DE-MYSTIFYING DIPOLES AND DOUBLETS

PRESENTED AT THE
GREATER NORWALK ANATEUR RADIO CLUB (GNARC.ORG)

September 14, 2022

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Hams often complain about not getting out …

"Over the years, I have discovered that many multi-band wire-antenna users remain unaware of the patterns produced by their antennas on different bands"
– L. B. Cebik, W4RNL

Primary Information sources for this presentation

- The ARRL Antenna Book
- L.B. Cebik, W4RNL (SK 2008) numerous articles. – ARRL Technical Adviser and antenna authority. WR1B, *QEX* Editor, called Cebik "probably the most widely published and often read author of Amateur Radio antenna articles ever to write on the subject.“
- Joel Halas. W1ZR (SK 2021) – numerous articles. QST Technical editor. Prolific author of *QST* articles and ARRL books.
- Owen Duffy, VK1OD blog at owenduffy.net The myth buster and quoted in the ARRL antenna book on efficient EFHW matching transformer and various antenna topics. I have corresponded with him on accurate EFHW transformer models using SimSmith.
- Steve Hunt, G3TXQ (SK 2017) (Hexbeam expert and other in-depth technical topics at Karinya.net)
- My own simulations using ***EZNEC Pro+ v. 7.0*** **(**now free) by Roy W. Lewallen W7EL and ***SimNec 1.2*** **(**Formerly SimSmith) by Ward Harriman. I have corresponded with Ward Harriman many times re: SimSmith. I plan to learn MMANA-GAL and the Excel tool Auto-EZ. Note: Simulations are only a tool. The proof is in actual measurements which validates simulations. The combination of EZNEC and SimNec or SimNec by itself allow easy visually observable effects of transmission line length and impedance on VSWR plots for a multiband antenna.

Main Topics

- Intro stuff
- Cebik's favorite backyard antennas and if he only had one simple wire antenna (40-10M with known direction)
- Dipole vs doublet definition
- Dipole details and multibanding
- Doublet details and multibanding
- Feed-line considerations
- Antenna tuner considerations

Narrowing down which simple antenna(s) to use

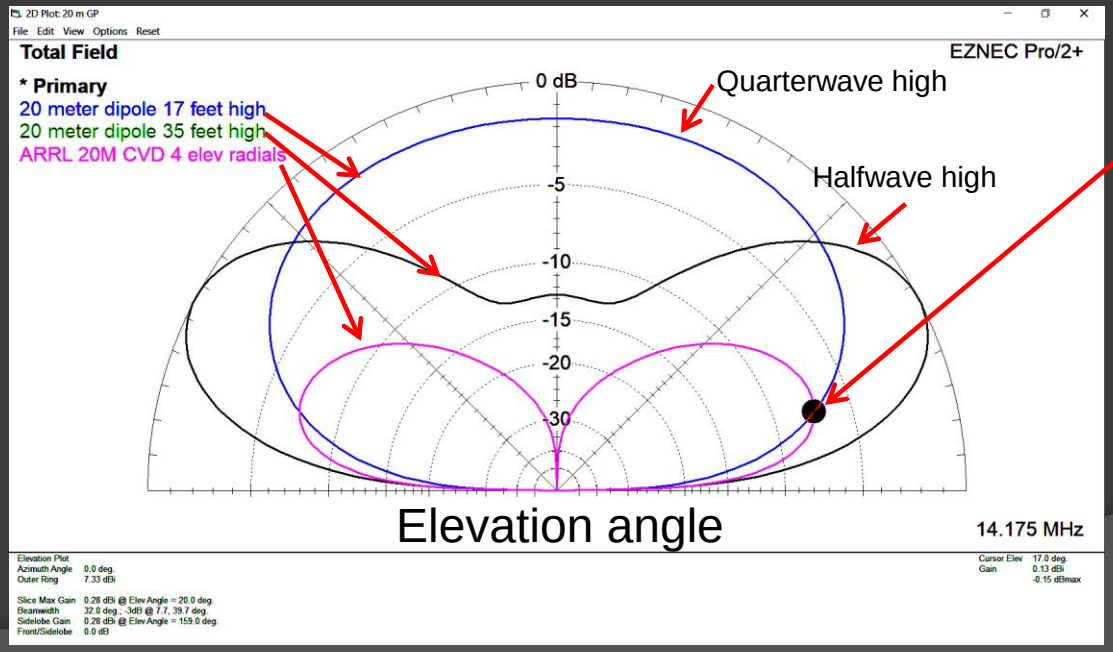
- Operation dependent
  - Home use – semi-permanent installation, available real estate and mounting options, bands and operating modes
  - Field Day – moderately quick deployment, available mounting provisions, co-located setups where interference is an issue
  - POTA – portable/lightweight with very quick deployment and limited mounting provisions
  - SOTA – very portable/lightweight and very quick deployment and limited mounting provisions
  - DxPeditions – Good performing antennas with moderately quick deployment

Hard to believe but …

- First a definition: dBi = dB with respect to an isotropic antenna – a conceptual one that radiates equally in all directions (spherical pattern). 3dBi = 2X power, 6dBi = 4X power, 9dBi=8X power of isotropic antenna
- Gain of quarter-wave vertical with 16 quarterwave ground radials over average ground: **0.22dBi** at 22 degrees (**1.052X**)
- Gain of a dipole in free space: 2.15dBi (1.64X)
- Gain of a dipole half wave above average ground: **7.9dBi** at 28 degrees (**6.17X**)
- Gain of an extended double Zepp (88 feet long doublet on 20 meters 35 ft high): with average ground: **10.49dBi** @28 deg (**11.2X!!!**)
- Gain of 560 ft long horizontal loop 70 ft high on 20 meters: **12.9dBi** at 12 degrees (**19.5X!!!!**!)

Dipole vs. Vertical

- So how can a vertical still work well, especially for DX, if it's peak power is ~6.8dB or ~6X weaker than a dipole mounted ~ a half wave high? Well, read on.
- It's all about Elevation angle. Elevation angle, elevation angle! Many backyard dipoles are mounted too low with NVIS elevation pattern! A 40M dipole mounted 35 ft high will lose to the vertical at elevation angles below about 17 degrees!



20M Quarterwave vertical beats 17 foot high 20M dipole below 17 deg. elevation angle!

…but 20 meter dipole mounted 35 feet high beats quarterwave vertical even at low radiation angles !!!!

Cebik's favorite backyard multiband wire antennas

- In no particular order.
  - 1. The dipole-doublet(s)
  - 2. The broadside doublet(s)
  - 3. Fanned dipoles
  - 4. The hohpl--horizontally oriented and polarized loop
  - 5. The inverted-L
- If he had only one antenna that covers 40M-10M with known direction:
  - The 44 foot doublet

An important fact about all horizontal antennas

- “Every horizontal antenna is subject to essentially the same general phenomena that affect horizontal dipoles in terms of their height above ground. The lower the antenna as a fraction of a wavelength, the lower will be the overall gain and the higher the elevation angle of the radiation.”

  -My Top Five Backyard Multi-Band Wire HF Antennas - L.B. Cebilk W4RNL

- A good rule of thumb to strive for: Height should be at least equal to width of antenna. This is about a half wavelength for a dipole. Difficult to do at the lower HF bands.

Difficult height to achieve for the average ham

Band, Meters	Frequency MHz	Half Wave, ft	Full wave, ft
80	3.7	126.8	253.6
60	5.3	88.52	177.04
40	7.1	66.08	132.16
30	10.1	46.5	93
20	14.175	33.1	66.2
17	18.1	25.92	51.84
15	21.2	22.13	44.26
12	24.9	18.84	37.68
10	28.5	16.46	32.92

Think Wavelengths, not feet!

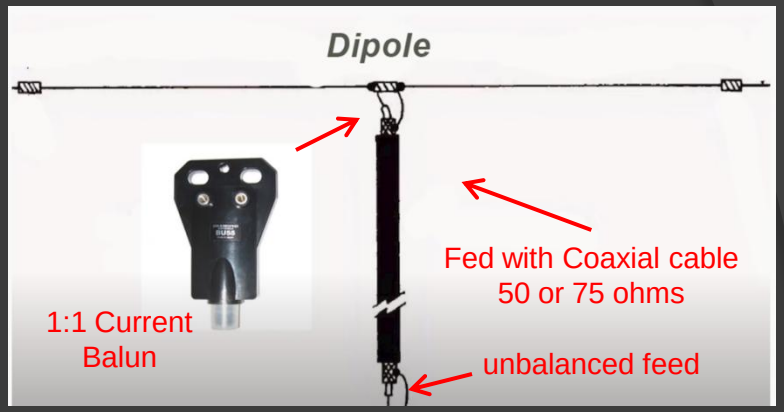
Dipole or Doublet?

