Chapter 9

Antennas
and Feed Lines

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Chapter 9

* Basics of Antennas
* Practical Antennas
* Transmission Lines
* Antenna Systems
* Antenna Design

Thanks to:

* Information from:
  * The ARRL Library
  * ARRL Extra Class License Manual
  * Gordon West Extra Class License Class

Near and Far Fields

Technician and General Review

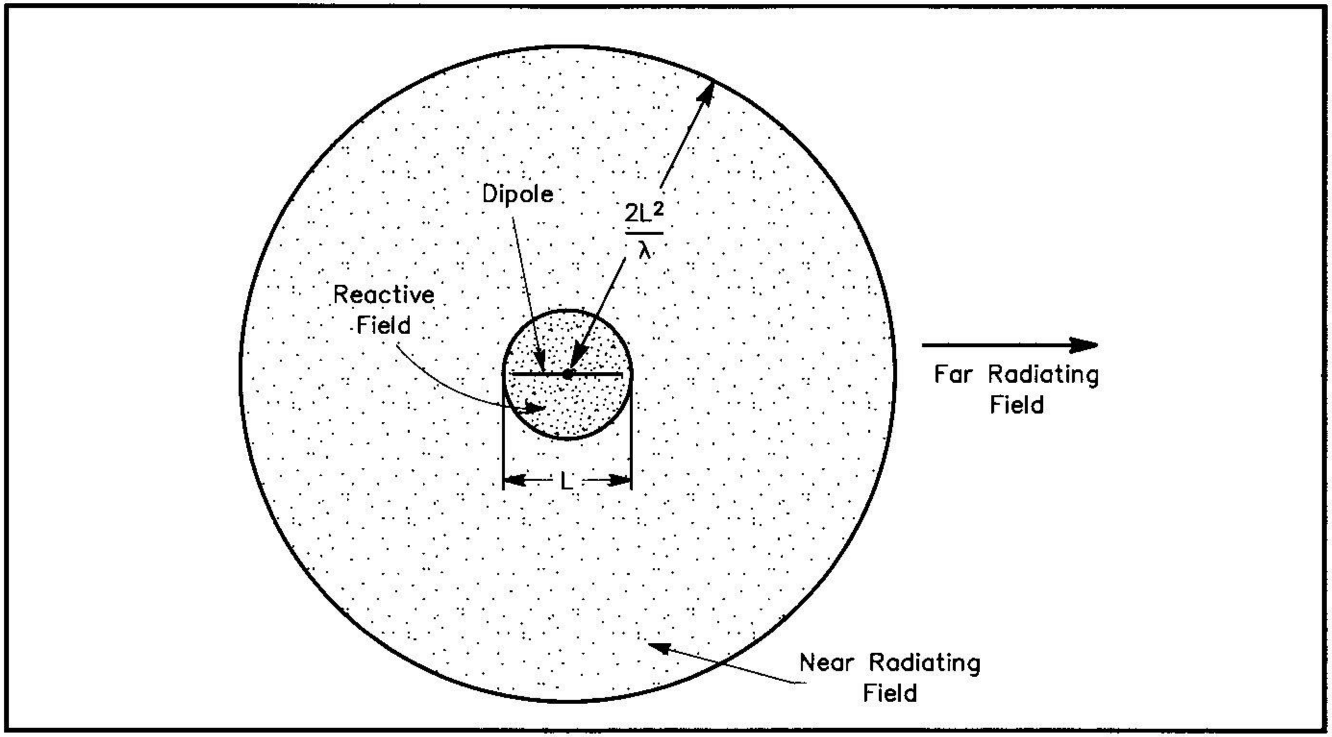


Figure 10-2 — This drawing illustrates the reactive near field, the radiating near field and the far field around a half wavelength dipole antenna.

L is the largest dimension of the physical antenna

- The far field begins at several wavelengths and extends forever!

Dipole Radiation Pattern

Pg. 9-2

* In the far field, the pattern is independent of distance
* The radiation pattern is usually drawn so that it just touches the outer circle at the point of its maximum strength.

Far Field Pattern

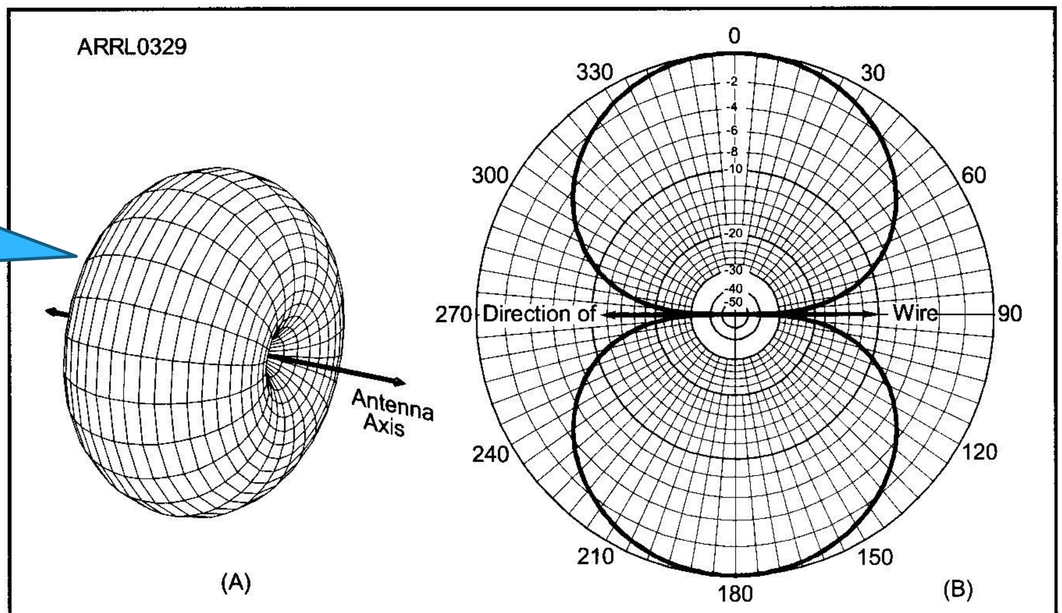
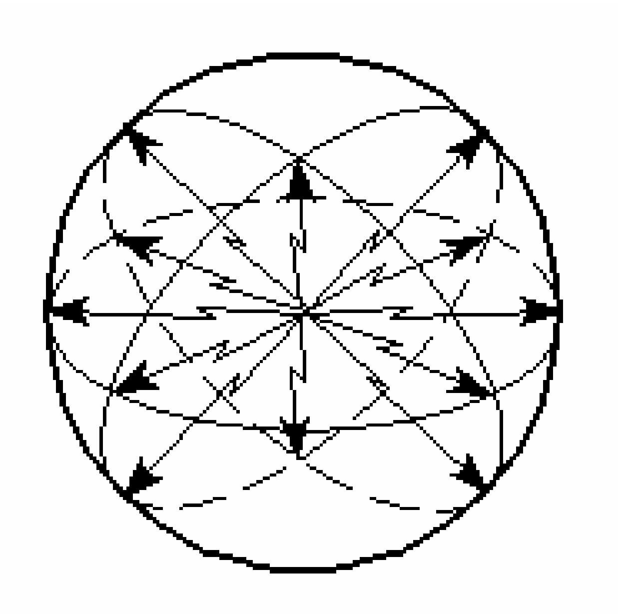


Fig. 9-1

Isotropic Radiator

Pg. 9-2

* *It's is only theoretical – it does not really exist*
* The Isotropic antenna is a useful reference for comparing the differences among real antennas.



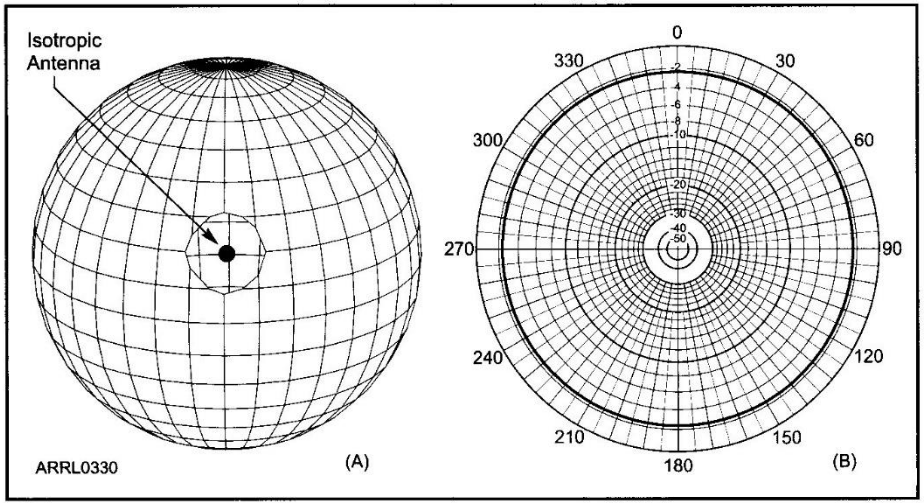


Figure 9-2 — The three-dimensional radiation pattern of an isotropic radiator is shown at A. B shows the radiation pattern of the isotropic antenna in any plane. This plot has been reduced by 2.15 dB so that it can be compared with the radiation pattern of the dipole in Figure 9-1.

Directional Antennas

Pg. 9-3

* The radiation pattern from a practical antenna never has the same intensity in all directions.

* Directional antennas concentrate the energy in one (or more) directions.
  * Major lobe(s)
  * Minor lobe(s)

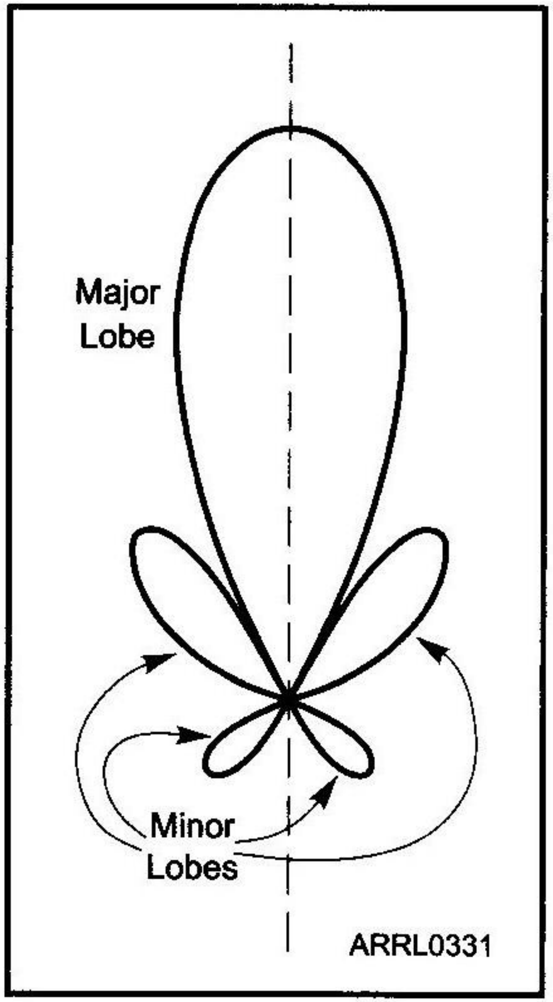


Fig. 9-3

Directional Antennas

Pg. 9-3

* The antenna's gain (expressed in dB) is the signal from the antenna in the direction of the main lobe and the signal from a reference antenna.

* Reference antennas:
  * Isotropic
  * Dipole

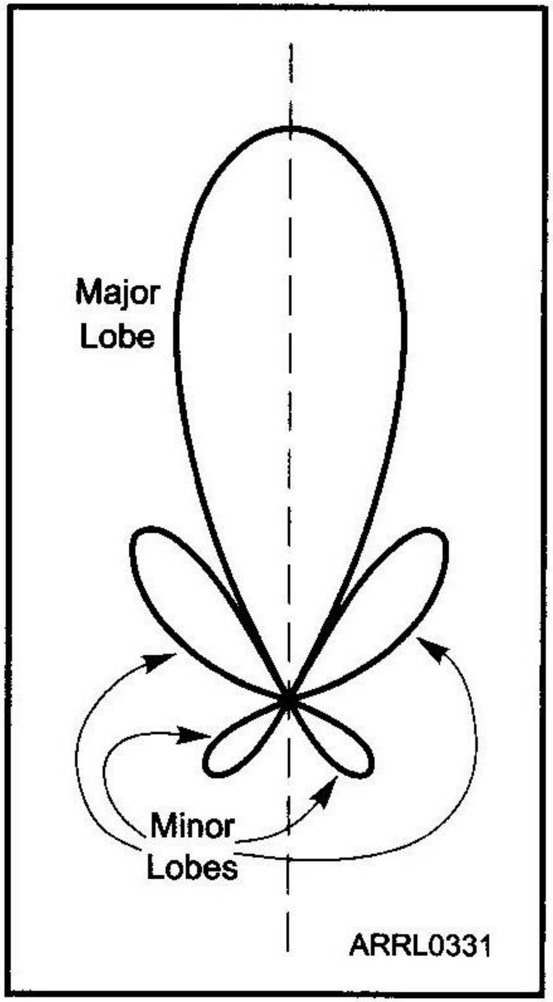


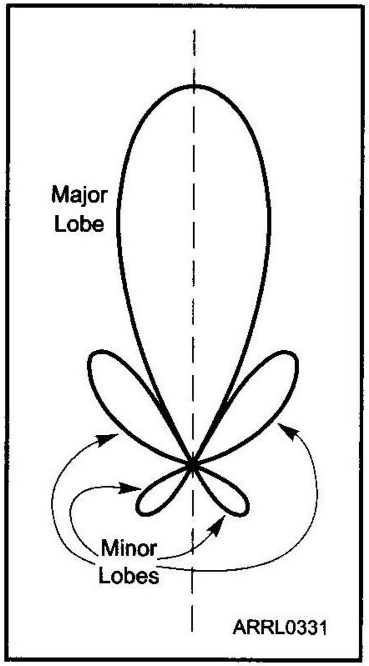
Fig. 9-3

Directional Antennas

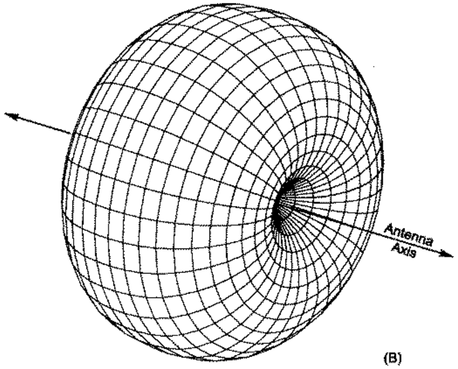
Pg. 9-3

* The gain of the antenna is the result of concentration the energy in one direction.

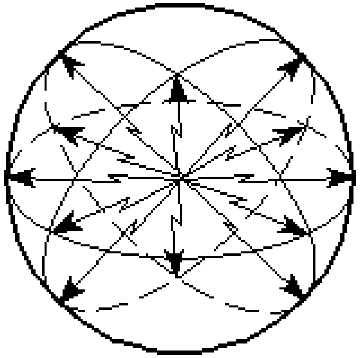
* There is no difference in the total amount of power radiated.



Gain Antenna
Top View
Fig. 9-3



Dipole Antenna



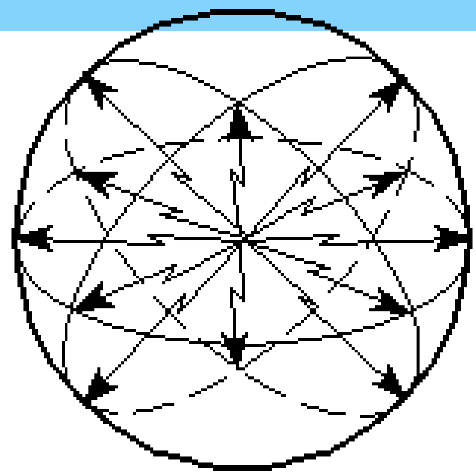
Isotropic Antenna

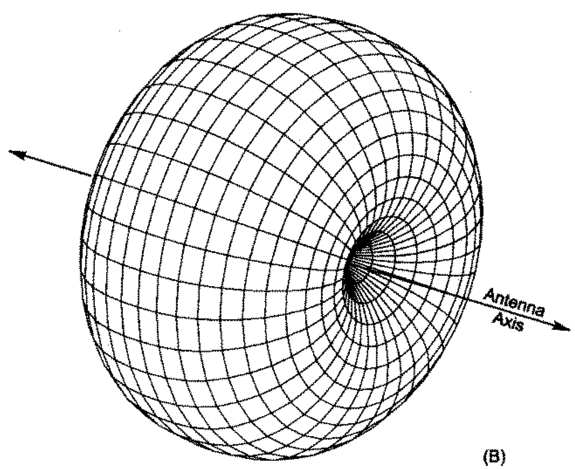
A Look at Gain

Pg. 9-3

When we talk about the gain of other antennas

* The Isotropic radiator has no gain in any direction.
* The Radiation of the main lobe of a dipole is 2.15 dB greater than would be expected from an Isotopic antenna.



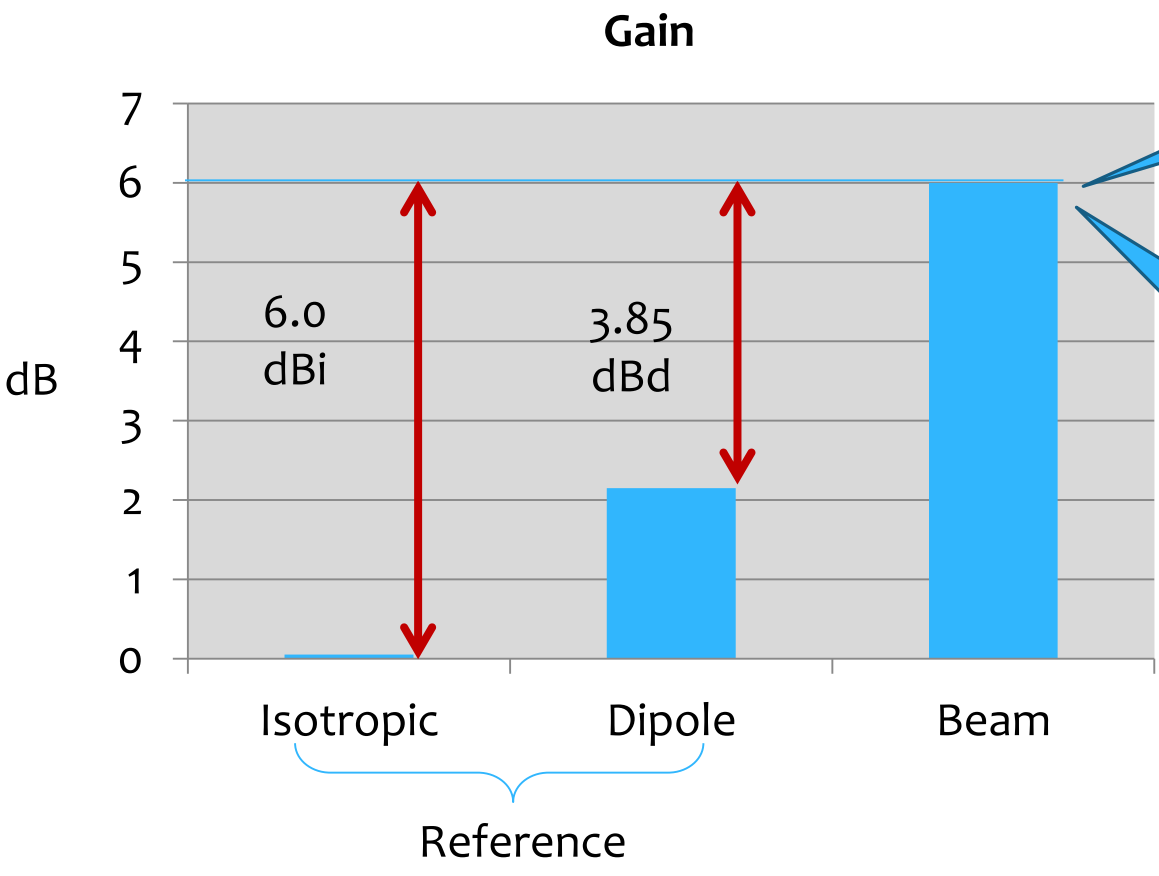


… we can reference the gain to an **isotropic** radiator (**dBi**)

… or we can reference the gain to a **dipole** antenna (**dBd**)

dBi and dBd

The beam antenna we want to buy advertises a gain of **6 dBi**



Or the same antenna could be advertised as having a gain of **3.85 dBd**

Example 9-1

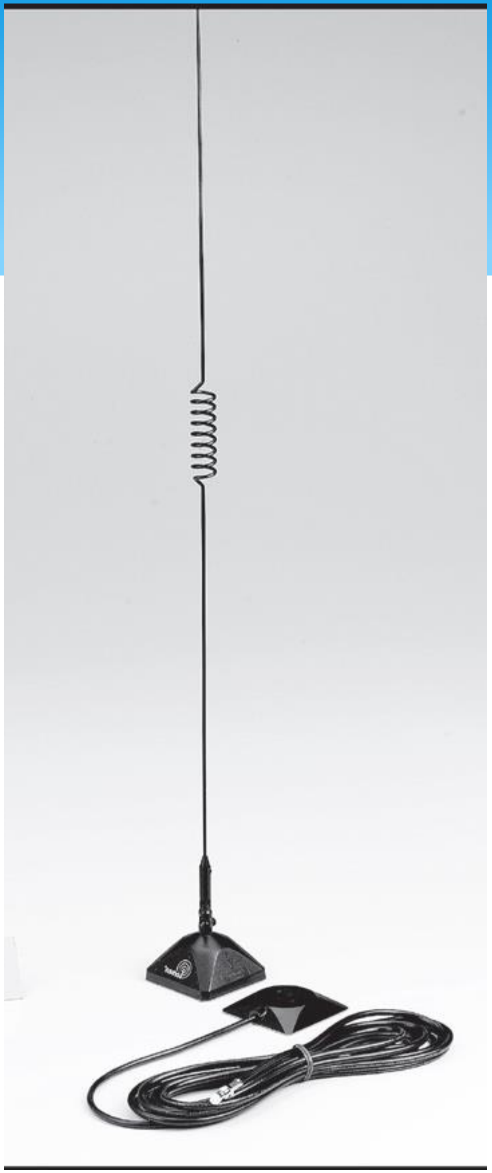
A Look at Advertised Gain

Comet SBB-224/SBB-224NMO

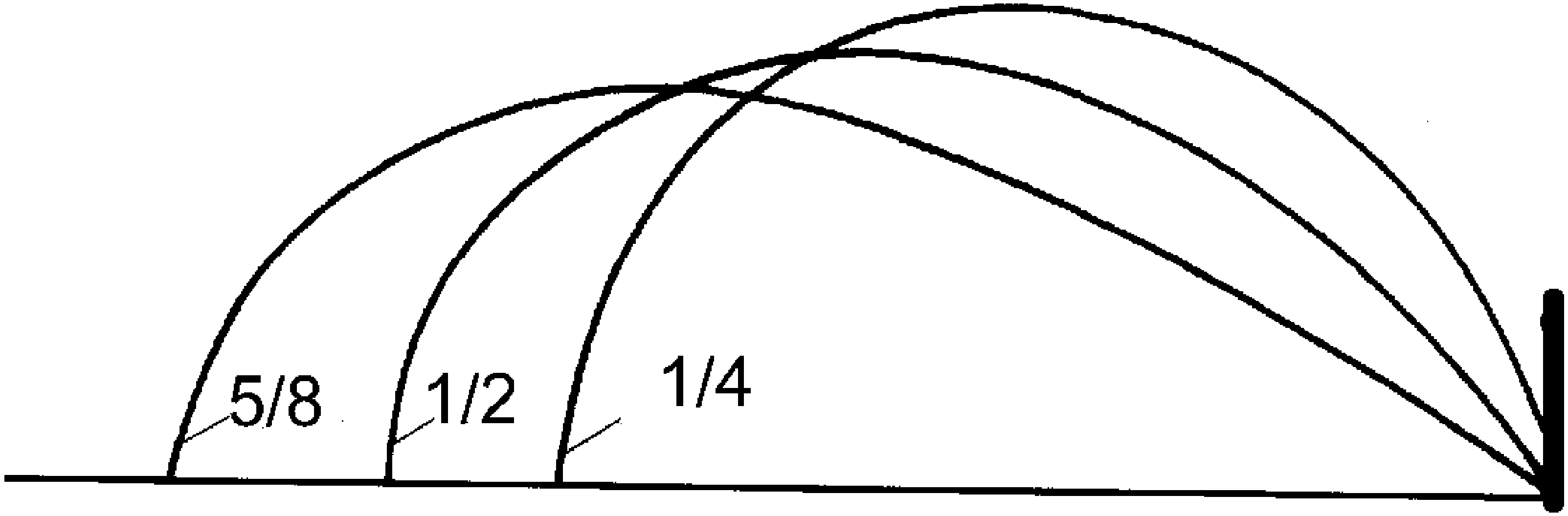
* Tri-Band 146/220/446MHz
  Gain & Wave:
  146MHz 2.15dBi 1⁄4 wave
  220MHz 3.5dBi 5⁄8 wave
  446MHz 6.0dBi 5⁄8 wave x 2
  VSWR: 1.5:1 or less
  Max Power: 100 watts
  Length: 36”
  Connector:
  SBB-224 PL-259
  SBB-224NMO NMO Type

½ λ End-fed Mobile

- **LARSEN MODEL** KG2/70CXPL **FREQUENCY (MHz)** 144 - 148 / 442 - 448
- **SPECIFICATIONS**
  - GAIN VHF: 0 dBd / 2 dBi
  - UHF: 2 dBd / 4.2 dBi



Many Antennas will exhibit **gain**.



Side View

dBi and dBd

Pg. 9-3&4

* Equation 9-1
  * **Gain in dBd = Gain in dBi -2.15 dB**
* Equation 9-2
  * **Gain in dBi = Gain in dBd +2.15 dB**
* Example 9-2
  * If an antenna has 12 dB more gain than an isotropic radiator, how much gain does it have compared to a dipole?
* Gain in dBd = 12 dBi – 2.15 dB = **9.85 dBd**

The gain in **dbi** will always be a **bigger** number **than dBd** by about **2 dB.**

Beamwidth and Pattern Ratios

Pg. 9-4

* Beamwidth is the angular distance between the point on either side of the major lobe at which the gain is 3 dB below the maximum.
  * Also called the -3 dB beamwidth.
* As gain is increased, the beamwidth **decreases**

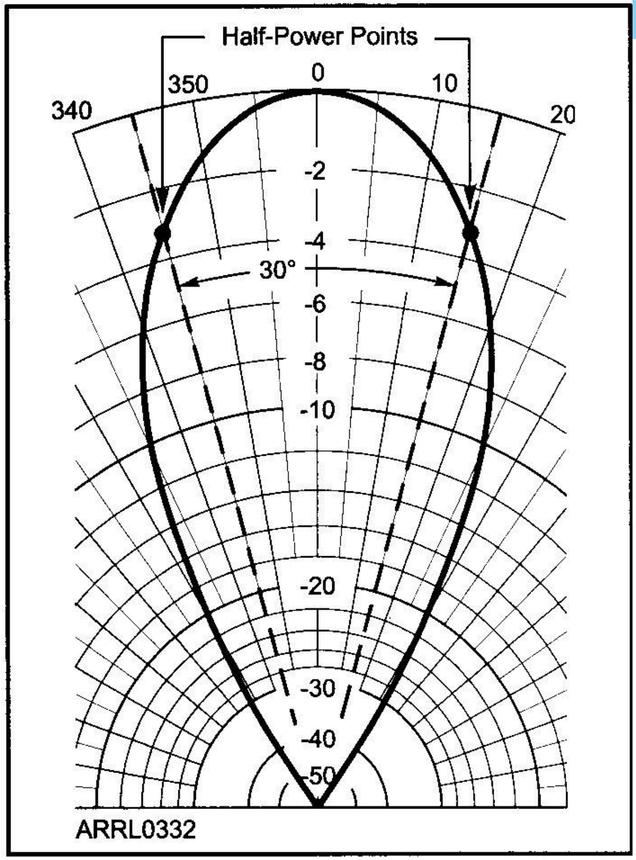


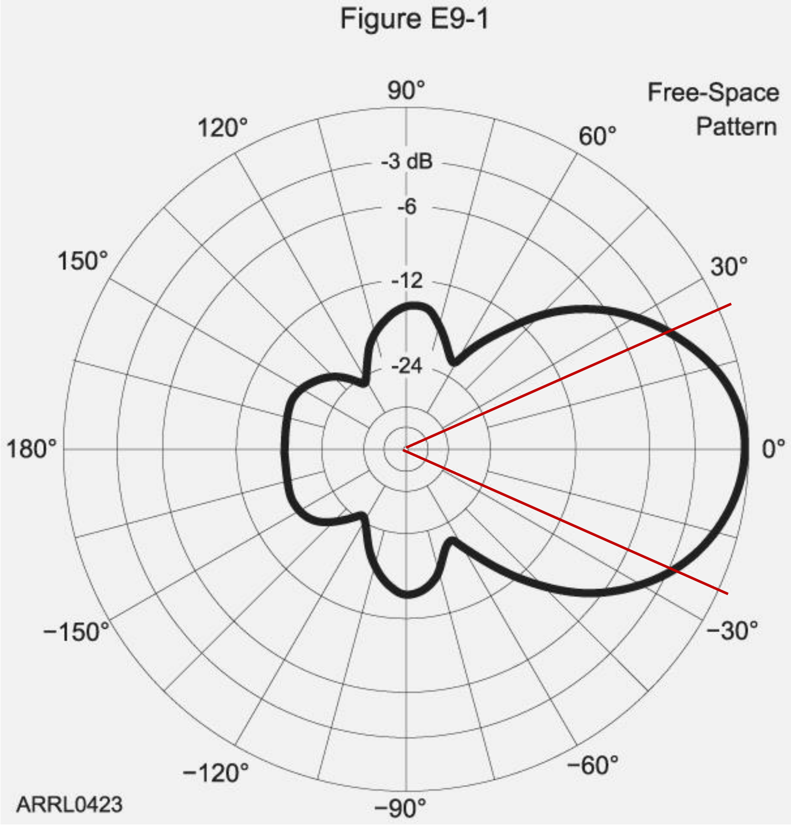
Figure 9-4 — The beamwidth of an antenna is the angular distance between the directions at which the antenna gain is one-half (–3 dB) its maximum value.

Top View

What is the -3dB Beamwidth?

Pgs. 9-4 & 5

Azimuth – Top View



1) Figure out where the – 3dB ring is.
2) Observe where the pattern lines cross the – 3dB ring.
3) Estimate the total angular distance.

