PHYSICS 18L Lab 6: Fun with Making Radios

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(Dated: Feb. 25, 2019)

Abstract. We present the construction and testing of two radio designs, where one is a simple crystal radio with an LC circuit, a diode and antenna, and an improved version with MK484 AM Radio Integrated Circuit. We are able to receive audible radio signals from at least 2 local stations with the simple radio, and 4stations in total with the amplified radio. We record the announced call sign or station name of each station and use this information to determine the station's frequency, location and broadcast power. The converted sound signals from the amplified radio are also recorded into .wav form using a National Instrument's myDAQ acquisition system with a labVIEW interface.

I. INTRODUCTION TO AM RADIOS AND OBJECTIVES OF THE LAB

Radio waves are a form of electromagnetic waves. One can use a transmitter to generate and send out certain radio signals containing certain information through air, and the signals can be picked up by an antenna of a receiver via electric conduction.

A. Generating of an AM Radio Signal (Double-sideband full carrier AM modulation)

Consider a carrier signal $C(t)$ as a function of time of the following form:

$$C(t) = C\cos(\omega_c t + \phi_c) \tag{1}$$

where C is the amplitude, ω_c is the signal's angular frequency, and ϕ_c is some phase which we set to 0 for convenience without loss of context. The carrier signal contains many components of the audio frequencies $f = \frac{\omega_c}{2\pi}$.

An audio signal $m(t)$ at a particular frequency has the following form:

$$m(t) = M\cos(\omega_a t + \phi_a) \tag{2}$$

where M is the amplitude, ω_a is the audio angular frequency, and ω_a is some phase which we set to 0 as above.

Amplitude modulating the signal results in

$$V(t) = (A + m(t))C(t) \tag{3}$$
$$\Rightarrow V(t) = (A + M\cos\omega_a t)\cos\omega_c t \tag{4}$$

Using the trigonometry identity: $\cos x \cos y = \frac{1}{2}[\cos(x+y) + cos(x-y)]$, Eqn (4) can be expressed as:

$$V(t) = A\cos\omega_c t + \frac{M}{2}[\cos(\omega_c+\omega_a)t + \cos(\omega_c-\omega_a)t] \tag{5}$$

If we want to send out an audio signal of a pure tone ω_a, this signal $V(t)$, containing the carrier frequency ω_c and two sidebands $\omega_c \pm \omega_a$, is the radio wave being generated and transmitted.

B. Receiving and Turning Radio Wave into Sound Wave

To receive the radio signal created of form Eqn (5), one can use a very simple radio receiver whose scheme is shown in Figure 1: The antenna is used to pick up the electromagnetic radio waves in the air by electric conduction, and the LC filter is set to only pass signals at a certain frequency ω_a and rejects other frequencies. The diode is used to de-modulate the radio wave of form $V(t)$ into current oscillating at ω_a, which then drives the speaker and produces audible sound waves at that frequency.

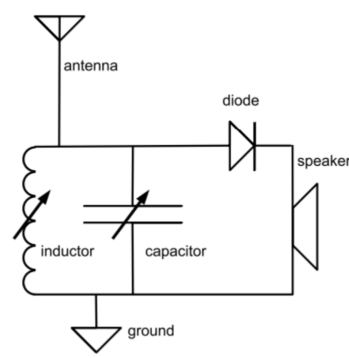

FIG. 1. Schematics of a simple radio receiver, consisting of an antenna, an LC filter, a diode, and a speaker.

How does a diode de-code the radio signal $V(t)$ by turning it into current signal? The Schockley diode equation describes the relationship between the voltage V and the current I across a diode a diode as:

$$I = I_s(e^{\frac{V}{\eta V_T}} - 1) \tag{6}$$

where I_s is the saturation current, η is the emission coefficient, and $V_T = k_B T/e$. For small voltage V, the current can be Taylor-expanded:

$$I = I_s[\frac{V}{\eta V)T} + \frac{1}{2}(\frac{V}{\eta V_T})^2 + ...] \tag{7}$$

Plugging in the radio signal from Eqn (5), the first-order terms is $\propto A\cos\omega_c t + \frac{M}{2}[\cos(\omega_c+\omega_a)t + \cos(\omega_c-\omega_a)t]$.

