Amateur Extra License Class

1

Amateur Extra Class

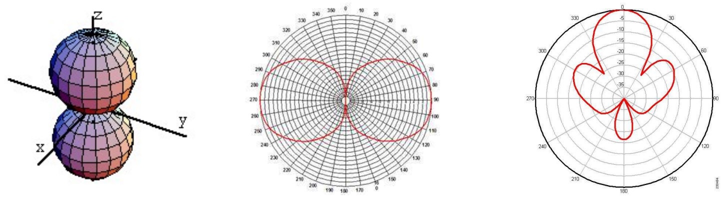
Chapter 9 Antennas and Feedlines

2

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.



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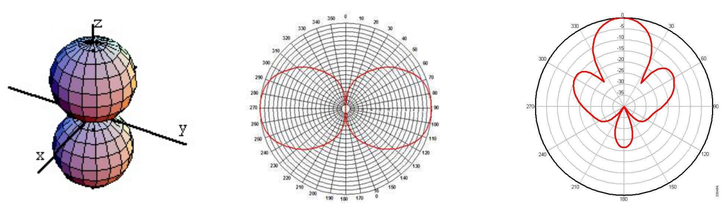
Basics of Antennas

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.



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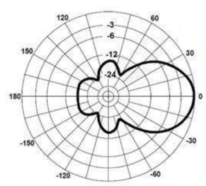
Basics of Antennas

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.



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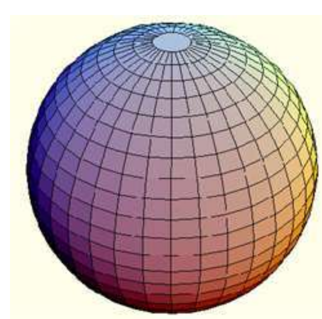
Basics of Antennas

- 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.



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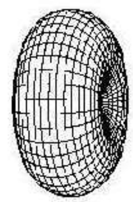
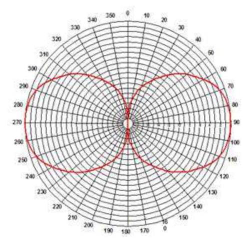
Basics of Antennas

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





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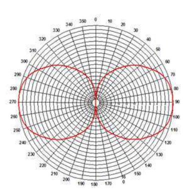
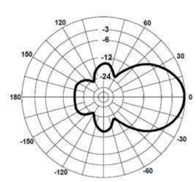
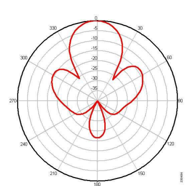
Basics of Antennas

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.







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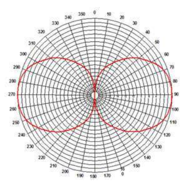
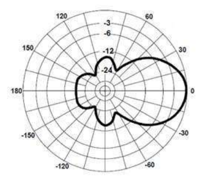
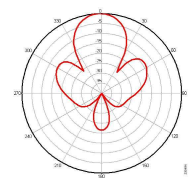
Basics of Antennas

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.

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E9A01 – What is an isotropic radiator?

A. A calibrated, unidirectional antenna used to make precise antenna gain measurements

B. An omnidirectional, horizontally polarized, precisely calibrated antenna used to make field measurements of antenna gain

C. A hypothetical, lossless antenna having equal radiation intensity in all directions used as a reference for antenna gain

D. A spacecraft antenna used to direct signals toward Earth

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E9A12 -- How much gain does an antenna have compared to a half-wavelength dipole if it has 6 dB gain over an isotropic radiator?

A. 3.85 dB
B. 6.0 dB
C. 8.15 dB
D. 2.79 dB

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E9B07 -- What is the difference in radiated power between a lossless antenna with gain and an isotropic radiator driven by the same power?

A. The power radiated from the directional antenna is increased by the gain of the antenna
B. The power radiated from the directional antenna is stronger by its front-to-back ratio
C. They are the same
D. The power radiated from the isotropic radiator is 2.15 dB greater than that from the directional antenna

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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

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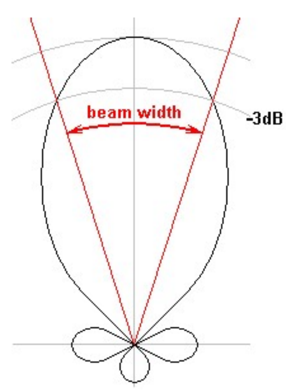
Basics of Antennas

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.



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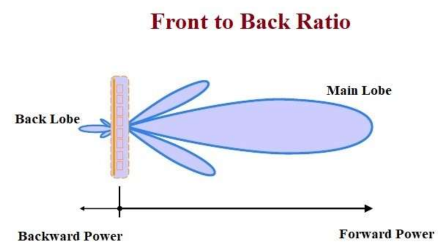
Basics of Antennas

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.



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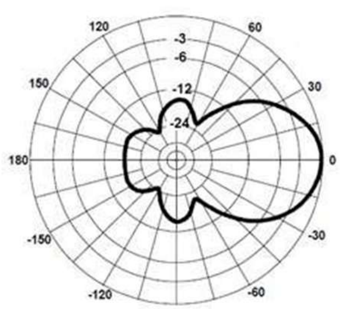
Basics of Antennas

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 90º from the forward direction.
    - Assuming a symmetrical pattern.



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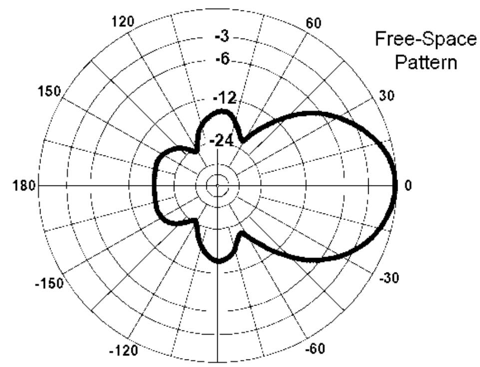
E9B01 -- What is the 3 dB beamwidth of the antenna radiation pattern shown in Figure E9-1?

A. 75 degrees
B. 50 degrees
C. 25 degrees
D. 30 degrees

Figure E9-1



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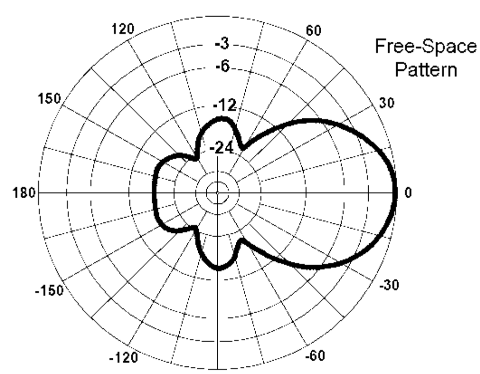
E9B02 -- What is the front-to-back ratio of the antenna radiation pattern shown in Figure E9-1?

