

Lecture 2-- Pre-lecture reading

Wires and Waves- The Age of Fast Communications

In the tens of thousands of years of human history before 1800 there have been many important discoveries (from fire, to tools, to agriculture, to the beginnings of modern science and technology), but in 1800 information still traveled at the speed of a person. You could put the messenger on a horse, or stagecoach, or train to move the message faster, or on a ship to cross oceans, but communications were still moving at the speed of the messenger. If something happened in California or England, people in New York wouldn't hear about it for weeks. If it happened in China or Africa or Australia, it would take months for the news to arrive. Even on a local level, if you were living in lower Manhattan and your friend lived in upper Manhattan, you would probably use the postal system to communicate. Today we feel a direct and immediate connection to everyone we know, and to events all over the world. All that started when communication went from the speed of a messenger to the speed of an electrical signal in a wire or on a radio wave— when communication became “instant.”

It's worth noting that some innovative “special cases” of fast communication have existed through the ages. In some cases, when people knew that an important message would have to be sent from one particular place to another, they could make special plans. In the Iliad, which was written about 800BC about the Trojan War, Homer mentions the use of signal fires, an early example of communication at the speed of light. Similarly, we've heard about smoke signals, flashing mirrors and semaphore flags. When the Erie Canal was completed, the event was communicated back to New York City by a series of cannons, spaced so that each crew could hear the one before them, allowing long distance communication at the speed of sound.

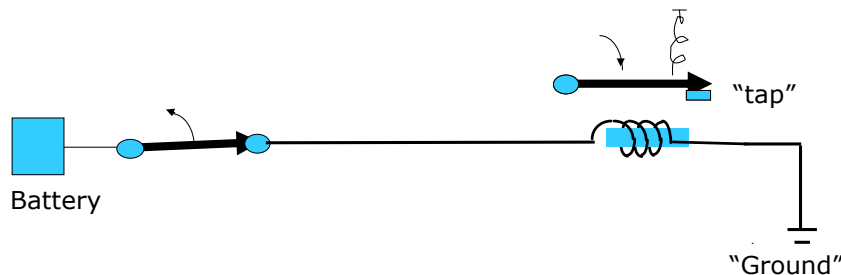
What all these methods had in common is that they required elaborate preparations and carried very little information. Fires and mirrors and smoke signals (and cannons along the Erie Canal) required the participants to be put in specific places, and could only handle a few prearranged messages. The fire might mean “the Greeks are coming,” but if it turned out that they were coming with more ships than expected, or landing in an unexpected location, the fire couldn't convey that information. Semaphore flags were more “general purpose” but were still slow and still required the participants to know special codes and to be positioned so as to see one another. Admiral Nelson could use semaphore to tell his captains at Trafalgar to change direction, but the news that he had won (and died in) the battle traveled back to England at the speed of a ship.

When scientists discovered that electrical signals traveled through wires at a very high speed (they didn't know how fast) and had certain magnetic properties (which they didn't understand), inventors began to look for ways to use that electrical signal for fast communication, but how was it to work? As has often been the case, they invented a method to exploit science without really understanding the science they were exploiting.

This sort of thinking happens whenever a new phenomenon is discovered. Inventors may not know what is happening, but they want to use it and they have great confidence that they will change the world. Their many ideas for using electricity to carry information are a fascinating history. A practical solution was provided by the strange connection between electricity and magnetism, decades before Maxwell figured out

what was actually happening. What they noticed was that when an electric current passes through a coil of wire, it creates a magnet. A telegraph “key” could be used at one end of the wire, to start and stop the current from a battery, and a coil at the other end would attract and release an iron bar, mimicking the motion of the sending key. If the sender used a prearranged “tapping code” like Morse code, a person at the receiving end would hear the same code [slide 11]. The telegraph changed the world with batteries (another fascinating “science” that inventors were trying to use) and wires that could be strung from poles without breaking (they used iron wires) when the true nature of electricity was not understood, and the very existence of radio waves was not yet imagined.

