Washington State University

School of Electrical Engineering and Computer Science

EE 352 Electrical Engineering Laboratory

Semester Project

Final Report

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Abstract

The purpose of this project is to design, construct, test, and demonstrate a working AM radio capable of modulating, transmitting, and demodulating a tone for all frequencies between 300 and 3kHz. This report contains detailed information on the processes followed in simulating and implementing the hardware necessary to complete the design requirements. The successful implementation of the radio contains the following major components in order: oscillator, mixer, band-pass filter, power amplifier, peak detector, low pass filter, high pass filter, Schmitt trigger, and speaker. There are also buffers added to the mix as needed, and those will be discussed when they come up.

1.0 - Introduction

One of the earliest forms of modulation for radio transmission is Amplitude Modulation, also known as AM modulation. This means that the data is encoded into the radio signal by modulating the amplitude, or height, of the radio signal. In figure 2 below, you can see how the sine wave of the AM signal increases and decreases in magnitude to encode the signal, which is seen in red.

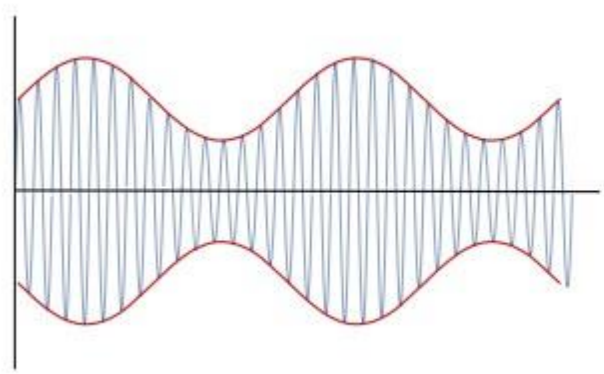

Figure 1: Amplitude Modulation

This signal is created in the mixer, which is essentially just a summing amplifier, which takes both the signal from the oscillator, and function generator, to create a signal, this is then sent through a series of diodes and filters to clean up the signal and remove resonate frequencies.

The AM signal can be described in another manner, through the Frequency domain, or FFT. This is essentially just a way to look at the dB levels of different frequencies output by the radio. An FFT graph can be seen in figure 3. This shows the dB levels of the carrier frequency (fc) and the two side frequencies, (fc+fm) and (fc-fm), where fm is the modulation frequency, which is the frequency being transmitted. This signal is then sent into the bandpass filter, which removes the resonate frequencies, otherwise this signal would be repeated every so often, like how a 60Hz signal is also seen at 120Hz and 180Hz if one doesn't filter out the frequencies above 100 Hz. In the project the carrier frequency is supposed to be around 55kHz with a bandwidth on the filter of at least 6000Hz, to allow for the 3000Hz signal being passed through.

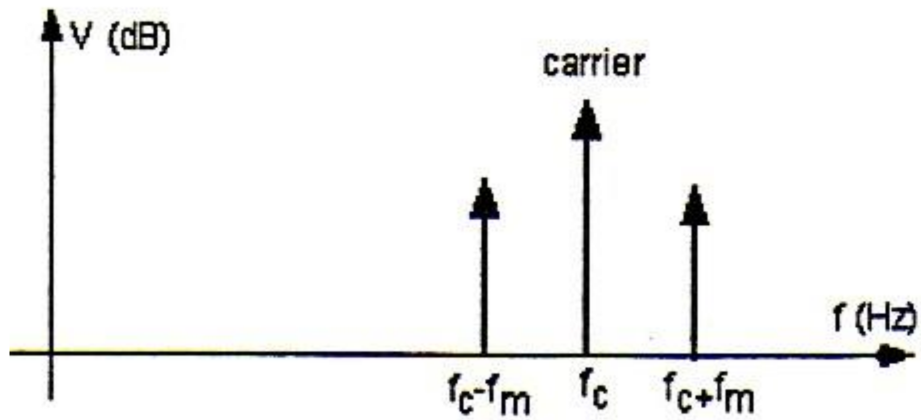

Figure 2: FFT of AM signal

After the signal is passed through the bandpass filter it is then passed along to the power amplifier, this takes the low power signal that is generated, and simply increases the output power, this is so that the signal is more easily detected on the other end, without it, the signal would not be strong enough to be detected on the other end, and when you are broadcasting a signal, the signal will lose potency over distance. The stronger the output signal, the better.

Before heading to the design for the circuit, the rest of the design specifications should be covered. The only parts able to be used in this radio are the parts included in the analog parts kit for the class, this is the parts kit that is able to be purchased from Digilent. Any other parts that students may want to use must be approved by the professor of the course ahead of time. The power supplies, which are used to supply power to the op-amps and power amplifier, are to be set to +12/-12V, no higher, no lower. The signal generator is to be a sine wave, with frequency values between 300Hz and 3000kHz. As stated before, the carrier frequency must be between 50kHz and 60kHz, with the goal being 55kHz.

The circuit for the radio is broken down into two main parts, the transmitter, and receiver, which are joined by a set of cables to transmit the signal between the two. The transmitter, seen in figure 3 below, consists of a signal generator, which is fulfilled by the laboratory function generator, an oscillator, a mixer, a high-Q bandpass filter, and lastly the power amplifier.

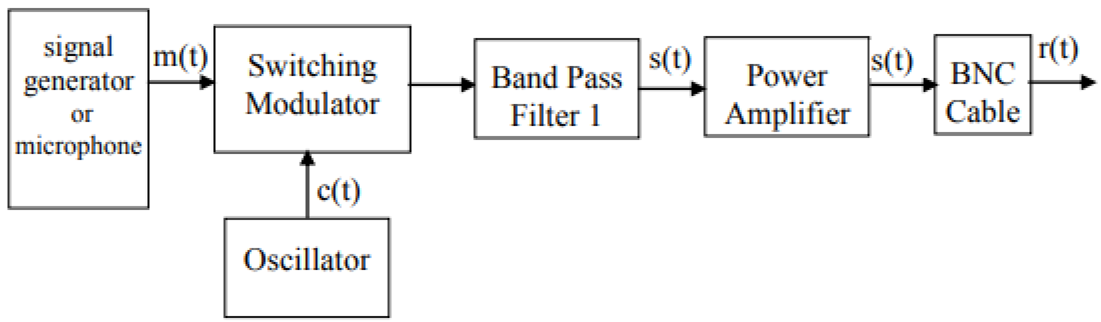

Figure 3: AM Transmitter Block Diagram

The receiver half of the radio circuit can be seen below in figure 4, in block diagram form. The job of the receiver is to take the AM signal being sent out by the transmitter, decode it, clean out the noise, and then transform the signal into one that can be played by the speaker. This half of the circuit contains a peak detector, which feeds into a bandpass filter, this bandpass filter is composed of a high and low pass filter in series, after which, a Schmitt trigger is used to create a square wave which gets passed into the speaker.

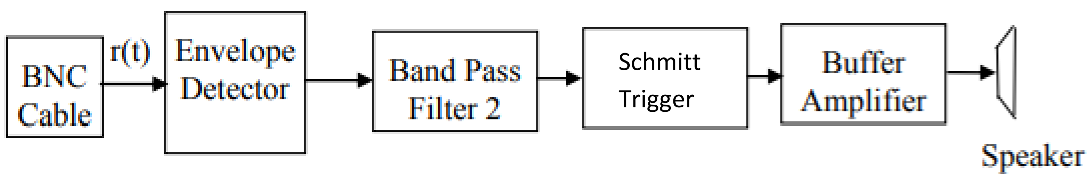

Figure 4: Radio Receiver Block Diagram

2.0 – Theory

In this section, the theory behind each component will be covered. This includes how the circuit works, the purpose to the overall design, the equations that govern the output of the circuit, and the simulation results obtained in making the circuit fit to the design constraints.

Oscillator

Ultimately, an oscillator is exactly what it sounds like, it is a circuit that oscillates at a specific frequency. The oscillator designed for the radio can be seen in figure 5 below. As you can see, the oscillator doesn't have any input, it generates the output signal on its own. It does this because there is noise generated in the circuit via the voltage used to power the op-amp. Once this noise starts up, it is fed back into the positive input of the op-amp, causing a positive feedback loop that over time will hit a resonate frequency and sit there, generating an output sine wave at this frequency. The frequency that the circuit will sit at is determined by the equation

Wo=1/RC=2*pi*f

The diagram for the circuit can be seen below in figure 5. This is what was simulated to work. The two important factors to consider here are R3 and R4 need to be the same value, as does C1 and C2. Using the values shown in the diagram, a resonance frequency of 51.4kHz, which is shown in figure 6. The peak to peak values for the output of the oscillator should be the value of the op-amp power, meaning a zero to peak value of 12 volts.

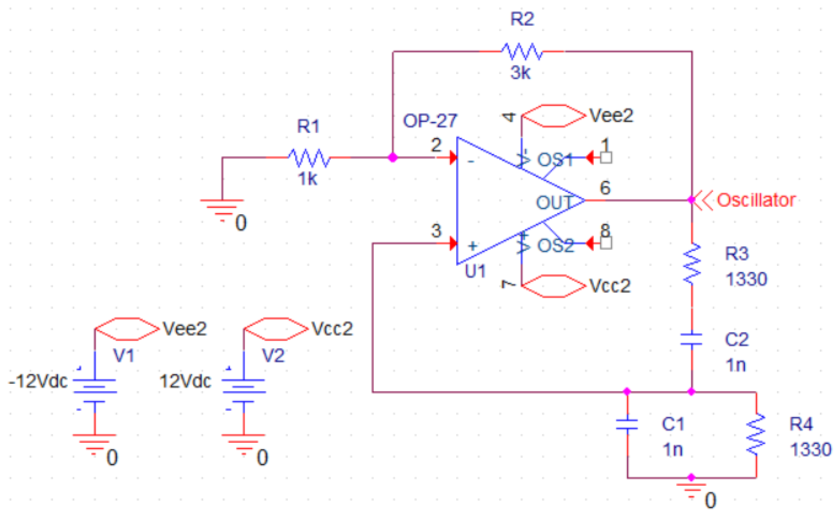

Figure 5: Oscillator Diagram for Simulation

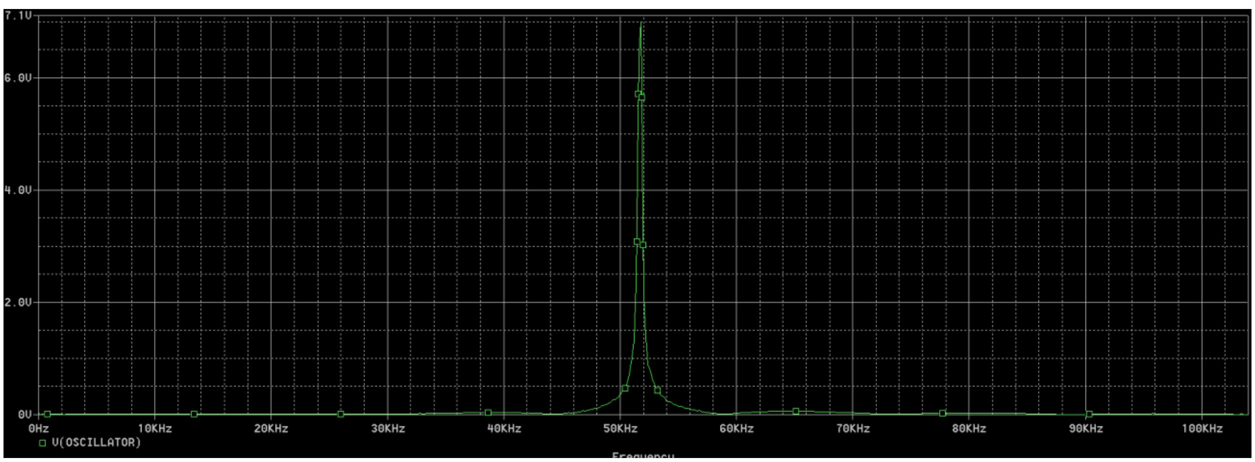

Figure 6: Oscillator Resonance Frequency FFT

With a 51.4kHz sine wave output, and a 12v zero to peak value, the simulated oscillator falls well within the design constraints for the circuit, however, the simulated values will not be the actual values in the implemented circuit, this will be discussed further in the methodology section of this report.

