Washington State University

School of Electrical Engineering and Computer Science

EE 352 Electrical Engineering Laboratory

Final Project Report

AM Radio

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Abstract

The purpose of the project is the design and construct an AM radio capable of modulating, transmitting, and demodulating a single tone signal s(t) for all single tone's frequencies between 300Hz and 3000Hz. In the AM Radio, an oscillator is needed to send a clock frequency, a mixer is needed to combine two non-linear circuits to create a new frequency from both signals applied to it. A band pass filter will be used to filter out frequencies outside the bandwidth of the bandpass filter, and the power amplifier is used to amplify the signals amplitude. Both the simulated and constructed circuits met the requirements of applying a clock frequency from the oscillator, then combining both the sin input and oscillator frequency through the mixer generating a modulating signal. The band pass filter then filters out frequencies outside the range of frequencies. The power amplifier met the desired requirement of amplifying the signal amplitude.

Part 1: Transmitter

Introduction:

A transmitter in an AM radio has five different components in order to generate a successful AM signal. The first being an oscillator circuit. The oscillator used is the Wien Bridge Oscillator which has low distortion and low resonance frequency that can be easily adjusted. The frequency is adjusted through the changes in resistor and capacitor values. The second component used is the signal generator/microphone which is simply a signal applied through the AM radio at a given AC amplitude at a specific frequency. The third component is the mixer which takes the signal generators AC signal and combines into the clock frequency that carries the signal by modulating the AM signal. The fourth component is a band pass filter which is a circuit that has both a low pass and high pass filter to create a bandwidth of frequencies to be sent. The bandwidth filters out frequencies outside the bandwidth range which helps reduce noise in the AM radio. The fifth component of the transmitter is the power amplifier which has a gain more than one in which the power amplifier can absorb a great amount of power. The power amplifier is used to amplify the AM signals amplitude.

AM Modulation is used for radio transmission and two-way radio communication applications. Amplitude modulation needs a carrier amplitude to be modulated. The signal is carried in the graph shown in Fig.1

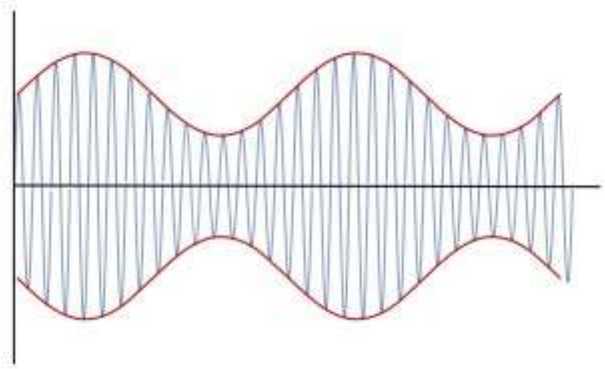

Fig.1 – AM Modulation Signal

For a radio signal to carry information, the signal must be modulated or changed. To achieve this, the amplitude in variation with sound is changed where the change in amplitude is a result of enveloping shown in Fig.2

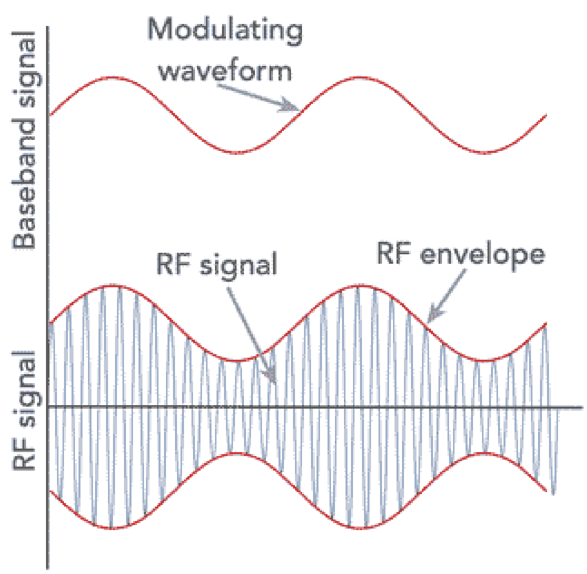

Fig.2 – Enveloping, Modulating waveform, RF signal

In Fig.2 the signal is the wave carried within the waveform where the enveloping is each amplitudes peak. This results in the broadcasting signal to be carried within the RF signal at the oscillators clock frequency. The mathematical expressions for time-domains of the waves are

$$m\left(t\right) = A_m \cos(2\pi f_m t)$$

$$c(t) = A_c \cos(2\pi f_c t)$$

Where m(t) is the modulating signal and c(t) is the carrier signal. The constant A for each signal is the amplitudes of both the modulation signal and carrier signal and *f* is the frequency of both signals. The AM modulation equation with both the modulating signal and carrier signal is given by

$$s(t) = [A_c + A_m \cos(2\pi f_m t)] \cos(2\pi f_c t)$$

The time domain of the AM signal is the time vs. carrier amplitude shown in Fig.3

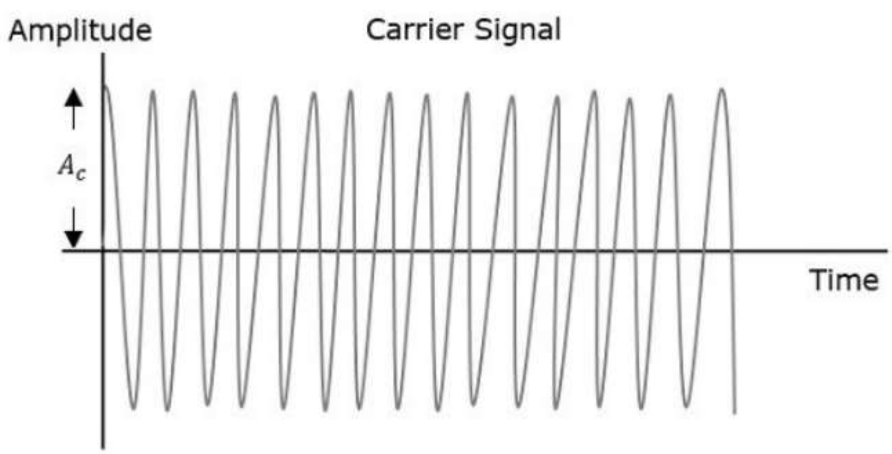

Fig.3 – Time domain of AM signal

The carrier signal contains no information but is a high frequency signal. The modulating wave in Fig.1 contains the message signal, and when combined the carrier signal and modulating wave result in an AM modulated wave. The frequency domain of an AM radio produces more information about the audio signal due to each signal amplitude at each specific frequency rather than an averaged RMS amplitude value such as the time domain. The carrier signal is within the frequency domain like Fig.4

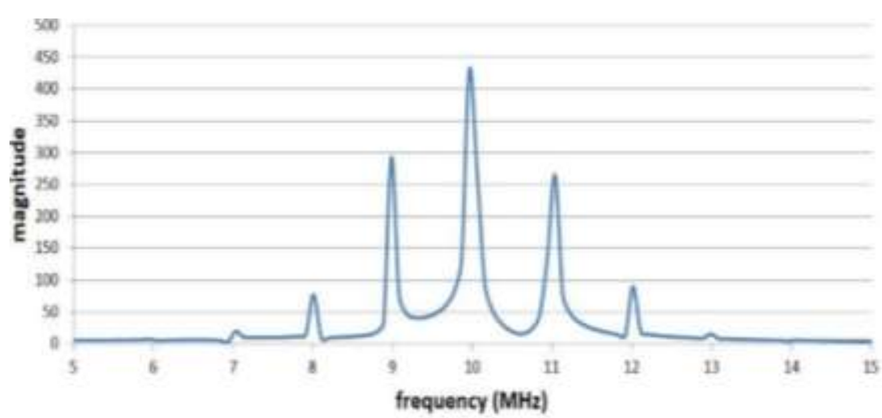

Fig.4 – Frequency Domain

The Wein Bridge Oscillator will create a clock frequency where a steady signal like Fig.5

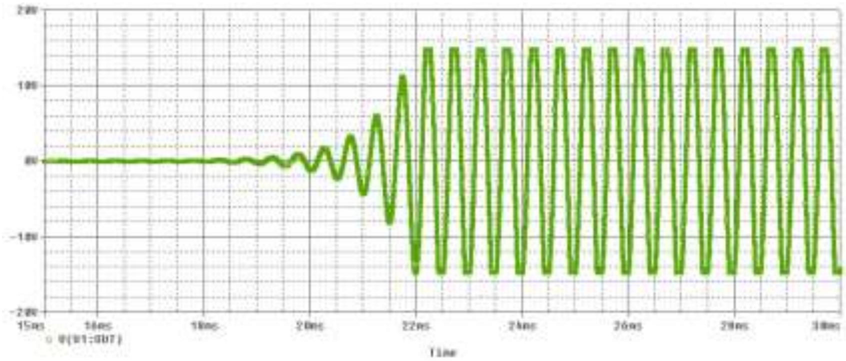

Fig.5 – Oscillator signal

In Fig.5 as time increases the signal will be generated as a base that will carry the information signal when going through the mixer. The signal will provide a base that the mixer will take and combine the input signal in order to transfer it to the receiver to output the signal. The mixer will take two signals, one being the clock frequency of the Wien bridge oscillator and the second being the input signal with a specified amplitude and frequency. The mixer will combine both signals into one creating an AM modulation signal where the information is carried through the modulating waveform and moved with the carrier signal which causes enveloping at each peak amplitude. A band pass filter is used to filter out signals not in the bandwidth of frequencies. The signals outside the bandwidth is noise which causes a random disturbance within the signal itself. The bandpass filter will help eliminate the noise minimizing the random disturbances to get clean signals within the AM radio. Transmitters amplitude can be relatively low due to a specific design. To help amplify the radio frequency a power amplifier is used to amplify the signals amplitude increasing the power signal.

The specifications for the transmitter include the oscillators gain to be greater than 2 and less than 5. When designing the circuits, the capacitor values must be kept simple following analog parts kit capacitor values to avoid mass use of capacitors. Also, resistor values must be kept to at least 1 or 2 resistors to combine into one resistor by itself or 2 in parallel or in series to minimize noise from circuit. The input signal will be a signal generator of an amplitude of 1VAC at a range of 300Hz to 3000Hz. The output will be a single tone sin wave where the output is a clear signal from 300Hz to 3000Hz. The carrier frequency must be within the range of 50000Hz to 60000Hz where the design is expected to work for only one carrier frequency. The carrier frequency is found through the Wien bridge oscillator by adjusting capacitor and resistor values in order to have a gain greater than 2 and within the range of 50000-60000Hz. The transmitter bandpass filters frequency response must have a lower stop band less than 3000Hz, an upper stop band of double the carrier frequency, and a pass band of a bandwidth of 6000Hz from the carrier frequency obtained within the design.