Communications goes from the speed of a person to the speed of electricity



Invent a “tapping code” and you have “instant” communications at a distance. Resistance in the wire limited the range but relaying messages at intermediate points allowed messages to cross the country

Once we had wires in place, the telegraph (1837) could transmit any written message almost instantly. Running wires for thousands of miles would have been an immense task but railroads were expanding in every direction and they needed communication along those routes (to schedule trains on single tracks, for example). This also led to “standard” time and synchronized time across the country. The telegraph began along railroad routes, for railroad purposes, but soon was carrying general-purpose messages. Western Union made it a “common carrier” service in 1865, so personal messages could be sent across the country, and undersea cables (another difficult invention) soon connected continents.

The telegraph also revolutionized “mass” communications. Going back to the Middle Ages, people relied on stories told by traveling merchants, which were slow and likely to be inaccurate. Printing, and particularly newspapers, could preserve somewhat more accurate information, but that information still took a long time to arrive. With the telegraph, the newspapers suddenly had current information about far-off events, so the “news” became more immediate and more accurate. In our modern age of

communications, we take all this for granted, but the effect at the time was sudden and dramatic—places that were “a month away” suddenly felt nearby and the world became a smaller place.

Of course, the telegraph may have moved information at the speed of electricity, but it required experienced operators and messengers at the endpoints. It was like writing a letter (in the fewest words possible, since you paid by the word) and then the letter went to another person in a few hours instead of days or weeks.

Inventors like Alexander Graham Bell had a new vision— that people could speak directly to one another over wires at great distances. For telegraphy, the instantaneous transmission in the wire was nice, but not absolutely necessary. If it had taken 5 minutes for a telegraph message to travel through the wire, it wouldn't have really mattered, since the message had to be brought to and from the telegraph office by messengers and coded by operators. A two-way conversation, in contrast, requires communication to be just about instantaneous. The problem that Bell and others faced was that voice is complex pressure wave (not a simple on/off code). Turning that pressure wave into an “analog” electric current (a current that mimics and preserves the pressure wave when it travels through the wire), and then turning that electrical signal back into an audible pressure wave at the other end, was a formidable problem that took decades to solve.

Alexander Graham Bell (1847-1922)

□ Fascination and obsession with acoustics

- Grandfather, father, brother worked on elocution
- Mother and wife were deaf

□ The patent (March 7, 1876)

"the method of, and apparatus for, transmitting vocal or other sounds telegraphically ... by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sound"

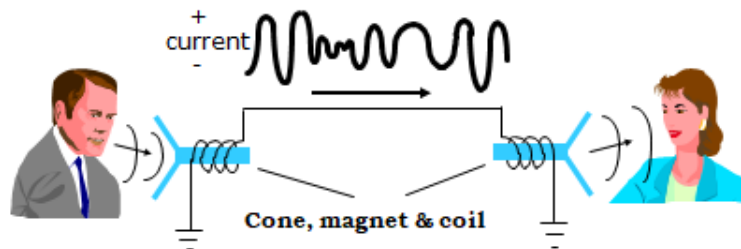
□ First successful experiment (March 10, 1876)

"Mr. Watson—Come here—I want to see you"

Once again, however, the answer was in the relationship between magnetism and electricity. The pressure wave could vibrate a cardboard cone with an attached magnet. The vibrating magnet would create an “analog” electrical signal in a coil of wire, and that signal would travel through the wire. At the other end, the process was reversed. The analog electrical signal would pass through a coil, causing a magnet to vibrate an

identical cardboard cone that served as a “speaker,” thus recreating the original pressure wave as sound. The problem was that the electrical signal created by the original microphone was very weak and could only travel a short distance.

Bell's idea: make a magnet vibrate

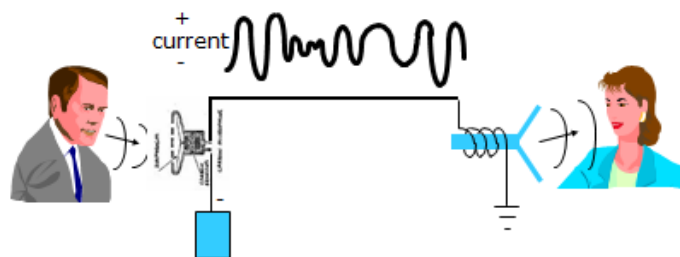


Turning pressure waves into electrical waves—and back again, but the analog electrical signal created by Bell's telephone was not strong enough to travel long distances

25

What was needed to create a useful phone was an amplifier, but what we think of as an amplifier did not exist before vacuum tubes and transistors in the next century. The problem was solved with an ingenious invention called a carbon microphone, which allowed the air vibration from a voice to change the resistance of some granular carbon. Instead of creating a weak analog electrical signal with the voice wave, the carbon microphone could “modulate” the much higher voltage from a battery, creating a much stronger analog electrical signal that could travel many miles through a wire.

