The Crystal Radio:

An Inexpensive Form of Mass Communication

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Introduction

Technology has always been developing, and with it so have methods and access to communication. One such example is the internet, which has been rapidly growing in the past years. Yet, despite all of these advancements, there is still a large population that lacks internet. During distraught times, such as the coronavirus pandemic, having access to information is important, but not everyone is able to access urgent information. Roughly 10% of the United States population does not have access to the internet (Anderson, Perrin, Jiang, & Kumar, 2020). This proportion translates to over 30 million United States citizens, which is quite a substantial population size. In fact, there appears to be a correlation between income level and the proportion of those in a certain economic bracket that have internet. At an annual income of less than $30,000, 18% of citizens lack access to the internet. Withal, 7% of those making between $30,000 and $50,000 annually, 3% of those making $50,000 to $75,000 annually, and 2% of those making anything upwards annually lack that access (Anderson et al., 2020). See *Figure 1* for more data on the demographics of those using the internet. It is evident that one's income level is positively correlated with higher frequencies of internet usage.

Figure 1

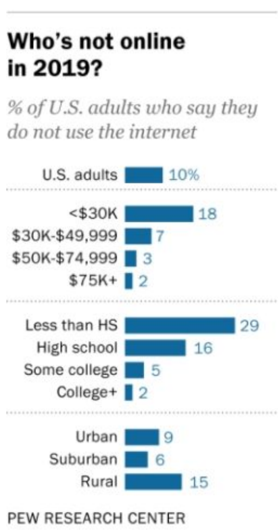

Figure 1 - PewResearch Data on Internet Usage
Data shows the demographics of those who do not use the internet; those with less income use it less
Anderson, M., Perrin, A., Jiang, J., & Kumar, M. (2020, July 28). 10% of Americans don't use the internet. Who are they? Retrieved from https://www.pewresearch.org/fact-tank/2019/04/22/some-americans-dont-use-the-internet-who-are-they/

The internet is but one of many mediums of mass communication, and it is certainly one dominating form. As of 2018, roughly 41% of U.S. adults receive their news from television, 37% from online means, 13% from physical newspapers, and 8% from radio

(Geiger, 2020). Since 2016, internet-based forms of communication have increased in usage among the general populace, while others either remained stagnant or decreased in usage. More specifically, the use of television plummeted by 8% as well as newspaper usages by 4%, while news websites increased in usage by 5% and social media by 2% (Geiger, 2020). These trends will further progress as time continues; internet-based media will grow more and more, surpassing televisions as the primary method.

Methods of Communication

Common Methods

Internet may be a common and growing form of communication, yet as seen from Anderson et al. (2020), there does appear to be an economic-based issue of accessing the internet. Television can be quite costly for those who make little money, as well as physical newspapers; these ways of communication, as seen from Geiger (2020), have also been decreasing in usage rates among adults in the United States. Radio, however, may be a viable option for communication at low costs. Although radio theory is an under-researched field and radios are referred to as secondary media, radio has a long history, being one of the oldest forms of media in the household. Not only does radio have an extensive history, but it is also quite cheap to produce and manufacture (Tacchi, 2000). Although radio requires broadcasting stations that must transmit signals for the radio to pick up, which may seem to go obsolete due to the research provided in Geiger (2020), radio stations are not as expensive as they may seem and can be run locally for quite a minimal cost (McLeish & Link, 2005). According to McLeish & Link, not only are radio stations cheap to run and maintain, radio itself is cheap to the consumer due to technology that allows for their mass production. It is even stated that a radio is cheaper than a set of books, as well as stating that in relation to other forms of mass media, radio's one-time expenses are affordable, and any other expenses from then on are not expensive. However, there are multiple types of radios, one of which being an old variant, the crystal radio.

