A Remote Tuner System for 160 to 40 Meters

An Antenna tuner located at the antenna elements for 1.5 kW 160 to 40 meter antennas with a simple manual controller in the radio shack is discussed in this article. A PCB design including Gerber files are provided which can be built at low cost. It is similar to a tuner design published in CQ Magazine in August, 2023. The tuner PCB can be configured for a wide range of dipoles, inverted vees, bent leg dipoles or verticals. The tuner is best suited for 160, 80 and 40 meter mono-band and multi-band antennas to provide full-band coverage. This is not a general purpose tuner, but it is designed to provide full band coverage with good matching on antennas that are resonant near the top of the band. The tuner is located in the center unit for dipoles and inverted vee's or at the base for verticals to provide impedance matching and step tuning across the band directly on the antenna elements in an integrated fashion.

This tuner placed at the antenna elements eliminates high SWR on the coax and station equipment providing good efficiency and performance. A manual controller can be constructed using an 8 position and 3 pole rotary switch in the radio shack with a 12 VDC power supply for control and connected to the tuner with a 4-wire cable. Ham radio operators often use general purpose automatic or manual antenna tuners (usually located in the radio shack but sometimes remote) and sometimes custom remote band or band segment switched tuning and matching circuits. This tuner is very simple, low cost and easy to build, even for full power 1.5 kW operation. It works for many antenna arrangements as long as they are inherently resonant near the top of the desired band. The use of large loading coils to resonant significantly shortened antennas will result in a very narrow SWR bandwidth and sensitive tuning adjustment and is not recommended with this tuner. But shortened dipoles or inverted vees or shortened verticals will work well with this tuner if they use bent legs or tophats to resonant near the top of the band. A number of examples of such antennas on 160 and 80 meters are provided as EZNEC models in a ZIP file.

MFJ manufactured and sold several remote antenna tuner systems, including a unit rated for 1.5 kw operation, the MFJ998RT. With the shutdown of MFJ, that equipment is no longer available except on the used market. Most antenna tuners, manual or automatic, are designed for desktop operation and do not eliminate SWR losses in coax. There are a few remote general purpose automatic tuners available such as the Stockcorner JC-4s which is rated at 1000 watts PEP. Stockcorner is located in the Netherlands. It sells for 1050 Euro's. LDG and a few others sell remote tuners for 100 watt operation, but options for high power remote tuners are limited. The use of general purpose remote tuners with short antennas or with element lengths with very high impedances (such as about ½ wavelength) can result in very high voltages and/or currents in the tuners and then both relays and inductors may be subject to damage, especially for high power operation. It is desirable to have some characterization of antenna elements for the frequencies of operation to make sure that the RF voltages and currents are not extreme, especially for high power. The 3-inductor tuner discussed here avoids extreme voltages and currents by requiring operation with antenna elements that at fairly close to resonance and then

tuning the antenna to low SWR across the full band. This requires more design/testing effort and constrains the antennas, but it also allows efficient, safe and full power operations with full frequency coverage on 160 and 80 meters with low cost parts.

The tuner PCB is simple to build with 3 T200-2 toroids, 3 relays, and an FT240-43 BALUN/UNUN. It provides 8 steps of tuning across the band using 3 loading inductors switched by relays arranged in a binary sequence (the second inductor is about 2x the value of the first inductor and the third inductor is about 4x the value of the first inductor). At the input, an RF transformer BALUN for dipoles and inverted vees or an UNUN for verticals is used to match the impedance of the antenna followed by the loading inductors and relays for frequency tuning. The 3 loading inductors are wound on T200-2 toroid cores and the BALUN or UNUN is wound on an FT240-43 core. The inductor values and BALUN/UNUN primary/secondary ratios can be adjusted for optimal performance depending on the antenna.

