General Class License Theory III

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Introduction

In this session we will learn about:

- Feed Lines
- Antennas
- Safety

As in the other theory classes, we will try to present enough theory to create a context for understanding and focus on the things that which are necessary to pass the General Class License test subsections G9 &G0

Characteristic Impedance

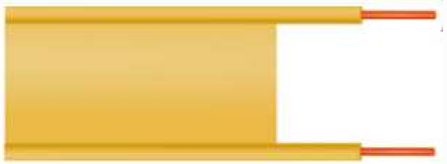
- A Feed line is a wire or cable of two wires which connects a transceiver to an antenna.
- A Transmission Line is a more technical term used in electrical engineering for a feed line.
- Transmission Lines have property called

  Characteristic Impedance or Z_0.
- Characteristic Impedance is defined as the ratio of the voltage and current (e.g. Ohm's law) of a wave propagating on the transmission line. It is not the same as the resistance of the line.

Z_0

Z_0 (Characteristic Impedance) is determined by the physical geometry of the transmission line. It can be measured or calculated.

$$Z = \frac{Z_0}{\pi\sqrt{\epsilon_r}} \operatorname{arcosh}\left(\frac{D}{d}\right)$$

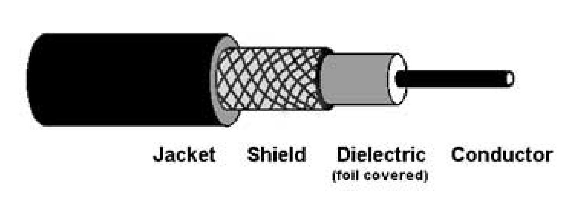


Twin lead, AKA parallel cables.

For parallel cables the factors that determine the Characteristic Impedance are the distance between centers of conductors and radius of parallel antenna feed line.

Typical Z_0's

Coax cable: 50Ω and 75Ω



TV Ribbon Line: 300Ω

450Ω Ribbon Line: 450 Ω

Feed Line Loss

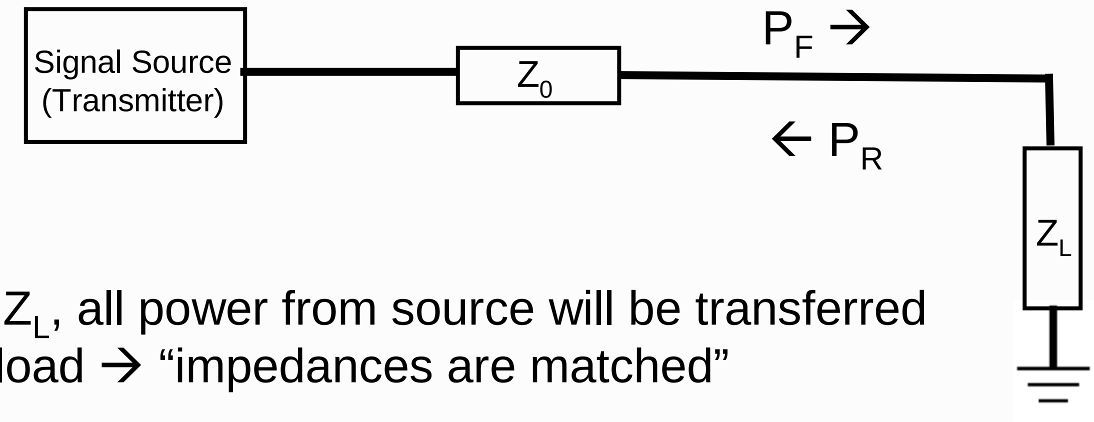
Attenuation or loss of signal occur along the length of feed line due to resistance of conductors and absorption of energy in insulating material between conductors. This loss is generally in the form of heat.

Loss is usually measured in dB/100ft of cable.

Type	Impedance	Loss per 100 ft at 28.4Mz	Loss at 100 ft at 144Mhz
RG-174	50Ω	4.4 dB	10.2 dB
RG-58	50Ω	2.4 dB	5.6dB
RG-8X	50Ω	1.9dB	4.5dB
¾" CATV hardline	75Ω	.26dB	.62dB
450 Ω Ladder Line	~450Ω	.3dB	

Attenuation ↑ in feed line as frequency ↑

Forward and Reflected Power



If $Z_0 = Z_L$, all power from source will be transferred to the load → "impedances are matched"

However, if $Z_0 \neq Z_L$, some power will be reflected from the load back to the source.

Forward power → power to load
Reflected power → power from the load

What might cause reflected power at the point where a feed line connects to an antenna?

Ans: Difference between feed line impedance and antenna feed point impedance.

Standing Wave Ratio (SWR)

At a signal frequency when lines aren't matched, the forward and reflected power will generate "standing waves". The Standing Wave Ratio is a measure of relative magnitude of these two waves along the feed line.

SWR = peak voltage to minimum voltage in a standing waveform

$$\text{SWR} = \frac{\text{feed point impedance (of antenna system)}}{\text{line impedance}}$$

or

SWR must be ≥ 1

$$\text{SWR} = \frac{\text{Line impedance}}{\text{feed point impedance}}$$

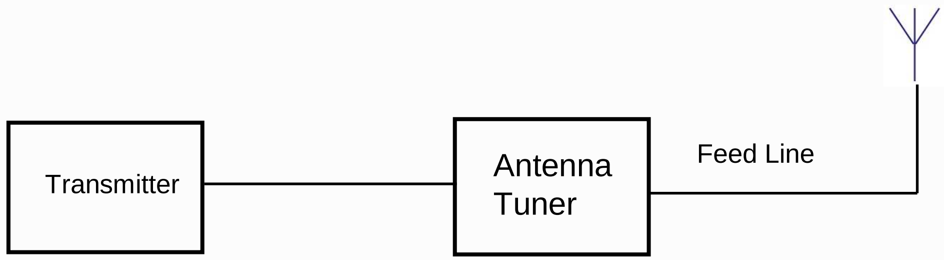
SWR Examples

Example:

What standing wave ratio will result when connecting a 50Ω feed line to a non-reactive load having 200Ω impedance

$$\text{SWR} = \frac{200}{50} = 4$$

Impedance Matching



The Antenna tuner matches the antenna system impedance to the transmitter (or transceiver) output impedance. Antenna tuners are also called impedance matchers, transmatch, or antenna coupler.

To achieve low SWR use an antenna tuner to match impedance between a transmitter and feed line.

