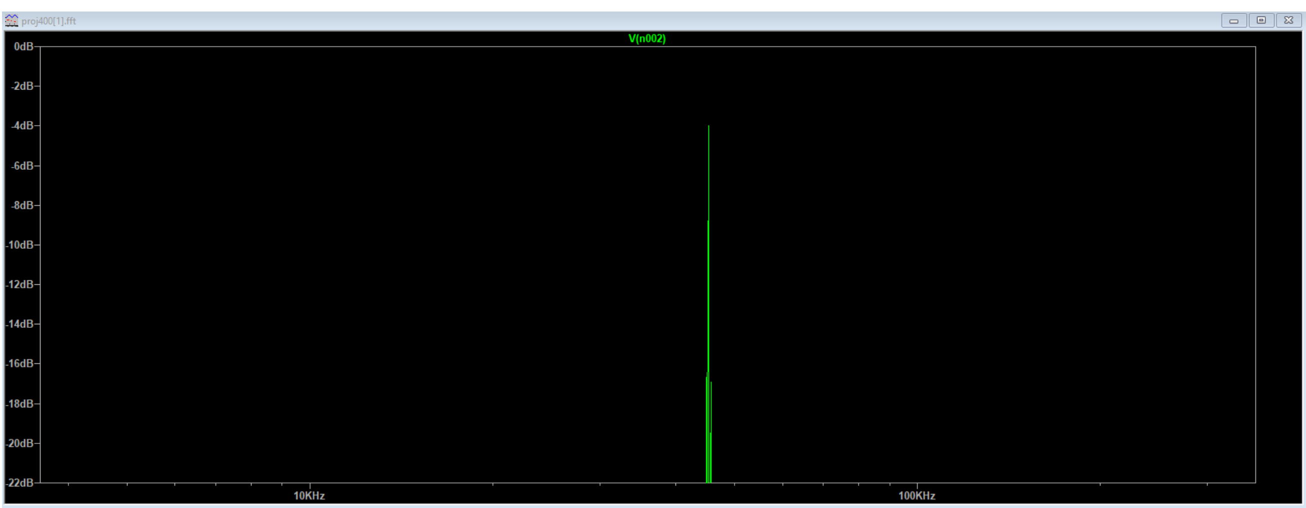

Figure 17: FFT Output of High Q Bandpass Filter

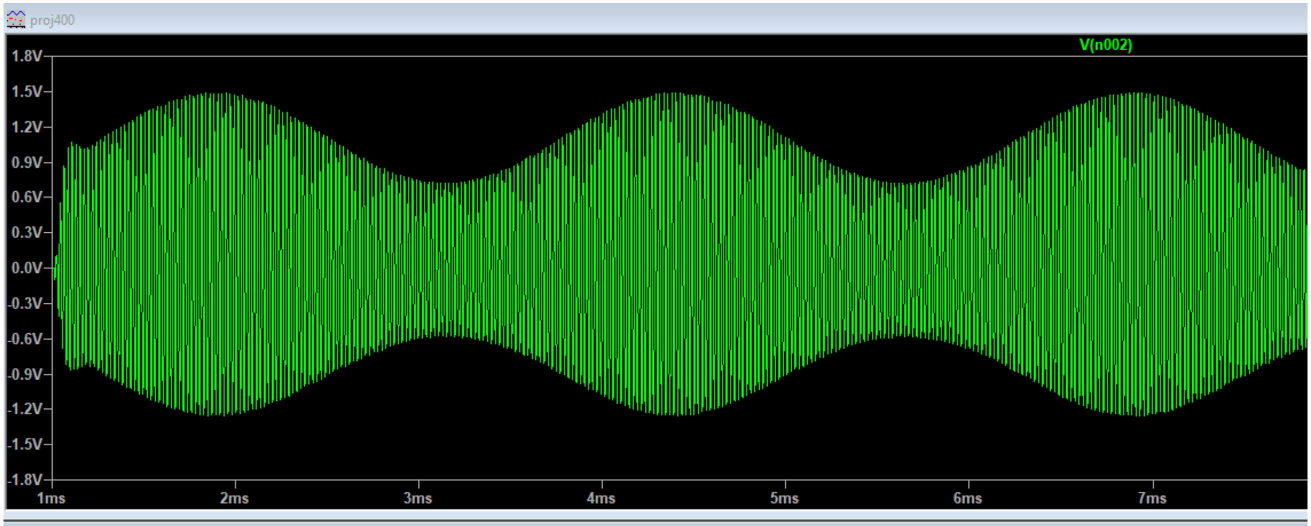

Figure 19: Output of High Q BPF at 400 Hz

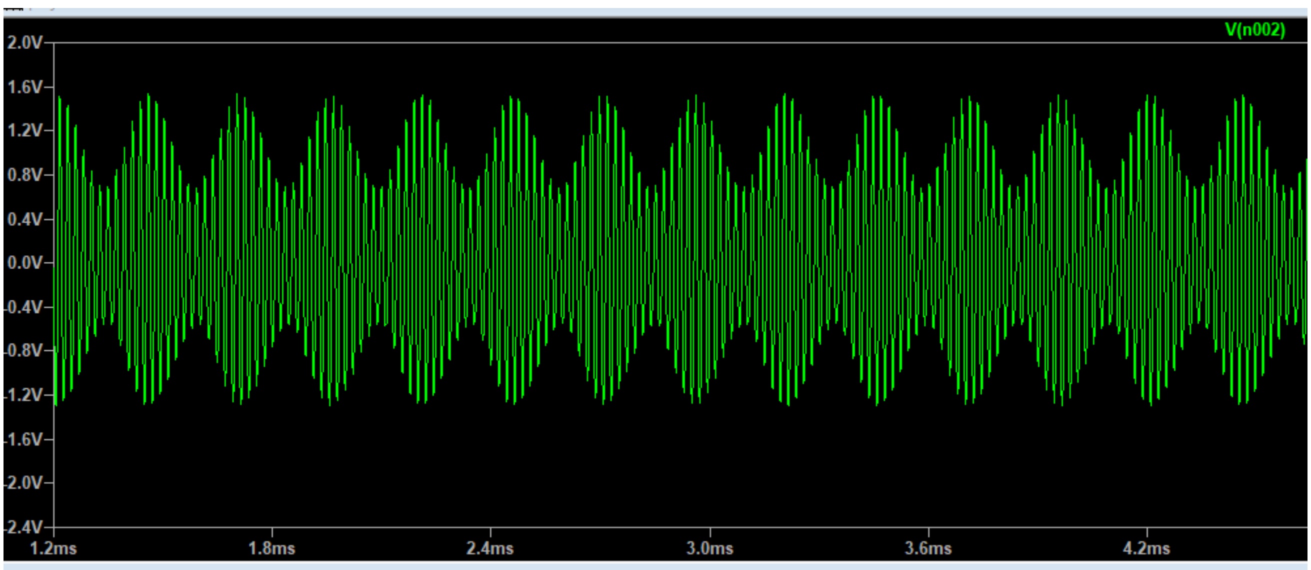

Figure 20: Output of High Q BPF 4 kHz

Once all the components were individually tested and verified, they were connected together and connected to a power amplifier to amplify the AM signal so it can be sent to the receiving side of the radio. A model of the power amplifier can be found below in figure 21. The amplifier gain was determined by the resister values according to the following equation.

$$G = -R_{13}/R_{12} \quad (15)$$

Since R13 was chosen to be 2.2kΩ and R12 was chosen to be 470 Ω the resulting gain of the amplifier calculates to be 4.6 V/V. A model of the entire transmitter circuit is shown below in figure 22. Also plots of the output of the entire transmitter circuit for 400Hz and 4kHz can be found below in figures 23 & 24. It can be seen from these plots that the circuit is working correctly and meets the design requirements. Thus, we have completed the transmitter portion of the AM radio.

