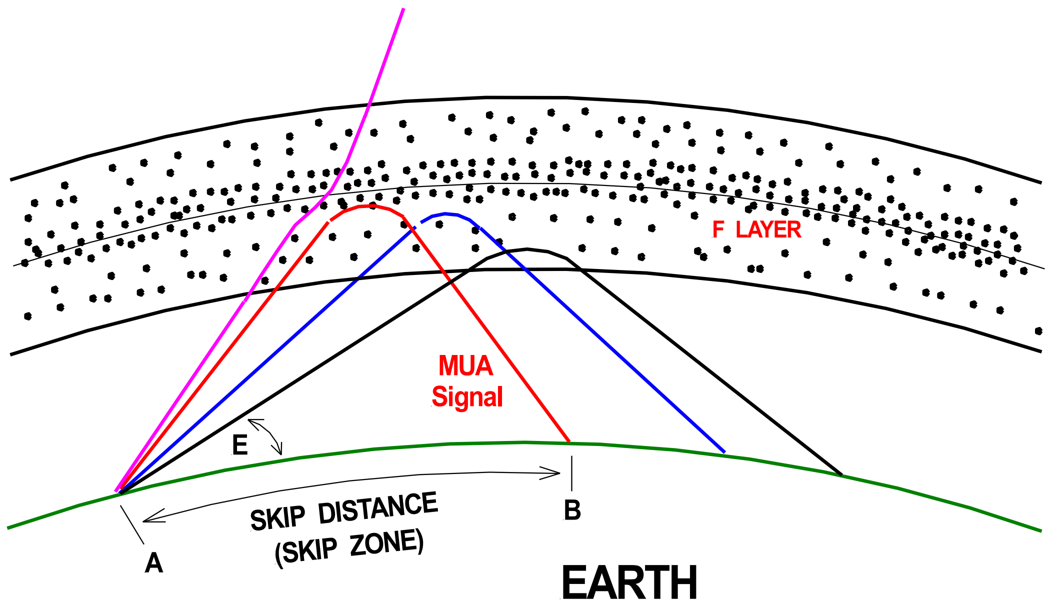
Skip Distance

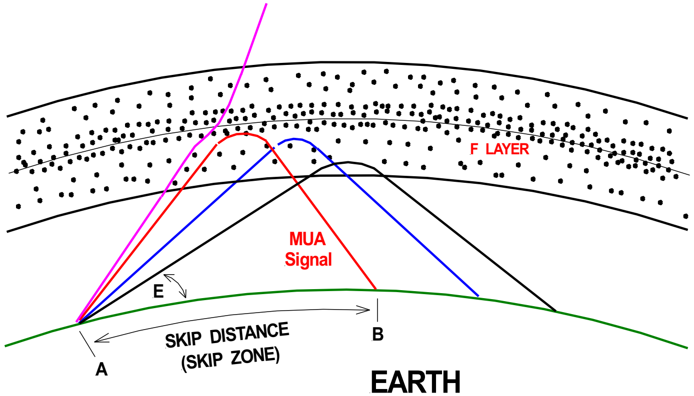


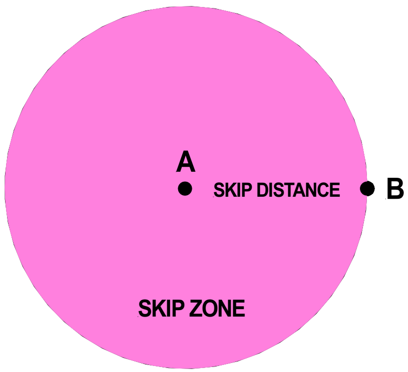
Ken Larson KJ6RZ

March 2024

www.skywave-radio.org

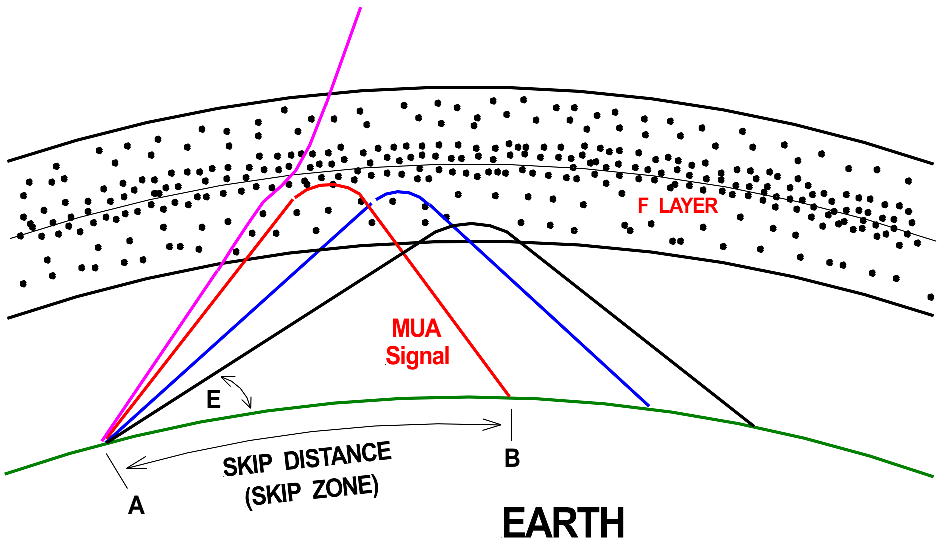
What Is A Skip Zone and Skip Distance ?





- A skip zone is a region relatively close to a transmitting station in which the transmitter's signals can not be heard due to ionospheric propagation phenomena
- In the above figure Station A can communicate with stations located at B and beyond but can not communicate with closer stations located in the skip zone from A to B. Stations in the skip zone are "skipped over"
- From the perspective of transmitting Station A, the skip zone is circular in shape with Station A located at the center
- 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

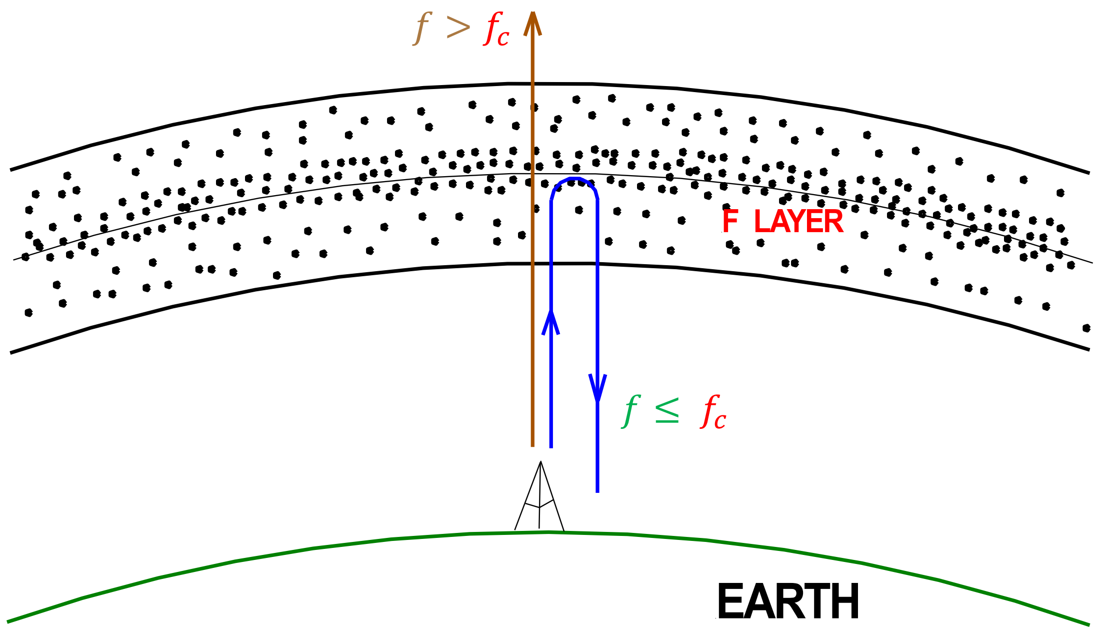
What Determines Skip Distance ?



Skip distance, and the associated skip zone, are a function of

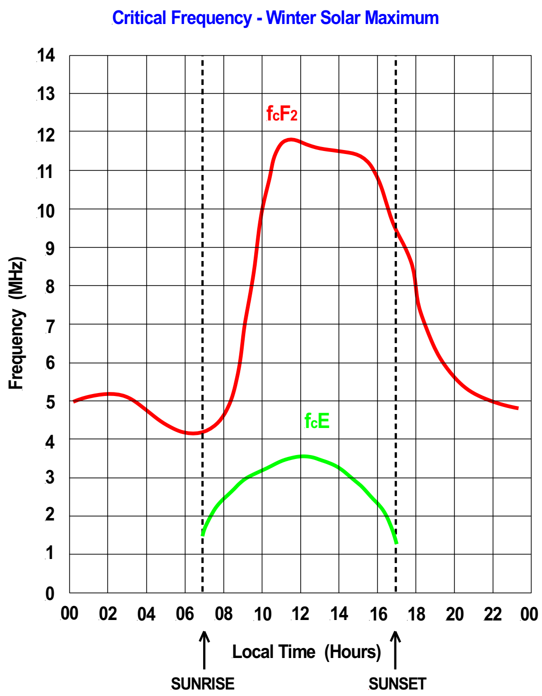
- The ionosphere's Critical Frequency,
- A radio station's Operating Frequency, and
- A signal's Maximum Usable Angle (MUA) relative to Earth's surface

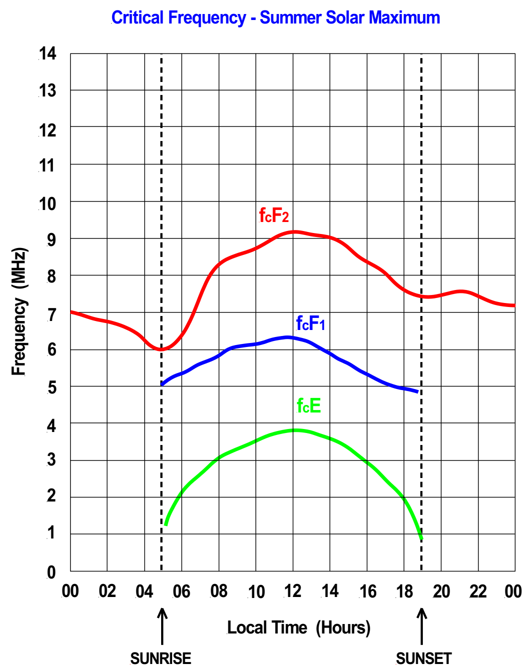
Critical Frequency

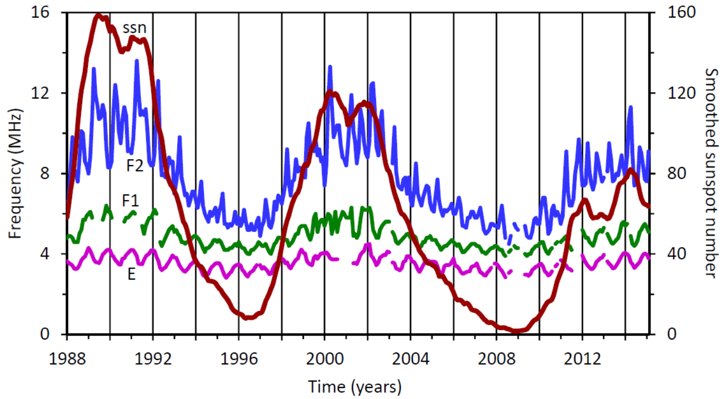


- Critical Frequency f_c is the **highest** frequency signal that can be transmitted straight up and reflected back down to Earth
- All signals lower in frequency than f_c will also be reflected back to Earth
- But, signals higher in frequency transmitted straight up will penetrate the ionosphere and be lost to outer space

Critical Frequency Varies

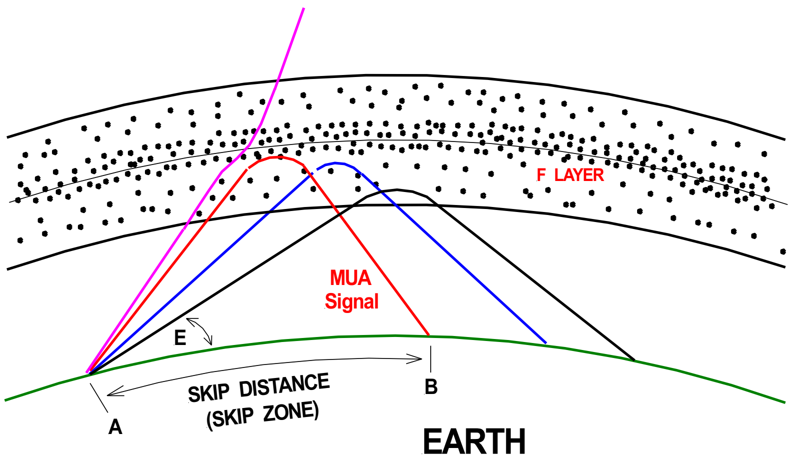


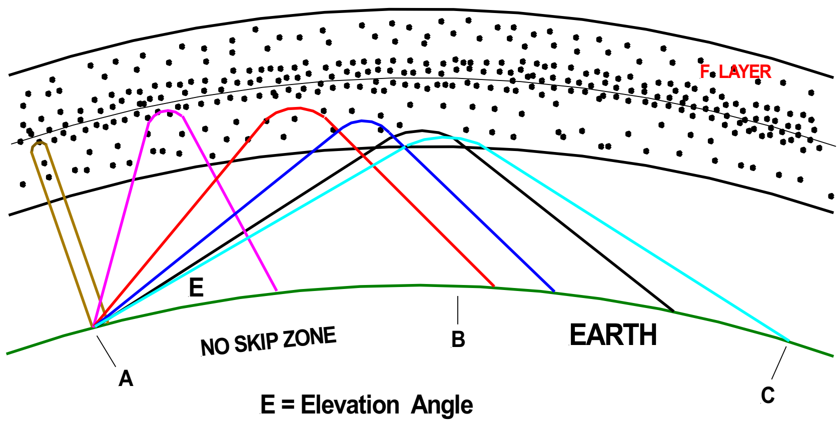




- Critical Frequency varies:
  - Throughout the day as the Earth rotates,
  - Seasonally as the Earth's upper atmosphere changes, and
  - With the 11 year solar cycle as Extreme Ultra-Violate (EUV) & X-ray radiation from the Sun changes

When Will A Skip Zone Be Present ?



