AD5X

The 43-Foot Vertical

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Outline

- Why a vertical?
- Ground Losses and Antenna Efficiency
- Why a 43-foot vertical?
- SWR-related coax and unun losses
- RF Voltages
- Matching Networks for 160- and 80-meters
- Building your own 43-foot vertical

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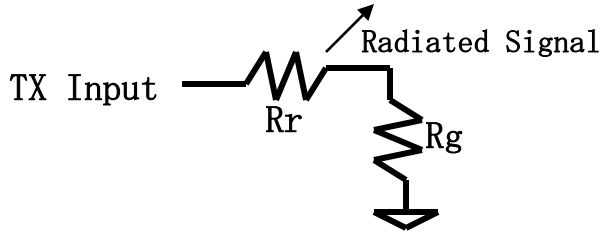
Why Use a Vertical?

- Advantages
  - Generally are inexpensive
  - Relatively unobtrusive
  - Self-Supporting
  - Easy to ground mount
  - Low angle of radiation
    - Good DX performance
  - Omni-directional (no rotator needed!)
- Disadvantages
  - Omnidirectional (no gain or F/B)
  - Needs a ***good*** radial system for best performance

AD5X Ground Loss & Antenna Efficiency

- ***Radiation Resistance*** (Rr) is the "resistance" of the antenna such that the antenna will radiate all power delivered into this resistance.
- ***Ground loss*** (Rg) is antenna efficiency-robbing loss resistance that looks like a voltage-divider to your transmitter output.



- ***Antenna Efficiency*** (%) = 100 x Rr/(Rg + Rr)

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Simple Calculations

- You can get very close to actual short antenna impedances using simple calculations.
  - Rr = (Actual length ÷ ¼ wave length)^2 x 36 ohms
  - Cpf = 3.5pf/ft X Actual length
- 43-foot 160 meter examples
  - Rr = 43/128 X 36 = 4 ohms
    - EZNEC = 3 ohms
  - C = 3.5 x 43 = 150.5pf = -j580
    - EZNEC = -j640 ***BUT*** VNA actually measured –j580
    - Nearby objects add some stray capacitance

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Efficiency Calculation

- A ¼-wave vertical has a radiation resistance of 36 ohms.
- Assume 10 ohms of ground loss
  - Probably a ***much*** better ground than most hams have
- Your SWR = 1.09:1
  - Rr + Rg = 36 + 10 = 46 ohms
  - SWR = 50/46 = 1.09
- Your antenna efficiency is 78%
  - If you have a 100 watt transmitter, you will radiate 78 watts

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Electrically Short Antennas have Low Radiation Resitance

- A Hustler 6BTV 80/40/30/20/15/10 meter vertical is 24 feet tall.
- On 80 meters, it is only 0.092 wavelength long.
- Rr decreases approximately as 1/length^2.
- So Rr is approximately 5 ohms.
- With 10 ohms ground loss, the efficiency is 33%
  - Assumes *no* trap/inductor losses
- Now your 100 watt transmit signal results in only 33 watts being radiated.

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Electrically short antenna (Cont)?

- A Butternut HF-9VX with TBR-160 160M loading coil is 26 feet tall.
- On 160 meters, it is only 0.051 wavelength long.
- Rr decreases as 1/length^2.
- So Rr is approximately 1.5 ohms.
- With 10 ohms ground loss, the efficiency is 13%
  - Assumes no inductor/loading coil/matching losses
- Now your 100 watt transmit signal results in only 13 watts being radiated.

The 43-foot Vertical Antenna

- Advantages
  - Still can be self-supporting & moderately unobtrusive
  - Approximately 3X higher radiation resistance than the typical trap or loaded vertical.
  - No trap or loading coil losses to worry about
  - Modest compromise SWR from 60-10 meters when fed with a 1:4 unun.
- Disadvantages
  - Take-off angle is not optimum on 12/10 meters
    - More on this later)
  - You need an in-shack tuner

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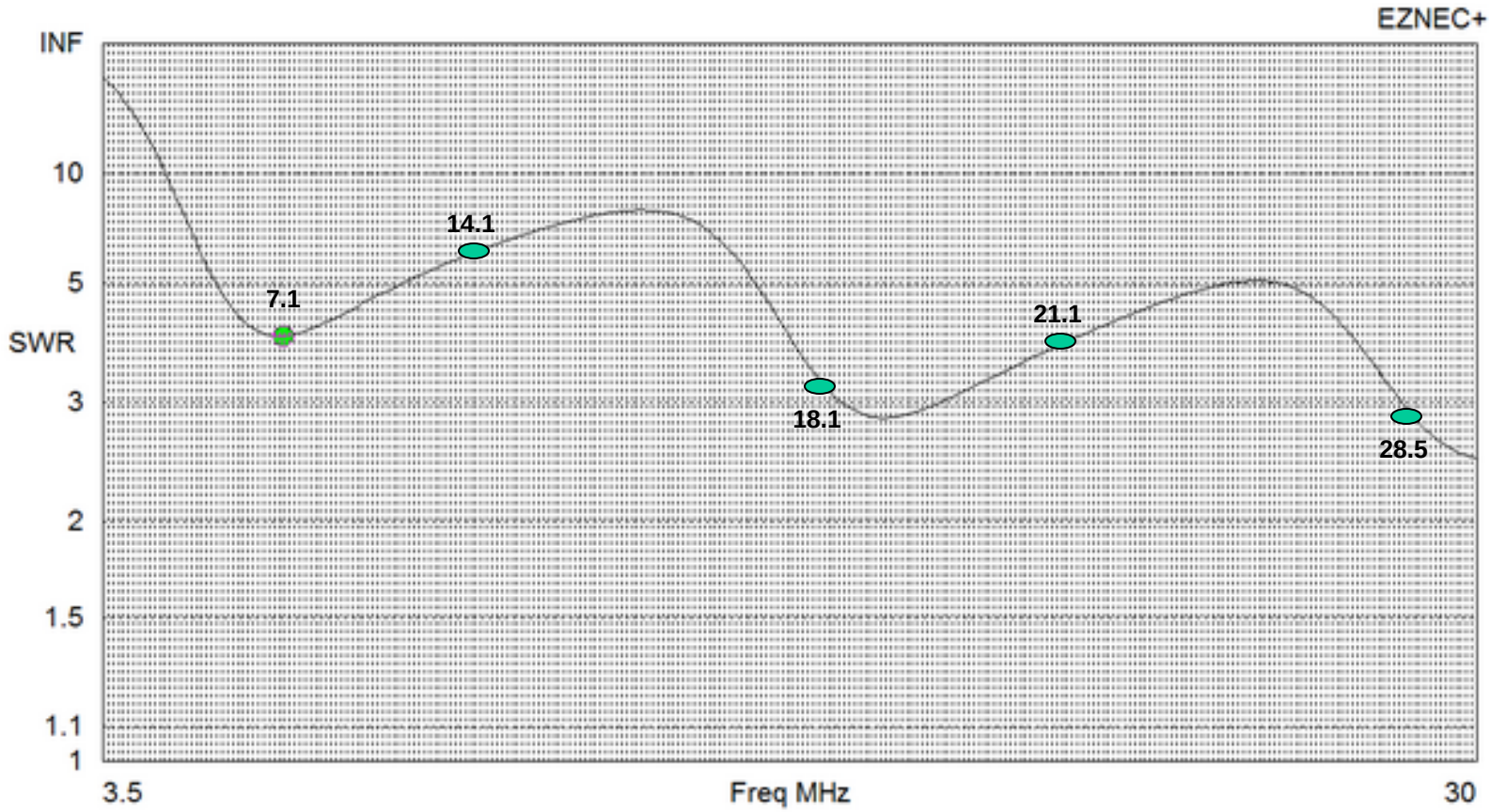
43-foot SWR over Perfect Ground with 1:4 Unun at the Antenna



