Surveillance Technologies

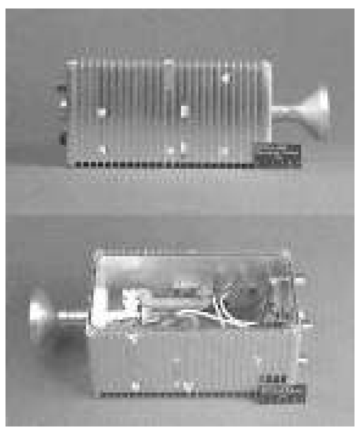
Electromagnetic

Section 3

Electromagnetic Surveillance

5

Radio



1. Introduction

Radio surveillance is one of the most significant surveillance technologies ever developed. Radio waves are invisible to humans. They can pass through most walls and many types of objects. Radio waves travel well; they can be directed around the globe by bouncing them off the ionosphere or they can be sent far out into space. They can operate over a range of frequencies and they can be used at low or high intensities. Like other electromagnetic technologies, they do not require a medium through which to travel. Unlike sound waves, radio waves can pass through a vacuum.

Radio waves comprise a broad segment of the electromagnetic spectrum, far broader than the visible spectrum, for example. Because radio signals can be sent on many different frequencies, radio waves are remarkably versatile and are used in many different types of applications, including television and radio broadcasting, phone and computer communications, and radar sensing and imaging.

Two views of an ultra-small-aperture radio-frequency and intermediate-frequency transceiver for the space program, where compactness is essential in the limited space of a space shuttle or station and communication with Earth is through radio frequencies. [NASA/GRC 1994 news photo by Q. Schwinn, released.]

Radio waves of different wavelengths can coexist. The tuner in your AM or FM radio allows you to select the station of your choice from hundreds that are broadcasting at the same time. The same goes for broadcast television. The *tuner* is a radio-wave-receiving instrument inside the radio or TV which is designed to resonate and respond to whichever frequency you indicate with a pushbutton or dial.

Radio waves are fast, flexible, invisible, and relatively easy to generate, but they are not unlimited in availability. If you have a low-power radio transmitter sending out a signal at a particular frequency and your next door neighbor has a high-power radio transmitter transmitting at the same frequency, the strong signal will clobber the weak signal just as surely as a semi-trailer will clobber a motorcycle if it tries to inhabit the same physical space at the same time. These constraints must be taken into consideration when designing and using radio systems and they are the reason why we have regulatory agencies to allocate *bandwidth* to various commercial, government, and amateur organizations.

Radio waves are relatively easy to intercept. Once a radio transmitter sends out a signal, it radiates out in all directs. The sender has no control over what or who it might encounter along its path. Once a radio signal comes in contact with a receiver that is tuned to the same frequency, it is beyond the control of the sender to do anything to change the content or character of the transmission. For this reason, the most common strategies to prevent eavesdropping on a radio transmission include encrypting the signal, changing the sending frequencies (either between transmissions or during transmissions), or sending out short random or apparently random transmissions. All of these common strategies take place at the time of the transmission, rather than after the signal has been sent or apprehended. While these strategies can safeguard a majority of communications, they are not infallible. Every time a new means of hiding the content or character of a transmission is invented, someone comes along and 'cracks' the code or strategy. Sometimes this is done for reasons of national defense or to enable private or institutional eavesdropping, and sometimes it is done for the thrill of solving a problem. There are many avid chess-players and puzzle-solvers who are also amateur or professional radio hobbyists.

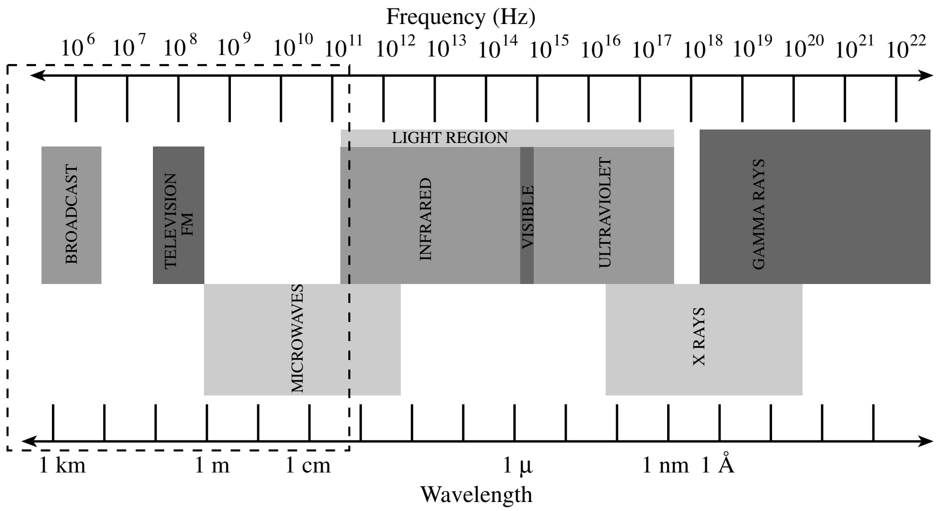
This chapter focuses mainly on radio technology as it is used in broadcasting, amateur radio, and government communications. It puts a greater emphasis on radio receiving than it does on radio transmission, because this is the aspect that is important to surveillance, but a certain amount of attention to transmitting is necessary because the character of the transmission will determine the strategy that is needed to apprehend the signal. It also puts greater emphasis on the auditory aspects of radio technology, as visual technologies using radio waves are covered more fully in Visual Surveillance.

Radar (radio direction/detection and ranging) is a specific aspect of radio technology that is so prevalent in surveillance activities that it warrants a separate chapter. It is recommended that you cross-reference this chapter for a general understanding of radio technology when reading the Radar Surveillance chapter.

2. Types and Variations

Basic Terms and Concepts

Radio waves are a type of electromagnetic radiation that are generally categorized together with light, X-rays, and gamma-rays. Radio waves are longer than light waves and quite a bit longer than X-rays. We cannot hear them, see them, or smell them, so we must convert the energy from radio waves into a form that we can sense in order for the information to be useful for most applications. We usually choose to convert radio frequencies into audio frequencies within human hearing ranges and, in the case of television, into light frequencies that create images that we are able to interpret through our visual senses. Sometimes we translate them into beeps, buzzes, lights, and alarms.



Radio waves form a large part of the electromagnetic spectrum, compared to visible wavelengths, and are extremely versatile. They range from microwaves at the longer-wave end of the infrared spectrum out past the extremely long wavelengths used by broadcast technologies. Because radio waves of the same frequency can interfere with one another, they are carefully regulated and administered by the Federal Communications Commission, which assigns licenses for broadcasting, depending on frequencies and power levels.

Due to the versatility of radio technologies, it's hard to organize them into just a few categories, but for the purposes of surveillance, radio technologies are common in a few general areas, including

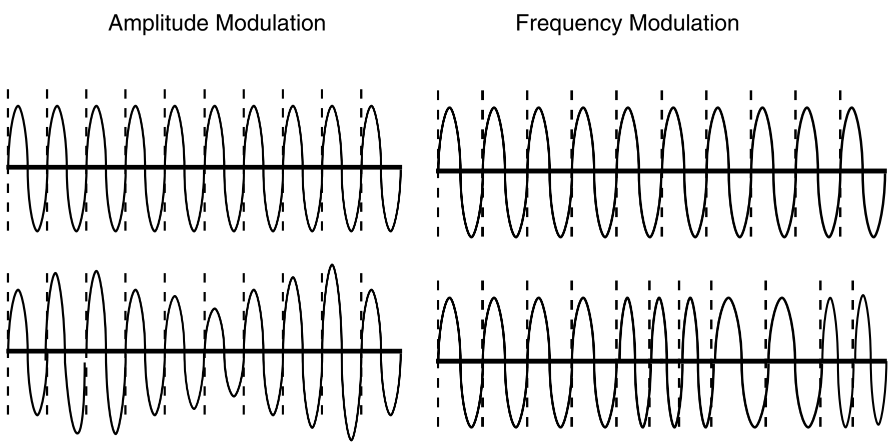
broadcasting (transmitting and/or receiving) - Radio waves are used to communicate instructions, locations, intentions, and activity reports. Broadcasting is done through broadcast stations, amateur systems, cell phones, remote controls (for components, appliances, and robots), and small-scale radio transmitters.

signaling - Radio waves are used to indicate that alarms, perimeter detectors, traps, or other objects have been activated, changed, moved, or deactivated in some way, allowing them to be used in many types of security systems, obstacle or hazard detection and avoidance systems, and wildlife management programs.

tracking - Radio waves can be used to indicate the position, movement, and speed of an object or living organism. Radio beacons have been attached to ships, cars, aircraft, spacecraft, people, animals, birds, bees, bicycles, kites, whales, and just about anything else that's big enough to carry a small electronic device and power cell.

A radio wave doesn't inherently carry communications information. In order to carry information, a radio wave called a *carrier wave* is *modulated* to add the informational content. Sometimes only part of the wave is sent and the rest (usually a symmetric portion) is mathematically reconstructed at the receiving end to save transmission resources.

The two prevalent schemes for modulating radio waves are *amplitude modulation* (AM) and *frequency modulation* (FM). Amplitude modulation is the more common and the more technically accessible means of modulating a radio signal. Amplitude modulation was discovered long before frequency-modulation. In fact, many engineers claimed that frequency-modulation was impossible. Well, it wasn't impossible, but it took a brilliant engineer a decade of devoted work to prove them wrong. Frequency modulation is now an essential technology used not only in FM radio broadcasting but in many phones, tracking beacons, and other small-scale electronic devices. The chief advantage of FM over AM is the clarity of the signals. This comes at a price, however. FM signals are sent with *guard bands*, which are 'empty' frequencies on either side of the frequency that is being broadcast, to prevent interference. This uses up precious bandwidth, but is still preferred for applications where signal fidelity is important.



Radio waves don't inherently carry communications; it is necessary to add information to the waves as they are broadcast. The top signal is unmodulated. Amplitude modulation (bottom left) and frequency modulation (bottom right) are the two primary means by which 'carrier waves' are modulated to add information to the signal, usually in the form of speech, music, or data. [Classic Concepts ©1998 diagram, used with permission.]

3. Context

Radio wave energies are used everywhere, in broadcasting, consumer appliances, telephones, satellites, vehicles, alarm systems, electronic article surveillance systems, appliances, tracking tags, radio collars, leg collars, and wireless networks. Radio technologies are one of the most prevalent tools of our society. The capability to communicate without wires has many advantages.

Radio technologies that are used for surveillance are not tied to any particular industry. They are used just as readily in home and commercial applications as they are in professional or military applications.

For surveillance uses, radio technology has pros and cons. The most obvious advantage is the ability to send information invisibly without wires over distances, sometimes considerable distances. The biggest disadvantage is that radio waves are indiscriminate. They don't care where they go or who intercepts them, making them vulnerable to detection and interception. While it's difficult to hide the presence of radio waves, it is becoming easier, with advanced hardware and software technologies, to hide the content of radio communications.

4. Origins and Evolution

By the late 1700s, emigration to the "New World" had greatly increased and people were searching for more efficient ways to communicate over long distances. All non-oral communications in those days were delivered by hand, animals, or birds (e.g., carrier pigeons). Carrier pigeon communications had some advantages over messages carried by people, but they also had some drawbacks. Pigeon-mail didn't work well over oceans, it was essentially a one-way system, and there was no guarantee that the pigeon would make it home. There was also a limit to how much information a pigeon could carry. Inventors sought ways to send longer messages over greater distances, preferably in two directions. Thus, telegraphs, telephones, and wireless communications evolved over the next two centuries.

4.a. Distance Communications Through Wires

The Telegraph

Invention depends on dreaming new dreams. The dream of radio grew out of the eye-opening invention of the telegraph. The very fact that information could be transmitted almost instantaneously over great distances is probably the single most revolutionary discovery in the history of communications. The telegraph demonstrated that communications at astounding speeds were possible over wires, so inventors thought "Well, how can it be done *without* wires?" Since the invention of the telegraph, most new forms of communications, including radio, have been evolutionary rather than revolutionary in nature.

France and Switzerland led the way in conceptualizing early telegraph systems, but it took about 80 years before practical electrical telegraphs, as we know them, were implemented in England and, soon after, in America.

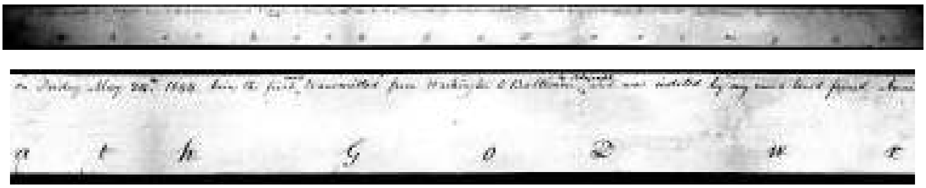
The concept of electric telegraphy is recorded in a letter from 1753, but the initials "C.M." do not reveal the identity of the inventor. The first *frictional telegraph*, which used wires to electrically stimulate movement in pith balls at the receiving end, was introduced in Switzerland twenty years later, in 1774, by George Louis Lesage.

The first 'wireless' *optical telegraph*, using a system of towers and semaphores, was invented in the early 1790s by Claude Chappé (1763-1805), with assistance from his brothers. Stations were established across France but the system was somewhat cumbersome and impractical in bad weather.

Electromagnetic energy is the basis for the great majority of surveillance technologies and yet, surprisingly, electromagnetism was not demonstrated until 1819 by Hans Christian Ørsted (1777-1851). Ørsted was a Danish scientist and professor who discovered the *electromagnetic effect* while demonstrating how current could influence the behavior of a magnetic needle to a class of physics students in Kiel. His reports on the electromagnetic effect enlightened many scientists and established the foundation for electric telegraphs. Both André-Marie Ampère (1775-1836) and Johann Karl Friedrich Gauss (1777-1855) subsequently demonstrated electromagnetic telegraph systems, but they were not yet fully practical.

Europeans invented the first telegraph systems, but Americans were equally interested in developing the technology. In the 1830s, Joseph Henry (1797-1878) was experimenting with electromagnets in America and also actively assisting inventors on both continents. There was a lot of emigration in the early 1800s and the Atlantic increasingly separated families and colleagues; the motivation to find a way to communicate across the ocean must have been very powerful. Finally, in England, in 1836, Charles Wheatstone (1802-1875) and William Fothergill Cooke succeeded in making the first practical working telegraph. The next year, in

America, Samuel Finly Breese Morse (1791-1872) developed a working telegraph. Joseph Henry had encouraged both these inventors, so it may not be coincidental that their discoveries occurred at approximately the same time.



This is the historic paper tape from the first public demonstration of the Morse telegraph on the Baltimore line on 24 May 1844 with the coded and subsequently handwritten message "What hath God Wrought?" The message was sent by Morse from the U.S. Supreme Court to Vail in Baltimore and subsequently given by Mrs. George Inness to the Library of Congress. [Library of Congress Prints & Photographs Division, copyright expired by date.]

Telegraphic Surveillance

Like so many aspects of surveillance, we don't have records on how often early telegraph messages were intercepted. Social expectations and codes of conduct were different in those days. Telegraph operators had a professional responsibility not to repeat confidential communications and most of them respected this code of honor. Yet, even then, there were pieces of news that were whispered to family or friends or news reporters willing to pay for information on deaths, disasters, or business transactions. Since telegraph technology was relatively simple, surveillance didn't require highly technical skills. To eavesdrop, all you had to do was learn Morse code and tap into a wire. Even learning Morse code could be avoided if the eavesdropper had an informant working in the telegraph office.

The Morse code system wasn't invented to hide communications, however, but rather to enable communications on the simple on/off electrical/mechanical systems of the time. Samuel Morse had originally developed a somewhat cumbersome 'lookup book' for coding and decoding messages. This would have made telegraph communications harder to translate but also harder to intercept, as it would require possession of the relatively large lookup volume. However, history took a turn when Morse's assistant, Alfred Vail (1807-1859), came up with a simpler idea. The younger Vail was from an ambitious, mechanically apt manufacturing family. He was responsible for constructing and adjusting many of Morse's mechanical devices. While Morse developed the lookup code, Vail was altering the telegraph key from horizontal to vertical to allow easier finger motion and to permit spaces on the paper tape. This suggested an idea for a simple dot-dash code that would be easier to learn. A colleague who worked with Vail reports in Century Magazine that he and Vail visited typesetters to see which letters of the alphabet were more frequently used and that Vail used this information as the basis of the system that became Morse code. Since Vail had a contract with Morse to turn over his inventions in exchange for a percentage of commercial profits, his employer received the credit and the system became known as American Morse Code.

