LAB III RADIO RECEIVERS

Purpose:

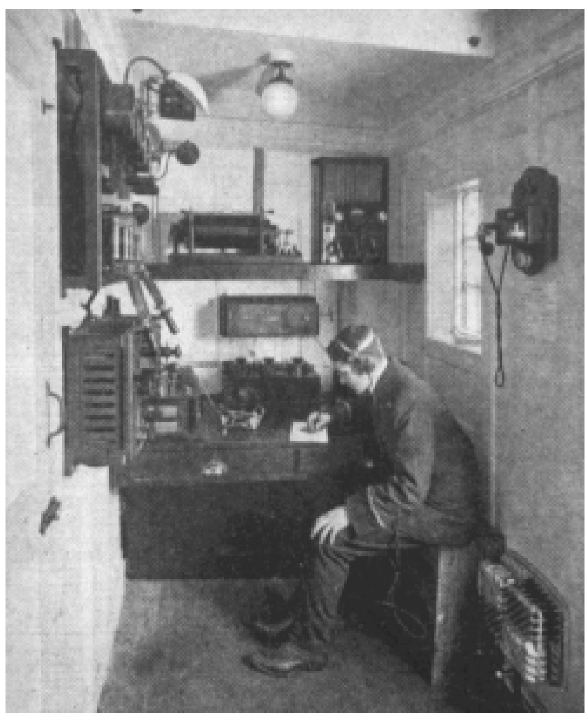
The purpose of this lab is to learn the history of radio: from birth to broadcast. In addition, we will study key scientific developments: LC circuits, induction coil, etc. and design and construct an AM radio.

Introduction: A Brief History of Radio

The history of radio can essentially be traced back to the theoretical work of great 19th century scientists such as Faraday, Thompson, Maxwell, Helmholtz (who first detected radio waves in 1887), and Kirchoff. However, the title of the "grandfather" of broadcast radio, in many circles, is given to the infamous Gugliemo Marconi (see figure 1). In 1894 Marconi invented the first spark transmitter with an antenna (see figure 2), which he patented in 1896. By 1897 he had formed his first wireless telegraph company. In 1906, in what proved to be his most important invention, he patented a new version of the Fleming Valve (see figure 3), which acted as a diode tube to amplify current in one direction. He also was key in the development of point-to-point, or two party, radio transmission. However, by 1906 Lee de Forest had patented both an audion tube and a spade detector, which led to the idea of multi-point broadcasting, or broadcasting to a public. Perhaps one of the most important inventors was Edwin H. Armstrong (see figure 5). He was responsible for the Regenerative Circuit (1912), that fed a radio signal through an audion tube 20,000 times per second to caused stronger oscillations in the tube that generated radio waves, the Superheterodyne Circuit (1918), that combined high and low frequency waves, the Superregenerative Circuit (1922) and discovery of FM transmission (1933). His inventions and developments form the backbone of radio communications as we know it.

Of course there are many other important figures in the history of radio. Since I am a Hamm radio, amature radio, operator, call sign KC2LVF, I thought that I would dedicate a brief paragraph on the essence and importance of Hamm radio in the development of radio technology. In fact, I am surprised that not once in this lab have we made reference to the contribution that Hamm radio operators made in the development of radio. One of the greatest achievements in amateur radio history was the spanning of the Atlantic by shortwave (~200 meters) in December of 1921, the first successful transatlantic shortwave *voice* broadcasts ever made (not to be confused with Marconi's Morse code transmission in 1901). Even the father of radio astronomy Karl Jansky, who in 1933 discovered the existance of radio waves in space, was an early Ham radio operator (see figure 6). From figure 7, you can see that even though there are relatively few Ham bands today, as the majority of them are used by commercial radio and tv stations, cell phone servecies, etc. However, even with such little air space Ham radio operators continue to play an important part in the continuation of the radio culture that inventors like Armstrong began.

