Introduction to Wire Antennas

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Part I

Introduction

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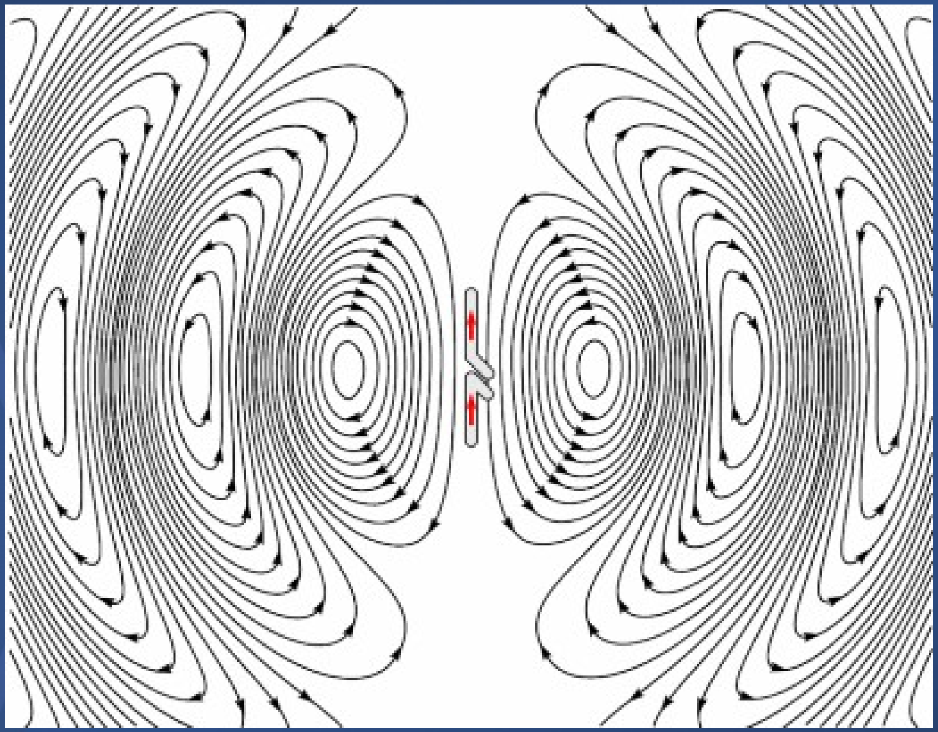
What is an Antenna?

- An antenna is a device that:
  - Converts RF current applied to its feed point into electromagnetic radiation.
  - Intercepts energy from a passing electromagnetic wave, which appears as an RF voltage across the antenna's feed point.
- Any object that can carry an electric current can act as an antenna.

Transmitting Antenna



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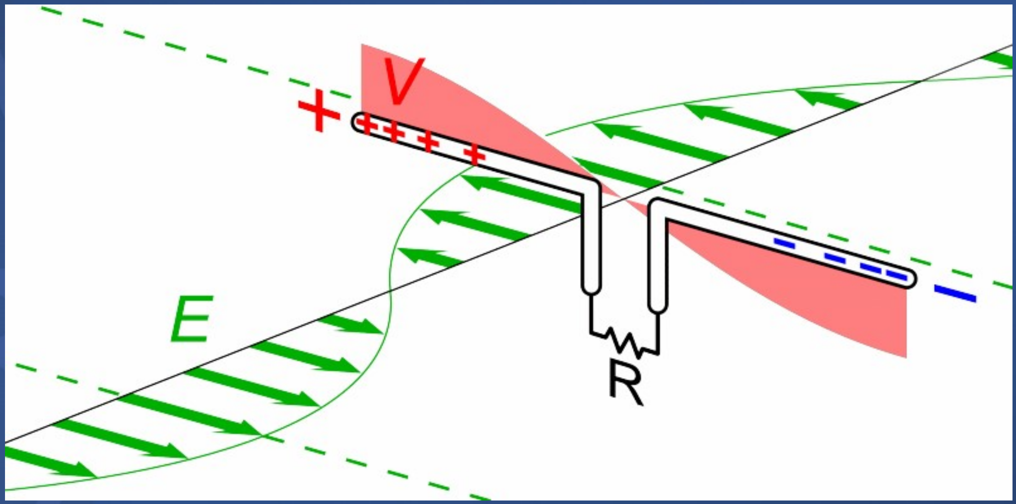
Receiving Antenna



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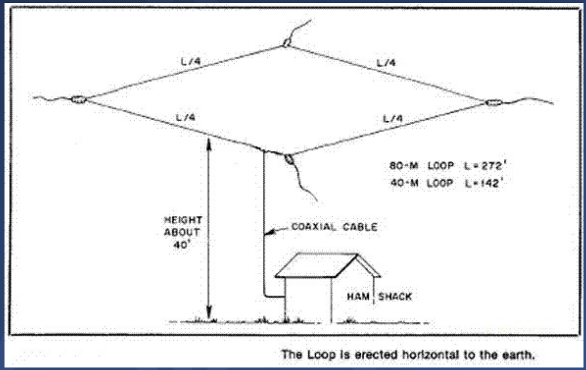
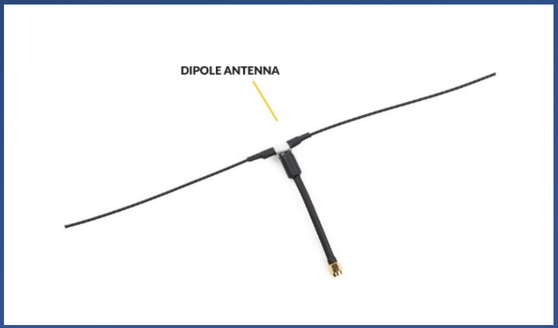
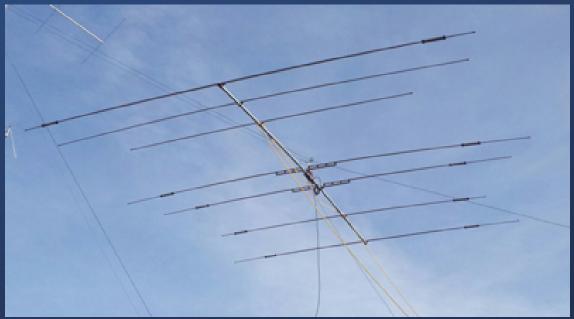
Types of Antennas



The Loop is erected horizontal to the earth.





