Chapter 9
Antennas &Feed Lines

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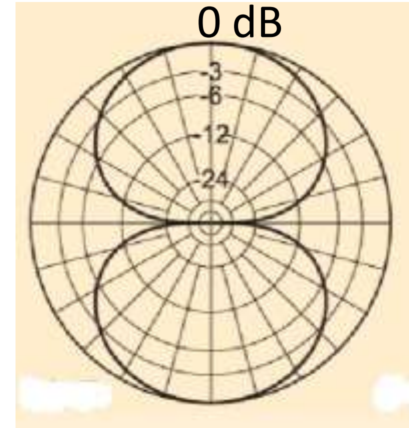
200 Antennas

Easy source for homebrew antennas:

http://www.qsl.net/va3iul/Antenna/Wire%20Antennas%20for%20Ham%20Radio/Wire_antennas_for_ham_radio.htm

Potato Gun

Basics of Antennas

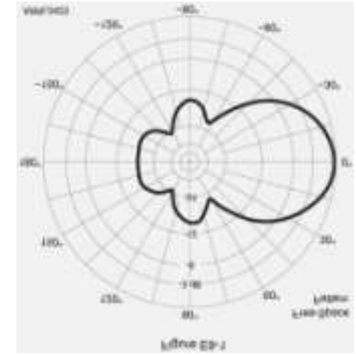


- Antenna Radiation Patterns
  - Dipole (fig. 9-1a, pg 9-2)
    - Strength Scale from the center to the edge of the pattern is measured in decibels
    - Comparing antennas – make the scale is the same
    - The scale shows the relative strength of signal radiated in any direction with the maximum point representing 0dB with respect ot all other directions
    - Radiation pattern shows the "*Far Field*" extending several wavelengths from the antenna
    - The "*Near Field*" is too close to show a pattern

Antenna Gain

- The most important antenna property is the ability to concentrate it's radiated power in a useful direction
  - Istropic Radiator – **theoretical antenna** assumed to radiate equally in all directions
    - Reference for comparing the differences in real antennas, Zero Gain
  - Directional Antennas – concentrate their radiated power in one or more directions

Antenna Gain



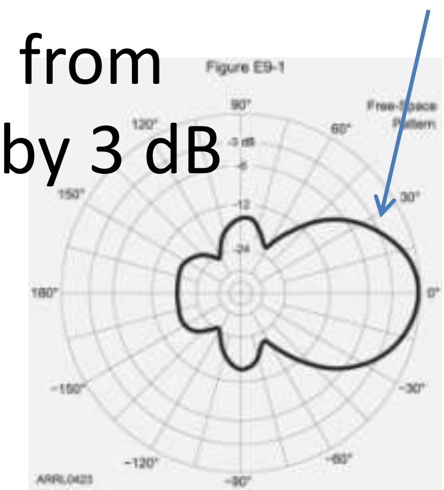
- Directional antennas
  - In a perfect antenna, radio energy would be concentrated in one direction only, forward direction (main or major lobe)
  - Real world antennas have minor lobes to the sides and rear direction
  - Antenna gain is expressed in decibels from the main lobe compared to a reference antenna (usually a dipole)

Antenna Gain

- Antenna comparison measurements
  - **dBd** is antenna gain compared to a reference dipole
  - **dBi** is antenna gain compared to an istropic radiator
  - Dipoles have 2.15 dB of gain over an Isotropic radiator
  - Gain in dBd = Gain in dBi - 2.15 dB
    - 6 dB gain over Isotropic is: 6 – 2.15 = 3.85 dBd
    - 12 dB gain over Isotropic is: 12 – 2.15 = 9.85 dBd

