13.1 Introduction

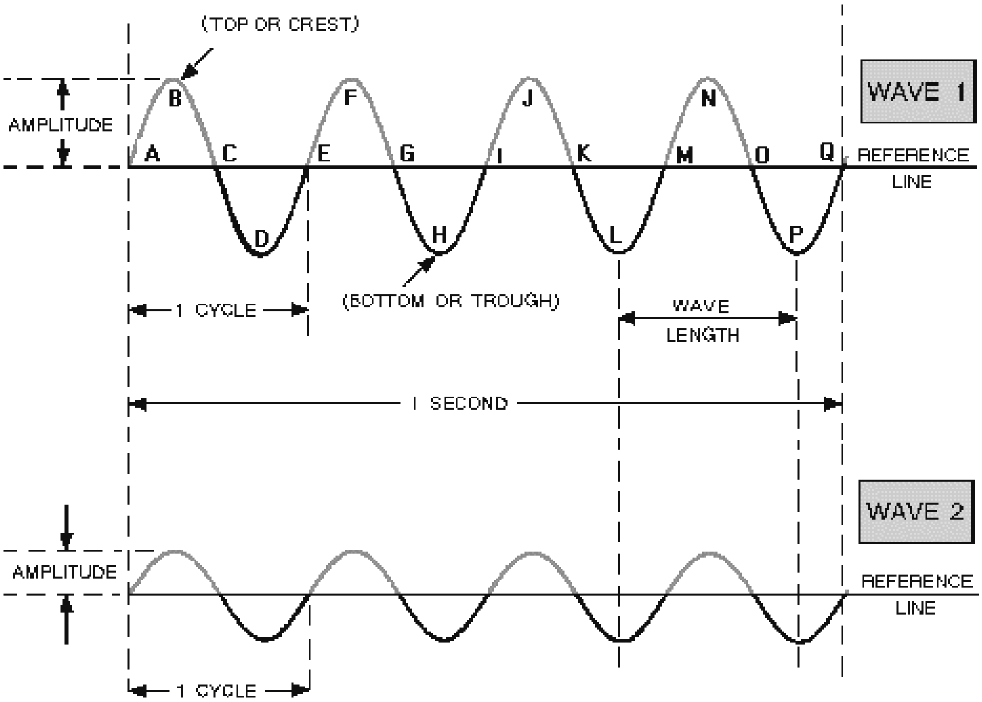
The wave propagation is an invisible force that cannot be detected by the sense of sight or touch. Radio waves are a form of radiant energy, similar to light and heat. Although they can neither be seen nor felt, their presence can be detected through the use of sensitive measuring devices. The speed at which both forms of waves travel is the same; they both travel at the speed of light. You may wonder why you can see light but not radio waves, which consist of the same form of energy as light. The reason is that you can only "see" what your eyes can detect. Your eyes can detect radiant energy only within a fixed range of frequencies. Since the frequencies of radio waves are below the frequencies your eyes can detect, you cannot see radio waves.

13.2 Principles of Wave Motion

All things on the earth—on the land, or in the water—are showered continually with waves of energy. Some of these waves stimulate our senses and can be seen, felt, or heard. For instance, we can see light, hear sound, and feel heat. However, there are some waves that do not stimulate our senses. For example, radio waves, such as those received by our portable radio or television sets, cannot be seen, heard, or felt. A device must be used to convert radio waves into light (TV pictures) and sound (audio) for us to sense them. A wave can be defined as a disturbance (sound, light, radio waves) that moves through a medium (air, water, vacuum). To help you understand what is meant by "a disturbance which moves through a medium," picture the following illustration. You are standing in the middle of a wheat field. As the wind blows across the field toward you, you can see the wheat stalks bending and rising as the force of the wind moves into and across them. The wheat appears to be moving toward you, but it isn't. Instead, the stalks are actually moving back and forth. We can then say that the "medium" in this illustration is the wheat and the "disturbance" is the wind moving the stalks of wheat. wave motion can be defined as a recurring disturbance advancing through space with or without the use of a physical medium. Wave motion, therefore, is a means of moving or transferring energy from one point to another point. For example, when sound waves strike a microphone, sound energy is converted into electrical energy. When light waves strike a phototransistor or radio waves strike an antenna, they are likewise converted into electrical energy. Therefore, sound, light, and radio waves are all forms of energy that are moved by wave motion.

13.3 Terms Used in Wave Motion

Refer to wave 1 in Figure below. Wave 1 has four complete cycles. Points ABCDE comprise one complete cycle having a maximum value above and a maximum value below the reference line. The portion above the reference line (between points A and C) is called a positive alternation and the portion below the reference line (between points C and E) is known as a negative alternation. The combination of one complete positive and one complete negative alternation represents one cycle of the wave. At point E, the wave begins to repeat itself with a second cycle completed at point I, a third at point M, etc. The peak of the positive alternation (maximum value above the line) is sometimes referred to as the **TOP** or **CREST**, and the peak of the negative alternation (maximum value below the line) is sometimes called the **BOTTOM** or **TROUGH**, as depicted in the figure. Therefore, one cycle has one crest and one trough.