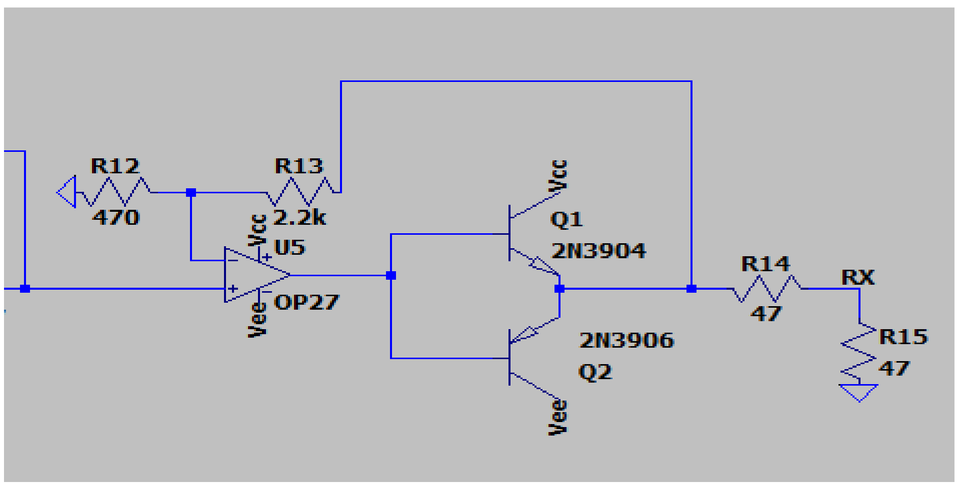

Figure 21: Power Amplifier

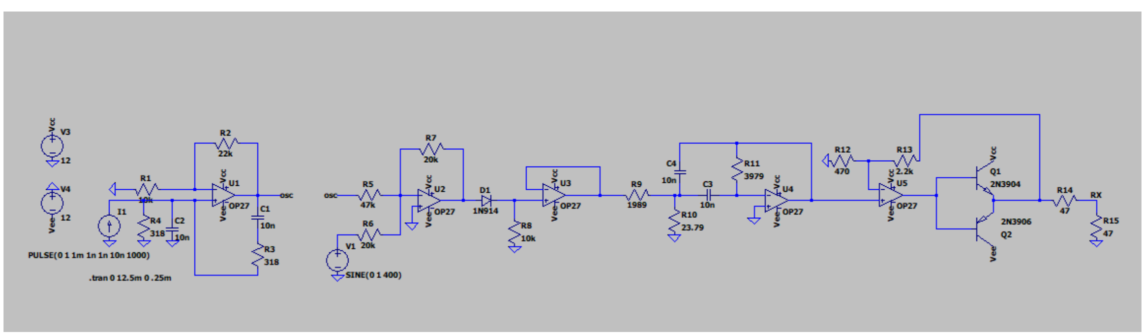

Figure 22: Entire Transmitter circuit

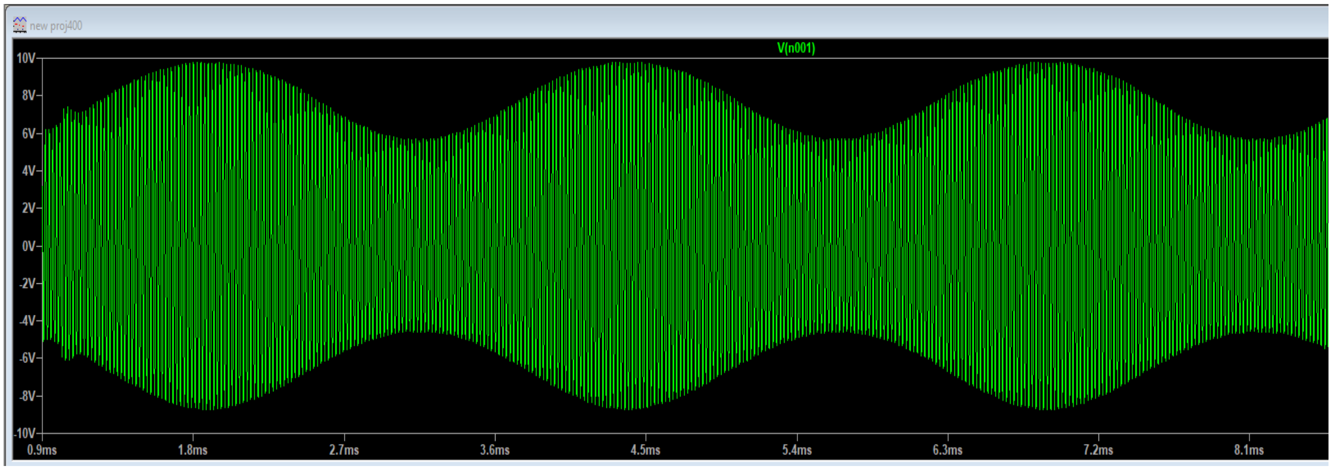

Figure 23: Output of entire transmitter circuit at 400Hz

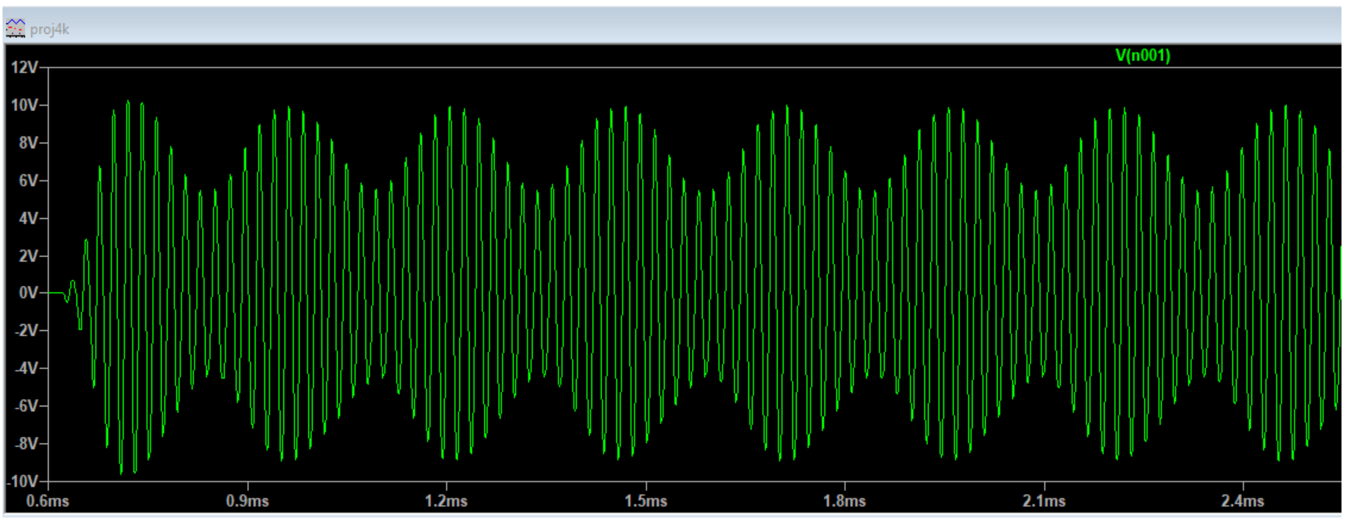

Figure 24: Output of entire transmitter at 4kHz

On the receiving end of the AM radio, the first component that was implemented was the peak detector. The peak detector circuit consists of a diode, 2 resistors and a capacitor, the circuit detects the peaks of the input so the message signal can be recovered. A circuit diagram of the peak detector circuit can be found below in figure 25 (note that R24 is R15 in figure 21). The following equation was used to solve for R16

$$R16 = \frac{1}{\ln\left(\frac{Vo}{V1}\right) C_5 f_c} \quad (16)$$

Where f_c is the carrier frequency that was decided on the transmitter side (in our case it is 45.28kHz), Vo is the amplitude measurement of peak 1, V1 is the amplitude measurement of peak 2, and C_5 was chosen to be 100nF. R16 was calculated to be 655 Ω with these values. Simulated output and input voltages can be found in the figures below, figures 26 & 27 for 400Hz, and figures 28 & 29 for 4kHz. Note that the green signal is the input signal, and the blue signal is the output signal

