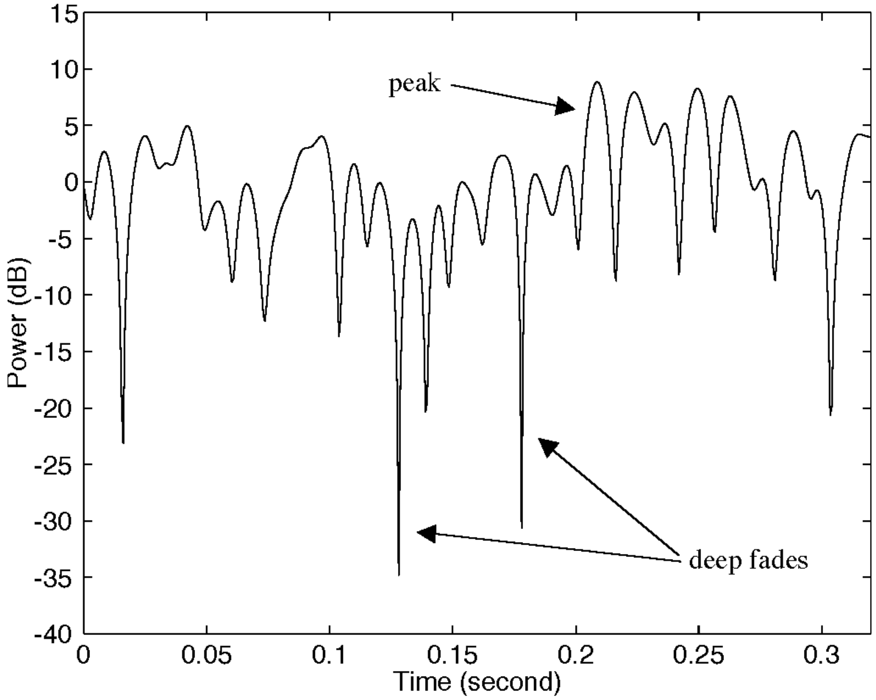
Signal Fading and Background Noise

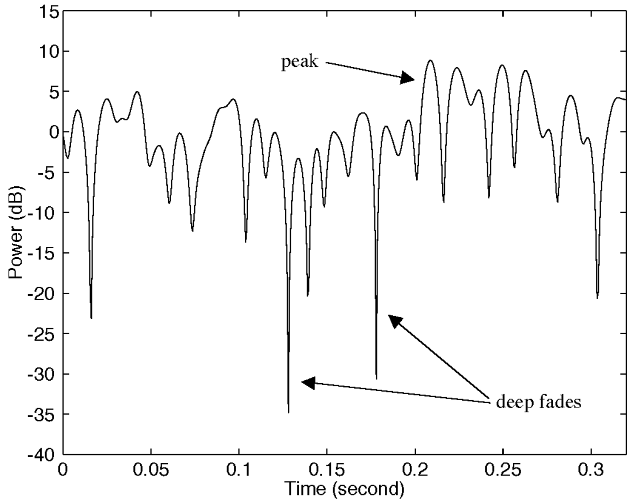


Ken Larson KJ6RZ
March 2024

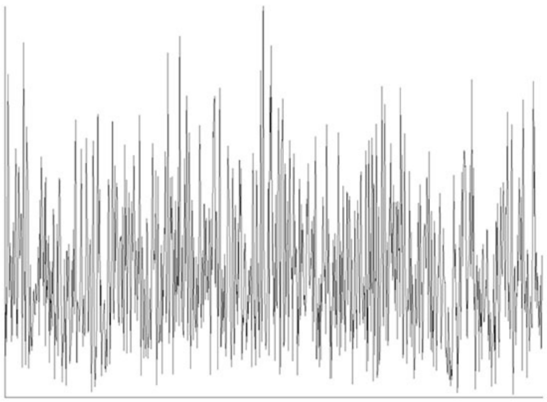
www.skywave-radio.org

Signal Fading and Noise

Ericsson Inc.



Signal Fading

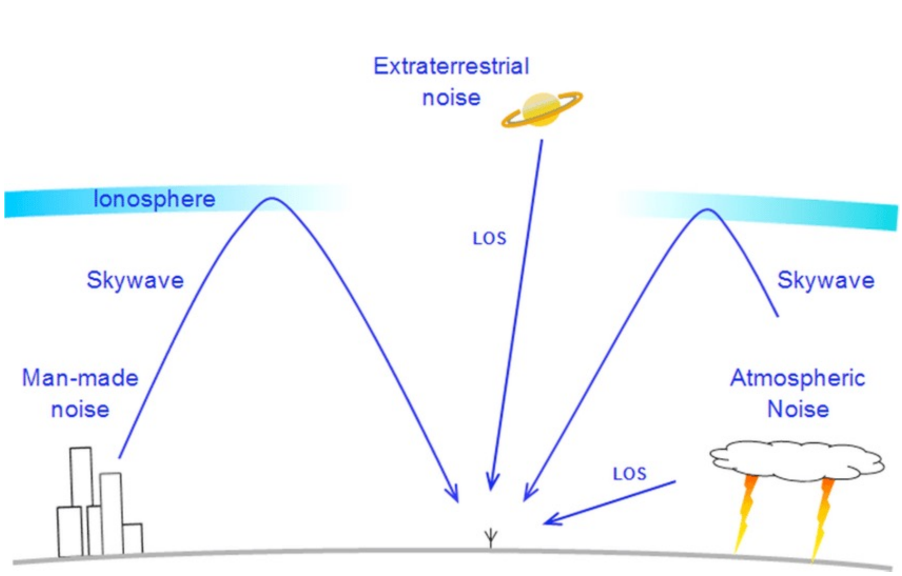


Vitrek

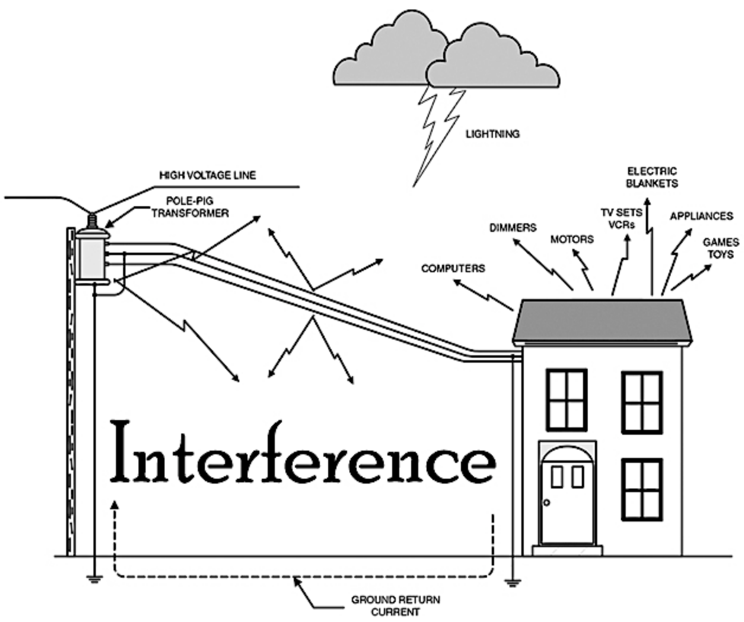
Background Noise

- Signal fading and background noise are two of the most serious problems affecting HF radio communications
- Signals that sink into the background noise can not be received
- Signals that fade in and out are very difficult to copy

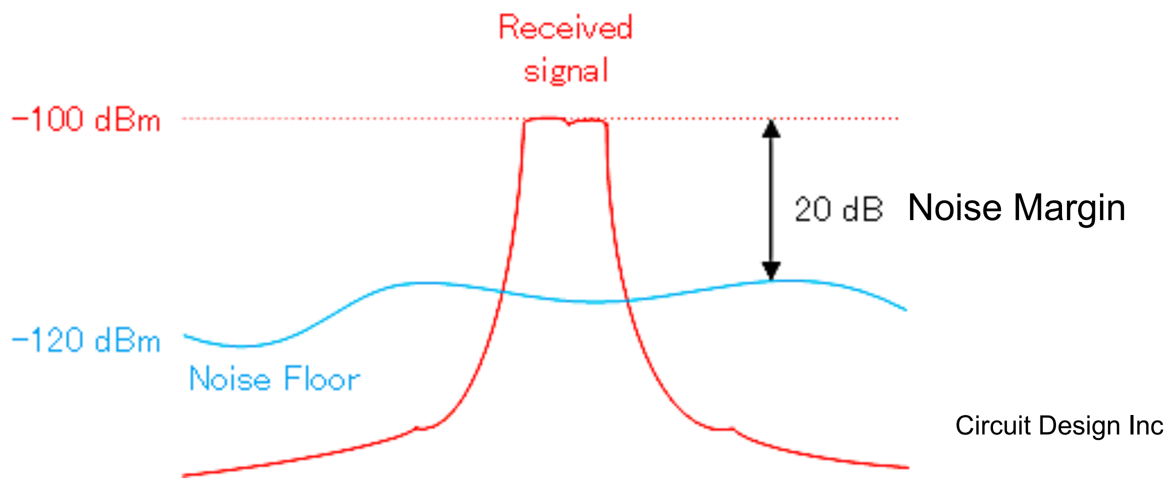
Background Noise and Interference



Background Noise

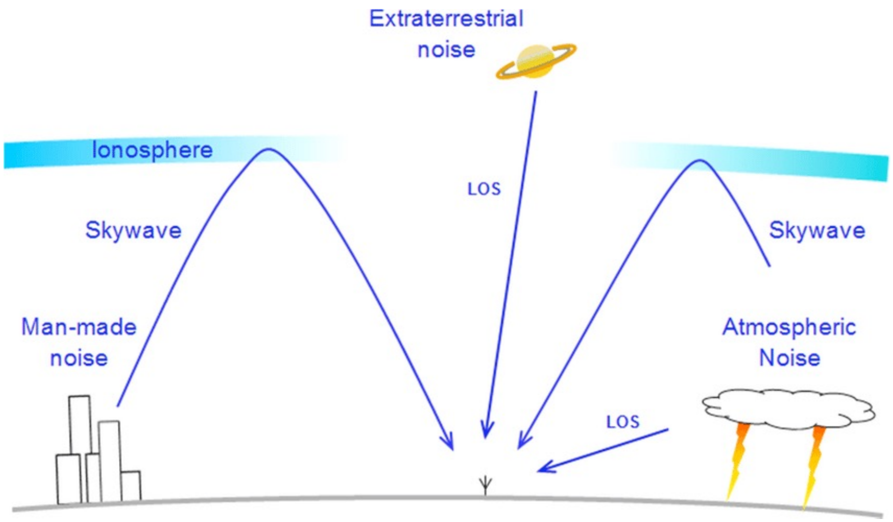


Noise Floor



- There is always a certain amount of background noise and interference associated with HF radio communications – it can not be avoided
- Signals weaker than the background noise (below the noise floor) can not be heard
- Successful HF radio communications depends on operating at power levels above the noise floor
- In addition, there must be a sufficient noise margin so that the transmitted signal does not fade below the noise level

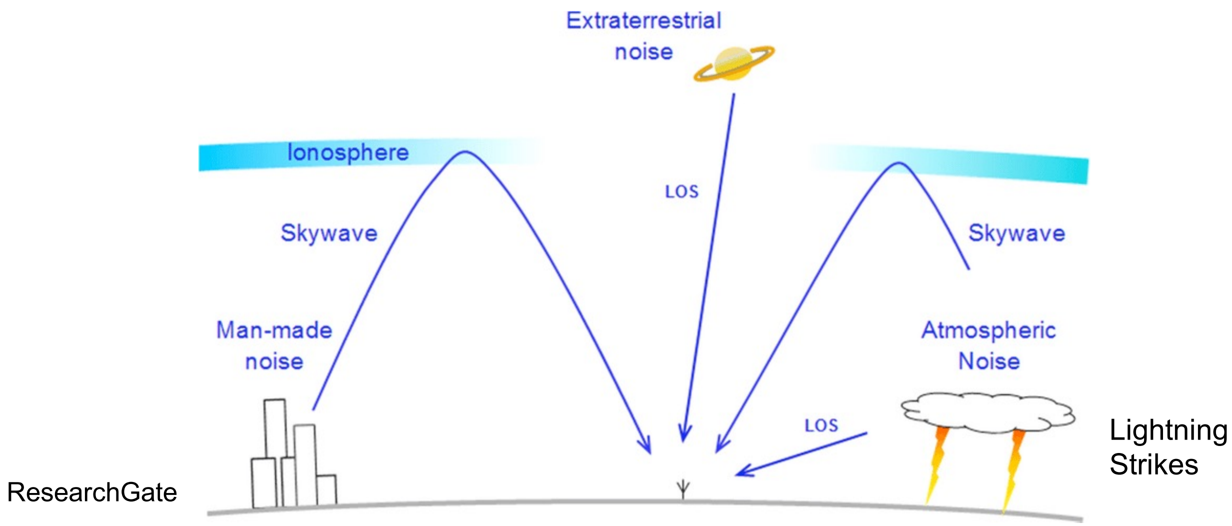
Background Noise Sources



ResearchGate

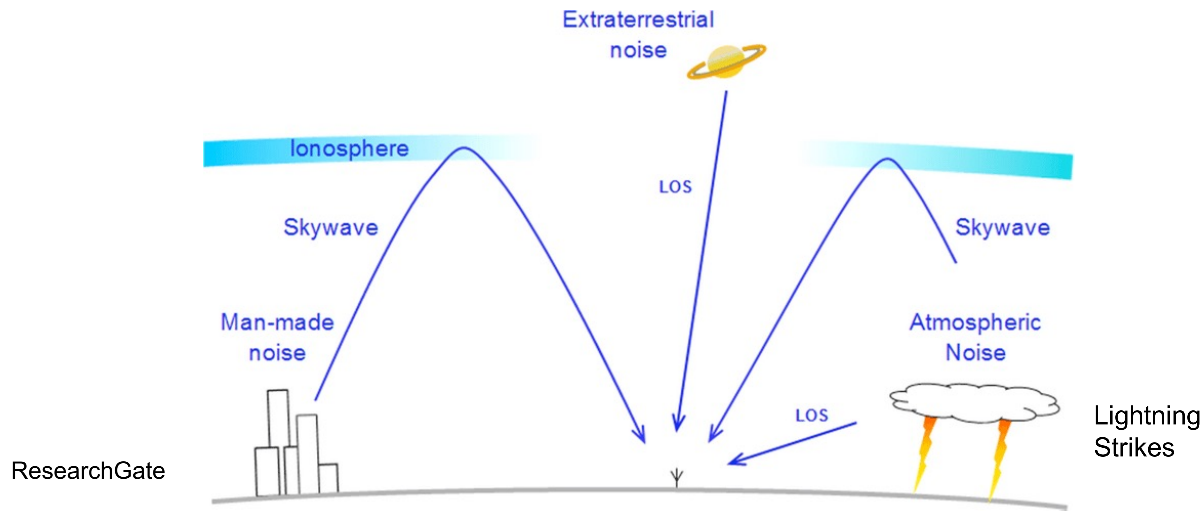
- The primary sources of background noise include:
  - Atmospheric noise,
  - Galactic Extraterrestrial noise, and
  - Man made noise

