Lab 9

Communication
&
Wireless Technologies

Introduction

In this lab you will learn about wireless communication.

- You will build a capacitor and use it to build a frequency based filter.
- You will build a simple AM radio receiver.

Before we do this, we should learn about:

- Types and uses of various wireless technologies.
- Filters and tuners.
- Signal modulation and coding.
- Some history of communication technologies.

Wireless Technologies

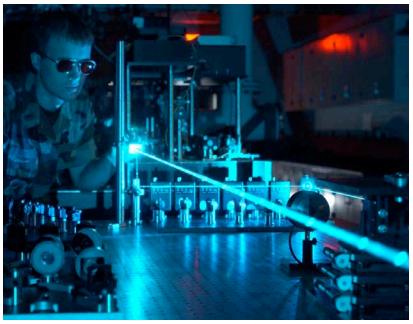
Wireless Technologies

The AM receiver that you are building today is just one of the many communication and wireless technologies that electrical and computer engineers develop.

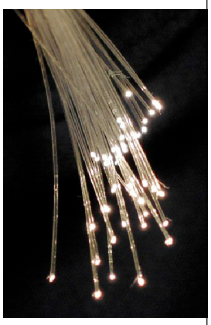
- Some others are shown on the following slides.

Antenna Laboratory in Electrical and Computer Engineering

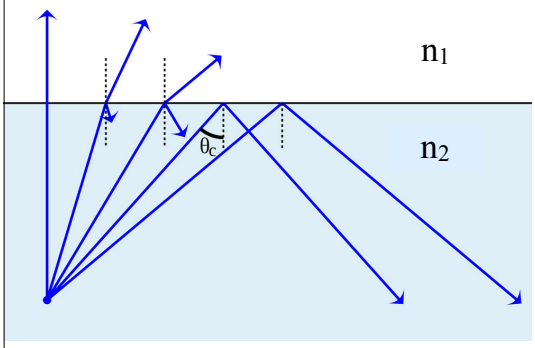
Lasers & Optical Technologies



Lasers and optoelectronic technologies are used in many applications, such as DVD players, medical imaging, and optical communications.



Fibre optic cables can transmit signals with very low energy loss over long distances.



Light is contained in a fibre optic cable due to total internal reflection. This occurs as long as the light strikes the interior wall of the fibre at an angle greater than the critical angle.

$$\theta_C = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$ Note $n_2 > n_1$

Pictures from Wikipedia

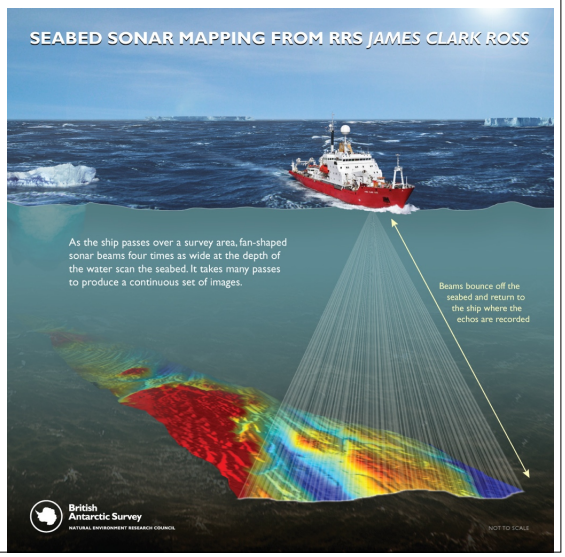
Ultrasound & Sonar

Sound waves are used to locate objects, or image the interior of objects.

- Sound waves reflect when they encounter objects of different density, or regions in a solid object (such as a crack) which have different density.

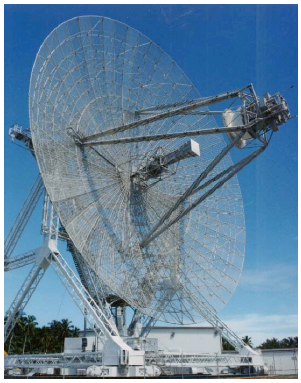
Checking a pipe weld by ultrasound imaging.

Mapping the sea floor with sonar.



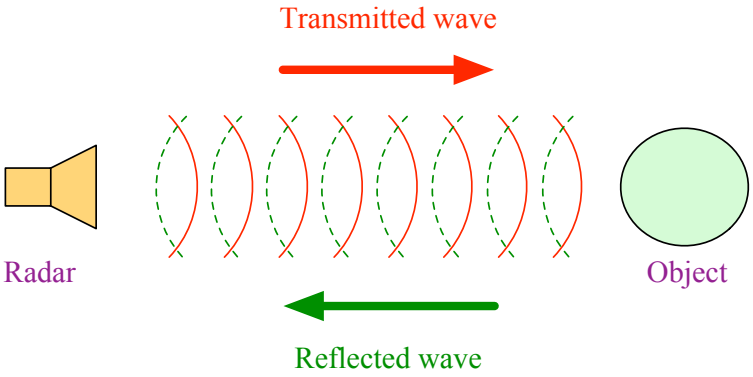
British Antarctic Survey

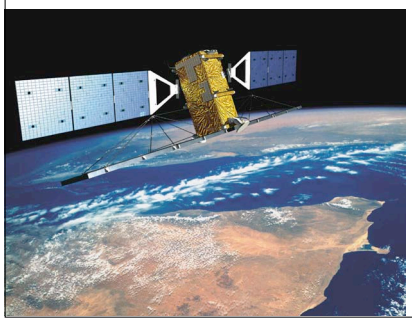
Radar



Radar uses radio waves to locate and track objects.

