Radio Aerial Systems and the Art of Compromise

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What is an Aerial System?

An aerial (or antenna) system connects a radio transmitter and receiver to the world.

It has three functions:

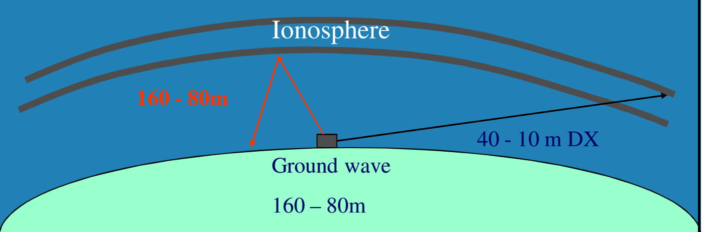
- **To transport the energy from the transmitter to the radiating system [Aerial or Antenna] with minimal loss**
- **To radiate the signal in the desired direction.**
- **To present the transmitter output with the correct load impedance (Usually 50Ω or 75Ω non-reactive).**

Background Theory

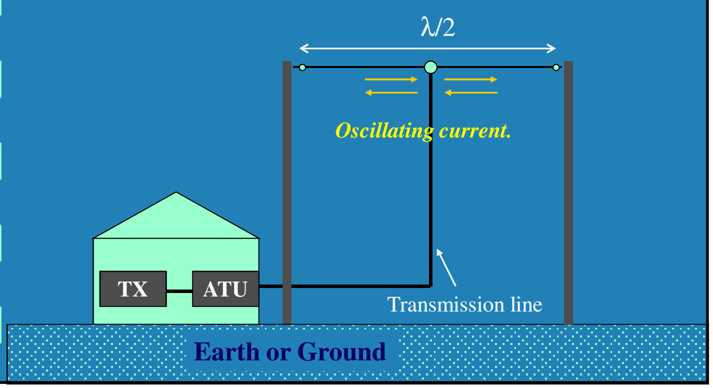
- Radio Propagation
- Radiation from a dipole
- Transmission lines
- Ground Reflections
- Vertical Aerials

Radio Propagation

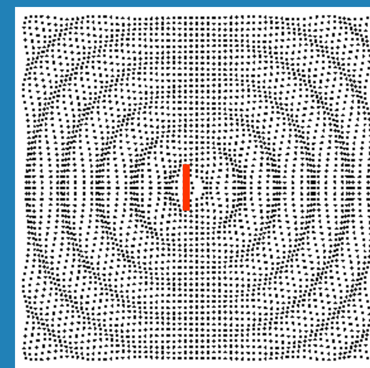
- **Low angle (15 - 30°) radiation for HF DX**
- **High angle (40 - 60°) sky-wave and ground wave for short and medium distance 160 & 80 m contacts.**
- **Almost Horizontal radiation for terrestrial VHF**

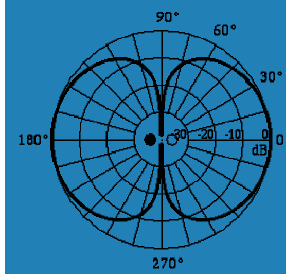


The Aerial System

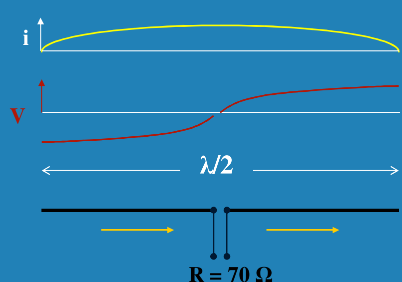


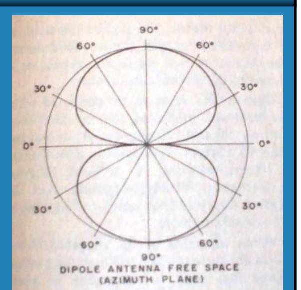
Dipole Radiation Animation





Half - wave Dipole

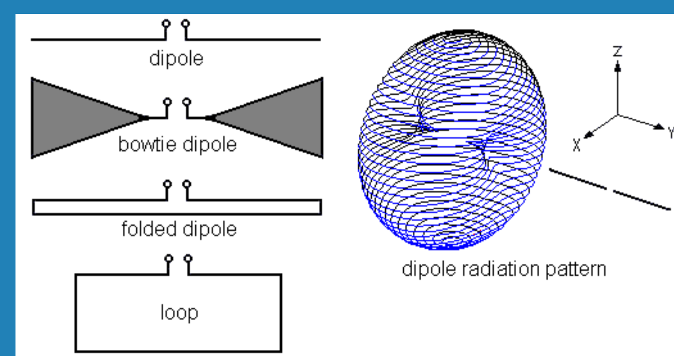




Theoretical gain 1.8 dB relative to isotropic source

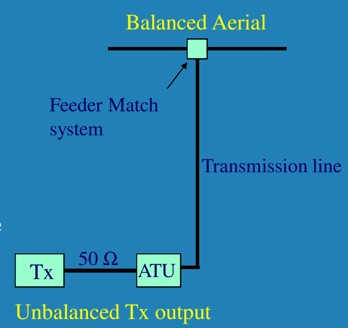
There is no isotropic radio antenna

Variations on a Dipole



Connecting the Dipole to the Radio

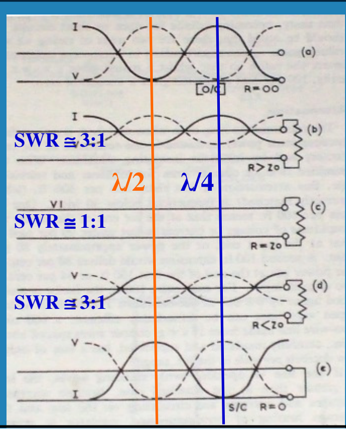
- A *Transmission Line* connects the dipole to the transmitter.
- A *Balun* is needed to convert the balanced dipole to the unbalanced transmitter output.
- The input impedance of the coaxial cable must present a suitable load for the transmitter.