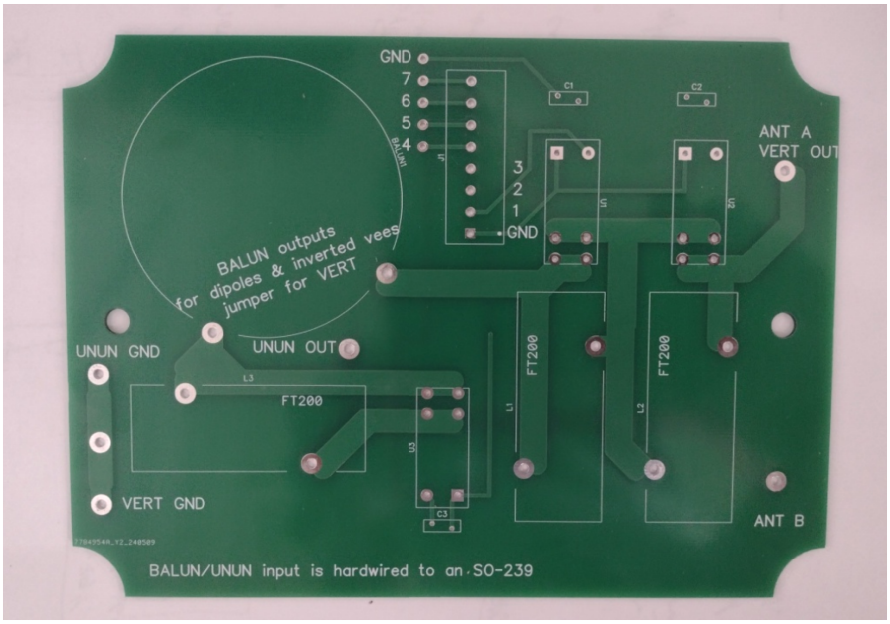


Figure: The Tuner PCB

An example of the tuner is detailed in CQ Magazine in August of 2023 providing full-band coverage with SWR less than 1.5 to 1 with a simple 80 meters dipole (but without the PCB detailed here). The tuner schematic, PCB designs, Gerber files and details are available at www.ka2c.com. Diptrace tools were used to design the PCB's (the tools are free for small designs) and the PCB's were fabricated by JLCPCB at low cost. See www.JLCPCB.com. As of 2024, 5 of these PCB's can be fabricated for $13.40 and shipping at lowest cost to the USA is only $12.36. On their home page, click into the 1- 4 layers "QuoteNow", upload the ZIP file of the gerber PCB files, and proceed through the checkout process including setting up a simple account.

A number of antenna designs for 160, 80 and 40 meters and related tuner designs and EZNEC models are also detailed and provided in a ZIP file. These antennas were modeled with NEC5 (requires a license

and is not free) which supports buried radials. The antennas without buried radials can be modeled with NEC2 provided free with EZNEC.

