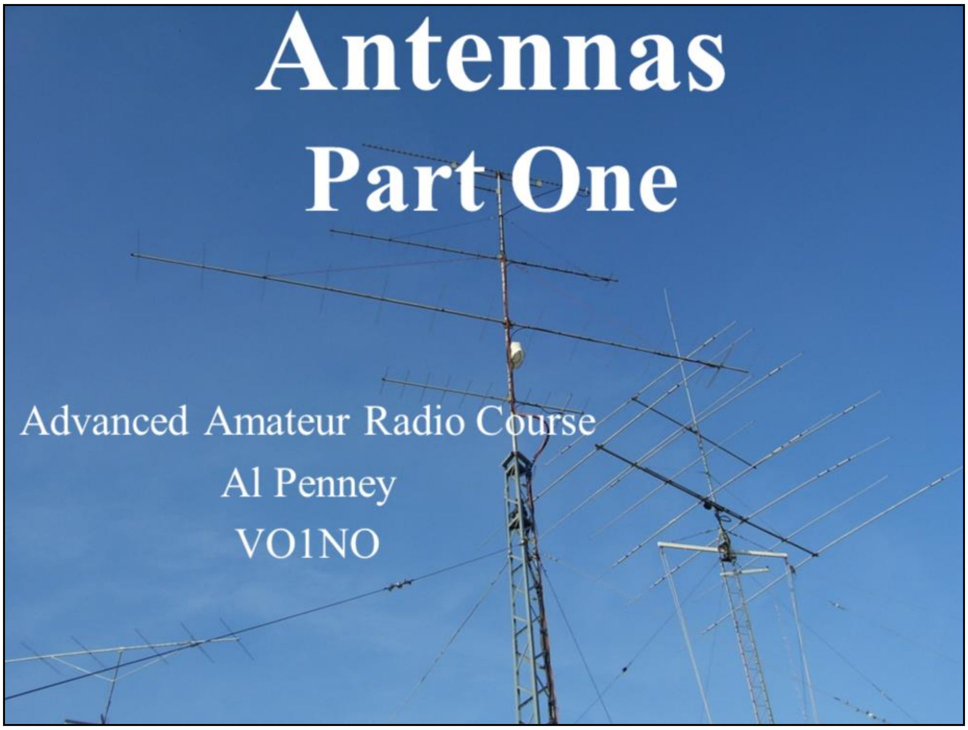
Antennas
Part One
Advanced Amateur Radio Course
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What do Antennas actually do?

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- They convert **Radio Frequency (RF)** energy from the transmitter into **radio waves** which are in turn **radiated** by the antenna into space.

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What do Antennas actually do?

- They convert **Radio Frequency (RF)** energy from the transmitter into **radio waves** which are in turn **radiated** by the antenna into space.
- They also convert **radio waves** from free space into **electrical current** which is transformed into information by the radio.

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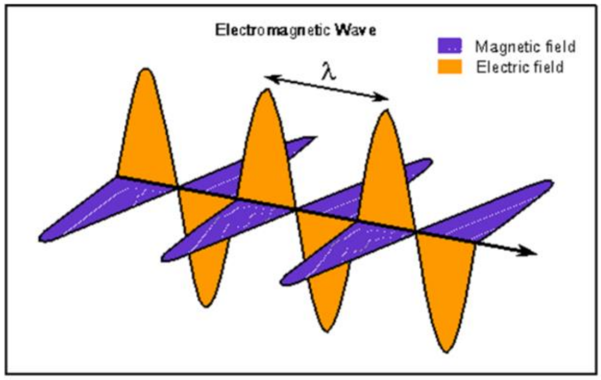
Electromagnetic Waves



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Electromagnetic Waves

- Composed of an **Electric Field ("E")** and a **Magnetic Field ("H").**
- **E and H fields are transverse** – ie: they are at right angles to the direction of propagation of the wave.
- **E and H fields** are **mutually perpendicular.**
- The two fields are **in phase.**
- **Velocity** of an EM Wave is the **speed of light.**
- **Polarization** of the **EM wave** is defined by the orientation of the **E field.**
- **Circular Polarization** is also possible.

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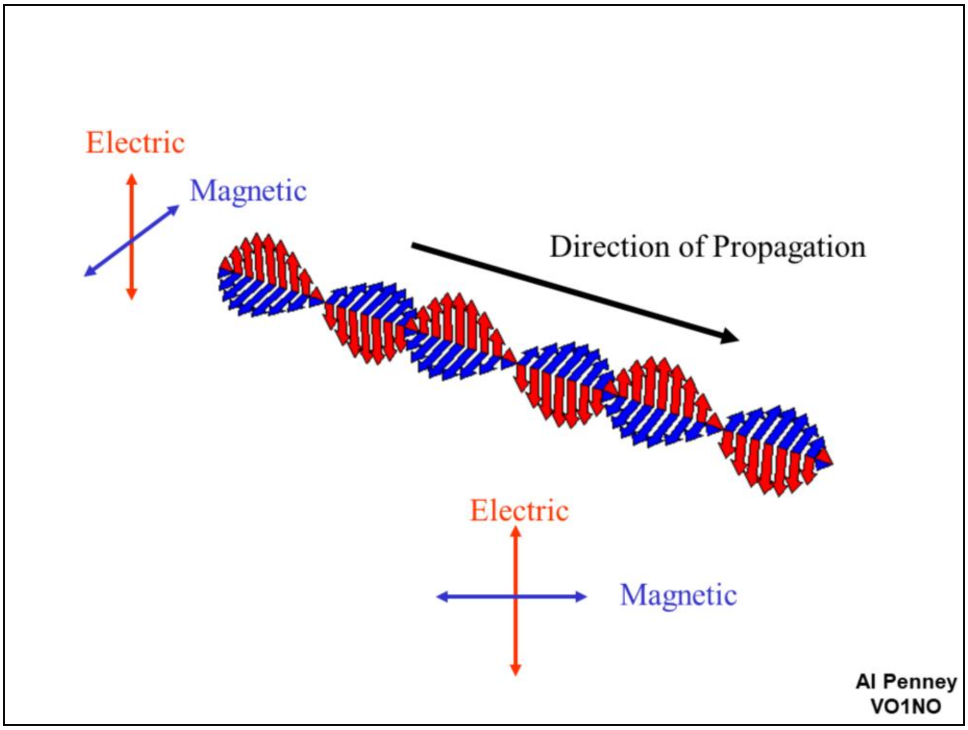
Electric
Magnetic
Direction of Propagation
Electric
Magnetic
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Antenna Basics

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Antenna Impedance

- Just as with Transmission Lines, Antennas have an **Impedance** at their **Feedpoint.**
- Consists of at least two, sometimes three components:
  - **Ohmic Resistance**;
  - **Radiation Resistance**; and
  - **Reactance.**

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Antenna impedance may be either resistive or complex (that is, containing resistance and reactance). This will depend on whether or not the antenna is *resonant*

at the operating frequency. You need to know the impedance in order to match the feeder to the feedpoint. Some operators mistakenly believe that a mismatch, however

small, is a serious matter. This is not true. The importance of a matched line is described in detail in the **Transmission Lines** chapter of the ARRL Handbook. The significance

of a perfect match becomes more pronounced only at VHF and higher, where feed-line losses are a major factor. Some antennas possess a theoretical input

impedance at the feedpoint close to that of certain transmission lines. For example, a 0.5-⎿ (or half-wave) center-fed dipole placed at a correct height above ground,

will have a feedpoint impedance of approximately 75 ∧. In such a case it is practical to use a 75-∧ coaxial or balanced line to feed the antenna. But few amateur halfwave

dipoles actually exhibit a 75-∧ impedance. This is because at the lower end of the high-frequency spectrum the typical height above ground is rarely more than

1/4⎣ . The 75-^ feed-point impedance is most likely to be realized in a practical installation when the horizontal dipole is approximately 1/2, 3/4 or 1 wavelength above

ground. Coax cable having a 50-^ characteristic impedance is the most common transmission line used in amateur work.

A radio antenna is like any other form of RF load or signal source. It has a load or source impedance.

In order to obtain the optimum performance the antenna feeder must be matched to antenna to ensure the maximum power transfer.

Accordingly it important to understand the feed impedance of any antenna so that the best performance can be obtained.

Antenna feed impedance basics

This impedance is known as the antenna feed impedance. It is a complex impedance and it is made up from several constituents: resistance, capacitance and inductance.

The feed impedance of the antenna results from a number of factors including the size and shape of the RF antenna, the frequency of operation and its environment. The impedance seen is normally complex, i.e. consisting of resistive elements as well as reactive ones.

Antenna feed impedance resistive elements

The resistive elements are made up from two constituents. These add together to form the sum of the total resistive elements.

•***Loss resistance:*** The loss resistance arises from the actual resistance of the elements in the aRF ntenna, and power dissipated in this manner is lost as heat. Although it may appear that the "DC" resistance is low, at higher frequencies the skin effect is in evidence and only the surface areas of the conductor are used. As a result the effective resistance is higher than would be measured at DC. It is proportional to the circumference of the conductor and to the square root of the frequency.

The resistance can become particularly significant in high current sections of an RF antenna where the effective resistance is low. Accordingly to reduce the effect of the loss resistance it is necessary to ensure the use of very low resistance conductors.

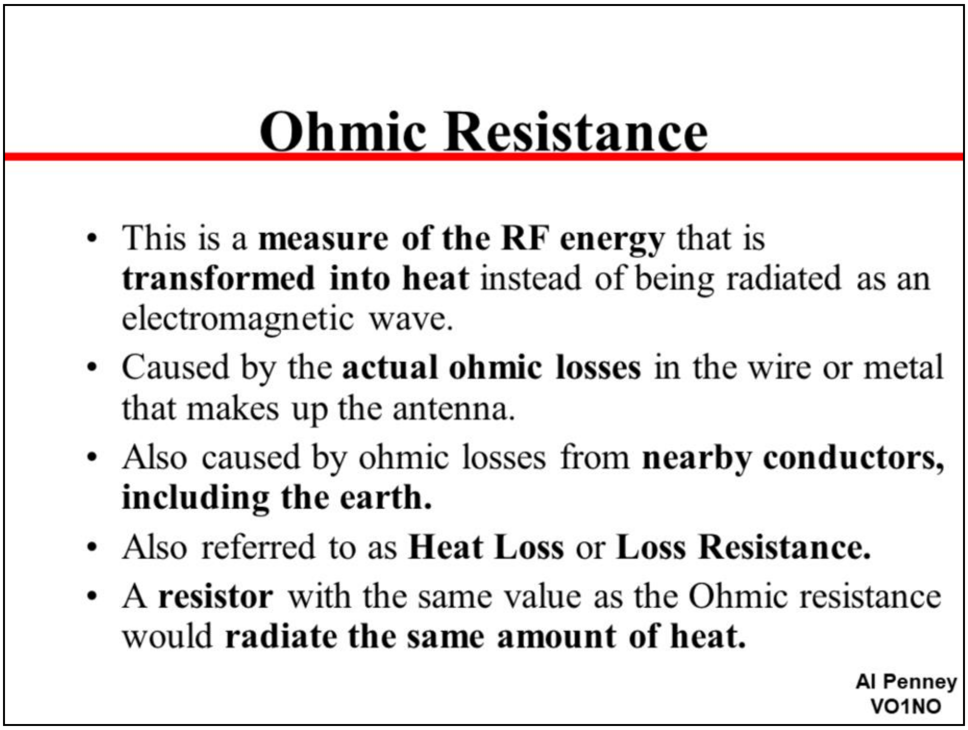
•***Radiation resistance:*** The other resistive element of the impedance is the "radiation resistance". This can be thought of as virtual resistor. It arises from the fact that power is "dissipated" when it is radiated from the RF antenna. The aim is to "dissipate" as much power in this way as possible. The actual value for the radiation resistance varies from one type of antenna to another, and from one design to another. It is dependent upon a variety of factors. However a typical half wave dipole operating in free space has a radiation resistance of around 73 Ohms.

The current that flows into an antenna’s feed point must be supplied at a finite voltage. The self impedance of the antenna is simply equal to the voltage applied to its feed point divided by the current

flowing into the feed point. Where the current and voltage are exactly in phase, the impedance is purely resistive, with zero reactive component. For this case the antenna is termed *resonant*. (Amateurs

often use the term “resonant” rather loosely, usually meaning “nearly resonant” or “close-to resonant.”)

You should recognize that an antenna *need not be resonant* in order to be an effective radiator.



Conductor Loss

An unavoidable part of the loss resistance comes from electrical resistance in the conductor the antenna is made of. Electrons moving through any metal are scattered off its metallic crystal lattice which also diminishes the electrons' momentum, transferring energy from the electrons to the lattice by impulse. The Ohmic resistance represents the energy lost by the electrons from collision with the metal atoms in the lattice, and the resulting vibrations of the lattice are perceived as heat.

Ground loss

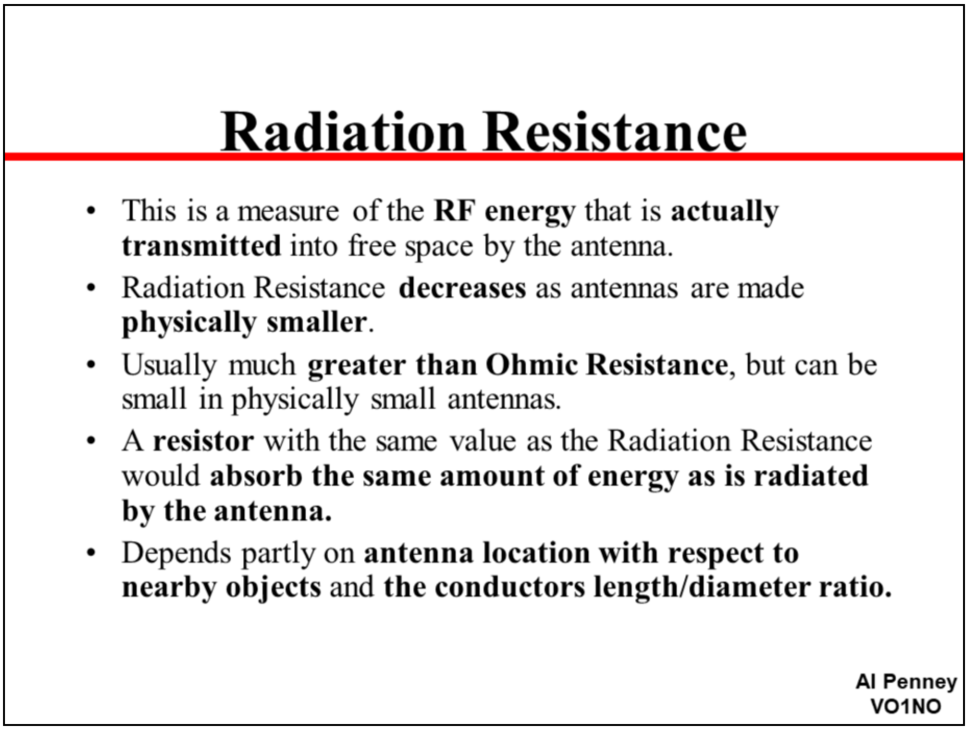
Loss resistance can also include loss from heating the earth below the antenna and in conductive objects nearby, called *ground loss*, even though the loss is not *always* in the earth. Except for aviation, spacecraft, and maritime antennas, the majority of radio antenna power loss is *nearly* always from heating the soil. The loss results from electrical and magnetic fields generated by the antenna accelerating electrons in the soil or an adjacent conductor, such as the metal roof of a nearby building. The resulting collisions in that material generate heat similarly to the heat losses in the metal lattice of the antenna, discussed in the prior section.

These losses can be understood as disturbance of the antenna′s field lines by an electric or magnetic obstacle, absorbing the fields or diverting the field lines from the most expedient route bridging the gap between one pole of the dipole antenna to the other pole, and thereby impeding the electrical circuit through the antenna; likewise, electric field lines interrupted between a monopole antenna and its counterpoise or ground plane.[a]

All antennas′ most intense fields are local, and rapidly diminish with distance from the antenna, so ground losses *can* be reduced or effectively eliminated if the antenna can be placed strategically far away from any electrical or magnetic obstacle. For example, very high frequency (VHF) quarter-wavelengths are about 5 feet (1.5 m), so a quarter-wave or half-wave VHF antenna is small enough to be feasibly mounted on a non-conducting mast several quarter-wavelengths above the earth and far from other antennas, metal-clad or cement buildings, or metal-frame structures.

In most ordinary antennas operated at amateur frequencies, the power lost as heat in the conductor does not exceed a few percent of the total power supplied to the antenna. Expressed in decibels, the loss is less than 0.1 dB. The RF loss resistance of copper wire even as small as #14 is very low compared with the radiation resistance of an antenna that is reasonably clear of surrounding objects and is not too

close to the ground. You can therefore assume that the ohmic loss in a reasonably well-located antenna is negligible, and that the total resistance shown by the antenna (the feed-point resistance) is radiation resistance. As a radiator of electromagnetic waves, such an antenna is a highly efficient device.



The **radiation resistance of an antenna** is defined as the equivalent **resistance** that would dissipate the same amount of power as is radiated by the **antenna**

Radiation resistance is caused by the radiation reaction of the conduction electrons in the antenna. The radiation resistance represents reduction of the electrons’ momentum due to the energy lost from creating electromagnetic waves:

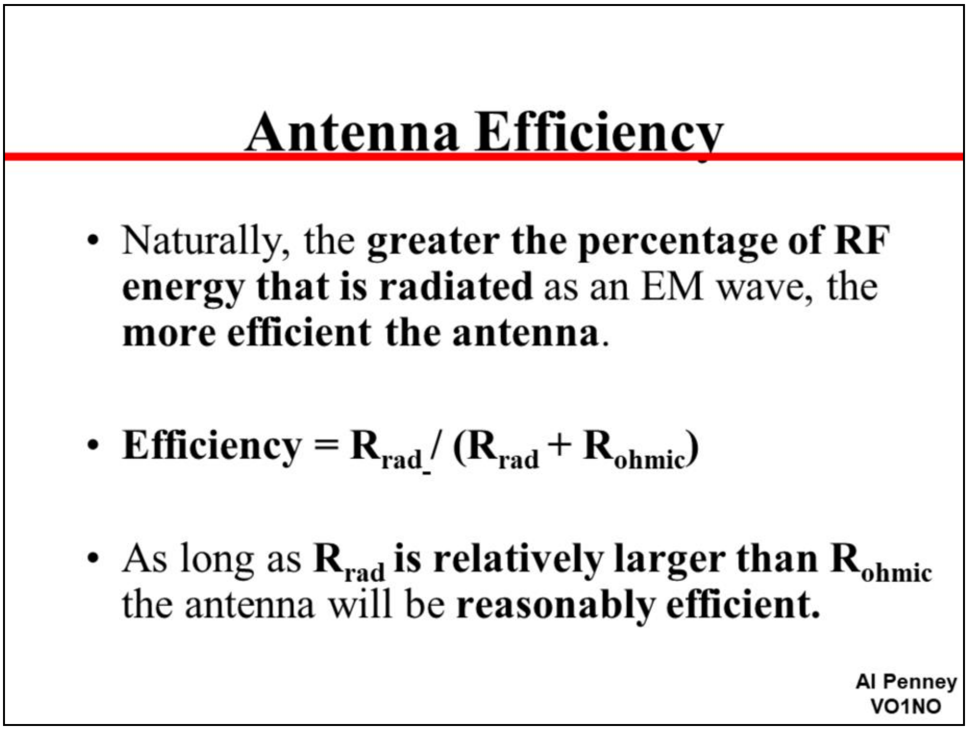
The alternation of AC current flowing through an antenna accelerates the electrons in its conductor, pulling them forward and backward in sync with the frequency of the current. When accelerated, electrons radiate electromagnetic waves which also have momentum. The momentum of the departing waves subtracts from the electrons’ momentum, causing the electrons to slow down, which is seen as a drop in voltage. That voltage drop represents radiation resistance.

The power supplied to an antenna is dissipated in two ways: radiation of electromagnetic waves, and heat losses in the wire and nearby dielectrics. The radiated power is what we want, the useful part,

but it represents a form of “loss” just as much as the power used in heating the wire or nearby dielectrics is a loss. In either case, the dissipated power is equal to I2R. In the case of heat losses, R is a real

resistance. In the case of radiation, however, R is a “virtual” resistance, which, if replaced with an actual resistor of the same value, would dissipate the power that is actually radiated from the antenna.

This resistance is called the *radiation resistance*. The total power in the antenna is therefore equal to I2(R0+R), where R0 is the radiation resistance and R represents the total of all the loss resistances.

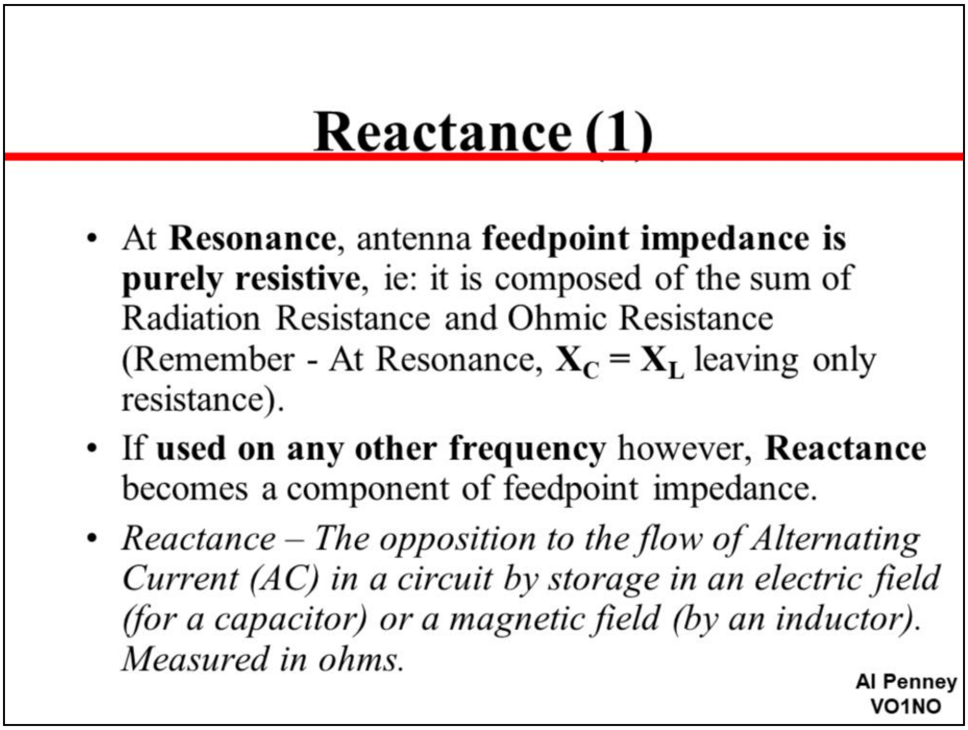


Efficiency

It is naturally important to ensure that the proportion of the power dissipated in the loss resistance is as low as possible, leaving the highest proportion to be dissipated in the radiation resistance as a radiated signal. The proportion of the power dissipated in the radiation resistance divided by the power applied to the antenna is the efficiency.

A variety of means can be employed to ensure that the efficiency remains as high as possible. These include the use of optimum materials for the conductors to ensure low values of resistance, large circumference conductors to ensure large surface area to overcome the skin effect, and not using designs where very high currents and low feed impedance values are present. Other constraints may require that not all these requirements can be met, but by using engineering judgement it is normally possible to obtain a suitable compromise.

It can be seen that the antenna feed impedance is particularly important when considering any RF antenna design. However by maximising the energy transfer by matching the feeder to the antenna feed impedance the antenna design can be optimised and the best performance obtained.



Antenna reactive elements

There are also reactive elements to the feed impedance. These arise from the fact that the antenna elements act as tuned circuits that possess inductance and capacitance. At resonance where most antennas are operated the inductance and capacitance cancel one another out to leave only the resistance of the combined radiation resistance and loss resistance. However either side of resonance the feed impedance quickly becomes either inductive (if operated above the resonant frequency) or capacitive (if operated below the resonant frequency).

