the VHF/UHF primer: an introduction to propagation

To *really* work DX, try a new mode

One of the most interesting aspects of the world above 10 meters is radio wave propagation. Sure, we've all heard about F2, tropo, meteor scatter, ducting, EME, and perhaps auroral propagation. But are these the prime or only ways of working DX on VHF/UHF? No way!

In preparing my monthly column for *ham radio*, I've noticed that I'll occasionally identify a propagation mode without providing any explanation about how that mode works. Sometimes it's difficult to readily identify a particular mode of propagation on the VHF/UHF frequencies because not all modes are well understood. And different propagation modes are frequently combined, making identification difficult at best.

Over the years, the many articles written about VHF/UHF propagation have only rarely covered more than a few modes at a time. Lesser known modes have been hidden away and almost forgotten. In this article, I'll identify and explain the most common modes of radio propagation, discuss some newly discovered, less common ones, and try to provide some insight into how you can exploit them and perhaps discover some new modes yourself. Wherever possible, references will be listed for those interested in pursuing the individual subjects further.

Before we proceed, remember that communications on any frequency is limited not only by the propagation mode and path length, but by several other factors such as transmitter power, receiver sensitivity, and antenna gain, among others. A full discussion of the latter parameters would fill an entire article, if not a book; hence, I'll limit this discussion to a basic introduction and a review of most of the identified VHF/UHF propagation modes, as well as the operating techniques that make use of these modes. I'll begin with the propagation modes on the lowest VHF frequencies and move on upward through SHF, adding some of my own observations and suggestions about how to use each mode to its best advantage.

line-of-sight

Line-of-sight, surely the most common form of VHF/UHF propagation, is easily understood.[1,2] At one time it was thought to be the *only* reason to use VHF/UHF; even now, the idea of QRM-free local communications is appealing.

Light and radio signals usually travel in relatively straight lines. If the antenna height is known, a simple formula can be used to determine the distance to the horizon:

$$D\ (miles) = \sqrt{1.5H} \qquad (1)$$

where H is in feet,

$$D'\ (km) = \sqrt{12.75H'} \qquad (2)$$

where H' is in meters.

Because of changes in air pressure, temperature, and humidity along the path, the refractive index of the atmosphere may change and bend or refract signals over a greater distance than the normal line-of-sight. Generally speaking, this refractive index averages 1.33, meaning that we can normally communicate over a distance 33 percent further than the normal line-of-sight. To account for this we can modify **eqs. 1** and **2** as follows:

$$D\ (miles) = \sqrt{2H} \qquad (3)$$

or

$$D'\ (km) = \sqrt{17H'} \qquad (4)$$

For example, station "A" has a 50-foot (15.24 meter) tower. It has a horizon of approximately 8.66 miles (13.94 km) and a radio horizon of 10 miles (16.09 km).

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table 1. Claimed 2-meter (and up) terrestrial DX records.

frequency band	record holder	date	mode	DX miles	DX km
144-148 MHz	I4EAT-ZS3B	30 March 1979	Trans. Eq.	4840	7788
220-225 MHz	KP4EOR-LU7DJZ	9 March 1983	Trans. Eq.	3670	5906
420-450 MHz	KD6R-KH6IAA	28 July 1980	Tropo. duct.	2550	4103
1240-1300 MHz	VK5MC-VK7KZ/P	23 Jan. 1980	Tropo. duct.	1422	2290
2300-2450 MHz	VK5QR-VK6WG/P	27 Jan. 1978	Tropo. duct.	1190	1883
3300-3500 MHz	G3LQR-SM6HYG	11 July 1983	Tropo.	576	927
5650-5925 MHz	G3ZEZ-SM6HYG	12 July 1983	Tropo.	610	981
10-10.5 GHz	IØSNY/EA9-IØYLI/IT9	18 July 1983	Tropo. duct.	1034	1663
24-24.5 GHz	DJ2UH/P-DJ4YJ/P	21 Feb. 1982	Tropo.	152	244
48 GHz and up:	none reported				

Note: EME hasn't been included since it would distort the records significantly. EME DX of over 11,000 miles (17,699 km) has been accomplished on 2 meters, 70 cm and 23 cm. 220 MHz is only limited by the lack of frequency allocations worldwide. 13 cm is the highest band where Amateur EME QSOs have been claimed.

Station "B" has a 100-foot (30.48 meter) tower. It has a horizon of approximately 12.25 miles (19.71 km) and a radio horizon of 14.14 miles (22.76 km). If stations "A" and "B" are on opposite ends of a straight line between the same point on the horizon, the distances can be added to find the maximum path length. In this example the line-of-sight distance would be 20.91 miles (33.65 km) and the radio horizon would be 24.14 miles (38.85 km). If two stations are attempting to communicate, any obstructions or trees at the common point on their respective horizons may attenuate signals!

path loss attenuation

Space does not permit me to discuss path loss attenuation at length; see reference 2 for a detailed summary of this phenomenon. In brief, it may be useful to know that typical line-of-sight attenuations for a 10-mile (16 km) unobstructed radio path are 90.5 dB at 50 MHz, 109.3 dB at 432 MHz, 123.8 dB at 2304 MHz and 136.6 dB at 10 GHz. Due to the inverse square law, attenuation increases or decreases by 6 dB every time you either double or half the path length or frequency, respectively. Hence, if you try to double the path length (providing you have line-of-sight), the path loss will be 6 dB greater.

F2 propagation

The supreme propagation mode for DX and the workhorse of the HF bands is F2 propagation. Once it was thought that ultraviolet radiation from the sun would never be sufficient to ionize the ionosphere sufficiently to support communications on 50 MHz via the F2 layer (approximately 150 to 250 miles or 250 to 400 km above the earth), but the experts were proven wrong when W1HDQ contacted G6DH crossband (6 to 10 meters) via this mode on November 26, 1946. Only hours later a transcontinental 6-meter two-way QSO using the same mode between W4GJO in Florida and W6QG in California occurred. Six-meter F2 was not too common during solar cycle 18, and the sun "cooled down" by November, 1947.

The International Geophysical Year (1957-1958) helped numerous stations obtain 6-meter permits where operation was normally forbidden. In October 1957 W4UMF worked SM5CHH, signaling what may have been the start of the greatest F2 openings ever recorded on 6 meters. Later that year K6GDI submitted the QSLs to qualify for the first WAC above 10 meters, showing the worldwide participation. In 1957, solar cycle 19 hit a tremendous peak, the highest recorded in history, when on December 24 to 25, the sunspot count reached 355 and worldwide propagation, even via the long path, became commonplace on 6 meters. But by early 1960, this cycle was on the decline, and unfortunately, solar cycle 20 displayed a more normal solar activity peak level with some 6-meter F2 contacts reported between November, 1967, and February, 1970. Most were single-hop contacts. It began to look as if we'd never see F2 on 6 meters again in our lifetime.