Crystal Radios

Crystal radios are a simple, but also extremely old, form of radio, being developed in the early 20th century. Crystal radios have a true basis and foundation before even the 20th century, when Jagdish Chandra Bose used galena crystals to detect and pick up radio waves all the way back in 1894 (Emerson, 1997). These galena crystals were used in the development of receivers that picked up short-wavelength radio waves, as well as even white and ultraviolet light. Bose had a great impact on the research and development of radios and the study of waves, and one type of radio he influenced the development of was the crystal radio. Nearly a decade later, in 1902, G.W. Pickard found how to undergo a process called demodulation (see *Demodulation* for the description of the process) using crystals (Douglas, 1981). Despite having a long history, crystal radios were replaced by newer innovations due to the nature of technology. Therefore, they were deemed commercially obsolete by the 1920s (Basalla, 1989). However, although they may not be ordinarily sold, they are still occasionally used. During World War II, soldiers created make-shift radios, being very resource-limited, for the purpose of listening to local stations for entertainment, and the radios were dubbed the name of "foxhole radios". These make-shift radios were essentially crystal radios, just made from the bare minimum. In fact, even in modern days crystal radios are used, such as for hands-on learning of radios, and are even collected by hobbyists. Although deemed outdated by the market, crystal radios still hold value and potential. Crystal radios are versatile, being able to pick up different radio signals, such as amplitude-modulated waves (AM) being the most common, frequency-modulated waves (FM), and shortwave signals, although not many crystal radios are designed to pick up the latter

(Petruzzellis, 2007). According to this same source, crystal radio receivers are the simplest form of receiving AM signal waves to have ever been invented. Beyond this, crystal radios do not even require batteries or any form of external power to operate, as they receive the power required to operate the radio simply from the transmitting radio station.

Demodulation

Demodulation is the inverse of a process with a similar name, which is modulation. Modulation is the process in which a signal that is being sent is converted and outputted into a different, new signal. The signal that sends the information is called the message signal, which is usually low-frequency. Frequency is a measure of a wavelength given a certain period of time and is measured in hertz. This message signal is combined with a carrier signal, a signal that is used to undergo the process of modulation. This carrier signal is high-frequency, and it is essentially merged with the message signal to output a new signal. The new signal has the same high-frequency as the carrier signal, but with varying amplitude, which is the height of oscillation of a wave, of the message signal. This is one type of modulation; however, other types, such as frequency modulation, undergo a similar process, but instead of keeping a constant frequency and changing amplitude, the converse occurs, resulting in a wave with differing frequency and constant amplitude (BYJU's, n.d.). Demodulation takes an already-processed signal from the process of modulation and gives the original message signal as a result.

The Fundamentals Behind Crystal Radios

Inductors

Inductors are crucial to crystal radios, and most radios in general, due to the fact that they play a role in the antenna of the radio. Inductance is a unit of measurement denoted by H, which stands for one henry. Inductance is simply the resistance to change of the flow of electrons, current, which is measured in amperes (A), and comes from inductors. Inductors are parts of circuits that consist of wire that is wrapped in the shape of a coil, which produces a strong magnetic field. The reason for this is the fact that whenever electricity is passed through a wire, a small magnetic field is formed, but since the inductors are created in the shape of a coil, the wire is compact and close together, creating multiple magnetic fields that act as one field that is substantially bigger than the magnetic field of one individual wire. These magnetic fields are able to store energy so that when the power supply is cut off, the magnetic field is converted into energy, keeping the circuit running for a short period of time. Inductors work in a continuous manner; when there is a power supply, instead of the inductor rapidly forming a magnetic field, this magnetic field gradually increases in size until it reaches some maximum. Inversely, when the power supply ceases to continue, the magnetic field does not simply instantaneously disappear, but rather gradually decreases in size until it has dissipated. Inductors work in this manner since, by the definition of inductance previously defined, they attempt to resist any change in current, and since current is proportional to voltage according to Ohm's law ($V = IR$, where V is the voltage, I is the current, and R is the resistance), this will occur when there is a change in voltage (Evans, 2019a). Special inductors are able to differentiate between different frequencies, which holds great importance in picking up radio signals of a certain station since each sends out signals of differing frequencies. Due to these reasons, inductors are important for a crystal radio.

Capacitance

Capacitors are used in crystal radios since there is a development of resonance (see Resonance and Audio) in conjunction with the inductor, which is used to output audio signals. Capacitance is a unit denoted by F, which is one farad, although generally capacitance is measured in microfarads (μF); capacitance is defined as a ratio between charge and voltage. Capacitors are made of two sheets of conductive metal that are separated between some insulating material. When there is a power supply connected, capacitors build up electrons on one of the plates until the voltage between the battery and capacitor is equivalent. Capacitors store energy since when the power supply is disconnected and the voltage is high enough in the capacitor, the electrons that build up are released into the circuit. This gives a flow of electrons until those electrons flow back into the other side of the capacitor, releasing all of its power (Evans, 2019b).