- Radio waves reflect (scatter) when they encounter objects with a different conductivity or dielectric constant.





Uses of Canada's RADARSAT-2 satellite include forest and agriculture mapping, discerning ocean currents and ice, finding oil, geology, and marine surveillance.

GPR & Radio Astronomy

Radio interferometry techniques mix the signals from multiple telescopes, creating a virtual telescope possessing a resolution equivalent to a telescope the size of the entire array.

Working together, all these antennas emulate a single 8,611 km wide telescope.

Ground penetrating radar (GPR) is used for archeology, geophysics, finding land mines, and much more.

Student GPR Research

Radar can be used to study ice thickness, which is useful for environmental science in the arctic.

Electrical engineering has developed ice mapping radar for the CCGS Amundsen, Canada's arctic research icebreaker.

One of our students, seen on the right, has learnt that to work in the arctic you need to stay alert and be well armed.

Phased Array Technologies

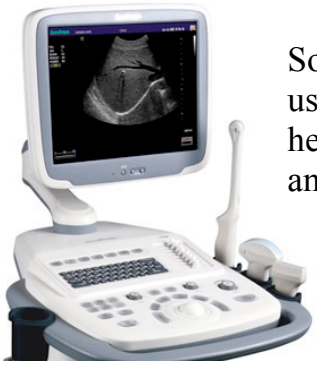
Phased array systems are made of many individual antennas, and can turn their scan beam in different directions electronically, without moving the antenna itself.

- Directional scanning is achieved by combining signals from multiple antennas, with each antenna having its scan signal slightly delayed in time (phase) from neighbouring antennas.

Not needing to physically move your radar has advantages.

- Scan speeds are very fast (fractions of seconds).
- You don't need to worry about dirt or ice jamming antenna scanning motors. This is a benefit in applications such as automotive radar.

Phased Array Examples



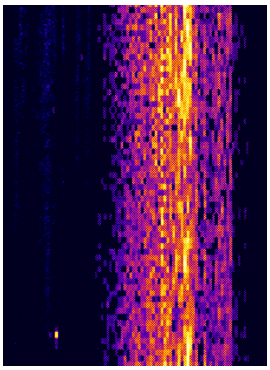
Sound based phased array technologies are used in applications such as directional hearing aids, medical ultrasound systems, and ultrasonic inspection.

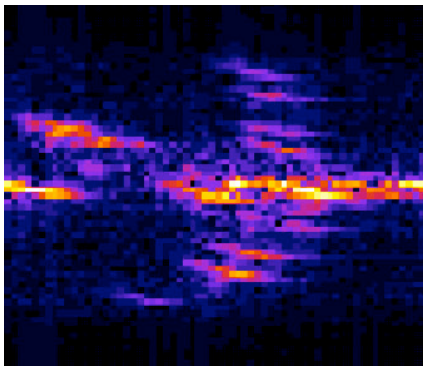
The F-22's phased array antenna can:

- Track multiple targets simultaneously.
- Change frequencies over 1,000 times per second to reduce the chance of being intercepted.
- Focus on and overload enemy sensors.

Signal Processing Mathematics

Signal processing algorithms are used for encoding and decoding communications, or to interpret the reflections received from radar, sonar, or optical imaging systems.





Radar reflection data from a moving aircraft. The signal depends on factors such as the aircraft shape, orientation, velocity, and weather conditions.

Using digital motion compensation, the unique radar signature of a Boeing 727 is revealed.

Communication with Electrical Signals

"Instantaneous" Transmission of Signals

Radio waves travel through air at the speed of light (300,000 km/s), and electromagnetic waves travelling in wires move almost as fast.

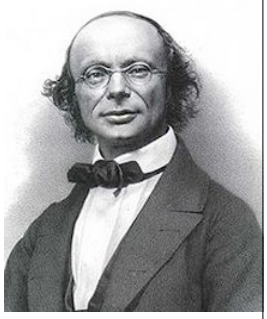
- Once people discovered that electrical signals travelled very fast, they started to think about using it to transmit information.

In 1746, the French clergyman and physicist Jean-Antoine Nollet (1700 - 1770) demonstrated that electricity travels very fast.

- He gathered 200 monks into a circle ~ 1.6 km in circumference, with 25 foot long pieces of iron wire connecting them.
- He discharged a battery through them and observed that each man reacted to the electric shock at the same time.