What is a Transmission Line ?

- A transmission line is a RF extension cable.
- Characteristic surge impedance $Z_0 = \sqrt{(L/C)}$
- If load impedance <> Line impedance
  - Some forward power will be reflected and set up standing waves on the line.
  - The feed impedance will be different to the load impedance
  - SWR = Max voltage/Min voltage on line
  - SWR = Load impedance/Line impedance

Standing Wave Ratio



Open circuit line

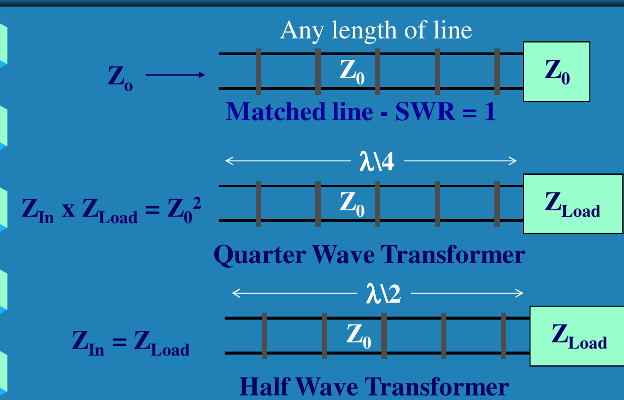
$R_{Load} > R_{Line}$

$R_{Load} = R_{Line}$

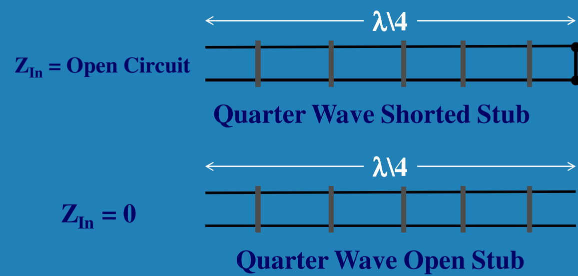
$R_{Load} < R_{Line}$

$R_{Load} = 0$

Transmission Line Basics



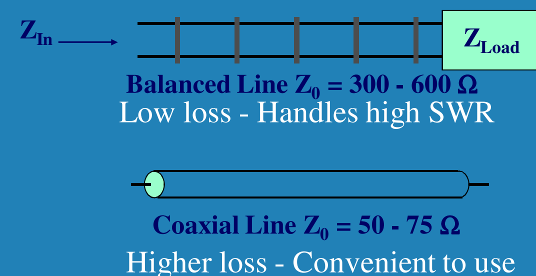
Transmission line Stubs



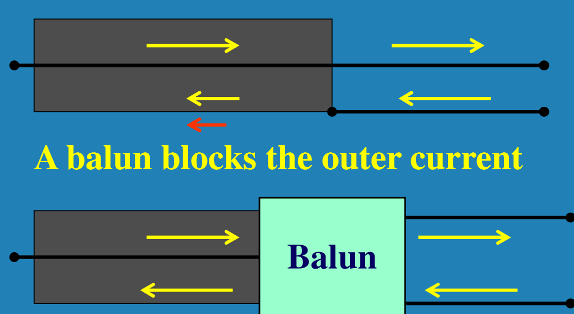
Balanced & Unbalanced Lines

Z_0 = Characteristic impedance = $\sqrt{L/C}$

SWR = Z_{load} / Z_0 or Z_{load} / Z_0



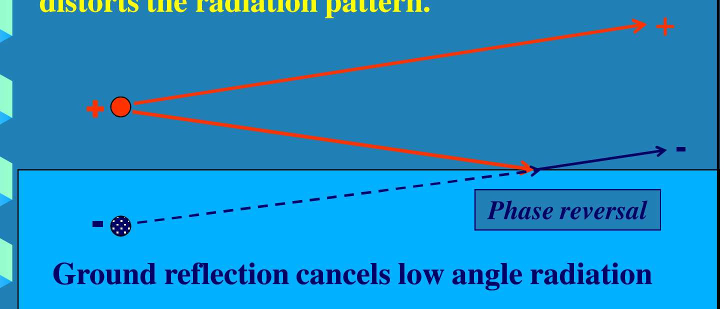
BALUNS
BALanced to UNbalanced transformer