Similarly, the second-order term is $\propto A^2\cos^2\omega_c t + (\frac{M}{2})^2[\cos(\omega_c+\omega_a)t + \cos(\omega_c-\omega_a)t]^2$.

Since we only care about signals at audio frequency ω_a, we regroup and take out the terms with ω_a, and the audio frequency current is:

$$I_{\text{audio}} \propto cos(\omega_a t) + \frac{M}{4A}\cos(2\omega_a t) \tag{8}$$

And this is the current that will then drive the speaker to produce sound waves.

To see the theories in action, we build two types of radio in this lab: The simplified crystal radio as shown in Fig. 1, and an amplified radio as an improved version of the simple radio. In this report, we present the construction and testing of these two radios.

II. RADIO CONSTRUCTION

A. A Simple Crystal Radio

To make the inductor in the LC filter variable, we wrap a 10ft-long copper coils tightly for many turns and use electric tape to hold the winding. Inserting a ferrite core in the winding and pulling it in and out allows us to adjust the frequency passed by the LC circuit. Following the circuit design presented in Fig. 1, we connect the inductor in parallel with variable capacitor (using the capacitor's middle leg and a side leg to maximize tuning range) on a breardboard. We then put in the diode, whose direction has been tested with a digital volt meter, and a speaker accordingly. A very long wire as an antenna, because longer the antennas, larger the signals. The final circuit assembly is depicted in Fig.2 and its testing is described in Section III.

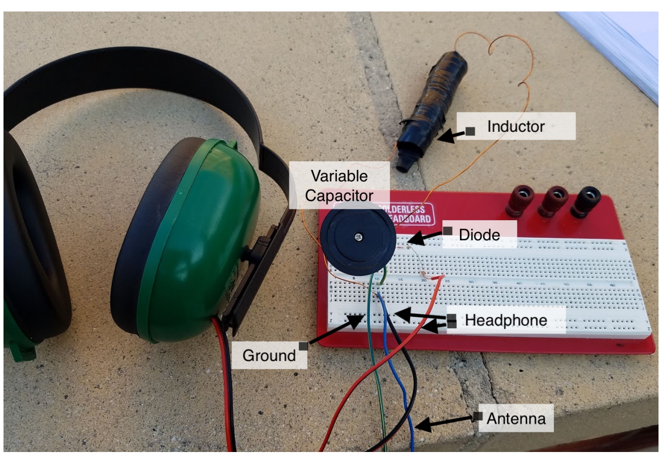

FIG. 2. A simple radio receiver constructed following the design in Fig. 1.

B. Amplified Radio with MK 484

The improve on the simple crystal radio which gives barely audible signal, we build an amplified radio, following the circuit design shown in Fig. 3, where an MK484 AM Radio Integrated Circuit is used. The frequency tuning is identical to that of simple crystal radio, where we can adjust the ferrite to change the inductance and turning the variable capacitor to change the capacitance. The converted sound signal is inputted into myDAQ acquisition system and we use a simple LabVIEW DAQ assistant interface to record and save the sound on a laptop.

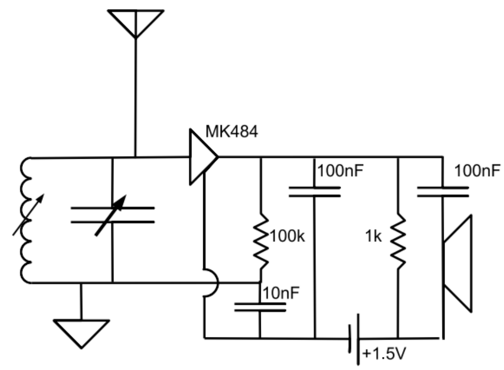

FIG. 3. Schematics of a simple radio receiver, consisting of an antenna, an LC filter, a diode, and a speaker.