Mixer

The mixer has the important job of combining the messenger signal, aka the output of the oscillator, with the message signal, which is the output of the function generator. It does this by simply being a summing amplifier. The design for the circuit can be seen below in figure 7.

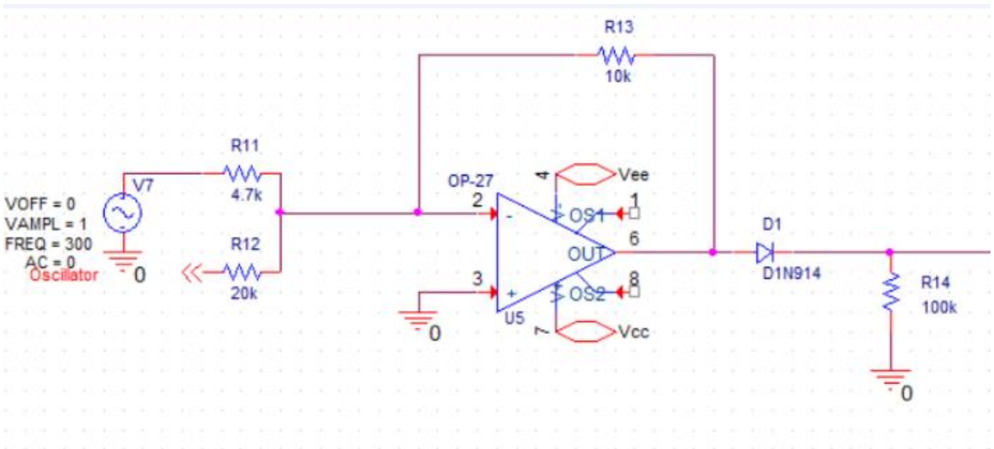

Figure 7: Radio Transmitter Mixer

The output of the mixer passes through a diode, this removes the negative values of the output. The signal before the diode is in figure 8, and after the diode is in figure 9. This is done to allow the signal to be mirrored down the rode, the mirroring is an important part in the final product, as it allows the receiver to decode the AM modulation. This circuit does not contain any components that are drastically affected by stray capacitance in the breadboard, as such, the final design follows the simulated design closely.

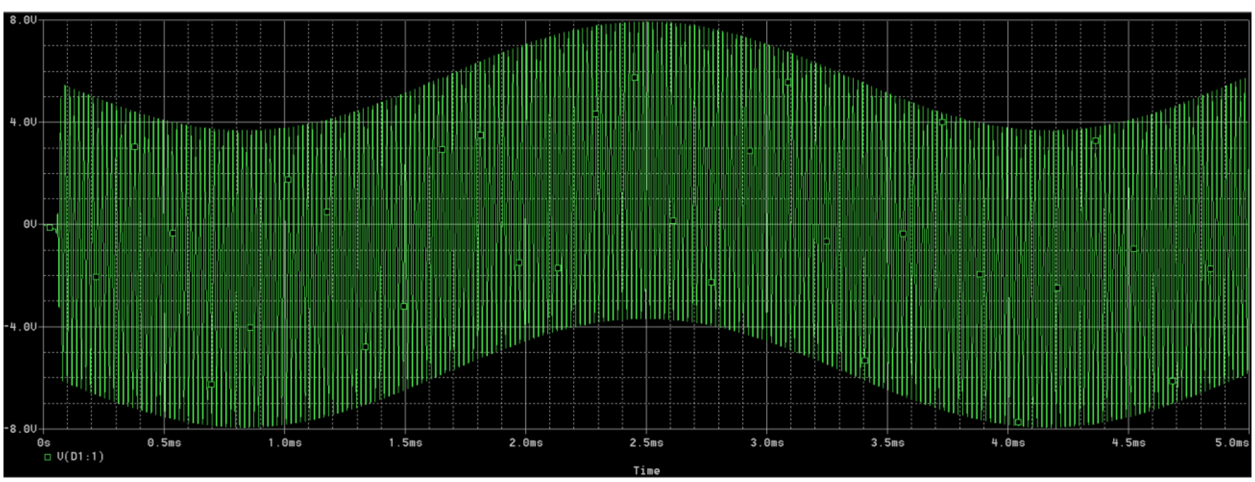

Figure 8: Mixer output no diode

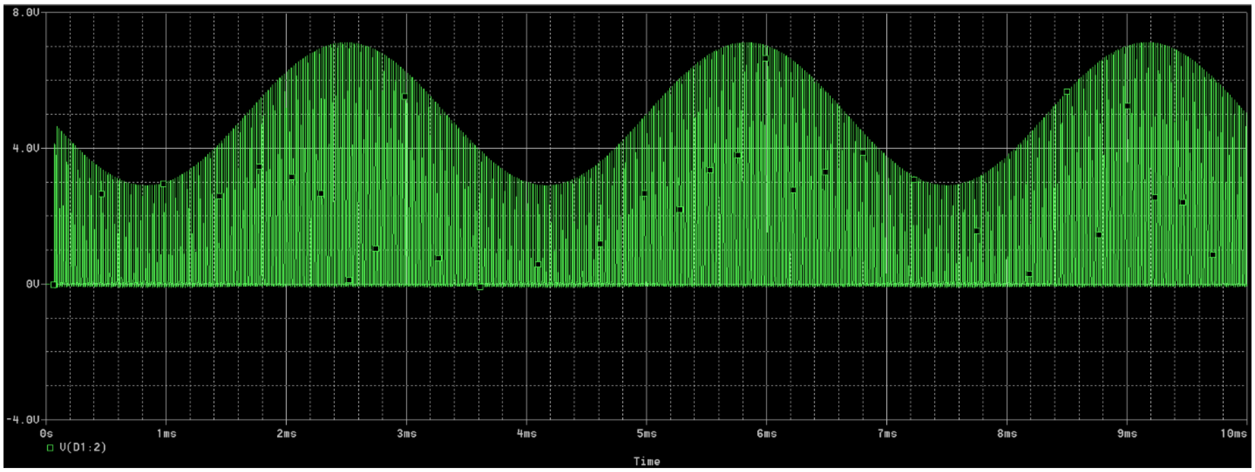

Figure 9: Mixer output with diode

Bandpass Filter

The bandpass filter does two jobs in the transmitter, the first is that it mirrors the input across the time axis, this means that the output once again looks like the graph in figure 2. The second of the jobs is to prevent resonant frequencies from propagating in the circuit. Say your output was existing at 50kHz, then at 100kHz the output would be seen again, due to the way signals work. By adding in the bandpass filter, which is a combination of low-pass and high-pass filters, you create a band of frequencies that you allow through. A diagram showing this process is seen in figure 10 below.

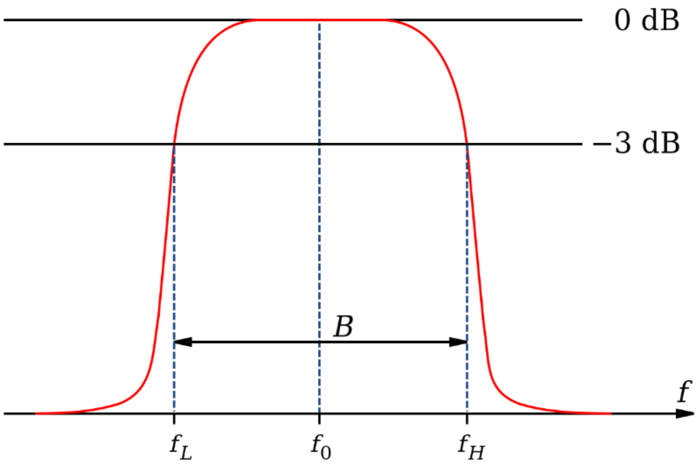

Figure 10: Bandpass filter diagram

The bandwidth for the filter can be any value greater than 6000, this is because the message frequency is 3000 above and below the carrier frequency, and if the bandwidth of the filter was less than 6000, the filter would chop off the output once you tried to pass 3000Hz as your message, but letting through the lower frequencies. The other important value for the filter is the gain, ideally the gain for the filter would be a gain of 2. The original simulated circuit is seen below in figure 11.

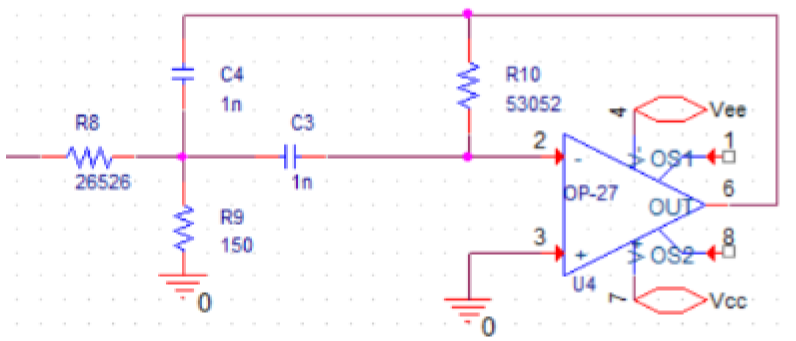

Figure 11: Bandpass filter 1

The gain for the filter is determined by resistors R10 and R8. A gain of 2 or greater is needed for the filter, this is why R8/R10=2 in the diagram. The two capacitors C3 and C4 must be equal to eachother for the circuit to work properly. The bandwidth for the circuit is given by the equation

B=2/(R10*C4).

This gives a simulated bandwidth of about 18,000rad/s or 6005Hz. The output for the filter can be seen in figure 12 for 3kHz and 13 for 300Hz.

