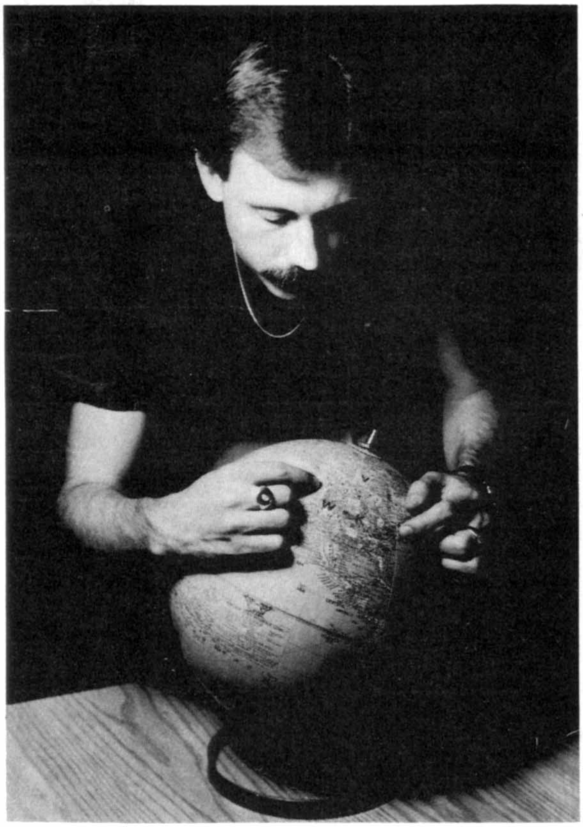
# HF Propagation: The Basics

Say it's 10 P.M. in Savannah, and you'd like to reach out and QSO someone in southern Europe. A solid knowledge of how signals travel will help you decide if you've got a fighting chance.

By Dennis J. Lusis,* W1LJ/DL



Perhaps no other topic in Amateur Radio is as intriguing, yet confounding to the beginner as propagation — how signals travel from one station to another. Regardless of how you view it, propagation is essential to each and every QSO we make, be it a stateside ragchew or a rare DX contact. Some basic knowledge of how radio waves travel will go a long way in making your hobby a more interesting and enjoyable one. This article will introduce you to the primary modes of hf propagation. Vhf and uhf propagation is an entirely different subject.

### Ground and Sky Waves

Regardless of what type of antenna you are using, the radio waves emanating from it can be categorized broadly into two types — *ground waves* and *sky waves.* Simply stated, a ground wave is one that travels directly from the transmitter to the receiver without leaving the lower atmosphere (Fig. 1). Ground-wave propagation occurs, for example, when you contact another station across town on an hf band. Amateur communications of up to 50 miles are typically possible via ground wave.[1] It is the sky wave that provides amateurs with the potential for worldwide communications.

A sky wave, just as the name implies, is one that does *not* follow the earth's surface; it travels up into the sky, away from the earth (Fig. 1). At this point, you are probably wondering how we can communicate via signals that travel out into space? After all, our receivers are down here on earth! Somehow, the signals must return here to be captured by our receiving antennas — plain and simple. And just what "persuades" our signals to come back down? Fortunately, there is a region in our upper atmosphere that is pretty good (and occasionally not so good!) at performing this task. This region is named the *ionosphere,* and it is here that we must look to understand the basic mechanisms of hf propagation.

### Ionospheric Characteristics

The ionosphere derives its name from the term *ion,* which is a free electron or other charged particle. In our atmosphere, ionization (or the charging of particles) occurs in the region that lies roughly between 25 and 250 miles above the earth. In this region, air pressure is low enough so that ions can travel freely for a considerable length of time without colliding and recombining into neutral atoms. When radio waves enter the ionosphere, their courses are altered by the process of *refraction,* or bending (Fig. 2). Under proper conditions, the wave is diverted enough to head back down to earth, where it can be received.