A. 36 dB
B. 14 dB
C. 24 dB
D. 18 dB

Figure E9-1



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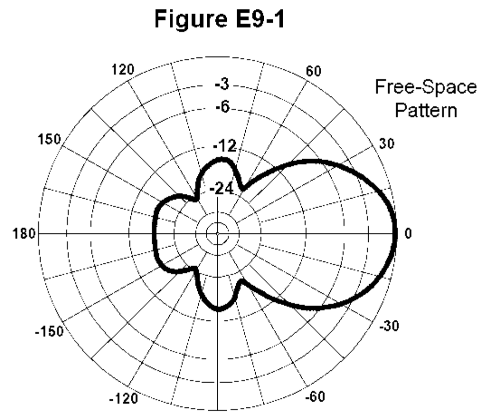
E9B03 -- What is the front-to-side ratio of the antenna radiation pattern shown in Figure E9-1?

A. 12 dB

B. 24 dB

C. 18 dB

D. 14 dB



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Basics of Antennas

Radiation and Ohmic Resistance

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

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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.

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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 the voltage and current are in phase:
    - The antenna is resonant.
    - The impedance is purely resistive.
  - If the voltage and current are not in phase:
    - The impedance will include either inductive or capacitive reactance.

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Basics of Antennas

Feed Point Impedance

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

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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

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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

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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.

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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

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Basics of Antennas

Link Budgets and Margins.

- *Link Budget* is a term used in the communications industry to denote the overall signal gain/loss, in dB, over its journey from origin to destination.
  - Includes antenna system gain/losses at both the transmitter and receiver ends plus the path loss.
- *Link Margin* is the difference, in dB, between the weakest signal that can be decoded and the actual signal received.

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Basics of Antennas

Link Budgets and Margins.

- Link Margin is calculated with the formula:
  - Link Margin = $P_{TX} + G_{TX} - L_{TX} - L_{FS} + G_{RX} - L_{RX} + R_{MDS} - SN$
    - P_{TX} = Transmitted power (in dBm).
    - G_{TX} = Transmitter antenna gain.
    - L_{TX} = Transmitter antenna system loss.
    - L_{FS} = Path loss.
    - G_{RX} = Receiver antenna gain.
    - L_{RX} = Receiver antenna system loss.
    - R_{MDS} = Receiver minimum discernable signal.
    - SN = required signal-to-noise ratio.

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E4D12 -- What is the link margin in a system with a transmit power level of 10 W (+40 dBm), a system antenna gain of 10 dBi, a cable loss of 3 dB, a path loss of 136 dB, a receiver minimum discernable signal of -103 dBm, and a required signal-to-noise ratio of 6 dB?

A. -8dB

B. -14dB

C. +8dB

D. +14dB

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E4D13 -- What is the received signal level with a transmit power of 10 W (+40 dBm), a transmit antenna gain of 6 dBi, a receive antenna gain of 3 dBi, and a path loss of 100 dB?

A. -51 dBm

B. -54 dBm

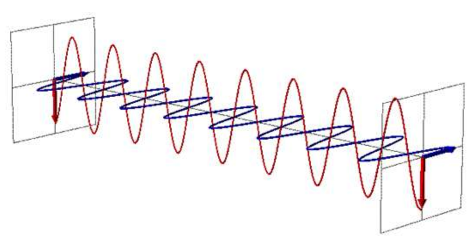
C. -57 dBm

D. -60 dBm

Basics of Antennas

Antenna Pattern Types.

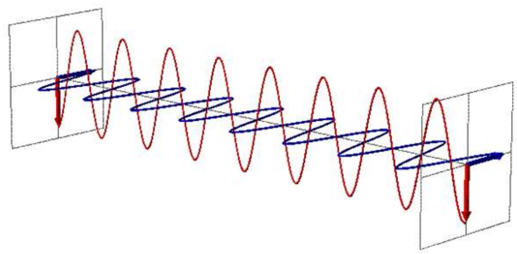
- E and H planes.
  - A radio wave consists of an electric field and a magnetic field at right angles to each other.



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).



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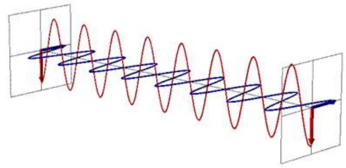
Basics of Antennas

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.



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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.

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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.

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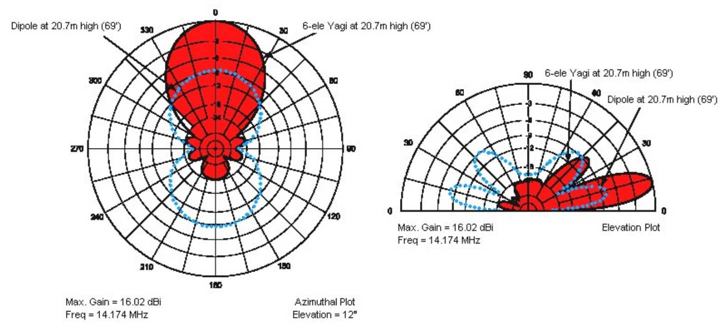
Basics of Antennas

Antenna Pattern Types

- Azimuthal and Elevation Patterns.



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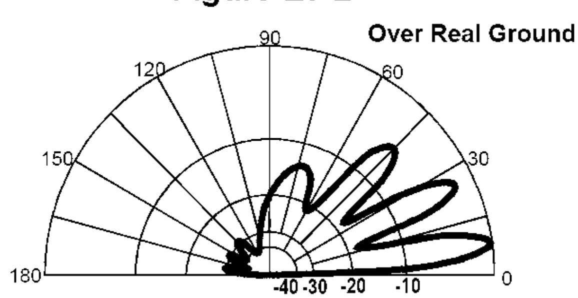
E9B04 -- What is the front-to-back ratio of the radiation pattern shown in Figure E9-2?