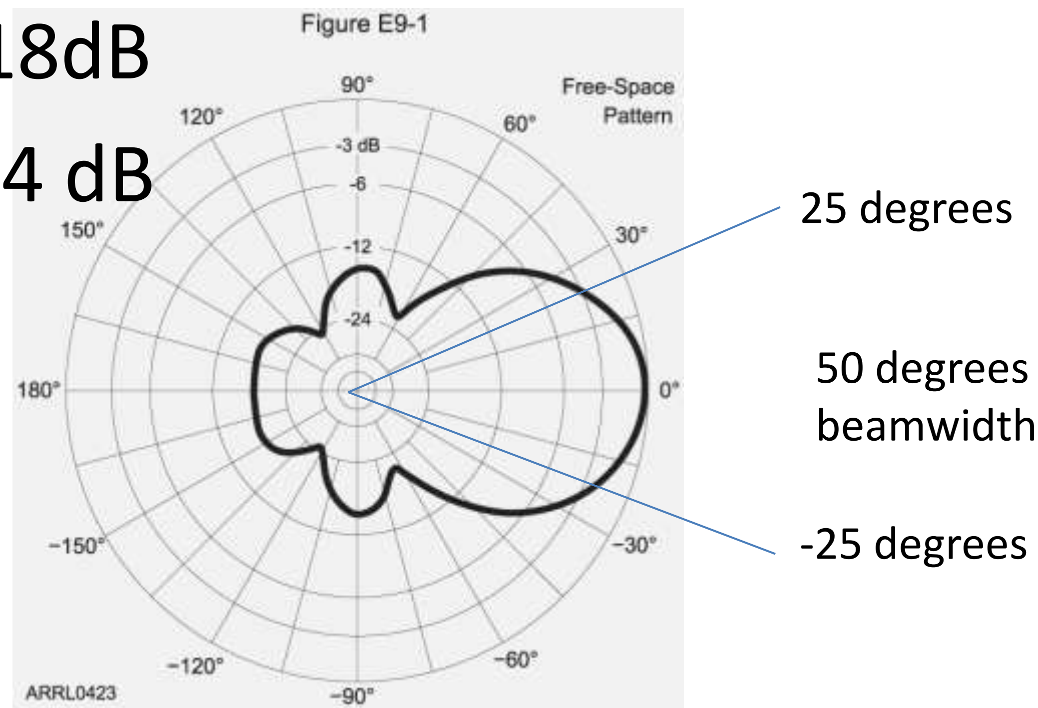
Beamwidth & Pattern Ratios

- Beamwidth is the angular distance between the points on either side of the major lobe at which the gain is 3 dB below the maximum.
  - A 30 degree beamwidth is 15 degrees either side of the maximum signal (fig 9-4, pg 9-4)
  - If you rotate your antenna 15 degrees from optimum, the receive signal will drop by 3 dB



Beamwidth & Pattern Ratios

- <u>As gain increases, beamwidth decreases</u>
- Beamwidth is measured from the center of the graph through the -3 dB point
- Front to Back 18dB
- Front to Side 14 dB



Radiation & Ohmic Resistance

- Power supplied to the antenna is dissipated in the form of radio waves and heat
  - Heat losses are (R) a real or ohmic resistance that gets warm
  - Radiated power is an assumed resistance called radiation resistance (R_R)
  - Total power dissipated $I^2(R+R_R)=R_T$ (Total Resistance)
  - Ohmic (heat) loss in reasonably located antennas is negligible and all the resistance shown is radiation resistance (copper wire has very low resistance)

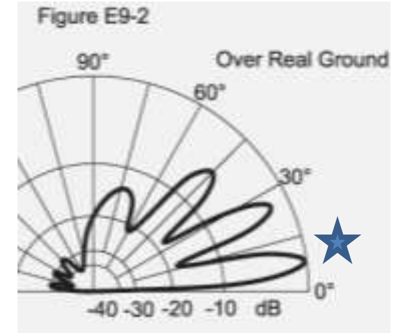
Feed Point Impedance

- Feed point impedance: is simply the ratio of RF voltage to current where the feed line is attached to the antenna
  - If the voltage and current are in-phase, the feed point impedance is resistive and the antenna is resonant regardless of the value of resistance
  - If the voltage and current or out of phase, the load will be reactive (inductive or captive)
  - Impedance is affected by a number of factors
    - Height, object nearby, length to diameter ratio of wire

Antenna Efficiency

- Antenna efficiency – is the ratio of power radiated as radio waves to the total power input to the antenna
  - Efficiency = $(R_R/R_T) \times 100\%$
  - R_R = Radiation Resistance, R_T = Total Resistance
  - Dipole = 70 ohms, total resistance is 75 ohms, the efficiency = (70/75) x 100% = 93.3%
  - Half-wave dipole is very efficient because conductor resistance is very low
  - ¼ wave ground mounted vertical requires ground radial wires laid out like spokes on a wheel