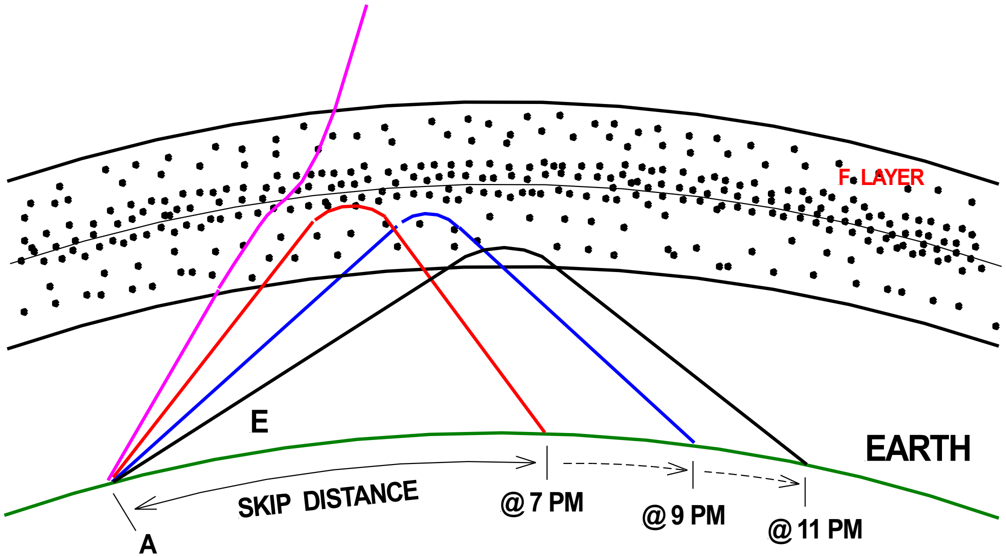


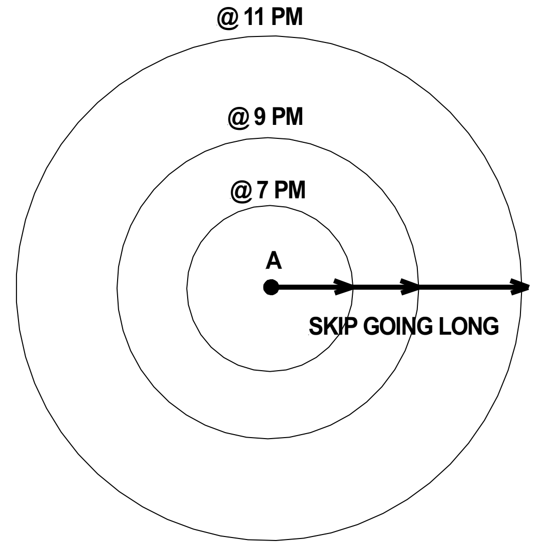
Skip Zone Present if $f_c < f_o$

No Skip Zone if $f_c > f_o$

- 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 $f_c < f_o$
- A skip zone will not exist if the critical frequency is above the operating frequency, i.e. if $f_c > f_o$
- In that 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

Skip Going Long





- 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

Part of 40 Meter Skip Distance Test --- $f_c > f_o$

Time	Frequency MHZ	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

- The concept of skip zones, or the lack of, in addition to skip going long are dramatically illustrated in the 20, 40, and 80 meter skip distance tests documented under the Test Results tab of the web site www.skywave-radio.org
- In the above 4 PM test f_c = 10.5 MHz which is greater than the 7.1 MHz operating frequency
- Consequently there is no skip zone resulting in excellent communications with all stations from 11 out to 845 miles away

Part of 40 Meter Skip Distance Test --- $f_c < f_o$

Time	Frequency MHZ	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

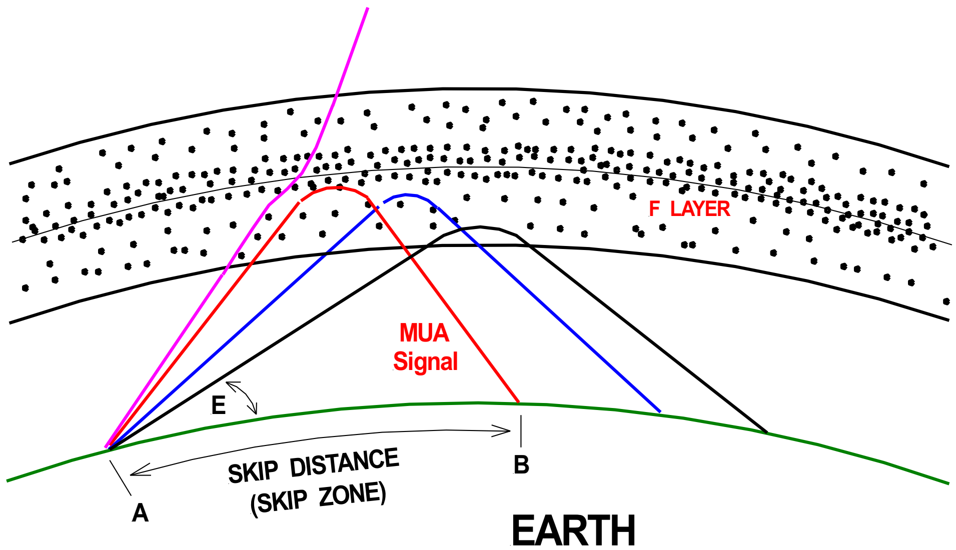
- In the evening (~ 7 PM) critical frequency dropped to 5 MHz which was less than the 7.1 MHz operating frequency resulting in a skip zone
- Red entries are failed attempts to contact stations in the 500 mile skip zone (nc = no contact)
- Green entries are successful contacts made beyond the skip zone
- The duration of these contacts are short, generally 16 to 28 seconds

Part of 40 Meter Skip Distance Test --- Band Dead

Time	Frequency MHZ	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

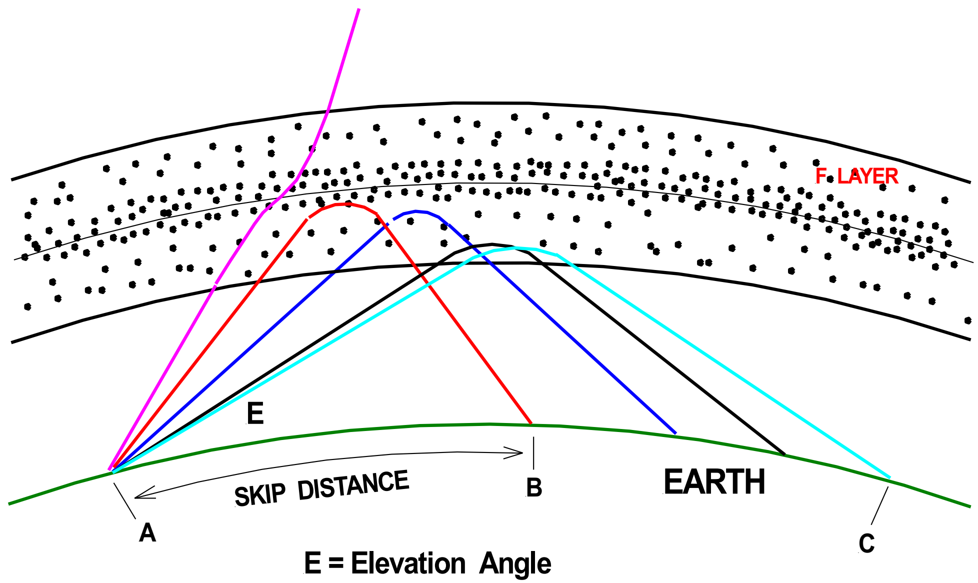
- Later in the evening the skip went long with the only reachable stations located over 700 miles away
- At 20:00 hours PST (~ 8 PM) 40 meter stations could no longer be contacted
- The band became dead as the critical frequency dropped below 3.5 MHz

Regional Net Skip Distance Problem



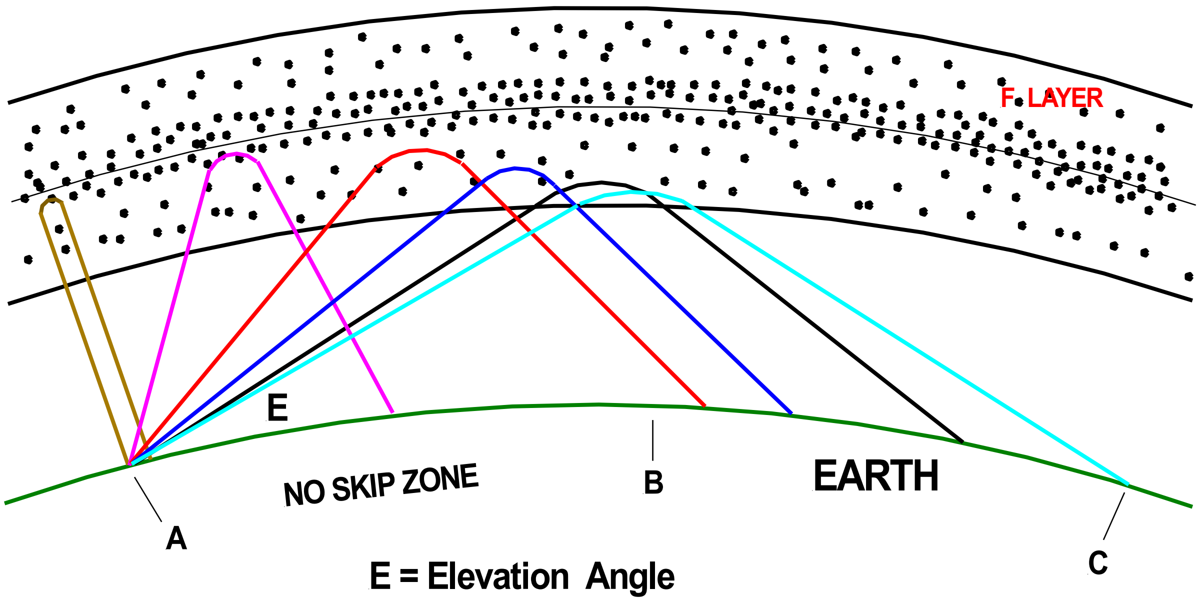
- Skip distance can cause a regional (state wide) net serious problems
- Stations close to Net Control Station-A can not hear net control because they are in net control's skip zone

Solving The Regional Net Skip Problem



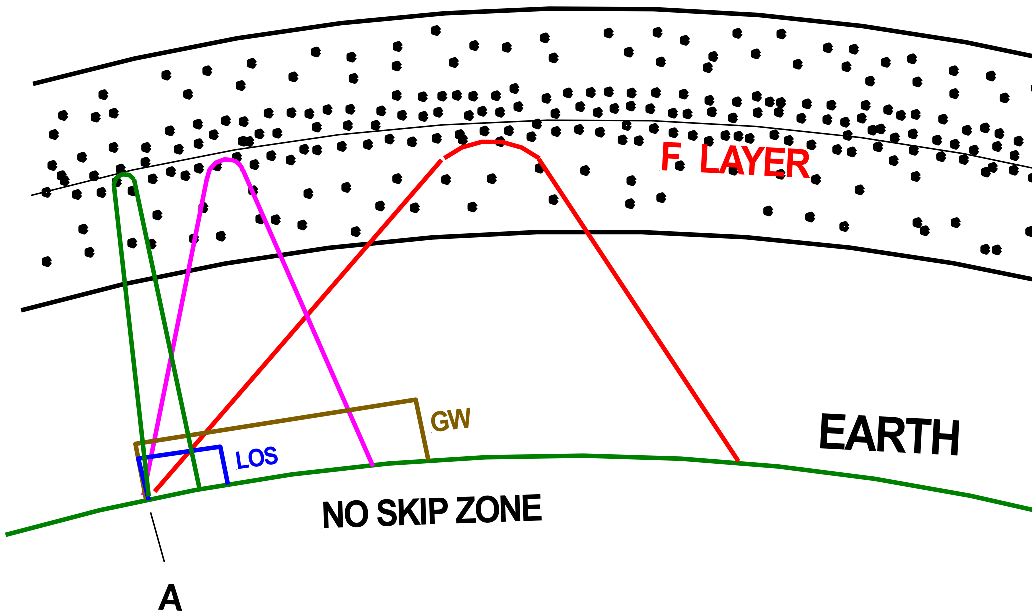
- The problem can be solved by creating a second Alternate Net Control Station-C located such that Station-C is outside Station-A's skip zone and visa versa
- In this case Stations A and C can communicate with each other
- In addition, Station-C can communicate with stations in Station-A's skip zone and visa versa.
- With this scheme all net traffic can be heard by all stations either directly from net control or indirectly from alternate net control

Regional Net Skip Problem Avoided



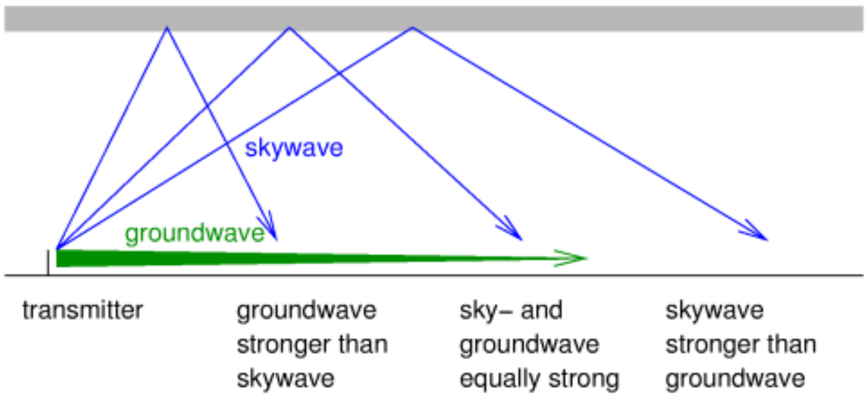
- There is, of course, no skip distance problem if the critical frequency (for example 8 MHz) is above the net frequency (say 7.2 MHz)
- In this case there is no skip zone
- Everyone can directly hear Net Control Station-A

Close-in Multipath NVIS Problem

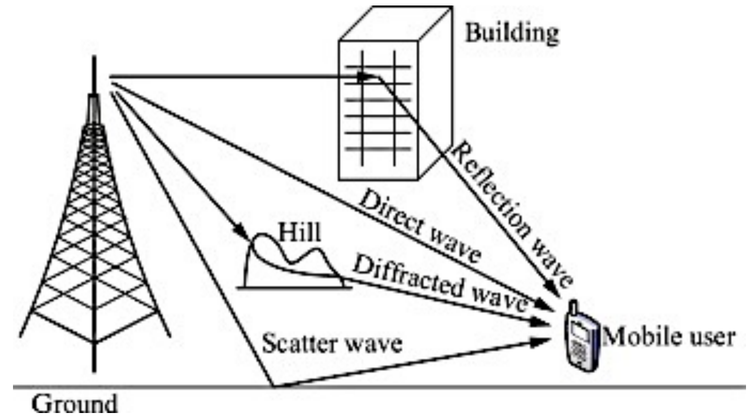


- If there is no skip, all NVIS stations can be reached from the base of your antenna outward for many hundreds of miles
- However, like it or not, line-of-site (LOS) and ground wave (GW) propagation always exist from your antenna out 30 to 40 miles or so
- Consequently, multi-path interference problems between NVIS, ground wave, and line-of-site propagation can cause signal degradation and fading problems close-in when NVIS conditions are otherwise excellent

Close-in Multipath Problems



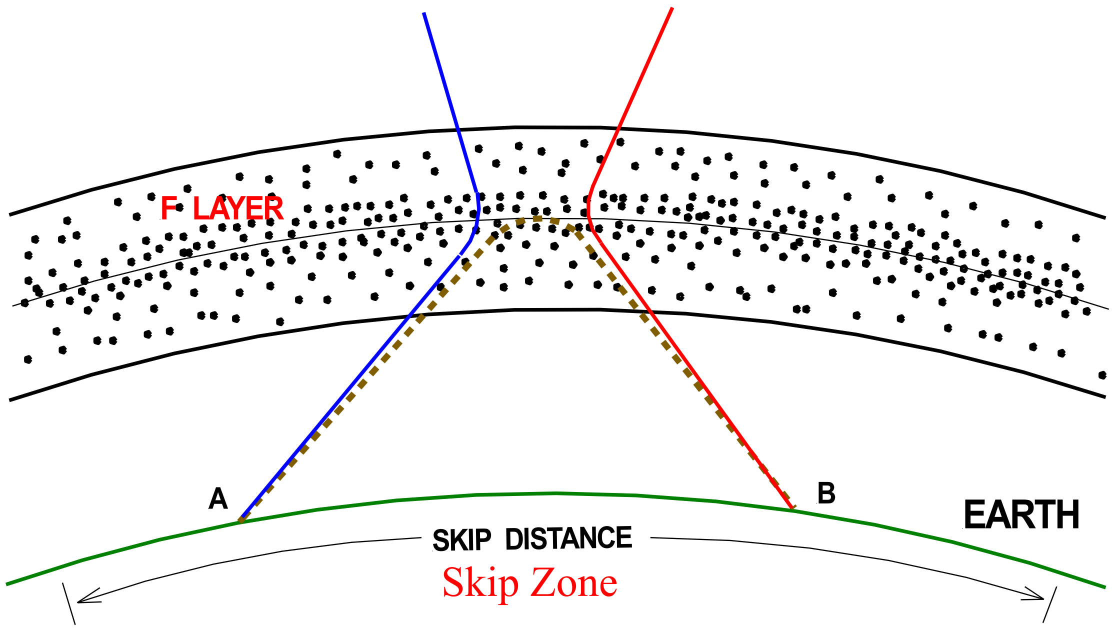
PA3FWM pa3fwm@amsat.org



https://www.sciencedirect.com

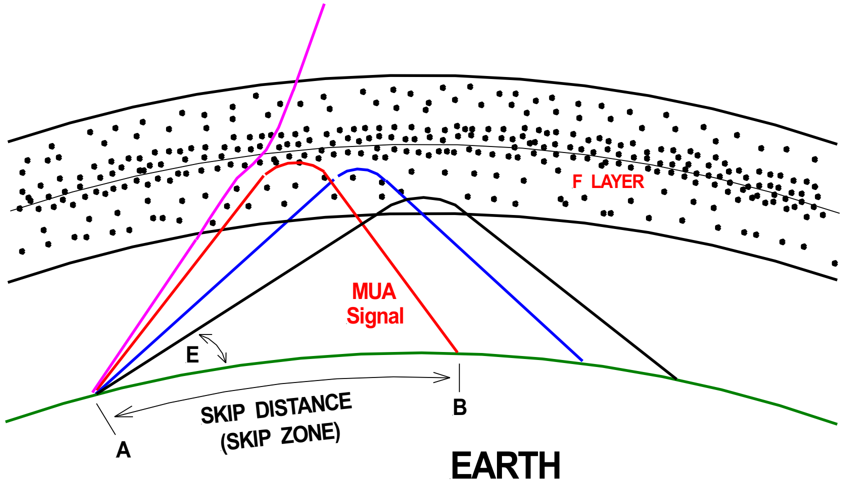
- Multi-path interference problems between NVIS skywave and ground wave propagation is most severe when skywave and ground wave signals are equally strong
- HF line of sight signals suffer the same reflection, diffraction, and scattering problems as VHF and UHF signals
- In addition to interference from ground and skywave signals
- All resulting in distortion and fading