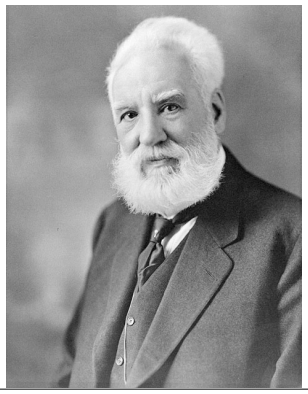
Wired Connections Came First

In 1833 in Germany, the mathematician and scientist Carl Gauss (1777 - 1855) and the physicist Wilhelm Weber (1804 - 1891) constructed the first electric telegraph used for regular communication.



Carl Gauss

Wilhelm Weber



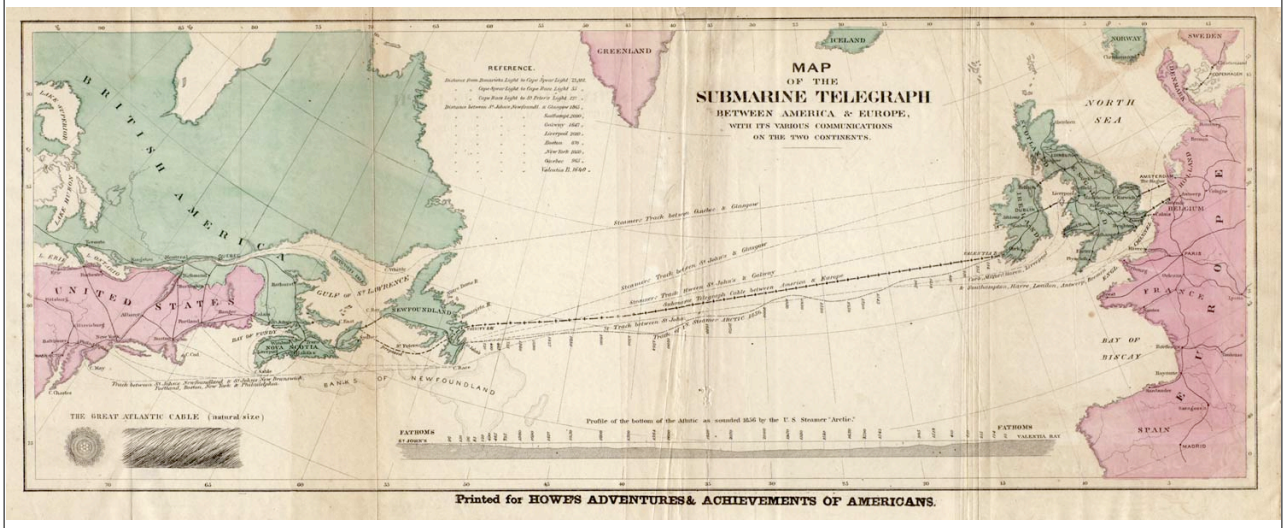
In 1876, Alexander Graham Bell (1847 - 1922) was awarded a United States patent for the telephone.

- He was born in Scotland, and his family moved to Canada when he was 23 years old.

He refused to have a telephone in his study.

Communication Across Oceans

Telegraph and telephone enabled instant long distance communication over land. But oceans remained an obstacle, until 1866. This was when the first successful transatlantic telegraph cable was completed.

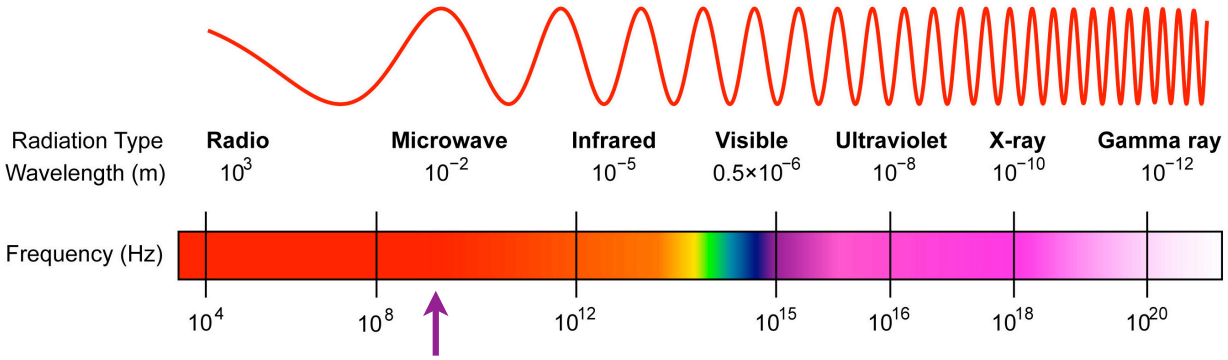


Picture from Wikipedia

Wireless Telegraph - Radio

Wired connections are not needed if you use radio communication. Radio waves, microwaves, light, x-rays, and gamma rays are all electromagnetic (EM) waves.

- EM waves are made up of photons, which are massless particles moving at the speed of light.



Cellular phone frequencies (~ 10^{9} Hz)

The only difference between the various forms of EM radiation is the energy of the photons.

