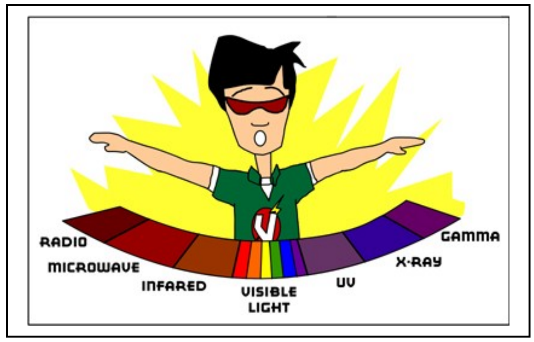
ARRL Amateur Radio Education
& Technology Program

Unit 2 Wireless Phenomena

ELECTROMAGNETIC SPECTRUM



To understand how radio signals travel through space, we must first understand the nature of *electromagnetic* waves.

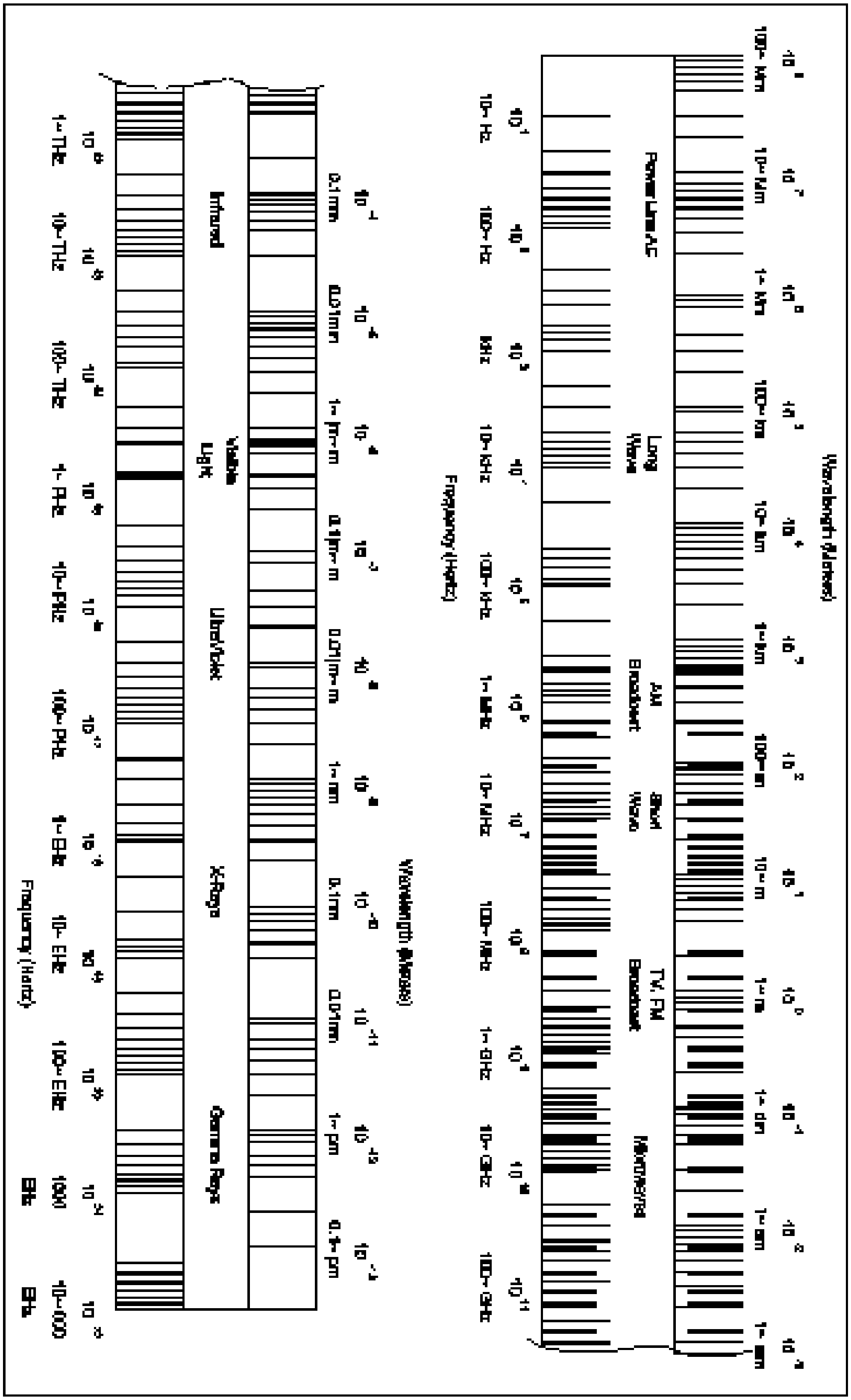
In nature there are two kinds of energy waves: *compression* and *transverse.* Sound waves are an example of compression waves. They transfer their energy through things such as air and water. Electromagnetic waves, which include radio waves, are examples of transverse waves. Transverse, radio waves do not need a material to transfer their energy through. That is, they can transfer their energy through a vacuum, like space. They do this by creating electric and magnetic fields that cycle back and forth very fast – hundreds, thousands, millions, billions and even trillions of times each second. *The number of cycles the wave goes through each second is called its frequency*. We'll discuss this in more detail in a moment.