If the SWR on the antenna feed line is 5 to 1 and the matching network at the transmitter end of the feed line is adjusted to SWR =1, what is the resulting SWR on the feed line. Ans = 5:1

Feed Line Loss and SWR

If there is SWR in the antenna and feed line system, then there will be more reflected signals and higher loss. Further, if the transmission line is lossy, high SWR will in crease the loss.

If there is high loss in the transmission line, however, less reflected power returns to the input of the line. So the SWR at the input to the feed line will measure lower.

What is the effect of transmission line loss on SWR measurement at the input to the line?

Ans: The higher the transmission line loss, the more the SWR will read artificially low.

Assuming the feed line impedance matches the output impedance of the transceiver, the best place for the antenna tuner is between the feed line and the antenna.

Feed Line Summary

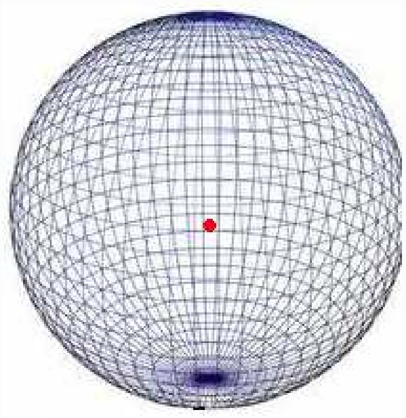
- The characteristic impedance of the feed line, transmitter, and antenna should ideally all match.
- The SWR is a measure of how well they match.
- If they don't match, then an antenna tuner is necessary to adjust impedance for a match.
- Low loss feed line helps get more signal to the antenna.
- High loss feed line will make the SWR appear lower than it is in the antenna system
- Putting the antenna tuner physically at the antenna is often a good solution for high SWR antenna systems.

Antenna Basics

- Antennas are used to transmit and receive electromagnetic (EM) energy. This is the basis of radio communication.
- Radiation pattern is the direction of strength of the radio waves from the antenna.
- Azimuthal – radiation pattern in horizontal directions (look down on antenna)
- Elevation – radiation pattern in vertical directions (look at same level as antenna)
- Polarization – orientation of electrical and magnetic parts of the EM wave relative to the earth

Isotropic Antenna

An Isotropic antenna is a theoretical antenna which radiates and receives equally in every possible direction. An isotropic antenna is used as a reference for other antennas.

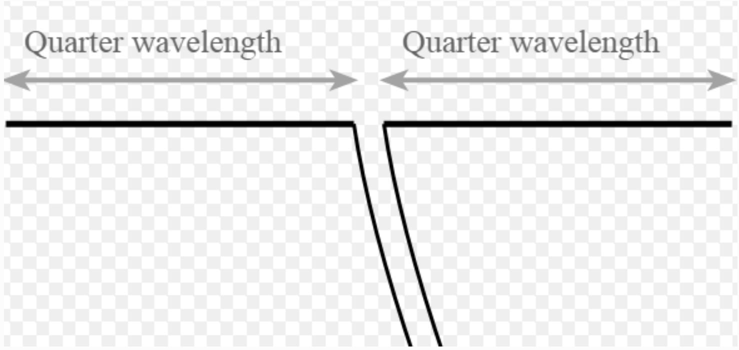


The Gain of an antenna describes the focusing of the antenna's radiated energy in the maximum direction and is measure dBi

The gain of an isotropic antenna is 0 dBi in all directions

The Dipole

A dipole is a an antenna approximately ½ wavelength long feed at the middle.

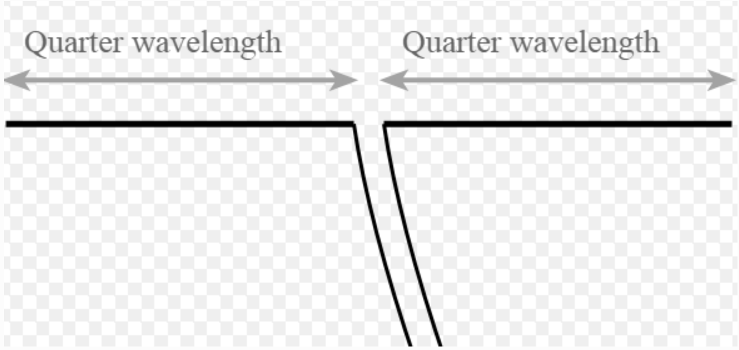


Characteristics of a Dipole:

- Z_0 = 72Ω (dependent on height of antenna)
- Current is maximum at the feed point
- Voltage is maximum at the ends
- Dipole impedance ↑ as move from feed point to end of the antenna
- Maximum radiation for a dipole is referred to as dBd
- Gain = 2.15dBi or 0 dBd

The Dipole

A dipole is a an antenna approximately ½ wavelength long feed at the middle.



In free space this is ½ wavelength is 492 ft / frequency. However, the common equation used by hams for estimating the length of a dipole is

L = 468 ft / frequency.

