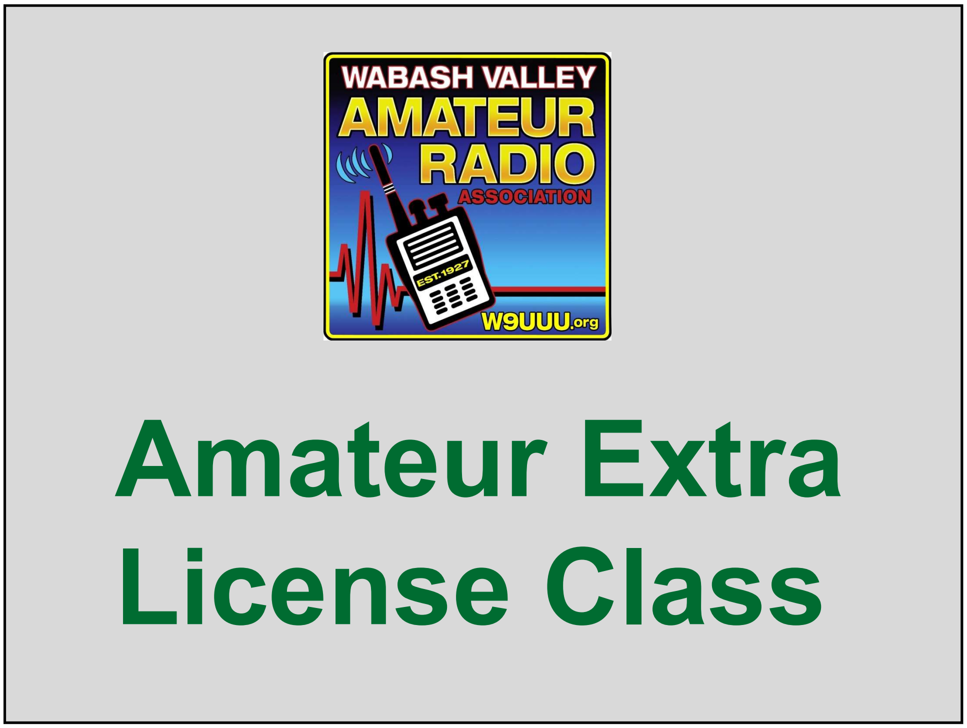
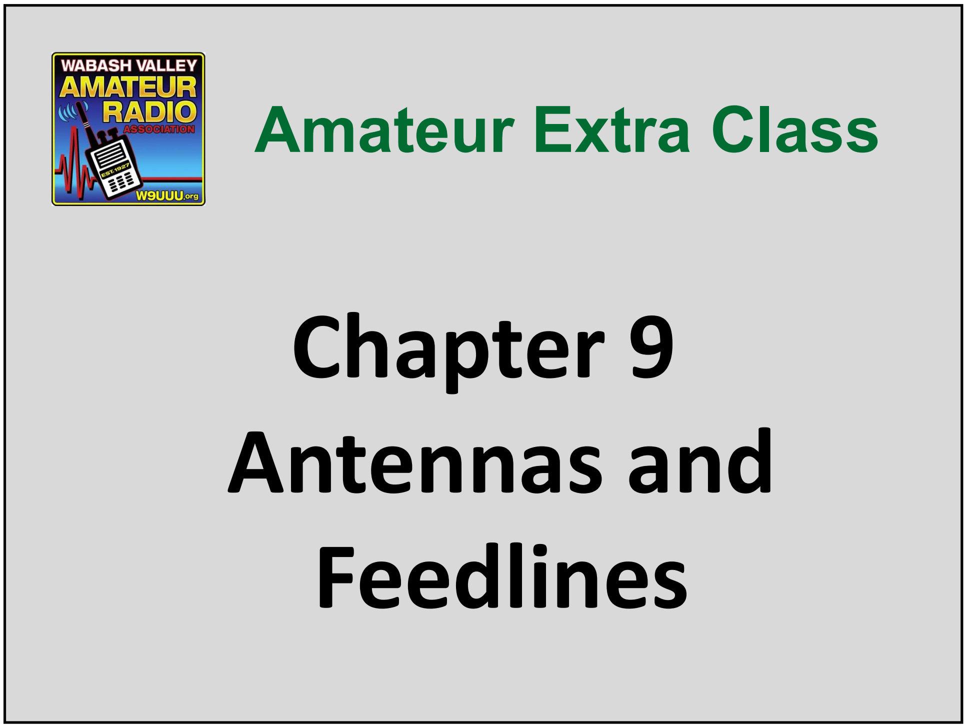


Amateur Extra License Class



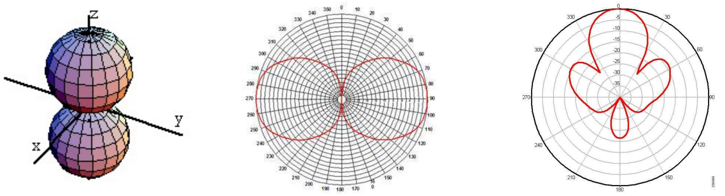
Amateur Extra Class

Chapter 9
Antennas and Feedlines

Basics of Antennas

Antenna Radiation Patterns.

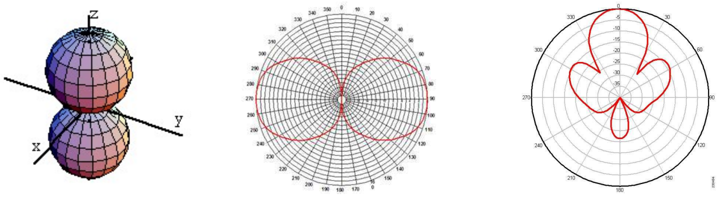
- Graphical representations of the spatial distribution of the energy around an antenna.
  - 3D = Full representation.
  - 2D = "Slice" through pattern.



Basics of Antennas

Antenna Radiation Patterns.

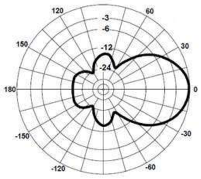
- Represent the radiation pattern in the "far field" of the antenna.
  - 10 wavelengths or more from antenna.
  - Radiation pattern does not change with distance.



Basics of Antennas

Antenna Gain.

- Antennas are passive devices.
  - The power radiated is always less than the power fed to the antenna.
  - Gain comes from increasing the power in one direction at the expense of another direction.

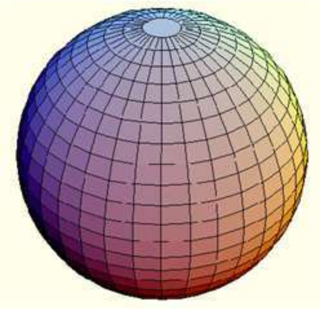


Basics of Antennas

- Antenna Gain.

  Isotropic Radiator.

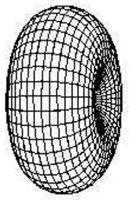
  - A theoretical point radiator.
    - Impossible to build.
  - Radiates equally in **ALL** directions.
  - Used as a reference for antenna gain.
  - Gain referenced to an isotropic radiator is expressed as dBi.

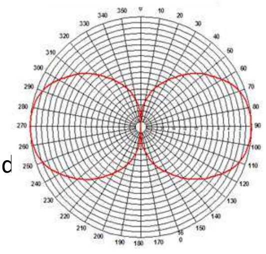


Basics of Antennas

Antenna Gain.

- Directional Antennas.
  - Half-wave dipole antenna.
    - The most basic real-world antenna.
      - Most other antenna designs are based on the half-wave dipole.
    - Easily constructed.
    - Also used as a reference for antenna gain.
    - Gain referenced to a dipole is expressed as dBd.
      - 0 dBd = 2.15 dBi

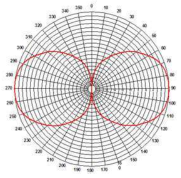


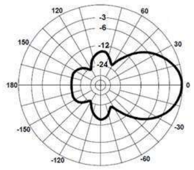


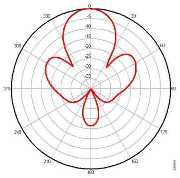
Basics of Antennas

Antenna Gain.

- Directional Antennas.
  - ALL real-world antennas are directional in one or more planes.
    - “Omni-directional” antennas are omni-directional in the horizontal plane, but directional in the vertical plane.





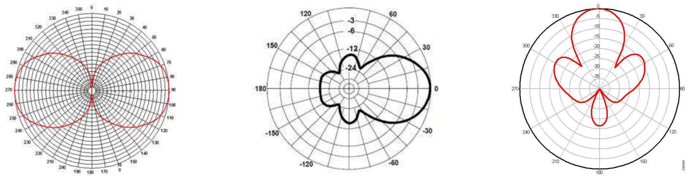


Basics of Antennas

Antenna Gain.

Directional Antennas.

- Major lobe = Direction of most energy.
  - a.k.a. – Main lobe or forward direction.
- Minor lobes = Additional lobes to side or rear of main lobe.



E9A01 – What is an isotropic antenna?

A. A grounded antenna used to measure Earth conductivity

B. A horizontally polarized antenna used to compare Yagi antennas

➡ C. A theoretical antenna used as a reference for antenna gain

D. A spacecraft antenna used to direct signals toward Earth

E9A12 -- How much gain does an antenna have compared to a 1/2-wavelength dipole when it has 6 dB gain over an isotropic antenna?

[✓ A. 3.85 dB]
B. 6.0 dB
C. 8.15 dB
D. 2.79 dB

E9B07 -- How does the total amount of radiation emitted by a directional gain antenna compare with the total amount of radiation emitted from an isotropic antenna, assuming each is driven by the same amount of power?

A. The total amount of radiation from the directional antenna is increased by the gain of the antenna
B. The total amount of radiation from the directional antenna is stronger by its front to back ratio
[✓ C. They are the same]
D. The radiation from the isotropic antenna is 2.15 dB stronger than that from the directional antenna

E9B08 -- What is the far field of an antenna?

A. The region of the ionosphere where radiated power is not refracted

B. The region where radiated power dissipates over a specified time period

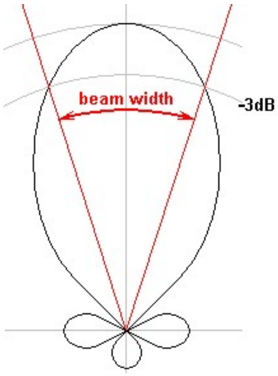
C. The region where radiated field strengths are constant

➡ D. The region where the shape of the antenna pattern is independent of distance

Basics of Antennas

Beamwidth and Pattern Ratios

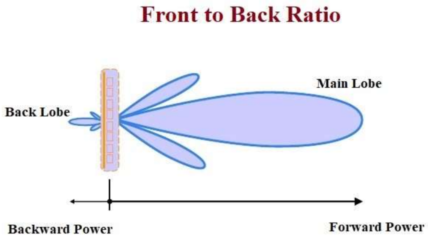
- Beamwidth.
  - The beamwidth is defined as the angle between the half-power (-3 dB) points.
  - The higher the gain, the narrower the beamwidth.
  - The narrower the beamwidth, the higher the gain.



Basics of Antennas

Beamwidth and Pattern Ratios

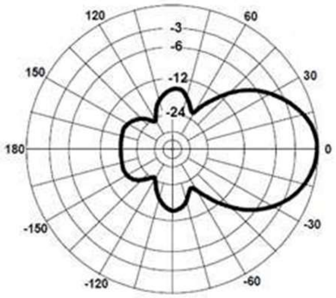
- Front-to-Back ratio.
  - The front-to-back ratio is the ratio of the power in the forward direction to the power in the reverse direction.



Basics of Antennas

Beamwidth and Pattern Ratios

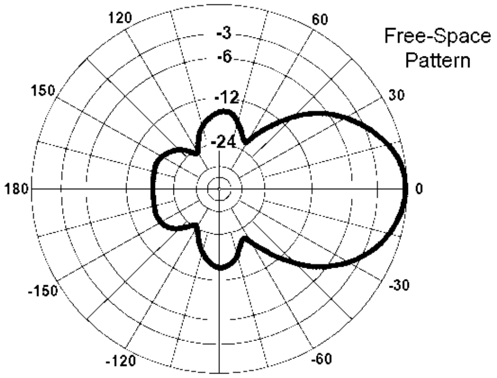
- Front-to-Side ratio.
  - The front-to-side ratio is the ratio of the power in the forward direction to the power 90^o from the forward direction.
    - Assuming a symmetrical pattern.



E9B01 -- In the antenna radiation pattern shown in Figure E9-1, what is the beamwidth?

A. 75 degrees
[✓ B. 50 degrees]
C. 25 degrees
D. 30 degrees

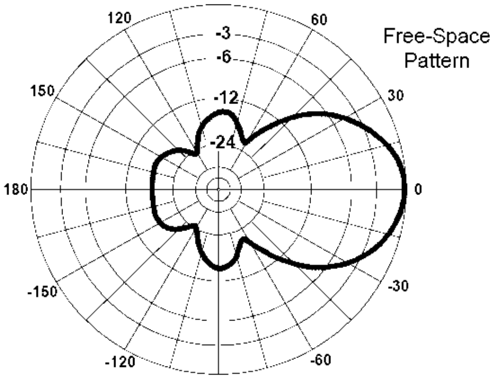
Figure E9-1



E9B02 -- In the antenna radiation pattern shown in Figure E9-1, what is the front-to-back ratio?

A. 36 dB
[✓ B. 18 dB]
C. 24 dB
D. 14 dB

Figure E9-1



E9B03 -- In the antenna radiation pattern shown in Figure E9-1, what is the front-to-side ratio?

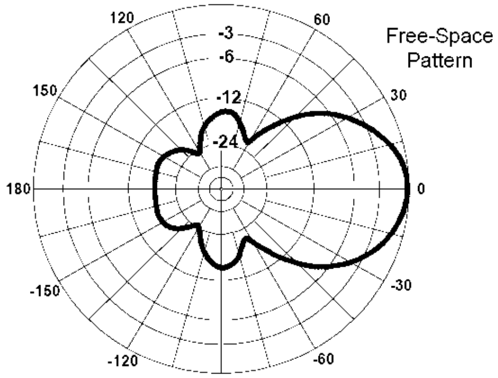
A. 12 dB

➡ B. 14 dB

C. 18 dB

D. 24 dB

Figure E9-1



Basics of Antennas

Radiation and Ohmic Resistance

- Power in antenna is either:
  - Radiated into space, or
  - Dissipated as heat (ohmic losses).
- Want more power radiated into space.
- Want less power dissipated as heat.

Basics of Antennas

Radiation and Ohmic Resistance

- Radiation Resistance.
  - The resistance that would dissipate an amount of power equal to that radiated by the antenna is called the “radiation resistance”.

Basics of Antennas

Radiation and Ohmic Resistance

- Radiation Resistance.
  - The radiation resistance is affected by the ground & other nearby conductive objects.
    - Closer to the ground or other objects results in a lower radiation resistance.
  - The radiation resistance is affected by the length/diameter ratio of the conductors.
    - Larger diameter conductors results in a lower radiation resistance.

