160- and 80-Meter Matching Network for your 43-foot Vertical - UPDATED
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The popular 43-foot vertical is self supporting, not too obtrusive, and has higher radiation resistance than many popular trapped- or loaded verticals (increased radiation resistance minimizes efficiency-robbing ground losses). And when fed with a 1:4 unun, the 43-foot vertical has a reasonable SWR on 60-10 meters, minimizing SWR-related cable- and unun-losses on these bands. However, this antenna is a poor performer on 160- and 80-meters due to the severe mismatch on these bands – bad enough that it is difficult to match from your shack if you use low loss coax. And even if you can match the antenna system from your shack, you will throw away power in your coax and unun due to the very bad antenna mismatch on 160- and 80-meters. The external impedance matching device described here will significantly eliminate SWR-related coax and unun mismatch losses on 160- and 80-meters, and will preserve the compromise SWR and relatively low SWR-related losses of the original antenna from 60-10 meters.

The Matching Requirement

According to my AIM4170C analyzer, my 43-foot vertical antenna has a capacitive reactance of ~580 ohms on 160 meters. This will vary based on the construction of your 43-foot vertical, its proximity to other objects, etc. However the antenna reactance will almost certainly be in the 550-650 ohm range, requiring ~50uHy of inductance for antenna matching. On 80-meters, ~9uHy is needed for antenna matching.

First – A Word About RF Voltages

My matching assembly uses relays for selecting the different bands, so a discussion of RF voltages is appropriate. RF voltages at the base of an un-tuned vertical can be quite high. As the antenna becomes shorter, the capacitive reactance becomes higher and so the resultant voltage drop across the resulting impedance increases. With the 43-foot vertical, the worst situation occurs on 160 meters where the capacitive reactance is ~600 Ω and the radiation resistance is ~3Ω. Let's look at a few examples:

1) Assuming no ground loss and 1500 watts of power properly matched to the antenna, all power will be absorbed by the 3-ohm radiation resistance. Since $Pwr = I^2R$:

   $I = \sqrt{(1500/3)} = 22.4$ amps rms. $|Z| = \sqrt{(3^2 + 600^2)} = 600$

   So, Vrms = 22.4 x 600 = 13,440
   Vpk = 19,007 volts

2) Very few hams have a lossless ground system. Even 10 ohms of ground loss is better than most hams have, especially on 160 meters. However, for this next exercise we will assume a ground loss of 10 ohms, which means we will be matching our power into a total ground-plus-radiation resistance of 13 ohms. Therefore,

   $I = \sqrt{(1500/13)} = 10.74$ amps rms. $|Z| = \sqrt{(13^2 + 600^2)} = 600.1$

So, Vrms = 10.74 x 600.1 = 6,445.
Vpk = 9,115 volts

3) In my case, I have a 500 watt Elecraft KPA500 amplifier. Assuming 10 ohms ground loss:

   I = √(500/13) = 6.2 amps rms.

   So, Vrms = 6.2 x 600.1 = 3,721
   Vpk = 5,262 volts

The relay I used is a 3PDT Deltrol 375TM, part number 21014-81. It is available from www.galco.com/buy/Deltrol-Controls/21014-81 as well as other on-line sources. This relay has 3.1KV peak contact-to-contact and 5.3KV peak contact-to-coil voltage breakdown ratings, and three sets of contacts that can be put in series to increase the breakdown voltage rating. This relay can be used in a full legal limit application if applied properly. If you use a different relay, make the calculations to determine if your substituted relay will be adequate for your power level.

Because the feed-point voltage can be so high, you can have arcing across the box from a simple output screw terminal when operating on 160 meters. To minimize the possibility of arcing, a ceramic feedthru insulator is used on the output of the matching unit, and the high-voltage ends of the large and short coils are supported with nylon hardware.

<u>The All-Band Matching Solution</u>
The matching unit schematics are shown in Figures 1 & 2. Figure 2 is used with a BiasT if operating voltages are provided via the coax cable. The internal bias-T consists of three 0.01uf 3KV capacitors in parallel (Mouser 581-5ST103MCMCA) for DC blocking, and a 100uhy choke (Mouser 542-4632-RC) for RF isolation. This RF choke has no resonances in the HF ham bands (details on a BiasT can be found elsewhere on this website). When unpowered, the 1:4 unun connects directly to the antenna preserving the original 60-10 meter compromise SWR. +12V or -12V resonates the antenna on 80- or 160-meters respectively. The unun secondary taps into the inductor at the 200 ohm point on 80- and 160-meters.

