

ANTENNAS for the Communications Volunteer

Tech Nite Topic Alachua County ARES(R)

North Florida Amateur Radio Club

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Gordon Gibby KX4Z NCS521 NND4FL

Outline: Theory versus Practice

- **THEORY**

- What actually *is* an antenna? [A small dive into the Physics that Maxwell & others figured out]
- How is an **antenna** measured differently from a **dummy load**? [Both have their uses!]
- How are the compromises of an antenna system design measured?
 - Efficiency, gain/loss, aperture, radiation resistance, SWR, impedance: key measurements you should know!
- What is the **basic radiating element**?
 - And how does the simplest antenna jump right from this physics?
- What are the **important variations of antennas**?
 - *There are basically only a handful of key variations*

- **...AND PRACTICE**

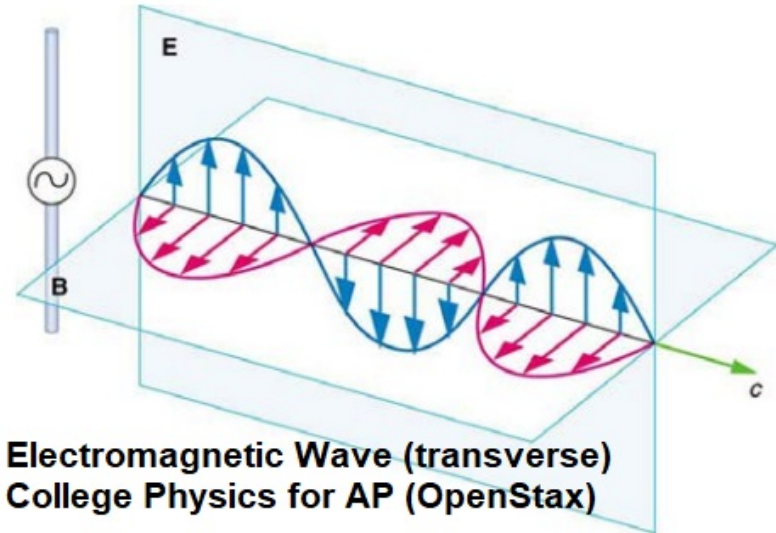
- **Strengths and weaknesses** of more than a DOZEN kinds of antennas
 - **Every antenna is a compromise.** Understanding WHAT has been compromised and to what degree helps you choose which one FITS YOUR NEED in the given situation.
 - **Examples of every basic variation of an antenna that you are likely to need, build, or purchase.**

What is an Antenna?

- **Transducers** convert energy from one presentation to another.
 - **Speakers** convert *electrical energy* into longitudinal *sound waves* (compression/rarefaction of air medium)
- Transducers are generally **BI-DIRECTIONAL** because they are **PASSIVE DEVICES**.
- **Antennas convert electrical energy into ELECTROMAGNETIC WAVES**. And vice-versa, too! Antennas are a kind of passive transducer.

Electromagnetic Waves

- **Electromagnetic waves** literally **transport energy** across empty space or a non-conducting medium (They cannot exist inside a perfect conductor)
- Consist of two fields at right angles (“transverse”) E and H (electrical and magnetic) – and right angles to the direction of travel, also!
 - Confusingly the magnetic field can be spoken of in two different vectors, the H field (magnetic field) and the B field, Magnetic flux density. Normally $B = (\mu) * H$.
- **Electromagnetic waves are created by causing charges to be accelerated:** as in pumping current INTO one half of an antenna, and pulling it OUT of the other part. The WIRE provides a linear path to SEPARATE CHARGES. The separation of charges creates an E field, and the movement of the charges creates a magnetic field....



Electromagnetic Wave (transverse)
College Physics for AP (OpenStax)

- Both the E and H fields are sine waves at whatever frequency you are transmitting (or receiving).
- The GOAL of an antenna is to provide this bidirectional transducing of
 - Electrical energy \rightarrow electromagnetic wave (when transmitting)
 - Electromagnet wave \rightarrow electrical energy (when receiving)
- Energy is “conserved” – cannot be destroyed, only turned into other forms (or matter). **Inefficiency of transformation** \rightarrow HEAT (loss)
- Normally, in an ANTENNA we do not like inefficiency (loss)