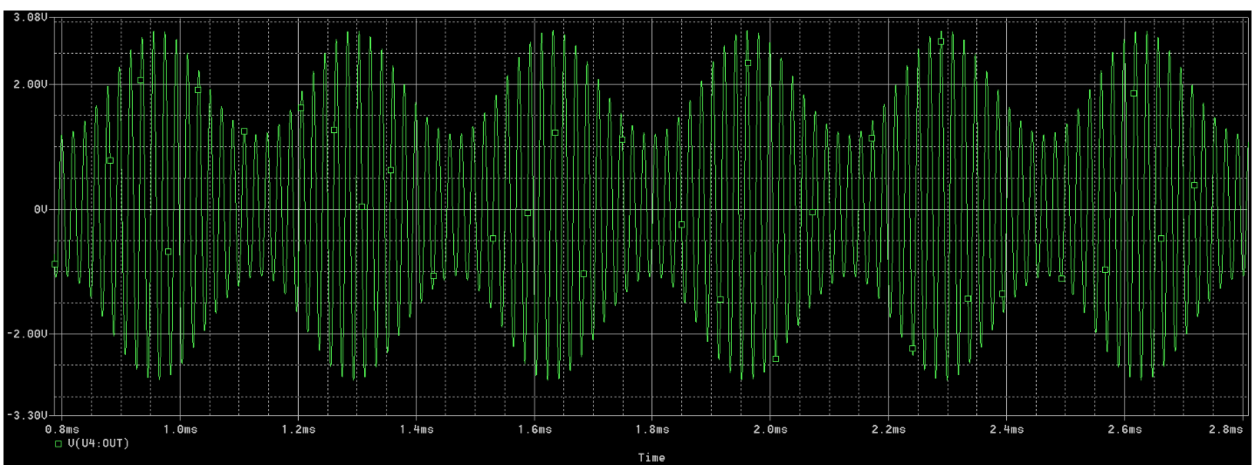

Figure 12: Bandpass Filter 3kHz

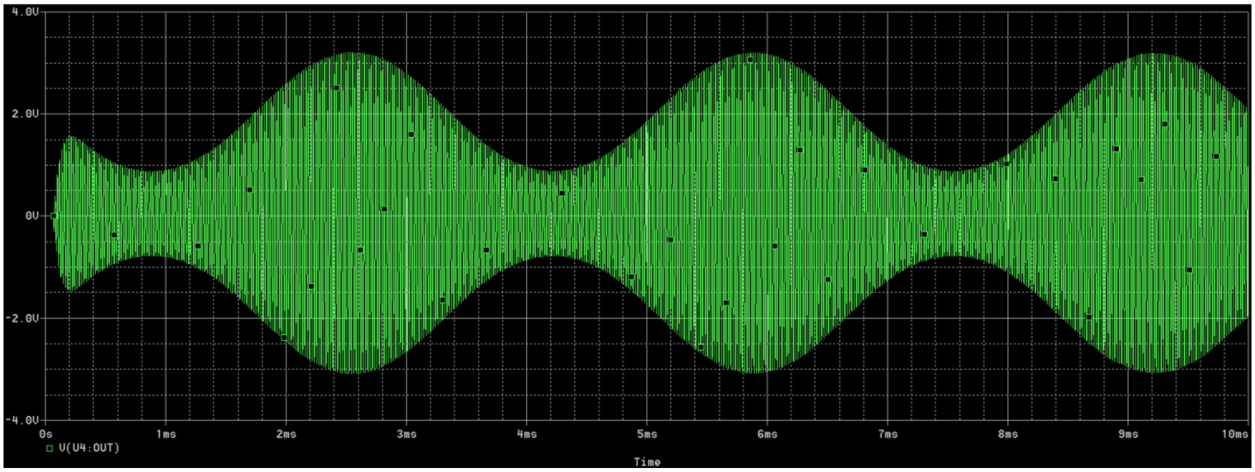

Figure 13: Bandpass Filter 300Hz

Power Amplifier

The power amplifier is the last part of the radio transmitter, it amps up the power of the signal that is to be transmitted. This is important because a more powerful signal is both easier to decode and able to be detected at a further range; however only the first aspect is important in the project. The op amp in the design is there to reduce crossover distortion. The resistor values were chosen through a process of trial and error, this component was not simulated. The circuit design is in figure 14. The RL was chosen to be a lower value due to a high value causing a very noisy output, it is unclear why this is the case, as normally a high load resistor is ideal, but implementations can vary case by case.

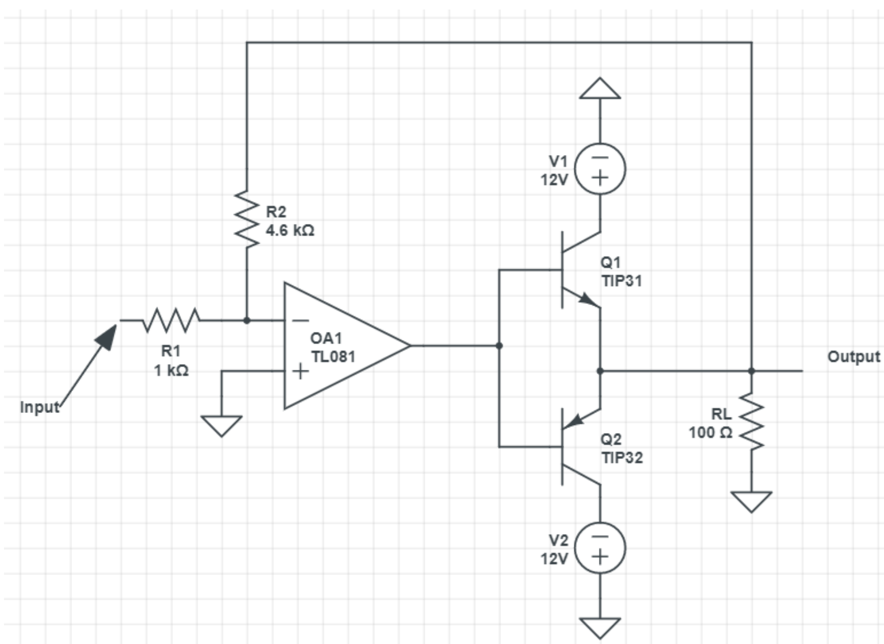

Figure 14: Power amplifier circuit layout

Peak Detector

The first component in the radio receiver is the peak detector. This is a simple circuit layout, which is seen in figure 15, that has a very important job. What the peak detector does is it gets fed the modulated sine wave from the power amplifier, and it turns the signal back into the message signal, meaning the 300-3kHz signal. It does this by following the peaks of the input. You want the circuit to catch the peak at its fastest point, and be able to hold charge to the next point. If it loses charge too fast, the signal will be noisy, if the detector holds onto the charge for too long, it'll miss dips in the input, skipping over important data, an example of a peak detector is in figure 16 [4]. The equations used to determine the values for the circuit are as follows:

T=1/fc
V'peak=Vpeak*exp(-T/RC)
(delta)V=Vpeak/(fc*RC)
tmax=1/fmax
1/fmax > 1/RC > 1/fc
T- period, fc- carrier freq (51.4kHz), fmax- highest modulation frequency (3kHz)

What this means is the capacitor and resistor values are tied together, if one increases, the other needs to decrease in order to maintain the ratio. Ideally the two values are chosen in such a way that 1/3000 > 1/RC, and 1/RC > 1/fc. You also want 1/RC to hug 1/fmax as closely as possible to prevent rippling in the signal, with 1/RC=1/fmax being ideal. Using the values from the final design, the equations are:

Fc=51.4kHz, fmax=3kHz, R=986 ohm, C= 73nF
T=1/51.4k
1/3000 > 1/(986*73*10^-9) > 1/51,400

This shows the circuit implementation fell within the constraints.

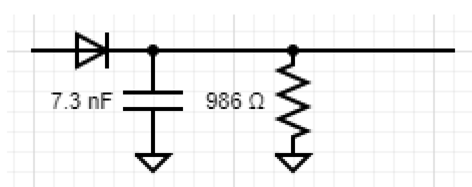

Figure 15: Peak detector

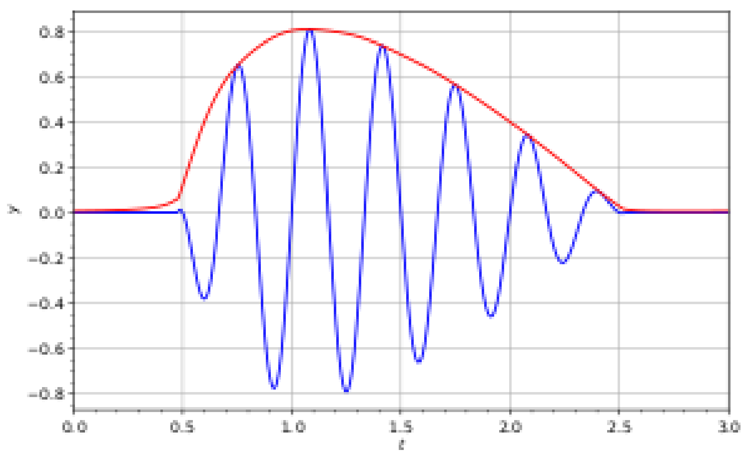

Figure 16: Peak detector example

Cascading Filters

One of the most common ways to implement a bandpass filter is through the use of a high-pass in series with a low-pass filter. This is what is implemented next in the radio receiver. This does the exact same job as the previous filter, only in a different manner. This filter needs a lower cutoff at 300Hz and a higher cutoff at 3kHz, this can be seen in figure 17. This is to not only remove noise, but also prevent harmonics from being picked up and sent to the speaker. The combined filter layout can be seen in figure 18.

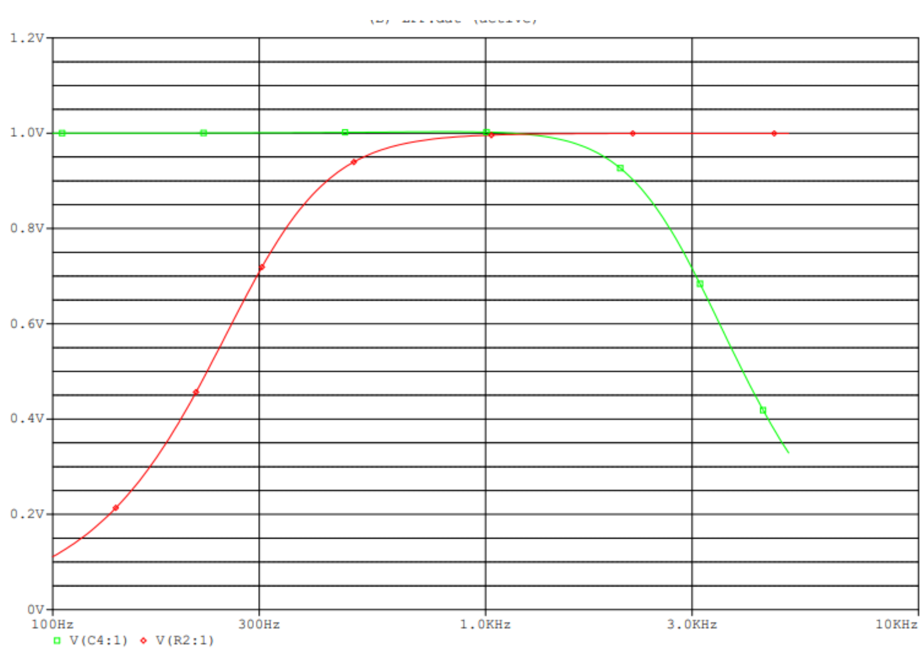

Figure 17: Filter Simulation Cutoff

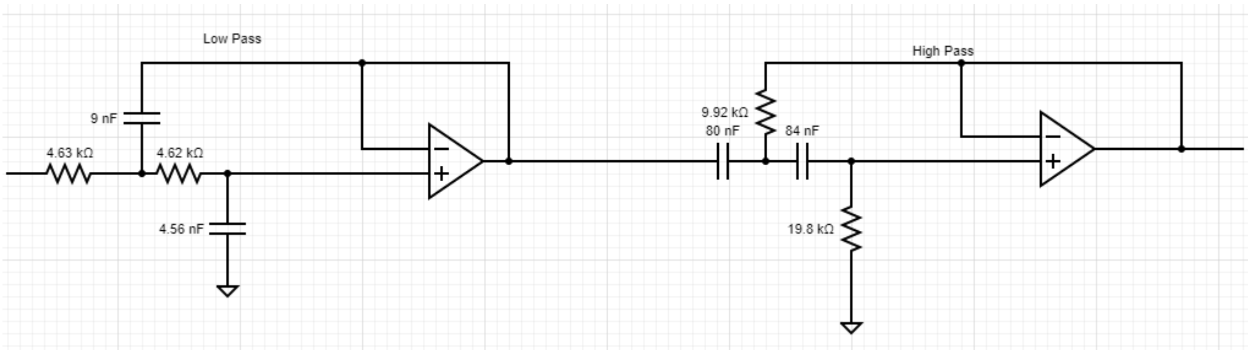

Figure 18: Cascading Filter Diagram

The above diagram includes the implemented values not the original simulated values from figure 17. These were changed on the fly to fix noise issues. The original values are able to be seen in figure 19, and were decided through using the following set of equations

