Chapter 9

Antennas
and Feed Lines

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Last Week

9.1 Basics of Antennas

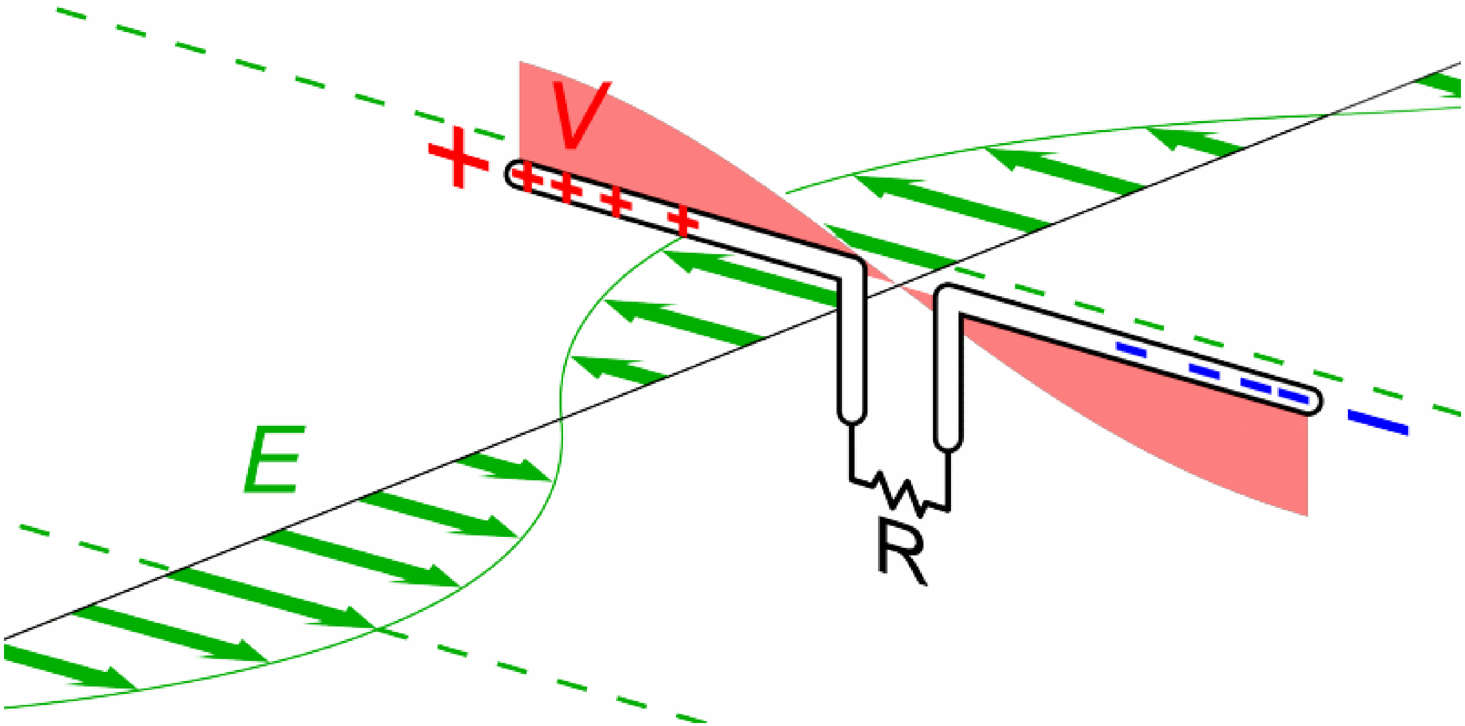
* Radiation Patterns
* Antenna Gain
* Beamwidths and Pattern Ratios
* Radiation and Ohmic Resistance
* Feedpoint Impedance
* Antenna Efficiency
* Pattern Types and Bandwidth
* Effects of Ground and Grounding

This Week

* 9.2 Practical Antennas
* 9.3 Antenna Systems
* 9.4 Transmission Lines
* 9.5 Antenna Design (Modeling)
  * Page 9-44
  * Slide 106

Section 9.2

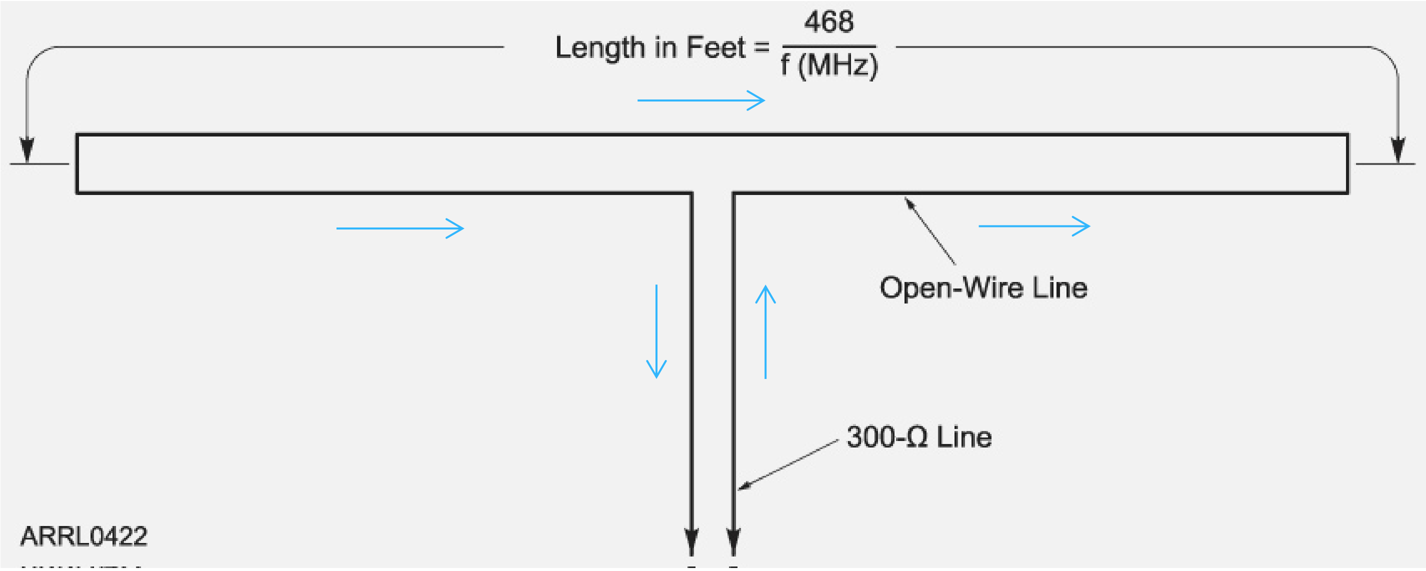
Practical Antenna



Folded Dipole

Pgs. 9-11

* ½ wavelength long wire that has a parallel wire connection the two ends. (A thin loop antenna) E9C08
* The feed point is close to **300 ohms** E9C07
  * Compatible with twin lead feed lines.

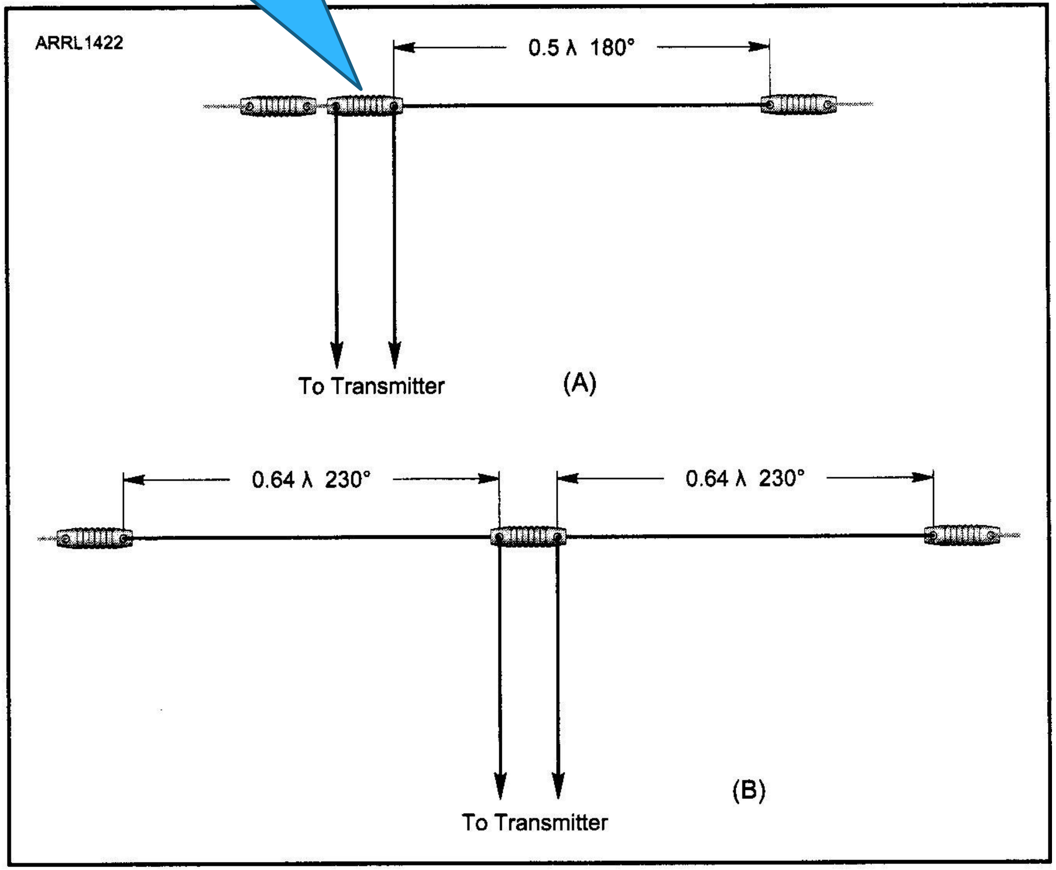


Zepp Antennas

Pgs. 9-12

* The Zepp is simply an end-fed halfwave (EFHW) dipole fed with open wire feeder. E9C10
  * A more modern EFHW uses a unun and coax feed.
* An Extended Double Zepp is 1.25 wavelengths long and fed in the center E9C12
  * This lowers the feed point impedance

Very high Impedance

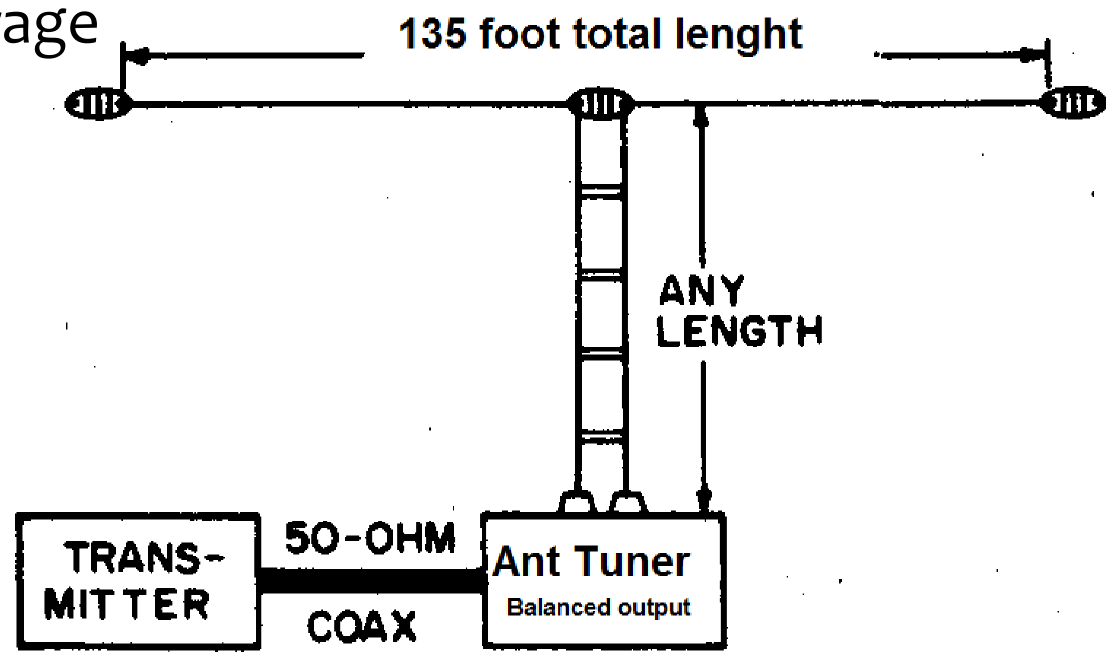


80m Dipole Fed with Ladder-line

May also be called a Zepp or Double Zepp

FYI

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



—A center-fed antenna system for multiband use.

G5RV Antenna

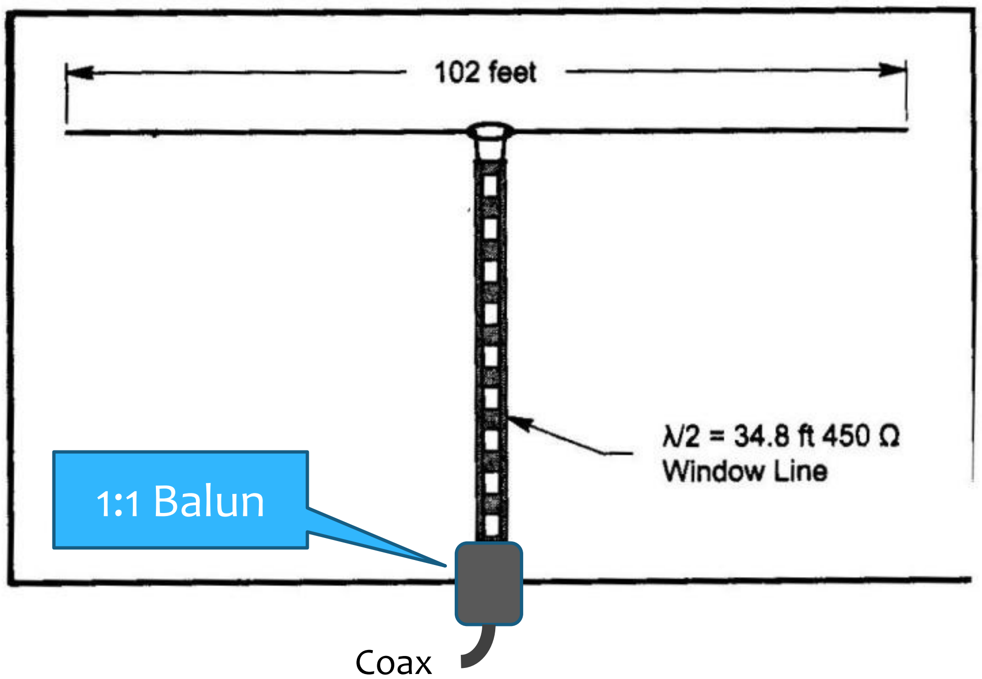
Pgs. 9-12 & 13

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

E9C09

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

* Requires an antenna tuner for most bands.

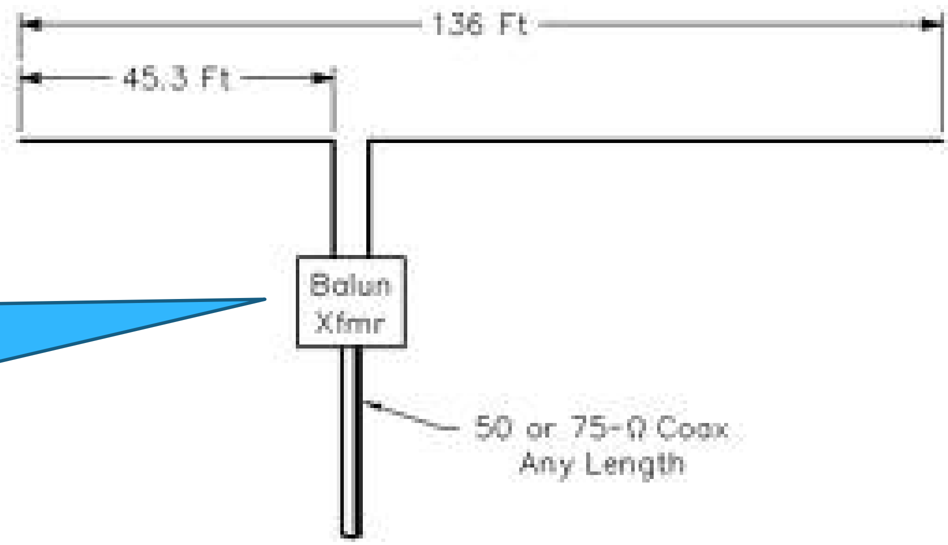


Off-Center-Fed Dipole

Pgs. 9-13

* An off-center fed dipole, fed approximately 1/3 way from the end with a 4:1 Balun.
  - **The feed point impedance is similar on multiple bands.**
  - Typically, **150 – 300Ω**

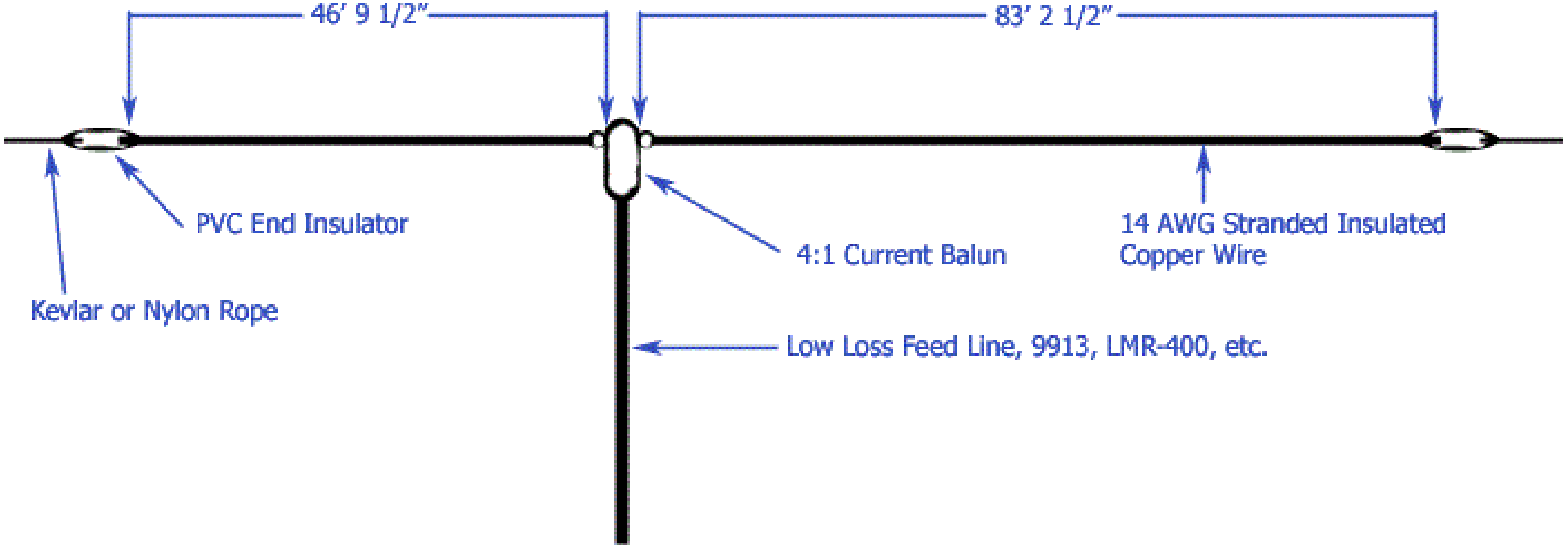
E9C05 -



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

Off-Center-Fed Dipole (Windom)

FYI



- 80, 40, 20, 17, 12, & 10 meter typical.
- A tuner may be required.
- Some designs use ~80/20 ratio instead of 67/33

Balun

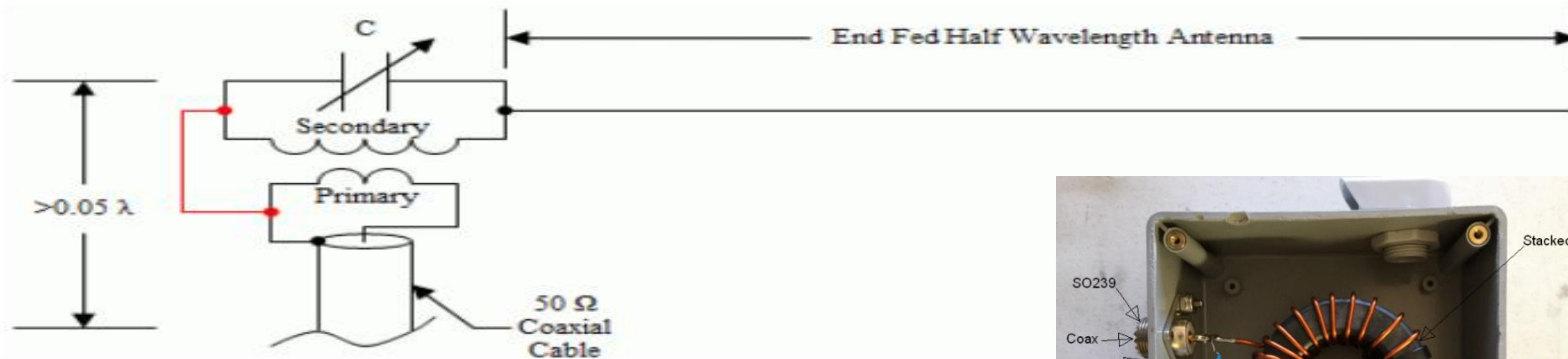
FYI

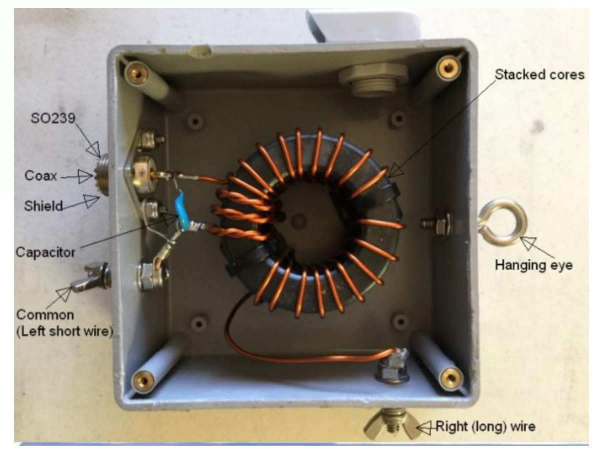
* A **balun** is usually a transformer-type device that is generally mounted at the feedpoint of the antenna.
* It can be used to **step up or step down an impedance**.
  - Common impedance ratios are: **1:1, 4:1** and **9:1**
* They match between a **bal**anced antenna (dipole) and an **un**balanced 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.

End Fed Halfwave (EFHW)

FYI

G0KYA's HF End Fed Half Wave (EFHW) antenna – construction details





49:1 Impedance Ratio

- An end-fed half wave antenna can be thought of as being like a dipole, only fed at one end.
- http://hamfest.w7yrc.org/wp-content/uploads/2019/06/EFHWslides.pdf
- https://www.norfolkamateurradio.org/pdf/G0KYA%20EFHW%20Ant%20+%20shopping%20list.pdf
- https://www.hfkits.com/end-fed-antennas-a-critical-view/

40 -10m 66 ft 250W EFHW
MFJ: $84; ARRL $80
80 – 10m 130 ft 1 kW EFHW
EFHW-8010 130 ft 1 kW
MyAntennas ~$200

Shortened Multiband Antennas

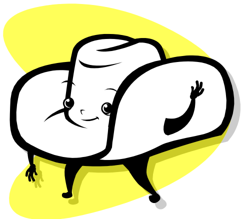
(Mobile Whips)

Pgs. 9-13 & 14

As the frequency of operation of a base-fed whip antenna is lowered below its resonant frequency, the its radiation resistance will go down E9D10

* And the capacitive reactance will increase

Both of these effects will increase the SWR and can contribute to lower efficiency



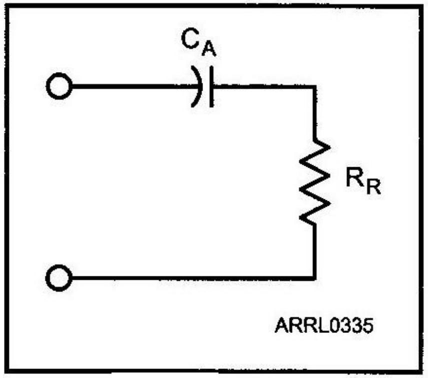


Figure 9-11 At frequencies below its resonant frequency, the feed point impedance of a whip antenna can be represented as a capacitive reactance, C_A, in series with the antenna's radiation resistance, R_R.