There is in fact nothing magic about having a resonant antenna, provided of course that you can devise some efficient means to feed the antenna. Many amateurs use non-resonant (even random-length)

antennas fed with open-wire transmission lines and antenna tuners. They radiate signals just as well as those using coaxial cable and resonant antennas, and as a bonus they usually can use these antenna systems on multiple frequency bands. It is important to consider an antenna and its feed line as a *system*, in which all losses should be kept to a minimum.

Except at the one frequency where it is truly resonant, the current in an antenna is at a different phase compared to the applied voltage. In other words, the antenna exhibits a feed-point *impedance*,

not just a pure resistance. The feed-point impedance is composed of either capacitive or inductive reactance in series with a resistance.

Reactance (2)

- **Below the Resonant Frequency**, feedpoint impedance consists of resistance and **capacitive reactance** (antenna is too short).
- **Above the Resonant Frequency**, feedpoint impedance consists of resistance and **inductive reactance** (antenna is too long).

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Reactance (3)

- **Reactance** does not absorb or radiate power, but can cause an **impedance mismatch** between the antenna and feedpoint.
- Reactance **can be eliminated** using capacitance or inductance, leaving just the resistive component.
- **An antenna does not have to be resonant to radiate!**

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Typical Antenna Impedances

- Dipole, free space: 73 Ohms
- Inverted V: 50 Ohms
- Folded Dipole: 300 Ohms
- Yagi Driven Element: 25 Ohms
- Quarter Wave vertical: 36 Ohms
- Rhombic: 600 Ohms

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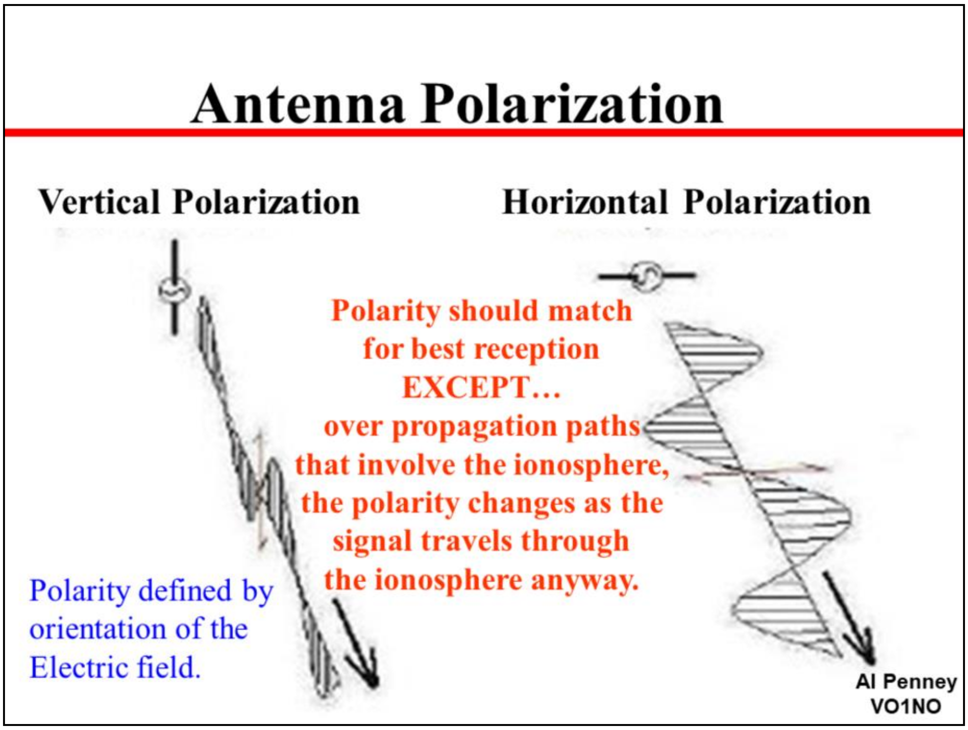


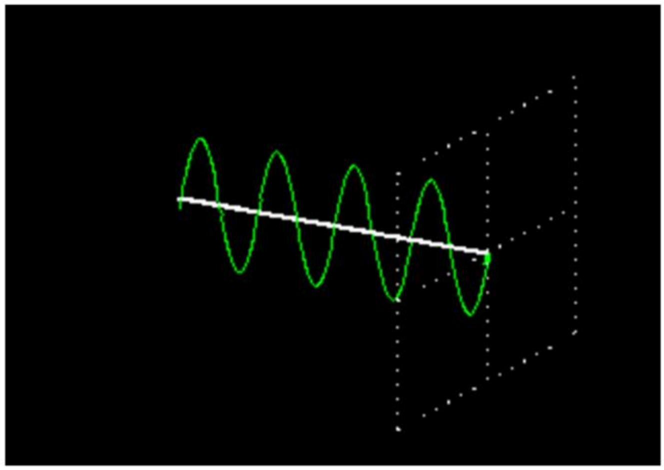
For best results in line-of-sight communications, antennas at both ends of the circuit should have the same polarization; cross polarization results in many decibels

of signal reduction. However, it is not essential for both stations to use the same antenna polarity for ionospheric propagation (sky wave). This is because

the radiated wave is bent and it tumbles considerably during its travel through the ionosphere. At the far end of the communications path the wave may be horizontal,

vertical or somewhere in between at any given instant. For that reason, the main consideration for a good DX antenna is a low angle of radiation rather than the polarization.

Vertical Polarization



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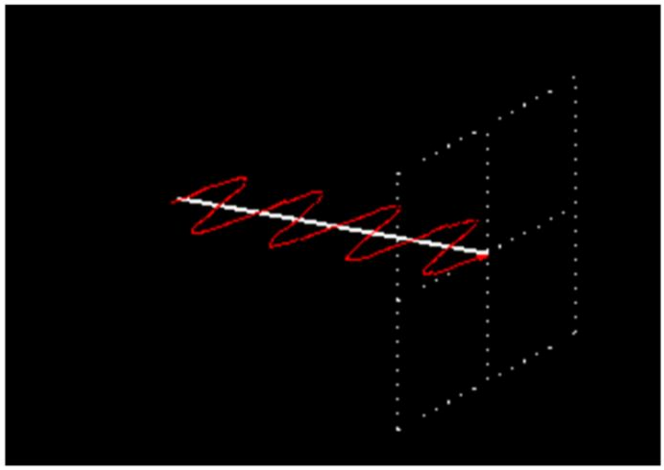
Polarity defined by orientation of the Electric Field.

Horizontal Polarization



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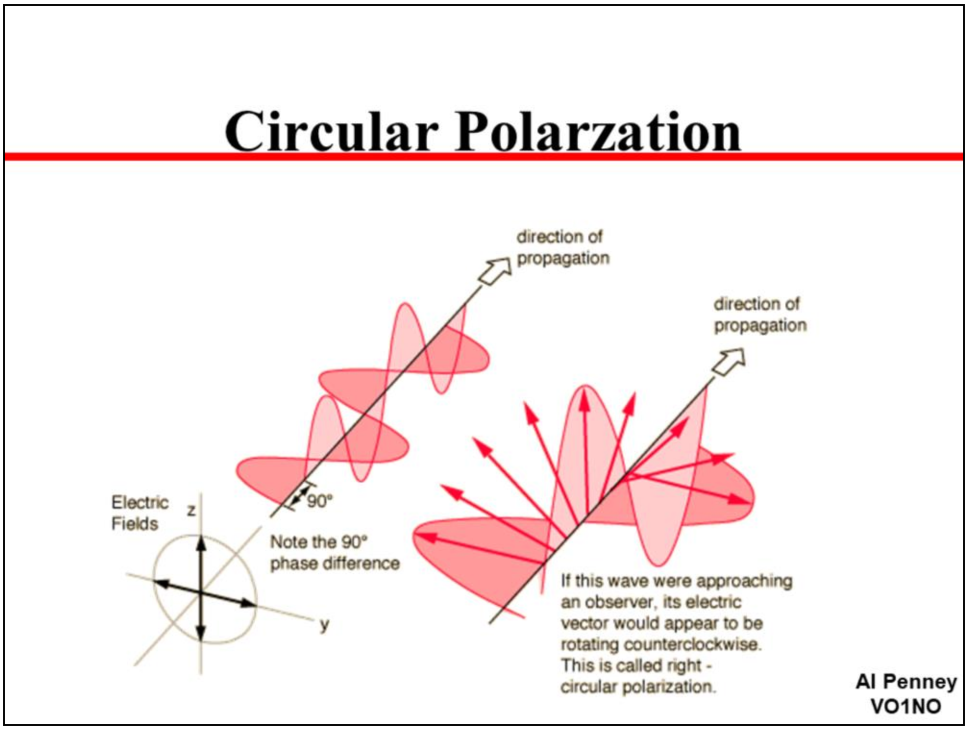
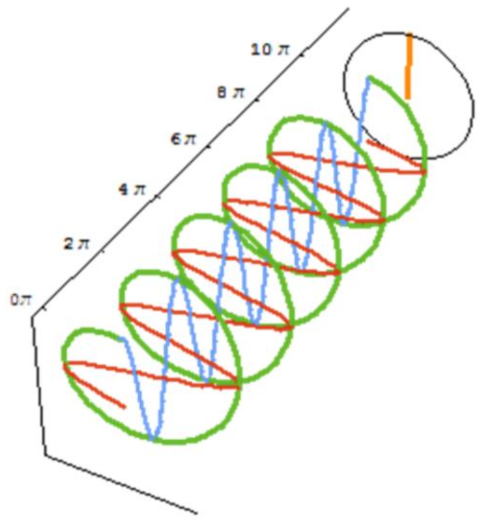
Polarity defined by orientation of the Electric Field.



In electrodynamics, **circular polarization** of an electromagnetic wave is a polarization state in which, at each point, the electric field of the wave has a constant magnitude but its direction rotates at a constant rate in a plane perpendicular to the direction of the wave.

In electrodynamics the strength and direction of an electric field is defined by its electric field vector. In the case of a circularly polarized wave, as seen in the accompanying animation, the tip of the electric field vector, at a given point in space, describes a circle as time progresses. At any instant of time, the electric field vector of the wave indicates a point on a helix oriented along the direction of propagation. A circularly polarized wave can rotate in one of two possible senses: *right circular polarization* in which the electric field vector rotates in a right-hand sense with respect to the direction of propagation, and *left circular polarization* in which the vector rotates in a left-hand sense.

Circular Polarzation



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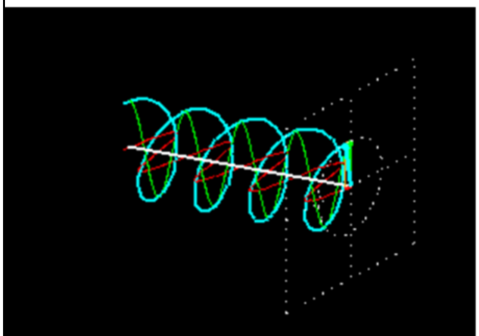
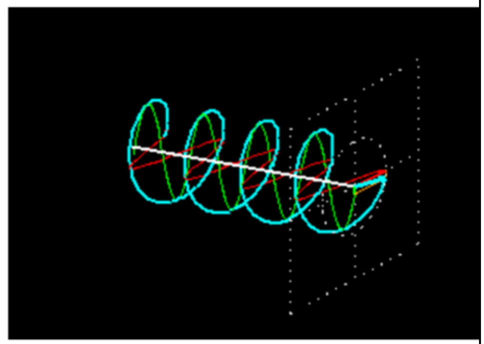
Circular Polarzation





Left-Hand Circular Polarization **Right-Hand Circular Polarization**

Note: Both TX and RX should use same polarization (LHCP or RHCP) for best results. Linearly polarized signals on one end will suffer a 3 dB signal strength loss.

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Circular Polarization Methods

- Using antennas that are inherently circularly polarized e.g.: Helical Antenna.
- Feeding two orthogonal dipoles 90 degrees out of phase:
  - Space the dipoles $\lambda/4$ along the boom; or
  - Mount the dipoles in the same plane and use a $\lambda/4$ phasing line to obtain the 90 degree difference.

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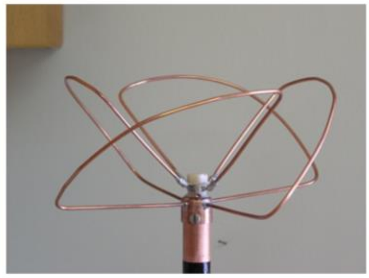
Inherently Circular Polarized

Helical



Skew Planar Wheel

Quadrifilar Helix

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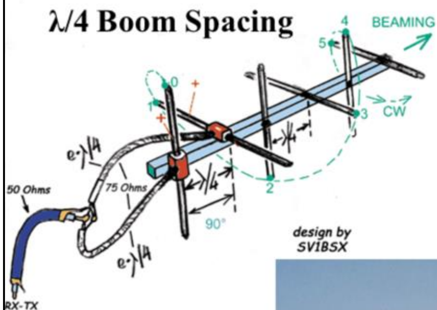
Two Dipoles λ/4 Phase Difference

λ/4 Boom Spacing



λ/4 Phasing Line

Turnstile Antenna

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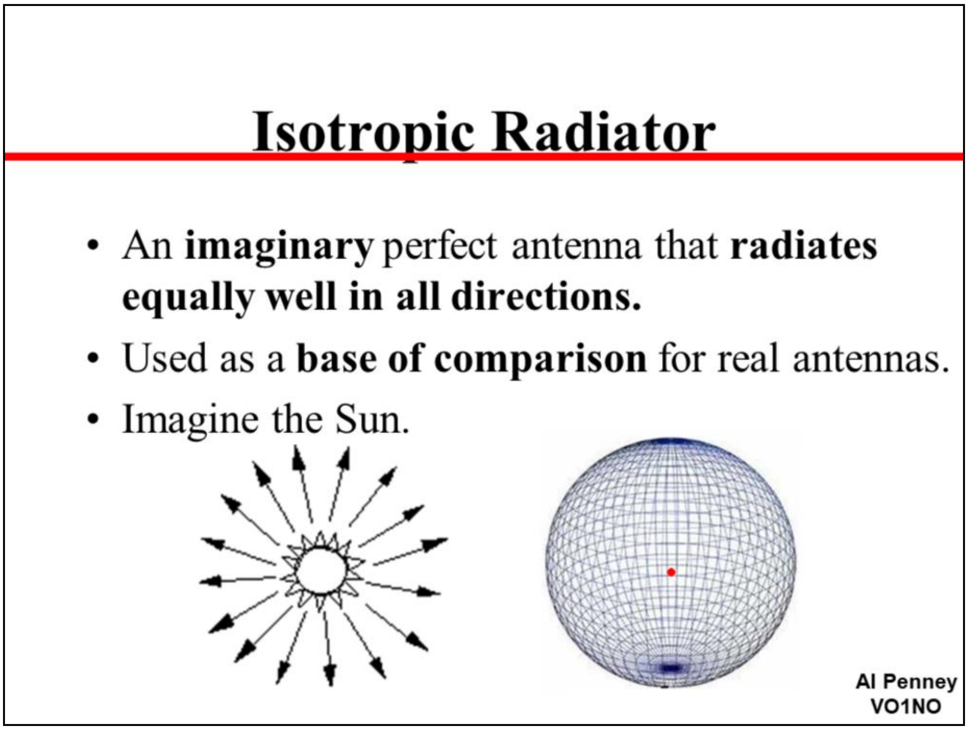

An **isotropic radiator** is a theoretical point source of electromagnetic or sound waves which radiates the same intensity of radiation in all directions. It has no preferred direction of radiation. It radiates uniformly in all directions over a sphere centred on the source. Isotropic radiators are used as reference radiators with which other sources are compared, for example in determining the gain of antennas. In antenna theory, an **isotropic antenna** is a hypothetical antenna radiating the same intensity of radio waves in all directions. It thus is said to have a directivity of 0 dBi (dB relative to isotropic) in all directions.

The Isotropic Radiator

Before we can fully describe practical antennas, we must first introduce a completely theoretical antenna, the *isotropic radiator*. Envision, if you will, an infinitely small antenna, a point located in

outer space, completely removed from anything else around it. Then consider an infinitely small transmitter feeding this infinitely small, point antenna. You now have an isotropic radiator.

The uniquely useful property of this theoretical *point-source* antenna is that it radiates equally well in all directions. That is to say, an isotropic antenna favors no direction at the expense of any other—in

other words, it has absolutely no *directivity*. The isotropic radiator is useful as a "measuring stick" for comparison with actual antenna systems.

You will find later that real, practical antennas all exhibit some degree of directivity, which is the property of radiating more strongly in some directions than in others. The radiation from a practical

antenna never has the same intensity in all directions and may even have zero radiation in some directions. The fact that a practical antenna displays directivity (while an isotropic radiator does not) is not

necessarily a bad thing. The directivity of a real antenna is often carefully tailored to emphasize radiation in particular directions. For example, a receiving antenna that favors certain directions can discriminate against interference or noise coming from other directions, thereby increasing the signal-to-noise ratio for desired signals coming from the favored direction.

Dipole Antenna (1)

- The **half-wave dipole** antenna is an **efficient** and commonly used **practical antenna.**
- It is also used as a **comparison antenna** for gain measurements, using the term **dBd.**
- Because it **does not radiate equally well** in all directions though, it has **2.15 dB gain** compared to an isotropic antenna.
  - *Therefore Gain of a Dipole Antenna dBd = 2.15 dBi*
  - ***Note that this is in free space – the presence of the Earth will change the radiation pattern of a dipole!***

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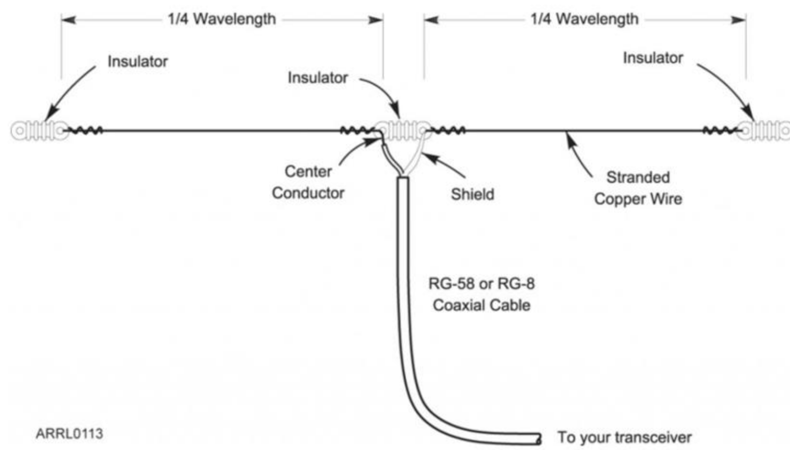
Dipole Antenna (2)



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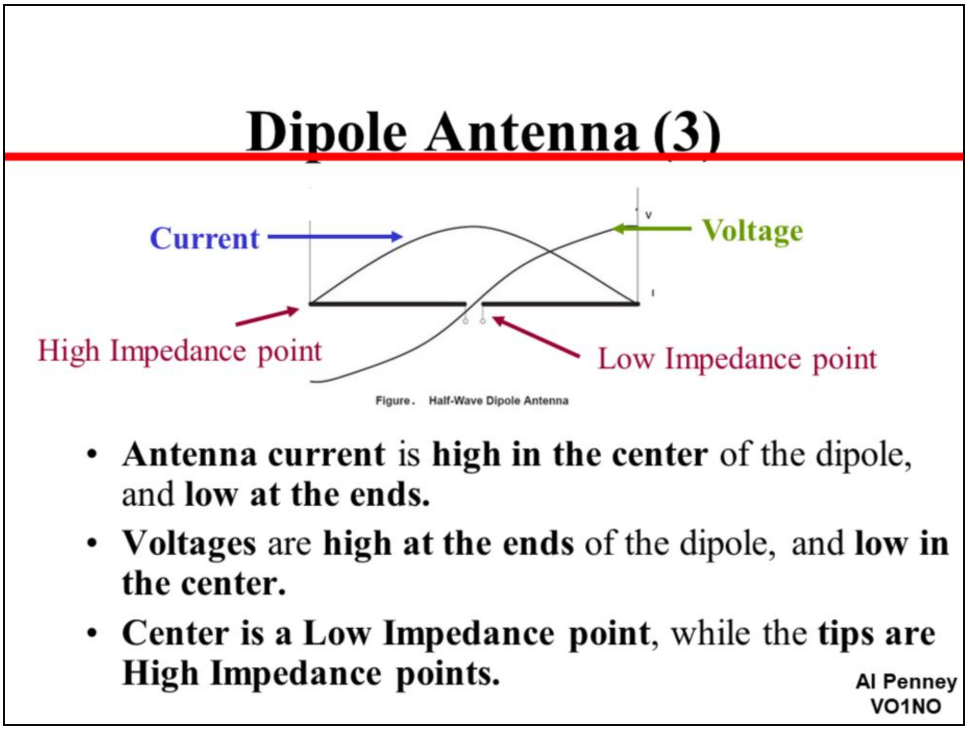


The current and voltage waveforms that appear along the length of a dipole antenna are of importance in many instances.

Both the dipole current and voltage waveforms may impact the way that the antenna is used, and therefore an understanding of these is important.

Dipole current & voltage

The current and voltage on any radiating element vary along its length, and this is true for the dipole as well as for any other antenna.

The current variation occurs because standing waves are set up along the length of the radiating element. This result peaks and troughs along the length of the antenna element.

The current falls to zero at the end and then varies sinusoidally reaching a peak a quarter wavelength away from the end.

Conversely, the voltage peaks at the end and then varies as the cosine as the distance away from the end increases. It reaches a minimum a quarter wavelength from the end.

Dependent upon the length of the antenna, there may be several peaks and troughs of current and voltage along the length of the radiating element.

The most popular form of dipole antenna is the half wave and for this, the current is at a minimum at the ends and rises to a maximum in the middle where the feed is applied.

Conversely the voltage is low at the middle and rises to a maximum at the ends. It is generally fed at the centre, at the point where the current is at a maximum and the voltage a minimum. This provides a low impedance feed point which is convenient to handle. High voltage feed points are far less convenient and more difficult to use.

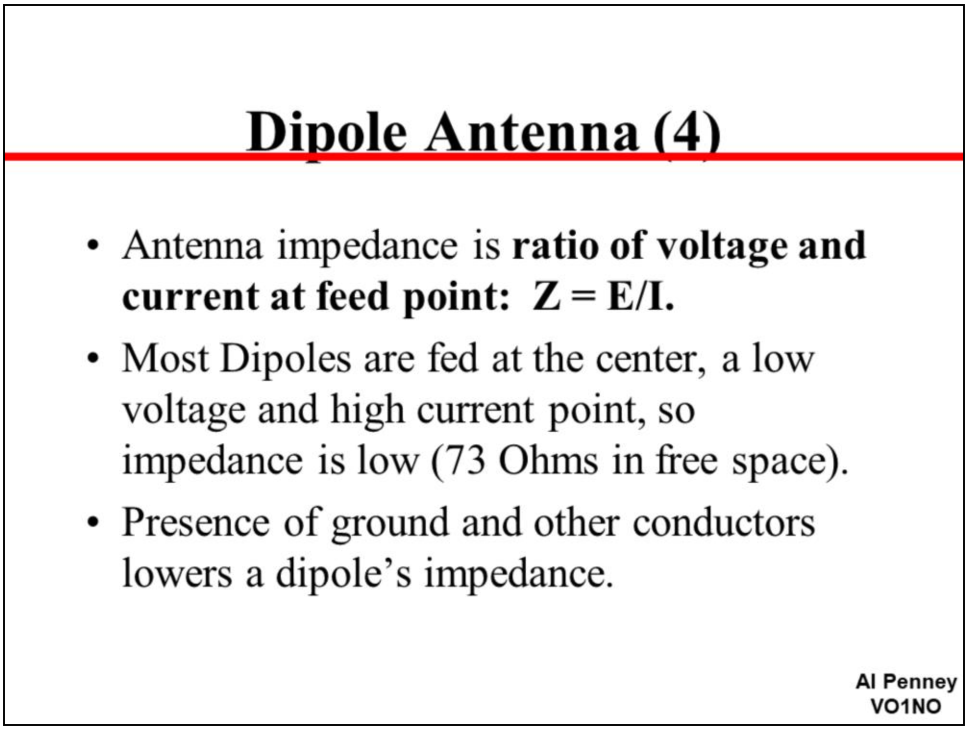
It is easy to remember where the current and voltage minima are. As an aide memoire it can be thought of that the voltage is at a maximum at the ends because it is the point where it is effectively open circuit, and the current is zero there, because there is nowhere for it to flow.

