Module 4

Transmission Lines and Antennas

References

- Canadian Amateur Radio Basic Qualification Study Guide (8th Ed), Chapters 7 and 8
- RIC-7

Outline

- Transmission Lines
  - Characteristics of Transmission Lines
  - Characteristic Impedance
  - Balanced v. Unbalanced
  - Types
  - Line Losses
  - Baluns
  - Standing Waves

Outline (cont'd)

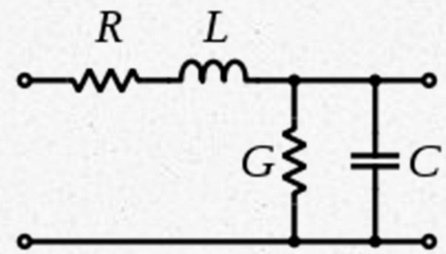
- Antennas
  - EM Wave
  - Terms
  - Current and Voltage Distribution
  - Antenna and Length
  - Radiation Patterns
  - Design
  - Types
  - Arrays
  - Dummy Loads, Tuning and Matching

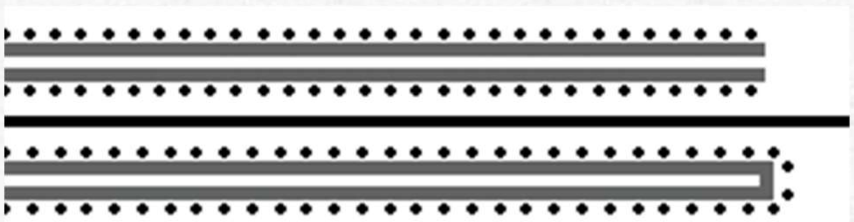
Transmission Line

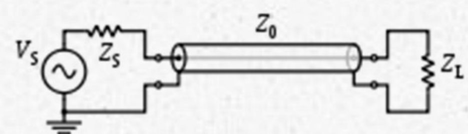
Characteristics of Transmission Lines

- also known as feeders or feed lines
- means by which RF energy is efficiently transferred from antenna to transmitter
- all have two ends
  - input or source end
  - output or load end
- Optimally
  - no radiation from line itself
  - no loss of signal passing along the line
  - constant electrical characteristics throughout length
- Reality – there are some losses

Transmission Lines







Characteristic Impedance

- two conductors
- distributed capacitance
- distributed inductance
- apparent impedance stays constant over wide range of frequencies
- Z_0
- Surge impedance of the line
- value determined by physical dimension of line and positions of conductors

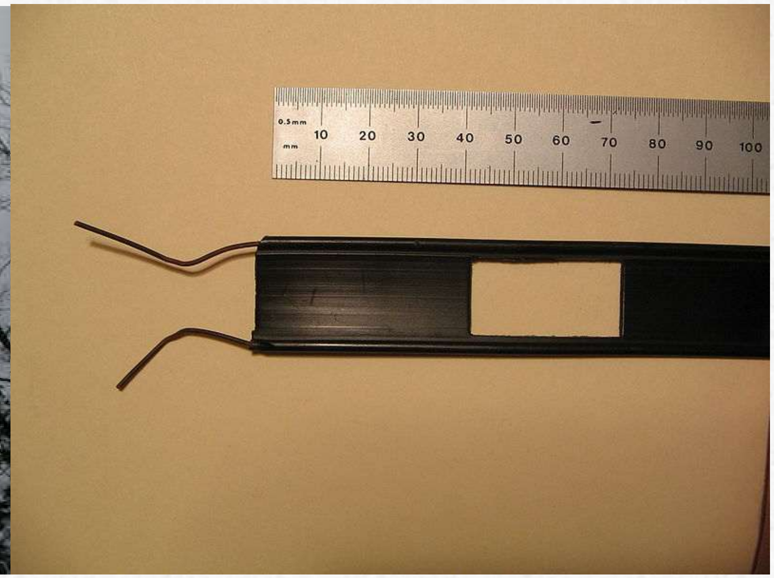
Z_o

- characteristic impedance is ratio of the voltage across the line to the current flowing in the line at any given point
- not affected by length
- characteristic impedance is an AC effect and has nothing to do with DC resistance of line
- power is not dissipated by characteristic impedance
- always some loss in the line – copper loss

Balanced Transmission Line

- $Z_0 = 276 log \frac{2S}{D}$
- characteristic impedance of air-insulated balanced transmission line where Z_0 is the characteristic impedance in ohms, S is centre-to-centre distance between two conductors, and d is the diameter of the conductors