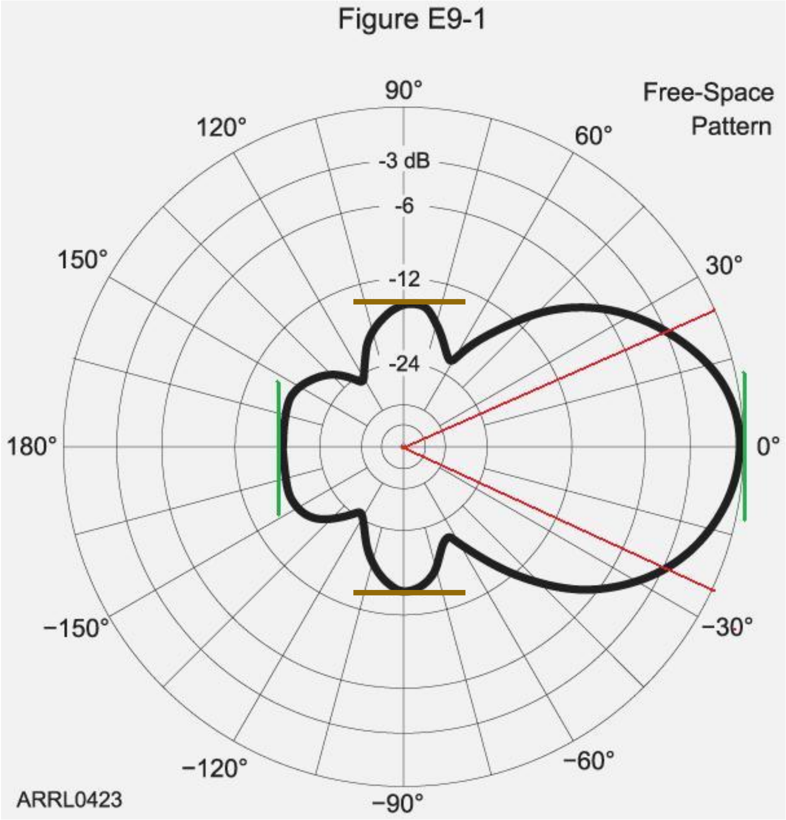
$25^{\circ} + 25^{\circ} = 50^{\circ}$

Gain Ratios

Pg. 9-5

- Beam antennas are also specified by certain **ratios:**
  - Front to Back
  - Front to Side

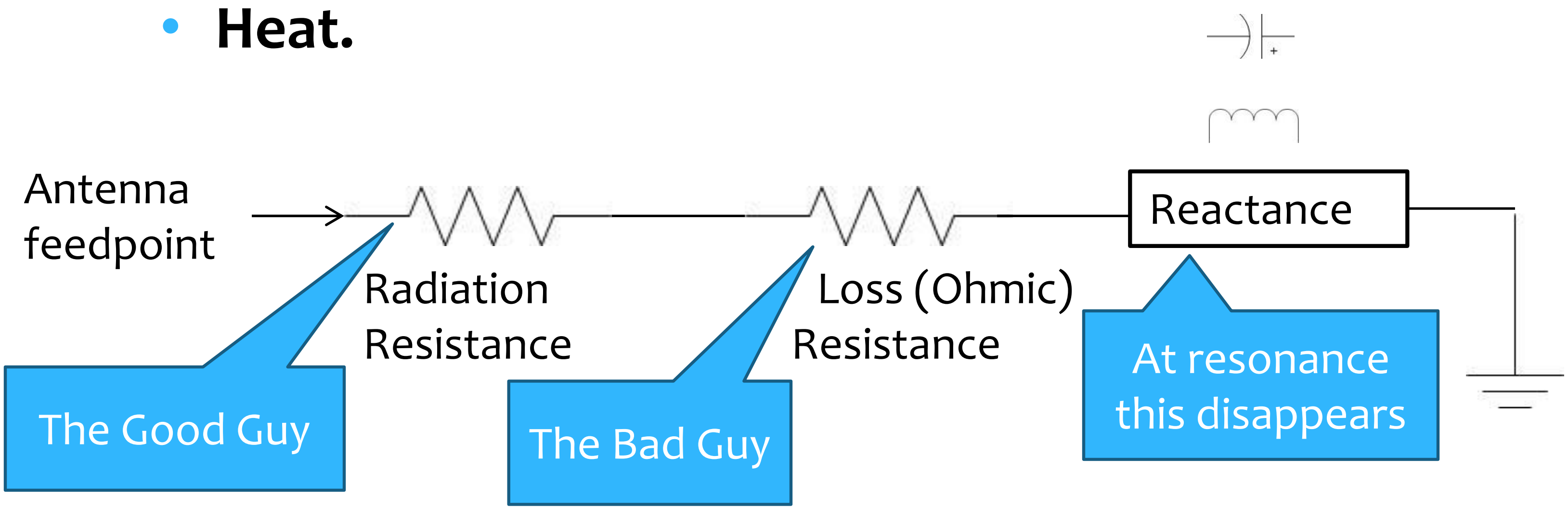
- F/B = 18 dB
- F/S = 14 dB



Radiation and Ohmic Resistance

Pg. 9-6

- RF power supplied to the antenna is dissipated in the form of:
  - **Radio waves**
  - **Heat.**



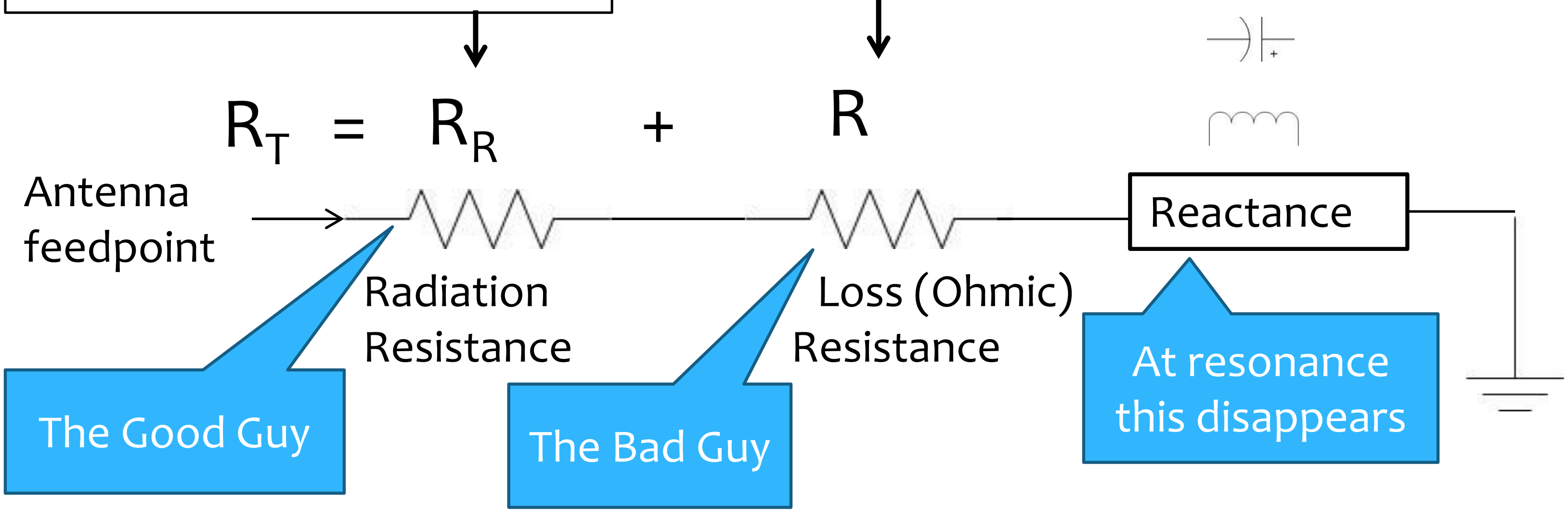
Radiation and Ohmic Resistance

Pg. 9-6

- $R_T = R_R + R$

The value of resistance that would dissipate the same amount of power as that **radiated from the antenna** as radio waves.

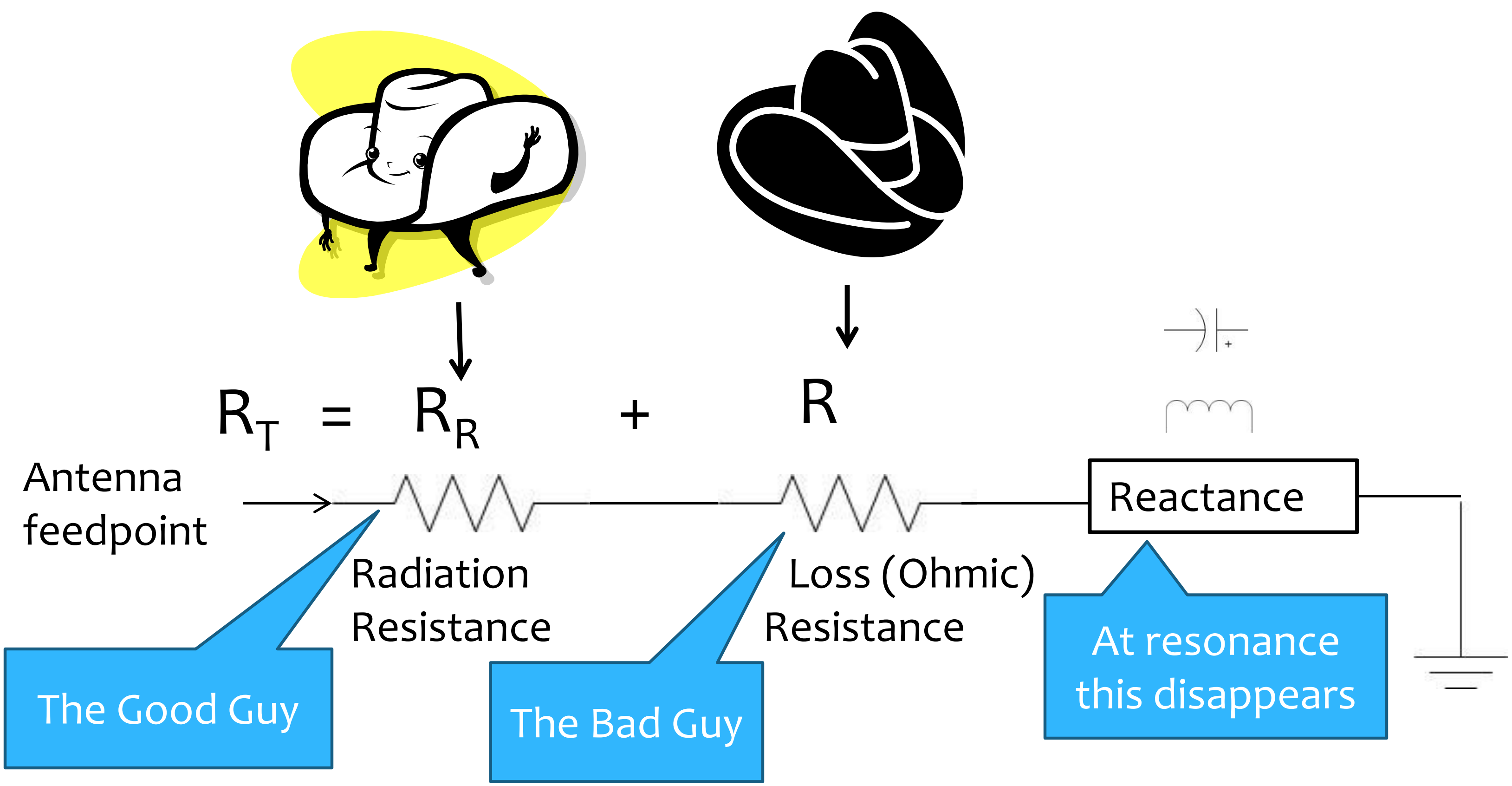
The value of resistance that would dissipate the same amount of power that is **lost to heat.**



Radiation and Ohmic Resistance

Pg. 9-6

* $R_T = R_R + R$



Feed Point Impedance

Pg. 9-6

The feed point impedance can vary over a wide range:

* The impedance can be resistive only (at resonance)
* Or have a reactive (L or C) component off resonance

Many factors determine the feed point impedance:

* The location of the antenna with respect to other antennas and objects, especially its location to the earth (height)
* The Length/Diameter ratio.
* The design of the antenna

Antenna Efficiency

Pg. 9-6

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

where:

R_R = radiation resistance.

R_T = total resistance.

$R_T = R_R + R$

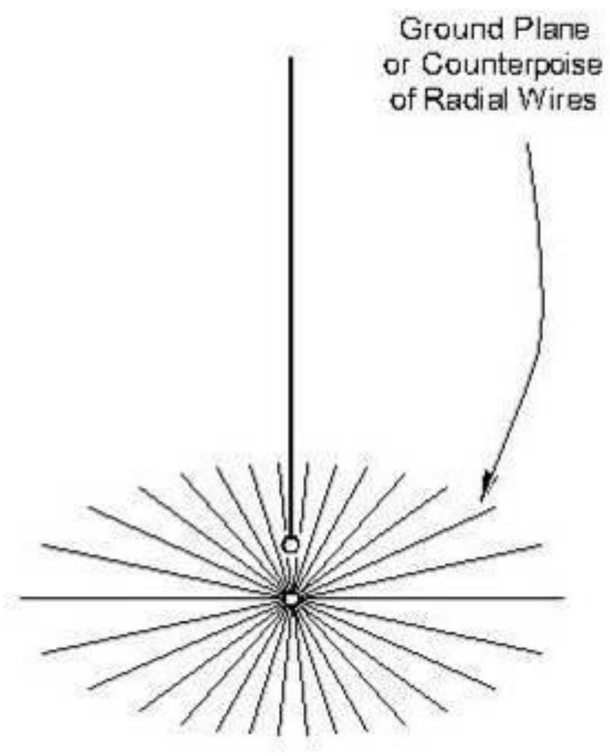
- If a half-wave dipole antenna has a radiation resistance of 70 Ω and a total resistance of 75Ω, what is it's efficiency?
- Efficiency = 70 / 75 x 100% = 93.3%

A Practical Look at Antenna Efficiency

Pg. 9-7

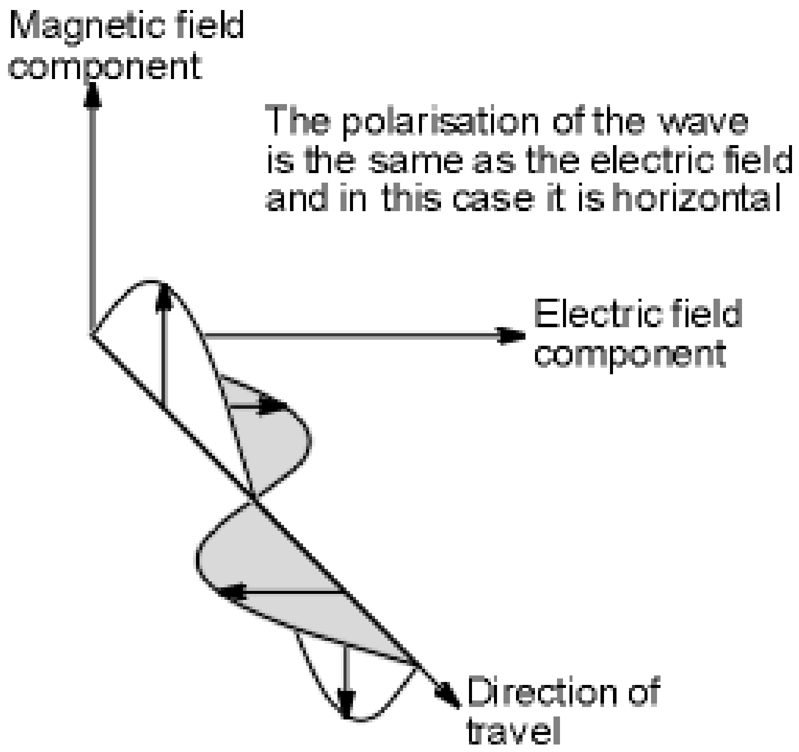
- Mobile HF whips may have very low efficiency because the radiation resistance tends to be low due to the short length.

- To be effective, a ¼ wavelength ground mounted vertical antenna requires a ground system of radials.



Polarization

Pg. 9-7



Antenna polarization is defined by the E field.

An antenna with horizontal elements is horizontally polarized .

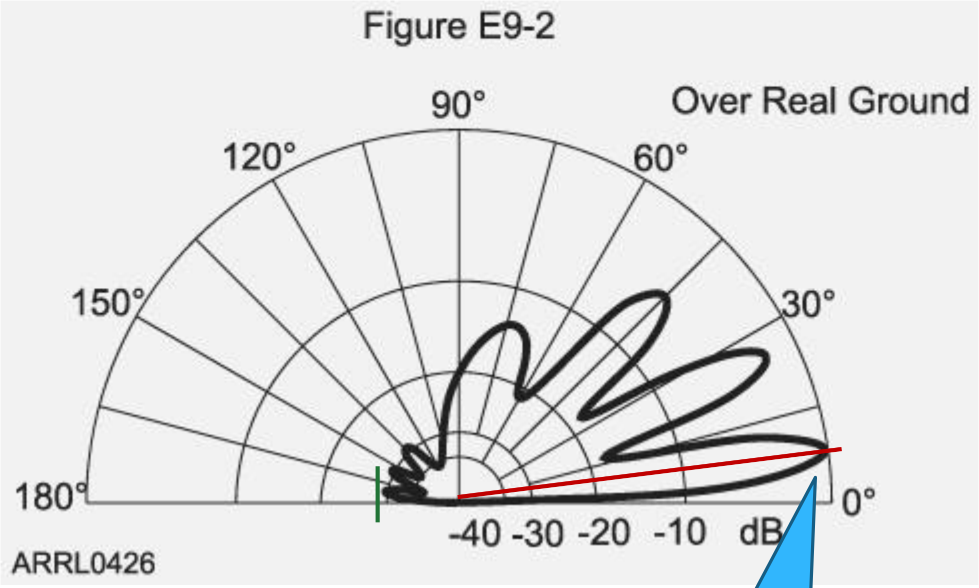
An antenna with vertical elements is vertically polarized.

Typical Beam Elevation Pattern

Pg. 9-7

What we see:

* **Four forward lobes**
* Three rear lobes
* The vertical angle at which the antenna's major lobe has its maximum radiation is called the **takeoff (elevation) angle.** About 7.5 degrees
* F/B Ratio of ~ 28 dB



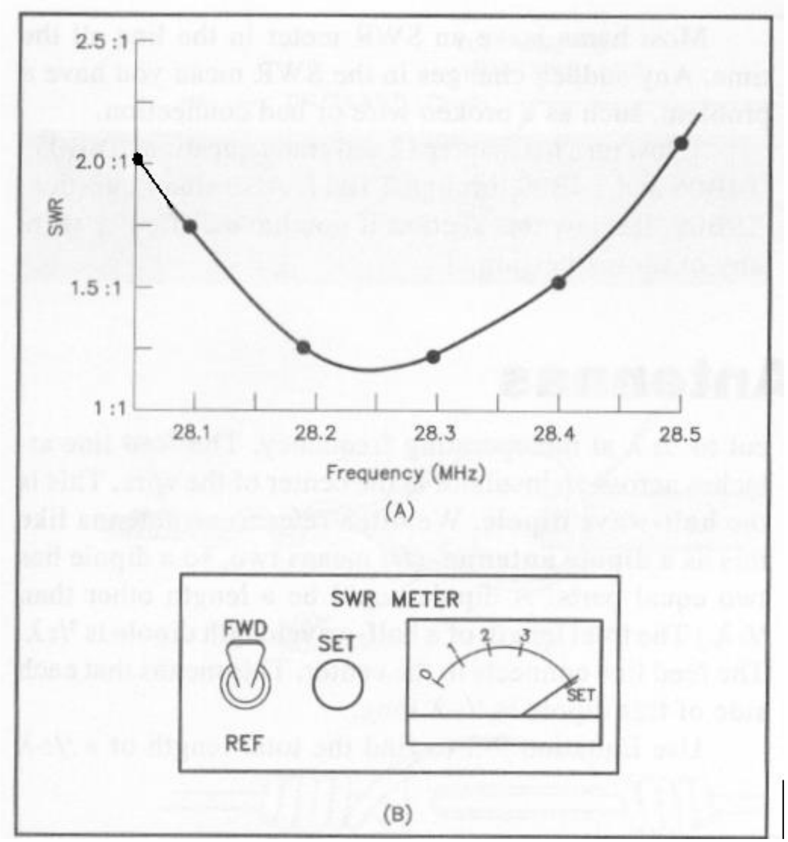
Elevation - Side View

The low angle is good for DX

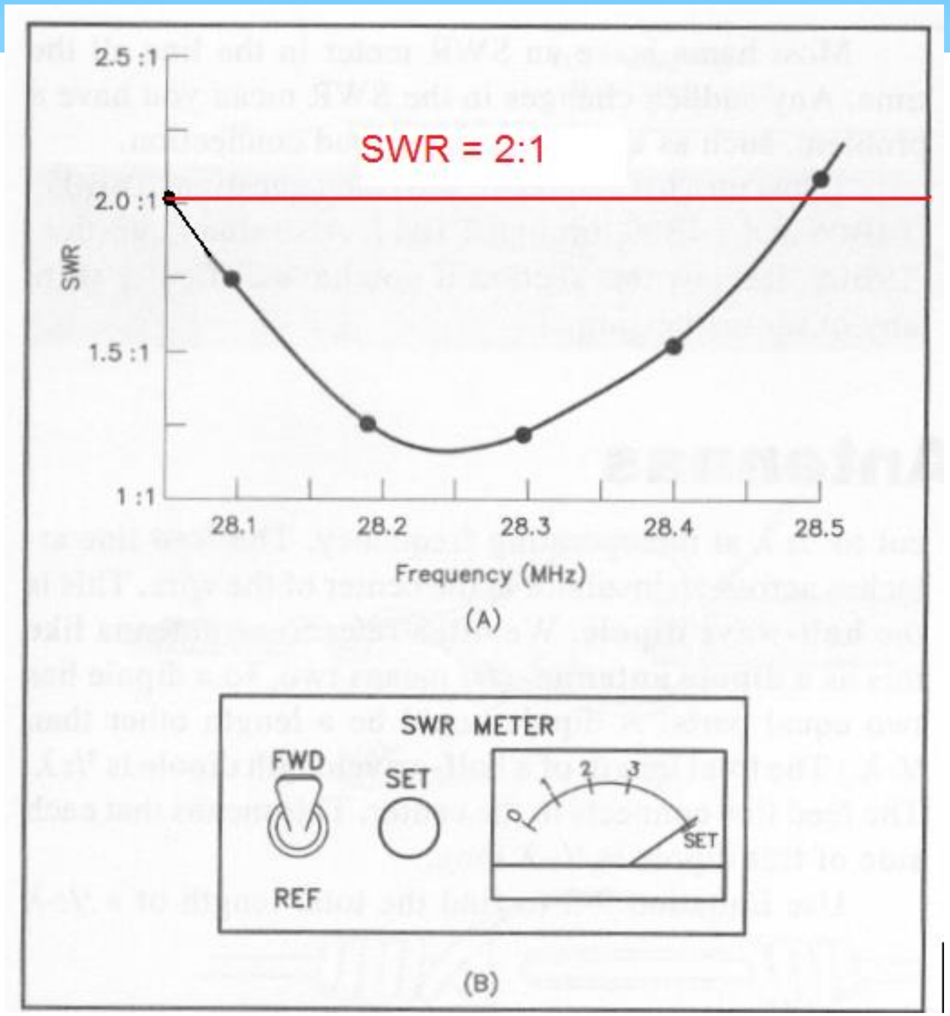
Bandwidth

Pg. 9-8

- The bandwidth of an antenna is the frequency range over which it satisfies a performance requirement.
- One key requirement is often the SWR.



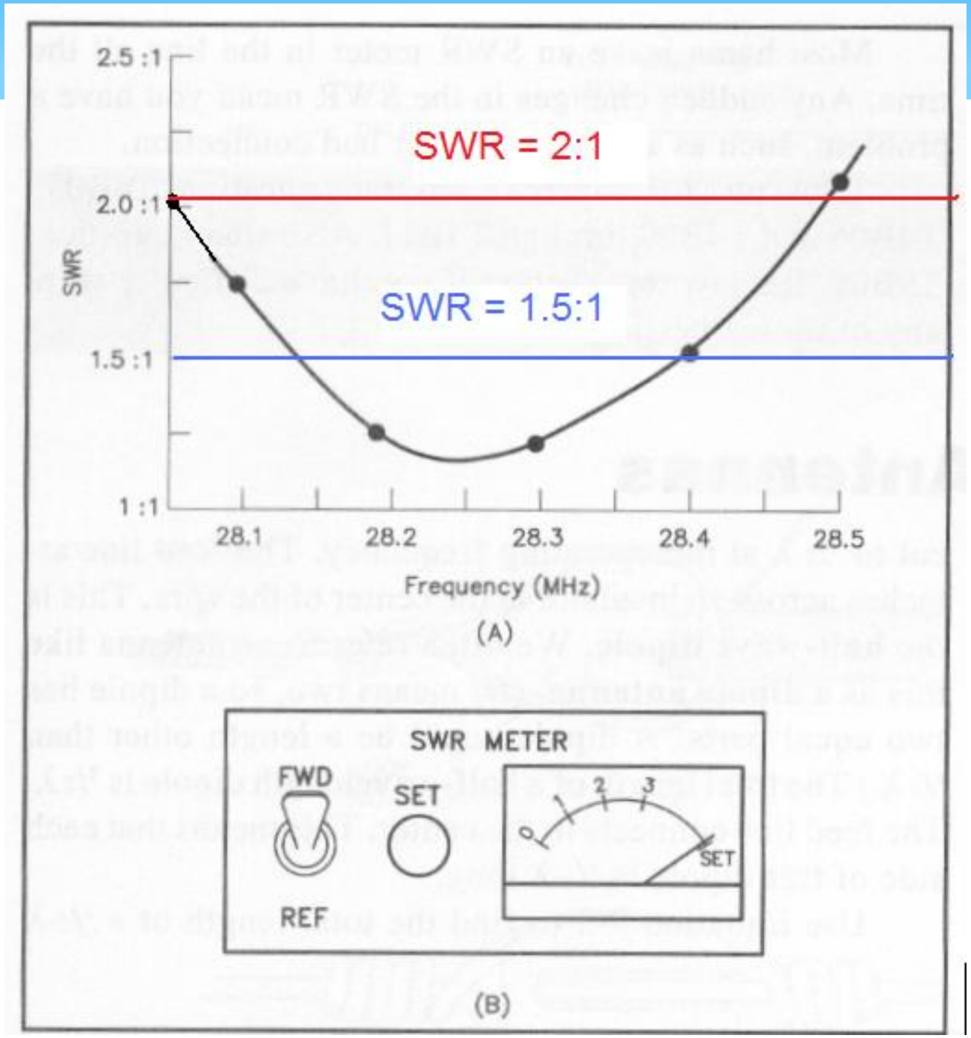
SWR Bandwidth



SWR Bandwidth

2:1 SWR is the highest SWR that most radios will work at properly. Some reduction in power may be observed

With a 1.5:1 SWR, most radios will deliver full power.



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

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

E9B08 How can the approximate beamwidth in a given plane of a directional antenna be determined?

A. Note the two points where the signal strength of the antenna is 3 dB less than maximum and compute the angular difference

B. Measure the ratio of the signal strengths of the radiated power lobes from the front and rear of the antenna

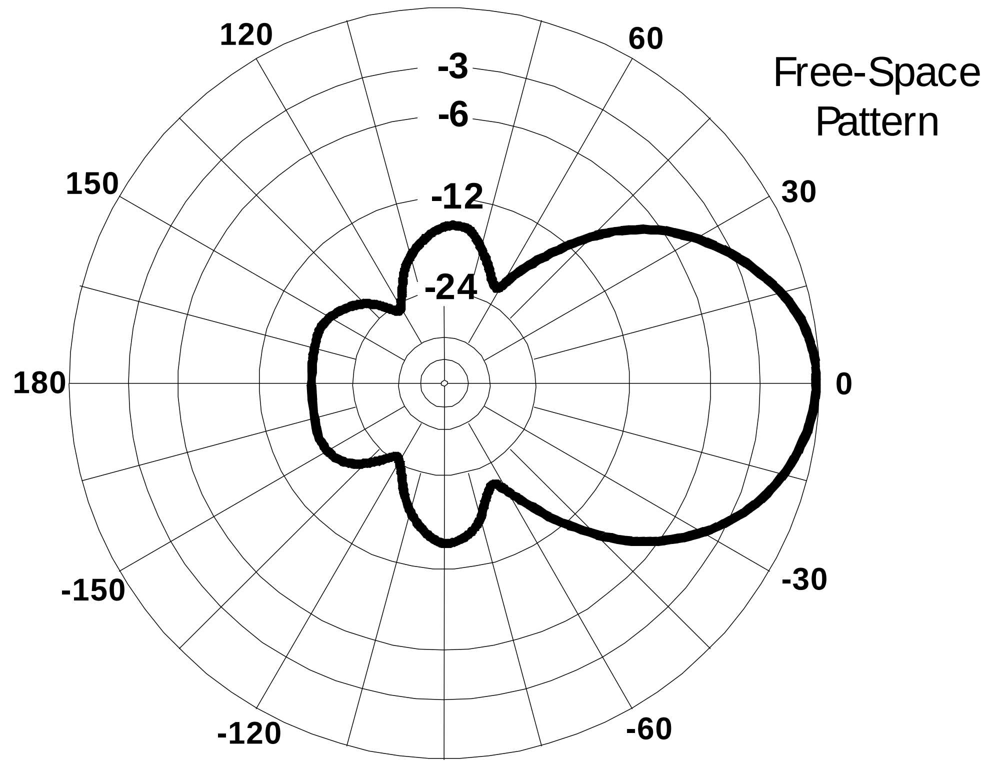
C. Draw two imaginary lines through the ends of the elements and measure the angle between the lines

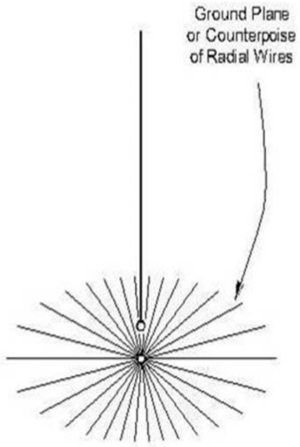
D. Measure the ratio of the signal strengths of the radiated power lobes from the front and side of the antenna

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

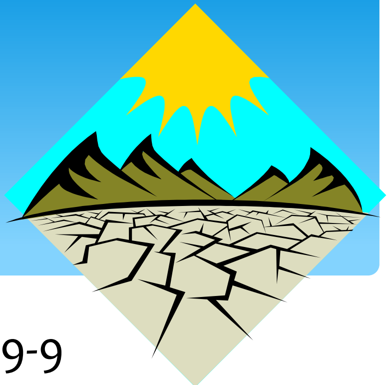
A. 36 dB
B. 18 dB
C. 24 dB
D. 14 dB

Figure E9-1



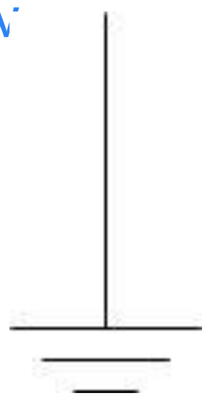


Effects of Ground

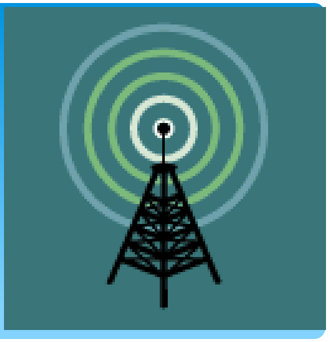


Pg. 9-9

- By far, the biggest effect on antenna systems is the losses in the nearby ground.
- Losses caused by low conductivity in the soil near the antenna dramatically reduce signal strengths at low angles.
- Low angle radiation from a vertically polarized antenna over seawater will be much stronger than over poorly conducting soil.
- Adding radials or a wire mesh will help.
  - It would have to extend many wavelengths to be really effective



Height Above Ground



Pgs. 9-9 & 10

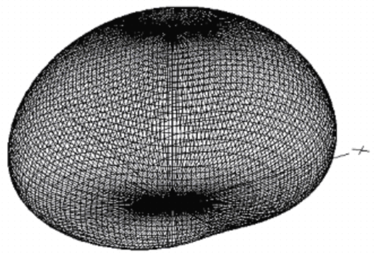
* In general, raising an antenna off the ground lowers the vertical takeoff angle of peak radiation.
* Horizontally polarized antennas have less ground loss than ground-mounted vertical antennas.
* As Horizontal antennas are raised, the vertical angle of maximum radiation dips until a height a of ½ wavelength is reached.
* In general, mounting a horizontally polarized antenna as high as possible is a good rule (for long-range com).