Basics of Antennas

Radiation and Ohmic Resistance

- Ohmic Resistance.
  - The resistance of the materials used in the construction of the antenna is called the “Ohmic resistance” or the “loss resistance”.
    - The Ohmic resistance includes the ground losses.
- Total Resistance.
  - The total resistance is the sum of the radiation resistance and the Ohmic resistance.

E9A03 -- What is the radiation resistance of an antenna?

A. The combined losses of the antenna elements and feed line

B. The specific impedance of the antenna

➡ C. The value of a resistance that would dissipate the same amount of power as that radiated from an antenna

D. The resistance in the atmosphere that an antenna must overcome to be able to radiate a signal

E9A05 -- What is included in the total resistance of an antenna system?

A. Radiation resistance plus space impedance

B. Radiation resistance plus transmission resistance

C. Transmission-line resistance plus radiation resistance

➡ D. Radiation resistance plus loss resistance

Basics of Antennas

Feed Point Impedance

- The feed point impedance is the ratio of the RF voltage to the RF current at the point where the feedline is connected to the antenna.
  - If voltage and current are in phase:
    - Antenna is resonant.
    - Impedance is purely resistive.
  - If voltage and current are not in phase:
    - Impedance will include either inductive or capacitive reactance.

Basics of Antennas

Feed Point Impedance

- The feed point impedance changes with:
  - Frequency.
  - Position of the feed point along antenna.
  - The length/diameter ratio of conductor.
  - The distance to nearby objects.
    - Height above ground.
    - Other antennas.
    - Buildings.
    - Power lines.

E9A04 -- Which of the following factors affect the feed point impedance of an antenna?

A. Transmission line length

➡ B. Antenna height

C. The settings of an antenna tuner at the transmitter

D. The input power level

Basics of Antennas

Antenna Efficiency

- The efficiency of an antenna is defined as the radiation resistance divided by the total resistance

$$R_T = R_R + R_L$$

$$\text{Efficiency} = 100\% \times R_R / R_T$$

R_T = Total Resistance
R_R = Radiation Resistance
R_L = Loss (ohmic) Resistance

Basics of Antennas

Antenna Efficiency.

- A 1/2 λ dipole has a high efficiency because the conductor resistance is very low compared to the radiation resistance.
- A ground-mounted 1/4 λ vertical requires a good ground radial system to achieve high efficiency.
  - Ground losses increase the ohmic resistance.
- A shortened antenna with a loading coil may have low efficiency because the resistance of the loading coil may be significant.

E9A09 -- What is antenna efficiency?

A. Radiation resistance divided by transmission resistance

➡ B. Radiation resistance divided by total resistance

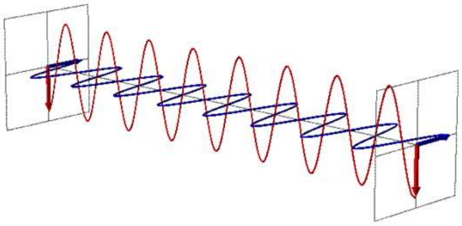
C. Total resistance divided by radiation resistance

D. Effective radiated power divided by transmitter output

Basics of Antennas

Antenna Pattern Types.

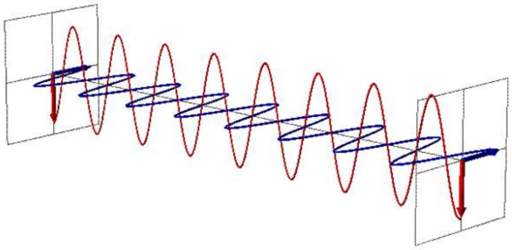
- E and H planes.
  - A radio wave consists of an electric field and a magnetic field at right angles to each other.



Basics of Antennas

Antenna Pattern Types.

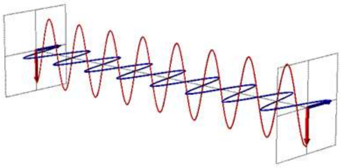
- E and H planes.
    - We can draw antenna radiation patterns using either the electric field (the E plane) or the magnetic field (the H plane).



Basics of Antennas

Antenna Pattern Types.

- E and H planes.
    - For most antennas, the electric field is in the same plane as the antenna elements.
        - If the elements are parallel to the ground, the antenna is horizontally polarized.
        - If the elements are perpendicular to the ground, the antenna is vertically polarized.



Basics of Antennas

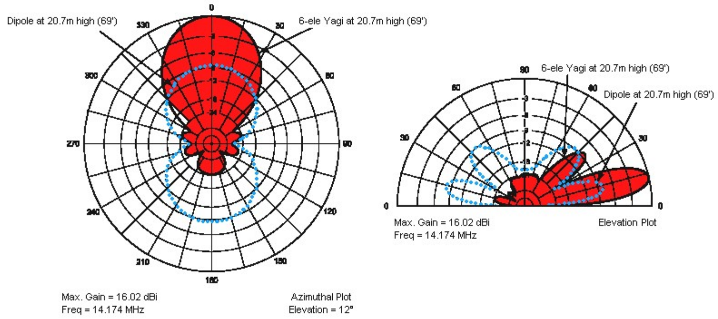
Antenna Pattern Types

- Azimuthal and Elevation Patterns.
  - For a horizontally-polarized antenna:
    - The E plane pattern is parallel to the surface of the Earth and shows the intensity of the electric field at different directions from the antenna.
      - This is called the “azimuthal” pattern.
    - The H plane pattern is perpendicular to the surface of the Earth and shows the intensity of the electric field at different elevation angles from the antenna.
      - This is called the “elevation” pattern.

Basics of Antennas

Antenna Pattern Types

- Azimuthal and Elevation Patterns.



Basics of Antennas

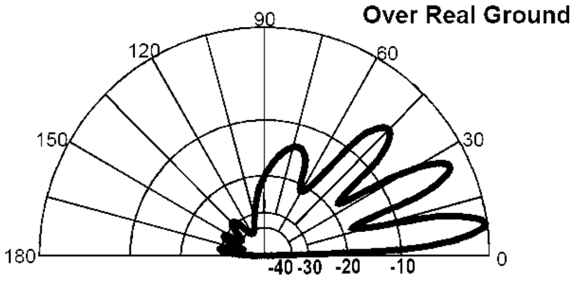
Antenna Pattern Types

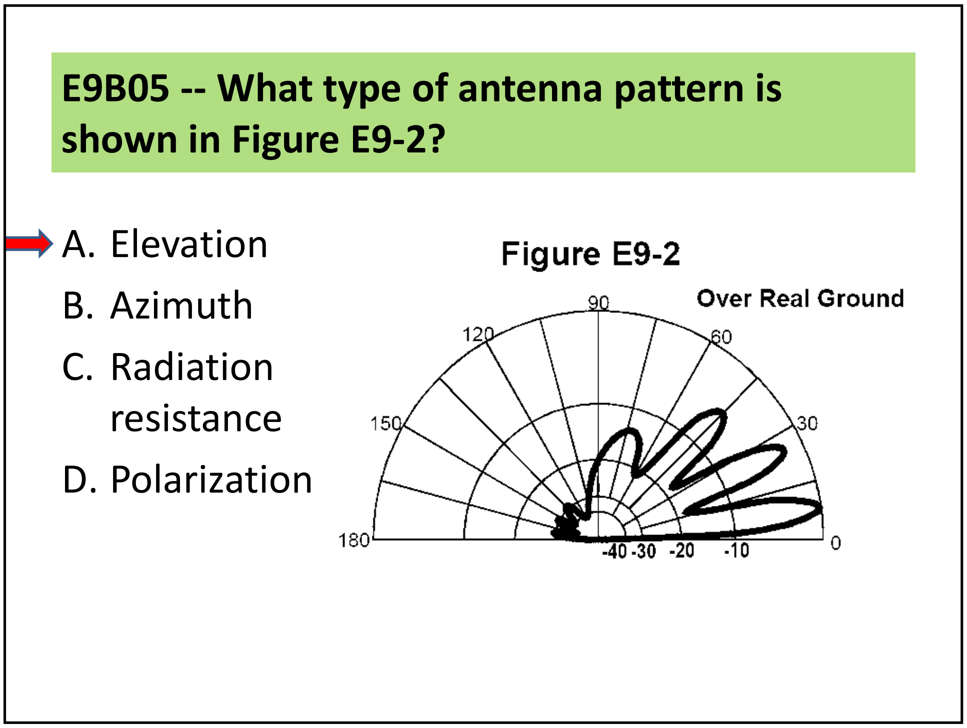
- Azimuthal and Elevation Patterns.
  - The azimuthal pattern shows the radiation around the antenna.
  - The elevation pattern shows the radiation at various angles above the horizontal.
    - An important part of the elevation pattern is the angle above horizontal where the field is the strongest.
      - This is called the “take-off angle”.
      - For DX operations, the lower the take-off angle, the better.
      - For close-in communications, a higher take-off angle is better.

E9B04 -- What is the front-to-back ratio of the radiation pattern shown in Figure E9-2?

A. 15 dB
[✓ B. 28 dB]
C. 3 dB
D. 24 dB

Figure E9-2

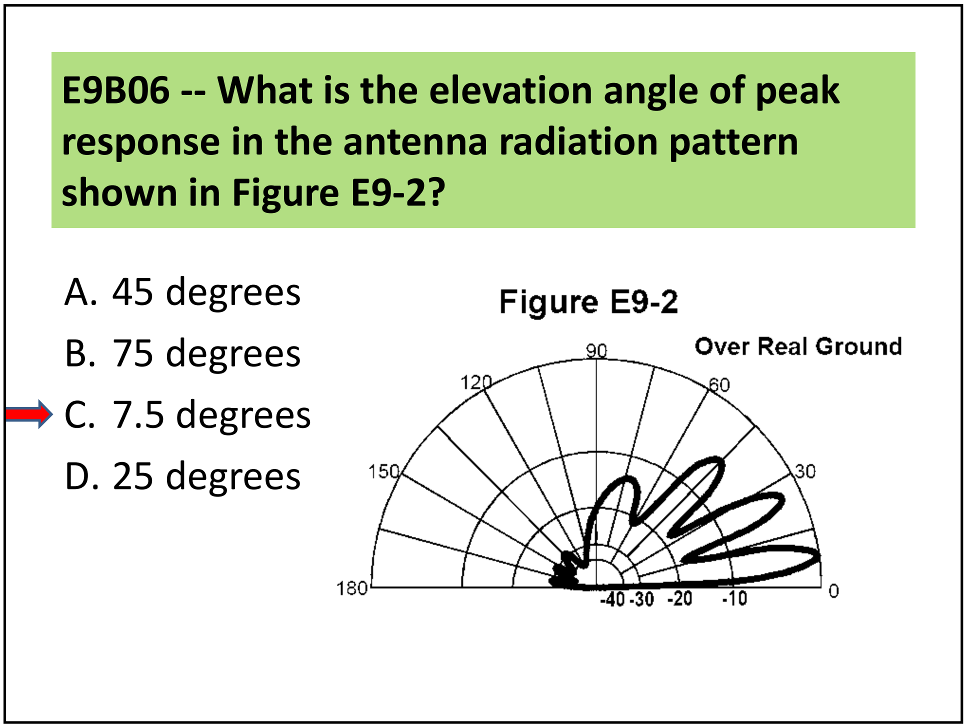




E9B05 -- What type of antenna pattern is shown in Figure E9-2?

- ➡ A. Elevation
- B. Azimuth
- C. Radiation resistance
- D. Polarization

Figure E9-2



E9B06 -- What is the elevation angle of peak response in the antenna radiation pattern shown in Figure E9-2?

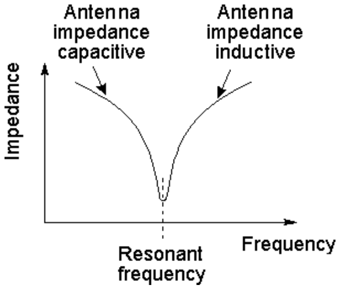
- A. 45 degrees
- B. 75 degrees
- ➡ C. 7.5 degrees
- D. 25 degrees

Figure E9-2

Basics of Antennas

Bandwidth.

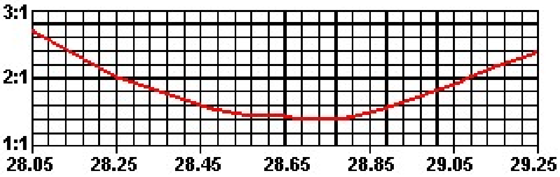
- As frequency changes, the feed point impedance, the radiation pattern, & the gain all change.



Basics of Antennas

Bandwidth.

- The bandwidth of an antenna is defined as the range of frequencies over which an antenna meets a published performance requirement.
  - Often stated as 2:1 SWR bandwidth.



Basics of Antennas

Bandwidth.

- As the Q of a tuned circuit increases, the bandwidth of the circuit decreases.
  - A resonant antenna is equivalent to a tuned circuit.
  - Increasing the Q of a tuned circuit decreases its bandwidth.
    - Therefore, increasing the Q of an antenna will decrease the bandwidth.

E9A08 -- What is antenna bandwidth?

A. Antenna length divided by the number of elements

➡ B. The frequency range over which an antenna satisfies a performance requirement

C. The angle between the half-power radiation points

D. The angle formed between two imaginary lines drawn through the element ends

E9D08 -- What happens as the Q of an antenna increases?

A. SWR bandwidth increases

➡ B. SWR bandwidth decreases

C. Gain is reduced

D. More common-mode current is present on the feed line

Practical Antennas

Effects of Ground and Ground Systems.

- The factors that effect on antenna system efficiency the most are losses in the ground, nearby grounded structures, and the antenna ground system.

Practical Antennas

Effects of Ground and Ground Systems.

- The radiation pattern of an antenna over real ground is **ALWAYS** affected by the conductivity and dielectric constant of the soil.
  - True for horizontally-polarized mounted at some distance above the ground.
  - **Especially** true for vertically-polarized antennas mounted on the ground.
    - Poor ground conductivity raises the take-off angle.

Practical Antennas

Effects of Ground and Ground Systems.

- Height Above Ground.
  - The height above ground that an antenna is mounted also affects the radiation pattern.
    - The higher the better.
      - Lower ground losses.
      - Lower angle radiation increases.
        - Lower take-off angle.

Practical Antennas

Effects of Ground and Ground Systems.

- Terrain.
  - Radiation patterns approach their published values only on flat open terrain.
  - Add hills and/or buildings & all bets are off!
  - If an antenna is mounted on a slope or hillside, the radiation pattern is tilted.
    - Higher take-off angle in uphill direction.
    - Lower take-off angle in downhill direction.
  - Hilltops are good, but not because of elevation.
    - All directions are downhill – therefore lower take-off angle.

E9A10 -- Which of the following improves the efficiency of a ground-mounted quarter-wave vertical antenna?

