CRYSTAL SETS TO SIDEBAND

A guide to building your own amateur radio station

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Chapter 1

THE FASCINATION OF RADIO

Radio produces action at immense distances with no physical connection that can be perceived by our senses. A modern way to demystify radio is to say that radio is simply a kind of light that our eyes cannot see. To those of us addicted to shortwave radio, it's an adventurous realm that can be explored. When we listen to our radio receivers it is comparable to using the Hubble telescope to explore the heavens. Shortwave is fascinating because you can't predict what you are going to hear. You might hear a radio broadcast from an exotic foreign capitol. You might pick up an SOS from a ship sinking in a storm or maybe weather reports from a radio amateur on Pitcairn Island. The next evening the same frequency band might be completely empty except for two hams on the other side of your own town discussing the Super Bowl. Or you might receive coded messages intended for some undercover spy lurking in our country.

I'm not kidding. I routinely hear such coded messages consisting of groups of letters on the 10.1 and 28.1 MHz ham bands. The codes are usually sent in Morse code, but sometimes you will hear a voice reciting the letter groups. Sometimes the woman announcer finishes by saying, "Thank you for decoding this message!" Since hams are forbidden to use codes or modulation modes that are not easily decoded, these communications are at least illegal.

Yes, it's true that shortwave isn't as vital to world activities as it once was, but if there's any romance in your soul, shortwave is still entrancing and always will be. This book is about using amateur radio to recapture the adventure of early day radio and bring it into the present. It is also about learning electronics and radio technology. If you can get through this book, shortwave radio will still be fascinating, but no longer mysterious.

Admiral Byrd at the South Pole

I first became intrigued by shortwave when I read Admiral Byrd's book on his last expedition to the Antarctic. Admiral Richard Byrd was in the business of launching expeditions to explore the Earth's poles. These expeditions had no inherent commercial value except for book sales and sponsoring grants from companies hoping to gain visibility for their products. In order for Byrd to get those grants, the public had to be sufficiently interested in the expeditions to generate advertising value. With each polar expedition, finding new expedition goals that would be exciting to the public became increasingly difficult. Studying rocks, glaciers, and penguins was scientifically important, but not particularly interesting to the public. By the 1940's all the neat stuff, like walking to the North and South Poles had been done decades before.

On his last expedition to Antarctica, Byrd established a base on the Antarctic coast like all previous large expeditions. However, he succeeded in maintaining public interest by setting up a tiny second outpost on the polar icecap hundreds of miles south of the coast. Then he attempted to spend the Antarctic winter alone in his little under-snow cabin totally isolated from the world in the cold and dark. His one connection with his base camp at “Little America” and the outside world was Morse code radio contact. Other than producing some interesting weather reports, the outpost had little real value. However, it did attract attention. Who could help but be captivated by the ordeal of a man totally isolated, hundreds of miles from the nearest humans? It was like being marooned on the moon, utterly alone.

Byrd’s messages were relayed from his big base back out to the rest of the world. As a boy I was fascinated by Byrd’s lonely vigil. I imagined what it would be like to be shut off from the world for months on end. I pictured Byrd bundled up in a fur parka huddled over his little table sending and receiving Morse code. His connection with the world was reduced to musical notes barely audible above the soft purring static of the polar night. The Morse tones came into his headphones and he wrote down their meaning, one letter at a time. The decoded messages appeared on his pad, one word at time. He fumbled with his pencil. “Was that a ‘C’ or a ‘K?’” he asked himself. He pushed his indecision aside and kept writing down new letters. Fretting about one letter can destroy the whole sentence. A radiotelegraph operator learns to focus on the stream of characters and not dwell on each one.

After a few weeks in his frozen prison, Byrd began to suffer from headaches, nausea, weakness, and confusion. His Morse code became harder and harder to read and his team back at Little America became greatly concerned. Unknown to Byrd, his cabin heater was leaking carbon monoxide and was slowly killing him. Finally, when Byrd’s condition became desperate, his crew drove hundreds of miles over the ice cap through winter darkness, howling wind, and below zero temperatures to rescue him.

Growing up at the end of the Morse code age

As late as 1960, Morse code was still commonly used commercially and by the military. Since Morse code had an exotic sound, news broadcasts were routinely introduced by snippets of code. When the word “NEWS” is spelled out in Morse and repeated rapidly, it makes a pleasant, rhythmic, musical phrase that blends in well with Hollywood-style introduction music. The public often assumed that messages from the other side of the world arrived by Morse code, although in reality its importance had been fading since the 1930s.

The Morse code used for radio communications in the English language

The “dashes” are three times longer in duration than the “dots.”

A ._	**G** _ _ .	**M** _ _	**S** . . .	**Y** _ . _ _
B _ . . .	**H**	**N** _ .	**T** _	**Z** _ _ . .
C _ . _ .	**I** . .	**O** _ _ _	**U** . . _	
D _ . .	**J** . _ _ _	**P** . _ _ .	**V** . . . _	

E .	**K _ . _**	**Q _ _ . _**	**W . _ _**
F . . _ .	**L . _ . .**	**R . _ .**	**X _ .. _**

Numbers and Commonly Used Punctuation

1 . _ _ _ _	**3 . . . _ _**	**5 . . . . .**	**7 _ _ . . .**	**9 _ _ _ _ .**
2 . . _ _ _	**4 . . . . _**	**6 _ . . . .**	**8 _ _ _ . .**	
Ø(zero) _ _ _ _ _	**(, comma) _ _ . . _ _**	**(. Period) . _ . _ . _**	**(/ slash) _ . . _ .**	

When I was a kid in New Jersey, my closest friend was Garth McKenzie. My introduction to ham radio was through his dad, Alexander ("Mac") McKenzie. Mac's call letters were W2SOU and his radio station was crammed into an alcove off the dining room. In the 1940s, quality radio equipment was packaged behind somber black aluminum panels 22 inches wide, eight inches high, and mounted in tall racks. The controls were enigmatic black knobs with strange labels like "grid drive" and "loading." The displays were usually just meters with equally arcane titles such as "S-meter" and "plate current."

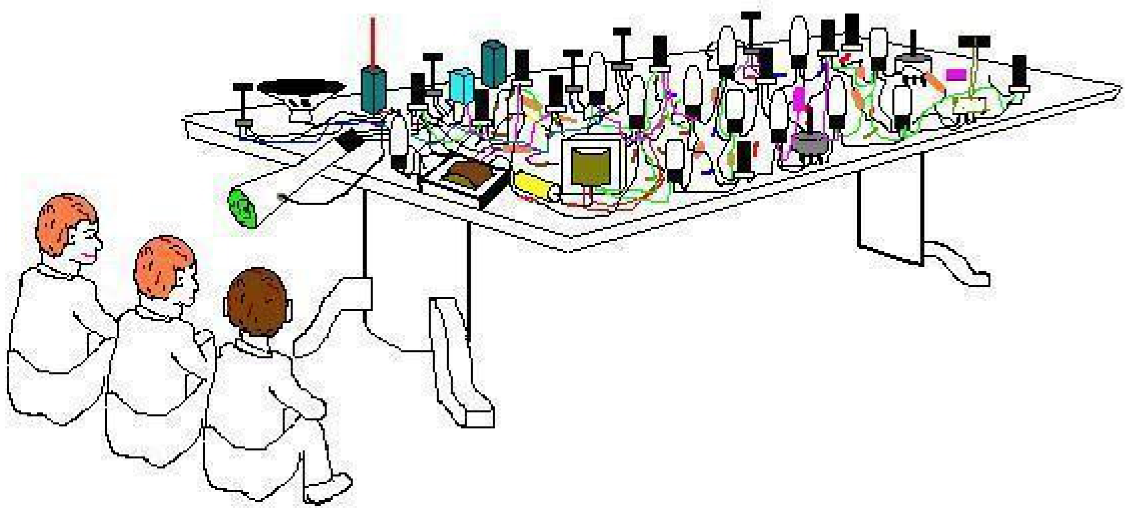
The McKenzies had a cabin up in New Hampshire. Mrs. McKenzie and the kids spent most of every summer up at the cabin. Mac went up to New Hampshire on weekends when he could, but most of the time he stayed in touch with his family by radio. A friend of Garth's dad, Mr. Henny, lived near the McKenzies' cabin. He was also a ham, so on Saturday mornings Mac had a regular schedule to talk with Mr. Henny using Morse code, or CW (continuous wave) as it is still known. I was intrigued when I heard about these scheduled contacts and wanted to see Mac operate his station. I arrived at the McKenzie house at the appointed time. Sure enough, right on schedule, Morse code appeared out of the static. Mac wrote down the letters on a pad. I watched over his shoulder and stared at his pencil tip. It was mesmerizing to hear the code and watch the words and sentences appear on the paper. Unfortunately I couldn't understand even one letter of what Mac was sending, so I quickly tired of the one-sided conversation. In spite of that, Morse code had a mysterious, other-world quality and I was hooked.

Among the other equipment in Mac's radio shack was a Loran set. Loran was a long-range direction finder, the 1950 version of today's global positioning system (GPS). Mac demonstrated for me how to find latitude and longitude using a tiny green oscilloscope screen. The little round screen was only 2 or 3 inches wide and peered out from another one of those black, 22-inch wide black rack panels. Mac had it set up just for fun, of course. The Loran was designed for use on a ship and the McKenzie's house certainly wasn't going anywhere. Other toys included a pair of war surplus teletype machines. He could type on one machine and the other would print out his message 5 feet away.

