Amateur Radio Technician Exam Preparation

ARRL
The National Association for Amateur Radio®

Amateur Radio Technician Exam Prep Course

Module 4

Propagation, Antennas, and Feed Lines

Propagation

- Radio waves propagate in many ways depending on …
  - Frequency of the wave
  - Characteristics of the environment

- We will discuss three basic ways:
  - Line of sight
  - Ground wave
  - Sky wave

Line of Sight

- Radio energy can travel in a straight line from a transmitting antenna to a receiving antenna – called the *direct path*
- There is some attenuation of the signal as the radio wave travels due to spreading out
- This is the primary propagation mode for VHF and UHF signals
- Radio waves can be reflected by any sudden change in the path they are traveling, such as a building, hill, or even weather-related changes in the atmosphere
- Vegetation can also absorb VHF and UHF radio waves
- Precipitation such as fog and rain can absorb microwave and UHF radio waves although it has little effect at HF and on the lower VHF Bands

Ground Wave

- At lower HF frequencies radio waves can follow the Earth's surface
- These waves will travel beyond the range of line-of-sight
- Range of a few hundred miles

Reflect, Refract, Diffract

- Radio waves are reflected by any conductive surface
  - Ground, water, buildings
- *Refraction* or bending occurs when waves encounter a medium having a different speed of light, such as water or an electrical feed line
- By bending signals slightly back towards the ground, refraction counteracts the curvature of the Earth and allows signals to be received at distances beyond the visual horizon
- *Knife edge diffraction*: Diffraction as waves travel past sharp edges of large objects

Multipath

- Radio signals arriving at a receiver after taking different paths from the transmitter
- Results in irregular fading, even when reception is generally good
- Because "dead spots" from multipath are usually spaced about ½-wavelength apart, VHF or UHF signals from a station in motion can take on a rapid variation in strength known as *mobile flutter* or *picket-fencing*
- Distortion caused by multipath can also cause VHF and UHF digital data signals to be received with a higher error rate, even though the signal may be strong

Tropospheric Propagation

- Propagation at and above VHF frequencies are assisted by variations in the atmosphere
- Variations such as weather fronts or temperature inversions create layers of air next to each other that have different characteristics
- The layers form structures called ducts that can guide even microwave signals for long distances
- Regularly used by amateurs to make VHF and UHF contacts that would otherwise be impossible by line-of-sight propagation (300 miles or more)

PRACTICE QUESTIONS

Why do VHF signal strengths sometimes vary greatly when the antenna is moved only a few feet?

A. The signal path encounters different concentrations of water vapor
B. VHF ionospheric propagation is very sensitive to path length
C. Multipath propagation cancels or reinforces signals
D. All these choices are correct

T3A01 C 4-1

What is the effect of vegetation on UHF and microwave signals?

A. Knife-edge diffraction
B. Absorption
C. Amplification
D. Polarization rotation

T3A02 B 4-1

What is the meaning of the term “picket fencing”?

A. Alternating transmissions during a net operation
B. Rapid flutter on mobile signals due to multipath propagation
C. A type of ground system used with vertical antennas
D. Local vs long-distance communications

T3A06 B 4-1

What weather condition might decrease range at microwave frequencies?

A. High winds
B. Low barometric pressure
C. Precipitation
D. Colder temperatures

T3A07 C 4-1

What is a likely cause of irregular fading of signals propagated by the ionosphere?

A. Frequency shift due to Faraday rotation
B. Interference from thunderstorms
C. Intermodulation distortion
D. Random combining of signals arriving via different paths

T3A08 D 4-1

What effect does multi-path propagation have on data transmissions?

A. Transmission rates must be increased by a factor equal to the number of separate paths observed
B. Transmission rates must be decreased by a factor equal to the number of separate paths observed
C. No significant changes will occur if the signals are transmitted using FM
D. Error rates are likely to increase

T3A10 D 4-1

What is the effect of fog and rain on signals in the 10 meter and 6 meter bands?

A. Absorption
B. There is little effect
C. Deflection
D. Range increase

T3A12 B 4-1

Which of the following effects may allow radio signals to travel beyond obstructions between the transmitting and receiving stations?

A. Knife-edge diffraction
B. Faraday rotation
C. Quantum tunneling
D. Doppler shift

T3C05 A 4-1

What type of propagation is responsible for allowing over-the-horizon VHF and UHF communications to ranges of approximately 300 miles on a regular basis?

A. Tropospheric ducting
B. D region refraction
C. F2 region refraction
D. Faraday rotation

T3C06 A 4-1

What causes tropospheric ducting?

A. Discharges of lightning during electrical storms
B. Sunspots and solar flares
C. Updrafts from hurricanes and tornadoes
D. Temperature inversions in the atmosphere

