# AM Radio Receiver Project

Physics 4BL Lab 1
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# Introduction

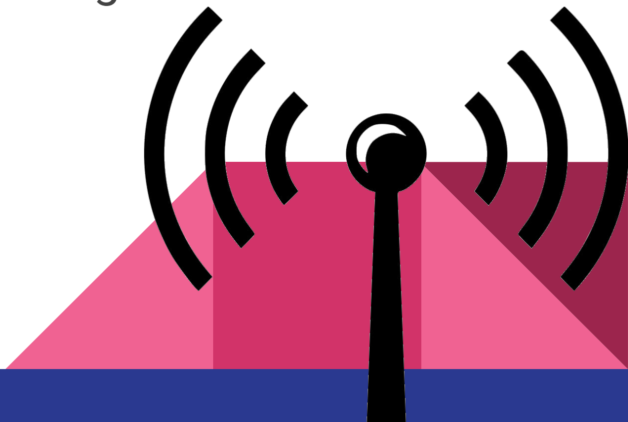
- The goal of our project was to receive an AM radio wave and recover the information signal from the carrier wave
- Our project relies on the physics of wave interference and resonance to detect Amplitude Modulated signals
- We attempted to utilize an LC circuit, amplifier, diode, a high pass filter, and an RC low pass filter to detect the message carried by an Amplitude Modulated Wave

# Motivation

- Radios were created in the late 1890s - early 1900s and are an essential form of light speed communication.
- Today, two types of radio waves: FM and AM radio waves.
- FM radio waves oscillate between 88 MHz - 108 MHz.
- AM radio waves oscillate between 540 kHz - 1700 kHz
- We chose AM radio receiver because they oscillate at a much lower frequency, making it easier to make circuits with a resonant frequency within that range.
- AM radio receivers are also much cheaper and easier to build than FM radio receivers
- An AM receiver reproduces the modulated electromagnetic radio waves into sound waves
- AM Radio waves are used for broadcasting

# Amplitude Modulation Theory

- Radio waves are a type of electromagnetic wave in a frequency between 3kHz-300GHz that are often adjusted to hold and send information
- AM (amplitude modulated) radio waves are the lowest range of radio frequencies around 540kHz-1700kHz. They are composed of an information signal and a carrier signal
- An LC circuit can be used to receive an AM wave by tuning its resonant frequency to that of the carrier wave

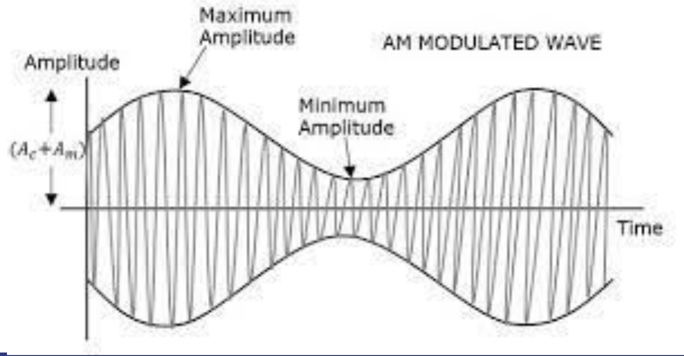


# Amplitude Modulation Theory

- An AM wave is composed of an information signal and a carrier wave whose amplitude is varied to that of the original wave.
- These waves are combined using an AM Modulator, which generates the carrier wave in phase with the information signal, according to the equation:

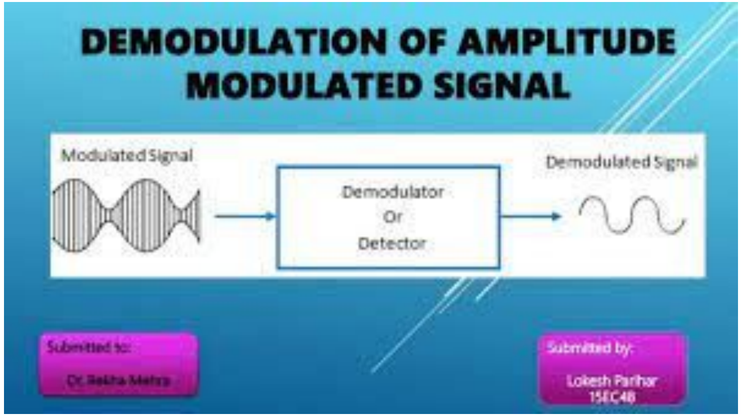
$$y(t) = [1 + m\cos(2\pi f_m t + \phi)]A\sin(2\pi f_c t)$$