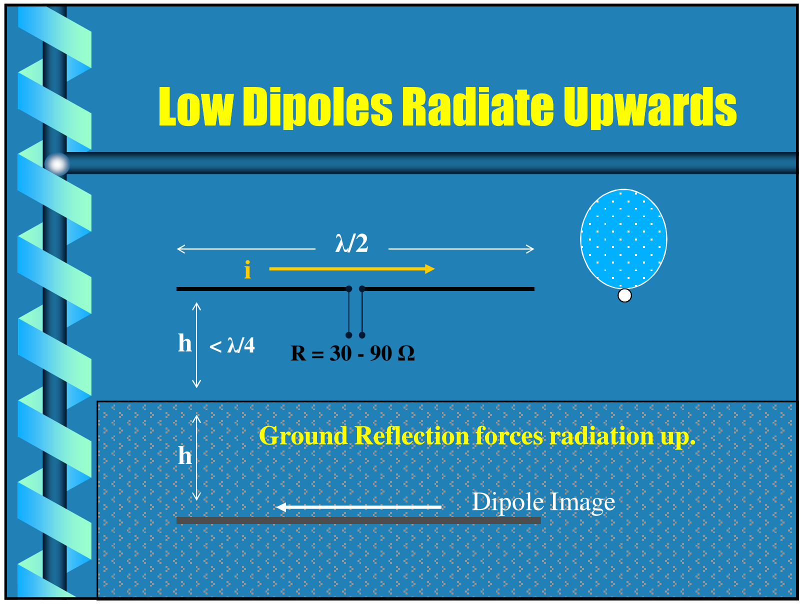


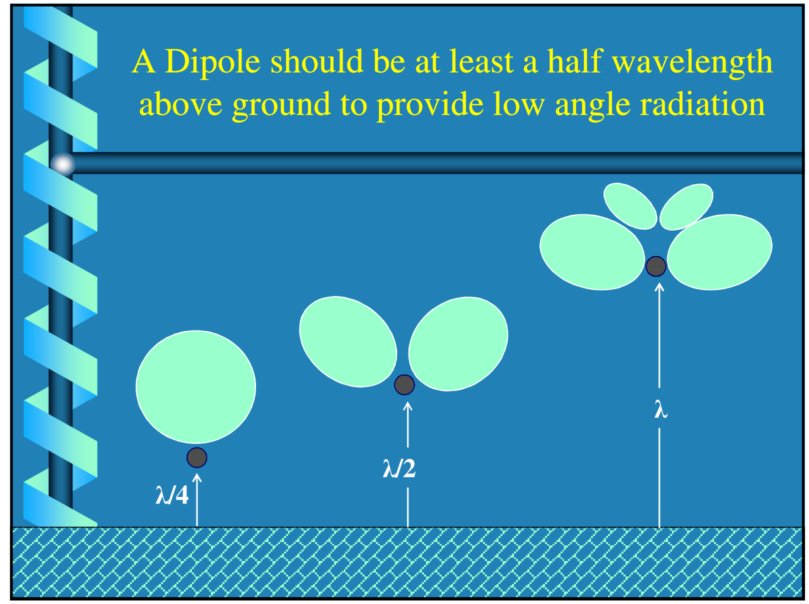
Baluns come in 1:1, 4:1 and 9:1 ratios

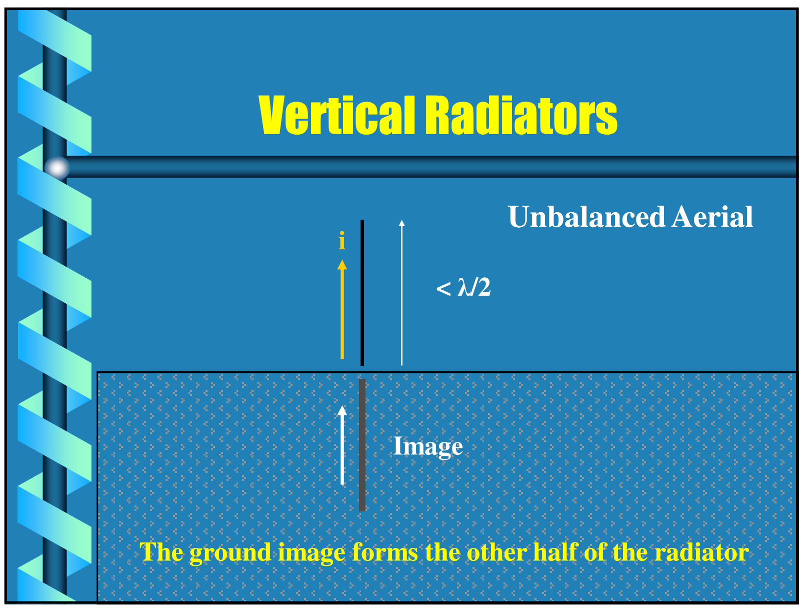
Ground Reflections

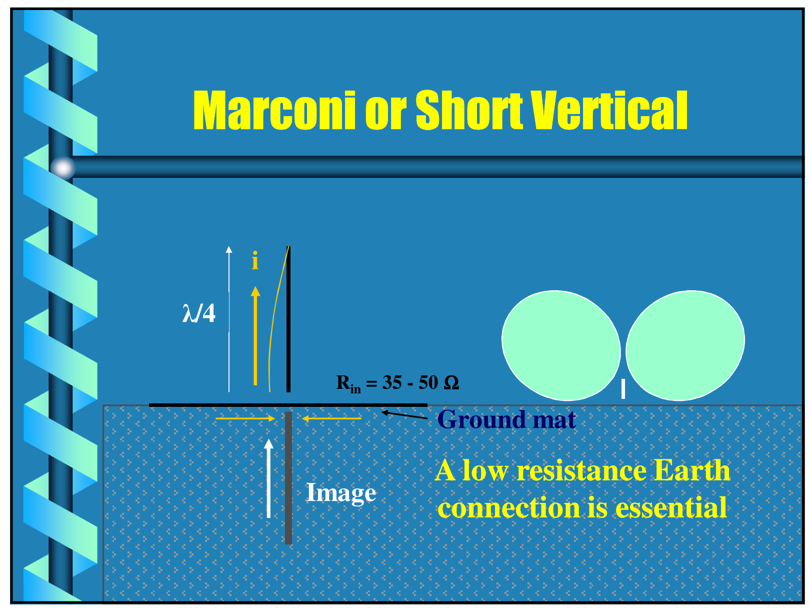
All aerials are mounted above a ground plane which reflects some of the radiated signal and distorts the radiation pattern.

