PHYS219_2020 - Alexander Shevchuk
Exp. 5 (Final Project)/Exp. 5 AM Radio

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Dec 05, 2020 @11:12 PM PST

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Exp. 5 AM Radio

Alexander Shevchuk - Dec 04, 2020, 1:04 PM PST

Introduction

Radio technologies are fundamental to the operation of modern society. The ability to transmit information nearly instantaneously over large distances is a prime example of sufficiently advanced technology being indistinguishable from magic, as said by Arthur C. Clarke. The invention of radio was, like all science, primarily a collaborative effort. The first apparatus was created by Guglielmo Marconi, in the mid 1890s. Today, radio powers our modern devices and almost every communication system. In this lab we will examine its roots.

The AM radio works by first receiving EM waves via a long antenna connected to a circuit tuned to resonate at the desired frequency. This way, only waves of a fixed frequency are received. After passing through the resonant circuit, the signal is passed through a low pass filer. This serves to demodulate the signal, so that the high frequency carrier signal is removed and only the acoustic, lower frequency signal remains. This signal is then amplified using a non-inverting Op-Amp, and fed to a speaker to be converted back into sound.

Alexander Shevchuk - Dec 04, 2020, 8:19 PM PST

Measurements

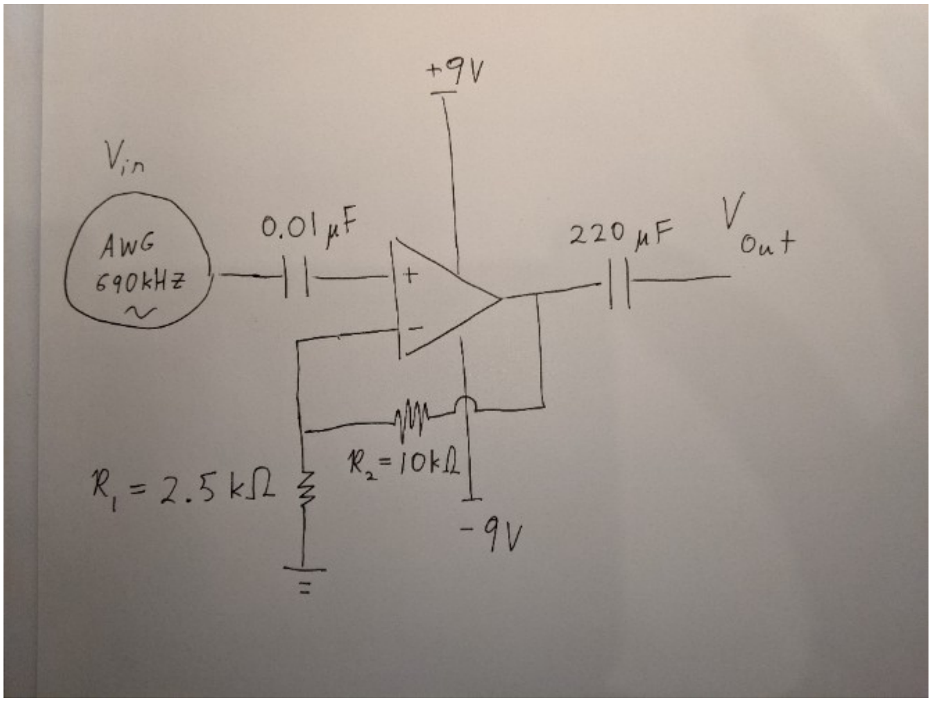
Below are measurements of the components used. Uncertainties were calculated using the Hantek manual, with the exception of the 220uF capacitor, which the DMM could not measure. An uncertainty of 10% was assumed for this.

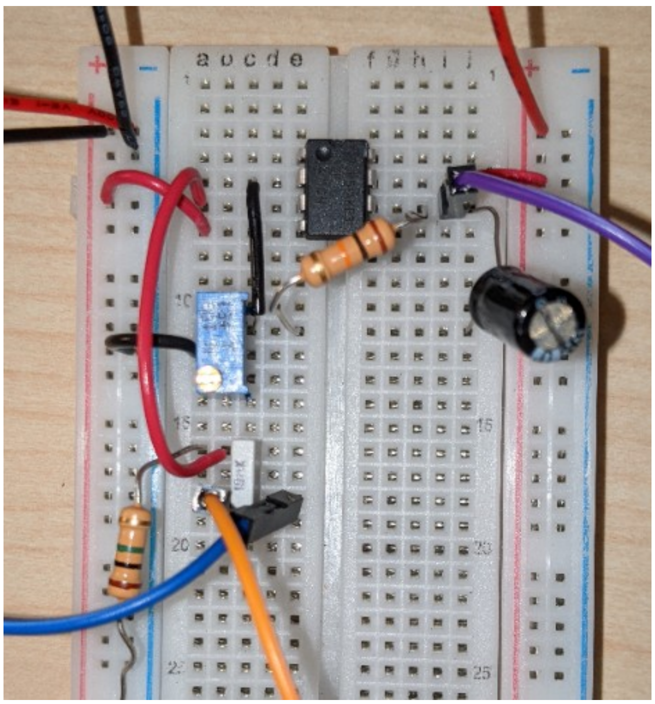
Component	Value	Uncertainty
R = 10 kOhm	9.87 kOhm	1.13 kOhm
R = 1 MOhm	0.995 MOhm	0.097 MOhm
C = 10 nF	9.44 nF	1.04 nF
C = 220 uF	220 uF	22 uF
C = 0.5 nF	0.65 nF	0.076 nF
R = 100 kOhm	99.3 kOhm	11.96 kOhm
R = 100 Ohm	98.7 Ohm	1.12 Ohm

Alexander Shevchuk - Dec 04, 2020, 12:35 PM PST

4.1 Amplifier

The circuit and schematic set up to test the amplifier is shown below:





Below are some properties of this setup:

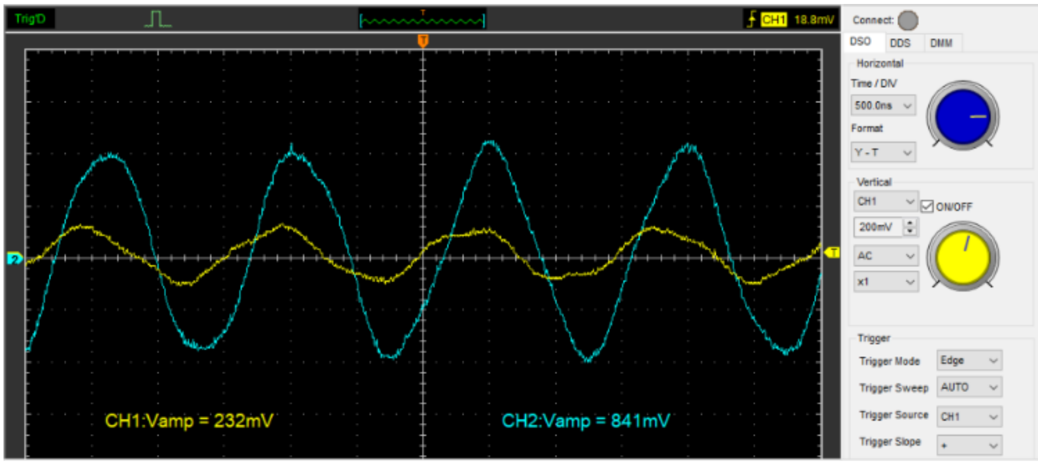
1. +5V input is on row 5, right side
2. -5V input is on row 7, left side
3. Op-Amp output is row 6, right side
4. Two 9V batteries are connected in series for power. The positive terminal of this connection (+9V) is connected to the + column of the right power rail, and the negative terminal (-9V) to the + column of the left power rail, oriented as the picture.
5. The ground (0V connection between the batteries) is connected to the - terminal of the left power rail
6. Output fed via AWG Gen Out cable through capacitor, row 18 (orange wire)
7. CH1 reads Vin, row 18
8. CH2 has Vout, on the Op-Amp output row

Alexander Shevchuk - Dec 04, 2020, 2:32 PM PST

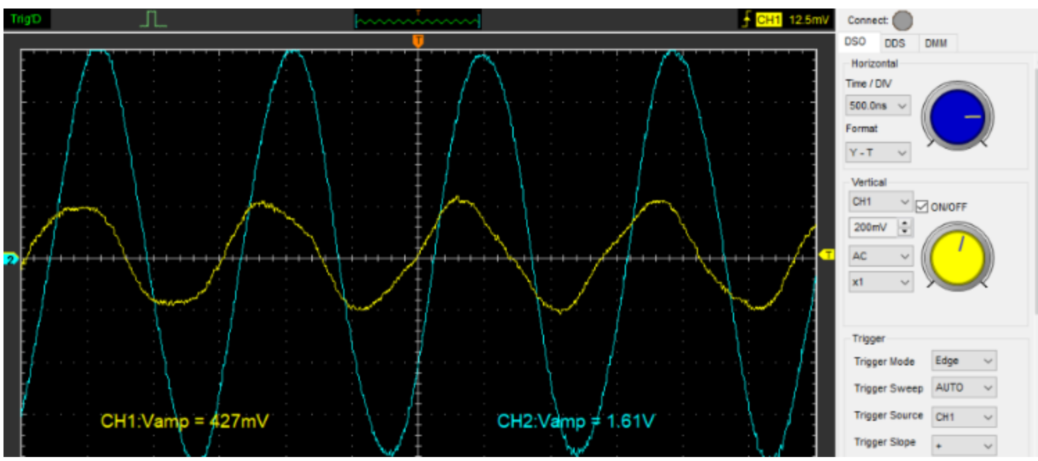
From our work during the prelab, we know that the expected voltage gain is given by $G_V = 1 + \frac{R_2}{R_1}$. Here we have R2 = 10kOhm, and R1 = 1kOhm, and therefore should expect to get a voltage gain of 4.

