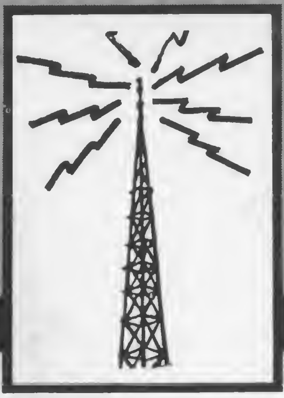
HAM TIPS



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Radio Propagation

And the Amateur Radio Operator

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In the following article, the author reviews the subject of radio propagation as it applies to the amateur operator. The data should aid the amateur in understanding how his signals reach their destination, whether by skywave or groundwave propagation, and help him to use his frequencies more efficiently, and thereby communicate more effectively.

Long-range transmission in the amateur bands below 30 megacycles is dependent primarily upon the skywave mode of radio-wave propagation. This mode of propagation is made possible by five ionospheric regions, collectively called the *ionosphere*, which are found at distances from 50 to 350 kilometers (about 31 to 217 miles) above the earth. It is important to visualize the structure of the ionosphere to understand more fully the mechanism by which the ham operator's signals reach their destination in the skywave mode. Some knowledge of the response of the ionospheric regions to different frequencies; of their signal-absorption characteristics; and of unusual transmission effects attributed to them is also essential if effective use is to be made of skywave propagation.

Structure of the Ionosphere

The ultraviolet radiation from the sun is believed to supply the energy to ionize the five ionospheric regions. This belief is supported by the significant increase in the ionization levels that occurs during the peak of sunspot activity; it is known that the ultraviolet radiation is maximum during such peaks.

The two ionospheric regions nearest the earth, the D and E layers, exist during the daylight hours only. At the relatively low altitudes of these layers, atmospheric particles recombine so rapidly that a constant source of radiation is required to sustain ionization. The D layer is found from 50 to 90 kilometers above the earth; the E layer, from 90 to 140 kilometers above the earth. Both the height and the ionization level of the layers vary over different parts of the earth and with the season-to-season changes in the zenith angle of the sun. The ionization level also changes with the time of the day and reaches a peak at local noon in any given region of the earth. In the E layer, variations in the ionization level are particularly noticeable, and significant changes can be observed from hour to hour.

In the D layer, because of its lower altitude, atmospheric particles are more abundant, and there is a resultant higher incidence of particle collisions. The signal absorption by this layer is, therefore, greater than that by any of the other atmospheric layers. Particle collisions are also relatively frequent in the E layer, and

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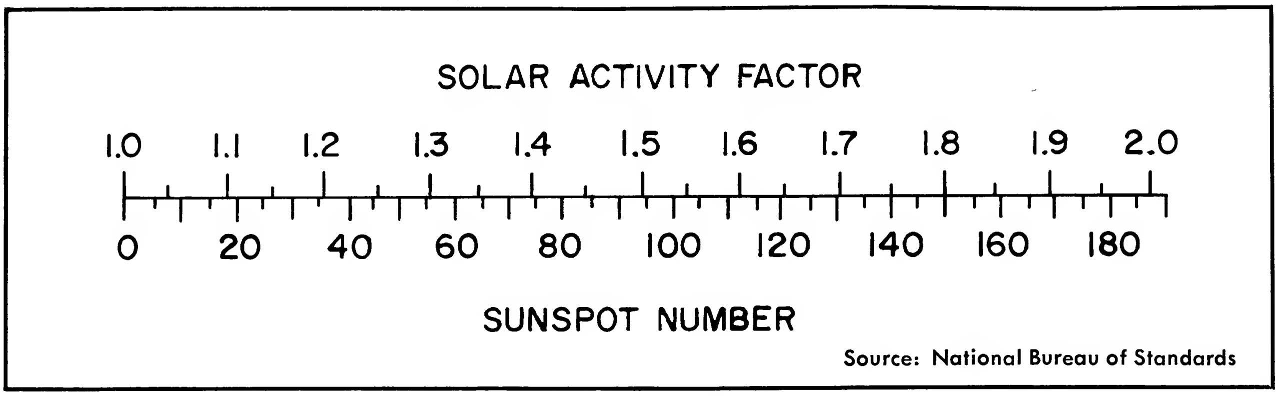