➡ A. Installing a radial system

B. Isolating the coax shield from ground

C. Shortening the radiating element

D. All these choices are correct

E9A11 -- Which of the following factors determines ground losses for a ground-mounted vertical antenna operating in the 3 MHz to 30 MHz range?

A. The standing-wave ratio

B. Distance from the transmitter

➡ C. Soil conductivity

D. Take-off angle

E9C11 -- How is the far-field elevation pattern of a vertically polarized antenna affected by being mounted over seawater versus soil?

A. The low-angle radiation decreases

B. Additional higher vertical angle lobes will appear

C. Fewer vertical angle lobes will be present

➡ D. The low-angle radiation increases

E9C13 -- How does the radiation pattern of a horizontally polarized 3-element beam antenna vary with increasing height above ground?

A. The takeoff angle of the lowest elevation lobe increases

➡ B. The takeoff angle of the lowest elevation lobe decreases

C. The horizontal beamwidth increases

D. The horizontal beamwidth decreases

E9C14 -- How does the performance of a horizontally polarized antenna mounted on the side of a hill compare with the same antenna mounted on flat ground?

A. The main lobe takeoff angle increases in the downhill direction

➡ B. The main lobe takeoff angle decreases in the downhill direction

C. The horizontal beam width decreases in the downhill direction

D. The horizontal beam width increases in the uphill direction

Practical Antennas

Effects of Ground and Ground Systems.

- Ground Connections.
  - Ground connections must be short compared to a wavelength.
    - If a ground connection is 0.1λ long or more, it begins to act like an antenna or a transmission line.

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Practical Antennas

Effects of Ground and Ground Systems.

- Ground Connections.
  - The object is to create a path to ground with as low an impedance as possible.
    - The inductance of 1 foot of #10 wire is > 0.1 µH.
    - At RF frequencies the skin effect also increases the impedance.
      - For best results, use wide, flat copper strap.
    - Use 3 or 4 inter-connected ground rods.
      - For RF grounding, 4-ft rods work just as well as 8-ft rods.

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E9D11 -- Which of the following conductors would be best for minimizing losses in a station's RF ground system?

A. Resistive wire, such as spark plug wire
➡ B. Wide flat copper strap
C. Stranded wire
D. Solid wire

E9D12 -- Which of the following would provide the best RF ground for your station?

A. A 50-ohm resistor connected to ground
B. An electrically short connection to a metal water pipe
➡ C. An electrically short connection to 3 or 4 interconnected ground rods driven into the Earth
D. An electrically short connection to 3 or 4 interconnected ground rods via a series RF choke

Practical Antennas

Dipole Variations

- The center-fed 1/2λ dipole is the most basic real-world antenna.
  - Most antenna designs are based on the 1/2λ dipole.
  - There are several commonly used variations of the center-fed 1/2λ dipole.

Practical Antennas

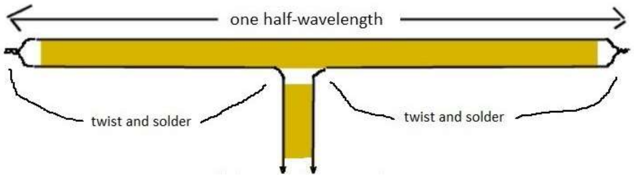
Dipole Variations

- Folded Dipole.
  - A folded dipole is a wire 1λ long folded to form a long, thin loop 1/2λ long.
  - The feed point impedance of a folded dipole is approximately 300Ω.
    - Often constructed using 300Ω tv twin lead.
  - The SWR bandwidth of a folded dipole is greater than that of a standard dipole.

Practical Antennas

Dipole Variations

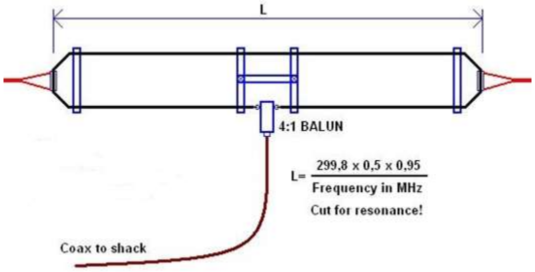
- Folded Dipole.
  - Often constructed using 300Ω TV twin lead.



Practical Antennas

Dipole Variations.

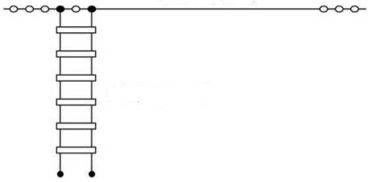
- Folded Dipole.



Practical Antennas

Dipole Variations.

- Zepp and Extended Zepp Antennas.
  - A Zepp antenna is a 1/2λ dipole fed at one end with open-wire line.
    - The name comes from the fact that it was originally used by the German **Zepp**elin airships.



Practical Antennas

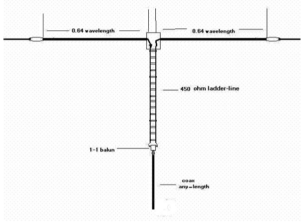
Dipole Variations.

- Zepp and Extended Zepp Antennas.
  - The end of a 1/2λ dipole is a very high impedance point.
  - The impedance can be reduced by extending the antenna to 5/8λ in length.
    - This is called the extended Zepp antenna.

Practical Antennas

Dipole Variations.

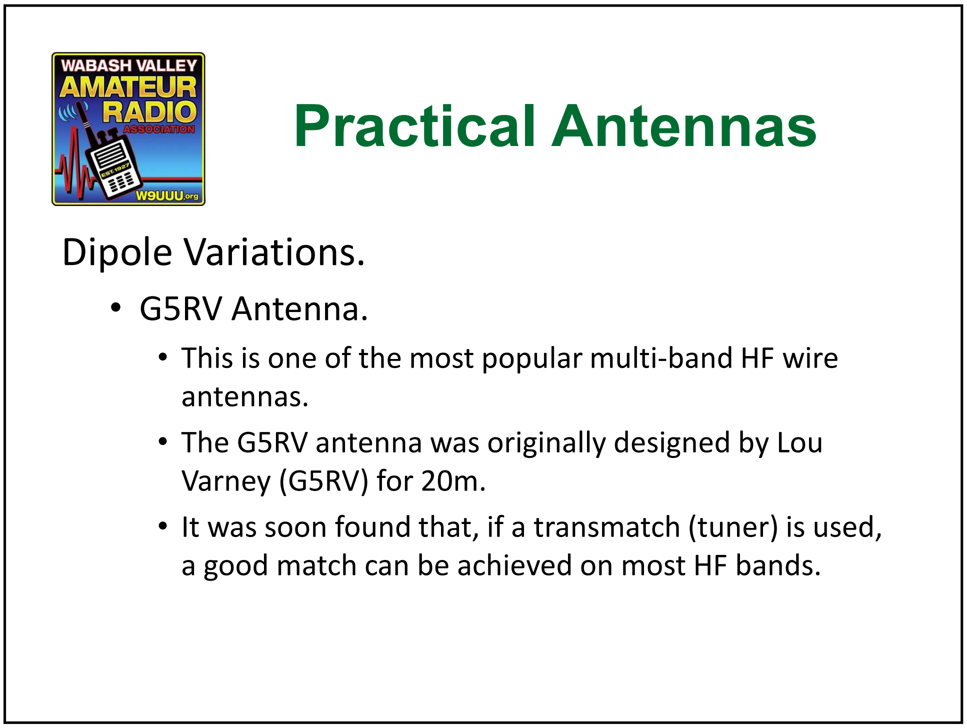
- Zepp and Extended Zepp Antennas.
  - Two extended Zepp antennas can be connected back-to-back to create the double extended Zepp antenna.
    - 1.25λ long antenna with two 5/8λ elements fed in phase.



Practical Antennas

Dipole Variations.

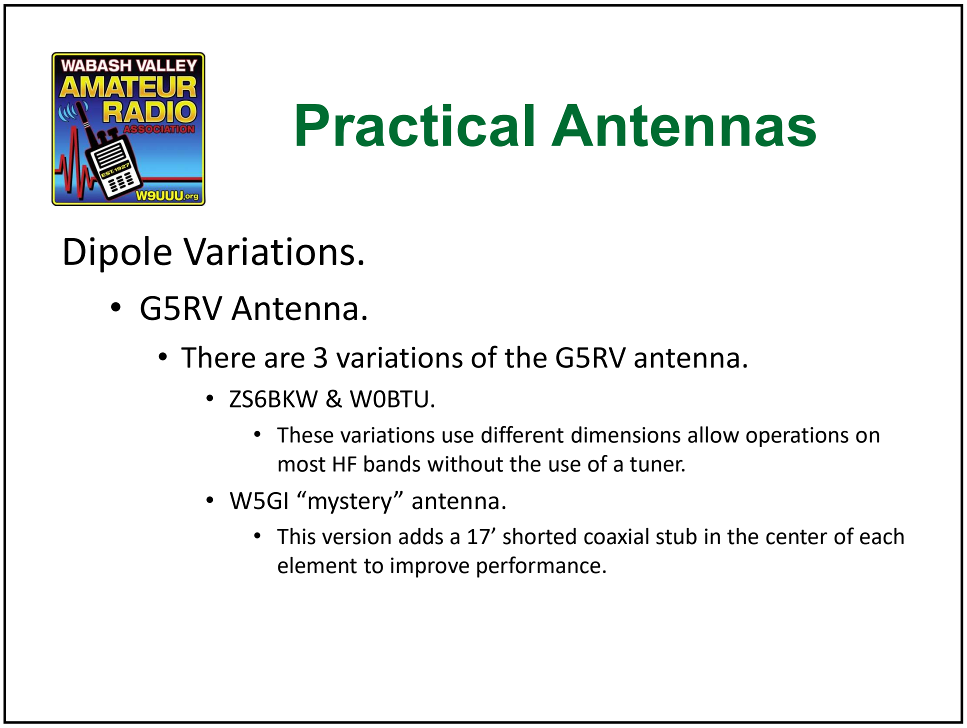
- G5RV Antenna.
  - The G%RV antenna is one of the most popular multi-band HF wire antennas.
  - The G5RV antenna was originally designed by Lou Varney (G5RV) for 20m.
  - It was found to present a good match on most HF bands with a tuner.



Practical Antennas

Dipole Variations.

- G5RV Antenna.
  - This is one of the most popular multi-band HF wire antennas.
  - The G5RV antenna was originally designed by Lou Varney (G5RV) for 20m.
  - It was soon found that, if a transmatch (tuner) is used, a good match can be achieved on most HF bands.



Practical Antennas

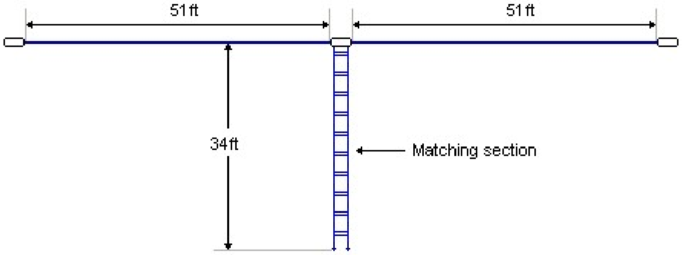
Dipole Variations.

- G5RV Antenna.
  - There are 3 variations of the G5RV antenna.
    - ZS6BKW & W0BTU.
      - These variations use different dimensions allow operations on most HF bands without the use of a tuner.
    - W5GI “mystery” antenna.
      - This version adds a 17’ shorted coaxial stub in the center of each element to improve performance.

Practical Antennas

Dipole Variations.

- G5RV Antenna.



Practical Antennas

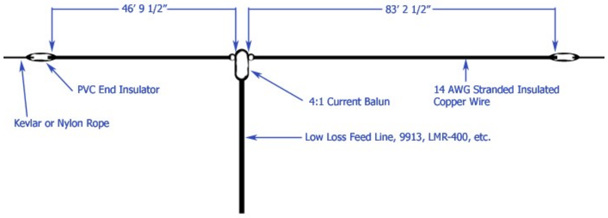
Dipole Variations.

- Off-Center Fed Dipole.
  - Often incorrectly referred to as a Windom antenna.
  - On the fundamental frequency and its odd harmonics, the center of a dipole is a relatively low impedance.
  - On the even harmonics, the center of a dipole presents a very high impedance.
  - By moving the feed point away from the center, a point can be found where the feed point impedance is similar on most or all HF bands.

Practical Antennas

Dipole Variations.

- Off-Center Fed Dipole (OCFD).
  - At about 1/3 of the length from one end, the feed point impedance on most bands will be 150Ω to 300Ω.
    - Feed the antenna through a 4:1 balun.



E9C05 -- Which of the following is a type of OCFD antenna?

➡ A. A dipole fed approximately 1/3 the way from one end with a 4:1 balun to provide multiband operation

B. A remotely tunable dipole antenna using orthogonally controlled frequency diversity

C. A folded dipole center-fed with 300-ohm transmission line

D. A multiband dipole antenna using one-way circular polarization for frequency diversity

E9C07 -- What is the approximate feed point impedance at the center of a two-wire folded dipole antenna?

- ➡ A. 300 ohms
- B. 72 ohms
- C. 50 ohms
- D. 450 ohms

E9C08 -- What is a folded dipole antenna?

- A. A dipole one-quarter wavelength long
- B. A type of ground-plane antenna
- ➡ C. A half-wave dipole with an additional parallel wire connecting its two ends
- D. A dipole configured to provide forward gain

E9C09 -- Which of the following describes a G5RV antenna?

➡ A. A multi-band dipole antenna fed with coax and a balun through a selected length of open wire transmission line
B. A multi-band trap antenna
C. A phased array antenna consisting of multiple loops
D. A wide band dipole using shorted coaxial cable for the radiating elements and fed with aÿ4:1 balun

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E9C10 -- Which of the following describes a Zepp antenna?

A. A dipole constructed from zip cord
➡ B. An end fed dipole antenna
C. An omni-directional antenna commonly used for satellite communications
D. A vertical array capable of quickly changing the direction of maximum radiation by changing phasing lines

E9C12 -- Which of the following describes an Extended Double Zepp antenna?

A. A wideband vertical antenna constructed from precisely tapered aluminum tubing

B. A portable antenna erected using two push support poles

➡ C. A center fed 1.25 wavelength antenna (two 5/8 wave elements in phase)

D. An end fed folded dipole antenna

Practical Antennas

Loaded Whips

- Except for 12m & above, full-sized 1/4λ verticals are not practical for mobile operation.
- The radiation resistance of a full-sized 1/4λ vertical is about 36Ω.
  - At less than 1/4λ, the radiation resistance decreases, & capacitive reactance is added.
  - Some way to cancel the capacitive reactance is needed.

Practical Antennas

Loaded Whips

- The most common way to cancel the capacitive reactance is to add a loading coil in series with the radiating element.
  - Adding a loading coils adds loss.
  - Adding a loading coil narrows the SWR bandwidth.

Practical Antennas

Loaded Whips

- The loading coil can be placed anywhere along the length of the radiator.
  - Most antenna designs place the loading coil at the bottom of the radiator.
    - This is called base loading.
    - Base loading requires the least inductance for a given radiator length.