13.4 Amplitude

Two waves may have the same wavelength, but the crest of one may rise higher above the reference line than the crest of the other. Compare wave 1 and wave 2 of above Figure. The height of a wave crest above the reference line is called the amplitude of the wave. The amplitude of a wave gives a relative indication of the amount of energy the wave transmits.

13.5 Frequency and Time

a) The period, which is the time (T) in which one complete vibratory cycle of events occurs.

b) The frequency of vibration (f), which is the number of cycles taking place in one second.

c) The wavelength, which is the distance the disturbance travels during one period of vibration.

$$time(T)of \quad one \quad vibration = \frac{1}{frequency} = \frac{1}{f}$$

13.6 Radio frequency (RF)

Radio frequency refers to electromagnetic waves that have the wavelengths suitable for use in radio communication systems. RF signals range from very low frequency (VLF), which has the range from 3kHz to 30kHz, to extremely high frequency (EHF), from 30GHz to 300 GHz.

13.7 Radio Propagation

Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere. Like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.

13.8 Electromagnetic Waves Spectrum

13.8.1 Extremely Low Frequency (ELF)

Radio band: **E**xtremely **L**ow **F**requency **(ELF)**
Frequency: 30-3000 Hz
Wavelength: 10Mm-100Km
Propagation Via: ELF waves can penetrate seawater
Application: Used in communications between submarines and also used in the alternating power (50-60 Hz) and audio frequencies

13.8.2 Very Low Frequency (VLF)

Radio band: **V**ery **L**ow **F**requency **(VLF)**
Frequency: (3-30) kHz
Wavelength: (100-10) km
Propagation Via: Since VLF waves can penetrate at least 40 meters (120 ft) into saltwater, they are used for military communication with submarines.
Application: The VLF band is used for a few radio navigation services, government time radio stations (broadcasting time signals to set radio clocks) and for secure military communication.

13.8.3 Low Frequency (LF)

Radio band: **L**ow **F**requency **(LF)**

Frequency: (30-300) kHz

Wavelength: (10 – 1) km

Propagation Via: Guided between the earth and the ionosphere, Ground Waves.

Application: LF radio waves exhibit low signal attenuation, making them suitable for long-distance communications. In Europe and areas of Northern Africa and Asia, part of the LF spectrum is used for AM broadcasting as the "longwave" band. In the western hemisphere, its main use is for aircraft beacon, navigation, information, and weather systems. A number of time signal broadcasts are also broadcast in this band.

13.8.4 Medium Frequency (MF)

Radio band: **M**edium **F**requency (**MF)**

Frequency: 300kHz-3MHz

Wavelength: (1000 -100) m

Propagation Via: Ground waves, E layer ionospheric refraction at night, when D layer absorption disappears

Application: MF is mostly used for AM radio broadcasting, navigational radio beacons, maritime ship-to-shore communication, and transoceanic air traffic control.

13.8.5 High Frequency (Short Wave) (HF)

Radio band: **H**igh **F**requency (Short Wave) **(HF)**

Frequency: (3-30) MHz

Wavelength: (100 – 10) m

Propagation Via: Radio waves in the shortwave band can be reflected or refracted from a layer of electrically charged atoms in the atmosphere called the ionosphere. Therefore, short waves directed at an angle into the sky can be reflected back to Earth at great distances, beyond the horizon. This is called skywave or "skip" propagation.

Application: Thus shortwave radio can be used for very long distance communication, in contrast to radio waves of higher frequency which travel in straight lines (line-of-sight propagation) and are limited by the visual horizon, about 40 miles (64 km). Shortwave radio is used for broadcasting of voice and music to shortwave listeners over very large areas; sometimes entire continents or beyond. It is also used for military over-the-horizon radar, diplomatic communication, and two-way international communication by amateur radio enthusiasts for hobby, educational and emergency purposes.

13.8.6 Very High Frequency (VHF)

Radio band: **V**ery **H**igh **F**requency **(VHF)**

Frequency: (30-300) MHz

Wavelength: (10 – 1) m

Propagation Via: Line-of-sight

Application: Common uses for VHF are FM radio broadcasting, television broadcasting, two way land mobile radio systems (emergency, business, private use and military), long range data communication up to several tens of kilometers with radio modems, amateur radio, and marine communications. Air traffic control communications and air navigation systems work at distances of 100 kilometers or more to aircraft at cruising altitude.