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. E9D09
  * Remember, resonance occurs where the feed point is purely resistive.
* But the use of a loading coil reduces the SWR bandwidth. E9D06

Top Loading

Center Loading

Base Loading

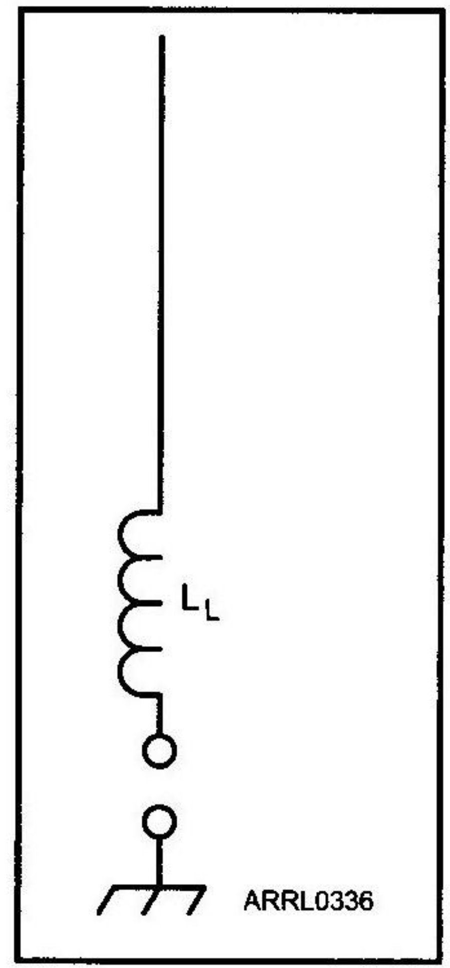


Fig 9-12

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 efficiency in an electrically short vertical. E9D03
- Loading coils should have a high ratio of reactance to resistance (i.e.: high Q) for maximum efficiency. E9D04

Capacity Hat

Pg. 9-14

- 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

Traveling Wave Antennas

Long Wire

Pg. 9-16

* The Traveling wave antenna is the *long-wire* antenna
  * Greater than long 1λ
* The longer the wire, the closer to the axis of the wire the major lobes become. E9C04

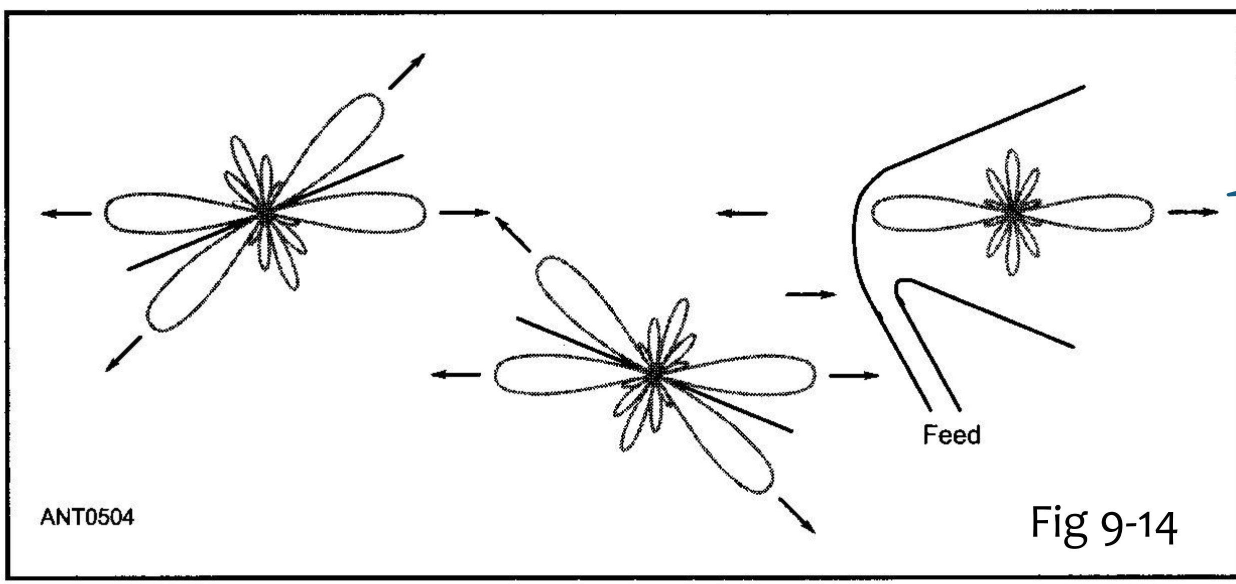


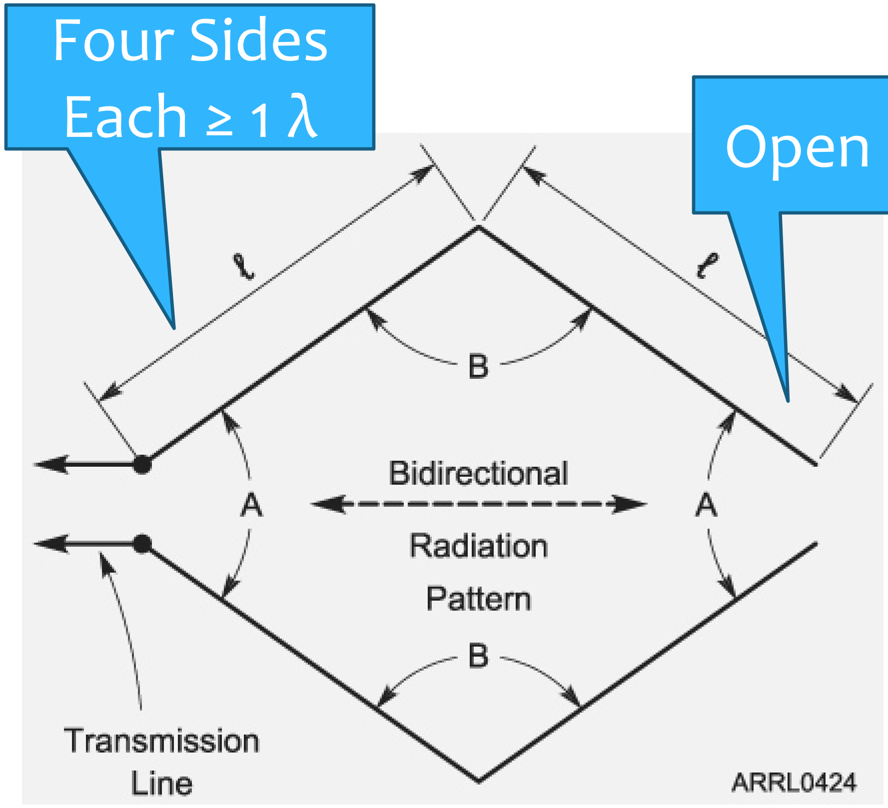
Fig 9-14

Vee Beam

Rhombic Antennas

Pg 9-16

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



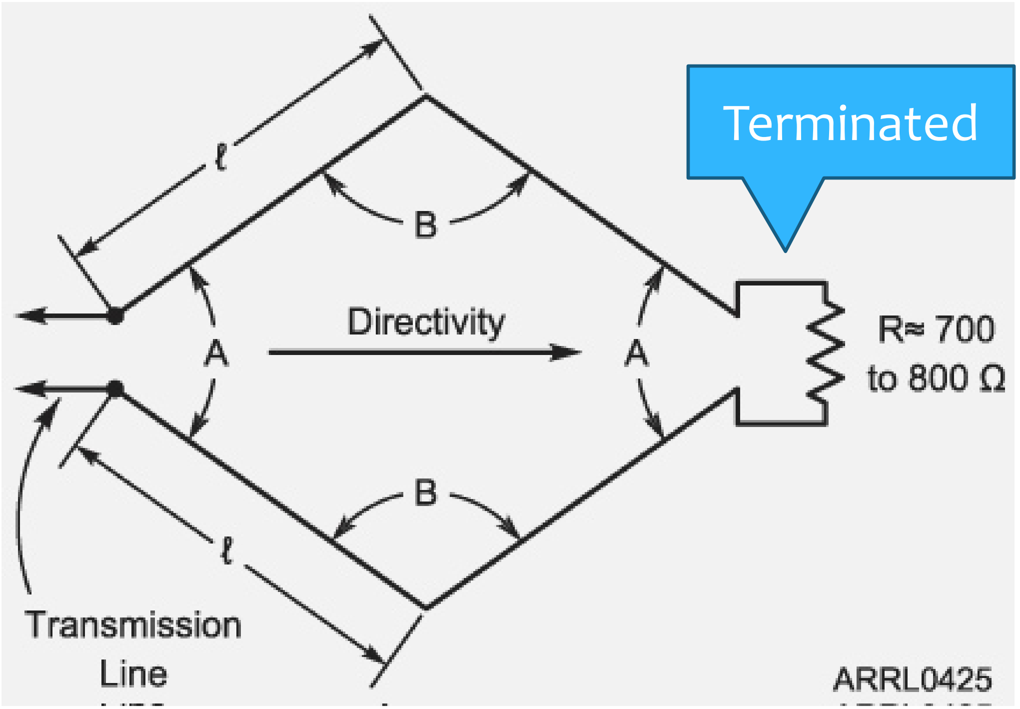
Resonant (non-terminated) is bidirectional

Rhombic Antenna

Non-resonant -- Terminated

Pg 9-15

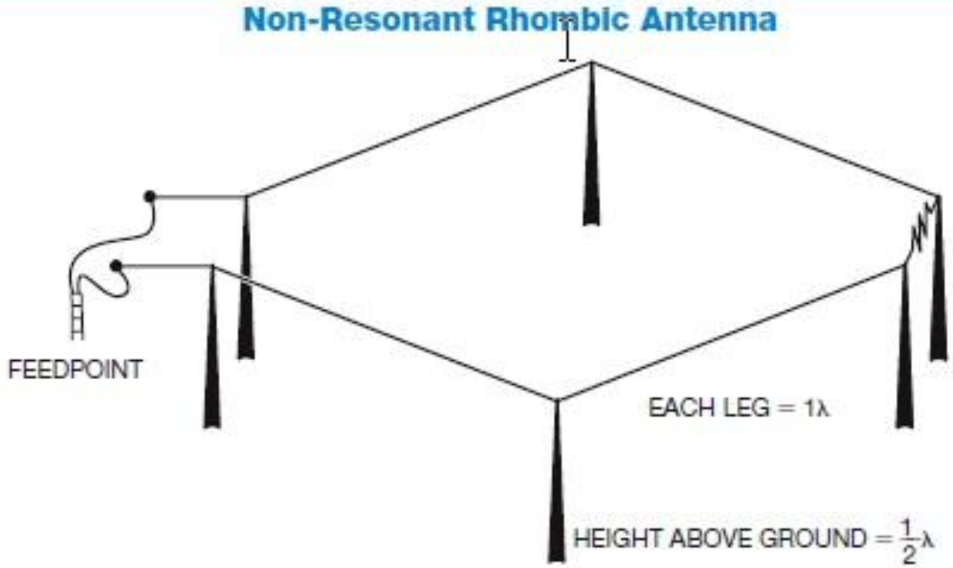
* The terminating resistor causes the antenna to be unidirectional. E9C06
* Offers a resistive and constant load over a wide frequency range.
* All rhombics require a large area and at least 4 sturdy supports.



Non-resonant (Terminated) -- Unidirectional

Rhombic Antenna

FYI



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

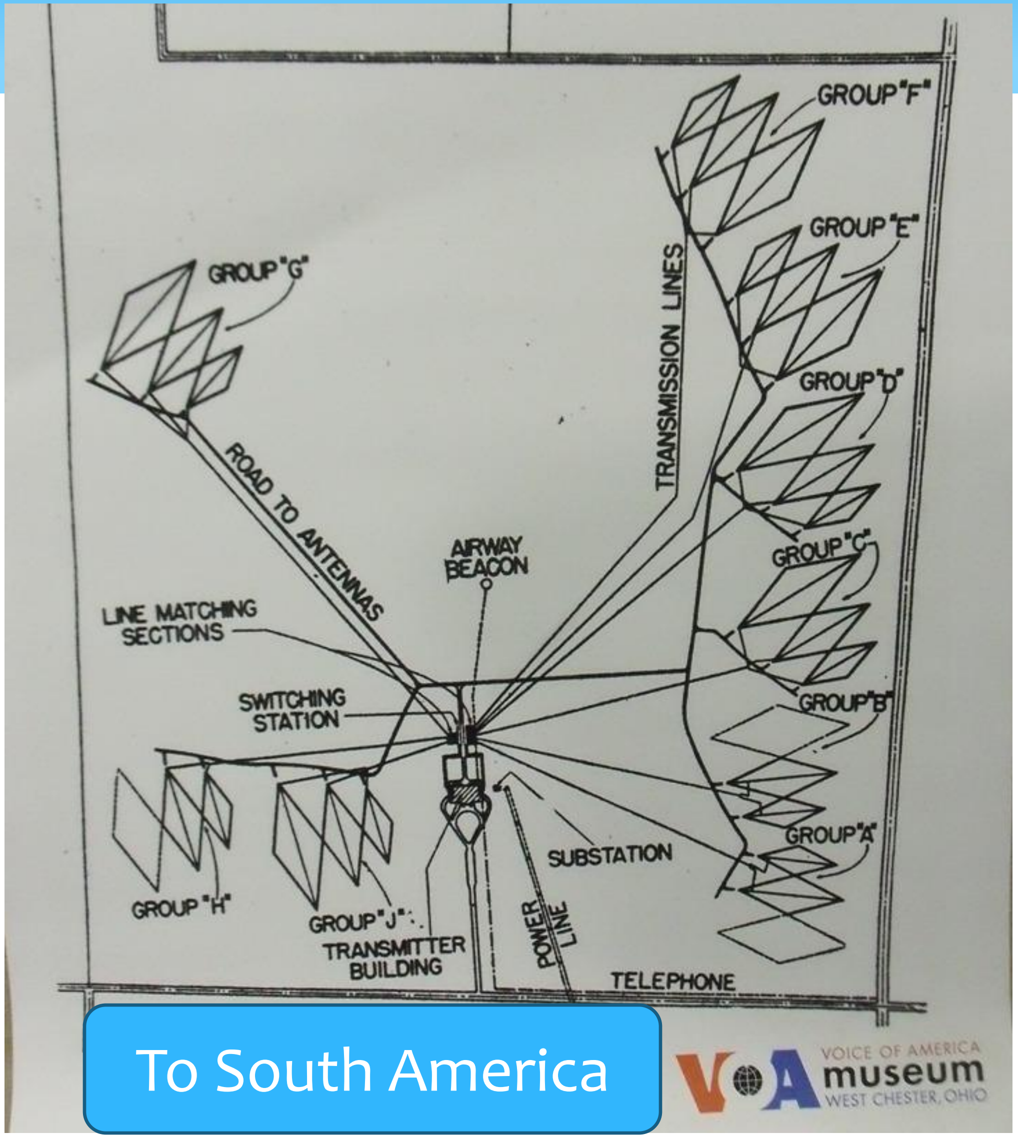
Voice Of America Museum
West Chester Ohio

Began operation during WW2 in February 1942 to counter Nazi propaganda

Active during the Cold War

Decommissioned in 1994

VOA's Rhombic HF Antenna Farm

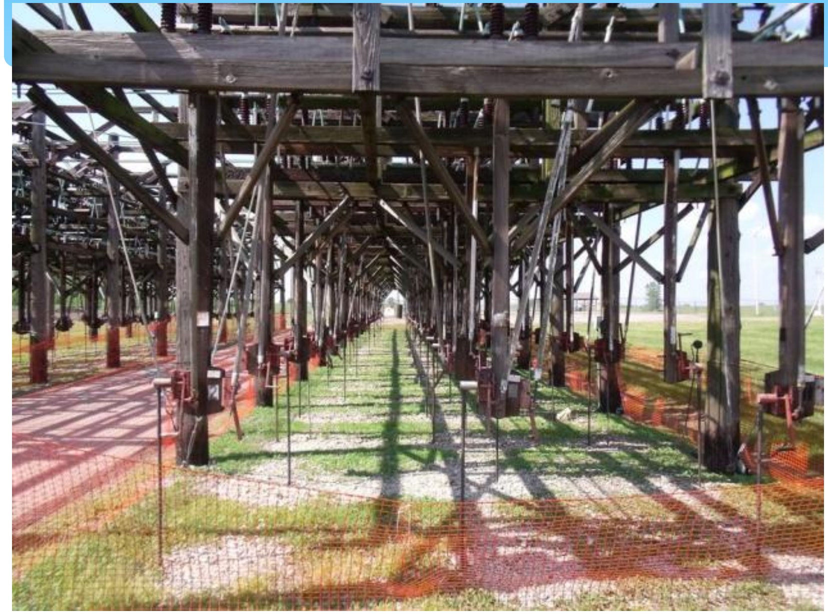


To Europe

To Africa

To South America

Antenna Switches – VOA Style

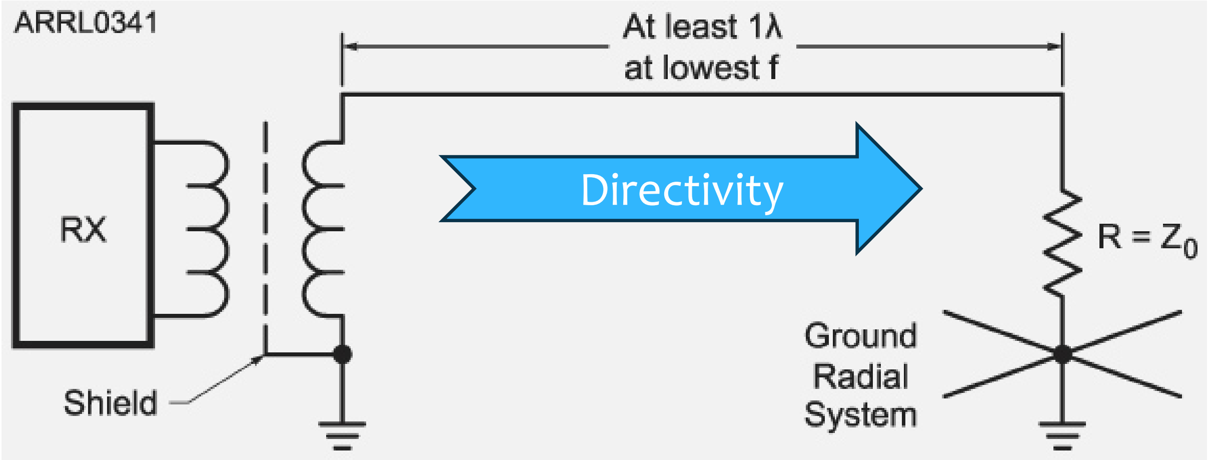


Beverage Antenna

Low-noise **Receiving** Antenna

Pg. 9-16

* A straight wire, 8 – 10 feet above the ground
* At least one wavelength long at the lowest frequency E9H01
  * Longer antenna provide increased gain and directivity
* Requires a terminating resistor on the far end
* On the 160 m and 80 m bands, the atmospheric noise is generally so high that gain over a dipole is not important 9H02



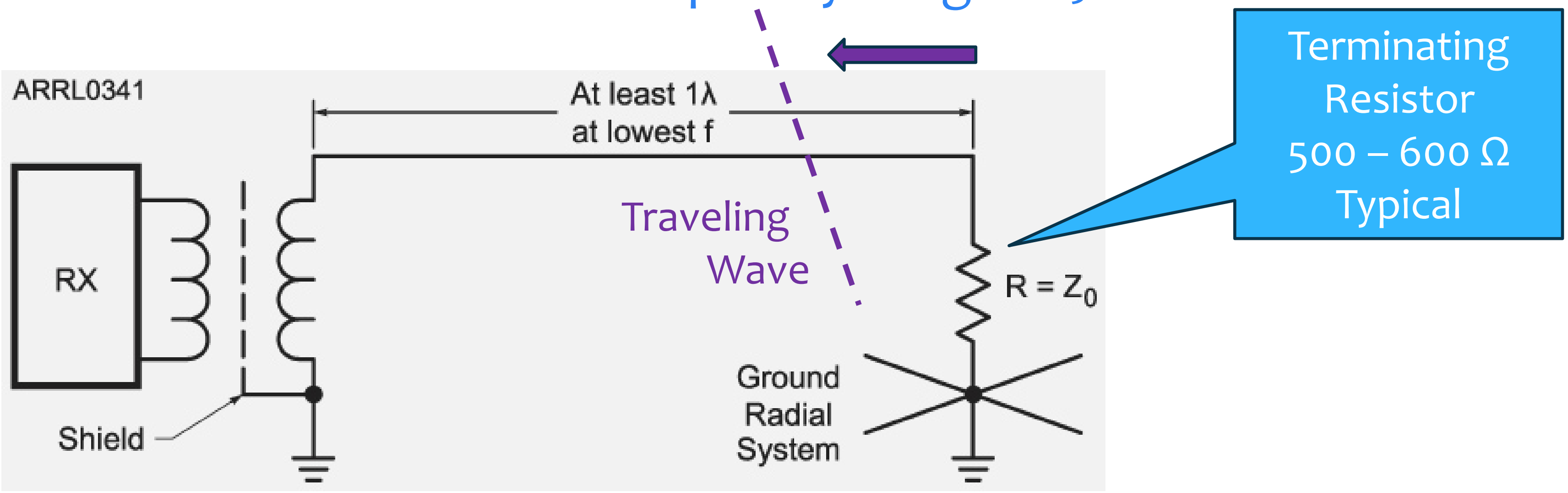
This is a lossy antenna – but it rejects noise very effectively

Beverage Antenna

Terminating Resistor

Pg. 9-16

- Remember, this is **not** a transmitting antenna.
- A terminating resistor at the far end of the antenna absorbs signals in the reverse direction. E9H01
- The value of the terminating resistor is selected for minimum SWR over the desired frequency range. E9H01



Phased Arrays

Verticals

Pg. 9-17

* 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.

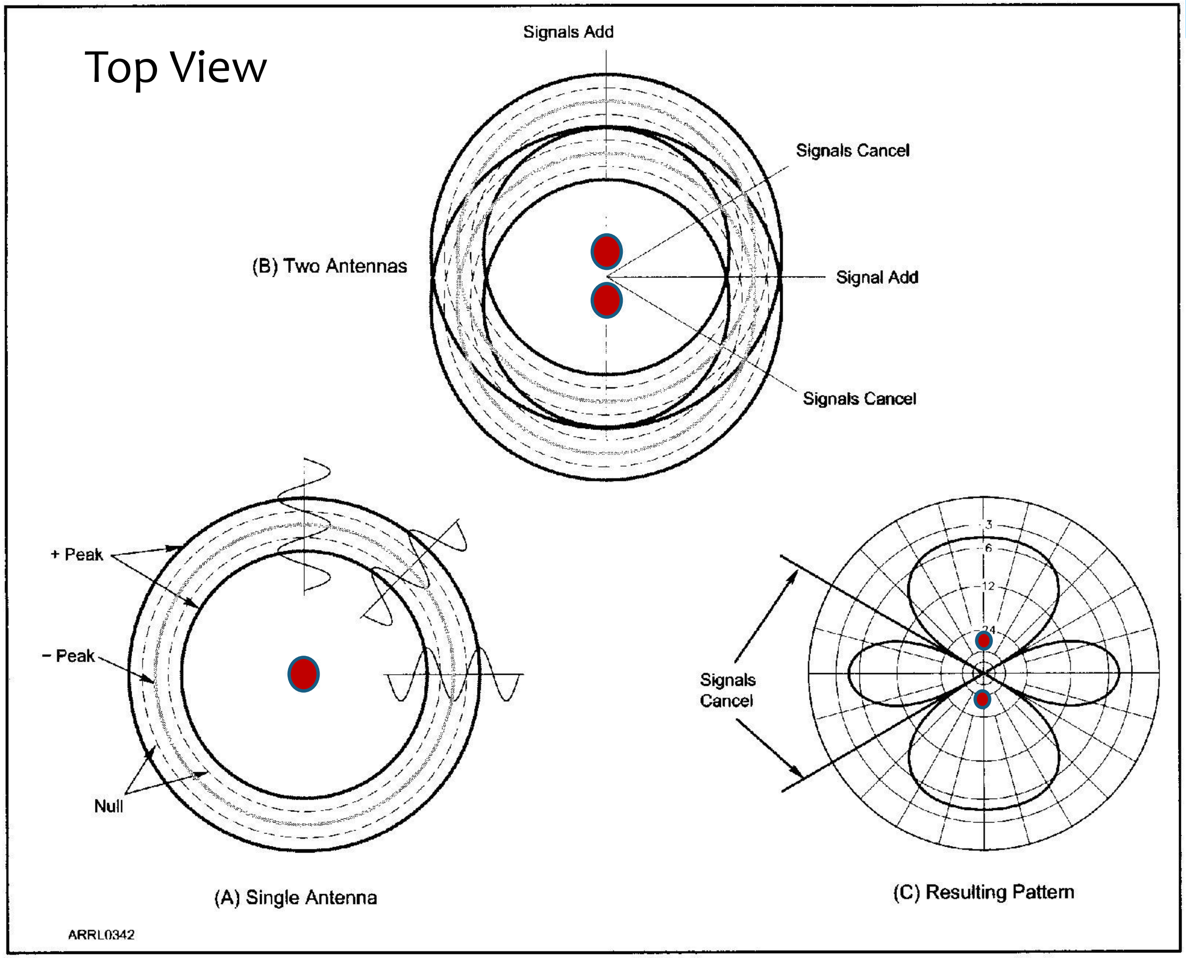
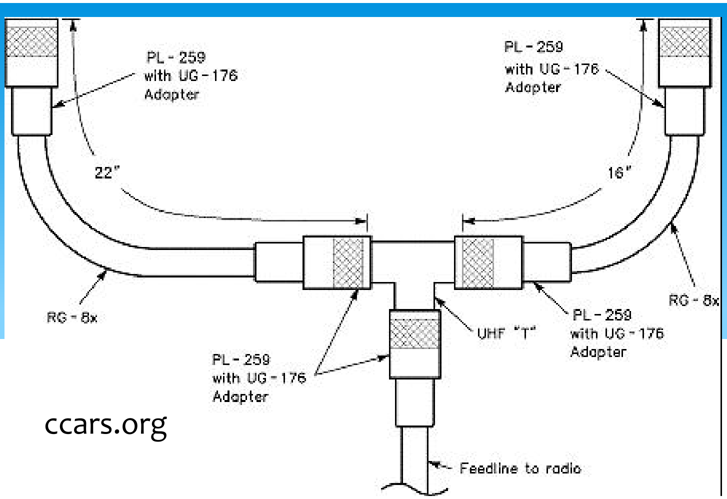


Figure 9-15 — (A) shows the signal being radiated from a single antenna with its current (I) flowing perpendicularly to the page. At (B) a second antenna has been added and the radiated signals reinforce and cancel along different directions, leading to the radiation pattern for the array in (C).

