Physics 219_2018 - Nick Pun/Exp. 5 (Final Project)/Exp 5 Final Project

SIGNED by Nick Pun Dec 03, 2018 @04:44 PM PST

Nick Pun Dec 03, 2018 @10:52 AM PST

Introduction

In this lab we build an AM radio receiver. The main components of the AM radio receiver are the antenna, tank circuit, diode, low pass filter, amplifier, and speaker. For this lab, we replace the antenna with a function generator in order to investigate the components of our circuit. Throughout our lab, we learn the purpose of each of the individual components. The antenna provides a signal; the tank circuit induces the signal; the diode rectifies the signal, filtering out negative voltages; the low pass filter removes signal spikes to get only the audio signal; and the amplifier increases the signal so that the speaker can play it at an audible level.

For electromagnetic radiation at 690 kHz, the wavelength is 435 m.

Nick Pun Dec 03, 2018 @04:19 PM PST

4.1 Amplifier

The data for this section of the lab was taken while the version of the lab manual was still one that called for a gain of 3 in the amplifier. The highest V_in we could apply before seeing any distortion was about 9.2 V, after this, the signal gets cut off at both the top and bottom. The lowest V_in we could apply was about 0.1 V, before this, the signal becomes too noisy to achieve an accurate and reliable measurement. Since the formula for a non-inverting amplifier is Gain = $(1+R_2/R_1)$, the following resistors were used:

R_{100k1} = 97.718 +/- 0.001 kOhm

R_{100k2} = 98.248 +/- 0.001 kOhm

R_{100k3} = 99.282 +/- 0.001 kOhm

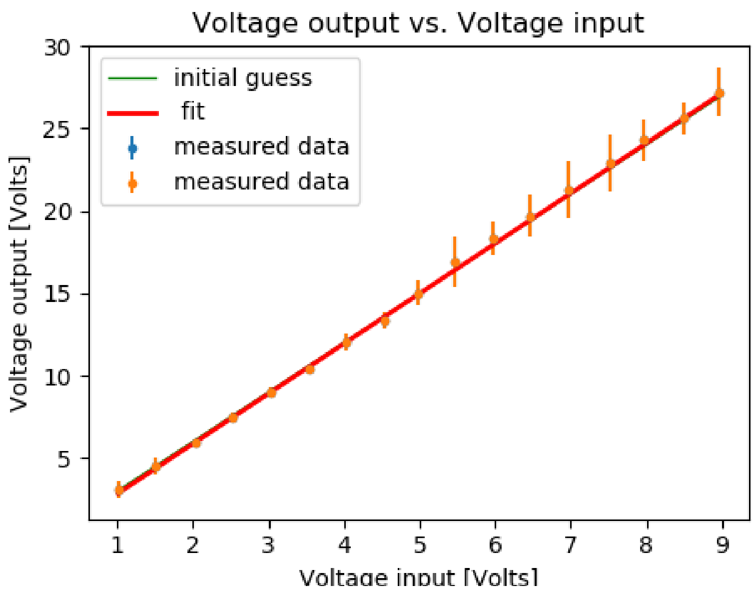
$R_1 = R_{100k3}$ = 99.282 +/- 0.001 kOhm

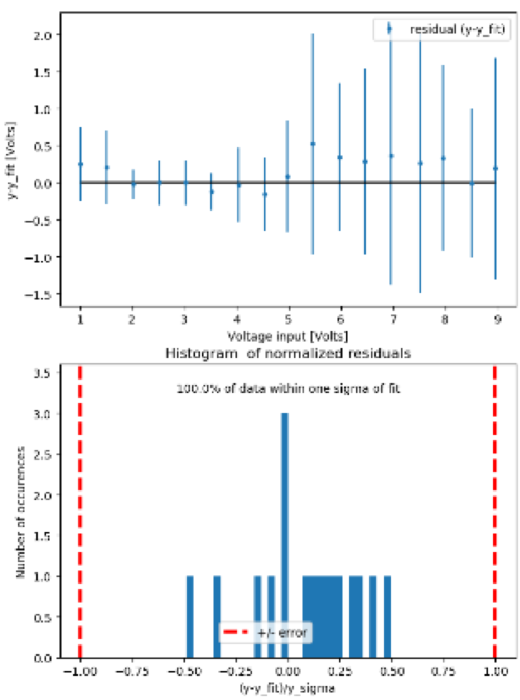
$R_2 = R_{100k1} + R_{100k2}$ = 195.966 +/- 0.002 kOhm

Calculated Gain = 2.97383 +/- 0.00003

The following is a plot of V_out vs. Vin:

guesses = (3, 0)





Goodness of fit - chi square measure:
Chi2 = 1.2200111707500045, Chi2/dof = 0.0813340780500003

Fit parameters:
gain = 3.037e+00 +/- 7.699e-02
y intercept = -2.027e-01 +/- 2.546e-01

Residual information:
100.0% of data points agree with fit

This is a good fit because Chi^2/dof is very small. This means that we can take the relationship between V_out and V_in to be linear. The measured gain agrees with the calculated game in that it is about 3.

