2020 Final Project: AM Radio Receiver

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November 16, 2020

1 Pre lab exercise

- What are the main elements of an AM radio and what is the function of each element.**(4 marks)**
- Consider the tank circuit on the left side of Fig. 2. If L=470 μHenry estimate capacitance on the variable capacitor you need to pick up the CBC 690 AM radio station. **(4 marks)**
- In the middle section of Fig. 2 labeled low pass filter what is the RC time constant?. What is the ratio of this time constant relative to the period of the 690 AM carrier frequency? **(4 marks)**.
- Consider the amplifier shown on the right side of Fig. 2 What is the Vout/Vin in terms of R1 and R2 where Vin is the voltage at the + input of the Opamp. hint: It is not quite the same as for in the inverting amplifier which we did in Exp 4. In the lowest level approximation you can assume the voltage at the -ve and +ve inputs of the Opamp are both equal to Vin and that the current passing through R1 is the same as going through R2. **(4 marks)**

2 Objective

Your objective is to construct the main circuit components of an AM radio receiver and characterize each part of the circuit i.e. the tank circuit used to pick up the radio carrier frequency, the rectifier/filter used to extract the audio signal from the carrier frequency and the amplifier used to amplify and drive a speaker.

3 Introduction/Background

Grading comment: There is a concise and clear introduction to the AM radio. Your introduction should include information on who invented the radio and when, how it works, and why it is important. 4 marks

Radio stations transmit electromagnetic waves at specific frequencies. When you dial a particular channel on the your radio you are tuning a resonant circuit to match the carrier frequency of the particular station you are listening to. The CBC in Vancouver (690 AM) broadcasts at a frequency of 690 kHz. The carrier frequency is much higher than the audio frequencies you hear from the speaker of the radio. Note you can only hear audible frequencies up to about 20 kHz. Microphones are used to convert sound into electrical signals which have the same acoustic frequencies. Radio stations mix (multiply) the acoustic electrical signals with the carrier frequency and then broadcast the resulting mixed signal as an electromagnetic wave. AM radio stations mix the acoustic signal with the carrier signal in such a way that the amplitude of the carrier signal varies in time or is modulated in time. In this way the acoustic signal is imbedded in the carrier signal. Your car radio receives/detects the electromagnetic waves, converts them to electrical signals, separates the audio signal from the carrier frequency, amplifies the audio signal and sends the amplified audio signal to your speakers. Radios use one of the two methods to mix audio signal with the carrier radio frequency signal. They are called frequency modulation (F.M.) and amplitude modulation (A.M.).This lab is solely concerned with detection of amplitude modulated radio signals.

Fig. 1(a) shows the carrier frequency with no audio frequency mixed in. Note the amplitude of the signal is constant in time. Fig. 1(b) shows a radio signal with a single audio frequency mixed in. Note how the amplitude of the carrier frequency varies in time periodically at the audio frequency which is much lower than the carrier frequency that the radio station broadcasts at.

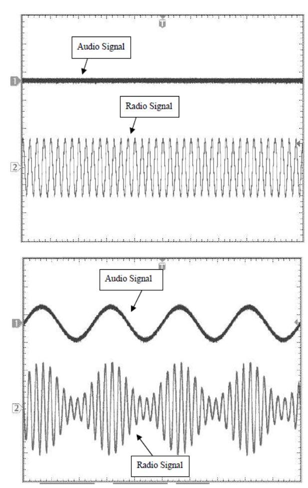

Figure 1: (a) The top figure shows the AM radio signal with no modulation and thus no audio signal mixed in (b) The bottom figure shows an AM radio signal whose amplitude is modulated at the audio frequency.

The main parts of an AM radio receiver are shown in Fig. 2.