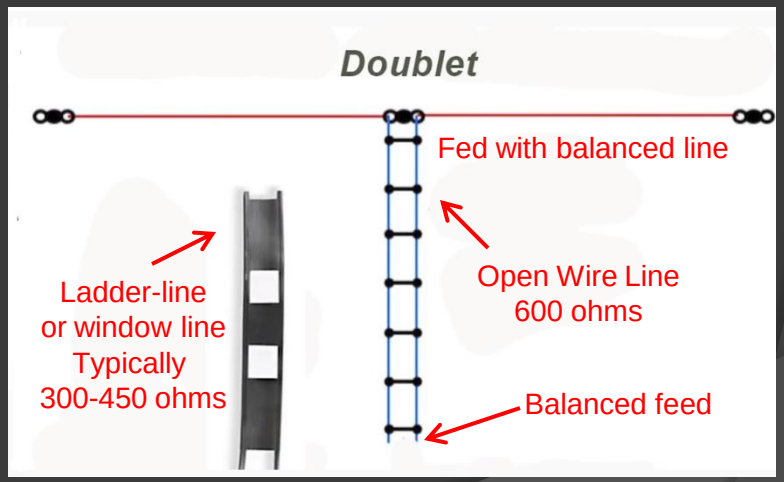
Half-wave Length ~ 468/MHz

- "When does a dipole become a doublet and vice-versa? There is no formal difference. - These are just two different names for the same antenna.
- The term "doublet" is often applied to symmetrical center-fed antennas that are not resonant or that are used on multiple bands to distinguish them from the resonant center-fed dipole. This is a matter of convention only."

  -ARRL Antenna Book

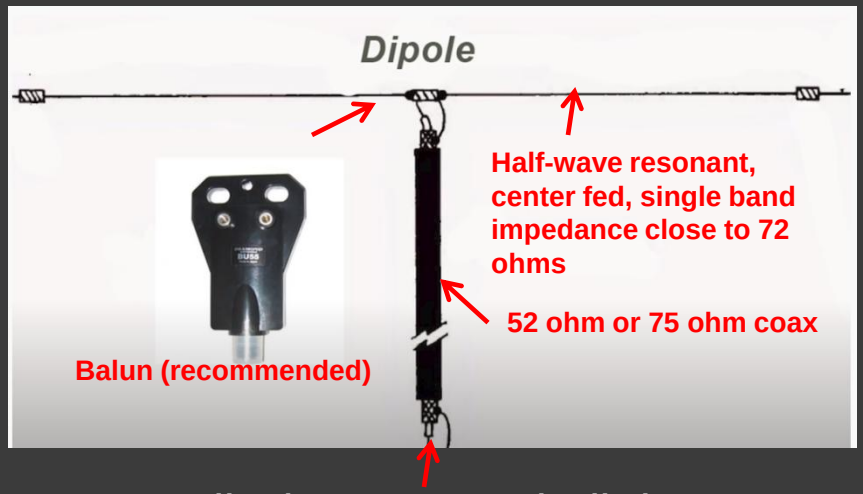
- So we'll use this convention in the rest of the presentation.



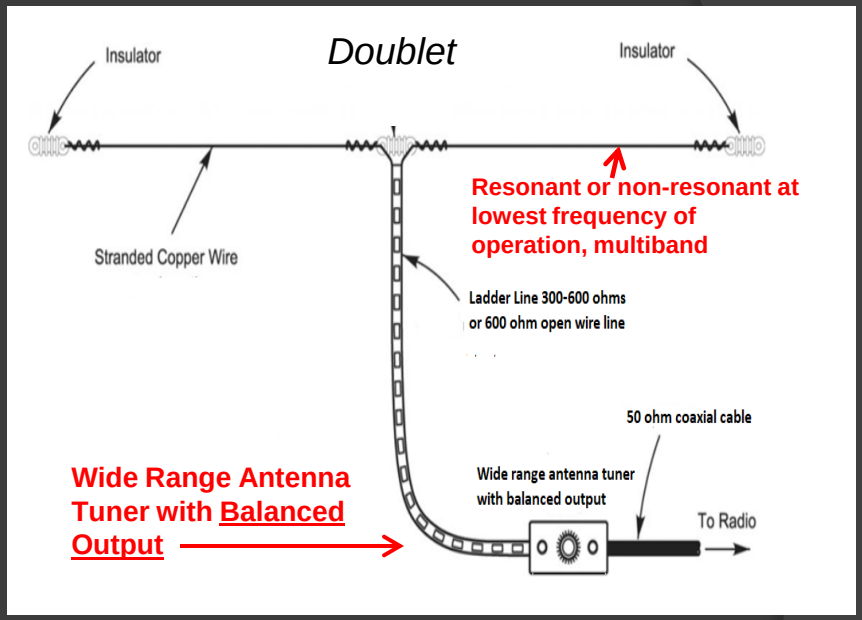


Courtesy Waters and Stanton

Driving a dipole or doublet



To radio (no tuner or built-in "Touch-up" antenna tuner, 3:1 VSWR capable)

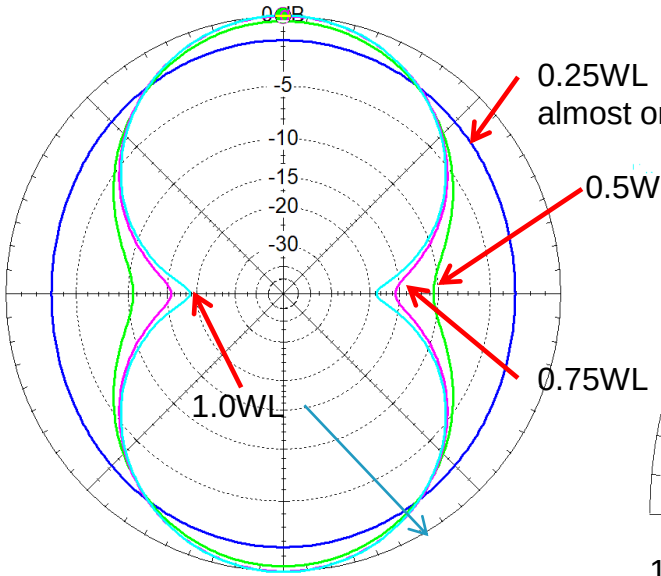


Dipole – requires no antenna tuner or "touch up' tuner (3:1 VSWR max) built into most modern radios with unbalanced output

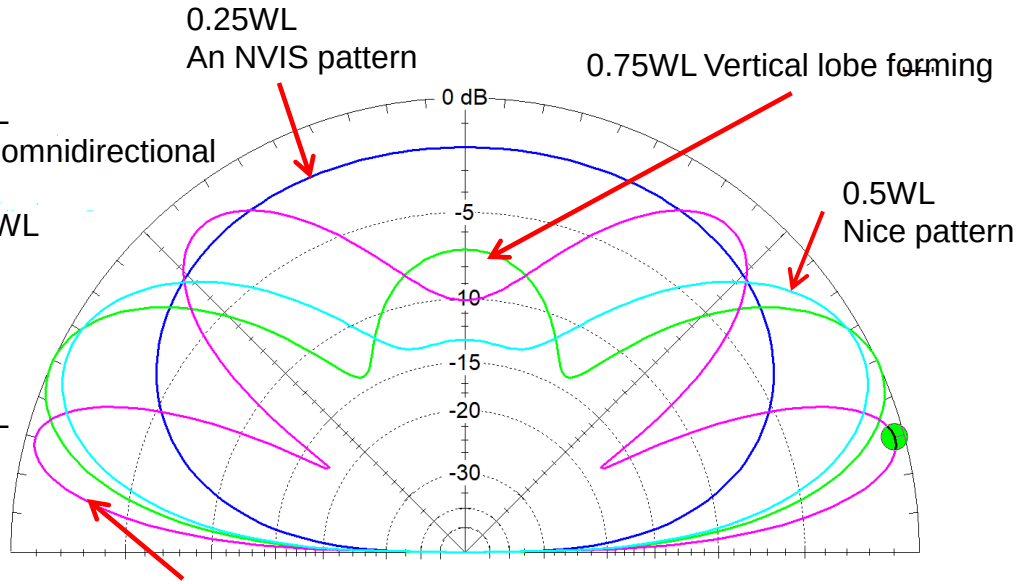
(Multiband Doublet) – requires wide range antenna tuner with balanced output

Dipole antenna patterns vs. height

Every horizontal antenna is subject to essentially the same general phenomena that affect horizontal dipoles in terms of their height above ground. The lower the antenna as a fraction of a wavelength, the lower will be the overall gain and the higher the elevation angle of the radiation. **Fig.** illustrates the principle for a dipole placed at 1/4, 3/8, 1/2, and 1 wavelength above average ground. Unlike vertical monopoles, horizontal wires do not change their gain or elevation angle significantly with changes in soil quality.