Atmospheric Noise



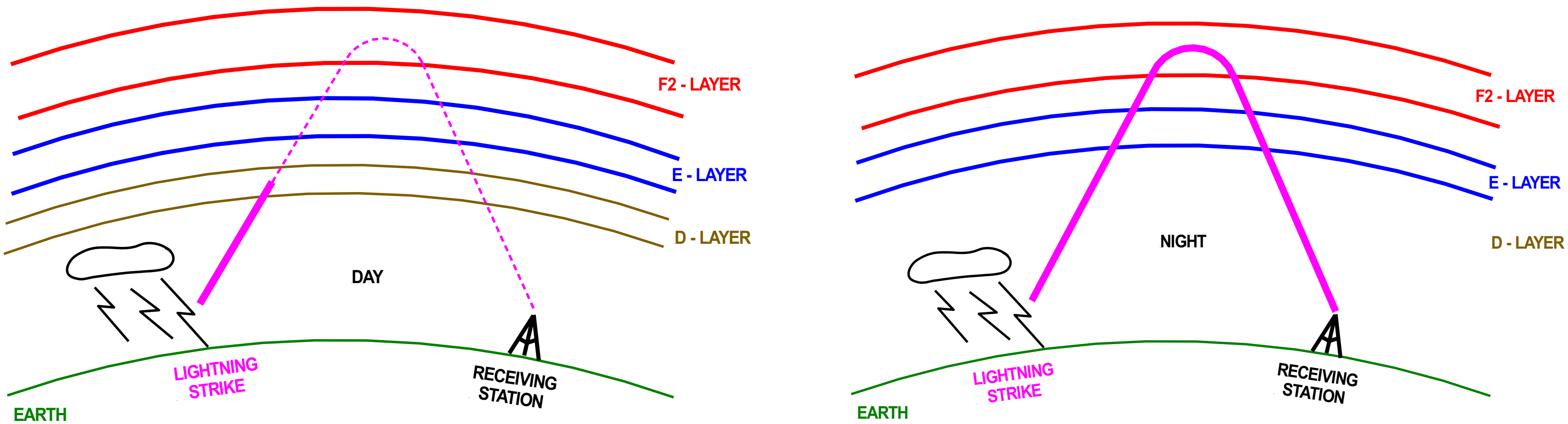
- Atmospheric noise is created primarily by local and distant lightning strikes
- A single lightning stroke emits hundreds of megawatts of radio frequency energy over a very broad range of frequencies from medium frequency (MF) through the HF bands
- Radio waves emitted by lightning travel via skywave propagation throughout the world just like the radio waves from HF transmitters

Local Lightning Strikes



- In addition, RF energy from local lightning strikes can travel by line of sight (LOS) directly to your radio receiver
- Often with sufficient energy to destroy your receiver's front end
- It is imperative that you disconnect your antennas from your radio equipment during a lightning storm

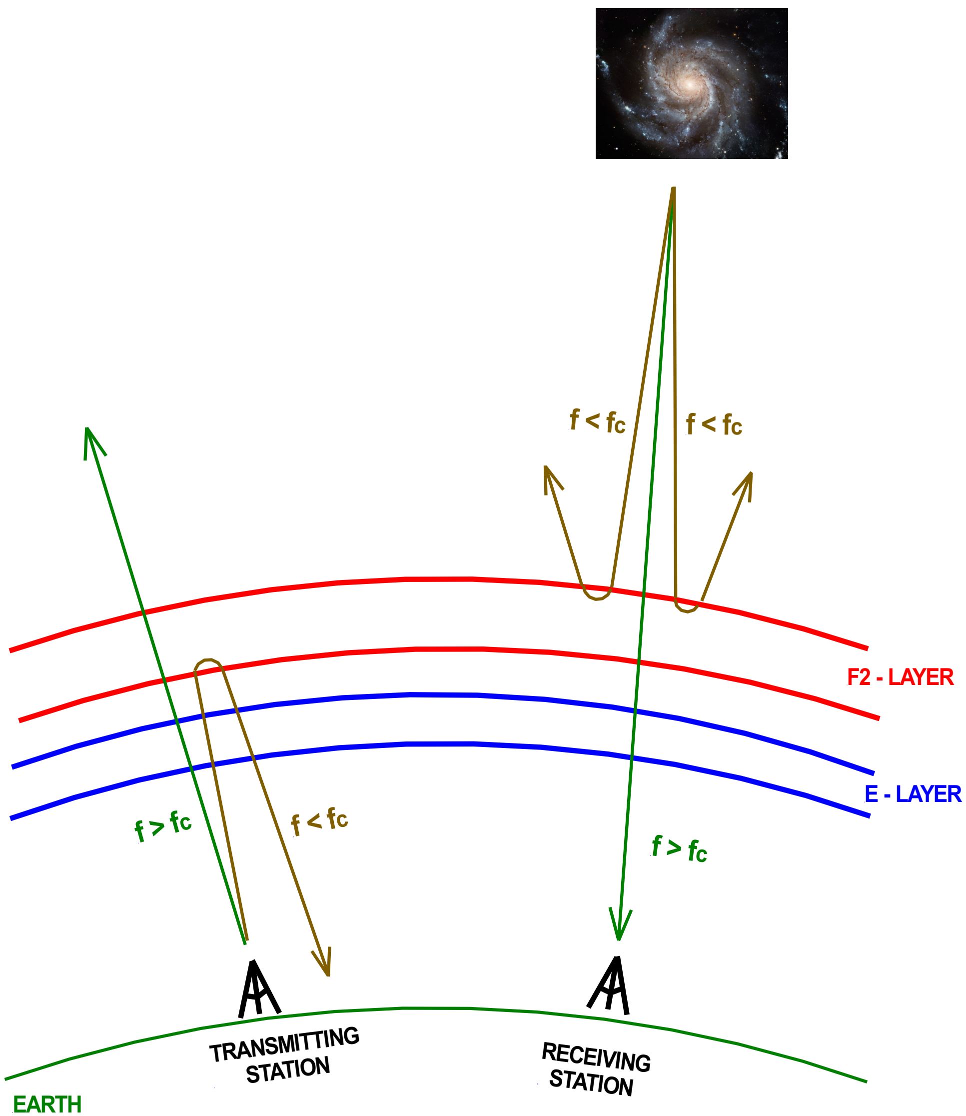
Atmospheric Noise Day vs Night



Author

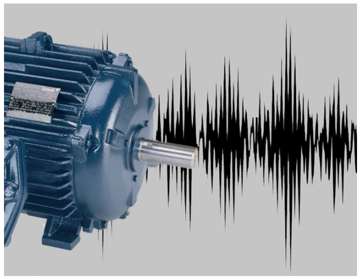
- Atmospheric noise (lightning strikes, etc.) are partially absorbed in the D region of the ionosphere during the day resulting in less atmospheric noise
- At night, the protection afforded by the D layer is gone, causing atmospheric noise to increase
- In addition, atmospheric noise is greatest in the summer when there are more thunderstorms and at low latitudes which incur the greatest number of thunderstorms

Galactic Noise



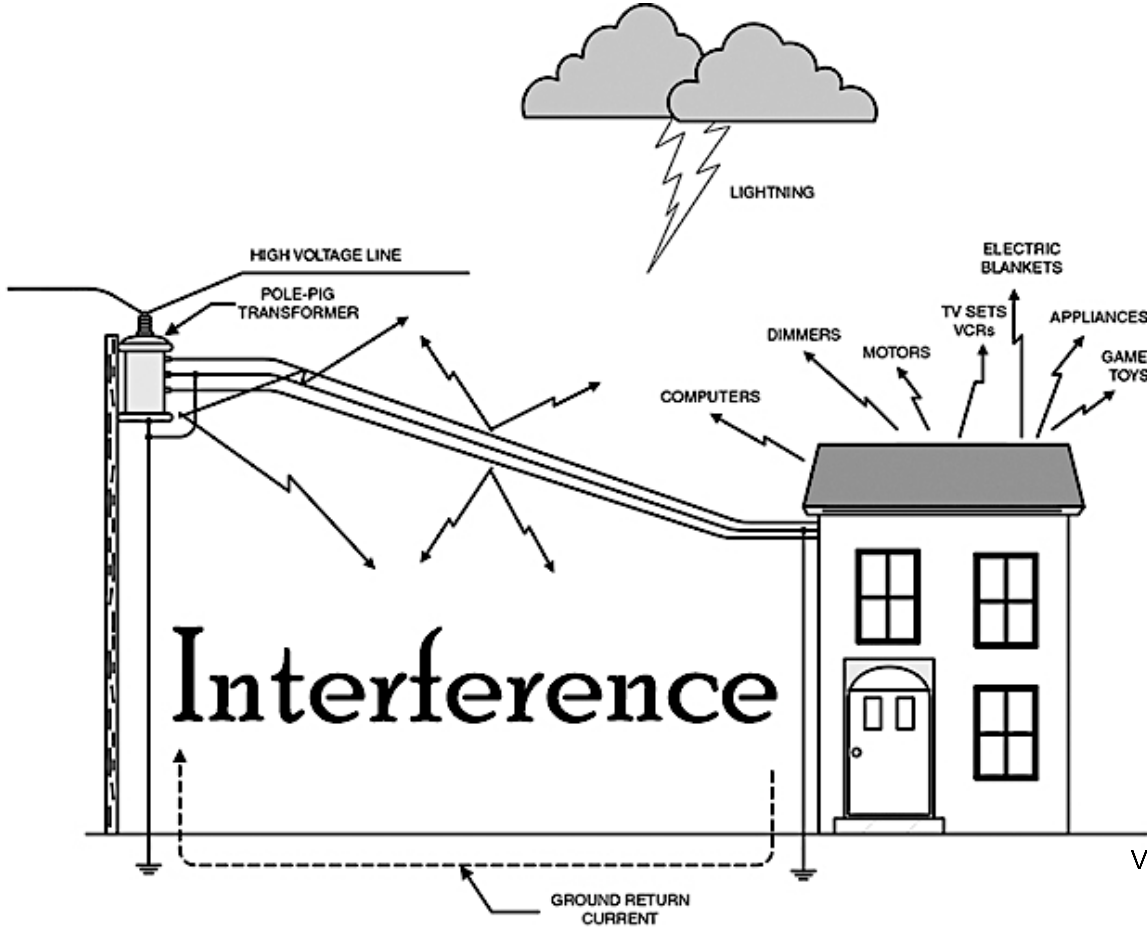
- Galactic noise is the result of radio emissions within our galaxy
- We are affected by galactic noise only at frequencies above the F2 critical frequency
- Lower frequency galactic noise can not penetrate the ionosphere
- Instead, it is refracted back into outer space
- Galactic noise that does make it through the ionosphere is generally not as important as atmospheric noise, except in remote areas far from urban centers where it can be detected at frequencies above 10 MHz

Man Made Noise & Interference



Power Transmission World

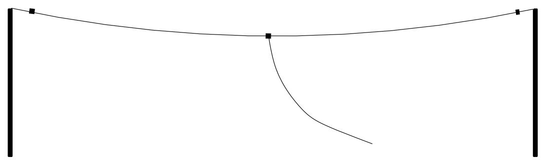
Autoguide.com

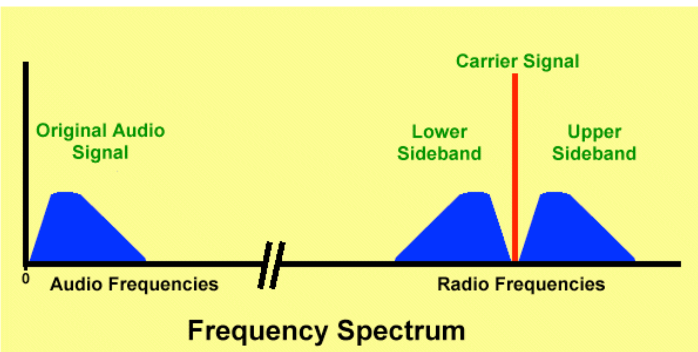


VU2EXO

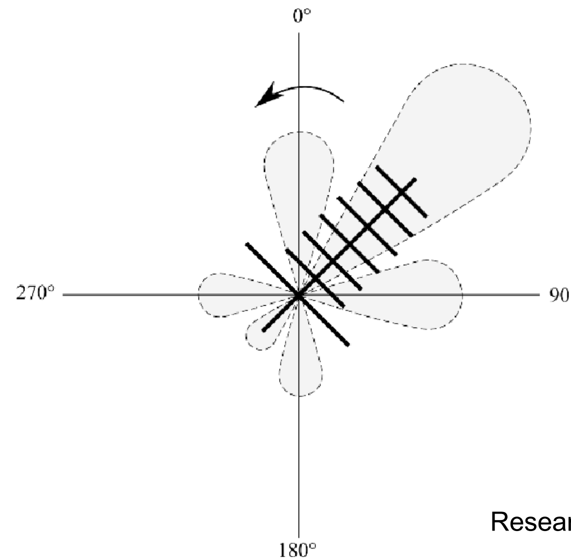
- Man made noise and interference is created by power distribution systems, welding equipment, electric motors, vehicle ignitions, home appliances etc.
- Man made noise in urban areas can at times be greater than atmospheric and galactic noise combined seriously interfering with HF radio communications

