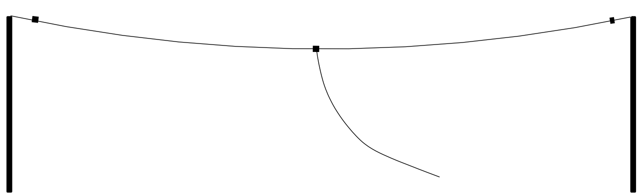
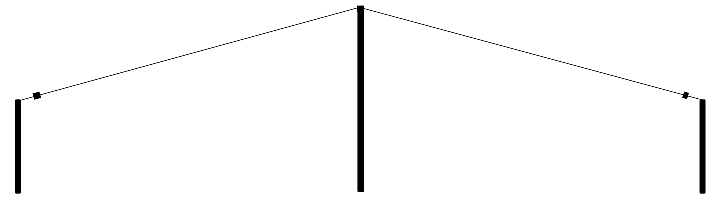
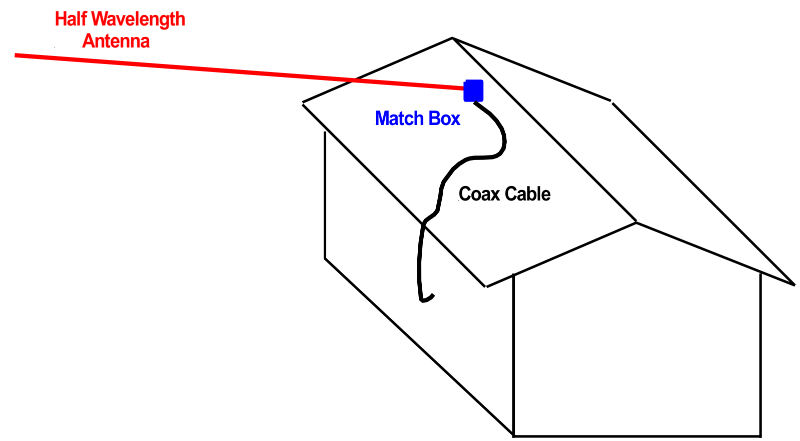
Antenna Fundamentals







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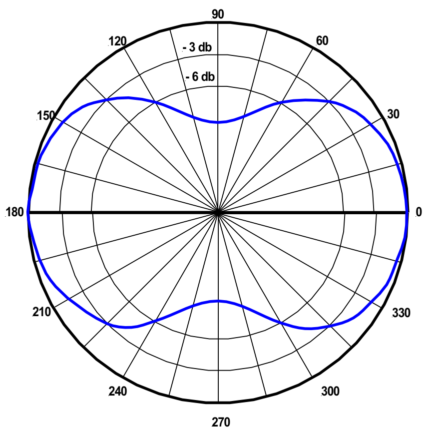
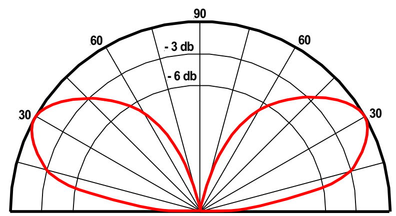
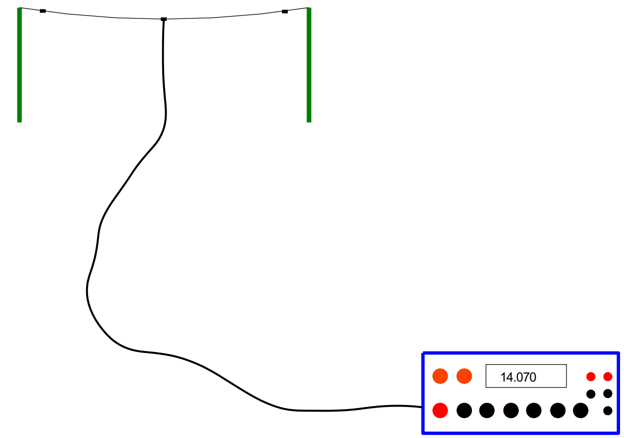
What is an Antenna?



1/2 Wave Dipole Horizontal Pattern

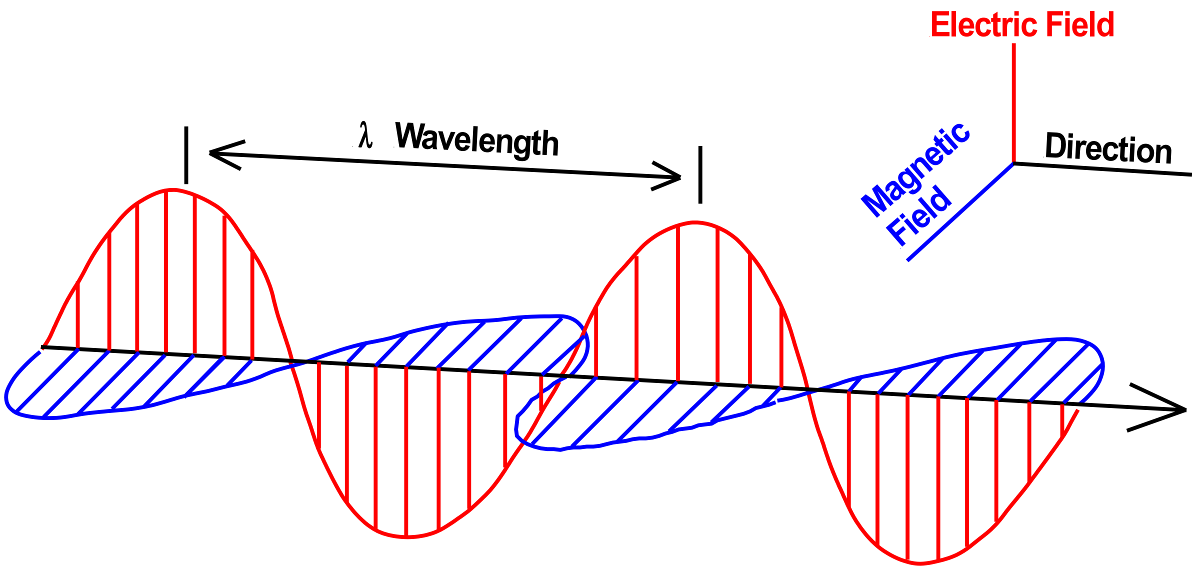


1/2 Wave Dipole Vertical Pattern



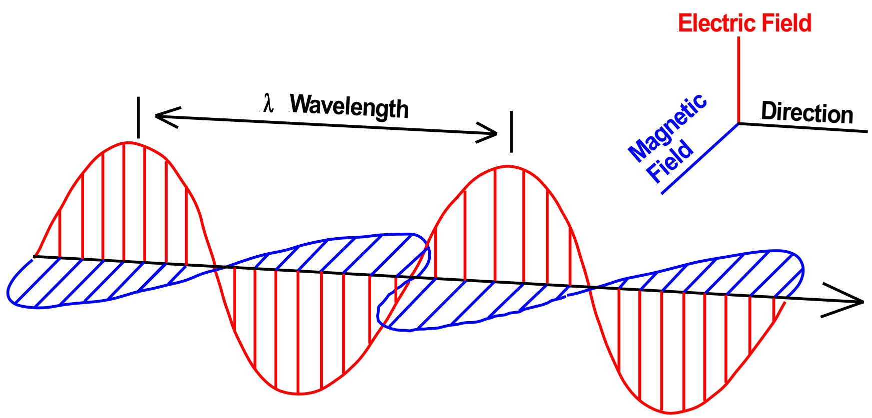
- Any wire carrying an RF current, whether in an electrical circuit or not, will radiate electromagnetic energy if it is more than about 0.01 wavelengths long
- An antenna is an electrical circuit designed specifically to radiate a major portion of its RF energy in the form of an electromagnetic wave

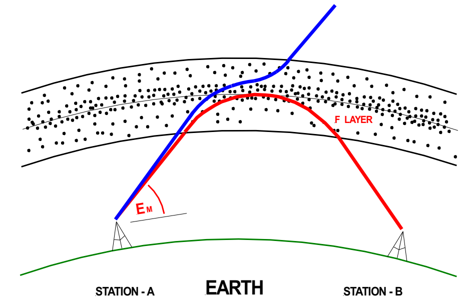
Electromagnetic Wave

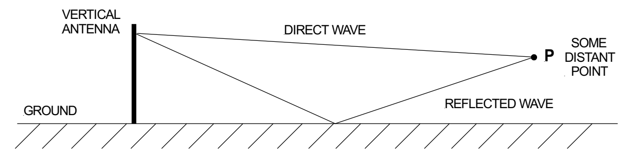


- An electromagnetic radio wave consists of two perpendicular fields:
  - An electric field (E) and
  - A magnetic field (H).
- The two fields are inseparable, one field can not exist without the other.
- An alternating electric field induces an alternating magnetic field.
- An alternating magnetic field induces an alternating electric field
- The direction of wave travel is perpendicular to both the E and H fields

The Electric Field

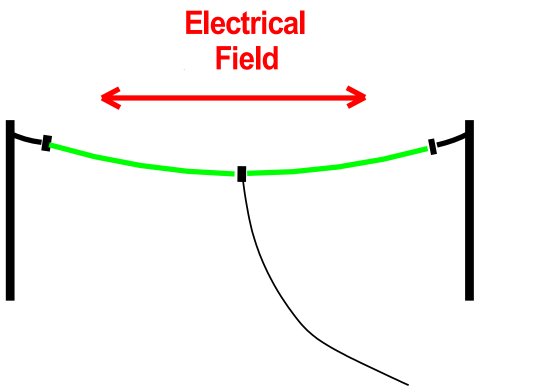




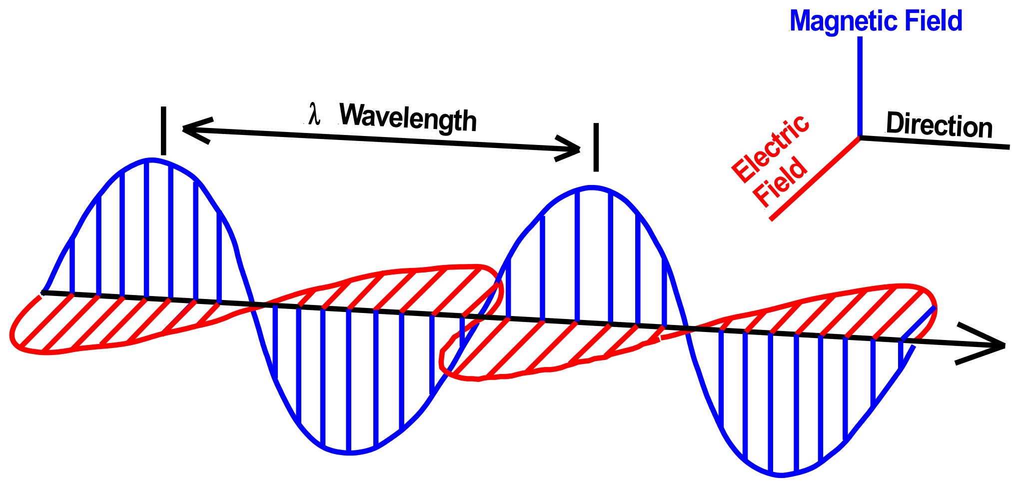


- The Electric Field is responsible for most of **the good**, ***<u>and bad</u>***, things that happen to radio waves.
- It is the electric field interacting with free electrons in the ionosphere that causes radio waves to bend back to Earth.
- It is the electric field that interacts with Earth's surface causing the propagation characteristics of vertical and horizontal antennas to be different.
- The magnetic field mostly goes along for the ride.
- Yet, the electric and magnetic fields are inseparable

