

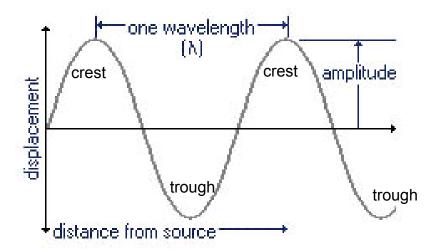
Yerkes Summer Institute 2002



Before we begin our investigations into radio waves you should review the following material on your trip up to Yerkes. For some of you this will be a refresher, but others may want to spend more time learning about the basic properties of waves and radio so that you will be able to get the most out of this years summer institute. If you don't understand something be sure to ask one of your instructors when you see them!

Waves 101

Everyone has seen waves on the surface of water. You made them in the bathtub when you were small, and you have seen them on Lake Michigan. All of you have listened to radio waves from your favorite radio stations. All waves have certain things in common. Let's look at the diagram below to learn more about the parts of wave.



(Fig 1)
All waves have **crest** (high points), **troughs** (low points), a **wavelength** (the distance from one crest to another or one trough to another), **amplitude** (the height of a crest or trough), and a **frequency** (the number of complete wavelengths that pass a given point in a second.) When we talk about frequency

the unit that is associated with it is **Hertz (Hz)**. When you say that a wave has a frequency of 1-Hz you are saying that it has one cycle per second. Another way of saying this is that one complete wave passes a given point in one second of time.

Common Frequency Units

Hz = hertz = 1 cycle/second

KHz = kilohertz = thousand (1,000) cycles/second

MHz = megahertz = million (1,000,000) cycles/second

GHz = gigahertz = a thousand million (1,000,000,000) cycles/second

Waves that you see and make in water are **mechanical waves**, as are sound waves. Both require stuff or a medium to travel through. The sound waves that you hear when someone speaks push air that hits your eardrum. The

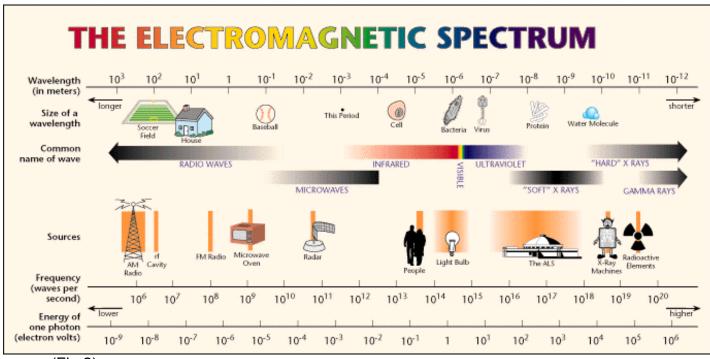
compressions of the wave cause a vibration on your eardrum, which you translate into sound. This sound can be speech, music, or simply noise. The media that water waves travel in is, not surprisingly, water. Mechanical waves can switch media that they are traveling in. For instance, when a wave crashes on the beach we can hear it or if music is played really, really loud



it can vibrate walls. However mechanical waves always need something to travel in. There is another group of waves called electromagnetic waves that can travel in certain media and in a vacuum.



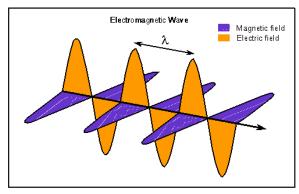
Electromagnetic waves have the same characteristic parts as mechanical waves (e.g., wavelength, amplitude, frequency, etc), but they behave very differently. Sound waves travel in air at a speed of approximately 344 meters/second, while electromagnetic waves travel at the speed of light (300,000,000 meters/second). While mechanical waves need something to move in e.g., air or water, electromagnetic waves can travel in a vacuum. Another important characteristic of electromagnetic waves is that they will travel in a straight line unless something changes their course (e.g., think of a laser beam). Electromagnetic waves have many uses and span an enormous range of frequencies and corresponding wavelengths as you can see in the diagram below.



(Fig 2)

Long (low energy, low frequency) electromagnetic waves like radio and television are on one end of the spectrum, while short (high energy, high frequency) waves like x-rays and gamma rays are on the other end of the spectrum. As you can see visible light, the electromagnetic radiation that our eyes can sense, occupies only a very small sliver of the spectrum.