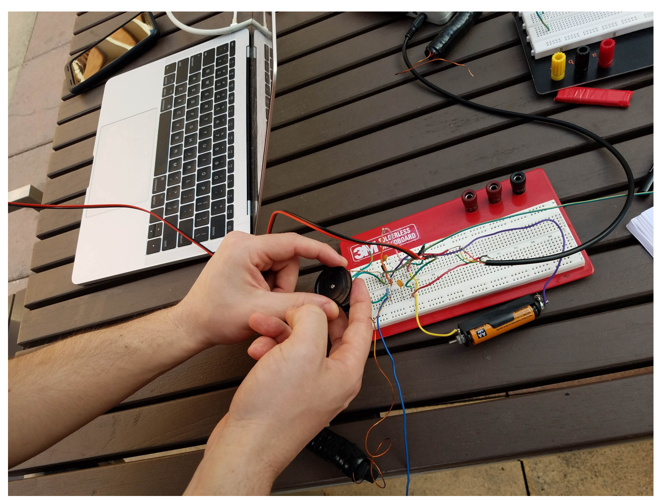

FIG. 4. A simple radio receiver constructed following the design in Fig. 1.

III. MEASUREMENTS AND DISCUSSION

A. A Simple Crystal Radio

The assembled simple radio receiver is taken to the patio of Physics and Astronomy Building, where we stretch out the antenna, and ground the circuit to earth through a power outlet. After trying to point the antenna in different orientations, switching from speaker to headphones, and changing the inductance by pulling the ferrite in and out of the coils, we are able to hear a very faint but audible sound through the headphone. We notice that wiggling the connections of the circuit results in more static noise in the output sound.

Despite the low signal to noise ratio as expected from an un-amplified radio running with no battery, we recognized the sound of a female radio host. By changing the inductance a little bit, the receiving frequency shifted immediately, and we heard a male voice announcing "This station is operated by UCLA Emergency Management..."!

B. Amplified Radio with MK 484

Upon taking the amplified circuit to the patio for testing, where we stretch our the antenna as long as possible, ground the circuit to earth via a wall outlet, and change the inductance as before, we immediately start to a clear and much louder sound through the headphone. By listening to the radio station's call sign, which is usually repeatedly announced periodically, we use this information to find the station on *radio-locator.com* to further determine the carrier frequency, location of the radio transmitter, and broadcast power of the station.

Through changing the inductance alone, we receive distinct and clear signals from 4 stations. The summary of all the received stations, their call signs and relevant information are shown in Table 1. The sound signal received with the amplified circuit is also recorded with labVIEW.

Finally we change up the design of the simple radio circuit by replacing the diode with an LED, which is also an diode (Fig. 5). The battery power is barely enough to light up the LED alone, the sound signal output of this modified circuit is mostly static noise and no station is detected. (Our TA, Andy, said that this is enough for the purpose for this lab so we did not pursue further.)

Discussion and remark:
Interestingly, we find that grounding did not make a difference to the received signal with our simple crystal radio, whereas grounding is absolutely needed for us to get a signal using the amplified circuit. After the lab, we wanted to estimate the inductance and capacitance values but realized since both were variable in our experiment, we cannot determine them separately based on the tuned radio frequency.
This lab has been very eye-opening for me because before the lab, I was quite surprised by the idea that a a radio can function without battery. Learning about AM radios is also a first for me, as I had always assume it required fair bit of analog electronics background to just to get started with it, so I was very glad when we were able to build functional home-made radios with ordinary electronics parts.

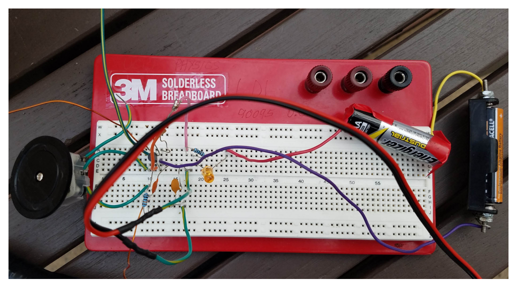

FIG. 5. Modified simple circuit where the diode is replaced with an LED with battery

IV. REFERENCES

[1] Huang, H. *Modern Physics Lab Manual*. January, 2019.

Station	Call Sign	Frequency	Transmitter Location	Broadcast Power
UCLA Emergency Management	"AM 1630"	1.63MHz	34.0682 N, 118.4452 W	Unknown
A Mexican radio (in Spanish)	/	/	/	/
KNX LA Newsradio	KNX1070	1.07MHz	33 51' 35" N, 118 20' 59" W	50,000 W
Relevant Radio	KHJ	930kHz	34 05' 08" N, 118 15' 27" W	5000 W

TABLE 1. Relevant information about each of the radio station received by our amplified radio.