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Reconstructing the Radio

Cover Page Footnote

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RECONSTRUCTING THE RADIO

By Daniel Burzek

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ABSTRACT— The goal of the research presented in this paper is to examine the techniques used for the construction of early radios, specifically crystal radios. The paper begins with a brief summary of the history that led to the transition from wired to wireless communication. Next, the paper examines the components used in building a crystal radio including basic antenna design and the resonant circuit, and it also takes a close look at the point-contact rectifier, which was a catalyst in the use of radio waves for communications and allowed for even the most inexperienced person to construct their own home radio system. The paper includes a detailed description of the construction of the crystal radio including the winding of a custom-made inductor and shows the construction of a point contact for a galena crystal to act as an AC rectifier.

Keywords: crystal radio, radio history, galena crystal, hobby radio

Acknowledgment: The work presented in this paper was supported by the Undergraduate Research Fellowship Summer 2021.

1. INTRODUCTION

These days, we all take it for granted that when we turn on a TV, answer a cell phone call, connect to a Bluetooth device, or listen on a radio, something – whether voice, or video, or just data – will be transmitted to us through the airwaves. But just how did we figure out that we could use these invisible waves to send information and how do we translate these waves into content that we can hear, see, or read? There are a multitude of devices capable of picking up these waves and turning them into different forms: audio, video, images, text, or simply data for machines to use. One of the earliest forms of wirelessly transmitted information was the broadcast radio, which opened the door to the vast world of wireless communications to the masses. The few simple components needed to make a crystal radio and their relative inexpensiveness allowed for the rapid spread of radios to communities in the United States and around the globe. Examining the history that led up to the discovery of radio communications and the early experiments conducted with radio waves, as well as the hardware implementation of the earliest radio models, are the goals of this paper. While all radio communications moved recently into the digital realm and hardware radios started to be replaced by software defined radios, the scope of this research is mostly educational.

2. A Short History of Radio Broadcasting: From Wired to Wireless

There were many notable steps that led up to the development of the first radios, and it would be worthwhile looking at a few of these achievements to show the progression of events that led to the invention of broadcast radio. Prior to the use of radios, the transmission of messages over long distances was done using the telegraph. In 1831, Joseph Henry demonstrated the first telegraph by transmitting a signal over 1 mile by using a horseshoe magnetand a bell [1]. By 1844 there was a telegraph line between Washington DC and Baltimore, and Samuel Morse was able to send the message “What hath God wrought?” [1]. For several more decades, people remained reliant on wires to transmit messages, but new discoveries would eventually change this. In 1866, Mahlon Loomis demonstrated a form of wireless communication using two kites attached to a rectangular copper wire aerial. Standing on two separate mountain ridges in the Blue Ridge Mountains, he connected and disconnected a wire to a galvanometer and was able to cause a deflection on the galvanometer attached to the other kite [1]. At this point he did not fully understand the significance of what he had accomplished; in fact, he thought the atmosphere itself was conducting the signal. In reality, he had created two antennas that were resonant at the same frequency and was transmitting electromagnetic radio waves. Although this is far from transmitting voice over radio waves, the pieces were coming into place for wireless communication. By 1888, Heinrich Hertz was able to prove the existence of the electromagnetic waves, previously predicted by James Clerk Maxwell in 1864 [1]. At this point experiments using these newly discovered waves occurred in many places around the world. One of these experimenters was J.C Bose, a physicist in India, who, in 1895, demonstrated the use of these waves during a lecture where he transmitted a radio wave 75 feet through several rooms to trigger a circuit that rang a bell and discharged a pistol that then exploded a miniature mine [1]. By 1902, Guglielmo Marconi sent the first Morse transmission to cross the Atlantic Ocean, and his company soon became the pinnacle of radio technology of the time [1]. But, at this point, signals were limited to transmissions like Morse code and used inventions such as the "coherer," a glass tube filled with metal shavings, to detect the radio waves. It was the work of Reginald Fessenden, now known as the Father of AM Radio, who demonstrated wireless telephony over radio waves in 1905 [1]. In 1910, Lee de Forest furthered this wireless technology by transmitting the first ever radio broadcast from the Metropolitan Opera House in New York City of the tenor Enrico Caruso [1]. These achievements marked the birth of the radio broadcast and concurrently of the wireless communications field. Once regular radio broadcast stations became established, the growth of radio communications was rapid. In 1921, there were only 5 stations broadcasting in the United States, but within 2 years, there were 556 [2]. The simplicity and inexpensiveness of some of the early designs, not even requiring a power source to operate, is in large part what led to the explosion of the radio use. Designs for crystal radios were picked up by young hobbyists, and soon households across America became the receivers of wireless radio.

3. THE RADIO RECEIVER DESIGN

When it comes to building a crystal radio there are four main parts that need to be examined and understood. An additional fifth section, an amplifier, can be added to increase the amplitude of the received signal. Although it is not required for the radio to function, the amplifier may be necessary to bring the signal to a power level suitable for processing. The basic design can be broken down into a simple block diagram, as shown in Figure 1, with variouspossible designs available for each of the blocks.