T3C08 D 4-2

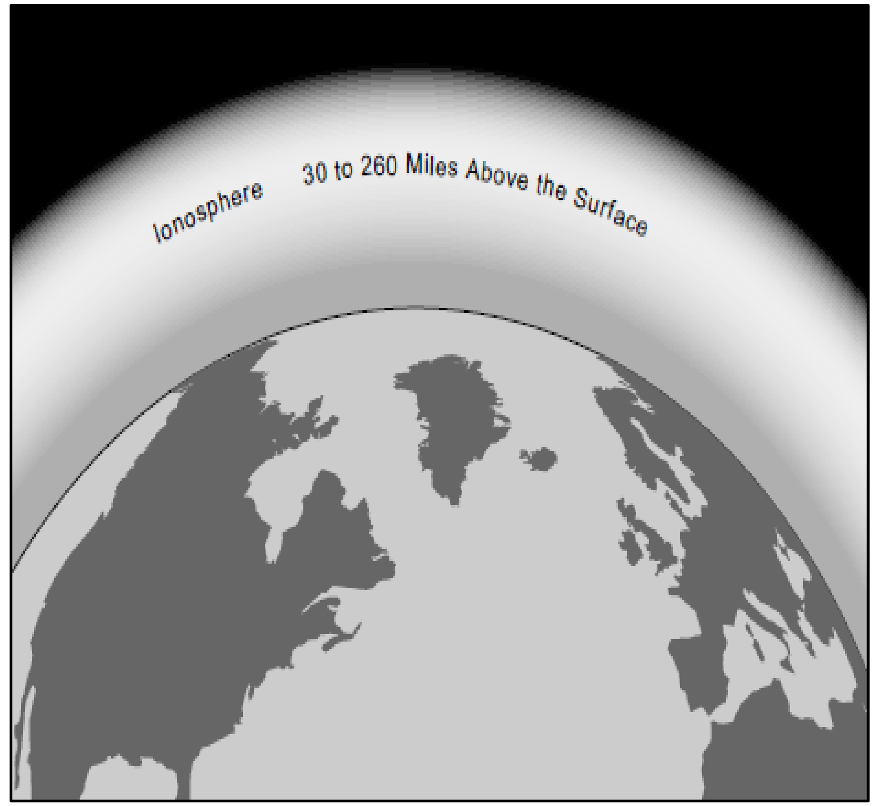
Why is the radio horizon for VHF and UHF signals more distant than the visual horizon?

A. Radio signals move somewhat faster than the speed of light
B. Radio waves are not blocked by dust particles
C. The atmosphere refracts radio waves slightly
D. Radio waves are blocked by dust particles

T3C11 C 4-2

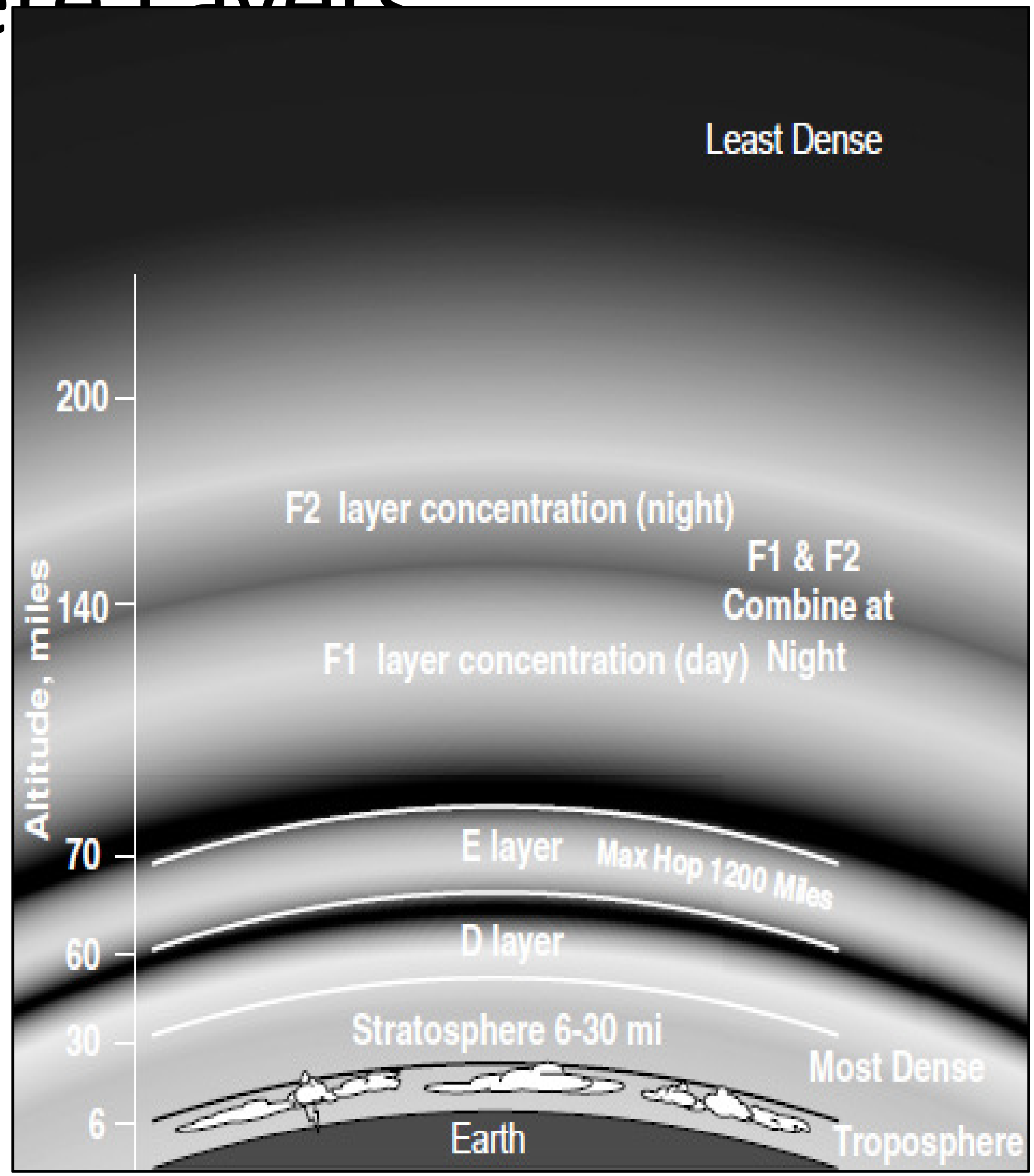
The Ionosphere

- 30 to 260 miles above Earth's surface
- Atmosphere thin enough for atoms to be ionized by solar ultraviolet radiation
- Ions are electrically *conductive*
- Because of varying density, the ionosphere