Polarization of a Horizontal Dipole

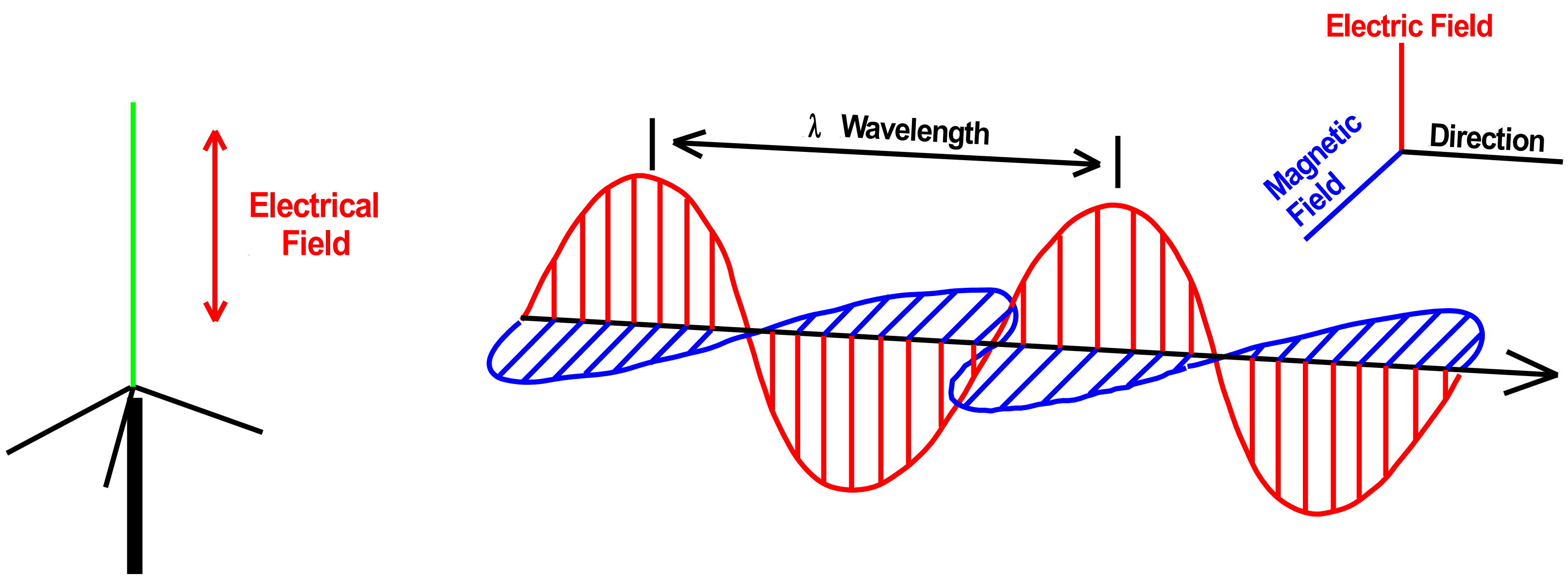


Horizontal Dipole Antenna



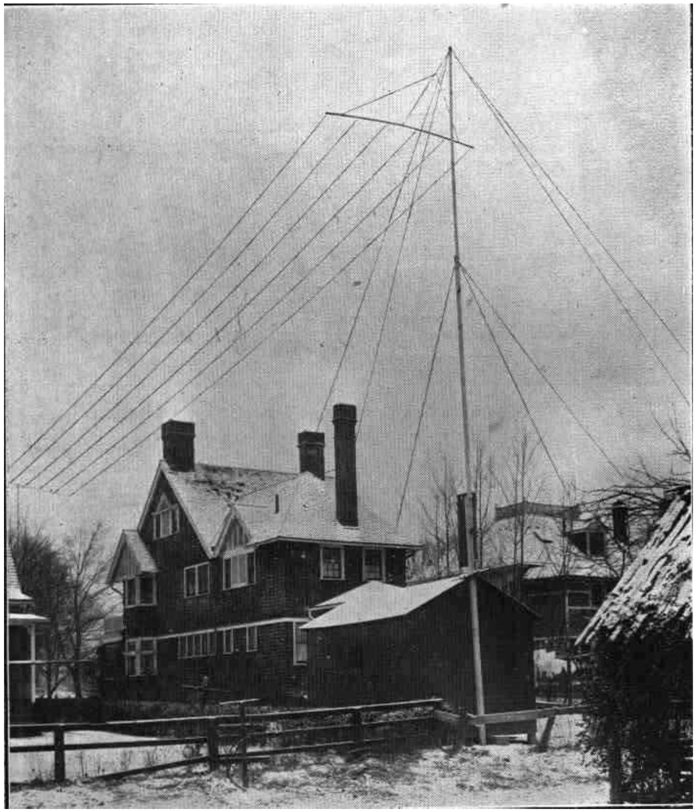
- A horizontal dipole antenna is horizontally polarized
- That is, the Electric Field component of the electro-magnetic wave radiated by a horizontal dipole is parallel to the Earth

Polarization of a Vertical Antenna



- A vertical antenna is vertically polarized
- That is, the Electric Field component of the electro-magnetic wave radiated by a vertical antenna is perpendicular to the Earth
- Notice that the Electric Field is in the same direction as the electrical current flowing in the antenna for both vertical and horizontal antennas

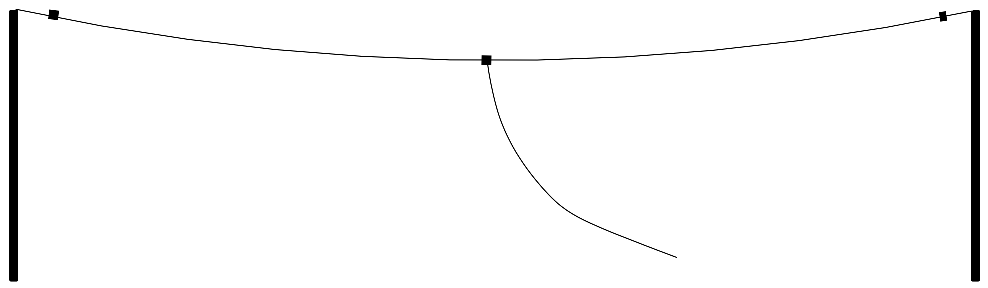
Field Strength



In the early days of radio multiple parallel wires were used in an attempt to get more current flowing in the antenna

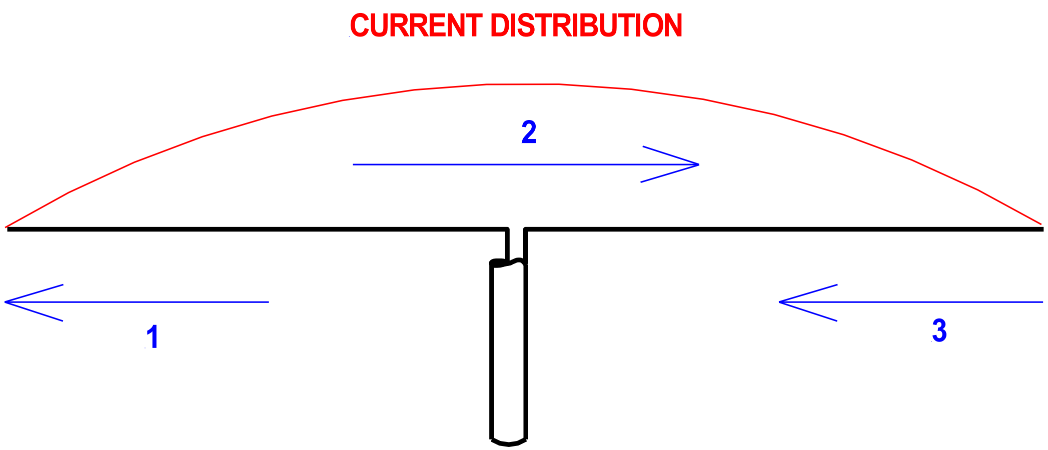
- The strength of the electromagnetic field radiated by an antenna depends on:
  - The antenna's length, and
  - The amount of electrical current flowing in the antenna
- Field strength is directly proportional to antenna current
- For maximum field strength antenna current must be as large as possible for a given amount of transmitter power

Field Strength and Antenna Impedance



- Antenna impedance consists of both resistance and reactance (inductive and capacitive reactance)
- The largest current flows when reactance is “tuned out”, that is when the antenna impedance is purely resistive
- This occurs when the antenna is resonant at the operating frequency

Antenna Resonance



$$\lambda = \frac{300\text{ Mm}}{f(\text{MHz})}$$

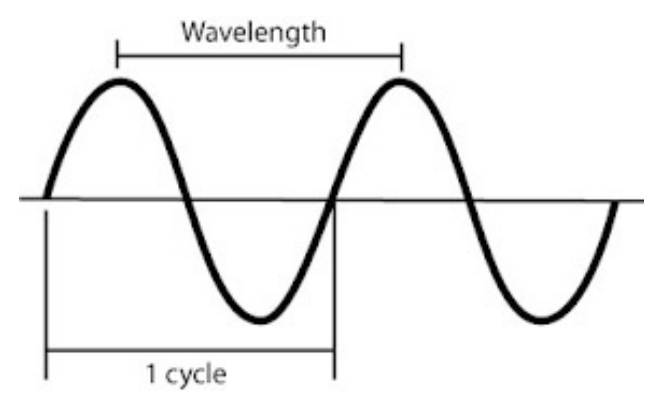
At the speed of light

- The shortest length of wire that resonates at a given frequency is one just long enough to permit an electric charge to travel

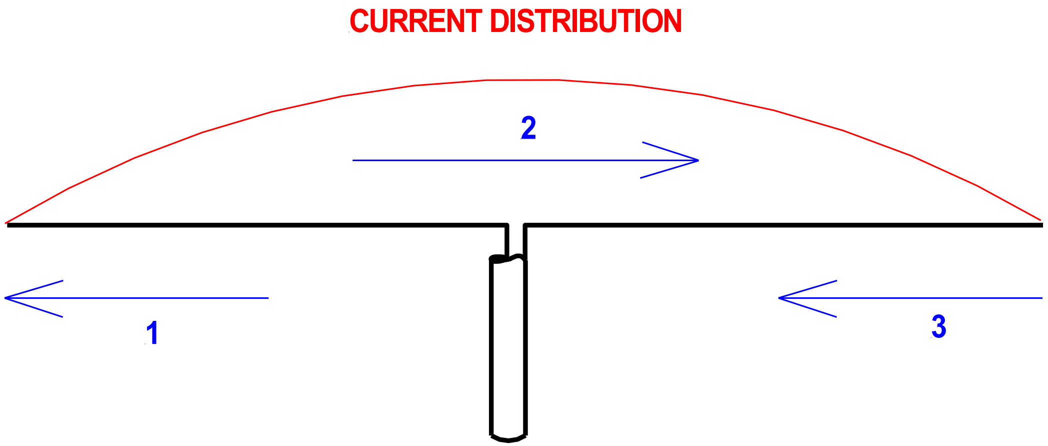
    1. From the middle to one end of the antenna,
    2. To the other end of the antenna, and
    3. Back to the middle

in the time of one RF cycle

One > Cycle



Shortest Resonant Antenna

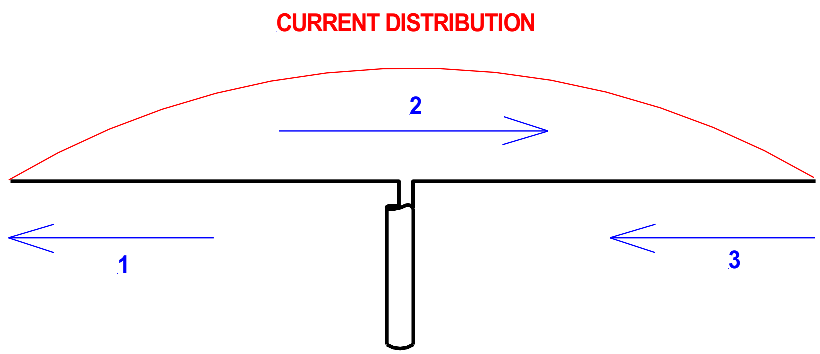


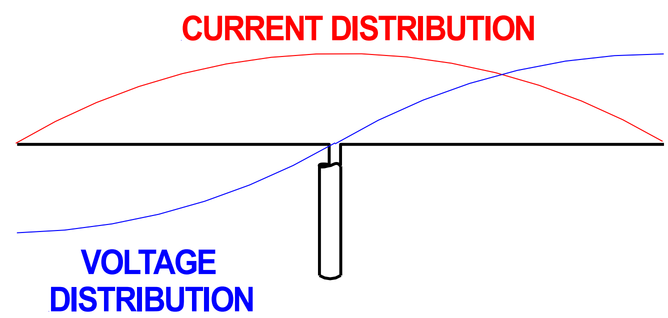
$$\lambda = \frac{300\ \text{Mm}}{f(\text{MHz})}$$