Dipole Antennas Pattern

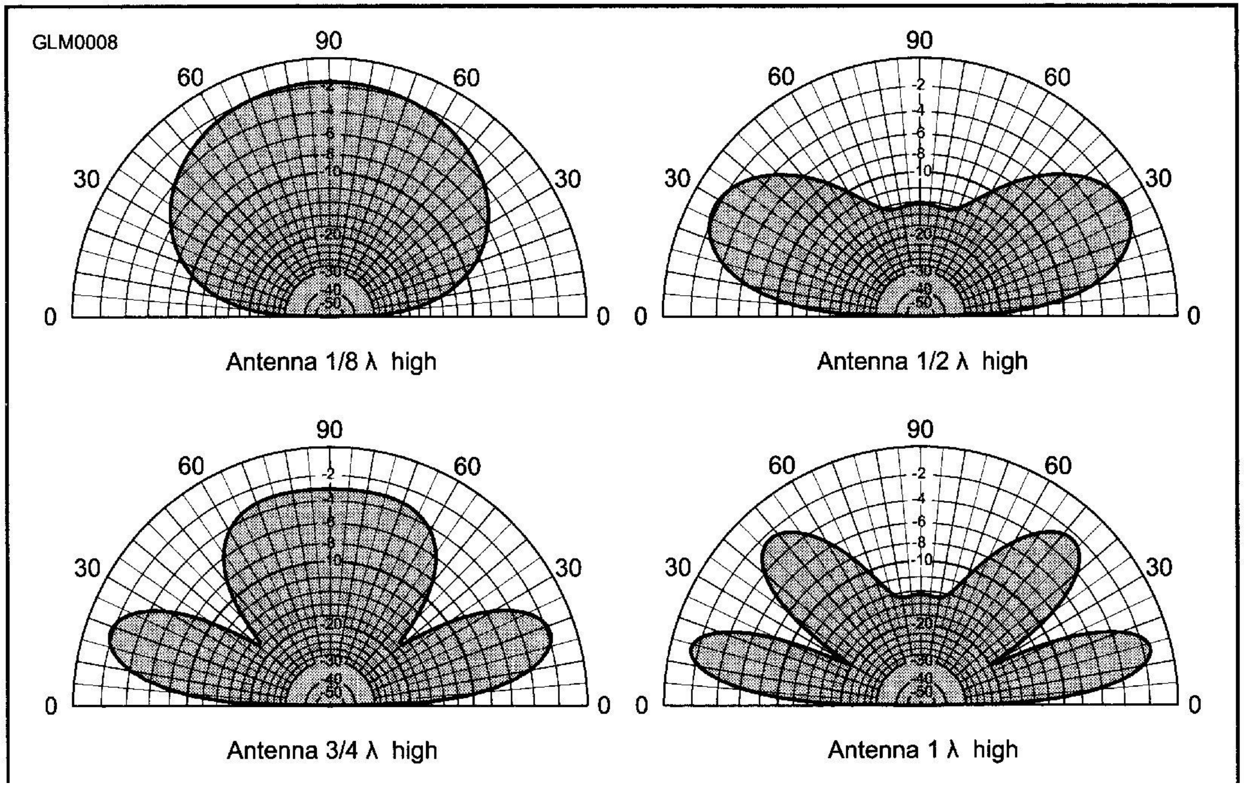
General Review

- **Patterns change as height above ground is varied**

Viewed from the end of the dipole



Omni-directional pattern



The Effects of Dipole Height

General Review

Broadside View End View

Dashed lines show the pattern with no reflections from the ground

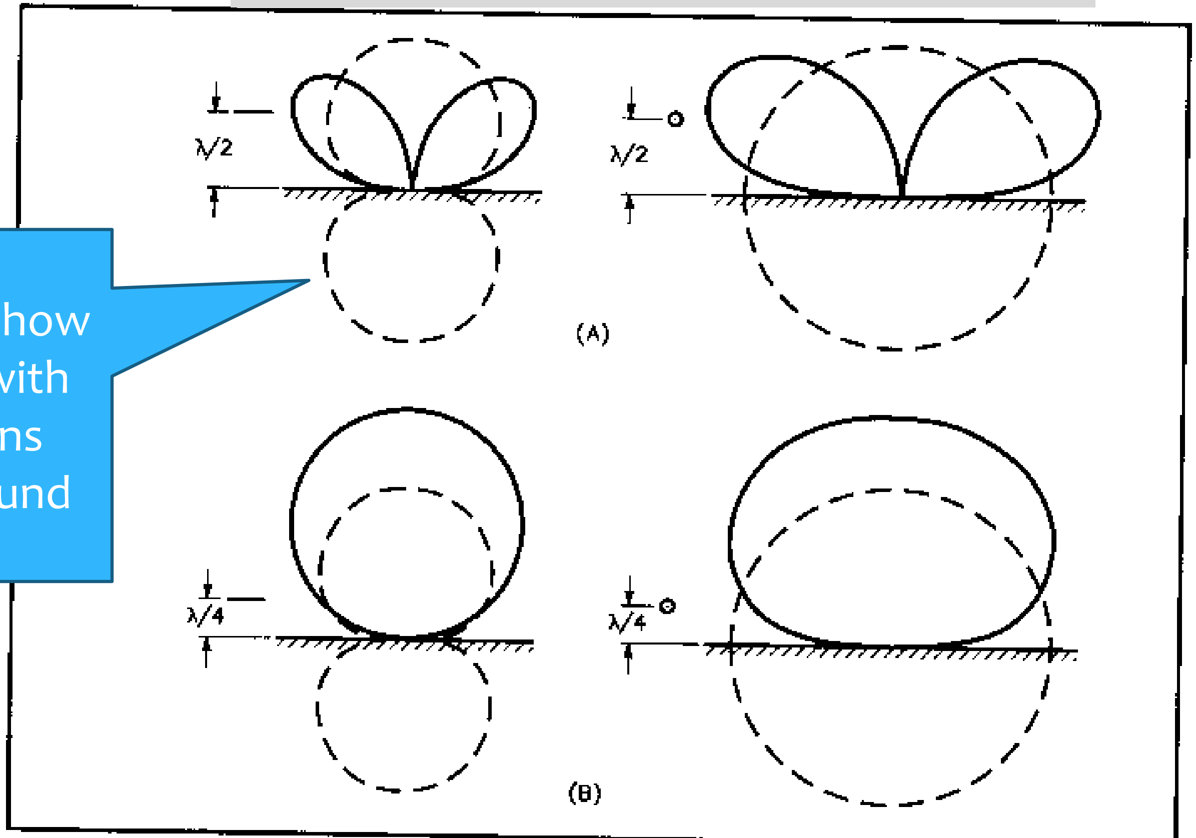
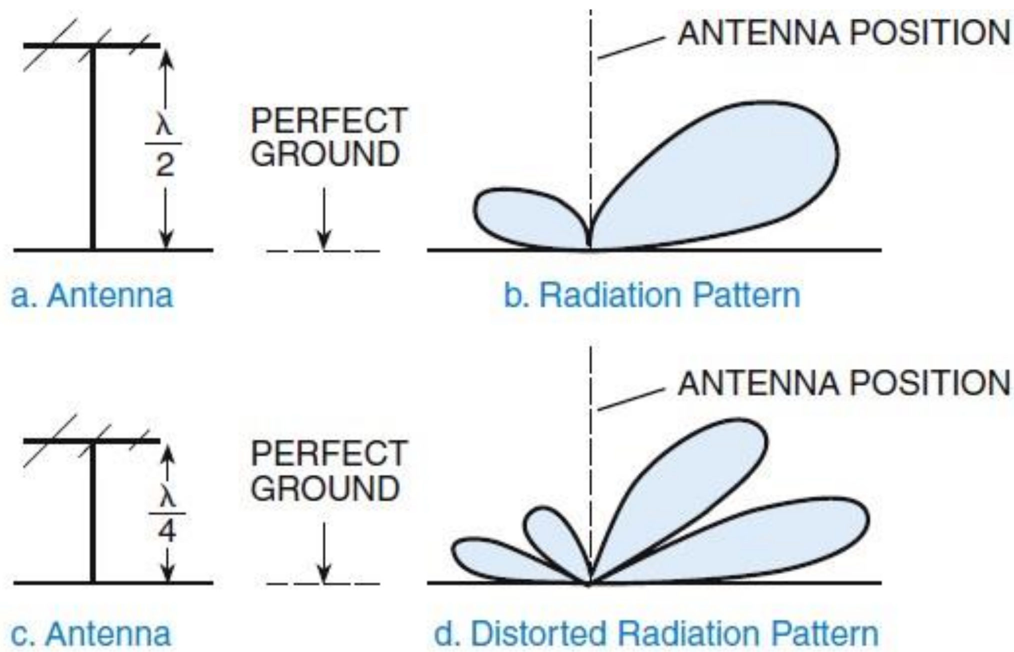


Figure 9-5 — The effect of ground on the radiation from a horizontal half-wavelength antenna, for heights of one-half (A) and one-quarter (B) wavelength is shown. The dashed lines show what the pattern would be if there were no reflection from the ground.

Effects of Height

* Those with a motorized telescopic tower can lower and raise the antenna to control the takeoff angle



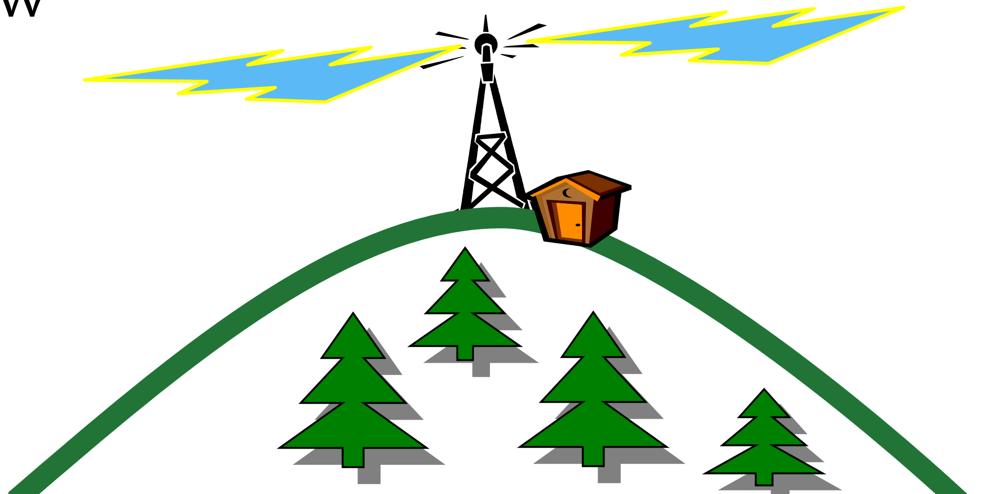
Radiation of 3-Element Yagi for Different Antenna Heights

Gordon West

Effects of Ground

Pg. 9-10

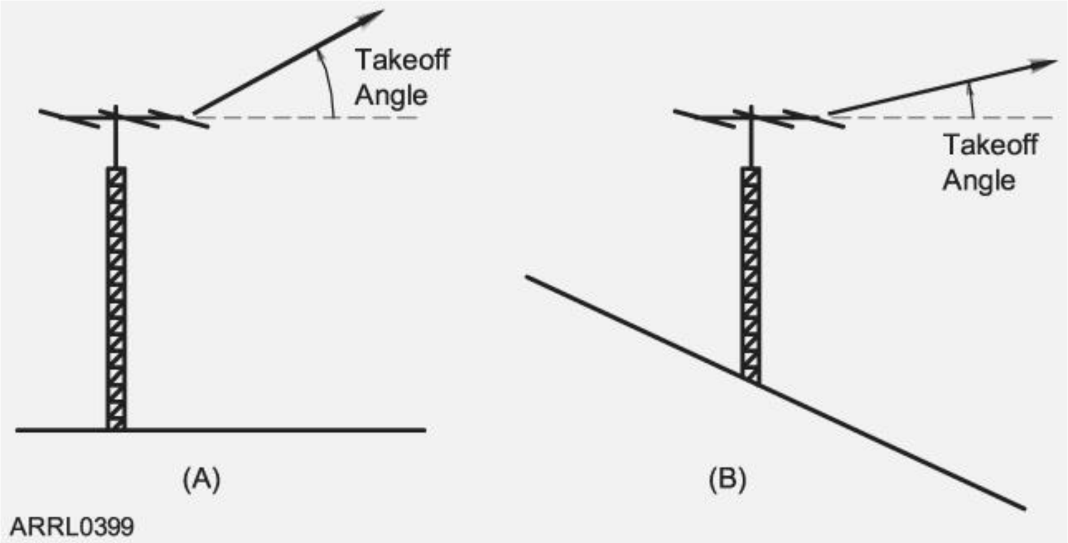
- The terrain on which an antenna is mounted affects both the azimuthal and elevation patterns.
- A hilltop is highly sought after for radio work because the reflections are either reduced or are more likely to reinforce the signal at low takeoff angles.



Living on a Slope

Pg. 9-10

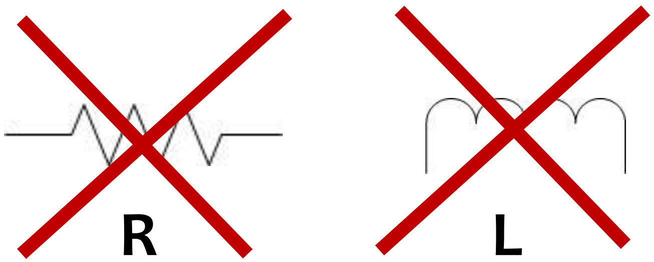
* Hills and slopes have an effect on both the azimuthal and elevation patterns.
* The major takeoff angle will typically be lower in the direction of the slope.



Grounding

Pg. 9-10

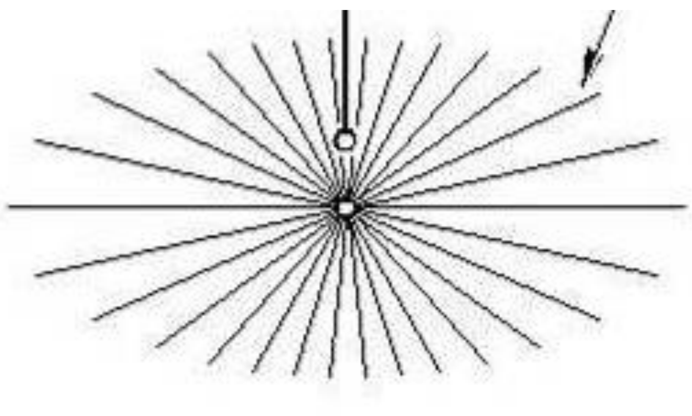
- The object is to create a path to ground that has as little impedance as possible.
- Wide flat copper straps are best for minimizing losses and the impedance of the stations RF ground system.



Grounding

Pg. 9-10

* Three or four interconnected ground rods make a good RF ground.
  * Full 8 foot rods are not required
* Or use radials

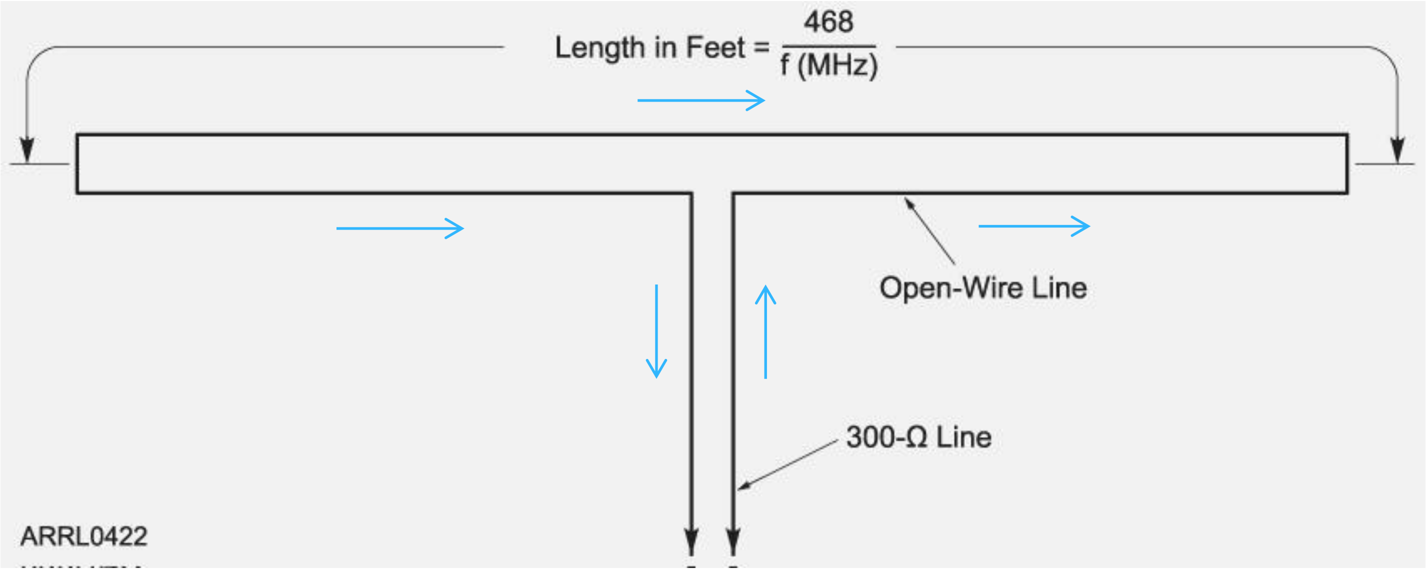


W3yy.com

Folded Dipole

Pgs. 9-11

* 1-wavelength long wire that is formed into a very thin loop.
* The feed point is close to **300 ohms**
  * Compatible with twin lead feed lines.



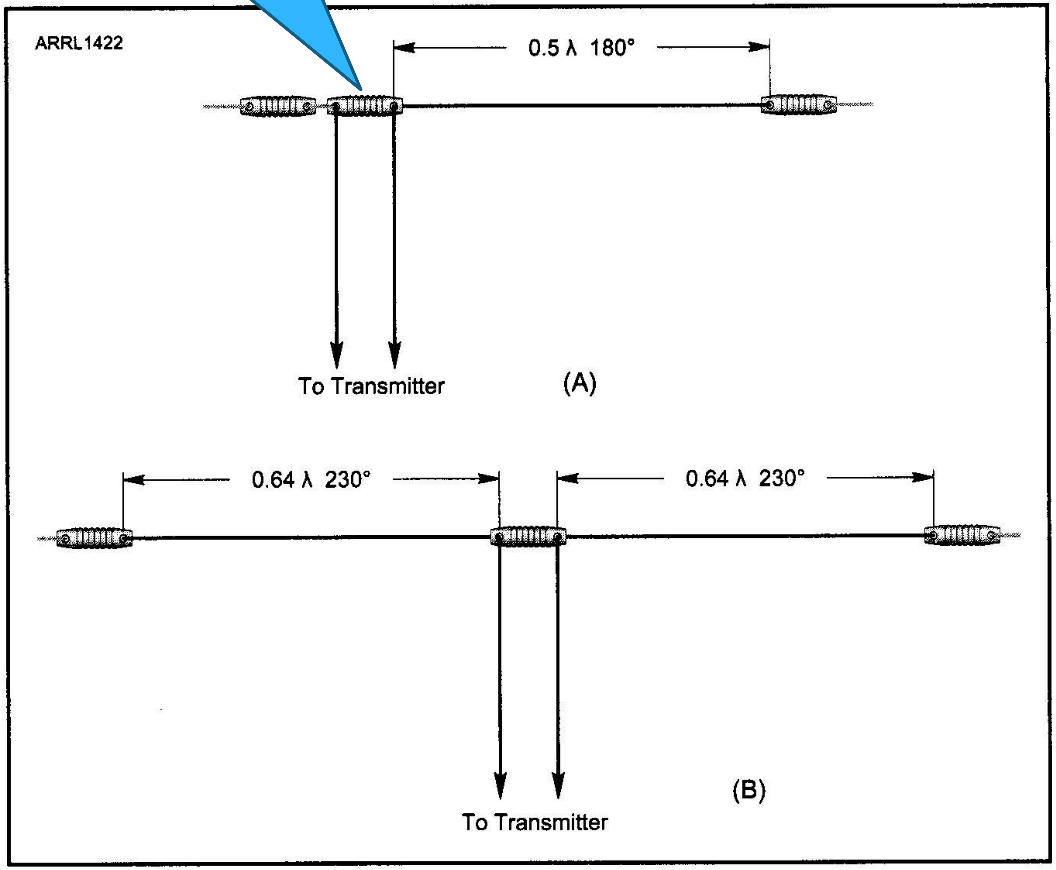
Zepp Antennas

Pgs. 9-12

Very high Impedance

* The Zepp is simply a halfwave dipole fed at the end with open wire feeder.

* An Extended Double Zepp is 1.25 wavelengths long and fed in the center
  * This lowers the feedpoint impedance

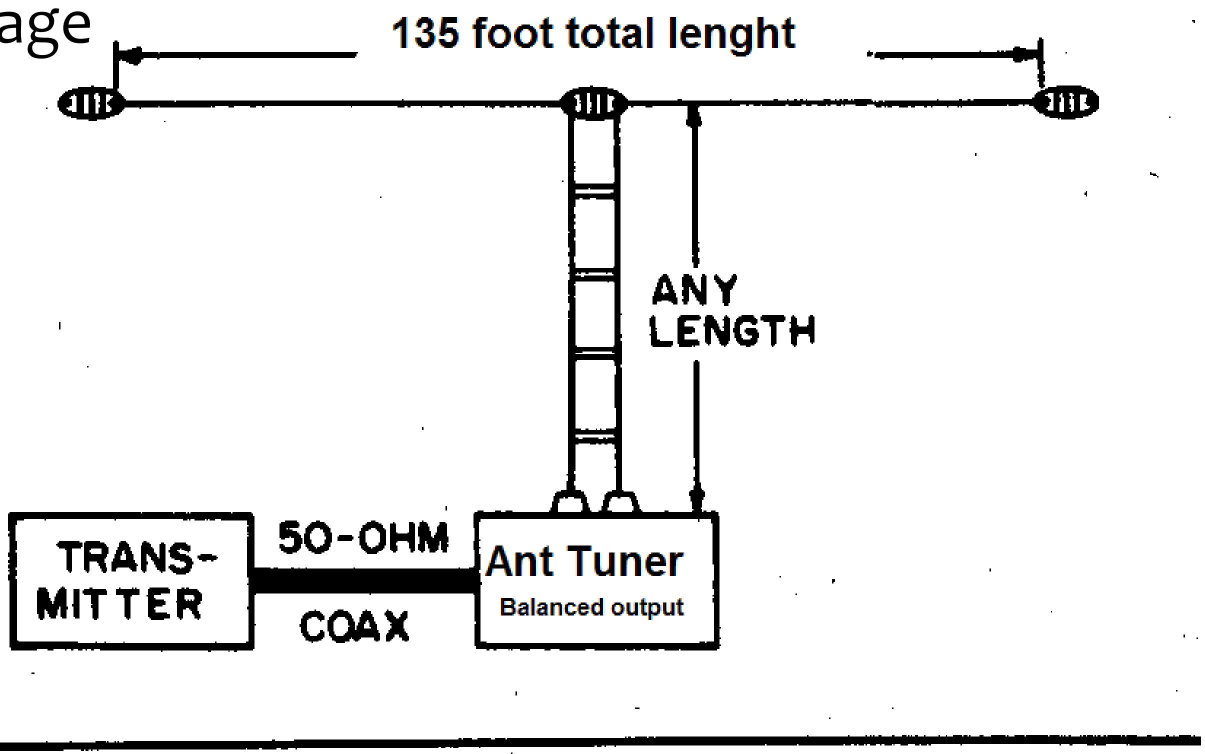


80m Dipole Fed with Ladder-line

May also be called a Zepp

KONK's Favorite

* Requires an antenna tuner with a balanced output
* 80 – 10 meter coverage



—A center-fed antenna system for multiband use.

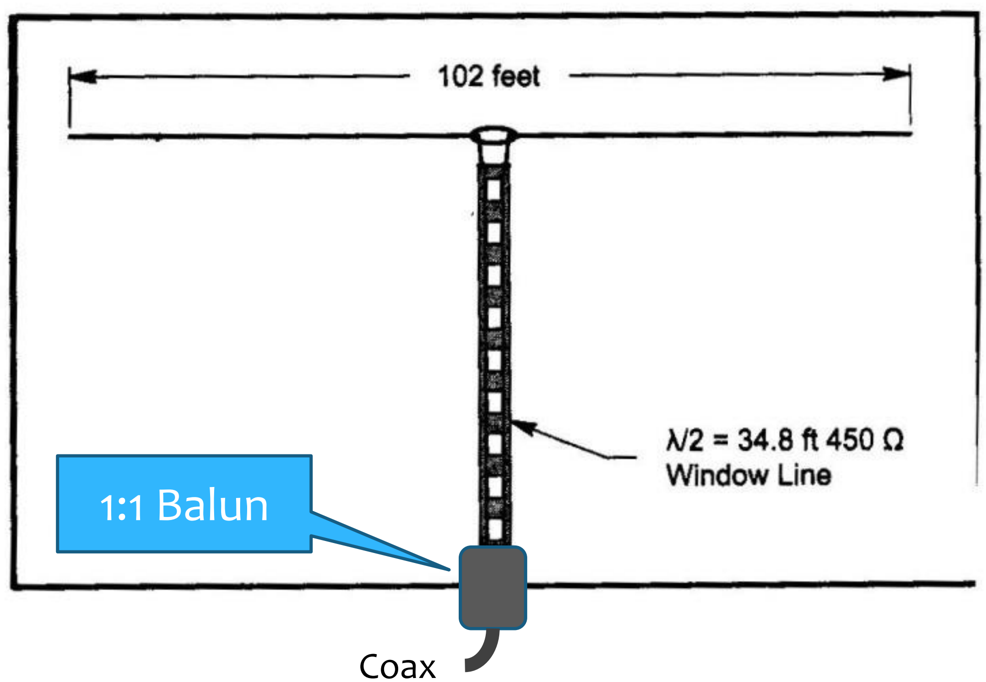
G5RV Antenna

Pgs. 9-13

* A center fed dipole (102 ft long) fed with open wire line and a 1:1 Balun that attaches to 50-Ohm coax.

* Often used as a multi-band antenna for 80m through 10 m.

* Requires an antenna tuner for most bands.

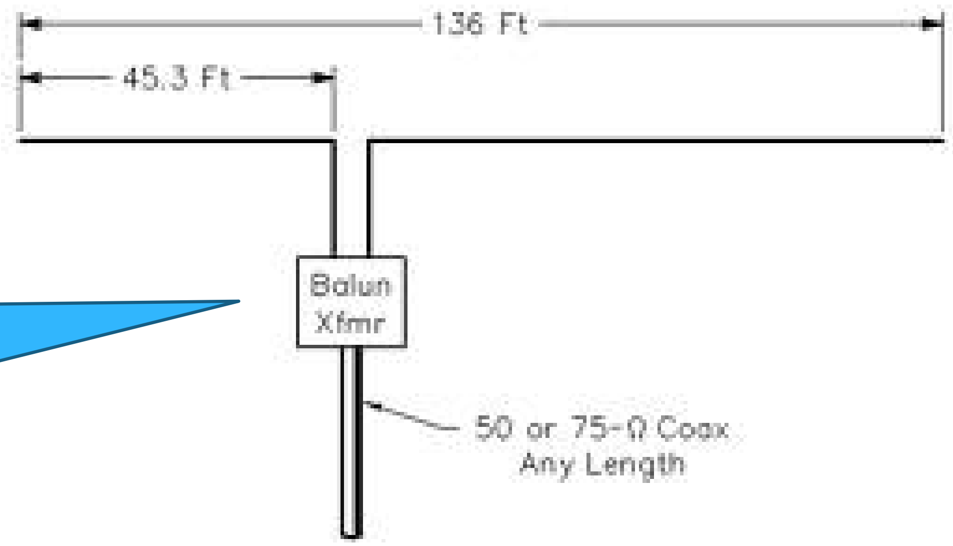


Off-Center-Fed Dipole

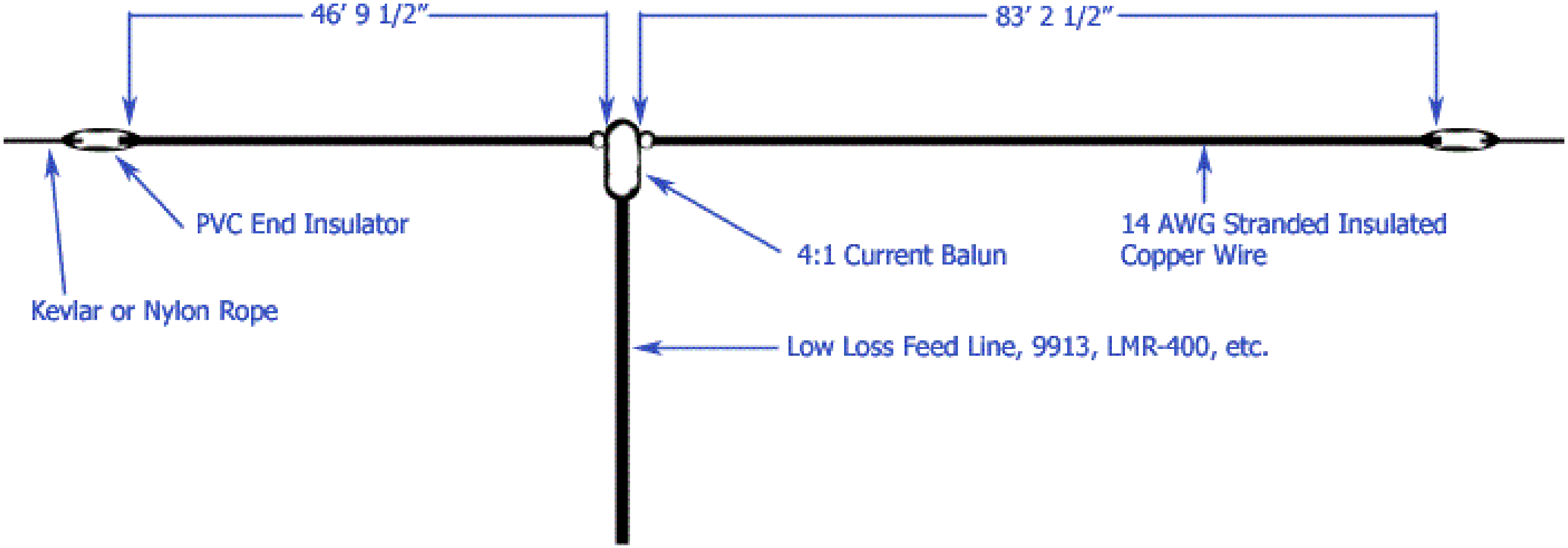
Pgs. 9-13

* An off-center fed dipole fed aproximatley 1/3 way from the end with a 4:1 Balun.
* The feed point impedance is in the **150 - 300** ohm on multiple bands.

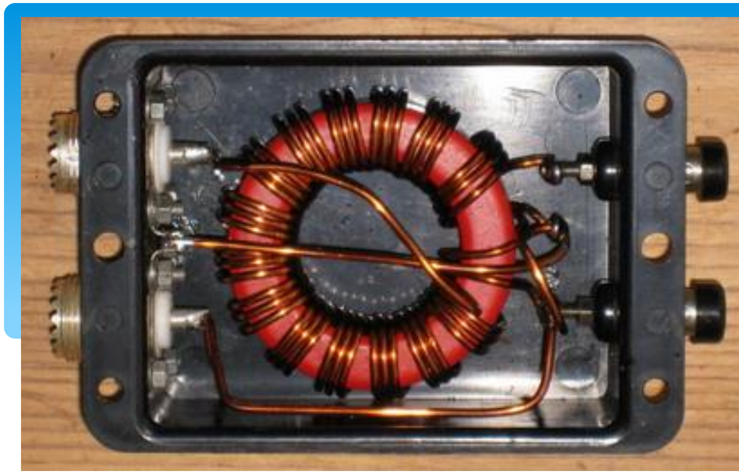
The balun will transform the 150 – 300 ohms down to a value closer to 50 ohms



Off-Center-Fed Dipole (Windom)



- 80, 40, 20, 17, 12, & 10 meter typical.
- A tuner may be required.
- Some designs use ~80/20 ratio instead of 66/33



Balun

- A **balun** is usually a transformer-type device that is generally mounted at the feedpoint of the antenna.
- It can be used to **step up or step down an impedance**.
  - Common impedance ratios are: **1:1**, **4:1** and **9:1**
- They match between a **bal**anced antenna (dipole) and an **un**balanced feed line (coax).
  - A balun can force the currents or voltages to be equal at the feedpoint in both legs of the antenna.
- The balun also isolates the coax from the antenna, so that the coax does not radiate.