Practical Antennas

Loaded Whips

- The loading coil can be placed anywhere along the length of the radiator.
  - Some antenna designs place the loading coil somewhere in the middle of the radiator.
    - This is called center loading.
    - Center loading increases the radiation resistance, increasing the efficiency.
    - The higher inductance required results in higher losses.
    - Center-loaded radiators are more difficult to construct mechanically.

Practical Antennas

Loaded Whips

- Hamsticks.
  - A very popular base-loaded antenna for HF mobile operation is the Hamstick® antenna.
    - Hamstick-style antennas are base-loaded antennas with a long loading coil.
    - The loading coil is wound on a fiberglass tube about 3-4 feet long.
    - The turns of the loading coil are widely-spaced.

Practical Antennas

Loaded Whips

- Hamsticks.
  - Hamstick-style antennas are more efficient than conventional base-loaded mobile antennas.
  - Hamstick-style antennas are relatively low cost.
    - About $20 to $30.
  - Hamstick-style are designed for a single band.
    - You must change the antenna to change bands.

Practical Antennas

Loaded Whips

- Screwdriver antennas.
  - A screwdriver antenna is a base-loaded whip with a motor-driven adjustable inductor.
  - Screwdriver antennas are relatively high cost.
    - About $350 to $900.
  - Screwdriver antennas make it convenient to change bands

Practical Antennas

Loaded Whips

- Top Loading
  - Capacity hat.
    - Placed just above loading coil or near top of antenna.
    - Adds series capacitance.
    - Lowers capacitive reactance.
    - Less inductance required.
    - Improves efficiency.

E9D03 -- Where should a high Q loading coil be placed to minimize losses in a shortened vertical antenna?

➡ A. Near the center of the vertical radiator

B. As low as possible on the vertical radiator

C. As close to the transmitter as possible

D. At a voltage node

E9D04 -- Why should an HF mobile antenna loading coil have a high ratio of reactance to resistance?

A. To swamp out harmonics
B. To maximize losses
➡ C. To minimize losses
D. To minimize the Q

E9D06 -- What happens to the SWR bandwidth when one or more loading coils are used to resonate an electrically short antenna?

A. It is increased
➡ B. It is decreased
C. It is unchanged if the loading coil is located at the feed point
D. It is unchanged if the loading coil is located at a voltage maximum point

E9D07 -- What is an advantage of using top loading in a shortened HF vertical antenna?

A. Lower Q
B. Greater structural strength
C. Higher losses
➡ D. Improved radiation efficiency

E9D09 -- What is the function of a loading coil used as part of an HF mobile antenna?

A. To increase the SWR bandwidth
B. To lower the losses
C. To lower the Q
➡ D. To cancel capacitive reactance

E9D10 -- What happens to feed-point impedance at the base of a fixed length HF mobile antenna when operated below its resonant frequency?

A. The radiation resistance decreases and the capacitive reactance decreases
➡ B. The radiation resistance decreases and the capacitive reactance increases
C. The radiation resistance increases and the capacitive reactance decreases
D. The radiation resistance increases and the capacitive reactance increases

Practical Antennas

Traveling Wave Antennas

- Traveling wave antennas are antennas where the radiating element is 1λ long or more.
- There are several types of traveling wave antennas is common use.

Practical Antennas

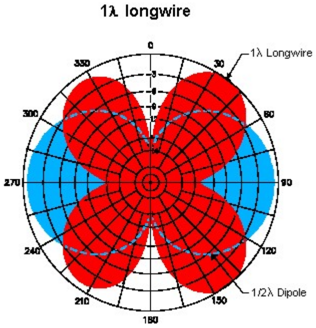
Traveling Wave Antennas

- Long-wire antennas.
  - The simplest traveling wave antenna is the long wire.
  - A long-wire antenna is 1λ long or more.
  - A long-wire antenna is typically fed 1/4λ from one end.
    - It is a dipole with one leg extended.
  - A long-wire antenna has 4 major lobes & many minor lobes.
    - The longer the wire, the closer the major lobes are to the wire.

Practical Antennas

Traveling Wave Antennas

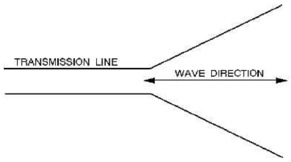
- Long-wire antennas.



Practical Antennas

Traveling Wave Antennas.

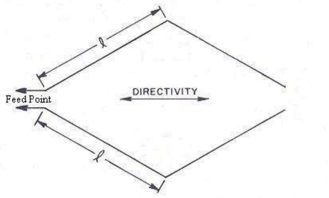
- Teo long wire antennas can be combined to form a V-beam antenna.
  - A V-beam antenna consists of 2 long wire antennas fed 180° out of phase.
  - A V-beam antenna is bi-directional (2 major lobes).



Practical Antennas

Traveling Wave Antennas

- Rhombic Antennas.
  - 2 V-beam antennas can be combined end-to-end to create the resonant rhombic antenna.
    - A resonant rhombic antenna is bi-directional (2 major lobes).
    - The resonant rhombic antenna is not widely used.



Practical Antennas

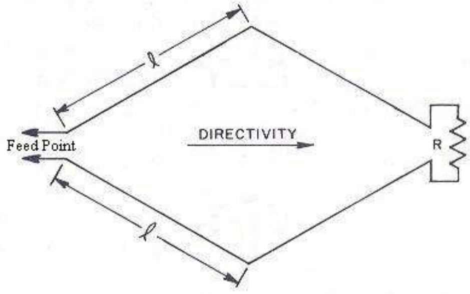
Traveling Wave Antennas.

- Rhombic Antennas.
  - Adding a termination resistor at the far end of a resonant rhombic antenna changes it into a non-resonant rhombic antenna.
    - a.k.a. – Terminated rhombic antenna.
    - A terminated rhombic antenna is uni-directional.
    - A terminated rhombic antenna presents a resistive load over a wide frequency range.
    - A very large area is required.
    - 4 tall supports are needed.

Practical Antennas

Traveling Wave Antennas.

- Rhombic Antennas.
  - Non-resonant rhombic antenna.



Practical Antennas

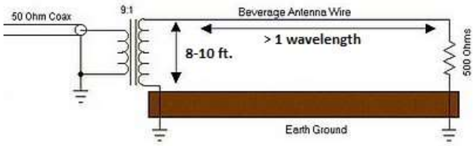
Traveling Wave Antennas.

- Beverage Antennas.
  - Most amateur radio station antennas are used for both receiving and transmitting.
  - On 160m & 80m, a separate antenna is often used for receiving.
    - These receive-only antennas are often lossy antennas that reject noise.
      - The atmospheric noise on the lower bands is high enough that antenna gain is not important.
      - A dramatic improvement in signal-to-noise ratio can be achieved.

Practical Antennas

Traveling Wave Antennas.

- Beverage Antennas.
  - The most popular receive antenna for 160m & 80m is the Beverage antenna.
    - At least 1λ long.
    - Uni-directional.
    - Very high losses, but very low noise.



E9C04 -- What happens to the radiation pattern of an unterminated long wire antenna as the wire length is increased?

A. The lobes become more perpendicular to the wire

➡ B. The lobes align more in the direction of the wire

C. The vertical angle increases

D. The front-to-back ratio decreases

E9C06 -- What is the effect of adding a terminating resistor to a rhombic antenna?

A. It reflects the standing waves on the antenna elements back to the transmitter

➡ B. It changes the radiation pattern from bidirectional to unidirectional

C. It changes the radiation pattern from horizontal to vertical polarization

D. It decreases the ground loss

E9H01 -- When constructing a Beverage antenna, which of the following factors should be included in the design to achieve good performance at the desired frequency?

A. Its overall length must not exceed 1/4 wavelength

B. It must be mounted more than 1 wavelength above ground

C. It should be configured as a four-sided loop

➡ D. It should be one or more wavelengths long

E9H02 -- Which is generally true for low band (160 meter and 80 meter) receiving antennas?

➡ A. Atmospheric noise is so high that gain over a dipole is not important

B. They must be erected at least 1/2 wavelength above the ground to attain good directivity

C. Low loss coax transmission line is essential for good performance

D. All of these choices are correct

Practical Antennas

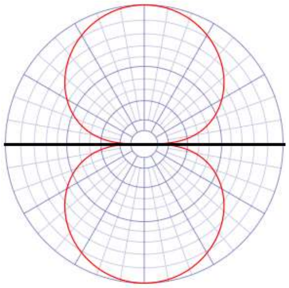
Phased Arrays

- A phased array is 2 (or more) vertical antennas (elements) fed with specific phase relationships.
  - Most AM broadcast station antennas are phased arrays.

Practical Antennas

Phased Arrays

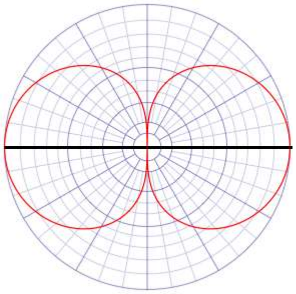
- If the elements are fed in-phase, a pattern broadside to the elements results.
  - If the elements are 1/2λ apart, a figure-8 pattern broadside to the array results.



Practical Antennas

Phased Arrays

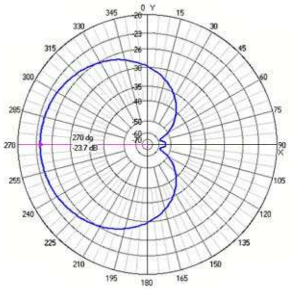
- If the elements are fed 180° out-of-phase, a pattern in line with the elements results.
  - If the elements are 1/2λ apart, a figure-8 pattern in line with the array results.



Practical Antennas

Phased Arrays.

- If the elements are 1/4λ apart & are fed 90° out-of phase, a cardioid pattern results.



Practical Antennas

Phased Arrays

- The desired radiation pattern is created by changing the phase relationship of the elements of the array.
  - Transmission lines with specific electrical lengths are used to create the desired phase relationships.
    - Called "phasing lines".

Practical Antennas

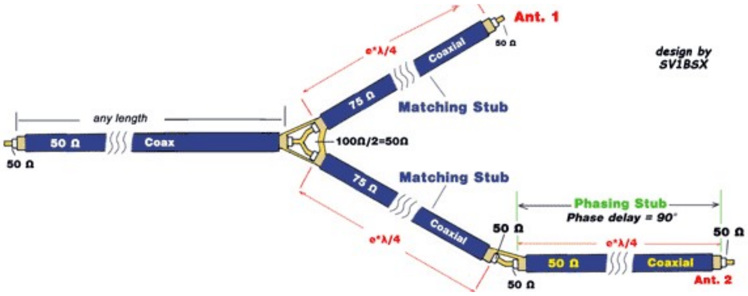
Phased Arrays

- If identical antennas are being fed in phase, a device called a Wilkinson divider can be used to divide the power equally between the elements.
  - A change in the load on one "branch" of the divider will not affect the power going to the other branches.

Practical Antennas

Phased Arrays.

- Wilkinson divider.



E9C01 -- What is the radiation pattern of two 1/4-wavelength vertical antennas spaced 1/2-wavelength apart and fed 180 degrees out of phase?

A. Cardioid

B. Omni-directional

C. A figure-8 broadside to the axis of the array

[✓ D. A figure-8 oriented along the axis of the array]

E9C02 -- What is the radiation pattern of two 1/4-wavelength vertical antennas spaced 1/4-wavelength apart and fed 90 degrees out of phase?

[✓ A. Cardioid]
B. A figure-8 end-fire along the axis of the array
C. A figure-8 broadside to the axis of the array
D. Omni-directional

E9C03 -- What is the radiation pattern of two 1/4-wavelength vertical antennas spaced 1/2-wavelength apart and fed in phase?

A. Omni-directional
B. Cardioid
[✓ C. A Figure-8 broadside to the axis of the array]
D. A Figure-8 end-fire along the axis of the array

E9E08 -- What is a use for a Wilkinson divider?

A. It divides the operating frequency of a transmitter signal so it can be used on a lower frequency band

B. It is used to feed high-impedance antennas from a low-impedance source

➡ C. It is used to divide power equally between two 50-ohm loads while maintaining 50-ohm input impedance

D. It is used to feed low-impedance loads from a high-impedance source

E9E11 -- What is the primary purpose of phasing lines when used with an antenna having multiple driven elements?

➡ A. It ensures that each driven element operates in concert with the others to create the desired antenna pattern

B. It prevents reflected power from traveling back down the feed line and causing harmonic radiation from the transmitter

C. It allows single-band antennas to operate on other bands

D. It creates a low-angle radiation pattern

Practical Antennas

Antennas for Space Communications

- Gain and antenna size.
  - At VHF & UHF, Yagi antennas are the most commonly-used type for satellite communications.
  - At microwave frequencies, parabolic dish antennas are often required.
  - For both types of antennas, the following rule-of-thumb applies:
    - The bigger the antenna (in wavelengths) the more gain.
    - A Yagi antenna with a longer boom has more gain.
    - A dish antenna with twice the diameter has 4x the gain (6dB).

Practical Antennas

Antennas for Space Communications

- How much gain is required?
  - The more the better – **NOT!**
    - Higher gain → narrower beamwidth.
    - Narrower beamwidth → harder to aim antenna.
  - At VHF/UHF, Yagi antennas are usually sufficient.

Practical Antennas

Antennas for Space Communications

- Pointing the antenna.
  - Directional antennas for terrestrial communications use a single rotator.
    - Azimuth.
  - Directional antennas for satellite communications often use 2 rotators to more accurately point antenna at satellite.
    - Azimuth.
    - Elevation.

Practical Antennas

Antennas for Space Communications

- Effects of Polarization.
  - Circular polarization gives the best results.
  - 2 Yagis constructed on the same boom at right-angles to each other & fed 90° out-of-phase will result in a circularly–polarized signal.

E9D01 -- How much does the gain of an ideal parabolic dish antenna change when the operating frequency is doubled?

A. 2 dB
B. 3 dB
C. 4 dB
➡ D. 6 dB

E9D02 -- How can linearly polarized Yagi antennas be used to produce circular polarization?

A. Stack two Yagis, fed 90 degrees out of phase, to form an array with the respective elements in parallel planes
B. Stack two Yagis, fed in phase, to form an array with the respective elements in parallel planes
➡ C. Arrange two Yagis perpendicular to each other with the driven elements at the same point on the boom and fed 90 degrees out of phase
D. Arrange two Yagis collinear to each other, with the driven elements fed 180 degrees out of phase

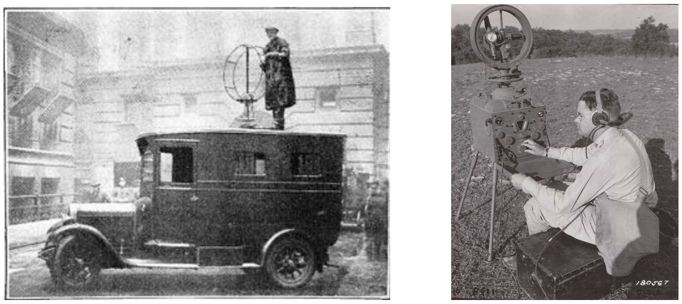
Practical Antennas

Receiving Loop Antennas for Direction Finding

- The basic loop antenna used for HF receiving consists of one or more turns of wire in an open loop.