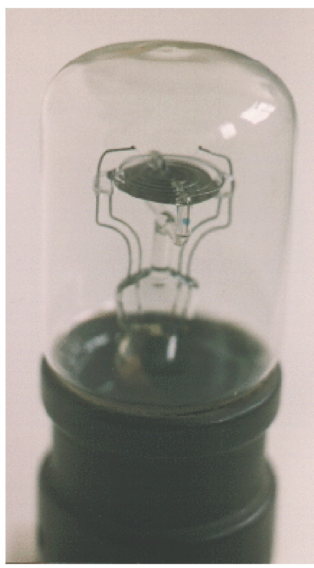
Figure 1[1]: Gugliemo Marconi in his, at the time "state of the art", radio room on the S.S Fraconia.



[1] Picture courtesy of http://home.luna.nl/~arjan-muil/radio/history.html

Figure 2[2]: Spark transmitter invented by Marconi in 1894

Figure 3[3]: In 1904 Fleming patented the diode rectifier/detector. The next development, the triode amplifier, was patented by Lee de Forest in 1906.



[2] Picture courtesy of: http://history.acusd.edu/gen/recording/radio.html
[3] Picture courtesy of: http://home.luna.nl/~arjan-muil/radio/early-tubes.html

Figure 4[4]: During the pioneering days of broadcasting crystal radio receivers were very popular. These sets were also called "Cats Whisker". The Cats Whisker is named after the tiny wire that connects to the detector crystal. Many constructions were made to adjust the wire finding a sensitive spot on the crystal.

Figure 5[5]: Edwin Armstrong and his portable radio, circa 1923.

[4] Picture courtesy of: http://home.luna.nl/~arjan-muil/radio/history/history-frame.html
[5] Picture courtesy of: http://www.acmi.net.au/AIC/ARMSTRONG_RCVR.html

Figure 6[6]: Karl Jansky with the antenna he used to detect radio frequencies in space.