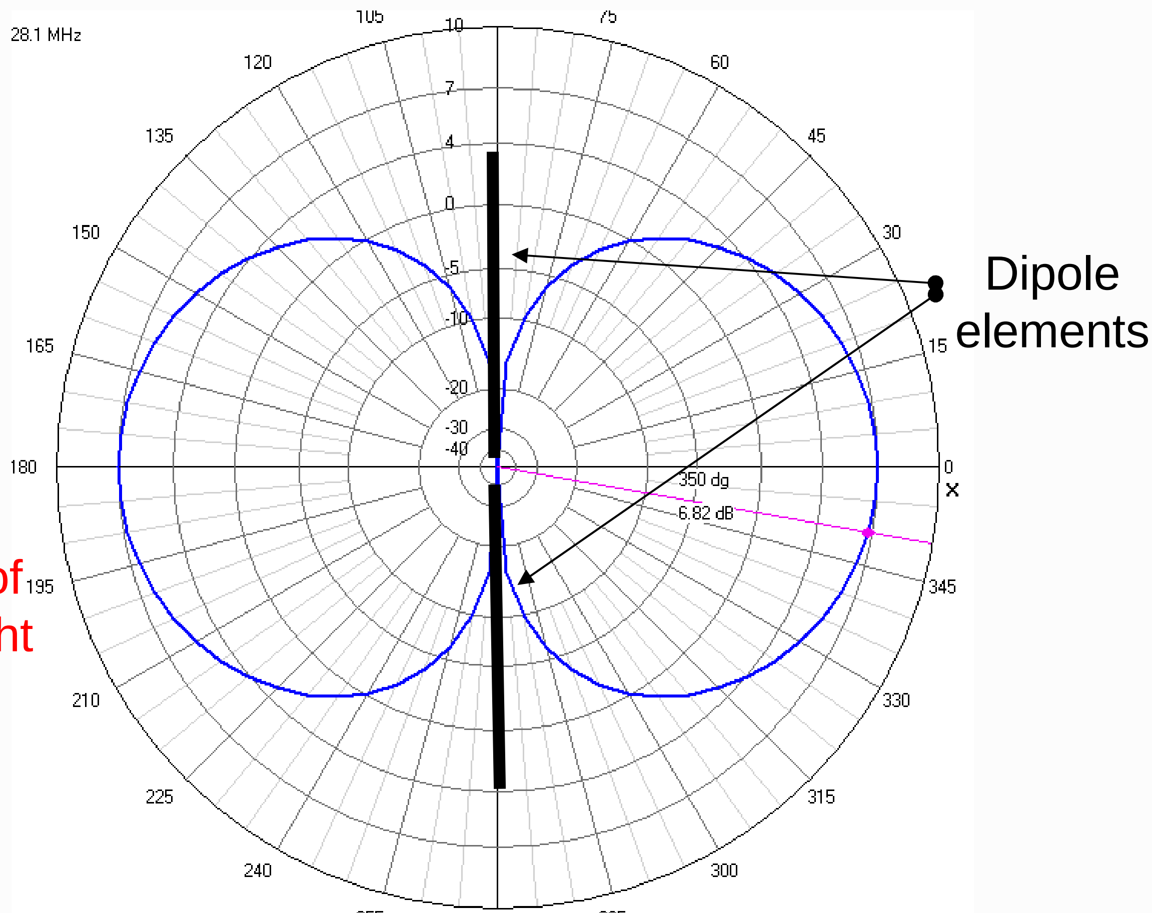
Example: What is the approximate length in feet of a ½ wave dipole for 14.250 Mhz (20M phone).

L = 468ft/14.250 = 32.8 ft

Dipole Azimuth Pattern

Azimuth pattern for a Dipole:
The highest gain is off the sides of the dipole and the least off the ends.

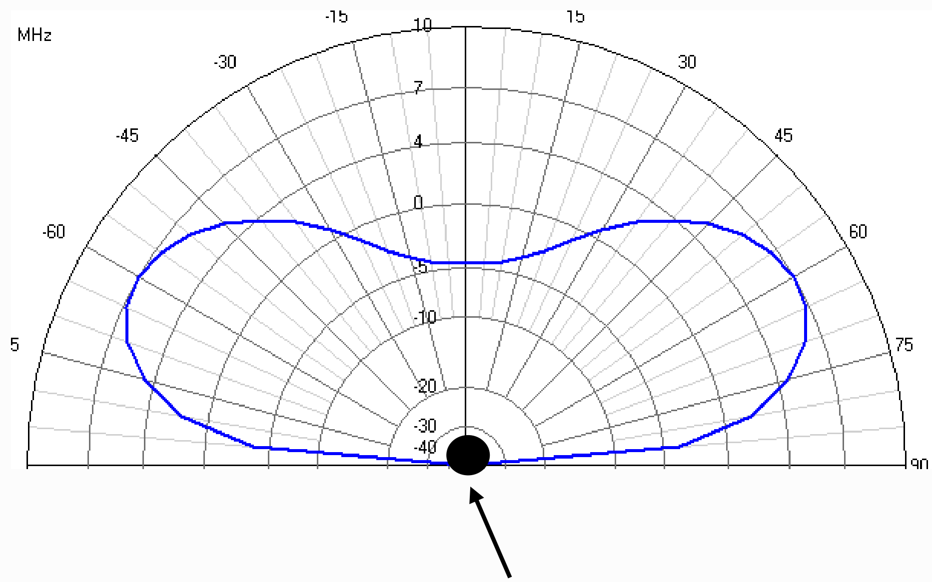
The radiation pattern of a dipole is a figure eight at right angles to the antenna.



Dipole Elevation Pattern

Elevation radiation pattern for a dipole:

For this height above ground, the maximum radiation lobes are at about 30° from the horizontal. This is known as the take-off angle and is very important for DX.



Dipole viewed end on

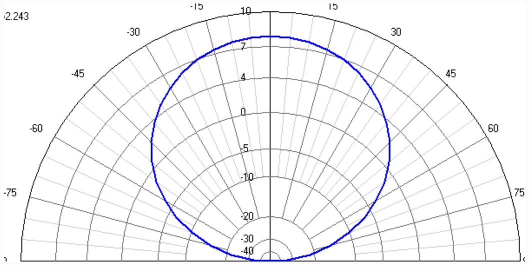
Dipole height vs. Radiation Pattern

Height has a big effect on the radiation pattern of a dipole as well.

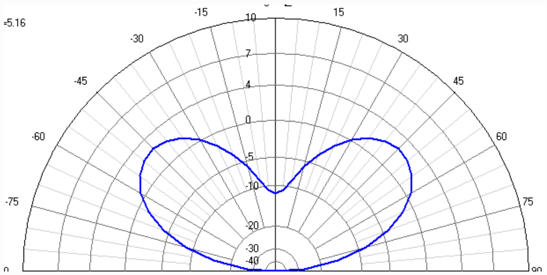
At ⅛ λ, an antenna radiates almost omni-directionally and is maximum straight up.

At ½ λ high, the dipole has its traditional two lob pattern.

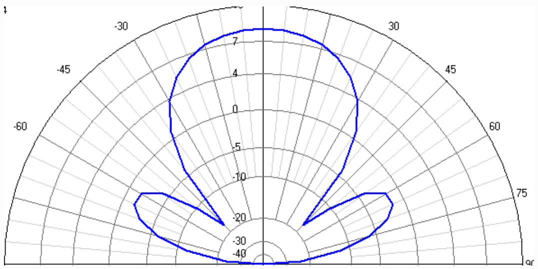
Above ½ λ, the dipole starts to develop more lobes and will direct energy in different (and often unwanted) directions.



