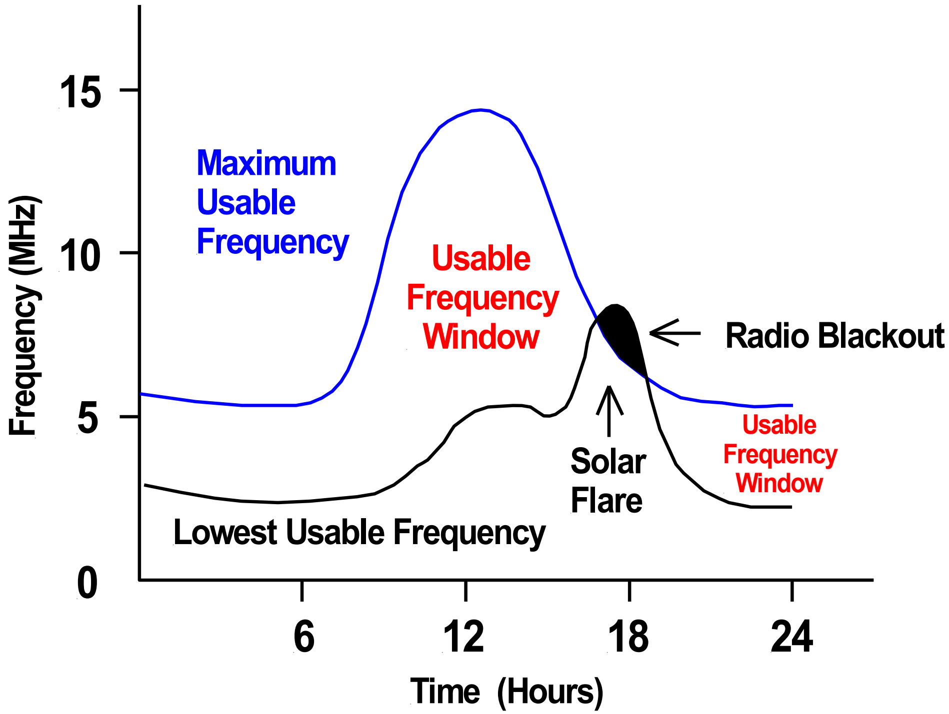
Maximum Usable Frequency
and its Derivatives



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June, 2020

www.skywave-radio.org

Why Bother With MUF ?

- We turn the radio on
- Check the bands
- If the bands are open
  - We dive into a contest, or
  - Work new DX, or
  - Have fun just rag-chewing
- If band conditions are really terrible, we turn the radio off and try again on an other day
- After all, amateur radio is suppose to be a fun, relaxing, low stress hobby.

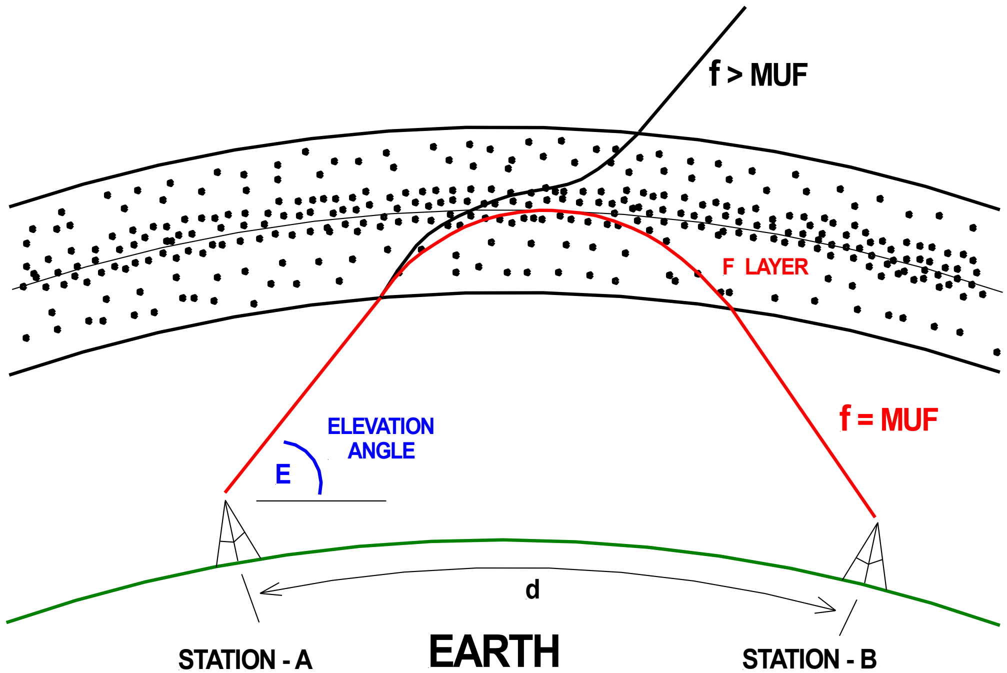
But What If HF Isn't Just a Hobby?

- Suppose HF is the only means of contact you have with the outside world …… then it gets more serious
- We depended heavily on HF communications during WW II
  - Communications across Europe, Africa, throughout the Pacific
  - The only communications with ships at sea and aircraft
  - Failure to communicate was not an option
  - Solar conditions degraded throughout the war
    - Solar Maximum occurred in 1937
    - Solar Minimum in 1944
  - QRM was really bad
    - Amateur radio, of course, was prohibited
    - Heavy military traffic packed the HF bands
    - And half of the traffic was that of the enemy
    - CW and RTTY used, it could be encrypted, voice couldn't

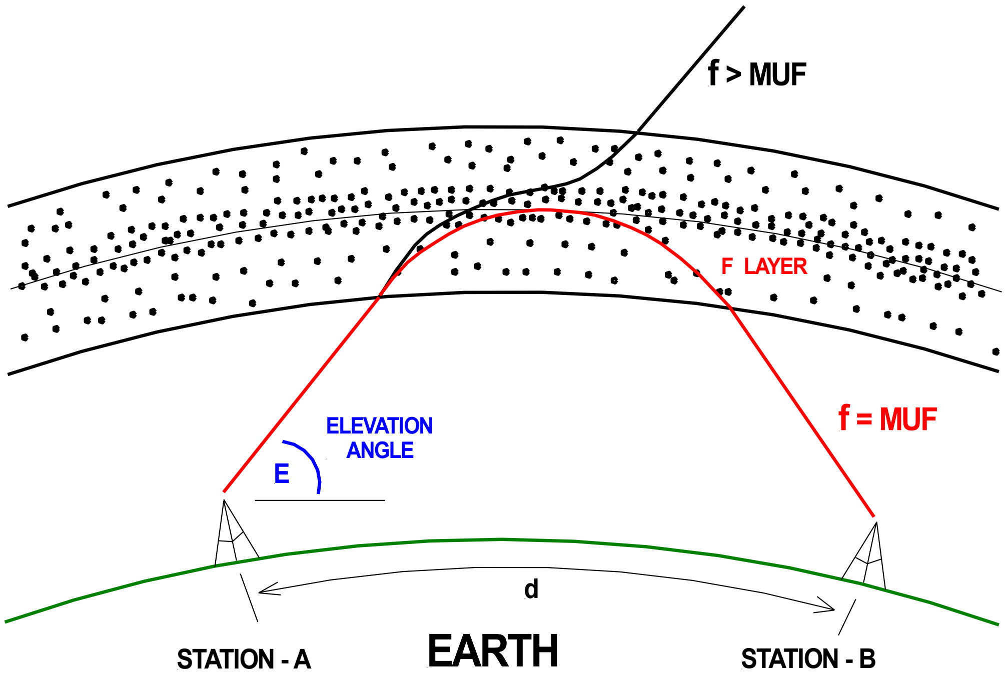
When All Else Fails ……

- Applies directly to HF
- HF is the only means of electronic communications that does NOT depend on an infrastructure
- You can communicate from anywhere via HF if:
  - You have a power source (portable or otherwise),
  - You have an HF transceiver, and
  - You can get an antenna up.
  - I always carry an HF radio in my RV, including vertical and horizontal antennas.
- We study MUF and the other parameters because HF is often serious business.

Maximum Usable Frequency

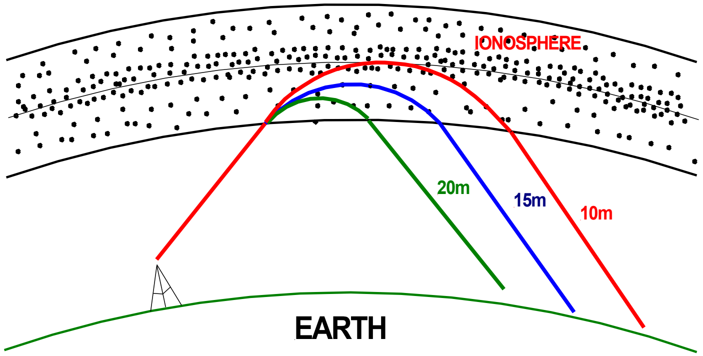


Maximum Usable Frequency is:

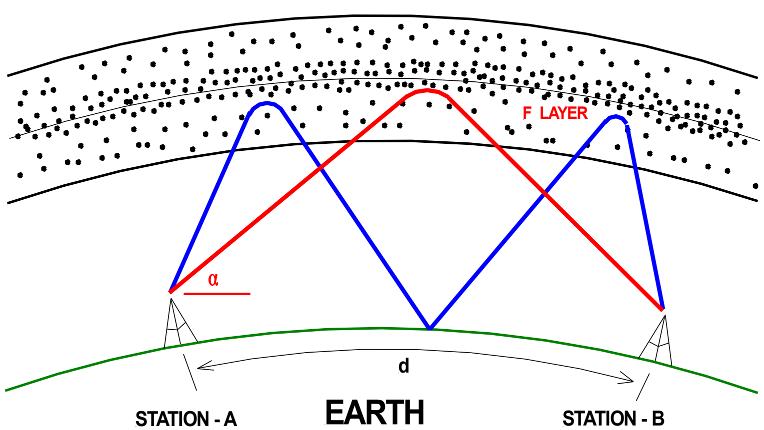


- The highest frequency radio signal that can be
- Transmitted through the ionosphere
- From one **specific** radio station to an other.
- Attempting to operate at a higher frequency will cause the radio signal to penetrate the ionosphere and be lost to outer space.

Advantages of Operating at the MUF

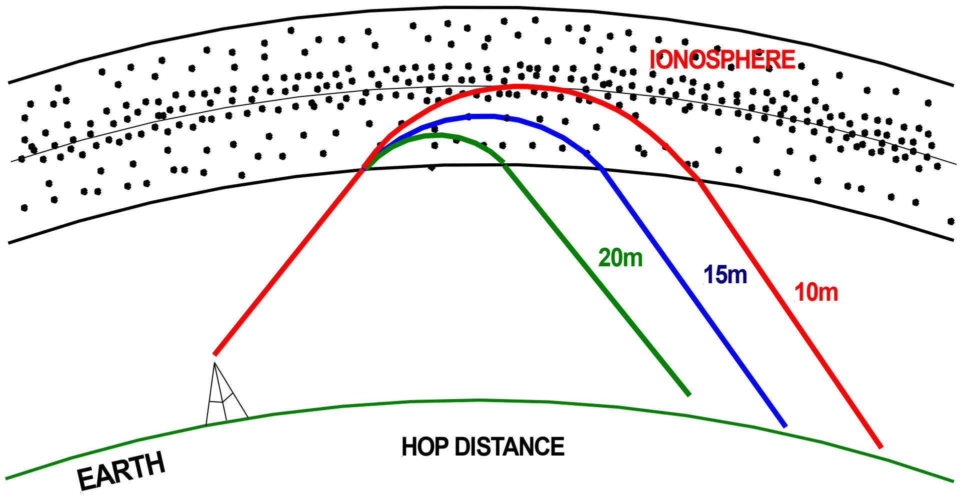


$$\text{Absorption} \propto \frac{1}{f^2}$$



- The longest hops, best DX occurs at the MUF
  - When it is open, DX on 15m is better than on 20m
  - DX is the best on 10m
- Operating at the MUF minimizes D Layer absorption
  - D Layer absorption is inversely proportional to freq squared
  - To avoid absorption, want to operate at the highest freq possible
- Operating at the MUF often reduces multi-path interference

Frequency Dependency of Refraction



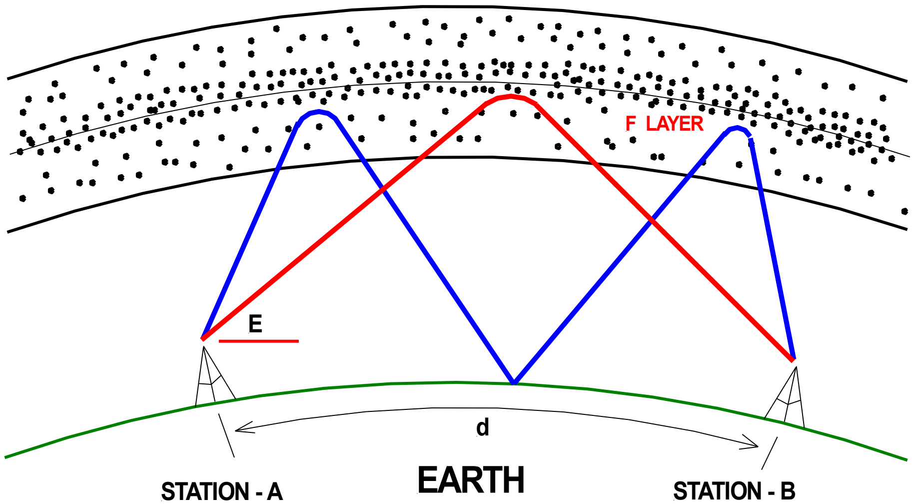
- Radio signals penetrate further into the ionosphere as the transmitting frequency increases, increasing the hop distance.
- The hop distance on 10 meters is greater than that on 15 meters, and both are greater than the 20 meter hop distance.
- With longer hops, DX is better on 15 meters than on 20 meters, and even better on 10 meters.
- For the best DX we want to operate at the MUF.

Absorption vs Frequency

$$\text{Absorption} \propto \frac{1}{f^2}$$

- D Layer absorption is inversely proportional to frequency squared.
- Absorption on 40 meters is only 1/4 that on 80 meters.
- Absorption on 20 meters is only 1/16 that on 80 meters.
- And D Layer absorption on 15 meters is insignificant.
- To avoid absorption, we want to operate at the highest frequency possible.

Controlling Multi-path Problems



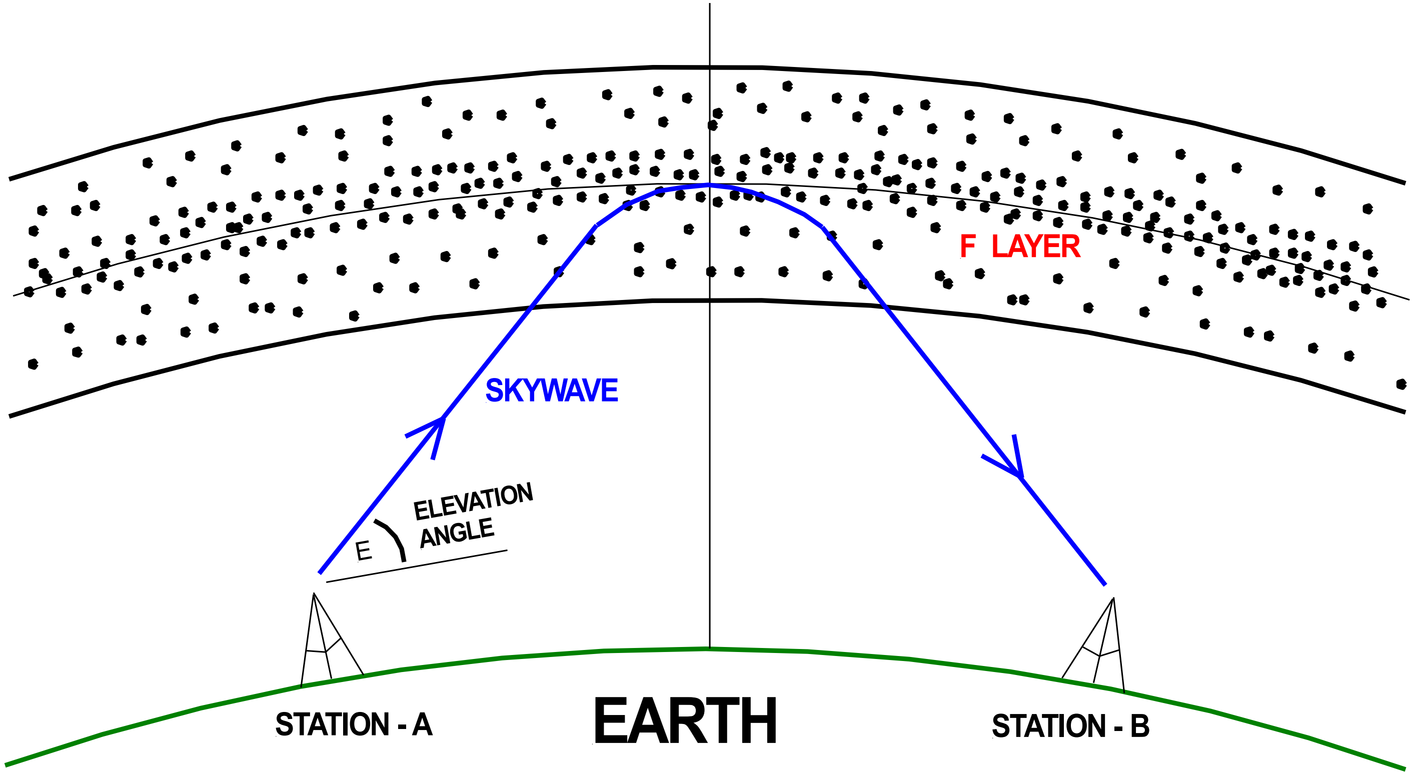
- Communications between Los Angeles and Denver on 40 meters, a distance of 830 miles, often occurs by both single hop and double hop propagation.
- The double hop path is much longer than the single hop path.
- Result: destructive interference between the single & double hop propagation paths seriously weakens and distorts communications.
- At higher frequencies (for example 20 meters) the double hop path penetrates the ionosphere and disappears into outer space.
- The lower angle single hop path is the only path remaining eliminating multi-path interference.
- Operating at the highest possible freq (MUF) often solves multi-path problems.

MUF Equation

$$\text{MUF} = \frac{f_c}{\sin E}$$

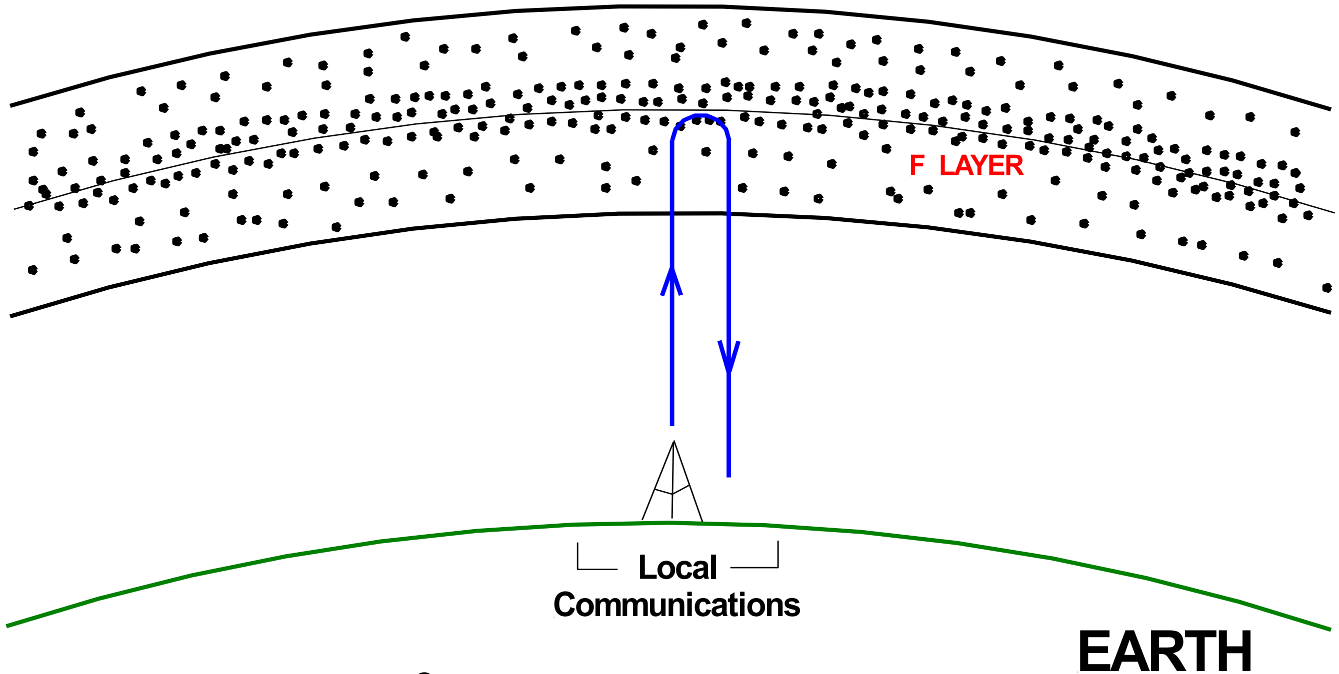
- MUF = Maximum Usable Frequency
- E = Elevation angle of the signal radiating from your antenna.
- **fc** = The ionosphere's Critical Frequency.

Elevation Angle E



$$\mathrm{MUF} = \frac{f_c}{\sin E}$$

Critical Frequency

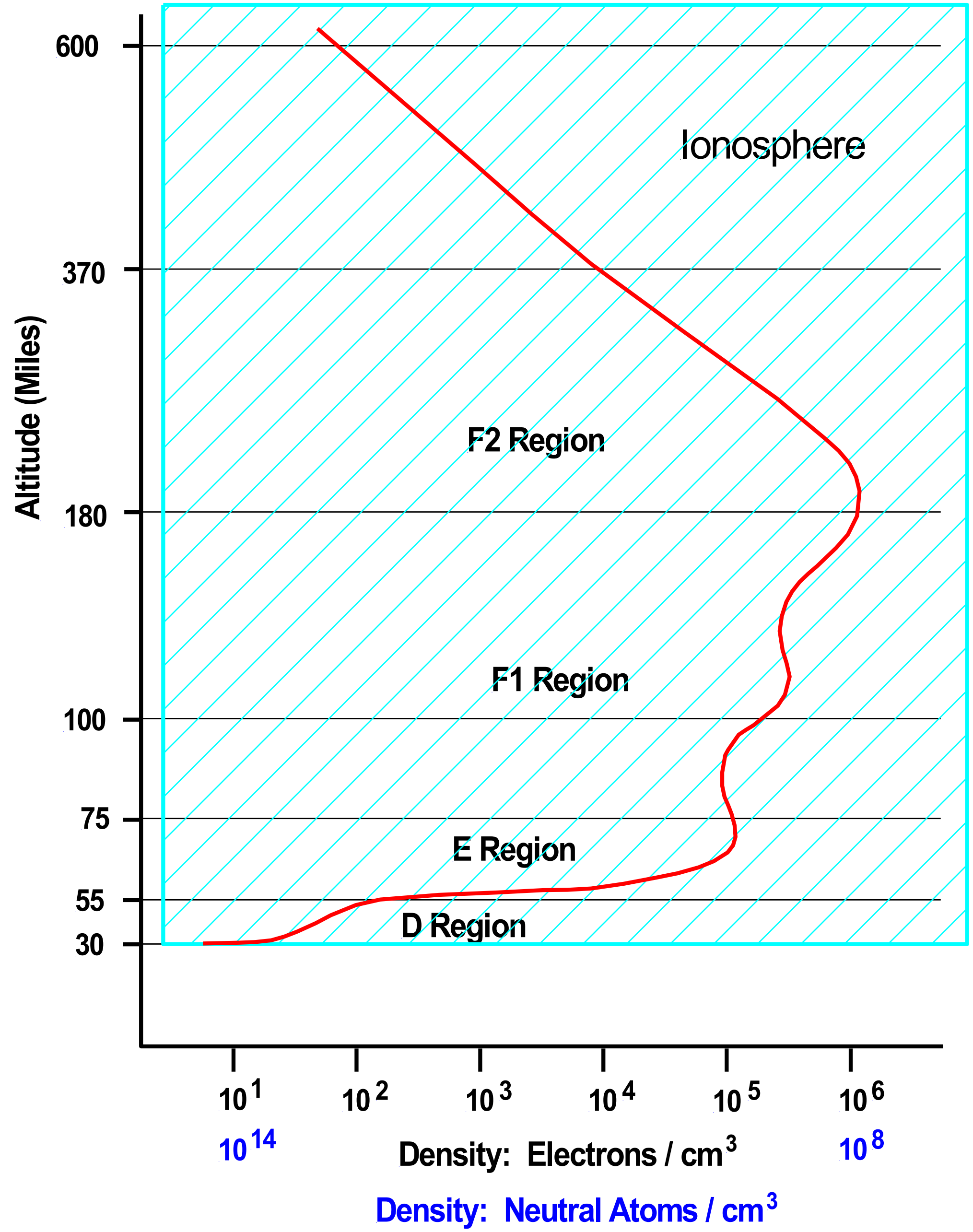


$$MUF = \frac{f_c}{\sin E}$$

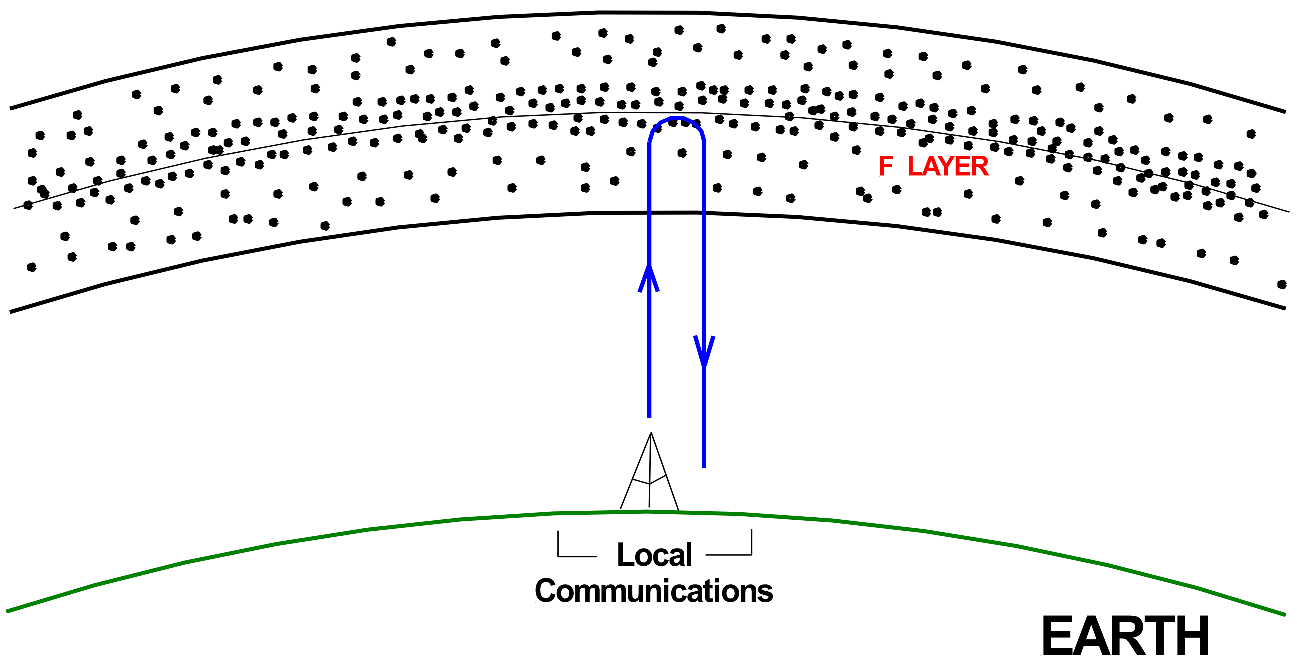
- Critical Frequency **f_c** is the highest frequency signal that can be transmitted straight up and reflected back down to Earth.