Diodes

Diodes are a necessary component to a crystal radio; in fact, the diode is where the crystal is stored, hence the name “crystal” radio. Diodes tend to be relatively small pieces, and their purpose is to restrict the flow of current on one side while allowing electrons to pass on the other side. This essentially creates a dichotomy in the sides of the diode, one side being called the cathode, and the other, the anode. If electrons flow into one end, the cathode, they pass by and the diode does not impede the flow of electrons. On the contrary, if electrons attempt to flow into the anode, the flow will stop, in which the diode acts as a resistor. Based upon the direction of electron flow, diodes can either be conductors, allowing for the flow of electrons or, conversely, insulators, impeding the flow of electrons. This works due to valence electrons and what electricity truly is, that being the free flow of electrons among atoms. Copper is generally used as wire for circuits and crystal radios because it is a conductor. Elements that are conductors have between one and three electrons in their valence shell, making the exchange of electrons between atoms easy. There is a shell that is further out than the valence shell, however, being the conduction band. Electrons that can reach this shell are able to break free from the atom and move between other atoms. Metal atoms generally have their conduction band intersect with the valence shell, allowing for electrons to move around with ease, making metals effective conductors (Evans, 2020).

On the contrary, insulators have between five and eight valence electrons, making the valence shell packed with electrons. Furthermore, the conduction band is far away from the valence shell, as well as the fact that the nucleus has a strong grasp on the electrons. Due to this, electrons are not able to move between one another, and thus electricity cannot flow when there is an insulator. There not only exist just conductors and insulators, but also semiconductors, which take on qualities of both conductors and insulators. Semiconductors have four valence electrons, which is right between the amount to be considered a conductor or insulator. In their isolated state, semiconductors will function as insulators, due to the fact that atoms must have at most three valence electrons to be conductors. However, the conduction band of a semiconductor is near the valence shell, so with some external power, a few electrons are able to accumulate enough energy to go into the conduction band, meaning they can flow between atoms, and thus semiconductors act as conductors in this scenario (Evans, 2020).

Figure 2

Circuit for crystal radio made from scraps.

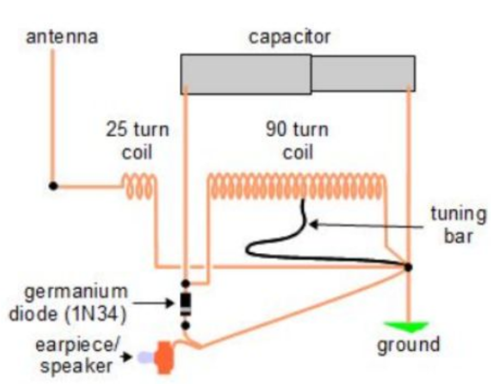

Figure 2 - Simple Crystal Radio Diagram
This diagram shows the connections of each component and wire of the radio.
Dufresne. (2020). Crystal Radios. Rimstar.Org. https://rimstar.org/equip/crystal_radios.htm

Silicon is the most abundant example of a semiconductor, but in its pure state, silicon has no free electrons. To work around this problem, small amounts of other materials can be introduced into the silicon in a process called “doping”. Two different doped materials, one of which is a p-type doping and the other an n-type doping, are combined, in which the combination of these two, as well as the anode and cathode leads, create a simple diode. Silicon is the main semiconductor used in modern diodes, but germanium, another semiconductor, is generally used in crystal radios. If there is no doping, each semiconductor atom will be surrounded by four other atoms of the same element, but each atom only has four valence electrons. Since, according to the octet rule, atoms strive for eight valence electrons, covalent bonding will occur with adjacent atoms, in which they share outer electrons, thus each atom having their valence shell full at eight electrons. If one were to implement n-type material, which would be atoms with five valence electrons, there is an abundance of valence electrons, in which any extra electrons are free to move around. With the addition of p-type material, atoms with three outer electrons, there will be a lack of electrons and in the covalent bonding process not every atom will have a full eight valence electrons, leaving holes. Between the two materials, the n-type and p-type, there is a pn junction, where some excess electrons from the n-type move over to the p-type, filling holes there but also creating some in the n-type side; this region is called the depletion region. Thus, there will be two regions, one that is slightly positively charged, and one that is slightly negatively charged, which creates an electrical field that prevents any additional electrons from moving to the other side of the junction. When connecting the positive side of a power supply to the p-type, and the negative to the n-type, a flow of electrons is created, which offers no resistance. If the connection is flipped, with the positive side to the n-type and negative to the p-type, the barrier between the p-type and n-type greatly expands, allowing no flow of electrons, and thus behaving as an insulator (Evans, 2020).