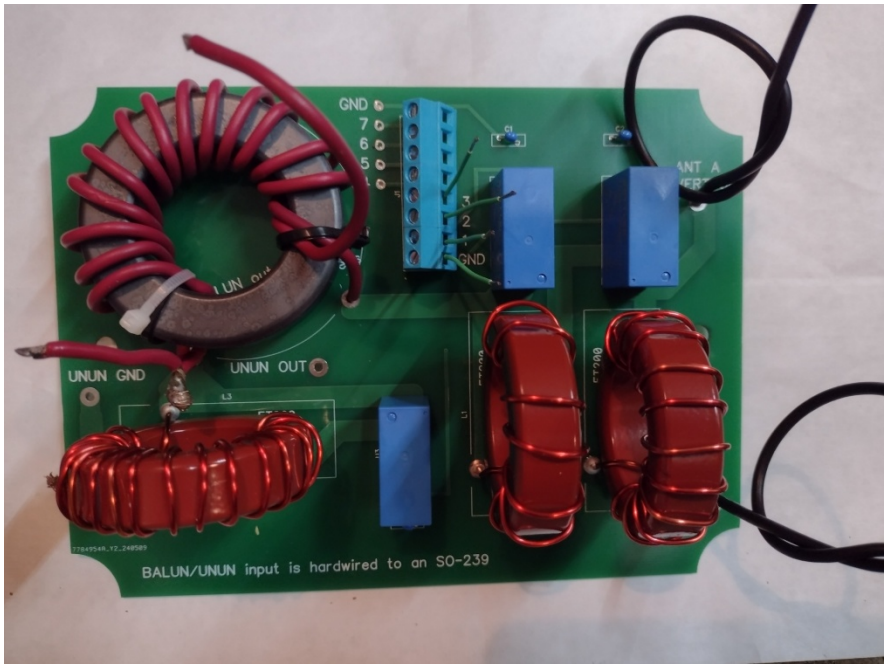


Figure: Assembled PCB Example based on the non-PCB August 2023 CQ Magazine Design

The tuner PCB has a BALUN using an FT240-43 core with 8 primary and 7 secondary turns interleaved for the 80 meters dipole example at only 30 to 40 feet height. The inductors on T200-2 cores have 19, 12 and 8 turns for L3, L2 and L1 respectively. KitsandParts is a good source for the cores, but others also source these cores. The relays are AZ7555–1A–12DSK SPST, available for less than $2 each. A small 10 nF ceramic capacitor is placed across the coil of each relay to filter RF on the control wires and to limit coil kickback. The 8 pin connector is a TB008A-508-08BE and a 4-wire cable connects to the first 4 terminals to control the tuner.

The integrated antenna tuner uses a 2-sided PCB about 7.3” x 5.3” that mounts in a weatherproof Zulkit electrical box measuring 8.7” x 6.7” x 4.3” which acts as a center unit for dipoles and inverted vees:

The enclosure needs 1) an SO-239 connection to the coax for RF to the shack; 2) a connection and cable gland for a 4-wire control cable; and 3) connections for the 2 wire elements. For verticals, the box is placed at the bottom of the vertical with similar connections except connection to the vertical and to the ground or counterpoise. In the case of a vertical, an UNUN should be used instead of a BALUN. A jumper is added to the PCB to place all 3 inductors in series with the active element of the vertical (in the case of a dipole or inverted vee, the 2 smaller inductors are in series with one element of the antenna and the largest inductor is in series with the other element of the antenna). Four small holes close to the corners on the bottom side of enclosure should be drilled to allow drainage of any moisture that enters the enclosure.

Insulated 12 or 14 gauge flexweave is a good choice to connect from the PCB to the external antenna elements to allow flexibility in the connections and robustness against wind. Holes can be drilled on opposite sides of the enclosure close to the top, just large enough for the flexweave or similar copper stranded wire to pass and then a knot tied in the wire inside the enclosure to prevent pressure on the PCB solder joints for those wires. Where the wires connect to the antenna elements, which may be copperweld or stranded copper antenna wire, the joints may be soldered, but then using electrical tape to wrap the wires as they separate at a widening angle for stress relief is helpful for robustness with wind. The SO-239 for the coax connection is mounted near the middle on the bottom side of the enclosure with the BALUN/UNUN just above it on the PCB, and a cable gland for the 4-wire control cable is located near the SO-239 connector on the bottom side of the Zulkit enclosure. If the Zulkit center unit is raised to operating position with a rope and pulley, using a short piece of rope secured to the coax with several tie wraps and electrical tape and similarly for the control cable with those short rope pieces then tied to a main support rope above the Zulkit enclosure is useful to relieve stress on the coax connectors and the control cable gland.

https://www.amazon.com/gp/product/B09FL1XX8F/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&th=1