EZNEC Generated SWR Curve: 43-foot vertical over perfect ground with 1:4 unun
Thanks to Dave Cuthbert WX7G

AD5X 43-Foot Vertical SWR (Cont.)

- SWR-related cable losses are fairly minimal.
  - Refer to SWR-related cable loss curves in the ARRL Handbook & ARRL Antenna Book
- SWR over real ground is better
  - My worst case SWR is 5:1 on 20 meters
    - vs EZNEC calculated 6.5:1 over perfect ground
    - 60 feet LMR-400 SWR-related coax losses: 0.4dB on 20 meters

A couple of references

- Dave Cuthbert WX7G: “The 43' Vertical -- a Theoretical Analysis”, www.eham.net/articles/21272.
- W. Griffith W5CSU "The Truth About the Vertical Antenna“, May 1952 QST
  - This antenna has been around a long time!

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43-Foot Antenna Efficiency

- The Hustler 6BTV on 40 meters
  - The 24-foot Hustler is 0.188 wavelengths long
  - Hustler Rr = 20 ohms
  - Efficiency = 67% (assumes Rg = 10Ω & *no* coil losses)
    - ***Note:*** There are multiple inductors (traps) in-line on 40 meters

- The 43-foot vertical on 40 meters
  - Antenna is 0.34 wavelengths long
  - Rr = 65 ohms
  - Efficiency = 87% (with Rg = 10Ω with ***no coils/traps***)

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43-foot Antenna Disadvantages?

- Can be moderately expensive
  - But you can build your own (we live close to Texas Towers!)
- High take-off angle above 15 meters
  - DX performance ≥ 1/4-wave vertical 60-15 meters, but 5dB down from 10 meter ¼-wave vertical at 10 degree take off angle (but higher Rr compensates some)
- Really needs base matching on 160/80-meters
  - Regardless of what the 43-foot antenna vendors say
- Example: With Rg = 10Ω,
  - 160 Meter SWR = 324:1, 80 Meter SWR = 41:1

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Matching & Coax Losses

- Some 43-foot antenna vendors claim the antenna can be matched from 160-10 meters with your in-shack tuner.
- One vendor says to use 150 feet of RG-213 for best all-band operation of the 43-foot antenna (so you can tune from the tuner in your shack). Another vendor says to ***ADD*** 150 feet of RG-213 to your cable run.
- The typical 160 meter base impedance of a 43-foot antenna with the 1:4 UNUN is 2-j183. 150 feet of coax transforms this to a matchable 38 + j180 at the shack.
- But the antenna SWR is ~ 150:1 resulting in 12dB (two S-units) of ***coax losses*** due to the SWR at the antenna. Plus about ≥6dB ground loss. Total loss ~18dB.
  - TX = 100W results in ***2-watts radiated***

Matching & Coax Losses (Cont.)

- Add to this additional unun losses due to the severe mismatch, plus internal losses in your antenna tuner.
- On 80 meters, SWR-related coax cable loss (150 feet) is 4.7 dB, plus 3 dB ground loss. Total loss ~8 dB.
  - TX = 100 watts results in ***16-watts radiated***
    - Again, don't forget to add in unun and tuner losses
- Will shack matching work? Sure – because QRP works. But sometimes you want more than QRP power on 160 & 80 meters!

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First: Minimize Coax Losses

- Use LMR-400 (I use ½-inch Andrew Heliax)
- Length should be that necessary for your antenna system
- Assume 60-feet of LMR-400 (the length from my shack to my 43-foot vertical).
- Worst-case SWR on 60-10 meters is on 20 meters where SWR = 5:1.
  - SWR-related cable loss is only 0.39 dB, plus 0.27 dB matched cable loss = 0.66 dB total cable loss.
- FYI - With 150 feet of RG-213, the 20 meter SWR-related cable loss would be 1 dB, plus 0.8 dB matched cable loss
  - Total cable loss = 1.8 dB

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160/80 Meter Matching

- Difficult to match the 43-foot vertical on 160/80-meters from your shack when low-loss coax is used! The mismatch may be too great for most manual- or auto-antenna tuners (though adding coax can help the match as discussed earlier).
  - But don't forget about the significant SWR-related losses also discussed earlier!
- The right thing to do is to match the antenna directly at the base on 160- and 80-meters.
- This virtually eliminates SWR-related coax and unun losses, reduces antenna tuner losses, and makes final matching from the shack very easy.