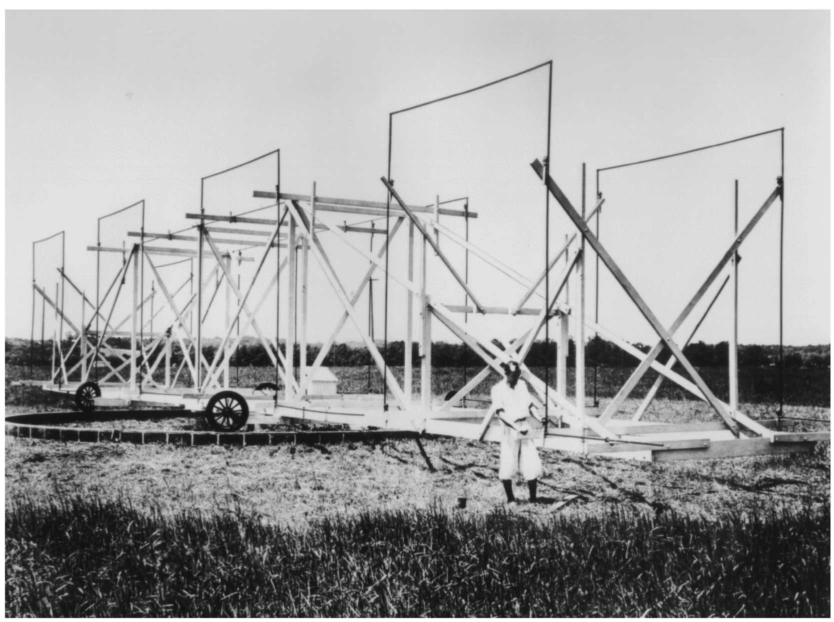


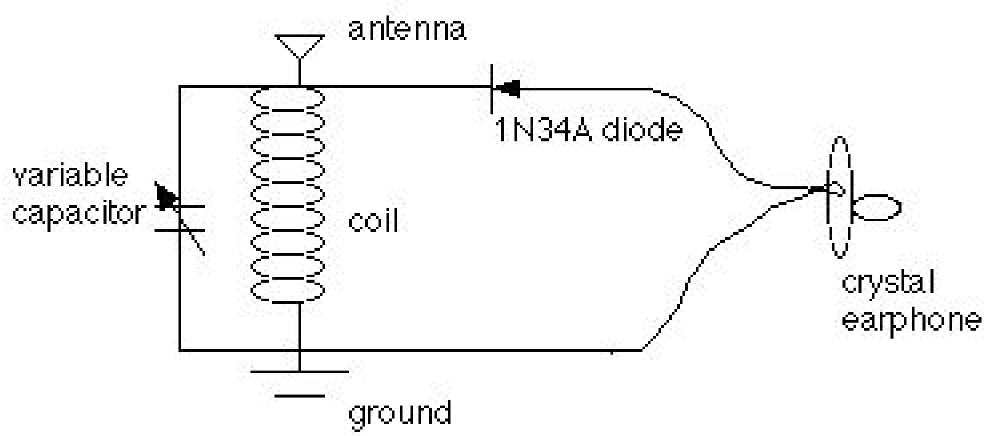
Figure 7: FCC allocation of radio frequency bands in the United States

[6] Picture courtesy of: http://www.gb.nrao.edu/~fghigo/fgdocs/jansky/jansky.html

PART I: A tiny Voice from the Heavens

How does a Crystal Radio work anyway?

Figure 8[7]: Schematic diagram of a crystal radio (similar to the one in our lab).



A crystal radio works just like any other radio, but without the amplifiers for radio/audio frequency signals, or local oscillators as used in the common superheterodyne radio. The transmitted signal is a carrier wave at the transmitting radio frequency of the radio station. For an AM (amplitude modulation) broadcast station, the carrier signal is modulated by an audio frequency signal ranging up to several thousand Hertz (for example 1010 WINS broadcasts at 1Mhz which is 1000 KH (thousands of cycles per second), which causes the signal to vary in amplitude at the frequency of the audio signal. When the modulated wave reaches the receiver antenna, some of its energy is captured by the antenna. Ideally, the antenna is resonant at the radio frequency of interest, that is, at least a quarter wavelength long. Generally, the longer and more tuned to resonance the receiving antenna is, the more signal from the station is available to be heard. The received signal is carried to a "tank" circuit, in our case an inductor, or coil of wire, and a parrallel plate capacitor. The circuit acts as a band pass filter, and when it is resonant at the frequency of the received signal, it will "ring", just as a tuning fork does, storing the energy of the signal. Signals of different frequencies will not be stored in the tank circuit, but will pass on to "ground". In this lab we use only a coil of wire with taps on it for the tank circuit, which relies on the self capacitance between the turns of wire in conjunction

[7] Picture courtesy of: http://www.thebest.net/wuggy/rs99fun.htm

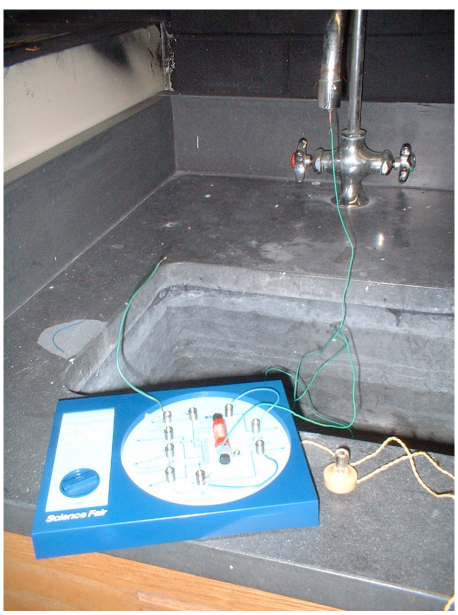
with the inductance of the coil to achieve a resonant condition. Tuning this circuit is done by selecting different taps for the antenna, which brings different amounts of inductance (and capacitance) into play.