Dipole feed impedance basics

The dipole feed impedance is determined by the ratio of the voltage and the current at the feed point – it is simply calculated using Ohm’s Law.

Although a dipole can be fed at any point, it is normal for the feed point to be at the middle of the dipole. This is the current maximum and voltage minimum point. This gives a low impedance for the dipole as can be assumed from Ohm's Law (V / I = R). This is far easier to accommodate than a high impedance feed impedance where very high voltages may be present when transmitting with even modest power levels.

Although the most common for of dipole is the half wave dipole, others can be multiples of a half wavelength. It is therefore possible to feed the dipole at any one of these voltage minimum or current maximum points which occur at a point that is a quarter wavelength from the end, and then at half wavelength intervals. As resonant dipoles are multiple of a half wavelength, this means that the most common point is still at the centre point of the antenna.



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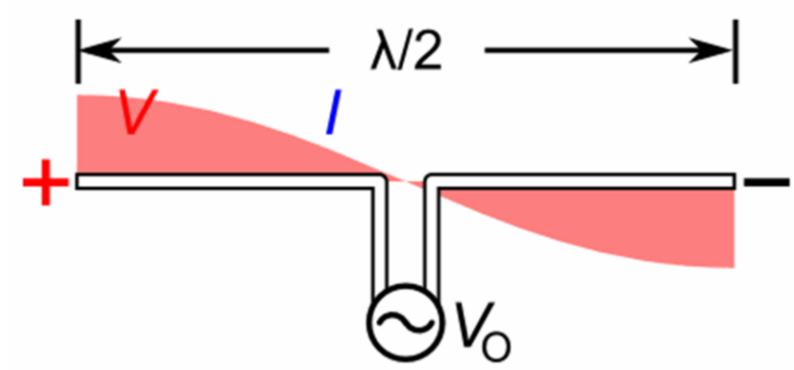
Factors that alter the dipole feed impedance

Although the standard feed impedance of a dipole is 73Ω this value is rarely seen as the impedance is changed by a number of different factors.

One of the major factors affecting dipoles used n the HF bands can be the proximity of the ground.

For dipoles radiating at any frequency, if it forms the radiating element for a more complicated form of RF antenna, then elements of the antenna will have an effect. This normally lowers the impedance,. It can fall to values of 10 Ω or even less. Thus it is necessary to ensure a good match is maintained with the feeder.

Dipole Voltage/Current



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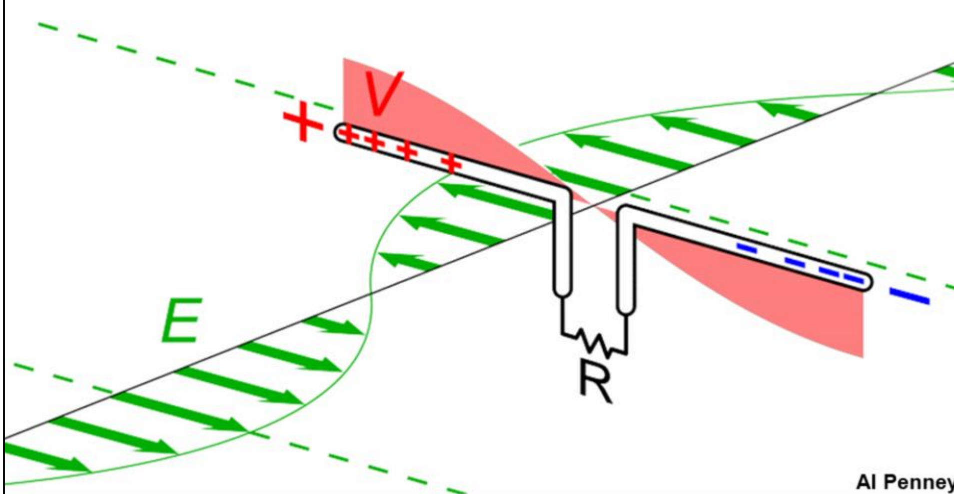
Animation showing the sinusoidal standing waves of voltage, V, and current, I, on a half-wave dipole driven by an AC voltage at its resonant frequency.

https://owenduffy.net/blog/?p=7763

Receiving a Signal



A half-wave dipole antenna receiving a radio signal. The incoming radio wave *(whose electric field is shown as **E**, green arrows)* causes an oscillating electric current within the antenna elements *(black arrows)*, alternately charging the two sides of the antenna positively (+) and negatively (−). Since the antenna is one half a wavelength long at the radio wave's frequency, the voltage (shown as ***V***, *red bands*) and current in the antenna form a standing wave. This oscillating current flows down the antenna's transmission line through the radio receiver (represented by resistor **R**).

Antenna Gain

- A measure of the **antenna's ability to concentrate the radiated signal** into a beam.
- Defined as the **ratio between the power** required by a **reference antenna** to produce a signal at a given location to the power required by the **real antenna** to produce the same signal in the same location.
- Always indicated as a **comparison to a standard reference antenna**, usually an **Isotropic Antenna**, or a **Dipole Antenna.**
- Gain is measured in **Decibels (dB).**

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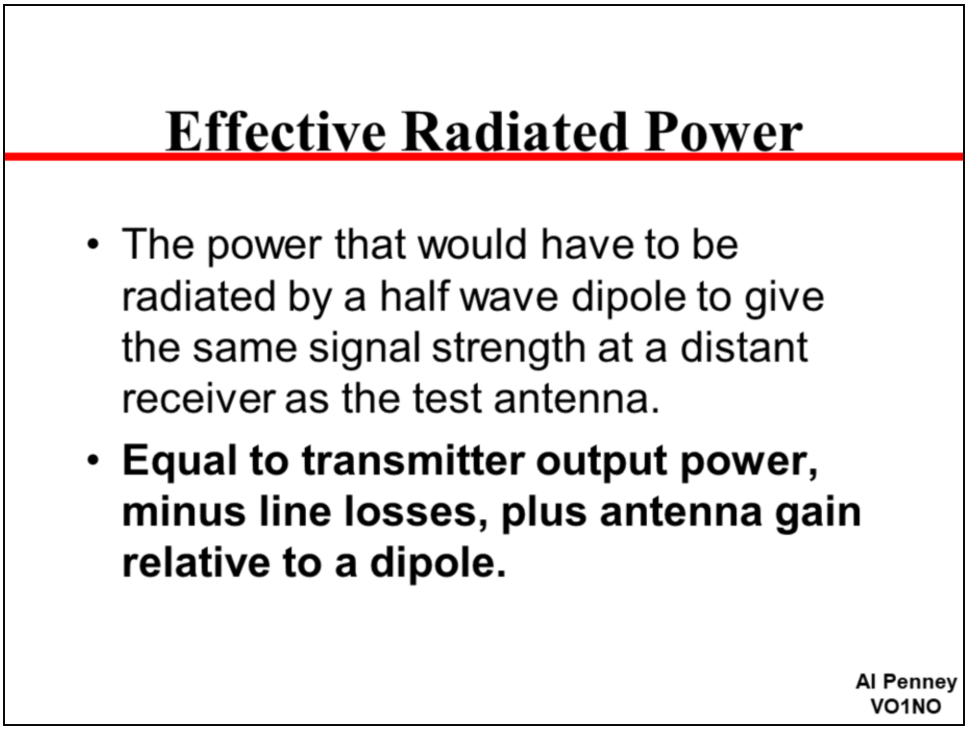
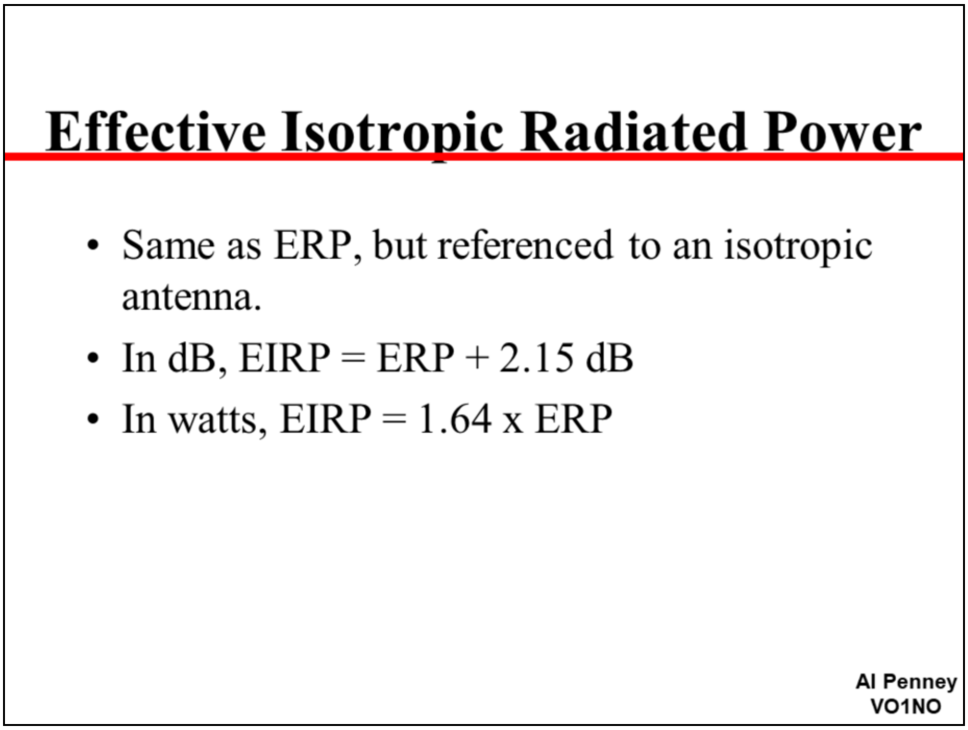


Effective Radiated Power (ERP) is the total power in watts that would have to be radiated by a half-wave dipole antenna to give the same radiation intensity (signal strength in watts per square meter) as the actual source at a distant receiver located in the direction of the antenna's strongest beam (main lobe). ERP measures the combination of the power emitted by the transmitter and the ability of the antenna to direct that power in a given direction. It is equal to the input power to the antenna multiplied by the gain of the antenna. It is used in electronics and telecommunications, particularly in broadcasting to quantify the apparent power of a broadcasting station experienced by listeners in its reception area.

An alternate parameter that measures the same thing is **effective isotropic radiated power** (**EIRP**). Effective isotropic radiated power is the total power that would have to be radiated by a hypothetical isotropic antenna to give the same signal strength as the actual source in the direction of the antenna's strongest beam. The difference between EIRP and ERP is that ERP compares the actual antenna to a half-wave dipole antenna, while EIRP compares it to a theoretical isotropic antenna. Since a half-wave dipole antenna has a gain of 1.64, or 2.15 decibels compared to an isotropic radiator, if ERP and EIRP are expressed in watts their relation is

In dB, EIRP = ERP + 2.15 dB

In watts, EIRP = 1.64 x ERP



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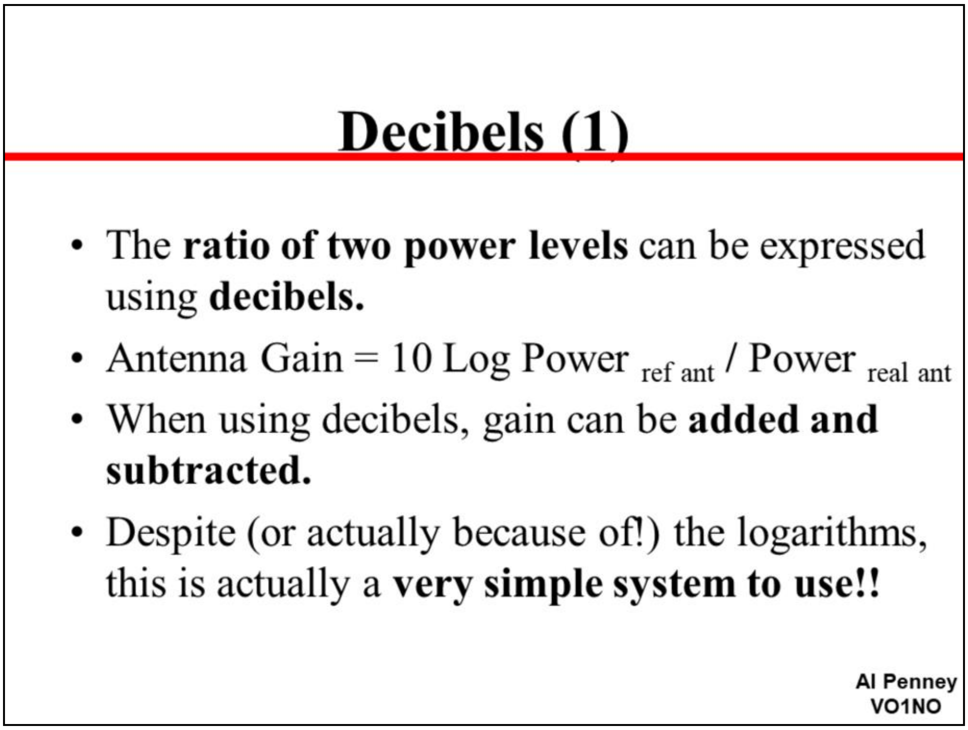

INTRODUCTION TO THE DECIBEL

The power gain of an antenna system is usually expressed in decibels. The decibel is a practical unit for measuring power ratios because it is more closely

related to the actual effect produced at a distant receiver than the power ratio itself. One decibel represents a just-detectable change in signal strength, regardless of

the actual value of the signal voltage. A 20-decibel (20-dB) increase in signal, for example, represents 20 observable “steps” in increased signal. The power ratio

(100 to 1) corresponding to 20 dB gives an entirely exaggerated idea of the improvement in communication to be expected. The number of decibels corresponding

to any power ratio is equal to 10 times the common logarithm of the power ratio, or

dB = 10 log P1/P2

If the voltage ratio is given, the number of decibels is equal to 20 times the common logarithm of the ratio. That is,

$$dB = 20 \log V1/V2$$

When a voltage ratio is used, both voltages must be measured across the same value of impedance. Unless this is done the decibel figure is meaningless, because it

is fundamentally a measure of a power ratio. The main reason a decibel is used is that successive power gains expressed in decibels may simply be

added together. Thus a gain of 3 dB followed by a gain of 6 dB gives a total gain of 9 dB. In ordinary power ratios, the ratios must be multiplied together to find the

total gain.

A reduction in power is handled simply by subtracting the requisite number of decibels. Thus, reducing the power to 1/2 is the same as subtracting 3 decibels. For

example, a power gain of 4 in one part of a system and a reduction to 1/2 in another part gives a total power gain of 4 ξ 1/2 = 2. In decibels, this is 6 – 3 = 3 dB. A power

reduction or “loss” is simply indicated by including a negative sign in front of the appropriate number of decibels.

Decibels (2)

- Every **3 dB change double or halves** the power.
- Every **10 db change** increases or decreases the power by **10 times.**

- *Example: An amplifier advertises that it can increase your transmit power by 6 db. If your transmitter is 50 watts, what is the output power of the amplifier?*
  - 6 db is 3 db + 3 db.
  - The first 3 db doubles your power: 50 watts x 2 = 100 watts
  - The second 3 db doubles it again: 100 watts x 2 = 200 watts

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Decibels (3)

- *Example: Your feedline has 3 db loss on 2 meters. The antenna, a long boom Yagi, has a gain of 13 db compared to an isotropic antenna. If your transmitter power is 150 watts, what is your effective isotropic radiated power?*
  - 3 dB loss in the feedline = 150 watts/2 = 75 watts
  - 13 dB gain in the antenna = 10 db + 3 db
  - 10 db gain gives 75 watts x 10 = 750 watts
  - Next 3 dB gain gives 750 watts x 2 = 1500 watts
- Therefore, 150 watts into this particular antenna system is the equivalent of 1500 watts into an isotropic antenna.

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Decibels (4)

- Another way to do this is to add the gain and loss of each component, and apply it to the transmitter power:
  - -3 dB + 13 dB = 10 dB gain overall compared to an isotropic antenna.
  - 10 dB gain with 150 watt transmitter gives
    150 watts x 10 = 1500 watts compared to an isotropic antenna.
- So the answer is the same no matter how the dB calculations are made.

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Decibels (5)

dB	Power Chng
1	1.25
2	1.58
3	2.0
4	2.5
5	3.15
6	4.0
7	5.0
8	6.3
9	8.0

dB	Power Chng
10	10.0
11	12.6
12	15.8
13	20.0
14	25.1
15	31.6
20	100
30	1,000
40	10,000

Radiation Patterns

- Most antennas **do not transmit/receive equally well in all directions,** either in azimuth or in elevation above the horizon.
- To illustrate this behavior, we use **radiation plots.**

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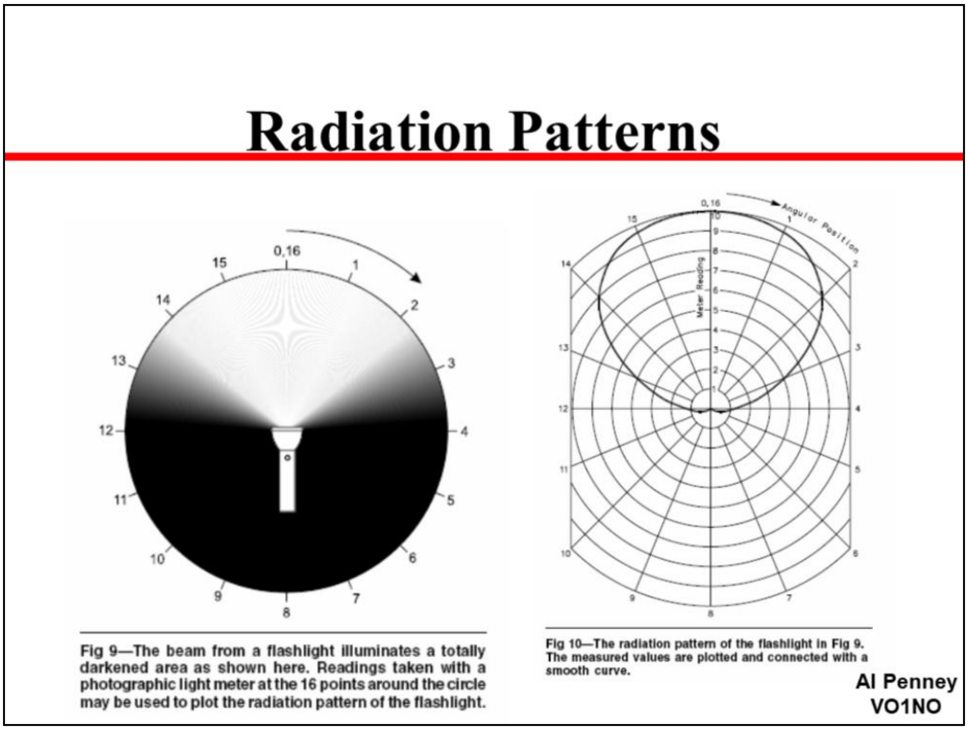


Directivity and the Radiation Pattern—a Flashlight Analogy

The directivity of an antenna is directly related to the *pattern* of its radiated field intensity in free space. A graph showing the actual or relative field intensity at a fixed distance, as a function

of the direction from the antenna system, is called a *radiation pattern*. Since we can't actually see electromagnetic waves making up the radiation pattern of an antenna, we can consider

an analogous situation.

Fig represents a flashlight shining in a totally darkened room. To quantify what our eyes are seeing, we use a sensitive light meter like those used by photographers, with a scale graduated

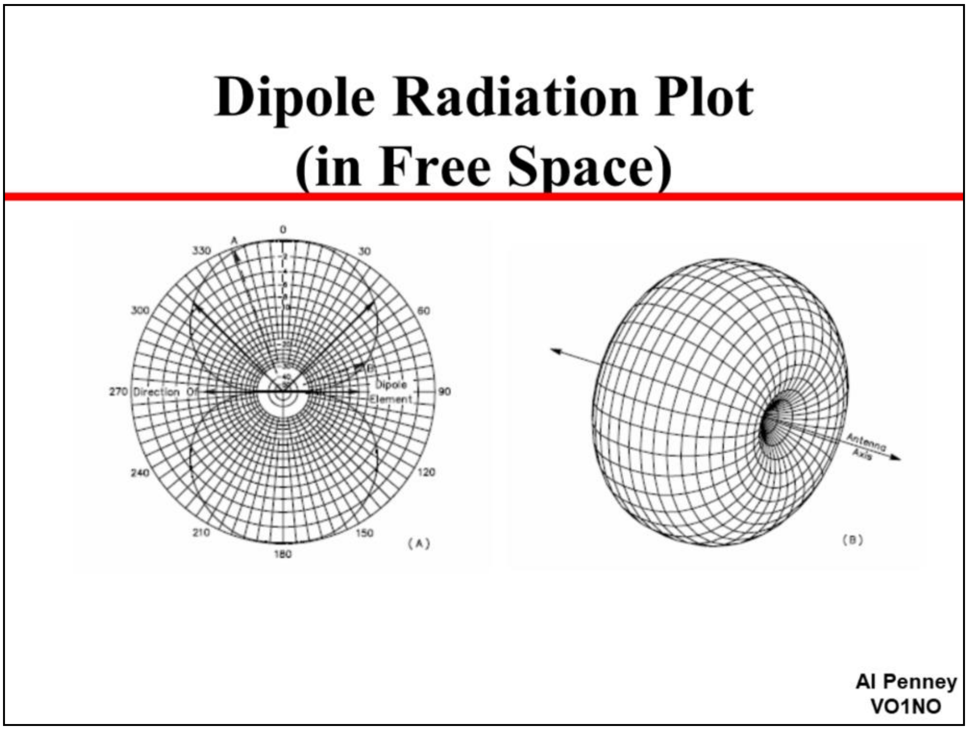
in units from 0 to 10. We place the meter directly in front of the flashlight and adjust the distance so the meter reads 10, exactly full scale.

We also carefully note the distance. Then, always keeping the meter the same distance from the flashlight and keeping it at the same height above the floor, we move the light meter around the

flashlight, as indicated by the arrow, and take light readings at a number of different positions.

After all the readings have been taken and recorded, we plot those values on a sheet of polar graph paper, like that shown in **Fig 9**. The values read on the meter are plotted at an angular position

corresponding to that for which each meter reading was taken. Following this, we connect the plotted points with a smooth curve, also shown in Fig 9. When this is finished, we have completed a radiation pattern for the flashlight.



