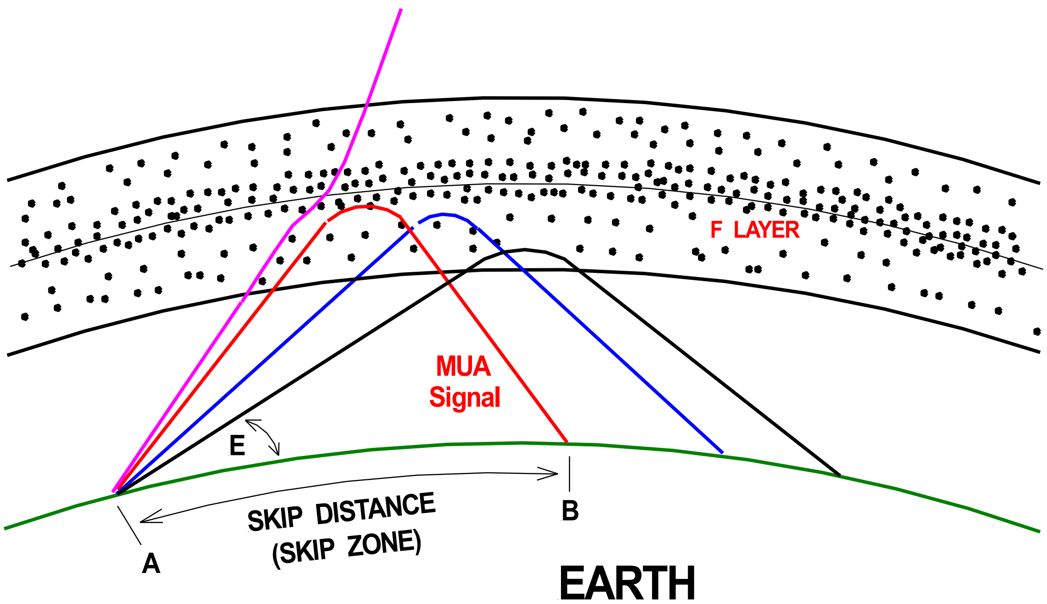
Chapter 17

Skip Distance



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Revised May 2024

17 Skip Distance

In the early days of radio, amateur radio operators, using their home built wireless radio equipment, crowded the commercial frequency bands. This was a serious problem from the perspective of commercial and military radio operators. To solve the problem legislation was enacted restricting the frequencies at which amateurs could operate. From 1912 on amateurs were exiled to the seemingly worthless short-wave frequencies of 200 meters and down, better known today as the 160, 80, 40, 20, and 10 meter frequency bands. While most amateurs operated at 200 meters (around 1.5 MHz), a few ventured down into the shorter wavelength frequency bands of 80 through 10 meters. In 1924 they discovered the long-distance capabilities of “short wave” radio. Amateurs began communicating from the United States to Europe, New Zealand, and the Pacific rim on a regular basis using transmitters operating at relatively low power levels of 1,000 watts or less and small 20 meter antennas. In contrast, military and commercial companies operating in the 300 to 1,000 meter frequency bands required transmitters ranging in power from a hundred thousand to a million watts and huge antennas to cover the same distances.

Amateur radio operators contributed significantly to the understanding of long-distance radio communications. They discovered that short wave radio disobeyed the accepted theories of radio propagation. Short wave propagation, unlike long wave, seemed to involve only the atmosphere. Strange things happened at short wavelength frequencies. For example, it was possible to communicate with distant radio stations while closer radio stations could not be heard. Radio signals seemed to skip over the close by radio station creating what became known as the skip zone.

The skip zone and the associated skip distance are illustrated in Figure 1. In this figure Station-B is the closest station that Station-A can communicate with. Closer in stations cannot hear Station-A, nor can Station-A hear them. These stations are in the skip zone.

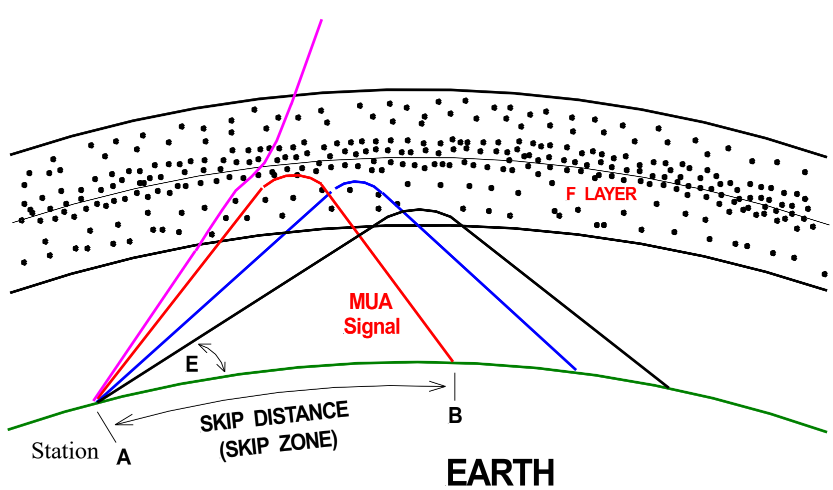


Figure 1 Skip distance and associated skip zone (source: author)

From the perspective of Station A, the skip zone is circular in shape with Station A located at the center, as illustrated in Figure 2. The skip zone extends out horizontally in every direction from Station-A. The radius of the skip zone is defined as the skip distance. Skip distance is generally several hundred miles

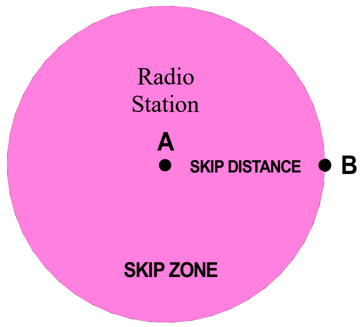


Figure 2 Circular skip zone (source: author)

17.1 What Determines Skip Distance?

Skip distance is a function of

- The ionosphere's Critical Frequency,
- A radio station's Operating Frequency, and
- A signal's Maximum Usable Angle (MUA) relative to Earth's surface

17.1.1 Critical Frequency

Critical Frequency f_c is the highest frequency signal that can be transmitted straight up and reflected back down to Earth as illustrated in Figure 3 by the blue trace. All signals lower in frequency than f_c will also be reflected back to Earth. But, signals higher in frequency transmitted straight up will penetrate the ionosphere and be lost to outer space as illustrated by the brown trace.

Critical Frequency varies:

- Throughout the day as the Earth rotates,
- Seasonally as the Earth's upper atmosphere changes, and
- With the 11 year solar cycle as Extreme Ultra-Violate (EUV) and X-ray radiation from the Sun changes.

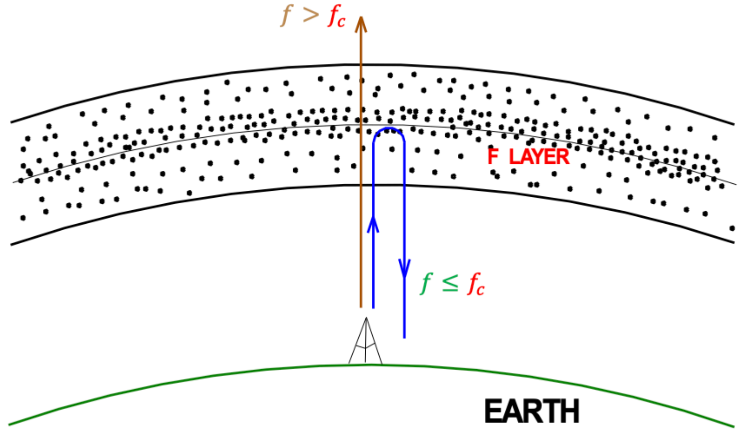


Figure 3 Critical frequency (source: author)

The ionosphere's F2 region critical frequency (f_cF2) is lowest at sunrise after declining throughout the night due to continuous recombination of free electrons with ions. Critical frequency in Figure 4 builds quickly following sunrise with the resumption of solar photo-ionization. Maximum critical frequency occurs around local noon as photo-ionization and electron-ion recombination reach equilibrium. Critical frequency declines in the afternoon and throughout the night as photo-ionization slowly decreases and finally disappears with nightfall.

In the winter the F2 critical frequency is much higher than in the summer. This is known as the winter anomaly. One would expect f_cF2 to be highest during the summer when the Sun is more overhead. However, the ionosphere cools during the winter retarding the rate of electron-ion recombination resulting in critical frequencies being higher in the winter than expected.

Figure 5 shows the variation of critical frequency with the solar cycle. The variation in f_cF2 (blue trace in Figure 5) follows closely the variation in the smoothed sunspot number (ssn – magenta trace in Figure 5). During solar maximum the Sun is very active with large numbers of sunspots and high ssn numbers leading to high F2 critical frequencies. At solar minimum the Sun is relatively quiet with few if any sunspots and low ssn numbers. During solar minimum F2 critical frequencies are at their lowest level as illustrated by Figure 5.

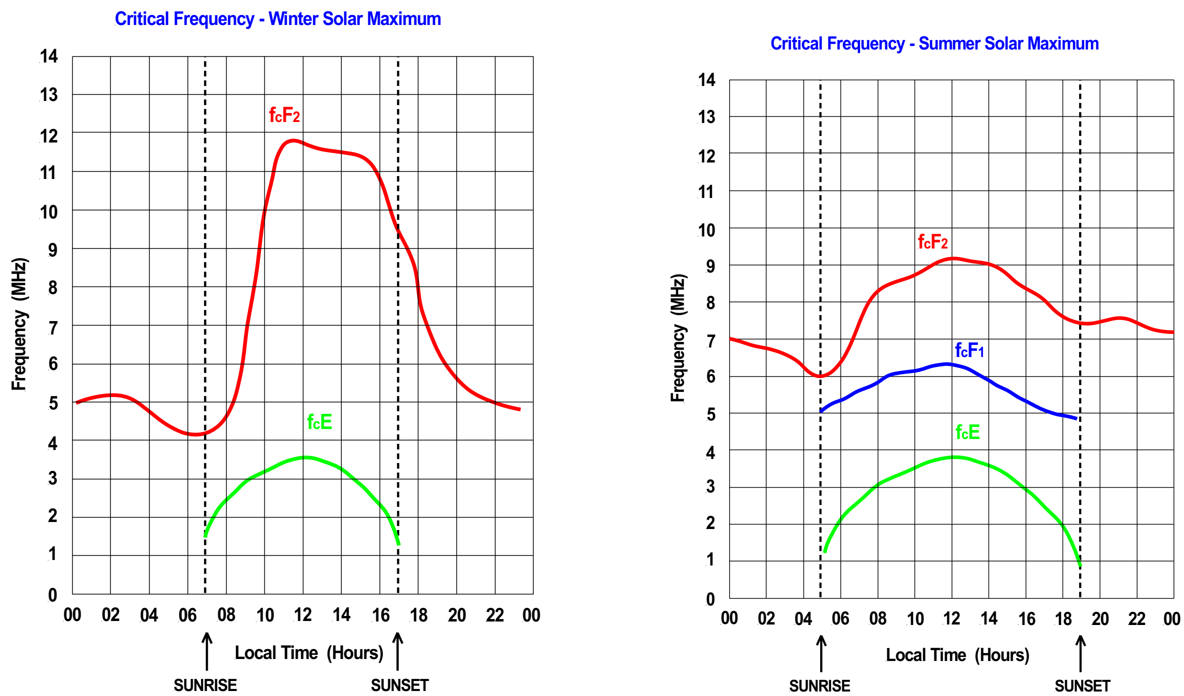


Figure 4 Critical frequency diurnal and seasonal variations (source: author)