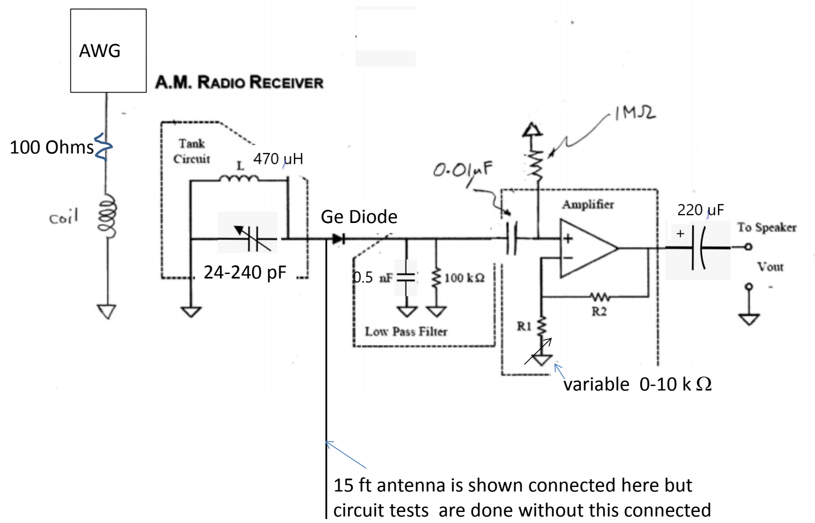

Figure 2: Main components of an AM radio receiver. The antenna picks up the electromagnetic radiation from nearby radio broadcast station. This is coupled (or directly connected) to the tank circuit, which is tuned so that it resonates at the carrier frequency. This results in electric current and charge oscillations in the tank circuit which in turn produces an oscillating voltage signal on input side of the diode which is proportional to the mixed radio signal. A Ge diode rectifies this signal, passing only the positive voltages. A low pass filter suppresses the high frequency spikes which occur at the carrier frequency, leaving only the modulation frequency which is the audio frequency signal. This process is called "demodulation". The resulting audio signal is then amplified and fed to the speaker.

The AM radio receiver has the following elements with associated functions:

- The antenna is a long wire which senses or pick ups the broadcast electromagnetic signal from the radio transmitter and produces a small voltage signal in the wire. Ideally it would be equal to a quarter of the wavelength of the radiation but it still works well at shorter lengths. What is the wavelength of the electromagnetic radiation at 690 kHz?
- The antenna must be connected to or coupled to a resonant LC circuit (the tank circuit) in Fig. 2. You can think of the LC circuit as an LRC circuit where R is small, basically the resistance of the wire and the inductor and capacitor. Recall the resonant frequency of the LRC

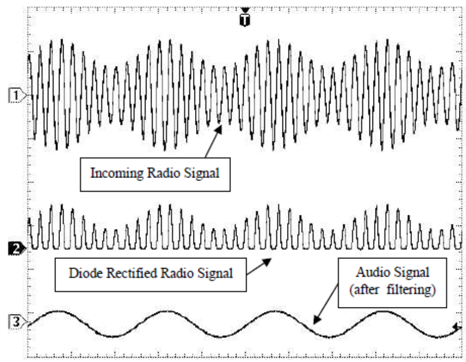

Figure 3: Top trace shows the voltage signal on the side of the diode next to the tank circuit in fig. 2 which is proportional to the modulated radio signal. The signal output on the right side of the diode is rectified as shown in the middle trace of fig. 3. The low pass filter suppresses the high frequency spikes so only the audio signal from the modulation reaches the amplifier. The resulting audio signal is then amplified and fed to the speaker.

circuit is $f_o = 1/(2\pi\sqrt{LC})$ independent of R when R is small. The tank circuit will resonate if the resonant frequency is tuned close to the carrier frequency of the radio station. In this case the signal from the antenna drives electrical charge oscillations in the tank circuit. The energy in the circuit builds up and oscillates back and forth between the capacitor and inductor. Note this is similar to the driven harmonic oscillator.

- The charge/current oscillations in the tank circuit produce a voltage signal on the input side of the diode which is proportional the the amplitude modulated radio signal. The diode rectifies this signal and the low pass filter suppresses the high frequency spikes in the rectified signal. The output from the low pass filter is then only the low frequency audio signal from the amplitude modulation of the radio signal with a DC offset. This is shown in fig.3.

- The signal from the low pass filter is too weak to drive a speaker so one needs to use an amplifier to provide enough power to operate a speaker. This is achieved using a 411 Op-amp arranged so that it is a non inverting amplifier. The 0.01 μF capacitor and 1 M Ohm resistor just before the amplifier are to remove the DC offset in the signal at the input of the Op-amp. The 220 μF capacitor on the output of the amplifier blocks any DC current going to the speaker.