The coil does dissipate some power. The calculated inductor Q = 427, XL = 534 and RL (loss resistance) = 1.22 ohms. See http://hamwaves.com/antennas/inductance.html (don't forget to convert to millimeters). All power (1500 watts) is matched into the ground loss (assume 10 ohms), inductor loss (1.22 ohms), and radiation resistance (3 ohms). So:

I = √[1500/(10+3+1.22)] = 10.27 amps rms. So power dissipated in the inductor is: Pd = $I^2R = 10.27^2 x1.22$ = 127 watts at full legal limit power. Remember that operating at 1500 watts on 160 meters with low duty cycle modes like CW and SSB will result in a reduction of the inductor power dissipation to about 25-30% of the maximum value.

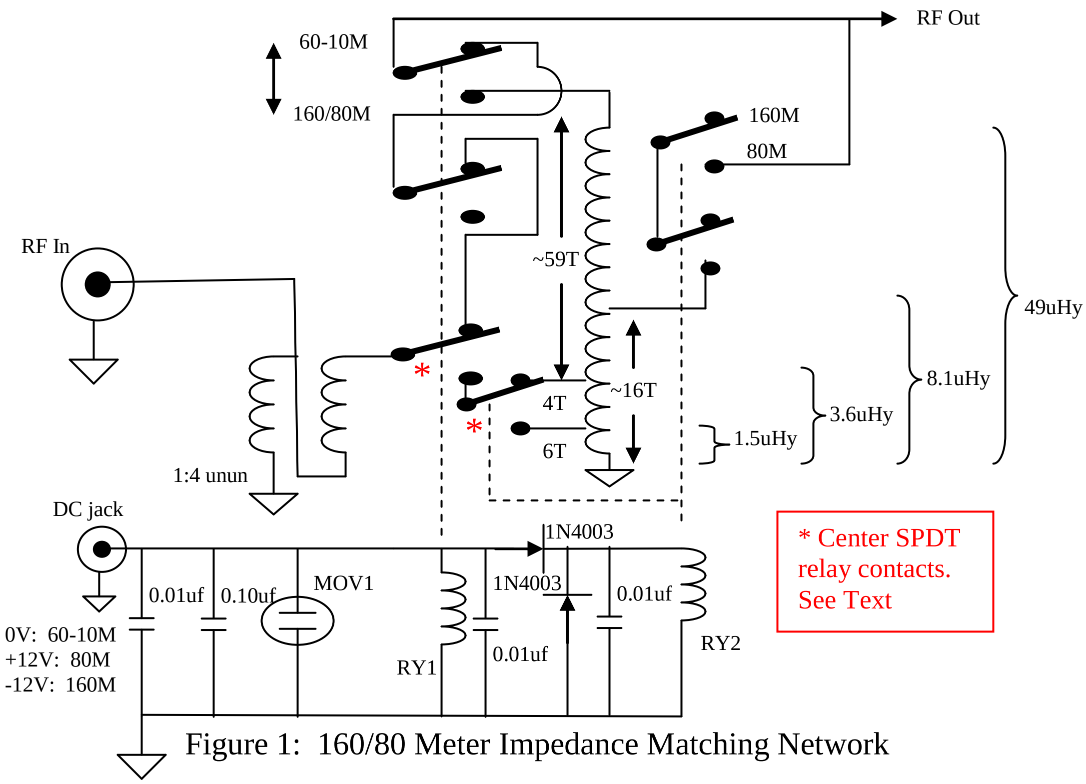

Figure 1: 160/80 Meter Impedance Matching Network

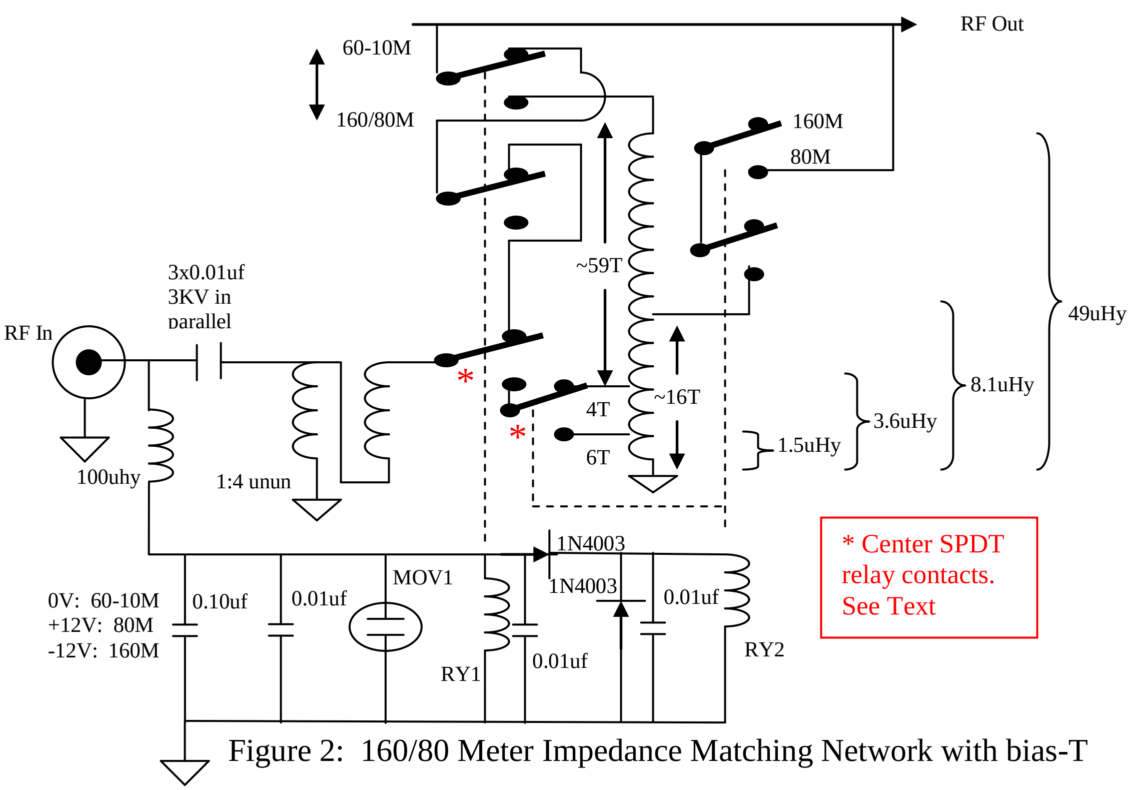

Figure 2: 160/80 Meter Impedance Matching Network with bias-T

The matching unit is built into an 8”x8”x4” electrical junction box. Start by placing an 8-inch length of 2” wide aluminum duct tape along the internal right side of the box.

Mount the 1:4 unun, SO-239 connector, DC jack, terminal strip and coil ground terminal & screw as shown in Figures 3, 4 and 5. Use a piece of bare pc board material and a 2" #8 stainless steel screw and hardware to support the unun. Drill a hole with a step-drill so the DC jack just fits. Then solder #22 gauge leads to the jack, squirt hot glue into the hole, and insert the jack into the hole. As the box won't fit the full inductor length needed, cut the coil into two pieces of 61 turns and 13 turns. Cut the coil at 63 turns and unwrap the wire to 61 turns. This leaves some plastic support at the high-voltage end of the coil. File the plastic support ends if the coil fits too tight, then hot-glue the coil in place (the bottom coil turn is soldered to the ground lug). Support the smaller coil on #6 nylon screws/nuts and #6 solder lugs as shown in Figure 6. Solder the bottom coil turn to the ground lug. Tin the coil at 6T and 10T above ground for the 80M and 160M input tap points. And tin the coil at turns 13, 14, 15, 16, and 17 for the 80M shorting requirement. Mount the relays to the bottom of the case as shown in Figure 7. I used 14-gauge solid wire (house wiring) for most wiring, and 14-gauge stranded wire for the relay-to-coil interfaces. Figure 8 is a close-up of the relay wiring. #8 stainless-steel hardware and a #8 solder lug is used for coil ground. Note the terminal strip with the diodes, MOV and bypass capacitors. Table 1 lists the parts and part sources.