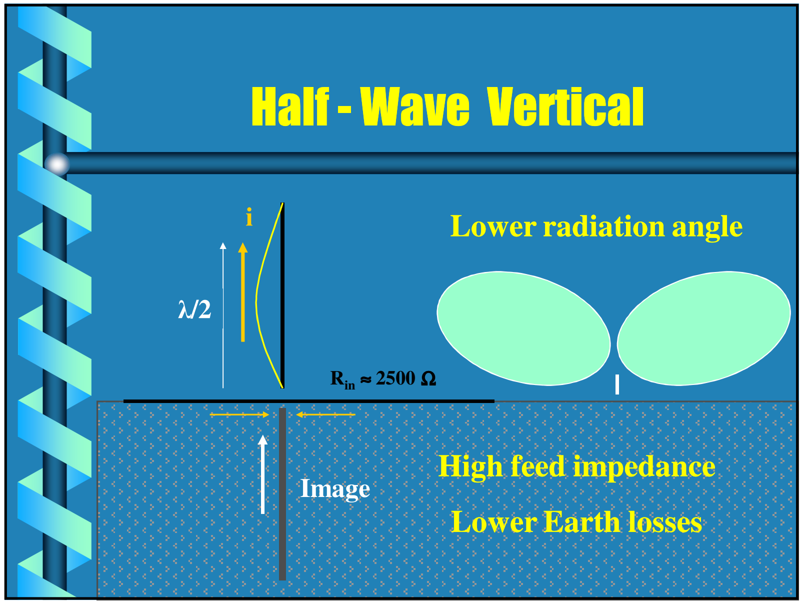


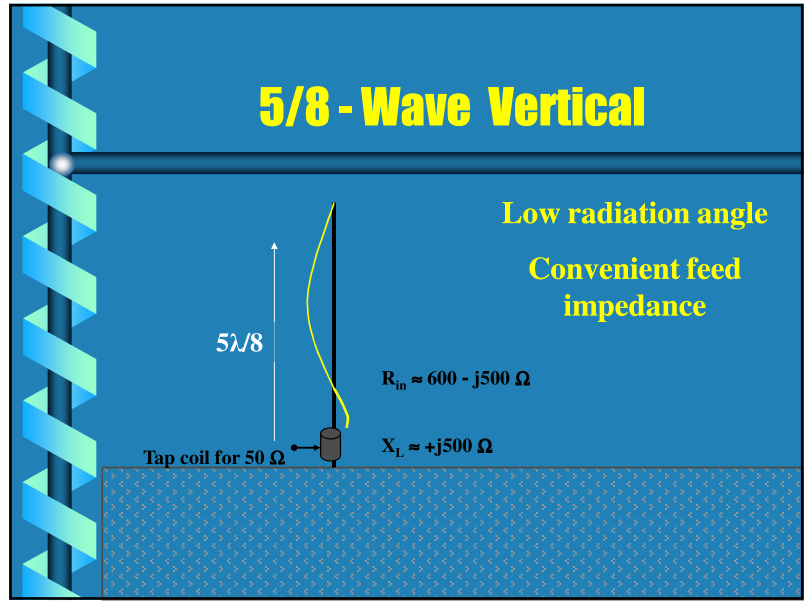

Low Dipoles Radiate Upwards
λ/2
i
h
< λ/4
R = 30 - 90 Ω
Ground Reflection forces radiation up.
h
Dipole Image

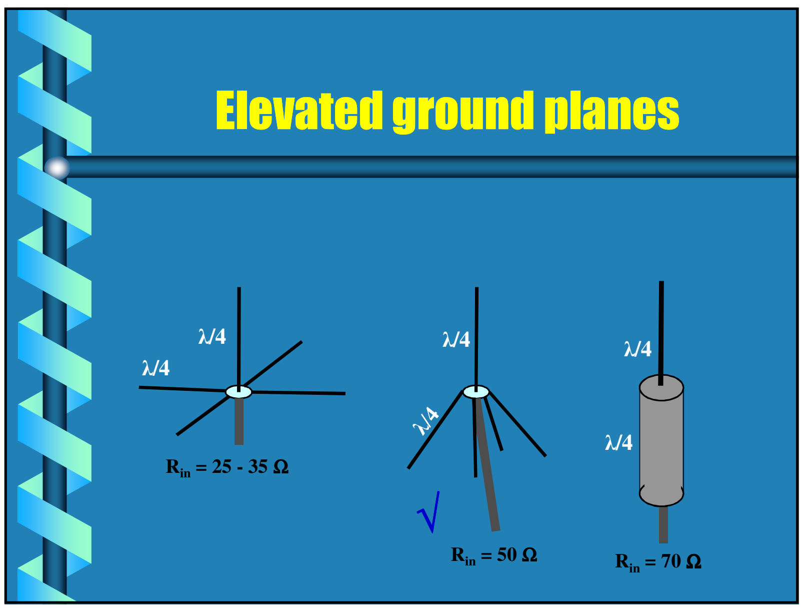

A Dipole should be at least a half wavelength above ground to provide low angle radiation
λ/4
λ/2
λ