The primary cause of atmospheric ionization is ultraviolet radiation from the sun. Therefore, solar conditions are of great importance to propagation. Exactly which solar indicators concern us will be discussed later in this article.

### An Ionic "Layer Cake"

A closer look at the ionosphere reveals that it consists of dense layers stacked one on top of another, concentric with the earth's curvature. Each of the layers has maximum density in the center, with regions of gradually deteriorating density extending out toward the edges (Fig. 3). However, the absolute level of ionization is changing constantly with the time of day, season, solar conditions and other long-term variations. These variables contribute directly to the constant changes in hf propagation that often frustrate the most seasoned operators.

### Each Layer Is Different

Although each ionospheric layer is comprised of free ions, their similarity (at least for our purposes) ends there. Each layer of the "cake" has special characteristics of its own, and you may be surprised to find out what effect each has on propagation.

The bottommost ionized region is known

[1]Notes appear on page 15.

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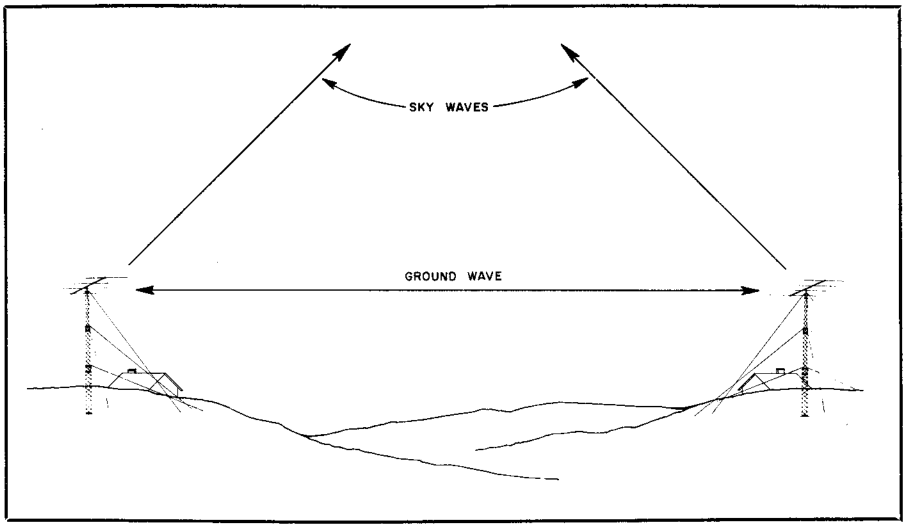


Fig. 1 — An example of the difference between ground waves and sky waves.

