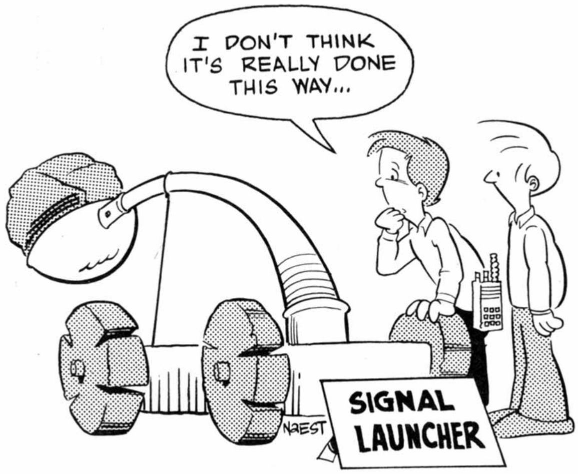
Radio Waves and Communications Distance



Part 13: It is important to choose the correct amateur band and the right time of day for communications over great distances. Other important factors in amateur communications are the time of year and the sunspot cycle.

By Doug DeMaw,* W1FB

Most new ham radio operators are confused about which band they should use at a given time of day to communicate with certain parts of the country or the world. Have you been confused about these matters? No doubt you have pondered this subject while deciding which band to concentrate on for all-round coverage in terms of distance.

Communications over long distances, such as from the U.S. to Europe or Asia, are referred to as "DX" contacts. Since the word "distance" is relative with regard to miles or kilometers, it is best that we define DX as relating to Amateur Radio contacts over paths in excess of 1000 miles in the high-frequency bands (3.5 to 30 MHz).[1] DX takes on a different meaning (in terms of distance) when we consider the VHF (30-300 MHz), UHF (300-3000 MHz) or microwave parts of the amateur spectrum: We may consider those frequencies above 3000 MHz as the microwave region. At VHF and higher, DX may be an appropriate term when we consider communications distances as short as 100 miles, for example. This is because the higher the operating frequency, the shorter the effective signal path over the earth's surface. This is not true of space communications, where there is acceptable attenuation (power reduction) between the transmitting and receiving antennas.

The new amateur is concerned mainly with HF (high-frequency) communications, since the Novice license is restricted to use of the 80, 40, 15 and 10-meter CW bands. A Technician class licensee has these frequencies available, along with privileges from 6 meters upward.

When you first receive your license and go on the air, chances are you will be thrilled to contact just "anybody" for the first few days. But, as you hear other hams discussing the DX they "worked" (made contact with), your appetite for DX will be stimulated! Knowledge of band characteristics for a specific time of day or year are vital if you are to be successful in talking to stations around the world. Let's examine the various parts of the HF spectrum and learn when we should use them for various communications distances.

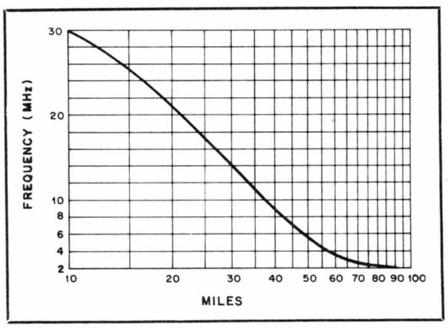


Fig. 1 — Typical high-frequency range, in miles, for ground waves compared to frequency. km = mi × 1.609.

Close-In Contacts

There are many occasions when we may desire to have good, solid communications across town or out to, say, 100 miles. If this is our desire, we need to select a frequency band that is best for *ground-wave* communication. A ground-wave signal is one that follows a path along the earth's surface between two antennas. The signal wave may or may not touch the ground, but it remains within the lower atmosphere during the period of travel. The lower the frequency of the HF band, the greater the ground-wave distance. Fig. 1 shows the typical ground-wave range versus frequency from 2 to 30 MHz. A vertical antenna works best for ground-wave communications. This is why commercial AM broadcast stations use vertical antennas (towers): The broadcaster wants maximum signal coverage from the station for a given transmitter output power. The amateur 160-meter band is in the MF (medium-frequency) spectrum, as are the AM broadcast stations. At 160 meters (1.8-2.0 MHz), we can expect very good ground-wave distances, compared to the bands from 80 meters through 10 meters.

Field Intensity of Waves

We have just considered the effective strength of ground waves versus frequency (Fig. 1), but we should recognize that

[1]km = mi × 1.609

*ARRL Contributing Editor, P.O. Box 250, Luther, MI 49656

the signal strength at the receiving antenna is measured in terms of voltage. Radio signals are very weak, so they are measured in microvolts (μV) rather than volts, as would be the case when measuring the ac from a wall outlet. A microvolt is 1/1,000,000 of a volt. Radio waves are of the ac (alternating current) type. The intensity of a signal from a transmitting antenna is always measured in terms of microvolts per meter at a distance from the antenna or signal source. The receiver S meter does not yield accurate signal-intensity readings, and is not calibrated in microvolts. An S meter is useful only for making relative measurements of signal strength, such as comparing the signal strength of two or more amateur stations, or the relative difference between two or more antennas at a given station with which you are communicating.