Energy ∝ frequency

Picture from Wikipedia

The Physics of Electromagnetic Waves

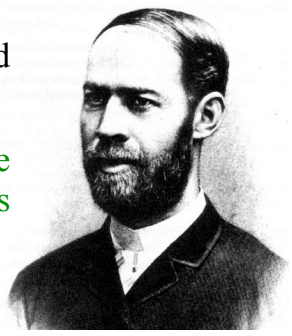
The Scottish physicist and mathematician James Clerk Maxwell (1831 - 1879) developed a unified model of electromagnetism.

- His equations unified electricity and magnetism, and show that light is an electromagnetic phenomenon.

Maxwell is considered the third greatest physicist of all time, behind only Newton and Einstein.

The German physicist Heinrich Hertz (1857 - 1894) demonstrated the transmission and reception of radio waves.

- He found that radio waves could travel through some materials, while being reflected by others. This concept is used in radar.



Famously, he saw no practical use for these discoveries.

Invention of Radio

There are various claims about who invented radio. Tesla and Marconi were only two of the many scientists researching radio.

- In 1893, Nikola Tesla gave a public demonstration of radio communication.
- In 1901, the Italian inventor Guglielmo Marconi (1874 - 1937) transmitted radio signals 3,500 km from Poldhu England to St. John's Newfoundland.

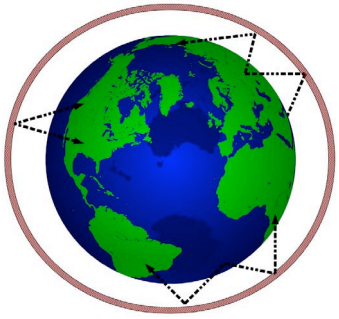
Marconi in Newfoundland

Many lawsuits were filed between various claimants.

- In 1943, the Supreme Court of the United States credited Nikola Tesla as being the inventor radio. This was the year he died, and so he did not benefit.
- At the time, the US Army was involved in a patent infringement lawsuit with Marconi's company. Earlier, the US government fought against Tesla's patents.

Long Distance Radio Transmission

Radio signals travel in a straight line, but the Earth is curved. So how do you send a radio signal beyond "line of sight" (~ 50 km)?



Build a very tall tower to increase your line of slight.

Use "shortwave" (3 - 30 MHz). These frequencies travel 100's of km, because they bounce between the Earth's surface and the ionosphere.

The ionosphere is a region of electrons and ions, stretching from a height of about 50 - 1000 km. It is created primarily due to UV radiation from the sun.

Place a satellite high above the Earth.

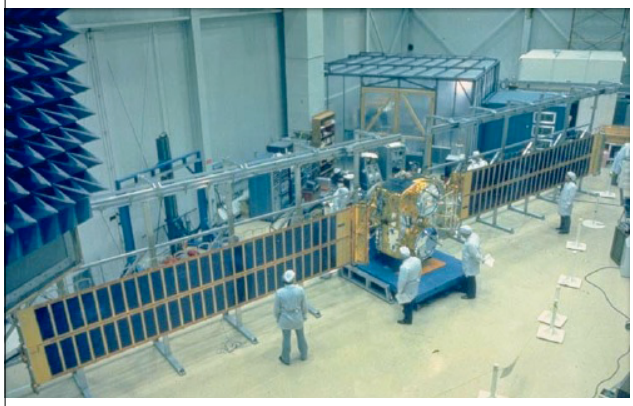
Satellites in geosynchronous orbit are ~ 36,000 km above the Earth.

Pictures from Wikipedia

Canadian Satellite World Firsts

Canada has been a pioneer in satellite technologies.

In 1972, Canada launched Anik A1, and became the first country to have a communications satellite in geostationary orbit for domestic purposes.



Launched in 1976, the Canadian Hermes satellite demonstrated for the first time the broadcasting of live video by satellite.

U of M staff in electrical and computer engineering helped develop its antenna technology.

Modulation & Transmission of Signals

Modulation of Signals

In today's lab you will build an AM receiver.

- The acronym AM is short for Amplitude Modulation.

AM is a technique used to transmit a low frequency signal using a higher frequency carrier signal.

- For example, humans hear sound frequencies from ~ 20 Hz to ~ 20 kHz, and human speech lies within that range. However, these low frequencies cannot easily be transmitted by radio waves.
- Therefore, human voice needs to be somehow loaded onto high frequency radio waves, which have a sinusoidal waveform.

The term modulation refers to the technique used to load the information (voice in the case of radio) onto the high frequency carrier wave.

What Are AM & FM Modulation?

Amplitude modulation (AM): The amplitude of the high frequency carrier wave varies in accordance to the data transmitted.

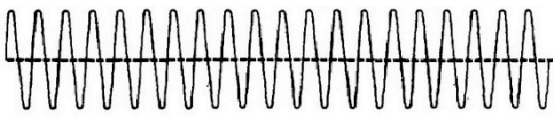
- Therefore, the information is contained in the varying amplitude of the signal.
- In 1906, the first AM radio broadcast was made by Reginald Fessenden (1866 - 1932), a Canadian-born electrical engineer.

Frequency modulation (FM): The frequency of the carrier wave is modulated in accordance to the data transmitted.