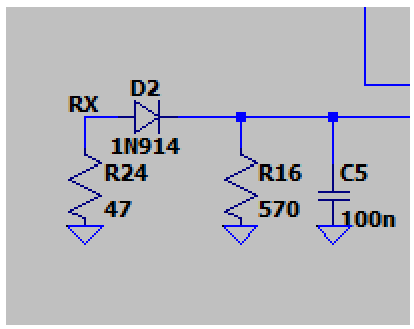

Figure 25. Peak detector circuit

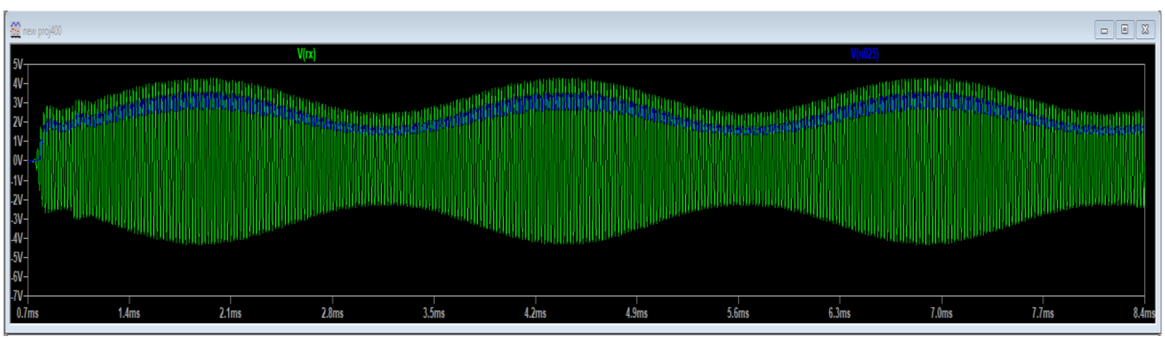

Figure 26. Peak detector at 400Hz

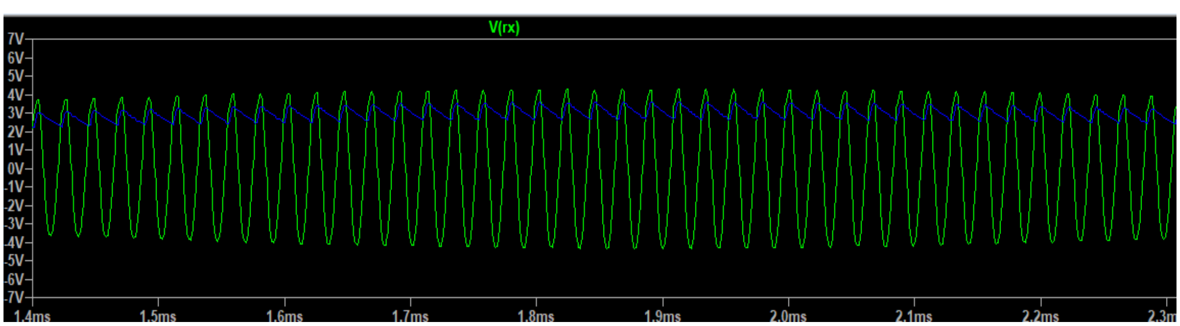

Figure 27. Peak detector at 400Hz enhanced

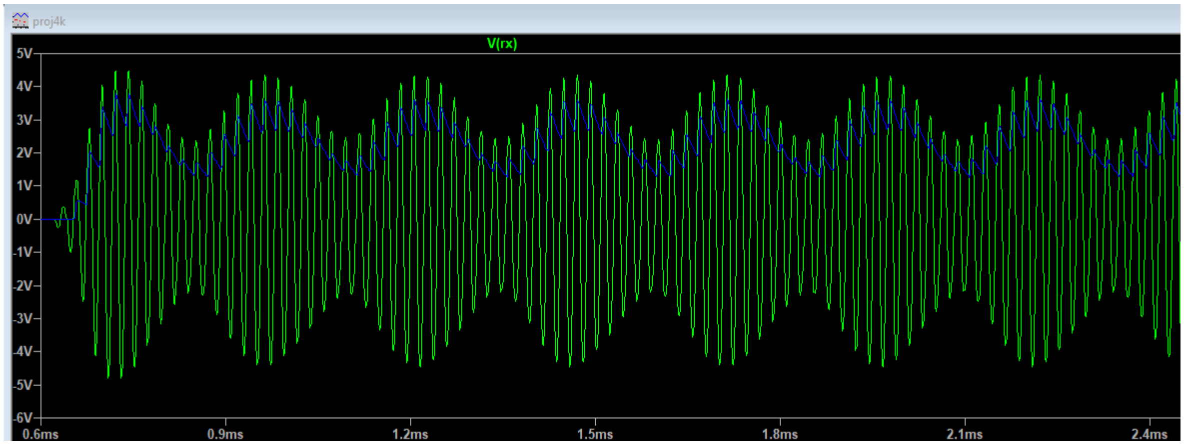

Figure 28. Peak detector at 4kHz

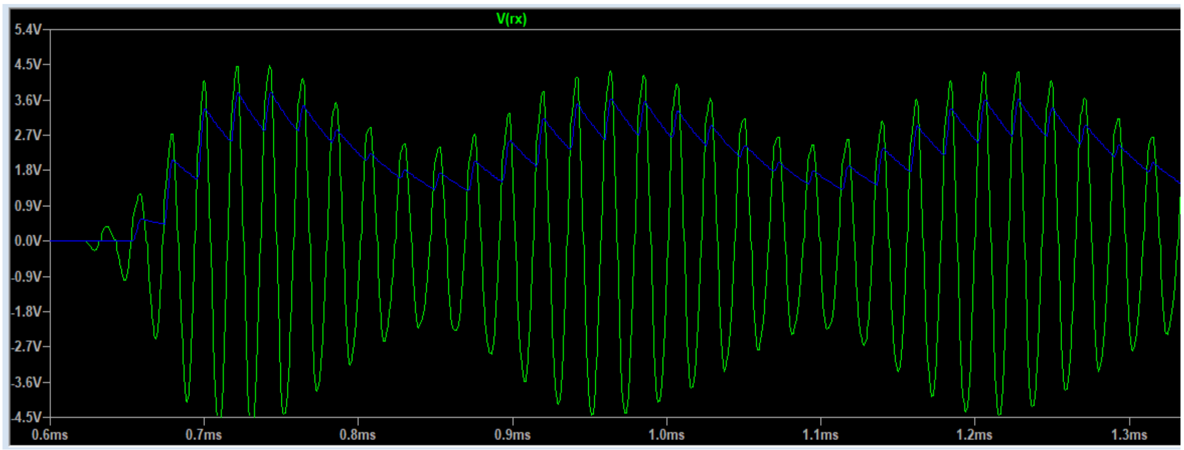

Figure 29. Peak detector at 4kHz enhanced

After the peak detector, a two stage Butterworth bandpass filter was used to filter out the DC voltage offset and the carrier frequency. The Filter was comprised of a highpass filter and lowpass filter cascaded together shown in figure 30 below. The following equations were derived from the circuits transfer functions and were used to solve for the circuit components.

$$R18 = \frac{\sqrt{2}}{\omega_L C} \quad (17)$$

$$R17 = \frac{1}{R17\omega_L{}^2C^2} \quad (18)$$

Where ω_L is the low cutoff frequency (400Hz) and C = C6 = C7 which was chosen to be 100nF.

$$R19 = R20 = \frac{\sqrt{2}}{\omega_H C_8} \quad (19)$$

$$C9 = \frac{1}{\omega_H{}^2 R_{19}{}^2 C_8} \quad (20)$$

Where ω_H is the high cutoff frequency (4kHz) and C8 was chosen to be 100nF. The value of R18 was calculated to be 5.627kΩ, the value of R17 was calculated to be 2.813kΩ, the values for R19 & R20 were calculated to be 562.7Ω, and the value for C9 was calculated to be 49.98nF. The bandpass filter was simulated in LTspice and a graph of the amplitude and phase frequency response can be found below in figure 31. Outputs of the butterworth bandpass filter can be found below in figures 32 & 33.