Theory

There are two main components to building an AM radio. One being a transmitter and the other being a receiver. Within each component lies several subcomponents within both the transmitter and receiver. The internal components that make up the AM radios transmitter is shown in Fig.6

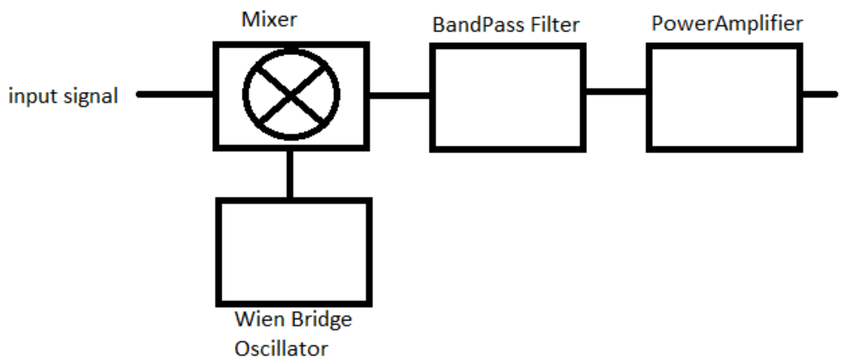

Fig.6 – AM Radio Transmitter block diagram

The transmitter has 5 components to transmit a signal where one of the components is simply an input signal of a specific amplitude and frequency. The Wien Bridge Oscillator shown in Fig.6 is the component that generates the base signal that will carry the input signal. The values of the Wien bridge oscillator determine the cutoff frequency. The Wien Bridge oscillator in the AM radio is shown in Fig.7

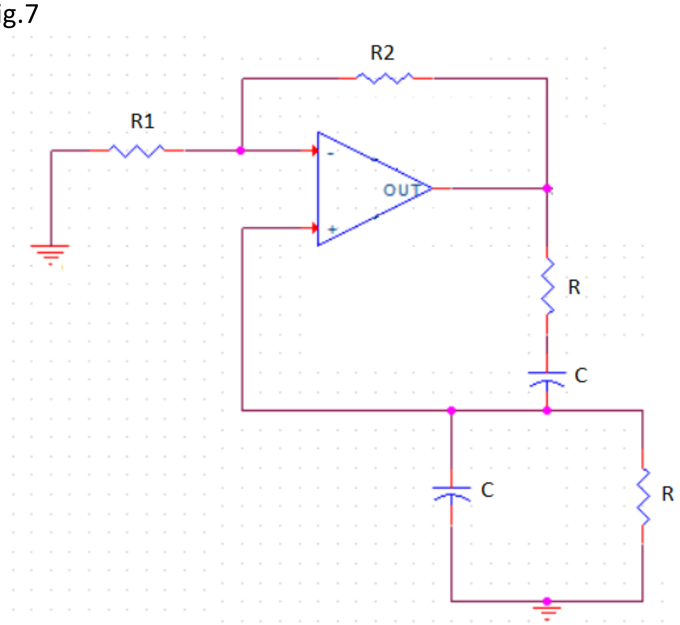

Fig.7 – Wien Bridge Oscillator

Within this design, there will be 4 total resistor values used where the resistor value R will be used to help determine the carrier frequency. The other two resistor values R_1 and R_2 will be used as a simple inverting amplifier to design a specific gain based on the AM radio specifications. Two capacitors are used which help contribute to determining the carrier frequency. The carrier frequency can be determined by the following equation

$$w_o = \frac{1}{RC}$$

The gain of the oscillator is given by the following

$$\text{Gain} = 1 + R_2/R_1$$

All the values used will determine the center frequency, but the resistor R_1 and R_2 will be a set value where the gain will be between 2 and 5. By choosing a capacitor value the resistor R will be the only value changed until a steady clock frequency is generated.

The mixer shown in Fig.8 is the circuit that combines both the carrier signal and waveform signal to create an AM modulating signal.

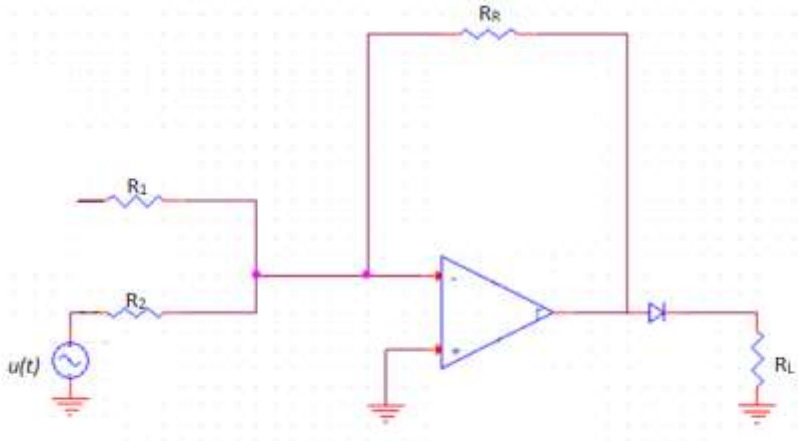

Fig.8 – Mixer

The mixer will take two separate signals and combine into 1 signal called an Amplitude Modulated Signal shown in Fig.9

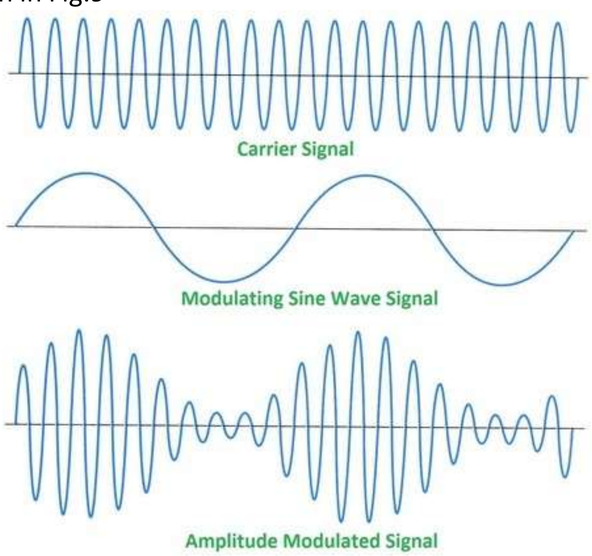

Fig.9 – Amplitude Modulating Signal

From Fig.9 the oscillator creates the carrier signal or a clock frequency of a steady signal, while the input signal is a sin wave signal. The diode in the mixer will remove the lower half of the signal as the positive signal is what will carry this information. The Band Pass Filter shown in Fig.10 is a circuit that passes frequencies within a certain range and rejects frequencies outside the bandwidth. This help eliminate noise within the information signal minimizing the distortion.

The band pass filter used 3 resistor values and 2 capacitors. The capacitor values will both remain the same while the resistor values will change.

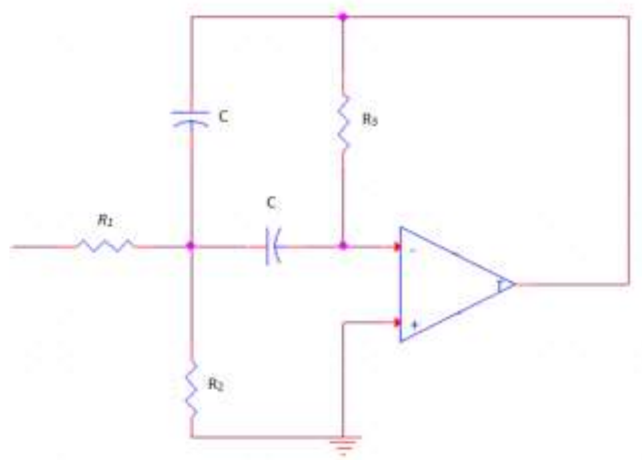

Fig.10 – Band Pass Filter

A band pass filter is a second order circuit where a rand of frequencies are defined within a bandwidth of frequencies shown in Fig.11

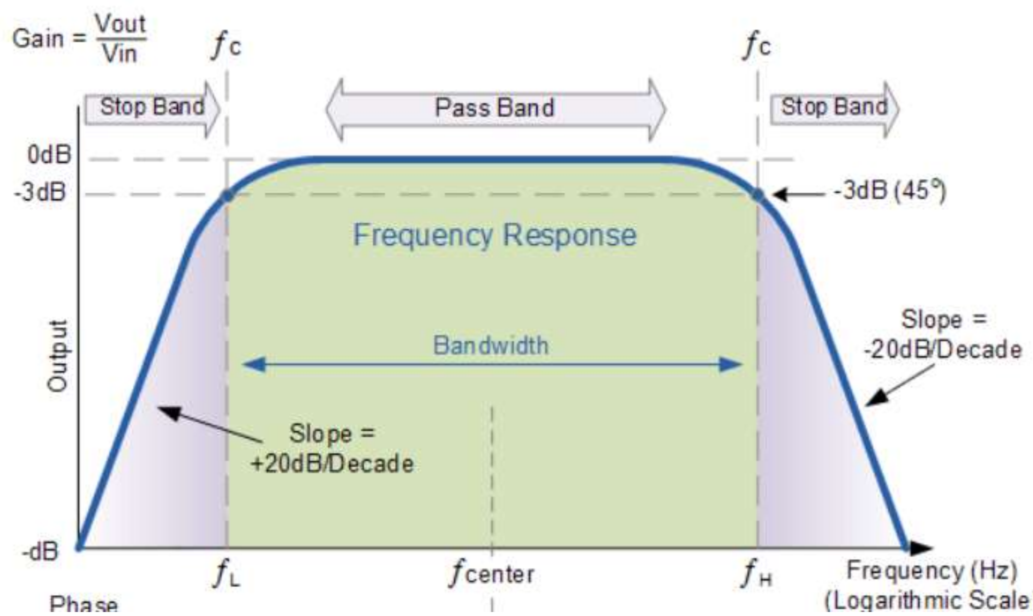

Fig.11 – Band Pass Filter

The bandpass filter will eliminate noise based on values obtained through the center frequency found from the oscillator and by choosing a capacitor value within the band pass filter. The transfer function of the bandpass filter is by the following