To measure the linear range of the amplifier, various measurements of Vout vs Vin were taken. These were measured using the Hantek software "Measure" function, and the amplitude it gave was examined. This can also be seen in the pictures.

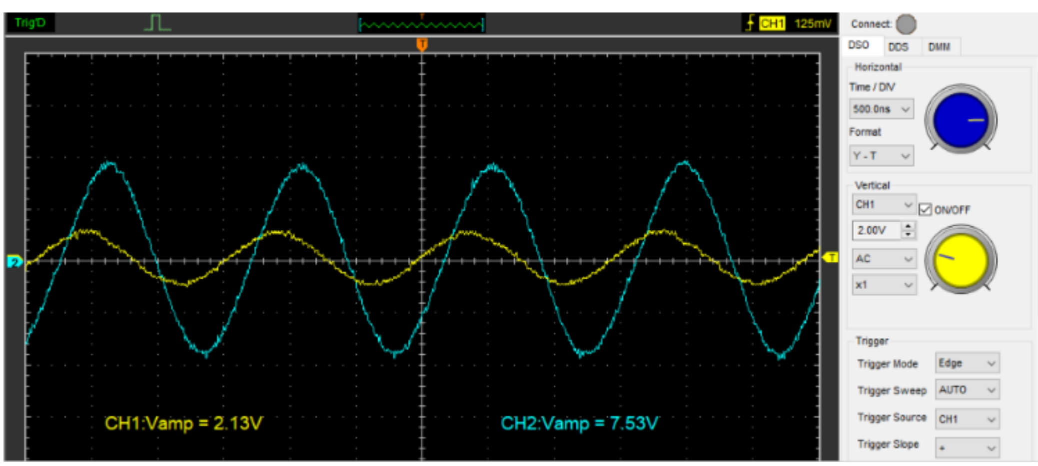
Below is an image with Vin at 0.10V, an offset of 0V, a time scale if 500ns, and channel amplitudes of 200mV. We can see that a gain of 4 is achieved.



And here is a picture with Vin at 0.20V:

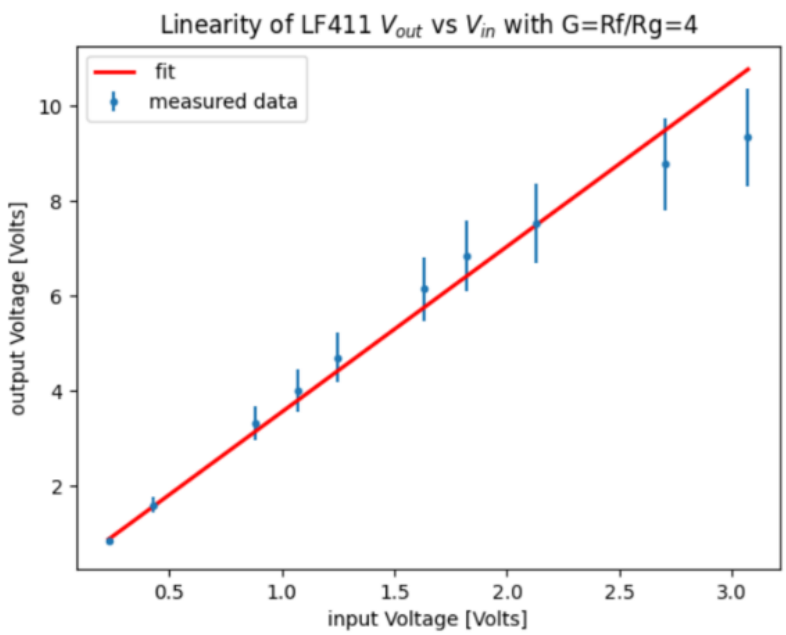


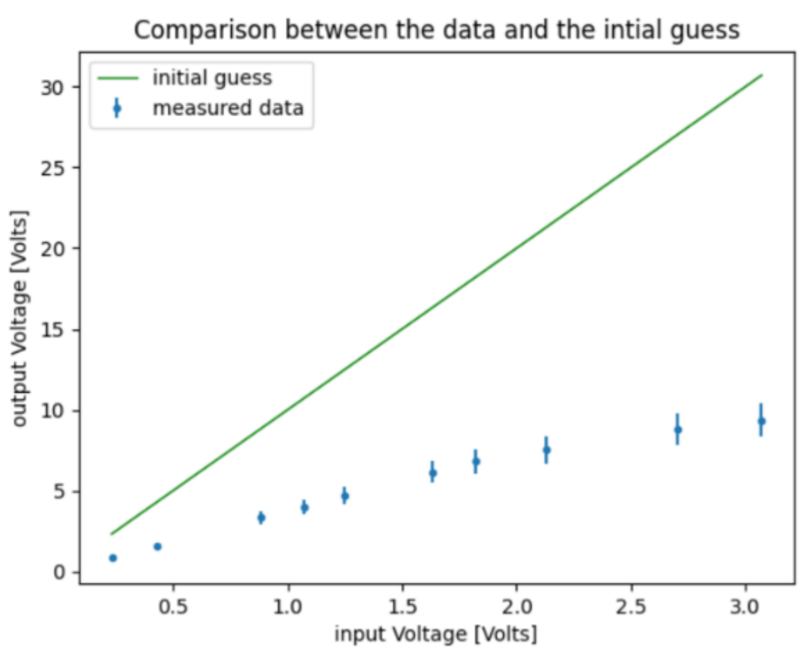
The gain slowly started decreasing at higher voltages:

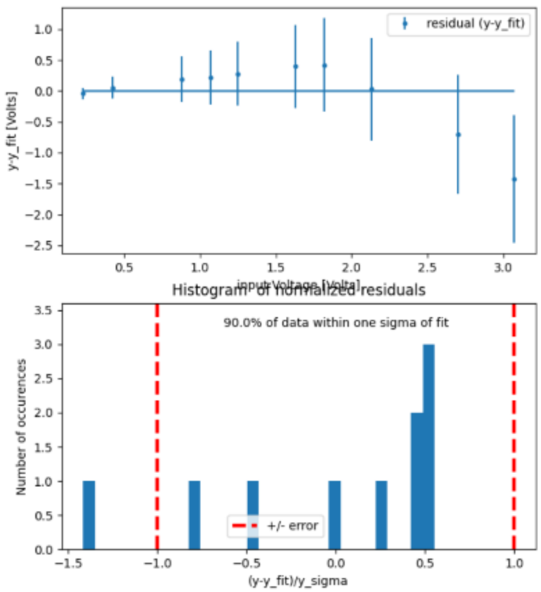


From these graphs, we can see that Vout is phase shifted to the right relative to Vin. This is in contrast the inverting amplifier configuration from the previous lab.

After recording Vin and Vout values for a range of values of Vin, it was noticed that the voltage gain stopped being linear approximately when a voltage greater than 1.0V was applied (which corresponded to a Vin value of about 2.0V). This is likely to be different across setups, and this value, which has a setup using two 9V batteries, is likely higher than setups using +- 5V power supplies. Here is a plot obtained from the Python script Curvefitlinear.py:







Goodness of fit - chi square measure:
Chi2 = 4.16830059266118, Chi2/dof = 0.5210375740826475

Fit parameters:
gain = 3.486e+00 +/- 1.726e-01
y intercept = 7.220e-02 +/- 1.056e-01
Displaying plot 2

