MF/HF Radio Wave Propagation

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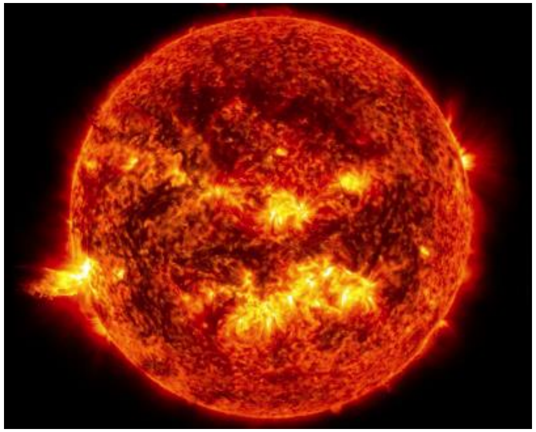
MF/HF Radio Wave Propagation

- Radio wave propagation is a vast topic but of keen interest to Amateur Radio operators. The ARRL provides a propagation forecast bulletin:



QST de W1AW
Propagation Forecast Bulletin 32 ARLP032
From ARRL Headquarters
Newington CT August 29, 2025
To all radio amateurs

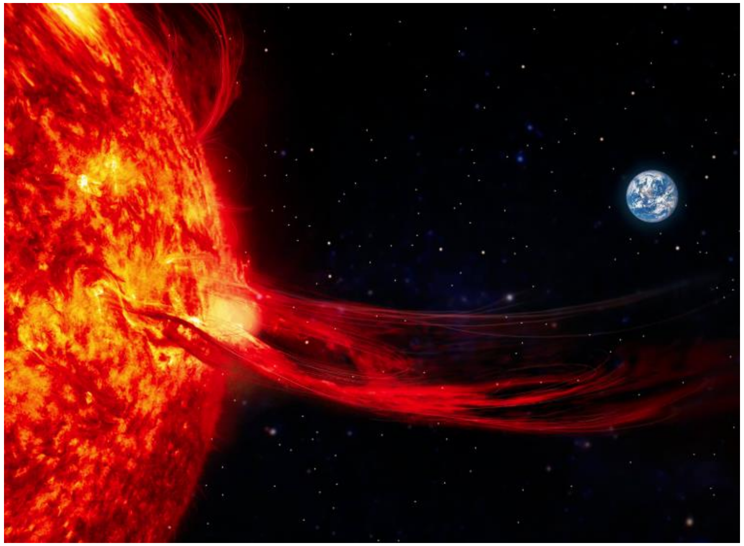
SB PROP ARL ARLP032
ARLP032 The ARRL Solar Report

Solar activity was at low levels on 18, 20, and 21 August with only C-class flares observed. Activity increased to moderate levels on 19 August following an M1.1 flare at 19/0439 UTC from an area beyond the Eastern limb. Moderate levels were also observed on 22 August as Region 4191 produced a long-duration M1.7/Sf flare. Associated with this flare was a Type II radio sweep with an estimated shock speed of 521 km/s. The associated CME was deemed to be behind the Sun-Earth line.

Moderate levels continued into 23 and 24 August with an M1.9 and an M1.3 flare, both originating from beyond the NE limb. While multiple CMEs were observed in coronagraph imagery over the period, nearly all were at or beyond the Eastern limb and none were considered to have an Earth-directed component.

MF/HF Radio Wave Propagation

- However, since it is so vast what can not be discussed here in this short presentation includes:
  - ❖ sunspots and the 11-year solar cycle
  - ❖ solar flares and coronal mass ejections
  - ❖ ionospheric fading
  - ❖ propagation forecasting
- First, the ***modes*** of low frequency radio wave propagation are presented.



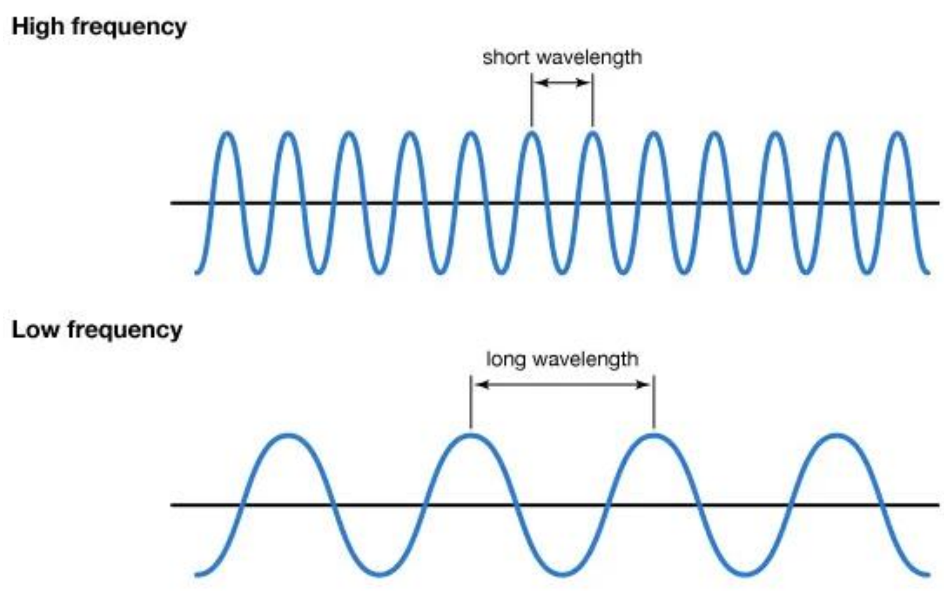
MF/HF Radio Wave Propagation – Fundamentals

- The ***frequency*** (***f***) and ***wavelength*** (***λ***) of a radio wave is a reciprocal relationship and in a vacuum is given by:

$$c = f\lambda \qquad f = c / \lambda \qquad \lambda = c / f$$

- Here ***c*** is the speed of light in a vacuum of approximately 3 x 10^8 meters/sec or 186 450 miles/sec

- Frequency in Hz is the inverse of the period in seconds.

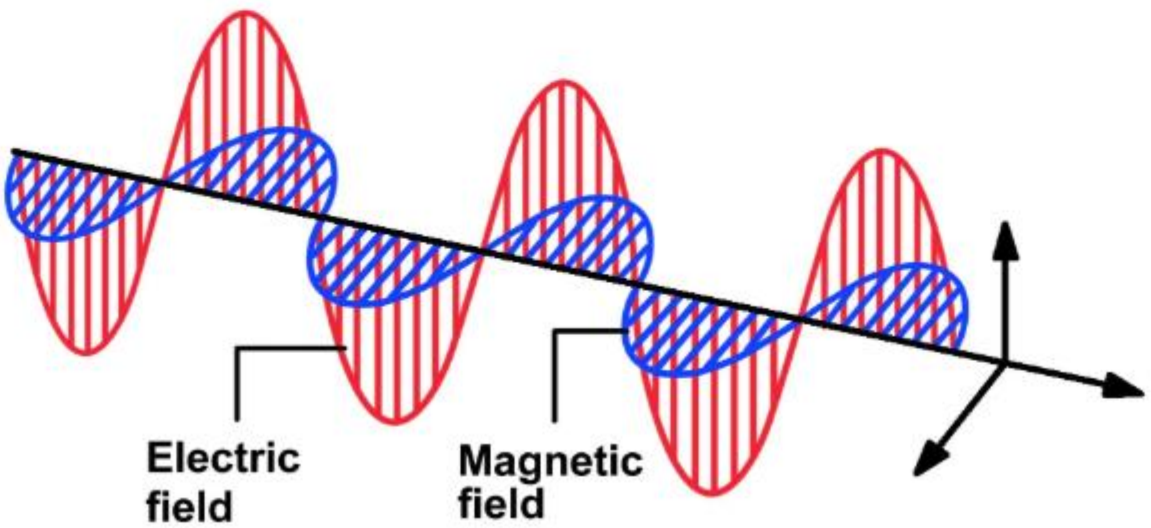


MF/HF Radio Wave Propagation – Fundamentals

- The waves are ***electromagnetic***, which are coupled electric and magnetic fields.

- Radio waves have the same characteristics as light but at a much lower frequency.

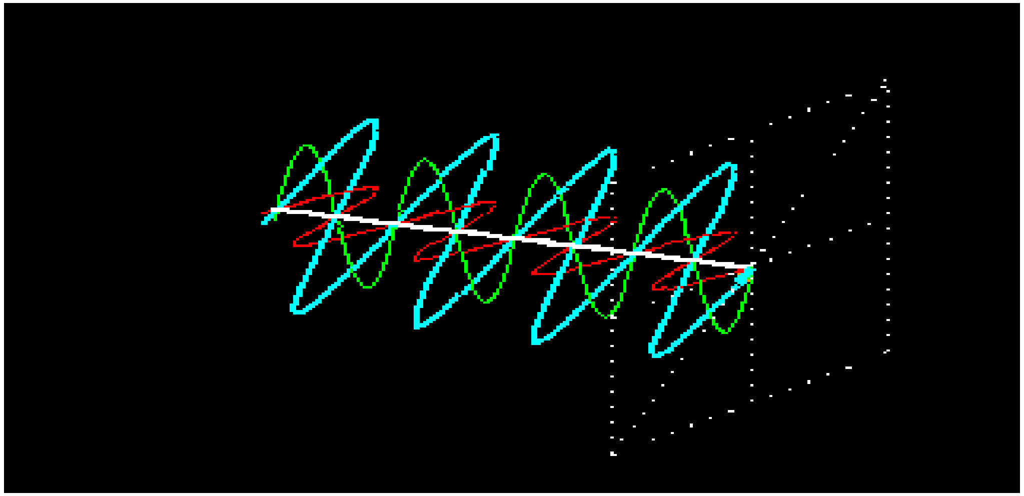
- Light has a frequency of 430 to 750 THz (terahertz or a million MHz).

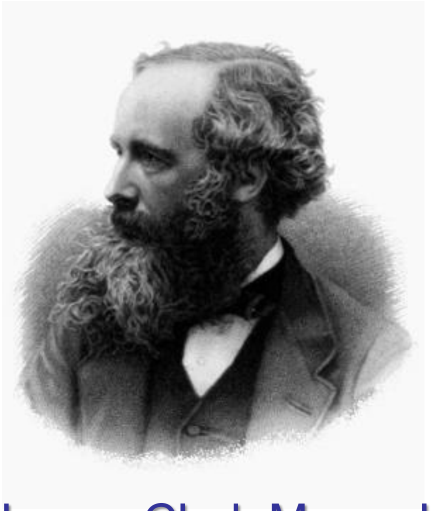


MF/HF Radio Wave Propagation – Fundamentals

- James Clerk Maxwell in the 1870s demonstrated that changing electric and magnetic fields could couple to form a propagating waves, a concept that united electricity, magnetism, and light.