Antenna versus Dummy Load

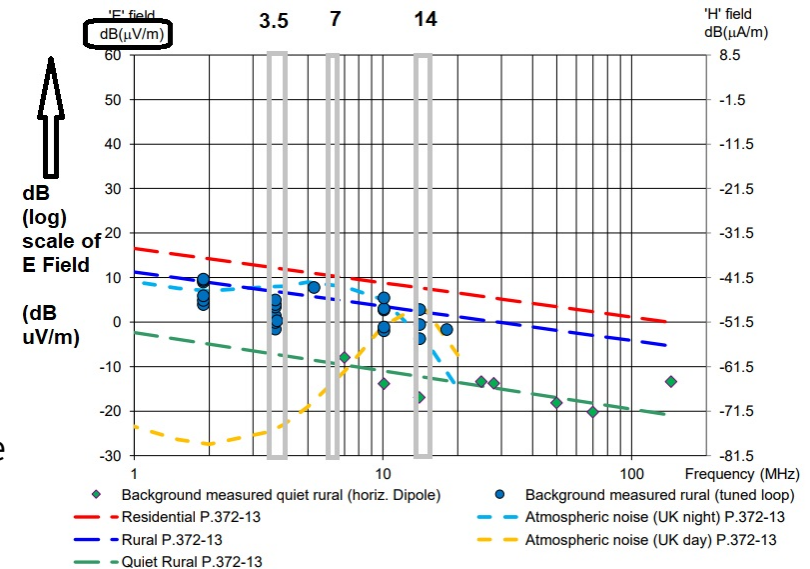
- **Dummy load** is a resistive device designed to turn electrical energy into HEAT rather than an electromagnetic wave. DESIGNED TO HAVE LOSS. Typical 50 ohms for modern radios. SWR = 1:1
- Dummy loads create a TINY bit of received noise due to quantum effects of electrons that create “white noise” across all of the spectrum.
- Dummy loads intentionally create the least amount of ELECTROMAGNETIC WAVE possible.
- **Dummy loads will appear to be very “quiet” when mistaken as an antenna** – because they DONT respond to the E and H fields surrounding us.



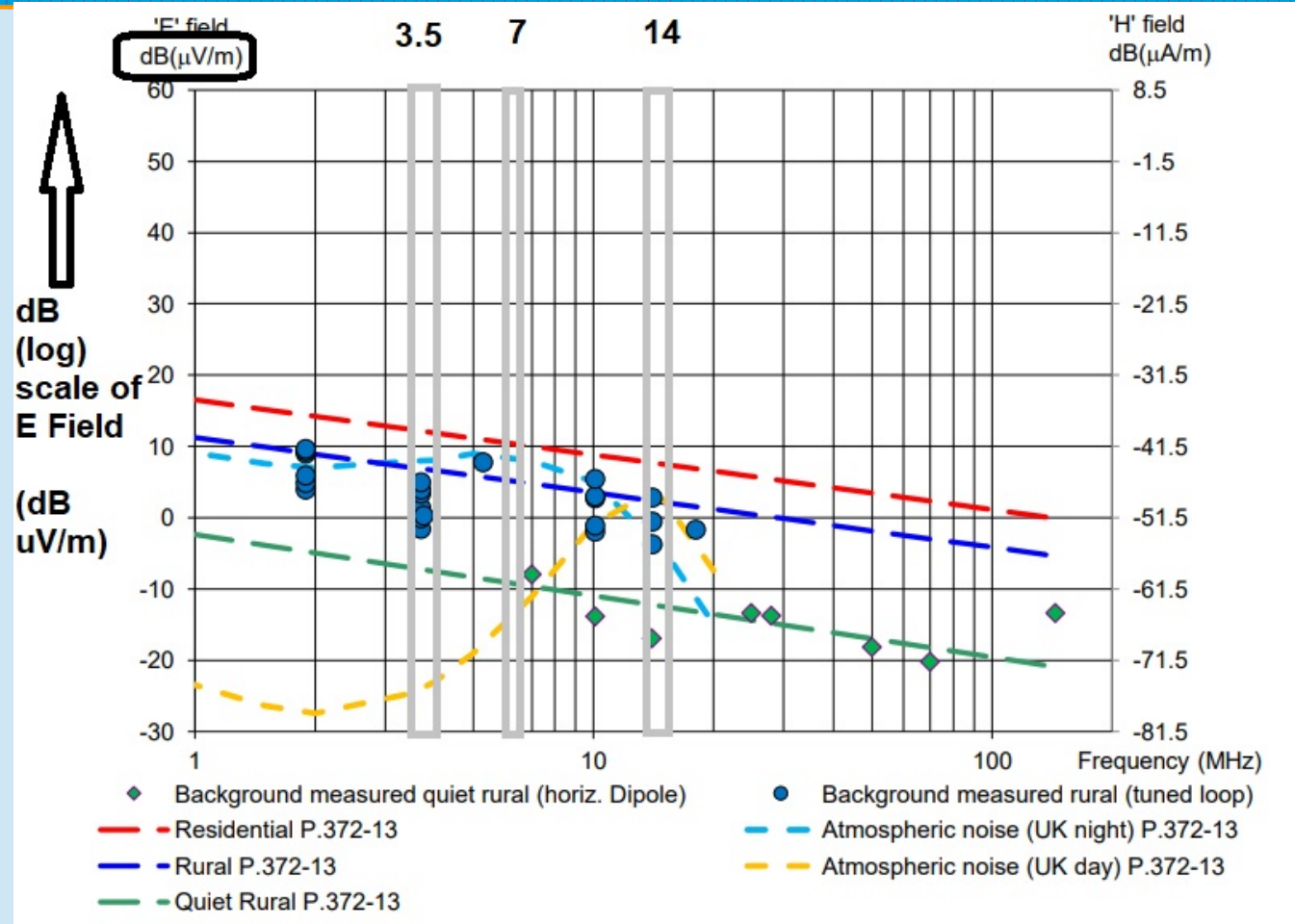
<https://www.dxengineering.com/parts/ame-adl-1500x>

Galactic Noise – The Free Signal Source To Test Antennas!