The V_out signal coming from the non-inverting amplifier is in phase with the V_in signal whereas the V_out signal coming from the inverting amplifier is out of phase by 180 degrees. Similar to that of the inverting amplifier, the relationship between V_out vs V_in is linear for a low frequency of 3 kHz.

With all the circuit components in place, no amount of offset voltage can change the undistorted range of the output signal. This is because V_offset is a DC signal added to the V_output signal to make it higher, but the 0.001 uF capacitor does not allow DC signals to pass through.

Without the 0.01 uF capacitor and 1 MOhm resistor, the larger the absolute value of the offset, the smaller Vin has to be. However, it does not cutoff at 15 V because of the presence of internal resistances and the 220 uF capacitor. The distortion we see is that the signal becomes cut off at the top.

Without the 0.01 uF capacitor, 1 MOhm resistor, and 220 uF capacitor, the signal is also cut off at the top, except at 15 V. It was also interesting to see that at the end of each plateau, there is a small notch which I believe are due to some internal flaw in some of the equipment. This means that the 220 uF capacitor also blocks off DC signals to prevent the desired signal from going too high and getting cut off.

4.2 Demodulation-rectifier/low pass filter

Resistors used: same as before

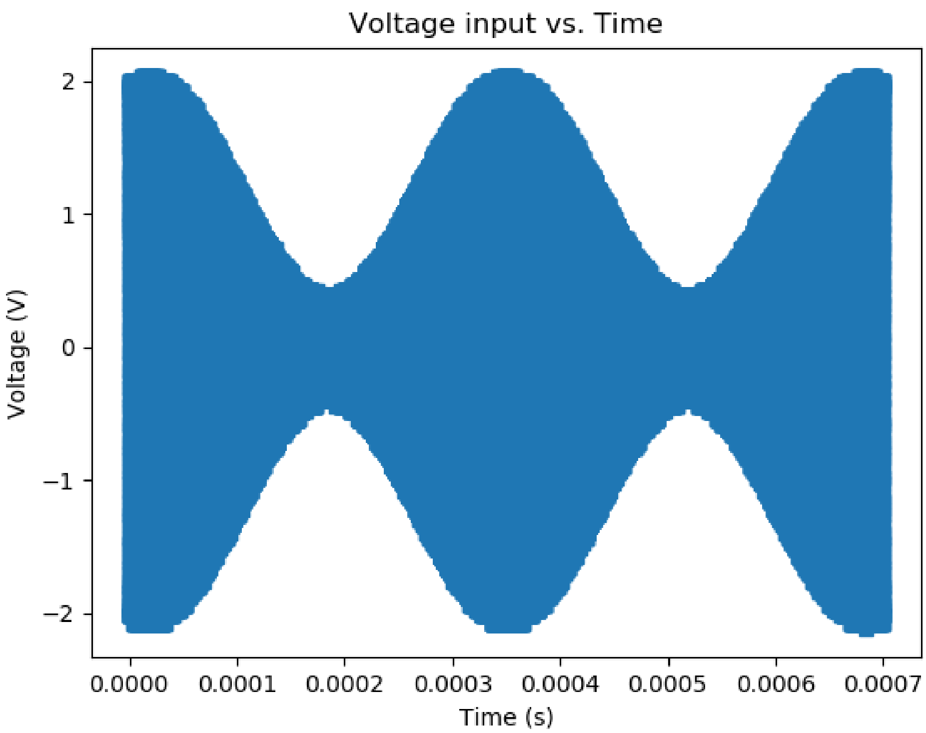
In this section we investigate the properties of a modulated wave. Here, the input signal is connected to the left end of the diode and the output signal is taken from the ungrounded end of the 100 kOhm resistor. We set the following settings on the function generator:

carrier frequency = f_car = 690 kHz

modulation frequency = f_mod = 3 kHz

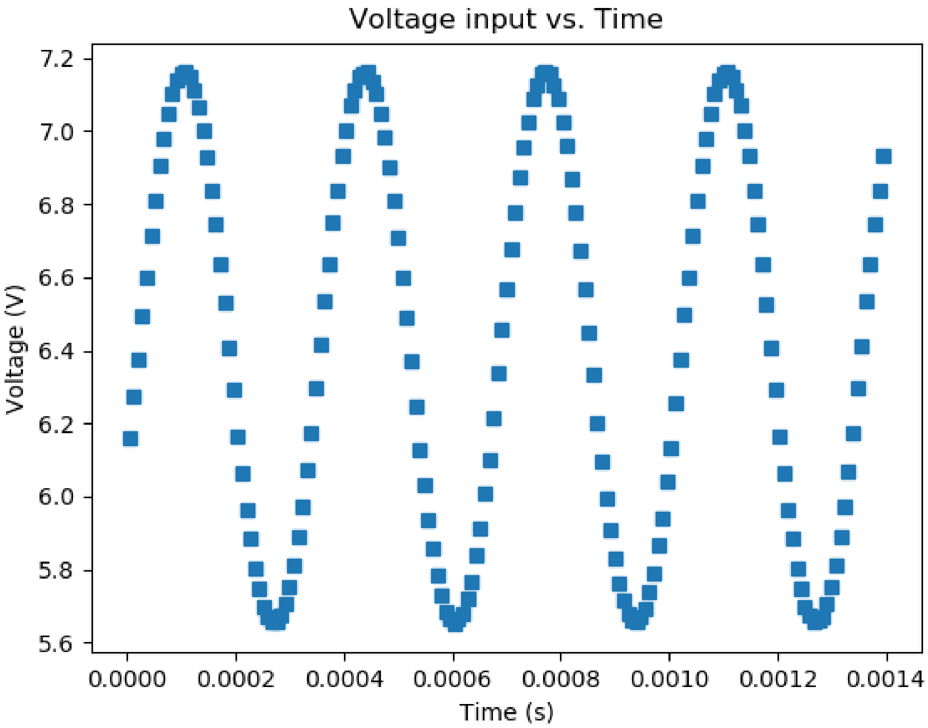
modulation depth = 70%

The following is a plot of the input signal set so we can see the modulation frequency:



The amplitude of the modulation frequency was measured by ((largest pk-pk)-(smallest pk-pk))/2 = (4.16-0.8)/2 = 1.68 V

The following is a plot of the output signal with npac = 500 and set so we can see at least 5 complete oscillations:



The period is measured with cursors to be ~336 us, and so the frequency is then ~2.98 kHz, which is about the same as the modulation frequency.

The amplitude is measured with cursors to be ~1.69 V, which is about the same as the amplitude of the modulation frequency calculated from the previous plot.

The DC offset is measured by (pk-pk)/2+(minimum voltage) = 1.69/2 + 4.29 = 5.14 V.

4.3 Tank Resonator Circuit

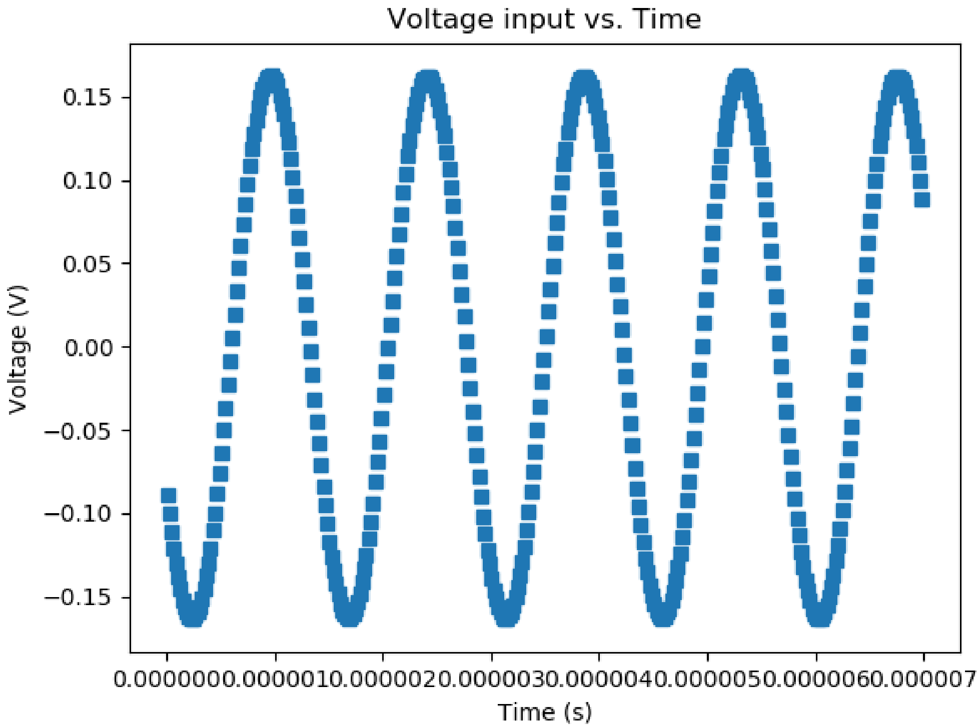
In this section we investigate how a tank resonator circuit converts a signal from an antenna (or in our case a function generator that is not directly connected to our circuit) to an oscillating voltage to that can be passed through the circuit. The signal from the function generator passed through a coil that is wrapped around the inductor. A 100 Ohm resistor is also added in series with the coil to keep the current constant. The oscilloscope is connected in parallel across the variable capacitor. The following are the settings for the function generator and the measurement of the 100 Ohm resistor:

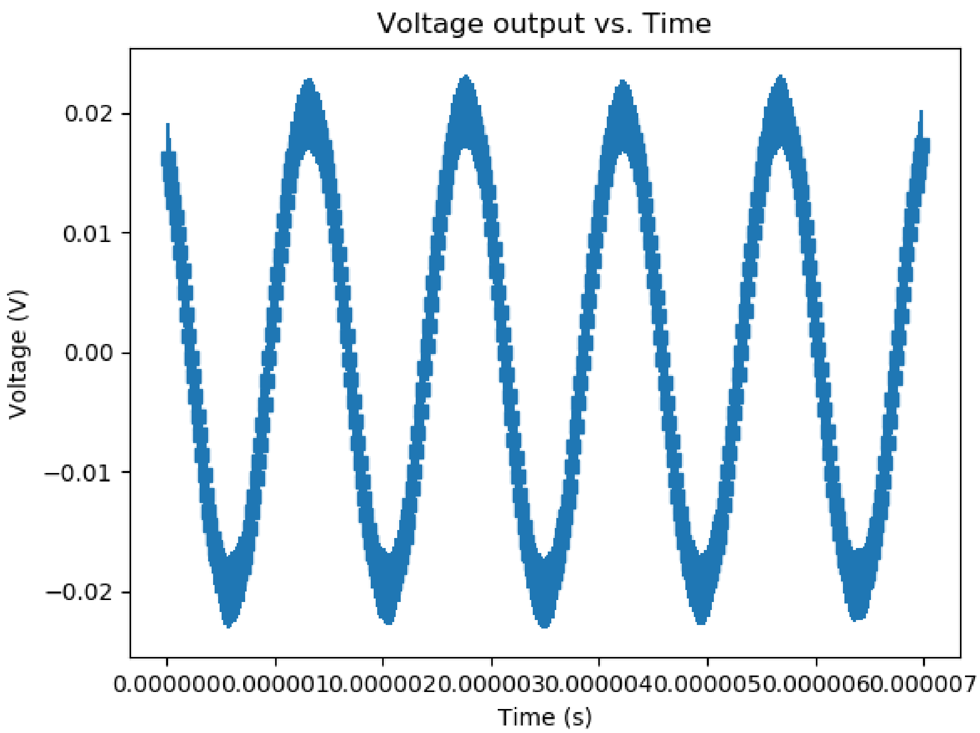
Vpp = 500 mV

f = 690 kHz

R_{100} = 98.025 +/- 0.001 Ohm

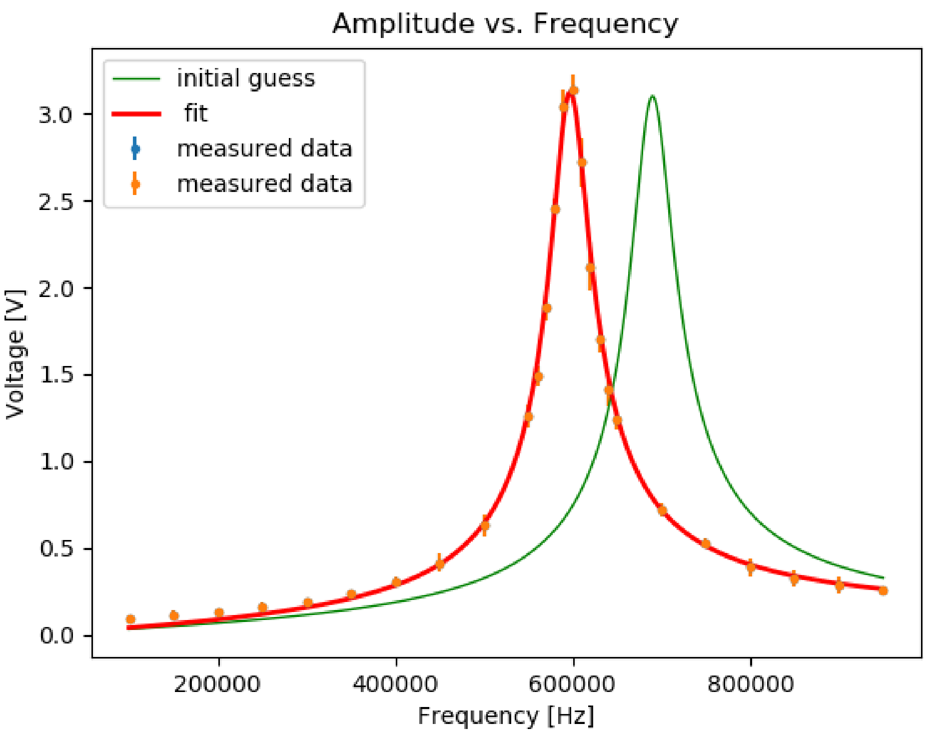
Without the coil wrapped around the inductor, the output signal is a flat line at 0 V with some small noise to the degree of ~3 mV. This is because there is no electromagnetic field for the inductor to induce, and therefore no current generated by the inductor. No current generated by the inductor means there is no voltage measured on the output of the capacitor. The electromagnetic field would normally be produced by changing current in the coil wrapped around the inductor. The following is an example of what is displayed on the oscilloscope while the coil is wrapped around the inductor with npac = 10.

