2018 Final Project: AM Radio Receiver

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1 Pre lab exercise

- What are the main elements of an AM radio and what is the function of each element.**(1 mark)**
- 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. **(1 mark)**
- 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? **(1 mark)**.
- 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. **(1 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 drive a speaker or headphones.

3 Introduction/Background

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.

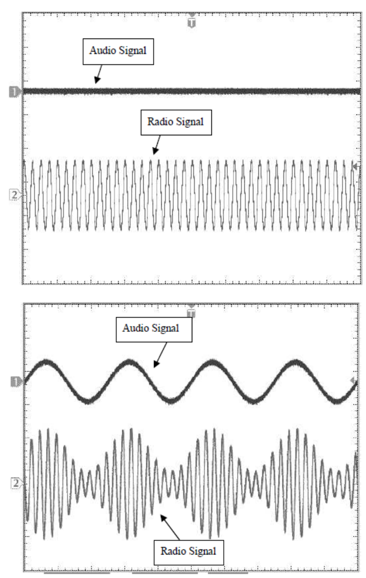

Figure 1: (a) The top figure shows the AM radio signal with no modulation and thus no audio signal mixed in (b) The bottom figure shows an AM radio signal whose amplitude is modulated at the audio frequency.

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

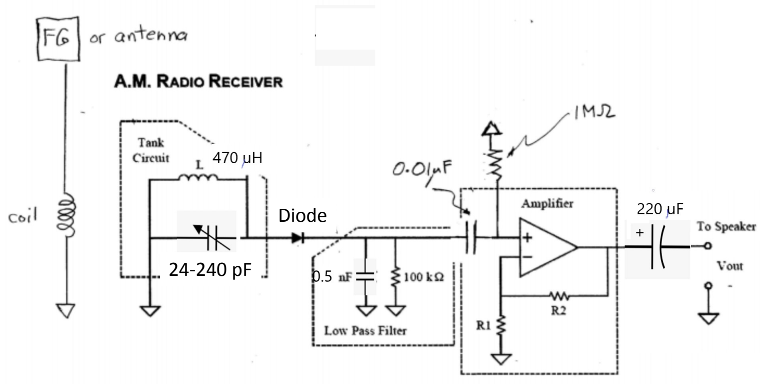

Figure 2: Main components of an AM radio receiver. The antenna picks up the electromagnetic radiation from nearby radio broadcast station. This is coupled (or directly connected) to the tank circuit, which is tuned so that it resonates at the carrier frequency. This results in electric charge oscillations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

The AM radio receiver has the following elements and functions:

- The antenna is a long wire which senses or pick ups the broadcast electromagnetic signal from the radio transmitter and produces a 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 very small, basically the resistance of the wire and the inductor and capacitor. Recall the resonant frequency of the LRC 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 radio carrier frequency. 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 conductor. Note this is similar to the driven harmonic oscillator.

- The charge 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 or headphone. This is achieved using a 741 Op-amp arranged so that it is a non inverting amplifier with a gain of about 11. 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 component going to the headphones or 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 individually. Then you will connect them together so you can test the radio receiver. Use the small protoboards without power so you can keep the circuit intact from week to week.

4.1 Amplifier

- Assemble the circuit for a non inverting amplifier shown on the right side in Fig. 1 including the 0.01 μF capacitor and 1 M Ohm resistor and also the 220 μF capacitor on the output. Choose the resistors R1=1kOhm and R2=10 kOhm to give an approximate gain of 11. The Op amp serves to amplify the voltage signal from the filter 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. (Actually the 741 isn't the best amplifier for this purpose and can just barely drive the speaker. Your eardrums are safe)

