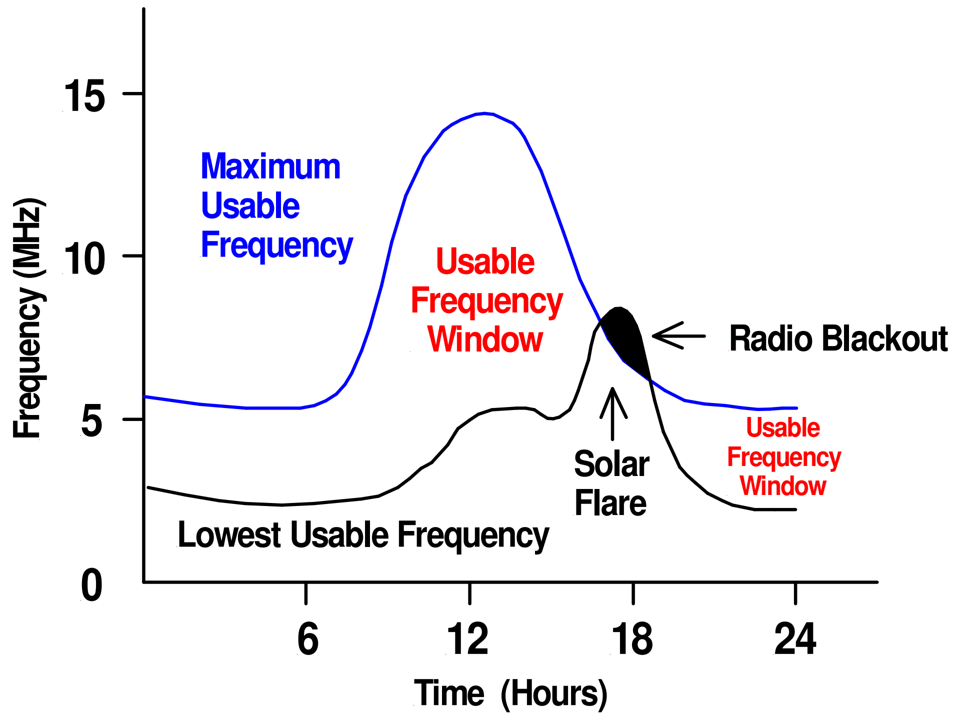
Maximum Usable Frequency



Ken Larson KJ6RZ

August 21, 2014

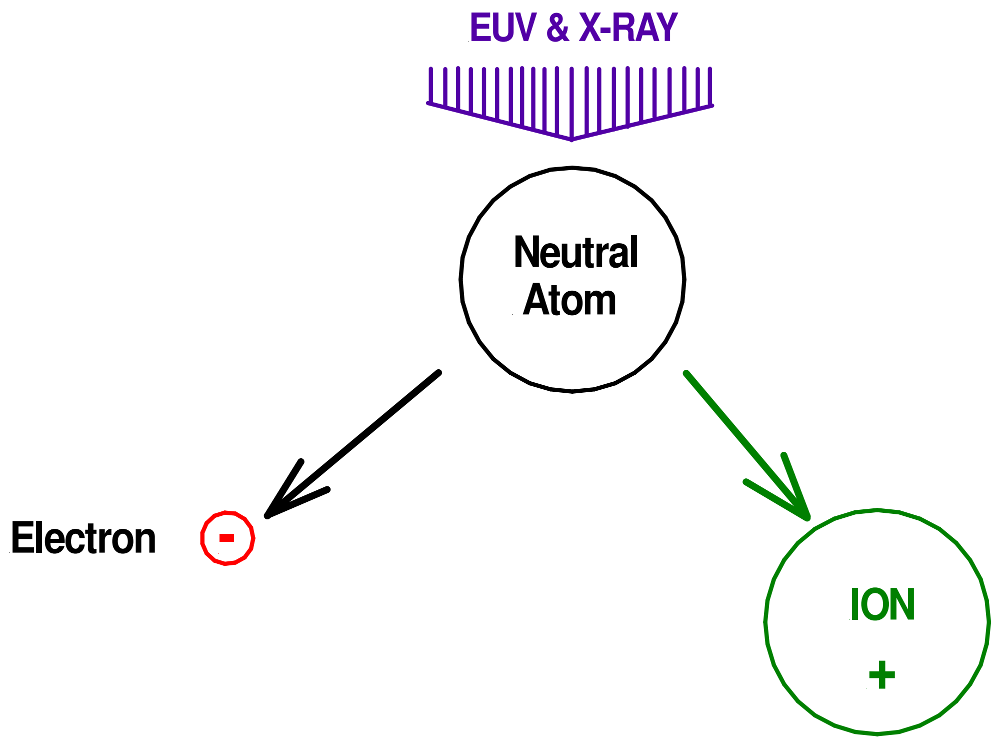
Reliable HF Communications

- Meaning: Successfully transmitting and receiving messages any time
  - Day or night
  - Regardless of HF conditions
- Specifically
  - 24 hours a day
  - 7 days a week
  - Throughout the 11 year solar cycle.

Why Study MUF and its Variants?

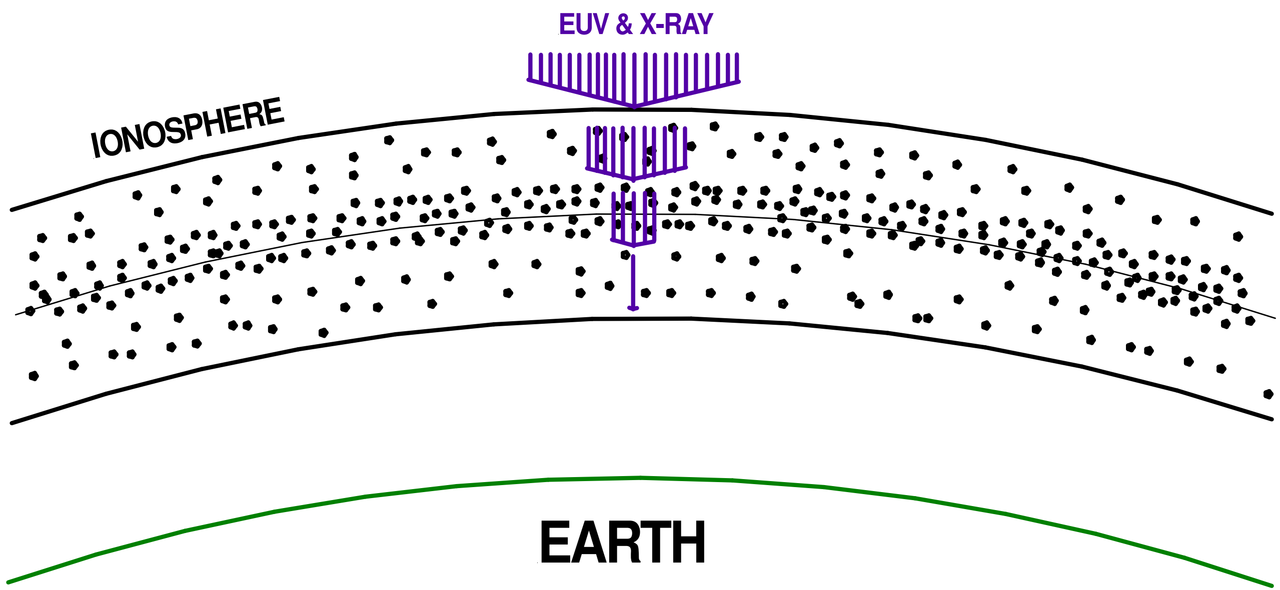
- Despite the difficulties
- WWII HF radio operators were successful
  - 90% of the time, in getting their radio traffic through, and
  - Their radios were not nearly as good as what we have today.
- For over 50 years, HF was the only viable means of communications in many remote areas of the world.
  - Australia outback,
  - South Pacific
  - Ships at sea
- The goal is to achieve the same level of success that they enjoyed.

Upper Atmosphere Ionization



- Solar EUV & X-ray radiation ionizes atoms in the upper atmosphere.
- Neutral atom absorbs some of the radiation.
- Absorbed energy excites an electron in the neutral atom.
- Electron breaks free from the atom.
- Result: free electron and a positively charged ion.

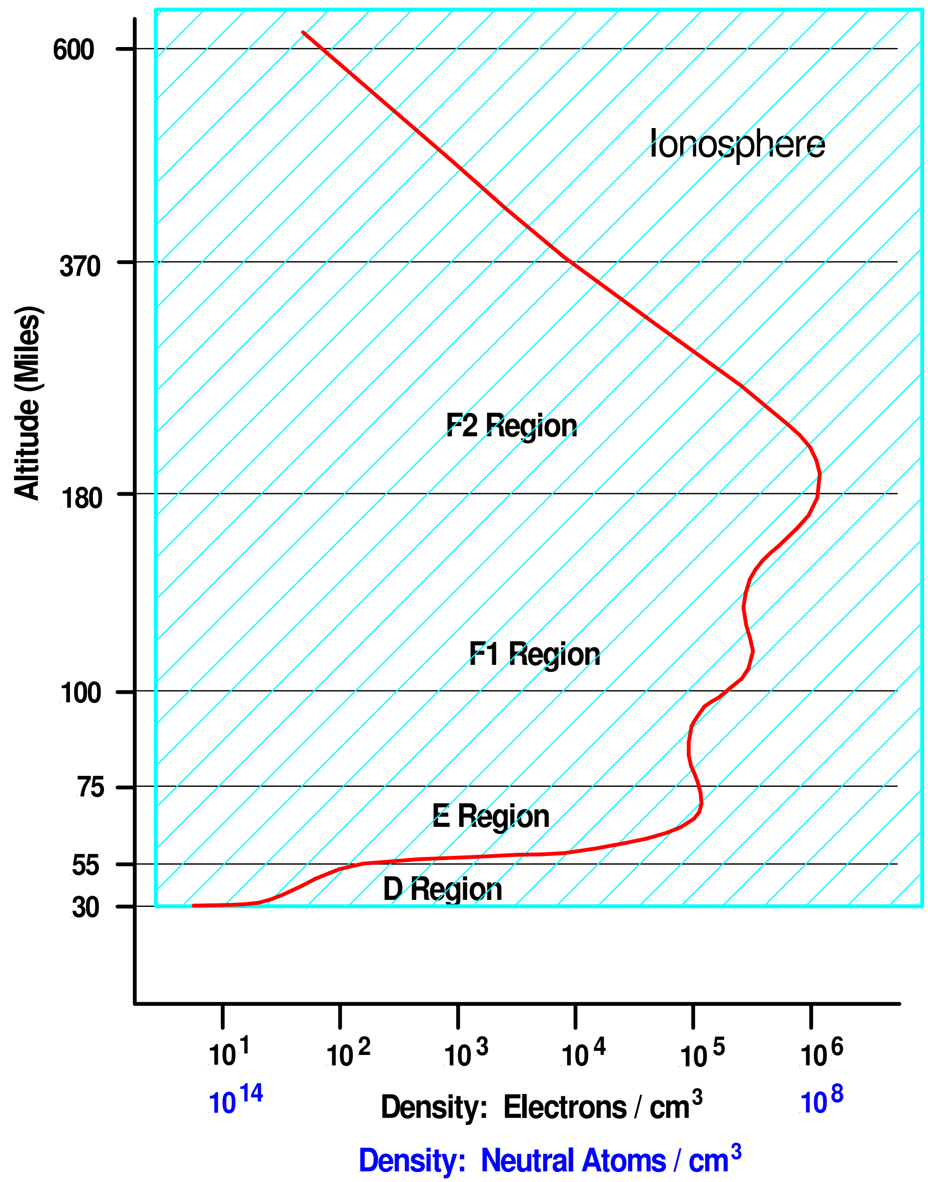
Formation of the Ionosphere



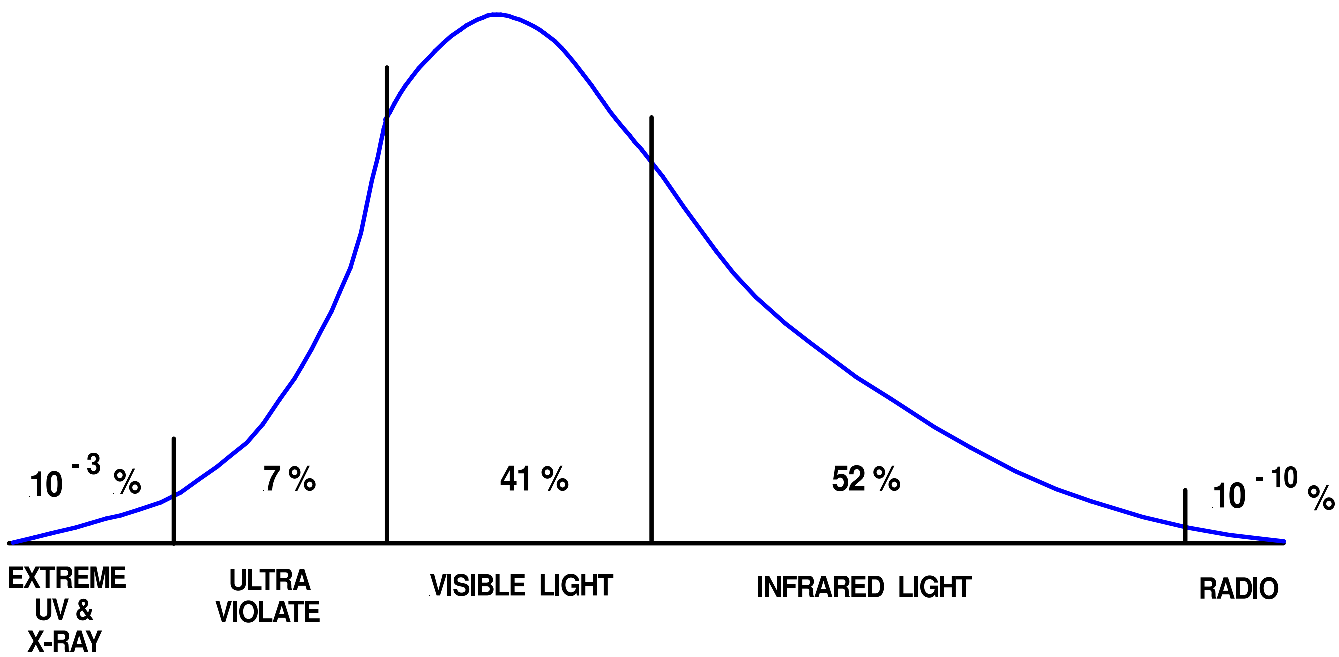
- EUV & X-ray radiation intense at top of atmosphere but few atoms to ionize.
- As the radiation penetrates deeper into the atmosphere, the density of the atmosphere increases (more atoms) resulting in higher levels of ionization.
- Ionization process continuously weakens EUV & X-ray radiation, thus the number of atoms ionized decreases as the radiation penetrates further into the atmosphere, even though the density of atoms continues to increases.
- Consequently, ionizations levels drop and eventually disappear.

Ionosphere Ionization Levels

- Solar Flux Index SFI provides a good measure of solar activity and level of ionization. (2.8 GHz,10.7 cm)
- http://www.solarham.net
- 50 < SFI <300
- SFI = 60 very poor radio conditions
- SFI = 200 very good conditions
- Neutral atmosphere is hundreds to billions of times more dense than the ionosphere.
- The ionosphere is very thin and wispy. Easily blow around by very high altitude winds.

