Your Grandfather's Crystal Radio Toy May Be the Global Internet Of The Future

- Nuclear weapon-proof
- Solar storm proof
- Free Internet forever

Cell Phone companies, Comcast, Cox Cable and politicians paid by them, will do anything to stop you from finding out about this!

Did you know that the Internet does not actually have any pipes? There is nothing in physics that stops you from running your current Internet connection a thousand times faster than you are ALLOWED to run it today. You can watch, share, make and upload 4K video all day long, on the same internet you have from any provider, except THEY won't let you. The only thing that stops you, are the corporations that you get your Internet from. They don't like you having “too much power”.

These companies make money by controlling information. That is the biggest service they sell. Lobbyists and other corporations buy that service. If you could see anything that was going on and broadcast anything that you wanted to, you would break their media control system.

Now you can!

You will see old black and white TV shows, and movies that show an old codger twiddling a dial on a little box while he listened, intently, to a set of headphones. That box had no more than a little rock, a piece of crystal, and a strand of wire, to make it operate. It was called a crystal radio set. You can still buy them on Ebay and in retro-toy stores on-line and in hipster shopping neighborhoods.

Buy one, they are not very expensive. The shocking thing about them is that they are so simple and they work with, essentially, a rock and a wire.

Nuclear attacks and solar storms fry all electronics except these. Some enthusiasts even use versions of these to listen to solar storms, for fun.

Now, a number of open-source project teams are taking this simple technology and building mesh networked peer-to-peer Internet's with them. The devices are self-powered by ambient energy that is already flying around right next to you, it is in the air, everywhere.

They do not need to be very powerful. They only need to reach the person, or unit, near you. They form an instant mesh that IS part of the internet. You can add more range, power and features with battery, or solar powered, add-ons, but the basic device is self-sufficient.

Image the structure of a spider-web or a football stadium full of audience members performing “The Wave”; it's like that. Many tiny connection points, or many individuals, all connect together to make a much bigger thing happen simply because they shared a connection or a common activity.

That is the power of this new type of device. It requires little, or no power, yet it offers the greatest power on Earth: Free, unlimited, communication.

HOW CRYSTAL RADIOS WORK

Crystal radio

- This article is about unpowered radio receivers. For crystal-controlled oscillators (as used in radios), see Crystal oscillator.

"Crystal set" redirects here. For the Australian rock band, see The Crystal Set.

- Boy listening to a modern crystal radio

A **crystal radio receiver**, also called a **crystal set** or **cat's whisker receiver**, is a very simple radio receiver, popular in the early days of radio. It needs no other power source but that received solely from the power of radio waves received by a wire antenna. It gets its name from its most important component, known as a crystal detector, originally made from a piece of crystalline mineral such as galena.[1] This component is now called a diode.

Crystal radios are the simplest type of radio receiver[2] and can be made with a few inexpensive parts, such as a wire for an antenna, a coil of copper wire for adjustment, a capacitor, a crystal detector, and earphones.[3] They are distinct from ordinary radios as they are passive receivers, while other radios use a separate source of electric power such as a battery or the mains power to amplify the weak radio signal so as to make it louder. Thus, crystal sets produce rather weak sound and must be listened to with sensitive earphones, and can only receive stations within a limited range.[4]

The rectifying property of crystals was discovered in 1874 by Karl Ferdinand Braun,[5][6][7] and crystal detectors were developed and applied to radio receivers in 1904 by Jagadish Chandra Bose,[8][9] G. W. Pickard[10] and others.

Crystal radios were the first widely used type of radio receiver,[11] and the main type used during the wireless telegraphy era.[12] Sold and homemade by the millions, the inexpensive and reliable crystal radio was a major driving force in the introduction of radio to the public, contributing to the development of radio as an entertainment medium around 1920.[13]

After about 1920, crystal sets were superseded by the first amplifying receivers, which used vacuum tubes (Audions), and became obsolete for commercial use.[11] They, however, continued to be built by hobbyists, youth groups, and the Boy Scouts[14] as a way of learning about the technology of radio. Today they are still sold as educational devices, and there are groups of enthusiasts devoted to their construction[15][16][17][18][19][20] who hold competitions comparing the performance of their home-built designs.[21][22]

Crystal radios receive amplitude modulated (AM) signals, and can be designed to receive almost any radio frequency band, but most receive the AM broadcast band.[23] A few receive shortwave bands, but strong signals are required. The first crystal sets received wireless telegraphy signals broadcast by spark-gap transmitters at frequencies as low as 20 kHz.[24][25]

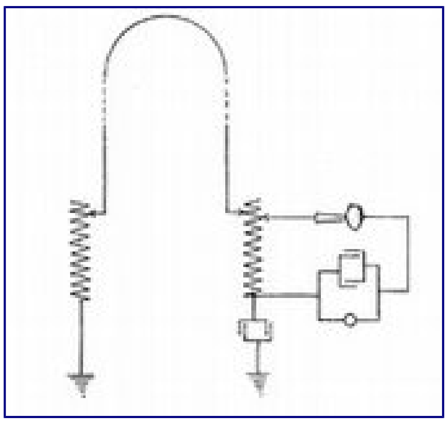
Contents

- 1 History
  - 1.1 Early years
  - 1.2 1920s and 1930s
  - 1.3 Valveless amplifier
  - 1.4 Crystodyne
  - 1.5 "Foxhole radios"
  - 1.6 Later years
- 2 Design
  - 2.1 Antenna
  - 2.2 Ground
  - 2.3 Tuned circuit
    - 2.3.1 Impedance matching
    - 2.3.2 Problem of selectivity
    - 2.3.3 Inductively coupled receivers
  - 2.4 Crystal detector
  - 2.5 Earphones
- 3 Use as a power source
- 4 Gallery
- 5 See also
- 6 References
- 7 Further reading

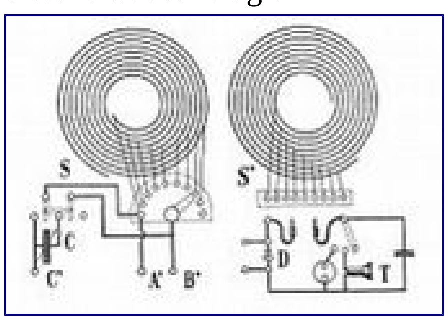
- 8 External links

History

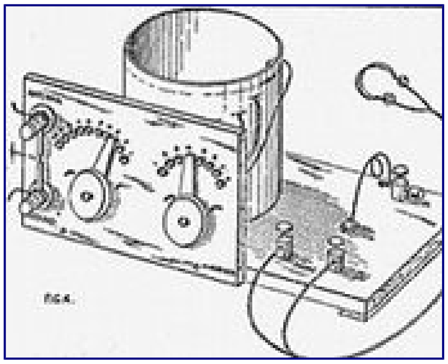
A family listening to a crystal radio in the 1920s



Greenleaf Whittier Pickard's US Patent 836,531 "Means for receiving intelligence communicated by electric waves" diagram



Radio receiver, Basel, Switzerland, 1914



NBS Circular 120 Home Crystal Radio Project

Crystal radio was invented by a long, partly obscure chain of discoveries in the late 19th century that gradually evolved into more and more practical radio receivers in the early 20th century; it constitutes the origin of the field of electronics. The earliest practical use of crystal radio was to receive Morse code radio signals transmitted, from spark-gap transmitters, by early amateur radio experimenters. As electronics evolved, the ability to send voice signals by radio caused a technological explosion in the years around 1920 that evolved into today's radio broadcasting industry.