Phasing

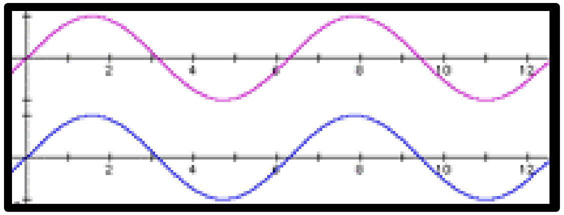
FYI



ccars.org

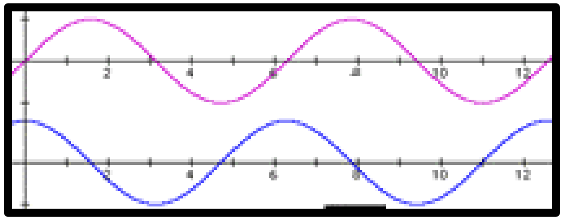
* IN PHASE
  0 degrees

$\Phi = 0°$



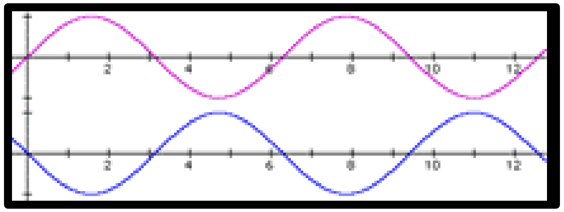
* 90 degrees
  out of phase

$\Phi = 90°$



* 180 degrees
  out of phase

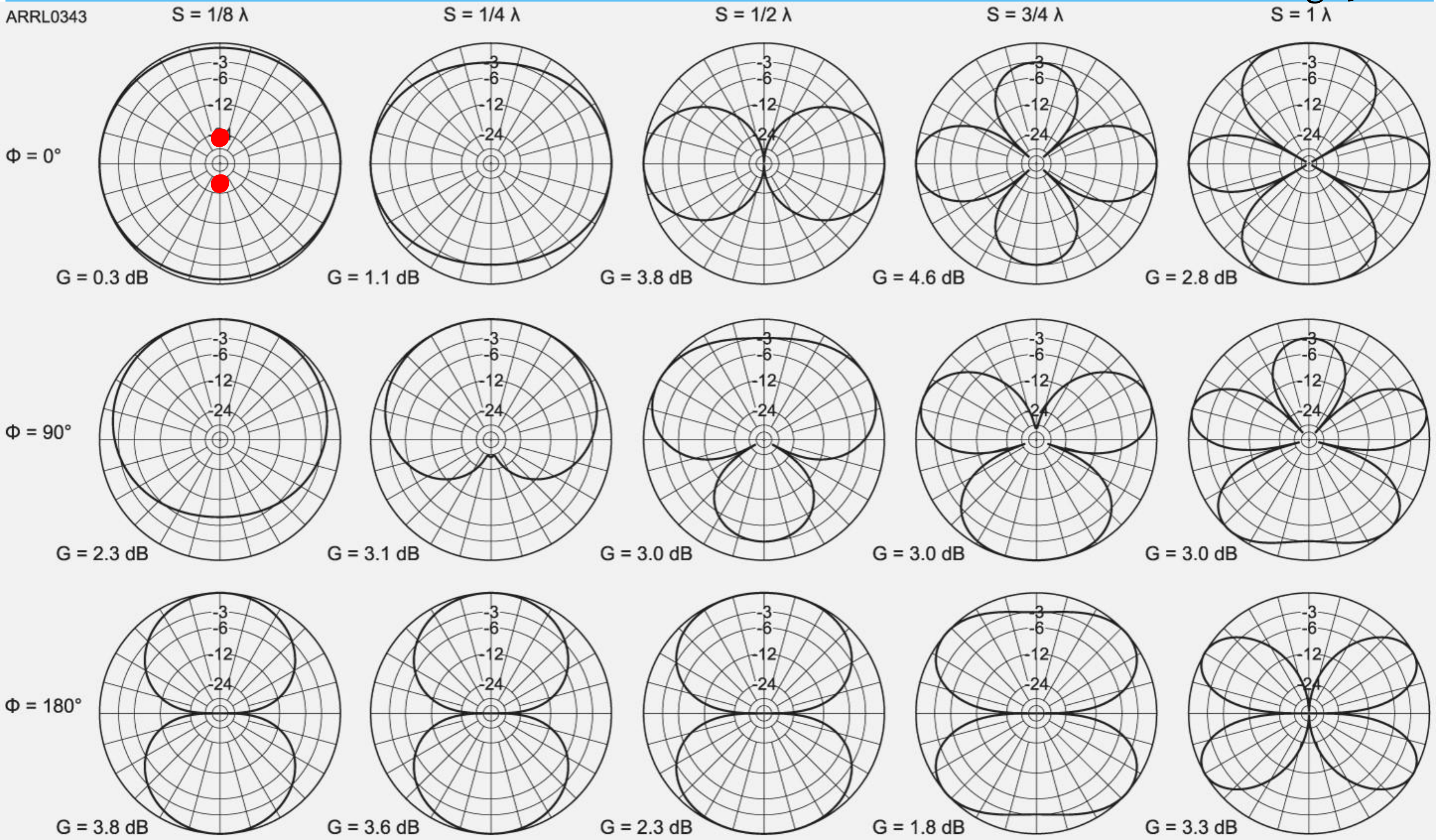
$\Phi = 180°$



Φ is the Greek Letter Phi

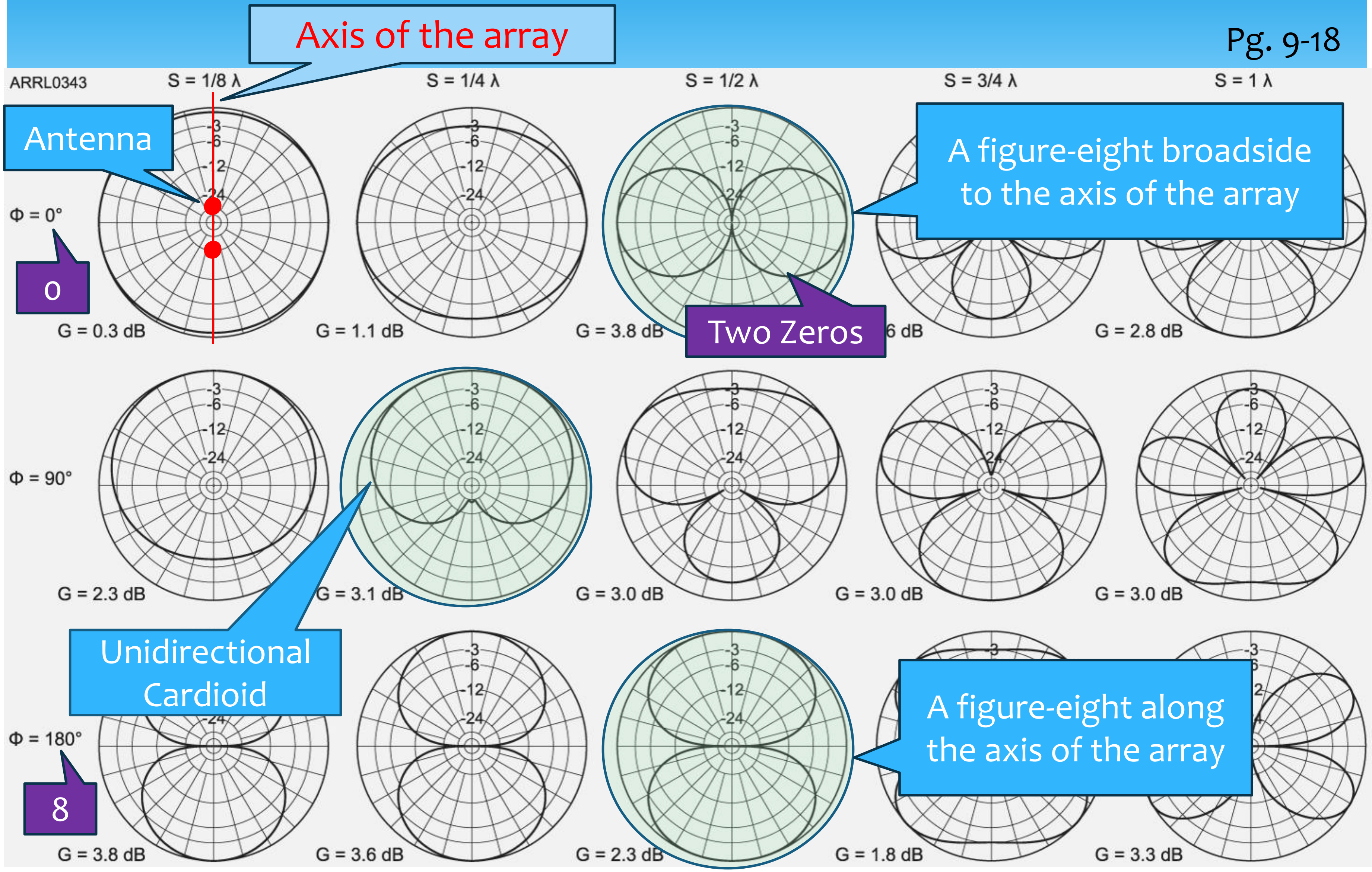
Two-Vertical Radiation Pattern

Two Variables: Phase and Separation Distance



Two-Vertical Radiation Pattern

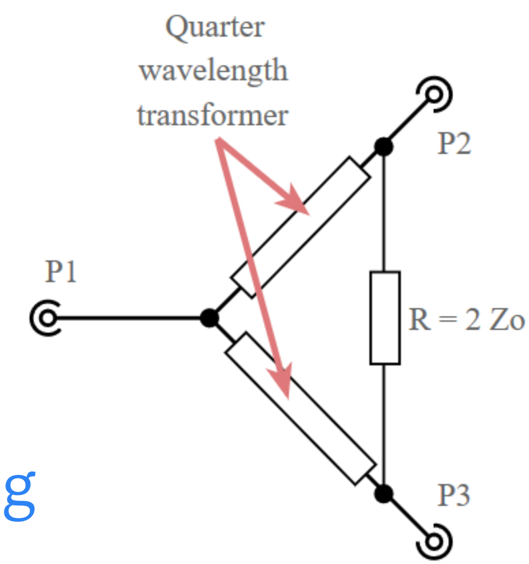
Pg. 9-18



Phased Verticals

Pg 9-20

- **Multiple driven elements with phasing lines control the antenna's radiation pattern.** E9E11
  - The lines are of a carefully calculated and measured lengths
  - Useful for 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. E9E08

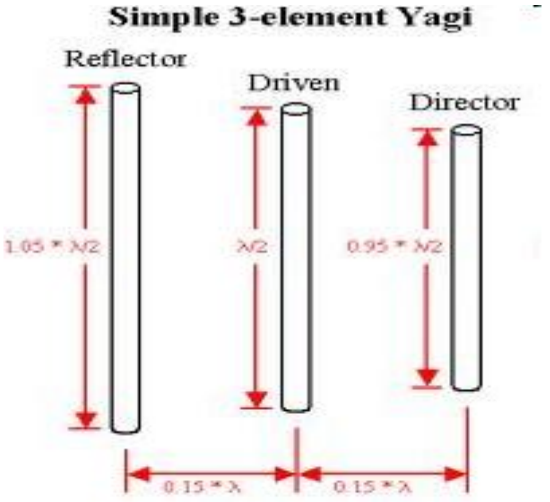


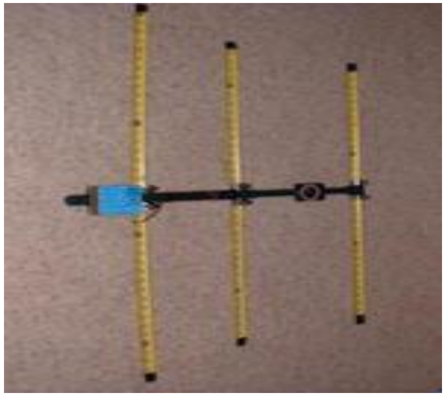
Wilkerson Divider
www.electronicnotes.com

Yagi Antennas

9-20

- The approximate length of the driven element of a Yagi antenna is **1/2 wavelength.** E9D05
- A **two-element** Yagi will normally consist of a **driven element and a reflector** because it has higher gain than a driven element and a reflector E9D11
- **The reflector is longer than resonance and the director shorter than resonance in order to control the phase shift.** E9D12

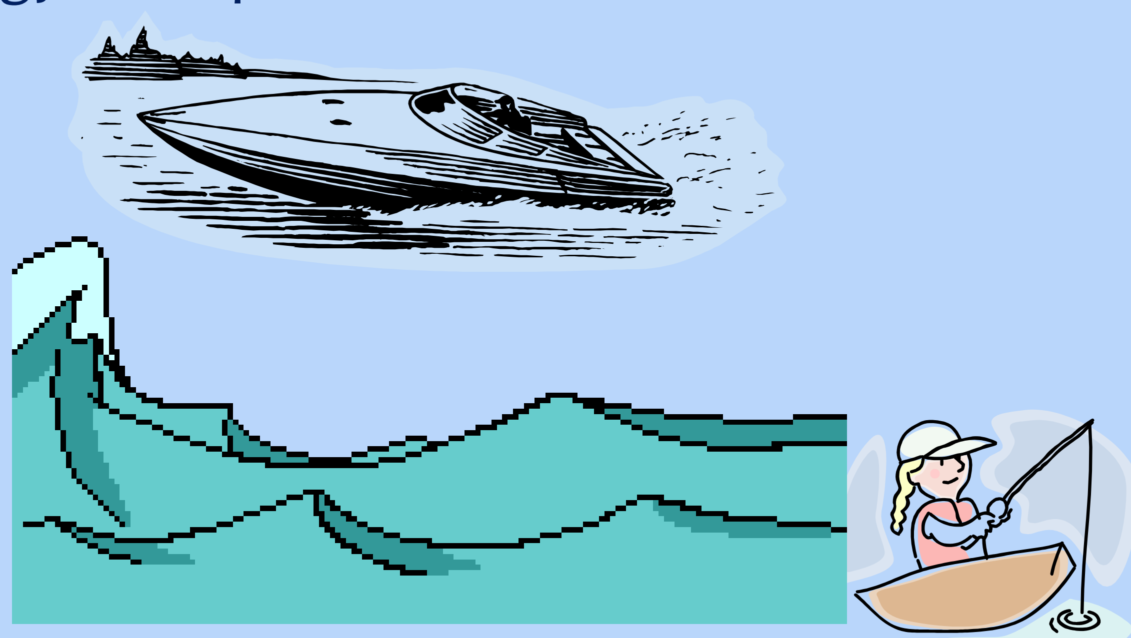




Parasitic Energy

With only one driven element, how do we get energy into the other elements?

* Energy is coupled from one boat into the other.



Yagi Antennas

FYI

- This Parasitic action creates:
  - GAIN in the forward direction
  - REJECTION in other directions

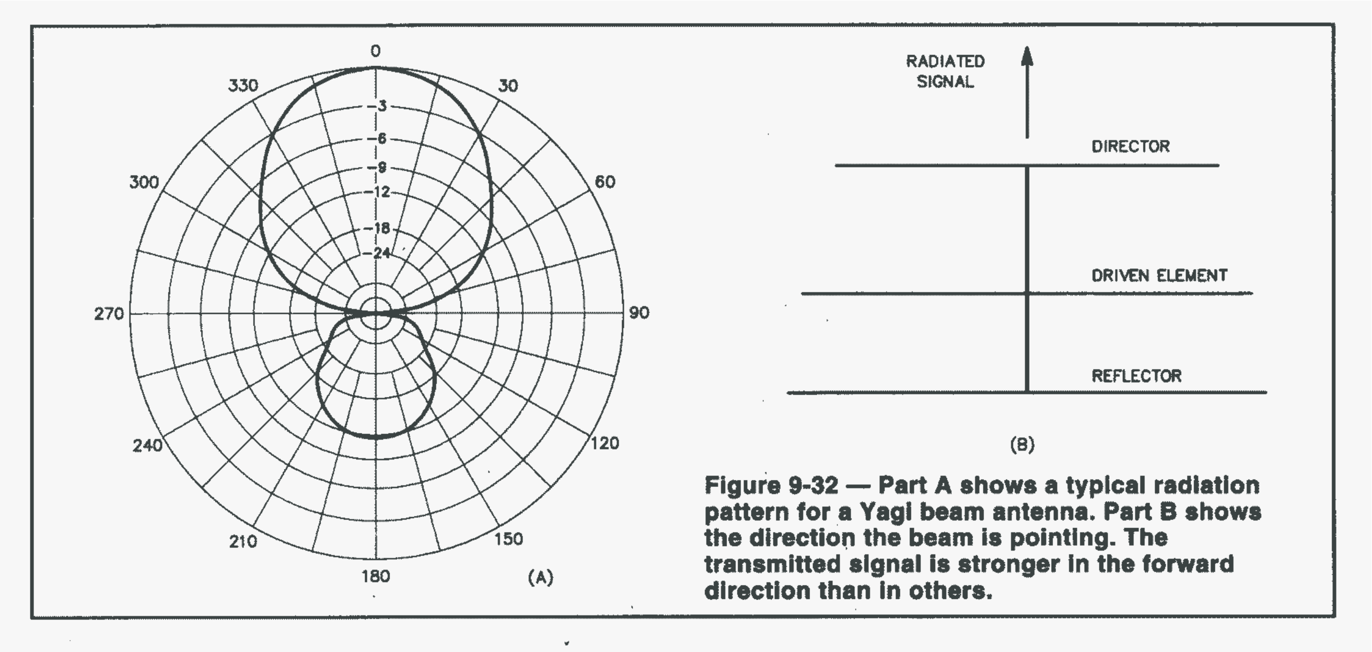


Figure 9-32 — Part A shows a typical radiation pattern for a Yagi beam antenna. Part B shows the direction the beam is pointing. The transmitted signal is stronger in the forward direction than in others.

Satellite Antenna Systems

Pg. 9-21

Yagi Antennas

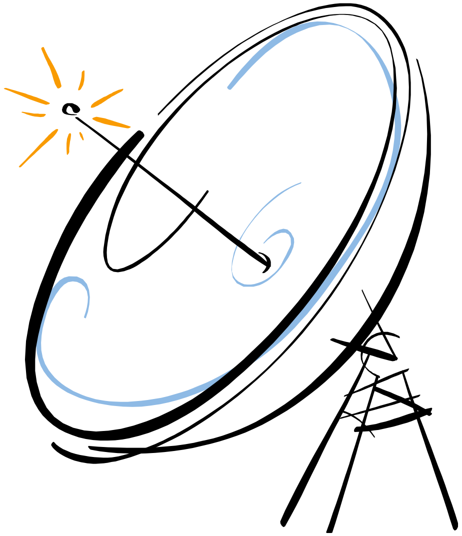
http://kb5v… …ogspot.com/

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

Dish Antennas:

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

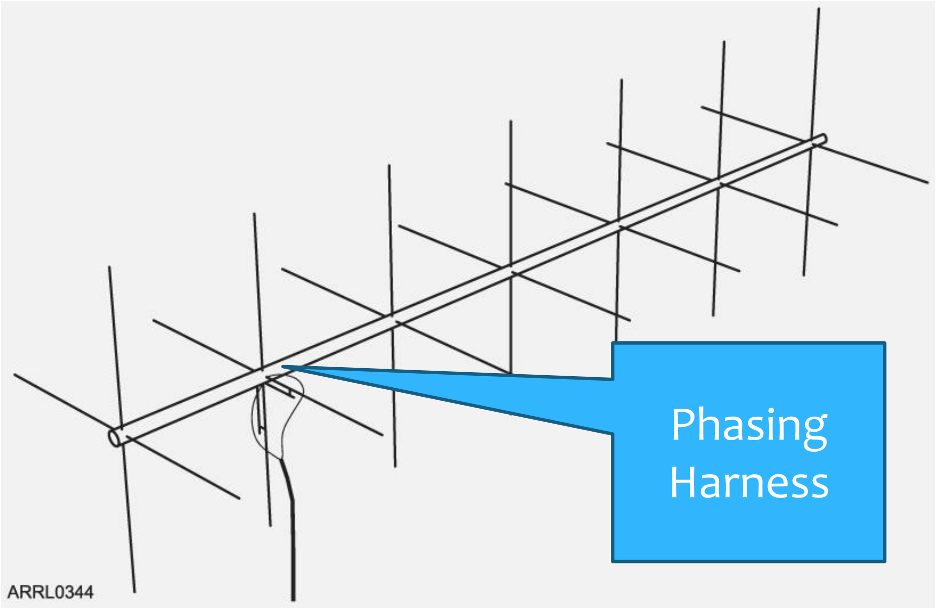
* E9E01



Polarization

Pg. 9-21

* Circularly polarized antennas are preferred for satellite work because the orientation of the satellite may be constantly changing.

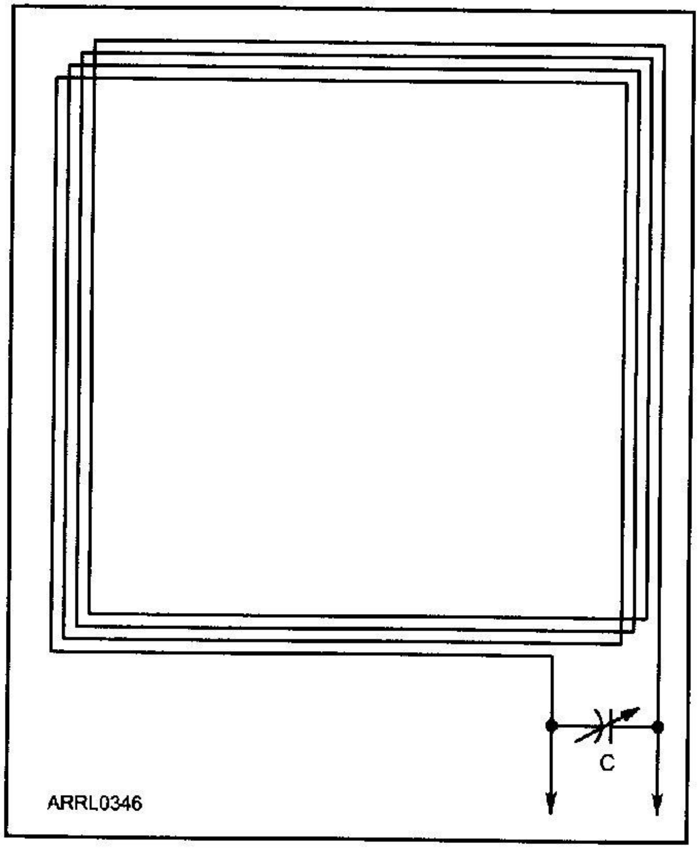


* A circularly polarized antenna can be constructed from two dipoles or Yagis mounted 90 degrees with respect to each other and fed 90° out of phase. E9E01

Receiving Loops

Pg. 9-20

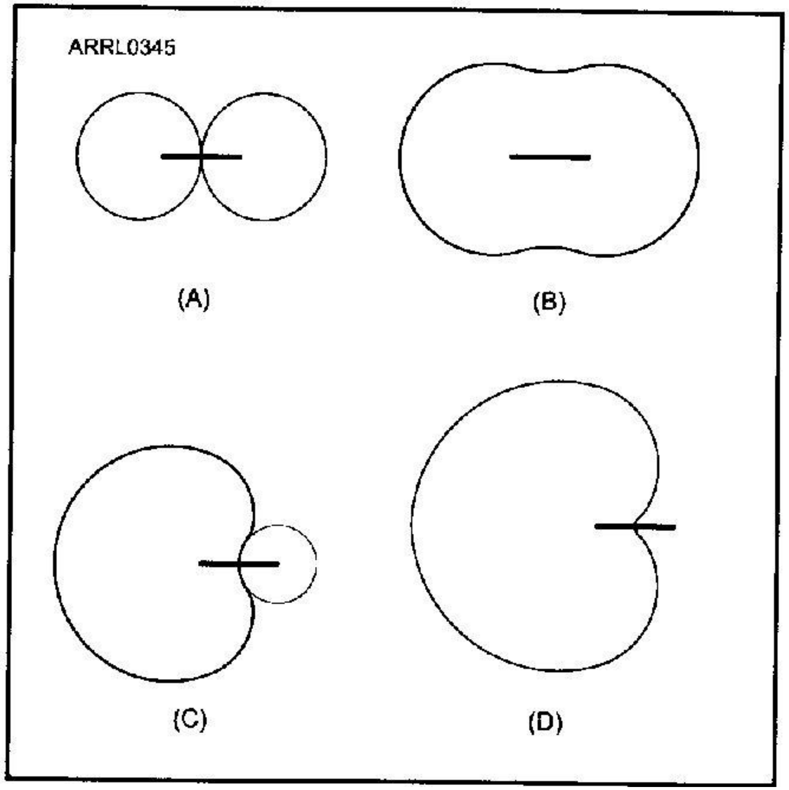
* A simple receiving antenna at MF and HF is a small loop antenna consisting of one or more turns of wire wound in the shape of a large open inductor or coil.
* Loops can provide good nulls
  * Nulls are useful for radio direction finding
* The output voltage of the loop can be increased by increasing the number of turns in the loop or the loop area. E9H10



Small Loops

Pg. 9-20

- Maximum response is in the plane of the loop.
  - Very short: ≤ 0.08 λ
  - Receives the magnetic field and exhibits two nulls (A)
    - If unshielded, it also receives some stray electric field, degrading the null (B)
  - An electrostatically shielded loop eliminates unbalance capacitive coupling to the antenna's surroundings, improving the depth of the nulls. E9E04



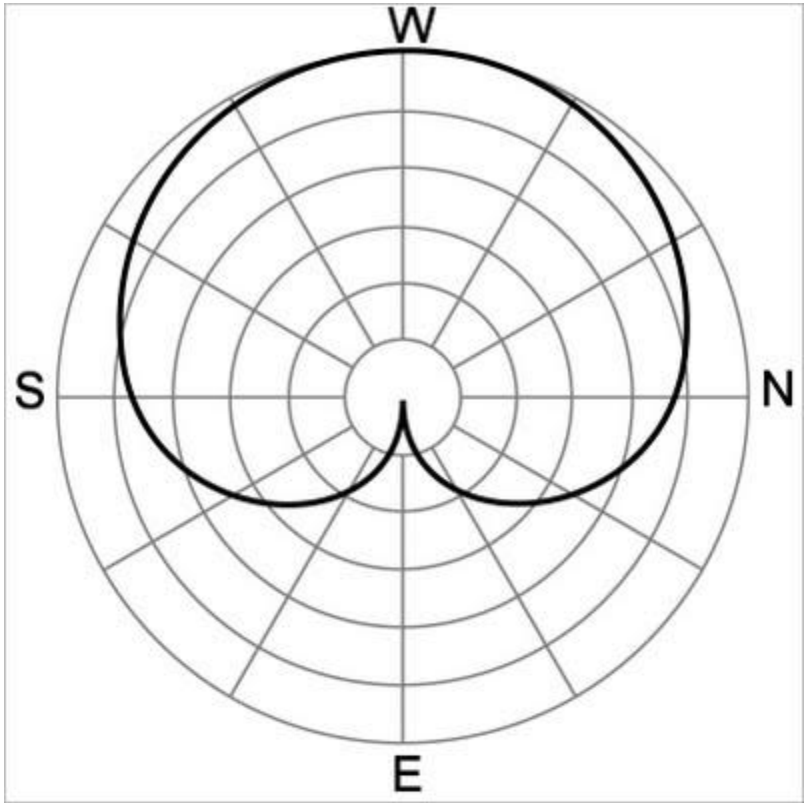
Loops

Pg. 9-18

tighr.org

* The simple wire loop is bidirectional. E9H05
* By adding a sense antenna (omnidirectional whip) a loop can be made to have only one null. E9H08
* The loop and the sense antenna combine to form a **cardioid pattern that can have a very sharp null.**
  * **Great for Direction Finding!**

E9H04



Single-Turn Loops

Pg. 9-23

- Receive only operation
- < 0.1 λ in circumference
- Typically configured vertically
- Exhibit a **cardioid** pattern E9H09

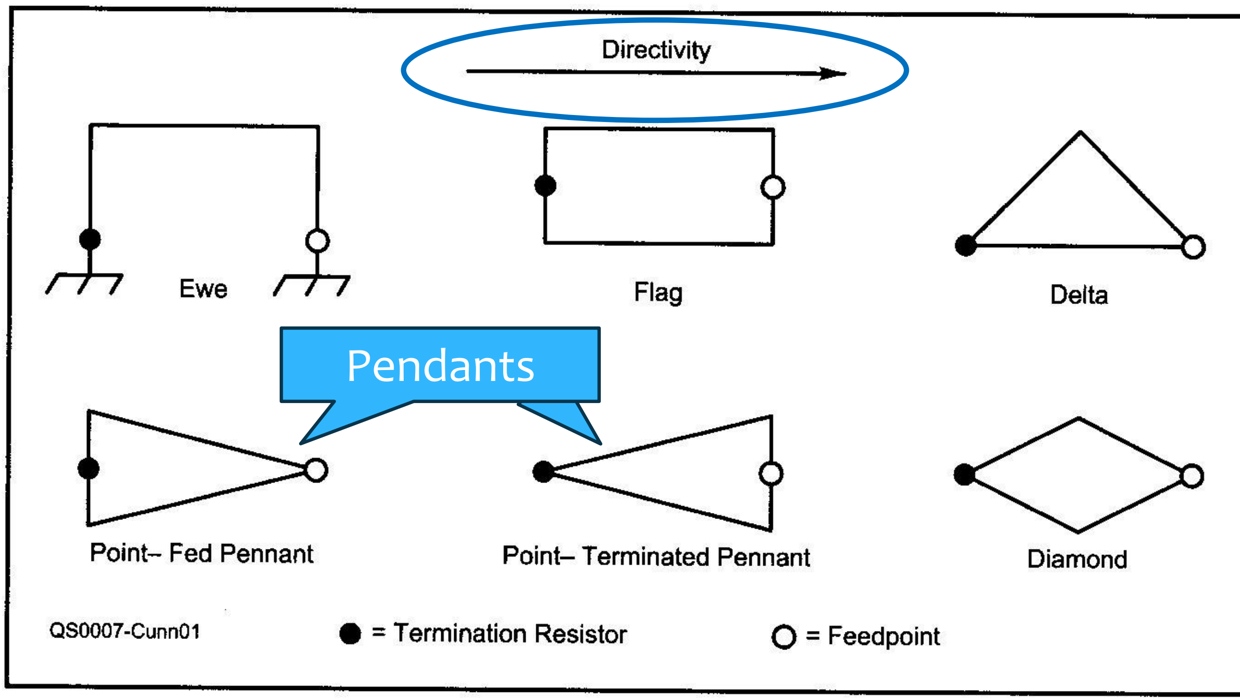


Figure 9.22 — Configurations of single-turn low-frequency receiving antennas showing termination and directivity. Termination resistance is typically around 900 Ω.