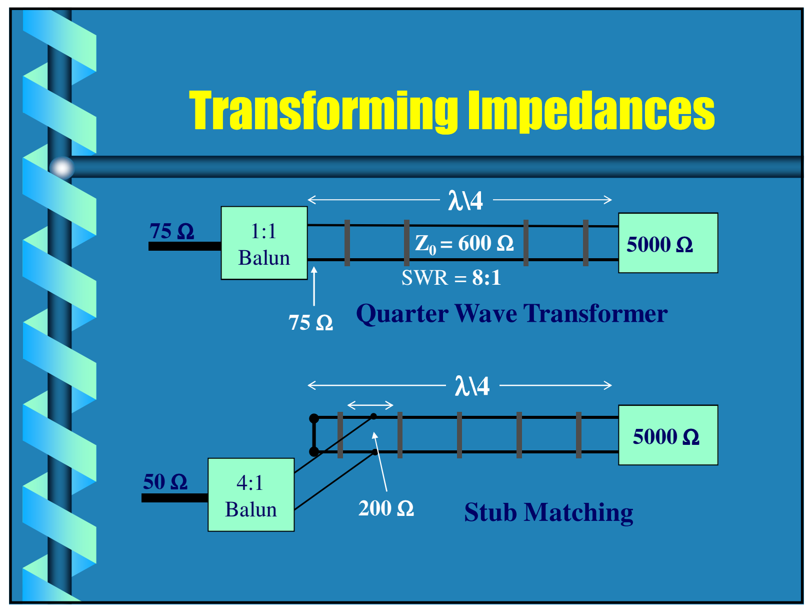

Vertical Radiators
Unbalanced Aerial
i
< λ/2
Image
The ground image forms the other half of the radiator


Marconi or Short Vertical
λ/4
i
R_{in} = 35 - 50 Ω
Ground mat
Image
A low resistance Earth connection is essential

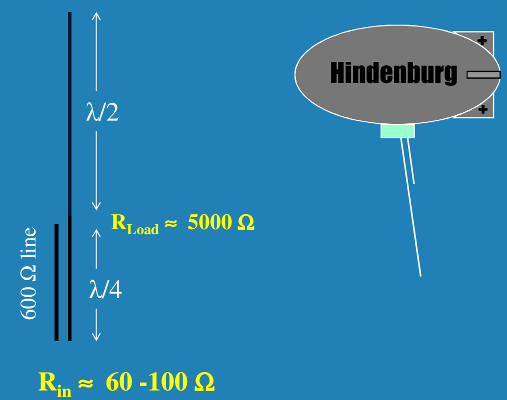

Half - Wave Vertical
Lower radiation angle
i
λ/2
R_in ≈ 2500 Ω
Image
High feed impedance
Lower Earth losses


5/8 - Wave Vertical
Low radiation angle
Convenient feed impedance
5λ/8
R_in ≈ 600 - j500 Ω
Tap coil for 50 Ω
X_L ≈ +j500 Ω

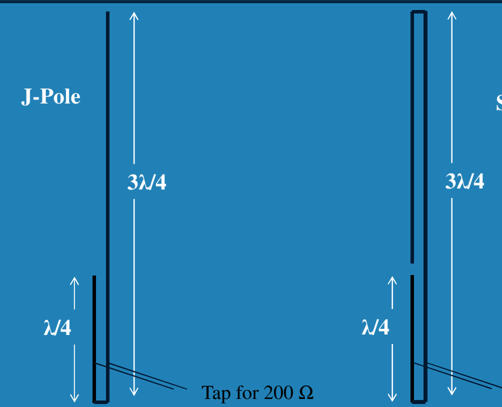

Elevated ground planes
λ/4
λ/4
R_in = 25 - 35 Ω
λ/4
λ/4
√
R_in = 50 Ω
λ/4
λ/4
R_in = 70 Ω


Transforming Impedances
λ\4
75 Ω
1:1 Balun
Z_0 = 600 Ω
5000 Ω
SWR = 8:1
75 Ω
Quarter Wave Transformer
λ\4
5000 Ω
50 Ω
4:1 Balun
200 Ω
Stub Matching

Zeppelin End - Fed Dipole



Stub-Tuned End - Fed Dipoles

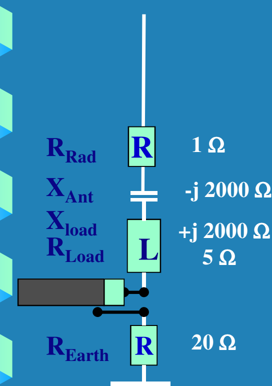


Electrically Short Aerials

Aerials less than a quarter wavelength.

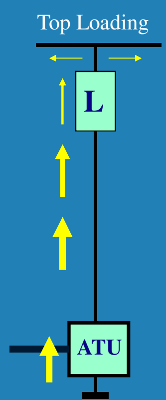
- HF Mobile operation
  - Aerial length typically less than 3 metres
- 80m & 160m aerials in small backyards
- LF Experimental Stations ($\lambda > 2000$m)
- HF Maritime mobile

Typical Mobile Whip Aerial



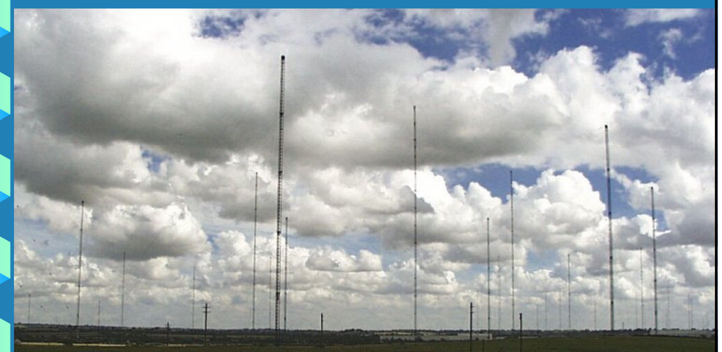
- Very low radiation resistance with large capacitive reactance.
- High Q -Narrow bandwidth
- Large resistive losses.
- Low Radiation efficiency (< 5% of input power)