Ionosphere Layers

- Layers: D, E, F1 and F2
- Depending on whether it is night or day and on the intensity of solar radiation, these layers can *refract* (E, F1 and F2 layers) or *absorb* (D and E



Sunspot Cycle / Activity

- The level of ionization depends on the intensity of radiation from the Sun
- Radiation from the Sun varies with the number of sunspots on the Sun's surface
- High number of sunspots results in high levels of ionizing radiation emitted from the Sun
- Sunspot activity follows an 11-year cycle
- *F* layers can reflect 6 meter (50 MHz) signals at the sunspot cycle's peak

The Ionosphere – An RF Mirror

- Ionosphere can refract radio waves back to Earth – acts like reflection
- Most refraction occurs in the *F* layer
- Reflection

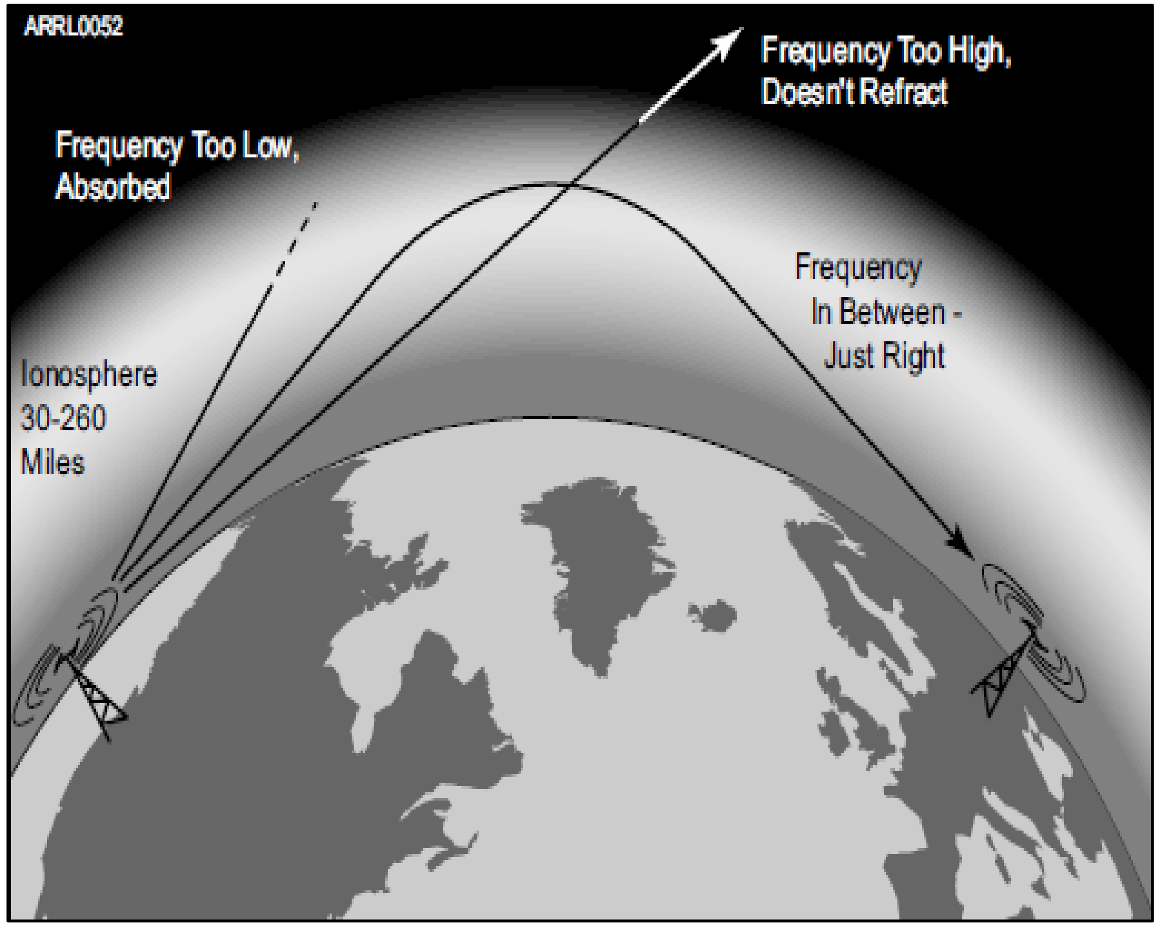


Fig 4.2: Signals in the right range of frequencies are refracted back toward the Earth and are received hundreds or thousands

Ionosphere (cont.)

- The highest frequency signal that can be reflected back to a point on the Earth between the transmitter and receiver is the *maximum usable frequency*
- Sky-wave or skip propagation is responsible for most over-the-horizon propagation on HF and low VHF (10 and 6 meters) during peaks of the sunspot cycle
- Skip is very rare on the 144 MHz and higher UHF bands
- *E* region of the ionosphere is also home to

PRACTICE QUESTIONS

Which region of the atmosphere can refract or bend HF and VHF radio waves?