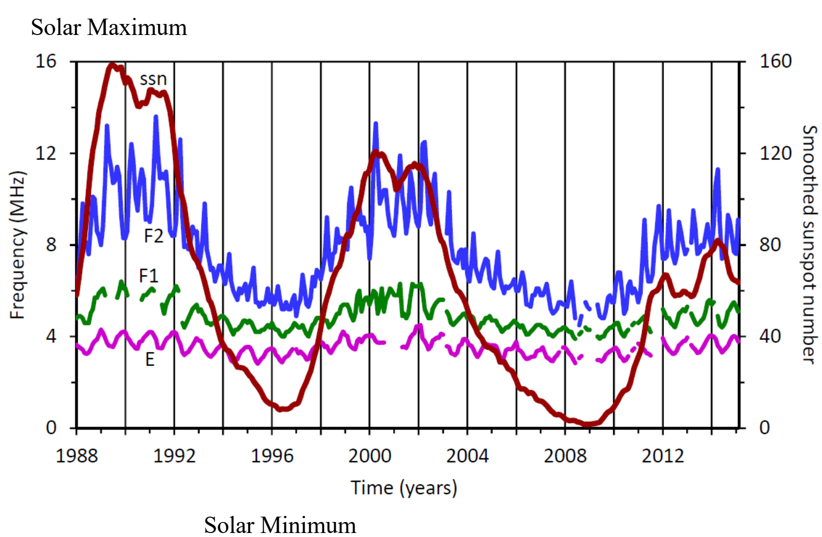


Figure 5 Critical frequency variation with the solar cycle (source: sws.bom.gov.au)

17.1.2 Operating Frequency

As illustrated in Figure 6, a skip zone exists ONLY if the ionosphere's critical frequency f_c is below a station's operating frequency f_o that is if $f_c < f_o$. There will not be a skip zone if the critical frequency is above the operating frequency, i.e. if $f_c > f_o$. In this second case, a station utilizing Near Vertical Incident Skywave (NVIS) propagation can communicate with all stations from the base of its antenna out hundreds of miles. In contrast, NVIS propagation is impossible when there is a skip zone.

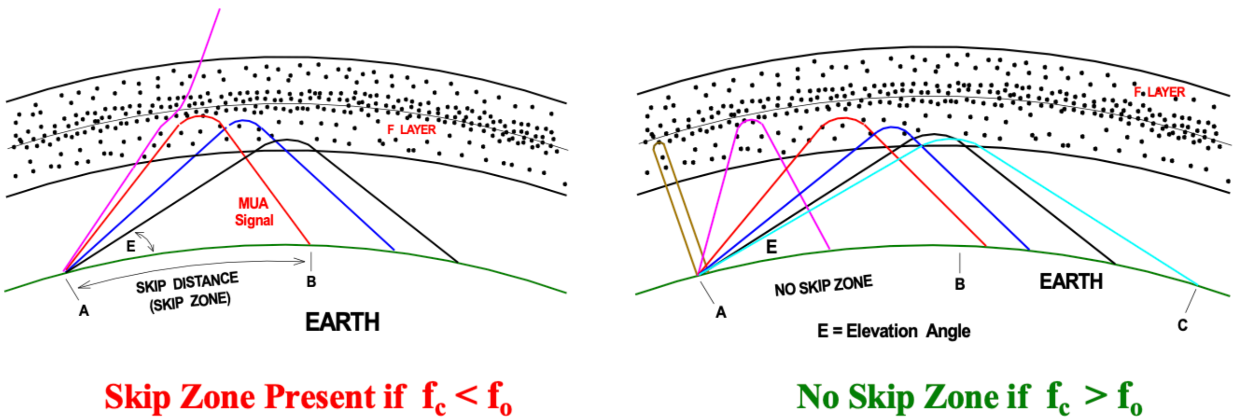


Figure 6 Skip zone presence (source: author)

When a skip zone does exist, i.e. $f_c < f_o$, it becomes larger, producing a longer skip distance, as the critical frequency drops further and further below a station's operating frequency. That is," skip goes long" as the critical frequency drops. This generally happens at night. Figure 7 illustrates the skip going long during the early evening. At 7 PM the skip distance is relatively short. By 9 PM the skip distance has increased significantly. Skip distance is very long around 11 PM. A frequency band becomes dead when the skip has gone so long that no stations can be reached.

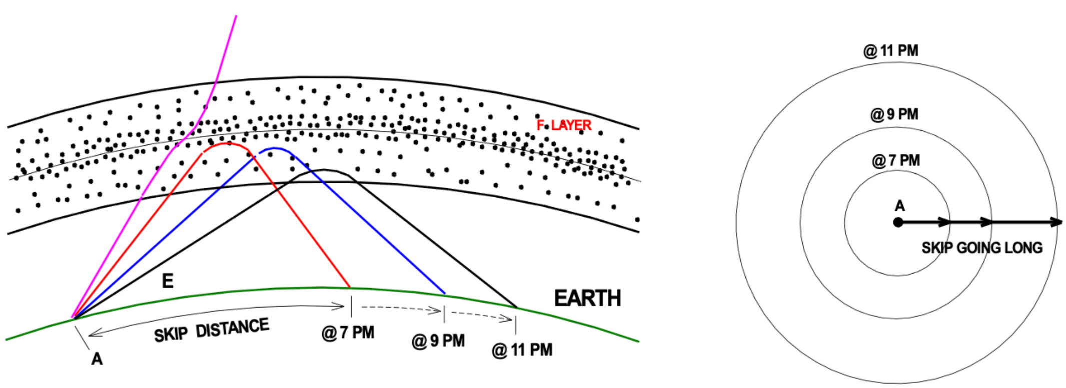


Figure 7 Skip going long (source: author)

Figure 8 documents a series of 40 meter skip distance tests conducted on January 30, 2024. This series of tests illustrate the concept of skip distance and skip going long. A set of 22 Winlink RMS stations were used in the test. RMS stations were selected because they operate 24 hours a day 7 days a week on multiple frequency bands.

At 16:00 local time the critical frequency f_c was10.5 MHz which was above the operation frequency f_o that ranged from 7.0665 to 7.1085 MHz. Consequently, there was not a skip zone and all stations from a distance of 11 out to 845 miles were successfully reached. That is, all stations were "in the green" signifying the short 16 to 28 second contact durations shown in Figure 8A. A short contact duration means that no retransmissions were required. Each transmission in the message exchange sequence was received the first time.

Time	Frequency KHZ	Call	Distance Miles	Contact Duration (min)	Power Watts	Antenna	Tries	Comments
					10	Yellow		fc = 10.5 MHz
16:08	7102.100	W6BI	11	0:18				Simi Valley, CA
16:06	7106.500	KD6LLB	13	0:18				Oxnard, CA
16:10	7101.500	NR6V	20	0:21				Northridge, CA
16:11	7100.500	AJ7C	31	0:18				Culver City,CA
16:13	7100.000	KN6BKT	48	0:18				San Gabrile, CA
16:14	7106.000	N7OP	52	0:21				Lancaster, CA
16:15	7106.500	KT2KT	86	0:16				Bakersfield, CA
16:17	7066.500	XE2BC	160	0:21				Tijuana, Mexico
17:07	7094.500	W6CTT	187	0:19				Clovis, CA
16:22	7084.000	KB6HOH-12	338	0:25				Novato, CA [N of San Francisco]
16:23	7102.000	W7DEM	345	0:19				Minden, NV [S of Carson City]
16:26	7105.000	W6LHR	349	0:17				Lincoln, CA. [NE of Sacramento]
16:29	7108.500	KJ7GSK	386	0:16				Chandler, AZ. [SE of Phoenix]
16:30	7099.700	K7RRR	411	0:31				Gilbert, AZ. [SE of Phoenix]
	7103.000	KF7KLA	577					Klamath Falls, OR
16:32	7095.500	KD6OAT	585	0:31				Sandy, UT
16:39	7102.000	AG7MM	638	0:26				Burley, ID. [E of Twin Falls]
16:52	7102.000	KG7AV	693	1:11				Bend, OR
16:43	7099.700	W7INL	741	0:18				Rigby, ID. [N of Idaho Falls]
16:46	7095.000	K7UNI	769	0:21				La Grande, OR. [SE of Pendleton]
	7104.000	W7OWO	798					Dundee, OR. [SE of Portland]
16:48	7101.000	KD0SFY	845	0:23				Colorado Springs, CO

Figure 8A 40 meter skip distance test at 1600 hours (source: author)

At 19:00 hours the critical frequency had dropped to 5 MHz, below the 7.0665 to 7.1085 MHz operating frequency. This produced the significant 500 mile skip zone shown in Figure 8B. Stations within the skip zone (marked in red) could not be contacted (nc). There were two exceptions. KD6LLB at a distance of 13 miles was contacted but the duration of the contact was long lasting 1 minute and 39 seconds indicating that many retransmissions were required to complete the contact. At a distance of 13 miles it is quite likely that communications with KD6LLB occurred by ground wave propagation instead of skywave propagation through the ionosphere. The contact with KB6HOH is interesting. At a distance of 338 miles, KB6HOH was well within the skip zone, yet a successful connection occurred with KB6HOH lasting 25 seconds. It is possible that the KB6HOH contact was the result of back scatter from a ground reflection point well outside the skip zone. Beyond 500 miles all stations, with the exception of AG7MM, were easily reached with green contact durations ranging from 16 to 28 seconds. The test data indicates that these stations were outside the skip zone.