At the speed of light

- Because the charge traverses the wire twice, the length of wire needed to permit the charge to travel a distance of one wavelength in one cycle is one-half wavelength
- The shortest resonant wire is therefore one-half wavelength long.

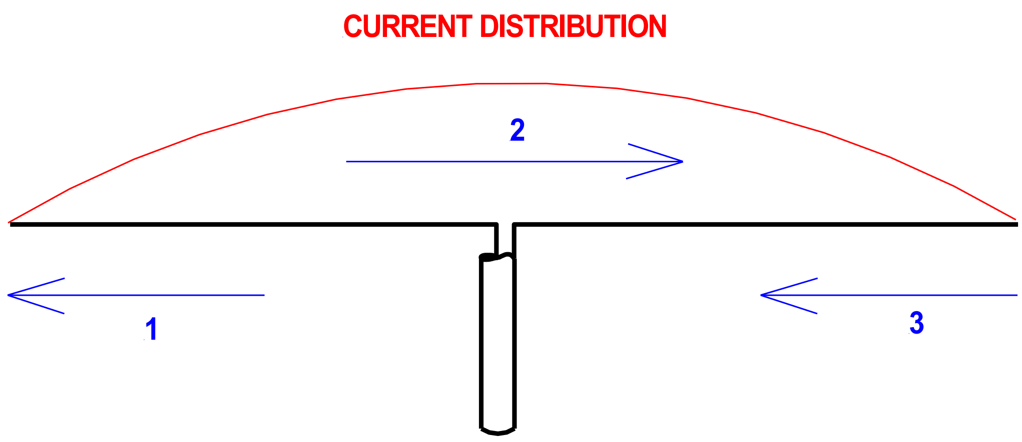
Halfwave Antenna Current & Voltage Distribution

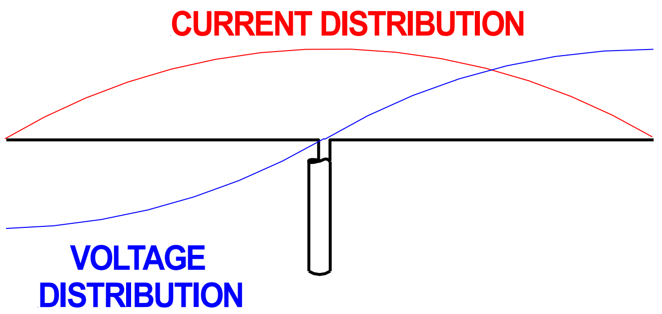




- The current arriving at the end of the antenna exactly cancels the current leaving (reflected from) the end of the antenna, thus the current at the end of the antenna is zero.
- The current entering the antenna from the coax at the middle of the antenna is exactly in phase with the current flowing on the antenna (in one direction or the other) at that instant creating a current maximum at the middle of the antenna

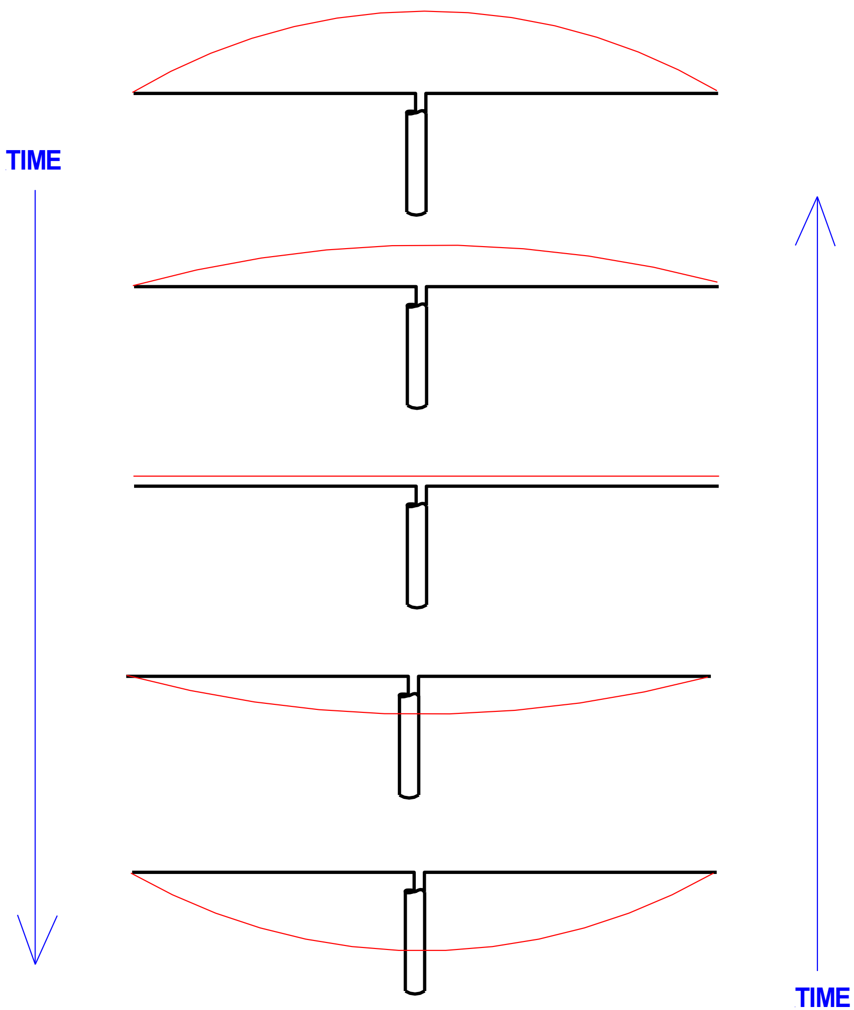
Halfwave Antenna Current & Voltage Distribution





- Voltage is maximum at the ends of the antenna, and
- Minimum at the center of the antenna
- R = V / I   (R = resistance, I = current, V = voltage)
- Antenna resistance R is low at the center of the antenna (I large) and very high at the ends of the antenna (I near zero)

Antenna Standing Wave Current Distribution



- The magnitude of the current distribution on the antenna changes sinusoidally with the applied RF signal from the transmitter
- The current at the middle of the antenna is a maximum, it decreases to zero, increases to a maximum in the other direction, then back to zero, etc
- The shape of the current distribution, however, always remains the same
- This “pumping action” causes a radio signal to radiate away from the antenna

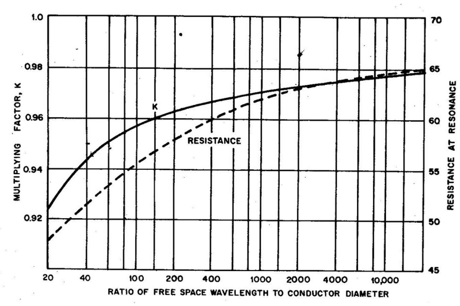
Velocity of Propagation

- The velocity at which electromagnetic waves travel through a medium depends upon the dielectric constant of the medium.
- The dielectric constant of free space is 1.000
- The dielectric constant of all media, other than free space, is always greater than one
- The dielectric constant of air at 1 atm pressure is 1.00059
- Thus a radio wave traveling though air travels at essentially the speed of light in a vacuum.
- The velocity of an electromagnetic wave traveling along a bare copper antenna wire is about 0.95 times the speed of light

Physical and Electrical Length

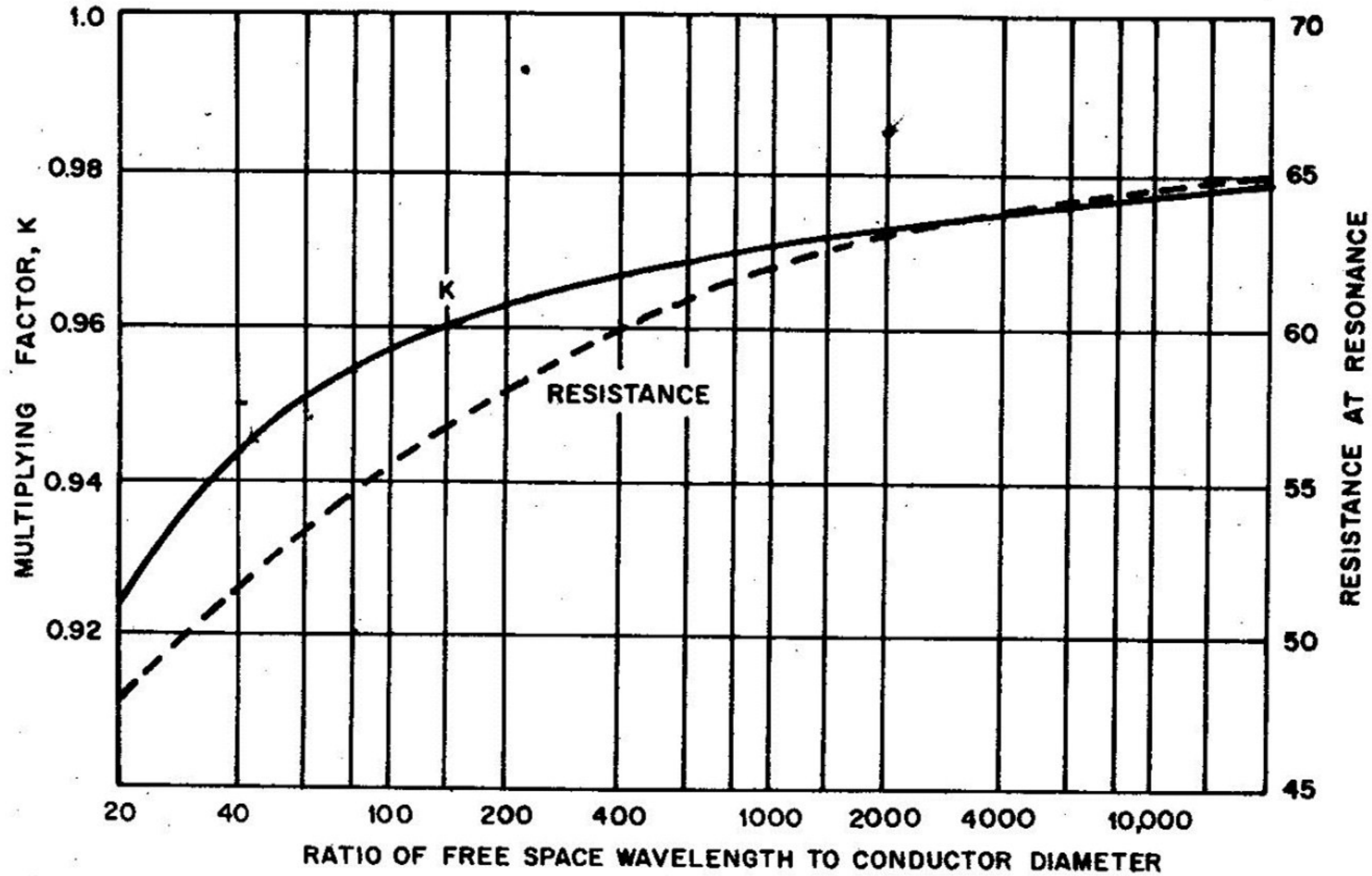
- The velocity of an electromagnetic wave traveling along an **insulated wire** is about 0.9 times the speed of light because the dielectric constant of the insulated wire is greater than 1 and also greater than that of bare wire
- The "Physical Length" of a resonant half-wave antenna constructed using insulated wire is shorter than a bare copper wire antenna because the radio wave travels slower along the insulated antenna wire.
- However, the "Electrical Length" of the physically shorter resonant insulated wire antenna is still one half wavelength.
- It is the electrical length, taking into account the associated dielectric constants, that is important
- A resonant half-wave dipole must be "electrically" one half wavelength long