A. The stratosphere
B. The troposphere
C. The ionosphere
D. The mesosphere

T3A11 C 4-3

Why are simplex UHF signals rarely heard beyond their radio horizon?

A. They are too weak to go very far
B. FCC regulations prohibit them from going more than 50 miles
C. UHF signals are usually not propagated by the ionosphere
D. UHF signals are absorbed by the ionospheric D region

T3C01 C 4-3

What is a characteristic of HF communication compared with communications on VHF and higher frequencies?

A. HF antennas are generally smaller
B. HF accommodates wider bandwidth signals
C. Long-distance ionospheric propagation is far more common on HF
D. There is less atmospheric interference (static) on HF

T3C02 C 4-3

What is a characteristic of VHF signals received via auroral backscatter?

A. They are often received from 10,000 miles or more
B. They are distorted and signal strength varies considerably
C. They occur only during winter nighttime hours
D. They are generally strongest when your antenna is aimed west

T3C03 B 4-3

Which of the following types of propagation is most commonly associated with occasional strong signals on the 10, 6, and 2 meter bands from beyond the radio horizon?

A. Backscatter
B. Sporadic E
C. D region absorption
D. Gray-line propagation

T3C04 B 4-3

What band is best suited for communicating via meteor scatter?

A. 33 centimeters
B. 6 meters
C. 2 meters
D. 70 centimeters

T3C07 B 4-3

What is generally the best time for long-distance 10 meter band propagation via the F region?

A. From dawn to shortly after sunset during periods of high sunspot activity
B. From shortly after sunset to dawn during periods of high sunspot activity
C. From dawn to shortly after sunset during periods of low sunspot activity
D. From shortly after sunset to dawn during periods of low sunspot activity

T3C09 A 4-3

Which of the following bands may provide long-distance communications via the ionosphere’s F region during the peak of the sunspot cycle?

A. 6 and 10 meters
B. 23 centimeters
C. 70 centimeters and 1.25 meters
D. All these choices are correct

T3C10 A 4-3

Antenna and Radio Wave Basics

- The antenna system …
  - Antenna: Transforms current into radio waves (transmit) and vice versa (receive)
  - Feed line: Connects your station to the antenna
  - Test and matching equipment: Allows you to monitor and optimize antenna system performance
- For an antenna to do that job efficiently, its dimensions must be an appreciable fraction of the signal's wavelength

Antenna Vocabulary

- *Element*: The conducting part or parts of an antenna designed to radiate or receive radio waves
- *Driven element*: The element supplied directly with power from the transmitter
- *Array*: An antenna with more than one element
- *Parasitic element*: Elements not connected directly to a feed line
- *Resonant*: An antenna is resonant when its feed point impedance has zero reactance
- *Feed point*: Where the transmitted energy enters the antenna

Electromagnetic Waves

Radio waves are electromagnetic waves

- Electric and magnetic fields at right angles to each other, oscillating at the wave's frequency
- Spread out into space from the antenna
- Created by AC current
- Wave and current have the same frequency

Wave Polarization

- Refers to the orientation of the radio wave's electric field
  - Vertical or horizontal – determined by elements
  - Can be circular if the orientation twists as the wave spreads through space
  - Combinations of polarization are called *elliptical polarization* (both vertical and horizontal antennas are effective for receiving and transmitting on the HF bands where skip propagation is common)
- When the polarizations of transmit and receive antennas aren't aligned the same

PRACTICE QUESTIONS

What happens when antennas at opposite ends of a VHF or UHF line of sight radio link are not using the same polarization?

A. The modulation sidebands might become inverted
B. Received signal strength is reduced
C. Signals have an echo effect
D. Nothing significant will happen

T3A04 B 4-5

Which of the following results from the fact that signals propagated by the ionosphere are elliptically polarized?

A. Digital modes are unusable
B. Either vertically or horizontally polarized antennas may be used for transmission or reception
C. FM voice is unusable
D. Both the transmitting and receiving antennas must be of the same polarization

T3A09 B 4-5

What is the relationship between the electric and magnetic fields of an electromagnetic wave?

A. They travel at different speeds
B. They are in parallel
C. They revolve in opposite directions
D. They are at right angles

T3B01 D 4-5

What property of a radio wave defines its polarization?

A. The orientation of the electric field
B. The orientation of the magnetic field
C. The ratio of the energy in the magnetic field to the energy in the electric field
D. The ratio of the velocity to the wavelength

T3B02 A 4-5

What are the two components of a radio wave?

