

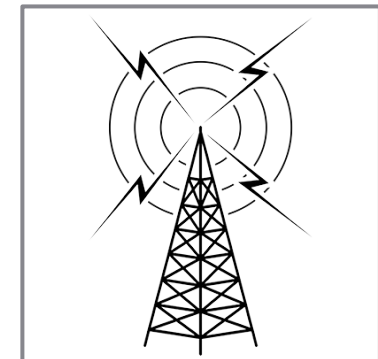
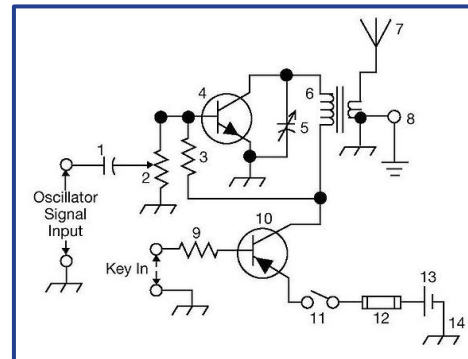
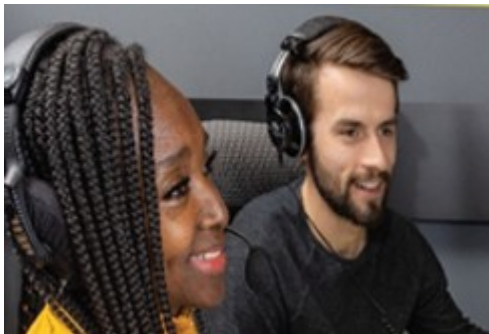
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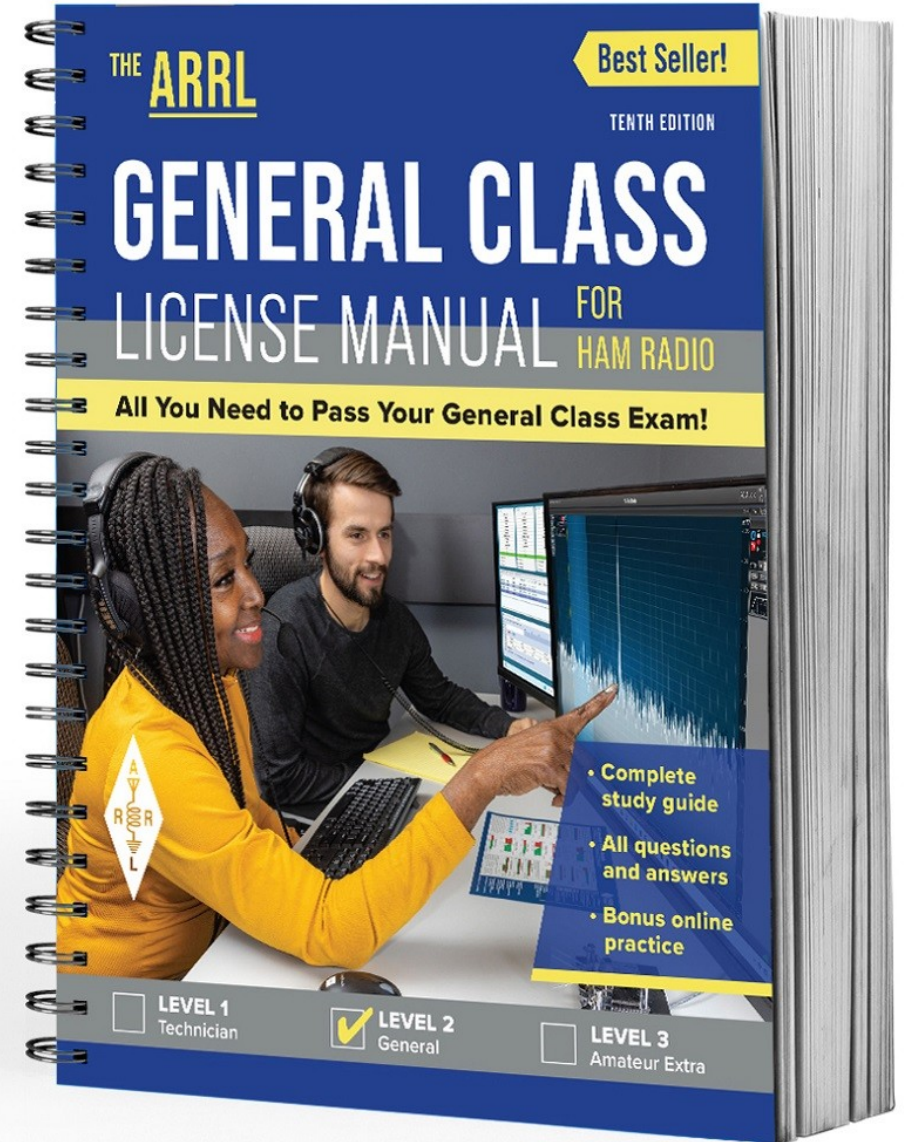
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Chapter 8 Part 1 of 1

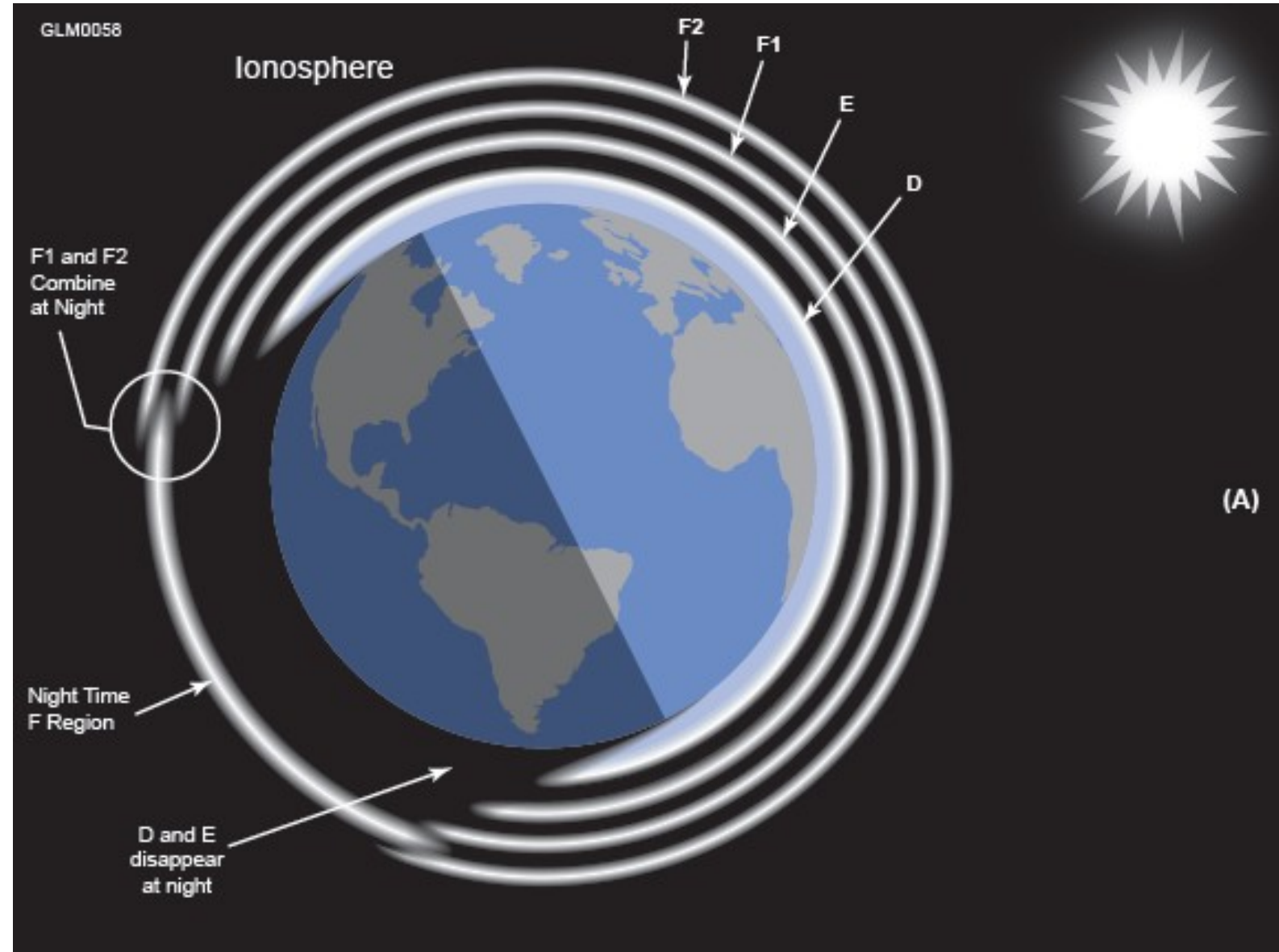
ARRL General Class
Propagation
Sections 8.1, 8.2, 8.3