No NVIS Between Stations Within The Skip Zone



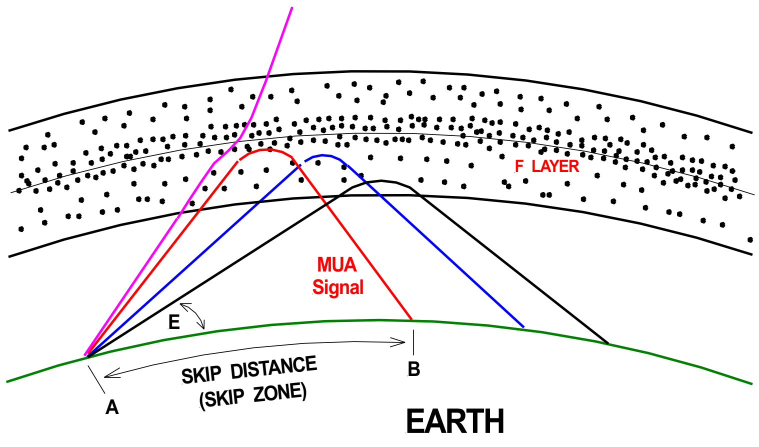
- When Stations A and B are located within the skip zone the desired NVIS communications along the dotted brown propagation path is impossible
- The high elevation angles required for NVIS between two such stations cause the signals to penetrate the ionosphere and be lost to outer space
- Under these conditions **line-of-site** and **ground wave** are the only propagation modes available provided the stations are located close to one an other (within about 30 miles or so)

Local HF Net Skip Zone Problem

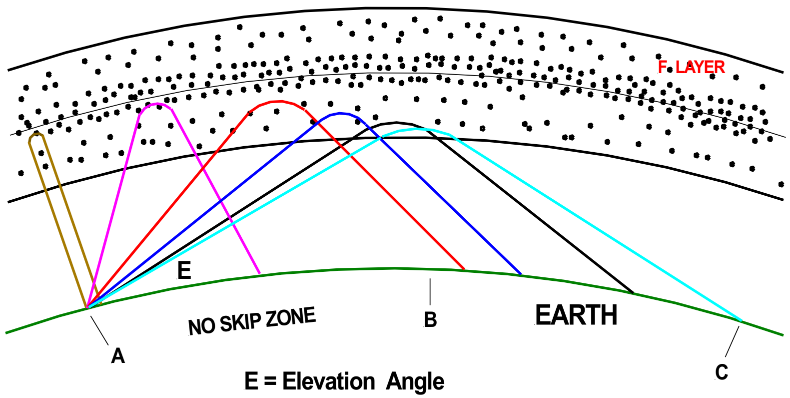


- A local county wide HF net will experience problems if a skip zone exists ($f_c < f_{net}$)
- If present, a skip zone will typically cover the entire county (and much more) meaning that all stations participating in the net will be within the skip zone
- NVIS propagation between the participating net 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

Resolving Local HF Net Skip Zone Problem



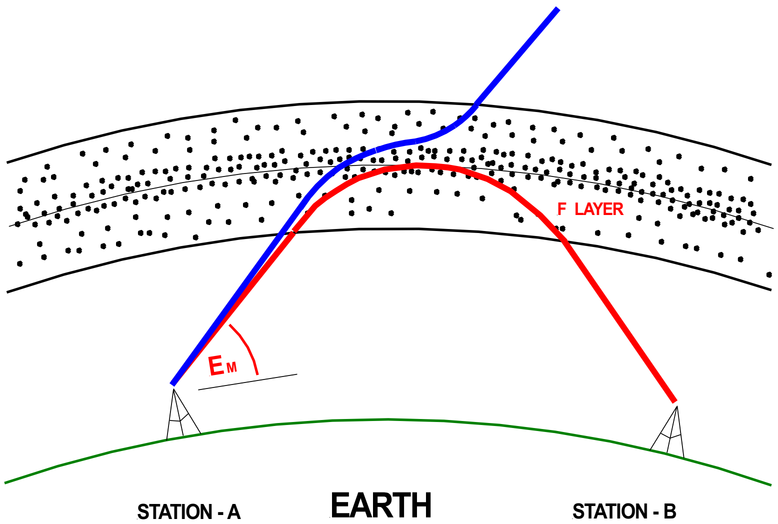
Skip Zone $f_c < f_{net}$



No Skip Zone $f_c > f_{net}$

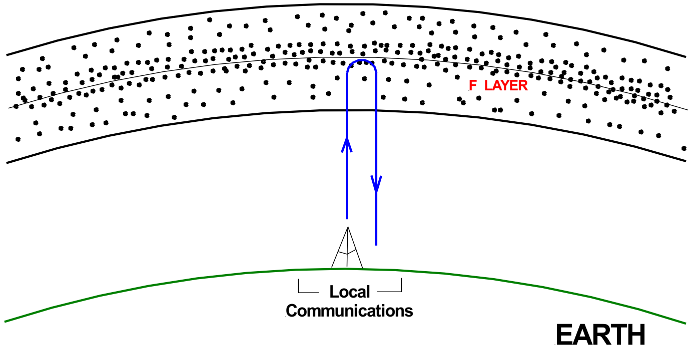
- The skip zone problem is resolved by
- Positioning two or more net control stations strategically within the county so that the net control stations can hear each other and each can hear its local stations
- There is NO skip zone problem if the critical frequency (say $f_c = 6$ MHz) is greater than the net frequency (for example $f_{net} = 3.987$ MHz)
- In that case, everyone in the net can hear everyone else utilizing a combination of NVIS, ground wave, and line of sight, and
- Only one net control station will be needed

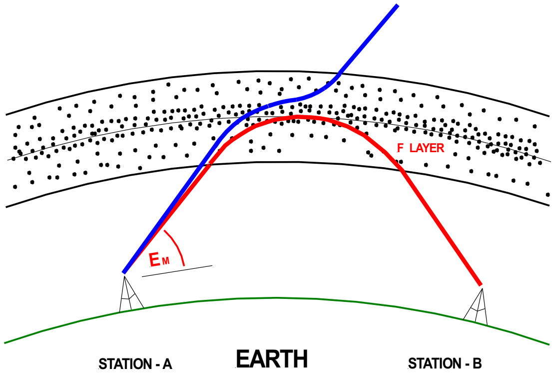
Maximum Usable Angle



- Maximum Usable Angle plays an important role in determining skip distances
- 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
- Signals transmitted at higher elevation angles (blue signals) penetrate the ionosphere and are lost to outer space

Maximum Usable Angle and Critical Frequency



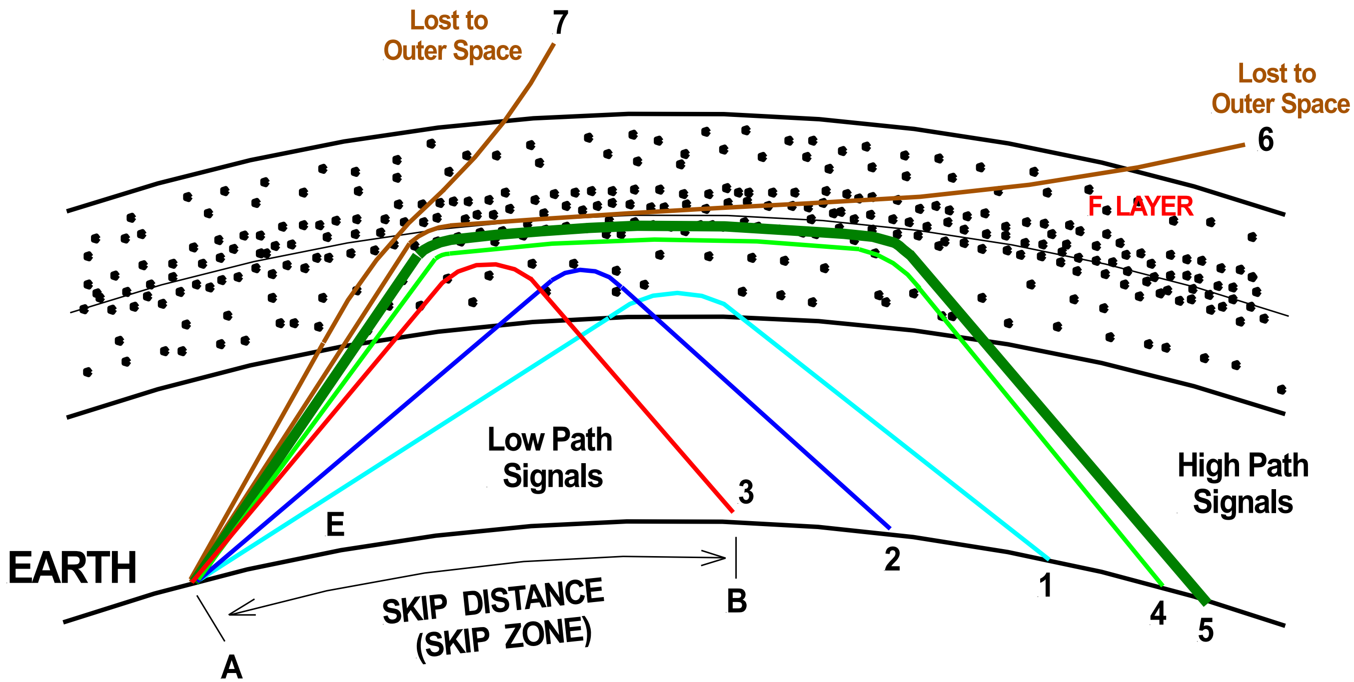


$$\text{MUA} = E_M = \sin^{-1}\left(\frac{f_c}{f_o}\right)$$

- The Maximum Usable Angle is 90º, 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 $f_c / f_o \geq 1$ and $\sin^{-1}\frac{f_c}{f_o} = \sin^{-1} 1 = 90°$
- At all other frequencies, with $f_c < f_o$, the ratio $f_c / f_o < 1$ and the maximum usable angle is less than 90º , for example if $f_c = 5$ MHz and $f_o = 7.2$ MHz then

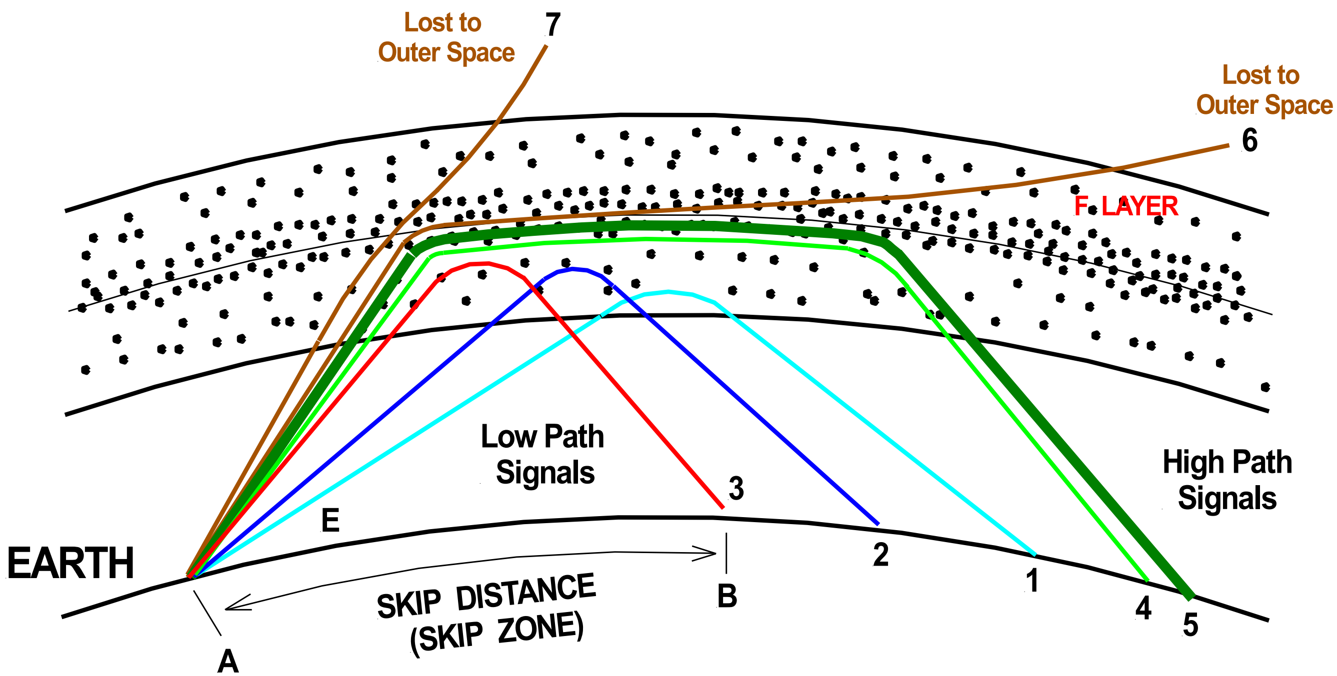
$$MUA = \sin^{-1}\left[\frac{5}{7.2}\right] = \sin^{-1} 0.69 = 44°$$

Hop Distance



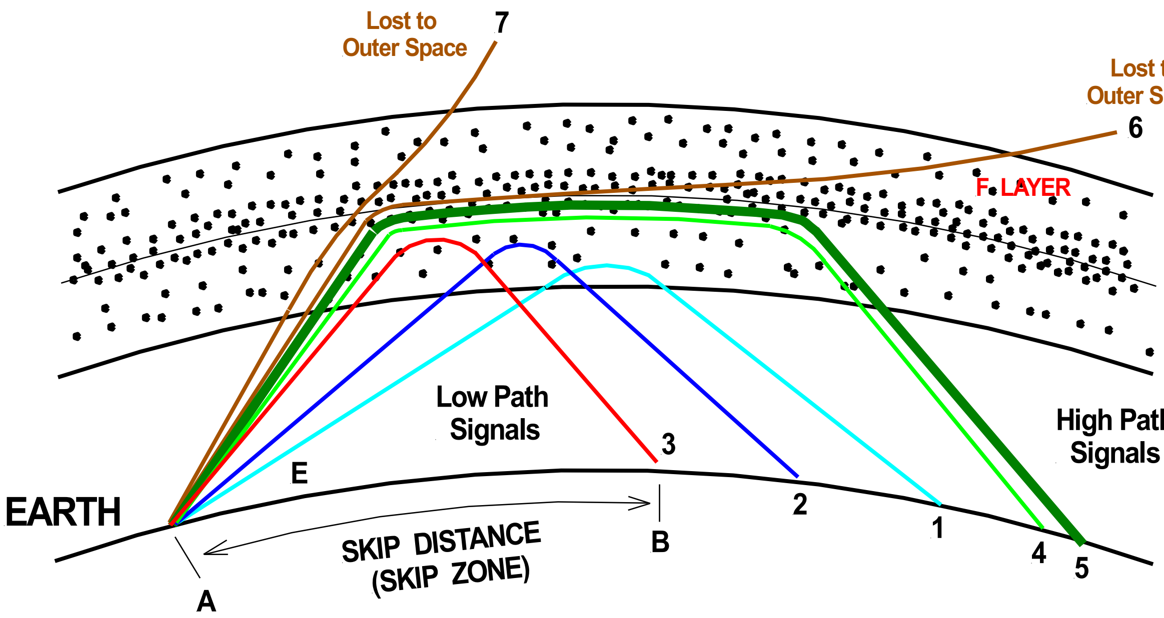
- The distance that a radio signal travels in one hop through the ionosphere depends on the angle E at which it is transmitted
- Increasing angle E shortens the hop distance, for example from point 1 to point 2 to point 3 as E increases

Hop Distance and Elevation Angle



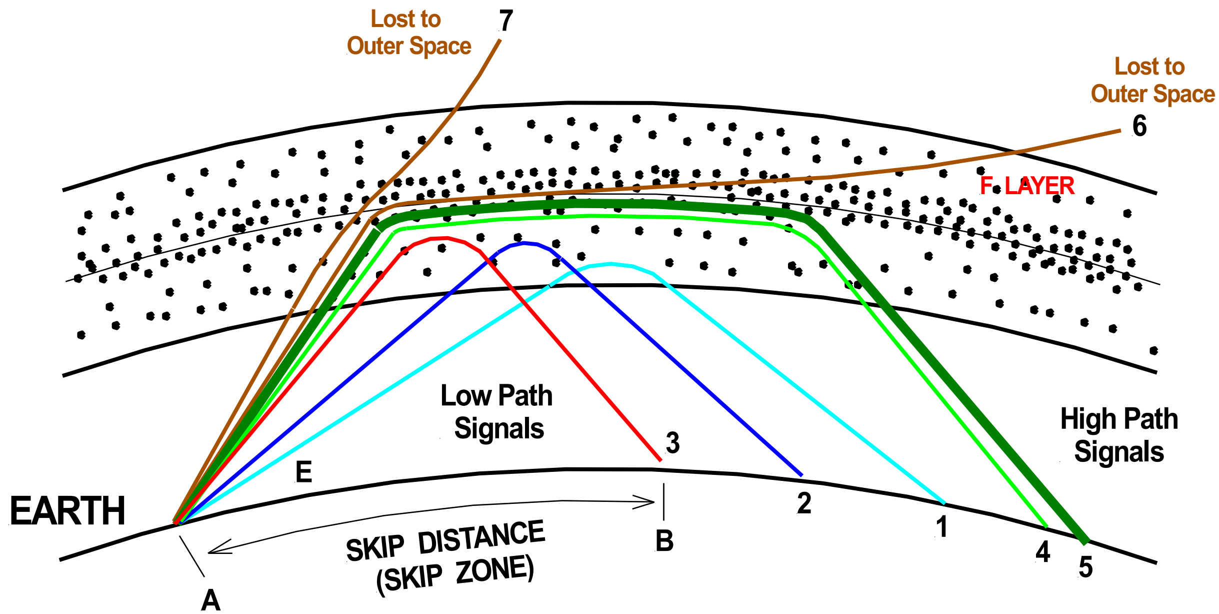
- Increasing E a little more causes a strange thing to happen
- Instead of the hop distance becoming shorter, it becomes dramatically longer, reaching points 4 and 5 instead
- Increasing E slightly more causes the signal to penetrate the densest part of the ionosphere and be lost to outer space as illustrated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

