Crystal Radio: An Historical Survey

An Honors Thesis (ID 499)

by

Christine D. Craddock

Thesis Director

Ball State University

Muncie, Indiana

March 24, 1987

Expected date of graduation -- May 1987

TABLE OF CONTENTS

LIST OF FIGURES

CRYSTAL RADIO: AN HISTORICAL SURVEY

Introduction

Crystal Radio is a name given to one of the earliest forms of radio receivers known to science. It comes from the same era as the original "spark-gap" radio transmitter -- the age of Heinrich Hertz, Guglielmo Marconi, and Nikola Tesla. In a short time it grew to know a widespread popularity, both in the home and in the laboratory, and then finally it was overwhelmed by the technological revolution of World War II. Today it has become an archival relic, obsolete in its simplicity, known only as a children's toy if it is known at all.

In the beginning, all radio operated on the principle of amplitude modulation (AM) broadcasting. AM broadcasting is the process of varying the amplitude of a radio-frequency wave to reproduce sound. This process was once further divided into two broad catagories. The early spark-gap transmissions were known as wireless telegraphy, because they were created with a telegraph key. The waveform so produced consisted of groups of oscillations repeated at regular intervals, with the amplitude of the oscillations within each group decreasing continuously. These transmissions were called damped waves, and they produced in the receiver telegraphic dots and dashes of a single audio tone. A later radio," was then called _wireless telephony_, from its use of a telephone-type microphone to impose changes in amplitude on a continuous oscillation. This produced _undamped waves_, with an outline or _envelope_ which varied according to the waveform of the sound waves or speech patterns entering the microphone. Both wireless telegraphy and wireless telephony are true forms of AM transmission, because they utilize variations in the amplitude of an oscillation.

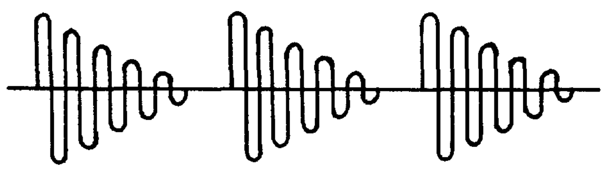

Figure 1: Damped Waves

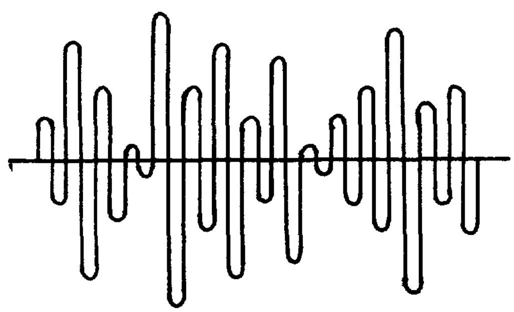

Figure 2: Undamped Waves

Crystal radio was invented while the world was still using wireless telegraphy exclusively, but it was later discovered that it would receive either form of AM transmission. The reception of an AM broadcast involves three fundamental steps -- 1) as the radio wave passes the aerial, the oscillation must be transferred to the wire of the receiving circuit, 2) the alternating current so produced in the circuit must be rectified, or half of it removed, so that it becomes direct current pulses, and 3) the direct current pulses must be made to produce audible sound. A modern electronic receiver will amplify the voltage in the circuit at some time during this process, to increase its capability to produce sound. The crystal receiver, on the other hand, depends on the power of the transmitting station to provide sufficient energy to produce the sound. This is the major reason crystal radio has such a limited range of reception. It is also for this reason that the crystal receiver is unique among radios of every era.

AM broadcasting was a milestone in the history of communication. Many men labored long years to bring radio to the forefront of an unprepared world. From a scientific curiosity it became a means to bring people together, and to bridge oceans, mountains, and those parts of the world that lay as yet unexplored. The history of the crystal receiver is concurrent with the history of radio itself, of the first great communication between people since the invention of the telegraph. From its beginnings to the age of the technology that was to cast it aside, here then is the story of crystal radio.

The Crystal Radio

In its simplest form a crystal receiver is composed of four parts -- the aerial or antenna as it is now called, the closed receiving circuit containing inductance and capacitance which are both variable, the rectifying crystal which acts as a detector, and the headphones which reproduce the radio broadcast in audible sound. In a more complex form of crystal receiver these same components may be elaborated on and the size of the circuit increased, but their individual functions remain the same. The basic circuit is illustrated in Figure 3.