Antenna Polarization



- Real antennas near the Earth are polarized in relation to the ground
  - Horizontally polarized – electric field parallel to the Earth’s surface
  - Vertically polarized – electric field is perpendicular to the Earth’s surface
  - E & H planes
    - E-plane is the electric field (azimuthal pattern)
    - H-plane is the magnetic field (elevation pattern)

Practical Antennas

- Effects of Ground and Ground Systems
  - Biggest effect on antenna systems efficiency is the losses in nearby ground, ground structures, or the antenna’s ground system.
    - Radiation pattern over ground is effected by the electrical conductivity and dielectric constant of the soil
    - If the Signals are in phase when they combine (antenna radiation & ground reflections), the signals will increase, if out of phase will decrease in strength
    - Losses caused by low conductivity in the soil near the antenna dramatically reduce signal strength at low angles
      - Adding radials helps reduce near-field ground losses
    - Low-angle radiation from a vertically polarized antenna mounted over seawater will be much stronger than for a similar antenna mounted over rocky soil

Practical Antennas

- Height above Ground
  - Moving antenna away from ground reduces losses
    - Reflections from the ground will reinforce the direct radiation
    - Raising the antenna lowers the vertical takeoff angle of the peak radiation
  - Horizontal antennas have less ground losses
    - ½ wavelength above ground is an optimum height
    - Horizontal antenna mounted as high as you can is a good rule of thumb (wallet usually sets the limits)

Practical Antennas

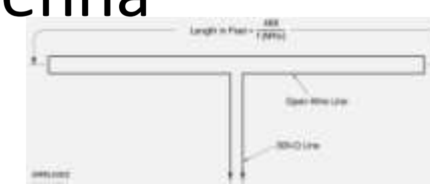
- Ground Systems
  - Station equipment & antennas similar
    - Create a path to ground or earth potential that has as little impedance as possible.
      - Electrically short distance as possible (1/10 wavelength or more acts like an antenna)
      - Run in a straight line as possible
      - type of conductor that has a low impedance to RF (current flows on the surface of the conductor)
        - » Wide copper straps (large surface area)
        - » Multiple ground rods (3 or 4) 8’ long

Practical Antennas

- Shortened Antennas:
  - Loaded Whips – Mobile installations usually are less than a ¼ wavelength long (1/4 wave 36 ohms)
    - As the operating frequency lowers, the feed point impedance shows a decrease in radiation resistance and an increase in captive reactance requiring a loading coil to balance the inductive reactance creating a pure resistive load
      - The amount of inductance is determined by the operating frequency
      - Antennas with loading coils have narrow bandwidth

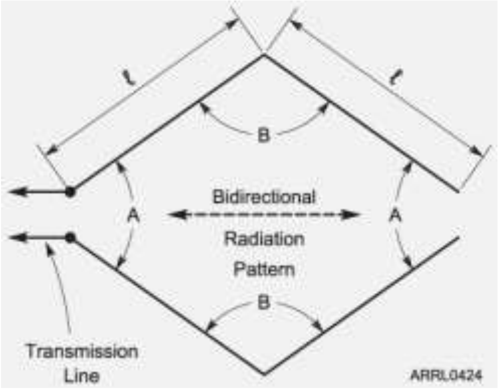
Practical Antennas

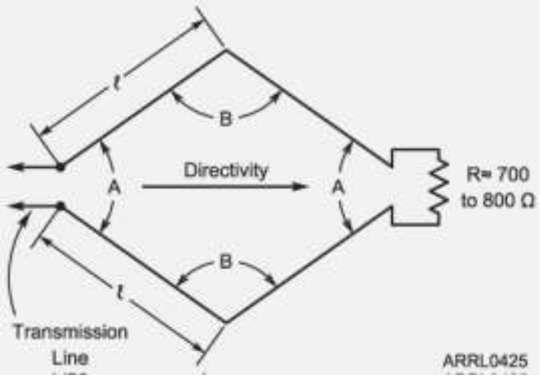
- Multiband antennas:
  - Trapped antennas use tuned circuits strategically placed to make the antenna resonant on multiple bands.
    - Disadvantage is they radiate harmonics
    - Series inductance in the traps raises the Q of the antenna and reduces the bandwidth
  - Folded Dipole is a full wave wire folded into a half wave thin loop that exhibits a wider SWR Bandwidth than a standard dipole antenna