- The are some of the many types of antennas in use
- This presentation focuses on wire antennas

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Basic Antenna Properties

- Radiation Pattern
  - Variation of antenna radiation with direction
  - Most common 2D patterns: azimuth (parallel to ground) and elevation (perpendicular to ground)
- Directivity (Gain)
  - Ratio of maximum radiation of an antenna under test to a reference antenna
- Input Impedance
  - Measured at the antenna's input – varies with frequency
- Bandwidth
  - Range frequencies over which SWR <2.0
- Reciprocity
  - Antennas exhibit the same characteristics when receiving or transmitting

Part II

The Dipole

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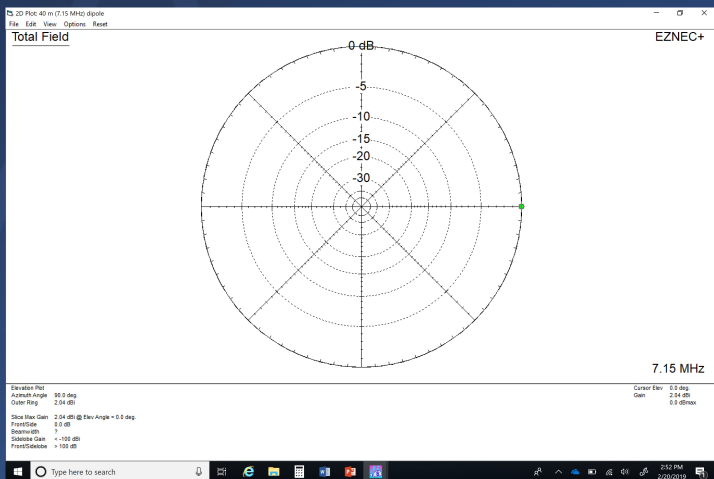
The Simplest Antenna

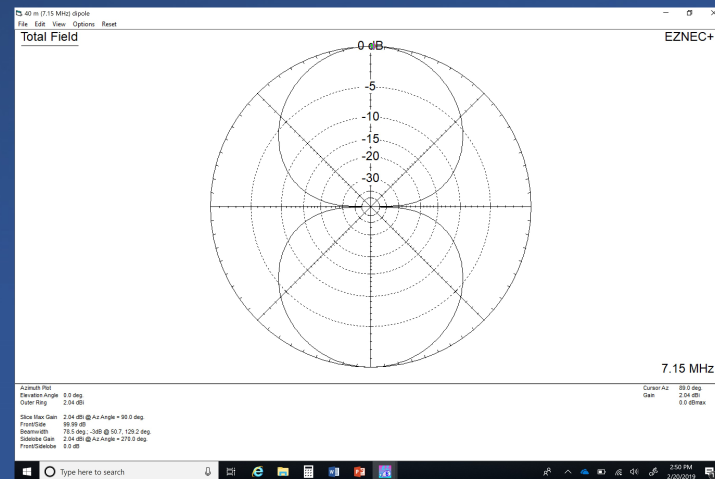
- A dipole antenna is created when we break a wire somewhere along its length and feed RF into it.
- A dipole's properties are determined by:
  - Relative length of the wire in wavelengths
  - Position of the feed point
  - Diameter of the wire
- This definition is very general, but there are some specific types of dipoles worth looking at more closely

