



Chapter 10

Radio Propagation

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Chapter 10

- * **Review - General Class Propagation**
- * **Electromagnetic Waves**
- * **Solar Effects**
- * **HF Propagation**
- * **VHF / UHF/Microwave Propagation**

Review of General Class Propagation

Following review slides are from the current
9th Edition ARRL General Class License Manual

ARRL References

- * ARRL Handbook
- * ARRL Antenna Book

Introduction

Propagation involves everything between the transmit and receive antennas.



- * Propagation is the source of a great deal of the “*magic*” of Amateur Radio
- * Our frequency Bands all have different propagation characteristics
- * Perhaps placed in 3 Broad groups
 - Long Wave Bands (LF: 30-300 kHz*) and Lower HF:160m
 - Middle & Upper HF (40m - 10m)
 - VHF / UHF / Microwave Bands (6m and up)

Technology plays an ever bigger factor in predicting signal path success

Ionosphere

- * Starts ~30miles above Earth
- * Atmosphere there is a thin gas
- * Ionized by UV Radiation
- * Regions: D,E,F,F1,F2

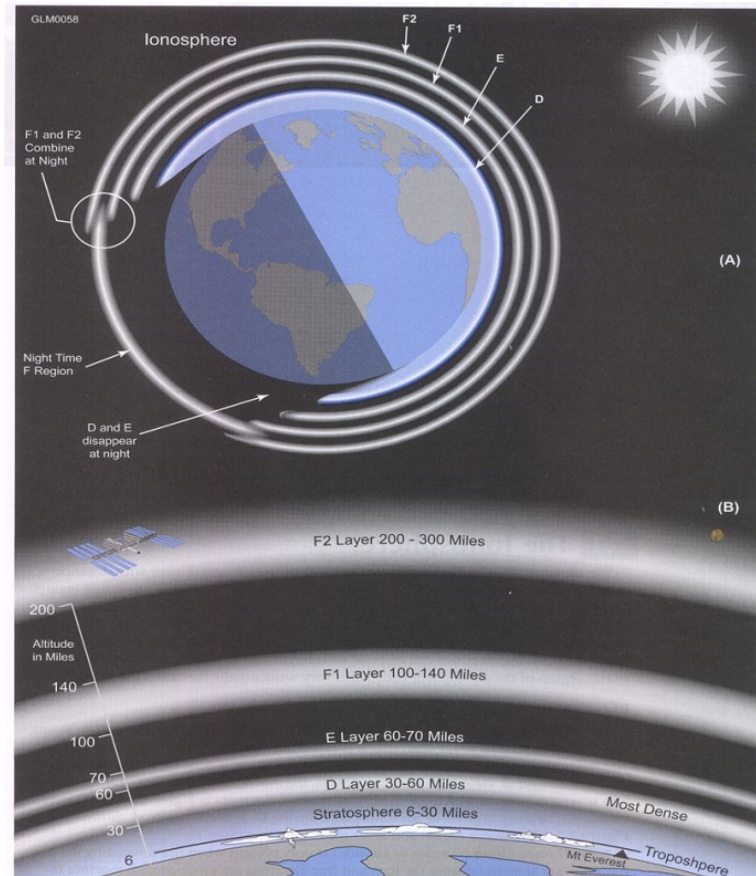


Figure 8.1— The ionosphere consists of several regions of ionized particles at different heights above the Earth. At night, the D and E regions disappear and the F1 and F2 regions combine to form a single F region.

Radio Wave Refraction

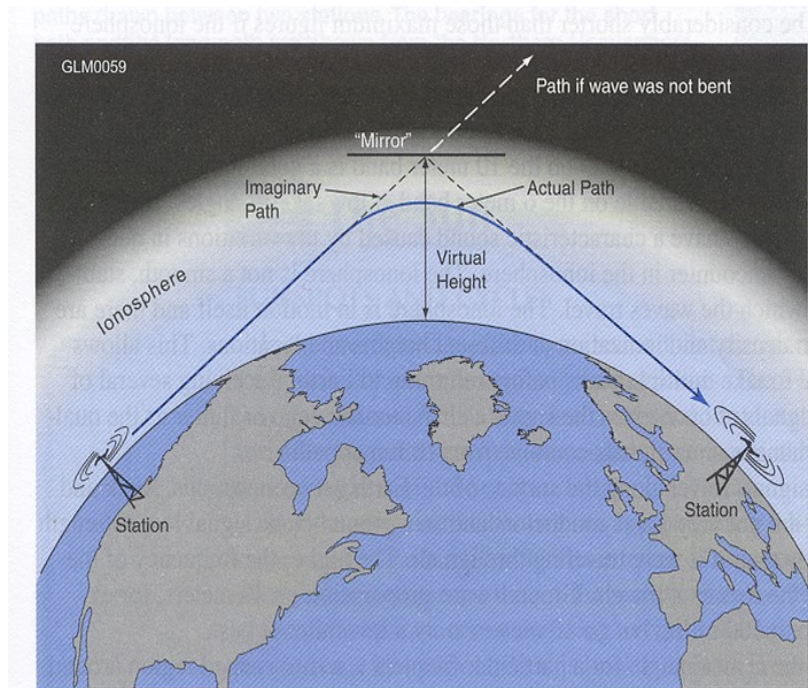


Figure 8.2— Radio waves are refracted (bent) in the ionosphere, so they return to Earth far from the transmitting station. Without refraction in the ionosphere, radio waves would pass into space.

Critical Angle

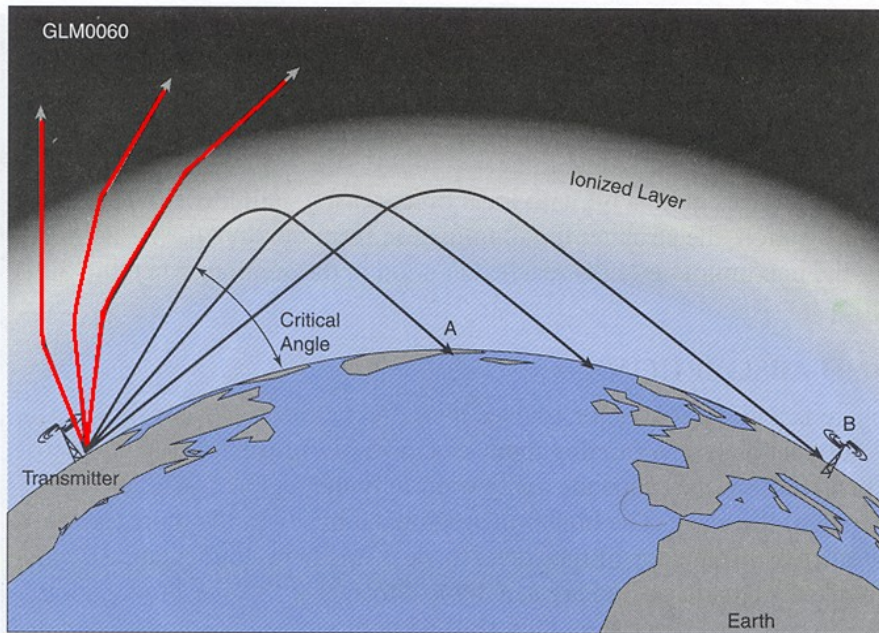


Figure 8.3 — Waves that leave the transmitter above the critical angle are refracted in the ionosphere, but not enough to return to Earth. Waves at and below the critical angle will return to Earth. The lowest angle waves return to Earth at the greatest distance, which is why low angles of radiation are often best for contacting DX stations.

- * Signals above the “Critical Angle” are not bent back to earth, but escape into outer space.