Source: National Bureau of Standards

Figure 1(a): Solar-activity factor.

it too exhibits a comparatively high degree of signal absorption. The E layer, however, reflects zero-incidence radio waves (those directed straight up) far more consistently than does the D layer and is much more useful for communications.

The E_s (or sporadic E) layer is the most unusual and unpredictable of the ionospheric layers. This layer, which can be found at any hour of the day or night in all latitudes, is best visualized as intermittent clouds of ionized particles slightly above the E layer in which the ionization level may change radically from hour to hour. The source of ionization of the E_s layer is still somewhat a mystery. According to some hypotheses, the layer is ionized by particle radiation from the sun, rather than by ultraviolet radiation; other hypotheses suggest that the layer is formed by ionized particles trapped in the earth's magnetic field.

In general, the appearance or disappearance of the E_s layer is unpredictable, although in northern latitudes the existence of the layer has been found to be very closely related to the presence of the aurora. Although its effects are unpredictable, the late-evening "short-skips" are often attributed to it, and the E_s layer is very useful for radio communications.

The uppermost regions of the ionosphere are the most useful for long-range radio-wave transmission. During the daylight hours, these regions are divided into two separate layers: the F_1 layer at heights of 140 to 250 kilometers and the F_2 layer at heights of 200 to 350 kilometers. At night, these layers merge to form a single F layer that ranges from 140 to 250 kilometers above the earth. As in all the ionospheric regions, the ionization levels in the F layers follow the sun. The ionization reaches a peak just after local noon and declines slowly until sunrise. Because the atmosphere is thin at the altitudes of the F layers, particle collisions (and recombinations) are relatively infrequent; thus, the ionization of these layers can be sustained throughout the night. Because of the lower collision rate, there is also less absorption as electromagnetic energy is reflected from the F region.

