Radio direction finding (RDF) deals with the direction of arrival of radio waves. Therefore, it is necessary to understand the basic principles involved in the propagation of radio waves from the transmitting station to the DF equipment.

CHARACTERISTICS

The distance between two points of corresponding phase in consecutive cycles is known as a wavelength. A wavelength can be expressed in any unit of measure. However, it is normally expressed in meters. The number of complete waves that move past a given point in one second is called frequency. A unit of frequency is called Hertz (Hz). One unit is equal to one cycle per second (Figure 2-1). The radio wave’s strength or intensity is called its amplitude. The radio wave, which is electromagnetic in nature, consists of an electrical field (E field) and a magnetic field (H field). Each field supports the other, and neither can be propagated by itself. Table 2-1, page 2-2, lists frequency bands, their designators, and the commonly accepted limits of each band.

![Figure 2-1. Wavelength characteristics.](image)

A – FREQUENCY (THE NUMBER OF CYCLES PER SECOND)
B – ONE COMPLETE CYCLE
C – AMPLITUDE (THE STRENGTH OR INTENSITY OF THE WAVE)
The direction of the E field of a radio wave, relative to the ground, determines the polarization of the wave. Polarization can either be horizontal, vertical, or a mutation which adopts portions of vertical and horizontal. The latter results in a circular or a hybrid form of a wave. If a whip or other vertical type transmitting antenna is used to propagate radio waves, the transmitted wave is considered to be vertically polarized. If the transmitting antenna is horizontal, relative to the earth’s surface, the transmitted wave is horizontally polarized.

To illustrate vertical wave polarization, imagine a rope lying reasonably straight on the ground. One end is attached to a tree or other support (Figure 2-2). If the loose end of the rope is raised, tightened, and given a violent up and down motion, a series of undulating waves will travel along the rope. The movement of the waves will be vertical to the earth and clearly visible.

If the same rope had a similar movement applied in a horizontal manner, the waves would be in a horizontal plane. These waves would be called horizontally polarized (Figure 2-3).
PROPAGATION FACTORS

Radio waves are electromagnetic waves which travel through space at the same speed as light. They travel approximately 186,000 miles per second or 300,000,000 meters per second. A conversion formula for wavelength and frequency is shown below. If the measurement in Hertz is known and a conversion to wavelength is desired, apply—

\[
\text{Wavelength (meters)} = \frac{300,000,000}{\text{Frequency (Hz)}}
\]

If wavelength (in meters) is known and a conversion to frequency (Hz) is desired, apply—

\[
\text{Frequency (Hz)} = \frac{300,000,000}{\text{Wavelength (meters)}}
\]

Radio wave propagation is defined as extending or transmitting electromagnetic energy through space. Wavelength, frequency, and polarization are all essential elements of the actual wave and are factors which affect the radio wave propagation. The simplest form of propagation is through the space wave. The wave is radiated from the transmitter and continues through space in a line of sight (LOS) fashion until it reaches the receiver. Over a flat surface there are few problems in interception or direction finding. However, we do not live on a flat surface. The curved surface of the earth, while appearing to be flat over a short distance, limits the effective LOS range.

Radio waves tend to travel in straight lines unless they are acted on by some force. They can be reflected off the surface of any sharply defined object such as the earth’s surface. The radio waves can also meet other obstructions or objects that will scatter or reflect the signal. They can be reflected, refracted, or diffracted. Factors which affect radio wave propagation include—

- Wavelength.
- Polarization.
- Space (or the medium through which waves travel).
- Physical obstructions.

All of the above factors contribute to or create additional considerations. Personnel engaged in or using direction finding results must understand these factors.
Reflection

When observing oneself in a mirror, the light beams or waves reflected directly off the mirror’s silver finish give the identical or mirror image, barring an optical distortion. Radio waves are reflected similar to light waves traveling at the same speed. Although light waves can be seen, radio waves must be detected by electronic equipment. Figure 2-4 illustrates how radio waves are reflected off the ionosphere. The reflective components of light beams are further illustrated in Figure 2-5.

Refraction

Refraction can best be illustrated by a pencil held obliquely so that a portion of it is beneath the surface of some water (Figure 2-6). From most viewpoints, the pencil will have the appearance of being bent at the point where it enters the water. This effect is because light waves travel more slowly in water than in air. This causes a change in direction of travel of the refracted light. Also, radio waves travel at a different speed over water than land. Therefore, when passing from land to water or vice versa, the radio wave is refracted or bent. Note, refraction occurs only when the wave or light beam approaches the new medium at an oblique angle. If the whole wave front arrives at the new medium at the same moment (perpendicularly), it is slowed uniformly and no bending occurs.