Solar Flares

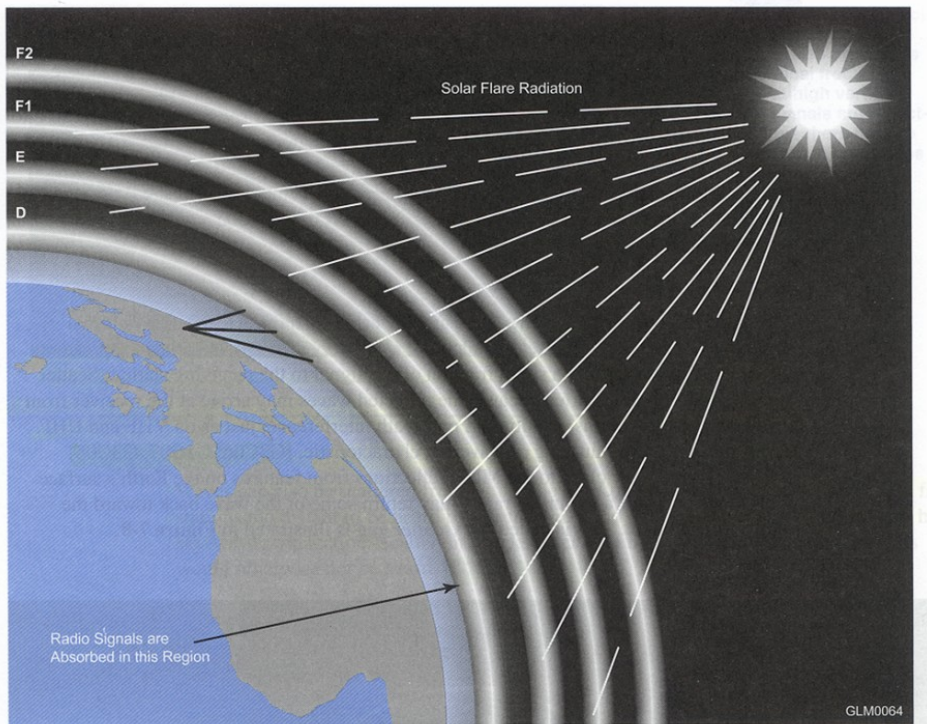


Figure 8.7 — Approximately eight minutes after a solar flare occurs on the Sun, the ultraviolet and X-ray radiation released by the flare reaches the Earth. This radiation causes increased ionization and radio wave absorption in the D region.

Solar Flares result from:

1. Ultraviolet rays
2. X-rays

Causing Increases in:

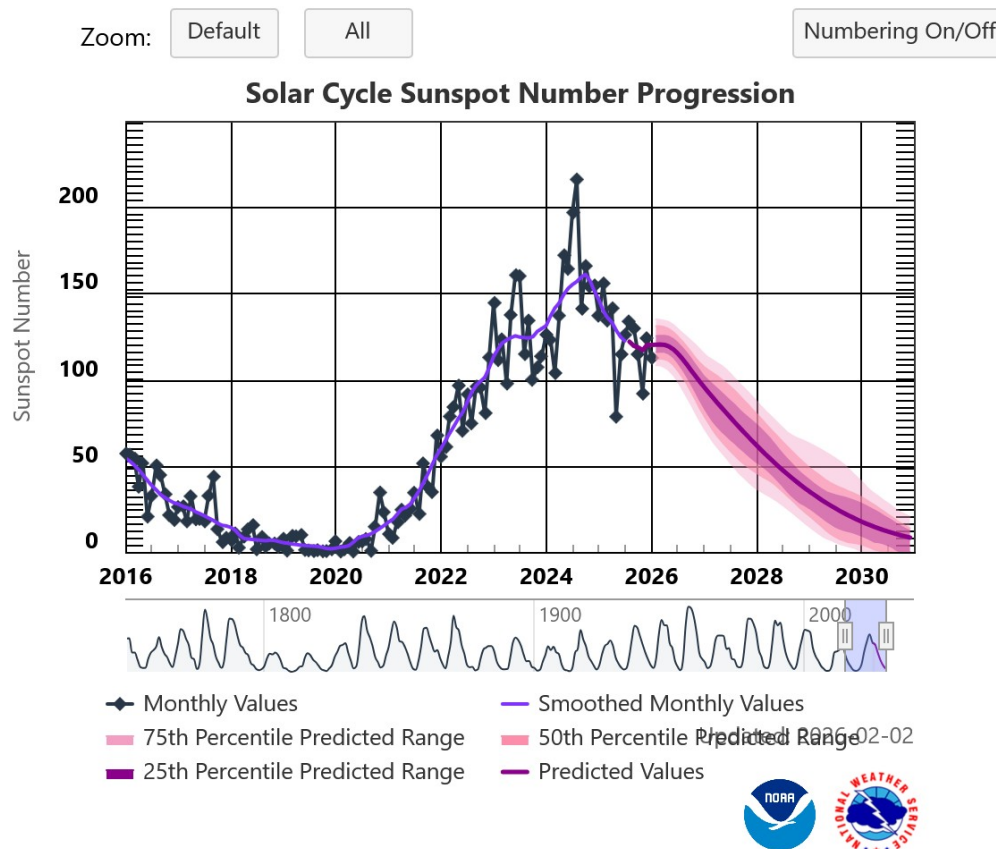
- * Ionization
- * D layer radio wave absorption

Daytime and Nighttime Propagation Ranges

Table 7-1
Daytime/Nighttime HF Propagation

<i>HF Band (meters)</i>	<i>Daytime</i>	<i>Nighttime</i>
160, 80, 60	Local and regional to 100-200 miles	Local to long distance with DX best near sunset or sunrise at one or both ends of the contact
40, 30	Local and regional to 300-400 miles	Short-range (20 or 30 miles) and medium distances (150 miles) to worldwide
20, 17	Regional to long distance, opening at or near sunrise and closing at night	20 meters is often open to the west at night and may be open 24 hours a day
15, 12, 10	Primarily long distance (1000 miles and more), opening to the east after sunrise and to the west in the afternoon.	10 meters is often used for local communications 24 hours a day

Current Sun Spot Progression



Section 10.1

Electromagnetic Waves

Wave Propagation

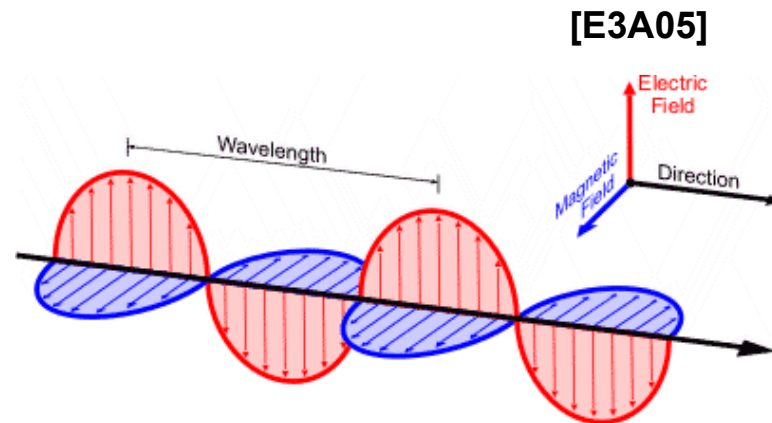
Pg. 10-1

- * **Electromagnetic waves** or EM waves are **waves that are created when an electric field or magnetic field changes.**
- * These waves propagate through space carrying both electric and magnetic energy.
- * Propagate at speed of light (3×10^8 m/s) in a vacuum.
- * **Propagation velocity (%)** defines the speed of light in a specific medium.
- * Propagation velocity in a coaxial cable is typically 67%

Wavefronts

Pg. 10-3

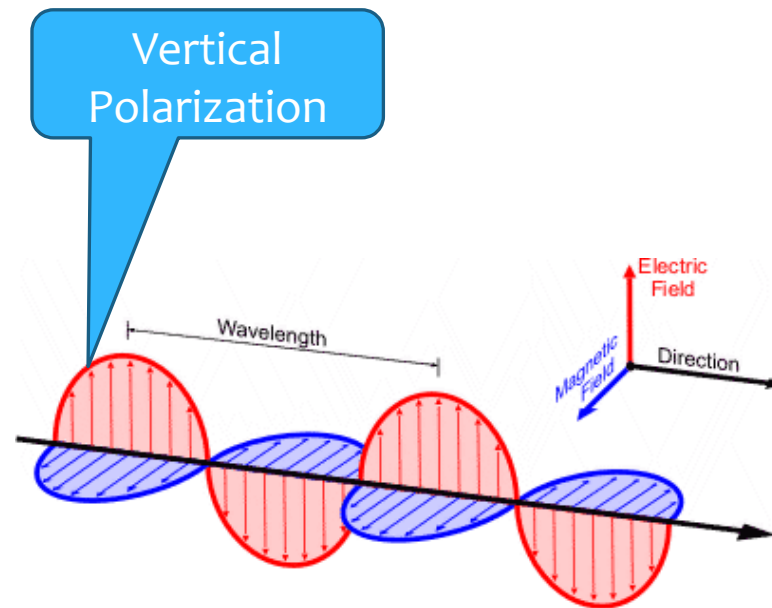
- * A Wavefront of an electromagnetic wave is represented as a flat surface or plane moving through space on which the **electric** and **magnetic** fields have a constant value.
- * The changing fields in the propagated wave transfer energy into the electrons in the antenna creating a sine wave current at the frequency of the field changes



Polarization

Pg. 10-3

- * **Polarization** is determined by the orientation of the **electric field** with respect to the earth
- * Antenna orientation determines polarization
- * **Cross-polarization** occurs between transmit and receive antennas with different orientations (typically -20db loss)
- * Refracted or reflected radio waves can change polarization
- * **Circular polarization** uses a rotating magnetic and electric field [E3A14]



What direction does an electromagnetic wave travel ?