Examples



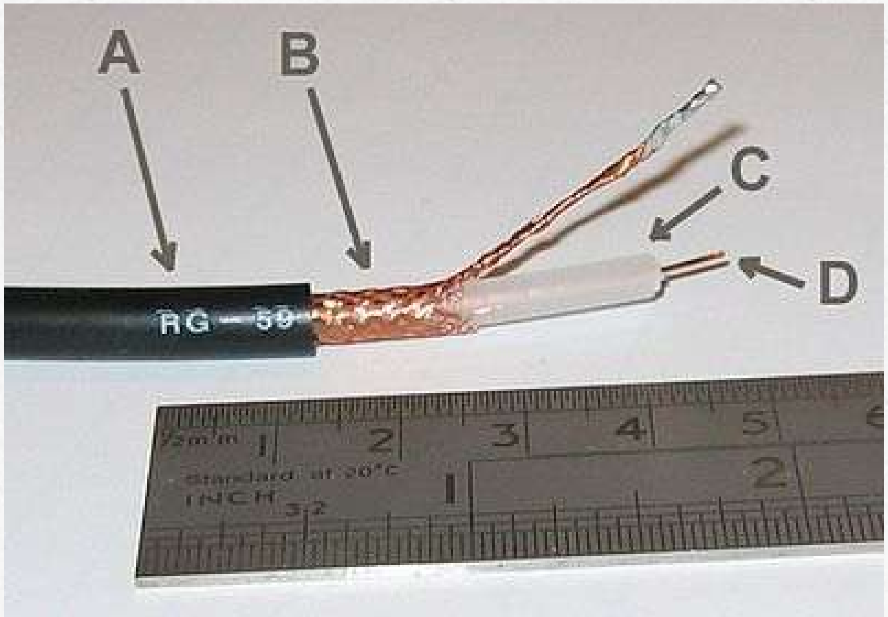
Parallel-conductor feed lines

- open wire line (feeder) – two parallel conductors with air between – may have non conductive spacers, spreaders or separators – cannot be buried
- insulated twin lead – two parallel conductors enclosed in plastic sheath – TV twin lead most common – Z_0 is 300 ohms
- Ladder line – variant of open wire line – lines are further apart - Z_0 is 450 ohms

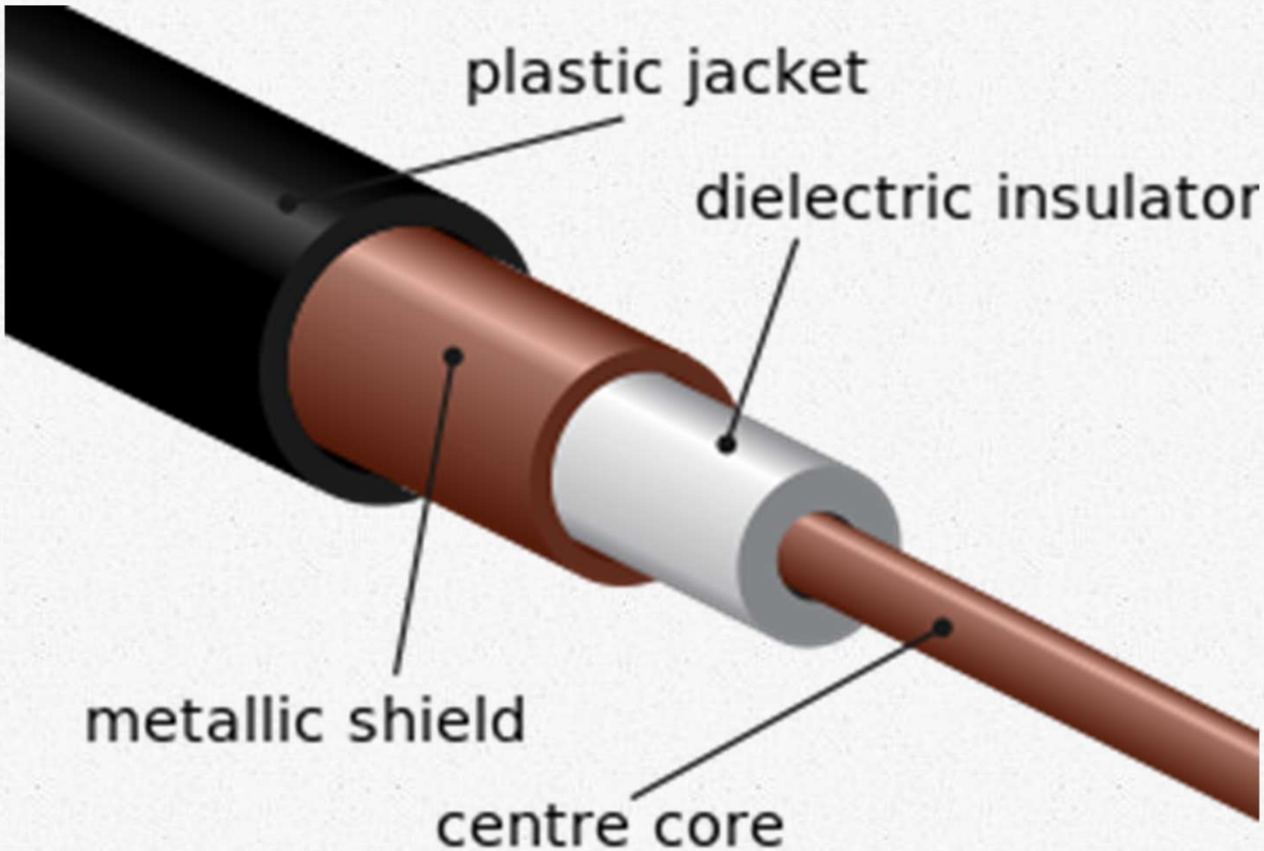
Unbalanced Transmission Line

- has one conductor connected to ground potential and the other carries RF
- coaxial cable
- centre conductor
- dielectric
- outer conductor, shield or braid