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

The value of K will remain constant of 1 while the value of B is the bandwidth from the center frequency is rad/s. with the value of K, B, center frequency, and capacitor value, the three resistor values can be found by the following 3 equations

$$R_1 = Q/K$$

$$R_2 = Q/(2Q^2 - K)$$

$R_3 = 2Q$

Results and Analysis:

The simulation in PSPICE for the oscillator was designed by choosing a specific gain of 3.13V/V. These resistor values where R_1 = 22k, and R_2 = 47k. The chosen capacitor value is 470nF which was used to find the value of R to get a center frequency of 55k. The desired result ended in a R value of 470Ω. The PSPICE circuit for the oscillator is shown in Fig.12

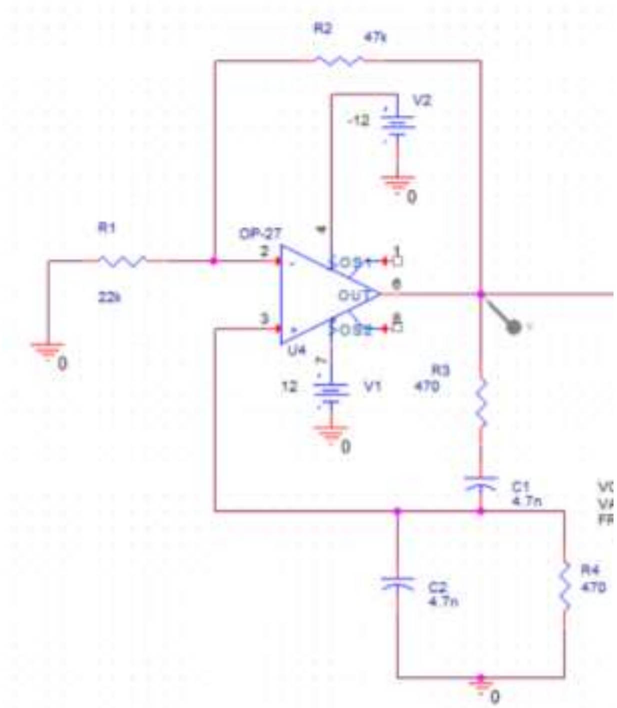

Fig.12 – PSPICE oscillator circuit

The output voltage is measured after the feedback resistor just before entering the mixer. There is no AC or DC signal sourcing the circuit as the oscillator will create a clock frequency based on the circuit itself. When simulated, the output signal is shown inFig.13

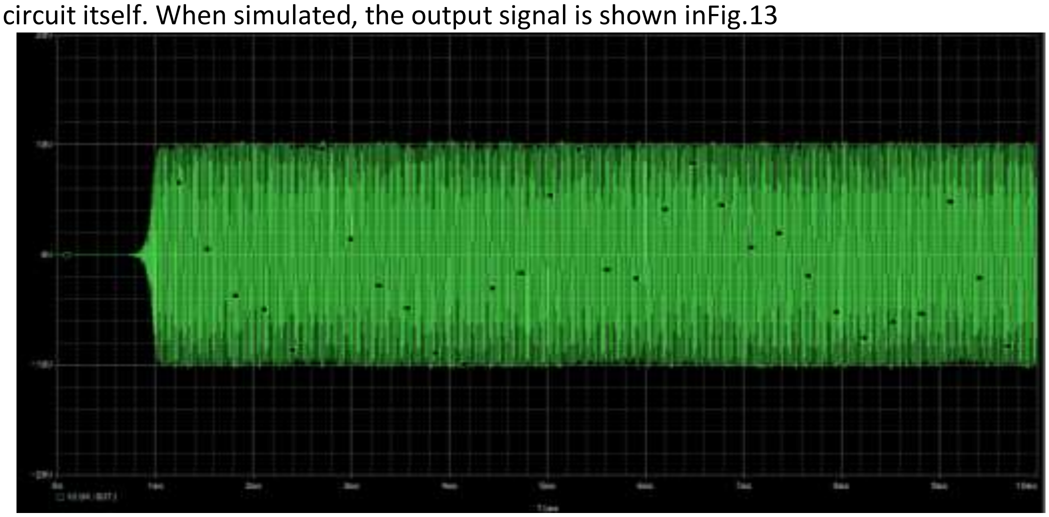

Fig.13 – Oscillator output signal

The simulated oscillator matches how the oscillator is supposed to work by generating a steady signal. The oscillator worked on the first values tried within the oscillator. The center frequency from this signal is shown in Fig.14

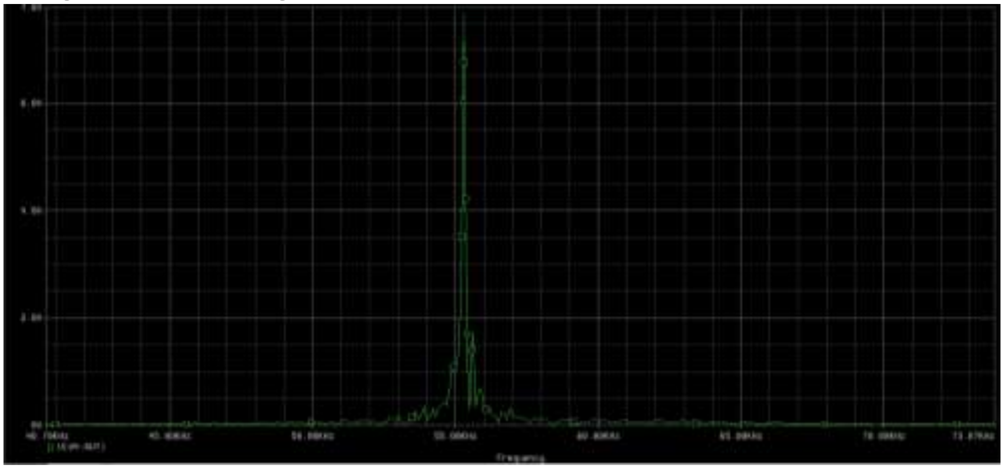

Fig.14 – Center frequency

The center frequency is seen at around 55.2kHz which is in the range of 50k-60kHz. The values of the capacitor and resistors meet the design specification for the Wien bridge oscillator as the gain is between 2 and 5, and the center frequency is at about 55k.

The mixer is designed with R_1 = 20k, R_R = 10k, R_L =1000 and R_2 = 4700. The simulated circuit is shown in Fig.15

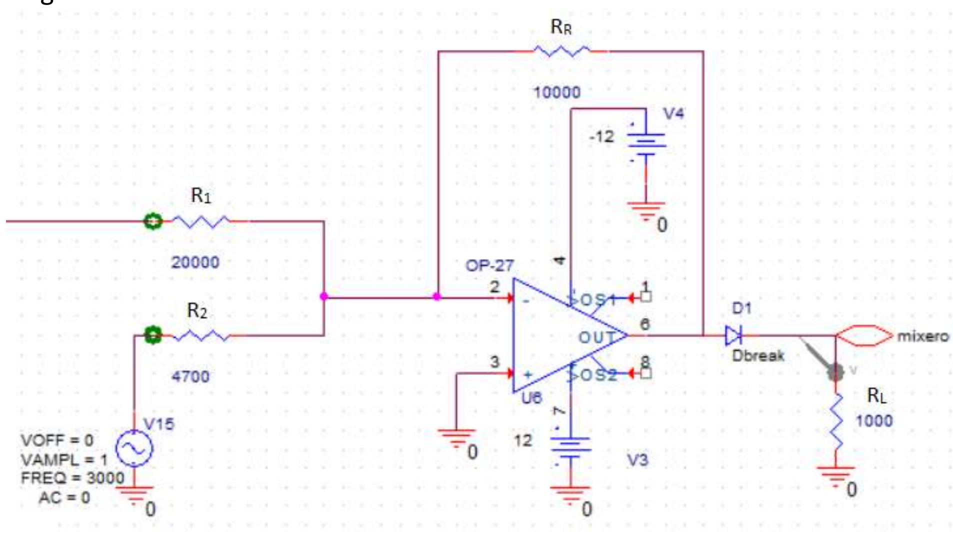

Fig.15 – PSPICE mixer circuit

From Fig.15 the op amp must be powered with +12V and -12V. The circuit is implemented where the input signal is at an amplitude of 1V and a frequency of both 300Hz and 3000Hz. The output signal for both frequencies is shown in Fig.16ab and Fig.17