Antenna ~ ⅛ λ high



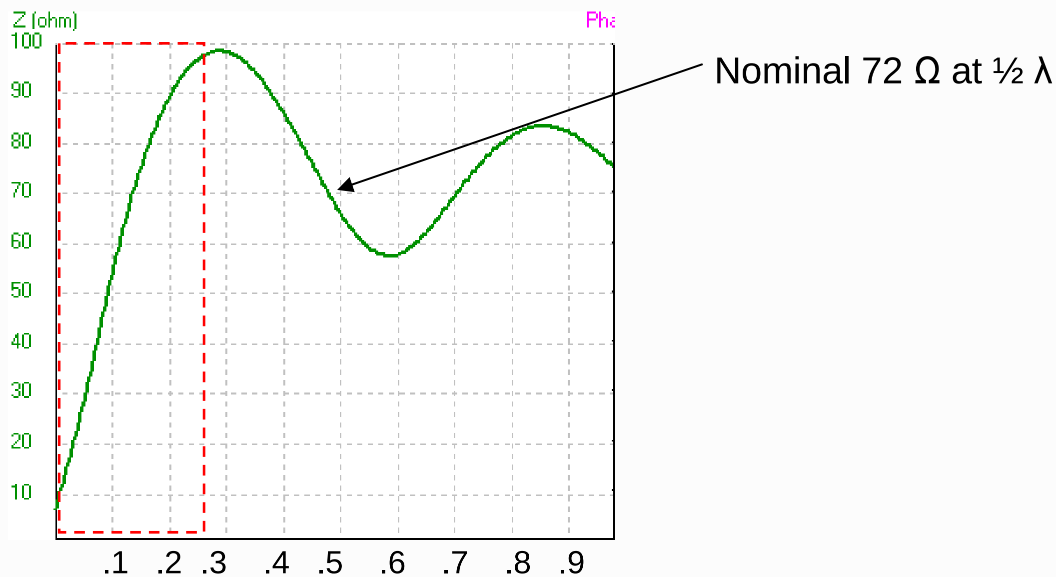
Antenna ~ ½ λ high



Antenna ~ ¾ λ high

Dipole Height vs. Impedance

Ground is an important part of an antenna system



Height of dipole in wavelengths
above perfect ground

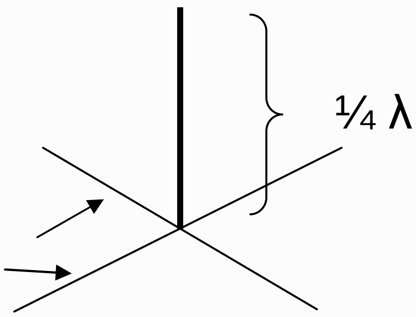
Height of a dipole affects the feed point impedance and radiation pattern. As the height of antenna ↓below ¼ λ, Z_0 ↓

Ground Plane or Vertical Antennas

A vertical or ground plane antenna can be viewed as a ½ λ dipole with the missing part made up by a ground plane.

The ground plane is usually created with radial wires on or under the ground.

The radials are on the ground or a few inches below.



Vertical antennas

Vertical antennas radiate and receive in all directions.

Advantages:

- Hear signals from all directions
- Verticals typically have a low take-off angle which is good for DX

Disadvantages:

- Hear signals in all directions so they often are considered “noisy”
- There is no way to focus the energy as with a dipole (or as we will see) a Yagi

Vertical Antennas

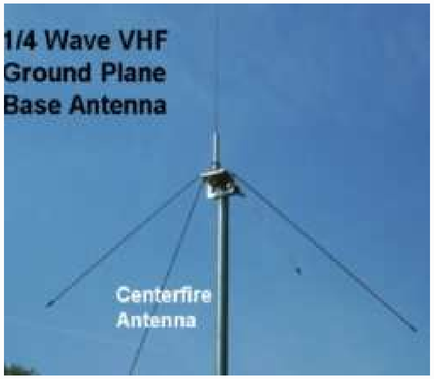
Since the height of a vertical is ½ that of a dipole, the height is λ/4 or 246 / freq. (height in ft, frequency in Mhz)

Example: What is the approximate length for a ¼ wave vertical antenna resonate at 28.5 Mhz.

Ans: 246/28.5 = 8.6 ft (Closest exam answer is 8 ft)

The feed point resistance of a 1/4 λ vertical antenna is 35 Ω. If the radials are angled down, then the feed point impedance will go up.

A droop angle of the radials between 30 and 45° results in a Z0 of approximately 50Ω.



Vertical Antennas

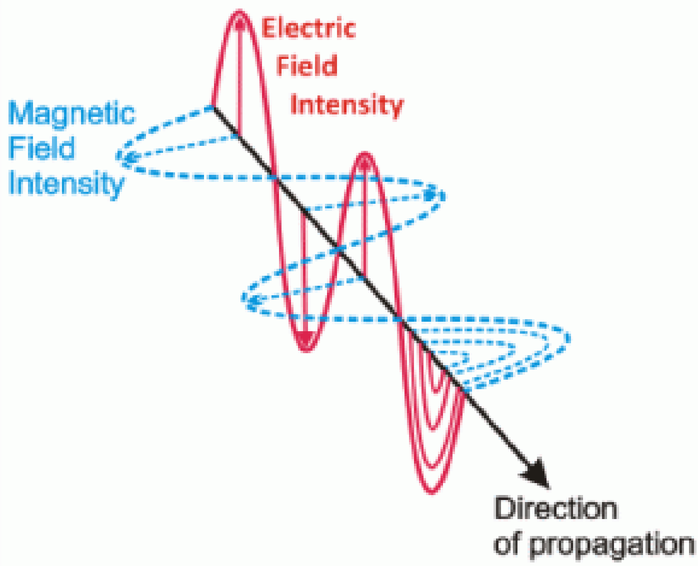
- Not all vertical antennas can be ¼ λ.
- At HF bands below 10M, they become very high and for mobile operations the requirements are even more demanding.
- The effective height can be electrically adjusted by means of adding inductance or capacitance to the antenna.
- The inductance is usually a loading coil

- The capacitance can be a "hat" or corona ball. These are often found on mobile antennas.

- The trade-off of shortening the antenna is that bandwidth is reduced and retuning is required when changing frequency in the band.

Polarization

Radio wave are electromagnetic waves that are composed of electrical and magnetic fields at right angles moving through space.



The term “polarization” describes whether describes whether the electrical field is oriented vertically or horizontally with respect to earth.

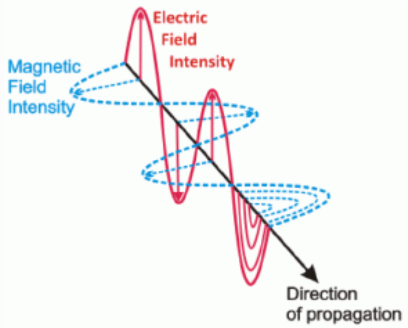
Circularly polarization occurs when the fields are rotation about each other rather than having fixed orientation.

