Washington State University

School of Electrical Engineering and Computer Science

EE352 Electrical Engineering Laboratory

Final Project Report

AM Radio

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Due Date: 04/30/2021

Abstract

In this project, an AM radio was designed and simulated in LTSPICE. This radio was designed to modulate, transmit, and demodulate a single-tone AM-Modulated signal for all single tone frequencies between 350 Hz and 3.5 kHz. The transmitter consisted of the Wien Oscillator, a switching modulator, a high band pass filter and a power amplifier. Next, the receiver was designed, which consisted of a peak detector, lowpass butterworth filter, a high pass butterworth filter, a comparator, and a buffer amplifier. Every component of this was simulated individually in LTSPICE with a message signal of 350 Hz then with 3.5 kHz. Finally, the R and C values of every circuit were calculated or chosen to produce a voltage signal of 3.73 V when the message signal was either 350 Hz or 3.5 kHz, with the final frequency being the same. Overall, this project was successful in meeting all requirements for both the individual circuits and when combined.

1.0 Introduction:

The overall project was to design, construct and demonstrate an AM radio using LTSPICE that is capable of modulating, transmitting, and demodulating a single tone AM-modulated signal s(t) for all single tone frequencies between 350 Hz and 3500 Hz. The received and demodulated single tone sine “message” signal m(t) is displayed without distortion on the digital oscilloscopes and have clear audible when played on the speaker. Another piece of the project was to analyze the AM transmitter and receiver, test the overall deployed system, and compare analytical results with material test data. For the interim report, the pieces designed and tested were the signal generator, the switching modulator, the oscillator, and the high band pass filter 1 shown in Fig. 1 below.

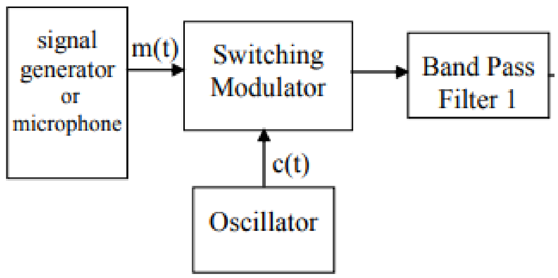
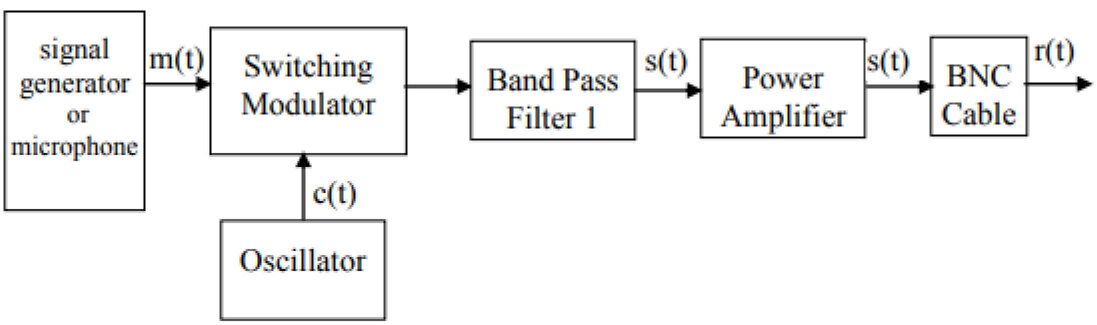
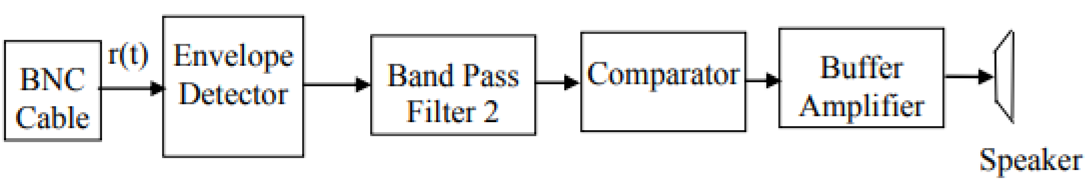


Figure 1: 1st 3 Circuit blocks designed for the AM transmitter.

Fig. 2 shows the rest of the general circuit designed that was then created in the final project.



(a) Block diagram of a suggested design for the AM transmitter.



(b) Block diagram of a suggested design for the AM receiver.

Figure 2.

AM modulation is defined as a process in which the amplitude of the carrier wave is varied about a mean value. This is shown linearly with the baseband signal m(t), while the carrier wave is expressed as c(t). The amplitude modulation is the oldest method of the performing modulation, and it is accomplished rather simply in the transmitter using a switching modulator. The net result is that an amplitude modulating system is relatively cheap to build but the transmission of its carrier wave represents a waste of power. This means that only a fraction of the total transmitted power is affected by m(t). Equation (1) below shows the sinusoidal carrier wave equation where A_c is the carrier amplitude and f_c is the carrier frequency. The assumption made for this expression is that the phase of the carrier wave is zero so that the exposition is simplified without effecting the results obtained. The source carrier wave c(t) is physically independent of the source responsible for generating m(t) and is produced by an oscillator.

$$c(t) = A_c \cos(2\pi f_c t) \qquad (1)$$

Equation (2) below shows the amplitude-modulated wave in its general form as a function of time. The baseband signal that carried the specification of the message is denoted by m(t). k_a is the constant representing the amplitude sensitivity of the modulator responsible for the generation of the modulated signal s(t). The carrier amplitude and the message signal are typically measured in volts, so the amplitude sensitivity is measured in inverse volts.

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

Fig. 3 below shows the amplitude modulation process, (a) being the baseband signal m(t), (b) showing the corresponding AM wave s(t) for when $k_a m(t) < 1$ for all t, and (c) is the AM wave for when $|k_a m(t)| > 1$ for some t. The A_c is equal to 1 V. By observation, s(t), the envelope has almost the same shape as m(t) provided that the amplitude of $k_a m(t)$ is always less than the unity, and that the carrier frequency is much greater than the highest frequency component W of the message signal m(t).

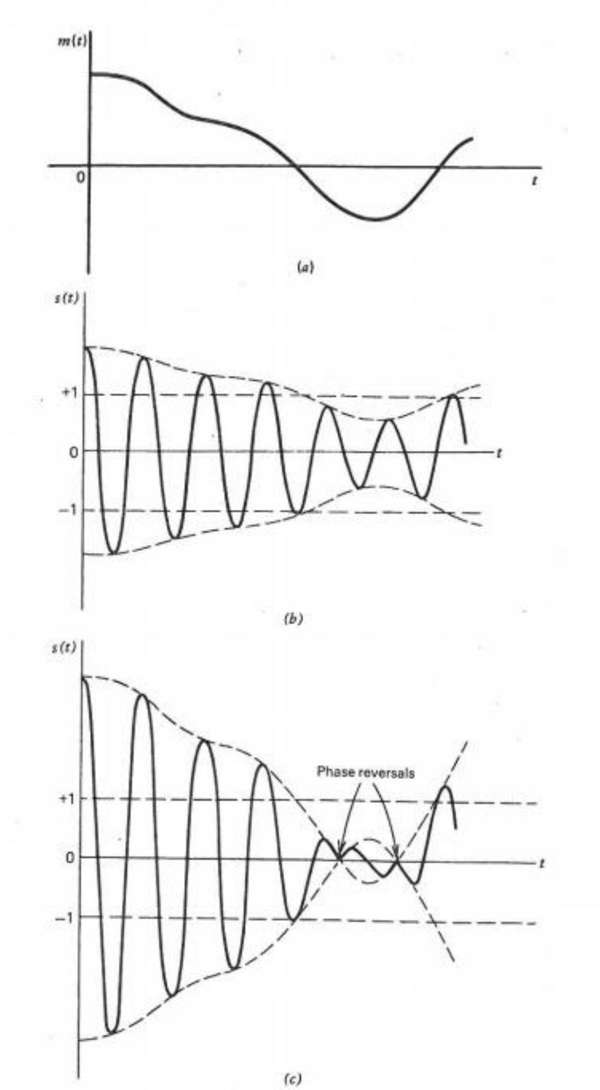


Figure 3: illustrating the amplitude modulation process (a) Baseband signal m(t). (b) AM wave for $k_a m(t) < 1$ for all t. (c) is the AM wave for when $|k_a m(t)| > 1$ for some t.

When $k_a m(t) < 1$ is met then 1+$k_a m(t)$ is always positive, causing the envelope to be a positive function. When $|k_a m(t)| > 1$, this means the amplitude sensitivity is large enough to also cause the carrier wave to be over modulated resulting in carrier phase reversals whenever the factor 1+$k_a m(t)$ crosses zero. This kind of modulated wave exhibits distortion as shown in Fig. 3c.

Now addressing the carrier frequency being much greater than the highest frequency component W, it is important to note that if this is not satisfied, an envelope cannot be visualized satisfactorily. If the baseband signal m(t) is band-limited to the interval $-W \leq f \leq W$ then as aresult of the modulation process, the spectrum of the message signal for negative frequencies extending from -W to 0 become completely visible for positive frequencies provided that $f_c > W$. For the positive frequencies within the spectrum of the AM wave, a portion that lies above the carrier frequency is the upper sideband. The portion below is the lower sideband. For negative frequencies, the upper sideband is labeled as the portion below the negative carrier frequency and the lower sideband is the portion above. For the positive frequencies, the highest frequency component of the AM wave equals $f_c + W$ while the lowest is $f_c - W$. The difference between these two is defined as the transmission bandwidth B_T for an AM wave, which is 2W exactly.

For a single tone modulation, Fig. 4 below illustrates the time-domain and the frequency-domain characteristics of standard amplitude modulation produced, these being the modulating wave, the carrier wave, and the AM wave. Equation (3) below shows the resulting expression for a modulating wave that consists of a single tone or frequency component, or signal generator. For this expression, A_m is the amplitude of the sinusoidal modulating wave and f_m is its frequency. The corresponding AM wave is therefore given as equation (4) below. This is where the dimensionless constant μ is the modulation factor. The modulation factor must be under unity otherwise envelope distortion due to overmodulation occurs. Part c of Fig. 4 shows when the modulation factor is less than unity.

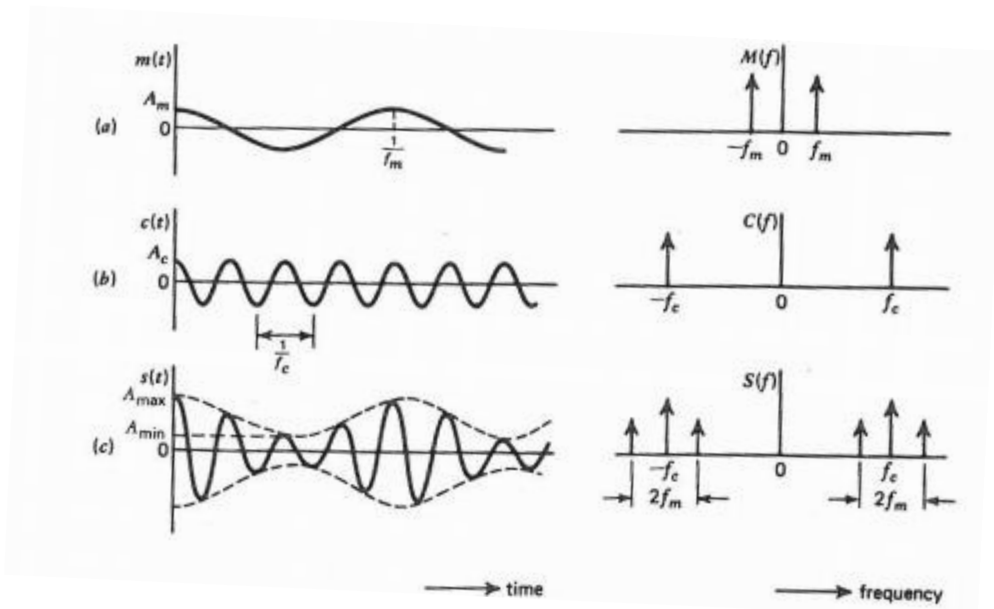


Figure 4: Showing the illustration of the time-domain (left) and frequency-domain (right) characteristics of standard amplitude modulation produced by a single tone. (a) Modulating wave. (b) Carrier wave. (c) AM wave.

$$m(t) = A_m \cos(2\pi f_m t) \qquad (3)$$

$$s(t) = A_c[1 + \mu \cos(2\pi f_m t)] \cos(2\pi f_c t) \qquad (4)$$

When expressing s(t) with two cosines in equation (4) as the sum of two sinusoidal waves with one having frequency being $f_c + f_m$ and the other being $f_c - f_m$, the equation turns into equation (5) below. It is important to note that in practice, the AM wave is a voltage or current wave. In either case of expression, the average power delivered to a 1-ohm resistor by s(t) is comprised of three main components: carrier power, upper side-frequency power, and lower side-frequency power.

$$s(t) = A_c[\cos(2\pi f_c t)] + \frac{1}{2}\mu A_c \cos(2\pi(f_c + f_m)t) + \frac{1}{2}\mu A_c \cos(2\pi(f_c - f_m)t) \quad (5)$$

Having highlighted the oscillator, signal generator and the switching modulator, the last component for the interim report is the high band pass filter that functions to limit the bandwidth of the output signal of the switching modulator to allocate the band for transmission. This basically takes out most of the noise that occurs in the signal being inputted into the band pass filter.

For the expected output of each component, as described in Fig. 3, the signal generator should output a sinewave signal, the switching modulator should then output a signal like Fig. 4c since the 2nd input would be a carrier signal from the oscilloscope. The oscilloscope should generate a constant sinusoidal signal since the frequency is inputted to be a constant. Then the expected output for the high band pass filter should then have a condensed voltage output signal as compared to the switching modulator signal. The power amplifier is expected to increase the amplitude of the signal generated from the high q band pass filter.

Going into the receiver part of the AM radio shown in Fig. 2b the overall expected output signal is a pulse wave of about 4 V. The envelope detector only allows the peaks of the signal through. The signal is noisy, so the bandpass filter only allows signals through with the desired signal. The comparator then increases the amplitude drastically, removes the negative voltages, and sends the signal to the buffer amplifier. Lastly, the buffer amplifier allows current through the speaker.

Equipment and Specifications:

1. Components: Signal Generator, Switching Modulator, Oscillator, High Band Pass Filter.
2. Power Supply set to ± 12 Volts to power all modules.
3. Input: Single sine wave m(t) as a messaged signal from LTSPICE.
4. Output: It is a recovered single tone sine wave m(t) displayed and compared to the input signal at both 350Hz and 3.5kHz, as well as any frequencies in between.
5. Special: The carrier frequency fc of the carrier wave c(t) must be between 60000 and 70000 Hz and the design work for a single signal between this range.
6. Oscilloscope: $\frac{R_2}{R_1}$ should be between 2.1 to 2.2 kohms due to transfer function in equation (6)

$$L(jw) = \frac{1+\frac{R_2}{R_1}}{3(jwRc-\frac{1}{wRc}} \qquad (6)$$

7. AM signal has a bandwidth of about 7 kHz.
8. Plots should show about 10 cycles.
9. Transmitter bandpass filter frequency response |H(f)| specifications:
   a. Lower stop band: 20log10(|H(f)|) ≤ -20 dB for f < 3.5 kHz.
   b. Upper stop band: 20log10(|H(f)|) ≤ -10 dB for f ≥ 2fc.
   c. Pass band: -1 dB ≤ 20log10(|H(f)|) ≤ 1 dB for fc–3.5 kHz≤ f ≤ fc+3.5 kHz.