Critical Frequency

- Each region of the ionosphere has its own critical frequency
- Critical frequency is determined by the maximum electron density in each region
  - F2 Layer = f_{cF2}
  - F1 Layer = f_{cF1}
  - E Layer = f_{cE}



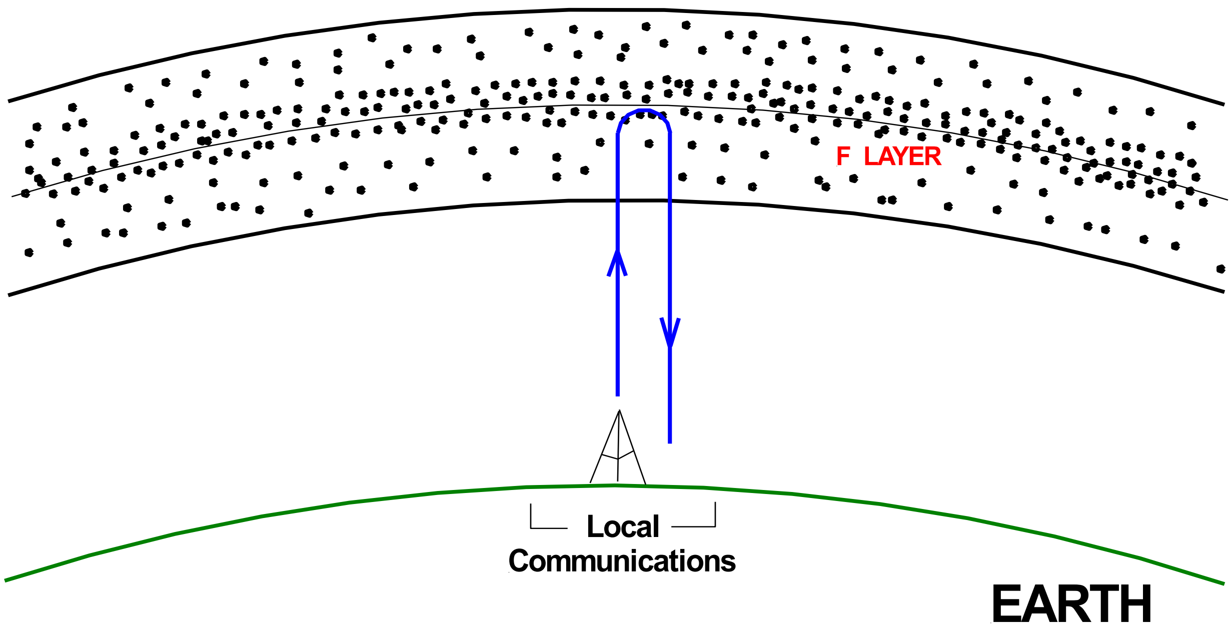
MUF is Greater Than or Equal To fc



- At an elevation angle of 90 deg, MUF = fc
- MUF increases, becomes greater than fc , as elevation angle E decreases

$$\mathrm{MUF} = \frac{f_c}{\sin E} = \frac{f_c}{\sin 90^o} = \frac{f_c}{1} = f_c \qquad \mathrm{MUF} = \frac{f_c}{\sin E} = \frac{f_c}{\sin 45^o} = \frac{f_c}{0.707} = 1.41\, f_c$$

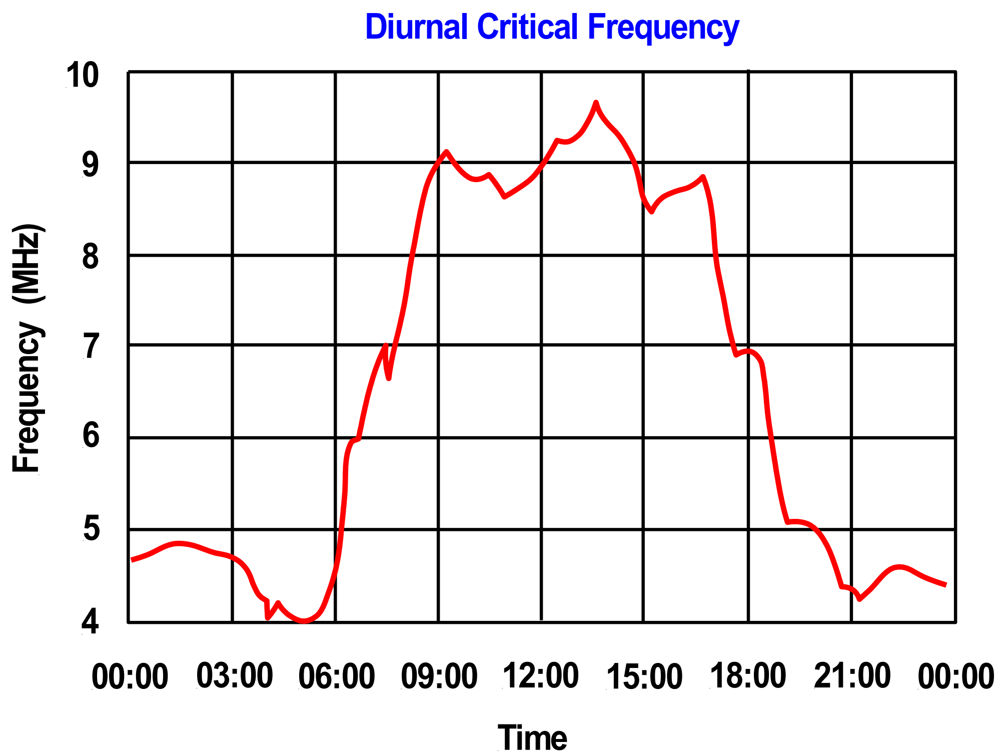
Critical Frequency Varies



$$MUF = \frac{f_c}{\sin E}$$

- The ionosphere is formed by Extreme Ultra Violate radiation from the Sun.
- Thus, Critical Frequency (and MUF) varies:
  - Throughout the day.
  - Seasonally.
  - In accordance with the 11 year solar cycle.

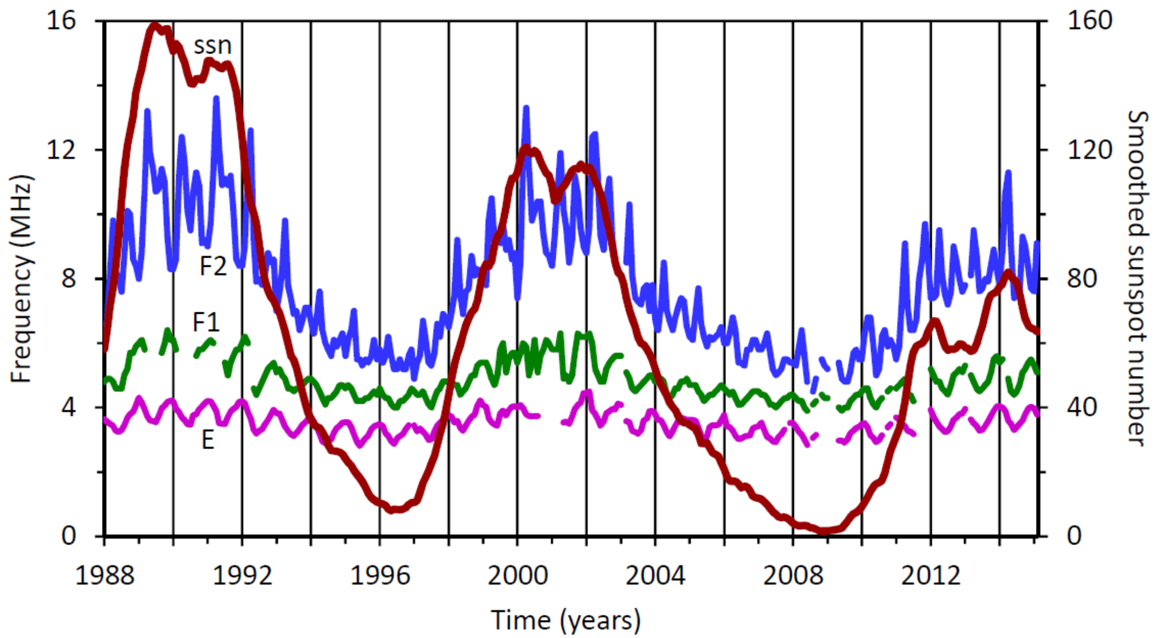
Typical F2 Layer Diurnal Critical Frequency



$$MUF = \frac{f_c}{\sin E}$$

- The F2 Layer critical frequency varies throughout the day.
- It is at its lowest level just before sunrise.
- It increases quickly following sunrise.
- Reaches a maximum from noon to about 2 PM (1400 hours).
- Then declines in the late afternoon and throughout the evening.

Critical Frequency Variation With Solar Cycle

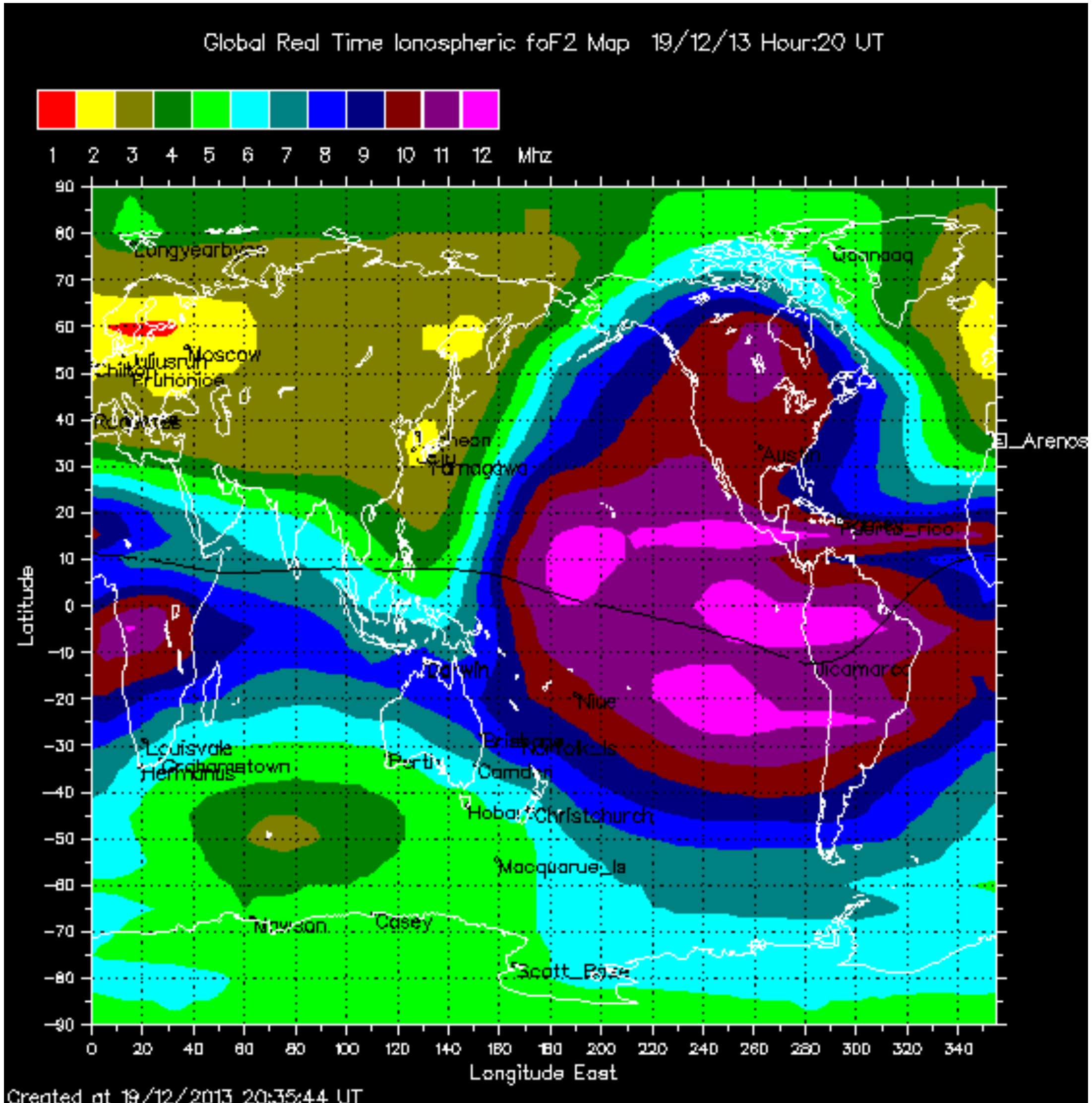


$$MUF = \frac{f_c}{\sin E}$$

- Since the EUV energy from the Sun varies with the 11 year solar cycle, the level of ionization in the ionosphere also varies with the solar cycle.
- This variation is particularly evident in the variation of the F2 critical frequency.
- As can be seen in the above figure, f_{cF2} tracks the solar cycle very closely (solar cycle represented by the smoothed sunspot number - ssn)
- The F1 and E critical freq also track the solar cycle, but not as dramatically.

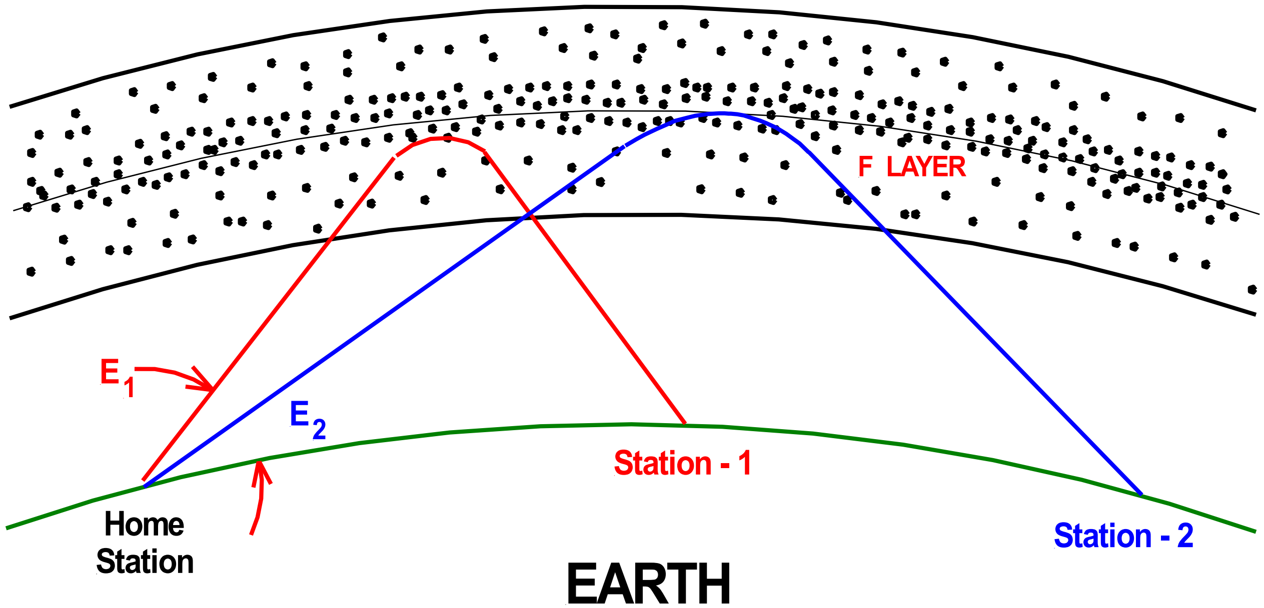
F2 Critical Frequency Map

http://www.sws.bom.gov.au/HF_Systems/6/5



- A global F2 critical frequency map is available on the internet from the Australian Government.
- The critical freq map is updated every 15 minutes.
- The map is created automatically from reports received from ionosonde monitoring stations around the world.
- **Seasonal Variation**: Shape of f_c profiles are different in N. Hemisphere (summer) than in S. Hemisphere (winter).

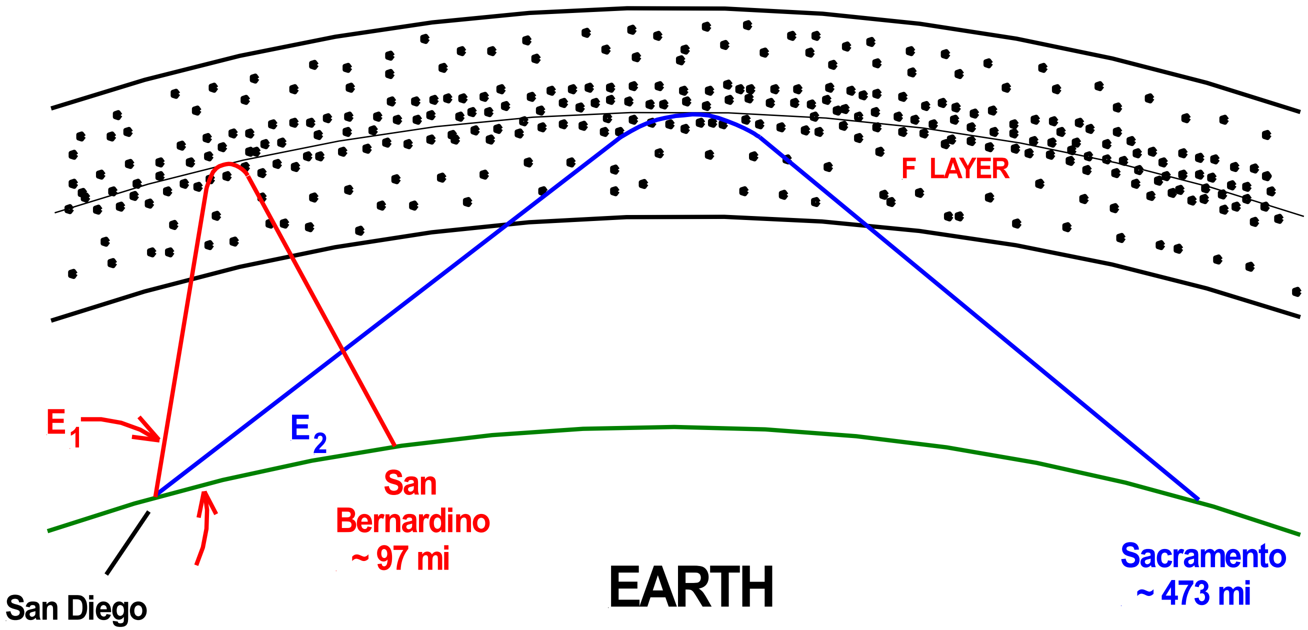
MUF Depends on the Path



$$\text{MUF} = \frac{f_c}{\sin E}$$

- MUF increases as the angle E gets smaller.
- Thus MUF_2 is greater than MUF_1.
- Lets take a look at an example.

MUF Example - CESN



$$MUF = \frac{f_c}{\sin E}$$

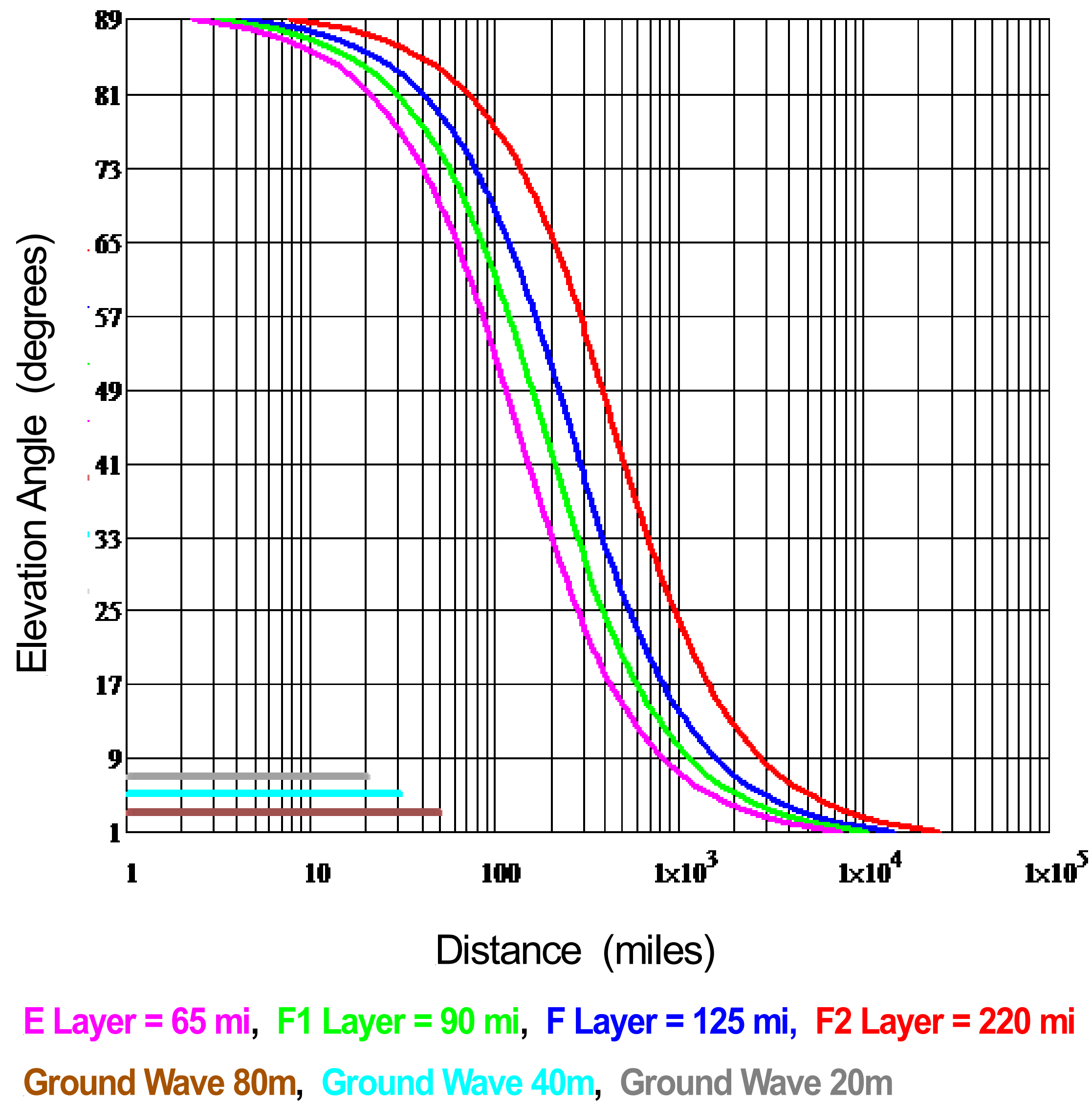
- Sacramento is CESN net control, San Bernardino is backup NC.
- What is the MUF from San Diego to Sacramento, California?
- What is the MUF from San Diego to San Bernardino?
- First must determine the elevation angle E.

(CESN = California Emergency Services Net.)

Elevation Angle vs Distance

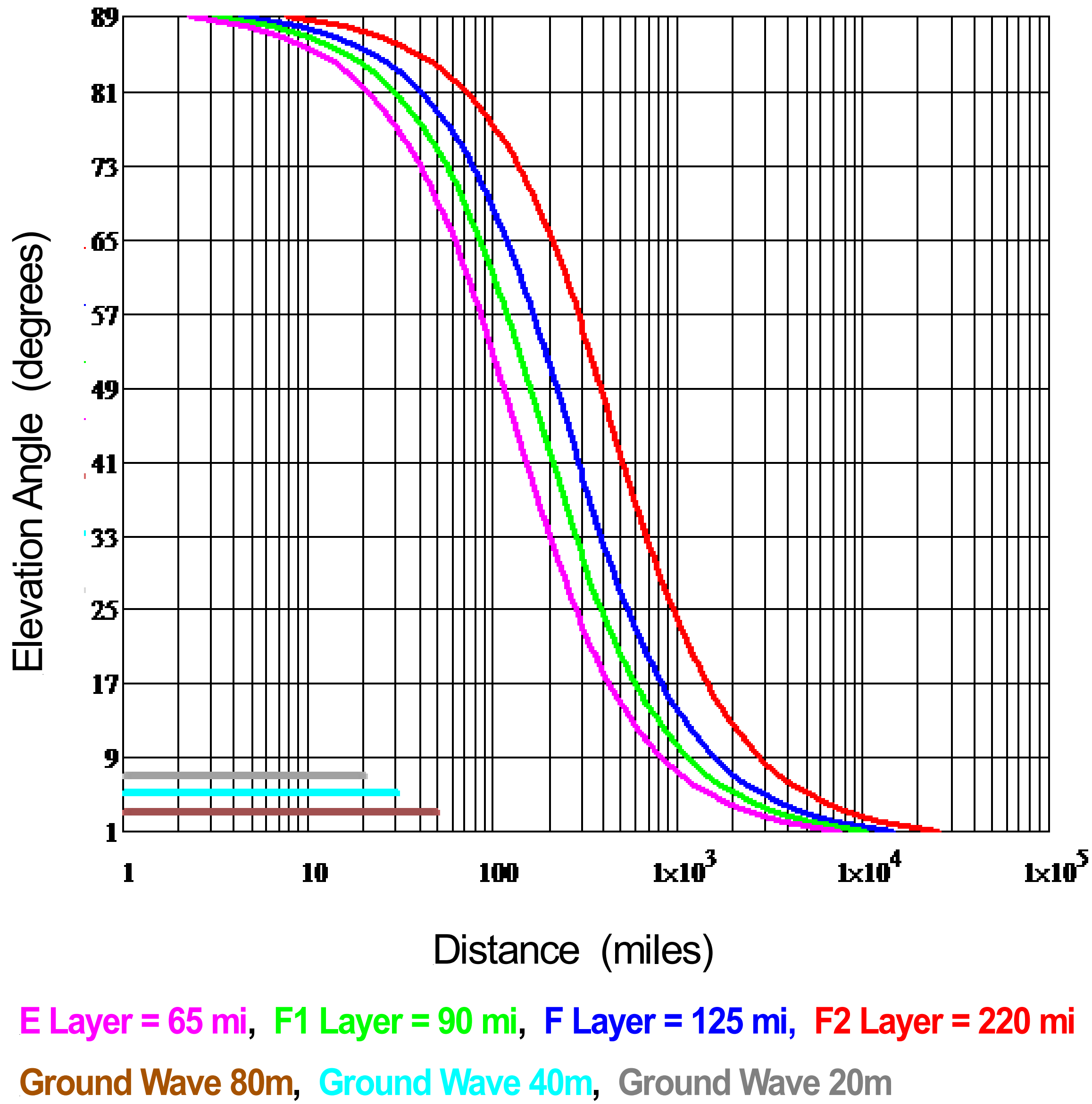
$$MUF = \frac{f_c}{\sin E}$$

- **Red** curve is the Distance vs Elevation Angle for signals refracting near the top of the ionosphere F Layer
- **Blue** curve is the Distance vs Elevation Angle for signals refracting near the bottom of F Layer
- Actual signal refraction takes place somewhere between these two extremes

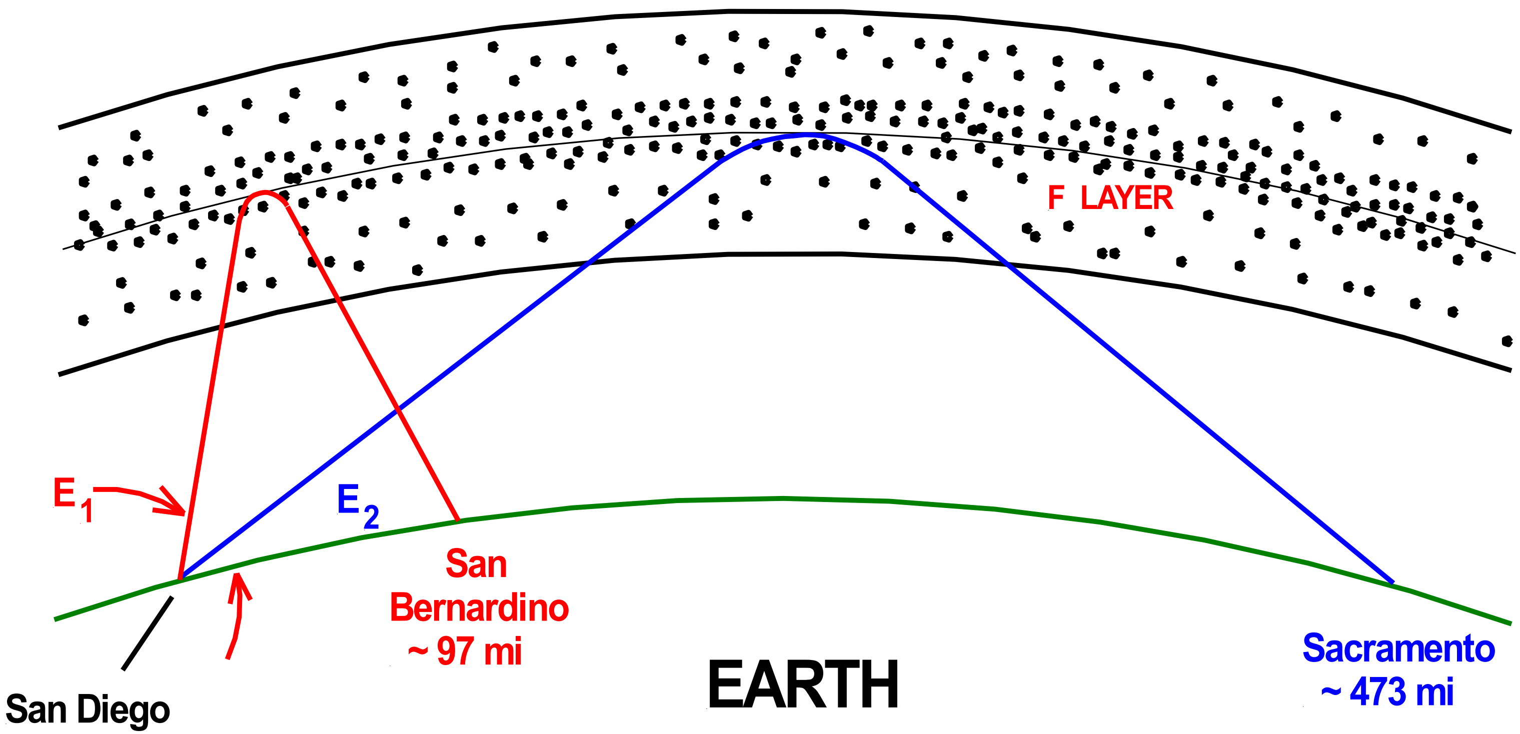


Calculating Elevation Angle

- For Sacramento find 473 mi on the Distance scale
- Read vertically to the point mid way between the **blue** and **red** distance vs elevation angle curves
- Read horizontally to the Elevation Angle axis.
- Elevation angle for Sacramento is about E_2 = 35 deg
- Similarly the elevation angle for San Bernardino @ 97 miles is E_1 = 73 deg