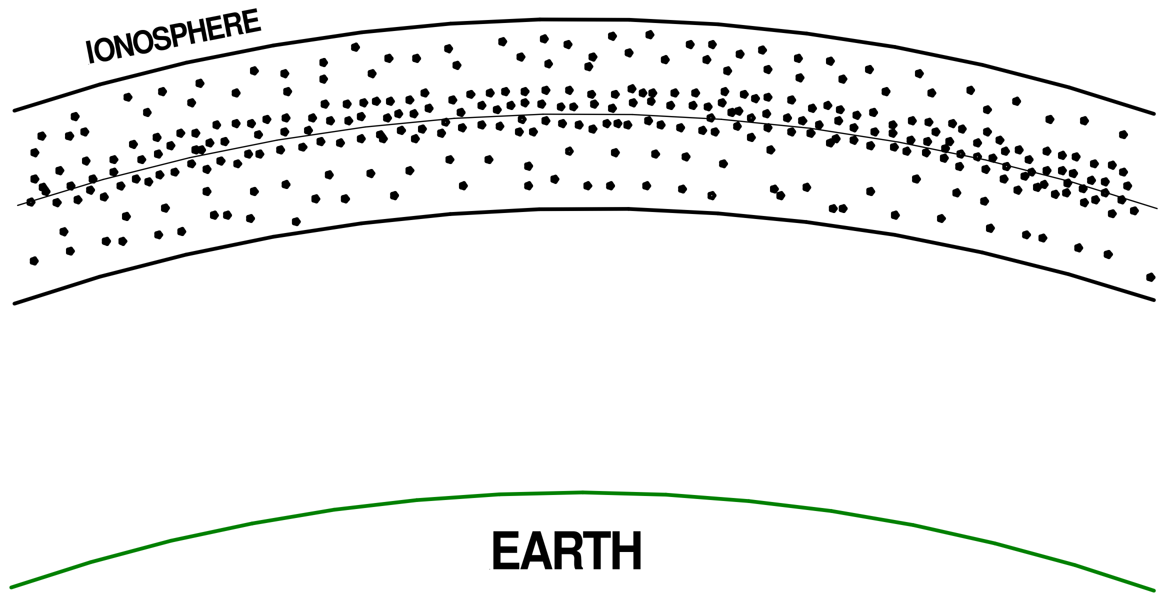


Solar Spectrum



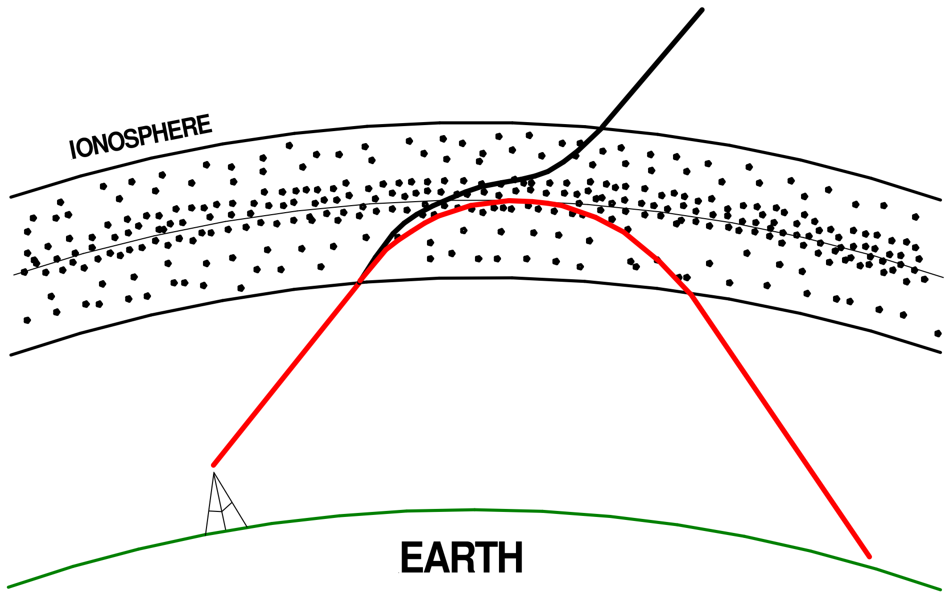
- The Extreme UV and X-Ray radiation that we depend upon to create the ionosphere accounts for only 0.001% of solar energy output.
- EUV & X-Ray radiation is also deadly.
- The ionosphere shields us from EUV & X-Ray radiation making live on Earth possible.

Why We Have HF Radio



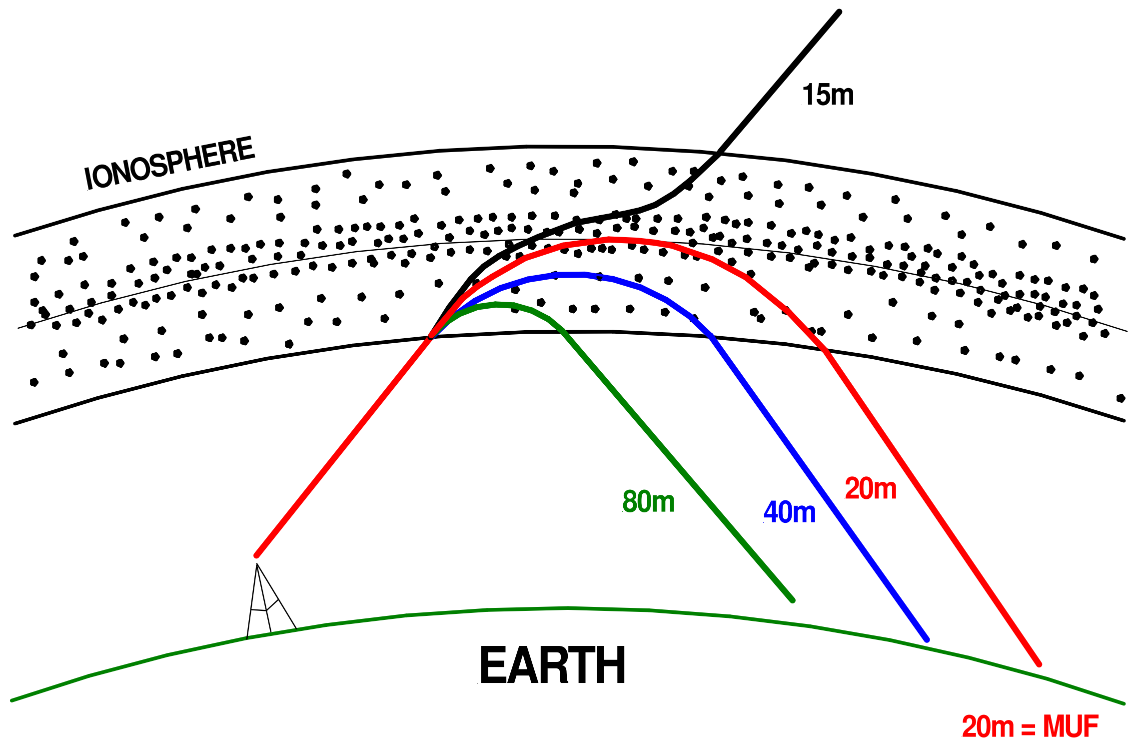
- Increasing levels of ionization from the bottom to the middle of the ionosphere is why we have HF radio.
- If it were not for this characteristic of the ionosphere:
  - We would never of heard of Marconi,
  - There would not be an ARRL,
  - There probably would not be amateur radio.

Ionosphere Refraction



- Radio waves bends back toward the Earth as they travel through increasing levels of ionization from the bottom to the middle of the ionosphere.
- When the radio waves travel back down toward the Earth, they bend in the opposite direction (straighten out) as the levels of ionization decreases.
- Similarly, radio waves that pass through the most dense part of the ionosphere bend away from the Earth, as they travel through decreasing levels of ionization, and are lost to outer space.

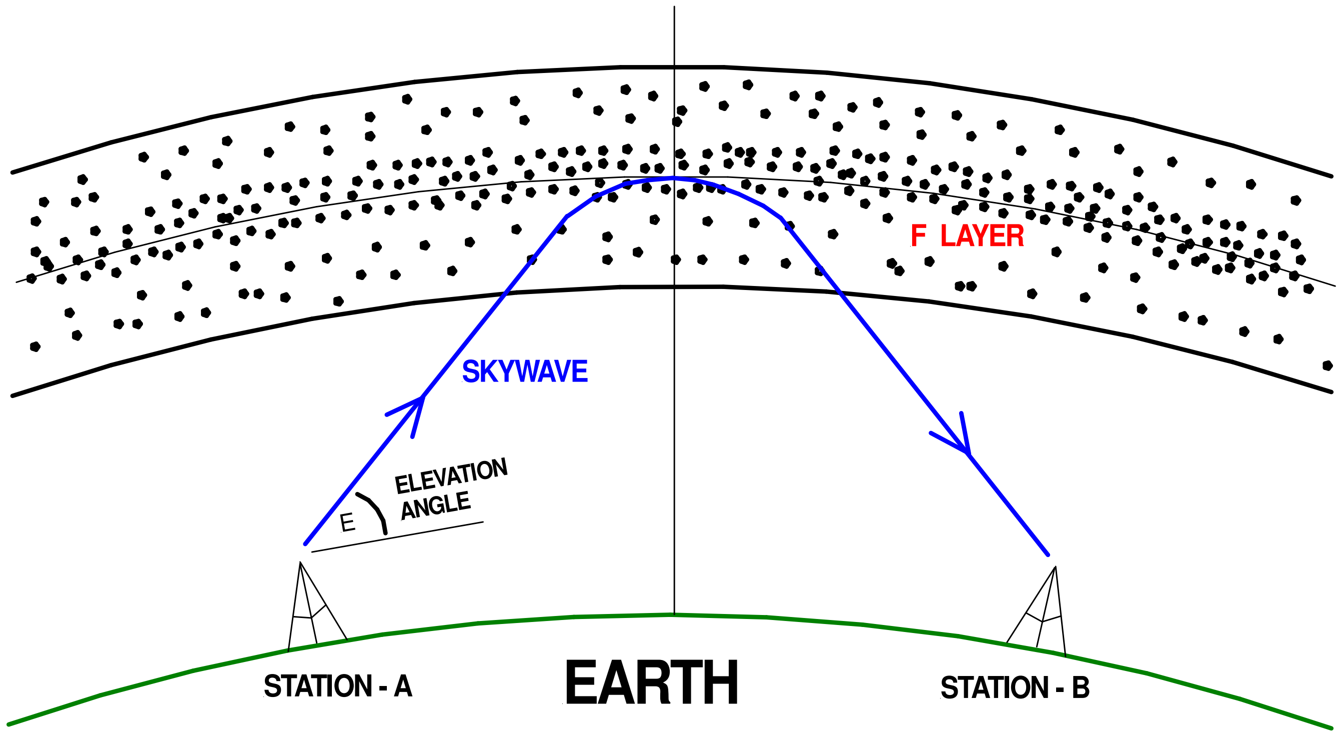
Frequency Dependency of Refraction



- A radio signal penetrates further into the ionosphere as the transmitting frequency increases,
- Until the MUF is reached.
- Transmitting at a frequency greater than MUF results in the signal passing completely through the ionosphere and lost to outer space.

The Maximum Usable Frequency is:

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



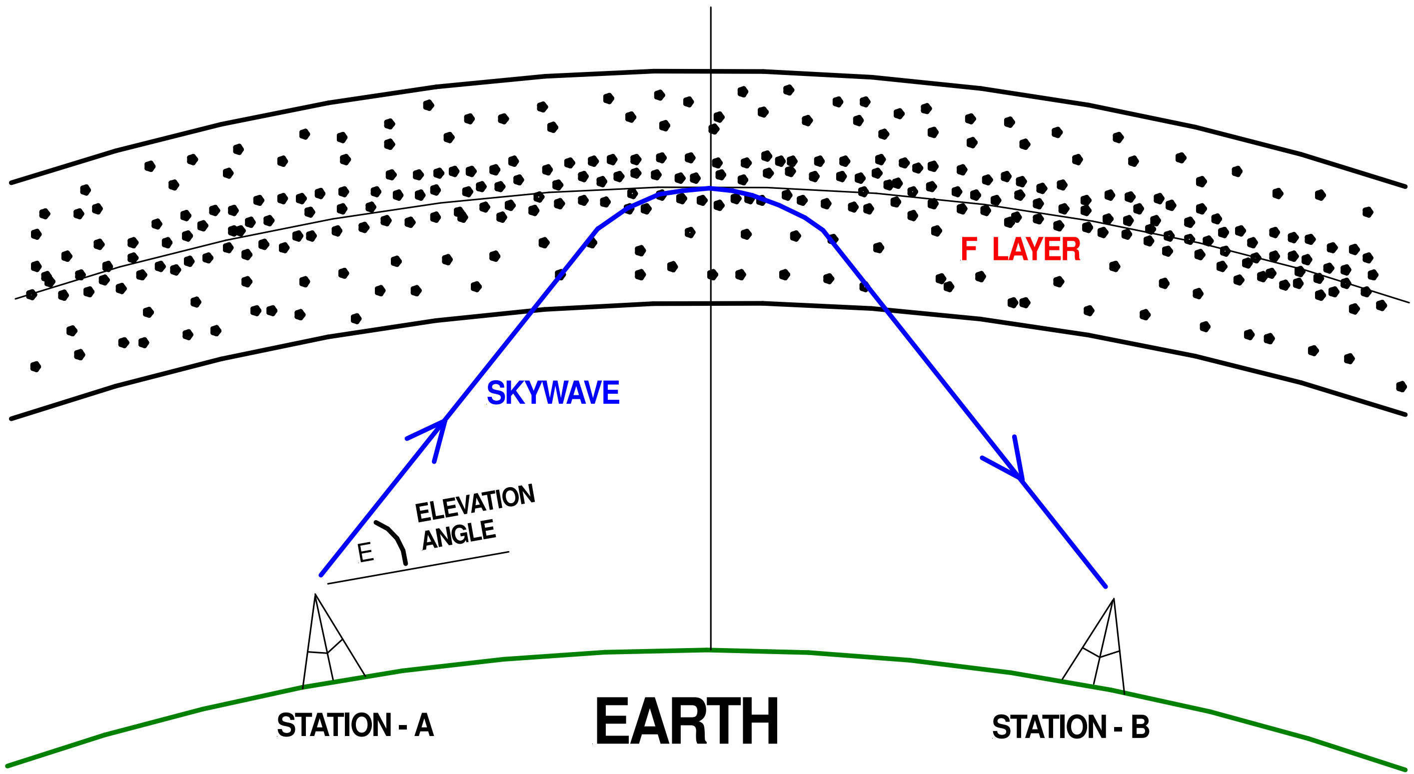
MUF Equation

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

- **fc** = Critical Frequency of the ionosphere at the refraction point.
  - Critical Frequency is the highest frequency signal that can be transmitted straight up and reflected from the ionosphere.
- E = The angle of elevation of the signal radiating from your antenna.

- We will use this equation a lot in its various forms !