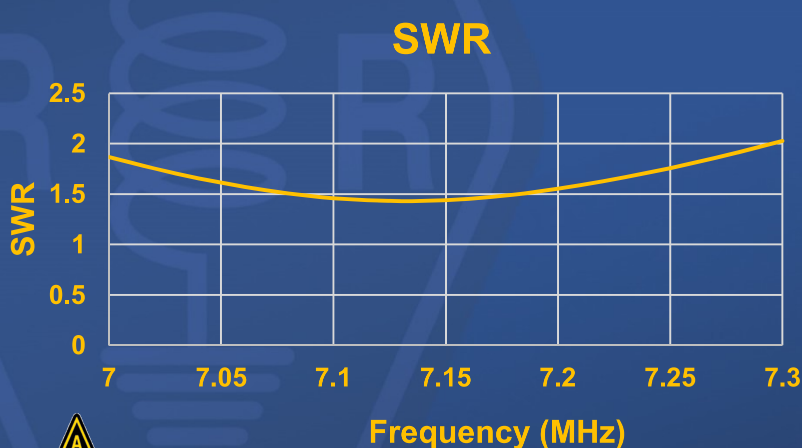
The Half-Wave (λ/2) Dipole

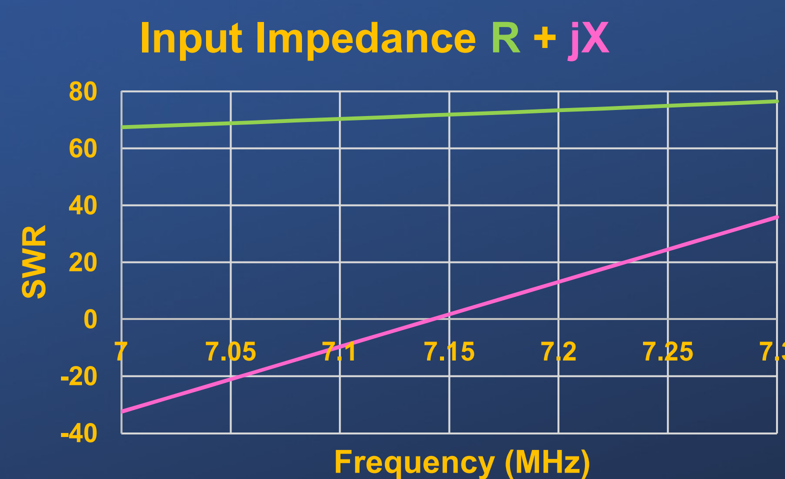
- A dipole whose length is approximately λ/2 has some useful properties:
  - Its input impedance is generally between 30 and 80 ohms, so it can be fed directly with 50 or 75 ohm coaxial cable.
  - The physical length is manageable (between 16.5 and 133 feet on the HF bands)
  - It can be hung between two supports or from a single center support (inverted-vee)

(λ/2) Dipole Properties









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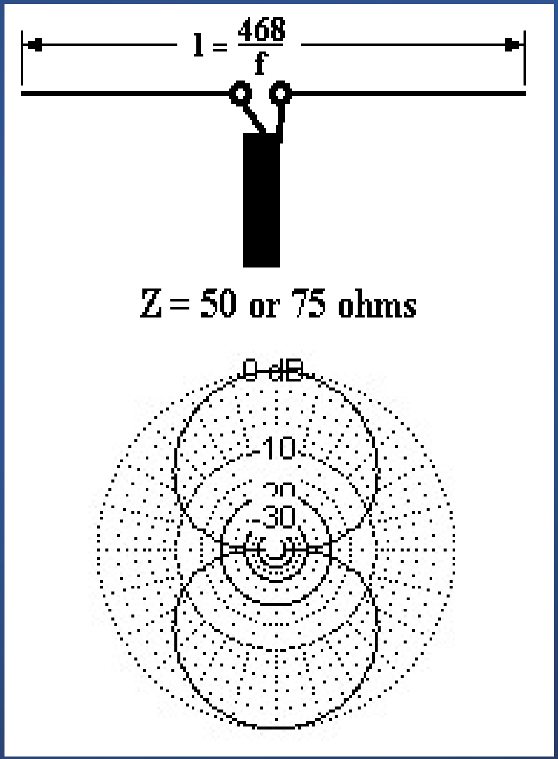
Design Table: λ/2 Dipole

BAND	LENGTH (#14 THHN WIRE)
160 (1.83 MHz)	255 ft 9 in
80 (3.8 MHz)	132 ft 2 in
40 (7.1 MHz)	65 ft 11 in
30	46 ft 3 in
20	33 ft 0 in
17	25 ft 10 in
15	22 ft 1 in
12	18 ft 9 in
10 (28.4 MHz)	16 ft 6 in



Variations on a Theme: 1λ, 1.28 λ and 3λ/2 Dipole

- 1λ dipole (2 half waves in phase)
  - Wire length is ~0.95 λ
  - Input Z~5000 Ω – could be matched with λ/4 450 Ω series section
  - Directivity = 1.5 dBd
- 1.28 λ dipole
  - Provides maximum broadside gain from a single wire, ~ 3dBd
  - Input Z = 200-j1000 Ω (can be matched with 3λ/16 450 Ω series section)
- 3λ/2 dipole (original G5RV)
  - Provides some gain in several directions
  - Input Z = 110 Ω (can be matched with λ/4 75 Ω series section)