Figure 1. The overall Block Diagram of a Radio Receiver

3.1. The Antenna

The one of the most common types of antennas used for radio is the monopole, or whip antenna, which consists of a single wire or metal pole. This type of antenna is resonant at one quarter of the wavelength of the wave to be received. With this in consideration, to create an ideal antenna for listening to AM radio we would need an antenna that would resonate in the range of 535 kHz to 1605 kHz [3]. Using calculations for the wavelength, it is shown that for AM reception one would need an antenna that is somewhere between ¼ of 560m and ¼ of 187m, making it somewhere between 140m and 47m:

$$\lambda_1 = \frac{C}{f_1} = \frac{3*10^8 m/s}{535kHz} = 560m \quad , \qquad \lambda_2 = \frac{C}{f_2} = \frac{3*10^8 m/s}{1605kHz} = 187m \qquad (1)$$

As can be seen, even having an antenna that is set up to resonate at the high end of the AM scale, one would need a very tall antenna of 47m or 155ft. These calculations give the ideal antenna lengths for a specific frequency, and in most practical cases these lengths are difficult to achieve. Fortunately, one does not need to have a perfect length to tune into the radio stations, but the closer to the ideal length one makes the antenna, the better the reception of the signal.

The layout of the antenna can also have an impact on the overall design. An inverted L design is commonly used because getting an antenna high enough vertically with a tower or pole is difficult in most situations. The inverted L design consists of a vertical segment to get the wire off the ground and then transverses horizontally – similar to a clothesline (see Figure 2.). This allows the antenna to use a large length of wire for picking up the radio waves but does not require a tall mast for the vertical section.

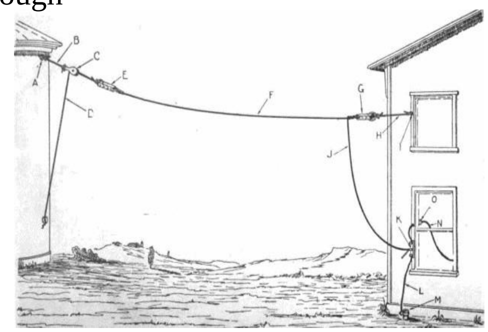

Figure 2. Inverted L Antenna

Source: Adapted from [4]

There is a drawback to this design, however; as the antenna will pick up most of its signal from waves that are parallel to it, and therefore having the antenna in a horizontal plane can make it more sensitive in terms of the directional alignment [5]. There are many other designs for suitable antennas. One such alternative antenna is the T design, or a dipole antenna. The dipoledesign would require 2 lengths of wire cut ¼ the wavelength each [5]. In most cases this is an even more challenging layout considering there would be two long strands to support, but this design can result in better reception. A last resort design could be a non-resonant style of antenna, which could simply be a wire strung up around a room [5]. Due to its non-resonant design, there may be issues with interference from other radio frequencies, making the tuning of the radio more difficult. Apart from these methods there are many other antennae designs to choose from, but these 3 methods are the simplest ones as a starting point.

Aside from the general layout of the antenna, tuning should be added to improve the resonance. In some early radio designs, a separate tuning coil was added to the antenna on the same plane as the inductor used for the radio tuning [5]. One simple antenna tuning method is to add a variable capacitor in series with an antenna coil to provide an additional method to tune the antenna separate from the tuning of the resonant circuit.

Perhaps the most important part of the antenna is the grounding, without which this type of radio will not function. For high sensitivity reception, the antenna must have a solid connection to earth ground [5]. In the past, this could be achieved with a connection to a cold-water pipe in someone's home, but modern plumbing consists mostly of PVC pipes which make this method no longer suitable. Another method that can be used is a connection to the ground connection that all homes have outside to provide the grounding for their home electric service and is usually located near their service input. If these sources are not available, a metal sheet or spike driven several feet into the ground would solve the problem.

1.2. The Resonant Circuit

The next component needed in a crystal radio design is the resonant circuit, which in thiscase consists of an LC tank circuit. In early designs, the inductor would have been the sole variable component which allowed for the tuning of the resonant circuit. Later, variable capacitors, or "condensers" as they were known at the time, became and additional tuning component [3]. Since we are attempting to tune our circuit for AM radio, we need to calculate the values for our inductor and capacitor.

The resonant frequency of an LC circuit may be calculated as $f_{res} = \frac{1}{2\pi\sqrt{LC}}$. As stated earlier, the AM frequency range is from 535 kHz to 1605 kHz, which is a ratio of approximately

3:1. Since the square root of the LC is used in the design, this ratio should be squared. A minimum variance of 9:1 is needed between the inductor and the capacitor [3]. A common variable capacitor found in older radios is a 365pF air-gap capacitor, which would be a good choice to use for the capacitor of the tank circuit. In the setup used in this paper an air-gap variable capacitor with range from 12pf to 455pF was used. With the capacitance set, the necessary inductance must be calculated. Since this will be winded manually, the inductance can be easily adjusted to match the capacitor value selected. Re-arranging the previous equation and using the chosen capacitance, we can find that

$$L = \frac{1}{C(2\pi f_{res})^2} = \frac{1}{455pf(2\pi * 535kHz)^2} = 194.5\ \mu H. \qquad (2)$$

Table 1: 240μH Air Core Coils

Source: Adapted from: [6]

AM Broadcast Band Coil Winding Data:

* Use Standard "Off-The-Shelf" Magnet Wire.
* All Coils Are "Cylindrical" and "Single Layer".
* Use All Coils with 365 pf. Variable Capacitor.
* All Coils Are 240 uhy., + or - 2%
* Coils Indicated In Heavy Outline Are:
"Ideally Square Coils" and Most Recommended

Wire Gauge	Form Diameter	Number of Turns	Coil Length
20	2-1/8"	96	3-5/16"
20	2-1/4"	88	3-1/16"
20	2-3/8"	82	2-7/8"
20	2-1/2"	76	2-5/8"
20	2-5/8"	72	2-1/2"
20	2-3/4"	68	2-3/8"
20	2-7/8"	64	2-1/4"
20	3"	61	2-1/8"
20	3-1/8"	58	2"

