Basic Radio Propagation And Antennas

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A Propagating Electromagnetic Wave Consists of Orthogonal Electric and Magnetic Fields Oscillating in a Plane Perpendicular to the Direction of Propagation. Examples: Radio, Light, X-rays, and Gamma-rays.

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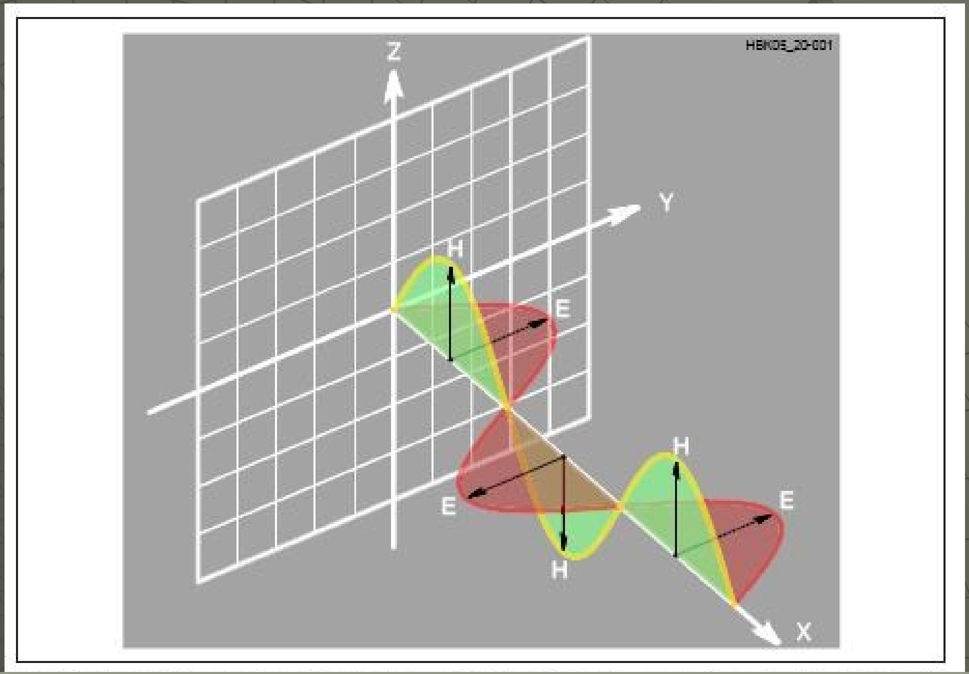
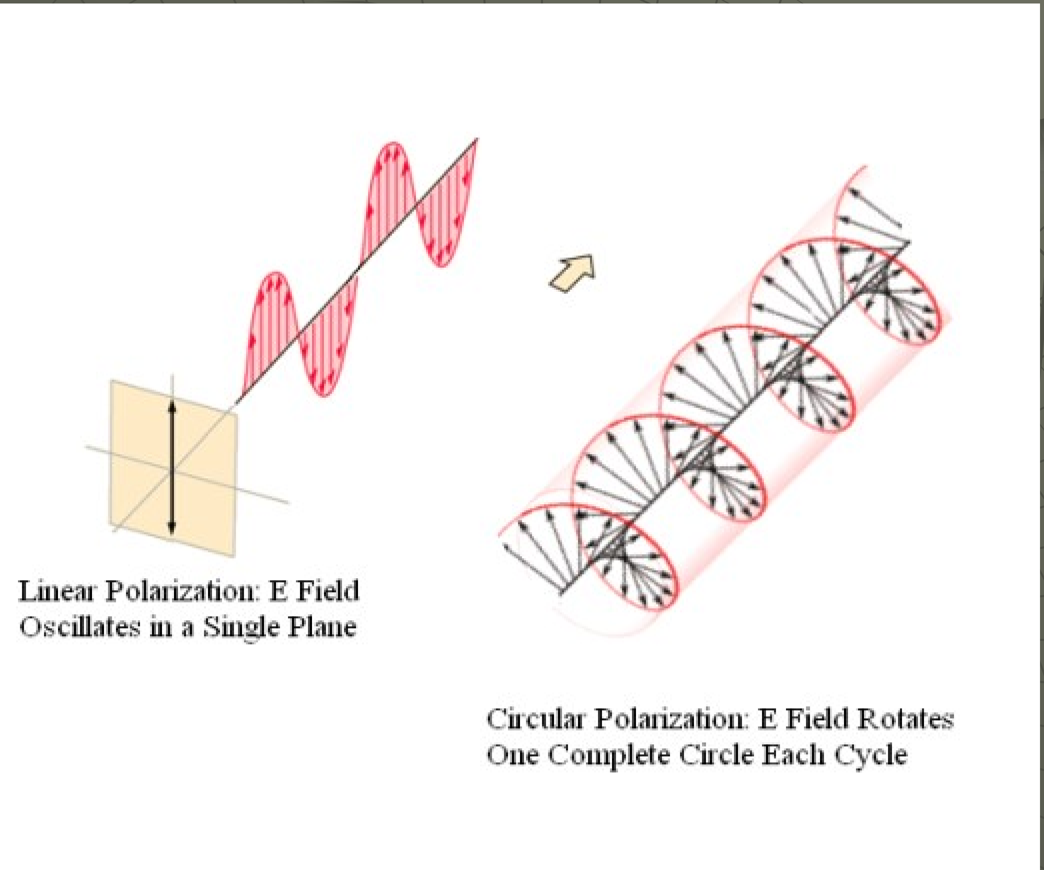


The fields are in-phase and oscillate sinusoidally at the characteristic frequency of the signal. The wave propagates at the speed of light, 300x10^6 m/sec or 186,000 miles/sec in free space.

The electric and magnetic fields curl around each other in a self-reinforcing symbiosis to create a propagating electromagnetic wave capable of transferring energy from one antenna to another. In the absence of an absorber the wave could propagate forever. Example: 13-billion-year-old light now entering James Webb Telescope.

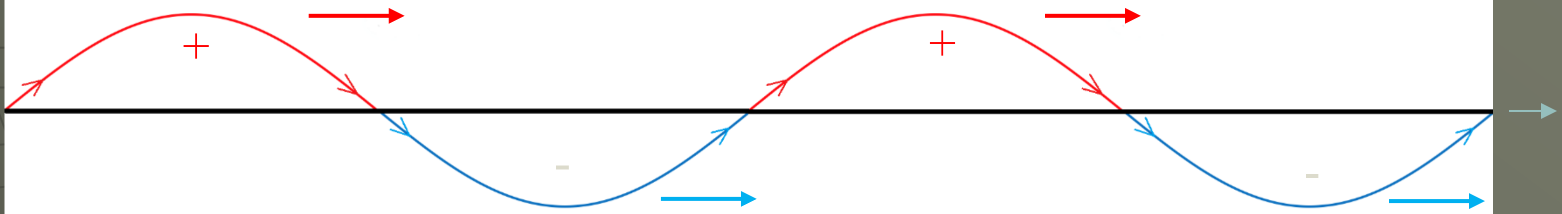
Polarization



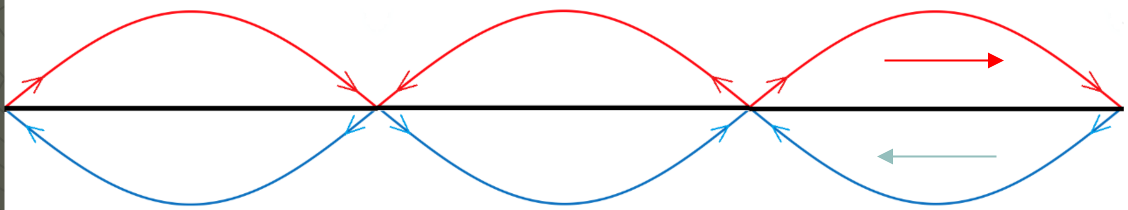
The radio wave has a polarization that is set by the disposition of the plane containing the E-field vector. If the E-field oscillates in only one plane, the wave is linearly polarized. Circular polarization occurs when the plane of the E-field vector rotates with each cycle of the wave. Both right- and left-hand circular polarizations are possible.

Half Wave Dipole Formed by End Reflections

1. Traveling Wave of RF Current Moving Left-Right on a Long Wire

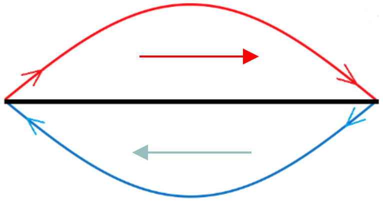


2. Counter Propagating Waves Created by Terminating Wire on One End



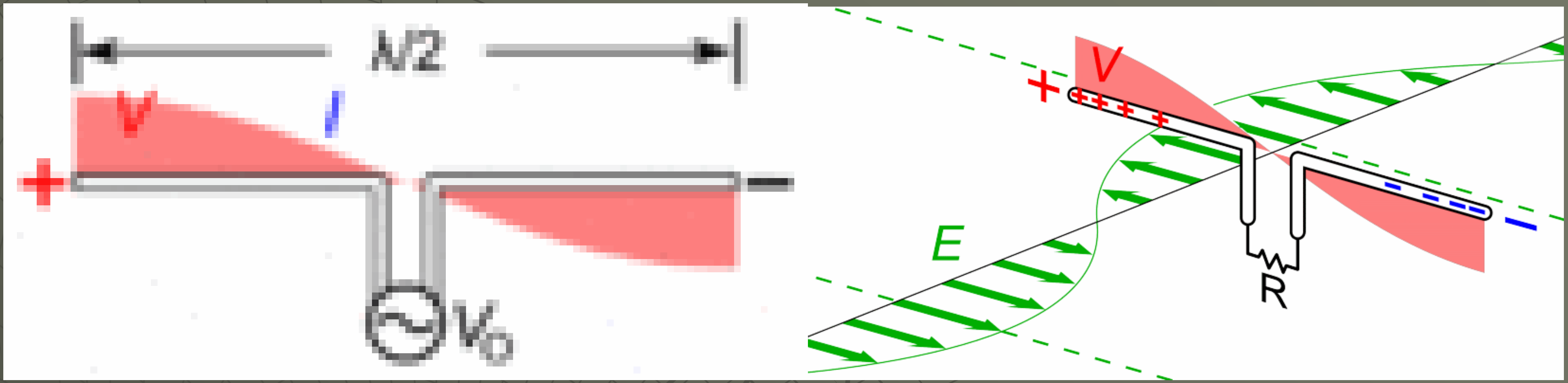
3. End Reflection Sends Wave Back Towards Source

4. Terminating Both Ends to Trap Exactly One-Half Wavelength of Current Forms the Fundamental Half-Wave Dipole



5. Resulting Standing Wave where Current is always Maximum in the Middle and Zero on the Ends.

Dipole: The Fundamental Antenna



A dipole is a wire long enough to hold exactly one-half wavelength of voltage and current. It is a dynamic resonant structure. The end reflections cause the current and voltage distributions to congruently lie exactly on top of one another.

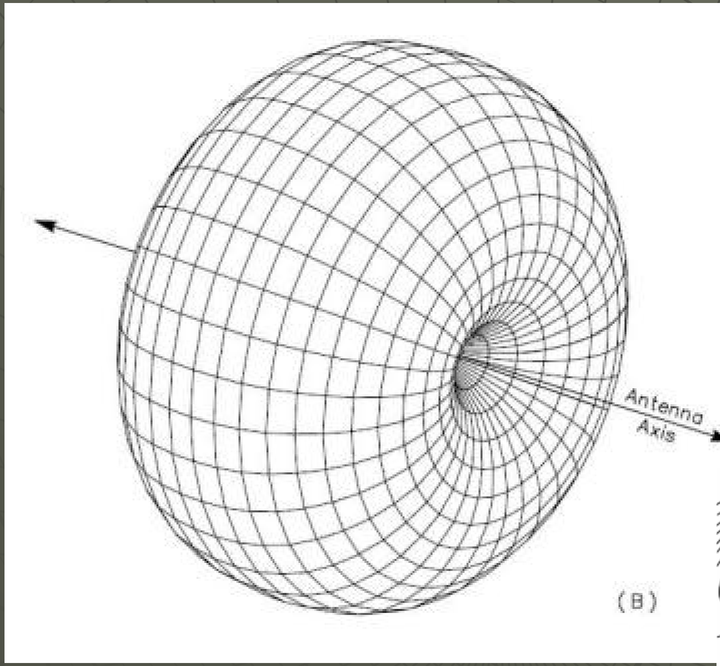
Transmit: back-and-forth oscillations accelerate electric charge which causes radiation of an electromagnetic wave.

Receive: a passing radio wave induces oscillating charges on the dipole that transfer power to a connected receiver.