(a) Construction of the Crystal Radio

Procedure:

In this part of the lab I built the Radio Shack Crystal Radio Kit. See figure 9. By following the simple directions in the kit and using the parts provided (variable air capacitor, cylindrical solenoid inductor, diode, wire for antenna and ground, and high impedance ear-phone) I was able to connect the parts to the "mother" board. I used a screwdriver as my ground by wrapping the ground wire around the screwdriver and staking it in the earth. I then turned the dial of the radio and was surprised when I actually heard stations coming through, although very faint (I actually think it would have been interesting to get an amplifier and connect it to the radio to make it louder, maybe over break). It is amazing how simple it is to make your own radio and with relatively few parts! This was the most fun I have had in all my labs, ever!

Figure 9: Picture of the Crystal radio. In the lab the grounding wire was connected to the faucet in the sink, which is connected to the ground.



Questions:

#1 The stations that came in the most clear were 1010 WINS, 1015 ESPN, 1130 Bloomberg radio, and a number of other stations that I was not patient enough to listen to long enough for them to announce their call sign. With regards to the dial (from 1-10) of the crystal radio, most stations did not start coming in until after the 5 marker. Before the 5 marker I heard nothing, not even static, but after the 5 marker the stations came in pretty steadily at 5, 7, 8, 9, and 10, with 1010 WINS being at about 8.

#2 When I switched my antenna from terminal 1, for short, and 5, for long, the signal did slightly improve. It was easier for me to pick up the stations that I had previously not picked up, like some Spanish language channel. When I hooked up my long antenna to terminal 6, 1010 WINS came in loud and clear, and I mean loud. For some reason, even the sound quality improved.

(b) Deconstruction

Procedure:

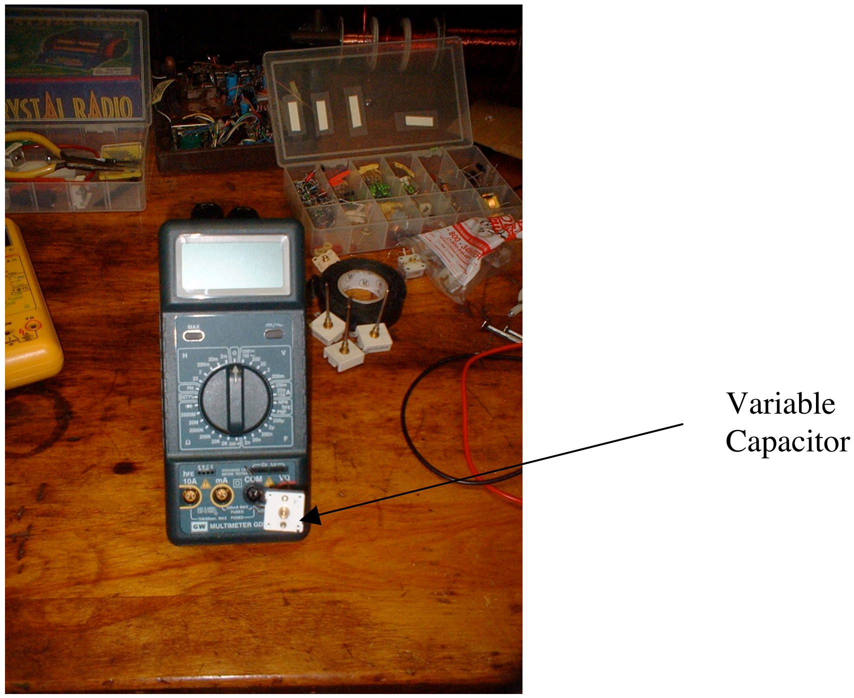
For this part of the lab we deconstructed the radio in order to get a feel for the inner workings of the components. First I set the radio to 1010 WINS, my most clear station. Then I measured the voltage across terminal 6 and 7, the leads where the variable capacitor was connected. Doing this I determined V=0.003μV.