Reducing Noise & Interference





Hawaii.edu



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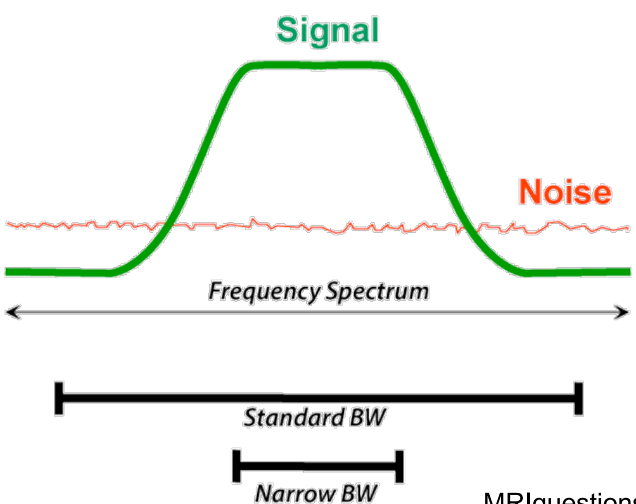
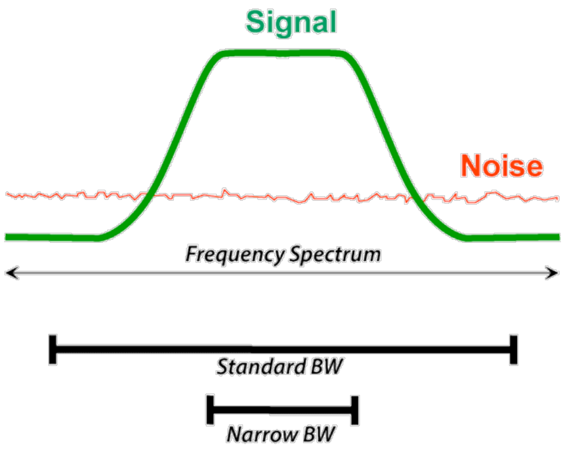


MRIquestions.com

- Noise and interference problems are reduced by
  - Minimizing receiver bandwidth,
  - Modulation and encoding techniques,
  - Horizontally polarized antennas, and
  - Directional antennas

Narrow Receiver Bandwidth



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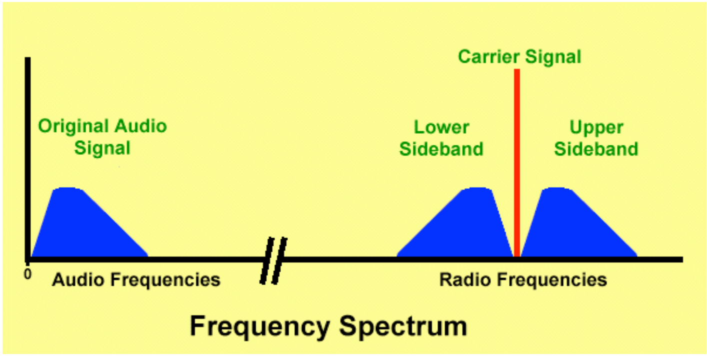
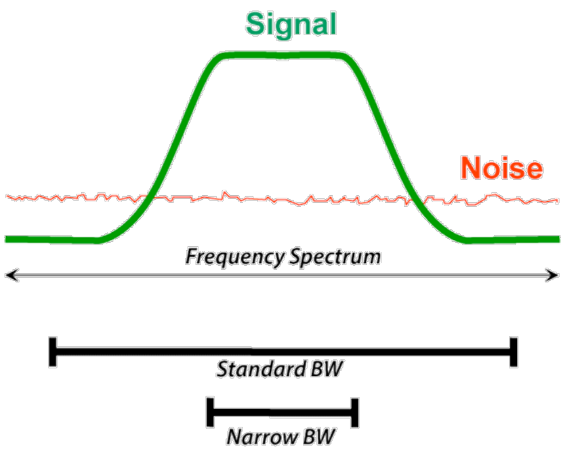


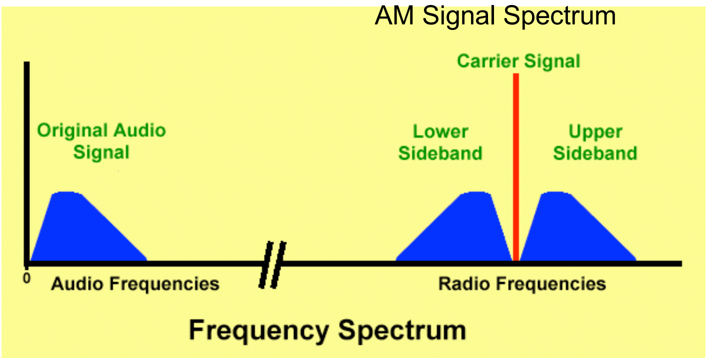
Hawaii.edu

- A wide receiver bandwidth allows more noise and interference to enter your receiver.
- Consequently, one of the most effective ways to minimize noise and interference is to operate your receiver using the narrowest bandwidth filter suitable for your mode of operation
- CW has the narrowest bandwidth of all the operating modes (AM, SSB, & Digital)

Narrow Receiver Bandwidth SSB vs AM



MRIquestions.com



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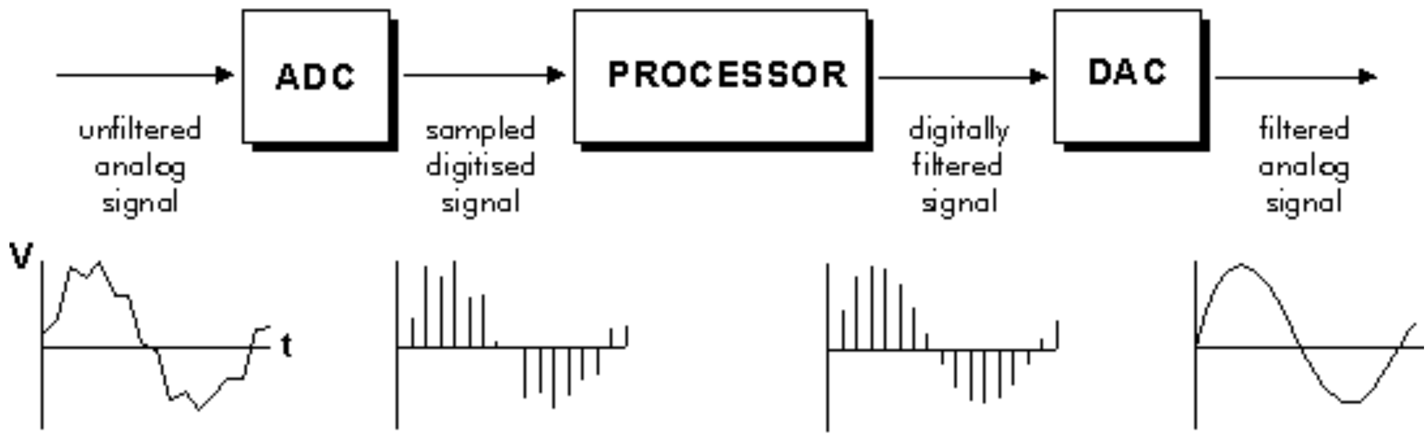
- Reducing receiver bandwidth was one of the motivations for switching from Amplitude Modulation (AM) to single Side Band (SSB)
- The receiver bandwidth required to receive a SSB signal (the upper sideband, or the lower sideband) is half that required for AM

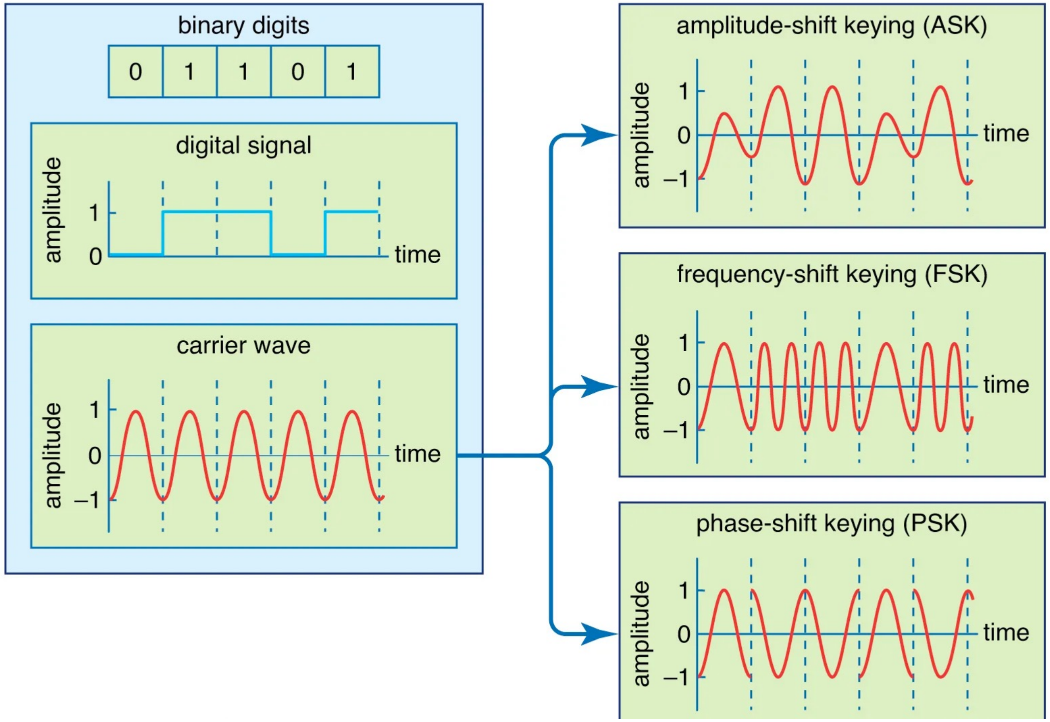
Digital Signal Processing



cs.indiana.edu

- Most modern day receivers incorporate digital signal processing (DSP) circuitry
- DSP allows the receiver's bandwidth to be varied and shifted beyond that allowed by the receiver's crystal filters alone
- In addition, DSP circuitry improves reception and receiver performance by
  - Notch filtering which takes out close-by carriers,
  - Noise blanking which eliminates ignition and other spark noise,
  - Noise reduction circuitry which reduces atmospheric, galactic, and some man made noise

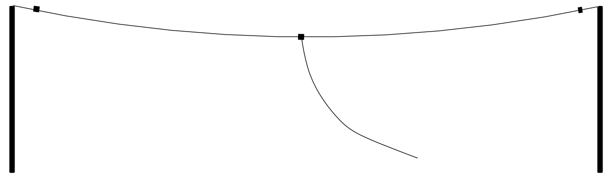
Digital Signal Encoding

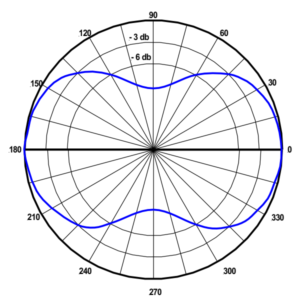


Encyclopaedia Britannica

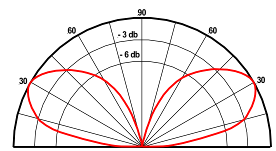
- Signal encoding and digital signal processing techniques that allow signals to be pulled out of the background noise are very effective
- Early digital transmission modes, including radio teletype (RTTY), were very susceptible to frequency selective fading and noise
- Modern modulation and signal encoding techniques take into account selective fading and noise problems resulting in very robust digital communication modes