Directive diagram of a free-space dipole. At A, the pattern in the plane containing the wire axis. The length of each dashed-line arrow

represents the relative field strength in that direction, referenced to the direction of maximum radiation, which is at right angles to

the wire's axis. The arrows at approximately 45° and 315° are the half-power or –3 dB points. At B, a wire grid representation of the "solid pattern"

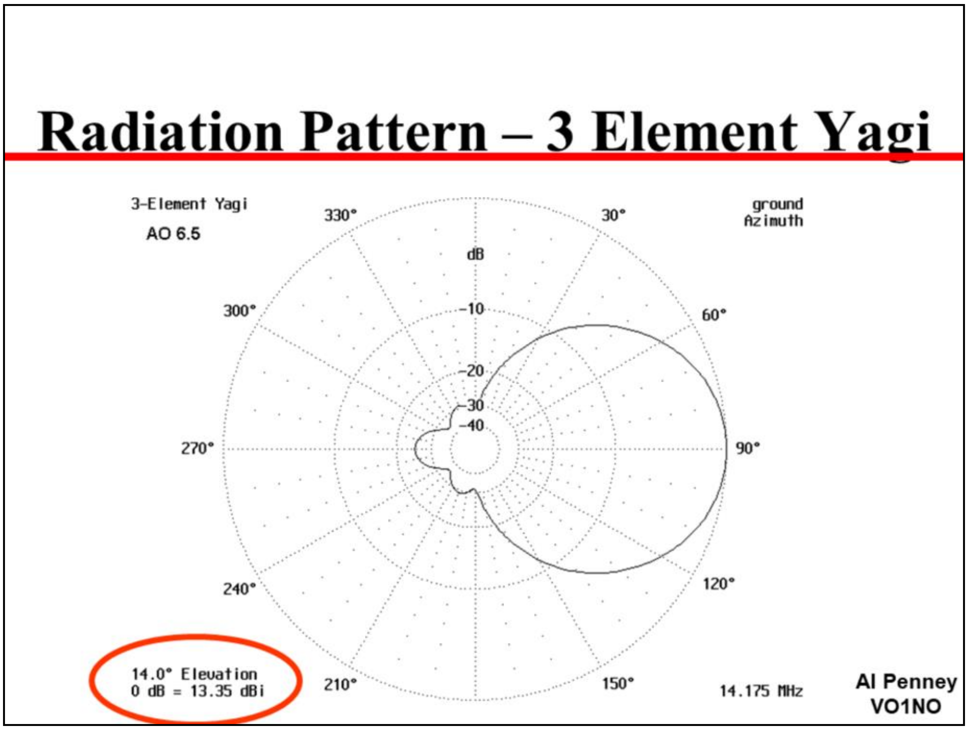
for the same antenna. These same patterns apply to any center-fed dipole antenna less than a half wavelength long.

Pattern Planes

Patterns obtained above represent the antenna radiation in just one plane. In the example of the flashlight, the plane of measurement was at one height above the floor. Actually, the pattern for any

antenna is three dimensional, and therefore cannot be represented in a single-plane drawing. The "solid" radiation pattern of an antenna in free space would be found by measuring the field strength at

every point on the surface of an imaginary sphere having the antenna at its center. The information so obtained would then be used to construct a solid figure, where the distance from a fixed point (representing the antenna) to the surface of the figure is proportional to the field strength from the antenna in any given direction. **Fig 11B** shows a three-dimensional wire-grid representation of the radiation pattern of a half-wave dipole.



For amateur work, *relative* values of field strength (rather than absolute) are quite adequate in pattern plotting. In other words, it is not necessary

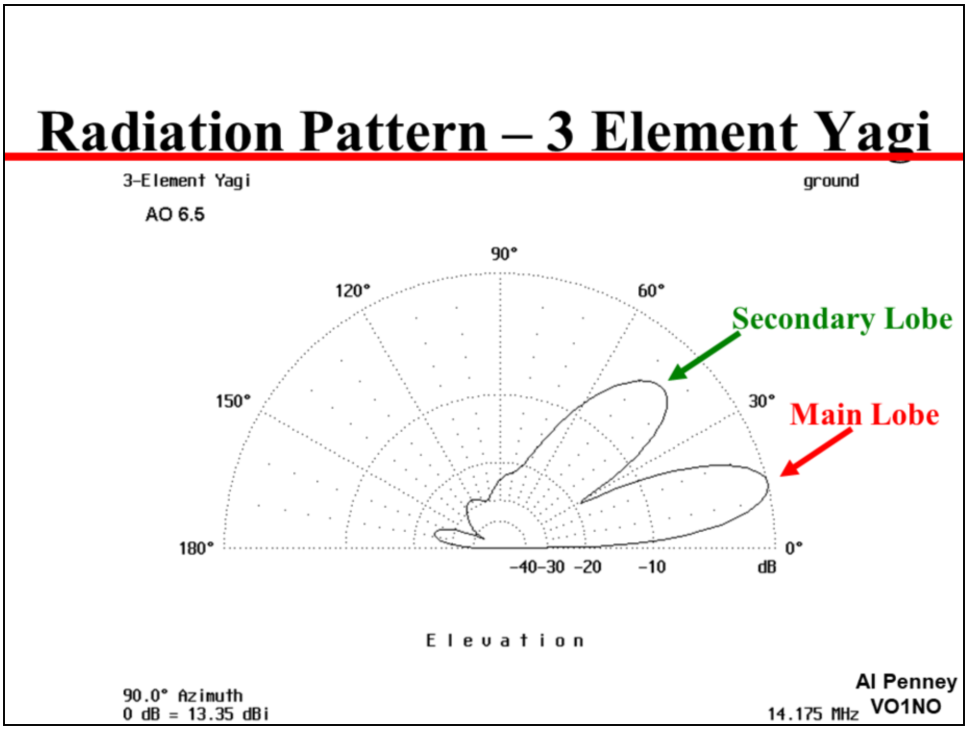
to know how many microvolts per meter a particular antenna will produce at a distance of 1 mile when excited with a specified power level. (This is the kind

of specifications that AM broadcast stations must meet to certify their antenna systems to the FCC.)

For whatever data is collected (or calculated from theoretical equations), it is common to normalize the plotted values so the field strength in the direction of maximum radiation coincides with

the outer edge of the chart. On a given system of polar coordinate scales, the *shape* of the pattern is not altered by proper normalization, only its size.

IMPORTANT: The antenna pattern applies only to a single plane, in this case the pattern at 14 degrees elevation. We need to look at the side profile to get a complete understanding of what the antenna's radiation pattern looks like.



The side profile indicates that the antenna's strongest lobe is at 14 degrees, with another lobe at ~48 degrees at ~3.5 dB down from the main lobe.

Real Life Antennas…

- In **real life** however, we have to consider the **effect of the Earth** on the **antenna pattern.**
- Energy **reflected off the ground** reinforces the antenna's radiation pattern in some areas, and weakens it in others.
- A **dipole over salt water** might have as much as **6 dB gain** over a dipole in free space!
- The lesson to be learned here is that before comparing gain figures, you must ensure that you have **taken everything to the same baseline!**

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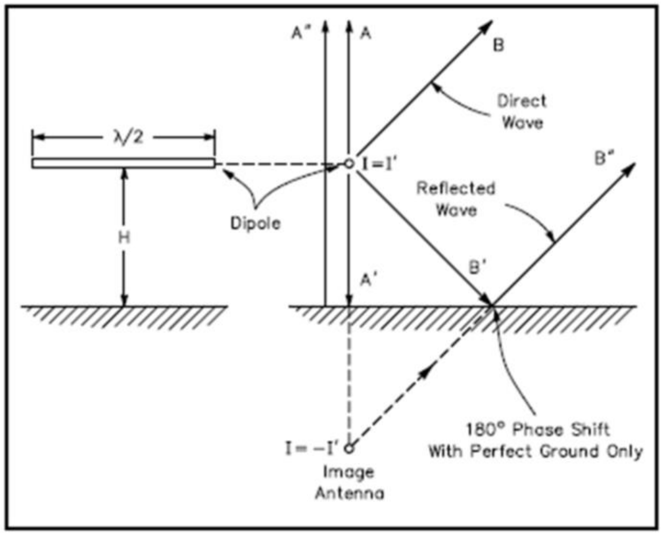
Reflections off the Ground



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The ground acts as a mirror for radio waves. The better the ground (I.e. the more conductive it is) the more reflective it is. The direct and reflected signals will combine, giving areas radiating outwards from the antenna where signals are in phase and so reinforce each other, and areas where the signals are out of phase and so cancel each other. The phase difference depends on the difference in path length (length is directly proportional to time as the velocity is the same), and on the amount of phase shift caused by the reflection. A perfect ground causes a 180 degree shift.

Vertical Pattern

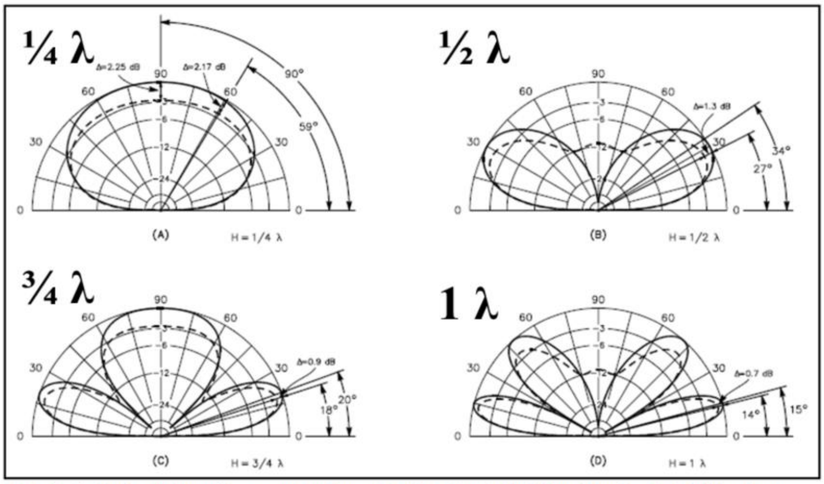


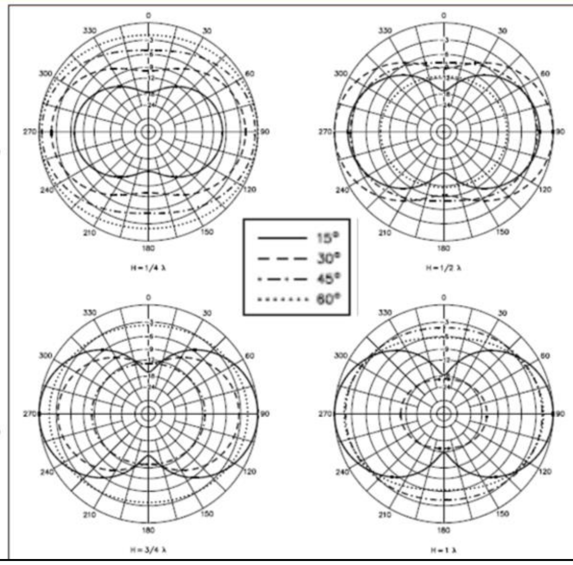
Fig 8-4 — Vertical radiation patterns over two types of earth: saltwater (solid line in each set of plots) and very poor ground (broken line in each sets of plots). The wave angles as well as the gain difference between saltwater and poor ground are given for four antenna heights.

At low height, the direct and reflected waves will cancel each other at low angles, and reinforce each other at high angles. As the height starts to increase, lower angle signals start to reinforce each other, and higher angles cancel. Thus, the radiation pattern depends primarily on the height above ground, and to a lesser extent on the quality of the ground.

Horizontal Pattern

¼ λ

½ λ



¾ λ

1 λ

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Still radiation off the ends of dipoles, especially those closer to the ground.

Try to orient your dipole broadside to the directions you want to work, or put up two at right angles. If the antennas are below ¼ wavelength, then it isn't worth the bother however.

To improve the efficiency of a low dipole (less than one quarter wavelength) put wires directly under the antenna running in same direction. Remember that most of the radiation will go straight up however – an NVIS antenna (Near Vertical Incidence Skywave).

Horizontal Antenna Height

- Horizontal antennas must be mounted **at least half wavelength high to exhibit directivity**.
- At $\lambda/2$, upward radiation is **effectively cancelled**.
- Below $\lambda/2$, most radiation is directed **vertically upwards** (or absorbed in ground!).
- Going higher generates **additional lobes**.
- Height also affects feedpoint impedance.
- Situation is **different for vertical antennas!**
- **For all antennas, low angle radiation best for DX.**

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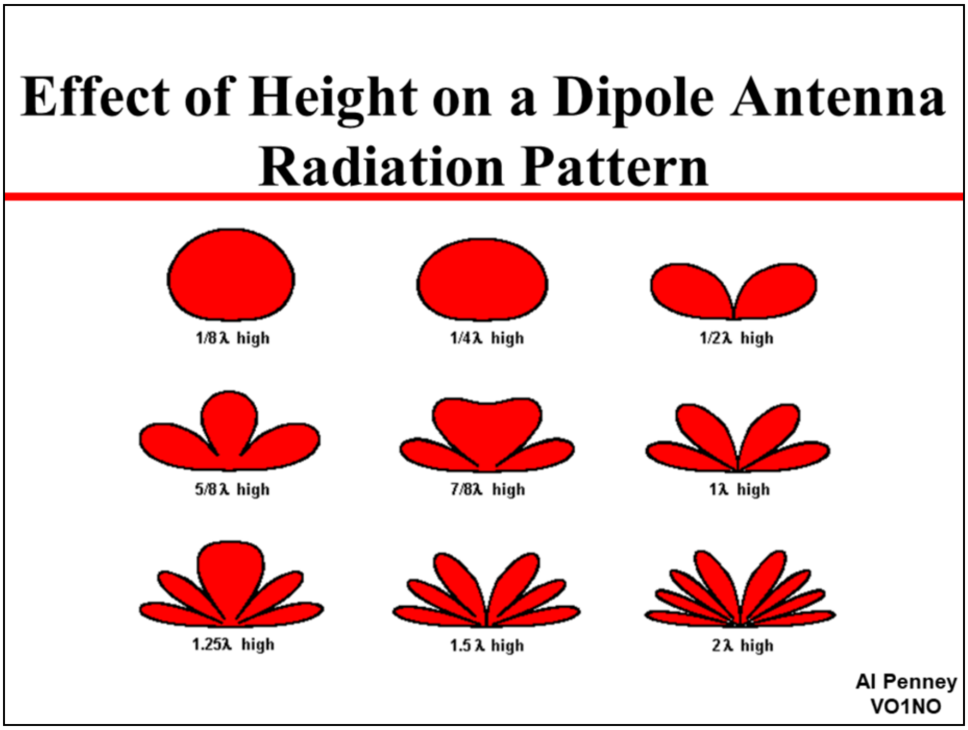

Effect of Height on a Dipole Antenna Radiation Pattern
1/8λ high
1/4λ high
1/2λ high
5/8λ high
7/8λ high
1λ high
1.25λ high
1.5 λ high
2 λ high
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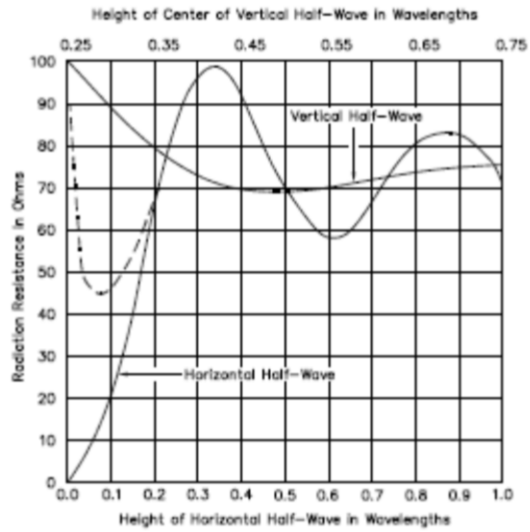
Effect of Height – Dipole Impedance



Variation in radiation resistance of vertical and horizontal half-wave antennas at various heights above flat ground. Solid lines are for perfectly conducting ground; the broken line is the radiation resistance of horizontal half-wave antennas at low heights over real ground.

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This diagram shows the way in which the radiation resistance of horizontal and vertical half-wave antennas vary with height above ground (in **λ**, wavelengths).

For horizontally polarized half-wave antennas, the differences between the effects of perfect ground and real earth are negligible if the antenna

height is greater than 0.2 **λ**. At lower heights, the feed-point resistance over perfect ground decreases rapidly as the antenna is brought closer to

a theoretically perfect ground, but this does not occur so rapidly for actual ground. Over real earth, the resistance begins increasing at heights below

about 0.08 **λ**. The reason for the increasing resistance at very low heights is that more and more of the reactive (induction) field of the antenna is absorbed

by the lossy ground in close proximity. For a vertically polarized **λ** /2-long dipole, differences between the effects of perfect ground

and real earth on the feed-point impedance is negligible, as seen in the diagram. The theoretical half-wave antennas on which this chart is based are assumed to

have infinitely thin conductors.

Dipole height above ground

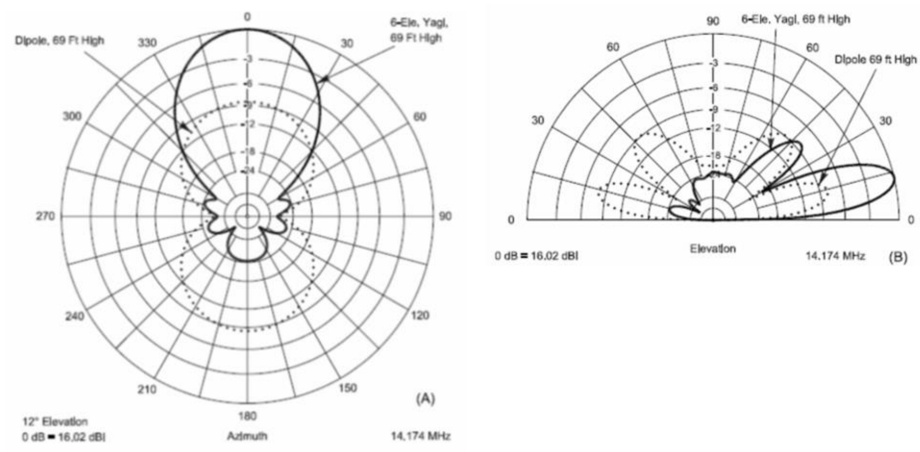
For larger dipole antennas like those used for frequencies below about 30 to 50 MHz, the height above ground can be a major influence on the feed impedance.

At these frequencies the distance between the antenna and the ground may be only a wavelength or two in many instances. At these sorts of heights, the ground can have a major influence on the impedance, especially when the antenna is mounted horizontally as is often the case.

As can be seen from the impedance variation plot, the largest swings of impedance are seen when the dipole antenna is closest to the ground. It then closes in on the free space value. This means that the actual value for many HF dipoles will be relatively low as it is not possible to raise them very high in many cases. Feeding with 50Ω coaxial feeder is often a good compromise.

For VHF / UHF dipoles, it is possible to raise them much higher, although mounting poles and masts may interact to reduce the impedance. Also dipoles are not often used on their own as they are often incorporated into antennas like the Yagi.

6 Element Yagi vs Dipole



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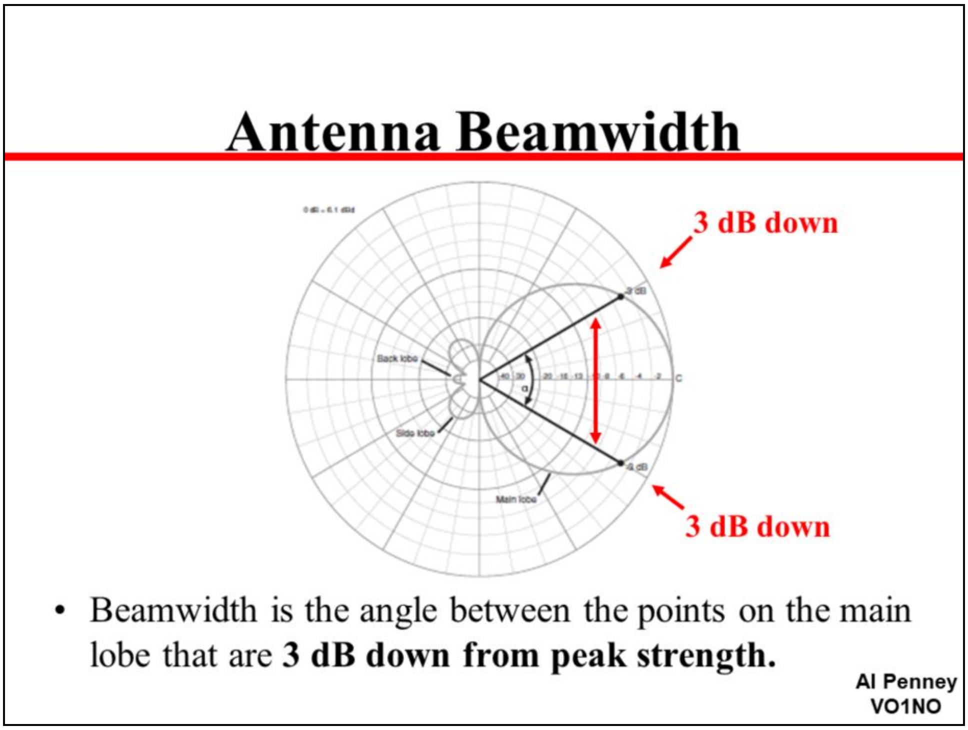
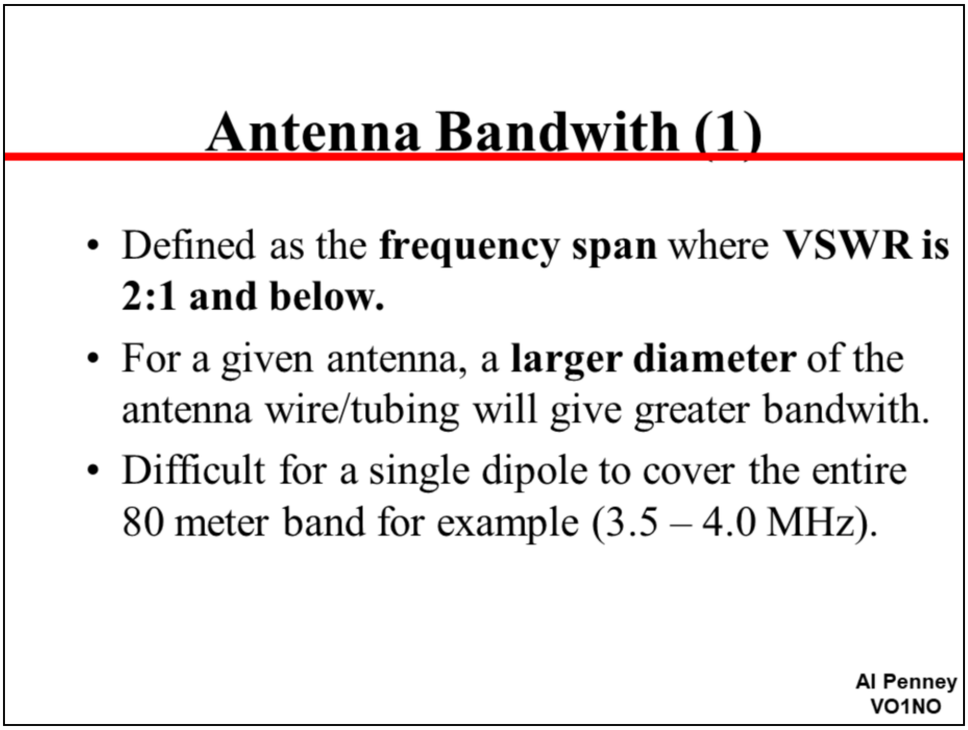
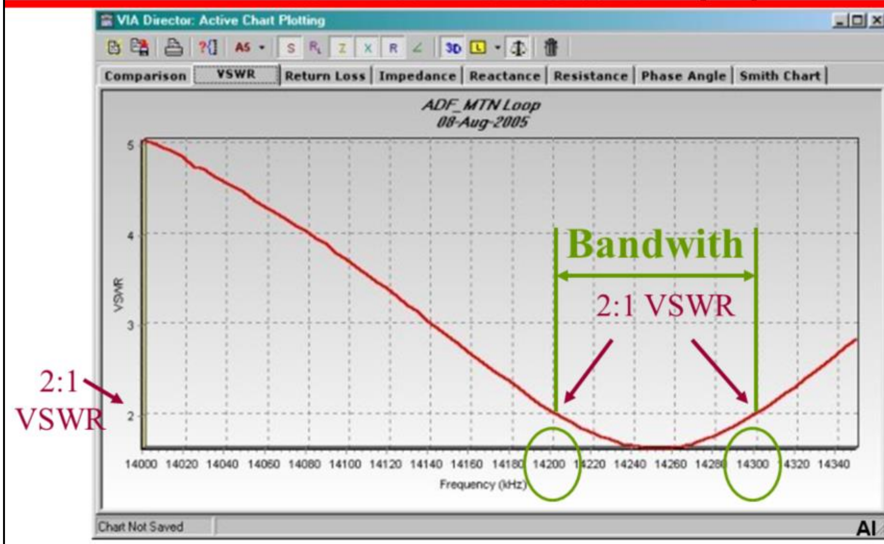


The *beamwidth* of the antenna is defined as the angle between the points on the main lobe that are 3 dB down from the peak at point *C.*



Bandwidth The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1.