The joy of building it yourself

It was hard for an eight year old like me to imagine getting a ham license and affording all that massive equipment. The Loran was quite alien to me and the teletype machines were interesting, but seemed like clumsy typewriters. What turned me on was Mac's television set. In the late 1940s, television stations were on the air, but no one I knew other than Mac actually owned a TV. That wasn't surprising. TVs cost as much as an automobile. Talk about a luxury! Undaunted, Mac built his own television from old radio parts and an army surplus, five-inch diameter, green oscilloscope tube.

A real, white phosphor, (black and white) TV cathode ray tube cost a fortune back then, so Mac couldn't even afford the picture tube. And because the TV tubes were designed for magnetic deflection and the oscilloscope tube used electric deflection, Mac couldn't just copy the deflection circuits from an RCA TV. Instead, he had to design his own custom picture tube drive and sweep circuits. Perfecting a new circuit meant that it had to be built and tested one small piece at a time. Since Mac had little idea how large the final circuit would be, he couldn't assemble his TV in a cabinet right away. Instead, he built his TV as a giant "breadboard" circuit with all the glowing tubes, wires, resistors, transformers, capacitors, and components all laid out in a huge spider-web matrix.



A TV is extremely complicated and a large breadboard was needed. Fortunately Barbara McKenzie was a tolerant woman. For several months the dining room table, including the extension leaves, was completely covered with about four by eight feet of television circuitry. Then Mac moved it upstairs into the master bedroom - probably not much of an improvement from Barbara's perspective. Toward the end of the year the TV began to work. We kids used to come home from school and sit on the floor and watch programs on the tiny five-inch round picture tube dangling off the end of the table. The pictures were in living "black and green." We watched "Zoo parade" with Marlin Perkins and our favorite program, "Flash Gordon," an early Star Trek–like show. TV was different back then. Flash Gordon was 15 minute film clips but most other programs were live. Even the commercials were live. I remember laughing silly over a commercial for a vacuum cleaner in which the fellow plugged the hose into the wrong end of the cleaner. The machine blew dust all over the room while the announcer tried to pretend it was working perfectly.

Eventually Mac installed his TV in an old record player cabinet. To make the picture larger, he put a big magnifying lens in front of the screen. When he watched TV, he propped up the hinged lid of the cabinet at a 45 degree angle and watched the enlarged picture in a mirror mounted on the underside of the lid. Mac showed me that, with patience, you can build almost anything. And, in the long run, it's usually much more rewarding to build a possession rather than to buy it. He also taught me that projects must be built and tested one tiny part at a time. ***If you build it all at once without testing the parts as you go, it might fit in the cabinet, but it almost certainly won't work***. There are very few short cuts.

The complete radio amateur

This book is about building ham radio equipment. To be sure, it's much, much easier to buy the equipment. In fact, commercial ham equipment today is so cheap, that buying it is far less expensive than buying the parts one at a time. The good news is that equipment you build yourself will have a value and meaning for you that can't be purchased. Along the way you'll learn more about electricity than you will ever learn reading the operator's manual of commercial equipment. Most of us will never be an Edison, Marconi, or Armstrong, but we can learn what they knew and we can share some of the thrill they felt when their inventions began to work. When your homemade station is finally on the air, you'll have all the same fun the other hams are having. But unlike the rest of the herd, you will be "***The Complete Radio Amateur."***

A brief history of radio communication

Radio is based on phenomena that have been known since ancient times, namely static electricity and magnets. These phenomena also produce action at a distance with no visible connection, but only over extremely short distances. In 600 BC the philosopher Thales of Melitus described how, after rubbing amber with cloth, the amber could attract bits of straw. At about the same time the Greeks observed that natural magnetite ore (iron oxide, Fe_3O_4) could attract other bits of magnetite rock. This strange rock was found in a region of Turkey then known as "Magnesia," hence the name. Knowledge of natural magnets eventually led to the discovery of the magnetic compass. Compasses were a Godsend to sailors lost in fog and must have seemed magical to those who first used them. The compass was in wide use in Europe by 1000 AD.

Magnets and electricity appeared to be separate phenomena until 1820 when Hans Christian Oersted noticed that an electric current in a wire generates a magnetic field that can move a compass needle. Faraday and Henry studied and quantified the generation of magnetic fields produced by coils of wire that we now call called "inductors." In one of the all-time greatest triumphs of theoretical physics, James Maxwell published four equations in 1884 that summarized the connection between magnetism and electrical force. Maxwell's equations not only quantified and connected what was already known about these forces, they also predicted that magnetism and electric force could be combined to form a free-flying radiation. From the equations it appeared that these radio waves should be able to propagate great distances through space, much like light and heat. He may or may not have known that light and infra-red heat are also forms of electromagnetic radiation - radio!

What exactly is a radio wave?

An electric field and a magnetic field can both temporarily store energy in free space. For example, a refrigerator magnet generates a magnetic field in the space surrounding it. This magnetic energy hovers in "cloud" or "field" surrounding the metal magnet. Similarly, electric field energy is present in the space between the terminals of an ordinary flashlight battery. Suppose that magnets and charged batteries were sent into outer space and turned loose to float in the void. These devices would still generate their magnetic and electric fields in the vacuum surrounding the devices. However, if the devices could suddenly disappear, the magnetic and electric fields would not be maintained. The fields would quickly collapse and the energy would dissipate in all directions at the speed of light.

A battery or a magnet can be compared to a glass of water on a table. The glass holds the water in place and the water will rest there indefinitely. But if the glass were to suddenly break or vanish, the water would flood out in all directions. If either a magnet or battery floating in free space could be made to suddenly disappear, it would generate a radio wave that would propagate outward in all directions making a spherical shell of expanding waves. It turns out that ***collapsing magnetic field energy in free space is converted into electric field energy.*** Then, ***a moment later, the electric field energy similarly collapses back into a magnetic field.***

One way to look at it is that the collapsing magnetic field forces the storage of that same energy as an electric field in neighboring space. In other words, a collapsing field becomes a "device" that establishes the opposite kind of field in adjacent space. The end result is a wavefront of energy propagating across the void. As it travels, the energy oscillates back and forth in its form between electric and magnet fields. In the vacuum of space there is no dissipation of the original energy except that the energy becomes more dilute as it spreads out in all directions like ripples from a stone thrown into a pond.

The water analogy has other similarities with radio waves. The crests of the ripples on the pond represent the storage of mechanical energy as ***potential energy***. The potential energy is proportional to the height of the ripples or waves. The higher the wave, the more energy it stores. As the water falls back down, the energy from this descent is converted into ***kinetic energy***, that is, the outward velocity. As the wave spreads outward, the water stacks up to form another wave crest, restoring the energy to its potential energy form.

In 1887 Heinrich Hertz, a professor at the University of Bonn, Germany, managed to demonstrate in his laboratory that Maxwell's radio waves actually existed. From then on other experimenters built "Hertzian apparatus" and tried to use it for communication or remote control. Experiments much like the ones Hertz performed are described in Chapter 4. Using rocks, copper wire, iron, and other materials available in 1880, you can build a short-range communicator to send and receive radio waves from one end of your house to the other. You can even demonstrate "standing waves" on an antenna.

How inventions happen

Big inventions usually begin with a novel observation. Faraday first invented the AC transformer with independent coils. An alternating current (AC) introduced into one coil on the transformer causes a second current to appear in a tightly coupled similar coil a fraction of an inch away. Today we still routinely use transformers to convert the ratio of current to voltage. For example, inside your flashlight battery charger, there is a transformer that converts a tiny current at 120 volts AC into a large current at 1.5 volts AC. If you applied 120 volts directly to your battery, it could be disastrous. Chargers would be quite impractical (or at least horribly inefficient) without transformers. We shall discuss these principles in detail in later chapters.

Getting back to Faraday, he must have marveled when he thought about the implications of electrical energy fed into one coil appearing in a neighboring coil. That is, the energy was "transmitted" across a gap. Yes, the gap may have only been a fraction of an inch, but certainly the thought must have occurred to him, "how far can it transmit?" In a letter in 1832 he proposed to a friend that electric energy could probably travel through space as waves. Unfortunately, he had no evidence, experiments, or equations to support this idea.

Many early radio communication experiments began when the first high frequency transformers were made. Unlike low frequency, like our 60 Hz line current, high frequency transformers of 500 KHz and above readily couple energy several inches through air. High frequency currents couple from one coil to another and begin to resemble radio.

It's surprisingly easy to build a high frequency transformer and demonstrate crude, short-range radio communications. All that's needed is a powerful battery, a large coil of wire, and a second coil wrapped around the first coil. The second coil is arranged so that the two ends of the wire are fixed a tiny distance apart, perhaps a sixteenth of an inch. The two ends of the first coil of wire are scratched transiently across the terminals of the battery. Huge currents flow in the first coil and establish a magnetic field around that coil. Since the same space is shared with the second coil, the magnetic field induces voltage across the second coil and a spark appears in the gap on the second coil. In other words, electric current was converted into magnetic energy, jumped across a short distance and then was reconverted back into electrical current. Now if the two coils are moved far apart, there will continue to be energy transmitted from one coil to other. However, with such a crude detection system, a spark probably won't be visible and a much more sensitive detector would be needed to prove that energy was actually transmitted.