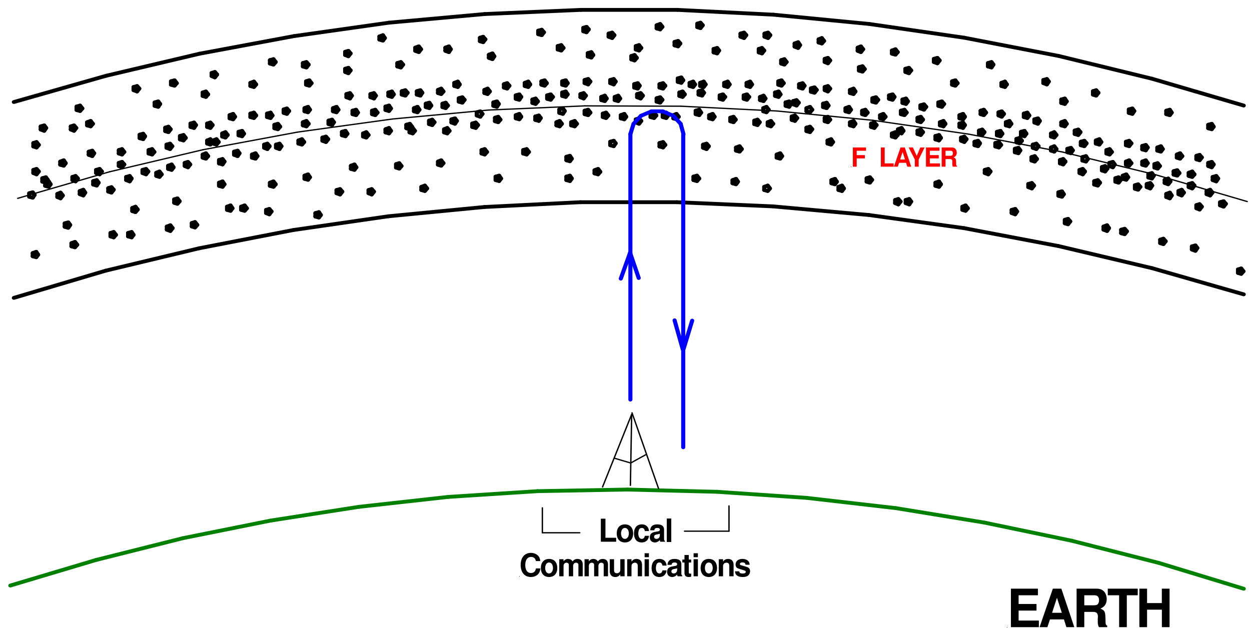
Elevation Angle E



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

Critical Frequency

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



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

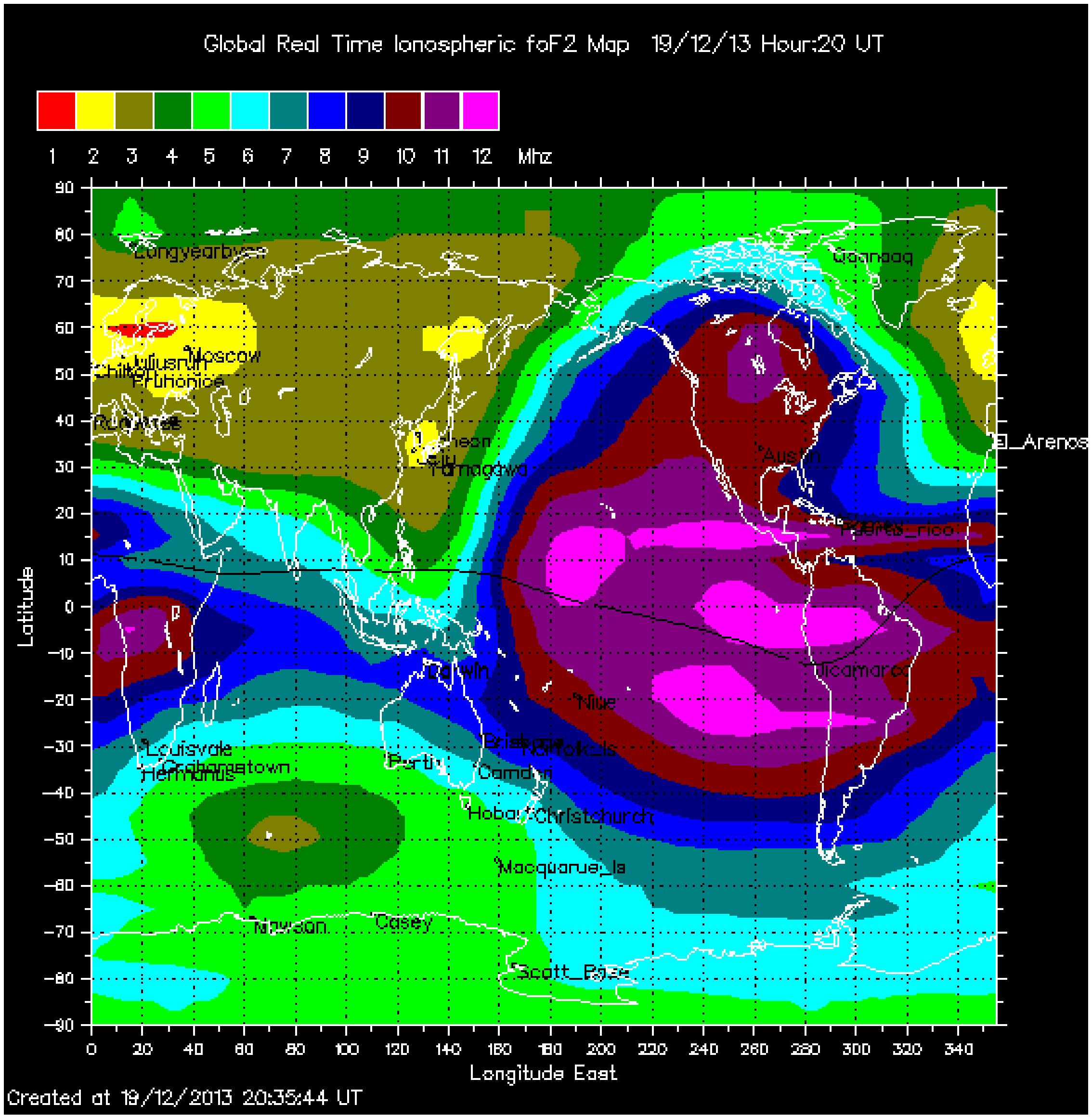
$$MUF = \frac{f_c}{\sin E} = \frac{f_c}{\sin 90^o} = \frac{f_c}{1} = f_c$$

$$MUF \geq f_c$$

So how do you know what the critical frequency is at a particular time of day?

Hourly F2 Critical Frequency Chart

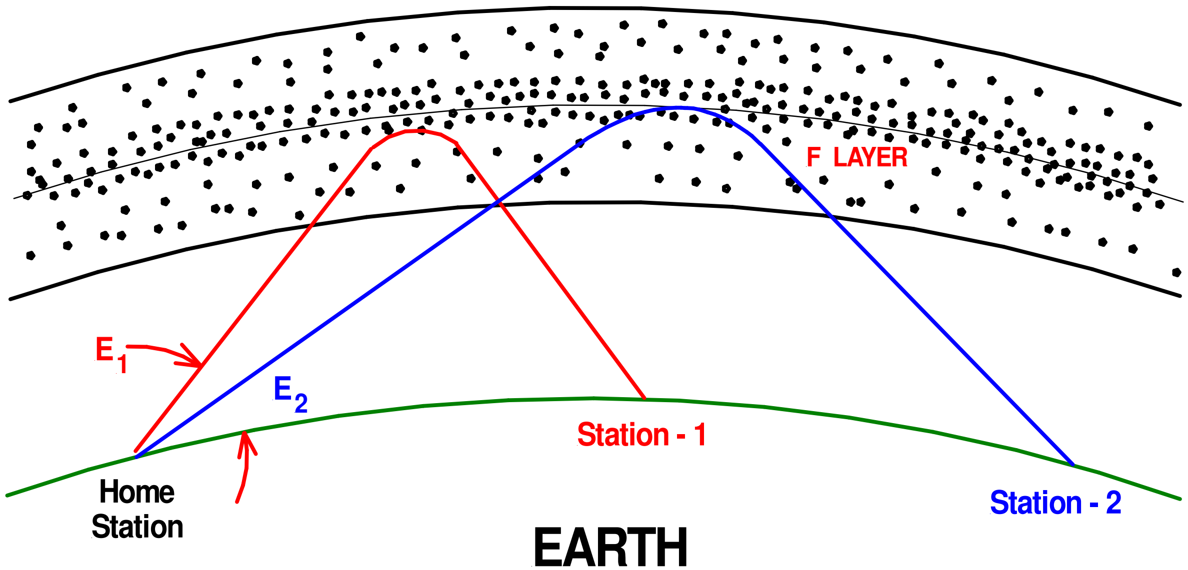
http://www.ips.gov.au/HF_Systems/6/5



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

- Winter anomaly
- Equatorial anomaly
- Ducting

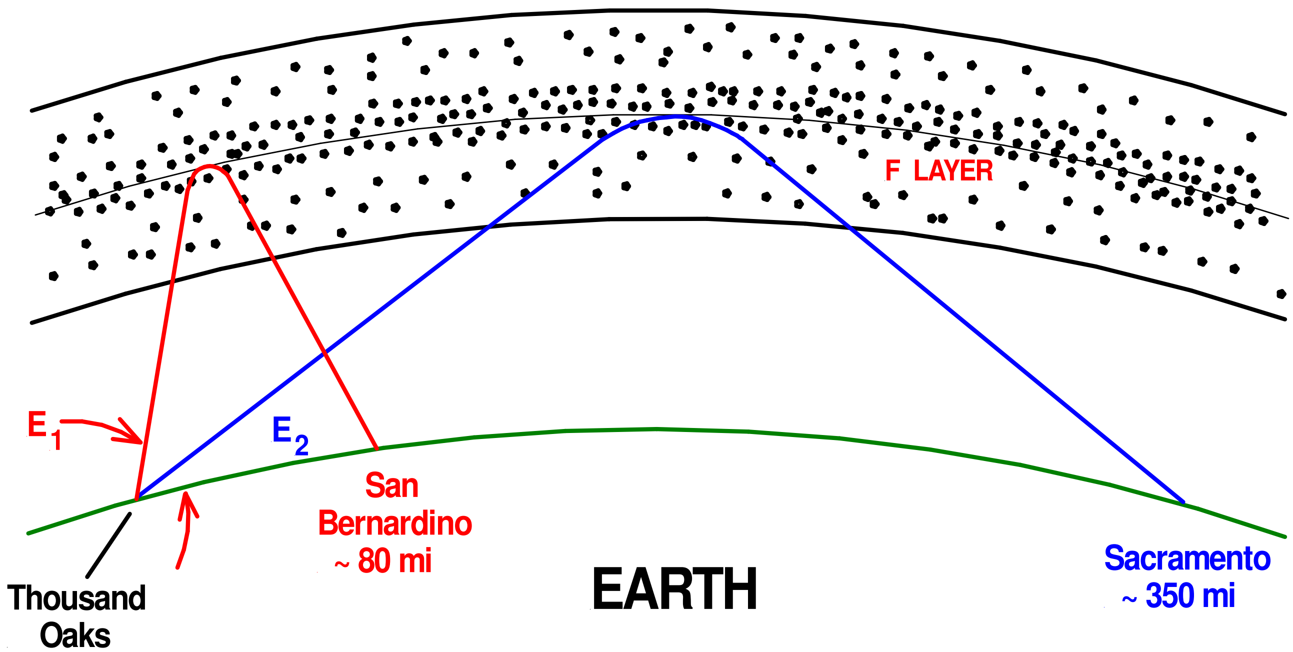
MUF Depends on the Path



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

- 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 1 - CESN



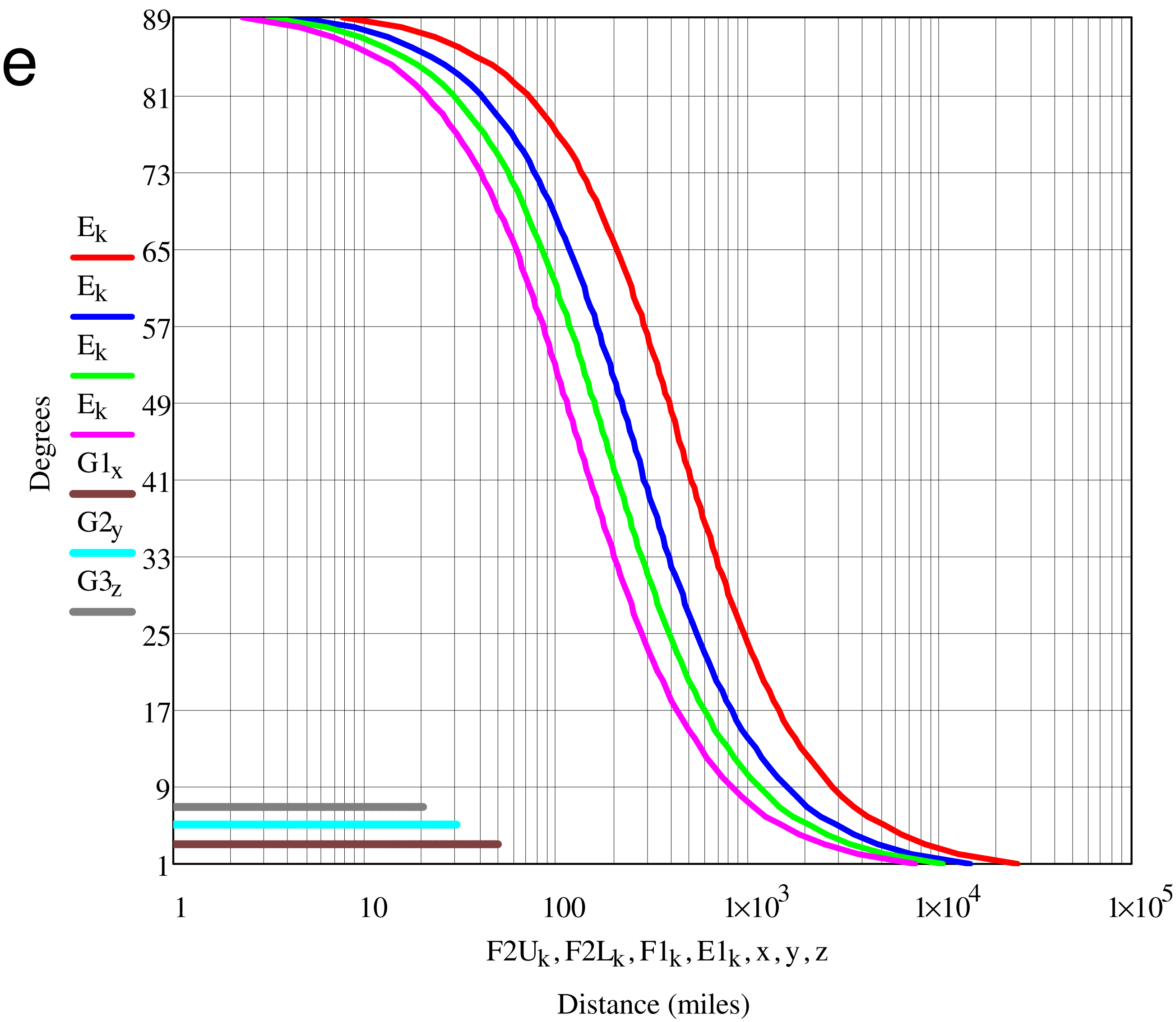
$$MUF = \frac{f_c}{\sin E}$$

- What is the MUF from Thousand Oaks to San Bernardino?
- What is the MUF from Thousand Oaks to Sacramento?
- First must determine the elevation angle E.