Antenna Bandwith (2)



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Antenna Length (1)

- In free space wavelength **λ (meters) = 300/f (MHz).**
- But, the electrical length of a conductor is affected by:
  - **Speed of EM wave** in that conductor;
  - **Diameter/length ratio** of the conductor; and
  - **End effect of the insulators.**
- All these factors **tend to shorten the antenna** with respect to free space.
- On VHF and UHF antennas, the last factor does not affect antenna length appreciably.
- Therefore need to use **different equations for HF and VHF/UHF antenna lengths.**

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Antenna Length (2)

- **Above 30 MHz:**
  - λ (meters) = 300 / freq (MHz)
  - λ /2 (meters) = 150 / freq (MHz)
- **Or**
  - λ (feet) = 984 / freq (MHz)
  - λ /2 (feet) = 492 / freq (MHz)

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Antenna Length (3)

- **Below 30 MHz:**
  - λ (meters) = 286 / freq (MHz)
  - λ /2 (meters) = 143 / freq (MHz)
- **Or**
  - λ (feet) = 936 / freq (MHz)
  - λ /2 (feet) = 468 / freq (MHz)
- **Remember:**
  - The higher the frequency, the shorter the antenna
  - The lower the frequency, the longer the antenna.

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Practical Antennas

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Practical Dipole Antenna

- Impedance approximately **73 ohms.**
- Advantages:
  - Cheap;
  - Easy to build;
  - Rugged; and
  - One feedline can serve several antennas.
- Disadvantages:
  - Narrow bandwith;
  - Requires 2 supports, sometimes 3;
  - Must be fed at center; and
  - One band only.

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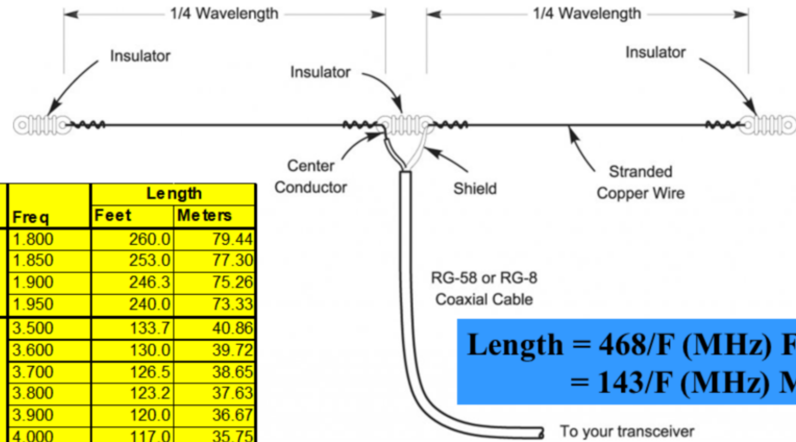
Dipole Antenna



Band	Freq	Length Feet	Length Meters
160M	1.800	260.0	79.44
	1.850	253.0	77.30
	1.900	246.3	75.26
	1.950	240.0	73.33
80M	3.500	133.7	40.86
	3.600	130.0	39.72
	3.700	126.5	38.65
	3.800	123.2	37.63
	3.900	120.0	36.67
	4.000	117.0	35.75
60M	5.358	87.3	26.69
40M	7.000	66.9	20.43
	7.100	65.9	20.14
	7.200	65.0	19.86

Length = 468/F (MHz) Feet
= 143/F (MHz) Meters

Note: Cut a little long and trim for best SWR

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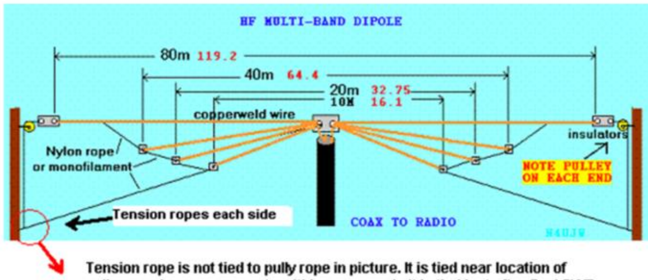
Fan Dipole



Tension rope is not tied to pully rope in picture. It is tied near location of pully rope down on supports within easy reach. It is tied last after final SWR adjustment and the antenna is in it's final position.

Suggested total lengths:
80 meters - 120 feet
40 meters - 65 to 66 feet
20 meters - 34 feet
10 meters - 17 feet
These lengths are not exact. Some tuning may be required. Use the standard formula 468 / freqmhz for total feet for each band (freq) of interest. Adjust each length longer or shorter as needed.

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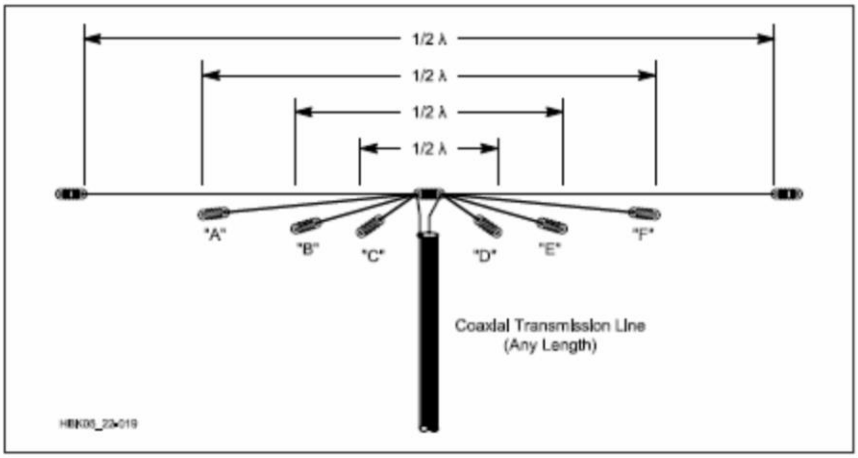

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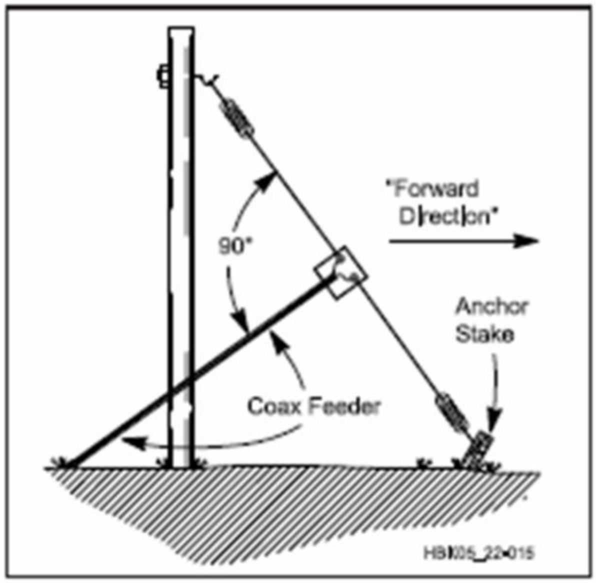
Sloping Dipole



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Inverted V Antenna

- Variation of the Dipole.
- Impedance approximately 50 ohms.
- Advantages:
  – Requires only one support; and
  – Provides a better match to 50 ohm coax cable.
- Disadvantages:
  – Those of a Dipole; and
  – The ends close to the ground present a safety hazard.

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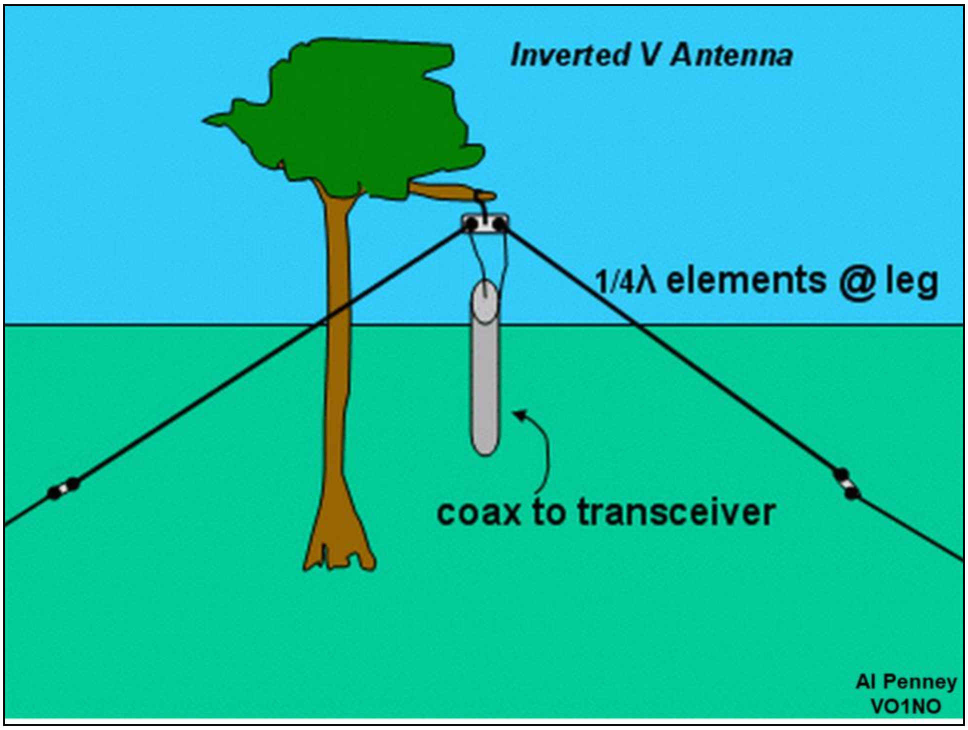
Inverted V Antenna
1/4λ elements @ leg
coax to transceiver
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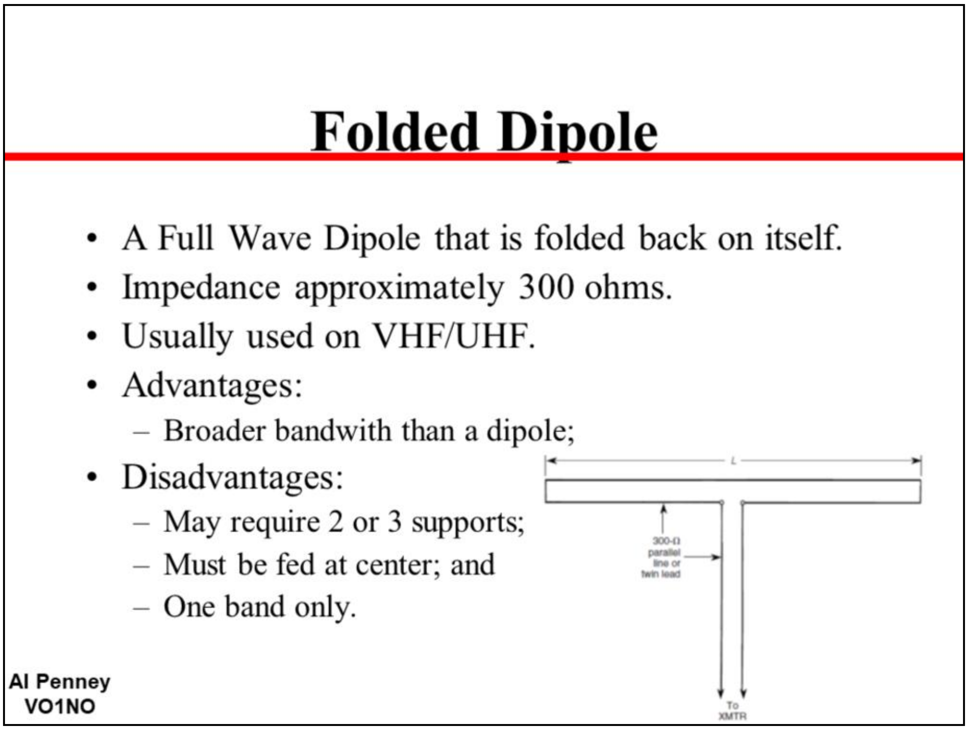


Folded Dipole

This antenna consists of two or more halfwavelength conductors of identical diameter shorted together at both ends and fed in

the middle of *one* conductor. Except at the ends, the two conductors are held a few inches apart (at HF, at least) by insulated spacers. The two-wire folded dipole is often

made with 300-∧ television antenna twin-lead transmission line. Because the free-space feedpoint impedance is nearly 300 ∧, or four times that of a conventional dipole, the

antenna is a reasonably good match (depending on the height of the antenna above ground) for the same type of twin-lead used as the transmission line. Such a dipole will

exhibit a 50 percent improvement in 2:1 VWSR bandwidth compared to a single-wire dipole. On 80 m, for instance, a folded dipole resonant at 3.750 MHz will cover from 3.6

to 3.9 MHz with an SWR of 2:1 or lower.

Why is the input impedance *four* times the input impedance of a conventional dipole when one of the two wires is fed? Recognize that the folded dipole is a continuous

1–λ loop. At each end of the fed wire, the current does a U–turn and continues into the unfed wire. If this current were of the same phase everywhere, it would thus be flowing

in a spatial direction opposite to the current near the feedpoint. But it's also true that at or near the antenna design frequency the current in the fed half–wave element goes to

zero at each end. Since the current in a wire that is longer than $\lambda/2$ reverses direction in adjacent $\lambda/2$ sections (i.e., at each current *node*), the current reverses at both ends of the

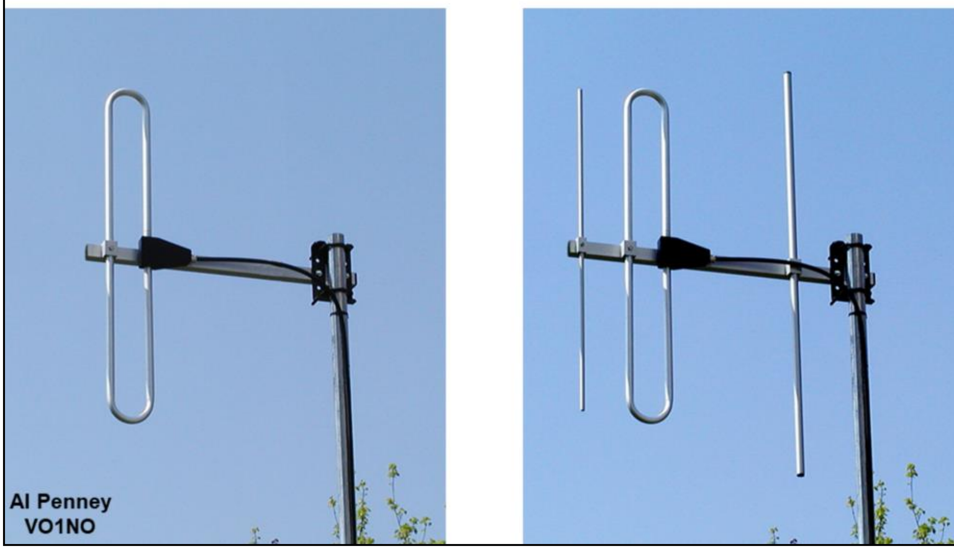
folded dipole. When viewed from inside the wire (if that were possible), the current flowing in the unfed wire is thus 180 degrees out of phase *electrically* with the drive current,

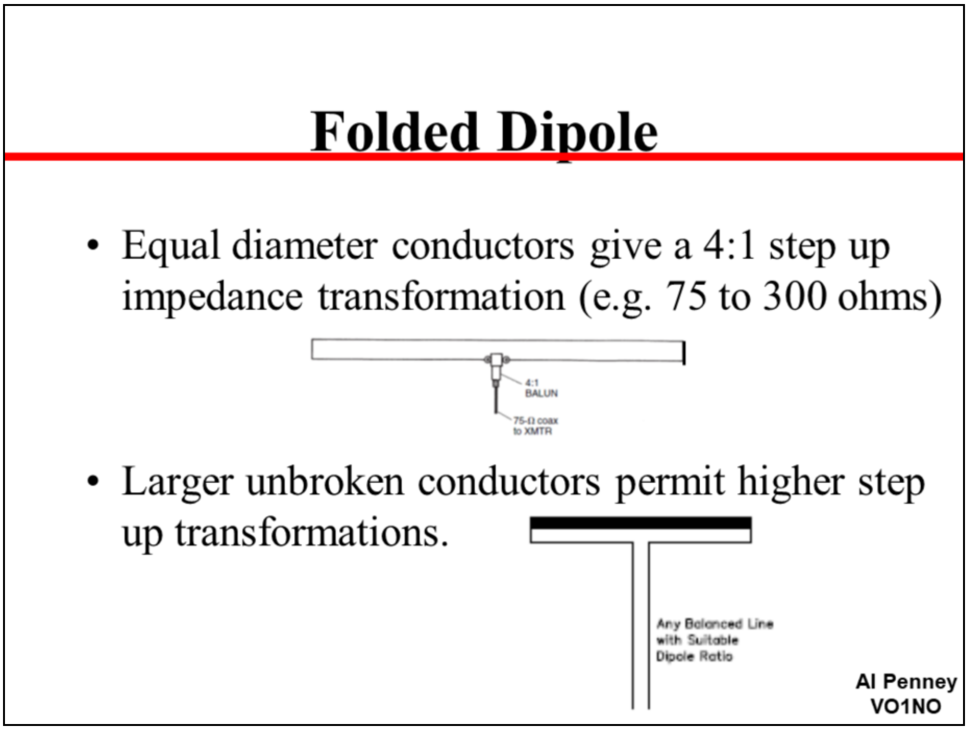
but its nominal *spatial* direction is the opposite of the current in the driven wire. The two effects (wire path and phase reversal) combine to put the unfed wire's current

in phase with the drive current, as viewed from outside the wires. The current in the unfed wire is virtually identical in amplitude to that in the fed wire, suffering only a

very slight reduction in amplitude from ohmic and radiation losses.

Folded Dipole





Folded Dipole

The impedance of a ½ wavelength antenna broken at its center is about 70 Ω. If a single conductor of uniform size is folded to make a ½ wavelength dipole, the impedance is stepped up four times. Such a folded dipole can be fed directly with 300-Ω line with no appreciable mismatch. If a 4:1 balun is used, the antenna can be fed with 75-Ω coaxial cable. Higher step-up impedance transformation can be obtained if the unbroken portion is made larger in cross-section than the fed portion,as shown in the figure.

The *impedance step-up ratio* for a two-wire folded dipole is 4:1 if the two conductors are of equal diameter. When they're not, the relationship is more complicated but the

impedance step-up is generally proportional to the ratio of the unfed wire diameter to the fed wire diameter. Thus, a folded dipole can be designed to provide a specific feedpoint

impedance to the transmitter and transmission line, within limits, by making one of the two wires larger than the other.

In many installations, the best feedline for the folded dipole will be 300-Λ twin-lead or, better yet, open-wire line connected to a balanced wire ATU at the transmitter end.

Trap Dipole

- Traps isolate sections of the antenna, permitting multi-band use.
- Advantages:
  - Multi-band operation.
- Disadvantages:
  - Those of a Dipole;
  - Not as efficient as separate dipoles;
  - Weight of the traps makes it difficult to hold up;
  - Pattern can be distorted; and
  - **Can radiate Harmonics (?).**

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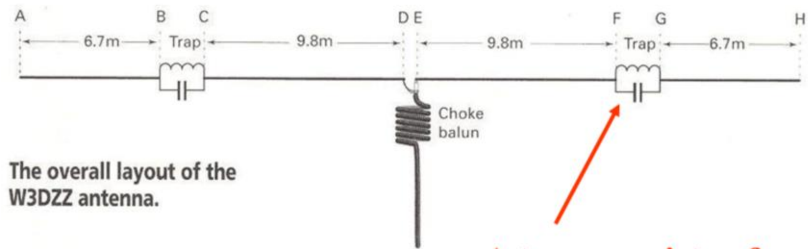
Trap Dipole



A trap consists of a Capacitor and Inductor

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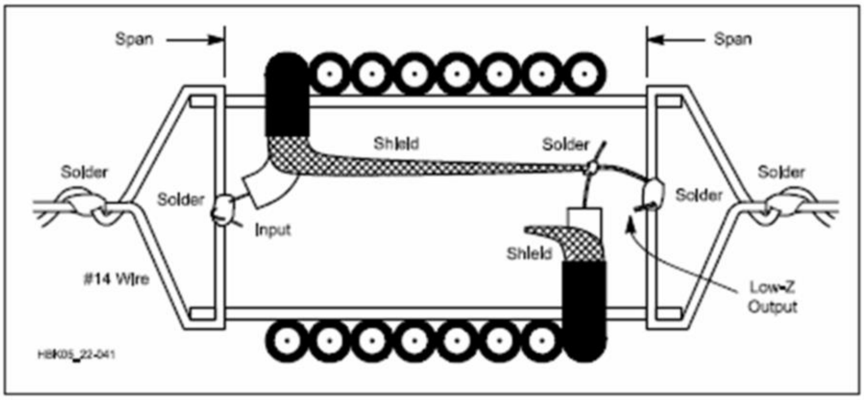
Trap Dipole



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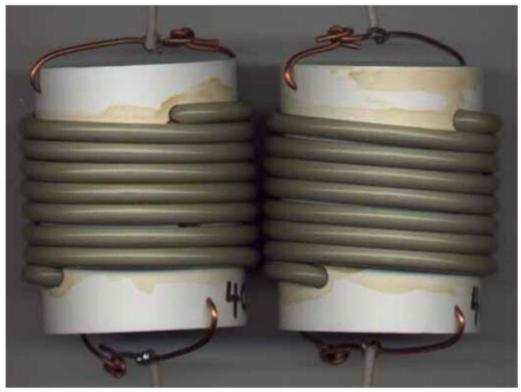
Trap Dipole



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End Fed Long Wire Antenna

- Should be as long (at least ¾ λ) and high as possible.
- Must have a good ground.
- Advantages:
  - Multiband;
  - Can bend to fit as necessary; and
  - Feedpoint is at the end.
- Disadvantages:
  - Requires a matching unit;
  - Pattern difficult to predict;
  - High voltages on the antenna; and
  - **RF present in the shack.**

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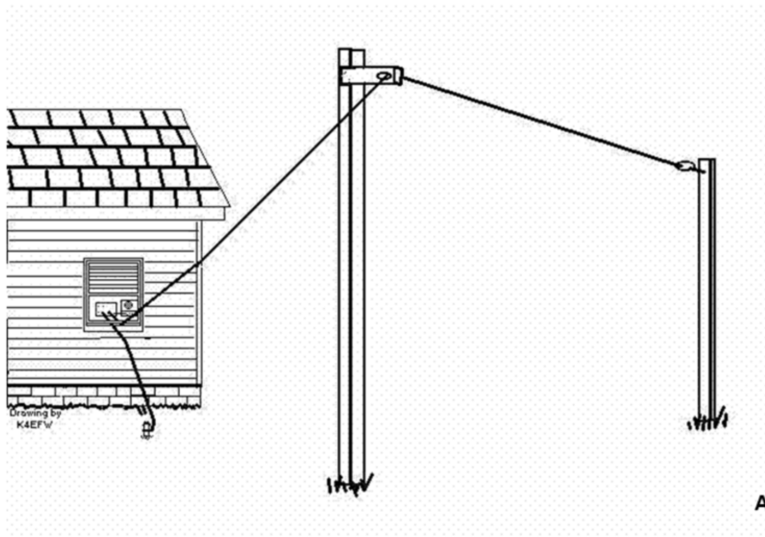
End Fed Long Wire Antenna



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Transmatch

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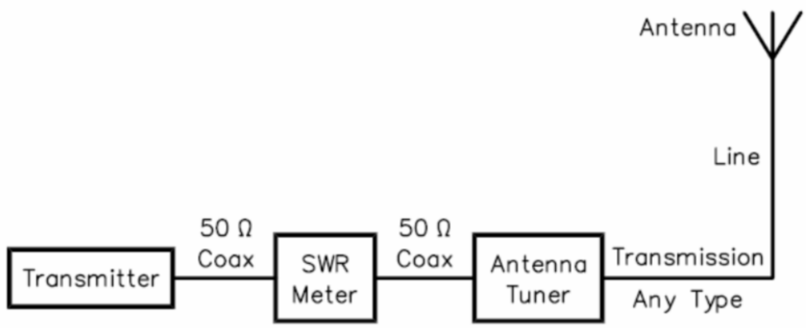
Connecting a Transmatch



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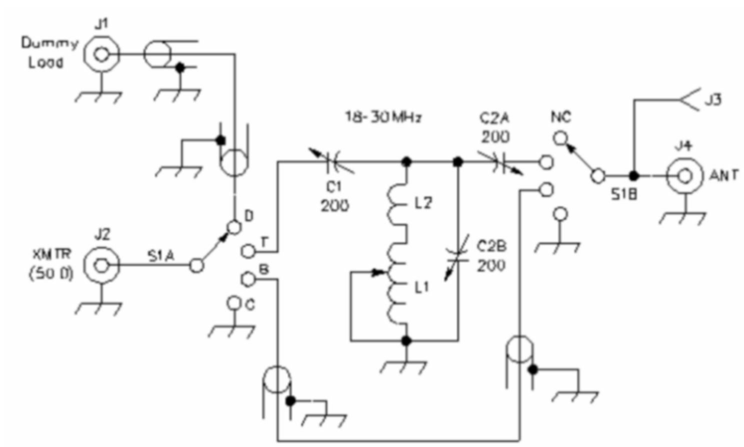
Transmatch Schematic Circuit



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Yagi-Uda Antenna

- Driven Element, Reflector and one or more Directors (AKA **Parasitic Elements**) give gain and directivity.
- Advantages:
  - Effective antenna;
  - Easily rotated;
  - Can be multi-band; and
  - Can be stacked for more gain.
- Disadvantages:
  - Can be expensive;
  - Requires a tower and rotator;
  - Single bearing at a time; and
  - Wind and ice an enemy!