Antenna Design

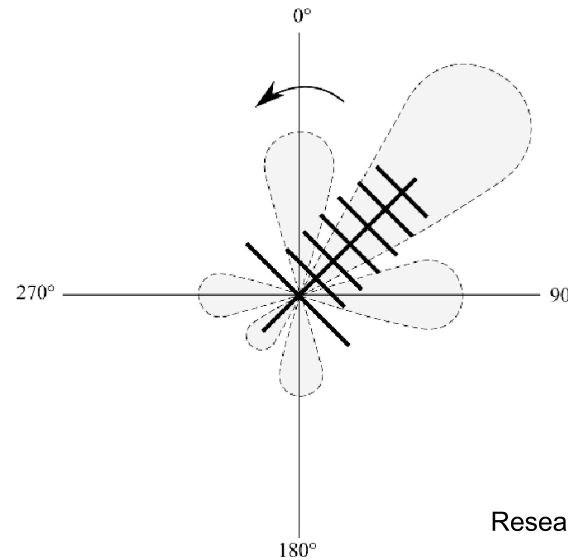




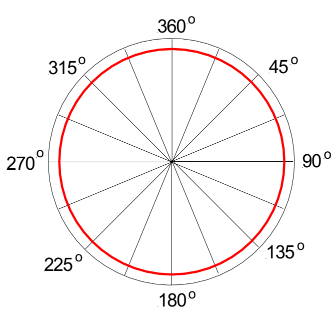
1/2 Wave Dipole Horizontal Pattern



1/2 Wave Dipole Vertical Pattern



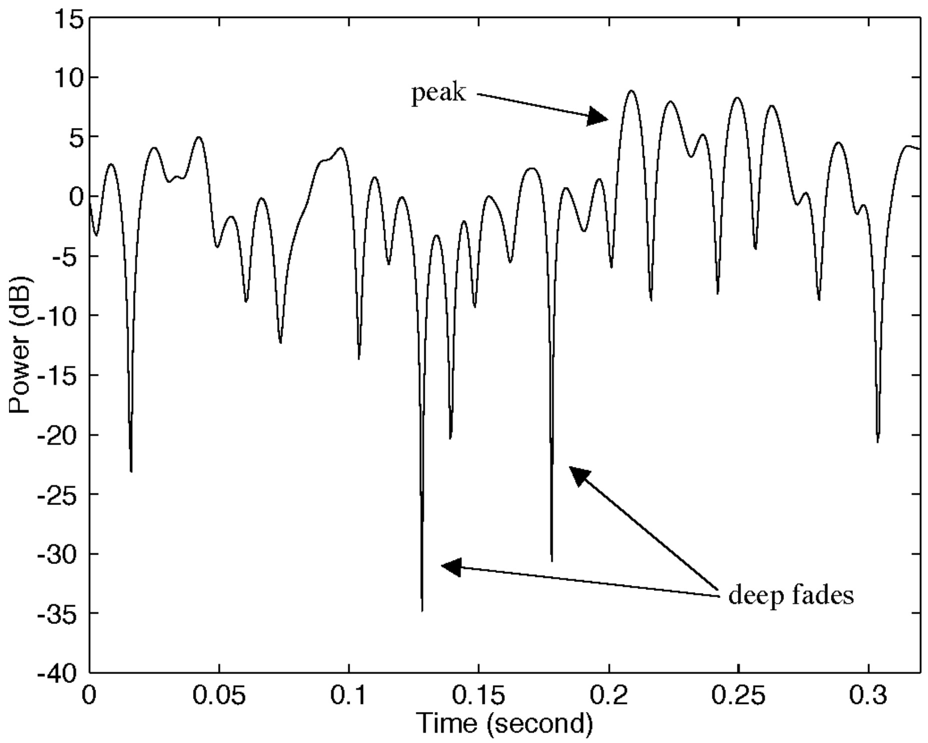
ResearchGate



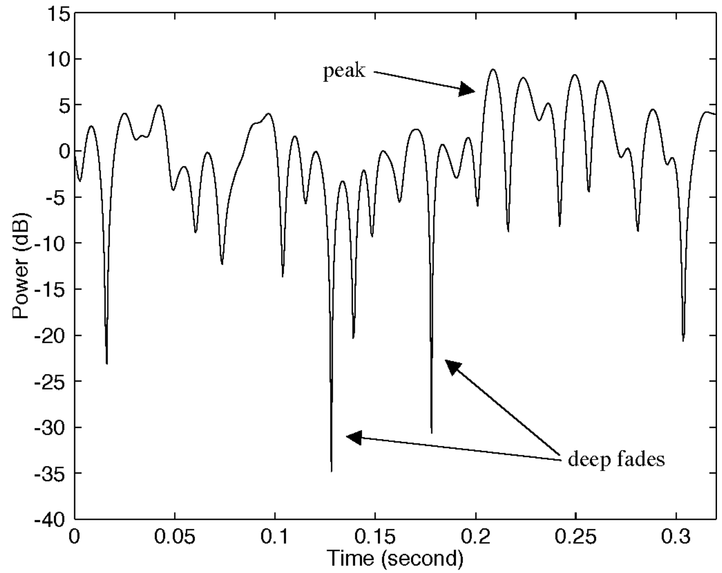
Horizontal Radiation Pattern
Vertical Antenna

- Horizontal antennas tend to be lower noise antennas than verticals because most man made noise is vertically polarized
- Directional antennas reduces noise, including atmospheric noise, by attenuating signals coming in from the back of the antenna
- Horizontal antenna’s attenuate some noise, particular man made noise
- Vertical antenna’s do not attenuate any noise

Signal Fading



Signal Fading



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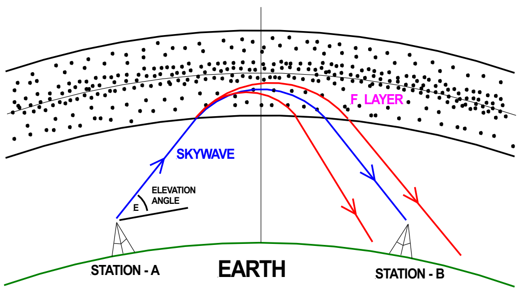
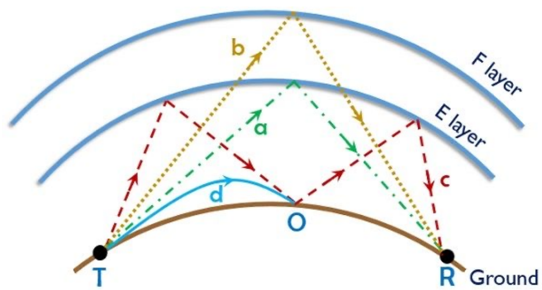
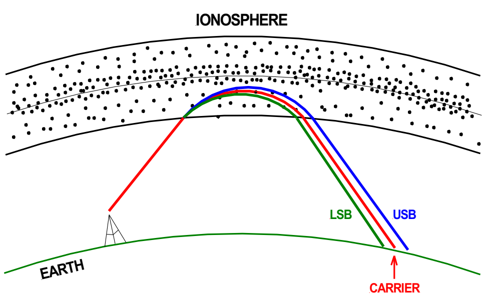
- Signal fading is what makes skywave communications difficult
- We can generally receive a steady signal, even if the signal is weak
- But a signal that repeatedly peaks, fades below the noise level, reappears, and fades again is difficult to deal with
- Fades vary in depth from shallow, only a db or so, to deep, fading more than 40 db
- The duration of fades also varies from short, a fraction of a second, to long lasting fades several hours long

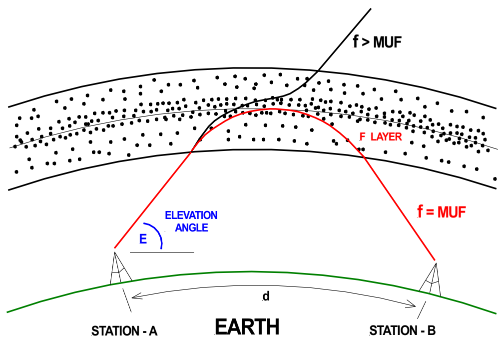
Seven Types of Fading

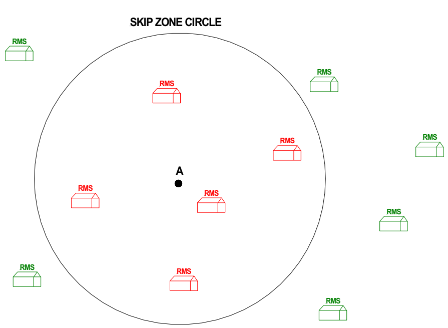


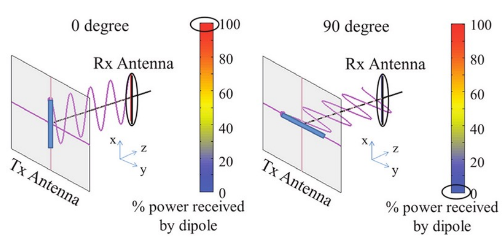


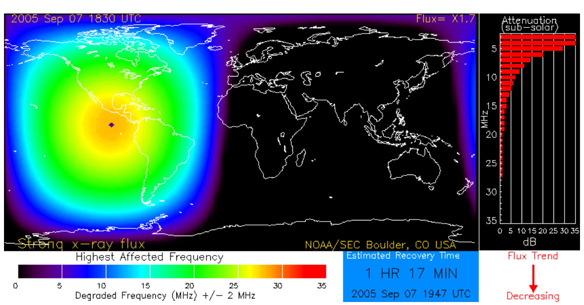
- Ionospheric Path Fading
- Interference Fading,
- Frequency Selective, Fading,
- MUF Fading,
- Skip Fading,
- Polarization Fading,
- Absorption Fading









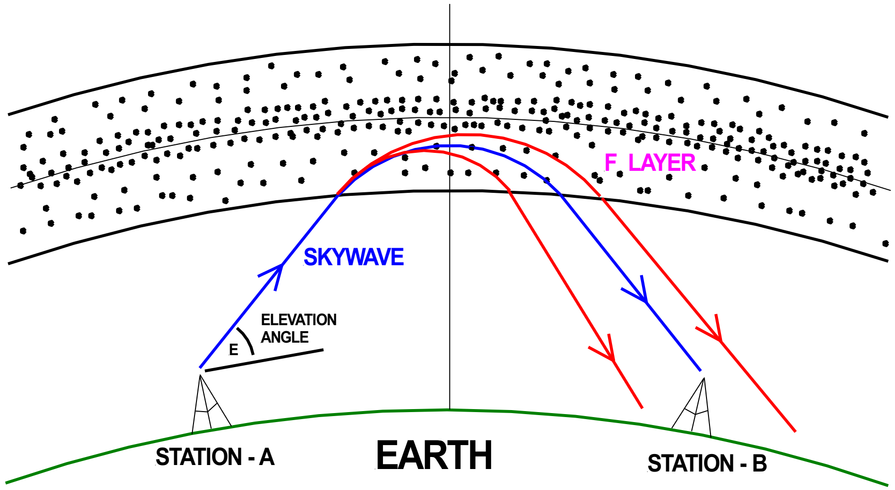


Ionospheric Path Fading

Wikipedia

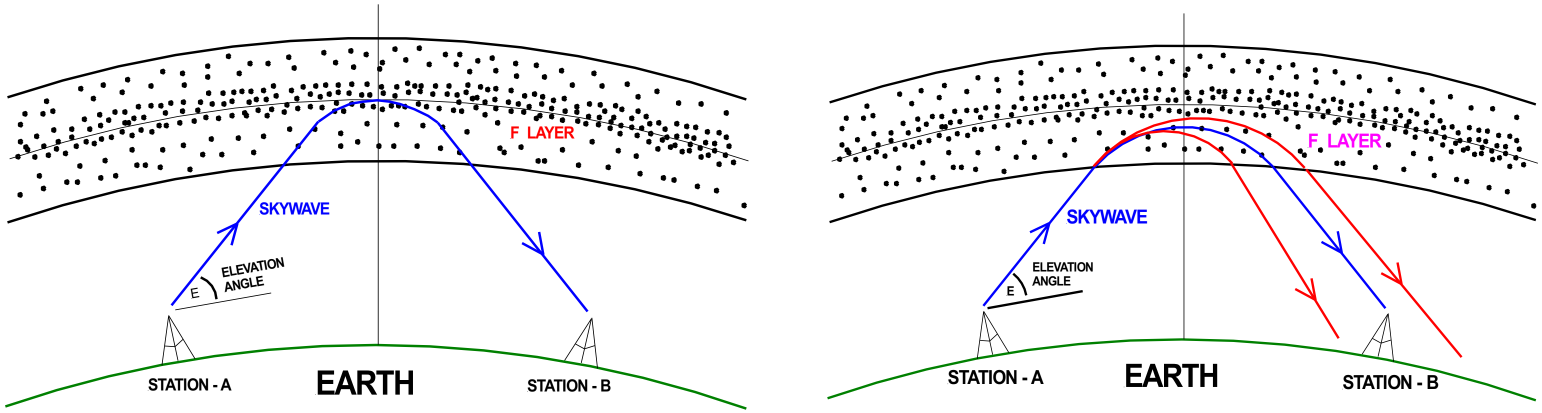
- We tend to think of the ionosphere as a smooth flat surface that reflects our radio waves much like the reflections from a perfectly smooth lake
- But the ionosphere is not a smooth flat surface
- It is wispy
- It tends to drift around, wobble, and wrinkle
- In addition, the electron densities of its D, E, and F regions are constantly changing altering signal propagation characteristics

Path Fading continued



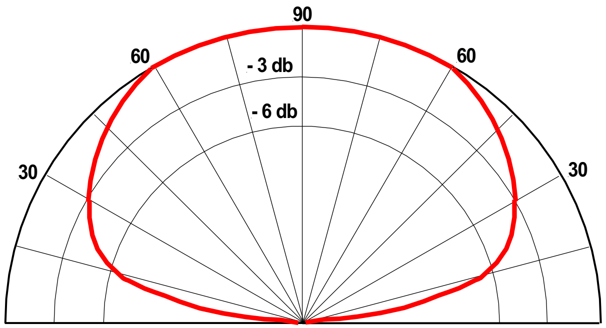
- Consequently, the path followed by a signal through the ionosphere is constantly changing
- A signal that arrives at the **intended destination** one moment ends up some place else the next moment
- Causing the signal at the receiving site to fade in and out

Not A Laser Beam

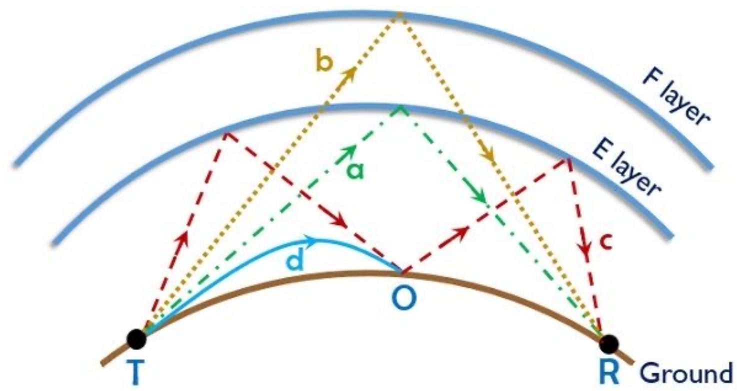


- We tend to think of our transmitted radio signal as being a very narrow laser like beam of radio frequency (RF) energy that travels from the transmitter to the receiver
- However, this is NOT the case
- In fact, skywave communications would be impossible if our signal really was a laser like beam of energy since
- The turbulent ionosphere constantly alters the path followed by a single ray of energy