(CESN = California Emergency Services Net.)

Elevation Angle vs Distance

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



E Layer = 65 mi F1 Layer = 90 mi F Layer = 125 mi F2 Layer = 220 mi

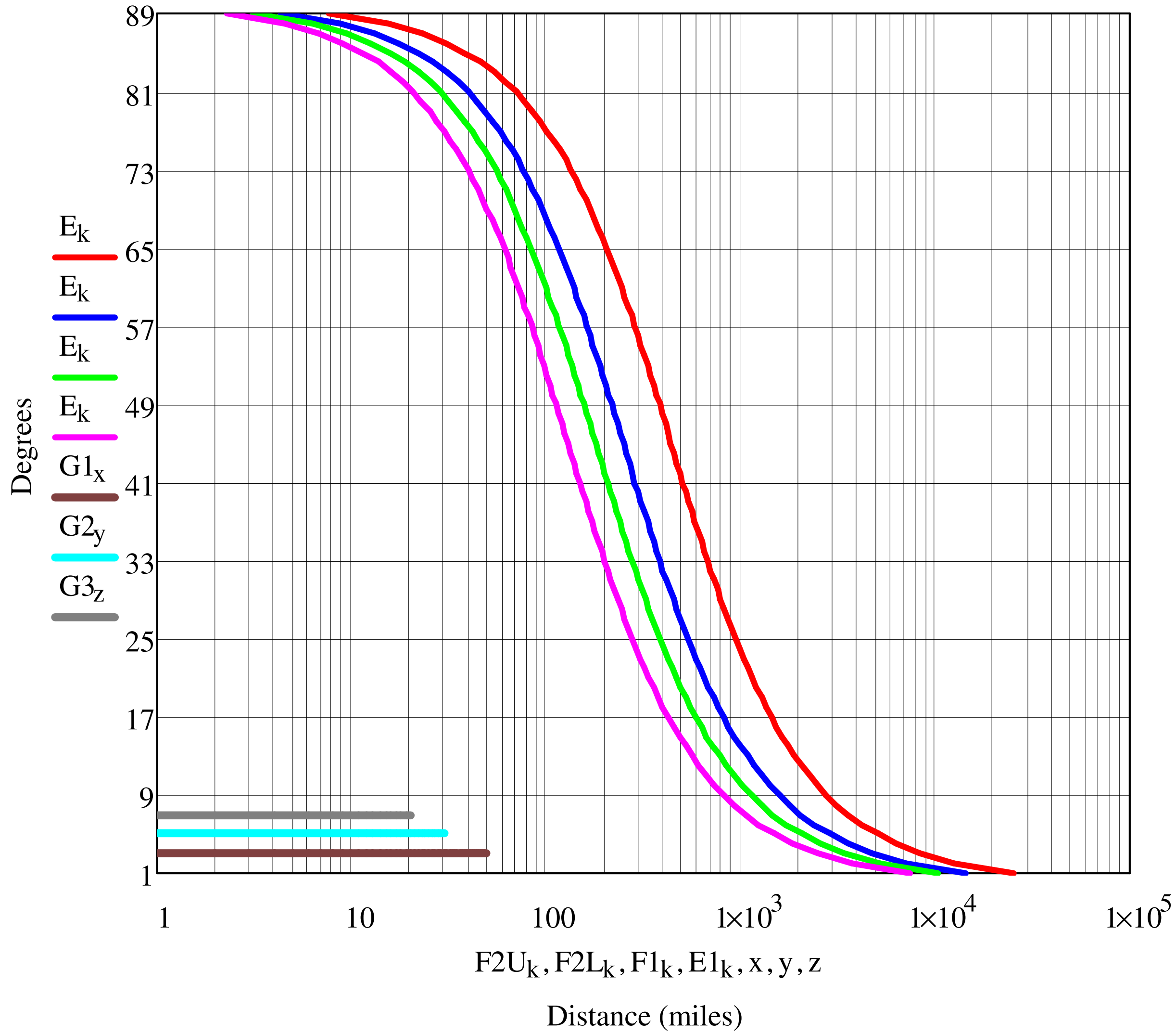
Ground Wave 80m Ground Wave 40m Ground Wave 20m

Calculating Elevation Angle

Sacramento = 350 mi
E2 = 45 deg

San Bernardino = 80 mi
E1 = 77 deg

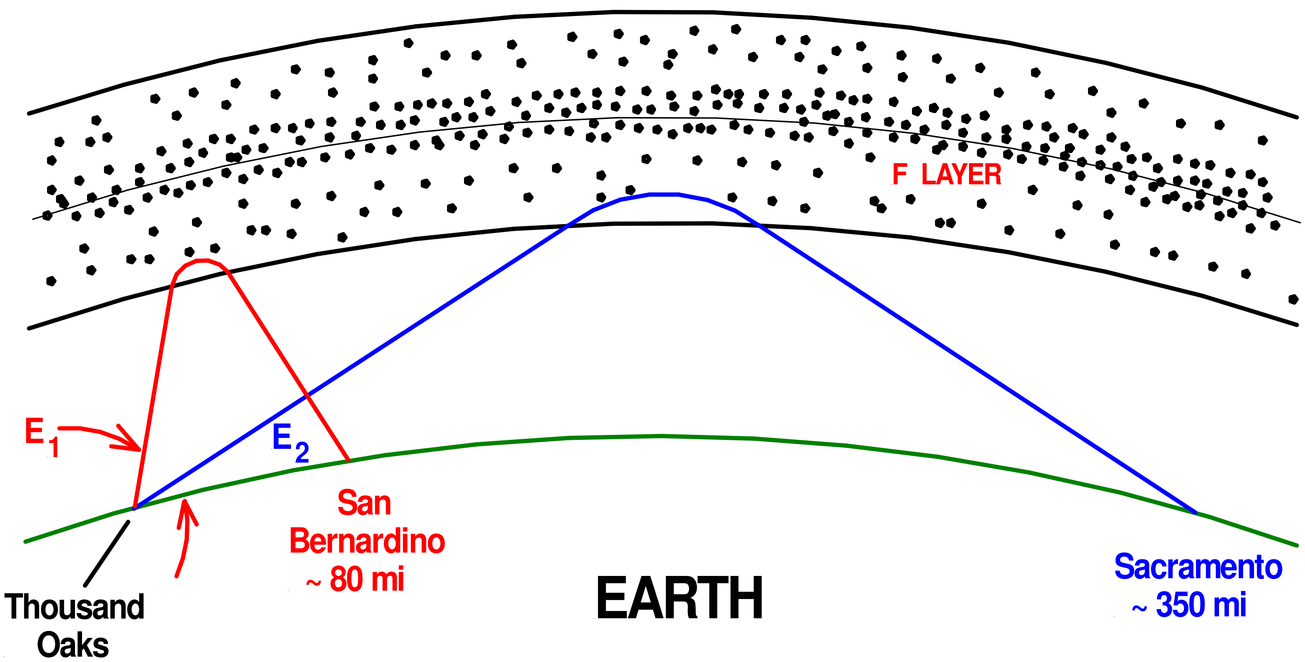
$$MUF = \frac{f_c}{\sin E}$$



E Layer = 65 mi **F1 Layer = 90 mi** **F Layer = 125 mi** **F2 Layer = 220 mi**

Ground Wave 80m Ground Wave 40m Ground Wave 20m

Determine Critical Frequency



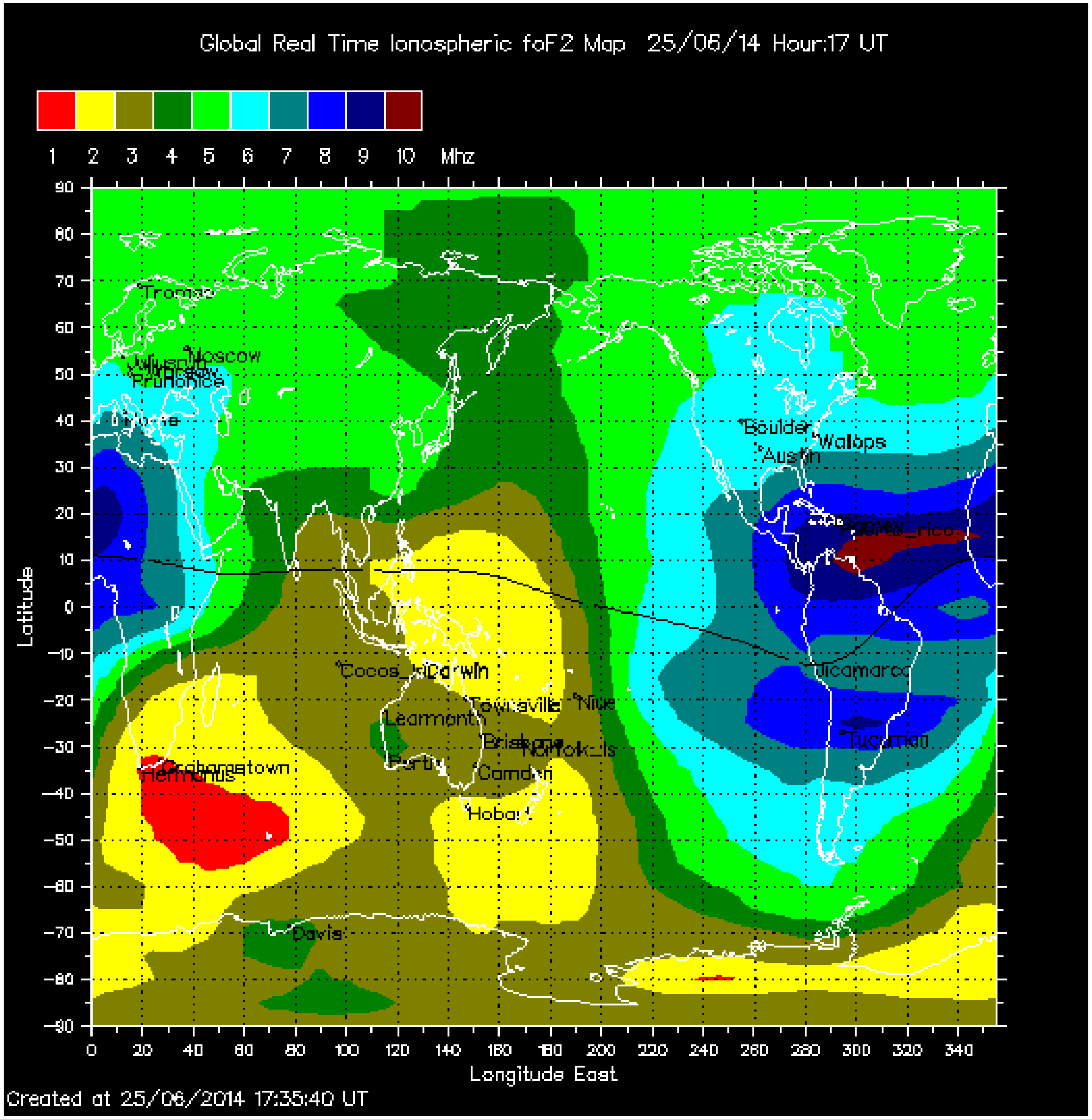
- E_1 = 77 deg
- E_2 = 45 deg
- f_c = ?

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

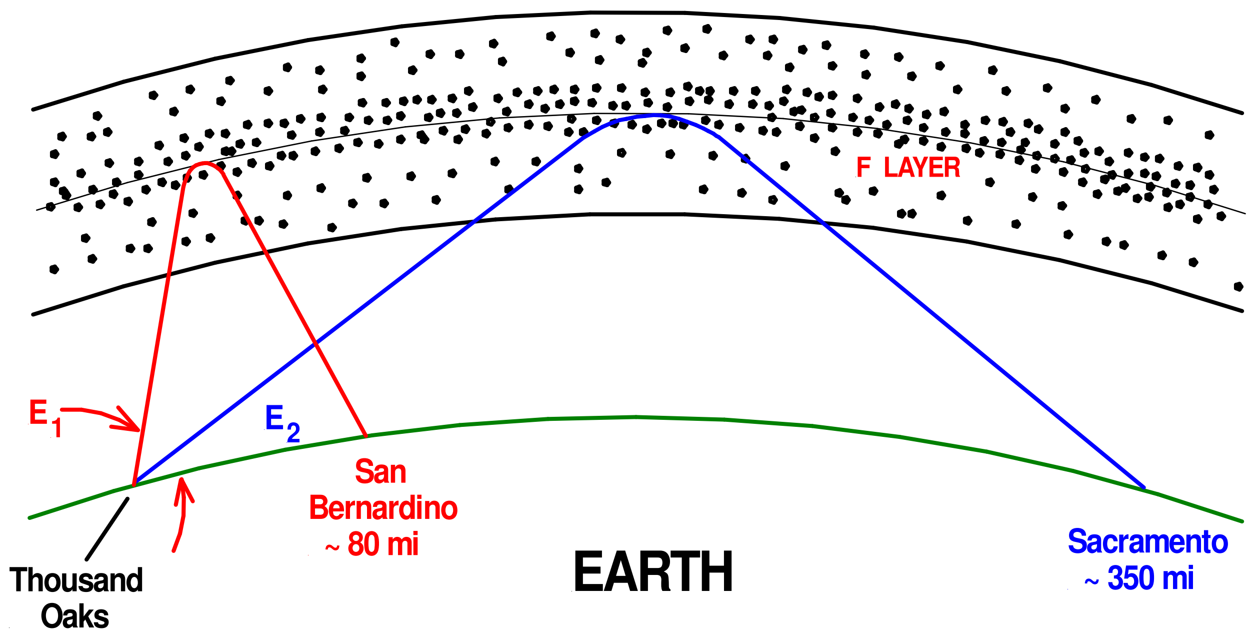
Determine Critical Frequency

- On 6/25/2014 Critical Freq is about 6.5 MHz for California

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



Determine MUF



$$MUF_1 = \frac{f_c}{\sin E_1} = \frac{6.5\ \text{MHz}}{\sin 77^o} = 6.671\ \text{MHz}$$