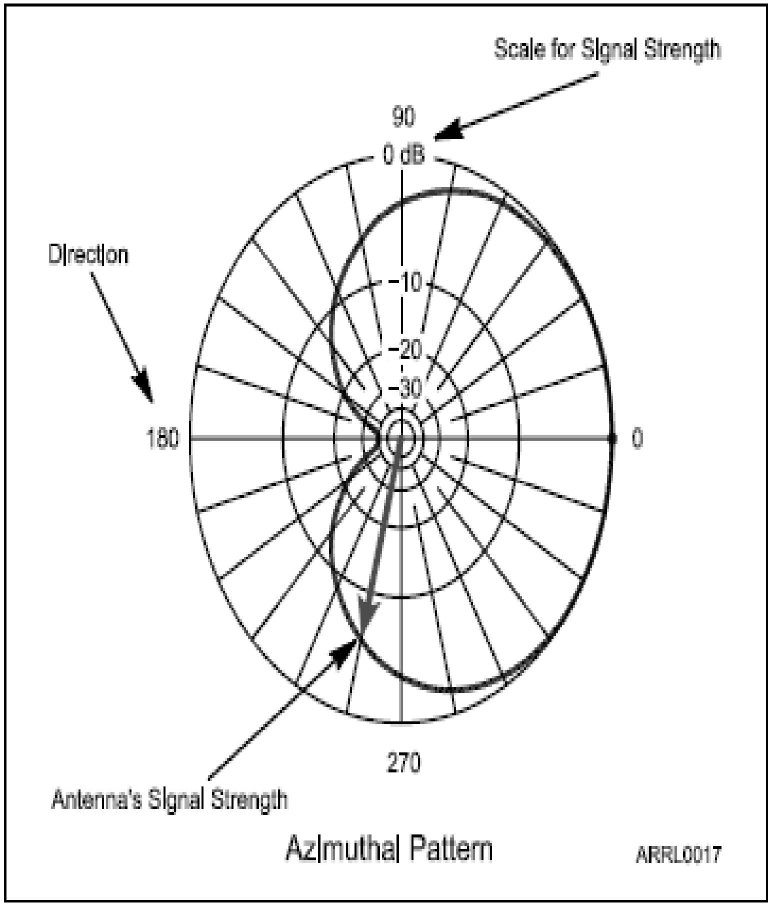
A. Impedance and reactance
B. Voltage and current
C. Electric and magnetic fields
D. Ionizing and non-ionizing radiation

T3B03 C 4-5

Antenna (Some Vocabulary)

- *Gain*: Apparent increase in power in a particular direction by focusing radiation in that direction. Measured in decibels (dB).
- *Isotropic*: Equal radiation in all directions
- *Omnidirectional*: No preferred horizontal direction
- *Directional*: Antenna that focuses radiation in specific directions

Antenna Radiation Patterns



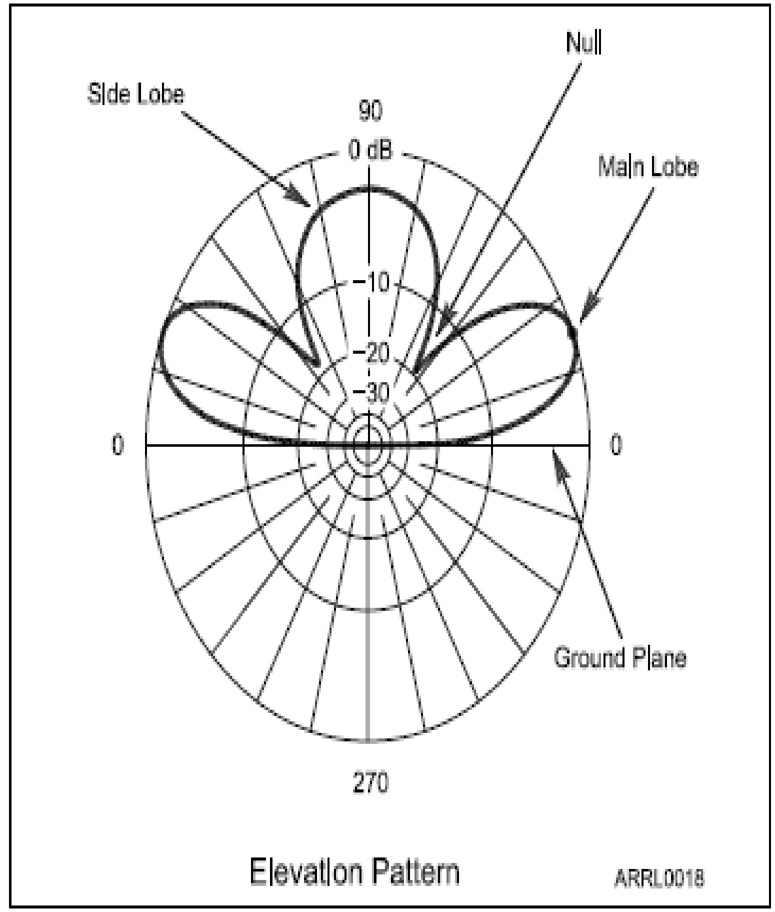


Figure 4.5 — As if looking down on the antenna from above, the azimuth radiation pattern shows how well the antenna transmits or receives in all horizontal directions. The distance from the center of the graph to the solid line is a measure of the antenna's ability to receive or transmit in that direction.

Figure 4.6 — The elevation pattern looks at the antenna from the side to see how well it receives and transmits at different angles above a horizontal plane.

Antenna Radiation Patterns (cont.)

(from previous screen)

- Radiation patterns are a way of visualizing antenna performance
- The further the line is from the center of the graph, the stronger the signal at that point
- Graphs calibrated in dB
- Most common type of radiation pattern is an *azimuthal pattern* that shows the antenna's gain in horizontal directions around the antenna

Radiation Pattern Vocabulary

- *Nulls*: Directions of minimum gain
- *Lobes*: Regions between nulls
- *Main lobe*: Lobe with highest gain
- *Side lobe*: Any lobe other than the main lobe
- *Forward gain*: Gain in the direction assigned as forward
- *Azimuth pattern*: Radiation pattern showing gain in all horizontal directions around the antenna
- *Elevation pattern*: Radiation pattern showing gain at all vertical angles from the antenna
  - Often restricted to angles above horizontal

The Decibel (dB*)

- A ratio expressed as a power of 10 to make large numbers easier to work with
- Decibel measures the ratio of two quantities as a power of 10
  - dB = 10 log (power ratio)
  - dB = 20 log (voltage ratio)
- Positive values in dB indicate ratios > 1 and negative values of dB are for ratios < 1
- Antenna gain is discussed in terms of dB

* *Pronounced "dee-bee"*

PRACTICE QUESTIONS

What is antenna gain?