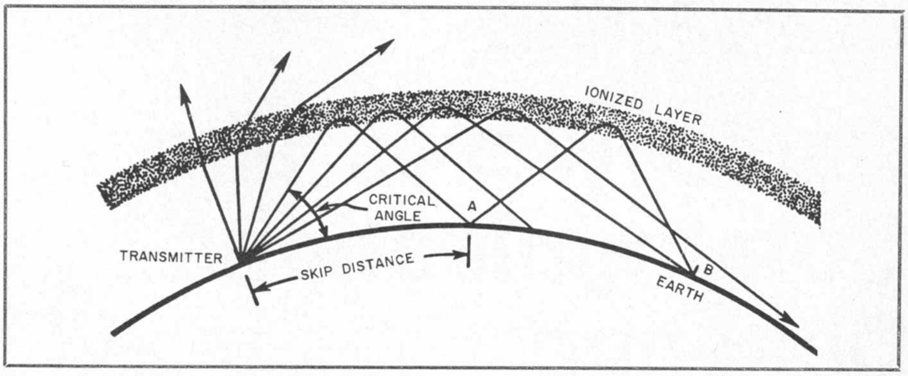


Fig. 2 — Radio signals as they are affected by the ionosphere. Some waves penetrate the ionosphere or are absorbed, while others are refracted earthward from these ionized layers (see text). Points A and B on the earth's surface in this drawing illustrate multihop skip.

Sky Waves

Distant communications may take place by means of sky waves. Sky waves travel in that area above the earth where there is no atmosphere. This region is the *ionosphere*. The condition of the ionosphere is subject to countless changes that are caused by the activity of the sun and associated changes in the earth's magnetic field. Therefore, we cannot rely on having the same sky-wave conditions from hour to hour, or from day to day. Communications by means of sky-wave propagation are often referred to as "skip communications." This is because our signals are refracted off one of the ionospheric layers and returned to earth. This is similar to bouncing a ball off a bumper in the game of pool. Fig. 2 illustrates this principle. A signal can bounce more than once, as shown.

The Ionosphere Defined

The ionosphere is a region where the air pressure is so low that free ions and electrons can move about for some time without combining to form neutral atoms. Rather lofty talk for beginners, to be certain, but I know of no other way to describe the condition. When a radio wave enters this rarified atmosphere, which is a region of numerous free electrons, it encounters a barrier, in effect, and its direction of travel is changed. This causes it to bend and deflect earthward.

Ultraviolet radiation from the sun causes the outer atmosphere to become ionized. Relatively dense areas of ionization take place, and these are called *layers*. They lie parallel to the earth's surface and occur at well-defined distances of 25 to 200 miles. Some radio waves penetrate an ionized layer deeply and then bend back toward earth. Others penetrate the layer slightly before bending downward.

Ionization is not constant within a given atmospheric layer. It tapers gradually, either wide of the maximum-intensity area of the layer. The total ionization caused by the sun is never constant at a given spot for the time of day or season of the year. Because of this, there is an almost constant variation in long-distance communications effectiveness.

Ionospheric Layers

The D layer is situated 37 to 57 miles above earth. The ionization of this layer is related directly to sunlight. It commences at daybreak, peaks at noon and vanishes at sunset. During this period our 160- and 80-meter signals suffer high *absorption* loss, which limits us pretty much to ground-wave communications. At times of high solar activity (sun spots and solar flares), these bands can become completely dead. Under severe solar storms we may even find the 40-meter band severely affected. It is easy to get the false impression that our receivers are defective, for we may tune one or two bands and find no signals present!

The D layer is ineffective for refracting HF signals back to earth. Therefore, it is not useful for DX communications. We can think of it more as a nuisance than a benefit.

Now that we have properly vilified the D layer, let's look at the next layer — the E layer, some 62 to 71 miles above the earth. The E region is useful for DX work at the upper end of the HF spectrum and the lower end of the VHF spectrum. MF and lower HF signals are absorbed by the E layer in a manner similar to that of the D layer. Maximum E layer intensity occurs near the noon hour, and commences and declines in the same manner as does the D layer. The sun is not the sole ionizing agent. Ionization occurs also from solar X-rays and meteors entering the earth's atmosphere.

Our most useful layer for DX communications in the HF bands is the F layer. The height may be from 130 to 260 miles above earth. This can be compared to the E layer (see Fig. 3). The F layer may split into two layers during the daytime. If this happens, the weaker, lower layer is called F1. It is about 100 miles high and acts somewhat like the E layer. The upper F layer (F2) remains the useful one for long-distance communications. The F1 layer dissipates after sundown. DX prediction charts appear regularly in *QST*. You may also monitor W1AW bulletins for information on propagation conditions for the immediate time period.