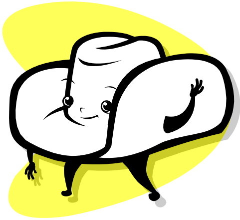
Shortened Multiband Antennas

(Mobile Whips)

Pgs. 9-14

As the frequency of operation is lowered for a short whip antenna, the:

* Radiation resistance will go down
* The capacitive reactance will increase



Both of these will increase the SWR

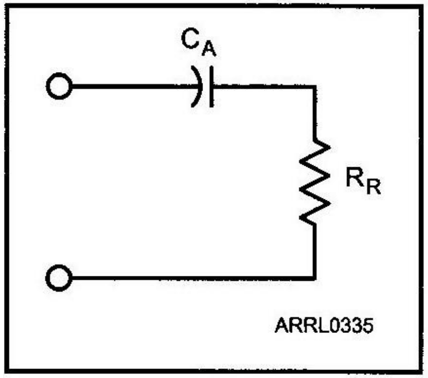


Figure 9-11 · At frequencies below its resonant frequency, the feed point impedance of a whip antenna can be represented as a capacitive reactance, C_A, in series with the antenna's radiation resistance, R_R.

Shortened Multiband Antennas
(Mobile Whips)

Pg. 9-14

* To tune out the capacitive reactance and resonate the antenna, a series inductive reactance, or loading coil, is used.
  * Remember, resonance occurs where the feed point is purely resistive.
* But the use of a loading coil reduces the SWR bandwidth.

Top Loading

Center Loading

Base Loading

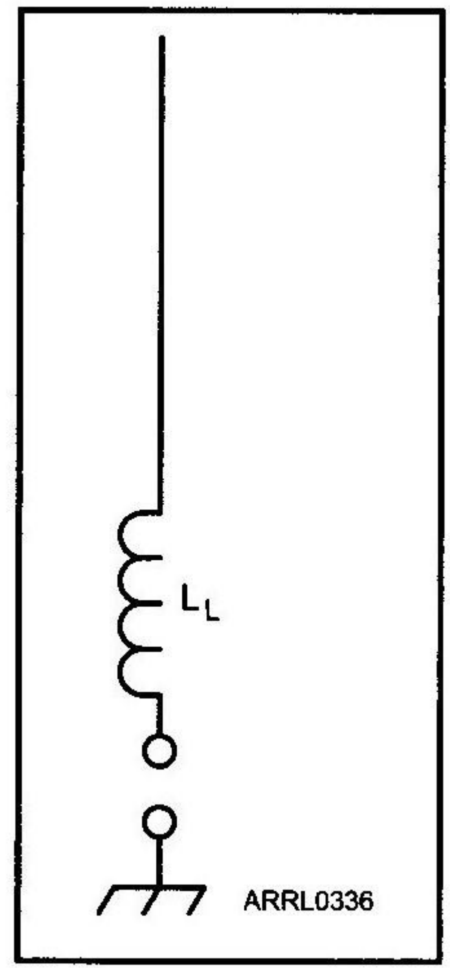


Fig 9-12

Center Loading

Pg. 9-14

* An advantage of placing the loading coil at least part way up the whip is that the current distribution along the whip is improved.
* Center loading offers the best compromise for minimizing losses in an electrically short vertical.
* Loading coils should have high Q for low loss.

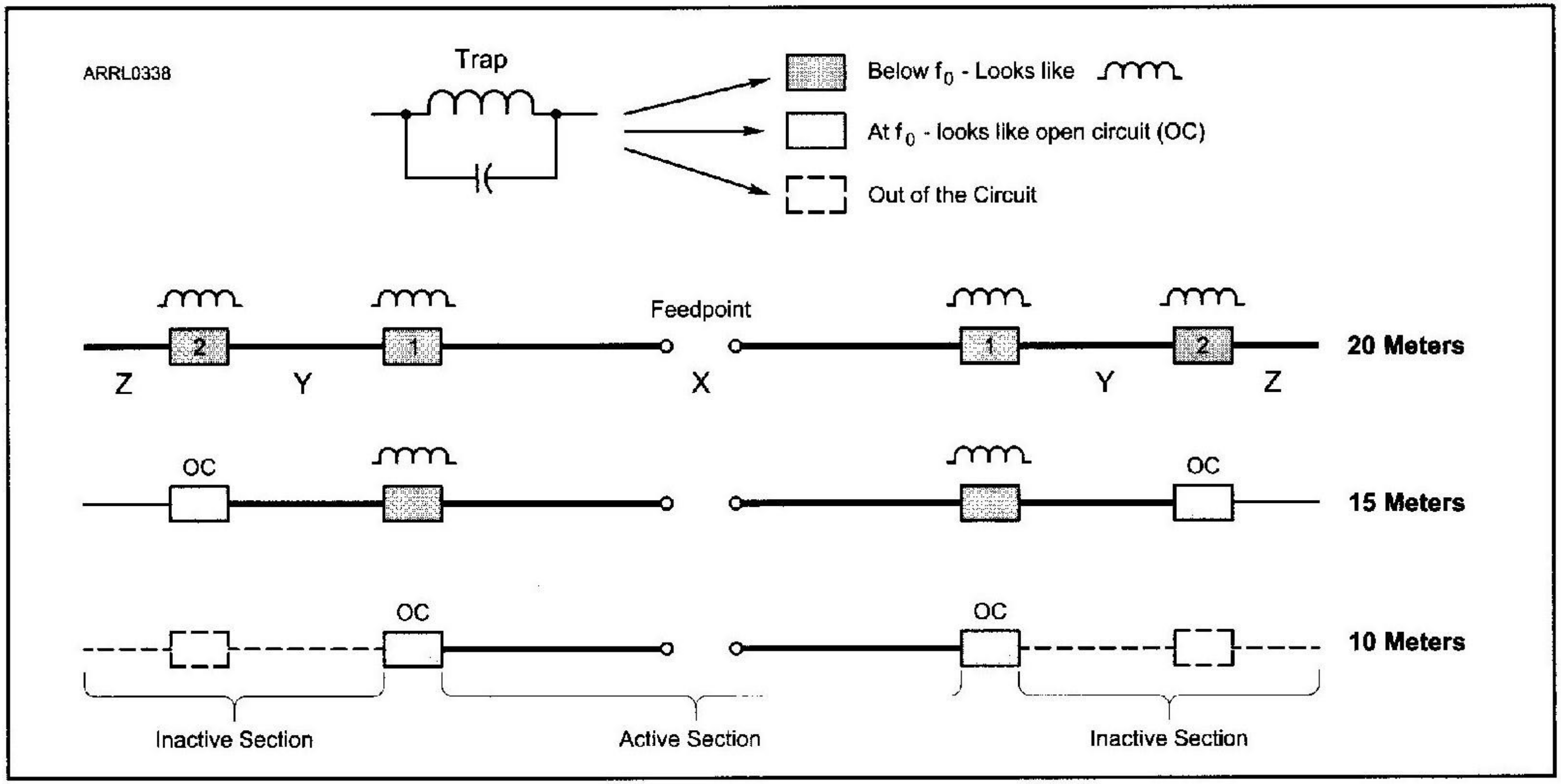
Capacity Hat

Pg. 9-15

* Top loading with a **capacity hat** improves the system's radiation efficiency.
  * Reduces the required inductance of the coil
  * Increases the SWR band width

www.w5nig.com

Trap Antennas



— A tri-band antenna for 20, 15 and 10 meters can be constructed using traps. On the resonant band for each trap, it acts like an open-circuit, isolating the outer portions of the antenna. Below resonance, the trap is inductive, acting as a loading coil.

- Traps strategically placed in a dipole can be made to resonate at a number of different frequencies.

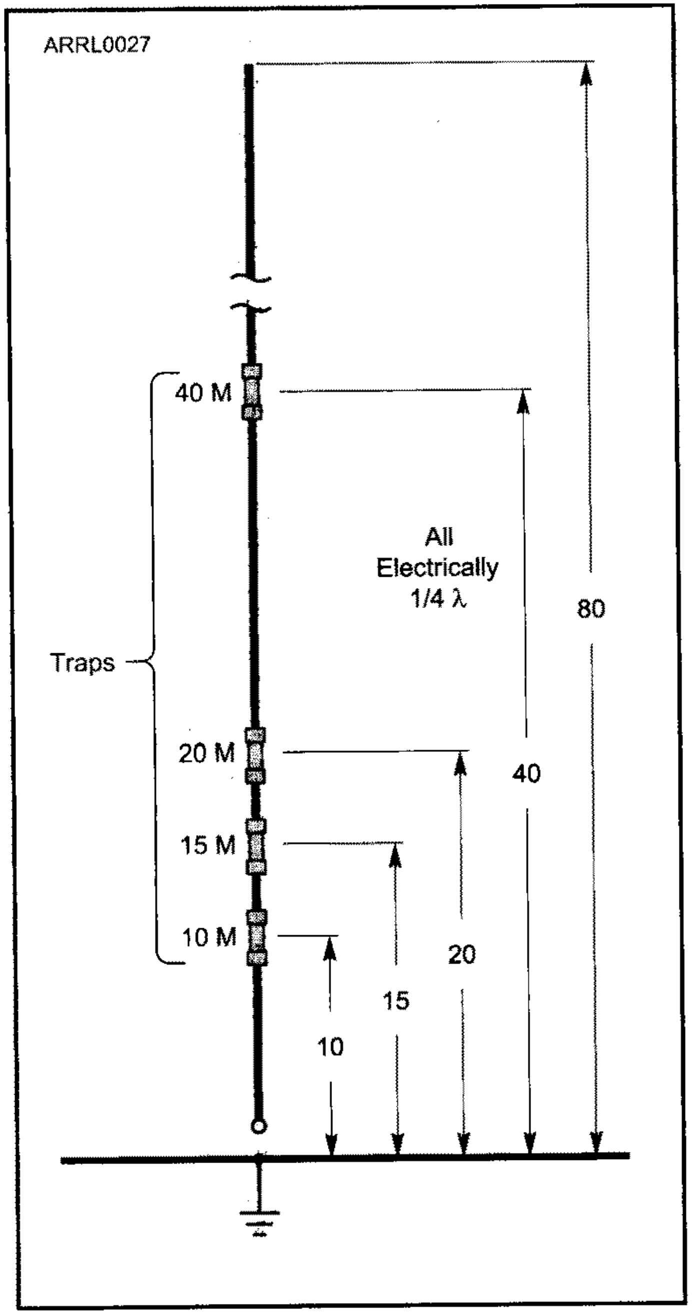
Trap Antennas

Trap Vertical

Pgs. 9-16

Disadvantages:

* They also do a good job of radiating any harmonics from the transmitter.
* The SWR bandwidth will be lower.
* Requires high-Q coils to minimize the loss.



Traveling Wave Antennas

Long Wire

Pg. 9-17

* The Traveling wave antenna is the *long-wire* antenna
  * Greater than long 1λ
* The longer the wire, the closer to the wire the major lobes become

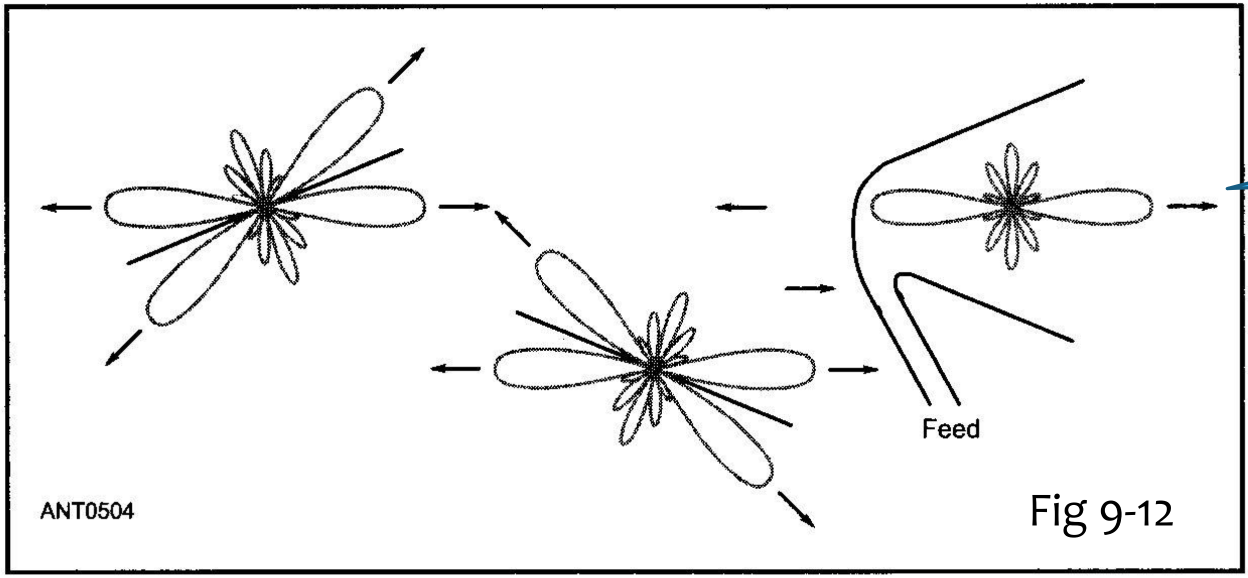


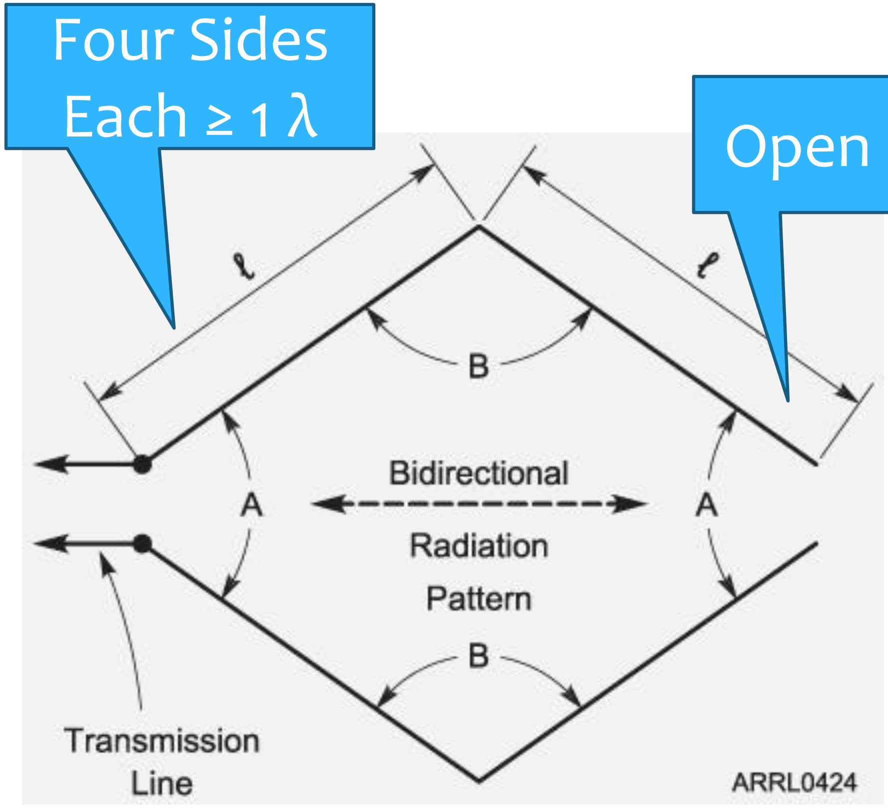
Fig 9-12

Vee Beam

Rhombic Antennas

Pg 9-17

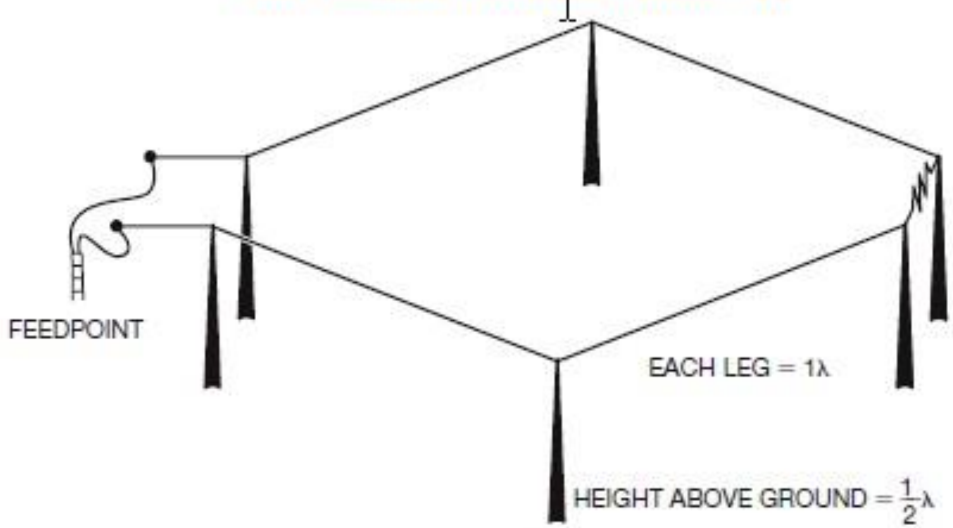
* **They are huge!**
* High-gain antennas that may be used over a wide frequency range.
* Two types:
  * Resonant (non-terminated)
  * Non-resonant (terminated)



Resonant (non-terminated) is bidirectional

Rhombic Antenna

Non-Resonant Rhombic Antenna



The non-resonant rhombic antenna will use a non-inductive resistor to terminate the opposite end from the feedpoint. Feedpoint impedance is typically 600-900 ohms. The terminating non-inductive resistor should be around 800 ohms. The non-resonant rhombic radiates in a substantially uni-directional path toward the terminating resistor. But like its brother, the non-resonant rhombic requires plenty of real estate plus multiple poles to keep each leg absolutely straight.

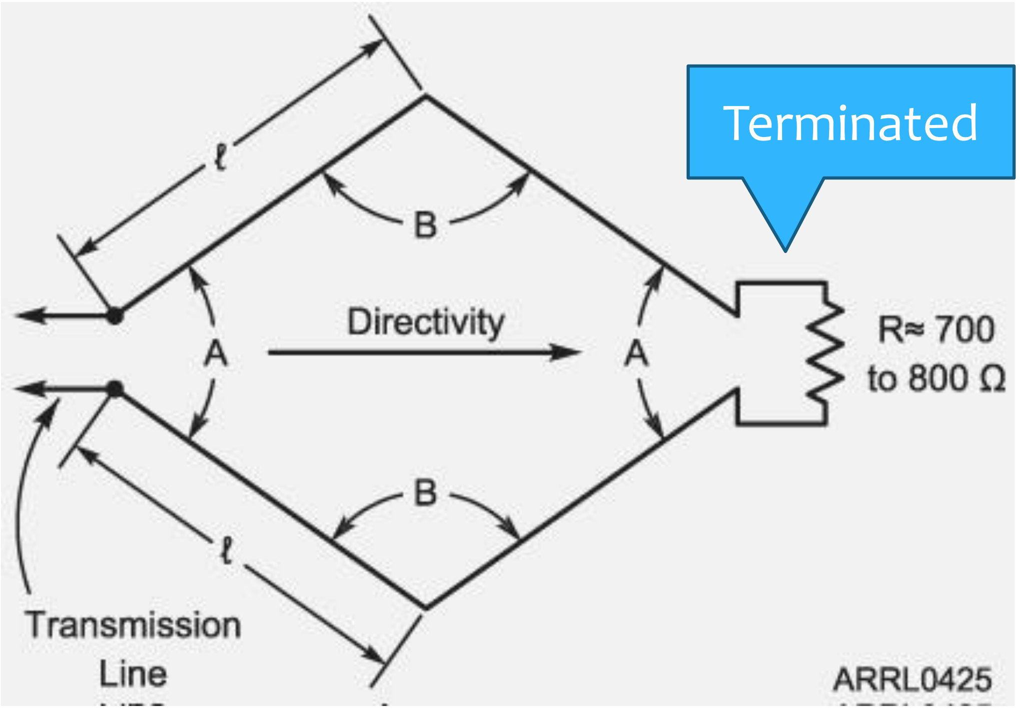
Gordon West

Rhombic Antenna

Non-resonant -- Terminated

Pg 9-17

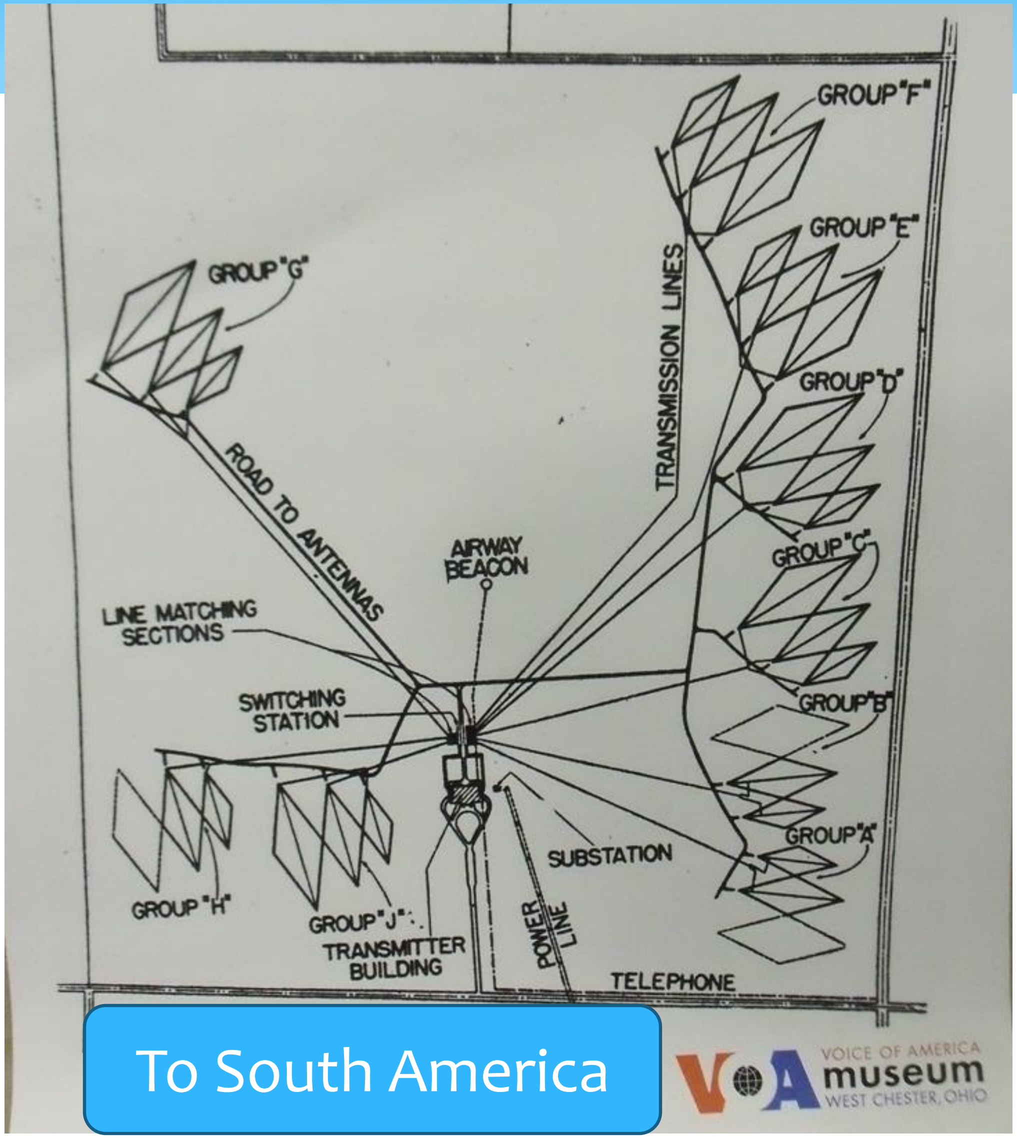
* The terminating resistor causes the antenna to be unidirectional.
* Offers a resistive and constant load over a wide frequency range.
* All rhombics require a large area and 4 sturdy supports.



Non-resonant (Terminated) -- Unidirectional

Voice Of America Museum
West Chester Ohio

VOA Rhombic Antenna Farm



To Europe

To Africa

To South America

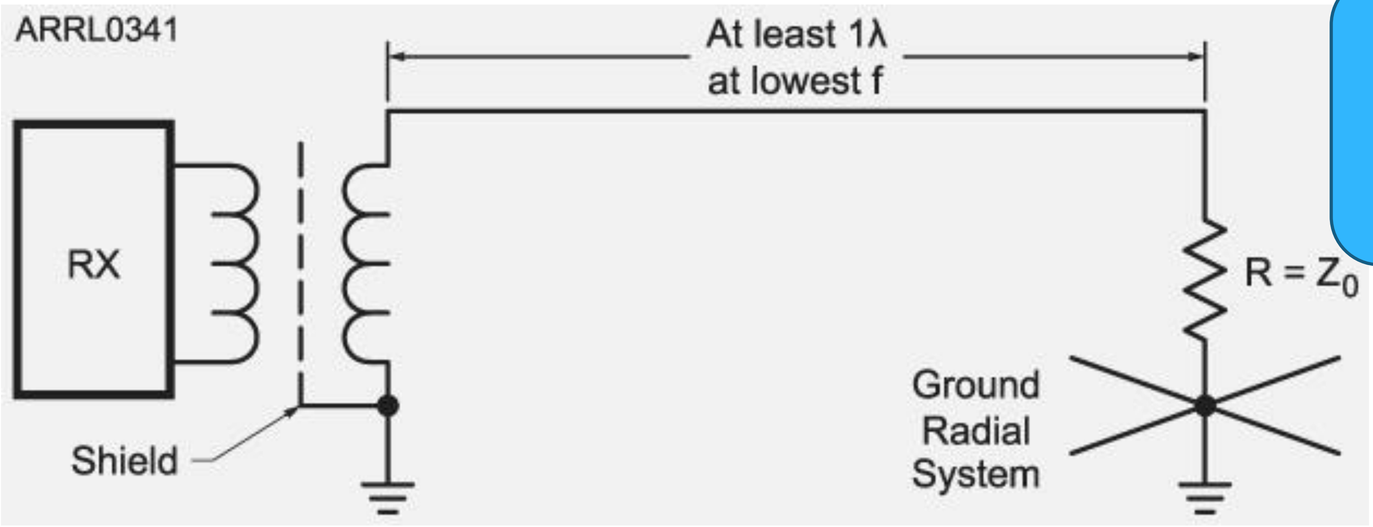
Antenna Switches – VOA Style

Beverage Antenna

Low-noise **Receiving** Antenna

Pg. 9-18

* A straight wire, 8 – 10 feet above the ground
* At least one wavelength long at the lowest frequency
  * Longer antenna provide increased gain and directivity
* Requires a terminating resistor on the far end



This is a lossy antenna – but it rejects noise very effectively

Phased Arrays

Verticals

* A) A single vertical with peaks and nulls in the radiated field.
* B) The radiated field with two phased verticals.
* C) The resultant radiation pattern.

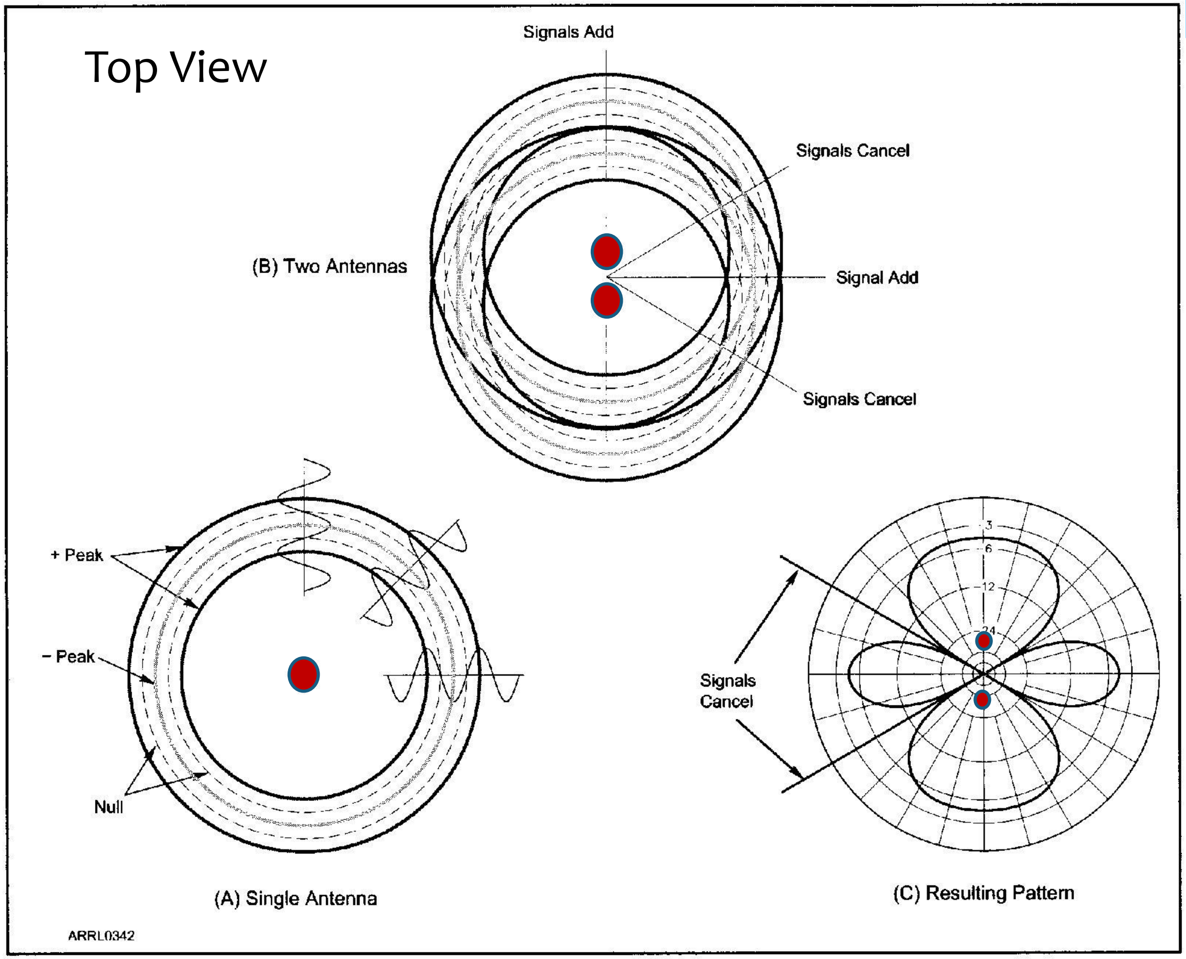
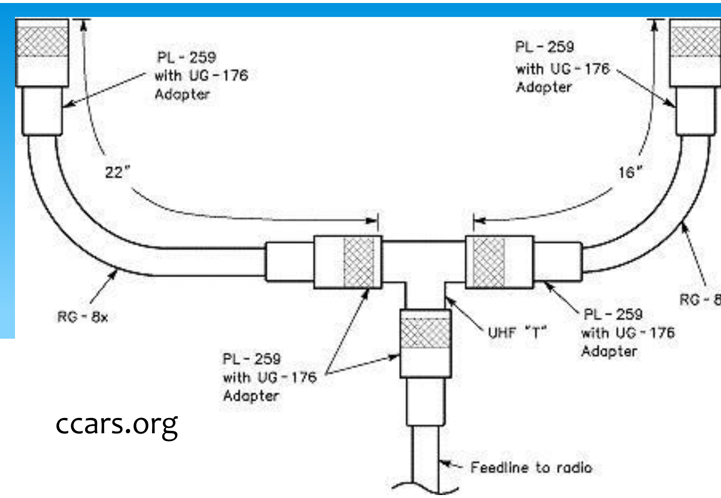


Figure 9-15 — (A) shows the signal being radiated from a single antenna with its current (I) flowing perpendicularly to the page. At (B) a second antenna has been added and the radiated signals reinforce and cancel along different directions, leading to the radiation pattern for the array in (C).