Practical Antennas

Receiving Loop Antennas for Direction Finding



Practical Antennas

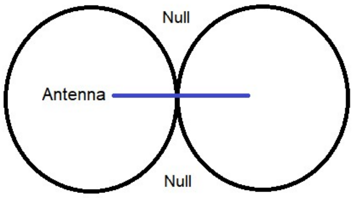
Receiving Loop Antennas for Direction Finding

- For a single-turn loop, the size must be small compared to the wavelength.
  - The length of the wire should be 0.08λ or less.
- Adding turns or making the loop bigger results in a higher output voltage (gain).
- Loop antennas are used for receiving because of their noise-rejecting properties rather than their gain.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- The radiation pattern of a small loop antenna is bi-directional in the plane of the loop.
  - For radio direction finding (RDF) work, the nulls are normally used because they give a more accurate bearing.



Practical Antennas

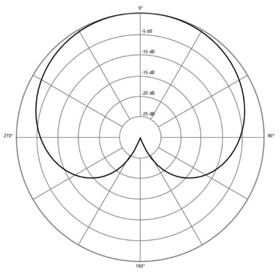
Receiving Loop Antennas for Direction Finding

- The fact that the radiation pattern of a small loop antenna has 2 nulls is a major disadvantage for radio direction finding.
  - The direction to the transmitter is ambiguous. There are 2 possible bearings.
    - The correct bearing cannot be determined from a single location.

Practical Antennas

Receiving Loop Antennas for Direction Finding

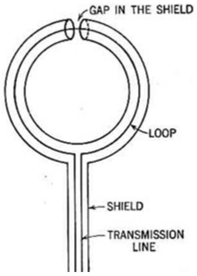
- Adding an omni-directional antenna, called a “sense antenna”, to the loop changes the radiation pattern to a cardioid pattern with a single null.



Practical Antennas

Receiving Loop Antennas for Direction Finding

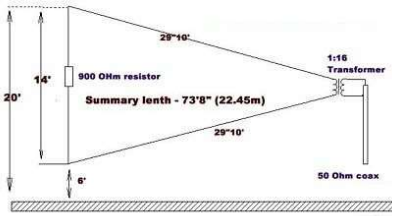
- If you enclose the wire of the loop with a grounded electrostatic shield, it will reduce coupling to nearby object and improve the nulls.
  - Construct the loop using coaxial cable.



Practical Antennas

Receiving Loop Antennas for Direction Finding

- A popular receiving antenna for the low bands is the pennant flag antenna.
  - A single-turn, vertically-oriented, triangular loop terminated with a 900Ω resistor.



Practical Antennas

Receiving Loop Antennas for Direction Finding

- The pennant flag antenna, the Beverage antenna, & other low-band receive antennas are all used because they reject noise; resulting in a better signal-to-noise ratio even though the signal level is reduced.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- A “figure of merit” for the noise reduction is called the “receiving directivity factor” or “relative directivity factor” (RDF).
  - The RDF equals the gain in the forward direction divided by the average of the gain in all other directions.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- Now we will talk about a different type of RDF – Radio Direction Finding.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- Radio direction finding is used by amateur radio operators for:
  - A fun activity.
    - “Fox hunting”.
  - Finding sources of interference.
    - Stuck transmitters.
    - Noise sources.
  - Assisting with search-and-rescue efforts.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- In order to perform radio direction finding (RDF), you need:
  - A directional antenna.
  - A signal detector.
    - A receiver with an S-meter.
    - A field-strength meter.
    - etc.

Practical Antennas

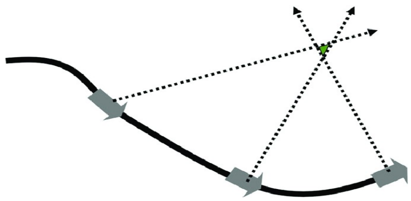
Receiving Loop Antennas for Direction Finding

- Mobile/portable stations with a unidirectional antenna can find a transmitter by “following the signal”.
- Mobile/portable stations with a bidirectional antenna or fixed stations with a directional antenna can find a transmitter by triangulation.

Practical Antennas

Receiving Loop Antennas for Direction Finding

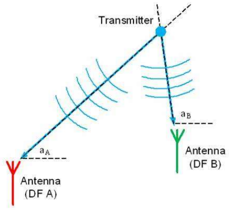
- Mobile/portable station triangulation.
  - Take bearings from several different locations & plot on a map.
    - At least 3 readings from 3 different locations is recommended.



Practical Antennas

Receiving Loop Antennas for Direction Finding

- Fixed station triangulation.
  - Have 2 or more fixed stations in widely-spaced locations take bearings & plot on a map.
    - At least 3 stations is recommended.



Practical Antennas

Receiving Loop Antennas for Direction Finding

- It is important for mobile/portable stations have some way to attenuate the received signal to prevent receiver overload & to improve the accuracy of the bearings as the station gets closer to the transmitter.

Practical Antennas

Receiving Loop Antennas for Direction Finding

- When taking reading, the physical surroundings can cause false bearings.
  - Terrain.
  - Nearby buildings, water towers, radio towers, etc.
  - Overhead power/utility lines.

E9H03 -- What is Receiving Directivity Factor (RDF)?

A. Forward gain compared to the gain in the reverse direction

B. Relative directivity compared to isotropic

C. Relative directivity compared to a dipole

➡ D. Forward gain compared to average gain over the entire hemisphere

E9H04 -- What is an advantage of placing a grounded electrostatic shield around a small loop direction-finding antenna?

A. It adds capacitive loading, increasing the bandwidth of the antenna

➡ B. It eliminates unbalanced capacitive coupling to the surroundings, improving the nulls

C. It eliminates tracking errors caused by strong out-of-band signals

D. It increases signal strength by providing a better match to the feed line

E9H05 -- What is the main drawback of a small wire-loop antenna for direction finding?

➡ A. It has a bidirectional pattern

B. It has no clearly defined null

C. It is practical for use only on VHF and higher bands

D. All these choices are correct

E9H06 -- What is the triangulation method of direction finding?

A. The geometric angles of sky waves from the source are used to determine its position

B. A fixed receiving station plots three headings to the signal source

➡ C. Antenna headings from several different receiving locations are used to locate the signal source

D. A fixed receiving station uses three different antennas to plot the location of the signal source

E9H07 -- Why is RF attenuation used when direction-finding?

A. To narrow the receiver bandwidth
B. To compensate for isotropic directivity and the antenna effect of feed lines
C. To increase receiver sensitivity
➡ D. To prevent receiver overload which reduces pattern nulls

E9H08 -- What is the function of a sense antenna?

➡ A. It modifies the pattern of a DF antenna array to provide a null in one direction
B. It increases the sensitivity of a DF antenna array
C. It allows DF antennas to receive signals at different vertical angles
D. It provides diversity reception that cancels multipath signals

E9H09 -- What is a Pennant antenna?

A. A four-element, high-gain vertical array invented by George Pennant

➡ B. A small, vertically oriented receiving antenna consisting of a triangular loop terminated in approximately 900 ohms

C. A form of rhombic antenna terminated in a variable capacitor to provide frequency diversity

D. A stealth antenna built to look like a flagpole

E9H10 -- How can the output voltage of a multi-turn receiving loop antenna be increased?

A. By reducing the permeability of the loop shield

B. By utilizing high impedance wire for the coupling loop

C. By winding adjacent turns in opposing directions

➡ D. By increasing the number of turns and/or the area

E9H11 -- What feature of a cardioid pattern antenna makes it useful for direction finding?

A. A very sharp peak

➡ B. A very sharp single null

C. Broadband response

D. High radiation angle

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Break

Antenna Systems

An antenna system is more than just the antenna itself.

- Antenna.
- Supports.
- Feed line.
- Matching devices.
- Metering devices.

Practical Antennas

Effective Radiated Power

- The effective radiated power (ERP) is the power that would be required from a reference antenna to create the same field strength.
- There are 2 types of antennas commonly used as the reference for calculating ERP:
  - A 1/2λ dipole.
    - Used for most calculations.
    - Used in FCC Rules.
  - An isotropic radiator.
    - Used for space communications calculations.

Practical Antennas

Effective Radiated Power

- When calculating the ERP, include:
  - Transmitter power output (PEP).
  - Antenna gain (dBi or dBd).
  - Feed line loss (dB).
  - Other system losses (dB).
  - ERP = Power Output + Antenna Gain – System Losses

E9A02 -- What is the effective radiated power relative to a dipole of a repeater station with 150 watts transmitter power output, 2 dB feed line loss, 2.2 dB duplexer loss and 7 dBd antenna gain?

A. 1977 watts

B. 78.7 watts

C. 420 watts

[✓ D. 286 watts]

E9A06 -- What is the effective radiated power relative to a dipole of a repeater station with 200 watts transmitter power output, 4 dB feed line loss, 3.2 dB duplexer loss, 0.8 dB circulator loss and 10 dBd antenna gain?

➡ A. 317 watts
B. 2000 watts
C. 126 watts
D. 300 watts

E9A07 -- What is the effective radiated power of a repeater station with 200 watts transmitter power output, 2 dB feed line loss, 2.8 dB duplexer loss, 1.2 dB circulator loss, and 7 dBi antenna gain?

A. 159 watts
➡ B. 252 watts
C. 632 watts
D. 63.2 watts

E9A13 -- What term describes station output, taking into account all gains and losses?

A. Power factor
B. Half-power bandwidth
➡ C. Effective radiated power
D. Apparent power

Antenna Systems

Impedance Matching

- The feedpoint impedance of an antenna rarely matches that of the feed line.
- The impedance of the feed line used is not always 50Ω.
  - e.g. -- 600Ω open-wire line.
- Some form of impedance matching is required to present a 50Ω resistive load to the transmitter.

Antenna Systems

Impedance Matching

- If the impedance of the antenna does not match the impedance of the feed line, the best solution is to do the impedance matching at the feedpoint of the antenna.

Antenna Systems

Impedance Matching

- Impedance matching done at the feedpoint of the antenna:
  - Is not convenient.
    - Adjustments must be made at the antenna instead of from the operating position.
  - Is less expensive.
    - A simple L-C network can be used.
  - Has lower transmission line losses.
    - The SWR on the transmission line is low.

Antenna Systems

Impedance Matching

- Impedance matching done at the transmitter:
  - Is convenient.
    - Adjustments can be made at the operating position
  - Is usually more expensive.
    - An external antenna tuner may be required.
  - Has higher transmission line losses.
    - The SWR on the transmission line is high.

Antenna Systems

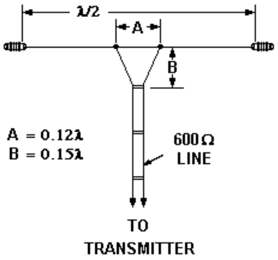
Impedance Matching

- Few real-world antennas have a 50Ω resistive impedance at the feedpoint.
  - e.g. – The feedpoint impedance of the driven element of a 3-element Yagi is about 25-30Ω.
- Several techniques have been developed to match the antenna impedance to the feed line.

Antenna Systems

Impedance Matching

- The delta match:
  - Matches a higher impedance transmission line to a lower impedance antenna.
  - Inherently balanced.
  - There is some radiation from the delta.
  - Is difficult to adjust.
  - No center insulator is required.



Antenna Systems

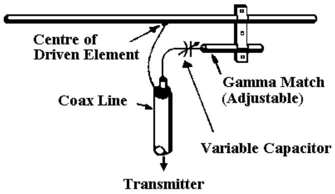
Impedance Matching

- A common matching method for beams is the gamma match.
- A gamma match is also commonly used to feed towers which are used as vertical antennas.
- Electrically, a gamma match is a short section of transmission line connected between the center of the antenna and a short distance away from the center.

Antenna Systems

Impedance Matching

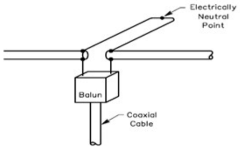
- The gamma match is inherently unbalanced so no balun is needed.



Antenna Systems

Impedance Matching

- The hairpin match (a.k.a. – Beta match) is a common matching method for beams.
  - The driven element must have a capacitive reactance.
    - Shorter than 1/2λ.
  - Is electrically the equivalent of a shunt inductor.



Antenna Systems

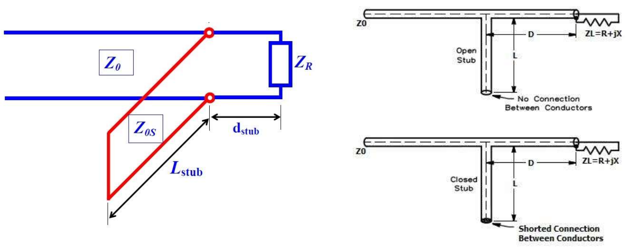
Impedance Matching

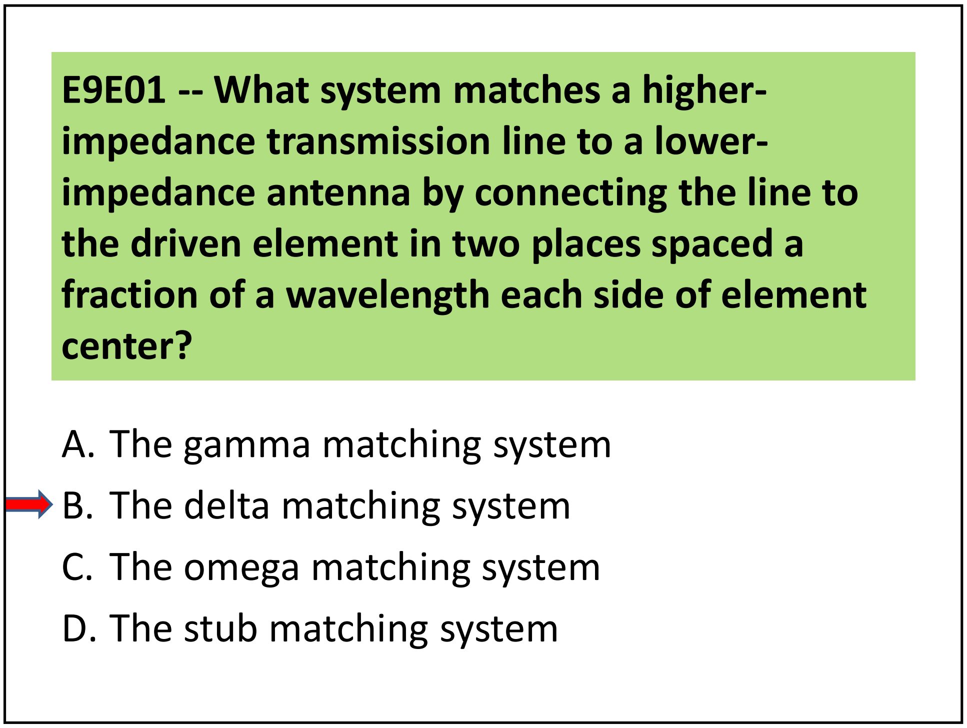
- A short length of transmission line connected in parallel with the antenna & feed line is called a stub match.
  - A stub match can match highly reactive loads.
  - A stub match can be made from a piece of coax.
  - The “universal stub system” is often used at VHF & UHF when the impedances to be matched are unknown & the stub lengths are manageable.