Conductor Length To Conductor Diameter Ratio



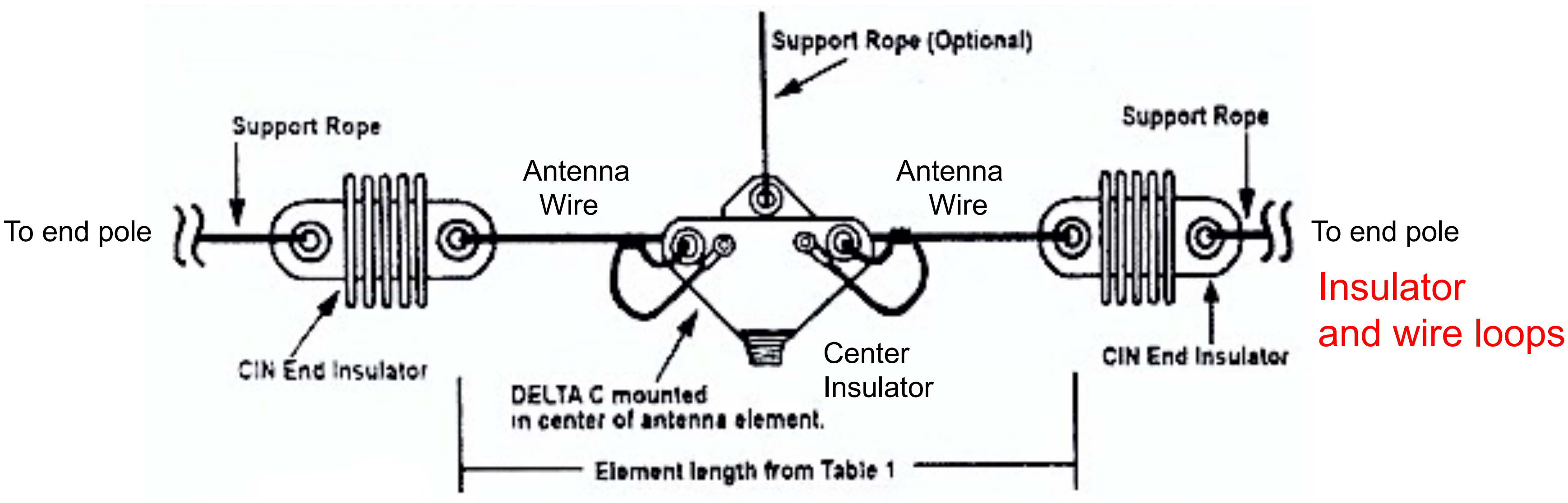
- In addition to the associated dielectric constants
- The resonant length of an antenna also depends on the ratio between the length of a one wave-length long antenna conductor (wire, tubing, etc) to the diameter of the conductor
- The smaller this ratio (the thicker the wire), the shorter the antenna will be for a given electrical length
- The factor K (less than 1) by which a free-space antenna must be multiplied to find its resonant length is shown on the next slide.
- The wave-length to diameter ratio for a typical #12 gauge antenna wire is approximately 20,000

Length to Conductor Diameter Chart



- The shortening effect is most pronounced for thick conductors where the ratio is 200 or less

End Effect



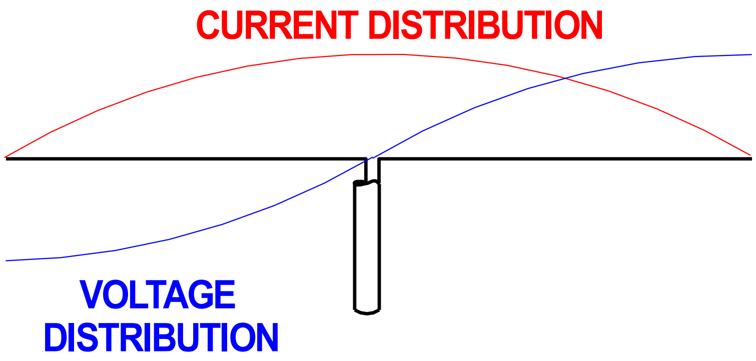
- The insulators and wire loops that tie the insulators to the antenna wire add a small amount of capacitance to the antenna.
- This capacitance slightly lowers the antenna's resonant frequency (causes the electrical length of the antenna to be longer)
- Because of end effect the current at the end of the antenna does not quite reach zero since there is some current flowing into the end capacitance

Electrical Resonant Length Equation

$$\lambda = \frac{300\,(K_{dielect}\,K_{dia}\,K_{end})}{f(MHz)}$$

- The electrical wavelength λ for an antenna is equal to
  - 300 Mega-meters, times
  - The dielectric constant factor, times
  - The factor for the conductor length to diameter ratio, times
  - The antenna end effect factor
  - Divided by the desired resonant frequency in MHz
- At frequencies up to 30 MHz, experience shows that the length of a 1/2 wavelength antenna is on the order of 5 - 10% shorter than the length of a half wave antenna in space ($0.90 < K_{dielect} + K_{dia} + K_{end} < 0.95$)

Antenna Impedance

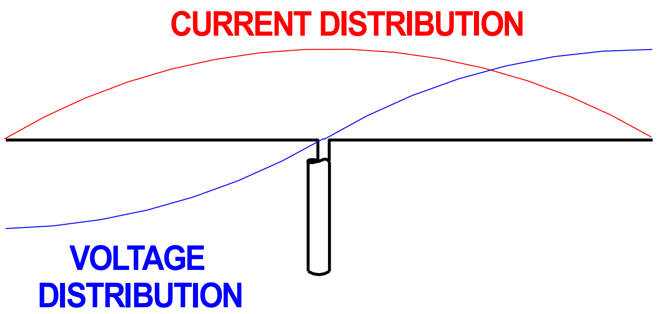


- The impedance Z of an antenna is equal to the voltage V applied across the antenna terminals divided by the current I flowing into the terminals

$$Z = V / I$$

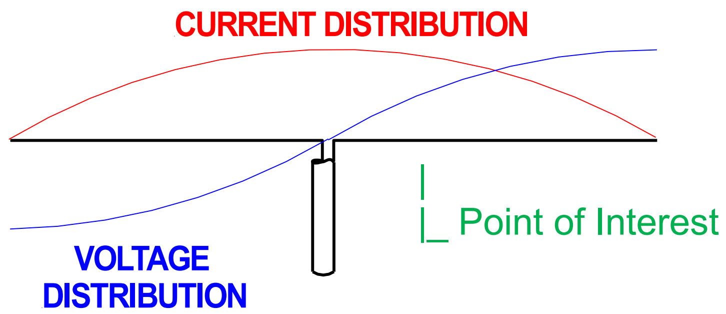
  - The terminals are in the middle of a center fed antenna
  - The terminals are located some place else along the antenna for an Off Center Fed (OCF) antenna

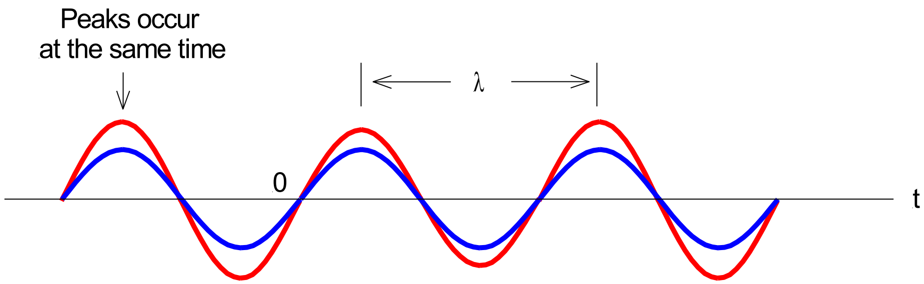
Antenna Impedance



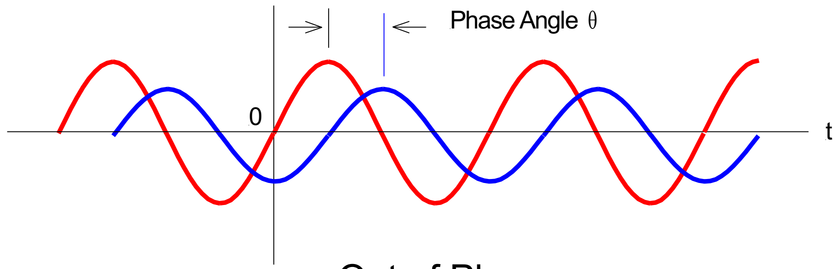
- Because of the voltage and current distributions along an antenna, the impedance of a center fed antenna is different from an OCF antenna
  - The impedance (Z = V / I) is low for a center fed antenna because of the large current and small voltage at the center of the antenna
  - The impedance is very high at the ends of the antenna because of the large voltage and small current
  - Impedance of the antenna some place between the center and end of the antenna is between the low center impedance and the very high end impedance