Receiving Directivity Factor

Pg. 9-25

* The "claim-to-fame" of these receiving antennas (including the Beverage) is their ability to reject unwanted noise in particular directions, yielding an improved signal-to-noise ratio.
* The **Receiving Directivity Factor** (RDF) is the peak antenna gain compared to the average gain over the hemisphere around and above the antenna. E9H03
* The desired received signal strength may be dramatically lower than what a dipole would exhibit, but the noise is even lower.

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.

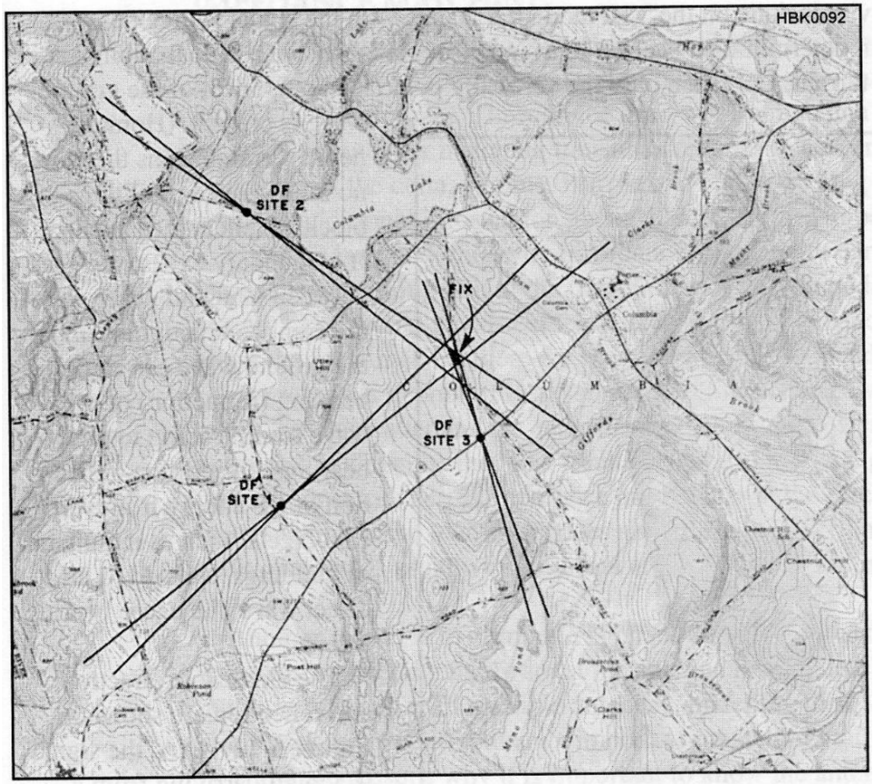


Figure 9-20 — Bearings from three RDF positions are drawn on a map to perform triangulation of a signal source. This technique allows antennas with bidirectional patterns to be used since the lines on multiple bearings will only intersect at the signal source.

Direction Finding

Fox Hunting

Pg 9-25

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)

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%

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

A. The radiation resistance increases
B. The radiation resistance decreases
C. The radiation resistance becomes imaginary
D. The radiation resistance does not depend on frequency

Section 9.3

Antenna Systems

Effective Radiated Power

Pg. 9-25

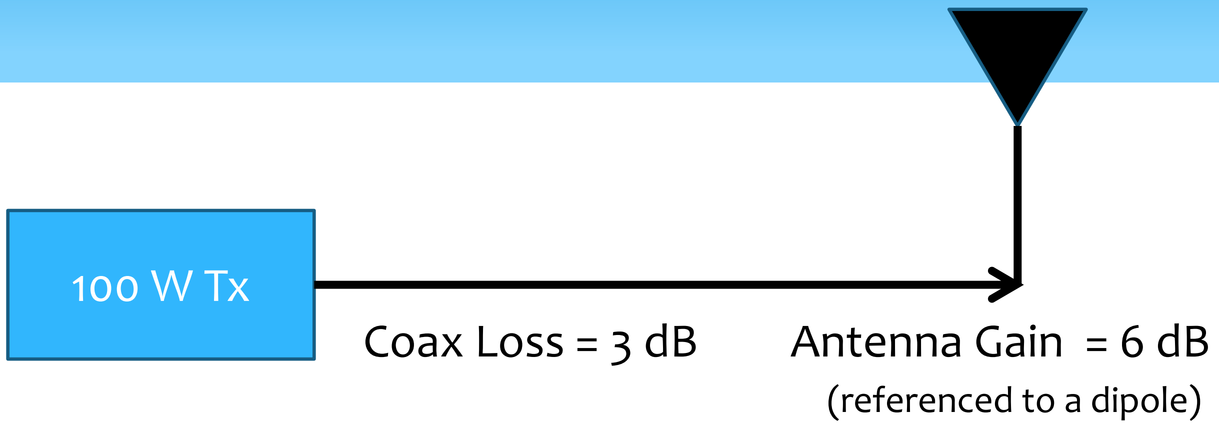
* **ERP** Effective Radiated Power (referenced to a dipole)
* **EIRP** Effective Isotropic Radiated Power
* **HAAT** Height Above Average Terrain
* **TPO** Transmitter Power Output

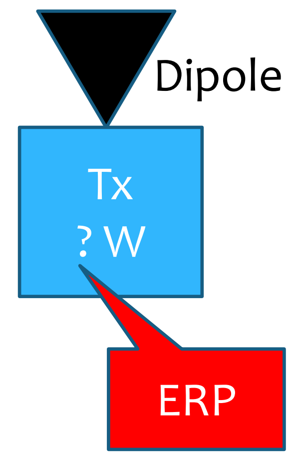
* **How much RF power does my station radiate as compared to that if my antenna was a simple dipole?**

* **ERP is the term describing total radiated power taking into account all gains and losses. E9A02**

Effective Radiated Power

Pg 9-22





- 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 9-26

Total Transmitter Power

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)

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

* **System Gain = sum of the Gains – sum of the Losses**
* Gains: Antenna gain
* Losses: Feedline; duplexer, circulator …

System ERP

Pg 9-27

Example 9-6

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?

E9A02

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

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

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

[E9A06]
200 W transmitter
System Gain of 2 dB

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

[E9A07]
200 W transmitter
System Gain of 1 dB

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

Antenna Systems
Impedance Matching

Pg. 9-28

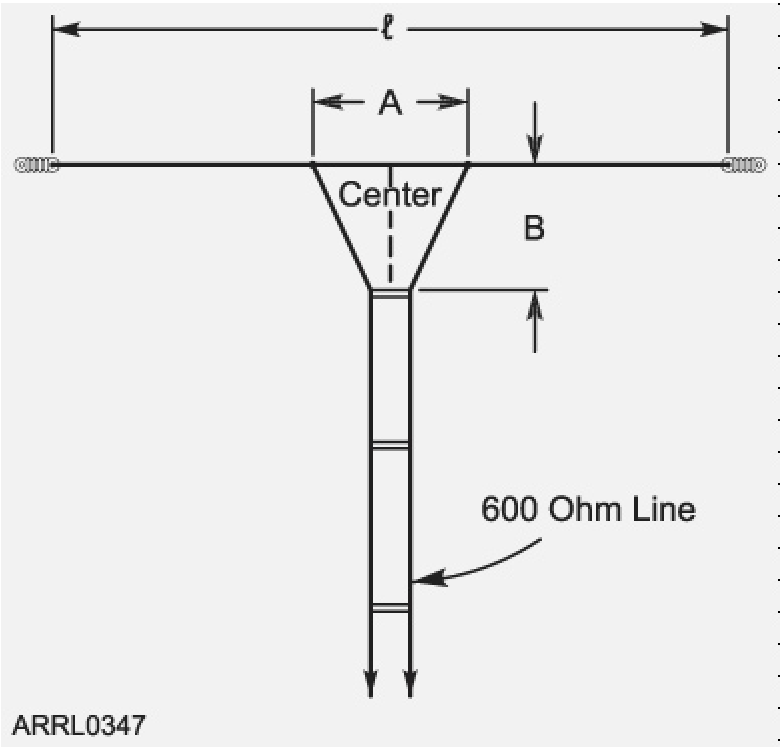
- When an antenna is matched to the feedline, maximum power transfer to the antenna is achieved and the standing wave ratio is minimized.
  - This is of benefit in both transmit and receive
- Various forms of matching the feedline to the antenna
  - Delta
  - Gama
  - Hairpin
  - Stub
  - Balun

NOTE: Except for the Balun, these matching forms are generally useful only on monoband antennas

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.
* Matches a higher impedance transmission line to a lower impedance antenna.

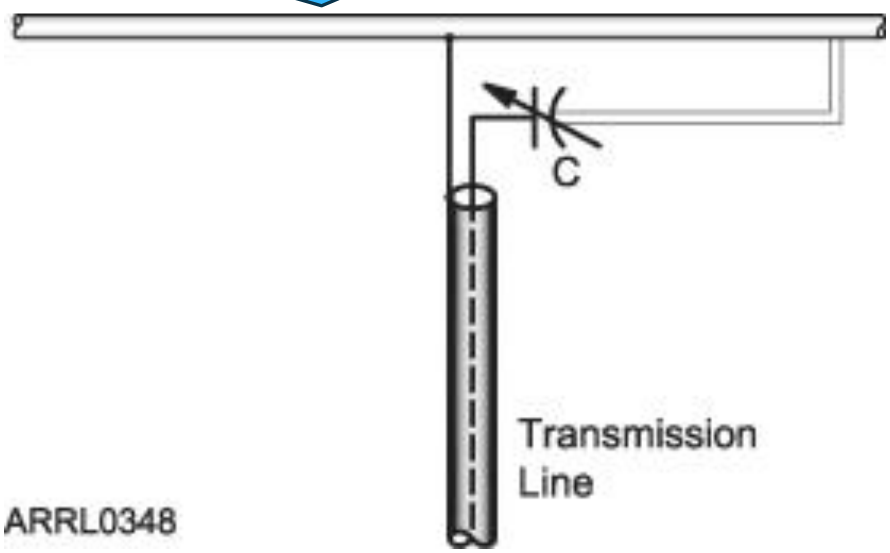


The Gama Match

Pg. 9-25

* Resembles the Greek letter Gamma Γ
* Matches an unbalanced feed line to an antenna by connecting the shield to the center of the antenna's driven element and the coax's center conductor a fraction of a wavelength to one side of the driven element. E9E02

The Driven Element can be grounded



Capacitive reactance can be added in series to cancel out the inductive reactance. E9E04

The Gamma Matched Tower

Pg. 9-26

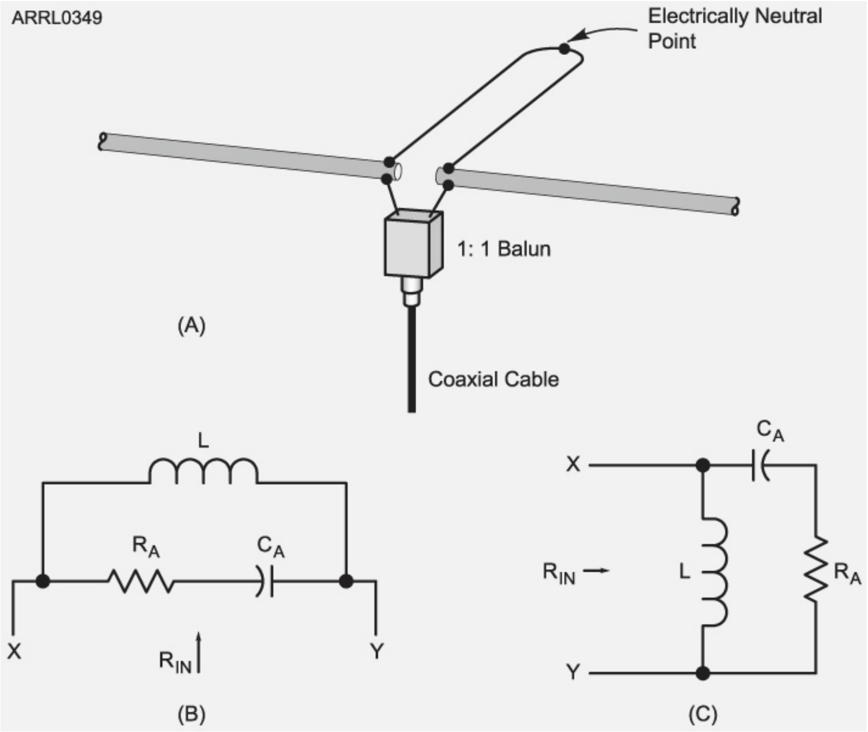
- Gamma matches can also be used to match the impedance at the base of a grounded towed to be used as a vertical antenna. E9E09
- In this application the driven element is turned on its side and the missing half of the antenna is provided by the ground system.

www.iv3prk.it

The Hairpin (Beta) Match

Pg. 9-29

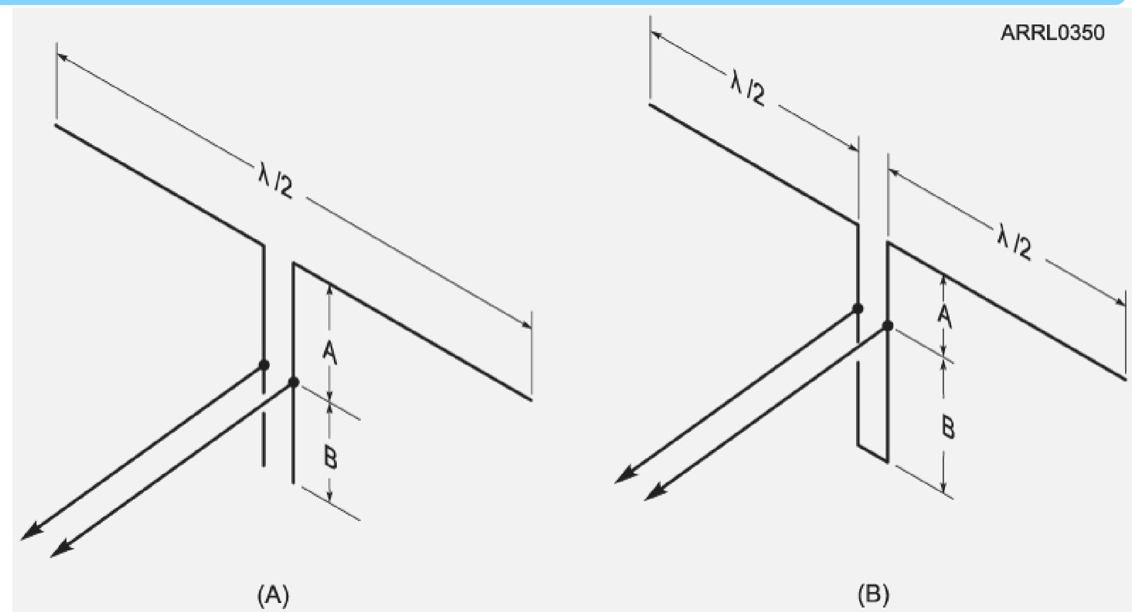
- The driven element must be insulated from the boom. E9E01
- The driven element is cut a bit short, making it **capacitive**. E9E05
- The hairpin's inductance cancels out the capacitive reactance.
- Viewed as an equivalent **lumped constant network**, we can see that this is the equivalent of a "L" network.

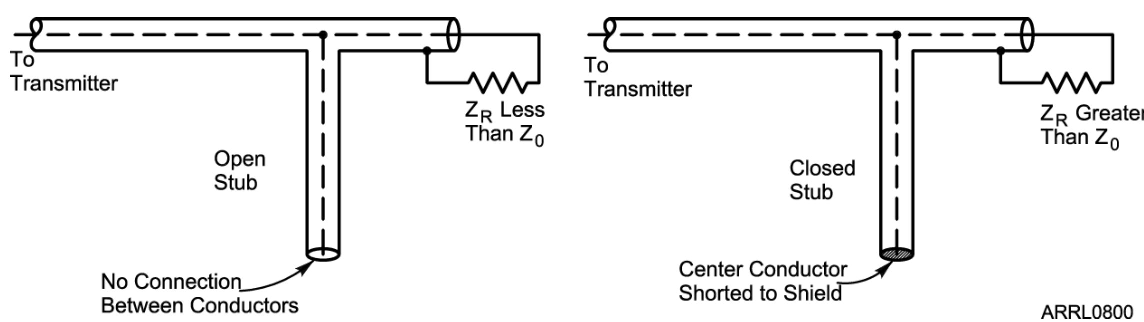


The Stub Match

Pg. 30

* We can **stub match** a transmission line to an antenna by connecting an appropriate section of transmission line in parallel with the feed point. E9E03
  * An open stub looks like a capacitor
  * A shorted stub looks like an inductor

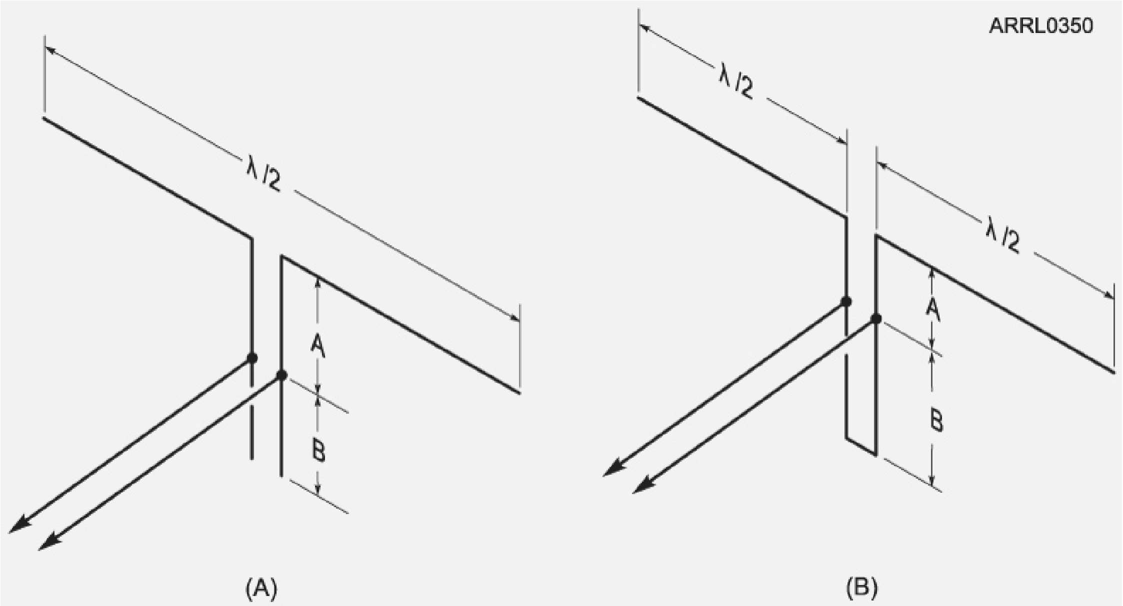




The Stub Match

Pg. 9-30

* With a stub match, the challenge is to find the right stub impedance and the right point in the main feedline to attach it.
* The **Smith Chart** is a tool that helps determine the length and position of the stub. E9G05



A = ?

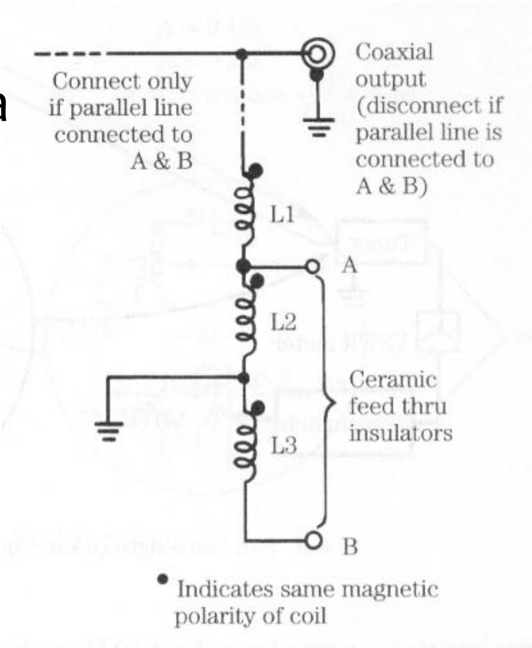
B = ?

The Balun Match

FYI

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 impedance 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

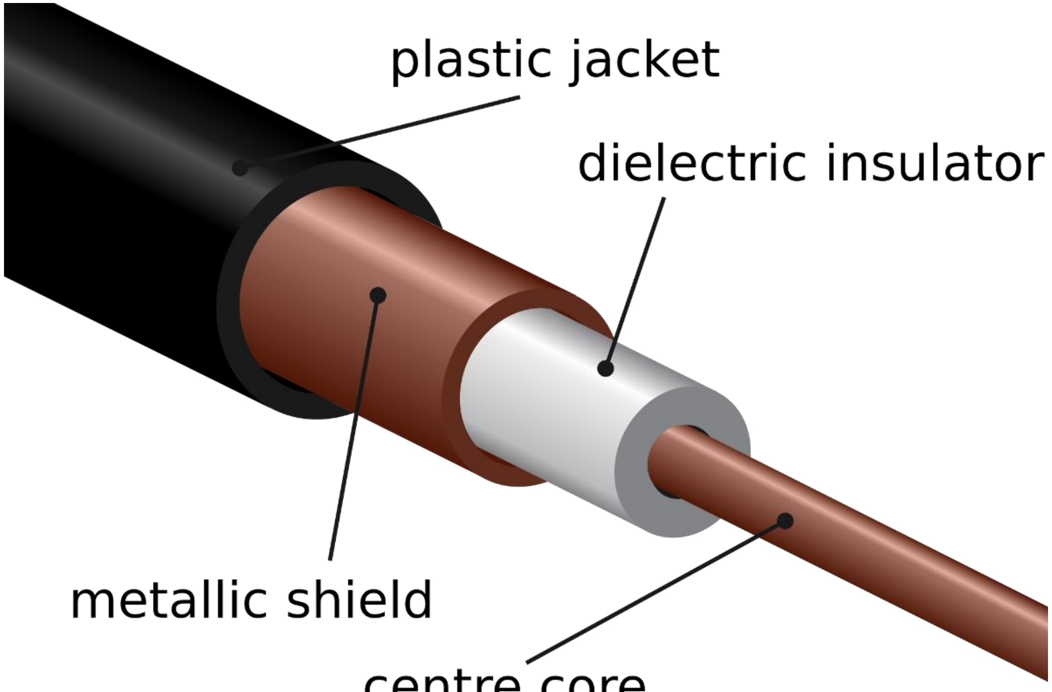


E9E02 What is the name of an antenna matching system that matches an unbalanced feed line to an antenna by feeding the driven element both at the center of the element and at a fraction of a wavelength to one side of center?