Flooding The Ionosphere

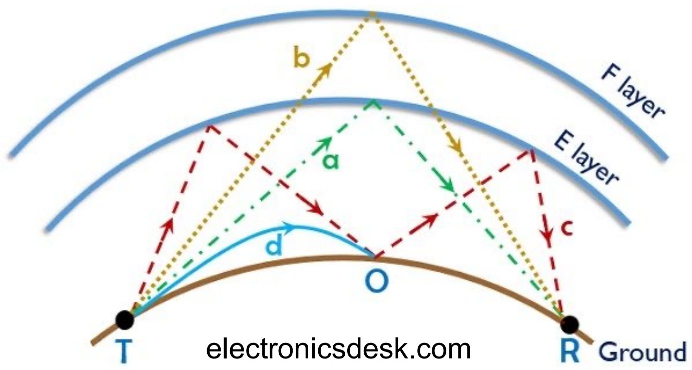


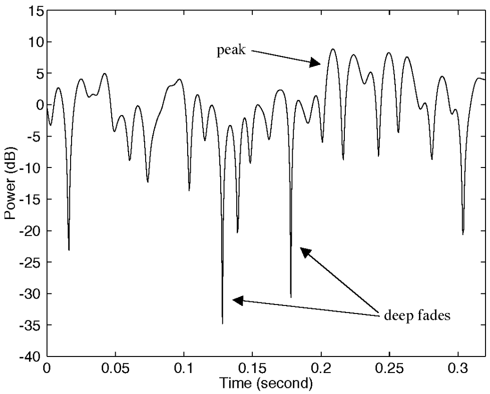
NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground



- Successful skywave communications occurs only because we flood the ionosphere with RF energy, hoping that at least a small part of that energy will end up at the intended destination
- Our rather crude antennas are what flood the ionosphere with RF energy, illuminating large sections of the sky
- The antenna above illuminates most of the sky, particularly at elevation angles above
- 30^{o}
- While flooding the ionosphere makes skywave communications possible, it also causes interference fading problems

Interference Fading

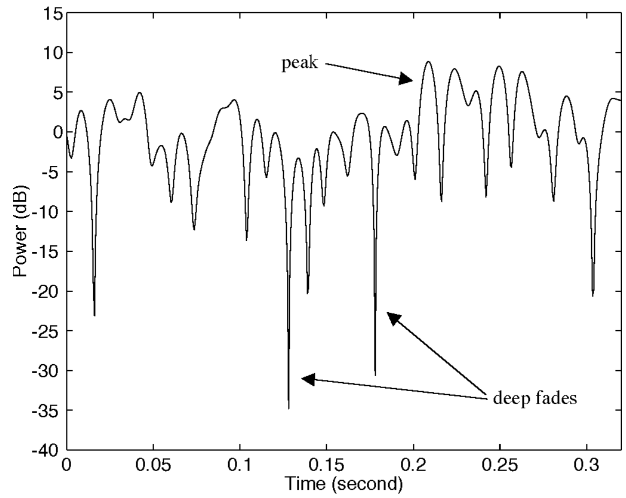




Ericsson Inc.

- Interference fading is caused by signals radiating from the transmitting antenna over a broad range of elevation angles
- The wide swath of radiation travels to a receiving station over many different paths of continuously varying lengths
- What is actually received at a distant location is not a single signal but a multitude of signals, originating from the same transmitter, but arriving via different paths with different amplitudes and phase angles
- These signals interfere with each other both constructively, creating signal peaks, and destructively creating deep fades, perhaps even complete momentary loss of signal

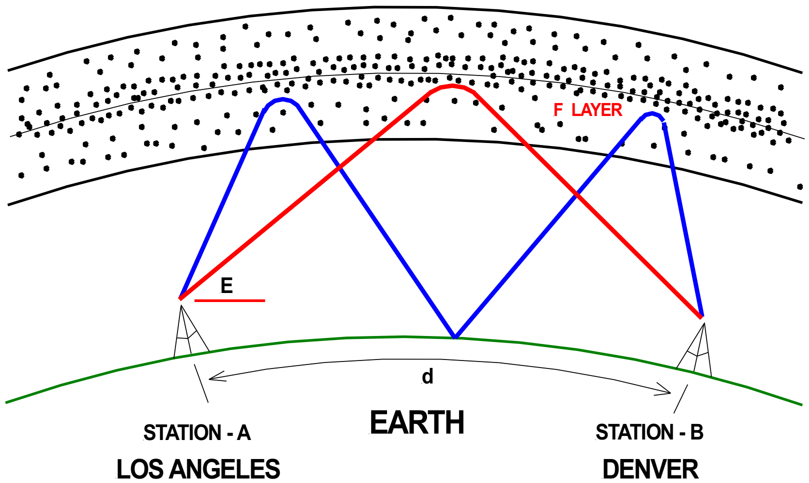
Automatic Gain Control (AGC)



Ericsson Inc.

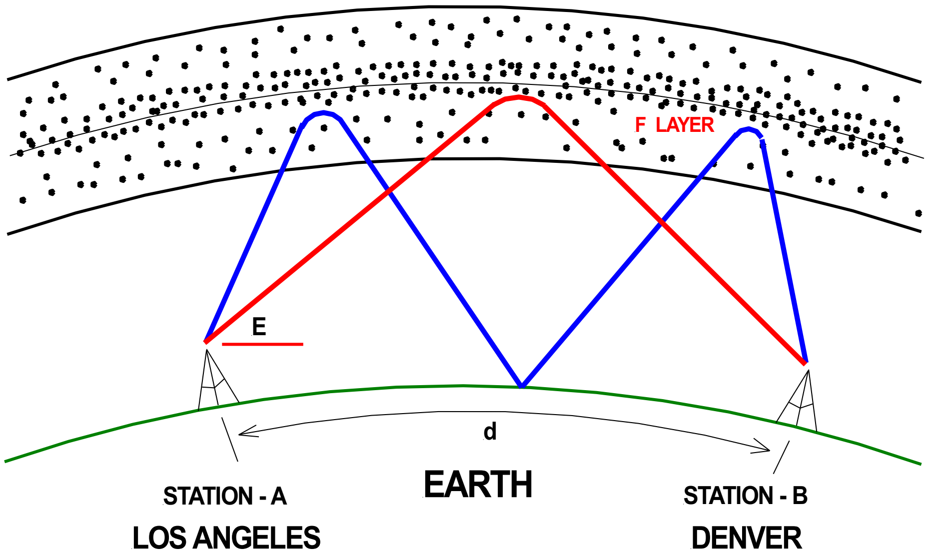
- Receiver Automatic Gain Control (AGC) was invented in part to deal with ionospheric and interference fading
- An AGC circuit detects the strength of the received signal and automatically adjusts the receiver gain to maintain the receiver's audio output within an acceptable range
- The effects of deep fading can be substantially reduced if the AGC attack and recovery times are closely matched to ionospheric and interference fading characteristics

F Layer Multipath Fading



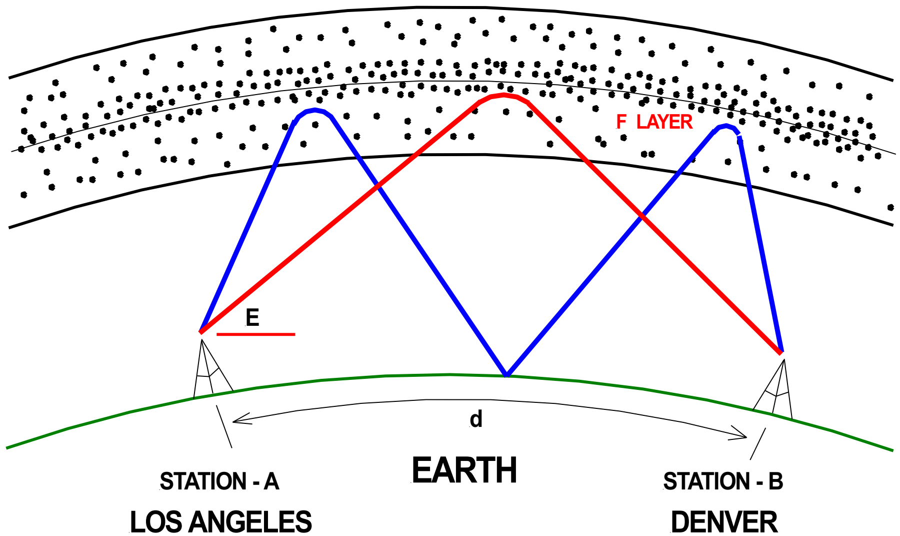
- Multipath fading will likely occur on radio circuits in which single and double hop paths simultaneously exist between the transmitting and receiving sites
- Signals arriving via the two paths will most likely be out of phase when they reach the receiving site since the double hop (blue) signal has to travel a longer distance
- The out of phase signals will interfere seriously weakening and distorting the received signal

F Layer Multi-path Fading continued



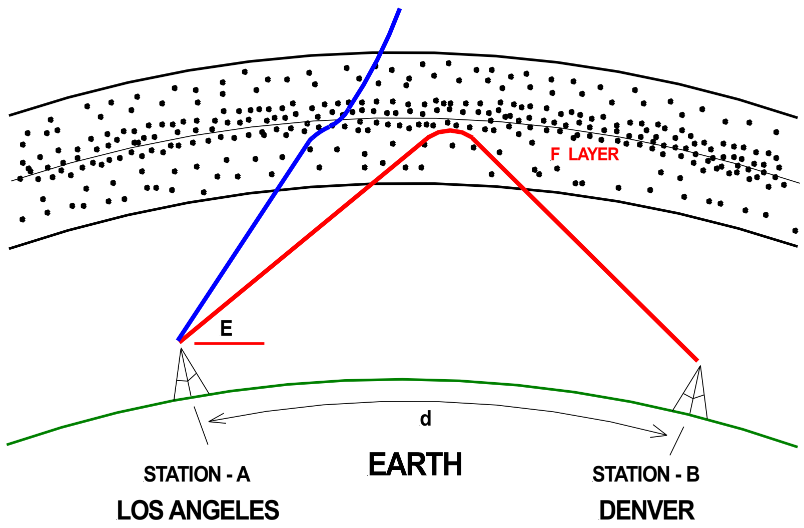
- The interference itself is generally not a problem if the phase difference between the two signals remains constant
- If that is the case, the received signal will remain at a constant level
- A constant signal strength, even a weak one, is relatively easy to copy
- However, the phase difference between the two signals is constantly varying, since the single hop and double hop paths themselves are continuously changing

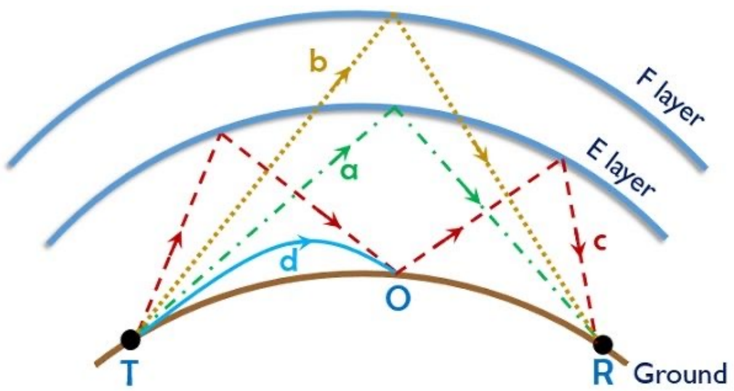
F Layer Multi-path Fading Example



- Communications between Los Angeles and Denver on 40 meters, a distance of 830 miles, often occurs by both single hop (E = 20^{o}) and double hop (E = 38^{o}) propagation
- The double hop path is much longer than the single hop path causing it to be received out of phase with the single hop signal
- Result: destructive interference between the single & double hop propagation paths can seriously weaken and distort LA to Denver communications

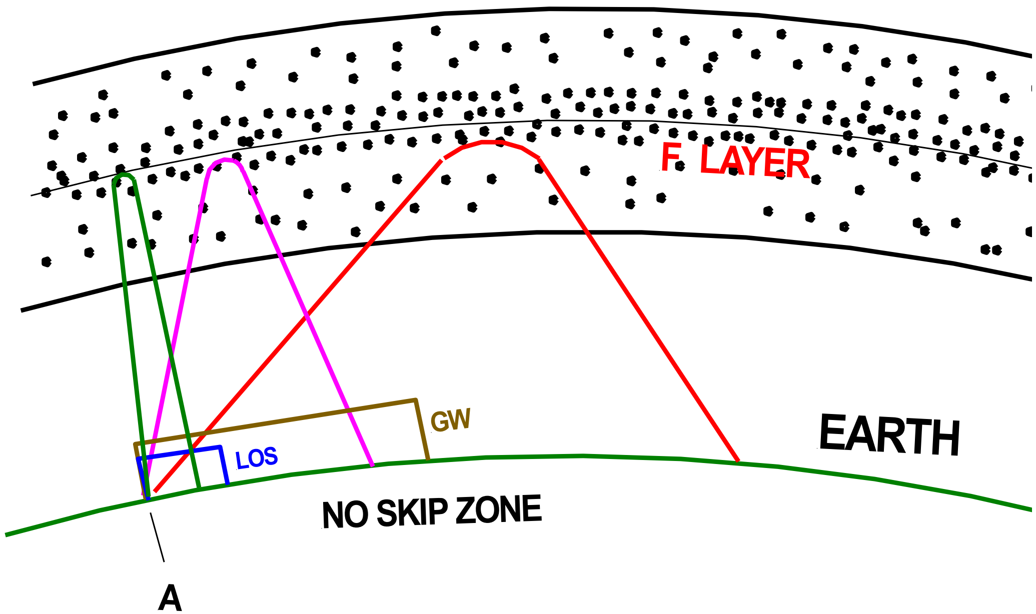
Solving F Layer Multi-path Problem





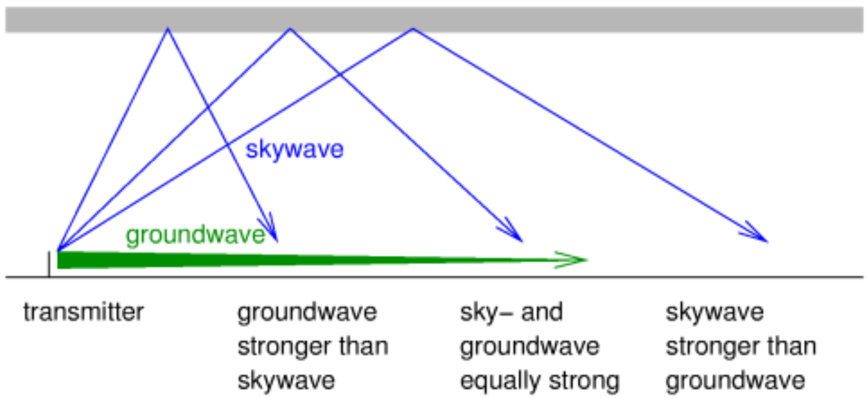
- Moving to a higher frequency (for example 20 meters) will cause the 38º double hop path to penetrate the ionosphere and disappear into outer space
- The lower angle 20º single hop path is the only path remaining eliminating multi-path interference
- Operating at the highest possible frequency, i.e. MUF often solves multi-path problems
- Operating at the MUF (path b in figure to the right) also tends to illuminate the multitude of other paths from T to R resulting from flooding the ionosphere with RF

