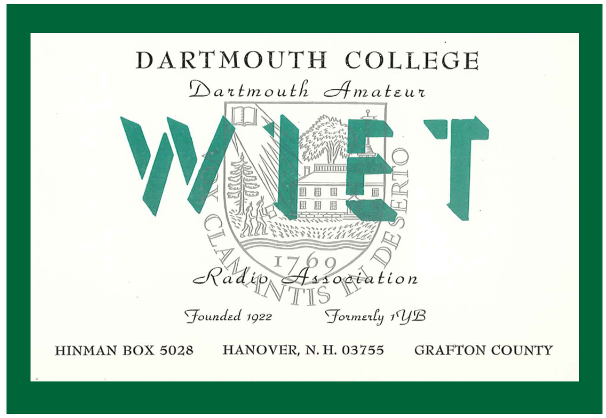


# Antennas 101

Eric Hansen, KB1VUN

## How does radio work?

- Transmitter: Convert message to radio frequency (RF) voltage
- Antenna: Convert RF to propagating electromagnetic (EM) wave
- Propagation path
- Antenna: Convert EM wave to RF voltage
- Receiver: Extract message from RF

- **This session: antennas**

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Figure from *ARRL Antenna Handbook, 22nd edition*

# Electromagnetic wave

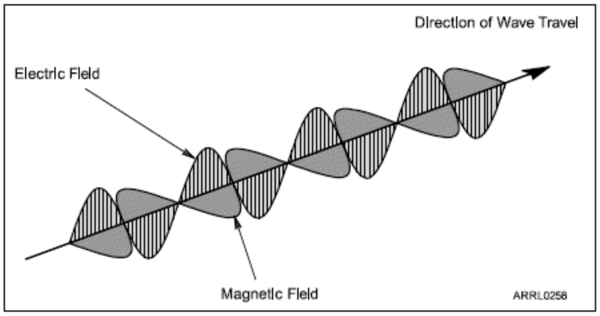



**Figure 1.4 — Representation of the magnetic and electric field strengths of an electromagnetic wave. In the diagram, the electric field is oriented vertically and the magnetic field horizontally.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Basic dipole antenna

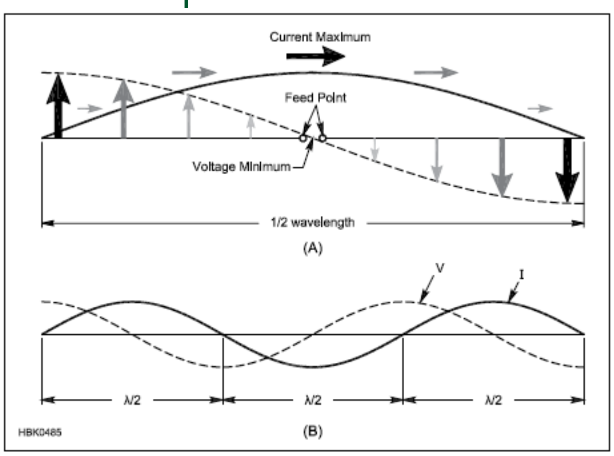



**Figure 1.6 — The current and voltage distribution along a half-wave dipole (A) and for an antenna made from a series of half-wave dipoles.**

- Fundamental phenomenon: accelerating charges (*e.g.*, sinusoidal current in a wire) radiate EM fields (Tx); EM field induces current in wire (Rx).
- Tx is a generator connected to the **feedpoint** of the **dipole**. Rx is a load connected to the feedpoint.

# Two main considerations

- What is the **radiation pattern** of the antenna (where does the radiated energy go)?
- What is the load (**impedance**) that the antenna presents to the transmitter (how efficiently can we get energy into the antenna?)