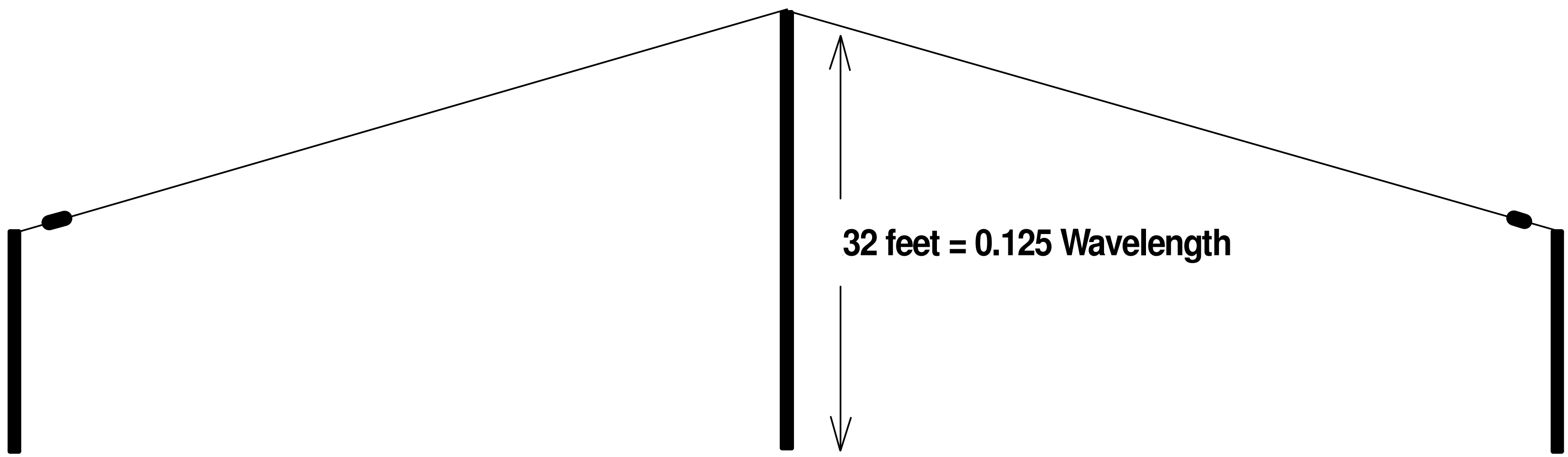
$$MUF_2 = \frac{f_c}{\sin E_2} = \frac{6.5\ \text{MHz}}{\sin 45^o} = 9.192\ \text{MHz}$$

CESN Net = 7.230 MHz

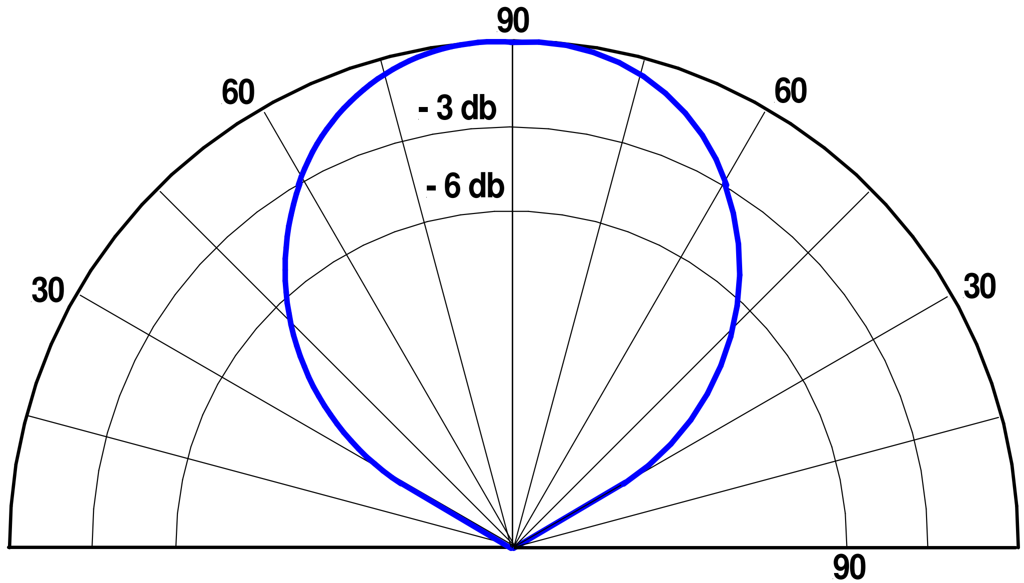
Example – 2 The 80 meter Episode

- 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 Radiation Pattern



80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

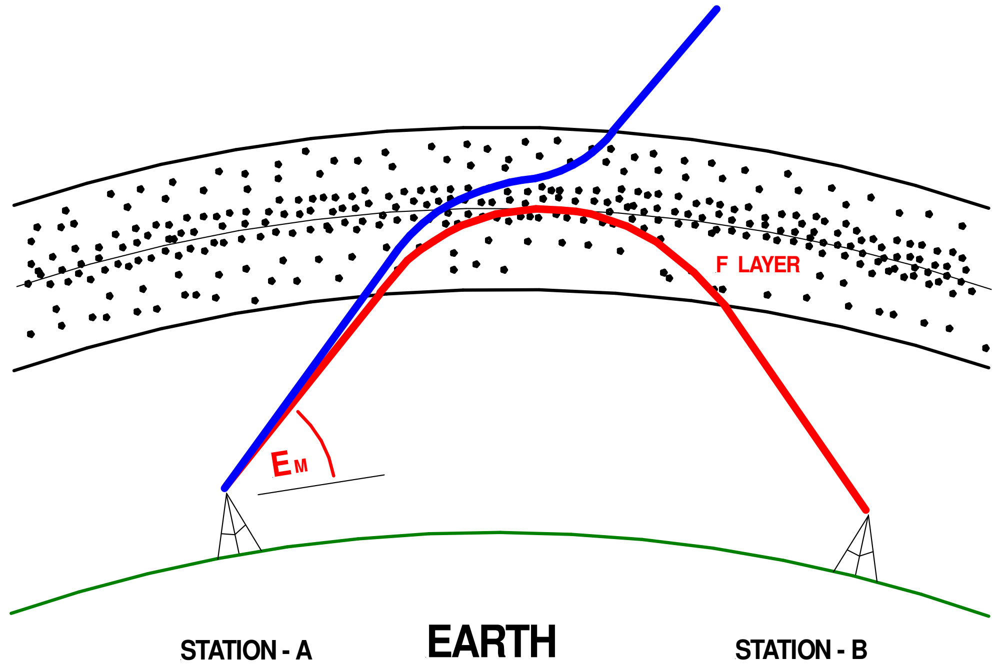
- Good NVIS antenna
- Can talk to stations close in and throughout southern California
- At 70 degrees maybe stations in New Mexico, Utah, Oregon, etc.
- A good antenna

80 meter Antenna Doesn't Work at Night !

- Around 10 PM the antenna stops working.
- Plenty of stations being heard on 80 meters.
- The Critical Frequency is approximately 3 MHz.
- MUF apparently not a problem ???
- Is the high angle radiation from the Inverted V antenna a problem?
- To find out, solve the MUF equation for angle instead of frequency.
- The result is 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 is the highest angle signal that can be transmitted,
- At an operating frequency of f_o , and
- Still be refracted by the ionosphere if the critical frequency is f_c .

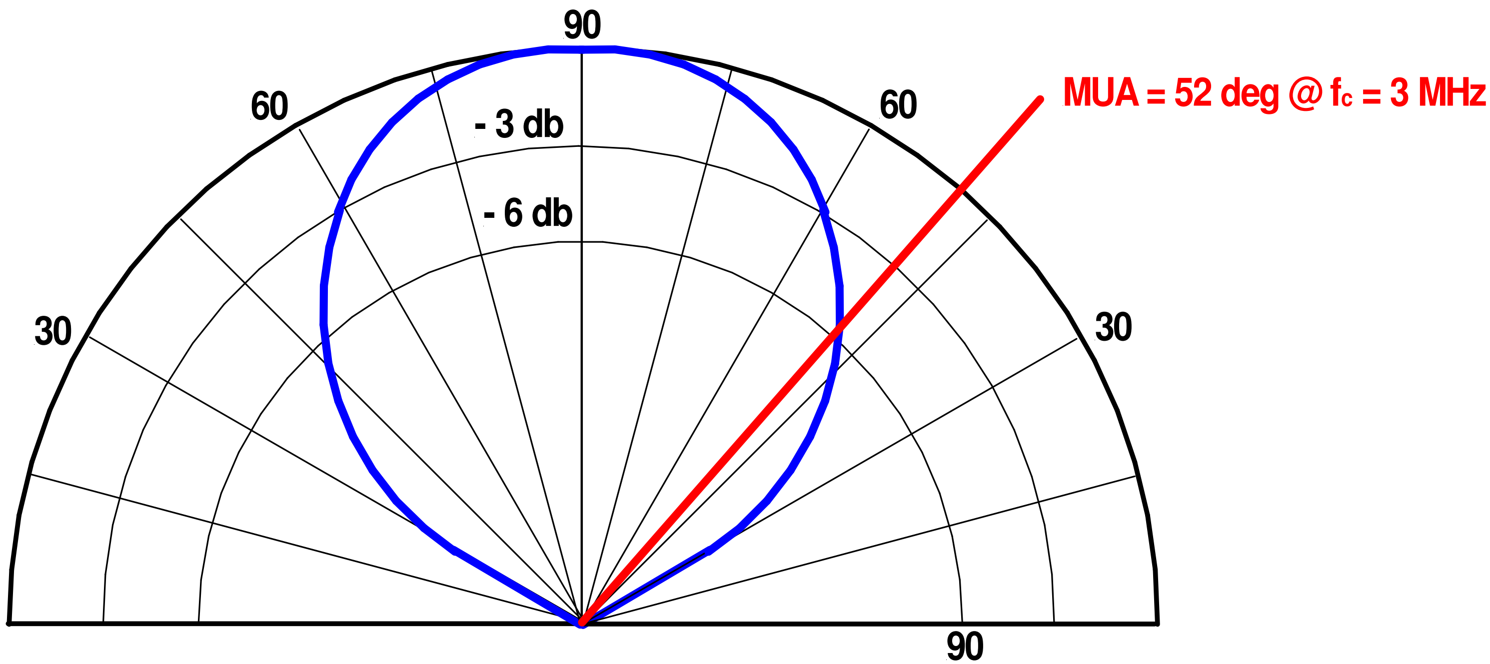
80 meter Maximum Usable Angle

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

Maximum Usable Angle (MUA) for:

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

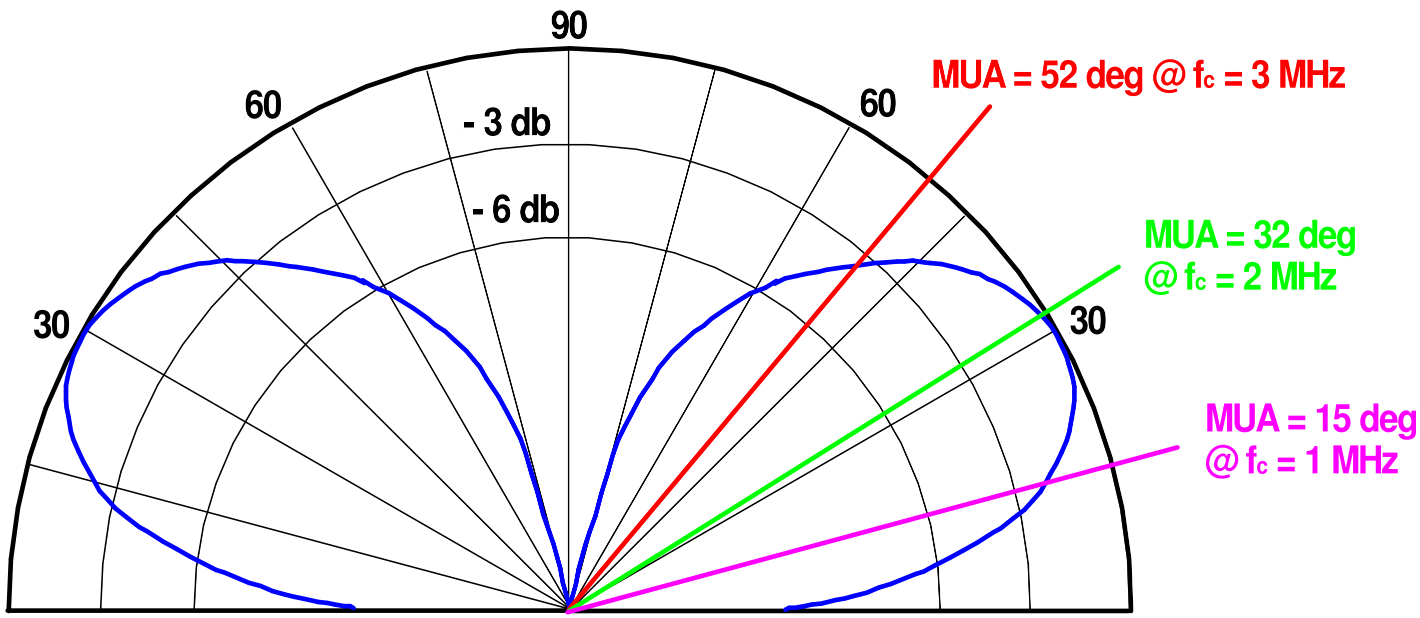
MUA Too Low For The 80 m Inverted V Antenna



80 meter Inverted V Antenna 1/8 Wavelenth Above Ground

- What needs to be done to operate late at night on 80 meters?

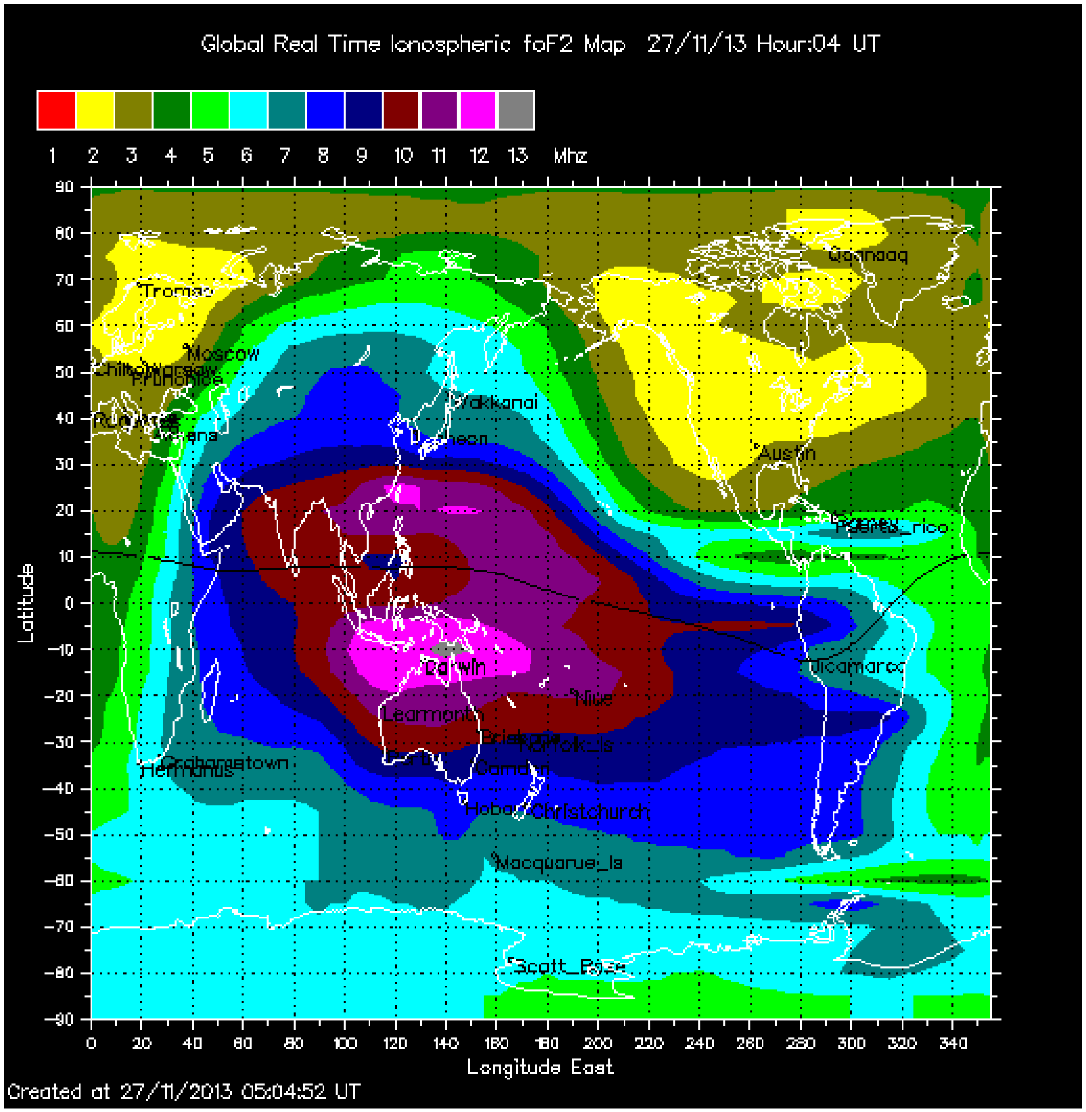
80 m Vertical Needed For Late Night Operation