Diffraction

Diffraction of a radio wave is the phenomena of bending the wave around a solid object. The lower the frequency or the longer the wavelength, the greater the bending of the wave. Therefore, radio waves are more readily diffracted than light waves. Sound waves are more readily diffracted than radio waves. Figure 2-7 illustrates why radio waves of the proper frequency can be received on the far side of a hill or other natural obstruction. It also illustrates why sound waves can be heard readily around the corner of a large building. Diffraction is an important consideration in the propagation of radio waves over long distances. The largest object to contend with is the curvature of the earth. It prevents the direct passage of the waves from the transmitter to the DF receiver.
The earth's atmosphere plays a crucial role in long distance radio communications. Radio waves may be reflected in the atmosphere and returned to earth. This technique is discussed later in this chapter. As shown in Table 2-2, the atmosphere consists of multiple layers, of which only a few have any discernible effect on radio waves. The ionosphere is the primary layer that is used to return a radio wave back to earth.

ATMOSPHERE

Table 2-2. Characteristics of the atmosphere.

<table>
<thead>
<tr>
<th>ATMOSPHERIC REGION</th>
<th>LOCATION (Km)</th>
<th>FEATURES</th>
<th>EFFECT ON COMMUNICATIONS (Radio Frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionosphere</td>
<td>Extending 50-600 km from the earth's surface.</td>
<td>Electrically charged set of layers, with large amounts of free electrons.</td>
<td>Excellent reflection/refraction of MF and HF signals. Some VHF may be propagated as well. Primary medium for sky wave communications.</td>
</tr>
<tr>
<td>Stratosphere</td>
<td>Extending 15-50 km from the earth's surface.</td>
<td>The only isothermal region of the atmosphere.</td>
<td>No effect.</td>
</tr>
<tr>
<td>Troposphere</td>
<td>From earth's surface to 10-15 km.</td>
<td>Lowest region of the atmosphere. Sustains life. Temperature decreases with increasing altitude.</td>
<td>Negligible effect. Allows direct, surface, and ground wave communications of all frequencies.</td>
</tr>
</tbody>
</table>
**Ionosphere**

The ionosphere is a region of ionized (electrically charged) gasses located approximately 50-600 kilometers (km) above the earth's surface. As illustrated in Table 2-3, there are essentially four layers (D, E, F1, and F2) of the ionosphere which affect communications and DF. These layers vary in ionization and height above the earth's surface, depending on the amount of exposure to the sun.

The ionosphere is formed when extreme ultraviolet light from the sun strips the electrons from neutral atoms in the ionosphere. Thus, the electrons become *free* (unbound), and the remaining atom becomes positively ionized. The free electrons reflect/refract radio waves of a certain frequency. Due to this process, the E and F layers become positively ionized. However, the free electrons may attach to neutral atoms. When such attachments occur, the atoms become negatively ionized. This process is common in the D layer, making the region of the ionosphere negatively ionized.

Factors which influence the ionosphere and its effect on radio waves include—
- The time of day.
- The seasons of the year.
- Solar flares.
- Magnetic storms.
- Certain man-made disturbances such as nuclear detonations.

An important relationship between radio waves and the ionosphere is that the higher the frequency, the less its tendency to bend. Depending upon ionospheric conditions and the angle of the signal's arrival at the ionosphere, the bending may be slight. The radio waves may not be sent back to earth (Figure 2-8).