Low Path Signals



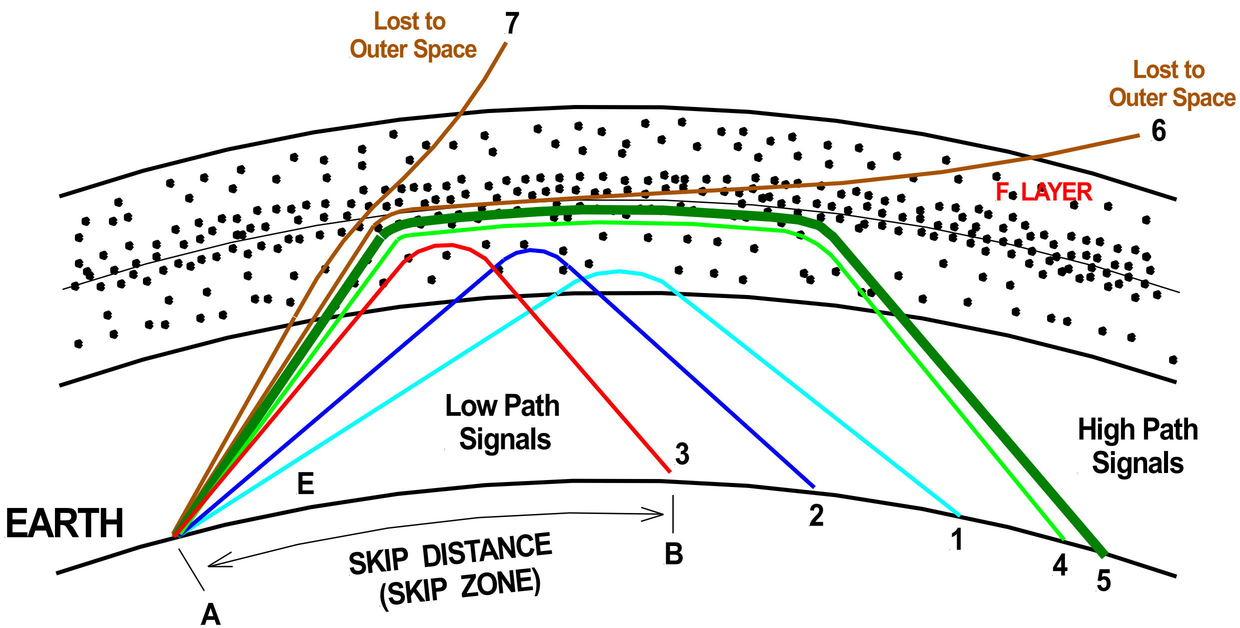
- Rays 1, 2, and 3 are low path signals
- These signals travel through the lower part of the ionosphere and are relatively stable

High Path Signals



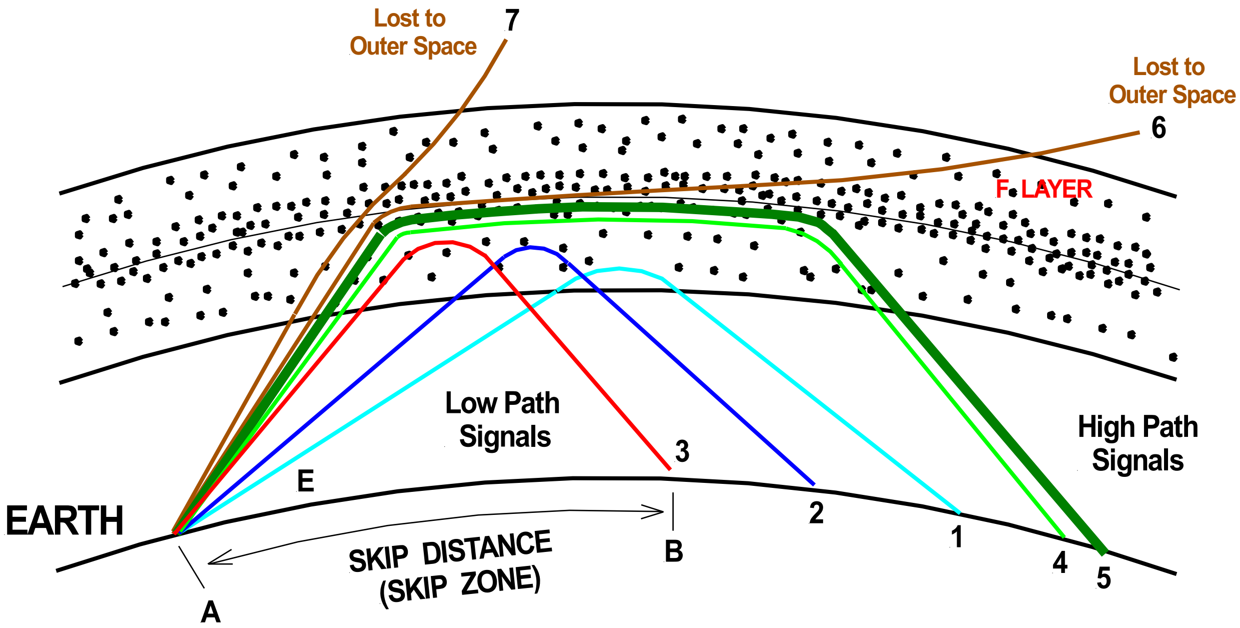
- High path signals (rays 4 & 5) travel parallel to the Earth along the most dense part of the ionosphere before eventually returning to Earth or being lost to outer space
- High path signals are often highly attenuated and very erratic returning to Earth at locations that change rapidly (rays 4 & 5)
- Sometimes high path signals penetrate the ionosphere (ray 6) and are lost to outer space
- High path signals are also know as Pedersen Rays

MUA Defined by the High Path Signal



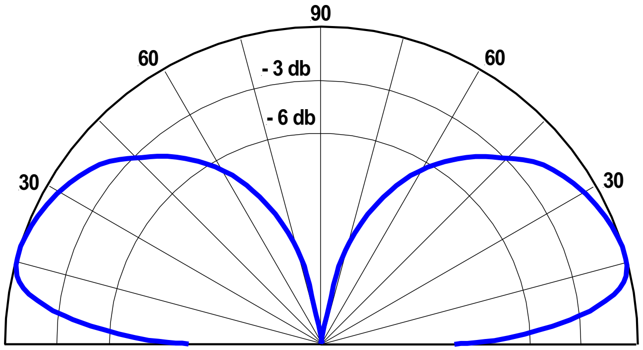
- An elevation angle E slightly greater than E_5 (the elevation angle for ray 5) causes a signal to penetrate the ionosphere and be lost to outer space
- Elevation angle E_5 is thus the Maximum Usable Angle, MUA

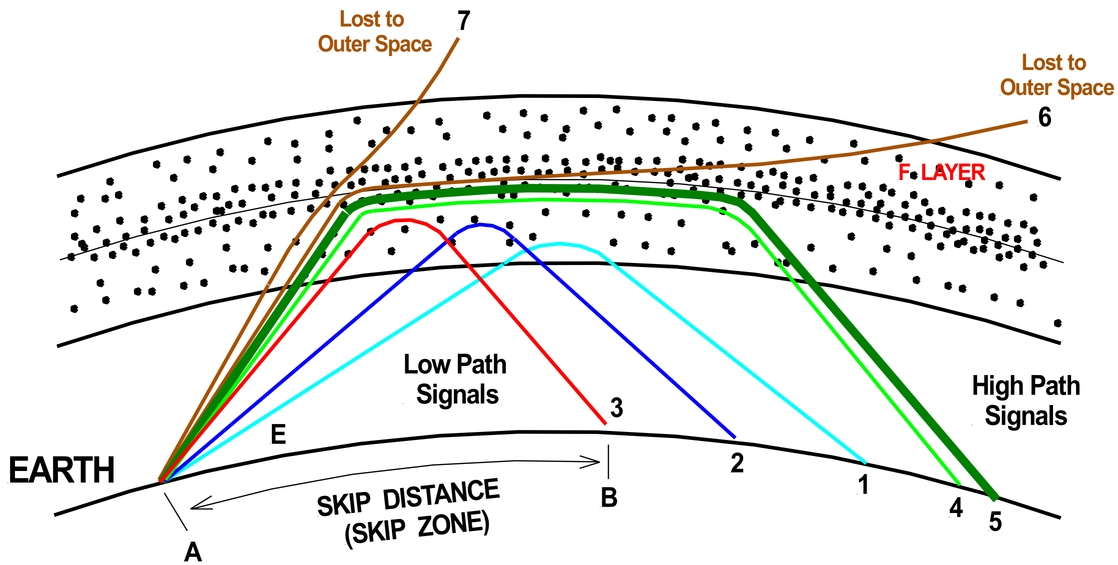
MUA Defined by the High Path Signal continued



- The difference between E_5 and E_3 (the elevation angle for ray 3) is very small
- Consequently, E_3 is frequently defined as the MUA, because
- Ray 3 is special, it is the shortest possible ray, and the ray at which the high and low paths coincide producing a relatively strong stable signal

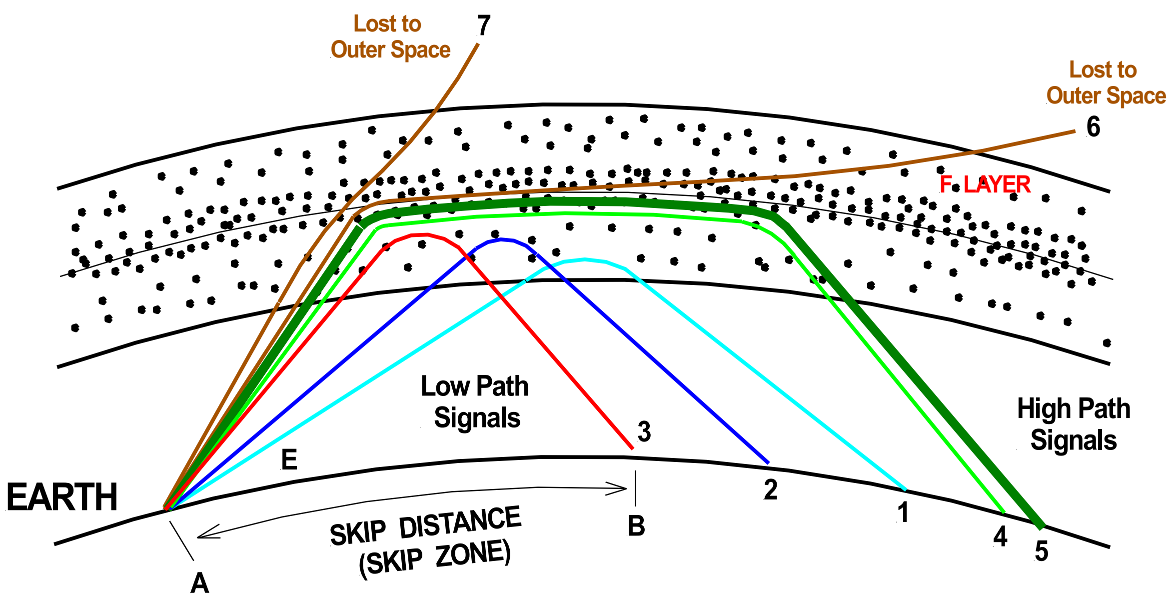
A Typical Transmission Includes Both High & Low Path Signals





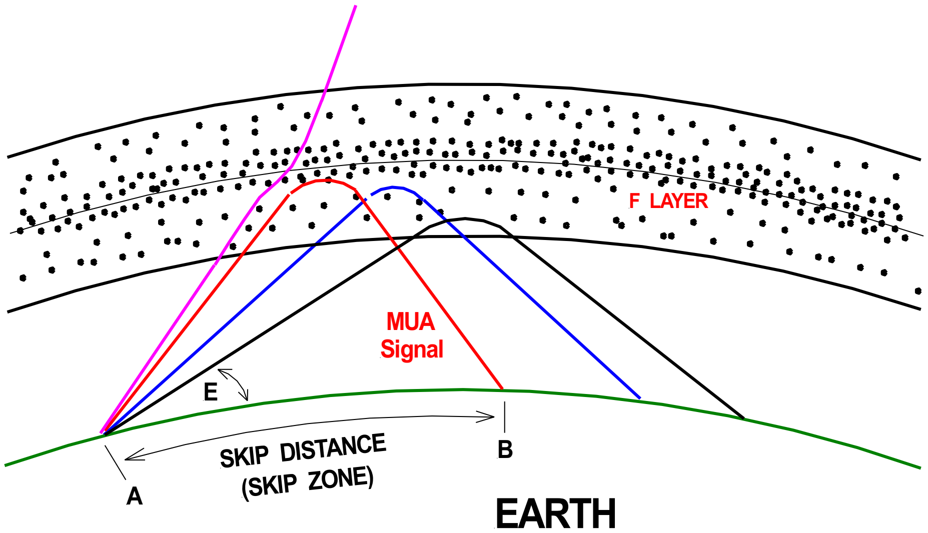
- The signals radiated by radio antennas are not laser beams !
- Amateur radio antennas in particular are relatively crude devices radiating energy over a wide range of elevation angles (illuminating a large region of the sky)
- Consequently, the various propagation paths 1 through 7 are always present making possible communications with many different radio stations

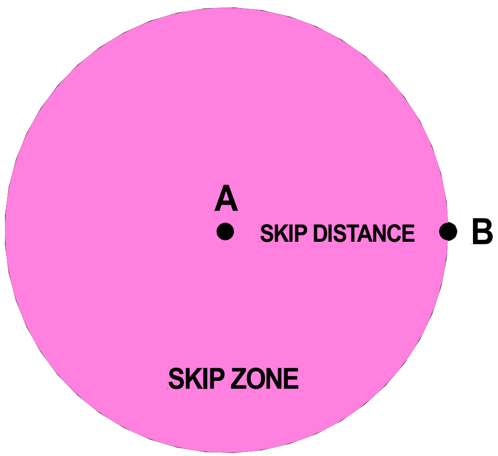
Redefining Skip Distance



- Ray 3 is the shortest possible path for a signal transmitted from Point A
- Increasing E_3 slightly increases the hop distance to point 4
- Decreasing E_3 also increases the hop distance, this time to point 2
- Station A can not transmit a signal to any location closer than Station B
- Thus the region from Station-A to Station-B is the skip zone