Figure 2.1 shows what is called "The Electromagnetic Spectrum." The electromagnetic spectrum shows electromagnetic waves varying in frequency from waves of a few hertz (or cycles) all the way through gamma rays. We use these waves to do everything from transmitting radio and television signals to cooking our food. Yes, we can use electromagnetic waves to cook our food. Do you have a microwave oven at home? Notice on the electromagnetic spectrum chart, microwaves are just above TV & FM broadcast frequencies. These electromagnetic waves can be described by their wavelength, frequency or the amount of energy they contain. We use different units to describe the three. Radio waves are usually described by their frequency, measured in Hertz (Hz), thousands of Hertz (kHz) or millions of Hertz (MHz); light waves are usually described by their wavelength measured in meters (m); and X-rays in terms of energy measured in Electron-volts (eV).

Looking at the electromagnetic spectrum chart, what kind of electromagnetic radiation has the shortest wavelength? Which one has the longest?

THE NATURE OF RADIO WAVES

What do all these frequencies mean to us? In Amateur Radio we work with a wide range of frequencies starting as low as 1800 kHz to up above 300 GHz. Yes, that's Giga Hertz. Much of the operation, however, takes place in the lower frequencies, from 1800 kHz to 450 MHz. There is a direct relationship between the frequency of a radio wave and its wavelength. To best understand this relationship, let's look at the typical "ac" wave – the kind that brings power to your house or school. Even though it travels through wires, an "ac" (ac means *alternating current*) wave is a radio wave, too.



Wavelength (Meters)
Power Lines AC
Long Wave
AM Broadcast
Short Wave
TV, FM Broadcast
Microwaves
Frequency (Hertz)
Infrared
Visible Light
Ultraviolet
X-Rays
Gamma Rays
Wavelength (Meters)
Frequency (Hertz)

Figure 2.1

The power company uses a large machine called an *alternator* to produce power at its generating stations. The ac supplied to your home goes through 60 complete cycles (shifting from a positive voltage to negative and back to positive again) each second. So, the electricity from the power company has a frequency of 60 Hz. See **Figure 2.2.**

This 60-hertz ac electricity builds slowly to a peak current or voltage in one direction, then decreases to zero and reverses to build to a peak in the opposite direction. If you plot these changes on a graph, you get a gentle up-and-down curve. We call this curve a *sine wave*. **Figure 2.2A** shows two cycles of a sine-wave ac signal.