Impedance of a Resonant Antenna





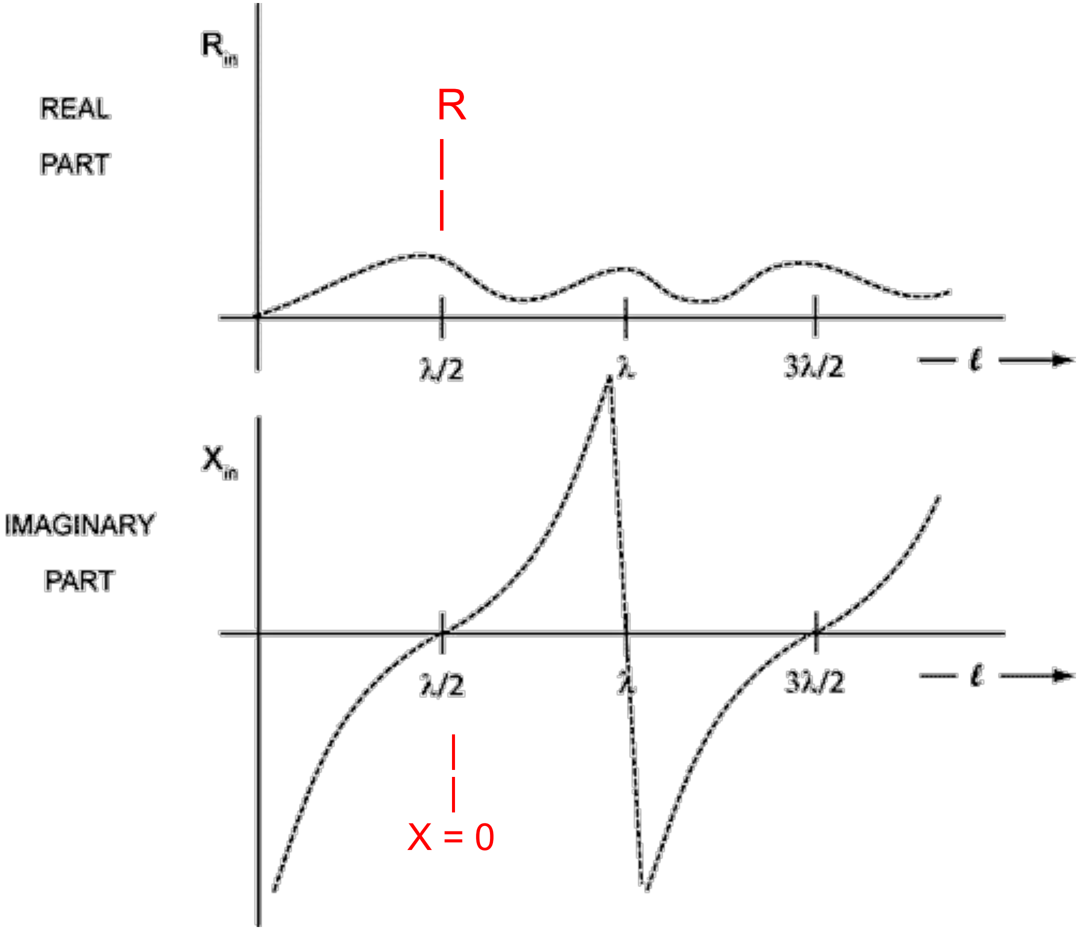
In Phase

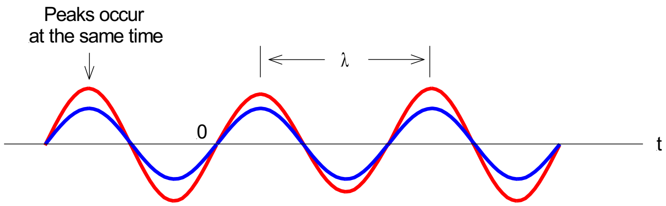


Out of Phase

- For a resonant antenna the voltage (blue) and current (red) are in phase at any point of interest along the antenna
- Their amplitudes will generally be different because of the current and voltage distributions along the antenna
- But they will be in phase regardless of what their amplitudes may be

Impedance of a Resonant Antenna

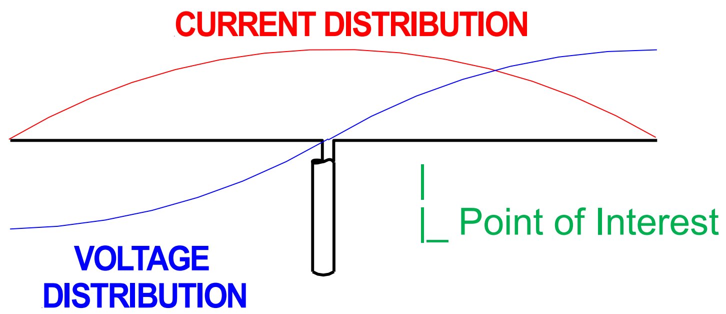


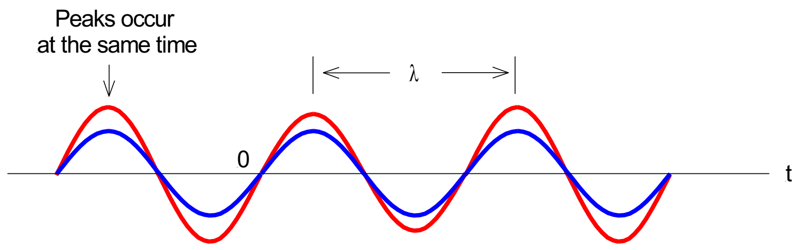


Voltage and Current are in phase

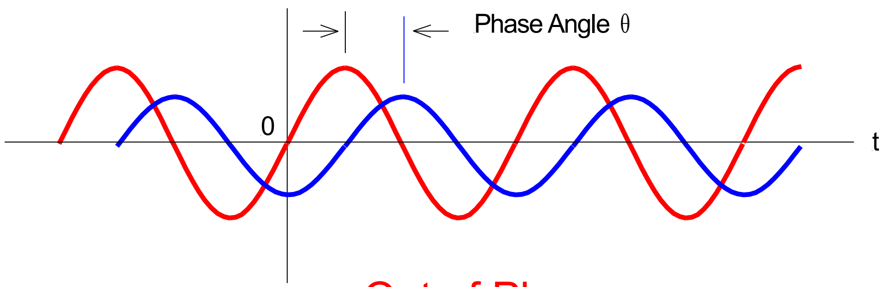
- In general impedance Z = R + X, where R is the impedance resistance and X is the reactive (capacitive or inductive) part of the impedance
- Since the antenna voltage and current are in phase at resonance the antenna's impedance is purely resistive (X = 0)

Impedance of a Non-resonant Antenna





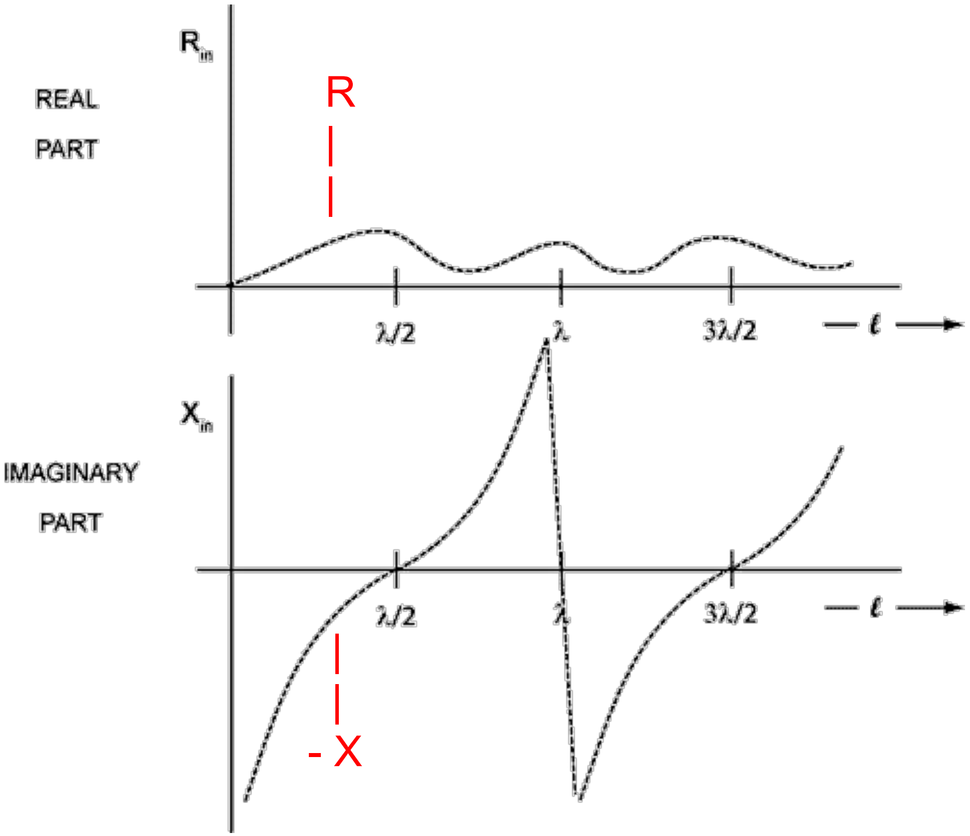
In Phase

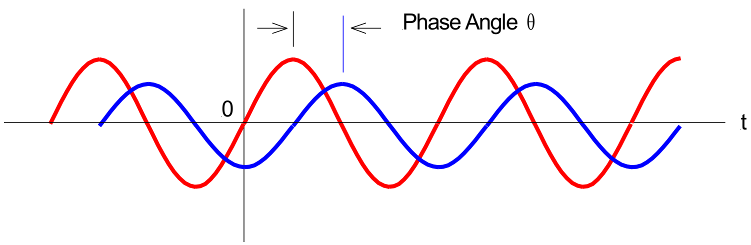


Out of Phase

- For a non-resonant antenna the voltage (blue) and current (red) are out of phase at any point of interest along the antenna
- Because the voltage and current are out of phase a non-resonant antenna has a complex impedance Z = R + X (That is, X is not zero)

Impedance of a Short Non-resonant Antenna

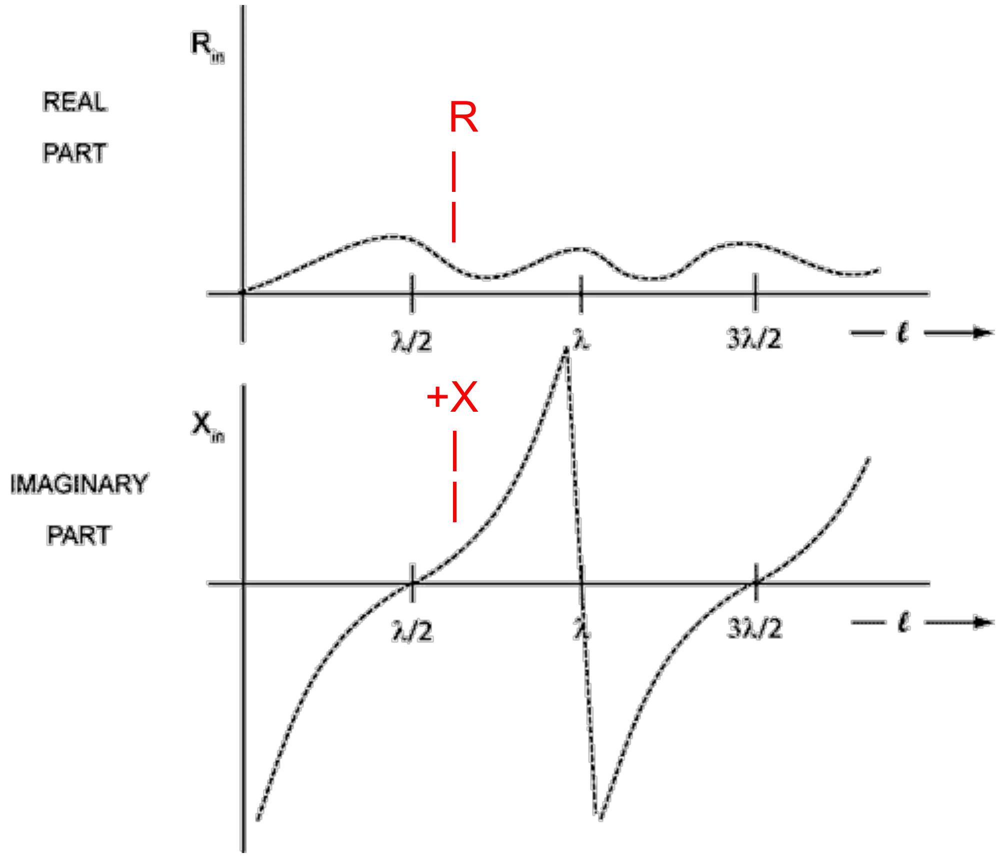


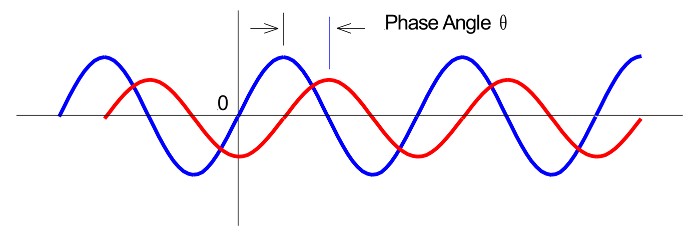


Voltage and Current are out of phase
Current leads voltage

- An antenna that is too short (< 1/2 wavelength) looks like a series resistor – capacitor circuit with a negative reactance X and impedance Z = R - X
- To bring the antenna into resonance, with an impedance Z = R, an inductance (loading coil) must be added to the antenna to cancel out the capacitance forcing the impedance reactive term X to zero