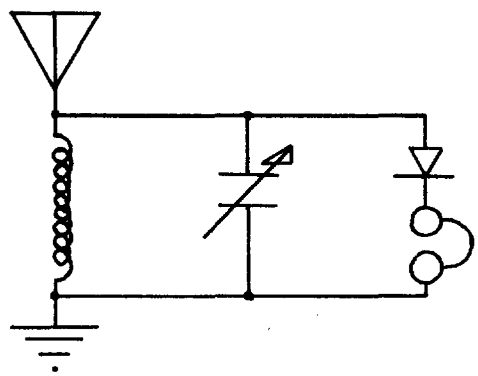

Figure 3: Crystal Radio In Schematic

The aerial absorbs the incident radio waves from a transmitting station, thereby setting up electric oscillations in the wire. The wave energy captured by the receiving aerial is partly dissipated as heat in the aerial itself and in the ground connection, and partly transferred to the rest of the receiving circuit. In the crystal receiver, where there is no amplifying force to supplement the energy of the radio waves, the capability of the aerial to absorb the wave energy and transfer it to the rest of the circuit becomes critical. Together with the ground, the aerial becomes the driving component of the circuit. To capitalize on its function, the common crystal receiver aerial is a long wire strung either vertically or horizontally. The most efficient form of aerial has a length of one-half the desired wavelength of reception.

Once the wave energy passes through the aerial, it enters the closed receiving circuit, or induction coil and associated variable capacitor, which is now referred to as a tank circuit. It functions as a resonant tuning component, determining the radio frequency or frequencies to be received. Oscillations of many frequencies enter the aerial. The tuning circuit provides maximum voltage to the rest of the receiver when the incoming frequency is its resonant frequency. By adjusting the inductance and capacitance of the circuit, its resonant frequency can be varied to correspond with a set of desired radio frequencies. This tunes the receiver circuit to different broadcasts. Without this component, the crystal receiver always responds to the strongest radio signal entering the aerial, as it will provide the greatest voltage.

The current in the receiver at this point is still AC or alternating current. To produce sound in the headphones it must be rectified or converted to direct current (DC). A large number of naturally occurring minerals rectify alternating current at very low voltages such as those produced in a crystal receiver. The efficiency of these rectifying minerals decreases proportionally as the voltage increases. These minerals are all poor conductors, and are mostly metallic oxides or sulphides such as galena (PbS), iron pyrite (FeS_2), chalcopyrite ($Cu_2SFe_2S_2$), zincite (ZnO), molybdenite (MoS), and copper pyrite ($FeCuS_2$). In light contact with a metal wire called a "cat's whisker," or in some cases with the pressure contact of a screw, a rectifying crystal serves as a detector in the receiving circuit.

Although it has been rectified, the signal retains its outline or envelope which was formed in the image of the sound patterns being transmitted. Because the envelope of an oscillation is identical in both directions, none of the outline has been lost by eliminating one direction. In this way the original programming imposed on the oscillation has been transferred from AC to DC, which will later produce sound.

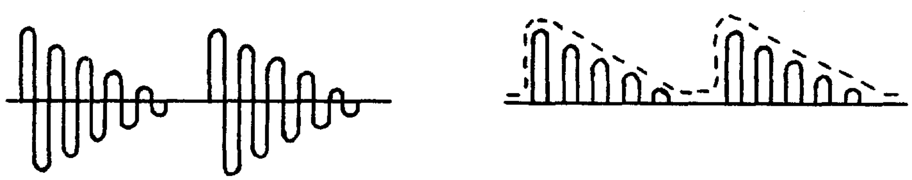

Figure 4: Oscillation and Rectified Oscillation

The sound is produced in magnetic headphones by activating and deactivating the electromagnet. There have been more modern forms of headphones since the magnetic type was invented, but it still works the best for crystal receivers because of its high impedence. Low resistance headphones are not suitable for crystal radio work due to the high resistance of the detector, which may be several thousand ohms. Headphones for such use should have an impedence nearly equal to that of the detector. Ordinary magnetic headphones from 1,000 to 2,500 ohms impedence in each side can be efficiently used. The headphones and the detector are connected with each other in series, and then together in parallel across the tuning circuit for maximum efficiency.

The crystal radio came in when "wireless" was bright and exciting, and stayed through the darkness of Hitler's Europe in World War II. Its technical simplicity was behind both its timeless popularity and its brusque demise. While now thought of mostly as a toy, it has seen action in all walks of life. Even today, if it serves no other purpose, an understanding of the technology of crystal radio imparts an understanding of the fundamentals of AM radio reception.

Historical Development

During the development of radio apparatus in the late 1890's and early 1900's, the U. S. Patent Office was kept busy with inventors protecting their finds. In the field of radio detectors were such names as G. W. Pickard, General H. H. C. Dunwoody, and G. W. Pierce. Experimental radio stations were just beginning, as Heinrich Hertz had only conducted his experiments on electromagnetic waves in the early 1890's, and Nikola Tesla worked on his spark-gap experiments in the latter part of the same decade.