Inventions appear when all the conditions are in place

New technologies appear whenever the necessary knowledge and affordable raw materials become available. For example, cell phones could have been built 50 years ago, but they would have been the size of suitcases, served few people and would have only been available to the most wealthy. Even today it's possible to introduce useful technology too early to be profitable. The Iridium phone system is a world-wide direct satellite telephone system. Unfortunately, the Iridium "phone" is big and clumsy and the phone calls cost a fortune. Sure, you can reliably talk to a guy on dog sled at the North Pole, but there aren't many people who actually need to do that. As of 2008 the Iridium satellites were still working, but five years ago there was talk of Iridium going bankrupt and crashing the satellites into the Pacific Ocean.

Radio was invented between the years 1884 and 1910 at a time when all the pieces to make it practical were in place. Many inventors had the chance to pursue radio communication, but most turned it down. To be more than a parlor trick, radio had to have a commercial reason for its development. The concept of broadcasting voices, music, and even motion pictures to the masses seems obvious to us now. But in 1900 it wasn't obvious that radio could be more than an unreliable way to send telegrams. Hardly anyone back then imagined that speech and music might be transmitted.

Nicola Tesla, the archetype "mad scientist"

Nicola Tesla was born in Smiljan near Gospic in Croatia in 1856. In college he studied what was then the exotic field of electrical engineering. He once proposed to his professor that an AC generator could be built that would be simpler than DC power generation and which would have several other advantages. The professor ridiculed his idea mercilessly. Today we call these "alternators." We use gigantic alternators to generate electricity in all large power plants. And we use little ones in our cars to recharge our batteries. When his father died, Nicola was forced to leave school and go to work. Like most electrical engineers of his time, he worked on DC motors and DC generators. At that time the DC motor was beginning to replace the belt and pulley as a means of powering industrial machinery such as looms and mine hoists.

Tesla migrated to America and arrived almost penniless. He even worked briefly as a ditch digger in order to eat. He applied for work with Edison who tested his skills by assigning him to fix a DC generator on a ship. Tesla rebuilt the generator right on the ship and made it produce more electricity than its original design. Tesla worked briefly for Edison, then he struck out on his own. He built his own small laboratory and worked on gadgets of all sorts. He soon acquired a reputation as a "science wizard." He enjoyed putting on "magic shows" with giant sparks flying off his fingers and whirling fluorescent light bulbs. His reputation as a science magician encouraged him to put show business into everything he did. After reading his biography, it appears to me that his ability to gain awe and respect through showmanship eventually ruined his career. (1)

As money ran short, Tesla got a job with the Westinghouse Company and developed the alternator into a practical power generator. Tesla's greatest contribution to the world was the power generation and distribution system which he demonstrated at a brand new power plant at Niagara Falls, New York. He invented the three phase AC alternators, transformers, and high-tension power lines that are still in use world-wide. After Tesla left Westinghouse, he set up his own laboratory in New York City to experiment with uses for radio frequency current.

The missed opportunity

Ship owners have probably always wished they could communicate with ships at sea. Until the late 19th century the fate of a ship might be totally unknown for months or even a year. When the ship finally sailed into homeport, the owner might suddenly learn that he was extremely wealthy. Or the ship might never return and the owner would have lost a huge investment. Being able to communicate a few hundred miles or even a dozen miles out to sea might be life saving in an emergency.

By 1900 scientists knew that "wireless telegraph" could communicate across the English Channel using giant transmitters and antennas, but no one had been able to transmit a message much farther than that. At that time J.P. Morgan was a financier and banker and one of the richest men in the world. Among his empire of enterprises he owned a fleet of ships. If a practical long-range telegraph could be developed, he wanted it on his ships. Marconi already had a good start on a ship-to-shore radio and had already demonstrated short-range ship-to-shore communication, both in England and America. In spite of that lead, Morgan approached Tesla who certainly had the knowledge and experience to develop practical radio communications. J.P. Morgan gave Tesla a big financial grant to do this work. Tesla set up a laboratory in Colorado Springs to invent long distance radio, or so he allowed Morgan to believe.

Unfortunately, merely talking to ships was boring to Tesla. Tesla wanted to develop what he called "The World Telegraphy Center." Tesla planned to set up a communications center that could not only talk to ships, but also to everyone else on earth. His vision of what he was trying to build sounds to modern ears like a one-way Internet or perhaps CNN. He doesn't seem to have thought about the difficulties of handling all the messages in the world through one single gigantic low frequency transmitter. Back then, there were no Internet servers to organize all that message traffic into digital streams of information. Considering the operating frequency of his transmitters, his data rate would have been limited to a few kilobytes per second rather than the terabytes handled today by a single node on the Internet.

Tesla's radio transmitters were certainly adequate for transoceanic communication. But instead of also developing a sensitive radio receiver, Tesla spent nearly all his effort developing ever larger low frequency radio transmitters. His transmitters were so powerful, he experimented with transmitting electric power as well as information. Tesla proposed using tuned coils to energize fluorescent light bulbs miles away from his transmitter. Yes, his idea worked, but only at an extremely low efficiency. Yes, the lights glowed just as he said, but damp soil, cows, people, barbed wire fences, and every other electric conductor within range would be heated with wasted energy, just like a microwave oven.

Tesla built an enormous "Tesla coil" that produced radio frequency sparks 60 feet long. Always the showman, Tesla liked to be photographed sitting among the sparks and fire, while calmly reading a book. Actually, he used double exposures to create the illusion of sitting among the sparks. Tesla's machine was so huge and had such unique capability that the U.S. Air Force built a copy of it 80 years later for research.

With all this dramatic futuristic activity, Tesla never got around to building the dinky ship-to-shore radio that Morgan was paying him to develop. When he gave Morgan a progress report, Tesla tried to sell Morgan on his futuristic schemes. Morgan was furious at him for not sticking to the assignment and had little interest in any of Tesla's ideas. Morgan did however force Tesla to assign him the ownership of any useful patents that might arise out of the work. Morgan was not known for generosity.

After Morgan gave Tesla a tongue lashing, he also gave him a second chance. But instead of getting serious about ship-to-shore communication, Tesla blew the money on building his "World Telegraphy Center" out at Wardenclyff, Long Island, New York. It was an imposing building with a huge tower housing the Tesla coil transmitter. The communications center came to nothing and Morgan stopped the funds. Thereafter Tesla lived at the Waldorf Astoria Hotel in New York City and became a sort of self-absorbed lounge lizard. He dressed in a Tuxedo and top hat and mooched off his friends.

In the following decades Tesla dabbled in inventing and came up with several interesting devices that were almost good enough to become standard technology. For example, he designed a "bladeless turbine" heat engine, the functional equivalent of a steam engine or the internal combustion engine. There are few successful heat engine designs that are fundamentally different, so inventing a new one was an intellectual triumph. Unfortunately, Tesla's heat engine was not as efficient as other methods and, so far, there have been no good uses for it. He also developed a speedometer gauge that was excellent and was used in several luxury cars. Converting the speed of a rotating shaft into smooth, linear needle movement is much harder than it looks. Unfortunately Tesla's method was more expensive than the meter design that eventually became universally used for that purpose.

Tesla ended up as a lonely old man feeding pigeons in a third rate hotel in New York.

After he died in 1943, it turned out that he had paid his rent for several months by giving the hotel manager a "death ray" to hold as collateral. Tesla told the manager the death ray was worth $10,000. The ray gun was actually a Wheatstone bridge, a sensitive resistance-measuring device commonly found in electrical labs.

Marconi gets the job done

Guglielmo Marconi was born into a prosperous family in Bologna, Italy on April 25, 1874. He was educated in Bologna then later in Florence. He studied physics at Leghorn College. He was fascinated by Hertz's discovery of radio waves and he became interested in wireless telegraphy in 1890. Starting in 1894, Marconi worked at home building prototypes in his basement.

Today most of us think of a radio receiver as a kind of amplified stethoscope that lets us listen in on the hidden world of the radio spectrum. In Marconi's time the main precedent for radio was telegraphy. This concept of one telegraph operator banging out telegrams to another operator using Morse code dominated Marconi's vision of what he was trying to build. In conventional telegraphy the signal over the wire triggered a "sounder" which was a kind of electro-magnetic relay. The sounder made clickity-clack noises that the receiving operator interpreted as dots and dashes.

Similarly, Marconi's first radio transmission to another room in the house rang a bell when the signal was detected. There were no headphones that a person listened to. Most early experimenters built radios that resembled radio control systems rather than listening devices. As the technology developed, the radio operator gradually became a vital part of the system. The operator's skill and trained ears became responsible for most of the range and practicality of the system. A trained operator can hear Morse code signals that are no stronger than the atmospheric static. Unlike a simple bell system, an operator can copy one Morse code signal while ignoring another. It took a hundred years for computerized digital signal processing to exceed the ability of a trained radio operator and return to Marconi's vision of a robotic receiver.

Radio detectors – An early challenge

The most popular early radio detector, the "***coherer***," was invented by the English physicist Lodge. Coherers were first used with long distance wire telegraph lines. They greatly extended the practical range of a telegraph wire and it was natural that they would be applied to the earliest radio experiments.