Unbalanced Transmission Line



Coaxial Cable



Unbalanced Transmission Line

- $Z_0 = \frac{138}{\sqrt{e}} \log(\frac{D}{d})$
- Z_0 is characteristic impedance
- e is the dielectric constant of the dielectric
- D is diameter of outer conductor
- d is diameter of inner conductor
- Hardline or Heliax
- energy transferred to antenna is inside line
- propagation delay/velocity factor
  - <1 and 1 is if propagated in free space
  - influence of dielectric in particular
  - often for VHF lines become lossy

Types

- RG58/U – HF note VHF/UHF
- RG8/U – HF and VHF and UHF
- RG213/U – excellent for HF
- RG59/U – 75 ohms
- Relatively weather proof
- Connectors – see VE8PAT
- SO239 connector, BNC, N, F, SMA & adapters
- cold solder joints, kinks
  - min radius for any loop should be 5 to 10 times diameter of cable else kink

Weatherproofing

- effects of water
- effects of UV light
- non-contaminating jacket

Baluns

- balanced transmission line ⇔ unbalanced
- common
  - 75 ohm TV coaxial cable to 300 ohm TV twin lead
  - transformer (recall $\frac{E_S}{E_P} = \frac{N_S}{N_P}$ and that V=IR)
  - Step down transformer where 4 turns on primary and 1 on secondary

Standing Waves

- voltage standing wave ratio, standing wave ratio
- SWR and VSWR
- measure of effectiveness of coupling between two transmission lines
- has to do with reflections, transmission etc. (boundary interface conditions between media – Maxwell's Equations)
- If there are reflections, this reduces power transmitted and may also damage radio

Standing Waves

- reflected wave + transmitted wave in transmission line superimposed (superposition) and end up with interference pattern called a standing wave
- measured on SWR meter or bridge or network/antenna analyzer
- SWR is comparison betwee forward voltage and reflected voltage
  - $SWR = \frac{V_F + V_R}{V_F - V_R}$ OR $SWR = \frac{Z_0}{Z_L}$
  - where Z_0 is impedance of the load (antenna) and Z_L is impedance of the line
  - e.g. what is SWR of system if transceiver and coax of 50 ohms connected to folded dipole with feed point of 300 ohms? [6]

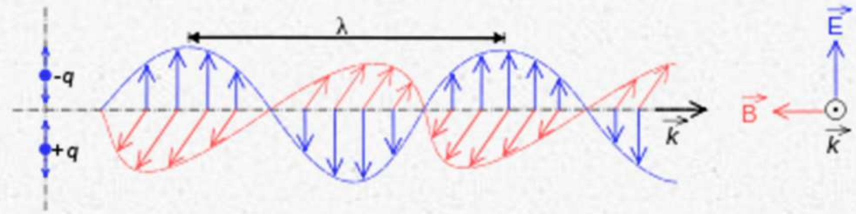
Standing Waves

Antennas

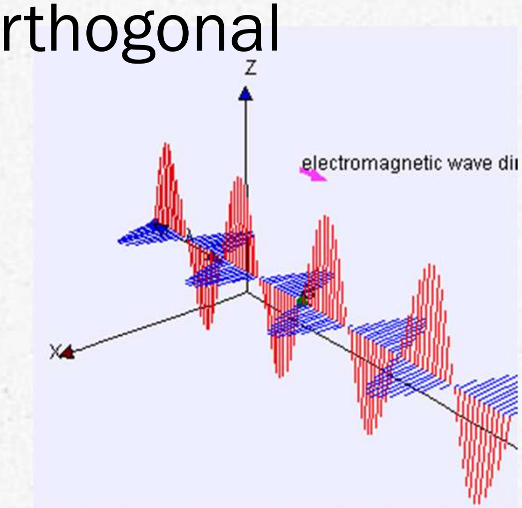
What is it?