In terms of communication, the Vail approach greatly streamlined the sending of messages. From a surveillance point of view, it also made it easier to eavesdrop on telegraph signals anywhere along the line, since a lookup reference wasn't needed. People who were determined to intercept the communications of others could tie into a wire somewhere out of sight, or even out in the wilderness, without worrying about being detected. These were the first examples of *wiretapping* in the surveillance industry. If the eavesdroppers weren't mechanically inclined, their options were more limited but they could still try to interpret or acquire the paper tape on which the message was recorded in code, or strike a deal with a telegraph operator to reveal the contents. No matter how simple or sophisticated the technology, the human element then, as now, was usually the weakest point in the chain.

When *sounders* were developed, telegraph receivers could emit a *click* instead of creating a paper tape. While paper-tape telegraph receivers didn't disappear right away (actually, they evolved into teletype machines), many telegraph offices adopted the sounders instead of tape.

THE WESTERN UNION TELEGRAPH COMPANY.

RECEIVED at

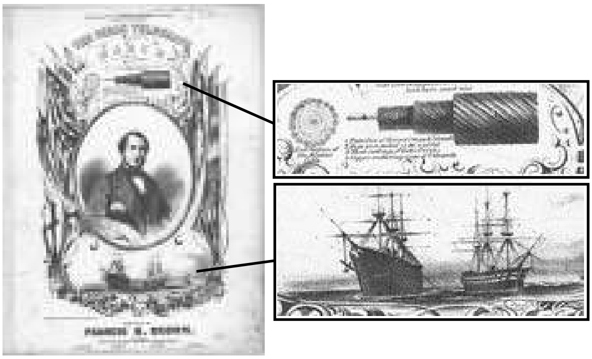
Left: An early telegraph key from the Bellingham Radio Museum collection. Right: The historic Western Union telegram from Orville and Wilbur Wright to their father, announcing the success of their first airplane flights at Kitty Hawk, in December 1903. [Classic Concepts ©1998, used with permission; Library of Congress Words and Deeds Collection, copyright expired by date.]

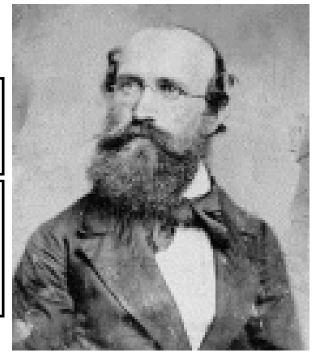
With sounders, an eavesdropper who understood Morse code could listen to an incoming message from a nearby room or window, without having to physically hook into the electrical line. No doubt many communications were 'overheard' this way. The telegraph sounder also changed other aspects of telegraph surveillance. With the original paper tape machines, there were at least two records of a transaction, the original Morse code on the tape, and the operator's written transcript of the message. When sounders replaced paper tape receivers, someone had to be staffing the station at all times to receive an incoming message. In addition, there was no way to verify the accuracy of the message as transcribed by the telegraph operator. The operator could make mistakes or could deliberately alter the contents of the message. This was especially easy in large telegraph offices where many sounders were operating at the same time and the resulting noise would obscure the actions of any one person. Sounding systems were thus less accountable than paper tape systems, but also harder to intercept 'after the fact' by stealing the paper transcript of the message, since there was now only a translated message rather than a translated message and an original paper tape message.

Laying Down the Lines

Inventors were already looking for ways to send 'wireless telegraphs,' but they hadn't yet discovered radio technology. Consequently, the early telegraph systems needed a physical medium through which to send electrical impulses and laying telegraph wires became an international passion. By 1851, France and England had been connected by an underwater cable and efforts were underway to connect England and Canada. Gutta-percha, a rubbery substance that could protect deep-sea cables, was a key element in establishing oceanic connections.

Cyrus W. Field is remembered for heading the project that resulted in the laying of the transatlantic telegraph cable, a project that had its disappointments and ultimate success. In fact, the two attempts to lay the cable in 1858 (and a previous attempt in 1857) were unsuccessful. It took experiences from the failed missions and the procurement of gutta-percha (an insulating, protective substance) to make the project viable and successful.





Left: This 1858 sheet music cover commemorates the laying of the transatlantic telegraph cable. At the top of the cover is the cable, showing the various layers over a copper core. In the center is a portrait of Cyrus Field, the coordinator (inadvertently reversed by the printer) and below are the ships used to lay the cable. Right: Cyrus W. Field was a young, wealthy New York merchant who came out of early retirement to tackle the project. It was an ambitious venture that ended up taking many years of effort on the part of the 'retired' Field and the others involved in the project. [Library of Congress Historical American Sheet Music Collection and America's First Look into the Camer Collection, copyrights expired by date.]

Transcontinental Cables

Overland connections were being established as well. By October 1861, through the remarkable efforts of Hiram Sibley, Ezra Cornell, and a small crew, the first transcontinental telegraph spanned America from east to west. This feat was remarkable not only because it was accomplished in six months under budget, but because America was still a wilderness with many regions unsettled. The transcontinental telegraph was completed when buffalo still freely roamed the plains, only eight years after white pioneers settled in the Pacific Northwest.

For separated families, the telegraph was a wonderful invention. People in Europe and America no longer had to wait half a year for a message to travel by boat from one continent to the other and back. But it still required specialized knowledge to directly receive a message. You either had to learn Morse code or depend on the veracity of the message as interpreted by the operator.

Like a tree sending root tendrils into fertile ground, new inventions seem to always spark more inventions in ever-increasing numbers. Now that the viability of distance communications had been established, the public was eager for more scientific wonders. They wanted a way to speak directly to friends and business associates, without the impediment of Morse code and they didn't like those annoying (and unsightly) wires.

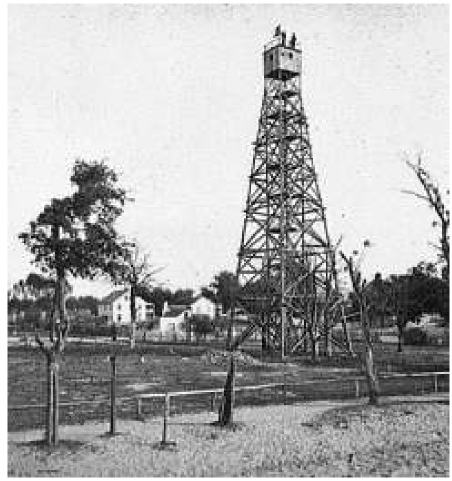
Service providers didn't like the wires either; they were expensive to install and maintain and buffalo were knocking over the telegraph poles in their quest for better scratching posts. Inventors and entrepreneurs were eager to find solutions, since the commercial potential for wireless communications was huge.

By 1864, the telegraph had shown its value as a wartime communications tool. Most Union headquarters could communicate with the leaders, coordinating troop movements and receiving progress reports. However, the lines were vulnerable to wiretapping and false messages could be sent to mislead the unwary. Union forces apparently issued decoy messages that enabled General Sherman to draw Confederate troops out into the open on the pretense of sending a Union troop to Savannah.

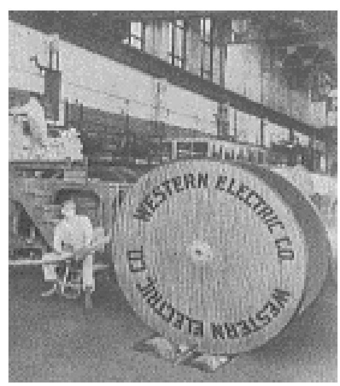
By 1866, Mahlon Loomis (1826-1886) had discovered that the Earth could act as a conductor, which meant a telegraph could potentially be devised with one wire rather than two. He had also demonstrated with kites that a signal could travel through the air without direct contact between kite strings (or wires). By the 1870s, several breakthroughs were on the horizon. Loomis received a patent for a wireless telegraphic system in 1872 and the telephone was poised to make its debut. The convergent development of wireless telegraphy and voice telephony gradually led to the birth of radio communications.

Setting up the first telegraph lines was a significant challenge. The landscape was rough and untamed, supplies were scarce, and everything had to be done by hand. Here, laborers perched atop telegraph poles like crows as the poles were being erected and the lines slung, in April 1864. Once the wires were in place, using them wasn't easy either. The typical 'telegraph station' was little more than a 25-square-foot covered wagon posted near a telegraph pole. [Library of Congress photo by Timothy O'Sullivan, copyright expired by date.]

Once their value had been demonstrated, the nation began laying communications lines anywhere they could travel. A transcontinental line was laid in 1861 and local lines were erected in the more distant communities, gradually being connected to the national infrastructure over the next several decades. The men shown here were installing the Juneau-Skagway telegraph cable. [Alaska State Library Winter and Pond Collection photo, copyright expired by date.]

Left: This giant wooden structure was the Butler's Signal Tower at Cobb's Hill, near New Market, Virginia in 1864. Right: A similarly constructed signal tower in Jacksonville, Florida, photographed at about the same time as the tower on the left. Towers are still used for radio communications. [Library of Congress Civil War Photographs, copyrights expired by date.]

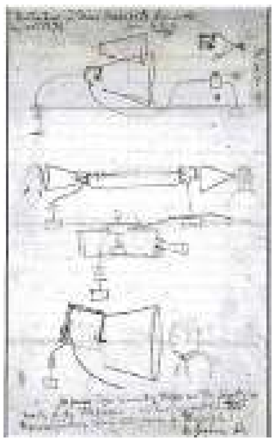
Left: Irwin M. Ellestad at his wireless telegraph station in his home in Lanesboro in 1909. Right: Western Electric cable wound on huge reels. There was a tremendous expansion of transportation and communications technologies in the 1920s with a need for great quantities of cable for cable cars, bridges, electricity, and telegraph lines. The telephone didn't supersede the telegraph system, however, as they came to be used for different types of applications. [Minnesota Historical Society photos, 1909; Library of Congress gift from the State Historical Society of Colorado, ca. 1920; copyrights expired by date.]

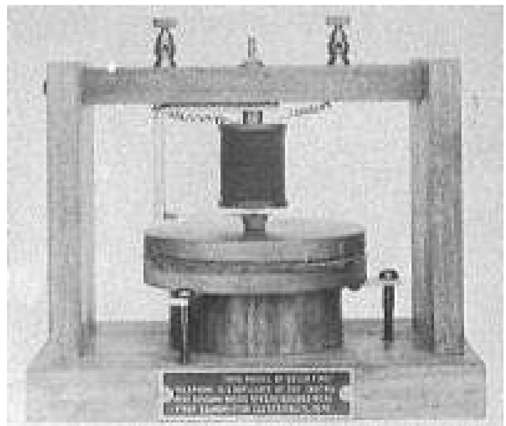
The Telephone

The telephone was originally conceptualized as a 'harmonic telegraph' (a telegraph able to convey tones) by early inventors trying to find a way to send tones, music, or voice over telegraph installations.

The radio telephone is an important tool of modern life, but most telephone communications for the first century were sent over wires. The telephone was invented at almost the same time in both Europe and America, primarily by Johann Philip Reis (1834-1874), Elisha

Gray (1835-1901), and Alexander Graham Bell (1847-1922). A little-credited Italian inventor in Cuba, Antonia Meucci, preceded even Reis and Gray but, unfortunately, his distant location prevented his discoveries from significantly impacting the rest of the world.



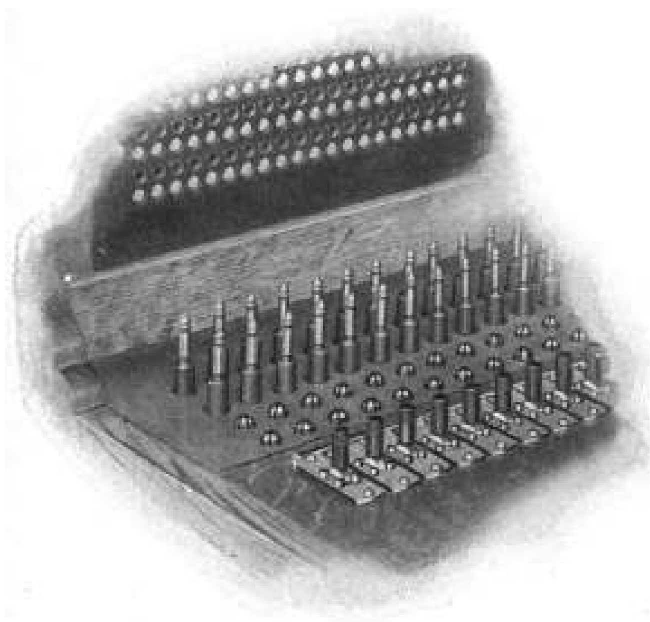


Left: Bell's drawing shows a 'harmonic telegraph' that evolved into the Bell telephone. This drawing shows one person speaking into a cone and another listening at the other end. It is dated 21 March 1876. The date may have been estimated later as there is a subsequent note by Bell at the bottom of the page that states, "As far as I can remember these are the first drawings made of a telephone ..." Right: A model built to reproduce Bell's telephone. It was photographed around 1920. [Library of Congress Alexander Graham Bell Family Papers; Library of Congress Detroit Publishing Company Collection, copyrights expired by date.]

Compared to a telegraph key, a telephone was easy to use, so it's understandable that telephone technology developed and spread rapidly. By 1878, Connecticut had a commercial telephone exchange based on human operators, batteries, and hand-placed fiber-wound cords for establishing electrical connections. The era of the 'Hello Girls' and a new class of telephone surveillants was born ... almost.

In fact, the first switchboard operators were predominantly men. Women were barred from most professional occupations at the time (including most clerical work) and even when they managed to find jobs, they were usually required to quit as soon as they were married. In those days, in many locations, there were town ordinances that a woman couldn't walk down the street unchaperoned by a man, so a single woman trying to seek work or travel to or from work was extraordinarily hampered by social restrictions. As it turned out, however, men didn't do well as switchboard operators. There surely were men who were good operators, but there are reports about men who were impatient, undisciplined, and rude, often cursing out the callers. This motivated business owners to try women instead. These female operators became known as *Voice with the Smile*, *Hello Girls*, and *Call Girls*, the latter taking on a different connotation over the years that may or may not have originated in the early days of telephone technology.

Anyone who has watched television shows from the forties and fifties has probably seen a clip of a telephone operator listening in on people's conversations. In some cases, the eavesdropping was known and expected, since operators at a central point in a marginal connection sometimes helped interpret the voices of the calling parties when they were hard to understand. Crackling lines full of static and noise were common in early telephony. As the connections improved, however, the operator was supposed to turn a deaf ear during the conversation, listening only if he or she was summoned or needed to end the connection or establish a new one. Nevertheless, anecdotes of phone operators eavesdropping are numerous.

Early switchboards consisted of a series of jacks and holes in which to place the jacks. When a call came in on a line associated with a jack, it was electrically connected to the line belonging to the callee by manually plugging the jack into the appropriate hole. A headset worn by the operator allowed the operator to monitor the call in order to ensure the connection and terminate it when appropriate. Later systems added lights to alert the operator of incoming calls and disconnections so that each call need not be monitored (which also ensured better privacy). These switchboards eventually evolved into multiline or private branch exchange (PBX) telephone systems which are more difficult to tap than single line phone systems. [Switchboard c1909, public domain by date.]

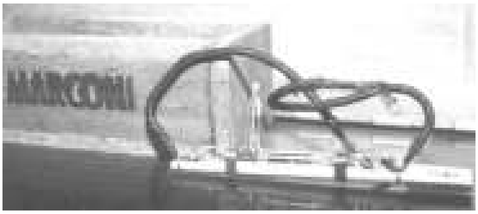
Coherers

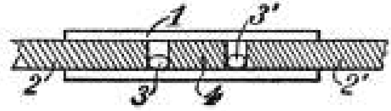
Wired telephone automation and technology improved and spread while inventors were seeking ways to devise practical wireless systems.

A number of individual discoveries in the late 1800s led to the development of simple but effective radio transmitters and receivers. One of the most important of these was the invention of the *coherer.*

David Hughes (1831-1900) emigrated from Britain to America where he became a schoolteacher and an inventor. He is responsible for a number of audio and telegraph devices that furthered the development of radio and telegraph technology. In 1877, Hughes invented a carbon microphone. By 1878, he had developed a coherer, a device which allows particles to clump together in response to an electrical discharge. He was also one of the first to devise a printing telegraph.