However, in the fall of 1978, during cycle 21, solar activity increased dramatically and F2 propagation began anew on 6 meters. The mean sunspot count in December, 1979, was 164.5, the highest for cycle 21. Unfortunately, many countries no longer permitted Amateur operation on 6 meters because of TV and other frequency allocations. As a result, many VHFers outside the United States had to be satisfied with SWLing or 6 to 10 meter crossband QSOs. 1980 saw a big F2 dip in the United States, but surprisingly, propagation returned for a strong second session in November, 1981, slowly diminishing in late 1982. (As I wrote this column, in March of 1984, F2 returned, with some USA areas working VK's and ZL's. No guess on how long it will last, but enjoy!)

F2 propagation requires a very high sunspot count, typically greater than 125, which is roughly equivalent to a 2800 MHz solar flux of 175 (as broadcast at 18 minutes after each hour on radio station WWV). Generally speaking, in the continental United States, openings start first at the southern latitudes, slowly working up to the northern latitudes over a period of days to weeks as the ionosphere gets "pumped up." Hence the solar activity has to be sustained for at least several days in a row. In the continental USA, openings usually occur between late October and March, favoring southern latitude stations.

At the first appearance of F2, single hop distances are right at the MUF and very long (typically 2500 miles or 4000 km), getting shorter as the ionization builds for several days. As the ionization increases, the MUF slowly rises, permitting operation above 52 MHz. Six-meter communications with low power (10 watts or less) become possible even with dipole antennas. If conditions remain favorable, multiple hops become possible.

The best propagation between two points usually occurs when the sun is about halfway between the stations and almost always requires that the entire path be in sunlight. At times the path can be rather selective, especially on multiple hops; this means that stations as few as 10 miles (16 km) apart may not be able to hear the same distant station. F2 can also link up with sporadic E (more on this later) and extend the path. When solar disturbances occur, the north-south paths show little or no change and often become enhanced soon after the storm subsides. However, the east-west paths drop off quickly and are usually good only during undisturbed solar periods.

Although several crossband 50-70 MHz QSOs were reported during cycle 21 between VE1ASJ and the United Kingdom, the 70 MHz signals were almost certainly not propagated by F2 but rather by sporadic E, since sporadic E propagation was in evidence on 6 meters during these openings.

Much of the success during cycle 21 can be attributed to improved gear, propagation beacons, monitoring of commercial paging and television stations (such as the BBC on 48.25 MHz), and the various liaison nets, especially those on 28.885 MHz (this frequency is still used whenever 10 meters is open). Most of the 6 to 10 meter crossband operation takes place near this frequency. Solar bulletins on radio station WWV at 18 minutes after each hour are also helpful because they report solar flux, an indication of sunspot count, and disturbance warnings via the "A" and "K" indices. Much more information on F2 can be found in "The World Above 50 MHz" column in *QST* during the appropriate years. It's doubtful that any widespread F2 propagation will occur on 6 meters again until about the year 2000, but it sure was great while it lasted!

backscatter

This mode of propagation, a form of radar, often preceeds sporadic E and F2 openings. It is most prevalent on 10, 15, and 20 meters and sometimes occurs even on 40 meters. Its presence indicates that the MUF is very high. In backscatter operation, what happens is that an area of the ionosphere is so highly charged that signals traversing the E or F2 layer path strike the earth at some distant point and are scattered. If two stations running reasonable power and antenna gain aim at this common scattering point, communication is made possible by reflection. Because signals arrive from several different directions at the same time (multipath), they are usually weak and distorted. A good time to look for 6-meter backscatter is when propagation is good on 10 meters; even then, it may be difficult to spot unless there is lots of activity. This mode is primarily limited to 6 through 40 meters and can be used for DX even up to 3000 miles (4825 km).

midlatitude intense sporadic E

This is truly the workhorse mode for DX on 6 meters. Propagation is typically from ionized clouds located in the E layer and usually approximately 60 miles (100 km) above the earth in the midlatitudes (25 to 55 degrees north latitude). There is also equatorial and polar sporadic E, but they are slightly different in nature and of little value for continental USA stations since they are too far south or north to be of any use.

In the continental USA, sporadic E propagation usually peaks near the summer solstice (June 21). Typical limits are from May to early August but can occur any time of year. Typical DX limits are about 300 to 1300 miles (485 to 2100 km) per hop but two and even three hops are not uncommon on 6 meters. A lesser peak occurs approximately within plus or minus one month of the winter solstice (December 21) but this peak is considerably shorter, weaker and usually limited to single hop. It is worthwhile noting that the peaks also occur in the southern hemisphere in reverse order. Although sporadic E propagation can start at any time of the day, it is most prevalent in the late morning, the late afternoon and into the early evening. There is some speculation that sporadic E occurrences are more common and stronger when sunspot activity is low. Hence propagation via this mode may improve in the next few years.

The exact mechanism that triggers sporadic E is still not known. Some people attribute it to weather-related phenomenon, especially wind shear and lightning storms. The late Mel Wilson, W1DEI/W2BOC, devoted much of his Amateur career to the study of sporadic E and wrote several very interesting articles on the subject.[3,4] He pointed out that the clouds that produce the propagation originate at a location he called the "birthplace" and usually travel in relatively straight lines at approximately 180 miles (290 km) per hour from southeast to northwest (**fig. 1**). For best propagation, he said, the cloud should be on or nearly on a line drawn between the two stations at the halfway point. Clouds ±5 degrees off the path can be used and up to ±10 degrees at the extreme. A single cloud will be usable for up to 5 minutes. The size of the cloud has been estimated to be in the order of tens to hundreds of feet (5 to 100 meters) vertically. Multiple clouds are often being formed in the same birthplace so they will pass by as they are generated. The best sporadic E propagation seems to occur when no major high pressure areas are present. (Mel's work will be carried on by his son Steve, W2CAP/1.)