A. The additional power that is added to the transmitter power
B. The additional power that is required in the antenna when transmitting on a higher frequency
C. The increase in signal strength in a specified direction compared to a reference antenna
D. The increase in impedance on receive or transmit compared to a reference antenna

T9A11 C 4-7

Which decibel value most closely represents a power increase from 5 watts to 10 watts?

A. 2 dB
B. 3 dB
C. 5 dB
D. 10 dB

T5B09 B 4-8

Which decibel value most closely represents a power decrease from 12 watts to 3 watts?

A. –1 dB
B. –3 dB
C. –6 dB
D. –9 dB

T5B10 C 4-8

Which decibel value represents a power increase from 20 watts to 200 watts?

A. 10 dB
B. 12 dB
C. 18 dB
D. 28 dB

T5B11 A 4-8

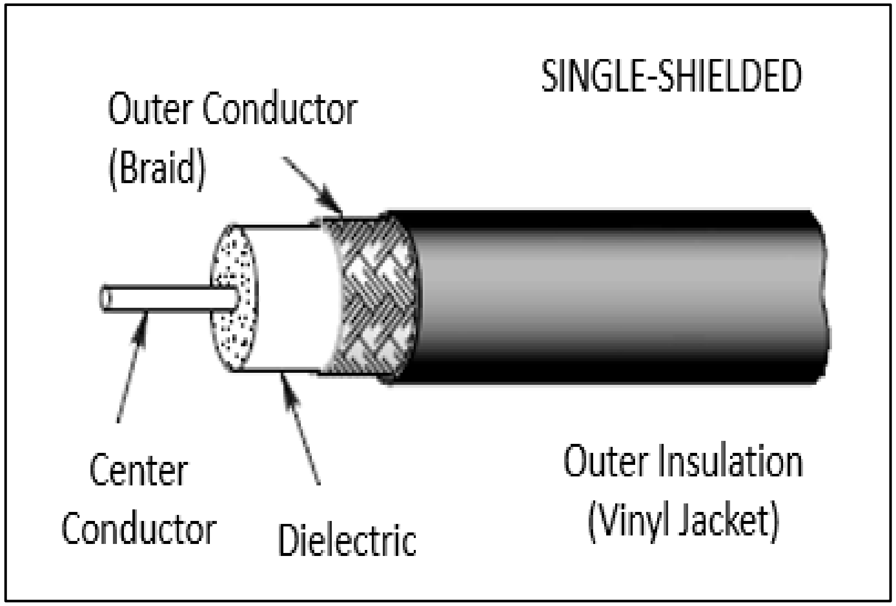
Feed Lines & SWR

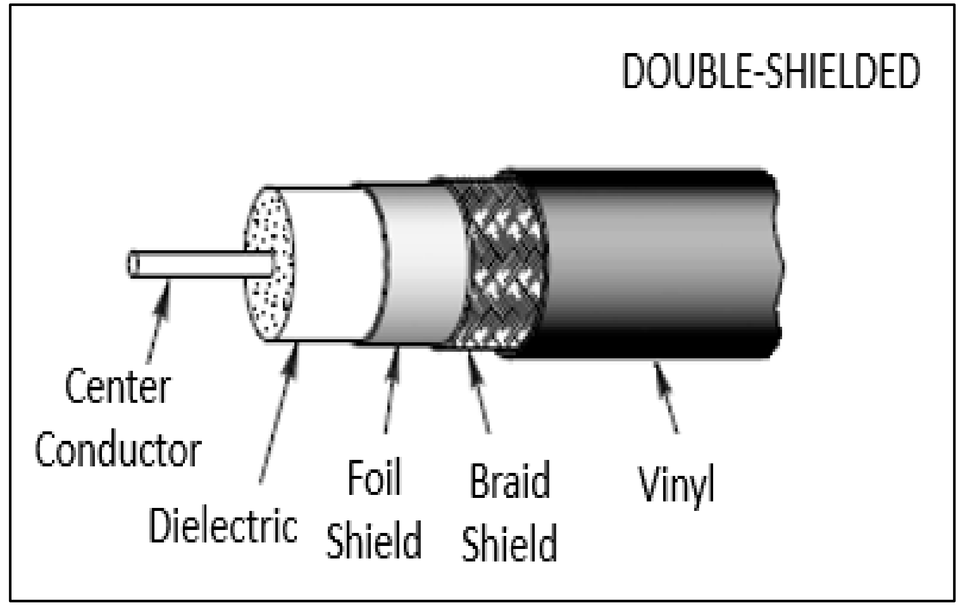
- The purpose of the feed line is to get RF power from your station to the antenna
- Basic feed line types
  - *Coaxial cable* (coax)
  - *Open-wire line* (OWL) also called *ladder line* or window line
- Power lost as heat in the feed line is called loss and it increases with frequency
- Feed lines used at radio frequencies use special materials and construction methods