Making the signal stronger- the carbon microphone



Microphone powered by battery
Audio signal vibrates membrane
Vibrations change resistance
Produce an “analog” signal

Person to person- directly
No training in codes
Truly instantaneous

It took almost 40 years and the invention of vacuum tube amplifiers to create the long-distance capability to allow a call to cross the US, and another decade for a call to cross the Atlantic. Telephony was an endless process of invention and refinement, providing longer distance, more capacity and better voice quality for a lower price. Local central office switches replaced operators and the ability to dial a “telephone number” was born. Local switches were connected by a network of cables and long-distance switches into a universal, interconnected telephone network. More and more people installed their own phones, until Bell’s vision of “universal service” was realized.

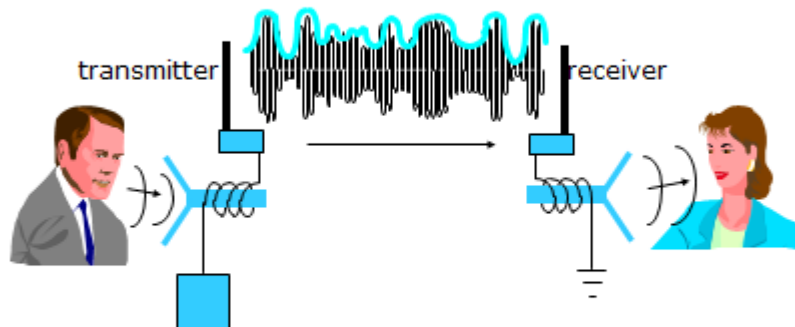
With the creation of the telephone network, anyone could talk to anyone else, using the natural medium of speech, and the age of instant, worldwide “personal” communications was born. Today, of course, the cell phone has taken personal communications to a new level. We take for granted that we can talk to anyone, anywhere, at any time, using voice, video or text. It is difficult for us to imagine how the world felt in 1825, or to appreciate the excitement these early inventions would have created.

And then came radio

That mysterious connection between electricity and magnetism continued to puzzle scientists until the 1860s, when James Clerk Maxwell theorized that they were two aspects of the same phenomenon— an electromagnetic wave. Without experimenting, he created the mathematics of electromagnetism, predicting that radio waves exist and that they would propagate through space at the speed of light. It took another decade before Heinrich Hertz could demonstrate that such waves were real (and to get his name applied to the unit of radio frequency— the Hertz). For Hertz, it was an interesting but not very useful result— it simply proved that Maxwell had been right— but practical inventors like Marconi and Tesla saw more important possibilities. They struggled to send information on radio waves, and in September 1899, Marconi succeeded. A boat in NY harbor sent a telegraph message to his receiving station at Twin Lights, in Highlands, New Jersey (where his equipment is still on display) and ushered in the age of radio communications. Progress after that moment was rapid-- only three years later, radio signals crossed the Atlantic.

Marconi’s first device used bursts of noise created by a spark generator to carry telegraphic information, so only one pair of radios could send and receive messages in any local area without interference. Soon, however, Lee De Forest’s vacuum tube allowed many radio “channels” to carry information at **different frequencies**, with **filters** at the receiver that could select a desired channel. Radio telegraphs were soon installed on all ocean-going vessels, allowing them to remain in contact with receivers on land and with other ships while at sea. When the Titanic sank in 1912, the event was relayed by radio-telegraph operators in nearby ships to bring help—and to report the disaster to the public “instantly.” By the 1920s, radio transmitters were creating “amplitude modulated” (AM) signals that could carry voice and even music. Ordinary people throughout a city could demodulate those signals with simple receivers, and the era of broadcast radio news and entertainment was born. In a few decades television would follow.