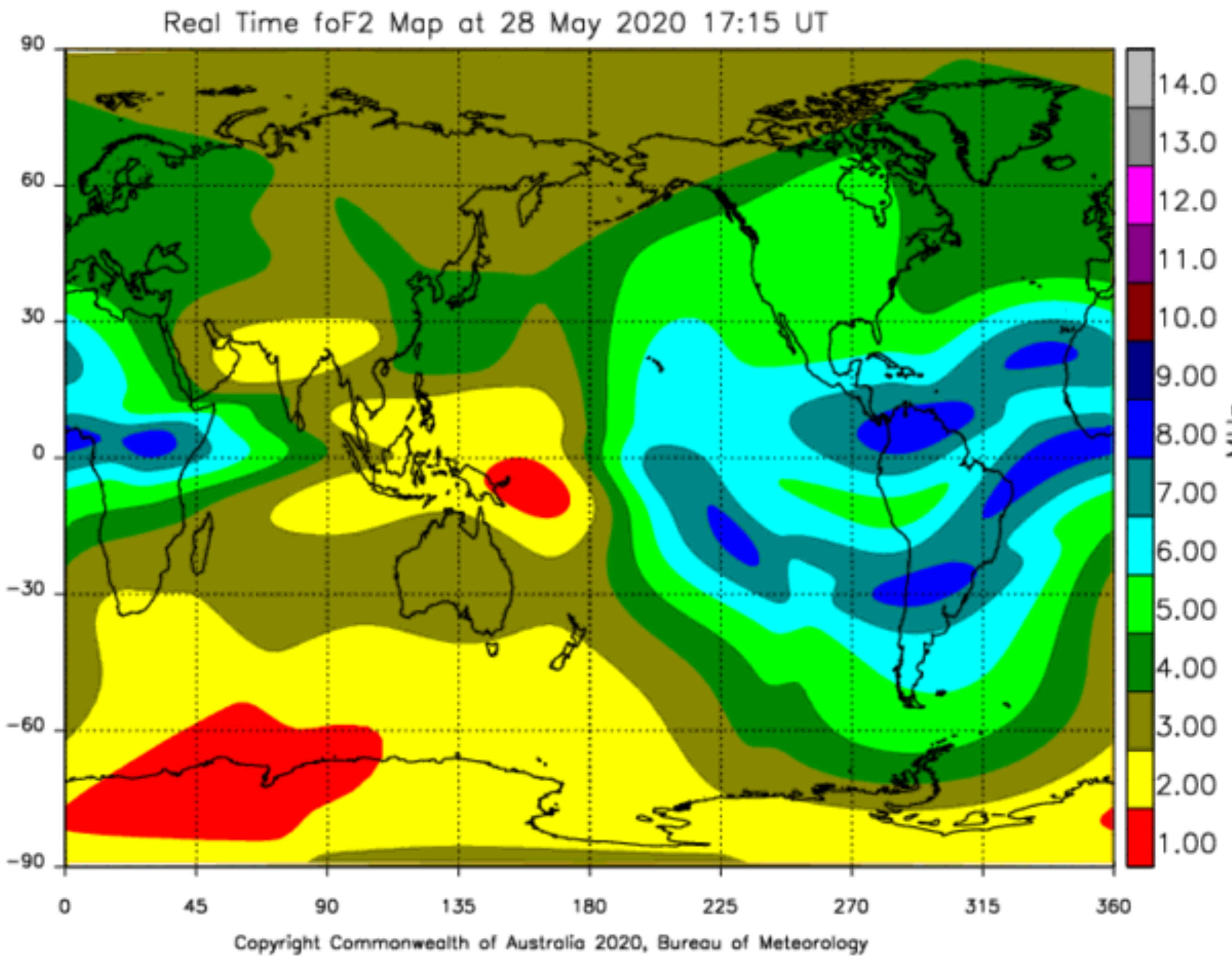
Determine Critical Frequency



- E_1 = 73 deg
- E_2 = 35 deg
- f_c = ?

$$MUF = \frac{f_c}{\sin E}$$

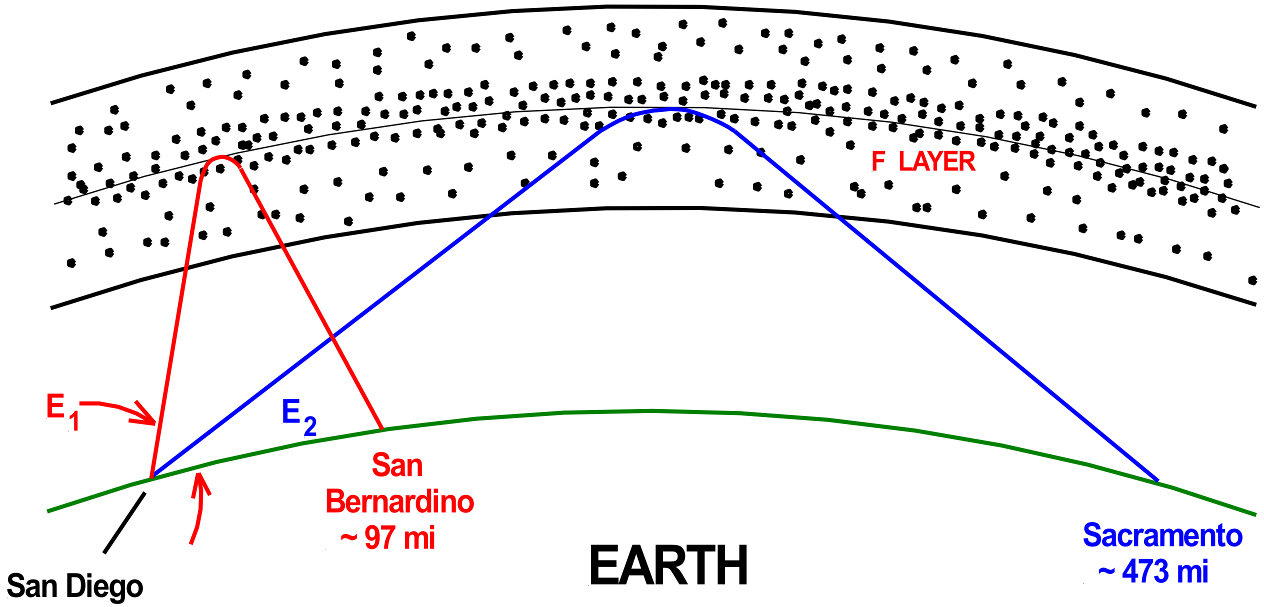
Determine Critical Frequency continued



$$\mathrm{MUF} = \frac{f_c}{\sin E}$$

- On 5/28/2020 Critical Freq was 5 MHz for California at the time of the Net

Calculate MUF



CESN Net = 7.230 MHz

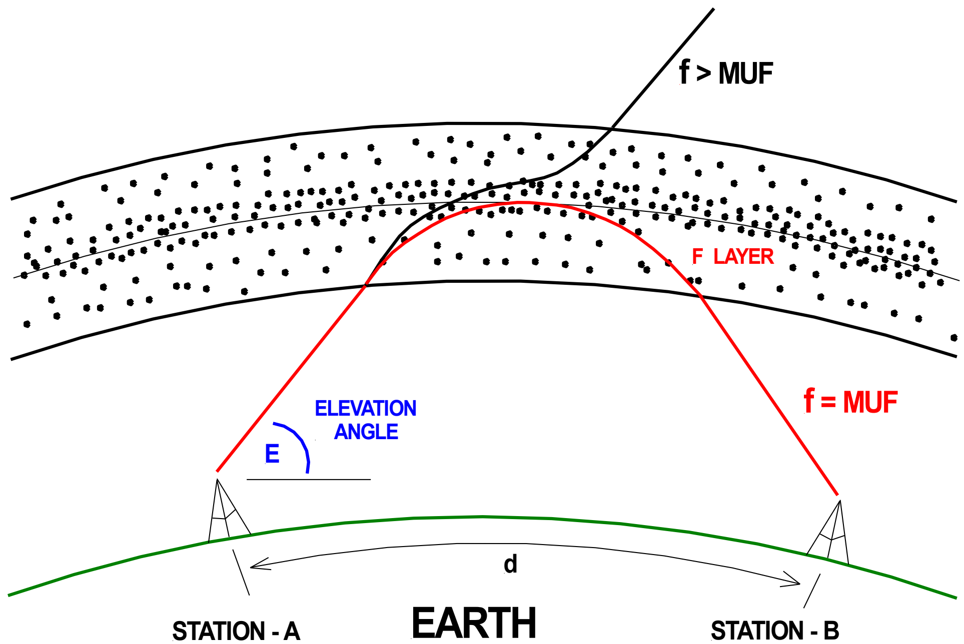
$$MUF_1 = \frac{f_c}{\sin E_1} = \frac{5\ \text{MHz}}{\sin 73^o} = 5.2\ \text{MHz}$$

$$MUF_2 = \frac{f_c}{\sin E_2} = \frac{5\ \text{MHz}}{\sin 35^o} = 8.7\ \text{MHz}$$

In this example, San Diego can not reach (or hear) San Bernardino because the MUF for that path is less than the CESN operation frequency. That is, signals from San Diego "skip over" San Bernardino.

Sacramento can be easily reached since its MUF is greater then the CESN operating freq.

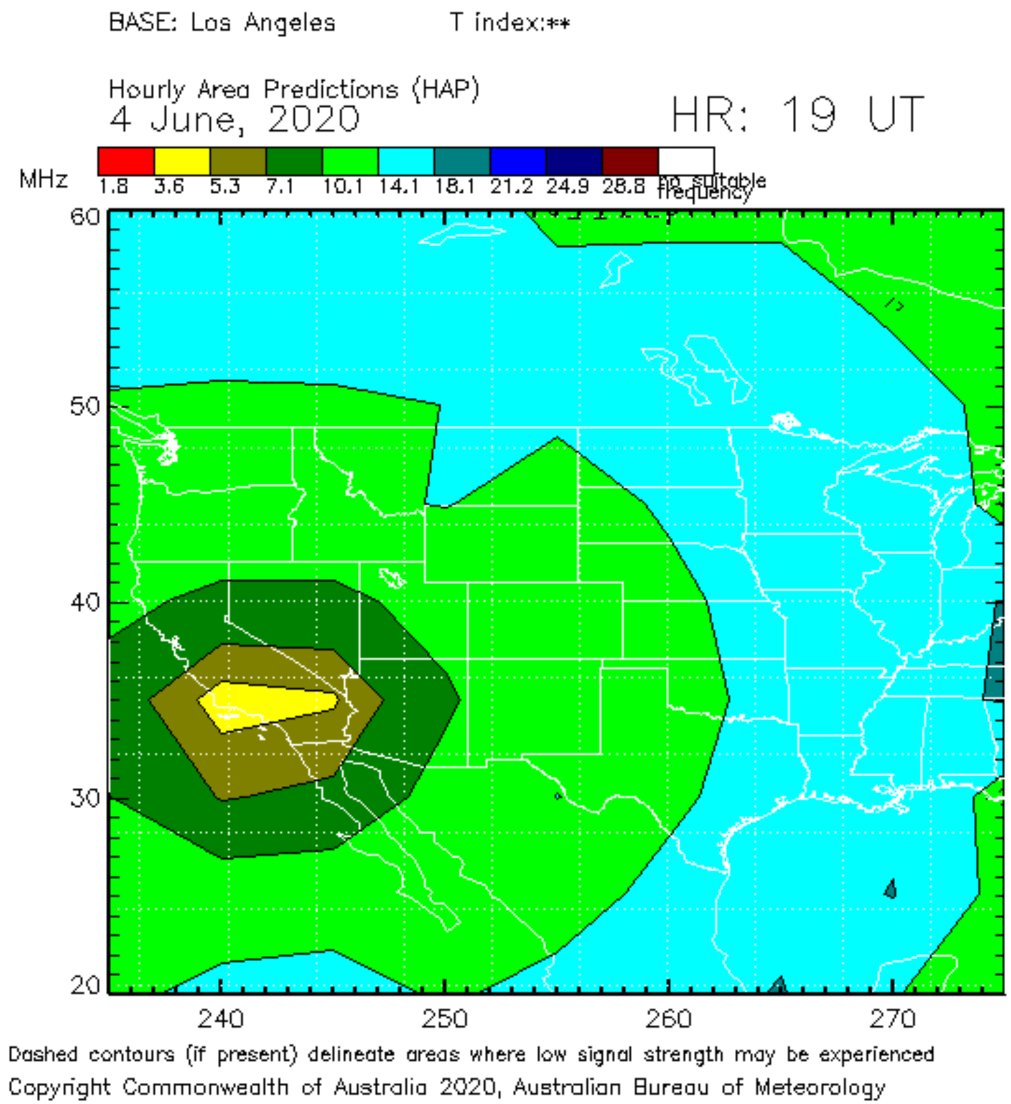
Frequency of Optimum Transmission (FOT)



- Working at the Maximum Usable Frequency is literally "living on the edge".
- Small changes in critical frequency and other ionospheric parameters cause the MUF to be in a continuous state of change.
- Signals transmitted at the MUF often fade in and out
- It is generally accepted that FOT is 80 to 85% of the MUF.

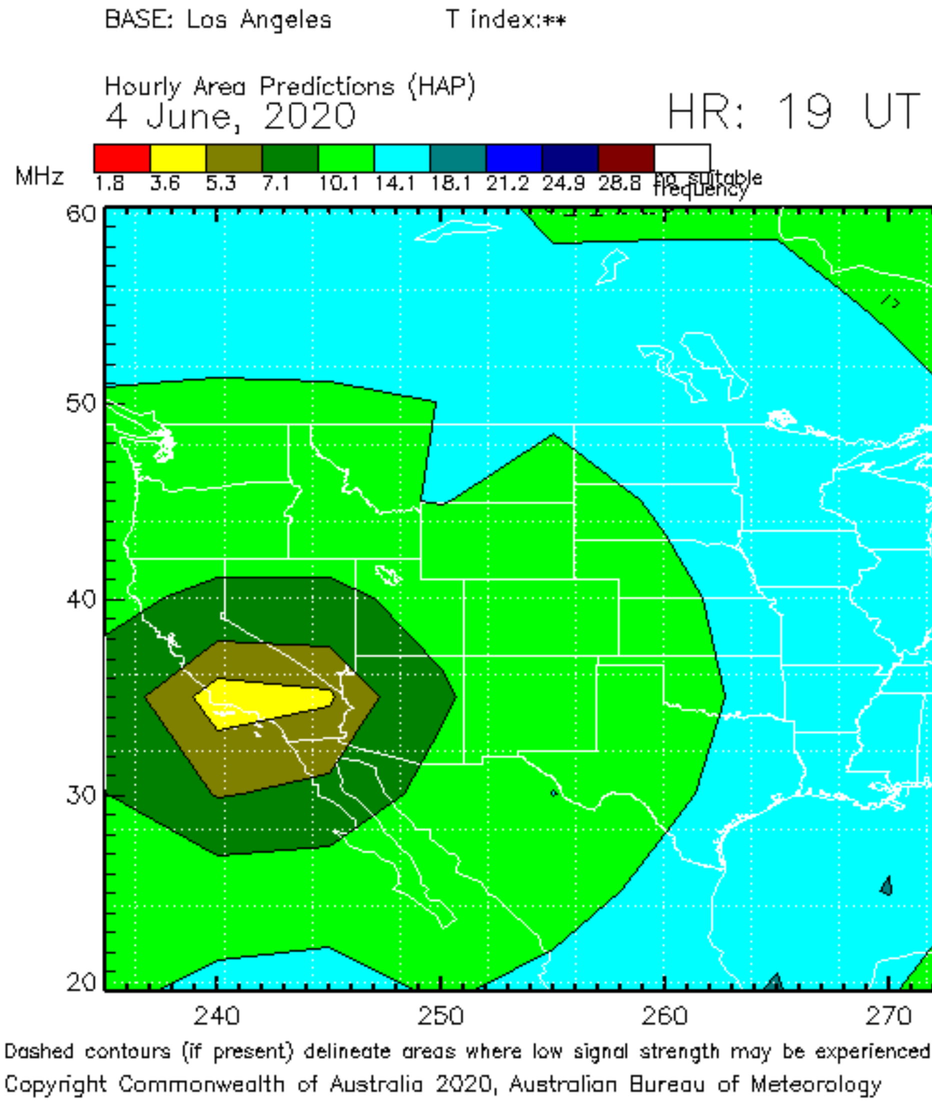
HAP Charts

- FOT can be directly read from Hourly Area Prediction (HAP) charts.
- HAP Charts are designed for predicting the optimum freq for communications between a specified city (the Base City) and a selected distant station.
- Los Angeles, CA is the base city for this map.



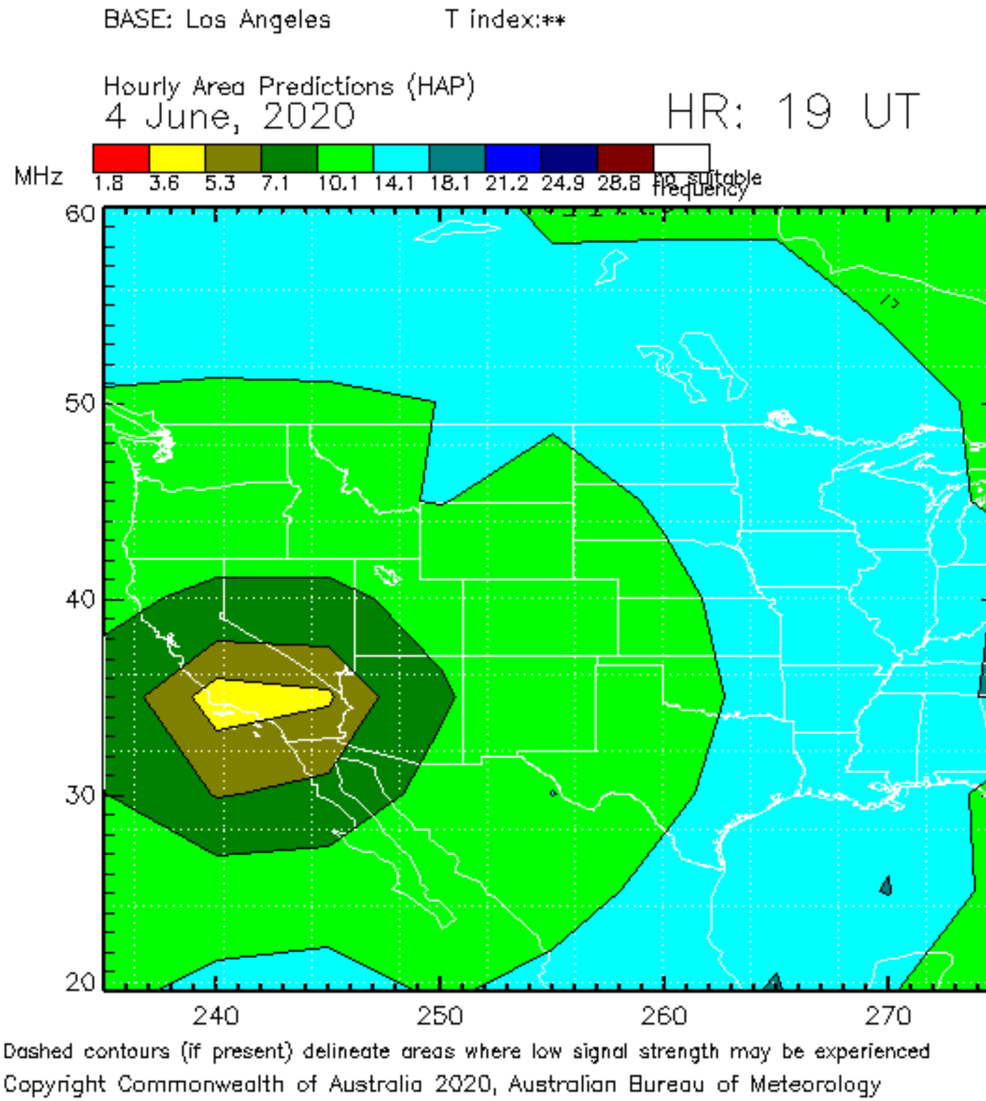
HAP Chart Coordinates

- The vertical axis of the chart is degrees Latitude.
- The horizontal axis is degrees East Longitude (measured eastward from the Prime Meridian around the Earth).
- The color band at the location of the base city (yellow in this example) is by definition the critical frequency fc at the time the chart was produced.
- fc being the highest frequency signal that can be transmitted straight up at the base city location and be reflected back down to Earth.



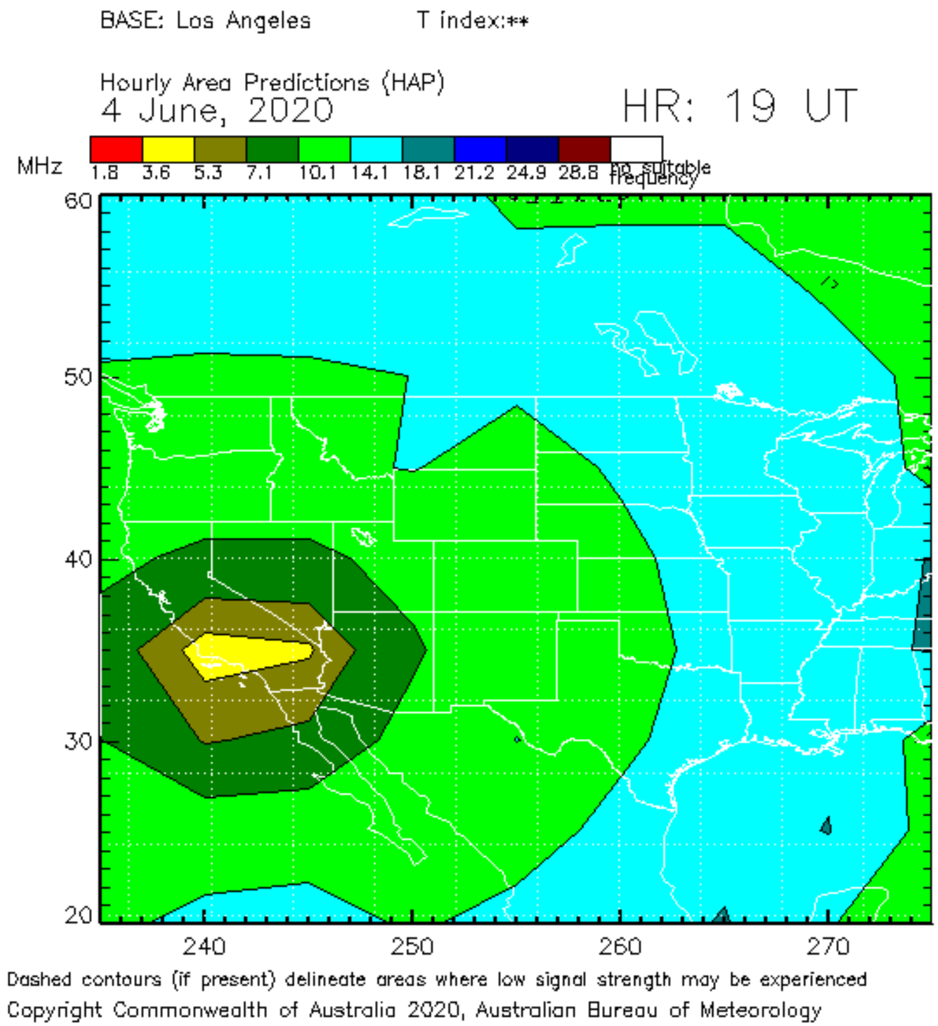
HAP Charts Color Bands

- The HAP Chart color bands represent the recommended HF frequency (FOT) for communications between the base city and a selected distant location for a given date and hour.
- For this version of the HAP Chart the color bands represent different amateur radio freq bands.
- For example, 30 meters (10.1 MHz) is the FOT for communications between Los Angeles and Portland at 1900 UT (noon local time) on 6/4/2020.



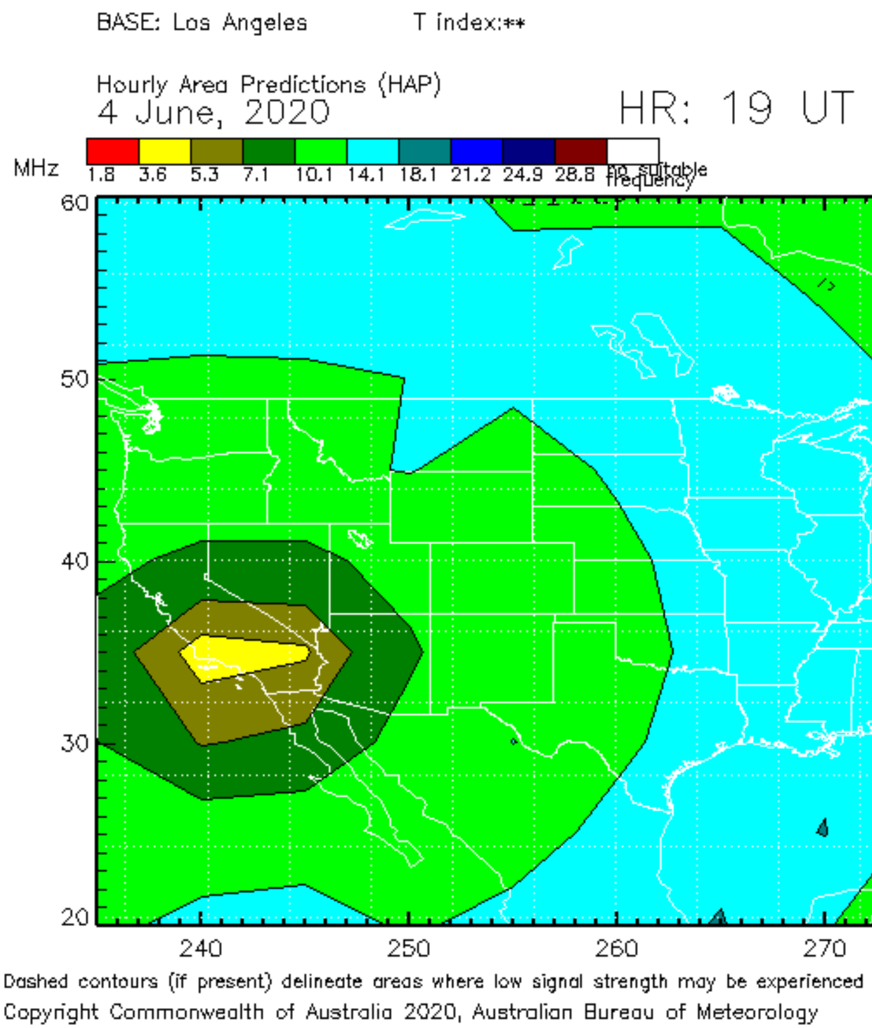
HAP Chart is an Estimate

- A HAP Chart is an estimate of the current FOT.
- Remember that MUF > FOT.
- So the MUF could actually be the next higher frequency band.
- For example, the MUF for Los Angeles to Portland could be 20 m instead of the 30 m FOT shown on the HAP Chart.
- However, it is unlikely that Portland could be reached on 17 meters.
- A HAP Chart is a starting point in selecting a frequency band.



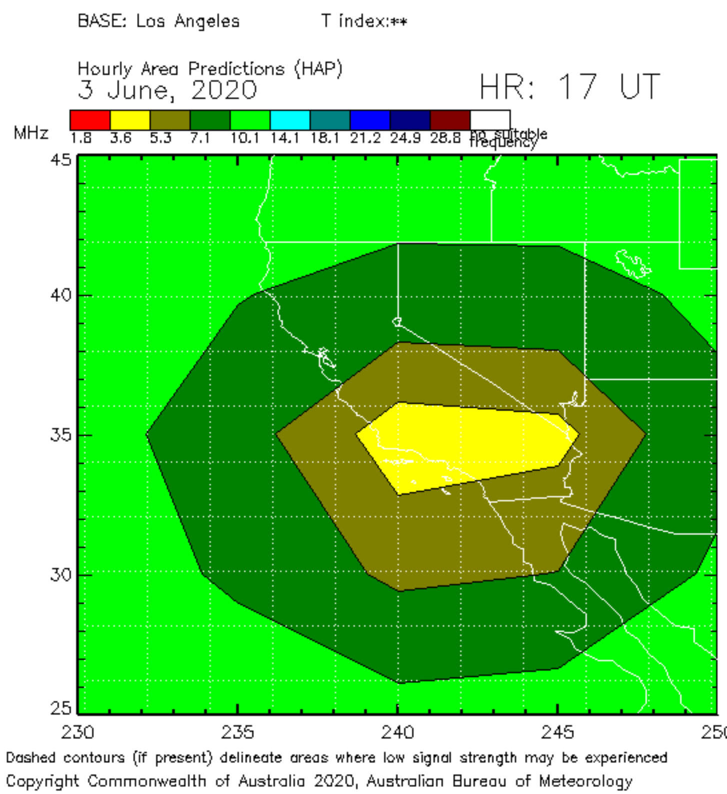
HAP Chart is Highest Freq

- The FOT shown on the HAP Chart for Los Angeles to Portland is 30 meters.
- This is the highest frequency band for dependable comm from Los Angeles to Portland.
- Any frequency band lower than the FOT could also be used.
- For example, 40 meters could be used for communications between Los Angeles and Portland.
- However, the 40 meter path could encounter multi-path interference & deep D Layer absorption not present at the 30 meter FOT frequency.



HAP Chart CESN Prediction

- The HAP Chart on the right can be used to predict the communications between San Diego, Sacramento, & San Bernardino during the Wednesday 6/3/2020 CESN.
- San Diego is not in the HAP Chart data base so the map is centered on the next closest large city (Los Angeles).
- The map must be visually shifted downward to be centered on San Diego.
- When this is done, the FOT to Sacramento is 40 meters, thus San Diego can hear Sacramento during the CESN net.
- The FOT to San Bernardino is 80 m, San Diego can not hear San Bernardino.
- San Bernardino CESN traffic must be relayed to San Diego thru Sacramento.