Close-in Multipath NVIS Problem

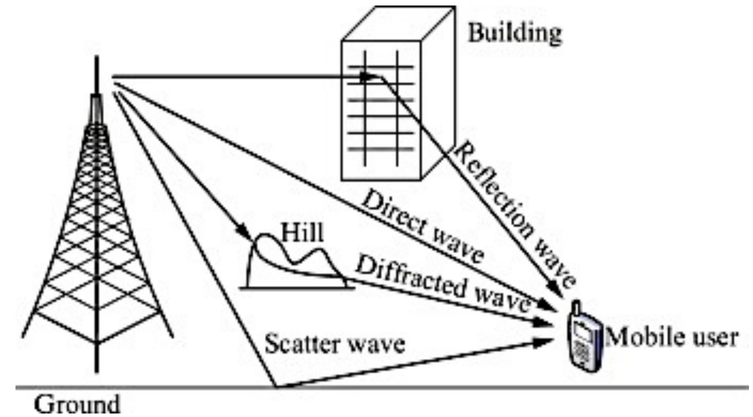


- If there is no skip, all Near Vertical Incident Skywave (NVIS) stations can be reached from the base of your antenna outward for many hundreds of miles
- However, like it or not, line-of-site (LOS) and ground wave (GW) propagation always exist from your antenna out 30 to 40 miles or so
- Consequently, 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



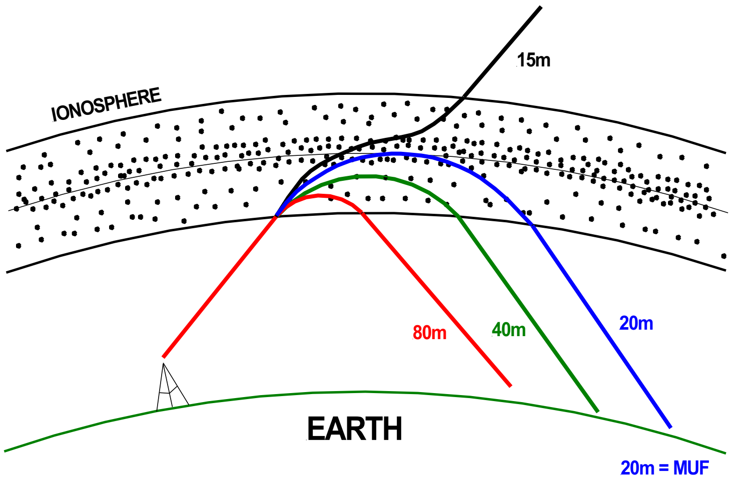
PA3FWM [*pa3fwm@amsat.org*](mailto:pa3fwm@amsat.org)



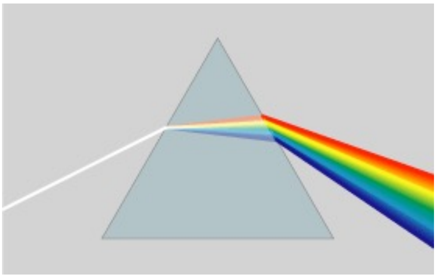
https://www.sciencedirect.com

- Multi-path interference problems between NVIS skywave and ground wave propagation is the 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 ground and skywave signals interfere with line of sight and visa versa
- All resulting in signal degradation and fading

Frequency Selective Fading



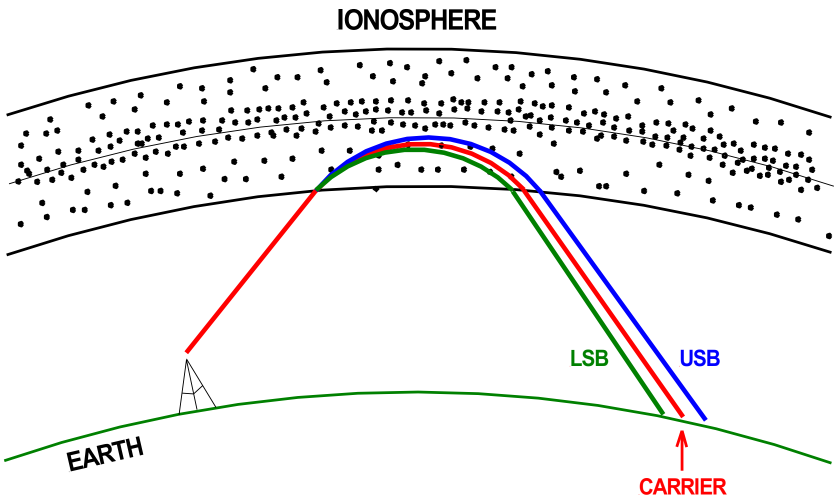
Author

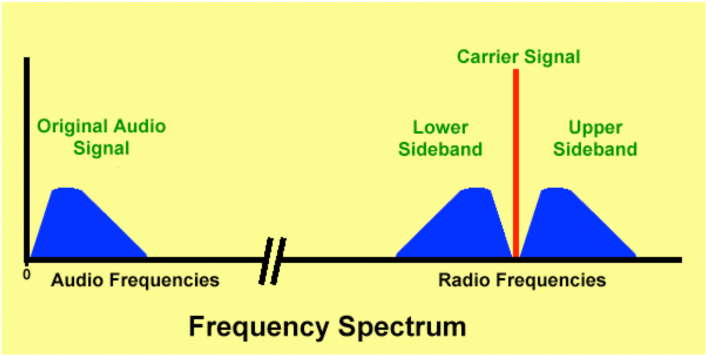


Wikipedia

- The ionosphere's index of refraction is frequency dependent
- Long wavelength signals (80 meters) are refracted back to Earth lower in the ionosphere than short wavelength (20 meters) signals
- While even shorter wavelength signals (15 meters) may penetrate the ionosphere and be lost to outer space
- That is, the ionosphere is frequency dispersive, just like sunlight through a prism
- What is not so obvious is that frequency dispersion also occurs **within** the bandwidth of a modulated signal

Frequency Selective Fading continued





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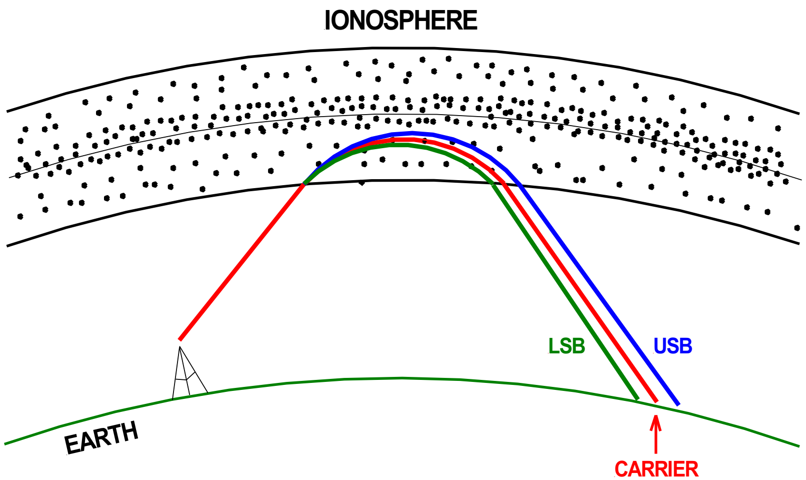
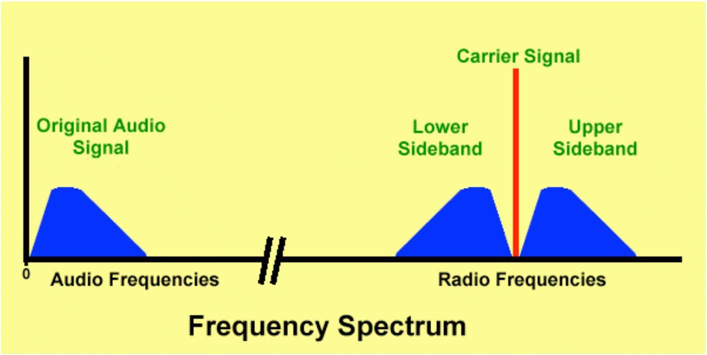
- The higher frequency (shorter wavelength) upper sideband of an amplitude modulated (AM) radio signal penetrates slightly further into the ionosphere than the lower frequency lower sideband
- The difference in penetration depth causes the upper and lower sideband signals to travel slightly different paths, resulting in them being out of phase when they reach the receiving station
- The path lengths are continuously changing due to the turbulent ionosphere
- This means that the phase difference is also constantly changing, resulting in the demodulated audio signal being distorted as well as fading in and out

Minimizing Frequency Selective Fading





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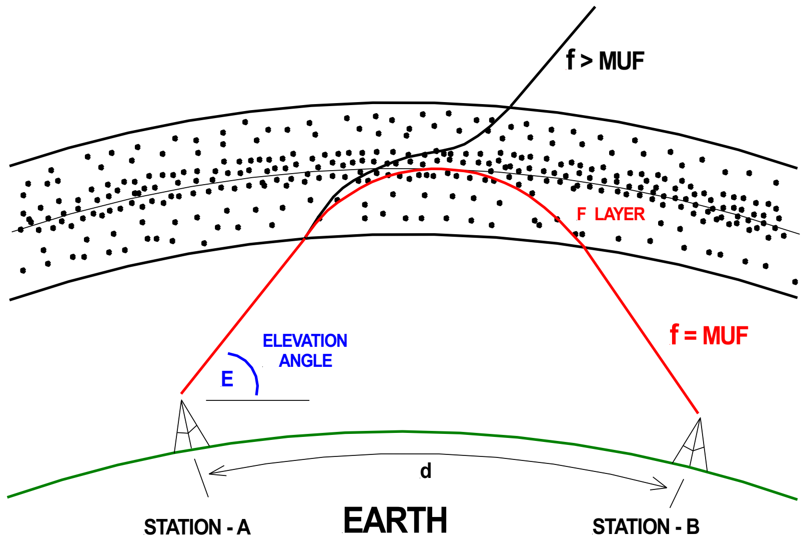
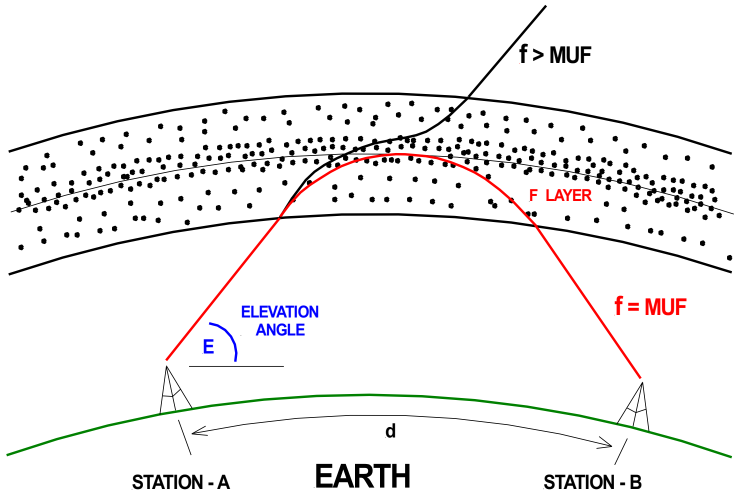
- Reducing frequency selective fading was another compelling reasons for switching from amplitude modulation (AM) to single side band (SSB), the other reasons being minimizing band crowding, plus reducing noise and interference entering a receiver
- When operating single side band, the two sidebands do not interfere since one of the sidebands has been eliminated

Maximum Usable Frequency (MUF) Fading



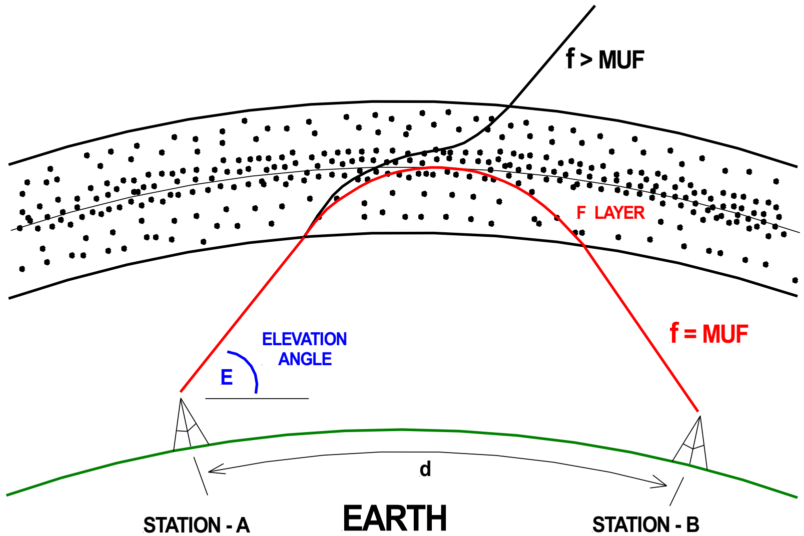
- Operating at the highest possible frequency is desirable
- Doing so results in long hops for DX work, minimizes D Layer absorption, and eliminates multipath interference
- However, operating at the maximum usable frequency (MUF) is living on the edge