Antenna Systems

Impedance Matching

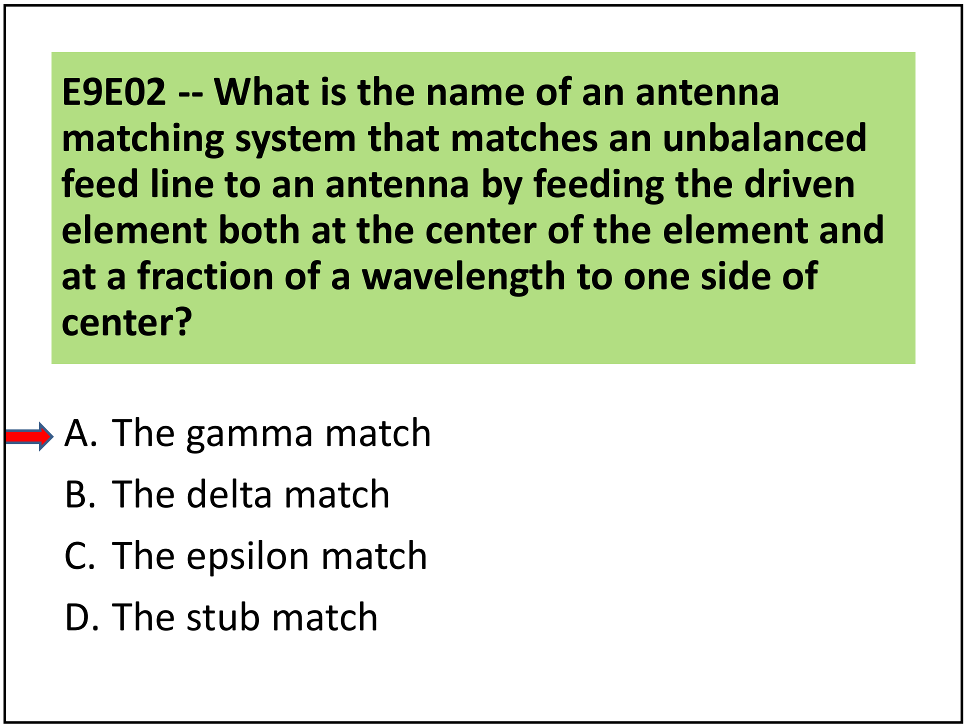
- Stub match.
  - A Smith chart can be used to calculate the length & position of the stub to achieve the desired match.





E9E01 -- What system matches a higher-impedance transmission line to a lower-impedance antenna by connecting the line to the driven element in two places spaced a fraction of a wavelength each side of element center?

A. The gamma matching system
➡ B. The delta matching system
C. The omega matching system
D. The stub matching system



E9E02 -- What is the name of an antenna matching system that matches an unbalanced feed line to an antenna by feeding the driven element both at the center of the element and at a fraction of a wavelength to one side of center?

➡ A. The gamma match
B. The delta match
C. The epsilon match
D. The stub match

E9E03 -- What is the name of the matching system that uses a section of transmission line connected in parallel with the feed line at or near the feed point?

A. The gamma match
B. The delta match
C. The omega match
➡ D. The stub match

E9E04 -- What is the purpose of the series capacitor in a gamma-type antenna matching network?

A. To provide DC isolation between the feed line and the antenna
➡ B. To cancel the inductive reactance of the matching network
C. To provide a rejection notch to prevent the radiation of harmonics
D. To transform the antenna impedance to a higher value

E9E05 -- How must an antenna's driven element be tuned to use a hairpin matching system?

➡ A. The driven element reactance must be capacitive

B. The driven element reactance must be inductive

C. The driven element resonance must be lower than the operating frequency

D. The driven element radiation resistance must be higher than the characteristic impedance of the transmission line

---

E9E09 -- Which of the following is used to shunt-feed a grounded tower at its base?

A. Double-bazooka match

B. Hairpin match

➡ C. Gamma match

D. All of these choices are correct

E9G05 -- Which of the following is a common use for a Smith chart?

➡ A. Determine the length and position of an impedance matching stub
B. Determine the impedance of a transmission line, given the physical dimensions
C. Determine the gain of an antenna given the physical and electrical parameters
D. Determine the loss/100 feet of a transmission line, given the velocity factor and conductor materials

---

Transmission Lines

Velocity Factor and Electrical Length

- Wavelength in a feed line.
  - A radio wave in free space travels at the speed of light.
    - 186,000 miles/second = 300 x 10^6 meters/second.
  - The current in a feed line travels at less than the speed of light.

Transmission Lines

Velocity Factor and Electrical Length

- The velocity of propagation (V_P) is the speed at which a wave travels down a feed line.
  - V_P is always less than the speed of light (C).
- The ratio of the velocity of propagation to the speed of light is called the "velocity factor".
  - $VF = V_P / C$.
  - VF is always less than 1.

Transmission Lines

Velocity Factor and Electrical Length

- The velocity factor is primarily determined by the dielectric constant (ε) of the insulator.

$$VF = 1 / \sqrt{\varepsilon}$$

  - The dielectric constant of air or a vacuum is 1.
  - The dielectric constant is close to 1 for parallel-wire feed lines.

Transmission Lines

Velocity Factor and Electrical Length

- Typical velocity factors for common types of transmission lines are:
  - Parallel wire line = ~100% (1.00).
  - Solid-dielectric coaxial cable = ~66% (0.66).
  - Foam-dielectric coaxial cable = ~82% (0.82).

Transmission Lines

Velocity Factor and Electrical Length

- Because of the velocity factor, the electrical length and the physical length of a transmission line are different.
  - The length of a transmission line can be express in terms of its physical length (feet, meters, etc.).
  - The length of a transmission line can also be expressed in terms of the wavelength at a given frequency. This is its electrical length.

Transmission Lines

Velocity Factor and Electrical Length

- Converting between physical length (L_P) and electrical length (L_E).
  - $L_E = L_P / VF$
  - $L_P = L_E \times VF$

Transmission Lines

Velocity Factor and Electrical Length

- Converting between physical length (L_P) and electrical length (L_E).
  - For example:
    - A physical 1/4λ at 14MHz is 5.3m (17’ 5”).
    - The physical length of an electrical 1/4λ of solid-dielectric coaxial cable at 14MHz would be:
      - 0.66 x 5.5m = 3.5m (11’ 6”).

E9F01 -- What is the velocity factor of a transmission line?

A. The ratio of the characteristic impedance of the line to the terminating impedance
B. The index of shielding for coaxial cable
C. The velocity of the wave in the transmission line multiplied by the velocity of light in a vacuum
➡ D. The velocity of the wave in the transmission line divided by the velocity of light in a vacuum

---

E9F02 -- Which of the following has the biggest effect on the velocity factor of a transmission line?

A. The termination impedance
B. The line length
➡ C. Dielectric materials used in the line
D. The center conductor resistivity

E9F03 -- Why is the physical length of a coaxial cable transmission line shorter than its electrical length?

A. Skin effect is less pronounced in the coaxial cable

B. The characteristic impedance is higher in a parallel feed line

C. The surge impedance is higher in a parallel feed line

➡ D. Electrical signals move more slowly in a coaxial cable than in air

E9F05 -- What is the approximate physical length of a solid polyethylene dielectric coaxial transmission line that is electrically 1/4 wavelength long at 14.1 MHz?

A. 10.6 meters

B. 5.3 meters

C. 4.3 meters

➡ D. 3.5 meters

E9F06 -- What is the approximate physical length of an air-insulated, parallel conductor transmission line that is electrically 1/2 wavelength long at 14.10 MHz?

A. 15 meters

B. 20 meters

➡ C. 10 meters

D. 71 meters

E9F09 -- What is the approximate physical length of a foam polyethylene dielectric coaxial transmission line that is electrically 1/4 wavelength long at 7.2 MHz?

A. 10.4 meters

B. 8.3 meters

➡ C. 6.9 meters

D. 5.2 meters

Transmission Lines

Feed Line Loss

- All physical feed lines have some loss.
- Parallel-conductor feed lines have the lowest loss.
- Regardless of the type of transmission line, the loss **always** increases as frequency increases.

Transmission Lines

Feed Line Loss

- Larger diameter cables tend to have lower loss.
- Foam dielectric cables have lower loss than solid dielectric cables of the same diameter.
  - Foam dielectric cables have a lower maximum voltage than solid dielectric cables of the same diameter.
- Feed line loss is normally expressed as dB/100ft at a specified frequency.

Transmission Lines

Cable Type	Z_0	VF (%)	OD (in)	V_{max} (RMS)	Loss (dB/100 ft) @ 100 MHz
RG-8 (Foam)	50Ω	82	.405	600	1.5
RG-8 (Solid)	52Ω	66	.405	3700	1.9
RG-8X	50Ω	82	.242	600	3.2
RG-58 (Solid)	52Ω	66	.195	1400	4.5
RG-58A Foam)	50Ω	73	.195	300	4.3
RG-174	50Ω	66	.110	1100	8.6
Twin Lead	300Ω	80	n/a	8,000	1.1
Ladder Line	450Ω	91	n/a	10,000	0.3
Open-Wire Line	600Ω	95-99	n/a	12,000	0.2

E9F07 -- How does ladder line compare to small-diameter coaxial cable such as RG-58 at 50 MHz?

[✓ A. Lower loss]
B. Higher SWR
C. Smaller reflection coefficient
D. Lower velocity factor

E9F08 -- Which of the following is a significant difference between foam dielectric coaxial cable and solid dielectric cable, assuming all other parameters are the same?

A. Foam dielectric has lower safe operating voltage limits

B. Foam dielectric has lower loss per unit of length

C. Foam dielectric has higher velocity factor

➡ D. All these choices are correct

Transmission Lines

Reflection Coefficient and SWR

- The ratio of the reflected voltage at a given point on a feed line to the incident (forward) voltage at the same point on the feed line is called the voltage reflection coefficient (ρ).
  - The voltage reflection coefficient is determined by the feed line impedance and the actual load impedance.
    - $\rho = (Z_L - Z_0) / (Z_L + Z_0)$
  - When ρ = 0, the voltage distribution along length of line is constant (the line is flat).

Transmission Lines

Reflection Coefficient and SWR

- If $\rho > 0$, then voltage distribution along line is not constant.
  - Ratio of voltage peaks to voltage minimums is called the voltage standing wave ratio (VSWR or simply SWR).
  - SWR = $(1 + \rho) / (1 - \rho)$
- SWR can easily be computed from line & load impedances.
  - If $Z_L > Z_0$ then SWR = Z_L / Z_0
  - If $Z_L < Z_0$ then SWR = Z_0 / Z_L

E9E07 -- What parameter describes the interactions at the load end of a mismatched transmission line?

A. Characteristic impedance

➡ B. Reflection coefficient

C. Velocity factor

D. Dielectric constant

Transmission Lines

Power Measurement

- There are several methods of measuring a transmitter's relative power output.
  - Neon bulb.
  - RF ammeter.
  - SWR meter.
  - Field strength meter.

Transmission Lines

Power Measurement

- Sometimes it is necessary to know the actual power output of a transmitter.
  - RF power meter.
  - Directional RF wattmeter.

Transmission Lines

Power Measurement

- Using a directional RF wattmeter, you can calculate the reflection coefficient from the forward & the reflected power.
    - $\rho = \sqrt{P_R/P_F}$
  - The power delivered to the load is:
    - $P_L = P_F - P_R$

E4B06 -- How much power is being absorbed by the load when a directional power meter connected between a transmitter and a terminating load reads 100 watts forward power and 25 watts reflected power?

A. 100 watts

B. 125 watts

C. 25 watts

[✓ D. 75 watts]

E4B09 -- What is indicated if the current reading on an RF ammeter placed in series with the antenna feed line of a transmitter increases as the transmitter is tuned to resonance?

A. There is possibly a short to ground in the feed line

B. The transmitter is not properly neutralized

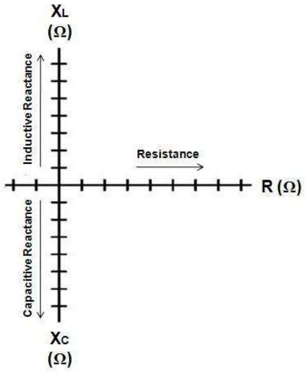
C. There is an impedance mismatch between the antenna and feed line

➡ D. There is more power going into the antenna

Transmission Lines

Smith Chart

- First a review.
  - Impedances consist of a resistance and a reactance.
  - All possible impedances can be plotted on a graph using rectangular coordinates.



Transmission Lines

Smith Chart

- First a review.
  - When a load (impedance) is connected to a transmission line & a signal source is connected to the other end of the line, energy is reflected back & forth along the line.
  - The ratio of voltage to current (impedance) varies at different points along the line.
  - At a distance of 1/2λ, the input impedance equals the load impedance.

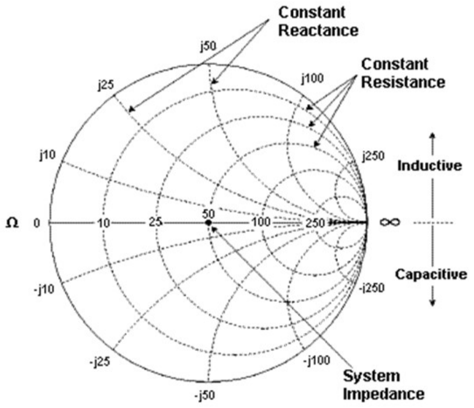
Transmission Lines

Smith Chart

- Plotting the impedance along a transmission line using rectangular coordinates is messy.
- If you bend the reactance axis into a circle, then the plot of the impedance along the line becomes a circle.
  - This is called a “Smith Chart”.