Green – electric field **Red** – magnetic field
Blue – resulting power



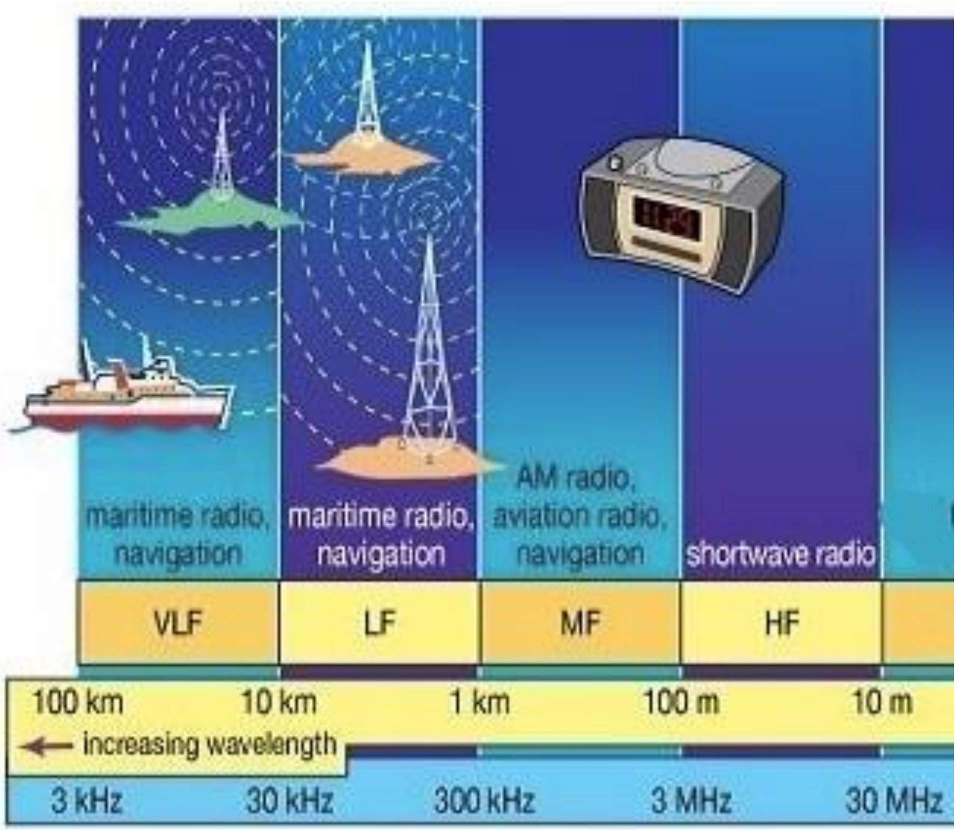


James Clerk Maxwell
1831-1879

MF/HF Radio Wave Propagation – Bands

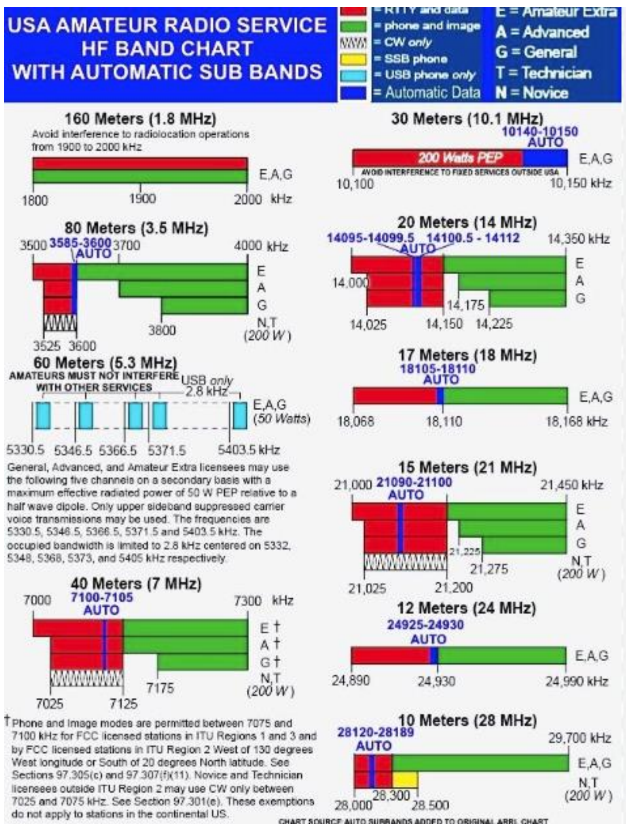
- Radio frequencies are organized as ***bands*** defined by their upper and lower frequency limits

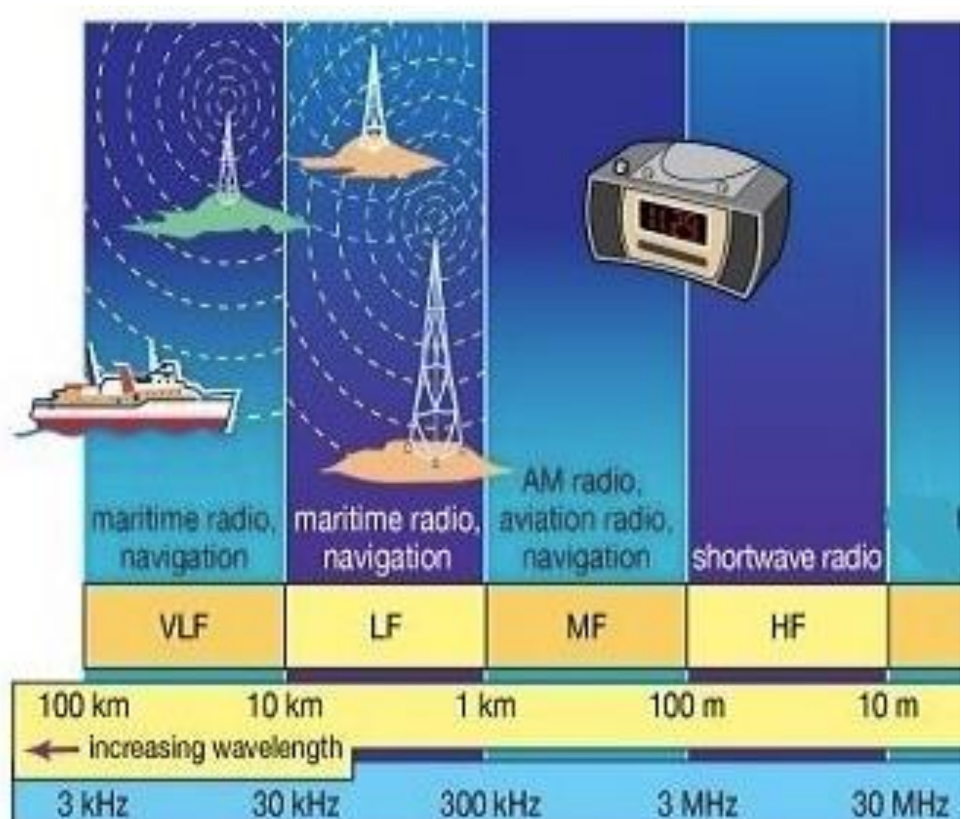
- The ***medium frequency*** (MF) band is from 300 kHz to 3 MHz and includes the Amateur Radio 160 meter allocation from 1.8 to 2 MHz.



MF/HF Radio Wave Propagation – Bands

- The ***high frequency*** (HF) band is from 3 to 30 MHz and includes the Amateur Radio 80, 40, 30, 20, 17, 15, 12 and 10 meter allocations.





MF/HF Radio Wave Propagation

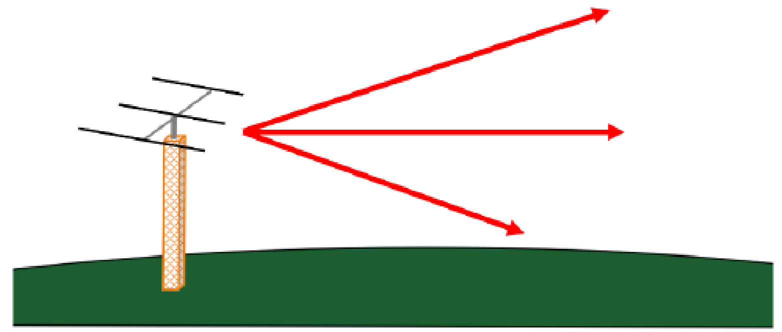
- One of the challenges is choosing the ***optimum frequency*** for communicating with a given location at a given date and time and under given propagation conditions.

- The choice of frequency is strongly dependent on the ***propagation mode***, that is the way in which HF signals travel between source and destination.

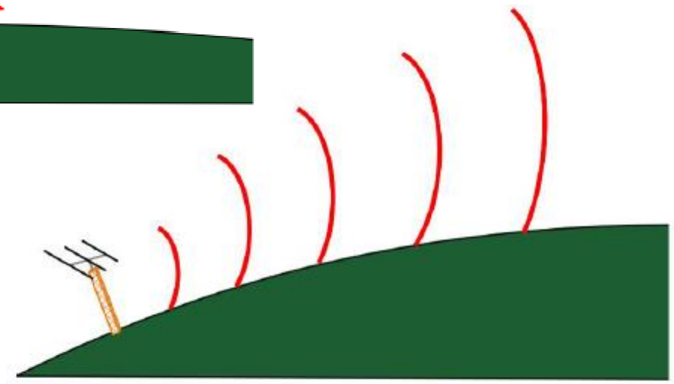
MF/HF Radio Wave Propagation - Modes

- There are three main ***propagation modes***:

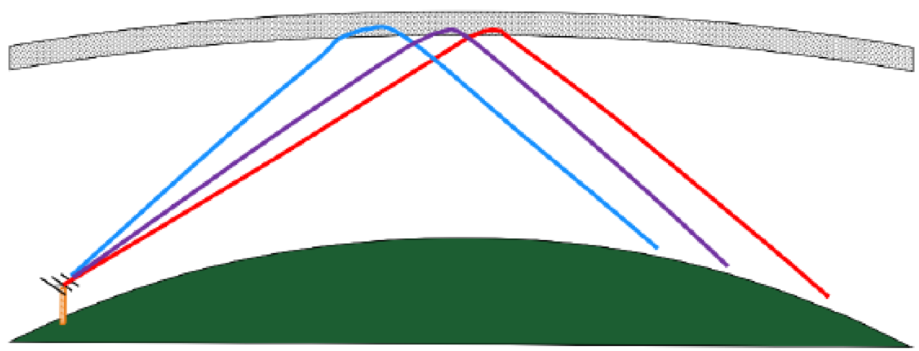
line of sight



groundwave



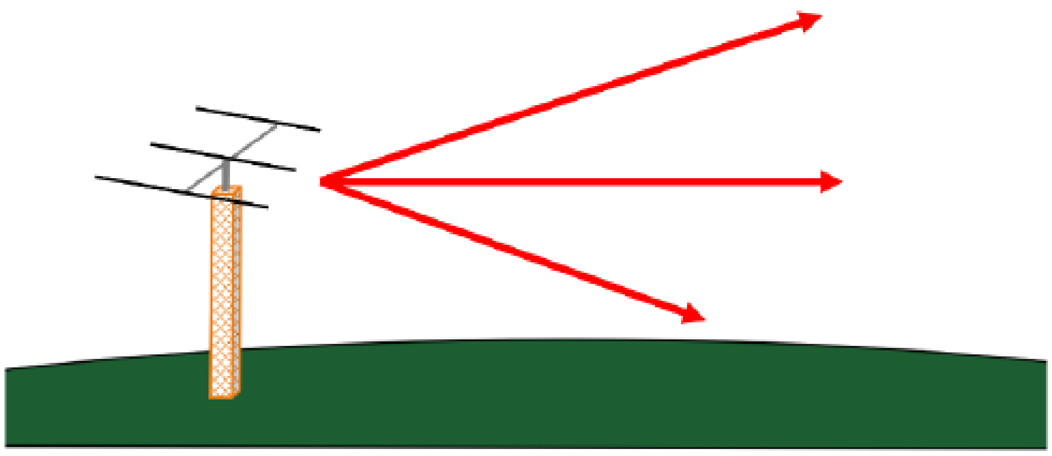
skywave



MF/HF Radio Wave Propagation – Line of Sight

- In ***line of sight*** or "direct wave" propagation, signals travel in a straight, unobstructed path between the transmitter and the receiver.