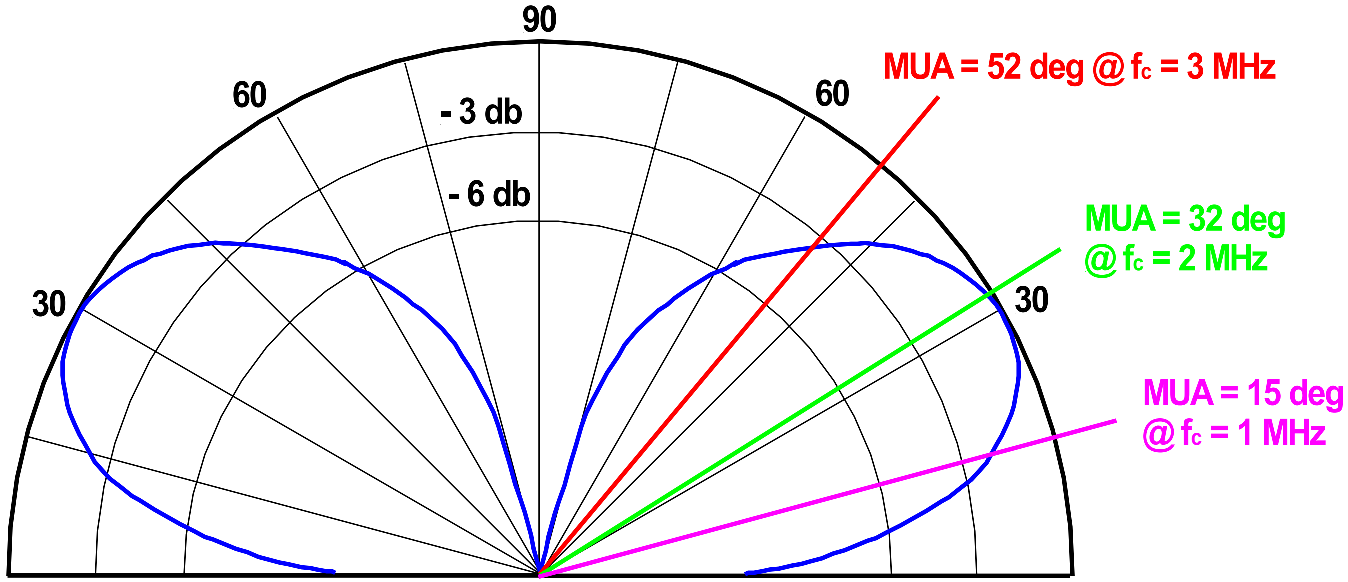


Statistical Forms of MUF

$$\mathrm{MUF} = \frac{f_c}{\sin E}$$

- MUF Median Value for the month
- Upper Decile
- Lower Decide
- MOF = Maximum Observed Frequency
- OWF = Optimum Working Frequency
- FOT = Frequency of Optimum Transmission
- Boulder MUF
  - Predicted MUF from Boulder Colorado,
  - For very low angle transmission, hop distance > 3000 miles
  - Not likely to achieve these results using your antenna!
  - **Provides an upper bound on what ham bands may be open.**

Maximum Usable Angle

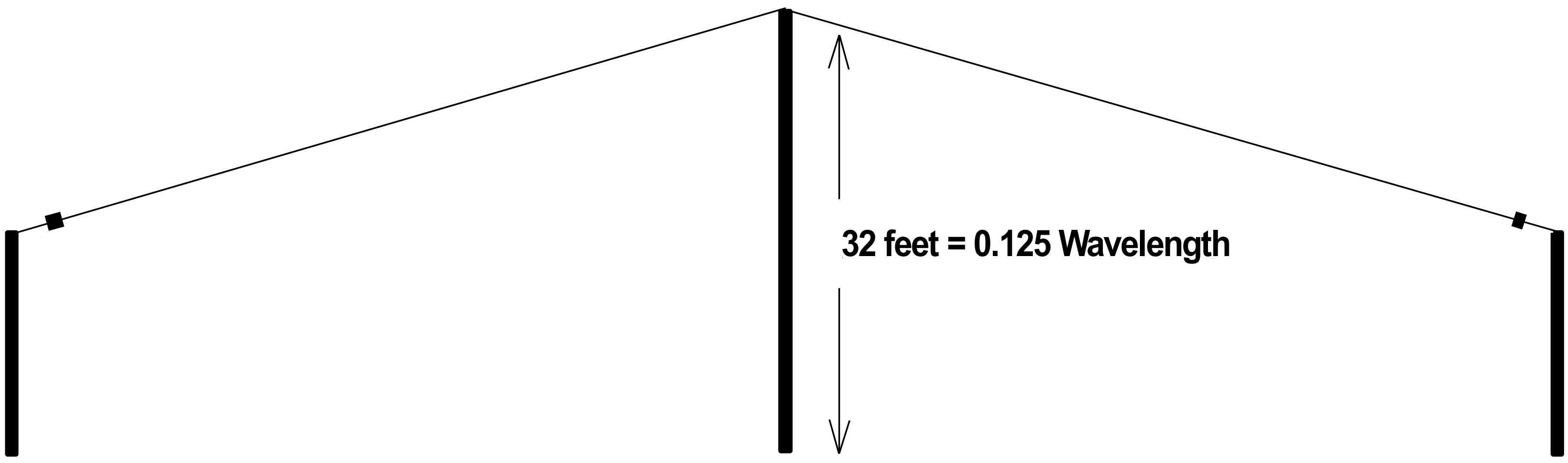


1/4 Wave Vertical Antenna

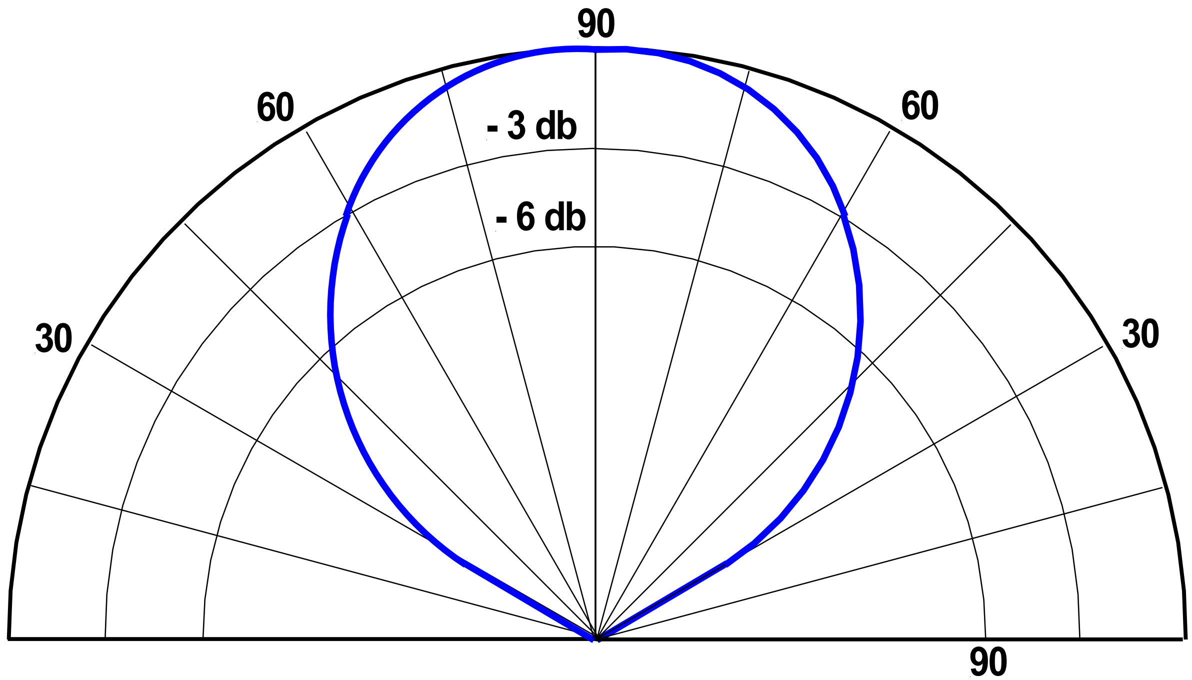
The 80 meter Episode

- 80 meters is a night time band.
- In fact, 80 meters is often open all through the night even though higher frequency bands shut down.
- It would be fun to operate 80 meters during the evening.
- Even operating all night long!

An 80 meter Inverted V Antenna Was Built



80 meter Antenna Vertical Radiation Pattern



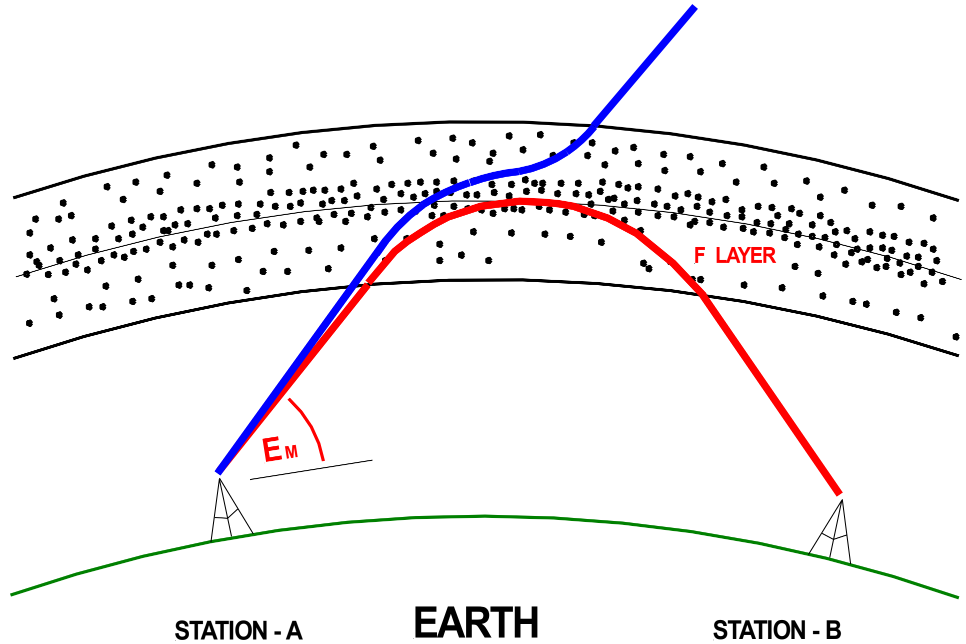
80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

- Good NVIS antenna
- Supports close in communications throughout southern California
- And often into Arizona and Nevada

80 meter Antenna Stops Working at Night !

- Around 10 PM the antenna stopped working.
- Plenty of stations being heard on 80 meters.
- The Critical Frequency was approximately 3 MHz.
- MUF apparently not an issue
- Was the high angle radiation from the Inverted V antenna a problem?
- To find out, the MUF equation was solved for angle instead of frequency.
- The result was an equation for Maximum Usable Angle (E_M) .

Maximum Usable Angle



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

- Maximum Usable Angle (MUA) is the highest angle signal that can be transmitted,
- At an operating frequency of fo , and
- Still be refracted back to Earth if the critical frequency is fc .
- Transmitting at an angle greater than MUA will cause the signal to penetrate the ionosphere and be lost to outer space.

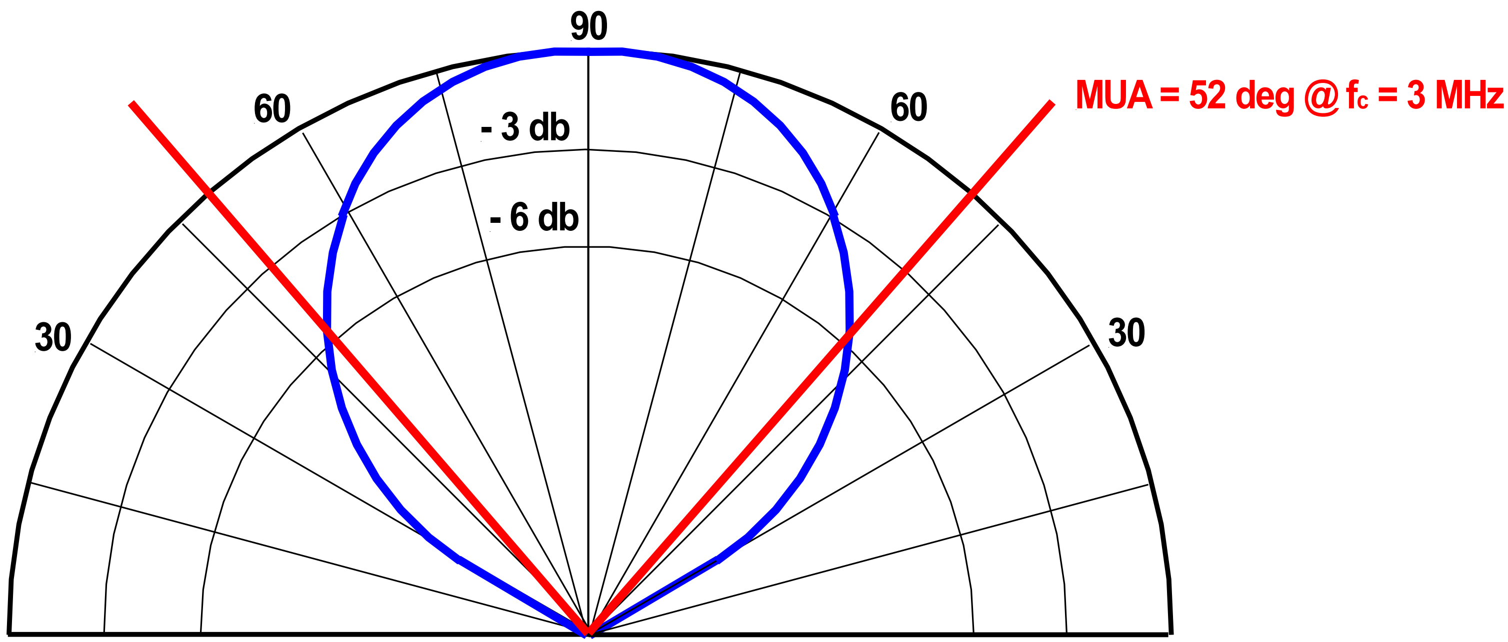
80 meter Maximum Usable Angle

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

Maximum Usable Angle (MUA) for:

- Critical frequency fc = 3.0 MHz,
- Operating frequency of fo = 3.8 MHz, is
- Approximately 52 degrees.

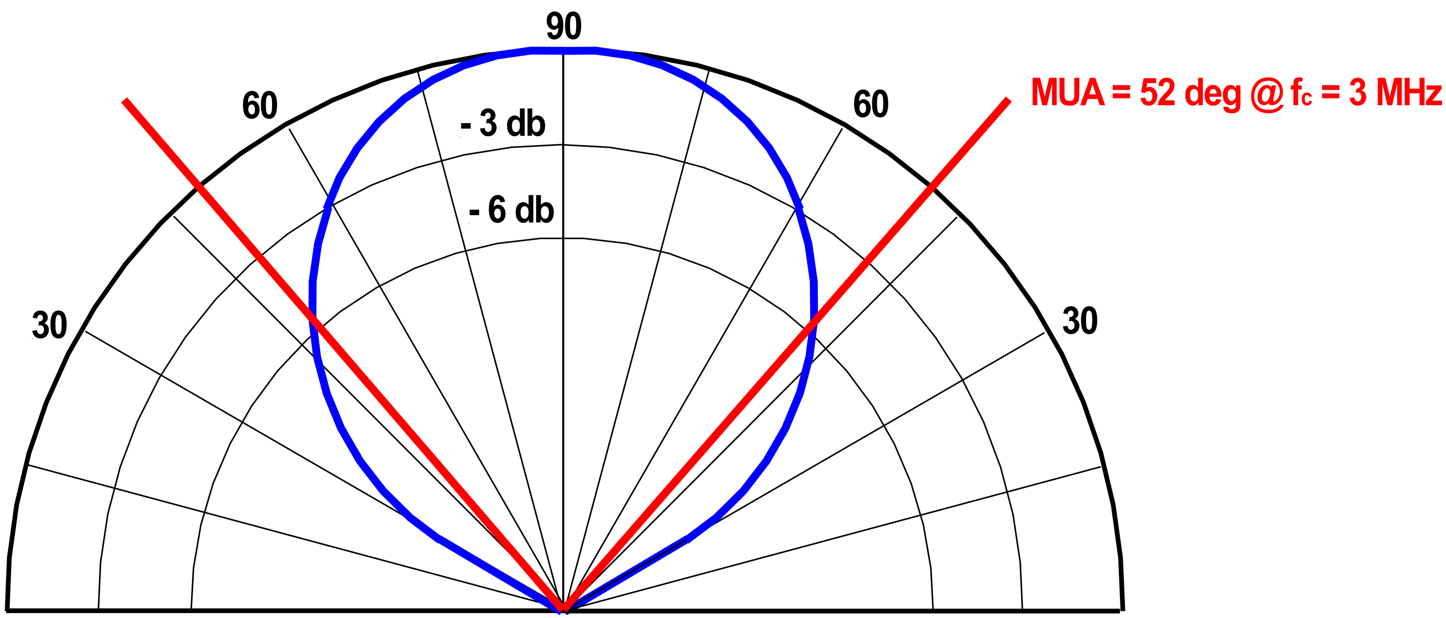
MUA Too Low For The 80 m Inverted V Antenna



80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

- Nearly all of the energy from the antenna is radiated at angles greater than the MUA and lost to outer space.

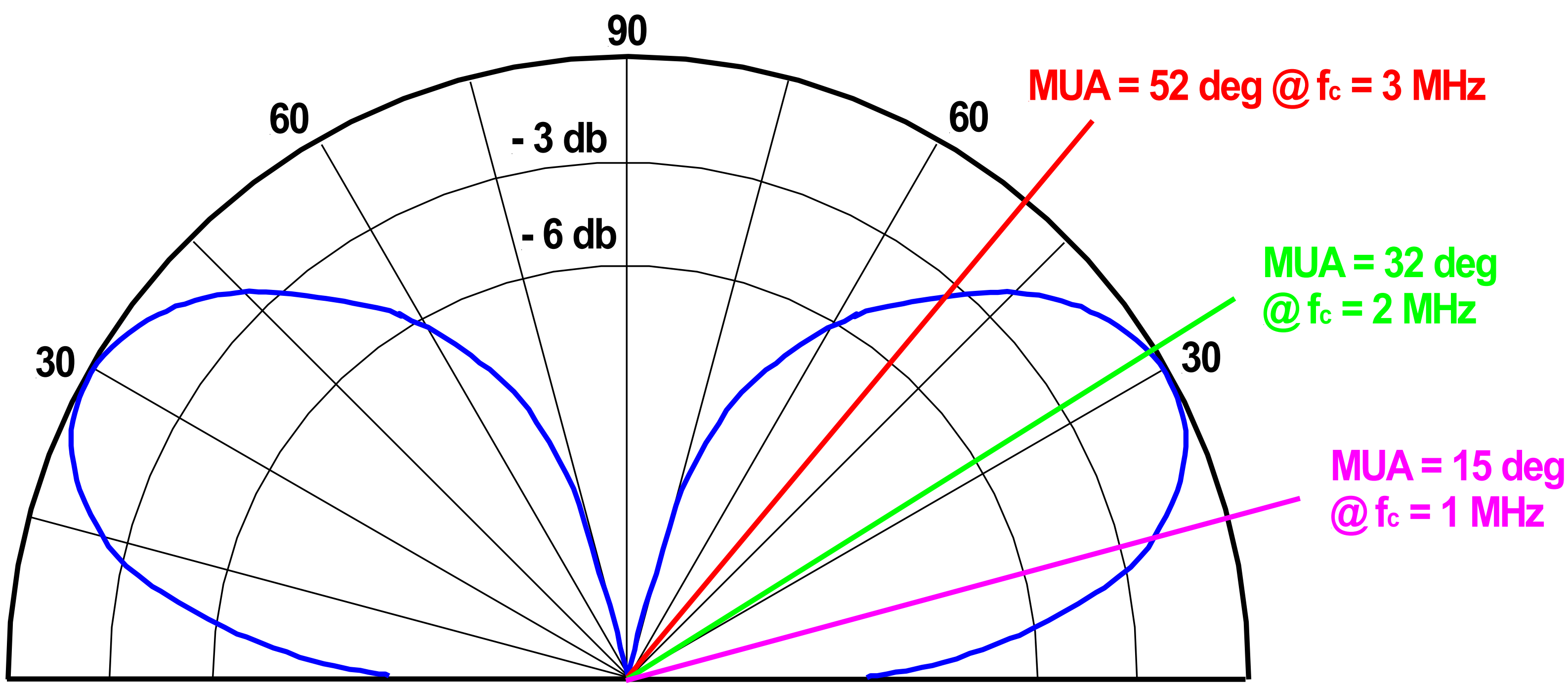
80 meter Night Time Operation



80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

- What needs to be done to operate late at night on 80 meters?
  - The height of the antenna must be greatly increased to get a lower angle radiation pattern.
  - If that is not possible, then a vertical antenna must be used.

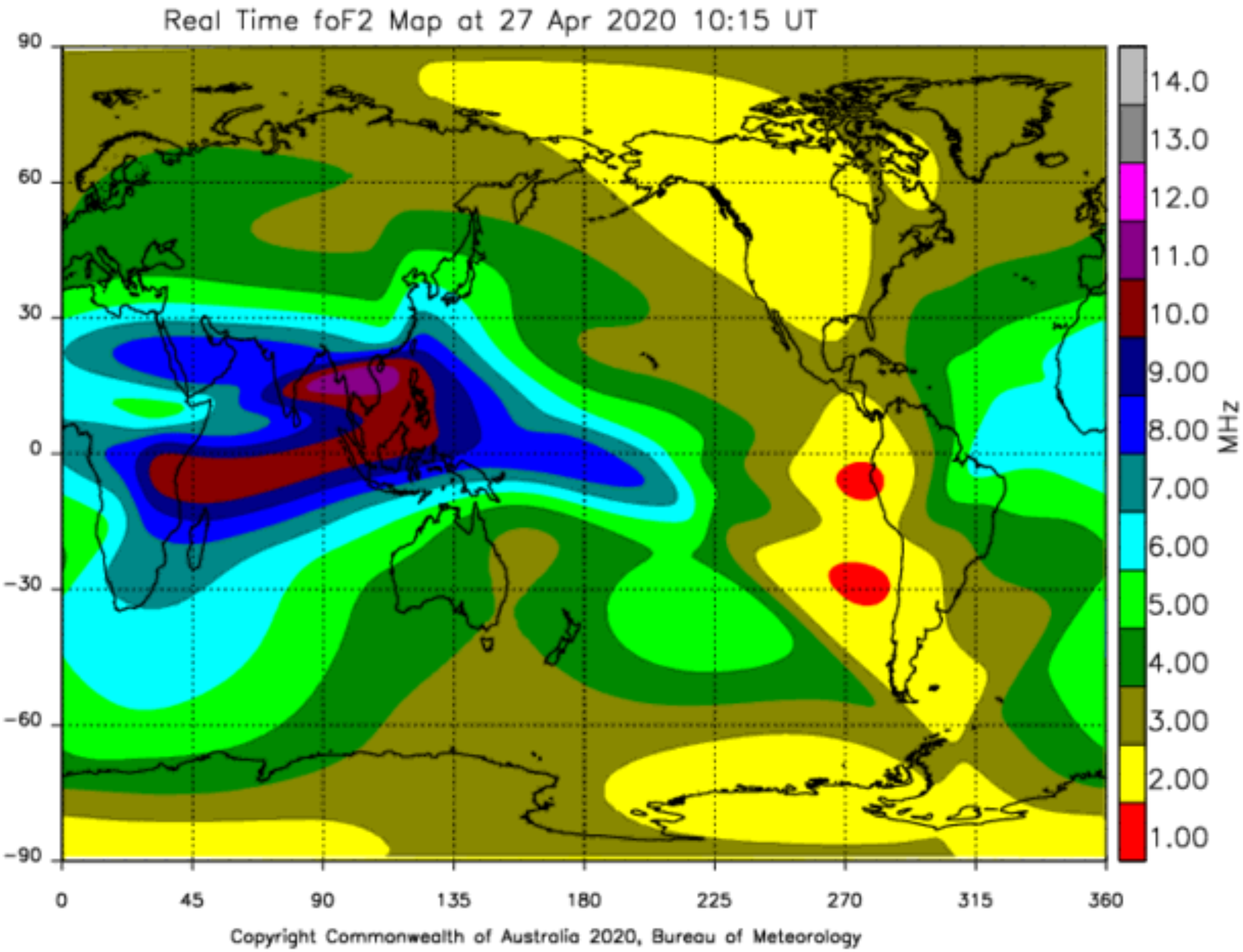
80 m Vertical Antenna For Late Night Operation



1/4 Wave Vertical Antenna

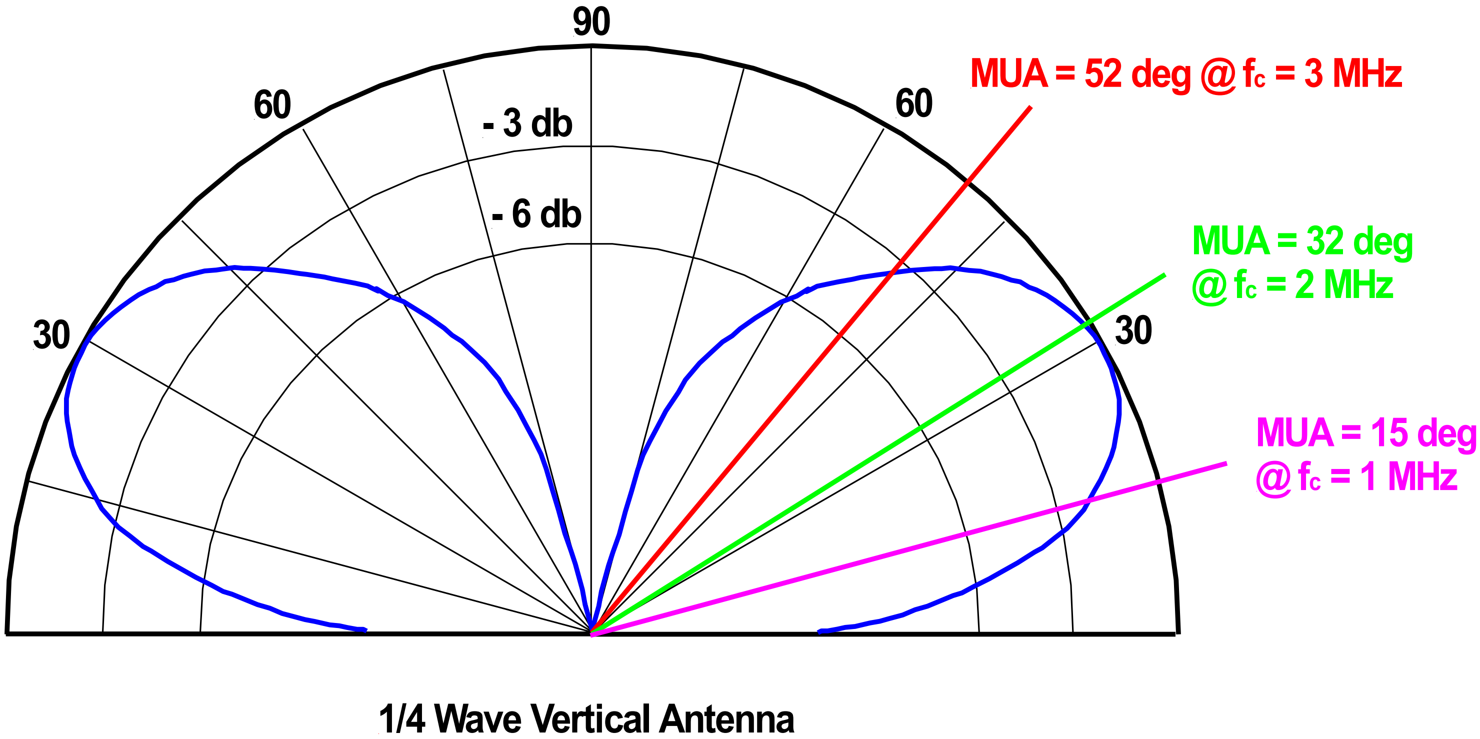
- Vertical antenna can work down to a critical frequency of ~ 1 MHz.

How Low Can The Critical Frequency Get?