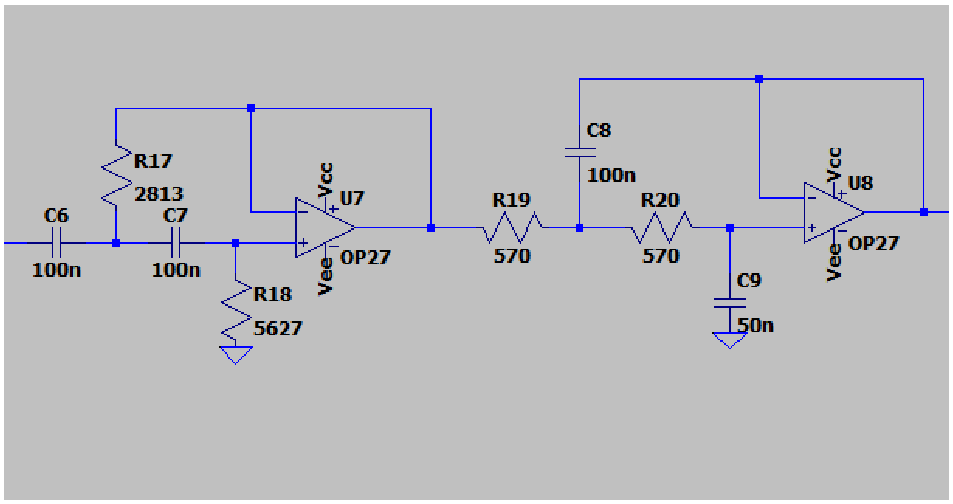

Figure 30. Butterworth Bandpass Filter circuit

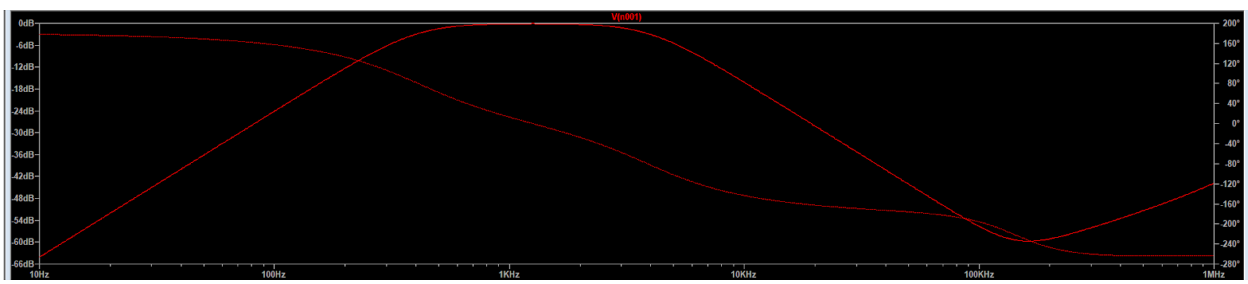

Figure 31. Bandpass filter Amplitude and Phase frequency response

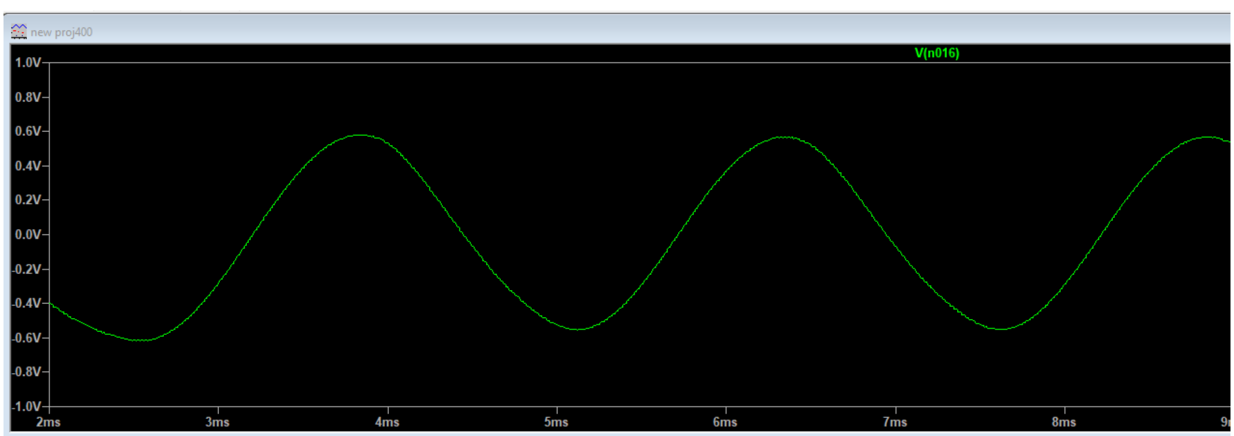

Figure 32. Output of Butterworth BPF at 400Hz

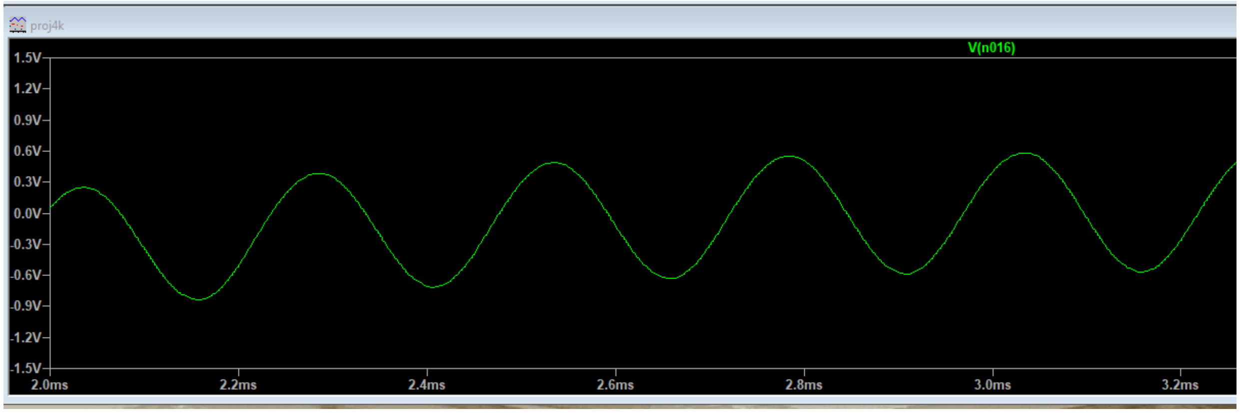

Figure 33. Output of Butterworth BPF at 4kHz

At the end of the receiver, before any signal is sent to the speaker the signal is amplified again using the same power amplifier circuit used at the end of the transmitter circuit. This time the resistor values are adjusted to obtain a gain suitable for what we need. The resistor values were calculated using the following equation

$$G = \frac{Vo}{Vin} = 1 + \frac{R22}{R21} \quad (21)$$

Where the gain (G) was needed to be 2. The values for R22 and R21 were both chosen to be 1KΩ. The circuit diagram of the power amplifier is shown below in figure 34 as well as a plot of the output of the entire transmitter + receiver circuit in figures 35 & 36.