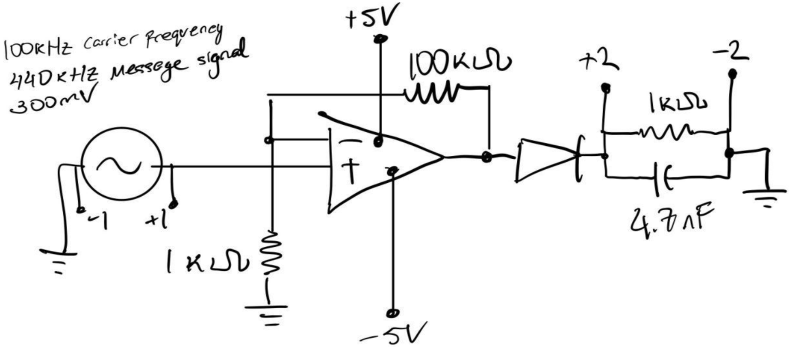
- m is the modulation index, f_c is the carrier wave frequency, f_m is the message wave frequency, A is amplitude of the carrier wave, and phi is the phase shift



# Amplitude Demodulation Theory

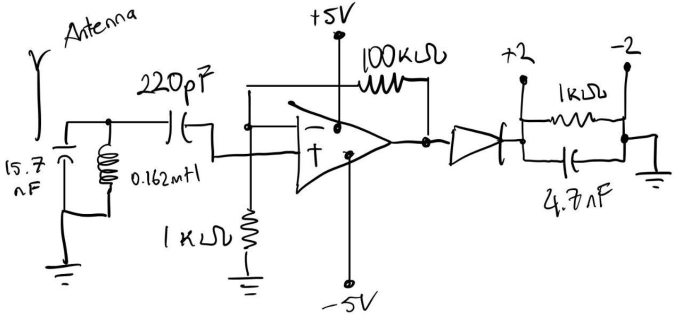
- Demodulation works to recover the information carried by the radio wave
- A circuit receives a modulated signal, and detects and filters out the carrier wave to detect the information signal, which we should be able to hear on a speaker.

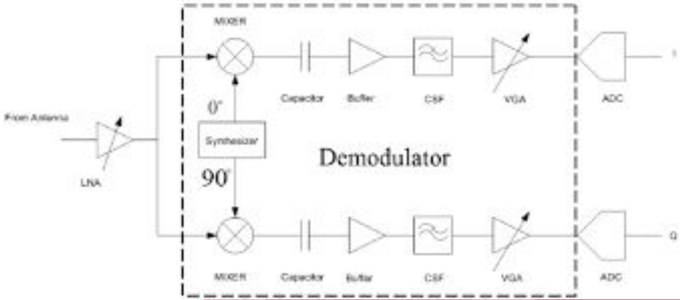


# Amplitude Demodulator Circuit Theory

- An LC Circuit is used to detect the AM radio wave received by an antenna by tuning its frequency to that of the carrier wave
- A diode is used to rectify the signal and the low pass filter removes frequencies at or above that of the carrier wave
- An operational amplifier boosts the voltage of the wave so that the diode can detect the carrier wave
- high pass filters can be added to eliminate any noise at particular frequencies that the antenna may have picked up



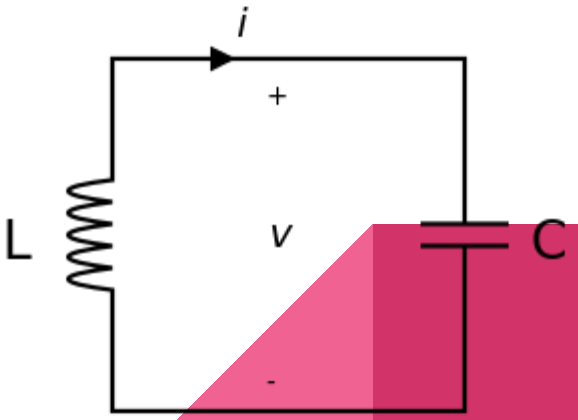
# LC Tank Circuit Resonance

Note: We assume the audience knows basic knowledge about complex numbers and impedance. The impedance of a Capacitor is $X_C = \frac{1}{iwC}$ and the impedance of an inductor is $X_L = iwL$ .