- Radio station is really a system of devices
  - operator
  - microphone
  - transceiver (black box)
  - antenna (line, antenna, tuner etc.)
  - path
  - other station…

EM Wave



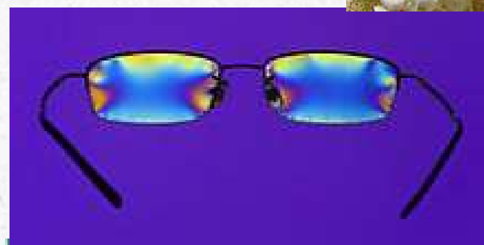
- Recall E and H
- Transverse Wave
- E and H are orthogonal (mutually perpendicular)
- Direction of propagation is also orthogonal to E and H
- Left Hand Rule
- Polarization

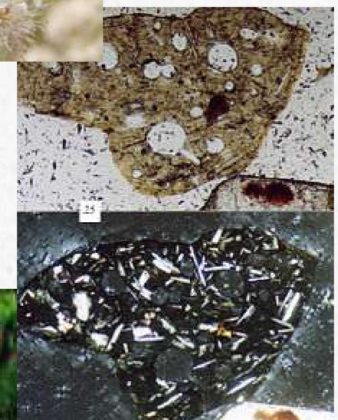


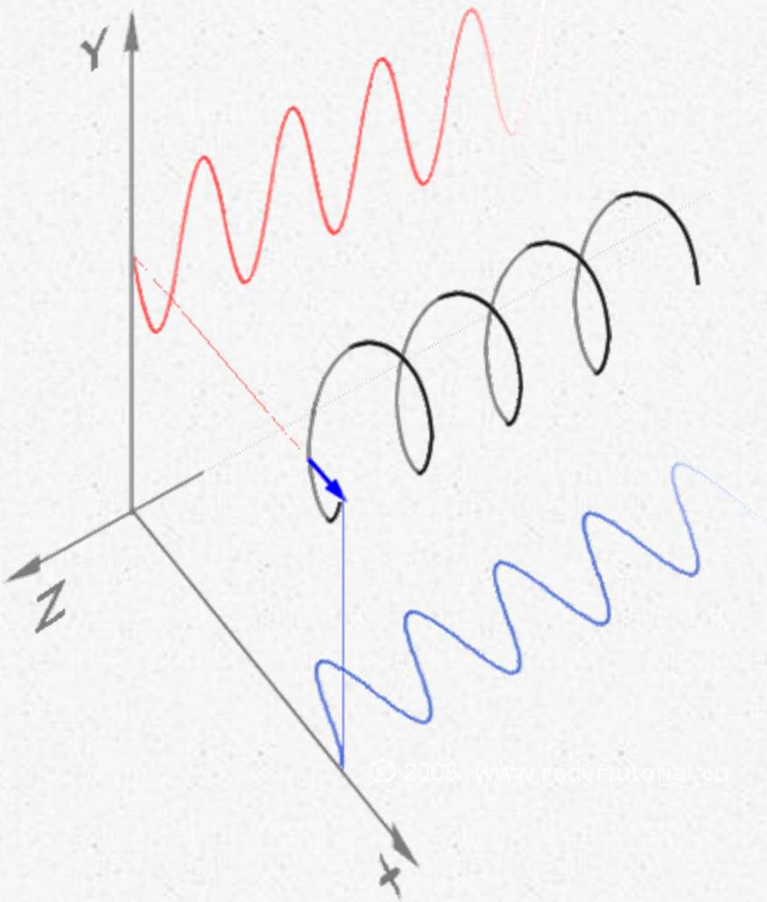
Polarization

- orientation of E w.r.t. surface of Earth
- Electromagnetic waves, such as light, and gravitational waves exhibit polarization; sound waves in a gas or liquid do not have polarization because the medium vibrates only along the direction in which the waves are travelling
- horizontal, vertical and circular

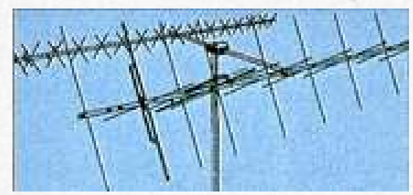
Polarization







Polarization



Terms

- isotropic radiator – perfect antenna that radiates in all directions – isotropic source is useful as a reference for antenna gain – OdB gain
- elementary dipole (doublet) – basis for many antenna calculation – perfect theoretical antenna – so short current distr is constant – not to be confused with the dipole antenna

Terms (cont'd)

- Antenna gain – measure of effectiveness of a directional antenna compared to a standard (dB always compared to x). Usually compared to isotropic radiator and gain expressed as dBi.
  - Common dipole has gain of 2.16 dBi
  - Sometimes the comparison is to a half wave dipole – so dBd used
  - manufacturers often vague on this point

Terms (cont'd)

- Antenna impedance – apparent value of termination which, if substituted for antenna, would have same I, V and reactance characteristics as antenna
  - determined by voltage and current at antenna terminals
  - may be purely resistive or complex (mix of resistance and reactance)
  - if antenna resonant then impedance pure resistance – if off resonance then has reactive component of impedance
  - radiation resistance (R_0) and ohmic resistance (R)
  - $P = I^2(R + R_0)$
  - I, R_0 and R measured at current max and for simple centre fed half wave antennas current max is at the antenna terminals