Time	Frequency KHZ	Call	Distance Miles	Contact Duration (min)	Power Watts	Antenna	Tries	Comments
					10	Yellow		fc = 5 MHz
	7102.100	W6BI	11					Simi Valley, CA
18:51	7106.500	KD6LLB	13	1:39		QRM		Oxnard, CA
	7101.500	NR6V	20					Northridge, CA
	7100.500	AJ7C	31					Culver City,CA
	7100.000	KN6BKT	48					San Gabrile, CA
19:04	7106.000	N7OP	52	nc		QRM	2	Lancaster, CA
	7106.500	KT2KT	86					Bakersfield, CA
18:55	7066.500	XE2BC	160	nc			2	Tijuana, Mexico
19:00	7094.500	W6CTT	187	nc			2	Clovis, CA
18:59	7084.000	KB6HOH-12	338	0:25				Novato, CA [N of San Francisco
	7102.000	W7DEM	345					Minden, NV [S of Carson City
19:29	7105.000	W6LHR	349	nc		QRM	2	Lincoln, CA. [NE of Sacramento
19:19	7108.500	KJ7GSK	386	nc			2	Chandler, AZ. [SE of Phoenix]
	7099.700	K7RRR	411	nc			2	Gilbert, AZ. [SE of Phoenix]
19:22	7103.000	KF7KLA	577	0:16				Klamath Falls, OR
19:06	7095.500	KD6OAT	585	0:18				Sandy, UT
19:38	7102.000	AG7MM	638	nc		QRM	2	Burley, ID. [E of Twin Falls]
19:40	7102.000	KG7AV	693	0:28				Bend, OR
19:07	7099.700	W7INL	741	0:18				Rigby, ID. [N of Idaho Falls]
19:09	7095.000	K7UNI	769	0:17				La Grande, OR. [SE of Pendleton]
19:33	7104.000	W7OWO	798	0:22				Dundee, OR. [SE of Portland]
19:35	7101.000	KD0SFY	845	0:19				Colorado Springs, CO

Figure 8B 40 meter skip distance test at 1900 hours (source: author)

At 20:00 hours the critical frequency had dropped to 3.5 MHz. With the exception of W7INL, none of the 22 Winlink RMS stations in Figure 8C could be reached and the contact with W7INL was poor. At roughly 20:00 hours the skip had gone so long the 40 meter band became dead.

Time	Frequency KHZ	Call	Distance Miles	Contact Duration (min)	Power Watts	Antenna	Tries	Comments
					10	Yellow		fc = 3.5 MHz
	7102.100	W6BI	11					Simi Valley, CA
19:49	7106.500	KD6LLB	13	nc			2	Oxnard, CA
	7101.500	NR6V	20					Northridge, CA
	7100.500	AJ7C	31					Culver City,CA
	7100.000	KN6BKT	48					San Gabrile, CA
20:13	7106.000	N7OP	52	nc			2	Lancaster, CA
	7106.500	KT2KT	86					Bakersfield, CA
19:52	7066.500	XE2BC	160	nc			2	Tijuana, Mexico
19:55	7094.500	W6CTT	187	nc			2	Clovis, CA
19:57	7084.000	KB6HOH-12	338	nc			2	Novato, CA [N of San Francisco
20:20	7102.000	W7DEM	345	nc				Minden, NV [S of Carson City
20:21	7105.000	W6LHR	349	nc			2	Lincoln, CA. [NE of Sacramento
20:23	7108.500	KJ7GSK	386	nc			2	Chandler, AZ. [SE of Phoenix]
	7099.700	K7RRR	411					Gilbert, AZ. [SE of Phoenix]
	7103.000	KF7KLA	577					Klamath Falls, OR
19:59	7095.500	KD6OAT	585	nc			2	Sandy, UT
20:15	7102.000	AG7MM	638	nc			2	Burley, ID. [E of Twin Falls]
20:18	7102.000	KG7AV	693	nc			2	Bend, OR
20:01	7099.700	W7INL	741	1:07				Rigby, ID. [N of Idaho Falls]
20:03	7095.000	K7UNI	769	nc			2	La Grande, OR. [SE of Pendleton]
	7104.000	W7OWO	798	nc			2	Dundee, OR. [SE of Portland]
20:05	7097.000	KD0SFY	845	nc			2	Colorado Springs, CO

Figure 8C 40 meter skip distance test at 2000 hours (source: author)

17.1.3 Maximum Usable Angle

Maximum Usable Angle plays an important role in determining skip distance. Elevation angle E is the angle with respect to the Earth's surface at which a signal is transmitted. Maximum Usable Angle (MUA) is the highest angle signal (E_M) that can be transmitted and still be refracted back to Earth, as illustrated by the red trace in Figure 9. Signals transmitted at higher elevation angles (blue trace) penetrate the ionosphere and are lost to outer space.

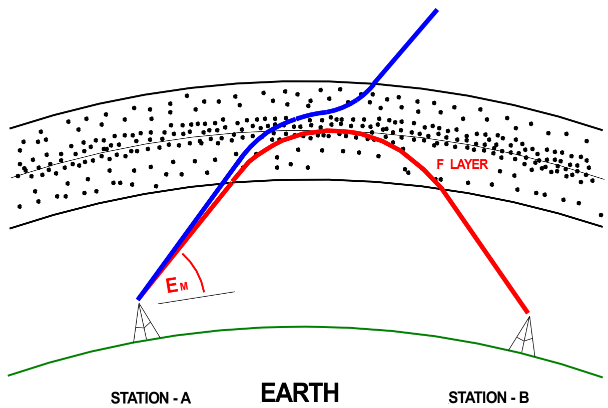


Figure 9 Maximum Usable Angle (source: author)

Maximum Usable Angle is a function of the ionosphere's critical frequency f_c and a station's operating frequency f_o according to the equation:

$$MUA = E_M = \sin^{-1}\left[\frac{f_c}{f_o}\right]$$

The Maximum Usable Angle is 90°, straight up, if a station's operating frequency f_o is equal to or less than the critical frequency, that is if $f_o \leq f_c$.

In that case $f_c / f_o = 1$ and $\sin^{-1}\frac{f_c}{f_o} = \sin^{-1} 1 = 90°$

At all frequencies with $f_o > f_c$ the ratio $f_c / f_o < 1$ and the maximum usable angle is less than 90°, for example if $f_c = 5$ MHz and $f_o = 7.2$ MHz then

$$MUA = \sin^{-1}\left[\frac{5}{7.2}\right] = \sin^{-1} 0.69 = 44°$$

17.1.3.1 Maximum Usable Angle Chart

The Maximum Usable Angle (MUA) for the 80 through 10 meter frequency bands is provided by the chart in Figure 10. 90º, represented by the black bar, is the highest possible angle. To determine the MUA read vertically from the current critical frequency to the frequency band of interest and then horizontally to the corresponding MUA. For example, the 40 meter MUA at a critical frequency of 5 MHz is approximately 44º. A 40 meter signal transmitted at an angle greater 44º will be lost to outer space. The current critical frequency is obtained by clicking on Critical Frequency under the Current Conditions tab of the www.skywave-radio.org web site.

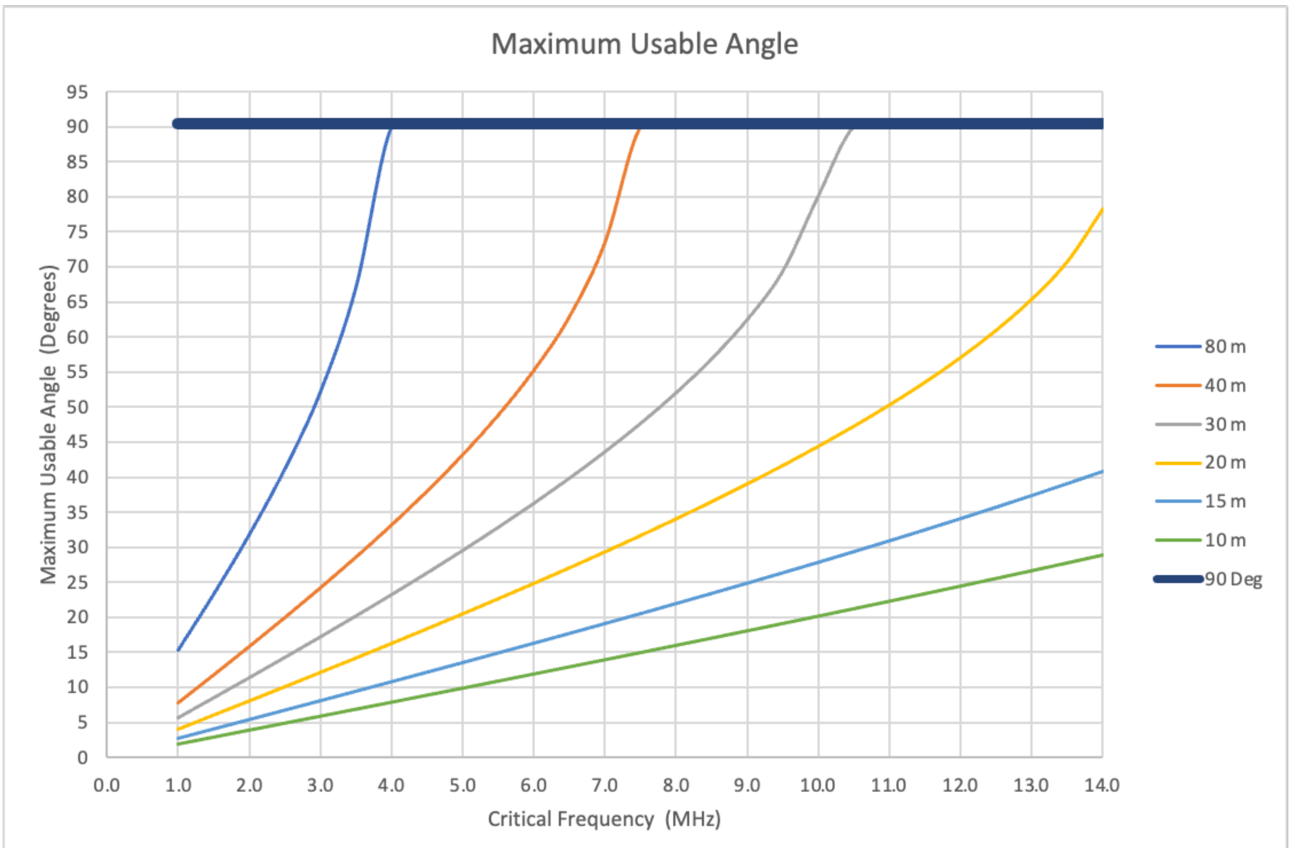


Figure 10 Maximum Usable Angle chart (source: author)

17.1.3.2 Importance of Maximum Usable Angle

Maximum Usable Angle is extremely important in determining skip distances, what stations can be reached and which cannot, the type of antenna to use, etc. The importance of MUA is illustrated by the following antenna example. When operating late at night on 80 meters (f_0 = 3.8 MHz) with a critical frequency of f_c = 3.0 MHz the maximum usable angle is

$$MUA = E_M = \sin^{-1}\left(\frac{f_c}{f_0}\right) = \sin^{-1}\left(\frac{3.0\ MHz}{3.8\ MHz}\right) = 52°$$

Under these conditions, signals transmitted at an elevation greater than 52° will be lost to outer space. This could be a serious problem!

The radiation pattern for a typical 80 meter Inverted-V antenna $\frac{1}{8}\lambda$ above ground is shown in Figure 11.