Midlatitude sporadic E is also usable on 2 meters with the first reported contacts made between northern Texas and southern California on July 10, 1951, for a distance of approximately 1300 miles (2090 km). At first, other 2-meter openings were rare, probably due to lack of activity, and weren't recorded again until July, 1956 and June, 1959. Nowadays 2-meter contacts are usually reported yearly and tend to occur between late June and early August, but can occur on the winter peak as described above. Strong lightning activity, especially the type that occurs above 60,000 feet (18,288 meters), is often present near the midpath of big 2-meter openings.[5] Tornadoes and hail storms are often present at the mid-point of the path during 2-meter openings. Typical 2-meter QSOs using sporadic E are shown in **fig. 2** from data given to me by the late Mel Wilson. Although we have had some very long DX (over 1600 miles or 2575 km) 2-meter openings in the United States, I have never heard of a documented double-hop QSO over 2000 miles (3218 km) such as has been recorded in Europe. The greater number of reported 2-meter openings "caught" in recent years is probably due to better monitoring and improved equipment as well as the new common 2-meter calling frequency, 144.2 MHz. The frequency limits for sporadic E are believed to extend above 220 MHz and W1JR and WØVB have both been heard on this frequency by other stations but in each case equipment problems at one end of the path prevented

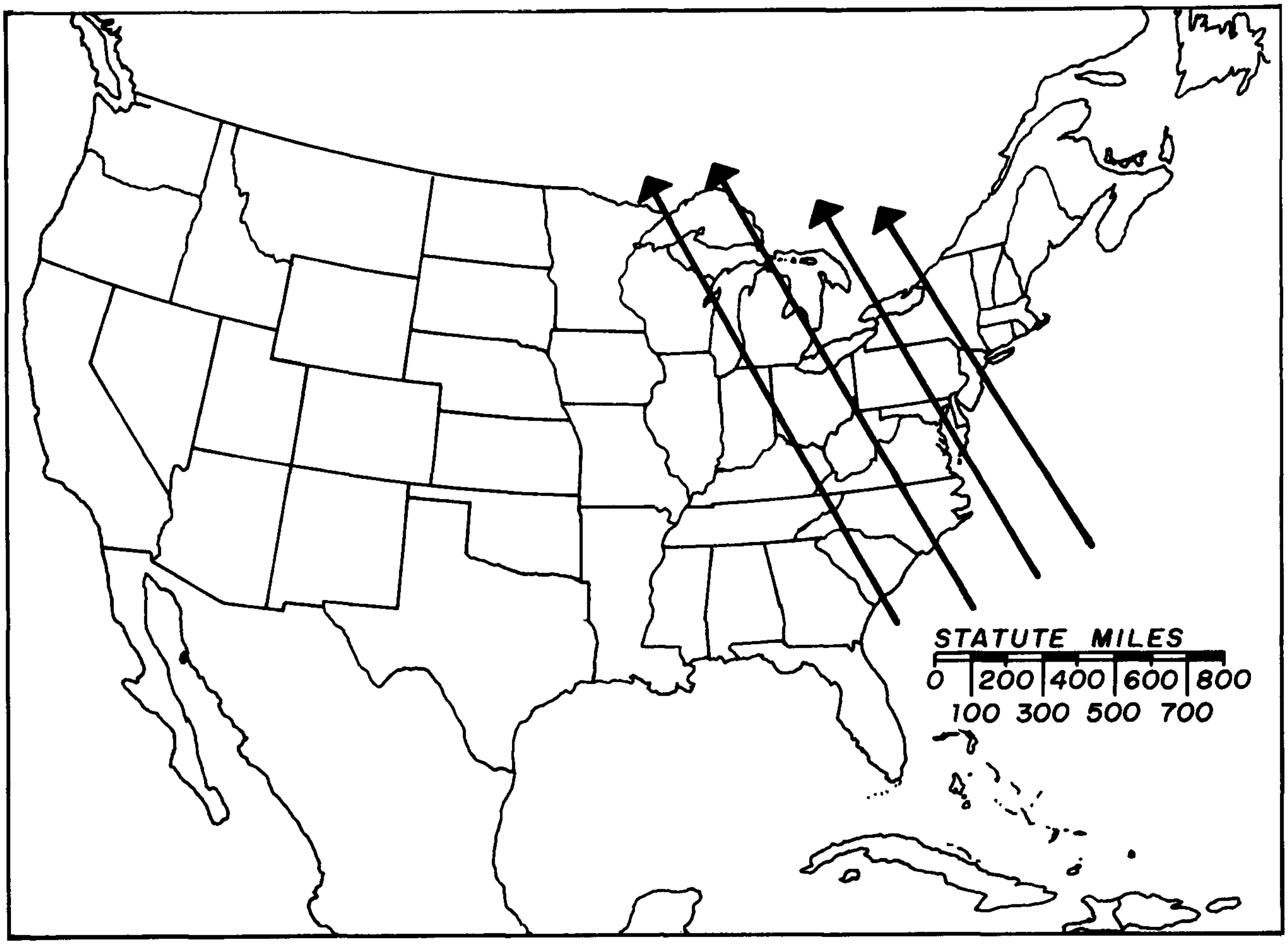

fig. 1. Clouds producing sporadic-E propagation generally travel from southeast to northwest at approximately 180 miles (290 km) per hour, moving in a relatively straight line.