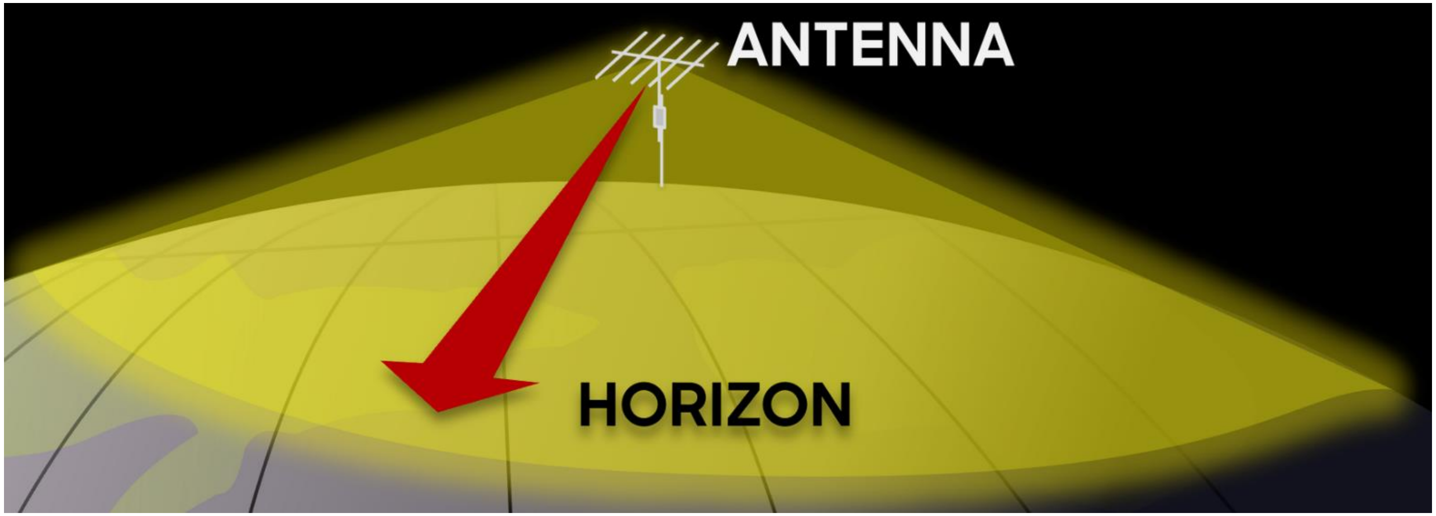
- Line of sight is the only MF/HF propagation mode which is ***fairly constant***. The ability to use line of sight to communicate with a given station doesn't vary substantially over periods of minutes, hours, days, months or years.



MF/HF Radio Wave Propagation – Line of Sight

- However, a potential disadvantage of line of sight MF/HF propagation is that any intervening objects between transmitter and receiver can significantly attenuate signals.

- But the ultimate limitation for MF/HF line of sight propagation is the ***horizon***.

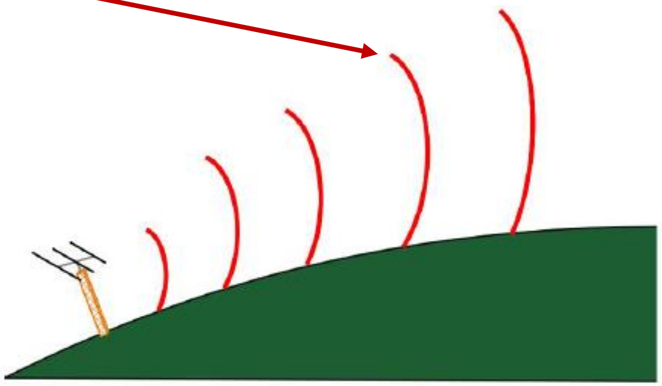


MF/HF Radio Wave Propagation – Groundwave

- ***Groundwave***, sometimes also called "surface wave," involves MF/HF signals propagating along the surface of the Earth.

- Interaction between the lower part of the transmitted wavefront and the Earth's surface causes the wave to ***tilt forward***.

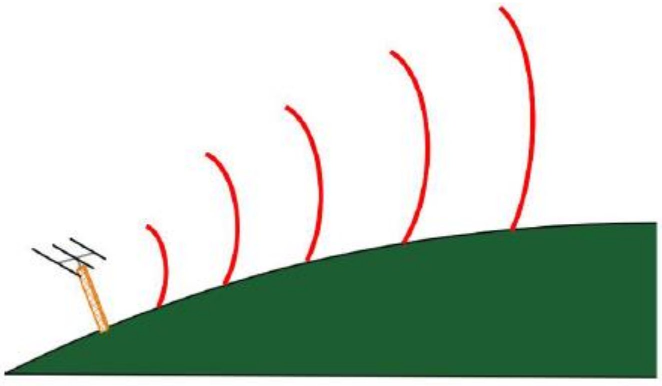
- This allows the signal to follow the curvature of the Earth, sometimes well beyond line of sight.



MF/HF Radio Wave Propagation – Groundwave

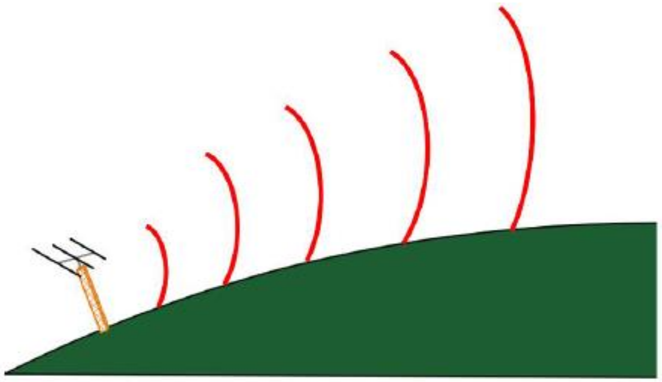
- Groundwave MF/HF propagation is, however, highly dependent on two different factors: the ***conductivity*** of the surface and the ***frequency*** of the transmitted signal.

- In general, higher surface conductivity gives better results in the form of greater distances that can be covered. ***Salt water*** has excellent conductivity, especially compared to dry or rocky land, so groundwave is a good choice for ship-to-ship or ship-to-shore communications.



MF/HF Radio Wave Propagation – Groundwave

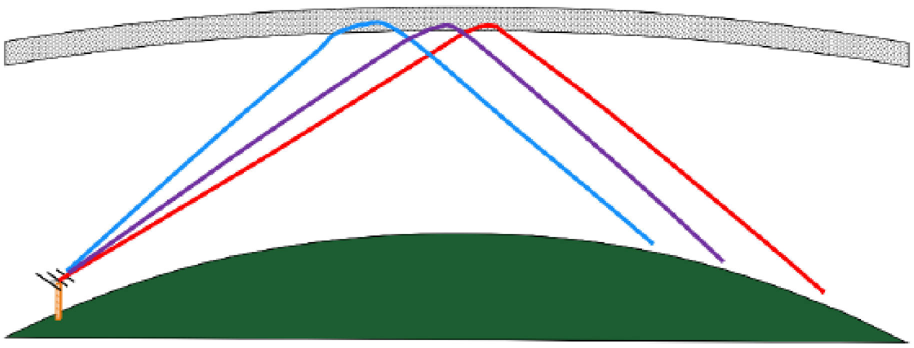
- Groundwave works best for lower frequencies.
- For example, the theoretical range of 150 watt transmitter at 7 MHz is 35 kilometers over land, and close to 250 kilometers over the sea.
- At 30 MHz, however, the theoretical range falls to only 13 kilometers over land and just over 100 kilometers at sea.



MF/HF Radio Wave Propagation - Skywave

- ***Skywave*** propagation enables beyond line of sight or even global communications, depending on propagation conditions.

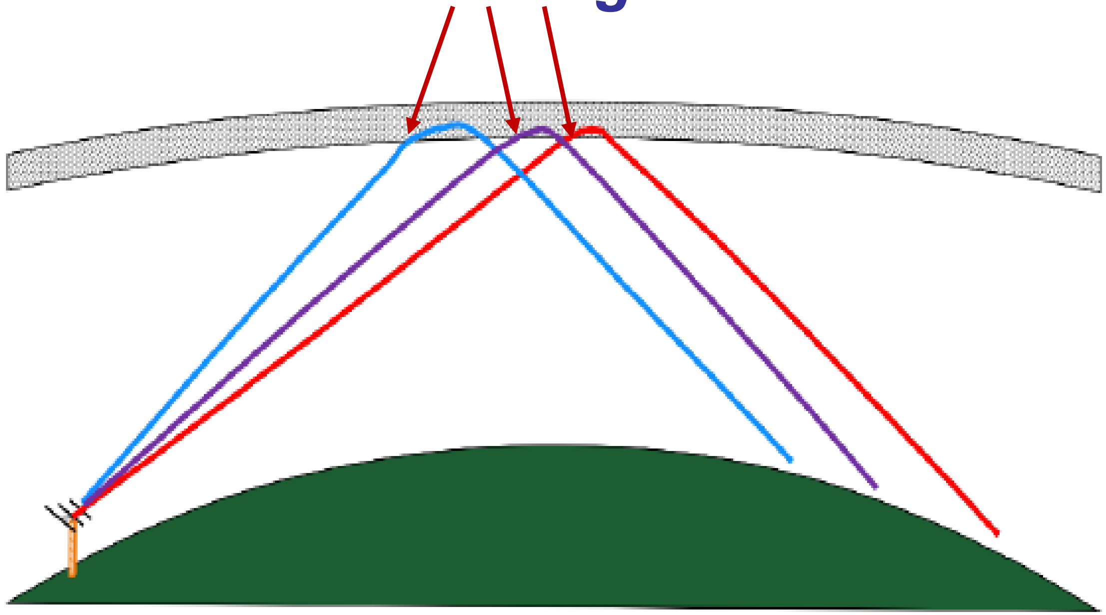
- In skywave, layers of ***ionized particles*** in the upper atmosphere ***refract*** HF signals back towards earth, allowing communications over many thousands of kilometers.



MF/HF Radio Wave Propagation - Skywave

- The distances that can be covered using a given frequency is primarily a function of two factors.

- The first is the ***state*** of these layers of ionized particles, collectively referred to as the ionosphere, and the second is the ***incidence angle***.

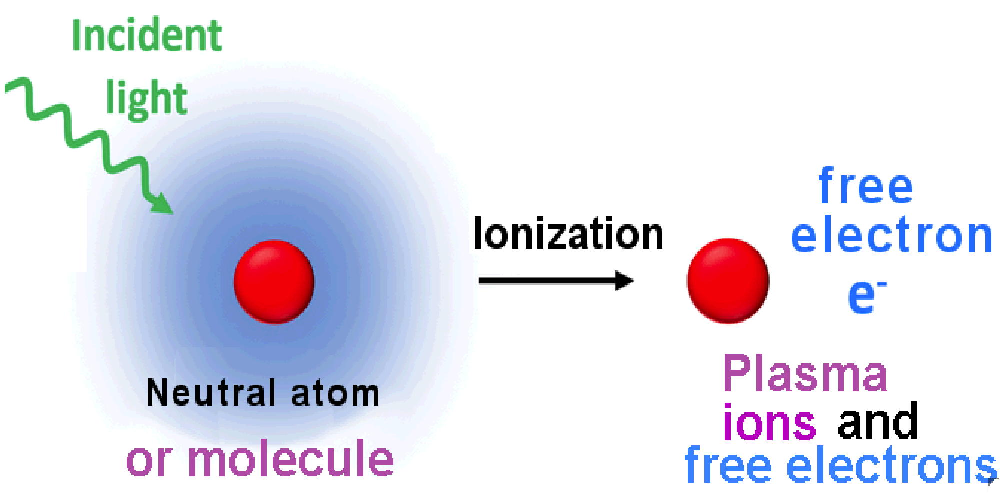


MF/HF Radio Wave Propagation - Ionization

- The ***ionosphere*** gets its name from the fact that this is the region where most atmospheric ionization occurs.