The Ionosphere, The Sun, Scatter Modes

Section 8.1

The Ionosphere

- Upper reaches of atmosphere gets thinner with distance
- Beginning at about 30 miles, remaining gas is thin enough for ionization to occur
- This region of the atmosphere becomes a very weak conductor



Ionosphere (cont.)

- D layer (30 to 60 miles in altitude) is only present when illuminated by the sun
- Disappears at night because ions and free electrons are close enough together to recombine quickly when no UV is present, returning to a neutral condition
- At night, the D and E regions disappear and the F1 and F2 regions combine to form a single F region

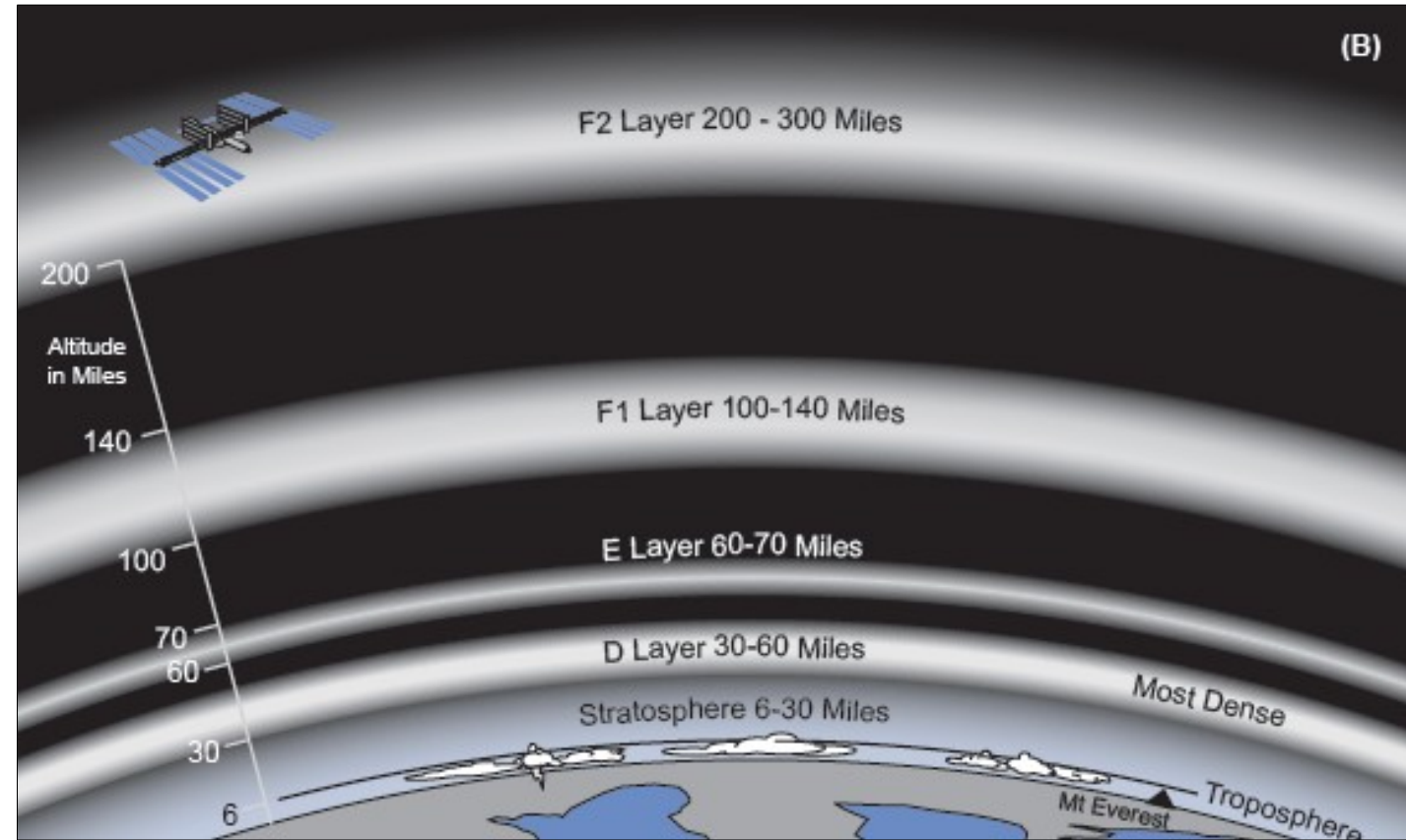


Figure 8.1 — The ionosphere consists of several regions of ionized particles at different heights above the Earth.

Ionosphere (cont.)

- E layer (60 to 70 miles in altitude) acts similarly to D
 - Higher and less dense than D region, enables it to last longer after sunset
- F layer (100 to 300 miles in altitude), least dense of the three
 - Remains partially ionized at night
 - During the day, F region splits into F1 and F2
 - Height of the F region varies quite a bit with local time, season, latitude, and solar activity
 - At any particular location, the stronger the illumination from the sun, the higher the F2 layer will be, so its maximum height is reached at noon when the sun is overhead

Reflection

- Ionosphere refracts radio waves (it's a weak conductor)
 - Refraction amount depends on amount of ionization and wave frequency
 - The HIGHER the ionization, the more the refraction
 - The LOWER the frequency, the more the refraction
 - HF signals ... relatively good refraction ... REFLECTED back to the Earth's surface
 - VHF & UHF signals ... essentially no refraction
 - See Figure 8.2
- Each reflection is a *hop*; allows signal to be received hundreds or thousands of miles away (called *skywave*; propagation via the ionosphere is called *skip*)

Reflection (cont.)