Questions:

#3 The magnitude associated with the current in the receiver circuit is on the order of micro-amps. Why is the voltage and current so small you ask? The crystal radio uses only the energy of the radio waves sent by radio transmitters from the stations, i.e no batteries. These radio transmitters send out enormous amounts of energy (tens of thousands of watts). However, because they are usually far away the amount of energy we receive with the crystal radio is measured in billionths of a watt. So it makes sense that there would be very little voltage and current across the capacitor.

#4 After removing the capacitor I was able to measure it using a muti-meter. See figure 10.

<u>Figure 10:</u> Measuring the capacitor with the multi-meter by sticking the leads directly into the meter. Since the capacitor is variable, it was measured twice at both high and low ends of its variance.



Since it is a variable capacitor I was able to measure the capacitance range by measuring once when the metal plates where not meshed and again when they were meshed. The measurements were:

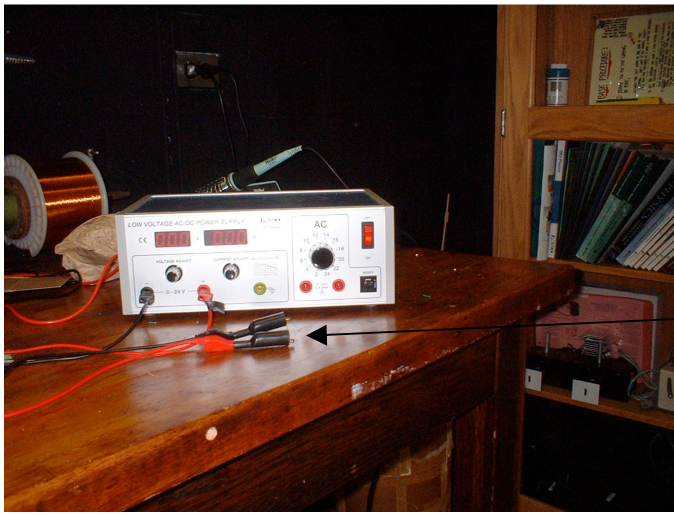
$$C_{max} = 196pf$$

$$C_{min} = 3pf$$

As you can see, even when the plates are unmeshed the capacitance is not zero because with the capicitor connected to the multimeter it forms its own little circuit. Therefore the instrament itself is contributing a small contribution to the overall capacitance. You can see this when you coil the wires as well. The readings are slightly off from the original ones.

#5 I then removed the diode from the circuit. I measured its voltage and corresponding current using a low voltage AC-DC power supply as shown in figure 11.

<u>Figure 11:</u>Measuring voltage and current of the diode.