Figure from *ARRL Antenna Handbook, 22nd edition*

# Dipole radiation pattern

- Dipole in "free space" (way above the earth)
- Upper plot shows relative field strength (dB) vs **azimuth**
- Lower plot shows pattern is isotropic with respect to **elevation** (no ground effects)

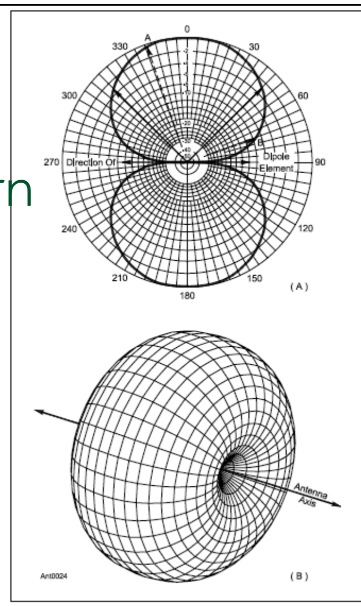
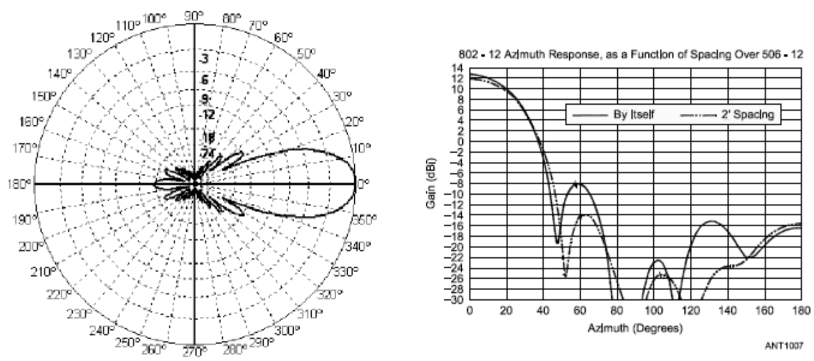



**Figure 1.10 — Radiation patterns of a half-wavelength dipole in free-space. At A, the pattern in the plane containing the wire axis. The length of each dashed-line arrow represents the relative field strength in that direction, referenced to the direction of maximum radiation at right angles to the 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.**

Figure from *ARRL Antenna Handbook, 22nd edition,* Fig. 1.A

# Radiation patterns

- Polar and rectangular plots




(C) (D)

# Dipole near ground

- Ideally, the ground is a perfect conductor, equipotential.
- Field from image dipole below ground matches boundary condition (E=0).
- Combination (magnitude, phase) of two fields changes elevation pattern.
- Real ground has non-ideal conductivity $\sigma$ and permittivity $\varepsilon$. Varies with geography.

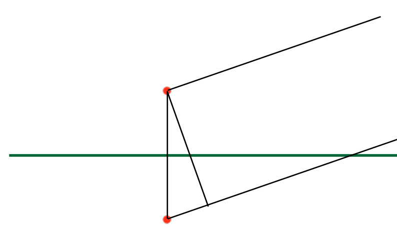


Figure from *ARRL Antenna Handbook, 22nd edition*

# Dipole near ground

- Boundary condition (zero E-field at ground) distorts the free-space radiation pattern.

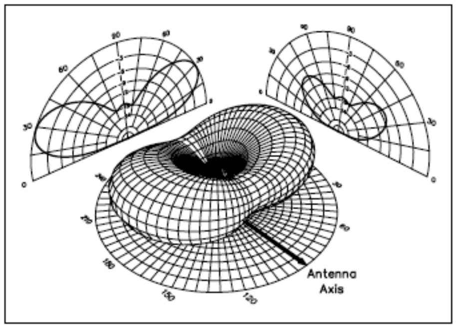



**Figure 2.5 — Three-dimensional representation of the radiation patterns of a half-wave dipole, ½ λ above ground.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Dipole near ground

- Higher antenna gives lower **takeoff angle**, good for DX. Rule of thumb: at least a half-wavelength above ground.
- Lower antenna is more omnidirectional in azimuth, and good for "near vertical-incidence skywave" (**NVIS**).
- Low antenna also called a "cloudwarmer".