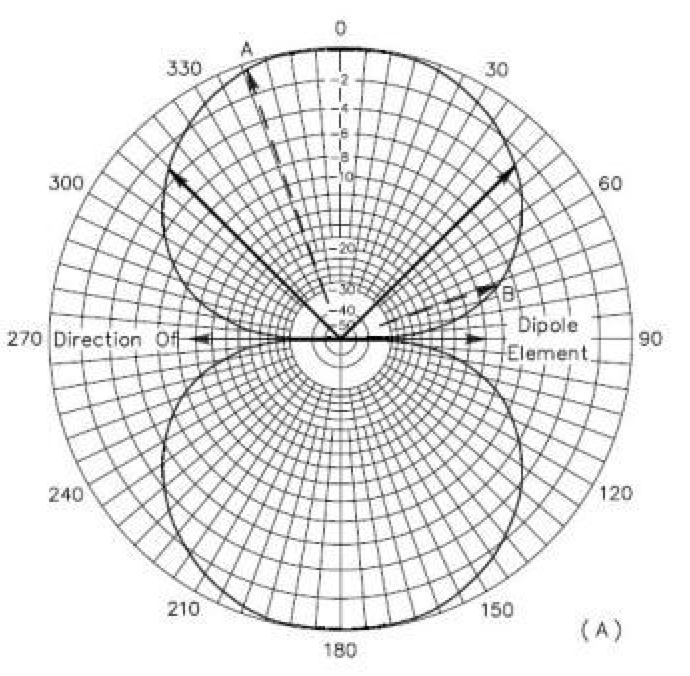
Current is always maximum in the center and zero on the ends. A common feed method is to break the dipole at the high current point and feed it with low impedance coaxial cable.

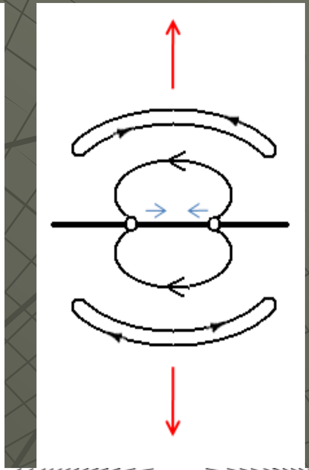
Dipole Radiation Pattern

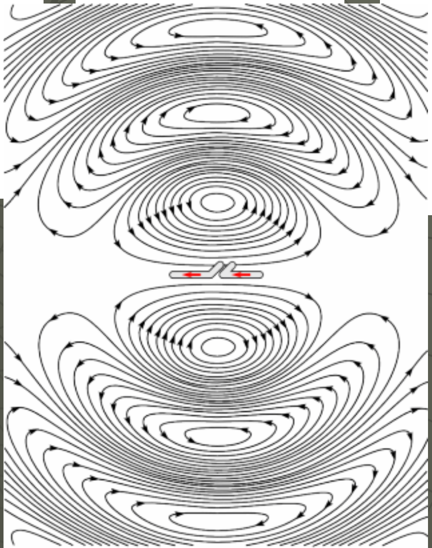
a) 3-Dimensional Pattern



b) Azimuth Slice





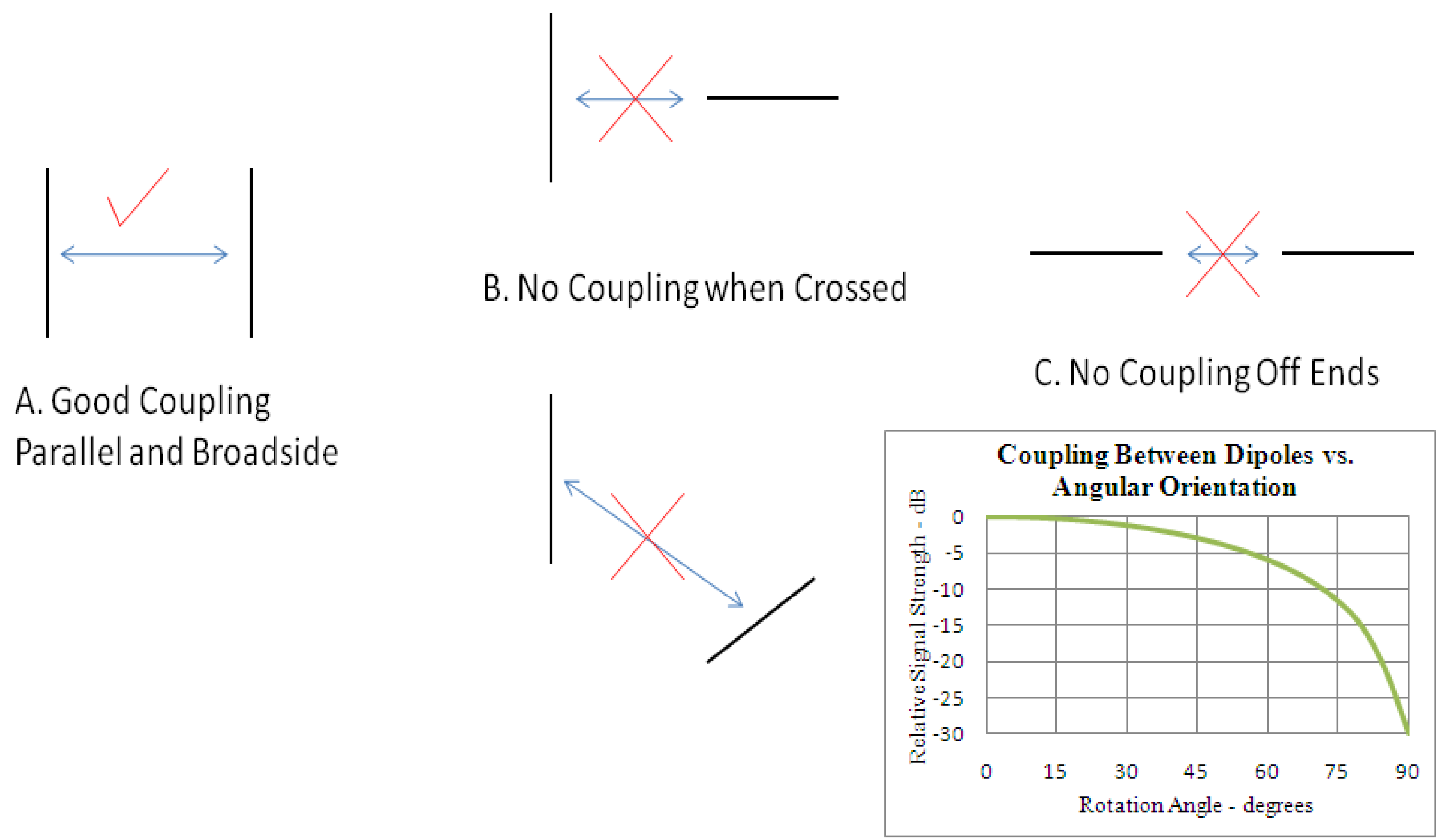


c) Electromagnetic Waves Launching from a Dipole

Orientation: ▬

A dipole radiates broadside, or radially to the dipole axis and has no radiation off the ends.

Dipole Orientation and Coupling



A. Good Coupling
Parallel and Broadside

B. No Coupling when Crossed

C. No Coupling Off Ends

Dipole-dipole coupling demonstration

Dipole – Dipole Coupling

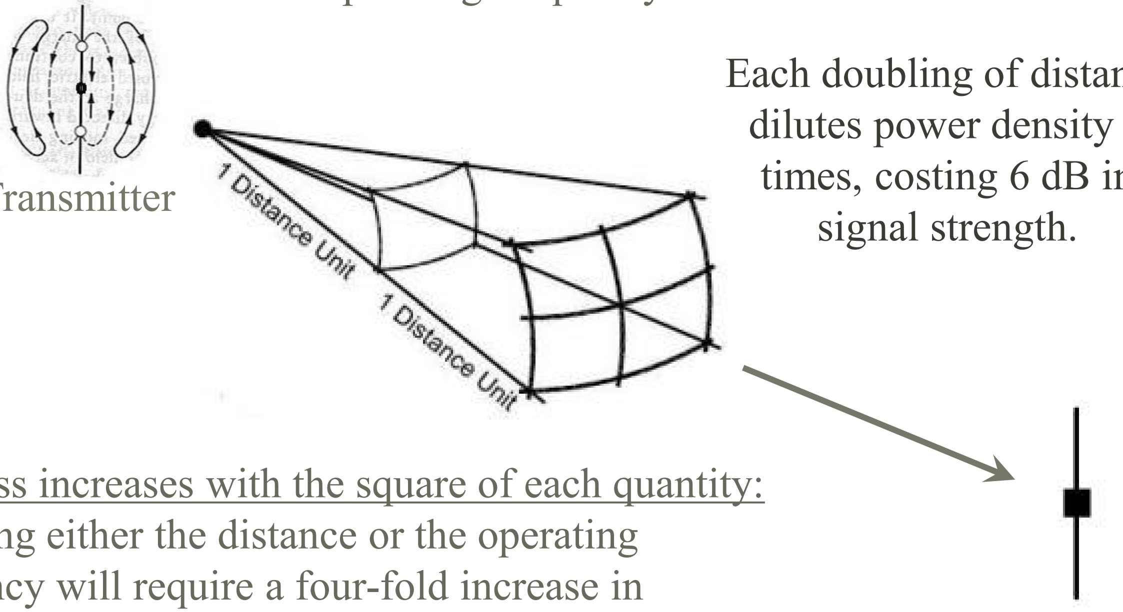
Maximum: Broadside and Parallel

Null: Cross Polarized or Off Dipole Ends

Line-of-sight Path Losses Between a Transmitter and Receiver

Two factors determine free space path loss:

1. The distance between the transmitter and receiver, and
2. The operating frequency.



Transmitter

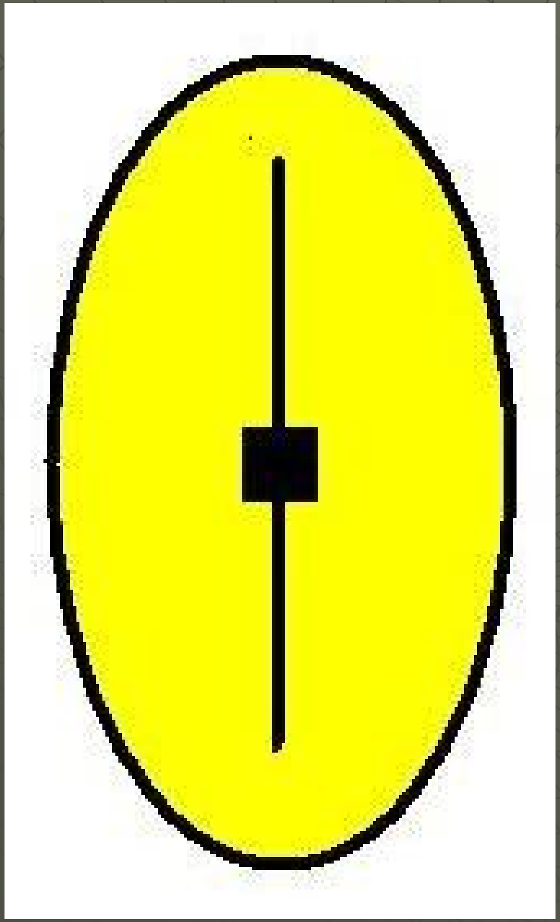
Each doubling of distance dilutes power density 4 times, costing 6 dB in signal strength.