- The last element of the AM radio is a speaker which converts the audio voltage signal to sound by driving a diaphragm.

4 Experiment

In the experiment you will construct the main elements of the AM radio and test and characterize each element. Then you will then connect them together, attach the speaker and antenna, and test the radio receiver.

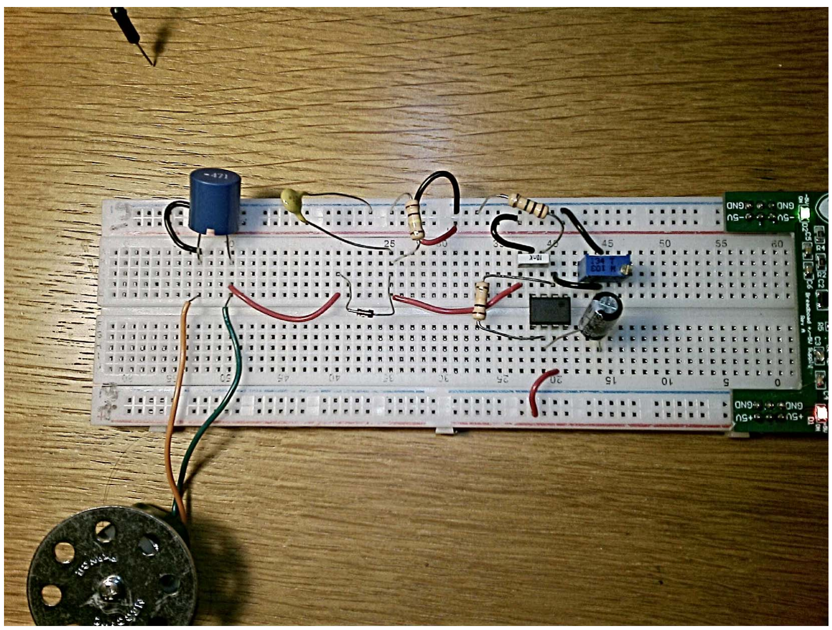

Figure 4: Main components of an AM radio receiver on the protoboard (minus the antenna and speaker). All the components on the right side of the protoboard (to the right of column 30) are the non inverting amplifier using the LF 411 op-amp. The low pass filter is in top middle section between columns 20 and 25. The tank circuit is composed of a 471 microH inductor and a variable 24-240 pF capacitor, each of which has one end in column 7 and one end in column 10. Note there is a small black jumper wire connecting column 7 to ground.

4.1 Amplifier

- Assemble the circuit for a non inverting amplifier shown on the right side in Fig. 1 and including the 0.01 μF capacitor and 1 M Ohm resistor and also the 220 μF capacitor on the output. Choose the resistor R2 to be 10 kOhm. Choose R1 to be a 0-10 kOhm variable resistor. This is same component you used in Exp 3 to make a variable voltage source. Adjust R1 to be 2.5 kOhm before installing it. Note using a variable R1 allows you to change the gain (and thus the speaker volume) which makes the radio more functional. It is easiest to test the components with a smaller gain so start with so set R1 at 2.5 kOhms. The component layout is shown in Fig. 4 . Which column and row is the V^+ input to the amplifier? Which column and row is the V^- input to the amplifier? Which column and row is the output of the amplifier? What is the expected gain for this amplifier? The Op amp serves to amplify the voltage signal from the demodulation circuit but is also needed to supply current so there is enough power to drive the speaker. The output from the demodulation circuit cannot provide much current.

Grading comment: There is an accurate diagram of your circuit used to test the amplifier. You have identified the location of the input and output columns for the amplifier in the photo and calculated the expected gain. (6 marks)

- Set the AWG to produce a sine function. Measure the gain and linearity of Vout versus Vin at 6.9 kHz over the range of Vin such that Vout is undistorted. Comment on the phase of Vout relative to Vin compared to what you observed for the inverting amplifier in Exp4. Compare the observed gain with the theoretical gain expected from the measured values of variable R1 and R2. Save and record scope images of Vin(t) and Vout(t) in your notebook.