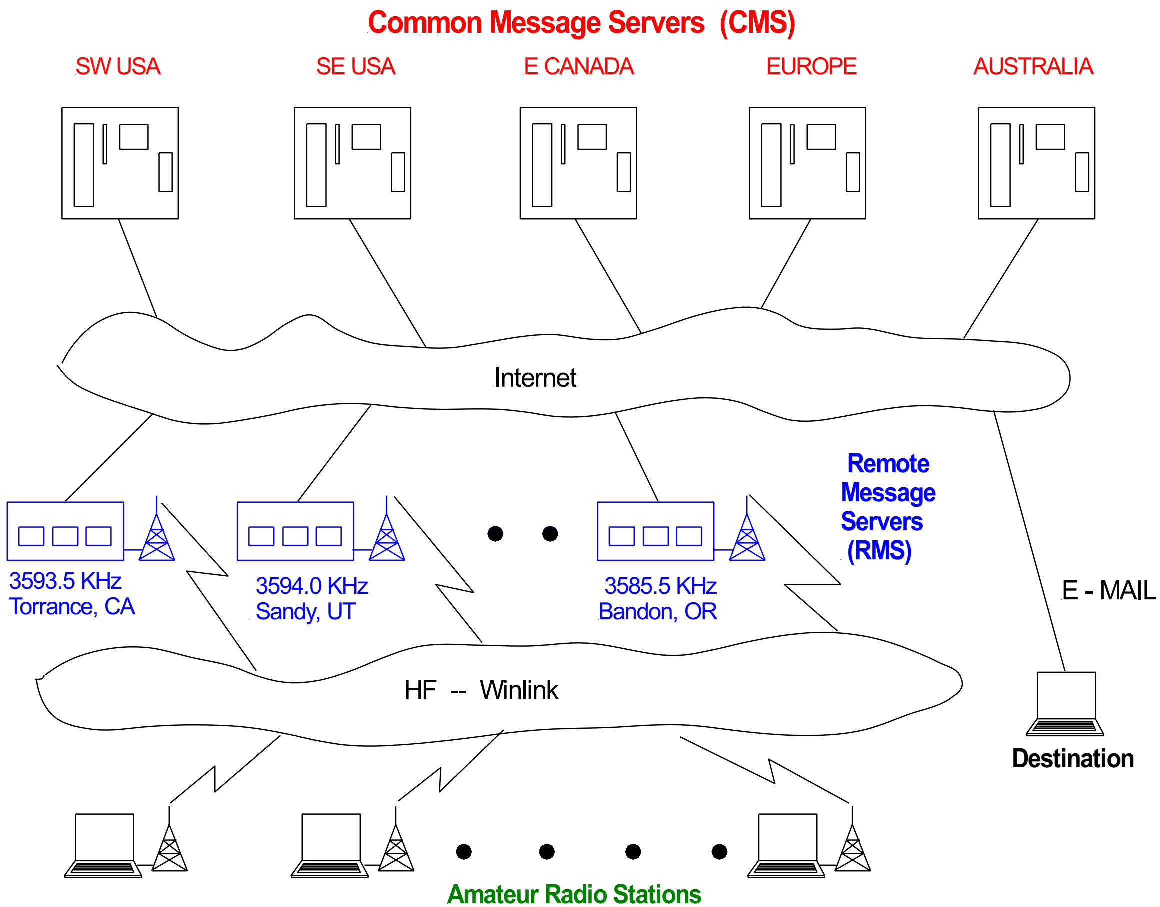
For HF Comm The Skip Distance Must Be Known





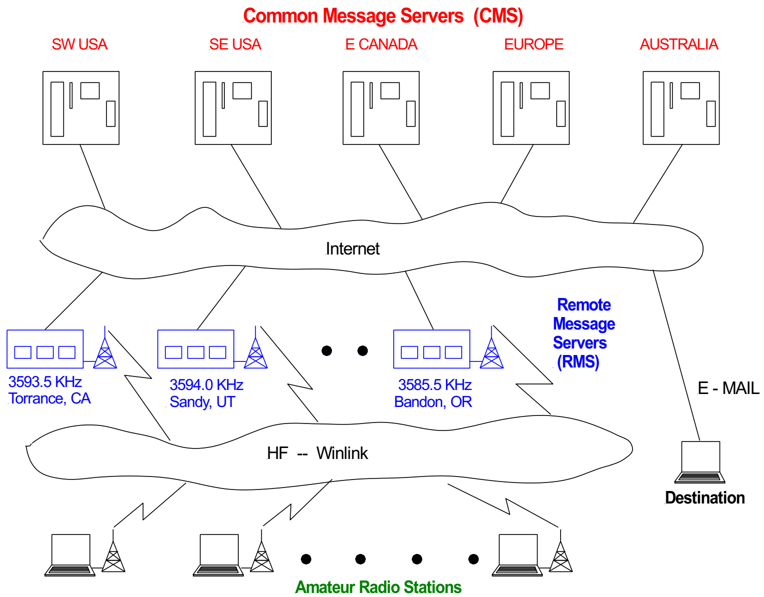
- When a skip zone exists, it is important to know where the edge of the skip zone is to determine what stations can be reached
- That is, the skip distance must be known

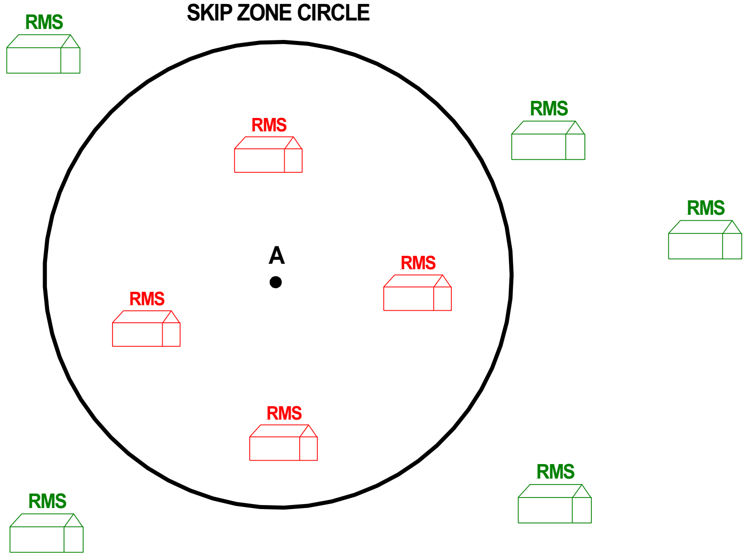
Winlink Example



- When using the Winlink emergency communications network it is important to know which RMS stations can be reached and which can not

Winlink Example continued

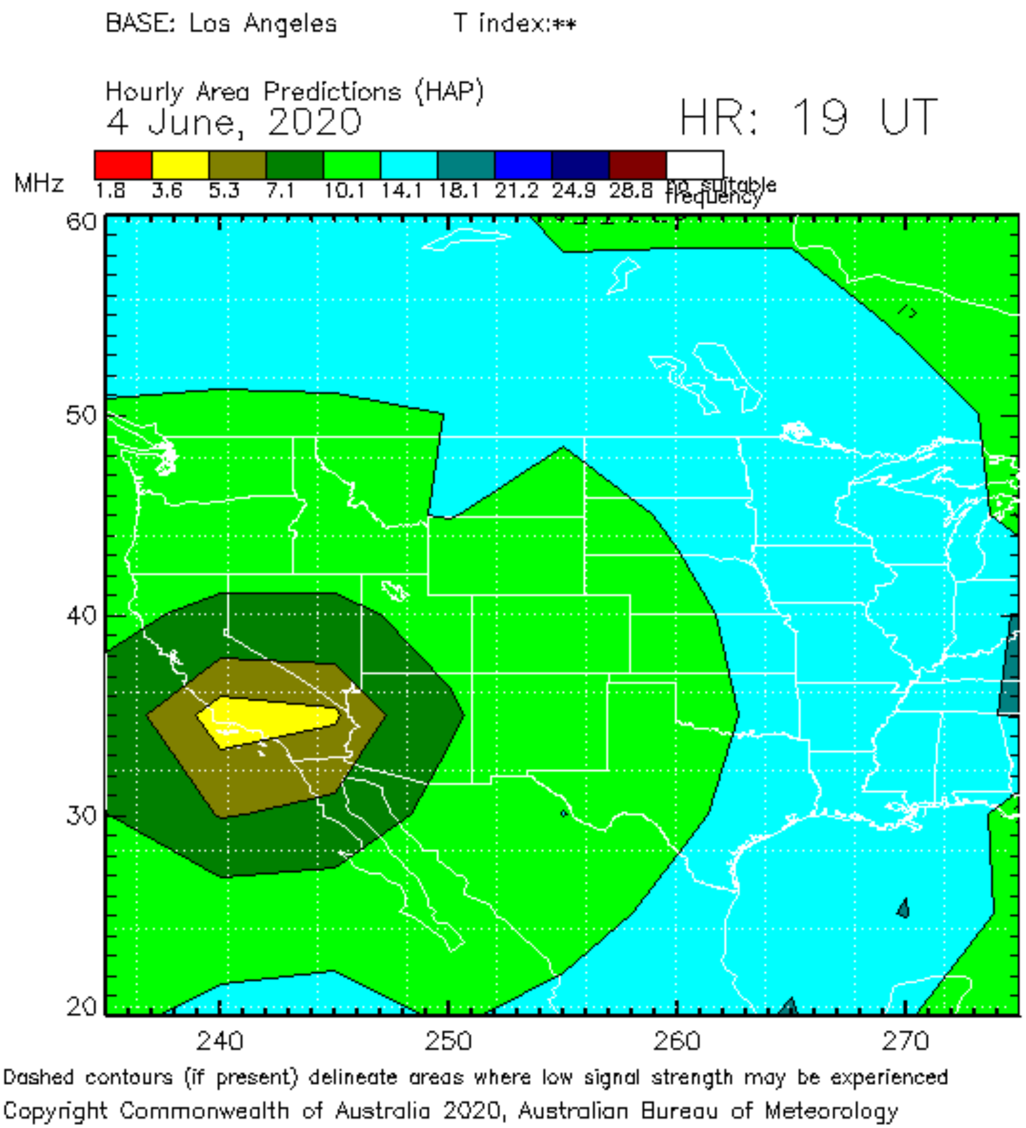




- Stations within the skip zone (red RMS houses) can not be reached
- Stations that can be contacted are outside the skip zone (green houses)
- Winlink projections of ”signal quality” do not take skip distance into account !
- The size of the skip zone, that is the skip distance, must be known to determine which RMS stations can be reached and which can not

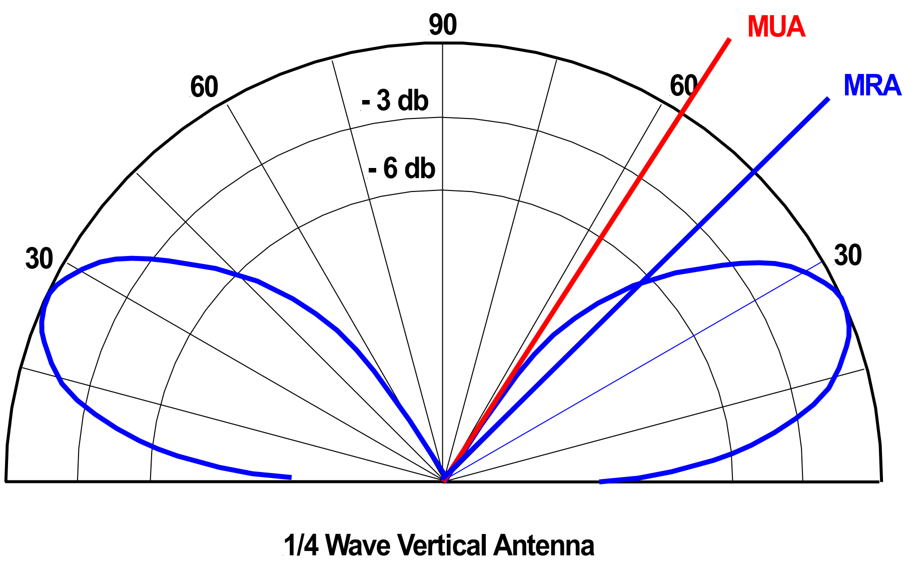
HAP Charts and Skip Distance

- Hourly Area Prediction - HAP charts - can be used to estimate skip distance.
- HAP charts are provided by the Australian Government
- They are available and explained under the Tools tab on the www.skywave-radio.org website
- In this HAP chart centered on Los Angles, California
- **The dark green region is the area of optimum 40 meter coverage**
- 40 meter coverage also extends into the light green and blue regions although multi-path problems may occur
- The brown and yellow areas are the 40 meter skip zone on this particular day and time of day



Skip Distance Determined By Your Antenna

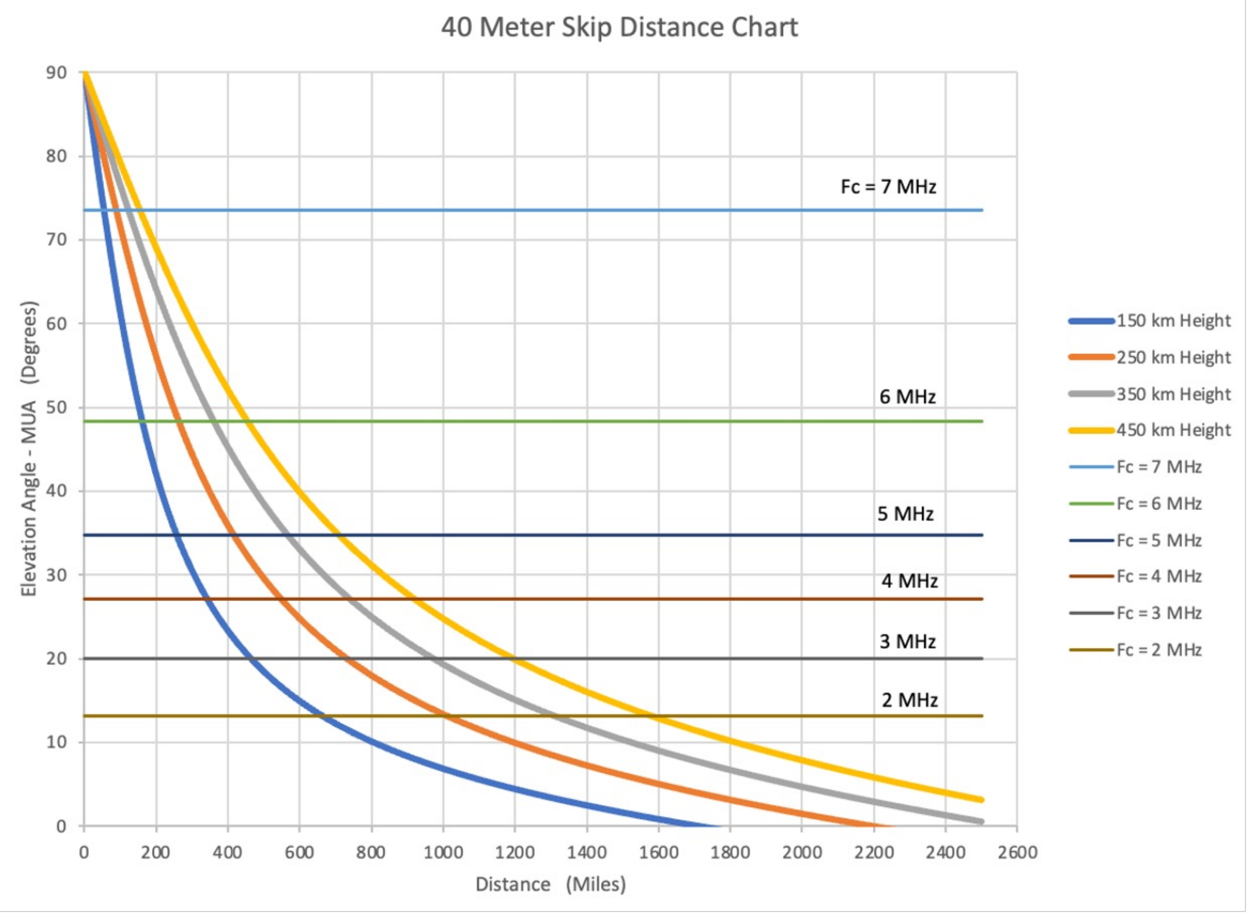
- Skip distance will be determined by your antenna
- IF
- The maximum radiated angle of your antenna MRA
- Is less than the MUA determined by the ionosphere's critical frequency f_c
- MRA = - 6db point



Example, skip distance at MUA = 60 degrees is about 200 miles (see next slide)

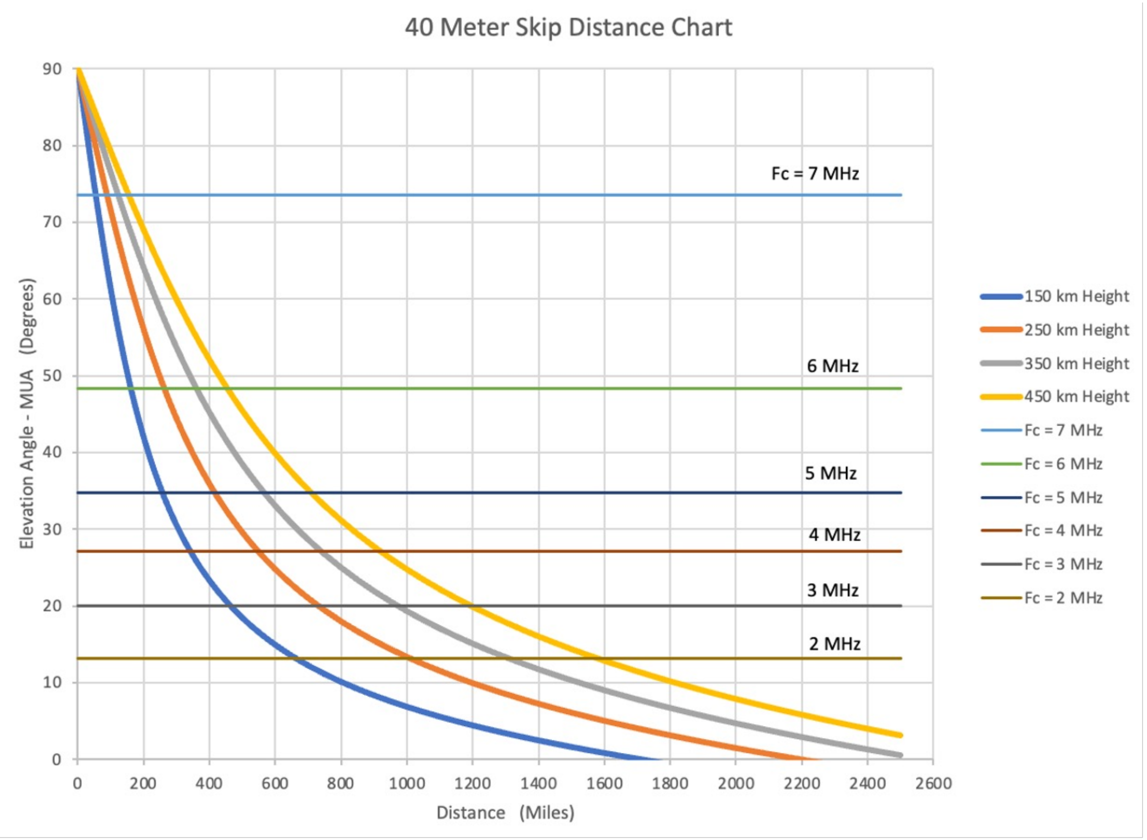
But the skip distance for a 40 m vertical antenna with an MRA of 45 deg is approximately 300 miles. Stations closer than 300 miles will be skipped over by the vertical antenna – a vertical is not a very good NVIS antenna