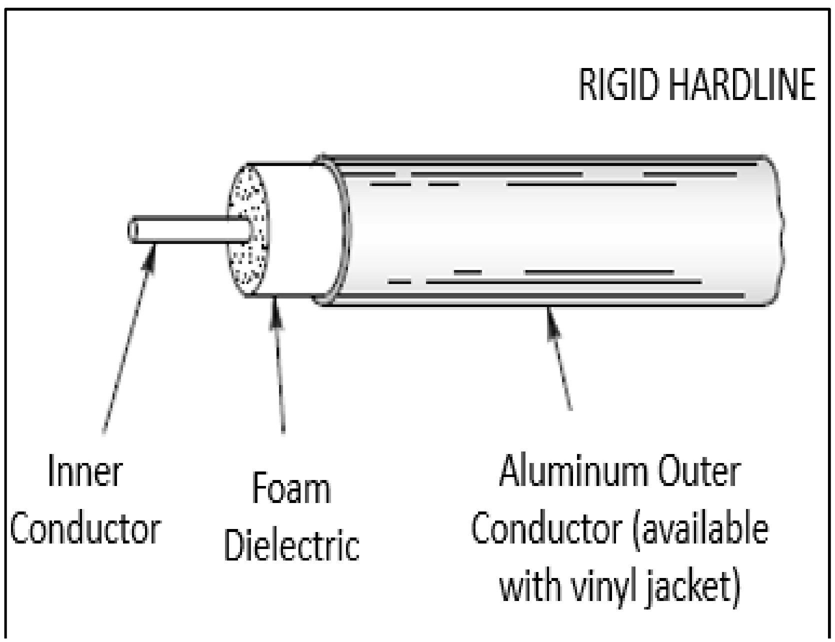
Feed Line Vocabulary

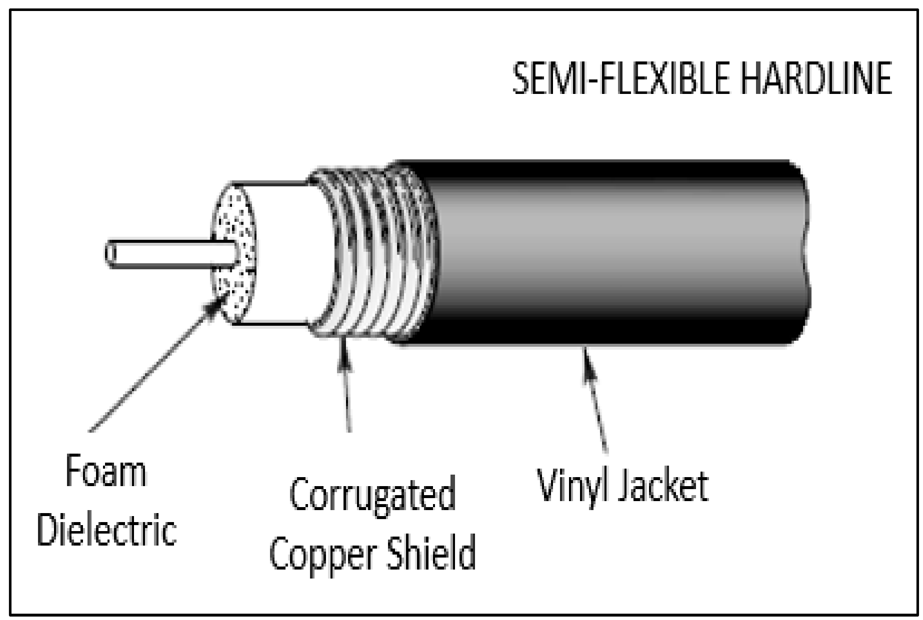
- *Center conductor*: Central wire
- *Dielectric*: Insulation surrounding center conductor
- *Shield*: Braid or foil surrounding dielectric
- *Jacket*: Protective outer plastic coating
- *Forward (reflected) power*: RF power traveling toward (away from) a load such as an antenna