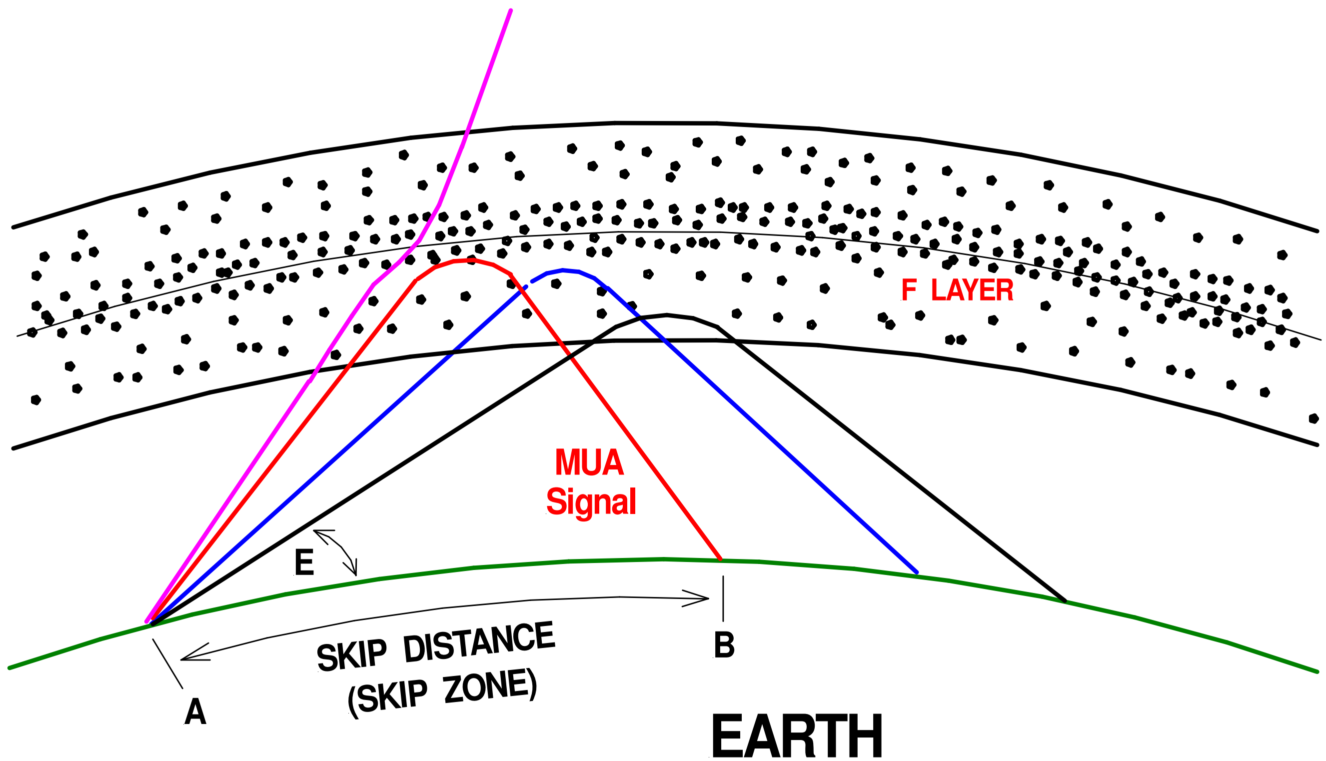
1/4 Wave Vertical Antenna

- Vertical antenna can work down to a critical frequency of ~ 1 MHz.
- Well into the early hours of the morning.
- Two 80 m antennas required for emergency communications.

How Low Does The Critical Frequency Get?



Skip Distance (Zone)



- Increasing angle E shortens the distance transmitted in a single hop.
- The shortest distance (from Point A to B) occurs when E = MUA.
- Thus Station B is the closest station that Station A can contact.
- Stations in the Skip Zone can not be heard, they are “skipped over”.

Skip Distance

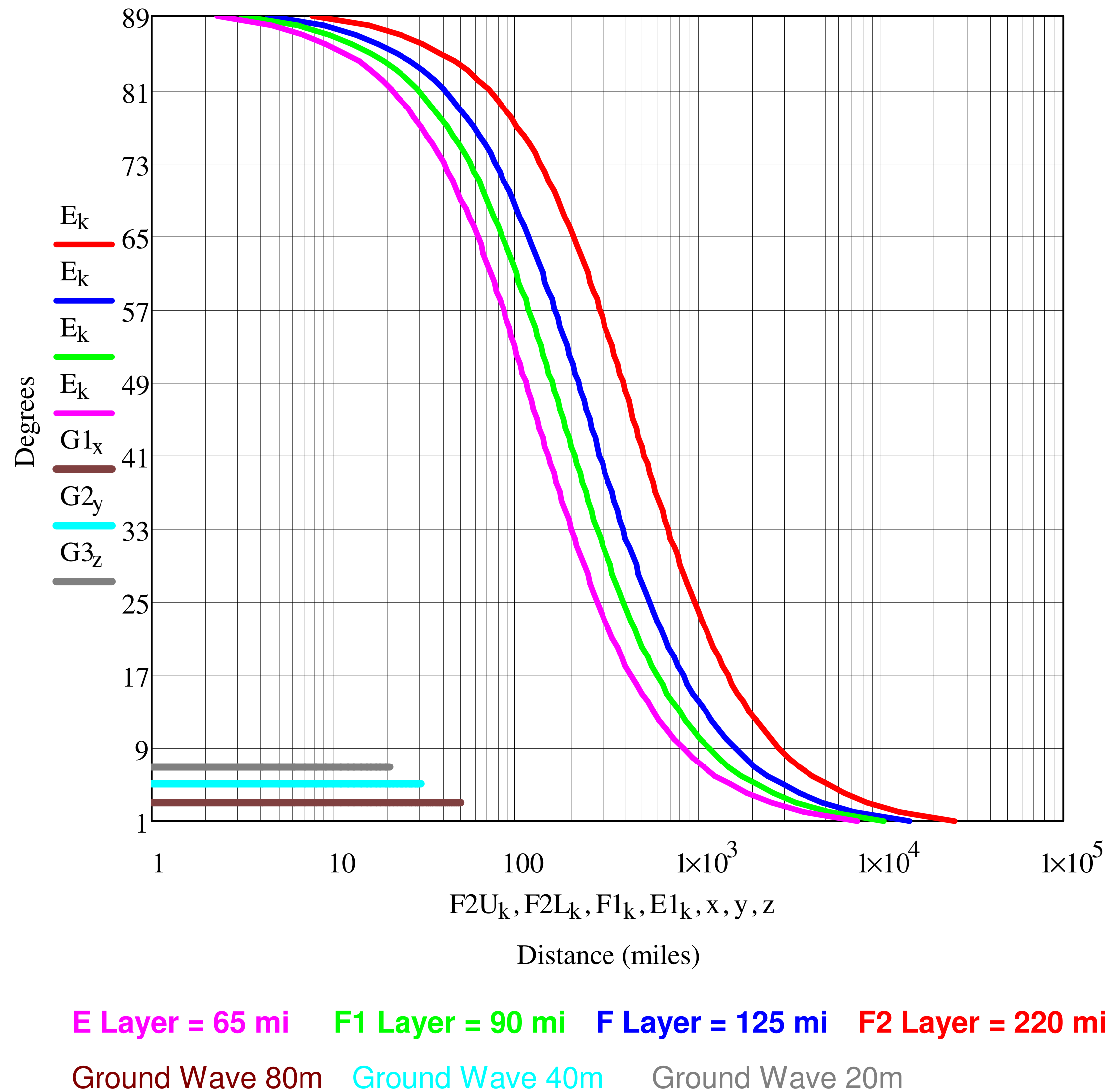
$$MUA = E_M = \sin^{-1}\left(\frac{f_c}{f_o}\right)$$

Knowing the critical frequency fc and your operating frequency fo

Calculate MUA.

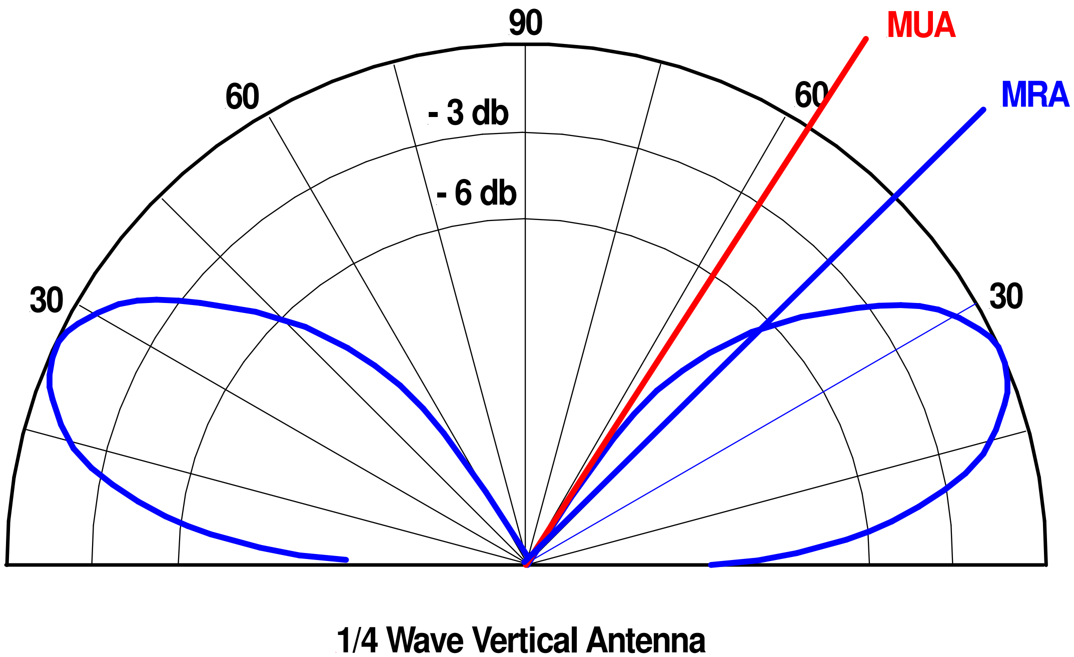
Using MUA, read the skip distance off the chart.

If MUA = 41 degrees Skip distance equals about 400 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



The skip distance for a 40 m vertical antenna with an MRA of 45 deg is approximately 350 miles.

Who Can You Contact?

- Need to know the characteristics of **YOUR** antenna for the frequency band that you will be operating on.
- Solve the MUF equation for critical frequency **fc**.
- Determine the minimum critical frequency **fcm** needed to support **YOUR** antenna.

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

- In theory, you can contact a distant station if the critical frequency along your path of propagation is at all points greater than **fcm**.
- In practice must also consider all of the attenuation that your signal encounters in traveling to a distance location.

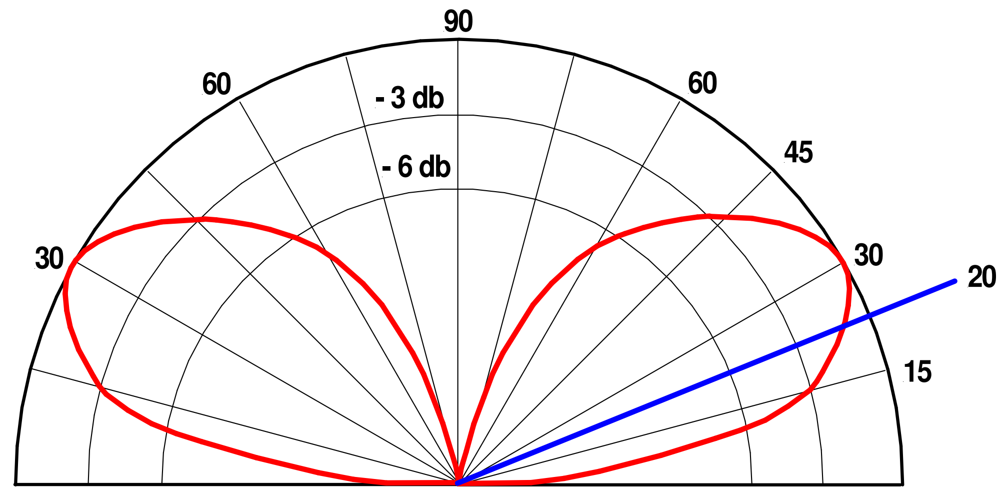
Minimum Critical Frequency

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

- Minimum critical frequency **fcm** is the lowest critical frequency capable of supporting transmissions from your antenna.
- fo = Your operating frequency
- Ea = The elevation angle of your antenna’s main lobe.
- **fcm** is a characteristic of **YOUR** antenna.