Azimuth



Elevation

As a rule of thumb…the TO angle of an antenna at 1/2 wavelength height is about 25-26 degrees. At 1 wavelength, the TO angle is 14 degrees. At 2 wavelengths, the angle drops to the 7-8-degree mark. One of the benefits of using a single multi-band wire antennas is that the TO angle tends to correlate with skip properties" – L. B. Cebik, W4RNL

Expanding dipoles to multiband

- *Maintains wide bandwidth of a standard dipole*
- *Broadside radiation pattern on all bands*
- *Eliminates the system stresses/losses of single wire multiband antennas requiring wide range tuners, sometimes transformers, baluns, and high VSWR on balanced feedlines*
- Amenable to use with diplexer or triplexer for field day use
- Flat top or inverted V
- Some approaches:
  - 40/15 dipole with added capacitance hats for 15
  - Coupled resonator dipole for any 2 bands
  - Fan dipole (with techniques for less tuning interactions) for 3 bands and higher.

A trick to make 40 meter dipole also work well on 15 meters with low VSWR on both bands

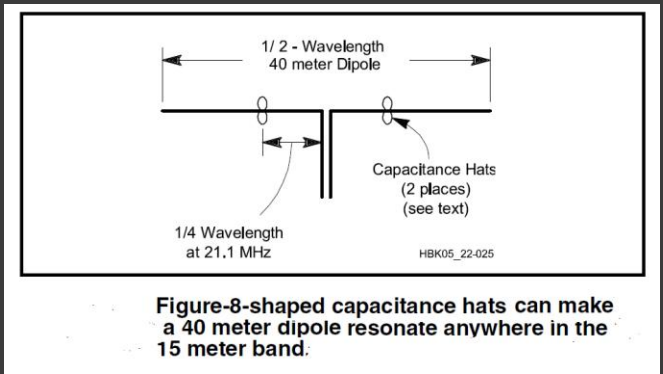
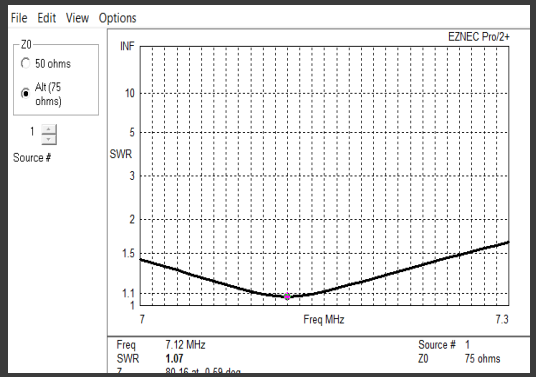
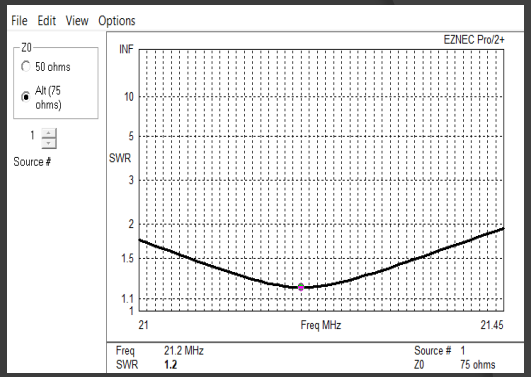


Figure-8-shaped capacitance hats can make a 40 meter dipole resonate anywhere in the 15 meter band.





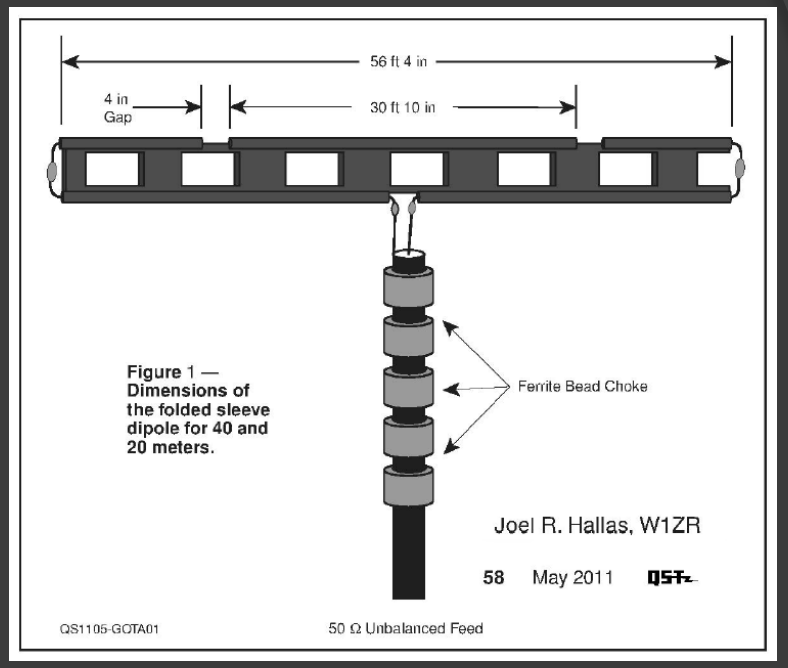
Simulated 66.1 ft dipole extra wires 1.8 ft long

- Measure, cut, and adjust the dipole to resonance at the desired 40 meter frequency.
- Then, cut two 2-foot-long pieces of stiff wire (such as #12 or #14 AWG house wire) and solder the ends of each one together to form loops.
- Twist the loops in the middle to form figure-8s, and strip and solder the wires where they cross. Install these capacitance hats on the dipole by stripping the antenna wire (if necessary) and soldering the hats to the dipole about a third of the way out from the feed point (placement isn't critical) on each wire.
- To resonate the antenna on 15 meters, adjust the loop shapes until the SWR is acceptable in the desired segment of the 15 meter band. Conversely, you can move the hats back and forth along the antenna until the desired SWR is achieved and then solder or clamp the hats to the antenna.

- Courtesy ARRL Antenna Book

Folded Skeleton Sleeve Antenna for any 2 bands by Joel Halas, W1ZR

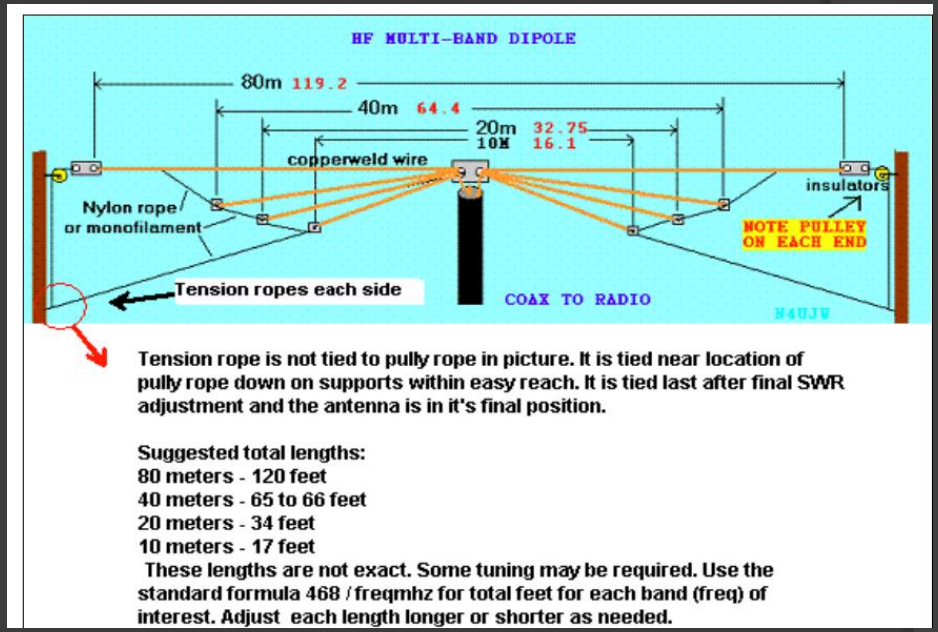
- VSWR < 2:1 across both bands
- Amenable to diplexer for field day.
- 50 ohm coax feed
- Unfolded version also available with slighter better efficiency.
- May 2011 QST pp58-60, Oct 2011 QST P48 (other bands) Nov 2011 QST-feedback, QST in-depth Oct 2011



Better directivity and gain on 40 and 20 compared to standard dipoles.
On 20M, EZNEC predicts about 1.5dB gain over a dipole
Add the capacitive hat trick for good VSWR on 15 meters as well!