In the early 1900's, magazines such as Scientific American were beginning to explore the science of "wireless telegraphy." Radio was still very much a scientists' field. Another decade would pass before the common man would enter the field of crystal radio construction, and begin to listen to the spark-gap transmissions around him. From the Bulletin of the U. S. Bureau of Standards in 1908 came the first real analysis of "contact rectifiers" in terms of Hertz's electromagnetic waves. The old theory of thermoelectric current action, applicable to the known sciences (since Hertzian waves were still very new), was difficult to overcome even through the next decade. It would be as late as World War II before the flow of scientific change would begin to move as fast as it is seen to move today.

The 1910's, while in some respects still reluctant to shake away the old science, forged ahead bravely into the new realm of "wireless" communication. Scientific American published a lengthy treatise in 1910 on the construction of a crystal radio capable of receiving a five-kilowatt broadcaster over a distance of 500 miles. Today many stations broadcast with ten times this much power. The Delineator, in its Department For Juniors, carried a column from "The Junior Wireless Club Of America," now -- under another name -- the oldest radio club still in existence in the nation. Overseas, the "Physical Society Of London" was examining contact rectifiers and "electrothermal" phenomena. Although their theory was wrong, they still made a valuable contribution in their appendix to the article, in which they elaborated on the use of such a device as a radiotelegraph detector. A later article compared detector types and rated their sensitivity.

Back in the States again, the field of industrial education was beginning to pick up what would be a great movement in the 1920's -- the teaching of radio reception in industrial arts classes. Surprisingly, it would be found in classes from such diverse areas as electricity, metal working, and even wood working. Newspapers and family magazines were beginning to cover the topic that would become a household project in the next decade. And at this same time, the U. S. Navy was using the first documented longwave crystal receiver, a landmark not only for being the first, but also simply for being documented. Recorded evidence of crystal radios actually being used for longwave reception is sparse at best, despite documentation of its theory.

The Roaring 20's were truly the decade of crystal radio in the home. The Literary Digest led the way with a detailed radio department in every issue, covering events at home and around the world. The fads were to see how small and/or simple a radio could be made and still have any kind of reception range. Contests were run, prizes offered, and every newspaper and magazine large enough to afford it entered the game. It was a "boys' technology" now, having come around the circle from a highly controversial scientific experiment. Now the latest designs were coming from the dining room table.

One young man designed a set in a billfold, consisting of three induction coils with a capacitor, and a crystal -- all constructed while recovering in bed from a long illness. A young man of twenty-one captured another contest by designing the whole radio on and around a cardboard corn meal box. Some little time later, Literary Digest reported the first publicized incident of two girls building a receiver -- they had copied the corn meal box design from the former issue "refusing all help from father and brother." But the smallest radio actually designed in the 1920's must have been Alfred Rinehart's ring radio. It contained only a crystal and single coil, with the crystal and coil taps (by which its inductance could be varied) mounted on top of the coil itself which was worn around the finger like a ring. Using only an umbrella for an aerial, it received WJZ in Newark, NJ, from Elizabeth, NJ, some five or ten miles away.

By the 1930's, industrial education was already looking back at the crystal receiver as a "project for the younger boy," in favor of the vacuum tube technology. The whole world was very much taken with the vacuum tube -- the family magazines were quick to drop the crystal radio fad in favor of this new technology. Science magazines still carried the old technology to some degree, but it was clear the fad had gone as quickly as it had come some ten years before. Not that radio itself was forgotten. The dining room table was still occupied, only now it was covered with tubes and batteries. Television was in its first experimental stages, made possible by the advent of the vacuum tube. The science of "wireless communication" was beginning to move faster now, and new ideas were taken up and as quickly cast aside as another came along. It was the beginning of a whole new world.

World War II in Europe began in the late 1930's. As Hitler moved seemingly unchecked across the land, the all-but-forgotten "children's toy" came back to the people again. They needed an easily hidden, easily assembled, no-power radio receiver that could be made cheaply out of household parts, and the crystal radio served them well. The Dutch Underground had a preference for putting them in telephones and hanging "Out of Order" signs over them for the Nazis. They lifted the receiver to hear the radio broadcasts from Allied nations and Underground transmitters. The French Underground sent to the BBC in London for crystal radio schematics using loop aerials. It is unfortunate that the BBC no longer has records of the specific schematics. And in what may have been the radio's most important application, prisoners in POW camps and soldiers in foxholes made receivers with a razor blade and pencil lead for a detector.