A coherer was a small glass vial containing loose powdered carbon or iron filings. This powder contacted two electrodes in the vial. When a small voltage appeared across the powder, it would break down the contact resistance between the powder granules and cause the resistance of the coherer to suddenly drop. The decrease in resistance was used to cause current to flow through the sounder relay. Coherers were often built onto the frame of a sounder so that the vibration of the sounder would keep the powder loose, thereby continually resetting the coherer to its original state.

The set - reset action of a coherer resembles a modern silicon controlled rectifier. A small input current causes a much bigger current to flow. Unfortunately, just like a silicon-controlled rectifier, the current through the coherer doesn't shut off by itself when the input is turned off. Because coherers turned on and off at rates below 20 cycles per second, the output from a coherer wasn't an audio signal that someone could listen to directly.

At first Marconi’s receiver sat on the table next to the transmitter. Then he was able to transmit across the room and then to other rooms in the house. As his range increased, he moved his operation into an unused granary behind his parents’ house where he could string up antennas. His next triumph was a transmission from the granary to the end of the garden, 100 meters away. During these years the existence of radio was widely known to scientists, but it was believed that radio waves were inherently line-of-sight, much like a signal lantern. Marconi had already observed that he was able to transmit to the receiver when it was behind walls and trees. Since he already knew the experts were wrong, he worked on the big question of whether radio waves could travel over mountains and perhaps over the horizon.

About this time Marconi must have graduated from coherers to some kind of rectifier detector. This detector produced an audio output that an operator could listen to directly with earphones. The earphone was already in use as a component in Alexander Graham Bell's telephone. The earliest rectifiers consisted of “crystals” which consisted of a piece of wire pressed against a crystalline chunk of sulfide ore. Crystal detectors are described in detail in chapter 4.

Marconi had a servant named Mignani. To test his receiver over distances, Mignani manned the receiver while Marconi sent test signals. One of Marconi’s breakthrough improvements was a directional antenna that focused his weak transmitter output directly toward the feeble receiver and thereby extended the range. Radio stopped being a toy the day that Marconi transmitted a test signal two miles over a hill. Mignani signaled back to Marconi that he had received the Morse code letter “S,” by firing a rifle into the air from the hilltop.

Radio reaches across the Atlantic

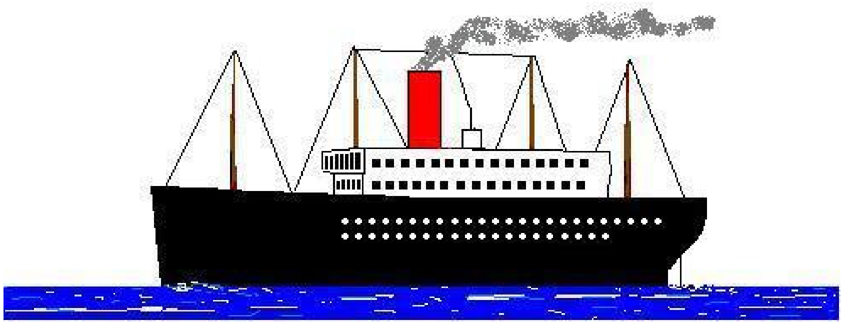
Following the success of his experiments at home, Marconi became obsessed with the possibility of transmitting a signal across the Atlantic. If he could do that, radio communication could cover the world. There was essentially no interest in radio in Italy. He was even unable to get a patent for his device. An Italian government minister told him that radiotelegraphy “was not suitable for communications.” Marconi moved to England where he patented his method of transmitting signals in 1895. In 1897 he was financed by the British Post Office to continue his experiments. Gradually the range of his transmissions was extended to 8, 15, 30, and 100 kilometers. In 1897 he founded the Marconi Wireless Telegraph Company, Ltd. in London. In 1899 he established a communications service across the English Channel.

Marconi built a huge transmitter, 100 times more powerful than any earlier transmitter, and set it up at Plodu, Cornwall in South-west England. One approach to building very large transmitters was to construct large, high-speed AC alternators. These resembled Tesla’s power generation alternators but ran at such high speeds that they produced a sinewave, not at 60 cycles per second like a modern power plant, but at low radio frequencies, 20,000 cycles per second. Marconi also built a complementary station at St. Johns, Newfoundland and on December 12, 1901, he received the first signals from across the ocean. Actually, modern analysis of the propagation conditions of that first communication suggests that the guys listening to the static may have been imagining Morse code that wasn't really there hiding in the hiss and crackle. Even if the first reports may have been premature, Marconi's team soon established real communication.

The British and Italian Navies promptly adopted his system and ship-to-shore radio became reality. By 1907 his system was available to the public as a transatlantic radio telegram service. Marconi was awarded the Nobel physics prize for 1909. In his later life he continued to experiment with short waves and microwaves. Marconi also briefly served as a statesmen. He was sent as a delegate to the Peace Conference in Paris after World War 1 where he signed the peace treaties with Austria and Bulgaria. He died in 1937.

Radio changes history

Until radios were put on ships, radio communication didn't make much difference to the course of history. Radio telegrams sent across the ocean or between cities were competing with undersea and overland cable telegrams. Ordinary hard-wired telegraph was just as fast as radio but was not vulnerable to atmospheric conditions. However, once radio transmitters were placed on ships, it was only a matter of time before radio was used to rescue the passengers and crew from a sinking ship. This first happened during the sinking of the RMS Republic.



At 5:40 AM, Saturday January 24, 1909, the 15,000 ton passenger steamship RMS Republic was steaming off Nantucket, Massachusetts through thick fog. The Republic was outbound from New York. This ship had a lot in common with the later Titanic. The Republic was owned by the same British White Star Line and was considered "unsinkable." Its hull was divided into multiple compartments by watertight bulkheads so that several compartments would have to flood before the ship could sink. Also like the Titanic, the Republic carried only half as many lifeboats as needed for her 800 passengers and crew.

As the Republic motored through the fog she sounded her foghorn periodically and ship's lookouts listened for other foghorns. The crew heard a foghorn from another ship and responded by sounding a steam whistle. It was the convention at that time that, when ships exchanged whistles, both ships would turn right and thereby avoid the collision. There is some evidence that the Italian passenger ship "Florida" turned left instead. The Florida suddenly appeared out of the fog and crashed into the Republic amidships. Seven people were killed outright by the collision. The Florida struck the bulkhead between the two engine rooms on the Republic, thereby flooding the two largest compartments below the waterline. The engines had to be shut down which also terminated the electricity needed to run the pumps and the radio.

Jack Binns saves the day

The Republic's radio shack was a wooden cabin that had been tacked onto the upper deck. It was located where it was easy to connect to the antennas that were strung up in the ship's rigging. With amazing bad luck, the bow of the Florida sliced part way through the radio cabin pushing equipment aside and disabling the radio. The operator John (Jack) R. Binns was sleeping on a bunk next to his operating station. He said later that if he had been still working at his radio he would have been gravely injured. Binns managed to piece his transmitter back together, but his little cabin was now open to the cold and fog. Because the ship's electricity was off, Binns had to rummage around in the dark below decks to find batteries to run his radio. Without the ship's electricity, Binn's transmitter range was limited to about 75 miles. His best hope was to reach a station on Cape Cod, 65 miles away. Even Binn's telegraph key was broken. He had to hold it together with one hand while he used his other hand to send out history's first emergency SOS.

Actually, the official distress call at that time was not SOS but "CQD." "CQ" meant calling any station, just as it still does today on the ham bands. CQ was supposed to be short for "Seeking You." "D" of course meant danger or distress. Binns managed to contact the station on Cape Cod. Through them, he continued to call for help and talked to rescue ships for 12 hours while the Republic slowly settled into the sea.

Since the Florida was in no danger of sinking, the Republic crew transferred the Republic passengers to the Florida by lifeboat. Meanwhile rescue ships criss-crossed the fog trying to find them. In addition to foghorns, ships of that era were equipped with "submarine bells" which had a greater range underwater than sound from horns was able to travel through air. The submarine bell of the Republic was heard by the liner Baltic and used its sound to guide it the final few miles to the Republic.

In another account of the rescue there was no submarine bell and the contact was made when the Baltic shot off "its very last aerial rocket bomb." The crew of the Republic heard the explosion and gave them the correct bearing by radio. When the Baltic arrived, the remaining crew on the Republic were rescued, then all 2,494 passengers from both the Republic and Florida were transferred by lifeboat to the Baltic. 39 hours after the collision the Republic sank. Meanwhile rescue ships managed to tow the Florida to New York City.

The success of the Republic rescue was a huge news story. Jack Binns was an overnight national celebrity. Radiotelegraph operators were instantly transformed from curiosities into heroes. It's bizarre and even criminal that the White Star Line didn't seem to learn anything from the sinking of the RMS Republic. However, in 1912 the Titanic sinking and the partial success of the Titantic's SOS emergency call further elevated the status of radio communications. The steamship Carpathian sailed 300 miles to rescue the Titanic survivors the morning after the sinking. Another freighter, the Californian, lay at sea anchor just 10 miles away. The captain of the Californian didn't want to risk steaming at night through the icebergs - smart man! The Californian radio operator sent an iceberg warning to Titanic, but the Titanic radio operator told the Californian to get off the frequency because he was handling telegrams for the passengers. The Californian radio operator shut down his radio and went to bed. The night crew on the Californian could plainly see the Titanic but didn't realize the Titanic was in trouble. When the Titanic shot red emergency rockets into the air, the Californian crew thought the rockets were fireworks to amuse the wealthy passengers.