- The higher the region from which the reflection takes place, the longer the hop
- Waves reflected from F2 layer travel up to 2,500 miles before returning to ground
- Hops from E layer are shorter, up to 1,200 miles, because of lower reflecting height
- Some combinations of frequency and ionization level result in weak bending ... wave must leave the Earth's surface at a *low enough angle* for the bending of the wave to send it back
 - Highest takeoff angle at which a wave can be returned to Earth is the *critical angle*
 - Critical angle depends on ionospheric conditions and frequency

Critical Angle

Highest takeoff angle at which a wave can be returned to Earth

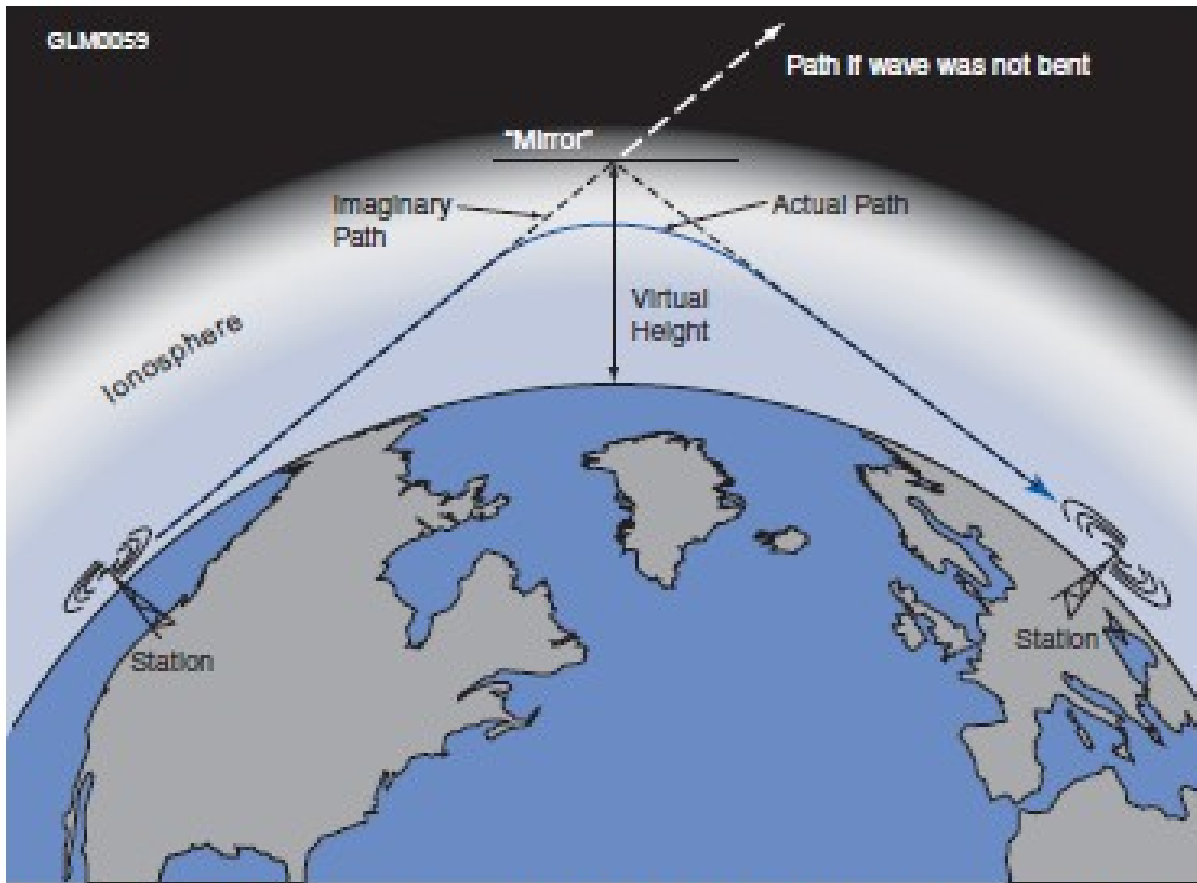


Figure 8.2 — Radio waves are refracted (bent) in the ionosphere, so they return to Earth far from the transmitting station. Without refraction in the ionosphere, radio waves would pass into space. (Not to scale)

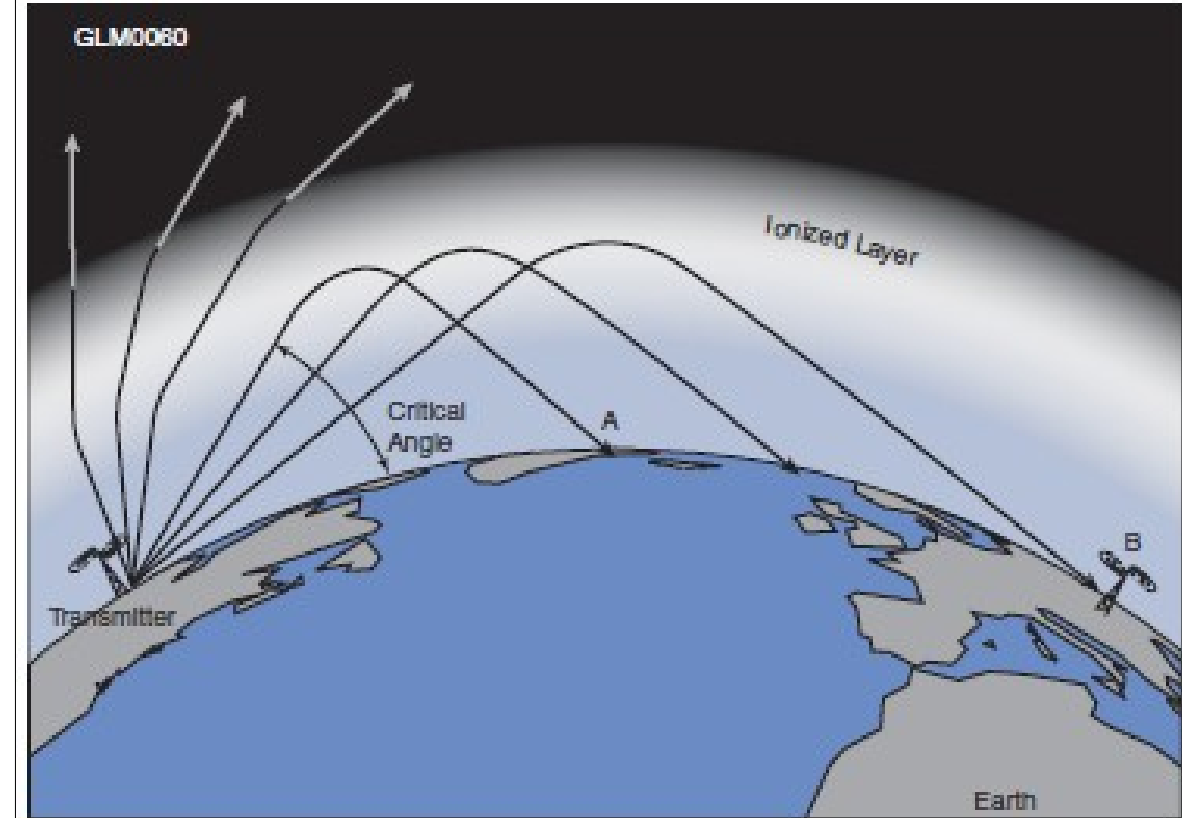


Figure 8.3 — Waves that leave the transmitting antenna above the critical angle are refracted in the ionosphere, but not enough to return to Earth. Waves at and below the critical angle will return to Earth. The lowest angle waves return to Earth at the greatest distance, which is why low angles of radiation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

Critical frequency: Highest frequency on which a wave transmitted straight up will be returned to Earth.

Absorption

- Enemy of propagation is *absorption*
 - In D and E regions, waves passing through the denser gas are partially absorbed (D region is not very good at refraction)
- In HF bands below 10 MHz, AM broadcast bands, and at lower frequencies, the D region completely absorbs radio waves *during the day*, preventing those waves from returning to Earth
- Absorption increases in daytime and when solar UV is more intense
 - **QUESTION:** When is the best time to transmit on HF below 10 MHz?