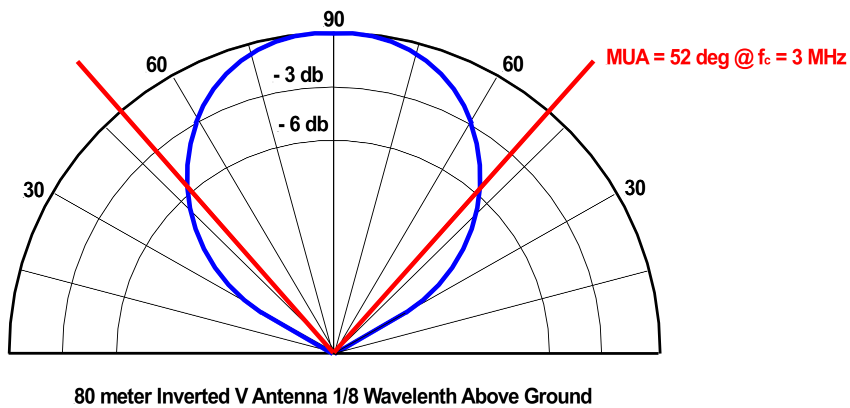


Figure 11 Radiation pattern for an 80 Inverted-V antenna (source: author)

Nearly all of the energy from the antenna is radiated at an angle greater than 60°. This generally is not a problem. The antenna is an excellent Near Vertical Incident Skywave (NVIS) antenna for local and regional communications, particularly for emergency communications work. However, on this particular night there is a problem. The MUA = 52°. This means that virtually all of the energy radiated by the antenna is above the 52° maximum usable angle and is thus lost to outer space. In effect, the antenna stops working at night when the MUA drops below 52°!

An 80 meter vertical antenna is required for operation throughout the night during years of solar minimum when the critical frequency is low. Figure 12 shows the radiation pattern for an 80 meter vertical antenna. This is an excellent night time antenna. Nearly all of the antenna's radiation is at an angle below the 52° MUA. In fact, the antenna works well all the way down to a critical frequency of 1 MHz (MUA = 15°). As illustrated in Figure 13, during solar minimum the critical frequency can easily get down to 2 MHz at night and at times down to even 1 MHz.

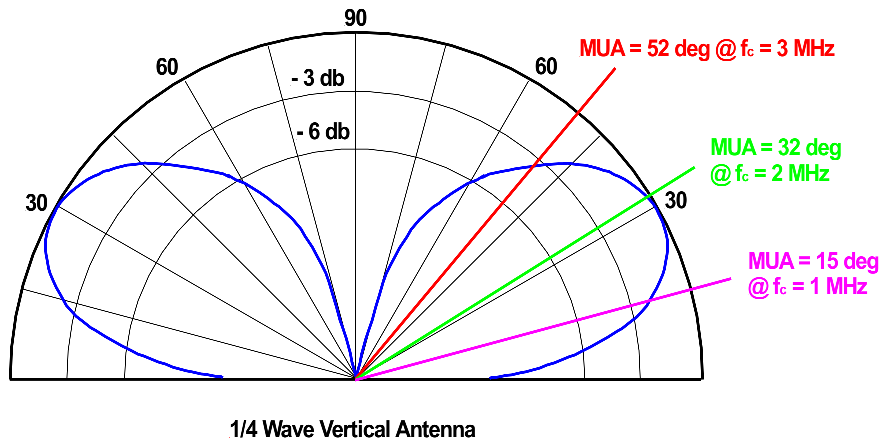


Figure 12 Radiation pattern for an 80 vertical antenna (source: author)

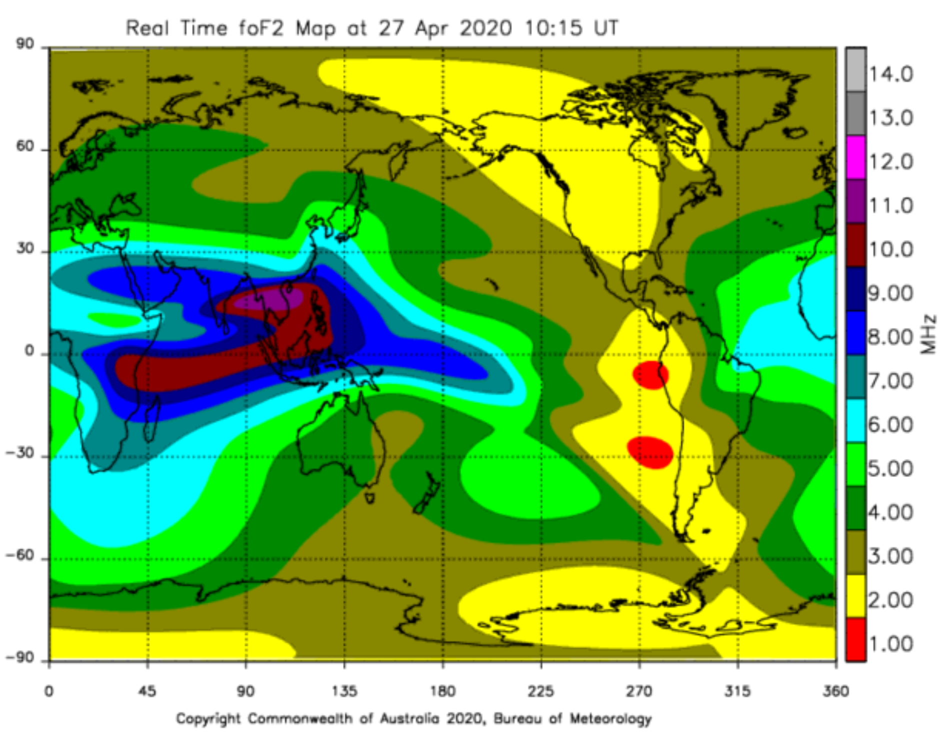


Figure 13 Typical nigh critical frequencies during solar minimum

17.1.3.3 Hop Distance and MUA

The distance that a radio signal travels in one hop through the ionosphere depends on the angle E at which it is transmitted. Increasing angle E shortens the hop distance, for example in Figure 14 from point 1 to point 2 to point 3.

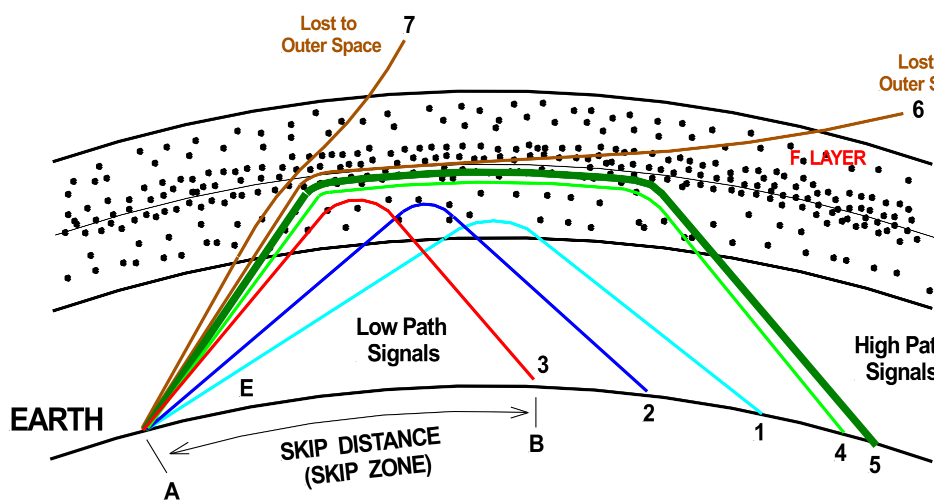


Figure 14 Hop Distance (source: author)

Increasing E a little more causes a strange thing to happen. Instead of the hop distance becoming shorter, it becomes dramatically longer, reaching points 4 and 5 instead. Increasing E slightly more causes the signal to penetrate the densest part of the ionosphere and be lost to outer space as illustrated by ray 6.

Rays 1, 2, and 3 are low path signals. These signals travel through the lower part of the ionosphere and are relatively stable. Rays 4 and 5 are high path signals. These signals travel parallel to the Earth along the densest part of the ionosphere before eventually returning to Earth or being lost to outer space. High path signals are often highly attenuated and very erratic returning to Earth at locations that change rapidly. High path signals are also known as Pedersen Rays.

An elevation angle E slightly greater than E5 (the elevation angle for ray 5) causes a signal to be lost to outer space. Elevation angle E5 is thus the Maximum Usable Angle, MUA. The difference between E5 and E3 (the elevation angle for ray 3) is very small. Consequently, E3 is frequently defined as the MUA, because Ray 3 is special. Ray 3 is the shortest possible ray and the ray at which the high and low paths coincide producing a relatively strong stable signal.

The signals radiated by radio antennas are not laser beams! Amateur radio antennas in particular are relatively crude devices radiating energy over a wide range of elevation angles. The NVIS antenna in Figure 15 radiates energy at all elevation angles from 30 to 90 degrees illuminating a large region of the sky. Consequently, in Figure 14 the various propagation paths 1 through 7 occur simultaneously. This makes possible communications with many different radio stations over a wide variety of propagation paths. But, it can also lead to multi-path interference and signal fading problems that we as amateur radio operators learn to deal with. Figure 16 illustrates some of the propagation paths to a single receiving station. These include both single and multi-hop paths through both the E and F regions of the ionosphere.

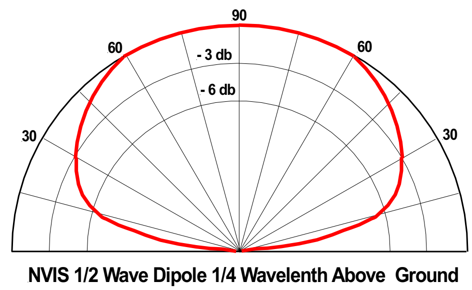


Figure 15 NVIS antenna floods most of the sky with RF energy (source: author)

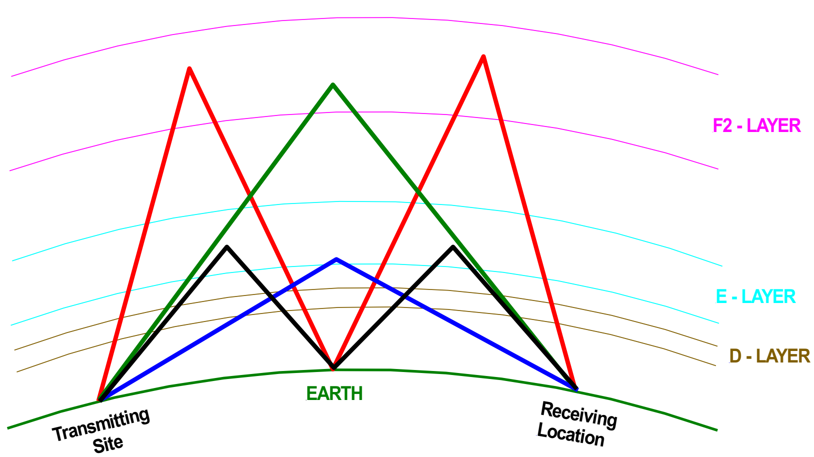


Figure 16 Signals following multiple paths to the receiving station (source: author)

In Figure 17 Ray 3 is the shortest possible path for a signal transmitted from Point A. Increasing E3 slightly increases the hop distance to point 4. Decreasing E3 also increases the hop distance, this time to point 2. No matter what it does, Station A cannot transmit a signal to any location closer than Station B. Thus, the region from Station-A to Station-B is the skip zone. Stations in this zone are skipped over by Station-A transmissions.