  Grading comment: There is an accurate description of how you measured Vout and Vin. There are images of Vout(t) and Vin(t) with a comment on the relative phase. There is a plot of Vout versus Vin with a fit using Curvefitlinear2020.py along with the fitted parameters. There is sufficient data to show the linear region of the amplifier. The fitted gain and uncertainty is compared with that expected from the measured values of R1 and R2. (6 marks)

- Describe in your notebook how the Vout signal taken from column 21 (bottom) changes in response to a DC offset in the input signal Vin applied at column 39 (bottom). Compare the output with and without an offset of 0.2 V with an input amplitude of 0.2V. Make sure CH1 and CH2 are DC coupled when you do this test. Please note the signal displayed on the Hantek scope will show some small offset from zero which is not real. Any real offset will disappear when the scope input coupling is changed from DC to AC. In other words if the signal does not shift going from DC to AC coupling the real offset is zero. Now apply the Vin signal on the left side of the 0.01 μF capacitor in column 37 (top) and repeat the test. What happens to output signal with and without the offset? Save scope images of the signals to help you describe the function of the $0.01 \mu F$ capacitor at the amplifier input.

Grading comment: The explanations are clear and there are images to demonstrate what is the effect of the $0.01\mu F$ input capacitor. In particular it is explained how the output signal changes in response to an offset voltage at input signal with and without this capacitor in the test circuit. (6 marks)

4.2 Demodulation-rectifier/low pass filter

- Assemble the circuit for demodulating an AM radio signal as shown in Fig. 4. This part of the circuit is shown in the middle of Fig. 2 between columns 20 and 25. Your low pass filter rectifier circuit is composed of a germanium diode going from column 20 to 25, a 0.5 nF capacitor going from column 25 to ground and a 100 kOhm resistor also going from column 25 to ground. Note the Ge diode is different than the Si diode used in Exp 3 and has a smaller "turn on" voltage needed for this application. Measure the turn on voltage using the diode function on the DMM. (press DMM and select page 4). Orient the diode so that it is forward biased with a positive voltage going from left to right. The black ring on the diode should be on the right side as shown in Fig. 4. To measure the properties of the demodulation circuit apply the input signal to the left side of the diode (column 20) and measure the the output signal in column 25.

- Generate an amplitude modulated signal by following these steps: (1) download the file modulatedsignal.csv from Canvas in the Experiments module near the bottom. (2) Connect the Hantek to your laptop (3) from the Hantek software window select DDS (top right) to control function generator (3) check "on". (4) select Arb (5) set ArbCH to Arb1 so the modulated signal gets stored as Arb1 when you need it. (6) Select Loadarb (7) select the file modulatedsignal.csv but make sure the selection box does not overlap with the Hantek scope window. (8) change the frequency to 6.90 kHz and set the amplitude to be 0.50 V. This is then stored as type Arb1 which you can select from the Hantek just like a sine or square wave function type. This means the pattern will repeat at a frequency of 6.90 kHz. The carrier frequency will be 100 times larger i.e. 690 kHz. Save images of the input signal applied to column 20 and output signal from column 25 at 50 μs /division. An example of what you should observe is shown in Fig. 5. Measure the amplitude and frequency of the amplitude modulation in the input signal using the cursors. Then measure the amplitude, offset and frequency of the output signal on CH2 using the cursors and measuring tool. Compare the amplitude and frequency of the modulation with that of the output signal seen in column 25. Explain the frequency, amplitude and offset of the output signal seen in column 25. Expand the time scale 1 μs/division so you can see observe the oscillations at the carrier frequency on the input signal. Describe what you observe and try to explain it given the arbitrary function used to generate the amplitude modulated signal has only 512 points. Measure the carrier frequency by counting the number of oscillations and dividing by the observation time.

Grading comment: There is an accurate diagram of your circuit used to test the demodulation of an AM signal. The input signal and output signals are fully described and characterized with the cursor measurements and images at 50 μs/division. There is an explanation for the observed output signal.There is also a description of the input signal at 1 μs/division and a measurement of the carrier frequency (9 marks)

- Now use CH2 to measure the output signal from the amplifier in column 16(bottom) while keeping the modulated signal input in column 20 (top). Measure the amplitude, offset and frequency. Save the image and comment on any differences compared to output signal from the demodulation circuit in column 37.