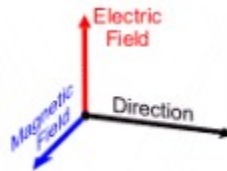
[E3A04]

- A. It depends on the phase angle of the magnetic field
- B. It travels parallel to the electric and magnetic fields
- C. It depends on the phase angle of the electric field
- D. It travels at a right angle to the electric and magnetic fields

What direction does an electromagnetic wave travel ?

[E3A03]

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What determines the speed of electromagnetic waves through a medium ?

[E3A10]

- A. Resistance and reactance
- B. Evanescence
- C. Birefringence
- D. The index of refraction

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[E3A10]

- A. Resistance and reactance
- B. Evanescence
- C. Birefringence
- D. **The index of refraction**

Section 10.2

Solar Effects

Solar Effects

Pg. 10-4

The Sun is the biggest source of effects on radio wave propagation on Earth.

- * HF propagation is dominated by:
 - Daily and seasonal effects
 - 11 year Sunspot Cycle
- * Sun data has been gathered by humans throughout the ages especially in the last hundreds of years.

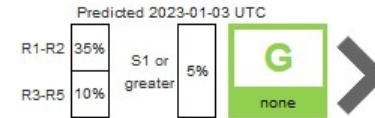
Solar Data Web Sites

Pg. 10-4

- * <http://www.swpc.noaa.gov/communities/radio-communications>
- * <http://www.spaceweather.com>
- * <http://www.solarham.net/>



SPACE WEATHER CONDITIONS on NOAA Scales



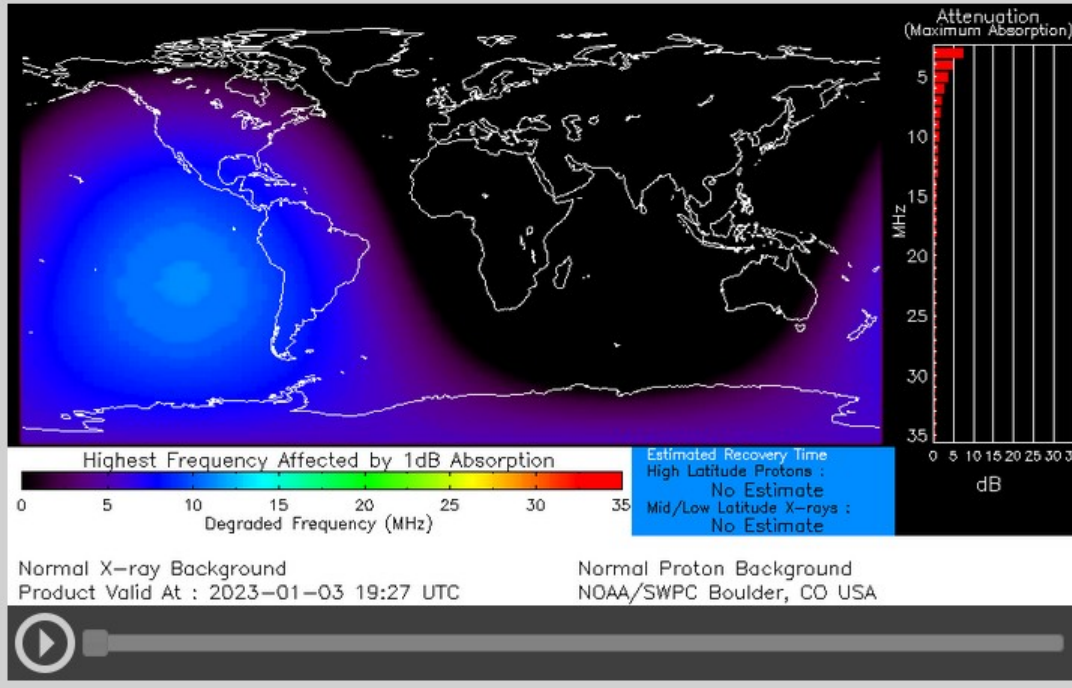
Solar Wind Speed: 400 km/sec

Solar Wind Magnetic Fields: Bt 6 nT, Bz 2 nT

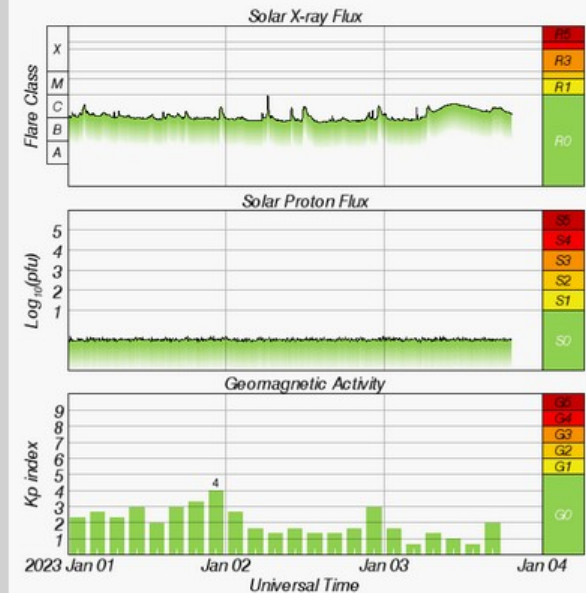
Noon 10.7cm Radio Flux: 146 sfu

RADIO COMMUNICATIONS DASHBOARD

D REGION ABSORPTION PREDICTION



SPACE WEATHER OVERVIEW



Solar Flux

Pg. 10-4

- * A measure known as the **Solar Flux** is used as the basic **indicator of solar activity**, and to determine the **level or radiation being received** from the Sun
 - Sun radiates energy into space at various wavelengths. The **extreme ultraviolet (EUV)** spectrum (10 – 120 nm) affects Amateur Radio waves the most.
 - EUV is completely absorbed in the upper atmosphere-creating the ionosphere.
 - Solar flux (10.7cm, 2.8GHz) is an averaged value of measurements from observatories around the world which track EUV.

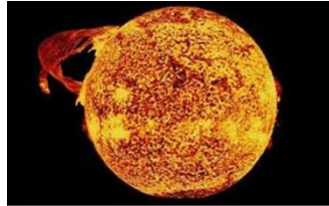
Sites Measuring Solar Flux

Pg. 10-5

- * A number of satellites observe the Sun (Flux) at many different wavelengths (10 - 120nm)
- * The Solar Dynamics Observatory (SDO) is an example
 - Displays a number of these photographs as they are taken at: [Sdo.gsfc.nasa.gov/data](https://sdo.gsfc.nasa.gov/data).
 - Photos are labeled by the wavelength,
Such as the AIA 304 image which shows the Sun at a wavelength of 304 angstroms [**E3C10**].