- There are **background galactic, weather- and man-made electromagnetic noises** constantly surrounding us. These come from outer space, lightning storms all around the world, and spark- or other man-made noise sources.
- Galactic and weather-noise is **predictable and follows roughly $1/f$ strength**. Worse at 80 meters, much much less at 10 meters and VHF.
- **Galactic noise can be used as an always-available signal source to evaluate the EFFICIENCY of any antenna.** Generally: Good antennas HEAR the noise; inefficient antennas hear LESS of the noise.
- CAVEAT: There are slight polarization effects to background noise, so there are slight differences between some otherwise EFFICIENT antennas.....but we aren't talking much difference.
- TAKE HOME MESSAGE: If your antenna is 3 S-units “quieter” than an efficient antenna – it is likely that you have 10dB or more LOSS built into your antenna. That might not be what you wanted??? A dummy load is VERY VERY QUIET.



RF Background Noise



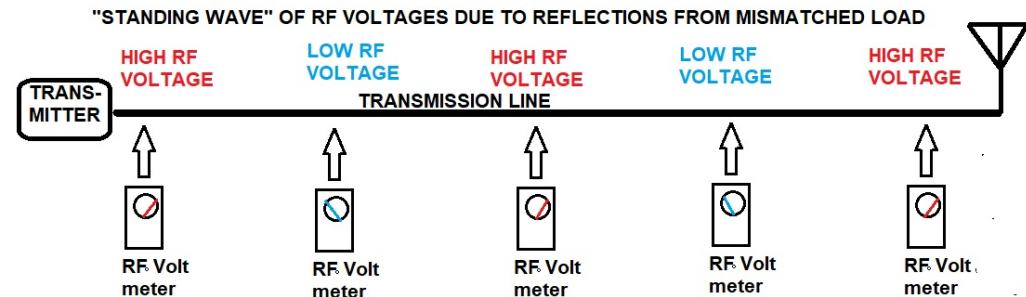
Quantifying ANTENNA versus DUMMY LOAD

SWR (standing wave ratio)

- Modern radios prefer 50 ohm loads. SWR = ratio of load:50 (adjusted to be > 1)
- Typically we wish a good LOAD because this results in maximum power transfer between antenna system and radio (in both directions)
- Good antenna systems AND good dummy loads will both have SWR 1:1 or close
- If the SWR is »1:1 then there are points along the transmission line where the AC voltage measured by a voltmeter will be HIGH and other points where it is LOW because of interactions between outgoing and reflected wave from the mismatched LOAD. These are “standing waves“ and they remain where they are. They reflect the radio-frequency-AC voltage right there on the line.



<https://www.dxengineering.com/parts/mfj-870>



Quantifying ANTENNA vs DUMMY LOAD

Measures of Efficiency

- **SWR** is *not a measurement of efficiency* of creating electromagnetic waves.
- **APERTURE** is a concept of the VOLUME of space from which an antenna captures energy and turns it into electrical signal when receiving. Bigger aperture means more efficiency, or even “gain“ *We like lots of APERTURE.*
- APERTURE is harder to conceptualize on TRANSMISSION.
- **Radiation resistance** is related to aperture but I don't know exactly how. Antennas present an impedance. Some of that reflects the transduction into electromagnetic waves and some of it reflects simply LOSS (into heat). Think, hot skinny wires, and hot RF-absorbing dielectric. *We desire the radiation resistance to be a lot greater than the loss resistance.* Radiation resistance is easy to conceptualize for transmission but also works on reception. Loss resistance just turns received waves into heat also.
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- Aperture goes DOWN for higher frequencies even for a full size dipole. They just don't intersect the same VOLUME of space.
- This shows up in the formulae for path length also – there is a penalty for higher frequencies. (See Right)
- The offset is that it is much easier to build HIGH GAIN antennas at VHF/UHF – and thus the adage that no matter what, you want a LOT OF METAL IN THE AIR to have strong signals.
- For Parabolic and Horn Antennas, the „aperture“ is somewhat more obvious.
- Don't know if this is part of why GALACTIC NOISE appears less at higher frequencies.

In terms of the distance and the transmitting frequency, the free space path loss is defined below:

$$FSPL = 20 \log(d) + 20 \log(f) + 92.45$$

The term enclosed in RED accounts for the impact of FREQUENCY on path loss, due to lower APERTURE of smaller antennas at higher frequencies.

RF link budget model

In this formula, we have FSPL in dB, d measured in km, and f measured in GHz. If the frequency were measured in another unit (MHz for example), then the constant on the right-hand side would take a different value due to a unit conversion.

