By Ian Poole, G3YWX

Radio Waves and the Ionosphere

Although hams are required to have a passing familiarity with the physics of the ionosphere, a more intimate understanding can make or break your enjoyment of the hobby. This primer will fill in some of the blanks and start you on a fascinating journey.

R adio propagation via the ionosphere is a fascinating and important means of long-distance radio communication. Thousands of hams and commercial operators use the ionosphere every day to make contacts over vast distances. To effectively use these propagation modes to their fullest, however, we must understand the physics behind the magic. Knowing when to listen, the best frequencies to use and where signals might come from enable experienced DXers to work stations when less-experienced operators come up short. In fact, knowledge of propagation and a "feel" for conditions and what each band might produce are valuable commodities for any radio operator.

The Atmosphere

Before we look at how signals are reflected by the ionosphere we must see where these reflections take place and how the reflecting areas are formed. The atmosphere can be split into a variety of different layers according to their properties. The most commonly used names are shown in Figure 1. Here we can see that the troposphere is the part of the atmosphere closest to the ground, extending to a height of about 10 km. At altitudes between 10 and 50 km we find the stratosphere, which contains the famous ozone layer at a height of about 20 km.

For shortwave communication the ionosphere is the most im-

portant, although the troposphere plays a key role in VHF and UHF communication. The ionosphere crosses several meteorological layers and extends from about 50 to 650 km.

The Ionosphere

The ionosphere is so named because it is a region in the atmosphere where ions exist. In most areas of the atmosphere molecules are in a combined state and remain electrically neutral. In the ionosphere, however, solar radiation (mainly ultraviolet light) is so intense that when it strikes gas molecules they split—ionize—and an electron is set free. What remains is a positive ion (a molecule that is "missing" an electron) and a free electron. Although ions give their name to the region, free electrons actually affect radio waves. The number of electrons starts to increase at an altitude of about 30 km, but the electron density isn't sufficient to affect radio waves until about 60 km.

We often think of the ionosphere as having a number of distinct layers. This is convenient for many explanations, but it's not entirely accurate as the entire ionosphere contains ionized molecules (and free electrons). Instead, the layers are best thought of as peaks in ionization levels.

To quickly identify the layers, peaks or regions, we refer to them by the letters D, E and F. (There is a C layer, but its level of ionization is so low that it has no effect on radio waves.)
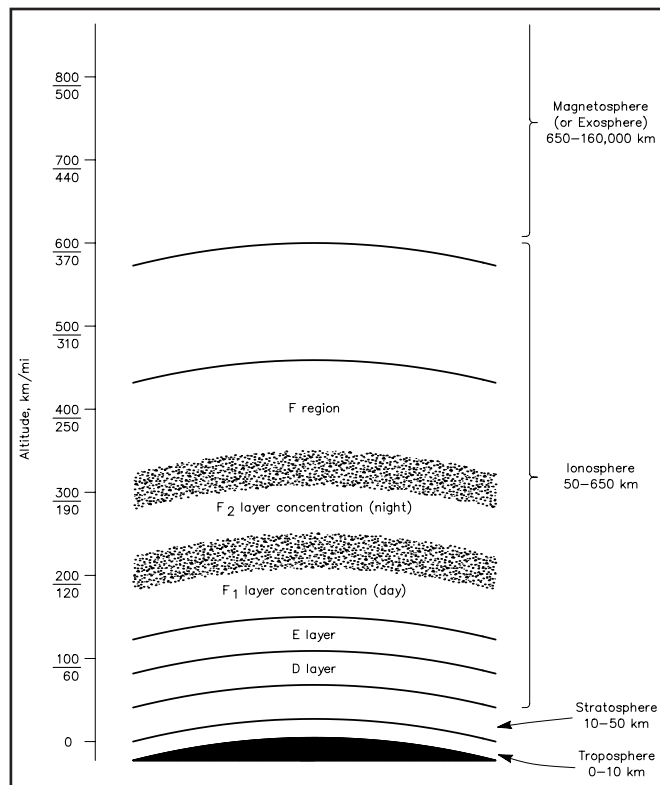
Layers