Early years

Early radio telegraphy used spark gap and arc transmitters as well as high-frequency alternators running at radio frequencies. At first a Branley Coherer was used to detect the presence of a radio signal. However, these lacked the sensitivity to detect weak signals.

In the early 20th century, various researchers discovered that certain metallic minerals, such as galena, could be used to detect radio signals.[26][27]

In 1901, Bose filed for a U.S. patent for "A Device for Detecting Electrical Disturbances" that mentioned the use of a galena crystal; this was granted in 1904, #755840.[28] The device depended on the large variation of a semiconductor's conductance with temperature; today we would call his invention a bolometer.[*citation needed*] Bose's patent is frequently, but erroneously, cited as a type of rectifying detector. On August 30, 1906, Greenleaf Whittier Pickard filed a patent for a silicon crystal detector, which was granted on November 20, 1906.[29] Pickard's detector was revolutionary in that he found that a fine pointed wire known as a "cat's whisker", in delicate contact with a mineral, produced the best semiconductor effect (that of rectification).

A crystal detector includes a crystal, a special thin wire that contacts the crystal and the stand that holds those components in place. The most common crystal used is a small piece of galena; pyrite was also often used, as it was a more easily adjusted and stable mineral, and quite sufficient for urban signal strengths. Several other minerals also performed well as detectors. Another benefit of crystals was that they could demodulate amplitude modulated signals. This mode was used in radiotelephones and voice broadcast to a public audience. Crystal sets represented an inexpensive and technologically simple method of receiving these signals at a time when the embryonic radio broadcasting industry was beginning to grow.

1920s and 1930s

In 1922 the (then named) US Bureau of Standards released a publication entitled *Construction and Operation of a Simple Homemade Radio Receiving Outfit*.[30] This article showed how almost any family having a member who was handy with simple tools could make a radio and tune into weather, crop prices, time, news and the opera. This design was significant in bringing radio to the general public. NBS followed that with a more selective two-circuit version, *Construction and Operation of a Two-Circuit Radio Receiving Equipment With Crystal Detector*, which was published the same year [31] and is still frequently built by enthusiasts today.

In the beginning of the 20th century, radio had little commercial use, and radio experimentation was a hobby for many people.[32] Some historians consider the autumn of 1920 to be the beginning of commercial radio broadcasting for entertainment purposes. Pittsburgh station KDKA, owned by Westinghouse, received its license from the United States Department of Commerce just in time to broadcast the Harding-Cox presidential election returns. In addition to reporting on special events, broadcasts to farmers of crop price reports were an important public service in the early days of radio.

In 1921, factory-made radios were very expensive. Since less-affluent families could not afford to own one, newspapers and magazines carried articles on how to build a crystal radio with common household items. To minimize the cost, many of the plans suggested winding the tuning coil on empty pasteboard containers such as oatmeal boxes, which became a common foundation for homemade radios.

Valveless amplifier

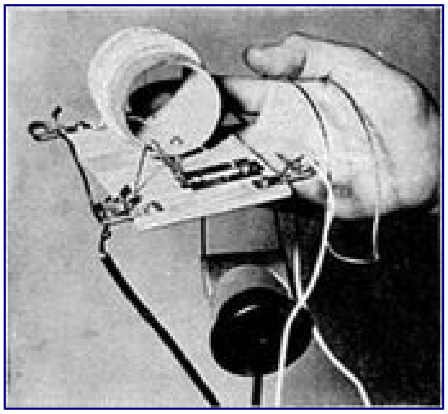
A "carbon amplifier" consists of a carbon microphone and an electromagnetic earpiece that shares a common membrane and case. This was used in the telephone industry and in hearing aids nearly since the invention of both components and long before vacuum tubes. This could be readily bought or made from surplus telephone parts for use with a crystal radio.[*citation needed*] Unlike vacuum tubes, it could run with only a flashlight or car battery.

Crystodyne

In early 1920s Russia, devastated by civil war, Oleg Losev was experimenting with applying voltage biases to various kinds of crystals for manufacture of radio detectors. The result was astonishing: with a zincite (zinc oxide) crystal he gained amplification.[33][34][35] This was negative resistance phenomenon, decades before the development of the tunnel diode. After the first experiments, Losev built regenerative and superheterodyne receivers, and even transmitters.

A crystodyne could be produced in primitive conditions; it can be made in a rural forge, unlike vacuum tubes and modern semiconductor devices. However, this discovery was not supported by authorities and soon forgotten; no device was produced in mass quantity beyond a few examples for research.

"Foxhole radios"



"Foxhole radio" used on the Italian Front in World War 2. It uses a pencil lead attached to a safety pin pressing against a razor blade for a detector.

In addition to mineral crystals, the oxide coatings that form on many metal surfaces are semiconductors and can rectify, and crystal radios have been improvised using detectors made from rusty nails, corroded pennies, and many other common objects.

When Allied troops were halted near Anzio, Italy during the spring of 1944, personal radio receivers were strictly prohibited as the Germans had equipment that could detect the local oscillator signal of superheterodyne receivers. Crystal sets lack local oscillators, hence they could not be detected, so some resourceful soldiers constructed "crystal" sets from discarded materials to listen to news and music. One type used a blue steel razor blade and a pencil lead for a detector. The lead point touching the semiconducting oxide coating (rust) on the blade formed a crude point-contact diode. By lightly dragging the pencil lead across the surface of the blade, they could find sensitive spots which could bring in stations. The lead of the pencil is made of graphite and clay and so it would inhibit further corrosion that would result if copper or iron wire was used in its place. Any further corrosion at the point of contact would ruin that diode effect. The sets were dubbed "foxhole radios" by the popular press, and they became part of the folklore of World War II.

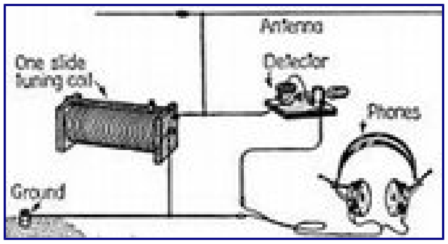
In some German-occupied countries during WW2 there were widespread confiscations of radio sets from the civilian population. This led determined listeners to build their own "clandestine receivers" which frequently amounted to little more than a basic crystal set. However, anyone doing so risked imprisonment or even death if caught, and in most parts of Europe the signals from the BBC (or other allied stations) were not strong enough to be received on such a set.

Later years

While it never regained the popularity and general use that it enjoyed at its beginnings, the circuit is still used. The Boy Scouts kept the construction of a radio set in their program since the 1920s. A large number of prefabricated novelty items and simple kits could be found through the 1950s and 1960s, and many children with an interest in electronics built one.

Building crystal radios was a craze in the 1920s, and again in the 1950s. Recently, hobbyists have started designing and building examples of the early instruments. Much effort goes into the visual appearance of these sets as well as their performance, and some outstanding examples can be found. Annual crystal radio 'DX' contests (long distance reception) and building contests allow these set owners to compete with each other and form a community of interest in the subject.