  Grading comment: The output signal from the amplifier is fully characterized and compared to the output signal measured in column 37 (i.e before the input capacitor in front of the amplifier). (3 marks)

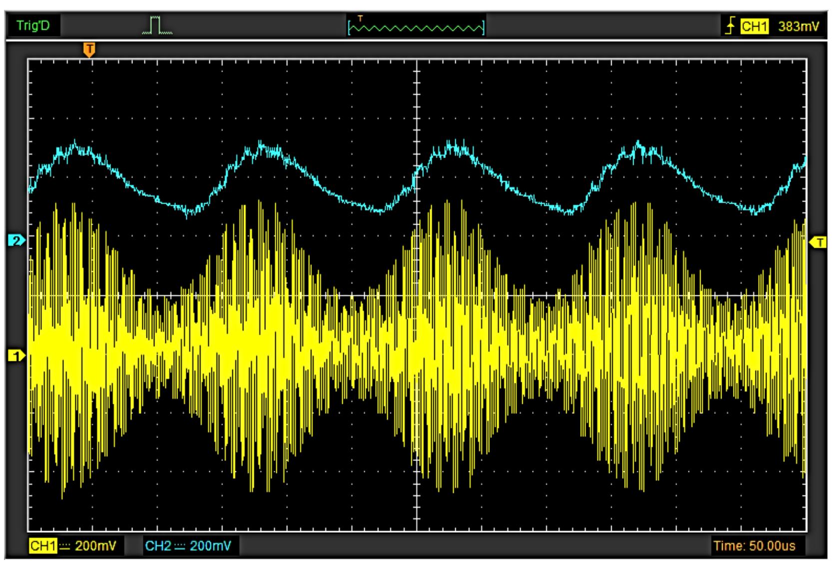

Figure 5: CH1 shows the modulated input signal to the demodulation circuit. CH2 shows the output signal from the demodulation circuit measured in column 25 or 37.

4.3 Tuning the Tank circuit

- Assemble the tank circuit on the left side of Figs. 2 and 4. This consists of a blue 471 microF inductor and a variable capacitor which allows the capacitance to vary between 24 and 240 pF. Note your variable capacitor may look a bit different than the one shown. Both the inductor and variable capacitor have one end in column 7 and one end in column 10. In addition there is a small black jumper wire connecting column 7 to ground.

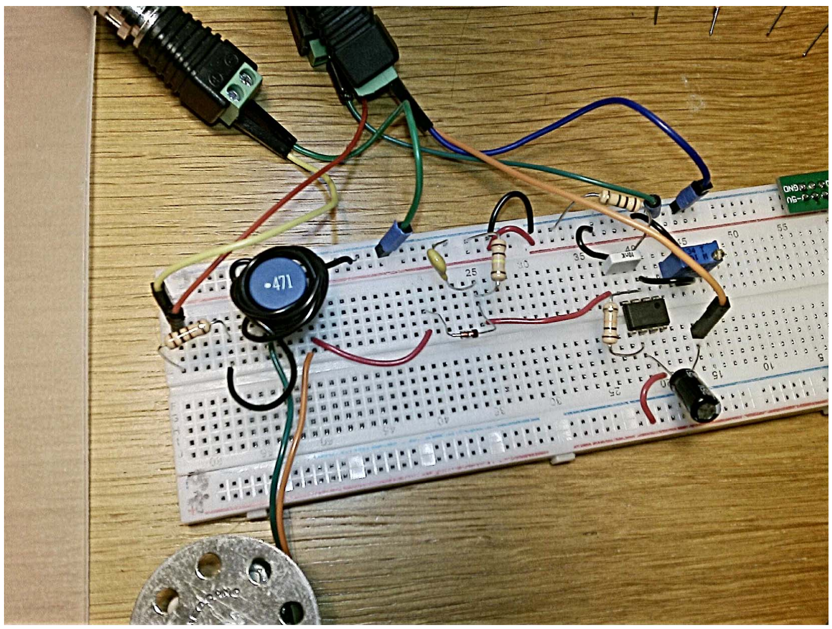

Figure 6: Setup to tune the tank circuit composed of a 471 microH inductor and a variable 24-240 pF capacitor, each of which has one end in column 7 and one end in column 10. There is a small black jumper wire connecting column 7 to ground. The signal from the AWG in column -1 (top) drives a current through a 100 Ohm resistor and a coil wrapped around the inductor. The output signal from the amplifier in column 16(bottom) is used to monitor the resonance.