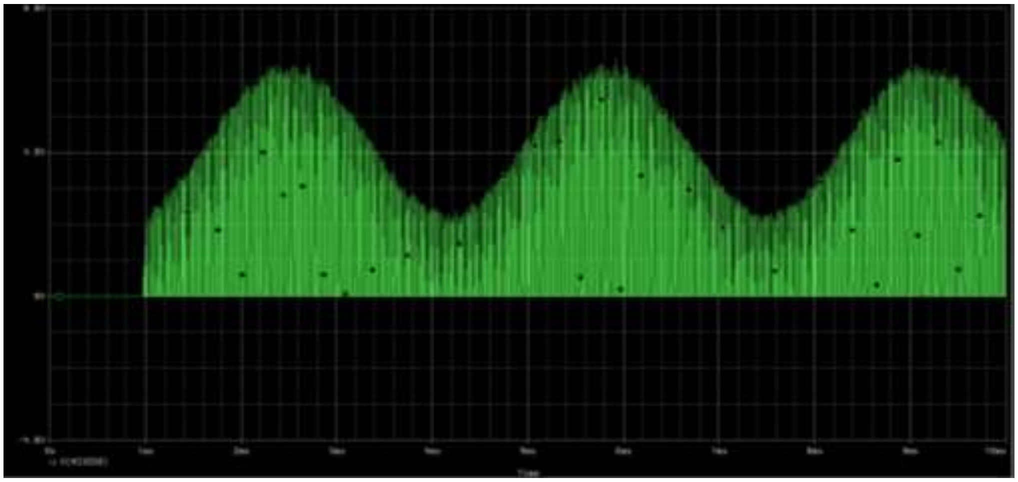

Fig.16a – Mixer output with 300Hz input frequency

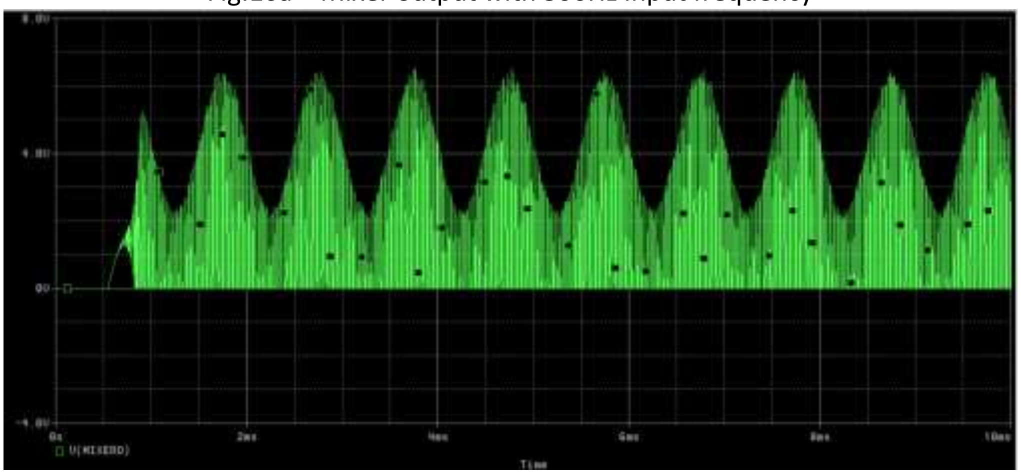

Fig.16b – Mixer output with 1000Hz input frequency

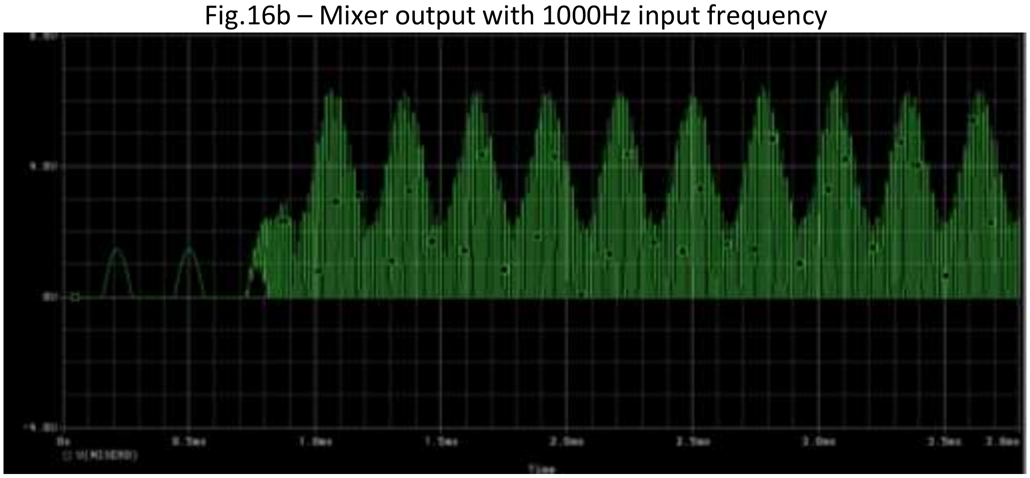

Fig. 17 – Mixer output with 3500Hz input frequency

From both figures of the output signal, the diode removes the lower half of the signal leaving the positive signal only. The mixer does meet the design requirements as at the minimum and maximum frequencies, the signal is an AM modulation signal. The enveloping can be seen at each peak's amplitude bounded by the modulating signal which also matches the functionality of the mixer.

The band pass filter is designed within MATLAB where the values are calculated for R_1, R_2, and R_3 with a set center frequency, bandwidth, K value, and chosen capacitor value. The capacitor value selected is a 1nF capacitor, a bandwidth of 18849rad/s, a cutoff frequency of 345575rad/s, and a K value of 1. From MATLAB the transfer function obtain is

$$\frac{-3.77e04}{s^2 + 3.77e04\ s + 1.194e11}$$

The Resistor values obtained are R_1 = 27k, R_2 = 51k, and R_3 = 158. The simulated band pass filter is shown in Fig.18

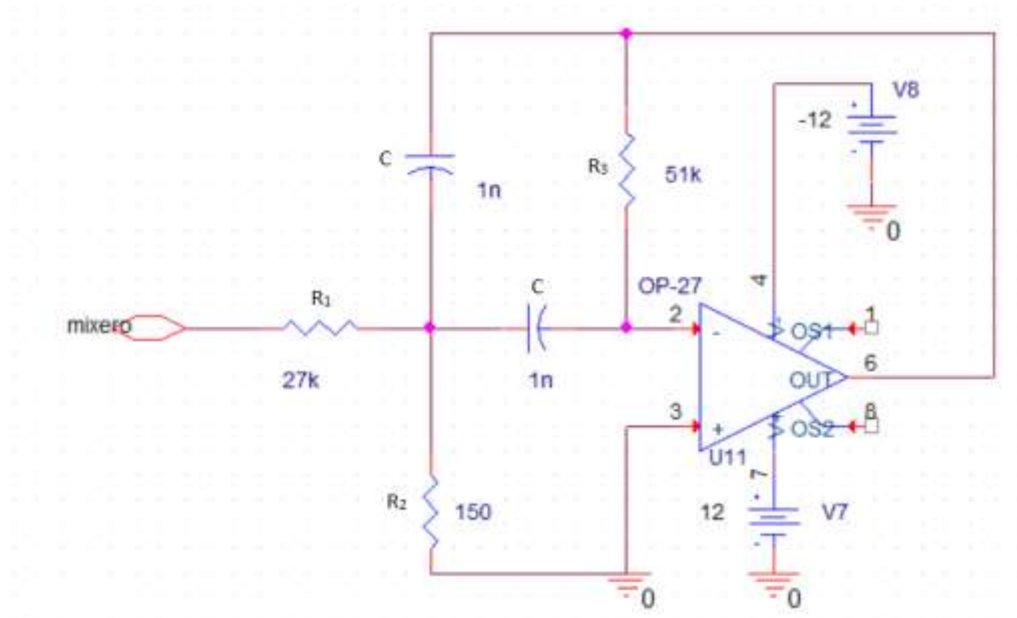

Fig.18 – PSPICE band pass filter circuit

The resulting output for the band pass filter is simulated and shown in Fig.19abc

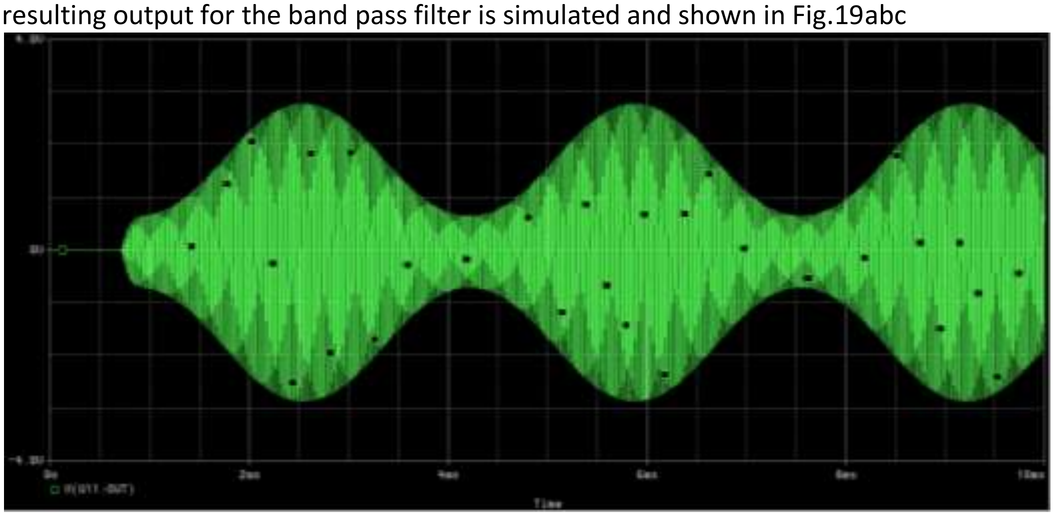

Fig.19a – Simulated Band pass filter output at 300Hz

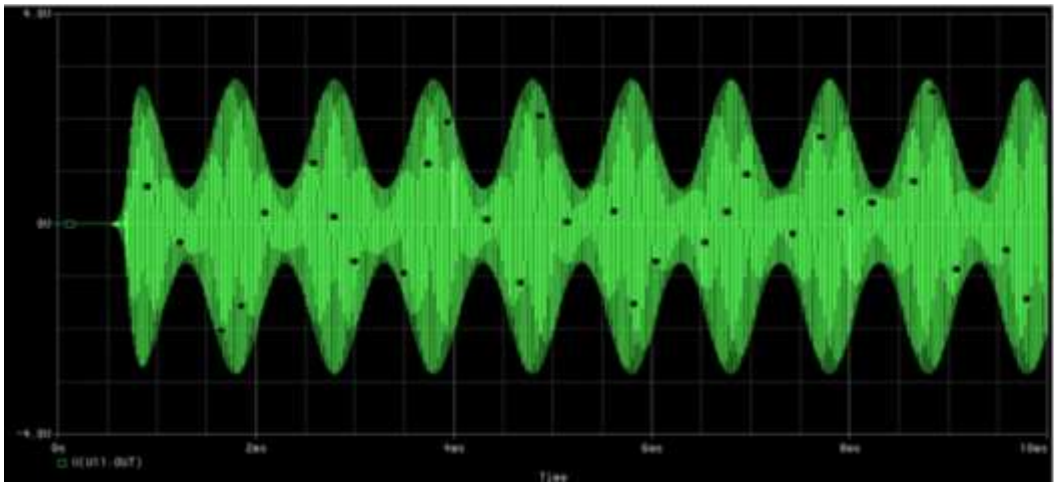

Fig.19b – Simulated Band pass filter output at 1000Hz

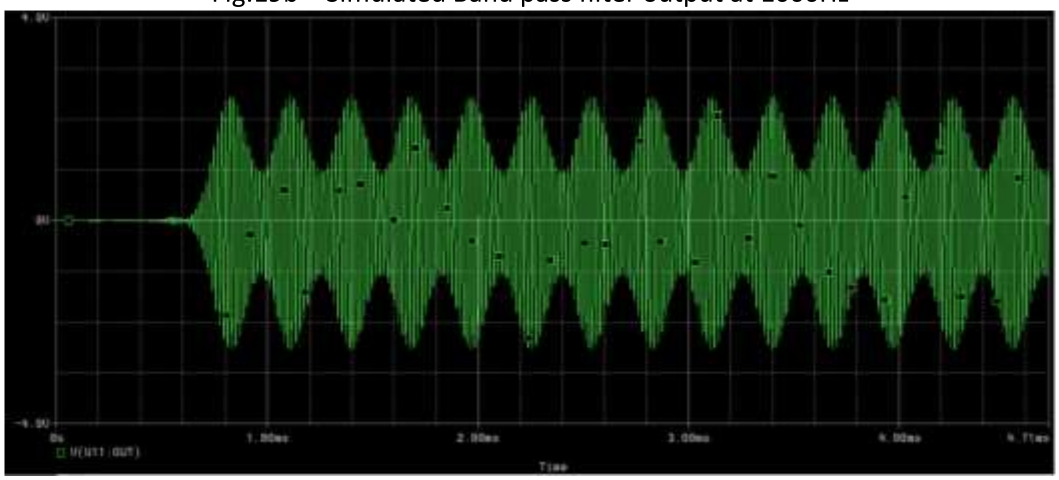

Fig.19c – Simulated Band pass filter output at 3500Hz

Fig.19 shows that the AM modulation signal looks much clearer than the output of the mixer. The band pass filter meets the requirements of filtering out signals outside of the bandwidth as the simulation shows a smooth modulating signal at both the negative and positive peaks. The signals amplitude is at a relatively low amplitude shown in Fig.19 with a 3.7 zero to peak amplitude. The design requirements must be within a range of 5 – 8V zero to peak. A power amplifier is used to achieve this where the gain of the power amplifier is relative to the amplitude needed for the circuit.