- When ***ultraviolet energy*** or radiation from the sun strikes gas atoms or molecules in the atmosphere, this energy can cause electrons to become detached.

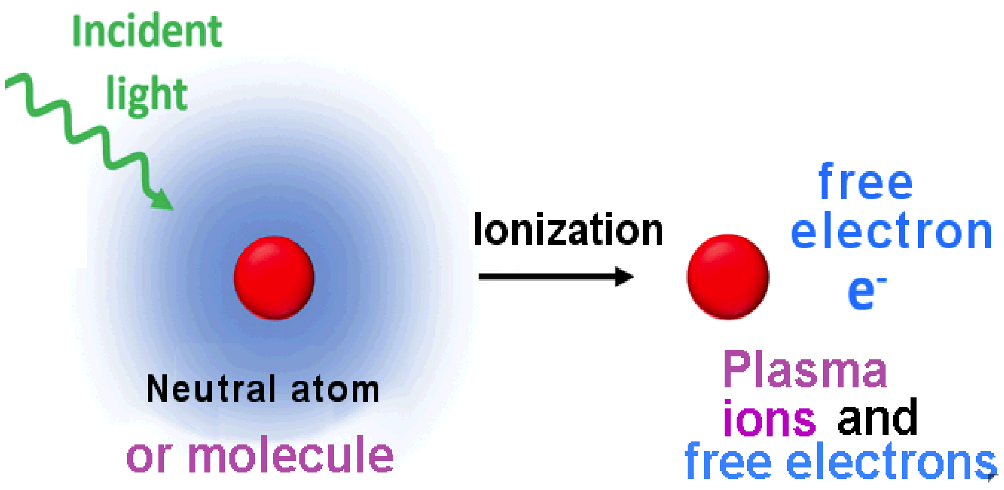
- The result is a ***positive ion*** and, more importantly, a ***free electron***.



MF/HF Radio Wave Propagation - Ionization

- The Earth's magnetic field keeps these free electrons roughly in place.

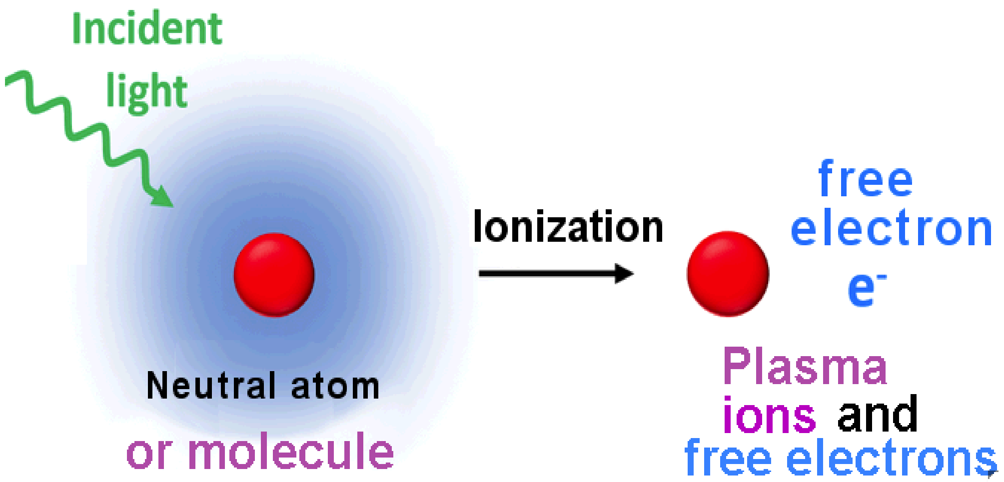
- The level of ionization and the number of free electrons increases as the amount of sunlight striking a given part of the atmosphere increases.



MF/HF Radio Wave Propagation - Ionization

- When a region of the atmosphere rotates away from the sun, that is at night, this ionization energy is removed and the ions recombine to form electrically neutral atoms.

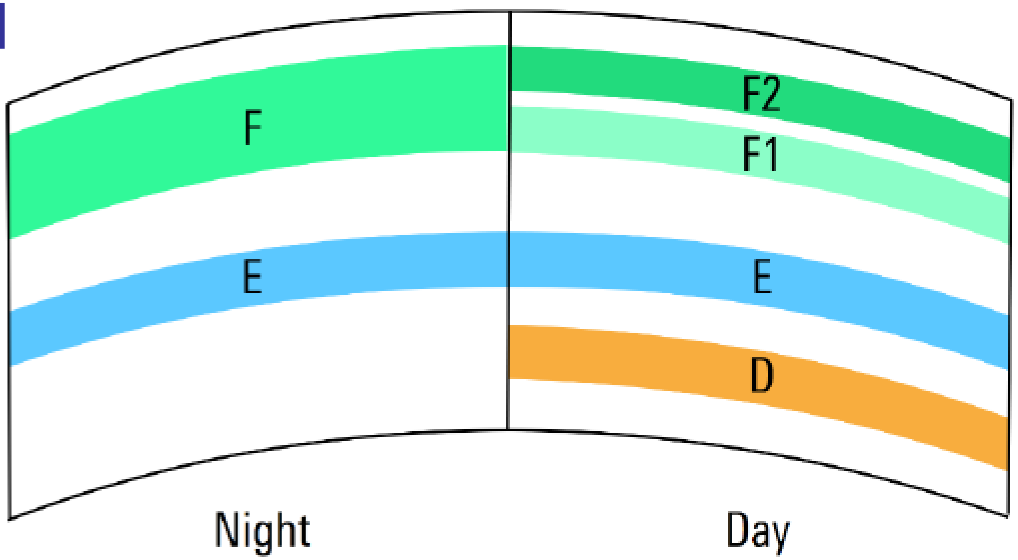
- Recombination is a slower process than ionization – atmospheric ionization increases rapidly at dawn, but decreases less rapidly after dusk.



MF/HF Radio Wave Propagation - Ionosphere

- The level or density of ionization in the ionosphere is different at different altitudes, and areas with ionization peaks are grouped into ***layers*** or ***regions***.

- The layers that are important for MF/HF radio wave skywave propagation are the ***D-layer***, from 30 to 56 miles (48 to 90 km); the ***E-layer***, from 56 to 93 miles (90 to 150 km); and the ***F-layers***, from 93 to potentially over 310 miles (150 to 500 km).

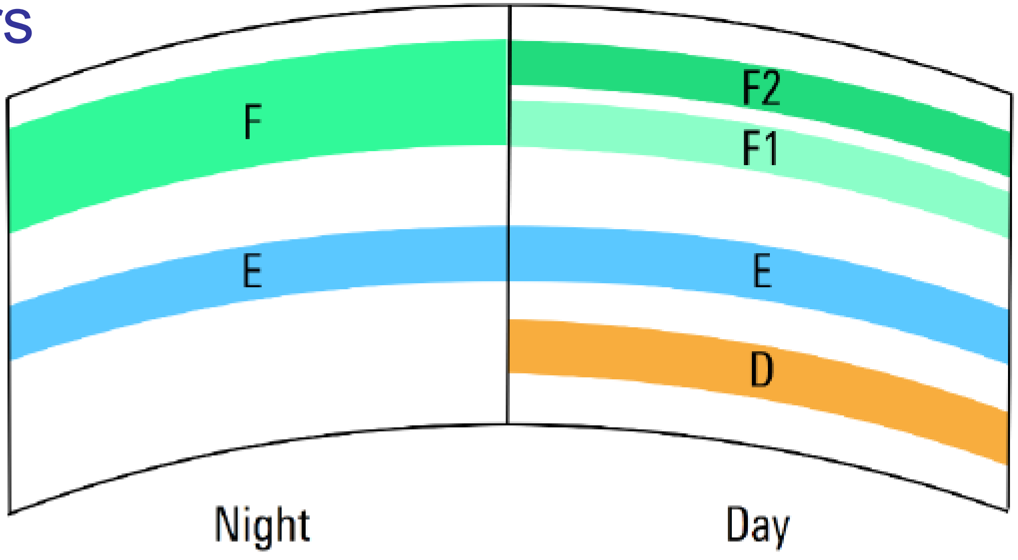


MF/HF Radio Wave Propagation - Ionosphere

- Note that the location and size of the ionospheric layers are only approximate values.

- The location and size of the ionospheric layers varies based on many factors such as the amount of solar radiation they receive.

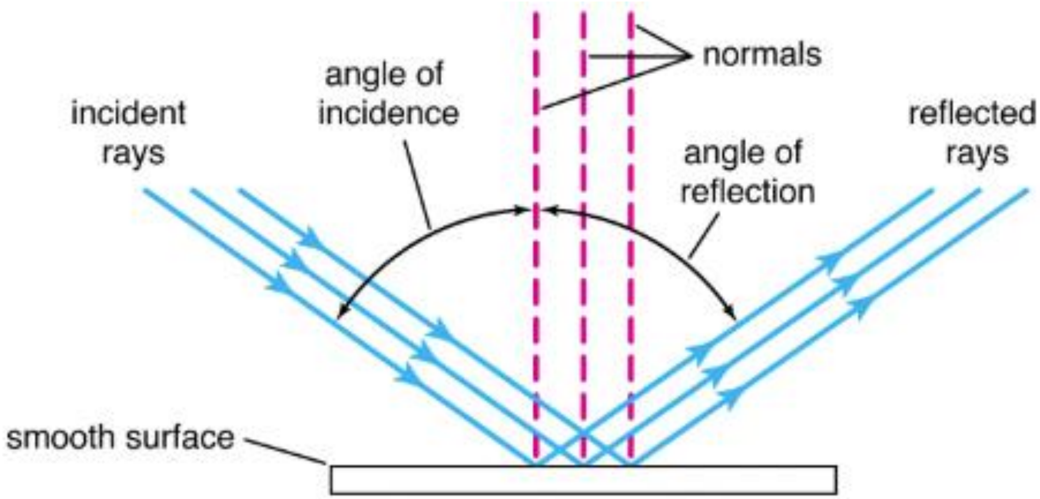
- Each of these layers affects MF/HF signals in different ways.



MF/HF Radio Wave Propagation - Ionosphere

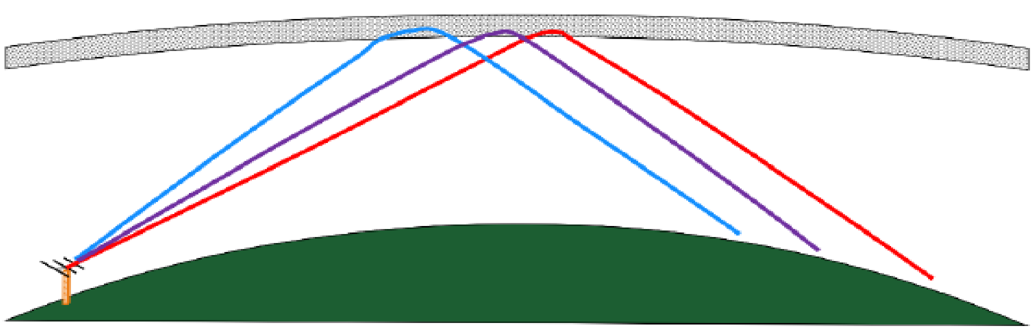
- However, it is important to remember that the ionosphere does not ***reflect*** MF/HF radio signals but rather ***refracts*** them.

- ***Reflection*** occurs when a propagating radio wave interacts with a conducting surface, such as with a *parabolic dish*.