Design



Pictorial diagram from 1922 showing the circuit of a crystal radio. This common circuit did not use a tuning capacitor, but used the capacitance of the antenna to form the tuned circuit with the coil. The detector might have been a piece of galena with a whisker wire in contact with it on a part of the crystal, making a diode contact

A crystal radio can be thought of as a radio receiver reduced to its essentials.[3][36] It consists of at least these components:[23][37][38]

- An antenna in which electric currents are induced by the radio waves.
- A tuned circuit able to select the frequency of the desired radio station out of all the frequencies received by the antenna, and to reject all others. This circuit consists of a coil of wire (called an inductor) and a capacitor connected together, so as to create a circuit that resonates at the frequency of the desired station, and hence "tune" in that station. One or both of the coil or capacitor is adjustable, allowing the circuit to be tuned to different frequencies. In some circuits a capacitor is not used, as the antenna also serves as the capacitor. The tuned circuit has a natural resonant frequency that allows radio waves at that frequency to pass, while rejecting waves at all other frequencies. Such a circuit is also known as a bandpass filter.
- A semiconductor crystal (detector) which extracts the audio signal (modulation) from the radio frequency carrier wave. The crystal does this by allowing current to pass through it in only one direction, blocking the other half of the oscillations of the radio wave. This *rectifies* the alternating current radio wave to a pulsing direct current, whose strength varies with the audio signal. This current can be converted to sound by the earphone, while the full un-rectified signal could not. Early sets used a cat's whisker detector, consisting of a fine wire touching the surface of a sample of crystalline mineral such as galena. It was this component that gave crystal sets their name.
- An earphone to convert the audio signal to sound waves so they can be heard. The low power produced by crystal radios is typically insufficient to power a loudspeaker, hence earphones are used.

The sound power produced by the earphone of a crystal set comes solely from the radio station being received, via the radio waves picked up by the antenna.[3] The power available to a receiving antenna decreases with the square of its distance from the radio transmitter.[39] Even for a powerful commercial broadcasting station, if it is more than a few miles from the receiver the power received by the antenna is very small, typically measured in microwatts or nanowatts.[3] In modern crystal sets, signals as weak as 50 picowatts at the antenna can be heard.[40] Crystal radios can receive such weak signals without using amplification only due to the great sensitivity of human hearing,[3][41] which can detect sounds with an intensity of only 10^{-16} W/cm^2.[42] Therefore, crystal receivers have to be designed to convert the energy from the radio waves into sound waves as efficiently as possible. Even so, they are usually only able to receive stations within distances of about 25 miles for AM broadcast stations,[43][44] although the radiotelegraphy signals used during the wireless telegraphy era could be received at hundreds of miles,[44] and crystal receivers were even used for transoceanic communication during that period.[45]

Commercial passive receiver development was abandoned with the advent of reliable vacuum tubes around 1920, and subsequent crystal radio research was primarily done by radio amateurs and hobbyists.[46] Many different circuits have been used.[2][47][48] The following sections discuss the parts of a crystal radio in greater detail.

Antenna

The antenna converts the energy in the electromagnetic radio waves striking it to an alternating electric current in the antenna, which is connected to the tuning coil. Since in a crystal radio all the power comes from the antenna, it is important that the antenna collect as much power from the radio wave as possible. The larger an antenna, the more power it can intercept. Antennas of the type commonly used with crystal sets are most effective when their length is close to a multiple of a quarter-wavelength of the radio waves they are receiving. Since the length of the waves used with crystal radios is very long (AM broadcast band waves are 182-566 m or 597–1857 ft. long)[49] the antenna is made as long as possible,[50] out of a long wire, in contrast to the whip antennas or ferrite loopstick antennas used in modern radios.

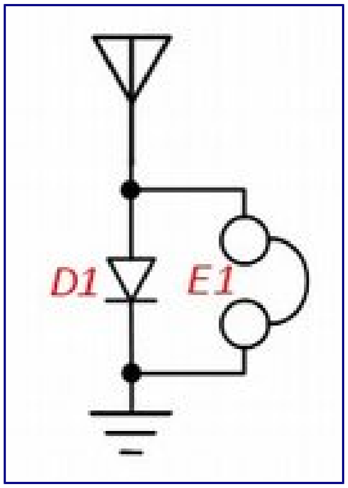
Serious crystal radio hobbyists use "inverted L" and "T" type antennas, consisting of hundreds of feet of wire suspended as high as possible between buildings or trees, with a feed wire attached in the center or at one end leading down to the receiver.[51][52] However more often random lengths of wire dangling out windows are used. A popular practice in early days (particularly among apartment dwellers) was to use existing large metal objects, such as bedsprings,[14] fire escapes, and barbed wire fences as antennas.[44][53][54]

Ground

The wire antennas used with crystal receivers are monopole antennas which develop their output voltage with respect to ground. They require a return circuit connected to ground (the earth). The ground wire was attached to a radiator, water pipe, or a metal stake driven into the ground.[55][56] In early days if an adequate ground connection could not be found a counterpoise was sometimes used.

[57][58] A good ground is more important for crystal sets than it is for powered receivers, as crystal sets are designed to have a low input impedance needed to transfer power efficiently from the antenna. A low resistance ground connection (preferably below 25 Ω) is necessary because any resistance in the ground dissipates power from the antenna.[50] In contrast, modern receivers are voltage-operated devices, with high input impedance, hence little current flows in the antenna/ground circuit. Also, mains powered receivers are grounded adequately through their power cords, which are in turn attached to the earth by way of a well established ground.

Tuned circuit



The earliest crystal receiver circuit did not have a tuned circuit

The tuned circuit, consisting of a coil and a capacitor connected together, acts as a resonator, similar to a tuning fork.[58] Electric charge, induced in the antenna by the radio waves, flows rapidly back and forth between the plates of the capacitor through the coil. The circuit has a high impedance at the desired radio signal's frequency, but a low impedance at all other frequencies.[59] Hence, signals at undesired frequencies pass through the tuned circuit to ground, while the desired frequency instead passes through the detector (diode) and stimulates the earpiece and is heard. The frequency of the station "received" is the resonant frequency f of the tuned circuit, determined by the capacitance C of the capacitor and the inductance L of the coil:[60]

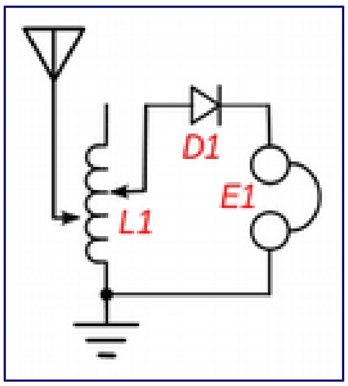
$$f = \frac{1}{2\pi\sqrt{LC}}$$

In inexpensive sets, the inductor coil had a sliding spring contact that pressed against the windings that could slide along the coil, thereby introducing a larger or smaller number of turns of the coil into the circuit, thus varying the inductance, "tuning" the circuit to the frequencies of different radio stations.[1] Alternatively, a variable capacitor is used to tune the circuit.[61] Some modern crystal sets use a ferrite core tuning coil, in which a ferrite magnetic core is moved into and out of the coil, thereby varying the inductance by changing the magnetic permeability.[62]

The antenna is an integral part of the tuned circuit and its reactance contributes to determining the circuit's resonant frequency. Antennas usually act as a capacitance, as antennas shorter than a quarter-wavelength have capacitive reactance.[50] Many early crystal sets did not have a tuning capacitor,[63] and relied instead on the capacitance inherent in the wire antenna (in addition to significant parasitic capacitance in the coil[64]) to form the tuned circuit with the coil.

