Least understood topics by most HAMs

- RF Safety
- Ground
- Antennas
- Matching & Feed Lines

Remember this question from the General License Exam?

G0A03 | (D) How can you determine that your station complies with FCC RF exposure regulations?

A. By calculation based on FCC OET Bulletin 65

B. By calculation based on computer modeling

C. By measurement of field strength using calibrated equipment

D. All of these choices are correct

RF Safety for your Flagpole Antenna:

This document details a typical TVARC member's Flagpole Antenna RF hazard calculations that predict the power density levels in occupied areas around the system antenna. This "worst case" estimate assumes the true average-radiated power from the antenna based on the maximum transmitter output for each band are compared to the Maximum Permissible Exposure (MPE). The results are expressed in power density at distance for far field determine a safe environment directly at the flagpole antenna.

Density Calculation:

Power density from an isotropic antenna

$$P_D = \frac{P_t}{4\pi R^2}$$

where: P_t = Average Transmitter Power
R = Range from Antenna (i.e. radius of sphere)

The power density at a distant point from an antenna gain of Gt is the antenna gain.

Power density equals;

$$P_D = \frac{P_t G_t}{4\pi R^2}$$

Assumptions:

Assumes; 100 W Transmitter, SSB, 100 Feet RG-8X, VSWR 1.5, 10 M

Watts	100	Steady State Transmitter Power in Watts (Example 100W SSB or 25W AM)
Factor	0.20	Modulation Factor (Am, FM, RTTY & Digital = 1, CW = 0.4, SSB = 0.2)

dB	0.3	Tuner or Duplexer Loss in dB
dB	1.5	Cable Loss in dB
dB	0.5	BALAN or Antenna Impedance Matching Loss in dB
dB	0.0	Antenna Gain in dBi (Vert = 0, Dipole = 2.1, Random Wire = 0, etc)

Feet	1	Distance in Feet from Antenna to your head (Controlled)
Feet	2	Distance in Feet from Antenna to your property line (Uncontrolled)

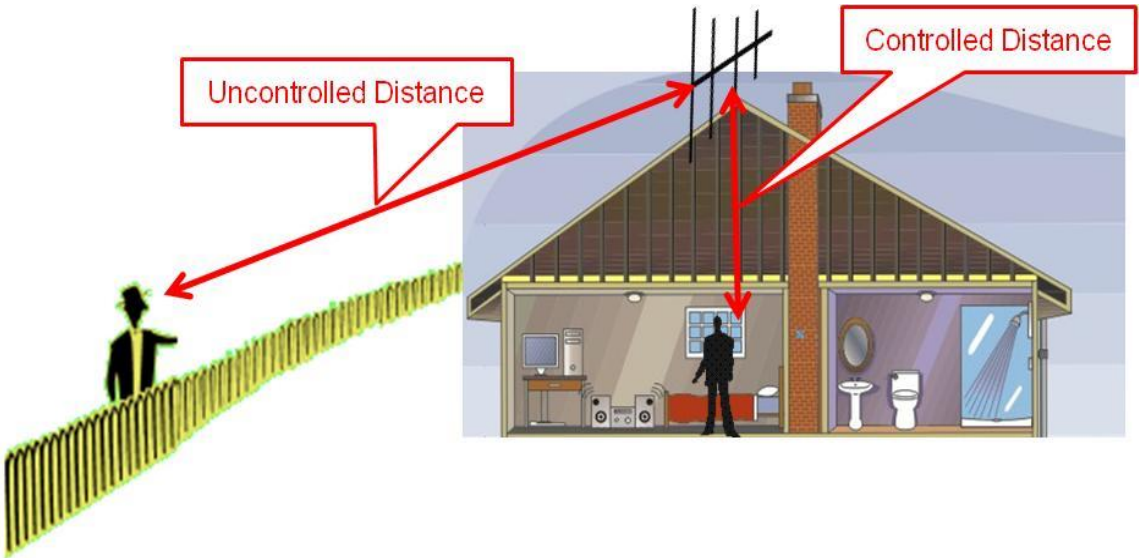
Exposure Limits:

The FCC Second Memorandum and Order dated August 27, 1997 adopted a sliding scale for categorical exemption to routine RF radiation compliance testing based on peak envelope power (PEP) at various Amateur Radio operating frequencies. While the RF radiation exposure compliance levels are based on average power, the categorical exemptions from the requirement for periodic station compliance testing are based upon peak envelope power (PEP). Stations operating at or below these respective PEP levels are categorically excluded from having to perform a routine RF radiation evaluation. However, all stations, regardless of power level, still must comply with the RF exposure limits. OST/OET Bulletin #65 sets the Maximum Permissible Exposure (MPE) to field levels.