The D layer is the lowest, at altitudes between 50 and 80 km. It is present during the day when radiation is beaming in from the sun. Because the density of the air is still high at this altitude, however, ions and electrons recombine relatively quickly. After
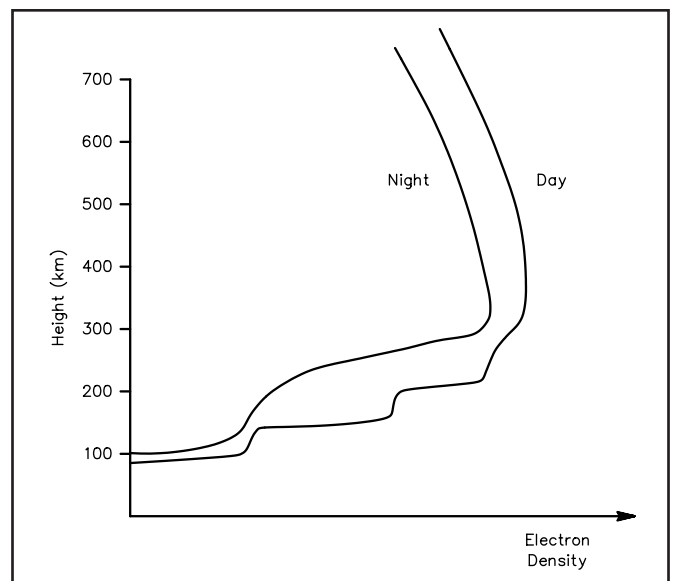

Figure 1—Areas of the atmosphere.

Figure 2—Typical electron distribution (day and night).

sunset, when solar radiation is blocked by the Earth, electron levels fall quickly and the D layer effectively disappears.

Above the D layer, the next ionization level is called the E layer. It can be found at altitudes between 100 and 125 km. Because electrons and ions recombine relatively quickly here, ionization levels drop quickly after sunset. Although a small amount of residual ionization persists, the E layer virtually disappears at night.

The most important layer for long-distance communication is the F layer. During the day it often splits into sub-layers we call F1 and F2, as shown in Figure 4. (At night the two layers merge back into a single F layer.) F-layer altitudes vary considerably and depend on the time of day, the season and the state of the sun. In the summer, the F1 layer may be at 300 km, with the F2 layer at 400 km or more. In the winter, these figures may be about 300 km and 200 km, respectively. At night, the F layer is generally around 250 to 300 km. These figures vary considerably, however, so consider them as approximates.

As with the D and E layers, ionization levels in the F layer decrease at night. The rate of recombination is much slower, however, because the layer is higher and air density is much lower. Because the ionization remains overnight, it can still affect radio signals

The Sun and the Ionosphere

It's not surprising that solar variations affect the ionosphere. One major factor is the number of visible sunspots. The spots appear on the surface of the sun as dark (relatively speaking) areas that can be seen when an image of the sun is projected onto a screen or a piece of paper. Sunspots affect the ionosphere because the areas around the spots emit greater amounts of the ultraviolet radiation—the main cause of ionization.

Note: *Never* look directly at the sun, even through darkened glasses. Doing so can permanently damage your sight.

The number of spots varies, roughly conforming to an 11-year period. This means that ionospheric conditions—and radio propagation—vary in sync with this cycle. At the low point of the cycle, HF bands above 20 MHz or so may not support ionospheric propagation. At or near the 11-year peak, frequencies at 50 MHz and higher may be effective.

Ground and Sky Waves

Signals in the medium and shortwave bands travel by two basic means: ground waves and sky waves.

Ground waves occur as the signal spreads out from the transmitter in all directions. Instead of traveling in a straight line (and
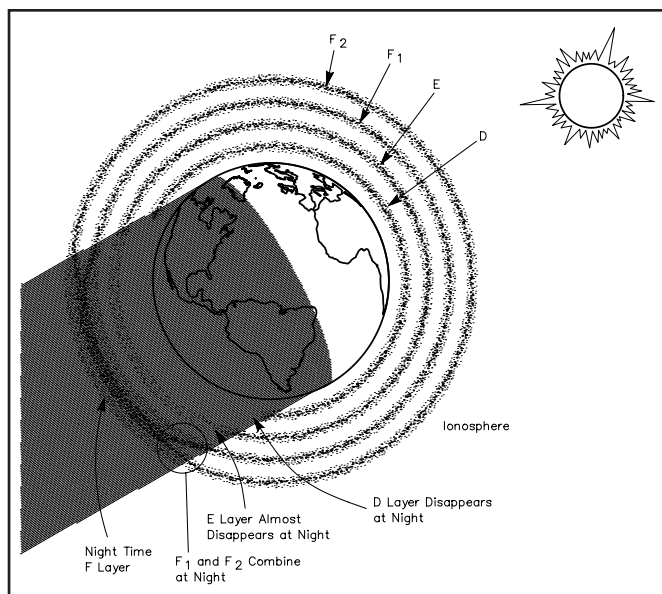
not being heard beyond the visual horizon), radio signal tends to follow the curvature of the Earth. This occurs because currents are induced in the surface of the Earth, which slows the wavefront near the ground. As a result, the wavefront tilts downward, enabling it to follow the curvature of the Earth and travel beyond the horizon.