Electromagnetic radiation consists of interconnected changing electric and magnetic fields (see Fig 3). One way to produce such waves is to wiggle something that is electrically charged such as an electron, a tiny charged particle that is part of an atom. Moving a charged particle back and forth produces

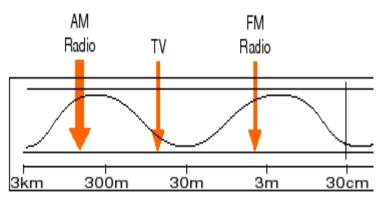


(Fig 3)

changing electric and magnetic fields. One should keep in mind that things need to wiggle very very fast as even low frequency radio waves are on the order of a million cycles per second. At each point along the wave there is an electric field and an associated magnetic field that are at a right angles to each other as well as to the direction of the forward movement of the wave.

Radio 101

If you look at the diagram of the electromagnetic spectrum above, you will



Radio Wave Region of the Electromagnetic Spectrum (Fig. 4)

notice that radio waves have the longest wavelengths of the spectrum. To give you an idea of how long radio waves can be AM radio waves can be longer than a football field, while FM radio waves are short in comparison – only about 3 meters long!

So how does a radio work?



A radio transmitter whose job it is to move electric charges rhythmically up and down its antenna sets the signal that is to be propagated in motion. These waves that are propagated carry signals that are received by antennae on your radio or television set. (note: antennas are used both to transmit or and receive signals)

The movement of the electric charges produces a changing electric field-a structure in space that pushes on electric charges--and a changing magnetic field--a structure in space that pushes on magnetic poles. Because the electric field changes with time, it creates the magnetic field and because the magnetic field changes with time, it creates the electric field. The two travel off across space as a pair, endlessly recreating one another in an electromagnetic wave that will continue to the ends of the universe. However, when this wave encounters the antenna of your radio, its electric field begins to push electric charges up and down on that antenna. Your radio senses this motion of electric charges and thus detects the passing radio wave. To convey audio information (sound) to you radio, the radio station makes one of several changes to the radio wave it transmits. In the AM or Amplitude Modulation technique, it adjusts the amount of charge it moves up and down its antenna, and hence the strength of its radio wave, in order to signal which way to move the speaker of your radio. These movements of the speaker are what cause your radio to emit sound. In the FM or Frequency Modulation technique. the radio station adjusts the precise frequency of the transmission.

(http://howthingswork.virginia.edu/radio.html).

You may think that only radio stations produce radio waves, but this is not the case. There is an entire field in astronomy called **radio astronomy** in which astronomer's study the universe by observing radio waves!

Can you make a list of the natural things in space that produce radio waves? List some of them below.



1. 2.

3.

4.

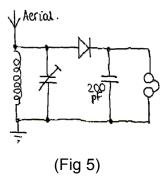
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6. 7.

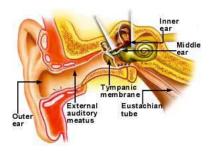
8.

(Fig 4)

How does this connect with what I did with Mr. Hennessy?



Earlier this year some of you built a crystal radio set with Mr. Hennessy and you were able to listen to AM radio stations. Do you know why? The reason a crystal radio works has to do with the amazing capabilities of the human ear, the amazing power of radio waves, and the amazing power of an electronic device called a crystal diode.



First, the ear is extremely sensitive to very faint sounds, second crystal radio uses only the energy of the radio waves sent by radio transmitters (i.e., no batteries were needed), and third a crystal radio uses a crystal diode to detect tiny fluctuating currents in its antenna system. When a radio wave passes across an antenna, the wave's electric field pushes electric charges up and down the antenna.

(Fig 6) The crystal diode acts as a one-way gate that allows some of this moving charge to flow onto another wire and then prevents it from returning to the antenna. Since the charge can't return to the antenna, it flows elsewhere-passing through a sensitive earphone and creating sound. Radio transmitters in the AM band send out enormous amounts of energy (tens of thousands of watts). However, because they are usually far away, you needed to have a very long antenna to collect the energy form their radio wave. The amount of energy we receive with the crystal radio is measured in billionths of a watt, but that is plenty of energy, because the human ear can detect sounds that are less than a millionth of even that.