The dawn of amateur radio

In the early days of radio anyone who wanted to get on the air could build his own transmitter and just do it. Frequency assignments were based on whoever was on the air first with the biggest transmitter and the best antenna. Basement inventors began building their own radio equipment and amateur radio was born. In those days there were no licenses so amateurs at first just gave themselves call letters. All radio communications in the beginning were low frequency, 200 meters wavelength and longer. This meant that all communications were happening at what is today AM radio (1,700,000 Hz to 550,000 Hz) and below. Higher frequencies were inefficient to generate and it was believed that higher frequencies were only good for local communication.

When modern amateur radio operators read descriptions of early radio transmitters and antennas, we are impressed by the industrial scale of the commercial equipment. For example, the rotary spark gap transmitter on the Titanic was rated at 5,000 watts. It was so huge and made so much noise and ozone stink, it was installed in a separate room from the receiver. With all that power and size, its reliable range during the day was only 250 miles. At night the range could be as far as a thousand miles. From our modern viewpoint, it's apparent that the biggest weakness of early day equipment was the insensitivity of their receivers. Back then amateur receivers were just as bad and probably worse. Moreover, amateurs were unable to compete with the power used by commercial stations. Consequently, hams were lucky to talk to the next county, let alone any significant distance.

Because early ham radios were limited to short range, radio amateurs banded together to form "relay nets" so that messages could be relayed to destinations many hundreds of miles away. This organization became formalized as the American Radio Relay League in 1914. During World War I the US government banned amateur radio as a national security measure. After the war in 1919 the American Radio Relay League under the leadership of Maxim Percy lobbied the government to allow hams back on the air. The government, especially the military, was unsympathetic. To placate them, the government eventually gave the hams all the "worthless" frequencies above 200 meters. That was roughly everything above present day AM radio.

Flemming develops the vacuum tube diode detector

The vacuum tube diode had actually first been built by Edison. During Edison's work on the electric light, he perfected the technology to put electrodes and filaments in evacuated glass bulbs. Edison was also the first to notice that electrons can flow from a hot filament across empty vacuum toward a positively charged electrode called a "***plate***." However, the electrons could not flow from the plate back to the filament. As a result, the diode behaved as a one-way check valve. Edison experimented with this and wrote about it. This effect became known as the "Edison effect."

Flemming was a British inventor who was intrigued with Edison's discovery and applied it to the detection of radio signals. He worked with Edison who shared his data on the Edison effect. A radio signal received on an antenna consists of a high frequency sinewave voltage that switches from positive to negative and back again hundreds of thousands (or millions) of times per second. These rapid alternating (AC) currents can't power a headphone until they are converted to lower frequency bursts of DC. By passing radio signals through a vacuum diode, one polarity of the signal is "sheared off" leaving just the polarity of the flowing negative electrons. When Morse code signals are received, this results in bursts of DC current that can be used to power a sounder, headphones, or other kind of transducer.

Flemming's detectors became known as the "Flemming Valve." In England thereafter, all vacuum tubes became known as "valves." In terms of sensitivity, the vacuum tube detector was not more sensitive than a crystal detector, but it was far more rugged, reliable, and versatile. Later on, when it was combined with the vacuum tube amplifier, its sensitivity was vastly improved.

Lee DeForest launches modern electronics

Tesla was not the only radio pioneer with an ego problem. In many ways DeForest had a personality similar to Tesla's. DeForest was industrious and gifted. While he was a young man he developed several important inventions. One of his cleverest was a telegraph multiplex system that allowed one wire to carry up to six telegraph messages simultaneously. It's hard to imagine how it could have worked. All he had to work with were switches, relays, transformers, and motors. Synchronizing such a signal separation system is easy with a microcomputer, but doing it with whirring motors and switches is amazing. De Forest's most important invention was the triode vacuum tube, which he called an "audion." The audion was the functional equivalent of the modern transistor. DeForest's triode vacuum tube was essentially a "Fleming valve" with a grid placed between the filament and the plate. DeForest used the audion to make receivers more sensitive by amplifying weak audio and radio signals.

Actually Edison built the first triode while he was studying "the Edison Effect." Edison added a grid-like electrode between the filament and the plate of his diode to learn more about the flow of electrons across a vacuum. Although Edison made his measurements, he didn't notice that the grid was like a sensitive "gate" that could control the current flow to the plate.

The grid can be compared to a matador's one-pound red cape steering a 2,000 pound bull. When little currents are able to control big currents, the device is said to "amplify." Little signals coming into the grid can modulate the big current into a larger, "amplified" version of the original signal. Notice that the original signal is not "inflated" in some way, but rather, the amplifier just directs the generation of a larger copy of the original signal. Notice that the copy may or may not be a good likeness of the original.

DeForest successfully applied his triode vacuum tube to radio receivers. The triode meant that weak signals could be amplified to a level high enough so that after detection they could drive a loudspeaker. Once amplifiers became available, nearly every kind electronic device known today became at least theoretically possible. Eventually even television was implemented with the descendents of the audion vacuum tube. During World War II the first computers were built using vacuum tubes.

The vacuum tube oscillator cleans up radio transmissions

A few early high power systems used alternators to generate low frequency radio signals. However, the frequency of an alternator is limited by the speed of a mechanical, rotating magnet. In practice, alternators couldn't get much higher than audio frequencies, 20 to 50 KHz. An advantage of an alternator was that it generated a pure sinewave signal. Unfortunately it could only cover the very bottom of the radio spectrum.

In contrast, the vacuum tube amplifier could amplify its own output, causing a self-sustained oscillation at any frequency up to hundreds of MegaHertz. Like an alternator, a vacuum tube oscillator could generate clean sinewave signals that were confined to a single frequency. Up until that time, radio transmissions from all high frequency transmitters were generated by discharging electric sparks, then letting the radio frequency signal components ring in a tuned circuit. "Spark gap" transmitters made a noisy, hissing signal that splattered energy all over the band.

Have you ever heard the clicking static in an AM radio from a passing automobile ignition? Similarly, lightning causes a pop or crash of static that can be heard over the entire radio spectrum. Other than having a filter to limit the noise to one band, early radio transmitters were like little lightning radio noise generators. These early sparkgap transmitters wasted power and frequency space. Because of the availability of vacuum tube oscillators, spark gaps became unusual in the early 1920's and were totally banned in the United States in 1927.

If an inventor is persistent, it's sometimes possible to invent wonderful things without really understanding why they work. This was the case with DeForest's audion. In the short run, ignorance can be OK, but in the long run the inventor had better figure out exactly what he has developed. Specifically, he must be able to explain how it works in his patent application.

Unfortunately, DeForest blew it. His patents failed to give valid explanations of how his vacuum tube devices worked. A dozen years after the invention of the audion, DeForest's patents came into conflict with later patents that were accurately explained. In court DeForest was literally unable to explain how a triode amplified. It is completely understandable how he might have been naive at the time of his inventions. But considering that the vacuum triode was his crowning achievement, it isn't flattering that he never bothered to keep in touch with the field of electronics well enough to find out how his own invention worked. Forty-five years after his invention of the audion, De Forest was still strutting around in formal clothes grandly referring to himself as “The Father of Television.”

Reginald Fessenden transmits speech

Professor Reginald Fessenden is an almost unknown hero of radio development. He is truly one of the most remarkable radio pioneers. Although Marconi first demonstrated transatlantic communication, Fessenden was the first to offer it as a regular service in 1906. Fessenden's most amazing accomplishment was the transmission of speech. He is not remarkable so much for what he did, but rather when he did it. In December 1900 he transmitted a voice signal to his assistant Alfred Thiessen over a distance of one mile from his laboratory on Cobb Island in the Potomac River. “One-two-three-four ... Is it snowing where you are, Mr. Thiessen? Telegraph back if it is.”

“Yes, it is!” tapped out Thiessen over a telegraph. From a modern perspective Fessenden's invention came at least 15 or 20 years before the parts were available to do it gracefully. What Fessenden needed was high power audion tubes. However, he didn't know that. So he transmitted AM modulated voice transmission using spark gap transmitters. That sounds impossible. And perhaps because spark gaps were “dead end technology,” it isn't totally surprising that Fessenden has been largely forgotten. The only articles on Fessenden that I have ever read don't describe his apparatus clearly. However, he seems to have succeeded by means of three major breakthroughs and many minor ones.

Fessenden smooths out the sparks

A smooth, pure carrier wave is needed to produce clear AM modulation, but there is nothing smooth about static from a spark gap. Fessenden reasoned that, if the static crashes occurred often enough, the frequency of the buzzing racket would be too high an audio frequency for human ears to hear. So instead of sparking a few dozen or a hundred times a second, Fessenden's generator sparked 10,000 times per second. Then (apparently) he filtered the heck out of the signal using inductor/ capacitor resonant circuits. The transmitter had its own steam engine power plant and was probably quite powerful. The steam engine had to be running at full speed before the speech became intelligible.