Wire Gauge	Form Diameter	Number of Turns	Coil Length
22	1-3/4"	113	3-1/4"
22	1-7/8"	103	3"
22	2"	92	2-5/8"
22	2-1/8"	85	2-7/16"
22	2-1/4"	80	2-5/16"
22	2-3/8"	74	2-1/8"
22	2-1/2"	69	2"
22	2-5/8"	65	1-7/8"
22	2-3/4"	62	1-13/16"

Wire Gauge	Form Diameter	Number of Turns	Coil Length
24	1-1/2"	120	2-11/16"
24	1-5/8"	107	2-3/8"
24	1-3/4"	97	2-3/16"
24	1-7/8"	89	2"
24	2"	82	1-7/8"
24	2-1/8"	75	1-11/16"
24	2-1/4"	71	1-5/8"
24	2-3/8"	66	1-1/2"
24	2-1/2"	63	1-7/16"

Wire Gauge	Form Diameter	Number of Turns	Coil Length
26	1-1/8"	160	2-7/8"
26	1-1/4"	136	2-7/16"
26	1-3/8"	118	2-1/8"
26	1-1/2"	105	1-7/8"
26	1-5/8"	94	1-11/16"
26	1-3/4"	86	1-9/16"
26	1-7/8"	79	1-7/16"
26	2"	73	1-5/16"
26	2-1/8"	69	1-1/4"

Wire Gauge	Form Diameter	Number of Turns	Coil Length
28	7/8"	207	3"
28	1"	165	2-3/8"
28	1-1/8"	137	2"
28	1-1/4"	120	1-3/4"
28	1-3/8"	104	1-1/2"
28	1-1/2"	92	1-5/16"
28	1-5/8"	85	1-1/4"
28	1-3/4"	78	1-1/8"
28	1-7/8"	72	1-1/16"

Wire Gauge	Form Diameter	Number of Turns	Coil Length
30	5/8"	285	3"
30	3/4"	207	2-3/16"
30	7/8"	164	1-3/4"
30	1"	135	1-7/16"
30	1-1/8"	114	1-3/16"
30	1-1/4"	100	1-1/16"
30	1-3/8"	89	15/16"
30	1-1/2"	82	7/8"
30	1-5/8"	75	13/16"

Using the calculated inductance, the number of turns of wire need to be determined next, for which the formula to use is $L = \mu_0 \frac{n^2 A}{l}$, where μ_0 is the permeability of free space, which is 1 for an air core coil, n is the number of turns, A is the area of the coil’s inner core, and l is the length of the coil. This calculation works if you have already built the coil and have a set length already, but in this case, the length is somewhat determined by the number of turns needed, so there are two unknowns in the expression. For this situation, we can attempt to use trial and error by winding sections of coil and calculating the resulting inductance based on the length of the windings. Alternatively, there are many tables of coils available in the literature, such as the one in Table 1 for an inductance of 240µH, which relates the wire gauges, the core diameter, the number of turns, and the overall length of the wire. To build an inductor the coil must be wrapped around a non-conductive surface such as PVC pipe, plastic drink bottles, or cardboard tubes to prevent the inductance from being altered (as would occur if there were a metal core). The wire used to make the coil can be of any type, but a solid core wire is optimal in this situation as it will hold its shape better as one winds the coils. It should be noted that it is desirable to keep the windings close together and it may be helpful to use an adhesive after making a few turns to keep the coil from unwrapping. To make this a variable inductor, one can make several "tap" locations by making a small loop of the wire, stripped of insulation, and standing it up from the core to allow a place to clip a wire, similar to Figure 3.

Figure 3: Variable Inductor with Wire Loop Taps
Source: Adapted from [7]

Figure 4: Variable Inductor with Sliding Contactor
Source: Adapted from [8]

An alternative method is to use a "slider" method by stripping a narrow line of insulation off of the wire to allow a sliding contact to run along the surface to vary the inductance as in Figure 4. The latter of these methods was used in the design of the crystal radio presented in this paper because the sliding contact inductor offers a more highly tunable circuit. Once the inductor coil is built, the inductor and the capacitor are both to be wired in parallel with the antenna to create the resonant tank circuit.

3.3. The Rectifier

The LC circuit connected with the antenna provides a way of receiving radio waves by tuning the tank circuit to resonate at the same frequency as a local AM radio station. The problem at this point is that the waveform that will be received will be an AC wave like the onein Figure 5, which was received at the output of the LC circuit of the designed crystal radio set.If this signal would be connected directly to a headset or other listening device, the positive and negative parts of the waveform will effectively cancel each other out and one would not hear anything coming out of the listening device.