A. 15 dB
B. 28 dB
C. 3 dB
D. 24 dB

Figure E9-2



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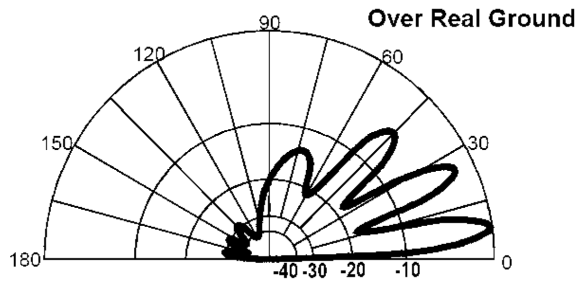
E9B05 -- What type of antenna pattern is shown in Figure E9-2?

- A. Elevation
- B. Azimuth
- C. Near field
- D. Polarization

Figure E9-2



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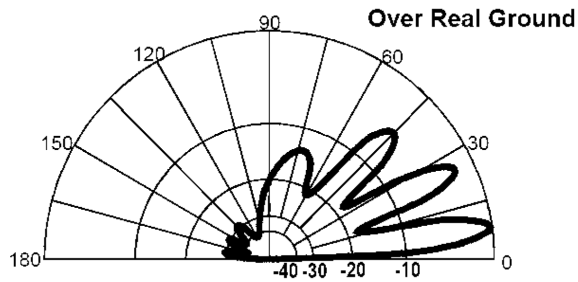
E9B06 -- What is the elevation angle of peak response in the antenna radiation pattern shown in Figure E9-2?

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

Figure E9-2



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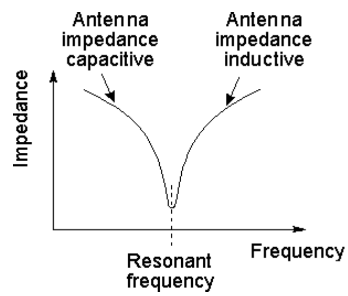
Basics of Antennas

Bandwidth.

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



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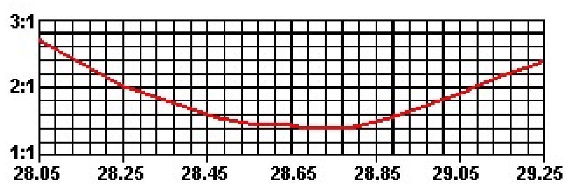
Basics of Antennas

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.



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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.

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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

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Practical Antennas

Effects of Ground and Ground Systems.

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

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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.
  - Somewhat 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.

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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.

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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.

50

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

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E9A11 -- Which of the following determines ground losses for a ground-mounted vertical antenna operating on HF?

A. The standing wave ratio
B. Distance from the transmitter
C. Soil conductivity
D. Take-off angle

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

A. Radiation at low angles decreases
B. Additional lobes appear at higher elevation angles
C. Separate elevation lobes will combine into a single lobe
D. Radiation at low angles increases

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E9C13 -- How does the radiation pattern of a horizontally polarized 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

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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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E9C14 -- How does the radiation pattern of a horizontally-polarized antenna mounted above a long slope compare with the same antenna mounted above 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 beamwidth decreases in the downhill direction
D. The horizontal beamwidth increases in the uphill direction

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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

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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

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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.

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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.

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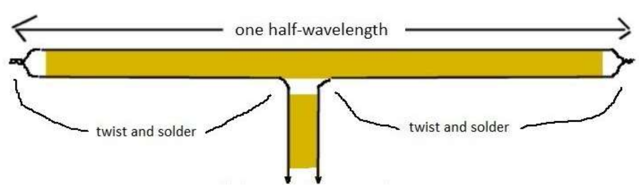
Practical Antennas

Dipole Variations

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



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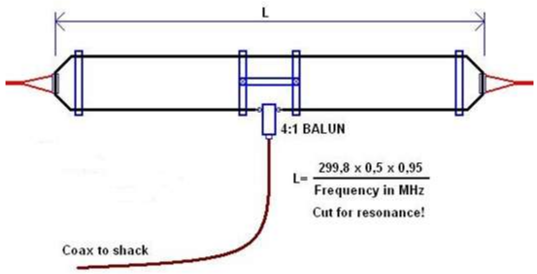
Practical Antennas

Dipole Variations.

- Folded Dipole.



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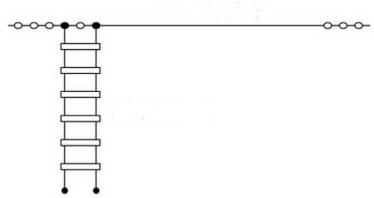
Practical Antennas

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.



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Practical Antennas

Dipole Variations.

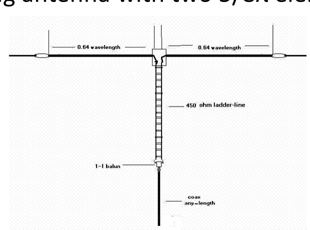
- Zepp and Extended Zepp Antennas.
  - The end of a 1/2λ dipole is a very high impedance point.
  - The impedance can be reduced by extending the antenna to 5/8λ in length.
    - This is called the extended Zepp antenna.

65

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.



66

Practical Antennas

Dipole Variations.

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

67

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 20m performance.

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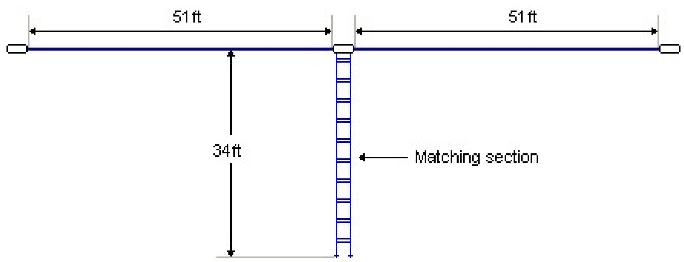
Practical Antennas

Dipole Variations.

- G5RV Antenna.



Practical Antennas

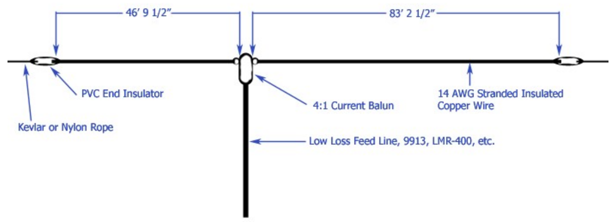
Dipole Variations.

- 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.



71

E9C05 -- What is the purpose of feeding an off-center-fed dipole (OCFD) between the center and one end instead of at the midpoint?