Figure 3: Split inductor & unun mounted

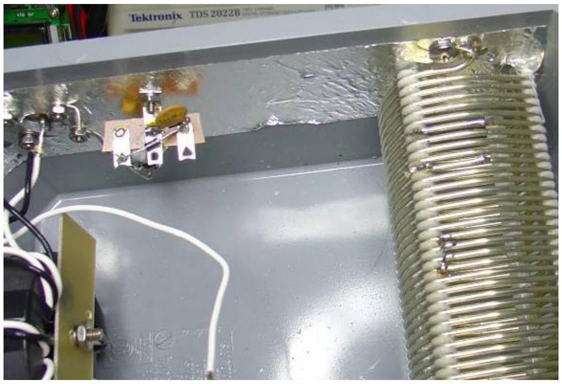

Figure 4: AL tape, term strip, & coil ground

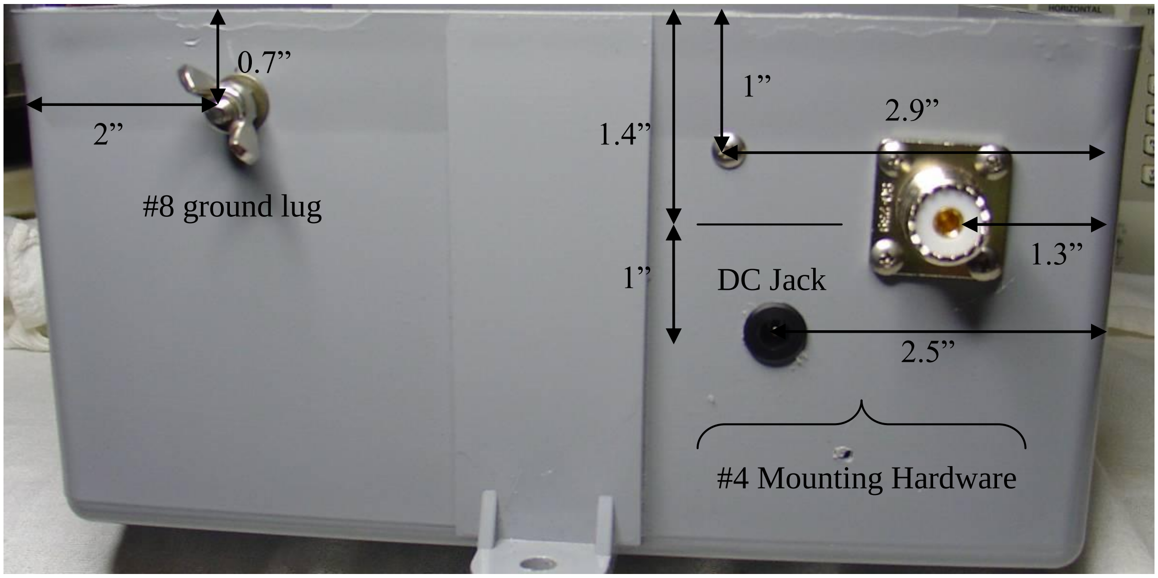

Figure 5: Ground, terminal strip, DC and RF mounting locations

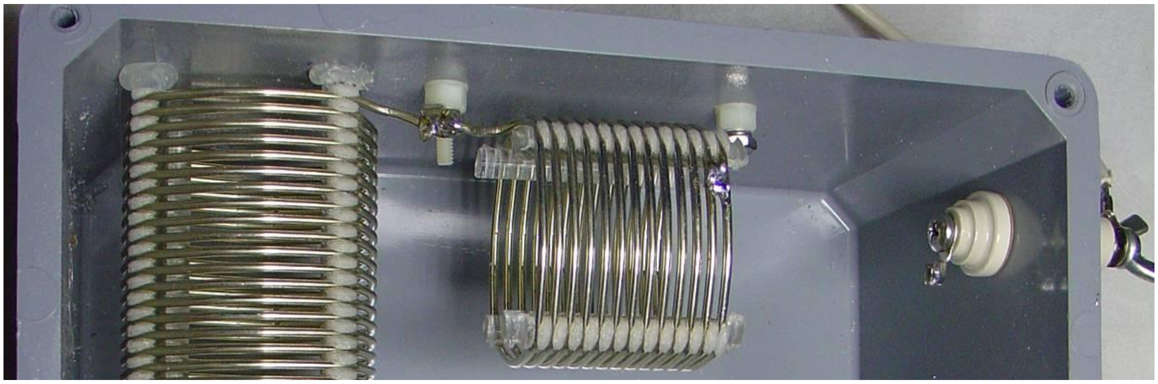
Figure 6: Hot glue and nylon-screw supports for the two coils