What you need to remember is that alternating currents can change direction at almost any rate. Some signals have *low frequencies*, like the 60-hertz ac electricity the power company supplies to your house. Other signals have *high frequencies* like, radio signals that can alternate at more than several million hertz. (Activity Sheet #2.1)

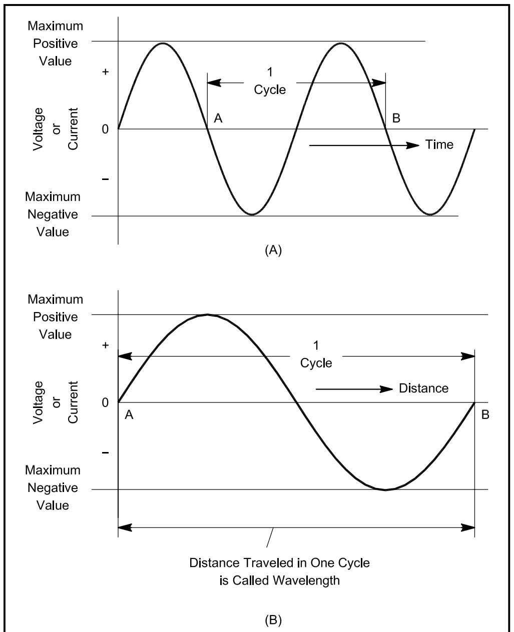


Figure 2.2

Wavelength is another unit that can be used to describe an ac signal. As its name implies, wavelength refers to the distance the wave will travel through space in one single cycle. See **Figure 2.2B**. All such signals travel through space at the speed of light, 300,000,000 meters per second. The Greek letter lambda (λ) is used to represent wavelength.

Here's another thing to remember. The faster a signal alternates, the less distance the signal will be able to travel during one cycle. There is an equation that relates the frequency and the wavelength of a signal to the speed of the wave. If you know either the frequency or the wavelength, you can determine the missing one.

$$c = f * \lambda \quad \textbf{(Equation 2.1)}$$

Where:

c is the speed of light, 3.00 x 10 (8) meters per second
f is the frequency of the wave in meters
λ is the wavelength of the wave in meters

We can solve this equation for either frequency or wavelength, depending on which quantity we want to find.

$$f = c / \lambda$$ **(Equation 2.2)**

And

$$\lambda = c / f$$ **(Equation 2.3)**

From these equations you can see that as the frequency increases the wavelength gets shorter. Figure 2.3 shows a simple diagram that will help you remember the frequency and wavelength relationships. You can practice using these equations on Student Worksheet #2.2

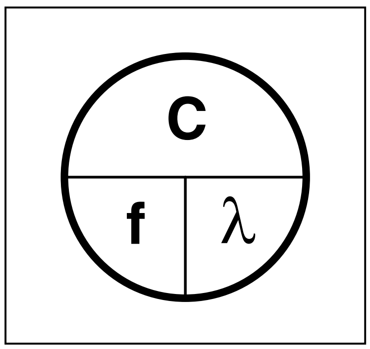


Figure 2.3

HOW RADIO WAVES TRAVEL

Have you ever wondered how the radio signal travels from your favorite AM or FM radio station to your radio? When you did the AM Dxing activity in unit one, did you notice how during the day you could only hear local radio stations, but at night, you could hear stations from far away? To understand this "phenomena" we need to understand how radio waves travel. The study of how radio waves travel from one point to another is called "*Propagation*." Radio waves travel to their destination in four ways. First, radio waves can travel directly from one point to another. This is called *line-of-sight propagation.* The second way radio waves travel is along the ground, bending slightly to follow the curvature of the Earth for some distance. This is called *ground-wave propagation.* Third, radio waves can be refracted or bent back to Earth by the ionosphere. This is known as *sky-wave propagation.* The ionosphere is a layer of charged particles called *ions* in the Earth's outer atmosphere. These ionized gases make long distance radio communications possible. Lastly, radio waves can be trapped in a layer of the Earth's atmosphere, traveling a longer distance than normal before coming back to the Earth's surface. This is known as tropospheric ducting. We will now take a look at each of these four types of propagation.