Transmission Lines

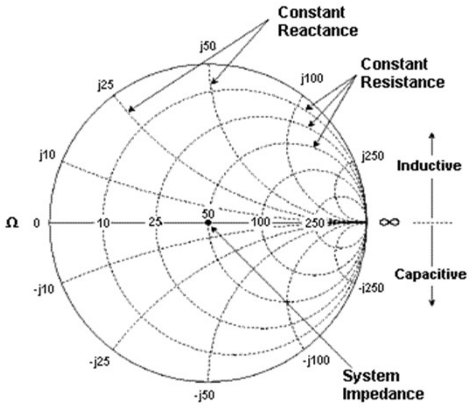
Smith Chart



Transmission Lines

Smith Chart

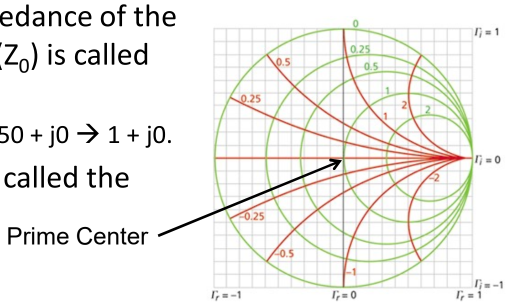
- Outermost circle.
  - Reactance axis.
  - Pure reactance.
- Horizontal line.
  - Resistance axis.
  - Pure resistance.
- Circles.
  - Constant resistance.
- Arcs.
  - Constant reactance.



Transmission Lines

Smith Chart

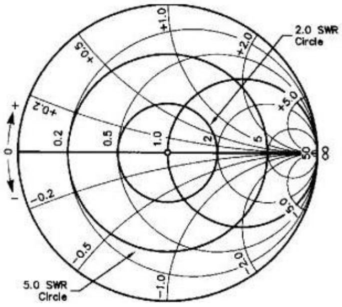
- Normalization.
  - Scaling all values to the characteristic impedance of the transmission line (Z_0) is called normalization.
    - If $Z_0 = 50\Omega$, then 50 + j0 → 1 + j0.
  - The point 1 + j0 is called the prime center.



Transmission Lines

Smith Chart

- Circles centered on the prime center are constant SWR circles.



Transmission Lines

Smith Chart

- Wavelength scales.
  - Additional scales around the outer edge of the chart are wavelength scales.
  - Wavelength scales are calibrated in fractions of an electrical wavelength in a transmission line.

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Transmission Lines

Smith Chart

- Wavelength scales.
  - The ratio of voltage to current (impedance) varies at different points along the line.
  - At 1/2λ the impedance equals the load impedance.
  - One trip around Smith Chart is 1/2λ (180°).
  - The wavelength scales can be used to calculate impedance at different points along a transmission line.

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E9G01 -- Which of the following can be calculated using a Smith chart?

- ➡ A. Impedance along transmission lines
- B. Radiation resistance
- C. Antenna radiation pattern
- D. Radio propagation

E9G02 -- What type of coordinate system is used in a Smith chart?

- A. Voltage circles and current arcs
- ➡ B. Resistance circles and reactance arcs
- C. Voltage lines and current chords
- D. Resistance lines and reactance chords

E9G03 -- Which of the following is often determined using a Smith chart?

A. Beam headings and radiation patterns
B. Satellite azimuth and elevation bearings
➡ C. Impedance and SWR values in transmission lines
D. Trigonometric functions

E9G04 -- What are the two families of circles and arcs that make up a Smith chart?

A. Resistance and voltage
B. Reactance and voltage
➡ C. Resistance and reactance
D. Voltage and impedance

E9G06 -- On the Smith chart shown in Figure E9-3, what is the name for the large outer circle on which the reactance arcs terminate?

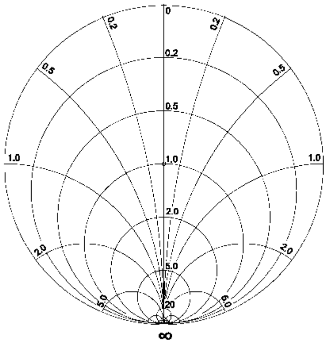
A. Prime axis

[✓ B. Reactance axis]

C. Impedance axis

D. Polar axis

Figure E9-3



E9G07 -- On the Smith chart shown in Figure E9-3, what is the only straight line shown?

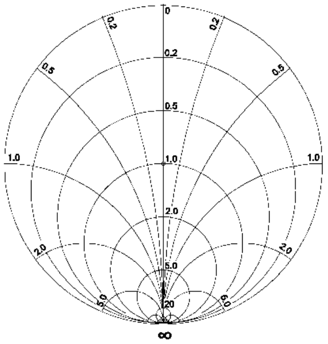
A. The reactance axis

B. The current axis

C. The voltage axis

[✓ D. The resistance axis]

Figure E9-3



E9G08 -- What is the process of normalization with regard to a Smith chart?

A. Reassigning resistance values with regard to the reactance axis

B. Reassigning reactance values with regard to the resistance axis

➡ C. Reassigning impedance values with regard to the prime center

D. Reassigning prime center with regard to the reactance axis

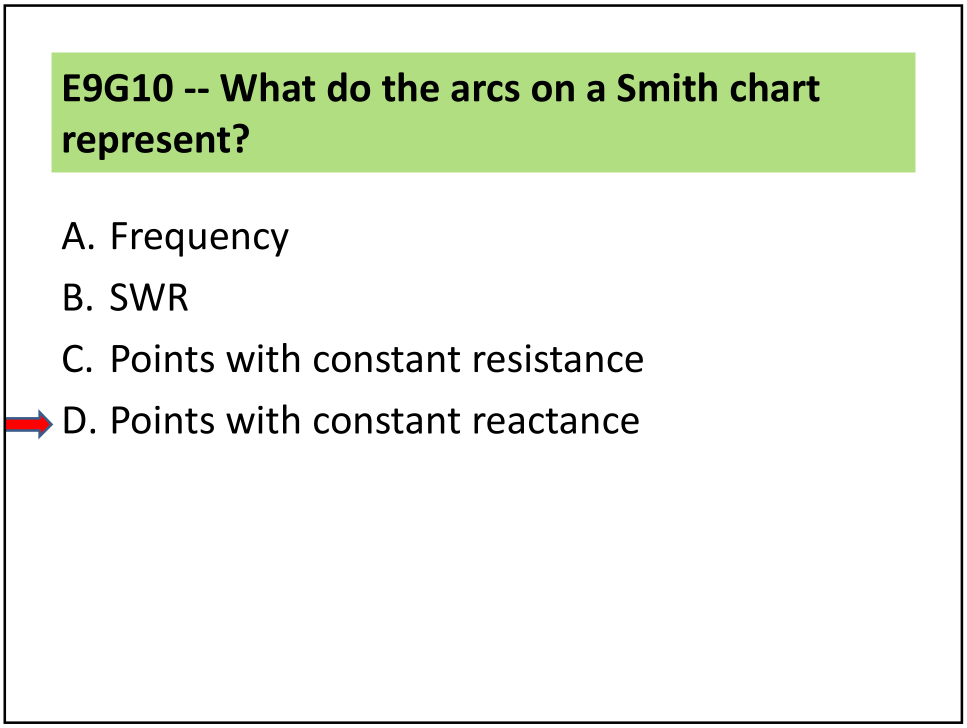
E9G09 -- What third family of circles is often added to a Smith chart during the process of solving problems?

➡ A. Standing-wave ratio circles

B. Antenna-length circles

C. Coaxial-length circles

D. Radiation-pattern circles



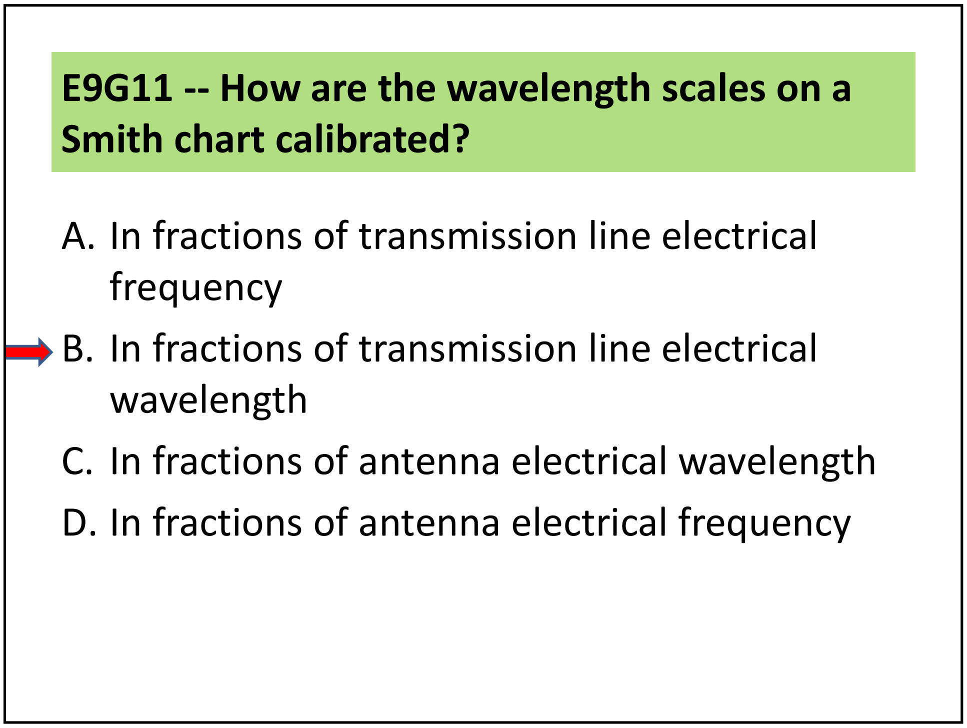
E9G10 -- What do the arcs on a Smith chart represent?

A. Frequency

B. SWR

C. Points with constant resistance

[✓ D. Points with constant reactance]



E9G11 -- How are the wavelength scales on a Smith chart calibrated?

A. In fractions of transmission line electrical frequency

[✓ B. In fractions of transmission line electrical wavelength]

C. In fractions of antenna electrical wavelength

D. In fractions of antenna electrical frequency

Transmission Lines

Transmission Line Stubs and Transformers

- If the impedance of the load does not match the characteristic impedance of the transmission line, a portion of the power is reflected back.
- The reflected power combines with the forward power to create standing waves.

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Transmission Lines

Transmission Line Stubs and Transformers

- The result of these standing waves is that the ratio of voltage to current (impedance) is different at different points along the line.
  - These impedance values repeat every 1/2λ.
  - If a transmission line is 1/2λ long, then the impedance seen at the input of the transmission line will equal the impedance of the load.

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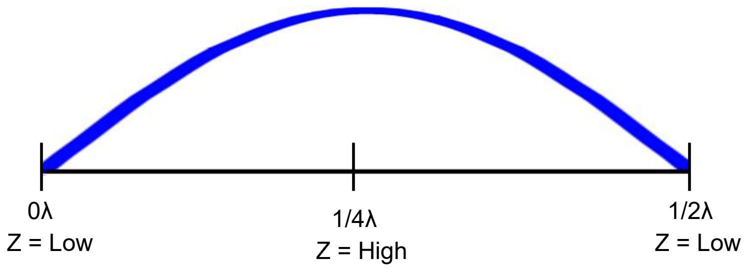
Transmission Lines

Transmission Line Stubs and Transformers

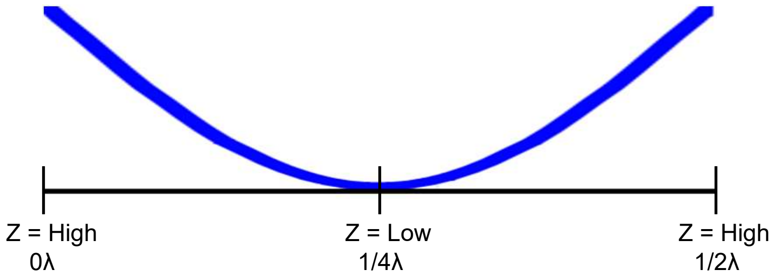
- The impedance along a 1/2λ long transmission line that is shorted at the far end:



Transmission Lines

Transmission Line Stubs and Transformers

- The impedance along a 1/2λ long transmission line that is an open circuit at the far end:



Transmission Lines

Transmission Line Stubs and Transformers

- Note that at odd multiples of 1/4λ along the line, the impedance is the opposite.
  - If the line is shorted at the far end, then the line will look like an open circuit.
  - If the line is open at the far end, then the line will look like a short circuit.

Transmission Lines

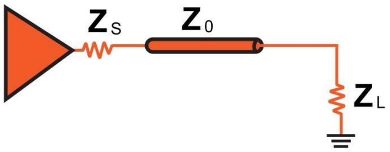
Transmission Line Stubs and Transformers

- Transmission lines 1/8λ long are not quite as easy to remember.
  - Open line = capacitive reactance.
    - The 2 conductors act like the 2 plates of a capacitor.
  - Shorted line = inductive reactance.
    - The 2 conductors plus the short at the far end look like a long single-turn coil of wire.

Transmission Lines

Transmission Line Stubs and Transformers

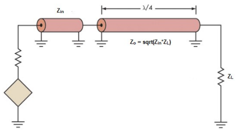
- For field-deployed antennas, the military often prescribes a specified length of transmission line in order to present the proper load to the transmitter.



Transmission Lines

Transmission Line Stubs and Transformers

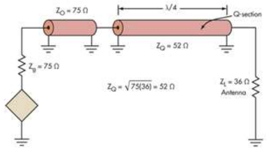
- Synchronous transformers.
  - 1/4λ matching line:



$$Z_{Xfmr} = \sqrt{Z_{Load} \times Z_{in}}$$

$$Z_{Load} = Z_{Xfmr}^2 / Z_{in}$$

$$Z_{In} = Z_{Xfmr}^2 / Z_{load}$$



Transmission Lines

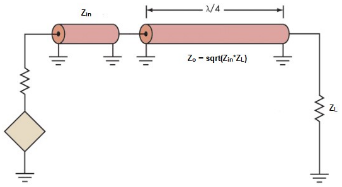
Transmission Line Stubs and Transformers

- Synchronous transformers.
  - A useful application of the impedance transformation performed by a transmission line 1/4λ long is the synchronous transformer.

$Z_{Xfmr} = \sqrt{Z_{Load} \times Z_{in}}$

$Z_{Load} = Z_{Xfmr}^2 / Z_{in}$

$Z_{In} = Z_{Xfmr}^2 / Z_{load}$



Transmission Lines

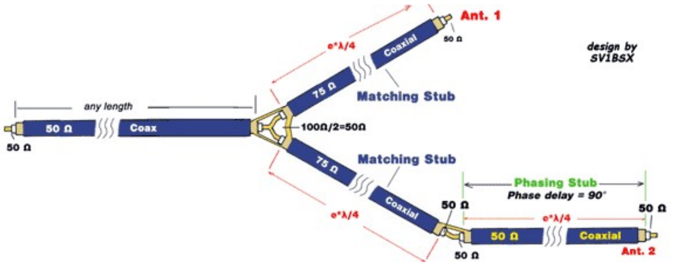
Transmission Line Stubs and Transformers.

- A practical application of the synchronous transformer:
  - We want to connect two 50Ω antennas in parallel & feed them with 50Ω transmission line.
  - If we use RG-6 or RG-11 cable for the transformer, then $Z_{Xfmr} = 75\Omega$.
    - $Z_{In} = Z_{Xfmr}^2 / Z_L$
    - $Z_{In} = 75^2 / 50 = 112.5\Omega$
    - 2 in parallel = 112.5Ω / 2 = 56.25Ω
    - SWR = 56.25/50 = 1.125:1

Transmission Lines

Transmission Line Stubs and Transformers.