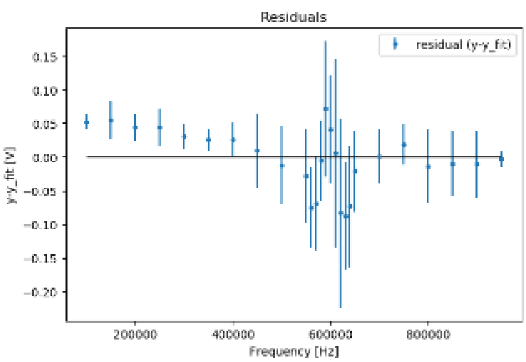


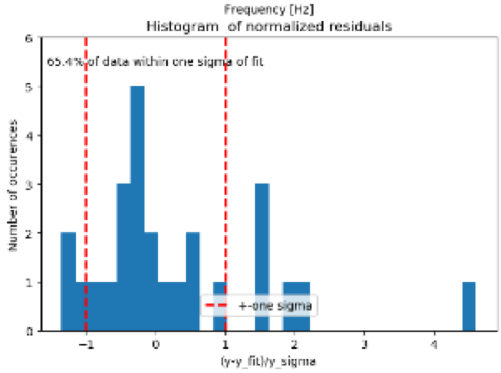


We then try to maximize V_out at 690 kHz by adjusting the variable capacitor. The following is a plot of V_out vs. f_in as we vary f_in. Unfortunately, we must have made an error in the adjustment of the capacitor or at another point of our setup as the peak does not appear to be at 690 kHz. It is instead around 600 kHz.

guesses = (3.1,690e3,3e5,0)







Goodness of fit - chi square measure:
Chi2 = 46.710103105078204, Chi2/dof = 2.123186504776282

Fit parameters:
amplitude = 3.114e+00 +/- 5.932e-02
resonant frequency = 5.972e+05 +/- 6.619e+02
gamma width = 2.790e+05 +/- 9.641e+03
background = 2.597e-14 +/- 1.559e-14

Residual information:
65.4% of data points agree with fit

The fit for our data is good but could be improved as the Chi^2/dof is relatively low but not as close to 0 as we might expect. I believe this is because in the mathematical model, the graph can approach 0 as frequency approaches 0 from the right, whereas in the real world, it appears that the data only approaches close to but not exactly 0. This is evident in the residuals. We could have also taken more data points around the peak for a better fit. It is important to note that since the output signal is very thick, the value of the uncertainties were measured using the tools in the oscilloscope: ((pk-pk)-(amp))/2. However, after taking the data, I realized that the difference should not have been divided by two, and so during the fit I simply multiplied the imported uncertainties by 2.

I believe a possible contributing factor for why our resonant frequency is at 600 kHz could be that the wire carrying the input signal has it's own capacitance on top of the variable capacitor's capacitance, but the variable capacitor was not able to be set low enough to counter this increase.

Effective resistance = R_eff = 131 Ohm

Expected resistance = R_exp = R_{100} 98.025 Ohm

The difference between these two numbers is 33 Ohm, which is a substantial amount. The effective resistance is larger than expected and could be due to resistances that we considered negligible. It could also be due to an impedence caused by the inductor and variable capacitor. We can test this hypothesis by redoing the experiment with a much larger resistor such that the impedence becomes negligible.

Nick Pun Dec 03, 2018 @04:18 PM PST

4.4 Testing the AM receiver

In this section we investigate the properties of the AM radio receiver as a whole. All the individual components are connected together where the antenna is replaced with the function generator that is set with the following settings:

Vpp = 5 V

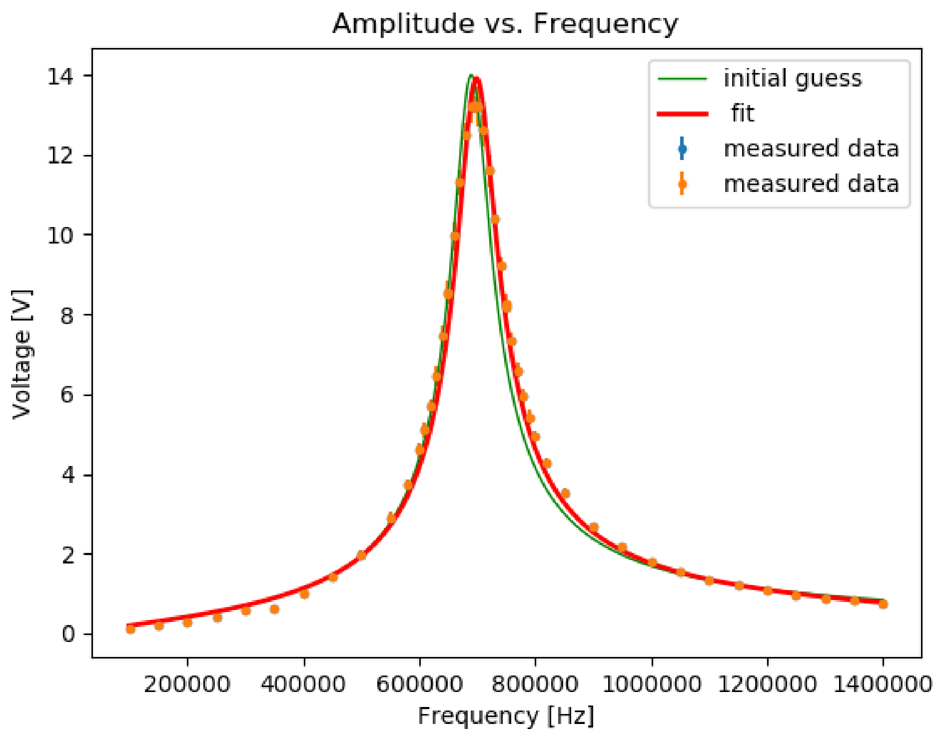
f_car = 690 kHz

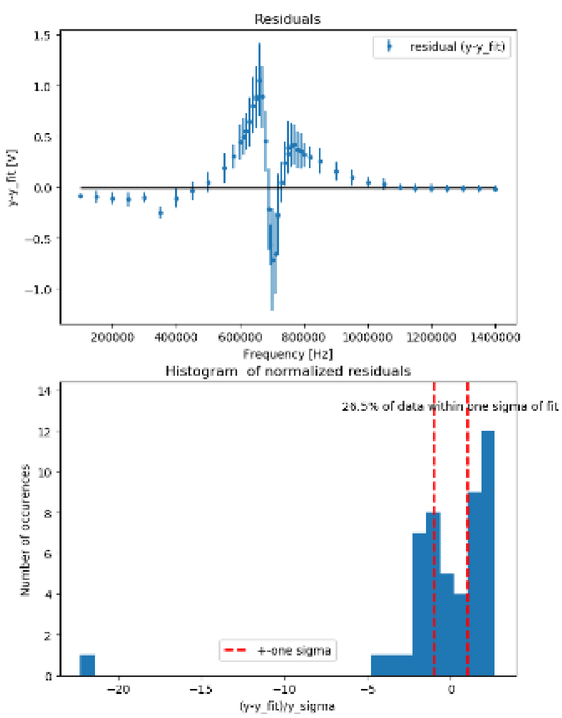
f_mod = 3 kHz

modulation depth = 70%

The following is a plot of the output amplitude versus the carries frequency:

guesses = (14,690e3,4e5,0)





Goodness of fit - chi square measure:
Chi2 = 659.2486199666125, Chi2/dof = 14.64996933259139

Fit parameters:
amplitude = 1.395e+01 +/- 1.319e-01
resonant frequency = 6.992e+05 +/- 5.097e+02
gamma width = 4.228e+05 +/- 6.034e+03
background = -6.099e-14 +/- 1.036e-14

Residual information:
26.5% of data points agree with fit

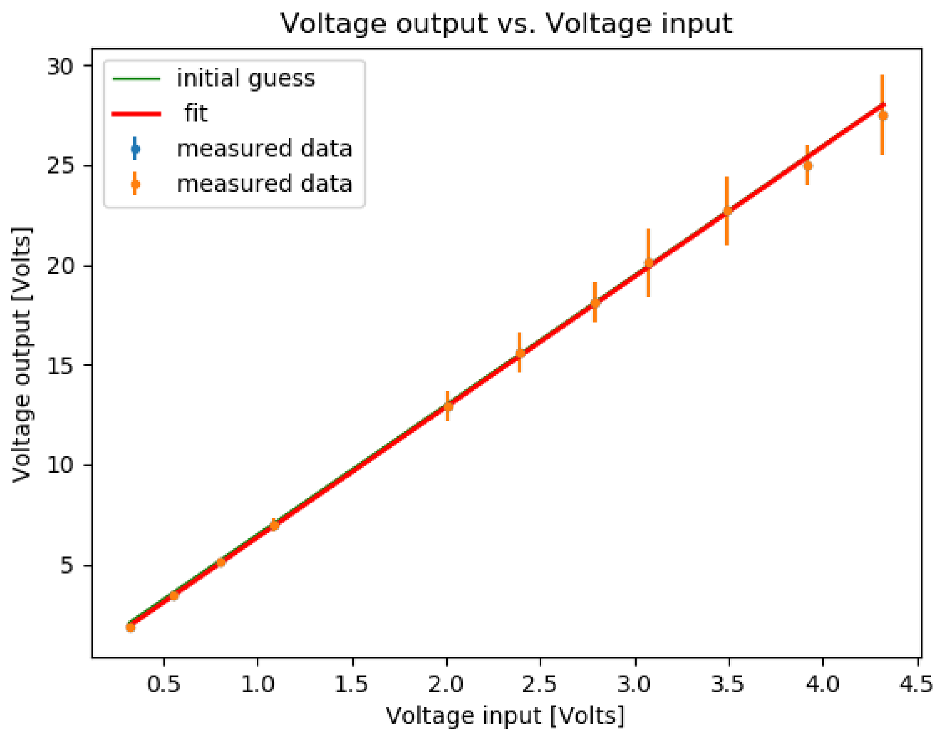
This fit is okay as the Chi^2/dof is relatively low, but not as low as we would like. I believe the reason for this is because we may have underestimated the magnitudes of the uncertainties. It is important to note that since the output signal is very thick, the value of the uncertainties were measured using the tools in the oscilloscope: ((pk-pk)-(amp))/2. However, after taking the data, I realized that the difference should not have been divided by two, and so during the fit I simply multiplied the imported uncertainties by 2.