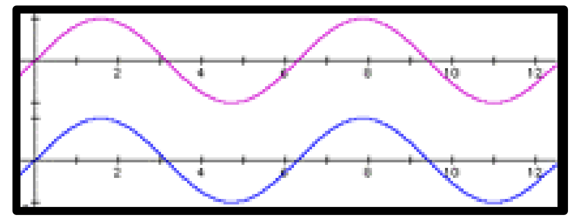
Phasing



ccars.org

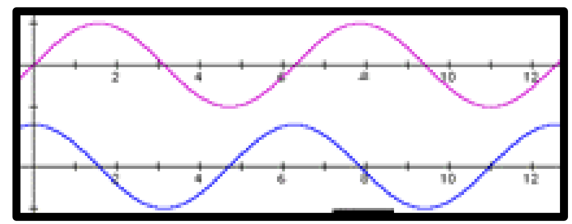
* IN PHASE
  0 degrees

$\Phi = 0°$



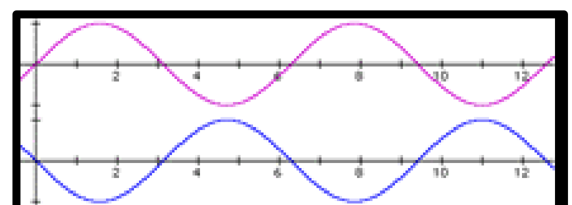
* 90 degrees
  out of phase

$\Phi = 90°$



* 180 degrees
  out of phase

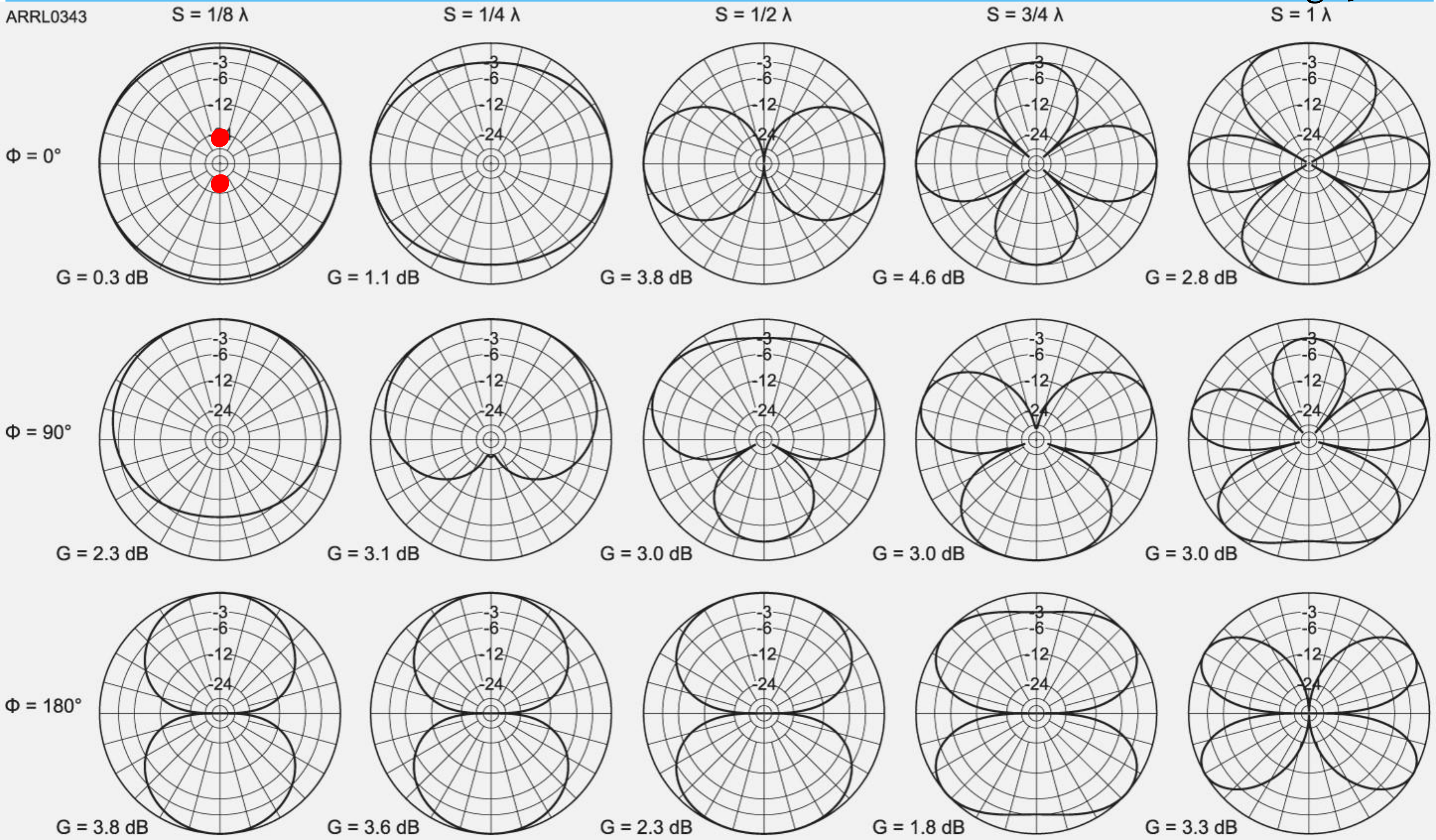
$\Phi = 180°$



Φ is the Greek Letter Phi

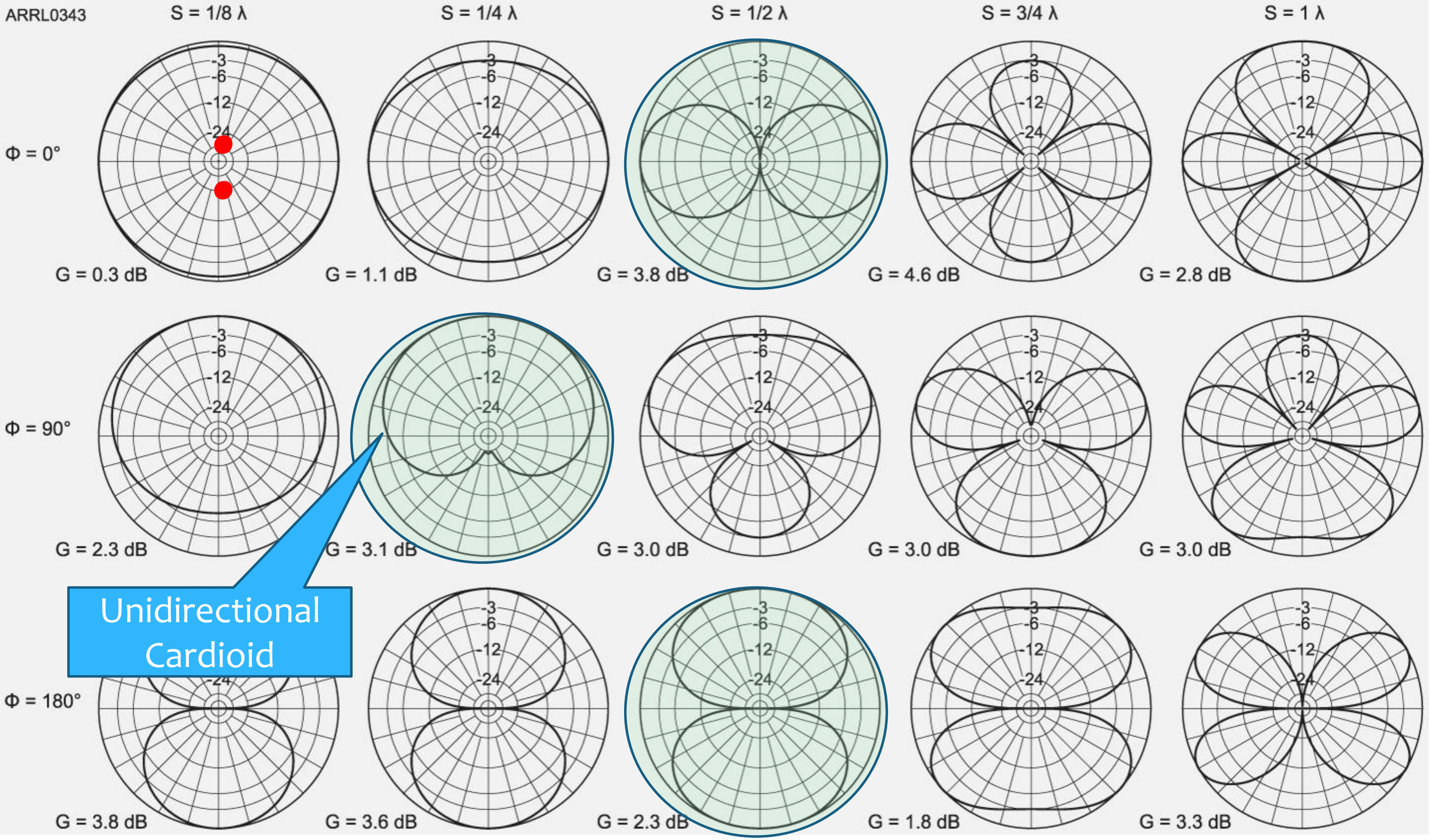
Two-Vertical Radiation Pattern

Pg. 9-20



Two-Vertical Radiation Pattern

Pg. 9-20

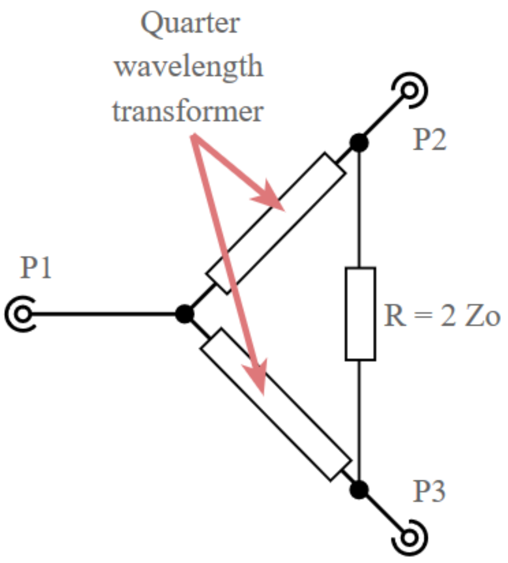


Phased Verticals

Pg 9-21

- These antennas are fed with **phasing lines** to **create the desired pattern**.
  - The lines are of a carefully calculated and measured lengths
  - Tends to make them single band arrays.

- To develop two in-phase signals, a **Wilkerson Divider** can be used to split the power into equal portions while preventing changes in the loads from affecting the power flow to the other loads.



Wilkerson Divider
www.electronicnotes.com

Satellite Antenna Systems

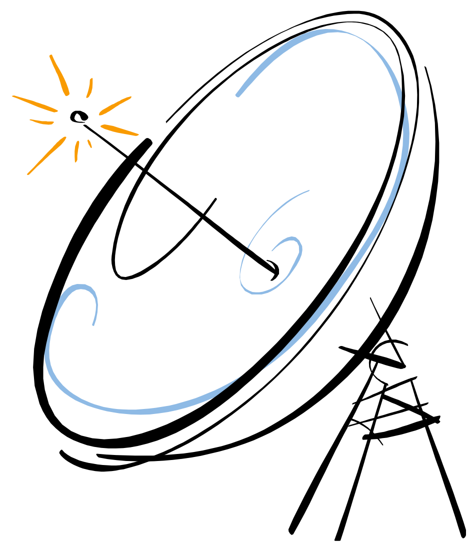
Pg. 9-22

Yagi Antennas

http://kb5v ogspot.com/

Dish Antennas

* The **gain** will be increased by 6 dB if
  * The diameter is doubled
  * The **frequency is doubled**

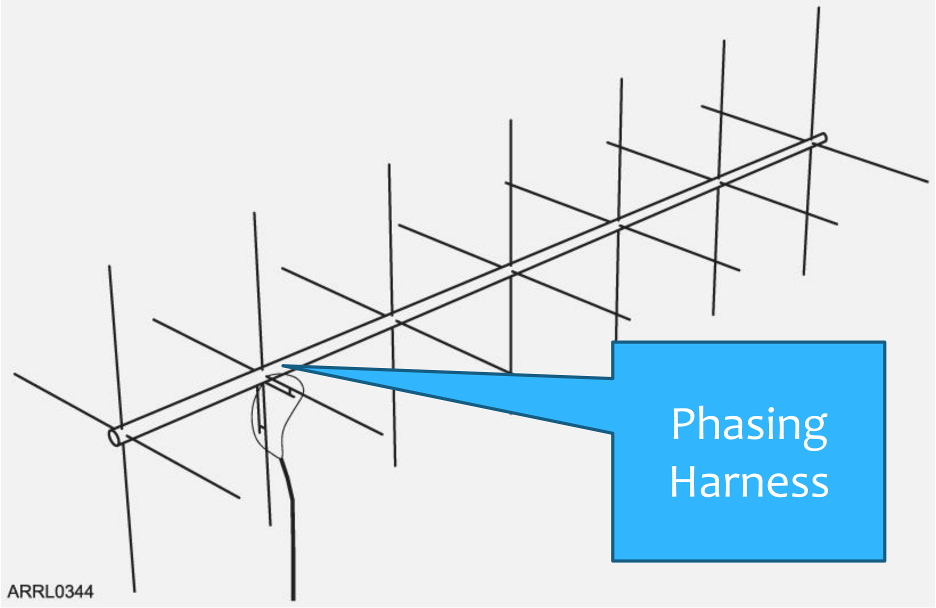


The rotor varies **both** the **azimuth** and the **elevation** to track the satellite as it orbits the earth

Polarization

Pg. 9-22

* Circularly polarized antenna are preferred for satellite work.

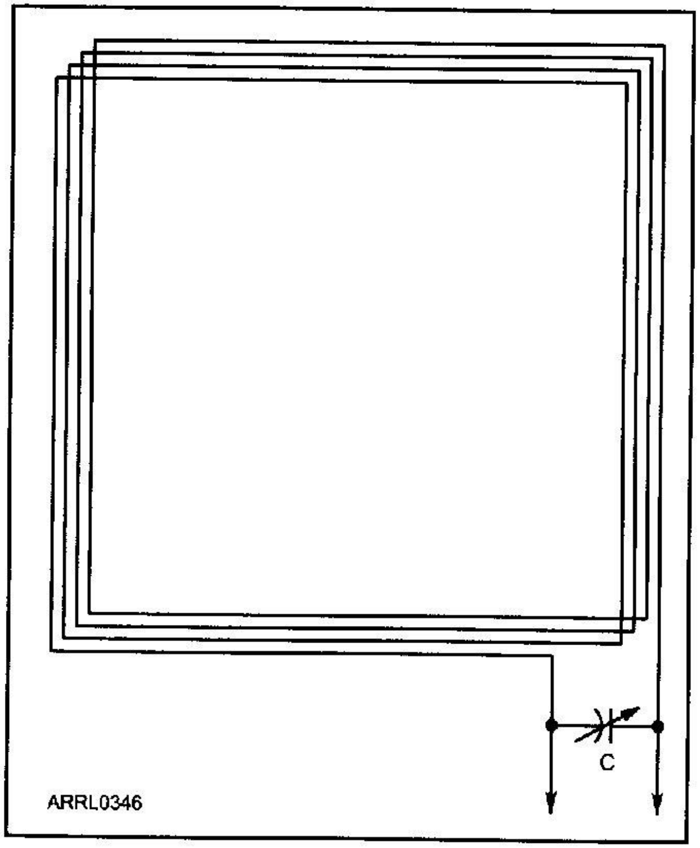


* A circularly polarized antenna can be constructed from two dipoles or Yagis mounted 90 degrees with respect to each other and fed 90° out of phase.

Receiving Loops

Pg. 9-23

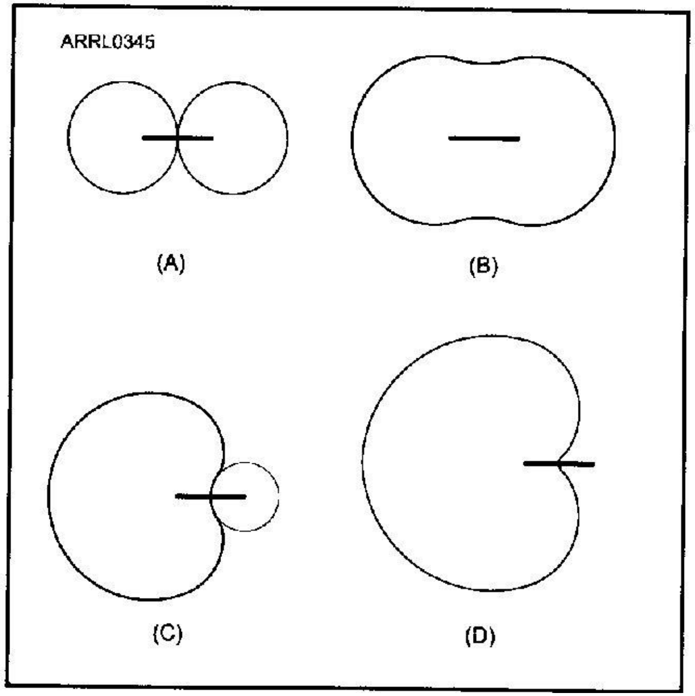
* A simple receiving antenna at MF and HF is a small loop antenna consisting of one or more turns of wire wound in the shape of a large open inductor or coil.
* Loops can provide good nulls
* The output voltage of the loop can be increased by increasing the number of turns in the loop or the loop area.



Small Loops

Pg. 9-23

* Maximum response in the plane of the loop.
* Very short: ≤ 0.08 λ
* Receives the magnetic field
* May be shielded to reduce the the electric field



Direction Finding

Fox Hunting

What you need:

* Directional antenna
* Receiver
* Attenuator to prevent overloading the receiver
  * You want to keep the desired signal rather weak
  * Tune for a null (minimum signal)

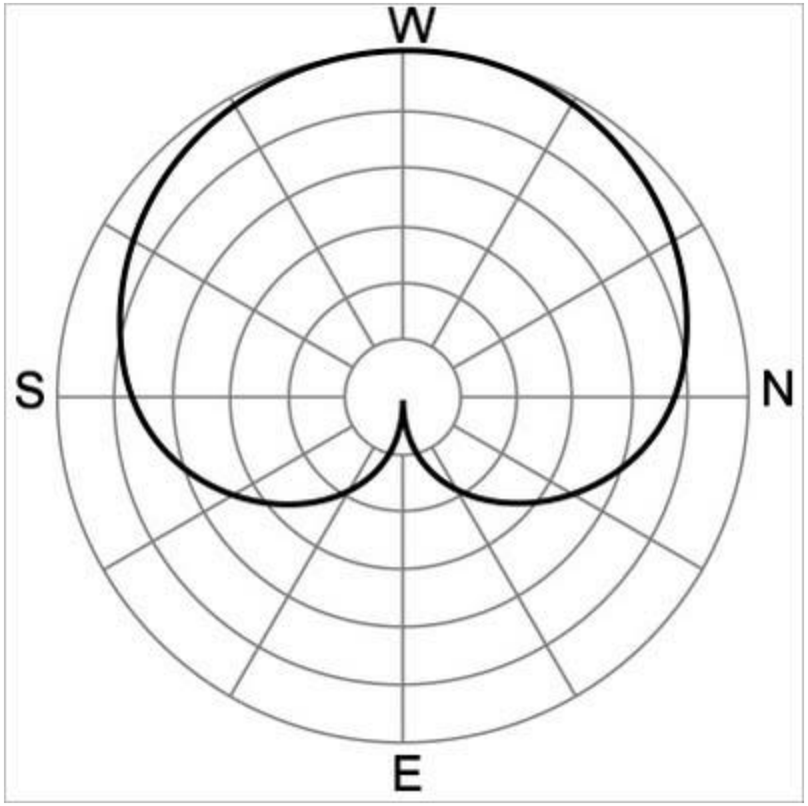
www.vk6fox.org.au

Loops

Pg. 9-24-25

tighr.org

* A shielded loop has the advantage of being electrostatically balanced with respect to ground, providing a sharper null.
* The simple wire loop is bidirectional.
* By adding a sense antenna (omnidirectional whip) a loop can be made to have only one null.
* The loop and the sense antenna combine to form a **cardioid pattern** that can have a very sharp null.



DF Techniques - Triangulation

Pgs. 9-24 & 25

* Triangulation involves making multiple measurements made at several locations separated by some significant distance.

* Where the lines cross is an *approximate* fix.

* Reflections and refractions off other structures and terrain can cause misleading results.

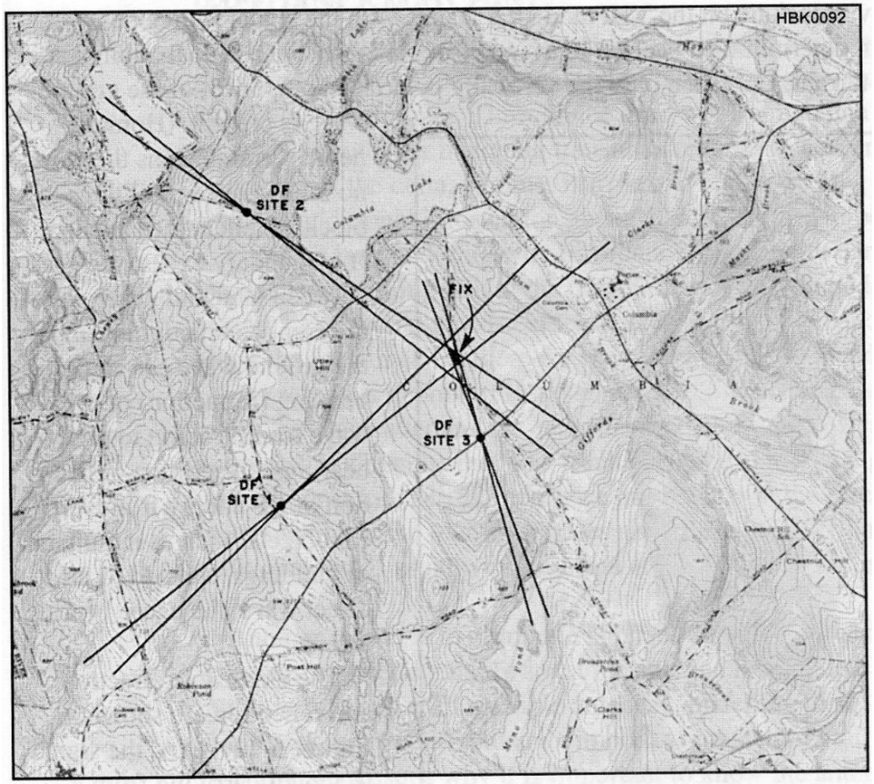


Figure 9-20 — Bearings from three RDF positions are drawn on a map to perform triangulation of a signal source. This technique allows antennas with bidirectional patterns to be used since the lines on multiple bearings will only intersect at the signal source.

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

A. Radiation resistance plus space impedance
B. Radiation resistance plus transmission resistance
C. Transmission-line resistance plus radiation resistance
D. Radiation resistance plus ohmic resistance

E9A09 How is antenna efficiency calculated?

A. (radiation resistance / transmission resistance) x 100%
B. (radiation resistance / total resistance) x 100%
C. (total resistance / radiation resistance) x 100%
D. (effective radiated power / transmitter output) x 100%

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. A electrically-short connection to 3 or 4 interconnected ground rods via a series RF choke

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

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

A. A cardioid

B. Omnidirectional

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

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

E9D10 What happens to feed point impedance at the base of a fixed-length HF mobile antenna as the frequency of operation is lowered?

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

Effective Radiated Power

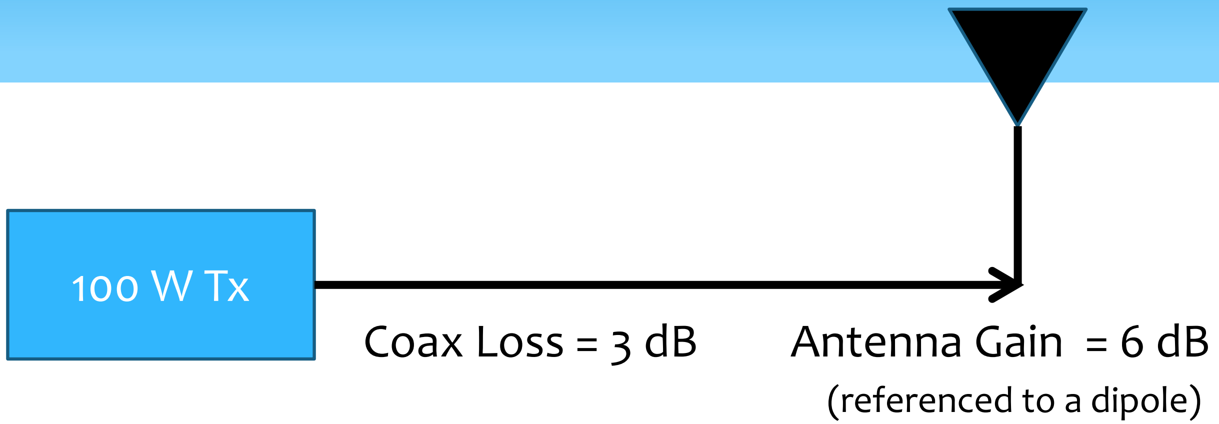
Pg. 9-26

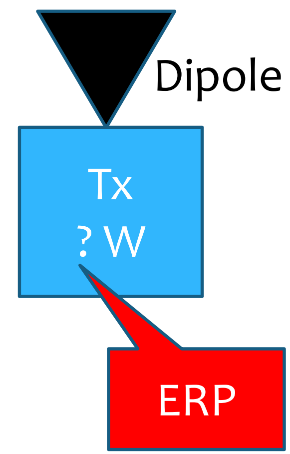
- **ERP** Effective Radiated Power (referenced to a dipole)
- **EIRP** Effective Isotropic Radiated Power
- **HAAT** Height Above Average Terrain
- **TPO** Transmitter Power Output

- **How much RF power does my station radiate as compared to that if my antenna was a simple dipole?**

Effective Radiated Power

Pg 9-26





- ERP = 100W - 3 dB + 6 dB
- ERP = 100W + 3 dB
    - (Remember, 3 dB is a doubling of power)
- ERP = 200 W
    - We are radiating the same power as a 200 W transmitter into a dipole antenna would radiate.

Effective Radiated Power

Pg 9-27

Gain in dB = 10 log p2/P1

P1/p2 = $\log^{-1}$ (gain/10)

Antilog

- ERP = TPO x System Gain (Equation 9-4A)
- ERP = TPO x $\log^{-1}$ (system gain / 10) (Equation 9-4B)

- ERP = 100W x $\log^{-1}$ (3 dB / 10)
- ERP = 100W x $\log^{-1}$ (.3)
- ERP = 100W x 2.0
- ERP = 200 W

Antilog
$\log^{-1}$
10^x

System ERP

Example 9-4

What is the effective radiated power 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? E9A15

System gain = –2 dB – 2.2 dB + 7 dBd = 2.8 dB

$$\text{ERP} = 150\ \text{W} \times \log^{-1}\left(\frac{\text{system gain}}{10}\right) = 150 \times \log^{-1}(0.28) = 150 \times 1.9 = 285\ \text{W}$$

A. 1977 watts
B. 78.7 watts
C. 420 watts
D. 286 watts

[E9A16]
200 W transmitter
System Gain of 2 dB

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

Antenna Systems
Impedance Matching

Pg. 9-29

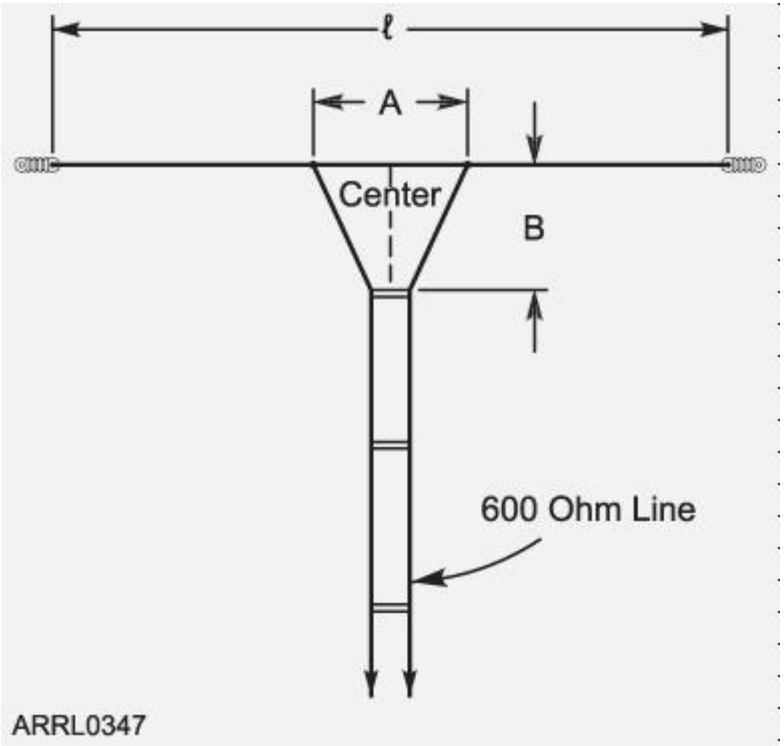
- When an antenna is matched to the feedline, maximum power transfer to the antenna is achieved and the standing wave ratio is minimized.
  - This is of benefit in both transmit and receive
- Various forms of matching the feedline to the antenna
  - Delta
  - Gama
  - Hairpin
  - Stub
  - Balun

If we know the feedpoint impedance of the antenna, we can better match impedances in order to minimize standing wave ratios on the line.

The Delta Match

Pg. 9-28

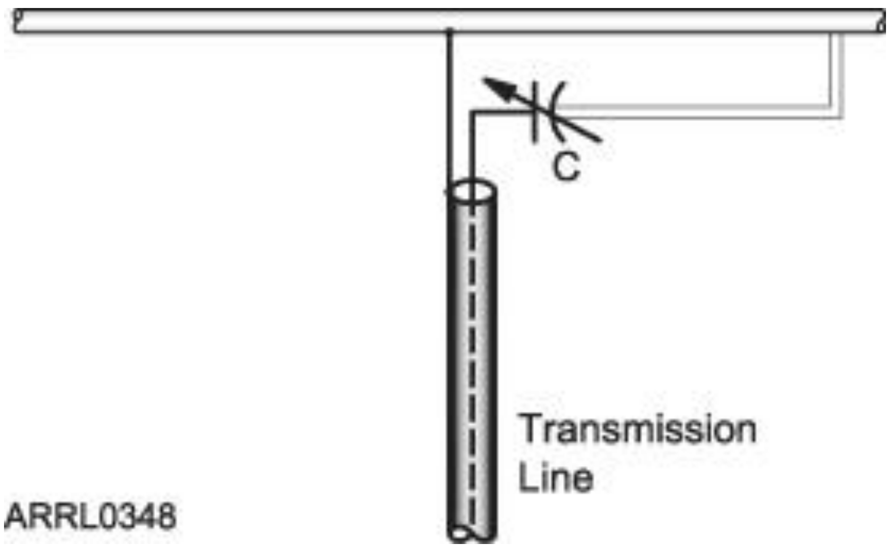
* Resembles the Greek letter delta Δ (upside down).
* The line connects to the driven element in two place, spaced a fraction of a wavelength on each side of the element center.