Coaxial Cable







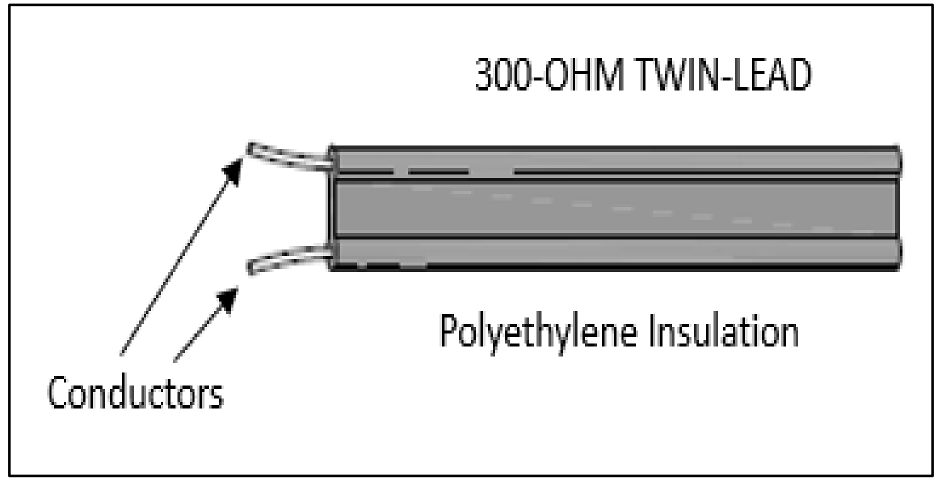


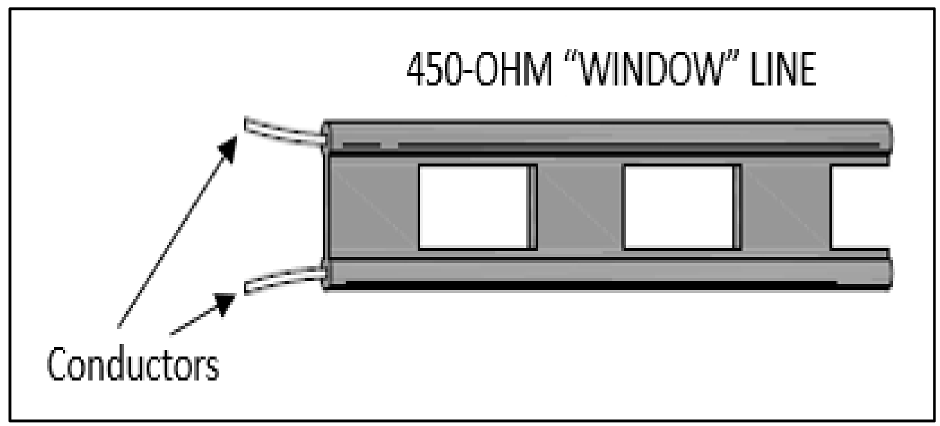
Coaxial Cable (cont.)

- Most common feed line
- Easy to use
- Carries the radio signal on the surface of the center conductor and the inside surface of the shield
  - Not affected by nearby materials
- Has higher loss than open-wire line at most frequencies
- Air-insulated *hard line* has lowest loss (but,

Open-Wire Line

- Lighter and less expensive than coax
- Lower loss than coax at most frequencies
- More difficult to use since it is affected by nearby materials
- Requires impedance matching equipment to use with most transceivers





Characteristic Impedance

- The impedance presented to a wave traveling through a feed line
- Given in ohms (Ω), symbolized as ZØ
- Depends on how the feed line is constructed and what materials are used
  - Coax: 50 and 75 Ω
  - OWL: 300, 450, and 600 Ω
- Most coaxial cable used in ham radio has a characteristic impedance of 50 Ω

Standing Wave Ratio (SWR)

- If the antenna feed point and feed line impedances are not identical, some RF power is reflected back toward the transmitter
  - Called a *mismatch*
  - Forward and reflected waves create a pattern of *standing waves* of voltage and current in the line
  - SWR is the ratio of standing wave max to min
- Measured with an *SWR meter* or *SWR bridge*

SWR (cont.)

- Reflected power is re-reflected at the transmitter and bounces back and forth
  - Some RF power is lost as *heat* on each trip back and forth through the feed line
  - All RF power is eventually lost as heat or transferred to the antenna or load
- High SWR means more reflections and more loss of RF power (less transferred to the antenna or load)
- SWR equals the ratio of feed point (or *load*) and feed line impedance, whichever is greater than 1 (SWR always greater than 1:1)

SWR (cont.)

- SWR above 3:1 is considered high in most cases
- Erratic SWR readings may indicate a faulty feed line, faulty feed line connectors, or a faulty antenna
- High SWR can be corrected by
  - Tuning or adjusting the antenna
  - With impedance matching equipment at the transmitter
  - Called an *antenna tuner* or *transmatch*

PRACTICE QUESTIONS

What happens to power lost in a feed line?

A. It increases the SWR
B. It is radiated as harmonics
C. It is converted into heat
D. It distorts the signal

T7C07 C 4-9

What is the most common impedance of coaxial cables used in amateur radio?

A. 8 ohms
B. 50 ohms
C. 600 ohms
D. 12 ohms

T9B02 B 4-9

Why is coaxial cable the most common feed line for amateur radio antenna systems?

A. It is easy to use and requires few special installation considerations
B. It has less loss than any other type of feed line
C. It can handle more power than any other type of feed line
D. It is less expensive than any other type of feed line

T9B03 A 4-9

What happens as the frequency of a signal in coaxial cable is increased?

A. The characteristic impedance decreases
B. The loss decreases
C. The characteristic impedance increases
D. The loss increases

T9B05 D 4-9

Which of the following types of feed line has the lowest loss at VHF and UHF?

A. 50-ohm flexible coax
B. Multi-conductor unbalanced cable
C. Air-insulated hardline
D. 75-ohm flexible coax

T9B11 C 4-17

Which of the following should be considered when selecting an accessory SWR meter?

A. The frequency and power level at which the measurements will be made
B. The distance that the meter will be located from the antenna
C. The types of modulation being used at the station
D. All these choices are correct

T4A02 A 4-10

What reading on an SWR meter indicates a perfect impedance match between the antenna and the feed line?

A. 50:50
B. Zero
C. 1:1
D. Full Scale

T7C04 C 4-10

Why do most solid-state transmitters reduce output power as SWR increases beyond a certain level?

A. To protect the output amplifier transistors
B. To comply with FCC rules on spectral purity
C. Because power supplies cannot supply enough current at high SWR
D. To lower the SWR on the transmission line

T7C05 A 4-10

What does an SWR reading of 4:1 indicate?

A. Loss of -4 dB
B. Good impedance match
C. Gain of +4 dB
D. Impedance mismatch

T7C06 D 4-10

What is a benefit of low SWR?

A. Reduced television interference
B. Reduced signal loss
C. Less antenna wear
D. All these choices are correct

T9B01 B 4-10

What can cause erratic changes in SWR?

A. Local thunderstorm
B. Loose connection in the antenna or feed line
C. Over-modulation
D. Overload from a strong local station

T9B09 B 4-10

What is standing wave ratio (SWR)?

A. A measure of how well a load is matched to a transmission line
B. The ratio of amplifier power output to input
C. The transmitter efficiency ratio
D. An indication of the quality of your station’s ground connection

T9B12 A 4-9