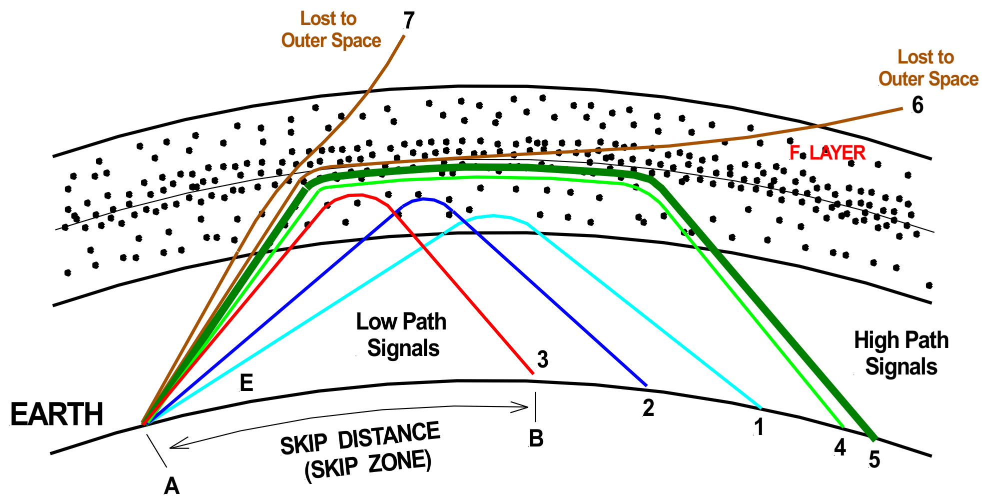


Figure 17 Hop Distance (source: author)

17.2 Skip Zone Problems

Skip zones create problems for regional and local communication nets in addition to limiting the stations that can be reached by NVIS propagation.

17.2.1 Regional Net Skip Zone Problems

A skip zone can cause a regional state wide net serious problems. In Figure 18, Station-B is the closest station capable of hearing transmissions from Net Control Station-A. Stations closer than Station-B cannot hear net control because they are in net control's skip zone. The problem can be solved by creating a second Alternate Net Control Station-C located such that Station-C is outside Station-A's skip zone and vice versa. In this case Stations A and C can communicate with each other. In addition, Station-C can communicate with stations in Station-A's skip zone and vice versa. With this scheme all net traffic can be heard by all stations either directly from net control or indirectly from alternate net control.

There is not a skip zone problem if the ionosphere's critical is above the net frequency. For example, there will not be a problem if the critical frequency is 8 MHz and the net operating frequency is 7.2 MHz. In this case everyone can directly hear Net Control Station-A as illustrated in Figure 19.

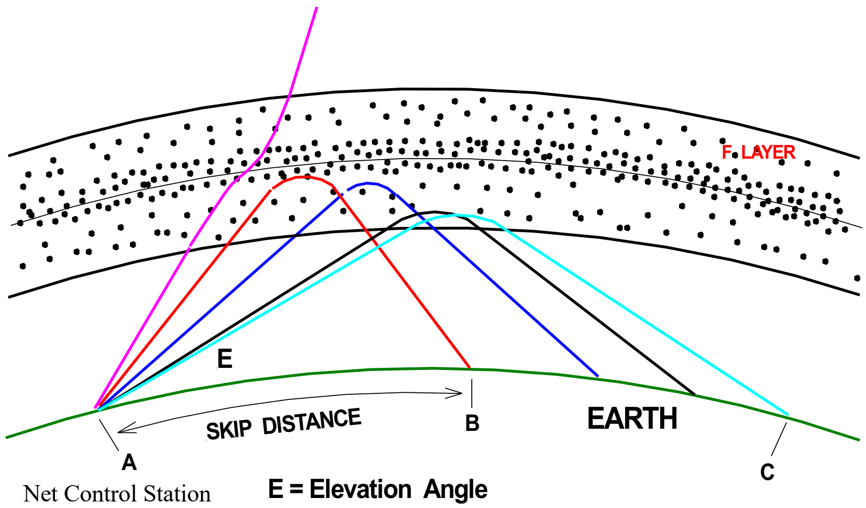


Figure 18 Regional net skip distance problem (source: author)

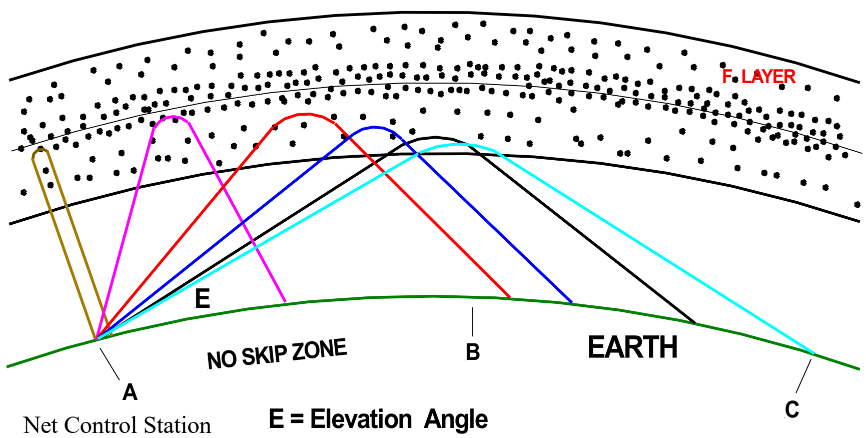


Figure 19 Regional net skip distance problem avoided (source: author)

17.2.2 Local Net Skip Zone Problems

A local county wide HF net will experience problems if a skip zone exists ($f_c < f_{net}$). If present, a skip zone will typically cover the entire county (and much more) meaning that all stations participating in the net will be within the skip zone illustrated in Figure 20. Under these conditions NVIS propagation between the participating net stations will be impossible. The only remaining means of communications between the net stations will be relatively short distance line of sight and ground wave propagation. Stations in one part of the county will likely have difficulty hearing stations in other parts of the county.

The local skip zone problem can be resolved by positioning two or more net control stations strategically within the county so that the net control stations can

- Hear each other via line of sight and ground wave propagation, and

- Each can hear its close by stations.

There is not a skip zone problem if the ionosphere's critical frequency is greater than the net frequency. There will not be a problem, for example, if f_c = 6 MHz and f_{net} = 3.987 MHz. In that case, everyone in the net can hear everyone else utilizing a combination of NVIS, ground wave, and line of sight as illustrated by the picture on the right in Figure 20. In addition, only one net control station will be needed.

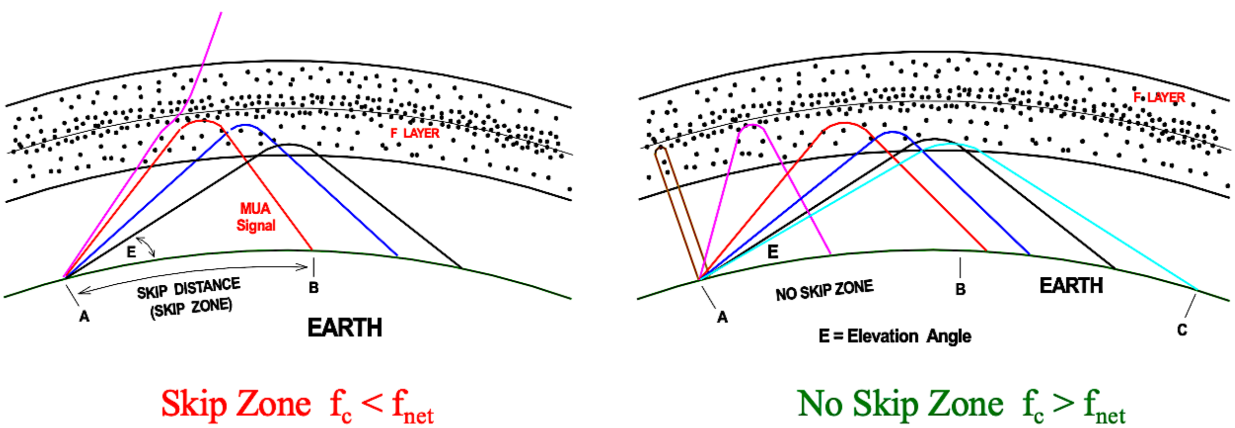


Figure 20 Local net skip distance problems (source: author)

17.2.3 NVIS Problems

If there is not a skip zone, all stations from the base of your antenna outward for many hundreds of miles can be reached via NVIS skywave propagation as illustrated in Figure 21. However, like it or not, line-of-site (LOS) and ground wave (GW) propagation always exist from your antenna out 30 to 40 miles or so. Consequently, multi-path interference problems between NVIS, ground wave, and line-of-site propagation can cause signal degradation and fading problems close-in when NVIS conditions are otherwise excellent.

Multi-path interference problems between NVIS skywave and ground wave propagation are most severe when skywave and ground wave signals are equally strong, as illustrate in Figure 22. The path traveled by an NVIS signal is relatively long, even to a close by station (green trace in Figure

21). The signal must travel from the transmitter into the F region of the ionosphere and reflect back to Earth, a distance of over 300 miles, including two passes through the ionosphere's signal absorbing D layer. In contrast the distance traveled by ground wave propagation to a station 10 miles away is only 10 miles. Over a short distance the ground wave signal is much stronger than the skywave NVIS signal. It is the ground wave signal that a station 10 miles away hears.

Ground wave signals attenuate quickly with distance. At a distance of approximately 20 miles the strength of a ground wave signal has typically dropped to that of the magenta NVIS signal in Figure 21, causing noticeable multi-path interference between the two signals. Beyond 30 to 40 miles the ground wave signal has completely died out leaving only the red NVIS signal which is easily received without interference.

