Radio and Television

Radio is the radiation (wireless transmission) of electromagnetic signals through the atmosphere or free space. Information, such as sound, is carried by systematically changing (modulating) some property of the radiated waves, such as their amplitude, frequency. When radio waves strike an electrical conductor, the oscillating fields induce an alternating current in the conductor. The information in the waves can be extracted and transformed back into its original form.

Radio systems need a transmitter to modulate (change) some property of the energy produced to impress a signal on it. Some types of modulation include amplitude modulation and frequency modulation. Radio systems also need an antenna to convert electric currents into radio waves, and vice versa. An antenna can be used for both transmitting and receiving. The electromagnetic wave is intercepted by a tuned receiving antenna. A radio receiver receives its input from an antenna and converts it into a form usable for the consumer, such as sound, pictures, digital data, measurement values, navigational positions. Radio frequencies occupy the range from a 3 kHz to 300 GHz, although commercially important uses of radio use only a small part of this spectrum.

November 2, 1920: KDKA, the first commercial radio station in the United States, goes on the air in Pittsburgh. July 1, 1941: WBNT, the first commercial TV station, starts broadcasting. April 3, 1973: Martin Cooper of Motorola makes the world’s first cell phone call.

Radio has transformed society three times, not to mention giving birth to the entire field of electronics. Perhaps no invention of modern times has delivered so much while initially promising so little. When radio arrived at the end of the 19th century, few thought that “wireless” communications, in which intangible signals could be sent through the air over long distances, would be competitive in a world dominated by the telegraph and telephone. The early inventors studied the work of Scottish physicist James Clerk Maxwell, who had formulated a set of equations—“Maxwell’s equations”—that expressed the basic laws of electricity and magnetism, but as a purely theoretical exercise in understanding how nature works. His equations explained light as one form of electromagnetic radiation and predicted that there should be many other forms, invisible to the human eye. In the 1880s the German physicist Heinrich Rudolf Hertz validated Maxwell’s laws by detecting radio waves—fundamentally similar to light but with wavelengths a million times longer. “Maestro Maxwell was right,” Hertz said, but he concluded that the existence of these other waves was “of no use whatsoever.”
Fortunately, other scientists and engineers saw the radio spectrum not as a curiosity but as a tool for a new kind of communication. The principle behind radio transmission is simple. Electrons moving through a wire create a magnetic field. Place another wire near the first and electrons will start to move in the second wire too. The signal travels between the wires because the magnetic field formed by the first wire—the transmitter—creates an electric field in space, which in turn creates a magnetic field, and so on, moving outward at the speed of light. When the second wire—the receiver—picks up that signal, the field is converted back into the motion of electrons, detectable as an electric current. In order to carry information, the transmitted signal has to vary over time. The easiest way to do this is simply to stop and start the current in the first wire, sending a message as a series of pulses. The flamboyant Serbian-born engineer Nikola Tesla followed that approach and transmitted a radio signal across a short distance in 1893. Soon after, Italian inventor Guglielmo Marconi accidentally discovered that grounded antennas could send signals more than a mile instead of a few hundred yards. He had inadvertently been using Earth to propagate a radio signal close to the ground. With further refinements, he found a way for ships to talk to each other using Morse code—the quintessential pulsed signal—and in 1896, just 21, he traveled to England and set up a radio company, British Marconi.

World events quickly proved the value of this work. In 1905 the Japanese navy all but destroyed the Russian fleet at the Battle of Tsushima, in part because of radio equipment the Japanese bought from Marconi. And in 1912, after ships responding to the sinking Titanic’s distress signals rescued 711 passengers, maritime authorities required every seagoing vessel to have a
wireless operator listening around the clock. But Marconi’s vision proved limited. He saw the airwaves as useful for point-to-point traffic between ships at sea and other clients untethered by cables, but that was about it. Marconi “took radio to the marketplace, but he never had the idea of broadcasting,” says Susan J. Douglas, a radio historian at the University of Michigan.