### Table 2-3. Characteristics of the ionosphere.

<table>
<thead>
<tr>
<th>IONOSPHERIC LAYERS</th>
<th>LOCATION (Km)</th>
<th>FEATURES</th>
<th>EFFECT ON COMMUNICATIONS (Radio Frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>50-100 km</td>
<td>Layer closest to earth. Negatively ionized layer, with relatively little free electrons. Exists during the day.</td>
<td>Primarily acts to absorb radio waves. Small amounts of refraction are possible, but unpredictable.</td>
</tr>
<tr>
<td>E</td>
<td>100-200 km</td>
<td>Positively ionized with varying amounts of free electrons. State changes with temperature, angle of the sun, magnetic fields, and time of day. Exists during the day.</td>
<td>Erratic behavior. Sometimes reflects/refracts radio waves in MF, HF, and lower VHF bands.</td>
</tr>
<tr>
<td>F</td>
<td>145-400 km</td>
<td>Very positively ionized with large amounts of free electrons. During the day, this region separates into the F1 and F2 layers. The F region decreases in ionization and increases in altitude at night.</td>
<td>Primary means of reflecting/refracting MF and HF signals in sky wave propagation. At night, behavior becomes slightly erratic, but communications distances are much greater.</td>
</tr>
<tr>
<td></td>
<td>(F1–145-200 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(F2–240-400 km)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
During daylight hours, the ionosphere is subject to full ultraviolet output from the sun. Therefore, the D, E, F1, and F2 layers reach their full potential. At night, the composition of the layers of the ionosphere changes as the F layers combine. Therefore, higher radio frequencies are more likely to penetrate the ionosphere and be lost. As a general rule, lower communication frequencies are used during the night.

Conversely, during the day when ionization of the atmosphere is more intense, higher communications frequencies can be used without undue loss of the signal. This is because penetration of the ionized layer is at a minimum. Changes in the relative proximity of the sun to the earth will also cause gradual changes in the ionosphere. The longer exposure of the ionosphere to the sun in the summer causes a greater degree of ionization during the night and day. Therefore, higher frequencies may be used for summer operations. Figure 2-9 illustrates the approximate heights of the various layers of the ionosphere.

Remember, however, that the actual number of layers, their heights above the earth, and the relative intensity of ionization present will vary. They vary from hour to hour, from day to day, from month to month, and from year to year.

Figure 2-9. Approximate heights of ionospheric layers.

Stratosphere

The stratosphere is that portion of the earth's atmosphere between the ionosphere and the troposphere. Since the temperature in this region is considered to be almost constant, it is also known as the isothermal region. The stratosphere has little, if any, effect on radio waves which are transmitted through it. It is mentioned only to differentiate the three major regions of the earth's atmosphere.
**Troposphere**

The troposphere greatly influences electromagnetic emissions. It is that portion of the earth’s atmosphere extending from the surface of the earth to heights of approximately 10 to 15 kilometers. This region contains the mixture of gasses we depend on for life. Additionally, most weather activity occurs in the troposphere.

**WAVE PATHS**

There are three distinct paths that a radio wave may take to reach the receiving antenna. They are—
- Direct.
- Reflected.
- Refracted.

The direct and reflected paths are shown in Figure 2-10. They are purposely exaggerated to enable the reader to clearly grasp the differences.

The direct path goes directly from the transmitting to the receiving antenna. The reflected path bounces off the ionosphere or the surface of the earth at the same angle at which it arrives and continues to the receiving antenna (angle of incidence = angle of arrival). The refracted path is the path caused by the bending of the waves in the same manner light waves are bent when seen through water.

If the waves are refracted by the earth, the distance they travel is severely limited due to large losses of energy in the form of heat dissipated into the earth’s crust.

**WAVE TYPES**

Radio waves may be classified as either ground waves or sky waves (Figure 2-11).

Ground waves are continually in contact with the earth’s surface. They do not make use of reflection from the ionosphere. They have a tendency to be refracted and, in some cases, reflected into the lower atmosphere. At frequencies above 1500 kilohertz, a ground wave is affected very little by the time of day or season. The ground wave loses much of its strength and dissipates energy as it travels over the earth’s surface. However, less strength is lost when it travels over water.
Sky waves are transmitted upward with respect to the earth's surface. Sky waves would not be useful for communications were it not for the ionosphere. Radio waves approaching the ionosphere at an angle are refracted back to earth. They may be detected and used for communications purposes or for DF exploitation. Figure 2-12 depicts the waves that penetrate the ionosphere and are lost for all practical purposes. It also illustrates those waves that return to earth for communication use.
**SKIP ZONE AND DISTANCE**

The skip zone is the area where the ground wave can no longer be detected (Figure 2-13) and the sky wave has not yet returned to earth after being reflected or refracted off the ionosphere or troposphere. The skip distance is that area where no sky wave reception will be possible. This is because the wave has not returned to earth after its first or subsequent bounce off the reflecting layer.

Depending upon the frequency and the transmitter power, multihop transmissions are routinely used for communications. Figure 2-14 illustrates multihop transmissions. There will be, however, skip zones between the points of the wave's return at each hop. Note, however, skip zones are not static or stable.

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**Figure 2-13. Skip zone and distance.**

**Figure 2-14. Multihop transmissions.**