In the U. S., perhaps fueled by wartime rationing and civilian preparations for potential emergencies, crystal radio reappeared in two places. Articles about emergency radio receivers began to appear, with crystal radios figuring prominently. And on the lighter side, popular magazines began to design crystal radios in tin cans for boys on bicycles, using the bicycle frame as a ground. The germanium diode, today considered the crystal detector, was a product of wartime technology and not released to the public until well after the height of the fad had passed.

While the Allied world was fighting the war, Ecuador, South America, who had not yet chosen sides, was building its very first radio station. In the 1940's, HCJB, "The Voice of the Andes," built and distributed quantities of crystal radios to the Indians in the mountain regions of the country who had no access to commercial sets. As it happened, a great number of Ecuadorian residents had no commercial sets, and this fact was promptly made known to HCJB. Ecuador was a ready country for this inexpensive system. Through the technology of crystal radio, HCJB spread the gospel of Jesus Christ over miles of "unreachable" terrain. Many a more-impressive technology can boast a less-honored lineage than the simple crystal receiver.

Conclusion

With the release of World War II's solid state technology, the crystal radio was relegated to the annals of history. There was a minor wave of revival during the 1970's when the self-sufficiency and environmentalist movements began, but neither it nor they gained much momentum. After a certain lapse of time, it takes a great deal of energy to search out the uncataloged technology of another era, and that is what crystal radio is. Without the complete knowledge of the 1920's dining room hobbyist at hand, the 1970's dining room hobbyist never came to be. Technology has moved too far too fast. There are few people today who would go back to that technology if they could. Modern science is too perfect. The flaws of a previous era, exciting and challenging then, have become too inconvenient to the modern hobbyist.

Someday, if there is a need, the crystal radio may rise again like a phoenix from the ashes of modern technology. But if there is no need, modern man will never willingly seek out the "home-brew" technology. Perhaps it has yet to be discovered that when the technology of the pioneers has been forgotten for a long enough time, it becomes a pioneering technology again. Its use belongs once more to the enterprising pioneer who wishes to make a statement to the rest of the world. Such now is the crystal radio.

BIBLIOGRAPHY

Books

Alth, Max. Collecting Old Radios and Crystal Sets. Wallace-Homestead Book Co., Des Moines, Iowa, 1977.

Applied Practical Radio-Television, Vol. 3: Radio and Television Circuits. Coyne Electrical School, Inc., Chicago, IL, 1958.

Bateman, Alan M. Economic Mineral Deposits, 2nd ed. John Wiley & Sons, Inc., NY, NY, 1950.

Bucher, Elmer E. The Wireless Experimenter's Manual. Wireless Press, Inc., NY, NY, 1920.

Cook, Frank S. Seeds In the Wind. The World Radio Missionary Fellowship, Inc., Opa Locka, FL, 1982.

Dunlap, Orrin E. Jr. Radio's 100 Men of Science. Harper & Brothers Pub., NY, NY, 1944.

Eccles, W. H. Wireless Telegraphy and Telephony: A Handbook of Formulae, Data, and Information, 2nd ed. Benn Brothers, Ltd., London, Eng., 1918.

Edwards, K. E. Radios That Work For Free. Hope & Allen Pub. Co., Belmont, CA, 1977.

Fleming, J. A. The Principles of Electric Wave Telegraphy and Telephony, 3rd ed. Longmans, Green, & Co., London, Eng., 1916.

Fleming, J. A. The Wireless Telegraphist's Pocket Book of Notes, Formulae, and Calculations. The Wireless Press, Ltd., London, Eng., 1915.

Harlow, Alvin F. Old Wires and New Waves. D. Appleton-Century Co., Inc., NY, NY, 1936.

Hawkhead, J. C., and H. M. Dowsett. Handbook of Technical Instruction for Wireless Telegraphists, 2nd ed. The Wireless Press, Ltd., London, Eng., 1915.

Hawkins Electrical Guide #8, 2nd ed. Theo Audel & Co., NY, NY, 1923-24.

Jones, W. R., and David Williams. Minerals and Mineral Deposits. Oxford University Press, London, Eng., 1960.

Loomis, Mary T. Radio Theory and Operating. Loomis Publishing Co., Wash., D.C., 1925.

Morgan, Alfred P. Wireless Telegraph Construction For Amateurs, 3rd ed. D. Van Nostrand Co., NY, NY, 1913.

Pierce, George W. Principles of Wireless Telegraphy. McGraw-Hill Book Co., NY, NY, 1910.

Ries, Heinrich. Economic Geology, 4th ed. John Wiley & Sons, Inc., NY, NY, 1910.