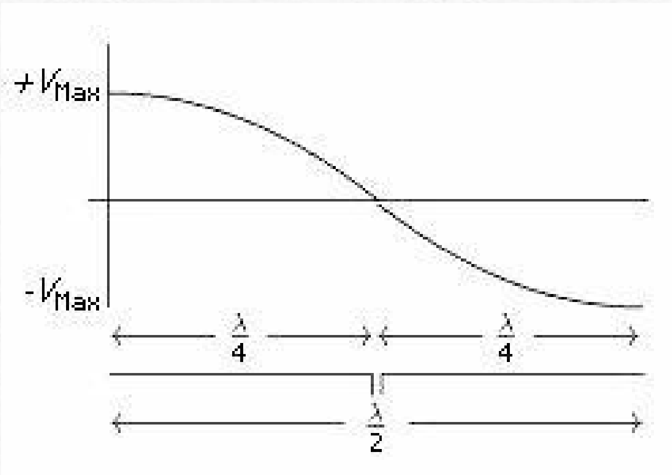
Terms

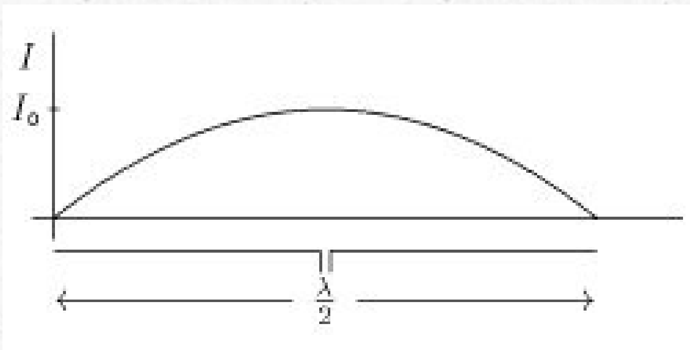
- Directivity – of antenna is measure of its radiation pattern
  - narrower and sharper, directivity increases
  - directivity and gain are related
- Polarization – position of E field of EM wave wrt the Earth's surface
  - not important for HF signals refracted and reflected from ionosphere – Faraday rotation
  - line of sight VHF – polarization is an issue EME and satellites
- Bandwidth – frequency span which produces VSWR of 2:1 or less – wide range then broadband else narrow-band antenna

Current and Voltage Distribution in an Antenna

- Current distribution – max current at feedpoint (but zero voltage)
- Ends of conductor current minima but voltage maxima
- If an antenna fully supports a standing wave, it is a resonant antenna – max power transfer from the radiator
- charge in the conductor moves more slowly than the supported EM wave – resonant length of conductor is shorter than the free space wavelength

Current and Voltage Distribution in an Antenna





Antenna and Length

- Efficient antennas must resonate
- radiator/radiating element/driven element
- $c = \lambda f; \lambda = \frac{3\times10^{9} m/s}{f}$
- Electrical wavelength of an antenna is length of conductor required to support a standing wave
  - function of diameter to length ratio of conductor – 10k:1 or 40 m antenna at 12 AWG causes about a 2% shortening
  - function of end effect – loading effect of the capacitance of the insulators and wire wrapped around them

Antenna Length

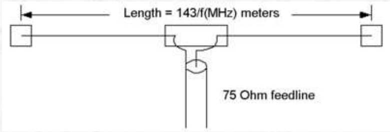
- <30 MHz shortening factor of 0.95
- $\lambda_E = \frac{300}{f} metres \; or \; \lambda_E = \frac{984}{f} feet$
- You want a ¼ wave ant cut for the 2 m band at 146.52 MHz. How long must it be?
  - $\lambda_E = \frac{300}{f}$m=$\frac{300}{146.520} metres = 2.048\, m$
  - But we want ¼ so length is 0.51 m
  - How many cm is this?

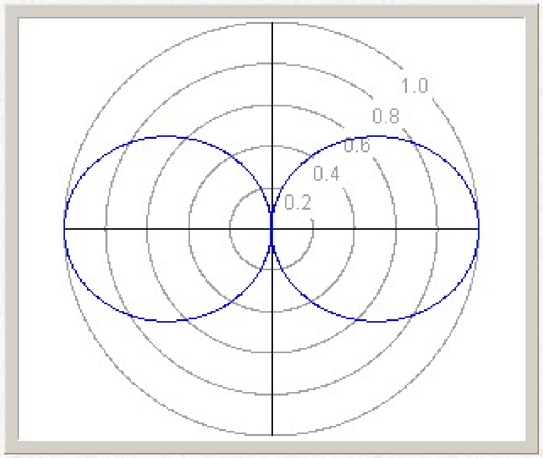
Antenna Length

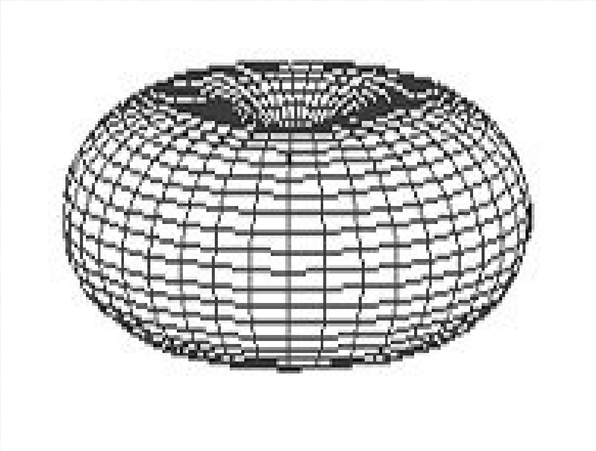
- always wise to cut antenna longer than calculated (easier to trim than to extend)
- also we are dealing with approximations
- often we operate on bands much wider than what an antenna will operate on
  - we tune the antenna with an antenna tunerso that it is in resonance or close to it
- higher frequency, shorter the antenna
- lower the frequency, longer the antenna
  - ELF transmitters for submarines