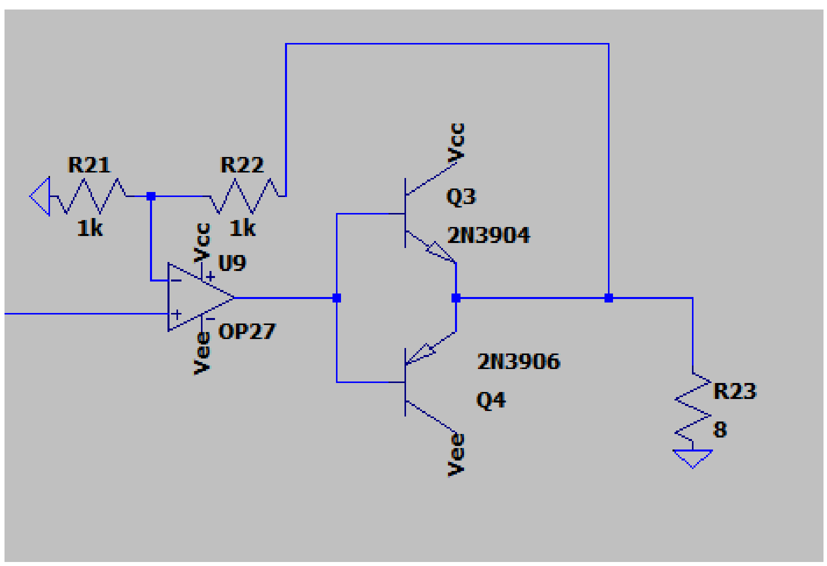

Figure 34. Power amplifier receiver

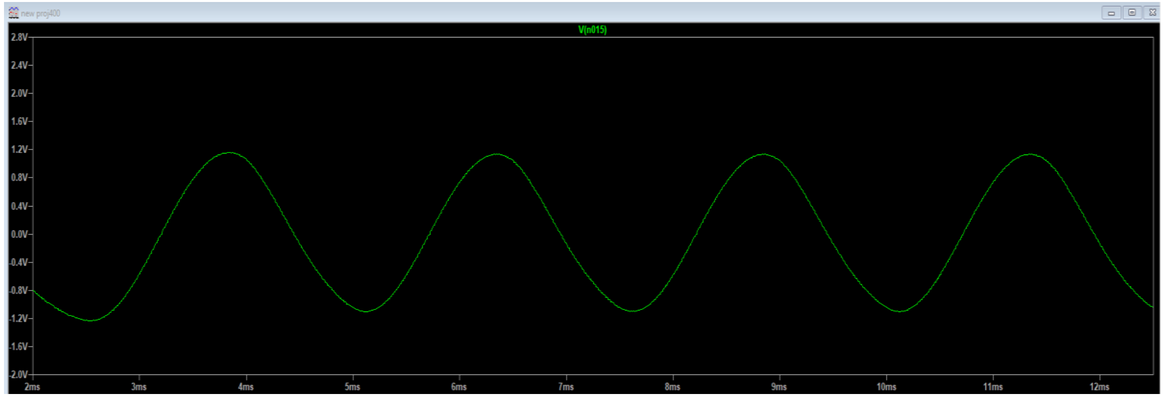

Figure 35. Output of entire transmitter + receiver 400Hz

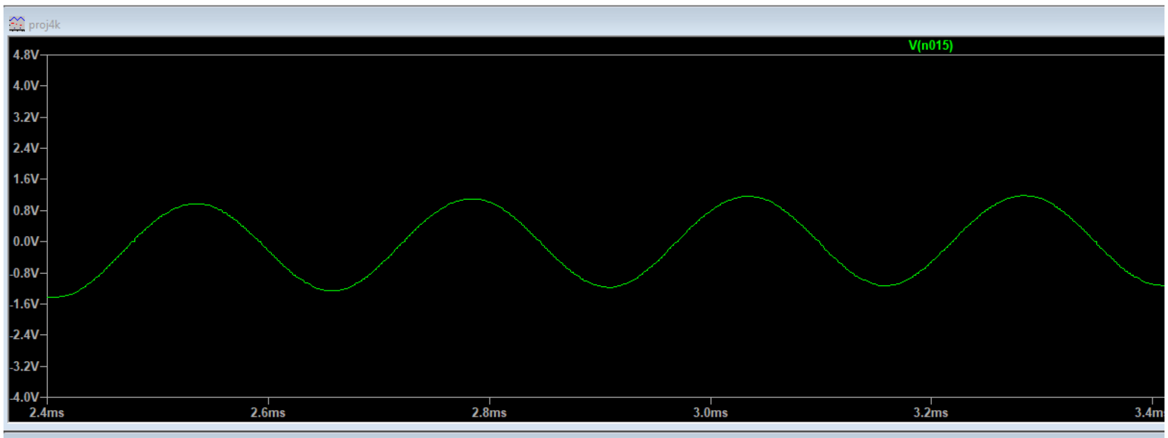

Figure 36. Output of entire transmitter + receiver 4kHz

3.0 Methodology

Before any physical building took place, the entire transmitter circuit was built and individually tested using LTspice. Each circuits components were fined tuned to meet the design specifications. After the simulated circuit was complete and met the requirements, the transmitter circuit was built by building and testing individual circuits in the lab. The approach was to build and test each module separately and then to integrate the modules in sequential order. The first circuit module built in the entire process was the oscillator. The oscillator was built and tested physically in the lab using an oscilloscope to measure the output. Once the oscillator was confirmed to have met the requirements the next module is added on to the circuit and tested again. The second module that was built was the switching modulator, after the values were confirmed in LTspice the circuit was integrated with the oscillator and the two circuits were tested together using an oscilloscope to measure the output of both circuits.

After the first 2 modules were confirmed to have met the specifications the 3rd module was implemented which was the high Q bandpass filter. The FFT of the bandpass filter was observed in the LTspice simulation to confirm that the higher harmonics were being filtered out. After the circuit was validated in LTspice the circuit was integrated with the previous 2 circuits and tested again using an oscilloscope to measure the output. The output was verified to have an AM signal that accurately carries the message signal. The final module of the transmitter, the power amplifier was then hooked up to the end of the previous 3 modules and the circuit is tested again to validate that the amplifier amplified the AM signal correctly by measuring the entire output with the oscilloscope.

Next, the peak detector was implemented after its behavior was validated on LTspice. The physical circuit was tested together with the transmitter and the output was measured with the oscilloscope to validate that the circuit is capturing the peaks correctly. After the values for the two stage butterworth filter were tuned and validated in LTspice, the circuit was built separately at first to validate the cutoff frequencies and then it was connected with the whole circuit and tested by measuring the output with an oscilloscope to make sure that the bandpass filter was filtering the message signal correctly. Finally, once the power amplifier on the receiving end was validated to have the correct output it was physically built with the entire circuit and was tested using an oscilloscope to measure the output and validate that it is amplifying the message signal to be sent to the speaker. The output was observed to be a smooth sine wave.

4.0 Results/Analysis

The output of the simulated wien oscillator was 50kHz (refer to fig. 7) and the output frequency of the physical oscillator was measured to be 50.07kHz, yielding a percent difference of 0.14%. This validates that out circuit meets the specifications. A table of the resistor and capacitor expected values and actual values are shown in Table 1. The output of the oscillator can be found in figure 37 below.

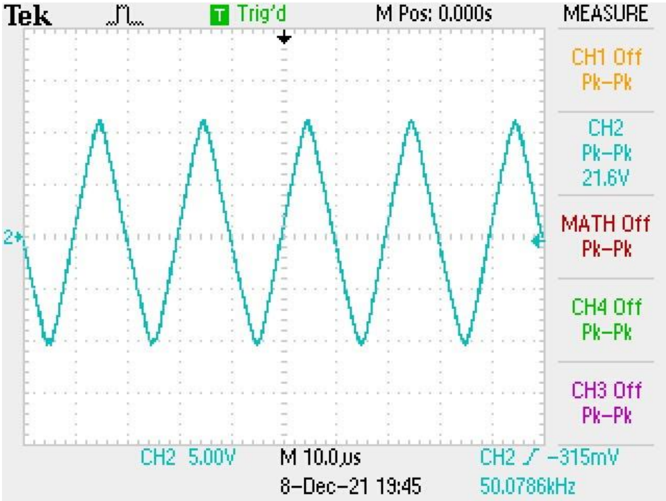

Figure 37. Wien Oscillator Output

Table 1. Component Values of Oscillator

Circuit Component	Expected Value	Actual Value	Percent error
R1	10kΩ	9.98kΩ	.2%
R2	22kΩ	18.89kΩ	14.13%
R3	318Ω	233.5Ω	26.5%
R4	318Ω	233.5Ω	26.5%
C1	10nF	10.52nF	5.2%
C2	10nF	9.9nF	1%

The input to the switching modulator is the signal we see in figure 37 and the message signal from the function generator. When comparing the physically tested output signals (figures 38 & 39) to the simulated output signals (figures 9 & 10) we can see for both 400Hz and 4kHz the plots are very similar, almost exact. Resister and capacitor values are provided in table 2 below.