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

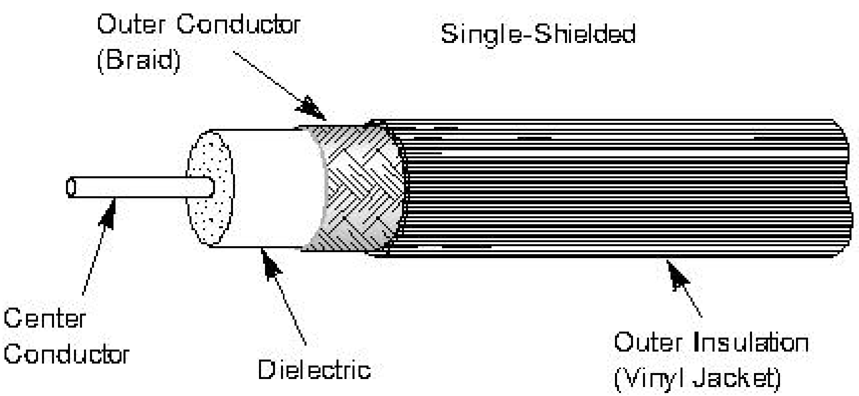
Section 9.4

Transmission Lines

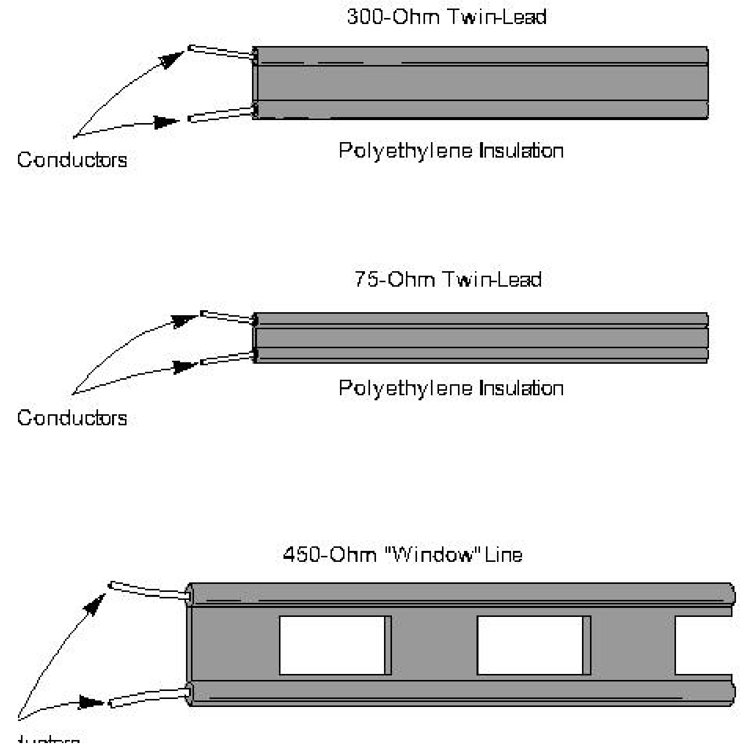


Transmission Lines

Pg 9-31



Coax

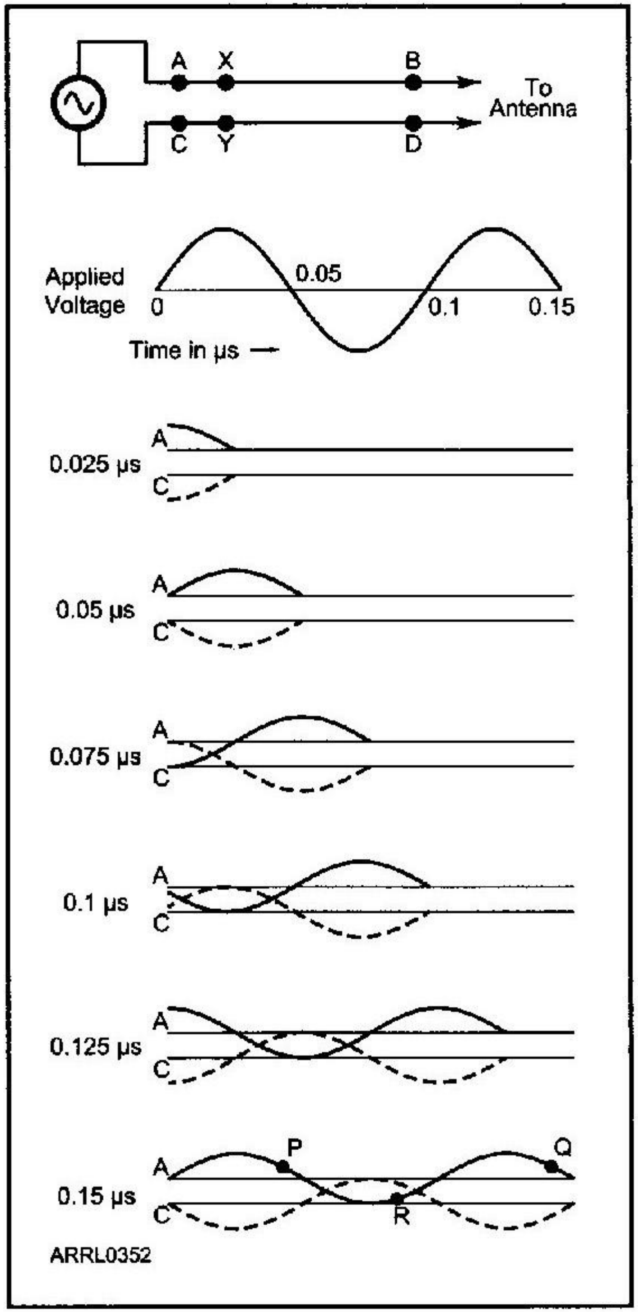


Parallel
Conductor

Current in a Transmission Line

Pg. 9-31

- 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. 9-31

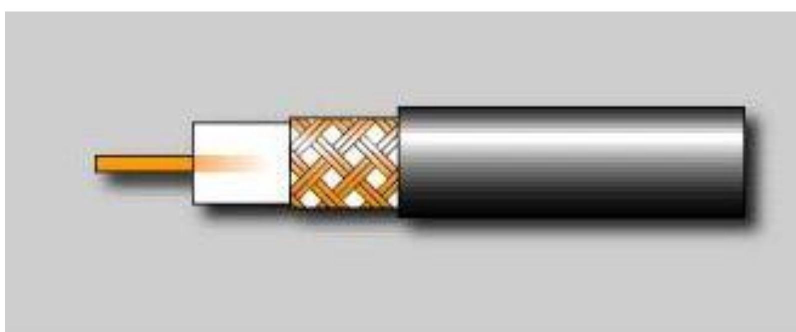
300,000,000

- 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 insulating dielectric has the biggest effect on the velocity factor of a transmission line. E9F02

Transmission Line Mechanics

Pg. 9-31

* The **velocity factor (VF)** is:
* The ratio of the actual velocity at which a signal travels along a line to the speed of light in a vacuum
* The **velocity factor** of a transmission line is the velocity of the wave in the line divided by the velocity of light in a vacuum E9F01
* Determined primarily by the dielectric materials used in the line.



Wavelength vs. Electrical Length

Pg. 9-32

- The **electrical length** of a transmission line is **not the same** as its **physical length.**
- The waves move slower in the line than in the air, so the physical length will always be shorter than the electrical length. E9F03

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

or

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

where:

f = operating frequency (in MHz).

VF = velocity factor.

Eqns 9-7 & 9-8

Example 9-7

Pg. 9-32

* What would be the physical length of an **air-insulated** transmission line that is electrically **one-half wavelength long** at 14.1 MHz. E9F06
* Note: The VF of an air-insulated line is almost **1 (100%)**
* L = VF x 300/f
* $L = 1 \times \frac{300}{14.1} = 1 \times 21.27 = 21.27$ meters for a full λ
* To find 1/2 λ, divide by 2: 21.27 / 2 = **10.6 meters**

Feed Line Specs

Pg 9-30

Table 9.1
Characteristics of Commonly Used Transmission Lines

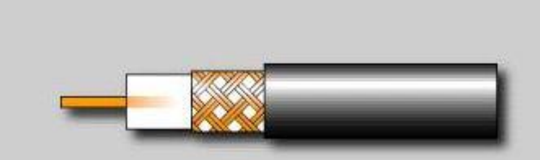
Type of Line	Z_0 Ω	*VF %*	*Cap. pF/ft*	*Diel. Type**	*OD inches*	*Max V (RMS)*	*Loss (dB/100 ft) at 100 MHz*
RG-8	50	82	24.8	FPE	0.405	600	1.5
RG-8	52	66	29.5	PE	0.405	3700	1.9
RG-8X	50	82	24.8	FPE	0.242	600	3.2
RG-58	52	66	28.5	PE	0.195	1400	4.3
RG-58A	53	73	26.5	FPE	0.195	300	4.5
RG-174	50	66	30.8	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* (23rd edition), Chapter 23, Table 1

Feed Line Losses

Pg 9- 33 & 34

- The most common feed lines are:
  - Coax
  - Ladder line
- Open wire or ladder lines has lower loss than coaxial cable with a plastic dielectric E9F07
- Compared to a solid dielectric coax cable, a **foam dielectric** cable will have:
  - **Lower losses**
  - **Lower ability to handle high voltages**
  - **Higher velocity factor** E9F08
- Remember, **foam dielectric** has air mixed in!



Vetco.net

Coax Data

Pg. 9-33

Table 9-1

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RG-174	50	66	30.8	PE	0.110	1100	8.6
CATV Hardline (Aluminum Jacket)							
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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

SWR

Technician and General Review

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

Pgs. 9-34

* Reflection coefficient and SWR are largely referring to the same thing: The mismatch between the load and the antenna.
* However, the reflection coefficient is a complex quantity, having both a magnitude and a phase.
* The **reflection coefficient** is a good parameter to describe the interactions of a load end and a transmission line. E9E07

Reflection Coefficient and SWR

Pg 9-34

* 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

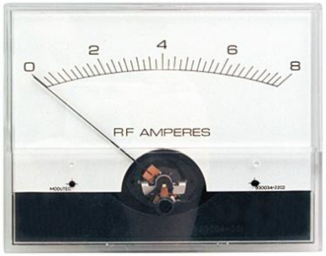
For $Z_L > Z_O$, SWR = Z_L/Z_O

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

Power Measurement

Pg 9-35

* If an RF Ammeter is placed in series with the antenna feedline, as the transmitter is tuned to resonance, higher current on the meter will indicate that there is more power going to the antenna.

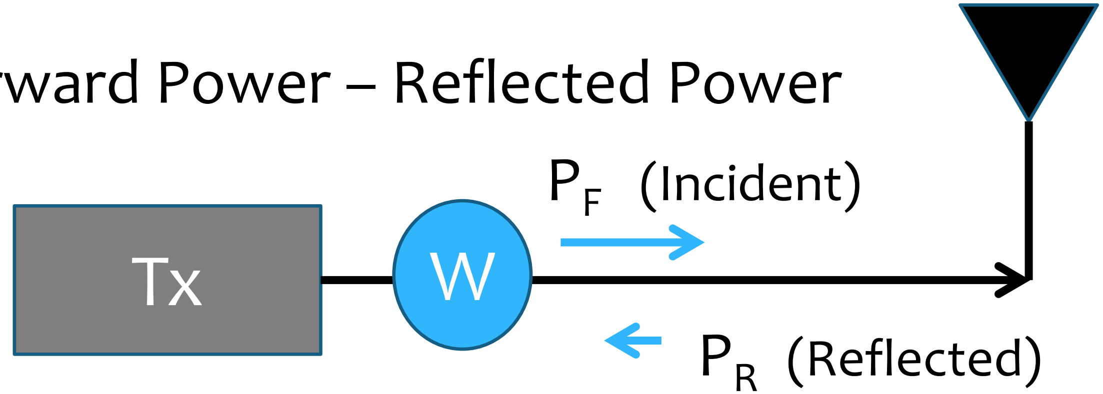


* An RF Wattmeter will also indicate forward power and reverse power near resonance

Power Measurements -- Wattmeter

Pg 9-35

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

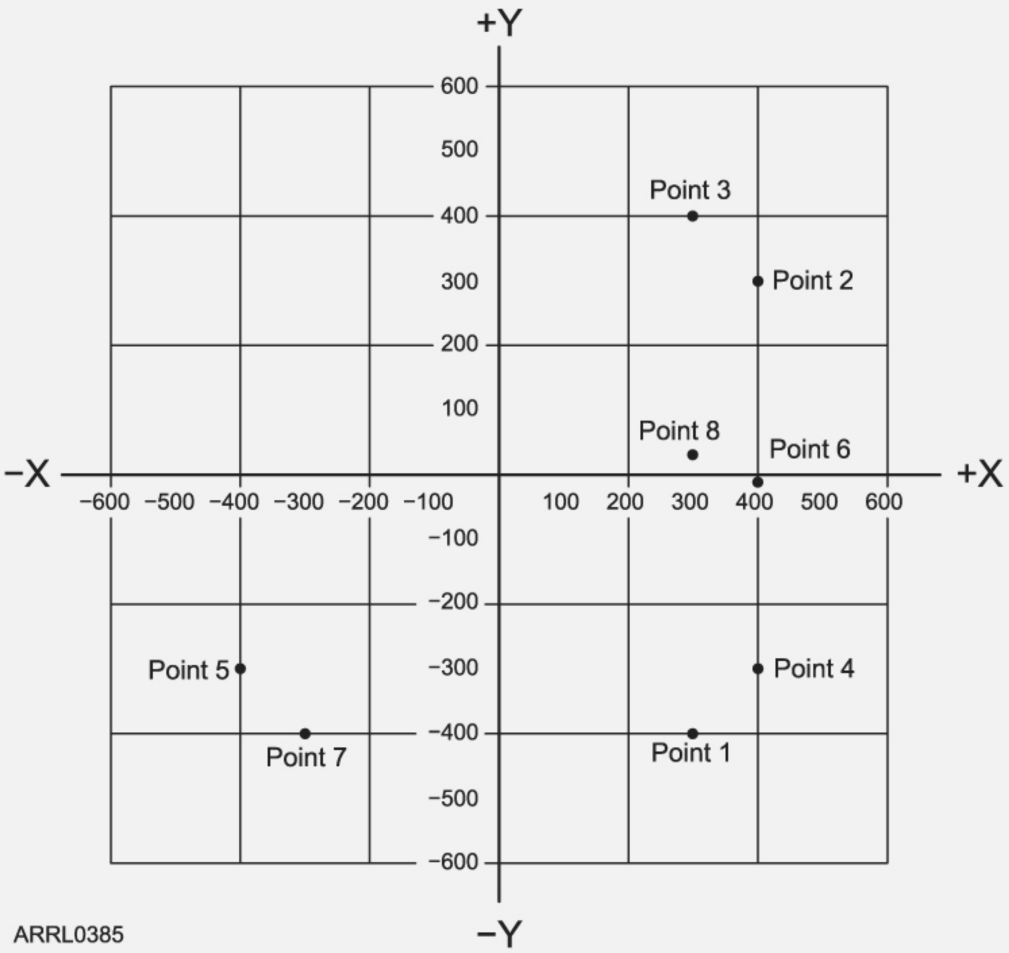


* How much power is absorbed by the load when a directional wattmeter reads 100 W forward and 25 W reflected? E4B06

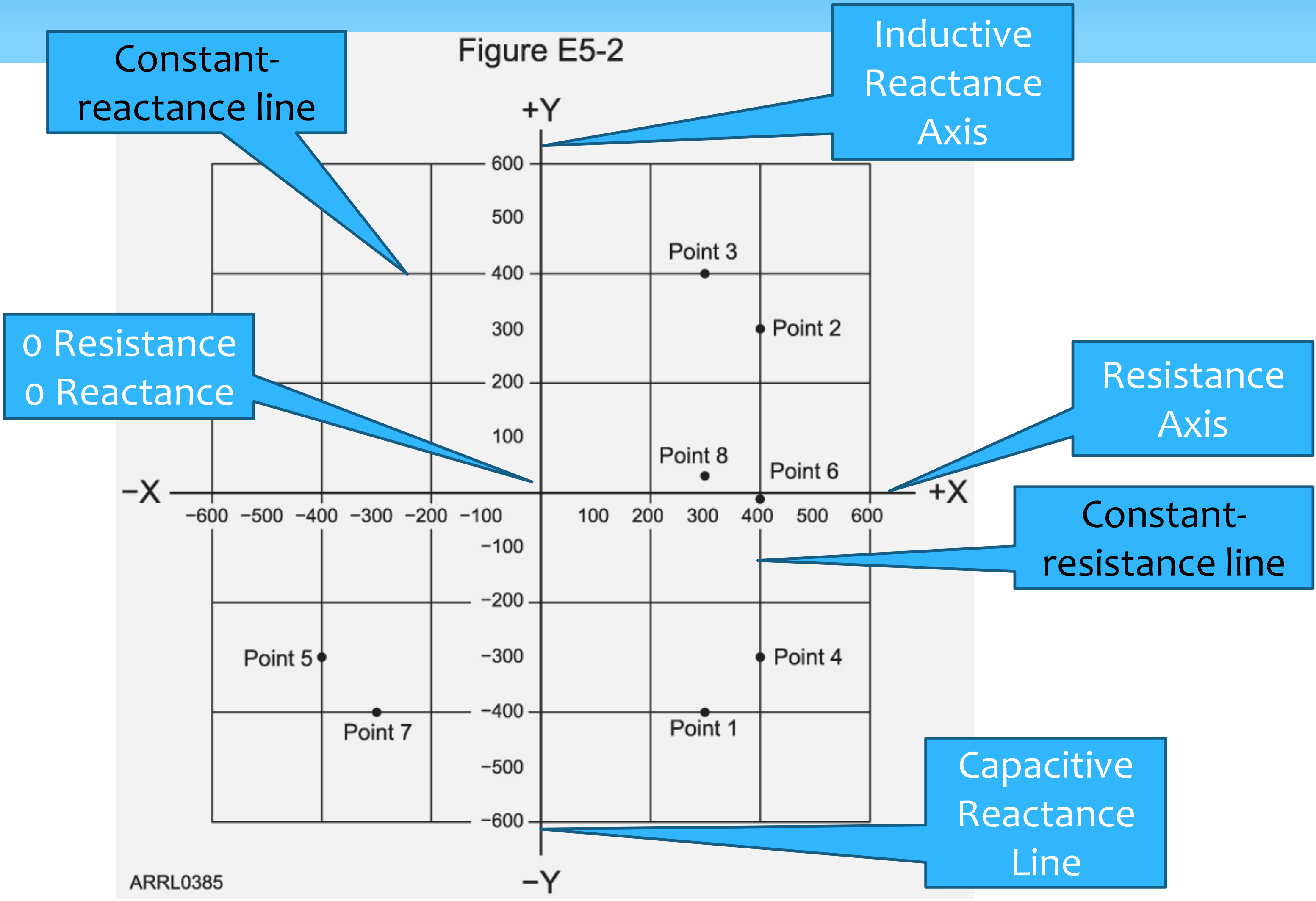
* $P_{LOAD} = P_F - P_R = 100\ W - 25\ W = 75W$

Plotting Impedance

Figure E5-2



Plotting Impedance



Folding the Rectangular Graph

Pg. 9-36

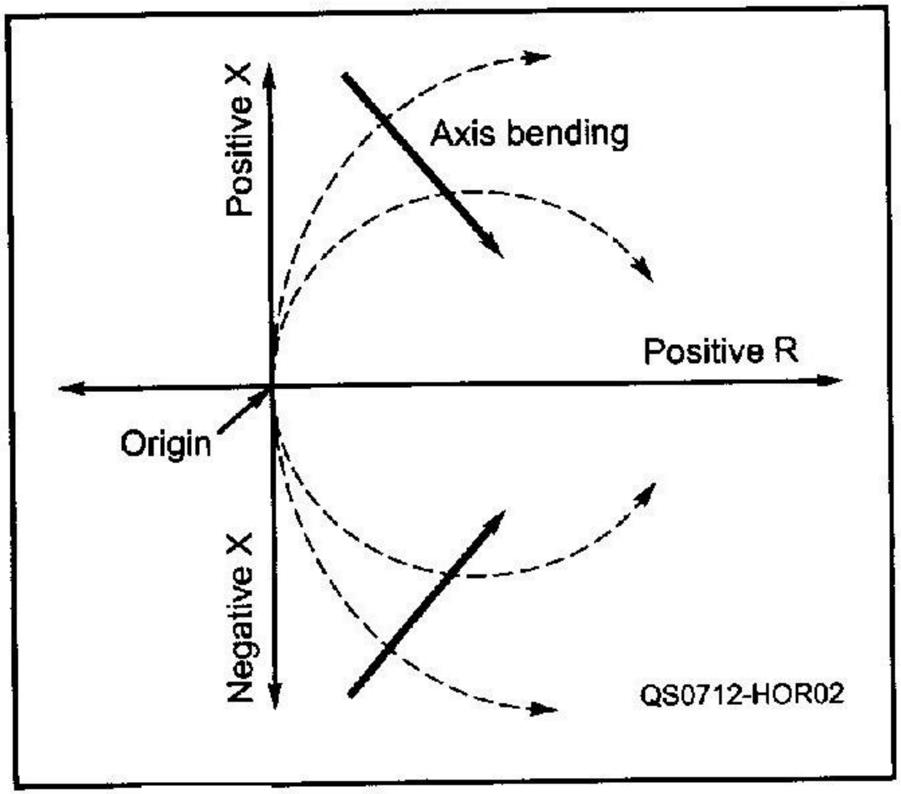
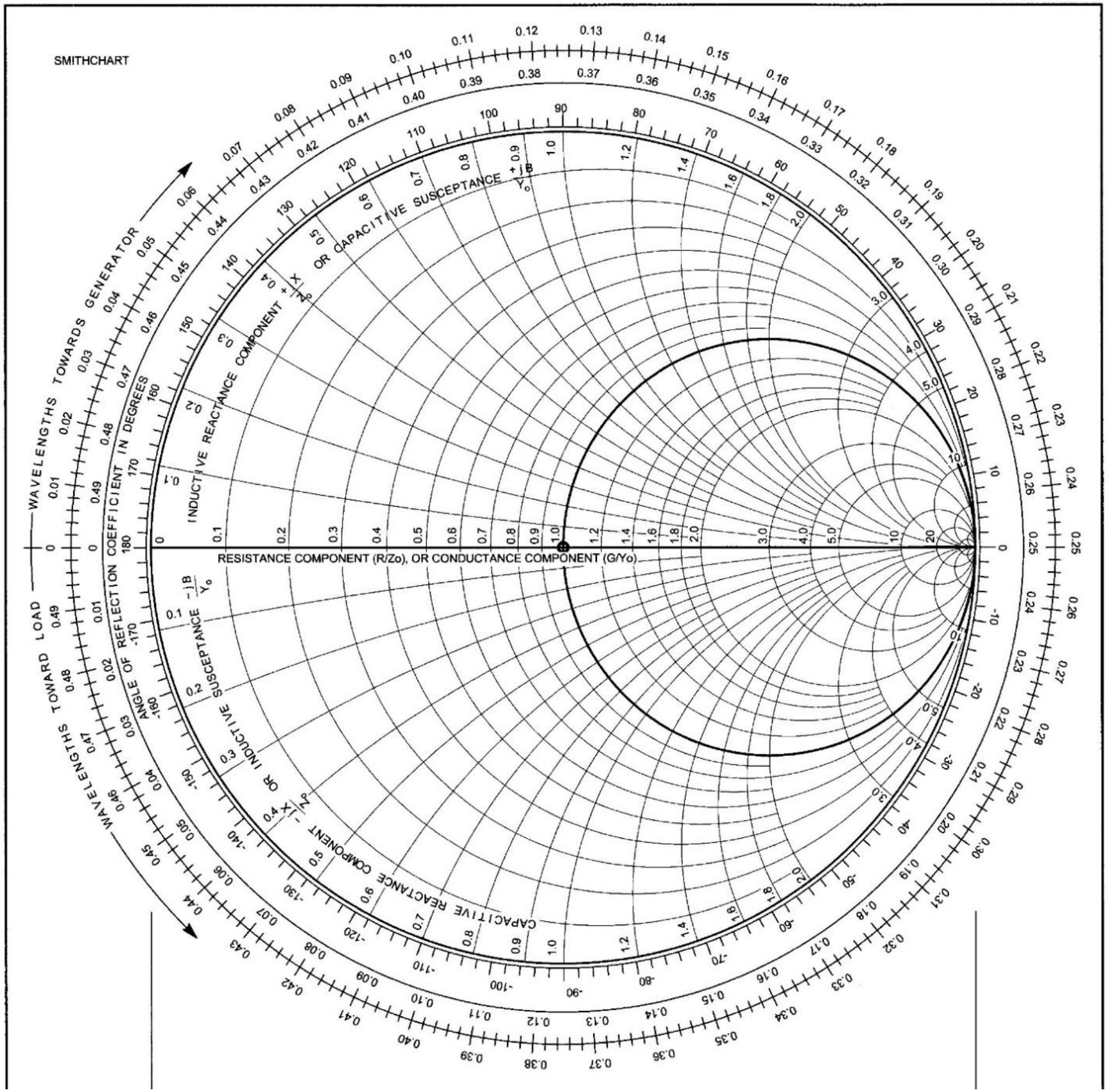


Figure 9-31 - Distorting or mapping the rectangular graph captures all of its right-hand side impedances inside the circle formed by the bent reactance axes. This is the basis of the Smith Chart.