HPF

w0=2*pi*300

w0^2=1/(R1*R2*C)

1/sqrt(2)*w0=1/(R2*C)

Choosing an arbitrary C value and solving for R1 and R2 gave

C=4.7u, R1=80ohm, R2=160ohm

LPF

w0=2*3000*pi

1/sqrt(2)*w0=1/(R*C1)

w0^2=1/(R*C1*C2)

Choosing an arbitrary R and solving for C1 and C2 gave

R=1kohm, C1=80nF, C2=37nF

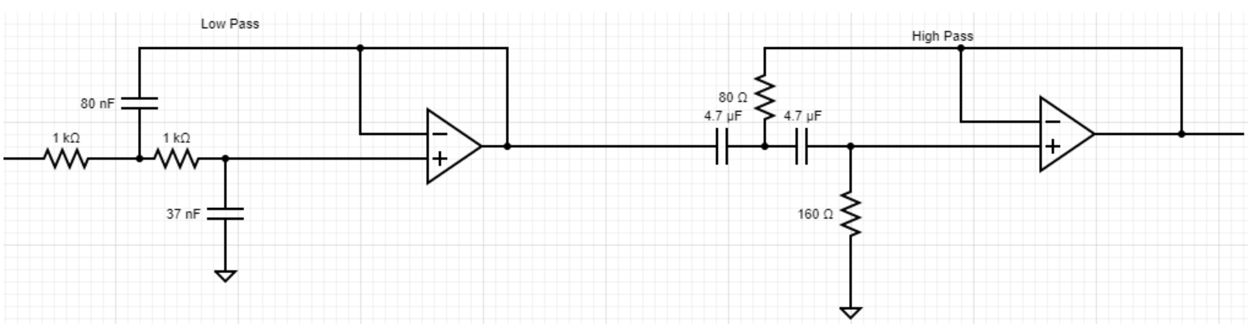

Figure 19: Simulated Cascading Filter Diagram

The output of this should be a nice smooth sine wave that mimics the output of the function generator, or the message signal. This is the fully decoded signal, the only thing left to do after this point is send the sine wave into a Schmitt trigger and then the speaker.

Schmitt Trigger

The job of the non-inverting Schmitt trigger is to take the clean sine wave from the filters and turn it into a square wave that can be played by the speaker. Essentially all this circuit is, is a very high gain non-inverting amplifier. It needs to be a high gain so that the input will rapidly saturate the op-amp, this causes the output to be a square wave. The circuit diagram can be seen in figure 20 below. The values for the amplifier were chosen arbitrarily to create a gain large enough to saturate the +/-12V power rails. The gain for this particular amplifier is:

$$G=Rf/Ri+1$$
$$Rf=47k, Ri=1k$$
$$G=47k/1k+1=48 \text{ V/V}$$

As the gain equation shows, even a voltage as small as +/-0.25v will saturate the amplifier, and when the input has a peak to peak of 5.4v, this fraction is a very minor part of the overall signal.

The diagram in figure 21 [3] shows the transfer function of the circuit. The circuit uses a process called "hysteresis" which is the action of switching between the upper and lower output values once an input threshold is met.

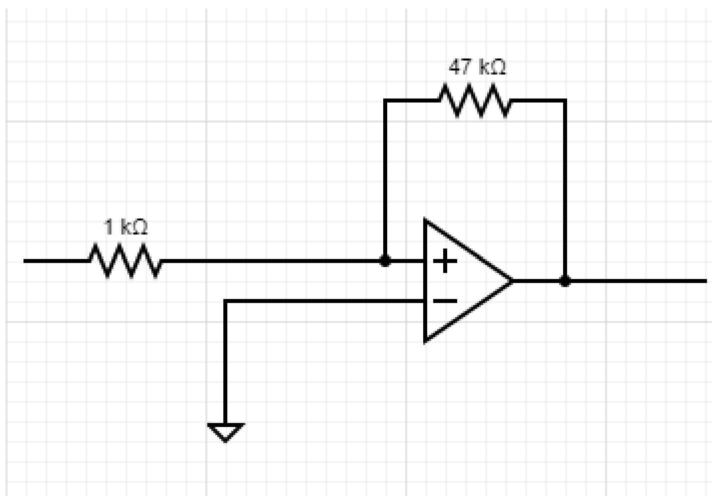

Figure 20: Schmitt Trigger Diagram

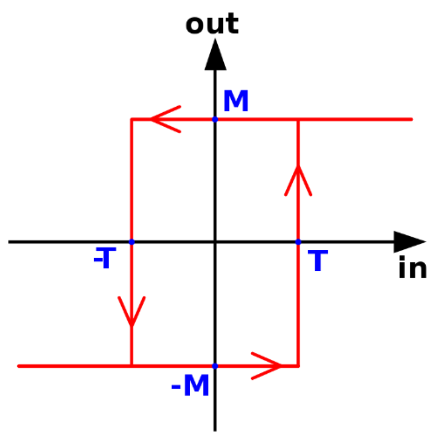

Figure 21: Schmitt Trigger Transfer Function / Hysteresis

3.0 – Methodology

This section of the report details how each circuit was designed and how the real world circuit differs from the simulated circuit, as well as any extra components, like buffers, that are added to the overall design of both the transmitter and the receiver. As stated previously, the only components used are ones actively supplied in the *Digilent Analog Parts Kit* required for the EE352 lab at WSU, with extra parts allowed by the professor as deemed necessary. Fitting within those constraints, as well as allowing for variance in components, changes the values from the calculated ones in simulation. Each individual module was built, tested, added where necessary to the overall circuit, and tuned as needed to fix noise and performance.

Oscillator

This is the first component in the circuit. The original capacitance and resistance values were changed to compensate for stray capacitance in the bread board, this capacitance was effecting the resonance frequency of the circuit. Figure 22 has the updated values for the circuit.

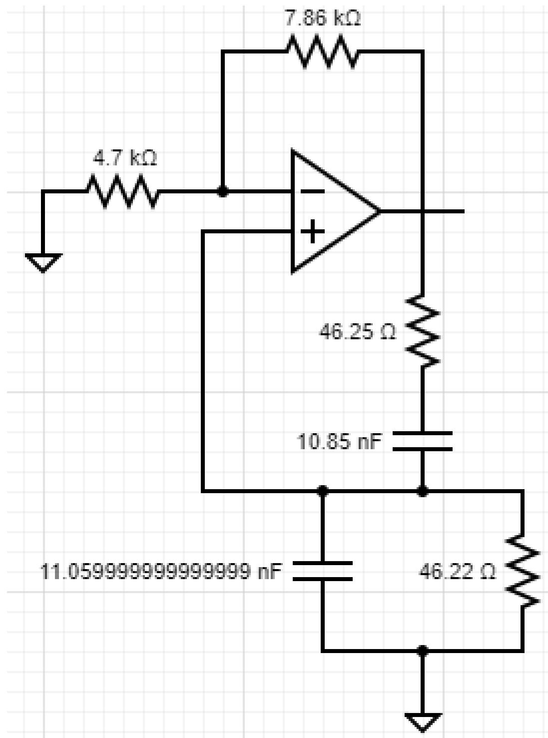

Figure 22: Updated Oscillator

The values here were changed due to the simulated values being noisy and not having a high enough resonance frequency to fit within the design constraints. The values shown are the actual measured values for the components, not what they are supposed to be, as these values also have an important factor in how the circuit performs. Extra things to consider is the 7.86ohm resistor is two resistors in series, and the design tool is glitching for showing the 11.06nF capacitors value.

Mixer

The real-world mixer does not differ from the simulated mixer in any way, the only variance is the mixer has a buffer between it and the high-Q filter to give the mixer a large output resistance to maintain optimal performance. Figure 23 shows the real-world values.

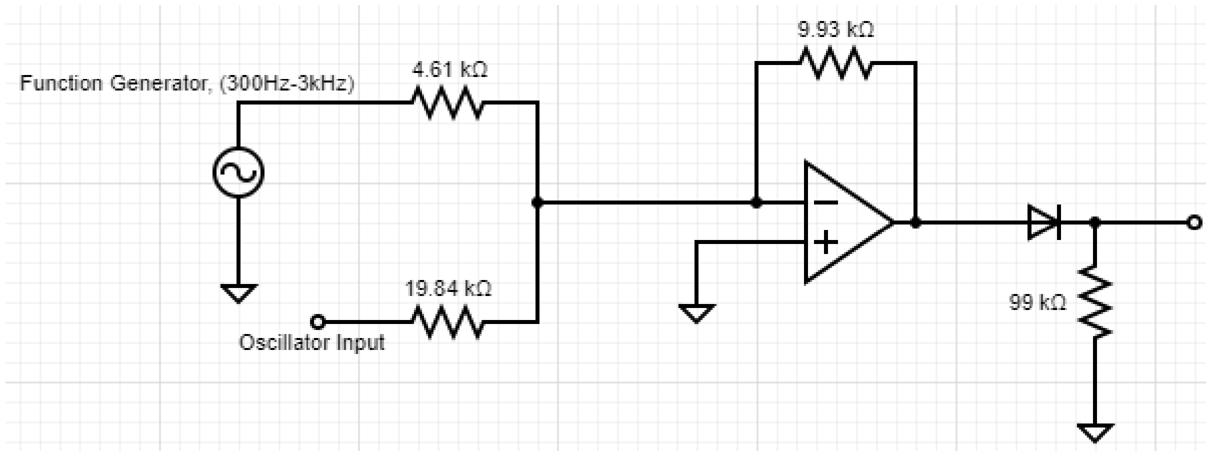

Figure 23: Real-World Mixer

Important notes to consider for this circuit is the 19.84k resistor is done by using two 10kohm resistors in series, as this part does not exist in the kits. The buffer that follows the circuit is included in diagram 24, which shows the first of the filters in the design. The diode is a 1N914 diode, although any basic diode should work.

High-Q Filter

This high-Q filter was far from the simulated circuit, this is due to the capacitors being changed from 1nF to 10nF to combat noise generated by stray capacitance. This required the resistors to also be brought down by a factor of 10. Beyond this, there are no differences in the component choices, other than using an additional op-amp to act as a buffer before the circuit, giving the filter a large input resistance. Figure 24 shows the updated real-world component values.

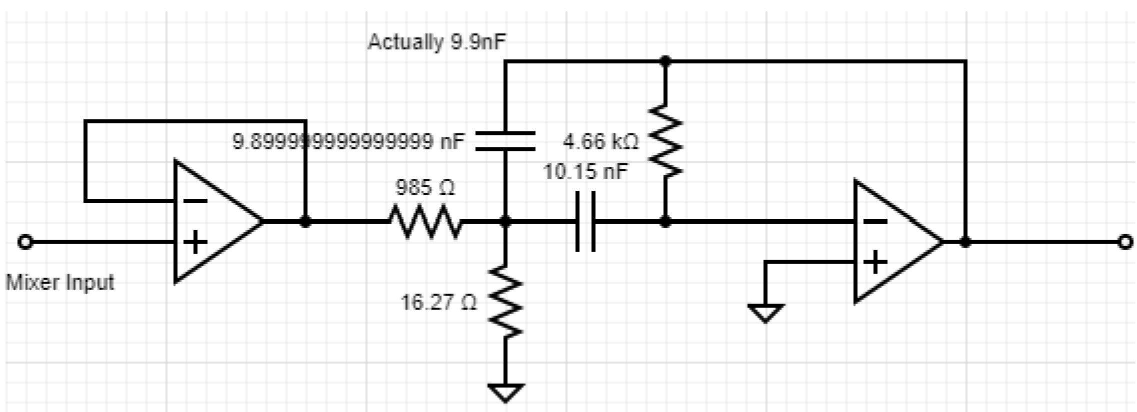

Figure 24: Real-World High-Q Bandpass Filter

Design notes to consider, the 16ohm resistor is created through using 3 very small resistors in series, this is due to the variance in actual resistance of the components. The resistors are 10ohm, 4.7 ohm, and 1.57ohm in series.