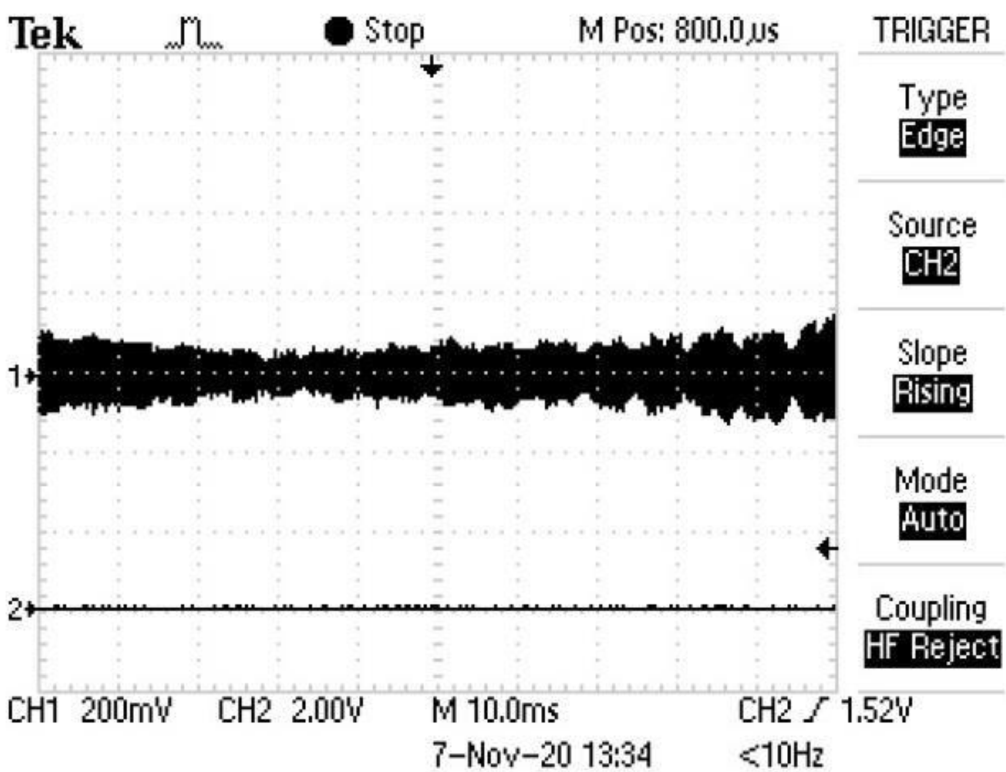

Figure 5: AM Radio Signal, Not Rectified, Captured on Oscilloscope

To solve this problem, a rectifier must be added to the circuit to eliminate the negative half of the waveform. A rectifier is a component that has low impedance to voltages in one direction but high impedances in the other. If an AC signal, which alternates between positive to negative values, would be applied to a rectifier, only half of the waveform would be allowed to pass through it. With modern components, this can be achieved simply using a diode. If a modern diode is used, one must remember that these waves have a very small amplitude, so it is best to use a diode with a very low forward voltage drop. A suitable option would be a germanium 1N34 diode that has a 0.3V bias versus other silicone diodes that typically require 0.7V [9]. However, for this project we will focus only on the very first radio implementations before the diodes were even invented. Thus, the original designs that used a galena crystal as the rectifier for the radio will be considered here.

Experiments with crystals used as rectifiers were conducted by many individuals with differing levels of success. Early rectifier experiments were initially conducted on crystals sandwiched between two metal plates which resulted in mostly inconclusive results. It was not until a German physicist, Ferdinand Braun, came up with a new method for these experiments that more reliable results were noted [5]. His idea was to hold a crystal in place with a ring of silver wire and use the point of a second silver wire to press into the remaining exposed crystal surface: a point contact [5]. This point contact proved to be the key to making a better rectifier using crystals, and he published his findings in 1874 [5]. By 1903, Whittier Pickard had filed a patent on a point-contact rectifier using silicon, and J.C. Bose had a patent for his design using

Figure 6: Sample of Galena, Pyrite and Quartz Crystals

galena in 1904, although he had filed for it in 1901 [1]. The point contact crystal rectifier became the center of crystal radio design for many years. Since galena, a lead sulfide, is an inexpensive mineral and crystal radios only required a small piece, it allowed virtually anyone with a little time and a few spare dollars to build their own radio receiver. A sample of galena can be seen in Figure 6, and it is the actual crystal that was used in this project. The sample in this figure has many fused pieces of galena crystals – the shiny silver crystals within it – but only one piece of crystal is necessary for the radio design.

Passing an AC signal through a rectifier has the effect of removing the negative portion of the voltage cycle of the radio signal, thus leaving only a pulsating, positive biased voltage. A simple experiment can be conducted to show how the diode rectifier works by applying an AC signal to a diode and looking at the output signal. It would also be useful to compare this output using a modern, commercially available diode with that of the crystal rectifier that will be used in this radio design. For this experiment, a 1N914 diode was used and the result was compared with those of two crystal rectifiers – one using galena and the other using silicon crystals. A DC signal was first applied across each rectifier to determine the forward bias voltage, shown in Figures 7a-c. This is the voltage required to "turn on" the diode to allow current to flow. As seen from this simple test, the 1N914 diode requires almost 0.6V (Figure 7a) to begin to allow current to flow. Looking at the silicon and galena crystal rectifiers, it can be seen that the forward bias voltage is between 0.1V and 0.2V (Figures 7b and 7c). This makes the rectifier much more sensitive to incoming signals, meaning that the rectifier will function with a much lower signal input. It is very useful to have such a low bias voltage for the rectifier in a radio because the received signal may have a low amplitude. The strength of the signal is partly dependent on the quality of the antenna and the distance to the radio broadcast transmitter, but the use of a low bias voltage rectifier can help mitigate the issues from the low voltages received.