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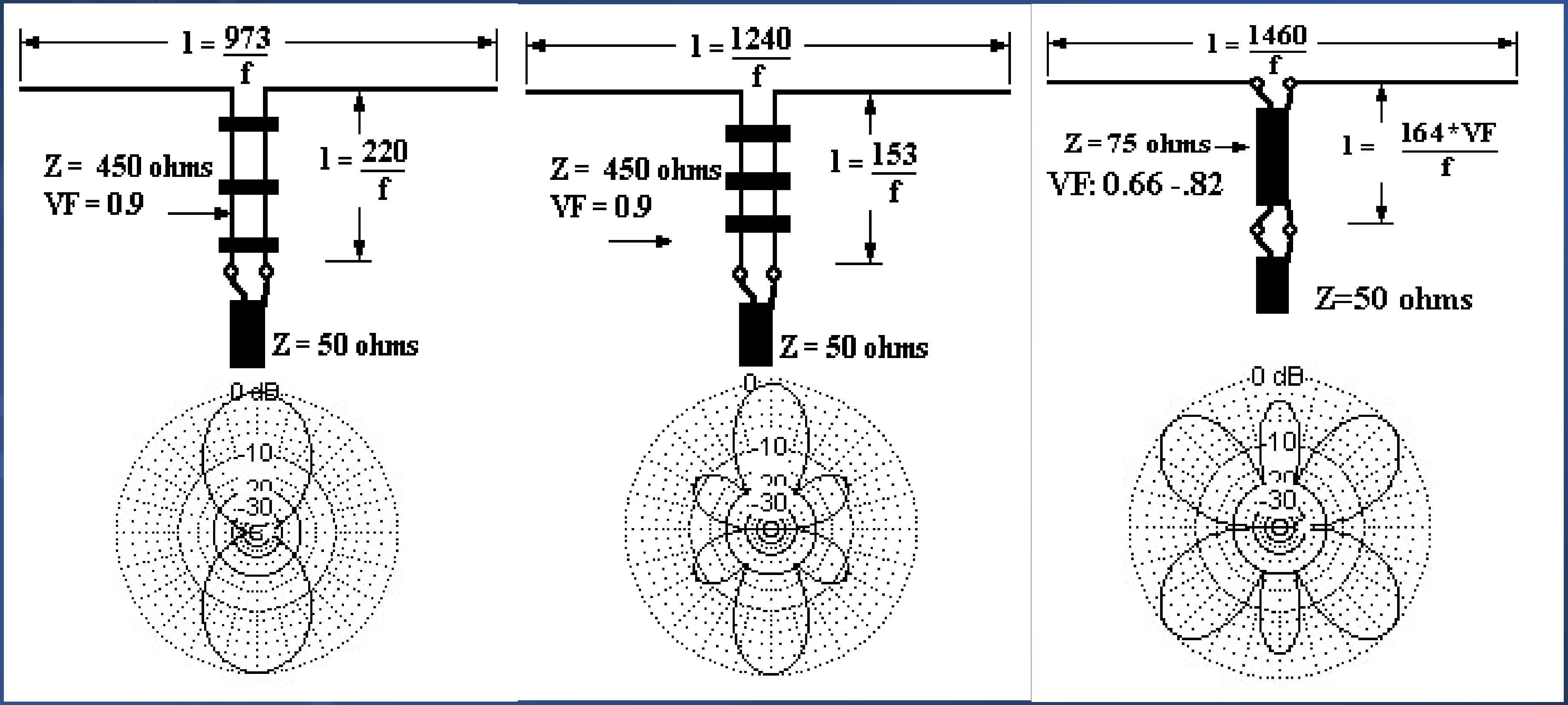
1λ, 1.28 λ and 3λ/2 Dipoles

- 1λ 1.28 λ 3λ/2



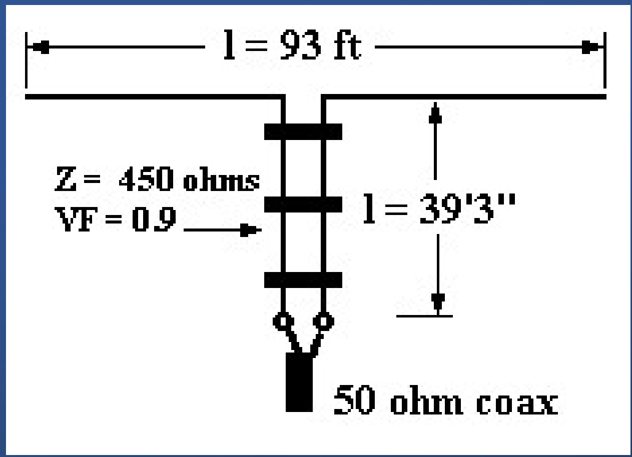
Design Table:
1λ, 1.28 λ and 3λ/2 Dipole

BAND	LENGTH (#14 THHN WIRE)		
	1λ DIPOLE	1.28λ DIPOLE	1.5λ DIPOLE
160 (1.83 MHz)	517 ft 0 in	677 in 7 in	775 ft 6 in
80 (3.8 MHz)	248 ft 4 in	326 ft 4 in	372 ft 6 in
60	175 ft 2 in	224 ft 2 in	262 ft 9 in
40 (7.1 MHz)	132 ft 2 in	169 ft 2 in	198 ft 3 in
30	92 ft 10 in	118 ft 10 in	139 ft 3 in
20	66 ft 0 in	84 ft 6 in	99 ft 0 in
17	51 ft 8 in	66 ft 2 in	77 ft 6 in
15	44 ft 0 in	56 ft 4 in	66 ft 0 in
12	37 ft 6 in	48 ft 0 in	56 ft 3 in
10 (28.4 MHz)	33 ft 0 in	42 ft 5 in	49 ft 6 in

BAND	SERIES MATCHING SECTIONS		
	1λ DIPOLE -450 Ω LINE	1.28λ DIPOLE - 450 Ω LINE	1.5λ DIPOLE - 75 Ω RG11
160 (1.83 MHz)	120 ft 3 in	83 ft 7 in	88 FT 9 IN
80 (3.8 MHz)	57 ft 11 in	40 ft 3 in	42 ft 9 in
60	41 ft 1 in	26 ft 7 in	30 ft 5 in
40 (7.1 MHz)	31 ft 0 in	21 ft 7 in	22 ft 11 in
30	21 ft 9 in	15 ft 1 in	16 ft 0 in
20	15 ft 6 in	10 ft 10 in	11 ft 6 in
17	12 ft 2 in	8 ft 6 in	9 ft 0 in
15	10 ft 4 in	7 ft 2 in	7 ft 8 in
12	8 ft 10 in	6 ft 2 in	6 ft 6 in
10 (28.4 MHz)	7 ft 9 in	5 ft 5 in	5 ft 9 in

The ZS6BKW Dipole

- This antenna consists of ~93 ft of #14 THHN wire fed in the center through a 39ft 3in section of 450 Ω ladder line:
- This antenna is a good match (SWR < 2.0) to 50 Ω coax on the following bands: (other bands require a matching network)
  - Bottom 100 KHz of 80m
  - 40m
  - 20m
  - 17m
  - 12m
  - 10m