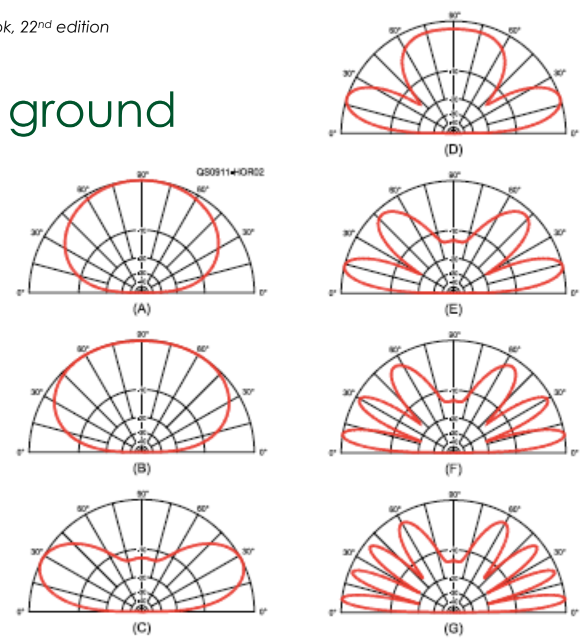



**Figure 2.4 — Six radiation patterns for the dipole at different heights: (A) ⅛ λ, (B) ¼ λ, (C) ½ λ, (D) ¾ λ, E) 1 λ, (F) 1½ λ, (G) 2 λ.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Monopole antenna

- Half of a dipole above ground + its image below ground will behave like a vertical dipole.
- **Omnidirectional** radiation pattern in azimuth.
- Low takeoff angle in elevation, good for DX.
- Natural ground usually inadequate. **Radial** wires make an artificial ground.
- Monopole is also the basis for mobile antennas and the "rubber duck" antennas used on handheld VHF radios.

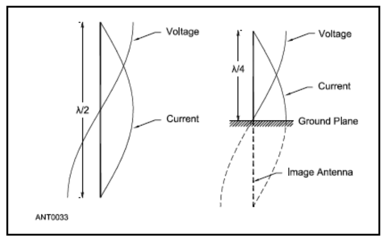


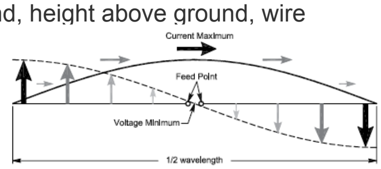

**Figure 2.25 — The λ/2 dipole antenna and its λ/4 ground-plane counterpart. The "missing" quarter wavelength is supplied as an image in "perfect" (that is, high-conductivity) ground.**

# Antenna polarization

- Horizontal antenna: E-field is horizontally polarized, H-field is perpendicular (E × H points in propagation direction).
- Vertical antenna: E-field is vertically polarized.
- For line-of-sight, antennas should be aligned (*e.g.*, verticals for VHF)
- For DX, ionospheric propagation mixes up the polarization, can use either kind of antenna.
- Can also generate circularly polarized waves, used for satellite communication.

# Antenna impedance

- V/I ratio at **feedpoint** is the antenna's **impedance**, Z.
- Impedance is frequency-dependent, and complex (Z = R + jX)
  - At **resonance**, impedance is purely resistive. Ideal resonant dipole is a half-wavelength long (a practical dipole is shorter).
    - A half-wave is, theoretically, 0.5c / f(Hz) = 492 / f(MHz) (in feet), but…
    - Rule of thumb: length of a half-wave dipole (in feet) is **468 / f(MHz)**.
  - Shorter than resonant, reactance X is capacitive
  - Longer than resonant, reactance X is inductive
- Feedpoint impedance also depends on ground, height above ground, wire diameter.
- **Antenna analyzer** measures Z.




# Antenna matching

- Transmitter is connected to antenna via a **feedline**. Most common feedline is **coaxial cable** with **50 ohm characteristic impedance**.
- Impedance mismatch at the feedpoint results in **standing waves** on the feedline.
- For maximum power to antenna:
  - Transmitter wants antenna + feedline impedance to look like 50 ohms. Transmitter reduces its output when there is a mismatch, to protect itself.
  - Antenna wants transmitter + feedline impedance to look like its impedance.
- Impedance mismatches are inefficient. Standing waves are not radiated, and are dissipated by **feedline loss (dB/100 feet)**