The earliest crystal receivers did not have a tuned circuit at all, and just consisted of a crystal detector connected between the antenna and ground, with an earphone across it.[1][63] Since this circuit lacked any frequency-selective elements besides the broad resonance of the antenna, it had little ability to reject unwanted stations, so all stations within a wide band of frequencies were heard in the earphone[46] (in practice the most powerful usually drowns out the others). It was used in the earliest days of radio, when only one or two stations were within a crystal set's limited range.

Impedance matching

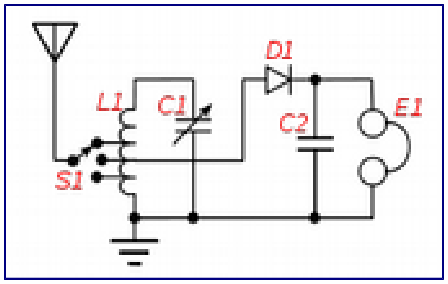


"Two slider" circuit.[46] The two sliding contacts on the coil allowed the impedance of the radio to be adjusted to match the antenna as the radio was tuned, resulting in stronger reception

An important principle used in crystal radio design to transfer maximum power to the earphone is impedance matching.[46][65][66] The maximum power is transferred from one part of a circuit to another when the impedance of one circuit is the complex conjugate of that of the other; this implies that the two circuits should have equal resistance.[1][67][68] However, in crystal sets, the impedance of the antenna-ground system (around 10-200 ohms[50]) is usually lower than the impedance of the receiver's tuned circuit (thousands of ohms at resonance),[69] and also varies depending on the quality of the ground attachment, length of the antenna, and the frequency to which the receiver is tuned.[40]

Therefore, in better receiver circuits, to match the antenna impedance to the receiver's impedance, the antenna was connected across only a portion of the tuning coil's turns.[60][63] This made the coil act as an impedance matching transformer (in an autotransformer connection) in addition to its tuning function. The aerial's low resistance was increased (transformed) by a factor equal to the square of the turns ratio (the number of turns the antenna was connected across, to the total number of turns of the coil), to match the resistance across the tuned circuit.[68] In the "two-slider" circuit, popular during the wireless era, both the antenna and the detector circuit were attached to the coil with sliding contacts, allowing (interactive)[70] adjustment of both the resonant frequency and the turns ratio.[71][72][73] Alternatively a multiposition switch was used to select taps on the coil. These controls were adjusted until the station sounded loudest in the earphone.

Problem of selectivity

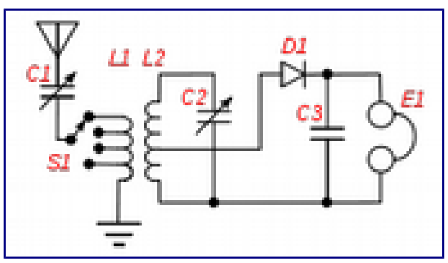


Direct-coupled circuit with impedance matching[46]

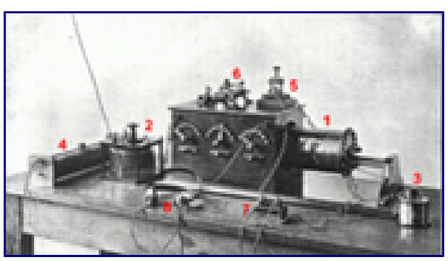
One of the drawbacks of crystal sets is that they are vulnerable to interference from stations near in frequency to the desired station; that is to say, they have low selectivity.[2][4][40] Often two or more stations are heard simultaneously. This is because the simple tuned circuit doesn't reject nearby signals well; it allows a wide band of frequencies to pass through, that is, it has a large bandwidth (low Q factor) compared to modern receivers.[4]

The crystal detector connected across it worsened the problem, because its relatively low resistance "loaded" the tuned circuit, thus damping the oscillations, and reducing its Q.[40][74] In many circuits, the selectivity was improved by connecting the detector and earphone circuit to a tap across only a fraction of the coil's turns.[46] This reduced the impedance loading of the tuned circuit, as well as improving the impedance match with the detector.[46]

Inductively coupled receivers



Inductively-coupled circuit with impedance matching. This type was used in most quality crystal receivers



Amateur-built crystal receiver with "loose coupler" antenna transformer, Belfast, around 1914

In more sophisticated crystal receivers, the tuning coil was replaced with an adjustable air core antenna coupling transformer[1][46] which improved the selectivity by a technique called *loose coupling*.[63][73][75] This consisted of two magnetically coupled coils of wire, one (the *primary*) attached to the antenna and ground and the other (the *secondary*) attached to the rest of the circuit. The current from the antenna created an alternating magnetic field in the primary coil, which induced a voltage in the secondary coil which was then rectified and powered the earphone. Each of the coils functioned as a tuned circuit that was tuned to the frequency of the station: the primary coil resonated with the capacitance of the antenna (or sometimes another capacitor), and the secondary coil resonated with the tuning capacitor. The two circuits interacted to form a resonant transformer.

Reducing the *coupling* between the coils, by physically separating them so less of the magnetic field of one intersects the other (reducing the mutual inductance), narrows the bandwidth, resulting in much sharper, more selective tuning than that produced by a single tuned circuit.[63][76] However this involved a tradeoff; the looser coupling also reduced the amount of signal getting through the transformer. The transformer was made with adjustable coupling, to allow the listener to experiment with various settings to get the best reception.

One design common in early days, called a "loose coupler", consisted of a smaller coil inside a larger coil.[46][77] The smaller coil was mounted on a rack so it could be slid linearly in or out of the larger coil. If interference was encountered, the smaller coil would be slid further out of the larger, loosening the coupling and narrowing the bandwidth, to better reject the interfering signal.

The antenna coupling transformer also functioned as an impedance matching transformer, to match the antenna impedance to the rest of the circuit. One or both of the coils usually had several taps which could be selected with a switch, to adjust the turns ratio.

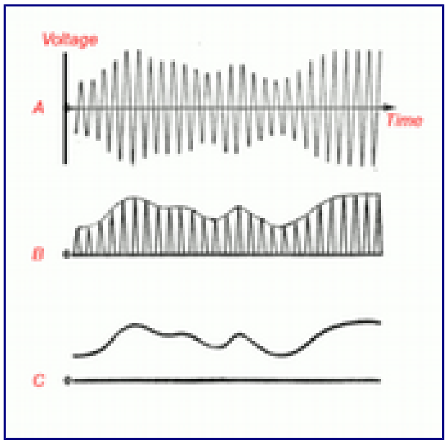
Coupling transformers were difficult to adjust, because the three adjustments, the tuning of the primary circuit, the tuning of the secondary circuit, and the coupling of the coils, were all interactive, and changing one affected the others.[78]

Crystal detector

Main article: Cat's whisker detector

Galena cat's whisker detector

Germanium diode used in modern crystal radios (about 3 mm long)



How the crystal detector works.[79][80] *(A)* The amplitude modulated radio signal from the tuned circuit. The rapid oscillations are the radio frequency carrier wave. The audio signal (the sound) is contained in the slow variations (modulation) of the size of the waves. This signal cannot be converted to sound by the earphone, because the audio excursions are the same on both sides of the axis, averaging out to zero, which would result in no net motion of the earphone's diaphragm. *(B)* The crystal conducts current better in one direction than the other, producing a signal whose amplitude does not average zero but varies with the audio signal. *(C)* A bypass capacitor is used to remove the radio frequency carrier pulses, leaving the audio signal