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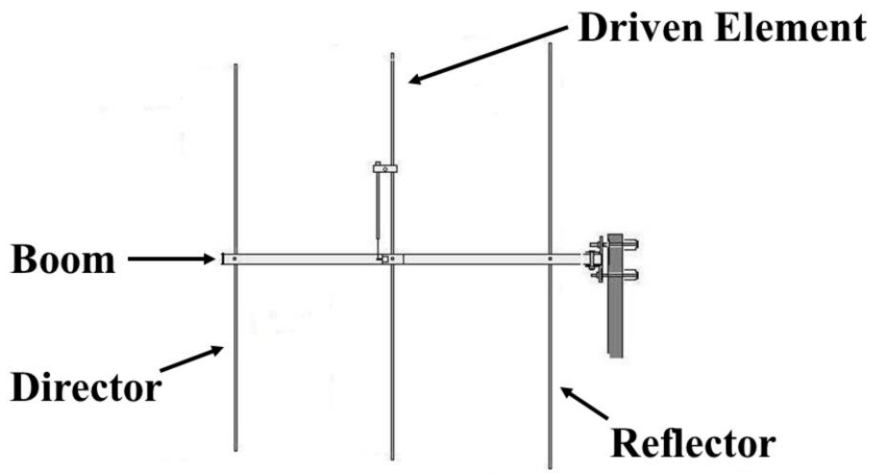
Yagi-Uda Antenna



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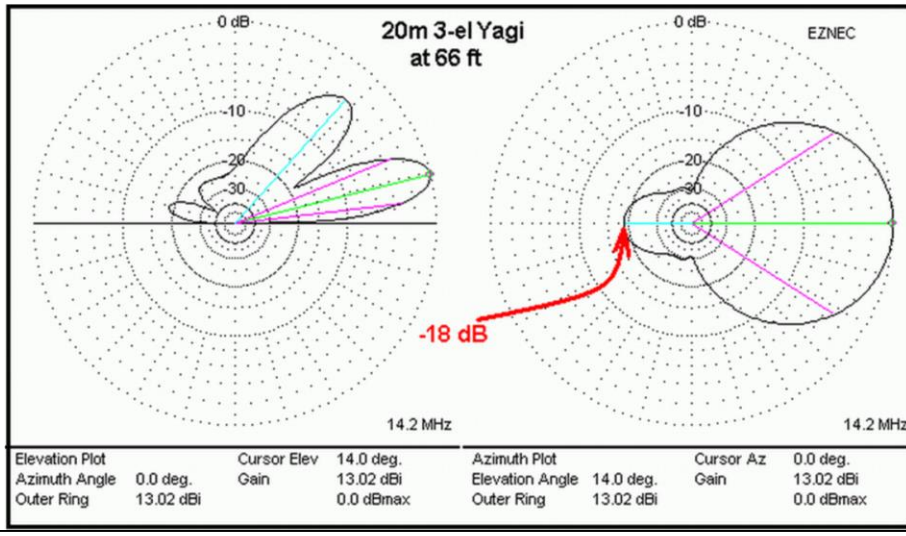
3 Element Yagi-Uda Antenna



Wide Element Spacing on Yagi-Uda

- **Spacing** the elements **further apart** (within reason) on a Yagi-Uda antenna gives three advantages:
  - **Greater Gain;**
  - **Less critical tuning; and**
  - **Wider bandwith.**
- Computer programs exist that will **optimize element spacing and lengths** to provide **maximum performance (0.2 wavelength spacing** is close to **optimum** for a **3-element** Yagi-Uda).

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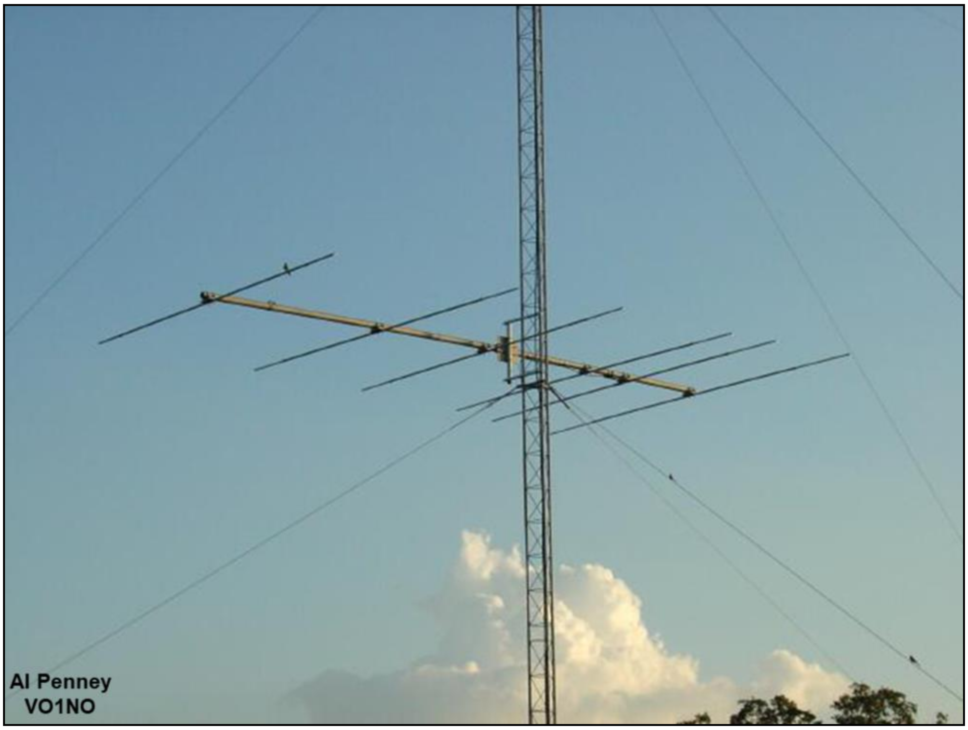
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Trapped Yagi-Uda

- Just as with dipoles, Yagi-Uda antennas can employ traps to enable the antenna to function on several different bands.
- All elements must use traps – the Driven Element, Reflector and Directors.

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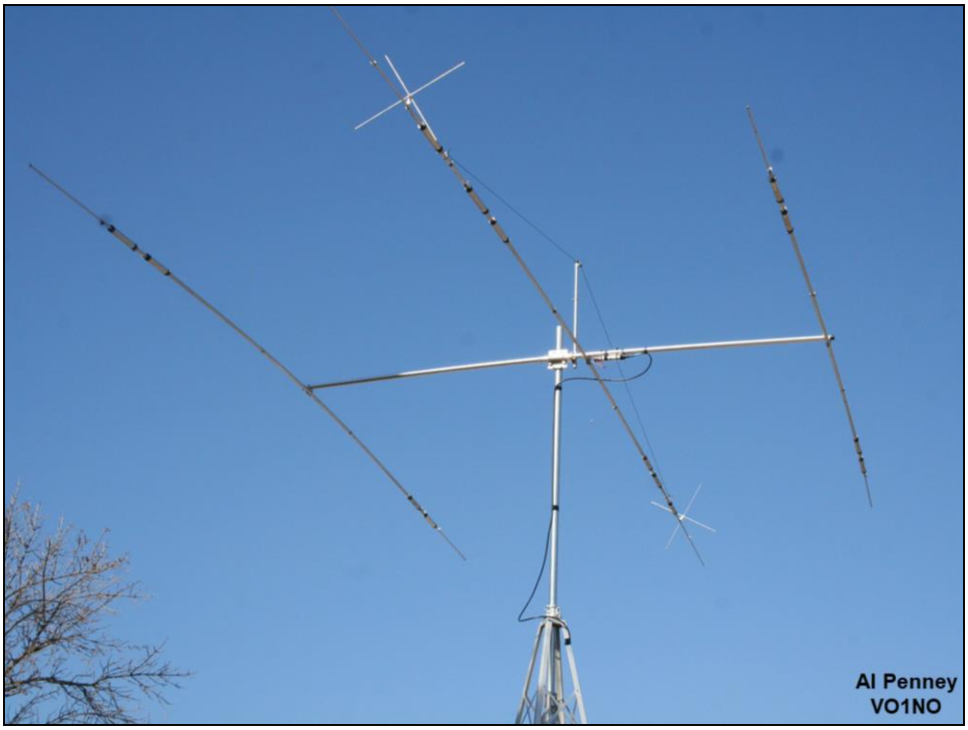
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Cubical Quad

- Uses closed loops of approximately **1 wavelength.**
- Driven Element, Reflector and one or more Directors.
- Advantages:
  - Effective, has gain and directivity;
  - Easily rotated;
  - Multiband; and
  - Lighter than a Yagi-Uda.
- Disadvantages:
  - Weaker than a Yagi-Uda, 3D antenna;
  - Requires a tower and rotator;
  - Single bearing only;
  - Wind and Ice!

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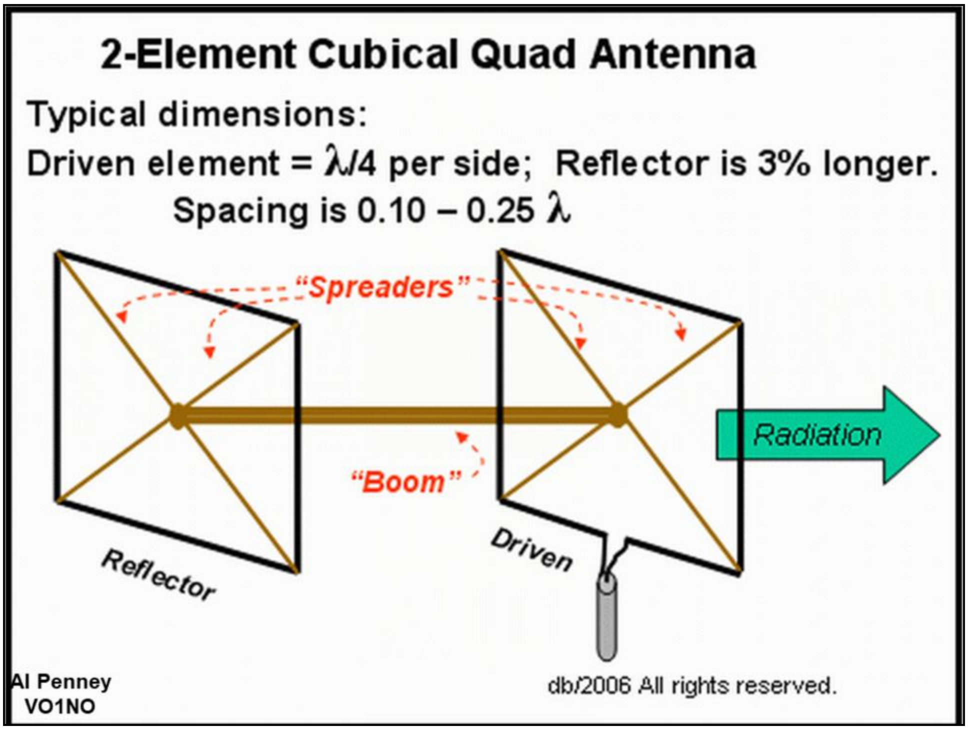
2-Element Cubical Quad Antenna
Typical dimensions:
Driven element = λ/4 per side; Reflector is 3% longer.
Spacing is 0.10 – 0.25 λ
"Spreaders"
"Boom"
Radiation
Reflector
Driven
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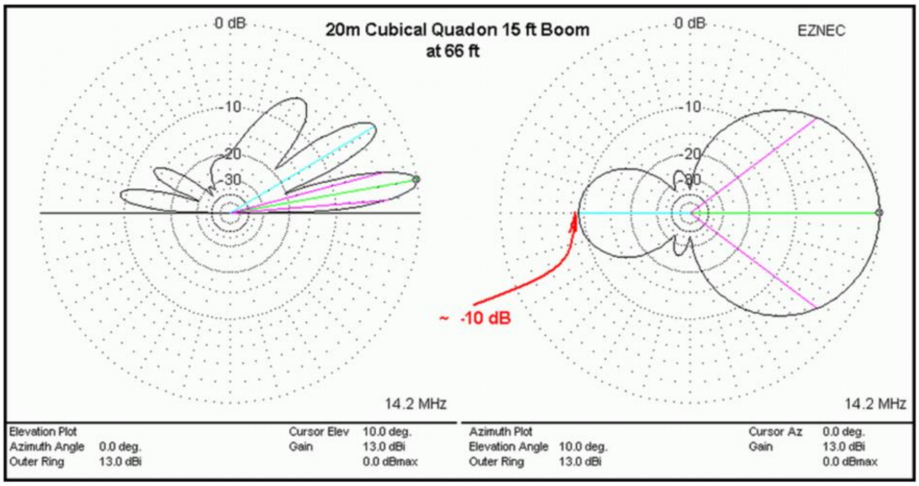
2 Element Cubical Quad

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Cubical Quad Notes

- In general, the performance of a **2-element Cubical Quad** compares to a **3-element Yagi-Uda antenna.**
- **Cubical Quad polarization:**
  - Feedpoint on side **parallel** to ground: **Horizontal**
  - Feedpoint on side **perpendicular** to ground: **Vertical**
- The elements of a Quad can also be **shaped as triangles**, and called a **Delta Quad.**

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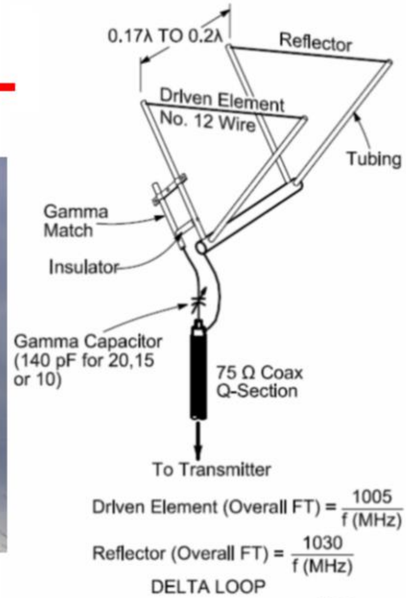
Delta Quad



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Quarter Wave Verticals

- Can be wire, tubular, or tower.
- Some describe them as limited space antennas, BUT you must consider the radial field.
- Offers a low angle of radiation if you can't put a dipole at ½ λ (125 feet on 80M!).

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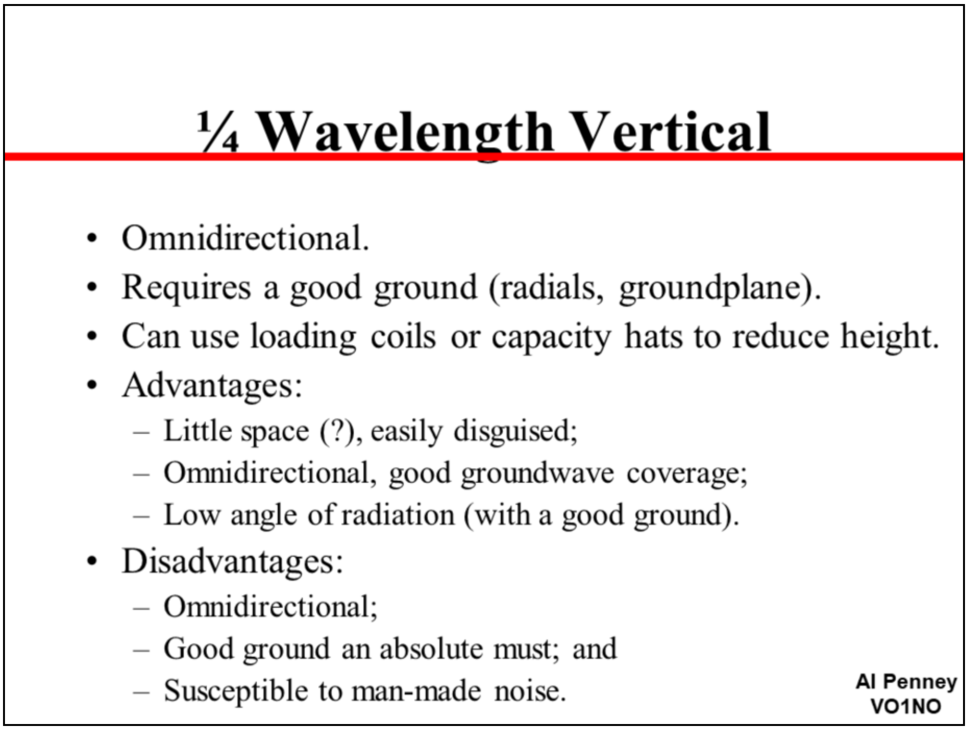
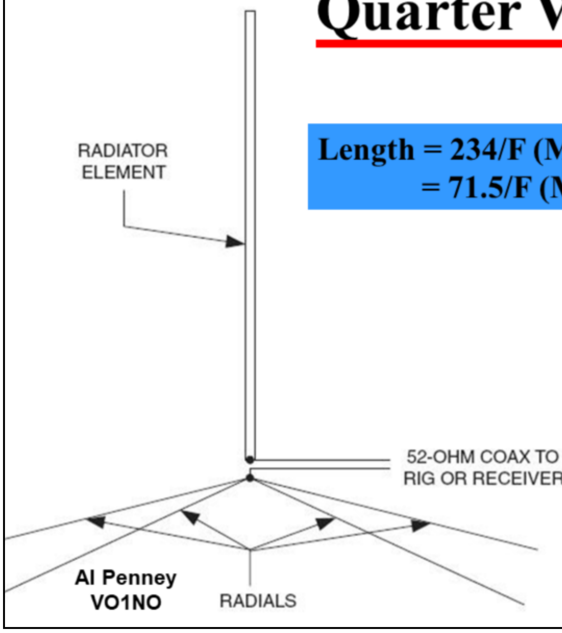


THE VERTICAL MONOPOLE

So far in this discussion on Antenna Fundamentals, we have been using the free-space, center- fed dipole as our main example. Another simple form of antenna derived from a dipole is

called a *monopole*. The name suggests that this is one half of a dipole, and so it is.

Quarter Wave Verticals



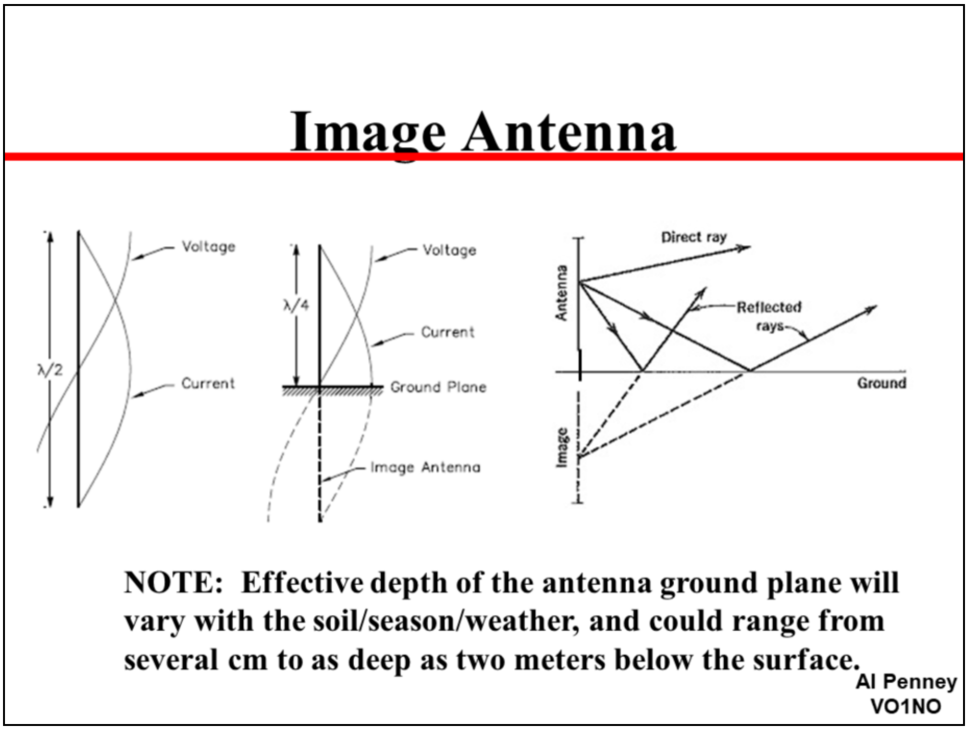
Length = 234/F (MHz) Feet
= 71.5/F (MHz) Meters

Band	Freq	Height	
		Feet	Meters
160M	1.800	130.0	39.72
	1.850	126.5	38.65
	1.900	123.2	37.60
	1.950	120.0	36.67
80M	3.500	66.9	20.43
	3.600	65.0	19.86
	3.700	63.2	19.32
	3.800	61.6	18.82
	3.900	60.0	18.33
	4.000	58.5	17.88
60M	5.358	43.7	13.34
40M	7.000	33.4	10.21
	7.100	33.0	10.07
	7.200	32.5	9.93

Heights are approximate. Actual height depends on diameter of radiator.

The monopole is always used in conjunction with a *ground plane*, which acts as a sort of electrical mirror. The *image antenna* for the monopole is the dotted line beneath the ground plane. The image forms the "missing second half" of the antenna, transforming a monopole into the functional equivalent of a dipole. From this explanation you can see where the term *image plane* is sometimes

used instead of ground plane.



The monopole is always used in conjunction with a *ground plane*, which acts as a sort of electrical mirror. See **Fig 20**, where a λ/2 dipole and a λ/4 monopole are

compared. The *image antenna* for the monopole is the dotted line beneath the ground plane. The image forms the “missing second half” of the antenna,

transforming a monopole into the functional equivalent of a dipole. From this explanation you can see where the term *image plane* is sometimes

used instead of ground plane. Although we have been focusing throughout this chapter on antennas in free space, practical monopoles are usually mounted vertically with

respect to the surface of the ground. As such, they are called *vertical monopoles*, or simply *verticals*.

A practical vertical is supplied power by feeding the radiator against a ground system, usually made up of a series of paralleled wires radiating from

and laid out in a circular pattern around the base of the antenna. These wires are termed *radials*.