Line-Of-Sight Propagation

Line-of-sight propagation occurs when signals travel in a straight-line form the transmitting antenna to the receiving antenna. These signals, also know as direct waves, are used mostly in very high frequency (VHF), ultra high frequency (UHF) and microwave ranges. The signals you receive from your local television stations and FM

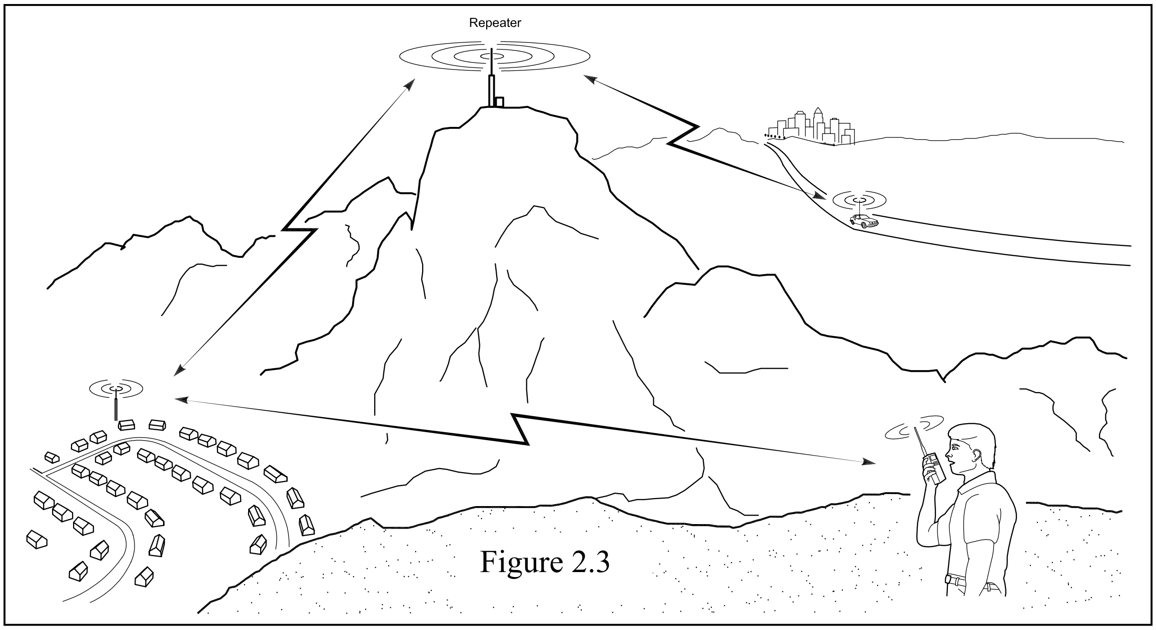
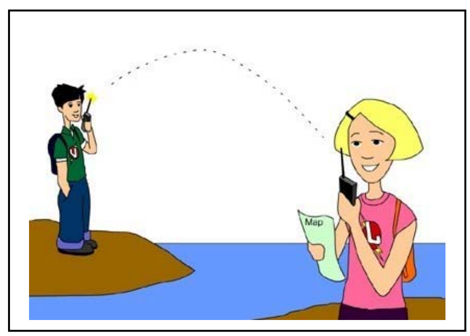


Figure 2.3

radio stations are examples of direct waves. Cable television is not considered an example of direct waves, however, because the signal travels through a cable instead of being transmitted through the air. Two-way radios, like police and fire departments and Amateur Radio operators use, is another good example of line-of-sight propagation. When transmitting on a local repeater frequency, direct waves generally travel in a straight line to the repeater. The repeater then retransmits the signal in a straight line to other station. See **Figure 2.3.**

Tall buildings, mountains and hills, and even airplanes affect line-of-sight propagation. These things can get in the way of radio signals and cause disruption of radio communications. (Activity Sheet #2.3)



Tropospheric Bending

About seven to ten miles above the Earth's surface is the region called the *troposphere*. Slight bending of radio waves occurs in this area. The troposphere can cause radio signals to "bend" back towards the Earth, a little beyond the visible horizon, and allow contacts between stations that are further away than would otherwise be possible. The radio horizon is generally about 15% farther away than the true horizon.