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Two Ways to Match

- Autotuner at antenna base
  - Autotuner needs > 50uHy for 160 meter matching.
  - Most autotuners will match 80-10 meters.
  - Evaluated CG-3000, CG-5000, MFJ-927 and SG-230
    - Only SG-230 has enough inductance to tune 160 meters, but you're limited to 200 watts PEP
    - MFJ-927 will tune 160 meters with external coil (see my website), but again you're limited to 200 watts PEP.
    - CG-3000/5000 claim enough inductance to tune 160 meters, but they don't!
- Relay-switched or manual tuner at antenna base
  - My preference is the relay-switched matching unit

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First A Word About RF Voltages

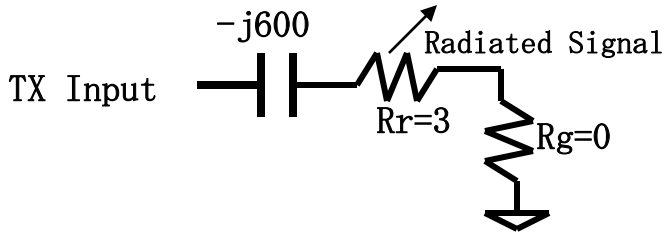
- An electrically short antenna has high capacitive reactance. This ***WILL*** cause high RF voltages across a matching network.
- Example: Assume 1500 watts and a perfect ground system (Rg = 0) on 160 meters. In this case all power is delivered to Rr.

$I = \sqrt{(1500/3)} = 22.4$ amps rms

$|Z| = \sqrt{(3^2 + 600^2)} = 600$

So, Vrms = 22.4 x 600 = 13,440

and Vpk = 19,007 volts



RF Voltages (Cont.)

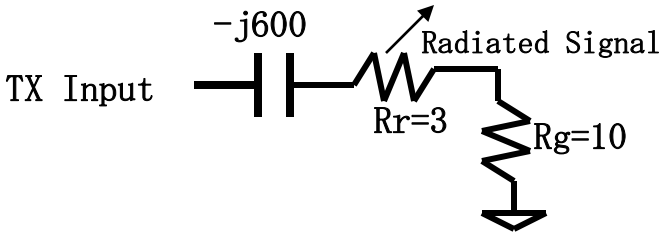
- Example: Assume 1500 watts and Rg = 10 ohms on 160 meters. Now all power is delivered into Rr+Rg:

I = √(1500/13) = 10.74 amps rms

|Z| = √(13^2 + 600^2) = 600.1

So, Vrms = 10.74 x 600.1 = 6,445

And Vpk = 9,115 volts



- My Case: 600 watt amplifier (ALS-600).

I = √(600/13) = 6.8 amps rms

So, Vrms = 6.8 x 600.1 = 4,081

Vpk = 5,770 volts

RF Voltages (Cont.)

- For switched matching networks, switches or relays must have high breakdown voltage ratings.
  - For relays:
    - Contact-to-contact (Put contacts in series to increase breakdown voltage)
    - Contact-to-coil
- Two relays:
  - Array Solutions RF-10 DPDT Relay good for about 500 watts
    - 1.7KV peak contact-to-contact breakdown voltage
    - 3.1KV peak contact-to-coil breakdown voltage
  - Array Solutions RF-15 3PDT Relay good for full legal limit if properly applied.
    - 3.1KV peak contact-to-contact breakdown voltage
    - 5.3KV peak contact-to-coil breakdown voltage

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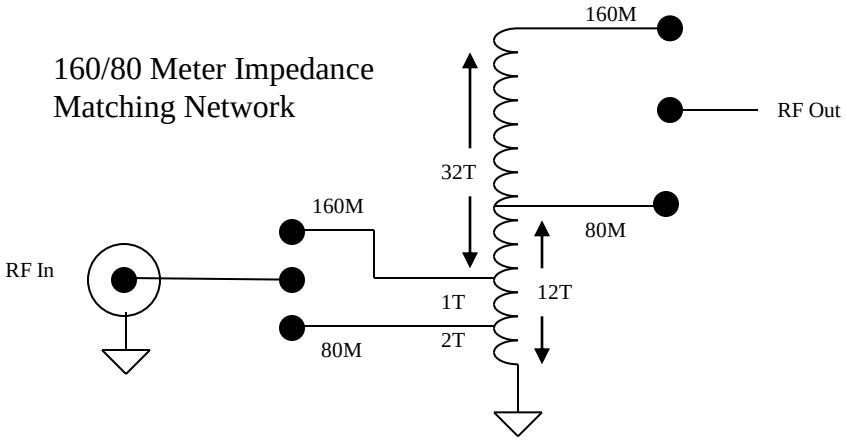
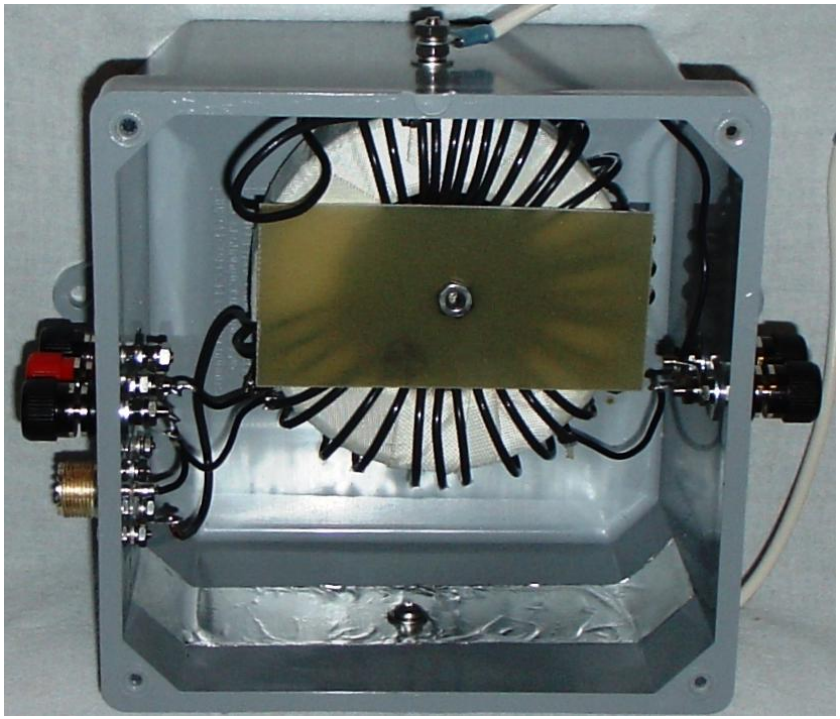
160- & 80-Meter Matching