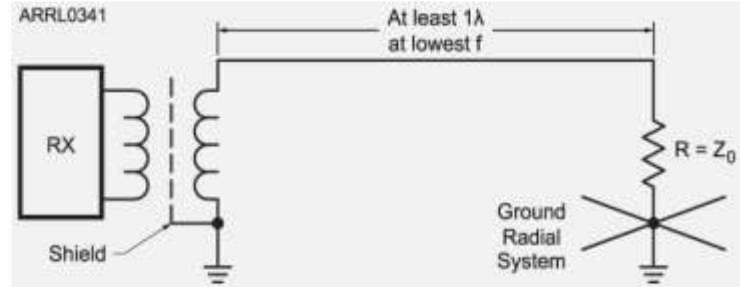
Practical Antennas

- Traveling Wave Antennas are the long wire antennas (one wavelength or longer)
  - The longer the wire the more directive it becomes
  - Bi-directional
- Rhombic Antennas – 2 vee beams placed end to end (High Gain, wide frequency range, un-terminated is bi-directional)





Practical Antennas



- Traveling Wave Antennas (Cont.)
  - <u>Beverage Antenna</u> is a receive antenna one or more wavelengths long
    - Antenna acts like a long transmission line with one lossy conductor (Earth) and one good conductor (wire)
    - Beverage antenna uses a terminating resistor to ground at the farthest end
    - Installed relatively low heights (8'–10') above ground
    - Longer antenna improves gain and directivity
    - Best suited for 160 and 80 meters (reduces noise)

Practical Antennas

- Phased Array
  - Different pattern shapes can be obtained using 2 vertical antennas
    - Spacing of the vertical antennas
    - Different length feed lines change phase angle canceling or adding to radio waves creating steered patterns (figure 9-16, pg 9-19)
    - If the antennas are ½ wavelength apart and fed in-phase the pattern is a figure 8 that is broadside to the antennas
    - If the antennas are 5/8 wavelength apart and feed 180 degrees out of phase, the pattern will be a figure 8 inline with the antennas (end-fire)

Effective Radiated Power

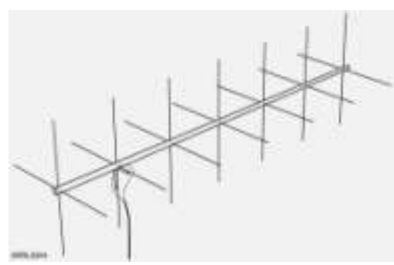
- Transmitter performance is usually computed as ERP with respect to a reference antenna system – usually a dipole antenna
  - ERP = TPO x System Gain
  - System gains and losses are measure in dB so they can be added or subtracted
  - System gain must be converted to a linear value from dB to calculate ERP

Effective Radiated Power

- ERP Calculation Problems: (Pg. 9-21)
  - <u>Calculator key strokes for ERP problems</u>
    - Calculate system gain (feed line loss + duplexer loss + circulator loss + antenna gain)
    - Divide gain result by 10
    - Hit the "anti-log" key on the calculator (2nd function "LOG" key)
    - Multiply result by TPO (Total Power Output) = ERP

Satellite Antenna Systems

- High gain antennas are not necessary
  - Narrow pattern, hard to point at a rapidly moving satellite
- Yagi antennas are most common for VHF/UHF
  - Circular Polarization – cross polarized Yagi antennas on the same boom fed 90 degrees out of phase provide the best results



- Parabolic Dish may be used on microwave frequencies
  - Gain will increase by 6 dB if either the dish diameter or the operating frequency is doubled