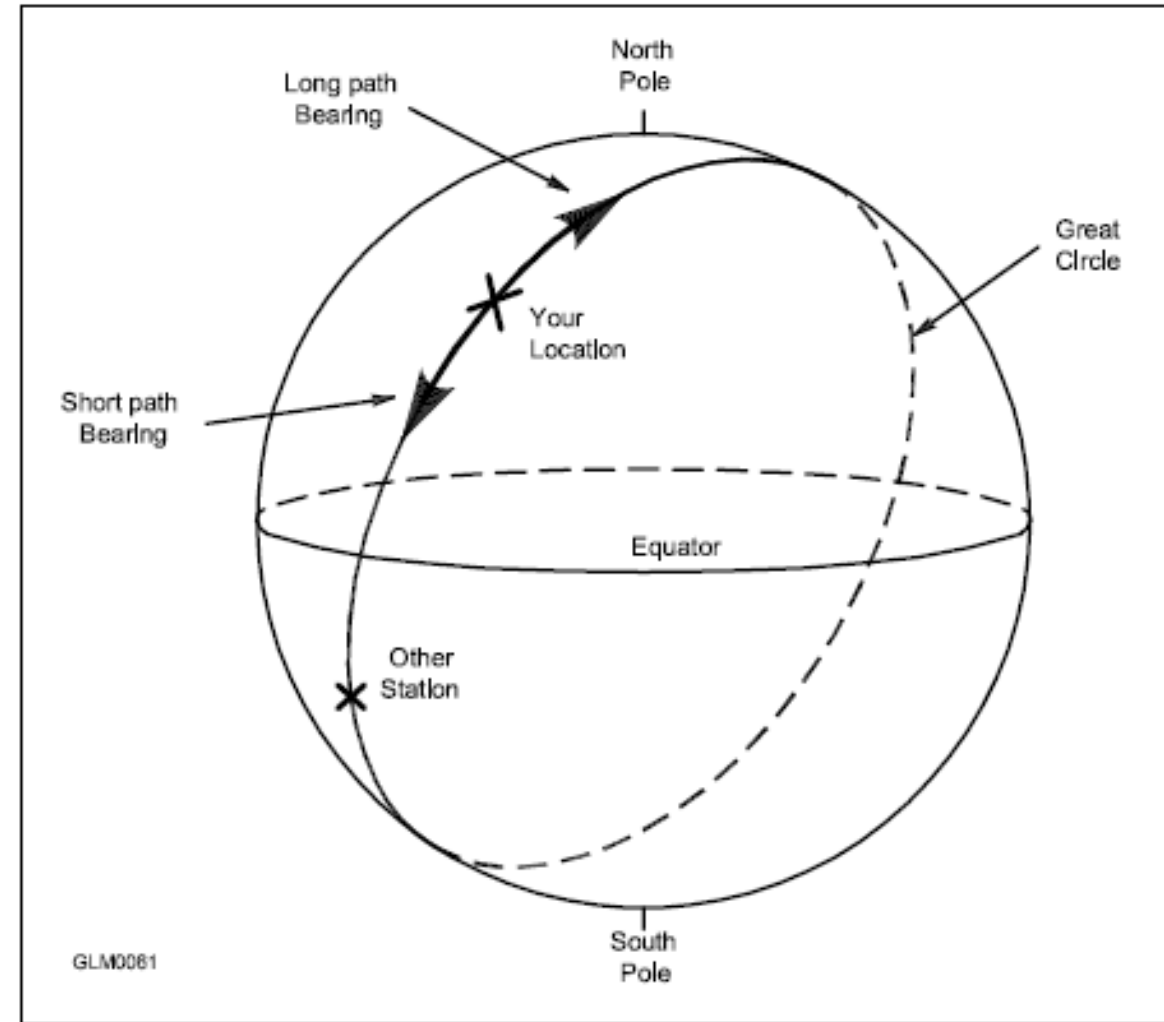
Answer: At night!

Noise

- Noise is another enemy of propagation (covers up weak signals)
- Stronger at frequencies below VHF (due to atmospheric disturbances)
- Lower you go in frequency, the stronger the noise or *static*
- Varies seasonally
- Most noticeable on lower frequency HF bands in the summer when atmospheric noise is strongest

Long Path and Short Path

- When ionosphere along short path does not support propagation, sometimes long path will
- Occasionally, propagation over both long and short paths will be supported (at same time)
- Unless the paths are almost equal there will be an echo (delayed signal arrives a fraction of a second later)
- **Round-the-world propagation:** you can hear your own signal coming all the way around to your location about 1/7 of a second later!
 - 25,000 miles divided by 186,000 miles/sec



This sketch of the Earth shows both great circle paths drawn between two stations. The bearings for the *short path* and the *long path* are shown from the Northern Hemisphere station.

PRACTICE QUESTIONS

How is a directional antenna pointed when making a “long-path” contact with another station?

- A. Toward the rising sun
- B. Along the grayline
- C. 180 degrees from the station’s short-path heading
- D. Toward the north

What is a characteristic of skywave signals arriving at your location by both short-path and longpath propagation?

- A. Periodic fading approximately every 10 seconds
- B. Signal strength increased by 3 dB
- C. The signal might be cancelled causing severe attenuation
- D. A slightly delayed echo might be heard

What is the approximate maximum distance along the Earth's surface normally covered in one hop using the F2 region?

- A. 180 miles
- B. 1,200 miles
- C. 2,500 miles
- D. 12,000 miles

What is the approximate maximum distance along the Earth's surface normally covered in one hop using the E region?

- A. 180 miles
- B. 1,200 miles
- C. 2,500 miles
- D. 12,000 miles

Which ionospheric region is closest to the surface of Earth?

- A. The D region
- B. The E region
- C. The F1 region
- D. The F2 region

What is meant by the term “critical frequency” at a given incidence angle?

- A. The highest frequency which is refracted back to Earth
- B. The lowest frequency which is refracted back to Earth
- C. The frequency at which the signal-to-noise ratio approaches unity
- D. The frequency at which the signal-to-noise ratio is 6 dB

Why is skip propagation via the F2 region longer than that via the other ionospheric regions?

- A. Because it is the densest
- B. Because of the Doppler effect
- C. Because it is the highest
- D. Because of temperature inversions

What does the term “critical angle” mean, as applied to radio wave propagation?

- A. The long path azimuth of a distant station
- B. The short path azimuth of a distant station
- C. The lowest takeoff angle that will return a radio wave to Earth under specific ionospheric conditions
- D. The highest takeoff angle that will return a radio wave to Earth under specific ionospheric conditions

Why is long-distance communication on the 40-, 60-, 80-, and 160-meter bands more difficult during the day?

- A. The F region absorbs signals at these frequencies during daylight hours
- B. The F region is unstable during daylight hours
- C. The D region absorbs signals at these frequencies during daylight hours
- D. The E region is unstable during daylight ho