Receiver

Path loss increases with the square of each quantity:

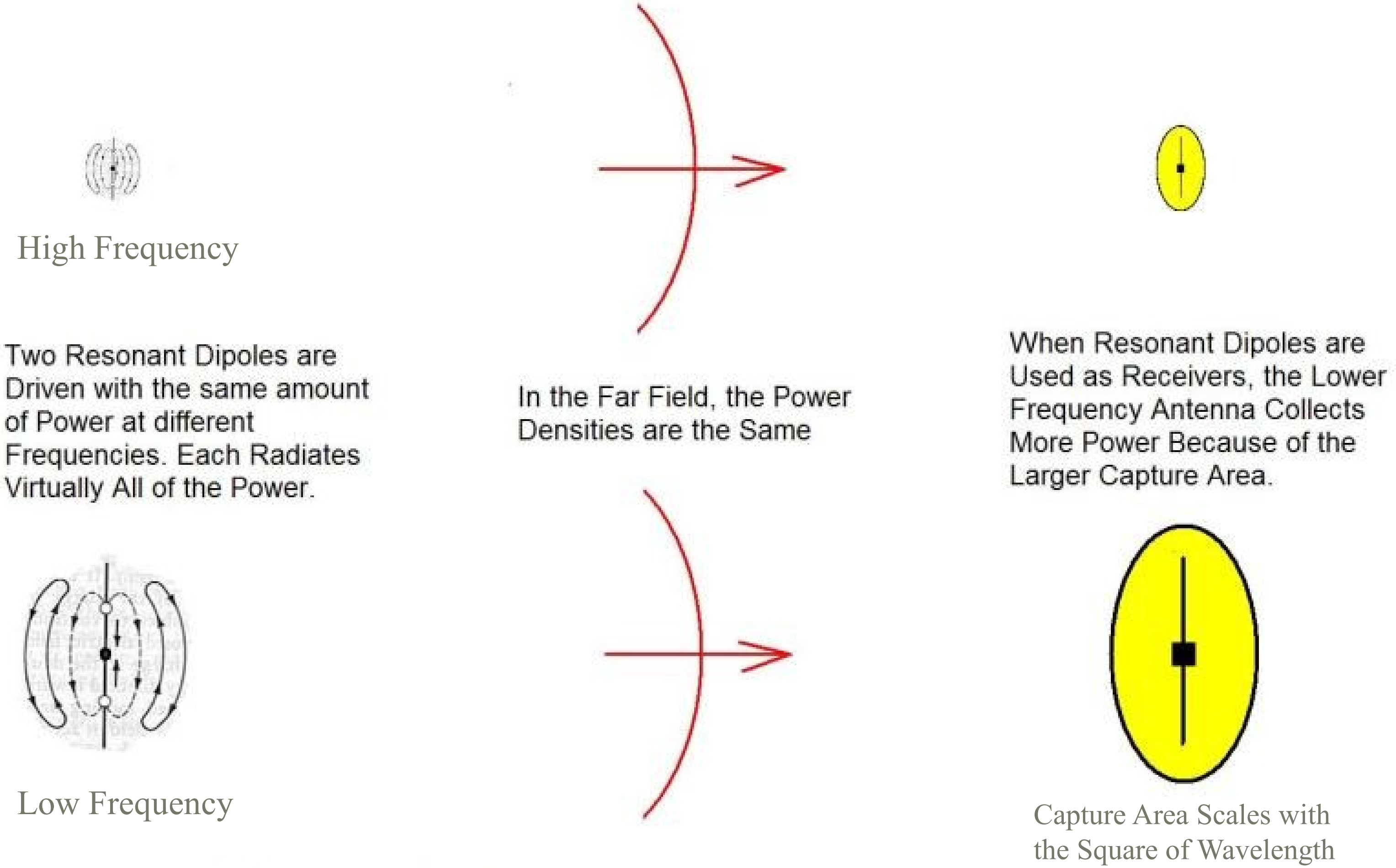
Doubling either the distance or the operating frequency will require a four-fold increase in transmitted power to maintain the same signal strength at the receiver.

Frequency-squared Loss Visualized in the Capture Area of the Dipole Used as Receive Antenna



- The Capture Area of a Dipole Antenna is an ellipse approximately ¾ wavelengths long by ¼ wavelength wide. Thus, the capture area scales directly with the square of wavelength or inversely with the square of frequency.
- Lower frequency antennas have bigger capture areas and collect more power from the passing radio wave.

Radio Links At Disparate Frequencies Demonstrate Frequency-squared Losses Occurring at the Receive End



High Frequency

Two Resonant Dipoles are Driven with the same amount of Power at different Frequencies. Each Radiates Virtually All of the Power.

In the Far Field, the Power Densities are the Same

When Resonant Dipoles are Used as Receivers, the Lower Frequency Antenna Collects More Power Because of the Larger Capture Area.

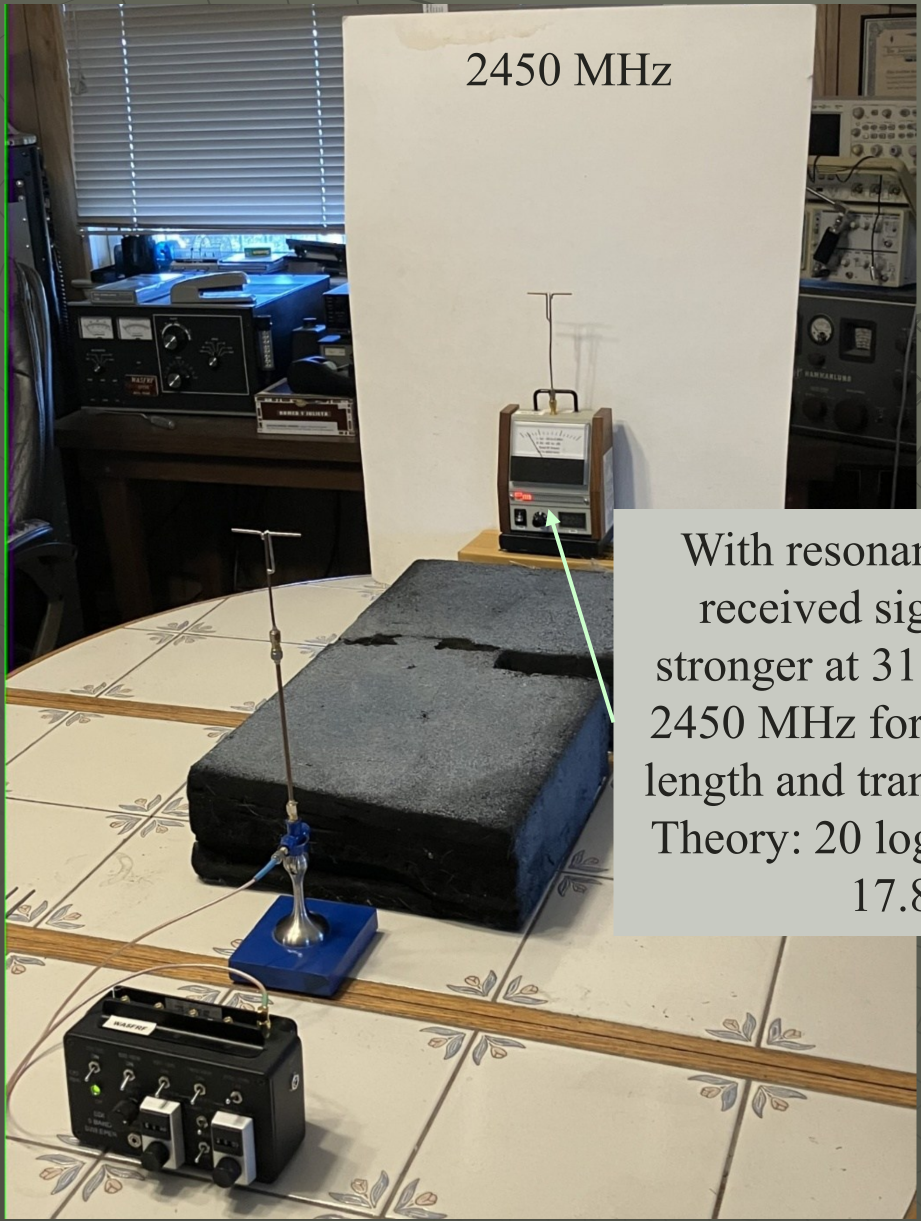
Low Frequency

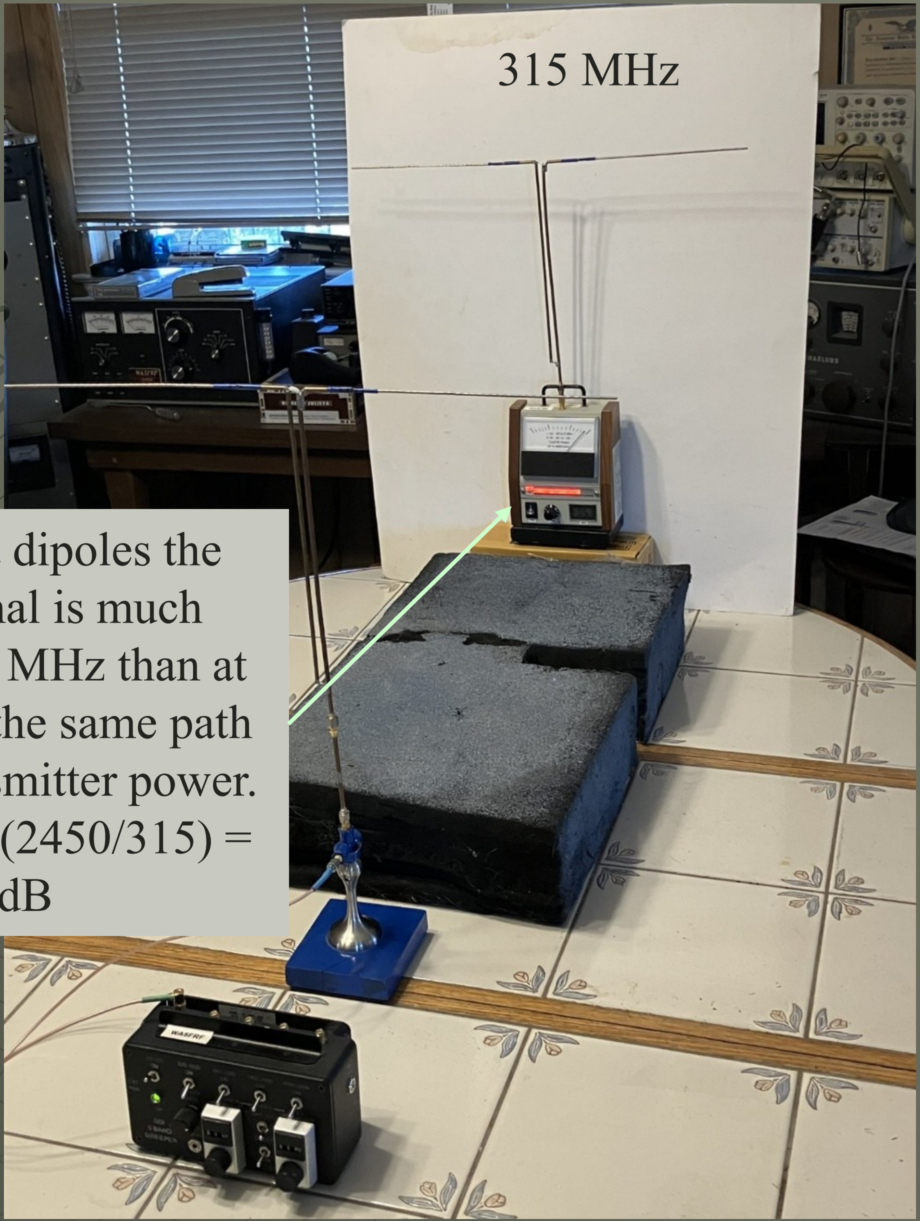
Capture Area Scales with the Square of Wavelength

Illustration of the Mechanism for Frequency Dependent Path Loss

Demonstrate frequency-dependent signal strength

Path Loss Increases with Frequency^2



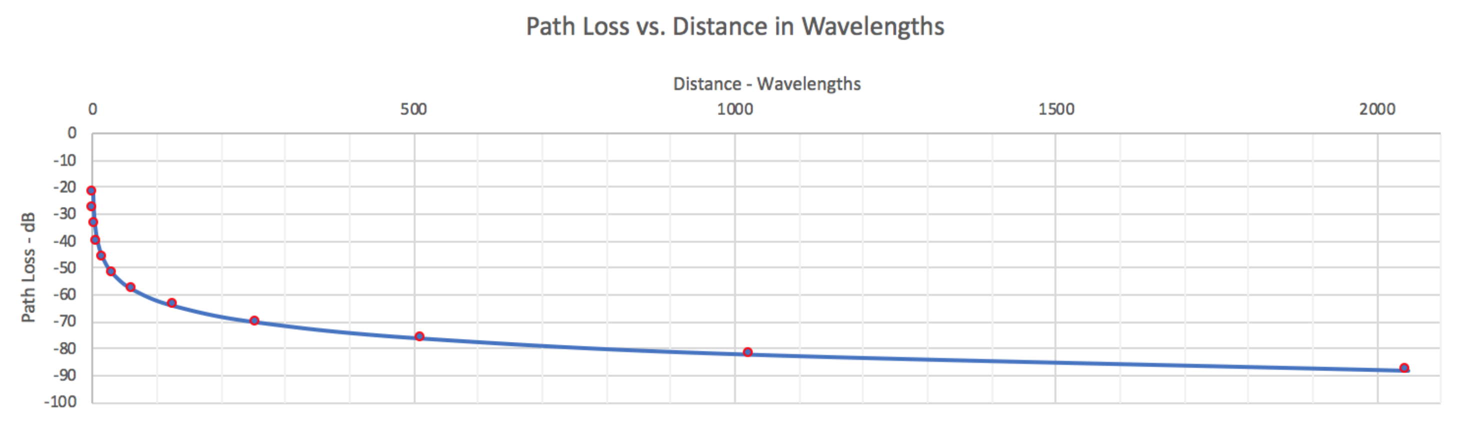


With resonant dipoles the received signal is much stronger at 315 MHz than at 2450 MHz for the same path length and transmitter power. Theory: 20 log (2450/315) = 17.8 dB