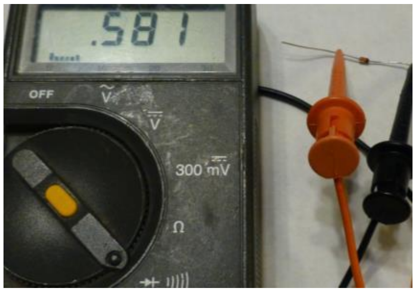

Figure 7a: 1N914 diode rectifier

Figure 7b: Silicon crystal rectifier

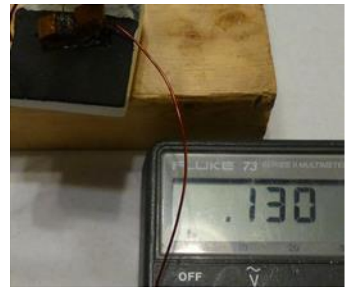

Figure 7c: Galena crystal rectifier

Next, each of these rectifiers were tested for an AC input, Figure 8a-c. The 1N914 diode provides a clearly definable rectification of the AC signal (Figure 8a). This form of rectification is the most desirable with the negative portion of the alternating signal being completely removed while the positive portion is preserved. Assuming a strong enough signal to overcome the voltage bias, this diode would work well to rectify a radio signal, and the positive portion of the waveform can be used to cause a vibration in an earpiece to create sound. Without this rectification, the positive and negative portions of the signal effectively cancel each other out, so no sound would be produced. Comparing the results of the three tests, shown in Figure 8a-c, the hand-crafted rectifiers using the silicon and galena crystals do provide some rectification (Figures 8b-c), but the rectification provided by the crystals is lower quality compared with that of the 1N914 diode. This was expected considering they were built in a rudimentary manner, and it indicates that this design would be challenging for a good functional radio. Problems like this are more easily anticipated with the aid of modern equipment to test and examine the outputs, but one must remember that the first radios were built for decades without such equipment to test the designs.

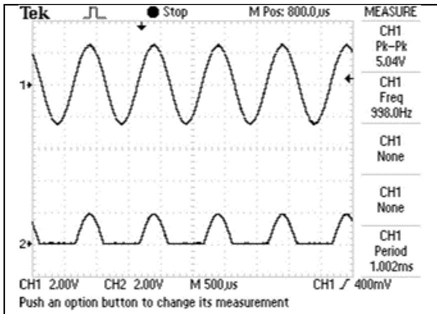

Figure 8-a: 1N914 diode rectifier

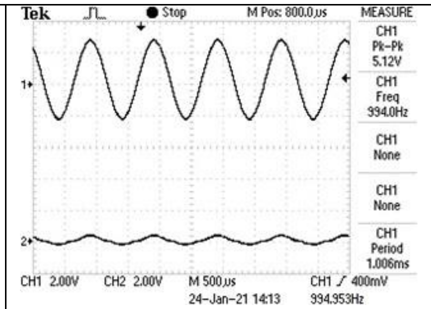

Figure 8-b: galena crystal rectifier

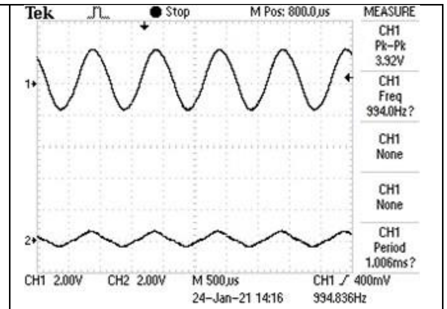

Figure 8-c: silicon crystal rectifier

Once a radio signal is applied to a crystal rectifier, the resulting variable voltage output may be further applied to a listening device. The listening device must have a diaphragm that vibrates with the voltage variations, creating the sound to be heard. A sample of a rectified radio signal can be seen in Figure 9. An amplifier circuit was added in the design, and as a result the output voltage seen in Figure 9 is much higher than the AC signal shown in Figure 5. The additional amplifier circuit will be discussed later.