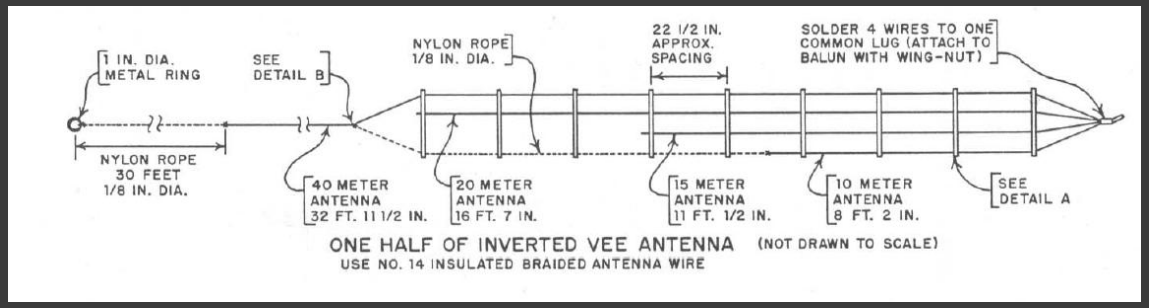
Fan dipole

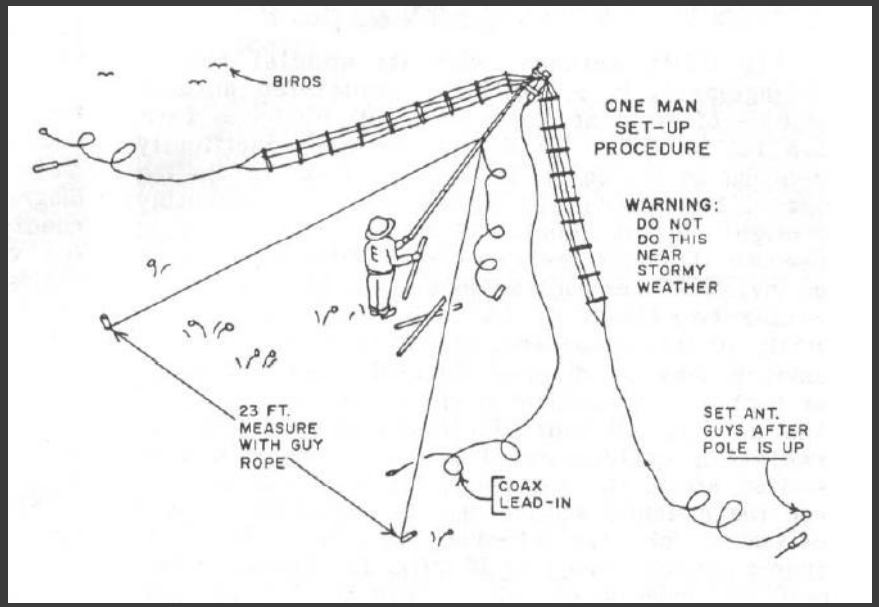
- Reputation for interaction between adjustments on multiple bands but there's a cure for up to 3 bands.
- Low VSWR on all bands similar to individual dipoles.
- 50 ohm coax feed
- Amenable to triplexer for Field DAY 80-40-20M or 20-15-10M
- More info at hamuniverse.com
- Can be used in inverted V configuration



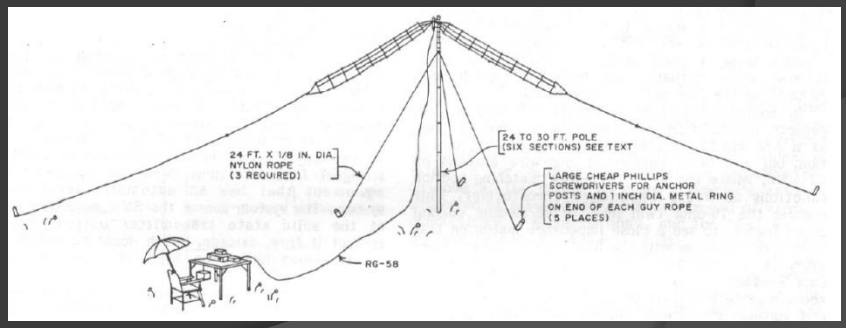
Stanford Research Institute found that wires at the center feed point had to be separated by at least 5 1/2 inches vertically and the ends separated by 38 inches in the 2 to 18 MHz range. In the SRI method, the separation between them at the feed point must be maintained.

Inverted V fan dipole 40-10M

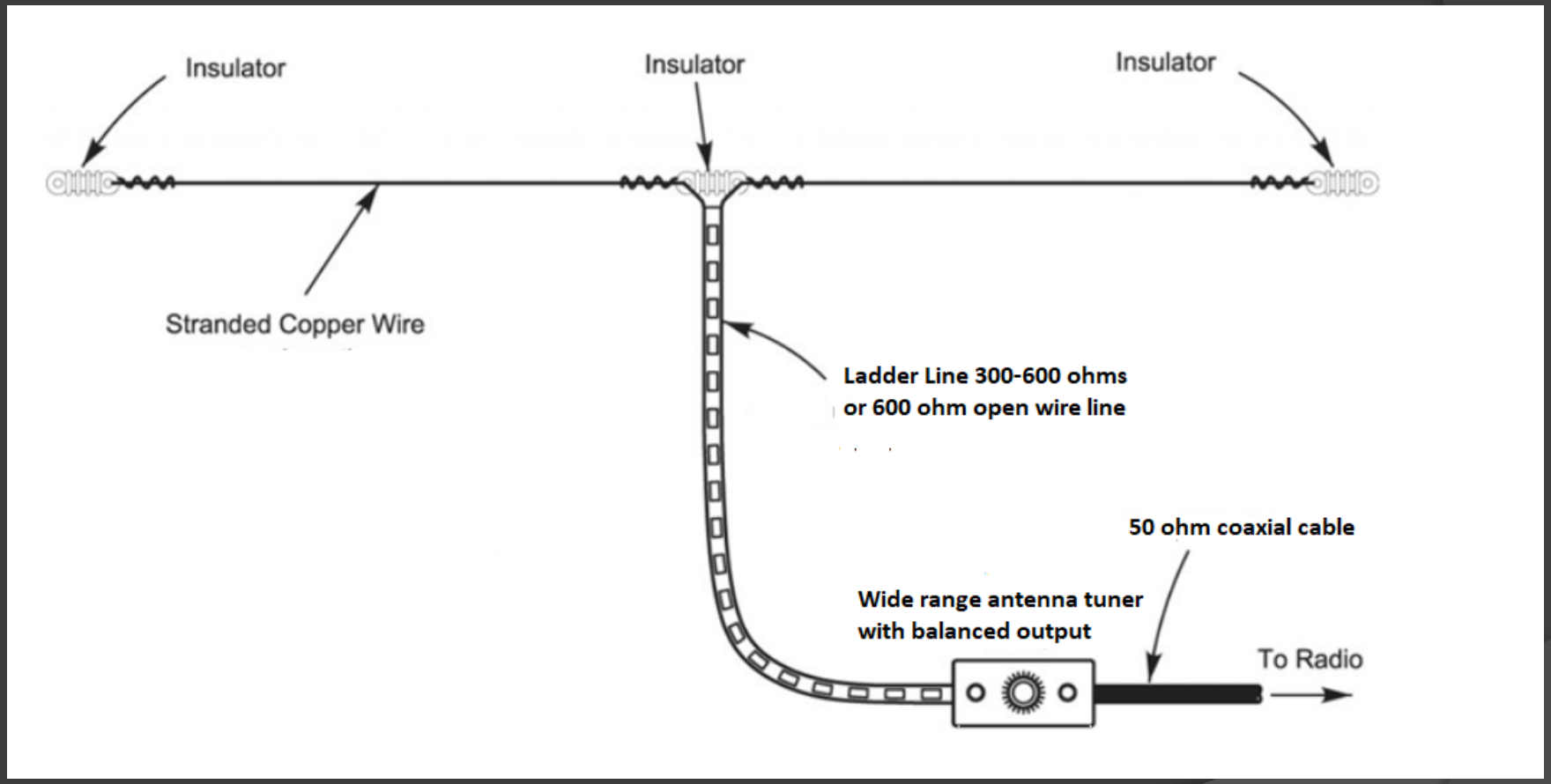




- Courtesy ARRL Antenna Compendium Vol. 1 -"A great 10-40 portable antenna" by Edward L Henry, K0GPD
- Can be setup in less than 15 minutes by one person.
- Except for poles, fits in less than one cubic foot for storage



Doublet antenna construction



What are the advantages of a Doublet compared to other multiband wire antennas?