Simplified Path Loss Calculation For Line-of-Sight Links

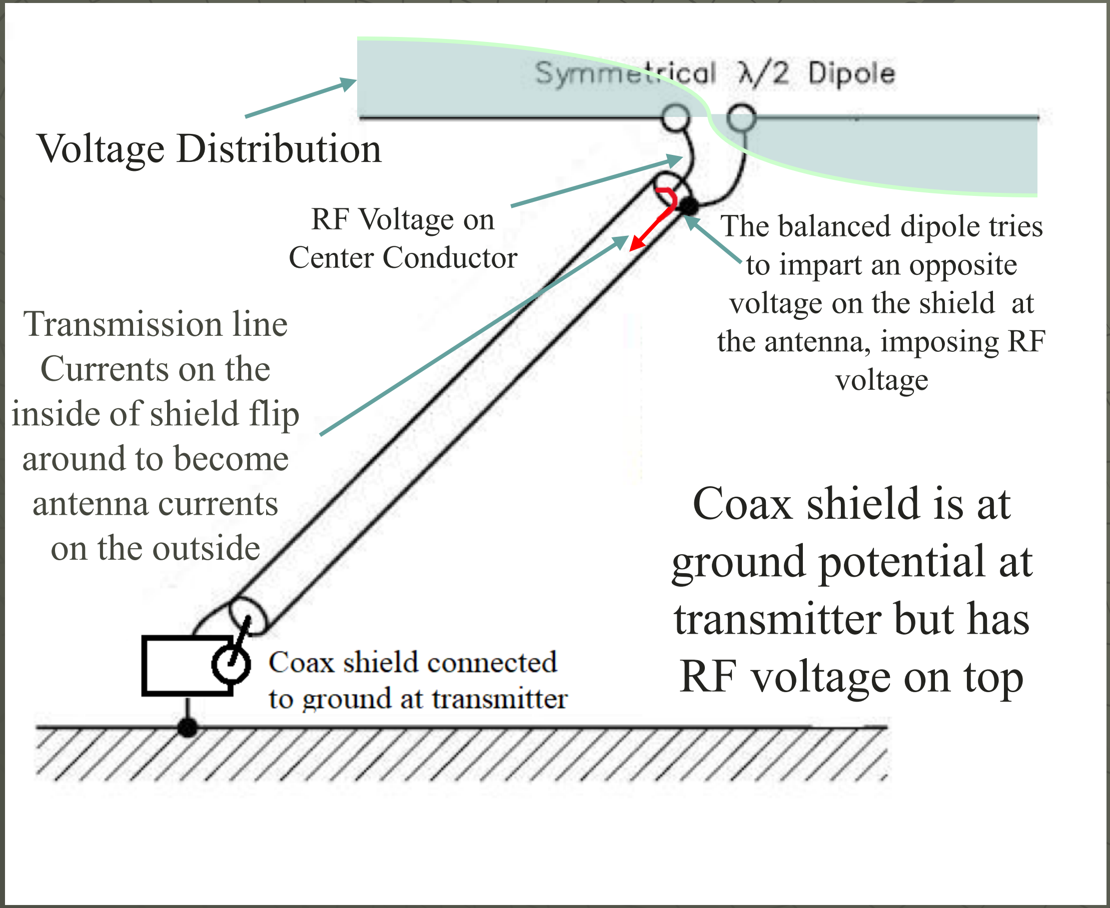
Rule of thumb:
The signal drops off 22dB in the first wavelength from the antenna, then 6dB more every time the distance doubles.

λ: 22dB
2λ: 28
4λ: 34
8λ: 40
16λ: 46
32λ: 52
64λ: 58
128λ: 64
256λ: 70dB
512λ: 76
1024λ: 82
2048λ: 88
4096λ: 94
8192λ: 100
16384λ: 106
32768λ: 112



As transmitter and receiver get farther apart the 6 dB per distance doubling adds up FAST at first. But then those factors of two in distance start getting LONG. Example: once you go ¼ million miles to the moon, its only 6 dB to go another ¼ million miles.

The Simplest Feed Method: Break the Dipole in the Center and Feed Directly with Coax. But what's Wrong with this Picture?



Voltage Distribution

RF Voltage on Center Conductor

Transmission line Currents on the inside of shield flip around to become antenna currents on the outside

The balanced dipole tries to impart an opposite voltage on the shield at the antenna, imposing RF voltage

Coax shield is at ground potential at transmitter but has RF voltage on top

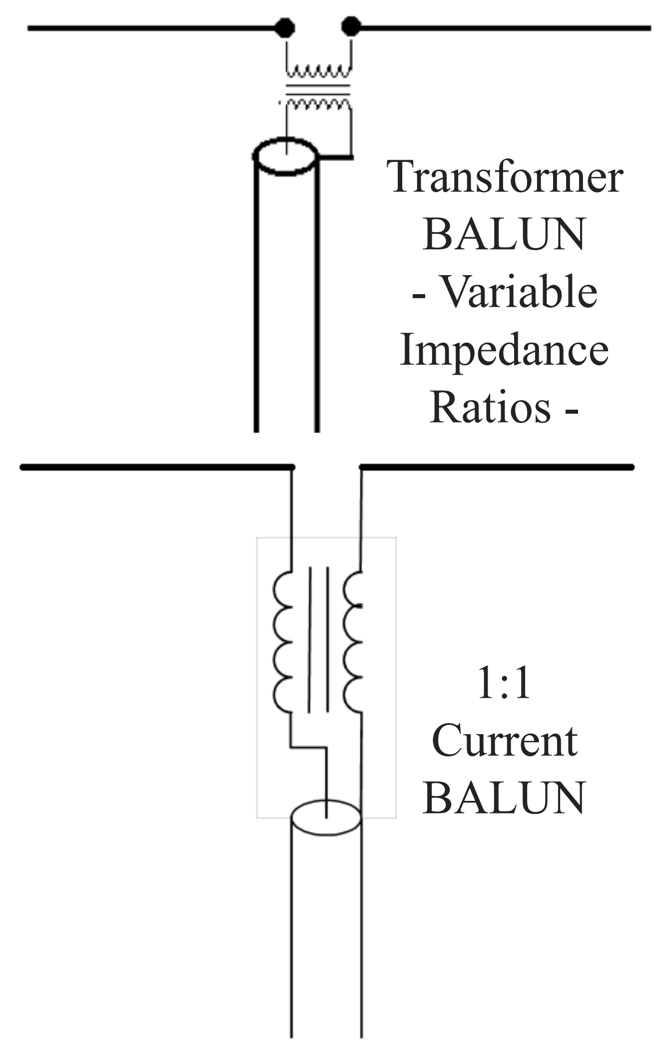
Coax shield connected to ground at transmitter

This feed method will work most of the time but makes the outside of the shield part of the antenna. This can cause problems with unwanted radiation to and from the feedline.

BALUNS: BALanced to UNbalanced Conversions

- BALUN is a contrived word consisting of the first letters of "BALanced" and "UNbalanced".
- It is used in antennas to strip antenna currents from the outside of coax feed lines.
- Problems with a hot feedline include:
  - The feed line becomes part of the antenna, scattering power out of the normal antenna pattern.
  - The length of the feedline can affect tuning.
  - Currents can be unequal on the two dipole halves, resulting in skewed radiation patterns and filled-in nulls.
  - Feedline currents strongly couple the antenna to the radio environment, leading to interference issues.

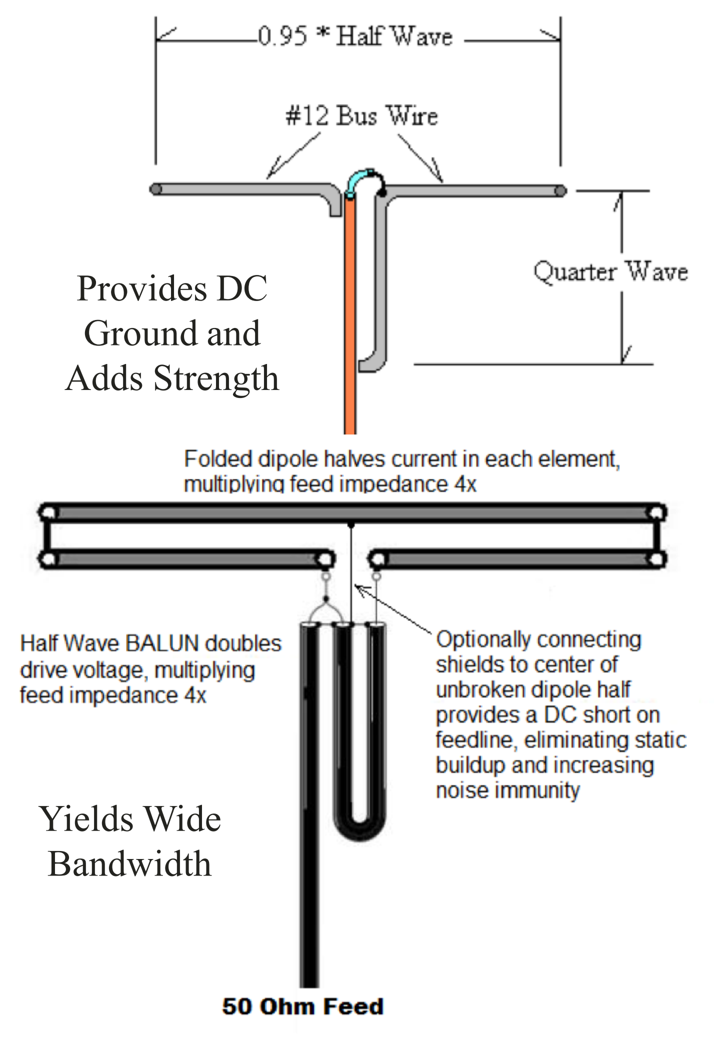
Common BALUN Topologies



Transformer BALUN
- Variable Impedance Ratios -

1:1 Current BALUN

Available as Surface Mount Parts



Provides DC Ground and Adds Strength

Folded dipole halves current in each element, multiplying feed impedance 4x

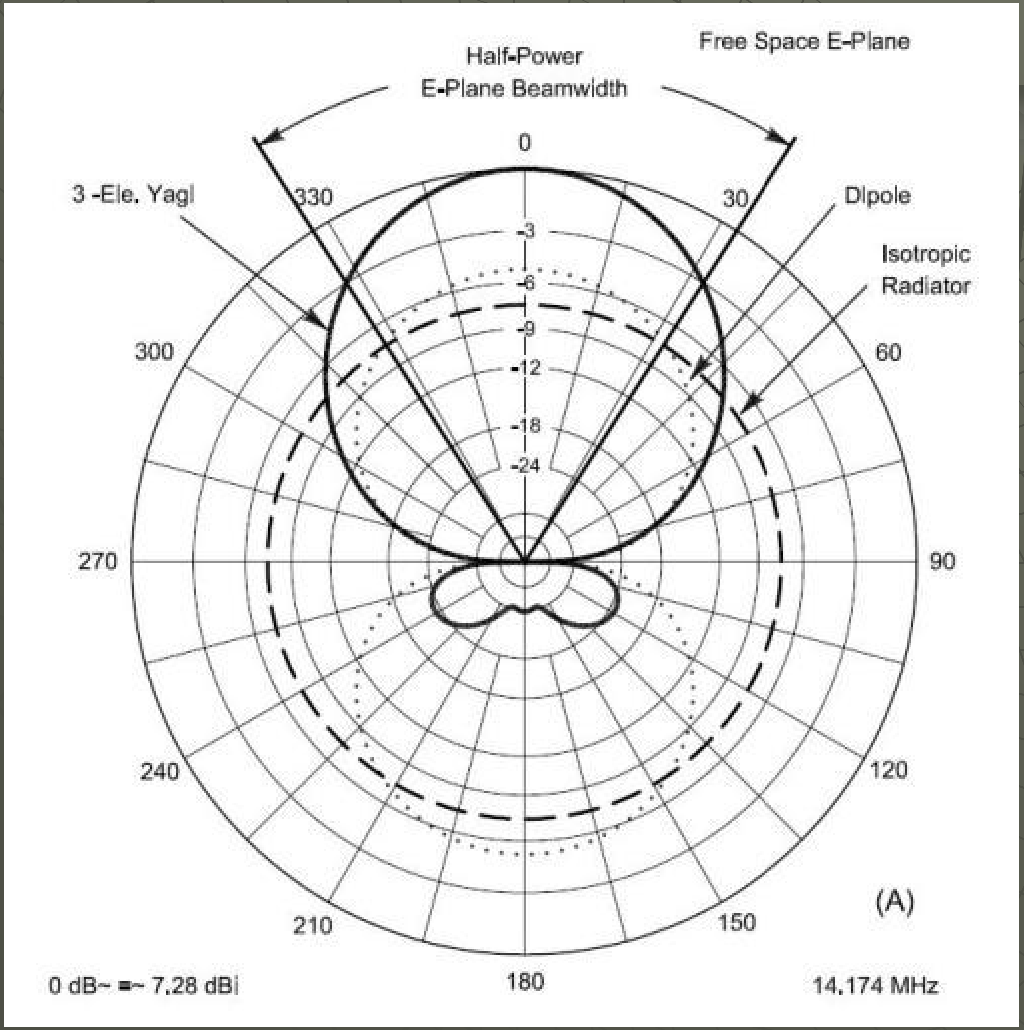
Half Wave BALUN doubles drive voltage, multiplying feed impedance 4x