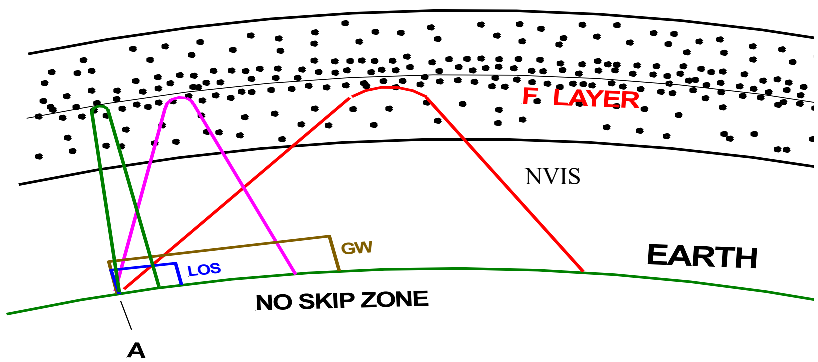


Figure 21 Local NVIS, ground wave, and line of sight propagation (source: author)

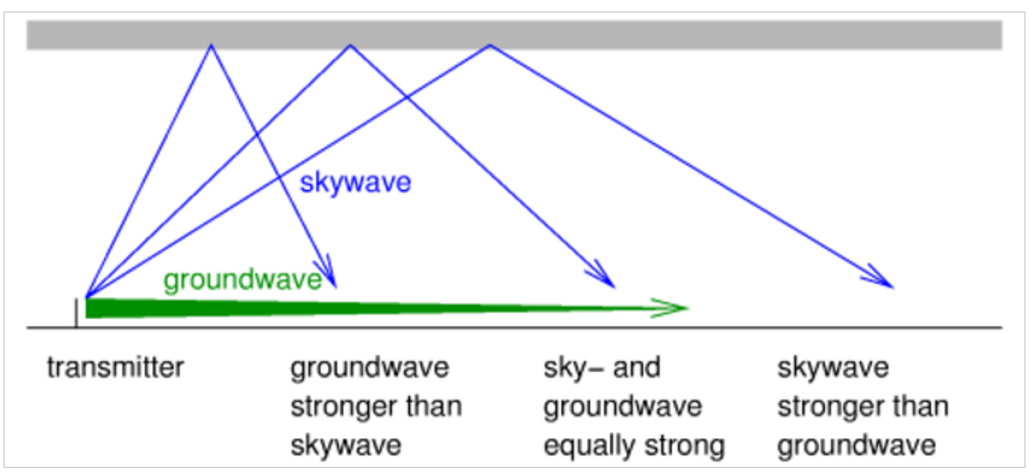


Figure 22 Skywave & ground wave multipath interference (source: *PA3FWM* pa3fwm@amsat.org)

HF line of sight signals suffer the same reflection, diffraction, and scattering problems that VHF and UHF signals encounter illustrated in Figure 23. In addition, in Figure 21 line of sight signals (blue region) encounter interference from both ground wave (brown area) and green skywave signals. Line of sight distances are generally less than 20 miles. Consequently, interference from ground wave propagation is more severe than from NVIS skywave propagation. All three forms of interference result in signal distortion and fading.

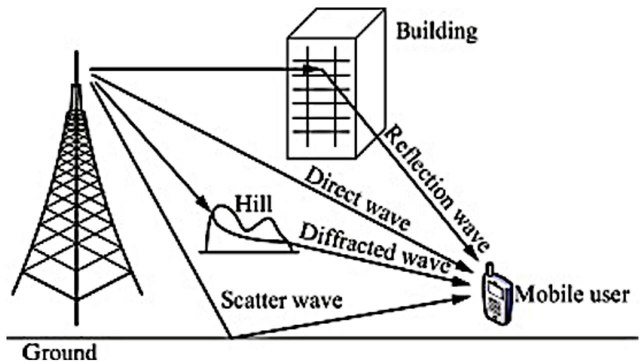


Figure 23 Line of sight propagation problems (source: www.sciencedirect.com)

NVIS communications between stations within the skip zone is impossible. The high elevation angles required for NVIS between two such stations cause the signals to penetrate the ionosphere and be lost to outer space as illustrated in Figure 24. Under these conditions line-of-site and ground wave are the only propagation modes available provided the stations are located close to one another (within about 30 miles or so). This is the problem encountered on local HF nets when a skip zone is present.

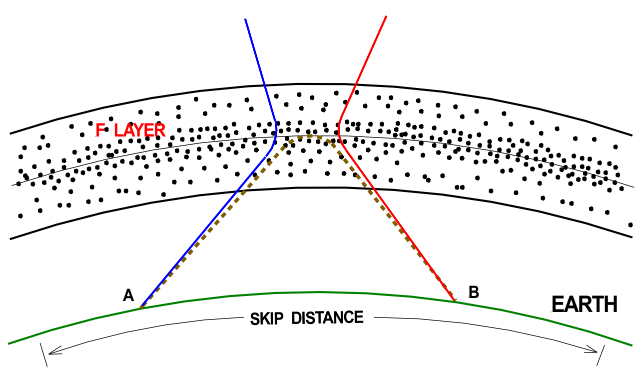


Figure 24 NVIS problems within the skip zone (source: author)

17.3 Determining Skip Distance

When a skip zone exists, it is important to know where the edge of the skip zone is to determine what stations can be reached. That is, the skip distance must be known. For example, when using the Winlink emergency communications network shown in Figure 25, it is important to know which RMS stations can be reached from a particular amateur radio station and which cannot. Stations within the skip zone (red RMS houses in Figure 26) cannot be reached by amateur radio Station-A. Stations that can be contacted are outside the skip zone (green houses). The size of the skip zone must be known to determine which RMS stations can be reached and which cannot.

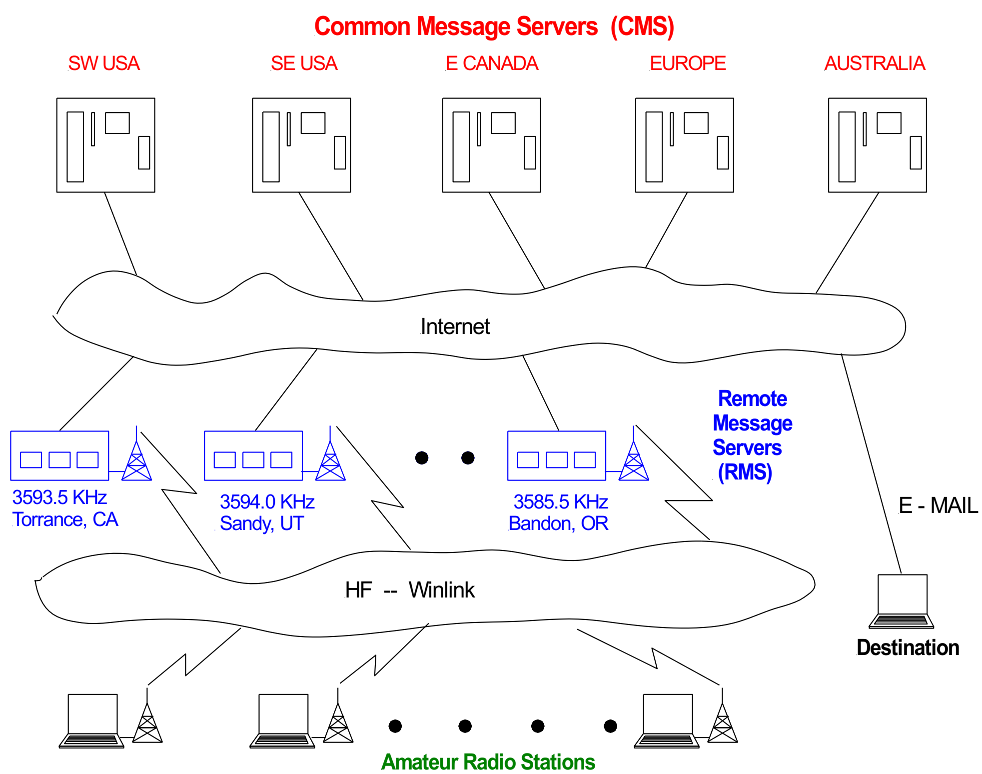


Figure 25 Winlink network (source: author)

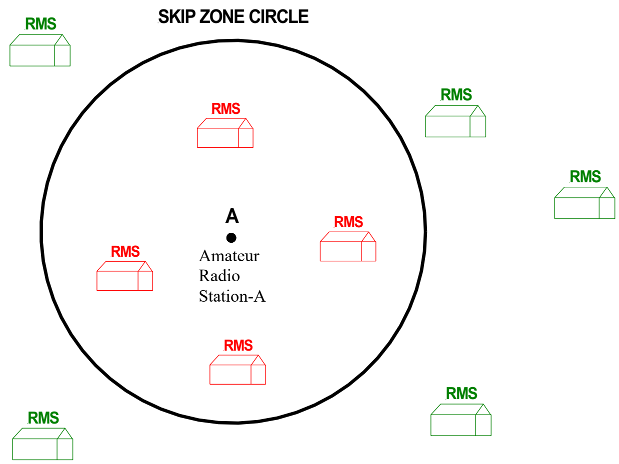


Figure 26 Reachable and non-reachable RMS stations (source: author)

17.3.1 HAP Charts

Hourly Area Prediction (HAP) charts like the one shown in Figure 27 can be used to estimate skip distance. HAP charts are provided by the Australian Bureau of Meteorology. The vertical axis of the chart is degrees Latitude. The horizontal axis is degrees East Longitude, that is measured eastward around the Earth from the Prime Meridian. HAP charts are available under the Tools tab of the www.skywave-radio.org website.

The June 4, 2020 HAP chart in Figure 27 is centered on Los Angles, California. The dark green region is the area of optimum 40 meter coverage at 17:00 UT (10 AM local time). 40 meter coverage also extends into the light green region, although 40 meter multi-path problems may occur. The chart in Figure 27 recommends that 30 meters be used to avoid multi-path problems when communicating with station in the light green region, for example when communicating with stations in central Oregon. The brown and yellow areas are the 40 meter skip zone on this particular time and day.

The HAP chart in Figure 27 provides a quick visual indication of the skip zone at 17:00 UT June 4th. For example, San Francisco (Latitude 38^{o}) is outside the skip zone and can be easily contacted by Los Angeles. However, all stations in Southern California are within the Los Angeles skip zone. Stations in the brown and yellow regions of the chart cannot hear Los Angeles, they are skipped over by the Los Angeles transmissions.

Figure 27 can be used to calculate the 40 meter skip distance for Los Angeles at 1700 UT on June 4th. Los Angeles is located at a Longitude of 241.73^{o}. The boundary between the brown and dark green regions east of Los Angeles is roughly 248^{o} Longitude. The 40 meter skip distance for Los Angeles is thus

$$Skip\ Distance = 5° = 247° - 242°$$

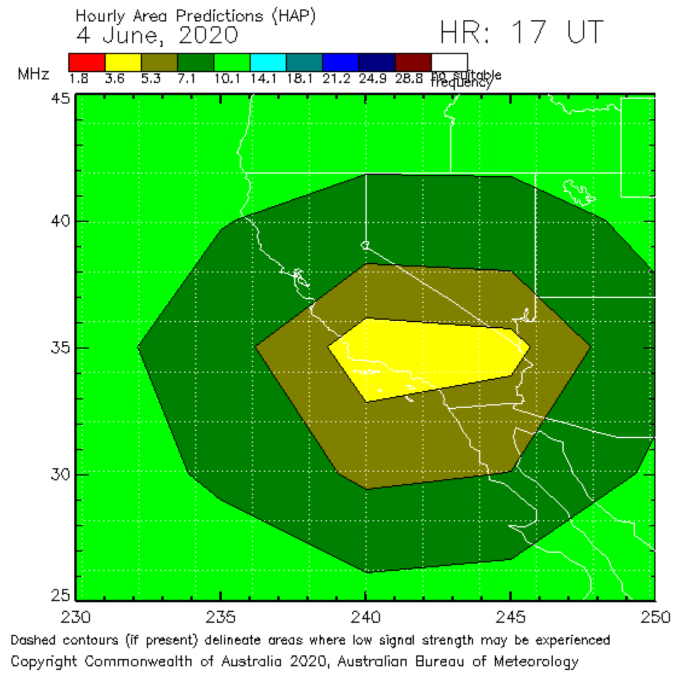


Figure 27 Hourly Area Prediction chart (source: Australian Bureau of Meteorology)

Expressing skip distance in degrees Longitude is not very useful for us. We want the skip distance measured in miles. The procedure for converting from degrees Longitude into miles is as follows.