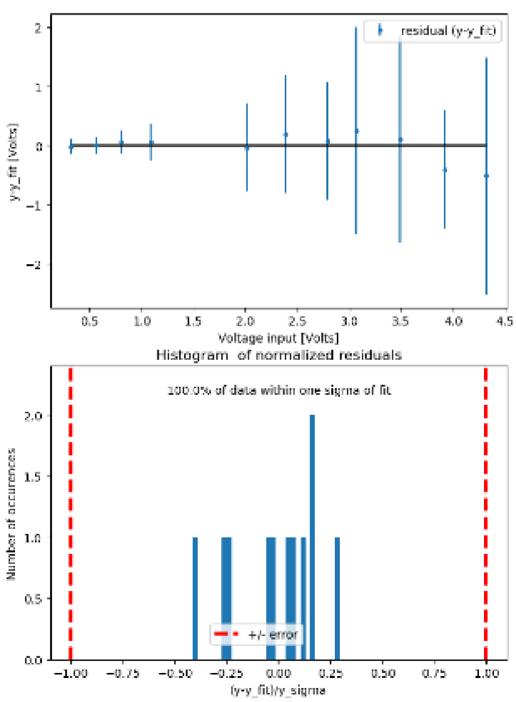
The value of the expected resonant frequency is close to the calculated resonant frequency. The difference could be due to the fact that the expected resonant frequency was set by eyeballing where V_out was largest at 690 kHz when tuning the variable capacitor. The reason why our data now peaks around 690 kHz could either be because we were more careful in tuning the variable capacitor this time, or because we were using a different set of equipment (but same circuit components).

There also seems to be one data point that is very misaligned with the fit as evident in the histogram of normalized residuals. This is also causing Chi^2/dof to be higher than desired.

The following is a plot of V_out vs. V_in on resonant frequency of 690 kHz. It is important to note that we discovered a flaw in our equipment at this point in the experiment as verified by the instructors and TAs. The flaw being that the oscilloscope does not obtain a signal of the same amplitude as that set on the function generator. The drop in voltage did not appear to be in a linear relationship either as at some points, the ratio of the amplitude on the oscilloscope to that on the function generator would be 1/2 and at other points it would be 1/3. Therefore, instead of using the value given by the function generator we used the value given by the oscilloscope, as the signal for V_out and V_in would both be equally affected by the flaw.

guesses = (6.5, 0)



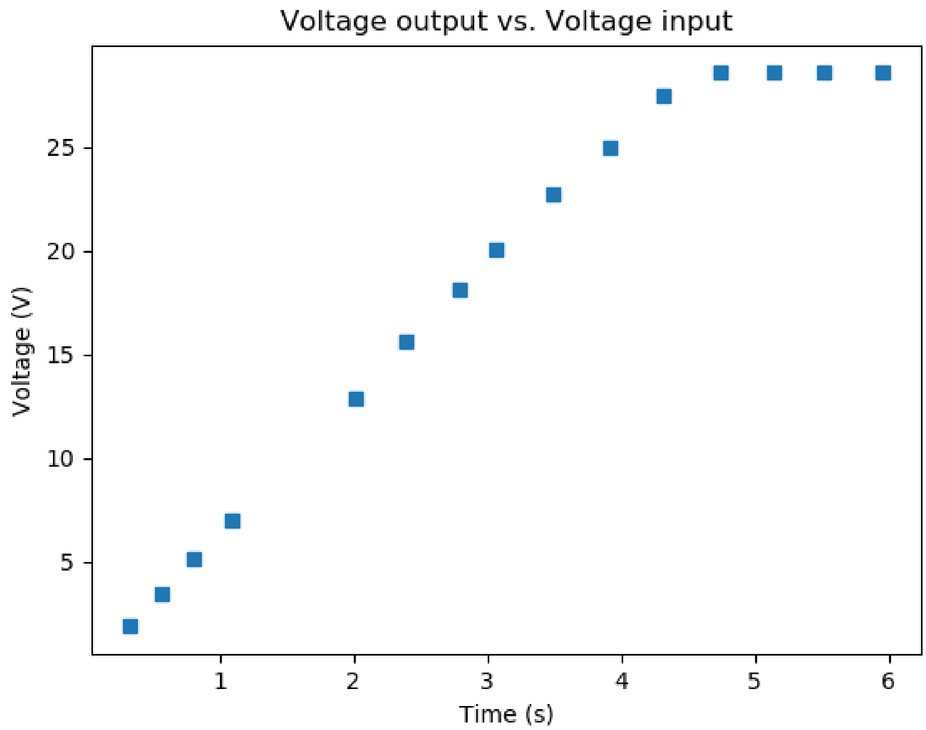


Goodness of fit - chi square measure:
Chi2 = 0.47349142108379677, Chi2/dof = 0.052610157898199644