During this time, research into wireless systems of communication continued and the electrostatic wireless telephone was patented by Amos Dolbear, a professor and science writer, in 1886.





The Marconi coherer from the Bellingham Radio Museum collection (left) is constructed of a thin glass tube with an ivory base and two fiber-wound wires to make the electrical connection. On the right is a diagram of a Castelli coherer used by Guglielmo Marconi in transatlantic communications experiments. The conductor plugs on the ends (2,2') are separated from an iron plug in the middle (4) by two mercury pockets (3,3'). [Classic Concepts ©1997, used with permission. Diagram: Scientific American 4 Oct. 1902, copyright expired by date.]

In 1890, a French inventor, Édouard Branly, developed the Branly detector, a radio-wave detector that incorporated a coherer. This detector was later adapted by Guglielmo Marconi. (Marconi was also known to have adapted the Castelli coherer for transatlantic experiments and to design some coherers of his own.) The coherer was an important component of the detector because it formed a sort of simple 'switch.' The particles in the tube could exhibit two *states*, loose and clumped. The electrical conductivity was lower or higher, depending on the state.

In 1894, Oliver Joseph Lodge (1851-1940) did a number of experiments with coherers. His research contributed to the knowledge on tuning in radio waves and transmitting over longer distances.

Automatic Telephone Switching and Marine Radio Systems

Technological surveillance as a field was about to become a powerful force in society. Now that radio technology was emerging and telephone systems were being improved, significant opportunities for monitoring newsworthy information or sensitive financial communications presented themselves. Some people recognized the potential for abuse and set about finding ways to reduce the opportunities for eavesdropping.

The invention of the *direct-dial* telephone system specifically came about because a businessman suspected his competitor of enlisting a phone operator (apparently the competitor's wife) to aid him in getting customers. Almon B. Strowger was an American mortician with a talent for invention. When he suspected that his business was being undermined by a competitor working in cahoots with the phone operator, he developed an automatic telephone switching system. Strowger designed a *step-by-step switch* which could connect a local call without assistance from a human operator. He patented the step-by-step system in 1889 and then a *dial-switch* system in 1892.

At about this time, Romaine Callender, a Canadian music teacher and instrument maker, began patenting telephone systems based on a different model. By 1895 he had developed a different type of automatic switching system, aided by the expertise of the Lorimer brothers. Automatic switching systems began to remove the human element from local calls.

As land-based telephone switching systems evolved, so did marine radio communications. Even though the technology was very new, British warships were being equipped with radios, by 1899, developed by the young Italian inventor, Guglielmo Marconi (1874-1937). The systems were limited in range, less than 100 miles, but they were important tools of strategic cooperation. Only two years later, Marconi demonstrated that it was possible to send signals across the Atlantic Ocean from Canada to England, a distance of more than 2,000 miles.

In 1901, Strowger founded Automatic Electric and marketed his equipment to independent phone companies that were in competition with the Bell Telephone company. Surprisingly, automatic systems didn't become prevalent in small communities until almost 50 years later, and in the 1960s there were still manual switchboards in small businesses and small communities throughout North America and Europe.

In spite of their slow introduction, automatic telephone switching systems changed the ways in which eavesdroppers tapped into phone conversations and a variety of wiretapping systems and devices were developed (or commandeered from telephone technicians). Many early incidences of wiretapping were carried out with telephone lineworker phonesets which consisted basically of a phone handset with clips to hook into a phone line. While it was a rather crude form of surveillance, this device was widely used.

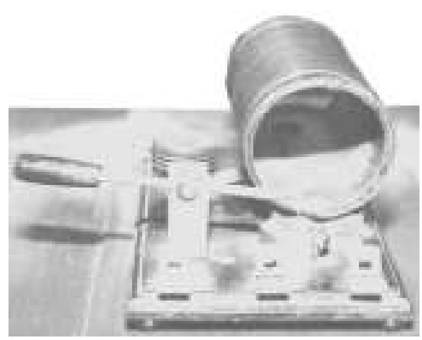
Assertion of Rights and Priorities

At the turn of the century, the U.S. government made a strong political move and acknowledged the importance of wired communications by granting broad rights of way for the installation of communications systems through public lands. In a U.S. Statute at Large published in 1901, known as the *Right of Way Act*, the Secretary of the Interior was authorized to "permit the use of rights of way through the public lands, forest and other reservations of the United States, and the Yosemite, Sequoia, and General Grant national parks, California" for electrical power, telephone, and telegraph communication, irrigation, and water supply.

4.b. Wireless Communications and the Birth of Radio

Crystal Detectors

The *crystal detector* was the next significant step in the development of radio communications. A crystal detector was an elegantly simple way of harnessing the natural resonating properties of a crystal and amplifying the vibrations so they could be heard by humans. Some types of crystals have natural rectifying properties. This means that they permit current to flow through them more readily in one direction than another. This is extremely useful in electronics because it allows a certain amount of control over the energy flow.



Left: A diagram of a crystal detector showing the round mounting base that holds a crystal, the catwhisker wire that makes physical contact with the crystal and transfers the vibrations to the main unit, and two leads for the headphones. Right: A crystal detector with a tuning coil, wound around a hollow cylinder, from the Bellingham Antique Radio Museum. [Classic Concepts, ©1997, used with permission.]

Galena and carborundum were two of the substances found to act as natural rectifiers. By mounting galena or carborundum crystals in a base so that they were constrained, but not too tightly (they needed to be able to vibrate), it was possible to detect their vibrations with a fine wire called a *catwhisker* and direct the vibrations to a pair of sensitive (high impedance) earphones or an amplifying component (amplifiers as we know them had not yet been invented). In other words, crystals were used to act as basic radio receiving units. The device didn't require any electricity and could be fairly easily transported. By carefully selecting the crystals, different radio broadcast frequencies could be tuned in.

In 1908, Greenleaf Whittier Pickard filed a patent for a crystal detector (they had been marketed as early as 1906) and in 1911 he patented a crystal detector with a catwhisker or *feeler*. Tuning coils, which consisted of specific lengths of wire wound carefully around hollow cores were added to some crystal detectors. In time, crystal detectors superseded cohering detectors, though some hobbyists still enjoy collecting and using them.

Electron Tube Technology

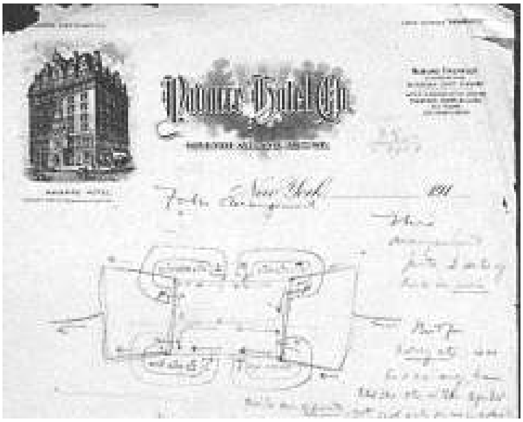
Crystal detectors (sometimes retroactively called crystal radios) had some great advantages. They didn't require power and they had new and exciting capabilities. They were sufficiently useful that the U.S. Armed Forces ordered quantities of 'industrial strength' crystal detectors for work in the field. Radio-operator training began to emerge. The detectors also had some significant disadvantages. The user had to select good crystals, keep them carefully oriented, adjust the contact tension of the catwhisker, and listen with earphones. The broadcast couldn't easily be heard by anyone else in the room. This was good for security, but not so good for conferencing or public information broadcasts.

Scientists sought diligently for ways to amplify the signal so that radio transmitters could send stronger signals and receivers could amplify the incoming signals. The solution came in two stages. The first was the Fleming valve and the second was the Audion triode.

John Ambrose Fleming (1849-1945) was an English engineer who had been investigating the *Edison effect*, discovered by Thomas Alva Edison (1847-1931) in 1883 (patented in 1884). Many significant discoveries are based on small observations. While working with light bulbs, Edison sealed a wire inside a glass bulb near a filament and noticed that a spark could jump the gap between the hot filament and the metal wire. Fleming had been trying to improve wireless receivers and also had been investigating the Edison effect in 1904. In the course of his research, he developed a two-electrode bulb which could be converted to direct current (DC) when attached to a radio-receiving system. The system didn't provide much improvement over previous methods but the concept opened up a new class of devices. Just as the crystal in a crystal detector acted as a rectifier, the elements in Fleming's *diode* also acted as a rectifier. The electron bulb just needed one more thing to make it a truly great invention. It wasn't Fleming, however, who made the breakthrough.

Lee de Forest (1873-1961) was an ambitious, prolific inventor. He was not quite as brilliant in physics as a few of his remarkable contemporaries and he was never blessed with good interpersonal skills, but de Forest was highly gifted and exceptionally tireless and persistent in his search for new discoveries and their practical applications.

De Forest acquired a Fleming valve and experimented with it, adding a third element, thus creating the first *triode*. This third element was the key to the future of electronics. In a Fleming valve, the electrons flowed at will from the cathode to the anode, but there was no way to harness their power. In the triode, the third element acted as a 'controlling grid,' providing a way to influence the flow. This was a significant achievement and de Forest recognized its commercial value, named it the *Audion*, and patented his most important invention in 1907. He devised many more inventions and developed a number of practical applications based on the Audion, including wireless telegraph receivers.



Left: A portion of Lee de Forest's notes on hotel stationery from around 1915. Right: A selection of electron tubes from the great variety that evolved from the original triode patented by de Forest in 1907. These examples are from the Bellingham Antique Radio Museum collection. [Library of Congress, copyright expired by date. Classic Concepts ©1997, used with permission.]

The age of electronics had begun. Electron tubes provided designers with a whole new way to build radio sets and thousands of other types of devices. The control and amplification of radio signals were greatly enhanced by this technology. The simple, tubeless crystal detectors were soon superseded by radios that included tubes. With a means to amplify radio wave signals, it was now possible to broadcast over longer distances to a bigger audience, ringing in the age of radio broadcasting and the age of radio surveillance.

4.c. Radio Broadcasting

Nathan Stubblefield broadcast his voice through the air without wires in a public demonstration in 1902, in Philadelphia. He had apparently first made it work in 1892, but did not obtain patents until 1908. Stubblefield's name has almost been forgotten, because he never managed to successfully market his invention [Kane, 1981].

Radio broadcasting essentially began in 1906 with the aircasts of inventor Reginald Aubrey Fessenden (1866-1932). From that time on, there were many amateurs and professionals who were excited about the technology and eager to try it out, but they discovered that airwaves had to be shared. Cooperation was essential to the orderly evolution of the field and not everyone was 'playing fair.' The government responded by passing an Act of Congress to regulate amateur broadcasts in order to prevent interference with government stations and marine communications.

The sinking of the Titanic had focused the nation's attention on the necessity of 24-hour monitoring of communications at sea. The Carpathia went to the aid of the stricken passengers, but the Carpathia was not the ship that was closest to the Titanic when it was sinking. The nearer ship had failed to respond to her distress calls because the wireless operator was off-duty and hence unaware of her plight.

As a result of the tragedy of the Titanic, by 1912 all ships were required to have wireless equipment and more stringent regulations as to how and when the wireless systems were to be monitored were stipulated.

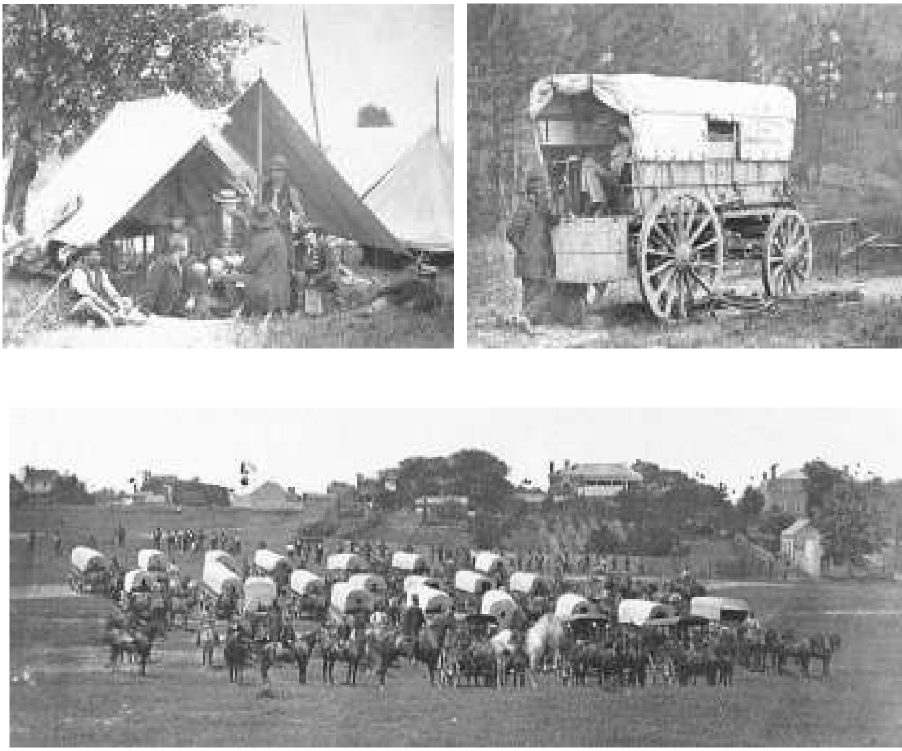
With the *International Radio Convention* and the *Radio Act of 1912*, the U.S. Department of Commerce was given regulatory authority by the U.S. Congress and unregulated use of the airwaves came to an end. It also marked a time when commercial, government, and amateur use began to become distinguished by wavelength regions in which they were permitted to operate. In terms of surveillance, this made designated 'government' frequencies of particular interest to foreign nations. It also made each group protective of its 'territory,' a situation which still exists today.

Early radio stations were often improvised out of whatever materials and space were available, but gradually, over the period of a few years, facilities and their organization improved. Top Left: Minnesota's first broadcasting station improvised at the side of a road, in 1914, with James A. Coles (left) speaking into a microphone. Top Right: The WLAG broadcast station's transmitter room in the Oak Grove Hotel, Minneapolis in 1920. Bottom Left: The WCCO broadcast station in 1920. Bottom Middle: The WBAH broadcast station in Dayton, 1922. Bottom Right: The Dayton Company Broadcast room in 1923. [Minnesota Historical Society photos, copyrights expired by date.]

The American Civil War and World War I

One of the results of the Civil War was the belated recognition of the rights of black Americans (in principle if not fully in practice). As a result, in 1887, African-American citizen Edward William Crosby, a writer and telegraph operator, was publicly acknowledged as the telegraph editor for the Buffalo Sunday Times.

Portable radios had some obvious advantages. In 1912, Ralph van Deman implemented the first U.S. Army mobile intercept van, called a Radio Tractor unit. In 1916, Brig. General John Pershing used a number of these radio systems to communicate among units crossing the Rio Grande on the way to Columbus, New Mexico.



Top: Military telegraph operators worked under less than ideal circumstances. They are shown here stationed in tents at Bealeton (left) and a Military Telegraph battery wagon in Petersburg (right) during the American Civil War. Bottom: The Military Telegraph Corps in fallen Richmond, Virginia in 1865. [Library of Congress Prints & Photographs Division, mid-1860s, copyrights expired by date.]

A wireless broadcasting being erected tower at Fort Brown in September 1914. Middle and Right: The erected wireless tower with men on the mast. [Library of Congress South Texas Border Collection of the Robert Runyon Photograph Collection, copyrights expired by date.]

In 1917, General John Pershing used major newspapers to recruit single female telephone operators for Signal Corps duties in France. They were required to be healthy, college-educated, and able to fluently speak French and English. Four hundred and fifty were selected for training and, in the spring of 1918, the first 33 operators were transported to France. Because they were near the front lines, the women were issued gas masks and steel helmets, and worked shifts that sometimes lasted as long as 48 hours.*

Commercial Broadcasting and Political Alliances

Commercial broadcasting began in Europe in 1913 and, by 1919, in America, Charles 'Doc' Herrold and Frank Conrad had provided broadcasts for local listeners out of primitive 'stations.' In 1920, KDKA became the first commercial station in America. The Radio Corporation of America (RCA) was also founded in 1920. David Sarnoff, who was associated with RCA, was instrumental in the forming of the National Broadcasting Corporation (NBC) in 1926. In 1927, the Columbia Broadcasting System (CBS) was formed. Commercial radio was born, and with it, competition for airwaves became big business.