Impedance of a Long Non-resonant Antenna

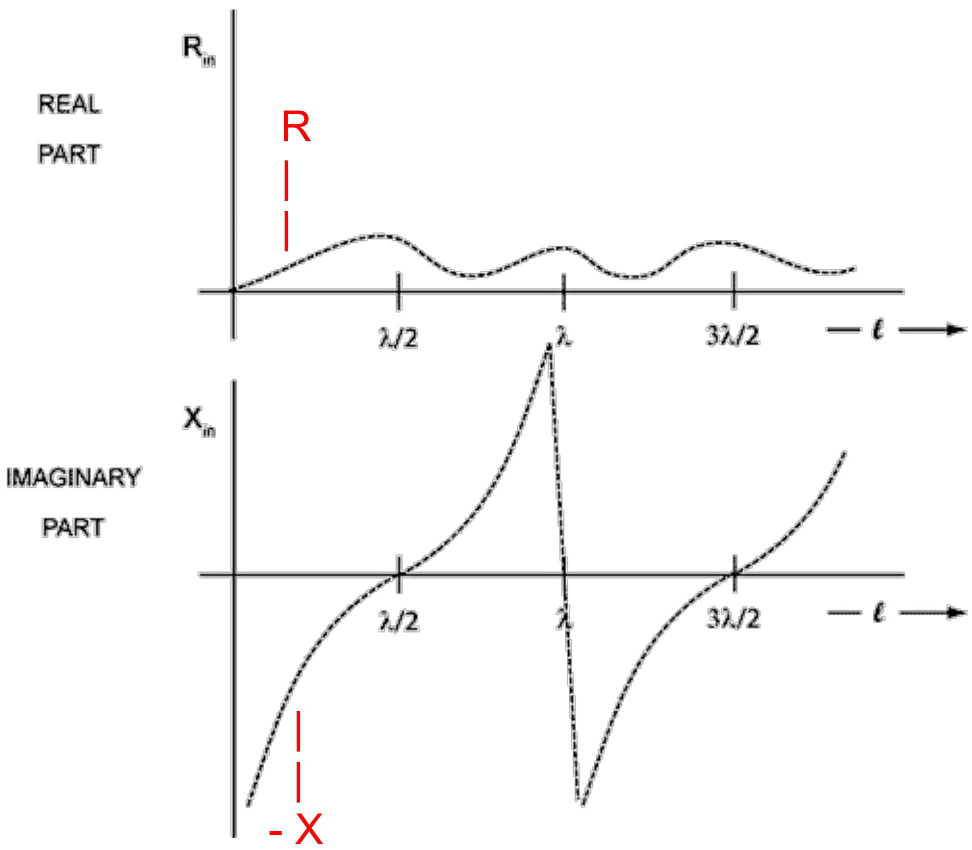




Voltage and Current are out of phase
Voltage leads current

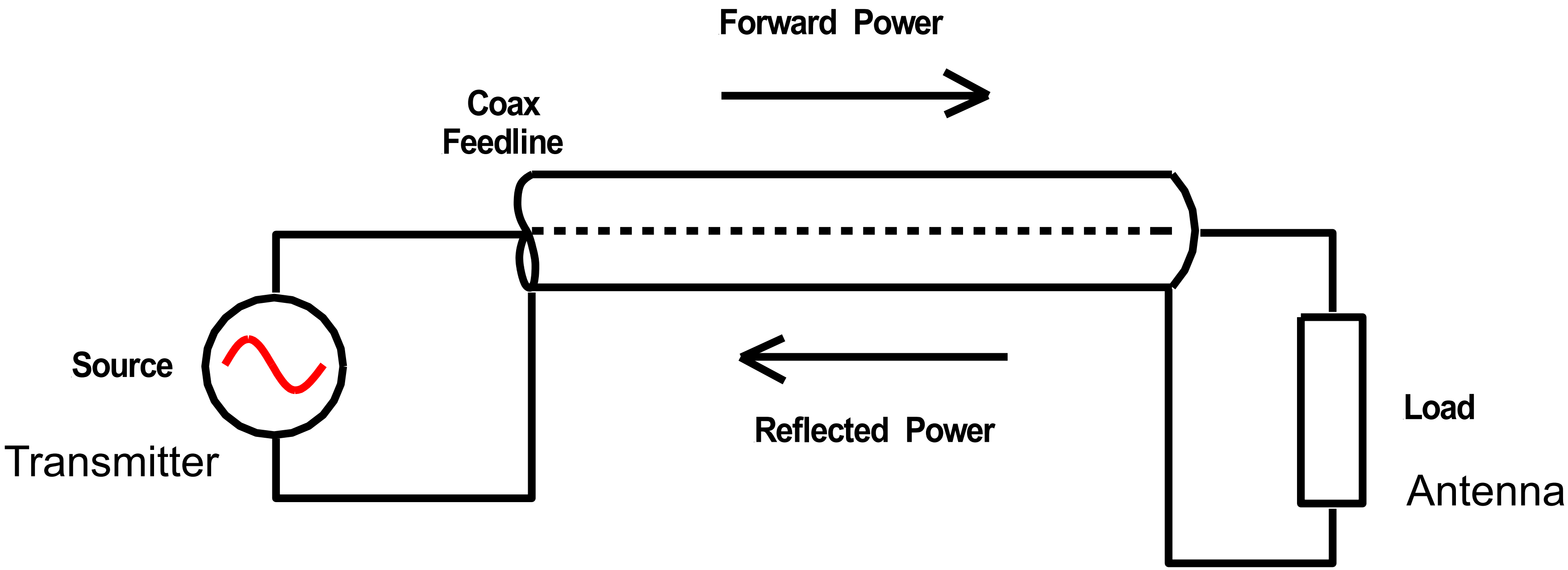
- An antenna that is too long (> 1/2 wavelength) looks like a series resistor – inductor circuit with a positive reactance X and impedance Z = R + X
- To bring the antenna into resonance, with an impedance Z = R, capacitance must be added to the antenna to cancel out the inductance forcing the impedance reactive term X to zero

Radiation vs Antenna Resonance



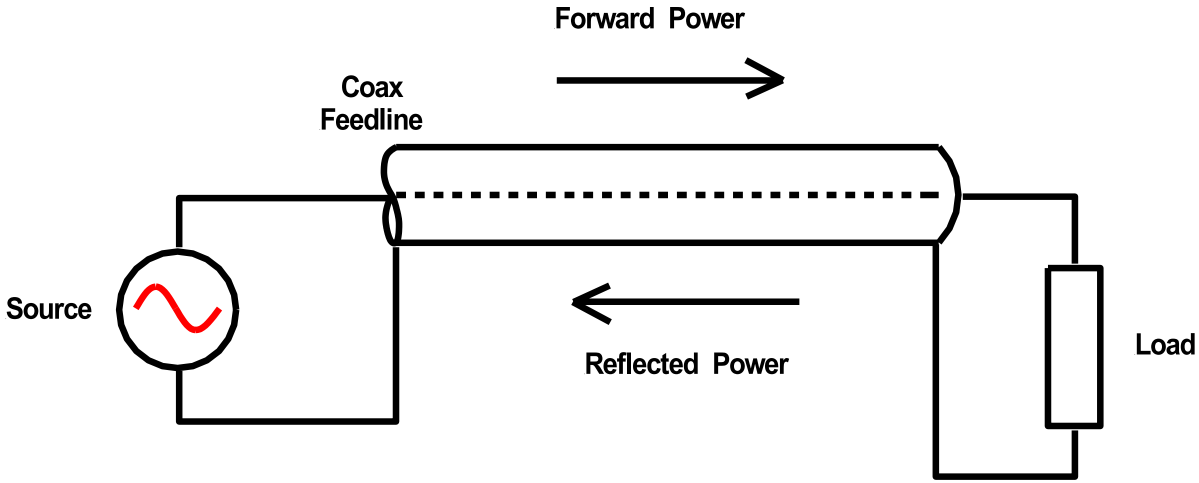
- A non-resonant antenna will radiate as well as a resonant antenna provided that you can get the same amount of power into both antennas
- The only issue with a non-resonant antenna is the ease of feeding the antenna.
- For example, the radiation resistance will be low in a really short antenna while its reactance will be extremely high making the antenna difficult to feed

Reflected Power



- All of the transmitted power will be radiated by the antenna if the antenna impedance is the same as that of the coax feed line and transmitter
- Some of the transmitted power will be reflected back down the feed line if the impedances are not the same