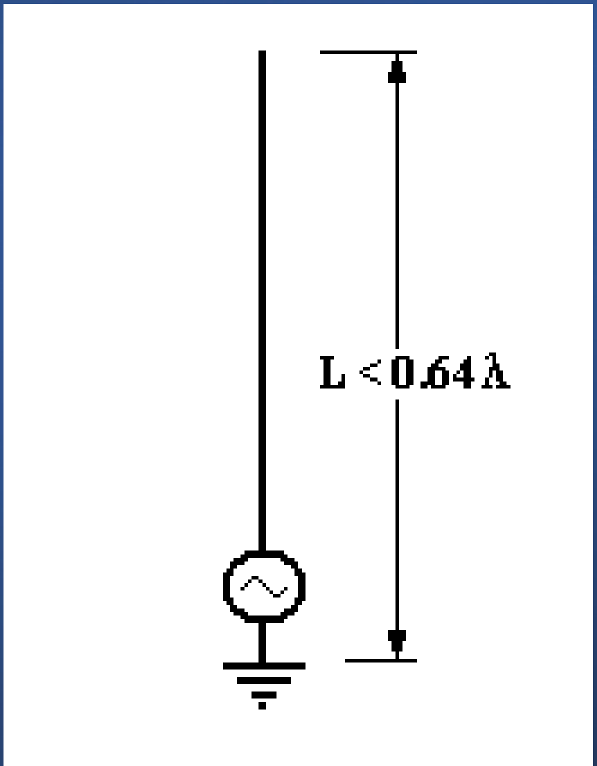
- If you can only put up one antenna, this is the one.

Part III

The Vertical Monopole
(Marconi Antenna)

Reflections and Images

- A vertical monopole (Marconi) antenna is a vertical wire fed against ground.
- The ground surrounding the antenna is very important - the monopole's image in the ground supplies the "missing half" of a vertical dipole
- RF reflections from the ground also greatly influence the antenna's impedance and radiation pattern

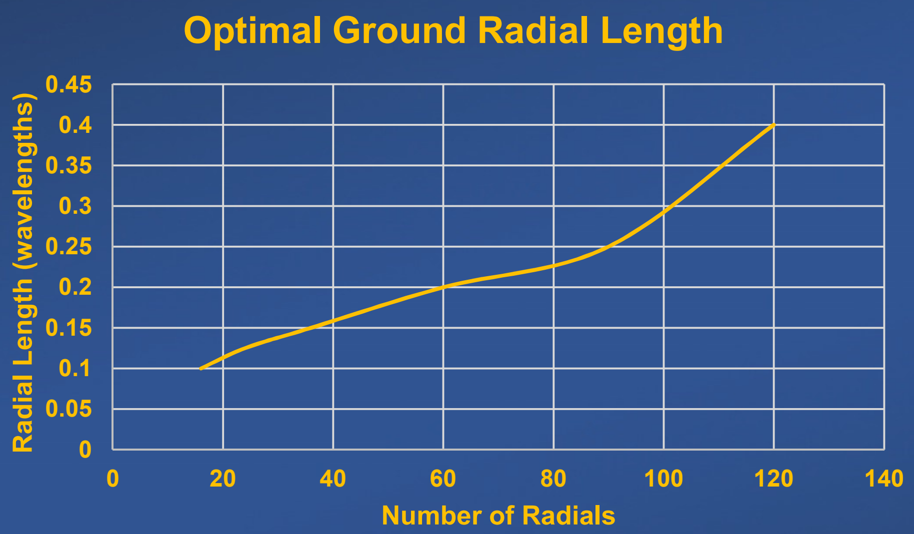


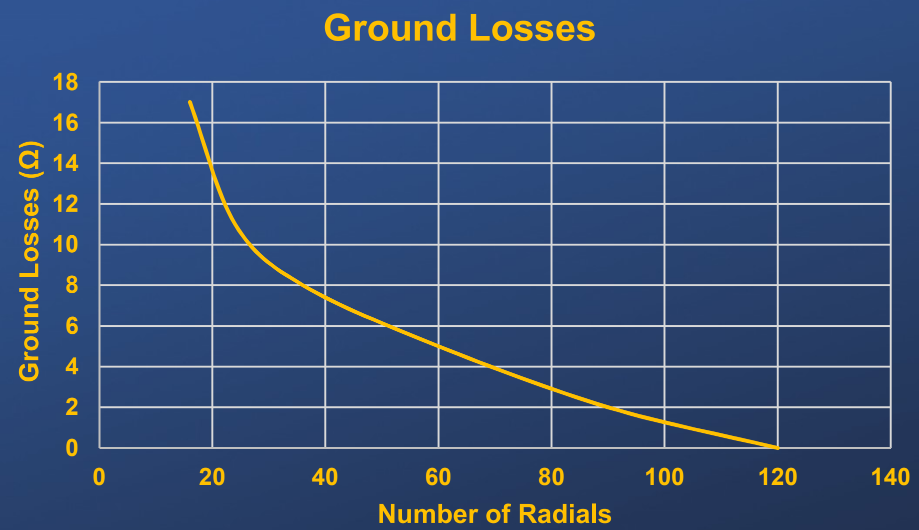
The Importance of a Good Ground

- The ground is part of the vertical antenna, not just a reflector of RF, unless the antenna is far removed from earth (usually only true in the VHF region)
- RF currents flow in the ground in the vicinity of a vertical antenna. The region of high current is near the feed point for verticals less that $\lambda/4$ long, and is ~ $\lambda/3$ out from the feed point for a $\lambda/2$ vertical.
- To minimize losses, the conductivity of the ground in the high current zones must be very high.
- Ground conductivity can be improved by using a ground radial system, or by providing an artificial ground plane.
- Ground planes are most practical in the VHF range. At HF, radial systems are generally used.