Polarization

Horizontally polarized → electrical waves parallel to earth

Dipoles → horizontally polarized.

Quarter wave vertical → vertically polarized



When radio waves are horizontally polarized, signals bounce off the ground so that ground plane losses are minimized.

What is the advantage of a horizontally polarized versus a vertically polarized HF antenna?

Ans. Lower ground reflection loss

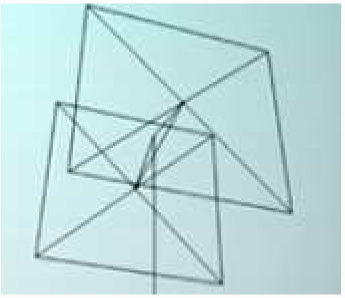
Directional Antennas

We have discussed the dipole which is a directional antenna and the vertical which is not. Now we will learn about three more directional antennas:

The Yagi

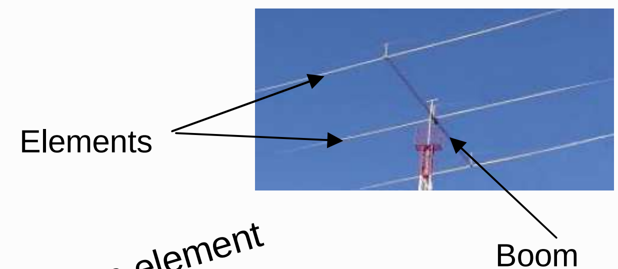
The Loop

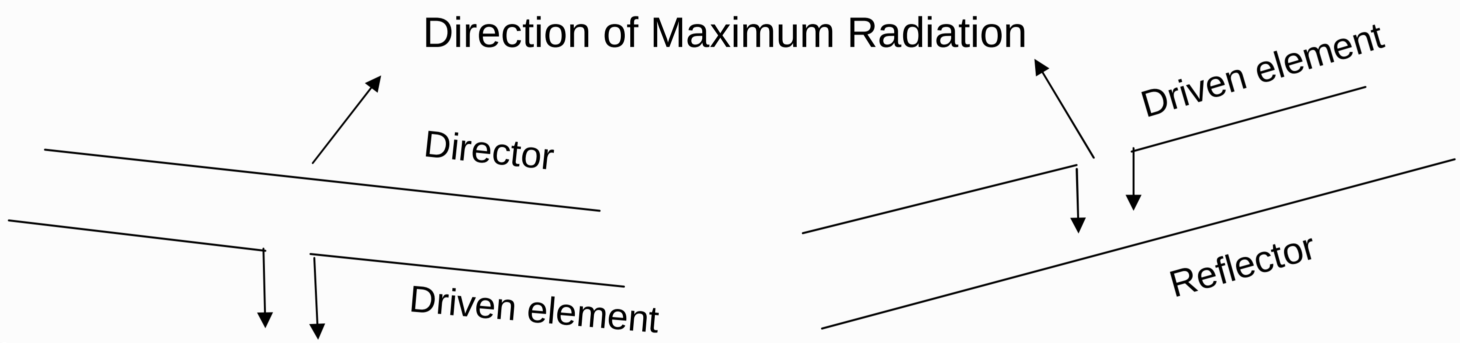
•The Quad



The Yagi

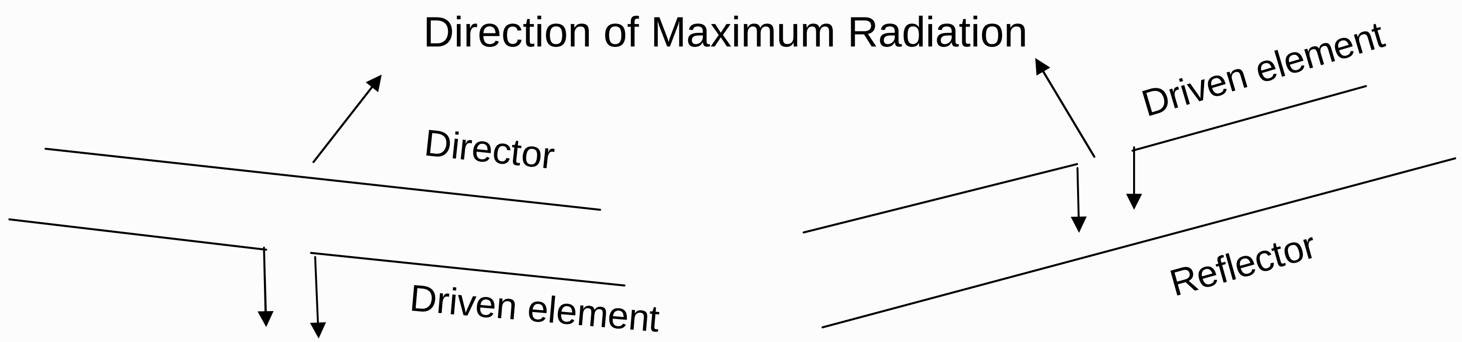
- The Yagi-Uda antenna is a multi-element highly directional antenna which is the “gold standard” for DXing.
- Elements are conducting or radiating parts of the antenna. They can either be driven or not.
- A non-driven element is called a parasitic element and is either a Reflector (if it is behind the Driver) or a Director (if is in front of the Driver)
- The boom is the central support for the Yagi array





Two-element Yagi’s

Yagi Elements

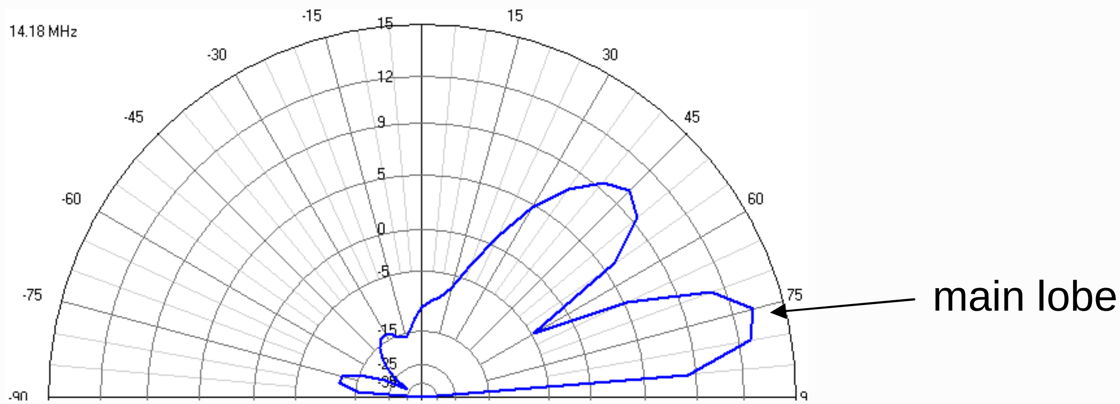


- The Driven Element of a Yagi is about ½ λ
- The Director is the shortest element
- The Reflector is the longest element ~ 5% longer than the driven element
- Larger diameter elements will increase the bandwidth of a Yagi

Yagi Radiation pattern

The elements of a Yagi reinforce and focus the radiation so that the radiation pattern is largely in one direction only.