2.0 Theory

Wein Oscillator:

The Wein oscillator is a circuit that will generate oscillating signal at some frequency (f_c). It is a non-inverting amplifier connected to an RC network. The Wein oscillator works by feeding a small information signal into the amplifier which sends the amplified signal into the RC network which then sends feedback into the amplifier. Thus, this creates a positive feedback loop which continues till the max gain is achieved. Fig. 5 below shows the circuit of the oscillator in the general form then the specific form for the project. Equation (6b) is then the transfer function representing the general form then the circuit for the project. The input voltage for the transfer function is the thermal noise which has all frequency constructs including ω_o. At a ω_o, the L(jω_o)=1 and $|H(j\omega_o)| = \infty$. The output voltage generates a signal that oscillates with ω_o. For the project, the part of the transfer function that is important to highlight is the transfer function for the loop gain ($AB(j\omega) = L(j\omega)$). So, the transfer function is the loop gain for the specific form.

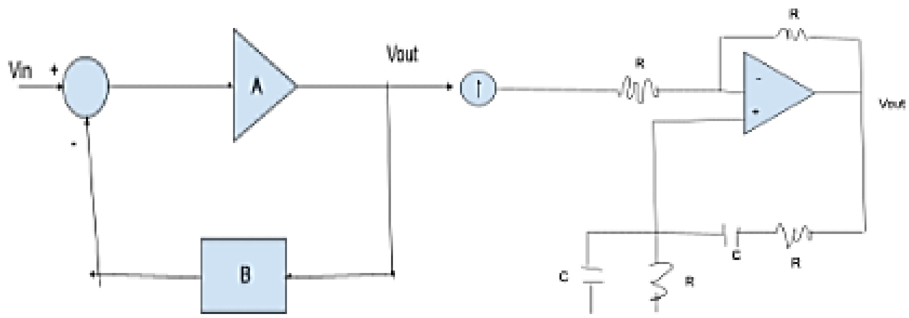


Figure 5: General Form negative Feedback oscillator to Oscillator for Project.

$$H(j\omega) = \frac{A(j\omega)}{1+AB(j\omega)} => L(j\omega) \text{ in Eqn (6)} \qquad (6b)$$

From this, it is concluded that $\omega_o = \frac{1}{RC}$ and $\frac{\left(1+\frac{R_2}{R_1}\right)}{3} = 1$; so $\frac{R_2}{R_1} = 2$. This means that in practice, $\frac{R_2}{R_1} > 2$. Ideally the aim is for this ratio to be 2.1 or 2.2. All resistors in this circuit must be greater than 200 Ω.

For the calculations, the chosen values to fit the above specifications was $R_2 = 2.1\ k\Omega$, $R_1 = 1\ k\Omega$, $f_o = 68\ kHz$, and C=8 nF. Using the $\omega_o = \frac{1}{RC}$ to find R with ω_o being simply $2\pi f_o$,resulted in R being 292 Ω which traced back to a LTSPICE FFT value of 63.97 kHz for the initial frequency. For the R, the closest realistic value is 250 Ω. The circuit built in LTSPICE to meet specifications is shown in Fig. 6 below.

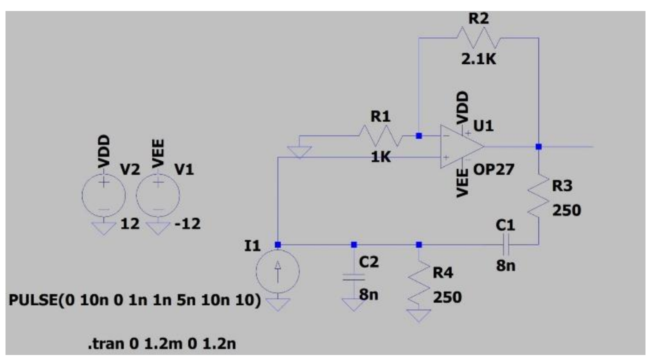


Figure 6: LTSPICE Circuit of Oscillator with all met specifications.

Switching Modulator:

The switching modulator has two components, the first being the summer and the second being the half-way rectifier. The purpose of the summer is to combine the local signal and the message signal and feed it into an op- amp to add the two signals together. The requirements for the project were that the signal oscillates between +- 8V with a difference of 4V. The ratio between $\frac{R_1}{R_2}$ is then 4. While the ratio between $\frac{R_1}{R_f}$ is then 2. To satisfy these ratios, the R_1 was chosen to be 24 kΩ, R_2 was found to be 6 kΩ, R_3 was found to be 10 kΩ, and R_f was found to be 12 kΩ. The signal generated for this part stays in steady state. The second component, the half-wave rectifier, only allows the positive values of the AM signal through the output. R_3 was added so that the voltage would flow through the diode to create the half-wave rectifier. Fig. 7 and 8 below show the switching modulation circuit on its own at 350 Hz and at 3.5 kHz.

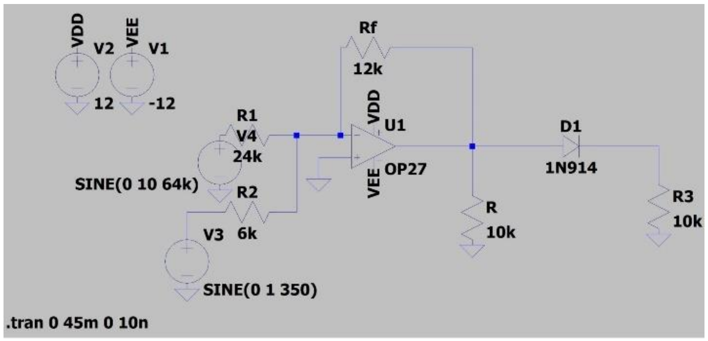


Figure 7: Switching Modulation Circuit at 350 Hz.

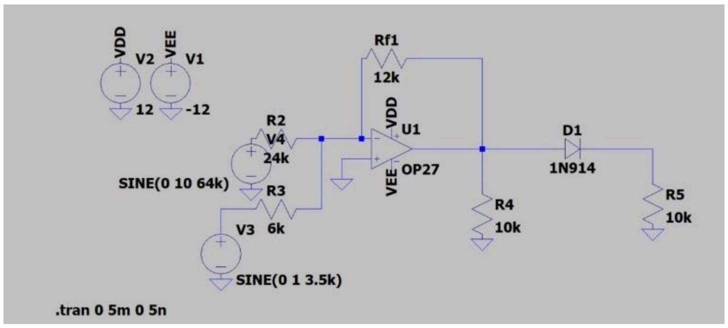


Figure 8: Switching Modulation Circuit at 3.5 kHz.

High Q Band Pass Filter 1:

The high pass band filter has the objective to filter out the extra signal generated to leave the AM signal which is shown in part c of Fig. 4. The allowed frequency range for the FFT output signal was between 60.5 kHz and 67.5 kHz because the bandwidth β=2W of the signal is targeted to be 7 kHz total based on the max $f_m = 3.5\ kHz$ and $f_c = 64\ kHz$ from the switching modulator to pass the three frequency values of the AM signal. The constant k was assumed to be 1 since the initial gain was aimed to be 0 dB from the peak frequency. The initial frequency entering the bandwidth was 1 kHz. To find the R and C values that fit these parameters, the C was chosen and carried through with equations (7) to (10) to find the resistor values. Equation (11) is the transfer function to which (7) to (10) were based.

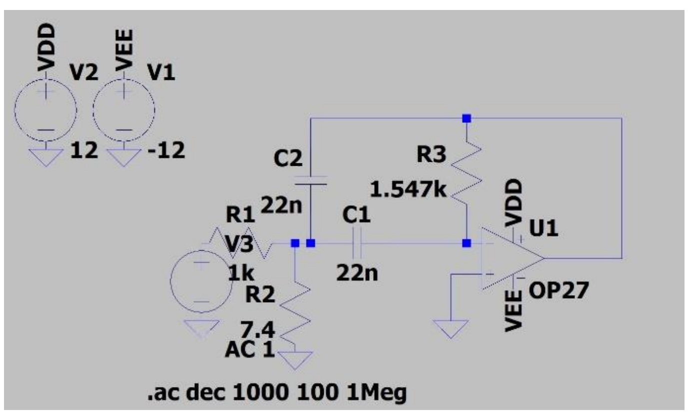


Figure 9: High Q Band Pass Filter with calculated variables.

$$\beta = \frac{2}{(R_3 C)} \qquad (7)$$

$$k\beta = \frac{1}{(R_1 C)} \quad (8)$$

$$R_{eq} = \frac{1}{R_3 C^2 \omega_o^2} \quad (9)$$

$$R_2 = \left(\frac{1}{R_{eq}} - \frac{1}{R_1}\right)^{-1} \quad (10)$$

$$H(s) = \frac{-k\beta s}{s^2 + \beta s + \omega_o^2} \quad (11)$$

Using equations (7) to (10) and the chosen value 22 nF for C based on trial and error in the Desmos system software, $R_3 = 1.547$ kΩ, $R_1 = 1$ kΩ, and $R_2 = 7.4$ Ω. To better understand the circuit, the larger the R_2 the wider the FFT AM signal, R_1 adjusts the height of the peak of the AM signal, and C shifts the peak.

AM Transmitter

Fig. 10 and 11 below shows the final product of the AM transmitter that successfully validated all specifications of the oscillator, switching modulator, and high q band pass filter.

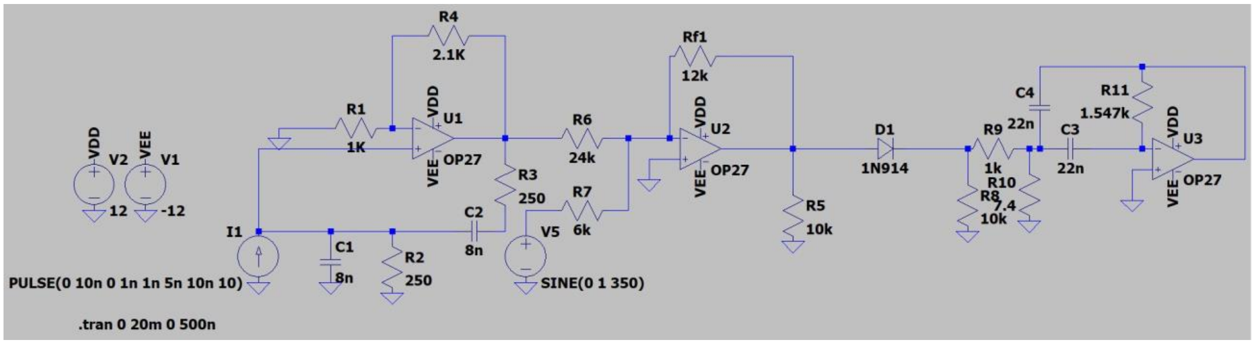


Figure 10: AM Transmitter before the Power Amplifier at 350 Hz

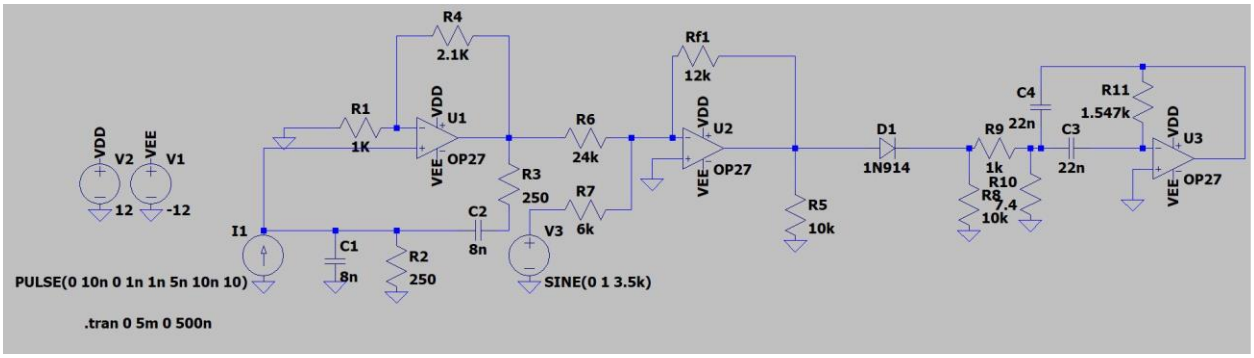


Figure 11: AM Transmitter before the Power Amplifier at 3.5 kHz

Power Amplifier

Fig.12 below shows the power amplifier circuit. For this circuit, the op-amp provides the necessary voltage to activate the NPN and PNP BJT transistors. The resistors R_1 and R_2 were chosen so that there was a gain of 3.2 V/V and to meet specifications using $1 + \frac{R_2}{R_1}$. The R_3 and R_4 resistors were chosen to have a value of 50 Ω to represent the resistance value of a BNC cable. The output of the op-amp leads to a voltage before R_3 of 8 V_{0-P}, the voltage output after the BNC cable leads to a 4 V_{0-P} value. The NPN amplifies the positive half wave cycle of the input signal, while the PNP amplifies the negative half wave cycle of the input signal. This is referred to as a push-pull dynamic of a CMOS amplifier.

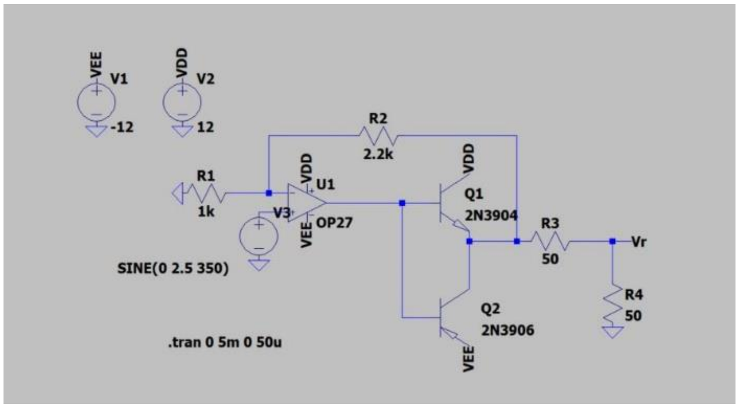


Figure 12: Power Amplifier.

Peak Detector

Fig. 13 below shows the peak detector circuit. This circuit was designed to demodulate the AM signal, allowing for the initial message signal to be recovered. The buffer, the first op amp of the circuit separates the received signal from the output, cleaning up the signal. The peak detector circuit functions by charging the capacitor while the received signal is above .7 V, then the capacitor discharges when the voltage is less than .7 V. The discharge continues until the voltage is above .7 V again. The diode is reverse-biased when the voltage is below .7 V, so the capacitor needs to discharge through the resistor. To find the right resistor and capacitor values equations (12) and (13) below were used.

$$t = \frac{1}{f_c} \qquad (12)$$

$$V(t) = V(0)e^{\frac{-t}{\tau}} \qquad (13)$$

C was chosen to be 47 nF, t was calculated to be 15.6 µs since f_c = 64 kHz using equation (12), and the voltage values get V(t) and V(0) were found by measuring two consecutive peak values from the plot shown is Fig. 37 below. Lastly, by rearranging equation (13) to solve for τ, τ was calculated to be .15 ms. Since τ is equivalent to RC, R was found to be 3.2 kΩ.