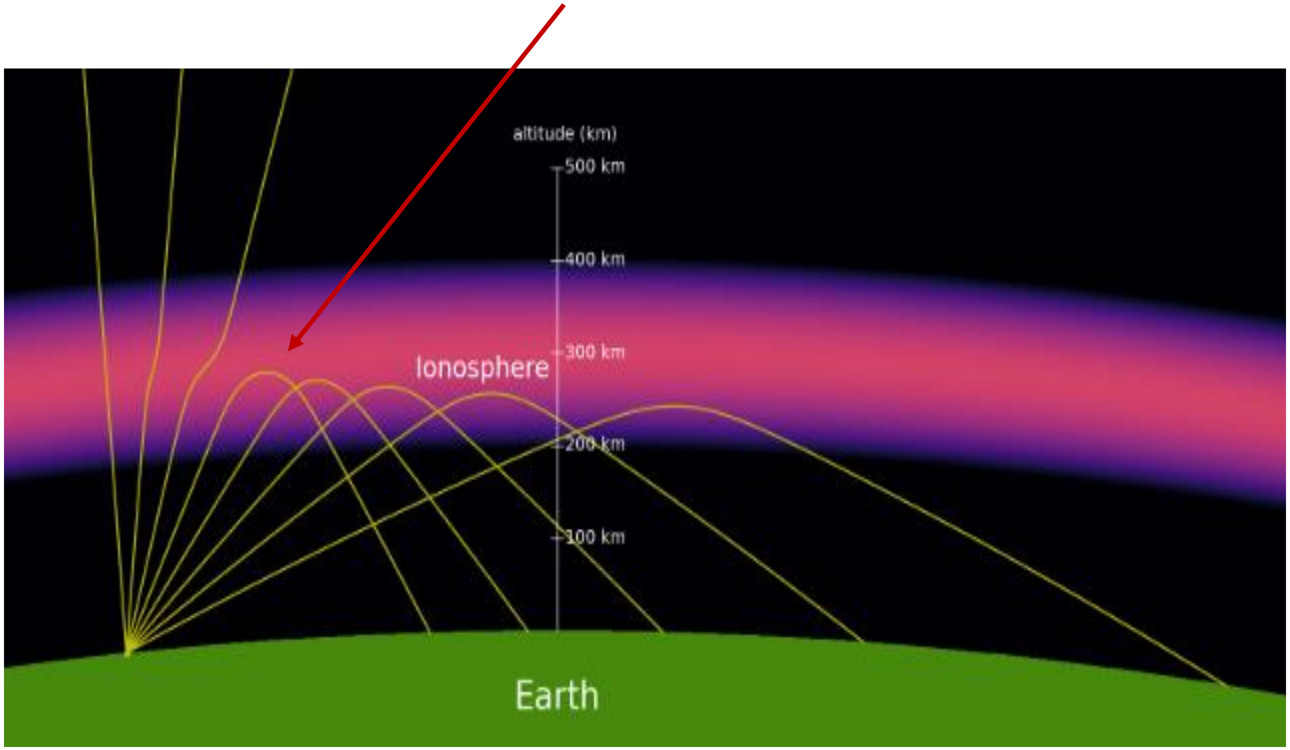
MF/HF Radio Wave Propagation - Ionosphere

- Ionospheric ***refraction*** is the ***bending*** of the propagating radio wave.
- The different electron densities at different altitudes is responsible for the ionospheric refraction.
- Since the electron density is diffuse the refraction occurs ***continuously*** resulting in MF/HF radio waves that only seems to be “reflected”.



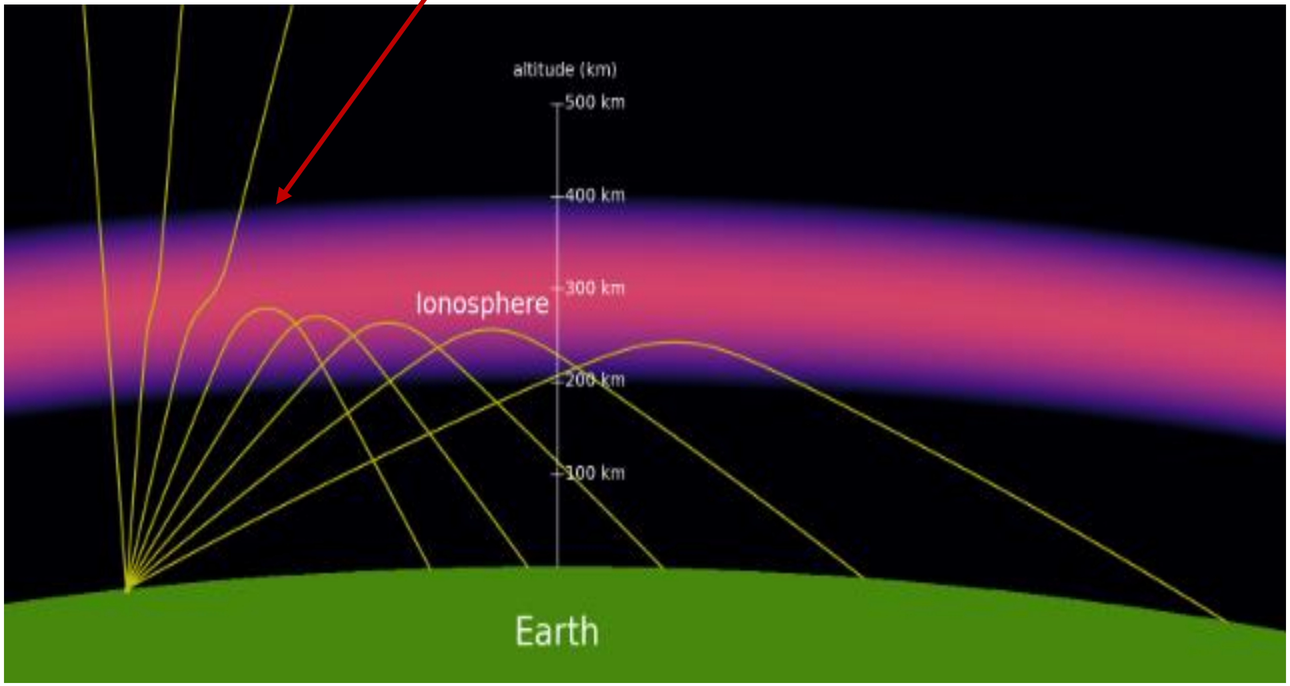
MF/HF Radio Wave Propagation - Ionosphere

- MF/HF radio waves, typically below 30 MHz but on occasion up to 100 MHz, are refracted by the ionosphere, thus bending back towards the Earth and enabling long-distance communication.



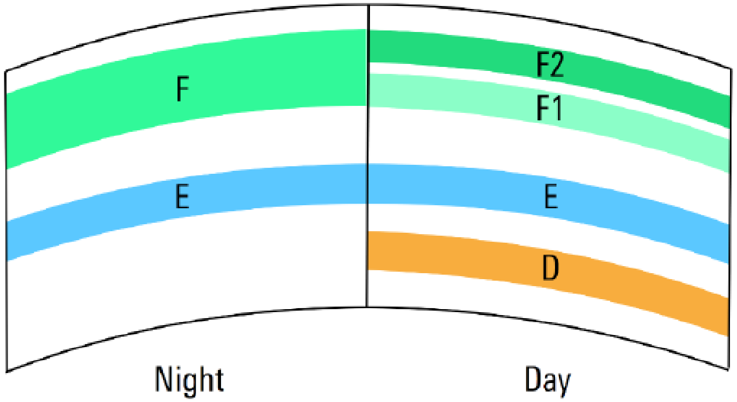
MF/HF Radio Wave Propagation - Ionosphere

- VHF, UHF and SHF radio waves greater than 100 MHz, such as those used in satellite communications, generally pass through the ionosphere with minimal bending.



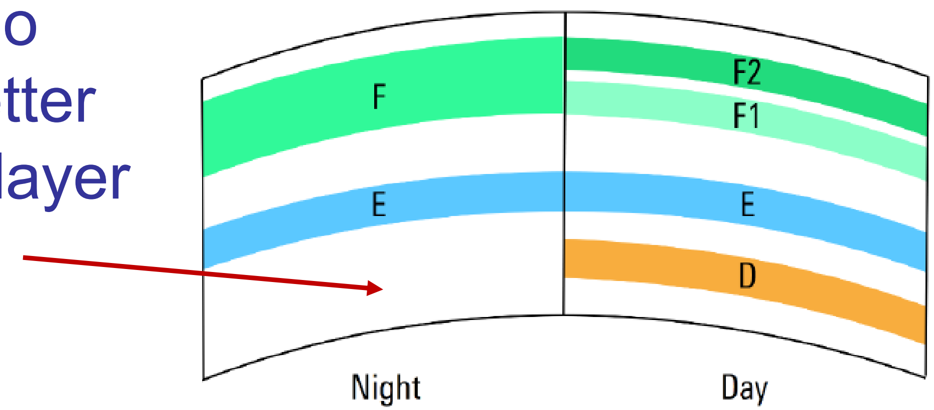
MF/HF Radio Wave Propagation – D-layer

- The D-layer only exists during ***daytime*** hours and disappears at night.
- Although the D-layer is ionized by solar radiation, the density of free electrons in the D-layer is too low to effectively refract MF/HF radio waves.
- The D-layer ***inhibits*** MF/HF skywave communications because it acts as an absorber of MF/HF radio waves.



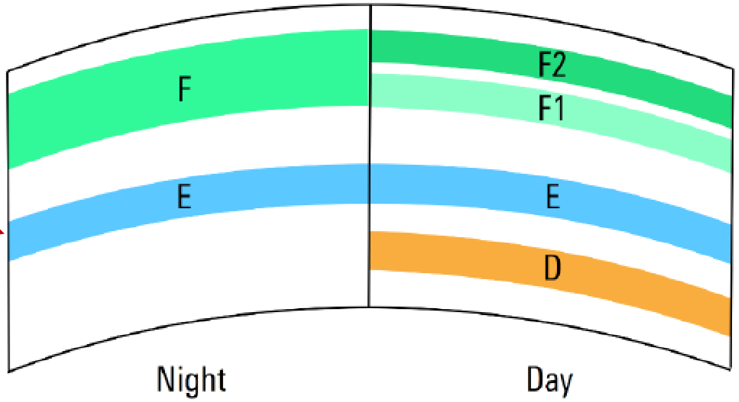
MF/HF Radio Wave Propagation – D-layer

- The lower the frequency of a radio wave, the more that signal is attenuated by D-layer absorption.
- D-layer absorption also increases with increasing ionization, so absorption is usually ***highest at midday***, when solar radiation is highest.
- Because of D-layer absorption, higher frequency radio waves propagate better during the daytime, whereas lower frequency radio waves propagate better at night, after the D-layer has disappeared.



MF/HF Radio Wave Propagation –E-layer

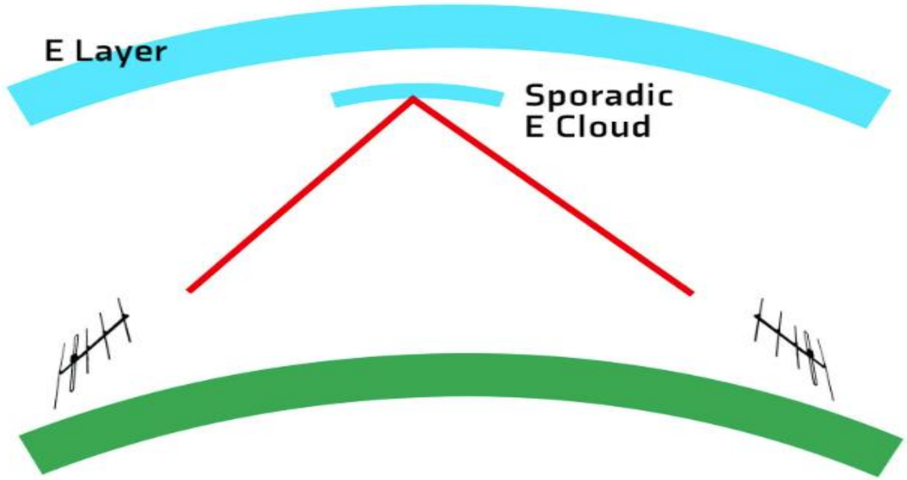
- The E-layer is the lowest layer of the ionosphere that has the ability to refract MF/HF radio waves back towards the Earth.
- Compared to the other layers of the ionosphere, the E-layer is relatively thin, usually approximately 5 to 15 miles (8 to 24 km).
- Like the D-layer, the E-layer is much more ***dense*** or ionized, during the day, but unlike the D-layer it does not completely disappear at night.