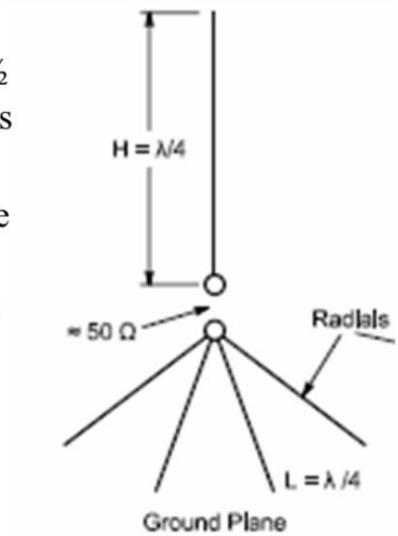
Keep in mind that these discussions of height above earth ground refer to the height of the *electrical* ground, not the sod. Depending upon ground conductivity and groundwater

content, the effective height of earth ground may lie some distance beneath the surface. The actual depth is best found from experimentation and may, unfortunately,

vary with precipitation and with the season—especially if the ground freezes and/or the local water table changes greatly.

¼ Wavelength Vertical

- Theoretical impedance is ½ that of a dipole, ie: 36 ohms
- By sloping radials down however, impedance can be brought closer to 50 ohms, providing a better match to 50 ohm coax cable.



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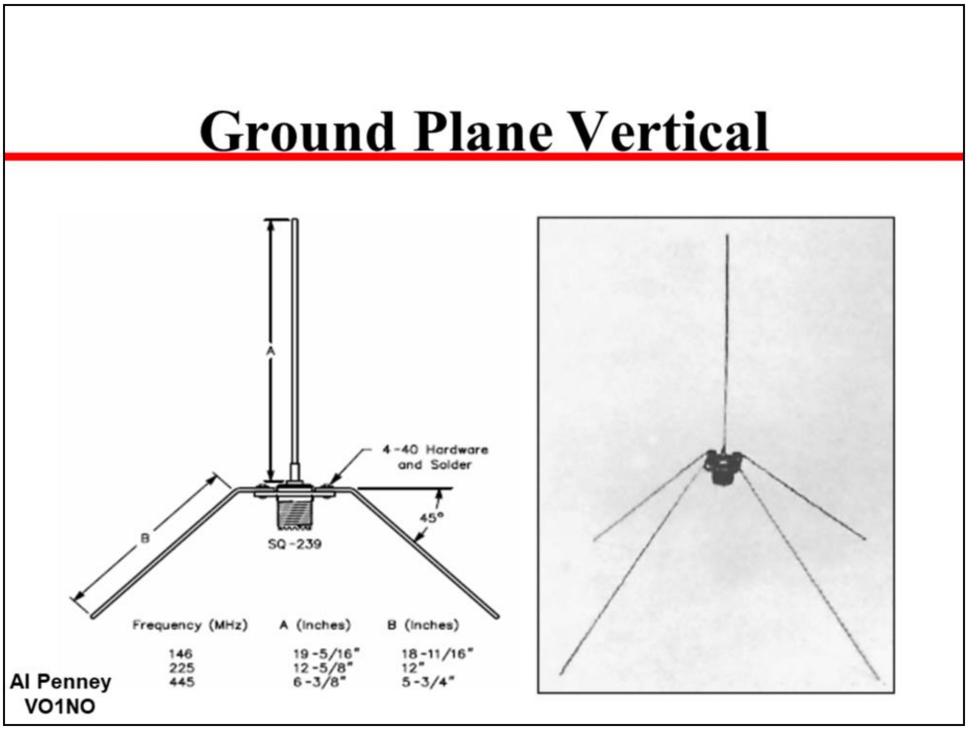


A very simple method of construction, shown in Figs 25 and 26, requires nothing more than an SO- 239 connector and some #4-40 hardware. A small loop

formed at the inside end of each radial is used to attach the radial directly to the mounting holes of the coaxial connector. After the radial is fastened to the

SO-239 with #4-40 hardware, a large soldering iron or propane torch is used to solder the radial and the mounting hardware to the coaxial connector. The radials

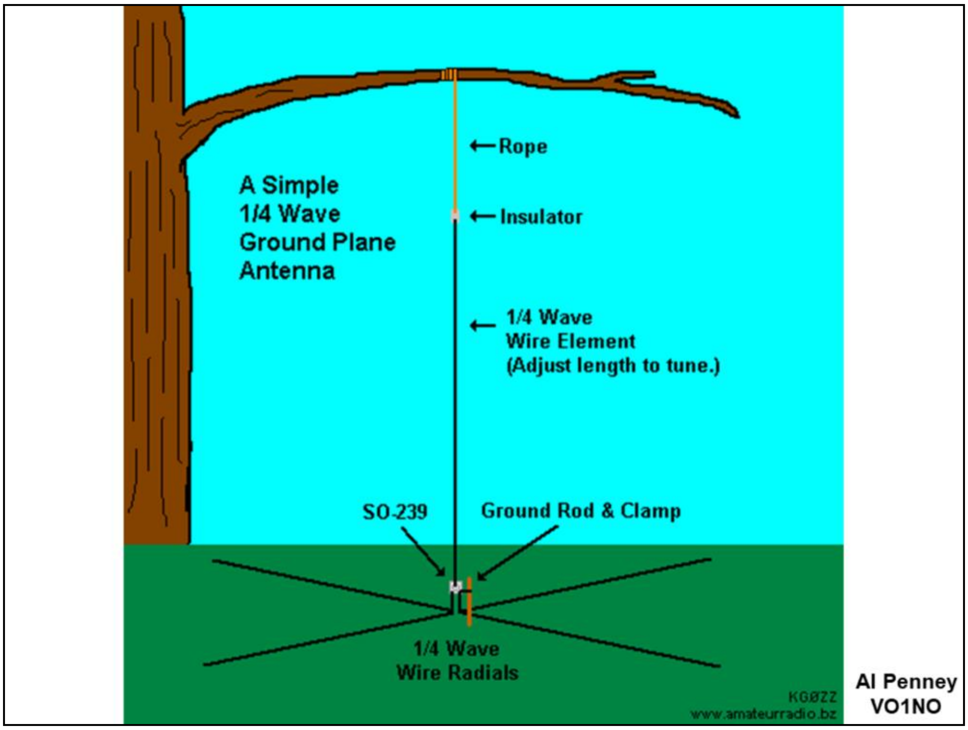
are bent to a 45° angle and the vertical portion is soldered to the center pin to complete the antenna. The antenna can be mounted by passing the feed line

through a mast of 3/4-inch ID plastic or aluminum tubing. A compression hose clamp can be used to securethe PL-259 connector, attached to the feed line, in

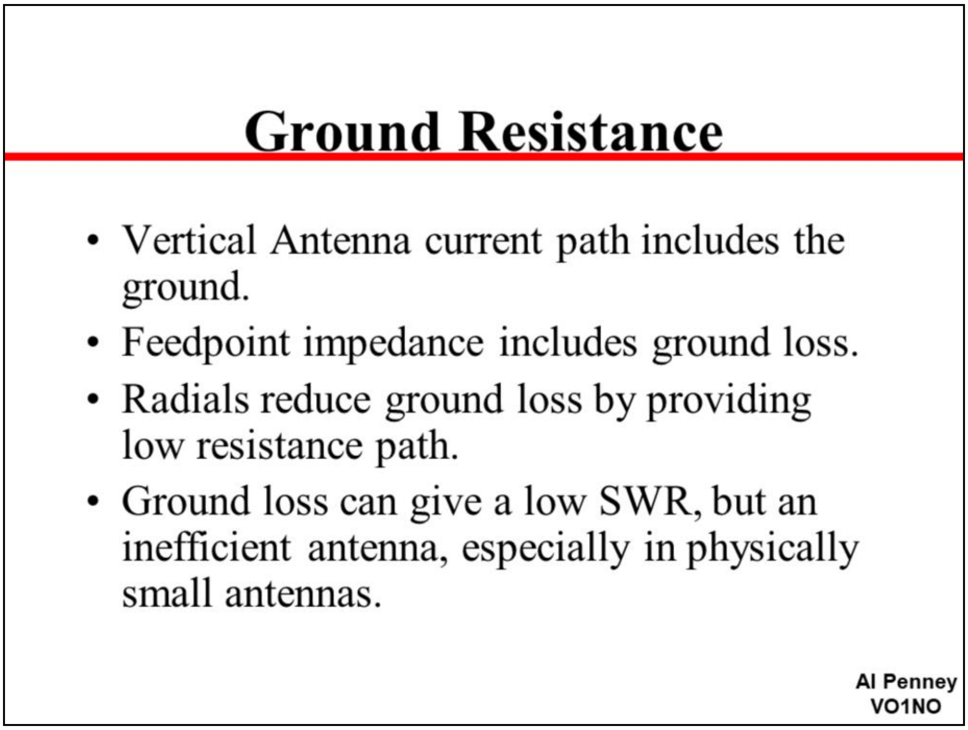
the end of the mast.

First is homebrew 40M vertical by Aaron VO1FOX. It consists of 8 x 4-foot long tent poles.

Second is 80M antenna of W8JI, made of Rohn 65 tower sections.



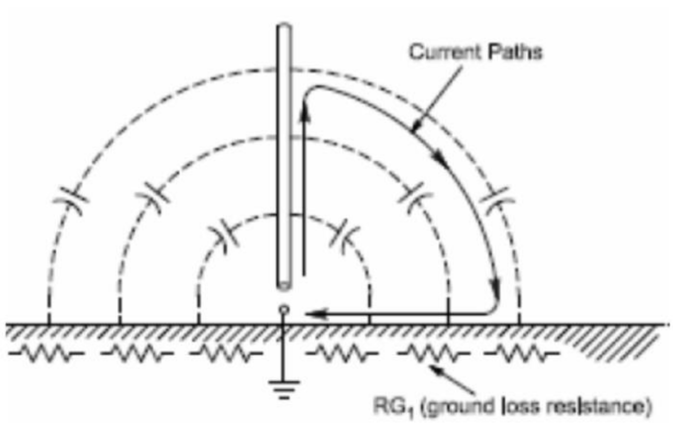
Can make a vertical from wire suspended from a tree. This is easily done for 40M, and may be possible for an 80M antenna.



In general, a large number of radials (even though some or all of them must be short) is preferable to a few long radials for a vertical antenna mounted on the ground. The conductor size is relatively

unimportant; #12 to #28 copper wire is suitable. The measurement of the actual ground-loss resistance at the operating frequency is difficult. The power loss in the ground depends on the current concentration near the base of the antenna, and this depends on the antenna height. Typical values for small radial systems (15 or less) have been measured to be from about 5 to 30 Ω, for antenna heights from λ/16 to λ/4 wavelength. The impedance seen at the feed point of the antenna is the sum of the loss and the radiation resistance.

Ground Resistance



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Radials

- Radials collect return current and provide something for the radiator to "push" against.
- Commercial antennas use 120 x ½ λ radials.
- Fortunately, Hams can make do with fewer!
- Number, length, buried, on or above ground?
- A complicated situation with lots of misconceptions!

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Angle of Radiation

- The angle of radiation of a vertical antenna depends primarily on the ground conditions in the far field (out to ~10 λ and further), NOT the radial field.
- The radial field determines the transmit efficiency of the antenna.
- A vertical with poor radial system over very good ground can have a low angle of radiation but a weak transmitted signal!

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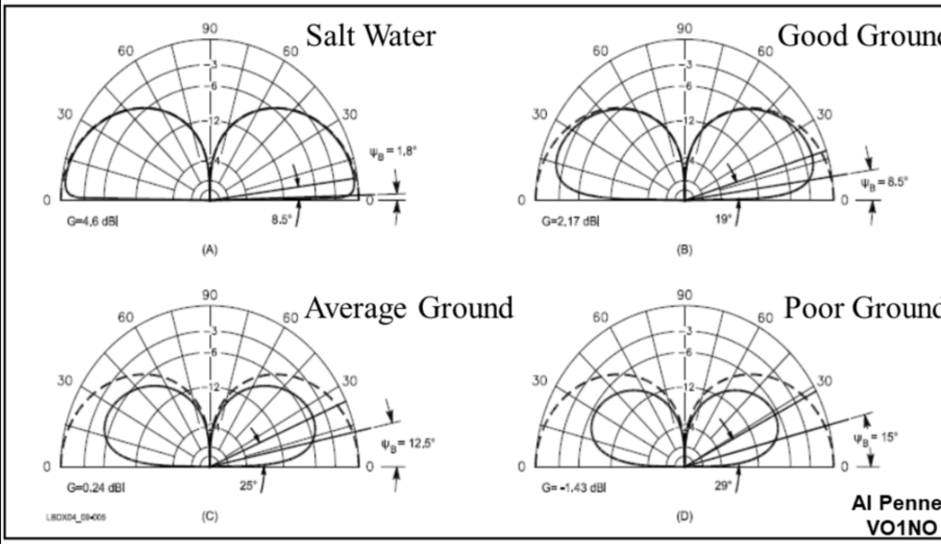
Over very poor ground (desert or rocky areas) it may be better to go with a horizontal dipole instead of a vertical as it may be impossible to get a strong signal at a low angle of radiation with a vertical under such conditions.

If you are close to the ocean, a vertical is the way to go!

Vertical Pattern



A good ground makes a big difference in the angle of radiation and strength of the signal radiated from a vertical antenna.

Radial Considerations…

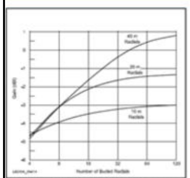


Fig 9-14 — Gain of 0.25-λ 80-meter vertical over very poor ground as a function of radial length and number of radials. For short (10-meter long) radials there is not much point in going above 16 radials. With 20-meter radials you are within 0.5 dB of maximum gain with 32 radials. If you want maximum benefit from 0.5-λ radials (40 meters), 120 radials are for you.

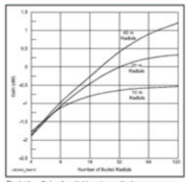


Fig 9-15 — Gain of a λ/4 80-meter vertical over average ground, as a function of radial length and number of radials. Note that for 10-meter long radials there is practically no gain beyond about 52 radials. For quarter wave radials there is little to be gained beyond 104 radials, and the difference between 26 λ/4 radials and 104 λ/4 radials is only 0.5 dB. These are exactly the same number N7CL came up with by experiment (see Section 2.1.3).

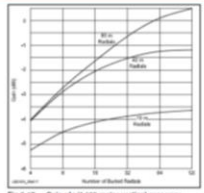


Fig 9-17 — Gain of λ/4 160-meter vertical over very poor ground as a function of radial length and number of radials. Note that 10-meter radials, no matter how many, are really too short for 160 meters.

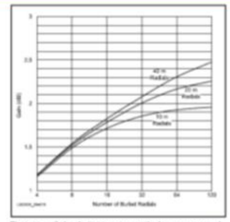


Fig 9-16 — Gain of λ/4 80-meter vertical over very good ground as a function of radial length and number of radials.

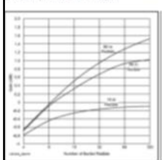


Fig 9-18 — Gain of λ/4 160-meter vertical over average ground as a function of radial length and number of radials.

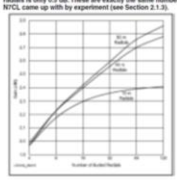


Table 9-3
Optimum Length Versus Number of Radials

Number of Radials	*Optimum Length (λ)*
4	0.10
12	0.15
24	0.25
48	0.35
96	0.45
120	0.50

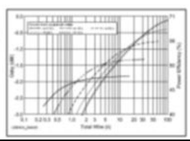
This table considers only the effect of providing a low-loss return path for the antenna current (near field). It does not consider ground losses in the far field, which determine the very low-angle radiation properties of the antenna.

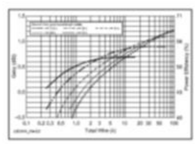
Table 9-4
From Brown, Lewis and Epstein
Signal Strength vs Length of Radials in Wavelengths

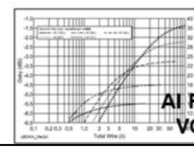
Number Radials	*Length 0.137 λ*	*Length 0.274λ*	*Length 0.411λ*
2	–4.36	–4.36	–4.05 dB
15	–2.4	–1.93	–1.65 dB
30	–2.4	–1.44	–0.97 dB
60	–2.0	–0.66	–0.42 dB
113	–2.0	–0.51	0 dB (Ref)

$$N = \frac{\sqrt{2 \times \pi \times L}}{A} \qquad \text{(Eq 9-6)}$$

where
N = number of radials
L = total wire length available
A = distance between wire tips (1.3 meters for 80, 2.5 meters for 160, or twice that if 0.5 dB loss is tolerated).







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Just some of the graphs, equations and charts dealing with radials in ON4UN's Low Band Dxing book.

Okay, Let's Simplify…

Table 9-3
Optimum Length Versus Number of Radials

Number of Radials	*Optimum Length (λ)*
4	0.10
12	0.15
24	0.25
48	0.35
96	0.45
120	0.50

This table considers only the effect of providing a low-loss return path for the antenna current (near field). It does not consider ground losses in the far field, which determine the very low-angle radiation properties of the antenna.

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Number of Radials…

- 30 x ¼ λ ground or buried radials should be plenty.
- 60 x ¼ λ ground or buried radials = point of diminishing return.
- Use at least 8 elevated ¼ λ radials – more is better.
- Given practical considerations, I recommend ground or buried radials instead of elevated.

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16 radials would give acceptable results, but 30 would be better.

Elevated radials can be tricky. While 2 elevated radials can work, it is difficult to obtain equal currents, reducing their effectiveness. People who have studied the issue recommend at least 8 elevated radials to ensure that current imbalances are not a problem. Given the practical difficulties in trying to keep them in the air without strangling someone, I recommend surface or lightly buried radials instead.

Trapped Vertical Antenna

- Just as with dipoles and Yagi-Uda antennas, traps can be added to verticals to give multiband capability.
- This example is a Cushcraft R7 vertical, covering 40m thru to 10M.

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Phased Arrays

- Yes, you CAN have a phased array in most back yards – well, at least on 40M!
- Phasing accomplished using coax delay line or inductors/capacitors.
- Everything already covered about radials and ground quality still applies.

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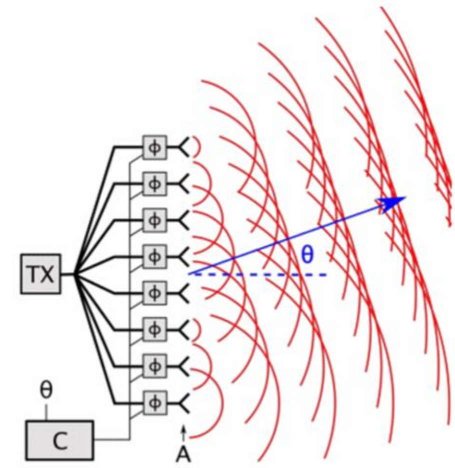
How does a Phased Array Work?



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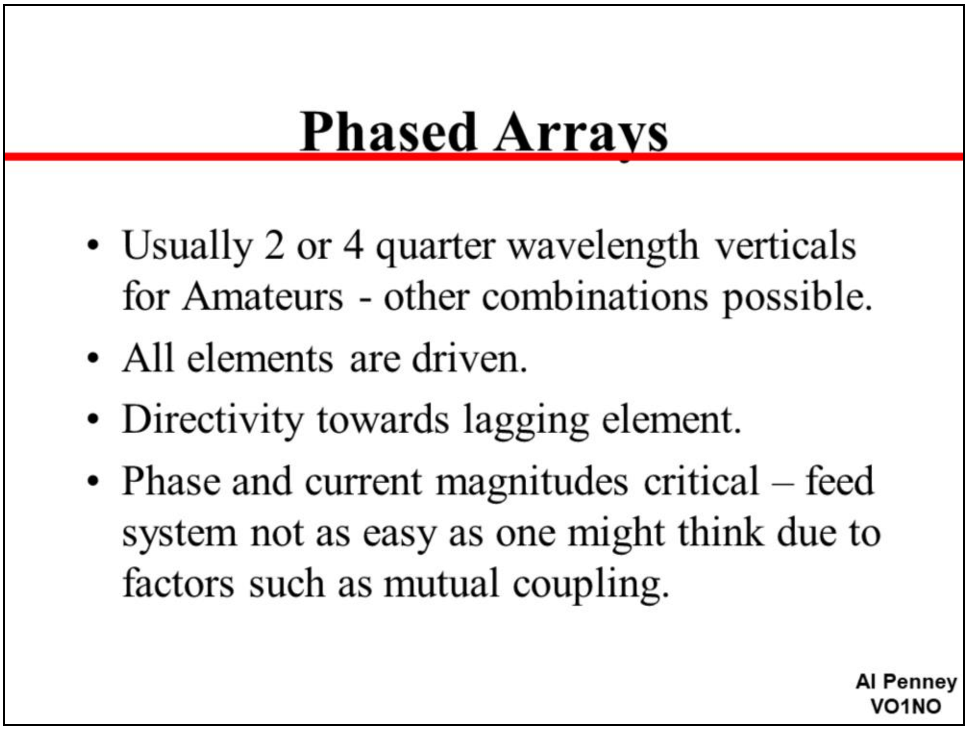
Animation showing how a phased array works. It consists of an array of antenna elements *(A)* powered by a transmitter *(TX)*. The feed current for each antenna passes through a phase shifter *(φ)* controlled by a computer *(C)*. The moving red lines show the wavefronts of the radio waves emitted by each element. The individual wavefronts are spherical, but they combine (superpose) in front of the antenna to create a plane wave, a beam of radio waves travelling in a specific direction. The phase shifters delay the radio waves progressively going up the line so each antenna emits its wavefront later than the one below it. This causes the resulting plane wave to be directed at an angle ϑ to the antenna's axis. By changing the phase shifts the computer can instantly change the angle ϑ of the beam. Most phased arrays have two-dimensional arrays of antennas instead of the linear array shown here, and the beam can be steered in two dimensions. The velocity of the radio waves is shown slowed down enormously.



Direction of Firing

The rule is simple: An array always fires in the direction of the element with the lagging feed current.

Quarter-wave elements have gained a reputation for giving a reasonable match to a 50-W line, which is certainly true for single vertical antennas. In this chapter we will learn

the reason why quarter-wave resonant verticals do not have a resistive 36-W feed-point impedance when operated in arrays (even assuming a perfect ground). Quarter-wave elements

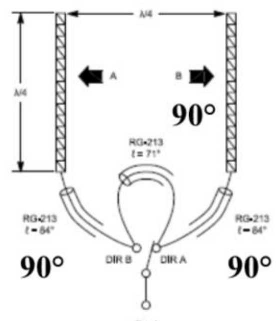
still remain a good choice, since they have a reasonably high radiation resistance. This ensures good overall efficiency. On 160 meters, the elements could be top-loaded vertical.

When we analyze an array with a modeling program, we notice that the feed-point impedances of the elements change from the value for a single element. If the feed-point impedance of a

single quarter-wave vertical is 36 W over perfect ground, it is almost always different from that value in an array because of mutual coupling.

Two Element Vertical Array

- Two quarter λ vertical elements spaced ¼ λ.
- Phasing achieved using a ¼ λ coax cable delay line.
- Possible to have two endfire directions and a bidirectional broadside direction.



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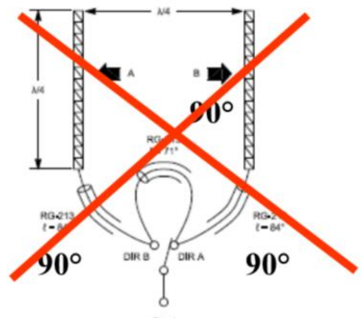
Directivity is in the direction of the antenna with the lagging current – the one with the delay line.

90 degree phasing delay – should work perfectly right?

Two Element Vertical Array

- One quarter λ vertical elements spaced ¼ λ.
- Phasing achieved using a ¼ λ coax cable delay line.
- Possible to have two endfire directions and a bidirectional broadside direction.