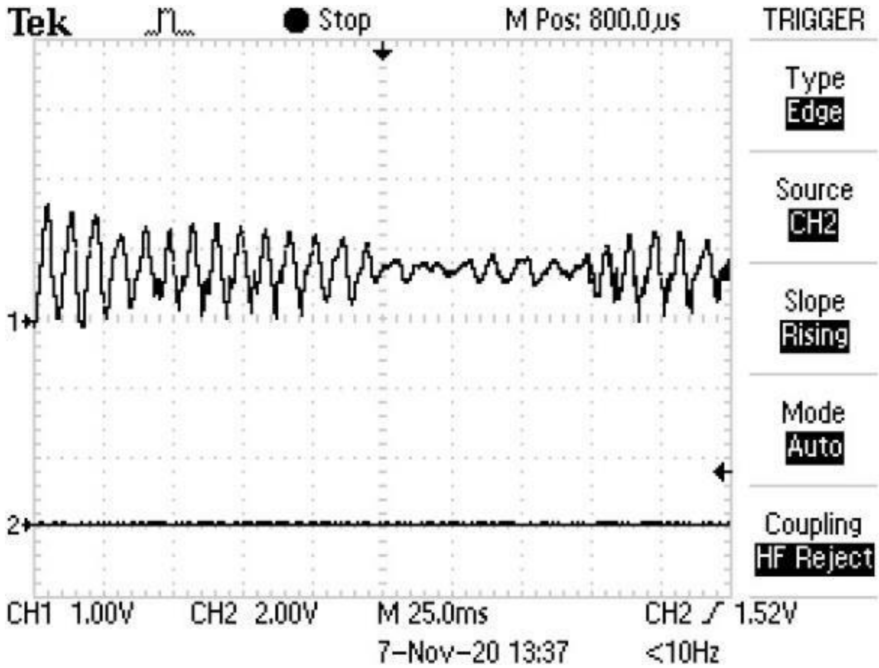

Figure 9: Rectified AM Radio Signal Captured on Oscilloscope

3.4. The Listening Device

The final portion of the circuit is the high impedance earpiece that is necessary for the listening part of this type of radio. The output of the rectified radio signal has a very low amplitude, and even with an optimally tuned signal, it is much too low for any modern listening device without additional amplification. Most modern speakers and headsets are in the range of 8 ohms impedance which is much too low for a crystal radio to drive without a large amplification circuit. However, there are other options for listening to a crystal radio signal. Onesuch device is a crystal earpiece, which has a high impedance. These Piezoelectric earpieces have an impedance in the 2kΩ range. The sound from these devices is generated when an electromagnetic signal changes the dimensions of the material inside of it, which drives the diaphragm of the earpiece to create the sound [5]. With one of these earpieces, a low voltage signal will be perceptible if connected directly to the output of the rectifier and to ground, although even with this type of device, the sound may still be difficult to hear. For this project, a single transistor amplification circuit was added, powered by a 9V battery as shown in Figure 10. This common emitter circuit provides a gain of approximately 10, which means that the circuit provides an amplification of approximately 10 times the input signal.

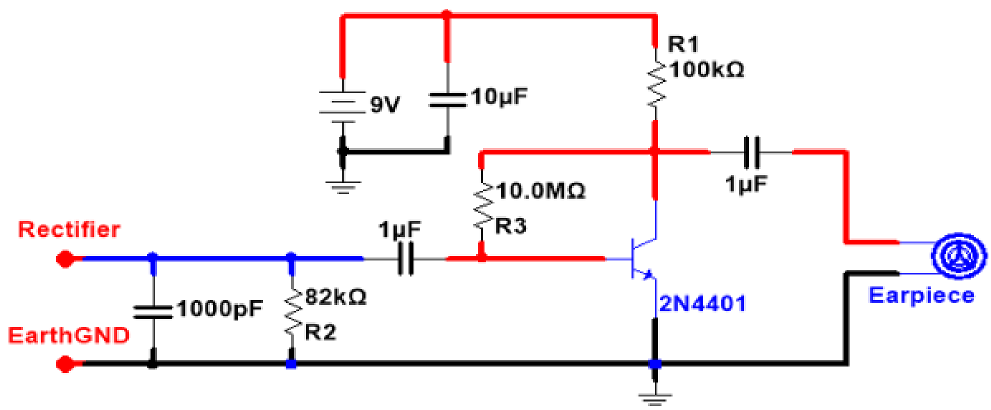

Figure 10: Common Emitter Amplifier Used to Amplify Radio Signal

3.3. The Assembly of the Complete Crystal Radio

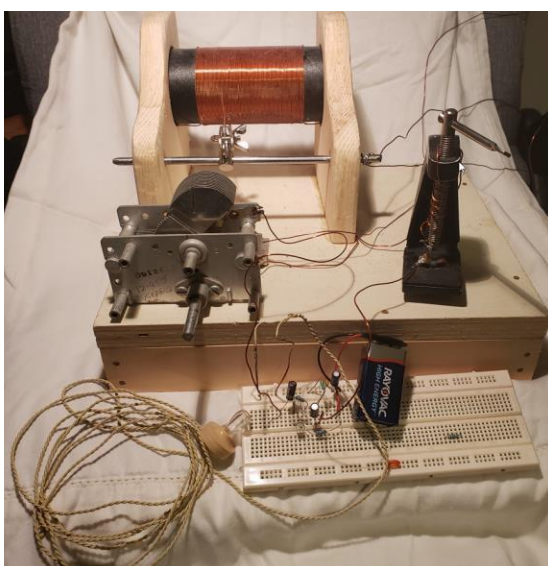

Figure 11. The Complete Crystal Radio

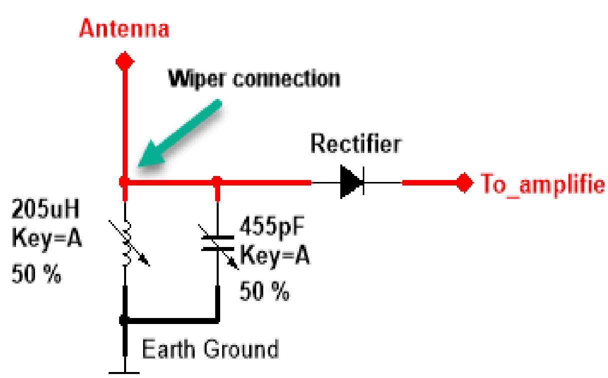

Figure 12: Crystal Radio Circuit Using a Galena Crystal Rectifier

The basic circuit for the proposed crystal radio is very simple and may work without an amplifier. The radio circuit without the amplifier is shown in Figure 12. If one does not wish to amplify the signal at this point, to keep it from requiring any external power source, an earpiece can be connected directly from the rectifier output to the Earth ground connection. For this project, however – for improved quality of reception – the amplifier shown in Figure 10 was added for the output sound to be loud enough to demonstrate over a video recording. The entire radio consists of all the parts described in the prior sections: an antenna, a variable inductor, and capacitor, the rectifying galena crystal, the connection to Earth ground, and a listening device.

The first step to assembling the radio was the antenna and ground portions. For this, 20-gauge wire was used for the ground connection, and approximately 60 feet of 12-gauge house wiring was used for the antenna. The antenna design implemented for the project was an inverted L type of antenna. Approximately 20' of the antenna wire was run horizontally from the radio, and out of the house to the telephone service line where the remainder of the wire was run approximately 75' horizontally to the power pole where it was secured as shown in Figure 13. A second design was done with a similar wire which was also run to the power pole in the same manner to attempt a dipole antenna. The overall design can still benefit from additional tuning and improved antenna designs, but this setup was sufficient for a proof of concept and would be a good starting point for further experimentations.