Solar Flares

Pg. 10-5

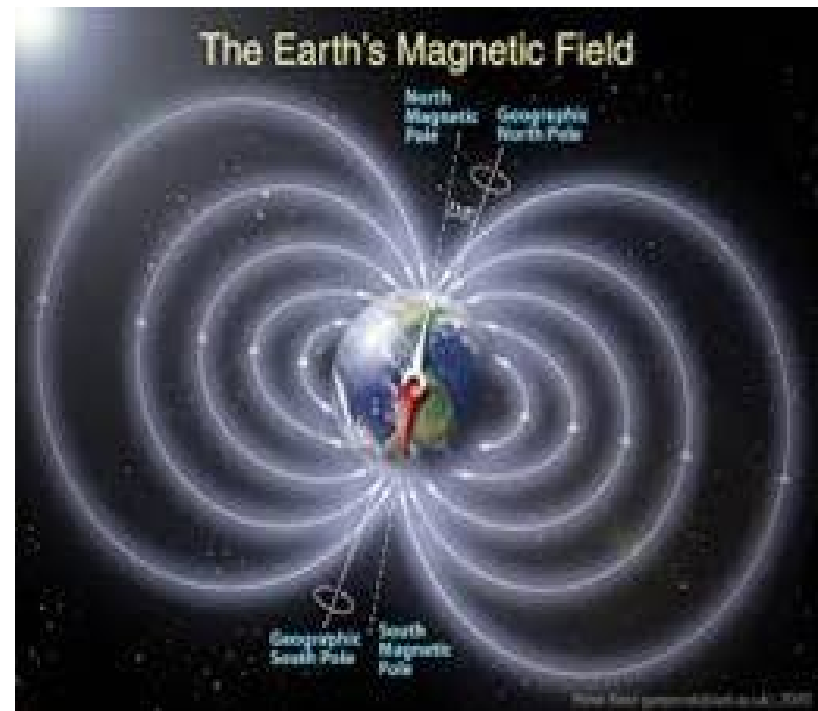


- * The Sun constantly undergoes processes, sometimes releasing large amounts of energy from X rays through EUV and beyond during **solar flares**.
 - When the energy reaches Earth it temporarily increases ionization and can disrupt the geomagnetic field.
 - Flares are ranked by classes of intensity: **A(small), B,C,M and X(very large)** [E3C07]
 - M Class have a moderate impact on HF while X Class can cause radio blackouts that last for days. [E3C01]
 - Within each class, increasing numeric values such as X1, X2, X3 correspond to increasing intensity.
 - For example, an X3 flare is 50% more intense as an X2 flare.
 - Geomagnetic storms are classified similarly, with G5 being extreme. [E3C08]

Geomagnetic Field

Pg. 10-5

- * Earth's **magnetic field**, also known as the **geomagnetic field** (GMF), is the magnetic field that extends from the Earth's interior out into space,
- * Roughly speaking it is the field of a magnetic dipole currently tilted at an angle of about 10 degrees with respect to Earth's rotational axis, as if there were a bar magnet placed at that angle at the center of the Earth.



Solar Particles

Pg. 10-5

- * The Earth's geomagnetic field is disrupted by the Sun's solar particles
- * This in turn disrupts the ionosphere, and the refraction of radio waves.

Geomagnetic Storm

- * When the geomagnetic field is highly disturbed it is called a **geomagnetic storm**.

HF Propagation Indicators

Pg. 10-5

- * **Bz**: A measurement of the intensity and orientation of the **interplanetary magnetic field (IMF)** generated by the Sun [EC304]
 - If Bz is negative, the direction of the IMF is aligned southward(north-to-south), that direction is also aligned with the GMF, so it is easier for charged particles to enter and disrupt the GMF [EC305]
- * **K Index**: An evaluation of how disturbed the GMF is at a particular location
 - 0: a minor storm to 9: a major storm
 - K_p index is an average of reported values worldwide
- * **A index**: Derived from the K Index with a wider range of 0 to 400
 - Increasing values of A and K indicate increasing disruption of the GMF [EC302]
- * **G Index**: Geomagnetic storminess, Based on value of A and K indices
 - 0 none, 1 minor, 2 moderate, 3 strong, 4 severe 5 extreme
 - The term G5 indicates there is an extreme geomagnetic storm

Which of the following indicates the greatest solar flare intensity ?

[E3C07]

- A. Class A
- B. Class Z
- C. Class M
- D. Class X

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- B. Class Z
- C. Class M
- D. **Class X**

What does the value of B_z ($B_{\text{sub } z}$) represent ?

[E3C04]

- A. Geomagnetic field stability
- B. Critical frequency for vertical transmissions
- C. North-south strength of the interplanetary magnetic field
- D. Duration of long-delay echoes

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HF Propagation

Section 10.3

HF Propagation Modes

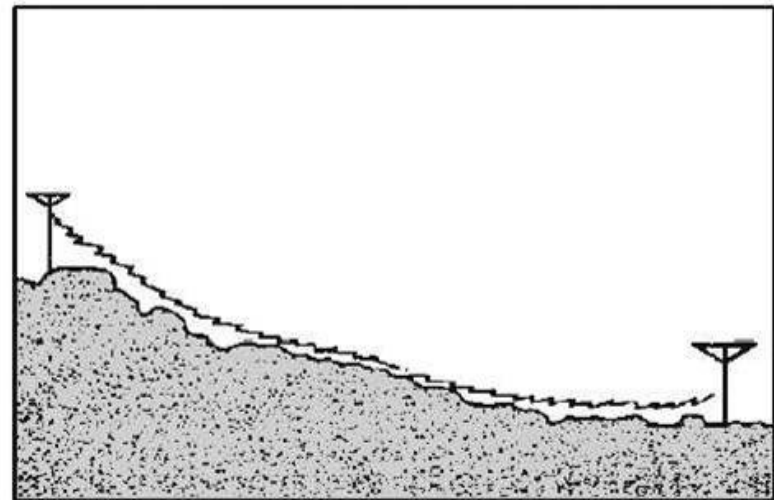
Pg. 10-6

- * To modes of propagation
 - **Ground-wave** – Follows along the ground
 - **Sky-wave** (skip)
- * Propagation is quite different across the HF bands (frequencies)

Ground-wave Propagation

Pg. 10-6

- * HF signals passing between stations by traveling along the surface of the Earth are using **ground wave** propagation
- * Both vertical and horizontal polarized waves are possible



Propagation Phenomena

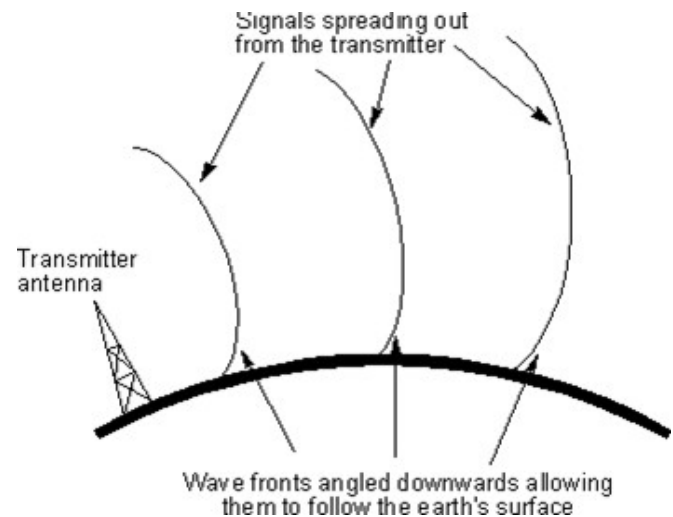
Pg. 10-6

- * All types of waves can change direction due to two different phenomena:
 - **Diffraction**
 - Created by the construction and reinforcement of wave fronts after the wave encounters a reflecting surface's corners or edges.
 - **Refraction**
 - Is a gradual bending of the wave due to velocity changes caused by the medium or material the wave travels through.

Vertically Polarized Ground Waves

Pg. 10-6

- * Special type of diffraction for vertically polarized waves.
 - Lower edge of wave (closest to the earth) loses energy due to induced ground currents.
 - Lower edge slows, tilting the wave front forward following the curvature of the Earth, allowing signal to be heard beyond the line of sight (50 – 100 mi).
 - Most noticeable on longer wavelengths; AM broadcast, 160M, & 80M.
 - Over distance, ground wave signal is absorbed, decreasing strength.
 - Most useful during daylight on 160M & 80M.
 - At 28Mhz (10M) the maximum range of a ground wave is only a few miles. [E3B08]