Power Amplifier

The last module in the radio transmitter half of the circuit is the power amplifier. There are no capacitors to be aware of in this module, and the values for the resistors were chosen through a trial and error basis. The op-amp inside the amplifier is there to reduce noise in the circuit. This component needs to be carefully built, as ignoring the leads of the transistors can lead to burning one or more out, and each kit only has 1 TIP32 and 1 TIP31 transistors. See figure 25 for the power amplifier design.

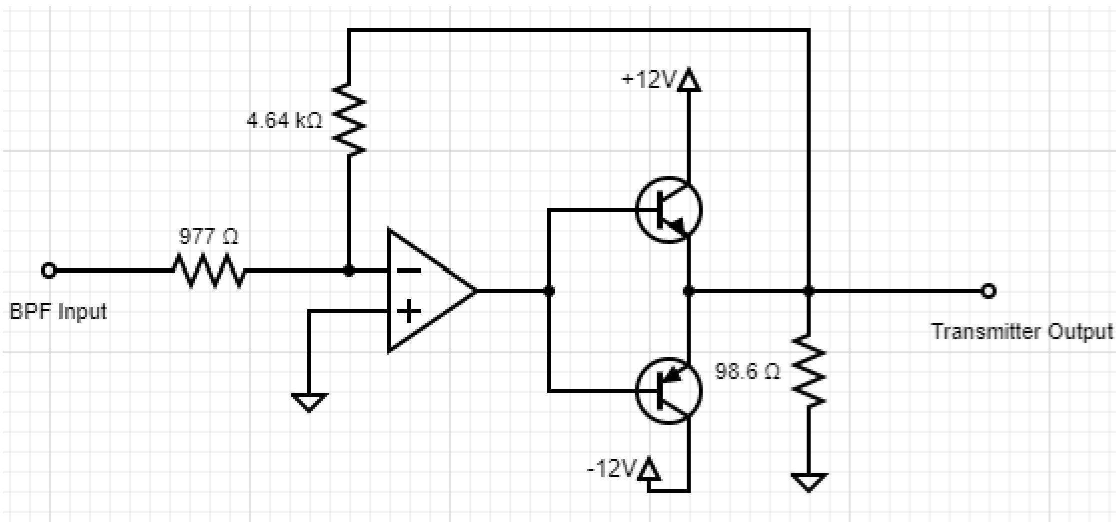

Figure 25: Radio Transmitter Amplifier

The 98.6 ohm resistor is not a typo, it was found that this needed to be a low ohm resistor, otherwise the output signal was extremely distorted for unknown reasons. The final product took some tweaking to ensure a strong connection between all the components, as a loose one caused more noise than allowable.

Peak Detector

The peak detector took a large amount of fine tuning to get the correct response. The variance in components made using calculated values nearly impossible, and it essentially boiled down to raising and lowering the resistance and capacitance by small amounts each, and retesting the circuit to see if it got the needed results. The circuit also includes an op-amp at the input to act as a buffer from the power amplifier at the output. There is also a buffer on the output of the circuit, but this will be included in the diagram for the cascading filters. Figure 26 has the diagram and values for the circuit module. The diode is the same 1N914 diode used previously.

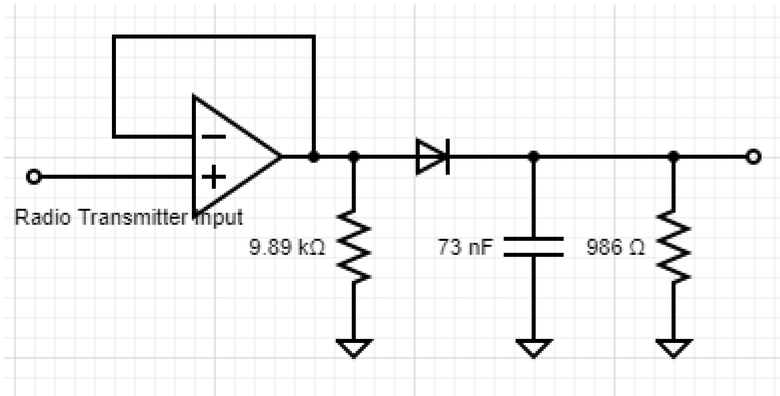

Figure 26: Peak Detector Module

Cascading Filters

Using a low pass in series with a high pass filter creates a type of bandpass filter. This filter needed to have a lower cutoff of 300Hz and an upper cutoff of 3kHz, and ideally having a very sharp frequency response to cut out additional noise and clean up the signal. Harmonics, if allowed to remain, would interfere with the hysteresis of the Schmitt trigger. This module does contain a buffer at the input to give a large input resistance, allowing for a more optimal performance. Figure 27 contains the layout for the set of filters, and the component values.

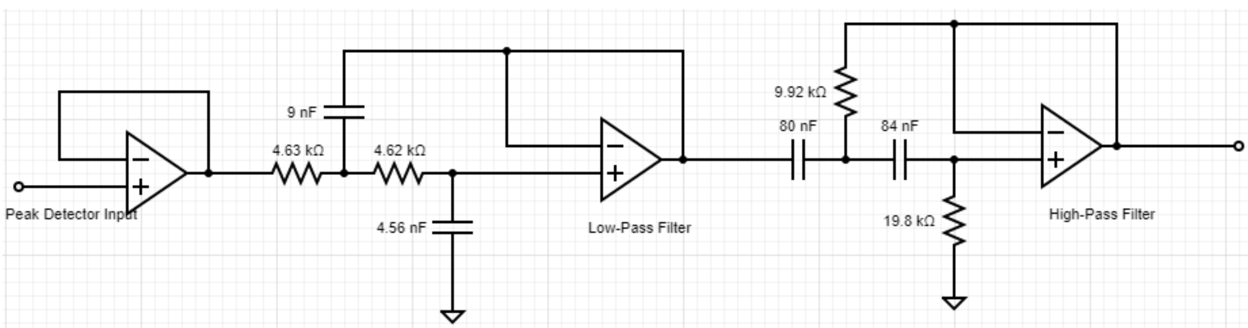

Figure 27: Cascading Filters Bandpass Filter

Some design notes to take into account here, the 19.8kohm resistor is made through two 10kohm resistors in series, due to this resistor needing to be double the other resistor, it made it simple to double up in this manner. The capacitors were chosen to be as large as they are to prevent the board noise from influencing their performance drastically. When smaller caps were in place, the output was too noisy to be usable. So these values were changed from the simulated values, but the ratios were maintained, some trial and error was needed, it was also important to have the 80nF and 84nF capacitors be as close as possible in value to prevent distortion, same with the 4.63kohm and 4.62kohm resistors. The two filters could also go in any order, and the output would not change, this layout does not need to be adhered to strictly. The frequency response of this filter will be covered in another section.

Schmitt Trigger

The last module before the speaker setup is the non-inverting Schmitt trigger. As stated previously, this takes the sine wave output from the filter, and uses the saturation behavior of an op-amp to create a square wave of about 24V peak-peak at the same frequency as the sine wave. The resistor values were chosen arbitrarily to create a large enough gain, the gain for this specific amplifier is 48.44 V/V. There was no tweaking done on this module, as the first attempt gave the desired output. See figure 28 below for the circuit layout and exact component values.

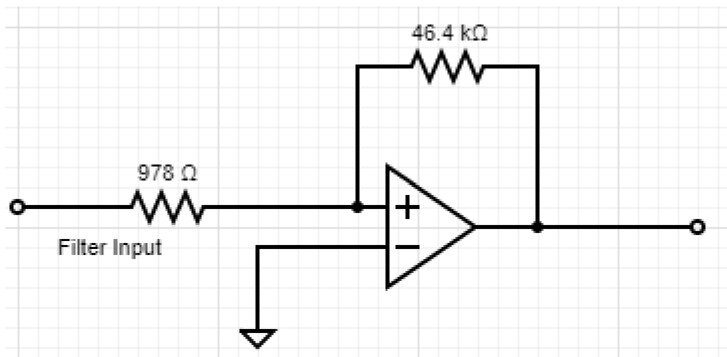

Figure 28: Non-Inverting Schmitt Trigger / High Gain Amplifier

Speaker Configuration

The receiver is built, but what good is it if there is no way to hear that beautiful 3kHz signal from the function generator? This module is designed to pass the square wave from the Schmitt trigger to the speaker. It uses a diode to reduce the 24V peak to peak wave into a 12v peak to peak wave with a 6V DC offset; meaning there is no negative component to the signal. This then gets passed through a voltage divider to reduce it further, into a 6V peak to peak signal, so as to not damage the transistor and buzzer speaker that follows it. The transistor is there to add further resistance to the line to prevent excess current from damaging the speaker. See figure 29 for the last bit of circuit layout in the design.

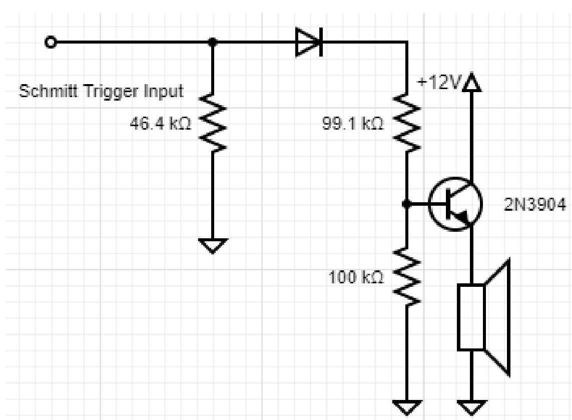

Figure 29: Speaker Configuration

For the voltage divider, any standard one-half divider should work, but 100kohm resistors were chosen here as they were readily available at the time of construction. The diode is the same model used in every other part of the radio, the 1N914. The speaker is the buzzer speaker included in the kit, the model is AC-1005G-RPA-LF.

Final Design Notes

The only additional notes that need to be included when it comes to the design of the radio transmitter and receiver, is the inclusion of buffer capacitors between the power rails and ground, as well as the use of star nodes for power and ground. Star nodes is a method to reduce noise caused by daisy chaining. When a circuit has ground and power daisy chained from one to another, it causes noise from each component's power line to be moved to its neighbors, and their noise passed along to their neighbors once again, star nodes give each component a direct line to the power-supply's lines, reducing the overall noise in the system, allowing for a cleaner input. Figure 30 has an example of a star node for visualization purposes. The buffer diodes were another method to help reduce noise. Both the transmitter and receiver used very large capacitors at both the input and output of the set of modules. These capacitors help reduce the fluctuations in the line, to again, help give a cleaner output. The capacitors were 220uF and 470uF capacitors that sat between the +12V, -12V, and GND rails connecting each rail to the other. Figure 31 has a visualization for how one section of this would look.