<https://resources.system-analysis.cadence.com/blog/rf-link-budget-calculation-guide>

Caution: UN-NECESSARY NOISE

- **There DOES EXIST unnecessary noise – man-made noise from your local environment** (motors, computers, switching systems)
- YOU SHOULD AVOID YOUR FEEDLINE PICKING THIS UP
- You CAN and SHOULD reduce your feedline picking up unnecessary noise IF THERE ARE NOISEMAKERS in its path
- You do this with COMMON MODE CHOKES that prevent both radiation from, and pickup by, your feedline.
- Easy to purchase or make. Simple ferrite with coils of wire/coax, or making lots of loops of your coax (“ugly balun“)
- **Learn what GALACTIC NOISE LEVELS are normal for your area....**and be suspicious when you see way more noise than that!

The basic physics of making an electromagnetic wave

- You accelerate charges, separating (+) and (-) charges.
- Hooking a radio frequency sine wave to two linear conductors is a fundamental method of separating and accelerating charges (electrons)
- Separating the Charges \rightarrow Electrical field
- The movement of charge = current \rightarrow Magnetic Field

Hertzian Element

- Hertzian Element is a PHYSICS concept of ***a bit of conductor*** (SHORT!) with current flowing creating a CHARGE SEPARATION of (+) and (-)
- The changing charge separation is theorized to create the Electromagnetic Wave. (Math is pretty high level.)
- **A real antenna can be thought of as a bunch of Hertzian Elements strung out in series, connected to each other.** FINITE ELEMENT ANALYSIS of theoretical Hertzian elements is how NEC and other antenna analysis systems work.

The Beginning: Center Fed Dipole

- The Center fed dipole springs directly from Hertzian elements. Just string a bunch in each of 2 directions and push (+) into one side and (-) into the other and you create a HUGE charge separation and bingo – an ANTENNA!
- Unless the wire is terribly small, **there is little loss** if the antenna is of the perfect length.
- Most of the incident electrical energy converts to radio wave (and vice versa). **Aperture of a full size half-wave dipole is approx. = $0.13 * (\text{wavelength})^2$ Radiation resistance is approximately 50-75 ohms and much greater than ohmic loss resistances of a fraction of an ohm for normal wire sizes.**
- Ta-Da!! Our first PRACTICAL ANTENNA!
- Aperture of full size dipole is much greater for longer wavelengths.

The Important Variations of Antennas

- 1) Where we feed power to it
 - Center fed, off-center-fed, end-fed
- 2) How long we make it
 - Half-wave, longer, shorter, or $\frac{1}{4}$ wave
- 3) Whether we have extra wires or reflecting physical elements
 - Reflector, whether „parabolic“ or corner or parastic (eg. YAGI)

1) Where we feed power → Impedance

- Where we feed power determines what impedance we confront
 - Resonant half-wave fed at center = 50-75 ohms (depends on height above ground, ground conductivity, etc)
 - Resonant half-wave fed at END = approx 2K – 4K ohms
 - Resonant half-wave fed at 1/3 of length = approx 200 ohms
 - Resonant 1/4 wave aimed vertically and using „ground“ as „other half“ = 1/2 of 50-75 ohms
- DOES NOT REALLY CHANGE THE ELECTROMAGNETIC WAVE STRENGTH OR PATTERN
- If you can provide the right source impedance, you can feed ANYWHERE.

2) How Long We Make It

- Half wave is the „baseline“
- Longer than half-wave adds reactance and resistance; at full-wave the reactance disappears (again) and the center experiences HIGH resistance
- *Longer than half-wave* allows potential interference patterns that can develop GAIN in sharpening the BROADSIDE strength somewhat
- **Shortening is much more of a problem:**
 - Radiation resistance / Aperture can get much much smaller
 - Reactance present (antenna appears capacitive)
 - Radiation resistance can become tiny compared to OHMIC LOSSES
 - Antenna becomes less and less efficient

3) Extra Wires/Surfaces

- Lots of ways to enhance the signal by concentrating it:
- Ideal reflector (parabolic) will concentrate our power into a single beam, like flashlight reflector
- Corner reflector simpler to make, still concentrates
- Parasitic elements that absorb and re-radiate power with phase differences due to length and spacing can concentrate power in certain directions (“gain“) and reduce power in others („front to back ratio“)
- The TOTAL POWER RADIATED is never changed.