Smith Chart

Pg 9-36

- One thing the Smith Chart is used for is to calculate the **impedance and SWR values** in the transmission line E9G03
- We can calculate the impedance along transmission lines E9G01



Smith Chart

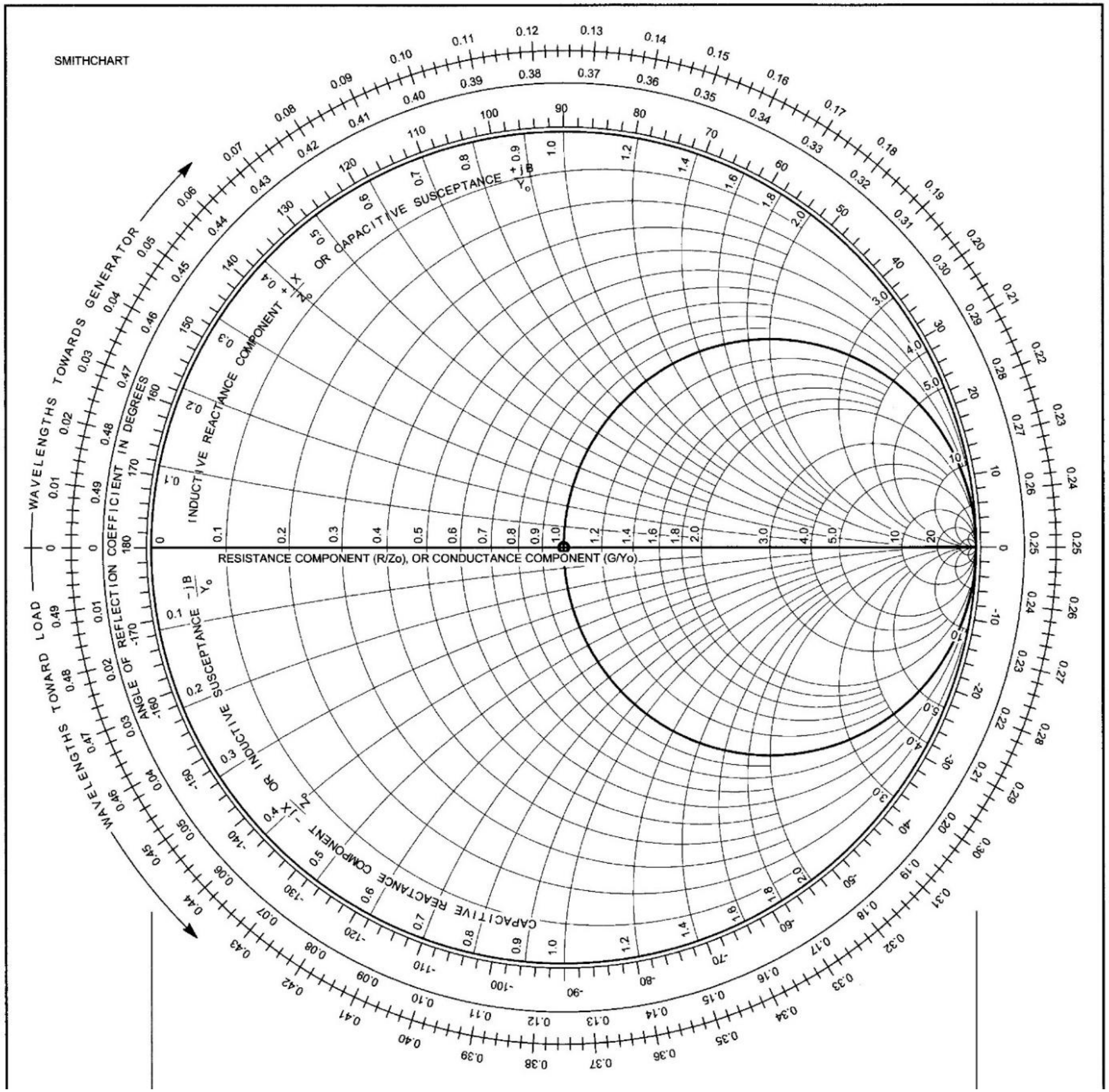
Pg 9-38

- Its coordinate system consists of **resistance circles** and **reactance arcs**

  E9G02

- It has two families of circles and arcs: **resistance** circles **& reactance** arcs

  E9G04



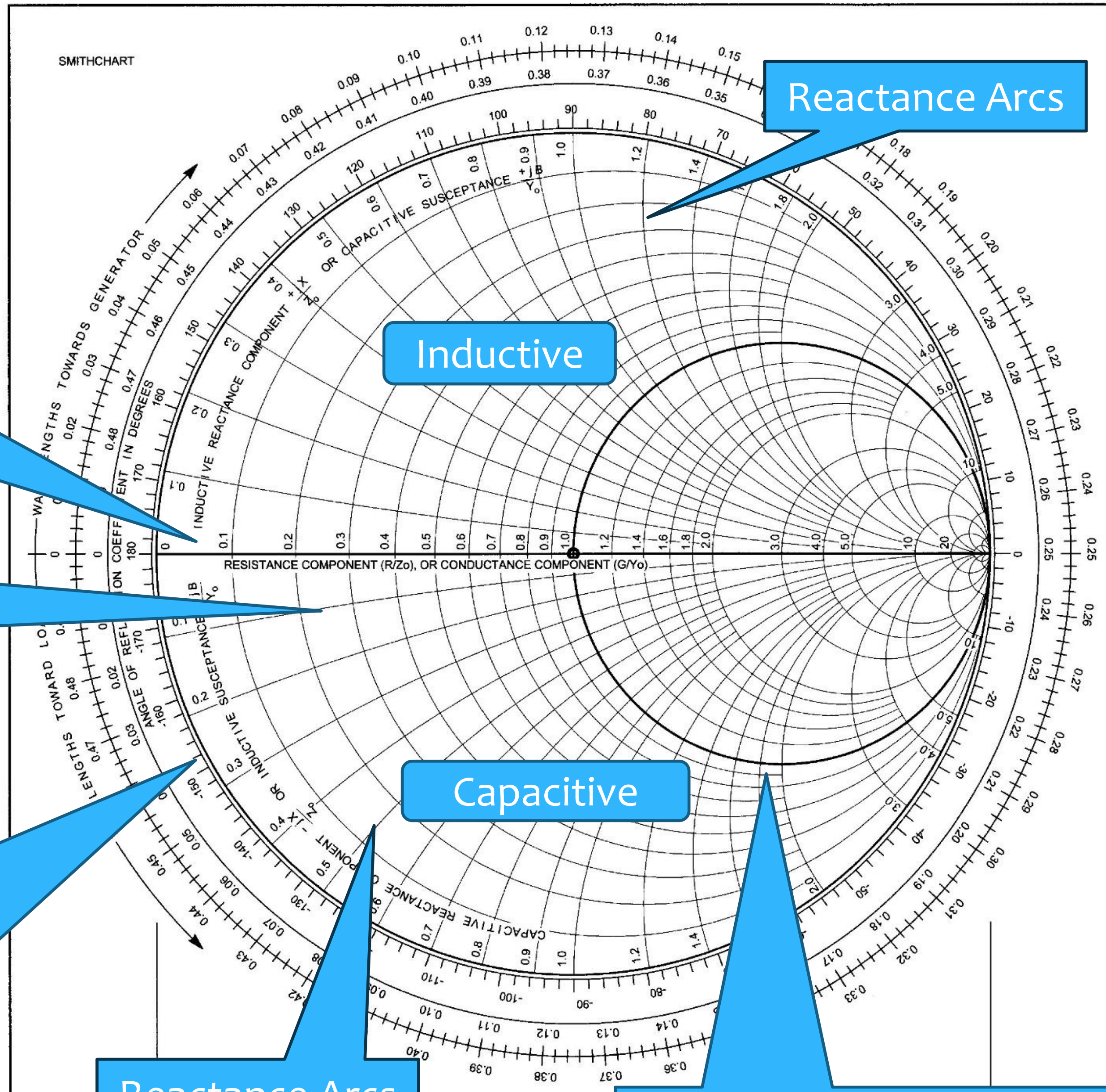
Smith Chart

Pgs. 9-36 & 38

The resistance axis is the only straight line. E9G07

Constant-reactance Arcs E9G10

The **Reactance Axis** is the large outer circle on which the reactance arcs terminate. E9G06



Reactance Arcs

Inductive

Capacitive

Reactance Arcs

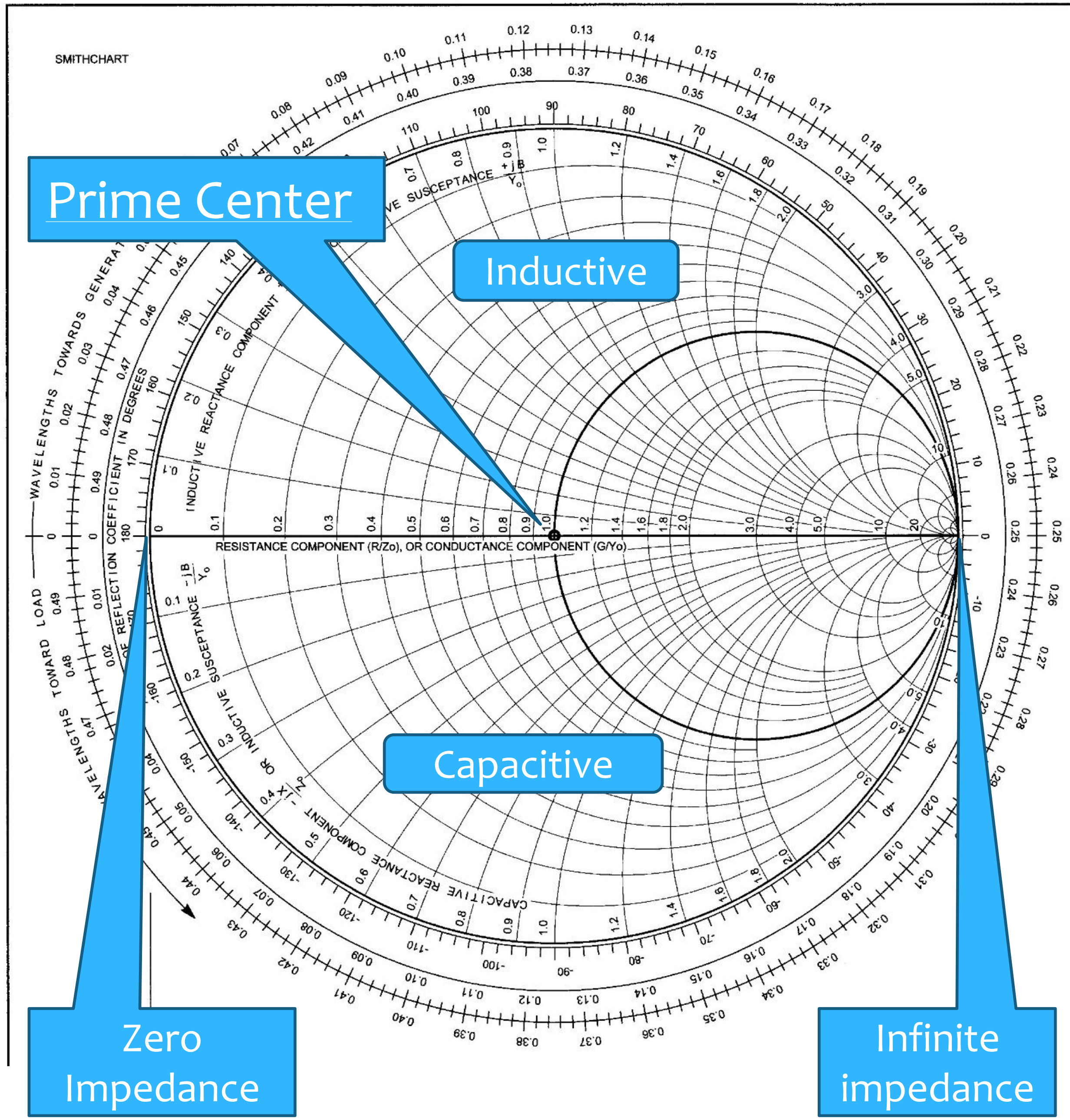
Constant-resistance circles

Smith Chart

Pg. 9-38

- A process called **normalization** reassigns the values of all the points according to their Z_O at the prime center. E9G08

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

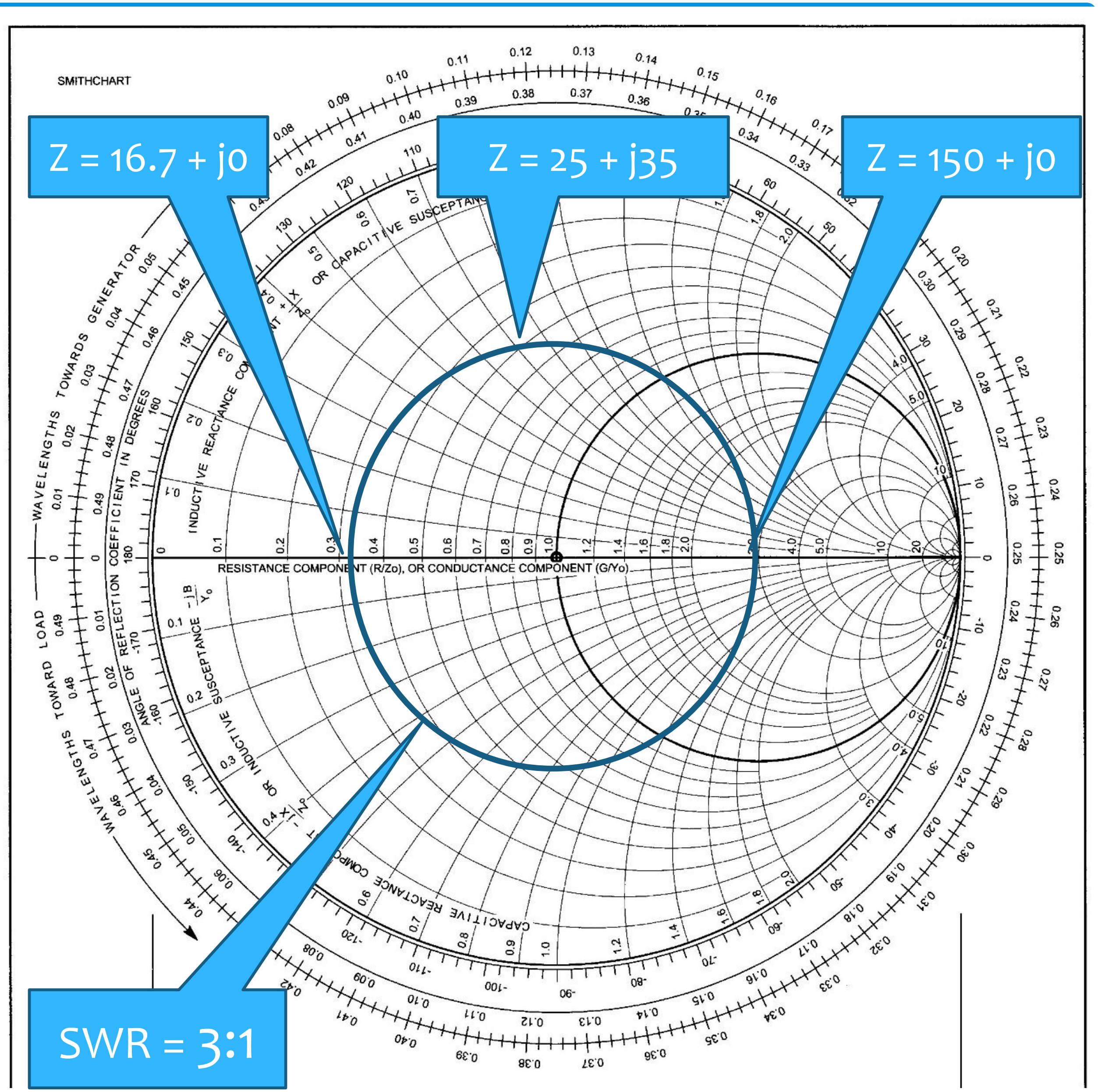


Smith Chart

Pg 9-38

* A third family of circles is called the constant SWR circles
E9G09

* 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.



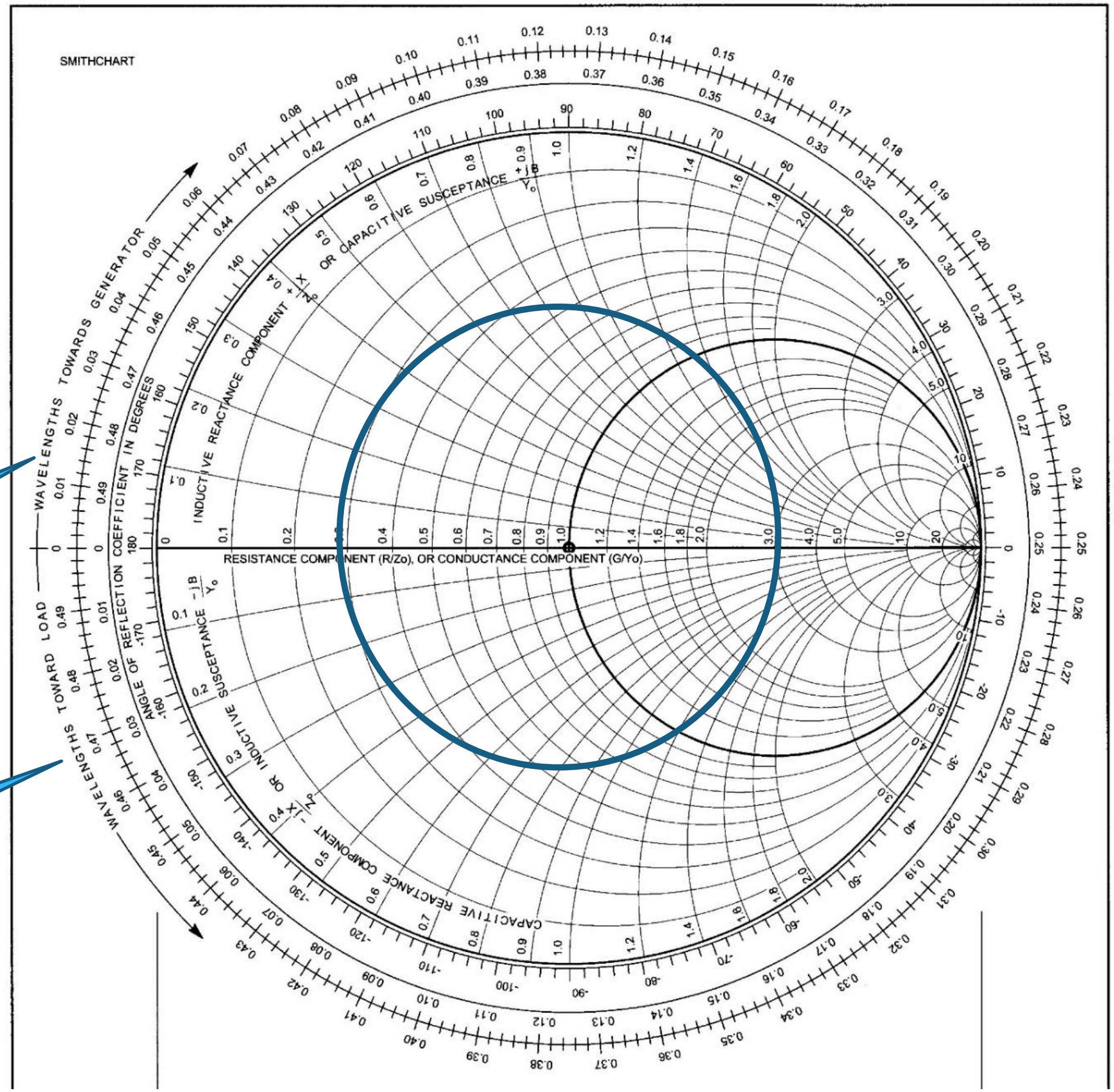
Smith Chart

Pg. 9-39

* Along the edge are 2 Wavelength scales.

Wavelengths towards the **generator**

Wavelengths towards the **load**

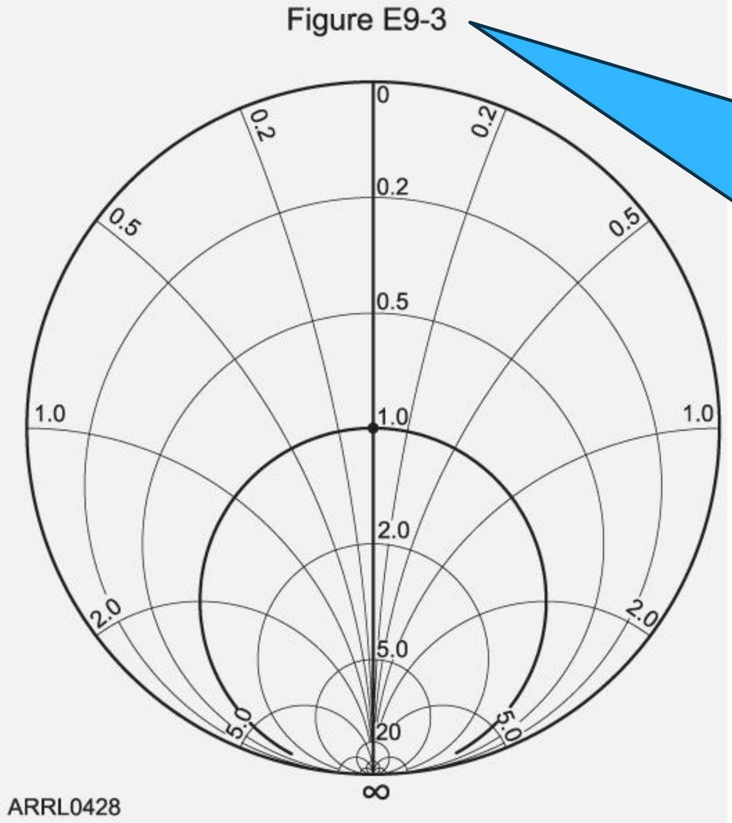


Both are calibrated in **fractions of transmission line electrical wavelength.** E9G11

What it this?

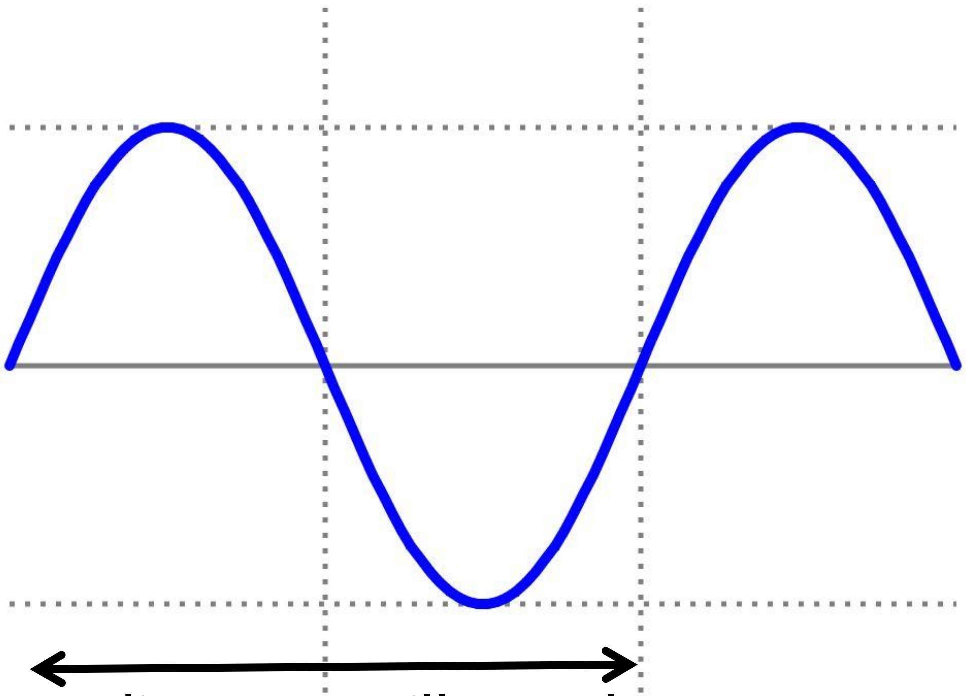
A Smith Chart

(stood on end)



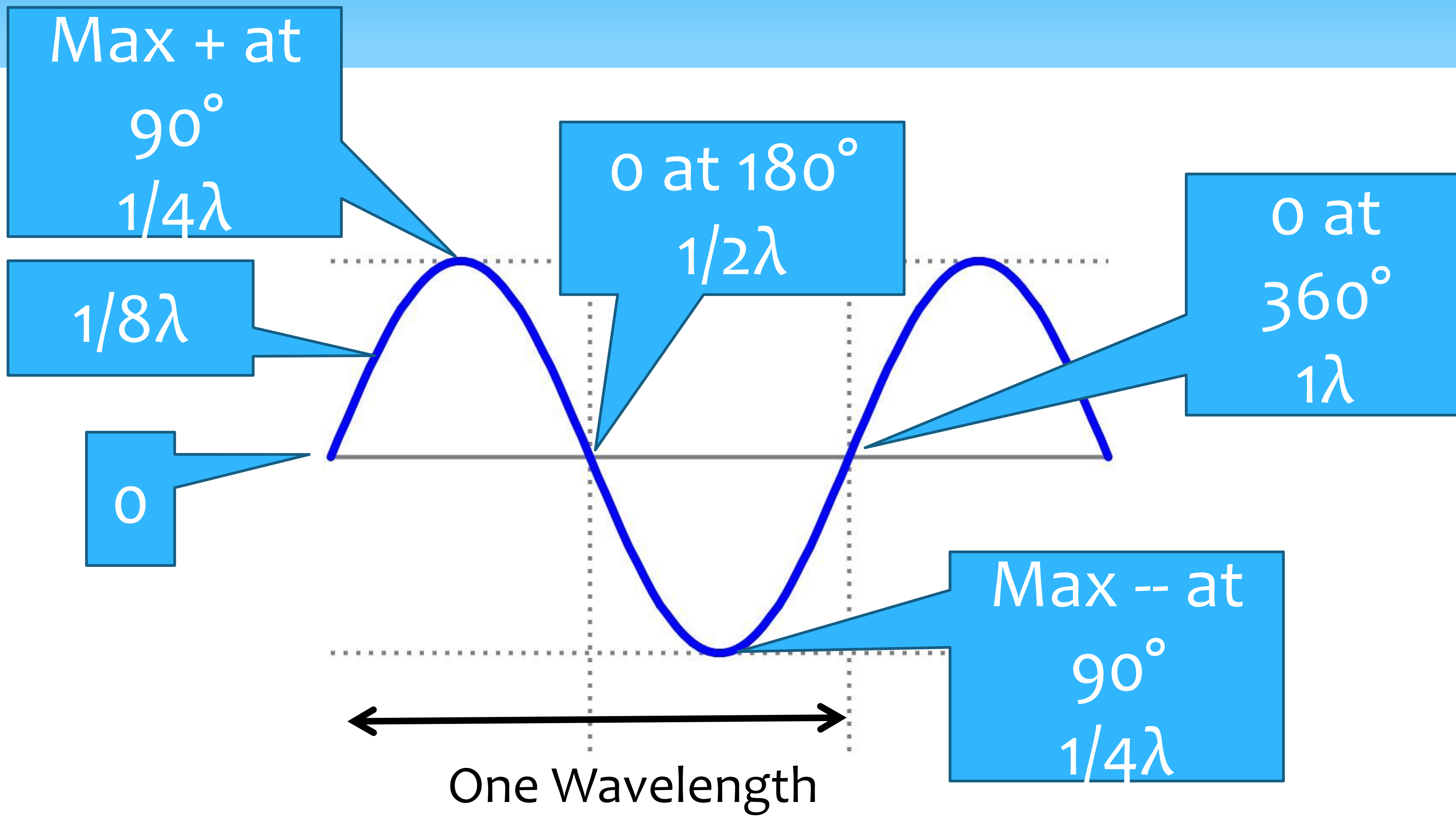
For some strange reason, this is how the Smith Chart is presented in the Question Pool