Radiation pattern for a three element Yagi:



The “main lobe” of a directive antenna is the direction of the maximum radiated field strength from the antenna.

The Ratio of front radiation lobe to the rear radiation lob is the front to back ratio.

Yagi Gain

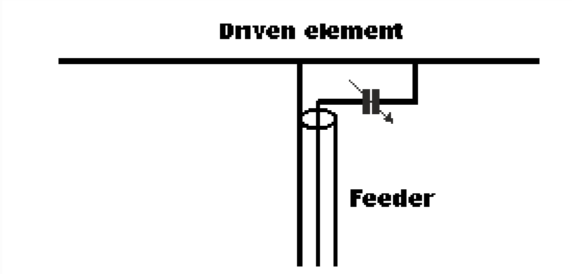
	Gain	F/B
Two element Yagi	+7dBi	10-15 dB
Three element Yagi	+9.7dBi	30-35 dB

- The design variables which an be adjusted to optimize forward gain, front/back ratio, or SWR bandwidth are
    - Physical length of the boom
    - Number of elements on the boom
    - Spacing of elements along the boom
- Increasing boom length and adding elements increases gain
- To increase gain and F/B of a Yagi increase the size of the boom and add elements
- Stacking Yagi's increases gain: Two Yagi's stacked ½ λ apart increase gain by 3 dB.
- The is the advantage of vertical stacking of Yagi's: narrows main lobe in elevation.

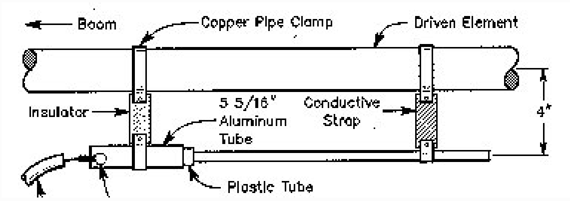
Matching a Yagi

Nothing is perfect in life: The Characteristic Impedance of a Yagi typically is 20 to 25Ω

One of the most common means of matching the feed line to a Yagi antenna is the Gamma Match



Gamma Match schematic

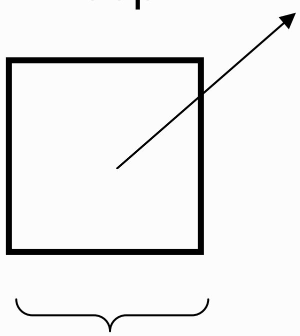


Gamma Match physical design

An Advantage of the gamma match technique is that the elements don't have to be electrically isolated from the boom

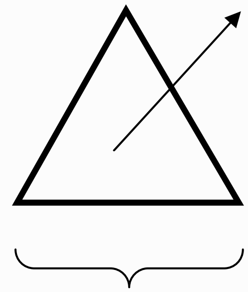
Loop Antennas

Loop:



λ/4

Delta or Triangle Loop:

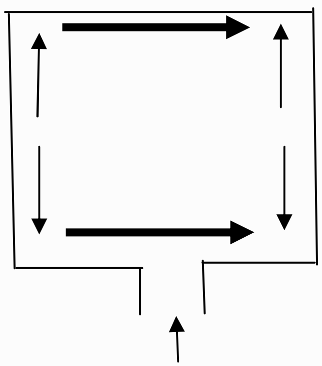


λ/3

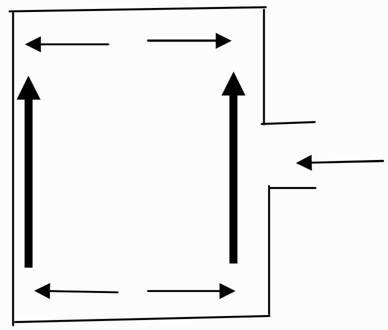
A loop antenna can be viewed as two dipoles. The radiation pattern for a full sized loop is broadside to the plane of the loop. If placed horizontally, most of the radiation goes straight up.

Polarization vs. Feed Point of a Loop

The location of a the feed point for a vertically oriented loop antenna effects the polarization of the antenna.



Feeding at the bottom forces larger currents through the bottom legs and creates horizontal polarization



Feeding on the side forces larger current through the side legs and creates vertical polarization

When the feed point of a loop antenna is moved from the midpoint of the top or bottom to the midpoint of either side, polarization of the radiated signal changes from horizontal to vertical.

The Quad

The Quad is two loops in an array.

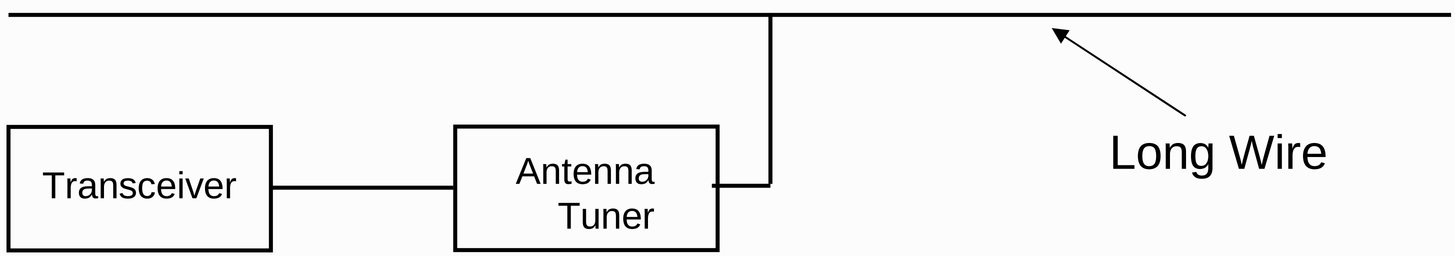
- Loop antennas have driven elements, reflectors and directors
- The reflector is about 5% larger than the driven loop or λ/4
- The gain a 2 element quad and delta loop are about the same
- The forward gain of a quad is about the same as a 3 element Yagi
- The quad is mechanically more complicated than a Yagi, however