- Resonance occurs when the reactance of the inductor matches that of the capacitor. Then:

$$Im\{X_C\} = Im\{X_L\} \rightarrow \frac{1}{w_0 C} = w_0 L \rightarrow w_0^2 = \frac{1}{LC}$$

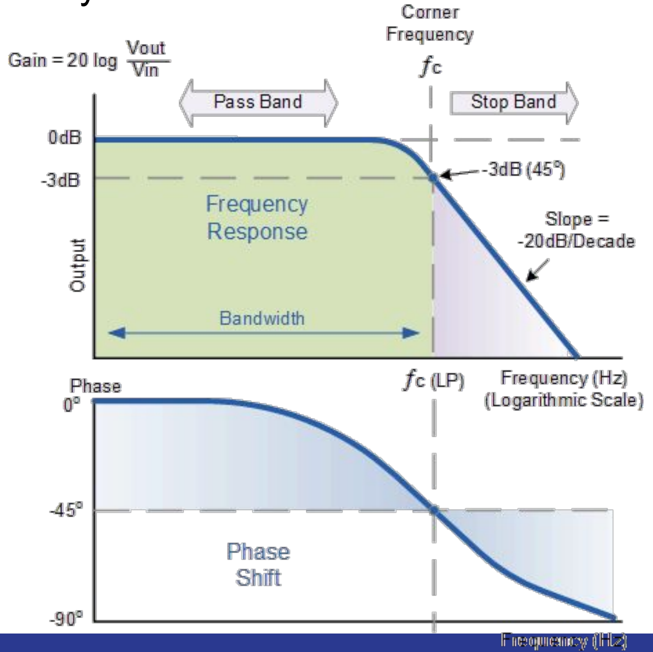
$$w_0 = 2\pi f_0 \rightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$$

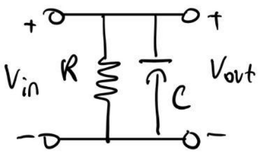


# RC Low pass filter

- Using Circuit Analysis we can derive the cut off frequency for an RC low pass filter.

Bode plots show the frequency response, that is, the changes in magnitude and phase as a function of frequency. This is done on two semi-log scale plots. The top plot is typically magnitude or "gain" in dB. The Bode plot below is that of a low pass filter. Notice that filtering starts after -3dB where the Output decreases drastically. We use this information to determine the cutoff frequency.




$V_{in} = I X_R$, $V_{out} = I X_C$

$V_{in} = IR$, $V_{out} = I \cdot \frac{1}{i\omega C}$

$\Rightarrow I = \frac{V_{in}}{R} \longrightarrow V_{out} = V_{in} \cdot \frac{1}{i\omega RC}$

The cut off frequency occurs at $\left|\frac{V_{out}}{V_{in}}(\omega)\right| = \frac{1}{\sqrt{2}}$ or 3dB

So, $\frac{1}{\omega_c RC} = \frac{1}{\sqrt{2}} \Rightarrow \omega_c = \frac{\sqrt{2}}{RC}$

since $\omega = 2\pi f$, $\boxed{f_c = \frac{\sqrt{2}}{2\pi RC}}$ is the cut off frequency

# Operational Amplifiers

## 5.5 The Noninverting-Amplifier Circuit

Figure 5.13 depicts a noninverting-amplifier circuit. The signal source is represented by $v_g$ in series with the resistor $R_g$. In deriving the expression for the output voltage as a function of the source voltage, we assume an ideal op amp operating within its linear region. Thus, as before, we use Eqs. 5.2 and 5.3 as the basis for the derivation. Because the op amp input current is zero, we can write $v_p = v_g$ and, from Eq. 5.2, $v_n = v_g$ as well. Now, because the input current is zero ($i_n = i_p = 0$), the resistors $R_f$ and $R_s$ form an unloaded voltage divider across $v_o$. Therefore,

$$v_n = v_g = \frac{v_o R_s}{R_s + R_f}. \tag{5.17}$$

Solving Eq. 5.17 for $v_o$ gives us the sought-after expression:

$$\boxed{v_o = \frac{R_s + R_f}{R_s} v_g.} \tag{5.18}$$

◀ **Noninverting-amplifier equation**

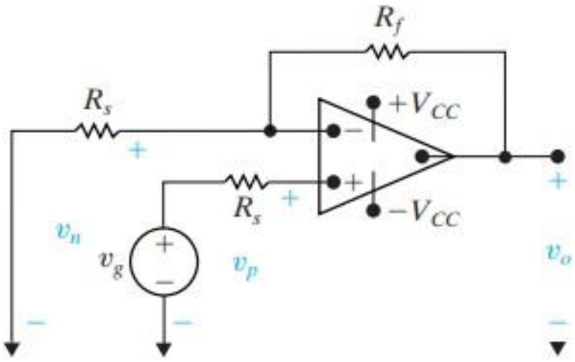
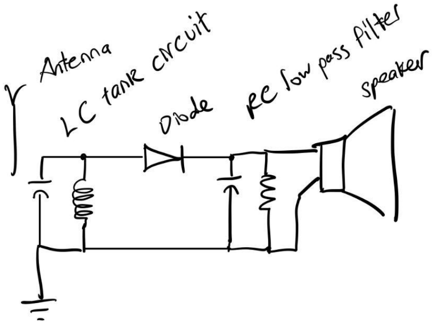