Short Vertical Aerials



- The current does the radiating
- Get as much of the current as high as possible
- Increase the end capacitance
- Get the best Earth connection

A Really Big Short Vertical Aerial



VLF Aerial – GBR Rugby, England

- Top loaded capacity hat 180m high & 500m wide.
- 60 kW @ 60kHz
- λ = 5000m
- 160 A at feed pt
- 15 kW erp
- $R_{Rad} = 0.6\ \Omega$
- $R_{Loss} = 1.8\ \Omega$

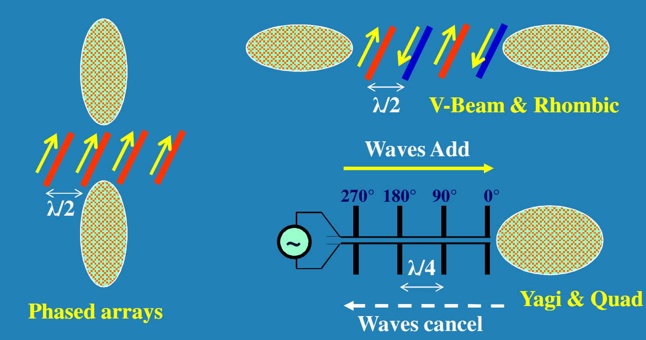
Practical HF Aerials

- Horizontal dipoles should be at least half a wavelength high to generate low angle radiation for DX contacts. Only practical for 40m and higher frequency bands.
- High angle radiation good for mid-range contacts on 160 & 80 metre bands.
- Verticals give good low angle radiation for DX and local ground wave contacts.
- Capacitive top loading raises the efficiency of short vertical aerials by raising the high current section and the radiation resistance.

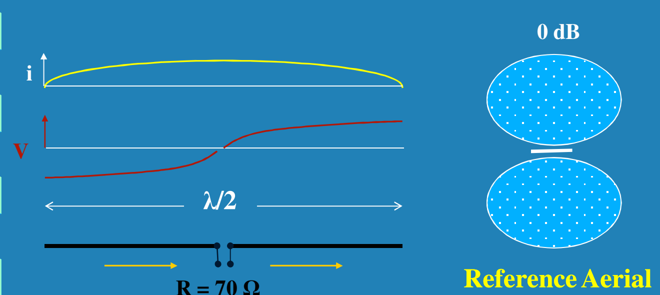
Beam Aerials

- Phased Arrays
  - Broadside and End fire
- Reflector Beams
- Parasitic Arrays
  - Yagis & Quads
- Travelling wave Aerials
  - Long wires,V-Beams &Rhombics

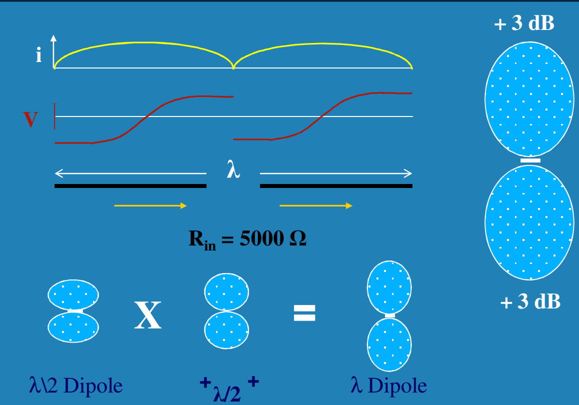
Radiation from phased dipoles



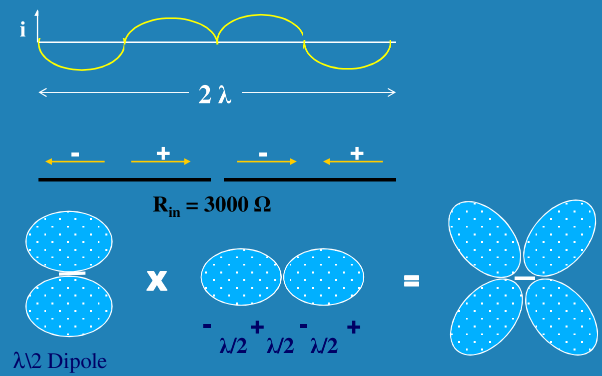
Half - wave Dipole



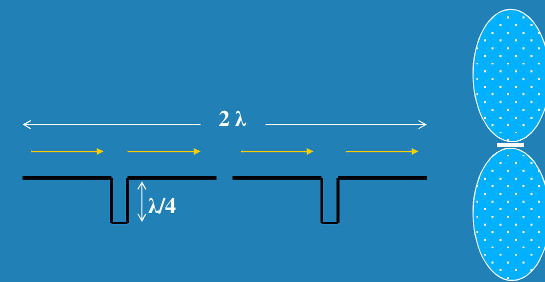
Full - wave Dipole



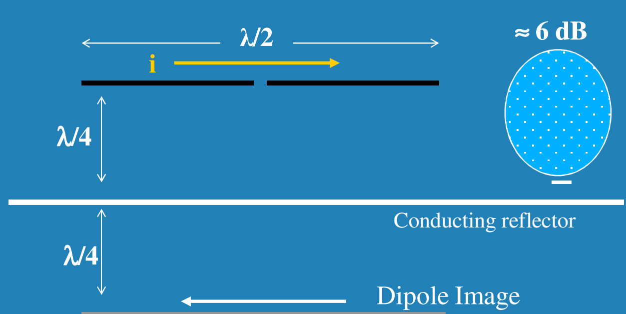
Two Wavelength Dipole



Two Wavelength co-linear Dipole



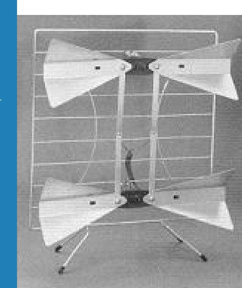
Plane Reflector



UHF TV Phased array + Plane Reflector

NOTE

- Bow Tie full-wave dipole elements for increased bandwidth
- Wire reflector is OK if wire spacing is less than 0.1 λ
- Reflector screen is a bit small.
- Wide bandwidth with good F/B ratio