A. To create a similar feed point impedance on multiple bands

B. To suppress off-center lobes at higher frequencies

C. To resonate the antenna across a wider range of frequencies

D. To reduce common-mode current coupling on the feed line shield

72

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

73

E9C08 -- What is a folded dipole antenna?

A. A dipole one-quarter wavelength long
B. A center-fed dipole with the ends folded down 90 degrees at the midpoint of each side
C. A half-wave dipole with an additional parallel wire connecting its two ends
D. A dipole configured to provide forward gain

74

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

A. A wire antenna center-fed through a specific length of open-wire line connected to a balun and coaxial feed 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 a 4:1 balun

75

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

A. A horizontal array capable of quickly changing the direction of maximum radiation by changing phasing lines
B. An end-fed half-wavelength dipole
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

76

E9C12 -- Which of the following describes an extended double Zepp antenna?

A. An end-fed full-wave dipole antenna
B. A center-fed 1.5-wavelength dipole antenna
C. A center-fed 1.25-wavelength dipole antenna
D. An end-fed 2-wavelength dipole antenna

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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 increased.
  - Some way to cancel the capacitive reactance is required.

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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.

79

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.

80

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.

81

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.

82

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 antennas are designed for a single band.
    - You must change the antenna to change bands.

83

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

84

Practical Antennas

Loaded Whips

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

85

E9D03 -- What is the most efficient location for a loading coil on an electrically short whip?

A. Near the center of the vertical radiator

B. As low as possible on the vertical radiator

C. At a voltage maximum

D. At a voltage null

86

E9D04 -- Why should antenna loading coils have a high ratio of reactance to resistance?

A. To swamp out harmonics
B. To lower the radiation angle
C. To maximize efficiency
D. To minimize the Q

87

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

88

E9D07 -- What is an advantage of top loading an electrically short HF vertical antenna?

A. Lower Q

B. Greater structural strength

C. Higher losses

D. Improved radiation efficiency

89

E9D09 -- What is the function of a loading coil in an electrically short antenna?

A. To increase the SWR bandwidth by increasing net reactance

B. To lower the losses

C. To lower the Q

D. To resonate the antenna by cancelling the capacitive reactance

90

E9D10 -- How does radiation resistance of a base-fed whip antenna change below its resonant frequency?

A. Radiation resistance increases

B. Radiation resistance decreases

C. Radiation resistance becomes imaginary

D. Radiation resistance does not depend on frequency

91

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.

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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, there are more lobes, and the major lobes are closer to the wire.

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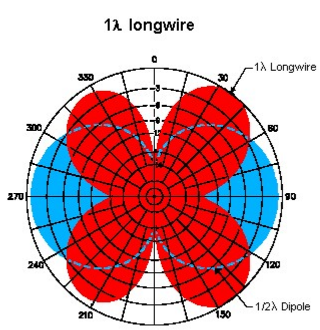
Practical Antennas

Traveling Wave Antennas

- Long-wire antennas.



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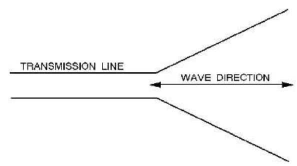
Practical Antennas

Traveling Wave Antennas.

- Two 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).



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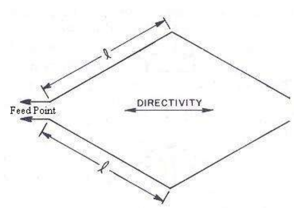
Practical Antennas

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.



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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.

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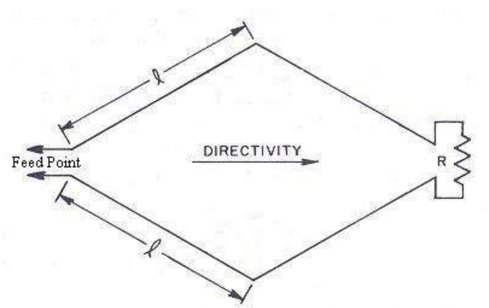
Practical Antennas

Traveling Wave Antennas.

- Rhombic Antennas.
  - Non-resonant rhombic antenna.



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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.

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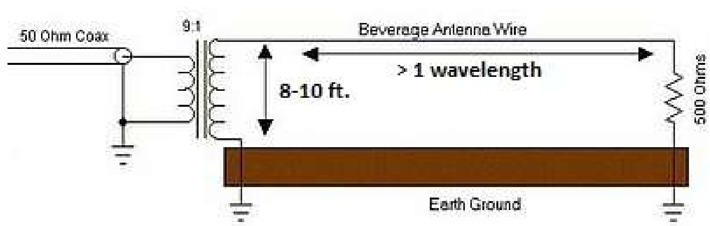
Practical Antennas

Traveling Wave Antennas.

- Beverage Antennas.
  - The most popular receive antenna for 160m & 80m is the Beverage antenna.



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Practical Antennas

Traveling Wave Antennas.

- Beverage Antennas.
  - At least 1λ long.
  - Uni-directional.
  - Very high losses, but very low noise.
  - Terminating resistor absorbs signals arriving from the reverse direction.
  - Terminating resistor is selected to give minimum variation in SWR across the frequency range of interest.

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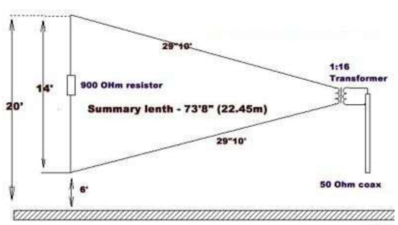
Practical Antennas

Receiving Loop Antennas for Direction Finding

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



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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.

103

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

A. Fewer lobes form with the major lobes increasing closer to broadside to the wire

B. Additional lobes form with major lobes increasingly aligned with the axis of the antenna

C. The elevation angle increases, and the front-to-rear ratio decreases

D. The elevation angle increases, while the front-to-rear ratio is unaffected

104

E9C06 -- What is the effect of adding a terminating resistor to a rhombic or long-wire 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

105

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 at least one wavelength long

106

E9H02 -- Which is generally true for 160- and 80-meter receiving antennas?

A. Atmospheric noise is so high that directivity is much more important than losses
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 these choices are correct

107

E9H06 -- What indicates the correct value of terminating resistance for a Beverage antenna?

A. Maximum feed point DC resistance at the center of the desired frequency range
B. Minimum low-angle front-to-back ratio at the design frequency
C. Maximum DC current in the terminating resistor
D. Minimum variation in SWR over the desired frequency range

108

E9H07 -- What is the function of a Beverage antenna s termination resistor?