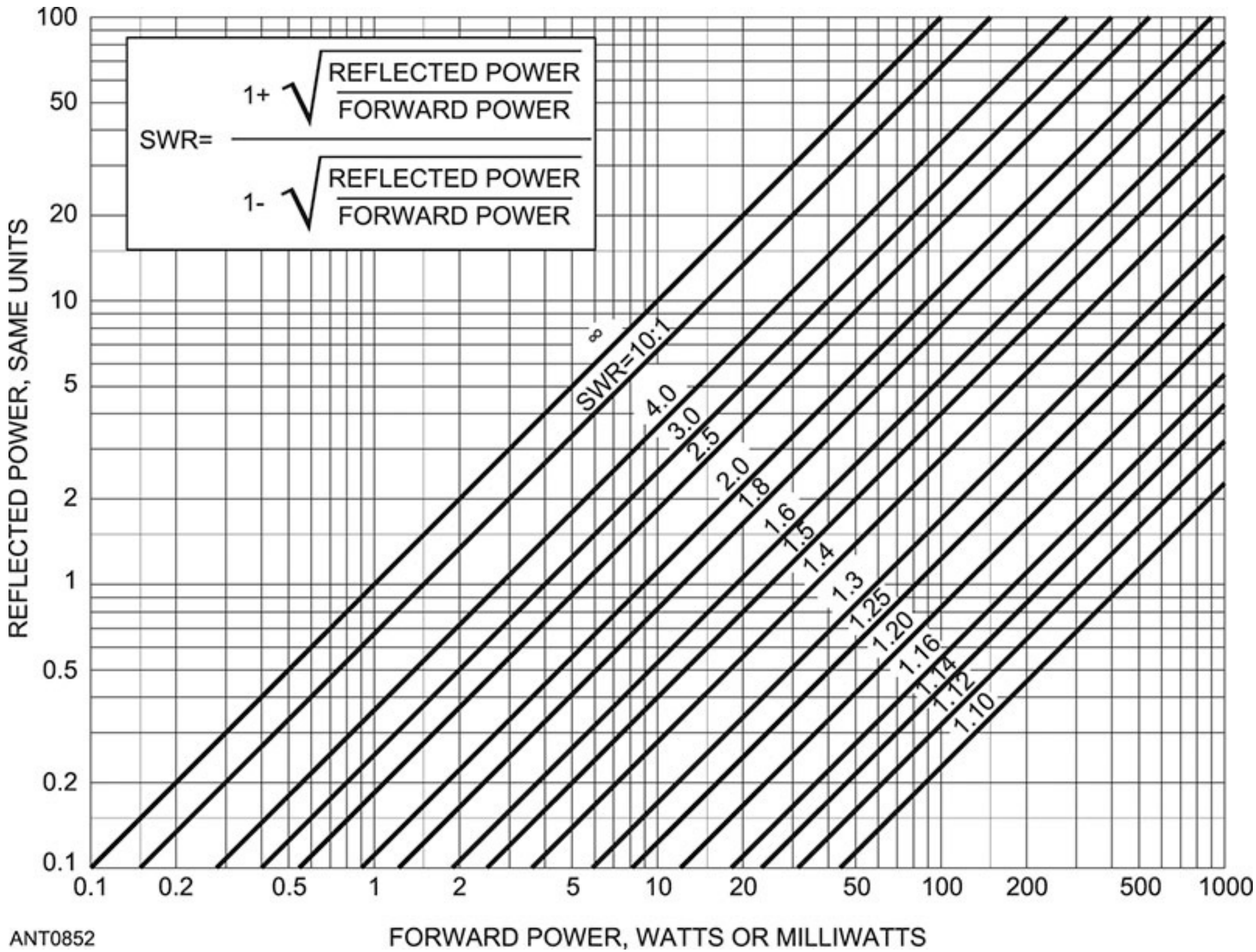
Standing Wave Ratio (SWR)



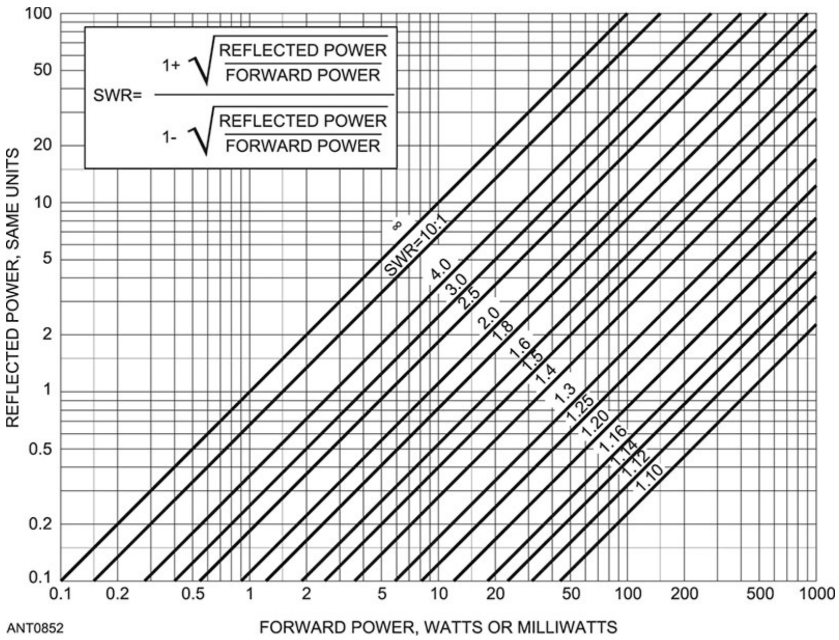
$$SWR = \frac{1 + \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}{1 - \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}$$

- The ratio of forward to reflected power, given by the above equation, is defined as the Standing Wave Ratio (SWR)

Standing Wave Ratio (SWR)



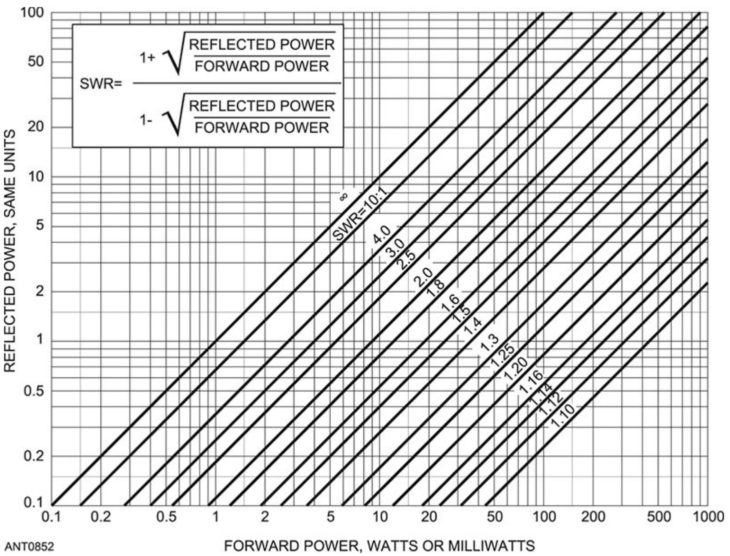
Standing Wave Ratio (SWR)



$$SWR = \frac{1 + \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}{1 - \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}$$

- Notice that if the reflected power is zero, the SWR is 1:1
- With a relatively high 3:1 SWR 20% of the transmitted power will be reflected, a loss in radiated power of about 1db
- This loss will be completely unnoticed at the receiving station
- SWRs of 3:1, or even higher, were common place in the old days of vacuum tube radios

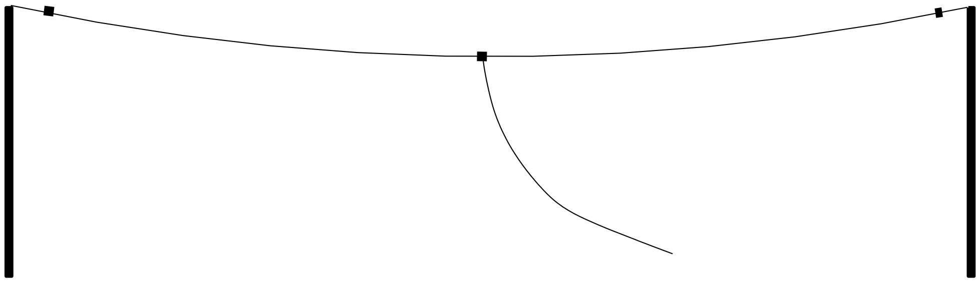
Standing Wave Ratio (SWR)



$$SWR = \frac{1 + \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}{1 - \sqrt{\frac{Reflected\ Power}{Forward\ Power}}}$$

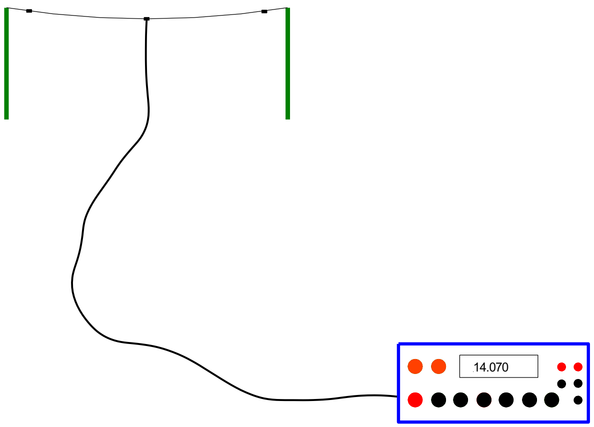
- While vacuum tube power amplifiers can handle an SWR of 3:1
- Semiconductor transmitters (or amplifiers) can not !
- For semiconductor equipment the SWR must be lower than 2:1
- In today's semiconductor world antenna's must be more carefully matched to the transmission line than in the old days, this is done by
  - Operating over narrower frequency bandwidths
  - Using a tuner at the radio
  - Using a match box at the antenna

Antenna Resonance and SWR



- The resonant frequency of an antenna is often not the frequency exhibiting the lowest SWR
- It is not important to know the <u>exact</u> resonant frequency of an antenna
- What is important to know is the frequency at which the antenna system exhibits the lowest SWR

Antenna Resonance and SWR



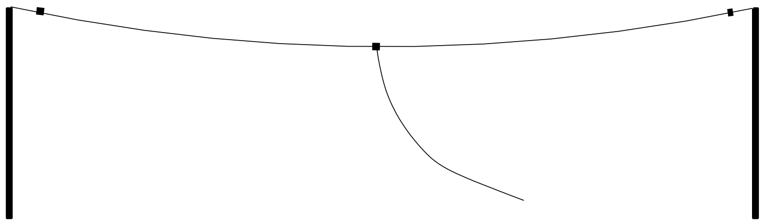
- A transmitter delivers the maximum amount of power to the antenna at the frequency exhibiting the lowest SWR
- Semiconductor transmitters automatically begin dropping output power if the SWR goes above 2:1 in order to protect the transmitter output stage
- Delivering the maximum amount of power to the antenna means:
  - The maximum electrical current flowing in the antenna, and
  - The maximum radiated field strength
- The goal is to adjust the antenna length so that the lowest SWR occurs in the center of the band we want to cover.

Antenna Tunning

SWR Meter

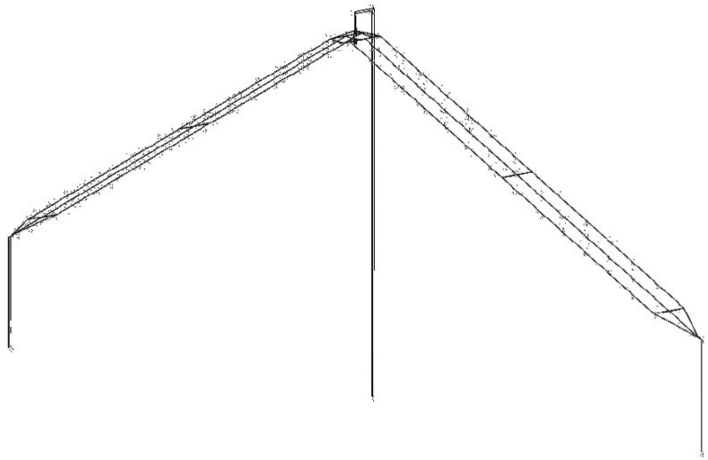
- An antenna is too long if the frequency with the lowest SWR is below the desired center frequency for the antenna
- For example, the antenna is too long if the frequency with the lowest SWR is 6.95 MHz and the desired center frequency is 7.15 MHz
- In this case shortening the antenna raises the antenna's frequency until the lowest SWR occurs at the desired center frequency
- The antenna is too short if the frequency with the lowest SWR is 7.25 MHz
- In this case lengthening the antenna decreases the antenna's frequency until the lowest SWR occurs at the desired center frequency