Skip Zone and Skip Distance

Under certain critical propagation conditions there is a distance between the limits of ground wave and the beginning of skywave refracted to earth, respective to the

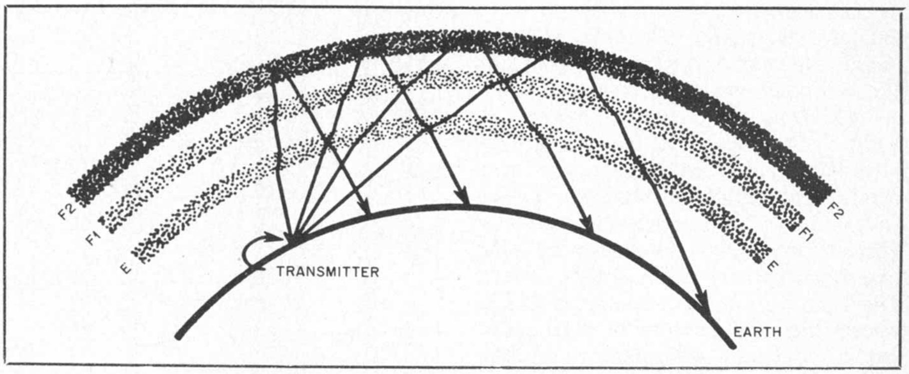


Fig. 3 — Typical daytime wave propagation at high frequency as compared to the ionospheric layers. The F2 layer is the most useful for long-range communications. The E layer is excellent for short-range skip communications at the high end of the HF spectrum and the lower part of the VHF spectrum.

location of the transmit antenna. This area between the two propagation paths is virtually dead, although there may be weak signal energy heard from the refracted wave. This ineffective communications area is called the "skip zone."

Skip distance is quite unlike the skip zone in definition. It can be described as the distance between the location of the originating signal and the point on earth where it returns to ground from the ionosphere. Therefore, with signal refraction from the F layer, the skip distance can be thousands of miles in length.

Single and Multihop Propagation

We learned earlier that a refracted signal can have more than one bounce from earth to the ionosphere and back, as illustrated in Fig. 2 at points A and B. We must understand that when we send our signal into the sky it does not follow a narrow-beam-like path in the manner of a flashlight beam. Rather, it is dispersed over a wide area, and it becomes further dispersed when it refracted from the ionosphere. When it returns to ground it is further dispersed, becoming weaker and weaker as it hops along. For this reason, multihop propagation will usually result in weak signal readings at the distant point, even though the signal may be completely readable by the other operator.

Antenna Radiation Angle

As the radio wave is launched from our antenna, it has a particular launch angle (radiation angle), respective to the horizon. Some antennas have more than one radiation lobe (in fact, most do), and each lobe has a different intensity and radiation angle. Our concern is for the *major lobe.* The remaining lobes are referred to as *minor lobes,* but even these lobes can be used for effective communications under certain propagation conditions.

The lower the radiation angle from the antenna, the better our chances to work DX. This is because a high-angle signal may require two or more hops to reach a distant point, which will weaken the signal, as we learned while discussing dispersion. On the other hand, a very low radiation angle may enable us to work the distant station with only one hop. Launch angles between, say, 10 and 20 degrees are considered good for DX communication. The higher radiation angles are much better for shorter distances, such as we encounter at 10 and 6 meters when using the E layer for our refractive medium. Fig. 4 shows how a radiation lobe from an antenna might appear if we could see the RF energy.

The most important factor, other than the design of an antenna, is the height above ground, respective to the angle of radiation. The higher the antenna the lower the radiation angle, generally speaking. Heights in excess of 0.5 wavelength are strongly recommended. Therefore, a horizontal antenna for 40 meters should be 70 feet or greater in height. The exception is when we use a vertical antenna with a good ground system (buried or on-ground radial wires). A vertical antenna has a low angle of radiation. The trade-off is that this antenna responds equally well to signals from all directions, which can create problems from QRM (signal interference) originating in some region apart from the direction of interest. A vertical antenna is, therefore, omnidirectional in response. Furthermore, a vertical antenna is more prone to pick up man-made noise than is the horizontal antenna. If you live in an electrically noisy neighborhood, the noise (QRN) in your receiver may be so great that weak-signal reception is nearly impossible.

Horizontal antennas exhibit directivity when they are high above ground. Some have nulls off the ends (dipole antennas), while beam antennas have deep nulls off the sides and back of the array. This aids in reducing QRM from undesired directions. Man-made noise is vertically polarized, and horizontal antennas reject much of that noise since the polarization is not the same.