A. Increase the front-to-side ratio

B. Absorb signals from the reverse direction

C. Decrease SWR bandwidth

D. Eliminate harmonic reception

109

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.

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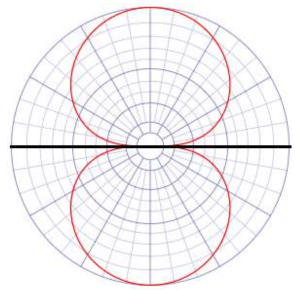
Practical Antennas

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.



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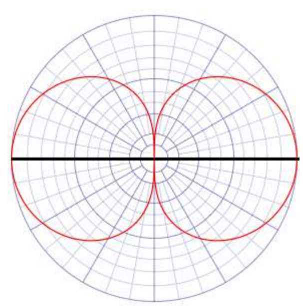
Practical Antennas

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.



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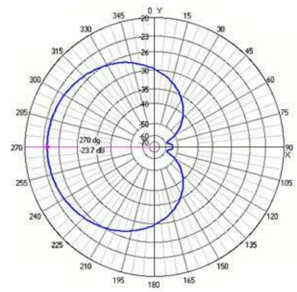
Practical Antennas

Phased Arrays.

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



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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”.

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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.

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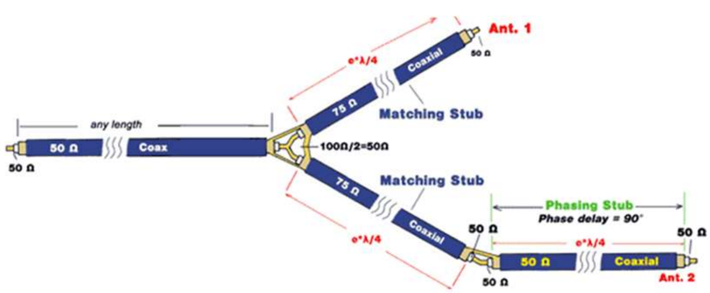
Practical Antennas

Phased Arrays.

- Wilkinson divider.



116

E9C01 -- What type of radiation pattern is created by 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-eight broadside to the axis of the array
D. A figure-eight oriented along the axis of the array

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

A. Cardioid
B. A figure-eight end-fire along the axis of the array
C. A figure-eight broadside to the axis of the array
D. Omni-directional

118

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

A. Omni-directional
B. Cardioid
C. A figure-eight broadside to the axis of the array
D. A figure-eight end-fire along the axis of the array

119

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

A. To divide the operating frequency of a transmitter signal so it can be used on a lower frequency band
B. To feed high-impedance antennas from a low-impedance source
C. To divide power equally between two 50-ohm loads while maintaining 50-ohm input impedance
D. To divide the frequency of the input to a counter to increase its frequency range

120

E9E11 -- What is the purpose of using multiple driven elements connected through phasing lines?

A. To control the antenna s radiation pattern
B. To prevent harmonic radiation from the transmitter
C. To allow single-band antennas to operate on other bands
D. To create a low-angle radiation pattern

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Practical Antennas

Yagi Antennas

- The most common type of beam antenna is the Yagi-Uda array.
  - Normally just called a “Yagi”.
  - Invented in 1926 by Dr. Shintaro Uda in collaboration with Dr. Hidetsugu Yagi.
  - Rod-like elements.
    - Similar to TV antennas.

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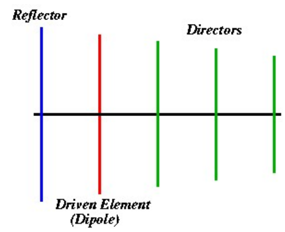
Practical Antennas

Yagi Antennas

- A Yagi consists of 2 or more elements mounted on a boom.
    - Driven element.
        - Connected to the radio by the feed line.
    - Reflector element.
        - Behind the driven element.
    - Director element(s).
        - In front of the driven element.
        - Can have 0, 1, or more directors.



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Practical Antennas

Yagi Antennas

- The driven element is a $1/2\lambda$ dipole.
- The reflector is mounted behind the driven element and is slightly longer than $1/2\lambda$.
- Any directors are mounted in front of the driven element and are slightly shorter than $1/2\lambda$.
- The different lengths are adjusted to control the phase relationships and therefore the radiation pattern and gain.

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Practical Antennas

Yagi Antennas

- A 2-element Yagi always has a driven element and a reflector because it results in higher gain than a driven element plus director combination.
- Adding additional directors can increase gain.
- Additional reflectors have no effect on antenna performance and are never used.

125

E9D05 -- Approximately how long is a Yagi s driven element?

A. 234 divided by frequency in MHz
B. 1005 divided by frequency in MHz
C. 1/4 wavelength
D. 1/2 wavelength

126

E9D11 -- What is the purpose of making a Yagi s parasitic elements either longer or shorter than resonance?

A. Wind torque cancellation

B. Mechanical balance

C. Control of phase shift

D. Minimize losses

127

E9D11 -- Why do most two-element Yagis with normal spacing have a reflector instead of a director?

A. Lower SWR

B. Higher receiving directivity factor

C. Greater front-to-side

D. Higher gain

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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).

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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.

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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 the antenna at the satellite.
    - Azimuth.
    - Elevation.

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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.

132

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

A. 2 dB
B. 3 dB
C. 4 dB
D. 6 dB

133

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

A. Stack two Yagis to form an array with the respective elements in parallel planes fed 90 degrees out of phase
B. Stack two Yagis to form an array with the respective elements in parallel planes fed in phase
C. Arrange two Yagis on the same axis and 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

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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.

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Practical Antennas

Receiving Loop Antennas for Direction Finding

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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 (more gain).
- Loop antennas are used for receiving because of their noise-rejecting properties rather than their gain.

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Practical Antennas

Receiving Loop Antennas for Direction Finding

- Large single turn loop antennas known as “pennants” or “flags” are popular for receiving on the lower frequency bands.
  - Less than 0.1λ in circumference.
  - Normally mounted vertically.
  - Includes a terminating resistor opposite the feedpoint.
    - Typically ~900Ω.
  - Have a cardioid pattern with a null to reject noise.

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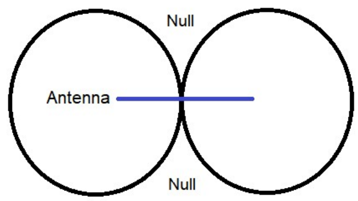
Practical Antennas

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.



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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.