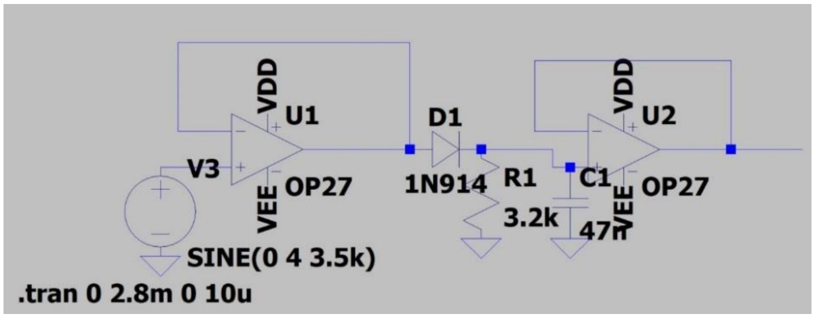


Figure 13: Peak Detector with Buffer.

Second Order Bandpass Filter

Fig. 14 below shows the second order bandpass filter circuit. This is comprised of the low pass Butterworth filter and the high pass Butterworth filter summed together. The output signal of this is to recover the message signal m(t).

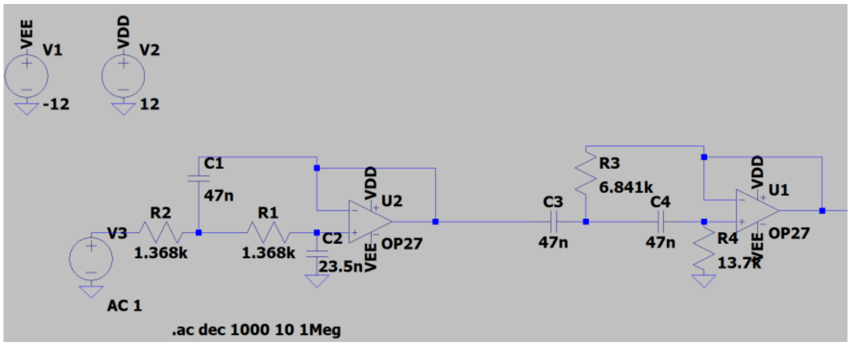


Figure 14: 2nd Order Bandpass Filter.

Low Pass Butterworth Filter

Fig. 15 below shows the first filter of the 2nd order bandpass filter, the low pass butterworth filter. The low pass butterworth filter does not allow a signal through that is above the high cutoff frequency. The equations governing this circuit are (14), (15), (16), and (17) below.

$$\omega_0 = 2\pi(f_c) \tag{14}$$

$$\zeta = 0.707 \tag{15}$$

$$2\zeta\omega_0 = \frac{2}{RC_1} \tag{16}$$

$$\omega_0{}^2 = \frac{1}{C_1 C_2 R^2} \tag{17}$$

To find the desired design values, f_c was 3.5 kHz, C_1 was chosen to be 47 nF, R was then calculated using (16) to be 1.368 kΩ, and C_2 was calculated using equation (17) to be 23.5 nF.

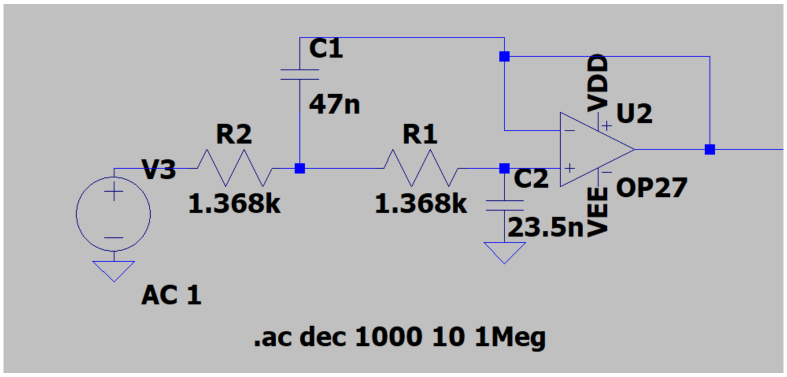


Figure 15: Low Pass Butterworth Filter.

High Pass Butterworth Filter

Fig. 16 below shows the second circuit of the 2nd order Bandpass Filter, the high pass butterworth filter. The high pass butterworth signal does not allow a frequency below the cutoff frequency. The equations needed to find the design values are (18), (19), (20), and (21).

$$\omega_0 = 2\pi(f_c) \quad (18)$$

$$\zeta = 0.707 \quad (19)$$

$$2\zeta\omega_0 = \frac{2}{R_2 C} \quad (20)$$

$${\omega_0}^2 = \frac{1}{R_1 R_2 C^2} \quad (21)$$

Here, f_c was 350 Hz, C was chosen to be 47 nF, using equation (20), R_2 was calculated to be 13.7 kΩ, and using equation (21) R_1 was calculated to be 6.841 kΩ. The AC sweep started collecting at 10 Hz and stopped at 1 MHz with 1000 points of data collection.

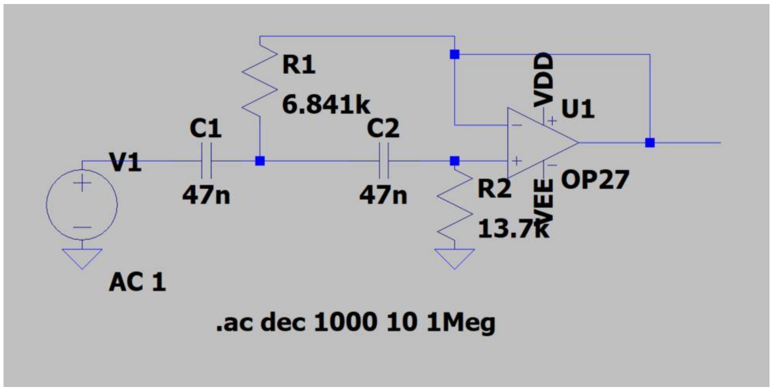


Figure 16: High Pass Butterworth Filter.

Comparator

Fig. 17 below shows the comparator circuit. This is comprised of a non-inverting amplifier that converts the input sinewave to a square pulse signal with an amplitude slightly within the positive and negative saturations of the op-amp. In this design the saturations values are ± 12 V. The op-amp is designed to have a high gain value of about 500 V/V to allow the signal conversion with a cycle of about 50%. The design values for this circuit were chosen to be 200 Ω for R_3, and 100 kΩ for R_4.

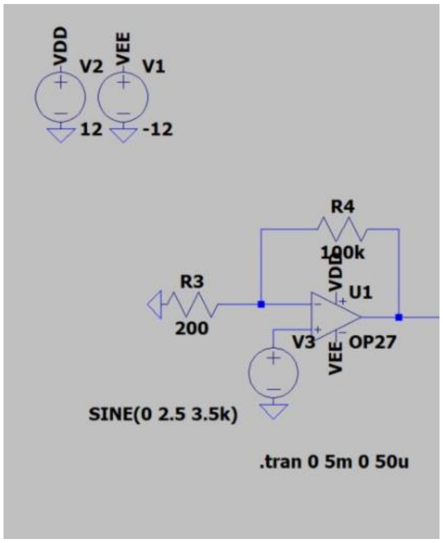


Figure 17: Comparator.

Buffer Amplifier

Fig. 18 below shows the buffer amplifier. This circuit allows only positive voltage to pass through the diode, then it uses the voltage divider to send the proper amount of voltage to the NMOS MOSFET transistor, which then supplies the load or speaker with current. The voltage past the diode was desired to be about 10 V, then once passed through the voltage divider would be about 7 V to then have the output voltage be about 5 V. The resistor values were chosen to be R_1 at 5 kΩ, R_2 to be 10 kΩ, and R_5 to be 8 Ω to represent to speaker.

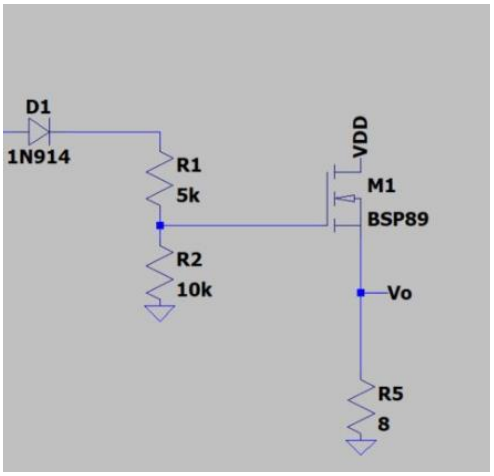


Figure 18: Buffer Amplifier.

AM Radio

Fig. 19 and 20 are then the final circuit showing the AM transmitter and AM receiver. These circuits generated the desired output square wave for both the low and high frequency values of the message signal.

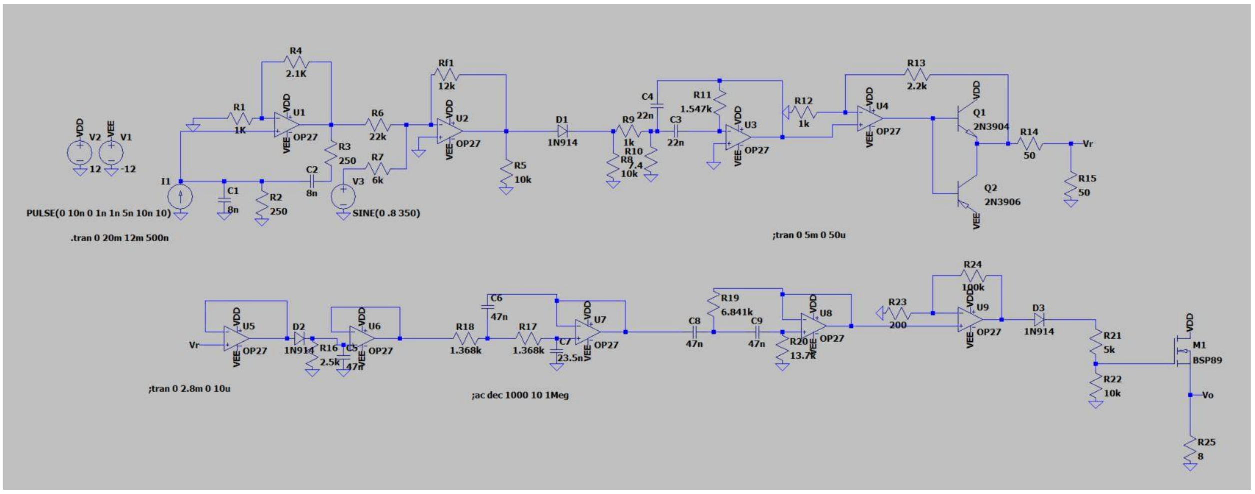


Figure 19: Final Circuit at 350 Hz.

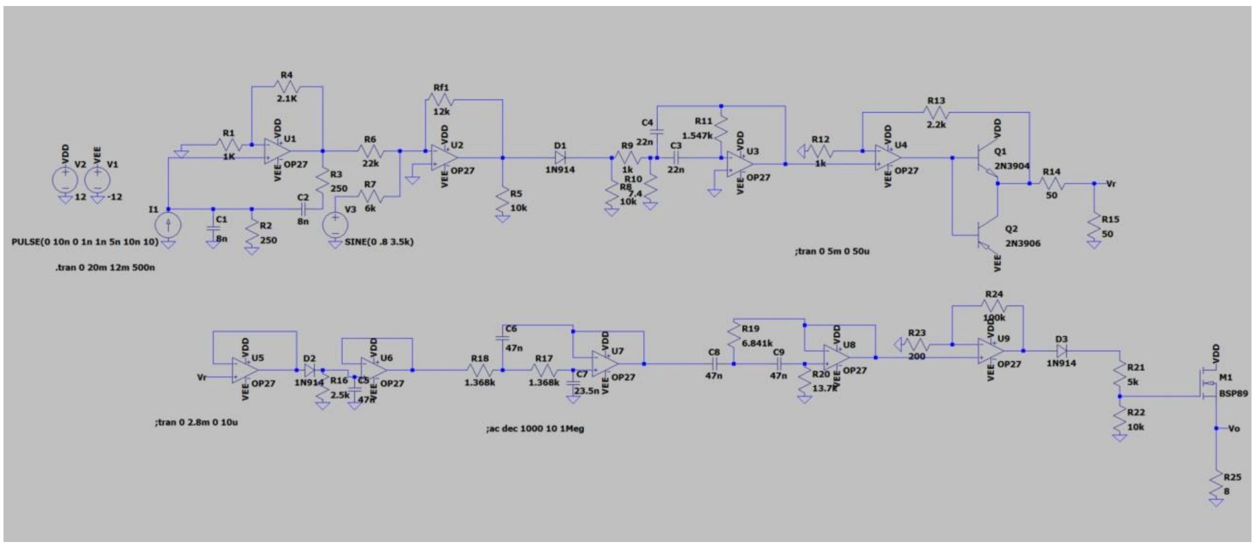


Figure 20: Final Circuit at 3.5 kHz.

3.0 Methodology:

The overall process to design the AM transmitter and receiver was to design each circuit individually and simulate it to make sure it met specifications. As each circuit was deemed successful it would be added onto the developing AM radio then adjusted to produce a successful result. Once every circuit was deemed successful both independently and combined, the entire AM radio was tested to produce a final output voltage signal.

Wein Oscillator

As described in the theory section, the oscillator's chosen values to fit specifications were $R_2 = 2.1\ k\Omega$**,** $R_1 = 1\ k\Omega$**,** $f_o = 68\ kHz$, and C=8 nF. These values were then inserted into the circuit shown in Fig.6 and simulated in LTSPICE. When the carrier frequency was shown to be close to the f_c at 64 kHz, and the $\omega_o = \frac{1}{RC}$ led to R being above 200 Ω, the circuit was shown to be successful.

Switching Modulator

For the switching modulator, the main requirements for the project are that the signal oscillates between +-8V with a difference of 4V. The ratio between $\frac{R_1}{R_2}$ is 4. While the ratio between $\frac{R_1}{R_f}$ is just over 2. The carrier frequency was expected to stay at 64 kHz. To be deemed successful, the FFT was to have a peak frequency gain of 0 dB so that k could be 1 for the band pass filter calculations and $f_m = 3.5\ kHz, or\ 350\ Hz$ for the width of the AM signal peak to match the initial f_m going into the circuit. To meet these design requirements, the R_1 was chosen to be 24 kΩ, R_2 was found to be 6 kΩ, R_3 was found to be 10 kΩ, and R_f was found to be 12 kΩ. Then to validate, the voltage graphs of the input and output and the FFT graphs were simulated in LTSPICE and the width and peak was measured with the cursors. The design of the circuit was based on wanting the desired voltage range to be between +- 8 V because if the range exceeds +-10 V then there would be clipping.

High Q Band Pass Filter

For the high q band pass filter, the design was determined by wanting to filter out the noise to leave the AM signal for a generated FFT graph that would meet the specifications stated in the theory section for the high q band pass filter. To get the desired results, the R and C values were calculated and placed within the circuit due to each variable having a different effect on the FFT plot. To explain, the larger the R_2 the wider the FFT AM signal, R_1 adjusts the height of the peak of the AM signal, and C shifts the peak. The values for these were shown to generate a different desired result between the calculations done with equations (7) to (10), so to find values that met the described specifications, Desmos was used by inserting the equations and the trial and erroring a C value until one fit within the specified range for both the calculations and LTSPICE simulations.

Power Amplifier

For the power amplifier, the design was determined by wanting to amplify the output voltage of the high q band pass filter. Once it passes through the BNC cable the sinewave was halved going from 8 V to 4 V from zero to peak. To get the desired results, the resistors R_1 and R_2 were chosen so that there is a gain of 3.2 V/V and to meet specifications using $1 + \frac{R_2}{R_1}$. The R_3 and R_4 resistors were chosen to have a value of 50 Ω to represent the resistance value of a BNC cable. R_4 was added in to offset the BNC cable of R_3. The resulting graphs when the power amplifier was combined with the rest of the transmitter was a wave going between ± 4 V to 1.73 V. This was an acceptable voltage range though the expected was from 4 to 2 V.