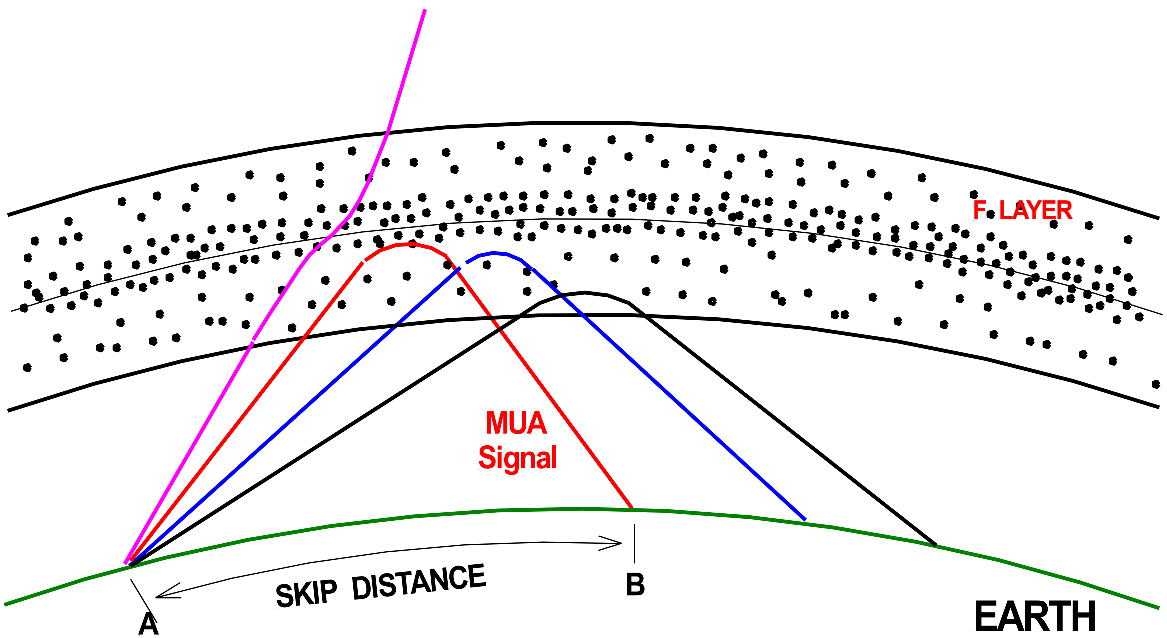
During solar minimum the critical frequency can easily get down to 2 MHz at night and at times down to even 1 MHz

80 m Emergency Communications Work

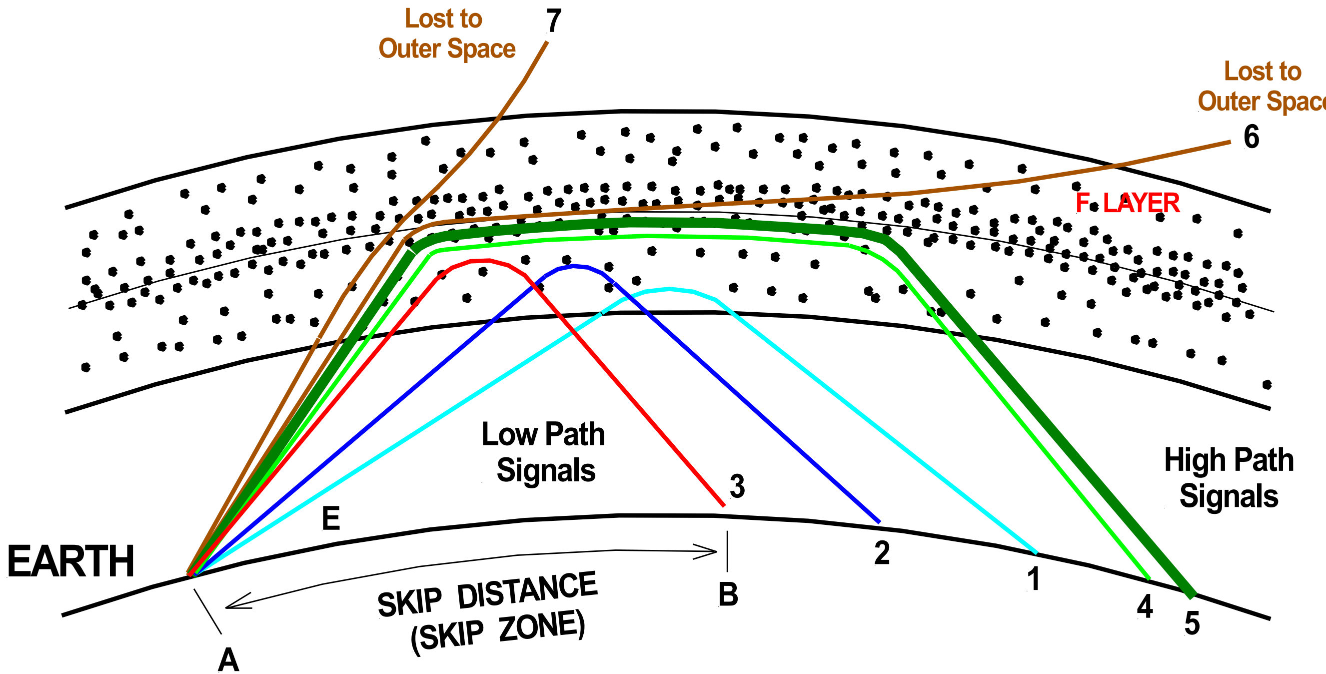


- Two 80 m antennas may be required for emergency communications work.
  - Inverted V NVIS antenna for close in work when supported by MUA
  - Vertical antenna for night (low MUA) work

Skip Distance

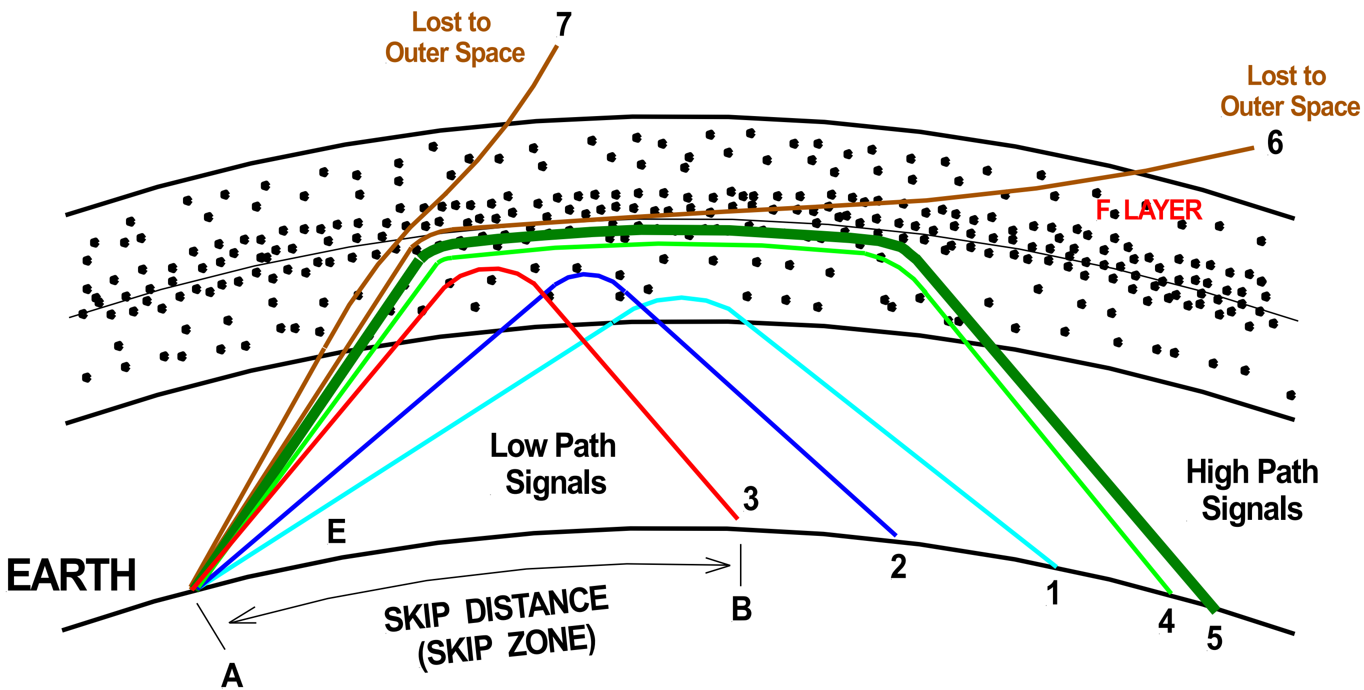


High and Low Ray Paths



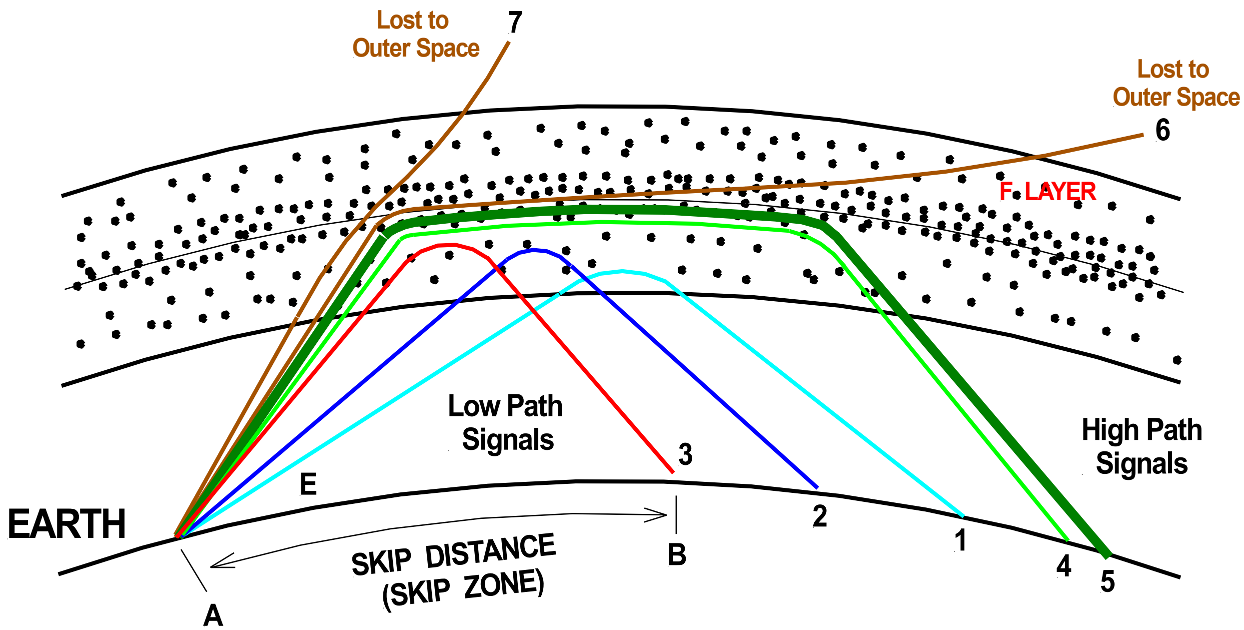
- Increasing angle E shortens the distance transmitted in a single hop, for example from point 1 to point 2 to point 3 as E increases.
- Increasing E a little more causes a strange thing to happen.
- Instead of the distance becoming shorter, it becomes dramatically longer, reaching points 4 and 5 instead.
- 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.

High Path vs Low Path



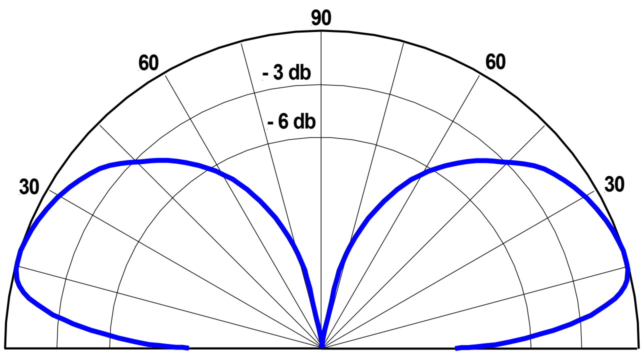
- Rays 1,2,and 3 are low path signals. These signals travel through the lower part of the ionosphere and are relatively stable.
- High path signals (rays 4 & 5) travel parallel to the Earth along the most dense part of the ionosphere before eventually returning to Earth.
- High path signals very erratic sometimes penetrating the ionosphere (ray 6) sometimes returning to Earth at rapidly changing locations (rays 4 & 5).
- High path signals are also know as Pedersen Rays.

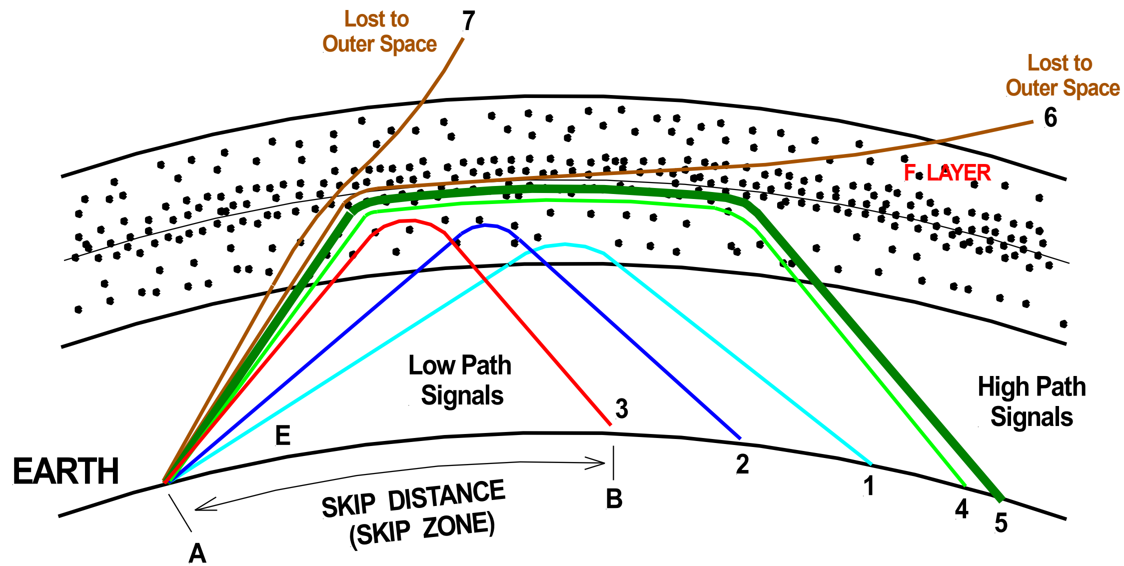
MUA Defined by the High Path Signal



- 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.
- 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 has the special significants of being the shortest possible ray, as well as being the ray at which the high and low paths coincide, in addition to producing a relatively strong stable signal.

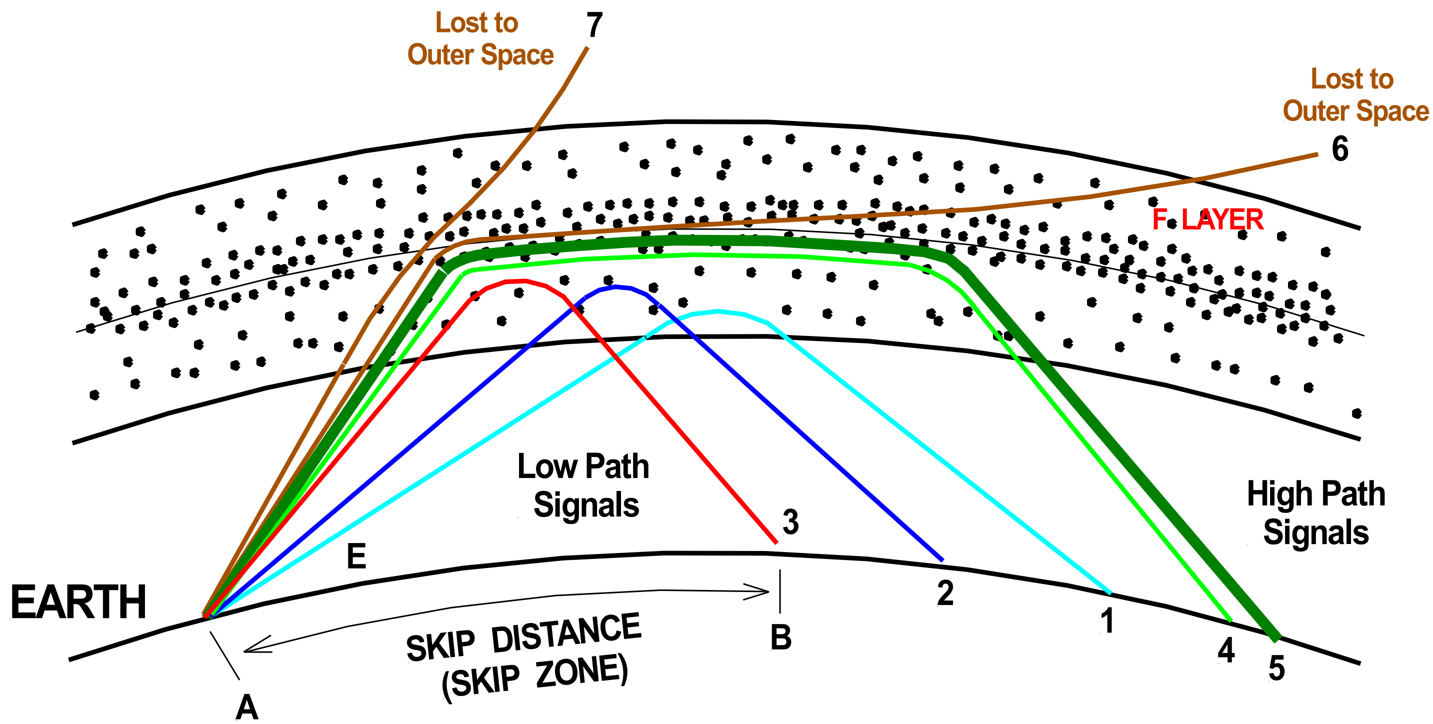
A Typical Transmission Includes Both High & Low Path Signals





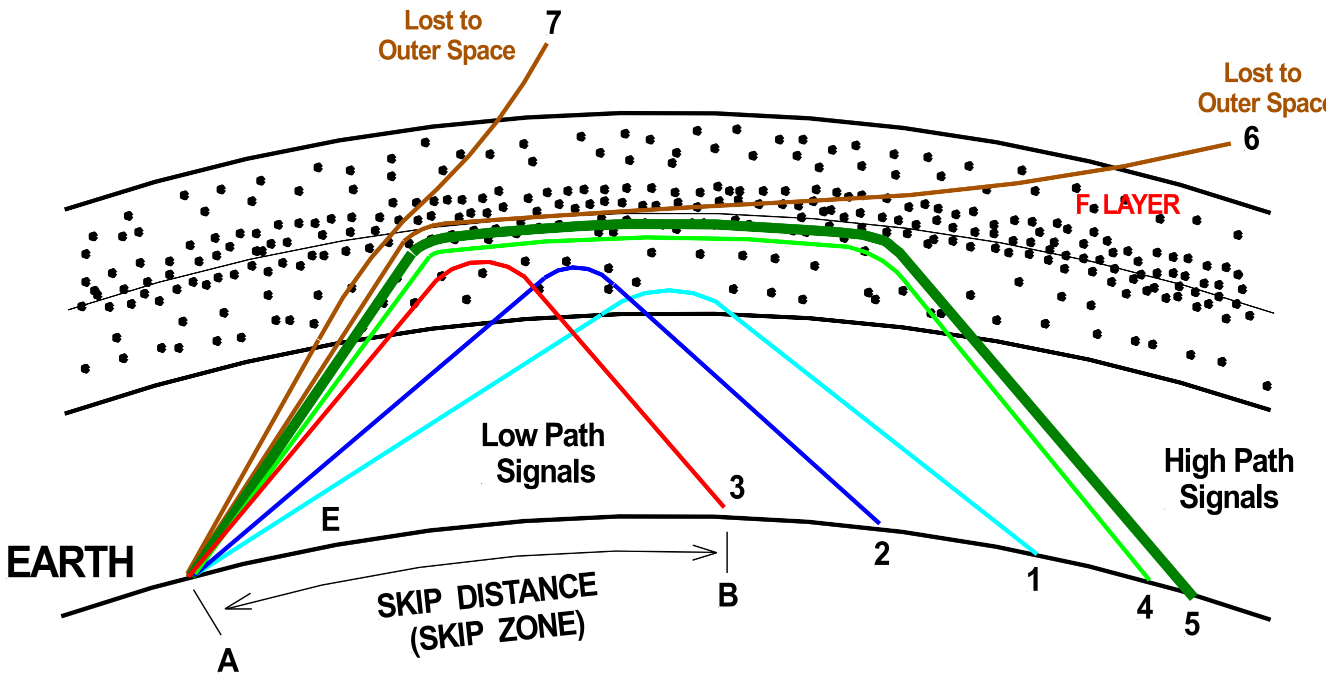
- Radio antennas are not laser beams !
- Amateur radio antennas in particular are relatively crude devices radiating energy over a wide range of elevation angles.
- Consequently the various propagation paths 1 through 7 typically all occur at the same time resulting in a complex array of distant stations that can and can not be reached.

Skip Distance



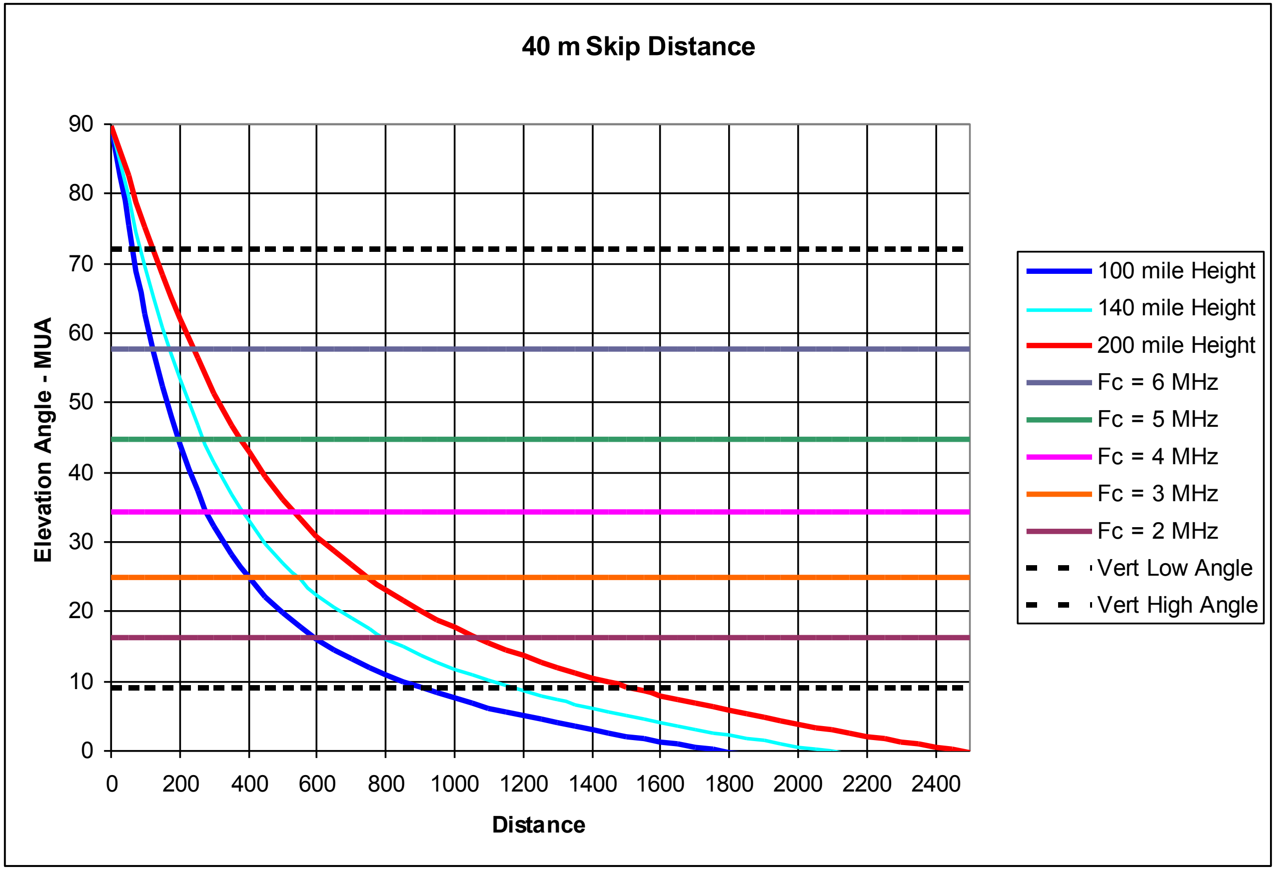
- Ray 3 is the shortest possible path for a signal transmitted from Point A.
- Increasing E_3 slightly increases the hop distance to point 4.
- Decreasing E_3 also increases the hop distance, this time to point 2.
- Station A can not transmit a signal to any location closer than Station B.

Skip Distance Defined



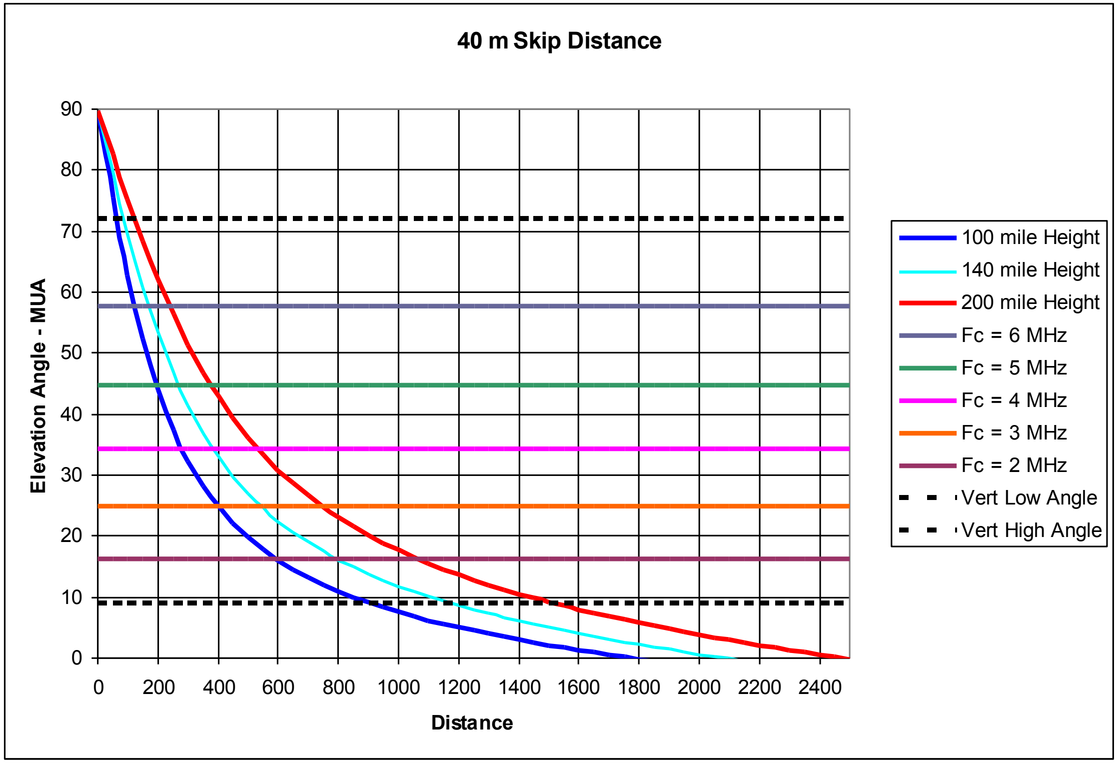
- Station B is the closest location that Station A can contact.
- The distance between Station A and Station B is defined as the skip distance.
- Stations closer to Station A (in the Skip Zone) can not be reached or heard, they are “skipped over”.

Skip Distance Chart



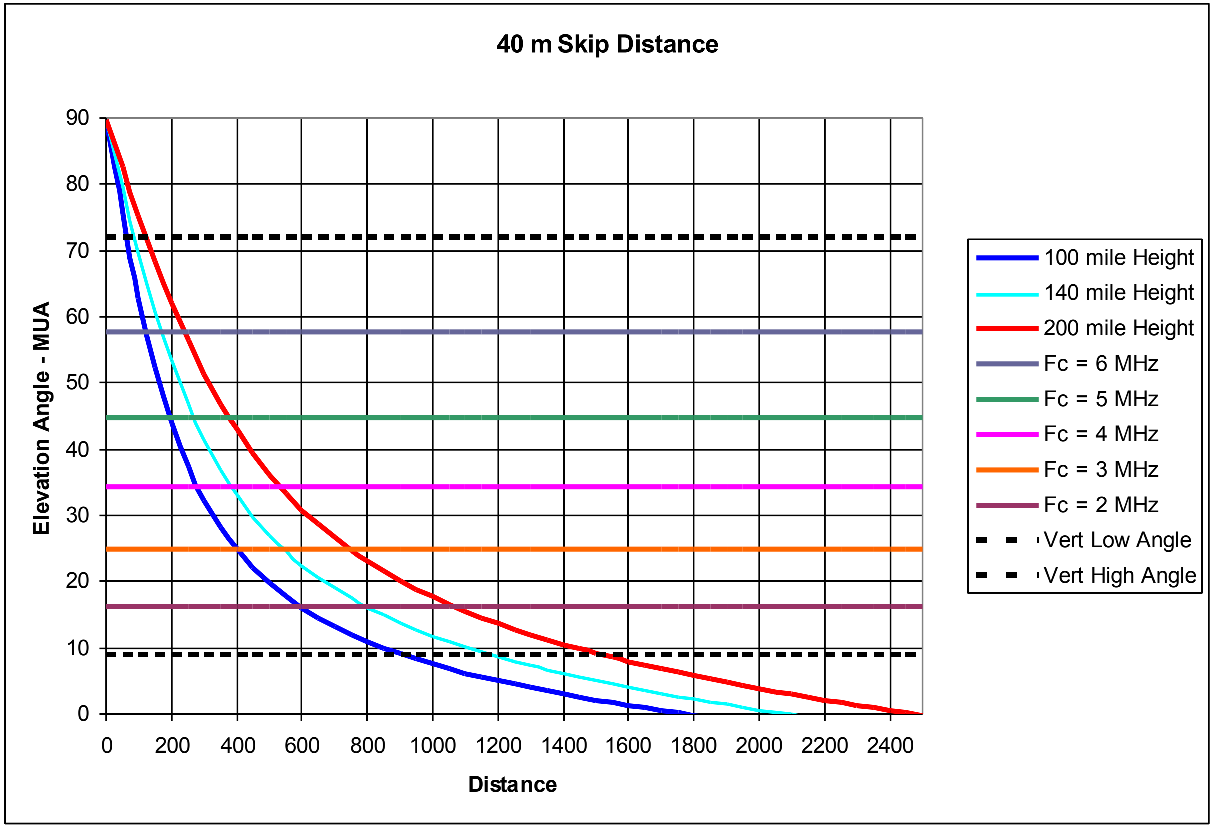
- Skip distance charts, like the one shown here, can be created for each frequency band.
- The chart provides an estimate of skip distance based on the current critical frequency Fc.

Skip Distance Chart continued



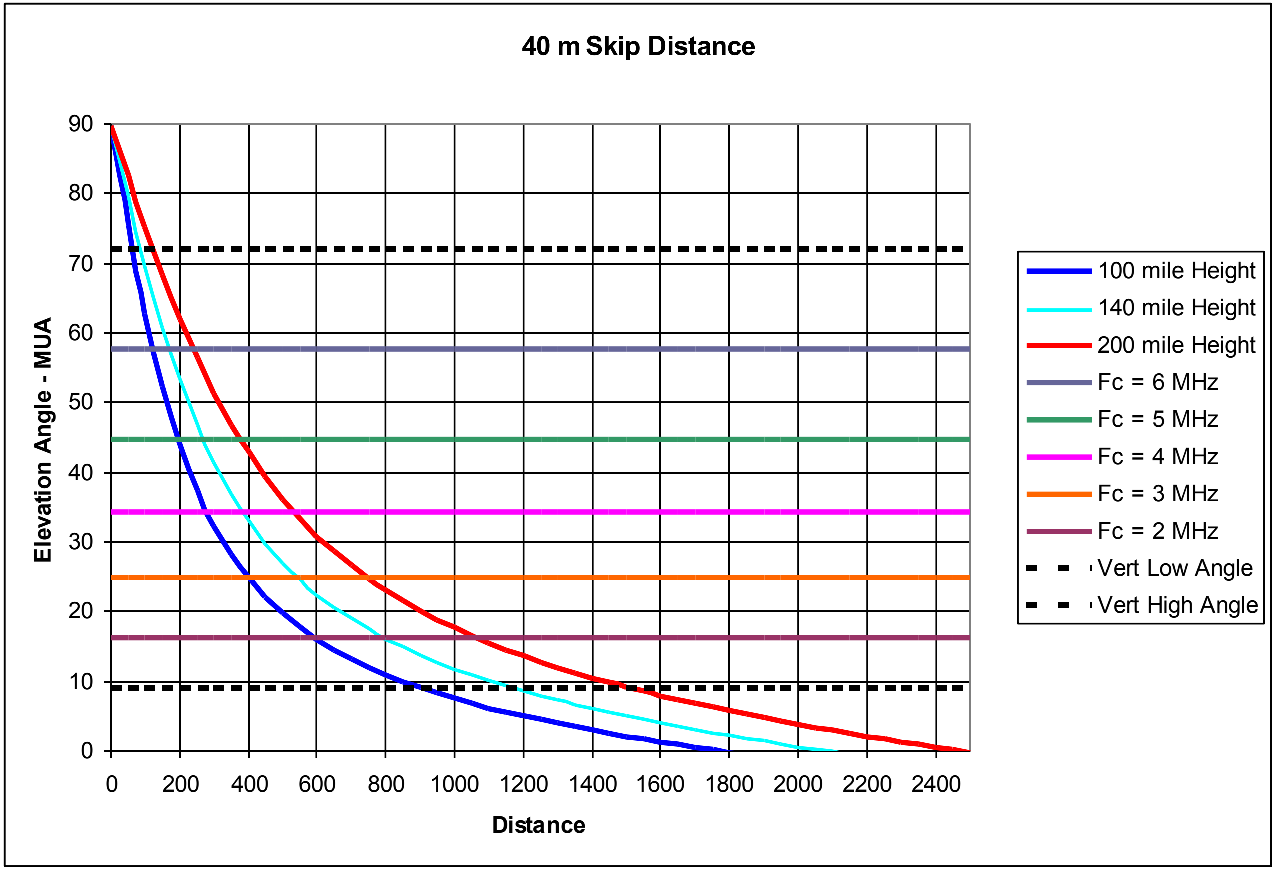
- **Red** curved line is distance vs elevation angle for a hypothetical signal refracted back to Earth at an altitude of 200 miles, near top of F Layer.
- **Blue** curved line is distance vs elevation angle for a signal refracted back at altitude of 100 miles, near the bottom of the F Layer.
- The horizontal lines show the Maximum Usable Angle for various critical frequencies F_c .