Robison, S. S. Robison's Manual of Radio Telegraphy and Telephony for the Use of Naval Electricians, 5th ed. The U. S. Naval Institute, Annapolis, MD, 1919.

Sleeper, M. B. Design Data for Radio Transmitters and Receivers. The Norman W. Henley Pub. Co., NY, NY, 1922.

Sleeper, M. B. The Radio Experimenter's Hand Book. The Norman W. Henley Pub. Co., NY, NY, 1922.

Taggart, Arthur F. Handbook of Mineral Dressing. John Wiley & Sons, Inc., NY, NY, 1945.

Articles

Amorosek, Joseph D. "Ferri-Loopstick Crystal Receiver." Radio and Television News, July 1953, pp. 42, 88.

Bellman, Clarence H. "Long Distance Crystal Receiving Set." Industrial Education Magazine, March 1925, pp. 272-4.

"'Big Town' Bike Receiver." Popular Mechanics, Dec. 1943, p. 144.

"A Detector Based on New Principle." Scientific American, May 13, 1916, p. 505.

Dexter, Guy. "Emergency Radio Receivers." Radio News, Jan. 1943, pp. 28-29, 50-51.

Faber, John F. "Chart of Standard Radio Symbols." Industrial Arts Magazine, Teaching supplement #56, May 1927.

Green, Charles. "Grandpa's Whisker." Elementary Electronics, Sept.-Oct. 1978, pp. 59-61, 96.

Groshong, F. M. "Radio Receiving Set." Industrial Education Magazine, July 1924, p. 22.

Guilford, Edward H. "A Wireless Telegraph Station." Scientific American Supplement, July 23, 1910, pp. 53-4; Oct. 8, 1910, pp. 229-30; Oct. 15, 1910, pp. 246-7; Oct. 22, 1910, pp. 268-9.

Harvie, Gordon A. "The Construction of a Crystal Detector Receiving Set." Industrial Arts Magazine, Aug. 1923, pp. 316-17.

"How To Make a Loose Coupler." The Literary Digest, June 10, 1922, p. 28.

Huges, F. Clarke. "Crystal Radio -- a Project For the Younger Boy." Industrial Education Magazine, Oct. 1930, pp. 138-9.

Junior Wireless Club of America. "How Boys Can Make Their Own Wireless." The Delineator, Aug. 1911, p. 134.

Kahle, Charles. "A Crystal Receiver." Industrial Arts Magazine, Dec. 1923, p. 483.

Kennedy, James. "An Amateur Wireless Set." Industrial Arts Magazine, May 1916, pp. 189-92.

Kneitel, Tom. "Radio Secrets of the French Underground." Popular Communications, Oct. 1985, pp. 17-19.

Kosloff, Albert. "A Crystal Receiver." Industrial Arts and Vocational Education, Nov. 1948, pp. 373-5.

MacFarland, Anson. "Build the Foxhole Radio Receiver." Popular Communications, Mar. 1983, p. 23.

MacFarland, Anson. "Secret Radios of the WW II Dutch Underground." Popular Communications, Nov. 1983, pp. 56-8.

"More and More Indoor Aerials." The Literary Digest, June 3, 1922, p. 33.

"A Pocketbook Radio Set." The Literary Digest, Apr. 22, 1922, p. 29.

"Radio From a Ring." The Literary Digest, June 3, 1922, p. 32.

"A Simple Variometer Receiving Set." The Literary Digest, June 3, 1922, p. 33.

"The Simplest Crystal Set." St. Nicholas, Feb. 1925, pp. 426-7.

"The Simplest Radio Receiver." The Literary Digest, Apr. 22, 1922, pp. 27-8.

"Wavelength-Frequency Chart." Radio News, June 1937, pp. 720-21.

Government Publications

Auxiliary Condensers and Loading Coil Used With Simple Homemade Radio Receiving Outfits. Circular #137, U. S. Bureau of Standards, Feb. 23, 1923.

Construction and Operation of a Simple Homemade Receiving Outfit. Circular #120, U. S. Bureau of Standards, Apr. 24, 1922.

Construction and Operation of a Two-Circuit Radio Receiving Equipment With Crystal Detector. Circular #121, U. S. Bureau of Standards, July 17, 1922.

The Principles Underlying Radio Communication, 2nd ed. Radio Communication Pamphlet #40, U. S. Bureau of Standards (for Signal Corps, U. S. Army), 1922.

Radio Instruments and Measurements. Circular #74, U. S. Bureau of Standards, Mar. 23, 1918.

Sources of Elementary Radio Information, 2nd ed. Circular #122, U. S. Bureau of Standards, Sept. 12, 1923.