Peak Detector

For the peak detector, the design was determined by wanting to detect the peak of the message signal. The output signal of the peak detector is distorted due to the capacitor of the circuit charging and draining. The diode of the circuit provides a voltage drop of about .7 V. From the power amplifier plot at 3.5 kHz, V_0 was determined by identifying the peak voltage value at 90° from the max peak voltage since that is the fastest drop. Then V_1 was found by going to the next peak from V_0. These values were found to be 3.207 V at 2.88 ms and 2.891 V at 2.89 ms, respectively. As described in the theory section, R was found to be 3.2 kΩ. This though did not produce the desired distortion when combined with the AM transmitter so then was adjusted to 2.5 kΩ when combined to have good distortion. When the diode is off the circuit will start to discharge cause the voltage of the capacitor is greater than the initial voltage. To create a good distortion, t_c must barely touch the f_m signal. If it is too fast, there will be too much distortion. The time that is calculated is when the sinewave is trending downward because when it scales up, the capacitor is charging, so equation (12) has a negative sign with tau.

Second Order Bandpass Filter

For the 2nd order band pass filter, the design was determined by having two stages. These stages being the low pass butterworth filter and the high pass butterworth filter. The desired output of this is circuit set up is to generate a recovered message signal. This is done by summing the low and high cutoff frequencies generated by the two stages into one.

Low Pass Butterworth Filter

The low pass butterworth filter was the first stage of the 2nd order bandpass filter. The capacitor and resistor values are stated in the theory section, as well as the method of which they were determined. The functionality of the capacitor and resistor values were based on the transfer function of a low pass filter. The limits for this circuit were that the requirement for ω_0 needed to be met. The output of the low pass filter is expected to be the message signal shifted by a DC voltage amount when connected to the peak detector.

H**igh Pass Butterworth Filter**

The high pass butterworth filter was the 2nd stage of the 2nd order bandpass filter. The capacitor and resistor values are stated in the theory section, as well as the method of which they were determined. The functionality of the capacitor and resistor values were based on the transfer function of a high pass filter. The limits for this circuit were that the requirement for ω_0 needed to be met. The output of the high pass filter connected to the lowpass filter with the rest of the AM receiver and transistor is recovered message signal.

Comparator

For the comparator, the design was determined by having a non-inverting amplifier with a high gain to successfully convert the recovered message signal from a sinewave to a square wave within the saturation max and min voltage as described in the theory section. If the voltage min and max is outside of the limits, then the comparator would have caused the signal to be over saturated and therefor have cutoff voltages.

Buffer Amplifier

For the buffer amplifier, the design was determined by having a voltage divider that causes the voltage to be high enough to power the NMOS. The NMOS then outputs a slightly reduced voltage for the final output due to the 8 Ω resistor which represents the speaker.

4.0 Results and Analysis:

Wien Oscillator

Fig. 21 below shows the simulation of the Wein Oscillator circuit without being connected to any other circuit. It shows the amplitude of the signal over time, which starts at .8 sec when the oscillations begin to shift to the maximum output of the circuit. Fig. 22 shows the FFT of the Wein Oscillator, with the large spike on 64 kHz.

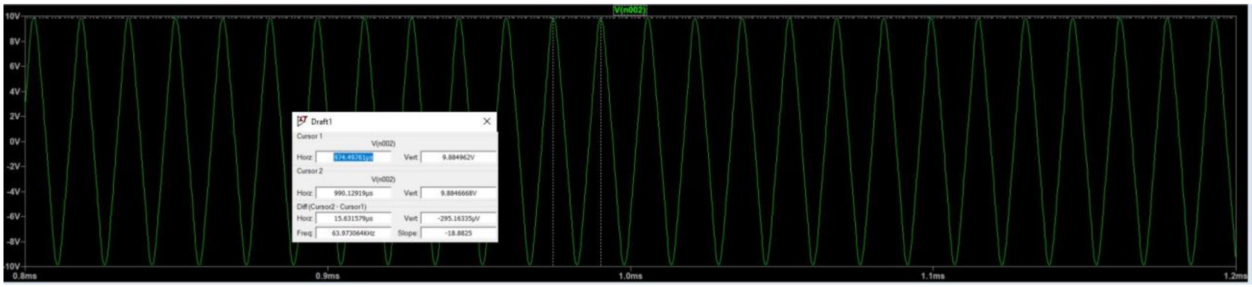


Figure 21: Oscillator graph showing Carrier Frequency of about 64 kHz.

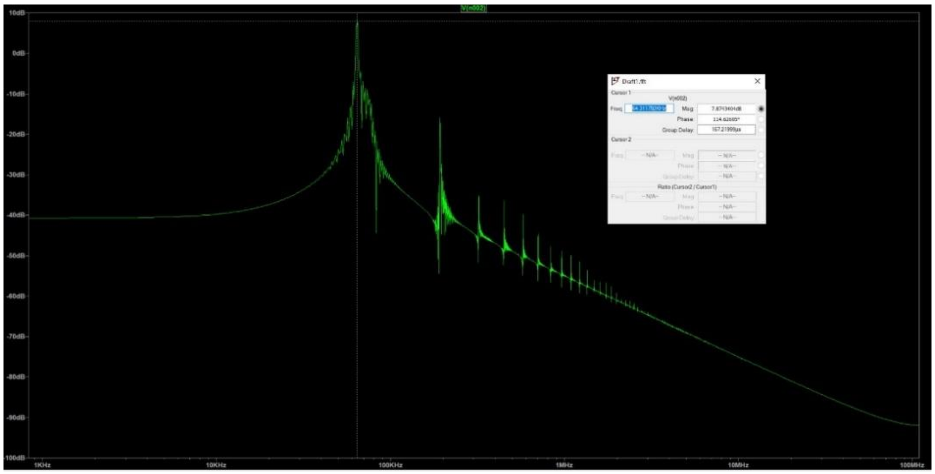


Figure 22: FFT of Oscillator.

Switching Modulator

Fig. 23 shows the simulation of the switching modulator for the output voltage before the half wave rectifier and after the half wave rectifier. The message signal for this it 350 Hz and the amplitude meet requirements since it is at about 3.5 V. Fig.24 and 25 are the FFT graphs for Fig. 23 with Fig. 24 representing before the diode and Fig. 25 representing after the diode.

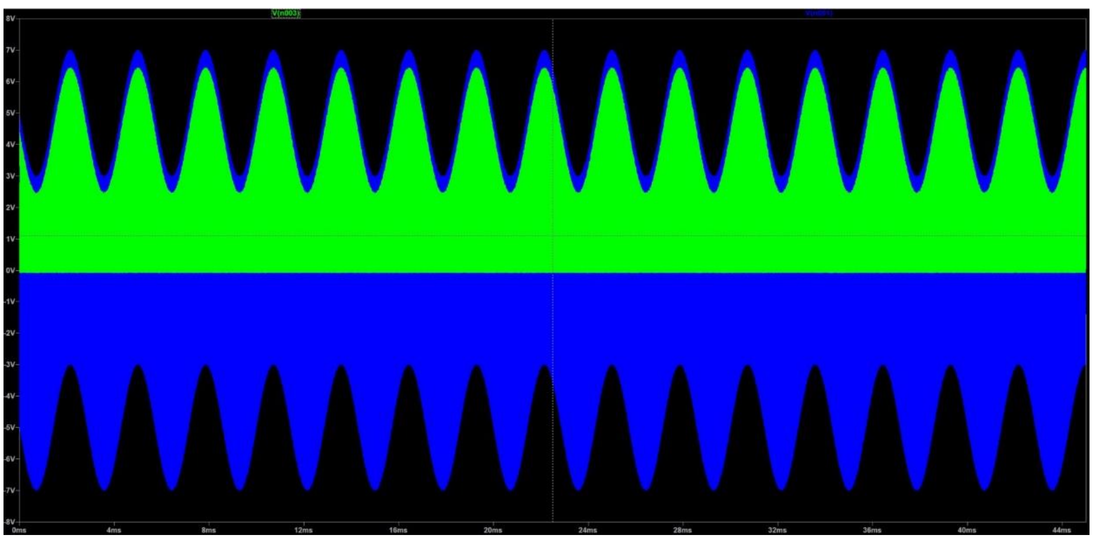


Figure 23: Switching Modulator with both components at 350 Hz.

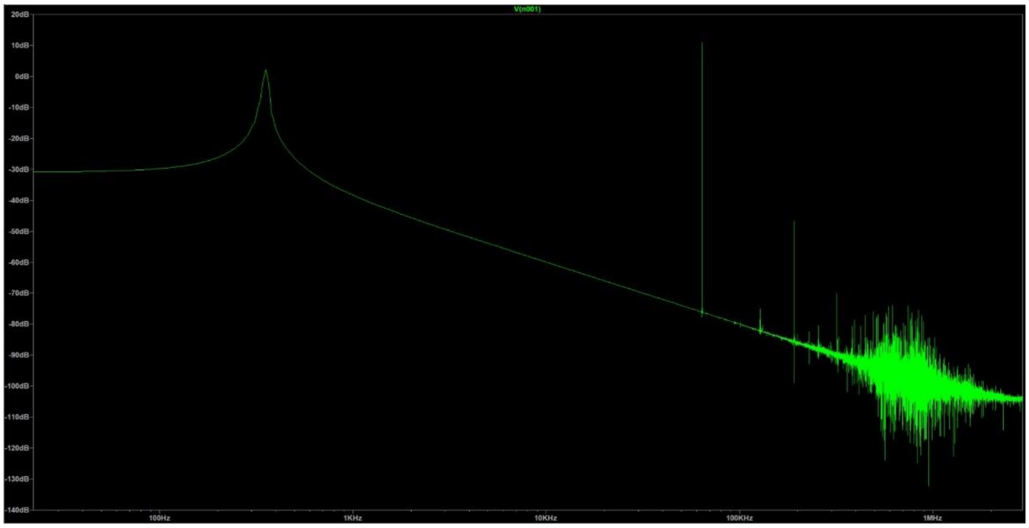


Figure 24: FFT of Switching Modulator before Halfwave Rectifier at 350 Hz.

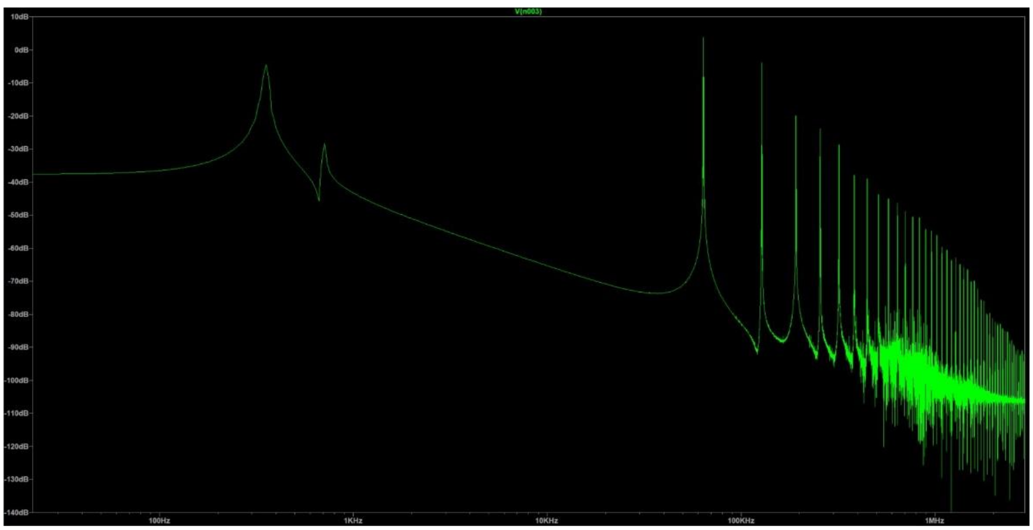


Figure 25: FFT of Switching Modulator output voltage at 350 Hz.

Fig. 26 shows the simulation of the switching modulator for the output voltage before the half wave rectifier and after the half wave rectifier. The message signal for this it 3.5 kHz and the amplitude meet requirements since it is at about 3.5 V. Fig.27 and 28 are the FFT graphs for Fig. 26 with Fig. 27 representing before the diode and Fig. 28 representing after the diode.

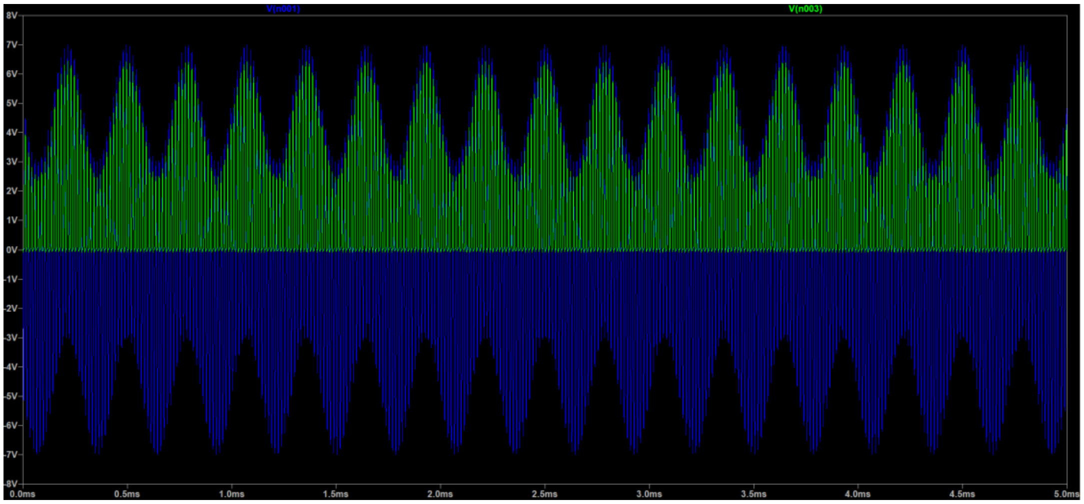


Figure 26: Switching Modulator with both components at 3.5 kHz.

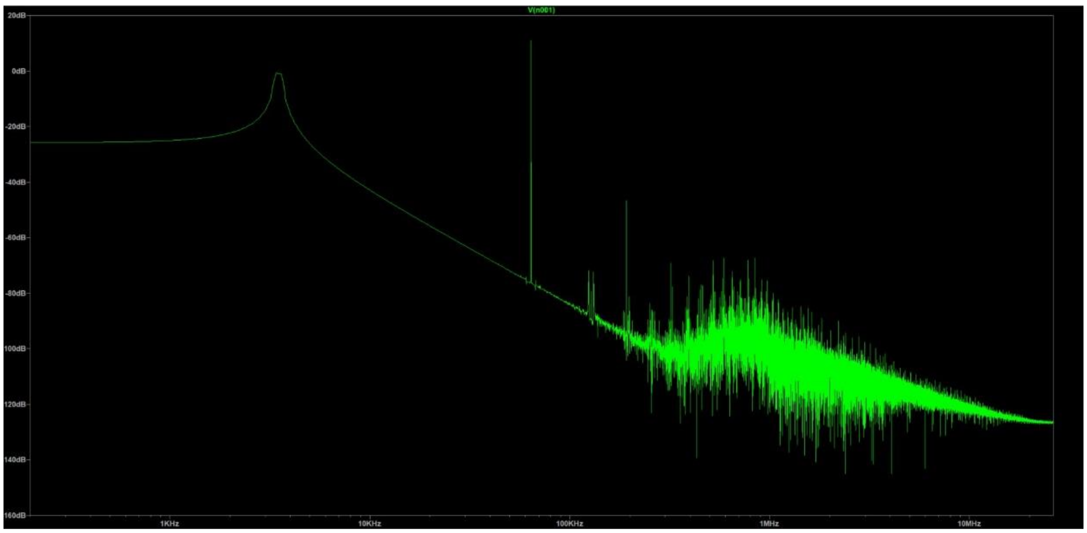


Figure 27: FFT of Switching Modulator before Halfwave Rectifier at 3.5 kHz.