Practical Ham Radio - 1

- MAJOR CATEGORIES:
- Full size half-wave, center fed (70 ohms)
- Full size half-wave, end fed (2500 ohms)
- Non resonant – radiation resistance varies with length, reactance varies with length
- $\frac{1}{4}$ wave “against ground” = 35 ohms (Ground resistance key here)
- “Short” antennas with or without base loading coils
- Various reflectors, directors, yagis

Practical Ham Radio – 2: Rules of Thumb

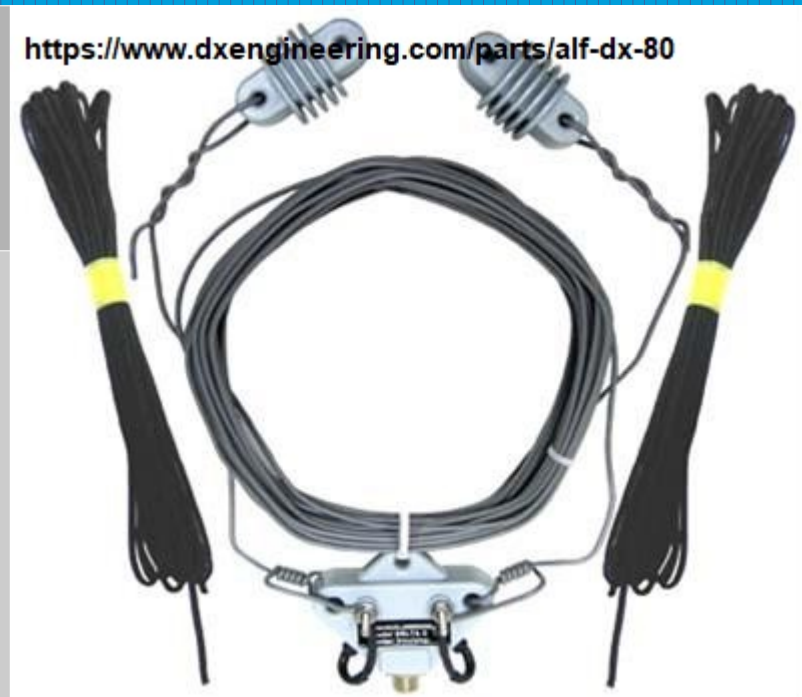
- “MORE METAL per WAVELENGTH“ (BIG Antennas) – **generally means more signal**
- “LESS METAL per WAVELENGTH“ (PETITE Antennas) – **generally means less signal**
- BETTER DIRT (more conductive) – **more signal**
- HIGHER – **more signal**
- “MYSTIQUE“ generally means more \$\$\$\$\$\$ but not necessarily more signal! Baluns can be amazingly overpriced – or fairly priced
- “EASY **AND** BROADBAND“ generally = LOSSY
- Always Remember: The Quietest Antenna.....is a dummy load!
- Much easier to build HIGH GAIN DIRECTIVE ANTENNAS.....at VHF/UHF

OFF TO THE RACES!

- Sixteen or so very popular antenna types, most commercially available AND can be home-constructed, that have stood the test of time!

The Simple Full Size Dipole / Coax

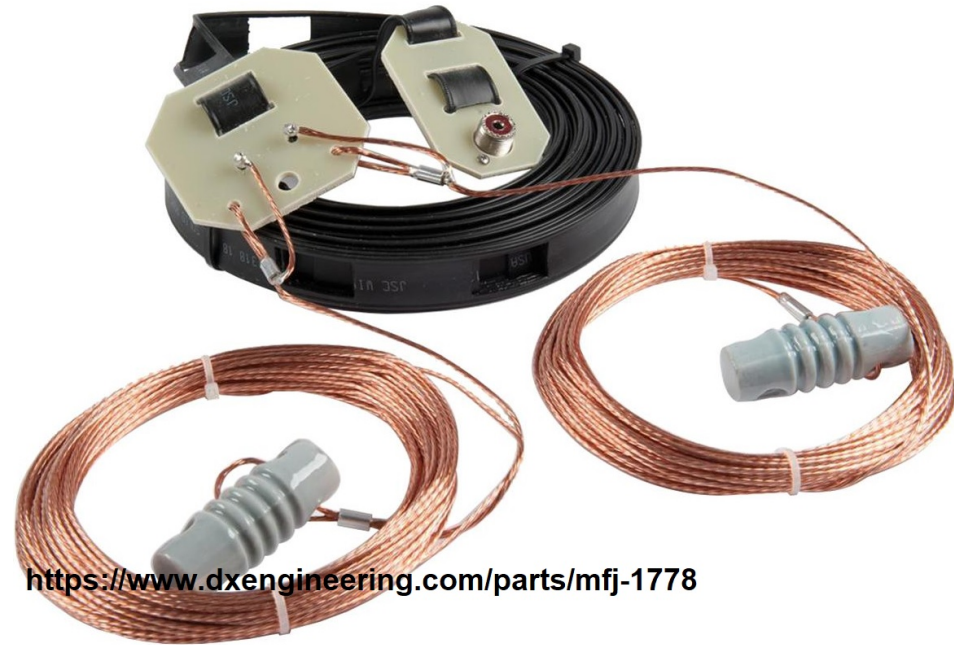
Antenna Type Example	Advantages	Disadvantages
Full size Horizontal / Sloping / Inv V Half Wave Center fed	Easy to feed with Coax Works on odd harmonics with modest rise in SWR Miniscule "loss" High takeoff angle good for EMComm	For lower frequencies, LONG Requires multiple high points Unless REALLY HIGH, difficult to get low angle rays for DX



Very simple, and they work!
Easy to homebrew.