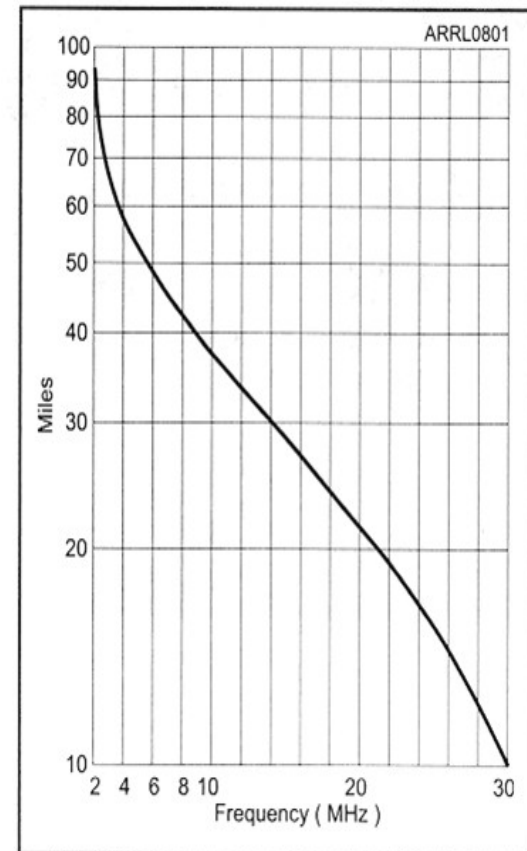


Ground Wave Signal Losses

Pg. 10-6

Ground Wave

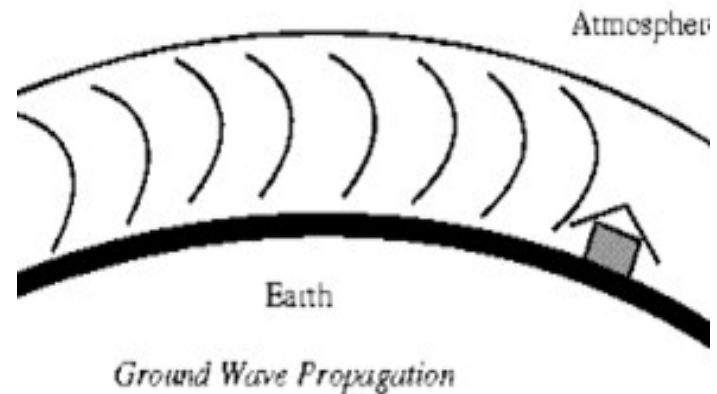
- * Is lossy because the vertically polarized portion of the waves electric field that extend into the ground is mostly absorbed.
- * Over distance the ground wave signal is increasingly absorbed as frequency increases until the signal is too weak to be received.
- * This loss increases with frequency until at 28MHz(10M) the maximum range of ground-wave is only a few miles.



Ground-wave Characteristics

Pg. 10-6

- * Ground-wave propagation is most useful during the day (1.8 & 3.5MHz) when ionosphere losses make sky-wave propagation impossible.
- * Vertical polarized antennas provide the best results for ground wave propagation. [E3B13]
- * Lowest losses over saltwater and highest over dry and rocky land.



Sky-Wave Propagation

Pg. 10-7

- * Signals that follow a path away from the earth are called **sky-waves**.
- * The path of a wave that returns to earth after being bent by the ionosphere is called a **hop**.
 - F layer one hop max – 2500 mi
 - E layer one hop max – 1500 mi
- * It is possible for signals to reflect between the E and F regions (or several times within the F region)
- * When the wave makes **two successive reflections from the same layer, without a reflection from ground**, it is called a **chordal hop**.
- * Avoiding a lossy ground reflection means the signal will be stronger at the receiving end of the path. **[E3B10, E3B12]**
- * In the evening as the MUF lowers change to a lower frequency band **[E3A06]**
- * Signals with lower take off angles result in longer distance communications. **[E3B07]**

Ordinary and Extraordinary Waves

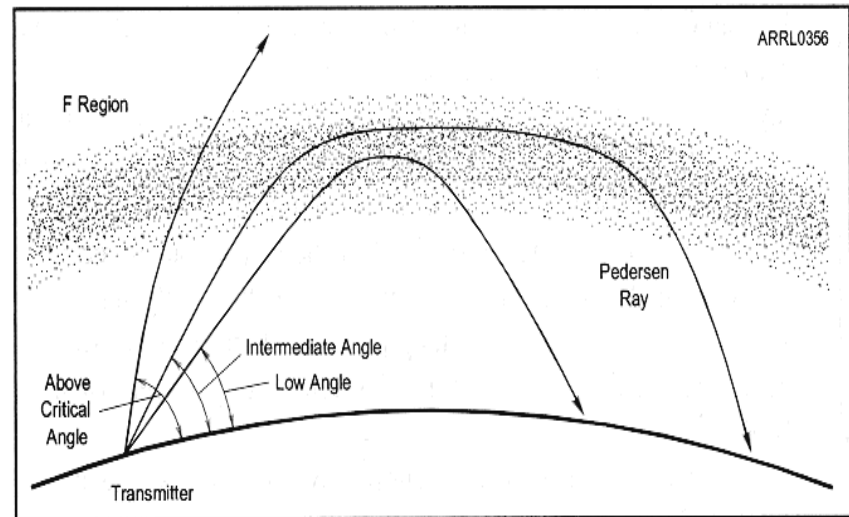
Pg. 10-8

- * Radio waves entering the ionosphere divide into two waves polarized at right angles to each other:
 - **Ordinary wave** or **o-wave** E field is parallel to the Earth's magnetic field. [E3B04]
 - **Extraordinary wave** or **x-wave** E field is perpendicular to the Earth's magnetic field. [E3B04]
- * Ordinary and extraordinary waves travel at slightly different speeds, creating a phase difference between them.
- * The result is that a **linearly polarized** wave becomes **elliptically polarized**.
- * At 10 MHz and above both waves travel almost identical paths.
- * At 7 MHz and lower the waves may travel different paths and directions.

Pedersen Ray

Pg. 10-8

- * A **Pedersen Ray** signal follows the upper most F2 region band for some distance before bending to Earth.
 - High angle wave.
 - Penetrates ionosphere higher than normal.
 - Provides propagation beyond normal maximum skip distance.
 - May travel completely around the earth in less time than multiple hops



Predicting and Observing Propagation

Pg. 10-9

- * Models of propagation, based upon measurements of the ionosphere, have been developed and incorporated into software to predict HF propagation between locations. [E3C11]
 - **VOACAP** software predicts HF propagation between locations.
 - Online prediction tools:
 - <https://www.voacap.com/prediction.html>
- * Following the possible paths through the ionosphere a wave may take is called **ray tracing**.
- * Propagation reporting networks (digital modes and CW) [E3C09]
 - [Wspn.net.org/drupal/wspn.net/map](https://wspn.net.org/drupal/wspn.net/map)
 - [Pskreporter.info/pskmap.html](https://pskreporter.info/pskmap.html)

Absorption

Pg. 10-9

- * **Ionospheric absorption:**

When waves cause D layer (35 – 60 mi) electrons to move-causing them to collide with other electrons and ions giving up a great deal of the wave's energy as heat.

- Ionized only during sunlight
- The longer the wavelength, the more absorption
- Eliminates long distance sky wave propagation on 160M & 80M during daylight hours – especially during high solar activity.
- **Near vertical incidence sky-wave (NVIS)** may be used on 160M & 80M during the day.

- * Polar paths experience high levels of absorption with elevated A or K index.

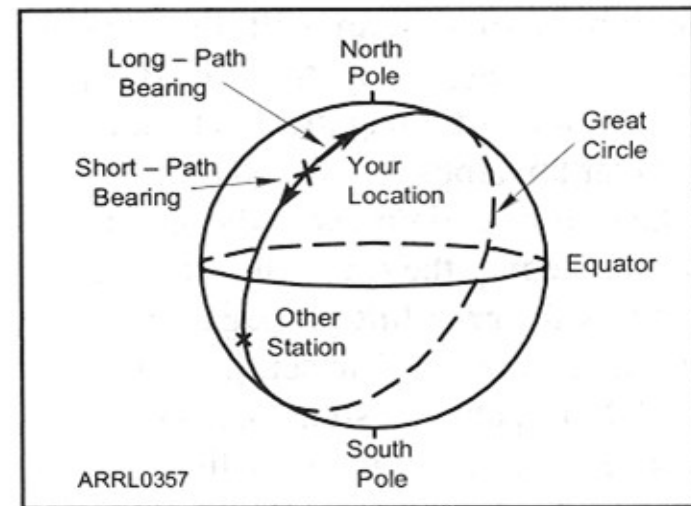
- As A and K indices rise, so does absorption, particularly along the polar paths that travel through the auroral zones where most charged particles from the Sun enter the Earth's atmosphere. [E3C03]

- * During a solar flares noise levels increase and signals fade. [Ec312]

Long Path Propagation

Pg. 10-10

- * **Great Circle:** A path around the Earth which signals travel.
- * **Short Path** Propagation:
 - Signal travels over the shorter of Great Circle paths(normal path).
- * **Long-Path** Propagation:
 - Signal travels over the Longer of Great Circle paths
(180° from the short path).
 - Requires a beam with low takeoff angles