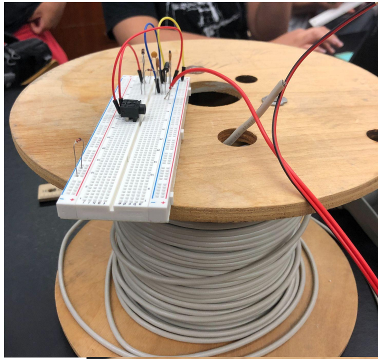

**Figure 5.13** ▲ A noninverting amplifier.

# Experimental Set-up (Initial Circuit)




- Using $f_0 = \frac{1}{2\pi\sqrt{LC}}$ we set the resonant frequency of our circuit to 1340kHz by using a 47H inductor and a 0.3pF capacitor

- We picked our Capacitance and Resistance to be 100Ω and 4.7nF in order to set the cut off frequency of the low pass filter below the carrier wave frequency using $f_c = \frac{\sqrt{2}}{2\pi \cdot \mathrm{RC}}$



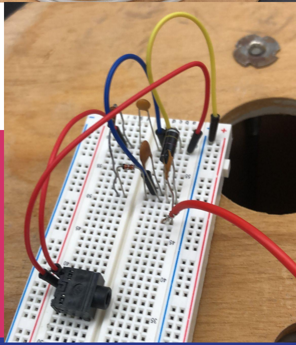
## Antenna
- Picks up various radio waves and transmits any signal via mutual inductance of the antenna and the inductor in the LC tank circuit

## LC Tank Circuit
- Acts as a tuner and only let Amplitude Modulated waves that are near its resonant frequency into the circuit while ignoring any other waves with a different frequency

## 1N4148 Small Signal Fast Switching Diode
- Used to rectify the Amplitude Modulated signals

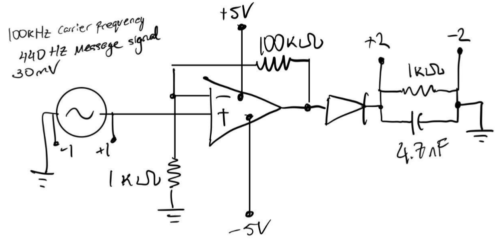
## RC Low Pass Filter
- Filters out the carrier wave so that the message wave could be sent to the speakers

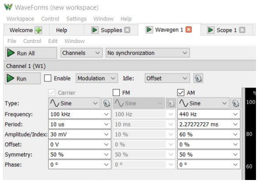
## Speaker
- Plays the message signal so the experimenters can confirm if the circuit works properly

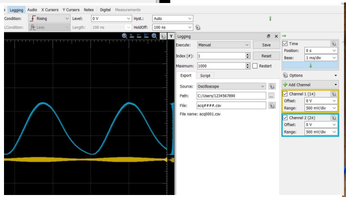


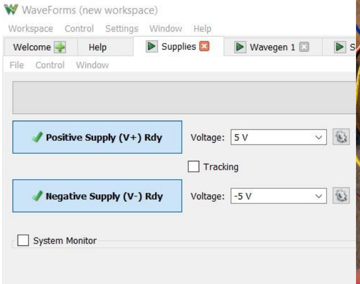
# Experimental Set-up (Audio Detection Circuit)

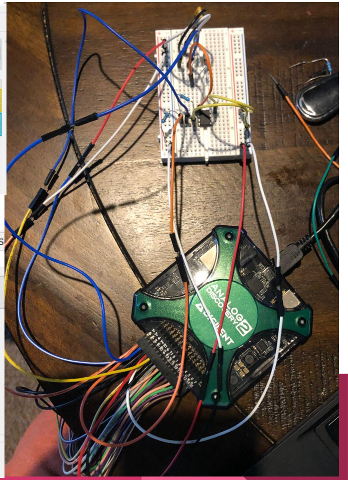
- The LC tank circuit and antenna were replicated with the Analog Discovery 2 (AD2) wavegen.
- Operational Amplifier was used to amplify the signal coming from the “LC tank circuit”or the AD2 wavegen.
- Measurements were taken using the Analog Discovery 2 Data Logger and Channels 1 and 2 (Waveforms Application)
- The Op-Amp was powered using the AD2