Radiation Patterns

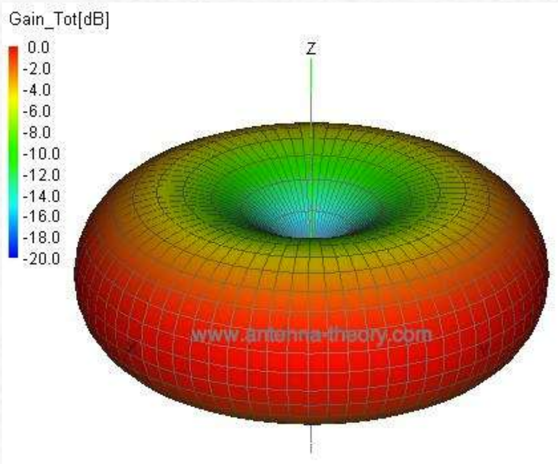
- isotropic radiator (all directions) – sphere
- elementary dipole exhibits directivity
- radiation max rt angles to dipole



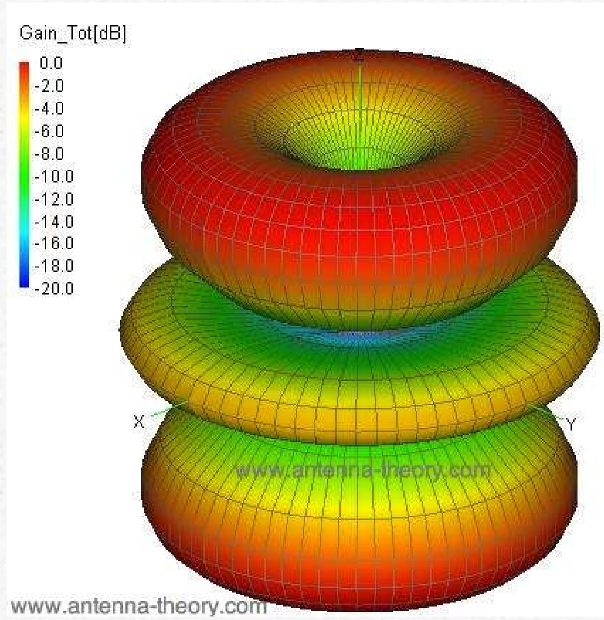




Radiation Patterns

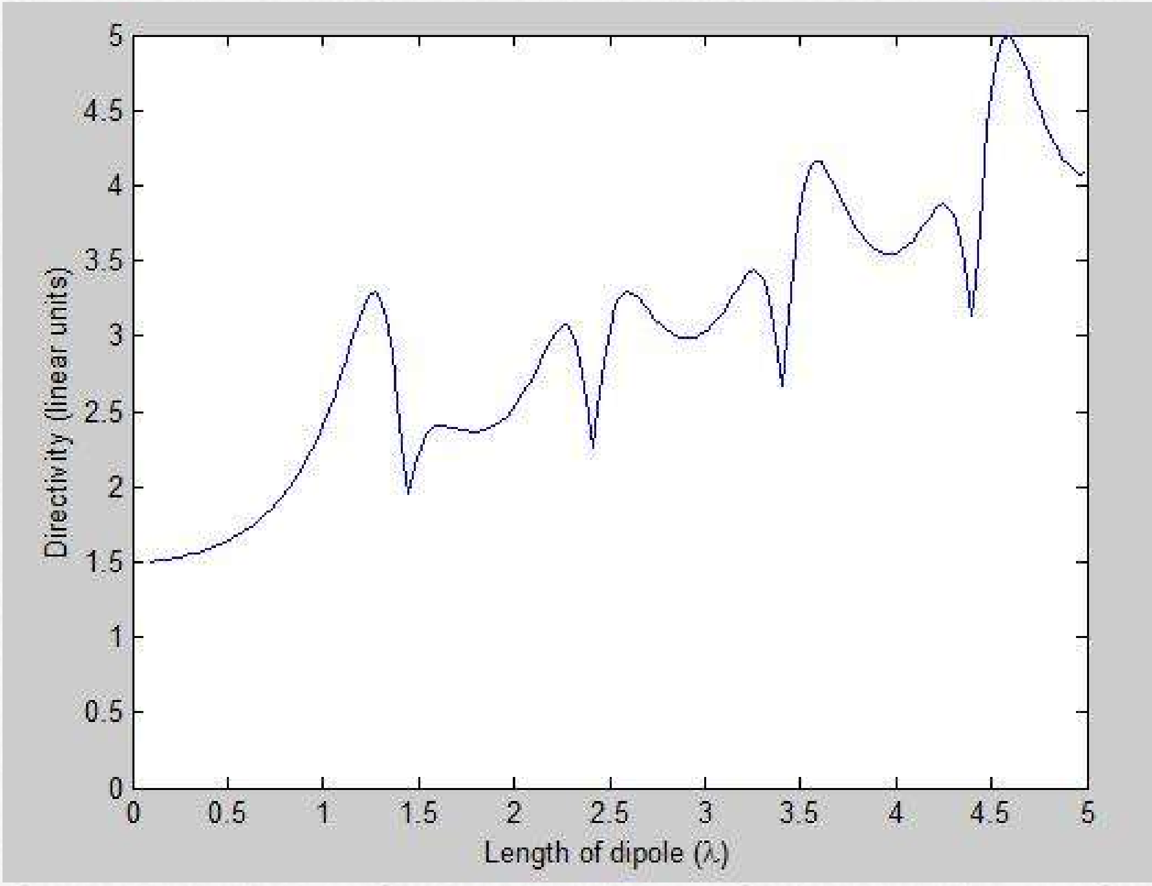


1 wavelength dipole



1.5 wavelength dipole

Notice How Directivity Changes



Radiation Patterns

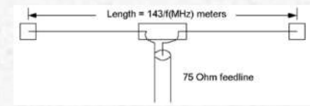
- If antenna is near ground, pattern is modified by reflections from ground (NVIS)
- Sometimes apparent reflection may occur virtually below ground (salt or marsh)
  - image antenna
- any horizontally polarized antenna must be mounted at least 0.5 wavelength above the surface of the ground if directivity is important – closer to ground, more distortion