The next big step was finding a way to manipulate radio waves so they could carry more than dots and dashes. Switching from pulses to continuous waves provided the key. Reginald Fessenden, a Canadian auto-didact, invented a way to transmit voice and music by altering the intensity of waves—called amplitude modulation—thus creating AM radio. (Amplitude modulation superimposes a varying audio wave onto a radio wave with a fixed frequency: Where the audio wave peaks, the modulated radio wave is at its highest intensity, and where the audio wave has a trough, the radio wave is at its lowest intensity.)

Fessenden ultimately earned money and fame from his invention. On the other hand, American radio engineer Edwin Howard Armstrong, regarded by many radio cognoscenti as the greatest of them all, is today almost forgotten. He noticed that by varying wave frequency instead of amplitude, stations could avoid the interference that often corrupted AM transmissions. The result was frequency modulation—FM radio. (In this case, a peak in the audio wave is represented by an increase in the frequency of the radio wave, while a trough is represented as a decrease in frequency.) A lifetime of patent lawsuits crushed Armstrong emotionally, and he committed suicide in 1954.

Although its commercial potential today seems obvious, broadcasting was actually kick-started by amateurs: “By the 19-teens, ham radio operators were everywhere,” Douglas says. The hams—a term coined as a slur by professional telegraph operators—“were sending homework and football scores and news in Morse code, and then they went to World War I and found out about vacuum tubes.” Thanks to the amplifying power of the newly invented vacuum tubes, hams started sending audio everywhere. “You could just set up a transmitter and start broadcasting stuff,” says radio industry consultant Rick Ducey, formerly the head of research for the National Association of Broadcasters. “That’s all it took.”

Westinghouse engineer Frank Conrad generally gets credit for transmitting the first regular AM broadcasts in the United States from his East Pittsburgh garage (although stations in San Jose, Detroit, and elsewhere were also active). His show aired every Wednesday and Saturday—some sports scores, some talk, but mostly music. When Conrad ran out of records, he struck a deal with a local store to supply him with more in return for on-air promotions. These are believed to be the first radio ads. But by the mid-1920s, so many people were doing it, the industry “needed a traffic cop,” Ducey says.

To bring some order to the growing number of broadcasters who were appropriating their own radio wavelengths, or frequencies, the government created the Federal Radio Commission. That agency, later re-formed as the Federal Communications Commission (today’s FCC), assigned specific frequency bands to different users. In 1920 Conrad applied for and received a license from the Commerce Department for radio station KDKA. Radio broadcast licensing was born, and a virtual real estate boom—the competition for slices of the radio band—began. The amateurs who stayed amateurs soon found themselves being moved by regulators to less
desirable locations farther up the radio spectrum. Roughly speaking, lower frequencies are cheaper to use than higher frequencies because they require less precise equipment, an important consideration for an industry that wanted to market radio receivers to the masses.

Soon the armed forces also wanted their slice of the radio spectrum. Military use of radio communications may have begun at Tsushima, but after World War I it expanded enormously. Governments started to understand radio’s immense potential, not only for communications but also as a weapon: radio detecting and ranging, better known as radar.

The first decades of the 20th century also saw video being transmitted over the airwaves. The first television system, developed in the U.K. in the early 1920s by John Logie Baird, used an electromechanical device akin to a film camera and projector to capture and reproduce images. He started broadcasting TV using just 30 scan lines per video frame—enough to send a rough image but crude compared with the 484 lines per frame used in U.S. analog TV broadcasts and the 1,080 lines possible with new digital systems. Several thousand Londoners were watching Baird’s television programs by the late 1930s, but the system was shut down when World War II started—German bombers could have used Baird’s transmission as a homing signal. The televisions in use today trace their heritage to American inventor Philo Farnsworth, who created the first all-electronic television system in 1928.