Long Path Characteristics

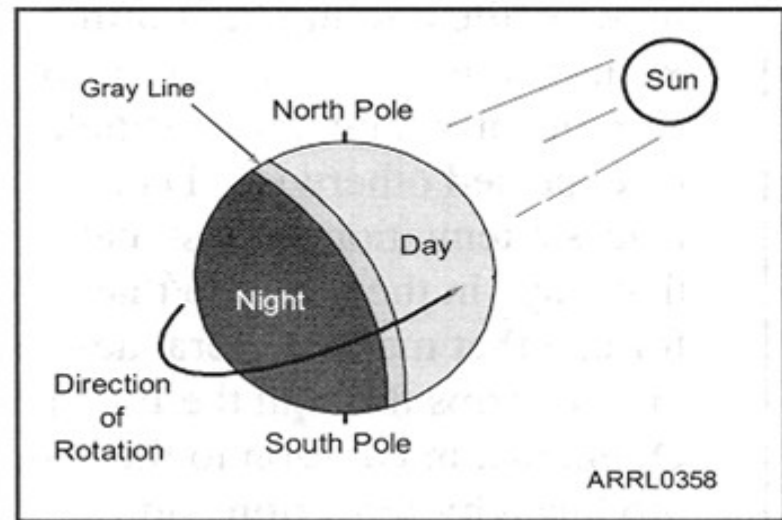
Pg. 10-10

- * If you notice an echo delayed by a fraction of a second you may be hearing the signal from both the short path and the long path
- * Long path propagation can occur on any band with sky wave propagation, 160 to 10 meters.
- * Long path enhancement most often occurs on 20 meters.
[E3B06]
- * For paths of less than 6000 miles the short path signal will almost always be stronger.
- * Short path longer than 6000 miles the long path occurs along the *gray line*

Gray Line Propagation

Pg. 10-11

- * **Gray-line** Is a band along the terminator between darkness and light that runs completely around the Earth.
- * Grey-Line propagation occurs when signals propagate through the terminator between daylight and darkness.
- * Gray-line propagation is caused when the D layer (which absorbs HF signals) disappears rapidly on the sunset side of the gray line before it has had time to build up on the sunrise side, at the same time the E and F layers at higher altitudes are still illuminated and providing propagation.



What type of polarization is best for ground wave propagation?

[E3B13]

- A. Vertical
- B. Horizontal
- C. Circular
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What effect does lowering a signal's transmitted elevation angle have on the ionospheric HF skip propagation ?

[E3B07]

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- B. The MUF decreases
- C. The distance covered by each hop increases
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What are “extraordinary” and “ordinary” waves ?

[E3B04]

- A. Extraordinary waves exhibit rare long-skip propagation, compared to ordinary waves, which travel shorter distances
- B. Independently propagating, elliptical polarized waves created in the ionosphere
- C. Log-path and short-path waves
- D. Refracted rays and reflected waves

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What does VOCAP software model ?

[E3C11]

- A. AC voltage and impedance
- B. VHF radio propagation
- C. HF propagation
- D. AC current and impedance

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- C. **HF propagation**
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What might be indicated by a sudden rise in radio background noise across a large portion of the HF spectrum ?

[E3C12]

- A. A temperature inversion has occurred
- B. A coronal mass ejection impact or a solar flare has occurred
- C. Trans-equatorial propagation on 6 meters is likely
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On which of the following amateur bands is long path propagation most frequent ?
[E3B06]

- A. 160 meters and 80 meters
- B. 40 meters and 20 meters
- C. 10 meters and 6 meters
- D. 6 meters and 2 meters

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Section 10.4

VHF/UHF/Microwave Propagation

Transmission Principles

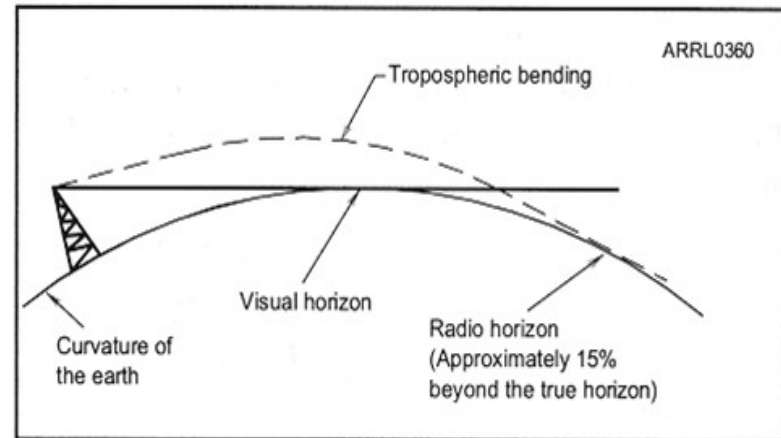
Pg. 10-11

- * Above 30 MHz, radio waves are rarely refracted back to earth by the ionosphere.
- * Must use alternative techniques for long-distance communications.
- * Low-angle of radiation from the antenna is more important than on HF.
- * Important for the **polarization** of the transmitting & receiving antennas to match
- * The polarization of a space wave remains constant as it travels.
- * There may be as much as 20dB of signal loss between **cross-polarized** antennas.

Radio Horizon

Pg. 10-11

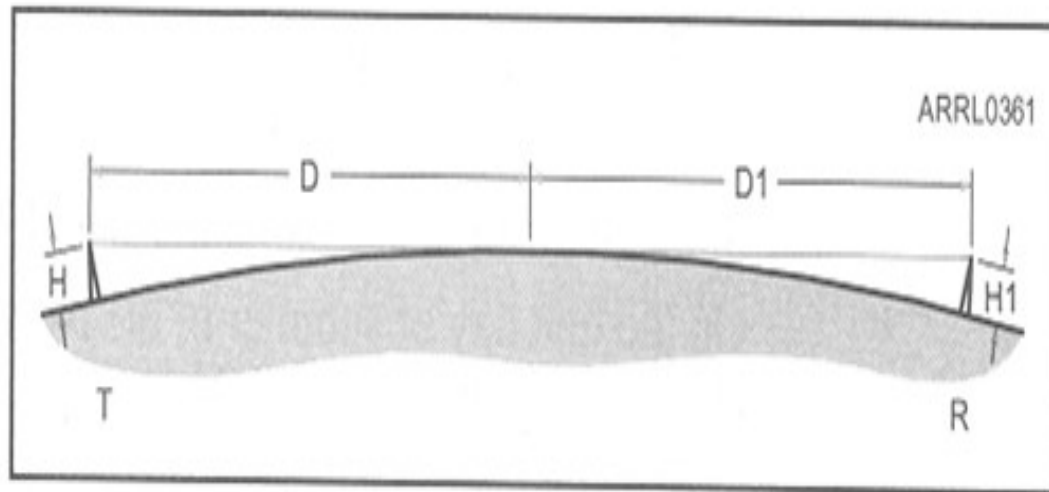
- * **Radio horizon** is not the same as visual horizon.
- * Density variations in the atmosphere cause bending of the wave causing the radio horizon distance to be greater than the visual horizon
- Radio horizon distance is about 15% beyond “**line-of-sight**” or the **geometric horizon**. [E3C06]



Space Wave Distance

Pg. 10-11

- * Fig. 10.9 illustrates the maximum space-wave distance between two antennas is equal to the sum of the distances of both the transmitting and receiving antennas to their radio horizons.