- note reflections of vertically polarized signals causes phase shift of 180 degrees

Designs

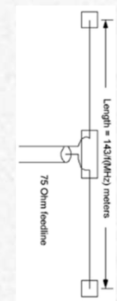
- F(bandwidth, directivity and gain)
- simple antenna – only 1 element with feedline (dipole)
- parasitic array – additional elements but only one is driven (Yagi)
- helical beam – circularly polarized
- parabolic beam antenna

Simple Antennas

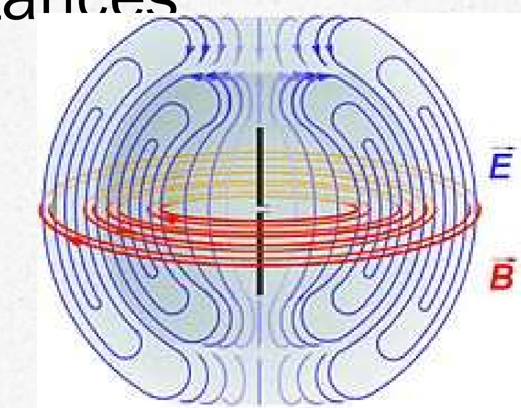
- half wave dipole (Hertzian antenna)



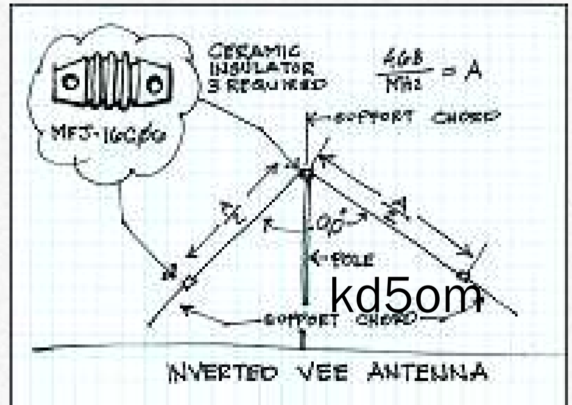
- doublet



- feed point
- torus
- loading coils and series inductances
  - reduce footprint
- economical, rugged, easy
- narrow bandwidth