Determining Skip Distance



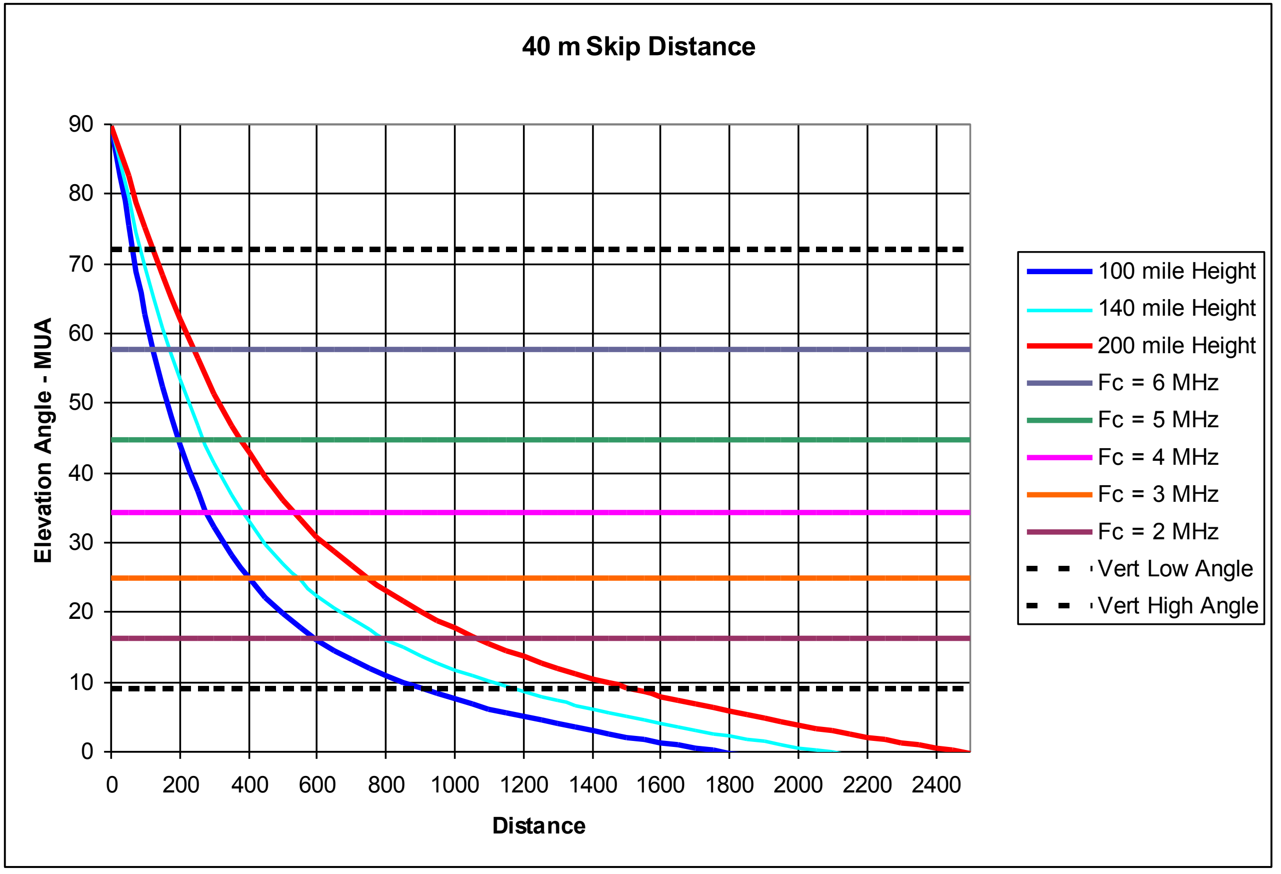
- The maximum elevation angle (MUA) a signal can be transmitted at to reach a station a certain distance away is limited by:
  - The maximum refraction point in the F Layer (the red curve) or
  - The current critical frequency (fc)
- whichever yields the smallest angle.

Determining Skip Distance continued



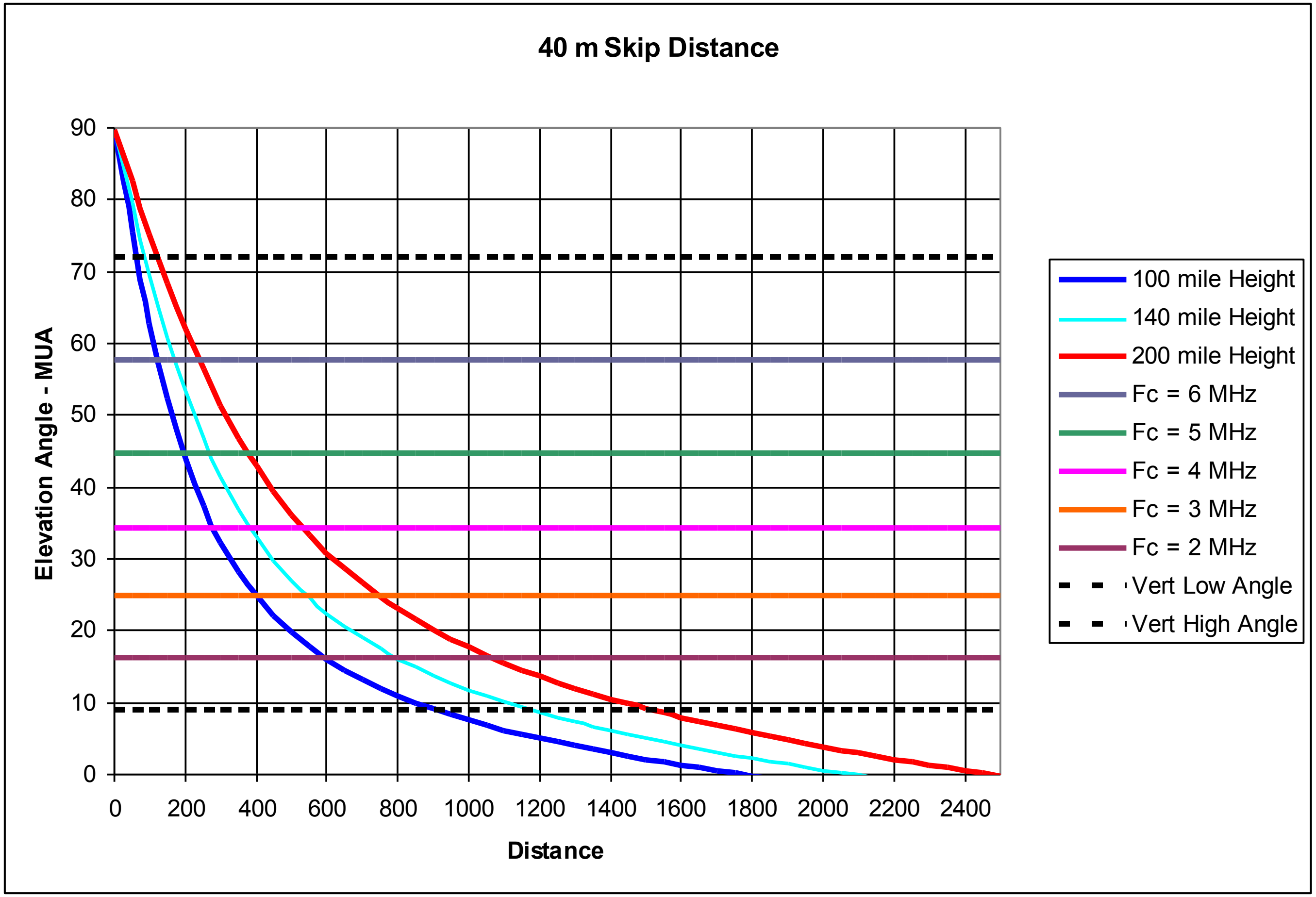
- The minimum elevation angle is determined by the lowest refraction point in the F Layer (the dark blue curve).
- The elevation angle for a signal actually arriving at the distant location is somewhere between these two extremes.

Determining Skip Distance continued



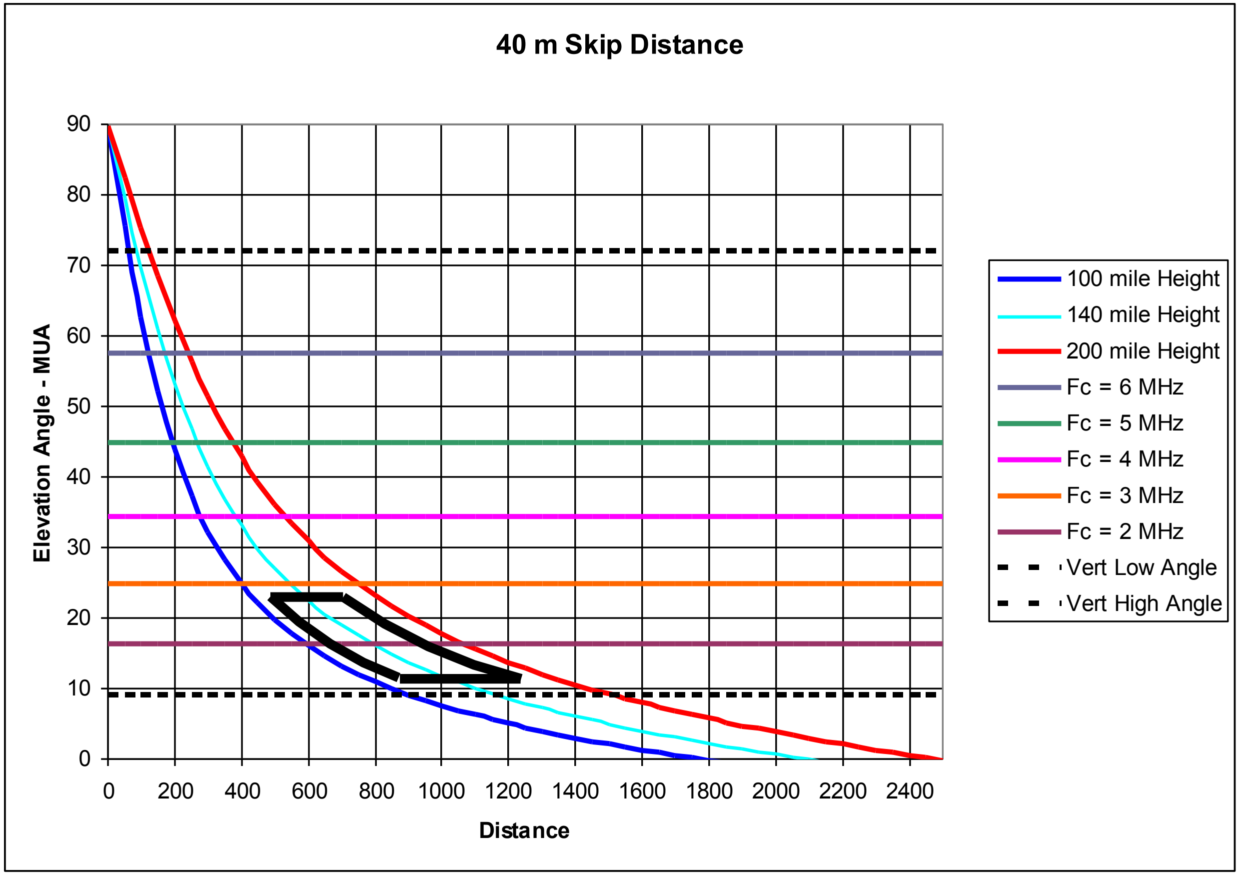
- Minimum skip distance is the distance at which the lowest refraction point, the blue curve, intersects the current critical frequency Fc. This is the closest station that can be reached. Skip distance is usually longer than this minimum.
- For a Fc = 3 MHz (the orange line) the min skip distance is about 400 miles.

Determining Skip Distance continued



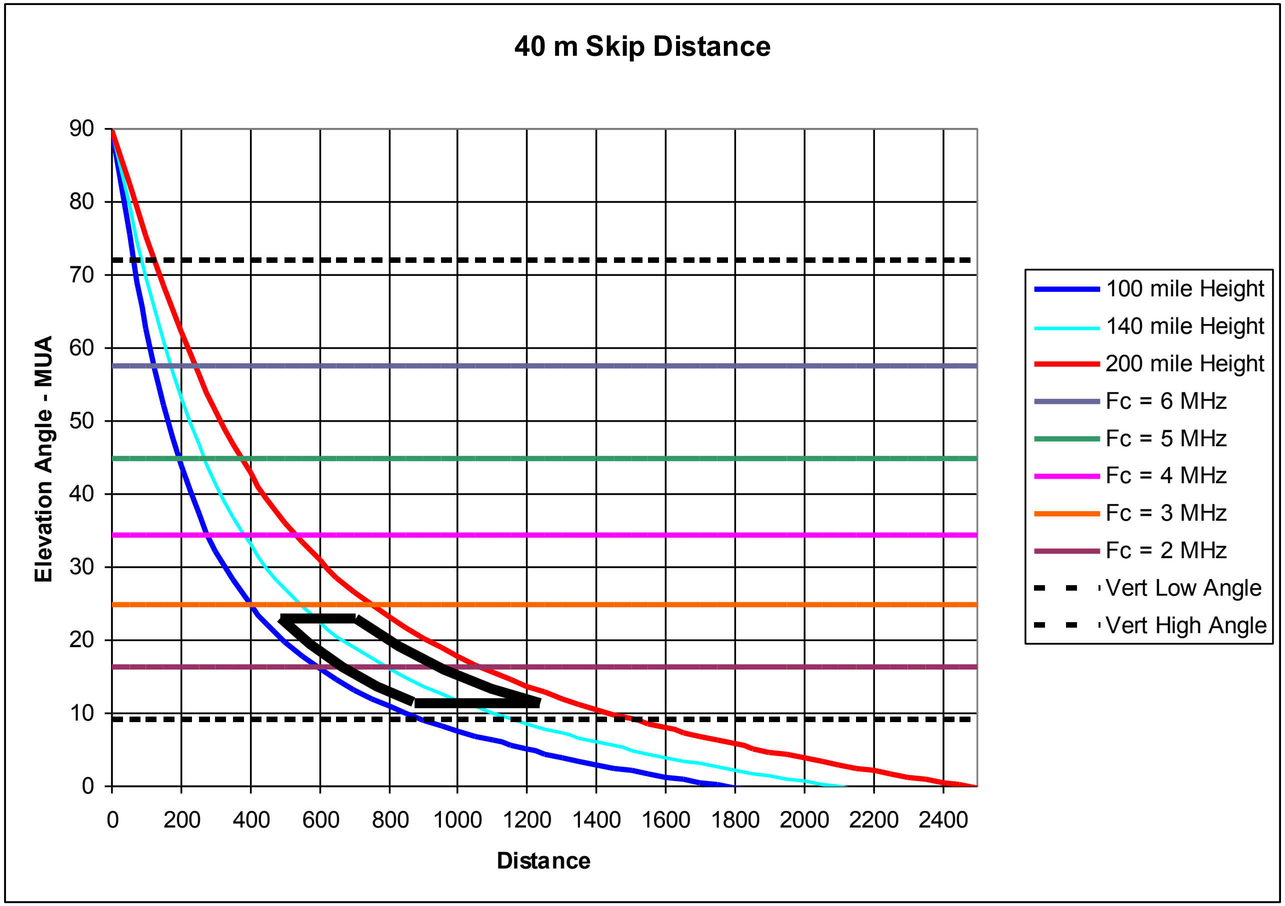
- The actual skip distance generally lies along the critical frequency line between the dark blue and the light blue curves.
- For a Fc = 3 MHz (the orange line) the skip distance is about 400 to 525 mi.

Reachable Single Hop Stations



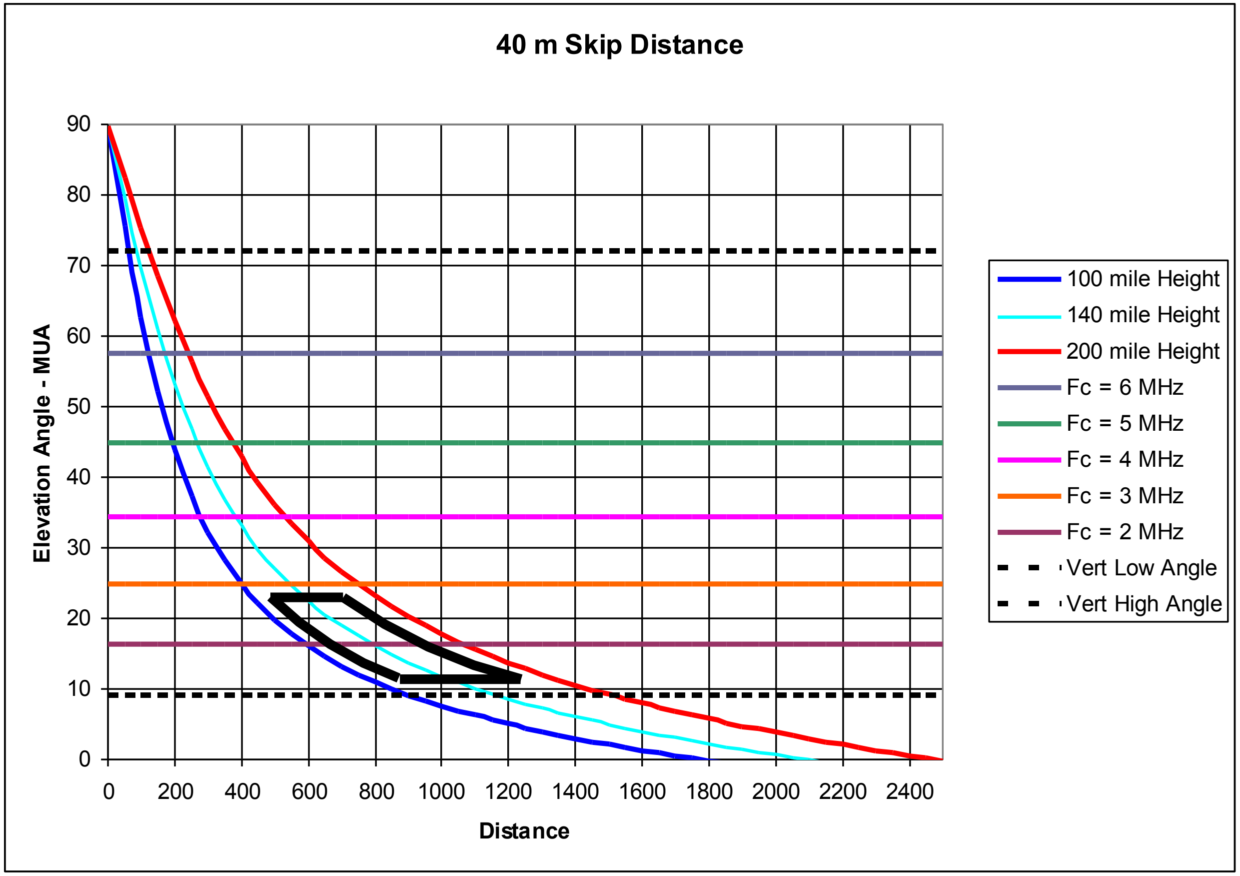
- The range of stations reachable in a single hop is bounded on top by the current critical frequency line, the dark blue curve to the left, the red curve to the right, and the lowest angle supported by the antenna on the bottom.
- At Fc = 3 MHz, stations that can be reached lie in range from 400 to 1400 miles.

Not All Stations Are Reachable



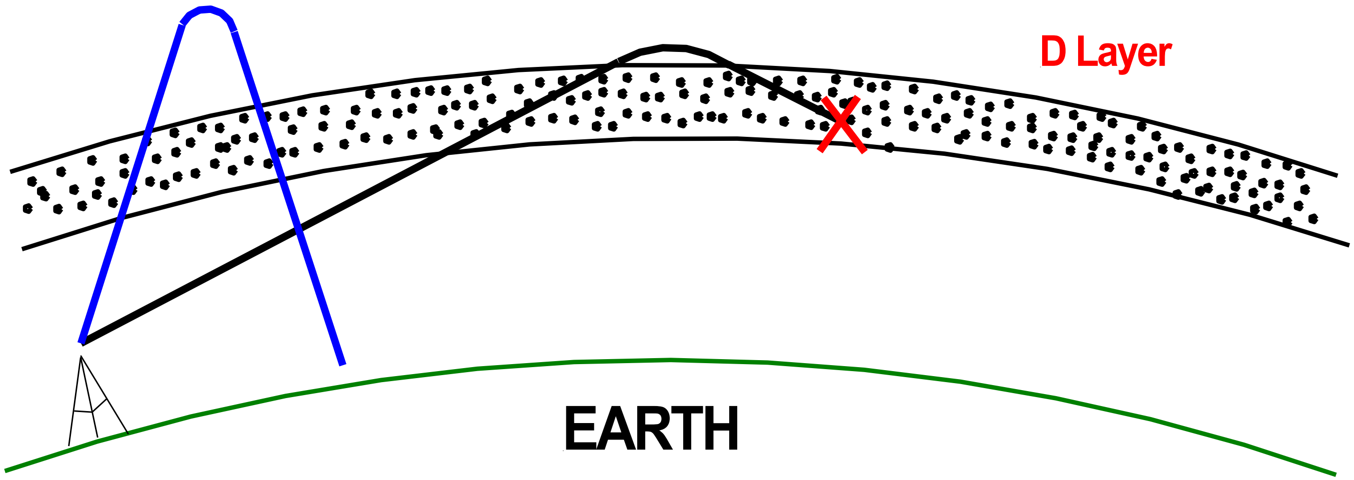
- It is important to note that not all stations in this range will be reachable.
- Ionospheric prorogation is very complex so some stations in this range will be strong, others weak, and some can not be heard at all.

Stations Just Beyond The Skip Zone



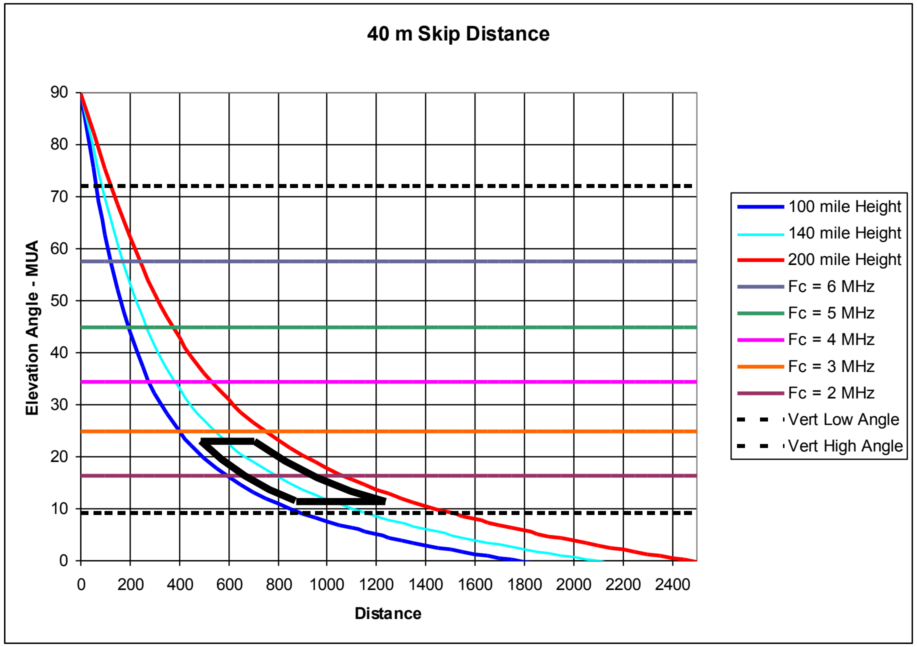
- Stations just beyond the skip zone are typically strong.
- At this distance the high and low path rays coincide increasing signal strength.
- Also, the elevation angle at this distance is high, nearly equal to MUA, meaning that the signal passes through the D Layer quickly minimizing absorption.

Long Hop Signals May Be Absorbed



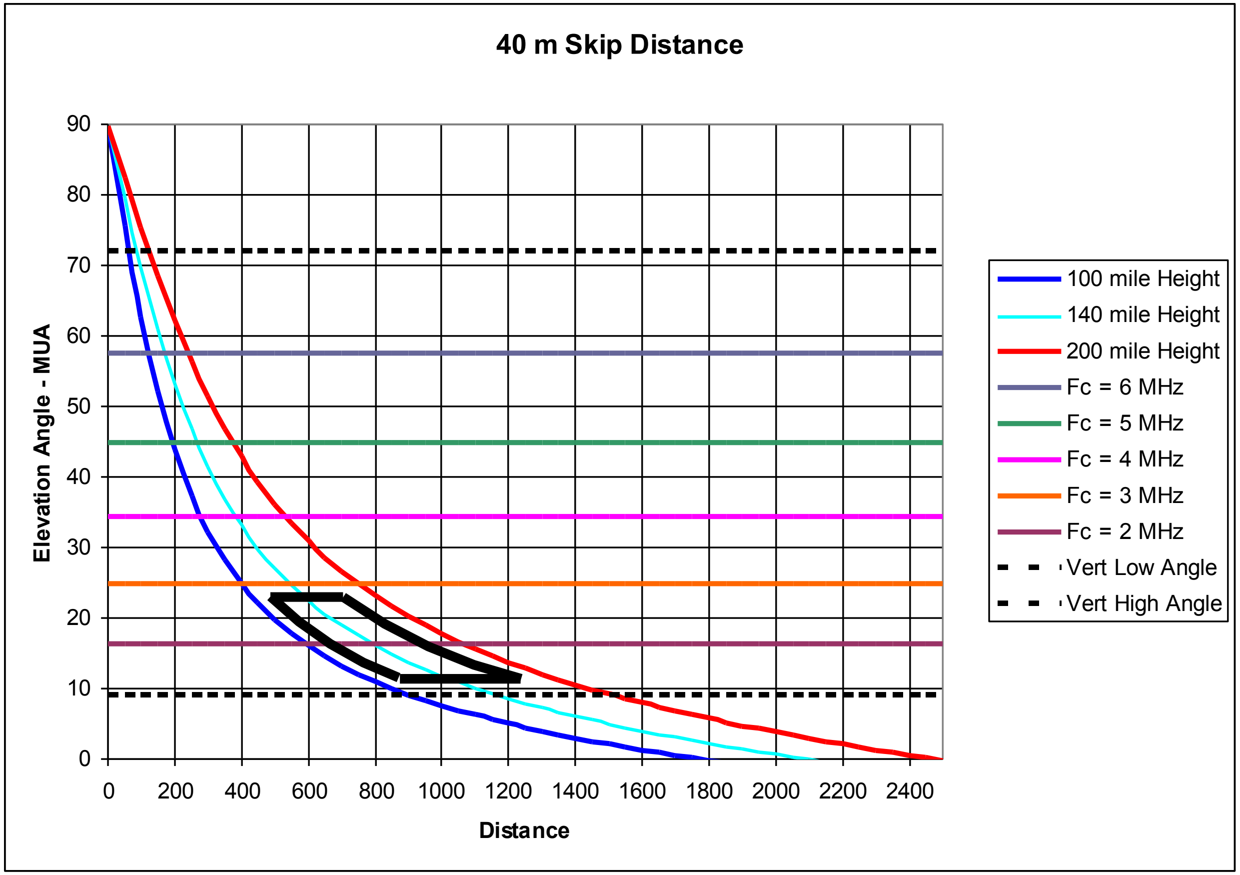
- A low elevation angle long hop signal spends more time traversing the D Layer than a high angle short hop signal.
- Consequently, a low angle long hop signal is more likely to be absorbed by the D Layer than a high angle short hop signal.

Stations Requiring 2 or More Hops



- 2 or more hops are required to reach many station that we communicate with.
- For multi-hop communications, the first hop must occur within the reachable single hop range.
- For Fc = 3 MHz, the first hop must occur within 400 to 1400 miles.
- Multi-path interference, both constructive (good) and destructive (bad) occur at first hop distances greater than 2 x [skip distance], at greater than 800 miles for Fc = 3 MHz.
- Beyond this distance, the propagation issue becomes very complex.