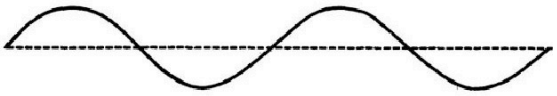
- Therefore, the information is contained in the varying frequency of the signal.
- In 1933, FM broadcasting was invented by Edwin Armstrong (1890 - 1953), an American electrical engineer.

AM & FM Modulation

Picture source: http://www.tpub.com/content/armycomsystems/SS03456/SS034560018.htm

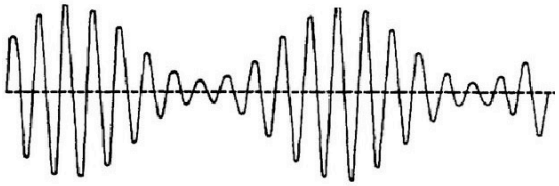


Carrier Wave



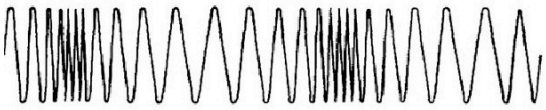
Signal

AM Modulation:
The information is carried in the varying amplitude of the wave.



Amplitude Modulated Wave

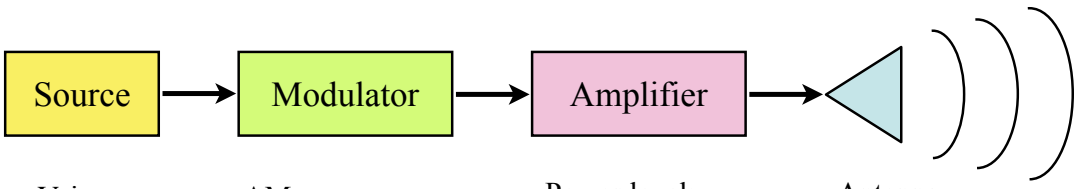
FM Modulation:
The information is carried in the varying frequency of the wave.



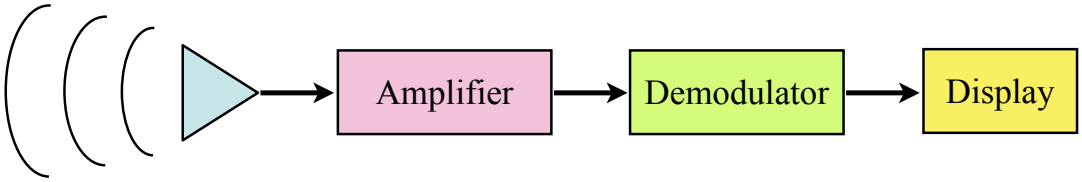
Frequency Modulated Wave

Transmitter / Receiver System Concept

Transmitter



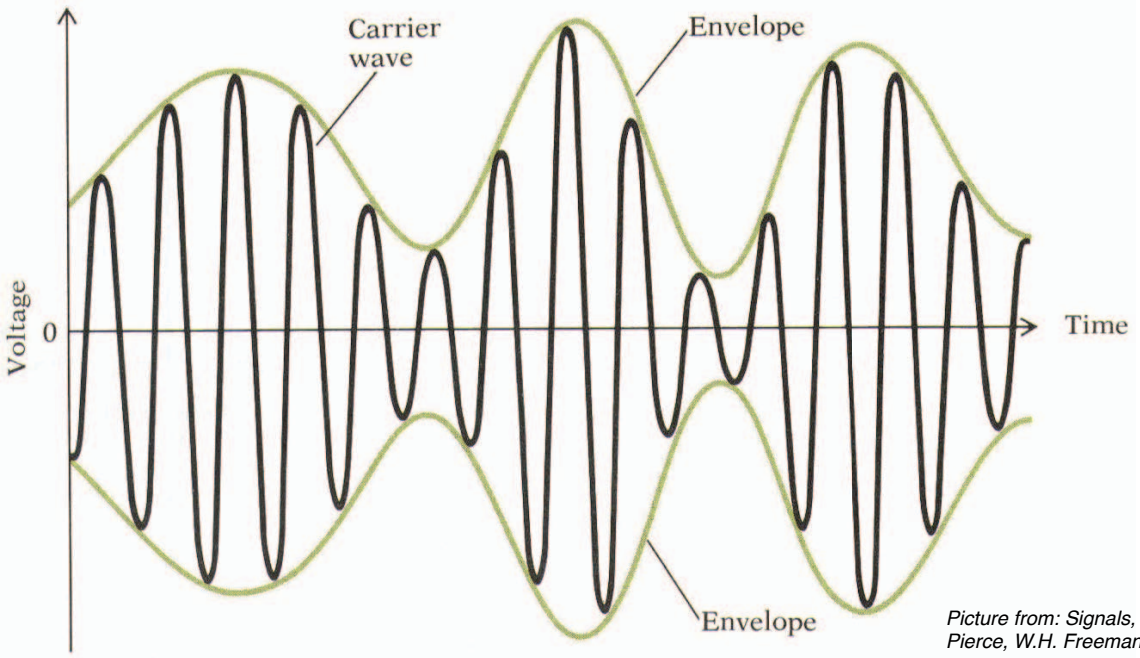
Receiver



Transmitted AM Signal

The transmitted AM signal is described by the following figure.