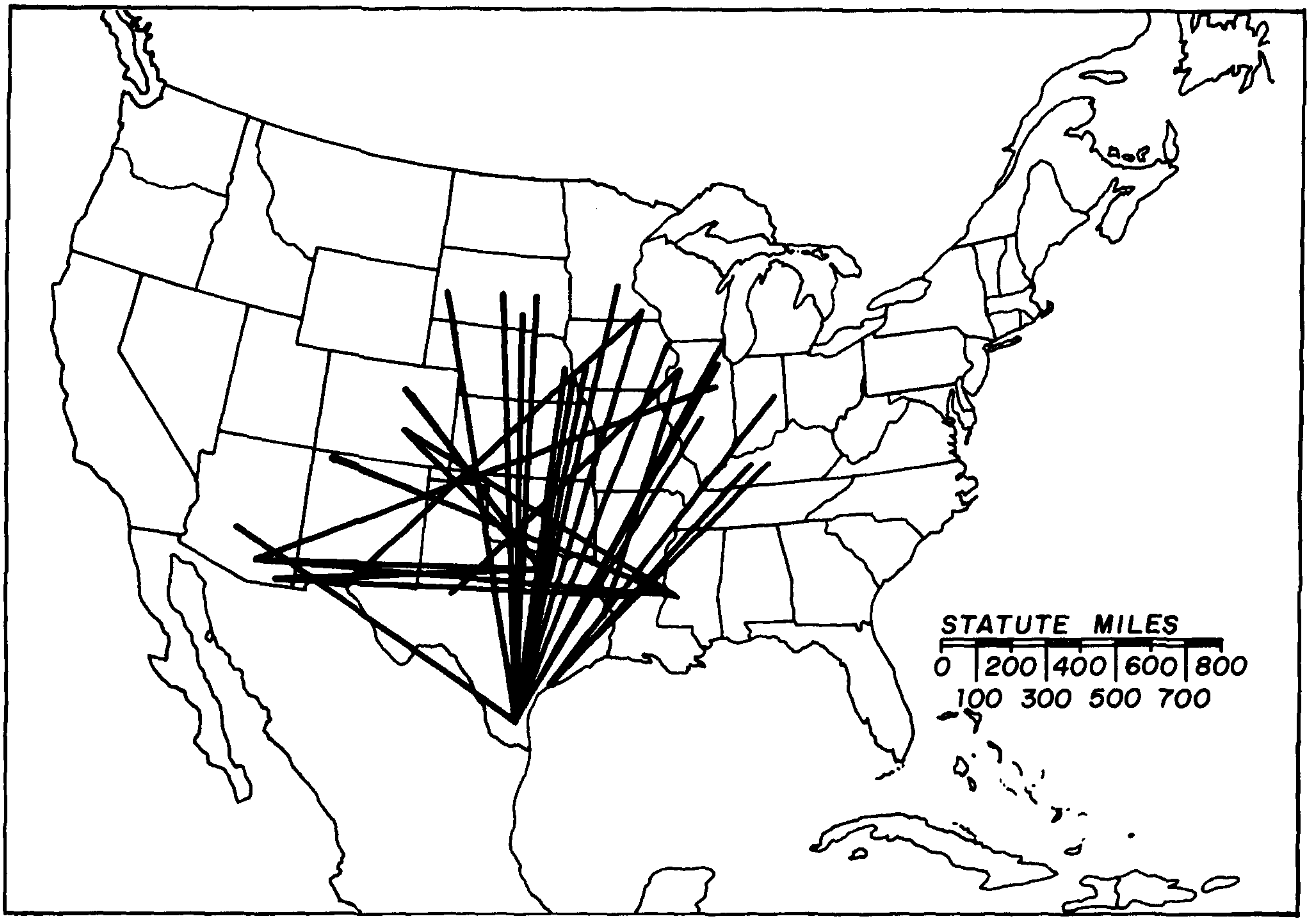

fig. 2. A typical 2-meter sporadic-E opening shows paths between stations in QSO on February 3, 1977, on 144 MHz (0000-0229 UTC).

completed QSOs! (I've noticed, by the way, that all the good east-to-west 2-meter sporadic E openings I've heard from the New England area in the past eight years have occurred within two weeks on either side of July 20th. Any comments?)

The best way to "catch" sporadic E openings is to listen on 10 meters for short skip conditions. When the 10-meter path gets down to 300 to 500 miles (483 to 805 km), the 6-meter band is probably ready to pop or is already open. Similarly, when the path on 6 meters gets very short (perhaps 400 to 500 miles or 645 to 805 km) and intense, try putting out a call on the 2-meter calling frequency. Remember that the reflection from the cloud will usually be different on 2 meters than on 6 meters. The distance will generally be much longer on the higher frequency, so judge accordingly if you're making schedules. Backscatter, especially from a local, is an indication that there are lots of clouds and a big opening is about to begin. You can't have a QSO without making some noise to alert others of an opening. W4WD has noticed that whenever WWV forecasts a "strat-warm," a sporadic E opening usually occurs within the following 12 to 24 hours.

TE (transequatorial) scatter

This was truly an Amateur Radio first when long-distance (5000 miles or 8000 km) propagation was established across the equator on 6 meters in August, 1947. It is significant that tests have verified that the signals first enter a bell-shaped ionized area midway between the station and the geomagnetic equator and then are ducted to the opposite ionized area without intermediate reflection from the earth.[6]

For best results, stations should be located about 1500 to 2500 miles (2400 to 4000 km) north and south of the geomagnetic equator and signals should cross the geomagnetic equator at close to right angles. However, deviations of up to ±20 degrees have been known to occur. It is also significant that propagation may not necessarily be present at the same time at lower frequencies. These contacts usually improve during the equinoctal periods, especially when solar activity is high, as occurs near the peaks of the solar cycles. Openings may start in the late afternoon with clear sounding signals but early evening (at the midpoint on the path) signals often have a flutter with up to a 15 Hz rate. Signals may last until midnight, long

after F2 has disappeared. The frequency usable is typically 1.5 times the MUF maximum that occurred earlier in the same day.

Unfortunately for stations in the continental United States, the geomagnetic equator runs about 15 degrees south of the true equator in this hemisphere. Consequently only stations in very southerly latitudes of the continental United States are optimally located. Stations in South Africa to the Mediterranean as well as Japan to Australia are in more favorable locations for this mode of radio propagation.

equatorial FAI (field aligned irregularities)

There was always the hope that someday there would be propagation as high as 2 meters across the equator. Then on October 29, 1977, it happened, when YV5ZZ/6 in Venezuela made a 2-meter contact with LU1DAU (in Argentina) at a distance of about 3135 miles (5045 km).[7] After this initial success, openings kept occurring and distances kept improving, and by February, 1979, contacts were established between Puerto Rico and Southern Argentina, Australia and Japan as well as between Rhodesia and Greece.

Often the signals had an auroral sound (more on this later). Stations with elevation control noticed that signals were optimized at 5 to 8 degrees elevation. And while 70 cm (432 MHz) signals could be heard no QSOs were made on that frequency. Finally, in 1983, a successful 220 MHz QSO was completed between KP4OER and LU7DJZ (see **table 1**). Some Amateurs speculated on the existence of a new propagation mode,[7] possibly one using a scatter mechanism and FAI from ionized bubbles. Others suggested ducts. At this time no one agrees except to say that more time and study is required.

We now know that propagation between stations equally spaced north and south of the geomagnetic equator can occur up to 70 cm. The best times and seasons for these contacts seem to be those most frequently observed for TE, as explained above. There is much more to be done in this important area — another Amateur Radio *first*.

ionospheric scatter

This mode of propagation,[9] a form of forward scatter, is believed to be due to scattering in the lower D region (30 to 55 miles or 50 to 90 km) of the ionosphere. Typical distances are 800 to 1300 miles (1300 to 2100 km). Signals are usually continuous, but weak and wavery with a broad peak around midday at the midpath and during the summer months. Signal attenuations are approximately 90 dB greater than free-space loss at 6 meters and 115 dB at 2 meters. Hence this mode of propagation is definitely within the capability of two well equipped stations with 2-meter EME capability and deserves more attention.

aurora

Aurora, caused by magnetic disturbances on the sun,[10] is called *aurora borealis* (or "northern lights") in the northern hemisphere and *aurora australis* in the southern hemisphere. Aurora borealis are most common around the equinoxes in March and September and usually begin in the late afternoon or early evening, though they can occur at any time of the year and are sometimes active in the early afternoon as well as all through the night and even into morning! The number of auroral occurrences tends to peak at the beginning and at the end of a solar cycle peak (e.g. 1978-79 and 1982-83) and decrease significantly when sunspot activity is low. They usually occur 24 to 48 hours after a major solar flare. A WWV "A" index of 30 or greater or a "K" index of 4 or more is a good warning of impending aurora. Weak or "watery" sounding HF signals are an excellent indicator of aurora presence although their presence does not guarantee that the openings will extend to VHF/UHF.