The Gama Match

Pg. 9-29

* Resembles the Greek letter Gamma Γ
* The matching section is inductive.
* The reactance must be tuned out to present a good match to the transmission line

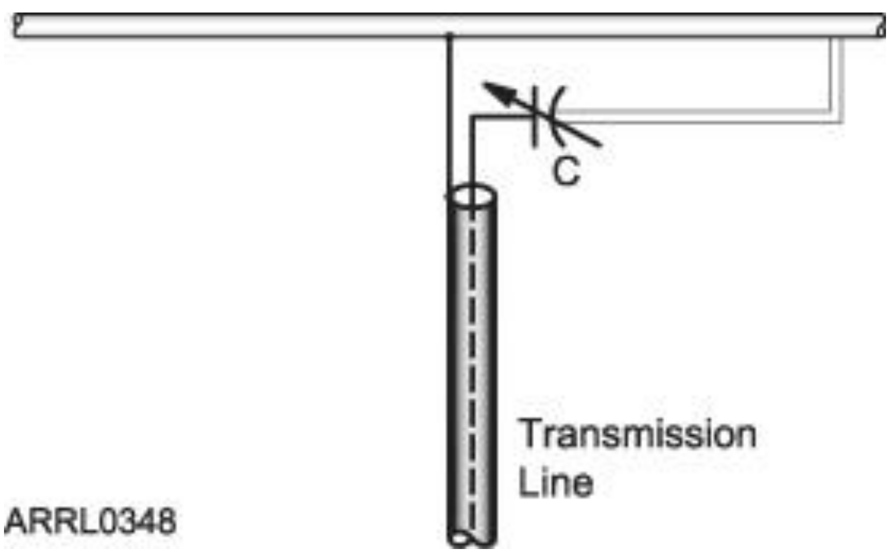


The Gama Match

Pg. 9-30

- The gamma match gives us a way to match the unbalanced feedline to an antenna.

- Capacitive reactance can be added in series to cancel out the inductive reactance.



The Gamma Matched Tower

Pg. 9-30

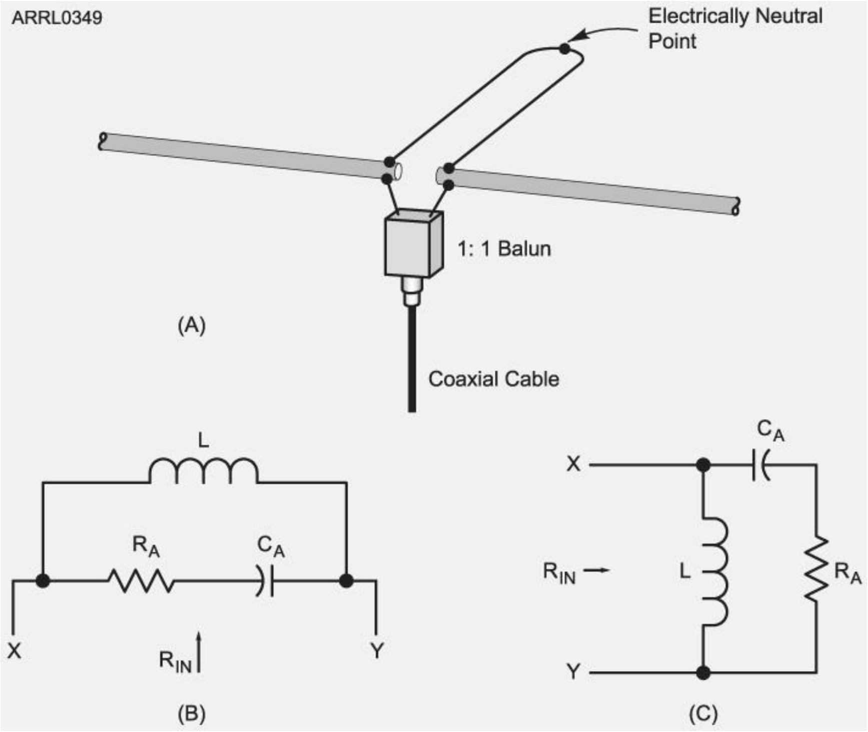
* Gamma matches can also be used to match the impedance at the base of a grounded towed to be used as a vertical antenna.
* In this application the driven element is turned on its side and the missing half of the antenna is provided by the ground system.

www.iv3prk.it

The Hairpin Match

Pg. 9-30

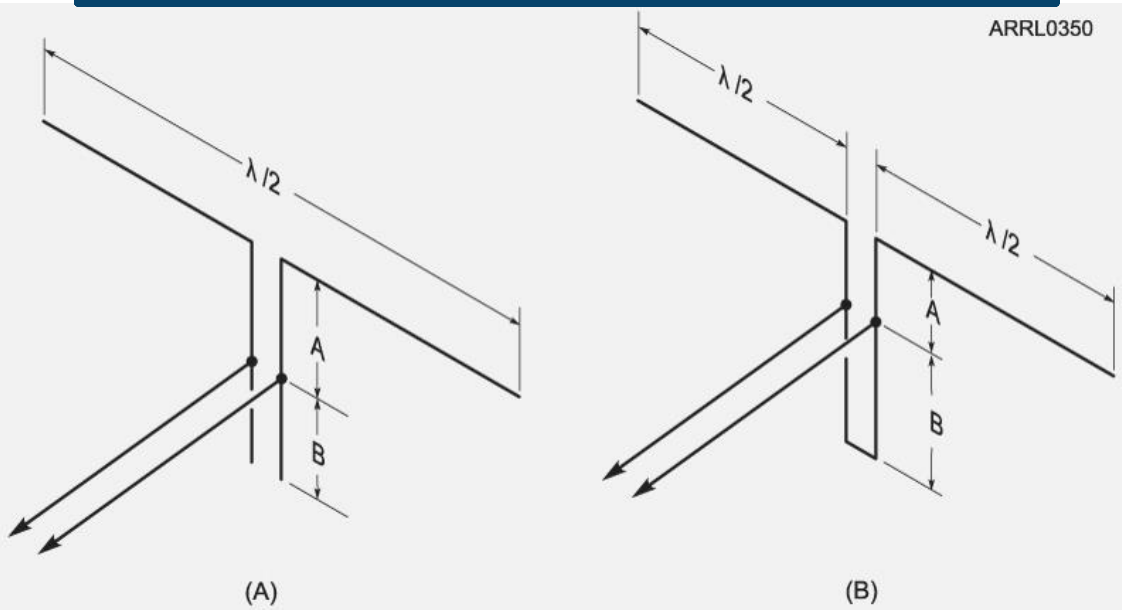
* The driven element is tuned so it has a capacitive reactance at the desired operating frequency (cut a bit short).
* The hairpin's inductance cancels out the capacitive reactance.
* Viewed as an equivalent **lumped constant network**, we can see that this is the equivalent of a "L" network.



The Stub Match

They allow a feed line and antenna impedance to be matched, even if both impedances are unknown.

* We can match a transmission line to an antenna by connecting an appropriate reactance in parallel with the feed point.
  * An open stub looks like a capacitor
  * A shorted stub looks like an inductor



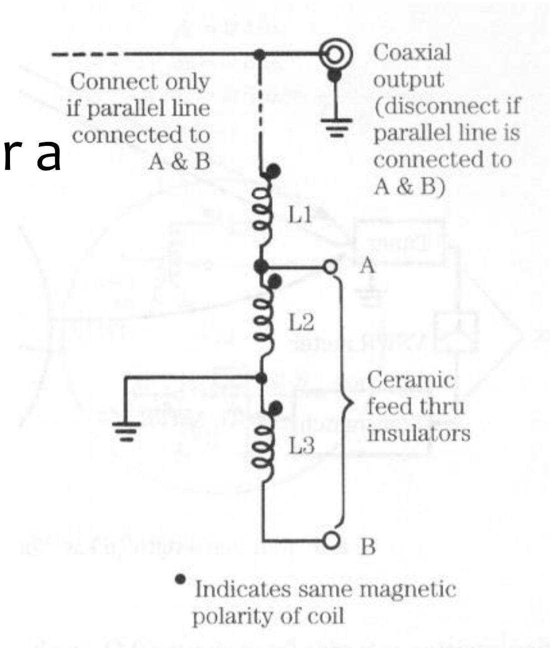
Reactances formed from lengths of transmission line are called stub matches.

The Balun Match

www.amateurradiosupplies.com/

* The previous matching techniques generally provide only single-band matching.

* The primary purpose of balun is to provide a balanced-to-unbalanced connection, often over a wide frequency range.



* A broadband balun can also provide matching over may bands. However we are generally limited to certain impedance ratios:
  - 1:1 Z ratio: 50 Ω to 50 Ω
  - 4:1 Z ratio: 200 Ω to 50Ω
  - 9: 1 Z ratio: 450 Ω to 50 Ω

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

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

E9E05 How must the driven element in a 3-element Yagi be tuned to use a hairpin matching system?

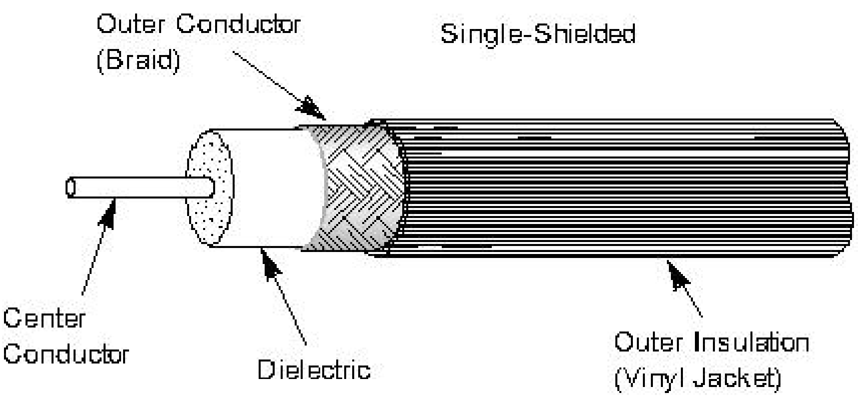
A. The driven element reactance must be capacitive
B. The driven element reactance must be inductive
C. The driven element resonance must be lower than the operating frequency
D. The driven element radiation resistance must be higher than the characteristic impedance of the transmission line

E9E06 What is the equivalent lumped-constant network for a hairpin matching system on a 3-element Yagi?

A. Pi network
B. Pi-L network
C. L network
D. Parallel-resonant tank

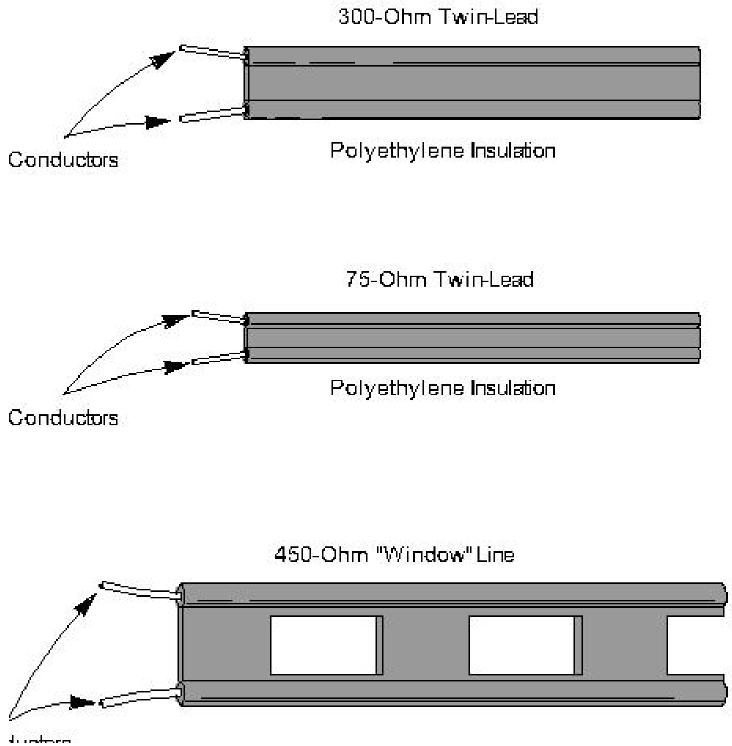
Transmission Lines

Pg 9-31



Coax

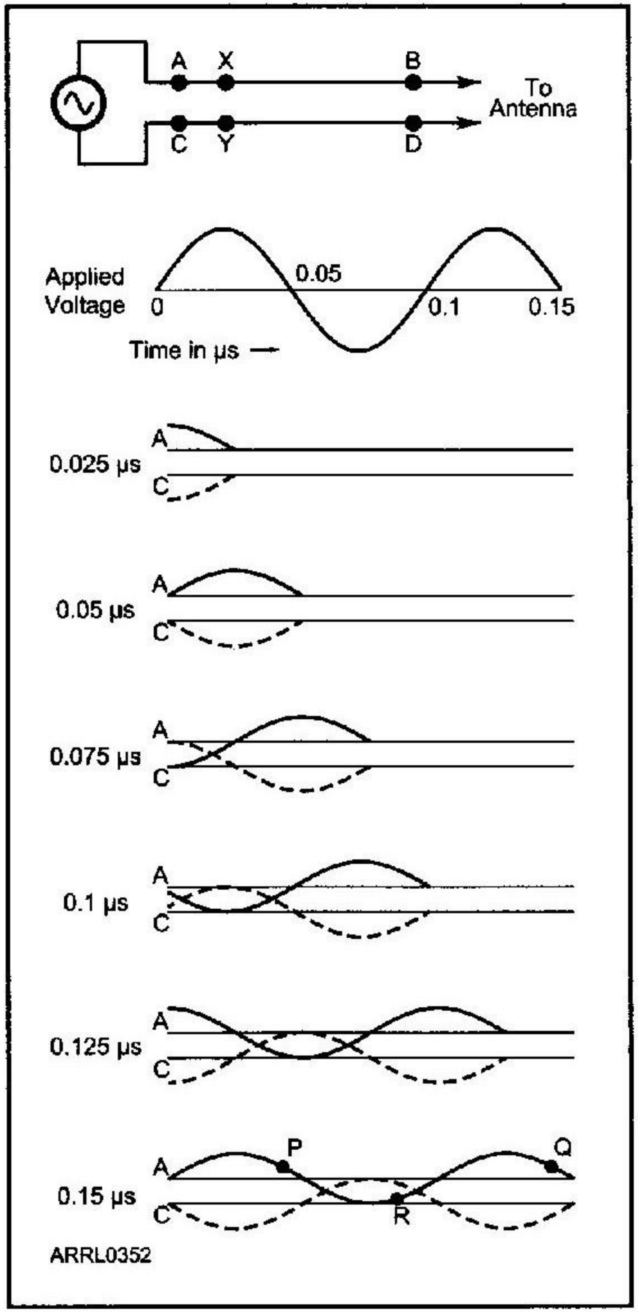
Parallel
Conductor



Current in a Transmission Line

Pg. 9-32

- The figure shows *instantaneous* current along a transmission line at successive time intervals.
- You are standing at points A & C, watching the current pass by from left to right.
- At any one point, the currents are equal and opposite in the two conductors.



Transmission Line Mechanics

Pg. 9-30 & 31

300,000,000

* Radio wave travel at 3×10^8 meters/sec thru space
* Wavelength = λ = 300 / f (in MHz)
* The presence of dielectric materials other than air reduces the velocity since electromagnetic wave travel more slowly in material other than a vacuum.
* The ratio of the actual velocity at which a signal travels along a line to the speed of light in a vacuum is called the **velocity factor (VF)**.

Wavelength vs. Electrical Length

Pg. 9-31

* The **electrical length** of a transmission line is **not the same** as its **physical length.**

* The wave move slower in the line than in the air, so the physical length will always be shorter than the electrical length.

$$\text{Length (meters)} = \text{VF} \times \frac{300}{\text{f (in MHz)}}$$

or

$$\text{Length (feet)} = \text{VF} \times \frac{984}{\text{f (in MHz)}}$$

where:

f = operating frequency (in MHz).
VF = velocity factor.

Eqns 9-7 & 9-8

Example 9-7

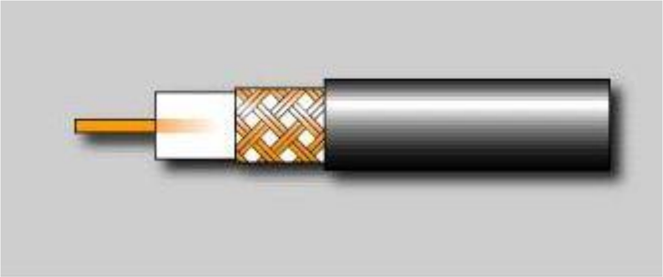
Pg. 9-33

* What would be the physical length of a typical coaxial transmission line that is electrically one-quarter wavelength long at 7.2 MHz. Assume a velocity factor of 0.66.
* $L = VF \times 300/f$
* $L = 0.66 \times \frac{300}{7.2} = 0.66 \times 41.7 = 27.5$ meters for a full λ
* To find ¼ λ, divide by 4: $27.5 / 4 =$ **6.9 meters**

Feed Line Losses

Pg 9-34

* The most common feed lines are:
  * Coax
  * Ladder line



* Open wire or ladder lines generally have lower loss than coaxial cables at any frequency.

* In a coax, the addition of air to the dielectric
  * Reduces the losses
  * Increases the velocity factor
  * But lowers the ability to handle high voltages
* This yields **foam** dielectric

Vetco.net

Coax Data

Pg. 9-33

Table 9-1

Characteristics of Commonly Used Transmission Lines

Type of Line	*Z_0 Ω*	*VF %*	*Cap. pF/ft*	*Diel. Type**	*OD inches*	*Max V (RMS)*	*Loss (dB/100 ft) at 100 MHz*
RG-8	50	82	24.8	FPE	0.405	600	1.5
RG-8	52	66	29.5	PE	0.405	3700	1.9
RG-8X	50	82	24.8	FPE	0.242	600	3.2
RG-58	52	66	28.5	PE	0.195	1400	4.3
RG-58A	53	73	26.5	FPE	0.195	300	4.5
RG-174	50	66	30.8	PE	0.110	1100	8.6
CATV Hardline (Aluminum Jacket)							
½ inch	75	81	16.7	FPE	0.500	2500	0.8
⅞ inch	75	81	16.7	FPE	0.875	4000	0.6
Parallel Lines							
Twin lead	300	80	4.4	PE	0.400	8000	1.1
Ladder line	450	91	2.5	PE	1.000	10000	0.3
Open-wire line	600	95-99	1.7	none	varies	12000	0.2

*Dielectric type: PE = solid polyethylene; FPE = foamed polyethylene

Excerpted from *The ARRL Antenna Book* (22nd edition), Chapter 23, Table 1

Reflection Coefficient and SWR

Pgs. 9-32 & 33

* Reflection coefficient and SWR are largely referring to the same thing: The mismatch between the load and the antenna.

* The reflection coefficient is a good parameter to describe the interactions at the load end of a mismatched transmission line.

SWR

SWR	% Power reflected back from the antenna	What it means
1:1	0%	Perfect Match
1.5:1	4%	Good Match
2:1	10%	Fair – Poor Match
3:1	25	Very Poor Match
4:1 or higher	38% or higher	Bad Match

Reflection Coefficient and SWR

Pg 9-34&35

* SWR values range from 1:1 (best match) to infinity (bad match)
  * For any impedance mismatch, the SWR will be greater than 1:1
  * A perfect match is 1:1
* Reflection coefficient ranges from zero (best match) to 1 (meaning that 100% of the energy is reflected).
* $p = \frac{Z_L - ZO}{Z_L + ZO}$

rho

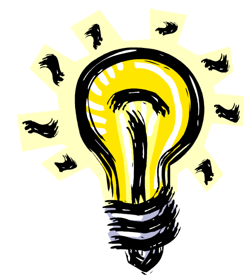
Equation 9.12

For $Z_L > Z_O$, SWR = Z_L/Z_O

For $Z_O > Z_L$, SWR = Z_O/Z_L

Power Measurement

Pg 9-35



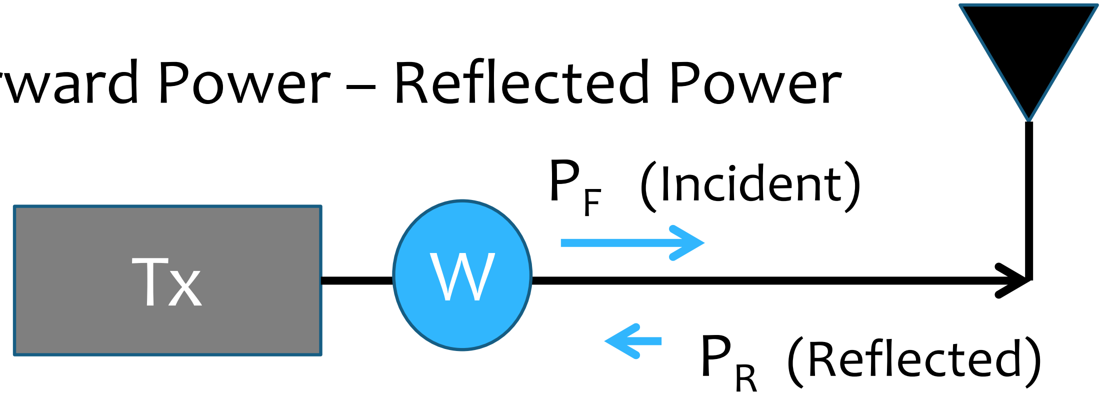
* How do you know that you have more power being delivered to the antenna as the transmitter is tuned to resonance?
* Neon bulb or fluorescent tube
  * Brighter

* RF Ammeter in series with the antenna
  * Higher current reading
* RF Wattmeter
  * Higher forward wattage

Power Measurements -- Wattmeter

Pg 9-36

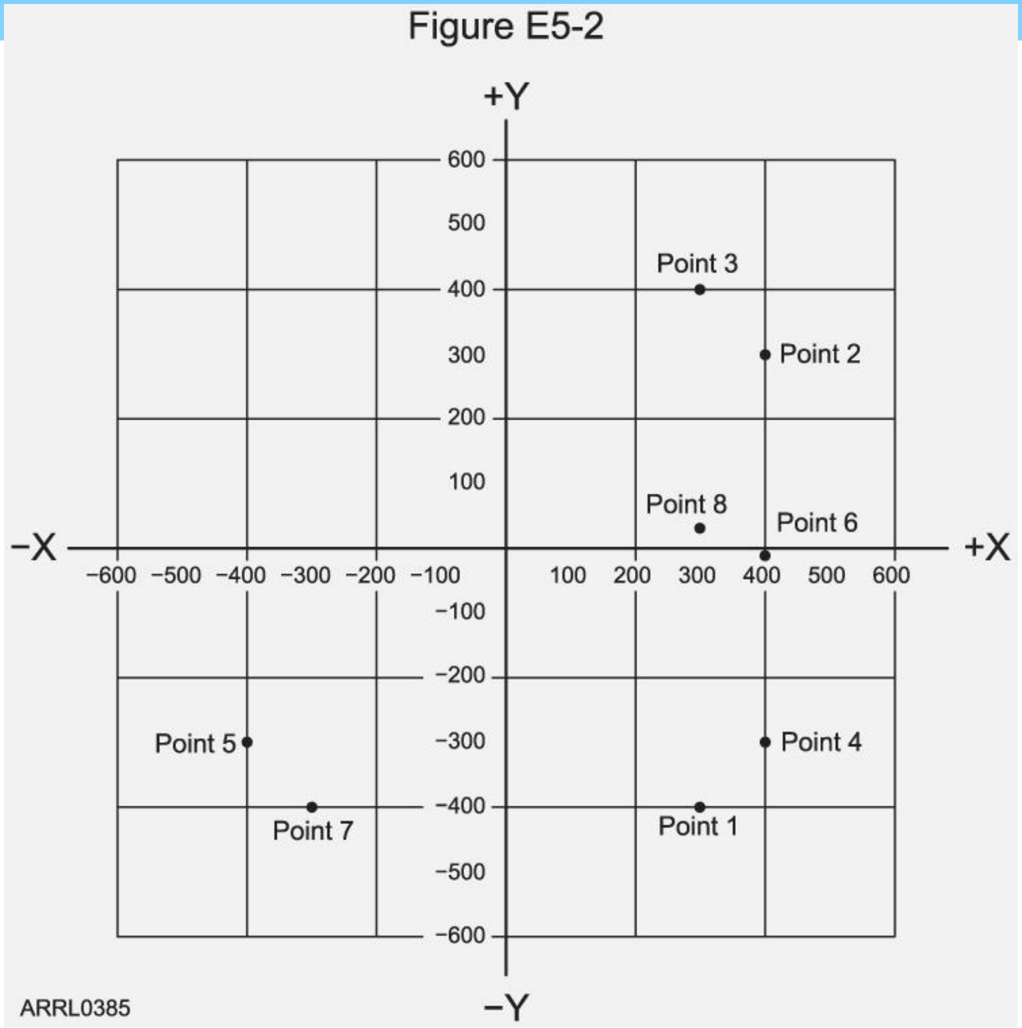
* Power to the Load = Forward Power – Reflected Power
* $P_{LOAD} = P_F - P_R$



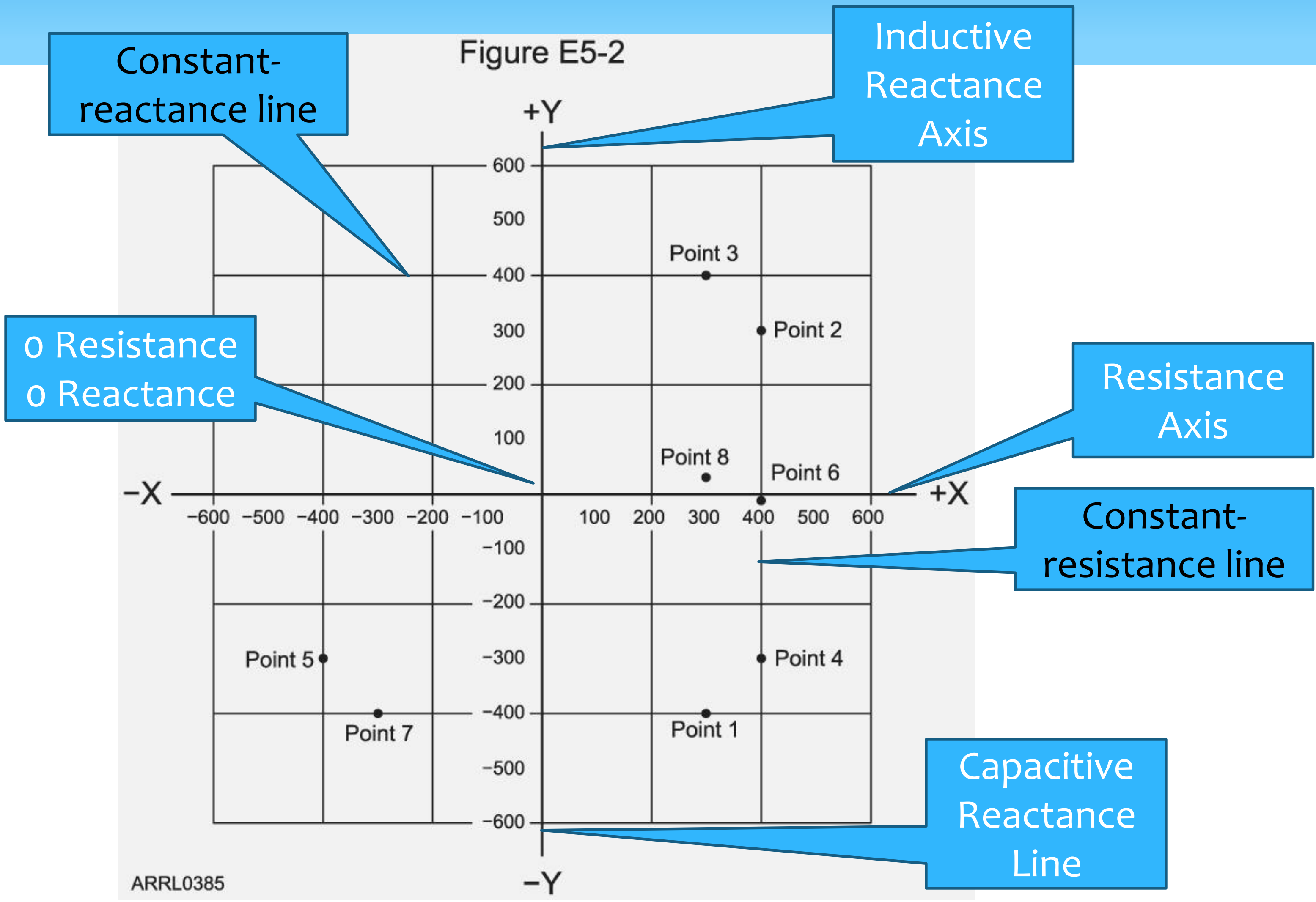
* How much power is absorbed by the load when a directional wattmeter reads 100 W forward and 25 W reflected?

* $P_{LOAD} = P_F - P_R = 100\text{ W} - 25\text{ W} = 75\text{W}$

Plotting Impedance



Plotting Impedance



Folding the Rectangular Graph

Pg. 9-36

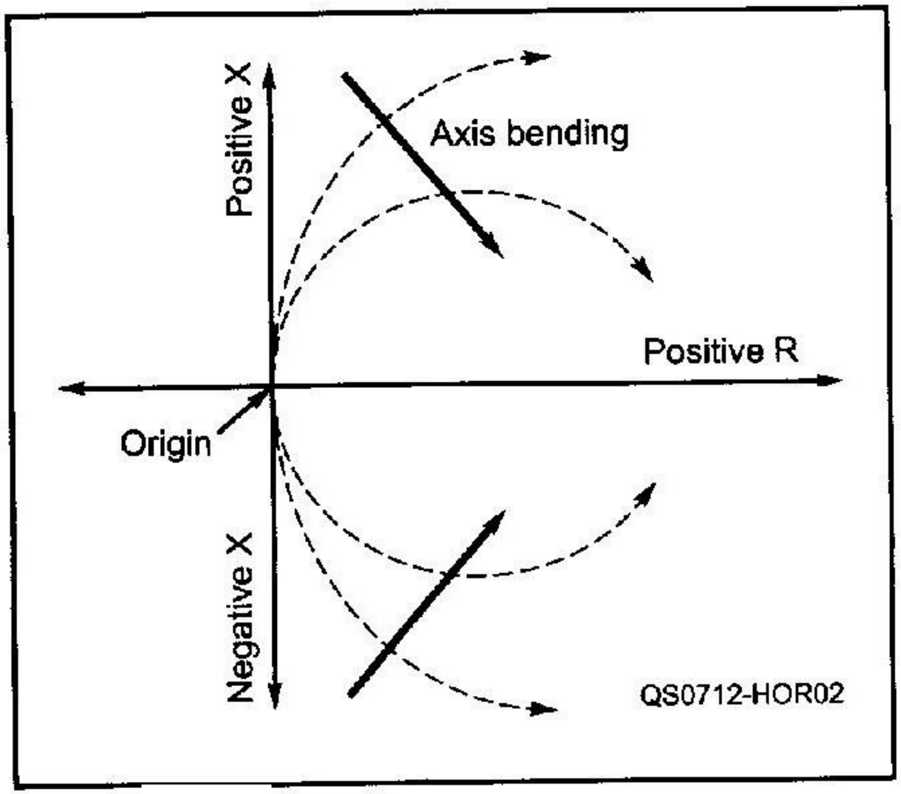
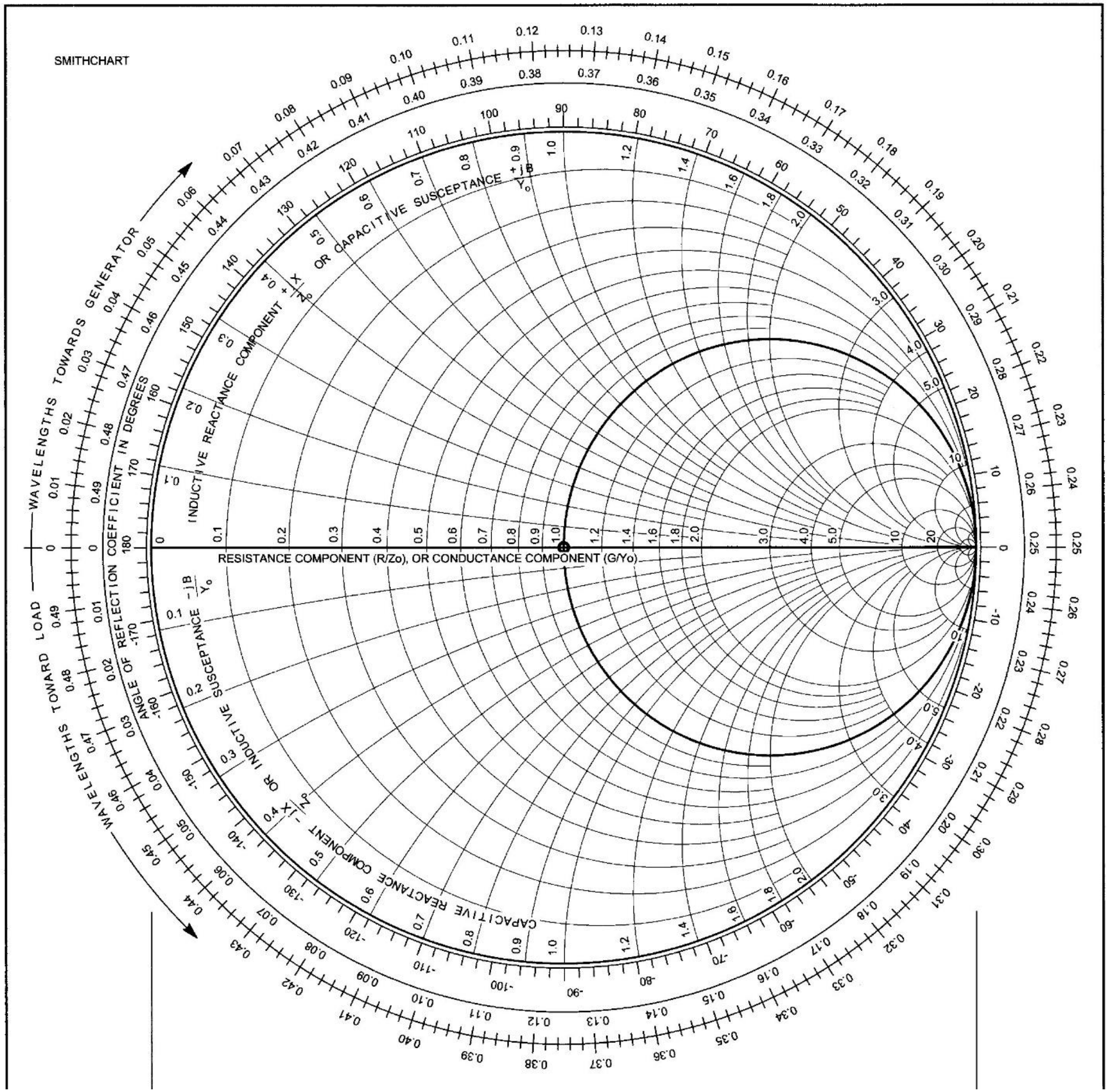


Figure 9-31 - Distorting or mapping the rectangular graph captures all of its right-hand side impedances inside the circle formed by the bent reactance axes. This is the basis of the Smith Chart.