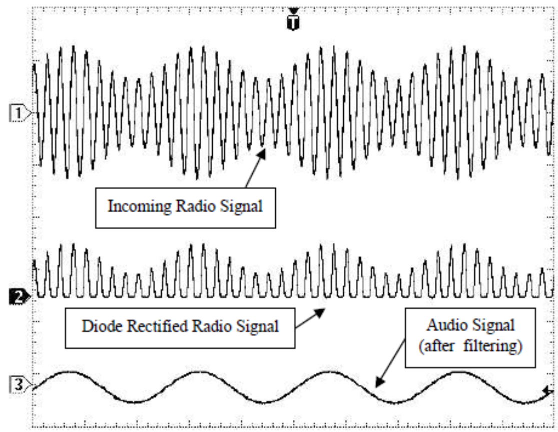

Figure 3: Top trace shows the voltage signal on the side of the diode next to the tank circuit in fig. 2 which is proportional to the modulated radio signal. The signal output on the right side of the diode is rectified as shown in the middle trace of fig. 3. The low pass filter suppresses the high frequency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

- Measure the gain and linearity of Vout/Vin versus Vin at 3 kHz over the range of Vin such that Vout is undistorted. Note the sign of the phase of the Vout versus Vin. Compare this with the inverting amplifier in Exp4.
- Report how the amplifier output (after the 220 μF capacitor) changes with and without an offset voltage from the function generator. Repeat without the 0.01 μF capacitor and 1 M Ohm resistor at the input and then without the 220 μF capacitor on the output. Explain the effect of having the capacitor-resistor combination on the input. Explain the effect of having the 220 μF capacitor on the output.

4.2 Demodulation-rectifier/low pass filter

- Assemble the circuit for demodulating an AM radio signal. This part of the circuit is shown in the middle of Fig. 2. Your test circuit should have a diode and the low pass filter immediately afterwards. The input from the function generator is applied to the left side of the diode and the output signal is taken from the ungrounded end of the 100 kOhm resistor.

- Setup the arbitrary function generator to give an amplitude modulated signal with a carrier frequency of 690 kHz and a modulation frequency of 3 kHz and a modulation depth of 70%. This is described in section 3-10 of the manual for the function generator.

- Display the input signal on the scope so you can see the modulation frequency of 3kHz. (note the carrier frequency itself appear as blur unless you expand the time scale). Measure the amplitude of the modulation frequency with cursors.(ie. what is the maximum amplitude of the carrier signal minus the minimum amplitude of the carrier signal?) Save the data to a csv file so it can be shown in the report.

- Display the output signal on the scope with DC coupling so you can see the demodulated signal showing about 5 complete oscillations. Measure the frequency and DC offset using the scope. Save the data to a .csv file so it can be shown in the report.

4.3 Tank Resonator Circuit

- Assemble the tank circuit on the left side of fig. 2. Wind a coil with about 10 turns tightly around the inductor of the tank circuit. Split the signal from the function generator. On one side use a BNC cable with two alligator clips to make the connections to the coil through a 100 Ohm resistor . (This resistor will keep the current constant). Monitor this signal on Channel 1 of the scope. Monitor the voltage drop across the capacitor on channel 2 using another BNC cable with clips. The oscillating current in the coil will induce a current in the tank circuit when the coil is wrapped around the inductor. Note what happens to the output when the coil is removed from the inductor. Set the function generator to 500 mV and 690 kHz with the coil wrapped around the inductor.

- Adjust the capacitor carefully and slowly to maximize the Vout. Then measure the amplitude of Vout versus the frequency of Vin and make a .csv file. There should be a peak at 690 kHz. Afterwards fit the data using 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.

4.4 Testing the AM receiver

Now you can connect the tank circuit , demodulation circuit and amplifier circuit as shown in fig. 2. Instead of the antenna use the function generator with a carrier frequency of 690 kHz and a modulation frequency of 3 kHz. Make sure the 10 turn coil is still wrapped around the inductor.

- Record the output signal from the Op-amp after the 220 μF capacitor for various input signals varying the carrier frequency and amplitude of the modulated signal. Make a plot of the output amplitude versus carrier frequency. On resonance make a plot of the output amplitude versus the input amplitude from the function generator.

- Connect the speaker with long enough wires so you can hold it to your ear. On resonance you should hear a 3 kHz tone whose amplitude scales with the input amplitude and peaks at 690 kHz.
- Finally bring your whole circuit (small one with no power and also the one used to provide power)to the back bench so it can be hooked up to the antenna inductively. You should be able to hear the CBC on the speaker.

5 Conclusion

Summarize the main results from your experiment. What are the main problems with receiver and how would you fix them or in general improve the operation of the radio.?