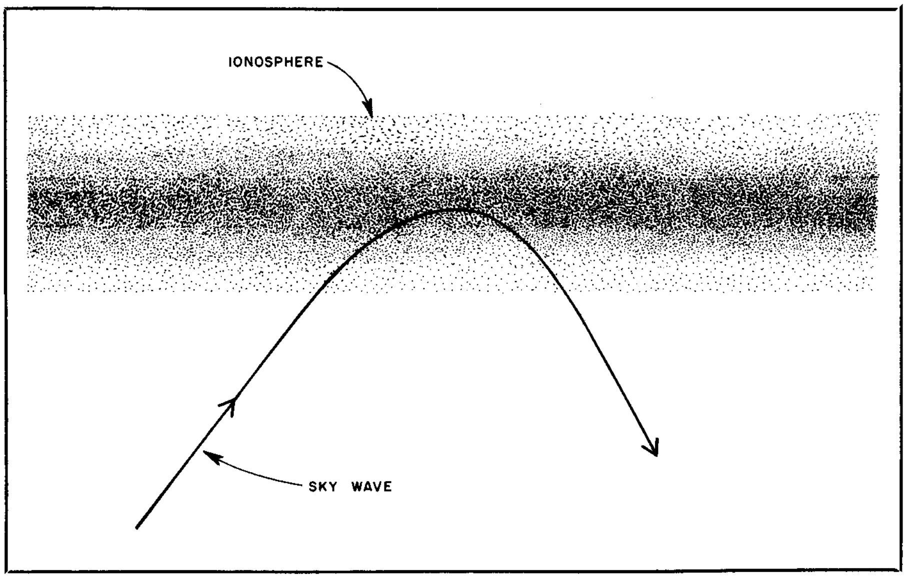


Fig. 2 — Under proper conditions, a radio wave entering the ionosphere will be refracted and follow a new course. This permits the signal to be heard on earth, perhaps thousands of miles from the transmitting antenna.

as the D layer, which lies between 37 and 57 miles above the earth (Fig. 3). This layer exists only during the daylight hours, and usually disappears within 30 minutes after sundown. Because it is located so close to the earth, the D layer is in a relatively dense part of the atmosphere. Here, ions often collide and recombine into neutral particles, which accounts for the rapid loss of this layer in darkness.

The D layer is not particularly useful to amateurs. Instead of refracting and propagating signals, it *absorbs* a great deal of them. A wave passing through this dense layer collides with a relatively large number of ions and sets them in motion. Much of the wave energy is thus used up through conversion to motion or heat energy.

Because a long wavefront will set more ions in motion than a short one, we can assume that the D layer will absorb more energy as the frequency of our signal decreases (Fig. 4). Additionally, the angle at which a wave enters the D layer has an effect on the degree of absorption. A wave going straight through has the shortest path and least absorption; a wave cutting through at a low angle has much farther to travel in the layer, and absorption will be greater. Because of these effects, the D layer is responsible for the 160, 80 and 40-meter bands being good only for short-distance communications in the daytime.

At night, when the D layer disappears, these same bands can often support DX communications of several thousand miles. This daytime absorption effect is insignificant on 20 meters and higher, which in part allows daytime DX communications on these bands.

The next higher ionospheric layer is the E layer, which is also the lowest one that will *support* radio wave propagation. This layer is located between 62 and 71 miles above the earth, and has characteristics similar to those of the D layer. For example, maximum E layer ionization occurs around noon local time, and rapidly drops off after sundown. During the period of peak ionization (midday), the E layer will absorb some energy in the lower-frequency amateur bands, but not nearly as much as the D layer. It is also interesting to note that X rays and meteors entering the atmosphere contribute to ionization of this layer. The E layer is also the scene of a spectacular type of vhf propagation known as *Sporadic E.* Because it is beyond the scope of this article, interested readers should consult the reference for an explanation of this phenomenon.[2]

Except for occasional propagation via the E layer, we rely almost exclusively on the outermost F layer to provide long-distance hf communications. Here, between 100 and 260 miles above the earth, rarification causes ions to recombine more slowly than in the other layers. Because of this, the F layer can often remain highly ionized throughout the night. As with the other layers, maximum ionization occurs around local noon time, with minimum occurring about an hour before local sunrise.

An interesting aspect of the F layer is its tendency to split up into two layers, known as the $F_1$ and $F_2$ layers. This separation occurs during the day, and causes the lower $F_1$ layer to take on much of the same characteristics as the E layer. Therefore, daytime propagation is largely supported by the $F_2$ layer. At night, the $F_1$ layer disperses and the $F_2$ layer slightly reduces its height above ground.

**Refraction: The Critical Element**

I mentioned briefly that refraction is the mechanism responsible for returning sky-wave signals back to earth. The most critical aspect of this phenomenon is the degree to which the waves are bent. There are two primary factors influencing this — the density of ionization and the length of the wave (or frequency). All other conditions being equal, bending will increase with higher ionization density. Also, bending increases with wavelength, or put another way, decreases as the frequency goes up. This sets up a condition in which both factors, working simultaneously, will finally determine whether a wave will be refracted back to earth.