- Three matching units were built
  - See www.ad5x.com for more details
- The first uses a large T400A-2 toroid
  - Must be manually inserted and 160/80 Meters selected with straps
- The second adds relays for remote switching
  - Remotely switchable for 160-, 80-, or 60-10 Meters
- The third uses an air-core inductor and relays
  - OK OK – so I like to keep tinkering!!
  - But this is the best solution (lowest inductor losses)

Toroid Matching Solution

- Fits into a 6x6x4” electrical box from Lowes





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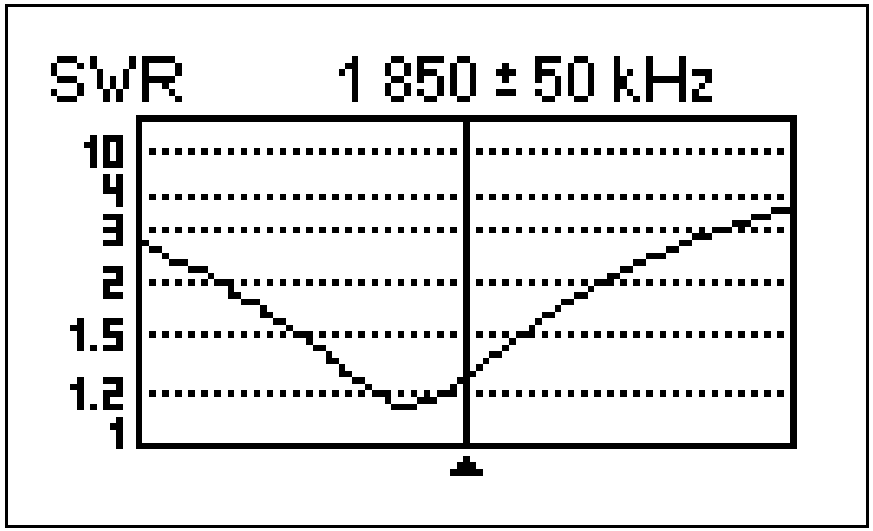
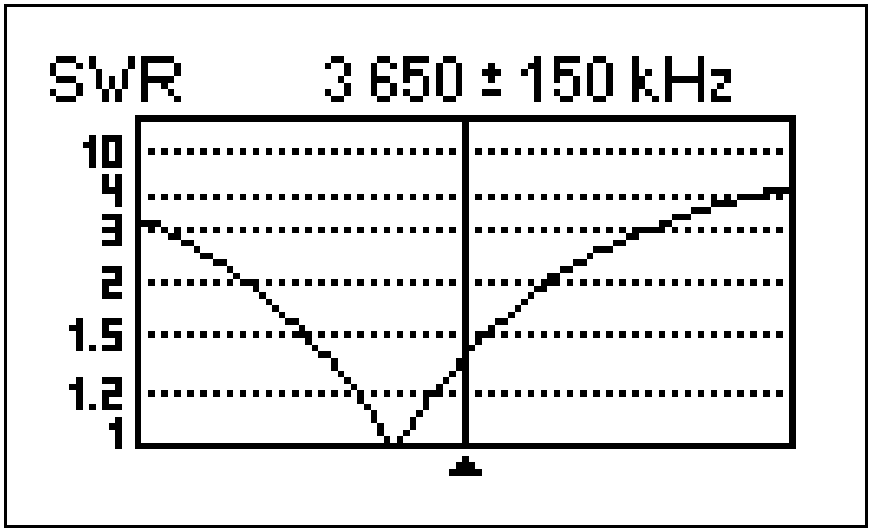
#1: Toroid Matching Solution

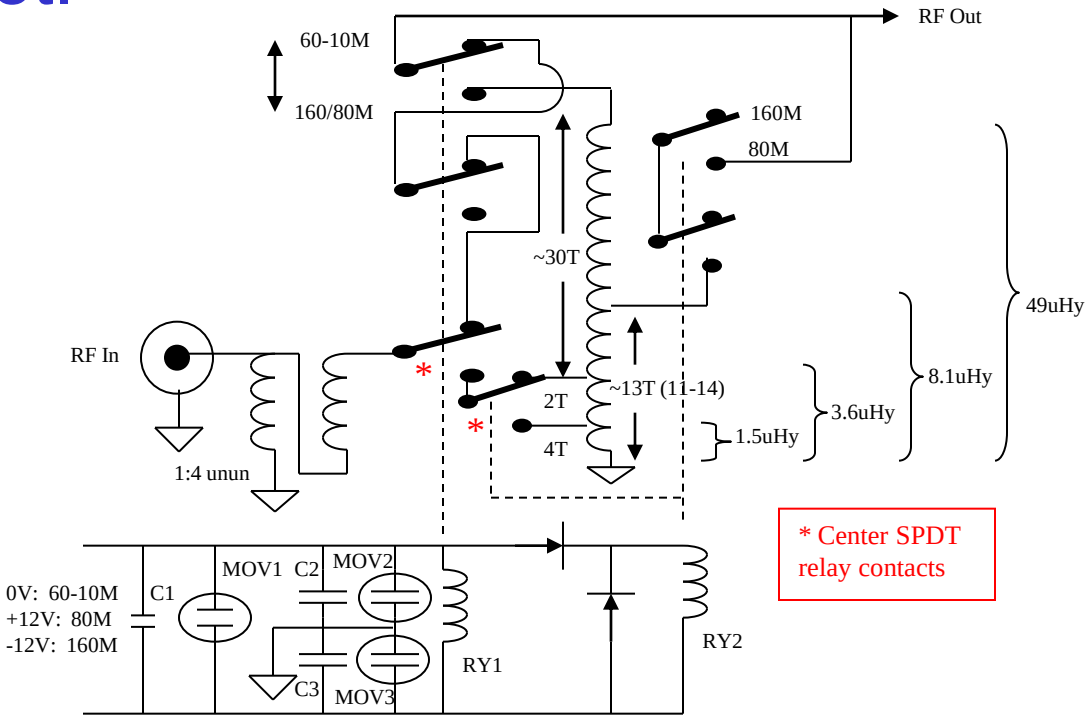
- How well does it work?