- Simple, low cost construction. A good field day antenna when dedicated to one rig.
- Reduced feed-line losses compared to coax feed at high VSWR
- Balanced feedline does not radiate and so does not affect antenna pattern and is more immune to field day interference via feedline pickup. It is also more immune to noise pickup than coax.
- Ease of building - No interactions between many bands which may occur with other wire antennas such as fan dipole.
- No lossy transformer on 15M and 10M found in many commercial end fed half wave antennas or 4-6 to 1 voltage baluns for OCFD
- For the broadside doublet, main lobe radiation is well-behaved and in the same direction across 4 bands and side rejection is in same direction on all bands!

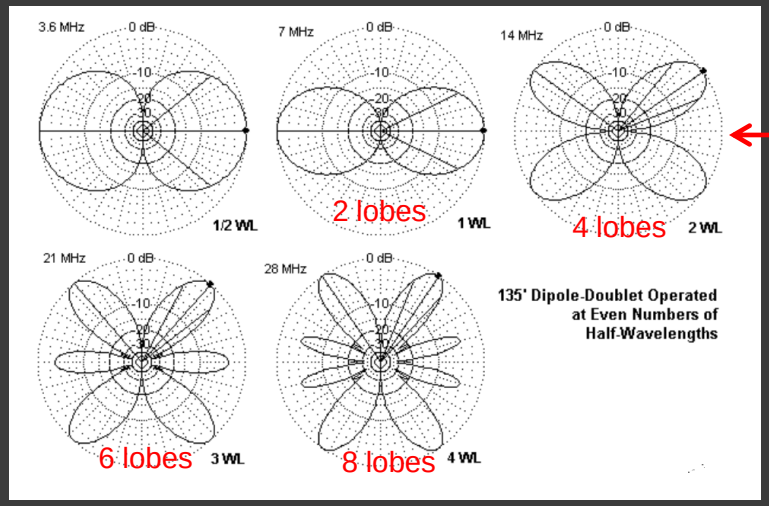
What are the disadvantages of a Doublet compared to other multiband wire antennas?

- Requires a wide range balanced antenna tuner
- Not amenable for use with a triplexer for Field Day
- Feed-line hangs in the air from center
- Requires two end supports and optional center support. Can be configured as an inverted V for easier installation.
- Ladder-line losses are sensitive to rain (~1dB loss) and age. Rain affects tuner adjustment. (Open wire line is rain-insensitive and doesn't degrade due to cracking and dirt over time.)

The Dipole Doublet Antenna

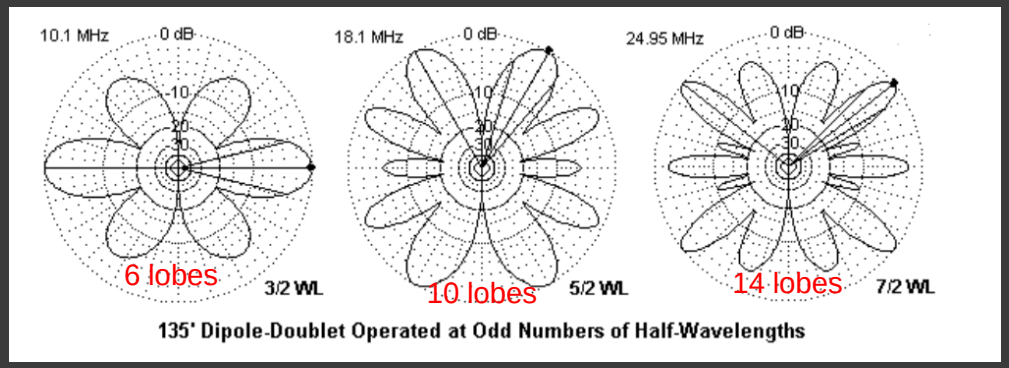
- Antenna length is selected to be a half-wave on the lowest frequency of operation.
  It chief advantages are simplicity and the ability to cover all of the HF bands above the frequency for which the wire is a 1/2-wavelength dipole
- But length greater 1.25 wavelengths on a given band will result in radiation no longer broadside to the wire with multiple lobes. As frequency goes up, number of lobes increases.
- Usually fed with balanced line driven by wide range balanced antenna tuner or single ended tuner with 1:1 or 1:4 balun. (1:1 preferable)

Dipole Doublet Antenna Azimuth Patterns



You're not transmitting in the direction you may think you're transmitting! 20 meter antenna pattern for 80 meter dipole-doublet. Deep null broadside. Major lobes way off broadside!

From "My Top Five Backyard Multi-Band Wire HF Antennas"
L. B. Cebik, W4RNL

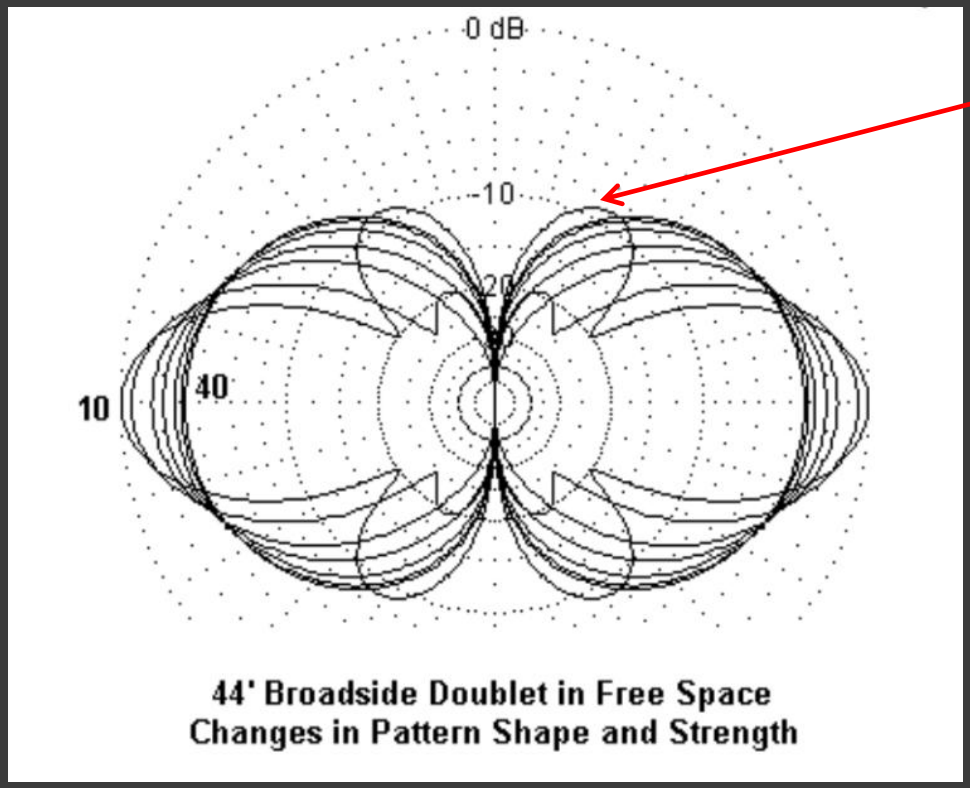


An 80 meter dipole-doublet operated on 20 meters has its deep nulls broadside to the antenna and 4 lobes almost 45 degrees off broadside!

The broadside doublet Antenna

- Length is determined by highest band and set to 1.25 wavelengths on that band (it is an extended double Zepp!)
- Lowest band is set to 4X lower than the highest band (approximately 33% shorter than a full length resonant dipole. Little loss in gain compared to a full length dipole on the lowest band
- The low end is limited by low impedance and high capacitive reactance, making it difficult to match beyond the 4:1 frequency range at the low end
- Radiation is always in the same direction on all 4 bands, off-broadside rejection is in the same direction on all bands.