## Analog Discovery 2 Wavegen

- Replicated a properly working LC tank Circuit and Antenna that picked up an Amplitude Modulated signal with 60% modulation, 100 kHz carrier frequency, 440 Hz message frequency, 30 mV amplitude

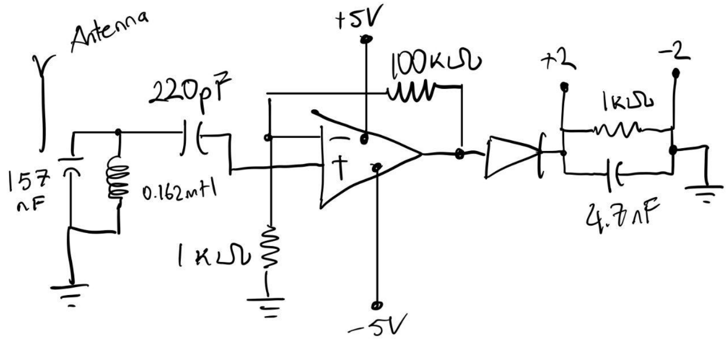
## MCP6022 Operational Amplifier

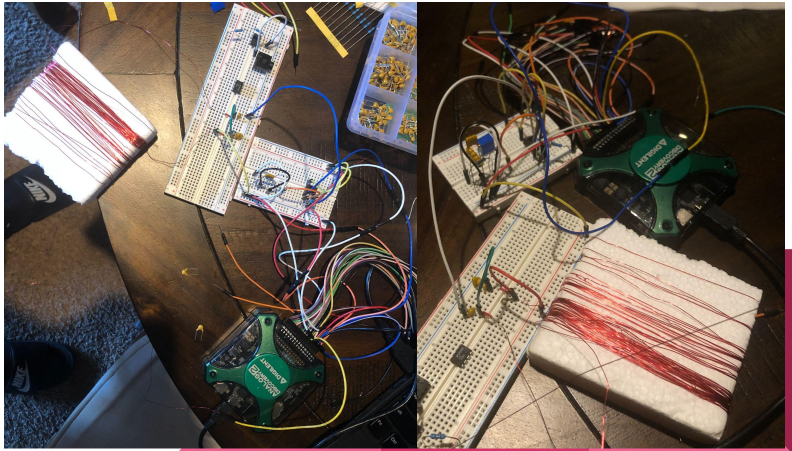
- Increased the voltage (amplitude) of the signal above the forward voltage of the diode so the signal can get rectified.

*No calibration for the AD2 was necessary

# Experimental Set-up (AM Radio Receiver Circuit)

- Used a hand-made inductor made from High Quality Polyurethane Enameled Copper Wire to increase inductance of LC tank Circuit
- The Antenna was changed to be the same material as the inductor
- A capacitor was added in between the Op-Amp input and the LC tank circuit to act as a High Pass Filter



High Pass Filter

- A 220pF Capacitor was used as a high pass filter in order to remove ambient room noise that the antenna picks up - about 60Hz entirely.

# Video

# Data Analysis

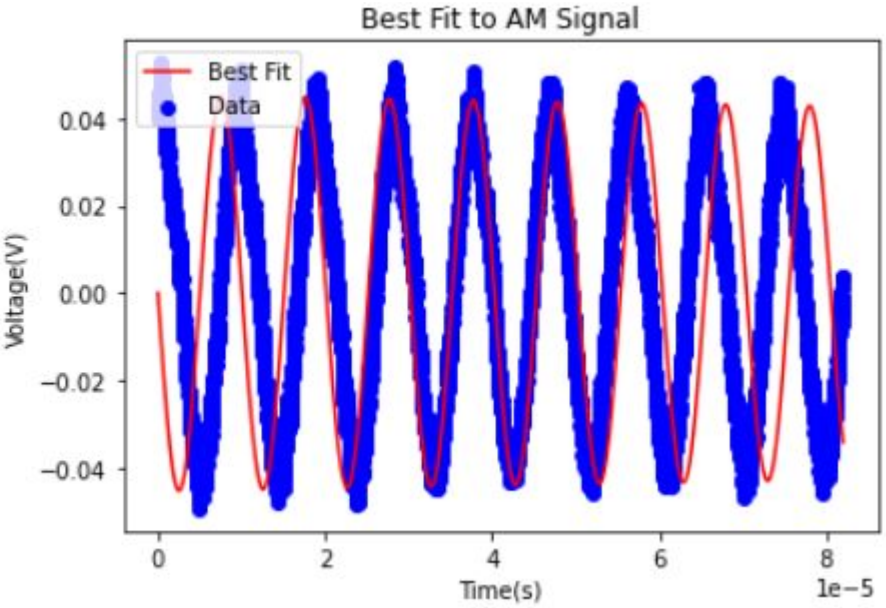
Portion of a complete oscillation of 100kHz generated AM signal