- Next wind a coil with about 10 turns tightly around the inductor and one end grounded. The other end should go to an unused column (e.g column 3) which connects to column -1 through a 100 Ohm resistor. This is shown in Fig. 6. One could use a sine wave to excite the tank circuit and monitor the voltage across the capacitor similar to how you tuned the LRC circuit in Exp2. However it is better to excite the tank circuit with your amplitude modulated signal and monitor the resonance at the amplifier output. The setup and pin connections for this tuning procedure are shown if Fig. 6. The modulated amplitude at the amplifier output will be a maximum when the carrier frequency is on resonance for the tank circuit.

- On the Hantek AWG select the Arb1 waveform (amplitude modulated signal) with an amplitude of 0.5 V, frequency of 6.90 kHz, zero offset. Connect this to column -1 and monitor this input voltage signal on CH1. Set the trigger on CH1. The trace may be a bit unstable due to the nature of the signal but that of OK for this purpose. The signal from the AWG drives a current through a 100 Ohm resistor and the coil wrapped around the inductor. The output signal from the amplifier in column 16(bottom) is used to monitor the resonance and should be connected to CH2. Now adjust the capacitor slowly to maximize the output amplitude. An example of what you should see close to resonance is shown in Fig. 7 . Save images of the signal on resonance and well off resonance. Describe what is observed as you vary the capacitance slowly through the resonance.

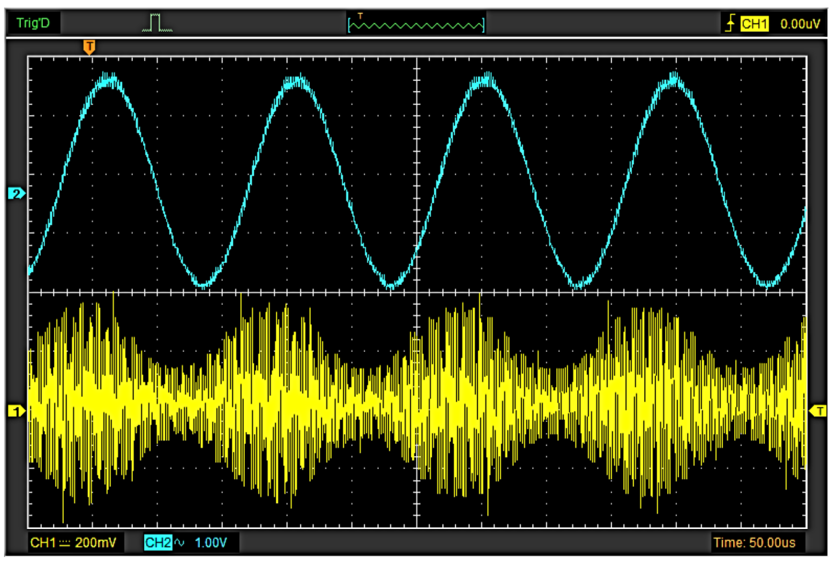

Figure 7: CH1 is the input signal to the coil wrapped around the inductor of the tank circuit. CH2 shows the output signal from the amplifier close to resonance.

Grading comment: There is an accurate diagram of your circuit used to test the tank circuit. There is a description and images to show what happens to the signals as the tank circuit is tuned by adjusting the capacitor. 8 marks

- Now measure the amplitude of Vout versus the frequency of Vin set on the

AWG. Create a .csv file of amplitude of Vout versus the carrier frequency which is 100 times the frequency setting on the AWG. There should be a peak near 690 kHz. Fit the data using the Python script Curvefitlcrresmod.py . Report a value for the effective resistance R in the tank circuit using the fact that the linewidth parameter from the fit $\gamma = R/L$. Compare this effective resistance with an estimate of the resistance in the tank circuit. Is there a big difference? Discuss.