Specialized Antennas

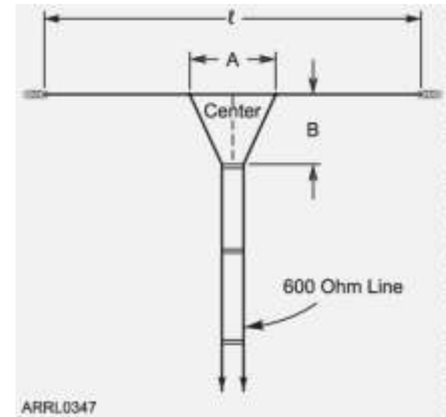
- Receiving Loop Antennas – MF & HF
  - Small loop consisting of one or more turns of wire wound in the shape of a large open inductor and tuned with a variable capacitor (< 0.08 wavelength)
- Direction-Finding Antennas
  - Triangulation - tune for nulls, plot on map
  - Sense Antenna - use to create a single signal null
  - Terrain Effect - refraction and reflection

Antenna Systems

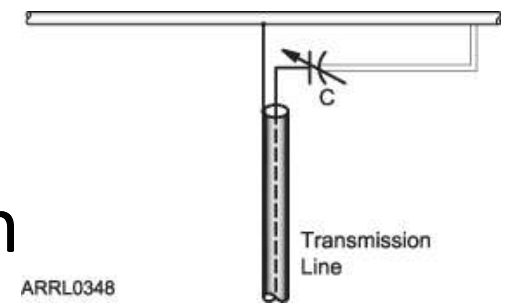
- Impedance Matching – when the antenna is matched to the feed line, maximum power transfer to the antenna is achieved and standing wave ratio is minimized
- Impedance matching at the antenna prevents losses in the feed line as the power is reflected back and forth between the transmitter and the antenna

Matching Techniques

- **Delta match** – feed line connects to the driven element in two places spaced a fraction of a wavelength on each side of the element center

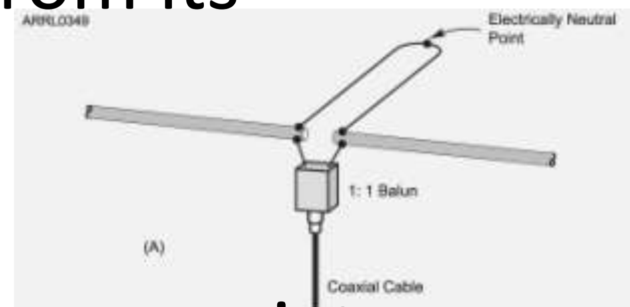


- **Gamma Match** – feed line attaches at the center of the driven element and at a Fraction of a wavelength on one side of center



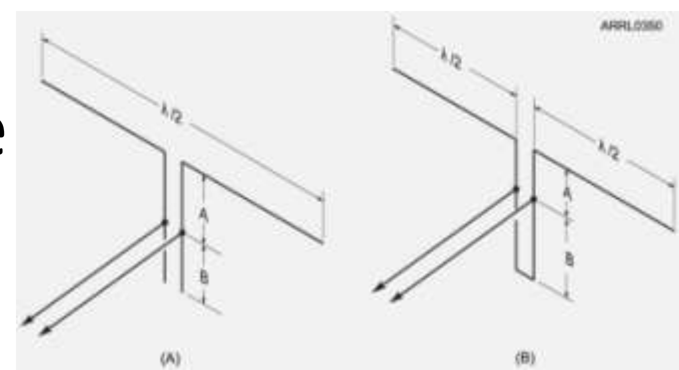
Matching Techniques

- <u>Hairpin Match</u> – driven element must be split in the middle and insulated from its supporting structure



- <u>Stub Match</u> – connecting an appropriate reactance in parallel with the feed line at the antenna feed point, loads

can be considerably reactive



Transmission Line Mechanics

- Velocity of Propagation – Dielectric material other than air reduces the velocity of the radio wave
- Velocity Factor is the ratio of the actual velocity at which a signal travels along a line to the speed of light in a vacuum. (see table 9-1, pg. 9-23)
- Electrical Length is not the same as physical length
  - Always shorter
  - Radio waves move slower in the line than in air

Transmission Line Mechanics

- **Feed Line Loss**: Line loss increases as the operating frequency increases (Table 9-1, pg9-33)
  - Low frequencies, can use less expensive coax cable
  - Open-wire or ladder-line feed lines generally have lower loss than coaxial cables at any frequency
  - Maximum rated voltage: addition of air to the dielectric reduces loss and increases velocity factor and considerably reduces the ability to handle high voltages