A = 27.1792157 mV

f_m = 155.120279 Hz

f_c = 99.3619947 kHz

phi = 8.43974118 or 123.5 degrees




$$y(t) = [1 + m\cos(2\pi f_m t + \phi)]A\sin(2\pi f_c t)$$

# Data taking and Analysis

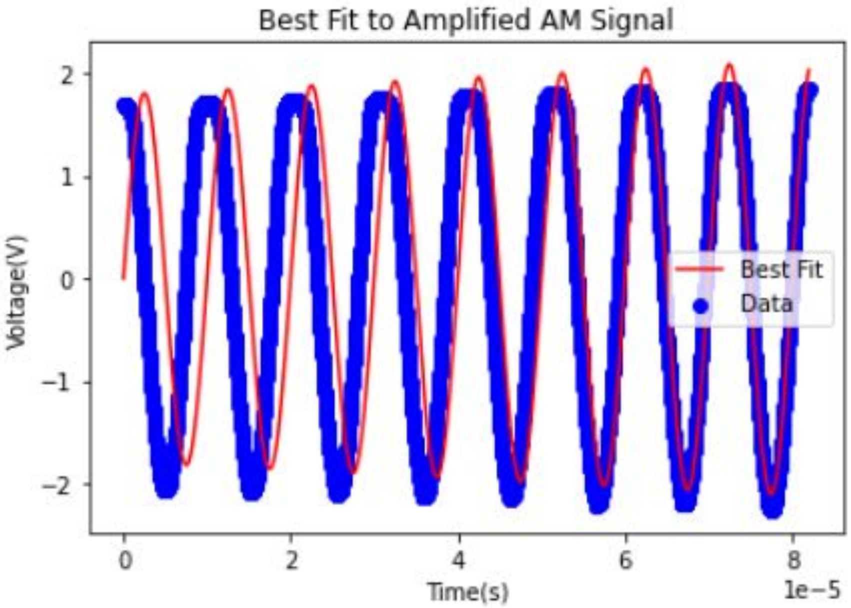
Portion of a complete oscillation of 100kHz amplified AM signal