Dipole – window line feed

Antenna Type Example	Advantages	Disadvantages
Full size – window line feed Horiz/ Slope/ V	Window line very low loss even on non-resonant frequencies Lightweight Same Elev. Angle Issues.	Generally requires CAPABLE external tuner



<https://www.dxengineering.com/parts/mfj-1778>

Full Size Parallel Dipoles / Coax / Multiband

Antenna Type Example	Advantages	Disadvantages
Full size Horizontal / Sloping / Inv V Half Wave Center fed – parallel dipoles - multiband	Easy to feed with Coax Works on odd harmonics with modest rise in SWR Miniscule “loss” High takeoff angle good for EMComm	For lower frequencies, LONG Requires multiple high points Unless REALLY HIGH, difficult to get low angle rays for DX



Built this antenna as a teen, and also on top of Dental Tower. Complicated mechanicals! Otherwise, works FINE.

Full Size Trap Dipoles (Resonant, multiband)

Antenna Type Example	Advantages	Disadvantages
Full size TRAP DIPOLE	Easy to feed with Coax Works on multiple bands because TRAPS act like parallel tuned circuits to progressive disconnect unnecessary end-wire to provide shorter antenna for higher transmit equipment.	Traps can make it a little narrower in frequency response. Pricey. Tougher to build at home.



I've used this type as well.

Off Center Fed – resonant (multiband)

Antenna Type Example	Advantages	Disadvantages
Full Size Horiz. Half Wave, Off center fed / Sloping/ Inv V	With balun, easy to feed with coax Works on a lot of bands with acceptable SWR Miniscule “loss” Same Elev. Angle issues	Requires Balun Current Balun (2 cores) Heavier but much less loss than cheaper voltage balun system. Requires center support as well as ends

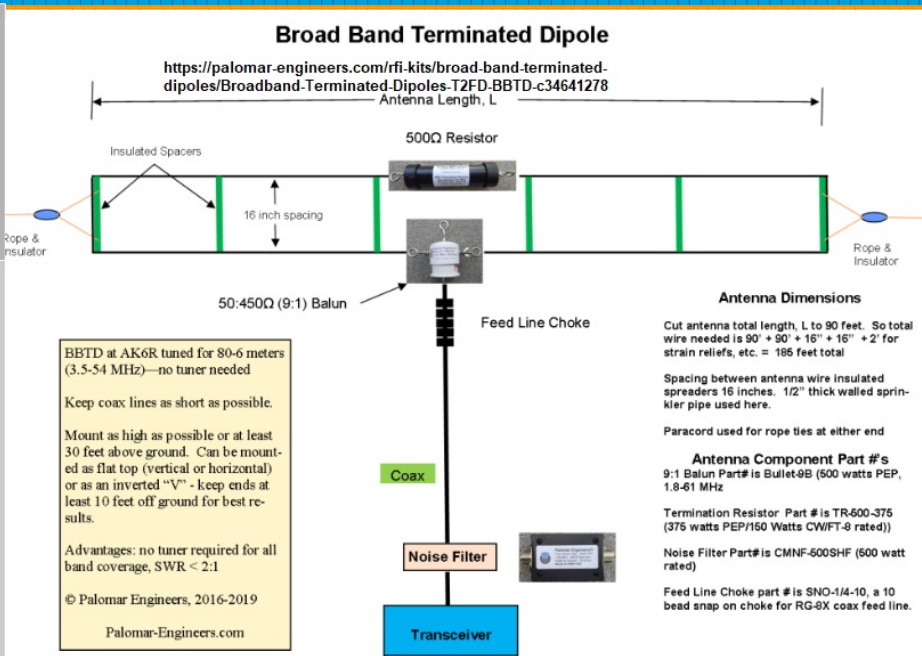
<https://www.dxengineering.com/parts/bmt-dx-ocf-hp40>



We have made many of this type antenna with a lower-loss balun, at 80% less cost....

Folded/Terminated – (multiband)

Antenna Type Example	Advantages	Disadvantages
Folded Terminated dipole	<p>Good SWR everywhere.</p> <p>Easy for minimally trained persons to use.</p>	<p>BUILT IN LOSS!!!</p> <p>Most prominent at the lowest frequencies where it can hit 10dB</p> <p>Usually \$\$\$\$</p>



End Fed 49:1 Resonant

<https://www.dxengineering.com/parts/pez-ef-40-10-kw>

Antenna Type Example	Advantages	Disadvantages
Full Size Half Wave, End Fed Horiz / Sloping/ V	Works on harmonic bands Often only one "high point" required Same Elev. Angle Issues	Need some tuning 49:1 baluns modest loss Same Elev. Angle Issues



One of our favorite simple HF antennas, we have made a ton of these....at much much lower cost!