Radio technologies, from the original telegraph that preceded radio to modern wireless telephones, have played an increasing role in all government activities from campaigning to running the Presidency.

One important milestone in government use of radio during this period of growth, was the broadcast of the Presidential election returns of 1920, but the full impact of radio on communications and the political system was not felt for another three or four years. The Coolidge papers illustrate how radio was further incorporated into political activities and how big business promoted the activities of selected politicians and vice versa. E. McDonald, President of the National Association of Broadcasters, wrote to President Calvin Coolidge on 5 Nov. 1923, with a compelling argument that radio was a better way to reach voters than 'stumping' (foot-campaigning). An excerpt from the letter states:

> "... I can see where you, for instance, may relieve yourself of the most malignant of all the breaking down processes to which you will be subject, the speech-making tour. This is the worst of presidential tensions.... I need hardly mention how a speech-making tour preys upon one's health. Talks from train platforms under all manner of weather conditions, talks in congested auditoriums, countless interviews between times, meals under more or less strain, ... all are incidents of the speech-making tour and all have a telling physical effect, and are unnecessary.
>
> Science comes to the rescue and offers radio as a pleasant substitute for the old nerve-racking method. A speech over radio can be made with no more tax than the reading of a paper into the delicate microphone. You could calmly, unobserved if you wished, certainly undisturbed, deliver your talks under the ideal conditions of your study in the White House and be heard by every citizen of the United States who chose to give ear by means of a radio set...."

McDonald wasn't entirely correct about personal campaigning being unnecessary, but he was a catalyst in an important chain of events that resulted in far greater use of the airwaves by those in power than in the past. Coolidge used radio to campaign and to broadcast messages to the nation's radio-listening population during the mid- and late-1920s. It may also be true that covert political communications were carried out to a greater extent from this point on, given increasing familiarity with the technology in White House circles. The radio-listening audience greatly increased over this period, partly in response to the political broadcasts.

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*Upon return to the United States, the female Signal Corp operators were not accorded veteran status or benefits, because Army Regulations were written in the male gender.

Calvin Coolidge addresses a crowd through large radio-broadcast megaphones in July 1924 (left) and stands next to a radio-equipped automobile with his hand on the speaker on 14 Aug. 1924, during his campaign for the Presidency. Right: Coolidge posing in a group shot with Hoover and members of the Radiomen's Association in Oct. 1924. [Library of Congress National Photo Company Collection, copyrights expired by date.]

A 1925 report on radio broadcasting prepared by C. Coolidge Parlin, a manager with the Curtis Publishing Company, indicates revenue growth from about $2 million in 1920 to over $350 million in 1924. The number of radio-tube-based receiving sets increased over the same period from about 60,000 to almost 4 million with over 560 licensed stations in operation. Thus, there was now a compelling way to send the same information to everyone across the continent at the same time.

Capitalism abhors a vacuum and the tremendous interest in radio communications spurred the growth of companies supplying radio services and equipment. In the 1930s, radio broadcasting was in the hands of big broadcast corporations and small amateur stations; consumers primarily purchased listening equipment (radio receivers) and most amateur radio transmitting systems were home-brewed from parts or kits. Regulation of the broadcast industry and the requirement to demonstrate competency further narrowed the field to the more technically inclined. For this reason, many of the radio products were sold in electronics stores, rather than department stores. Radio Shack got its start in 1934 and is still one of the better known sources of hobbyist supplies and consumer-level surveillance devices, including metal detectors, radio scanners, intercoms, video cameras, and phone recording devices.

By 1932, the New York Police Department was using mobile radio sets in patrol cars, receiving broadcasts from WPEG, the police department's radio station. More than 5,000 radio calls were made in the first six months of their operation. By 1937, the force was experimenting with two-way radios, but full implementation was delayed for a little over a decade by World War II.

By the late 1930s, television was being advertised to radio hobbyists (more about the history of television, which is a radio-wave technology, is covered in the Visual Surveillance chapter).

Regulation and Growth of the Radio Industry (Air Wars)

Airwaves are not unlimited and, in the name of competition, larger stations drowned out smaller ones in the early days of radio. Regulation of airwaves is handled by different agencies in different nations and a certain amount of international cooperation is essential because broadcast waves don't stop at international borders. In the United States, the jurisdiction for regulating the broadcast industry was passed from the U.S. Secretary of Commerce to the Federal Radio Commission (FRC) in 1927.

At first, mobile radio communications were strictly restricted to VHF broadcasting for aircraft operations only by the FRC, but the FRC eventually opened up "portable mobile" communications to broader use.

In 1933, the first radio 'scanners' in the form of *all-band receivers* were issued by the FRC to selected agencies to monitor radio communications. These were the first government-sanctioned general-purpose radio surveillance devices. Monitoring stations were responsible for monitoring communications for a couple of hours a day to check compliance with FRC broadcast regulations.

In 1934, the FRC responsibility was handed over to the Federal Communications Commission (FCC) and essentially remains there still. The FCC continued the regulatory monitoring of radio transmissions and acquired oscilloscopes to aid in this task. Radio surveillance tools were becoming more specialized and more sophisticated and the U.S. Congress accorded the FCC broad-ranging powers to listen into a wide spectrum of broadcasts. By this time there were hundreds of broadcast stations and about 60,000 amateur radio operators around the world, 75% of whom were in the United States and Canada.

Radio Weathercasting and Search and Rescue Surveillance

A substantial segment of the radio surveillance industry is dedicated to monitoring the airwaves for emergency calls, often resulting in the radio and television broadcasting of severe weather warnings or the coordination of search and rescue operations. The Amateur Relay Radio League (ARRL) Emergency Corps was established in the mid-1930s to provide emergency communications, as a result of storms, floods, and the loss of a plane in the Adirondacks in December 1934.

By 1938 FCC regulations for "portable mobile" was further expanded to permit maritime mobile communications within certain location and frequency restrictions.

The Evolution of Radio Devices

Alternating current (AC) systems were gradually beginning to replace direct current (DC) battery-operated systems in the early 1930s, a trend that continued until the early 1960s, when portable radios (and hybrids) became popular. The use of alternating current permitted larger, more complex devices to be manufactured.

The design of electron tubes continued to evolve until, in the early 1930s, higher-gain screen-grid tubes were beginning to replace the early triode tubes for radio applications.

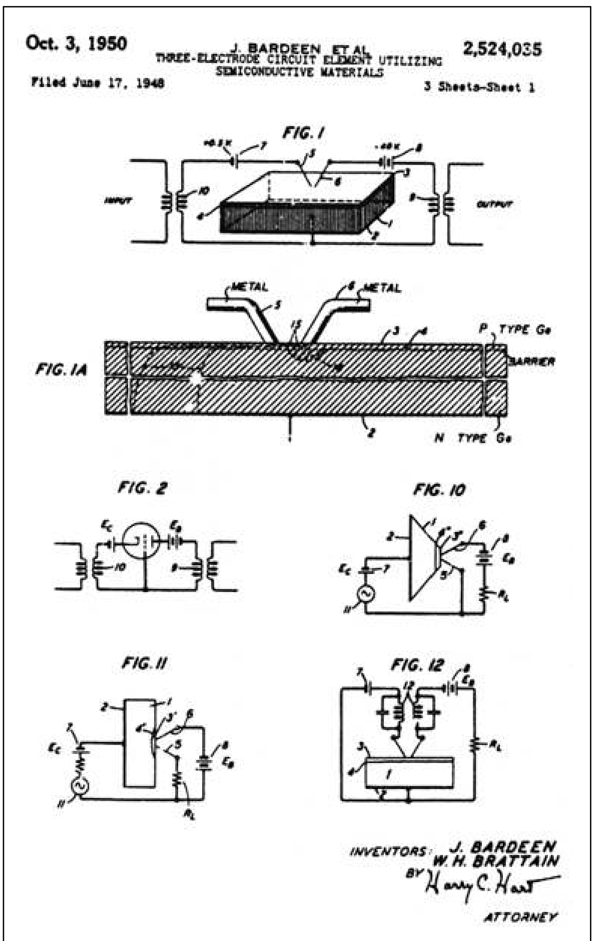
By the late 1930s, regenerative receivers, which had been a mainstay, were being replaced by superheterodyne receivers.

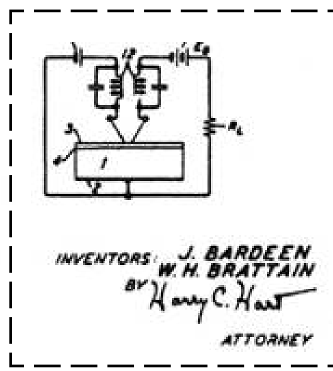
The Doppler effect has been mentioned in a number of chapters in this text. Briefly, it describes the changes in frequency that are created when an object generating a pressure wave is moving relative to the receiver. This important concept was being investigated for its potential use in radio systems. By the 1940s, Doppler concepts were being used to create radio direction-finding systems and in the late 1940s, Servo patented a quasi-Doppler direction-finding system. They have also been used in sonar and synthetic-aperture radar (SAR).

Up to this point, radio broadcasts used a method of modulating a carrier wave called *amplitude modulation* (AM). *Frequency modulation* had been discussed in scientific circles but the general consensus was that it was impossible. Almost everyone held this point of view except a gifted and persistent inventor named Edwin Howard Armstrong (1890-1954). In the early 1940s, after a decade of dedicated effort, Armstrong proved that FM broadcasting was not only possible, but had some important advantages over AM broadcasting.

Radio Communications in Wartime (Air Wars II - The Foreign Menace)

On 24 October 1940, J. Edgar Hoover described wartime espionage operations in a memo





Top: The inventors of the transistor were acknowledged on a first-day envelope by the U.S. Postal Service. Bottom: Diagrams from the original patent for the transistor, developed at Bell Laboratories in 1947. The patent document is signed by Bardeen and Brattain, although William Schockley and Ralph Brown are also credited with contributing to the technology. [First Day Cover from the collection of the author, used with permission; U.S. Patent and Trademark Office, public domain.]

to President Truman. The communication included information on infiltration of a German Intelligence Service radio station:

> "The Federal Bureau of Investigation has been operating for a period of many months on the eastern seaboard a shortwave radio station which is utilized by the German Intelligence Service for transmission of reports of German Agents in the United States to Germany. The Directors of the German Secret Service in Germany also communicate with this station furnishing instructions and requests for information to the operators of this station for transmittal to German Agents in the United States. Needless to say, no one knows that this German communication system is actually controlled and operated in the United States by Special Agents of the Federal Bureau of Investigation, who are considered both by German Intelligence Services in Germany and in the United States to be actual members of the German espionage ring. Through this station the Federal Bureau of Investigation has been able to develop voluminous information concerning the identity of German agents in the United States, their movements, interests and program...."
>
> ".... Arrest is considered inadvisable except in extraordinary cases because counter espionage methods of observation and surveillance result in a constantly growing reservoir of information concerning not only known but also new agents of these governments...."
>
> [John Edgar Hoover, FBI, *Memo to Major General Edwin M. Watson,* 24 October 1940, declassified 3 April 1975.]

In February 1941, a Presidential Directive established the Foreign Broadcast Monitoring Service within the FCC.

In December 1941, due to World War II, the U.S. government virtually shut down amateur radio.

Radio Security Innovations

During the War, many American celebrities offered their services as volunteers and entertainers to support the efforts of the U.S. Government and American service members. Hedy Lamarr (Hedwig Eva Maria Kiesler 1913-2000) had a keen analytical intelligence that matched her beauty and talent. In conjunction with George Anthiel, she worked out a system of radio security called *frequency hopping*. This is a *spread-spectrum* technique in which a radio transmission is 'hopped' through a series of frequencies in order to escape detection and, in some cases, to create a clearer signal by using good channels. Lamarr developed frequency hopping in her search for a better system for guiding torpedoes that was less likely to be jammed by opposing forces. Antheil suggested a means to synchronize the frequencies with paper tape, but it was not an easy method to implement at the time and didn't become practical until later when it could be handled automatically by electronics. Lamarr and Antheil received a patent in 1942 for their important innovation.

Frequency hopping became an essential aspect of military communications, and is now at the heart of a large proportion of wireless communications. Unfortunately, by the time electronics and the world caught up with Lamarr's idea, the patent had expired and she never received any monetary benefit. Unfortunately, she didn't receive credit for the idea either until decades later when women began to be acknowledged for their scientific contributions.

Meanwhile, surveillance of foreign communications continued to be a high national priority. In July 1942, the Foreign Broadcast Intelligence Service was established to succeed the Foreign Broadcast Monitoring Service by an order of the Federal Communications Bureau.

Its responsibility was to record, translate, and analyze foreign broadcast programs.

Radio Operator Robbins at his radio post in a hut in New Guinea. [U.S. Army May 1943 Signal Corps Historical Archive photo by Harold Newman, released.]

In December 1945, the FCC Foreign Broadcast Intelligence Service was transferred to the Military Intelligence Division, War Department, by an order of the Secretary of War and then, in August 1946 to the Central Intelligence Group (CIG), National Intelligence Authority. Following the war, it was succeeded by the Foreign Broadcast Information Service.

Wireless communications over distance improved but, even with improving technologies, it was found that radio waves still required good lines of sight, relay stations, or good reflective surfaces off which to bounce signals. In armed conflicts, these aids to radio communications were often absent. In the Korean War, in the early 1950s, for example, it was discovered that the rugged terrain significantly hindered radio signals. At the time, handheld portable FM radios (AN/PRC-*x*), with broadcast ranges varying from 1 to 8 miles (less in rough terrain) were favored for communications between service members. Since satellite relay stations were not yet available, ground-based radio relay stations had to be improvised and, to escape detection, often had to be moved, under less than ideal circumstances.

Innovations in Radio Communications

In 1946, Signal Corps technicians in New Jersey successfully managed to bounce radio signals off the Moon. Thus, it was demonstrated that radio waves could be used to communicate through space, a concept that would later be applied to communications satellites.

In 1947, scientists at Bell Laboratories developed the transistor, which would eventually supersede large, fragile, power-consuming vacuum tubes for most applications.

The demand for radio waves was beginning to exceed the supply by the late 1940s, so the Federal Communications Commission (FCC) imposed a temporary freeze on applications for TV broadcasting licenses. This doesn't seem to have discouraged innovation, however, and the technology continued to evolve. What was initially supposed to be a moratorium lasting only a few months, was finally lifted by the FCC four years later.

Because it is a visual medium, people often forget that television broadcasting is a radio technology (described in the Visual Surveillance chapter). By 1950 more than four million televisions were estimated to be in use in the United States and Canada, a number that more than doubled by the end of the year.

The use of radios was increasing as well, and transistors made it possible to fabricate small, handheld *transistor radios* and portable radio systems that could be mounted in cars.

In the 1950s, some innovative radio technologies were developed by the Stoddart Aircraft Radio Company, which had supplied a number of radio technologies to Howard Hughes and to the military during the war. Headed by Richard R. Stoddart (1900-1972), the company produced what has been called the first *audio-spectrum* receiver. We typically classify radio and audio spectrums as different phenomena. Radio is an electromagnetic wave-particle phenomenon that we can't sense, whereas audio is a longitudinal pressure-wave phenomenon that we can hear within audible frequencies. The Stoddart audio-spectrum receiver (NM-40A) was a detection instrument that could detect frequencies down to about 30 Hz. Up to this time, sets typically tuned to frequencies ranging from about 100 MHz to about 1 GHz. The NM-40A could be used as either a narrowband or a broadband receiving system, separately receiving the electrical and magnetic components of a wave, characteristics that made it suitable for scientific research [Layer, 1993].

Another historic milestone of the early 1950s, that took transistor technology to the next level, was the idea of creating electronics components as solid blocks, called *solid-state technology*, an innovation proposed by Geoffrey W. A. Drummer. This was the beginning of integrated circuits and large-scale integration (LSI) technology, which contributed dramatically to the evolution of electronics and the development of miniature components and microcomputer systems.

4.d. Modern Electronics

Miniaturization and Memory

The development of the transistor was one of the most significant inventions in all of electronics history. The evolution of large-scale integration (LSI) and very-large-scale integration (VLSI), following the invention of the transistor, eventually put small computers and handheld radios within economic reach of the general public. It also linked them in important ways. Radio and computer technologies had already been associated by shared mechanisms and physical attributes, but from this point on, their evolution would be inextricably intertwined, with a large amount of computer technology converging with almost every aspect of electronics and radio communications.