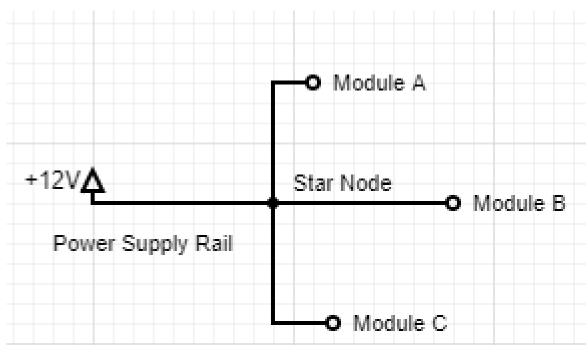

Figure 30: Star Node Visual

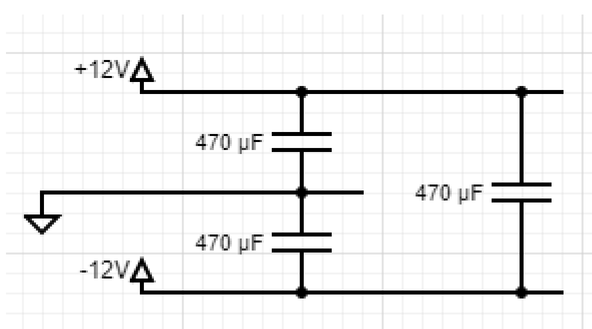

Figure 31: Buffer Capacitor Visual

4.0 Results and Analysis

This section of the report will contain the input and output of every module in the design, as well as the frequency response for the filters in the circuit, to allow every component to be understood at an individual level.

Oscillator

The output for the oscillator in figure 32 is the pink sine wave. This is showing the 51.4kHz resonance frequency of the oscillator. Not much is needed to be said here other than that it is working as intended, and has the necessary voltage output.

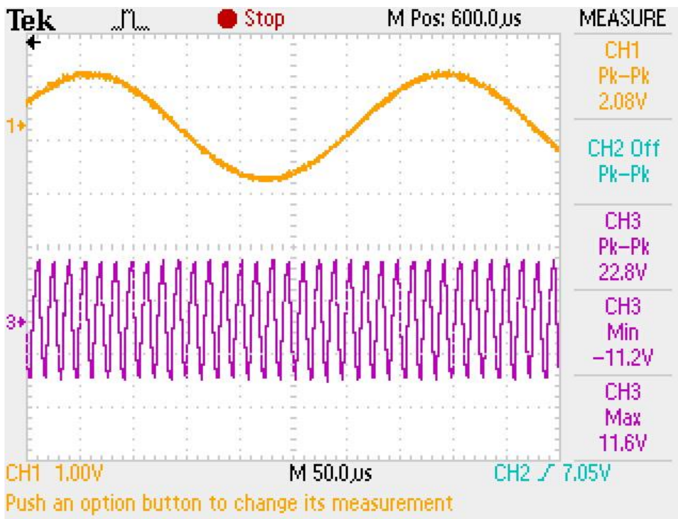

Figure 32: Oscillator Output

Mixer

The mixer combines the signals from the function generator at 300-3kHz and the oscillator to give a modulated sine wave. Figure 33 is the output at 3kHz and figure 34 is 300Hz. The output of the mixer is shown at the bottom of the image in pink, and it can be seen to be the combination of the oscillator in blue, and the function generator in yellow. The signal is beginning to look noisy, but the filter will help take care of this down the line. The needed signal can still be seen. Ignore the peak to peak values the scope is showing, those are inaccurate, and it is more accurate to measure the min and max values for this section of the circuit, which fell within the needed bounds. Figures 35 and 36 show how the signal looks after the diode removes the negative portion of the signal for 3kHz and 300Hz respectively. A minor dip can be seen on the lower portion of the signal, however this is not deal-breaking aspect, the filter will ignore this portion of the signal, and as such it has no influence on the final product. Diodes are not perfect. A recurring theme will be seen in regards to the output. The 3kHz signal will generally be cleaner than the 300Hz signal in all cases.

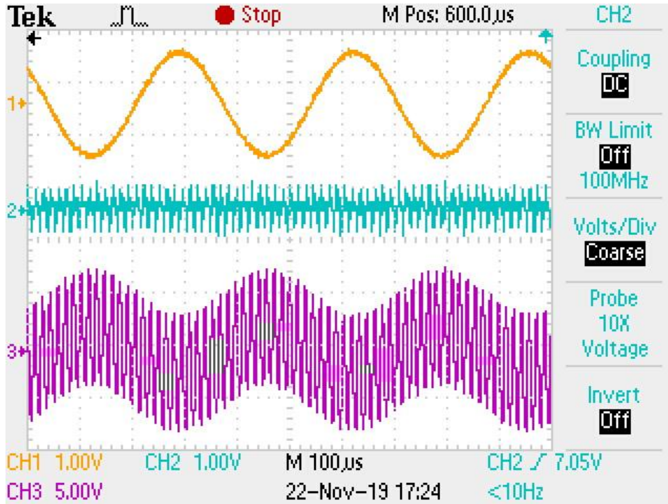

Figure 33: 3kHz Mixer

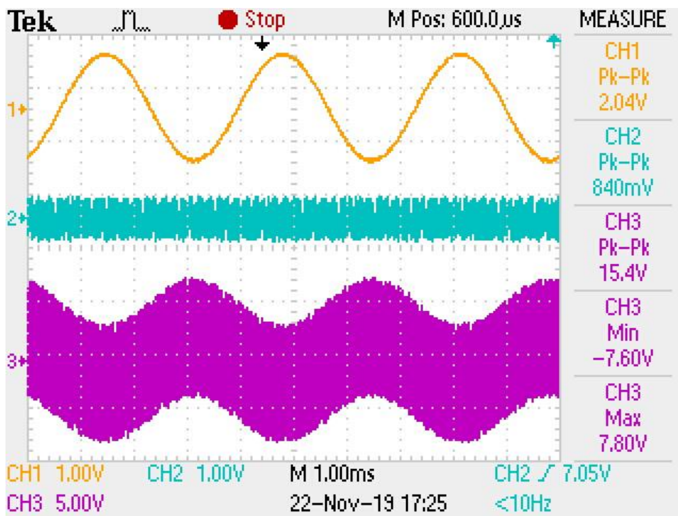

Figure 34: 300Hz Mixer

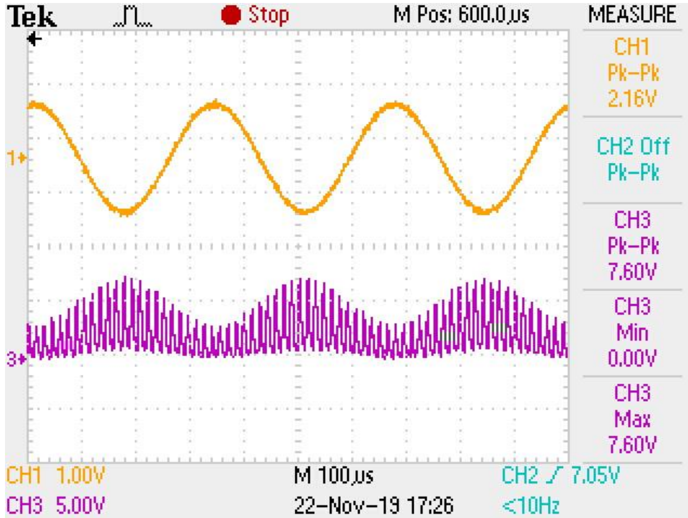

Figure 35: Diode 3kHz

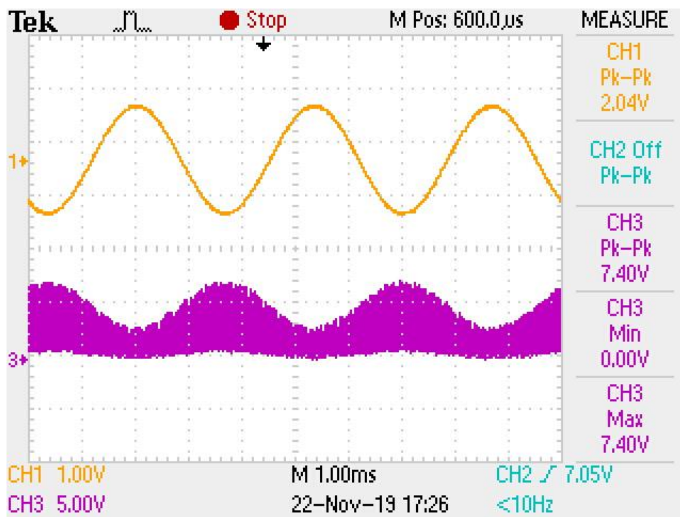

Figure 36: Diode 300Hz

High-Q Filter

After the diode takes out the negative portion of the signal, the filter cleans out any harmonics, and returns the signal to a modulated sine wave which has a more clear AM modulation to it. Once the filter has done its job, the power amplifier will increase the voltage output, and exert its own influence on the form of the signal. In figures 37 and 38 the diode signal is seen in blue, the filter output is in pink, and the original message signal is in yellow.

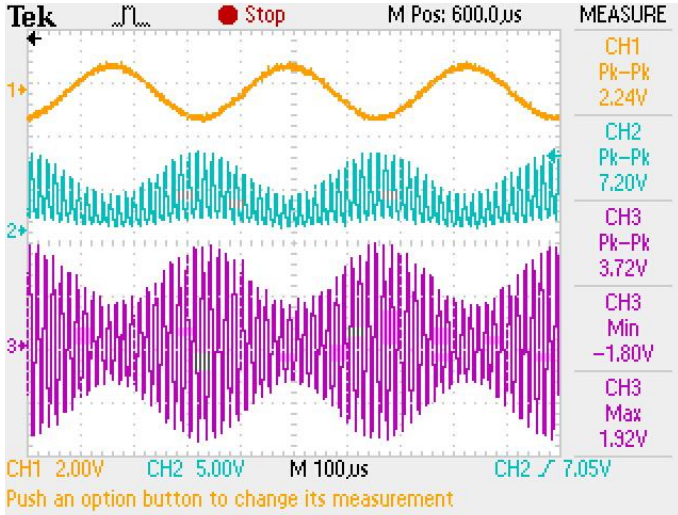

Figure 37: 3kHz Filter Output

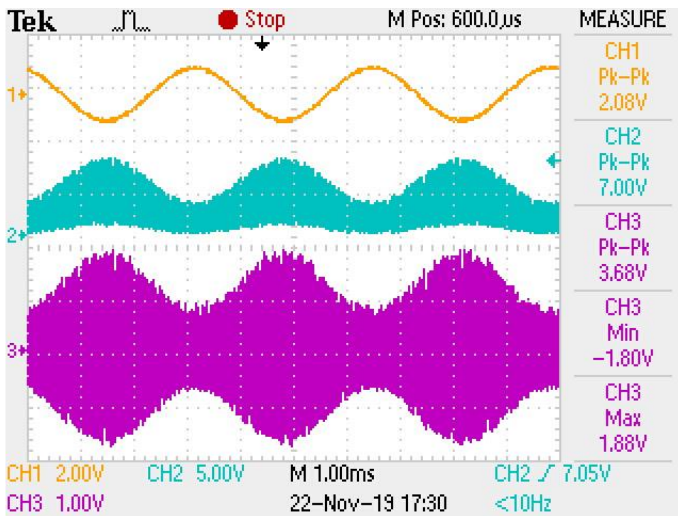

Figure 38: 300Hz Filter Output

The filter has a center point of 51.4khz, any frequencies above or below this point get dramatically reduced, as can be seen in the frequency response shown below in figure 39, which contains the excel plot of this filters response.