screen reflector

Phased Array with Plane Reflector

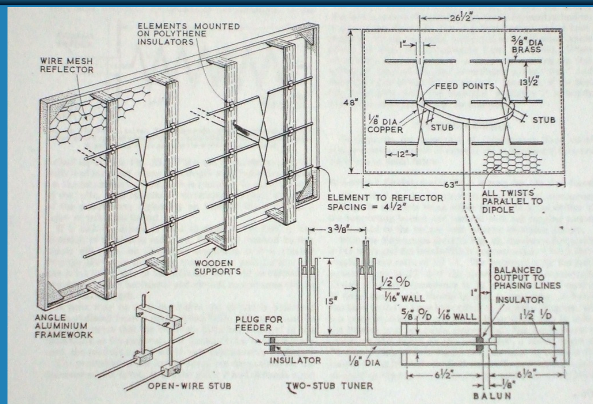


Fig. 31. A 12-element stack for 435 Mc/s, complete with two-stub tuner and enclosed coaxial balun.

Reflector Beam Aerials

Corner Reflector

Parabolic Reflector

Phased Arrays & Reflector Beams

- Low Q aerial, No critically tuned elements
- Relatively wide bandwidth
- Excellent Front/Back ratio
- Relatively large compared with yagi or parasitic element arrays.
- Consistent performer at 144 MHz and above.

Parasitic Arrays - Yagis & Quads

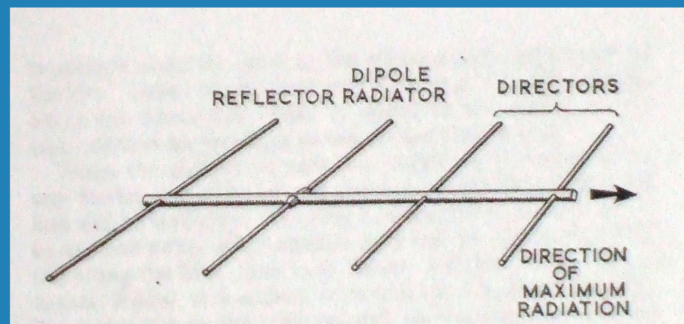
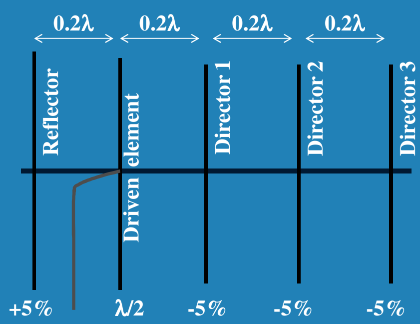


Fig. 12. Yagi array (4 elements). See Table 3 for typical dimensions

Use detuned parasitic elements to produce progressive phase shift

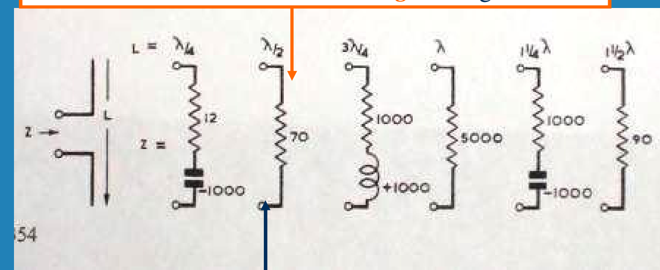


The Yagi is a *parasitic* array

The elements suck power from the driven element

Dipole Feed Impedance Revisited

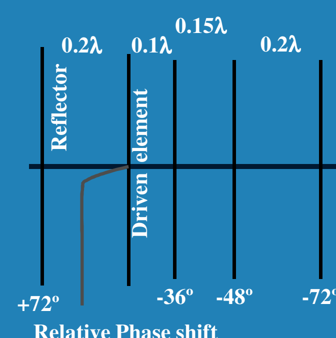
Reflector - 5% longer than resonance - *Inductive* reactance and Current *lags* voltage.



Director - 5% shorter than resonance - *Capacitive* reactance and Current *leads* voltage.

Parasitic Arrays - Yagis & Quads

The element spacing and element tuning are interdependent.

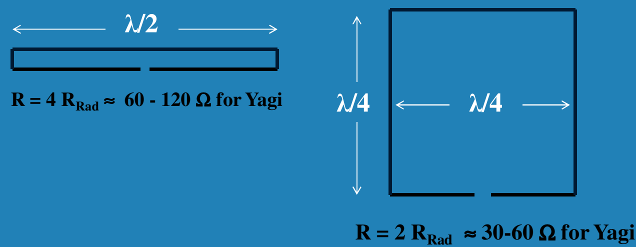


Close spacing of first director(s) improves forward energy coupling efficiency but tuning is more critical.