But what about those transmitters; how do they work?

An electronic device called an oscillator is the heart of the transmitter. Think of an oscillator as a type of electronic swing that swings voltage incredibly fast. You can buy oscillators to

swing voltage at various speeds. The oscillator that you will use swings voltage at 1,000,000 cycles per second and as such is referred to as a 1,000 kilohertz or 1 megahertz oscillator.

When the power is connected to the oscillator the voltage starts jumping between 0 volts and 5 volts, one million times each second. You need one more thing to make an AM transmitter and that is a transformer. A transformer modulates or adjusts the strength of the radio wave. The modulator changes the strength of the radio waves to match the loudness of the music or voice we want to transmit. When you are done building your transmitter it should look something like this.

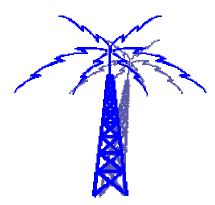
When you connect your transmitter to a transmitting antenna an electric charge travels up and down the wire antenna (at the rate of the oscillator), causing radio waves to be emitted from the wire. These radio waves are then picked up by your crystal radio, which are tuned to receive signals of 1,000-KHz. You will be able to attach a CD player or tape player to your



transmitter and actually broadcast music over a short range.

(Fig 7)

Okay, but what about those radio waves, I still don't understand how music or voice is transmitted on a radio wave?



Well, remember that radio waves consist of nothing more than electric and magnetic fields that are continuously recreating one another as they travel through space at the speed of light. An electric field exerts forces on electric charges and a magnetic field exerts forces on magnetic poles. Both electric and magnetic fields contain energy. In a radio wave, this energy moves along with the fields. Your transmitter uses electric power to create the radio wave and the radio wave delivers

that power to your

crystal radios via the antenna. To understand radio transmission you may want to think of a radio wave like a swing.

Radio waves contain electric and magnetic fields, and these fields will push on any electric charges they



(Fig 8)



encounter just like you push on a swing to make a person move back and forth. The amount of fields used for audio transmission depends on the transmitting power and on how the music or speech is encoding or formatted. Your crystal radios and transmitters that you will make are Amplitude Modulation so you receive AM radio waves. Each time the radio wave's strength goes up and down once, the speaker cone on your radio goes forward and backward once and produces sound. You remember sound, it a mechanical wave that exerts pressure on your ear, which you translate into music or speech. If we were talking about FM (Frequency Modulated) radio waves then the radio wave's strength remains steady but its precise frequency changes slightly. Each time the

1.0 (sign) 0.5 (vigor) 0.5 (vi

(Fig 9)

radio wave's frequency goes up and down once, the speaker cone on your radio moves forward and backward once. A radio receiver will work best when the antenna and internal circuits best match the wave that it is being used to catch. Since radio waves oscillate, the electrons in the antenna oscillate, and the radio circuit oscillates, when everything is in sync we say that they are resonant. Resonance occurs when things are well matched. We will study this more in the laboratory. Radio stations come in best when your receiver is tuned to the same frequency as

the transmitter, that is your receiver resonates with the radio wave. Antenna also works best when they are matched to the wave that you are catching. When radio waves hit antenna they push electrical and magnetic fields down the metal wire and into your radios. In order to best catch radio waves with an antenna it needs to match the waves that you are catching. You will explore the relationship of antenna length and ability in the laboratory.

With this background you should be ready to dive into radio waves – pardon the pun. Be sure to make use of the glossary if you need to refresh yourself on any of the term used in this review. ©

Glossary

Antenna-- a usually metallic device (such as a wire or rod) for radiating or receiving radio waves.

Electric Field -- a region associated with a distribution of electric charge or a varying magnetic field in which forces due to that charge or field act upon other electric charges.

Magnetic Field— the portion of space near a magnetic body or a current-carrying body in which the magnetic forces due to the body or current can be detected **Oscillator** — a device for producing alternating current, *especially*: a radio frequency or audio frequency generator.

Resonance -- a vibration of large amplitude in a mechanical or electrical system caused by a relatively small periodic stimulus of the same or nearly the same period as the natural vibration period of the system.

Transformer -- a device used to convert variations of current in a primary circuit into variations of voltage and current in a secondary circuit.

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