13.8.7 Ultra High Frequency (UHF)

Radio band: **U**ltra **H**igh **F**requency **(UHF)**

Frequency: (300MHz-3GHz)

Wavelength: (100 – 10) cm

Propagation Via: UHF radio waves propagate mainly by line of sight; they are blocked by hills and large buildings although the transmission through building walls is strong enough for indoor reception.

Application: They are used for television broadcasting, cell phones, satellite communication including GPS, personal radio services including Wi-Fi and Bluetooth, walkie-talkies, cordless phones, and numerous other applications.

13.8.8 Super High Frequency (SHF)

Radio band: **S**uper **H**igh **F**requency **(SHF)**

Frequency: (3-30) GHz

Wavelength: (10 – 1) cm

Propagation Via: Line-of-sight, these frequencies fall within the microwave band, so radio waves with these frequencies are called microwaves. The small wavelength of microwaves allows them to be directed in narrow beams by aperture antennas such as parabolic dishes and horn antennas.

Application: they are used for point-to-point communication and data links and for radar. This frequency range is used for most radar transmitters, wireless LANs, satellite communication, microwave radio relay links, and numerous short range terrestrial data links.

13.8.9 Extremely High Frequency (EHF)

Radio band: **E**xtremely **H**igh **F**requency **(EHF)**

Frequency: (30-300) GHz

Wavelength: (10 – 1) mm

Propagation Via: Line-of-sight limited by absorption.

Application: radio waves in this band have high atmospheric attenuation: they are absorbed by the gases in the atmosphere. Therefore, they have a short range and can only be used for terrestrial communication over about a kilometer. Absorption by humidity in the atmosphere is significant except in desert environments, and attenuation by rain (rain fade) is a serious problem even over short distances. However the short propagation range allows smaller frequency reuse distances than lower frequencies. The short wavelength allows modest size antennas to have a small beam width, further increasing frequency reuse potential.

13.8.10 Radar frequency bands

Radar Frequency Bands		
Band Designation	**Frequency Range**	**Typical Usage**
VHF	50-330 MHz	Very long-range surveillance
UHF	300-1000 MHz	Very long-range surveillance
L	1-2 GHz.	Long-range surveillance, enroute traffic control
S	2-4 GHz.	Moderate-range surveillance, terminal traffic control, long-range weather
C	4-8 GHz.	Long-range tracking, airborne weather
X	8-12 GHz.	Short-range tracking, missile guidance, mapping, marine radar, airborne intercept
K_u	12-18 GHz.	High resolution mapping, satellite altimetry
K	18-27 GHz.	Little used (H_20 absorption)
K_a	27-40 GHz.	Very high resolution mapping, airport surveillance
mm	40-100+ GHz.	Experimental

13.9 The electrical properties of the transmission medium

1- Permittivity (ε)

Since the electric field is independent only on flux density but also depends on the permittivity of the material or an ambient that the wave pass through its. Each material has certain constant limits the value of permittivity, and the permittivity is equal to

$$\varepsilon = \varepsilon_o \varepsilon_r$$

Where

ε_o is absolute permittivity and is equal to $\varepsilon_o = 8.85 \times 10^{-12}$ F/m

ε_r is the relative permittivity (dielectric constant) this value is different from medium to another and is equal to one in free space.

2- Permeability μ

Each material has certain constant limits the value of permeability, and the permeability is equal to

$$\mu = \mu_o \mu_r$$

Where

μ_o is absolute permeability and is equal to $\mu_o = 4\pi \times 10^{-7}$

μ_r is the relative permeability (dielectric constant) this value is different from medium to another and is equal to one in free space. The relative permittivity for diamagnetic materials are equal to one.

3- Conductivity σ

This constant determines the ability of the media on conduction the electricity energy. Perfect dielectric has the conductivity is equal to zero approximately.

13.10 Optical properties of electromagnetic waves

1- Refraction

Refraction of electromagnetic waves is variation in the direction of radiation ray's incident with oblique angle from medium to another that has different electrical properties about the first medium. Figure below shows incident wave from the first medium which has index refraction that different from the second medium. The second snell's law connect the relation between the incident wave in the first medium and the refracted wave in the second medium (The relationship between the angles and indices of refraction).

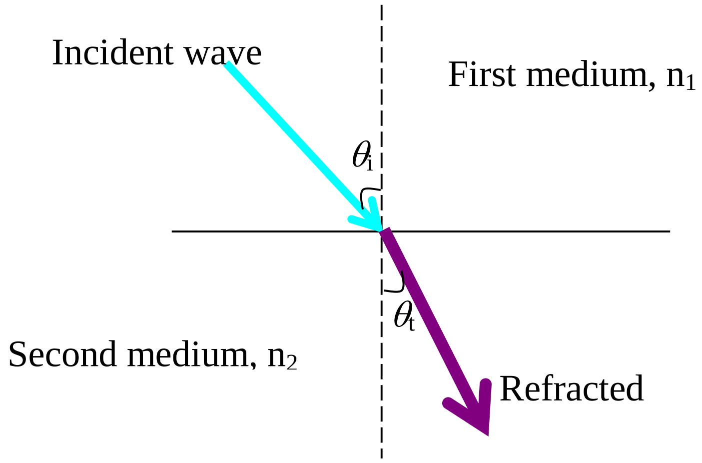
$$n_1 \sin(\theta_i) = n_2 \sin(\theta_t)$$