To test the difference between a monopole and dipole antenna, samples of the un-rectified signals were taken of the received signals in both cases. The monopole and dipole antennas were attached to the same point on the power pole as shown in Figure 13. The results illustrated in Figure 14 show significant difference between the monopole and the dipole antennas. This may be due in part to the placement of the poles close together and not set to the ideal lengths. This test would show a more accurate comparison of the two antennas if it would be conducted with a single tone signal.

Figure 13a: Power Pole with Antenna

Figure 13b: View of Antenna from Power Pole

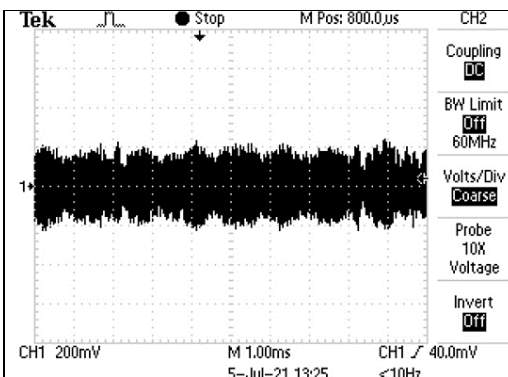

Fig 14a: Signal Received on Monopole Antenna

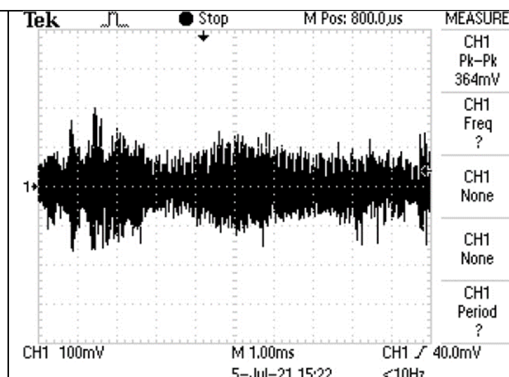

Fig 14b: Signal Received on Dipole Antenna

Figure 15: Earth Ground Connection

The Earth ground wire was also run from inside the house to the ground post that is used for the home electric service junction (Figure 15). This wire was then attached to the post to serve as the Earth ground for the radio circuit as shown in Figure 12. It was beneficial to file down an area on the post to clear any oxidation to ensure a solid connection to ground. Having a solid ground connection is vital for a crystal radio to function.

The next building step was to make the inductor coil. For a core, a hollow cardboard tube was used with a 2 1/8th inch diameter. Using the data of Table 1 for the same 20-gauge wire used for the ground wire, it was found that 96 turns are needed for a 240µH inductor. Since the inductance calculated for this project was of only 195µH, to work with the 455pF variable capacitor, the number of turns was reduced to 85. The type of wire used, having a solid core, allowed for the windings to hold their shape well as a single layer coil built around the cardboard tube. To ensure the windings did not unravel, a spot of adhesive was added after every 5 turns. Another benefit to this kind of wire is that it has a thin shielding which is allowed to scruboff a line of the coating to create a slide to adjust the inductance as needed. The finished coil was measured with a high precision LCR meter and indicated a value of 205µH. Since the inductor design includes a variable slider, any excess inductance would not be a problem in the overall design with the 195µH being the minimum needed value. A stand was built to hold the inductor in place along with a rod to attach a piece of heavy 12AWG solid core wire that would make up the slide for the inductor. The completed inductor is shown in Figure 16 and was then connected to the Earth ground on one end of the coil and the other end was soldered to the antenna wire. The variable capacitor was connected across the two ends of the inductor as shown in Figure 17. This completed the resonant tank circuit, which allows for tuning the circuit to the AM frequencies of the local stations.

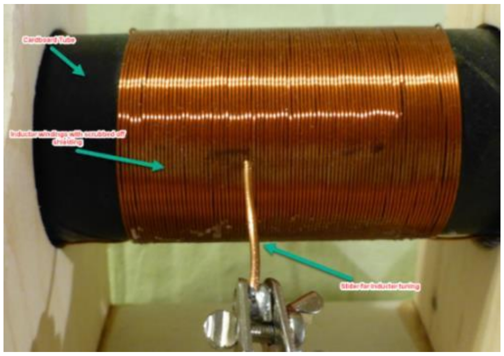

Figure 16: Completed Inductor with Variable Slider

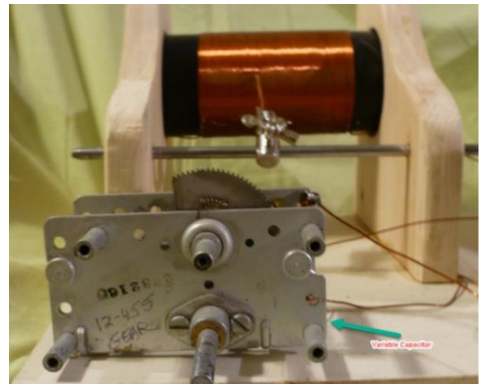

Figure 17: Variable Capacitor Attached in Parallel with Inductor Coil

A sample of the output of this resonant circuit was shown in Figure 5, which illustrates an amplitude modulated AC signal.