Residual information:
90.0% of data points agree with fit

Alexander Shevchuk - Dec 04, 2020, 5:51 PM PST

LinearOpAmp.csv(205 Bytes) - **download**

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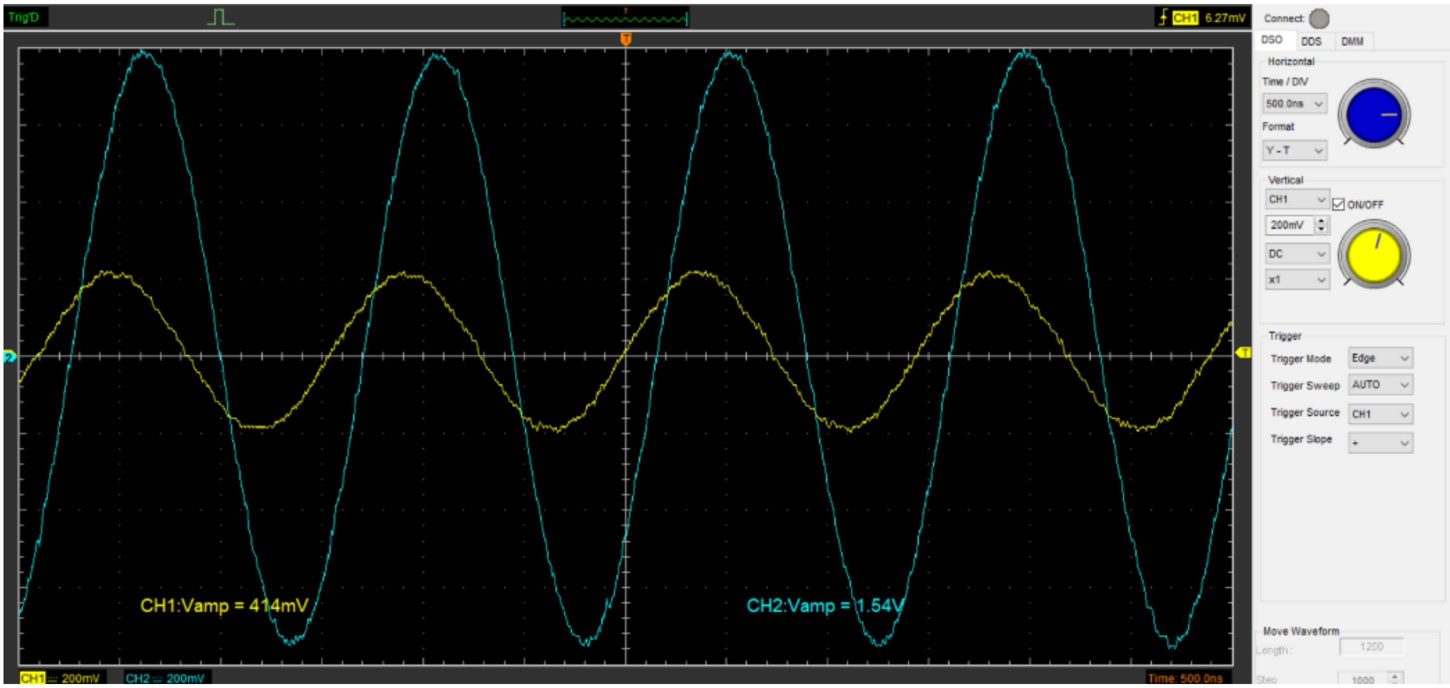
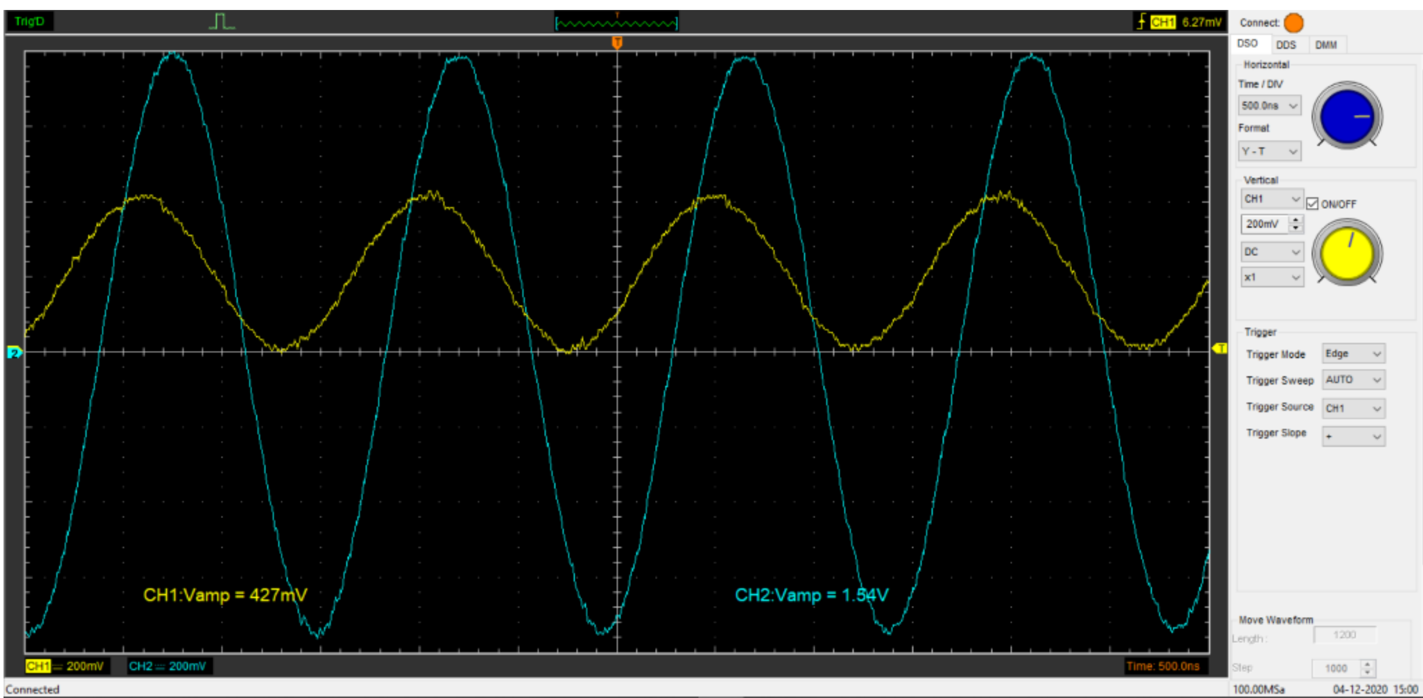
The response of the circuit to a DC offset was also tested. A signal of amplitude 0.2V and offset 0.2V was used, with frequency 690kHz. cases were analyzed: with capacitor and offset, capacitor and no offset, no capacitor and offset, and no capacitor and no offset.

The scope settings were the same thoughout, as previously described. Here is the graph with the capacitor and without an offset:

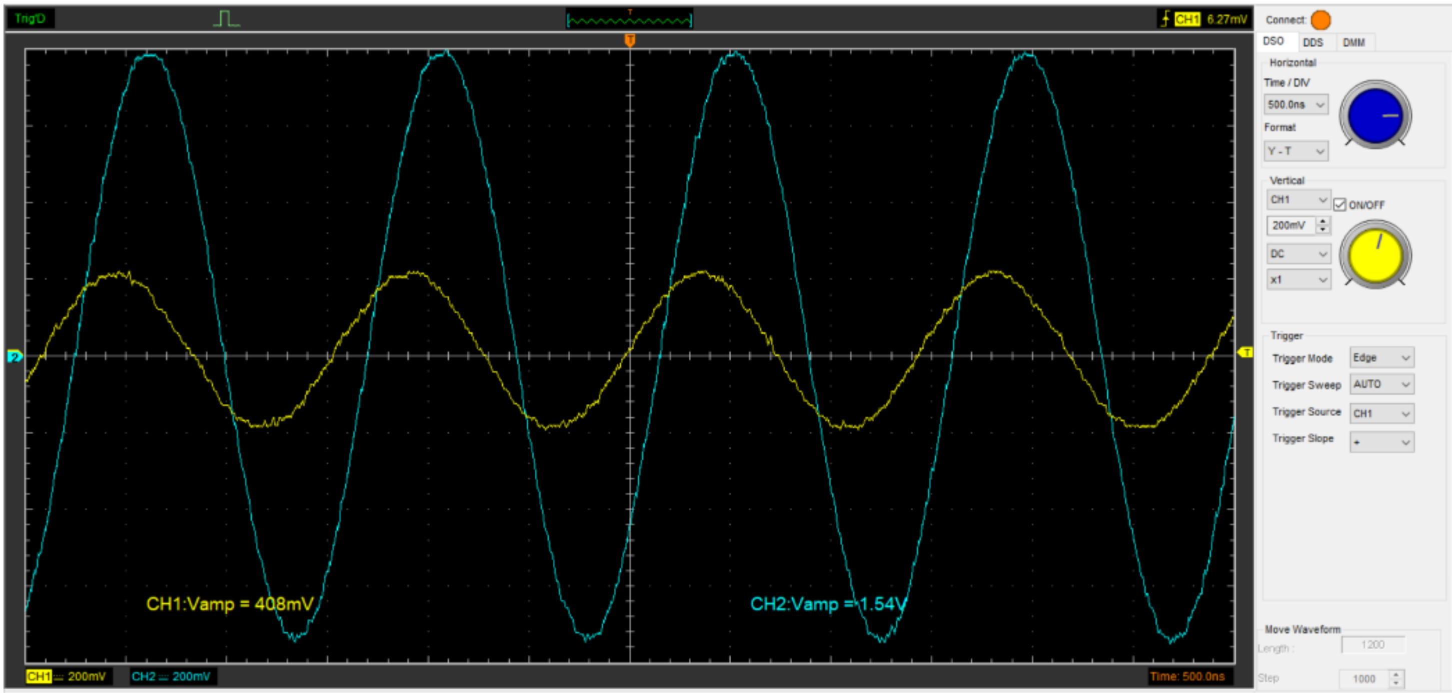


And here is the graph when an offset of 0.2V is applied:

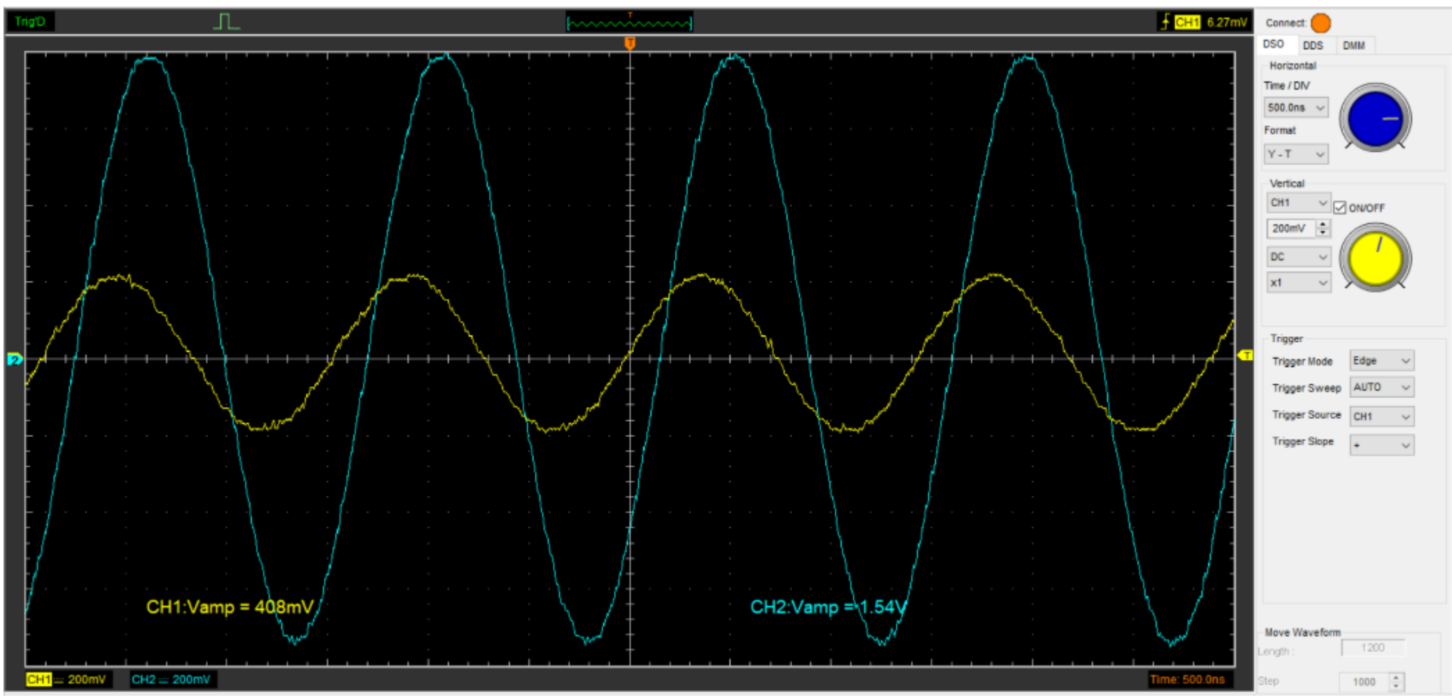


Clearly, changing the offset input voltage has to effect on the output voltage. Now, let's remove the capacitor an try the same thing.

The graph with no capacitor and no offset had no change from the very first graph, as shown below:



When an offset was added, however, Vout increased as well. The scale has been adjusted to show the full graph:

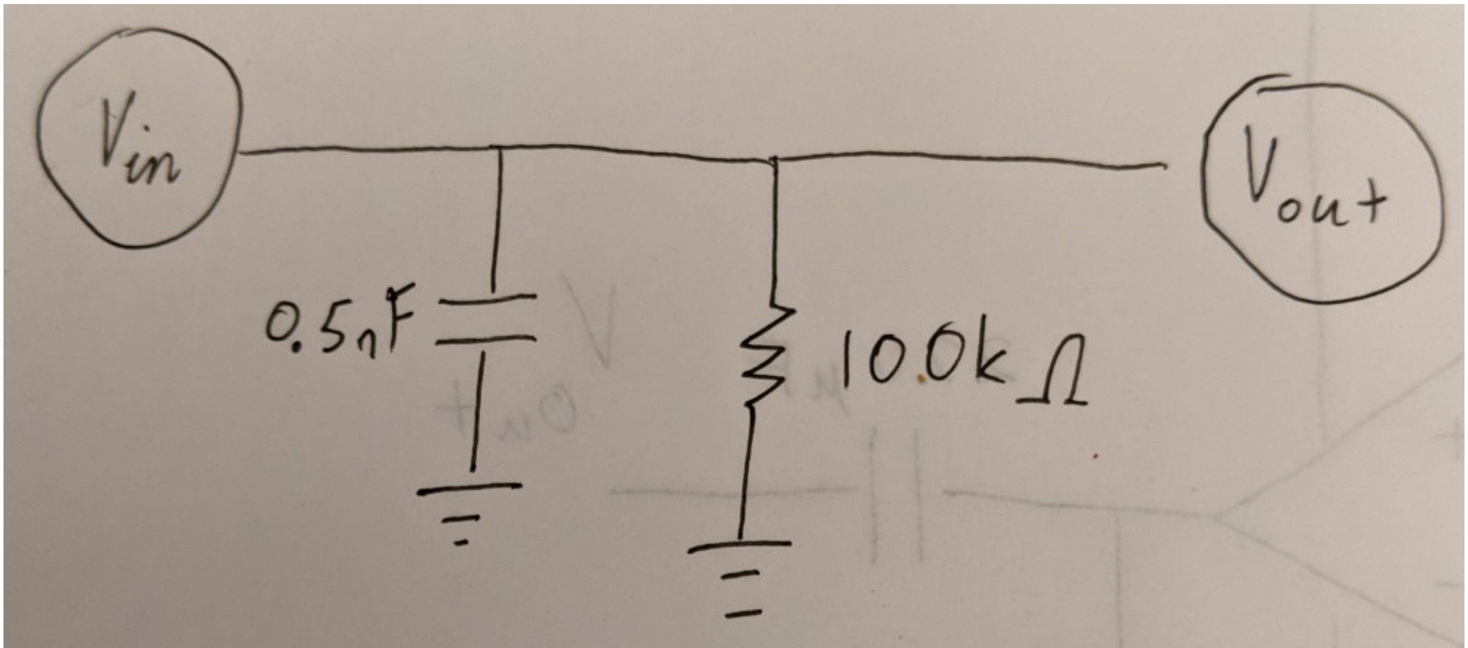


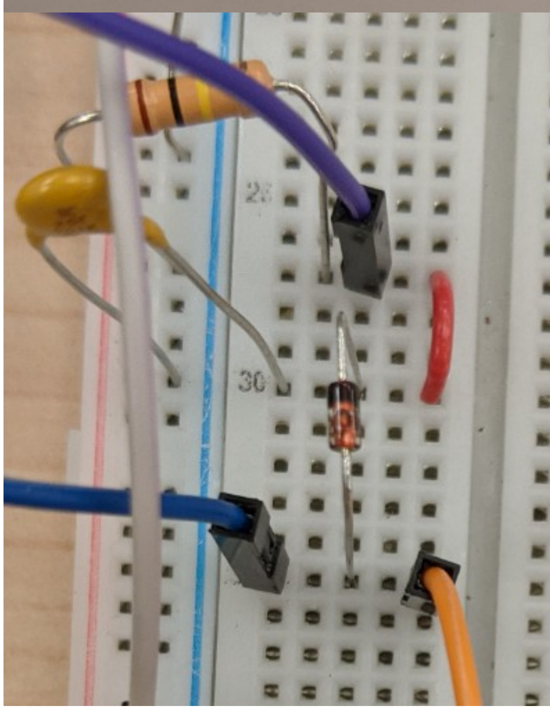
From these graphs, we can see that the capacitor serves to remove the DC offset from the input signal. This is because when a capacitor was present, changing the DC offset of Vin had no effect on Vout. Without a capacitor, however, Vout increased propotionally.