Broadside Doublet Azimuth antenna patterns for a 44 ft, 40-10 Meter antenna



Note the “ears” , typical for an extended double zepp at 1.25 wavelengths on 10 meters

Main lobes are all in the same direction

Off-broadside nulls are in the same direction

Courtesy “My Top Five Backyard Multi-Band Wire HF Antennas”
L. B. Cebik, W4RNL

Possible set of high performing field day antennas for known directionality and excellent antenna patterns if mounting and spacing permit

- 88 foot doublet for bands 80M-20M at least 70 ft high (100 ft is better)
  - Great antenna patterns and gain on 40, 20
  - Is a high gain Extended Double Zepp on 20M
- 44 foot doublet for bands 40M-10M at least 35 feet high (50 feet is better). Mount side by side with the 88 foot doublet but separated if mounting provisions allow.
  - Great antenna patterns and gain on 20,15,10
  - Is a high gain Extended Double Zepp on 10M
- Minimal interaction due to non-resonant antennas and additional sub-harmonics suppression by antenna tuners. In addition, each antenna is in the other's antenna's off-broadside nulls.
- Balanced feed minimizes feedline pickup from nearby xmtrs/antennas

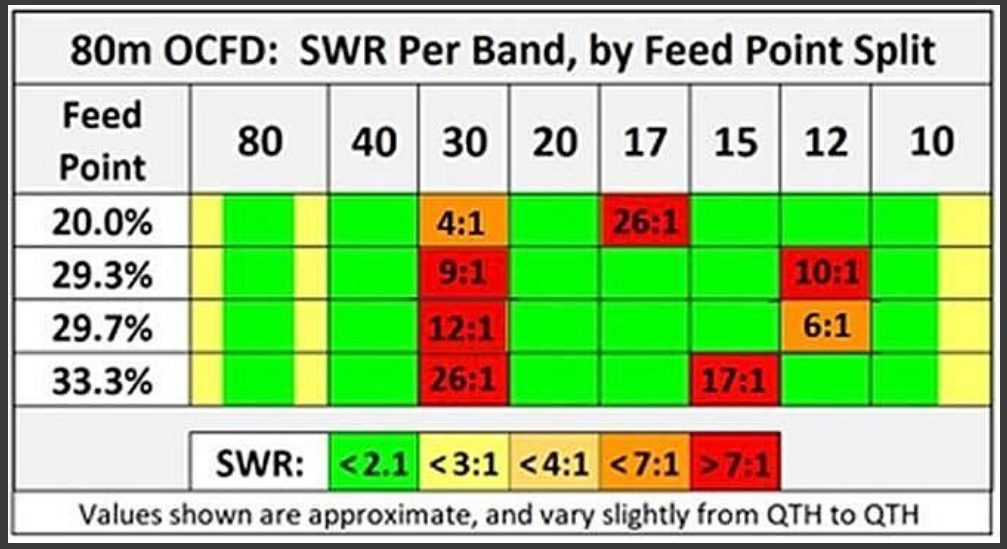
Both antennas need wide range balanced antenna tuners. Cannot use with a triplexer but works well with two stations.

What about:

- **Inverted Vs:** 1 mounting point but slightly less gain (~1.5dB or 70%), more omnidirectional than flat top.
- Off-Center-Fed Dipole
  - Good general purpose antenna. Inverted V or flat top. 50 ohm single ended coax feed. Requires a balun on antenna side of feed-line. Feedpoint position dictates bans covered. Feedline radiates to some degree. Article from Cebik on Off-Center_Fed Dipoles. Here's a great Center loaded OCFD by Serge Stroobandt, ON4AA with low VSWR, full documentation, Lots of info in groups.io ocfd group. I recommend a 4:1 hybrid balun. See following slide for more info..
- End Fed half wave
  - Good general purpose antenna. Low VSWR on 80-10 – only needs "touch-up" tuner or no tuner and covers 15M at low VSWR unlike some OCFDs and ZS6BKW.
    See this interesting article by Mike Mladejovsky, WA7ARK on ARRL' EFHW kit improvement
  - Easy deployment and options (horizontal, sloper, inverted V, Inverted L, etc). Xfmr can be mounted ~ 3-10 ft from ground so no heavy balun mounted topside required for OCFD.
  - Matching transformer often inefficient on upper bands (as much as 1.5-3dB loss and sometimes requires common mode choke to minimize RF on the feed-line.
- ZS6BKW (Optimized 102 ft G5RV). 93.6 ft. long doublet, 39.1 ft 450 ohm ladder-line matching section, 1:1 CMC at the bottom. Good general purpose antenna. Low VSWR on 40, 20, 17, 12, 10 and 6 meters. Can be used on 80 and 15 with wide range ATU. Negligible common mode current on feed-line compared to OCFD as it is a symmetrical antenna with balanced feed-line. No heavy transformer at the top.
- Recommended wire antenna/component vendors: Buckmaster, MyAntennas, Palomar Engineers, Aerial 51, Balun Designs

Same height comments previously discussed apply to all of these

On the “sweet spots” for 80M OCFD antennas



80m OCFD: SWR Per Band, by Feed Point Split								
Feed Point	80	40	30	20	17	15	12	10
20.0%			4:1		26:1			
29.3%			9:1				10:1	
29.7%			12:1				6:1	
33.3%			26:1			17:1		
SWR:		<2.1	<3:1	<4:1	<7:1	>7:1		
Values shown are approximate, and vary slightly from QTH to QTH								

- “The sweet spots have been known for at least 8 years now. It depends on which bands you want to use it on. Use either 20% or one of the two 29% feedpoints. More important is to use the right balun. I have personally built about 20 of the ones with 29.7%, hung them in many different locations, with various heights and angles of the inverted-V. They ALWAYS work on those 5 classic ham bands. Most of the time I don’t even need an antenna matchbox.

  73 - Rick, DJ0IP” - From Groups.io ocfd group

  Note: Recommended transformer is a 4:1 Hybrid balun (consisting of a 4:1 Ruthroff voltage balun at the antenna cascaded with a 1:1 Guanella Balun to the feedline)

On recommended feed-line line lengths for balanced feedlines

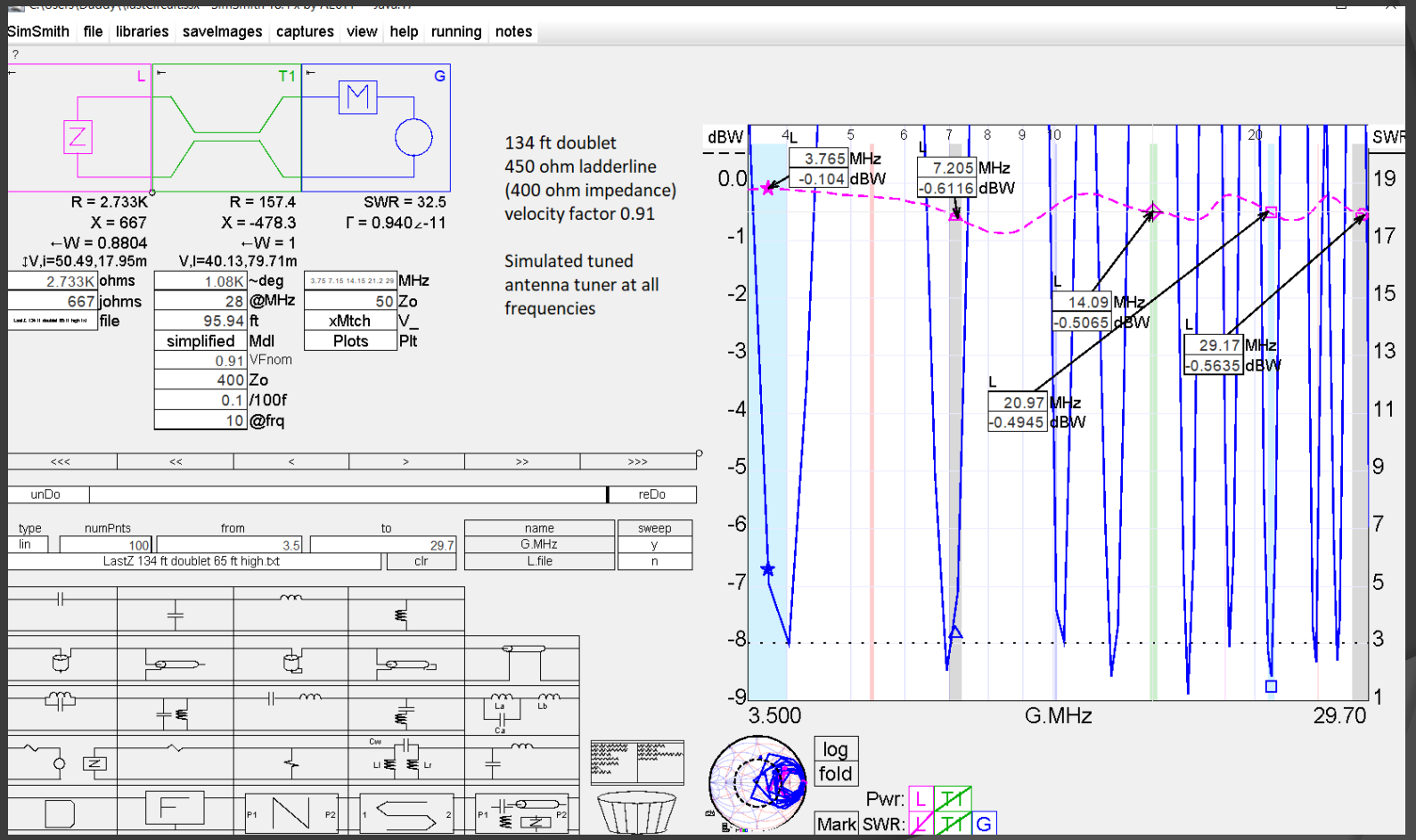
- An electrical half-wave reproduces the antenna's impedance at the tuner. Bad for tuner at high antenna impedances
- An electrical quarter-wave acts as an impedance transformer (An impedance higher than the transmission line impedance will be transferred to low and vice versa.)
- Many experts recommend avoiding both extremes by using the shortest required length of odd 1/8 wave multiples (1,3,5,7 etc) electrical length) at the lowest frequency of operation.