MF/HF Radio Wave Propagation – E-layer

- However, aside from mostly short-range, daytime communications, E-layer propagation is not responsible for the majority of MF/HF radio wave skywave communications.

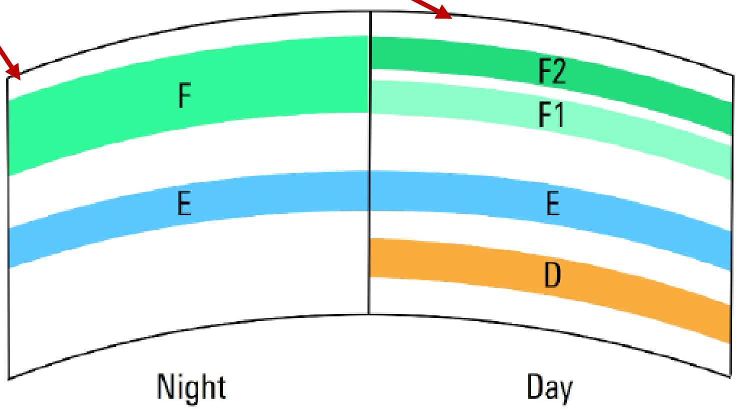
- However, E-layer propagation supports some rather exotic and less predictable propagation modes, such as ***sporadic-E***, that enable long-distance VHF communication over thousands of miles.



MF/HF Radio Wave Propagation – F-layer

- The F-layer is by far the most important ionospheric layer for MF/HF radio wave skywave propagation.

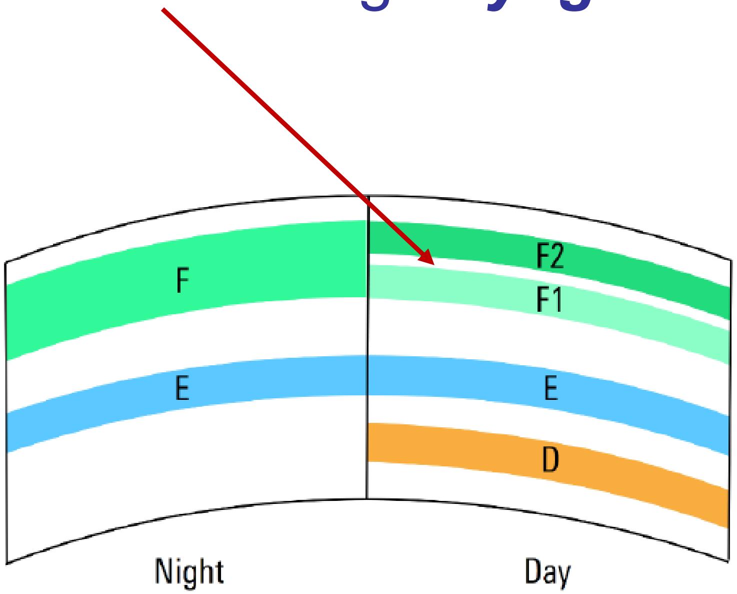
- During daylight hours, the F-layer splits into two sub-layers: F1 and F2, which then merge back into a single layer again at night.



MF/HF Radio Wave Propagation – F-layer

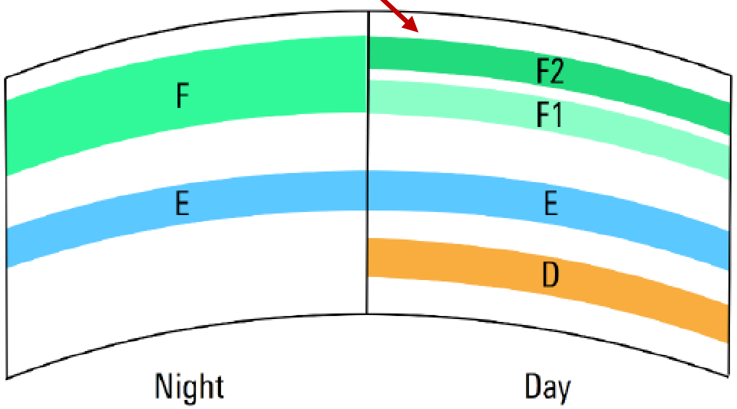
- Compared to the D and E layers, the height of the F-layer(s) changes considerably based on various factors such as time of day, season, and solar conditions.

- The lower F1-layer primarily supports short- to medium-distance communications during ***daylight hours***.



MF/HF Radio Wave Propagation – F-layer

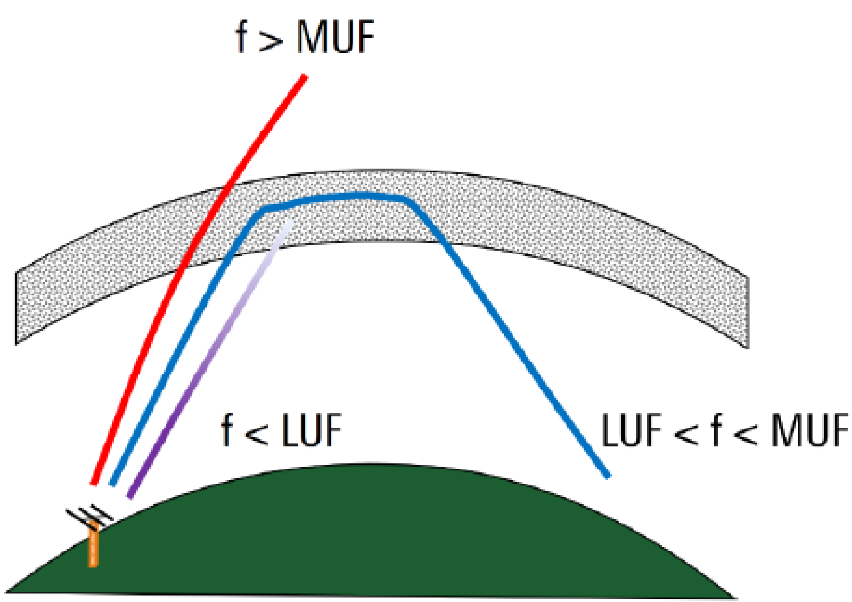
- The F2-layer, on the other hand, is present more or less around the clock.
- The F2-layer has the highest altitude and the highest ionization of all the layers and is therefore responsible for the vast majority of long-distance HF radio wave skywave communications.



MF/HF Radio Wave Propagation – MUF

- The degree to which the different layers of the ionosphere refract and/or absorb radio frequency signals is partly a function of that signal's frequency.

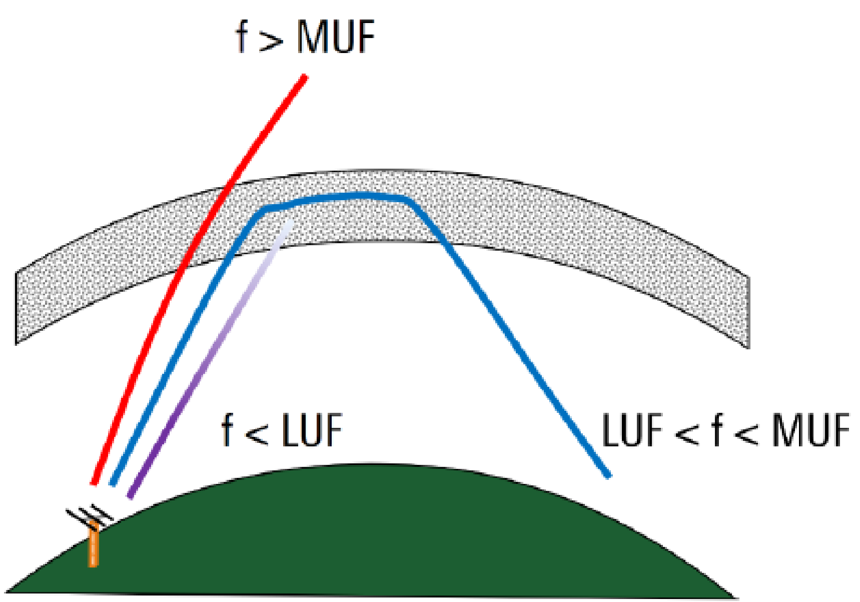
- The general rule for MF/HF skywave communications is to always use the highest possible frequency that will reach a given destination. This is called the ***maximum usable frequency*** (MUF).



MF/HF Radio Wave Propagation – MUF

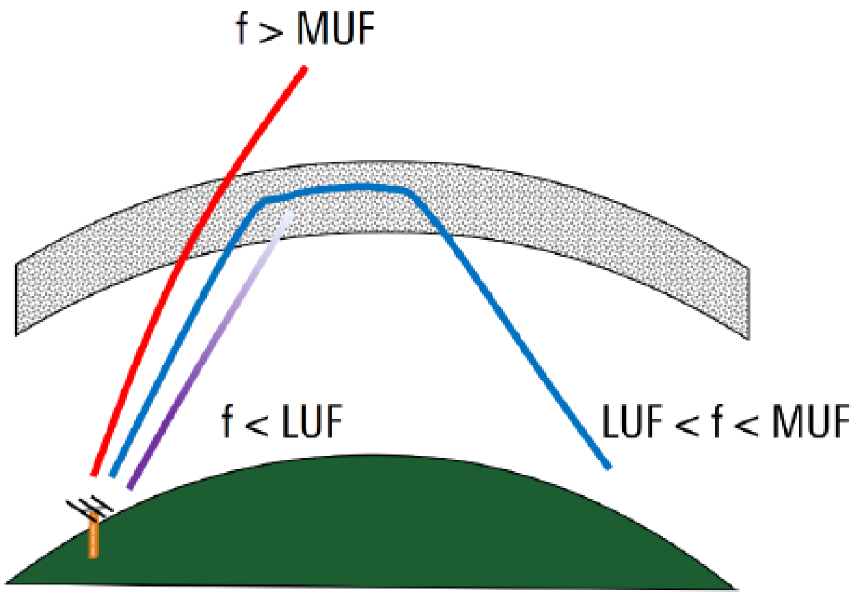
- Signals whose frequencies are higher than the MUF will not be refracted by the ionosphere, but will instead penetrate the ionosphere and continue to propagate into space without being returned to Earth.

- Generally speaking, the MUF increases with increasing ionization.