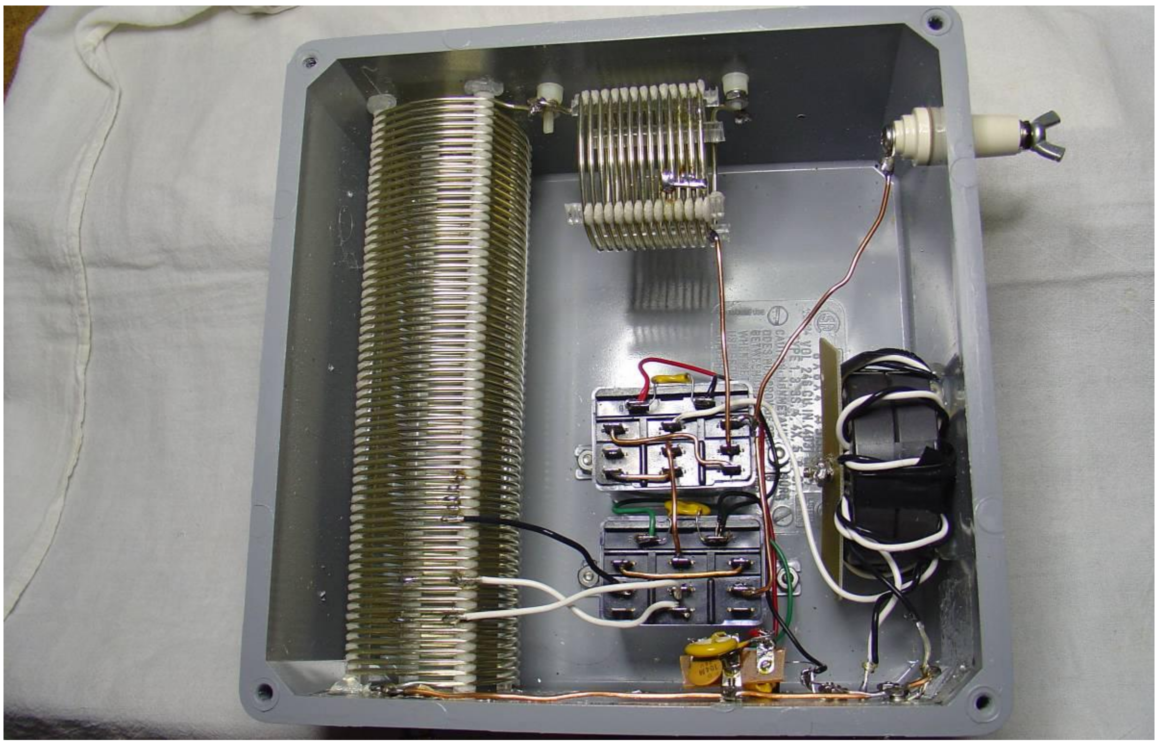
Figure 7: All components mounted

Relay Connections

Because the voltage across the coil can be very high on 160 meters, relay contacts are series-connected to increase the breakdown voltage. The inductor taps also result in more voltage-above-ground to increase the breakdown voltage. The problem is the contact-to-coil 5.3KV peak breakdown rating. Because the outer SPDT contacts are connected via insulated wires and separated from the coil by 0.1-0.2", the center SPDT relay common wires contact the coil. Both the coil and common wires are insulated but there is no air-gap separation between them. This common wire-to-coil contact determines the breakdown voltage rating. To get around this, use the center SPDT relay contacts for the lowest potential interfaces as indicated in the schematic. Just duplicate the relay wiring as shown in Figure 8.