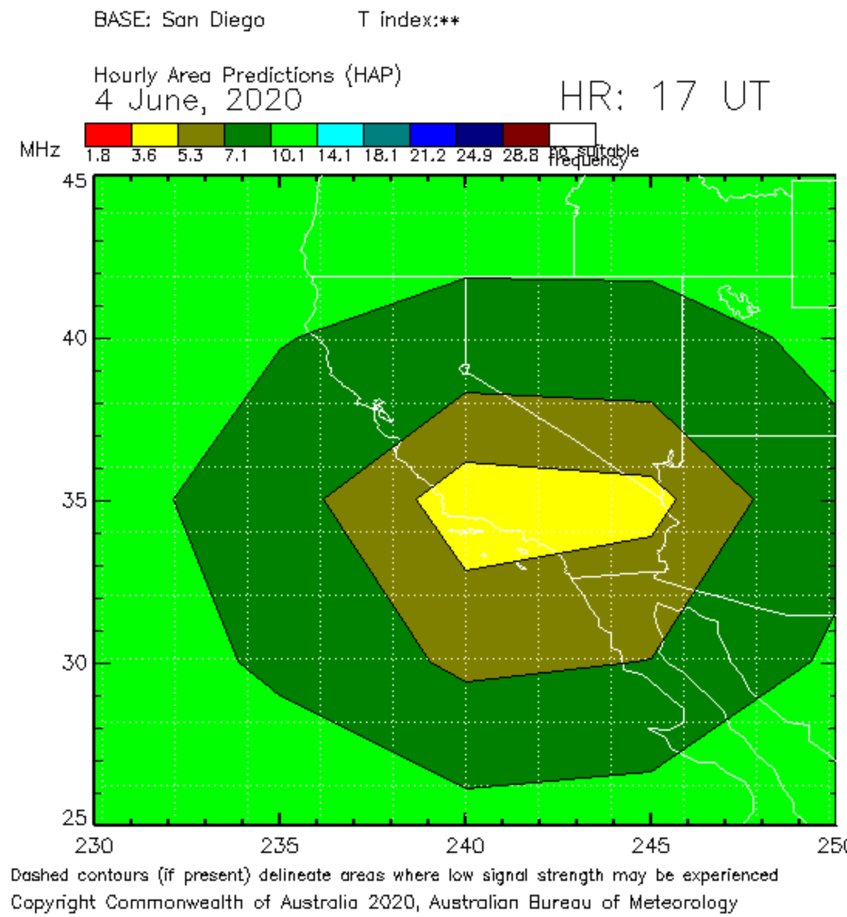
Observing High Path Propagation



- In some cases stations further away (1200 - 1400 mi at Fc = 3 MHz) are strongly received while closer station are either weak or can not be received at all.
- This is often an indication of high path propagation.

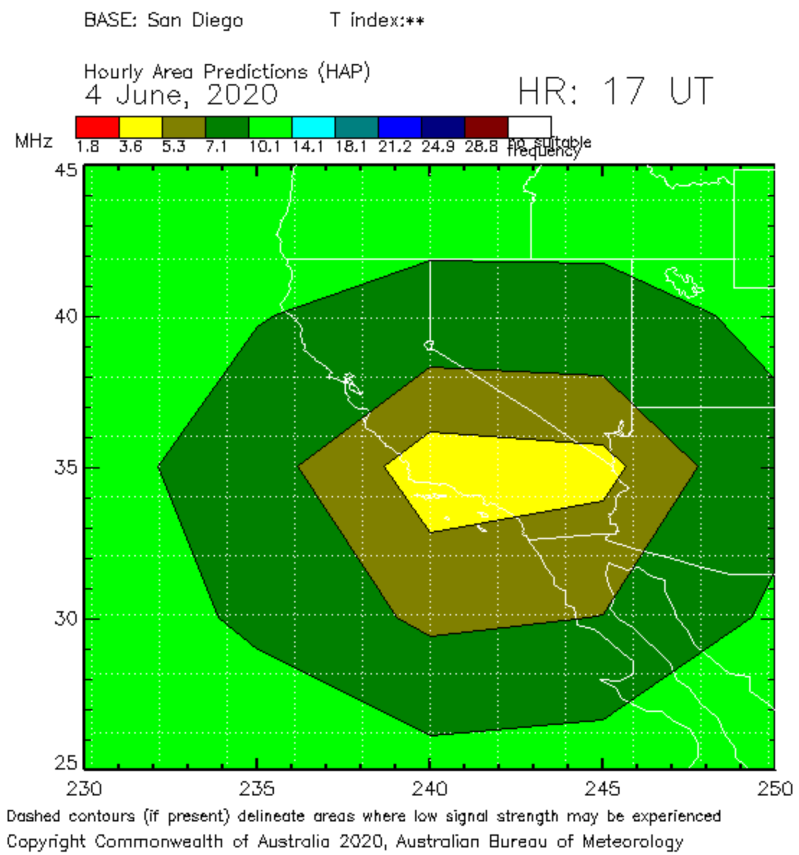
HAP Charts and Skip Distance

- HAP charts can be used to estimate skip distance.
- The 40 meter skip distance for Los Angeles at 1700 UT on June 4, 2020, measured in degrees Longitude, is equal to the Longitude of the 40 meter dark green band to the east of LA (about 248 deg) minus the Longitude of LA (241.73 deg).
- This skip distance is about 6.3 degrees.
- The Latitude of Los Angeles is 34.05 degrees.
- The next step is to convert degrees Longitude into miles.

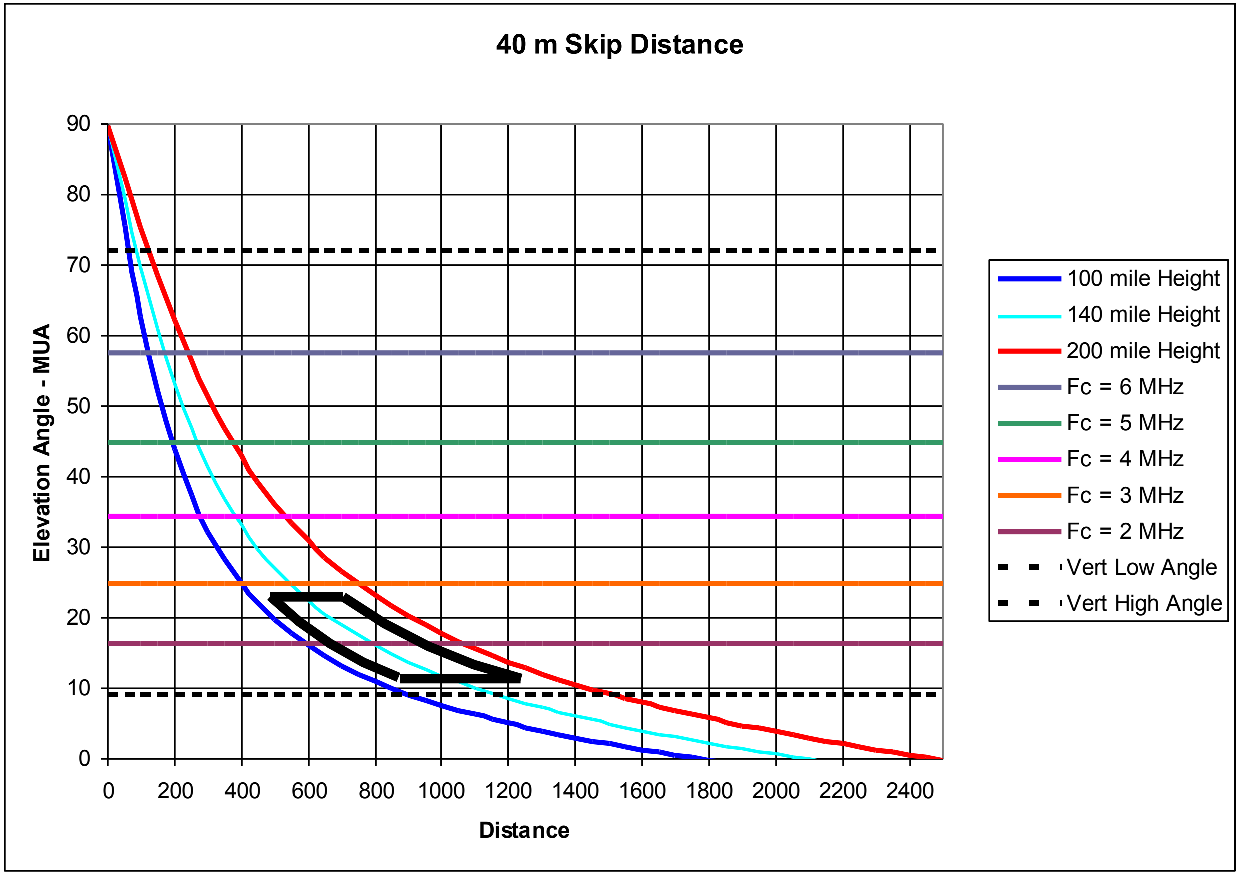


Converting Degrees Longitude To Miles

- Length of 1 degree Longitude = cosine (latitude in decimal degrees) * length of one degree in miles at the equator.
- Length of 1 degree of Longitude at the equator = 69.172 miles.
- Skip Distance = [Degree Longitude difference] * [cosine (latitude in decimal degrees) * length of 1 degree in miles at equator].
- The 40 m skip distance for Los Angeles at 1700 UT on June 4, 2020 is therefore:
- Skip Distance = [6.3] * [(cosine (34)) * 69] = 360 miles.
- Critical Frequency = 3.6 MHz



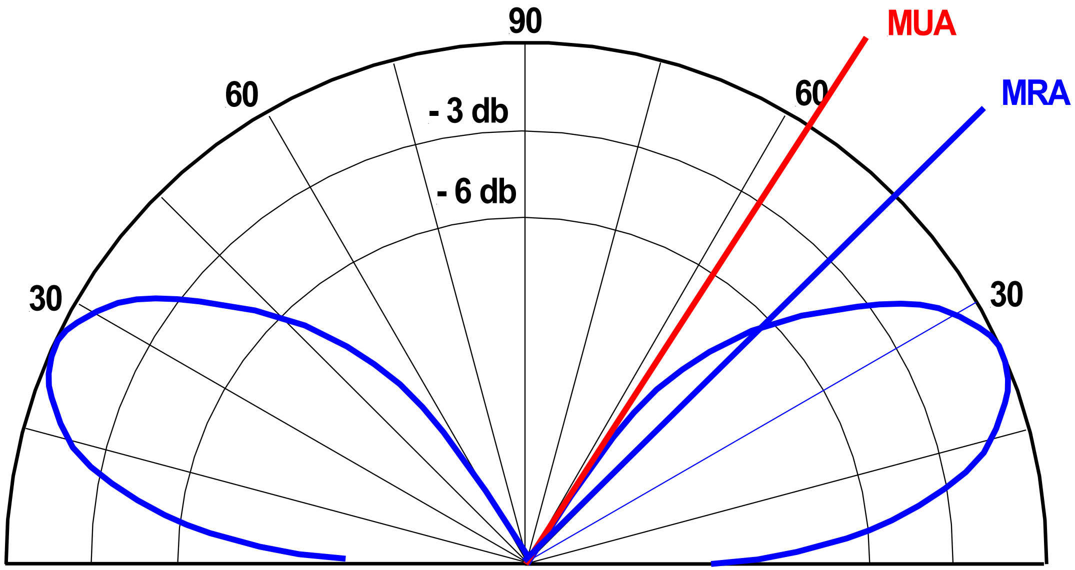
Skip Distance: Graph vs HAP Chart



- Graph shows the 40 m skip distance at Fc = 4 MHz is about 290 – 390 miles.
- This compares reasonably well with the HAP Cart skip distance of 360 miles.

Skip Distance Determined by 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 critical frequency fc

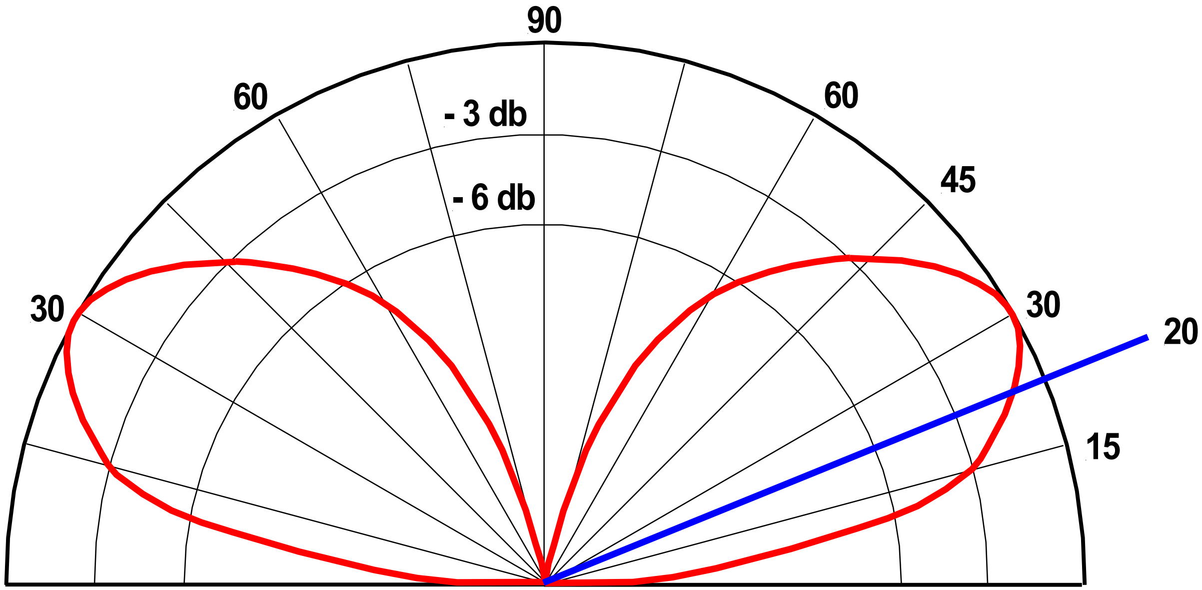


Example, skip distance at a MUA = 60 degrees is about 100 miles

But the skip distance for a 40 m vertical antenna with an MRA of 45 deg is approximately 200 miles. Stations closer than 200 miles will be skipped over by the vertical antenna.

Minimum Critical Frequency

$$f_{cm} = f_o \sin E_a$$



20 Meter 1/2 Wavelength Dipole Antenna At Optimum Height

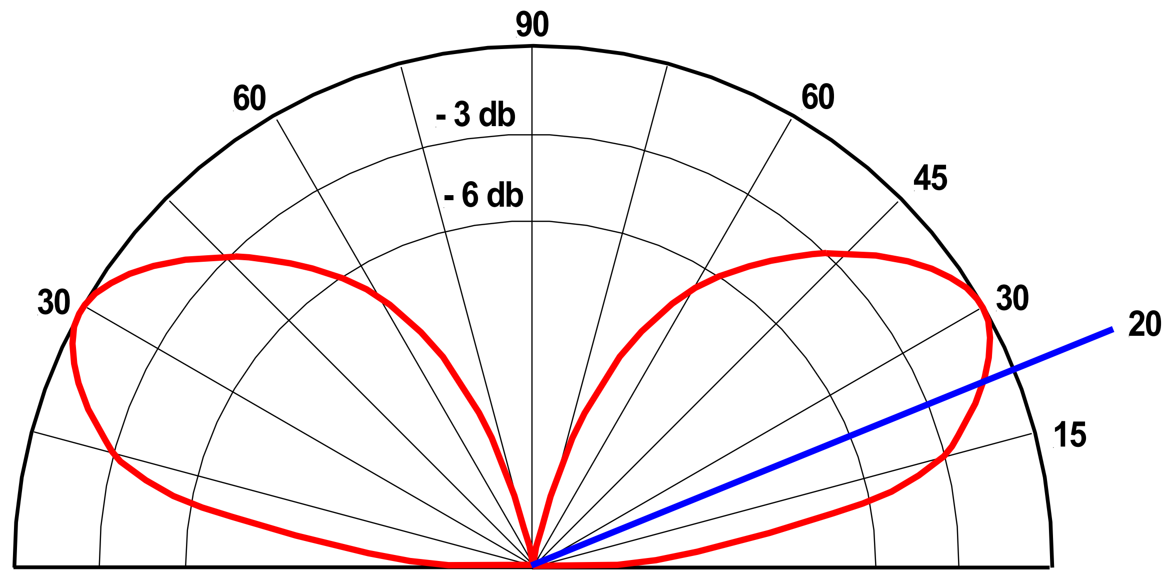
Minimum Critical Frequency

$$f_{cm} = f_o \sin E_a$$

- Minimum Critical Frequency is useful in determining band openings.
- Minimum critical frequency **f_{cm}** is the lowest critical frequency capable of supporting transmissions from your antenna at a given operating frequency.
- f_o = Your operating frequency
- E_a = The elevation angle of signals radiating from your antenna.
- Minimum critical frequency depends on the characteristics of your antenna, as illustrated in the following examples.

20 m Minimum Critical Frequency

$$f_{cm} = f_o \sin E_a$$



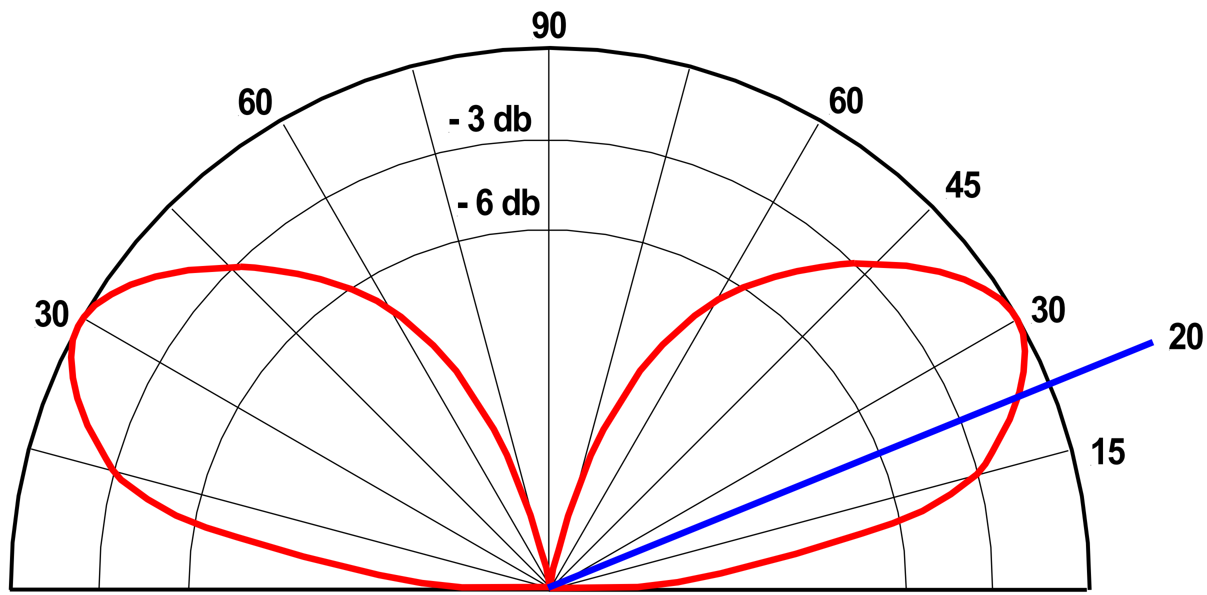
20 Meter 1/2 Wavelength Dipole Antenna At Optimum Height

- **fo = 14.2 MHz**
- f_{cm} = 7.1 MHz @ E_a = 30 deg
- f_{cm} = 4.9 MHz @ E_a = 20 deg
- f_{cm} = 3.7 MHz @ E_a = 15 deg (at -3 db point on this antenna pattern)

Band Opening Conditions

$$f_{cm} = f_o \sin E_a$$

For antennas with this vertical radiation pattern



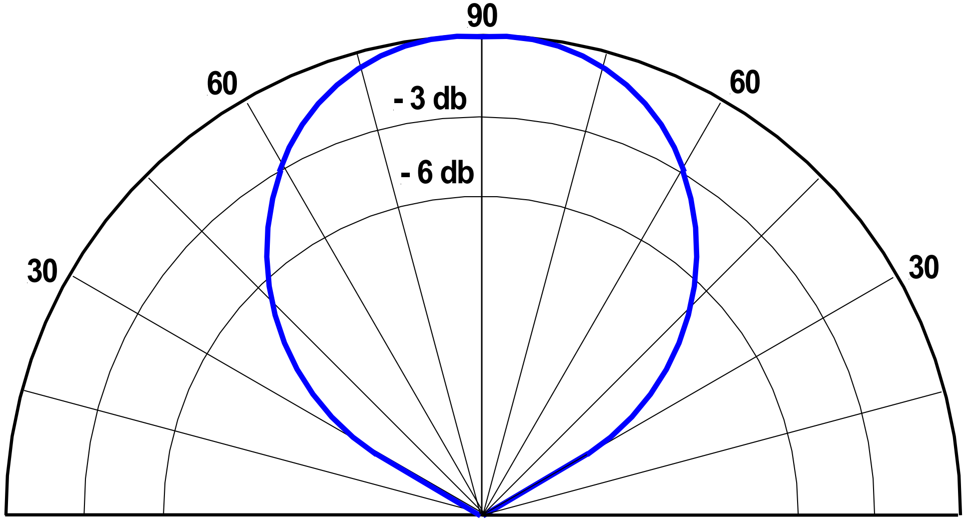
20 Meter 1/2 Wavelength Dipole Antenna At Optimum Height

- f_{cm} is about one half of the operating frequency f_o at an angle of 30 deg,
- At an angle of 14.5 deg, f_{cm} is about one quarter of operating frequency f_o.
- In very general terms, a band will be at least partially open if f_{cm} is about one quarter to one half of the operating frequency, one half being much better.

f_{cm} For High Elevation Angle Antennas

$$f_{cm} = f_o \sin E_a$$

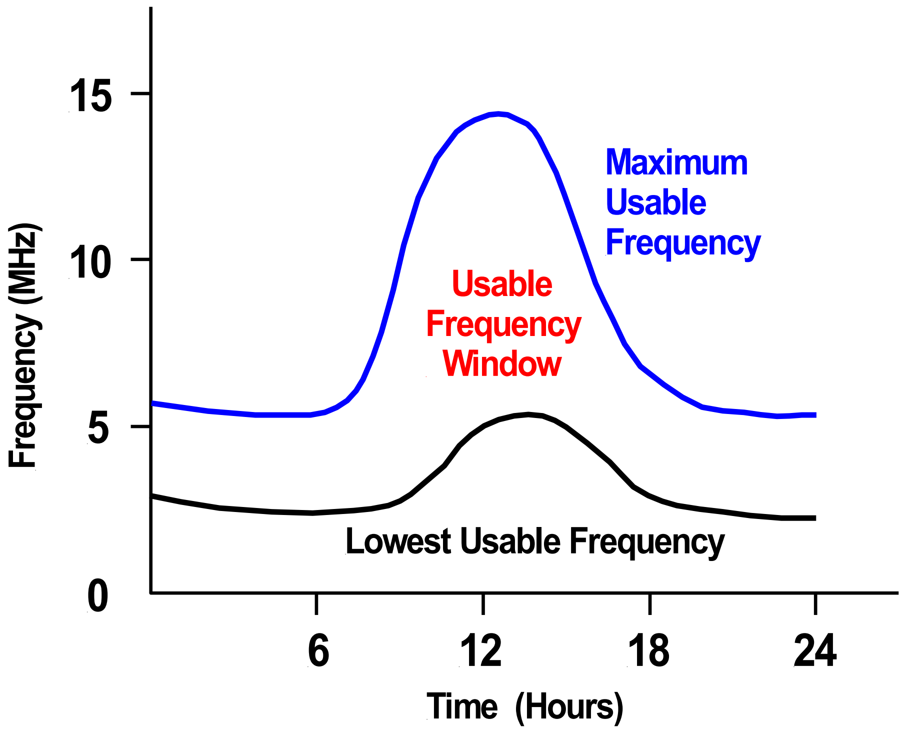
Antennas with high vertical radiation pattern



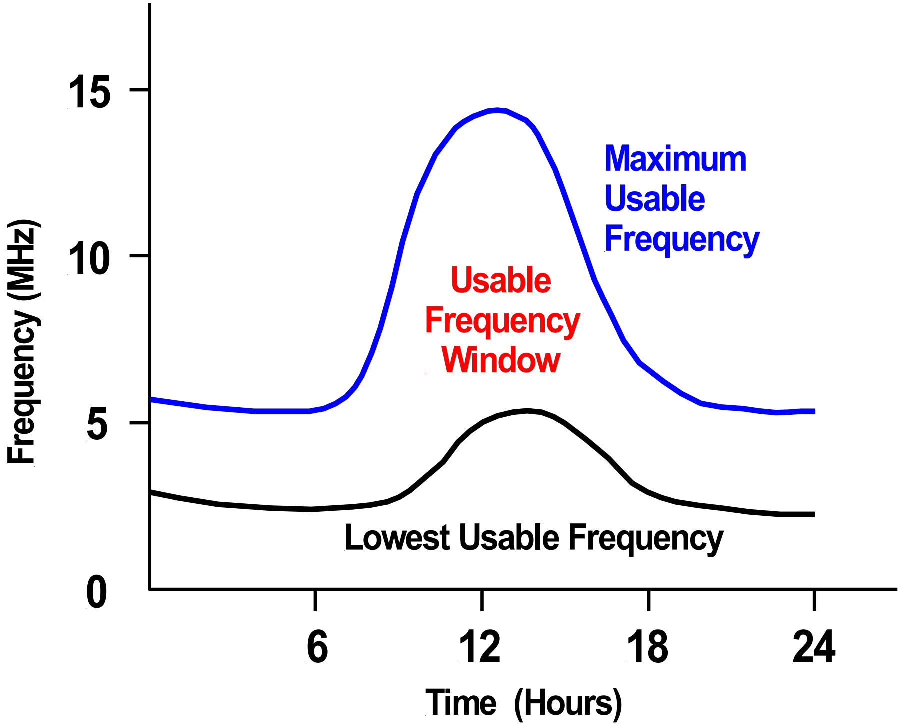
80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

- For this 80 m antenna the lowest usable elevation angle E_a is about 45 deg.
- At this angle, f_{cm} = 2.69 MHz at an operating frequency f_o = 3.8 MHz.
- Thus, the minimum critical frequency f_{cm} required to support a high elevation angle antenna is about 2/3 (0.7) the operating frequency f_o.
- This compares to about 1/2 the operating frequency f_o for antennas with lower angle radiation patterns.

Lowest Usable Frequency (LUF)



Lowest Usable Frequency (LUF) Is:



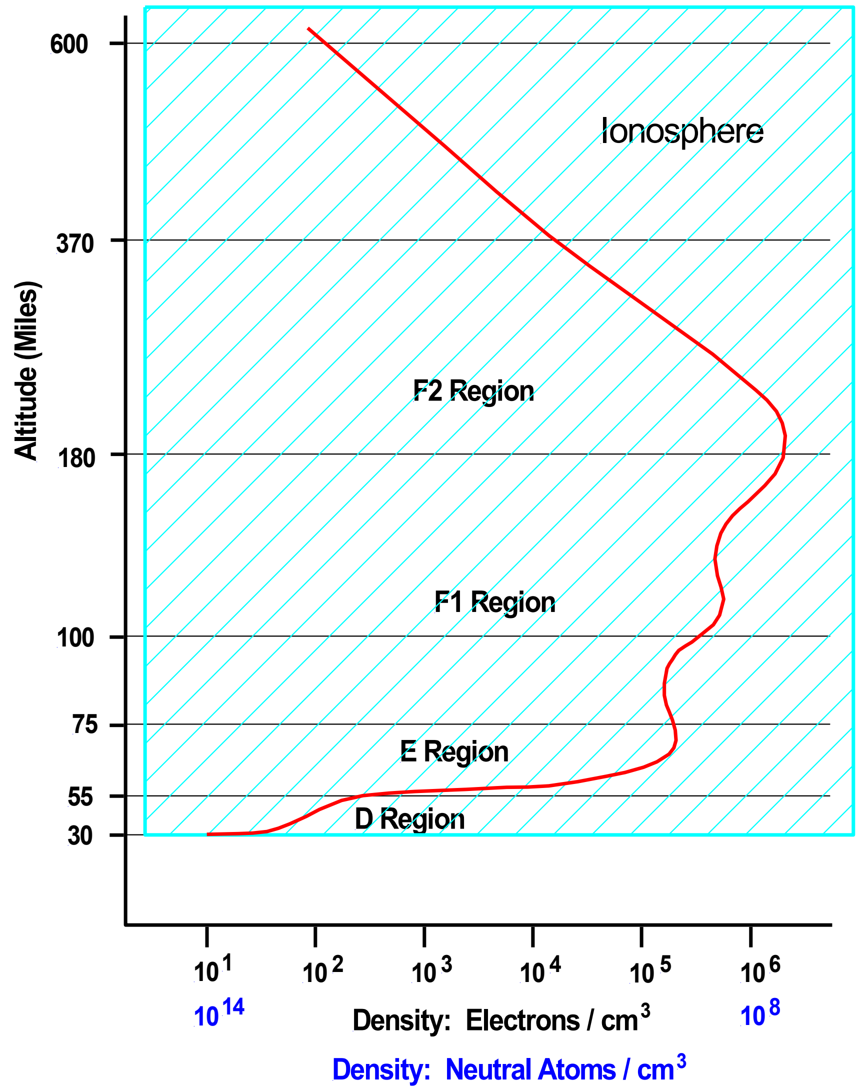
- The lowest frequency radio signal
- Capable of propagating through the ionosphere
- From one specific radio station to an other

What Determines Lowest Usable Frequency?

- LUF is primarily determined by :
  - Noise, and
  - Radio wave absorption in the D Layer
- The D Layer is formed by x-ray radiation from the Sun.
- Thus, Lowest Usable Frequency varies:
  - Throughout the day.
  - Seasonally.
  - In accordance with the 11 year solar cycle.
- Lowest Usable Frequency significantly affected by solar flares.

Anatomy of Absorption

- Free electrons absorb energy from the passing radio wave.
- Electrons vibrate at the same frequency as radio wave.
- Electrons reradiate absorbed radio wave energy in random directions.
- Causing radio wave to bend as it travels through the ionosphere
- **D Layer is different.**
- Electrons recombine with ions so fast they do not have time to reradiate radio wave energy.
- Absorbed radio wave energy dissipated as heat in D Layer.