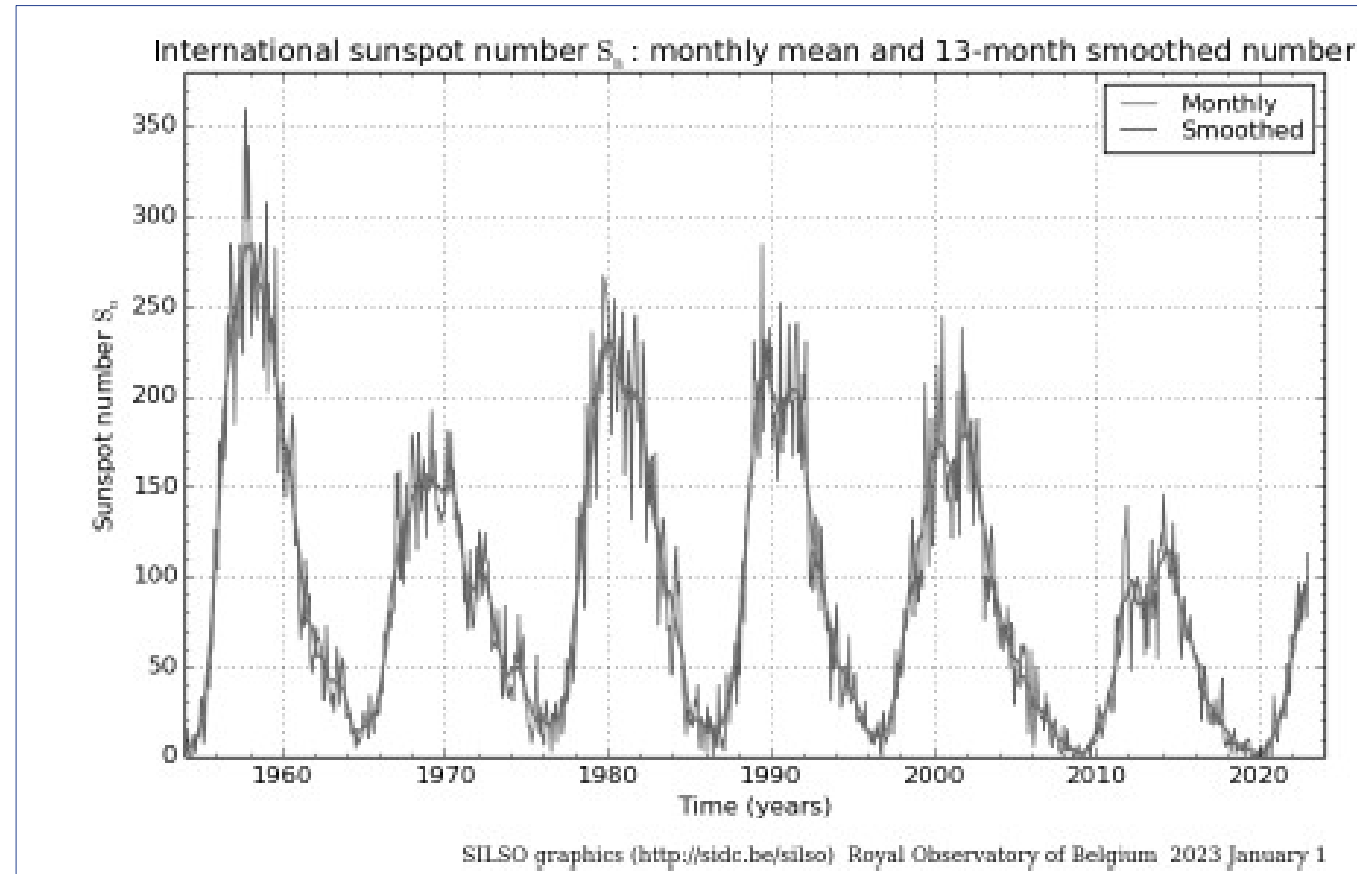
Which ionospheric region is the most absorbent of signals below 10 MHz during daylight hours?

- A. The F2 region
- B. The F1 region
- C. The E region
- D. The D region

Section 8.2: The Sun

Sunspots and Cycles

- Ionosphere is dependent on solar UV to separate electrons from atoms
- Much of the variation in UV radiation is due to sunspot activity
- One complete sunspot cycle lasts about 11 years
- When more sunspots are observed, more UV is being generated, creating more intense ionization and improving propagation on higher frequency bands above 10 MHz and even into lower VHF range



This graph shows the monthly mean sunspot numbers for several past cycles through October 2018. The NASA Solar Physics web page maintains complete data on the sunspot cycle.

In mid 2023, when this book is being published, Cycle 25 is heating up and propagation on 10 meters and other bands is increasing.

Sunspots and Cycles (cont.)

- At peak of cycle, there may be sufficient solar UV to cause higher frequency bands (10 meters) to stay open for long-distance contacts at night
- High ionization negatively impacts low frequency bands (80 and 160 m) because it increases absorption
- When solar activity is low, lower HF bands have good propagation and higher HF bands above 20 MHz (15 m and up) are often closed
- One band that seems to do well at all times in sunspot cycle is 20 meters (14 MHz), supporting daytime communications worldwide nearly every day

Table 8.1: Daytime/Nighttime HF Propagation

HF BAND (m)	DAYTIME	NIGHTTIME
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

Sunspots also seem to move across the sun’s surface because the sun rotates once every 28 days. That is why propagation conditions (good and bad) on the HF bands often repeat themselves in 28-day cycles as sunspots rotate back into view from Earth.

Measuring Solar Activity

Solar activity is so important to propagation and communications that it is monitored constantly by solar observatories worldwide

- Sunspot Number: See Fig 8.6
- Solar-Flux Index (SFI): Describes amount of 2800 MHz ($\lambda = 10.7$ cm) radio energy. Higher levels indicate higher solar activity and better HF propagation above 10 MHz (Fig 8.6)
- K-index: Values from 0 to 9 represent the short-term stability of the Earth's magnetic or geomagnetic field. Higher values indicate geomagnetic field is disturbed, which disrupts HF.
- A-index: Gives a good picture of long-term geomagnetic field stability. Ranges from 0 (stable) to 400 (greatly disturbed). Calculated from K-index.

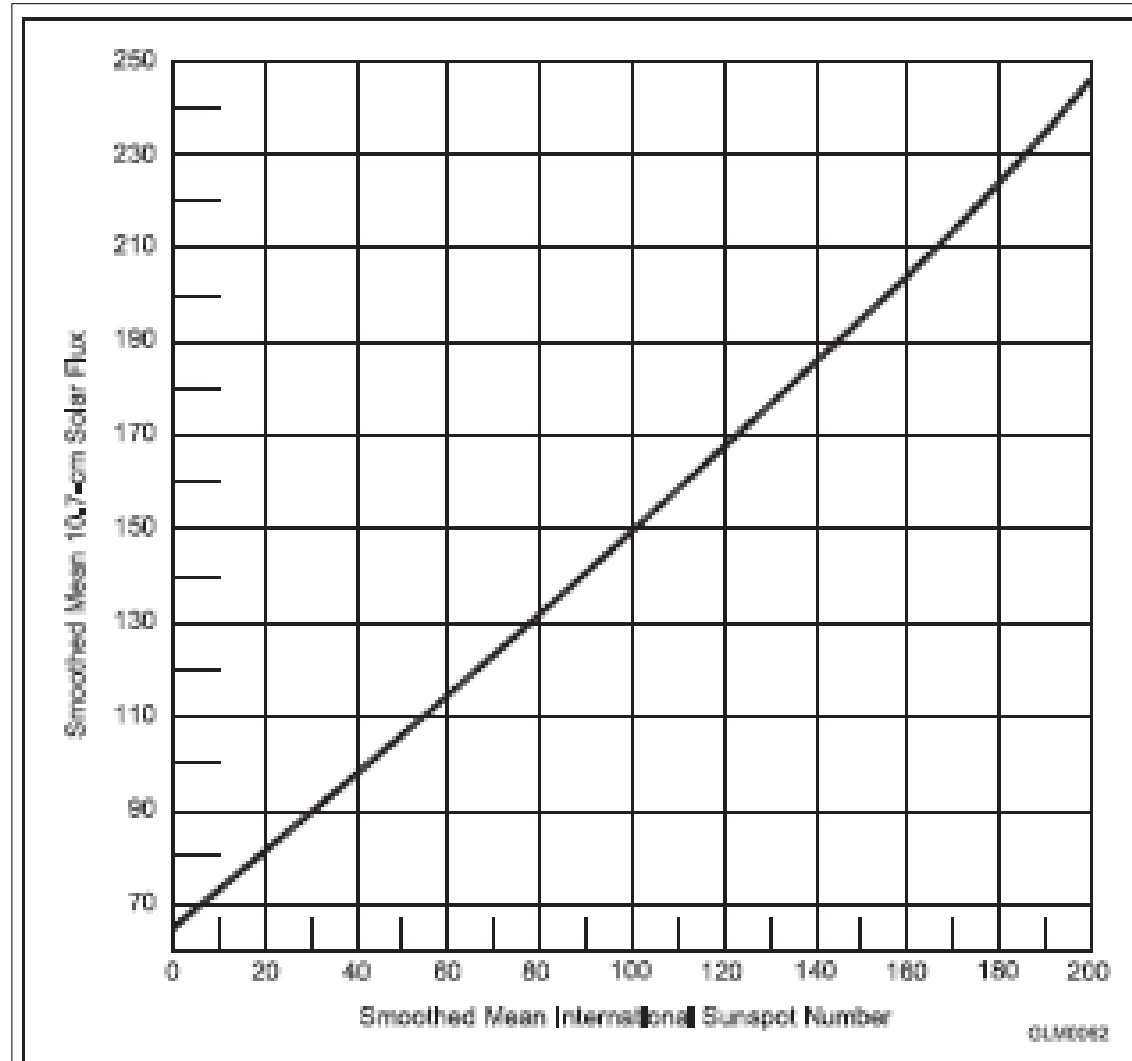


Figure 8.6 — This graph shows the approximate correlation between solar flux and sunspot number. Note that the minimum solar flux is 65, corresponding to a sunspot number of 0.