# Standing wave ratio (SWR)

- Traveling wave on feedline is partially reflected at a point of impedance mismatch (such as the feedpoint).
- Reflected wave and forward wave combine to make a standing wave.
- **SWR** (also called VSWR) = $V_{max}$ / $V_{min}$ of the standing wave. When there is no standing wave, $V_{max}$ = $V_{min}$ and the SWR is "1:1".
- SWR is also (1 + |ρ|) / (1 – |ρ|) where ρ is the complex **reflection coefficient** at the feedpoint.
- $|\rho|^2$ = Reflected power / Forward power. Forward and reflected power, and SWR, can be measured with a **directional wattmeter** and **SWR meter**.
- Practical SWR below 1.5:1 is OK. Below 3:1 is not bad.

# Antenna matching

- Trim the length of the dipole for best SWR across the band of interest. Antenna analyzer will give SWR vs frequency.
- An antenna that's too short can be made to look longer by adding inductance at the feedpoint (base-loaded mobile HF antenna).
- Various methods exist for matching antenna impedance to the transmission line's characteristic impedance (*e.g.*, **balun** transformer, **gamma match**)

## Feedline matching

- Transmission line + antenna present a combined effective impedance to the transmitter. We want this to look like a 50 ohm resistor.
- A so-called **antenna tuner** is an LC network that adds the right amount of reactance to match the feedline to the transmitter. It doesn't actually tune the antenna; the older name, "transmatch," is better.
- Note: the antenna tuner does nothing for feedline-antenna mismatch. Your transmitter can be well-matched to the feedline but your system can still radiate poorly.

## Directional antennas

- Basic dipole antenna is simple but the antenna pattern is broad and not steerable. Vertical antenna is omnidirectional.
- Directional antennas combine multiple elements to achieve narrower patterns.
- At higher frequencies, directional antennas are small enough to be mechanically rotated and pointed.

Figure from *ARRL Antenna Handbook, 22nd edition*

# Yagi antenna

- Invented by Yagi and Uda in Japan, 1920s.
- Driven element produces an EM field that induces a current in the parasitic element. The parasitic current produces a second EM field that interferes with the driven field.
- Length and spacing of parasitic elements produce the right phase relationship between the two fields for optimum reinforcement in front and cancellation in back.

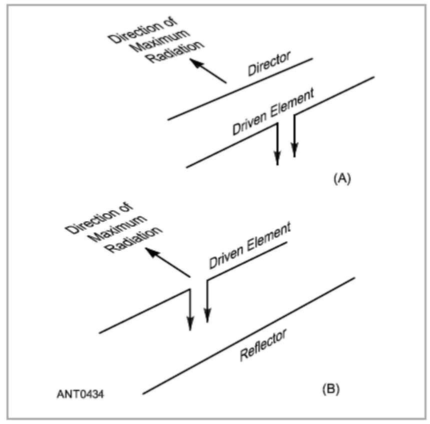



**Figure 11.1 — Two-element Yagi systems using a single parasitic element. At A the parasitic element acts as a director, and at B as a reflector. The arrows show the direction in which maximum radiation takes place.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Yagi antenna

- Three-element Yagi is typical. Driven element is approximately the length of a dipole. **Reflector** element is about 5% longer than the driven element, **director** element is about 5% shorter. Feedpoint impedance is lower than 50 ohms, needs a **matching network** at the antenna.
- Yagi has **gain** relative to a dipole; ideally, **9.7dBi** (relative to an isotropic antenna).
- Yagi has better directivity than a dipole—**front-to-back ratio**.
- Adding director elements increases the gain.