Optionally connecting shields to center of unbroken dipole half provides a DC short on feedline, eliminating static buildup and increasing noise immunity

Yields Wide Bandwidth

Transmission Line BALUNs

The Isotropic Radiator and the Concept of Gain

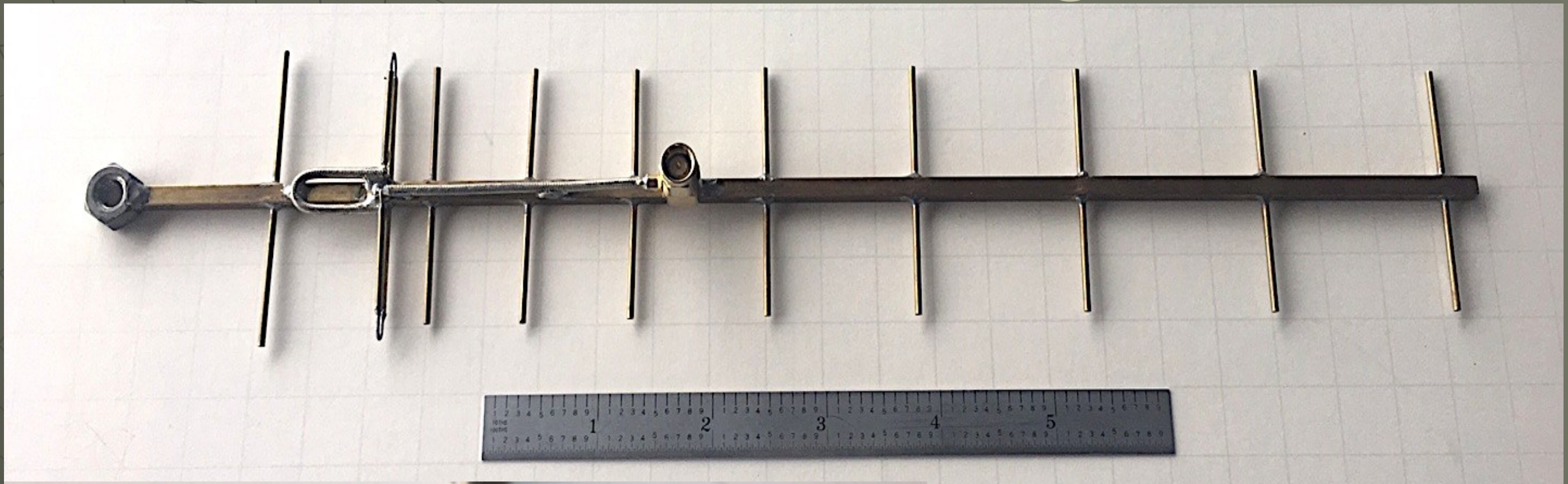


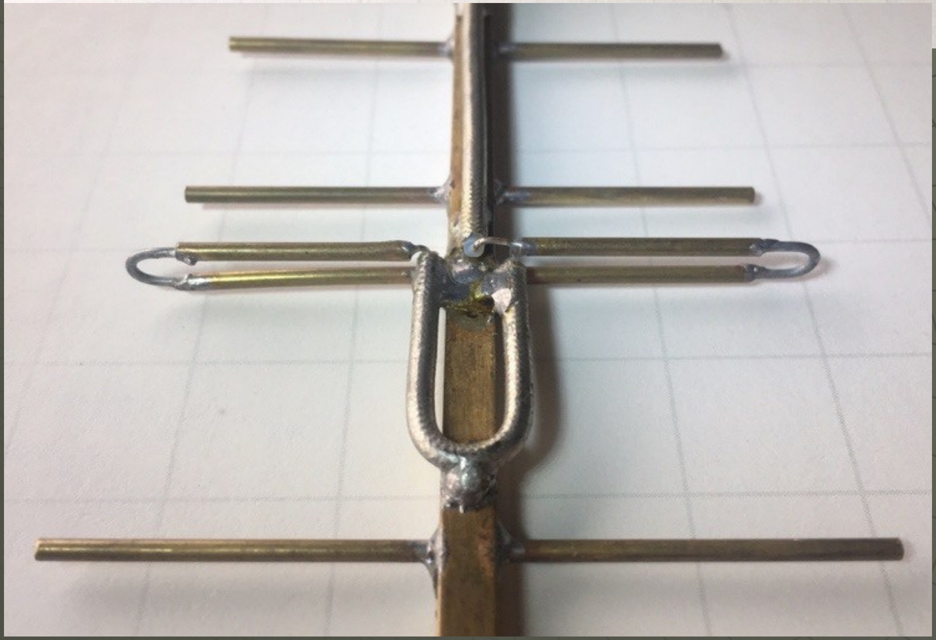
An antenna cannot radiate more power than is applied to it, but it can concentrate power in one direction at the expense of others. This is called directivity and is what makes gain. Shown here are the radiation patterns of an isotropic radiator, a dipole, and a gain-producing Yagi.

An Isotropic Radiator is a notional concept for an infinitely small radiator that radiates equally well in all directions – i.e., in a perfect sphere. None exist in the real world, but the concept serves as a valuable common point of reference.