Density Results:

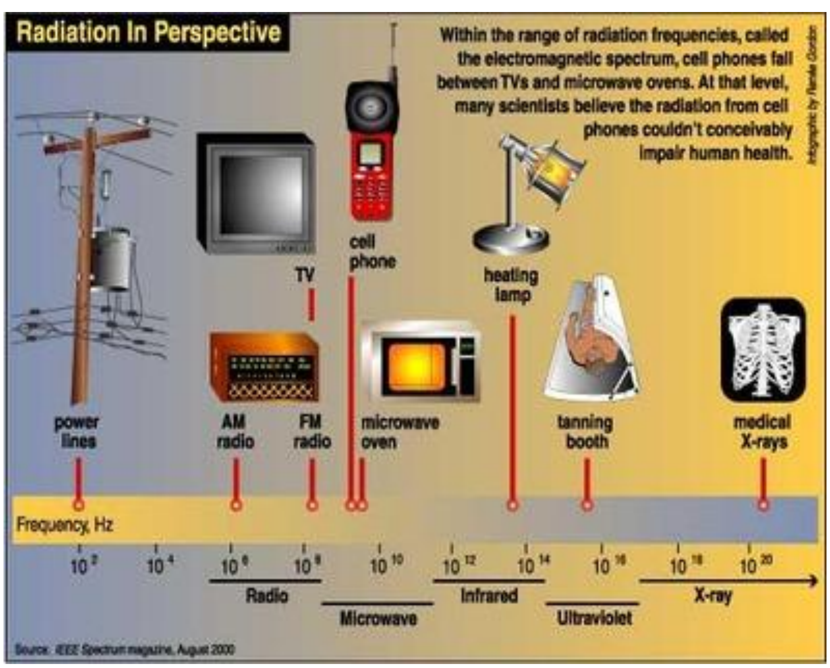
The calculated maximum power density for this station is shown at the top of the respective controlled and uncontrolled columns in the table below. The maximum MPE allowable strength of the RF fields around this station are listed descending in each column for the maximum frequency in each amateur band listed.

	0.8338	Controlled Power Density mW/cm2						
		0.1907	Uncontrolled Power Density mW/cm2					
				Routine RF Radiation Evaluations Required				
	Max PD Allowed mW/cm2	Max PD Allowed mW/cm2		Min MHz	Max MHz	Watts Peak	Amateur Band
OK	100.00	45.00	OK	1.80	2.00	500	160 M
OK	56.26	11.26	OK	3.50	4.00	500	80 M
OK	16.89	3.38	OK	7.00	7.30	500	40 M
OK	8.66	1.74	OK	10.10	10.15	425	30 M
OK	4.38	0.88	OK	14.00	14.35	225	20 M
OK	2.37	0.55	OK	18.07	18.17	125	17 M
OK	1.96	0.40	OK	21.00	21.45	100	15 M
OK	3.71	0.29	OK	24.89	24.99	75	12 M
OK	1.03	0.21	OK	28.00	29.70	50	10 M
OK	1.00	0.20	OK	50	54	50	6 M
OK	1.00	0.20	OK	144	148	50	2 M
OK	1.00	0.20	OK	222	225	50	1.25 M
OK	1.50	0.30	OK	420	450	70	70 cm