Prior to the development of VLSI electronics, computers and radio scanners were not very flexible. Computers were programmed by manually changing wires, somewhat like the old telephone switchboards. Radio scanners were tuned by replacing crystals that would resonate at specific frequencies. Without computer memory, everything had to be hard-wired and hand-tuned. Choices were limited to a few computer programs or a few radio frequencies. The ability to store and retrieve electronic information is, in itself, probably as important as the invention of the transistor to every aspect of surveillance devices as we know them today.

Global Politics and the Increase in Surveillance

Following World War II, bomb shelters, air raid siren tests, and war drills created a background to people's lives during the *Cold War,* the political unrest between the Soviet Union and western nations. The McCarthy witch-hunt was chilling evidence of repressed fears and the willingness of people to sell each other out when faced with threats from government representatives. Surveillance of the U.S.S.R. was considered a priority and surveillance devices and techniques flourished.

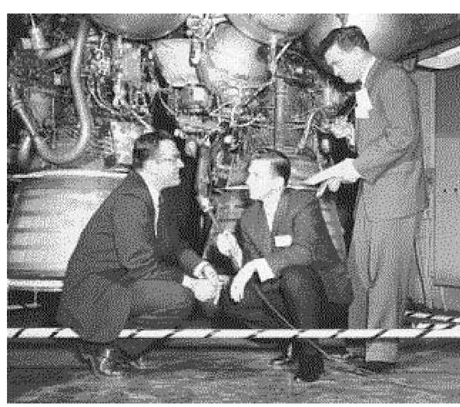
In 1963, the Emergency Broadcasting System (EBS) was established. Television viewers were periodically reminded of its existence by short interruptions in scheduled TV programming with a sustained tone followed by an announcement about emergency instructions. Baby boomers in western nations all came to recognize the announcement, even it they haven't heard it in years, "This is a test of the emergency broadcast system.... This is only a test...."

The Birth of Satellite Communications

Arthur Charles Clarke (1917-), an English scientist and science fiction writer, demonstrated remarkable foresight when he described in considerable detail in the late 1940s the future use of geostationary satellites for communications devices. A decade later, the Russians took the first step toward practical implementation when they launched Sputnik I and, a month later, Sputnik II, stimulating the competitive decade of the 'Space Race.'

The Score satellite was the first voice satellite launched into space by the American space program. Both voice and code could be sent over tremendous distances without underwater cables or dozens of relay stations. In 1958, President Eisenhower sent a Christmas greeting through the Score satellite. The world of global wireless communications through satellites opened up with these initial Russian and American developments.

Even their proud inventors will admit that satellites are some of the funniest things you've ever seen. Some look like garbage cans, others resemble umbrellas, still others look like oversized children's party balloons. The first amateur satellite looked kind of like a small homemade bomb and even some of the most sophisticated satellites look like they were built in an abandoned garage. Nevertheless the basic physics in these devices is extraordinary and their capabilities often go far beyond their homely exteriors. Both passive and active satellites were developed, although the early passive satellites, that merely reflected radio waves, were superseded, for the most part, by active satellites.



Left: An early 100-foot satellite named "Echo," designed by the Space Vehicle Group at the Langley Research Center in a test trial in June 1961, before being sent into space (uninflated) to be inflated when it reached the desired position. Right: The evolution of radio and television broadcasting brought the American people and their Government into a new relationship. It was now possible for taxpayers to see how their money was being spent, and the development of the space program, among other government-funded programs, could be shared with the viewing public. This is a WHK radio interview in December 1963 at the Space Power Chamber with Centaur in the background. [NASA/Langley Research Center news photo; NASA/GRC news photo by Reidel, released.]

A few years later, astronauts on the Moon began transmitting images and sound that ushered in a whole new era of exploration and communications. By the mid-1970s, media programming could be broadcast across the nation by satellite. The Turner network and PBS were two of the early organizations that took advantage of the new technology.*

The Microcomputer Revolution

In the early 1970s, Intel introduced new, tiny computer chips that would spur the evolution of the first desktop computers. By the mid-1970s, the quiet revolution in electronics miniaturization and memory-storage was beginning to result in programmable microcomputers and radio scanning devices. Prior to the mid-1970s, only the government and large corporations could afford the huge operating rooms, equipment, and staff that were necessary for complex computing or radio surveillance activities. Suddenly this was no longer true. By early 1975, some significant hobbyist electronics from the previous couple of years came into the mainstream (or at least the mainstream of consumer electronics buffs) and the commercialization of computing and surveillance industries was picking up speed.

Robotics benefited greatly from the creation of tiny chip technologies. It was now becoming possible to design small, 'intelligent' teaching, learning, detection, and surveillance devices that could explore their environments, gather objects and information, and report the information back to a central database or controlling console. Radio technology made it possible to control and communicate with the robots from a distance, making new forms of production and exploration possible.

Left: Rocky the Robot, a radio-controlled prototype for a planetary exploration robot, shows how it can navigate over rough terrain and pick up samples along the way. The 56-pound robot shown here in Sept. 1991 was a test robot for future lighter robotic rovers that could be sent to the Moon or Mars. Rocky III was designed and built at the Jet Propulsion Lab in California. Right: A radio frequency ACR location beacon weighing 190 grams was designed to be part of a survival kit taken into space by Mercury astronauts in 1962. [NASA/JPL news photo, released.]

Radio Communications and New Industries

By the early 1980s, business owners, educational institutions, and technophiles were arming themselves with radio scanners, sophisticated calculators, and programmable personal computers and using them to listen in on rest of the world. Marine radio and radar systems got smaller and cheaper and could now be purchased by small craft owners. Truckers and law enforcement personnel were no longer the only people using radios while driving; ordinary motorists could now afford them, too. The CB radio craze swung into high gear, computer

*The interesting evolution of satellite technologies is discussed further in the Aerial Surveillance chapter.

modems allowed people to intercommunicate in new ways, portable scanners could suddenly handle hundreds of channels, and portable radio players and headsets pervaded beaches, schoolyards, and shopping malls. The reprogrammable miniature electronics revolution of the 1970s may someday overshadow the industrial revolution in terms of its importance in our history books.

The value of radio technologies for emergency ambulance, firefighting, and law enforcement services had been recognized for many decades, but small, efficient, portable systems didn't really become prevalent until the 1970s and 1980s. Handheld radios would now become a great boon to field workers, rescue professionals, and scientific and military users. As the systems became less expensive, events organizers and crowd control professionals began using them, as well. Portable radio technologies were also beginning to be used by private detectives and private security agents on behalf of their clients, making it possible for them to work in closer cooperation with colleagues and accomplices.

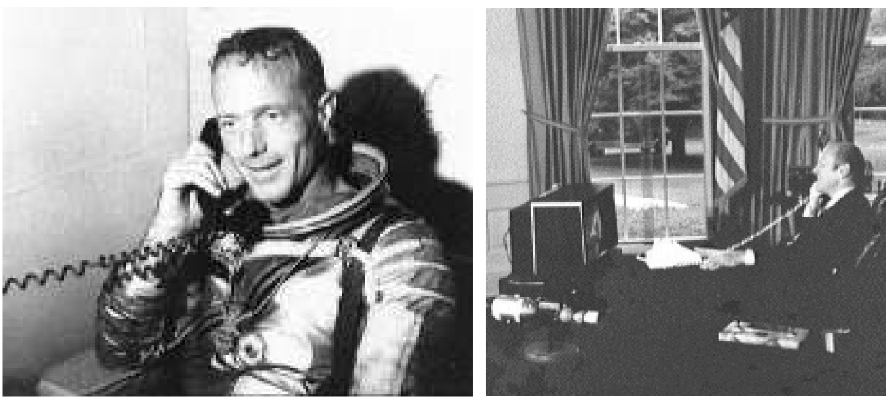
As cell phones caught on, it became clear that they could be used by stranded motorists to call for help, or to report crimes, or unexpected news events. Reporters began directly transmitting news features to their editors from their laptops, using radio-frequency modems.

The Pressure for Airwaves

At the same time that electronics was undergoing major evolutionary changes, our understanding of radio wavelengths was improving. Many radio frequencies were once considered 'junk frequencies,' in other words, we knew the frequencies existed but not how to harness their capabilities. Prior to the 1980s, ultra-high frequency (UHF) and very-high frequency (VHF) were used for a high proportion of radio broadcasting applications. Microwave frequencies were considered useful only for radar applications and many of the 'junk' frequencies were allocated to amateur radio buffs. But those amateur radio buffs were (and are) a bright bunch of people. They used their lemon frequencies to make lemonade. They were responsible for a number of important advancements in the use of radio technologies (and radio-related satellite technologies) that now utilize formerly unwanted wavelengths.

Left: Amateur radio hobbyists have been involved in many of the experiments and discoveries related to radio technologies and satellite communications. Left: Lou McFadden, an amateur radio operator at JSC, controls a console knob supporting the Space Shuttle Amateur Radio Experiment (SAREX) operations in July 1985. Right: Members of the STS-58 Spacelab Life Sciences crew training with amateur radio equipment. William McArthur and Richard Searfoss were scheduled to carry the Shuttle Amateur Radio Experiment (SAREX) payload along on the Shuttle mission in 1993. [NASA/JSC news photo; NASA/GRC news photo, released.]

Unfortunately, amateur radio buffs were rewarded for their efforts by having to fight to keep their new discoveries. The situation has, at times, been similar to the struggle for indigenous treaty rights. History is full of examples of people being forced out of their homelands onto land that was considered undesirable by incoming settlers. Then, if valuable resources like oil, gold or timber were subsequently discovered on those lands, the indigenous people were again relocated to less valuable lands. On a smaller scale, amateur radio 'territory' is sometimes difficult to safeguard. As soon as new technologies evolve to make use of 'junk frequencies,' commercial or government lobbying agencies apply to the FCC and vie with one another for access to the new resources. Because wavelengths are limited and wireless communications are increasing along with the population, various battles over radio bandwidth are ongoing and the situation may not be resolved in the near future, if ever.



Left: Astronaut Scott Carpenter receiving a call from President John F. Kennedy through a radio telephone while on board the USS Intrepid spacecraft on his 4 hour and 56 minute space mission, in July 1962. Right: President Gerald Ford uses a radio telephone to communicate with the crew aboard the orbiting Apollo spacecraft on 18 July 1975. [NASA/JSC news photos, released.]

Civilian Use of Radio Technologies

Wireless phone systems were not new in the 1980s. Many rural and small island populations used wireless radio phones to communicate with one another in the previous decades, but large-scale implementation of wireless networks and, in particular, cellular technologies began in the early 1980s and picked up considerable momentum in the mid-1990s. But inexpensive, wide-coverage wireless phones were new, as were the satellites that could carry the signals across continents, if desired.

Once again, the users of wireless technology began knocking on the FCC's door, requesting more bandwidth. In 1985, the FCC opened up three spread-spectrum frequency bands to unlicensed commercial use and adjustments continued to be made on a somewhat regular basis.

Miniaturization continued in the mid-1980s. Computers, radio sets, and components kept getting smaller and more efficient. There didn't seem to be an end to the process yet, at least not in the near future. Tiny microphones for a variety of purposes were being designed and wireless microphones were becoming more prevalent.

Local computer bulletin board systems (BBSs) began connecting to one another through computer networks. It was becoming possible to access a number of computers with just one dialup phone call, instead of having to make individual calls to each system. ARPANET and other networks were beginning to evolve into a global network that would eventually become the Internet. By the mid-1980s, radio engineers were developing ways to use computers and radio transceiving stations together and 'packet' radio was evolving. The marriage of radio technology and data storage and processing was well underway by the early 1990s.

While communications technologies evolved, so did the media through which the services were supplied. Television and radio programming had been broadcast for many years using radio frequencies, but now cable was starting to emerge. By using light and fiber-optic media, it was possible to deliver crisp, clean, fast programming that exceeded the quality that most people were getting with their low-cost home television antennas. Cable also made it possible to deliver airwave broadcasting from around the world to local subscribers. The television broadcast industry began to consolidate itself.

Modern Use of Radio Technologies

Throughout the 1980s and 1990s, as technology advanced, it became clear that frequencies that were once considered unimportant or unusable were very important indeed. Microwave frequencies could not only be used effectively for broadcasting, a fact that was once in dispute, they could also be used to cook food. In fact, the early microwave ovens were called radio ranges and radar ranges until the newer term caught on. Microwave broadcasting required different shapes and sizes of antennas from the traditional long-wave broadcasting frequencies.

These photos show how radio/television broadcasting has provided ground-based viewers with a look into space and how the technology has improved in three decades. Left: A historic, telecast of Astronauts Armstrong and Aldrin walking on the surface of the Moon during an Apollo II mission, in July 1969. Right: A radio station on Earth interviewing Susan Helms (holding a tiny microphone) through a wireless communications link. Helms, an astronaut aboard the Endeavour Orbiter Vehicle, and her colleagues were in orbit around the Earth in Jan. 1993 when this video image was captured. [NASA/JSC news photos, released.]

The explosion in the use of radio technologies in the 1990s was due mainly to the decreasing size and price of transmitters and receivers. In the 1970s and 1980s many people expressed interest in having satellite television services, but most considered the parabolic dishes to be too large and expensive. When the size and cost of the systems dropped, satellite services began to seriously compete with cable for a portion of the viewing audience.

The same was true of wireless phone services. When the cell phone handsets became smaller and less expensive and the service regions became broader, people began using them for business and research. As the price of the technology dropped, personal users began to increase.

Modern Surveillance Tools

There were three important trends that contributed to the dramatic increase in surveillance technologies in the mid- and late-1990s. These were decreased size, decreased cost, and increased availability. Radio technologies specifically related to surveillance were mainly restricted to law enforcement, detective, and espionage applications up until this time. Now they were available to anyone.

- In the mid-1990s, increased miniaturization was possible, and the price of components dropped dramatically. A color, wireless, pinhole camera in the early 1990s cost over $1,000, but dropped to less than $200 by the year 2000.
- The birth of the Internet created two significant dynamics in the marketing of radio surveillance devices. Educational articles explained how these devices worked and how to set them up, making people more willing to take a chance on buying them. At the same time, small electronics hobbyist manufacturers who had good technical skills but no marketing skills or distribution rights suddenly had a new way to sell their products on the Internet, without having to set up a physical retail outlet. By cutting out the 'middle man,' this not only greatly increased the number of vendors, it influenced the costs even more, since retail packaging and distribution costs are reduced.

Radio surveillance equipment has become part of the social landscape in a very short period of time, with a number of consequences that are discussed later. At the present time, the installation of radio-controlled visual and auditory surveillance devices is increasing. The implementation of radio-frequency security and tracking systems has only just begun, with many more expected over the next decade. The prevalence of radio transmitters for wearable surveillance systems is still in its infancy and is expected to increase. Currently these systems cost between $1,000 and $3,000, but it's not unlikely that they will drop to below $800 by 2005. We probably haven't even begun to feel the full impact of the changes that these devices will eventually bring.

5. Description and Functions

5.a. Consumer Technologies

The electronics revolution hasn't just resulted in more ways to use more frequencies, it has also created new classes of computer products that rely on radio wave technology. There are now home and office security systems, cordless phones, stereo transmitters, wireless intercoms, new types of devices that use radio waves to transmit within 300-foot or 1000-foot limits. Regulations for low-power, limited-range devices are less stringent than for higher-powered devices and so low-power products are proliferating in consumer applications.

5.b. Improving Security and Efficiency

Security

Radio broadcast communications are inherently open to anyone within broadcast range who has a receiver that can tune to the specific frequency that is being broadcast. This means it is not a secure means of exchanging confidential information. In the quest for confidentiality, a number of strategies have been adopted, including encryption, short-range communications for short periods of time, and spread-spectrum technologies. Spread-spectrum techniques are increasing in prevalence due to their effectiveness.

Code-division multiple-access (CDMA) is a digital, wireless communications system that was originally employed in military satellites. CDMA was favored for its resistance to jamming and greater security. CDMA provides access to multiple users with less interference than is encountered with some other techniques. Authentication of the source transmitter is possible, further limiting the possibility of eavesdropping.