Additional directors increase the gain but reduce the bandwidth

Radiation resistance is typically 15 - 30 Ω

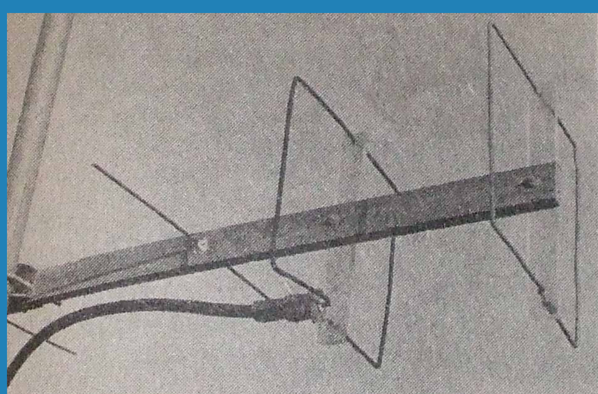
Folded Half - Wave Dipoles



Folding the dipole raises the feed impedance

Quad Yagi Aerial for 144 MHz

Quagi Feed systems



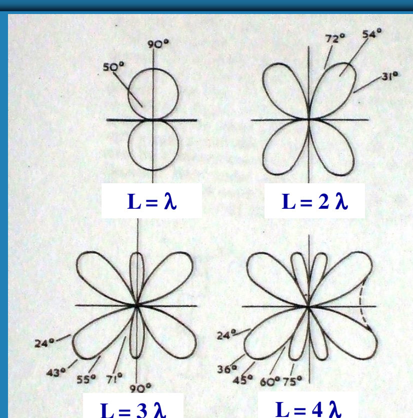
Broadbanding UHF Yagis

Is Boom Length a Status Symbol?

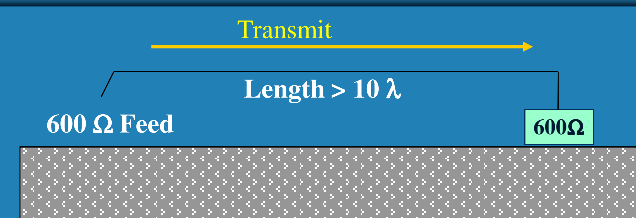
Yagi - Summary

- Highest gain for size
- Economic design
- Relatively narrow bandwidth (typically 1%) depending on gain.
- Flexible design
- High-Q aerial - Tuning can be critical
- Low radiation resistance (15 – 40 Ω)
- Quads less easily detuned by adjacent objects.

Radiation from Long Dipoles



Terminated Long Wire

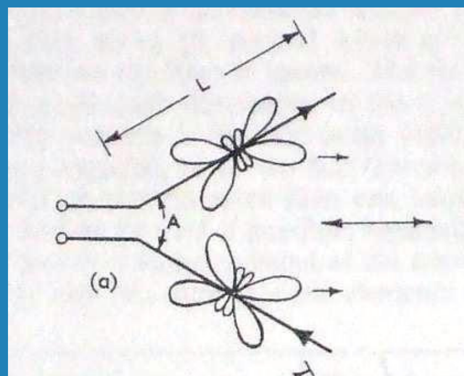


Travelling wave, minimal standing waves

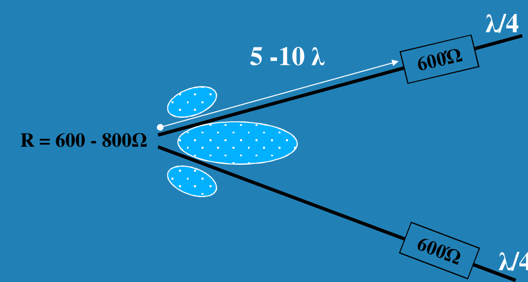
Radiation Directed towards distant end.

Beverage Aerial - MF & LF DX reception

Bent Long Dipole: V-Beam

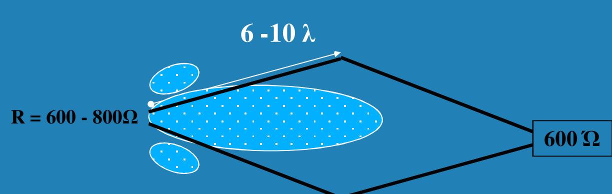


Terminated V - Beam



V-Beam + V-Beam = Rhombic

Broadband Travelling Wave aerial



10 – 12dB Gain over 3:1 frequency Range

HF Aerials - Revision

THERE IS NO MAGIC AERIAL

- Any dipole aerial below 14 MHz is going to produce high angle radiation over most soils.
- Vertical aerials produce low angle radiation but need a good earth system.
- Unbalanced aerials receive more noise and local QRM than a balanced aerial.
- Short vertical aerials have a very low radiation resistance and low radiation efficiencies
- KISS principle - *Keep It Short & Simple*

Multi-Band HF Aerials

- Any multiband aerial is a compromise.
  - Frequency bands required
  - Space and height limitations
  - Staying on good terms with XYL, Council & Neighbours
  - Cost constraints
  - RF environment –QRM sources or RFI sensitive neighbours
  - Operating convenience – Fast band-changing.
- Almost any aerial can be made to radiate on any frequency with a suitable Aerial Coupler, but some combinations are better than others.

Dipole Summary

- A dipole will operate on harmonic frequencies
  - Low feed impedance on odd harmonics
  - High feed impedance on even harmonics
- The Radiation pattern of dipoles longer than 1.5λ starts to break up into multiple lobes, but this is generally not important for low dipoles in amateur stations.
- Horizontal dipoles should be mounted at least half a wavelength above a ground plane to obtain low angle radiation.

Transmitting with a pair of steak knives