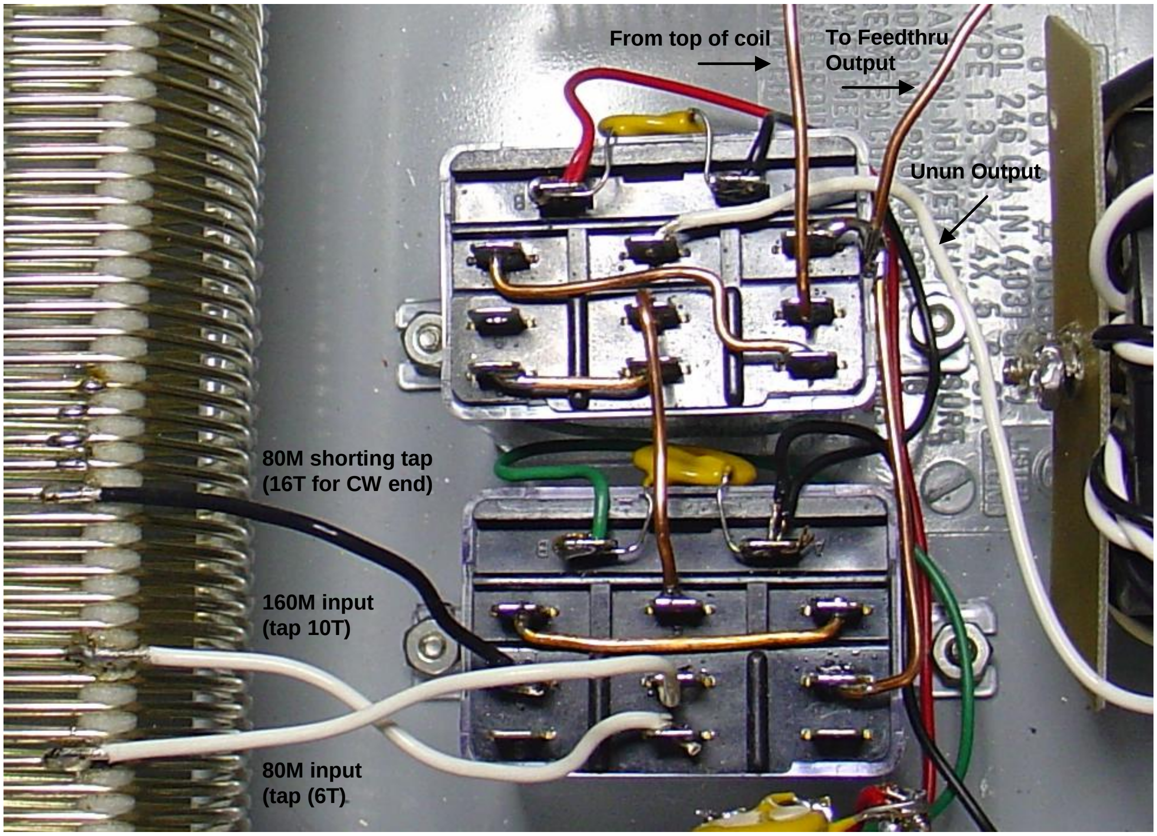

Figure 8: Close-up of relay wiring. Coil tap points are turns above ground.

One last thing: The electrical box is well sealed and water resistant. However, in humid climates with lots of temperature swings (like the Dallas area where I live) the box will "breath" and water can collect inside. I drilled three 1/16"D holes along the bottom of the unit, and a 1/16"D hole on each side to permit any water condensation to drain out. I angled the side holes so that they would be opposite any falling rain. You can see one side hole in Figure 5 – just above the "i" in "mounting".   This method works great to keep water from collecting inside the unit, and the holes are small enough that there has been no problem with ants (or other bugs) getting into the unit – also a real potential problem in my area!

Table 1: Air-Core 160 Meter/80 Meter Impedance Matching Assembly with 1:4 Unun

QTY	Description	Source/Part Number	Price ea.
1	8x8x4" electrical junction box	Lowes/Home Depot	$22.00
8"	2" wide aluminum duct tape	Lowes/Home Depot	
2	3PDT Power Relay (RY1/2)	Deltrol 375TM, 21014-81	$17.00
1	2"Dx12"L #12 79uHy coil	MFJ 404-0669	$37.95
1	SO-239 connector	MFJ-7721	$1.49
1	1:4 1.5KW unun	MFJ 10-10989D or build	$29.95
1	Ceramic Feedthru	MFJ 606-1006	$3.95
2	1N4003 diode	Mouser 512-1N4003	$0.07
3	2.1x5.5mm DC Jack	Mouser 163-1060-EX	$0.88
1	18VDC MOV (MOV1)	Mouser 576-V22ZA2P	$0.24