This is referred to as *tropospheric bending*. Tropospheric bending is used in the VHF/UHF frequency ranges. See **Figure 2.4.**

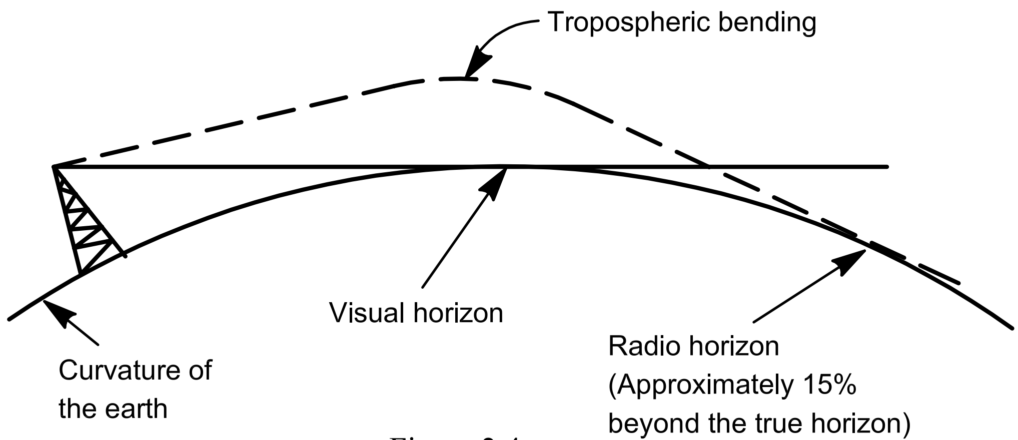
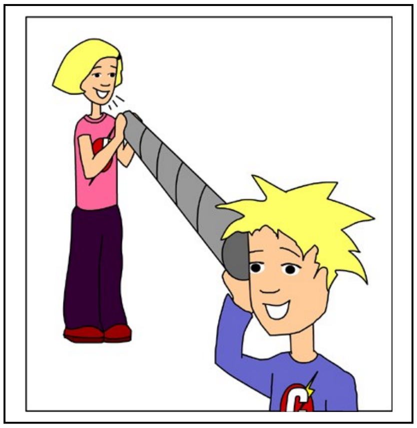


Figure 2.4

Tropospheric Ducting

Besides bending a radio signal back towards Earth, it is possible for a VHF or UHF radio signal to become trapped in the troposphere causing them to travel longer distances than normal before coming back to the Earth's surface. This is referred to as tropospheric ducting. See **Figure 2.5.** When a cold air mass moves in under a warm air mass, called a temperature inversion, it can act like a tube, or duct, and cause radio-waves to travel along the duct for many miles before returning to Earth. (Activity Sheet #2.4)



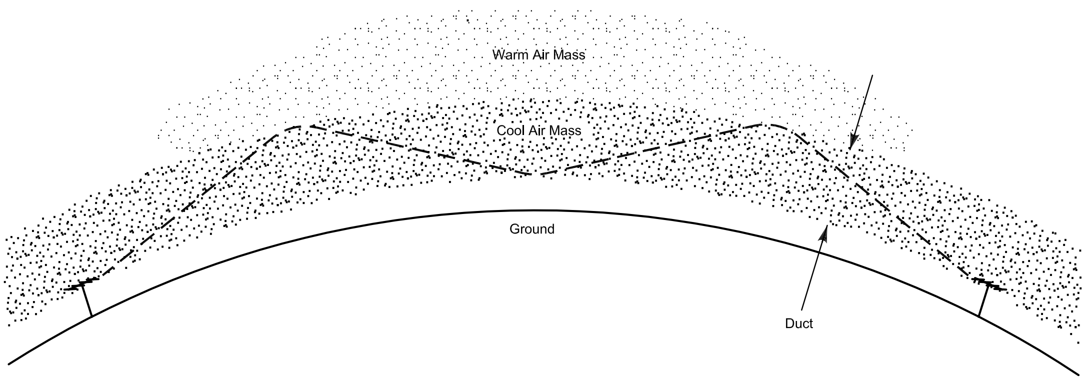


Figure 2.5

Ground Wave Propagation

In *ground wave propagation*, radio waves travel along the Earth's surface, even over hills. They follow the curvature of the earth for some distance. Signals from AM broadcast stations travel by ground wave propagation during the daytime. As you drive away from the station the signal begins to fade until you can't hear them anymore. Ground waves work best at lower frequencies. Another example of ground wave propagation is when a ham radio operator makes an HF daylight contact with a station just a few miles away. The signal travels along the ground to the other station.