The distance in miles of one degree Longitude is

$$D_{1^\circ Long} = D_{E1^\circ Long}(\cos d_{Lat})$$

where

$D_{1^\circ Long}$ = Distance in miles of 1° Longitude at the transmitting site (Los Angeles)

$D_{E1^\circ Long}$ = Distance in miles of 1° Longitude at Earth's equator = 69.172 miles

d_{Lat} = Latitude in degrees of the transmitting site (Los Angeles = 34.05°)

Skip distance in miles is then equal to

$$S = [L_T - L_R]\ D_{E1^\circ Long}(\cos d_{Lat})$$

The 40 meter skip distance in Figure 27 is

$$S = [L_T - L_R]\ D_{E1^\circ Long}(\cos d_{Lat}) = [247^\circ - 242^\circ](69.172\ )\cos 34.05^\circ$$

$$S = 287\ miles$$

Stations that can be reached by Los Angeles at this particular time and date must be more than 287 miles from Los Angeles. Note: to simplify the math this skip distance is calculated in the east-west direction. Since the skip zone is roughly circular, this skip distance is assumed to apply in the north-south direction as well.

Monterey, CA is south of San Francisco at Latitude 36.5°. It is 257 miles from Los Angeles and is thus on the edge of the 40 meter skip zone.

17.3.2 Skip Distance Charts

Skip distance charts, like the one shown in Figure 28, are available for each frequency band under the Tools tab of the www.skywave-radio.org website. The chart provides single hop Distance vs Elevation Angle based on the height of the ionosphere's F2 layer. In Figure 28 four heights are provided covering 150 to 450 km. For example, a hop distance of 600 miles will be obtained on 40 meters when a signal is transmitted at an elevation angle of 25° and the height of the F2 layer is 250 km (red trace).

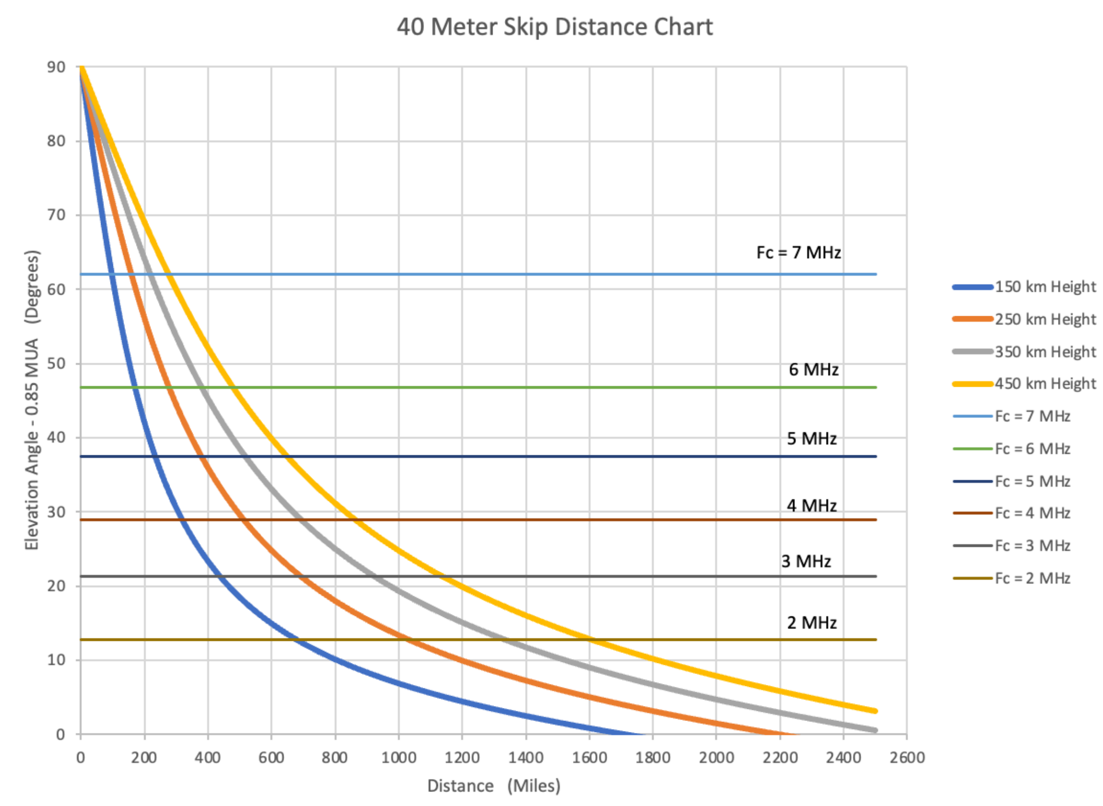


Figure 28 Skip distance chart for 40 meters (source: author)

The distance covered by a single hop becomes shorter as the elevation angle of the transmitted signal increases. However, the current critical frequency, the horizontal traces in Figure 28, place a cap on how short the hop distance can become by specifying the Maximum Usable Angle (MUA). [Note in Figure 28 the angle shown is actually 0.85 MUA to be consistent with Frequency of Optimum Transmission (FOT) data.] Signals transmitted at angles greater than the MUA will penetrate the ionosphere and be lost to outer space. For example, at a critical frequency of 5 MHz the MUA is 38°. Signals transmitted at angles higher than 38° cannot be used for communications since they will penetrate the ionosphere and be lost to outer space. Consequently, the intersection of the appropriate height curve and the current critical frequency defines the shortest possible hop for current conditions. 400 miles is the shortest possible hop for a critical frequency of 5 MHz and a F2 height of 250 km (red trace). You cannot transmit a shorter distance. By definition the length of this hop is the current skip distance.

In practice, skip distance is obtained by determining the current height (hmF2) of the ionosphere's F2 region from the appropriate Ionosonde Site. For California this is done by clicking on Ionogram under the Current Conditions tab of the www.skywave-radio.org website then clicking on Point Arguello, CA hmF2. This chart (Figure 29) shows hmF2 for the past 5 days in green, yesterday red, and today blue in UT time. At the time of this chart (Jan 31, 2024 @ 03:00 UT) hmF2 (Blue trace) was 250 km.

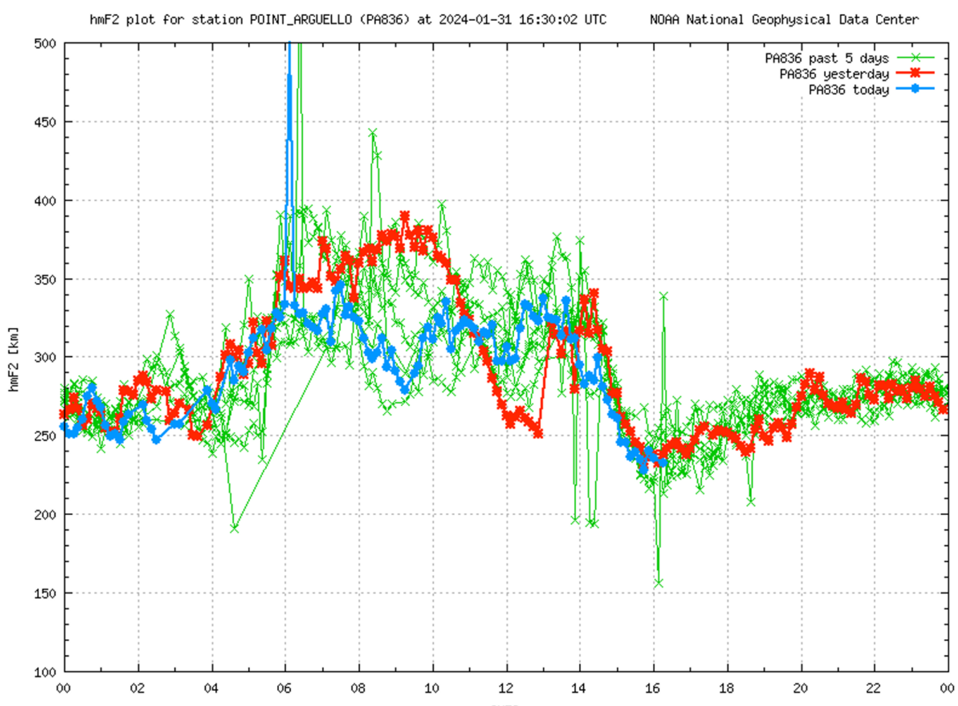


Figure 29 Ionosphere Height h_mF2 @ Point Arguello (source: NOAA)

Next, the current critical frequency Fc is obtained by clicking on Critical Frequency under the Current Conditions tab. In Figure 30 the critical frequency for January 31, 2024 at 03:00 UT over California was between 4 to 5 MHz.