Once a radio signal is received, the next step is to rectify it and further apply it to the earpiece. To accomplish this using the techniques used in the very first radio designs, the point contact was built using a galena crystal. The first step was to secure the galena crystal in place within a formed piece of copper that would act as a clamp while leaving a portion of the crystal exposed for the point contact to touch the surface of the crystal as shown in Figure 18a. This clamped piece of crystal was then placed on a screw type of mechanism that was salvaged from an old clamping desk lamp. To the screw mechanism, the wire was winded from the point contact down to the tip of the screw mechanism where it was soldered to a straightened-out spring from a retractable ball point pen. This straightened spring formed the point contact for the crystal, and the screw mechanism can be used to adjust the placement of the point contact as can been seen in Figure 18b.

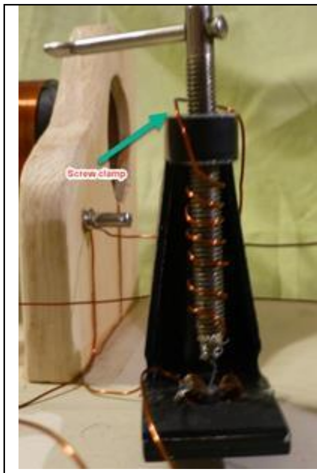

Figure 18a: Screw Clamp Mechanism

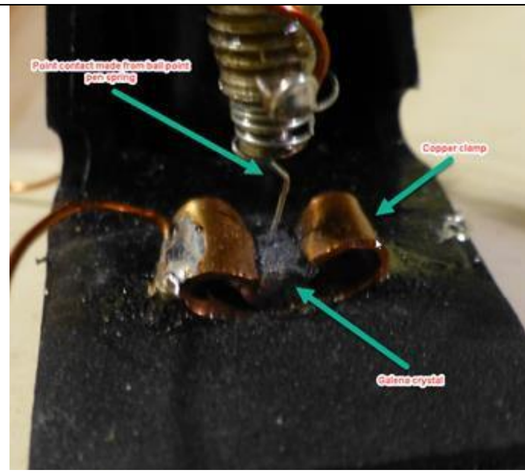

Figure 18b: Galena Crystal Clamped with Bent Copper Plate

The wire from the point contact was connected to the same point as the antenna – the non-grounded side of the variable capacitor and the variable inductor. The copper plate had a piece of wire soldered to it so a connection could be made from this to the Earth ground if no amplification solution would have been used. For this project, however, this wire was used to connect to the amplification circuit.

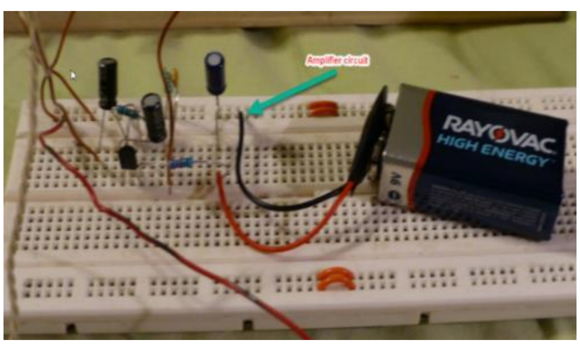

Figure 19: Amplifier Circuit on a Breadboard

Figure 20: Crystal Earpiece

Figure 19 shows the implementation of the amplifier on the breadboard, and Figure 20 shows the earpiece which was used as the listening device. There are other high impedance listening devices that could be attached, such as the earpieces from old telephones, or – if one wished to design better amplification – modern lower impedance headphones or speakers could be attached. In this project, the earpiece was then attached to the breadboard circuit from the output of the amplifier to the Earth ground connection. Once power was applied to the amplification circuit, the output of the radio circuit could be clearly heard and tuning the circuit to the local AM radio stations was possible.

Tuning the radio, for this early model radio, is a sensitive process. The inductor slider is adjusted along the coil until a broadcast station can be heard. With the slider locked into place, the capacitor can then be used to make any further fine-tune adjustments. One of the most sensitive aspect that was discovered with this project was the placement of the point contact. The point contact with the wire and the crystal needed to be carefully adjusted to provide the loudest output from the earpiece. When adjusting the point contact, it was found that there were some areas on the surface of the crystal that did not produce any output, which made the tuning of the circuit quite challenging. Once the circuit was fully tuned, the sound from the radio was very clear, and the radio was able to pick up any strong AM radio signals.

4. Conclusion

The history of the transition from wired to wireless communication includes a long list of small and large contributions of numerous scientists and experimenters that led to the birth of wireless technology. It is difficult to fully grasp the challenges that these people encountered intheir experiments. These days tuning to a radio station means simply turning a knob or pushing some numbers for the digital versions, but for the early experimenters there were no radio stations to tune to. Everything required theoretical calculations and the construction of equipment that could transmit these waves, as well as the device to detect them, required tedious, delicate work. However, once these technologies were developed, the simplicity of their designs led to a revolution in wireless communications. The design undertaken in this paper was not complicated, and the cost of the parts was minimal. But the fine-tuning of various components was more tedious than the final product may suggest. This low cost and simple construction were large contributors to the spread of the technology when the radio was first put into commercial use. One of the most important pieces of this technology was the discovery of the point-contact rectifier which directly led to the design of diodes and eventually transistors which are part of every electronic device. Today, these early technologies seem very simplistic, but it was the hard work and painstaking experimentation from the many people involved that led to the birth of wireless communications and to so many of the technologies that have changed our world over the last century.

When examining the design of the crystal radio presented in this project, there is room for improvement, such as the choice of the antenna, or to address the stability of the point contact. These areas of improvement are outside of the scope of this paper which was to showcase the overall historical design of a crystal radio and illustrate the functionality of the setup along with the difficulties encountered by early experimenters.

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