Fit parameters:
gain = 6.530e+00 +/- 1.592e-01
y intercept = -1.912e-01 +/- 1.282e-01

Residual information:
100.0% of data points agree with fit

This linear fit is very good as the Chi^2/dof is very close to 0. This clearly shows that the relationship between V_out and V_in is linear at the resonant frequency. It is important to note that beyond about V_in = 4.3 V, the graph plateaus due to the limitations of the amplifier. In an ideal world, the plateau would occur at V_in = 5 V, as an amplifier with a gain of 3 would amplify it to it's maximum of 15 V. The following is a plot that shows that plateau:



Conclusion

Through this experiment we investigated what each component of an AM radio receiver is responsible for.

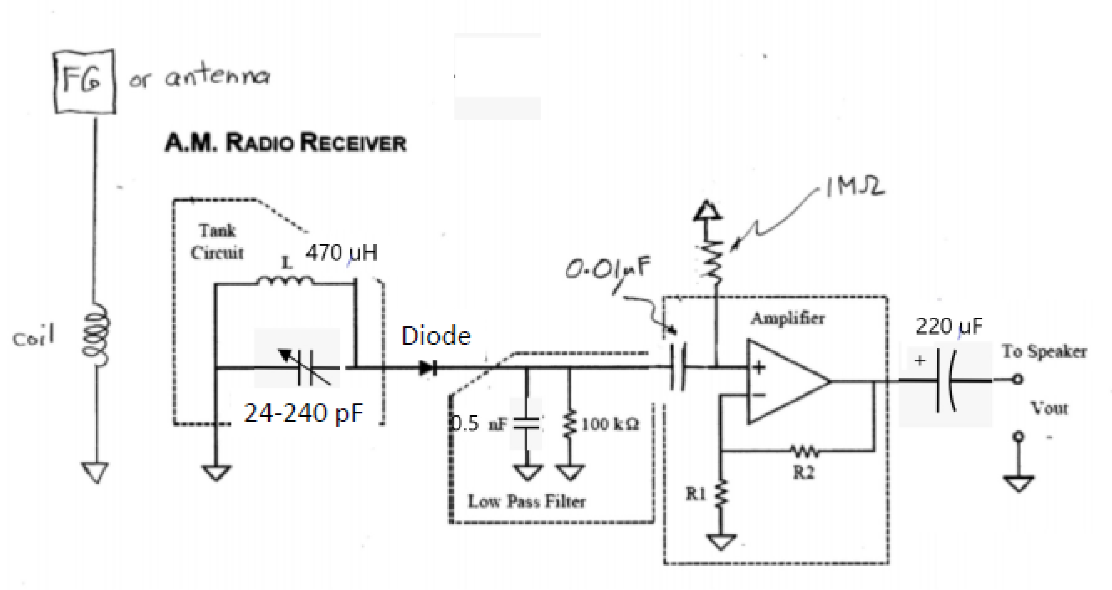
In 4.1, we measured a gain of 3.037e+00 +/- 7.699e-02 and found a linear relationship from the non-inverting amplifier. We also learned that capacitors are used to remove any DC offset signals from the input signal.

In 4.2 we see how just the positive and low frequency modulated part can be extracted from a high frequency carrier signal. We found that the amplitude of the output signal of 1.69 V is approximately the same as the amplitude of the modulated frequency of 1.68 V.

in 4.3, we observe that capacitance has an effect on the resonant frequency. We also observe that the effective resistance of the tank circuit of 131 Ohm is larger than what we would expect of 98.025 Ohm, and that it also has an effect on the resonant frequency. In future experiments, I would improve this part of the experiment by using a larger resistor in order to minimize the difference between these two numbers, and thus hopefully bringing the resonant frequency closer to 690 kHz.

In 4.4, we found that got a given V_in, V_out is at it's maximum when the frequency is on resonance. The function exponentially increases up to resonance, then exponentially decreases after resonance. We also found that on resonance, the relationship between V_in and V_out is linear.

The following is the circuit diagram we used and it's built counterpart respectively:


FG
or antenna
A.M. RADIO RECEIVER
Tank Circuit
L
470 µH
Coil
24-240 pF
Diode
0.01µF
1MΩ
Amplifier
0.5 nF
100 kΩ
Low Pass Filter
R1
R2
220 µF
+
To Speaker
Vout
-