Ground wave propagation on the ham bands means relatively short-range communications, usually 50 miles or less. But contacts of several hundred miles are possible under the right conditions. Stations near the high frequency end of the AM broadcast band (1600-kHz) generally carry less than a hundred miles during the day. Stations near the low frequency end of the AM broadcast band (540-kHz) can be heard up to a distance of 100 miles or more. Amateur Radio frequencies are higher than the AM broadcast band, so the ground-wave range is usually shorter.

Sky-Wave Propagation (Skip)

When Marconi sent the first message across the Atlantic Ocean in 1901, he didn't fully understand the science of radio wave propagation. The distance was too great for ground waves to travel. The frequencies were too low for tropospheric bending or ducting to take place. So there had to be another reason the radio waves traveled so far. The answer was *sky-wave propagation*.

We have since found that surrounding the Earth is a layer of particles called *ions*. These ions have a negative charge, just like radio waves. When the negatively charged radio wave is transmitted up near the ionosphere, they are refracted back towards the Earth. See **Figure 2.6.** We are able to "bounce" radio signals off the ionosphere back to Earth. We call the distance from the transmitting station to the receiving station the *skip distance*. The area between the two stations is called the *skip zone*. Two-way radio contacts of up to 2500 miles are possible with one *skip* off the ionosphere. Worldwide communications using several skips (or hops) can take place if conditions are right. This is the way long-distance (DX) radio signals travel.