Formula: $$\text{Length} = \frac{123}{\text{Freq (MHz)}} \times \text{Velocity Factor}$$

Where: 123 = 1/8-Wavelength Factor, Freq = Frequency in MHz,
0.88 = Velocity Factor of **DXE-LL300** 300 Ω Ladder Feedline

More info at: hamuniverse.com

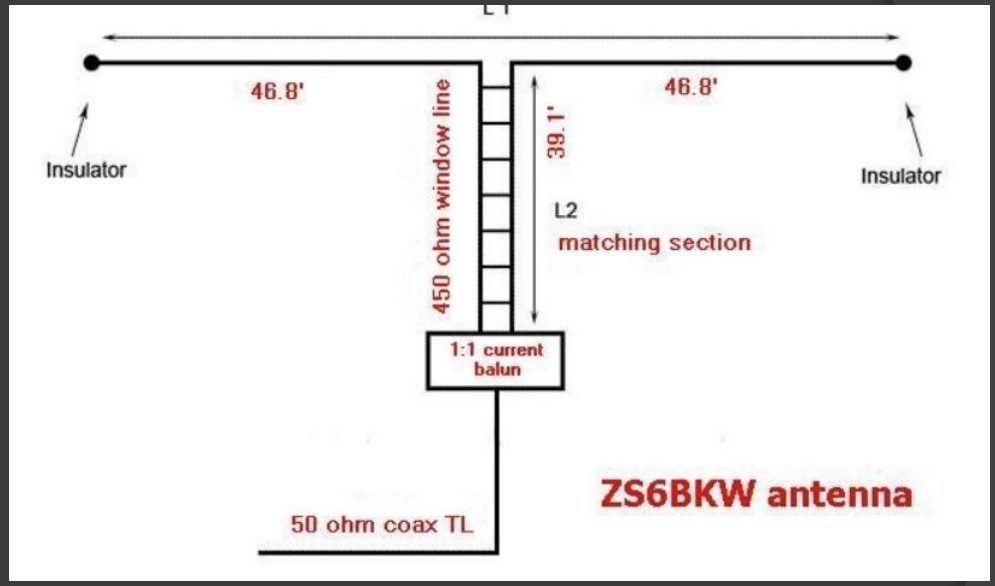
132 ft doublet 65 ft high, 450 ohm ladderline (400 impedance) Vf=.91 using the odd 1/8 wave formula for feedline length 95.94 ft



Losses vary from 0.102dB to 0.61dB. Pretty insignificant.

Using tuned feedlines

- Sometimes you want a certain length feed-line as part of the antenna for low VSWR on multiple bands.
- An example is the ZS6BKW antenna
  - Optimized G5RV
  - Low VSWR on 40, 20, 17, 12, 10 and 6 metres.

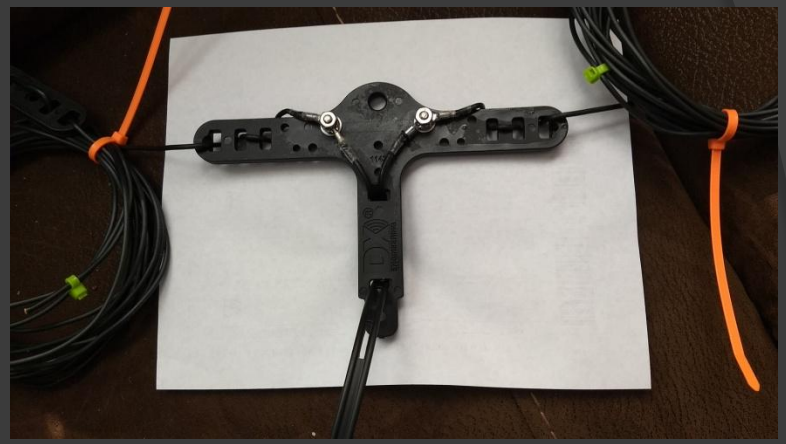


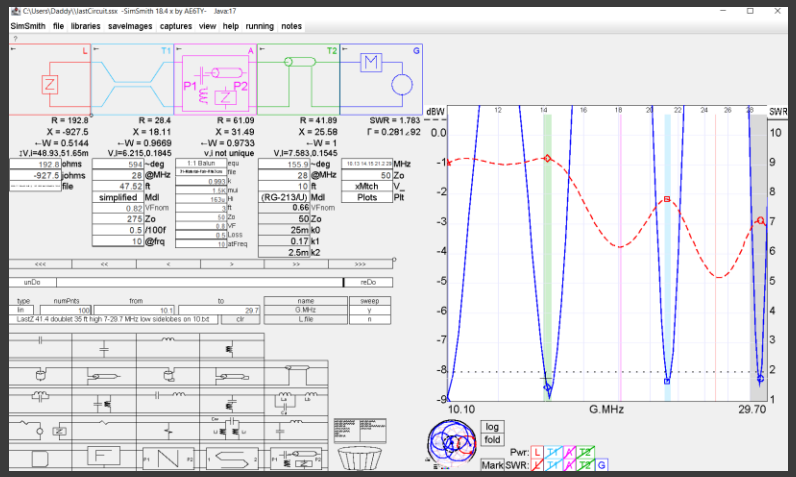
Courtesy [Albury Wodonga Amateur Radio Club]

In my simulations, I found actual 450 ohm ladder-line (unavailable) works better than actual 400 ohm. Best length 40.5 feet. 80M/15M with wide range antenna tuner, but 80 is inefficient.

Steve's experimental broadside doublet with tuned feedline

- Low VSWR on 30M, 20M, 15M, 10M
- Doublet length 41.4 ft 35 ft high, DXE 300 ohm ladder-line
- Simulated in EZNEC and SimNec





Losses are lower with 450 ohm LL
or 600 ohm open wire and wideband tuner

Dx Engineering components

Balanced antenna tuners

- “Balanced antenna tuner design is a complex subject. “An unbalanced T match followed by a 1:1 Guanella (current) balun in an external non conductive enclosure and having high choking impedance, very short coax connection to the ATU, and high voltage withstand is capable of excellent performance in a 'balanced ATU' role for general purpose HF application.”

  “Reduction of common mode current to a sufficiently low level that it is not troublesome is the best that can usually be achieved. “

  - Owen Duffy

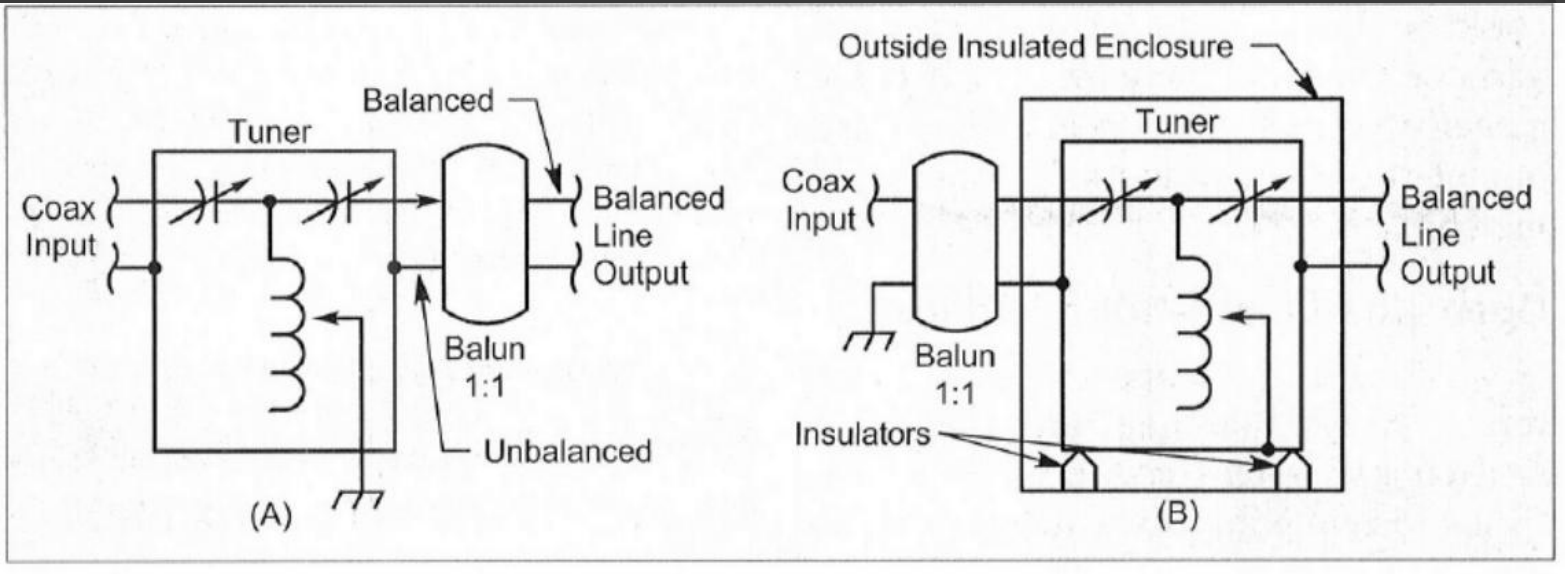
  Recommended reading:

  “A New Generation of Balanced Antenna Tuners” Product Review September 2004 QST -Joel Halas, W1ZR (SK) – good overview and efficiencies of different antenna tuner types

  Balanced ATUs and Common Mode Current
  -Owen Duffy

  Baluns – Karinya.net

Balun on input or output?



• Balun on output – balun sees high VSWR with wide range of impedances and sees higher voltage and current stresses. Provides good feedline balance if mounted in a non-conductive enclosure. Special design is required to handle stresses. (Recommend baluns specific to this application. Typically designed with higher impedance internal transmission line and high voltage withstand as well as high choking impedance to reduce power dissipation . (Balun Designs, Palomar Engineers have some.)

• Balun on input – sees a 1:1 VSWR when tuner is tuned so lower stresses on balun but feedline balance impacted by antenna imbalance and tuner stray capacitance to enclosure

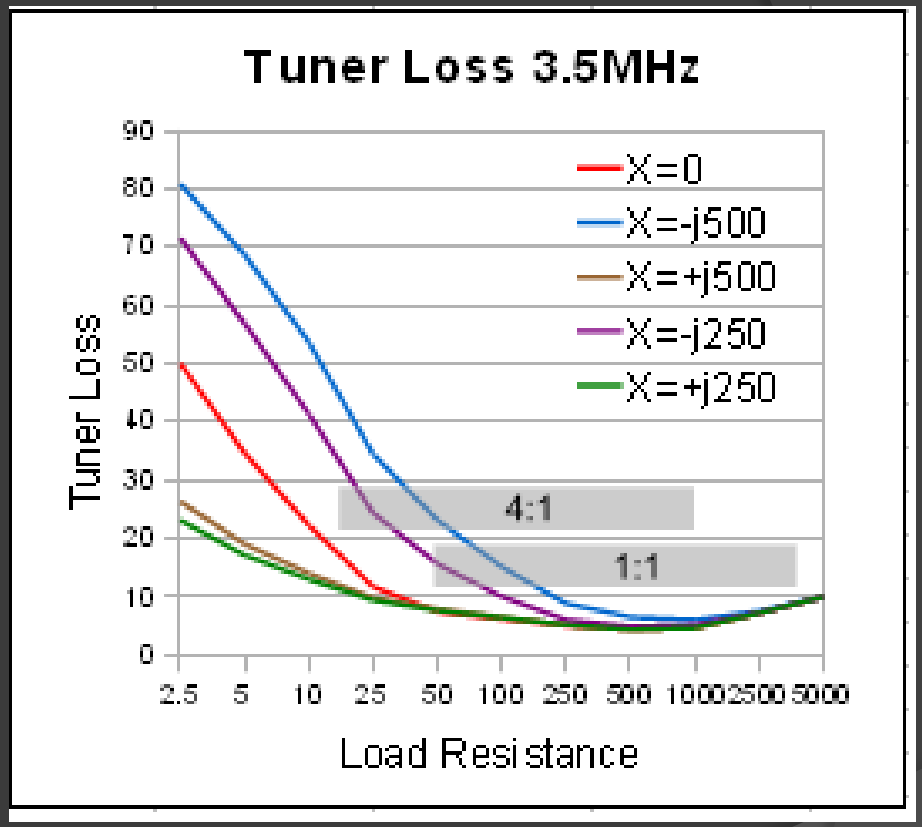
• In practical use, either one will work, trading balun stresses vs. better balance

1:1 or 4:1 balun for lowest tuner losses?

- An example :a half-wave 80m dipole fed with 450Ω ladder-line: The range of impedances seen at the tuner end of the ladder-line would have a “geometric mean” of 450Ω - that is they would swing equally below and above 450Ω, but once we introduce a 4:1 balun the geometric mean will reduce to 112.5Ω. One look at the loss chart tells you that centering the impedances at the higher value is the preferable option
- A 1:1 current balun only requires a single transformer core, A 4:1 current balun requires two transformer cores.
- Many single core 4:1 balun designs, for simplicity or low cost, are really a 4:1 voltage baluns or a single core sharing multiple windings, which have serious faults.

Owen Duffy also prefers the 1:1 balun.

See Owen Duffy’s article or Steve Hunt’s article for further discussion



Losses vs load resistance of a typical T-network tuner on 80m for several values of load reactance. - Courtesy G3TXQ (Karinyna.net)

In general, 1:1 balun is the preferred choice to minimize tuner losses.
Also, beware! A single core 4:1 balun is a voltage balun, not a current balun.

Of course, nothing beats a good beam.

Resources

- Many articles by L.B. Cebik,W4RNL
- "**My Top Five Backyard Multi-Band Wire HF Antennas**"
  L. B. Cebik, W4RNL
- "**Introducing the "All-Band" Doublet: What the Student and the Instructor Should Keep in Mind** "
  L. B. Cebik, W4RNL
- "**Suppose I Could Have Only One Wire**"
  L. B. Cebik - W4RNL
- "**MODELING AND UNDERSTANDING SMALL BEAMS PART 3: THE EDZ FAMILY OF ANTENNAS**"
- **L.B. Cebik – W4RNL**
- **"The Ideal Backup Antenna for 80-20 Meters"**
  L.B. Cebik W4RNL
- Doublet vs. Dipole vs.End Fed Antennas
  Watersstanton
- The G5RV antenna system revisited
  L.B. Cebik W4NRL

  "The ZS6BKW Antenna"
  Albury Wodonga Amateur Radio Club

  ZS6BKW vs G5RV
  Compiled by Larry James LeBlanc 2010 For the AARA Ham Radio Club

  KK4OBI antenna patterns for multiple antenna types
  Dik Reid, KK4OBI
- **How Much Coax Cable – A case study (OCF antenna)**
  L.B. Cebik W4RNL

Resources cont'd

- "A New Generation of Balanced Antenna Tuners" Product Review
  September 2004 QST
  -Joel Halas, W1ZR (SK)

- **Tuner Baluns- 1:1 or 4:1?**
  G3TXQ (Karinya.net)
- **Wet Ladderline**

  G3TXQ (Karinya.net)
- **Balanced ATUs and Common Mode Current**
  -Owen Duffy

  The vertical vs a dipole
  -DxCommander

  Fundamentrals of Off Center Fed Dipoles
  - L. B. Cebik, W4RNL

- **The Isolated Off-Center-Fed Antenna: Some Less-Explored Facets**
  - L. B. Cebik, W4RNL

- The G5RV Antenna
  - W8JI

- **Field Day OCF Antenna Project**
  N4CY in groups.io OCFD group

- 4:1 current baluns – identifying bad ones – Owen Duffy
- A review of the 4:1 Guanella balun with a shared magnetic circuit - Owen Duffy

- **Is a 4:1 balun a good choice for use with an ATU on HF**
- - Owen Duffy
- Baluns
  -Karinya.net
- Multiband Fan Dipole – Ham Universe
- A Field Guide to Simple HF Dipole (1967)
  Stanford Research Inst Menlo Park CA
- The ARRL EFHW Kit doing it cheaper and better
  Mike Mladejovsky, WA7ARK

- **Multiband HF Center-Loaded Off-Center-Fed Dipoles Serge Stroobandt, ON4AA.**

  N4CY buiit one. Article in files section of OCFD groups.io group.
- **A compact 4:1 Hybrid Balun for use on a OCF Antenna**
  -Everett Sharp N4CY