Where

θ_i is the incident angle

θ_t is the refracted angle

oblique n_2 is the refraction index for the second medium

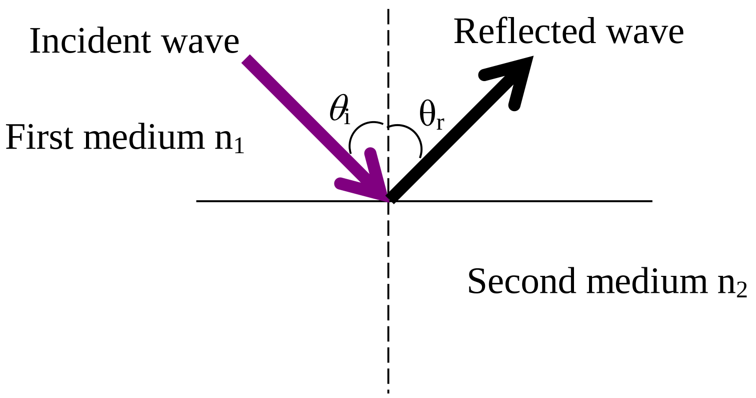


Electromagnetic waves propagate at the speed of light in a vacuum. In other mediums, like air or glass, the speed of propagation is slower. If the speed of light in a vacuum is given the symbol v_o, and the speed in some a medium is v, we can define the index of refraction, n as: $n = \frac{v_o}{v}$

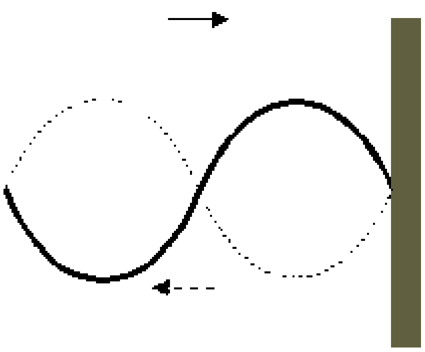
2- Reflection

When a plane wave encounters a change in medium, some or all of it may propagate into the new medium or be reflected from it. The part that enters the new medium is called the transmitted portion and the other the reflected portion. The part which is reflected has a very simple rule governing its behavior. Then the rule for reflection is simply stated as:

$$\theta_i = \theta_r$$

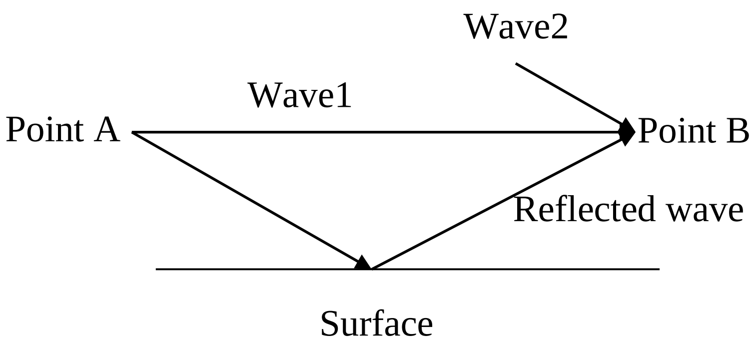


If the incident medium has a lower index of refraction, then the reflected wave has a 180° phase shift upon reflection. Conversely, if the incident medium has a larger index of refraction the reflected wave has no phase shift.



3- Interference

All electromagnetic waves can be superimposed upon each other without limit. The electric and magnetic fields simply add at each point. If two waves with the same frequency are combined there will a be a constant interference pattern caused by their superposition. Interference can either be constructive, meaning the strength increases as result, or destructive where the strength is reduced.



4- Absorption

The absorption of electromagnetic waves occurs when these waves incident on the bodies or particulars have the dimensions equal to or greater than the wavelength. For example, the electromagnetic wave has frequency is equal to (1 MHz). This mean the wavelength is equal to (300m). In this case the electromagnetic wave is diffracted when opposition it's the bodies has the dimension is equal to or greater than 300m.The following two materials is considered the largest absorption for microwaves

1- **Metals**: the electrons in the metals can moving freely through the metal, and then these electrons can be swinging and absorbed the electromagnetic waves that pass through the metal.
2- **Water**: the electromagnetic waves in the water causes jostling the particulars of the water about the electromagnetic waves, and then result in absorption the energy of these waves.