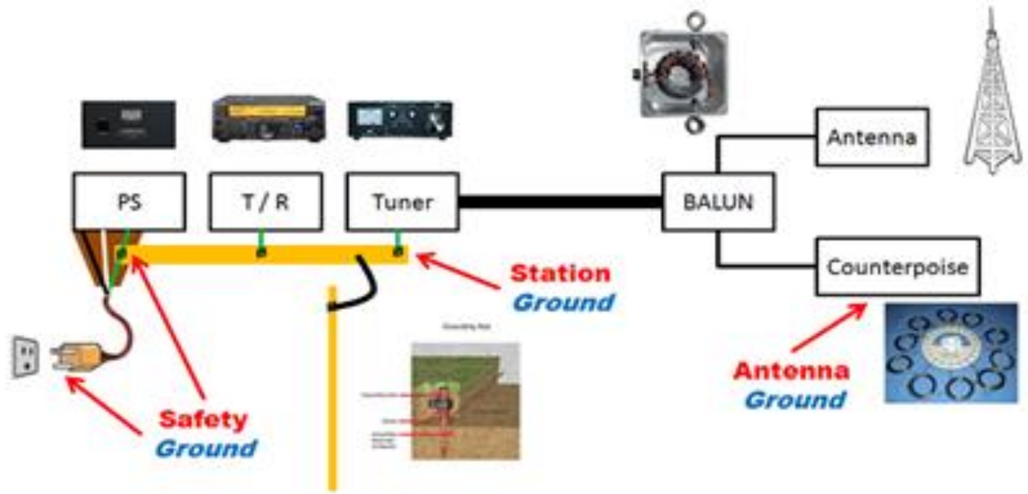


Safety CONOPS: The practical answer is operations in a safe environment that can be used under normal operating conditions without burden to the station operator. It is recommended that access to the planter be restricted when RF radiation is permitted. No additional precautions are required for a residential station as the operator has control over maintenance workers as the owner of the yard and controls both access and transmitter emissions. In reviewing the station MPE levels it has been determined the operator and neighbors have full unrestricted use of the yard during transmitter operation by taking the following actions.

- Radiating element inside PVC pipe to prevent direct contact
- Control Zone established by planter
- Control Zone = 1+ Feet
- Uncontrolled Zone = 2+ Feet
- Operator monitors site during transmissions

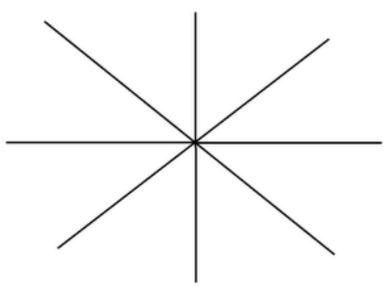


Grounding the least understood radio topic

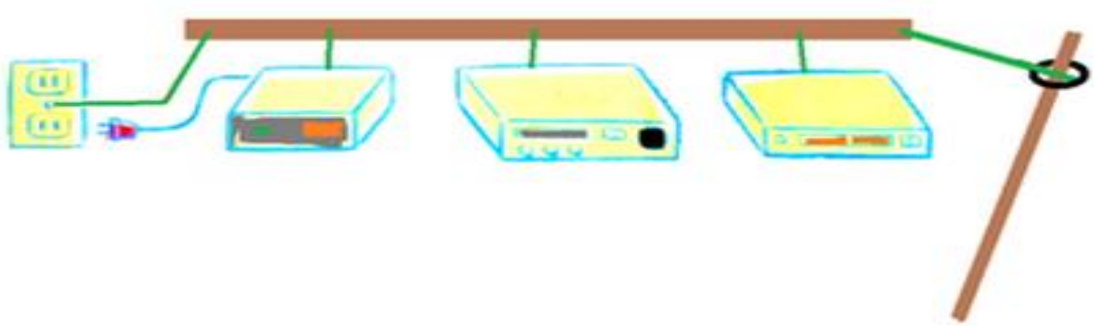


Amateur radio stations have three unique and separate grounding functions; Electrical (Safety) *Ground*, Antenna (Counterpoise) *Ground* & *Station* (RFI) *Ground*

Electrical Safety Ground is a connection to chassis to prevent operator contact with dangerous voltage if the electrical power source insulation fails. This connection provides a return path to trip the circuit breaker.



Antenna (Counterpoise) Ground is the other half of the antenna, normally a wire one-quarter wavelength long. It does not need to be straight. Before you dig remember placing radials in the sandy soil DEGRADEs effectiveness. A BALUN is needed to isolate to antenna ground from the station ground.



Station RFI Ground is a single point at which shack equipment ground lugs are connected together through a very short, low impedance lead. so any RF that reach the station will be largely shunted to Earth.

RF Bands > approx equal the **Speed of Light / Frequency =** (**300 Meters** / F MHz)

Physical Length (**Shorter is Higher Frequency**)
1/4 Wave Antenna = Physical Length of **234 Ft.** / F MHz)

1/2 Wave Antenna = Physical Length of **468 Ft.** / F MHz)

Full Wave Antenna = Physical Length of **936 Ft.** / F MHz)

Polarization

Vertical Antenna > Electric Field is perpendicular to the earth (Flag Pole)
Horizontal Antenna > Electric Field is parallel to the earth (Cloths Line)