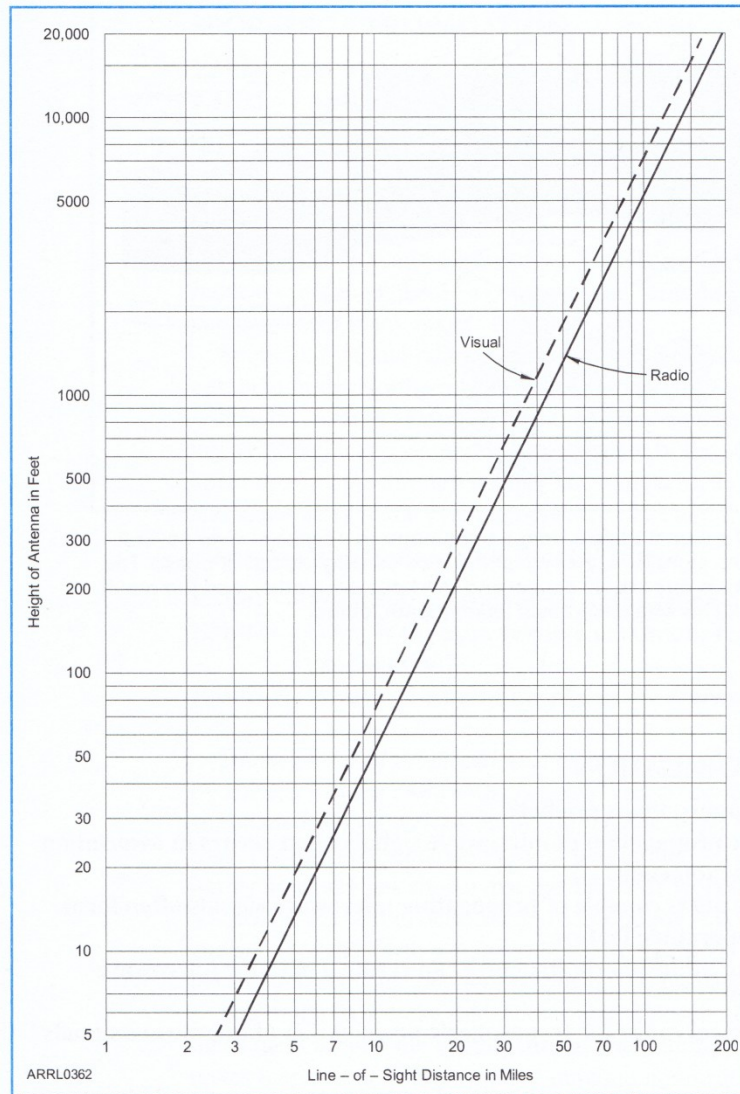


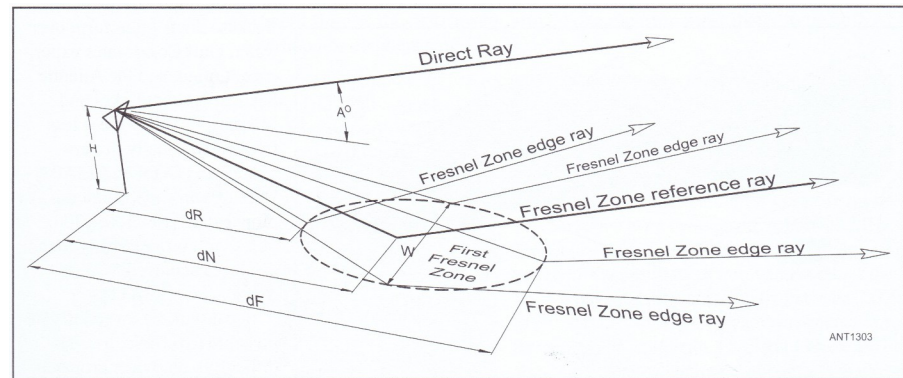
Figure 10.8 — Distance to the radio horizon from an antenna of given height above average terrain is indicated by the solid line. The broken line indicates the distance to the visual, or geometric, horizon. The radio horizon is approximately 15% farther than the visual horizon.

Fresnel Zone

Pg. 10-13

- * **First Fresnel Zone** (best reception) is the first area in front of the antenna from which the reflected ray reinforces the direct ray at the desired elevation angle
- * HF receivers in odd numbered Fresnel zones have stronger signals from the multiple in phase signals (**ground-gain**)
- * Even numbered zones produce lower signals resulting from the out of phase signals
- * At 5.8 Ghz the first Fresnel zone is small, at Hf is quite large.

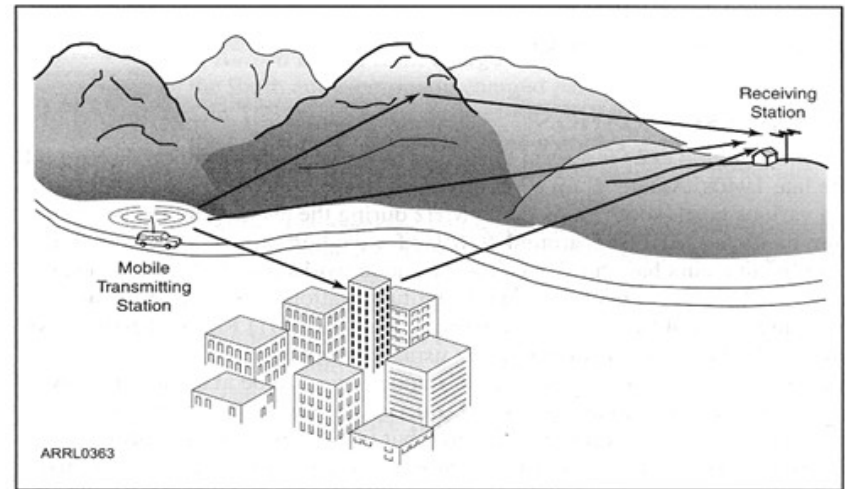
[E9A08]



Multipath

Pg. 10-14

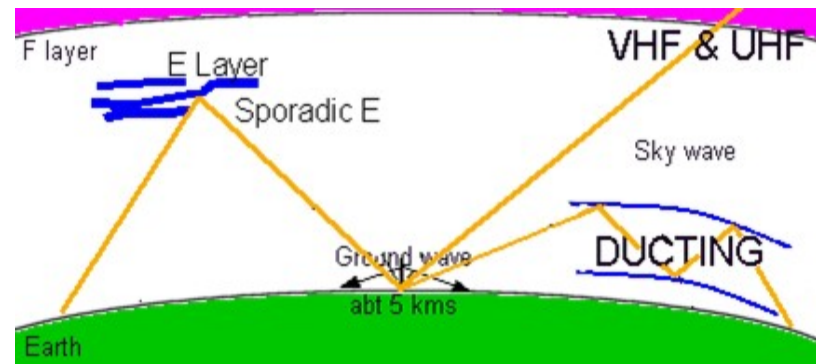
- * Radio waves reflected off of many objects arrive at receive antenna at different times known as ***multipath***.
- * Waves reinforce or cancel each other depending on phase relationship.
- * Multipath and the distortion it causes are a major challenge to high-speed digital service via wireless systems.



Tropospheric Propagation

Pg. 10-14

- * Weather conditions such as **temperature inversions** warm and cold fronts can create a “**duct**”, similar to a waveguide, at VHF, UHF and microwave frequencies.
- * This form of propagation is known as **tropospheric ducting**, 100 to 300 miles. [, E3A11]
- * Likely Tropospheric Propagation is shown on **Hepburn maps**.



Tropospheric Propagation Attributes

Pg. 10-14

- * Occurrence increases with frequency; 6m – rare, 2m – Fairly common and 70cm and above – common.
- * Most common over water primarily Gulf Coast states with the Atlantic Seaboard, Great Lakes and Mississippi Valley areas less frequently, usually in September and October. [E3A07]
- * Microwave propagation over 100 – 300 miles with longer distances at lower frequencies. [E3A11]

Sporadic E Propagation

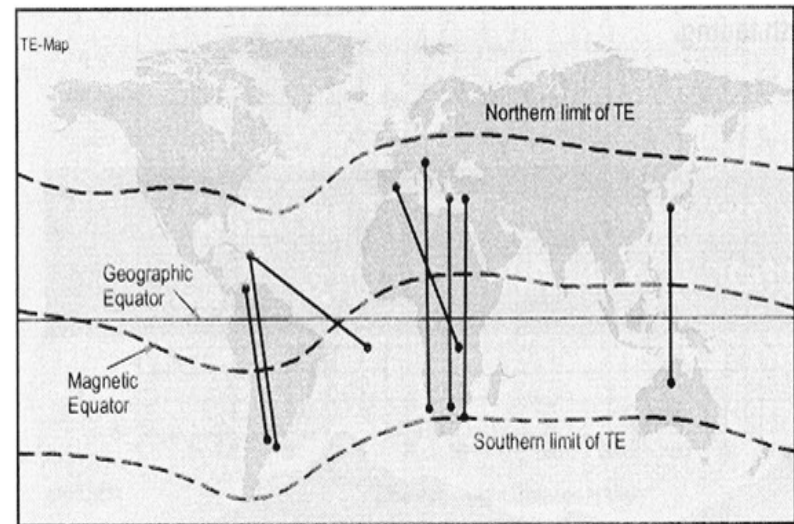
Pg. 10-15

- * **Sporadic E (Es)** propagation consist of propagation from thin highly ionized layers that form temporarily in the E layer.
 - Commonly propagates 28, 50 and 144 MHz signals from 300-1400 mi.
 - Signals can be extremely strong
 - Can last minutes to hours
- * Sporadic E at mid latitudes (roughly 15 to 45 degrees) may occur at any time, but it is most common in the Northern Hemisphere around the summer solstice during May, June and July. **[E3B09]**
- * Less-intense season around the winter solstice at the end of December and early January.
- * Sporadic E propagation can occur at any time through the day but is most likely to occur from 9 AM to noon local time, and again early in the evening between 5 PM and 8 PM. **[E3B11]**