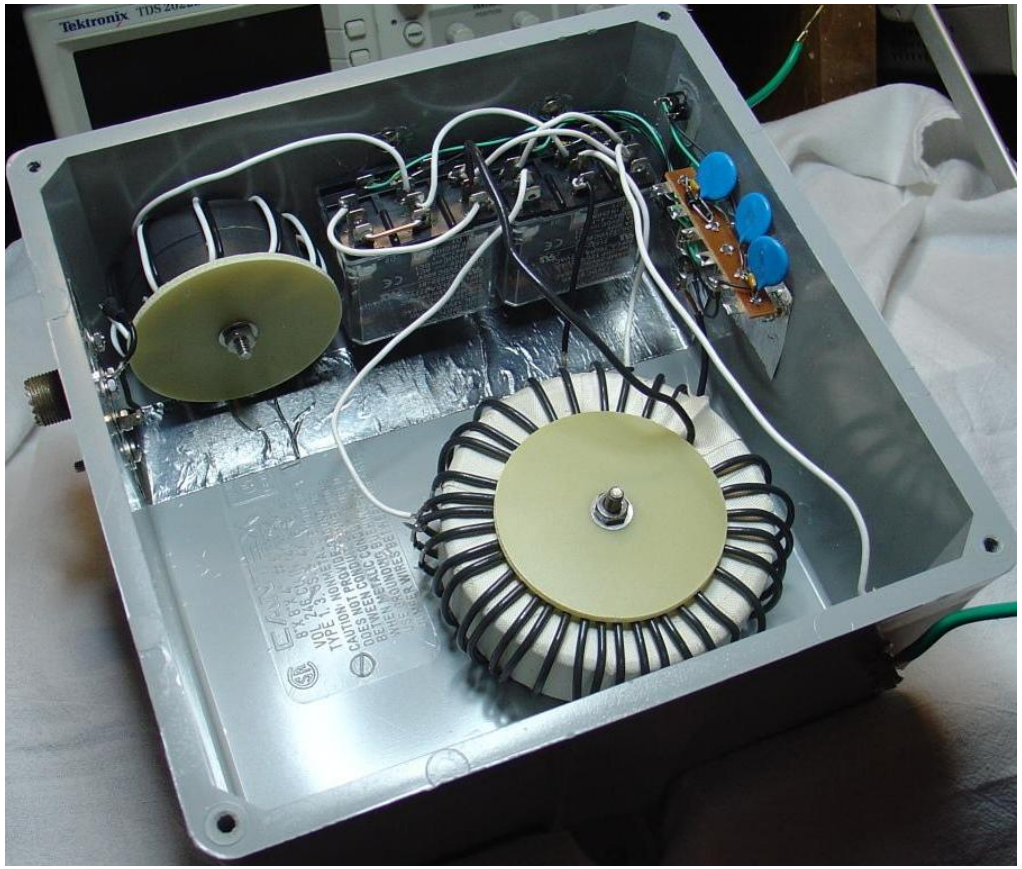
#2: Switchable Matching Solution

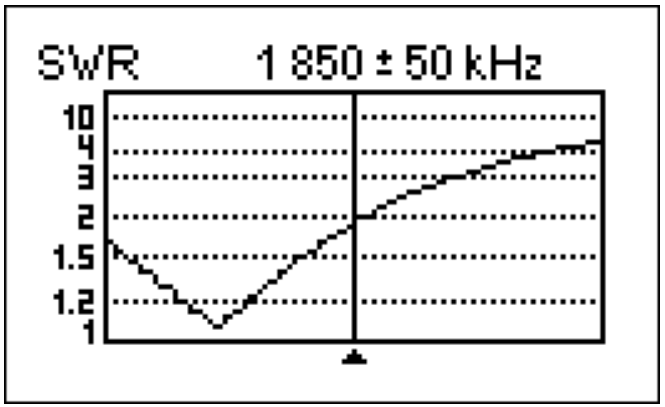
- Fits in 8x8x4” electrical box from Lowes/Home Depot.

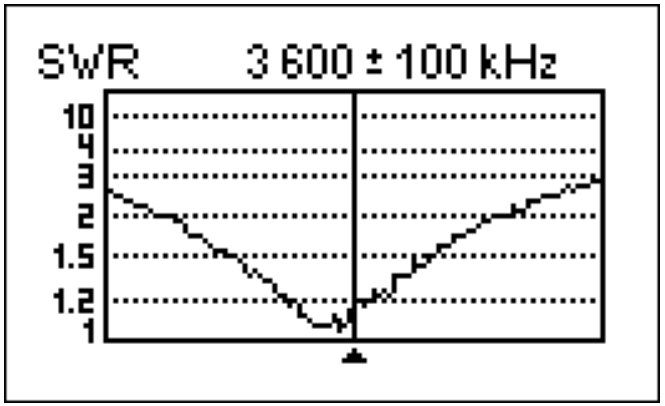


Toroid-based 160/80 Meter Impedance Matching Network

AD5X #2: Switchable Matching Solution







#3: Switchable Matching Solution

- Fits in 8x8x4” electrical box from Lowes/Home Depot.