In early sets, the detector was a cat's whisker detector, a fine metal wire on an adjustable arm that touched the surface of a crystal of a semiconducting mineral.[1][6][81] This formed a crude unstable semiconductor diode (Schottky diode), which allowed current to flow better in one direction than in the opposite direction.[82] Modern crystal sets use modern semiconductor diodes.[74] The detector rectified the alternating current radio signal to a pulsing direct current, the peaks of which traced out the audio signal, so it could be converted to sound by the earphone, which was connected in series (or sometimes in parallel) with the detector.[23][80]

The rectified current from the detector still had radio frequency pulses from the carrier in it, which did not pass well through the high inductance of the earphones. A small capacitor, called a blocking or bypass capacitor, was often placed across the earphone terminals to bypass these pulses around the earphone and then to ground,[83] although the earphone cord usually had enough capacitance that this component could be omitted.[41][63]

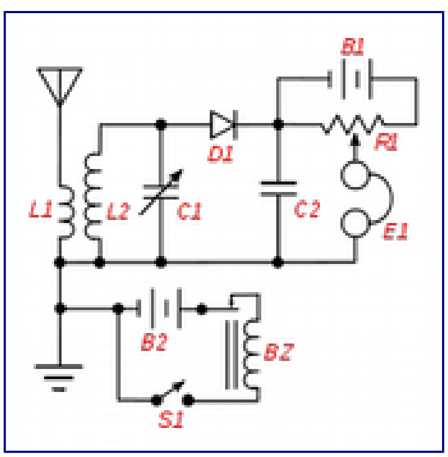
In a cat's whisker detector only certain sites on the crystal surface functioned as rectifying junctions, and the device was very sensitive to the pressure of the crystal-wire contact, which could be disrupted by the slightest vibration.[6][84] Therefore, a usable contact point had to be found by trial and error before each use. The operator dragged the wire across the crystal surface until a radio station or "static" sounds were heard in the earphones.[85] An alternative adjustment method was to use a battery-powered buzzer attached to the ground wire to provide a test signal.[85] The spark at the buzzer's electrical contacts served as a weak radio transmitter, so when the detector began working, the buzz could be heard in the earphones, and the buzzer was then turned off.

Galena (lead sulfide) was probably the most common crystal used in cat's whisker detectors,[73][84] but various other types of crystals were also used, the most common being iron pyrite (fool's gold, FeS_2), silicon, molybdenite (MoS_2), silicon carbide (carborundum, SiC), and a zincite-bornite ($ZnO-Cu_5FeS_4$) crystal-to-crystal junction trade-named *Perikon*.[41][86] Crystal radios have also been made with rectifying junctions improvised from a variety of common objects, such as blue steel razor blades and lead pencils,[41][87] rusty needles,[88] and pennies[41] In these, a semiconducting layer of oxide or sulfide on the metal surface is usually responsible for the rectifying action.[41]

In modern sets a semiconductor diode is used for the detector, which is much more reliable than a cat's whisker detector and requires no adjustments.[41][74][89] Germanium diodes (or sometimes Schottky diodes) are used instead of silicon diodes, because their lower forward voltage drop (roughly 0.3V compared to 0.6V[90]) makes them more sensitive.[74][91]

All semiconductor detectors function rather inefficiently in crystal receivers, because the low voltage signal level is too low to result in much difference between forward better conduction and reverse weaker conduction. To improve the sensitivity of some of the early crystal detectors, such as silicon carbide, a small forward bias voltage was applied across the detector by a battery and potentiometer.[92][93] Bias can move the diode's operating point higher on the detection curve to produce more signal voltage at the expense of less signal current (higher impedance). There is a limit to the benefit that this produces, depending on the other impedances of the radio. This improved sensitivity by moving the DC operating point to a more desirable voltage-current operating point (impedance) on the junction's I-V curve.

Earphones



Circuit with detector bias battery to improve sensitivity and buzzer to adjust cat's whisker

Modern crystal radio with piezoelectric earphone

The requirements for earphones used in crystal sets are different from earphones used with modern audio equipment. They have to be efficient at converting the electrical signal energy to sound waves, while most modern earphones are designed for high fidelity reproduction of the sound.[94] In early homebuilt sets, the earphones were the most costly component.[95]

The early earphones used with wireless-era crystal sets had moving iron drivers that worked in a similar way to the horn loudspeakers of the period; modern loudspeakers use a moving-coil principle. Each earpiece contained a magnet wound with coils of wire to form an electromagnet, with poles close to a steel diaphragm. When the audio signal from the radio was passed through the electromagnet's windings, it created a varying magnetic field that augmented or diminished that due to the permanent magnet. This varied the force of attraction on the diaphragm, causing it to vibrate. The vibrations of the diaphragm pushed and pulled on the air in front of it, creating sound waves. Standard headphones used in telephone work had a low impedance, often 75 Ω, and required more current than a crystal radio could supply, so the type used with radios was wound with more turns of finer wire and had an impedance of 2000-8000 Ω.[96][97][98]

Modern crystal sets use piezoelectric crystal earpieces, which are much more sensitive and also smaller.[94] They consist of a piezoelectric crystal with electrodes attached to each side, glued to a light diaphragm. When the audio signal from the radio set is applied to the electrodes, it causes the crystal to vibrate, vibrating the diaphragm. Crystal earphones are designed as ear buds that plug directly into the ear canal of the wearer, coupling the sound more efficiently to the eardrum. Their resistance is much higher (typically megohms) so they do not greatly "load" the tuned circuit, allowing increased selectivity of the receiver.

However the earphone's higher resistance, in parallel with its capacitance of around 9 pF, creates a low pass filter which removes the higher audio frequencies, distorting the sound.[99] So sometimes a bypass capacitor is not needed (although in practice a small one of around 0.68 to 1 nF is often used to help improve quality), and instead a 10-100 kΩ resistor must be added across the earphone's input.[100]

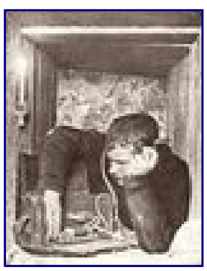
Although the low power produced by crystal radios is typically insufficient to drive a loudspeaker, some homemade 1960s sets have used one, with an audio transformer to match the low impedance of the speaker to the circuit.[101] Similarly, modern low-impedance (8 Ω) earphones cannot be used unmodified in crystal sets because the receiver does not produce enough current to drive them. They are sometimes used by adding an audio transformer to match their impedance with the higher impedance of the circuit.

Use as a power source

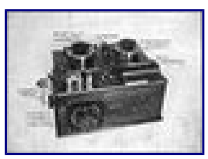
A crystal radio tuned to a strong local transmitter can be used as a power source for a second amplified receiver of a distant station that cannot be heard without amplification.[102]:122–123

There is a long history of unsuccessful attempts and unverified claims to recover the power in the carrier of the received signal itself. Traditional crystal sets use half-wave rectifiers. As AM signals have a modulation factor of only 30% by voltage at peaks[*citation needed*], no more than 9% of received signal power ($P = U^2/R$) is actual audio information, and 91% is just rectified DC voltage. Given that the audio signal is unlikely to be at peak all the time, the ratio of energy is, in practice, even greater. Considerable effort was made to convert this DC voltage into sound energy. Some earlier attempts include a one-transistor[103] amplifier in 1966. Sometimes efforts to recover this power are confused with other efforts to produce a more efficient detection.[104] This history continues now with designs as elaborate as "inverted two-wave switching power unit".[102]:129

Gallery


Soldier listening to a crystal radio during World War I, 1914


Australian signallers using a Marconi Mk III crystal receiver, 1916.