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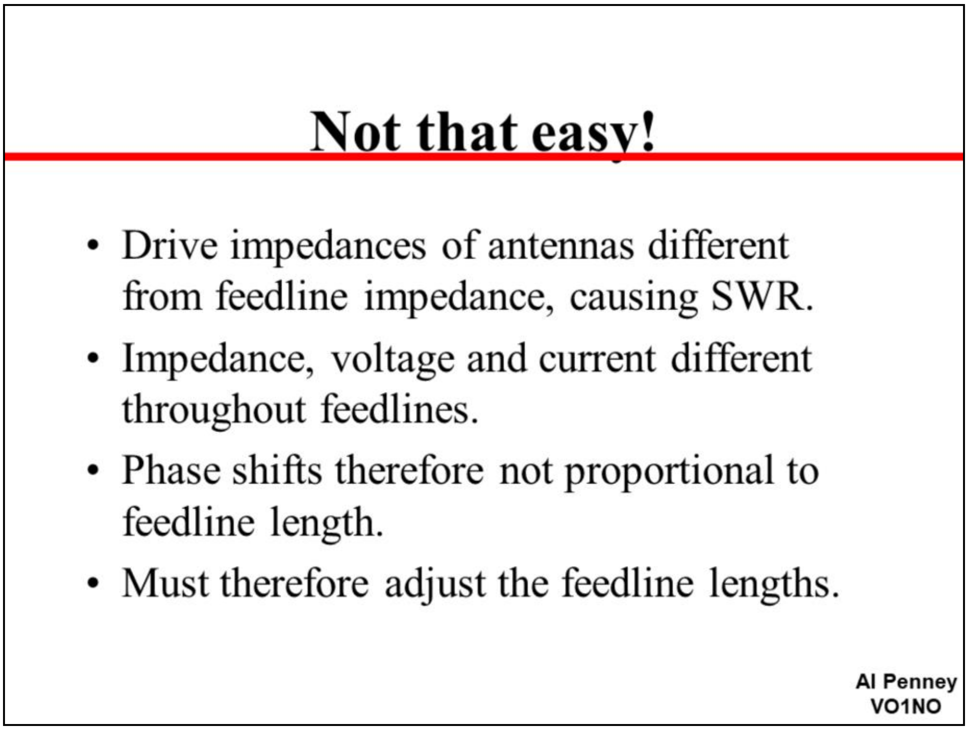
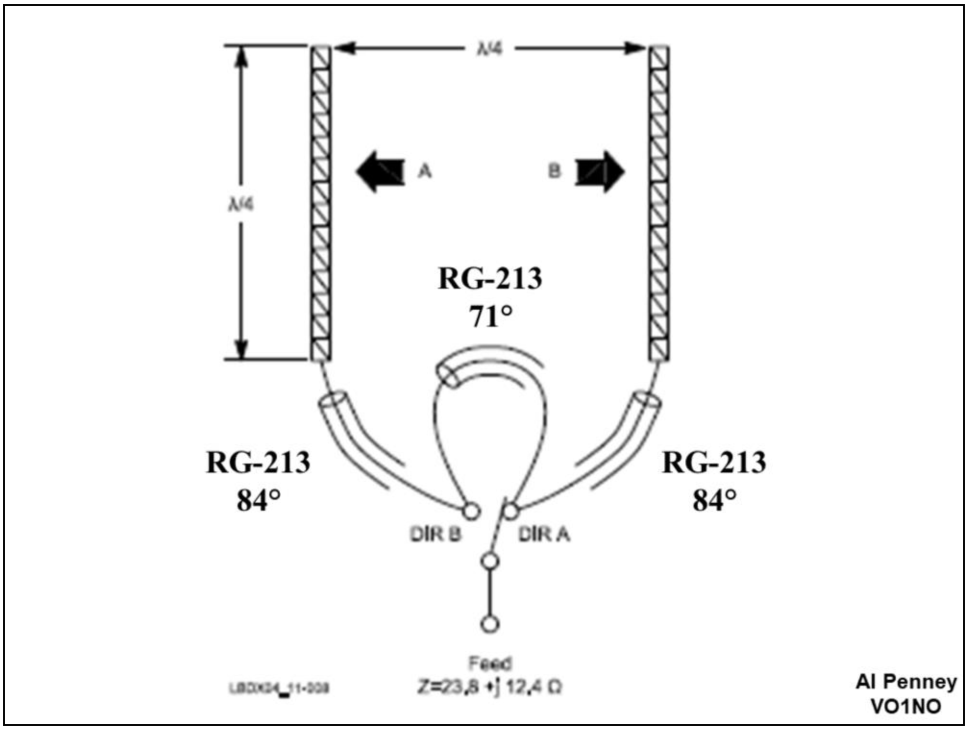
Afraid not!



In just about all cases, the drive impedance of each element will be different from the characteristic impedance of the feed line. This means that there will be standing waves on the line. This has the following consequences:

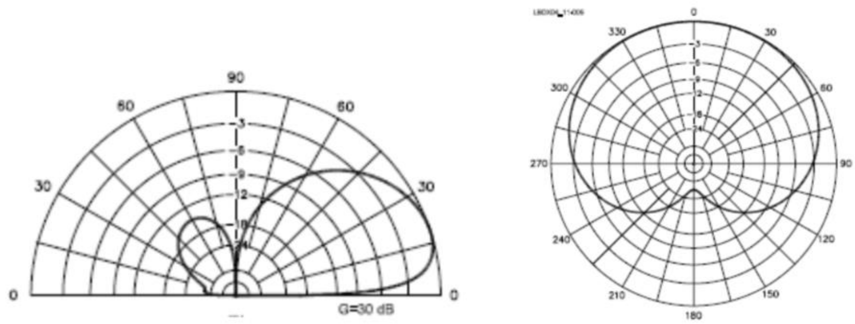
- The impedance, voltage and current will be different in each point of the feed line.
- The current and voltage phase shift is not proportional to the feed line length, except for a few special cases (eg, a half-wave-long feed line).

This means that if we feed these elements with 50-Ohm coaxial cable, we cannot simply use lengths of feed line as phasing lines by making the line length in degrees equal to the desired phase delay in degrees.



Fortunately, the experts have calculated optimum feedline lengths that will give the correct phasing, and give a reasonable match for the radio. Note that you may still need to use the radio's internal antenna tuner to get the radio to see a 1:1 match (50 ohm resistive load).

Radiation Pattern



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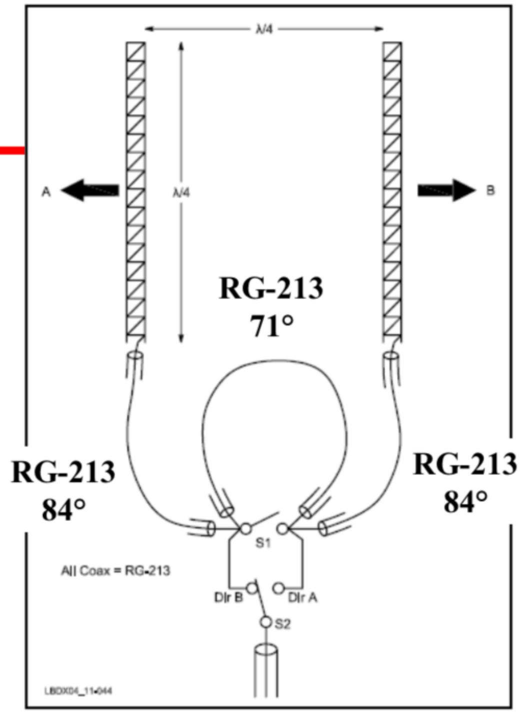
-Very good ground

-3 dB gain over a single vertical

Broadside Pattern

- Closing S1 shorts the delay line.
- This feeds both verticals in phase, giving bidirectional broadside pattern.



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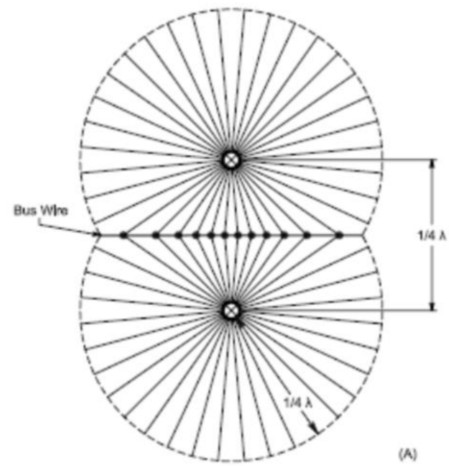
Radial Arrangement



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Measuring the Feed Lines

- Published Velocity Factor of coax cables may vary from batch to batch.
- Use high quality line from same spool.
- Cutting 84° and 71° lines can be tricky!
- Consult textbooks for proper techniques to determine correct lengths.
- Note that this phasing system will not give a 50 ohm resistive load – need radio's antenna tuner for final match.

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To cut the coax cable to the correct lengths for the 84 and 71 degree lengths you determine at what frequencies those lengths would be 90 degrees long. You then use those frequencies and an antenna analyzer to precisely trim the coax to the right length. ON4UN's Low Band DXing and other references describe the process.

Phased verticals for 40M, Bon Portage Island, 2018.

Two Element Array Summary

- Offer reasonable gain and front/back ratio.
- Phasing arrangement relatively easy to build.
- Antennas can be wires suspended from trees.
- Consider aluminum tubing from Princess Auto!
- Two element arrays work – personal experience!

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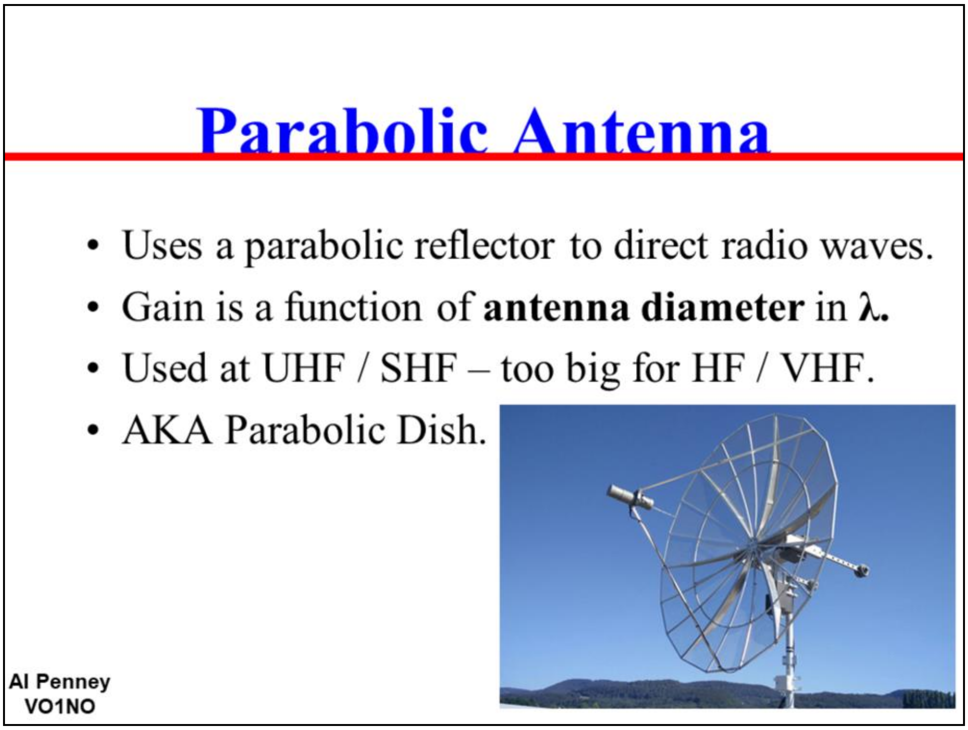
It is relatively easy to build vertical antennas for 40M using tubing from Princess Auto and scrounged from other sources, or from wire suspended from trees or a support rope. Two element arrays certainly work – they have been very effective on the IOTA DX'peditions that I participate in from Bon Portage Island.



A **parabolic antenna** is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a **dish antenna** or **parabolic dish**. The main advantage of a parabolic antenna is that it has high directivity. It functions similarly to a searchlight or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only. Parabolic antennas have some of the highest gains, meaning that they can produce the narrowest beamwidths, of any antenna type. In order to achieve narrow beamwidths, the parabolic reflector must be much larger than the wavelength of the radio waves used, so parabolic antennas are used in the high frequency part of the radio spectrum, at UHF and microwave (SHF) frequencies, at which the wavelengths are small enough that conveniently-sized reflectors can be used.

Benefits or advantages of Parabolic Reflector Antenna

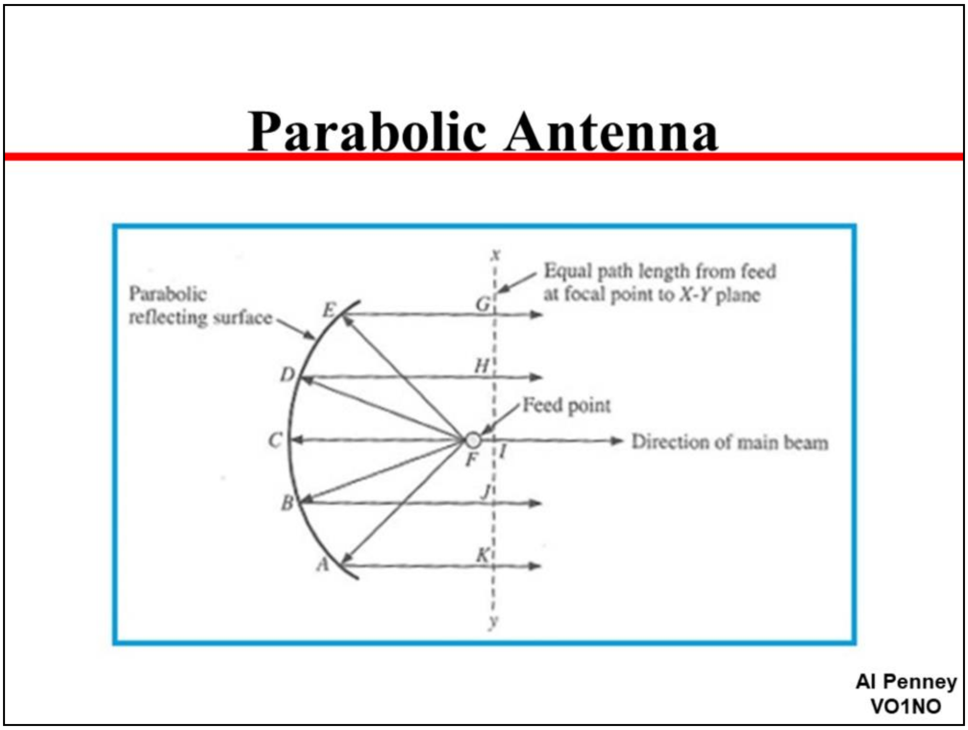
Following are the benefits or **advantages of Parabolic Reflector Antenna**:

➡It can be used both as transmitting antenna and receiving antenna due to principle of reciprocity.

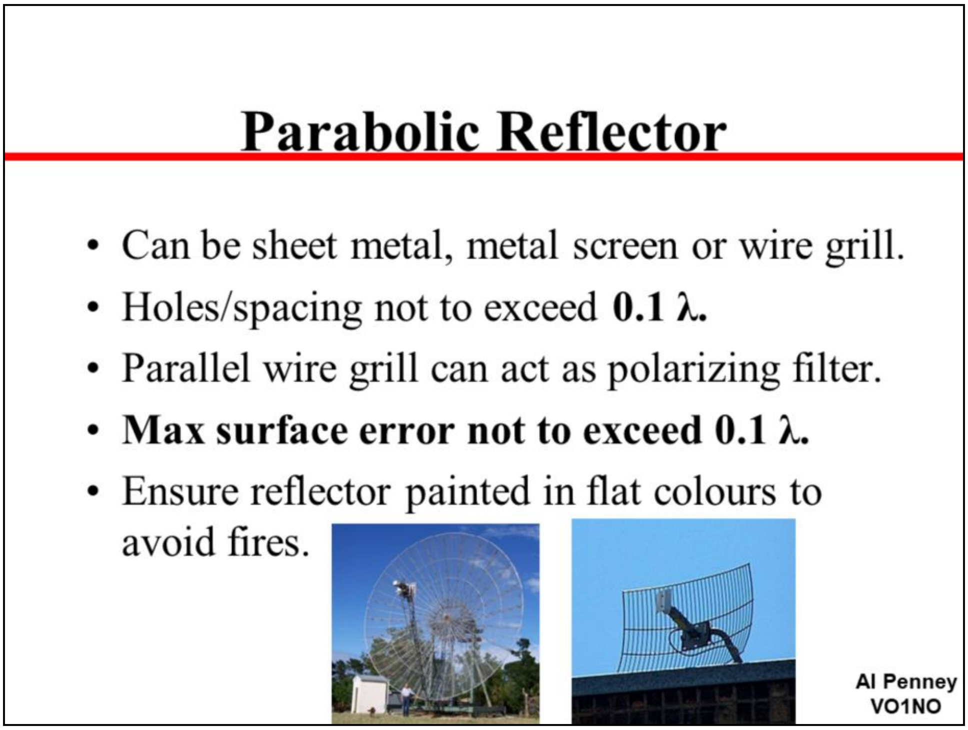
➡The feed can be used in various modes with parabolic reflector viz. centre feed, cassegrain feed or offset feed. Each of these configurations have their respective benefits and applications.
➡Smaller size and low cost

Drawbacks or disadvantages of Parabolic Reflector Antenna

Following are the **disadvantages of Parabolic Reflector Antenna**:
➡Feed antenna and reflector disc block certain amount of radiation from the main parabolic reflector antenna. This is about 1 to 2%.
➡The design of parabolic reflector is a complex process.
➡In spite of feed horn at focus and uniform illumination, certain amount of power from feed is bound to slop over the edges of parabolic reflector. This power is responsible to form side lobes in the radiation pattern.
➡Surface distortions can occur in very large dish. This is reduced by using wide mesh instead of continuous surface.
➡In order to achieve best performance results, feed should be placed exactly at the focus of the parabolic reflector antenna. This is difficult to achieve practically.



This antenna type is used both as transmitter and as receiver. The figure-1 depicts working principle of parabolic reflector as transmitter. As shown feed radiates power into reflecting surface having parabolic shape. The reflector reflects microwave power along the antenna axis which is direction of the beam. Similarly waves falling on the dish are concentrated towards the feed placed at focal point of the dish. This ways reception is carried out by the parabolic reflector antenna.

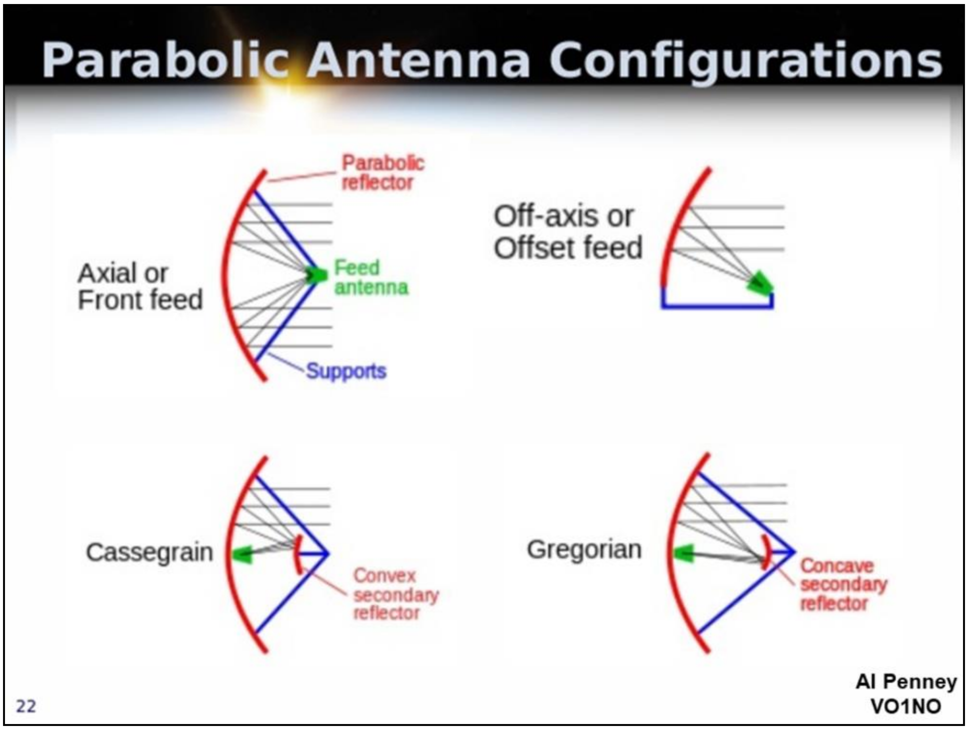


Parabolic reflector

The reflector can be of sheet metal, metal screen, or wire grill construction, and it can be either a circular "dish" or various other shapes to create different beam shapes. A metal screen reflects radio waves as well as a solid metal surface as long as the holes are smaller than one-tenth of a wavelength, so screen reflectors are often used to reduce weight and wind loads on the dish. To achieve the maximum gain, it is necessary that the shape of the dish be accurate within a small fraction of a wavelength, to ensure the waves from different parts of the antenna arrive at the focus in phase. Large dishes often require a supporting truss structure behind them to provide the required stiffness.

A reflector made of a grill of parallel wires or bars oriented in one direction acts as a *polarizing filter* as well as a reflector. It only reflects linearly polarized radio waves, with the electric field parallel to the grill elements. This type is often used in radar antennas. Combined with a linearly polarized feed horn, it helps filter out noise in the receiver and reduces false returns.

Since a shiny metal parabolic reflector can also focus the sun's rays, and most dishes could concentrate enough solar energy on the feed structure to severely overheat it if they happened to be pointed at the sun, solid reflectors are always given a coat of flat paint.



Parabolic antennas are also classified by the type of *feed*, that is, how the radio waves are supplied to the antenna:

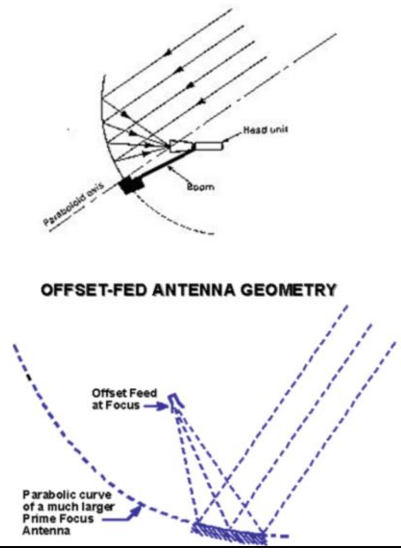
•***Axial***, ***prime focus***, or ***front feed*** – This is the most common type of feed, with the feed antenna located in front of the dish at the focus, on the beam axis, pointed back toward the dish. A disadvantage of this type is that the feed and its supports block some of the beam, which limits the aperture efficiency to only 55–60%.

•***Off-axis*** or ***offset feed*** – The reflector is an asymmetrical segment of a paraboloid, so the focus, and the feed antenna, are located to one side of the dish. The purpose of this design is to move the feed structure out of the beam path, so it does not block the beam. It is widely used in home satellite television dishes, which are small enough that the feed structure would otherwise block a significant percentage of the signal. Offset feed can also be used in multiple reflector designs such as the Cassegrain and Gregorian.

•***Cassegrain*** – In a Cassegrain antenna, the feed is located on or behind the dish, and radiates forward, illuminating a convex hyperboloidal secondary reflector at the focus of the dish. The radio waves from the feed reflect back off the secondary reflector to the dish, which reflects them forward again, forming the outgoing beam. An advantage of this configuration is that the feed, with its waveguides and "front end" electronics does not have to be suspended in front of the dish, so it is used for antennas with complicated or bulky feeds, such as large satellite communication antennas and radio telescopes. Aperture efficiency is on the order of 65–70%.

•***Gregorian*** – Similar to the Cassegrain design except that the secondary reflector is concave, (ellipsoidal) in shape. Aperture efficiency over 70% can be achieved.

Offset Feed



Can be adapted for Amateur Radio. The homebrew dish arrangement in the photo was the creation of Glenn McDonnell, VE3XRA (now president of RAC). That particular telephone operates on frequencies shared by Amateurs in the 5.8 GHz band. We used it on a grid expedition to FN04xa in Ontario in for the ARRL VHF/UHF contest, and were able to work two grids for points and multipliers. The biggest problem with it is that it is not possible to remove the antenna from the phone and position it properly at the focal point.

End of Part One

Let’s take a break!

Al Penney
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