Mag Light Demonstration

Gain Antenna Example: 10 Element Yagi





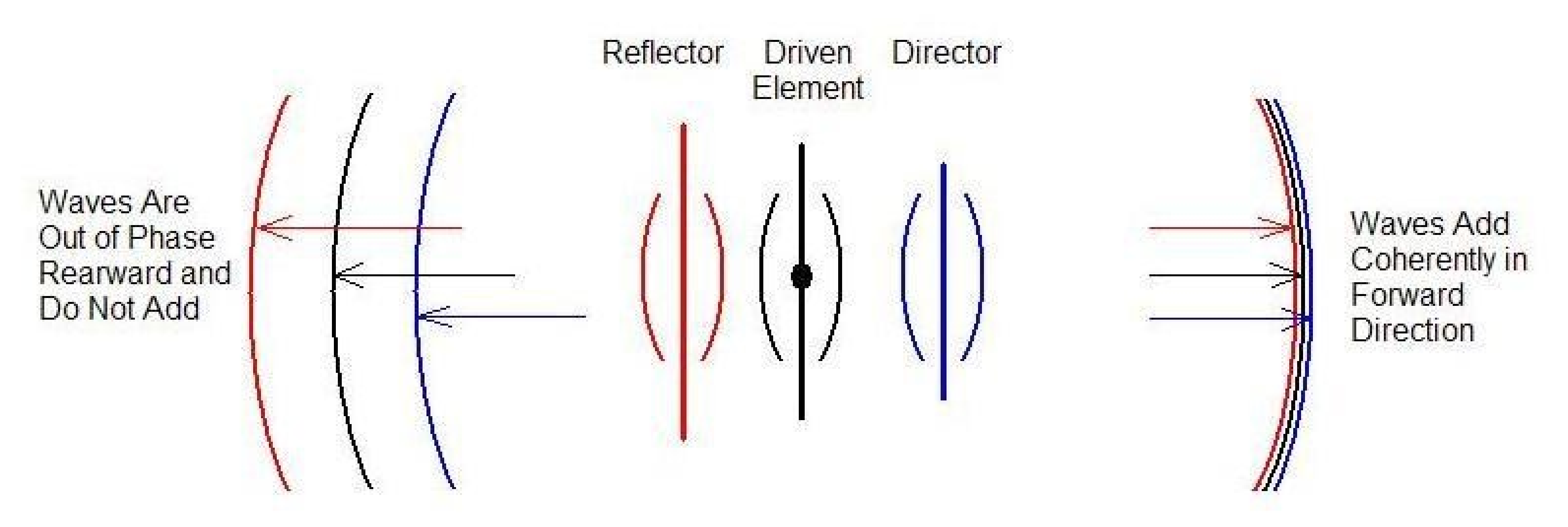
S-Band coverage: 2300-2500MHz

Gain: 14dBi

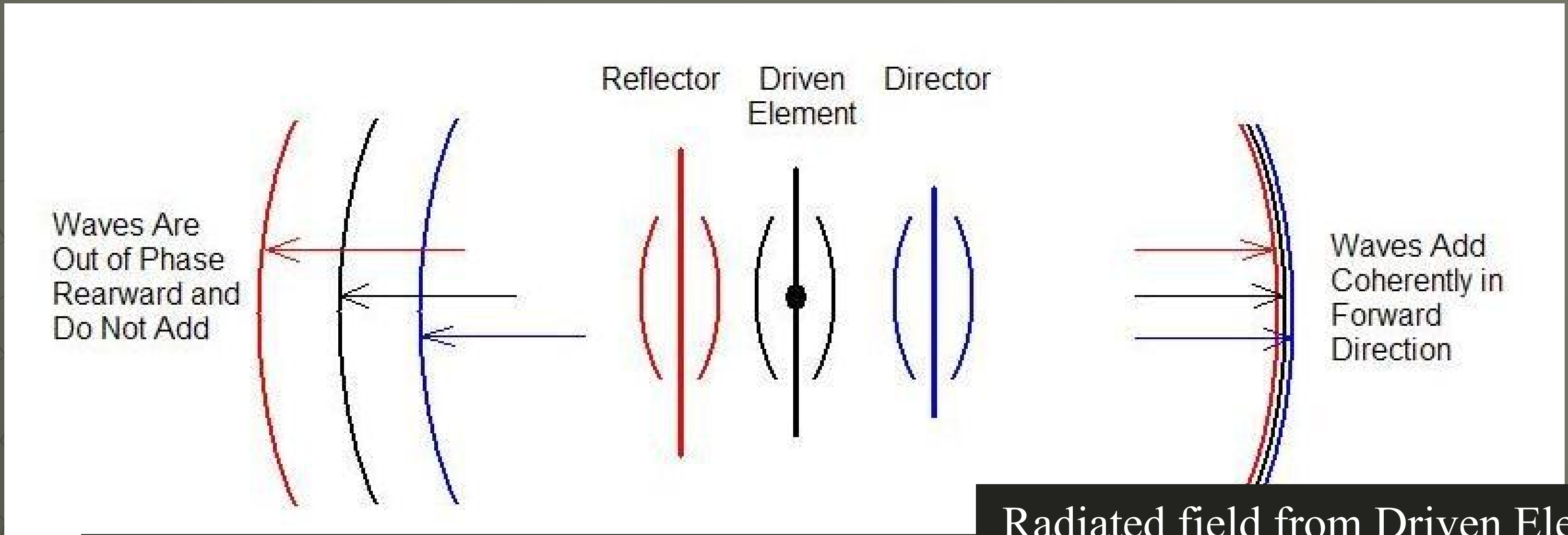
F/B: ~20dB, frequency dependent

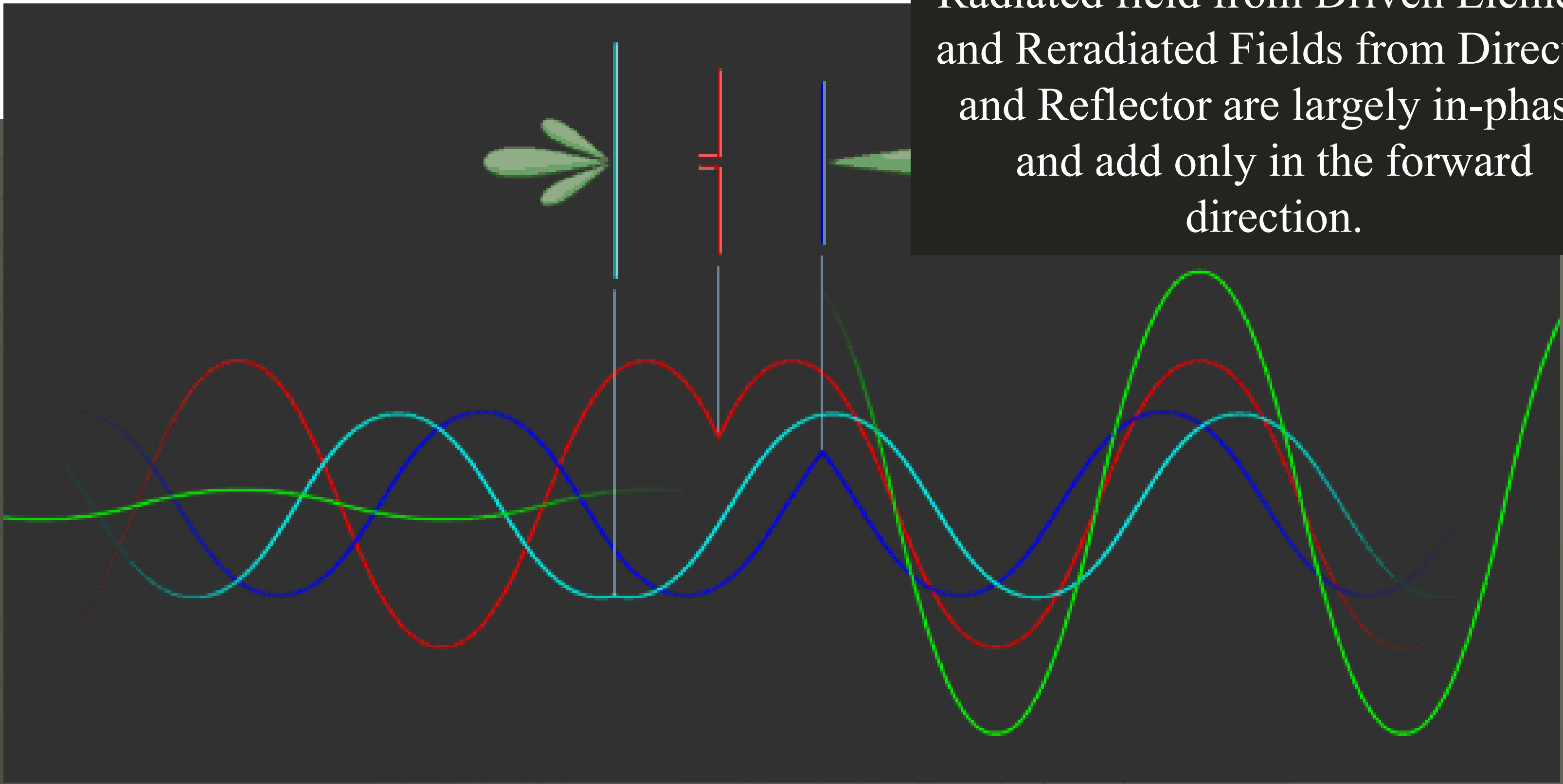
Driven Element: folded dipole with λ/2 BALUN

Operating Principle of a Yagi Beam Antenna



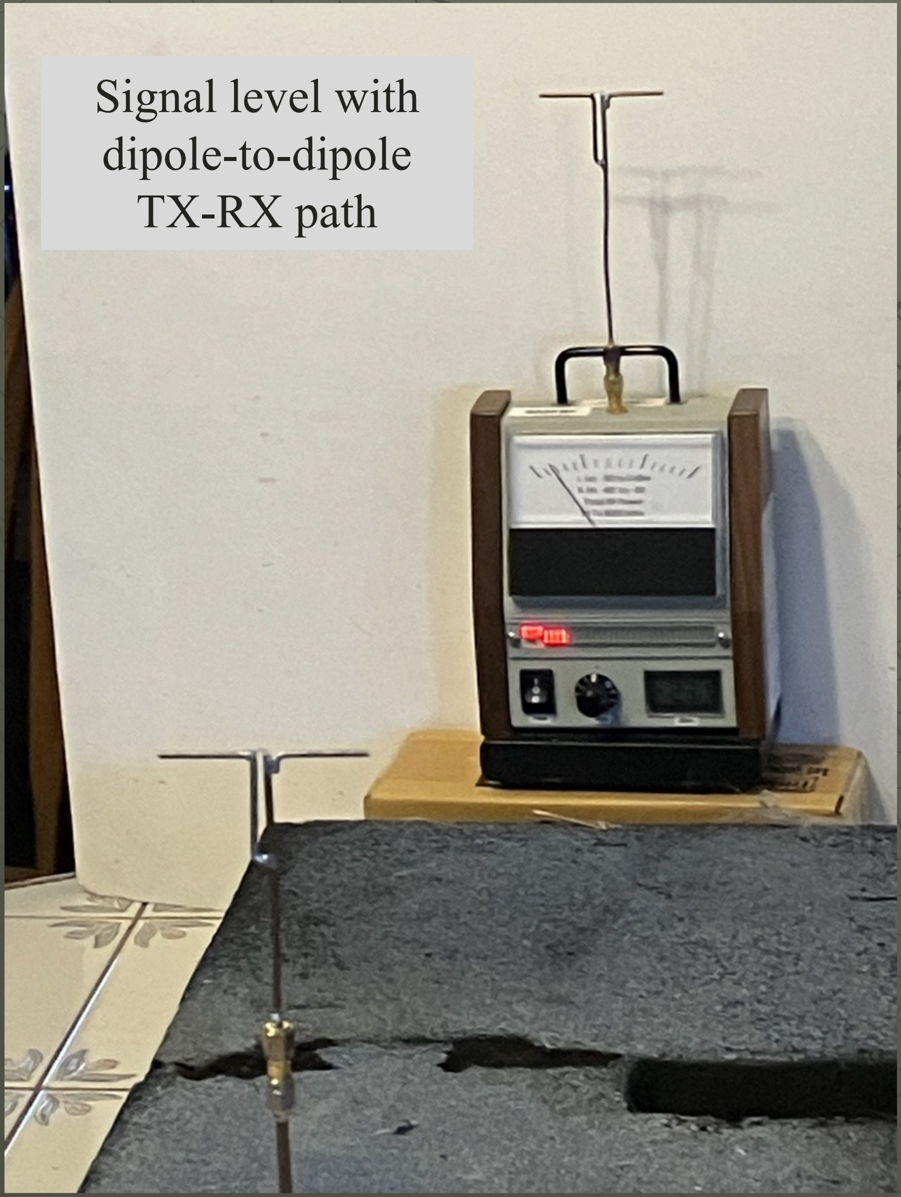
1. The resonant driven element radiates an electromagnetic wave in all directions.
2. The Reflector and Director parasitic elements absorb and reradiate energy in all directions with high efficiency.
3. The Reflector is longer than the resonant length causing it to have inductive reactance. This induces a phase lead in the reradiation, allowing it to “catch up” to the wave from the Driven Element in the forward direction.
4. The Director is shorter than the resonant length causing it to have capacitive reactance. This induces a phase lag in the reradiation, retarding the reradiation to align with the waves from the Driven Element and Reflector in the forward direction.
5. Wavefront reinforcement occurs only in one direction, giving the antenna directivity and gain.



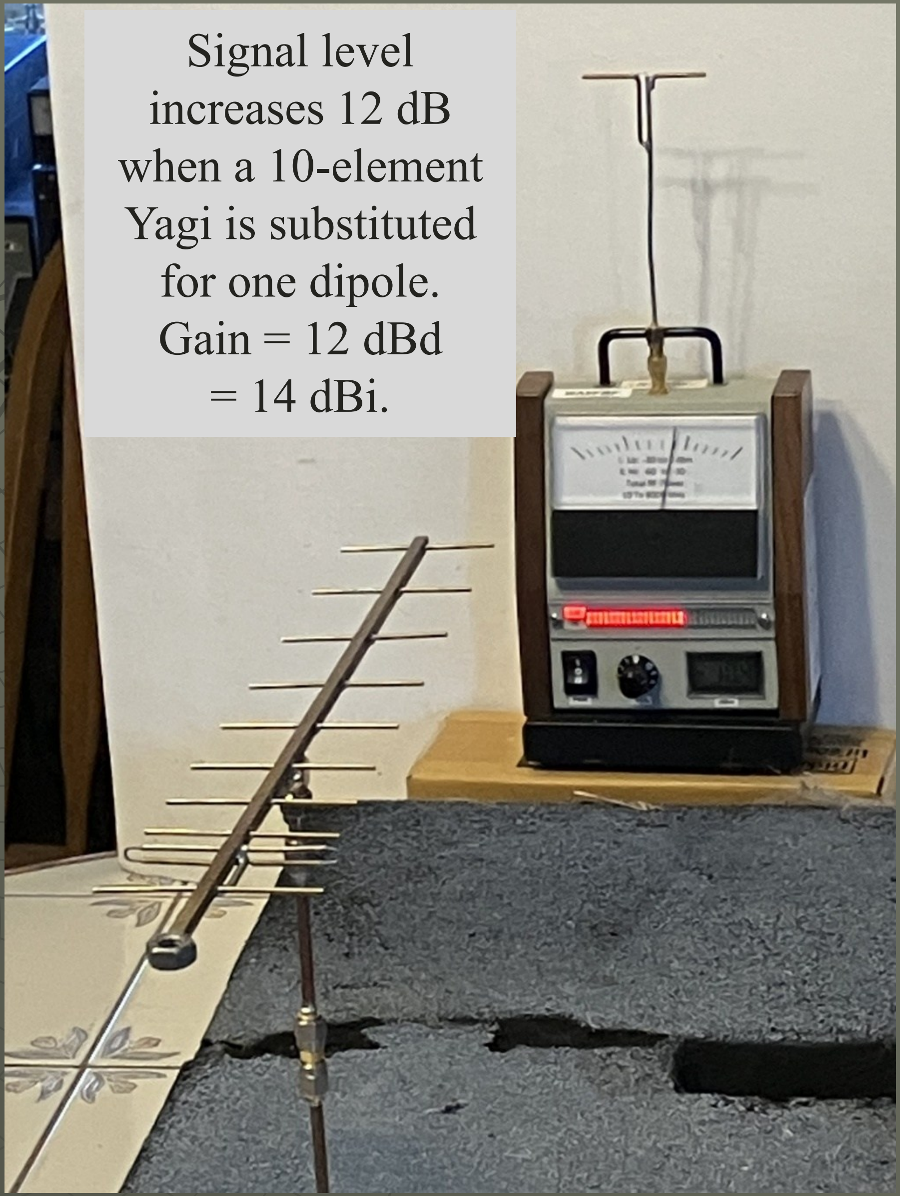


Radiated field from Driven Element and Reradiated Fields from Director and Reflector are largely in-phase and add only in the forward direction.

Antenna Gain: Dipole vs. Yagi



Signal level with dipole-to-dipole TX-RX path



Signal level increases 12 dB when a 10-element Yagi is substituted for one dipole.
Gain = 12 dBd
= 14 dBi.

Yagi Gain and Directivity

Beamwidth specification is 36 deg. Signal strength drops 3 dB if rotated 18 degrees off-axis and falls off rapidly thereafter.

Signal Peaks Directly On-Axis

Signal Diminishes Rapidly Off-Axis

Yagi Gain Is a Function of Boom Length

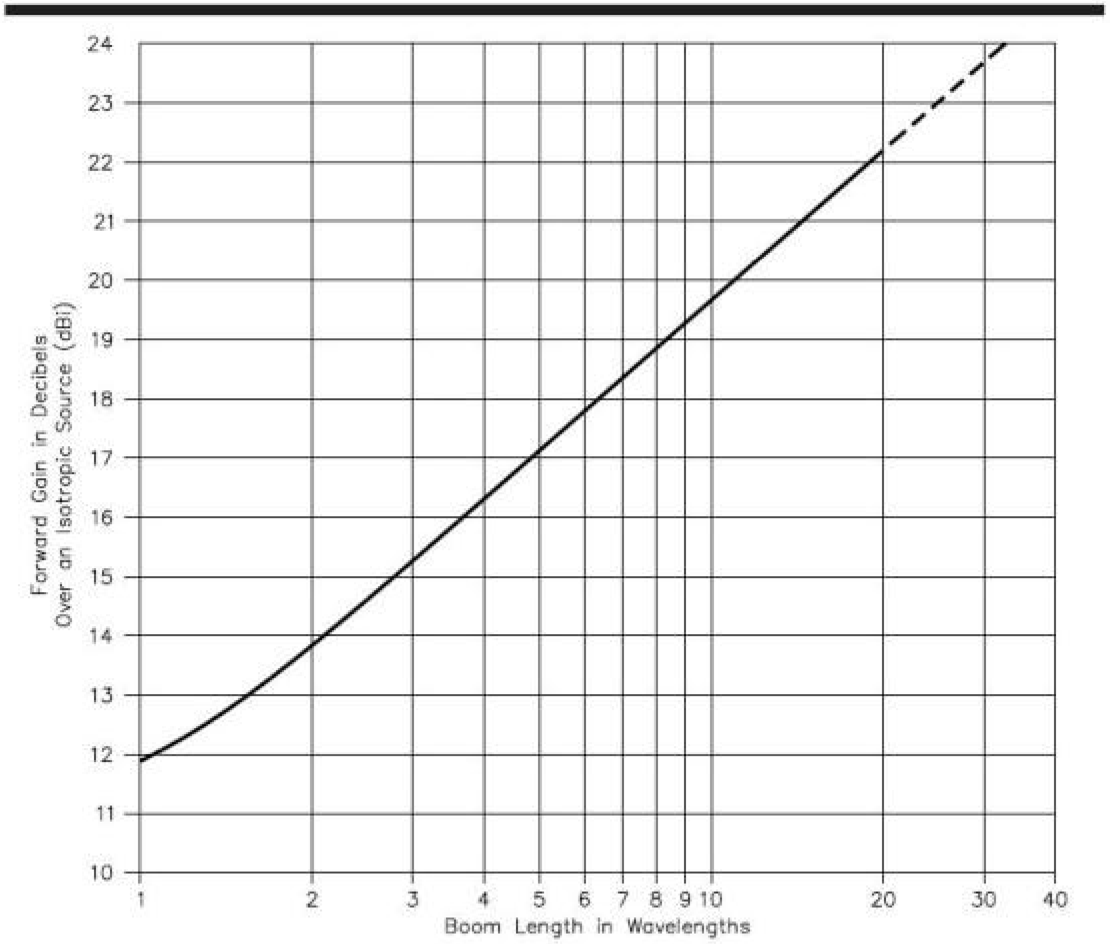


Fig 37—This chart shows maximum gain per boom length for optimally designed long Yagi antennas.