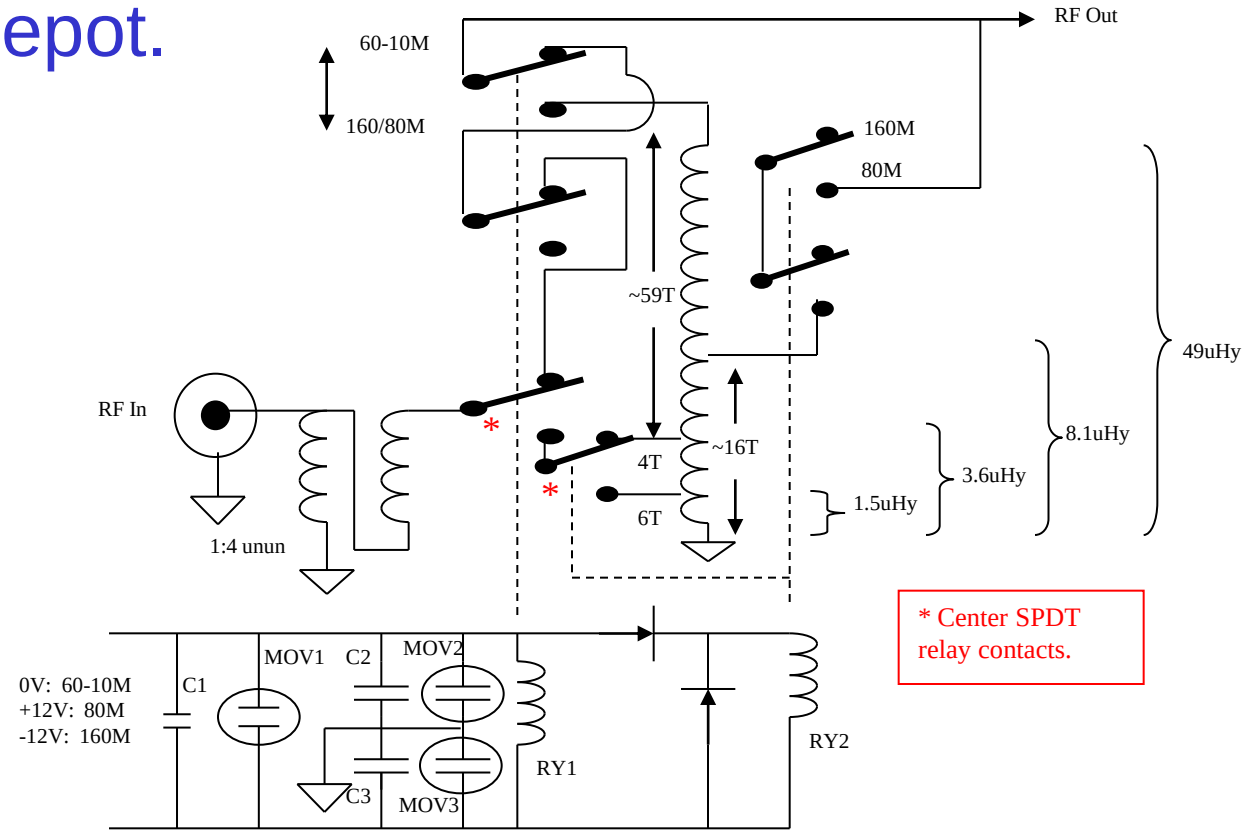


Figure 6: 160/80 Meter Impedance Matching Network

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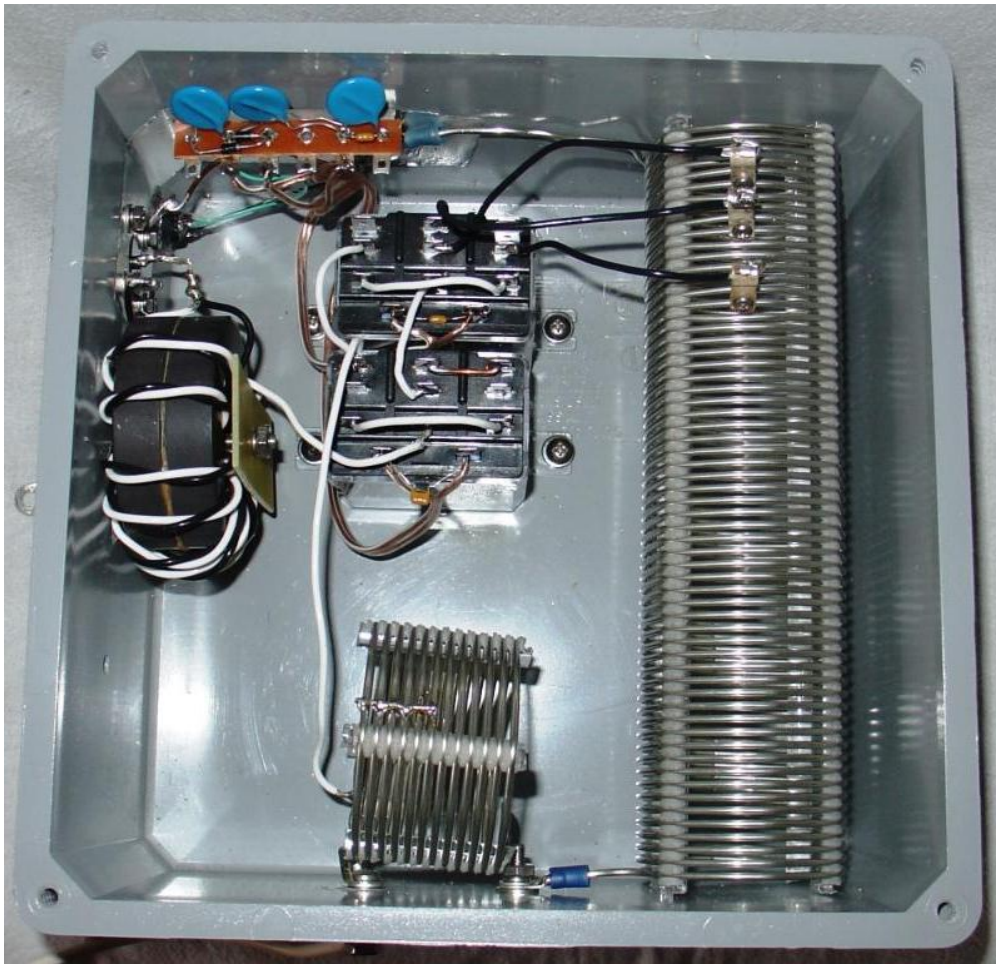
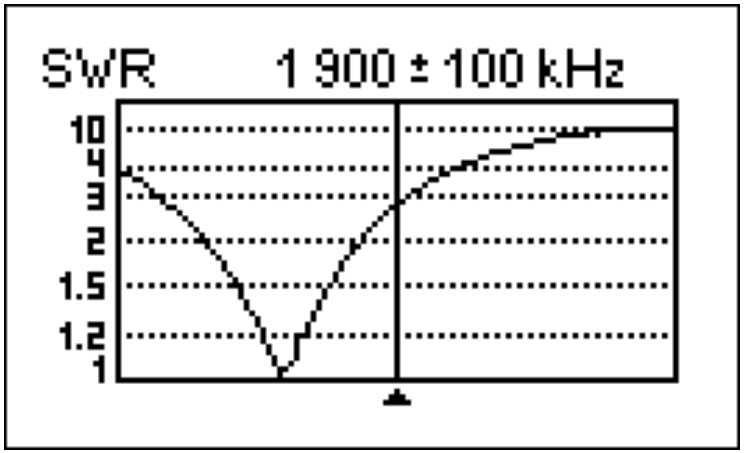
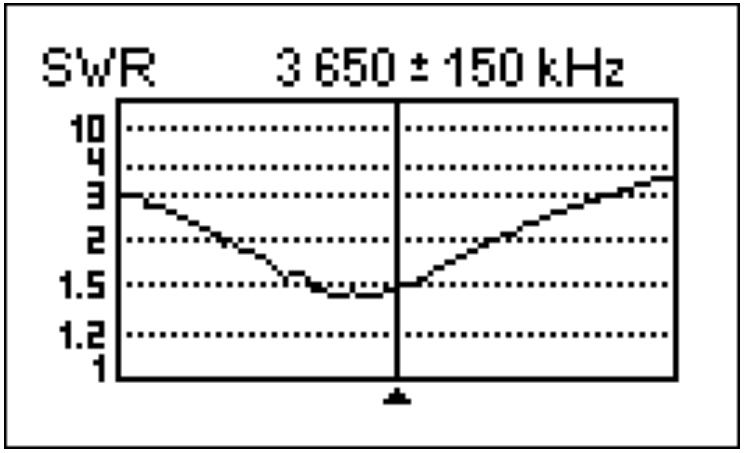
#3 Switchable Matching Solution







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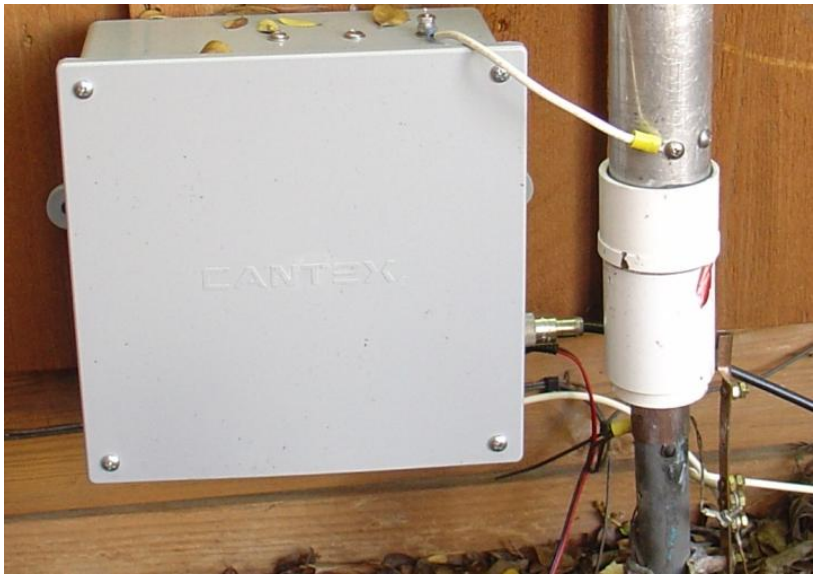
Which Solution Is For You?



If you run high power, the air-core inductor solution gives the lowest losses (Inductor Q>400). However, toroid dissipation is not an issue at lower powers as toroid heating increases linearly with power. Example:

1500 watts: Toroid dissipates ~240 watts
750 watts: Toroid dissipates ~120 watts.

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Build your own 43-Foot Vertical

Aluminum Tubing from Texas Towers:

- 2”ODx0.120”x6’ = $33.00
- 1.750”ODx0.058x6’ = $16.80
- 1.625”ODx0.058x6’ = $15.30
- 1.500”ODx0.058x6’ = $13.50
- 1.375”ODx0.058x6’ = $12.30
- 1.250”ODx0.058x6’ = $11.10
- 1.125”ODx0.058x6’ = $ 9.90
- 1.000”ODx0.058x6’ = $9.00
- 0.875”ODx0.058x6’ = $8.40
- 0.750”ODx0.058x6’ = $7.80

Total ~ $130.00 + Tax
+ 9 SS hose clamps.

Probably around $140 total

Note: Prices will change with time!

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Build Your Own Base Mount

2”OD Antenna

1-1/2”x1/2” PVC Bushing

1”x1/2” Copper Reducer

1” Copper pipe

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Base mount (Cont.)