Ground Radials

- Ground radials may be laid on the ground and should not be insulated from ground
- The radial wires should run radially out from the antenna feed point.
- The length of each radial is dependent on the number of radials
- In general, more short radials are preferable to a few long ones





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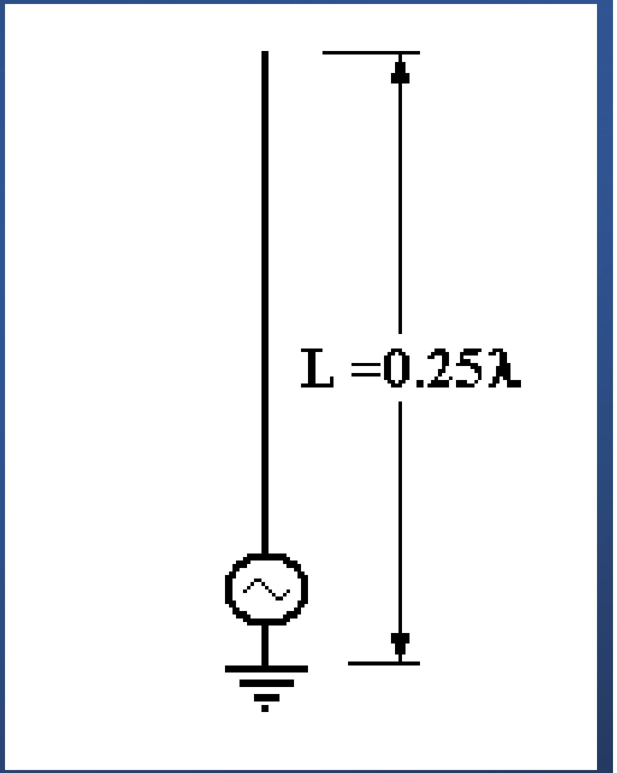
The Quarter-Wave (λ/4) Monopole

- The radiator is a vertical wire ~ λ/4 long
- Input Z = Z_{ANT}+ R_{GND} + R_{REF} (35-70Ω)
- Efficiency η **= $|Z_{ANT}|$ /$|Z_{IN}|$ -** often much less than 100%
- The big advantage of the λ/4 monopole is that it radiates better than a dipole at low angles (particularly on the lower bands)



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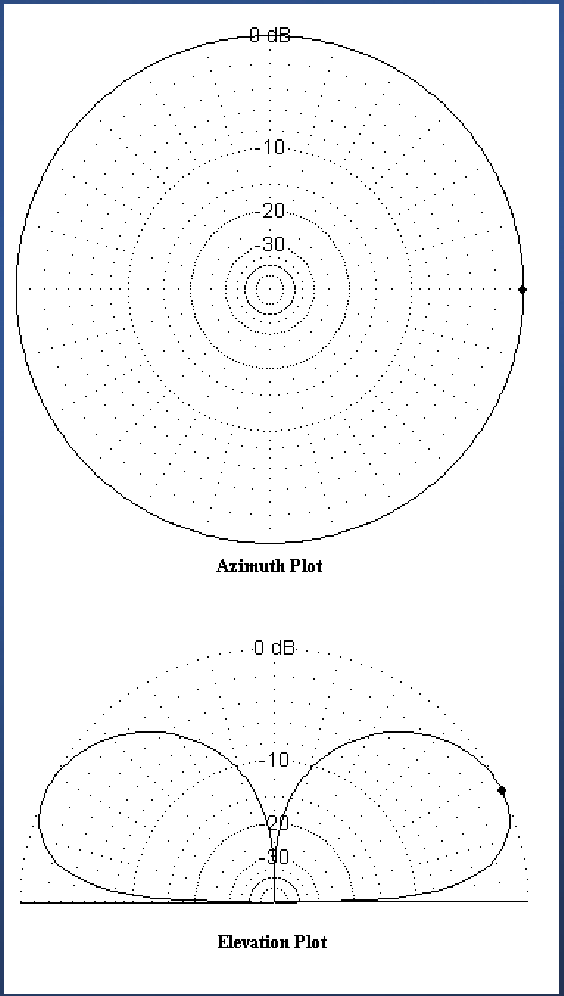
λ/4 Monopole Radiation Patterns

- The antenna is omnidirectional in the horizontal plane
- Radiation in the vertical plane is concentrated at low angles
- Increasing ground conductivity decreases the angle of maximum radiation in the vertical plane



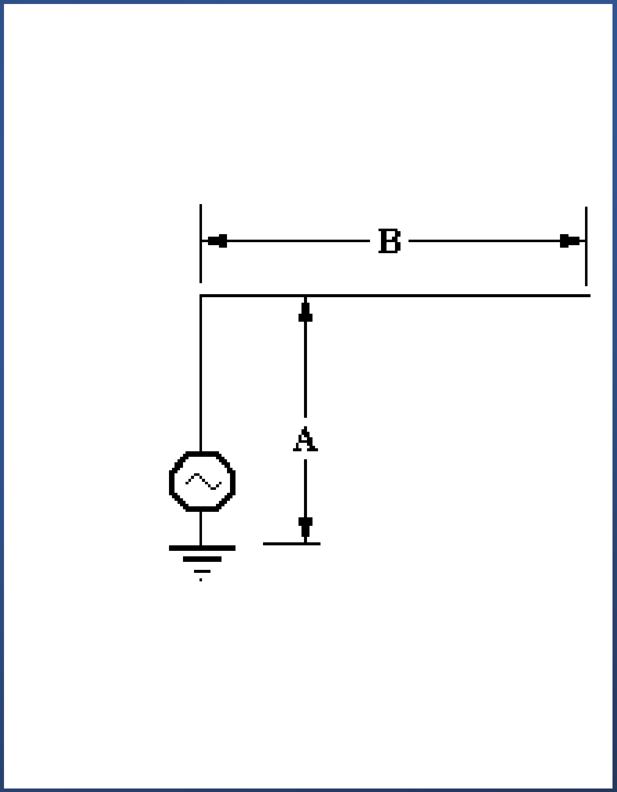
Design Table - λ/4 Monopole

BAND	RADIATOR LENGTH (#14 THHN)
160	127ft 10 in
80 (3.60 MHz)	65 ft 0 in
75 (3.90 MHz)	60 ft 0 in
60	43 ft 9 in
40 (7.1 MHz)	33 ft 0 in

- Data is only included for the low bands, because on the higher HF bands, in most cases, a horizontal wire antenna such as a dipole is a better choice.