MUF Fading



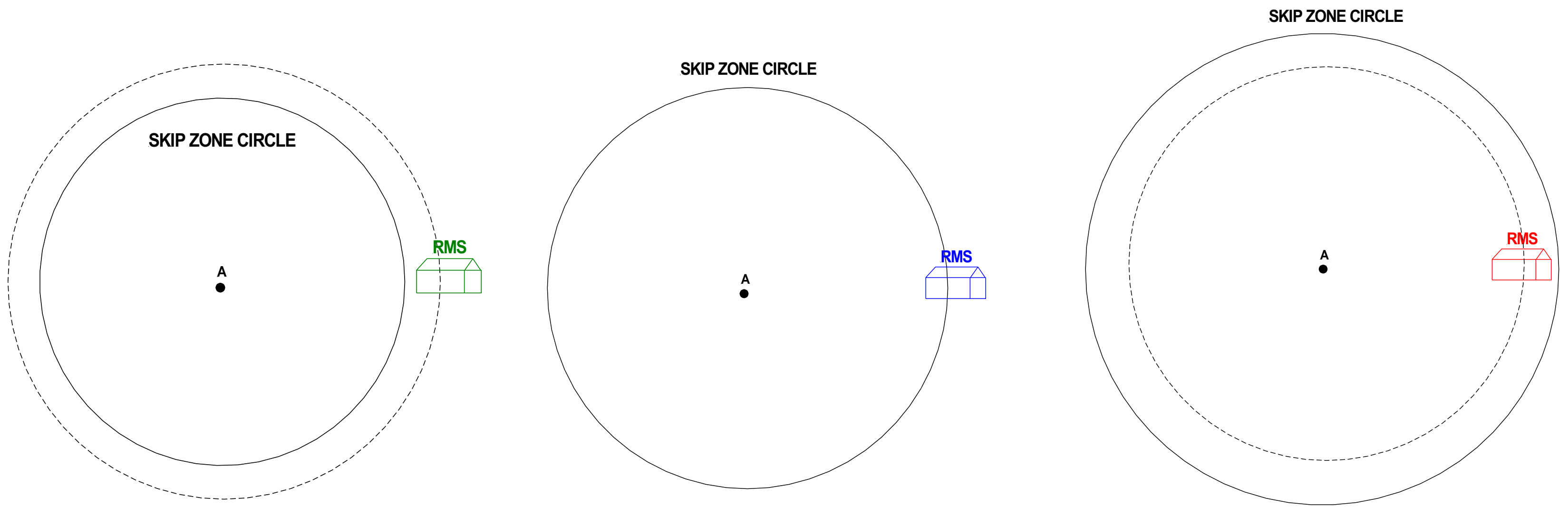
- The MUF signal from Station-A (red trace) achieves the desired long hop to Station-B
- But, if the turbulent ionosphere causes the maximum usable frequency to drop just slightly, the signal from Station-A will penetrate the ionosphere (black trace) and be lost to outer space instead of reaching Station-B
- If after a second or so the MUF returns to its original value Station-B will again hear Station-A
- What Station-B ends up hearing is the signal from Station-A fading in and out

Frequency of Optimum Transmission (FOT)



- MUF generally varies $\pm 5\ to\ 10\%$
- Operating at a frequency ~ 15% below the MUF will usually result in Station-B receiving a stable non-fading signal from Station-A
- This frequency is know as the Frequency of Optimum Transmission (FOT)

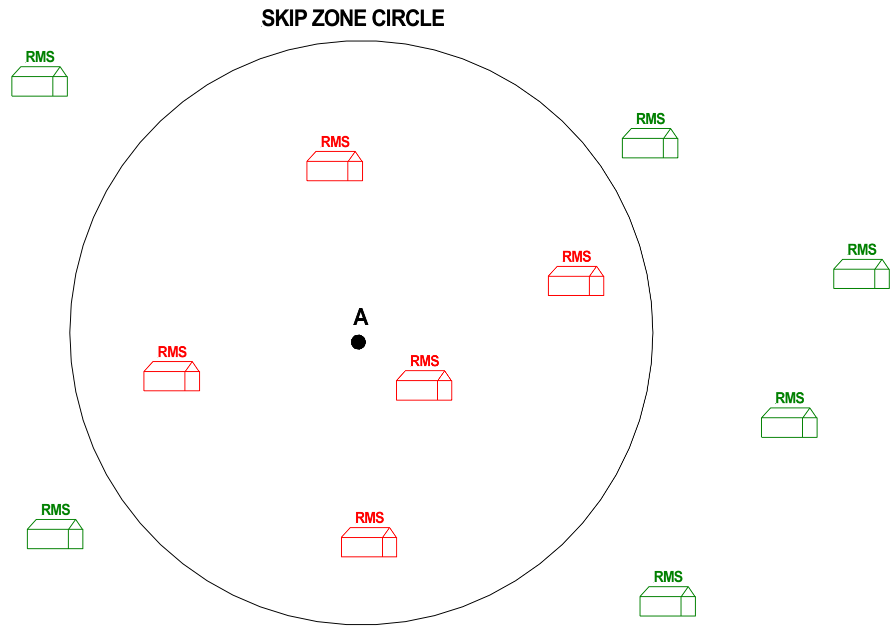
Skip Fading



Outside Skip Zone On Skip Zone Edge Inside Skip Zone

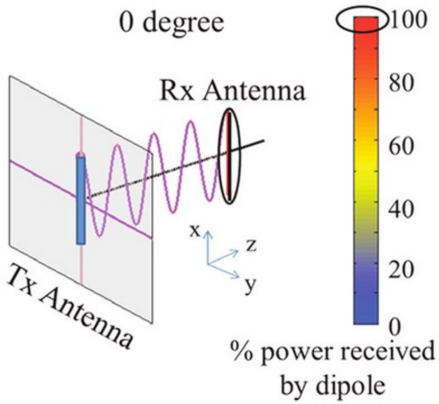
- Skip fading is encountered by a receiving station on the edge of the skip zone
- The skip zone "breaths" increasing and decreasing in size over seconds and minutes as turbulent ionospheric conditions change
- At one moment the receiving station is outside the skip zone clearly receiving Station-A
- Next moment the receiving station is inside the skip zone unable to hear Station-A
- Station-A continuously fades in and out as the skip zone expands and contracts

Avoiding Skip Fading

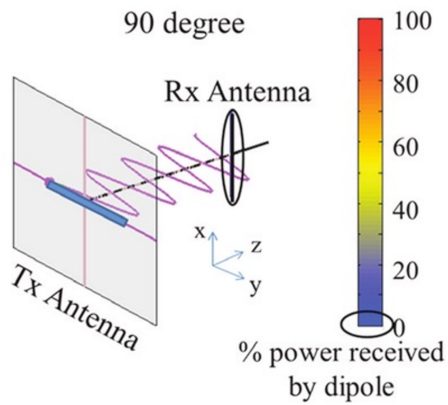


- For Winlink and other forms of HF emergency communications
- Skip fading is minimized by avoiding stations located near the skip zone circle
- Instead utilize Remote Message Server (RMS) stations well outside the skip zone to relay emergency traffic

Polarization Fading



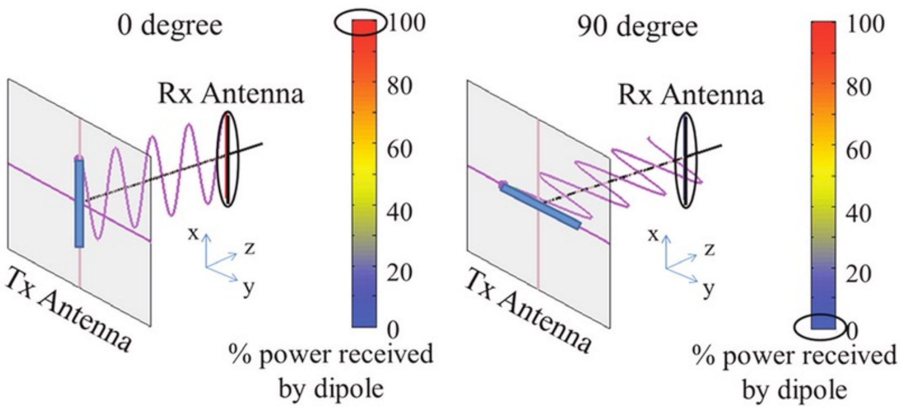
E field aligned with antenna



E field perpendicular to antenna

- Polarization fading is the result of the incoming signal orientation changing with respect to the receiving antenna due to changing path lengths and ionospheric conditions
- The strength of the received signal is maximum when the signal’s E field is aligned with the antenna
- Signal strength is minimum if the signal’s E field is perpendicular to the antenna

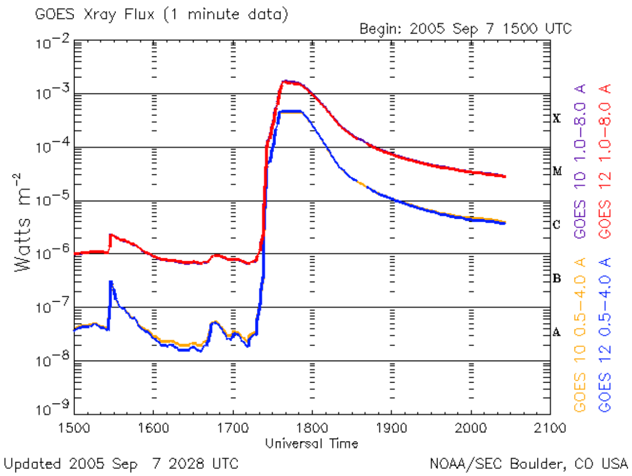
Minimizing Polarization Fading

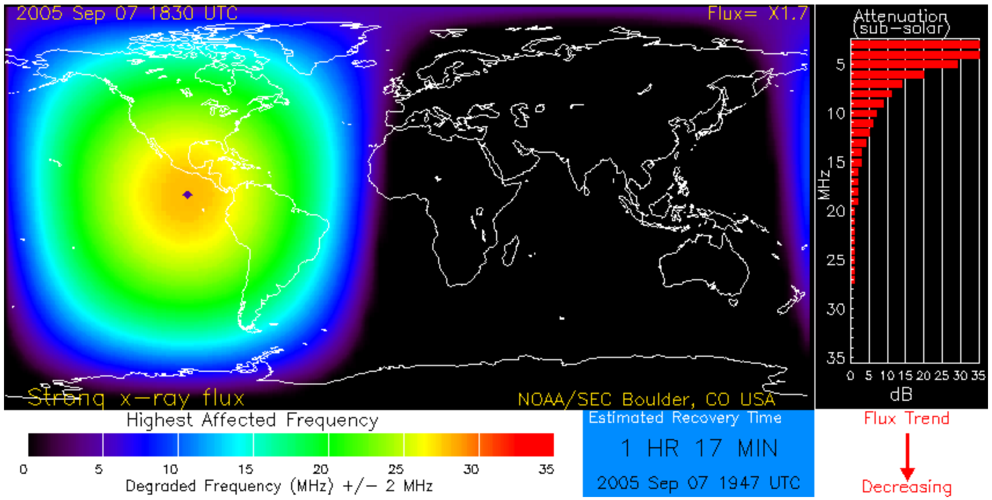


ResearchGate

- Polarization fading can be reduced by using two perpendicular receiving antennas, for example a vertical antenna and a horizontal dipole
- When an incoming signal fades on one antenna it likely peaks on the other antenna
- Many modern day HF transceivers are built with two identical receivers, a main receiver and a sub receiver, permitting diversity reception
- Diversity reception is achieved by routing the main receiver to the primary antenna and the sub receiver to an orthogonal receiving antenna
- When using earphones, instead of fading out, the received signal simply seems to “move around in your head” as signal strength peaks on one antenna and then on the other.

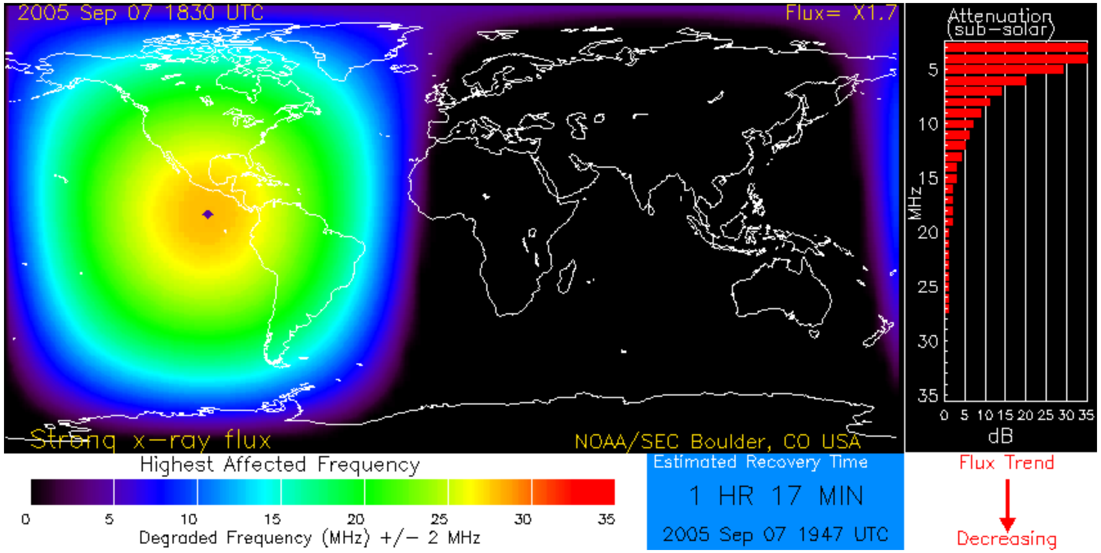
Absorption Fading





- Absorption fading is the result of continuously changing ionization levels and irregularities in the D region of the ionosphere
- An extreme example is the complete absorption of all signals from 3 to 15 MHz or more following a major solar flare
- Signals rapidly fade in & out first on 80m, then 40m, next on 20m, etc. as the flare develops quickly resulting in total loss of signal on all lower frequency bands
- Rapid in and out fading also occurs as stations move into and later out of the absorption zone as the zone drifts westward due to Earth's eastward rotation
- Fades can vary in length from a few minutes to several hours following a flare