Methodology:

1- Design Wien Bridge oscillator
2- Adjust oscillator until center frequency is between 50k-60kHz
3- Design the mixer to combine the clock signal and the modulation signal
4- Design the band pass filter to filter out frequencies outside the bandwidth

Conclusions

The AM radios transmitter was simulated successfully and each of the components met the requirements. The Wien bridge oscillator generates a clock frequency while the mixer takes the input signal and clock frequency and combines them in one AM modulating signal. The bandpass filter filters the frequencies outside of the bandwidth of frequencies while the power amplifier amplifies the signals amplitude.

Part 2: Receiver

Introduction:

A receiver in an AM radio consists of several circuits that will take the transmitters input signals and output them through a radio at specific frequencies based on capacitor and resistor values used in the Wien Bridge Oscillator. The receiver is made up of a peak detector which takes the enveloping signals peak amplitude, a low pass filter and a high pass filter combined into a bandpass filter to filter out noise, a Schmidt trigger which is a positive feedback to the noninverting input of a differential amplifier, and the speaker which takes the signal and outputs a sound signal through the speaker.

Theory:

A peak detector is a series connection of a diode and a capacitor outputting a DC voltage relative to its peak amplitude of the AC signal. The peak detectors peak is measured at every peak from the enveloping signal shown in Fig.1

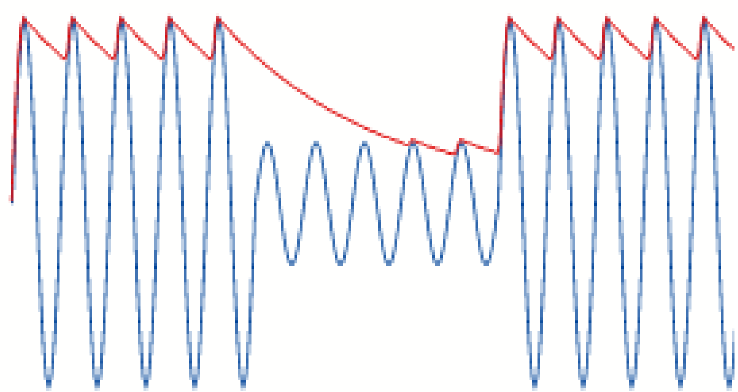

Fig.1 – Peak Detector Signal

After every peak, the peak measurement begins to discharge due to the RC time constant until the discharge signal reached the next AM signal. A diode is used in the peak detector to take positive half cycles when charging the capacitor to the peak amplitude. The peak detector works when the input wave falls below the peak amplitude stored in the capacitor, the diode is reversed biased which doesn't allow current in the opposite direction back to the source. This allows the capacitor to store the peak amplitude as the AM signal moves to zero. The second circuit used is the first order low pass filter cascaded with a first order high pass filter acting as a bandpass filter. In the AM radio the low pass filters resistor values $R_1 = R_2$. The low pass filter has a frequency response shown in Fig.3

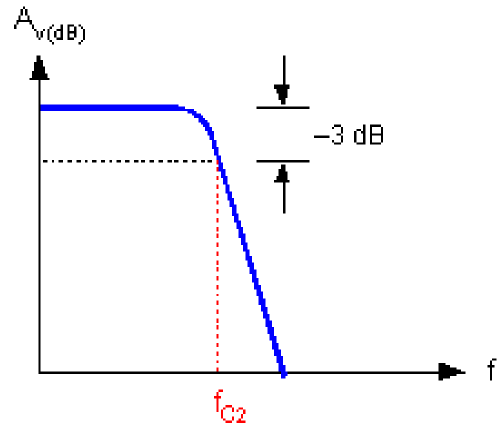

Fig.3 – frequency response of low pass filter

The frequency response shows at low frequencies the signal is passed high. At higher frequencies the signal is not passed. The high pass filter in the bandpass filter has a frequency response shown in Fig.4

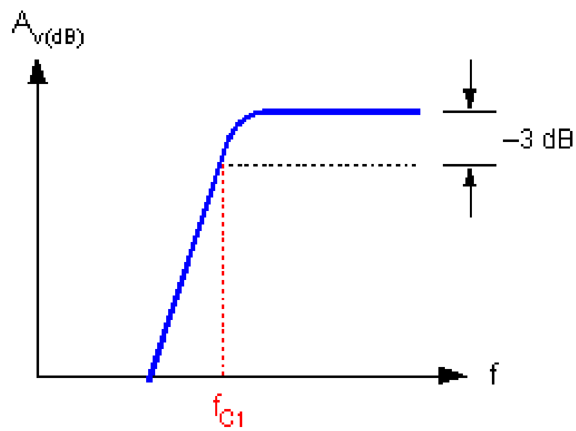

Fig.4 – frequency response of high pass filter

The frequency response of the high pass filter passes higher frequencies while at lower frequencies do not pass the signal. The low pass filter is cascaded with the high pass filter creating a second order bandpass filter shown in Fig.5

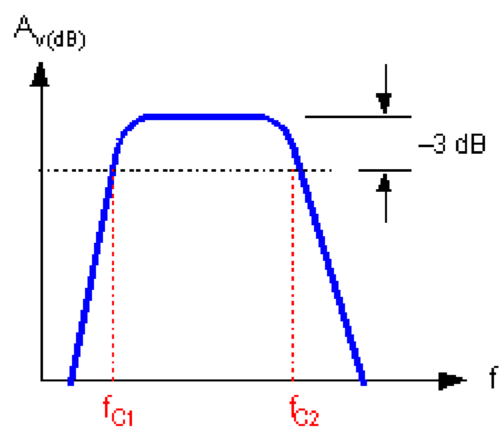

Fig.5 – frequency response of bandpass filter

The bandpass filter creates a frequency response that passes a signal within a bandwidth of frequencies while rejecting frequencies outside of the bandwidth. A Schmitt Trigger is used by switching the output negative when the input passes upward through a positive voltage. Then the Schmitt Trigger used the positive feedback of the negative voltage to prevent flipping the voltages state. The Schmitt Triggers output is shown in Fig.6

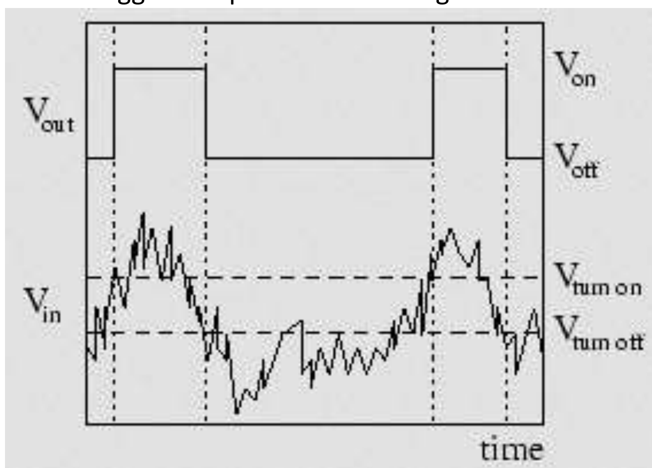

Fig.6 – Schmitt Trigger

The Schmitt Trigger can be seen that at every higher amplitude greater than half of the enveloping signal the square wave is a positive rising edge until the peak's amplitude reaches below half the enveloping signal. The final circuit is the buzzer circuit which is a nmos transistor with a voltage inputted through the drain and the speaker at the emitter. The AM signal flows through the base which allows the signal to flow to the emitter creating a buzzer noise at a specific bandwidth based on design. The block diagram for the receiver is shown in Fig.7

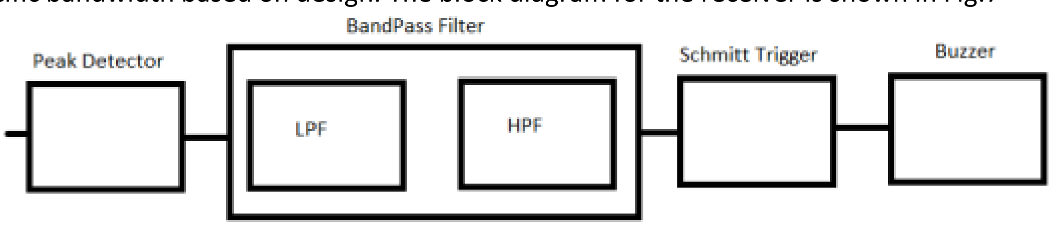

Fig.7 – Block Diagram for Receiver

Results and Analysis:

The peak detector was designed as a circuit and not through PSPICE with the circuit shown in Fig.8

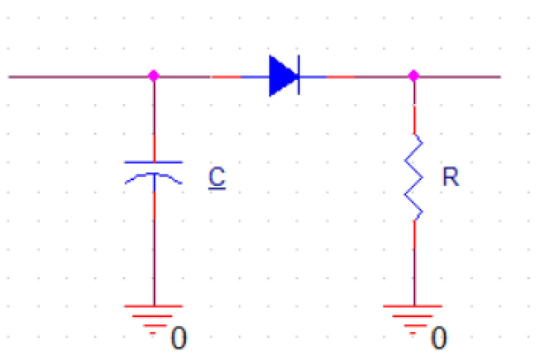

Fig.8 – Peak Detector

The peak detector was tested by selecting a specific capacitor value at 77nF. The RC time constant was used to find the value of the resistor. The resistor value used was at 350Ω and discharged the capacitor too fast before reaching the next enveloping signal. The resistor was changed to 1000Ω and tested. The results of the peak detector are shown in Fig.9 and Fig.10 at 300Hz and 3000Hz