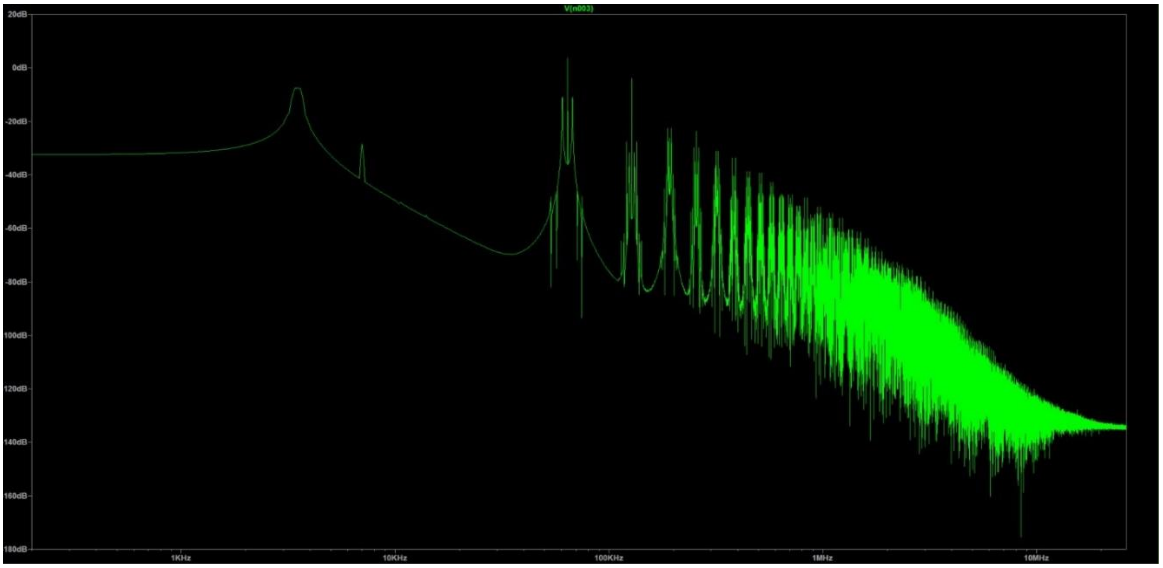


Figure 28: FFT of Switching Modulator output voltage at 3.5 kHz.

High Q Band Pass Filter

Fig. 29 shows the AC Sweep of the High Q Bandpass Filter, showing the cutoff frequencies.

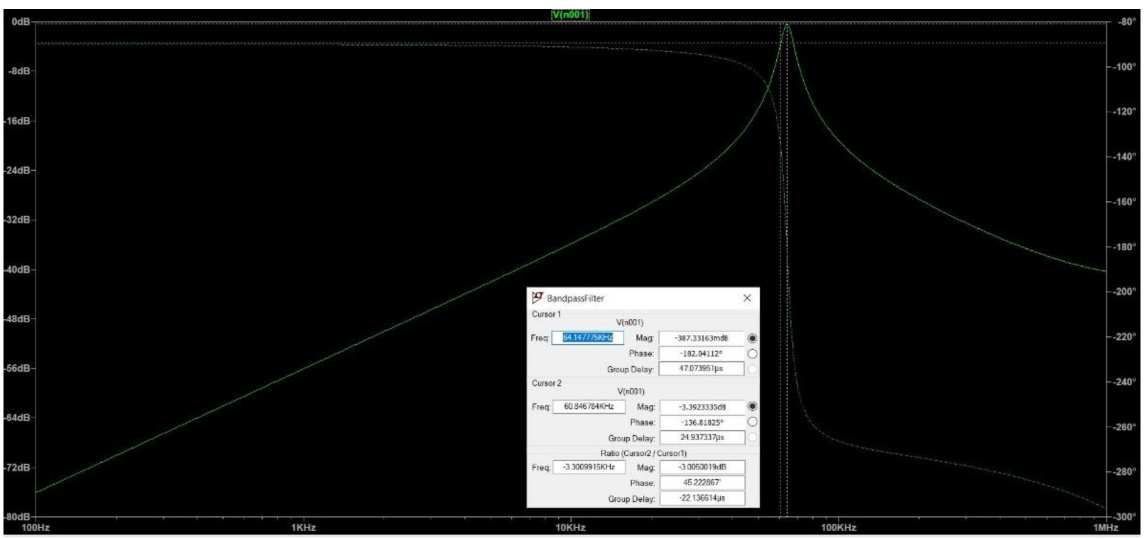


Figure 29: High Q Band Pass Filter FFT graph at 1 kHz input.

AC Transmitter

Fig. 30 shows the signal after it passes through the Wein Oscillator, switching modulator, and the high q bandpass filter at 350 Hz. Fig. 32 shows the signal after it passes through the Wein Oscillator, switching modulator, and the high q bandpass filter at 3.5 kHz. The highest amplitude of the signal is 2.6 V at the 350 Hz and 2.5 V at 3.5 kHz.

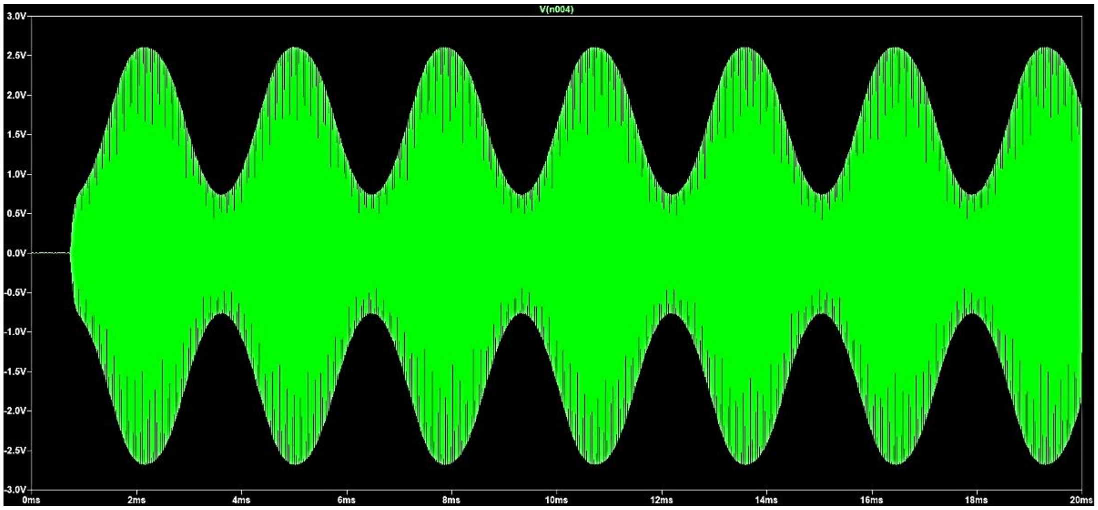


Figure 30: AC Transmitter before Power Amplifier at 350 Hz.

Fig. 31 shows the resulting FFT graph of Fig. 30 with the desired peak frequency at 0 dB and that it met all other desired specifications stated in theory. Fig. 33 shows the resulting FFT graph of Fig. 32 with the desired peak frequency at 0 dB and that it met all other desired specifications stated in theory.

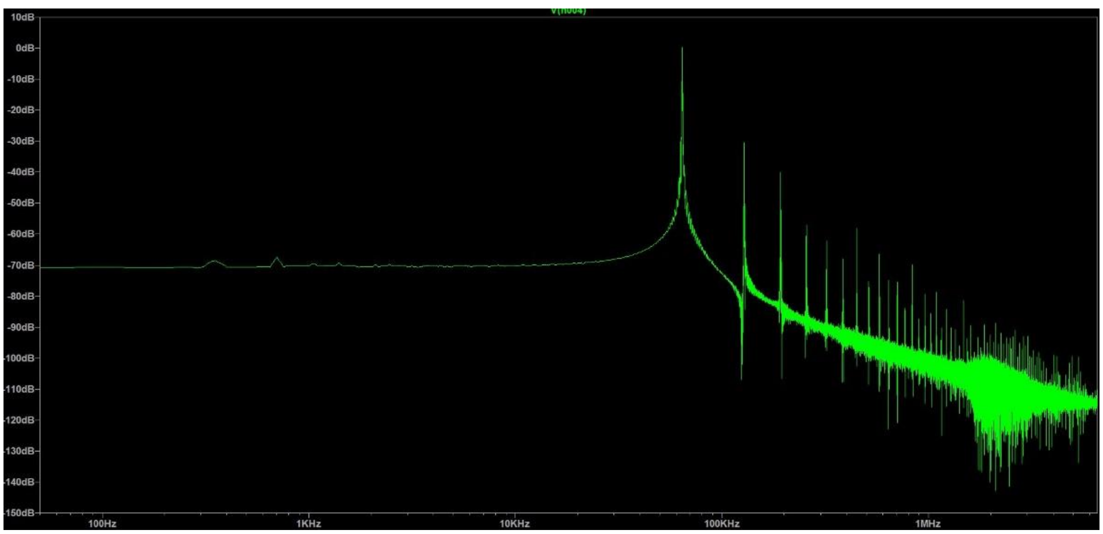


Figure 31: FFT of AC Transmitter before Power Amplifier at 350 Hz.

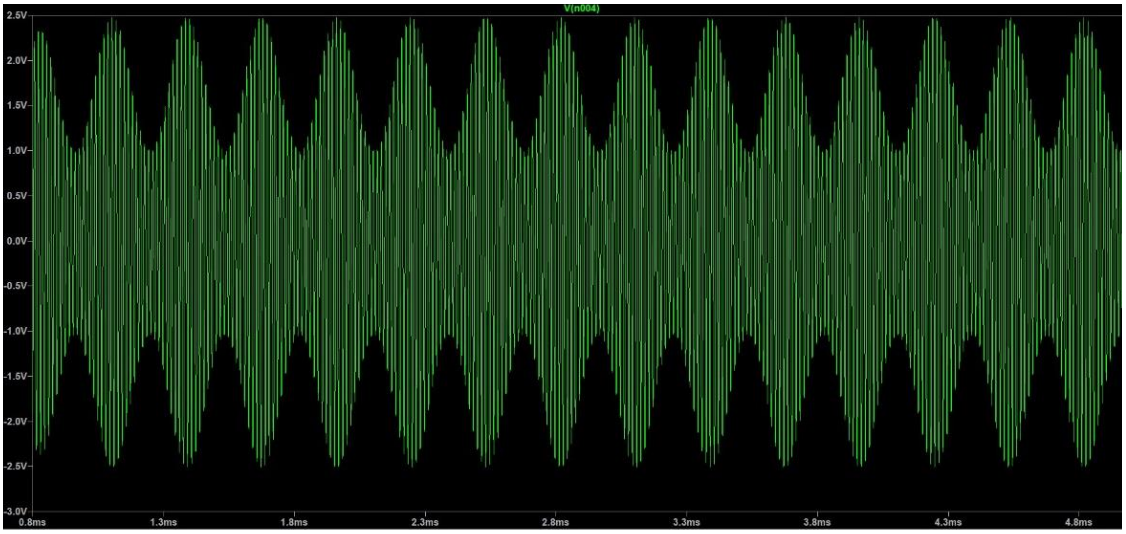


Figure 32: AC Transmitter before Power Amplifier at 3.5 kHz.

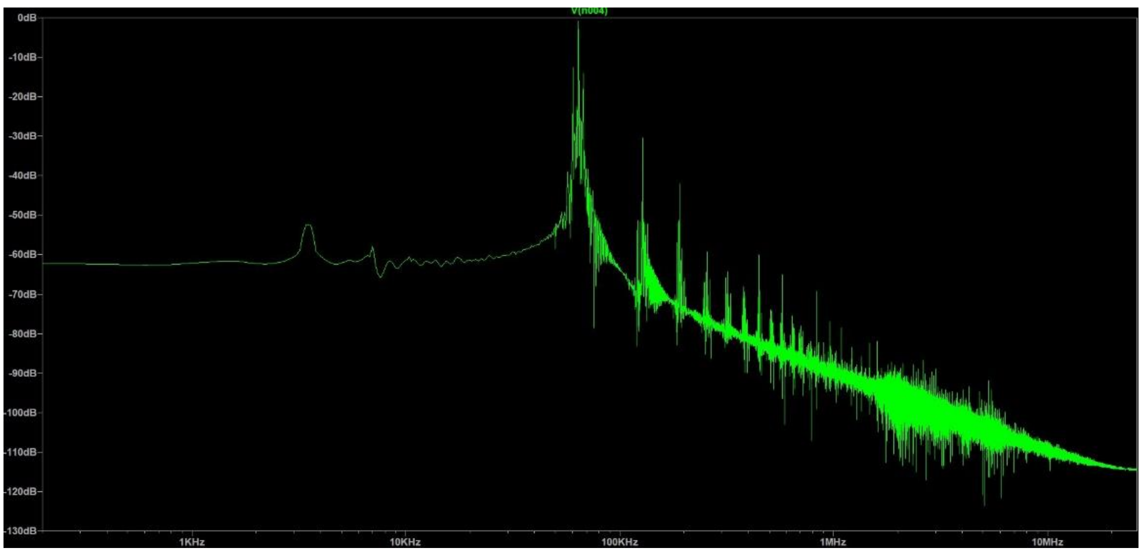


Figure 33: FFT of AC Transmitter before Power Amplifier at 3.5 kHz.

Power Amplifier

Fig. 34 below shows the power amplifier at 350 Hz. Fig. 35 shows the power amplifier with an input sinewave at 3.5 kHz. The desired gain was 3.2, which then the values for the resistors were $R_2 = 2.2\ k\Omega$, $R_1 = 1\ k\Omega$ which produced the desired sinewave when the power amplifier was independent of the rest of the AM transmitter. This met all desired requirement mentioned in the theory section.

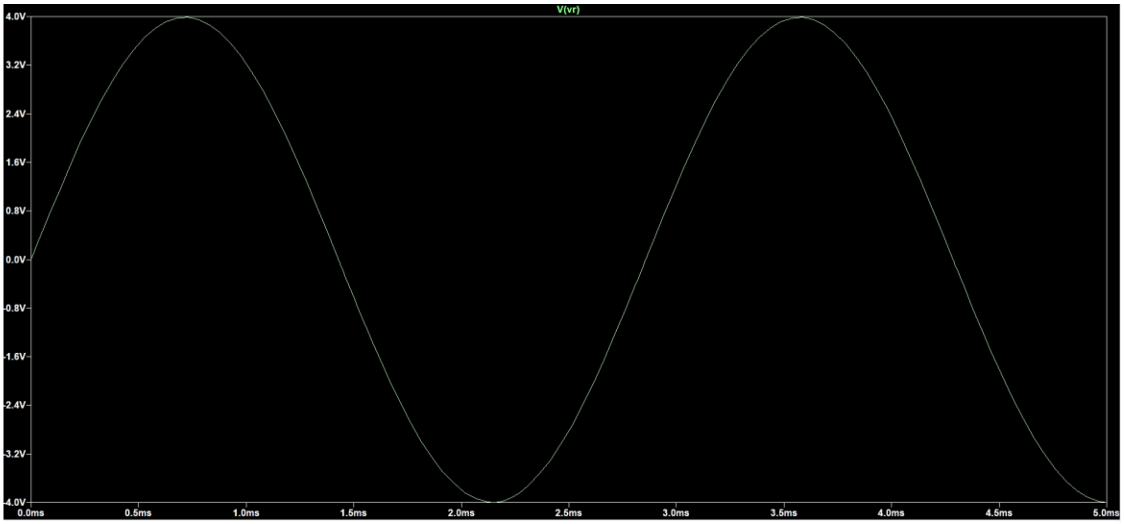


Figure 34: Power Amplifier at 350 Hz.