- The Wilkinson divider introduced earlier is actually a pair of synchronous transformers connected in parallel.



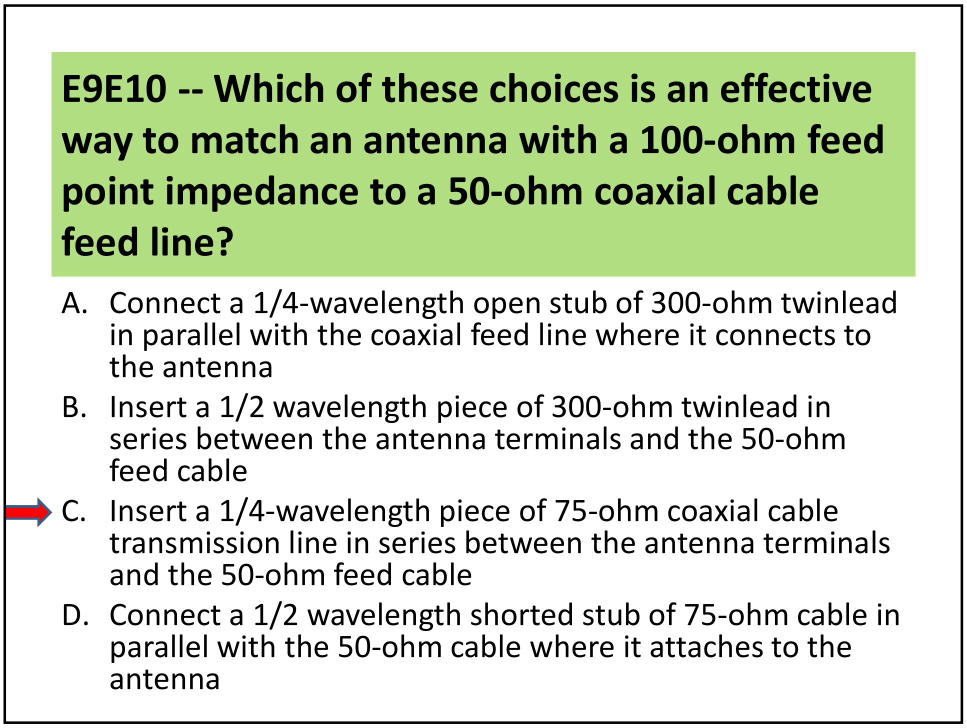
E9E06 -- Which of these feed line impedances would be suitable for constructing a quarter-wave Q-section for matching a 100-ohm loop to 50-ohm feed line?

A. 50 ohms

B. 62 ohms

[✓ C. 75 ohms]

D. 450 ohms



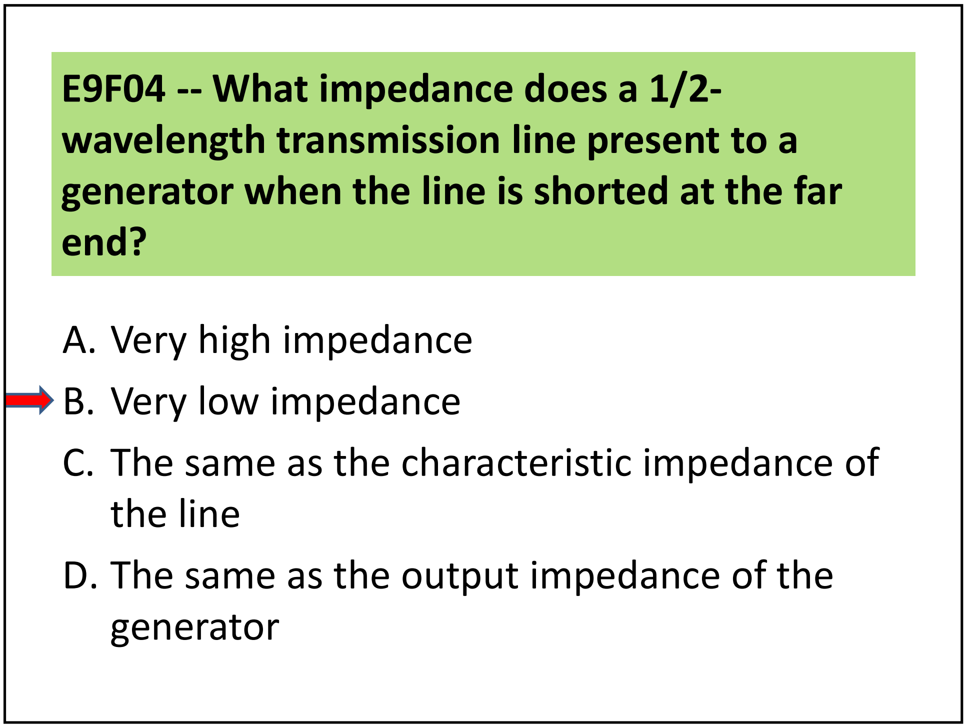
E9E10 -- Which of these choices is an effective way to match an antenna with a 100-ohm feed point impedance to a 50-ohm coaxial cable feed line?

A. Connect a 1/4-wavelength open stub of 300-ohm twinlead in parallel with the coaxial feed line where it connects to the antenna

B. Insert a 1/2 wavelength piece of 300-ohm twinlead in series between the antenna terminals and the 50-ohm feed cable

➡ C. Insert a 1/4-wavelength piece of 75-ohm coaxial cable transmission line in series between the antenna terminals and the 50-ohm feed cable

D. Connect a 1/2 wavelength shorted stub of 75-ohm cable in parallel with the 50-ohm cable where it attaches to the antenna



E9F04 -- What impedance does a 1/2-wavelength transmission line present to a generator when the line is shorted at the far end?

A. Very high impedance

➡ B. Very low impedance

C. The same as the characteristic impedance of the line

D. The same as the output impedance of the generator

E9F10 -- What impedance does a 1/8-wavelength transmission line present to a generator when the line is shorted at the far end?

A. A capacitive reactance

B. The same as the characteristic impedance of the line

➡ C. An inductive reactance

D. Zero

E9F11 -- What impedance does a 1/8-wavelength transmission line present to a generator when the line is open at the far end?

A. The same as the characteristic impedance of the line

B. An inductive reactance

➡ C. A capacitive reactance

D. Infinite

E9F12 -- What impedance does a 1/4-wavelength transmission line present to a generator when the line is open at the far end?

A. The same as the characteristic impedance of the line

B. The same as the input impedance to the generator

C. Very high impedance

➡ D. Very low impedance

E9F13 -- What impedance does a 1/4-wavelength transmission line present to a generator when the line is shorted at the far end?

➡ A. Very high impedance

B. Very low impedance

C. The same as the characteristic impedance of the transmission line

D. The same as the generator output impedance

Transmission Lines

Scattering (S) Parameters

- Scattering parameters or S parameters are a way of characterizing a circuit in terms of the signals appearing at the various connections (ports) to the circuit.
  - These signals may be:
    - Incident -- Applied to the port.
    - Reflected -- Reflected back from the port.
    - Transmitted -- Passed through the port.

Transmission Lines

Scattering (S) Parameters.

- The parameters are the ratio of 2 signals and are denoted by the letter "S" followed by 2 numbers.
  - e.g. – S_{ab}
    - "a" is port receiving the signal.
    - "b" is port originating the signal.
  - S_{11} = Reflection coefficient.
    - Can be converted to SWR.
    - Can be converted to return loss (RL).
  - S_{21} = Forward gain.

E4B03 -- Which S parameter is equivalent to forward gain?

A. S11
B. S12
[✓ C. S21]
D. S22

E4B04 -- Which S parameter represents input port return loss or reflection coefficient (equivalent to VSWR)?

[✓ A. S11]
B. S12
C. S21
D. S22

E4B07 -- What do the subscripts of S parameters represent?

[✓ A. The port or ports at which measurements are made]
B. The relative time between measurements
C. Relative quality of the data
D. Frequency order of the measurements

Transmission Lines

Antenna and Network Analyzers

- Antenna Analyzers.
  - Available on amateur market since the 1990’s.
  - A microprocessor-controlled impedance bridge with a tunable signal source & a frequency counter.

Transmission Lines

Antenna and Network Analyzers

- Antenna Analyzers.
  - The antenna feel line is connected directly the the antenna analyzer input port.
  - Since antenna analyzers contain their own signal source, no additional equipment is required.
    - Strong nearby signals may overwhelm the internal oscillator causing inaccurate readings.

Transmission Lines

Antenna and Network Analyzers

- Antenna Analyzers.
  - In addition to measuring antenna system impedance & SWR, an antenna analyzer can be used to determine many other items:
    - Inductance.
    - Capacitance.
    - Transmission line loss.
    - Transmission line velocity factor.
    - Distance to a fault in a transmission line.

Transmission Lines

Antenna and Network Analyzers.

- A vector network analyzer (VNA) is similar to an antenna analyzer, but is more powerful.
  - Antenna analyzers only measure S_{11}.
  - VNAs measure all four S parameters.
- VNAs use 3 known load impedances for self-calibration:
  - 0 Ω (Short circuit).
  - 50 Ω.
  - ∞ Ω (Open circuit).

E4A07 -- Which of the following is an advantage of using an antenna analyzer compared to an SWR bridge to measure antenna SWR?

A. Antenna analyzers automatically tune your antenna for resonance

➡ B. Antenna analyzers do not need an external RF source

C. Antenna analyzers display a time-varying representation of the modulation envelope

D. All of these choices are correct

E4A08 -- Which of the following measures SWR?

A. A spectrum analyzer

B. A Q meter

C. An ohmmeter

➡ D. An antenna analyzer

E4A11 -- How should an antenna analyzer be connected when measuring antenna resonance and feed point impedance?

A. Loosely couple the analyzer near the antenna base

B. Connect the analyzer via a high-impedance transformer to the antenna

C. Connect the antenna and a dummy load to the analyzer

➡ D. Connect the antenna feed line directly to the analyzer's connector

E4B05 -- What three test loads are used to calibrate an RF vector network analyzer?

A. 50 ohms, 75 ohms, and 90 ohms

➡ B. Short circuit, open circuit, and 50 ohms

C. Short circuit, open circuit, and resonant circuit

D. 50 ohms through 1/8 wavelength, 1/4 wavelength, and 1/2 wavelength of coaxial cable

E4B11 -- Which of the following can be measured with a vector network analyzer?

A. Input impedance

B. Output impedance

C. Reflection coefficient

➡ D. All these choices are correct

Antenna Design

Antenna Modeling and Design

- The radiation pattern and other operational factors depend upon whether the measurements are taken in the “near field” or the “far field” of the antenna.
  - The boundary between the near & far fields is not well-defined but is several wavelengths from antenna.
  - Typically, anything over 10λ from the antenna is considered to be in the far field.

Antenna Design

Antenna Modeling and Design

- In the near field:
  - The radiation pattern is dependent on the distance from the antenna.
  - The energy absorbed in the near field changes the load on transmitter.

Antenna Design

Antenna Modeling and Design

- In the far field:
  - The radiation pattern is not dependent on the distance from the antenna.
  - The energy absorbed in the far field does not change the load on the transmitter.
  - Antenna modeling software always calculates for the far field.

Antenna Design

Antenna Modeling and Design.

- The emergence of the personal computer has made the ability to mathematically model an antenna available to the average amateur radio operator.

Antenna Design

Antenna Modeling and Design.

- Most antenna modeling programs are based on the numerical electromagnetics code (NEC).
- The NEC uses a technique called “method of moments” to model an antenna & predict its performance.

Antenna Design

Antenna Modeling and Design

- Method of moments technique.
  - Each element of the antenna divided into segments.
  - The current in each segment is calculated.
  - The field resulting from that current is evaluated.
  - More segments → more accurate results.
  - More segments → greater processing time.
  - Many programs set a limit to number of segments.
  - Fewer than 10 segments per 1/2λ may produce an incorrect value for the feed point impedance.

Antenna Design

Antenna Modeling and Design.

- All antenna modeling programs provide just about everything you wanted to know about an antenna.
  - Gain.
  - Beamwidth.
  - Pattern ratios (front-to-back, front-to-side, etc.).
  - Polar plots of far-field radiation patterns.
    - Azimuth & elevation.
  - Feed point impedance.
  - SWR vs. frequency.

E9B09 -- What type of computer program technique is commonly used for modeling antennas?

A. Graphical analysis
[✓ B. Method of Moments]
C. Mutual impedance analysis
D. Calculus differentiation with respect to physical properties

E9B10 -- What is the principle of a Method of Moments analysis?

➡ A. A wire is modeled as a series of segments, each having a uniform value of current
B. A wire is modeled as a single sine-wave current generator
C. A wire is modeled as a single sine-wave voltage source
D. A wire is modeled as a series of segments, each having a distinct value of voltage across it

E9B11 -- What is a disadvantage of decreasing the number of wire segments in an antenna model below the guideline of 10 segments per half-wavelength?

A. Ground conductivity will not be accurately modeled
B. The resulting design will favor radiation of harmonic energy
➡ C. The computed feed point impedance may be incorrect
D. The antenna will become mechanically unstable

Antenna Design

Antenna Modeling and Design.

- Design Tradeoffs and Optimization.
  - Any antenna design is a compromise.
  - Antenna gain may drop significantly as the frequency is moved away from the design center frequency.

Antenna Design

Antenna Modeling and Design.

- Design Tradeoffs and Optimization.
  - The gain of a Yagi can be increased by lengthening the boom.
  - If a Yagi is optimized for maximum gain:
    - The front-to-back ratio will decrease,
    - The feedpoint impedance will become very low, and
    - The SWR bandwidth will be reduced.

E9D05 -- What usually occurs if a Yagi antenna is designed solely for maximum forward gain?

A. The front-to-back ratio increases

➡ B. The front-to-back ratio decreases

C. The frequency response is widened over the whole frequency band

D. The SWR is reduced

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Questions?

Amateur Extra Class

Next Week

Chapter 10

Topics in Radio Propagation

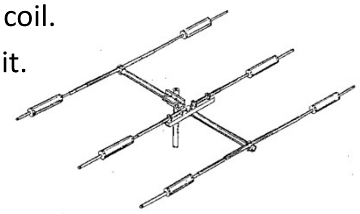
Chapter 11

Safety

Practical Antennas

Shortened and Multi-Band Antennas.

- Trap Antennas.
  - Most common design method for multi-band antenna.
  - Traps are parallel L-C circuits resonant on a particular band.
  - Below f_R trap acts as a loading coil.
  - At f_R trap acts as an open circuit.
  - Antenna efficiency depends on Q of trap.



Practical Antennas

Shortened and Multi-Band Antennas.

- Trap Antennas.
  - Disadvantages:
    - Will not reject harmonics.
    - Traps add loss.
      - Higher Q → Lower loss.
    - Traps narrow bandwidth.
      - Higher Q → Narrower bandwidth.