Marconi Type 103 crystal set.


SCR-54A crystal set used by US Signal Corps in World War I


Marconi Type 106 crystal receiver used for transatlantic communication, ca. 1921


Homemade "loose coupler" set *(top)*, Florida, ca. 1920


Polish Detefon brand radio, 1930-1939, using a "cartridge" type crystal *(top)*

During the wireless telegraphy era before 1920, crystal receivers were "state of the art", and sophisticated models were produced. After 1920 crystal sets became the cheap alternative to vacuum tube radios, used in emergencies and by youth and the poor.

See also

Radio portal

- Batteryless radio
- Camille Papin Tissot
- Cat's-whisker detector
- Coherer
- Demodulator
- Detector (radio)
- Electrolytic detector
- Foxhole radio
- History of radio

References

1.

- *Carr, Joseph J. (1990). Old Time Radios! Restoration and Repair. US: McGraw-Hill Professional. pp. 7–9. ISBN 0-8306-3342-1.*
- *Petruzellis, Thomas (2007). 22 Radio and Receiver Projects for the Evil Genius. US: McGraw-Hill Professional. pp. 40, 44. ISBN 978-0-07-148929-4.*
- *Field, Simon Quellen (2003). Gonzo gizmos: Projects and devices to channel your inner geek. US: Chicago Review Press. p. 85. ISBN 978-1-55652-520-9.*
- *Schaeffer, Derek K.; Thomas H. Lee (1999). The Design and Implementation of Low Power CMOS Receivers. Springer. pp. 3–4. ISBN 0-7923-8518-7.*
- *Braun, Ernest; Stuart MacDonald (1982). Revolution in Miniature: The history and impact of semiconductor electronics, 2nd Ed. UK: Cambridge Univ. Press. pp. 11–12. ISBN 978-0-521-28903-0.*
- *Riordan, Michael; Lillian Hoddeson (1988). Crystal fire: the invention of the transistor and the birth of the information age. US: W. W. Norton & Company. pp. 19–21. ISBN 0-393-31851-6.*
- *Sarkar, Tapan K. (2006). History of wireless. US: John Wiley and Sons. p. 333. ISBN 0-471-71814-9.*
- Bose was first to use a crystal as a radio wave detector, using galena detectors to receive microwaves starting around 1894 and receiving a patent in 1904. *Emerson, D. T. (Dec 1997). "The work of Jagadish Chandra Bose: 100 years of mm wave research". IEEE Transactions on Microwave Theory and Techniques* ***45*** *(12): 2267–2273. Bibcode:1997ITMTT..45.2267E. doi:10.1109/22.643830. Retrieved 2010-01-19.*
- Sarkar (2006) *History of wireless*, p.94, 291-308
- *Douglas, Alan (April 1981). "The crystal detector". IEEE Spectrum (New York: Inst. of Electrical and Electronic Engineers): 64. Retrieved 2010-03-14.* on Stay Tuned website

- *Basalla, George (1988). The Evolution of Technology. UK: Cambridge University Press. p. 44. ISBN 0-521-29681-1.*
- crystal detectors were used in receivers in greater numbers than any other type of detector after about 1907. *Marriott, Robert H. (September 17, 1915). "United States Radio Development". Proc. of the Inst. of Radio Engineers (US: Institute of Radio Engineers)* **5** *(3): 184. doi:10.1109/jrproc.1917.217311. Retrieved 2010-01-19.*
- *Corbin, Alfred (2006). The Third Element: A Brief History of Electronics. AuthorHouse. pp. 44–45. ISBN 1-4208-9084-0.*
- *Kent, Herb; David Smallwood; Richard M. Daley (2009). The Cool Gent: The Nine Lives of Radio Legend Herb Kent. US: Chicago Review Press. pp. 13–14. ISBN 1-55652-774-8.*
- Jack Bryant (2009) Birmingham Crystal Radio Group, Birmingham, Alabama, US. Retrieved 2010-01-18.
- The Xtal Set Society midnightscience.com . Retrieved 2010-01-18.
- Darryl Boyd (2006) Stay Tuned Crystal Radio website . Retrieved 2010-01-18.
- Al Klase Crystal Radios, Klase's SkyWaves website . Retrieved 2010-01-18.
- Mike Tuggle (2003) Designing a DX crystal set Antique Wireless Association journal . Retrieved 2010-01-18.
- Rainer Steinfuehr (2009) Gollum´s Crystal Receiver World *Wumpus's Old Radio World* website, Berlin, Germany. Retrieved 2010-01-18.
- Elmer Memorial Crystal Radio DX Contest, sponsored by Birmingham Crystal Radio Group, Birmingham, Alabama, US. Retrieved 2010-01-18.
- Crystal Radio Building Contest, by The Xtal Set Society midnightscience.com . Retrieved 2010-01-18.
- *Williams, Lyle R. (2006). The New Radio Receiver Building Handbook. The Alternative Electronics Press. pp. 20–23. ISBN 978-1-84728-526-3.*
- *Lescarboura, Austin C. (1922). Radio for Everybody. New York: Scientific American Publishing Co. pp. 4, 110, 268.*
- Long distance transoceanic stations of the era used wavelengths of 10,000 to 20,000 meters, correstponding to frequencies of 15 to 30 kHz.*Morecroft, John H.; A. Pinto; Walter A. Curry (1921). Principles of Radio Communication. New York: John Wiley & Sons. p. 187.*
- In May 1901, Karl Ferdinand Braun of Strasbourg used psilomelane, a manganese oxide ore, as an R.F. detector: Ferdinand Braun (December 27, 1906) "Ein neuer Wellenanzeiger (Unipolar-Detektor)" (A new R.F. detector (one-way detector)), *Elektrotechnische Zeitschrift*, **27** (52) : 1199-1200. From page 1119:
  "Im Mai 1901 habe ich einige Versuche im Laboratorium gemacht und dabei gefunden, daß in der Tat ein Fernhörer, der in einen aus Psilomelan und Elementen bestehenden Kreis eingeschaltet war, deutliche und scharfe Laute gab, wenn dem Kreise schwache schnelle Schwingungen zugeführt wurden. Das Ergebnis wurde nachgeprüft, und zwar mit überraschend gutem Erfolg, an den Stationen für drahtlose Telegraphie, an welchen zu dieser Zeit auf den

Straßburger Forts von der Königlichen Preußischen Luftschiffer-Abteilung unter Leitung des Hauptmannes von Sigsfeld gearbeitet wurde."
(In May 1901, I did some experiments in the lab and thereby found that in fact an earphone, which was connected in a circuit consisting of psilomelane and batteries, produced clear and strong sounds when weak, rapid oscillations were introduced to the circuit. The result was verified -- and indeed with surprising success -- at the stations for wireless telegraphy, which, at this time, were operated at the Strasbourg forts by the Royal Prussian Airship-Department under the direction of Capt. von Sigsfeld.)
Braun also states that he had been researching the conductive properties of semiconductors since 1874. See: Braun, F. (1874) "Ueber die Stromleitung durch Schwefelmetalle" (On current conduction through metal sulfides), *Annalen der Physik und Chemie*, **153** (4) : 556-563. In these experiments, Braun applied a cat's whisker to various semiconducting crystals and observed that current flowed in only one direction.
Braun patented an R.F. detector in 1906. See: (Ferdinand Braun), "Wellenempfindliche Kontaktstelle" (R.F. sensitive contact), Deutsches Reichspatent DE 178,871, (filed: Feb. 18, 1906 ; issued: Oct. 22, 1906). Available on-line at: Foundation for German communication and related technologies.