Take a look at the example in Fig. 5. In A, we have an F layer of relatively low ionization, typical of nighttime conditions. Our 28-MHz signal is not refracted enough under these conditions to return back to earth. The 3.5-MHz wave, however, being of greater wavelength, is refracted much more and does make it back down.

In Fig. 5B, the ionosphere is more highly charged than in A, simulating typical mid-

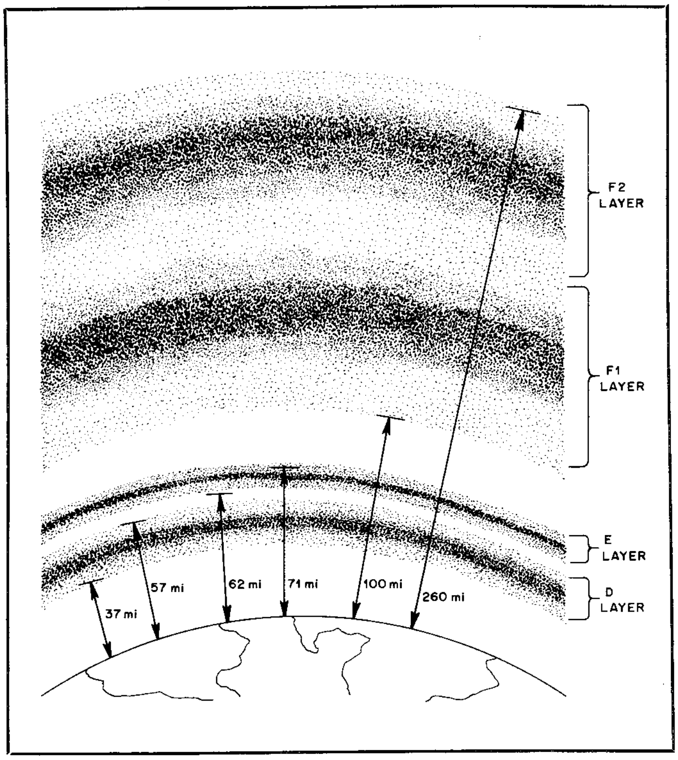


Fig. 3 — The various ionospheric layers with respect to the earth. Distances shown are not absolute, but vary with conditions as explained in the text.

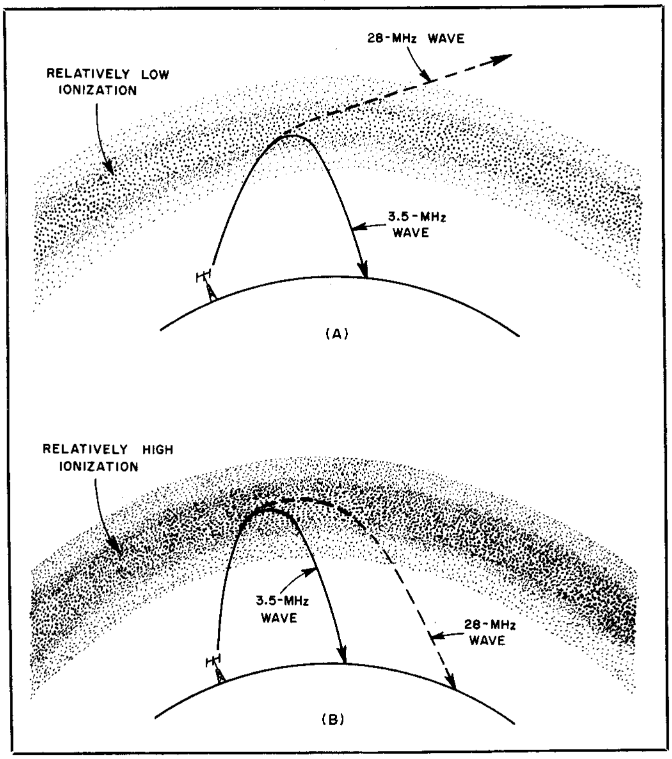


Fig. 5 — In A, the low-level ionization is insufficient to bend the 28-MHz wave back to earth; the level is high enough for 3.5-MHz propagation. Higher-level ionization in B is sufficient to refract the 28-MHz wave to earth.