Grading comment: You have a reasonable number of data points to fit the resonance and determine the parameters and resonant frequency. There is a reasonable discussion about the linewidth parameter and the size of the effective resistance in the tank circuit.8 marks

4.4 Testing the AM receiver

In order to test the radio receiver take the following steps:

- Leave all the connections between the Hantek and the protoboard i.e. the AWG and CH1 connected to 10 turn coil through column -1 and CH2 connected to the amplifier output column 16 (bottom). However now turn off the AWG, turn off CH1, leave CH2 on and trigger the scope on CH2. In addition be sure to leave the Hantek connected to your laptop for grounding purposes.

- *Unplug the (normal) USB connector from the wall plug adapter so there is no power going to the protoboard.* Install the speaker with one end connected to the amplifier output (column 16, bottom) and one end connected to ground. Then install a long the antenna wire (15 ft) to column 20. Double check your speaker and antenna connections. The antenna should then be connected to the right side of the variable capacitor which is also left side of the diode. The final configuration for testing the radio is shown in Fig. 8.

- *Now plug the (normal) USB connector into your laptop, instead of the wall plug adapter, so the power to the protoboard is coming from your laptop. This will reduce 60 Hz noise coming from the wall plug adapter.* You will need to retune the capacitor since the antenna changes the resonant frequency. Describe what you hear as you slowly adjust the capacitor. How many stations can you hear? Try this this during the day and also later at night. When is the reception better? Remove the speaker and adjust the trigger on CH2 so you can see the signal on CH2 that you heard on the speaker for the loudest station. Save some the images when the radio is tuned to the loudest station. Repeat when the radio is detuned away from any radio station. Try to explain in words what you observe on the scope and hear on the speaker.

- If you get to this point congratulations!

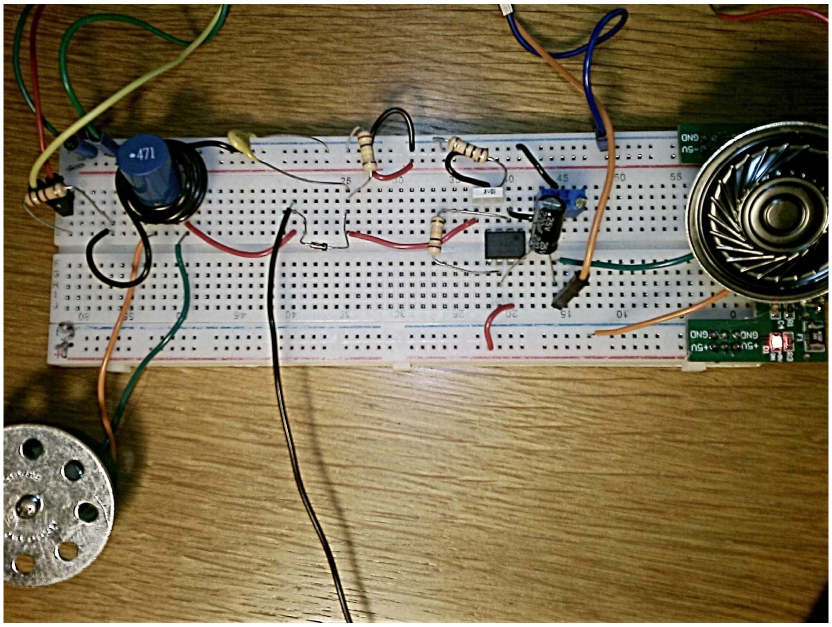

Figure 8: The setup to test the radio. Note the speaker has one end at the output of the amplifier and one end at ground. Also note one end of the black antenna wire is in column 20 which is connected to the variable capacitor and thus excites the tank circuit. The antenna should be about 15 ft long and stretched out as much as possible.

Grading comment: You have a photo you final setup with the antenna and speaker installed showing all the connections. There is discussion of what things you tried in order to make the radio work better. You have described everything you hear on the speaker and observed on CH2 as you adjust the capacitor. (8 marks)

5 Conclusion

Summarize the main results from your experiment. What are the main issues or problems with the receiver and how might you try to fix them.

Grading comment: (6 marks)