Sporadic E Skip

There is a form of E layer skip that is called "sporadic E." The E layer is ionized in patches rather than solidly, forming "clouds" of highly ionized atmosphere. These so-called clouds form and dissipate rapidly at times, and this is why the term "sporadic" is used. Skip from these clouds is over relatively short distances, 100 to 1000 miles. The 10- and 6-meter bands are affected the most by sporadic E skip. However, the useful effects of sporadic E have extended as high as 148 MHz at times. I experienced this while living in Connecticut some years ago: I worked a WØ station in Minnesota on 2-meter SSB while running 10 watts to my 10-meter Yagi antenna!

Best Bands Versus Time of Day

It is not possible to produce a list of bands, effective communication distances

(Continued on page 38)

Glossary

attenuation — reduction of signal power.
band — a range of frequencies, such as 3.5 to 4.0 MHz, allocated for amateur use. The bands are designated in meters — for example, the 80-meter band.
D layer — an ionized layer in the atmosphere 37 to 57 miles above the earth.
DX — long-distance in radio communications.
E layer — an ionized layer in the atmosphere 62 to 71 miles above the earth.
F layer — an ionized layer some 130 to 260 miles above the earth.
ground wave — a signal wave from an antenna that follows the earth's surface, or slightly above the surface, for a limited number of miles.
ionosphere — the region high above the earth that has no atmosphere, but contains free ions and electrons and very low air pressure.
lobe — a concentration of radio-frequency energy that leaves a transmitting antenna and is directed toward the sky a certain number of degrees, respective to the horizon.
QRM — interference from other radio stations.
QRN — interference from atmospheric and man-made noise.
radiation angle — the angle at which a wave departs from the antenna, referenced to the horizon.
skip — the process of a radio wave bouncing off the ionosphere and returning to earth at a distant point.
skip zone — a dead signal area on earth that occurs between the limits of ground-wave signals and the beginning of the useful sky-wave signal.
sky wave — a radio wave that uses the ionosphere as a refracting medium.

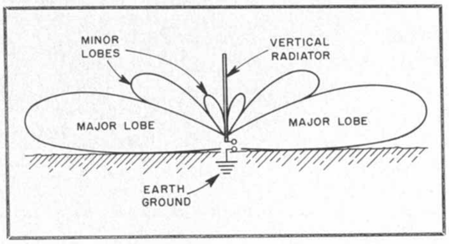


Fig. 4 — Illustration of various radiation angles versus major and minor lobes for a vertical antenna. Minor lobes occur also with most horizontal wire and beam antennas. All of these lobes are useful, depending on band conditions at a given instant and with regard to the desired communication distance (see text).

Table 1
Suggested DX Bands

Band (MHz)	*Typical Distance (Day)*	*Typical Distance (Night)*
1.8 (160 meters)	0-50 miles	0-3000 miles
3.5 (80 meters)	0-100 miles	0-3000 miles
7.0 (40 meters)	0-1000 miles	0-3000 miles
10.1 (30 meters)	0-2000 miles	0-4000 miles
14.0 (20 meters)	0-4000 miles	0-100 miles
21.0 (15 meters)	0-4000 miles	0-100 miles
28.0 (10 meters)	0-5000 miles	0-100 miles

These distances versus time of day are based on either daylight or total darkness. Average band conditions are assumed. The actual distance worked will depend on the antenna used, the amount of transmitter power and the condition of a band at a given moment. The mileage may be greater or less than stated above. Single-hop communications are assumed here. Multihop skip will provide worldwide communications under ideal band conditions.

(Continued from page 33)

and ideal times of day. We can only generalize because of the continual change in solar activity. We can, however, suggest the bands on which to concentrate for working local or DX contacts, day versus night. This data is presented in Table 1 for your assistance in setting up your antennas for favored bands.

Need a Copy of This Article or a Previous Installment?

Although each issue of *QST* is protected by copyright, we would like to make it as easy as possible for readers to obtain copies of each installment of First Steps in Radio. Provided that copies are made *for the personal use of an individual, or of a Novice class,* ARRL hereby grants permission for photocopies to be made of any article in this series. If your club plans to teach a Novice class, feel free to make a sufficient number of copies for students' personal use. If you are missing one or more installments, back issues are available for $2.75 apiece from the Circulation Department, ARRL Hq., 225 Main St., Newington, CT 06111.

Summary

Your best source of detailed information concerning the ionosphere and radio propagation is *The ARRL Antenna Book*. I have attempted here to provide a simplified, plain-language introduction to the propagation phenomenon, and to suggest steps you can take to make your first on-the-air experience a pleasant and rewarding one. Also, you will need some knowledge in this subject area if you are to pass your amateur license examination. The mysteries of the sky are many, and we have ignored a host of them in the interest of keeping this article short. I encourage you to engage in further study of this fascinating subject. QST