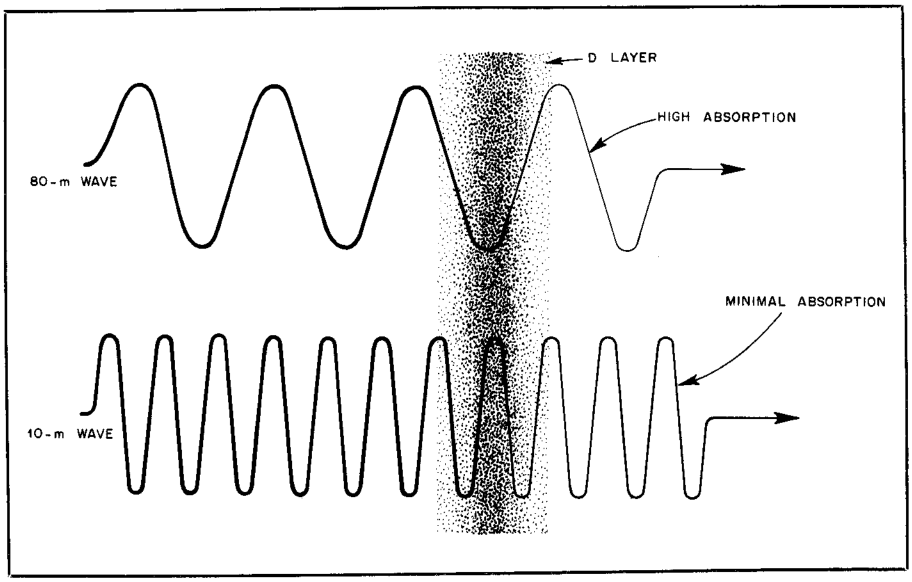


Fig. 4 — All other conditions being equal, a lower-frequency wave will undergo greater D-layer absorption than a higher-frequency one. The larger wavefront must travel a greater distance through the D layer.

day conditions. Now, with sufficient ionization we have a situation in which *both* waves are refracted back to earth. Note that the 28-MHz wave is not bent as much as the 3.5 MHz one, because of its shorter wavelength.

By now you should understand how the basic refraction process works. It's time to introduce a simple and valuable indicator that relates to our daily operating. The *maximum usable frequency (muf)* is, in the strictest sense, defined as the maximum frequency that will support communication between two specified points under existing conditions. For example, during one evening, the muf between New York City and Chicago could be 3.5 MHz, while at the same time, the muf between NYC and Denver is 28 MHz. And why is this? To answer the question, we must work one more factor into our discussion — *wave angle.*

We already know that the amount a wave is refracted depends on two factors: wavelength and the degree of ionization. But assume that for a fixed frequency and degree of ionization, waves penetrate the F layer at different angles. How does this affect propagation? Let's take a closer look.

Fig. 6A shows what typically occurs to a 28-MHz signal. Waves entering the ionosphere at high angles are not refracted back to earth, but continue out into space. As the wave angle decreases, there is a critical point where refraction causes the waves to return to earth. That angle is known as the *critical angle,* and all waves leaving at that angle or below will be propagated to earth.

The critical angle is also directly associated with a phenomenon known as the *skip distance* or *skip zone.* This zone or distance, as shown in Fig. 6, is a region where it is impossible for any regular sky-wave signals to be propagated. The length of the skip distance will vary according to the critical angle. Table 1 lists average skip distances for each band.