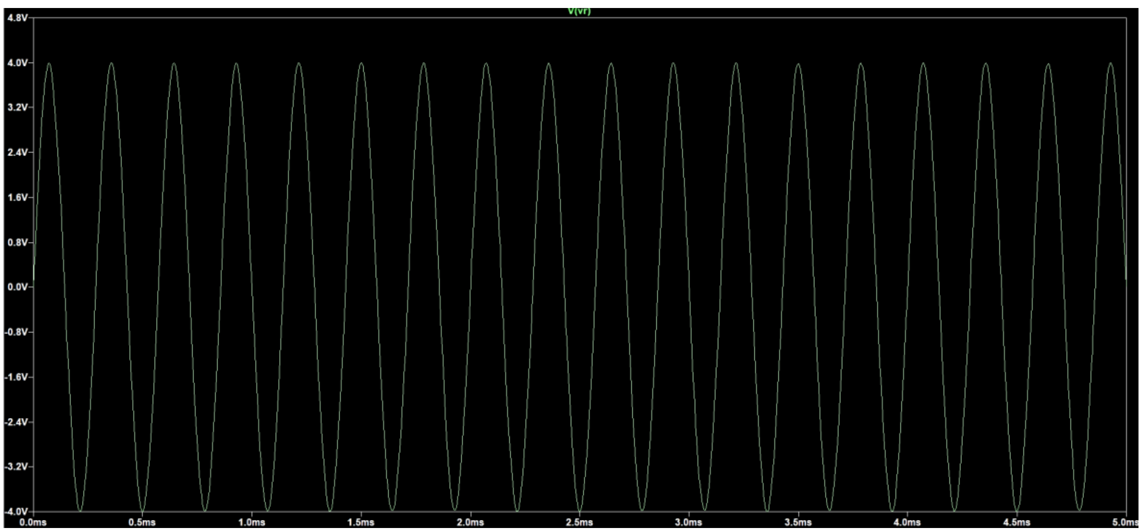


Figure 35: Power Amplifier at 3.5 kHz.

Fig. 36 shows the power amplifier integrated with the rest of the AM transmitter at 350 Hz, and Fig. 37 shows this at 3.5 kHz. The max peak was the desired 4 V zero to peak, the min value was 1.73 V which was less than the predicted value of 2 V. This was an 13.5% error for the min voltage value which was deemed acceptable. This error is due to in system factors in LTSPICE.

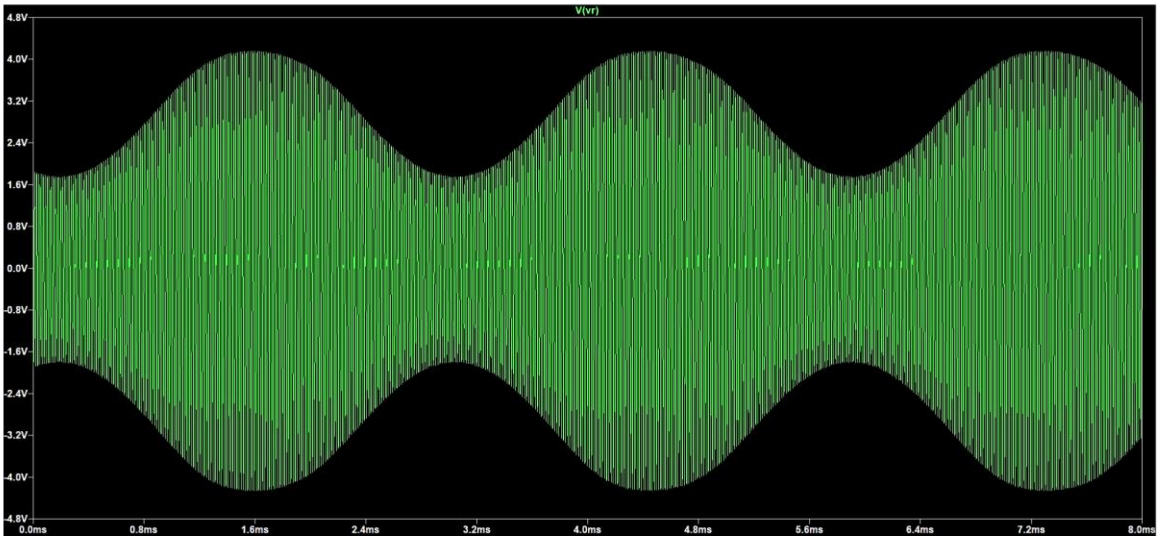


Figure 36: Power Amplifier integrated with rest of AM Transmitter at 350 Hz.

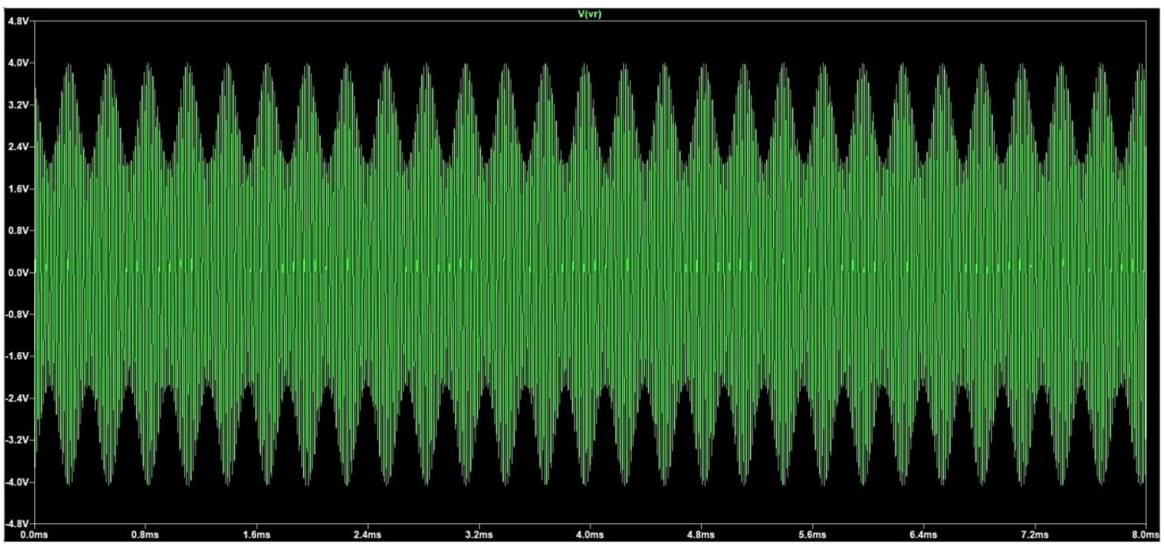


Figure 37: Power Amplifier integrated with rest of AM Transmitter at 3.5 kHz.

Peak Detector

Fig. 38 shows the peak detector plot when it is independent of the AM radio. The calculated R was 3.2 kΩ which led to a distorted wave with a max voltage of about 3.4 V and a min voltage value of about .8 V.

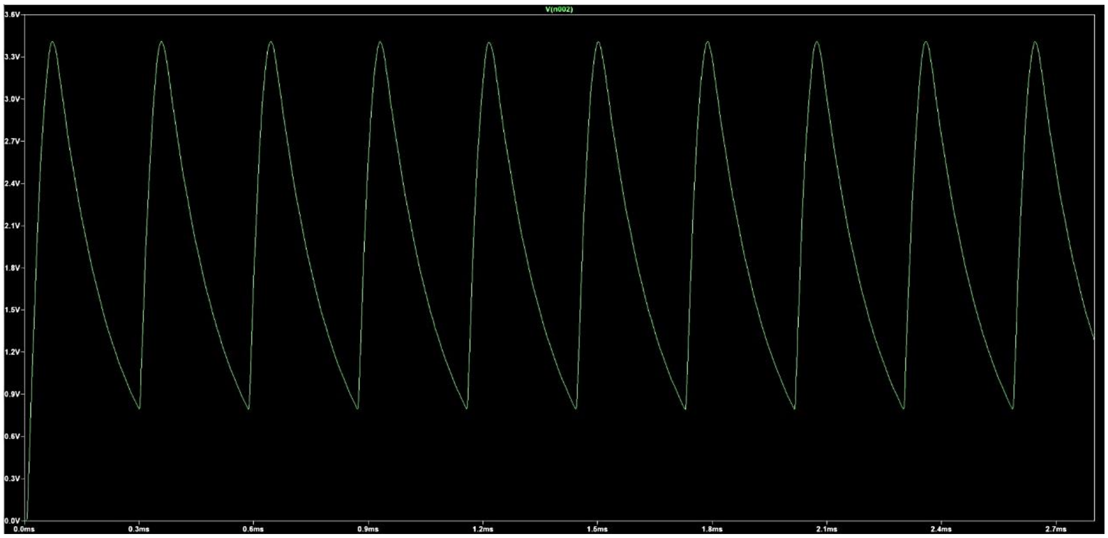


Figure 38: Peak Detector.

Fig. 39 and 40 show the peak detector integrated with the AM circuits at 350 Hz and 3.5 k Hz, respectively. When R was 3.2 kΩ the distortion was not good. The peaks of the peak detectors were not within the message signal. This required changing R to 2.5 kΩ, which produced good distortion because the distorted peaks were now within the message signal. The reason for this change is due to the system settings of LTSPICE. This met all desired requirement mentioned in the theory section.

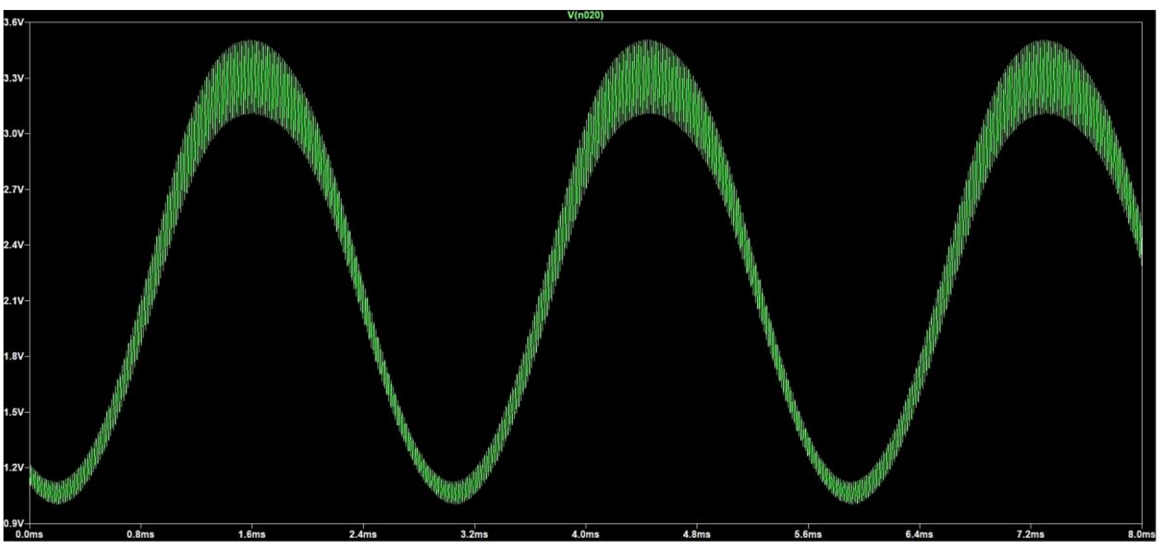


Figure 39: Peak Detector Integrated with 350 Hz AM Circuit.

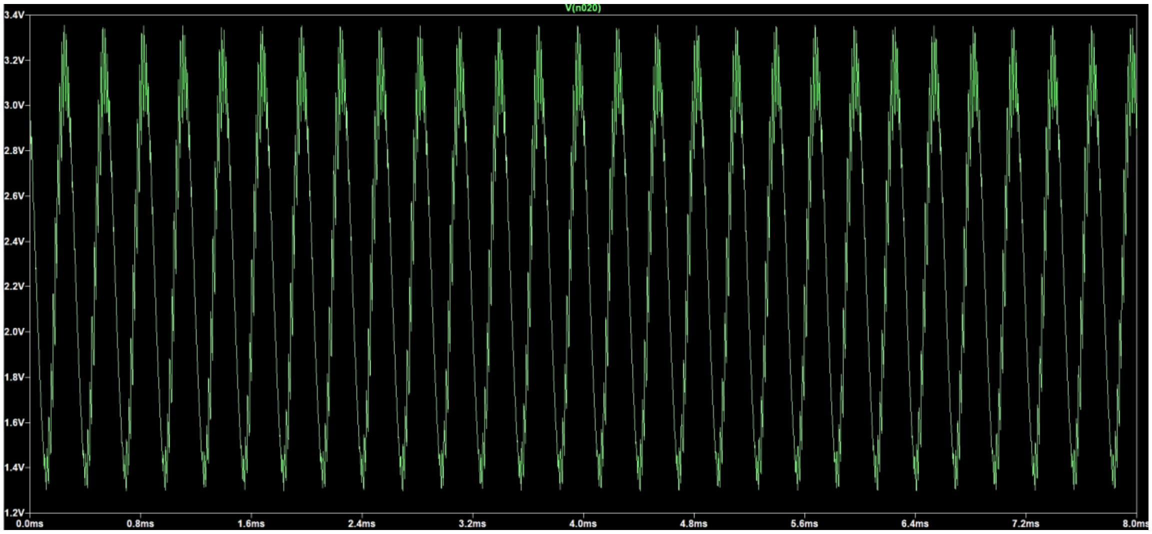


Figure 40: Peak Detector Integrated with 3.5 kHz AM Circuit.

Second Order Bandpass Filter

Fig. 41 shows 2nd order bandpass filter with both low and high cutoff frequencies. The cutoff frequencies generated were found to be nearly accurate to the expected frequencies of 350 Hz and 3.5 kHz. Fig. 42 and Fig. 43 show the resulting plots when the 2nd order bandpass filter was connected to the 350 AM radio and the 3.5 kHz AM radio, respectively. This met all desired requirement mentioned in the theory section.