Typical auroral propagation occurs in a region between 47 to 84 miles (75 to 135 km) above the earth. If you were to look down on the earth from directly over the magnetic pole, an aurora would appear to be shaped like a halo or doughnut. (See satellite photograph shown in reference 11.) From a vantage point on the earth, auroras appear to be thin sheets or columns of light that are not quite vertical but tipped at the local dip angle of the magnetic field. Those in the far north are usually green, while those that extend further south may be red. The further south the aurora extends, the greater the DX possibilities; they are, after all, a superb reflector of radio waves.

The auroral reflection occurs when the angle of incidence equals the angle of reflection, but incidence and reflection paths need not lie in the same plane. Propagation via auroral reflection has been verified up to about 3000 MHz, but no known Amateur contacts have been reported above 70 cm (432 MHz). The best reported DX is about 1336 miles (2150 km). High power (several hundred watts or greater) is beneficial, but even 10-watt stations have had confirmed 70 cm QSOs. Occasionally the aurora extends far enough south so that even stations in Florida, Texas, New Mexico, and Arizona can establish auroral contacts.

For communications via auroral propagation, both stations should aim their antennas at the same "hot" spot. The cross-section of reflection decreases with increasing frequency. The angle of perpendicularity with respect to the earth's magnetic field also decreases with frequency. Typical accuracies required are ±12 degrees at 220 MHz, ±9.5 degrees at 432 MHz and ±6 degrees at 780 MHz.[12] Since typical antenna installations have beamwidths that usually decrease in both the horizontal and vertical planes with increasing frequency, the path becomes more difficult and would definitely be improved above 220 MHz if both stations could also change antenna elevation. This is particularly true when trying to contact a station that is either several degrees of latitude north or south of you. Hence, higher power is definitely preferable to increased antenna gain.

Auroral signals usually sound like a "buzz" or white noise because of the Doppler spreading caused by the rapidly changing ionization. CW is preferred, but SSB is usable, though hard to understand and lacking high pitched sounds, if you are operating on the lower VHF bands and the aurora is strong. I've noticed that if a CW signal is narrow (1 to 2 kHz) on 2 meters, there is usually sufficient ionization to permit 220 MHz and maybe even 70 cm contacts. I've also noticed that the MUF usually peaks shortly after the onset of the aurora, perhaps in 15 to 30 minutes, and then slowly decreases as time passes. *Hence it is advisable to take advantage of the higher VHF/UHF bands as soon as the aurora gets going rather than discover later that the MUF has dropped.*

"Watery" or wavery sounding signals on HF (10 to 160 meters) are an excellent indication that aurora is present and can be a tip-off to look for VHF/UHF auroral propagation. Auroras can be easily detected using a TV video carrier monitor on channel 12 (205.25 MHz) or 13 (211.25 MHz), similar to the one I described in last month's column.[13] Just point your beam north and listen for the "buzz" on the carriers. This is also a good system for finding where the aurora is peaking and whether the MUF is high. I've noticed that the "hot" spot may be in a slightly different place at 220 MHz than on 6 or 2 meters (perhaps due to antenna patterns or other variables). This is invaluable information when trying to find 220 MHz and 70 cm signals.

Another observation I've made is that the Doppler shift may vary when you swing your beam back and forth while listening to an auroral signal. I've measured up to ± 1 kHz shift on 2 meters on locals and considerably more on 220 MHz and 70 cm. Consequently it's advisable to tune $\pm$ several kHz when listening for answers to a CQ. If you're using a modern transceiver, tune with your RIT so you don't transmit back on a new frequency! Lately I've noticed this happening more often — but doing so can be disasterous on aurora, since you may land on top of another signal and be completely unreadable in the QRM, causing confusion to the operator you've answered, who is no doubt wondering where you went! Likewise, be careful where you zero-beat your own signal if you want an answer.

Finally, look for activity on or near the VHF/UHF calling frequencies. During auroras, this is usually 50.100, 144.100, 220.100 and 432.100 MHz on CW and with 50.110 and 144.2 on SSB. By all means, call CQ. When you hear a reply, try to peak your beam quickly in order to optimize the path, since each station will come in at a slightly different direction depending on latitude and longitude.

artificial auroras

Attempts have been made to generate artificial auroras by using rockets to inject barium clouds into the ionosphere; in recent years, scientists in both the United States and the Soviet Union have created yet another form of artificial radio aurora.[14] This propagation mode is similar to the natural auroras described except in that it is generated by radiating very high amounts (typically 40 Megawatts of ERP) of HF (typically 3 to 10 MHz) CW power vertically into the ionosphere. The scattering center is directly above the transmitter. The principal tests have been conducted in Platteville, Colorado, with a 1-Megawatt transmitter and a large antenna array, and at Arecibo, Puerto Rico, with 100 kilowatts, using the 1000 foot (305 meter) spherical dish. Operations have been successful as high as 430 MHz, and the signals are usually narrower than those generated by natural aurora.

auroral "E_s"

This is a much sought after mode of propagation on 6 meters. According to WAØIQN,[15] ionospheric sounders have verified that sporadic E may be present just below an aurora, but the reasons for this are not known. When particle precipitation becomes strong enough, sufficient electrons collect at the bottom of the field line and form a "puddle" which can spread horizontally. It may then appear like sporadic E after the effects of the aurora wear off and thus yield DX in the northern regions of the United States and Canada. This may explain why some 6 meter auroras sound almost like sporadic E propagation. Auroral E_s usually occur within a few hours after an aurora fades out.

meteor scatter

Meteor scatter is one of the prime modes for DXing on VHF/UHF. Every day 50 to 100 million particles randomly enter the earth's atmosphere, where they burn up in the E region (50 to 150 km high) and leave ionized trails capable of reflecting radio signals. Due to the orbital characteristics of the earth, these random particles tend to increase slowly after midnight, reaching a broad peak at 6 AM and slowly decrease as the morning wears on, reaching a minimum at about 6 PM local time. The best months for random meteors in the continental United States are between June and August, with a minimum occurrence in February.

Even more important to the VHF/UHF DXer are meteor showers. They can occur at any hour of the day, and while they may be short in duration (any-where from a few hours to a day or two long), they do occur on predictable dates. The better known showers are the Perseids (approximately August 11) and the Geminids (approximately December 11). DX, typically 500 to 1400 miles (805 to 2250 km) is accomplished by reflecting signals off these meteor trails.[16]

Most meteor scatter operation is on 6 and 2 meters, but 220 MHz and occasionally 70 cm (although there have been only about a half dozen reported contacts on this frequency to date) can be used in the higher speed showers. A recent article[13] described how to optimize the use of this mode; readers who wish to know more should refer to that article.