A = 2.01427150 V

f_m = 443.345819 Hz

f_c = 100.012694 kHz

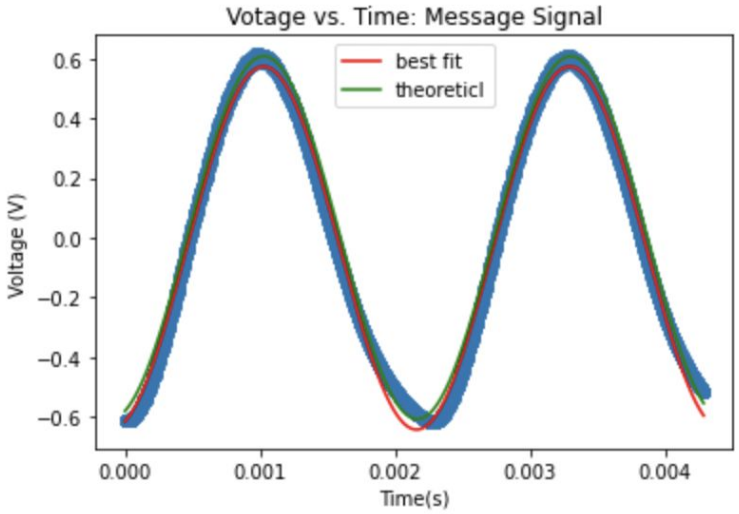
phi = -2.31544912 04 -132.66 degrees




$$y(t) = [1 + m\cos(2\pi f_m t + \phi)]A\sin(2\pi f_c t)$$

# Data taking and Analysis

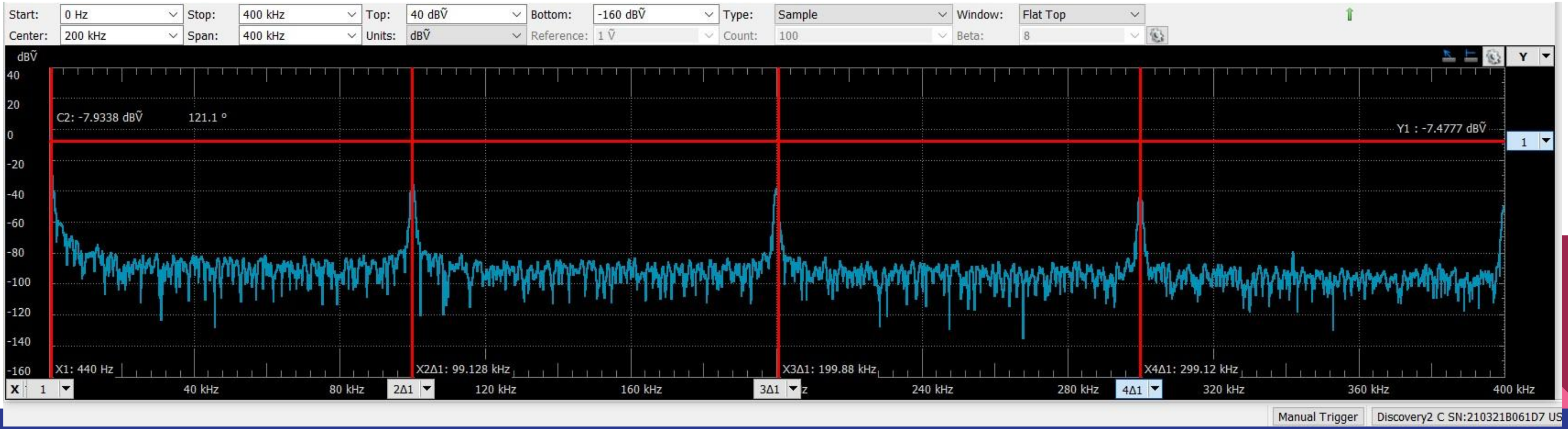
- Figure represents the sine message signal received by the arduino
- Message wave oscillates at 440Hz (Blue).
- Best fit line: $y = C + A*\sin(\omega t + \Phi)$
    - $C = 0$
    - $A = 0.60803$ V
    - $\omega = 2770.91$(441Hz)
    - phi = -1.26897
- Theoretical line parameters:
    - $C = 0$
    - $A = 0.60803$ V
    - $\omega = 2764.60$(439 Hz)
    - phi = -1.26997




$y = C + A*\sin(\omega t + \Phi)$

# Data taking and Analysis

- The highest peak of the Fourier Transform of the message signal occurs at 440 Hz which agrees with what we expect
- However, we do see some overtones most likely due to the amplification process done by the Operational Amplifier.



# Results

A 100 KHz AM signal was generated from a waveform generator with a 30 mV voltage drop. The circuit then amplified the voltage to an expected 3V to allow the diode to demodulate and process AM signal and process the 440 Hz sound wave.

The circuit was successful in demodulating the 100 KHz signal, allowing the 440 Hz signal to be filtered and read by the circuit. The opt-amp amplified the voltage to 2V, which did not reach the expected 3V. The percent error in the amplitude in both wave signal was 32.85%. The percent error in the frequency read by the arduino was 0.013% for the 100 KHz and 0.76% for the 440 Hz signal.

These low percent errors means that our circuit is precise at reading the wave signals. The huge percent error in the amplitude is due to the low gain bandwidth in our amplifier.

# Discussion

- Our carrier frequency values from our best fits were very accurate.
- Our message frequency for the amplified signal was very accurate. That of the Original AM signal was inaccurate due to the discrepancy of our best fit with our data
- Our Amplitude Errors were fairly high due to the fact that our operational amplifier did not have enough unit gain bandwidth and because the portion of the AM wave that we took data from was not large enough.

| Error | Amplitude | f_m | f_c |
|---|---|---|---|
| Original AM signal | 9.40% | 64.75% | 0.64% |
| Amplified AM signal | 32.85% | 0.76% | 0.013% |

# Discussion

- Our message signal frequency error was 0.23% which means our best fit was very accurate.
- The highest peak of the Fourier Transform of the message signal occurs at 440 Hz which agrees with what we expect.
- Overall, our Audio detection circuit worked very well and a major part of the errors can be attributed to the best fits that were used rather than problems with our circuit.
- Our results generally matched our predictions

# Conclusion and Future Prospects

- Overall, the initial circuit and the AM Radio Receiver Circuit did not work properly due to a variety of reasons.However, our Audio Detection circuit worked very well.
- An AM signal with 100 kHz carrier wave and a 400Hz message wave at 60% modulation and a 30 mV amplitude was input to the circuit.
- Data was collected at the input and output of the Op-Amp. The gain of the Op-Amp was determined to be 74.11 which was 26.62% off from the theoretical gain of 100.
- Using a best fit sine wave, we determined the frequency of the message signal to be 441.00Hz which was 0.23% of from the theoretical frequency of 440Hz. The Fourier Transform graph also showed that the most prominent frequency was 400Hz.