With some exceptions, ground-wave propagation is generally used for signals below 2 or 3 MHz. It is not used much at higher frequencies because the level of attenuation increases with frequency, and above these frequencies coverage becomes progressively less reliable. This is demonstrated by the fact that shortwave broadcast stations are only audible for short distances via ground wave. In comparison, medium-wave stations are audible over much greater distances—a typical high-power AM broadcast station may have a coverage area of a hundred miles or more. Total coverage is affected by a variety of factors, including transmitter power, the type of antenna and the terrain over which the signals are travelling.

Signals also leave the Earth's surface and travel toward the ionosphere. As we will see, some of these are returned to Earth. These signals are termed sky waves for obvious reasons.

The D Layer

The first layer a signal reaches is the D layer. This layer acts as an attenuator, especially at low frequencies. In fact, the attenuation varies as the inverse square of the frequency. That is, doubling the frequency reduces the level of attenuation by a factor of four. This is why low-frequency signals are prevented from reaching the higher layers, except at night when the D layer disappears.

Signals are attenuated as they pass through the D layer because they cause free electrons to vibrate. When this occurs, the electrons collide with other molecules, consuming a small amount of energy and dissipating a proportionally small amount of the radio signal.

We can see that the level of attenuation depends upon the number of collisions that take place. In turn, this depends on a number of other factors. One of the most obvious is the number of gas molecules that are present. More gas molecules mean more collisions and increased attenuation.

Ionization levels are also important, as is the frequency of the radio signal. As frequency increases, wavelengths become shorter and collisions between free electrons and gas molecules decrease. As a result, low-frequency signals are attenuated far more than those at higher frequencies. Even so, high-frequency signals still suffer some reduction in strength.

The E and F Layers

As with the D layer, when signals enter the E and F layers they cause free electrons to vibrate. Here the air density is much lower and there are fewer collisions. As a result, much less energy is lost and these layers affect radio signals in a different way. Rather than colliding with gas molecules and losing energy, the electrons tend to re-radiate the signal. Because the signal is traveling in an area where electron density is increasing, the farther it progresses
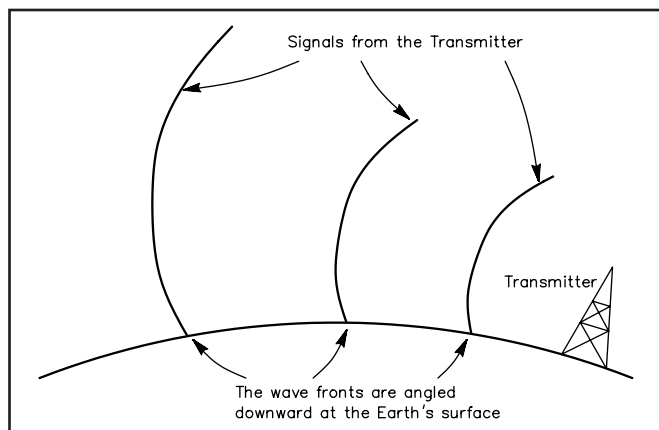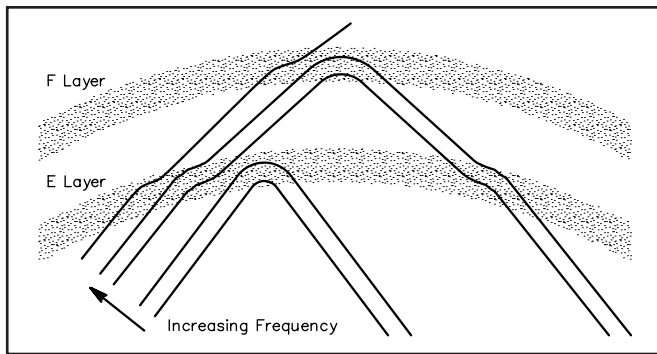

Figure 3—A simplified view of the layers of the ionosphere over the period of a day.

Figure 4—A ground-wave signal.

Figure 5—Refraction of a signal as it enters an ionized region.

Figure 6—Signals reflected by the E and F layers.

Figure 7—Multiple reflections.

Figure 8—Skip distance and dead zone.
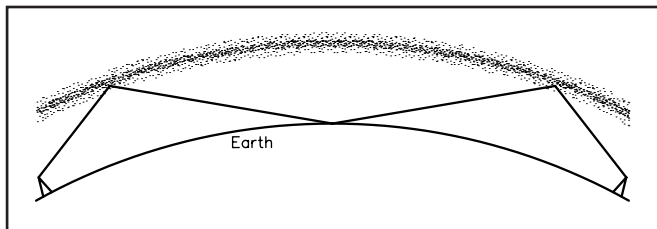
into the layer, the more the signal is refracted away from the area of higher electron density. At HF, this refraction is often sufficient to bend the signals back toward Earth. In effect, the layer appears to have "reflected" the signal.