FAI

The authors of reference 7 speculated that FAI similar in nature to that which produces the great TE FAI may be present in the midlatitude regions, and that signals in this mode would probably have an auroral quality. At the same time this article was published, K4GFG was conducting a nightly over-water tropo schedule in an attempt to QSO KP4EOR, who was also involved in the TE FAI experiment. What transpired was a QSO, not by tropo propagation, but by FAI with weak and "watery" signals peaking about 10 to 20 degrees north of the great circle path.[17]

During the following summer (1979), signals appeared over the United States and FAI-type QSOs were made from Florida to Texas and Alabama again, with auroral-type signals peaking north of the great circle path. Occurrences seem to be in the late evening, following sporadic E openings. Typical path loss is in the area of 218 to 230 dB at 2 meters and 248 dB at 220 MHz, meaning that fairly large setups (kW and modest gain antennas) are required to take advantage of this mode. Reference 17 provides charts for pointing antennas and speculates that this mode may be possible as high as 70 cm, although no known QSOs have taken place above 2 meters as of this writing. It is a fascinating possibility for VHFers and a nice way to work real DX when the band would otherwise be quiet!

EME

Earth-Moon-Earth, or "moonbounce" is one of my favorite subjects because it's *the* ultimate DX for the Radio Amateur. When you bounce your signal off the moon and listen for the returning signal, the path is up to 500,000 miles (804,500 km) in length and it takes the signal over 2.5 seconds to traverse the distance! Hence EME allows you to monitor your own signal after it is sent — and if you hear your own echoes, you know that your signal got where it was supposed to go, not like the dead-band syndrome on HF. You also know your equipment is operating successfully; by listening to the strength of the echo you can also tell how well it's working and whether your most recent improvement actually works.

While EME is not for the faint-hearted, it can be achieved by the typical VHF/UHFer. The first EME stations were highly experimental and results were marginal at best. However, with the advances in the state-of-the-art (such as good low-noise transistors and GaAs FETs, high performance Yagis and parabolic dishes as well as efficient amplifiers), EME really took off in the late 1960s. Nowadays, when conditions are good on 2 meters, you have the capability of hearing your own echoes; WAS as well as WAC are possible with 500 watts of output power and four 3.2 wavelength NBS-type Yagis. Even a single-Yagi station with a good low-noise antenna-mounted preamplifier can hear the larger EME 2-meter and 70 cm stations off the moon when conditions are good. Over 50 DXCC countries are now or have been active on EME in the last few years and EME expeditions are no longer uncommon.

Typical path losses for EME range from 251 dB on 2 meters to 276 dB on 13 cm (2300 MHz), the highest frequency band on which Amateur contacts have been claimed.[18] A few EME QSOs have been made on 6 meters, but the antenna systems were *very* large, and noise was a limiting factor. EME is now commonplace on 2 meters, 220 MHz, 70 cm, and 23 cm, where contacts are made almost daily and even SSB QSOs are not uncommon. Typical EME operating and calling frequencies are listed in **table 2**.

table 2. Typical EME operating and calling frequencies.

band	frequencies used	calling frequencies
2 meters	144.000-144.110	144.003-144.010
220 MHz	220.0-220.080	220.020
70 cm	432.000-432.070	432.010
23 cm	1296.000-1296.060	1296.010
13 cm	2304-2304.1 and 2320-2320.2	2304.050 and 2320.150*

*Most Europeans can no longer operate below 2320 MHz in the 13 cm band. The USA Amateurs may soon lose the frequencies between 2310-2390 MHz. Therefore, cross band operation may be required.

13 cm is now being tried, and DFØEME has reported several QSOs using a 9-meter dish. The interesting thing about 23 and 13 cm is that the power levels and antenna systems are small in comparison to 2 meters and 220 MHz. For example, some stations on 23 cm have been making QSOs rather routinely with dishes as small as 8 to 13 feet (2.5 to 4 meters) in diameter and with power as low as 100 watts at the feed. They're making good use of the new low-noise GaAs FET preamplifiers mounted right at the feed and of the

very low sky noise above 400 MHz. All things being equal, path loss and antenna gain increase directly with frequency. However, since the antenna gain is added twice (once on receive, and once on transmit), the overall signal-to-noise ratio increases with increasing frequency. Another advantage of EME is that you don't have to wait for a band opening!

The EIMAC EME notes[19] are a great help for the newcomer to EME. Reference 20 describes the requirements for 70 cm EME as well as helpful hints to improve your station and equipment both on EME and terrestrial. (A later column will describe 220 MHz requirements. See you off the moon!)

tropospheric scatter

This mode of propagation uses the reflections off dust particles, clouds and the refractive index variations that occur in the troposphere (1000-50,000 ft. or 305-15,250 meters above sea level) to provide reliable VHF/UHF propagation up to 1000 miles (1609 km) between well equipped stations. [21,22] For several years starting in 1953 Chisolm et al[22] conducted interesting tropo scatter tests over 98-830 mile (158-1335 Km) paths from Massachusetts to North Carolina. They proved that with adequate equipment, 70 cm signals could always get through with path loss varying from 190 dB at 98 miles (158 km) to 258 dB at 618 miles (994 km) and 300 dB at 830 miles 1335 km).

Both stations should aim their antennas at each other on the great circle path and their signals will scatter from the common volume of the atmosphere somewhere near the mid point in the path. For best long haul DX, a low angle of radiation is essential making it desirable to have your antenna fairly high (10 wavelengths minimum but greater than 20 wavelengths is unnecessary), in the clear, and a good low-angle horizon. Antenna gain is not fully realized since the power is not from a point source but from a volume in the atmosphere.

Typical path attenuations for the long DX (greater than 300 miles or 483 Km) are such that an EME type setup is desirable. However, many EME stations are now using their EME arrays with mast mounted preamplifiers so DX is no longer a problem on the VHF/UHF frequencies. Recent work in the U.K. on 3 cm (10 GHz) shows that troposcatter is a very reliable mode.[21] They predict that a 440 Km range is possible using 1 watt and 4 foot (1.22 meter) dishes by each station. This propagation mode deserves more attention especially on 70 cm and above!

tropospheric bending

Tropospheric communication utilizes weather-related changes in the atmosphere to propagate VHF/UHF signals over much greater than line-of-sight distances. Under normal weather conditions, the temperature of the atmosphere decreases in a more or less linear fashion with increasing altitude. However, if the temperature should abruptly increase with increasing altitude, the conditions are right for long haul DX. This usually happens between 3000 and 6000 feet (915 to 1930 meters) above local terrain and causes the refractive index to significantly increase beyond 1.33 as started earlier in the line-of-sight discussion. If you are at an elevated QTH, you could get above the temperature inversion and be unable to propagate through this layer!