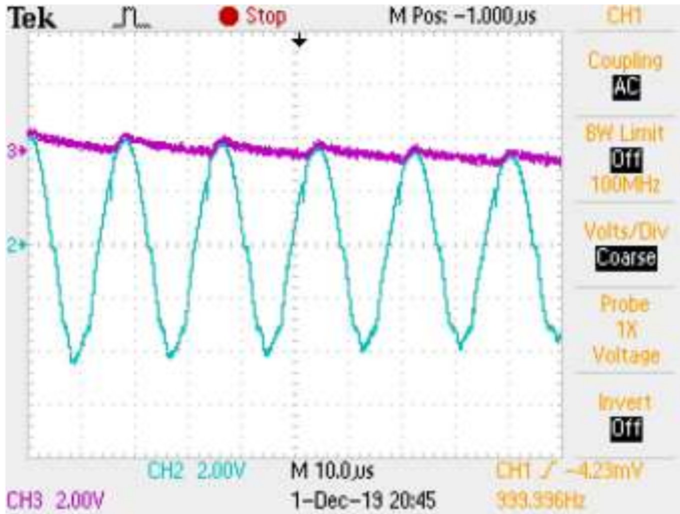

Fig.9 – Peak detector signal at 300Hz

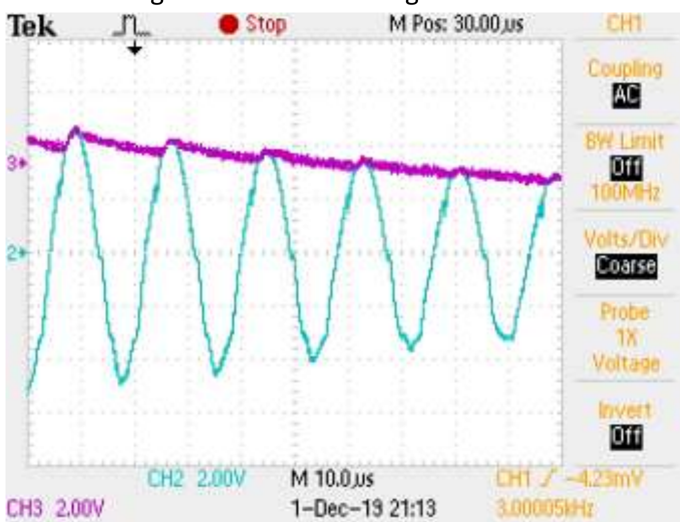

Fig.10 – Peal detector signal at 3000Hz

At 300Hz the peak detector can be seen the signal discharged faster than the 3000Hz signal as the 3000Hz signal appears almost at the capacitor does not discharge. The peak detectors are shown zoomed out to view the full enveloping signal with the peak detector shown In Fig.11 and Fig.12

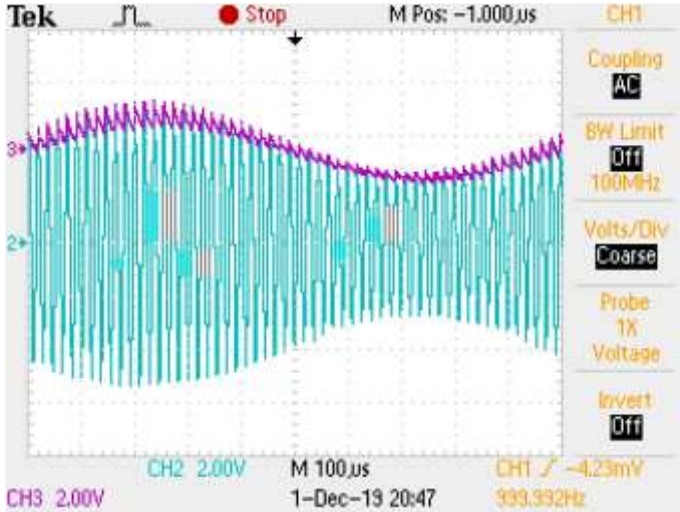

Fig.11 – Peak detector signal zoomed out at 300Hz

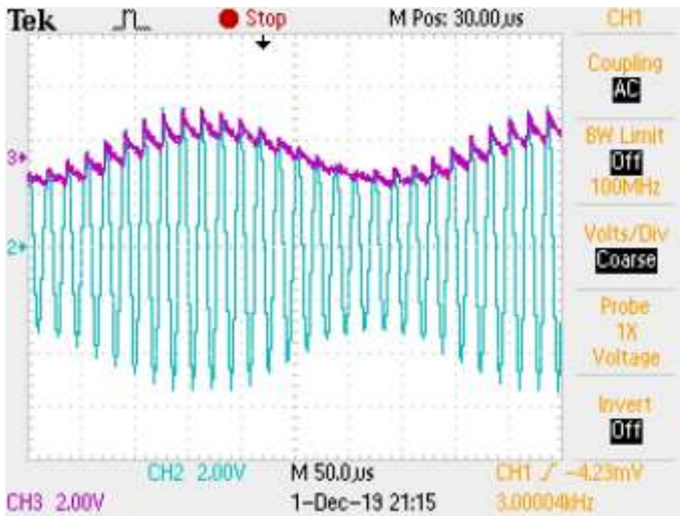

Fig.12 – Peak detector signal zoomed out at 3000Hz

The low pass filter within the bandpass filter circuit is shown in Fig.13

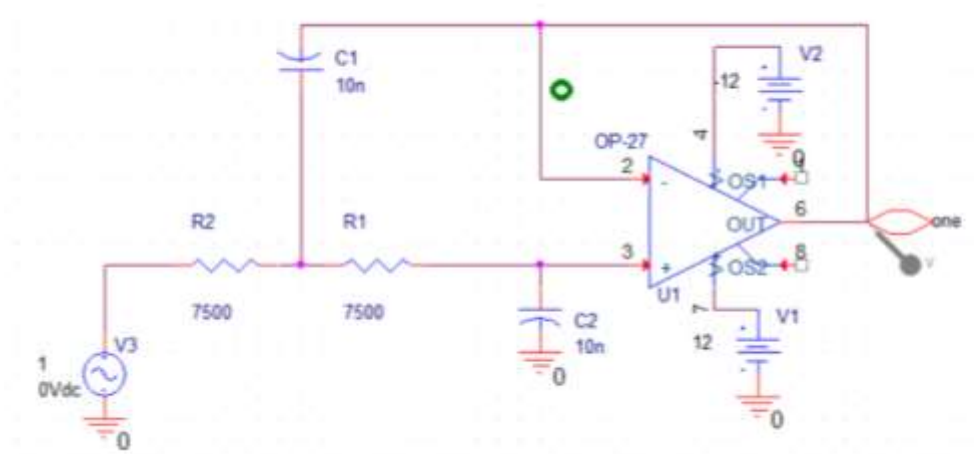

Fig.13 – Low Pass filter circuit from Bandpass filter

The lowpass filter was simulated in PSPICE in order to have a cutoff frequency at 300Hz. The PSPICE simulation is shown in Fig.14

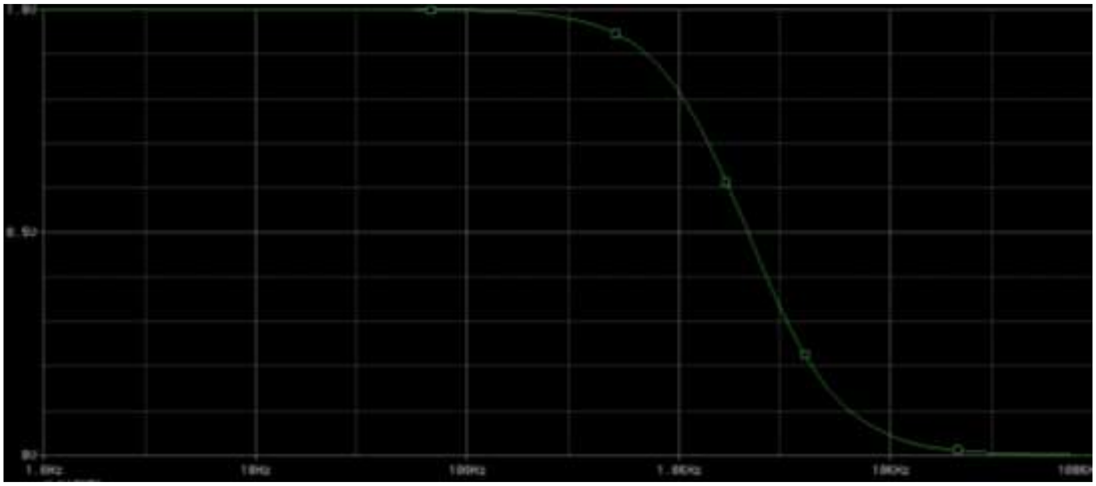

Fig.14 – PSPICE low pass filter simulation

The low pass filter has values shown in Fig.13 with the capacitor values $C_1 = C_2 = 10nF$, and the resistor values $R_1 = R_2 = 7500$. The frequency response of the low pass filter was tested in order to show the cutoff frequency is at 300Hz and 3000Hz shown in Fig.15 and Fig.16