Using high frequency noise to get rid of low frequency noise is reminiscent of the modern "Dolby sound" noise canceling principle. Rather than fight the noise inherent in any analog recording system, the Dolby system deliberately modulates the music with a high frequency sinewave at about 25,000 Hz to obliterate the noise.

I read another account of Fessenden's work in which his voice transmitter was described as a high-speed alternator. Oh, well. Transmitting speech with a high-speed alternator also sounds difficult. Garbled technical descriptions are a serious problem when studying the history of radio. It is hard to figure out exactly what they did.

Fessenden invents the barretter

Fessenden also invented a sensitive new detector that he called a ***barretter***. "Barrette" means "a small bar" in French. Modern barretters consist of a microscopic platinum wire that heats and cools rapidly when bursts of tiny radio frequency currents pass through the wire. As the wire changes temperature, its resistance changes rapidly and this can be used to modulate a DC current passing through a sensitive telephone earphone. Barretters are still used today as microwave detectors.

What I don't understand is how the professor got enough signal strength out of a 1900-era telephone microphone to modulate a powerful transmitter. In my opinion that would have been his third amazing breakthrough. In a commercial amplitude modulated (plate modulated) transmitter from the 1930s and later, the audio sound from the microphone had to be amplified up to half the power output of radio transmitter. For example, for a 1,000 watt transmitter, a 500 watt audio amplifier was needed. There was no way to build such a thing in 1900.

Perhaps he invented the "magnetic modulator." In the 1920s some phone transmitters used a transformer to impress amplitude modulation directly onto the RF signal. The microphone modulated a DC current on the transformer primary while the transmitter ground for the antenna went through the transformer secondary. By saturating the iron in the transformer, the current flowing through the secondary can be radically changed with a small signal, thereby providing the needed amplification. Fessenden must have been an obsessed genius to broadcast speech successfully with steam engines, iron bars, copper wire, and spark gaps.

At the time Fessenden's achievement didn't go unnoticed and he was able to raise money to start a broadcast company. His first public demonstration consisted of speaking and playing "Oh Holy Night" on the violin on Christmas Eve in 1906. However, his commercial progress was slow and by the time AM broadcast was beginning to work well, nearly everyone was stealing his ideas. The Marconi Company eventually licensed his patents in 1914. From a modern perspective, Fessenden's biggest problem was his lack of viable business plans. He invented neat stuff, but had difficulty getting paid for his work.

Edwin Howard Armstrong

Another engineer who understood his own inventions was Edwin Armstrong. He studied electrical engineering during World War One, then, right after graduation, he produced the first of his three great inventions, ***the super-regenerative receiver***. In the early days of radio, it was too expensive to build receivers with large numbers of large, costly, power-hungry vacuum tubes. Armstrong invented a way to use feedback on a vacuum tube amplifier to increase the sensitivity of the receiver by an order of magnitude. Super-regenerative receivers were crude and had to be adjusted just right to avoid an unpleasant squealing noise on top of the stations you were trying to hear. However, when super-regenerative receivers began to be used, the range of radio broadcasts soared to a thousand miles and more.

In spite of their severe limitations, ham radio operators commonly made homemade super-regenerative receivers as late as 1960. "Super-regens" were primitive, but they were a stepping-stone to the next generation of receivers. In the 1920s Armstrong developed ***the super-hetrodyne receiver.*** This is the basic design used today in most modern receivers, from television to cell phones. When I was a young ham, I built a Knight "Ocean Hopper" super-regenerative receiver from a kit. I only bought it because it was cheap. The high-pitched noise of the super-regen was so obnoxious, I couldn't wait to replace it with a high quality super-hetrodyne communications receiver.

The TRF receiver didn't cut it

To achieve the required amplification without super-regeneration, the obvious solution was to put several radio frequency tube amplifiers in series. These radios were called ***tuned radio frequency (TRF) receivers*** but they were never very popular. Each amplifier in the string had to be tuned separately to the desired station. This meant that the first TRF radios literally had three or four station tuning knobs that all had to be tweaked independently. Alternatively, in the best TRF radios the tuning capacitors were ganged together with gears and shafts so that they always tuned to the same station simultaneously. This method was extremely hard to synchronize and calibrate so that each tuned coil would track precisely over the entire frequency band. Another problem was that they were inherently "low Q" and tended to receive more than one station at once. The only practical TRF receivers were either extremely expensive or were designed to receive just one frequency.

The super-hetrodyne receiver

Armstrong's solution to the gain problem was to convert the incoming radio signals to a constant ***intermediate frequency***, an ***IF***. The IF frequency remains the same no matter what station the radio was tuned to. In other words, ***a superhetrodyne is a single-frequency TRF receiver with a tunable frequency converter on the front end.*** The IF strip is tuned up just once at the factory. It never needs to be tweaked again. Another important advantage was that the signal on the IF strip could be filtered so that it would only admit a bandpass equal to the actual width of the signal. For example, an AM radio receiver might have an IF bandpass of 20,000 cycles per second (one cps = one Hertz). However, a Morse code signal only needs 100 Hz of bandwidth or less. So when a narrow bandwidth filter is used in the IF, the receiver can select just one signal out of many that may be crowding the band. In contrast, a TRF receiver or even a super-regenerative receiver or may force you to listen to 50,000 Hz of bandwidth at once.

The super-hetrodyne generates the IF by means of a ***local RF oscillator, an "LO."*** The principle can be illustrated with audible sound. When two different frequencies of sound are mixed together, the sound waves cancel and reinforce each other generating frequency components that are the sum and difference of the two signals. For example, if you hit two adjacent keys on a piano simultaneously, the sound is discordant. That's because you're hearing those sum and difference frequencies. In another example, twin-engine, propeller-driven airplanes are equipped with engine speed synchronizers so that the engines don't make an obnoxious "WAH -WAH- WAH" beat frequency sound. This sound is the difference in frequency between the two speeds of the engines. The same principle works with electrical sinewaves at radio frequencies. Unlike the annoying audible examples, in radio the beat frequency is the desired product and that was Armstrong's invention.

A super-hetrodyne is tuned, not by tuning a sharp filter on the antenna, but rather by tuning a sinewave oscillator that is offset from the signal you wish to hear. The amount of offset frequency is equal to the IF frequency. For example, in a household FM radio, if you wish to tune to a station broadcasting on 100 MHz, then the local tuning oscillator is tuned to 110.7 MHz. The difference between the two frequencies is 10.7 MHz which is the IF commonly used in FM radios. Because the tuning oscillator generates only one precise frequency, and because the IF filtering can be quite narrow, the tuning of a superhetrodyne receiver can be extremely selective. The superhetrodyne is made sensitive by putting several IF amplifiers in series. Or, as explained earlier, you can think of the IF amplifiers as a single frequency TRF receiver.

By the late 1920s spark gap transmitters were banned and replaced by vacuum tube sinewave oscillators. The sinewave oscillators generate just one, discrete frequency. After this improvement hundreds of Morse code signals could share a band without interfering with each other. And using Armstrong's superhetrodyne, the receiver could select just one of these Morse code signals.

Beat Frequency Oscillators – where the musical Morse code tone comes from

Although a simple superhetrodyne receives AM broadcasts beautifully, Morse code is essentially inaudible because a pure sinewave signal is unmodulated. During the 1920s Morse code transmitters were often modulated with a mechanical motor driven switch device that made the Morse sound like a buzz and more like an old spark gap. Alternatively, they sometimes deliberately ran the transmitter on unfiltered DC from a rectifier so that the signal was modulated with AC hum from the power line.

To hear Morse code with a superhetrodyne, another oscillator in the receiver called a ***Beat Frequency Oscillator (BFO)*** is needed to produce the musical sound. For example, my first short wave receiver was one of those ancient all-band radios often found in living rooms in the 1940s. The receiver worked fine for receiving foreign AM radio stations like Radio Moscow. However, when I tuned to the ham bands, the Morse code signals were inaudible or just thumping noises. To receive Morse code I had to place a small table radio on top of the big shortwave radio. I used to tune the little radio until I could hear a harmonic of the table radio's tuning oscillator (local oscillator) in the big receiver. This signal beat with Morse code signals and made them audible. This was extremely finicky to adjust and barely practical. A communications receiver of course has a built-in BFO that typically oscillates at an RF frequency 500 to 700 Hz away from the IF. This produces the clear Morse code whistle we are accustomed to hearing, no matter what frequency the local tuning oscillator is tuned to.

Getting rid of the atmospheric static

Radio communication was essentially 100% Morse code until after World War I. Suddenly it became common to hear voices over the radio. In 1921 the first commercially successful Amplitude Modulated voice broadcasts began. With AM broadcasts, the transmitter was not turned on and off like Morse code, but rather the transmitter was left on continuously. The transmitter power was raised and lowered in time with the music or voice audio frequency. This process impressed or "modulated" voice and music onto the signal. In other words, with AM modulation the information content is proportional to the momentary strength of the signal.

So long as the strength of the signal is high and there is no interference from lightning storms, big DC motors, or nearby automobile ignitions, amplitude modulation (AM) radio works quite well. By 1930 AM radio was a standard appliance in American households. But with all that crackling and popping noise on weak signals, AM radio is never really high fidelity except when tuned to strong, local stations.