Best tips are to look for increased cloudiness following a period of fair and calm weather. Best periods occur after a long (two or more days) high steady barometer (greater than 30.3 inches or 1025 millibars) starts to drop due to the approach of a slow moving low pressure area from a few hundred miles away, especially when moist air masses are approaching such as from the Gulf of Mexico. Signals are usually strongest in the late evening and especially in the early morning around sunrise. For advanced warning watch weather maps especially on TV. Remember that weather maps in the newspapers may be 24-48 hours old and hence may be after the fact! The late Ross Hull wrote several interesting articles on this subject.[23]

I have also noticed that the really good overland tropospheric bending generally occurs in the winter months in the states bordering or near the Gulf of Mexico and between mid-August and late November in the central, northern and northeastern continental USA. Openings are also prevalent when there are large inversion layers with uncomfortably high humidity. The eastern USA should look for enhanced north to south DX when a weather condition called a "Bermuda High" is present. The best DX, especially east to west, seems to occur when a hurricane is bearing down on the area. Fortunately or unfortunately, the hurricanes that used to come roaring across the eastern half of the USA have been few in numbers since the early 1970s.

tropo ducting

This form of propagation is quite similar to the tropospheric bending just discussed but is more prevalent on the over water paths. In contrast to the normal tropospheric bending caused by an abrupt temperature change with increasing altitude, this form of propagation usually has two abrupt changes, one very low (maybe only a few meters above the surface) and the other one above it by perhaps 1000 feet (300 meters) or so. The net result is that a sort of waveguide is formed, the thickness of which determines the best frequencies of radio propagation. If you are in the duct, signals will propagate almost unattenuated until the duct deforms. If you are outside, take up another pastime!

Those who have studied ducting of radio signals tell me that at the onset of the duct, the optimum frequency is often quite high, typically 1500 MHz, and may slowly decrease as the duct stabilizes often going up again as the duct starts to disappear. During the great tropospheric ducting conditions between Hawaii and California in July, 1973, the openings were first heard on 70 cm and then slowly shifted to 2 meters. Two days later even 6-meter signals (viz. KH6IJ) were making the grade. It is noteworthy that this duct took place while two tropical (hurricane type) storms were traversing the path between Baja, California, and Hawaii just to the south of the path.

There are other pecularities about tropo ducting. If you are above or below the duct (as in tropospheric bending), you will not be able to couple sufficiently into the duct to take advantage of it. Seldom does an over-water duct extend very far inland. Instead, the duct may abruptly become elevated as it passes over land. Hence, if you are over 10 to 40 miles (16 to 64 km) inland, the only effective way to use the duct will be if you are elevated or have a reflection assist (more on this later).

Let me elaborate on the later point. Researchers in the United States Navy and others have studied the California to Hawaii ducting with aircraft and often found that the duct was elevated 1 to 2 miles (1.6 to 3.2 km) as it approached Hawaii. The Amateurs active in Hawaii frequently drove up and down the side on Mauna Loa to optimize this path. After several years of observing this path, they installed the 24-hour-a-day warning beacons well up the side of Mauna Loa to take advantage of this phenomenon. Unfortunately, if an opening takes place (as seen by monitoring the beacon from California), there has to be an able body to drive up to the sight as soon as possible to catch the opening, and this hasn't always been possible!

The farthest inland ducting I know of is the KD6R to KH6IAA QSO. Ironically, both stations were elevated. KD6R was about 38 miles (61 km) inland, but at an elevation of almost 6000 feet (1828 meters) on the side of Mount Palomar. Likewise, the Bermuda-to-USA path where coastal stations can often access the duct but inland stations can't except K2RIW who is about 10 miles (16 km) inland but elevated on one of the highest spots (400 feet or 121 meters) on Long Island. K1PXE, at sea level in Connecticut, has never heard Bermuda, perhaps because the signals have to first traverse Long Island and are thereby elevated beyond reasonable altitudes.

The best ducts observed and used for long DX are the "Great Australian Bight" off southern Australia, the Gulf of Mexico, the Mediterranean Sea, the North Sea, Bermuda to the United States, the Atlantic Ocean between the United Kingdom and the Canary Islands, and of course the California-to-Hawaii path. In fact, rumor has it that a 5 GHz microwave signal from the Philippines was intercepted in Southern California in the mid 1970s but that the news was suppressed because no one would believe the story! There is still much to be learned about tropospheric ducting and perhaps someday the United States-to-Europe path will finally be conquered using this mode.

super refraction

With a few exceptions, this mode is really an extension of tropospheric ducting. These ducts are usually very intense, over warm water, close to the surface and probably not as thick as the usual tropospheric ducts. Hence they are primarily good at 23 cm and above. The British were the first ones I know to really exploit this mode. In their somewhat casual manner (as we see it!) they would go to the beach for a Sunday outing with a pair of "GunnPlexers" or similar 3 cm gear. During the day they would occasionally go down to the beach and try to communicate with a station on another beach over an all-water path. By trial and error they would often find an optimum height and time for a QSO.

Another interesting story I've heard also comes from the UK. The English Channel is an ideal spot to try UHF between England and the European continent. As the story goes, an English station was in 3 cm communications across the channel with a French station, when communications abruptly ceased and then returned just as quickly a few moments later. Upon observation of the path with binoculars, it was discovered that a larger ship had apparently passed between the stations and momentarily broken up the duct!

Not to be outdone, the Italians and Yugoslavians used the Adriatic and Mediterranean Seas. They had many successes, the greatest DX being the 3 cm QSO between IØSNY/EA9 and IØYLI/IT9 (see **table 1**). This was an incredible DX record of 1034 miles (1663 km), using only 50 milliwatts of power and 1 meter dishes.[24] Once again, there is much to be learned about super refraction, but what is clear is that UHF/SHF ducts do appear on over-water paths during warm weather, especially during the summer months.

lightning scatter

The first known QSO via this mode took place on 70 cm between WØDRL (KS) and W5RCI (MS) on September 16, 1968, over a 449 mile (722 km) path. They noticed that signals peaked 15 to 18 degrees off the great circle path at an area which turned out to be a storm cell over Texas. Enhancements were up to 40 dB, some with durations of 25 seconds, with extremely rapid QSB and lots of Doppler shift. Since then, other observers have noticed the same phenomenon. This is a mode worth looking into, especially when severe lightning storms are in progress. I have observed this same type of propagation on 70 cm on somewhat shorter paths between New Jersey and Massachusetts when severe lightning was over the central Connecticut area. Since most VHFers tend to shut off their rigs during stormy weather, it may be well to rethink our operating habits — but only if the storm *isn't* nearby!

aircraft scatter

Few VHF/UHFers give this mode a thought or even are aware of its capabilities. While in California, I discovered (undoubtedly as others did), that aircraft make fine reflectors for radio signals, especially on 70 cm and above. Since commercial aircraft often fly as high as 40,000 feet (12,192 meters), they can be used for propagation via line-of-sight out to 500 miles (805 km) reflections on a regular basis. The best paths are over the central USA, since many aircraft are available and usually fly at high altitudes. Coastal QTHs are not as favored because these aircraft usually fly low or are in takeoff or landing patterns. But don't rule them out; the California coast and the eastern seaboard of the United States have lots of traffic though these areas aren't quite as good for the long DX via aircraft scatter.