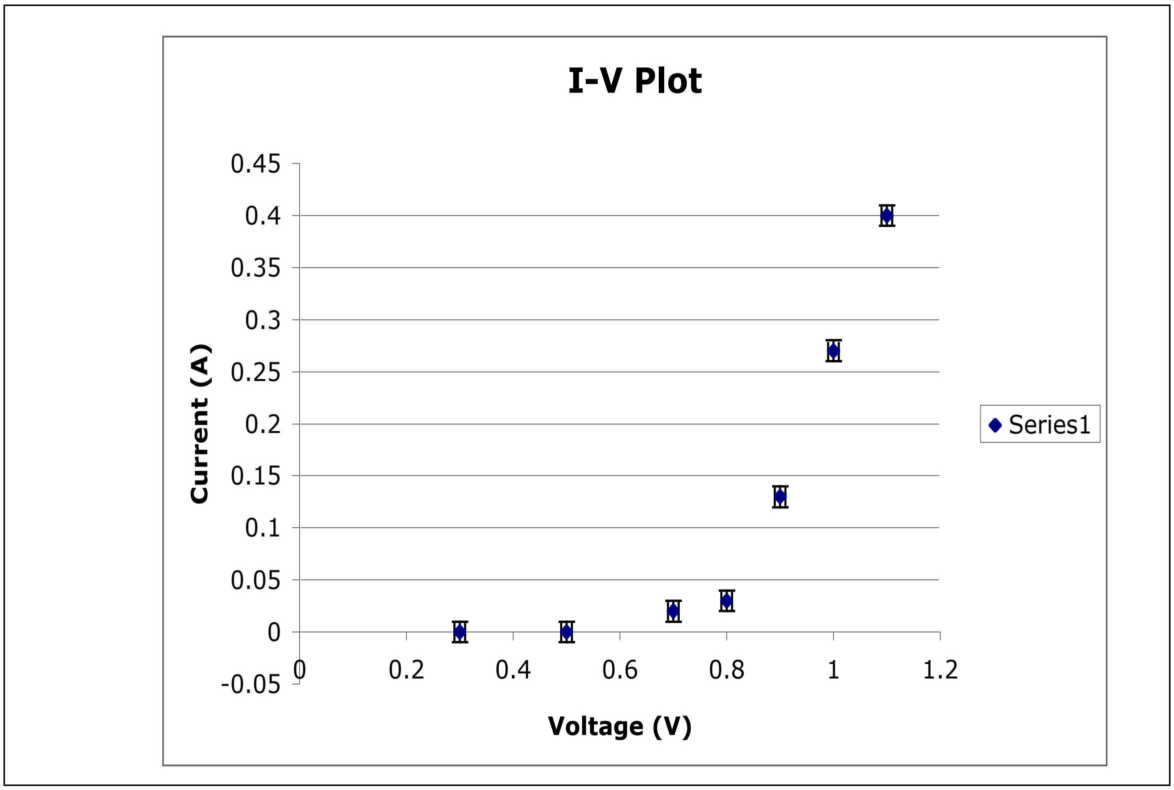
It is interesting to note that the diode is a "one way street". If you look closely there are some lines on the plastic shielding indicating a positive and negative direction. This means a diode only allows current to pass through it in one direction. The diode was connected to the leads and the voltage was increased in increments of 0.1V. The corresponding current was read and both numbers were recorded. Table 1 shows the data.

<u>Table 1:</u> Measurements of diode.

Voltage (V)	Current (A)
0.3	0
0.5	0
0.7	0.02
0.8	0.03
0.9	0.13
1	0.27
1.1	0.4

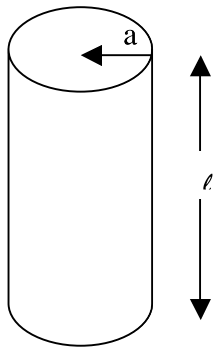
From the data I was able to make a plot to show the characteristics of the diode's voltage and current shown in figure 12. The error bars represent the error in the instrament ~0.01V. We can see that our plot closely resembles the curve shown in the lab handout—zeroing out for small voltages and gently rising exponentially as voltage increases.

Figure 12: Plot of the Current vs. Voltage for the diode



#6 To determine the self-inductance of a tightly wound solenoid use the following scheme:

Given a long cylinder of radius a and length ℓ as shown below,



with inductance L and current I, the magnetic field is given as:

$$B = \mu_0 I N/\ell$$

where I is the current in the wire around the solenoid, and N is the number of windings per unit length. The magnetic flux is then:

$$\phi = \int B\, da = B \pi a^2$$

$$\text{and } B = \mu_0 I N/\ell$$

The inductance is given as:

$$L = N \phi / I = \mu_0 N^2 \pi a^2/\ell$$

Therefore:

$$N = \sqrt{(\ell L / \mu_0 \pi a^2)}$$

Recall from Kirchoff that:

$$\omega = \sqrt{(1/LC)} = 2\pi f$$

Therefore,

$$L = 1/(4 \pi^2 f^2 C)$$

So for the inductor in the crystal radio kit for a frequency of 1010 kHz (the center of the AM band) and a capacitance of 96 pF (the center of the high and low values) is

L = 1/[(9.65 x 10^-11 F) $(4*\pi^2)$(1.010 x 10^6 Hz)^2] = 2.57 x 10^44 H=2.57 x 10^47mH

For an electric bandpass the Q factor is the peak frequency divided by the width of the bandwidth, which is defined by the frequencies where the gain is 3dB lower than the maximum.

$$Qfactor = R/L$$

Where the resistance is found by $V = IR$ or $R = V/I$.