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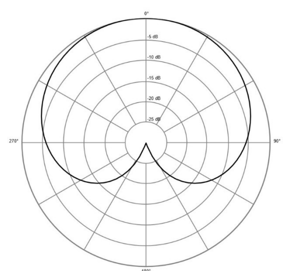
Practical Antennas

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.



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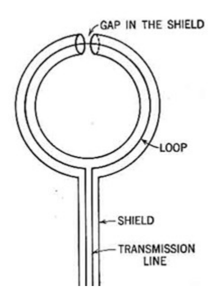
Practical Antennas

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 objects and improve the nulls.
  - Construct the loop using coaxial cable.



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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.

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Practical Antennas

Receiving Loop Antennas for Direction Finding

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



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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.

145

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.

146

Practical Antennas

Receiving Loop Antennas for Direction Finding

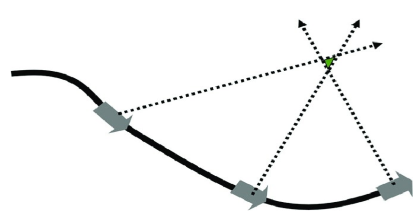
- Mobile/portable stations with a unidirectional antenna can find a transmitter by “following the signal”.
- Mobile/portable stations with a bidirectional antenna or fixed stations with a directional antenna can find a transmitter by triangulation.

147

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.

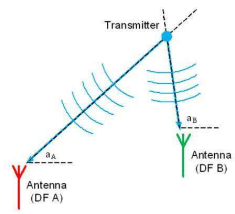


148

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.



149

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.

150

Practical Antennas

Receiving Loop Antennas for Direction Finding

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

151

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

152

E9H04 -- What is the purpose of placing an 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 antenna s surroundings, improving the depth of its 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

153

E9H05 -- What challenge is presented by a small wire-loop antenna for direction finding?

A. It has a bidirectional null pattern
B. It does not have a clearly defined null
C. It is practical for use only on VHF and higher bands
D. All these choices are correct

154

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

A. It modifies the pattern of a DF antenna to provide a null in only 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

155

E9H09 -- What type of radiation pattern is created by a single-turn, terminated loop such as a pennant antenna?

A. Cardioid
B. Bidirectional
C. Omnidirectional
D. Hyperbolic

156

E9H10 -- How can the output voltage of a multiple-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 increasing the number of turns and/or the area enclosed by the loop
D. All these choices are correct

157

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

A. A very sharp peak
B. A single null
C. Broadband response
D. High radiation angle

158

Break

159

Antenna Systems

An antenna system is more than just the antenna itself.

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

160

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.

161

Practical Antennas

Effective Radiated Power

- There are 2 types of antennas commonly used as the reference for calculating ERP:
  - A 1/2λ dipole (dBd).
    - Used for most calculations.
    - Used in FCC Rules.
      - Except for 60m.
  - An isotropic radiator (dBi).
    - Used for space communications calculations.
  - 0 dBd = 2.14 dBi

162

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 – Losses

163

E9A02 -- What is the effective radiated power (ERP) 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. 469 watts

B. 78.7 watts

C. 420 watts

D. 286 watts

164

E9A03 -- What term describing total radiated power takes into account all gains and losses?

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

165

E9A06 -- What is the effective radiated power (ERP) 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

166

E9A07 -- What is the effective isotropic radiated power (EIRP) 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

167

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.

168

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.

169

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.

170

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.

171

Antenna Systems

Impedance Matching

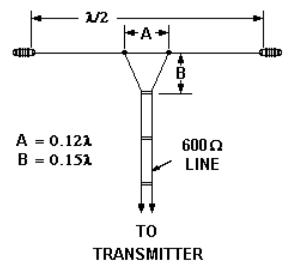
- Few real-world antennas have a 50Ω resistive impedance at the feedpoint.
  - e.g. – The feedpoint impedance of the driven element of a 3-element Yagi is about 25-30Ω.
- Several techniques have been developed to match the antenna impedance to the feed line.

172

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.



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Antenna Systems

Impedance Matching

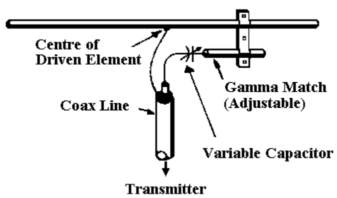
- The gamma match.
  - A common matching method for single-band beams is the gamma match.
  - A gamma match is also commonly used to feed towers when used as vertical antennas.
  - Electrically, a gamma match is a short section of transmission line connected between the center of the antenna and a short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

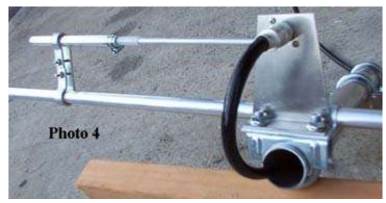
174

Antenna Systems

Impedance Matching

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



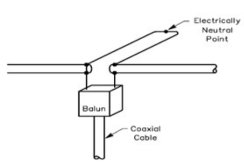


175

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.



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Antenna Systems

Impedance Matching

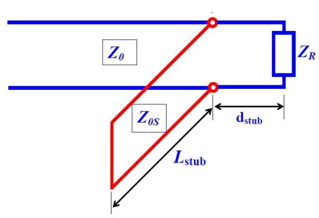
- A short length of transmission line connected in parallel with the antenna & feed line is called a stub match.
  - A stub match can match highly reactive loads.
  - A stub match can be made from a piece of coax.
  - The “universal stub system” is often used at VHF & UHF when the impedances to be matched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

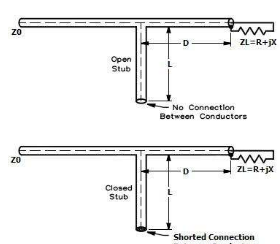
177

Antenna Systems

Impedance Matching

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





178

E9E01 -- Which matching system for Yagi antennas requires the driven element to be insulated from the boom?

A. Gamma
B. Beta or hairpin
C. Shunt-fed
D. T-match

179

E9E02 -- What antenna matching system matches coaxial cable to an antenna by connecting the shield to the center of the antenna and the conductor a fraction of a wavelength to one side?

A. Gamma match
B. Delta match
C. T-match
D. Stub match

180

E9E03 -- What matching system uses a short length of transmission line connected in parallel with the feed line at or near the feed point?

A. Gamma match
B. Delta match
C. T-match
D. Stub match

181

E9E04 -- What is the purpose of the series capacitor in a gamma match?

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

182

E9E05 -- What Yagi driven element feed point impedance is required to use a beta or hairpin matching system?