Skip Distance Charts



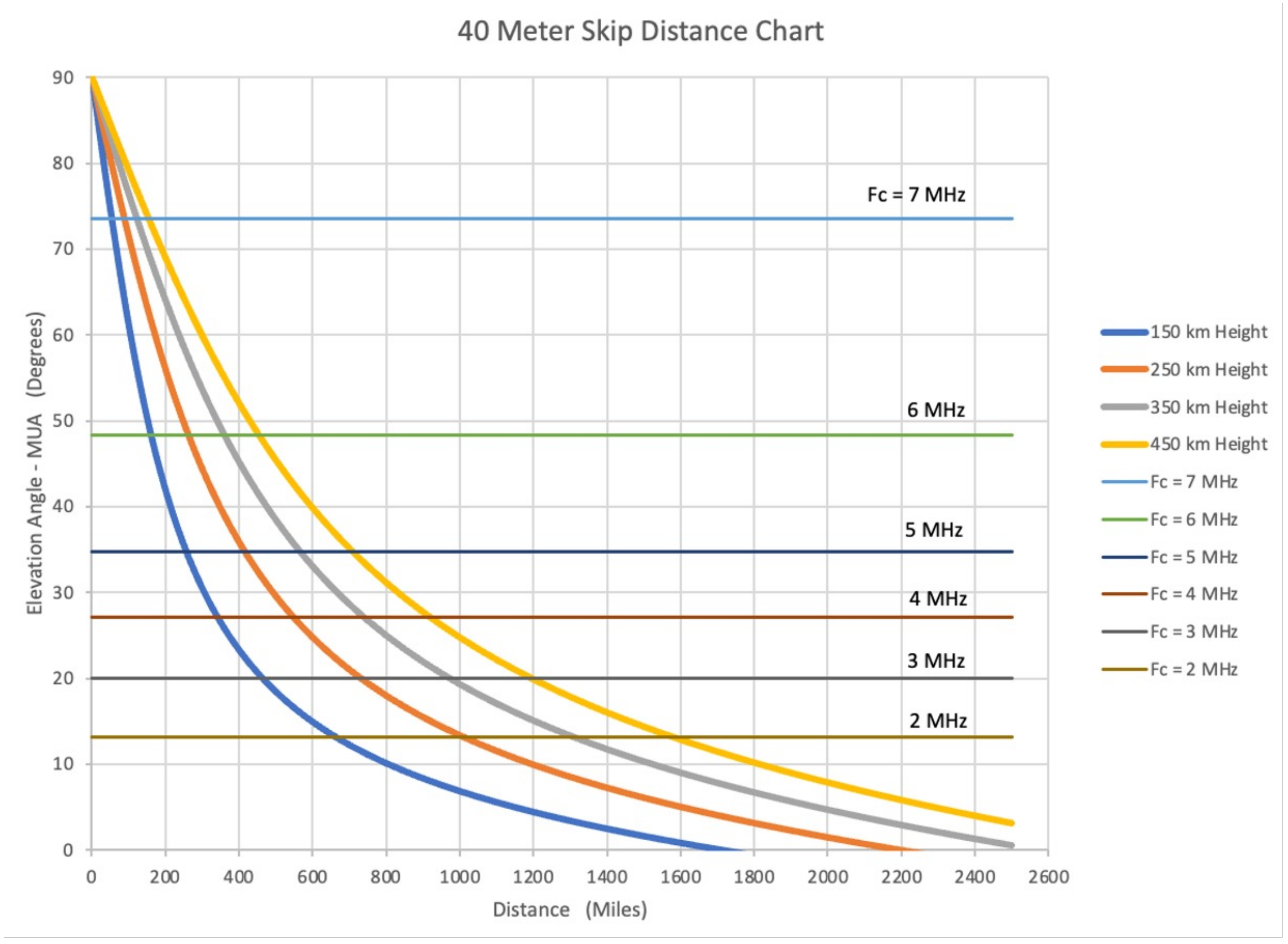
- Skip distance charts, like the one shown here, can be created for each frequency band and are available under the Tools tab of the website www.skywave-radio.org
- The chart provides single hop Distance vs Elevation Angle based on the height of the ionosphere's F2 layer (4 heights are illustrated)
- Example: A hop distance of 600 miles will be obtained when a signal is transmitted at an elevation angle of 25^{o} and the height of the F2 layer is 250 km

Skip Distance Chart continued



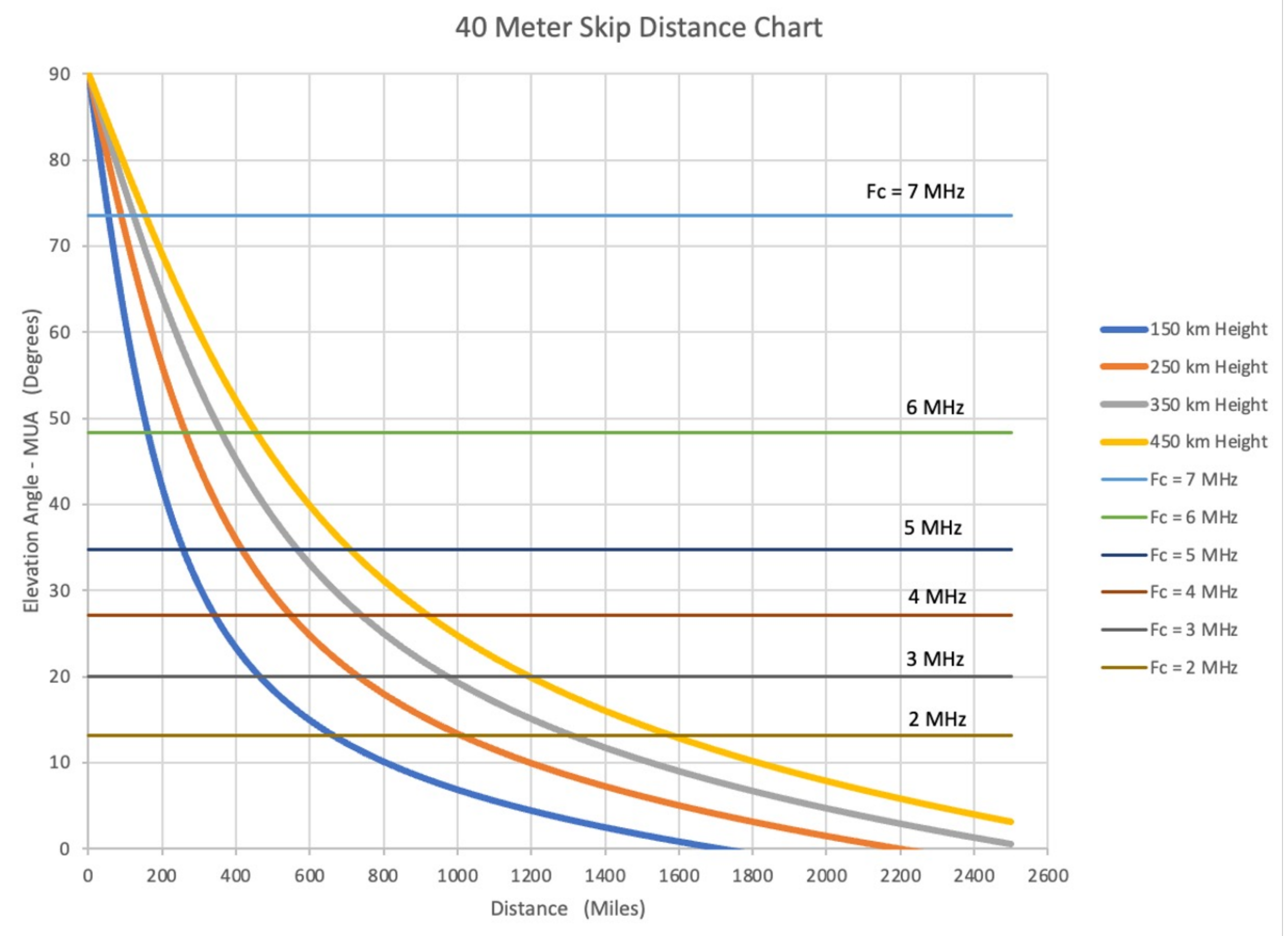
- The distance covered by a single hop becomes shorter as the elevation angle of the transmitted signal increase
- However, the current critical frequency places a cap on how short the hop distance can become by specifying the Maximum Usable Angle (MUA)
- Signals transmitted at angles greater than the MUA will penetrate the ionosphere and be lost to outer space

Skip Distance Chart continued



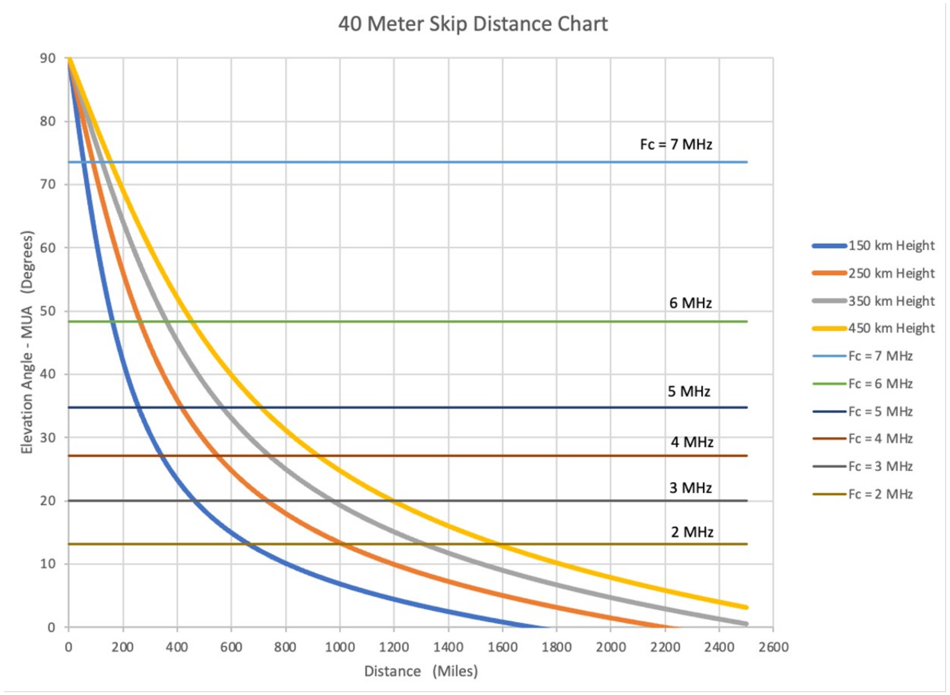
- Example: At a critical frequency of 5 MHz the MUA is 35°
- Signals transmitted at angles higher than this can not be used for communications since they will be lost to outer space

Skip Distance Chart continued



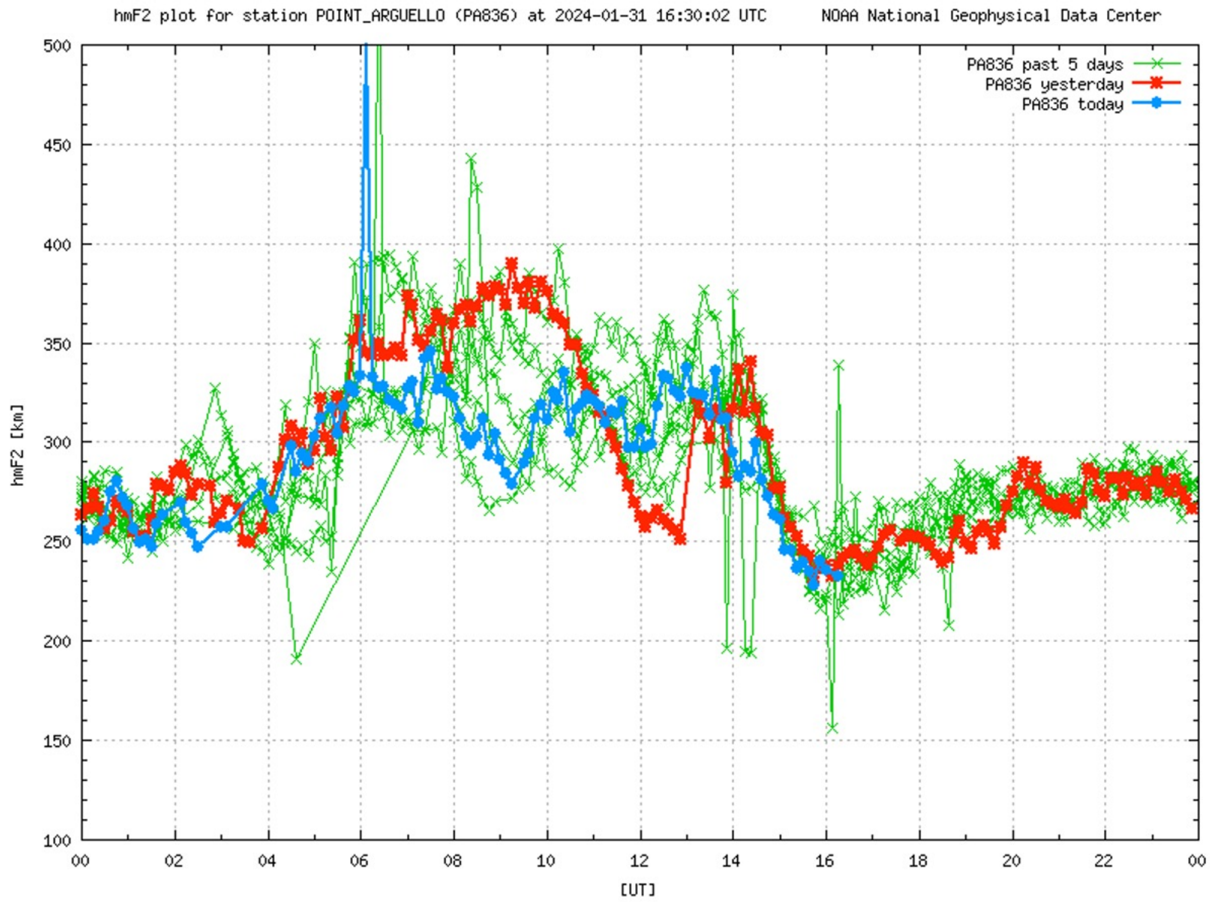
- Consequently, the intersection of the appropriate height curve and the current critical frequency defines the shortest possible hop for current conditions
- 400 miles is the shortest possible hop for a critical frequency of 5 MHz and a F2 height of 250 km – you can’t transmit a shorter distance without violating the MUA
- By definition the length of this hop is the current skip distance