Seasonal Correction Factors

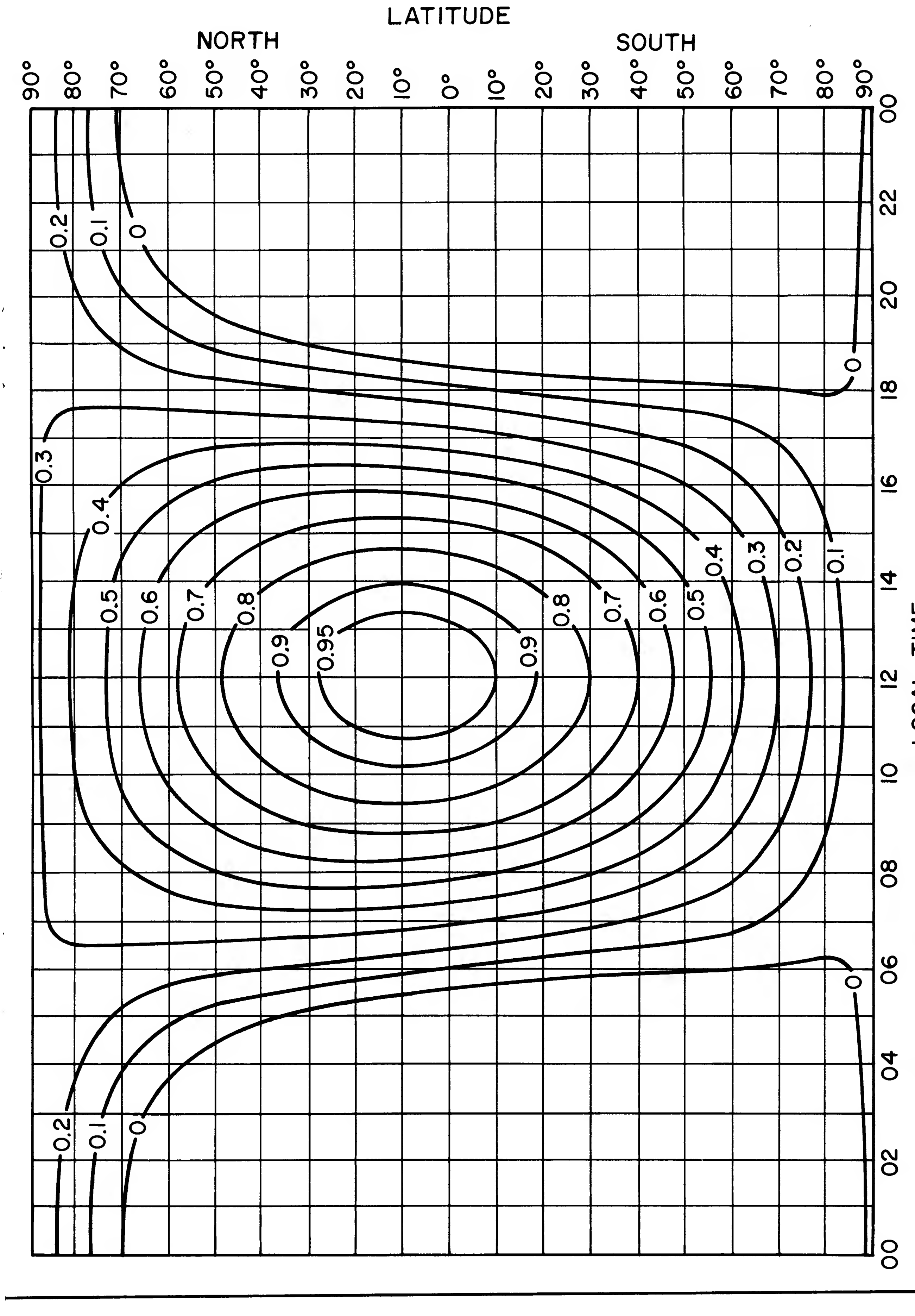
	Both Terminals		One Terminal N. Lat and
Month	N. Lat	S. Lat	Other S. Lat
Jan	0.9	0.7	0.8
Feb	0.9	0.7	0.8
Mar	0.8	0.8	0.8
Apr	0.8	0.8	0.8
May	0.7	0.9	0.8
Jun	0.7	0.9	0.8
Jul	0.7	0.9	0.8
Aug	0.7	0.9	0.8
Sep	0.8	0.8	0.8
Oct	0.8	0.8	0.8
Nov	0.9	0.7	0.8
Dec	0.9	0.7	0.8

Figure 1(b): Seasonal-correction factors.

Figure 1: Typical solar-activity and seasonal-correction factors. The solar-activity factor (a) must be multiplied by the seasonal-correction factor (b) and the time-of-day factor (see Figure 2) to obtain the absorption-factor K.

Critical Frequency

The ability of any of the ionospheric layers to reflect radio waves depends not only upon the degree of ionization of the layer, but also upon the frequency of the radio waves. In measurements to determine the structure and ionization level of the ionospheric layers, zero-incidence radio waves are often used. In order for any of the ionospheric layers to reflect a radio wave at zero incidence, the frequency of the wave must be below a critical value. This *critical frequency* is that frequency for which



Source: National Bureau of Standards

Figure 2: The chart for the month of April from which the time-of-day factor is obtained. The latter, in turn, is used to determine the absorption-factor K.

50% of the radio waves will penetrate the layer and 50% will be reflected.

The signals reflected to the earth become weaker as frequencies of zero-incidence radio waves deviate from the critical frequency in either direction. Below the critical frequency, a gradual decline occurs because of increased layer absorption. Above the critical frequency, the decline is much more rapid. With but a small increase, the radio wave will not be reflected at all, but instead will penetrate the layer.