A. Capacitive (driven element electrically shorter than 1/2 wavelength)
B. Inductive (driven element electrically longer than 1/2 wavelength)
C. Purely resistive
D. Purely reactive

183

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

A. Double-bazooka match
B. Beta or hairpin match
C. Gamma match
D. All these choices are correct

184

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

185

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.

186

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.

187

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.

188

Transmission Lines

Velocity Factor and Electrical Length

- The velocity factor is also dependent on the diameter of a conductor.
  - Larger diameter → higher velocity factor.

189

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).

190

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 expressed 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.

191

Transmission Lines

Velocity Factor and Electrical Length

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

192

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”).

193

E5D10 -- As a conductor’s diameter increases, what is the effect on its electrical length?

A. Thickness has no effect on electrical length

B. It varies randomly

C. It decreases

D. It increases

194

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

A. The ratio of its characteristic impedance to its termination impedance
B. The ratio of its termination impedance to its characteristic impedance
C. The velocity of a wave in the transmission line multiplied by the velocity of light in a vacuum
D. The velocity of a wave in the transmission line divided by the velocity of light in a vacuum

195

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

A. The characteristic impedance
B. The transmission line length
C. The insulating dielectric material
D. The center conductor resistivity

196

E9F03 -- Why is the electrical length of a coaxial cable longer than its physical length?

A. Skin effect is less pronounced in the coaxial cable
B. Skin effect is more pronounced in the coaxial cable
C. Electromagnetic waves move faster in coaxial cable than in air
D. Electromagnetic waves move more slowly in a coaxial cable than in air

197

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. 7.0 meters
B. 8.5 meters
C. 10.6 meters
D. 13.3 meters

198

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.

199

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.

200

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

201

E9F07 -- How does parallel conductor transmission line compare to coaxial cable with a plastic dielectric?

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

202

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

A. Foam dielectric coaxial cable has lower safe maximum operating voltage
B. Foam dielectric coaxial cable has lower loss per unit of length
C. Foam dielectric coaxial cable has higher velocity factor
D. All these choices are correct

203

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).

204

Transmission Lines

Reflection Coefficient and SWR

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

205

E9E07 -- What parameter describes the interaction of a load and transmission line?

A. Characteristic impedance

B. Reflection coefficient

C. Velocity factor

D. Dielectric constant

206

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.

207

Transmission Lines

Power Measurement

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

208

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:
    - $P_L = P_F - P_R$

209

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. 112.5 watts

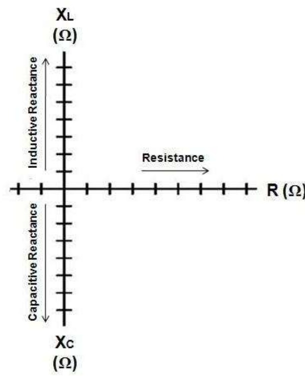
D. 75 watts

210

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.



211

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.

212

Transmission Lines

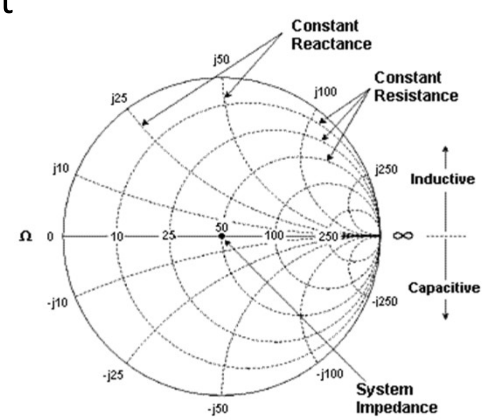
Smith Chart

- 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”.

213

Transmission Lines

Smith Chart



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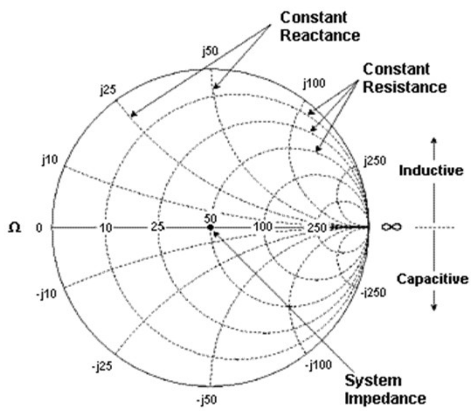
Transmission Lines

Smith Chart

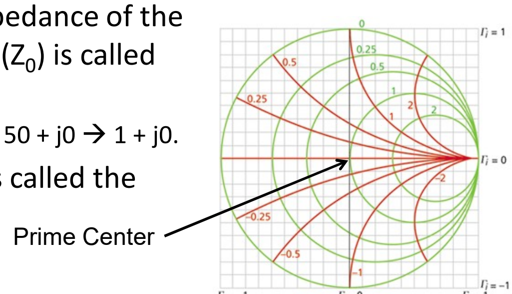
- Outermost circle.
  - Reactance axis.
  - Pure reactance.
- Horizontal line.
  - Resistance axis.
  - Pure resistance.
- Circles.
  - Constant resistance.
- Arcs.
  - Constant reactance.



Transmission Lines

Smith Chart

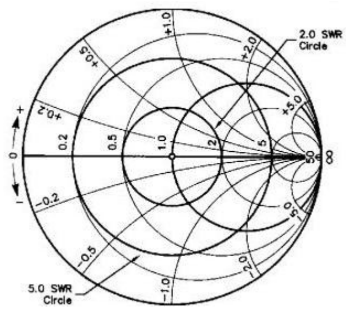
- Normalization.
  - Scaling all values to the characteristic impedance of the transmission line (Z_0) is called normalization.
    - If $Z_0 = 50\Omega$, then $50 + j0 \rightarrow 1 + j0$.
  - The point $1 + j0$ is called the prime center.



Transmission Lines

Smith Chart

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



217

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.

218

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 the impedance at different points along a transmission line.