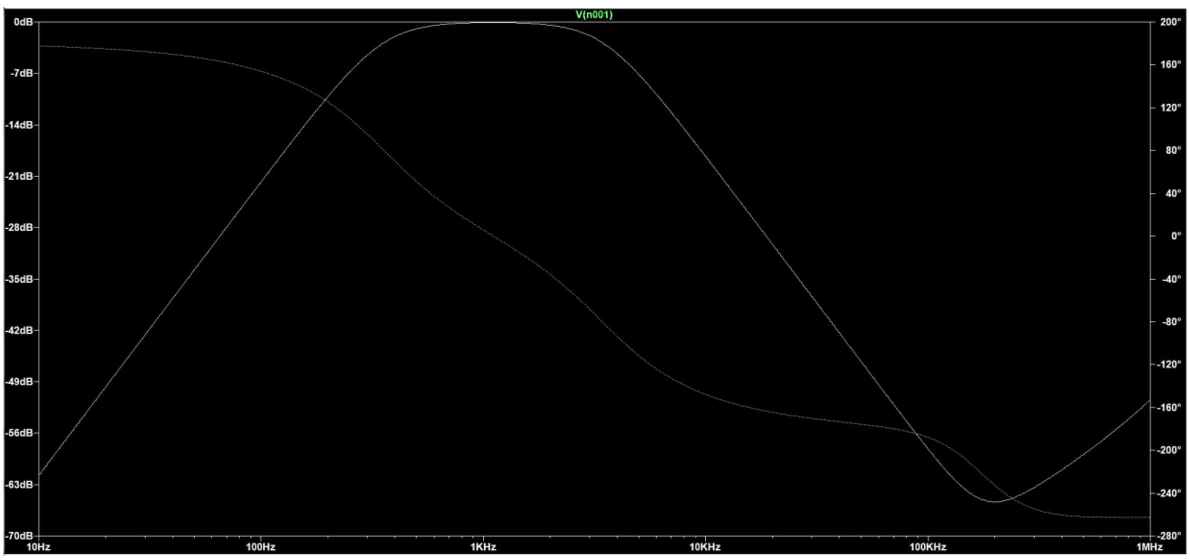


Figure 41: 2nd Order Bandpass Filter with both low and high cutoff Frequencies.

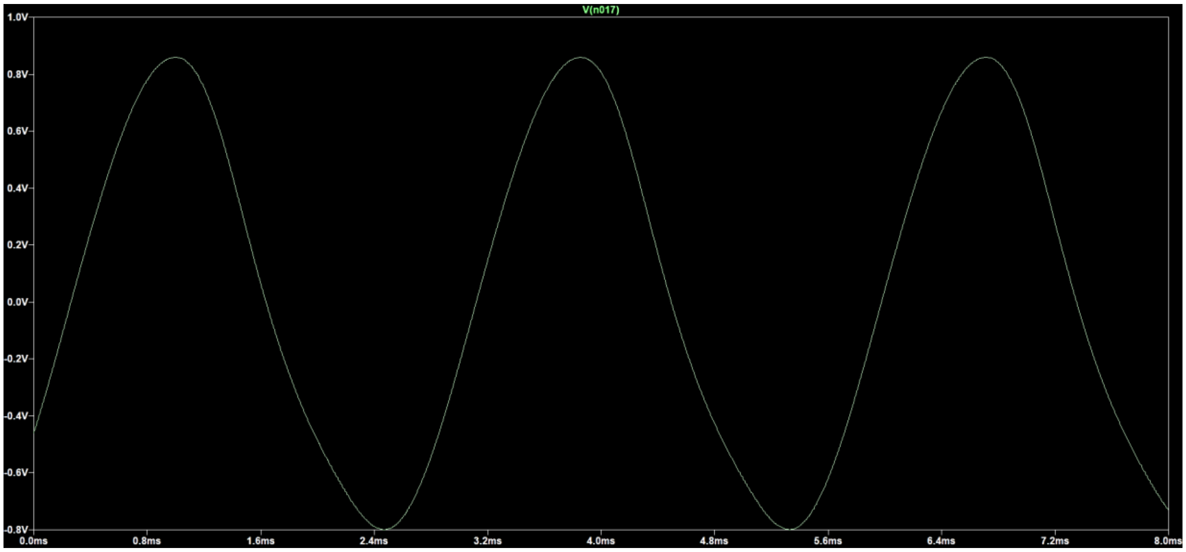


Figure 42: 2nd Order Bandpass Filter integrated with 350 Hz AM Radio.

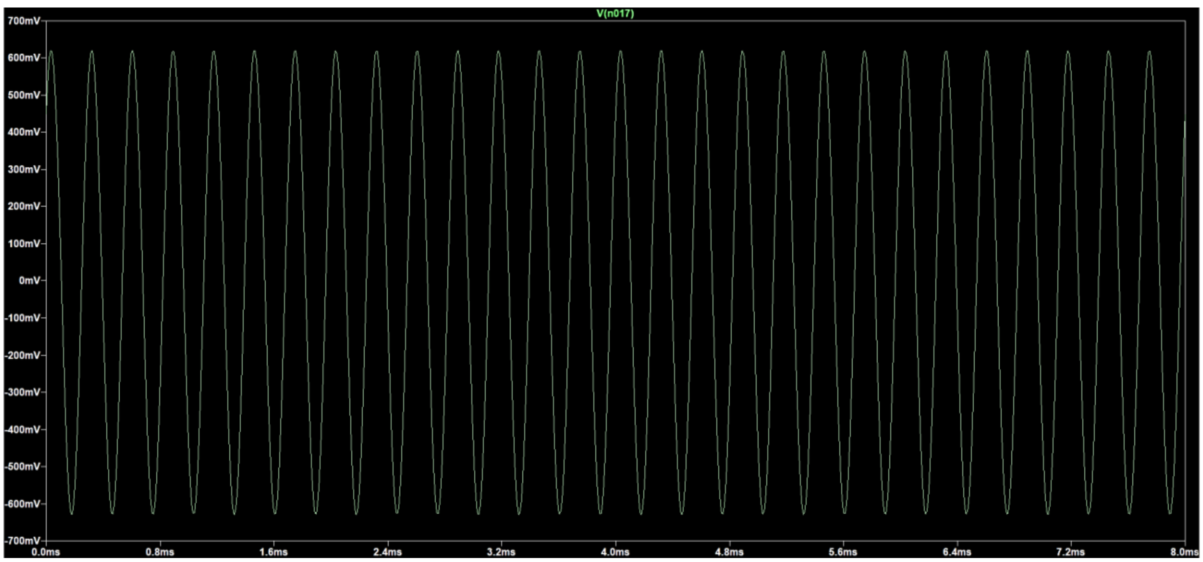


Figure 43: 2nd Order Bandpass Filter integrated with 3.5 kHz AM Radio.

Low Pass Butterworth Filter

Fig. 44 below shows the high cutoff frequency of the low pass butterworth circuit on its own. The cutoff frequency was measured to be 3.5 kHz which is equal to the expected frequency of 3.5 kHz.

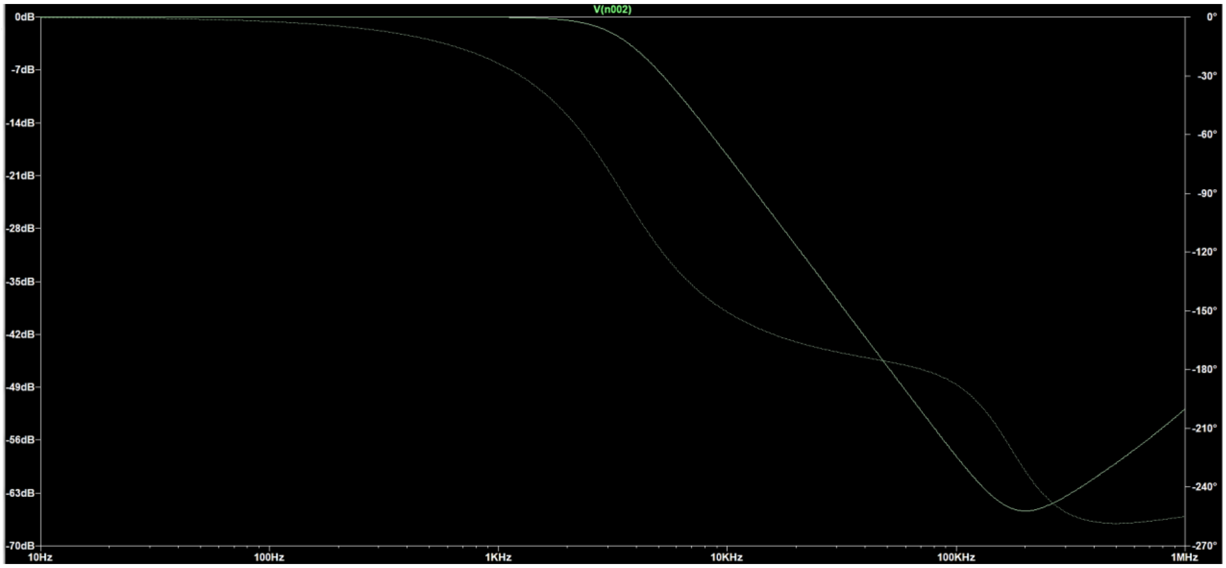


Figure 44: High cutoff frequency of Low Pass Butterworth.

High Pass Butterworth Filter

Fig. 45 below shows the low cutoff frequency of the high pass butterworth circuit on its own. The cutoff frequency was measured to be 349 Hz which is .28% error from the expected frequency of 350 Hz. This is deemed accurate because it is within 1% error.

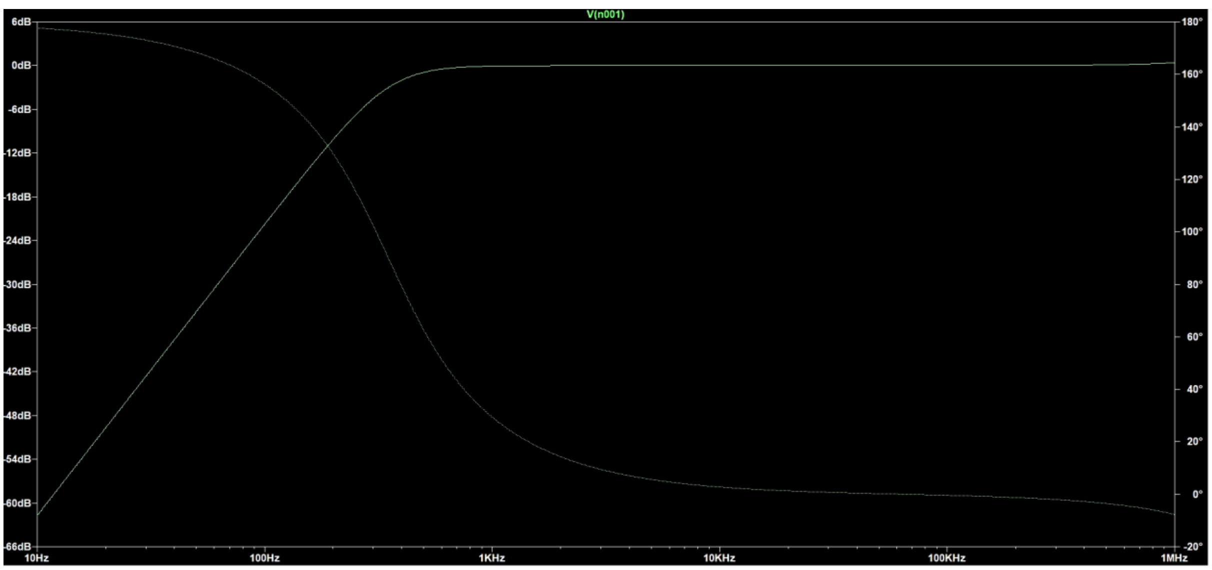


Figure 45: Low cutoff Frequency of High Pass Butterworth Filter.

Comparator

Fig. 46 below shows the comparator at 350 Hz and Fig. 47 shows the comparator at 3.5 kHz, both independent of the AM radio. The output voltage range is shown to be within ± 12 V, this was just as predicted as well as it being a pulse signal. This proved that the circuit is saturated, and the voltage output of the AM radio will not generate a cutoff voltage.

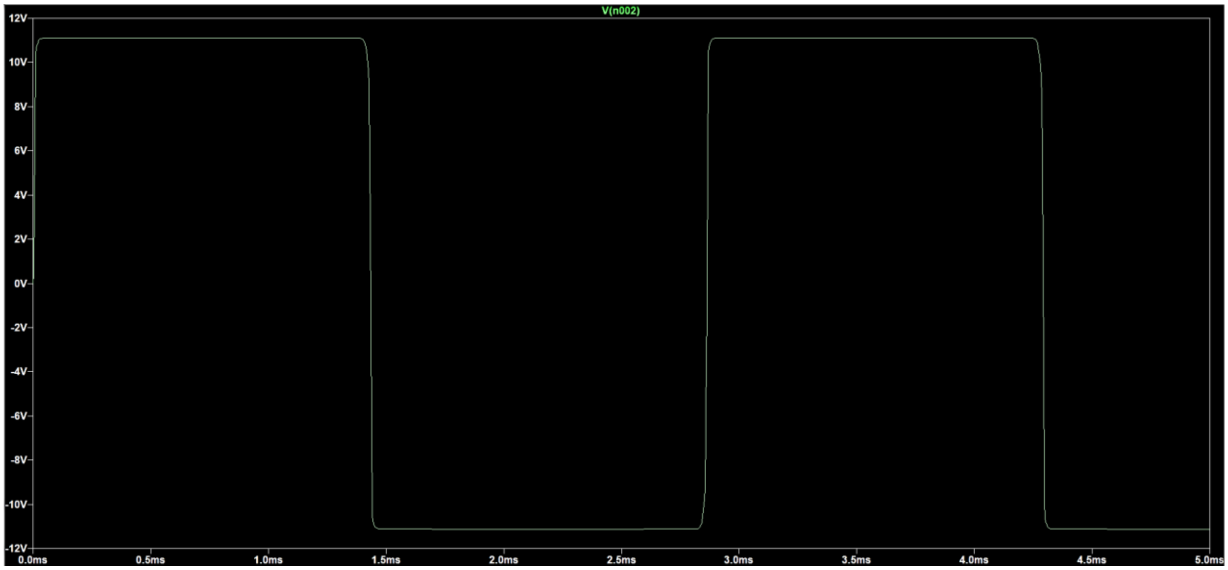


Figure 46: Comparator at 350 Hz.

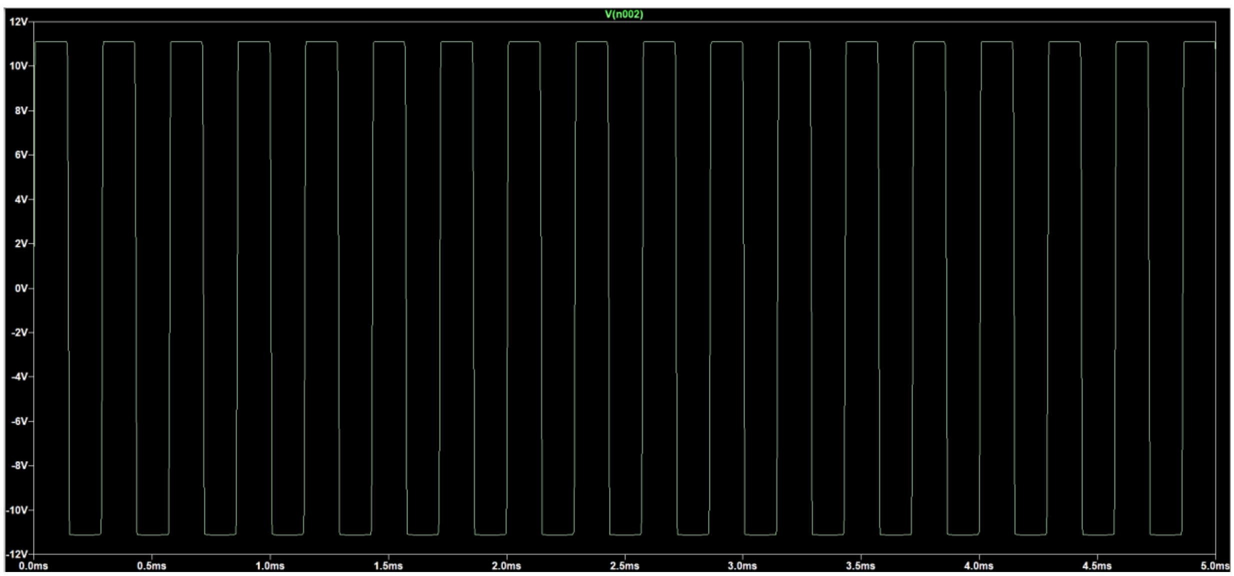


Figure 47: Comparator at 3.5 kHz.