1	0.10uf capacitor	Mouser 581-SR215C104KAR	$0.17
3	0.01uf capacitor	Mouser 581-5ST103MCMCA	$0.17
1	6-lug terminal strip	Mouser 158-1006	$1.14
2	#4 solder lugs	Mouser 534-7325	$0.17
2	#6 solder lugs	Mouser 534-7326	$0.17
1	#8 solder lug	Mouser 534-7327	$0.17
2	Micro-gator clips	Mouser 548-34	$0.48
2	Test Clips	Mouser 13AC130	$0.48
1	1.97x1.38x0.8" plastic box	Mouser 546-1551GBK	$1.60
1	DPDT Center-Off Switch	Mouser 633-M202301	$4.76
1	12VDC 1-amp Wall XFMR	All Electronics DCTX-1212	$7.50

Miscl: 8-32x1.25" stainless steel screw, nut, wingnut, lockwashers for ground stud at base of coil. 8-32x2" stainless steel screw, two nuts, two lockwashers and scrap pcb material for 1:4 unun support. 6-32x1" and 4-40x1" stainless-steel hardware for relay, connectorg and terminal strip mounting – Lowes, ACE, Home Depot.

Unun Discussion

Since the antenna is unbalanced, a current balun or voltage unun (NOT a voltage balun) is used. A voltage unun can be built (Figure 9) or purchased (Figure 10). Pay attention to the proper connections as shown in the figures.

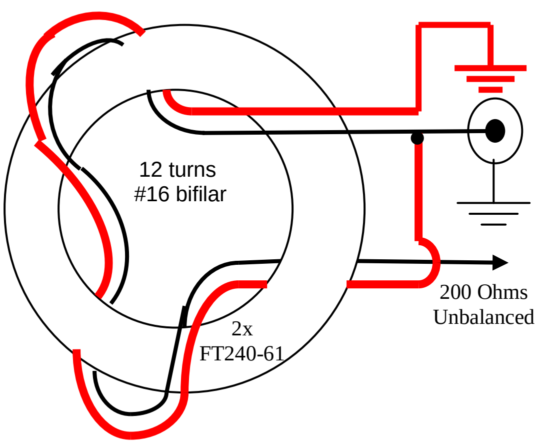

Figure 9: Voltage Unun Wiring

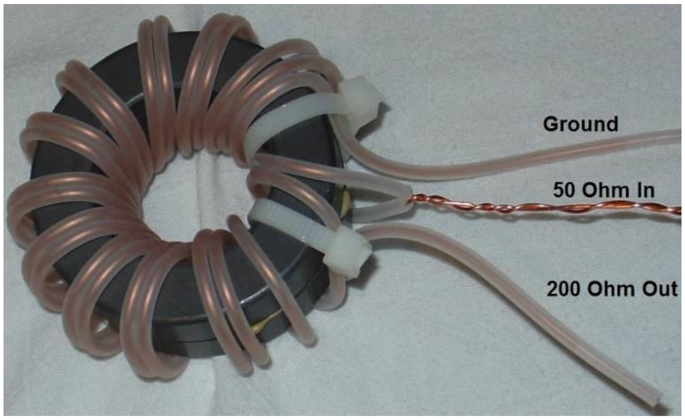

Figure 10: Voltage Unun (MFJ 10-10989D shown)

Switch Control

A 12VDC 1-amp wall wart provides the control voltages that are isolated from your station power supply. The parts list calls out the wall-wart I used, but this is not critical. The two relays draw close to ½-amp total, so you should use a 1-amp wall-wart. A DPDT/Center-Off switch is used for control switching, wired as shown in Figures 11 & 12 below. Figure 13 shows the switch mounted in the small plastic box. I used 2.1x5.5mm DC jacks for the DC input & output from the switch control box.