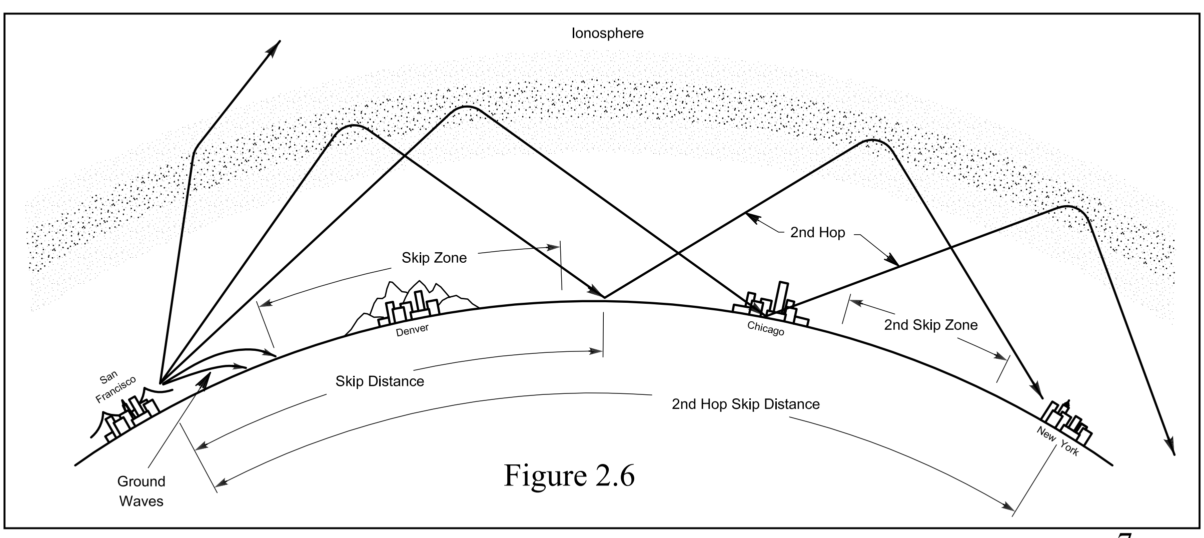


Figure 2.6

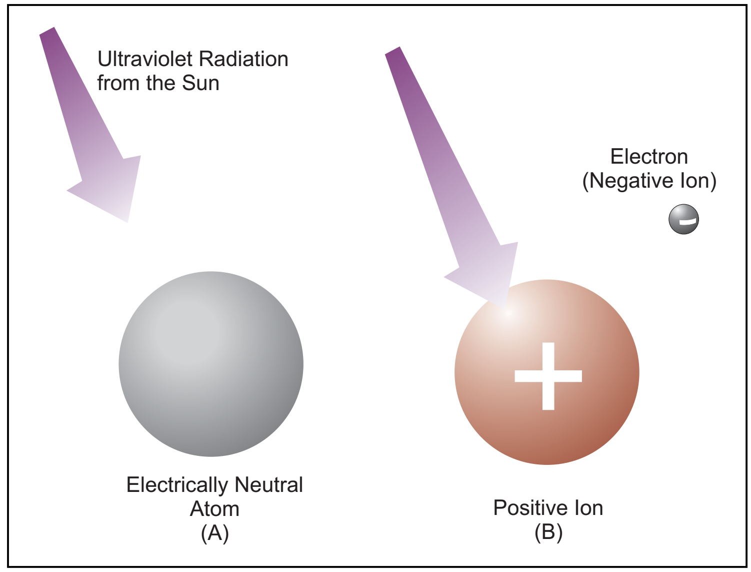
Two factors determine sky-wave propagation:

- *Frequency* of the radio wave
- Level of *ionization*

What causes the ions? The sun, or energy from the sun. Energy from the sun bombards the gasses in the ionosphere causing ions to form. We will be discussing how this happens in just a moment.

There is one more important piece of information you should know. The higher the frequency of the radio wave, the less it is bent by the ionosphere. The highest frequency at which the ionosphere bends radio waves back to Earth is called the maximum usable frequency (MUF).

Now, lets look at the ionosphere and see how it works.



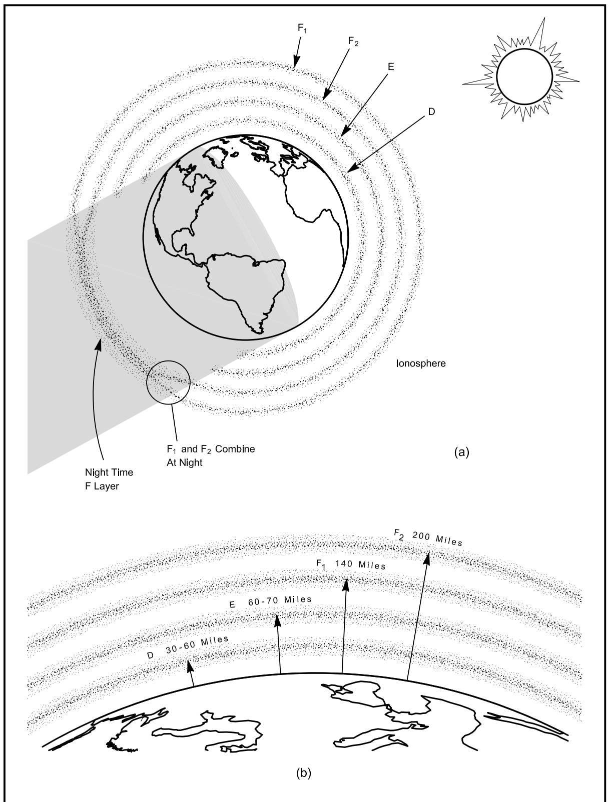


Figure 2.7

THE IONOSPHERE

The Earth's upper atmosphere (25 to 200 miles above the Earth) is made up of mainly oxygen and nitrogen, with traces of hydrogen, helium and several other gases. These gases are bombarded by ultraviolet radiation (energy) from the sun. This radiation knocks electrons out of the atoms of the gas forming negatively charged particles. The remaining portions of the gas atoms form positively charged particles. The positive and negative particles are called *ions*. The process by which ions are formed is called *ionization*. The area where ionization takes place is called the *ionosphere*.

The ionosphere is actually made up of several regions of charged particles. These regions have been given letter designations D through F, as shown in **Figure 2.7**. Why start with the letter D? Scientists started with D just in case there were any undiscovered lower regions. None have been found, so there is no A, B or C region.

As we mentioned, energy from the sun causes the ionization so the sun affects the way radio waves travel. The sun rotates through an eleven-year cycle of increasing, then decreasing sunspot activity; this is referred to as the *sunspot cycle*. During periods of increased sunspot activity, the ionosphere can become disturbed and disrupt radio communications worldwide.

Now lets look at the different layers (or regions) making up the ionosphere.