20 m Example

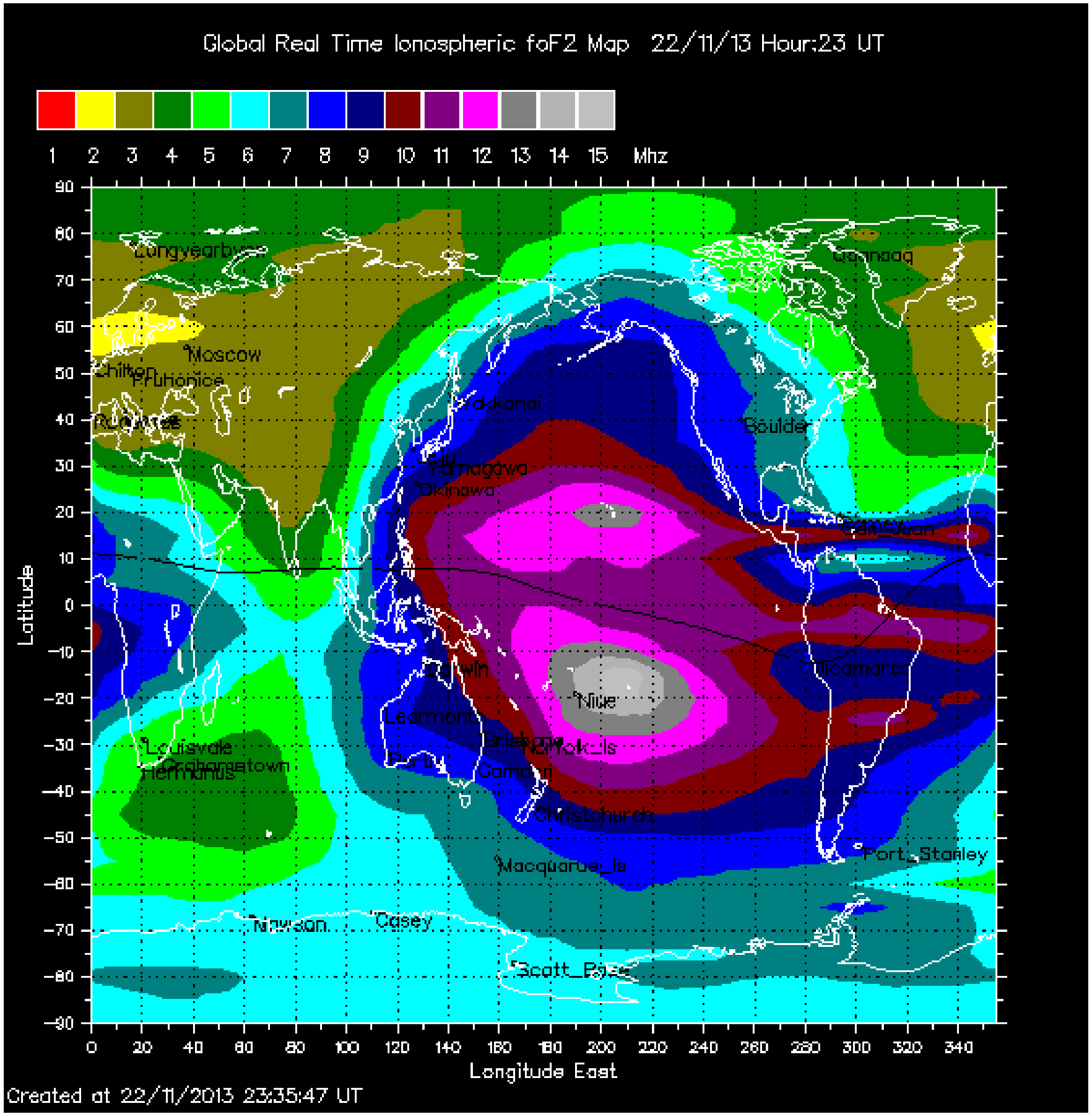
$$f_{cm} = f_o \sin E_a$$



20 Meter 1/2 Wavelength Dipole Antenna At Optimum Height

- f_o = 14.2 MHz
- **fcm** = 7.1 MHz @ Ea = 30 deg
- **fcm** = 4.9 MHz @ Ea = 20 deg
- A minimum critical frequency of about 5 to 7 MHz is required to support transmissions from this antenna.

Who Can You Contact?



fcm is a characteristic of YOUR antenna

20 Meters
fcm = 5 - 7 MHz

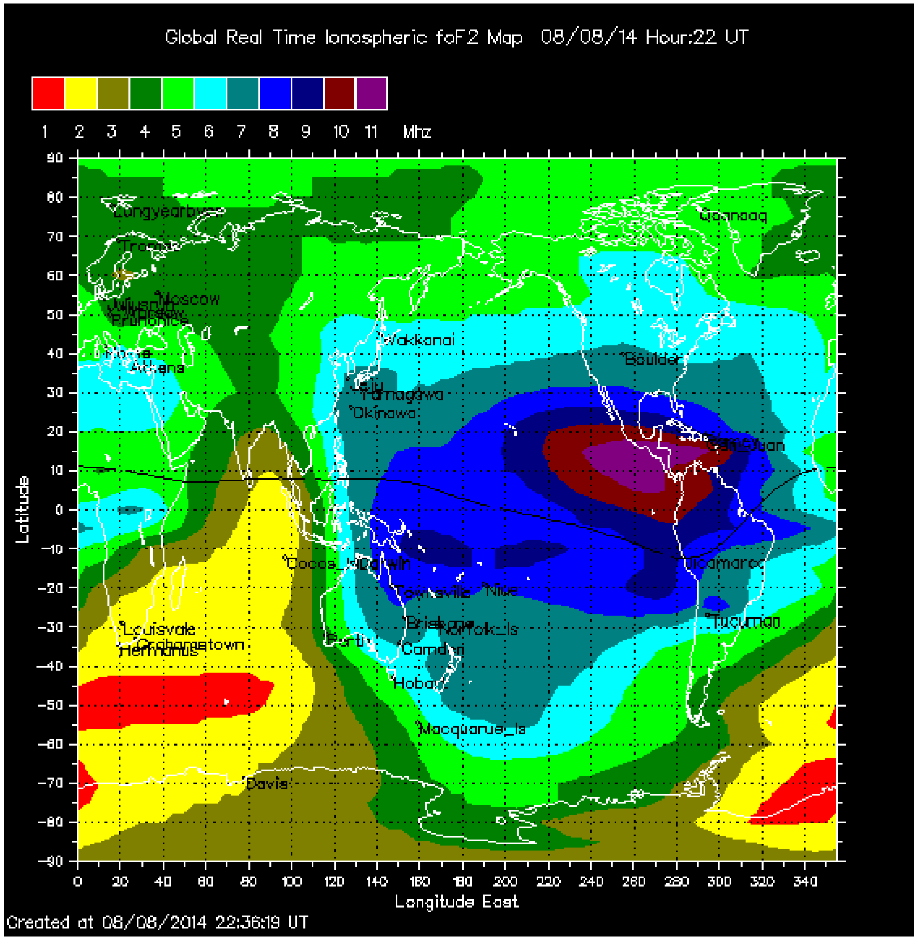
15 Meters
fcm = 7 - 9 MHz

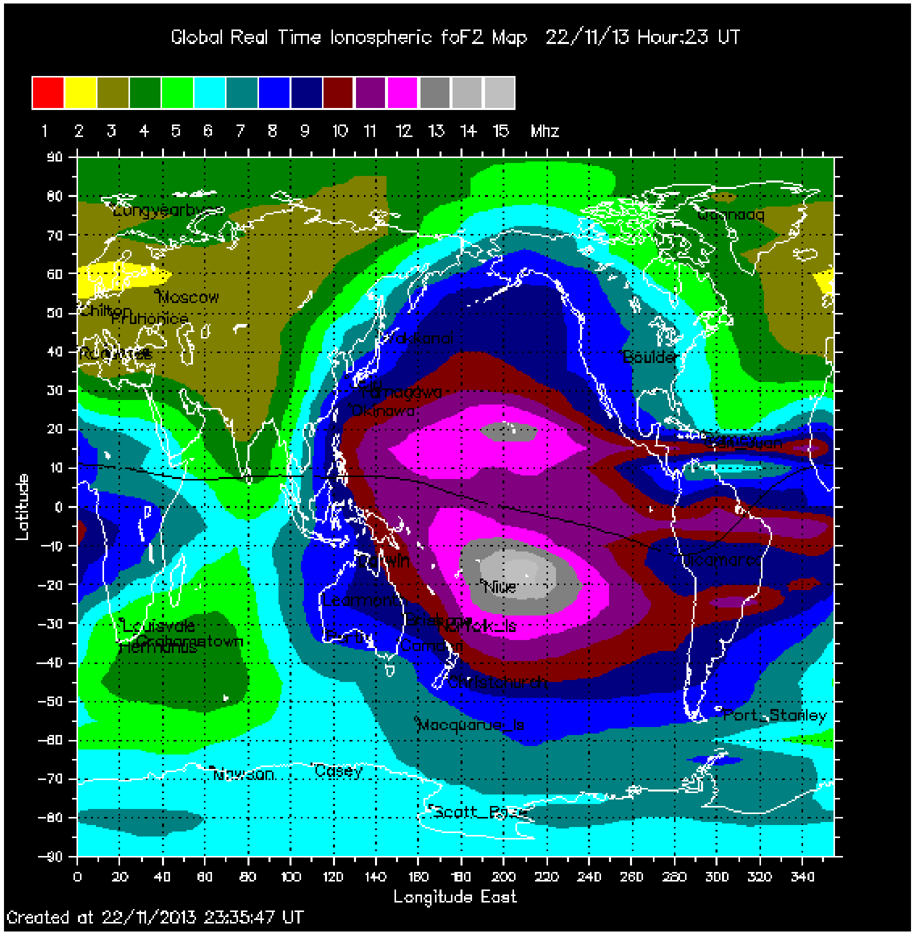
Keep ground and ionospheric attenuation in mind !!!

At 40m and below, must worry about D Layer absorption.

Short term prediction

15 Meter Band Conditions

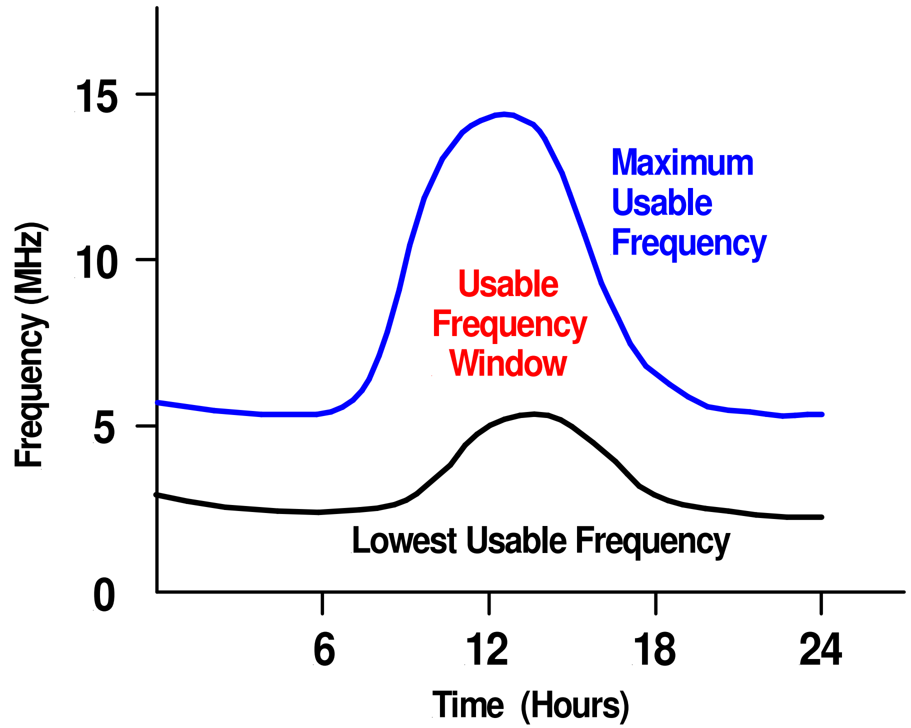




15 Meters Closed

15 Meters Open

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?

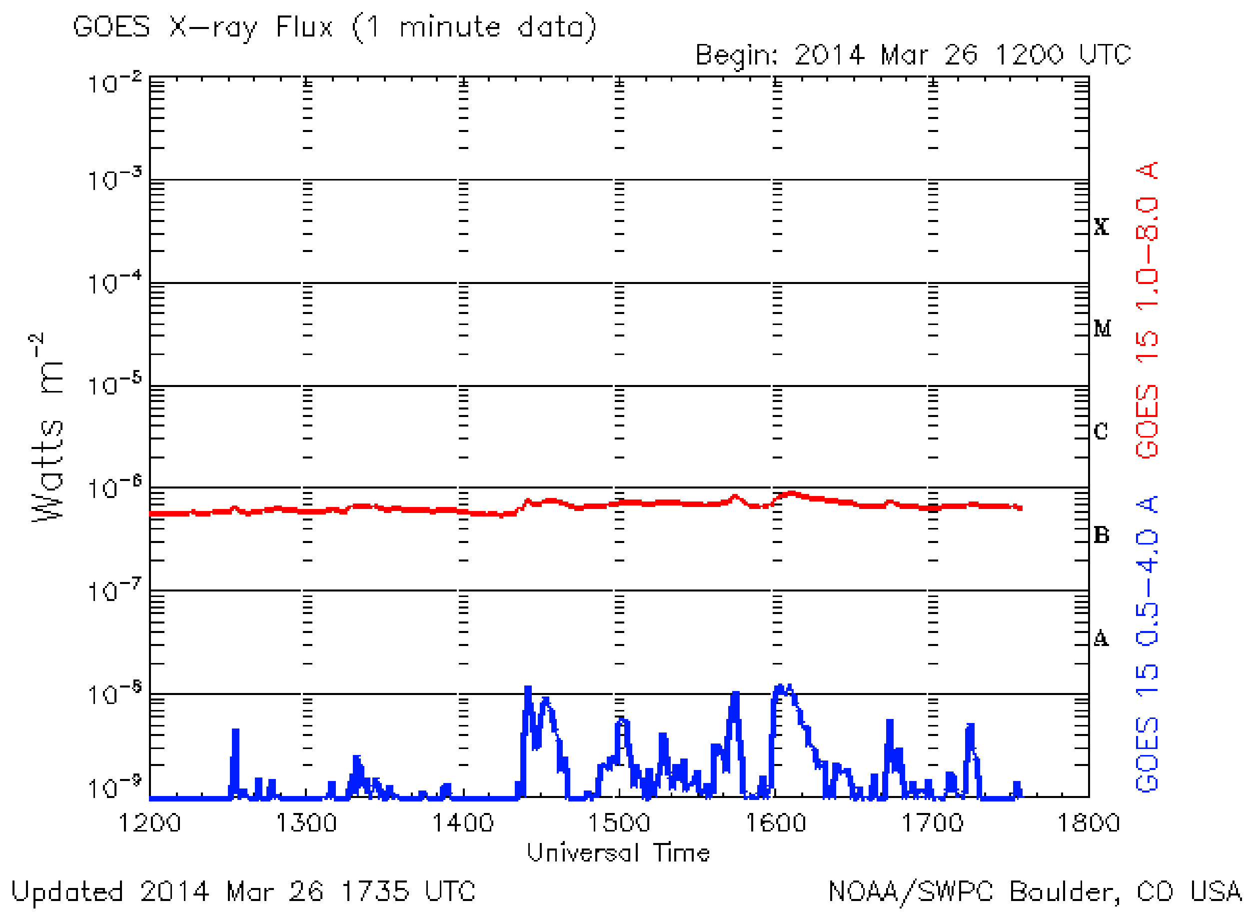
- LUF is primarily the result of :
  - Noise, and
  - Radio wave absorption in the D Layer
- The D Layer is formed by x-ray radiation from the Sun.
- Thus, Lowest Usable Frequency varies:
  - Throughout the day.
  - Seasonally.
  - In accordance with the 11 year solar cycle.
- Lowest Usable Frequency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