Simple Antennas

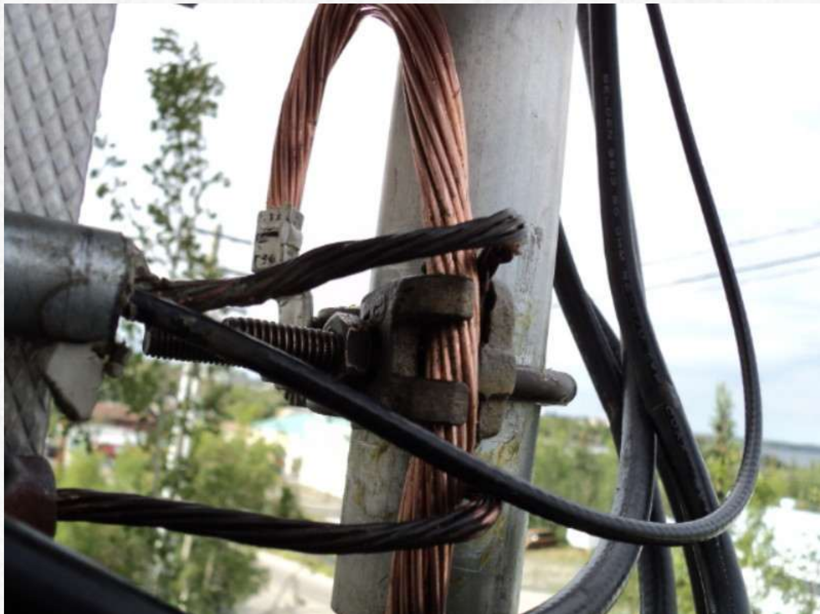


- Inverted Vee
- may achieve shorter range
- high voltage risk at ends
- multiple dipole in book
- insertion of traps (complexity) – easy to make but weatherproofing needed
  - weight goes up, multiband, poorer performance than a dipole
- folded dipole – cheap but needs tuner or balun
- end fed wire – several wavelengths

Vertical Antenna

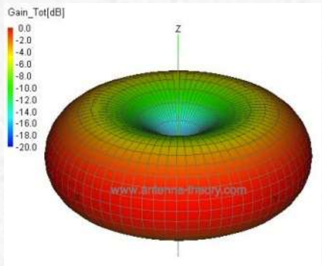
- omnidirectional radiation pattern
- properly grounded low radiation angle
- noisier
- ¼ wavelength tall – image or virtual antenna
  - ground plane
  - radial wire system
  - counterpoise

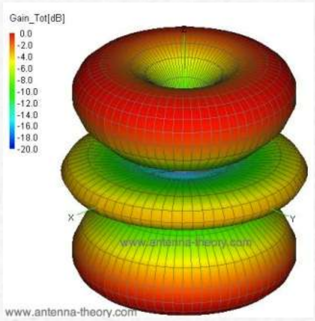
VE8PAT



Vertical Antenna

- radiation pattern is omnidirectional in horizontal plane
- 5/8 wavelength better than ¼
- loading coils needed to make resonant
- VHF and UHF mobiles





Parasitic Antennas

- Multi-element parasitic directional driven arrays (or beam)
- Driven Element
- Parasitic Element (director or reflector)
- Reflector Element
- Director Element
- Front to back ration
- YAGI-Uda

Beams

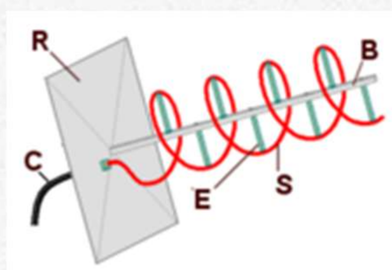
- reflector is 5%longer than DE is inductively reactive and lags in phase
- director is about 5% shorter than DE and capacitively reactive and leads in phase
- Gain can range from 5.5 dB to 25 dB
- multiband (with traps) or monobanders
- wind loading (ice loading too)
- tower issues
- Quads, Spiderbeams etc.

Beams

- log periodic, collinear, arrays of vertical Marconis
- Phased Arrays
- Fox Hunting
- Broadside antenna (dipoles in parallel) – Jove
- Log Periodic – all elements are driven - broadband

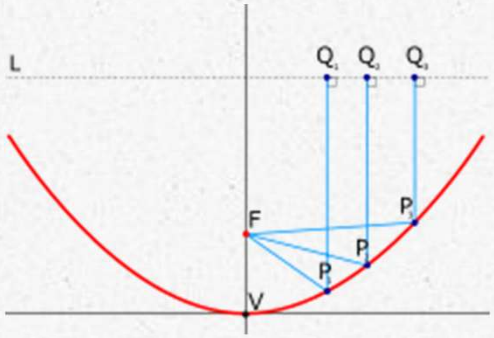
Helical Beam

- circularly polarized
- especially for satellites
  - tumbling in space



Parabolic Beam

- TV satellites and UHF
- optical properties
  - parabolic geometry
- Some EME



Dummy Loads

- accessory
- resistors with appropriate power rating
- allows transmitter to be adjusted without causing interference
- also for calibration of SWR meters

Antenna Bandwidth

- capability to be used over range of frequencies
- selectivity
- selectivity reduced by increasing effective diameter of radiating elements
- increased by present of objects or ground

SWR and Antennas

- 1:1 is perfect
- 2:1 is OK
- Anything higher is a problem and one needs a matching network
- SWR can also be used to measure an antenna’s performance – more trimming?

Baluns

- transformer
- balanced to unbalanced or unbalanced to balanced

Conclusion

- Antennas are not restricted with the Basic Qualification
- Lots of room for experimentation
- VE8IR built a VHF/UHF satellite antenna with 5 coat hangars, bamboo pole and duct tape
- SAFETY

Questions