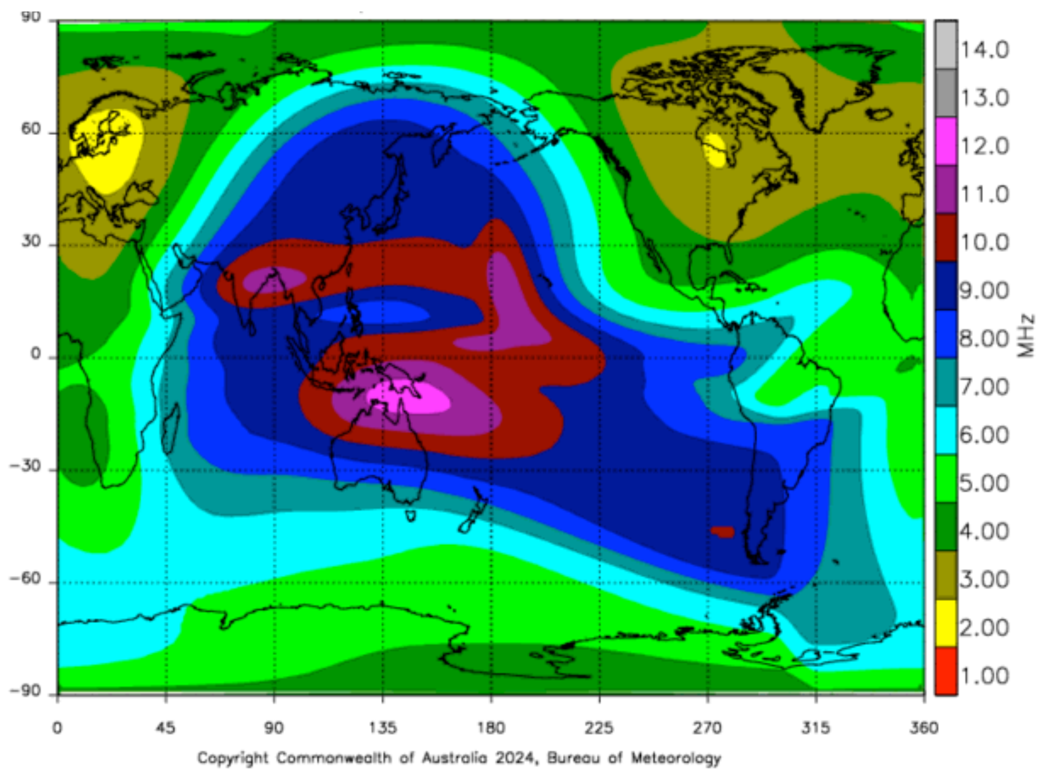


Figure 30 Critical frequency 03:00 UT January 31, 2024 (source: Australia Bureau of Meteorology)

The Point Arguello ionosonde provides more detailed critical frequency data for California. Figure 31 shows the Point Arguello foF2 data for the past 5 days (green), yesterday (red trace), and today (blue trace) in UT time. On January 31, 2024 at 03:00 UT the F2 critical frequency foF2 (blue trace) was 5 MHz.

Using this data the skip distance for January 31, 2024 at 03:00 UT can be determined using Figure 32. From the intersection of the Height (250 km) and Fc (4.5 MHz) traces read down to the Distance axis. This is the approximate skip distance (450 miles in this example) for the current conditions.

Stations that can be reached are those beyond the skip zone which in this example are below and to the right of the Fc = 4.5 MHz and hmF2 = 250 km junction. The stations that you can reach are also limited by the lowest radiation angle possible from your antenna. This angle is typically greater than 10°, often 15 to 20°.

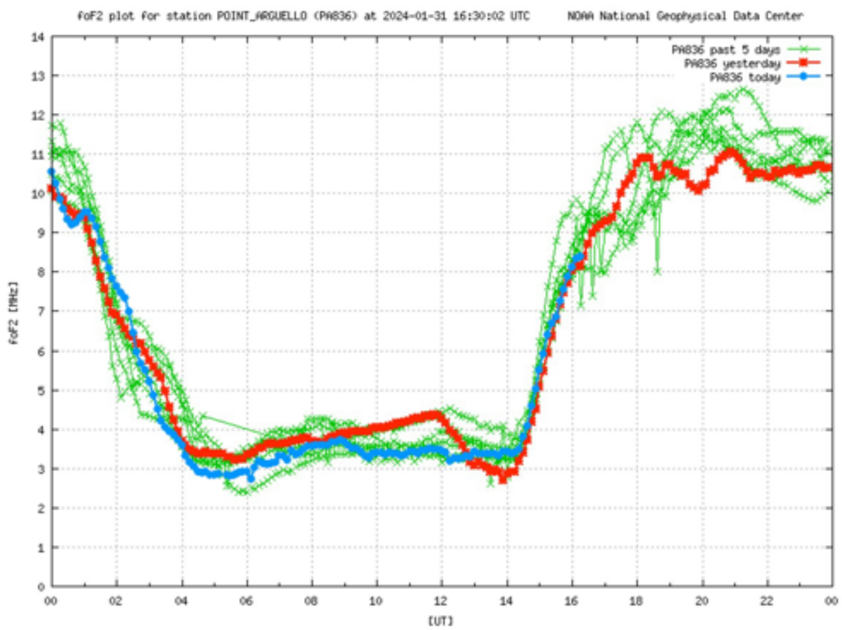
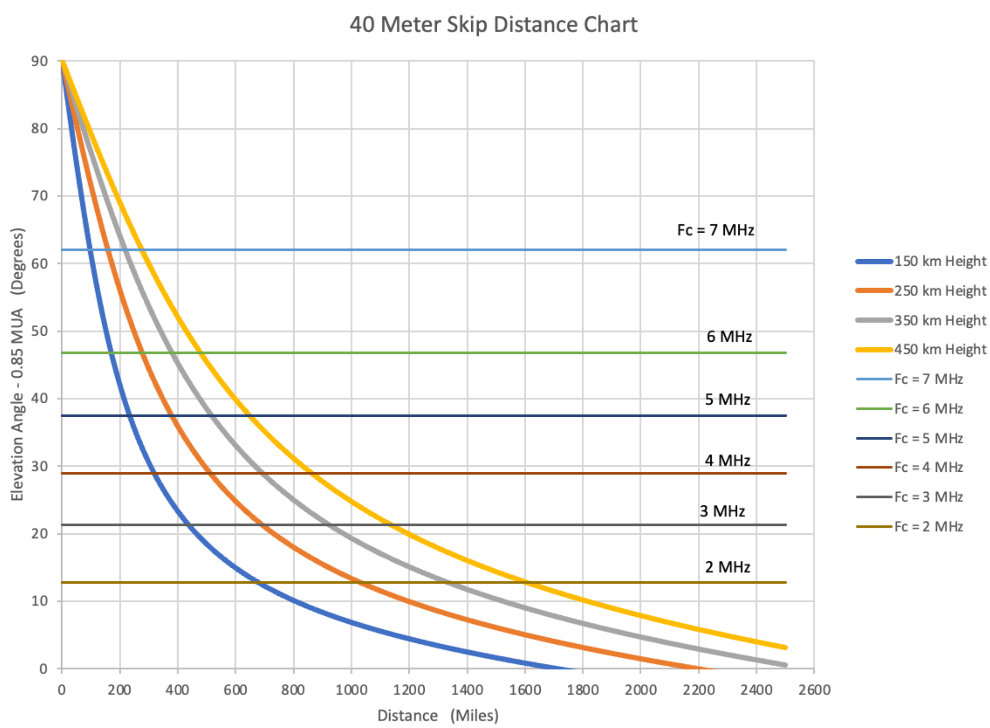


Figure 31 Point Arguello foF2 data (source: NOAA)



Bounded by MUA | Reachable Range | Bounded by antenna
Skip Zone |

Figure 32 Skip distance chart for 40 meters (source: author)

For this example, the furthest station that can be reached in one hop is defined by the antenna's 10^{o} elevation angle and hmF2 = 250 km junction. This distance is approximately 1,200 miles.

In Figure 32 the maximum usable angle prevents stations closer than 450 miles from being contacted, 450 miles being the skip distance in this example. Stations further away than 1,200 miles are prevented from being reached by the lowest radiated angle of your antenna. The stations that can be reached in a single hop are those between 450 and 1,200 miles.

A low elevation angle long hop signal (Figure 33) spends more time traversing the D Layer than a high angle short hop signal. Consequently, a low angle signal is more likely to be absorbed by the D Layer than a high angle short hop signal.

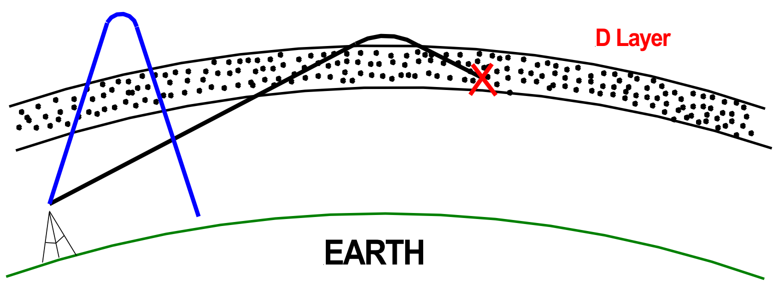


Figure 33 Long hop signal more likely to be absorbed in D layer (source: author)

Stations just beyond the skip zone (Figure 32) are typically strong. At this distance the high and low path rays coincide increasing signal strength. Also, the elevation angle at this distance is high, nearly equal to MUA, meaning that the signal passes through the D Layer quickly minimizing absorption.

Two or more hops are required to reach many stations that we communicate with. For multi-hop communications, the first hop must occur within the reachable single hop range, for this example in the range of 450 to 1,200 miles. In some cases, stations further away (for example 1200 - 1400 miles) are strongly received while closer stations are either weak or cannot be received at all. This is often an indication of high path propagation.

17.3.3 Skip Distance Determined By Antenna

Skip distance will be determined by your antenna IF the antenna's high radiated angle (HRA) is less than the MUA determined by the ionosphere's critical frequency f_c. HRA in Figure 34 is defined as the upper angle at which the antenna's radiated power drops 6 db below its maximum level. Radiated power drops off very quickly at angles above HRA. There is also a Low Radiated Angle (LRA) defined as the lower angle at which the antenna's radiated power drops 6 db below its maximum level. Radiated power also drops off very quickly at angles below LRA. In Figure 34 LRA is about 8º.

At a critical frequency of roughly 6.8 MHz the 40 meter MUA is around 58º producing a skip distance of about 200 miles, red trace in Figure 32. If a vertical transmit antenna is being used, the antenna's high radiation angle HRA is probably about 45º as shown in Figure 34. Referring back to Figure 32, the skip distance for an elevation angle of 45º is around 300 miles. Stations closer than 300 miles will be skipped over by the vertical antenna. Vertical antennas are long distance antennas not suited to close in Near Vertical Incident Skywave (NVIS) emergency communications.

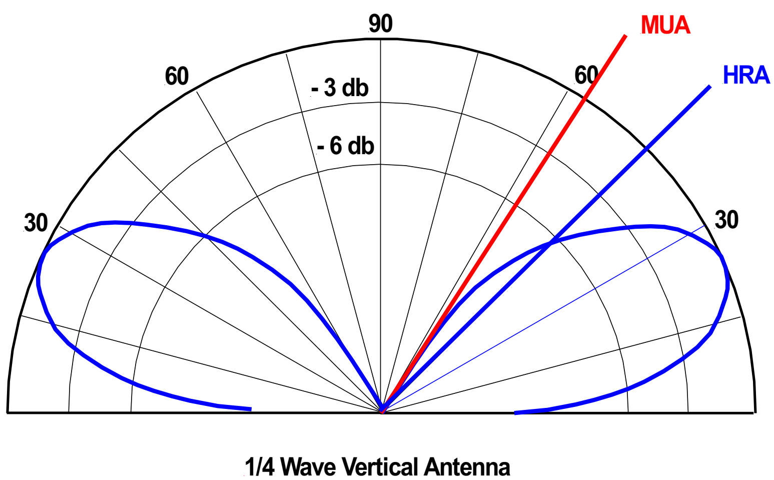


Figure 34 Vertical antenna elevation diagram (source: author)

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