- Other inventors who patented crystal R.F. detectors:

- In 1906, Henry Harrison Chase Dunwoody (1843-1933) of Washington, D.C., a retired general of the US Army's Signal Corps, received a patent for a carborundum R.F. detector. See: Dunwoody, Henry H. C. "Wireless-telegraph system," U. S. patent 837,616 (filed: March 23, 1906 ; issued: December 4, 1906).
- In 1907, Louis Winslow Austin received a patent for his R.F. detector consisting of tellurium and silicon. See: Louis W. Austin, "Receiver," US patent 846,081 (filed: Oct. 27, 1906 ; issued: March 5, 1907).
- In 1908, Wichi Torikata of the Imperial Japanese Electrotechnical Laboratory of the Ministry of Communications in Tokyo was granted Japanese patent 15,345 for the “Koseki” detector, consisting of crystals of zincite and bornite.

- Jagadis Chunder Bose, "Detector for electrical disturbances", US patent no. 755,840 (filed: September 30, 1901; issued: March 29, 1904).
- Greenleaf Whittier Pickard, "Means for receiving intelligence communicated by electric waves", US patent no. 836,531 (filed: August 30, 1906 ; issued: November 20, 1905).
- [1]
- [2]
- Bondi, Victor."American Decades:1930-1939"
- Peter Robin Morris, *A history of the world semiconductor industry*, IET, 1990, ISBN 0-86341-227-0, page 15
- http://earlyradiohistory.us/1924cry.htm

- In 1924, Losev's research was publicized in several French publications:

- *Radio Revue*, no. 28, p. 139 (1924)
- I. Podliasky (May 25, 1924) (Crystal detectors as oscillators), *Radio Électricité*, **5** : 196-197.
- Vinogradsky (September 1924) *L'Onde Electrique*

English-language publications noticed the French articles and also publicized Losev's work:

- Pocock (June 11, 1924)*The Wireless World and Radio Review*, **14** : 299-300.
- Victor Gabel (October 1 & 8, 1924) "The crystal as a generator and amplifier," *The Wireless World and Radio Review*, **15** : 2ff , 47ff.
- O. Lossev (October 1924) "Oscillating crystals," *The Wireless World and Radio Review*, **15** : 93-96.
- Round and Rust (August 19, 1925) *The Wireless World and Radio Review*, pp. 217-218.
- "The Crystodyne principle," *Radio News*, pages 294, 295, 431 (September 1924). See also the October 1924 issue of *Radio News*. (It was Hugo Gernsbach, publisher of *Radio News*, who coined the term "crystodyne".) This article is available on-line at: Radio Museum.org and E-Book Browse.

- *Purdie, Ian C. (2001). "Crystal Radio Set". electronics-tutorials.com. Ian Purdie. Retrieved 2009-12-05.*
- *Lescarboura, Austin C. (1922). Radio for Everybody. New York: Scientific American Publishing Co. pp. 93–94.*
- *Kuhn, Kenneth A. (Jan 6, 2008). "Introduction" (PDF). Crystal Radio Engineering. Prof. Kenneth Kuhn website, Univ. of Alabama. Retrieved 2009-12-07.*
- *Fette, Bruce A. (Dec 27, 2008). "RF Basics: Radio Propagation". RF Engineer Network. Retrieved 2010-01-18.*
- *Payor, Steve (June 1989). "Build a Matchbox Crystal Radio". Popular Electronics: 42. Retrieved 2010-05-28.* on Stay Tuned website
- *Lee, Thomas H. (2004). Planar Microwave Engineering: A practical guide to theory, measurement, and circuits. UK: Cambridge Univ. Press. pp. 297–304. ISBN 978-0-521-83526-8.*
- *Nave, C. Rod. "Threshold of hearing". HyperPhysics. Dept. of Physics, Georgia State University. Retrieved 2009-12-06.*
- Lescarboura, 1922, p. 144
- *Binns, Jack (November 1922). "Jack Binn's 10 commandments for the radio fan". Popular Science (New York: Modern Publishing Co.)* ***101*** *(5): 42–43. Retrieved 2010-01-18.*
- Marconi used carborundum detectors for a time around 1907 in his first commercial transatlantic wireless link between Newfoundland, Canada and Clifton, Ireland. *Beauchamp, Ken (2001). History of Telegraphy. Institution of Electrical Engineers. p. 191. ISBN 0852967926.*

- *Klase, Alan R. (1998). "Crystal Set Design 102". Skywaves. Alan Klase personal website. Retrieved 2010-02-07.*
- a list of circuits from the wireless era can be found in *Sleeper, Milton Blake (1922). Radio hook-ups: a reference and record book of circuits used for connecting wireless instruments. US: The Norman W. Henley publishing co. pp. 7–18.*
- *May, Walter J. (1954). The Boy's Book of Crystal Sets. London: Bernard's.* is a collection of 12 circuits
- *Purdie, Ian (1999). "A Basic Crystal Set". Ian Purdie's Amateur Radio Pages. personal website. Retrieved 2010-02-27.*
- *Kuhn, Kenneth (Dec 9, 2007). "Antenna and Ground System" (PDF). Crystal Radio Engineering. Kenneth Kuhn website, Univ. of Alabama. Retrieved 2009-12-07.*
- *Marx,, Harry J.; Adrian Van Muffling (1922). Radio Reception: A simple and complete explanation of the principles of radio telephony. US: G.P. Putnam's sons. pp. 130–131.*
- *Williams, Henry Smith (1922). Practical Radio. New York: Funk and Wagnalls. p. 58.*
- *Putnam, Robert (October 1922). "Make the aerial a good one". Tractor and Gas Engine Review (New York: Clarke Publishing Co.)* ***15*** *(10): 9. Retrieved 2010-01-18.*
- Lescarboura 1922, p.100
- *Collins, Archie Frederick (1922). The Radio Amateur's Hand Book. US: Forgotten Books. pp. 18–22. ISBN 1-60680-119-8.*
- Lescarboura, 1922, p. 102-104
- *Radio Communication Pamphlet No. 40: The Principles Underlying Radio Communication, 2nd Ed. United States Bureau of Standards. 1922. pp. 309–311.*
- *Hausmann, Erich; Goldsmith, Alfred Norton; Hazeltine, Louis Alan; et al. (1922). Radio Phone Receiving: A Practical Book for Everybody. D. Van Nostrand Company. pp. 44–45.* **Cite error: Invalid `<ref>` tag; name "Hausmann" defined multiple times with different content (see the help page).**
- *Hayt, William H.; Kemmerly, Jack E. (1971). Engineering Circuit Analysis, 2nd Ed. New York: McGraw-Hill. pp. 398–399. ISBN 978-0-07-027382-5.*
- *Kuhn, Kenneth A. (Jan 6, 2008). "Resonant Circuit" (PDF). Crystal Radio Engineering. Prof. Kenneth Kuhn website, Univ. of Alabama. Retrieved 2009-12-07.*
- *Clifford, Martin (July 1986). "The early days of radio". Radio Electronics: 61–64. Retrieved 2010-07-19.* on Stay Tuned website
- *Blanchard, T. A. (October 1962). "Vestpocket Crystal Radio". Radio-electronics: 196. Retrieved 2010-08-19.* on Crystal Radios and Plans, Stay Tuned website
- *The Principles Underlying Radio Communication, 2nd Ed., Radio pamphlet no. 40. US: Prepared by US National Bureau of Standards, United States Army Signal Corps. 1922. pp. 421–425.*
- Hausmann 1922, p. 57