Gain increases 2-3 dB each time Boom Length Doubles. Careful design and tuning can yield Yagi antennas with gains approaching 20dB. But consider a 20 wavelength Yagi on 2 meters. It would be nearly half a football field long. High gains with Yagis is best accomplished by arraying more than 1. Gain increases ~3 dB each time number of Yagis doubles.

Yagis Aren't Just for 2 meters!

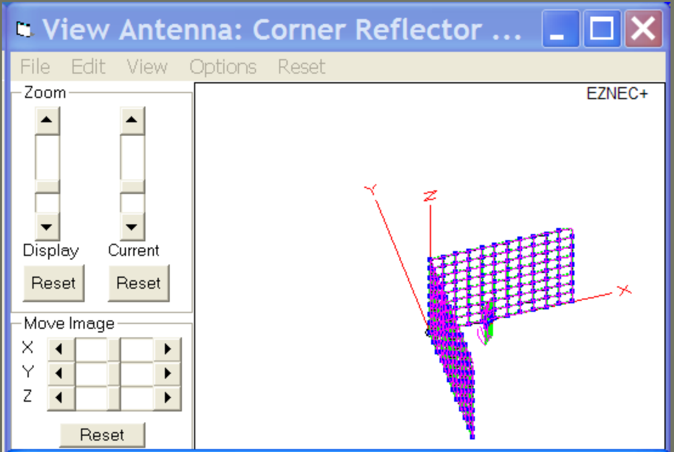
HIROSHIMA JAPAN

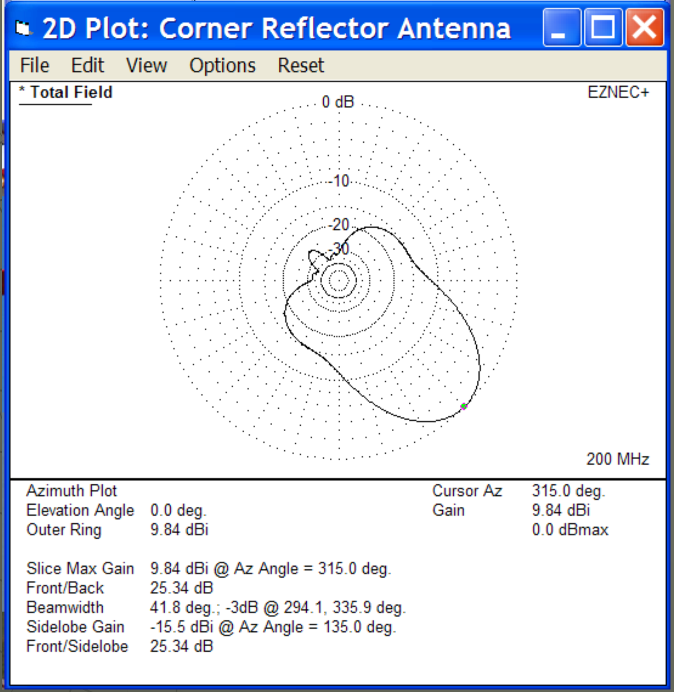
3.5/3.8MHz FULL SIZE 5EL
1.9MHz 1/2 λ DP 60mH
(Length of the boom 42m)

7J4AAL

The 90-degree Corner Reflector: Gain by Producing a Triple Reflection of a Single Driven Element

The corner reflector produces ~ 10 dBi gain by summing radiation from the real antenna and that of three virtual antennas created by reflections from the two sides and the corner. The three image antennas were captured optically in this photograph.





```
Azimuth Plot                                    Cursor Az   315.0 deg.
Elevation Angle  0.0 deg.                       Gain        9.84 dBi
Outer Ring       9.84 dBi                                   0.0 dBmax

Slice Max Gain   9.84 dBi @ Az Angle = 315.0 deg.
Front/Back       25.34 dB
Beamwidth        41.8 deg.; -3dB @ 294.1, 335.9 deg.
Sidelobe Gain    -15.5 dBi @ Az Angle = 135.0 deg.
Front/Sidelobe   25.34 dB
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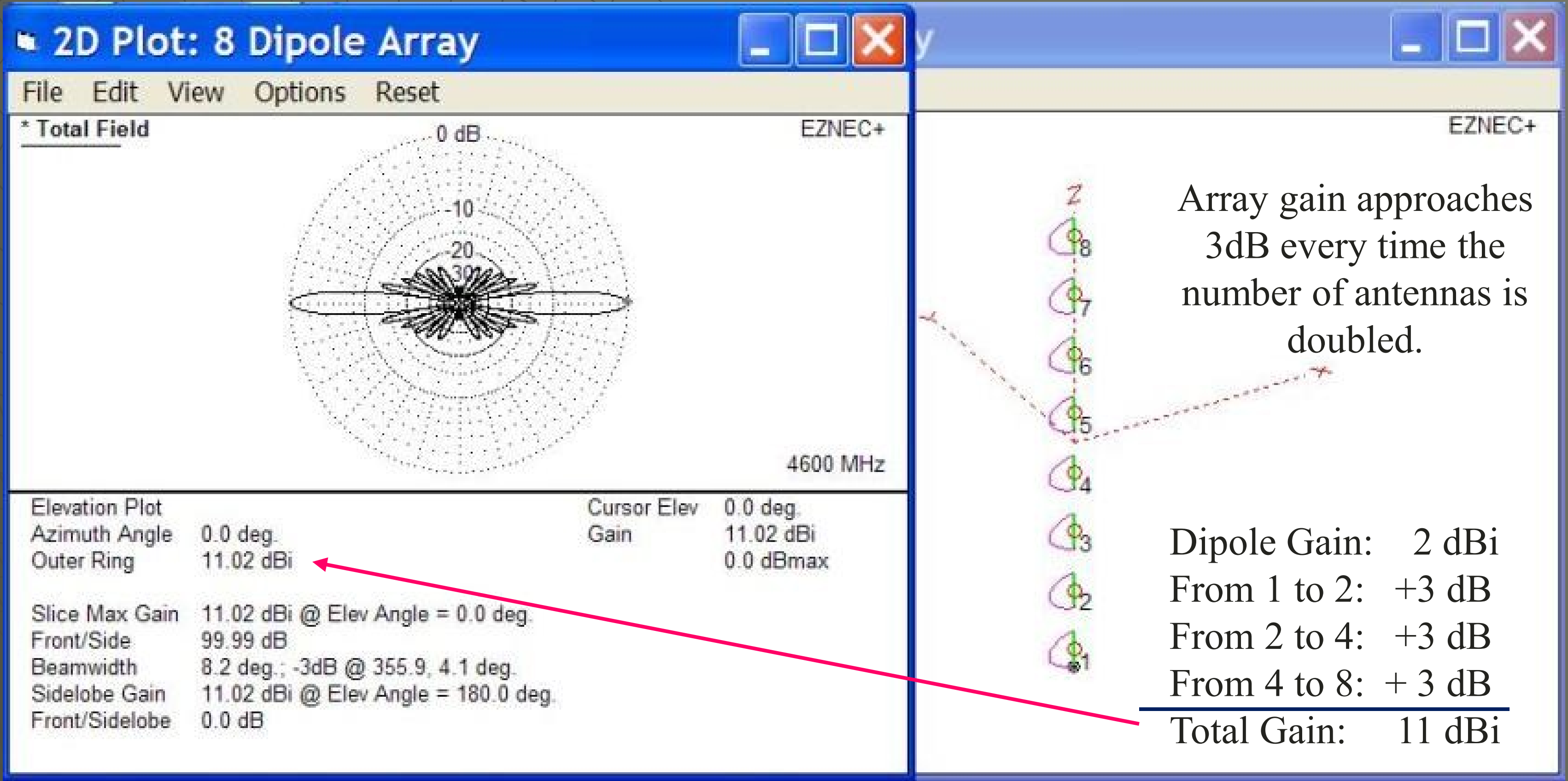
Stacking Radiating Elements Vertically Compresses the Vertical Pattern and Gives Significant Gain that is Omnidirectional in Azimuth



```
Elevation Plot                                         Cursor Elev   0.0 deg.
Azimuth Angle     0.0 deg.                             Gain          11.02 dBi
Outer Ring        11.02 dBi                                          0.0 dBmax