MF/HF Radio Wave Propagation – LUF

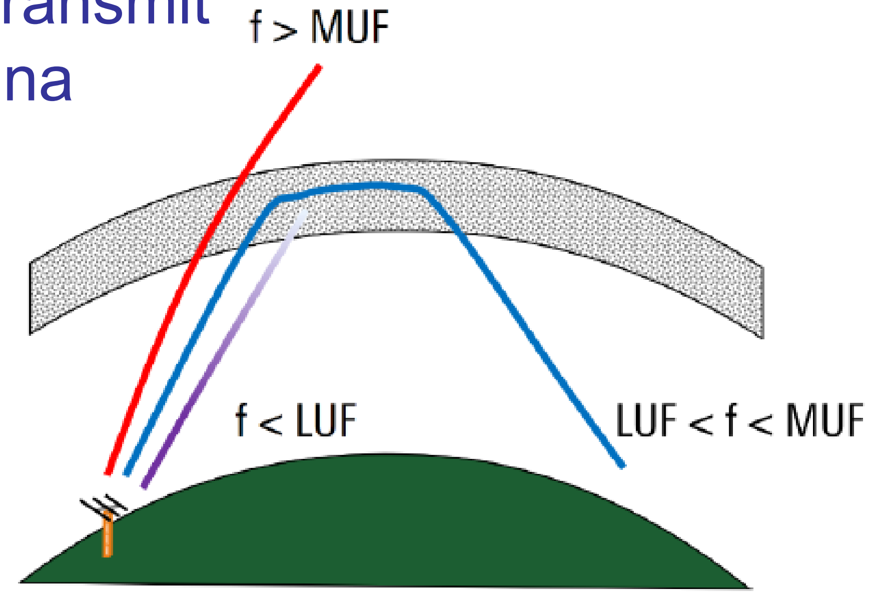
- The other frequency threshold is the ***lowest usable frequency*** (LUF).
- When the signal frequency is at or below the LUF, communication becomes difficult or impossible due to signal loss or attenuation.



MF/HF Radio Wave Propagation – MUF and LUF

- In MF/HF radio wave skywave communications, frequencies should therefore be chosen such that they fall ***between*** the LUF and MUF.

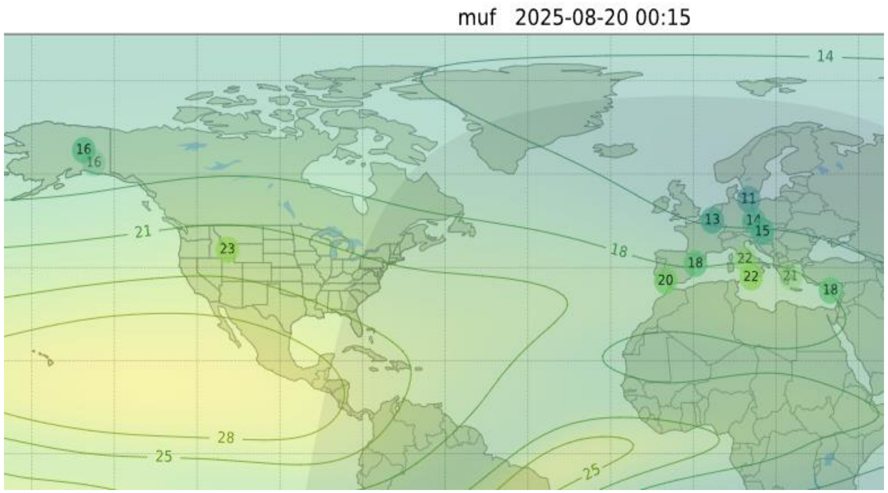
- However, there is a very important difference between MUF and LUF. Because the LUF is mostly determined by noise, using higher transmit power or a better antenna can lower the LUF.

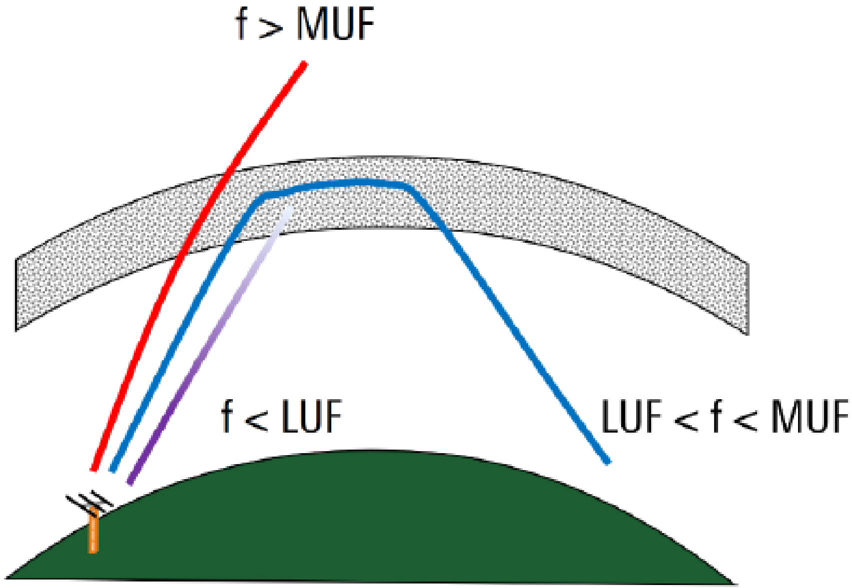


MF/HF Radio Wave Propagation – MUF

- On the other hand, MUF is entirely a function of the ionosphere.

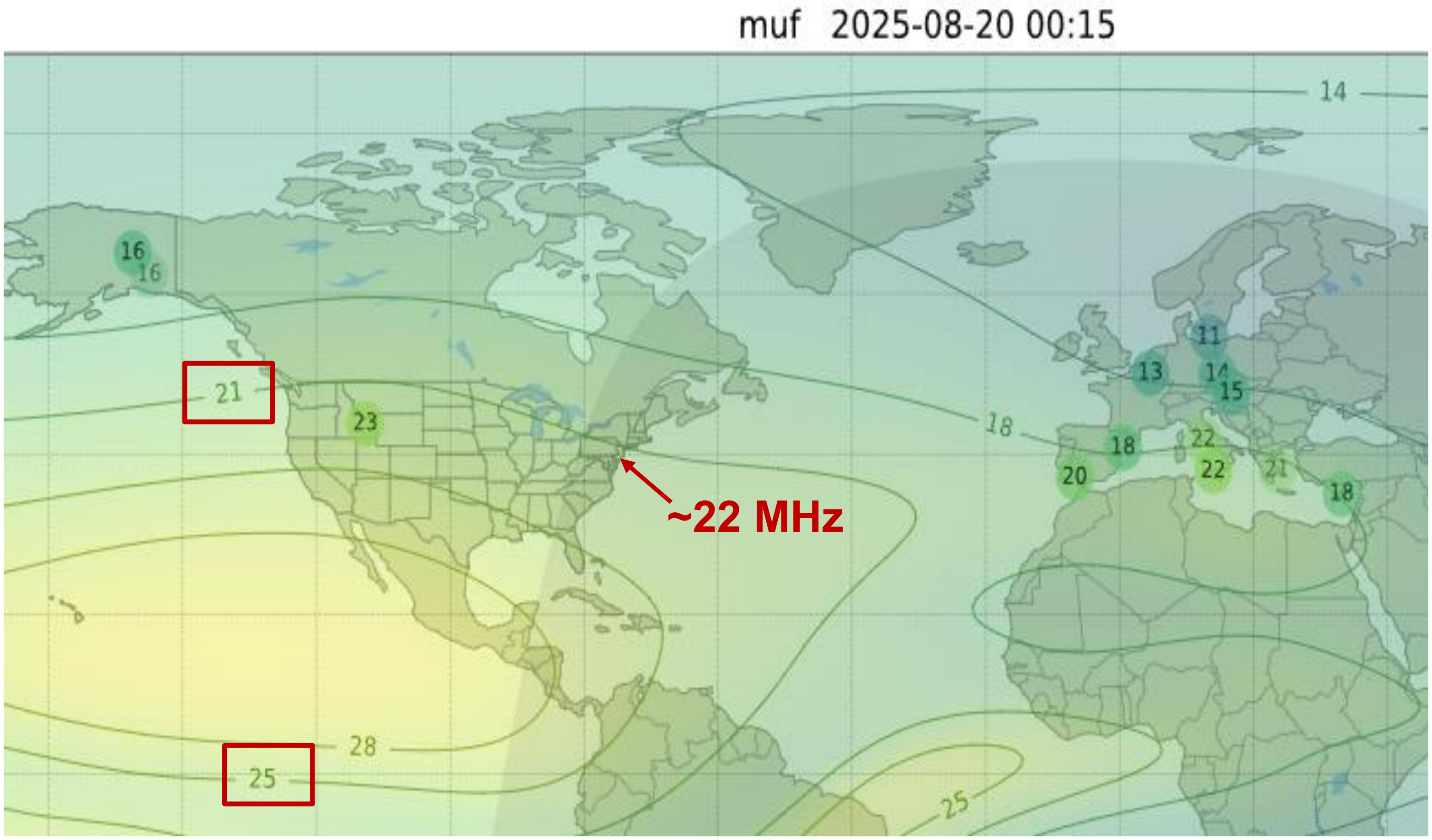
- Higher transmit power or a better antenna will not increase the MUF.





MF/HF Radio Wave Propagation – MUF and LUF

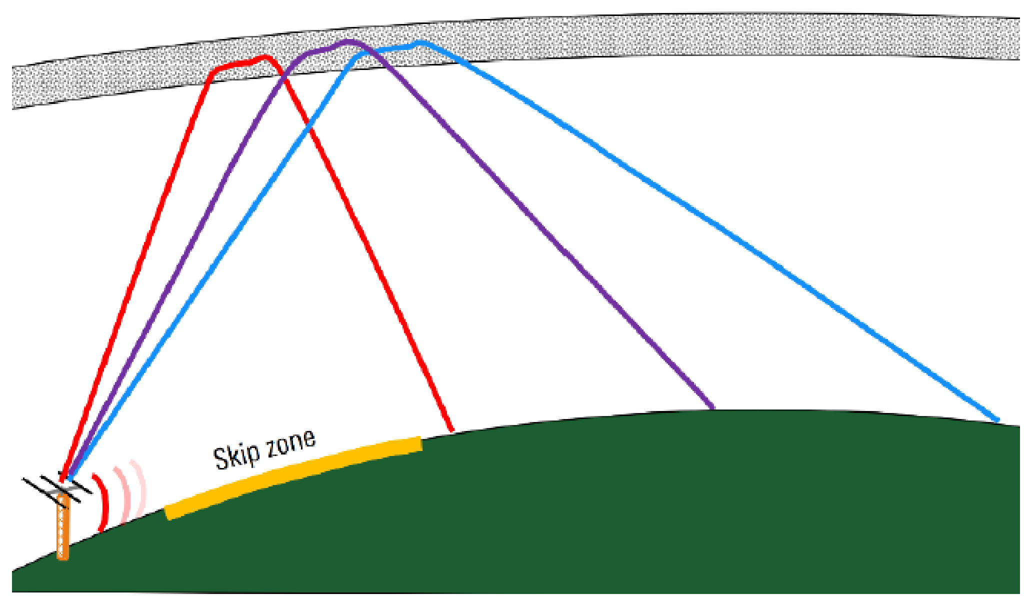
- MUF 1864 miles (3000 km) on August 20, 2025, 0015 UTC (2015 EST) *https://prop.kc2g.com/*



MF/HF Radio Wave Propagation – Incident Angle

- The ***incident angle*** is the angle at which a signal reaches the ionosphere.