# Conclusion and Future Prospects

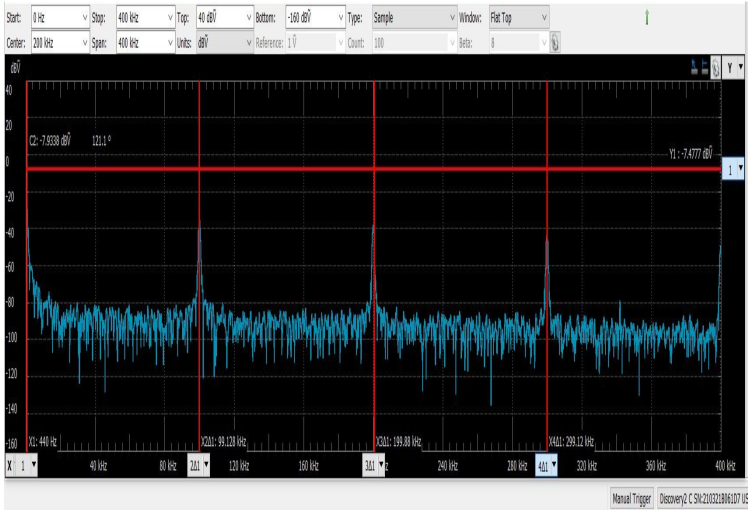
Initial Circuit

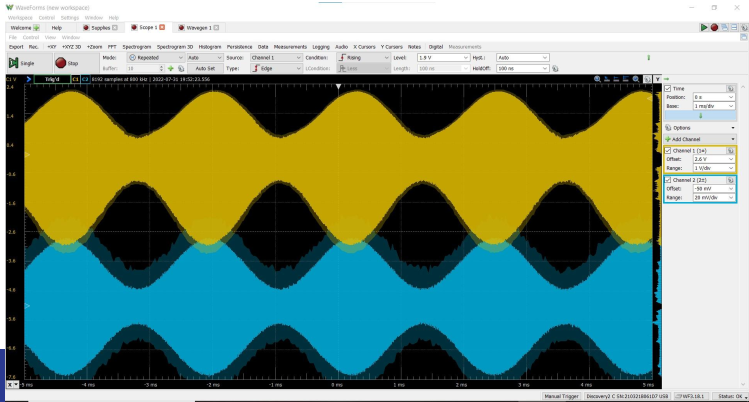
- The Inductor in the LC tank circuit did not have enough inductance to properly pick up AM Waves
- The AM waves that were picked up did not have high enough voltage to pass through the diode. This was because the LC tank circuit had a high output impedance.
- We did not have an amplifier for the speakers that was good enough to amplify the signal so that it could be heard through wired headphones

# Conclusion and Future Prospects

## Audio Detection Circuit

- Although the signal that we picked up was ideal, our signal was shifted down in voltage due to the impedance and voltage swing of the op amp
- The Fourier Transform of the message signal showed the presence of overtones which meant that the message signal that we extracted had noise due to the error that we previously mentioned.
- The gain of the Op-Amp was not as high as the predicted gain because the Op-Amp we were using was not good enough.
- The least squares fitting method did not work very well for our data because our data points were very close together. This caused inaccuracies in calculations and best fit parameters.



# Conclusion and Future Prospects

AM Radio Receiver Circuit

- We could not test on top of a building where there was an abundance of radio waves due to time constraints. Furthermore, our antenna was really short so we opted to use the AD2 wavegen to test our circuit
- The LC tank circuit and the antenna did not work really well due to the choice of materials and antenna length. This resulted in the circuit not working properly and no message signal could be extracted.

# Conclusion and Future Prospects

If we were to do this experiment again, we would:

- Order Operational Amplifiers that have a much higher unit gain bandwidth then the one we used so that it is suitable for radio wave applications.
- We would get a variable capacitor with a wide range of capacitance
- A pre-made inductor that is relatively big in size and suitable for the LC tank circuit
- A good antenna
- A good speaker and a good amplifier for that speaker
- Have another device to collect data or have a better fitting method than least squares
- Or alternative to all of these options, we would change our circuit design (3 transistor AM Radio Receiver circuit)

# Special Thanks To..

Dr. Mike Briggs (ECE 3 Continuing Lecturer)