Determining Skip Distance



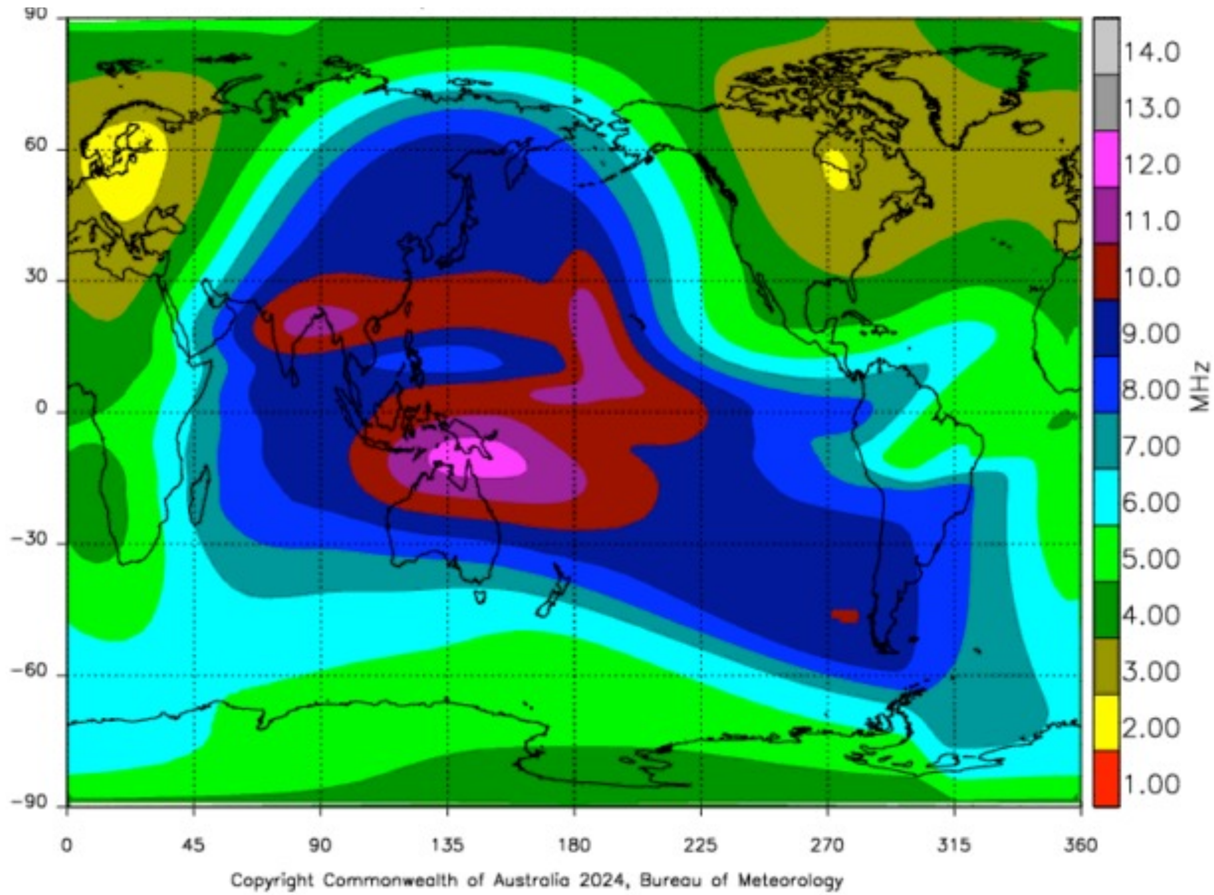
- Skip distance is determined by selecting the F2 layer ionospheric height h_mF2 from the appropriate Ionosonde Site
- For California this is done by clicking on Ionogram under the Current Conditions tab of the www.skywave-radio.org web site then clicking on Point Arguello, CA hmF2 (for example Point Arguello hmF2 = 250 km see following slides)
- Next, select the current critical frequency Fc by clicking on Critical Frequency under the Current Conditions tab (for example Fc = 4.5 MHz as shown below)
- The Point Arguello ionosonde provides more detailed critical frequency data

Ionosphere Height h_mF2 @ Point Arguello



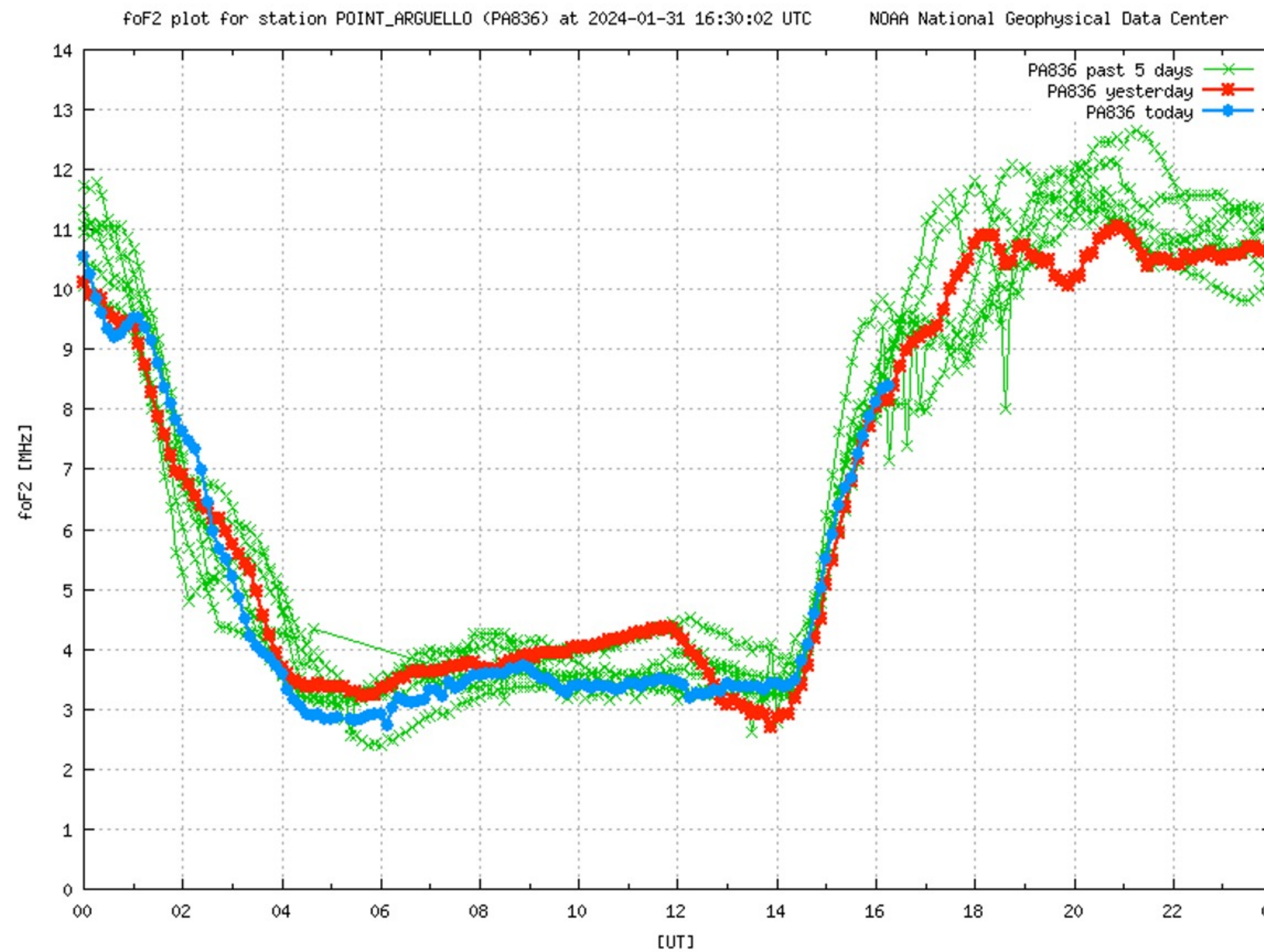
- This chart shows h_mF2 for the past 5 days, yesterday, and today in UT time
- At the time of this chart (Jan 31, 2024 @ 03:00 UT) h_mF2 Blue Trace was 250 km

Ionosphere Critical Frequency



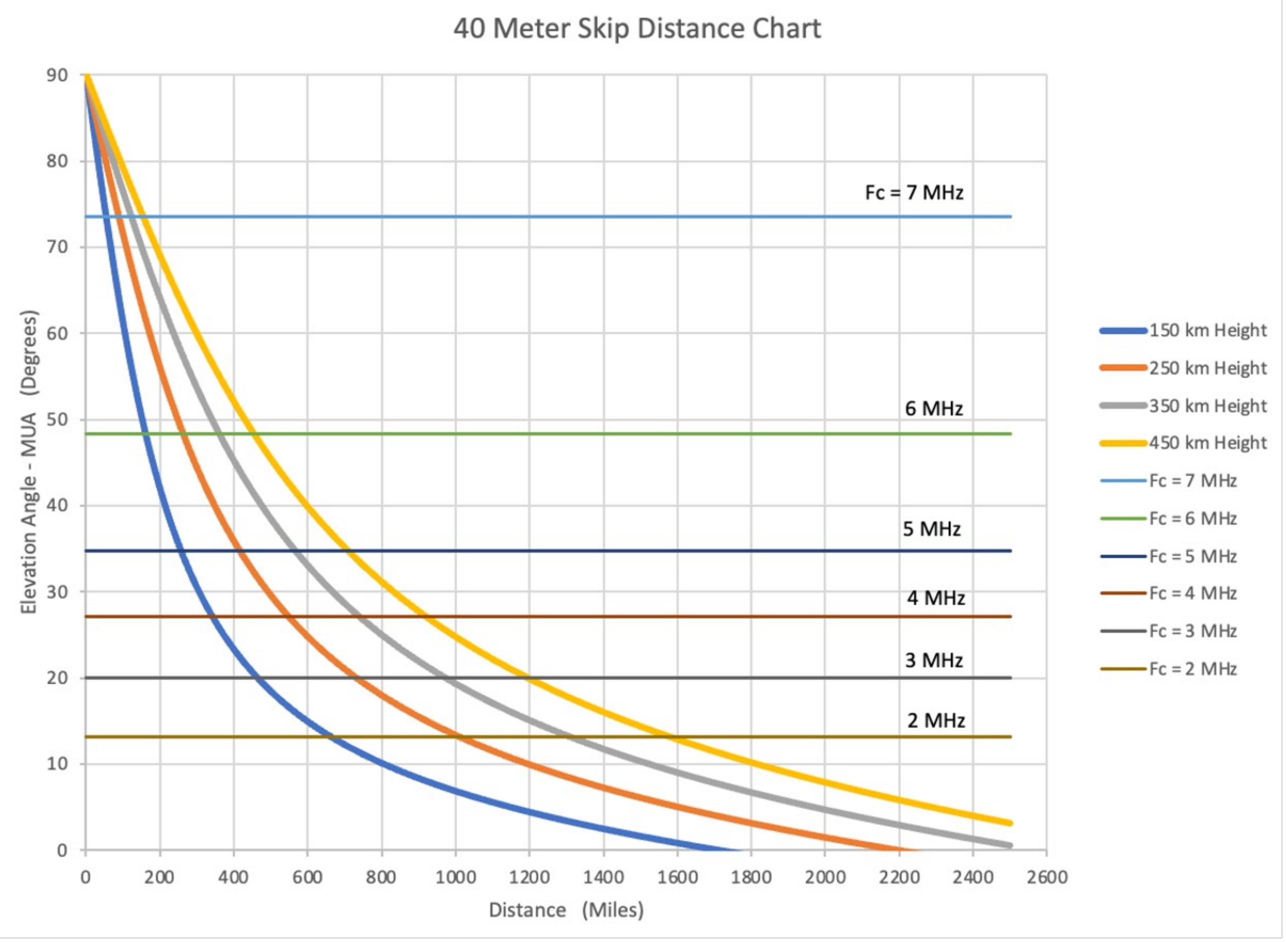
- This chart shows the Critical Frequency for January 31, 2024 at 03:00 UT
- Over California the Critical Frequency was between 4 to 5 MHz

Ionosphere Critical Frequency foF2 @ Point Arguello



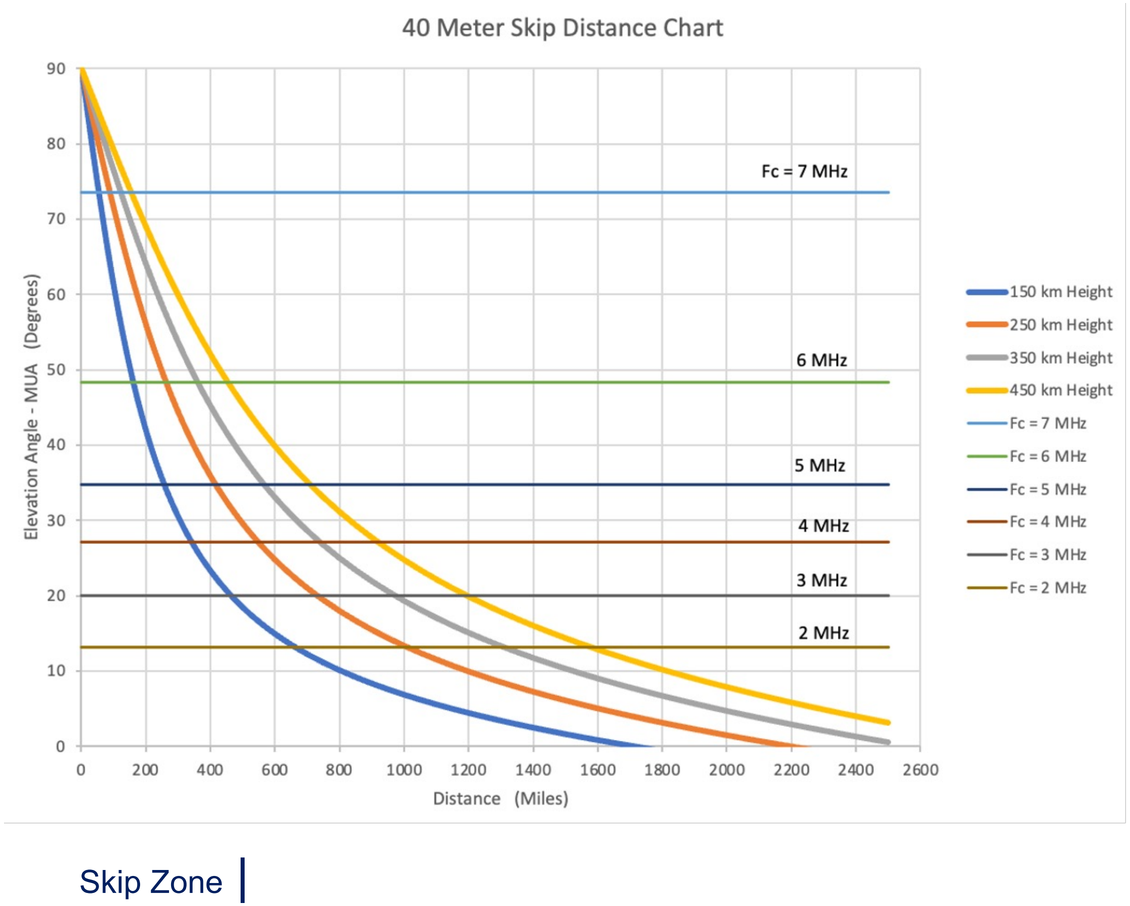
- Point Arguello provides a more detailed critical frequency chart for California
- This chart shows foF2 for the past 5 days, yesterday, and today in UT time
- At the time of this chart (Jan 31, 2024 @ 03:00 UT) foF2 Blue Trace was 5 MHz

Determining Skip Distance



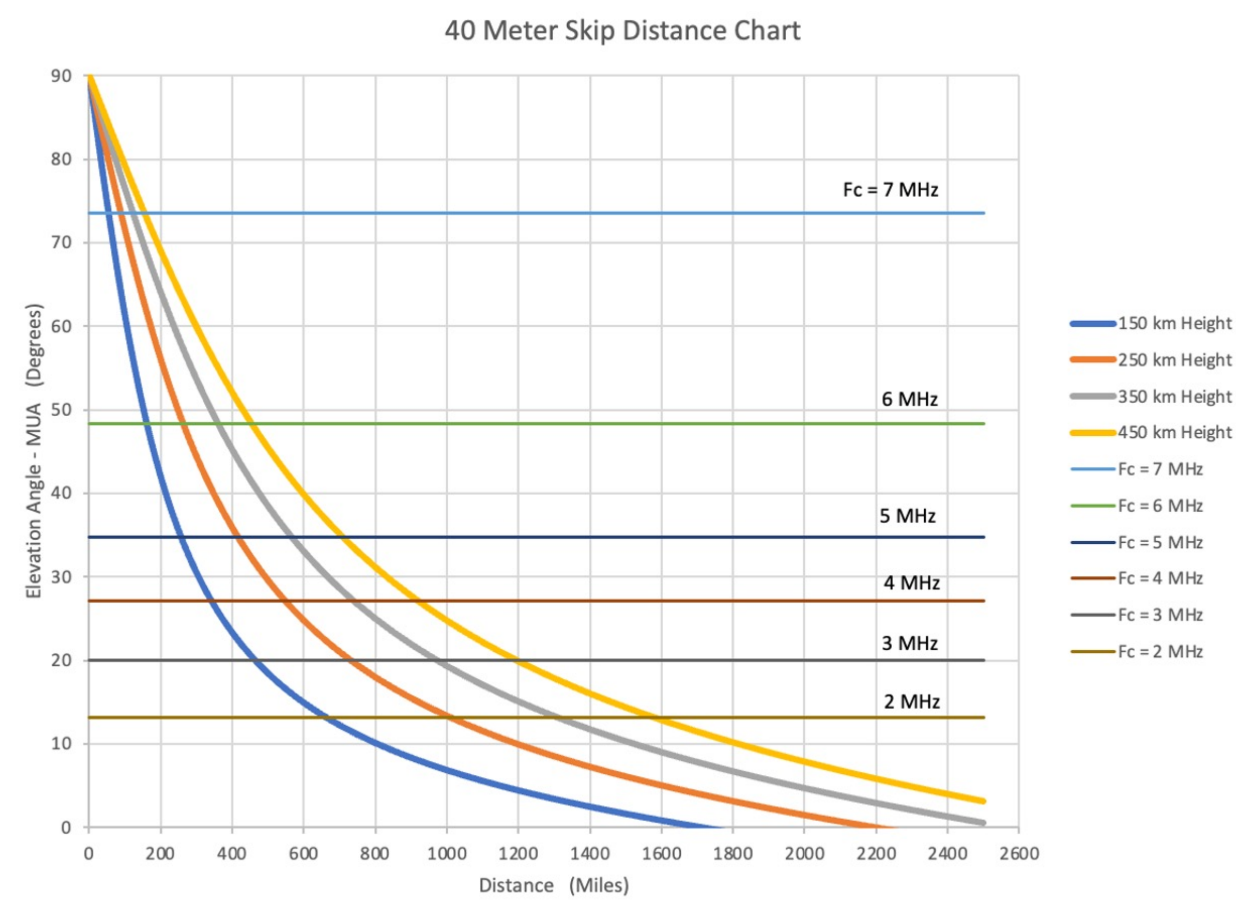
- From the intersection of the Height (250 km) and Fc (4.5 MHz) traces read down to the Distance axis
- This is the approximate skip distance (500 miles in this example) for the current conditions --- The same result obtained by the 40 meter skip distance experiment