The critical frequency is different for each layer and, in general, increases with the height of the layer. For example, the critical frequency of the F layer is usually higher than that of the E layer. If the frequency of a radio wave exceeds the critical frequency of the E layer, it is therefore possible that the wave will pass through the E layer but will be reflected by the F layer. As the wave passes through the E layer, however, it will be attenuated to some extent.

Maximum-Usable and Optimum-Traffic Frequencies

Closely related to the critical frequency is the *maximum usable frequency* (MUF). The MUF is essentially a measure of the ability of an ionospheric layer to reflect radio waves from one point to another. For any given path, it is the frequency at which 50% of the signal will be reflected and 50% will pass through the layer. Thus, for a zero-incidence wave, the MUF is equal to the critical frequency. For other paths, the MUF will vary with the angle of incidence.

Each month, the National Bureau of Standards predicts the MUF for the E and F_2 layers.[1] Average values for the month are given for zero-incidence waves and for waves reflected between two points 4,000 miles apart. If these two values are known, the operator can interpolate to find the MUF for any communications path in the world. The *frequency optimum for traffic* (FOT) is 85% of the MUF. For a radio wave having a frequency equal to the FOT, 90% of the signal will be reflected and only 10% will pass through the layer.

Path Absorption

As a radio wave is propagated by an ionized layer, some of the energy in the wave will be dissipated in the layer. This dissipation, called *path absorption*, is directly proportional to an absorption factor, K, which is given by the following equation:

$$K = T \times M \times S$$

where T is a time-of-day correction factor, M corrects for seasonal variations in the ionization level of the layer, and S is the solar activity correction factor based on the current sunspot number. These factors can be determined from tables and charts prepared monthly by the National Bureau of Standards.[1] Typical tables of the solar activity factor and corresponding sunspot number and of the seasonal correction factor for both