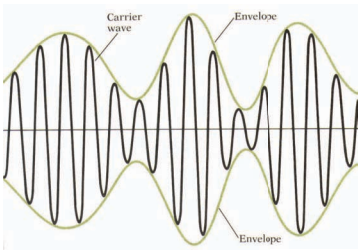
- The modulated signal information is carried in the amplitude envelope.



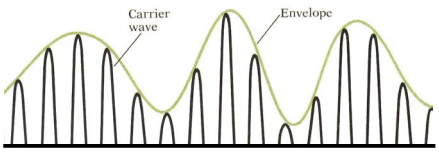
Picture from: Signals, by John Pierce, W.H. Freeman publishing.

Today's Lab - Simple AM Receiver

Waveform pictures from: Signals, by John Pierce, W.H. Freeman publishing.

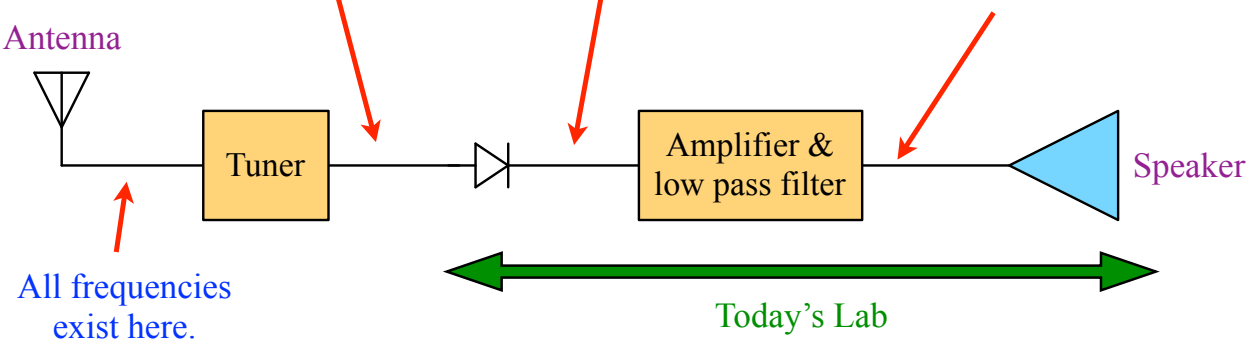


Only the frequency that you have tuned to exists here.



Rectified signal after the diode.

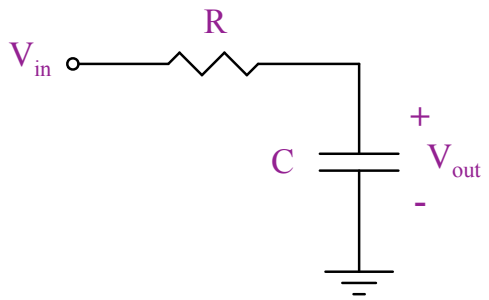
The low pass filter removes the high frequency carrier wave, leaving only the low frequency audio signal.



Low Pass Filter for AM Receiver

A filter is an electronic circuit that reduces (removes) select components of a signal.

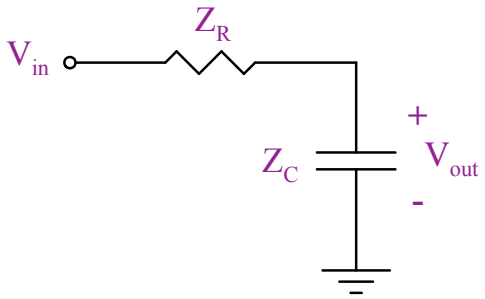
- A low pass filter will remove the high frequency carrier wave of your AM signal, leaving only the low frequency audio signal.



A simple low pass filter can be made using a resistor and a capacitor.

- The capacitor works to block DC signals, making $V_{out} = V_{in}$.
- But, the capacitor can short out very high frequency AC signals, making $V_{out} = 0$.

Low Pass Filter - Circuit Analysis



Using voltage division, we can solve for V_{out} in terms of V_{in} .

- First, we convert R and C into their impedance equivalents of Z_R and Z_C.

$$Z_R = R \qquad Z_C = \frac{1}{j2\pi fC}$$

Solving for V_{out} in terms of V_{in} yields, where f is the circuit frequency:

$$\frac{V_{out}}{V_{in}} = \frac{Z_C}{Z_R + Z_C} = \frac{\frac{1}{j2\pi fC}}{R + \frac{1}{j2\pi fC}} = \frac{1}{1 + j2\pi fRC}$$

This equation shows that for:

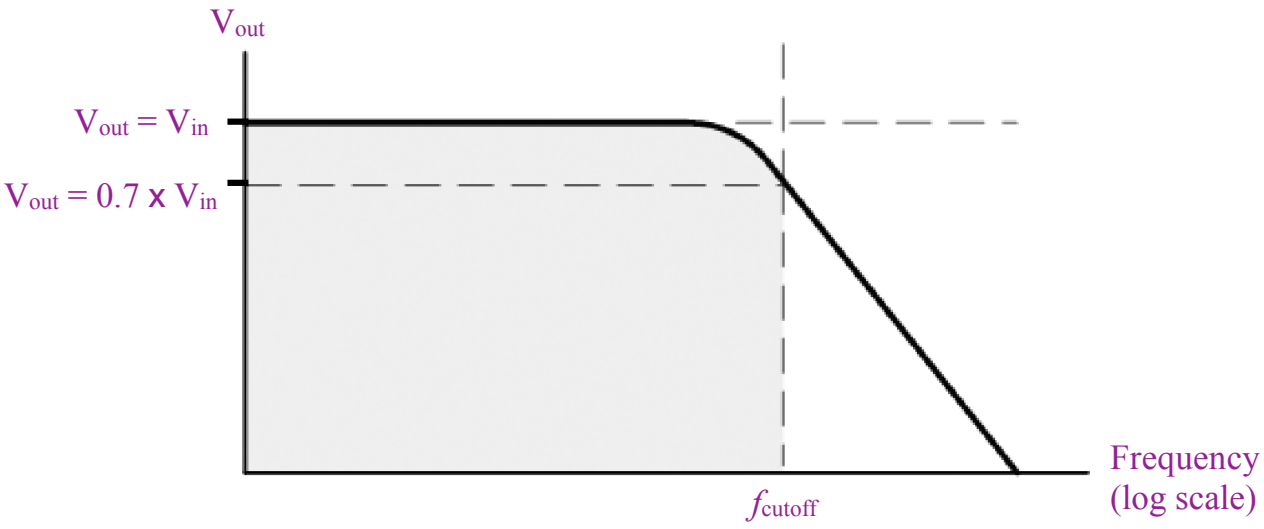
$fRC << 1$ then $V_{out} = V_{in}$ ← low frequencies pass

$fRC >> 1$ then $V_{out} = 0$ ← high frequencies are filtered

Frequency Cutoff of Low Pass Filter

By appropriately choosing R or C in your filter circuit, you can select what frequencies your low pass filter significantly attenuates.

- It can be shown that when the circuit operating frequency is: $f_{cutoff} = \frac{1}{2\pi RC}$ then the output voltage $V_{out} = 0.7 \times V_{in}$



Digital Cell Phones
&
Cellular Network Communication

Digital Cell Phones

Modern cell phones use a digital modulation method. Computer engineers study and develop many digital communication techniques.

Digital modulation concept:

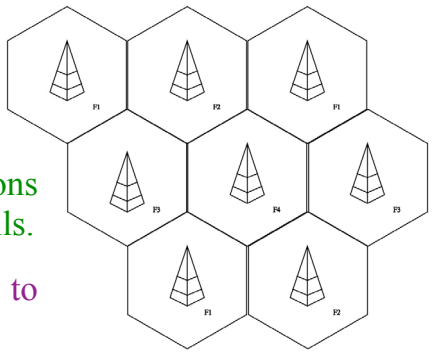
- Voice is converted to digital data (0's and 1's).
- The data is compressed. This reduces the traffic load on the cell towers, which enables the tower to serve more customers.
- The data is then loaded onto a high frequency carrier signal and transmitted.

Modern cell phones process millions of calculations per second in order to compress and decompress the voice stream.

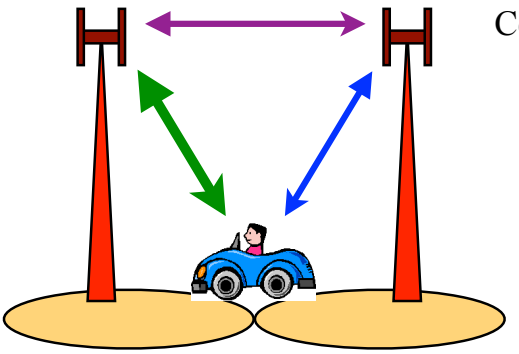
Cellular Networks

There are a limited number of available communication frequencies, but 1000's of mobile devices. What is the solution?

- Cities are divided into "cells", each with a base station assigned a range of allowed frequencies.
- Mobile devices communicate with local base stations using weak signals, reducing interference in other cells.
- Adjacent cells avoid using the same frequencies, to prevent co-channel interference.



Picture from Wikipedia



Cell phones in motion.

- As you move to the edge of a cell, its base station will notice your signal weakening.
- Meanwhile, the tower in the cell you are moving towards will notice your signal increasing.
- The two base stations communicate together and agree to "hand-off" your signal between them.

Transmitting Digital Signals

There are many methods by which the cell phone signal is sent over mobile communication networks. Three examples are FDMA, TDMA, CDMA.