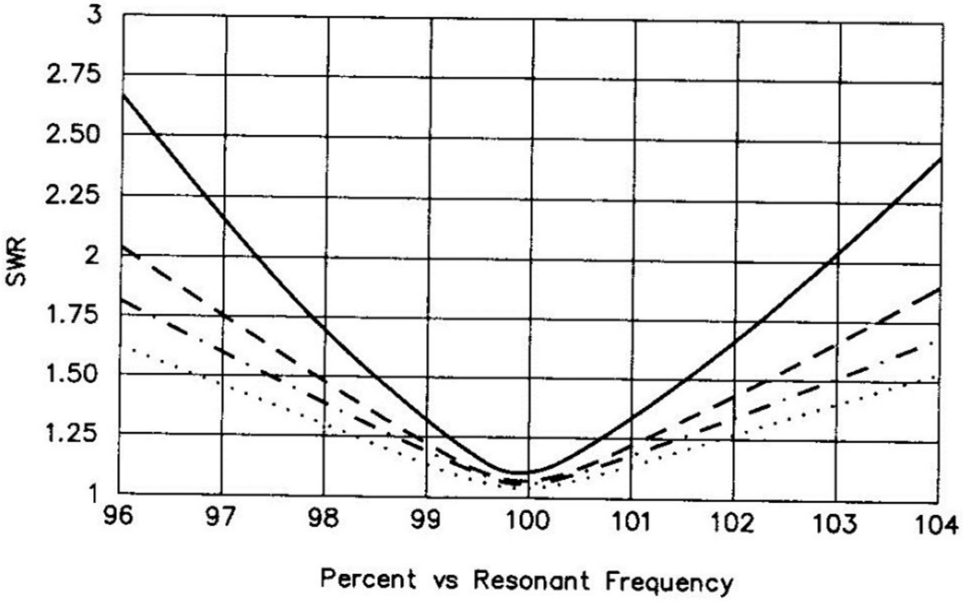
Antenna Bandwidth



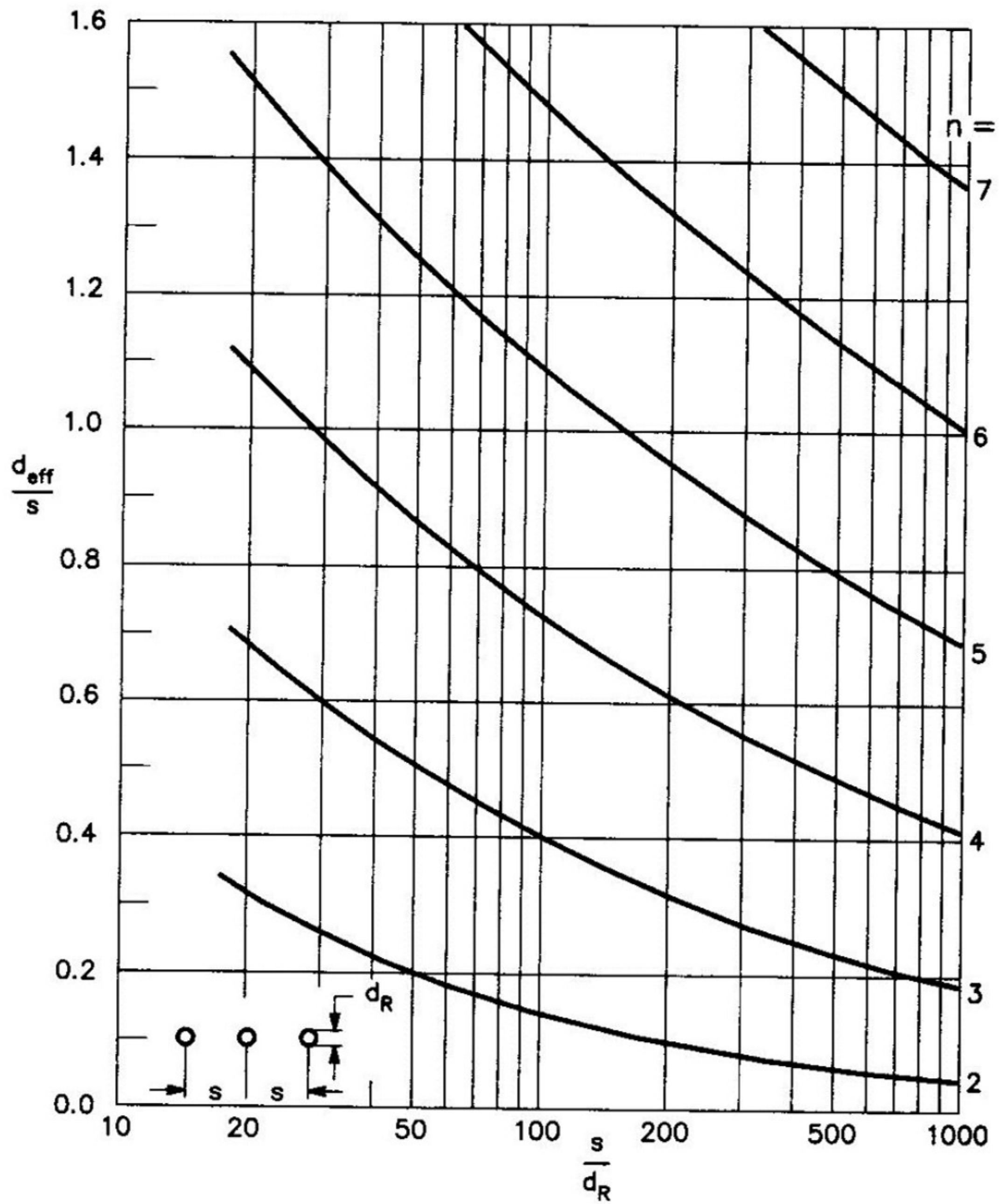
- Antenna bandwidth is defined as the range of frequencies at which an antenna can operate with an SWR below a specified level
- Example: A 75 meter antenna tuned for a frequency of 3,850 KHz has a SWR = 1:1 at that frequency
- At 4,000 KHz its SWR = 2:1
- At 3,700 KHz SWR = 2:1
- Between 3,700 and 4,000 KHz the antenna's SWR < 2:1
- Its 2:1 SWR bandwidth is thus BW = 4,000 – 3,700 KHz = 300 KHz

Broadband Antennas





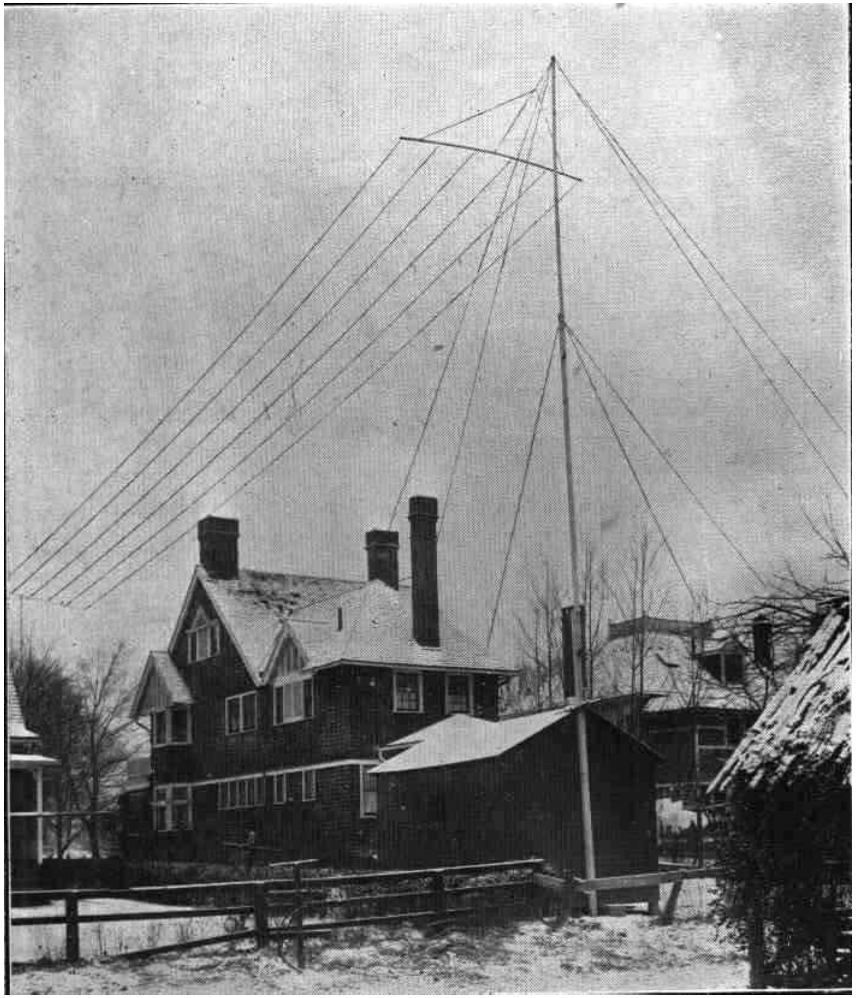
- The SWR bandwidth of a half wave dipole is determined in part by the diameter of the antenna wire
- An antenna built using thicker wire has a wider bandwidth
- Multiple parallel wires increase the effective diameter of the antenna wire & thus its bandwidth
- Solid = #12 wire
- Dashed = 3 wires spaced 4” apart
- Dotted = 3 wires spaced 12” apart



Flat Multi-wire Conductor Chart

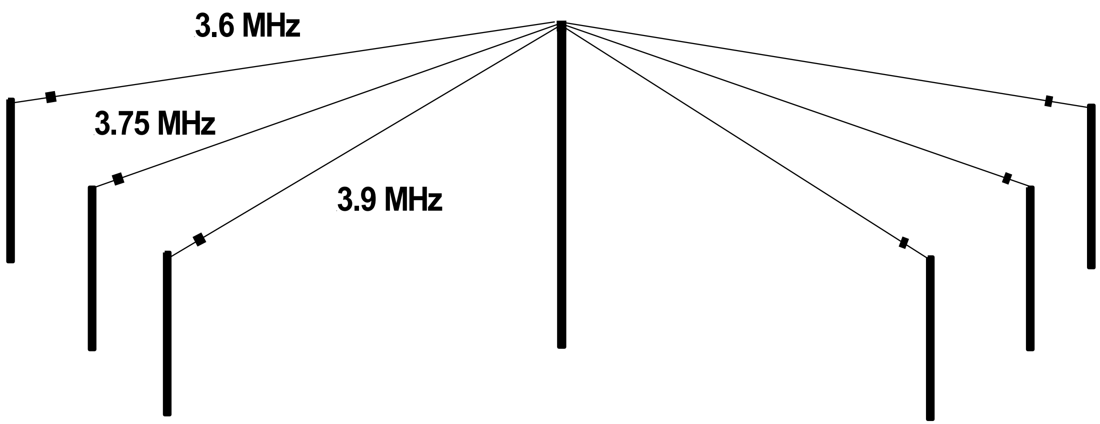
- The effective diameter for a flat multi-wire conductor made out of n small wires uniformly spaced with a spacing S is shown in the chart on the left
- Example: 3 parallel 2 mm dia wires spaced at 10 cm has an effective dia of: 10 cm x 0.5 = 50mm
- Note that
  - 1 inch = 2.54 cm
  - 1 inch = 25.4 mm
  - 12 AWG = 0.081" = 2 mm
  - 14 AWG = 0.064"

Wide Bandwidth Antennas



- In the early days of radio multiple parallel wires were used in an attempt:
- To get more current flowing in the antenna, and
- To achieve wider antenna bandwidths for the very low frequency bands being used at the time

80 Meter Fan Antenna



- The bandwidth of an 80 meter dipole generally does not cover the entire 80 meter band
- The problem can be solved by using 3 dipole antennas driven by a single coax cable
- One dipole antenna is cut for the bottom of the band
- Second antenna cut for the middle of the band
- Third antenna cut for the top of the band