- Base mount doesn't need to be tilt-over
- And it doesn't need to support the antenna if you can use your house or a fence for support.
- My solution:

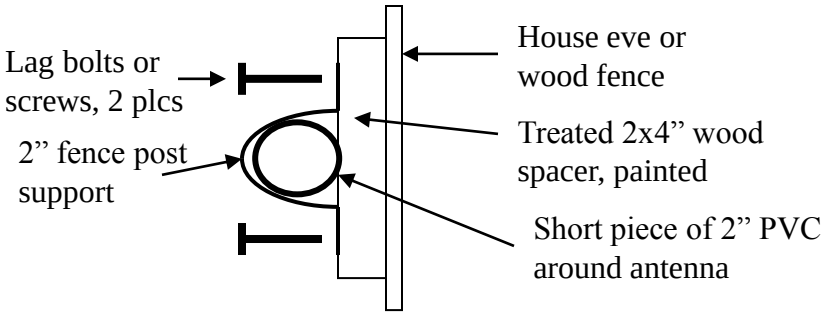

Figure 1: Alternative House or Fence Support

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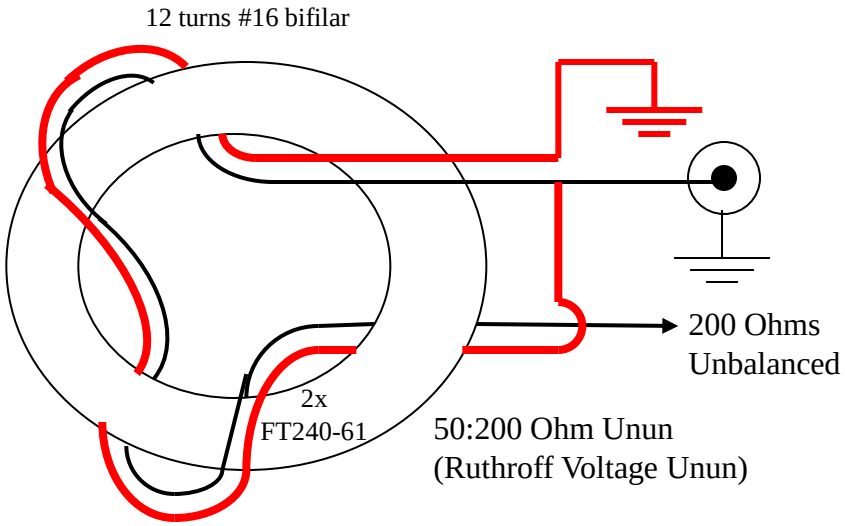
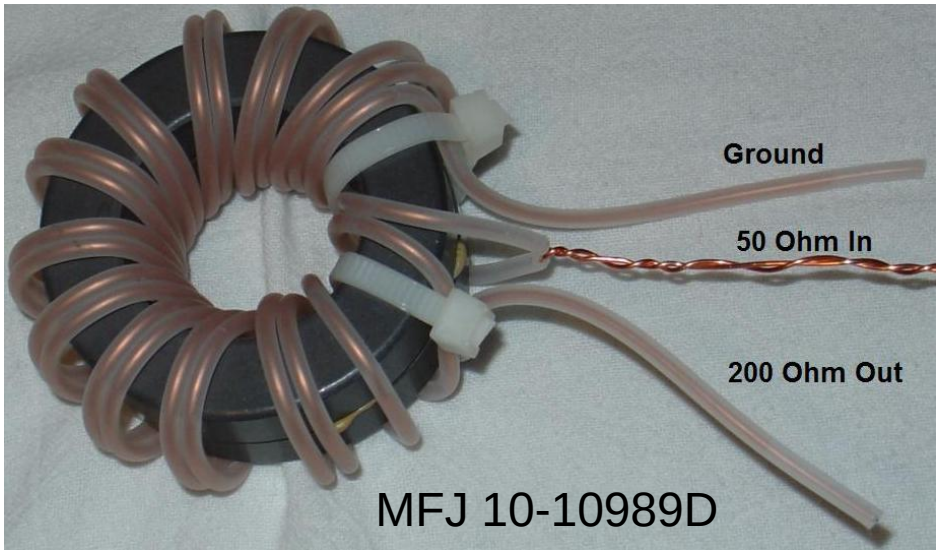
Build Your Own Unun

- 12 bi-filar turns #16 teflon insulated wire on two FT240-61 ferrite toroids
  - Excellent wire substitute: McMaster 9634T701 2-cond HV wire ($3/ft). This is 20KV-rated wire.





Build Your Own Antenna - Alternatives

- Purchase MFJ-1965 ($200)
  - 64-ft telescoping aluminum mast w/ slotted tubing & hose clamps
  - Telescope down to 43-ft. Good tubing overlap = robust antenna.

OR

- Purchase a self-supporting fiberglass 43-foot vertical from LDG (www.ldgelectronics.com) http://www.ldgelectronics.com/http://www.ldgelectronics.com/
  - At $200 (including 1:4 unun), this is very attractive

THEN

- Build your own base mount and unun.

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Summary

- The more metal in the air, the better the antenna
  - Radiation resistance increases as the square of the length change.
  - Increased radiation resistance improves antenna efficiency over real ground.
- A 43-foot antenna is very good for 60-10 meters
- A 43-foot antenna needs base matching to provide good results on 160- and 80-meters.
  - Detailed matching network details at www.ad5x.com

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Parts Sources

- MFJ Enterprises
  - 404-0669 coil, 10-10989D unun
- Array Solutions
  - RF-10, RF-15 relays
- Texas Towers
  - Aluminum tubing
- AutoZone
  - Stainless-steel muffler/hose clamps
- Lowes/Home Depot
  - Junction boxes, wire, hardware, Teflon™ or glass tape, fence-post clamps, copper pipe, PVC adapters
- CWS Bytemark
  - FT240-61 (CWS F-240-61), FT400A-2 (CWS T400-2D)