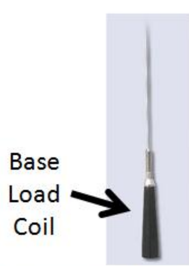
Common Antennas

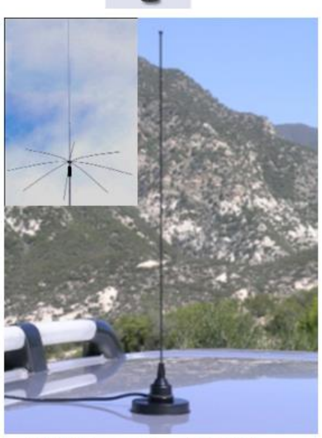
1/4 Wave > Common Mobile (whip, rubber duckie, flag pole)
5/8 Wave > Used as mobile for more Horz gain
3/4 Wave > Base for more Horz gain Least common due to size
J-Pole > Mostly VHF & UHF due to size but most gain for omni
Slim Jim > Like J Pole but even more gain for omni
Dipole > Most common of all has small gain
Dipole most common Multi-Band > Windom, OCF, G5RV
Loop > Provides high Gain & Low Noise less common due to size
Yagi > Most gain (Beam, Quad Beam, Array)

Load Coils, Matching Coils, Traps

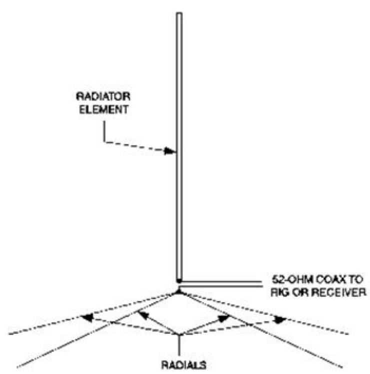
Load Coils make an antenna "look" longer to the RF
Matching Coils do same as load coils plus change input impedance
Traps in multi-band antennas make it "look" shorter as freq goes up
Multi-wire Dipoles (FAN) let the RF "select" best pair without loss

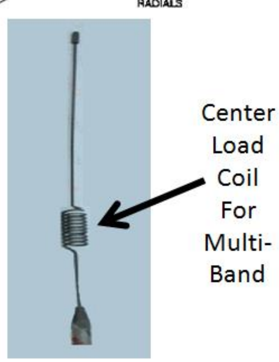
1 / 4 Wave Antenna > Commonly used antenna using ground plane for a counterpoise



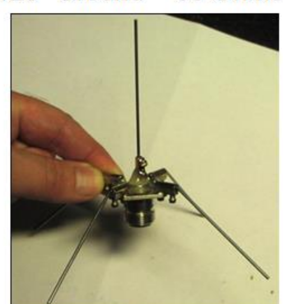


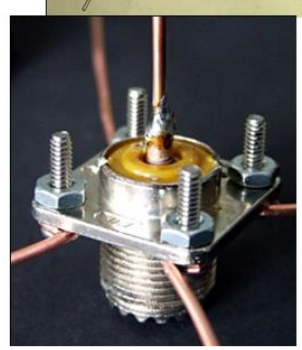
90° Ground = 36 Ohms





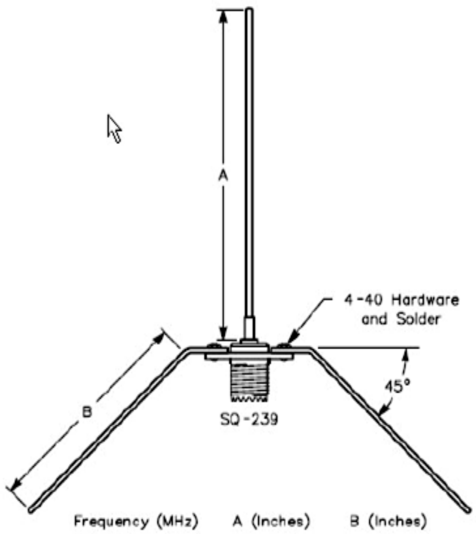
120° Ground = 50 Ohms





Simple VHF/UHF Ground Plane antennas for under $20

These antennas have appeared in numerous publications over the years, including the ARRL Antenna Book, and are only limited by your imagination as to their potential uses. Excellent for local repeater work, APRS, Field Day, Emergency deployment, Stealth installs, the list goes on. They are simple to make, simple to assemble, simple to get the parts for; do you see a pattern here? The most basic design will be shown first, with a few very slick improvements later.