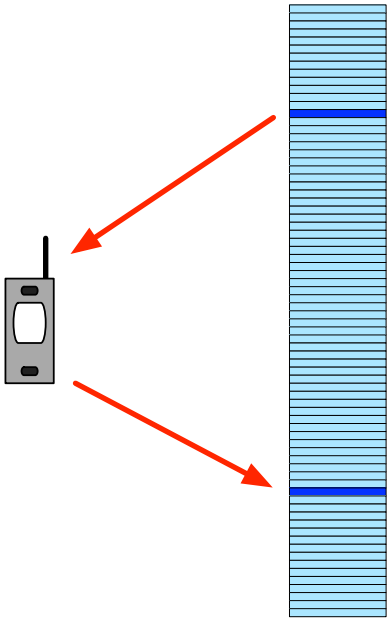
- Frequency Division Multiple Access: Each call is put on a separate frequency.
- Time Division Multiple Access: Each call is assigned a certain portion of time on a designated frequency.
- Code Division Multiple Access: Each call (transmitter) is given a unique code, and the call is spread over all the available frequencies.

A simple analogy. You are in a room with many people talking. If you want to distinguish between different people:

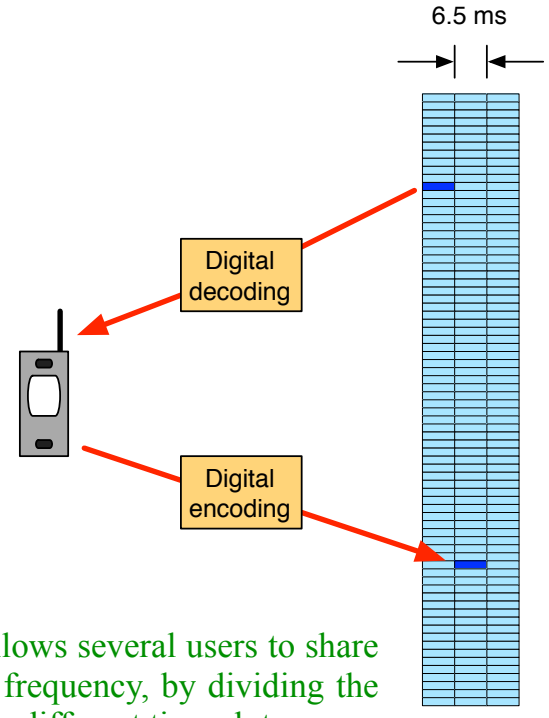
- FDMA: Each person talks at a different pitch.
- TDMA: Each person talks at different times.
- CDMA: Each person talks in a different language.

FDMA & TDMA

FDMA



TDMA

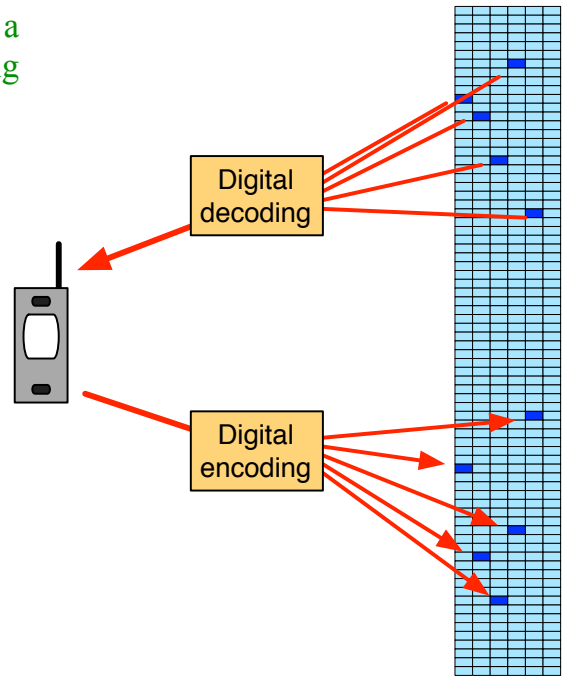


TDMA allows several users to share the same frequency, by dividing the signal into different time slots.

CDMA

CDMA

CDMA allows multiple calls to occupy a single transmission channel, optimizing the available bandwidth.



Spreading each call over multiple frequencies is called spread spectrum technology.

- There are trillions of possible frequency sequencing codes, enhancing privacy.

Spread Spectrum Concept

In spread spectrum communication, pieces of the message are transmitted over many different frequencies following a pseudorandom specific sequence.

- Spread spectrum signals are resistant to interference and difficult to intercept. An eavesdropper could only listen in if they knew the pseudorandom sequence.
- The concept was developed by many people, starting with Nikola Tesla in 1903.

The most celebrated invention, was by the Austrian-born actress Hedy Lamarr (1914 - 2000) and American composer George Antheil (1900 - 1959).

- In 1942, they received a US patent for a frequency hopping guidance system that made torpedoes harder to detect or jam.
- The patent is considered a foundational patent for spread spectrum technologies, such as CDMA used in some cell phones, and COFDM used in Wi-Fi networks.

Important Things To Remember

Important Points

In amplitude modulation (AM), the amplitude of the carrier signal is modulated by the signal being transmitted.

In frequency modulation (FM), the frequency of the carrier signal is modulated by the signal being transmitted.

Your AM receiver circuit: The diode rectified the signal. The low pass filter removed the high frequency carrier wave.

You should know what FDMA, TDAM, and CDMA stand for, and how they work.