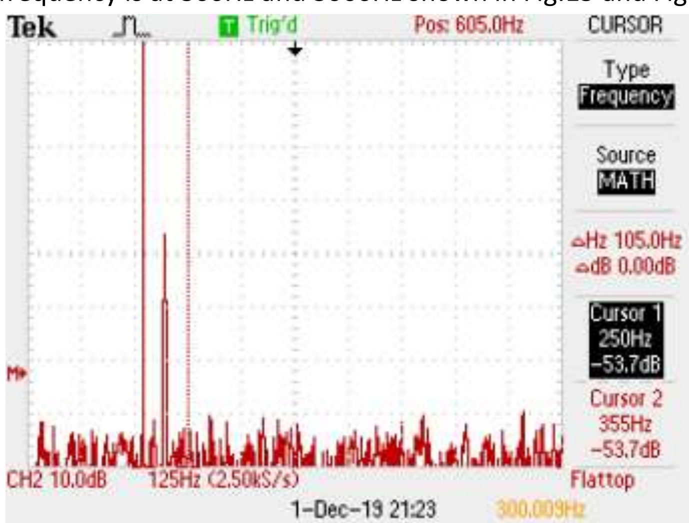

Fig.15 – frequency response of LPF at 300Hz

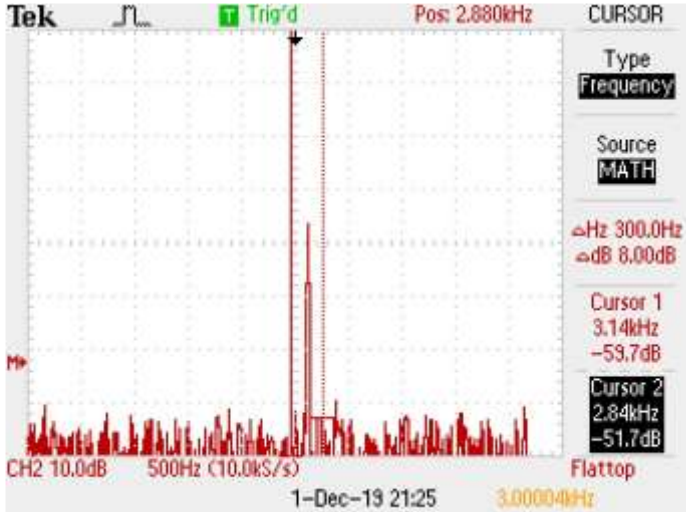

Fig.16 – Frequency response of LPF at 3000Hz

The frequency response for the low pass filter can be seen at both 300Hz and 3000Hz. The high pass filter used within the bandpass filter is shown in Fig.17

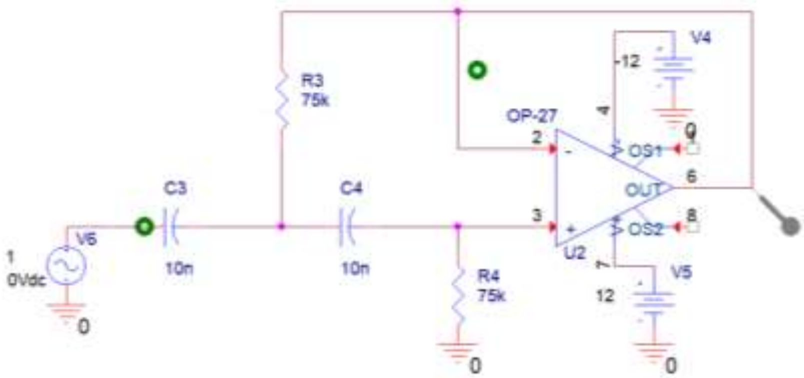

Fig.17 – High pass filter circuit within Bandpass filter

The values used in the high pass filter result in a cutoff frequency at 3000Hz. The capacitor values shown in Fig.17 $C_3 = C_4 = 10nF$, and the resistor values $R_3 = R_4 = 75k$. The high pass filter is simulated in PSPICE shown in Fig.18

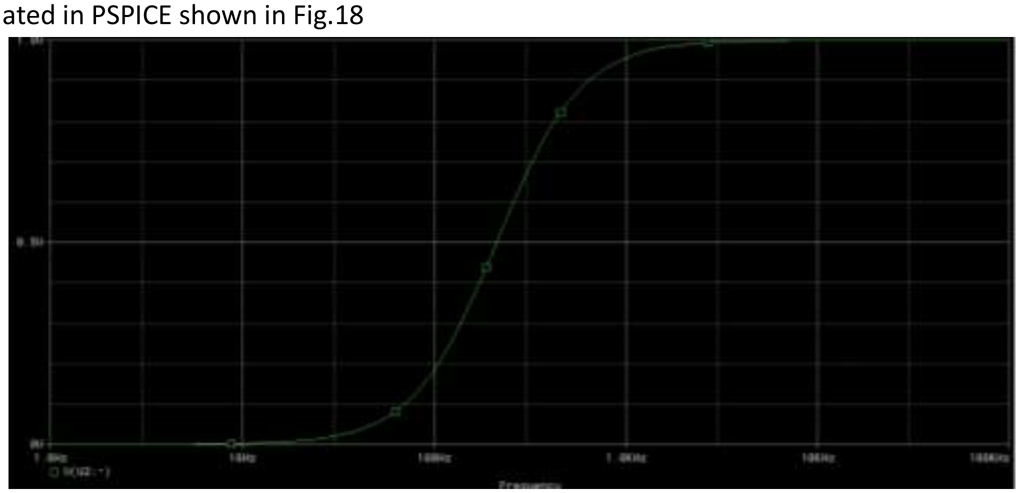

Fig.18 – PSPICE simulation of HPF

The PSPICE simulation can be seen that the cutoff frequency is at 3000Hz and does not pass low frequencies. The frequency response of the high pass filter is obtained at both 300Hz and 3000Hz shown in Fig.19 and Fig.20

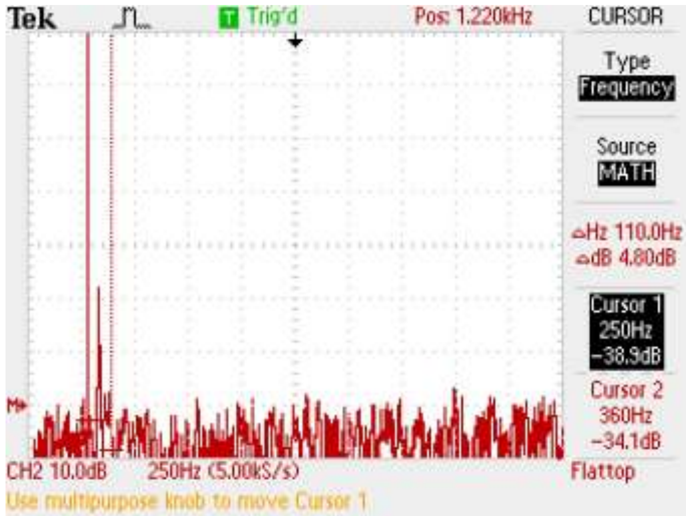

Fig.19 – Frequency response of HPF at 300Hz

Fig.20 – Frequency Response of HPF at 3000Hz

Both the signals at 300Hz and 3000Hz can be seen within the high pass filter. The result of the lowpass filter and the high pass filter creates a second order bandpass filter with the frequency response of the bandpass filter at 300Hz and 3000Hz shown in Fig.21 and Fig.22

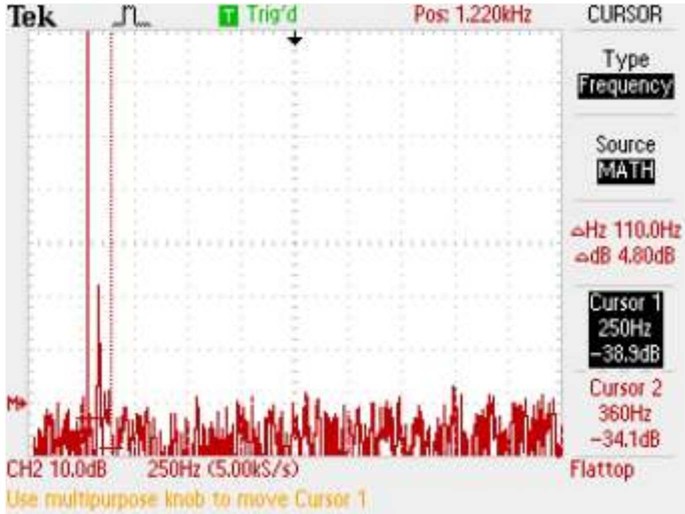

Fig.21 – Frequency Response of BPF at 300Hz

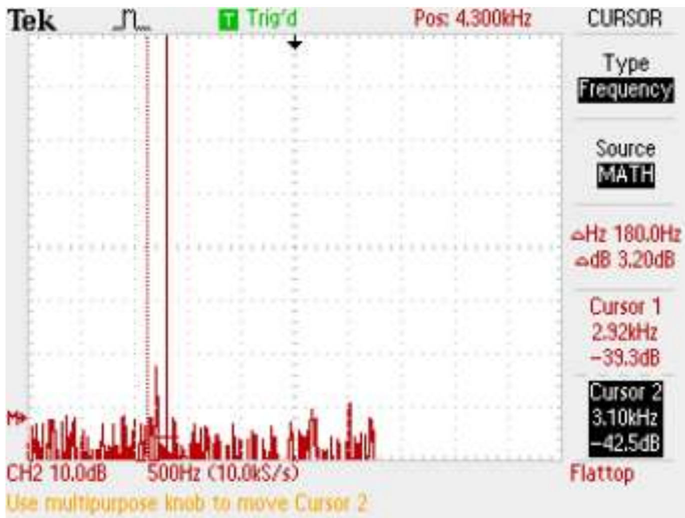

Fig.22 – Frequency Response of BPF at 3000Hz

The Bode of the bandpass filter was measured from an order magnitude under 300Hz and an order magnitude over 3000Hz. The bandpass filter is simulated in PSPICE shown in Fig.23

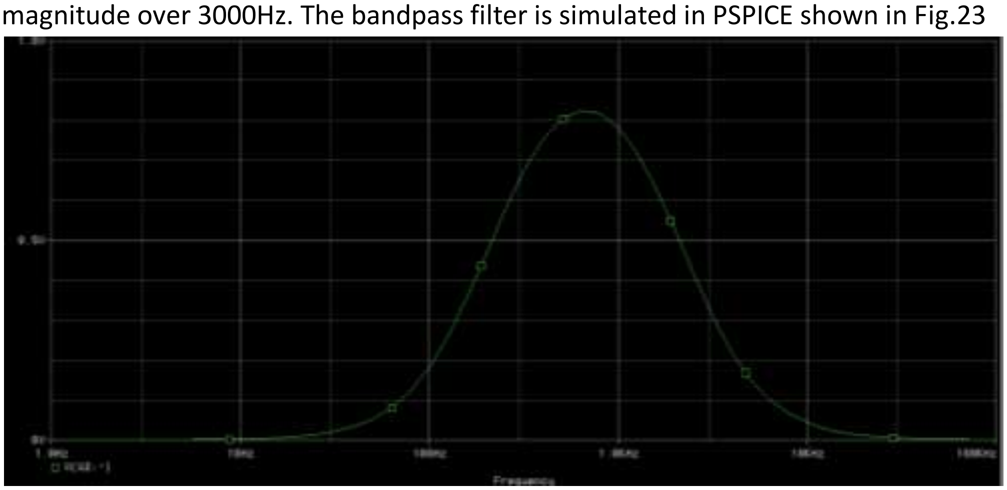

Fig.23 – Bode of Bandpass filter

The bode of the bandpass has a range of frequencies between 300Hz and 3000Hz. The bode of the bandpass filter tested in the circuit is shown in Fig.24