Minimizing Absorption Fading

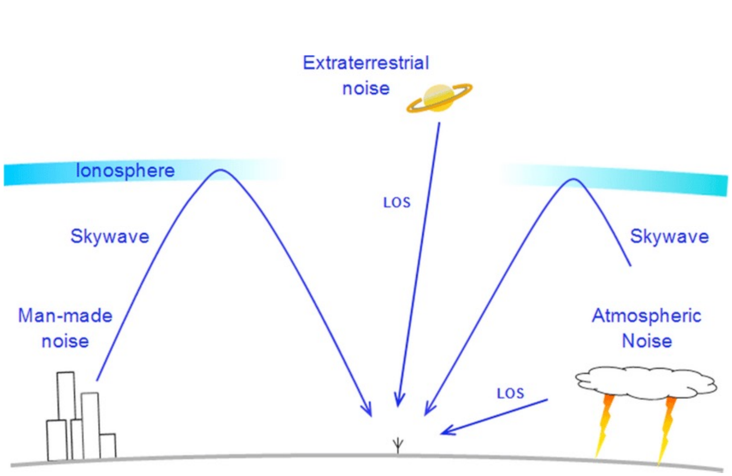


- Absorption fading is minimized by operating at the highest possible frequency,
- Typically the frequency of optimum transmission (FOT = 85% MUF),
- Since absorption is inversely proportional to frequency squared according to

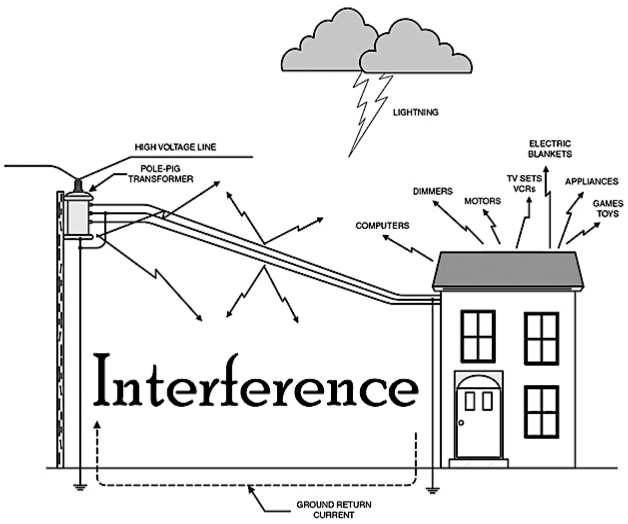
$$Absorption \propto \frac{1}{f^2}$$

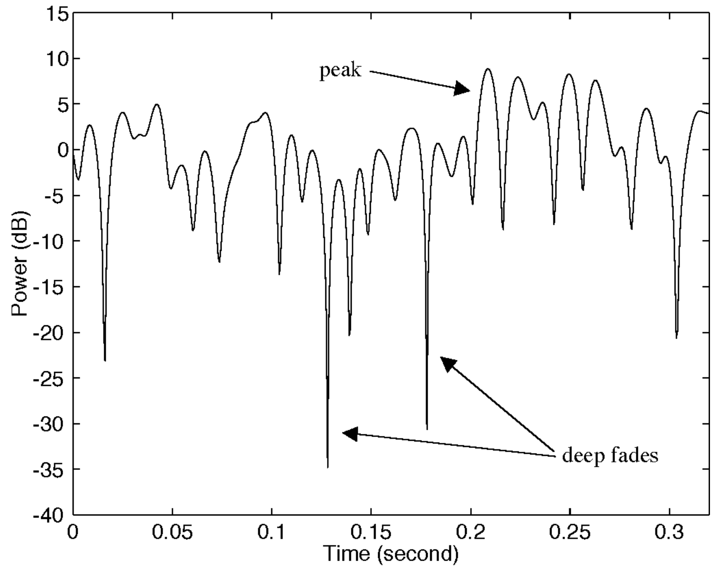
- Absorption on 20 meters is only 1/4 that on 40 meters and 1/16 th that on 80 meters

Background Noise, Interference and Fading Summary



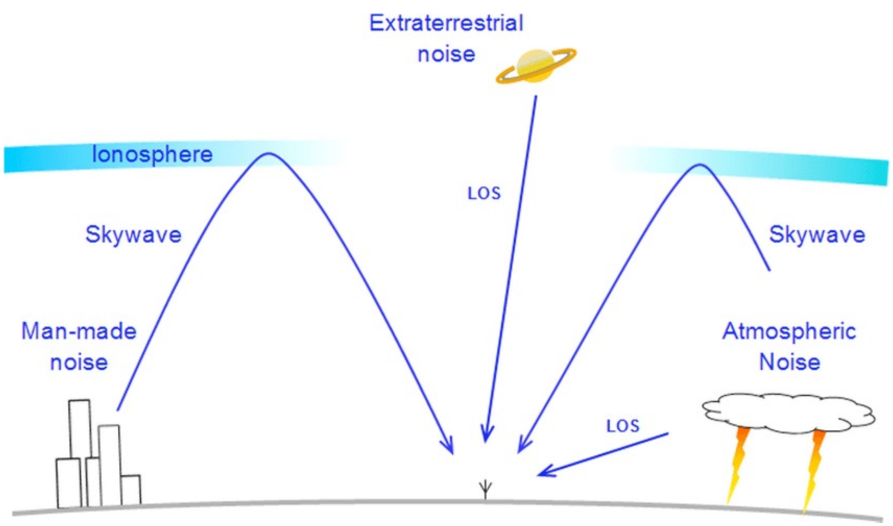
Background Noise





Signal Fading

Summary Background Noise Sources



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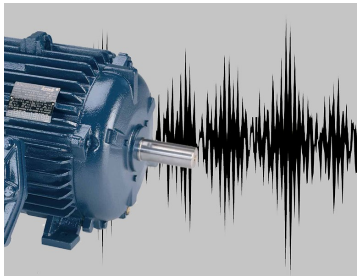
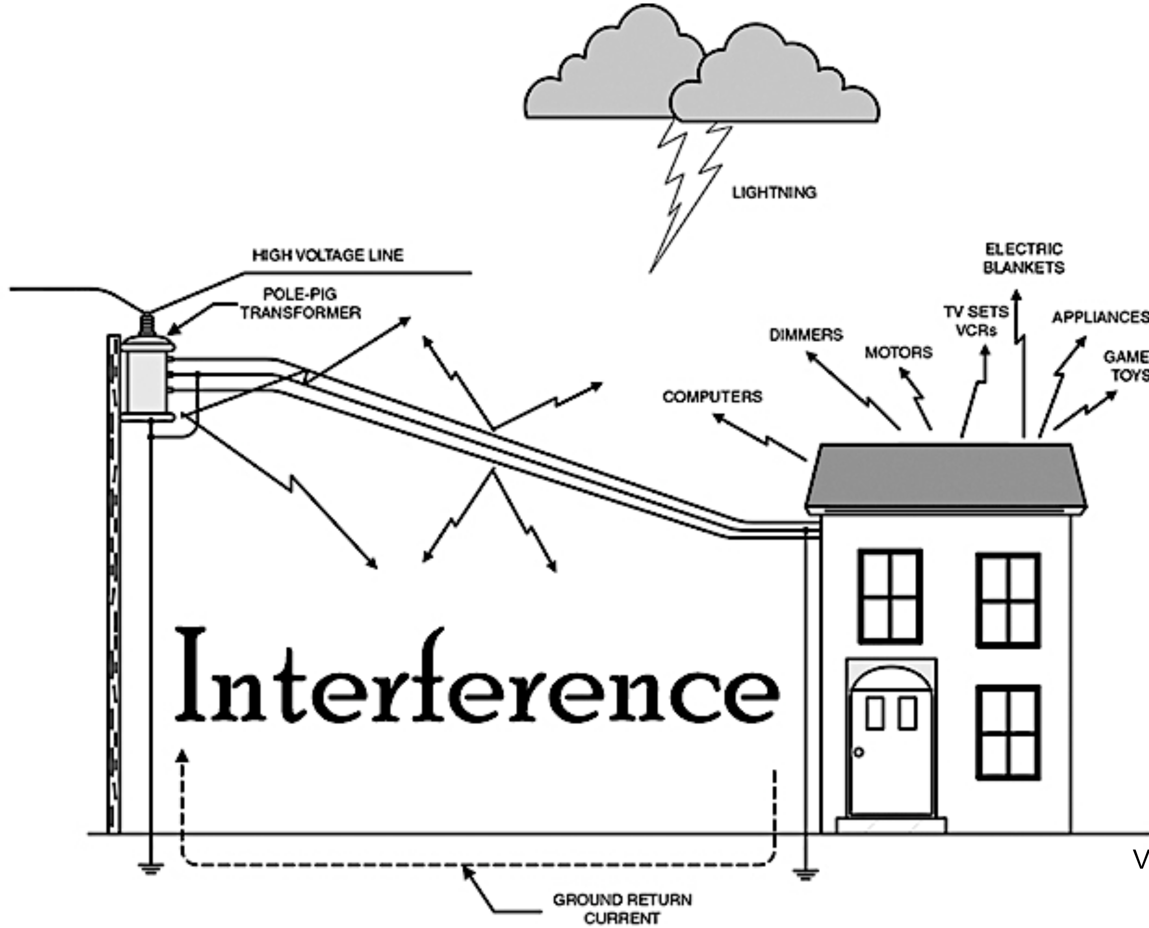
- The primary sources of background noise include:
  - Atmospheric noise,
  - Galactic Extraterrestrial noise, and
  - Man made noise

Man Made Noise & Interference



Power Transmission World

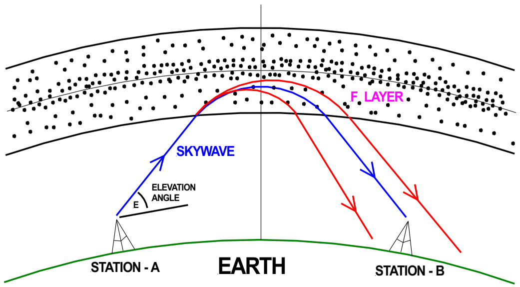
Autoguide.com

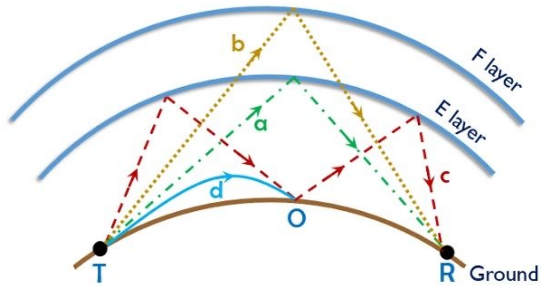


VU2EXO

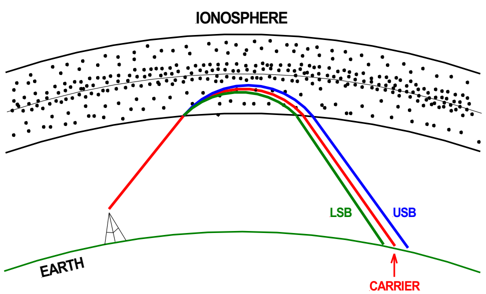
- Man made noise and interference is created by power distribution systems, welding equipment, electric motors, vehicle ignitions, home appliances etc.
- Man made noise in urban areas can at times be greater than atmospheric and galactic noise combined seriously interfering with HF radio communications

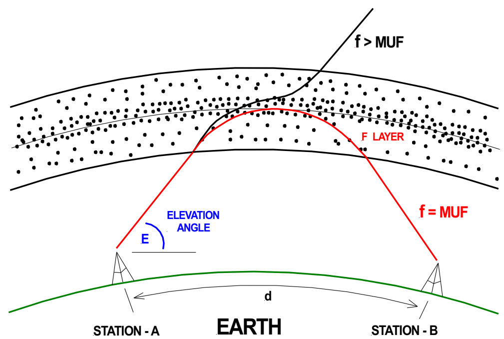
Seven Types of Fading

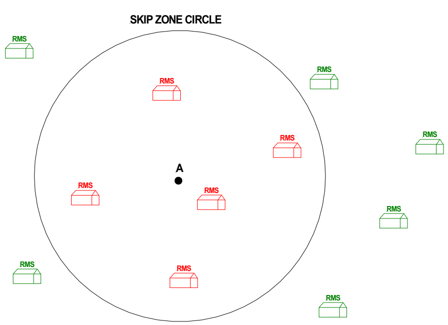


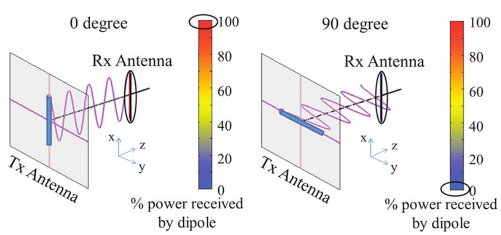


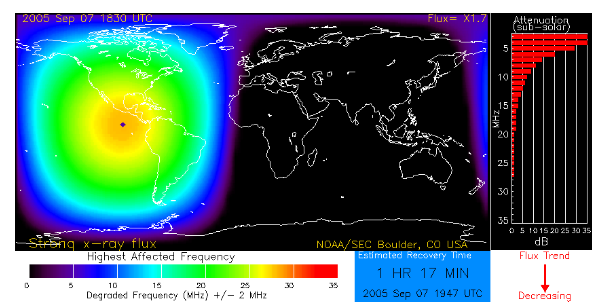
- Ionospheric Path Fading
- Interference Fading,
- Frequency Selective, Fading,
- MUF Fading,
- Skip Fading,
- Polarization Fading,
- Absorption Fading











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