One more look at a sine wave



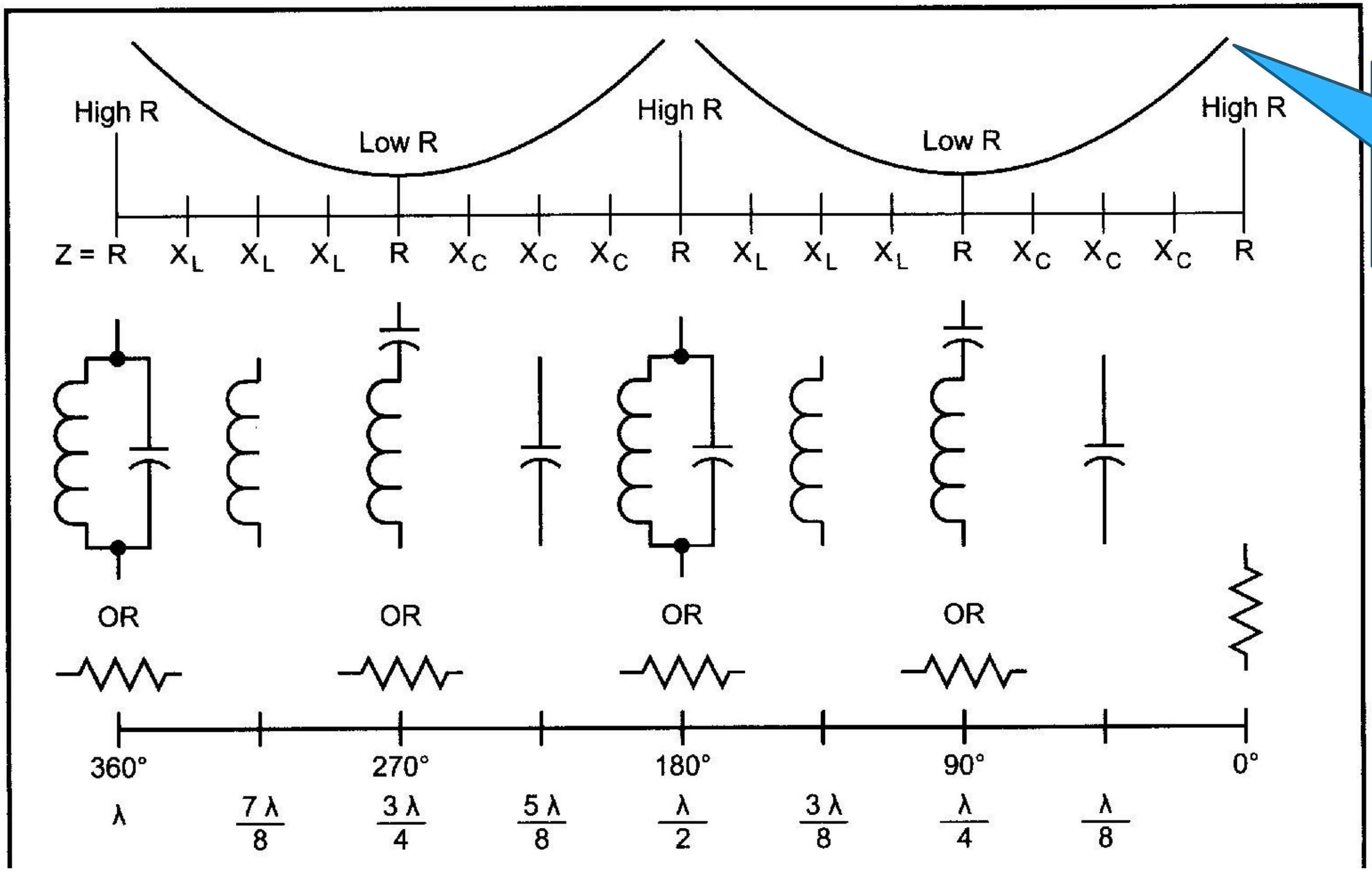
A radio wave will travel one wavelength in the time it takes to complete one cycle

One more look at a sine wave



Transmission Line Transformers

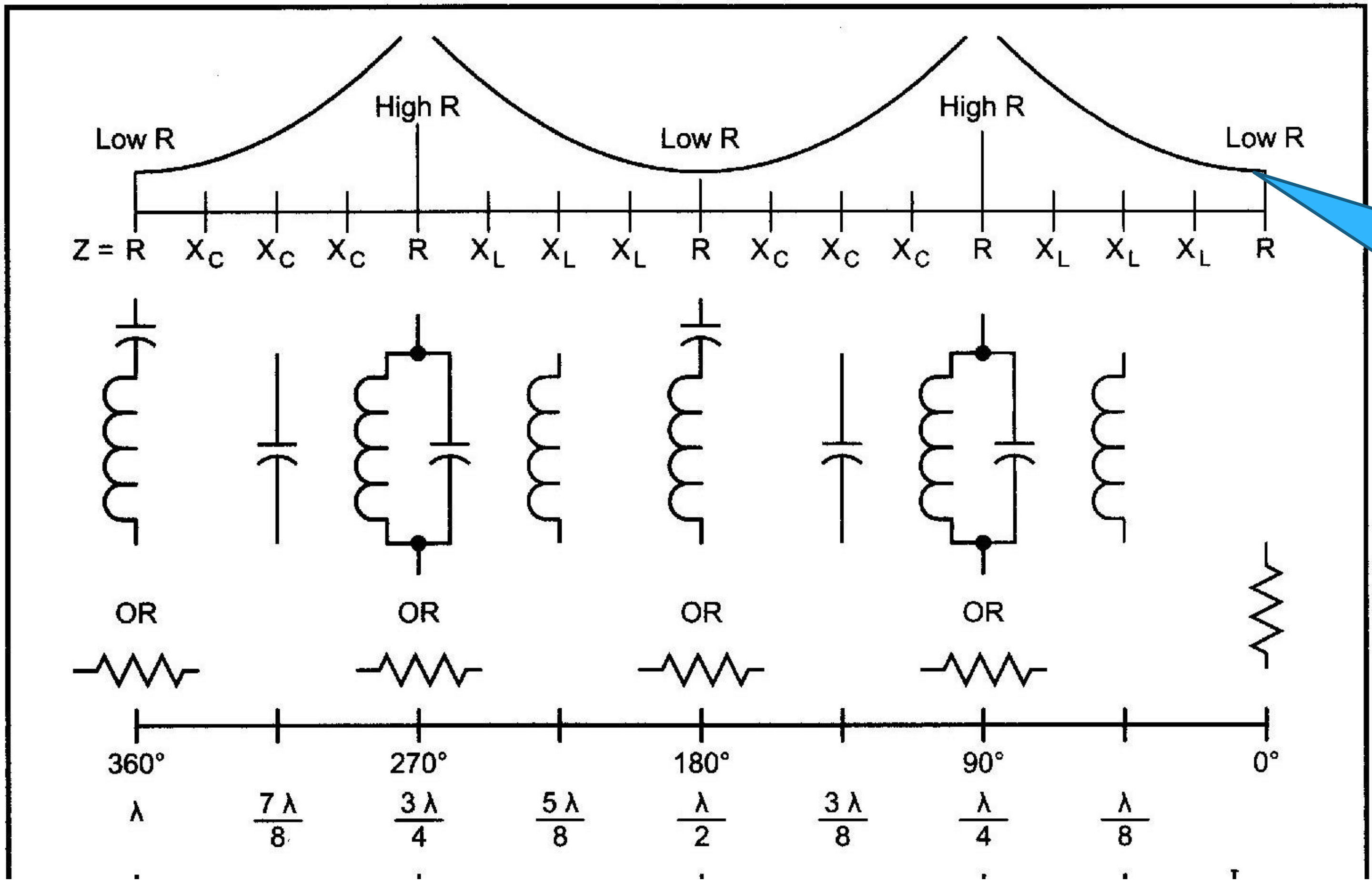
Pgs. 9-40



Open Load

Transmission Line Transformers

Pg. 9-41



Shorted Load

Transmission Line Transformers

Pg. 9-40 & 41

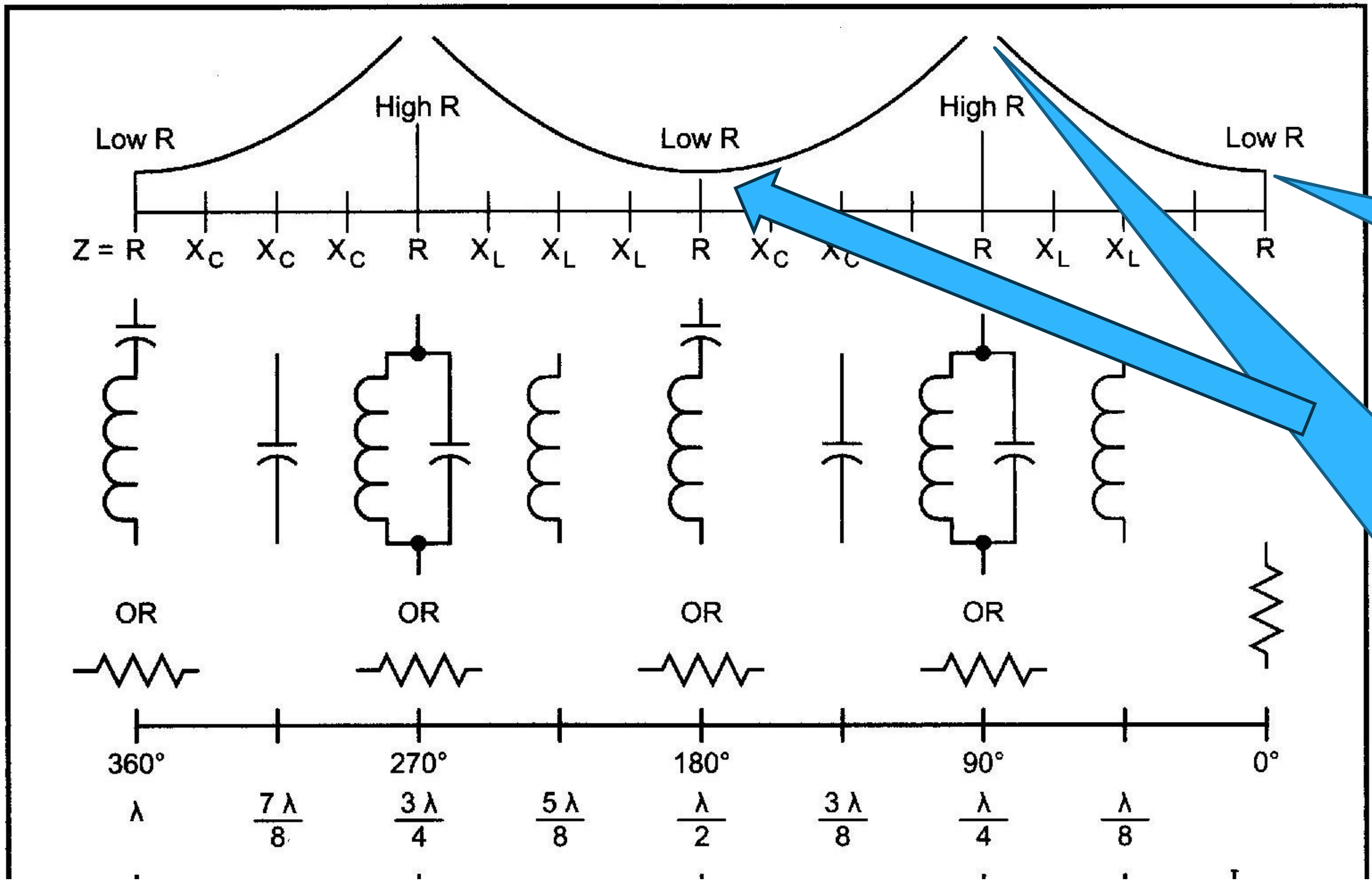
* Every ½ **wavelength** along the line the impedance ***repeats.***

* If the terminating impedance is a **short** circuit, we will see a **short** every ½ **wavelength.** E9F04

* If the terminating impedance is an **open** circuit, we will see an **open** every ½ **wavelength.**

Transmission Line Transformers

Pg. 9-40



Short

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

Transmission Line Transformers

Pg. 9-40 & 41

- Every **odd multiple** of **1/4 wavelength** along the line the impedance ***repeats.***
- If the terminating impedance is a **short** circuit, we will see a **very high impedance 1/4 wavelength away.** E9F09
- If the terminating impedance is an **open** circuit, we will see a **very low impedance** every **1/4 wavelength.** E9F12

Transmission Line Transformers

Pg. 9-40 & 41

* In between 1/4 wavelength multiples (i.e.: **1/8 wavelength from the end), we will see:**
  * **capacitive reactance from an open**
  * **inductive reactance from a short**

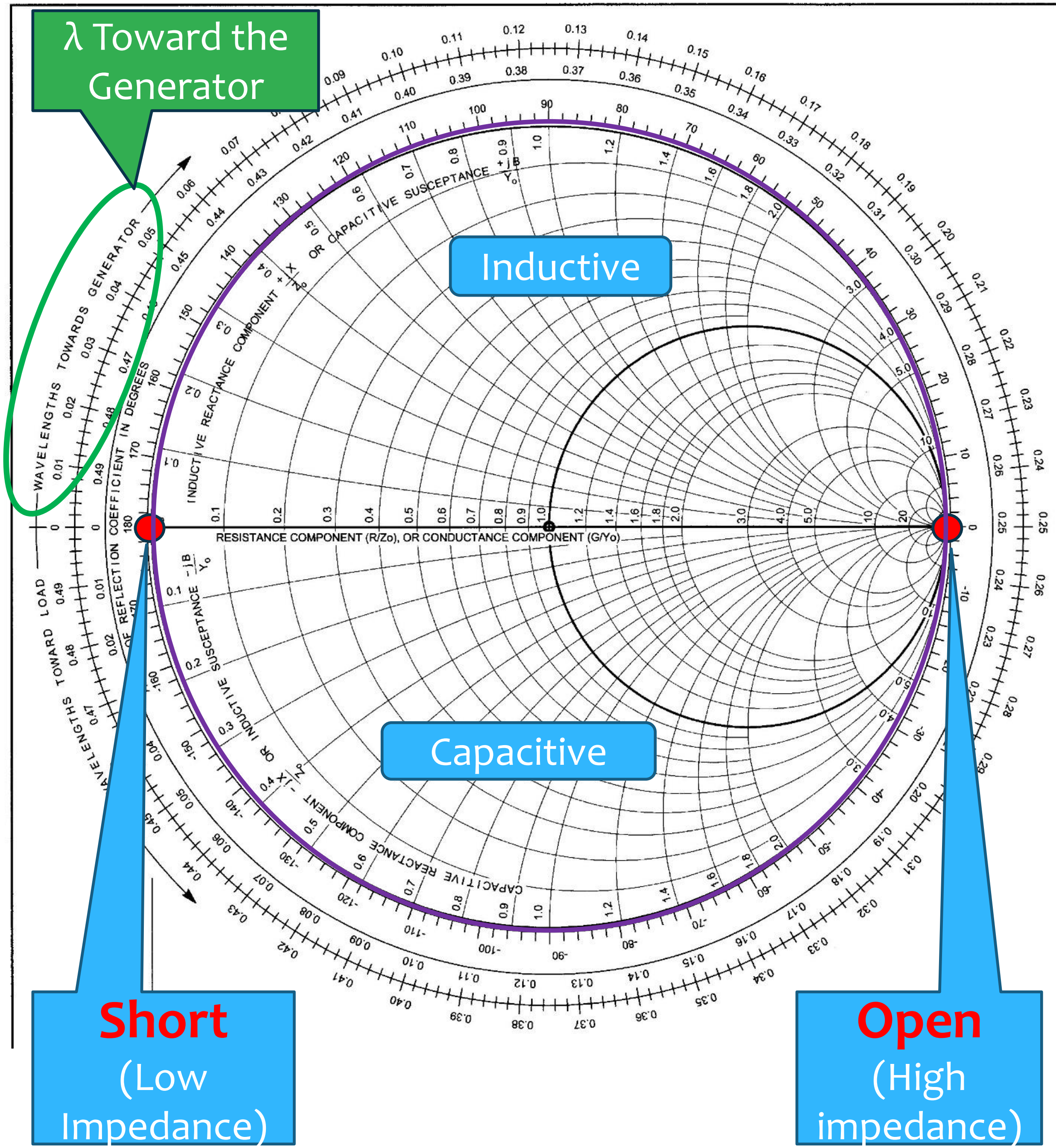
* If the terminating impedance is a **short** circuit, we will see **inductive reactance 1/8 wavelength away.** E9F10

* If the terminating impedance is an **open** circuit, we will see **inductive reactance 1/8 wavelength.** E9F11

Smith Chart

FYI

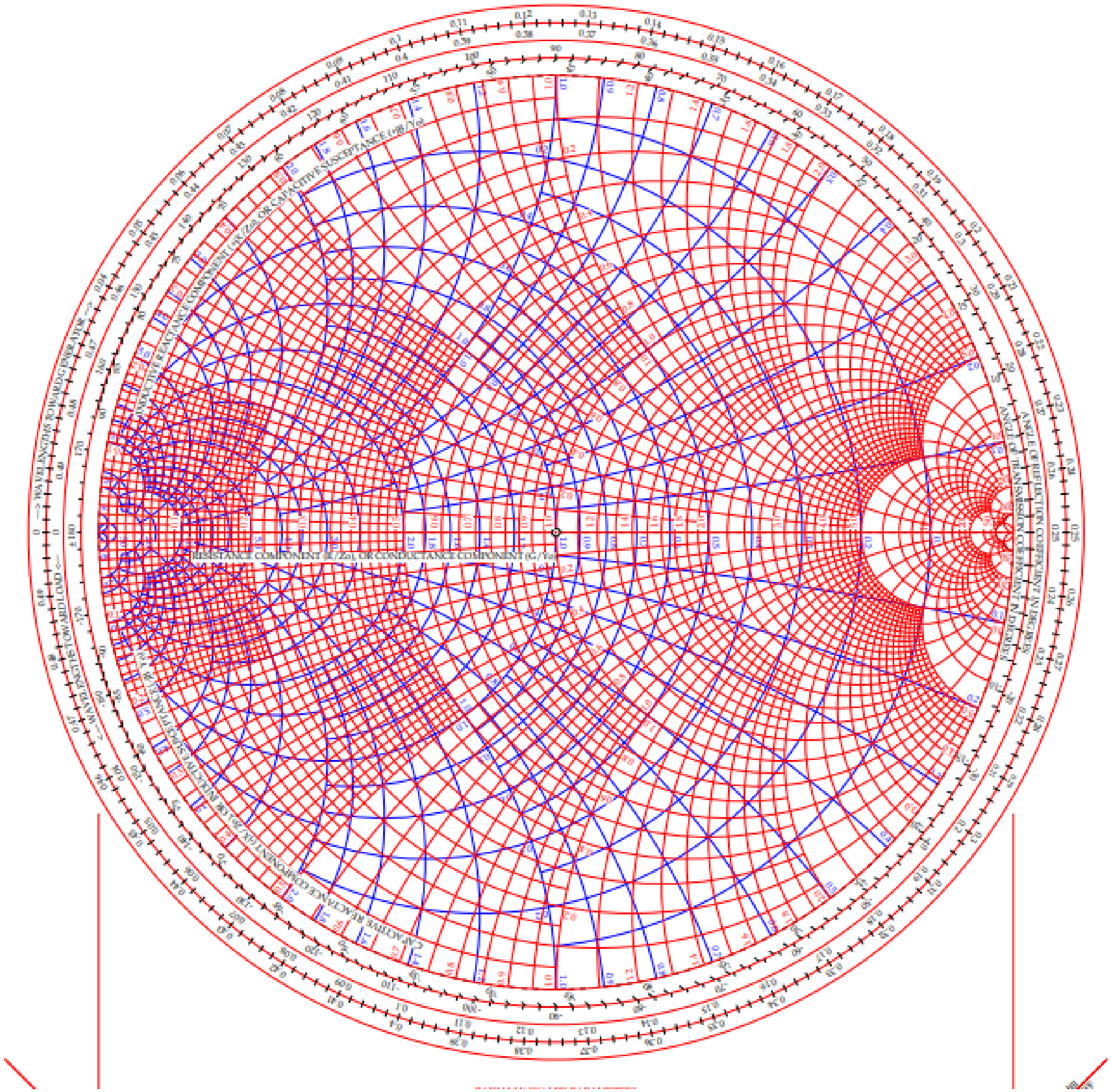
- All that we have been doing in the previous six slides is rotating the impedance around the edge of the Smith Chart
- Half way around the chart is ¼ λ
- A full circle around the chart is ½ λ



Another Variation of the Smith Chart

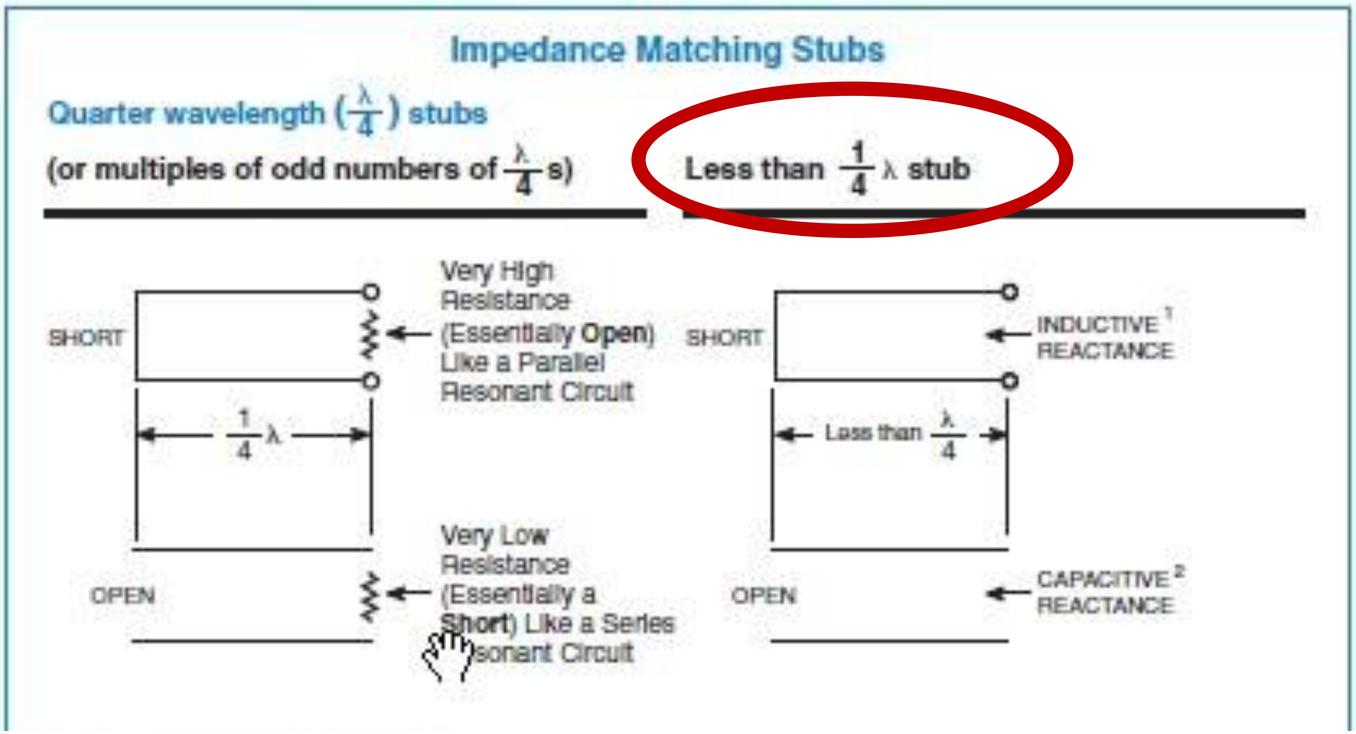
With Impedance in Red
- Resistance
- Reactance

With Admittance in Blue
- Conductance
- Susceptance



Short Transmission Line Stubs

FYI



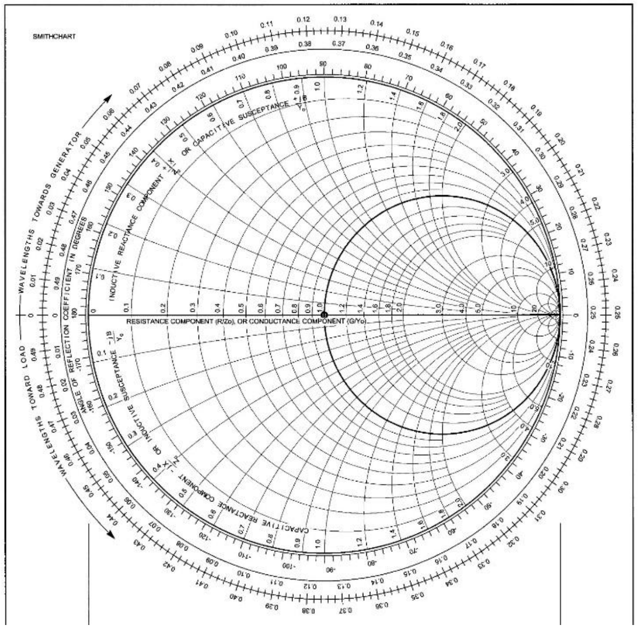
Gordon West

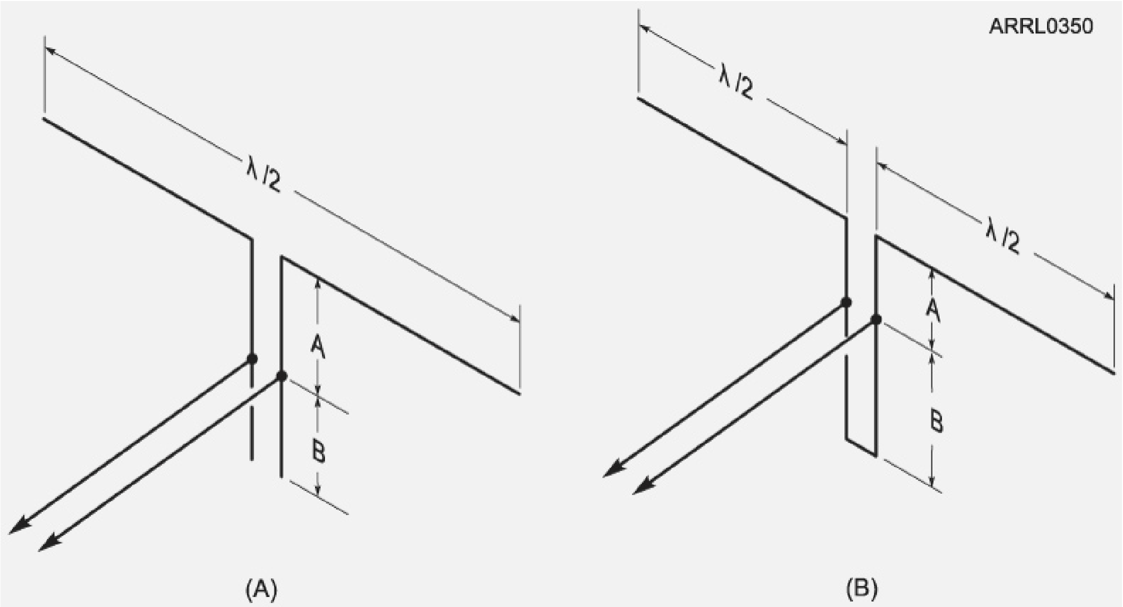
For stubs less than 1/4λ

* Shorted = L
  * Inductor
* Open = C
  * Capacitor

The Stub Match

Pg. 9-30





* The **Smith Chart** is a tool that helps determine the length and position of the stub.