Atmospheric static is a natural noise signal that has the same amplitude modulated form as man-made AM signals. Therefore it is impossible to get rid of the static without changing the method of modulation. Edwin Armstrong secluded himself in his laboratory in the Empire State Building in New York City and worked to find a way to eliminate the static in voice broadcasts. Armstrong needed to create an audio modulation that could be impressed on a transmitter signal without imitating the natural noise modulation produced by lightning and static discharge.

Armstrong eventually hit upon the idea of modulating the frequency of the signal rather than the intensity of the signal. In other words, as the announcer talks, the frequency of the transmitter moves up and down in time with the audio frequency and amplitude of the sound. The signal amplitude never changes. ***Frequency Modulation*** solved most of the noise problem and was the origin of the FM broadcasts we listen to today. Armstrong had been working for the Radio Corporation of American that manufactured superhetrodynes. Because of the superhetrodyne, RCA with its subsidiary, the National Broadcast Company, dominated AM radio for as long as that patent lasted. RCA was run by David Sarnoff who failed to reward Armstrong's contribution to the company. Armstrong left RCA and started his own FM radio broadcast network.

Sarnoff needed FM radio to transmit the audio signal with television so he simply stole the invention from Armstrong. Sarnoff, being able to hire more lawyers, was able to play the patent war two ways in his favor. His lawyers persuaded the court that RCA had invented FM, not Armstrong. Sarnoff also persuaded the FCC to force FM stations to broadcast on VHF frequencies at low power that restricted them to local broadcast. This prevented FM from ever being used by long-range stations like the 50,000 watt "clear channel" AM stations that are still scattered around the U.S. Ultimately Sarnoff won all the battles and ruined Armstrong. Armstrong, who loved to climb on high radio towers, ended his life by jumping out of a 13 story window in 1954.

The transistor miniaturizes electronics

The bipolar transistor was invented in 1947 by Shockley and Bardeen while working at Bell Laboratories. In function, the transistor can be thought of as a "miniature triode vacuum tube." Unlike a tube, a transistor consists of a tiny lump of semiconductor crystal with three wires attached. Like a triode, a control gate called the "***base***" allows a small current to control a much larger current that flows from the "***emitter***" wire to the "***collector***" wire. Unlike tubes, there is no vacuum chamber, no heated filament, no relatively high voltage, and no separate power supply needed to light the filament.

In vacuum tubes, the control grid of a vacuum tube must always be referenced to the negative pole of the circuit. That is, the grid is always operated at just a few volts different from the voltage on the filament (cathode). The vacuum tube plate potential is usually quite high, typically hundreds of volts, and is always positive polarity. In contrast, transistors can run on as little as one or two volts and can be built in two polarities. The control base can be referenced to either the negative pole, (***NPN transistors***) or the positive pole, (***PNP transistors***.) Because they are available in complementary designs, the two types can be used together to form compact, high gain circuits with fewer additional components such as resistors and transformers.

The first transistors were fragile devices called ***point contact transistors*** that never appeared in consumer products. (A homebrew attempt to build point contact transistors is described in chapter 4.) The first widely used transistors were made from germanium and not silicon. Early germanium transistors could only tolerate tiny power levels. For example, the 2N35 transistor would burn out if it dissipated more than 35 thousandths of a watt. In the 1950s they were sold to amateurs for experimentation, but it was difficult to get them to work before they burned up. I bought one for $5 and promptly ruined it. Today that amount of money would be like $50 each. Then in 1960 the Texas Instruments Company perfected silicon transistors and the dominance of the vacuum tube was doomed.

Radio covers the globe

The Sony Company in Japan realized that silicon transistors presented a unique opportunity. They jumped on it and revolutionized AM radio. They made tiny battery powered "transistor radios" that cost a few dollars and fit in a shirt pocket. Because they didn't need power from the wall and the batteries were small and cheap, suddenly even the poorest people on Earth could afford transistor radios.

In the 1960s another type of silicon transistor, the Field Effect Transistor (FET) appeared. FETs are also three wire devices. The control gate of an FET is actually called the "***gate***" and the gate uses tiny voltages, rather than tiny currents, to control the big current flowing from the "***source***" lead to the "***drain***" lead. Like bipolar transistors, FETs come in two polarities called "***N-channel***" and "***P-channel***." Today FETs are the basis of most integrated circuits used in computers and, as we'll see later, they are also valuable in radio circuits.

Becoming a ham radio operator

My serious shortwave listening began during the cold war. My big "all band radio" allowed me to tune the shortwave bands. This radio was three feet high, two feet wide and packaged in a beautiful wooden cabinet. But compared with a real communications receiver, this living room radio was extremely limited. It had poor selectivity and only covered a few ham bands. It had no "band spread" control so the hambands were only about 1/8 inch wide on 4 inches of dial. On the other hand, it wasn't worthless. I was able to hear occasional AM phone conversations between hams. Later I bought a World War II surplus "morale radio." These were shortwave receivers that were issued to the American troops so they could listen to broadcasts from home, Tokyo Rose, or other AM modulated stations. Morale radios also had no "beat frequency oscillator" and I could not receive Morse code without resorting to the second-radio-trick described earlier.

I learned Morse code in the Boy Scouts. One requirement for our Boy Scout First Class badge was to send and receive Morse Code using a signal flag. The flag was waved over one's head to the left for "dash" and to the right for "dot." Our Boy Scout manual admonished us to remember what the Dutchman said, "Dots right!" Today's Boy Scouts don't have to learn Morse code. That's a shame. In an emergency, the ability to communicate by tapping through a wall or waving across a canyon might not be a trivial skill. Prisoners throughout the world often communicate by tapping messages through walls using a universal code. The prisoners' code translates the alphabet into tapping in which the letter "A" equals one tap, "B" equals two taps and of course "Z" equals 26 taps. Good Grief! I guess prisoners have lots of time on their hands.

Several of my friends were also interested in shortwave and we started a shortwave listening (SWL) club. For code practice my buddy Eric Raimy (soon to be KØDUA), rigged up a telegraph system of buzzers that communicated between his bedroom, the downstairs hall closet, and the basement. We three middle school students sat at our posts and talked with our slow Morse code until we got our speed up to 5 words a minute and could pass the Novice class ham radio test. A local school principal, Glenn Johnson, WØFQK, taught us about ham radio administered the tests to us.

If you wish to get a ham license, you need to find a local ham radio club in your area. In America ham clubs generally conduct classes for new hams and give the license exams. Check the Internet for local clubs. Failing that, if you live in the USA, check the American Radio Relay League website, www.arrl.org or call (888) 277-5289. The ARRL will help you in many ways. They can provide you with study materials, magazines, books, and hams to contact in your area.

Ham radio in the last 80 years

Like electronics in general, amateur radio has exploded into many different facets since World War II. From a hobby that was originally just Morse code, it has exploded into a long list of capabilities and activities. Each decade has added more and more variations in the ways and methods for amateurs to use radio technology. As a rule, new technologies were first demonstrated ten years before they became commonplace. Of all the ham modalities that have ever been used, only spark gap transmitters are completely extinct. However, hams rarely use AM phone today.

1920s Continuous wave Morse code and early AM radio. (Vacuum tubes and the end of the spark gap transmitter.)

1930s AM phone, Very High Frequency (VHF) 54 MHz and above.

1940s Radio Teletype (RTTY), VHF FM communication, 2-way ham radios in cars.

1950s Single Side Band Phone (SSB), amateur television, slow scan television (a kind of radio Fax), UHF communication, 220 MHz and above, Directional Beam Antennas, radio transmitter hunts.

1960s Amateur microwave communication. Easy-to-use SSB HF transceivers. Moon bounce and meteor bounce communication.

1970s Amateur Satellite communication, VHF/ UHF relay stations.

1980s hand-held transceivers, computerized station log keeping, AMTOR packet message handling (a sort of radio e-mail)

1990s Spread Spectrum communication, radio control, robot beacon stations, PSK-31 messages (computer instant e-mail), IRLP (Internet-connected VHF relay stations), QRP (low power) stations, and amateur radio radio-controlled models, TV on small rockets.

2000s Software controlled radio receivers, complex digital signal processing, remote internet controlled stations, GPS locating for mobile transmitters (APRS) and, in general, the application of all the technologies found in cell phones and computers.

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From the point of view of variety of new equipment, amateur radio is booming. On the other hand, thanks to the Internet, fax machines, and cellphones, much of this technology can now be used by people who have no license and no interest in how the equipment works. On the other hand, some aspects of ham radio remain unique to this hobby and haven't changed. These are:

1. Morse code.

2. Exchanging QSL (contact confirmation) cards,

3. Homebuilding equipment.

4. Mastering new or exotic modes of communication, such as satellite relay or unusual signal propagation modes like moon bounce.

The future of ham radio frequency bands

The existence of ham radio as a hobby is totally dependent on our governments allowing us to transmit. For this we need allocations of the frequency spectrum. But every day there are more and more commercial uses for wireless communication. These applications fall into two categories. Short-range communications, so called "Part 15 applications," transmit less than 100 feet. They link printers to computers, support cordless phones, open garage doors, and unlock automobiles. Suitable frequencies can be low, say 1 Megahertz and below. Or they can use very high frequencies, 40 MHz and above. The high frequency (HF) range in between 1 and 40 MHz is not desirable for these applications because, when atmospheric conditions are right, signals from great distances, even the other side of the world, can trigger a local device.