<u>Circuits</u>

Crystal radios can be shown as circuit diagrams, similarly to the vast majority of electrical devices. These circuits show where each piece goes and the configuration of the wiring. Take, for instance, a simple crystal radio circuit diagram, seen in *Figure 2*. This diagram contains the blueprints for a crystal radio that requires a capacitor, inductor(s), diode, earpiece, ground, and antenna, most of which can be homemade (Dufresne, 2020). Other circuits are more complex and have a greater deal of components, such as more coils/inductors and capacitors, additional devices such as transistors, transformers, resistors, and so on and so forth. *Figure 3* gives an example of a far more complex circuit diagram for a crystal radio. These pieces are not necessary for the bare minimum of a crystal radio but can serve to improve the quality of the radio, although for a greater cost due to the extra materials (Wenzel, n.d.).

Figure 3

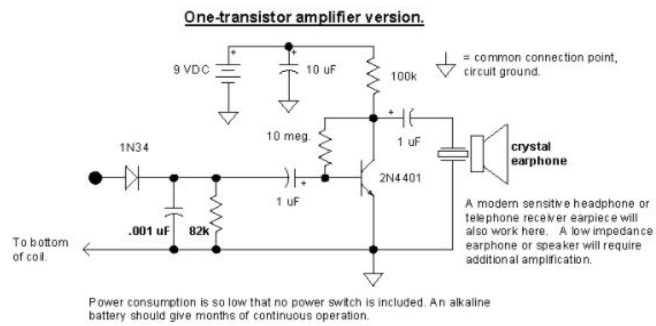

Figure 3 - Crystal Radio Diagram with Transistor
This diagram includes a more complex crystal radio circuit, which has multiple resistors, capacitors, grounds, and a transistor.
Wenzel, C. (n.d.). Crystal Radio Circuits. Retrieved from http://techlib.com/electronics/crystal.html

<u>Resonance and Audio</u>

Resonance is defined as the maximum of the velocity amplitude, v_m (the distance of a wavelength multiplied by the frequency), of oscillations (Halliday & Resnick, 2014). Resonance is something that can be seen in musical instruments, which output sound. Whenever something is struck, such as a drum, an oscillation occurs. Each instrument has its own rate of vibration, but when two instruments that are connected begin to vibrate, one of the objects vibrates at a greater frequency than it usually would, and this is also considered resonance, specifically acoustic resonance. Beyond this, electrical resonance exists, and it is defined by the levels of inductance and capacitance (BYJU's, 2020).

Piezoelectric earpieces are a crucial aspect of a crystal radio. Although other types of headphones and audio outputs can be utilized, they must be tweaked through the usage of devices such as transformers, which change the voltage and current in a system. Piezoelectric earpieces are constructed from a piezoelectric crystal attached to an electrically conductive diaphragm, as well as being connected to two wires. Voltage from the crystal radio that moves into the earpiece onto the crystal causes it to vibrate, which translates over to the diaphragm. When the diaphragm is oscillating, sound waves from this oscillation are created, and output to the user's ear. This creates resonance, and the resonance frequency of an average piezoelectric earpiece is about 3500 hertz, with a margin of error of 500 hertz. Due to the low voltage of a crystal radio, these earpieces are perfect for crystal radios, since other earpieces or audio output devices would not be able to perform (Dufresne, 2016).

Conclusion

Although there is a fair deal of research done on basic crystal radios, knowledge gaps regarding more complex crystal radios need to be filled. Further research must be done beyond the simple crystal radio, including further complex crystal radios with components mentioned previously, such as transistors, transformers, and more. Regardless, crystal radios are phenomenal and simple devices, and although not being powerful and luxurious radios, they are inexpensive and interesting devices. Through the combination of multiple key, yet cheap, components, such as piezoelectric earpieces, diodes, inductors, and more, the crystal radio is able to receive radio signals from nearby stations without the need of a battery or other power source. During periods of national and international despair, such as the COVID-19 pandemic, the ability to access key information is essential. Given the trends of mass communication and media, as well as how those with low income have a lesser frequency of using the ever-growing internet, the crystal radio can serve as a means of receiving important information through communication that many could not have previously afforded.

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