Fig. 48 and Fig. 49 is the comparator connected to the AM radio at 350 Hz and 3.5 kHz, respectively. The difference from Fig. 46 and 47 is the frequency of the pulse signal, the voltage max and min are the same. This met all desired requirement mentioned in the theory section.

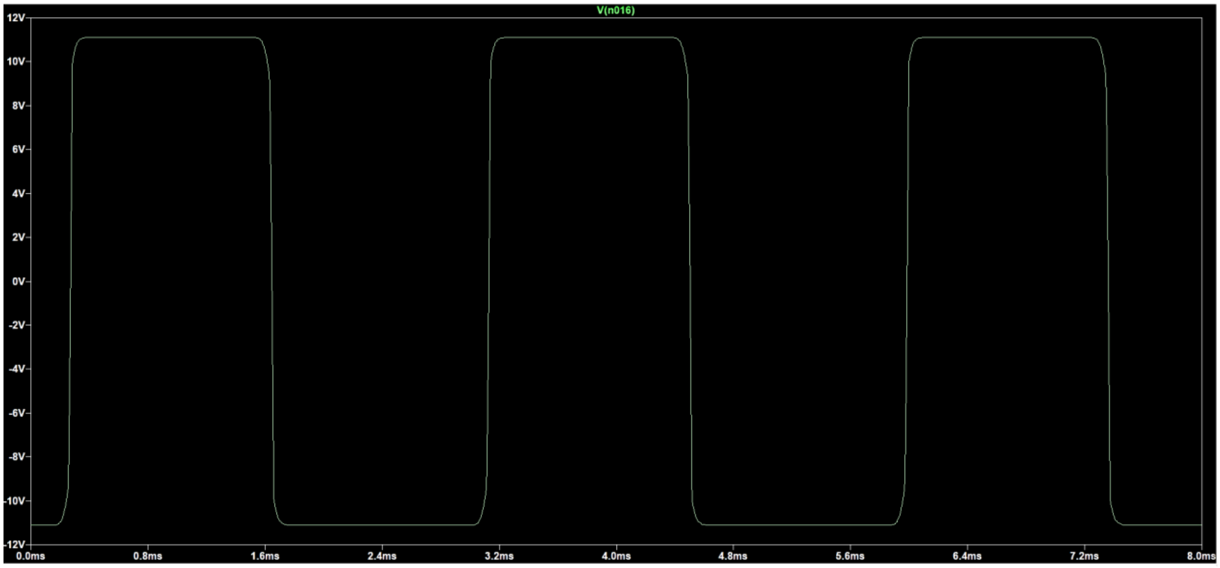


Figure 48: Comparator integrated with AM radio at 350 Hz.

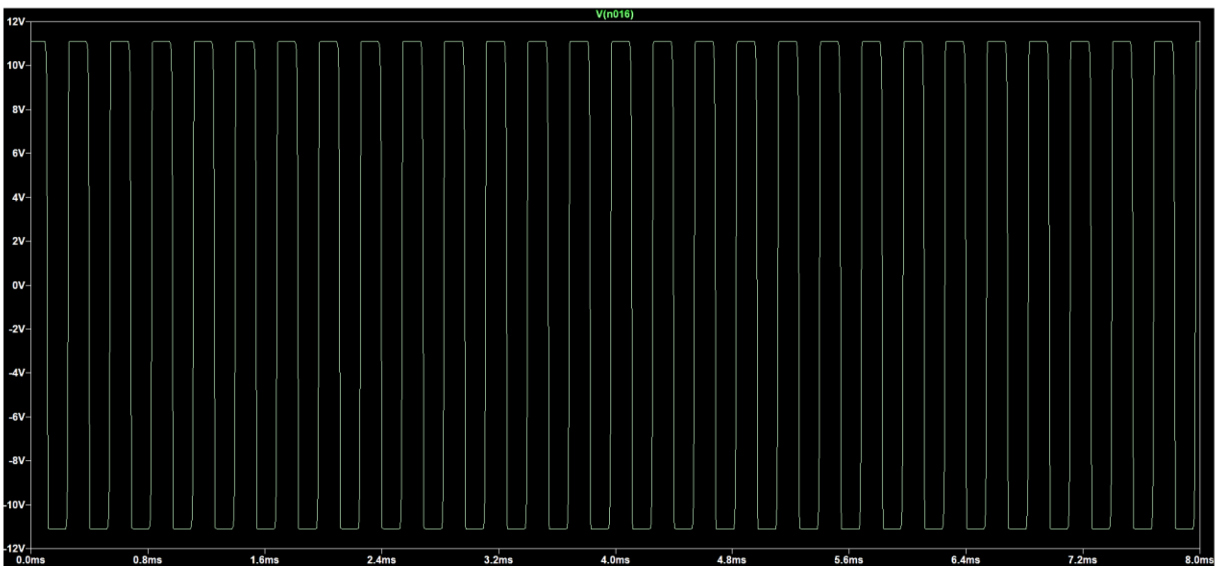


Figure 49: Comparator integrated with AM radio at 3.5 kHz.

Buffer Amplifier

Fig. 50 and 51 below shows the buffer amplifier connected to the comparator at 350 Hz and 3.5 kHz, respectively. Since the voltage signal going through the diode, voltage divider and the NMOS was expected to reduce, the output voltage was predicted to be between 4 V and 5 V. The output voltage ended up being 3.74 V which is a 6.5% error from 4 V. This was deemed acceptable for an output voltage. The cause for error was the LTSPICE settings. This met all desired requirement mentioned in the theory section.

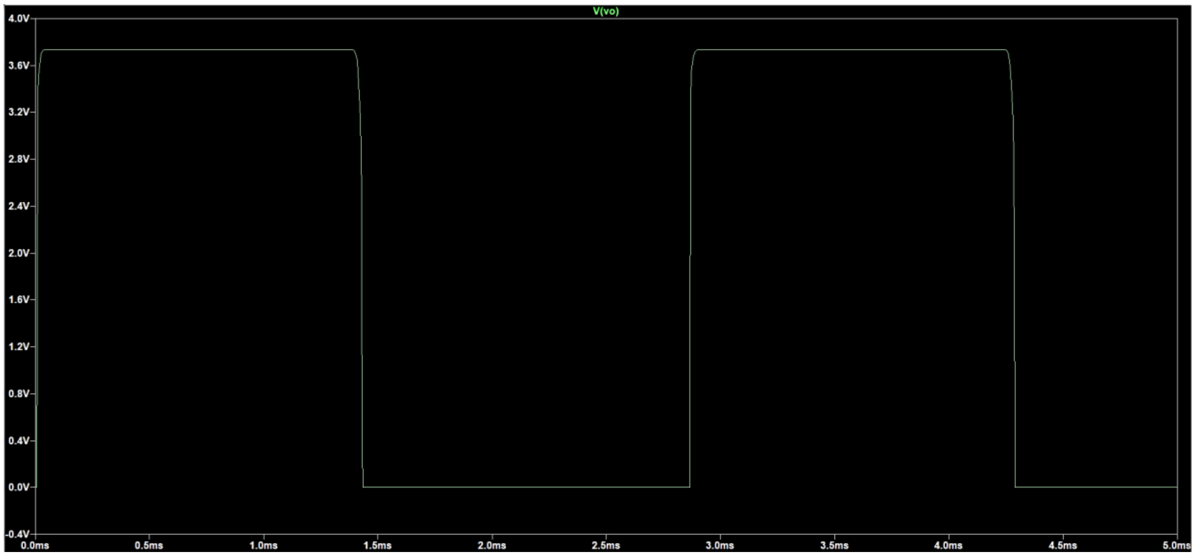


Figure 50: Buffer Amplifier connected to Comparator at 350 Hz.

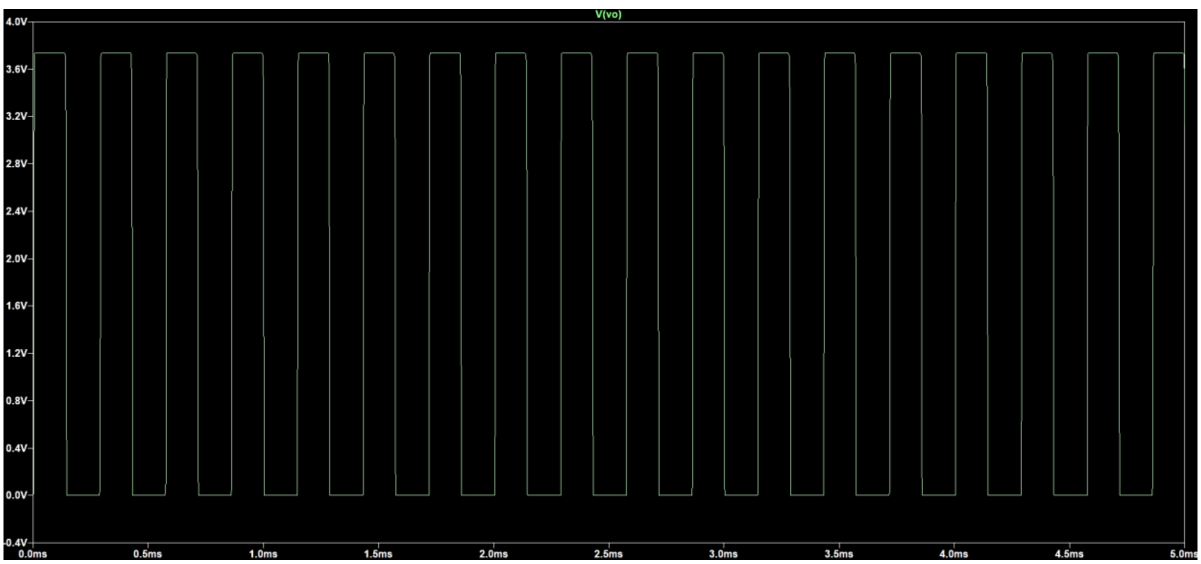


Figure 51: Buffer Amplifier connected to Comparator at 3.5 kHz.

AM Radio

Fig. 52 and 53 below shows the final signal simulation passing through the entire AM radio at 350 Hz and 3.5 kHz, respectively. The voltage peak error was the same as the buffer amplifier connected to the comparator with the same expected output voltage.

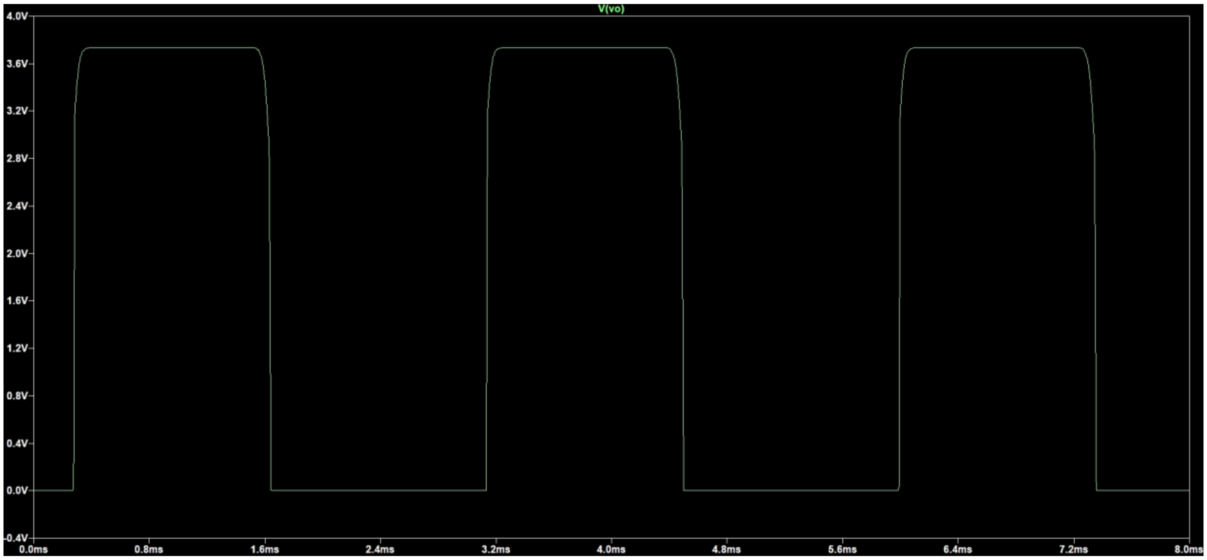


Figure 52: Simulation of Signal passing through entire AM Radio at 350 Hz.

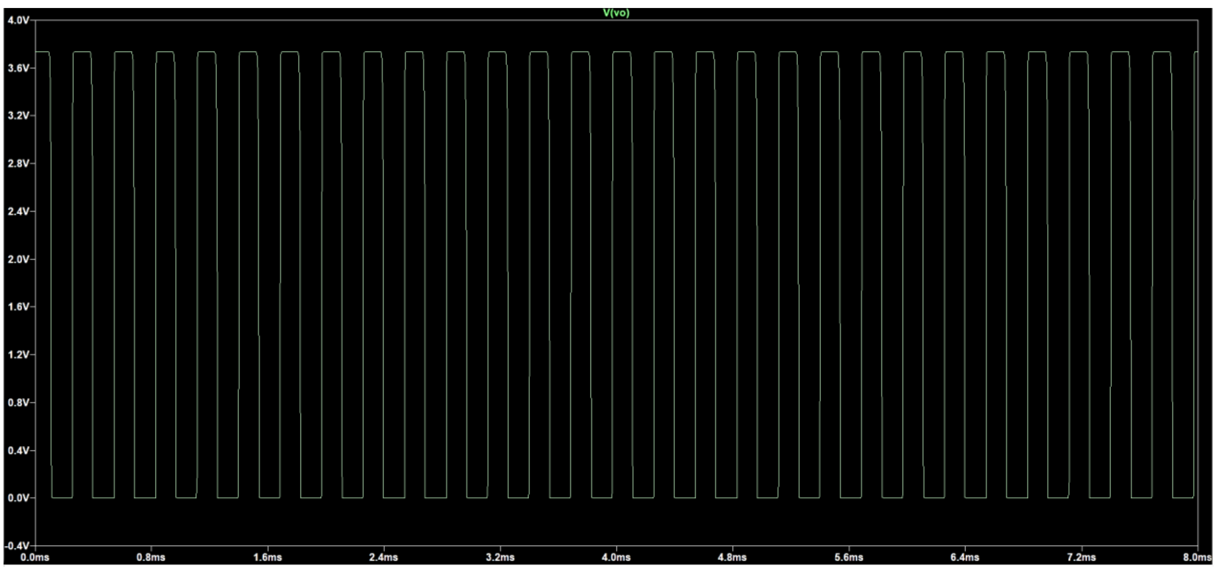


Figure 53: Simulation of Signal passing through entire AM Radio at 3.5 kHz.

5.0 Conclusions:

To conclude this final project report, the AM radio was successfully designed and simulated. Every component was simulated separately, the functions were verified, then was simulated all together. The frequency of the signal at the speaker matched the initial oscillator frequency at both 350 Hz for the message frequency and 3.5 kHz for the message frequency. The carrier frequency also met the special requirement by being within 60 kHz and 70 kHz. This project verifies the practice of AM modulation and demodulation.

References:

[1] A. Sedra and K. Smith, “Microelectronic Circuits,” Oxford University Press, Seventh Edition, 2015

[2] https://en.wikipedia.org/wiki/Colpitts_oscillator