The D – Region

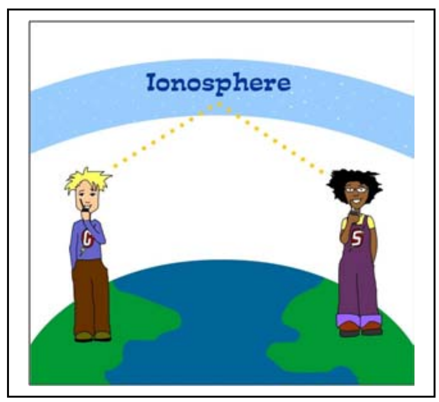
The *D region* is the lowest region of the ionosphere affecting propagation. This region is located about 35 to 60 miles above the Earth's surface. It is very dense and instead of refracting radio signals back to Earth, it absorbs them. So, when the D region is most ionized, at noontime, radio communications can be affected. Ionization only lasts while exposed to the suns rays. By sunset, the ionization has stopped and the D region disappears.

The E – Region

The next highest region, the *E-region*, is located about 60 to 70 miles above the Earth. Like the D-region, ionization lasts only while exposed to the sun's rays. The ionization level is lowest just before sunrise, local time. Ionization reaches its highest level about midday and by early evening the ionization level is very low again. Therefore, communication using the E-region is only possible during daylight hours.

The F – Region

The highest region of the ionosphere, and most responsible for long-distance radio communication, is the *F-region*. This region is very large. It ranges from about 100 to 310 miles above the Earth. The ionization in the F-region reaches its highest shortly after noon local time. It then tapers off very gradually toward sunset. At this altitude, the ions and electrons recombine very slowly. The F-region remains ionized during the night, reaching its lowest just before sunrise. After sunrise, ionization happens quickly for the first few hours, then it slows to its noontime high.



During the day, the F-region splits into two parts, *F1* and *F2*. The central part of the *F1* region forms about 140 miles above the Earth. For *F2* region, the central region forms at about 200 miles above the Earth. At night, these two regions recombine to form a single F-region. The F1 region does not have much to do with long-distance communications. Its effects are similar to those caused by the E-region. The F2 region is responsible for almost all long-distance communication on frequencies from 1.8 to 30

MHz. Using the F2 region, two-way radio contacts can be made up to 2500 miles in one skip.

The Scatter Modes

As we mentioned before, the area between where the ground wave ends and the point where the first signals return from the ionosphere is called the *skip zone*. Some radio signals that are refracted (bent) by the ionosphere are sometimes returned at a relatively wide angle. This can cause some signals to return to Earth within the skip zone, making communications in this area possible. This is referred to as *scatter propagation.* Under ideal conditions, scatter propagation is possible over 3000 miles or more. Scatter signals, however, are generally weak and may be distorted because the signal may arrive at the receiver from many different directions.

AMATEUR SATELLITE OPERATIONS

Satellites have been used for many years to relay signals from one point on the Earth to another. Government, military and businesses all have satellites circling the Earth providing such services as television, broadcast radio, telephone, and paging systems. Although we use these services, ham radio operators do not have direct access to these satellites for ham communication. So hams have built and launched their own satellites.

Since 1961, Amateur Radio operators have launched many of their own satellites. Amateurs use these Satellites Carrying Amateur Radio (OSCAR's) to communicate with other amateurs around the world. Most satellites use the VHF and UHF bands because radio signals on those bands normally go right through the ionosphere. The satellites retransmit signals to provide greater communications range than would be possible on those bands. Satellites use line-of-sight propagation so both operators must be in sight of the satellite. It is helpful, when working satellites, to have an antenna you can point directly at the satellite. To do this, you also need a computer satellite-tracking program to locate the satellite in space. Working satellites can be a challenging and rewarding experience in Amateur Radio.

EARTH-MOON-EARTH (EME) COMMUNICATIONS

For a real challenge, some Amateur Radio operators participate in a unique form of communications involving bouncing VHF and UHF signals off the surface of the Moon. Like satellite communications, it requires both stations to be in light of the Moon. There is one drawback to this communication method, however. Due to the distance to the Moon and back, a rather elaborate antenna array and an enormous amount of power is required.