9:1 Non Resonant (Expedient)

Antenna Type Example	Advantages	Disadvantages
NON-RESONANT Length – End fed with 9:1 balun Vert Or Horiz	Lightweight, expedient field antenna; with good tuner, short coax, can work on many bands (9:1 is a compromise) More vertical = More DX More vertical = Less NVIS	High SWR in coax can cause significant loss if LONG. Requires capable tuner! Requires 1:1 choke balun to avoid “hot” cases in shack With shorter wire – reduced aperture and efficiency



<https://www.ebay.com/itm/202786935032>

*Portable
Antenna Seller*

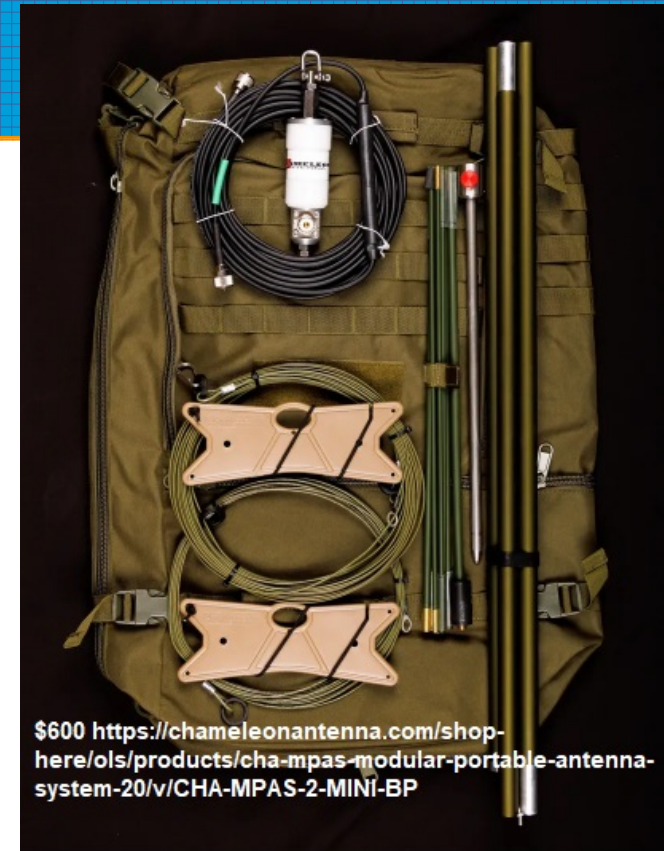
We make OUR 9:1 baluns using type 43 ferrite and losses approx 1/4 dB

Balun loss expert:

<https://www.g8jnj.net/balun-loss>

Short Expedient Verticals

Antenna Type Example	Advantages	Disadvantages
Really short with or without base loading inductor / balun	Lightweight, often self-supporting field expedient antenna. Some may have built-in LOSS to make SWR's appear better Often VERY EASY to set up!	Very short = High Loss Low Radiation Resistance Loss in wire of coil



Short, field expedient antennas with low-loss coil loading or low-loss balun make a lot of sense – and can be built using PVC tubing or tent poles for reasonable cost.

Improvements: Ground radials or Counterpoise

Antenna Type Example	Advantages	Disadvantages
Horizontal antenna, add wire on ground beneath it	Reduces ground loss, acts somewhat like a ground “reflector“	More wire Caught by lawnmower if not buried
Vertical, add ground radials	Reduce ground rod Loss Requires a LOT (>30) to be really good. Better if $\frac{1}{4}$ wavelength DX'ers LOVE the flat elevation take-off: great for Asia etc.	Bury an inch to avoid lawn mower NOT good for NVIS work in emergency comms

Majority of Commercial VHF/UHF Verticals

Antenna Type Example	Advantages	Disadvantages
VHF/UHF collinear	Modest Gain, often self Supporting RELATIVELY CHEAP, TOUGH	Easier built by companies

Internal matching network. Probably somewhat „off center fed“ Collinear segments. Work great, coax hangs down vertically, easy to mount with u-bolts

<https://www.dxengineering.com/parts/dmn-x50a>



VHF/UHF Ground Plane Antenna

Antenna Type Example	Advantages	Disadvantages
VHF/UHF Quarter wave vertical with ground plane radials	EASY, SIMPLE, and LOW LOSS Feed with Coax	Very few disadvantages other than the radials sticking out



<https://www.dxengineering.com/parts/mfj-1752>

Easy to build, and allows coax to drop vertically down.

J-Pole/ Slim Jim tuned end-fed

Antenna Type Example	Advantages	Disadvantages
VHF/UHF Halfwave end fed (Slim Jim, etc)	Self supporting and no need for radials	Generally requires some tuning of the matching system Avoid metal near the matching stub. Ignore the claims of "gain" Can have common mode current but „balun“ easy coils of coax