Over the years, more users have elbowed their way onto the radio spectrum as new technologies arrive. Some need ultrahigh frequencies that allow more information to be transmitted per second. It is no surprise to find a data networking technology like Wi-Fi operating at 2.4 gigahertz. AM and FM have been joined by many other modulation schemes with exotic names like “quadrature phase-shift keying” and “double-sideband suppressed-carrier transmission.”

Today the picture of the radio spectrum is a color-coded colossus composed of hundreds of bands allotted by the FCC from frequencies as low as 6 kilohertz to as high as 300 gigahertz. Very low frequencies—from 3 to 30 Hz, with wavelengths tens of thousands of miles long—are used to penetrate the oceans and communicate with submarines. Baby monitors operate at 49 megahertz. FM radio is positioned between 88 MHz and 108 MHz, and users as diverse as police dispatchers, air traffic controllers, and cell phone callers all have their own bands. At the upper end of the radio spectrum come microwaves, used for data transmission, radar, and of course, cooking. In what was probably the most unexpected application of Maxwell’s laws, the development of the microwave oven was sparked in 1945 when Percy Spencer, an engineer building radars, noticed that the peanut bar in his pocket had melted after he worked on some active equipment. (Scary thought: Your microwave operates at almost the exact same frequency as your Wi-Fi connection.)

Engineers keep finding more and more uses for radio, and frequencies never seem to end up on the scrap heap. You can even find Morse code transmissions still on the air. In 2009 analog broadcast TV will stop in the United States—but bidders are already lined up, preparing extravagant new uses for those slices of spectrum. “It’s marvelous,” Ducey says. “If you stop to think about it, it’s almost magic.”
TV Pixels and Your Brain

Let's start at the beginning with a quick note about your brain. There are two amazing things about your brain that make television possible. By understanding these two facts, you gain a good bit of insight into why televisions are designed the way they are.

The first principle is this: If you divide a still image into a collection of small colored dots, your brain will reassemble the dots into a meaningful image. This is no small feat, as any researcher who has tried to program a computer to understand images will tell you. The only way we can see that this is actually happening is to blow the dots up so big that our brains can no longer assemble them, like this:

Most people, sitting right up close to their computer screens, cannot tell what this is a picture of -- the dots are too big for your brain to handle. If you stand 10 to 15 feet away from your monitor, however, your brain will be able to assemble the dots in the image and you will clearly see that it is the baby's face. By standing at a distance, the dots become small enough for your brain to integrate them into a recognizable image.

Both televisions and computer screens (as well as newspaper and magazine photos) rely on this fusion-of-small-colored-dots capability in the human brain to chop pictures up into thousands of individual elements. On a TV or computer screen, the dots are called pixels. The resolution of your computer's screen might be 800x600 pixels, or maybe 1024x768 pixels.

TV Motion and Your Brain

The human brain's second amazing feature relating to television is this: If you divide a moving scene into a sequence of still pictures and show the still images in rapid succession, the brain will reassemble the still images into a single, moving scene. Fifteen per second is about the minimum possible -- any fewer than that and it looks jerky.

In television you see both of processes (pixelization and multiple still images as motion) at work simultaneously. Your brain is fusing the dots of each image together to form still images and then fusing the separate still images together into a moving scene. Without these two capabilities, TV as we know it would not be possible.

The Cathode Ray Tube

A few TVs in use today rely on a device known as the cathode ray tube, or CRT, to display their images. LCDs and plasma displays are other common technologies. It is even possible to make a television screen out of thousands of ordinary 60-watt light bulbs! You may have seen something like this at an outdoor event like a football game. Let's start with the CRT, however.
The terms anode and cathode are used in electronics as synonyms for positive and negative terminals. For example, you could refer to the positive terminal of a battery as the anode and the negative terminal as the cathode.

In a cathode ray tube, the "cathode" is a heated filament (not unlike the filament in a normal light bulb). The heated filament is in a vacuum created inside a glass "tube." The "ray" is a stream of electrons that naturally pour off a heated cathode into the vacuum.