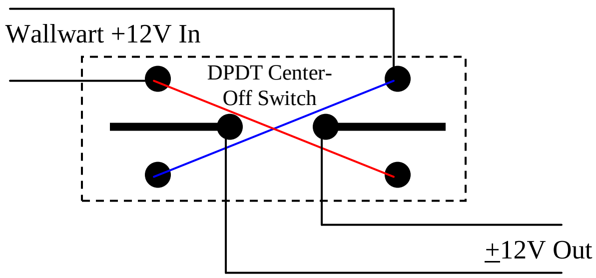

Figure 11: DC Switch Schematic

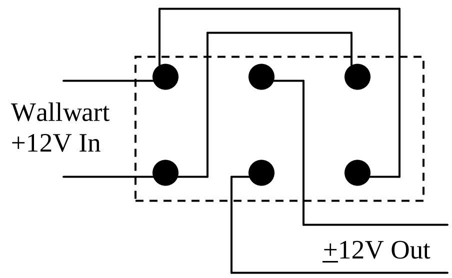

Figure12: Physical Switch Wiring

Figure 13: Relay Switching Unit

Matching Network Resonance

The coil input tap points (6T above ground for 160M & 10T above ground for 80M) can be soldered in place. But the total coil inductance must be adjusted for proper 160M and 80M operation. For tuning, use jumpers made with test-clips and micro-clips (Figure 14).


Figure 14: Test clips

One jumper is used to short turns at the upper end of the small coil for 160M, and the second jumper temporarily connects the relay contact and coil for 80M operation. With the matching assembly connected to the base of your 43-foot vertical, enable 160 meter operation by applying -12VDC. Jumper turns on the small coil to obtain your desired 160 meter resonance point. Then solder a piece of 14-gauge buss wire across these turns. As you can see in Figure 7, I shorted five turns on this coil. Next apply +12VDC to enable 80-meter operation and adjust the coil shorting point for your desired resonant frequency. For resonance at about 3600KHz, my tap point was exactly 16T above round. Finally remove the test clip lead and solder the 80M wire between the coil and relay.

My tuned results for 160- and 80-meters are shown in Figures 15 & 16 as measured directly at the matching network input at the base of the antenna. The 2:1 SWR bandwidth on 160 meters is about 50 kHz, and about 150 kHz on 80 meters. However even a 4:1 SWR results in negligible SWR-related cable and unun loss on the low bands when decent coax (like LMR-400) is used, and is easily matched with most in-shack tuners. Figure 17 shows the matching unit connected to the base of my 43-foot vertical.

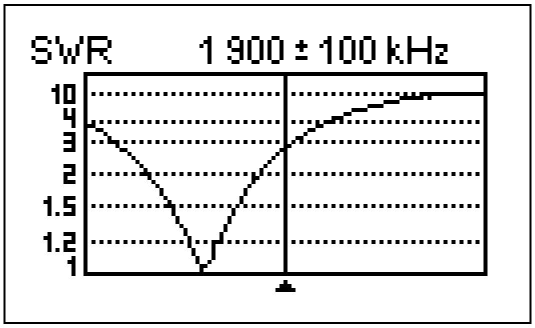

Figure 15: Remote-Switched 160M SWR

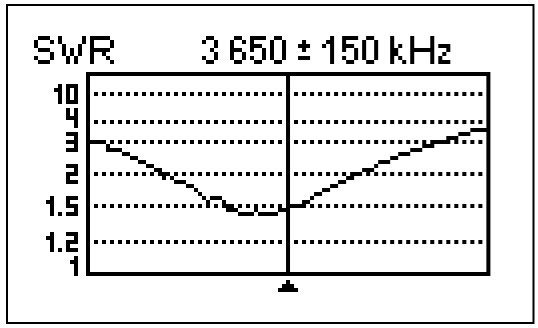

Figure 16: Remote-Switched 80M SWR

I checked the inductor temperature rise with a Kintrex IRT0421 IR Thermometer. With my amplifier keyed continuously at 500 watts output on 160 meters (simulates a 33% duty cycle which is high for SSB or CW), I observed 10° F inductor- and 13° F unun-rises. On 80 meters the temperature rises were even less than they were on 160 meters. This implies a pretty efficient matching network. The cover was off but there was no air movement (90° F ambient temperature, humid and no wind during the measurements).

Figure 17: 160/80M matching unit feeding the author's 43-foot vertical

Conclusion

The matching network discussed here permits effective operation of your 43-foot vertical on all bands from 160-10 meters. This unit is not difficult to build, and will be worth your time.