Smith Chart

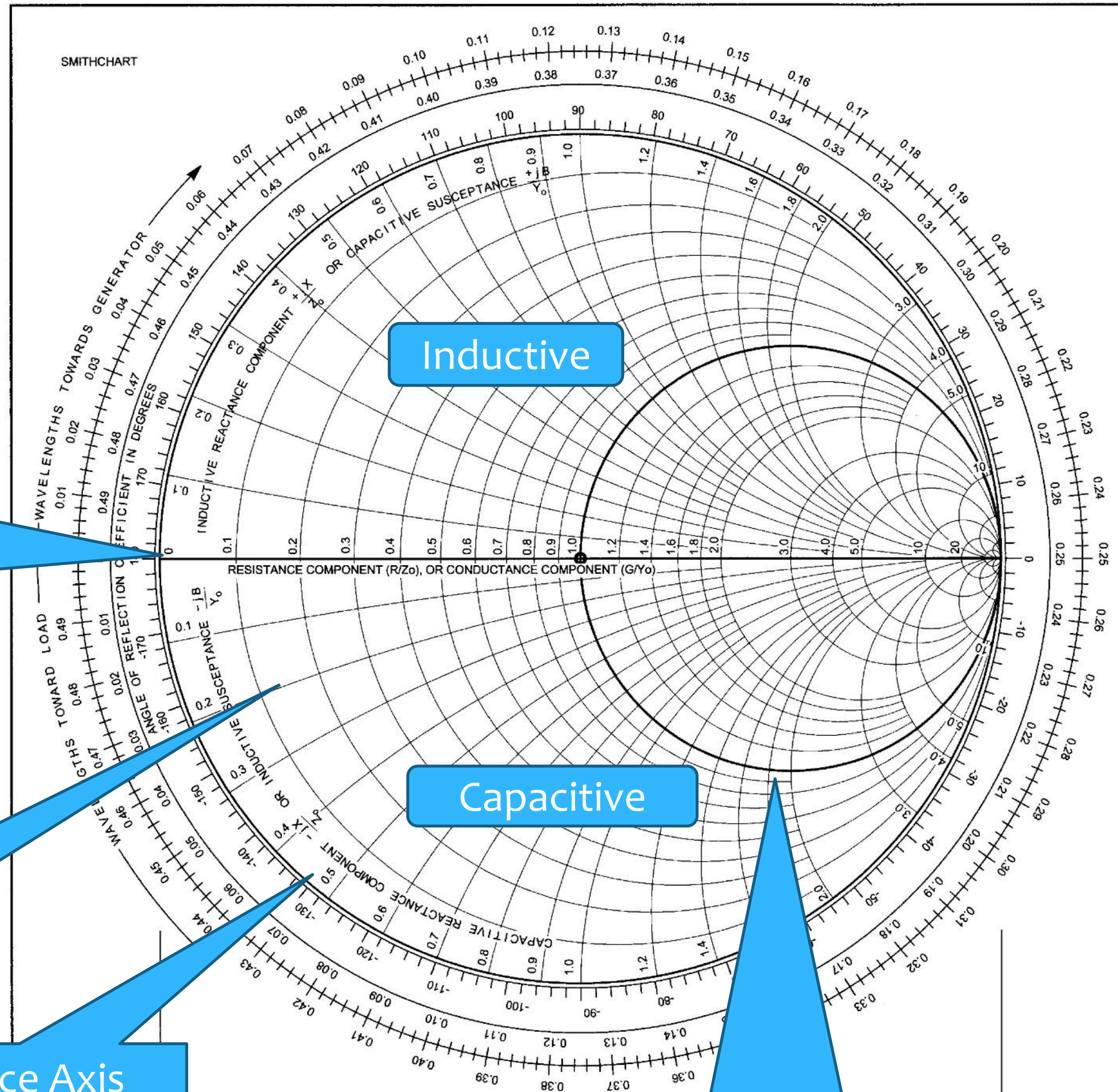
Pg 9-36

* One thing the Smith Chart is used for is to calculate the impedance and SWR anywhere along the transmission line.



Smith Chart

Pgs. 9-37



Inductive

Capacitive

The resistance axis is the only straight line.

Constant-reactance Arcs

Reactance Axis

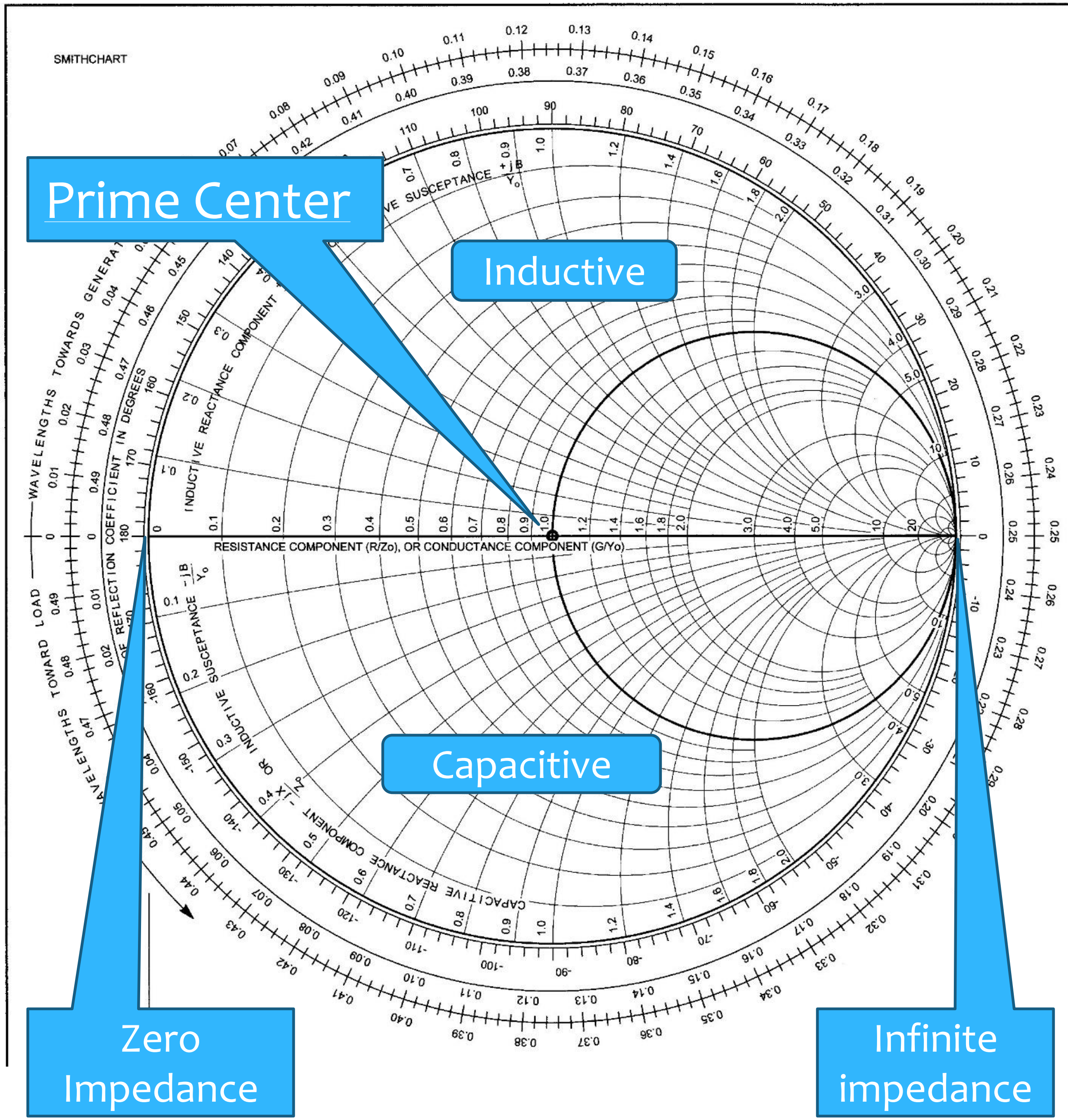
Constant-resistance circles

Smith Chart

Pg. 9-37

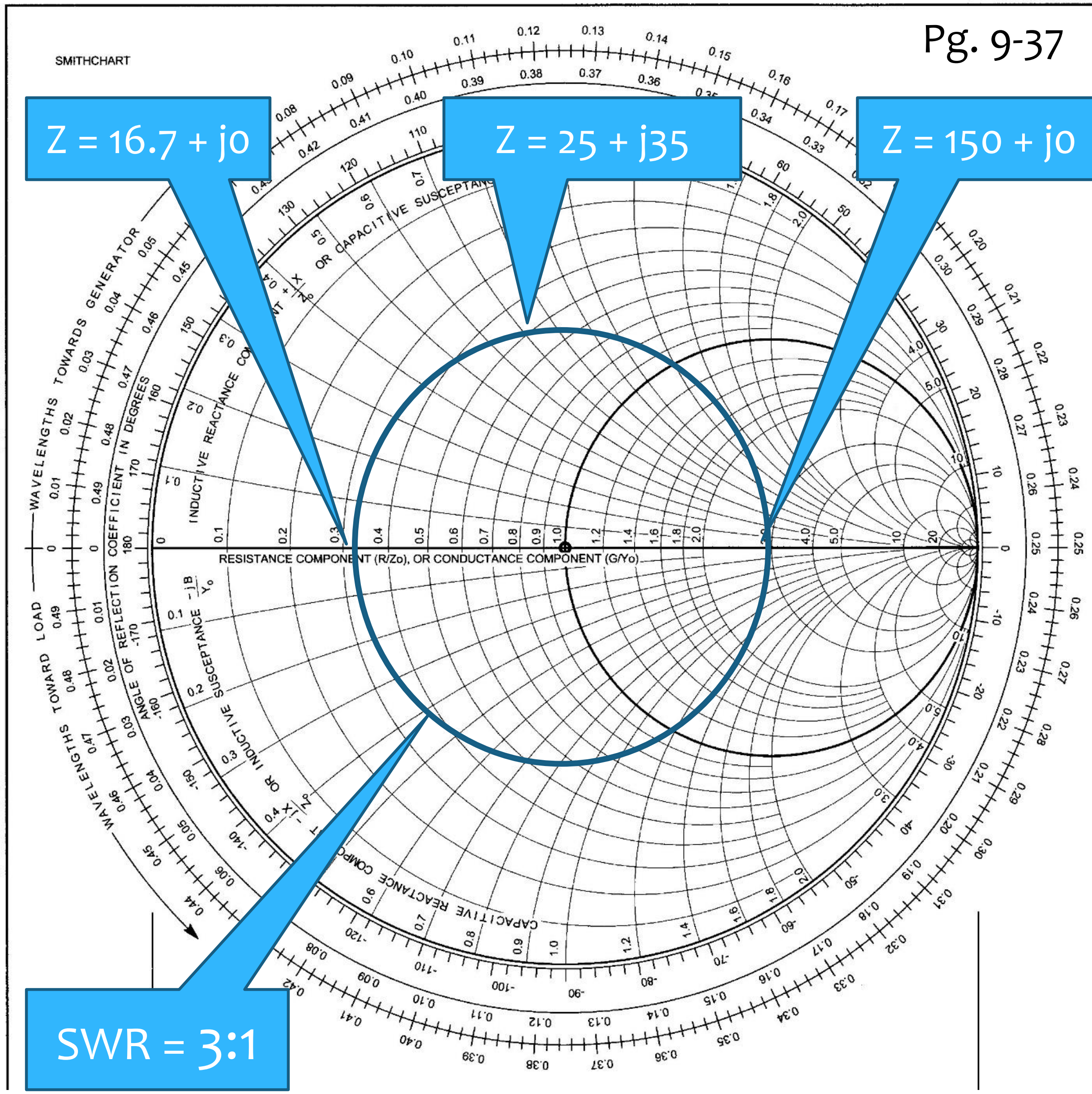
* A process called normalization reassigns the values of all the points according to their Z_O at the prime center.

* Z_O is called the characteristic impedance and is typically 50Ω.



Smith Chart

* A third family of circles is called the constant SWR circles
* If you take all of the normalized impedance points that create a certain value of SWR, you will find that the points make a circle.



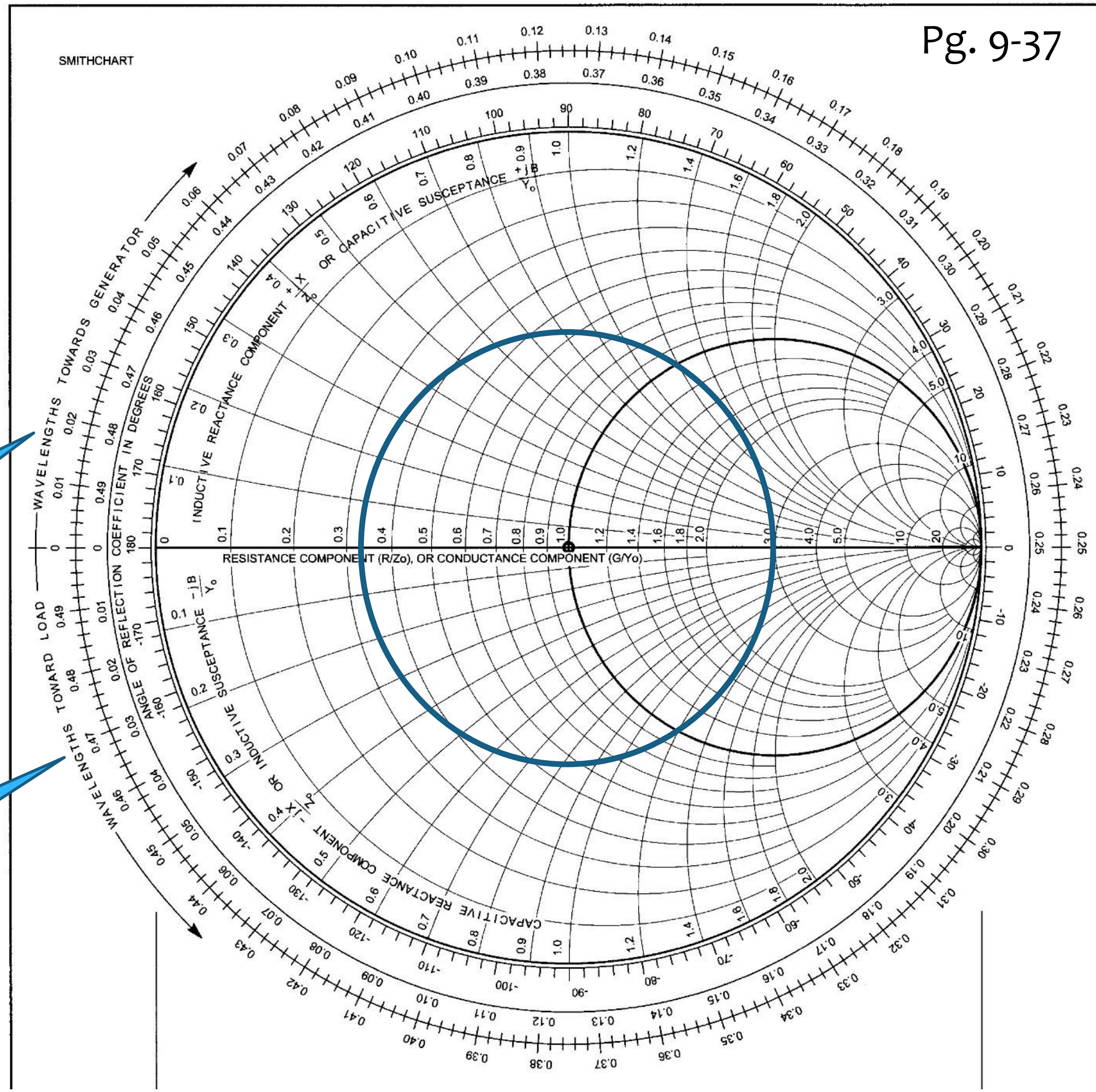
Smith Chart

* Along the edge are 2 Wavelength scales.

Wavelengths towards the **generator**

Wavelengths towards the **load**

Pg. 9-37

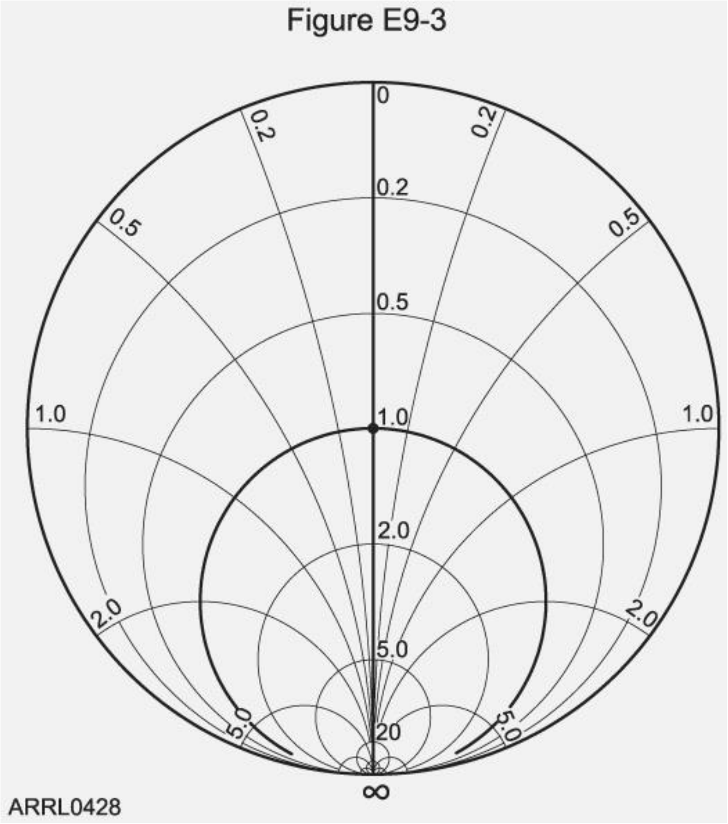


Both are calibrated in fractions of electrical wavelength inside the transmission line

What it this?

A Smith Chart

(stood on end)



E9F01 What is the velocity factor of a transmission line?

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

E9E12 What is the primary purpose of a phasing line when used with an antenna having multiple driven elements?

A. It ensures that each driven element operates in concert with the others to create the desired antenna pattern
B. It prevents reflected power from traveling back down the feed line and causing harmonic radiation from the transmitter
C. It allows single-band antennas to operate on other bands
D. It makes sure the antenna has a low-angle radiation pattern

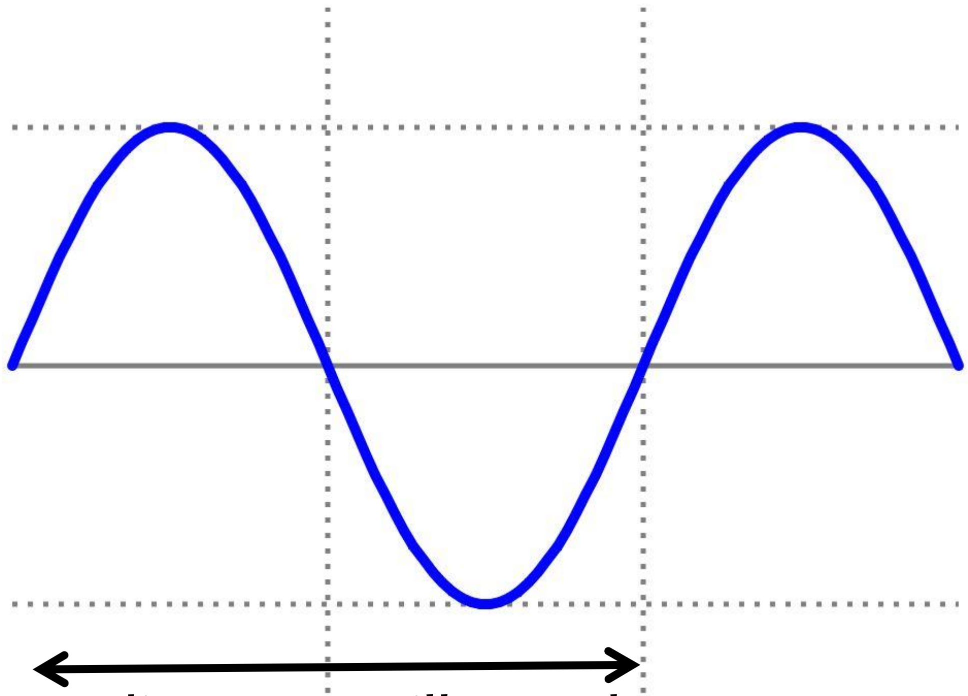
E9E07 What term best describes the interactions at the load end of a mismatched transmission line?

A. Characteristic impedance
B. Reflection coefficient
C. Velocity factor
D. Dielectric Constant

E9F05 What is the approximate physical length of a solid polyethylene coaxial transmission line that is electrically one-quarter wavelength long at 14.1 MHz?

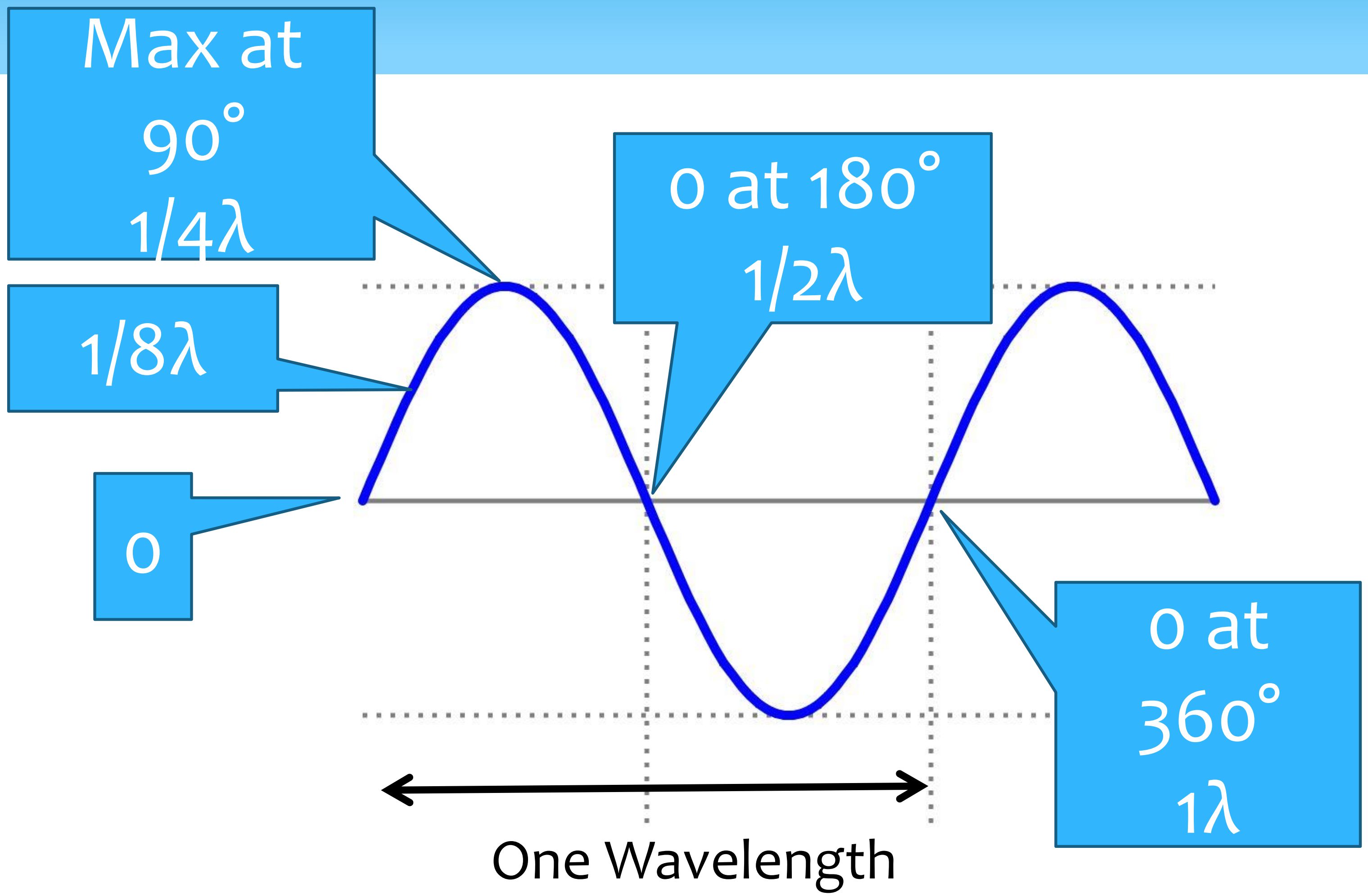
A. 20 meters
B. 2.3 meters
C. 3.5 meters
D. 0.2 meters

One more look at a sine wave



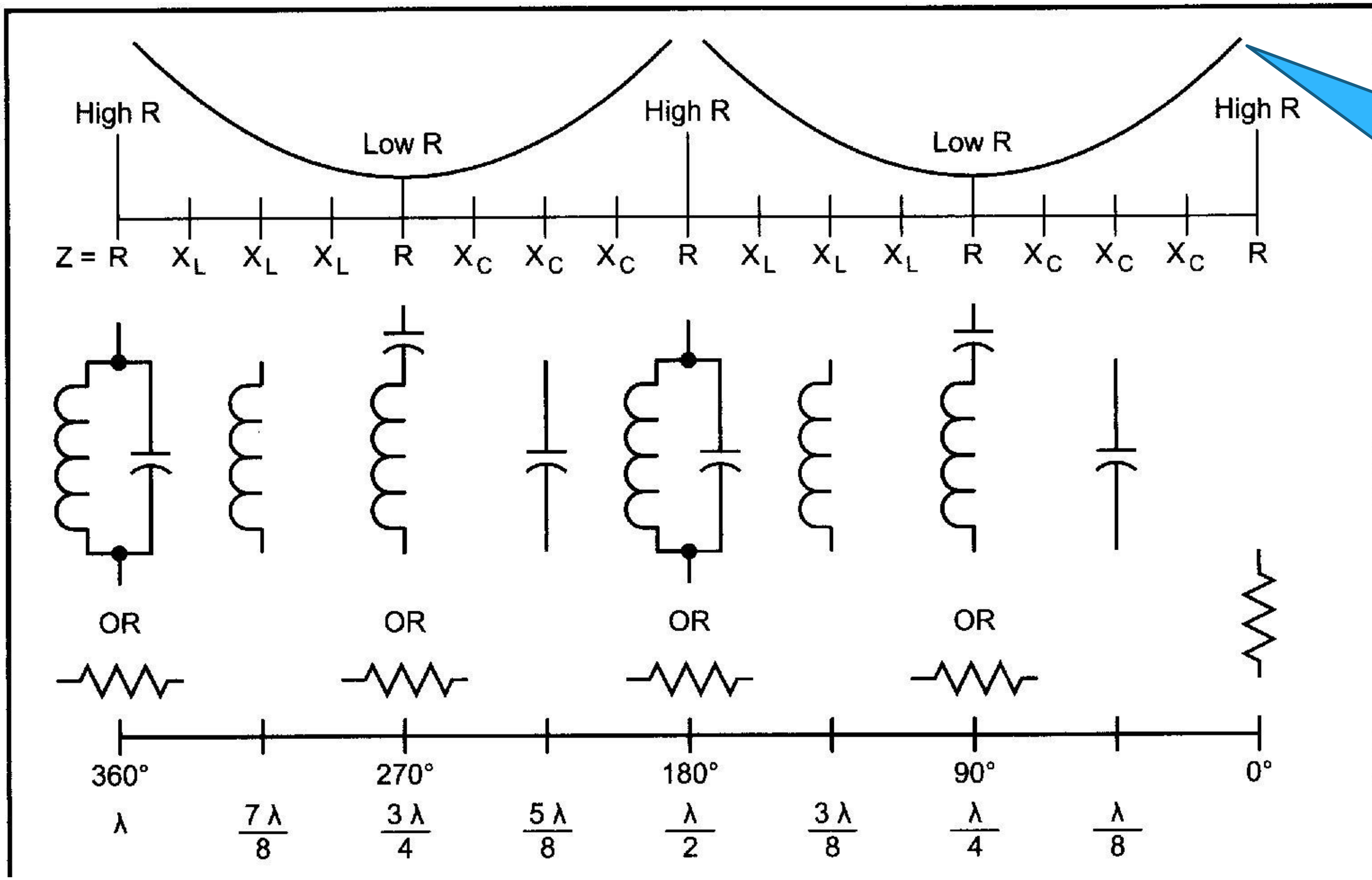
A radio wave will travel one wavelength in the time it takes to complete one cycle