Fig. 6B shows the effects of the ionosphere on a lower frequency (3.5-MHz) signal. With all other conditions being the same as in Fig. 6A, we now see that the critical angle is much higher and the skip distance much shorter than on 28 MHz. Under these conditions, we would be able

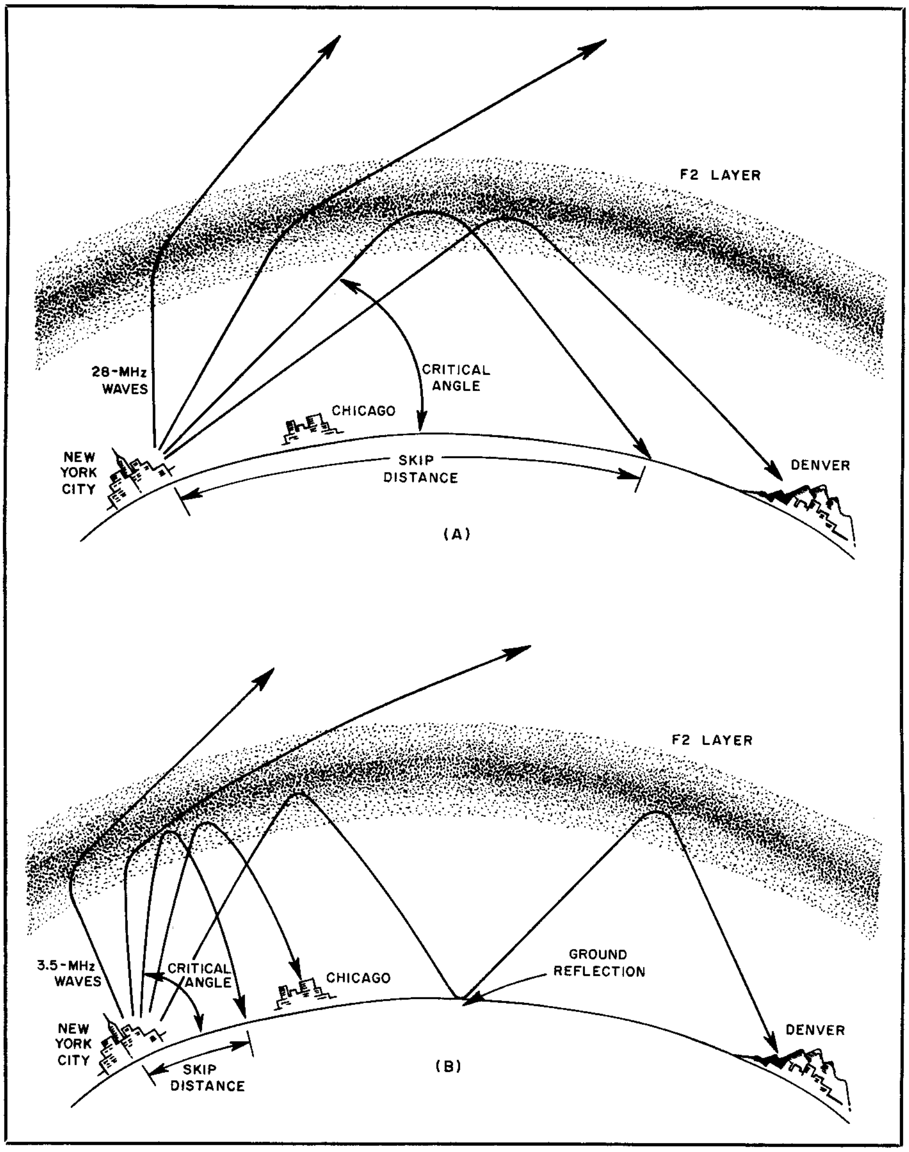


Fig. 6 — Illustration of how frequency, critical angle and skip distance are related. See text for explanation.