PART II: Minimalist Mode: Spartan Aesthetic

In this part of the lab we designed our own radios.

Questions:

#7 Using a multimeter I measured the capacity range of the capacitor. I had to do this by soldering leads onto the capacitor. I first stripped all the coating off the ends of two pieces of wire with sand paper. I then twisted the wire on the leads and soldered it in place. See figure 13.

Figure 13: Soldering station

The values I got for the capacitor are:

$$C_{max} = 0.010nf = 10pf$$

$$C_{min} = 0.003nf = 3pf$$

These numbers are not surprising because they seem to suggest that the maximal capacitance of the ARCO trimmer capacitor is about 10pf. This is a much smaller range than the crystal radio kit capacitor.

#8 We were given our own trimmer capacitors, or variable capacitors. I decided to use a Quaker oat box for the design of my inductor. In order to design and construct a solenoid inductor, we must find how many number of turns to use for the wire wrapping. Recall the scheme from before:

$$N = \sqrt{(\ell L / \mu_0 \pi a^2)}$$

$$L = 1/(3.5 \times 10^{-12} F)(4*\pi^2)(1.010 \times 10^6 Hz)^2 = 0.007095 H$$

Where ℓ = 7in = 0.1778m and a = 4in = 0.1016m

$$N = [(0.007*.007095) / (4 \pi 10^{-7} \pi 0.0508)]^{1/2} = 79 \text{ turns}$$

From this I was able to make an inductor with my Quaker oats box. See figure 14 for the schematic drawing and figure 15 for a picture of the finished producy.

<u>Figure 14:</u> Schematic diagram of home made radio.