All you have to do to work via aircraft scatter is to be alert, know when the flights are in between and set up a schedule! Don't use long transmissions: at the longer DX, the mutual location for best scatter may last only a minute or less! Beware also of the Doppler shift which can be as much as 100-300 Hz on 70 cm and up to 1.5 kHz on 2304. When I QSO'd Harley, WA6HXW, on 2304 MHz from W6FZJ, a path of 310 miles (500 km), I copied Harley on two different frequencies separated by almost 1.5 kHz, one via tropo and the other via aircraft. At times the aircraft-reflected signal was up to 5 degrees off the great circle path!

table 3. Typical selected aircraft reflection sizes and figures of merit (original source of data is unknown but was sent to me via K9MHR and WB0YSG). Intermediate sized aircraft can be easily estimated.

type of aircraft	reflecting area (square meters)	relative reflection (dB)
Cessna 336 Skymaster	1.3	1
Lear Jet	2.0	3
McDonald Douglas DC 9	8-10	9-10
Douglas DC 3	12.6	11
Boeing 707	16.0	12
McDonald Douglas DC 8	20.0	13
Boeing 747	63.0	18

Some relative data on aircraft sizes and figures of merit are listed in **table 3**. This data, which may be of use to those who want to make radar path loss calculations, show why larger aircraft are preferred. I have also noticed that aircraft scatter can often assist with another mode for a sort of link-up. For instance, on both the Bermuda to USA and the California to Hawaii paths, my 70 cm signals have been coupled into the duct and copied, probably via aircraft scatter at my end, but I was unable to complete the QSO due to insufficient access time before signals disappeared. This is an entertaining mode that deserves more attention since it is available 365 days a year as long as you have a reasonably good station. The possibilities for long DX on 3 cm and above are fascinating.

knife-edge diffraction

This mode of propagation, used for many years for Gigahertz microwave communications by commercial stations, is well documented. It is based on the theory that if a sharp peak or hill lies between two stations, signals can be diffracted over them. Losses of only 10 to 20 dB over the typical free space path loss are possible.[2] The sharper the peak, the better. Lack of foliage or reflecting objects is preferred at the peak; 3 cm signals do not go through tree leaves! Although this is a specialized propagation mode and is primarily for moderate DX, it is nevertheless interesting, especially to the UHFer who is in a low lying area or surrounded by hills or mountains.

rain scatter

This mode of propagation was discovered in 1978 by G3JVL and G3YGF/A when operating on the 3 cm band over a 110 km path during a rain squall.[25] They found that if two stations both aimed their antennas at the storm center, they could communicate at distances greater than 100 km. They were unable to reproduce this mode at lower Amateur frequencies. The signals are highly distorted and have an auroral quality with some noticeable Doppler. Signals tend to peak very broadly in azimuth and elevating the antenna can improve signals if the storm is nearby. 10-20 dB enhancements are typical. Other British Amateurs also participated and verified this phenomenon, even with low power stations. This mode is especially interesting when one or both of the stations have obstructed views or a poor VHF/UHF QTH since the scattering center may be well above the horizon at one or both ends of the path. Hopefully this mode will soon be more fully utilized here in the USA.

conclusion

VHF/UHF radio propagation is a fascinating subject to which every Amateur can contribute. All it takes is time, patience, good notes, and of course some reasonably good equipment. The records listed in **table 1** are good goals to pursue.

To review, VHF/UHF radio propagation is basically divided into four categories:

1. *Natural* (line-of-sight, tropo/ionospheric scatter),
2. *Weather-related* (tropospheric bending, ducting, sporadic E, precipitation scatter),
3. *Celestial* (EME, meteor scatter, F2, aurora), and
4. *Manmade* (satellite, aircraft scatter, artificial aurora).

A basic knowledge of all these types of radio propagation will show that the VHF/UHF bands are hardly a quiet and uninteresting place!

To predict radio propagation conditions we can use several sources of data such as: HF/VHF or satellite nets, propagation beacons, TV video carriers monitoring or the warning sounds on HF signals as well as alerts such as weather maps/reports and WWV forecasts at 18 minutes after each hour.

table 4. These are the typical United States VHF/UHF calling frequencies. It is common courtesy to QSY up or down after establishing contact to allow other stations to use the calling frequency.

band	frequency	mode
6 meters	50.110	SSB
2 meters	144.100	CW
2 meters	144.200	SSB
220 MHz	220.100	CW/SSB
70 cm	432.100	CW/SSB
23 cm	1296.100	CW/SSB
13 cm	2304.100	CW/SSB

Calling frequencies listed in **table 4** are also helpful. Sometimes there just aren't enough signals to go around and congregating on special frequencies can increase the probability of observing good conditions. However, you must put out an occasional call because silence doesn't convey much activity! Above all, when you do establish contact on a calling frequency, move off so that someone else can use it. Activity nights are also helpful. In the northeast, we concentrate 2 meter activity on Monday evenings, 220 MHz on Tuesdays, 70 cm on Wednesdays, and 23 cm on Thursdays.

acknowledgements

I want to thank all those who helped contribute information for this article, and in particular G3WDG, VE1YX, W4WD, WA4MVI, WB5LUA, W6ABN, and K6FV — it takes lots of cooperation to gather so much material. I hope that some of this information will be new or helpful to you and that you too will be able to help in the future.

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VHF/UHF coming events

July 3: EME perigee

July 20 (± 2 weeks): look for 2-meter E openings

July 27: (21:15 UTC) peak of Delta Aquarids Meteor Shower

July 27-29: Central States VHF Society Conference, Cedar Rapids, Iowa. (Contact WØOHU for further information.)

July 31: EME perigee

If you have any VHF/UHF events or contests planned, let me know at least 2 to 3 months in advance so I can let others know through this column. — **W1JR**

ham radio