PRACTICE QUESTIONS

How does a higher sunspot number affect HF propagation?

- A. Higher sunspot numbers generally indicate a greater probability of good propagation at higher frequencies
- B. Lower sunspot numbers generally indicate greater probability of sporadic E propagation
- C. A zero sunspot number indicates that radio propagation is not possible on any band
- D. A zero sunspot number indicates undisturbed conditions

Which of the following are least reliable for long-distance communications during periods of low solar activity?

- A. 80 meters and 160 meters
- B. 60 meters and 40 meters
- C. 30 meters and 20 meters
- D. 15 meters, 12 meters, and 10 meters

What is the solar flux index?

- A. A measure of the highest frequency that is useful for ionospheric propagation between two points on Earth
- B. A count of sunspots that is adjusted for solar emissions
- C. Another name for the American sunspot number
- D. A measure of solar radiation at 10.7 centimeters wavelength

At what point in the solar cycle does the 20-meter band usually support worldwide propagation during daylight hours?

- A. At the summer solstice
- B. Only at the maximum point of the solar cycle
- C. Only at the minimum point of the solar cycle
- D. At any point in the solar cycle

What causes HF propagation conditions to vary periodically in a 26- to 28-day cycle?

- A. Long term oscillations in the upper atmosphere
- B. Cyclic variation in Earth's radiation belts
- C. Rotation of the Sun's surface layers around its axis
- D. The position of the Moon in its orbit

What does the K-index measure?

- A. The relative position of sunspots on the surface of the Sun
- B. The short-term stability of Earth's geomagnetic field
- C. The short-term stability of the Sun's magnetic field
- D. The solar radio flux at Boulder, Colorado

What does the A-index measure?

- A. The relative position of sunspots on the surface of the Sun
- B. The amount of polarization of the Sun's electric field
- C. The long-term stability of Earth's geomagnetic field
- D. The solar radio flux at Boulder, Colorado

Which of the following is typical of the lower HF frequencies during the summer?

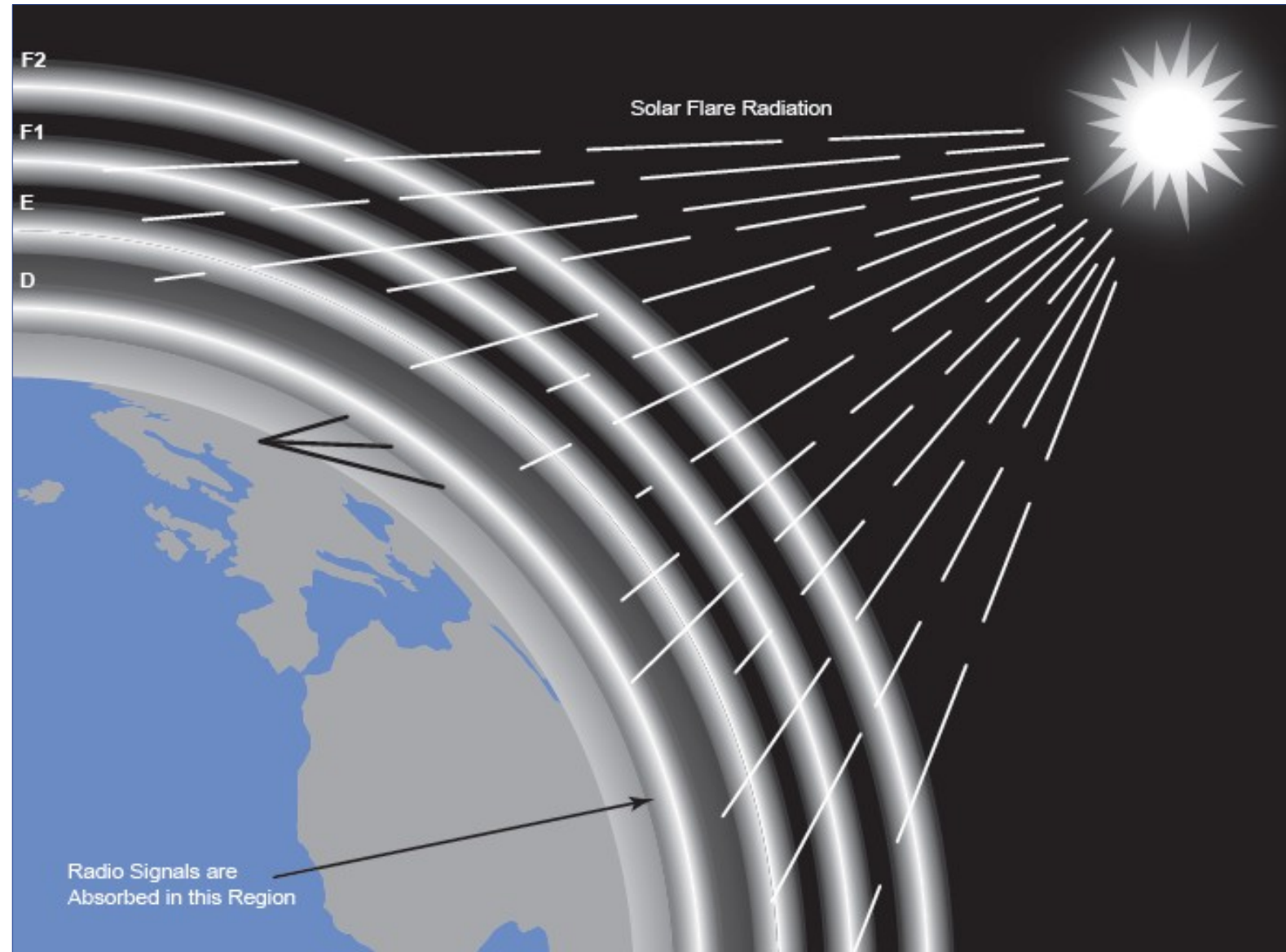
- A. Poor propagation at any time of day
- B. World-wide propagation during daylight hours
- C. Heavy distortion on signals due to photon absorption
- D. High levels of atmospheric noise or static

Assessing Propagation

- MUF: *Maximum usable frequency*. Highest frequency at which propagation exists between two points.
- LUF: *Lowest usable frequency*. Waves below the LUF will be completely absorbed by the ionosphere.
- MUF & LUF depend on specific path between two points — location and distance apart
- Varies with time of day, season, amount of solar radiation, and ionospheric stability
- Operating near MUF often gives excellent results; absorption is lowest just below it
- One way to check actual band conditions is to listen for propagation beacons; some provide real-time propagation information
 - Many stations between 28.190 and 28.225 MHz that are excellent sources of information about 10-meter propagation
- To make contact with a distant station, you will have to use a frequency between LUF and MUF so the wave is bent back to Earth but isn't absorbed
- If MUF drops below LUF, then no propagation exists between those two points via ordinary skywave

Solar Disturbances

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 Disturbances (cont.)