Transmission Line Mechanics

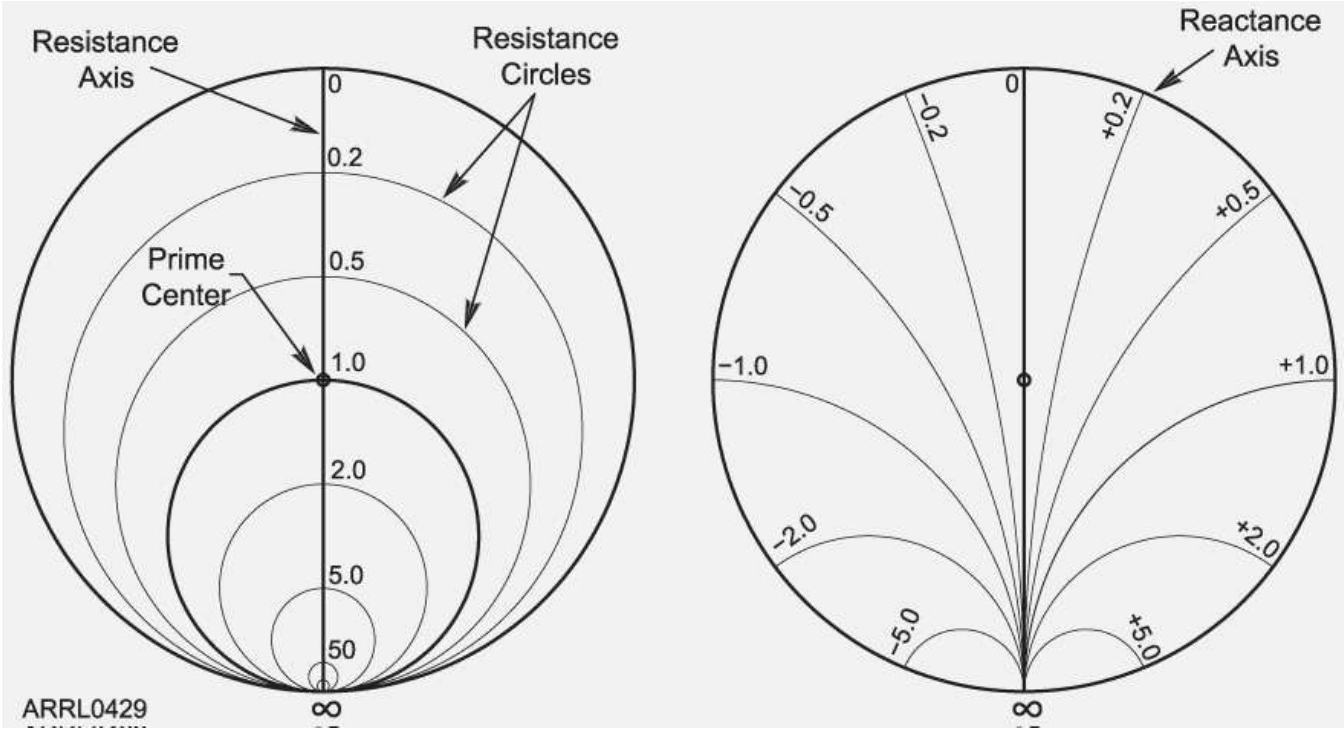
- **Reflection Coefficient**: is the ratio of the reflected voltage at some point on a feed line to the incident voltage at the same point
  - Reflection coefficient is a good parameter to describe the interaction of the load end of a mismatched transmission line
- **SWR**: is a ratio of maximum to minimum (current or voltage) never less than one-to-one
  - For any impedance mismatch the SWR will be greater than 1:1

Smith Chart

- All impedances consist of 2 components: Resistance & Reactance
- Graphically, these components are represented as a pair of axis
  - The rectangular coordinate system for graphing Impedance
    - Horizontal axis represents resistance
      - Positive to the right of the origin
      - Negative to the left of the origin
    - Vertical axis represents reactance
      - Positive (inductive) above the origin
      - Negative (capacitive) below the origin