These "reflections" are affected by frequency and the radio wave's angle of incidence. As frequency increases the amount of refraction decreases until a frequency is reached where the signals pass through the layer and on to the next. Eventually, a frequency is reached where signals pass through all the layers and into outer space.

Changing the Frequency

During the day, medium-wave signals propagate only via ground wave because the D layer absorbs signals that reach the ionosphere. As frequency increases, attenuation falls to a point where signals pass through the D layer and on to the E layer. Here signals are reflected and pass back through the D layer and return to Earth a considerable distance from the transmitter.

As frequency increases further, E-layer refraction becomes less efficient. Eventually, signals pass through to the F1 layer, where they may be reflected back through the D and E layers to reach Earth. Because the F1 layer is higher than the E layer, the distance traveled by signals reflected by the F layer will be greater.

As frequency increases still further, signals will eventually pass through the F1 layer to the F2 layer. Because this is the highest reflecting layer, the distance spanned by signals reflecting from it is the greatest. The maximum skip distance for the E layer is about 2000 km. For the F2 layer that increases to about 4000 km—a significant gain.

Several Hops

Considerable distances can be spanned by an E- or F-layer reflection, but that does not explain how signals can propagate to the other side of the globe. World-spanning propagation requires several reflections. Having returned to Earth from the ionosphere, the Earth's surface acts as a reflector and returns the signal back to the ionosphere, where it is reflected back to Earth yet again. In this way signals can travel around the globe (sometimes in several directions!).

The nature of the Earth's surface also has an effect. Desert areas are poor reflectors, but oceans are quite effective. This means that signals bounced off the Atlantic Ocean, for example, will be stronger than those reflected by areas such as the Sahara Desert.
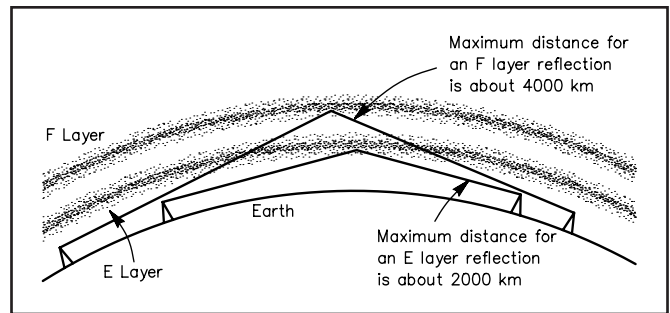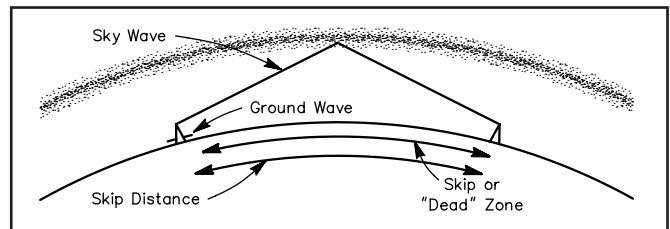
Apart from losses caused by reflections at the Earth's surface, signals are attenuated each time they pass through the D layer. In fact, D-layer attenuation is particularly significant when we remember that signals have to pass through the D layer twice for each E- or F-layer "round trip."

Apart from the fact that high-frequency paths are more likely to use the F2 layer and require fewer reflections, high-frequency paths also suffer less from D-layer attenuation. This means that (all other factors being equal), a 28-MHz signal, for example, will be stronger than one on 14 MHz if propagation is supported at both frequencies.

Skip Distance and the Skip Zone

Skip distance, skip zone and dead zone are important terms associated with ionospheric propagation. The distance a signal travels along the surface of the Earth when it is reflected by the ionosphere is known as the skip distance, as shown in Figure 8.

There is also a region known as the skip zone or dead zone. Ground-wave signals will be heard only at a certain distance from the transmitter because of signal attenuation. Signals traveling to the ionosphere may not be reflected until they reach distances well beyond that where ground-wave signals fade out. The result is an area or zone where no signals can be heard. This is known as the skip zone, or dead zone. This is particularly pronounced for high-frequency signals where ground waves fade away quickly and skip distances may be a thousand miles or more.

Summary

For hams, an understanding of radio propagation is practical and fascinating. The more you find out, however, the more interesting it becomes—so beware!

Ian Poole is the author of Your Guide to Propagation, *published by the RSGB;* Short Wave Listener's Guide, *published by Newnes (an imprint of Butterworth Heinemann);* and Basic Radio Principles and Technology, *published by Newnes— all available from the ARRL.*

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