One more look at a sine wave



Transmission Line Transformers

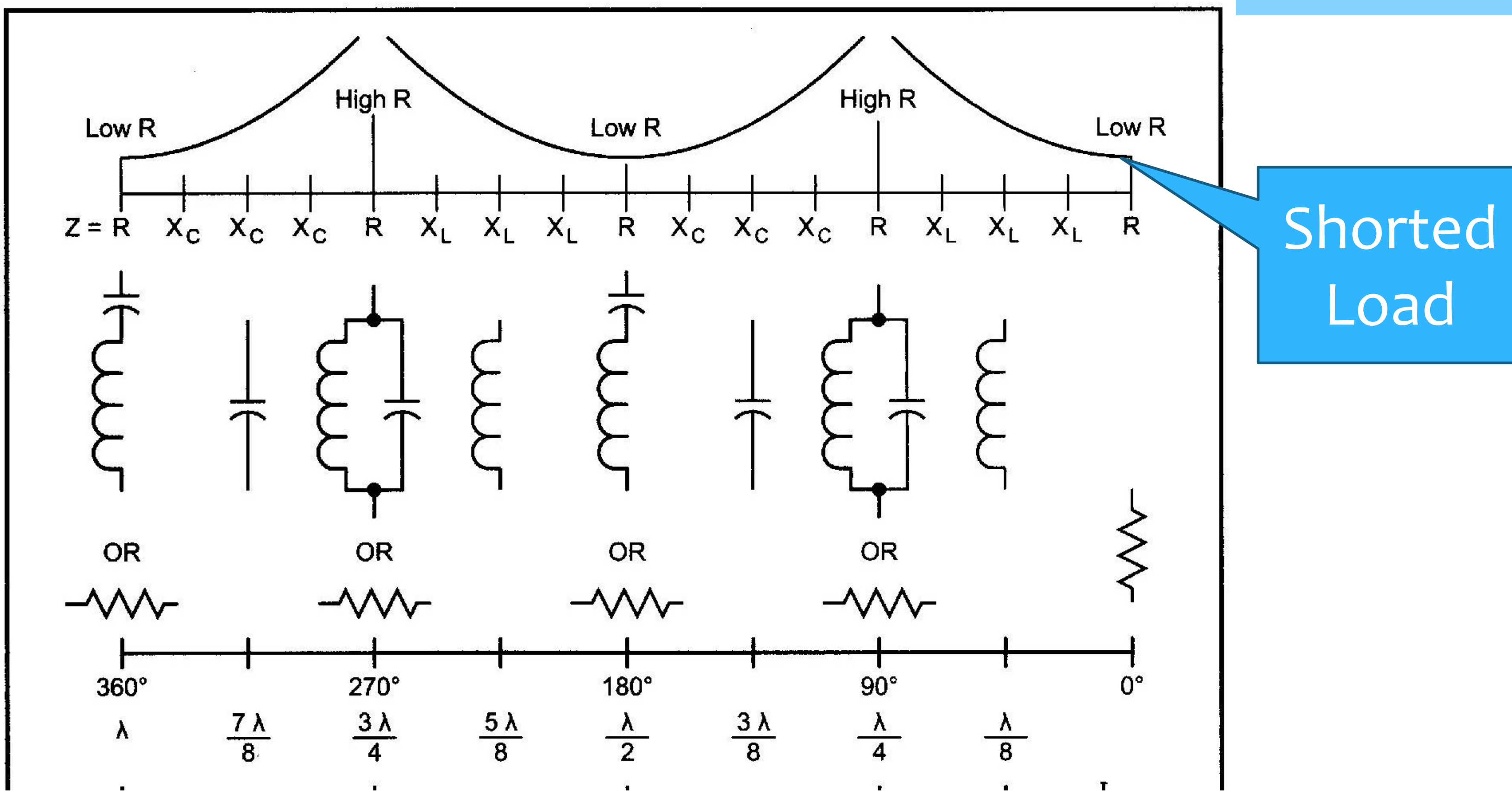
Pgs. 9-38 & 39



Open Load

Transmission Line Transformers

Pg. 9-39



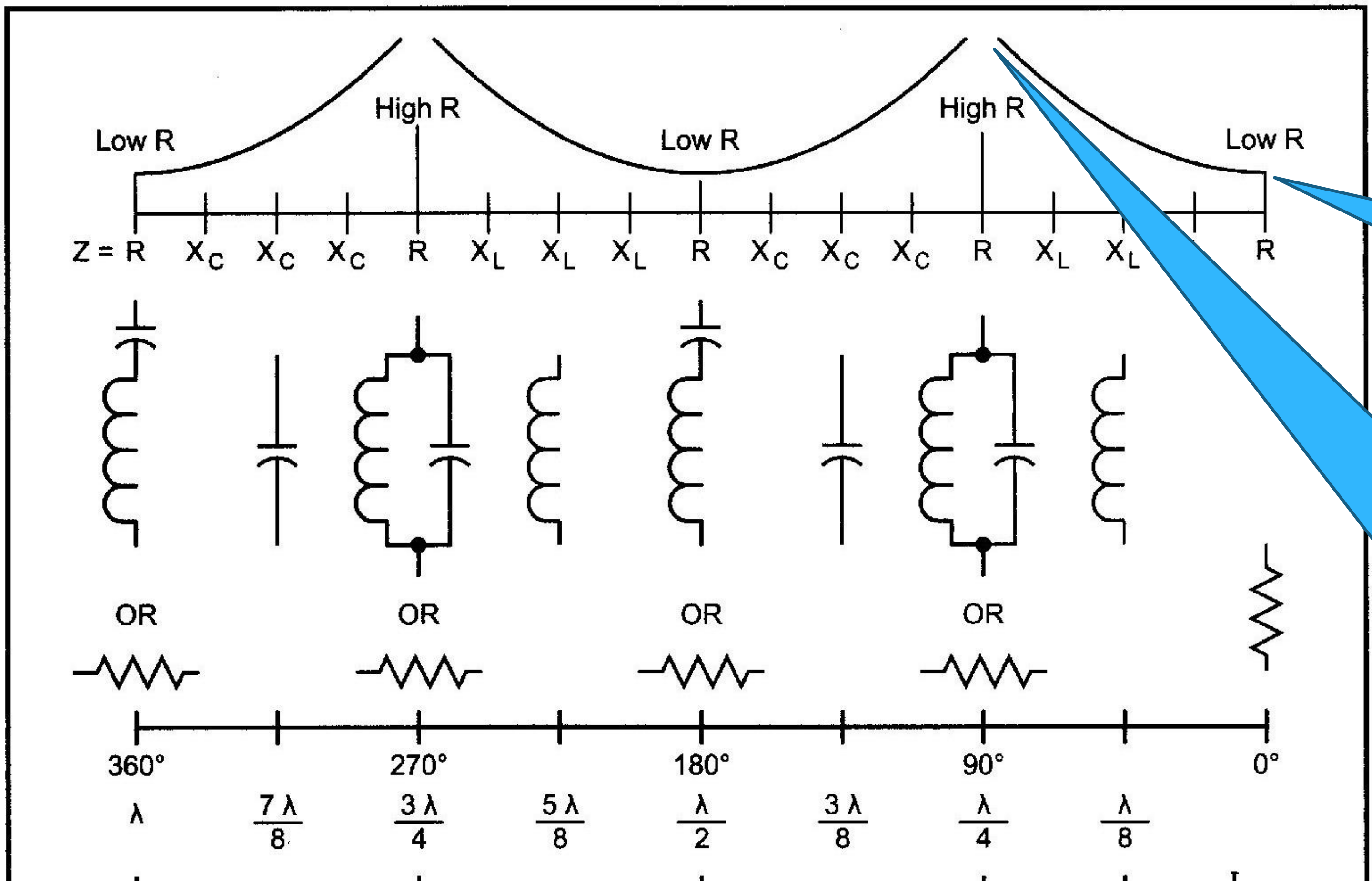
Transmission Line Transformers

Pg 9-39

* Every ½ **wavelength** along the line the impedance ***repeats.***
* If the terminating impedance is a **short** circuit, we will see a **short** every **½ wavelength.**
* If the terminating impedance is an **open** circuit, we will see an **open** every **½ wavelength.**

Transmission Line Transformers

Pg. 9-39



Short

Every odd multiple of ¼ λ there is an extreme change in the impedance

Transmission Line Transformers

Pg. 9-39

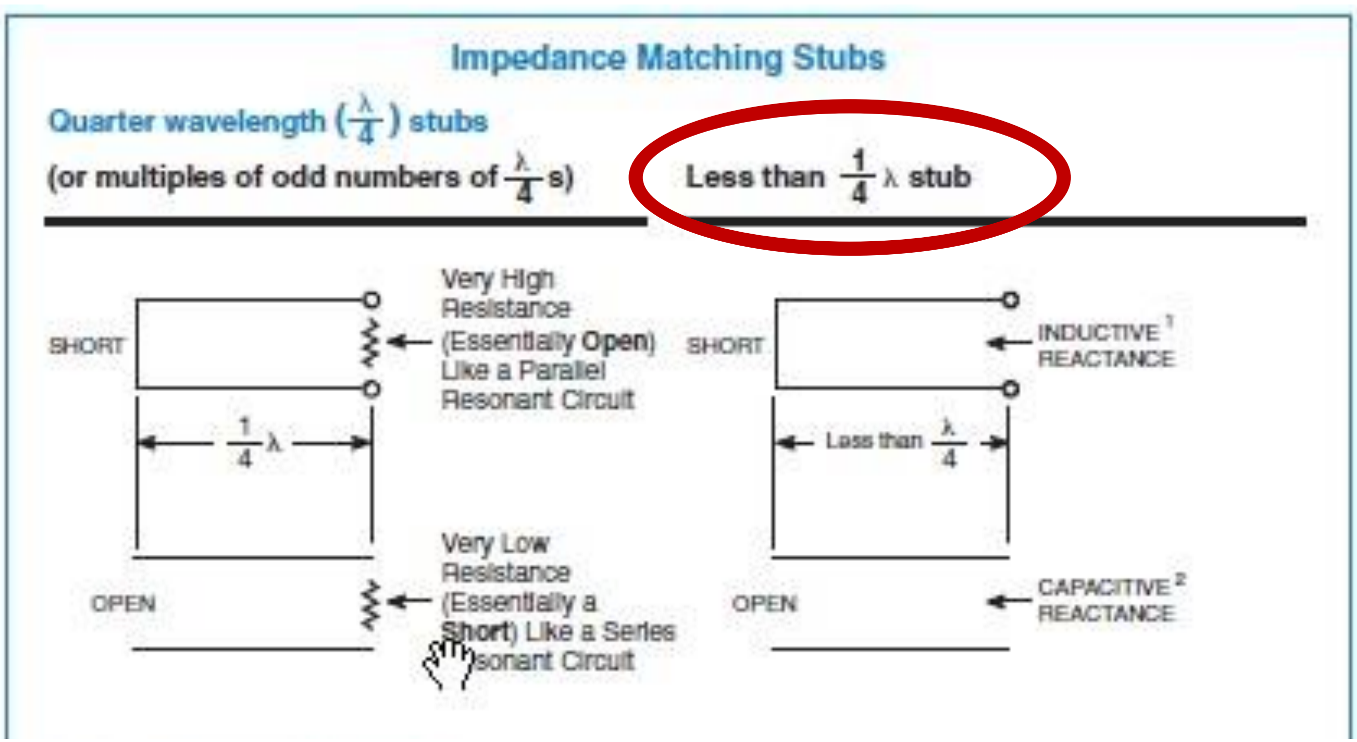
* Every **odd multiple** of **1/4 wavelength** along the line the impedance ***repeats.***

* If the terminating impedance is a **short** circuit, we will see an **open 1/4 wavelength away**.

* If the terminating impedance is an **open** circuit, we will see a **short** every **1/4 wavelength**.

Short Transmission Line Stubs

Pg. 9-39



Gordon West

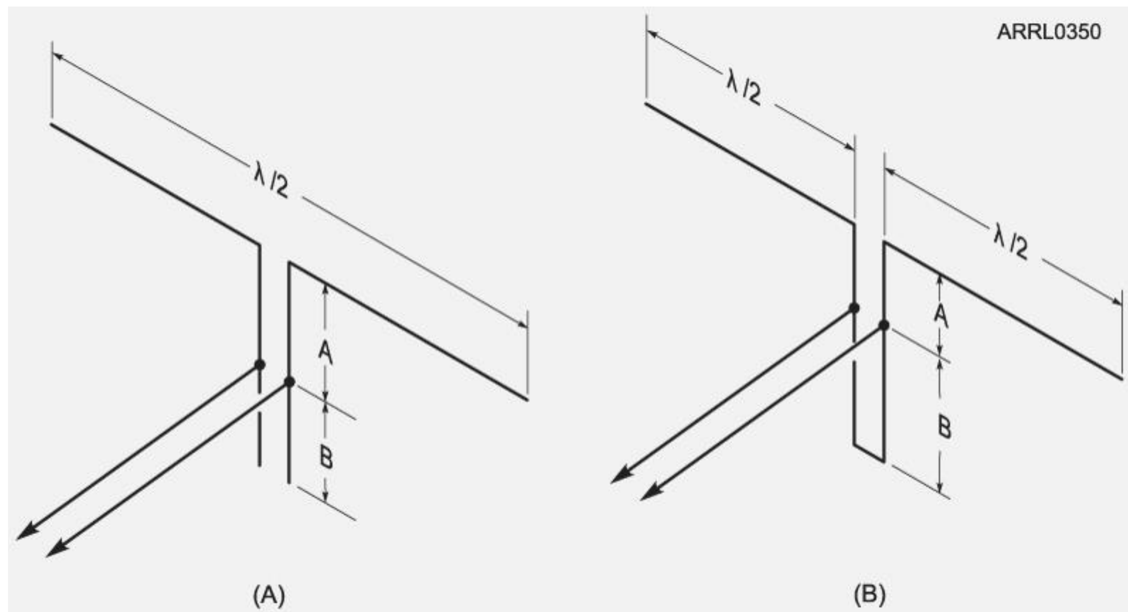
For stubs less than 1/4λ

- Shorted = L
  - Inductor
- Open = C
  - Capacitor

The Stub Match

Remember on Pg. 9-30

* Here we can see a practical use for stubs.
* Remember, this matching technique generally supports only one band at a time.



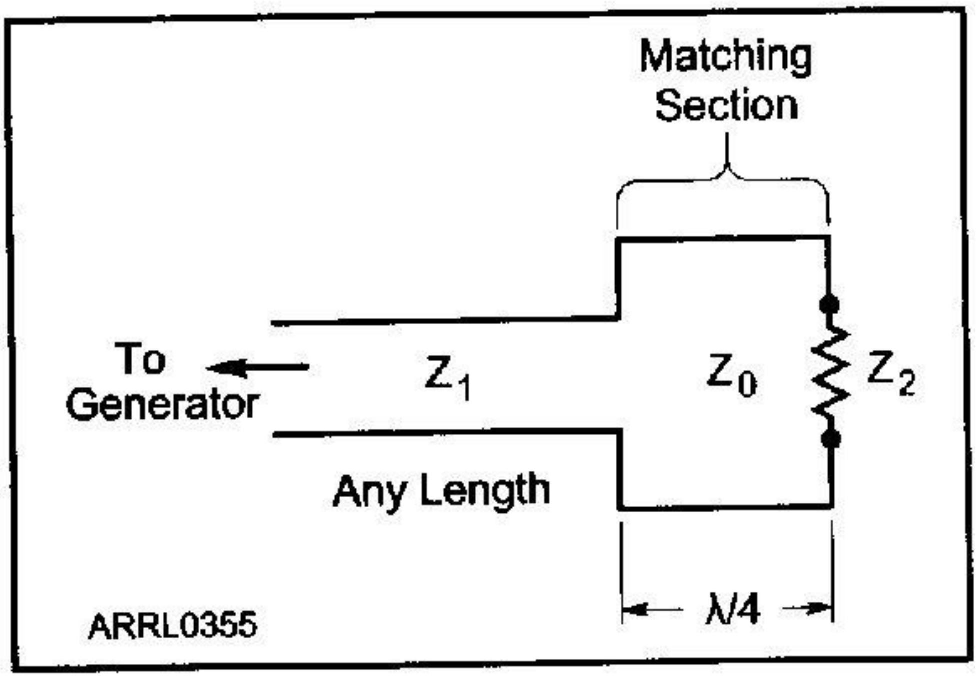
Synchronous Transformer
1/4-wave Matching Section

Pg. 9-41

- A ¼ wavelength transmission line of impedance Zo can be used to match between two other impedances, Z_1 and Z_2.

- $$Z_O = \sqrt{Z_1 \text{ x } Z_2}$$

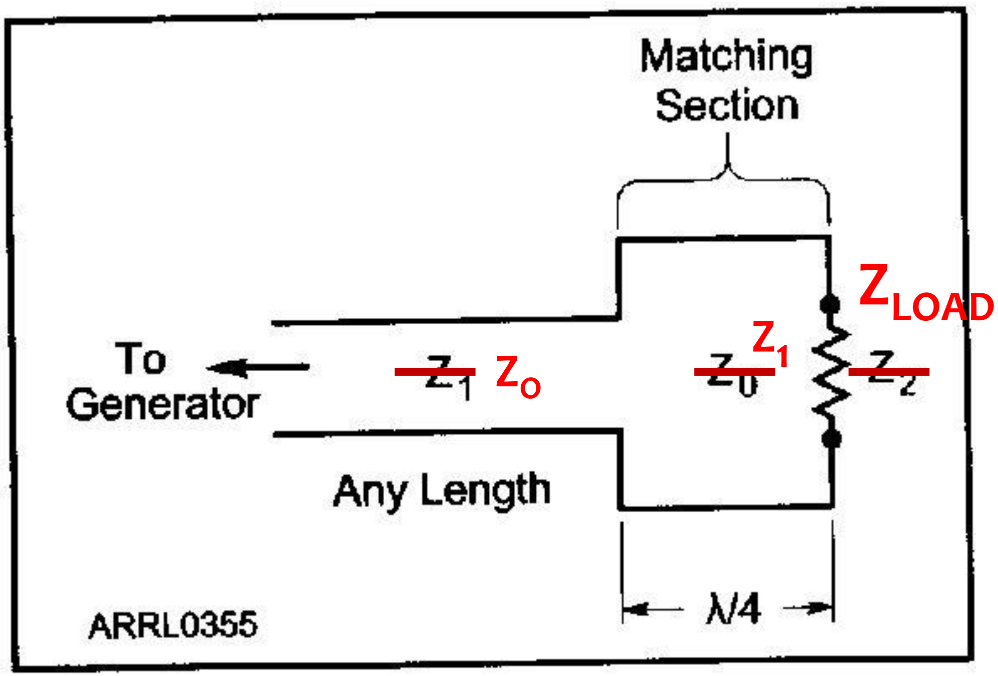
- Z_O is generally used to mean the characteristic impedance of our feed line.



Synchronous Transformer
using more common designators

Pg. 9-41

- A ¼ wavelength transmission line of impedance Z1 can be used to match between two other impedances, Z_O and Z_{LOAD}.
- $Z_1 = \sqrt{Z_0 \text{ x } ZL_{OAD}}$
  - Equation 9.14
- **Z_O** is generally used to mean the characteristic impedance of our feed line.

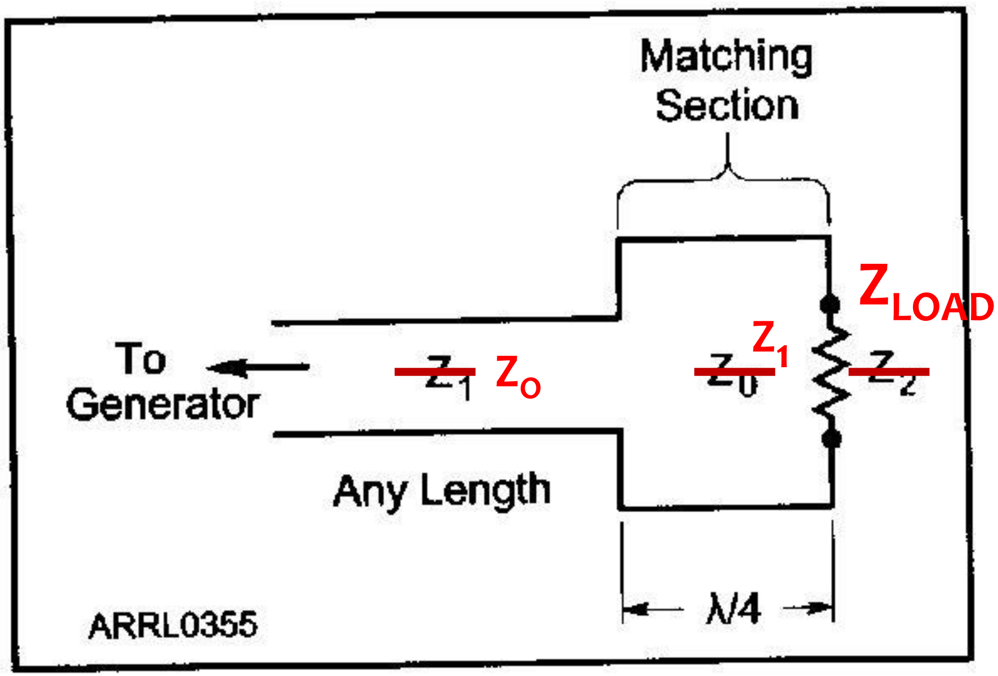


Synchronous Transformer

Example

Pg. 9-41

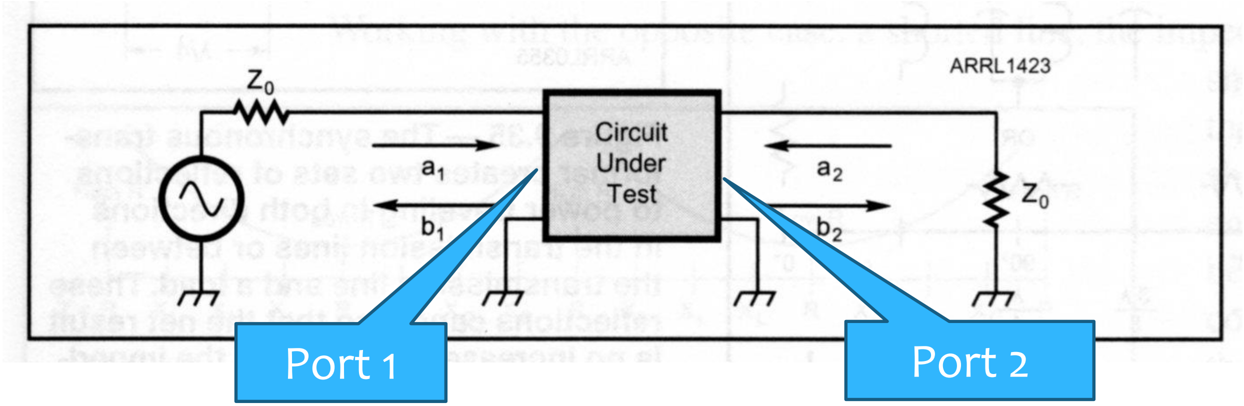
- Example: Assume a transmission line Z_0 = 50Ω and a Z_{LOAD} = 100Ω
- $Z_1 = \sqrt{Z_0 \text{ x } ZLO_{AD}}$
- $Z_1 = \sqrt{50 \text{ x } 100}$
- $Z_1 = \sqrt{5000}$
- Z_1 = 70.7Ω
- A ¼ λ section of 75Ω RG-59U coax is probably close enough



Scattering Parameters

Pg 9-42

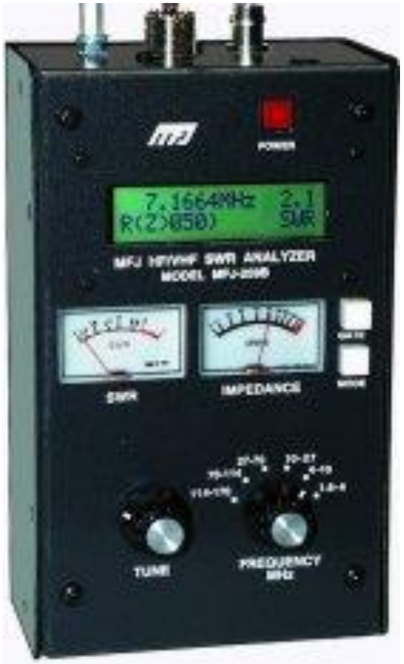
* Subscripts of the parameter shows the port or ports at which the measurements are made.
* Examples:
  * **S21** designates what is happening on **port 2** as a result of an input at **port 1** (**forward gain**).
  * **S11 can be converted to Return Loss** or SWR



Antenna Analyzers

Pg. 9-42 & 43

* Antenna Analyzers can measure:
  * SWR
  * Impedance (R + jX)
  * Reactance (component) values
  * Plus more!
* Can be connected directly to the impedance to be measured.
* Contains its own RF signal source – no external transmitter needed.



Beware: You can get fooled in SWR measurements

Network Analyzers $$$

Pg 9-43

* A **network analyzer h**as more measurement capability than an antenna analyzer.
  * Example: Can measure a signal going through a circuit or feedline (gain or loss).
* Uses three calibrated loads to calibrate itself
  * Short circuit
  * 50 ohms
  * Open Circuit

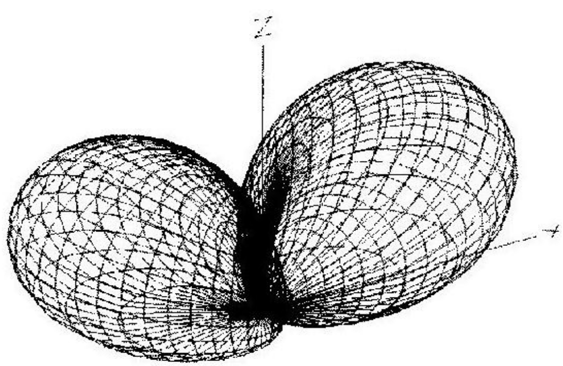
Antenna Modeling

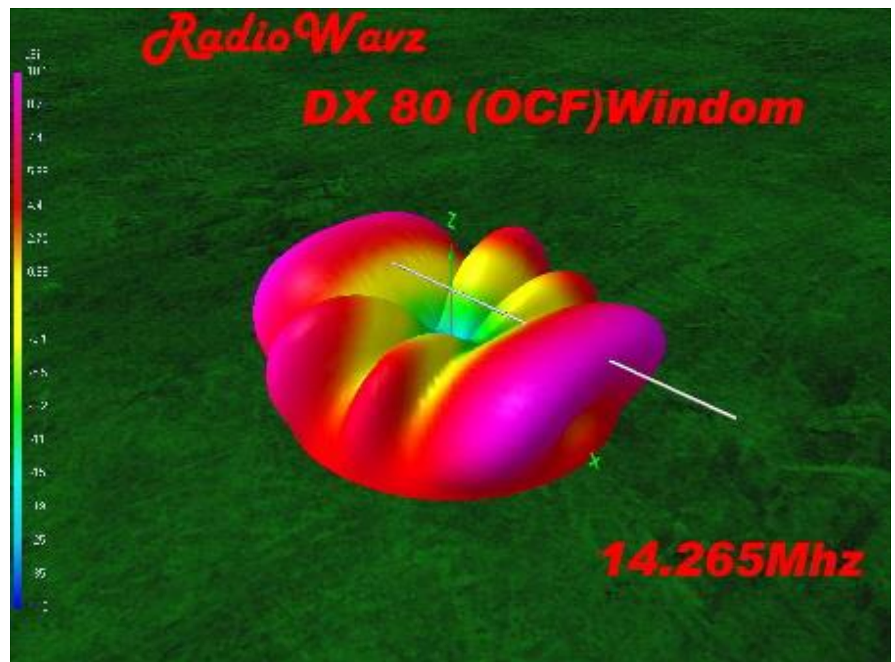
Pg 9-43 & 44

* Modeling programs for your PC let you “see” many of the antennas characteristics before you build it!
* Based on: **NEC** (Numerical Electromagnetics Code)
* Employs the **methods of moments** where each antenna wire element is modeled as a series of segments, each having a uniform value of current.
  * The more segments, the more accurate
  * The less segments, the less accurate.

Antenna Modeling

- You can compute:
  - SWR vs frequency charts
  - Polar plots of the far field elevation and azimuth
  - Antenna gain





We can look at design tradeoffs such as:

* How a directional antenna’s **gain may change** as you **move away from the design frequency.**
* Maximizing forward gain may hurt other parameters, such as the front-to-back ratio.
* How increasing the boom length on a Yagi will increase the gain if the elements are properly tuned.

E9E11 What is an effective way of matching a feed line to a VHF or UHF antenna when the impedances of both the antenna and feed line are unknown?

A. Use a 50-ohm 1:1 balun between the antenna and feed-line

B. Use the "universal stub" matching technique

C. Connect a series-resonant LC network across the antenna feed terminals

D. Connect a parallel-resonant LC network across the antenna feed terminals

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

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

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

A. A capacitive reactance
B. The same as the characteristic impedance of the line
C. An inductive reactance
D. The same as the input impedance to the final generator stage

E9F15 What impedance does a 1/2-wavelength transmission line present to a generator when the line is open at the far end?

A. A very high impedance
B. A very low impedance
C. The same as the characteristic impedance of the line
D. The same as the output impedance of the generator

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

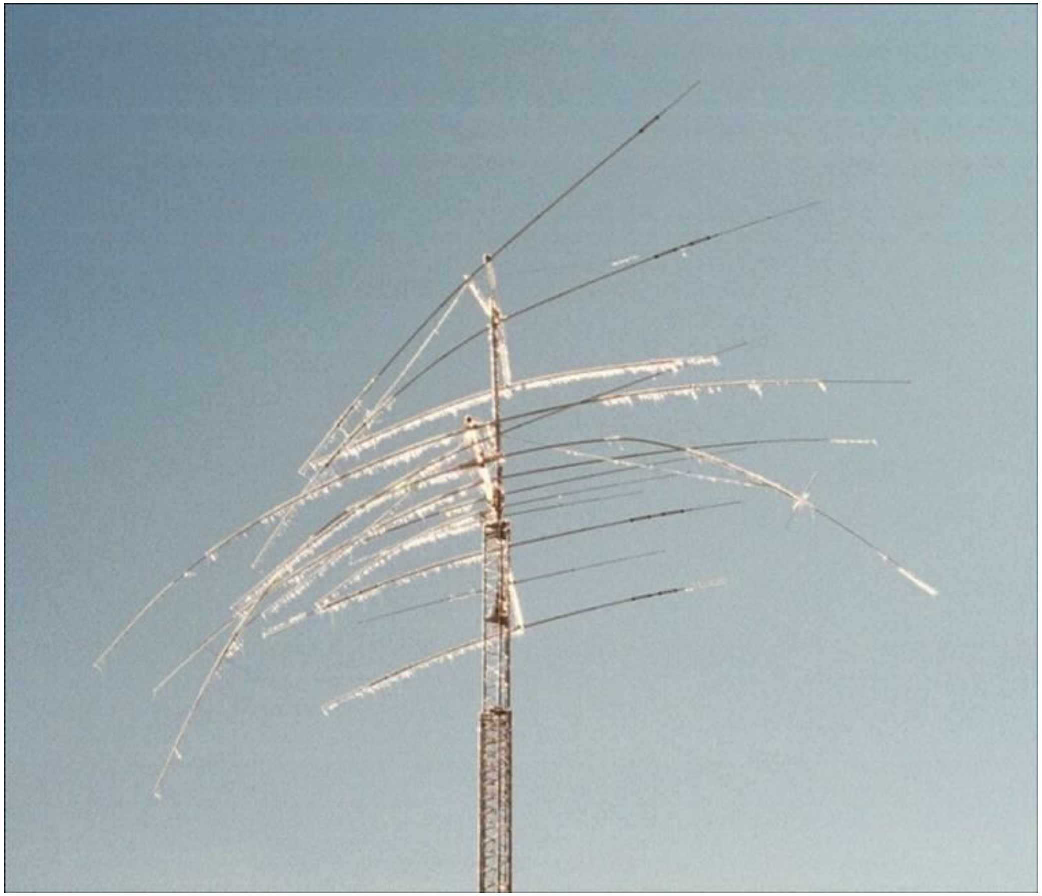
A. Voltage circles and current arcs
B. Resistance circles and reactance arcs
C. Voltage lines and current chords
D. Resistance lines and reactance chords

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

A. Reassigning resistance values with regard to the reactance axis
B. Reassigning reactance values with regard to the resistance axis
C. Reassigning impedance values with regard to the prime center
D. Reassigning prime center with regard to the reactance axis

Remember: The bigger the antenna the more ice it can collect!

KØGY's antennas



Tnx fer listening