Electrons are negative. The anode is positive, so it attracts the electrons pouring off the cathode. In a TV's cathode ray tube, the stream of electrons is focused by a focusing anode into a tight beam and then accelerated by an accelerating anode. This tight, high-speed beam of electrons flies through the vacuum in the tube and hits the flat screen at the other end of the tube. This screen is coated with phosphor, which glows when struck by the beam.

Inside a CRT

As you can see in the drawing, there's not a whole lot to a basic cathode ray tube.

There is a cathode and a pair (or more) of anodes. There is the phosphor-coated screen. There is a conductive coating inside the tube to soak up the electrons that pile up at the screen-end of the tube. However, in this diagram you can see no way to "steer" the beam -- the beam will always land in a tiny dot right in the center of the screen.

That's why, if you look inside any TV set, you will find that the tube is wrapped in coils of wires. TV Steering Coils

The steering coils are simply copper. These coils are able to create magnetic fields inside the tube, and the electron beam responds to the fields. One set of coils creates a magnetic field that moves the electron beam vertically, while another set moves the beam horizontally. By
controlling the voltages in the coils, you can position the electron beam at any point on the screen.

**TV Phosphors**

A phosphor is any material that, when exposed to radiation, emits visible light. The radiation might be ultraviolet light or a beam of electrons. Any fluorescent color is really a phosphor -- fluorescent colors absorb invisible ultraviolet light and emit visible light at a characteristic color.

In a CRT, phosphor coats the inside of the screen. When the electron beam strikes the phosphor, it makes the screen glow. In a black-and-white screen, there is one phosphor that glows white when struck. In a color screen, there are three phosphors arranged as dots or stripes that emit red, green and blue light. There are also three electron beams to illuminate the three different colors together.

There are thousands of different phosphors that have been formulated. They are characterized by their emission color and the length of time emission lasts after they are excited.

**The Black-and-White TV Signal**

In a black-and-white TV, the screen is coated with white phosphor and the electron beam "paints" an image onto the screen by moving the electron beam across the phosphor a line at a time. To "paint" the entire screen, electronic circuits inside the TV use the magnetic coils to move the electron beam in a "raster scan" pattern across and down the screen. The beam paints one line across the screen from left to right. It then quickly flies back to the left side, moves down slightly and paints another horizontal line, and so on down the screen.

As the beam paints each line from left to right, the intensity of the beam is changed to create different shades of black, gray and white across the screen. Because the lines are spaced very closely together, your brain integrates them into a single image. A TV screen normally has about
480 lines visible from top to bottom. In the next section, you'll find out how the TV "paints" these lines on the screen.

Painting the TV Screen

Standard TVs use an interlacing technique when painting the screen. In this technique, the screen is painted 60 times per second but only half of the lines are painted per frame. The beam paints every other line as it moves down the screen -- for example, every odd-numbered line. Then, the next time it moves down the screen it paints the even-numbered lines, alternating back and forth between even-numbered and odd-numbered lines on each pass. The entire screen, in two passes, is painted 30 times every second. The alternative to interlacing is called progressive scanning, which paints every line on the screen 60 times per second. Most computer monitors use progressive scanning because it significantly reduces flicker.

Because the electron beam is painting all 525 lines 30 times per second, it paints a total of 15,750 lines per second. (Some people can actually hear this frequency as a very high-pitched sound emitted when the television is on.)

When a television station wants to broadcast a signal to your TV, or when your VCR wants to display the movie on a video tape on your TV, the signal needs to mesh with the electronics controlling the beam so that the TV can accurately paint the picture that the TV station or VCR sends. The TV station or VCR therefore sends a well-known signal to the TV that contains three different parts:

- Intensity information for the beam as it paints each line
- Horizontal-retrace signals to tell the TV when to move the beam back at the end of each line
- Vertical-retrace signals 60 times per second to move the beam from bottom-right to top-left