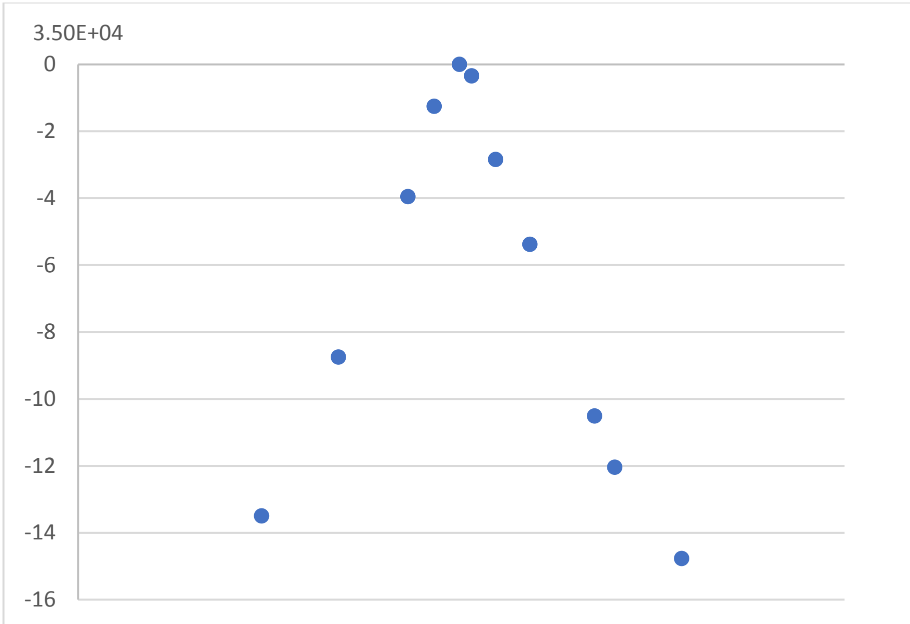

Figure 39: High-Q Filter Frequency Reponse

Power Amplifier

The power amplifier takes the 3.7V peak to peak signal and makes an 18.6v peak to peak signal, allowing for the differences in amplitude to be more easily perceived by the peak detector in the receiver side of the system. Figure 40 is 3kHz and 41 is 300Hz. The filter output is in blue, the power amplifier is in pink, and the message is in yellow. In regards to the 300Hz signal, the noise is seen to be drastically less after exiting the amplifier, this may be due to the amplifier's workings or it could be due to the buffer capacitors sitting right next to it in the final product.

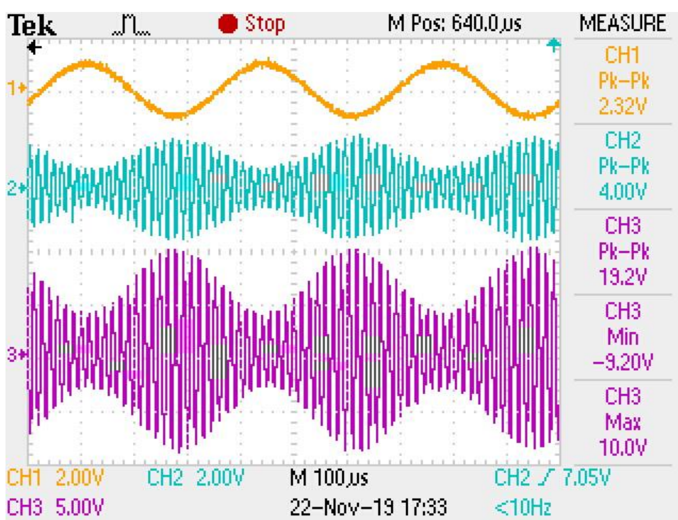

Figure 40: power amplifier 3kHz

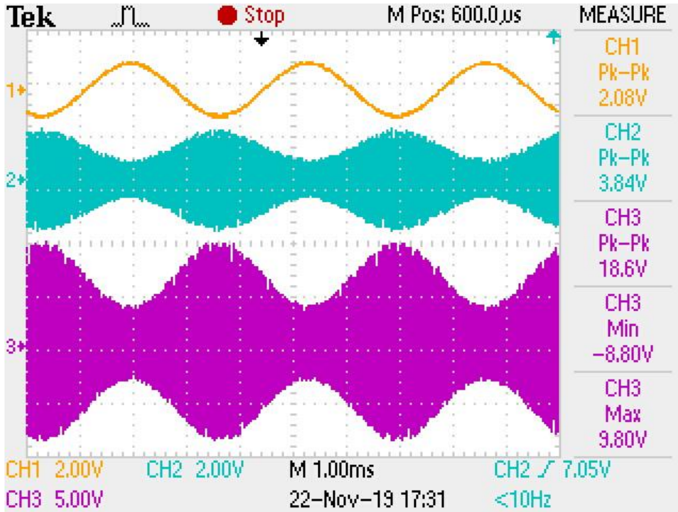

Figure 41: Power Amplifier 300Hz

Peak Detector

This module has the important part of beginning to decode the message sent by the transmitter, in figure 42, which shows the 3kHz signal, you can see the pink output of the detector riding along the blue input from the transmitter, hitting the peaks as it climbs, and following the dips down. Figure 43 contains the output for 300Hz. The line is a bit thicker, but it will be clean enough for the rest of the circuits to do their part in decoding the message.

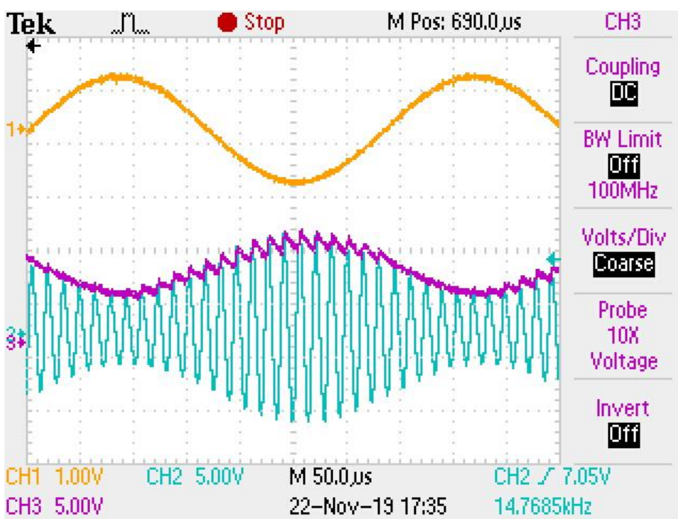

Figure 42: Peak Detector 3kHz

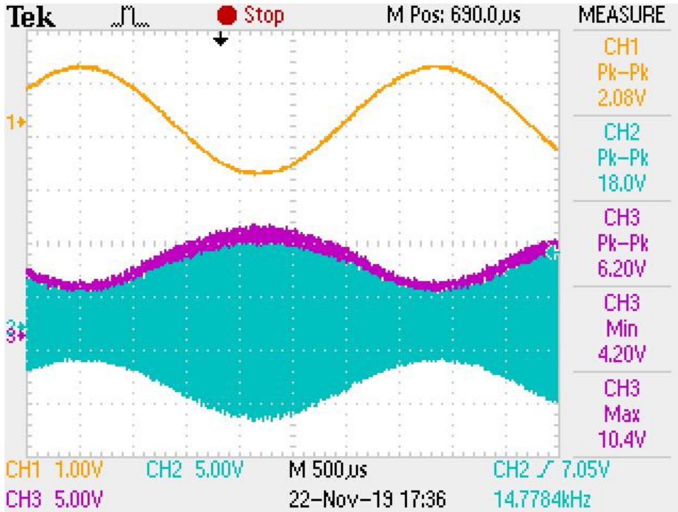

Figure 43: Peak Detector 300Hz

Cascading Bandpass Filter

This filter will do the same thing for the peak detector as the high-Q filter did for the diode output of the mixer, it will clean out the harmonics from the signal, and turn the output into a cleaner sine wave for the Schmitt trigger to turn into a square wave. Again, the output is in pink, and the input from the peak detector is in blue. In figure 44, the peaks from the 3kHz signal can be seen, but they are no longer there in the output. Figure 45 shows a similar thing for the 300Hz signal, albeit not as cleanly.

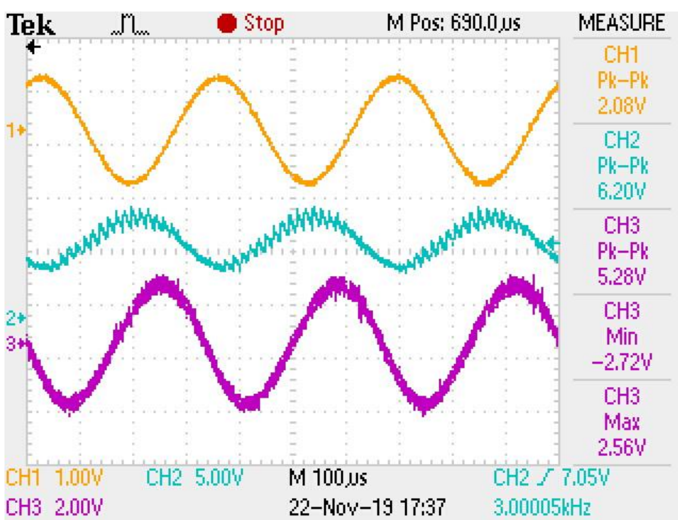

Figure 44: 3kHz Cascading Filter

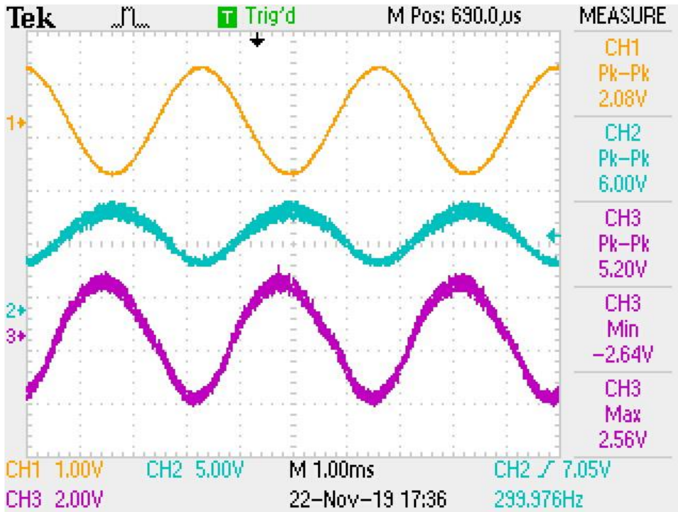

Figure 45: 300Hz Cascading Filter

A critical aspect of a filter is the frequency response, in regards to this filter, the cutoffs need to be at 300Hz and 3kHz so that any lower or higher harmonics or noise gets filtered out. In figure 46 the frequency response for this cascading bandpass filter can be seen. This was plotted out in excel, gathering various data points, and plotting in a log scale. Frequency is the X axis and amplitude in dB is the Y axis. As able to be seen, the frequency drops off dramatically after the 300Hz and 3kHz marks.