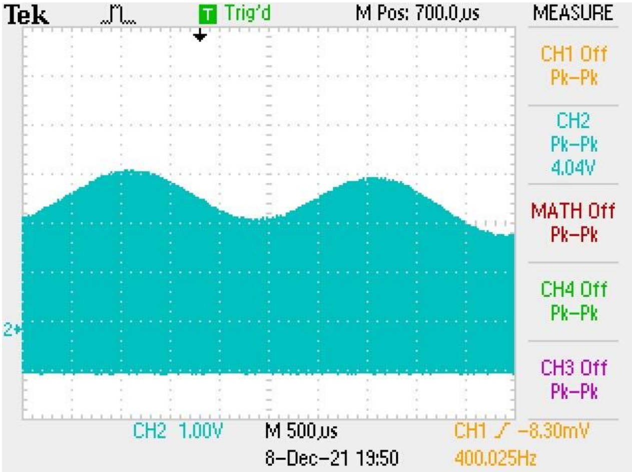

Figure 38. Switching modulator at 400Hz

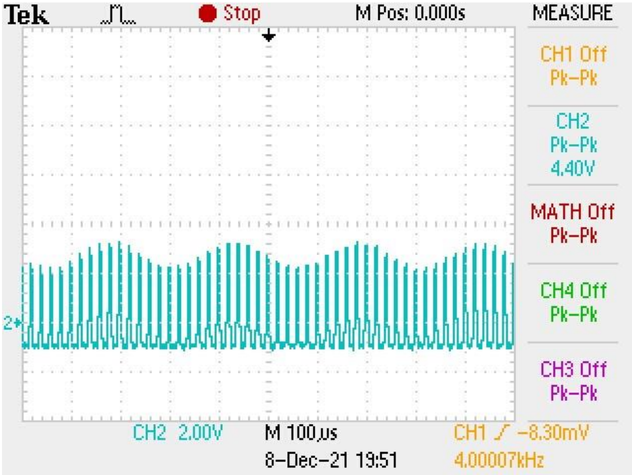

Figure 39. Switching modulator at 4kHz

Table 2. Switching modulator component values

Circuit Component	Expected Value	Actual Value	Percent error
R5	47kΩ	46.4kΩ	1.2%
R6	20kΩ	19.953kΩ	0.2%
R7	20kΩ	19.82kΩ	0.9%

The input to the high Q bandpass filter at 400Hz is the signal shown in figure 38. The output at 400Hz is the AM signal shown in figure 40. It can be seen that the signal is symmetric and accurately carries the message signal. The input to the high Q bandpass filter at 4kHz is the signal shown in figure 39, and the output at 4kHz is the signal shown in figure 41. The amplitude frequency response of the high Q band pass filter was plotted on excel and is provided below in figure 42. The simulated amplitude frequency response of the high Q band pass filter was previously provided in figure 14. When comparing the graphs of the simulated to the graphs of the physically tested, it can be seen that they are very similar, almost exact. Differences can be attributed to the resistor and capacitor tolerances. A table of the component values can be found below in table 3.

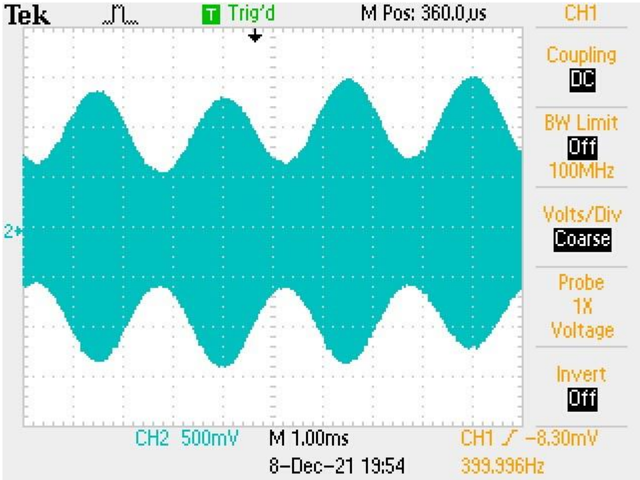

Figure 40. High Q BPF output at 400Hz

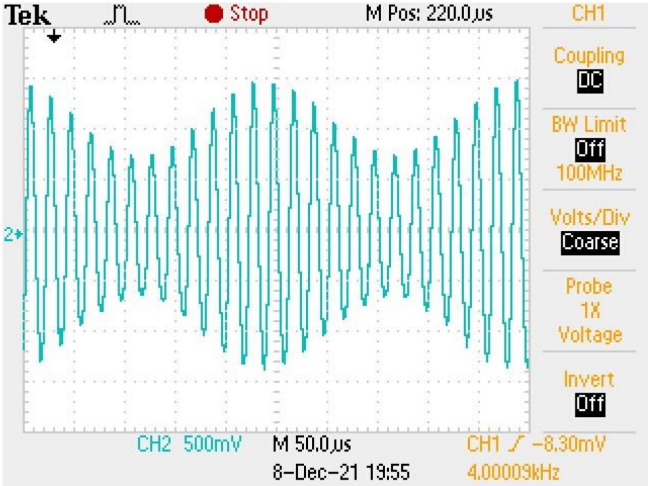

Figure 41. High Q BPF output at 4kHz

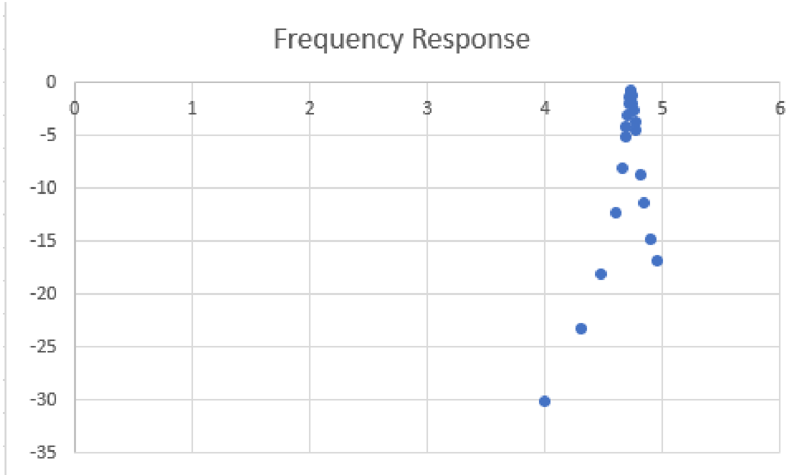

Figure 42. High Q BPF Frequency Response

Table 3. High Q BPF Component Values

Circuit Component	Expected Value	Actual Value	Percent error
R9	1.989kΩ	1.995kΩ	.3%
R10	25.79Ω	23.2Ω	10%
R11	3.797kΩ	3.99kΩ	5.08%
C3	10nF	9.76nF	2.4%
C4	10nF	10.19nF	1.9%

The input to the power amplifier at 400Hz is the output of the high Q band pass filter shown previously in figure 40. The power amplifier circuit increased the voltage amplitude and current to the receiver, the output of the power amplifier at 400Hz can be seen below in figure 43. The input to the power amplifier at 4kHz is the output of the high Q band pass filter shown previously in figure 41. The output of the power amplifier at 4kHz can be found below in figure 44. The simulated output of the power amplifier circuit can be found previously in figures 23 and 24 for both frequencies. When comparing the graphs of the simulated circuit to the graphs of the physically tested circuits it can be seen that they are very similar, almost exact. Both outputs are around 20V peak to peak. A table of the component values for this circuit can be found below in table 4.