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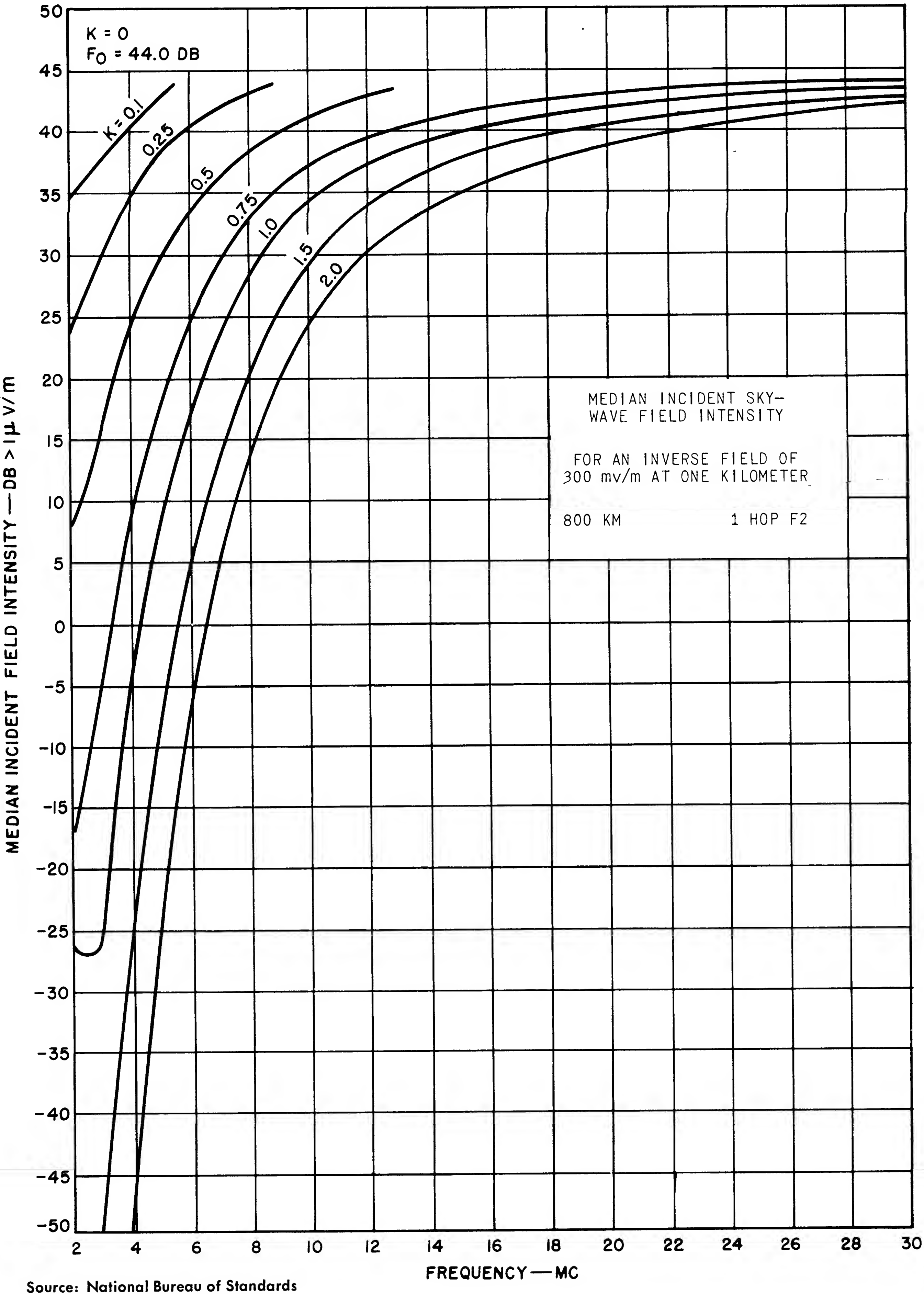
[1] CRPL-D Basic Radio Propagation Predictions; $0.10 each or $1.50 per year; Superintendent of Documents, U.S. Government Printing Office, Washington (25), D. C.



Source: National Bureau of Standards

Figure 3: A typical field-intensity graph for incident skywaves. The appropriate absorption-factor K is used to predict the received field strength in μv/meter (microvolts excited per meter of antenna length). The curves show the variations in received field strength for a kilowatt of RF power radiated from a dipole antenna. Corrections are required for different power outputs and antenna gains.

north and south latitudes are shown in Figure 1. A graph such as that shown in Figure 2 is used to determine the time-of-day factor.

If the absorption factor K is properly applied to a "received field strength" graph and the characteristics of the antennas used at the transmitting and receiving stations are taken into account, the ham operator can accurately predict the signal strength that will be received for a radio wave reflected from the ionosphere. Figure 3 shows a typical field-intensity graph for an incident skywave. The effect of different absorption-factor values is also shown.

Propagation Characteristics Of the Ionospheric Layers

The D layer will sometimes reflect radio waves from one point to another; however, reflections at zero incidence are rare. The D-layer path is "lossy," because of the high recombination rates, and, except for short-distance transmissions, is not very useful for radio communications.

The E layer is usable at frequencies higher than the D layer; however, there is some attenuation of the signals as they pass through the D layer both up and down. Because the D layer has higher recombination rates than the E layer, there are usually a few hours each day when the E layer may be used without the D layer presenting serious attenuation problems. These hours occur at sunrise before the D layer ionizes fully and at sunset after it has lost some of its ionization.

The E_s layer exhibits characteristics similar to those of the E layer, except for the sporadic nature of its appearance and disappearance.

The F_1 and F_2 layers are the "work horses" of communications. These layers are useful both day and night; however, daytime operation is usually "lossy," because of the presence of the D and E layers. At night, long-distance-communication paths are possible with very little loss and good dependability.