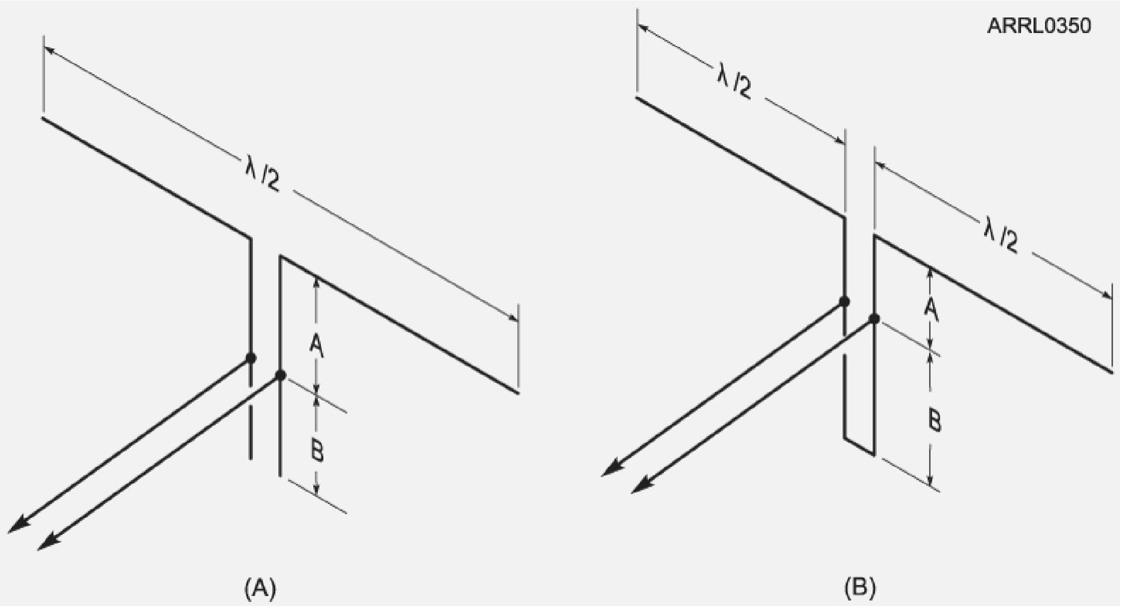
A = ?

B = ?

The Stub Match

Ref: Pg. 9-30

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

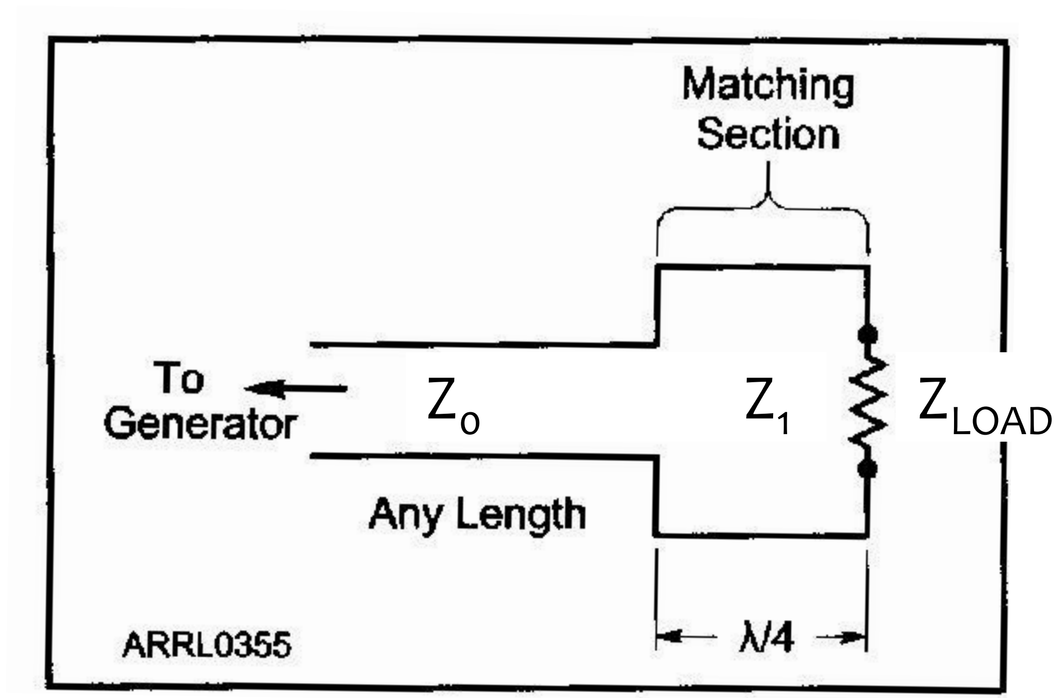


Synchronous Transformer

1/4-wave Matching Section

Pg. 9-39

- A ¼ wavelength transmission line of impedance Z1 can be used to match between two other impedances, Z_0 and Z_2.
- $Z_1 = \sqrt{Z_0 \text{ x } Z_{\text{LOAD}}}$
- **Z_1** in this example is the impedance of **matching-section**, rather than of the complete feed line.

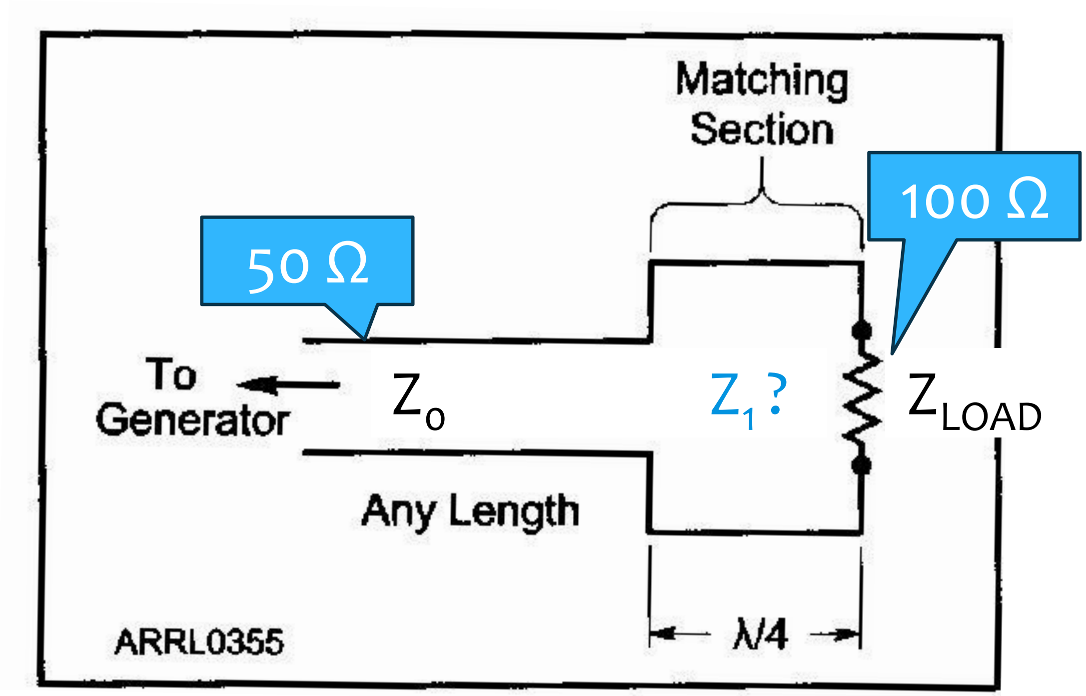


Synchronous Transformer
1/4-wave Matching Section

Pg. 9-41 & 42

* Example: Assume a transmission line Z_0 = 50Ω and Z_{LOAD} = 100Ω E9E06
* $Z_1 = \sqrt{Z_0 \text{ x } Z_{LOAD}}$
* $Z_1 = \sqrt{50 \text{ x } 100}$
* $Z_1 = \sqrt{5000}$
* $\boldsymbol{Z_1 = 70.7\Omega}$

* **A ¼ λ section of 75Ω** coax would be suitable.



Scattering Parameters

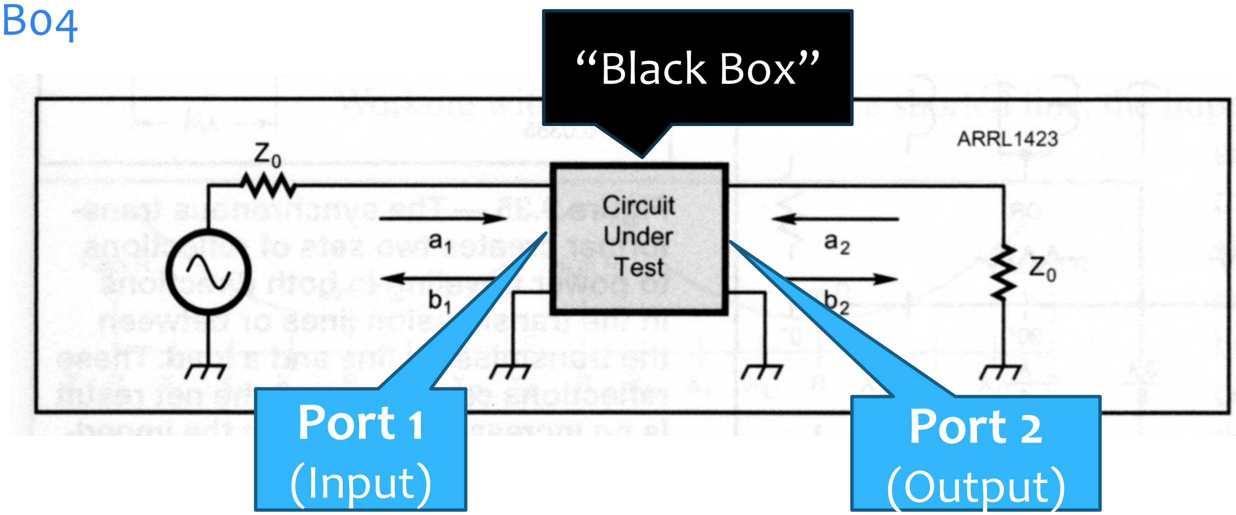
Pg 9-42

* Subscripts of the parameter shows the port or ports at which the measurements are made. E4B07
* Examples:
  * **S21** designates what is happening on **port 2** as a result of an input at **port 1 (forward gain).** E4B03
  * **S11 looks at the input-port return loss and is equivalent to SWR.** E4B04

Ideal short: S_{11} = -1

Ideal termination: S_{11} = 0

Ideal open: S_{11} = +1



Nano VNAs Use S-Parameter Designations

FYI

S-Parameters

FYI

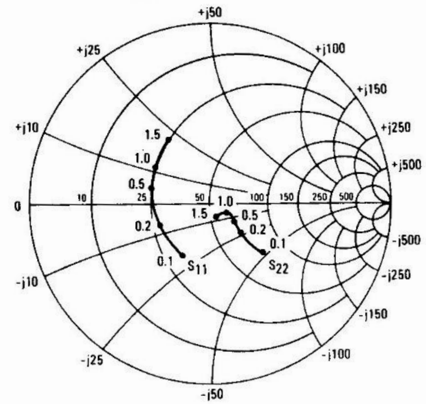
Motorola BRF 96

NPN Silicone High Frequency Transistor

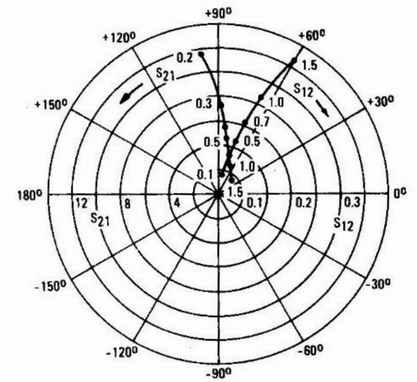
S-Parameters can be expressed graphically or in tabular from

BFR96 COMMON-EMITTER S-PARAMETERS

INPUT/OUTPUT REFLECTION COEFFICIENTS versus FREQUENCY (V_{CE} = 10 V, I_C = 50 mA)



FORWARD/REVERSE TRANSMISSION COEFFICIENTS versus FREQUENCY (V_{CE} = 10 V, I_C = 50 mA)

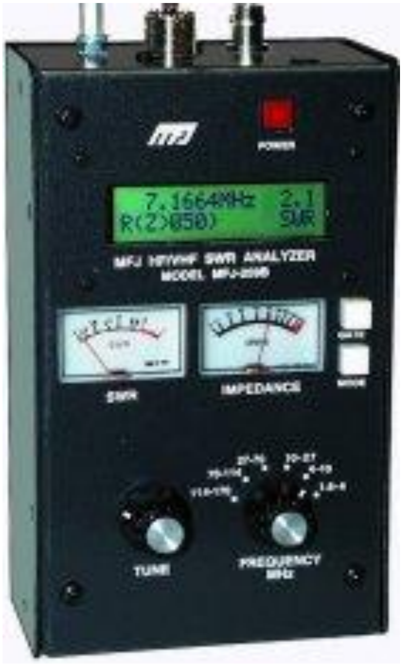


V_{CE} (Volts)	I_C (mA)	f (MHz)	S_{11} $\lvert S_{11}\rvert$	S_{11} $\angle\phi$	S_{21} $\lvert S_{21}\rvert$	S_{21} $\angle\phi$	S_{12} $\lvert S_{12}\rvert$	S_{12} $\angle\phi$	S_{22} $\lvert S_{22}\rvert$	S_{22} $\angle\phi$
5.0	10	100	0.51	−95	15.04	121	0.047	54	0.58	−48
		300	0.43	−163	5.87	92	0.082	58	0.26	−63
		500	0.46	174	3.61	79	0.120	63	0.19	−63
		700	0.48	162	2.65	68	0.161	63	0.15	−64
		1000	0.48	146	1.92	57	0.220	63	0.12	−79
		1500	0.54	121	1.40	43	0.320	58	0.13	−118
	25	100	0.39	−122	19.41	112	0.037	60	0.42	−68
		300	0.39	−176	6.81	89	0.079	68	0.16	−94
		500	0.42	166	4.11	78	0.129	70	0.10	−103
		700	0.44	156	3.05	69	0.176	68	0.06	−119
		1000	0.44	142	2.20	59	0.244	64	0.06	−159
		1500	0.49	118	1.62	45	0.348	57	0.10	177
	50	100	0.35	−140	21.10	106	0.032	64	0.33	−81
		300	0.38	176	7.11	88	0.081	72	0.13	−116
		500	0.42	162	4.28	78	0.133	72	0.09	−136
		700	0.43	153	3.16	70	0.183	69	0.07	−163
		1000	0.42	140	2.28	60	0.252	65	0.08	165
		1500	0.47	116	1.66	47	0.357	57	0.12	155
10	10	100	0.53	−83	15.96	124	0.039	58	0.65	−36
		300	0.38	−154	6.44	94	0.070	59	0.35	−41
		500	0.41	−179	3.98	81	0.102	64	0.30	−39
		700	0.42	166	2.94	70	0.138	65	0.27	−39
		1000	0.42	151	2.12	60	0.191	66	0.24	−47
		1500	0.49	125	1.50	44	0.278	63	0.22	−72
	25	100	0.38	−104	20.85	115	0.032	60	0.48	−48
		300	0.32	−169	7.54	91	0.070	68	0.23	−48
		500	0.35	170	4.61	80	0.109	71	0.19	−43
		700	0.37	160	3.37	70	0.152	69	0.16	−39
		1000	0.37	146	2.43	61	0.210	67	0.13	−44
		1500	0.43	121	1.73	47	0.304	61	0.10	−74
	50	100	0.33	−119	22.59	109	0.029	63	0.39	−51
		300	0.30	−176	7.74	88	0.069	72	0.19	−47
		500	0.34	166	4.70	79	0.113	73	0.16	−40
		700	0.36	158	3.45	70	0.156	70	0.14	−35
		1000	0.36	144	2.46	61	0.217	66	0.11	−39
		1500	0.42	119	1.75	47	0.310	60	0.08	−72

Antenna Analyzers

Pg. 9-43

- Antenna Analyzers are commonly used to measure:
  - **SWR**
  - Impedance   (R + jX)
  - Reactance (component) values
  - Frequency
- However more advanced measurements can also be made:
  - **Velocity factor**   E4A11
  - **Cable Length**
  - **Resonant frequency of a tuned circuit.**



Measuring SWR

Pg. 9-43

- There are several way to measure SWR:
  - Directional wattmeter (SWR meter)
  - Vector network analyzer
  - Antenna analyzer E4A08

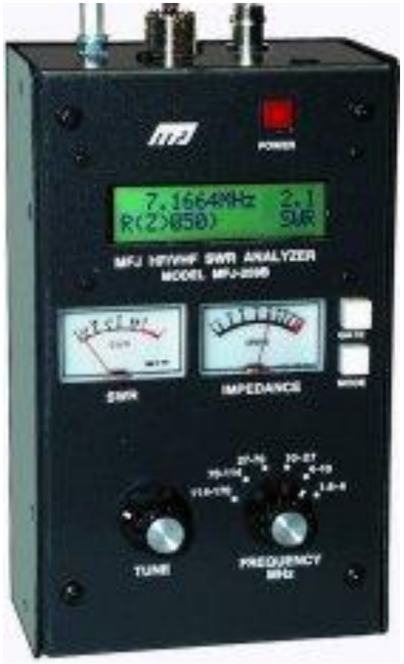
Antenna Analyzers

Pg. 9-40

* One advantage of an antenna analyzer is that it can compute SWR and impedance directly. E4A07

* Antenna analyzers are convenient:
  * They 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 due to external signals.



Vector Network Analyzers

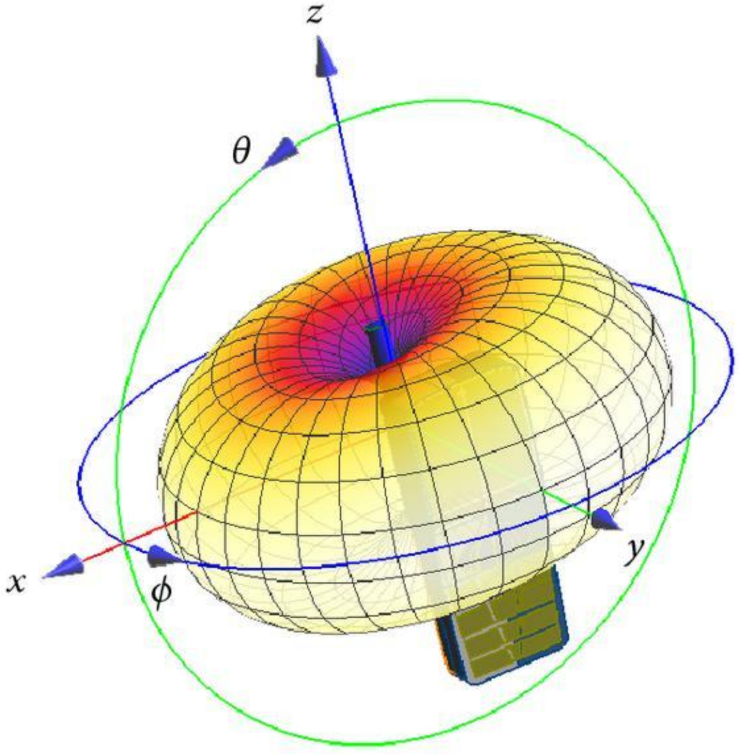
Pg 9-43 & 44

* A **network analyzer** can measure many parameters:
  * Input impedance
  * Output impedance
  * Reflection coefficient E4B11
* Uses three calibrated loads to calibrate itself:
  * Short circuit E4B08
  * 50 ohms
  * Open Circuit

* A two-port VNA can measure filter frequency response E4B09
  * This can be handy when tuning cavity filters, such as a repeater duplexer

Section 9.5

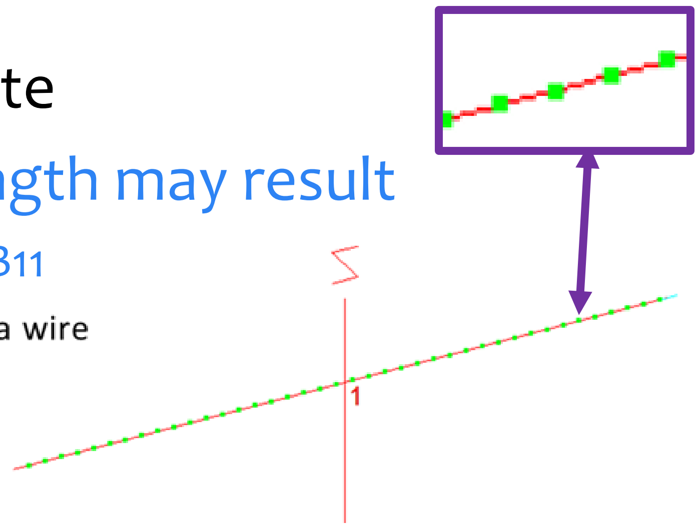
Antenna Design



Antenna Modeling

Pg 9-43 & 44

* Modeling programs for your PC let you “see” many of the antenna’s characteristics before you build it!
* Employs the **methods of moments where each antenna wire element is modeled as a series of segments**, each having a uniform value of current. E9B09 and E9B10
* The more segments, the more accurate
  * Less than 10 segments per wavelength may result in feed-point impedance errors. E9B11

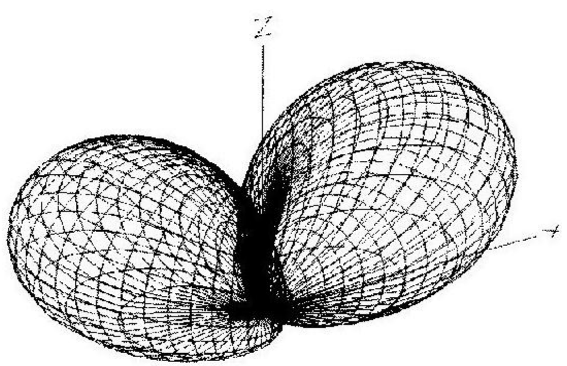


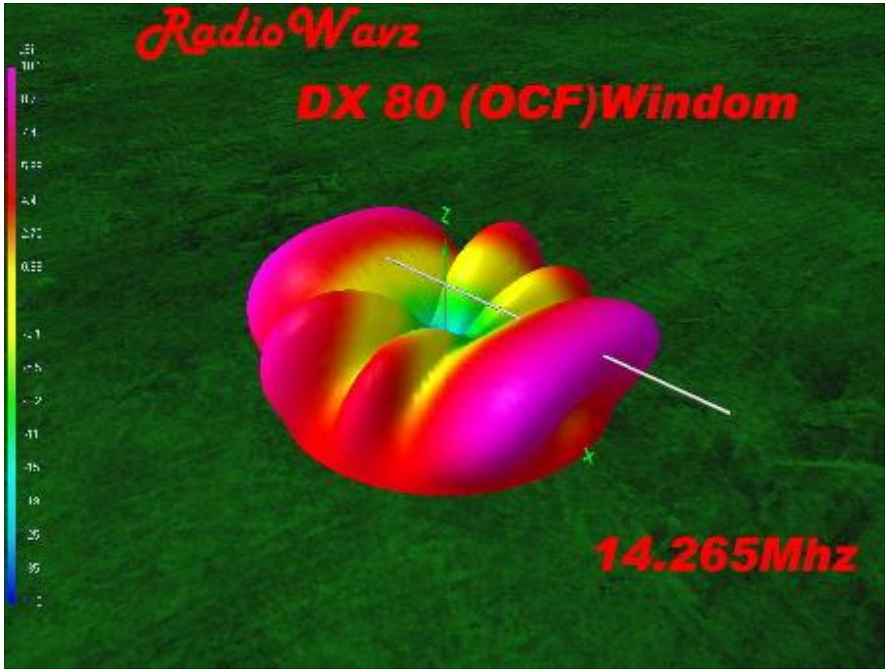
EZNEC shows the antenna wire broken into 41 segments

Antenna Modeling

Pg 9-45

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





Look at Design Tradeoffs

With modeling 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.

E9F07 How does ladder line compare to coaxial cable with a plastic dielectric?

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

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

A. A very low impedance
B. A very high 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

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

KØGY's antennas

Tnx fer listening