Frequency (MHz)	A (Inches)	B (Inches)
146	19-5/16"	18-11/16"
225	12-5/8"	12"
445	6-3/8"	5-3/4"

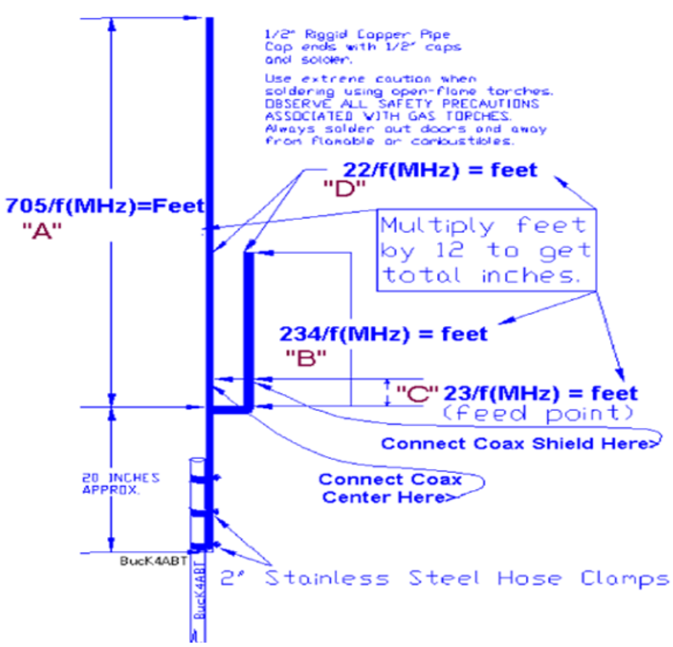
The entire antenna consists of a panel mount SO-239, some stiff wire (like aluminum welding wire, brazing rod, 12 GA bare copper wire, electric fence wire, etc) or thin brass tubing, some solder, and four 4-40 3/8" long screws, washers, and nuts

Cut the wires to length in accordance with the chart provided for the band you want. You will end up with 5 pieces of wire, 4 the same length (radials) and one slightly longer (driven element). Use a good high wattage soldering iron to tin one end of the driven element

HINT:Cut your radials extra long, mount them on the SO-239, mark the point to start the bend, remove the radials, make the 45deg bend, remount them, then measure and trim to length. When tuning for lowest SWR, remember that the angle of the radials affects the value, so feel free to adjust them anywhere between 30 and 45 deg for best reading. Also, if tubing is used, one end of each radial can be soldered to a ring terminal or hammered flat and drilled

J-Pole Antenna (¼ WL & ¾ WL)

Combination Antennas > **J-Pole concentrates signals in low elevation angle to increase range**



for 146 Mhz >>> A= 57.9 Inches, B= 19.2 Inches, C= 1.9 Inches, D= 1.8 Inches
for 440 Mhz >>> A= 19.22 Inches, B= 6.38 Inches, C= 0.63 Inches, D= 0.60 Inches

Basic Diplole Antenna > Two wire antenna (Rabbit Ears) Radiates to the **Broadside**
1/2 Wave Antenna or two 1/4 Wave Antennas together = Physical Length of **468 Ft.** / F MHz)