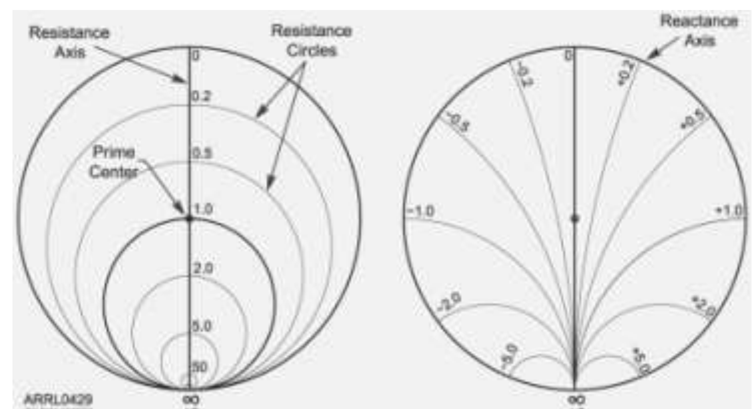
Smith Chart

All possible impedances can be plotted as one point (Z) on that graph corresponding to the values of resistance and reactance



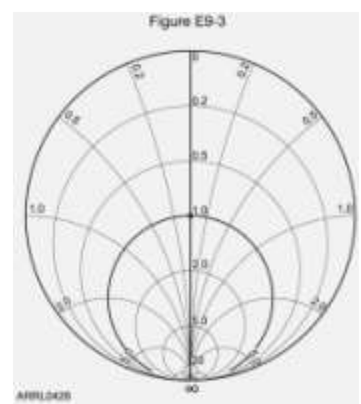
Smith Chart

- What can you do with a Smith Chart?
  - Calculate Impedance along transmission lines
  - Calculate Impedance & SWR values in Transmission lines
- What are the 2 families of circles and arcs that make up a Smith Chart?
  - Resistance (circles)
  - Reactance (arcs)



Smith Chart

- <u>What is the name for the large outer circle on which the reactance arcs terminate?</u>
  - Reactance Axis
- <u>What do the arcs on a Smith Chart represent?</u>
  - Points with constant reactance
- <u>What is the only straight line on the Smith Chart?</u>
  - Resistance Axis



Smith Chart

- What third family of circles is often added to a Smith Chart during the process of solving problems?
  - Standing-wave ratio circles
- What is the process of normalization with regard to a Smith Chart?
  - Reassigning impedance values with regard to the prime center
- Video: http://www.antenna-theory.com/tutorial/smith/chart.php

Transmission Line Stubs & Transformers

- **Rule #1** – If any transmission line is any integer multiple of ½ wavelength long, the impedance at one end will be the same as at the other.
  - Every ½ wavelength along the line the impedance repeats.
  - If the terminating impedance is a short circuit, the impedance meter will see a short circuit every ½ wavelength… the same for an open circuit.

Transmission Line Stubs & Transformers

- Rule 2 – If the transmission line is an odd multiple of ¼ wavelength long, the impedance at one end is inverted from that at the other end.
  - If the terminating impedance is open, the impedance ¼ wavelength away will be a short.
  - ¼, ¾, 1 ¼ etc.

Antenna Design

- Antenna Modeling – Personal computers makes it possible to design and analyze antennas by mathematically modeling the antenna
- Computer analysis allows us to study how performance changes as the height of the antenna changes
- (NEC) – Numerical Electromagnetics Code
  – modeling technique called "Method of Moments"

Antenna Design

- Modeling – In the Method of Moments, the antenna wires are modeled as a series of segments and a uniform value of current in each segment is computed
- The field resulting from the RF current in each segment is evaluated, along with the effects from other mutually coupled segments.
- The higher number of segments results in more accuracy.
- Most programs limit the number of segments because of memory and processing time

Antenna Design

- Design Tradeoffs & Optimization
  - When you evaluate the gain of an antenna, you have to take into account:
    - Feed Point Impedance
    - Loss resistance in the elements
    - Impedance-matching components
    - E-field & H-field radiation patterns
    - Performance across the entire frequency band
    - Gain may change drastically as you move away from the design frequency
    - Front to back may vary drastically across the band
    - Forward gain may be increased by using a longer boom and spacing the elements farther apart
    - Element length may need to be adjusted
  - Interdependency of gain, SWR bandwidth, and pattern ratios require compromises by the antenna modeler to achieve realistic goals.

Homework

- Read Chapter 10
- Do practice questions within the chapter
- Use the practice test CD included in the textbook