- *Nahin, Paul J. (2001). The science of radio: with MATLAB and Electronics Workbench demonstrations. US: Springer. pp. 60–62. ISBN 0-387-95150-4.*
- Technical discussions of impedance matching in crystal radios can be found in Ben H. Tongue (2007) *Practical considerations, etc.*, Crystal Radio Set Systems: Design, Measurement, and Improvement; Ben Tongue personal website and Berthold Bosch (2002) *Crystal Set analysis*, Gollum's Crystal Receiver World
- *Smith, K. c. a.; R. E. Alley (1992). Electrical circuits: An introduction. UK: Cambridge University Press. p. 218. ISBN 0-521-37769-2.*
- *Alley, Charles L.; Kenneth W. Atwood (1973). Electronic Engineering, 3rd Ed. New York: John Wiley & Sons. p. 269. ISBN 0-471-02450-3.*
- *Tongue, Ben H. (2007-11-06). "Practical considerations, helpful definitions of terms and useful explanations of some concepts used in this site". Crystal Radio Set Systems: Design, Measurement, and Improvement. Ben Tongue personal website. Retrieved 2010-02-07.*
- *Bucher, Elmer Eustace (1921). Practical Wireless Telegraphy: A complete text book for students of radio communication, Revised Ed. New York: Wireless Press, Inc. p. 133.*
- Marx & Van Muffling (1922) *Radio Reception*, p.94
- *Stanley, Rupert (1919). Textbook on Wireless Telegraphy, Vol. 1. London: Longman's Green & Co. pp. 280–281.*
- *Collins, Archie Frederick (1922). The Radio Amateur's Hand Book. US: Forgotten Books. pp. 23–25. ISBN 1-60680-119-8.*
- *Wenzel, Charles (1995). "Simple crystal radio". Crystal radio circuits. techlib.com. Retrieved 2009-12-07.* External link in `|publisher=` (help)
- *Hogan, John V. L. (October 1922). "The Selective Double-Circuit Receiver". Radio Broadcast (New York: Doubleday Page & Co.)* ***1*** *(6): 480–483. Retrieved 2010-02-10.*
- Alley & Atwood (1973) *Electronic Engineering*, p. 318
- Marx & Van Muffling (1922) *Radio Reception*, p.96-101
- *US Signal Corps (October 1916). Radiotelegraphy. US: Government Printing Office. p. 70.*
- Marx & Van Muffling (1922) *Radio Reception*, p.43, fig.22
- *Campbell, John W. (October 1944). "Radio Detectors and How They Work". Popular Science (New York: Popular Science Publishing Co.)* ***145*** *(4): 206–209. Retrieved 2010-03-06.*
- *Harte, Bernard (2002). When Radio Was the Cat's Whiskers. Rosanberg. pp. 149–150. ISBN 1-877058-08-4.*
- *Lee, Thomas H. (2004). The Design of CMOS Radio-Frequency Integrated Circuits. UK: Cambridge University Press. pp. 4–6. ISBN 0-521-83539-9.*
- Stanley (1919) *Text-book on Wireless Telegraphy*, p.282
- Hausmann (1922), p.60-61
- Lescarboura (1922), p.143-146
- Stanley (1919), p. 311-318

- *Gernsback, Hugo (September 1944). "Foxhole emergency radios". Radio-Craft (New York: Radcraft Publications) **16** (1): 730. Retrieved 2010-03-14.* on Crystal Plans and Circuits, Stay Tuned website
- *Douglas, Alan (April 1981). "The Crystal Detector". IEEE Spectrum (Inst. of Electrical and Electronic Engineers) **18** (4): 64–65. doi:10.1109/mspec.1981.6369482. Retrieved 2010-03-28.*
- *Kuhn, Kenneth A. (Jan 6, 2008). "Diode Detectors" (PDF). Crystal Radio Engineering. Prof. Kenneth Kuhn website, Univ. of Alabama. Retrieved 2009-12-07.*
- *Hadgraft, Peter. "The Crystal Set 5/6". The Crystal Corner. Kev's Vintage Radio and Hi-Fi page. Retrieved 2010-05-28.*
- *Kleijer, Dick. "Diodes". crystal-radio.eu. Retrieved 2010-05-27.*
- *The Principles Underlying Radio Communication* (1922), p.439-440
- *Bucher, Elmer Eustace (1921). Practical Wireless Telegraphy: A complete text book for students of radio communication, Revised Ed. New York: Wireless Press, Inc. pp. 134–135.*
- Field 2003, p.93-94
- Lescarboura (1922), p.285
- Collins (1922), p. 27-28
- Williams (1922), p. 79
- *The Principles Underlying Radio Communication* (1922), p. 441
- *Payor, Steve (June 1989). "Build a Matchbox Crystal Radio". Popular Electronics: 45. Retrieved 2010-05-28.*
- Field (2003), p. 94
- Walter B. Ford, "High Power Crystal Set", August 1960, *Popular Electronics*
- *Polyakov, V. T. (2001). "3.3.2 Питание полем мощных станций". [Receiving techniques. Simple receivers for AM signals] (in Russian). Moscow. p. 256. ISBN 5-94074-056-1.*
- Radio-Electronics, 1966, №2

104. QST [Amateur Radio Magazine] January 2007, "High Sensitivity Crystal Set" <http://www.arrl.org/files/file/Technology/tis/info/pdf/culter.pdf>

Further reading

- Ellery W. Stone (1919). Elements of Radiotelegraphy. D. Van Nostrand company. 267 pages.
- Elmer Eustice Bucher (1920). The Wireless Experimenter's Manual: Incorporating how to Conduct a Radio Club.
- Milton Blake Sleeper (1922). Radio Hook-ups: A Reference and Record Book of Circuits Used for Connecting Wireless Instruments. The Norman W. Henley publishing co.; 67 pages.
- JL Preston and HA Wheeler (1922) "Construction and operation of a simple homemade radio receiving outfit", Bu. of Standards, C-120: Apr. 24, 1922.
- PA Kinzie (1996). Crystal Radio: History, Fundamentals, and Design. Xtal Set Society.

- Ian L. Sanders. Tickling the Crystal — Domestic British Crystal Sets of the 1920s; Volumes 1-5. BVWS Books (2000–2010).

External links

Wikimedia Commons has media related to ***Crystal radios***.

Wikisource has original text related to this article:
An Interview with the Inventor of the Crystaloi Detector

- *A website with lots of information on early radio and crystal sets*
- *Hobbydyne Crystal Radios* History and Technical Information on Crystal Radios
- *Ben Tongue's Technical Talk* Section 1 links to "Crystal Radio Set Systems: Design, Measurements and Improvement".
- "*Semiconductor archeology or tribute to unknown precusors*". earthlink.net/~lenyr.
- Nyle Steiner K7NS, Zinc Negative Resistance RF Amplifier for Crystal Sets and Regenerative Receivers Uses No Tubes or Transistors. November 20, 2002.
- Crystal Set DX? Roger Lapthorn G3XBM
- Details of crystals used in crystal sets

- Thomas H. Lee, The Design of CMOS Radio-Frequency Integrated Circuits
- Derek K. Shaeffer and Thomas H. Lee, The Design and Implementation of Low-Power CMOS Radio Receivers