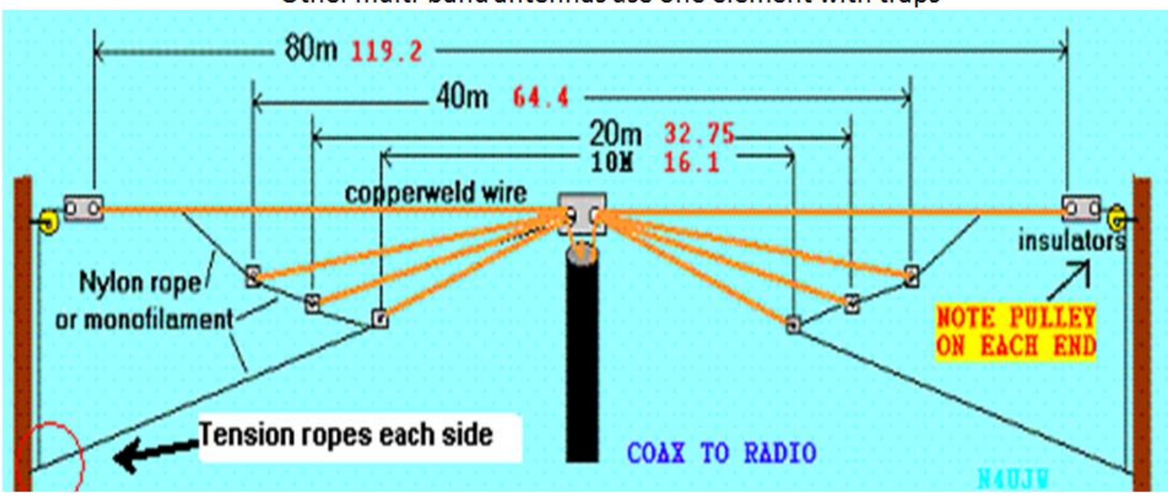
180° Elements = 72 Ohms

TV Rabbit Ears

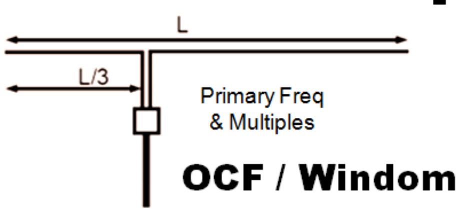
120° Elements = 50 Ohms

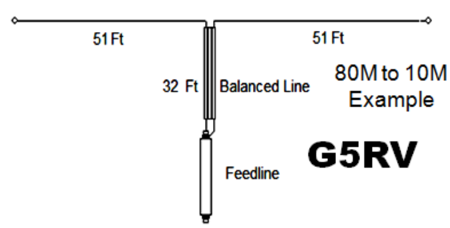
Multi-band HF Dipole Antenna using several tuned elements

Other multi-band antennas use one element with traps



Multi-band Dipoles





These antennas give wide bandwidth over more bands than regular dipoles. OCF dipole example: 68 Foot antenna that can provide a reasonably good match across 40, 20, 10 and 6M. The OCF dipole is like a standard horizontal dipole but fed at the 1/3 – 2/3 position with an impedance of 200 to 300 Ohms so you will need a 4:1 or 6:1 BALUN. The G5RV is a center fed dipole with balance line (most 300 Ohm) then connected to coax (most 50 Ohm) feedline. The combination of feed impedances / specific lengths combine to match to the coax impedance and act as a radiator. **WARNING – The G5RV balanced lines need to be perpendicular to the dipole and close to vertical and not near metal.**

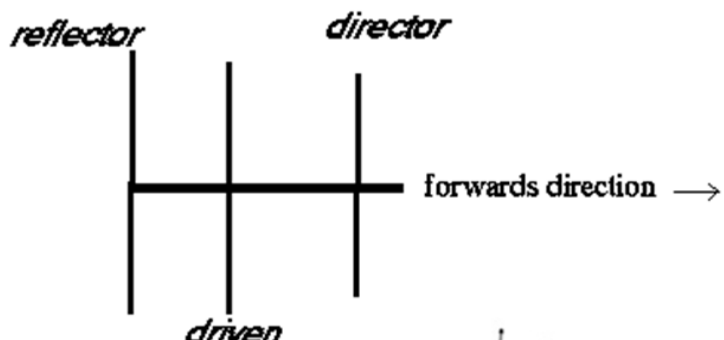
Full Wavelength Loops

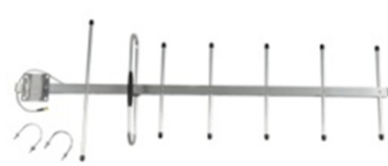
These are closed loops that are one full wavelength long with good gain and low noise. Horizontal loops may be fed at any convenient spot but must be more than ½ WL above ground. For best performance, make your horizontal loop into a square, especially if it is to be used on several bands. The Vertical Loop is a good DX antenna due to the low radiation angle better for skip. The shape can be a circle, square, rectangle or a triangle. The larger the area of the loop the better it will work. Feed square and rectangular loops at a corner. For best results, triangular loops should be supported apex-down. The design frequency, the feedpoint impedance, will be between 80 and 150 ohms. You may feed this antenna with a 4:1 BALUN unless you have a balanced tuner. The large loop usually has its strongest signal in the plane of the loop. The nulls are in the axis perpendicular to the plane of the loop.