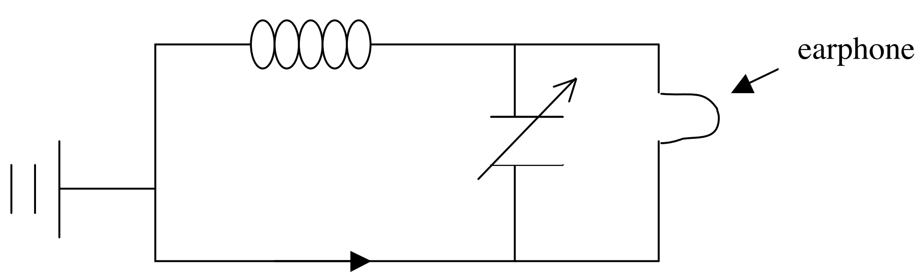
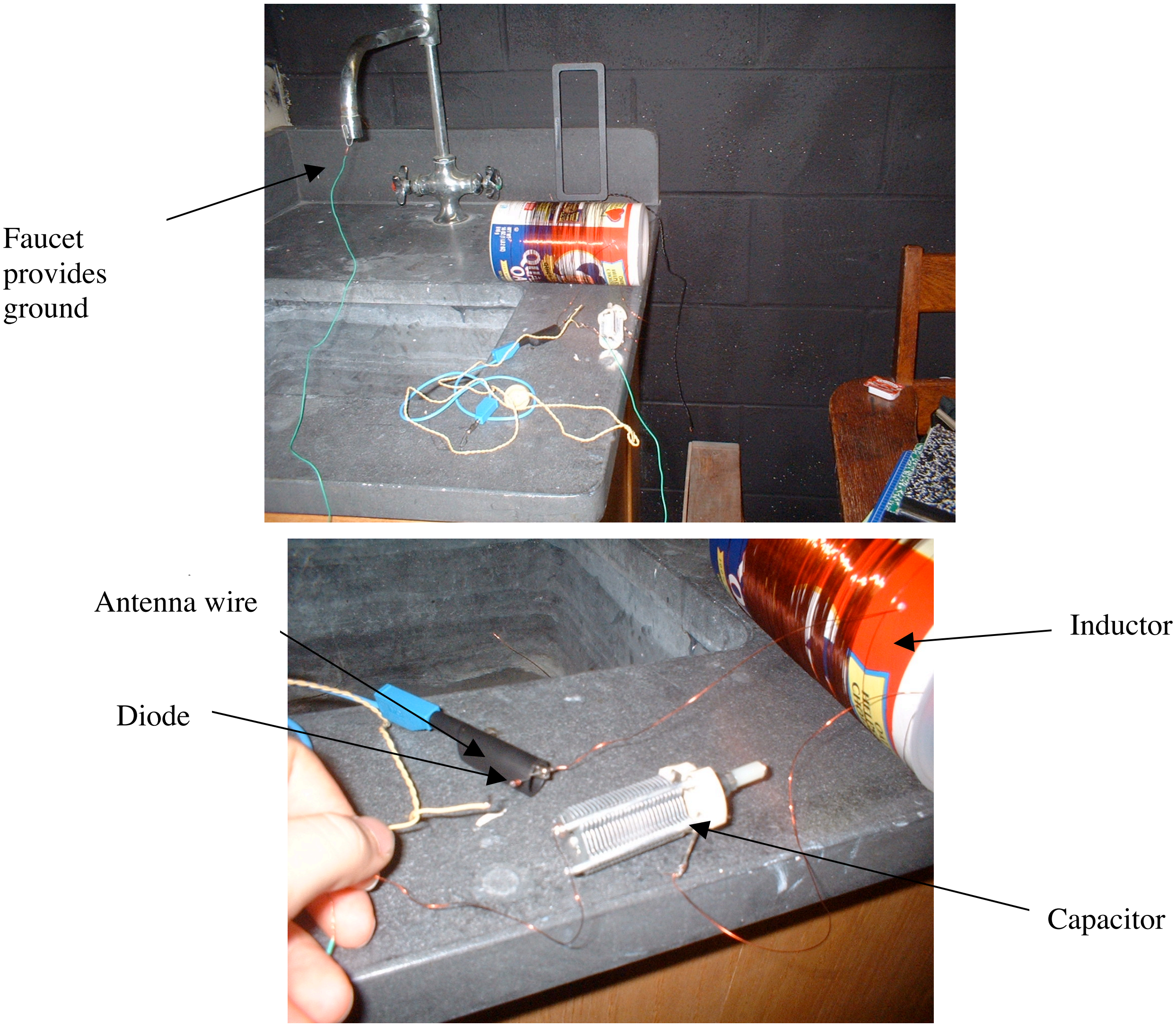


Figure 15: Home made radio with Quaker oat inductor.



Although I attempted to get my radio to tune into a radio station, 1010WINS, I never actually succeeded. See figure 15. I fiddled with it for a long time but all I ever got was static. It was definitely picking up some radio waves, but no clear station could come through. I experimented with different lengths of antenna wire. I also re-sanded the ends of all the wires and soldered all the connections, but nothing yielded a station. I even made a new solenoid out of a pencil, see figure 16, but still no luck.

Figure 16: Some other attempts at a radio with a pencil inductor. It just was not as smazzy as the quaker oat box, although I did hear some static using it!

My gut feeling in all of this is that I am very close to making it work. Even though Professor HH signed off on my radio, I still have faith in my Quaker oat box and plan on doing some more tinckering over break with my 12 year old nephew.

#9 If I lost my trimmer capacitor I could design my own with aluminum foil. Remember what a capacitor is, it is just two metal plates. So, essentially, you could just keep piling on the "metal plates", or cut up pieces of aluminum foil, to make a capacitor.

#10 The LC circuit is tuned (the resonant frequency changed) by varying either the capacitor or the inductor. Like the radios in this lab, many radios use a fixed inductor (also called a coil) and a variable capacitor: as you turn the dial to the left metal plates are rotated together increasing the plate area which increases the capacitance. Another option is to use a fixed capacitor and a variable inductor. The most common way to do this is by screwing an iron rod in or out of the coil to change the inductance.

THE END

Thanks for a great semester!