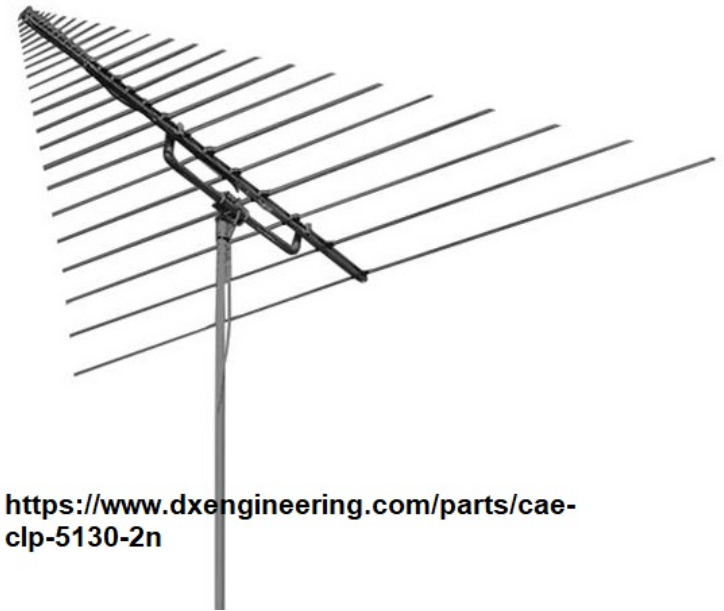


<https://www.gpscentral.ca/product/arrow-antenna-osj-146-440-dual-band-j-pole-so239/>

TOUGH antennas!!!

YAGI-UDA

Antenna Type Example	Advantages	Disadvantages
VHF/UHF YAGI	Relatively simple antenna can be built with rods Significant gain achievable! Expedient can	Bulkier than a no-gain vertical.

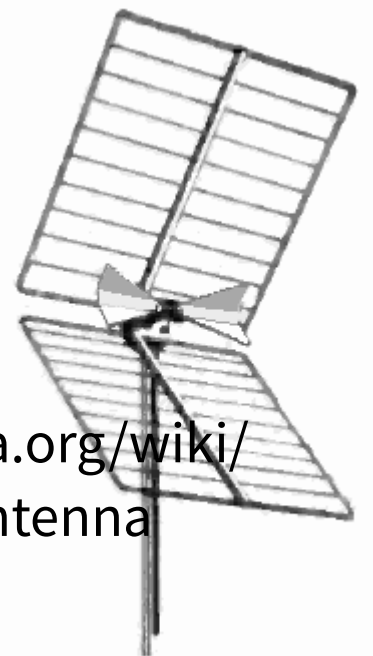
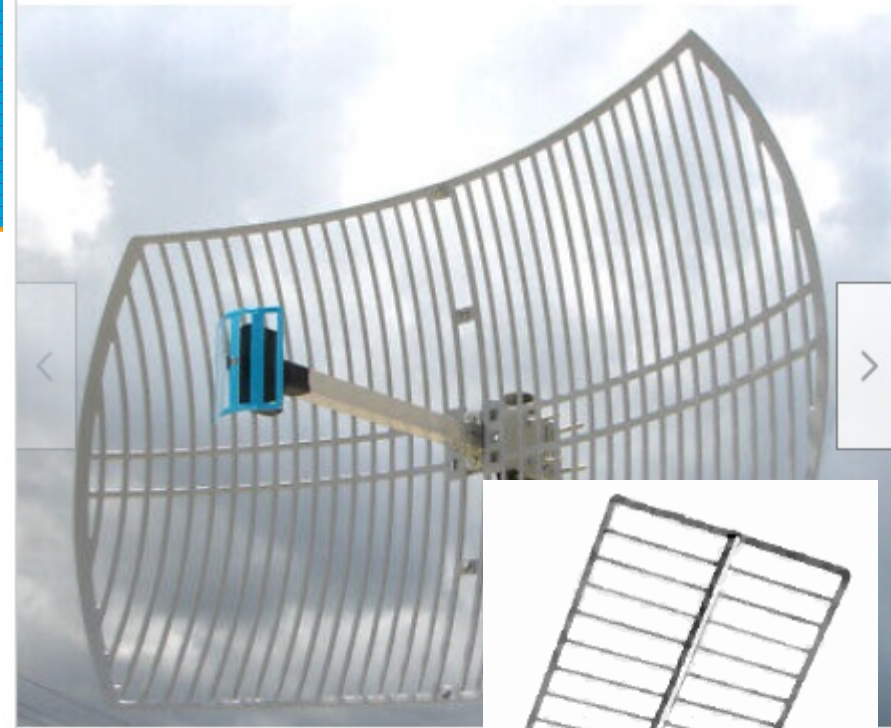


<https://www.dxengineering.com/parts/cae-clp-5130-2n>

Log Periodic Yagi: Works on wide frequency range

Very high gain

Antenna Type Example	Advantages	Disadvantages
VHF/UHF Parabolic or corner reflector	Impressive GAIN possible	Mechanical construction becomes more problematic



https://en.wikipedia.org/wiki/Corner_reflector_antenna

Stacked Yagi's

Antenna Type Example	Advantages	Disadvantages
VHF/ UHF stacked yagis's	Impressive GAIN possible	Mechanical construction becomes more problematic

<https://www.qsl.net/dk7zb/Stacking/stacking.htm>



The End

- There are many additional antenna designs, and innumerable VARIATIONS on them. But these cover a lot of the ground....