Other Antennas

We will end our tour of antennas with a few more varieties:

- Random Wire
- NVIS
- Multiband
- Log periodic
- Beverage

Random Wire Antenna



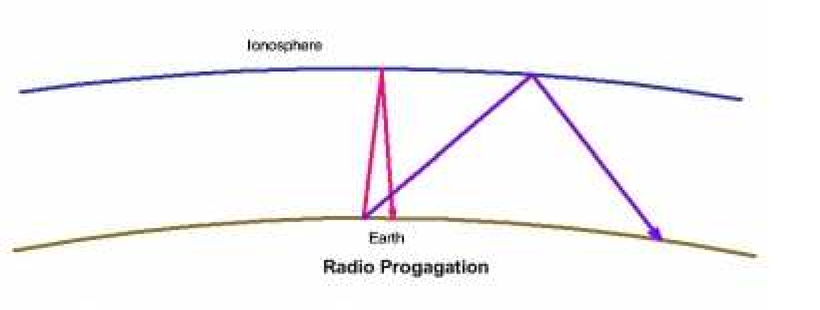
- A Random Wire antenna is a wire of any length connected to a transceiver usually through an antenna tuner
- This is a non-resonant antenna – the SWR can be quite high
- It only works when its impedance is matched
- Its radiation pattern can be computed, but probably isn't obvious
- There can be high voltages on the lead lines and considerable losses
- One disadvantage that the use of a random wire antenna can lead to high RF voltages that can cause RF burns when touching metal objects in the station.

•None-the-less, random wire antennas are a pretty easy way to get on the air

NVIS Antenna

NVIS – Nearly Vertical Incident Sky-Wave Antenna

NVIS direct radiation more vertically than normal antennas. They are good for communication with stations which you would normally be too close to work – within a range of a few hundred kilometers.



A dipole makes a very good NVIS antenna when it is close to the ground – between 1/10 and ¼ wavelength above ground.

Log Periodic Antenna

A Log Periodic Antenna is a frequency independent antenna whose elements dimensions and placement are a logarithmic pattern.

The over the air TV antenna is a classic log periodic

Advantage:

- Wide bandwidth

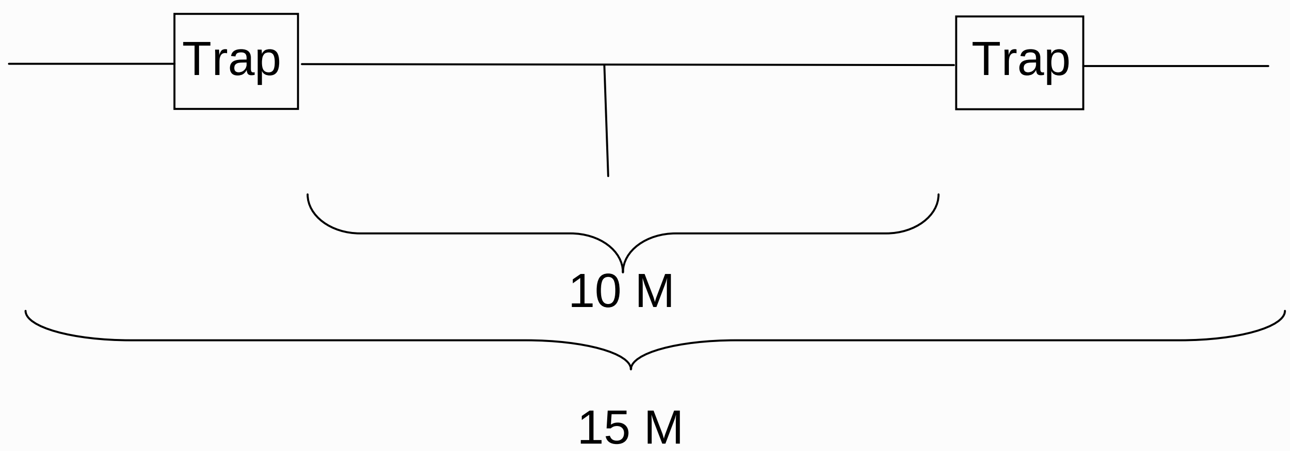
Disadvantage:

- Less gain and F/B ratio than Yagis

Multiband Antenna

Multiband antennas are resonate antennas which operate on more than one band.

There are multiple ways to make a multiband antenna, but one popular method is use traps. Traps are circuits (usually L's and C' in parallel) which appear as a high impedance at one band but low impedance on another.



In this example, the traps look like high impedance at 28 MHz, but low impedance at 21 Mhz.

Multiband Antennas

• Use traps to permit multiband antennas.

•One disadvantage of multiband antennas is that they have poor harmonic rejection.

• There are other multiband antenna implement approaches. I've had great success with the W1ZR Folded Skelton Sleeve

Beverage Antenna

A Beverage Antenna is a long wire (1 to 4 λ) near the ground with a terminating resistor at one end. It is a very long and low receiving antenna.

The Beverage Antenna:

- Is low gain, but lower noise
- Very directional
- A good to great reception antenna, but
- Not good for transmission since losses are high compared to other antennas
- Used for directional receiving of the low bands

Safety

Ham radio is basically safe, but there are risks which the license holder needs to understand. This is particularly true as the operator moves into the HF bands.

The areas of safety focus include:

- Physical safety
- Electrical safety
- Exposure to RF

Physical Safety

- Be careful on roofs, ladders and any high places
- Use care when installing antennas and feed lines so as to stay clear of power lines
- Special care needs to be taken with towers:
  - Be sure all circuits that supply power to the tower are tagged and locked out before attempting to work on tower antennas
  - When working on an antenna, be sure that the transmitter is turned off and disconnected from the feed line
  - When using a safe belt harness, confirm that it will support the weight of the climber and is within its service life