Alexander Shevchuk - Dec 04, 2020, 4:17 PM PST

4.2 Low Pass Filter

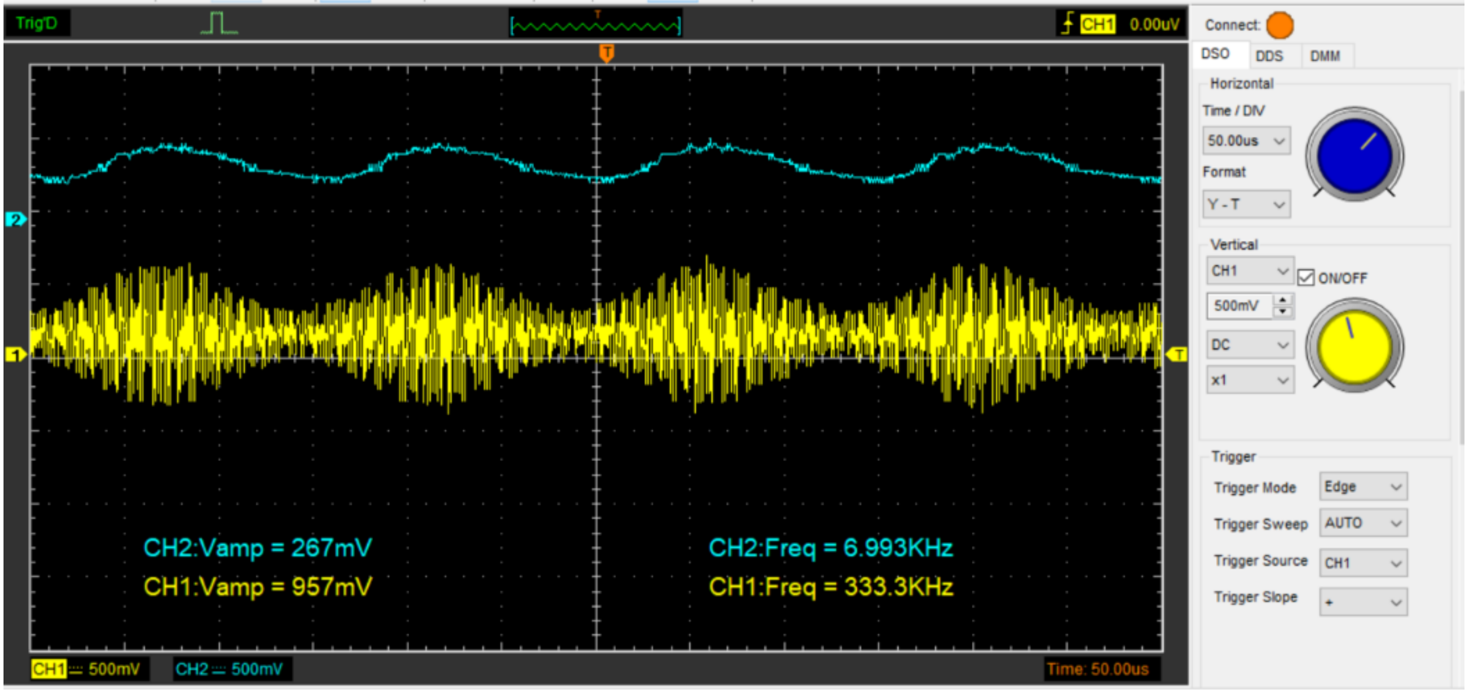
Below is a schematic and diagram of the circuit set up to test the low pass filter. Ground connections of the wires are not shown





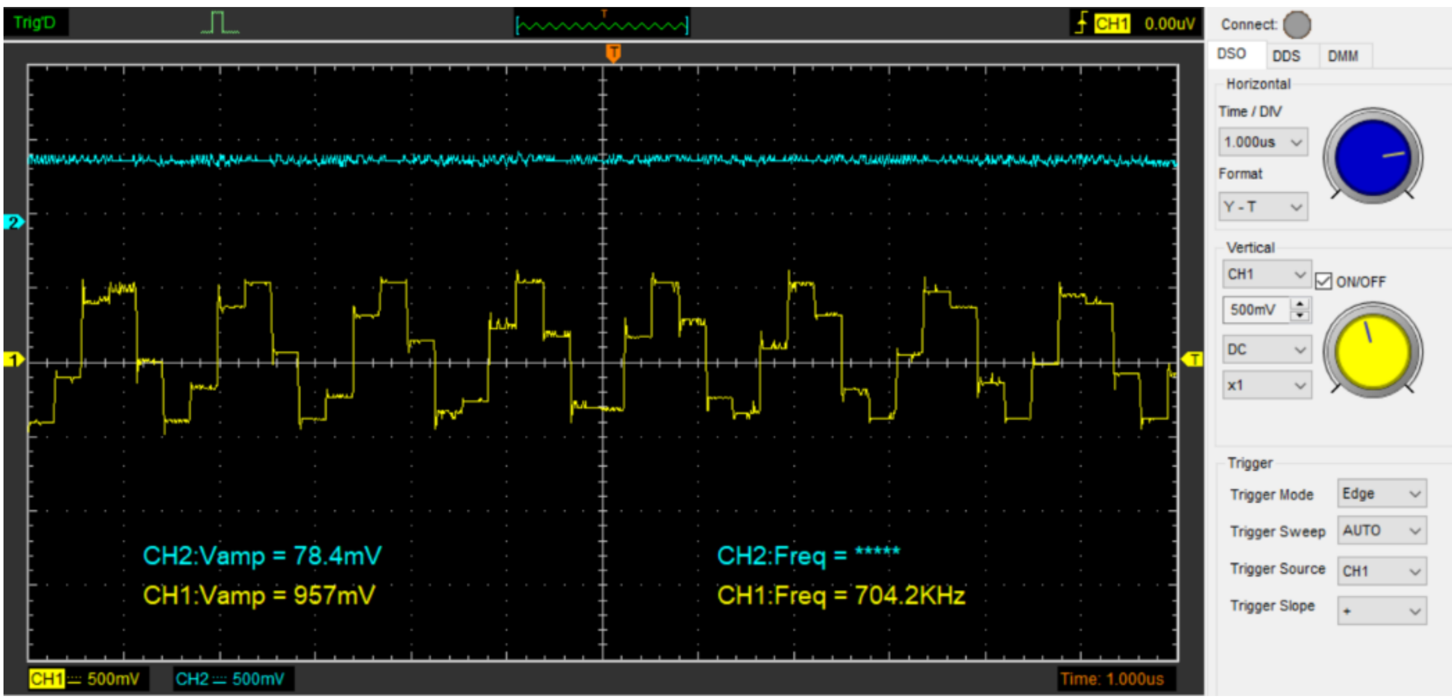
The blue and orange wires are the Gen Out and CH1 (Vin) connections of the Hantek. The purple wire is Vout, and is connected to CH2 of the Scope. An arbitrary singal obtained from modulatedsignal.csv was generated by the scope, using an offset of 0V, a frequency of 6.9kHz, and an amplitude of 0.50V. The frequency of the modulated and demodulated signals were then found using measure functionality.

For a time scale of 50us/division, the following output was observed:



From this, we can see that the output signal has a frequency of around 6.9kHz. This was validated using cursor measurement, and a value of around 6.4kHz was obtained. Since the measurements were made by hand, the discrepancy is likely due to eyeball approximation error.

Expanding the time axis to 1us/division, we can measure also the carrier signal frequency:



By using the measure functionality and validating with cursors, we see that the carrier frequency is 704.2kHz, which is fairly close to 690kHz, as expected.

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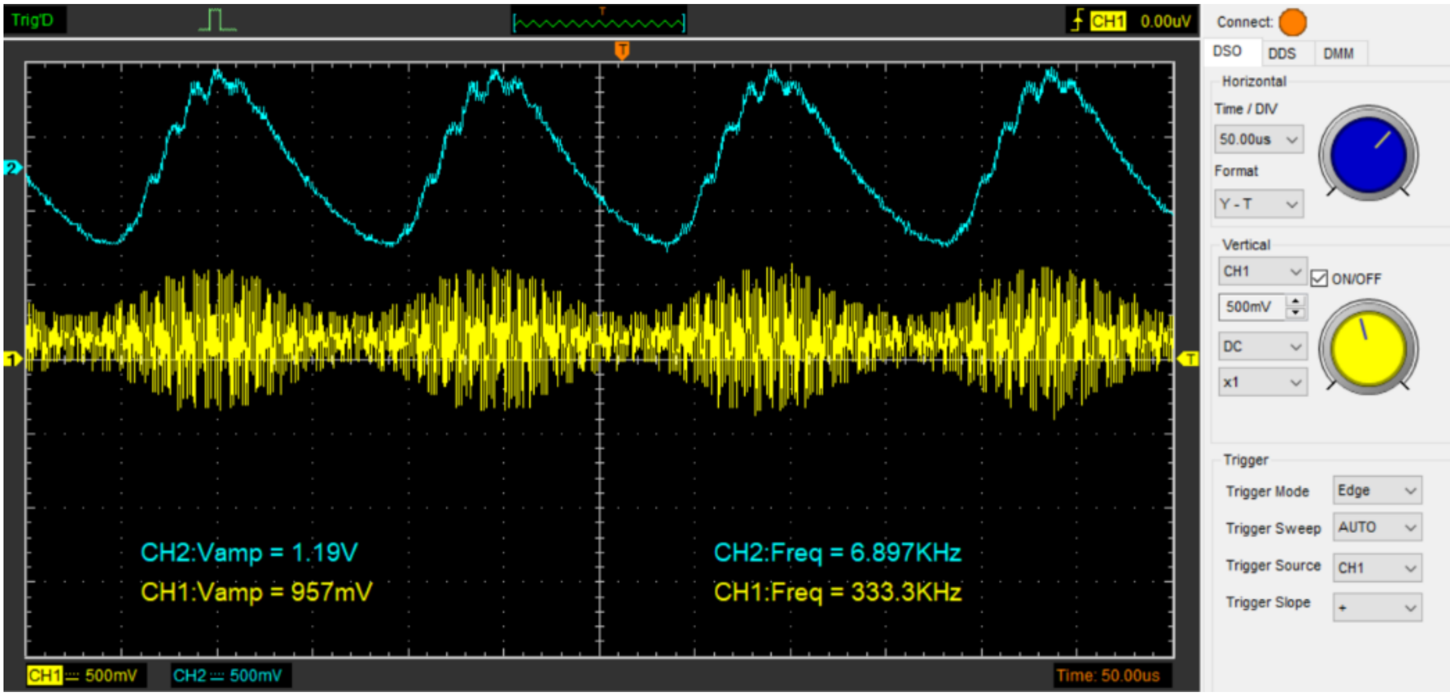
Next, the low pass filter was connected to the amplifier circuit constructed in the previous section, and the following was observed:

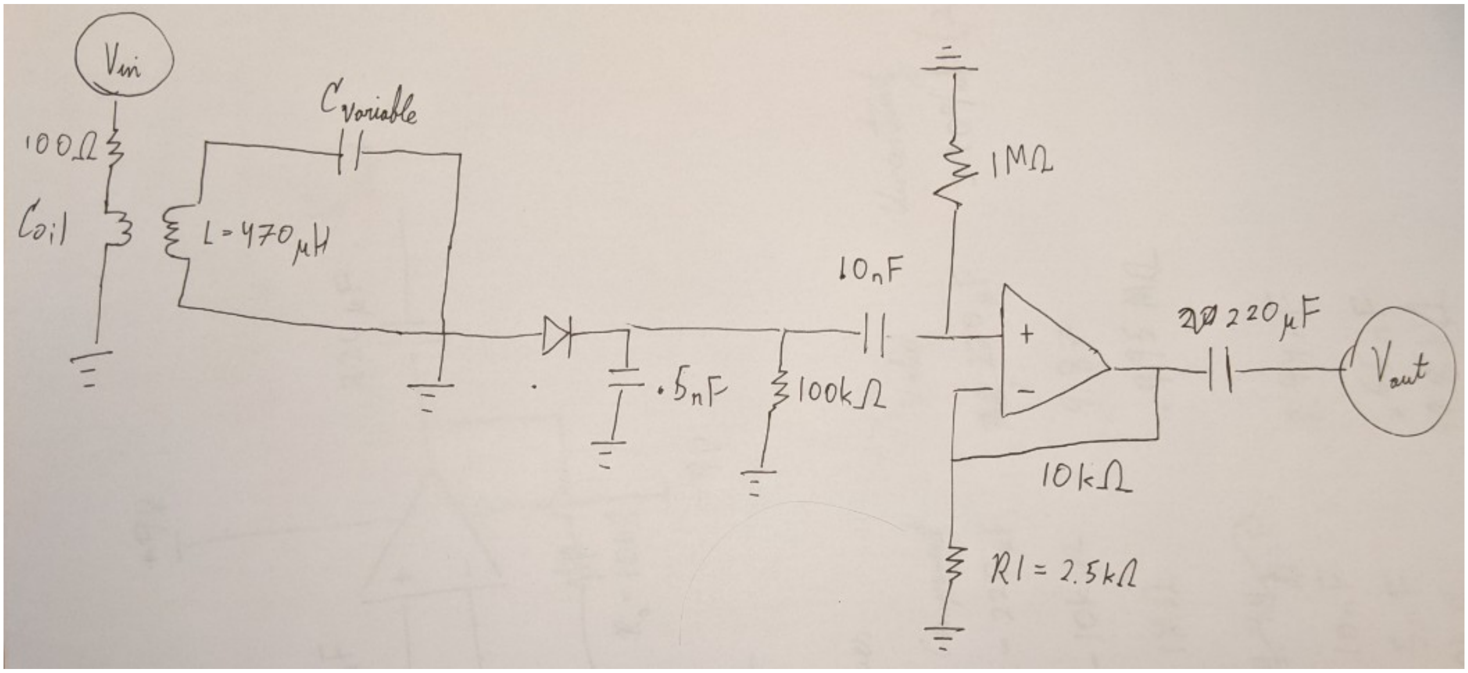


Comparing this with the signal observed when the circuit was not connected to the amplifier, we can see that the only change is that the amplitude has increased by a factor of around 4.45. This is close to the expected gain factor, and we can see the Op Amp is working properly. The output signal is also undistorted (has the same frequency, offset and shape as the output of the low pass filter), which means we are within the linear region.

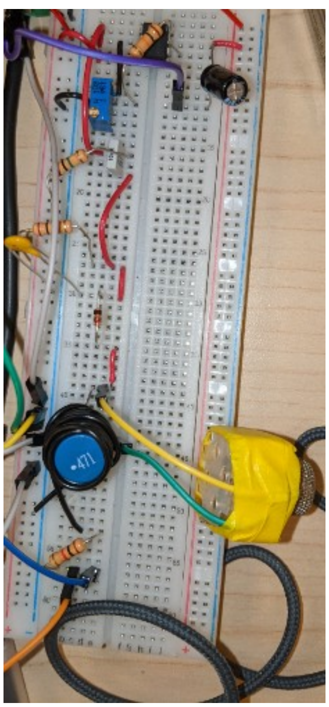
Alexander Shevchuk - Dec 04, 2020, 5:20 PM PST

4.3 Tank Circuit

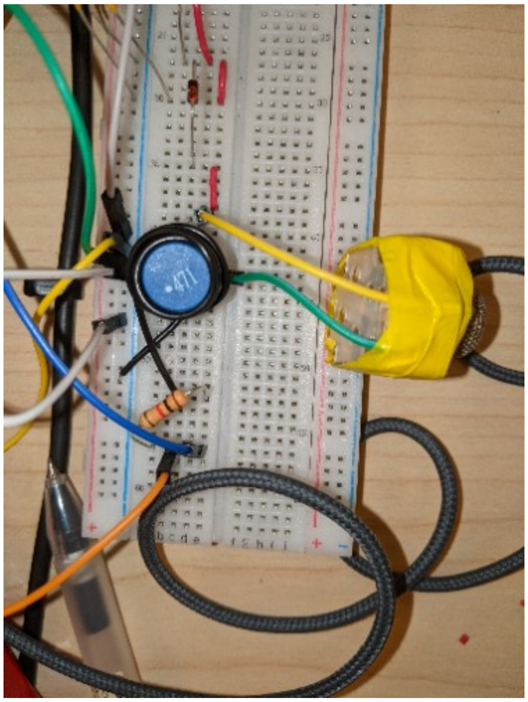
To assemble and tune the tank circuit, the following schematic was used:



Here is a picture of the circuit: parts are as in previous pictures, except now a 470uH inductor (blue) with black coil wrapped around and a variable capacitor has been added (yellow):

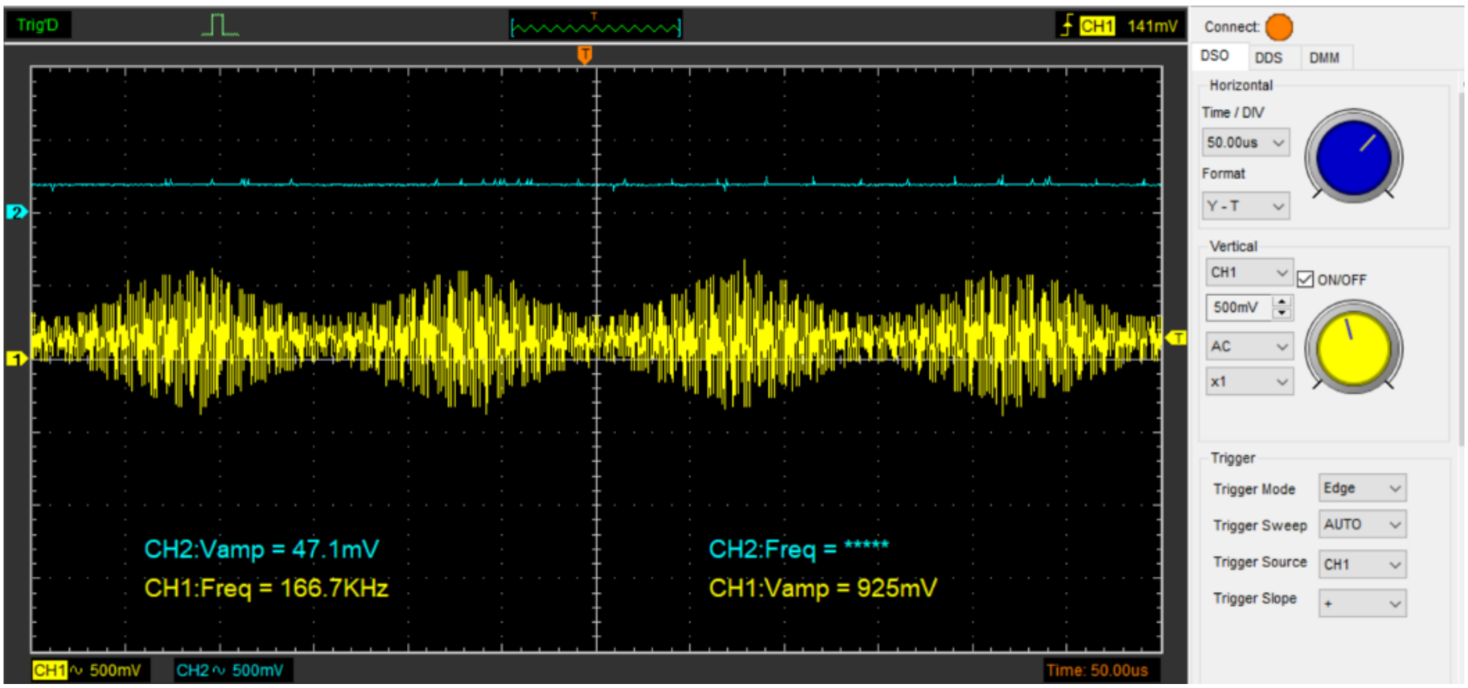


And here is a picture of just the tank circuit part:

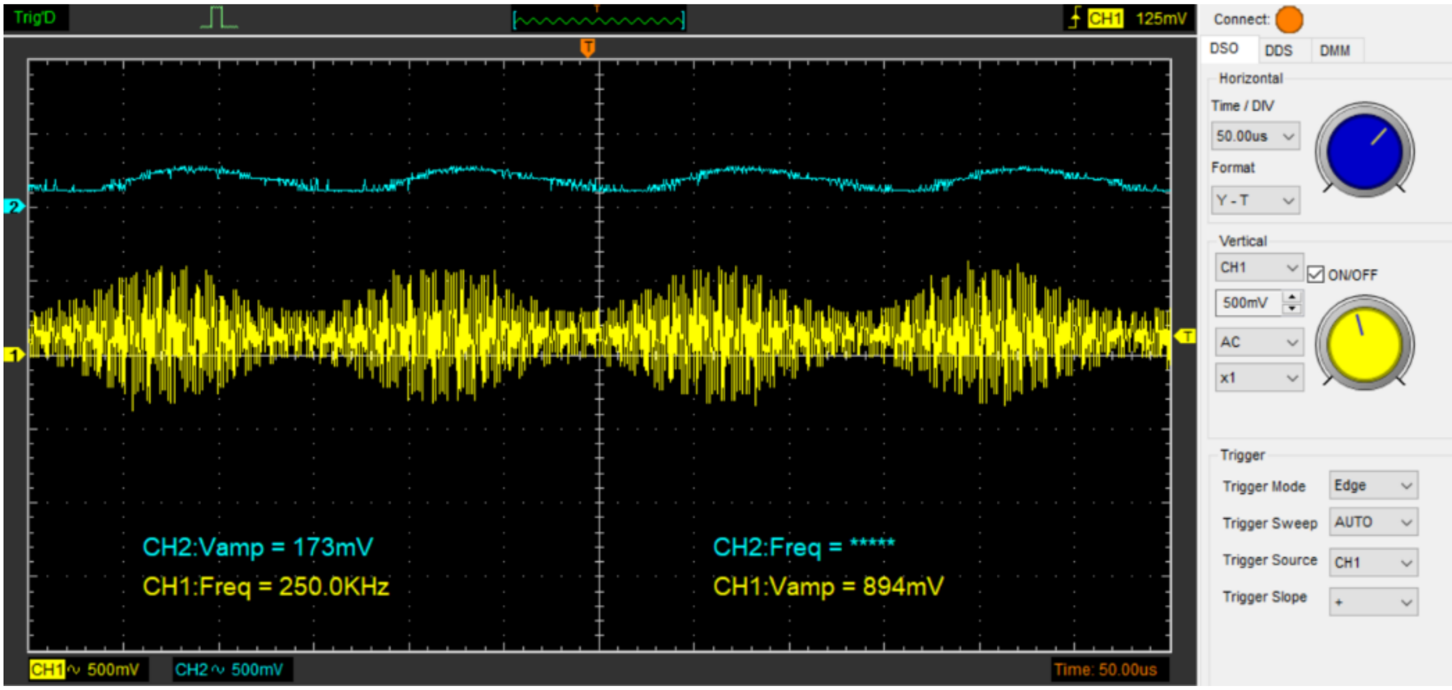


The blue and orange jumper cables at the bottom are the Vin and Gen out ports for the scope, and the purple wire at the top is Vout (CH2).

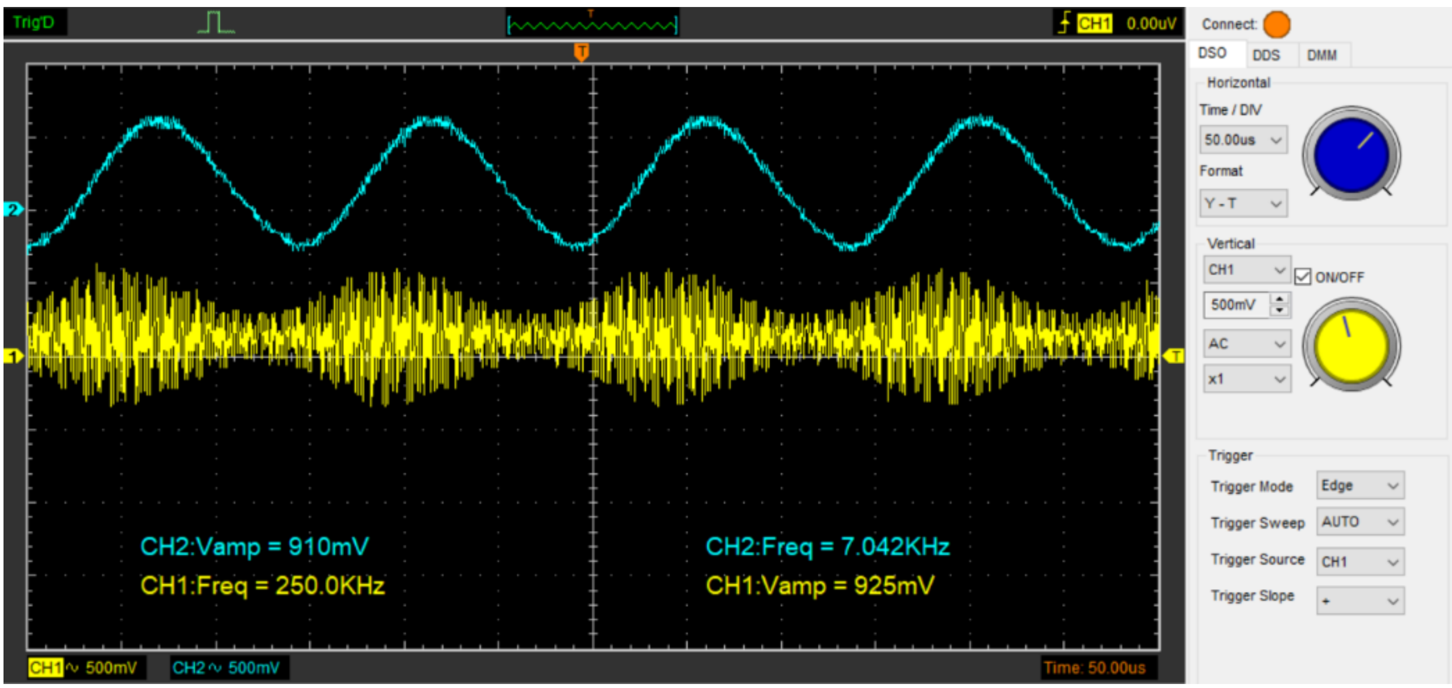
When the circuit was initially assembled, it was not in resonance. Here is a picture of this (scope settings shown on the bottom of picture):



To tune the circuit into resonance, the capacitance of the variable capacitor was adjusted until the oscillations in Vout were maximized. Adjusting the circuit gradually changed the amount of oscillations present in Vout. Here is an image of the circuit not fully in resonance to demonstrate this:



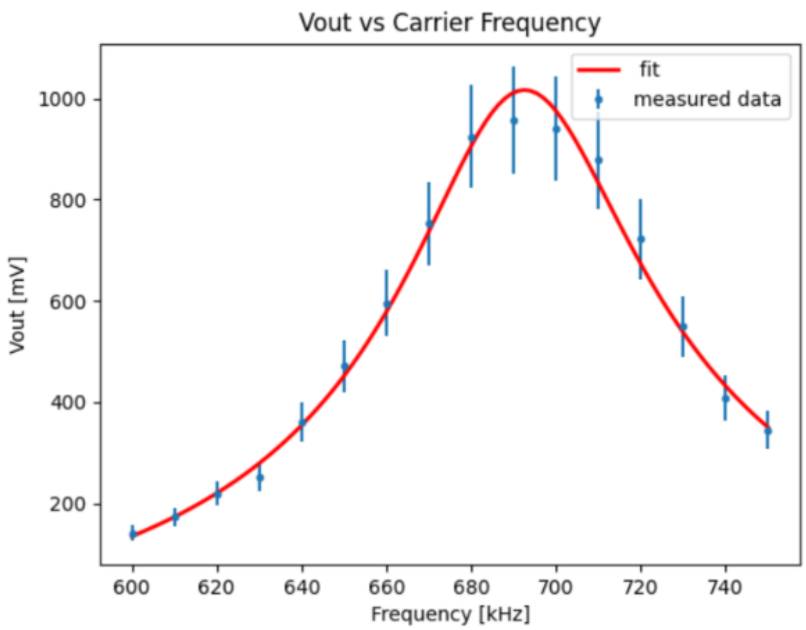
These oscillations of Vout peaked at a point, which is the resonance of the circuit. Thus, the tuned resonance signal below was obtained:

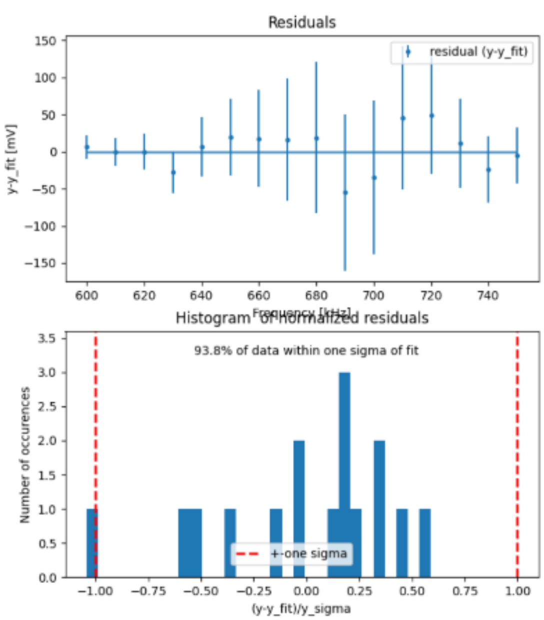


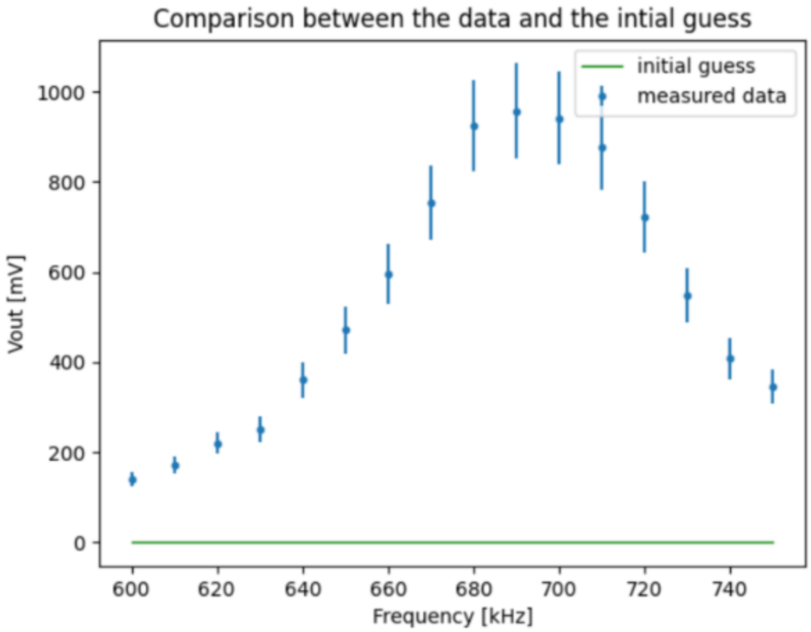
Alexander Shevchuk - Dec 05, 2020, 4:49 PM PST

Afterwards, the frequency response of the circuit was analyzed by measuring Vout as a function of the carrier frequency delivered by the Scope. The resonance was indeed observed to be around 690kHz.

Different frequencies were tried (data below), and were fitted to an exponential curve using the Curvefitlcrres2020.py provided. The pattern was clear after several points. The plots obtained are shown below:







And below is the analytics data produced by the script:

Goodness of fit - chi square measure:
Chi2 = 2.810166683787601, Chi2/dof = 0.2341805569823001

Fit parameters:
amplitude = 1.200e+03 +/- 6.182e+01
resonant frequency = -6.926e+02 +/- 1.513e+00
gamma width = 3.442e+02 +/- 4.485e+01
back = -1.831e+02 +/- 4.906e+01

Residual information:
93.8% of data points agree with fit

As we can see, it was found that the line width $\gamma \approx 344$.

To find the effective resistance of the circuit we can use the theoretical equation for gamma, $\gamma = \frac{R}{L}$ and the fact that L~=470uH to get $R = \gamma L \approx 0.162\Omega$.

To compare this with experimental results, the resistance of the tank circuit was directly measured. The resistance was measured to be 0.6Ohms. While not super close, it is off by less than an order of magnitude.

Alexander Shevchuk - Dec 04, 2020, 6:32 PM PST

ResonanceFreqFits.csv(278 Bytes) - download

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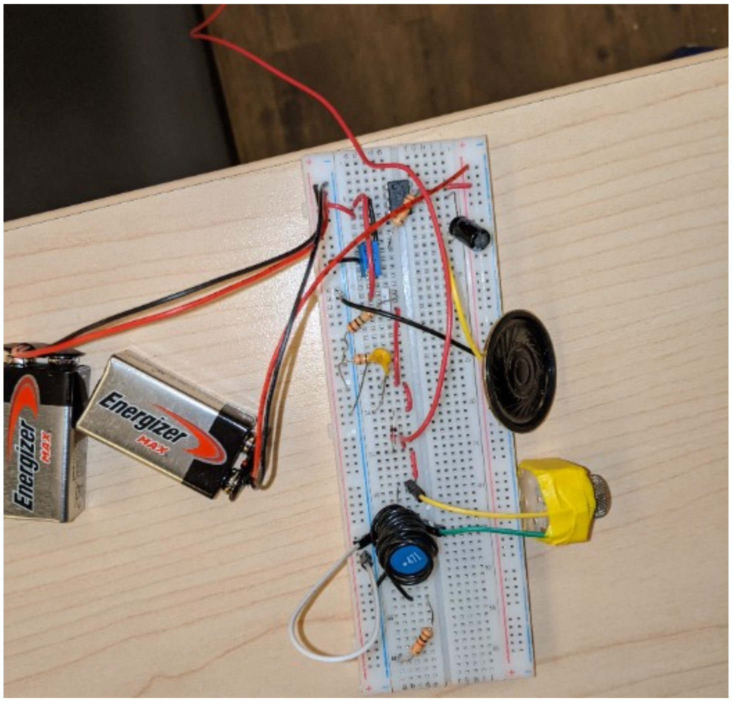
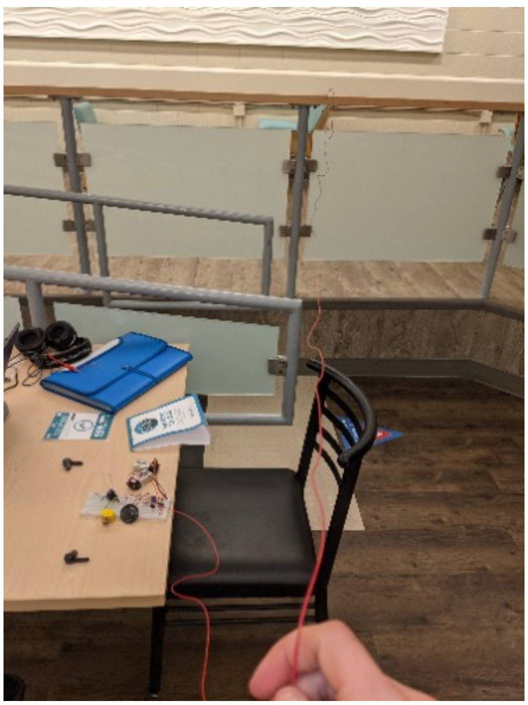
Below is the final setup, with the antenna attached to the circuit:





To make this radio worked, several things were tried. The antenna placement shown above did not yield the best results, so instead the procedure was repeated outside (the photos outside were taken late at night and had poor visibility, so they were not included). The remains of the red coil were tied to the remains of the black coil to make a longer antenna, and the far end of the antenna was tied to a tree branch. The circuit was placed far enough so that the antenna was taught. With this configuration, the speaker produced a decipherable sound. Even after resonance tuning the signal was very quiet, and the ear had to be placed right in front of the speaker to make out sounds. However, the sounds were there and clearly audible. A song was listened to, and then some speeches by a reporter. The results of this experiment were fascinating and rewarding. The Hantek was also connected to the output of the Op-Amp. When the tank circuit was not in resonance, no signal was noticeable. When resonance was achieved, however, a signal similar to the output of the Arb1 waveform was observed.

Alexander Shevchuk - Dec 04, 2020, 8:13 PM PST

Conclusion

During this experiment, an AM radio was constructed. This was done in several steps. First an Op-Amp circuit was built and tested. Its properties were briefly analyzed. Then a low-pass filter was assembled and tested to filter out the carrier signal. The Hantek Arb1 waveform was used to test the circuit's filtering and amplification ability at this point. Then, a tank circuit was constructed and tuned to resonate at a frequency of 6.9kHz. Lastly, an antenna was connected to the setup, replacing the role the Hantek played. After some adjustments a signal was indeed heard, presumably from the 690 AM radio station.

The model constructed in this experiment was fairly primitive, and improvements are bounded only by engineering ability. Some simple ones are outlined below. First, the Op-Amp gain could be increased. This could be done by adjusting the variable resistor R1 so that the Op-Amp delivers a higher gain. The voltage inputs of the op-amp could also be increased, so that the maximum allowable gain is greater. The voltage could also be passed through a transformer and fed to even more powerful speakers. Lastly, increasing the antenna length and material (removing insulation from wires would also help) would yield to a better signal.