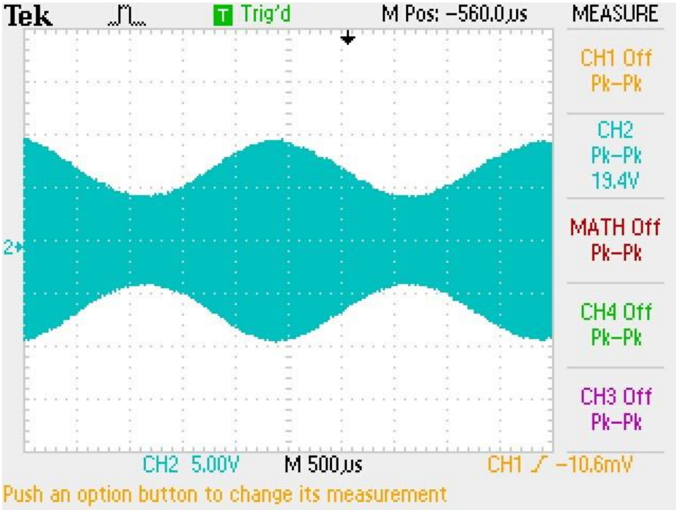

Figure 43. Output of entire transmitter circuit at 400Hz

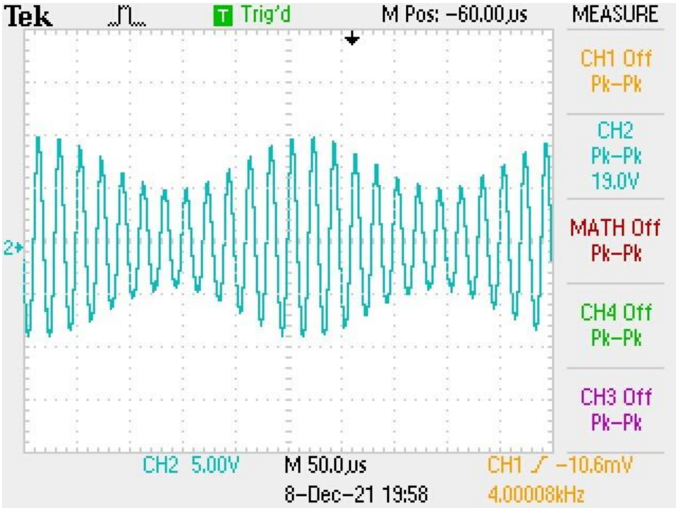

Figure 44. Output of entire transmitter circuit at 4kHz

Table 4. Power Amplifier Component Values

Circuit Component	Expected Value	Actual Value	Percent error
R12	470Ω	468Ω	0.4%
R13	2.2kΩ	2.14kΩ	2.7%

The input to the receiver was the AM signal output of the power amplifier shown in figures 43 & 44. The first component of the receiver was the peak detector. The input to the peak detector is the same signal coming into the receiver. The output of the peak detector module at 400Hz is shown below in figure 45. The output of the peak detector circuit at 4kHz is shown below in figure 46. Note that the purple signal is the input and the blue signal is the output of the peak detector. When these output plots are compared with the output plots of the simulated circuit (figures 26-29) it can be seen that they are very similar, almost exact. A table of the component values for this circuit can be found below in table 5.

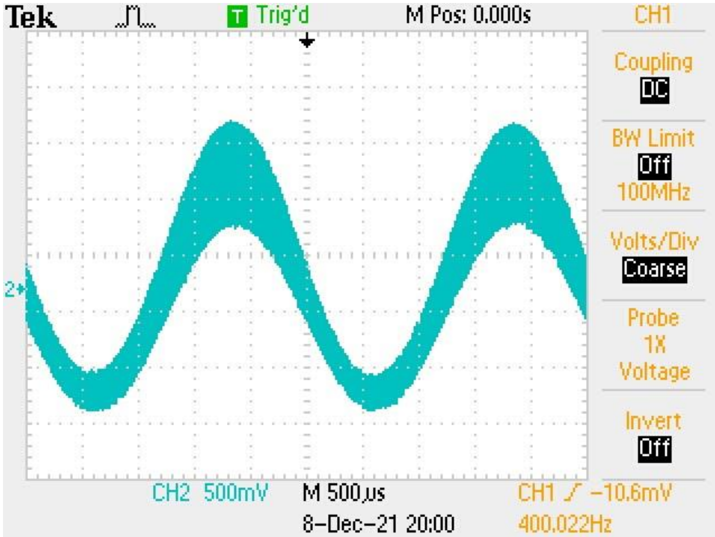

Figure 45. Output of peak detector at 440Hz

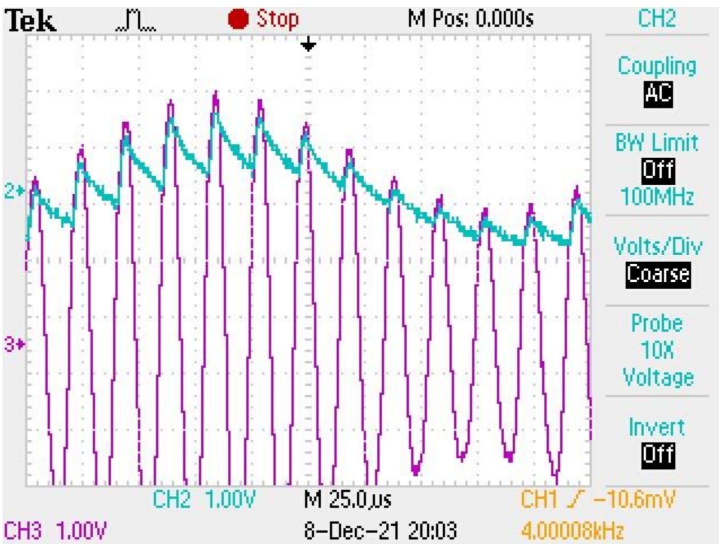

Figure 46. Output of peak detector at 4kHz zoomed in

Table 5. Peak Detector Component Values

Circuit Component	Expected Value	Actual Value	Percent error
R14	47 Ω	44 Ω	6.3%
R15	47 Ω	46.2 Ω	1.7%
R16	570 Ω	566 Ω	0.7%
C5	10nF	9.76nF	2.4%

The input to the two stage butterworth band pass filter at 400Hz was the rough message signal seen previously in figure 45. The output of both stages the bandpass filter at 400Hz was a smooth sine wave shown below in figure 47. The input to the bandpass filter at 4kHz was the rough message signal seen previously in figure 46. The output of both stages of the bandpass filter at 4kHz is a smooth sinewave shown below in figure 48. The frequency response for this circuit was measured, plotted in excel and is provided below in figures 49 & 50, note that each stage was plotted separately. When these graphs are compared to the graphs of the simulated circuit in figures 31, 32 & 33, it can be seen that they are very similar, almost exact. The cutoff frequencies matched the simulated cutoff frequencies, the low cutoff was around 400Hz, and the high cutoff was around 4kHz. A table of this circuit's component values is provided below in table 6.