**Table 1**
**Approximate Skip Distances for the Amateur MF and HF Bands**

| *Band* | *Noon** | *Midnight** |
|---|---|---|
| 160 m | 0 mi | 0 mi |
| 80 m | 0 mi | 0 mi |
| 40 m | 50 mi | 300 mi |
| 30 m | 300 mi | 600 mi |
| 20 m | 500 mi | 1000 mi |
| 15 m | 800 mi | (Daytime only) |
| 10 m | 1200 mi | (Daytime only) |

*Local time at the midpoint of the path.

to QSO with Chicago from New York City. On 28 MHz, the skip distance prevents this. The reasons should now be clear as to why there is a different muf for every distance over which we wish to communicate!

### Multihop Propagation

For the sake of simplicity, I have only mentioned wave propagation in terms of a single "hop" off the ionosphere. But the $F_2$ layer is at a certain altitude, and the maximum distance we can cover on a single hop is approximately 2500 miles. Therefore, communication over distances greater than this requires more than one hop, commonly known as *multihop propagation*. Fig. 6B shows how a wave returning to earth is reflected back up to the ionosphere, where it can be refracted again. This phenomenon can occur several times for a signal to be propagated around the earth. Because there is a considerable loss of signal strength with each hop, it is preferable to use lower-angle radiation, which takes fewer hops to reach the destination than higher-angle radiation. The factors determining radiation angle are covered in an excellent *QST* article by Hutchinson.[3]

Another factor in multihop path loss is whether signals reflect off a land mass or water. As you have probably guessed, water is the much better reflector of the two; signals will generally propagate more efficiently over it when multihop is involved. Is it any wonder that coastal stations have consistently big signals?[4]

### It's Up to the Sun

We know that the sun plays a major role in the short- and long-term propagation variations we encounter. The general reason for this is quite simple: Changes in solar activity affect the sun's output of ionizing radiation. This in turn affects the degree to which our atmosphere is ionized.

Logically, to predict propagation we must study solar activity. As with the weather, we are not able to predict this activity with 100% accuracy. However, we can use various solar indicators to predict band conditions with fairly good results.

By now you are undoubtedly aware that sunspots have a lot to do with band conditions. The presence of these grayish-black blemishes has been found to correlate directly with the sun's output of ionizing radiation; the more sunspots visible at one time, the more ionization we can expect.

Fortunately, sunspot behavior has been studied and well documented for the past 200 years. In this time, we have learned that sunspots (or groups thereof) move across the sun from east to west at a constant rate. This movement is caused by the sun's axial rotation, which takes about 27.5 days for a complete revolution.

Perhaps the most significant of all sunspot characteristics (at least for amateurs) is the 11-year sunspot cycle. Records indicate that a peak in sunspot activity occurs every 11 years, give or take a year. Along with this peak is a corresponding increase in the average muf, and general improvement of hf propagation conditions. Our last peak occurred in the spring of 1980, when 10 meters was open worldwide on a daily basis, and often well into the night. There were even occasions when 6-meter signals were propagated by the $F_2$ layer, indicating an extremely high level of ionization.

### Sunspot Number and Solar Flux

These are the two primary indicators used to measure the amount of solar activity. Daily observations for sunspot count (although not the actual number of spots) are recorded, and averages determined for the month and year. The *smoothed sunspot number* for any given month is the mean for the preceding and succeeding six months. This number is also known as the Wolf number, after its inventor, or the Zurich smoothed sunspot number, because international sunspot records were stored there until recently.[5] Typical smoothed number values range from the single digits, during 11-year sunspot minimums, to over 200 during the tremendous 1957-1958 sunspot peak.

The solar flux number provides another

indication of ionospheric conditions. This number represents the amount of solar noise found on the 2800-MHz band. Research has revealed that on this frequency, noise amplitude is closely related to ionization of the F layer. This indicator has been monitored and recorded since 1947. You can obtain the daily solar flux number by listening to the WWV propagation bulletins at 18 minutes past each hour. The method of interpreting these numbers is beyond the scope of this article; those interested should consult other references for more detailed information.[6,7]

### Propagation Predictions

Understanding the basics of propagation will help you avoid making gross misjudgments regarding signal paths. Normal fluctuations in conditions can catch you off guard, however, and perhaps even prevent you from keeping that schedule with a DX friend. In this respect, a little bit of forecasting can go a long way. Like weather forecasts, propagation forecasts are not 100% accurate, but can offer a bit of warning "before the storm."