The Inverted-L Monopole

- The radiator is a vertical wire that has been folded to fit available supports. Overall length A+B ~ 0.3λ
- Typically the vertical section is ~λ/8
- Zin ~30Ω - 75Ω
- Radiation patterns are similar to a λ/4 vertical, with a small amount of directivity in the horizontal pattern (typically less than 2 dB)



Design Table – Inverted-L

BAND	VERTICAL SECTION LENGTH	HORIZ. SECTION LENGTH
160	65 ft 9 in	77 ft 10 in
80 (3.60 MHz)	31 ft 11 in	37 ft 0 in

- Data is only included for the 160 and 80 meter bands, because the height required for a $\lambda/4$ vertical for the 60 and 40 meter bands is less and doesn’t usually necessitate installation as an inverted-L

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Part IV

Antenna Measurements

Characterizing Antenna Performance

- Ideally, we would like to know at least three things about an antenna:
  - Radiation Pattern
  - Input Impedance
  - Bandwidth
- Unfortunately, only one of these, bandwidth, is easy to measure

Making Antenna Performance Measurements

- Radiation patterns can be very useful, but are very difficult to measure. An antenna test range is required for accurate measurements.
- An impedance bridge or vector network analyzer ($$$) is required for Input Z measurements
- Bandwidth can be easily be determined from SWR measurements.

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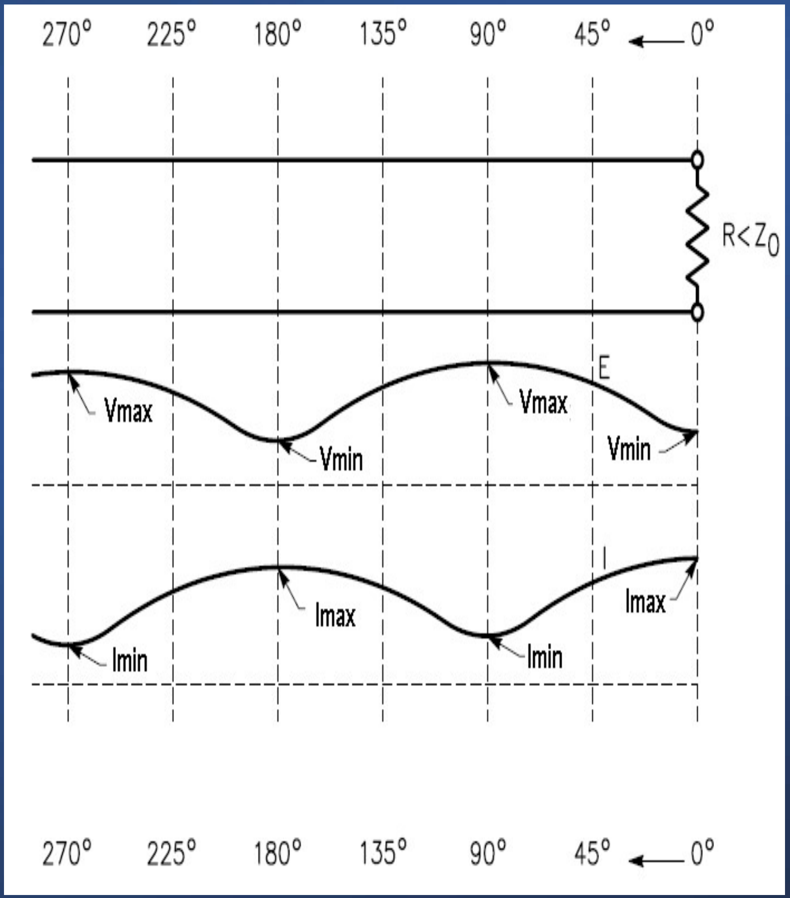
SWR

- It turns out that SWR is the simplest, cheapest measurement we can make on an antenna system.
- SWR is the ratio of maximum to minimum voltage on a transmission line.
- Most amateur stations have equipment for measuring SWR.
- What do SWR measurements tell us?
  - The degree of mismatch between the antenna and feed line
  - The bandwidth of the antenna system
- As with any measurement, some interpretation is required to get useful interpretation from SWR data

SWR – Mathematical Relationships

- Max Voltage $V_{max} = \sqrt{2PZ_0 * (SWR)}$
- Minimum Voltage $V_{min} = \sqrt{\frac{2PZ_0}{(SWR)}}$
- Reflection Coefficient $|\rho| = \sqrt{\frac{P_R}{P_F}}$
- SWR $SWR = \frac{1+|\rho|}{1-|\rho|}$