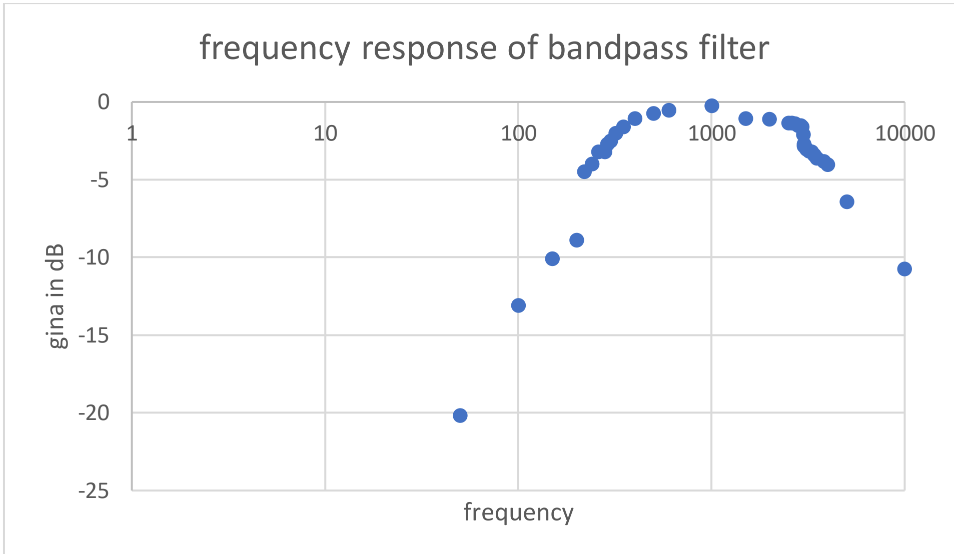

Fig.24 – Bode of Bandpass Filter

The frequency response matches the simulation as the range of frequencies both are between 300Hz and 3000Hz. The Schmitt Trigger circuit is shown in Fig.25

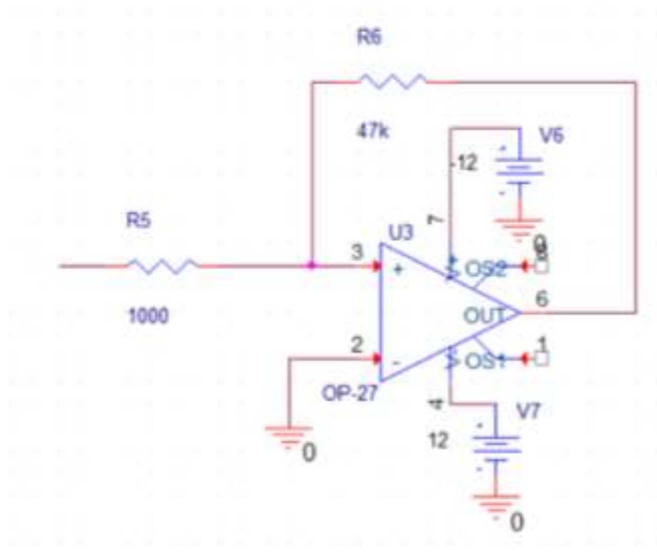

Fig.25 – Schmitt Trigger circuit

The Schmitt Trigger is designed so the gain is around 50V/V where R_5 = 1000 and R_6 = 47k which results in a gain of 48V/V. The gain is set at 48 so the amplitude of the circuit is between 10-16V peak to peak. The Schmitt Trigger is tested at 300Hz and 3000Hz in Fig.26 and Fig.27

Fig.26 – Schmitt Trigger at 300Hz

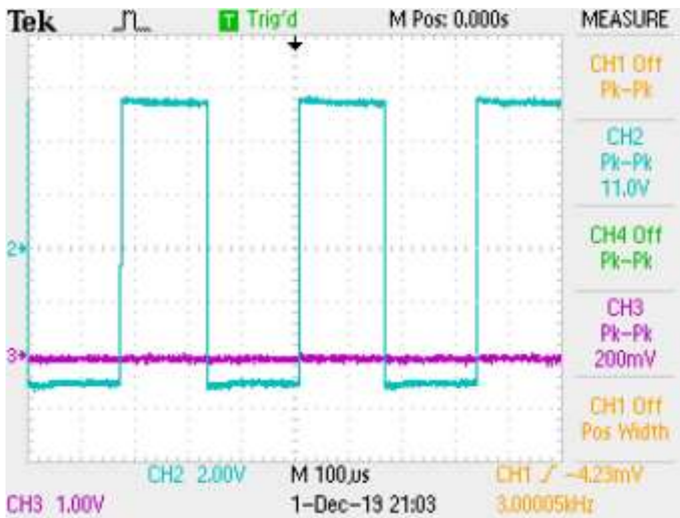

Fig.27 – Schmitt Trigger at 3000Hz

The amplitude in Fig.26 and Fig.27 both between 10-16V peak to peak at around 11V. The buzzer is tested at both 300Hz and 3000Hz shown in Fig.28 and Fig.29

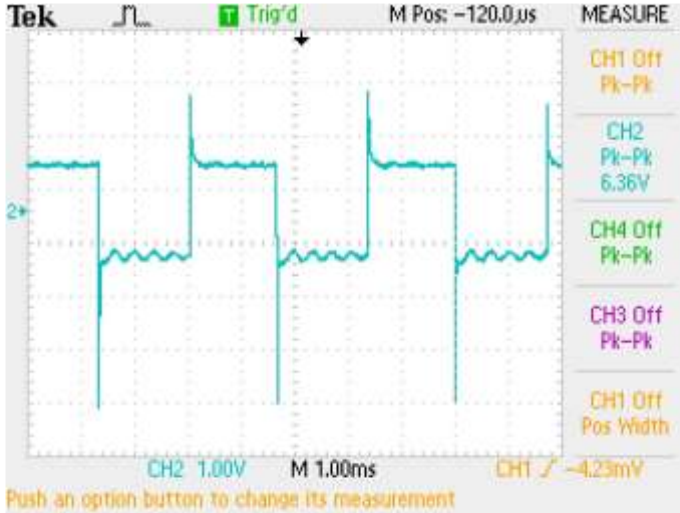

Fig.28 – Speaker output at 300Hz

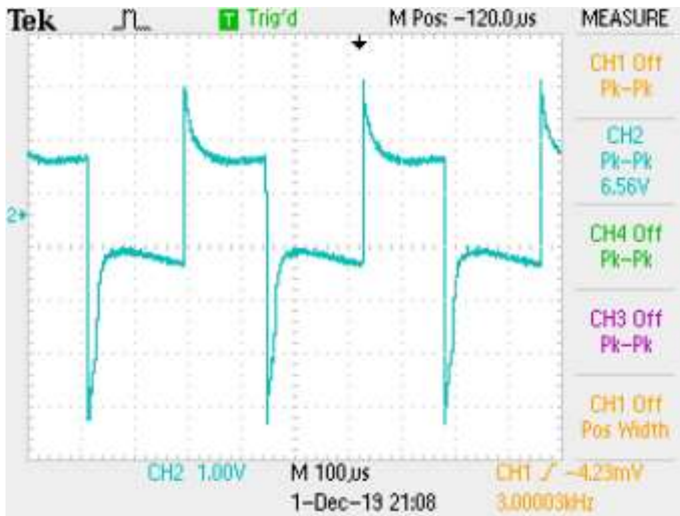

Fig.29 – Speaker output at 3000Hz

The output at the speaker results in a buzzing noise at a range of 300Hz to 3000Hz and rejects frequencies outside of that range.

Methodology:

1- Design Peak Detector by using RC time constant
2- Design a second order bandpass filter by designing a low pass filter cascaded with a high pass filter
3- Design a Schmitt Trigger that will turn the AC sin signal into an AC square signal
4- Design the buzzer by using a nmos transistor and applying a DC source at the drain

Conclusion:

The Transmitter received the enveloping signal and the peak of each sin wave was measured through the peak detector. The bandpass filter filtered out noise from a range of 300Hz to 3000Hz while the Schmitt Trigger took the sin wave and created a square wave and amplified to 11V peak to peak. The Buzzer output a buzzing noise within the range of frequencies and rejected the signal once the input sin wave was outside of the range of frequencies. The AM radio met the design requirements for each single component, as the center frequency of the oscillator was at 55kHz and the input signal was filtered and outputted between 300Hz and 3000Hz.

References

1- https://www.analog.com/media/en/training-seminars/design-handbooks/Basic-Linear-Design/Chapter8.pdf
2- https://www.electronics-tutorials.ws/filter/filter_4.html
3- https://www.electronics-notes.com/articles/analogue_circuits/operational-amplifier-op-amp/wien-bridge-sine-wave-oscillator-generator.php
4- https://www.allaboutcircuits.com/textbook/radio-frequency-analysis-design/radio-frequency-modulation/phase-modulation-theory-time-domain-frequency-domain/
5- http://hyperphysics.phy-astr.gsu.edu/hbase/Electronic/schmitt.html

AM Project Check List PSPICE Simulation for Interim Report

Name: Nicholas Keister

Partners :____________________

Partner :____________________

1- AG ___ Oscillator Circuit
2- ______ AM Modulator (Mixer)
3- ______ Bandpass Filter
4- ______ Power Amplifier

Each group needs to show progress demo by checking each module.

Items 1-4 are need to be checked by October 11, 2019. This will give you a jump start to finish the project on time and without affecting your study time in other courses.

AM Project Check List for implementing each circuit.

Name:________________________
Partners 1:______________________
Partner 2:_______________________

1- AG Oscillator Circuit
2- AG AM Modulator (Mixer)
3- AG Bandpass Filter
4- AG Power Amplifier
5- ________ Envelop Detector (Peak Detector)
6- ________ Baseband bandpass filter
7- ________ Audio amplifier (comparator & Buffer Amplifier)
8- ________ Speaker Sound (Buzzer)

Each group needs to show progress demo by checking each module.

Items 1-4 are need to be checked by November 1 2019. This will give you a jump start to finish the project on time and without affecting your study time in other courses.