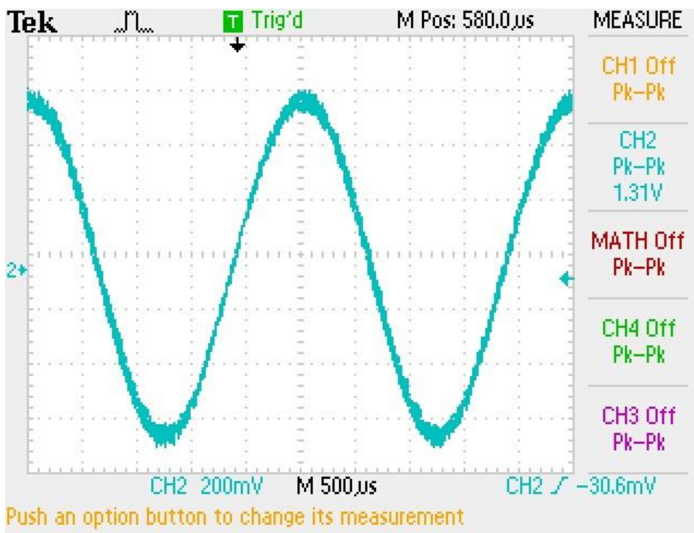

Figure 47. Output of Butterworth BPF at 400Hz

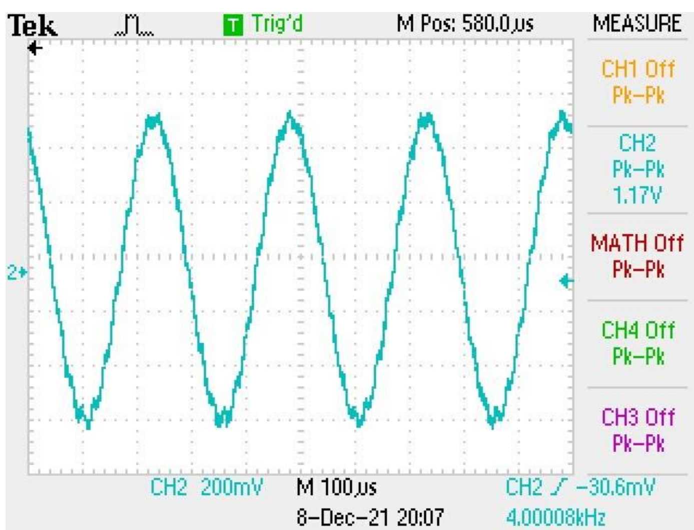

Figure 48. Output of Butterworth BPF at 4kHz

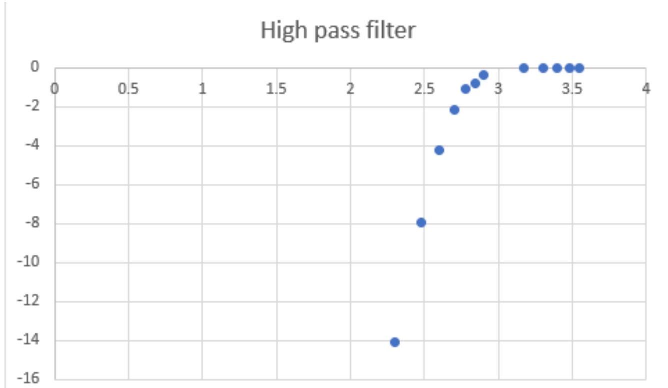

Figure 49. Butterworth high pass frequency response

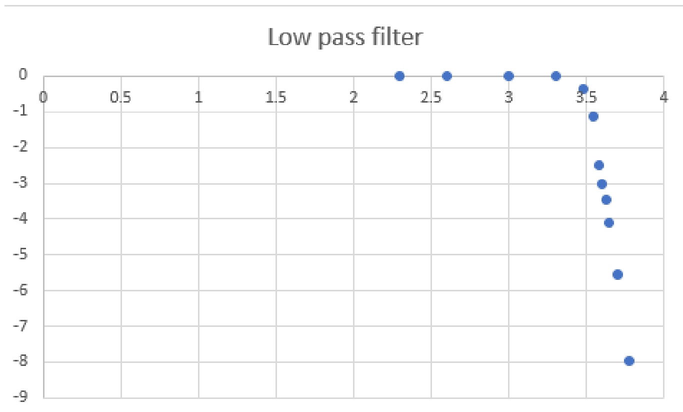

Figure 50. Butterworth lowpass frequency response

Table 6. Butterworth Bandpass Filter Component Values

Circuit Component	Expected Value	Actual Value	Percent error
R17	2.813kΩ	2.634kΩ	6.3%
R18	5.627kΩ	5.613kΩ	0.2%
R19	562Ω	584Ω	3.9%
R20	562Ω	582Ω	3.5%
C6	100nF	94.98nF	5.02%
C7	100nF	93.72nF	6.28%
C8	100nF	94.32nF	5.68%
C9	50nF	44.84nF	10.32%

The input to the final power amplifier at 400Hz is the sine wave signal shown previously in figure 47. The output of the power amplifier at 400Hz can be found below in figure 51. The input to the final power amplifier at 4kHz is the sine wave signal shown previously in figure 48. The output of the power amplifier at 4kHz can be found below in figure 52. When comparing these outputs to the outputs of the simulated circuit in figures 35 & 36, it can be seen that they are very similar, almost exact. A table of the component values for this circuit is provided in table 7 below.

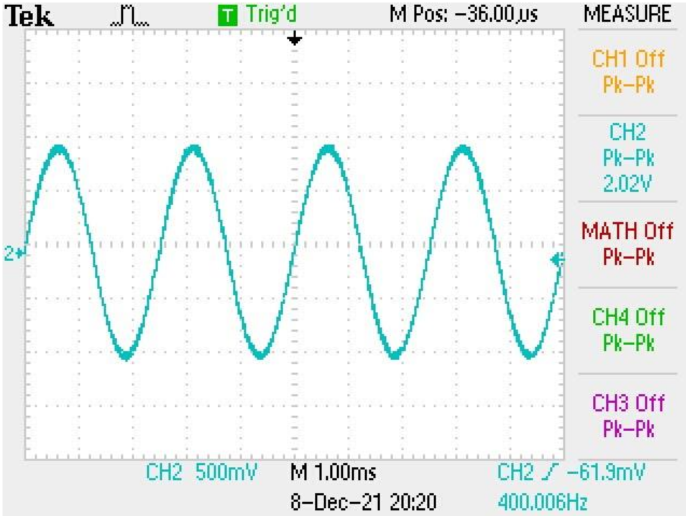

Figure 51. Output of entire transmitter + receiver at 400Hz

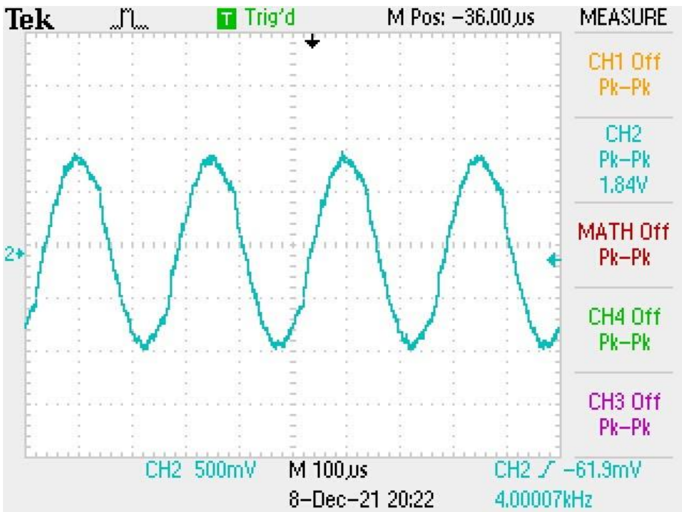

Figure 52. Output of entire transmitter + receiver at 4kHz

Circuit Component	Expected Value	Actual Value	Percent error
R21	1kΩ	998Ω	0.2%
R22	1kΩ	1.05kΩ	0.5%

5.0 Conclusion

The goal of this project was to design, construct, and demonstrate an AM radio capable of modulating, transmitting, and demodulating a single tone AM-modulated signal s(t) for all single tone frequencies between 400 Hz and 4kHz with a carrier frequency between 40kHz and 50kHz. This goal was met by building and testing the individual circuit modules, tuning them, and then integrating them together. The circuit was able to be produced into a working AM radio where on the transmitter side, the carrier signal met the frequency specifications, the circuits all met the design requirements, and the output of the transmitter was a symmetrical AM signal at both 400Hz and 4kHz. On the receiving portion of the AM radio, the receiver successfully demodulated the AM signal to recover the message signal, which was sent to a speaker and the message signal was played through the speaker. The design requirements of this project were met by the transmitter and receiver circuits.

References

[1] A. Sedra and K. Smith, “Microelectronic Circuits,” Oxford University Press, Seventh Edition, 2015
[2] Washington State University EE311 lecture notes – Fall 2021