Reachable Stations



- Stations that can be reached are those beyond the skip zone which in this example are below and to the right of the F_c = 4.5 MHz and h_mF2 = 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^o , often 15 to 20^o

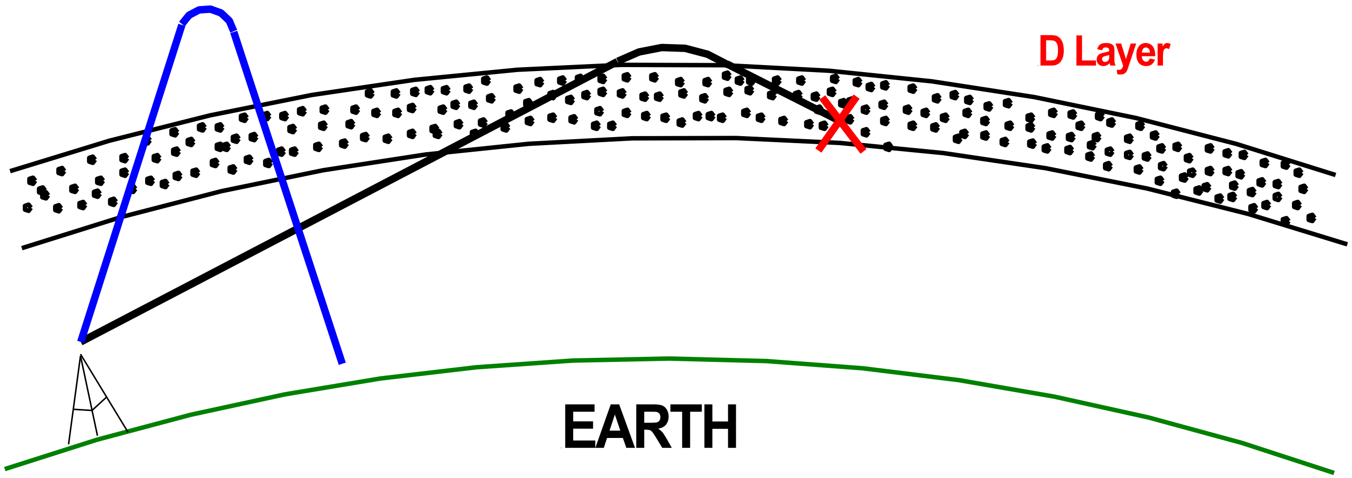
Reachable Stations continued



Bound by MUA | reachable range | Bound by antenna

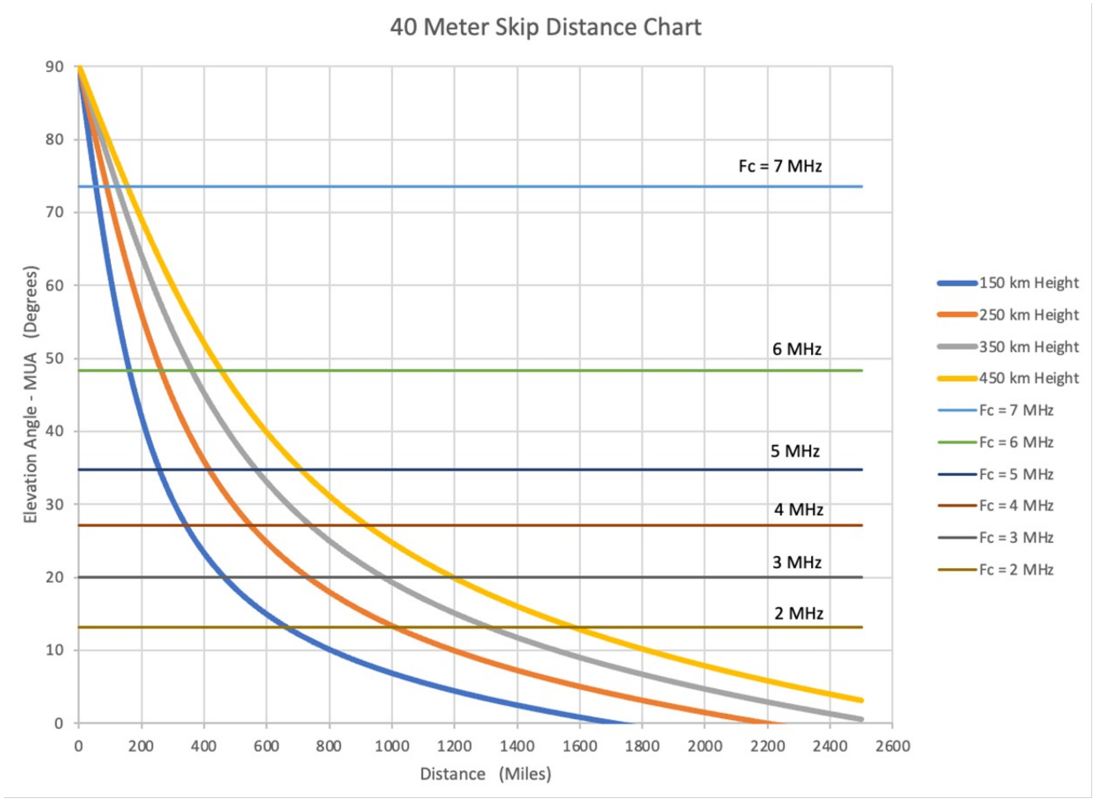
- For this example, the furthest station that can be reached in one hop is defined by the antenna's 10^{o} elevation angle and $h_mF2 = 250$ km junction
- This distance is approximately 1,200 miles

Long Hop Signals May Be Absorbed



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

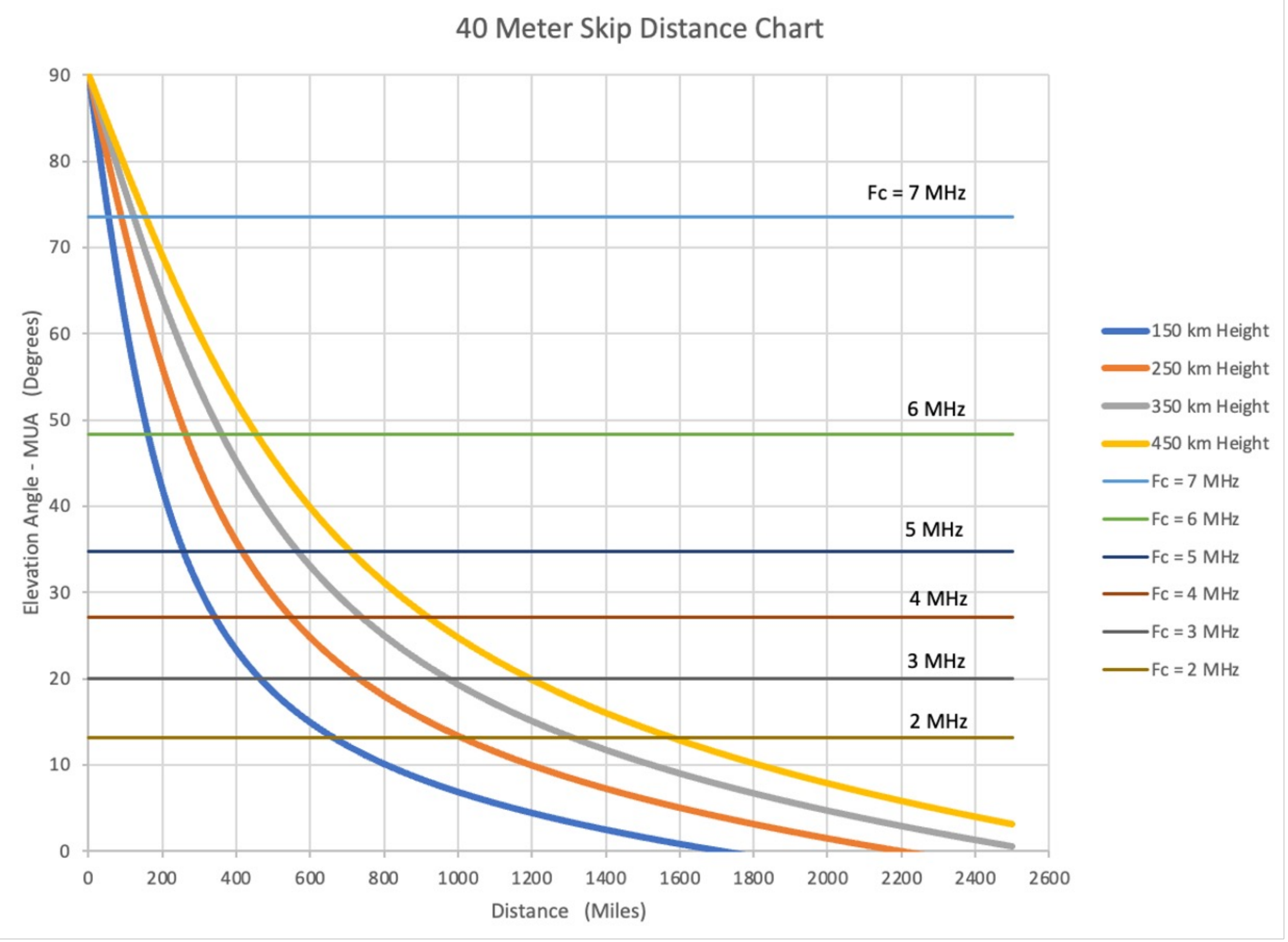
Stations Just Beyond The Skip Zone



Skip Zone

- Stations just beyond the skip zone 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

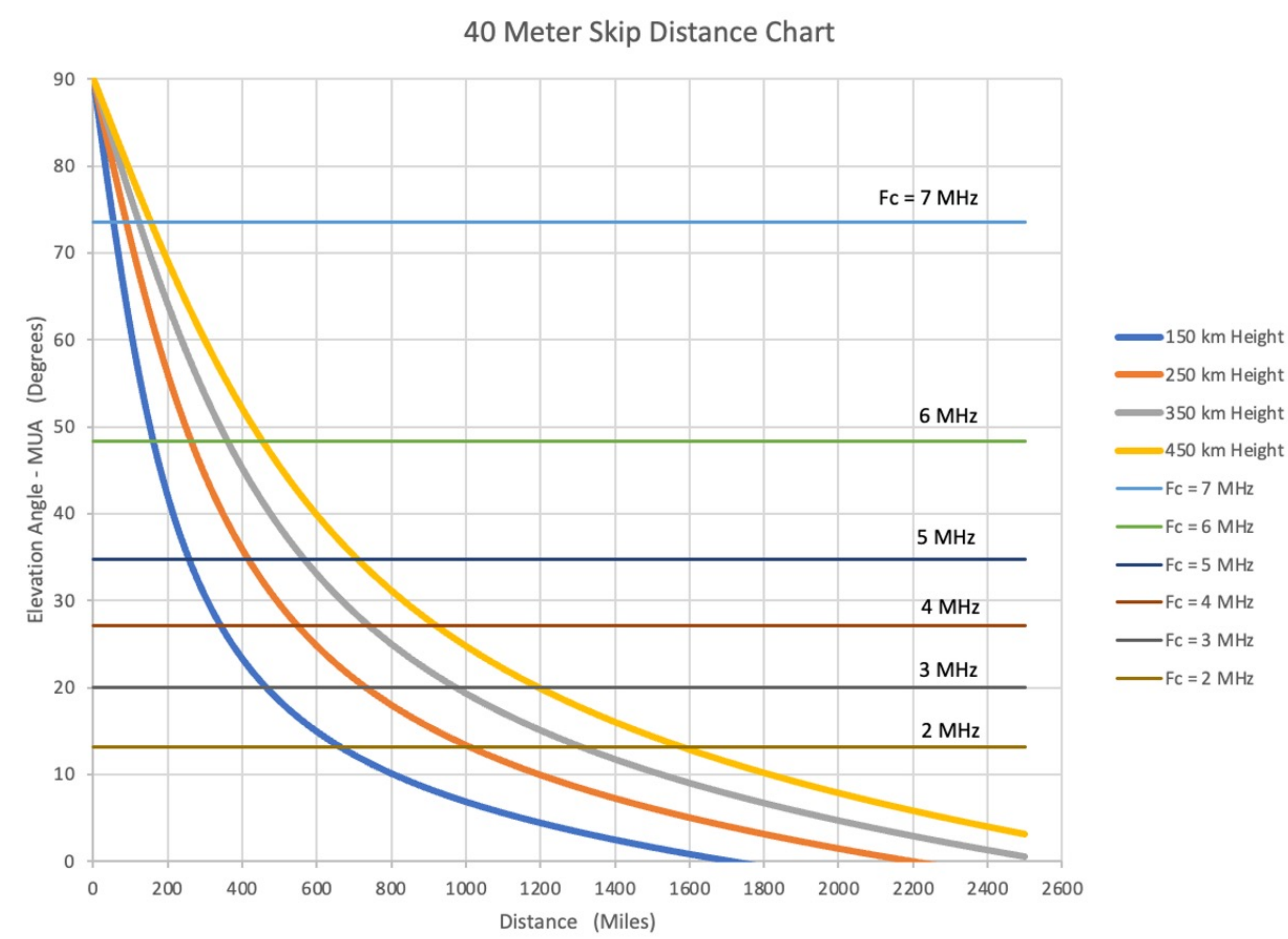
Stations Requiring Two or More Hops



| First Hop Range |

- 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 500 to 1,200 miles

Observing High Path Propagation

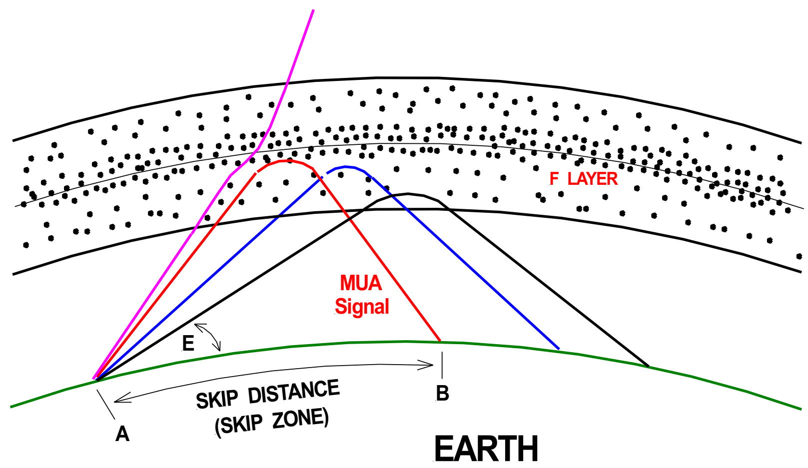


| Reachable Range |

- In some cases stations further away (for example 1200 - 1400 mi) are strongly received while closer stations are either weak or can not be received at all

- This is often an indication of high path propagation

Skip Distance Summary



Skip distance, and the associated skip zone, are a function of

- A radio station's operating frequency (f_o) – which is known,
- Critical Frequency (f_c) – determined by the global critical frequency map,
- Maximum Usable Angle (MAU) – $\mathrm{MUA} = E_M = \sin^{-1}\left(\dfrac{f_c}{f_o}\right)$
- Skip distance can be directly read from HAP charts
- Skip distance can also be determined using Skip Distance Charts
- A skip zone exists only if $f_c < f_o$, otherwise there is no skip

That’s it Folks - HF Radio is a LOT of FUN !