Directional Antennas

Yagi, Beam, Quad, etc
Concentrates signals in one direction

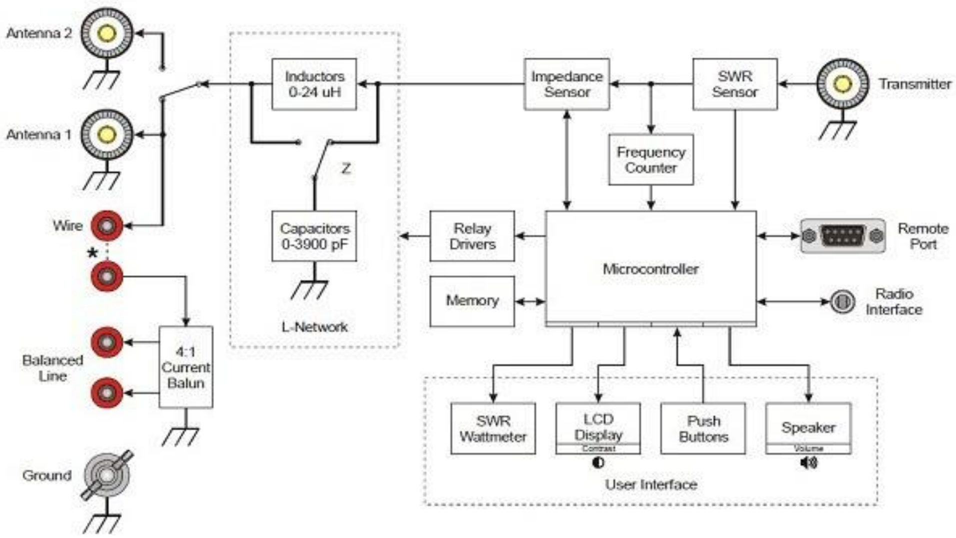
These antennas send most of feed energy in one direction. This "gained" energy is then ratio compared to an all direction antenna. A 3 element YAGI has almost 10 times the energy of a ¼ Vertical. Example: Driven = ½ WL, Refl=Driven + 5%, Dir=Driven - 5%. The feedpoint impedance is lower than a dipole and requires matching





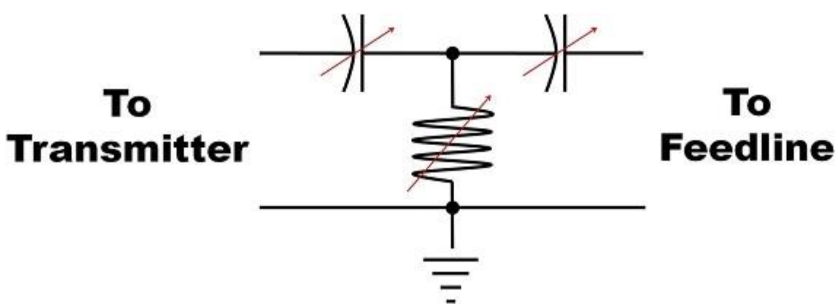
Antenna Matching

A tuner should be called matcher because it matches the impedance presented to the transceiver to the impedance on the feedline. You could say the tuner takes whatever you have on your feedline and makes it look like 50 Ohms resistive to the transceiver. This is a simplified answer that is not all true, but it is the general idea. Today automatic tuners are the standard; twenty years back the standard was an external manual tuner. Prior to 1980 transmitters normally had internal tuning and loading controls. Think about the controls, controls for matching, this was what you pay extra today is called a built-in tuner!



Typical Automatic Antenna Tuner Block Diagram

Looking at the schematic above you see many components but few are actually the key to tuning. Most are for the SWR, measuring forward and reverse power. So looking at the schematic above and the simplified version below you can start to see manufactures use switches to vary the inductance values. Other models use switches for both capacitance and inductance control. Most use series capacitors as this is generally a more efficient design. Capacitors do not contribute any significant loss in the circuit as they have very high Q. Q is the ratio of electrical resistance and reactance at resonance. Capacitor Q is much larger than the Q exhibited by most coils.



Simplified Schematic Antenna Tuner

In this design you will see a switch that moves the capacitor(s) from the transmitter side to the antenna side saving in hardware costs as well as practical design. It includes other features common to many commercial tuners with an antenna selector and current BALUN built-in.

Antenna Feedlines

Feedline is required to transfer the RF output from the tuner to the antenna and is normally 50 ohm coaxial cable because the transmitters made today are designed for 50 Ohm output. Notice I said the tuner is connected to the feedline not the transmitter. The tuner's job to match the impedance from the feed input to the transmitter's 50 Ohm output has just been covered by the previous section. A 50 Ohm coaxial feedline terminated into a 50 ohm antenna at a distance of an exact half wave length are 1 to 1 transformers with very minor resistive loss. Use any other length line and you are no longer terminated in 50 Ohm impedance this also changes the impedance into something else at the transmitter end. The changed value is a function of antenna impedance, line loss, and the length and characteristic impedance of the feedline. There are three feedline characteristics to consider in your antenna system;