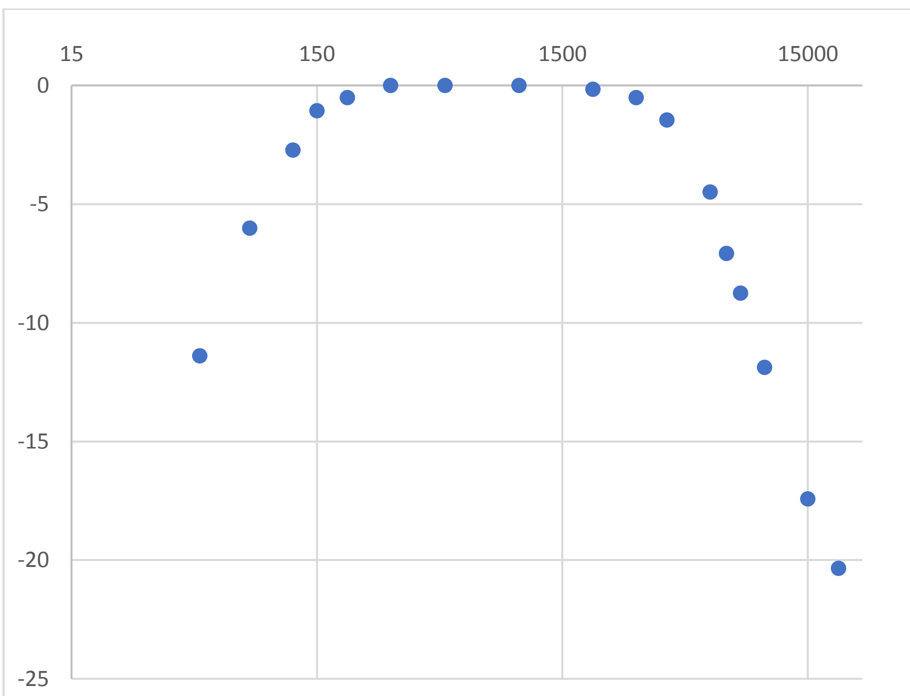

Figure 46: Cascading Filters Frequency Response

Schmitt Trigger

The non-inverting Schmitt trigger takes the sine wave output and turns it into a square wave that can be played by the speaker. This can be seen in figures 47 and 48, where the large gain causes the amplifier to saturate, and give a signal extremely close to a digital square wave. Blue is the sine wave input, pink is the square output, and yellow is the original message signal.

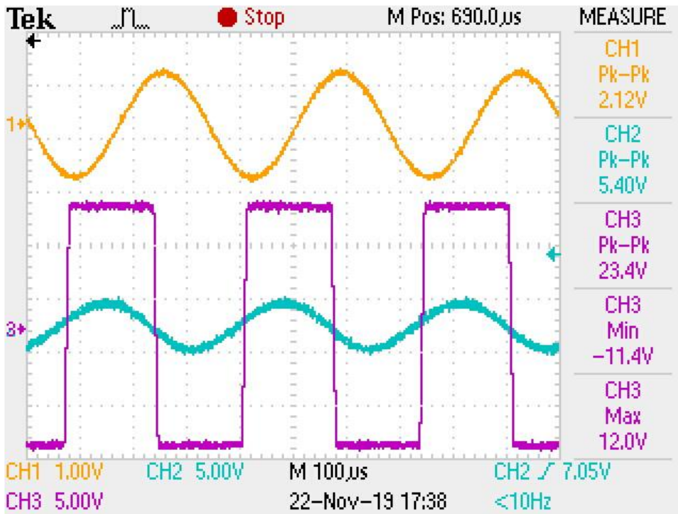

Figure 47: 3kHz Schmitt Trigger

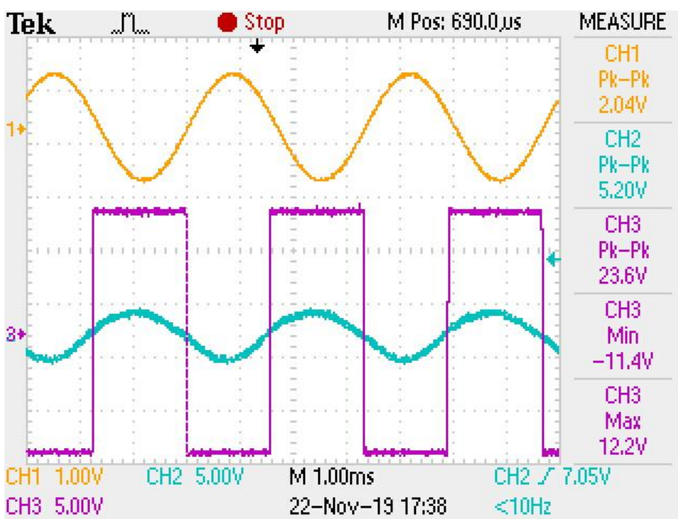

Figure 48: 300Hz Schmitt Trigger

As can be seen in the figures, the square wave is slightly offset from the original message, this is due to the slight time delays and phase changes caused by the large amount of components and capacitors in the full circuit design. It has no effect on the final product, it is just an interested thing to notice, it is also an important reason digital systems allow for audio to get a time delay for any cases where it is necessary.

The diode takes the 23V peak to peak output of the Schmitt trigger and chops out the negative half, reducing the signal to an all positive square wave. This has a minor effect on the shape of the signal for 3kHz, but not on 300Hz, seen in figures 49 and 50 respectively.

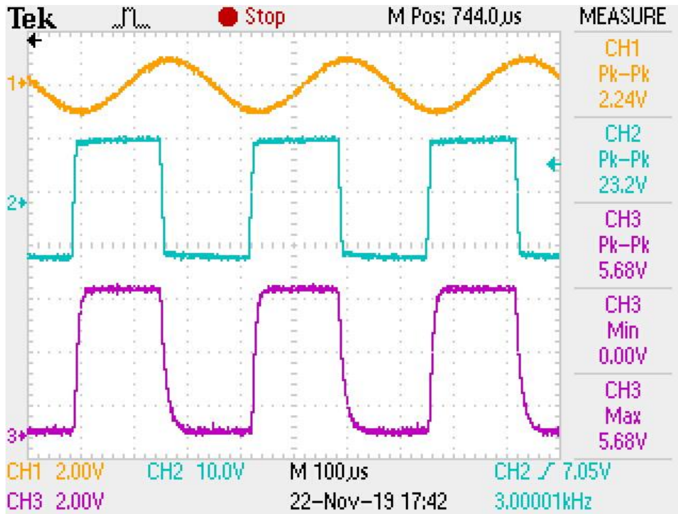

Figure 49: 3kHz Diode Square Wave

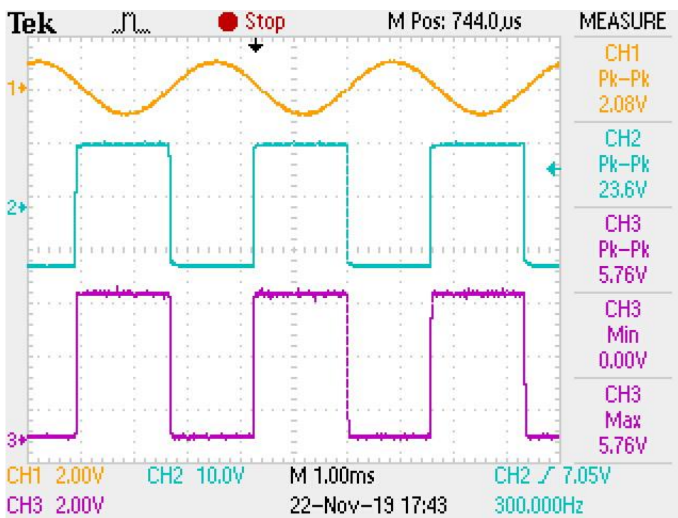

Figure 50: 300Hz Diode Square Wave

Speaker Configuration

Lastly the signal that the speaker sees. This is modified by the voltage divider and existence of the transistor, and it does not look like a square wave, the falling edged appear distorted, but the speaker plays the signal just fine, and the scope is likely effecting the measuring process due to its own impedance. Figure 51 has the 3kHz signal, where this distortion is much more easily seen than the 300hz signal in figure 52.

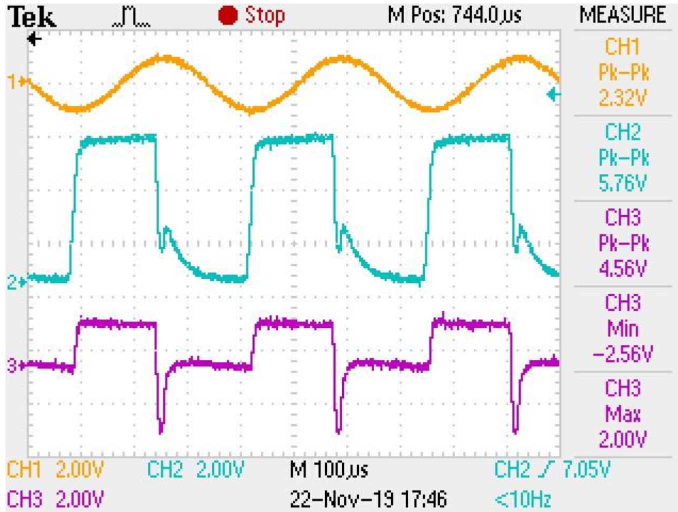

Figure 51: 3kHz Speaker

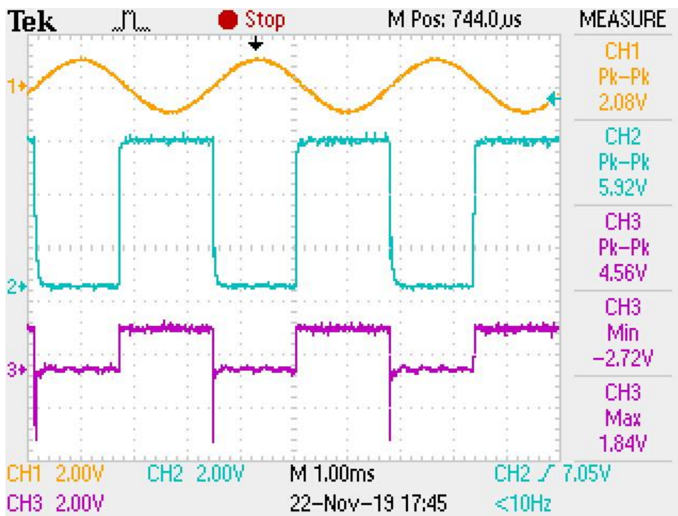

Figure 52: 300Hz Speaker

5.0 Conclusions

The biggest difference between simulated and real-world circuits is in simulation, the only things effecting your measurements are the components you choose to use, your input, and your output, which are all acting as ideal sources, and perfect components. In the real world, signals get mixed together, breadboards have stray capacitances, as well as all wires adding in minute amounts of resistance and impedance, and overall, components are not the exact values calculated. This means values need to be adjusted to compensate for extra noise, as well as allow the circuit to still work as intended, giving the right amplitudes and frequency responses. Power supplies are never perfect, they always inject their own noise into your circuit, whether it be through the power rails, or ground rails, not only that, but all of the components will be interacting with each other and talking over each other adding more noise that the designer needs to take into account and compensate for. While this project has had major modifications in the final product, the system still works as required, and falls within the design specifications. It modulates, demodulates, and plays a signal from the function generator ranging between 300Hz and 3kHz.

6.0 Recommendations

To anyone wanting to replicate this project for themselves, the only recommendation to give is do not expect the exact values to work for you, every component, from resistor to capacitor, to op amp and to diode will be slightly different, meaning minor changes to wiring, positioning, and values will likely be needed. So do not be afraid to make changes on the fly as needed. Test everything, and record everything. Mistakes in a circuit like this are easy to make, and wires are very easy to cross. Using this report as a baseline for your attempt will give you a good foundation to start from.

References

[1] A. Sedra and K. Smith, "Microelectronic Circuits," Oxford University Press, Seventh Edition, 2015
[2] https://en.wikipedia.org/wiki/Colpitts_oscillator
[3] https://en.wikipedia.org/wiki/Schmitt_trigger
[4] https://en.wikipedia.org/wiki/Envelope_detector

[1] & [2] were provided as sources by the professor of the course
[3] & [4] were where images in figures 21 and 16 were obtained