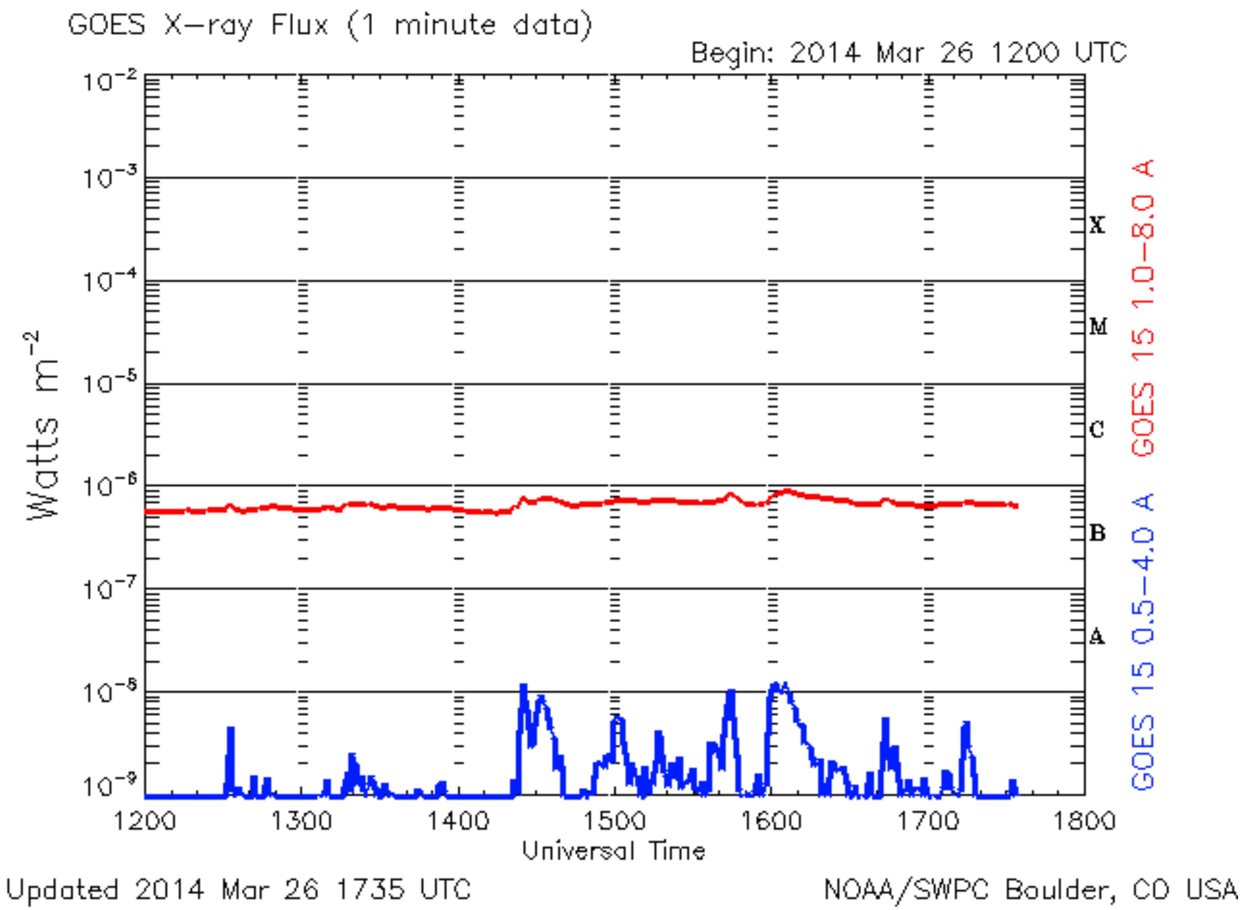


Absorption vs Frequency

$$\text{Absorption} \propto \frac{1}{f^2}$$

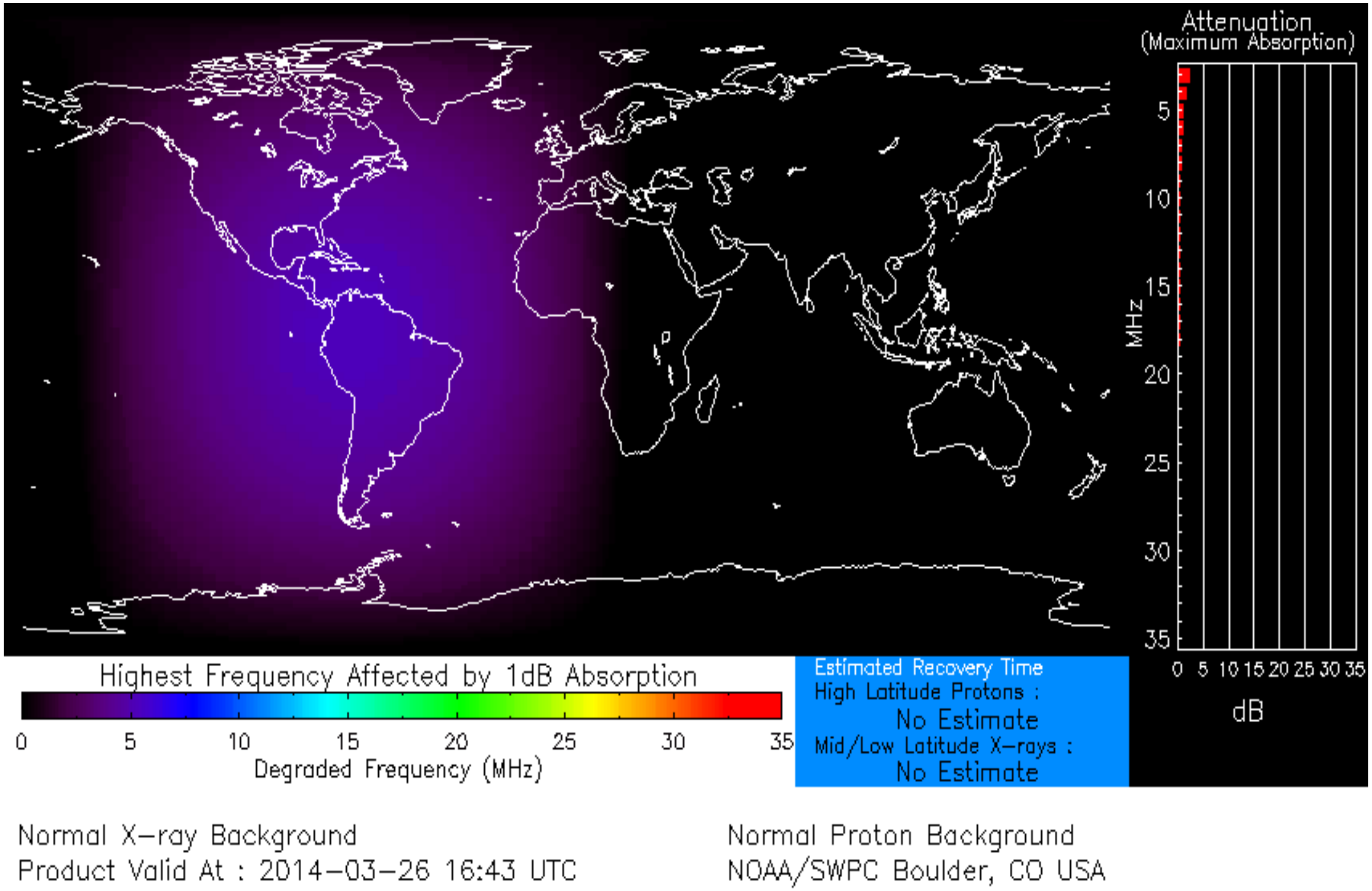
- D Layer absorption is inversely proportional to frequency squared.
- The absorption on 40 meters is only 1/4 that on 80 meters.
- The absorption on 20 meters is only 1/16 that on 80 meters.
- To avoid absorption, want to operate at the highest frequency possible, for example at the FOT.
- How do we know what the level of absorption is?

X-ray Flux a Good Measure of Absorption Levels



http://www.solarham.net/

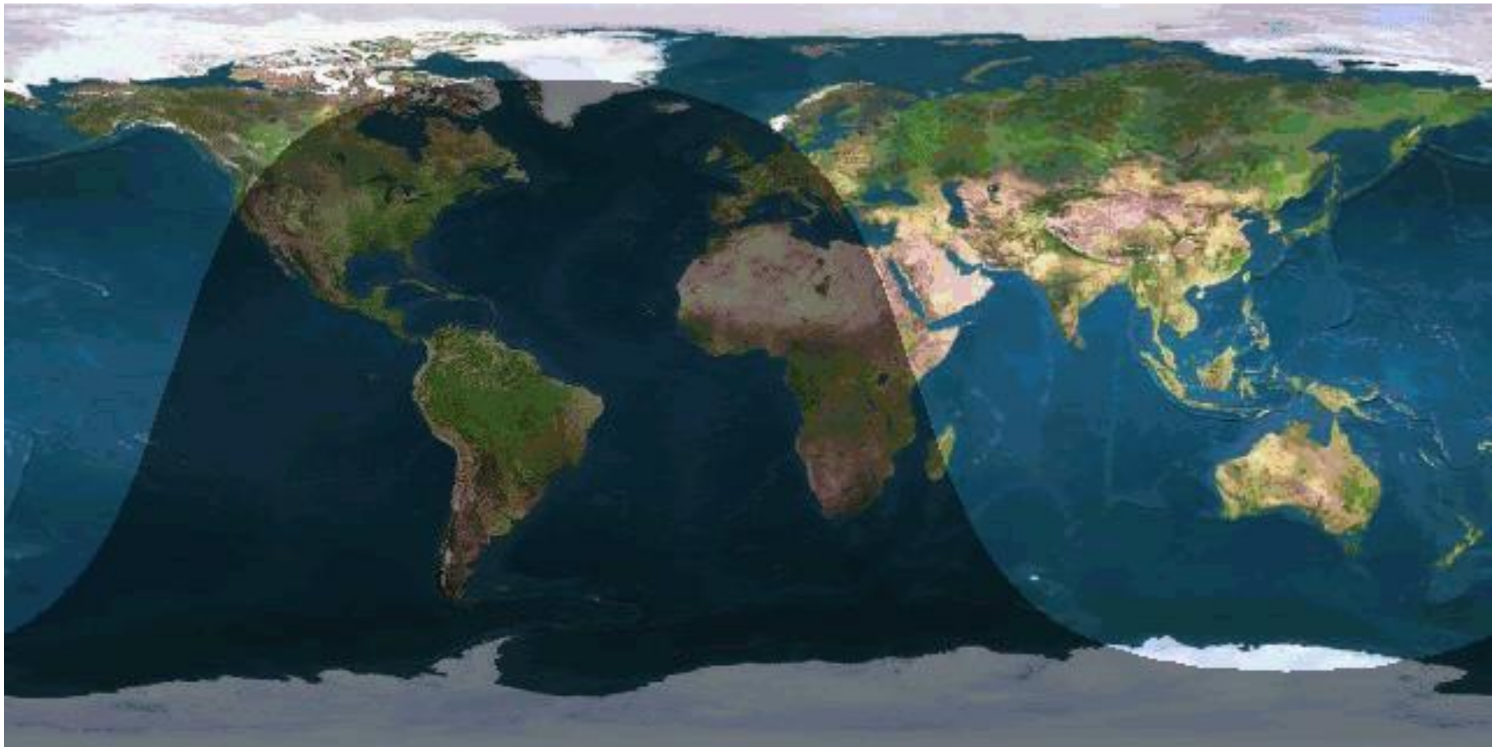
Lowest Usable Frequency Estimate



LUF ~ 6 MHZ

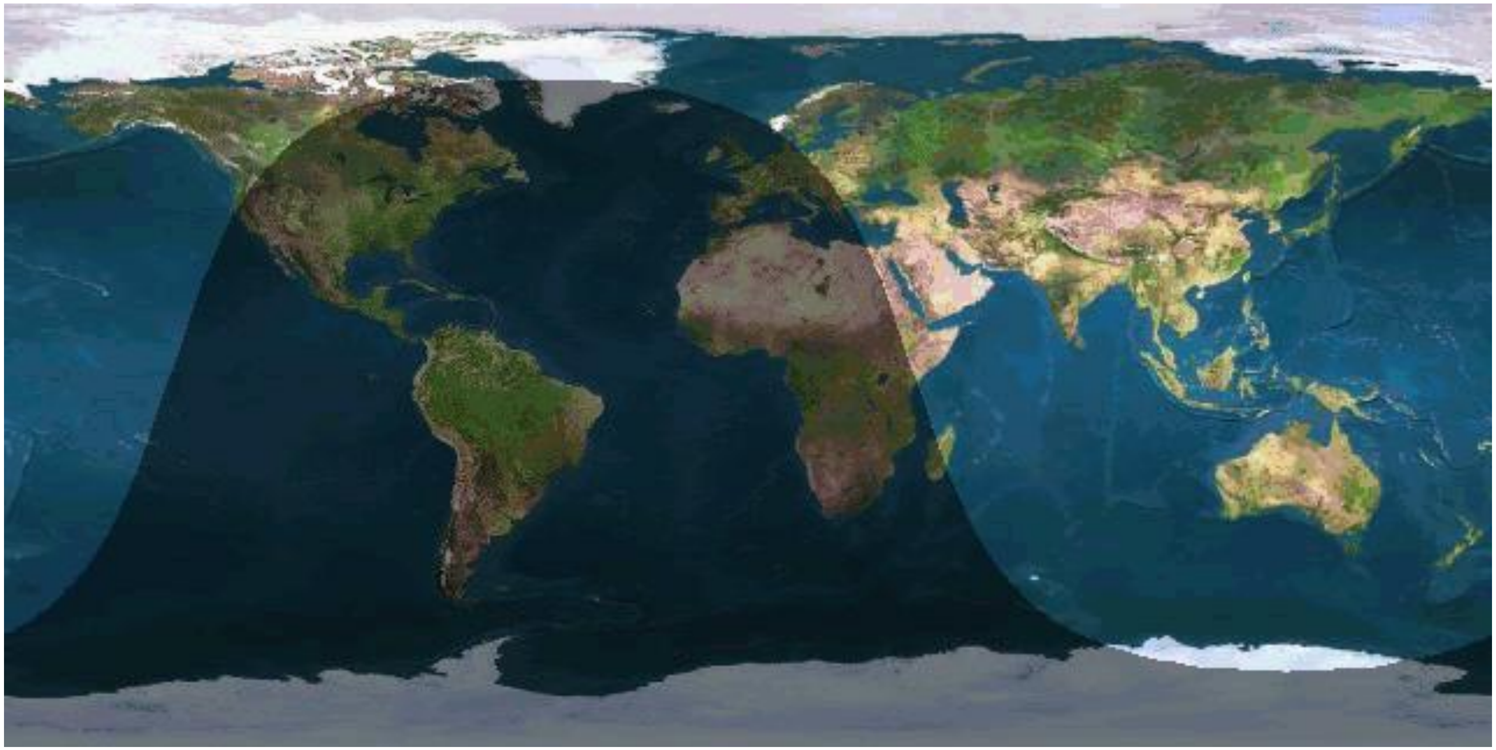
http://www.solarham.net/

Gray Line Propagation



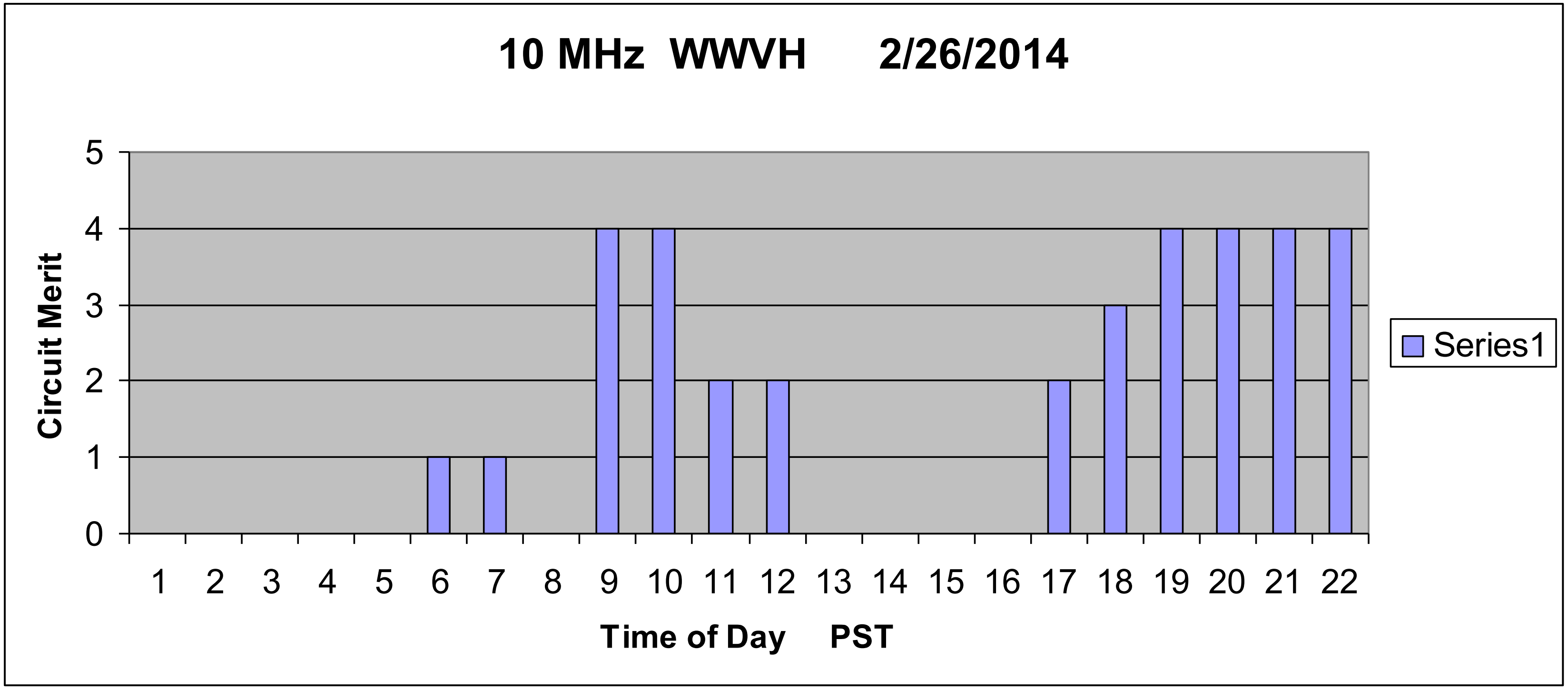
- The “Gray Line” is the terminator between day and night.
- Good F Layer ionization along the gray line
- However, D Level absorption has disappeared or not yet developed.
- Good F Layer ionization with no D Layer absorption leads to excellent propagation.

Importance of Gray Line Propagation



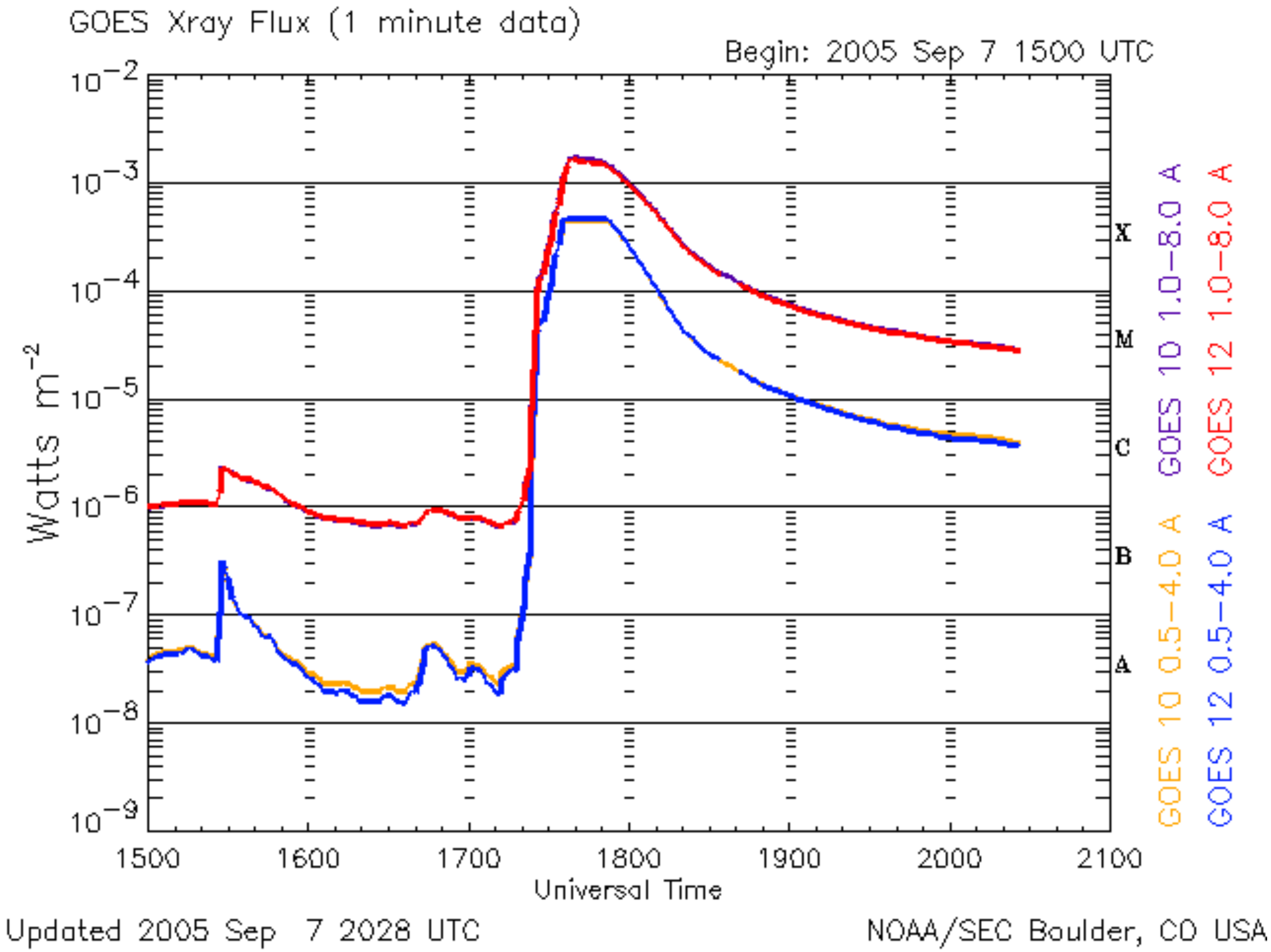
- Since absorption is inversely proportional to frequency squared:
- Gray line propagation very important for 80 m and 40 m DXing,
- Less so for 20 meters,
- Usually not relevant for 15 meters.

Morning Window to Hawaii

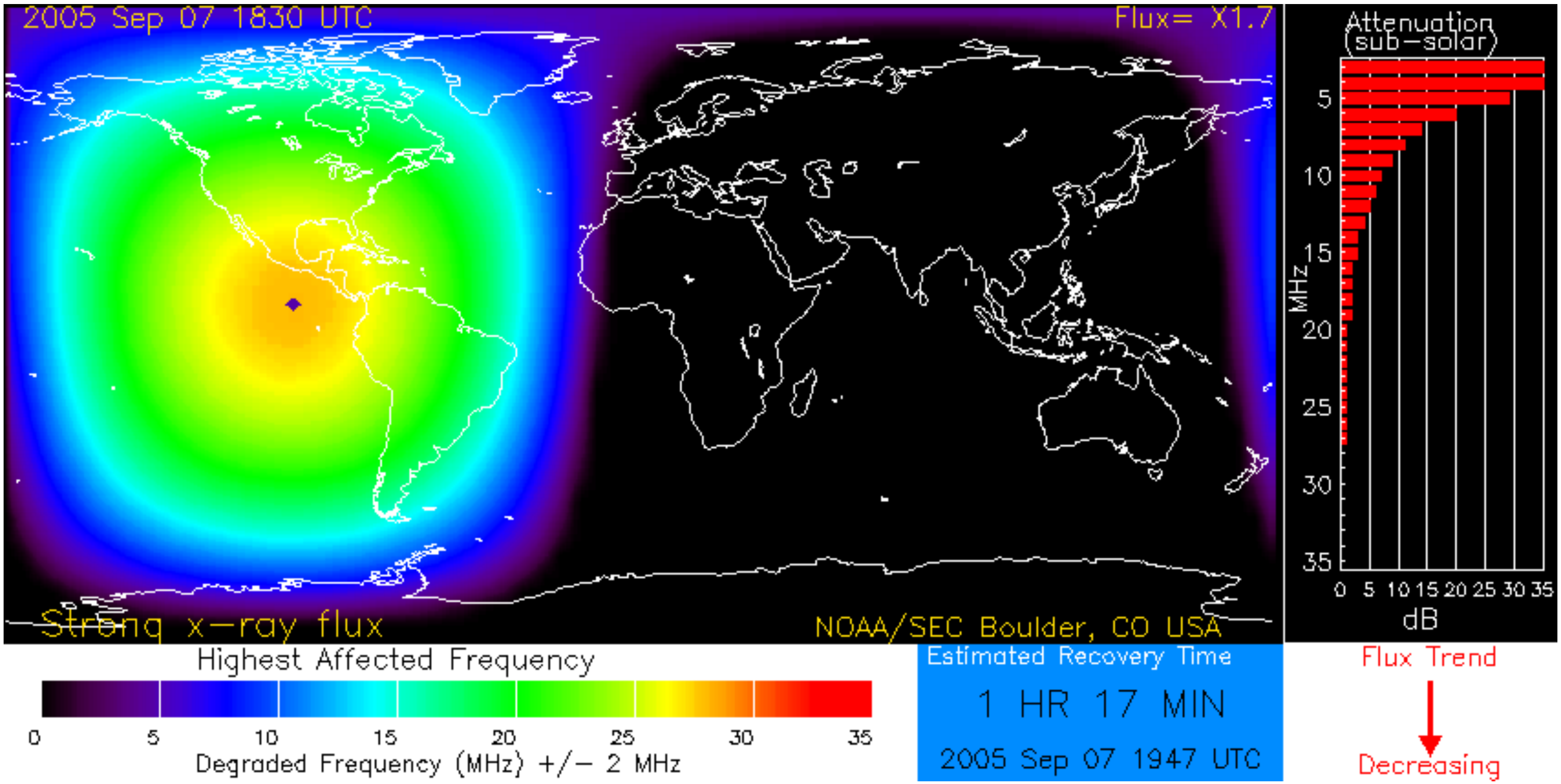


- 10 MHz WWVH appears strong at 900 PST when sun rises in Hawaii
- Begins to deteriorate between 1100 – 1200 PST due to D Layer absorption
- Lost to D Layer absorption from 1300 through 1600 PST.
- Reappears at 1700 PST as D Layer absorption decreases.

Solar Flares Cause Large Increases In X-ray Flux



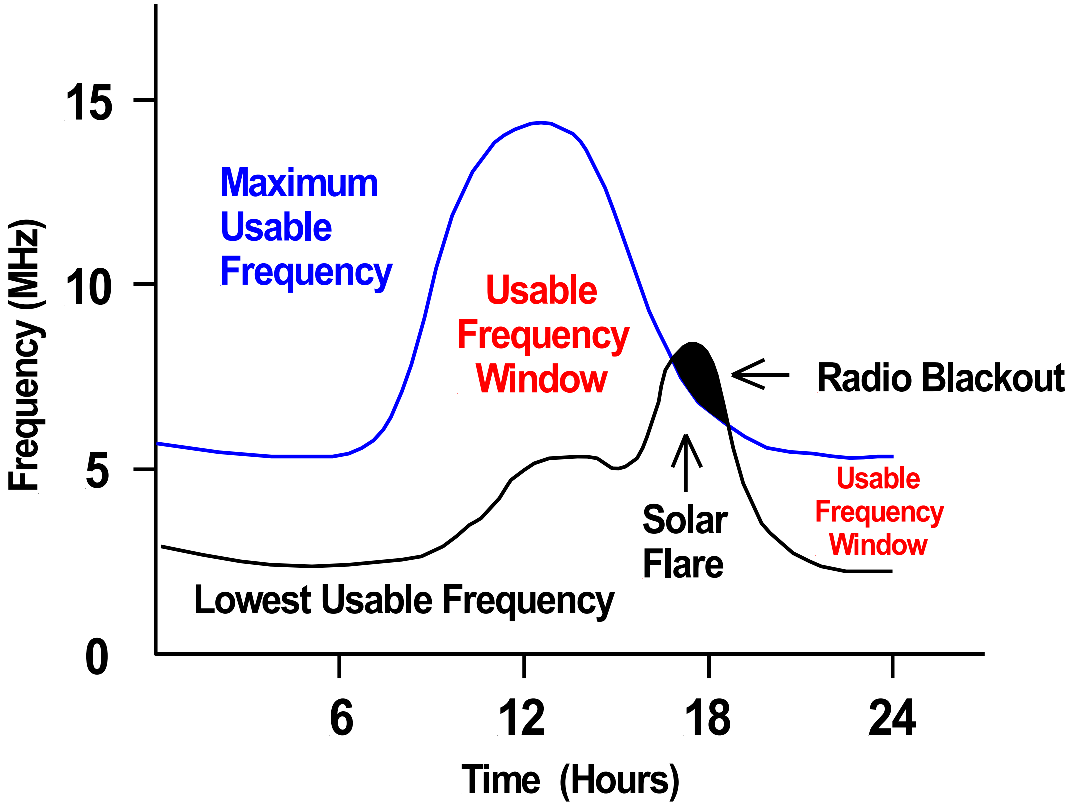
Elevated X-ray Flux Greatly Increases D Layer Absorption



LUF ~ 20 MHz

http://www.solarham.net/

These Conditions Can Lead to a Radio Blackout



- A radio blackout occurs whenever the LUF is greater than the MUF.
- A radio blackout can last for several minutes or hours depending on the magnitude of the solar flare.

In Summary

- A working knowledge of ionospheric parameters including:
  - Critical frequency,
  - Maximum usable frequency,
  - Maximum usable angle,
  - Skip distance, and
  - Lowest usable frequency.
- Along with tools such as:
  - Critical frequency maps,
  - HAP charts,
  - Skip distance charts, and
  - X-ray flux charts.
- Greatly assist in achieving dependable HF communications
  - From any where,
  - At any time,
  - Under any conditions
- As well as improving contesting scores and achieving great DX.

All of This Makes HF Radio a LOT of FUN !