Electrical Safety

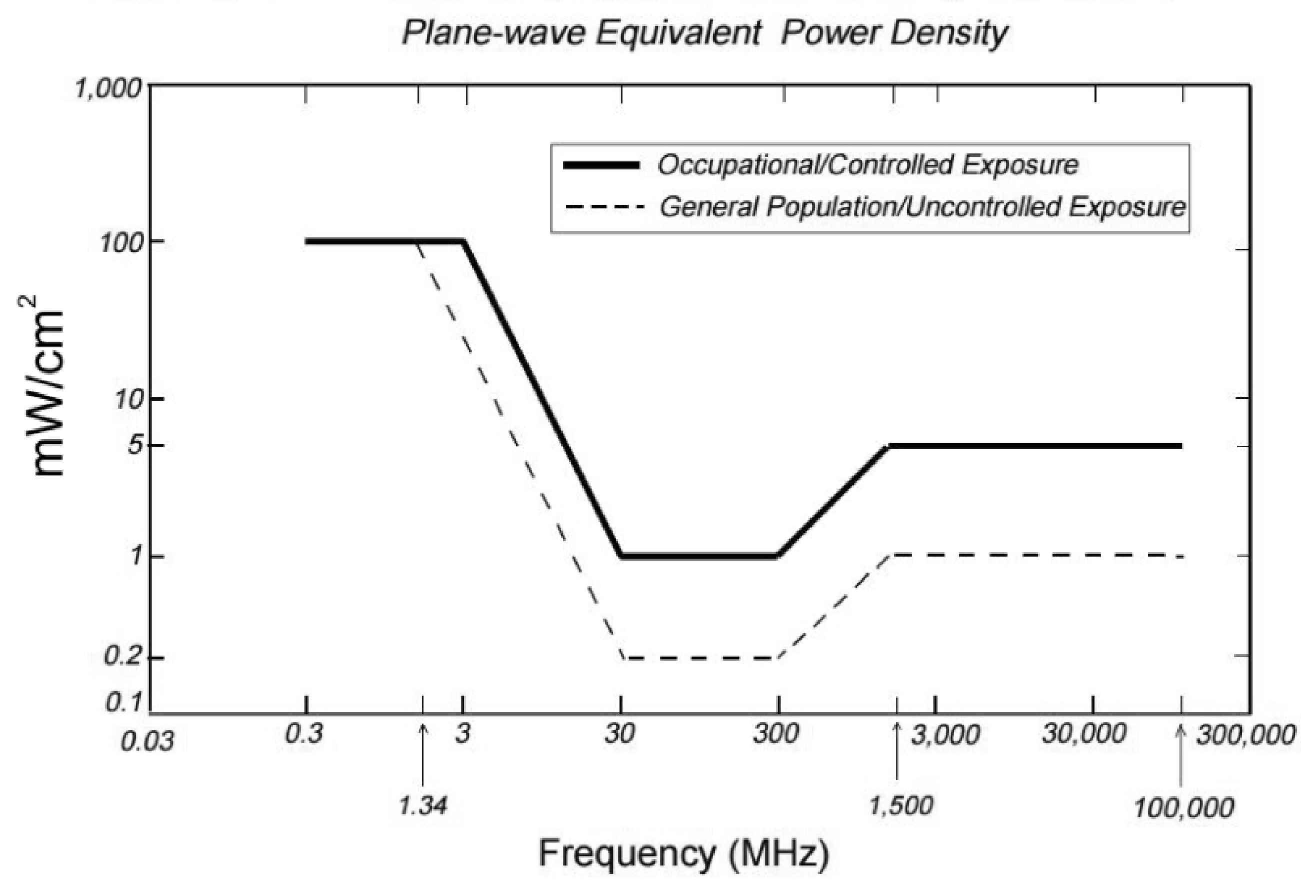
- Use common sense with electricity and “keep one hand in your pocket”
- Be sure all mental enclosures in the shack are grounded to ensure that hazardous voltages cannot appear on chassis
- Only put fuses on the voltage carrying conductors (never ground)
- Use the appropriate size wire and breakers for the current being drawn in the circuit (Example: 10 Amp → AWG 12 wire)
- GFCI (Ground Fault Circuit Interrupter) will disconnect when current is being sensed flowing to ground
- What out for carbon monoxide poisoning when a generator is being used in a closed area
- If you use lead-tin solder, be sure to wash your hands before eating
- There are few additional electrical safety questions in subsection G0B

RF Safety

- RF radiation is not hazardous at low levels
- The basic issue with RF radiation at higher levels can be the heating of body tissue due to absorption of radio waves
- So what is “not low levels”
- It depends on several factors:
    - Power level of density (measured in mw/cm^2)
    - Frequency
    - Average exposure time
    - Duty cycle of the transmission

Maximum Permissible Exposure

These are the limits established by FCC for acceptable RF radiation:



Controlled Exposure:

Understand exposure and will take steps to avoid

Factors in RF Exposure

- "Time averaging" means the total RF exposure over a certain time
- The duty cycle of the signal effects amount of exposure. For example:
  - SSB with compression: 40% duty cycle
  - CW: 40%
  - RTTY: 100%
  - JT65: 100% (never an issue because always low power)
- Lower duty cycle allows greater short term exposure levels
- The gain of the antenna system needs to be taken into account when considering exposure levels

RF Safety: Summing Up

- The operator is responsible to assure that the RF exposure of his transmission are within safety limits
- This can be done by:
    - Computer modeling
    - By Measurement
    - By use of FCC OET Bulletin 65
- RF Field Strength measurements can be made with a field strength meter and a calibrated antenna
- The easiest was to determine RF exposure level is by using an online calculator: http://hintlink.com/power_density.htm

RF Exposure Remediation

- If you have excess RF fields, take action to prevent human exposure to those fields
- What is one thing that can be done if evaluation shows that a neighbor might receive more than the allowable limit of RF exposure from the main lobe of a directional antenna? Ans: Take precautions to ensure the antenna can't be pointed in their direction
- What precaution should you take if you install an indoor transmitting antenna? Ans: Make sure that MPE (Maximum Permissible Exposure) limits are not exceeded in occupied areas
- If you have a ground-mounted vertical antenna, what precaution should you make? Ans: It should be installed such that it is protected against unauthorized access.

Final ten thoughts

What has been most valuable to me as a new ham:

1. A good antenna; the hexbeam was a game changer for me
2. Learn how to use your transceiver—quickly tune, do splits, adjust for noise, switch between modes
3. A panadaptor is a must—RSPlay and SDR Console work really well for me
4. Learn the digital modes and use them often
5. Get going early with a logging program including rig control, spotting, and QSL management
6. Use the web: spots, equipment info, propagation, user groups
7. Use contests and QSO parties to start making a lot of contacts
8. Learn CW (at least enough to make a DX QSO)
9. Build something (ideally with a friend)
10. Be ready when the next sunspot cycle appears

Thanks

Good luck on the test.