- Resistive Line Loss
- Antenna Impedance
- Length Relative to Wavelength

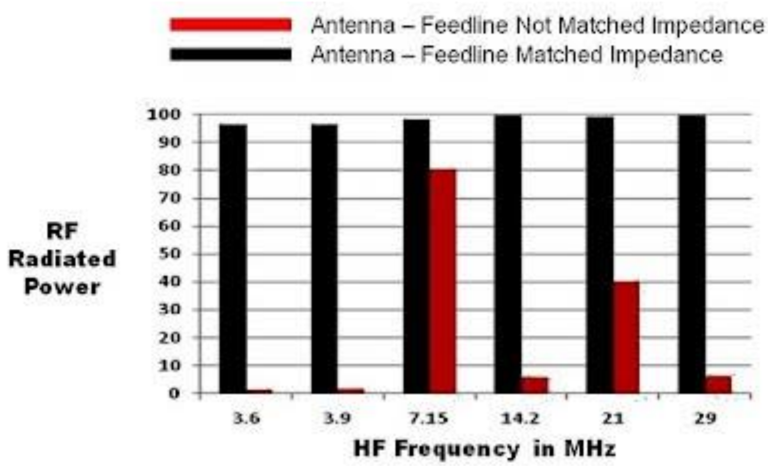
Coaxial cable resistive loss is a one factor in an antenna system that most HAMs consider but not always. In every run, there is some loss of signal strength as the signal travels between the antenna and the tuner. The longer the run of cable, the greater the loss will be is understood. At higher frequencies, the losses in the cable are much greater. We all know not kink the cable, or fit tightly around corners can lead to splits in the jacket and shield, which will lead to a downgrade in performance over time with water intrusion. So we are now good for losses when connecting a 50 Ohm coaxial cable to a resistive 50 Ohm antenna. These are the loss numbers published by the cable manufactures. These are not the values for mismatched loads!

Coax Cable Signal Loss (Attenuation) in dB per 100ft

Loss	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	9913
USE	HF	HF/VHF	HF	HF/VHF	VHF/UHF	HF/VHF	VHF/UHF
1MHz	1.9dB	0.4dB	0.5dB	0.2dB	0.2dB	0.2dB	0.2dB
10MHz	3.3dB	1.4dB	1.0dB	0.6dB	0.6dB	0.4dB	0.4dB
50MHz	6.6dB	3.3dB	2.5dB	1.6dB	1.4dB	1.0dB	0.9dB
100MHz	8.9dB	4.9dB	3.6dB	2.2dB	2.0dB	1.6dB	1.4dB
200MHz	11.9dB	7.3dB	5.4dB	3.3dB	2.8dB	2.3dB	1.8dB
400MHz	17.3dB	11.2dB	7.9dB	4.8dB	4.3dB	3.5dB	2.6dB
Imped	50ohm	50ohm	50ohm	50ohm	75ohm	75ohm	50ohm

Antenna impedance must be considered to prevent reflections at the antenna from causing standing waves. The feedline must match to the characteristic impedance of the antenna to prevent reflections. It is not difficult to select a feedline to match the antenna but it is often not even considered. Coaxial cable impedance is determined its dimensions and materials used and is a purchased item. Common coax values are 50 and 75 Ohms but an alternative using parallel conductors provides values of 300, 450 and 600 Ohms determined by spacing and materials. An example of the right way is the G5RV design that matches the higher impedance dipole to the 50 Ohm coax with a tuned length of parallel feedline. Another example of the right way is matching a Windom Dipole (OCF) design high impedance to the 50 Ohm coax with a 4:1 BALUM.

Looking at a typical case of a 100W transceiver connected to an 40M antenna with 100 Feet of RG-8U you can see a dramatic difference in antenna RF radiated power by matching at the antenna feed point to the feedline. The dramatic effects of matching are shown in the chart below.



Relative RF Power Radiated vs. Antenna to Feedline Matching

Any length of feedline can be used if you understand feedline SWR. A general rule is to use a feed length or ½ WL and measure the VSWR at the tuner-feedline connection prior to use in all bands. You can go from perfection to dead short by selecting a frequency that yields a wavelength equal to a ¼ WL multiple of the feedline length. Here is the kicker but not always, ¼ WL multiple feedline can also transform a high impedance to a low impedance. The contributions of a ¼ WL can be tricky on a multiband antenna. Sometimes HAMs blame their tuner for not working, some understand enough to add or subtract 1/8 WL from the feedline there is no magic in a ¼ WL just be aware of how it works. The feed impedance at one end is purely resistive, the impedance at the other end will also be resistive, and a random length section can be resistive at one end and yet have a complex impedance at the other end. Remember to measure your multiband antenna in all bands prior to use.