- Solar flare: A large eruption of energy and solar material when magnetic field disruptions occur on the surface of the sun.
- Coronal hole: A weak area in the sun's corona (the outer layer) through which plasma (ionized gas and charged particles) escapes the sun's magnetic field and streams away into space at high velocities.
- Coronal mass ejection (CME): An ejection of large amounts of material from the corona.

*All of these disrupt **HF** propagation*

Sudden Ionospheric Disturbances

- UV and X-ray radiation from a solar flare travels at speed of light to impact the ionosphere about 8 minutes later
- When radiation hits the ionosphere, the level of ionization increases rapidly, particularly in *D* region
- This increases absorption dramatically, causing a *sudden ionospheric disturbance* (SID) also known as a *radio blackout*
- Lower bands are more strongly affected, but communication may still be possible on a higher band
- SIDs affect only the sunlit side of the Earth; dark-side communications may be relatively unaffected

Geomagnetic Disturbances

- Interaction between *solar wind* and geomagnetic field creates a region of space called the *magnetosphere*
- Charged particles from coronal holes and coronal mass ejections travel considerably slower and take longer to reach Earth (15 to 40 hours)
- These particles deposit their energy into Earth's geomagnetic field and increase ionization in E region, causing auroral displays and creating a *geomagnetic storm* ... affects *higher HF* bands first
- Long-distance paths that traverse high latitudes, particularly those that pass near the magnetic poles, may be completely wiped out for hours to days
- Can create *auroras* that reflect radio waves above 20 MHz
- Auroral propagation is strongest on 6 and 2 m, modulating the signals with a hiss or buzz

PRACTICE QUESTIONS

What effect does a sudden ionospheric disturbance have on the daytime ionospheric propagation?

- A. It enhances propagation on all HF frequencies
- B. It disrupts signals on lower frequencies more than those on higher frequencies
- C. It disrupts communications via satellite more than direct communications
- D. None, because only areas on the night side of the Earth are affected

Approximately how long does it take the increased ultraviolet and X-ray radiation from solar flares to affect radio propagation on Earth?

- A. 28 days
- B. 1 to 2 hours
- C. 8 minutes
- D. 20 to 40 hours

What is a geomagnetic storm?

- A. A sudden drop in the solar flux index
- B. A thunderstorm that affects radio propagation
- C. Ripples in the geomagnetic force
- D. A temporary disturbance in Earth's geomagnetic field

How can a geomagnetic storm affect HF propagation?

- A. Improve high-latitude HF propagation
- B. Degrade ground wave propagation
- C. Improve ground wave propagation
- D. Degrade high-latitude HF propagation

How can high geomagnetic activity benefit radio communications?

- A. Creates auroras that can reflect VHF signals
- B. Increases signal strength for HF signals passing through the polar regions
- C. Improve HF long path propagation
- D. Reduce long delayed echoes

How long does it take a coronal mass ejection to affect radio propagation on Earth?

- A. 28 days
- B. 14 days
- C. 4 to 8 minutes
- D. 15 hours to several days

How is long distance radio communication usually affected by the charged particles that reach Earth from solar coronal holes?

- A. HF communication is improved
- B. HF communication is disturbed
- C. VHF/UHF ducting is improved
- D. VHF/UHF ducting is disturbed

What factors affect the MUF?

- A. Path distance and location
- B. Time of day and season
- C. Solar radiation and ionospheric disturbances
- D. All these choices are correct

Which frequency will have the least attenuation for long-distance skip propagation?

- A. Just below the MUF
- B. Just above the LUF
- C. Just below the critical frequency
- D. Just above the critical frequency

Which of the following is a way to determine current propagation on a desired band from your station?

- A. Use a network of automated receiving stations on the internet to see where your transmissions are being received
- B. Check the A-index
- C. Send a series of dots and listen for echoes
- D. All these choices are correct

How does the ionosphere affect radio waves with frequencies below the MUF and above the LUF?

- A. They are refracted back to Earth
- B. They pass through the ionosphere
- C. They are amplified by interaction with the ionosphere
- D. They are refracted and trapped in the ionosphere to circle Earth

What usually happens to radio waves with frequencies below the LUF?

- A. They are refracted back to Earth
- B. They pass through the ionosphere
- C. They are attenuated before reaching the destination
- D. They are refracted and trapped in the ionosphere to circle Earth

What does LUF stand for?

- A. The Lowest Usable Frequency for communications between two specific points
- B. Lowest Usable Frequency for communications to any point outside a 100-mile radius
- C. The Lowest Usable Frequency during a 24-hour period
- D. Lowest Usable Frequency during the past 60 minutes

What does MUF stand for?

- A. The Minimum Usable Frequency for communications between two points
- B. The Maximum Usable Frequency for communications between two points
- C. The Minimum Usable Frequency during a 24-hour period
- D. The Maximum Usable Frequency during a 24-hour period

What happens to HF propagation when the LUF exceeds the MUF?

- A. Propagation via ordinary skywave communications is not possible over that path
- B. HF communications over the path are enhanced
- C. Double-hop propagation along the path is more common
- D. Propagation over the path on all HF frequencies is enhanced