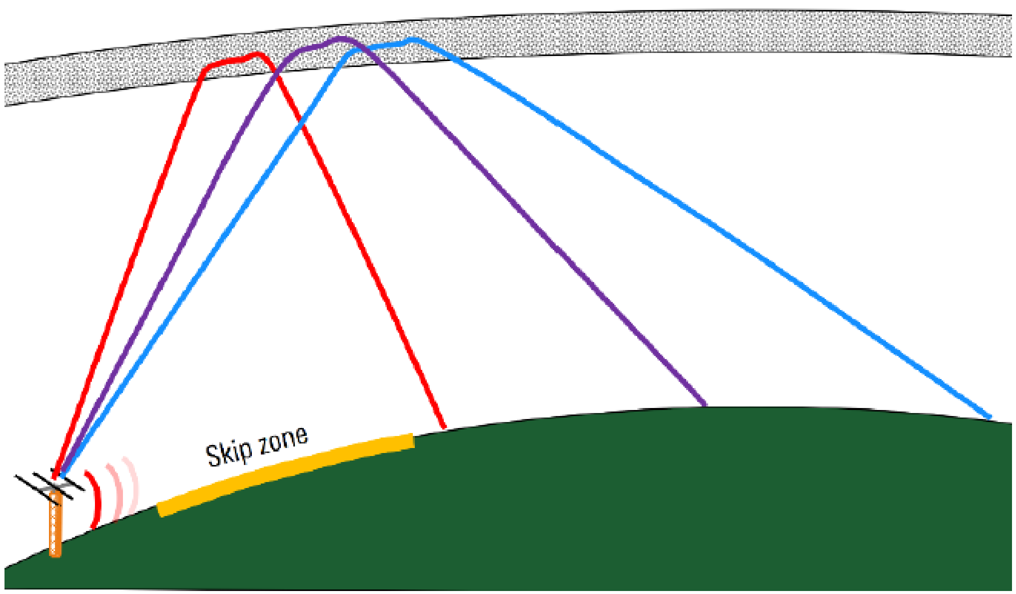
- The incidence angle plays an important role in determining how far an MF/HF radio wave skywave signal will propagate.



MF/HF Radio Wave Propagation – Incident Angle

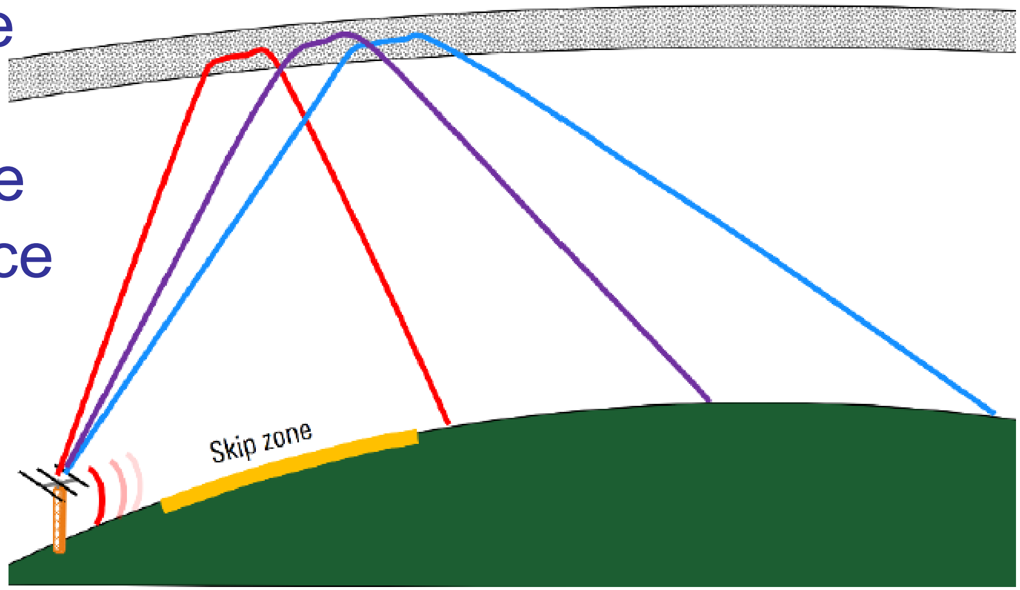
- The ***radiation angle*** of an antenna is primarily a function of both the type of antenna and the location at which the antenna is installed.

- Higher placement of an antenna usually ***lowers*** the incidence angles and the lower the incidence angle, the greater the distance covered by MF/HF radio wave skywave propagation.



MF/HF Radio Wave Propagation – Incident Angle

- A consequence of low incidence angles is the creation of ***skip zones***.
- In these skip zones, MF/HF signals cannot be received either via skywave or groundwave propagation.
- One way to provide coverage within a skip zone is the use of a higher incidence angle signals.



MF/HF Radio Wave Propagation – Summary

- ***Daytime Bands***

- During daylight hours, higher frequency bands are generally more effective for DX due to the ionization of the ionosphere.

- The 20 meter band is considered a primary daytime band, known for consistent long-haul communication.

20 meter, 3 element monoband Yagi antenna

MF/HF Radio Wave Propagation – Summary

- ***Daytime Bands***

- The 17, 15 and 12 meter bands are also effective during the day, particularly for long-distance contacts, with the 15 meter band being more dependent on solar cycle conditions.

- The 10 meter band is primarily a daytime band, with its effectiveness strongly tied to high solar activity.

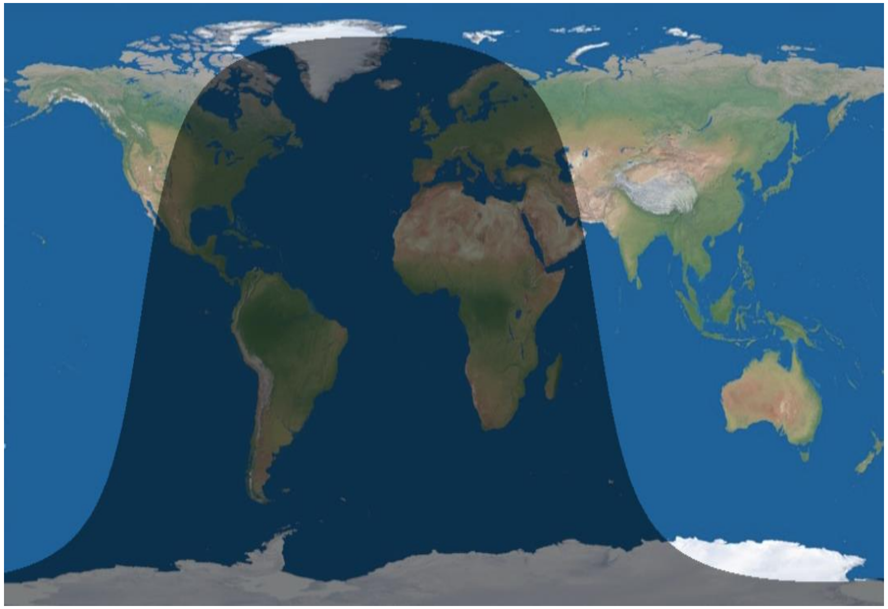
10 meter, 7 element monoband Yagi antenna

MF/HF Radio Wave Propagation – Summary

- ***Nighttime Bands***

- Lower frequency bands become more effective for long-distance communication during nighttime hours.

- This is because the ionosphere weakens at night, allowing lower frequencies to travel further via radio wave skywave propagation.



MF/HF Radio Wave Propagation – Summary

- ***Nighttime Bands***
- The 160 meter band is almost exclusively a nighttime band, with optimal performance during darkness or near-darkness conditions.
- The 80 meter band is primarily a nighttime band, offering reliable short-to-medium distance contacts and potential for worldwide communication during darkness.

MF/HF Radio Wave Propagation – Summary

- ***Nighttime Bands***

- The 40 meter band is effective for local and regional communication during the day, but its long-distance capabilities, including global DX, are enhanced after dark.

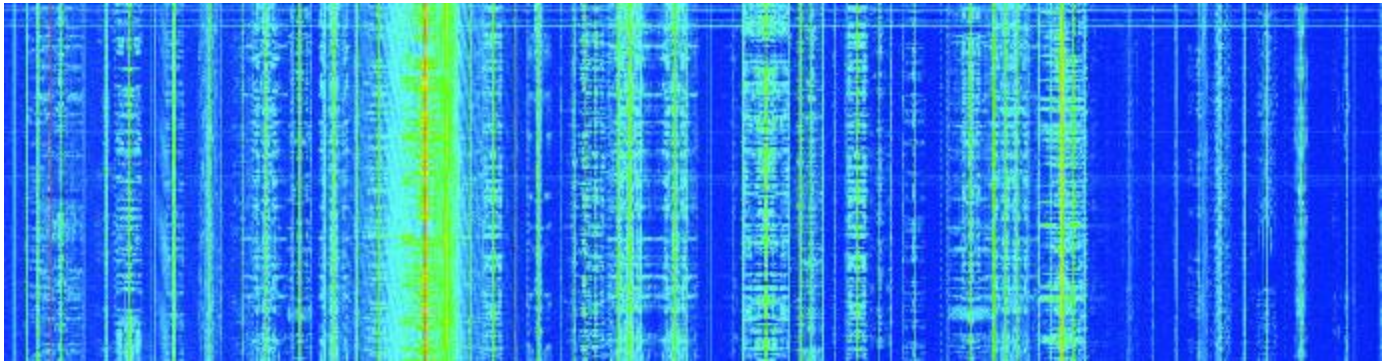
Full size 40 meter vertical antenna at HB9XBG

MF/HF Radio Wave Propagation – Summary

- ***Daytime and Nighttime Bands***

- The 30 meter band is known for its consistent 24 hour reliability and can facilitate DX contacts during periods of darkness along the radio wave propagation path. Only CW and various digital modes are allowed.

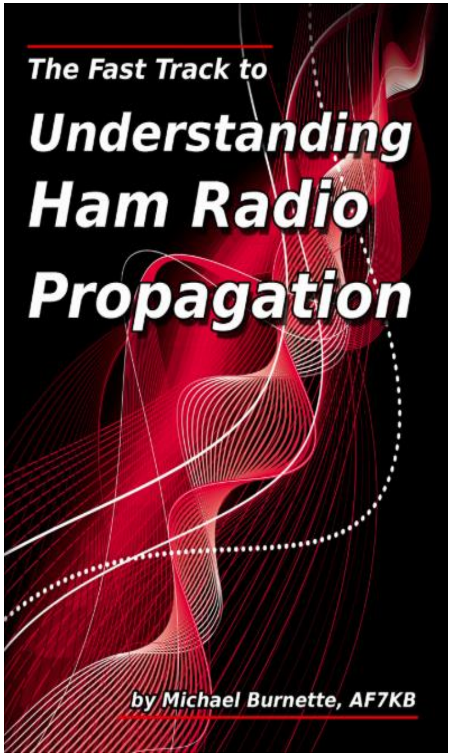
Waterfall spectral display on 30 meters



MF/HF Radio Wave Propagation - References

Understanding Ham Radio Propagation
ISBN: 1794054065

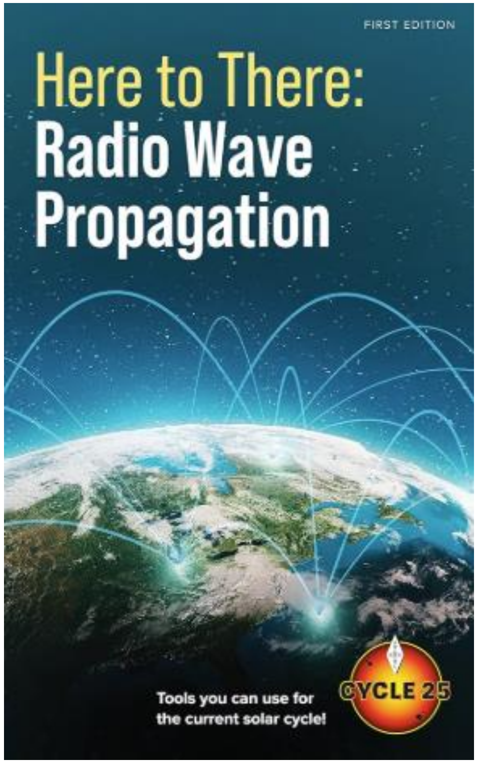
For each form of propagation, you'll learn the best ham radio practices to increase your chances of "making the hop", whether that's across town or across the globe.



MF/HF Radio Wave Propagation - References

Here to There: Radio Wave Propagation
ARRL ISBN: 978-1-62595-173-1

Presents the principles of amateur radio propagation in an easy-to-understand style.



MF/HF Radio Wave Propagation

Dennis Silage K3DS

Questions?