The science of propagation forecasting is indeed an involved one. It is therefore a good idea for beginners to acquaint themselves with the available ready-made forecasts. It's worth mentioning again that WWV offers a propagation bulletin at 18 minutes past each hour. Every month *QST* offers easy-to-use charts in the How's DX? column. These, combined with the WWV data comprise a very useful tool for planning your operating.

Additional propagation bulletins are a part of the W1AW bulletin service. The bulletin schedules can be found in *QST* every other month (see the Table of Contents) or obtained by writing the ARRL Communications Department. DX-minded amateurs may consider subscribing to one of the excellent DX bulletins available.[8-10] In addition to information about exotic DX locations on the air, these bulletins offer up-to-date propagation forecasts to help you "nab the rare ones."

### Happy Hunting

I hope this article has helped to eliminate some of the mysteries of propagation. As you continue to operate and gain experience on the bands, propagation conditions will become "old hat," and practically second nature to you. But beware, for as soon as you take propagation for granted, conditions will change abruptly and surprise you. Call it Murphy's Law or Mother Nature — that's what keeps propagation interesting!

**Notes**

[1]km = mi × 1.609.
[2]M. S. Wilson, "Midlatitude Intense Sporadic-E Propagation," *QST*, Dec. 1970 and March 1971.
[3]C. L. Hutchinson, "Getting the Most out of Your Antenna," *QST*, July 1983, p. 34.
[4]This explanation of multihop propagation may be a bit oversimplified. For an explanation of several other possible theories, see the *ARRL Antenna Book*, 14th edition, 1982, p. 1-8.
[5]Sunspot numbers are now being recorded and compiled by the Sunspot Index Data Center, 3 avenue Circulaire, B 1180 Brussels, Belgium.
[6]G. Hall, ed., *The ARRL Antenna Book*, 14th ed. (Newington: ARRL, 1982), Chapter 1.
[7]E. Tilton, "The DXer's Crystal Ball," *QST*, June, August and September 1975.
[8]The DX Bulletin, 306 Vernon Ave., Vernon, CT 06066.
[9]The Long Island DX Bulletin, P.O. Box 173, Huntington, NY 11743.
[10]QRZ DX, P.O. Box 4072, Richardson, TX 75080.

## Strays

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1) Before writing for technical assistance, search your files of *QST* and other ARRL publications. The answer you need may be there, available immediately. Consult the annual index of articles in each December issue.

2) Please do not ask for comparisons among commercial products. Choice of equipment is largely a matter of personal preference. Consult Product Review information in *QST;* compare manufacturers' specifications in their brochures.

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Do not ask advice on nonamateur matters. We cannot respond to questions about CB, marine radio, hi-fi, etc. (unless they concern interference caused by amateur gear).

3) Use a typewriter when possible; otherwise, write or print *clearly.* Please be reasonable in the number of questions you ask; try to limit your questions to three per letter.

4) When writing, please come right to the point, and be sure to share with us whatever experience you have had with the problem in question. This will avoid our reply covering ground you've already been over.

5) Address all technical questions to Technical Information Service, American Radio Relay League, 225 Main St., Newington, CT 06111. — *Bob Schetgen, KU7G, Technical Information Specialist*

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## Next Month in QST

To begin the new year, January *QST* will feature the first of a comprehensive series of articles designed expressly for those with little or no electronics background. You may want to pass the word to your pre-Novice friends and neighbors.

Also in January, look for word about the ARRL Antenna-Design Competition, and an article that will tell would-be *QST* authors how to put together a technical article. If you're into kit building, you'll want to take in the January article that provides practical hints to help make your next project one that you'll be proud of for years to come.