Various Modes of Radio-Wave Propagation

When an electromagnetic wave is radiated from an antenna, it is generally considered to have the potential for two kinds of communications: groundwave and skywave. Either or both methods may account for successful communications. In some instances, however, a skywave skip is impossible because of the MUF or the time of day.

Groundwave propagation is very dependent upon the type of path over which the signal travels. For convenience, the paths are classified poor, good, and seawater paths, based upon the relative conductivity of the intervening earth. Figure 4 shows typical groundwave field-intensity curves for radiation over "good-earth" paths. There are several generalizations that may be made concerning groundwave transmissions. They are usually limited to electrical line of sight. It therefore stands to reason that an increase in groundwave range may be realized by an increase in the antenna height. In some cases, however, an increase in power is required as well. The sensitivity of the receiver may well be another consideration.

Groundwave propagation is subject to a phenomenon called *shadow loss* caused by the inability of electromagnetic waves to bend around mountains or buildings. In groundwave work it is important to consider the natural and/or man-made obstacles that may introduce shadow loss over any given path.

Aside from the two principal means of propagation (groundwave and skywave), there are a few unusual methods, such as the ones described below:

In the northern latitudes, the aurora have unusual effects on the propagation of radio waves. At the lower frequencies (those below 30 megacycles), the aurora attenuate the signals severely, and this attenuation must be added to that for normal skywave reflection. In the peak auroral-attenuation regions, the auroral-attenuation factor may be as much as 5 orders of magnitude greater than the normal propagational-loss factor K.

The auroras that cause signal drop-out below 30 megacycles are often suitable means of propagation above 30 megacycles. The signals propagated, however, are usually unreadable unless continuous-wave transmission is used, because there is a tendency towards rapid fading and "flutter." Best results are usually obtained by aiming the beam at the auroral display, regardless of the location being received.

As meteors pass through the upper atmosphere, they leave a trail of highly ionized air behind them, which can propagate VHF signals. This technique is virtually useless except perhaps during a meteor shower. Straight CW must be used, because these signals "whistle" and "warble" quite badly.

A technique used more and more by com-

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[2] Circular Number 462; Ionospheric Radio Propagation; $1.25; Superintendent of Documents, U.S. Government Printing Office, Washington (25), D. C.