219

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

220

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 chords and current chords
D. Resistance lines and reactance chords

221

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. Point-to-point propagation reliability as a function of frequency

222

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

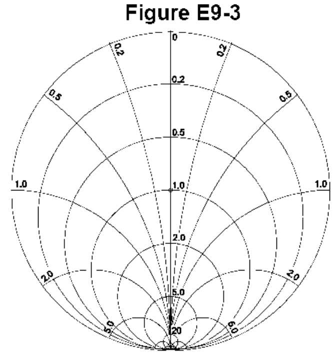
A. Inductance and capacitance
B. Reactance and voltage
C. Resistance and reactance
D. Voltage and impedance

223

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

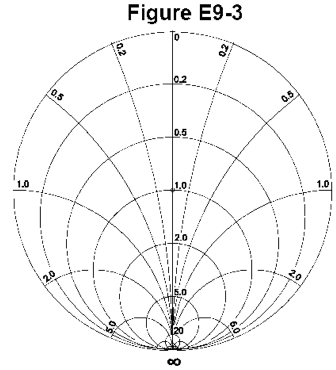


224

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



225

E9G08 -- How is a Smith chart normalized?

A. Reassign the reactance axis with resistance values
B. Reassign the resistance axis with reactance values
C. Reassign the prime center s impedance value
D. Reassign the prime center to the reactance axis

226

E9G09 -- What third family of circles is often added to a Smith chart during the process of designing impedance matching networks?

A. Constant-SWR circles
B. Transmission line length circles
C. Coaxial-length circles
D. Radiation-pattern circles

227

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

A. Frequency
B. SWR
C. Points with constant resistance
D. Points with constant reactance

228

E9G11 -- In what units 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

229

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.

230

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 be equal to the impedance of the load.

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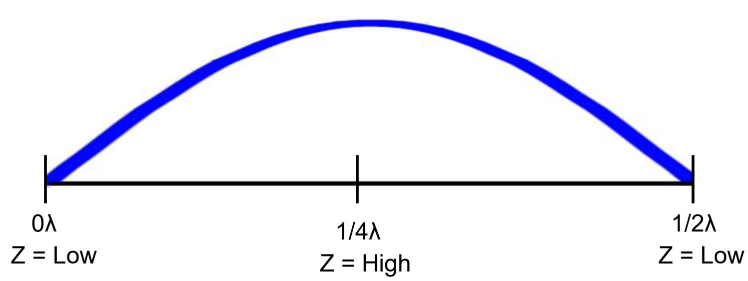
Transmission Lines

Transmission Line Stubs and Transformers

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

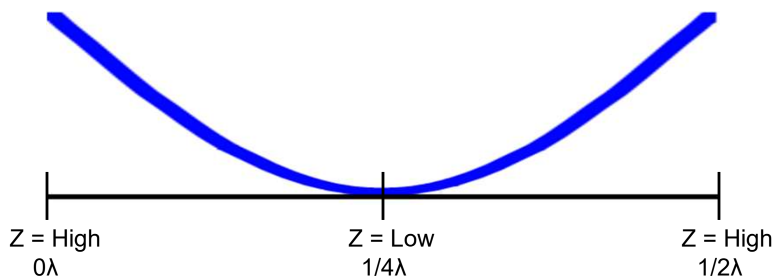


232

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:



233

Transmission Lines

Transmission Line Stubs and Transformers

- Note that at odd multiples of 1/4λ (1/4λ, 3/4λ, 1- 1/4λ, etc.), 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.

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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.

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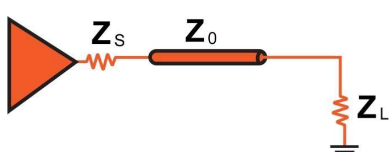
Transmission Lines

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 without the requirement to use a matching network.



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Transmission Lines

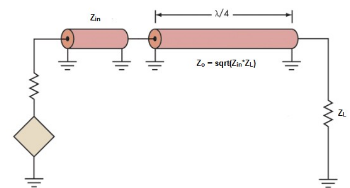
Transmission Line Stubs and Transformers

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

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

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

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



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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

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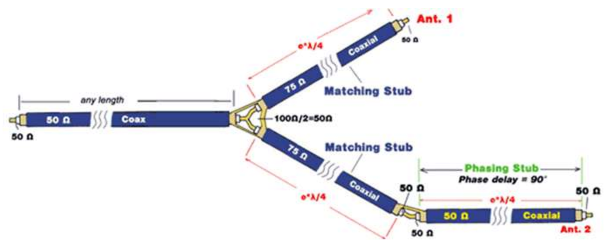
Transmission Lines

Transmission Line Stubs and Transformers.

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



239

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

A. 50 ohms
B. 62 ohms
C. 75 ohms
D. 450 ohms

240

E9F04 -- What impedance does a 1/2-wavelength transmission line present to an RF 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

241

E9F09 -- What impedance does a 1/4-wavelength transmission line present to an RF 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

242

E9F10 -- What impedance does a 1/8-wavelength transmission line present to an RF 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

243

E9F11 -- What impedance does a 1/8-wavelength transmission line present to an RF 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

244

E9F12 -- What impedance does a 1/4-wavelength transmission line present to an RF 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

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.

247

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

A. S11

B. S12

C. S21

D. S22

248

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

A. S11
B. S12
C. S21
D. S22

249

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

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Transmission Lines

Antenna and Network Analyzers

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

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Transmission Lines

Antenna and Network Analyzers

- Antenna Analyzers.
  - The antenna feed line is connected directly to 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.

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Transmission Lines

Antenna and Network Analyzers

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

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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).

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Transmission Lines

Antenna and Network Analyzers.

- A popular, inexpensive (<$100) portable VNA is the NanoVNA.

255

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

A. Antenna analyzers automatically tune your antenna for resonance

➡ B. Antenna analyzers compute SWR and impedance automatically

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

D. All these choices are correct

256

E4A08 -- Which of the following is used to measure SWR?

A. Directional wattmeter
B. Vector network analyzer
C. Antenna analyzer
D. All these choices are correct

257

E4A11 -- Which of the following can be measured with an antenna analyzer?

A. Velocity factor
B. Cable length
C. Resonant frequency of a tuned circuit
D. All these choices are correct

258

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

259

E4B09 -- Which of the following can be measured by a two-port vector network analyzer?

A. Phase noise

B. Filter frequency response

C. Pulse rise time

D. Forward power

260

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

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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 the transmitter.

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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.

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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.

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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.

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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.

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Antenna Design

Antenna Modeling and Design

- Method of moments technique.
  - 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.

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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.).
  - Plots of far-field radiation patterns.
    - Azimuth & elevation.
  - Feed point impedance.
  - SWR vs. frequency.

269

E9B09 -- What type of analysis 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

270

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

271

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

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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.

273

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 feed point impedance will become very low, and
    - The SWR bandwidth will be reduced.

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Questions?

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Amateur Extra Class

Next Week

Chapter 10

Topics in Radio Propagation

Chapter 11

Safety

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