Traditionally, radio communications were contained within a narrow-bandwidth frequency range which rarely varied during any individual communication. However, it was clear during times of political instability that more secure forms of communication were needed and the same is true for business transactions of economic importance. Thus, a number of ways of modulating the signal through a variety of frequencies, none of which could be predicted by an eavesdropper, substantially reduce the risk of being overheard.

Spread-spectrum techniques are commonly categorized as the following (and hybrid systems exist):

frequency-hopping (FH-CDMA) - A group of changing frequencies is modulated by the information bits in a two-step process. The carrier frequency is modulated first, then these modulated frequencies are modulated further, while keeping them independent. The receiver must be synchronized to the transmitter which hops among available frequencies. Both are tuned to a reference center-frequency.

direct-sequence (DS-CDMA) - Codes are used to modulate information bits such that each code is assigned to prevent the overlap of signals from user to user. The carrier is modulated to contain the information and the modulated signal is further modulated to spread it across spectrums. The code is regenerated by the receiver which uses the information to demodulate the transmission.

time-hopping - A carrier is on/off keyed with the speed of the keying determining the amount of signal spread.

chirp - A specialized form of spreading in which a carrier sweeps through a range of frequencies. It is primarily used in radio detecting and ranging (radar) applications.

Spread-spectrum technology has some interesting properties that increase its suitability for secure transmissions. Spreading a transmission over many frequencies makes it harder to intercept or to jam. It also tends to be more difficult to pick up the farther it travels from the transmitter. In other words, a listener some distance from the transmitter who is not expecting the signal is less likely to be aware of its presence.

For those involved in radio signal surveillance, spread-spectrum is more difficult to detect and decipher than traditional radio broadcast technologies.

Increasing Efficiency

There is a lot of motivation for using the limited radio transmissions frequencies more efficiently, especially as more individuals are using cell phone technologies and wireless computer data networks. As a consequence, many schemes have been developed to achieve this end. While the following basic examples are not specifically designed to increase security, some of them do add a small measure of security by the way in which they are implemented. Mainly, however, they are intended to enhance capacity:

frequency-division multiple-access (FDMA) - a means for increasing capacity on communications channels. It allows the available frequencies to be subdivided to allow more simultaneous links. The technique is common in cell phone and satellite communications systems.

time-division multiple-access (TDMA) - a digital technology that improves efficiency by assigning time slots to several calls within one bandwidth region, thus increasing capacity. *Extended-TDMA* (E-TDMA) is a further advancement on this general idea. TDMA is similar to CDMA and is used by some of the large wireless service providers. There are variations on TDMA in Japan and Europe.

5.c. Radio Transmitters

Covert Transmitters

Radio transmitters are widely used in surveillance activities. ‘Wearing a wire’ is an integral part of many law enforcement investigations and investigative journalism activities. Women who are being harassed by employers sometimes wear wires to acquire evidence of the harassment. Undercover agents wear wires to collect evidence of criminal activities such as intent to kill a spouse, intent to rob a bank, intent to kidnap a child, etc. Investigative journalists often wear wires when documenting corporate abuse of resources or employees, or employee theft, or abuse of privileges.

One interesting area with potential for innovation, now that radio transmitting units and microphones are so compact, is to incorporate them into the design of clothing items, rather than attaching them as separate components. For surveillance activities, this would be particularly advantageous as there would be no outward sign of the electronics, and there would be no bulges or lumps to give away the system’s location in a ‘pat search.’ That is not to say that clothing-incorporated microphones and transmitters couldn’t be found. Metal detectors and other surveillance devices might reveal the presence of anomalous threads or fabrics, but a visual or physical inspection wouldn’t immediately reveal their presence.

Radio Tags

Radio tags are tiny transmitting or receiving/transmitting units that can be attached to almost anything to provide information about the location, movements, or audio signals associated with their use. Since the tiny size of radio tags usually means their transmission distance is limited, it may be necessary to have many receivers spread over an area. This is not necessarily difficult. Small receivers can be built and deployed over a wide geographic area, like a receiving array. The data from these receivers can, in essence, create a visual picture, through computer processing, of the movement of tags within the receiving region. Another means of tracking the tags is to bring a hand or vehicle antenna and receiver into the region where the tags are expected to be. A further use of the tags is on vehicles and other objects that regularly move in the vicinity of receiving stations such as bridges, weigh stations, or other checkpoints.

Tag readers or receivers are sometimes called *interrogators*. Radio tags are used in wildlife tracking, industrial yards and construction sites, assembly lines, and military operations. They could potentially also be used to track livestock, individuals who are prone to wander and who might injure themselves or get lost, competing athletes (expedition racers, long-distance runners, or cyclists), inventory, or employees at large events such as fairs or rock concerts.

Vendors promoting the use of radio tags for identification refer to them as *RF/ID* (radio-frequency identification) and *RF/DCI* (radio-frequency data collection) systems. Some of the manufacturers of these systems are familiar names in the electronics industry, including Texas Instruments, Philips Semiconductors, Brady, and Gemplus.

RF/ID technology has improved significantly over the last five years. Not only has the cost of the tags recently dropped to below $1 per tag, but realtime tracking systems (as opposed to systems that report the location of the tag at the last checkpoint) are now starting to emerge. This opens up the possibility of individual object tracking that could be used for shipping or luggage services. It also opens up the more controversial possibility of equipping children with tracking tags so that parents have an idea of where the children may be on their way to schools, playgrounds, or the houses of friends.

Because of FCC emissions regulations and the small size of radio tags, most of them are short-range devices, usually from about half a meter to about six meters. Those used for wildlife tracking have longer ranges, due to the difficulty of getting close to wildlife in wilderness areas, and may have ranges up to about half a mile or more, depending on the size and power of the tag and the type of battery used. Tags for specialized purposes may be heat or water resistant.

Most radio tag systems used in ID and inventory systems work in the 900 MHz and 2.4 GHz regions of the spectrum, the same frequencies commonly used for short-range cordless phones, small home/office wireless transceivers, and local wireless computer network links.

Sometimes radio tag systems are used in conjunction with video cameras. When the tag passes a receiver or checkpoint, the video camera is activated and creates a record of the animal, bird, object, or vehicle that triggered the camera.

5.d. Radio Direction Finders

Direction finders are used in search and rescue, covert surveillance, wildlife tracking, and for locating unauthorized radio-frequency transmitters.

Radio direction finding is an important technology for navigation as well. Boats and vehicles use radio direction finding to chart a course or determine a position. Radio beacons are usually used in conjunction with direction finders. Several beacons make it possible to more quickly and precisely determine location and relative bearings.

Basic Concepts

There are a variety of types of direction finders, including Doppler, Adcock, and various multi-element arrays. Most of them depend on line-of-sight for effective transmissions. Basically, the direction finder uses a transmitted signal as a reference for determining the bearing to a target transmitter by evaluating the angle of the radio wave in relation to the antenna site. Theoretically, this is a fairly simple physical/mathematical determination. In real life, however, radio waves don't usually travel unimpeded. There are almost always trees, buildings, particles, and other reflective or absorbent surfaces that scatter and impede the signals so that what reaches the receiving antenna isn't a perfect wave.

To understand the technical issues, imagine throwing a pebble into the center of a still, smooth pond. Waves radiate out in clean, predictable lines to an 'antenna' near the shore. It is relatively easy to calculate the direction from which the pebble was dropped based on the direction of the waves hitting the antenna. Now imagine that there are a few rubber duckies, children's boats, and swans floating around in the pond. When you throw in the pebble, some of the waves will be impeded, deflected, or absorbed by the various objects in the water. By the time the 'signal' or wave reaches the antenna near the edge of the pond, there are complex wave patterns that must be processed for the information to be of any value. The directions and relative intensities of the waves must be assessed over time to make a good estimate of which waves are the significant ones.

It's not unusual to see wildlife or search and rescue shows in which the searchers are walking around in the wilderness holding up spindly devices that resemble old TV antennas, with several limbs sticking out from the main shaft. As the searcher moves this receiving antenna around, a beeping sound is usually emitted by the device to indicate the relative strength of an incoming radio signal. By rotating and waving the antenna, closer approximations to the right direction can be auditorily estimated by the loudness of the beep. With skill and a little bit of luck, the searchers can eventually locate the avalanche victim, whale, or grizzly bear that is wearing a radio beacon to emit the regular pulse that is picked up by the receiving antenna.

New Systems

Direction-finding systems have been used in marine navigation systems for decades and are now becoming very important in land-based systems, as well. Combined with Global Positioning System (GPS) consoles and databases of city or terrain maps, a direction finder becomes a very sophisticated positioning or tracking system. With onboard vehicle displays, these hybrid systems can show you where you are on the map, where you've been, and where you might like to go (based on previous trips or stated preferences, e.g., back roads). Intelligent vehicle systems that essentially drive themselves use adaptations of these technologies.

Direction finders can be used to track rental cars, police vehicles, or truck convoys. In fact, some new vehicles are being sold with radio tags or beacons that can be located with direction-finding technology as security measures against theft and to aid in the apprehension of the thief, if they have been stolen.

Packet radio engineers have developed various means to integrate the information from direction finders with computer networks. This makes it possible to tag and track whole systems of marine or ground-based vehicles from any location with an Internet connection. Thus, commercial industries can monitor their vehicle resources and shipments and law enforcement agents can cooperate with other state or federal authorities.

5.e. Radio Receivers

Roaming Radio

There has been a great deal of interest in developing powerful portable radio receiving units with good sound quality. Radio receivers provide a way for news, instructions, data, and other information to be relayed to a user in the field or in an office workplace. They also provide a way to control various types of electronic devices through radio signals or transmitted audio commands. Radio receivers also have many applications in robotics.

One project of interest that takes radio receiving to the next level, is *Nomadic Radio* being developed at MIT. Nomadic radio is a body-worn *roaming radio* receiver system. Through radio signals, the system is regularly downloading information from the transmission source. As a message system, it incorporates speech synthesis and speech recognition to provide a multi-information source. The types of input include news, voicemail, and email. Thus, a person on the move doesn't have to carry a computer or other handheld system to keep up to date on what is going on. Broadcasts are automatically downloaded to the system and transmitted auditorally to the user. Sportscasters, investigative journalists, field workers, undercover agents, stock traders, and marketing and sales representatives are all potential users of these hands-free systems.

This essential concept has many possibilities. A GPS location-base could allow location-relevant information to be downloaded, such as information on nearby shops, restaurants, hotels, police stations, or phone booths anywhere in the world. A heads-up system could add visual output on a small screen attached to a helmet or pair of glasses.

A patented sound neckset has been developed at Nortel for hands-free telephony which could just as easily be applied to a number of roaming radio technologies.

5.f. Satellite Communications

Satellite signals are now used for many types of communication, including television and radio broadcasts, satellite phones, and computer modems. Depending on the position of the satellites, their number, and the degree of ground-based support, communication over any particular satellite system may range from a few hours a day to 24 hours. The four basic components of satellite systems are transmitters, antennas, relay stations/repeaters, and receivers. In smaller systems, the transmitters or receivers may be housed in the same unit with the antenna. In larger systems, the antennas may be separate and may even be spaced out over several acres.

Satellite Transmitting and/or Receiving Units

Left: Satellites can now be used to relay voice messages around the globe. The U.S. Armed Forces use portable satellite phones that can be carried in a backpack and set up in the field. Here Cpl. Carlos Rivera, a radio operator, uses a satellite phone to send a message from the village of Skugrici, Bosnia/Herzegovina. Right: An Omni Tracs satellite transmitter is installed in a Humvee by R. Troxell. The Omni Tracs system reports the vehicle position to the Global Command and Control System in near-realtime. [U.S. DoD 1999 Army news photo by James Downen, Jr. and 1998 news photo by Christina Horne, released.]

A satellite phone is used outdoors in the Republic of Gabon to receive information about incoming aircraft and their cargos. This was part of a contingency plan for evacuating U.S. citizens from Zaire, if the need arose. Phone operator Air Force TSgt. Darrin Brown is an aerial porter for an Air Mobility Operation Squadron. [U.S. DoD 1997 news photo by Andy Dunaway, released.]

GPS

The Global Positioning System (GPS) is a space- and ground-based navigational system that was originally designed and used by the U.S. military as part of the Navy Navigation Satellite System. The satellite and ground stations intercommunicate in order to determine the location of a particular spot on or around the Earth. Three or more satellites can be used to 'triangulate' a position based on a point relative to the satellites. The satellites orbit in 12-hour cycles and provide 24-hour service.

GPS satellite technology was opened up to the commercial market, and designers immediately found hundreds of uses for the technology, including vehicle and aircraft navigation, search and rescue operations, wildlife tracking, and much more. GPS receivers are now routinely being built into cell phones and other electronic devices. Until recently, the resolution of the military GPS was much higher than civilian GPS frequencies, but the gap continues to narrow. As of May 2000, civilian frequencies were made accurate to about 10 to 20 meters.

Handheld Global Positioning System (GPS) units used by the U.S. Air Force. The GPS units provide navigational reference point, time, and date information. Here, SSgt. Bozeman demonstrates an operational check. To conserve memory space, the GPS clocks reset to zero after 1,023 weeks. However, not all manufacturers anticipated the consequences of clocks resetting, a problem not uncommon in electronics design and programming. [U.S. DoD 1999 news photo by Lance Cheung, released.]

Depending on how it is implemented and which electronics are included with the GPS technology, GPS can be used to determine longitude, latitude, altitude, and velocity. This information can further be cross-referenced to street and topographical maps, vehicle monitoring systems, and even to radio tracking beacons.

Satellite Antennas

A 20-foot Quick Reaction Satellite Antenna is installed by U.S. Air Force personnel in Southwest Asia as part of an Air Mobility Command Tanker Task Force. The antenna provides worldwide communications. [U.S. DoD 1998 news photos by Efrain Gonzalez, released.]

Radio stations, portable command sets, and mobile stations are often equipped with receiver, transmitter, and relay capabilities in one unit.

Two U.S. Army 58th Signal Company soldiers work in the confined space of the AN/TSC-85B satellite communications van near Kaposvar, Hungary, to support the NATO Implementation Force. [U.S. DoD 1996 news photo by Larry Aaron, released.]

5.g. Remote-Controlled Vehicles and Robots

The remote transmission of radio control signals has many applications in surveillance. They allows machines to go where people can't, including deep in the ocean, through the air, or into hostile or hazardous environments. Remotely operated vehicles (ROVs) typically use radio-frequency controllers, although some are tethered with fiber-optic cables.

Left: There are many strategies for surveilling for mines which involve detection and removal, but sometimes it's easier to have a heavy vehicle move over the transportation route to set off the mines before subsequent vehicles and people take the same path. In this case, a remotely controlled Panther, which is based on a modified M-60 tank hull, is used to detonate contact and magnetic mines and is controlled by the U.S. Army staff riding in the vehicle directly behind it. Right: Xavier is a Carnegie Mellon robot with a large variety of sensors that can communicate with the Internet through a radio-frequency Internet link. [U.S. DoD 1996 news photo by Jon Long; Carnegie Mellon news photo, released.]

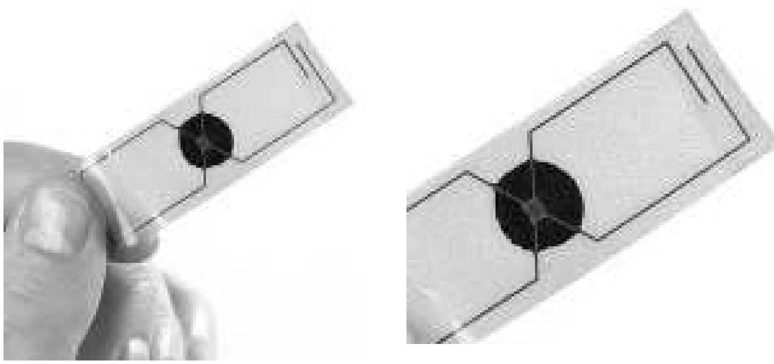
At Carnegie Mellon University's Learning Robot Lab, there is a mechanism named Xavier that looks like a cross between a trash can and a high-tech podium. Xavier is actually a sophisticated robot that wanders the halls of the university, learning and interacting with its environment. The base is a standard four-wheel synchro-drive, and the top is custom equipped built by the researchers. Xavier is sensor-rich with a sonar ring array with two dozen sensors, a laser light striper, and a Sony color camera mounted on a pan and tilt head. There are onboard microprocessors and a laptop attached to the top of the 'podium.' One of the most unique aspects of the robot is that it has a radio link through Ethernet to the Internet and Internet users can send commands to control Xavier through the Web site when the robot is online and active. The system has speech processing capabilities so that it can both talk and understand spoken commands.