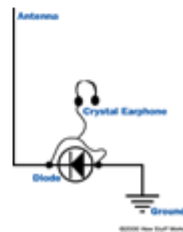
“Demodulating” an AM signal was really simple



The AM receiver is VERY simple

(as simple as a diode and a wire if the signal is near and strong)

Filters let you operate in the presence of signals on other channels



34

The Magic of Radio and its many uses

Radio waves have almost magical properties that capture the imagination and lead to a variety of important uses. Traveling throughout our planet or the universe, they connect points that could be connected in no other way. Scientists are even hoping to find radio signals from distant civilizations in other galaxies.

Traveling radially outward from a known point at a known speed (the speed of light) and being reflected back to the source by metal objects like aircraft, they allowed us to locate flying objects with radar. This became vitally important during the Battle of Britain in WWII, to locate incoming German bombers and activate the famed fighter pilots that protected their cities. Now we can pinpoint our own location within inches on the surface of the earth with “GPS” signals from satellites in space.

Perhaps no other property of the radio signal has been more important than what we might call its ability to “fill space.” While the radio signal may appear to move from point to point in a linear fashion, it is in fact expanding in every direction. It passes through many solids, and it fills in behind other obstructions (such as hills and buildings) through the mechanisms of reflection and diffraction, so that the information it carries is available almost “everywhere” throughout a large area of “coverage”. Before the era of “cable TV,” radio and TV broadcasting provided billions of people with news and entertainment services that were incredibly popular. Some of that importance still exists today, in cars and in places that cable hasn’t reached.

That property of radio waves that we have described as “filling space” also allows us to move through that space while sending or receiving the signal. This was never possible with wires. It made “mobile communications” (and this course) possible.

The earliest radios were too fragile and heavy to be installed in automobiles, but by 1924, Bell Labs engineers had broken through that barrier [slide 29, below]. In the 1930s, police vehicles were being equipped with radios, and in the 1940s, radio telephones emerged as a new service. There were immediate proposals from the Bell System to create a huge nationwide radiotelephone service as early as 1947, but the number of available channels were limited because low-cost radios were limited to relatively low frequencies. As a result, channels were a precious commodity and were generally reserved for “important” services like police, fire, commercial fleets, and military applications, and for popular applications like broadcast radio and TV. Only a few channels were assigned to mobile telephone systems before cellular, so service was limited and rather poor, as we will see in lecture 3.

A car phone in 1924? Bell Labs is on the case!



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29

The next 8 lectures will look at the cellular system from a variety of directions. Its technology is important, but we need to understand all the forces and issues that shaped its introduction and its world. The forces of technology, politics, economics and competition each played a role as the drama unfolded, and the creation of cellular took a decade longer than the creation of its technology. It is a fascinating and frustrating story, told from many viewpoints, as we will discover. For clarity we will look at these forces separately, but we will always see them interacting like battles in a war.

Lecture 3 will be a bridge. It is a continuation of the story told in Lecture 2, focusing on the early systems (before cellular) and the battle to get more channels. It was that battle that finally got the Federal Communications Commission (FCC) to offer a lot

more channels, but they demanded a more “spectrum efficient” system (a system that could serve many more people with the channels they were offering).

Lecture 4 will show how the cellular system provided the spectrum efficiency the FCC wanted, and Lecture 5 describes the strange economics it created. Cellular systems offered the spectrum efficiency and capacity the FCC wanted, but demanded a lot of channels if service providers were to offer service at an attractive price. Lecture 6 introduces the cost accounting methods that business use to measure profit and determine price, so we can turn that issue into real numbers. Lecture 7 shows how the issues of economics (cellular systems needed a lot of channels) became the politics of monopoly (AT&T asked for all the channels the FCC was offering, so the business of cellular would be an AT&T monopoly. This aroused strong objections from other manufacturers, service providers and the Department of Justice (DOJ). The DOJ had been trying to break up Bell’s AT&T monopoly for 50 years. The war about monopoly led to years of delay.

Lectures 8 and 9 tell how the story ended, and the channels were distributed, and the nationwide cellular networks evolved. Lecture 10 will be an interesting movie and a discussion following it. The first Midterm exam in the course will cover the first 10 lectures. What is most important about these early lectures is the passion of creation and how the interactions of technology, politics, economics and competition are the real driving forces of creation. It’s not just about engineers and their technology.