Section 8.3: Scatter Modes

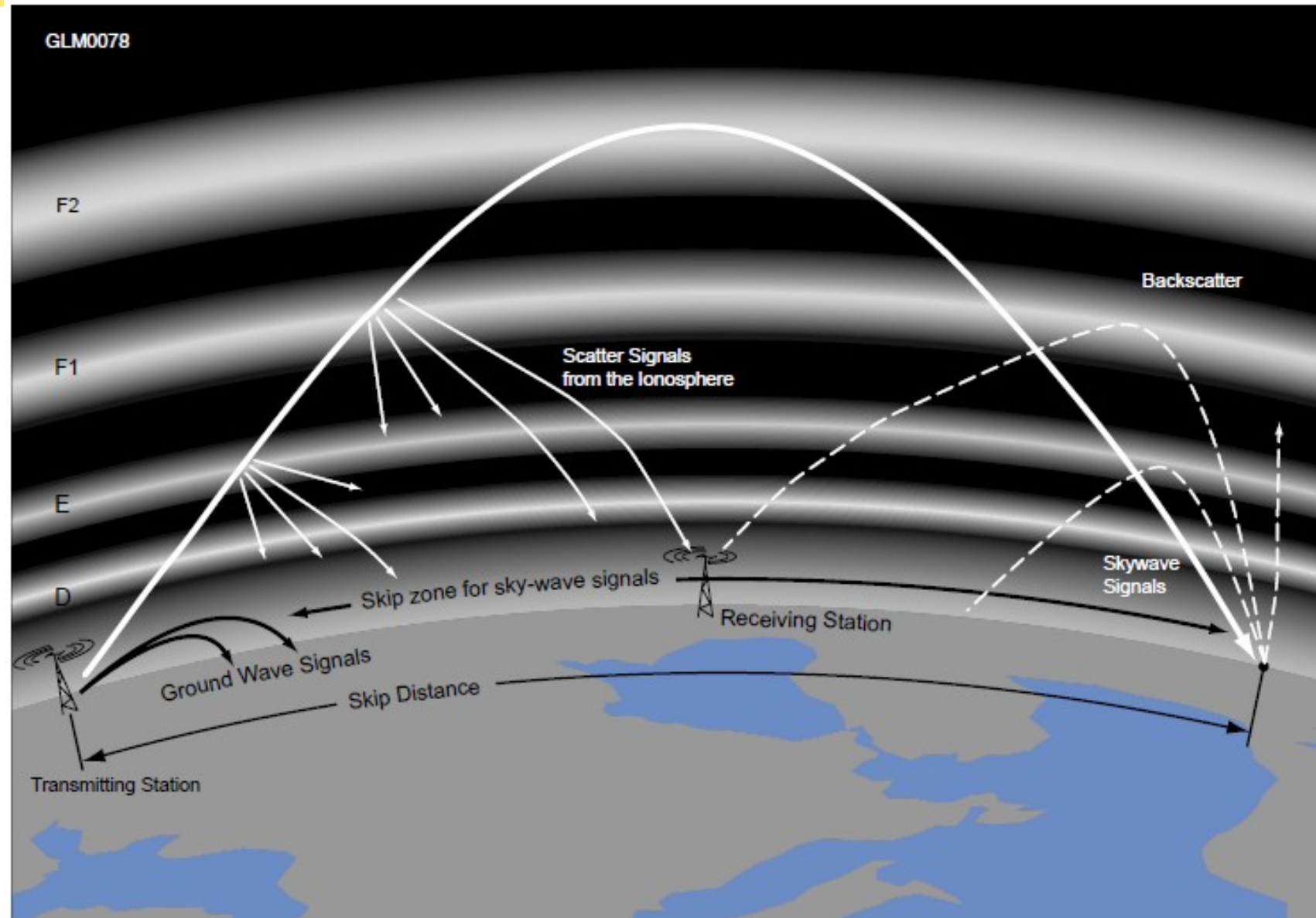
Scatter Characteristics

- Backscatter: Reflections from features on Earth's surface
- Waves can also be *scattered* from within the ionosphere, allowing signals to be heard from stations too distant to be heard by ground wave and on frequencies too high for short hop sky-wave propagation
- Scatter and backscatter help fill in the skip zone where signals would otherwise not be heard
- Signals received via HF scatter are usually weaker than those received by normal skywave propagation (reflection is not very efficient and tends to spread out the signal); such signals sound distorted, resulting in *fluttering* or *wavering*

Fig 8.8

Scatter and Backscatter

On striking the ground after ionospheric reflection, radio waves may be reflected back toward the transmitting station. Backscatter consists of signals reflected by the ground back into the skip zone. Backscatter supports communication between stations that would otherwise be in each other's skip zone.



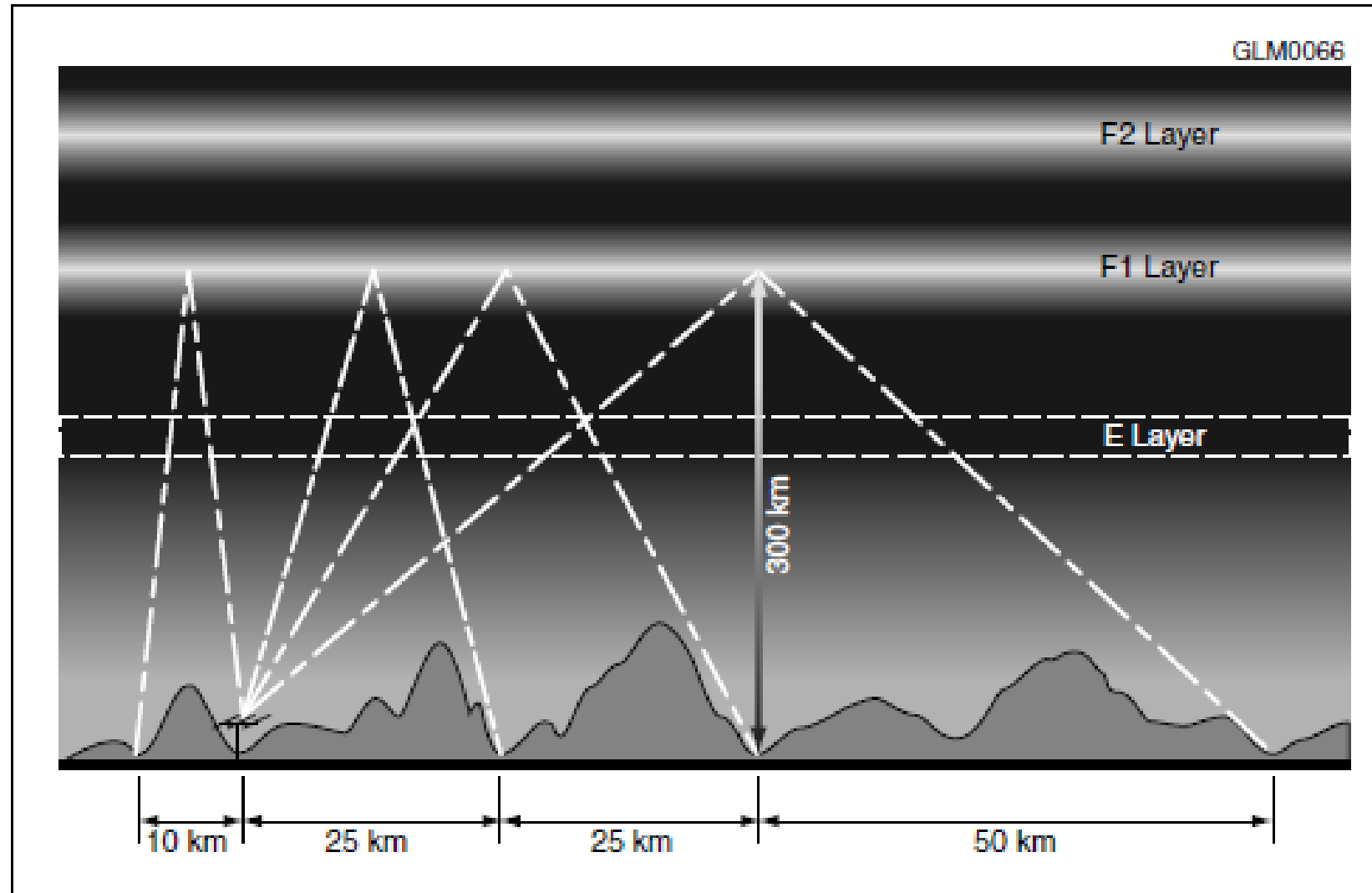
Near Vertical Incidence Sky-wave (NVIS)

- For a signal below the critical frequency, the ionosphere reflects waves arriving at any angle — even vertical (always above 5 MHz, up to 40 meters)
- NVIS Definition: For a signal below the critical frequency, when it is radiated vertically the reflection scatters the signal back to Earth throughout a region of up to 200-300 miles
- To make use of NVIS, horizontally polarized dipoles are placed low to the ground so that their radiation pattern is almost omnidirectional and concentrated at high elevation angles

Fig 8.9

NVIS Communications

Near vertical incidence sky-wave (NVIS) communications relies on signals below the critical frequency transmitted at high vertical angles. The signals are reflected by the ionosphere back to Earth in the region around the transmitter.



PRACTICE QUESTIONS

What is a characteristic of HF scatter?

- A. Phone signals have high intelligibility
- B. Signals have a fluttering sound
- C. There are very large, sudden swings in signal strength
- D. Scatter propagation occurs only at night

What makes HF scatter signals often sound distorted?

- A. The ionospheric region involved is unstable
- B. Ground waves are absorbing much of the signal
- C. The E region is not present
- D. Energy is scattered into the skip zone through several different paths

Why are HF scatter signals in the skip zone usually weak?

- A. Only a small part of the signal energy is scattered into the skip zone
- B. Signals are scattered from the magnetosphere, which is not a good reflector
- C. Propagation is via ground waves, which absorb most of the signal energy
- D. Propagation is via ducts in the F region, which absorb most of the energy

What type of propagation allows signals to be heard in the transmitting station's skip zone?

- A. Faraday rotation
- B. Scatter
- C. Chordal hop
- D. Short-path

What is near vertical incidence skywave (NVIS) propagation?

- A. Propagation near the MUF
- B. Short distance MF or HF propagation using high elevation angles
- C. Long path HF propagation at sunrise and sunset
- D. Double hop propagation near the LUF

END OF CHAPTER 8 PART 1 OF 1

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Feel free to contact me if you find errors or have suggestions for improvement.