Absorption vs Frequency

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

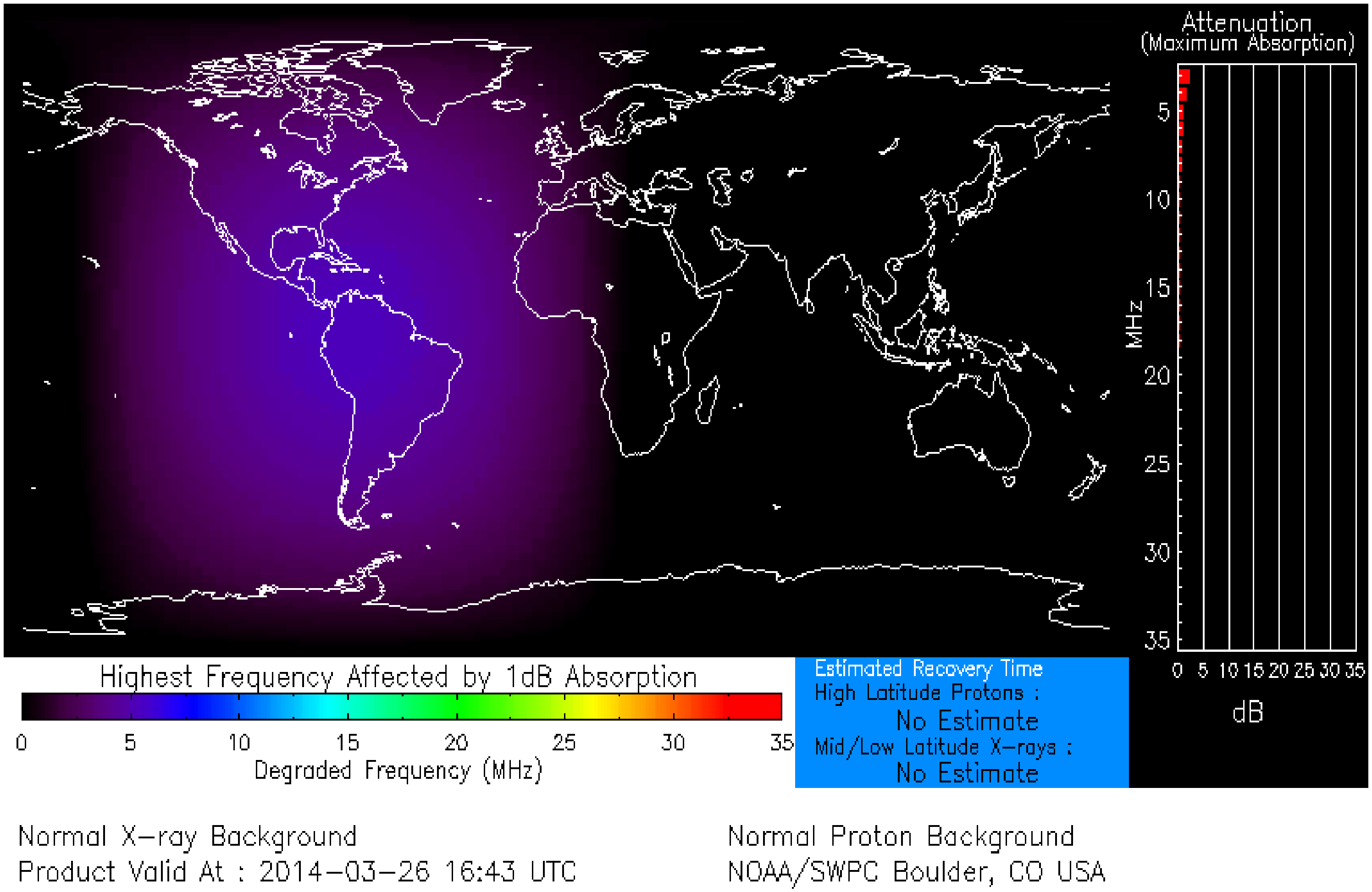
- Absorption is inversely proportional to frequency squared.
- The absorption on 40 meters is only 1/4 that on 80 meters.
- The absorption on 20 meters is only 1/16 that on 80 meters.
- To avoid absorption, want to operate at the highest frequency possible.
- How do we know what the level of absorption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

X-ray Flux a Good Measure of Absorption Levels



http://www.solarham.net/

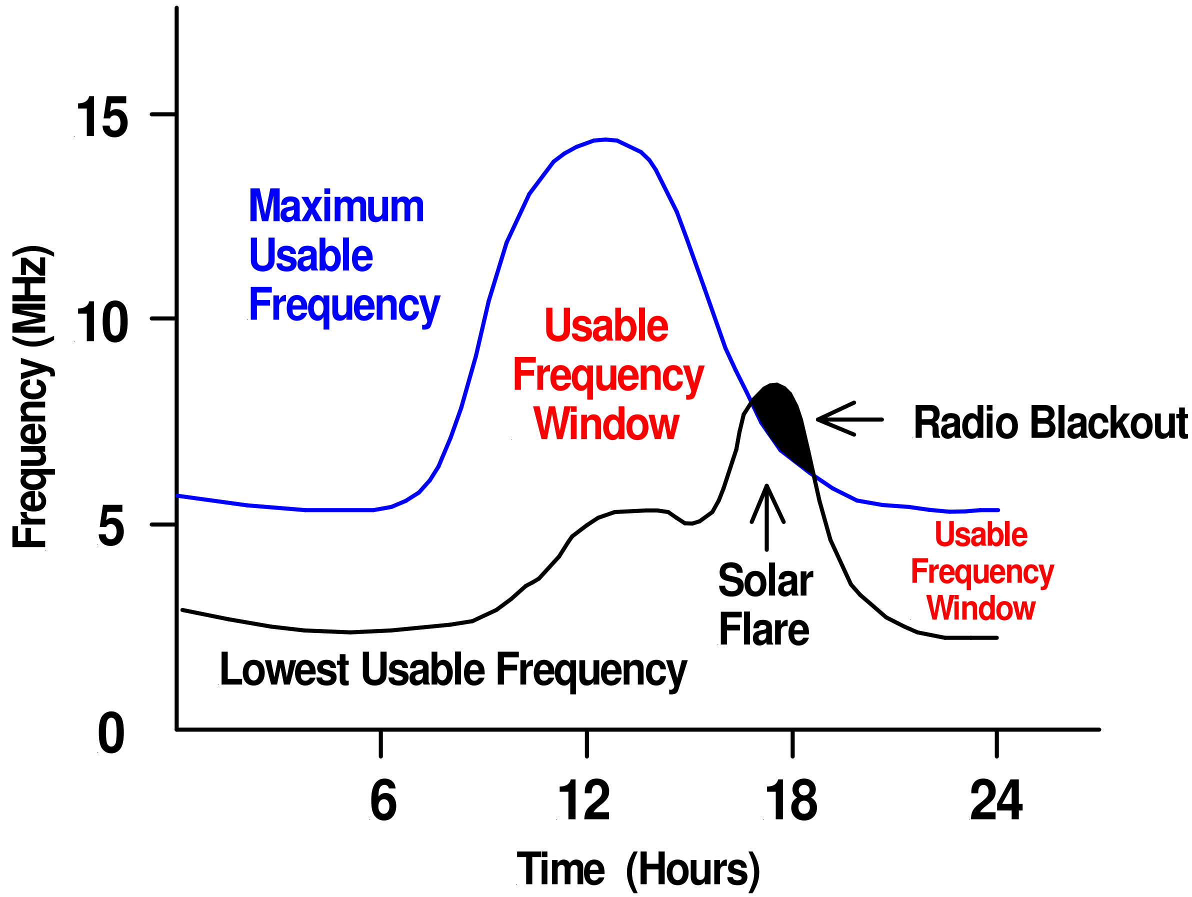
Lowest Usable Frequency Estimate



LUF ~ 6 MHZ

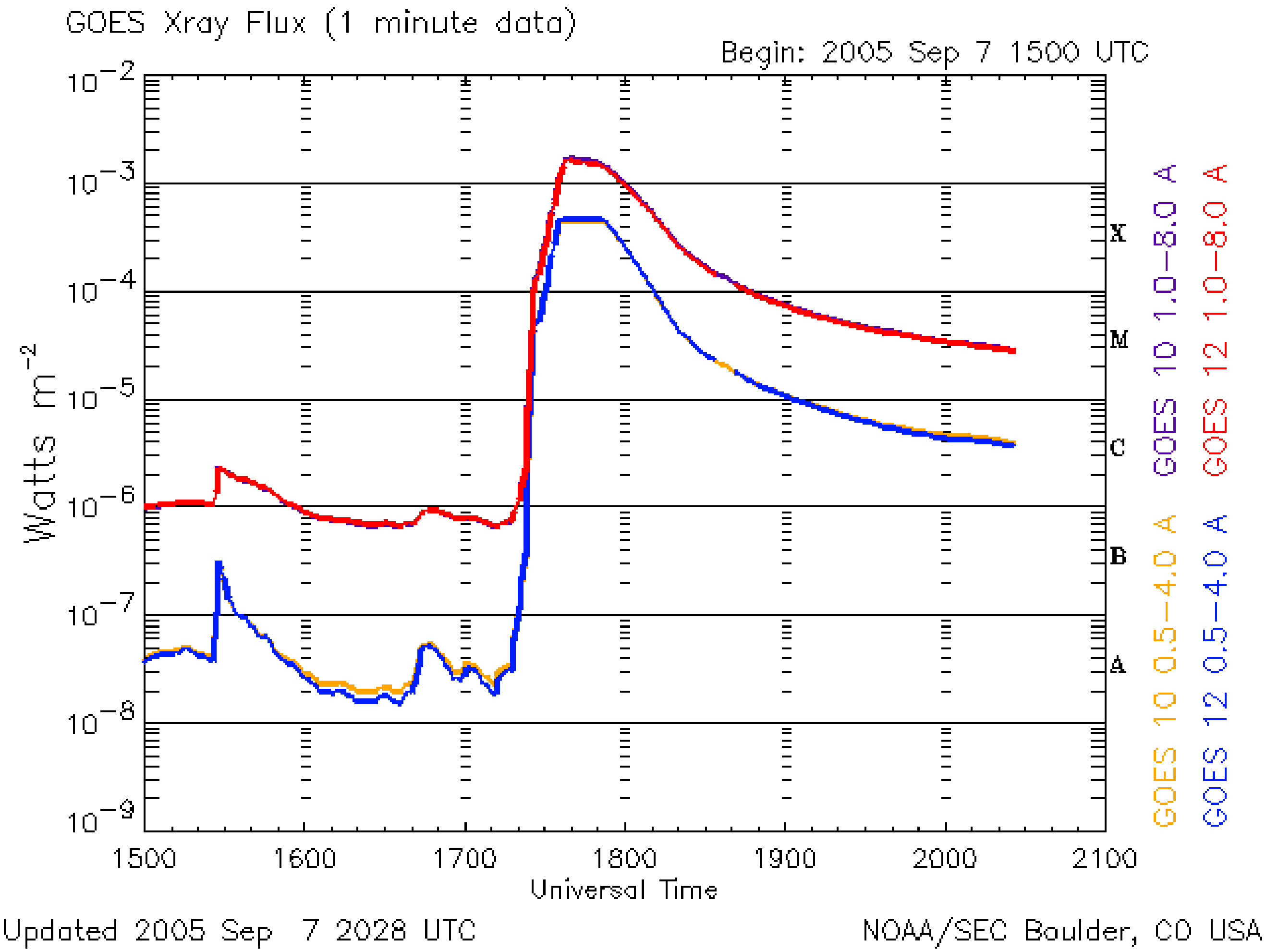
http://www.solarham.net/

A Solar Flare Can Cause a Radio Blackout

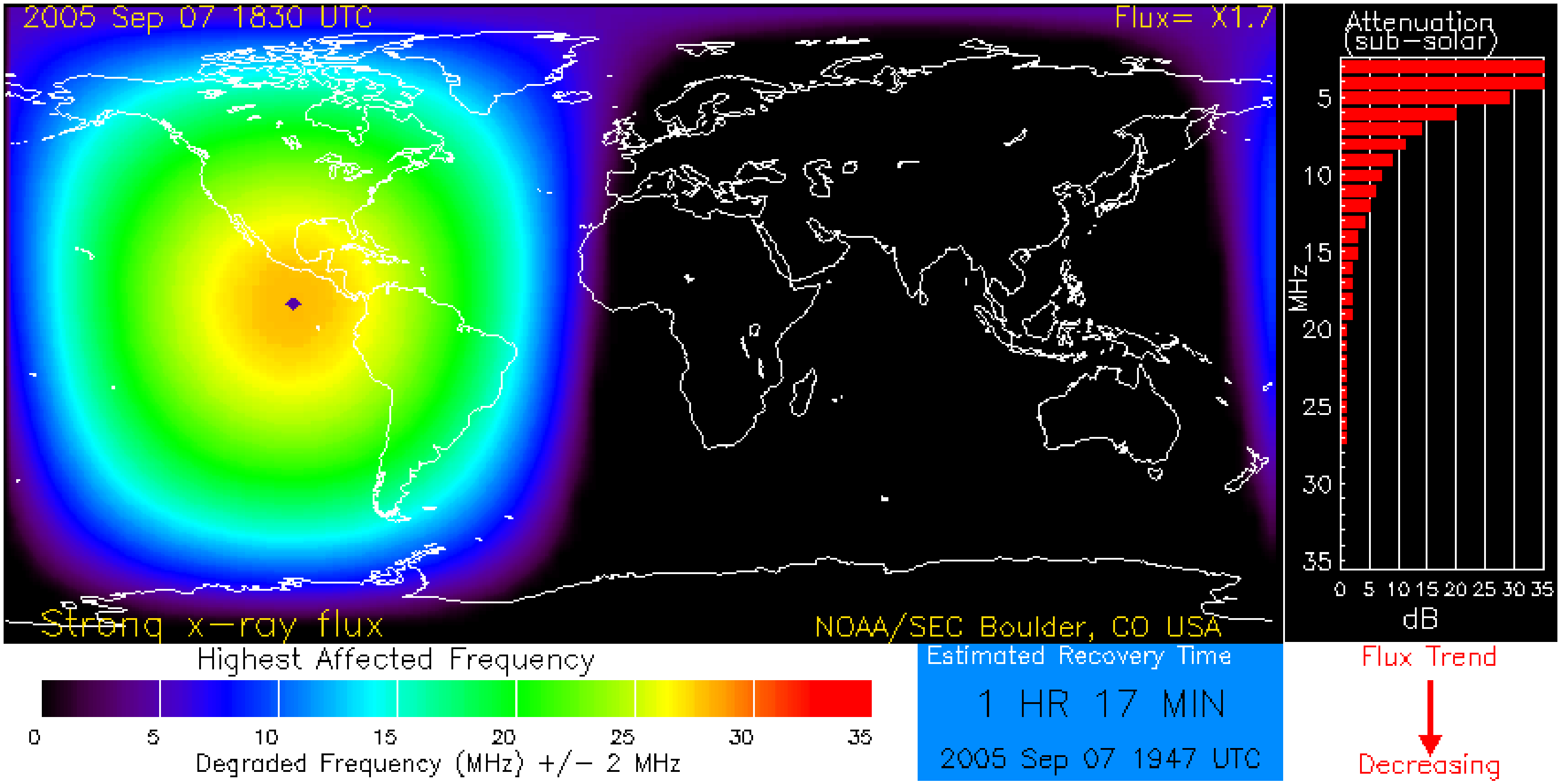


What does a large flare look like at radio frequencies?

Flare Cause Large Increase In X-ray Flux



X-ray Flux Greatly Increase D Layer Absorption



LUF ~ 20 MHz

http://www.solarham.net/

Statistical Forms of MUF

- MUF Median Value for the month
- Upper Decile
- Lower Decile
- 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.**

HF Radio is a LOT of FUN !