Transequatorial Propagation

Pg. 10-15

- * **Transequatorial Propagation (TEP)** is a form of *F* layer propagation discovered by Hams in the late 1940's.
 - Communications between stations located at mid latitudes of approximately equal distance north & south of the magnetic equator. **[E3B01]**
 - When the maximum ionization forms in two areas 10 deg-15 deg north and south of the magnetic equator.
 - Forms in morning – can last after midnight



Transequatorial Propagation Attributes

Pg. 10-15

- * Most prevalent around the spring & autumn equinoxes.
- * Maximum effect during afternoon & early evening.
- * Allows contacts up to about 5,000 miles. [E3B02]
- * Works on 2m & to a degree on 70cm.
- * Strong signals on HF during the afternoon and early evening hours. [E3B03]
- * As frequency increases, paths more restricted to exactly equidistant from and perpendicular to the magnetic equator.

Auroral Propagation

Pg. 10-16

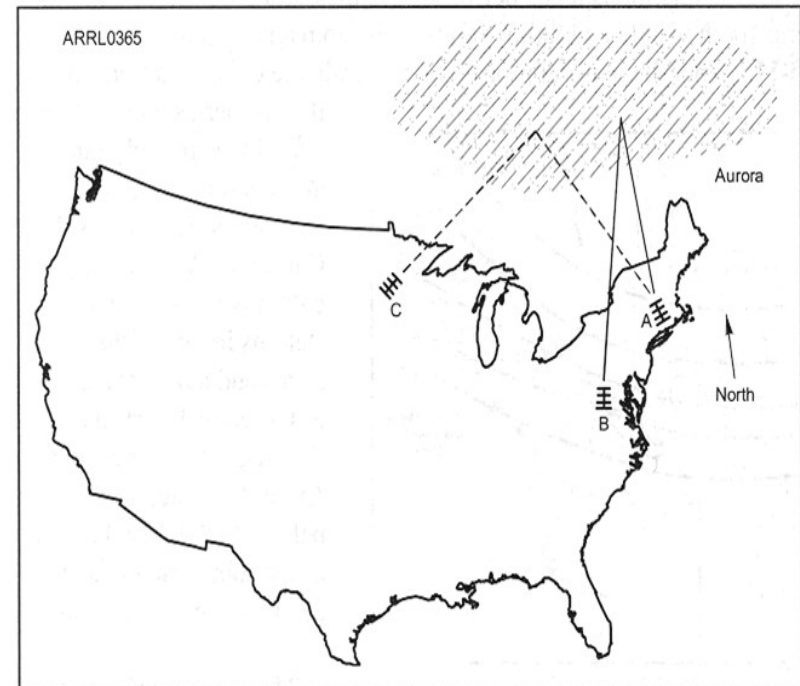
- * **Aurora** (seen visually as **Aurora Borealis**) is caused by a large-scale interaction between the E layer of the ionosphere, the magnetic field of the Earth and electrically charged particles of the **solar wind**, ejected from the surface of the sun. [E3A12]
 - Charged particles from the sun (solar wind) are concentrated over the magnetic poles by the earth's magnetic field & ionize the E-layer.
 - VHF & UHF propagation up to about 1,400 miles.



Using Auroral Propagation

Pg. 10-17

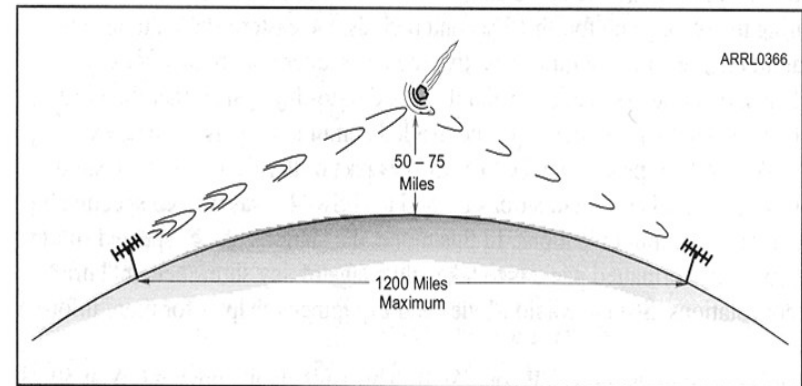
- * Most common on 10, 6, 2 meters with some on 222 and 432 MHz.
- * CW most effective mode. [E3A13]
- * Reflections change rapidly
 - All signals sound fluttery
 - SSB signals sound raspy
 - CW signals sound like they are modulated with white noise.
- * Stations should “bounce” their signals off the auroral zone.
- * Seen when K index values are 3 or higher, Max when K=7-9



Meteor Scatter Communications

Pg. 10-18

- * Meteors passing through the ionosphere collide with air molecules & strip off electrons.
- * Radio waves can be reflected by the ionized trail of a meteor
 - Best propagation: 28 MHz to 148 MHz. [E3A09]
 - Ionization occurs at or near the E-region 50 – 75 mile above the earth. [E3A08]



Meteor Scatter Techniques

Pg. 10-19

- * Keep transmissions SHORT.
- * Short transmissions & rapidly repeated call signs/reports.
- * Divide each minute into four 15-second segments.
 - Stations at west end of path transmit during 1st & 3rd segments.
 - Stations at east end of path transmit during 2nd & 4th segments.
- * Use high speed digital modes .
 - Computer generated & decoded digital modes such as MSK144 (part of WSJT-X software suite). **[E2D01]**

Earth-Moon-Earth Communications

Pg. 10-19

- * **Moon Bounce** or **Earth-Moon-Earth (EME)**
- * If both stations can “see” the moon (**mutual lunar window**), they can talk by reflecting VHF or UHF signals off the lunar surface.
- * Maximum station separation of about 12,000 miles.
[E3A01]
 - Half the circumference of Earth
- * Path losses are huge as compare to local VHF/UHF paths.
 - Least path loss for EME is when moon is at perigee – closet to the earth. **[E3A03]**

Libration Fading

Pg. 10-19

- * Caused by multipath effects of rough moon surface in combination with relative motion between the earth and the moon.
 - Fluttery, rapid, deep, irregular fading similar to what is observed with tropo scatter. [E3A02]
- * Digital EME uses a special mode – **Q65**
 - Uses alternating time synchronized transmissions. [E2D03, E2D06]
 - Advanced coding that allows low signal-to-noise ratios. [E2D05]

How does the VHF/UHF radio horizon compare to the geographic horizon ?

[E3C06]

- A. It is approximately 15 percent farther
- B. It is approximately 20 percent farther
- C. It is approximately 50 percent farther
- D. They are approximately the same

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Which frequency band has the smallest first Fresnel zone ?

[E9A08]

- A. 5.8 GHz
- B. 3.4 GHz
- C. 2.4 GHz
- D. 900 MHz

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**Atmospheric ducts capable of propagating microwave signals
often form over what geographic feature ?
[E3A07]**

- A. Mountain ranges
- B. Stratocumulus Clouds
- C. Large bodies of water
- D. Nimbus clouds

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At what time of year is sporadic-E most likely to occur ?

[E3B09]

- A. Around the solstices, especially the summer solstice
- B. Around the solstices, especially the winter solstice
- C. Around the equinoxes, especially the spring equinox
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What is the approximate maximum range for signals using transequatorial propagation ?

[E3B02]

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- B. 2500 miles
- C. 5000 miles
- D. 7500 miles

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Which of these emission modes is best for auroral propagation ?

[E3A13]

- A. CW
- B. SSB
- C. FM
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Which of the following digital modes is designed for meteor scatter communications ?

[E2D01]

- A. WSPR
- B. MSK144
- C. Hellschreiber
- D. APRS

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[E2D01]

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- B. **MSK144**
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Which of the following digital modes is designed for EME communications ?

[E2D03]

- A. MSK144
- B. PACTOR III
- C. WSPR
- D. Q65

Which of the following digital modes is designed for EME communications ?

[E2D03]

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- B. PACTOR III
- C. WSPR
- D. Q65