Slice Max Gain    11.02 dBi @ Elev Angle = 0.0 deg.
Front/Side        99.99 dB
Beamwidth         8.2 deg.; -3dB @ 355.9, 4.1 deg.
Sidelobe Gain     11.02 dBi @ Elev Angle = 180.0 deg.
Front/Sidelobe    0.0 dB
```

Array gain approaches 3dB every time the number of antennas is doubled.

Dipole Gain: 2 dBi
From 1 to 2: +3 dB
From 2 to 4: +3 dB
From 4 to 8: + 3 dB

Total Gain: 11 dBi

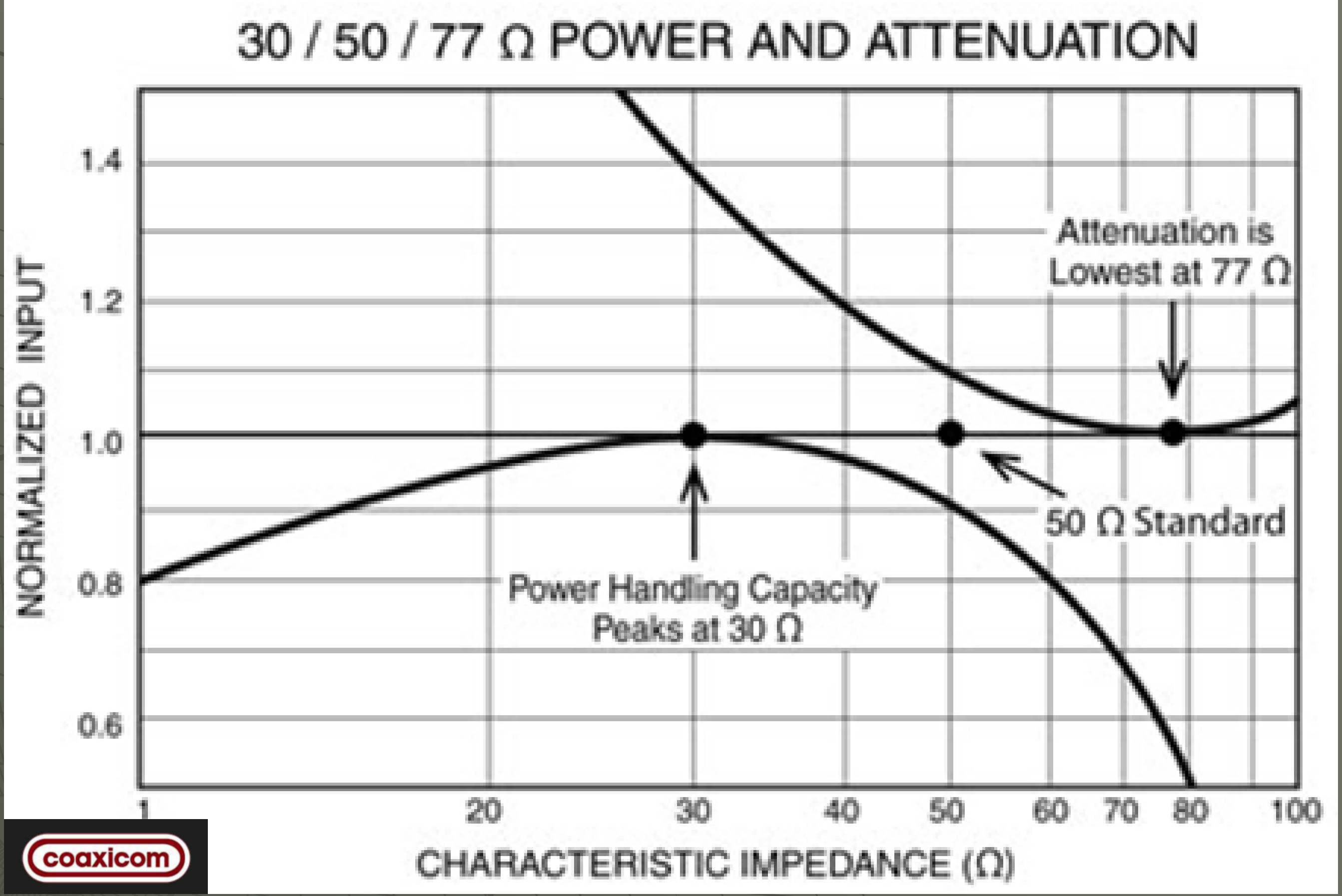
These antennas are common for police, fire, EMS, etc., base stations where high gain omnidirectional operation is required. Most FM and TV broadcast stations use a combination of transmitter power and antenna gain to achieve their large EIRP.

Why 50 Ohms?

77 Ohms. Lowest Small Signal Attenuation

30 Ohms. Best Power Handling Capacity

50 Ohms
Best Compromise



1. 77 Ohm coax has lowest small signal loss. but the small center conductor can not handle high power.
2. 30 Ohm coax handles high power best, but the low impedance creates too much Ohmic loss (Z=V/I. Smaller Z means more I for same Power).
3. 50 Ohm coax is near the average (53.5 Ohms) and has been adopted as the best compromise between low loss and power handling.

Attenuation Rates for CommonTransmission Lines

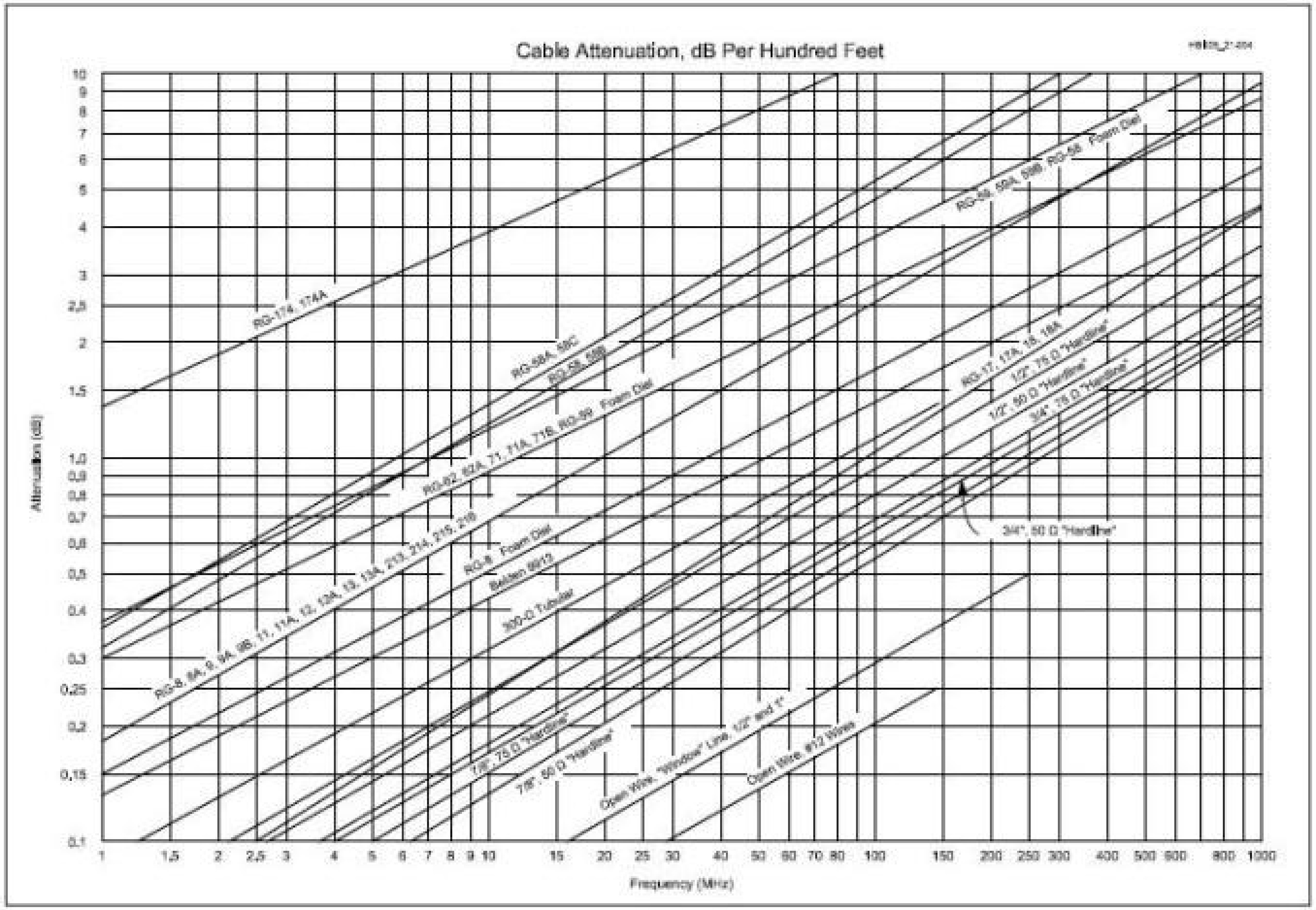
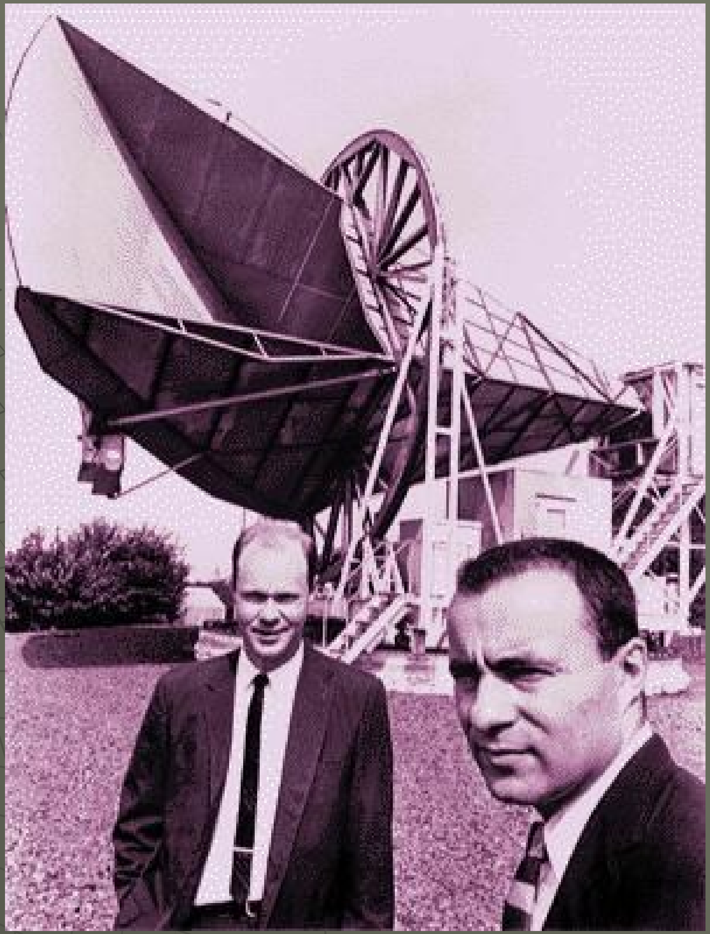


Fig 21.4—This graph displays the matched-line attenuation in decibels per 100 ft for many popular transmission lines. The vertical axis represents attenuation and the horizontal axis frequency. Note that these loss figures are only accurate for properly matched transmission lines.

Transmission line loss can seriously deteriorate station performance. A goal would be to lose no more than 10% range, which would require no more than 1 dB of transmission line loss. If the loss were 3 dB, only half the transmitter power would make it to and from the antenna.

Coax Cable Loss Demonstration

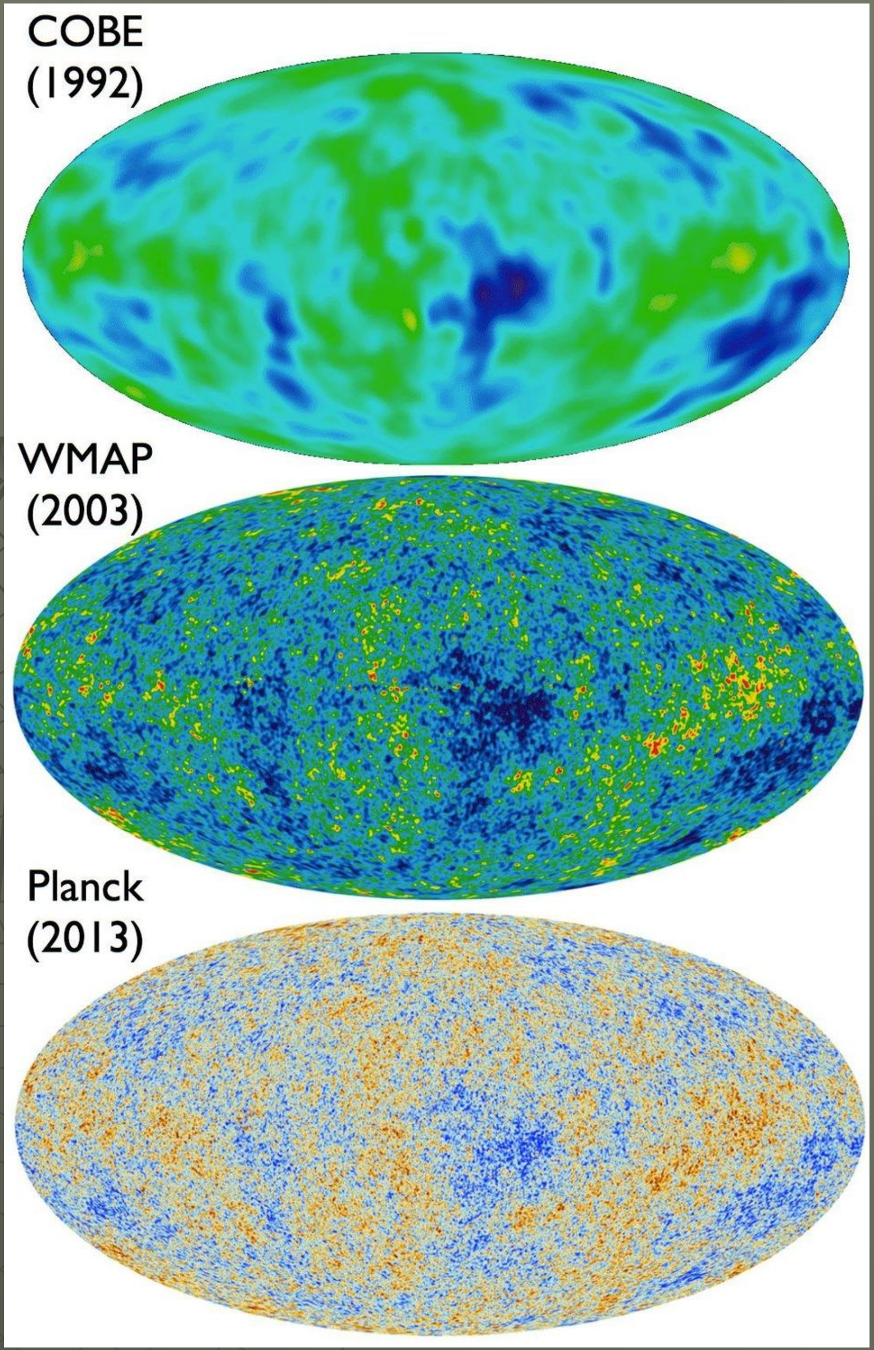
Big Things Can Come from Big Antennas



This is the horn antenna used by Penzias and Wilson to discover the Cosmic Microwave Background radiation.

The discovery was the first proof of the big bang theory, changed forever our understanding of the universe, and won them a Nobel Prize.

Successively Finer Resolution CMB Images Provided by Satellite Radiometers



1. Cosmic Background Explorer
2. Wilkinson Microwave Anisotropy Probe
3. Planck Satellite

Annoying Things Can Come from Big Antennas Too: The Duga OTH Radar Antenna


Low Frequency Antenna:150m High x 700m Long (492 x 2296 ft.)

Antennas of the Infamous Russian Woodpecker that Terrorized HF Frequencies Including Ham and SWL Bands