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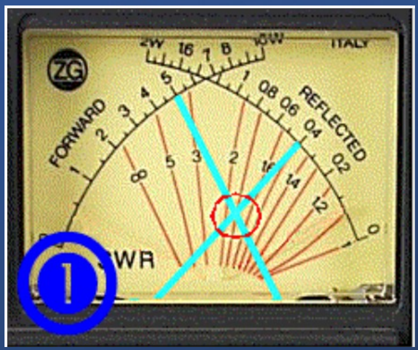
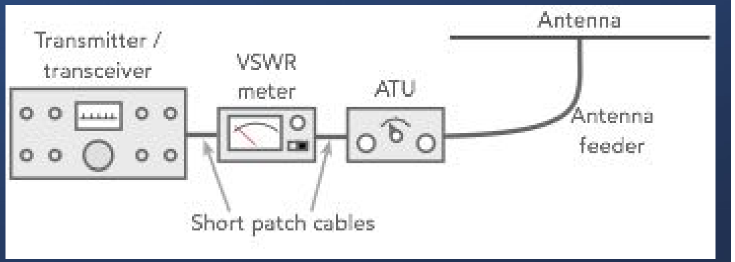
Measuring SWR

- Some transceivers have built in SWR meters. To measure SWR all one need do is look at the display
- An external SWR meter may also be used. There are two types:
  - Single needle unit – two step process
    - Meter sensitivity is adjusted to make meter read full scale on forward power setting.
    - In reverse power setting, SWR is read off meter scale
  - Crossed-Needle unit – one step process
    - SWR is indicated by point where forward and reverse power meter needles cross
- SWR is measured between the output of transmitter and the load (including matching networks)





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Power and SWR

- A power meter that can measure forward and reflected power may also be used to determine SWR.
  - Measure the forward power (P_F) and reverse power (P_R)
  - Use the following equation to compute SWR:

$$SWR = \frac{1 + \sqrt{\frac{P_R}{P_F}}}{1 - \sqrt{\frac{P_R}{P_F}}}$$

- Example: P_F = 108W P_R =12W

$$SWR = \frac{1+\sqrt{\frac{P_R}{P_F}}}{1-\sqrt{\frac{P_R}{P_F}}} = \frac{1+\sqrt{\frac{12}{108}}}{1-\sqrt{\frac{12}{108}}} = \frac{1+\sqrt{.111}}{1-\sqrt{.111}} = \frac{1+.333}{1-.333} = \frac{0.667}{0.333} = 2.0$$

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Using an SWR meter to set up and antenna matchbox

- These instructions apply to modern matchboxes using a T-network.
  - Set the “TRANSMITTER” and “ANTENNA” controls to their midrange position
  - Measure the SWR.
  - While watching the SWR meter, set the “INDUCTANCE” control to the value that results in minimum SWR
  - Then adjust the “TRANSMITTER” and “ANTENNA” controls until the SWR < 2.0
  - If SWR cannot be reduced to less than 2.0, change the “INDUCTANCE” setting and try again.

Bandwith and SWR

- Once the antenna and line are matched to the transmitter, one can use the SWR meter to determine the antenna system bandwidth.
  - Use the SWR meter to determine the lower frequency (F_L) at which SWR = 2.0
  - Use the SWR meter to determine the higher frequency (F_H) at which SWR = 2.0
  - The bandwidth can be computed using the following equation:

$$BW = F_H - F_L$$

- Example: F_L = 3.64 MHz F_H = 3.78 MHz

$$BW = F_H - F_L = 3.78 - 3.64 = 0.14\ MHz = 140\ KHz$$

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How important is SWR? Is high SWR bad?

- The fact we measure high SWR for a particular antenna system, DOES NOT MEAN that the antenna is not radiating!! The antenna gets all the transmitter's power, less any line loss.
  - Example: we transmit a1.8 MHz, 100W carrier into a short dipole antenna through 65 feet of RG-8 coax, whose loss is 0.17 dB. The SWR at the antenna is 19.0.
  - The forward power is 383W
  - The reflected power is 310 W
  - The power going into the antenna is 73W

SWR and Line Loss

- In the example on the last slide, we saw that 100 W transmitted into 65 feet of RG-8 connected to an antenna whose SWR = 19 resulted in 73 W reaching the antenna.
- If the SWR had been 1.0, 96W would have reached the antenna.
- Operating transmission lines under high SWR increases line loss!

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SWR and Line Selection

- Because coaxial cable is relatively lossy, it should only be used in situations where SWR < 3.0 because:
  - Attenuation in coax rises quickly with increasing SWR
  - High voltages associated with high SWR may break down the dielectric
- In situations where the SWR > 3.0, use open-wire line or ladder line
  - It has much lower loss, even when the SWR > 10.0
  - Dielectric breakdown is much less likely

Is low SWR always good?

- Absolutely not!!
- Consider a dummy load.
  - It is designed to show SWR = 1.0 over a wide range of frequencies
  - It is designed NOT TO RADIATE
- Not convinced? Consider a mobile antenna used for 75 phone operation, whose R_{IN} = 4 ohms.
  - Poor installation – $Z_{LOAD} = R_{IN} + R_{GROUND} = 4\Omega + 50\Omega = 54\Omega$. SWR = 1.1 η=7.4%
  - Good installation - $Z_{LOAD} = R_{IN} + R_{GROUND} = 4\Omega + 20\Omega = 24\Omega$. SWR = 2.1 η=17%
  - The antenna with higher SWR is actually more than twice as efficient!

SWR Recap

- SWR is the ratio of maximum to minimum voltage on a transmission line.
- Possible values for SWR range from 1.0 (perfect match) to ∞ (perfect mismatch)
- Line losses increase with increasing SWR
- High SWR is not necessarily bad
- Low SWR is not necessarily good
- Coaxial cable is a good feed line choice when SWR <3
- Open wire line is a good choice when SWR > 3.0
-

Questions and Comments

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