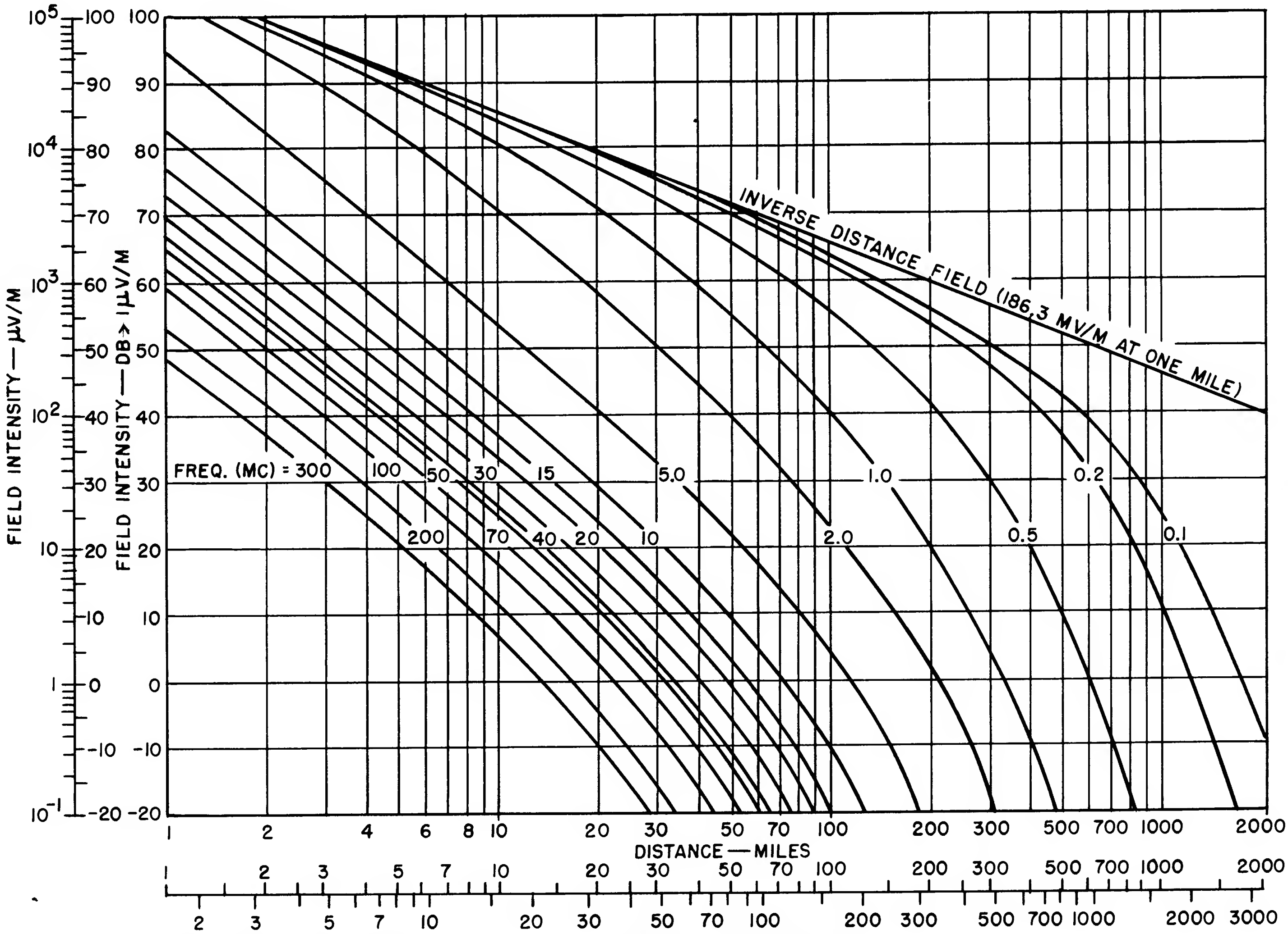
mercial radio links is *troposcatter.* A tendency for radio waves to scatter in the atmosphere is noticeable in the VHF region, but it is most effective and most widely used in the UHF bands. The mechanism of troposcatter allows communications beyond line of sight, with stable signals. The implementation of troposcatter links is complex, however, and requires the use of high-power transmitters and of high-gain antennas.

Tropospheric propagation in the VHF region is principally by means of *tropospheric bending.* At the boundary of air masses of different temperatures and humidities, the refractive index is different from that of either mass. It is therefore possible to communicate along a path (far exceeding line of sight) which falls along this refractive boundary. Signals are sometimes "tunneled" along such boundaries for hundreds of miles.

Recommendations

More effective communications by the ham operator is made possible by the use of the predicted propagation conditions as a guide for scheduling. The author cannot recommend too highly the propagation information offered by the National Bureau of Standards.[1,2] The predictions are based upon experimental data taken at several of the National Bureau of Standards' laboratory sites, and upon the knowledge of the effects of certain cyclic phenomena (sunspots, for example). This information is published three months in advance, and it enables the operator to predict the times, bands, and paths open to him. Or, he may ascertain what time or band would be best to arrange a scheduled contact with another ham. After all, propagation is the basis of all radio communications, both commercial and amateur.

Figure 4: Typical groundwave field-intensity curves for 1 kilowatt of RF power radiated from a short vertical antenna at ground level. (A "good-earth" intervening path is assumed.)



Source: National Bureau of Standards

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8122	Forced-air	400	2000	50 470	375 300
8462 (Quick-heating)	Conduction	100*	700	50 175 470	110 105 85

*May be higher, depending on heat-sink design

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