Carnegie Mellon's CyberATV program is developing a number of processing systems that can be integrated into surveillance robots. Shown here is a finished vehicle (left) and a 'look under the hood' (right) at the various sensors and components that make up the system. [Carnegie Mellon Institute for Complex Engineered Systems news photo, released.]

At the Institute for Complex Engineered Systems at Carnegie Mellon, there are also some distributed robotics projects specifically aimed at surveillance applications. One of these is the *Perception of Visual Surveillance* project within the CyberATV program, which includes a number of research activities for object detection, object classification, object correspondence, and object tracking, all essential components of good surveillance systems. As an example, the vision system can focus on a person, pick out relevant features and then look up these patterns in a database. Other robotics projects at CyberATV include vehicular control devices.

6. Applications

ID and Inventory Tracking



Not much longer than a thumb and much thinner, this radio-frequency (RF) tag can be used for a wide variety of tracking applications. Originally developed for inventory monitoring systems, RF tags are now used for shipping, vehicle monitoring, toll monitoring, and public events applications (e.g., season's ticket holders). Depending on the system, they can be individually programmed, or programmed in a bunch in an RF field. [Courtesy of the Pacific Northwest National Laboratory.]

Radio tags can be used in a wide variety of surveillance and monitoring programs. Here are just a few examples from a variety of industries:

- The *Heavy Vehicle Electronic License Plate* (HELP) program is a Canadian automatic truck weigh-in system in which radio tags are attached to license plates and read when the trucks pass through weigh stations and border entry points. The data from the tags is sent to a central processing facility and is used to improve flow of the trucks by automatically identifying and weighing them.
- The U.S. Postal Service, in conjunction with Savi Technology Inc., has been installing a system of radio tags to automatically track mail containers. In conjunction with Internet data communications, this system can provide realtime computer reports on the status of the mail containers, providing their location at any particular time. The programmable radio tags and automatic readers are designed to work in conjunction with the robotic tray-loading and sorting systems that are already in place.
- The TNO Institute of Applied Physics has developed an electronic ammunition identification system which incorporates radio tags. The Ammunition Registration System (ARES) identifies dummy ammunition as it is loaded using a detector on the simulator's firing chamber. Each piece of ammunition is fitted with an electronic

label transponder with a unique identification code. The transponders receive their energy from the detector, so that individual batteries for the transponders are not required. Data transmitted by the transponder are sent to an instruction console where an instructor can monitor and evaluate the actions of students.

- A number of ski resorts, amusement parks and other businesses that issue season's passes are beginning to incorporate radio tags into the systems for access control at lifts, gates, and rides. This allows them to monitor such aspects as location and frequency of use in order to manage traffic flow and safety mechanisms.

Employee Tracking

One of the ways in which radio tag technologies are used is to track employee movements while on the job (and some employers have even tried to enforce it off the job). It is possible to use radio tracking devices and computer processing to monitor an employee as he or she passes through checkpoints or to monitor them on a realtime basis. GPS technology is sometimes used to monitor employees who work outside of the office space, such as truck drivers and on-the-road sales and marketing representatives. Most of the current tracking systems are tied to vehicle movements, but more and more, the tracking of individual employees is being implemented in the workplace. For example, certain city governments have proposed using GPS technology to track their employees.

Inmate and Parolee Tracking

There have been several different types of systems developed in recent years in which radio transmitters are attached to pre-trial, medium-risk defendants, and to parolees and prison inmates. The radio units vary in size and style. They can be pagers, armbands, and legbands. Some proponents have even suggested using small radio implants under the skin or nanotech beacons injected into the bloodstream. All of these programs are controversial.

Critics of judicial tracking systems have expressed concerns about 'branding' or dehumanizing individuals beyond what a free and civil society would consider just or proper. Nevertheless, these programs continue to increase in number for a variety of economic and safety reasons. Here are examples of some of the current and proposed monitoring systems:

- There are now programs for sexual offenders which grant them parole, instead of incarcerating them, if they will wear a radio tracking system that ensures that they don't go within 500 yards of a school ground, for example. These programs permit the offender to work and interact with society instead of remaining in overcrowded prisons.
- Pre-trial defendants, out on bail, are monitored with radio tracking devices so that if they remove the device or leave town, their last position can be known and reported within minutes to the appropriate authorities.
- Sometimes biometrics are combined with radio technology. With offender voice-page systems, the offender's voice is first recorded on a reference system. He or she is then equipped with a pager and is beeped on a random or scheduled basis and must respond within a designated time limit, usually about 10 minutes. With current systems, the offender has to find an available phone. However, by incorporating a cell phone system with the pager, the offender wouldn't have to hunt for a working telephone to execute the callback. The caller's voice is verified against the voiceprint when she or he calls back. If the cell phone is equipped with GPS technology, the offender's whereabouts can be recorded at the same time the call is made. If the voice doesn't match or the location is out of bounds, an alert can be executed.

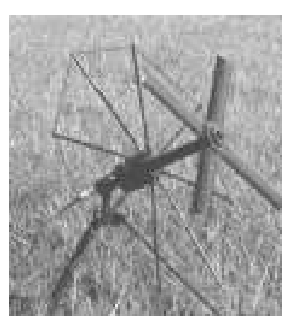
Search and Rescue

Radio technologies can be very valuable in search and rescue operations. A radio beacon can aid search crews in locating a buried avalanche victim. Handheld radios allow people to intercommunicate in dense woods or rough terrain where they can't see one another but need to keep in touch. Radios can warn of impending floods, hurricanes, and earthquakes. Radio communications systems further allow the coordination of rescue activities and communication between search craft (helicopters, planes, boats, snowmobiles, etc.) and foot crews.


Left: The Thailand Rescue Coordination Center and the U.S. Air Force have been engaged in cooperative search and rescue training in Khao Na Ting. Royal Thai Air Force Sgt. Jankeeree (left) and U.S. Air Force MSgt. Sitterly from the Pacific Rescue Coordination Center are shown here communicating on PRC-90 HF handheld radios. Right: A closeup of the PRC-90 HF radio used here by Air Force Major Jean Trakinat. [U.S. DoD 1996 news photos by Gloria J. Barry, released.]

The National Oceanographic and Atmospheric Administration (NOAA) carries an emergency surveillance system in the form of a *Search and Rescue Tracking System* (SARSAT) on its polar-orbiting satellites. The satellites can receive emergency transmissions from persons in distress and relay them to ground stations in the U.S. and abroad. The signals are forwarded to the nearest rescue-coordination center which, in turn, dispatches the information to emergency rescue personnel.





Humanitarian assistance training in Virginia using a radio setup that can be carried in a backpack and set up quickly in the field. P1C Eric Perez uses the radio to communicate with other Marines as part of the Marine Expeditionary Unit Service Support Group 26. [U.S. DoD 1998 news photo by J. T. Watkins, released.]

Rush Robinette of the Sandia National Laboratories has pointed out that strategies and algorithms for locating the point source of a chemical or biological attack can be applied to the location of a skier buried in an avalanche, thus providing another tool to aid search and rescue professionals. Following this line of reasoning, he and his group have developed computer programs to provide a form of 'group intelligence' to a swarm of mini-robots that could enable them to rapidly locate a source of contagion. Similarly, search and rescue workers with GPS receivers and radio equipment could be teamed with robots to locate avalanche victims faster. Since suffocation and hypothermia can claim a buried skier or hiker in a short period of time, any technology that speeds up the location of the victim can have life-saving consequences. Many skiers and hikers now routinely carry radio beacons, allowing them to send out a distress signal that can aid searchers in locating their position, even if they are buried or otherwise obscured.

The robot 'team' has been set up here to illustrate how radio-equipped group robots might be used to aid search and rescue operations in locating avalanche victims faster, thereby increasing their chances of survival. [Sandia National Laboratories 2000 news photo, released.]

The 'swarm algorithm' used in the Sandia simulations is called *distributed optimization* and was found in trials to locate theoretic victims four times faster than any previously published search scheme. In 'rough terrain' simulations, the results were even better. In their primary applications for the U.S. Department of Defense, the tiny robots intercommunicate through radio transmitters, thus allowing them to share information in order to home in on the desired target. Each robot broadcasts the strength of the radio beacon signal, from its current position, to the other robots, allowing the robots, as a group, to refine the area of search. Searchers equipped with palm-sized computers could be kept informed of the progress of the search and receive instructions as to where to go.

Natural Resources Management and Protection

Wildlife tracking collars are some of the more familiar radio technologies that are used in the study and management of resources, but radio technologies can also be used to study geophysical and astronomical phenomena.

The FORTE (Fast On-orbit Recording of Transient Events) satellite, developed jointly by the Los Alamos National Laboratory and Sandia National Laboratories, has a sophisticated radio-frequency receiving unit and 30-foot antenna that can record individual lightning strokes, providing new information in the atmospheric sciences. The recordings can further be linked with measurements taken by ground-based instruments. This in turn can help in weather surveillance. Meteorologists and weather forecasters can identify storm systems that might pose a danger through high winds or hail. The radio receiver can sample frequencies at a very high rate and store the information until it is transmitted to ground units. The system isn't just for weather surveillance, however, as it can further serve as a research platform for early warnings of nuclear detonations, which emit electromagnetic pulses similar to those generated by lightning. The measurements gathered by FORTE can aid in building up a knowledge base that could help scientists discriminate more easily between the different phenomena.

Another innovative use of radio frequencies is for the cleanup of contaminated sites. Just as a microwave oven uses radio frequencies to cook food, radio waves can be used to help sterilize materials in a number of industrial and commercial settings.

National Defense

Wireless portable or transportable radio and satellite links are an intrinsic part of national defense and military operations in the field.

Left: U.S. Marines from Communication Company and the 1st Light Armored Reconnaissance Battalion assemble a high-frequency radio communications antenna at a training exercise in Alaska. Right: A Troppo Scatter antenna protruding from camouflages 'terrain' at Fort Bliss, Texas. The Air Control Squadron uses antennas for long-range communications by bouncing radio signals off the troposphere. [U.S. DoD Released 1998 news photo; 1995 photo by Mike Doncell, released.]

Scanning

Devices which are designed specifically to surveil radio signals in order to locate broadcasts of interest are called scanners. Some are sold with police and fire frequencies preprogrammed to make it easy to locate and listen to these frequencies. News reporters and those who are simply curious will often listen to the emergency frequency bands. Scanners can range in price from less than $100 to thousands of dollars. Most of the consumer scanners are designed to be portable and easy to use. Some of them include memory for storing frequencies of interest for quick access later on, somewhat like the push-buttons on a car radio that let you quickly select your favorite stations.

Scanners usually have an LCD display to display the frequency currently set and some tabletop models have outputs for displaying information on computer systems or for hooking into better quality room speakers.

Many scanners are designed to jump over frequencies that are specifically allocated to certain applications, such as cell phone communications. Hobbyists will occasionally modify scanners to overcome this situation, so the device will scan continuously. Not all circuits can be modified to scan over the full spectrum.

Some of the emergency frequencies are allocated on a national basis, and some are suballocated on a regional basis. It's a good idea to look up local regulations.

Scientific Instruments

Radio technology has been used to enhance or extend a number of other surveillance technologies, such as optical spectrometers. An acousto-optical tunable filter (AOTF) is a tiny solid-state crystal with a radio-frequency driver attached. The driver allows a specific frequency to be applied to the acoustic driver, which sets up a wave (grating) within the crystal. Light can then be shone through the crystal, which is diffracted. Since radio frequencies can be quickly changed, the instrument can be stimulated at various parts of the spectrum with the narrowband AOTF prefilter extending the capabilities of the spectrometer [Baldwin and Zamzow, 1997].

7. Problems and Limitations

The main limitations in the use of radio wave technologies are power consumption, availability of bandwidth, and detection/interception of private messages.

Power Consumption

Some progress is being made on the problem of power consumption. Smaller systems and longer-life batteries have alleviated this problem to some extent. In some cases, rechargeable batteries and solar power can help, but these are not practical in all situations related to surveillance. Surveillance is sometimes carried out in remote areas where access to power is limited or absent.

Availability of Bandwidth

Because radio waves are a physical phenomenon which must share space in the physical world, they must be allocated and used wisely in much the same way as any renewable resource. The airwaves are not unlimited. More powerful signals will overwhelm less powerful signals of the same frequencies. The Federal Communications Commission has stringent bandwidth allocations and licensing requirements for the frequencies used and the strength of the signals. Radio systems used for surveillance must respect these regulations or those of foreign nations if the surveillance takes place abroad. With the increased prevalence of home security and control systems based on radio frequencies, along with cordless phones, radios, and roaming computer data systems, the pressure for more bandwidth is increasing, with commercial interests constantly clamoring for more.

Message Security

A great deal of progress has been made on safeguarding the privacy of messages. New spread-spectrum and encryption techniques help hide the presence of a transmission to some extent, and help protect the content of a transmission. This helps safeguard the confidentiality of communications related to surveillance. However, it also makes it more difficult to surveil suspicious communications by potentially hostile nations or individuals. Law enforcement agencies have been concerned about their eroding ability to tap into conversations of a criminal nature through authorized wiretaps, now that there are so many new ways in which criminals can communicate with one another through PCS, cells phones, handheld radios, laptop computers, etc. Congress has tried to balance the pressure for public privacy in radio communications with law enforcement requests for access to encryption keys and radio communications with no clear resolution at this time.

8. Restrictions and Regulations

When the U.S. Congress passed the Communications Act of 1934, regulation of the radio industry passed from the Federal Radio Commission (FRC) to the Federal Communications Commission (FCC). The FCC was made responsible for wired and wireless electrical and radio communications. The FCC is the chief regulatory body for radio communications. There are strict fines and penalties for violating FCC regulations and some even include prison terms. Radio broadcasting is big business and big businesses don't like intrusions into their operations, so the industry is policed as much by the people who use it as by the various justice agencies.

Some of the regulations related to audio communications and privacy are covered in the Audio Surveillance chapter. The FCC Web site is the best source of information for questions regarding broadcast, usage, and manufacturing of RF-related devices.

Wireless Privacy Enhancement Act of 1999. H.R. 514, a proposal to amend the Communications Act of 1934 to strengthen and clarify prohibitions on electronic eavesdropping, and other purposes. Referred to the Senate committee in March 1999.

Wireless Telephone Protection Act. Public Law 105-172 was passed in April 1998. It amends the Federal criminal code to prohibit the knowing use, production, trafficking, control, or custody of hardware or software that has been configured to insert/modify telecommunications identification information such that it can be used without proper authorization.

Originally secure communications were only available for military purposes, but gradually the technology has opened up to commercial markets. Consequently, there are some frequency-hopping and spread-spectrum regulations. Here is one example:

U.S. Title 47, Chapter 1, Subchapter A - Part 15, Subpart C This Subpart describes compliance provisions, including channel separation parameters, the number of hopping frequencies, permitted time of occupancy within a frequency, maximum peak output power of transmitters, and the processing gain of direct-sequence and hybrid systems. Priority of critical Government requirements are also noted. Government systems using these bands are typically airborne radio-locations systems.

9. Implications of Use

Short-Range Systems and Security

When homeowners or small business owners use common 900 MHz or 2.4 GHz cordless phones, wireless video transmitters, or wireless intercoms to talk to friends or business partners, they may not realize they're broadcasting to everyone within half a city block or so. In many cases, all that is needed to listen in on other people's conversations is a radio scanner, a device that can scan and tune a range of frequencies.

Similarly, if a homeowner buys a wireless video transmitter so the kids can watch cable TV on a computer monitor in the playroom while the adults watch the same show on the television set in the living room, the person next door, who might not have a cable hookup, can get 'cable for free' by watching the same broadcast through a wireless receiver tuned to the same frequency. While this probably isn't a common scenario, given the different viewing tastes and schedules of different families (and hopefully some commitment to honesty), it does illustrate how easy it is to spy on people's conversations or video broadcasts without their knowledge.

Radio frequencies are not like car keys. While the auto industry admits there is some duplication in car keys, the chances of finding a car that will open with your key in the same neighborhood or a nearby parking lot are very low. In contrast, the chance of many people in the same area using some of the same radio frequencies is very high. Anyone who has used a wireless handheld radio has probably talked or listened to dozens of strangers in the vicinity who are using the same frequencies.