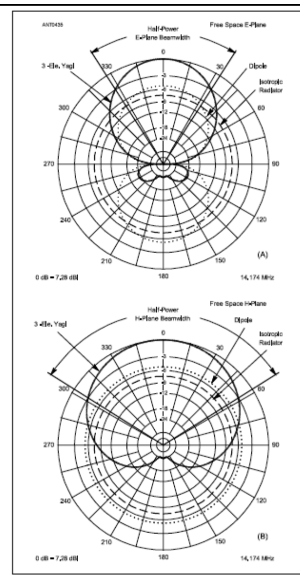



**Figure 11.2 — E-Plane (electric field) and H-Plane (magnetic field) response patterns for 3-element 20 meter Yagi in free space. At A the E-Plane pattern for a typical 3-element Yagi is compared with a dipole and an isotropic radiator. At B the H-Plane patterns are compared for the same antennas. The Yagi has an E-Plane half-power beamwidth of 66°, and an H-Plane half-power beamwidth of about 120°. The Yagi has 7.28 dBi (5.13 dBd) of gain. The front-to-back ratio, which compares the response at 0° and at 180°, is about 35 dB for this Yagi. The front-to-rear ratio, which compares the response at 0° to the largest lobe in the rearward 180° arc behind the antenna, is 24 dB, due to the lobes at 120° and 240°.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Other directional antennas

- **Quad** loop, quad beam
- **Delta** loop, delta beam

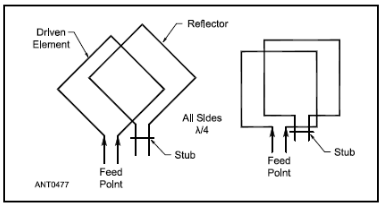



**Figure 11.28 — The basic two-element quad antenna, with driven-element loop and reflector loop. The driven loops are electrically one wavelength in circumference (¼ wavelength on a side); the reflectors are slightly longer. Both configurations shown give horizontal polarization. For vertical polarization, the driven element should be fed at one of the side corners in the arrangement at the left, or at the center of a vertical side in the "square" quad at the right.**

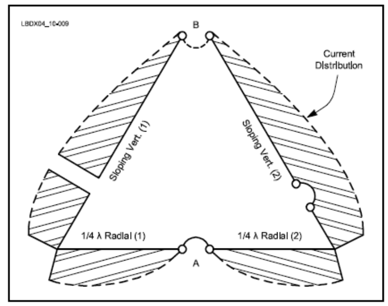



**Figure 5.9 — The delta loop can be seen as two λ/4 sloping verticals, each using one radial. Because of the current distribution in the radials, the radiation from the radials is effectively canceled.**

Figure from *ARRL Antenna Handbook, 22nd edition*

# Log-periodic antenna

- Multiple driven elements
- Length and spacing increases **logarithmically** from one end to the other (constant length/spacing ratio)
- **Broadband**, typically uniform behavior over a 1 octave frequency range
- You also see these used as rooftop TV antennas.

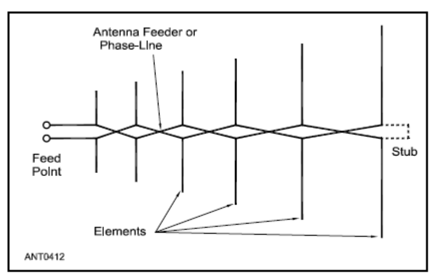



**Figure 7.1 — The basic components of a log periodic dipole array (LPDA). The forward direction is to the left in this sketch. Many variations of the basic design are possible.**

# Multiband antennas

- **Center-fed dipole** can operate well on odd harmonics of its lowest frequency, *e.g.*, 40 and 15 meters.
- A long center-fed antenna with **open-wire feedline** (not coax) may have high SWR, but the feedline loss is so low that it will work well with a good antenna tuner.
- **Off-center fed dipole** can operate well on even harmonics of its lowest frequency, *e.g.*, 80, 40, 20, 10 meters.
- **Fan dipole** has several dipoles with a common feedpoint. At a given frequency, one dipole is matched, the others have high impedance.
- **Trap dipole** uses LC networks (traps) inserted along the elements to block high frequencies from seeing the ends of the elements, making the antenna shorter.

# What does W1ET have?

- 20 meter dipole and 40-20-10 off-center fed dipole

In storage:

- Horizontal 80 meter loop (20, 40, 80 meters)
- 7-element 6 meter beam (Yagi)
- 17-element 2 meter beam
- 144 MHz beam & 440 MHz beam with preamplifiers (satellite antennas)
- Dual-band 144 MHz/440 MHz omnidirectional vertical (for repeaters)
- And a few other VHF antennas