For example, when the first Soviet Sputnik satellite was launched in 1957, it broadcast on 20 MHz. Every time the satellite went over the United States, many homeowners discovered their garage doors mysteriously cycling up and down. Through the use of selective receivers and digital coding, most of this kind of radio interference has been eliminated. But when the frequency bands become crowded with signals, even a sophisticated receiver will eventually be paralyzed by the interference and won't respond to the correct code.

Cell phones, global positioning, and Internet links transmit over distances of a few miles or up to satellites to provide reliable communications. The best frequencies for these applications are above 40 MHz because random signals from the rest of the world usually won't interfere. At 500 MHz and above, signals from over the horizon will almost never interfere. These frequencies can be relied upon day and night for dependable communication. In the modern era it's these UHF and microwave frequencies that have the most commercial value.

Hams have a few frequency bands in this high-value part of the spectrum. So far we have been allowed to keep them by sharing them with the military.

Thank goodness for the erratic nature of HF

Since the 1920s the most important ham bands have been the HF frequencies between 1.8 and 29.7 MHz. The good news for amateurs is that it is the unreliability of these bands that makes them attractive to us and unappealing for commercial users. When we hams turn on our receivers, we really don't know what we're going to hear. There may be just static or there may be two local guys discussing their golf game. Or we might hear a ham in Mongolia looking for a chat. It's like going fishing. That's the fun of it.

Bad signs for the future

As ham radio equipment becomes more complex, fewer and fewer hams understand how it works. It's fair to say that the vast majority of hams today are overwhelmed by the complexity of the equipment they use and no longer make a serious attempt to understand it. As a result only a tiny minority attempt to build their own. American FCC licensing for hams reflects this trend. As fewer hams build their own equipment, ham radios have become just another form of consumer electronics. The FCC has become more concerned about manufacturers building fool-proof equipment than it is about hams understanding their radios.

Forty years ago, ham radio license exams in America were administered directly by the Federal Communications Commission in somber and intimidating government offices. The tests were devoted to the technical details needed to be sure hams knew how to keep their homemade transmitters operating within assigned bands. Typical questions included calculations on crystal specifications to determine whether a given crystal could be relied upon to stay within a particular ham band. The privilege of using all the ham frequencies was only granted to the best-trained hams. They had to demonstrate 20 words per minute Morse code speed and take a complex test that included drawing circuit diagrams of various kinds of transmitters and calculating design parameters. Today the Morse code requirement has been eliminated altogether. The tests are now multiple-choice exams given by ham volunteers. In preparation for the exams, modern hams study the actual tests, rather than the material covered by the tests. In terms of engineering knowledge, the modern ham is a lightweight compared with hams 50 years ago.

Another alarming sign is that the number of ham radio operators is relatively fixed and the average age of hams continues to rise. It's a logical conclusion that eventually our frequencies will be taken away for lack of interest. Ham radio will have become another historical pastime in the same category with quilting-bees and buffalo hunting.

A recent threat to ham radio is the broadband power line initiative (BPL). Power companies wish to make money by using their power lines as Internet connection conduits into every house that receives electricity. Unfortunately the power lines leak this radio noise into the sky and produce a strong buzz of noise that would obliterate all weak to moderate radio signals between 2.0 and 80 MHz. This radio noise obliterates all but the most powerful ham radio and shortwave signals. So far, BPL installations are limited to just a few cities and the ARRL has been fighting the FCC to make the government enforce their own regulations on interference to FCC licensed stations. As of 2010, the hams seem to be winning this battle. Similarly, the radio racket from plasma TVs and other modern sources increases the background static and makes ham bands less usable than they used to be. The difference in static between the city and living out in the country is dramatic.

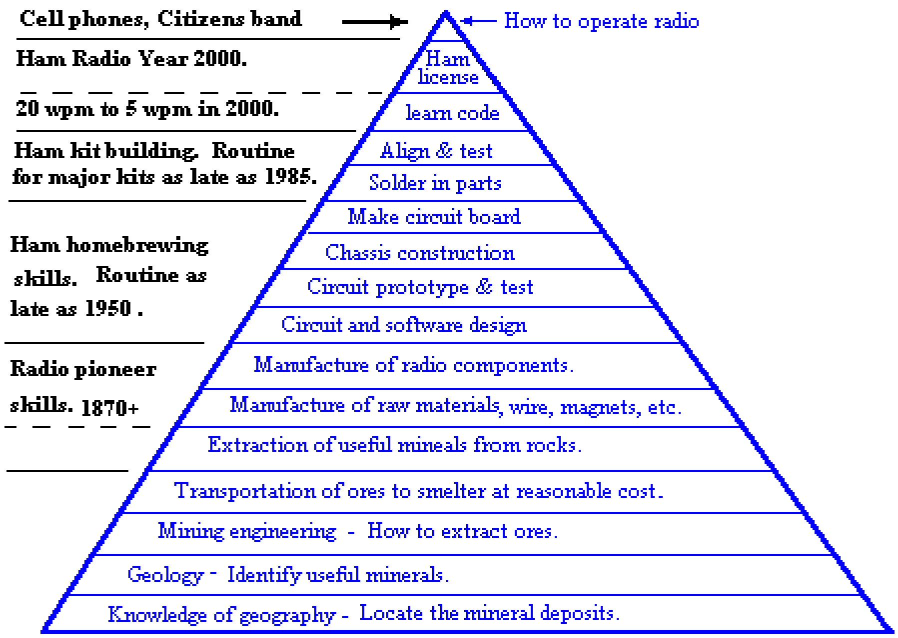
Mastering the technology

As civilization's technology becomes more sophisticated, the knowledge base among our population becomes more and more fractured. Although the amount of knowledge that individual educated people have in their heads may be the same, each citizen knows more and more about less and less. Operating modern ham radio transceivers resembles operating a complex VCR. Yes, the equipment can handle all the modern modes and frequencies. But first you must read the manual and push 48 buttons to select all the right menus and options. It's not easy to operate one of these do-everything wonders. But when you've succeeded, you really haven't learned much about electronics.

Modern radio transceivers remind me of integrated circuits. Transceivers are packed with dozens (or hundreds) of integrated circuits. Some of these contain literally millions of transistors. Like the transceiver as a whole, an integrated circuit cannot be fixed, its contents are mystery, and it is usually a black, rectangular solid with "feet" or leads. Even with the service manual of a modern radio transceiver in front of you, it's hard to get more than a general idea of its block diagram and how it works.

But surely the engineers who designed these wondrous modern radios know how they work! No, not really. Perhaps there are a handful of engineers in the world who have a good grasp of most the technologies in a modern transceiver. But I wouldn't bet on it! Each engineer specializes in assembling or programming modules that are bought from other factories. The modules are sealed and can't be repaired. Exactly what's inside those modules is probably as much a mystery to them as it is to the rest of us.

Over the last century, a radio operator's span of knowledge has continued to shrink. A hundred years ago, the early radio pioneers were not only on the air testing radios, they were also working on the materials to build the components for their radios.



This trend can be illustrated by a "technology pyramid" for ham radio technology. At the very top of the pyramid is the knowledge of how to operate a two-way radio. At the bottom of the pyramid is the prospector who explores the wilderness and first finds the raw materials needed to make a radio and every other modern technology. In the middle are the skills needed to build your own radio equipment.

One way to look at the change is that ham radio has slowly retreated up the pyramid to become just another consumer product like TVs and cellphones. Most hams argue that ham radio can do more things than ever and is therefore more interesting. We can transmit live amateur television, e-mail message nets, and faxes. Fortunately or unfortunately, the same technologies are becoming available to ordinary folks without licenses. Why bother with ham radio?

Homebuilt ham radio and the "QRP"

Building your own radios is commonly known as ***homebrewing***. Up until World War II, ham radio was homebrewing. In the early days decent commercial radio equipment was barely available and during the depression it was unaffordable to average people. If you couldn't build your own equipment, you probably couldn't afford to get on the air. In this respect a little poverty isn't always a bad thing. When life is too easy, it becomes boring.

After 1950 building transmitters at home remained common only among the young and impoverished. Good communications receivers were the hardest to build, so homemade receivers were the first to go. In the 1950s and 1960s pre-fabricated, well-designed kits from companies like Heath and Allied Radio replaced the homebuilt equipment. To have good, usable equipment, all you had to do was solder it together. Finally in the 1980s the kits became so complex, the kit companies couldn't trust us to do more than solder prefabricated assemblies together. When that happened, the kits became so boring that they disappeared altogether.

Today there is a growing interest in building low power QRP transmitters. These are transmitters with less than 5 watts output. "***QRP***" is an abbreviated way of saying, "please reduce power" in Morse code. The majority of QRP hams are once again building kits. A few modern pioneers are building them from discrete parts. One branch of this hobby builds transmitters in sardine cans to emphasize the small size of the transmitter. Another group uses metal "Altoid" candy boxes that are even smaller. In any case, QRP is the brightest hope our hobby has in remaining technically competent and attractive to young people.

(1) Wizard, The Life and Times of Nikola Tesla, by Marc J. Seifer, Carol Publishing Group, Secaucus, New Jersey, 1996.