To give another example of the ease with which people can 'tune in' on each other, suppose you have a wireless security system installed in your home or small office that has a range of up to about 300 or 1000 feet using a common frequency. Let's say it includes video cameras in the nursery, bedroom, hallway, office, or garage. When the system is activated you are broadcasting images of you in your private setting to anyone with a receiver that can be tuned to the same frequencies in the near vicinity. This might be a neighbor, business, or scanner in a mobile van. The transmission doesn't stop at the walls of the building.

Very few consumer-level wireless security systems are encrypted or otherwise protected from offsite receivers. The only 'protection' you have is selecting a 'house code' from one of a few choices, usually between 4 and 15 frequencies. All the house code is, is the choice of the specific frequency on which the transmission is occurring. In other words, it isn't very secure. What you see or hear on your own monitors, anyone within the range of the transmitters can also see or hear, if they are sufficiently interested. If they know what brand of security system you are using (many owners have stickers or signs giving away the brand), it makes it even easier to intercept the signals because they can narrow down the range of frequencies to check.

An unscrupulous person with some technical background could not only look in on what you are doing by scanning a wireless video or audio system, but might even be able to determine the layout of the house, the location of the cameras, your schedule, and the approximate value of your possessions. If the scanner is a thief rather than a voyeur, she or he may have enough information to enter your premises and still avoid the cameras. It isn't likely to happen, since it's far easier to break into a building without a security system, but technically it can be done right now with off-the-shelf products.

Radio Tracking Beacons

Radio tracking beacons are now so small that they can be used to track cargo, retail goods, and parolees. They can even be attached to tiny birds and bees to chart their movements. As the technology improves, it has become possible to transmit more than a simple radio beacon. Inventory systems are being designed which will be capable of transmitting a variety of information about the product with a 'smart tag.' Thus, it is only a matter of time before the checkpoints in retail stores can receive information about the products you are carrying in your shopping bag as you walk out of a store. This would include not just the purchases you made in that store, but purchases you made elsewhere, since most retails systems are standardized. Removing the tags is not always an option, since some of the products are being installed with 'source tags' which are imbedded in the wrapping or in the product itself and cannot be easily removed.

What can be done to safeguard privacy? Besides the option of not shopping in stores with smart tags, the tags could be designed so that there is a checkpoint code associated with the tags, so that each retailer is scanning at a different code and thus could not read the data from other retailers. This could be set up on a simple key encryption system in much the same way that computer data is currently protected. Retailers would be motivated to encrypt their tags so that they wouldn't be giving away valuable marketing information to other retailers.

Another consequence of the availability of tiny radio tracking beacons is the possibility that some people will implant them in children. One might expect parents to be strongly opposed to such an idea, but unfortunately, catastrophic events can cause people to take steps that they might otherwise oppose. If a series of child murders or kidnappings were to occur in a region, some parents would support the use of radio beacons in their efforts to try to protect their children. However, as the children grew older and were more able to fend for themselves, the motivation for the beacons may change on the part of the parents. Just as parents have been known to read their children's diaries to see what they are doing as teenagers (a questionable substitute for good communication and spending time with a child), there will be some parents willing to insist that their teenagers wear radio beacons. Children who resist this parental requirement might select some unpleasant options, including trying to remove the (implanted) beacon themselves.

If this scenario seems unlikely, consider that fact that there are already companies that market wearable beacons intended to help manage older people who might wander and injure themselves and for prison parolees as an option to incarceration. There are also companies who are beginning to market Global Positioning System (GPS) trackers for keeping track of children. Given the fact that these electronic gadgets are currently attached to arm or leg bands or incorporated into jewelry, it's not a long jump to assume that some company will eventually market implants for their convenience (and because they can't be easily removed). Some advocates of tracking have even suggested injecting nanites (microscopic robotic technologies) into a person's bloodstream.

New technologies open up new possibilities, some of which may have long-term negative effects on our social structure and relationships. There will always be companies willing to market these technologies, whether or not they have any positive benefit, if there is a profit to be made. It is hoped that the long-term implications of the use of tiny radio technologies will be considered carefully so that we don't create a future in which we gradually but irrevocably lose the freedoms that we currently enjoy.

10. Resources

Inclusion of the following companies does not constitute nor imply an endorsement of their products and services and, conversely, does not imply their endorsement of the contents of this text.

10.a. Organizations

American Communication Association (ACA) - The ACA is a not-for-profit organization which promotes academic and professional research and applications in the principles and theories of human communication. http://www.americancomm.org/

American Relay Radio League (ARRL) - One of the oldest and most significant radio organizations in the world with tens of thousands of members worldwide. The AARL was founded in 1914 by Hiram Percy Maxim, assisted by Clarence D. Tuska and their colleagues. The ARRL cooperates with various radio groups and governing authorities, including the FCC and the ITT. Their monthly publication QST has been published for over 80 years. http://www.arrl.org/

Association for Unmanned Vehicle Systems International (AUVS) - AUVS promotes the advancement of unmanned vehicles systems and publishes Unmanned Systems magazine. It hosts regional seminars and trade shows along with an aerial robotics competition. http://www.erols.com/auvsicc/

Federal Communications Commission (FCC) - The FCC has an enormous amount of information related to radio broadcasting and consumer devices and is worth visiting. There are historical sections, various bureaus, depending on your needs and interests, current news releases, information on various cable and wireless services, and a variety of FAQs. http://www.fcc.gov/

IEEE (formerly the American Institute of Electrical Engineers) - The AIEE was originally founded in 1884 to represent the EE profession and to develop standards for the industry. Bell and Edison were among the first vice-presidents. AIEE merged with the Institute of Radio Engineers (IRE) in 1963 to form the IEEE one of the foremost engineering organizations in the world. The IEEE hosts many professional gatherings a publishes a wide variety of documents and journals. http://www.ieee.org/

International Radio and Television Society Foundation, Inc. (IRTS) - Based in New York, the society provides educational programs, awards, and information on broadcasting-related events. http://www.irts.org/

National Association of Broadcasters (NAB) - The NAB has represented the technological and governmental interests of radio and television industries for over 75 years in order to promote the broadcasting industries. http://www.nab.org/

Robotic Industries Association (RIA) - An industry association which recommends robotics resources, books, videos, seminars, and other information of interest in the practical and industrial applications of robotics. http://www.robotics.org/

Society of Broadcast Engineers (SBE) - A professional organization providing support for education, certification, and seminars in the various broadcasting fields. Based in Indianapolis, Indiana. http://www.sbe.org/

Note that a number of universities and technical institutes have robotics labs, including MIT, Carnegie Mellon, Berkeley, Georgia Tech, Indiana University, and the University of Washington.

10.b Print Resources

The author has endeavored to select these carefully, reading and reviewing many of them, and consulting reviews by reputable professionals for many of them, as well. In a few cases, it was necessary to rely on publishers' descriptions on books that were very recent, or difficult to acquire. It is hoped that the annotations will assist the reader in selecting additional reading.

These annotated listings include both current and out-of-print books. Those which are not currently in print are sometimes available in local libraries and second-hand book stores, or through interlibrary loan systems.

Curtis, Anthony R., "Monitoring NASA Communications," Lake Geneva, Wi.: Tiare Publications, 1992.

"Directory of North American Military Aviation Communications," Hunterdon Aero, 1990.

Eisenson, Henry L., "Scanners & Secret Frequencies," San Diego: Index Publishing Group, 1997, 318 pages. A well laid-out, accessible introduction to scanning and radio hobby activities using scanners. The author is an ex-Marine and electronics technical specialist.

Helms, Harry L., "How to Tune the Secret Shortwave Spectrum," Blue Ridge Summit, Pa.: TAB Books, Inc., 1981. Out of print.

Kane, Joseph Nathan, "Famous First Facts," New York: H. W. Wilson, 1981, 1350 pages.

Parlin, Charles Coolidge, "The Merchandising of Radio," Philadelphia: The Curtis Publishing Company, 1925. Available through the Library of Congress.

Yoder, Andrew R., "Pirate Radio Stations: Tuning in to Underground Broadcasts," Summit, Pa.: TAB Books, Inc., 1990. Out of print.

Articles

"Advanced Electronic Monitoring for Tracking Persons on Probation or Parole," NCJ 162420, *Na-*

tional Institute of Justice Technical Report, 1996. Discusses electronic monitoring of pretrial-released offenders and of those on alternative imprisonment regimes.

Baldwin, D. P.; Zamzow, D. S., "Emissions Monitoring Using an AOTF-FFP Spectrometer," *Talanta.* 1997, V.45, pp. 229-235.

Baldwin, David, "Development of a Multielement Metal Continuous Emissions Monitor," *Characterization, Monitoring, & Sensor Technologies Reports,* September 1998.

Ballard, Nigel, "Radio Surveillance (Bugging) in the U.K.," *The Hacker Chronicles,* September 1998.

Diehl, Christopher P.; Saptharishi, Mahesh; Hampshire II, John B.; Khosla, Pradeep K., "Collaborative Surveillance Using Both Fixed and Mobile Unattended Ground Sensor Platforms," *Proceedings of AeroSense '99*, SPIE, 1999.

Dugan, James, "Using Nano-Technology to Rack Inmates and Parolees," Tunxis Community College, Program Class IV, 1998. The author describes the insertion of nanoprobes into inmates' and parolees' bloodstreams to provide a means to constantly track their whereabouts.

Trebi-Ollennu, A.; Dolan, John M., "An Autonomous Ground Vehicle for Distributed Surveillance: CyberScout Internal Report," Institute for Complex Engineered Systems, Carnegie Mellon University. April 1999.

Journals

"Amateur Radio Newsline," a written transcript prepared from the Newsline Radio scripts, an audio news service distributed by telephone, provided by Newsline Internet Services.
http://www.arnewsline.org/

The "IEEE Radio Communications Committee (RCC)" sponsors and promotes technical papers and tutorials on the engineering aspects of communications systems and equipment.
http://www.comsoc.org/

"QEX," ARRL forum for communications experimenters.

"QST," official publication of the Amateur Relay Radio League (ARRL). http://www.arrl.org/

10.c. Conferences and Workshops

Many of these conferences are annual events that are held at approximately the same time each year, so even if the conference listings are outdated, they can still help you determine the frequency and sometimes the time of year of upcoming events. It is very common for international conferences to be held in a different city each year, so contact the organizers for current locations.

Many of these organizations describe the upcoming conferences on the Web and may also archive conference proceedings for purchase or free download.

The following conferences are organized according to the calendar month in which they are usually held.

"INTIX EUROPE," sponsored by the International Ticketing Association, Barcelona, Spain, 24-28 May 2000. This is not specifically aimed at radio technologies, but a number of ticketing tracking systems using radio technologies are now displayed by exhibitors at these types of conferences.

"International Robots & Vision Show," Chicago, Il., 5-6 June 2001. A biennial conference with practical solutions to robotics applications.

"Unmanned Systems 2000," robotics and radio-controlled vehicles show and competitions, Orlando, Fl., 11-13 July 2000.

"Cognitive Robotics Workshop," Berlin, Germany, 21-22 Aug. 2000.

"Forum on Wildlife Telemetry," Snowmass, Co., 21-23 Sept. 1997. A report on this conference is available on the U.S. Geological Services site.

http://www.npwrc.usgs.gov/announce/press/wildtele.htm

"Intelligent Vehicles Symposium" and "Autonomous Vehicle Cooperation and Coordination," sponsored by IEEE, Dearborne, Mi., 4-5 Oct. 2000.

"NAB Radio Show," sponsored by the National Association of Broadcasters, this industry show includes a technical program for broadcast engineers, San Francisco, Ca., 20-23 Sept. 2000.

10.d. Online Sites

Frequency-Hopping and Spread-Spectrum Information. This surveillance supply site provides an article on radio technologies by A. Gil, A. Freeman, and M. Levin that explains frequency-hopping and there is also an explanation of digital spread-spectrum. http://www.midniteyes.com/freqhopping.html

Porthcurno Museum of Submarine Telegraphy Virtual Tour. This site shows the floorplan, exhibits, and history of exhibits related to submarine telegraphy and cable communications at Porthcurno Valley in the U.K. Many interesting stories and glimpses of the physical museum are available. http://www.porthcurno.org.uk/

Note that there are also numerous radio technology discussion groups on the Internet on USENET, including *alt.ham-radio*, *alt.radio*, and *rec.radio*.

Note, if you don't enjoy typing in those long Web addresses (URLs), there are links already set up for your convenience on the author's support site for this text. http://www.abiogenesis.com/surveil

10.e. Media Resources

"Marconi: Whispers in the Air," a *Biography Channel* show on the precocious inventor, Guglielmo Marconi, who developed many of the pioneering telegraph and radio technologies that emerged a century ago. VHS, 50 minutes. May not be shipped outside the U.S. and Canada.

"Radio: Out of Thin Air," a *History Channel* show from the Modern Marvels series that documents how the invention of radio changed society. Casey Kasem and Larry King explore the qualities of the medium and its development. VHS, 50 minutes. May not be shipped outside the U.S. and Canada.

"Sneakers," is a Universal City Studios feature film that stars Robert Redford, Ben Kingsley, and Dan Akroyd. It is an action thriller that features a wide variety of surveillance strategies and devices. 1992, just over 2 hours long.

11. Glossary

Titles, product names, organizations, and specific military designations are capitalized; common generic and colloquial terms and phrases are not.

ABS	automatic broadcast scheduler
ACC	access control center
ACI	adjacent channel interference
ACS	alternate control station
ACTS	Advanced Communications Technology Satellite
ADPCM	adaptive differential pulse code modulation
AF	audio frequency
AFSAT	Air Force Satellite System
AGC	automatic gain control
AJ	anti-jam

ALE	automatic link establishment
AM	amplitude modulation/modulator
AMP	amplifier, automated message processing
ASC	automatic switching center
ASK	amplitude shift keying
AT&T	American Telephone & Telegraph
BCST	broadcast
CDMA	code-division multiple-access
C3	Command, Control Communications
CCC	clear channel capacity
CCS	communications control system
CDM	code-division multiplexing
CDMA	code-division multiple-access
cellular	low-power radio coverage with transceiver 'cell' units
COMSAT	communications satellite
DDS	digital data service
DII	Defense Information Infrastructure
DMS	Defense Messaging System
DPCM	differential pulse code modulation
DPSK	differential phase shift keying
EAM	Emergency Action Message
EAS	Emergency Alert System (replace Emergency Broadcast System)
EM	electromagnetic
EMI	electromagnetic interference
FCC	Federal Communications System, chief radio regulating body
FIPS	federal information processing standard
FM	frequency modulation/modulator
FSK	frequency shift keying
GEOS	geostationary satellite
GLORI	Global Radio Interface
GPS	Global Positioning System
heterodyne	to produce a beat between two frequencies. A steady introduced current can be used to selectively create and control an electrical beat which can then be amplified. A heterodyne repeater can be used to create an intermediate frequency which can be amplified, modulated, and retransmitted.
I&A	identification and authentication
IEEE	Institute for Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
JRSC	jam-resistant secure communications
JTRS	Joint Tactical Radio System, a programmable military radio system
LEIS	Law Enforcement Information System
MBA	multi-beam antenna
MFSK	multiple frequency shift keying
MILSATCOM	military satellite communications

MILSTAR	Military Strategic and Relay (satellite)
NAVCAMS	U.S. Naval Communications Area Master Station
NAVTEX	Navigational Text, international marine information broadcast at 518 Hz
NBAM	narrowband amplitude modulation
NBFM	narrowband frequency modulation
NCA	National Command Authority
PCM	pulse code modulation
PM	phase modulation
POTS	plain old telephone/telecommunications service
PR	packet radio
PRT	packet radio terminal
RF	radio frequency
Rx	receiver
S/N	signal-to-noise ratio
SAMPS	semi-automated message-processing system
SARSAT	Search and Rescue Satellite
SATCOM	satellite communication
scanner	a system for detecting transmissions across a range of frequencies in order to locate transmissions of interest
SCF	satellite control facility
SDLS	satellite data-link system
SDMA	space division multiple access
SDN	secure data network
SDS	satellite data system
SRF	superconducting radio frequency
SS	spread spectrum, solid state
SST	spread-spectrum technology
SVN	secure voice network
TDM	time-division multiplexing
TDMA	time-division multiple-access
TH	time hopping
TRANSEC	transmission security
TS	top secret
Tx	transmitter
UNI	user-to-network interface
VOBRA	Voice Broadcast Automation
VSAT	very small aperture terminal