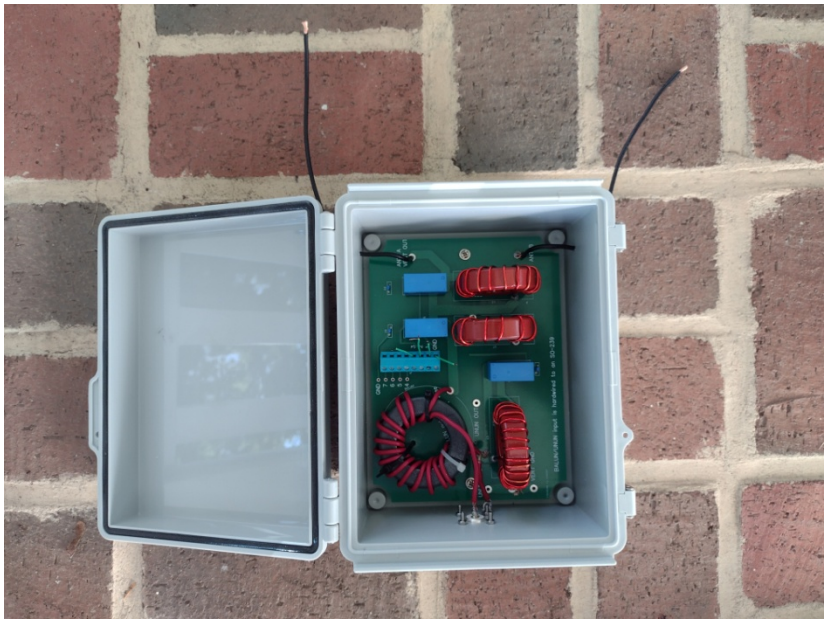


Figure: Complete 80 Meters inverted vee or dipole Tuner – without a control cable connected and with short jumper wires using flexweave to connect to the antenna elements (no knots in this case in the flexweave inside the enclosure, but that can be helpful)

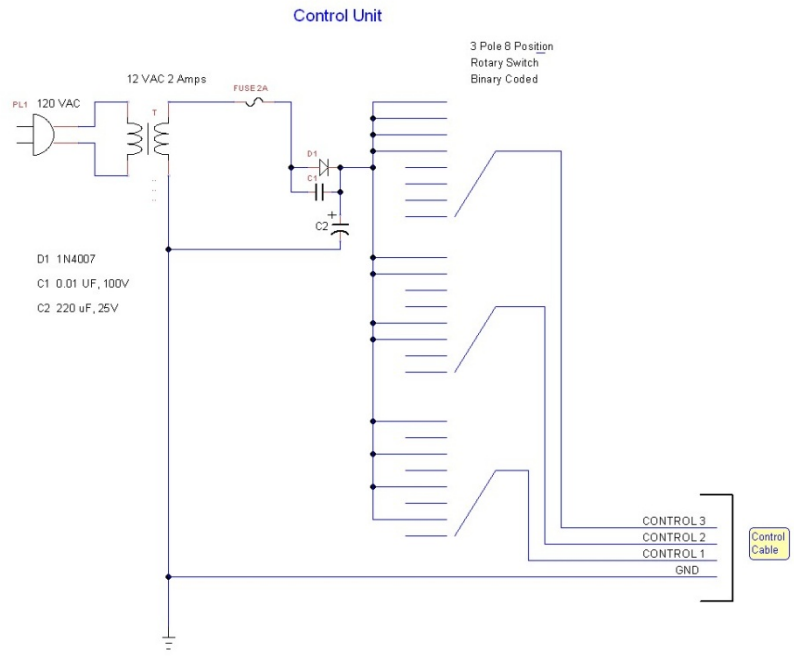


Figure: Manual Tuner Control Unit with an 8-position Rotary Switch

A wide range of dipole, inverted vee and vertical arrangements for 160 and 80 meters can be accommodated. For example, inverted vees with the legs bent at 90 degrees to fit on a small lot work well with this tuner. An inverted vee at 30 feet in the center, going +- 30 feet to a height of 15 feet and then with extensions on each leg at 90 degrees going 28 feet can provide a good capability for 80 meters and full band coverage with the basic tuner with worst case SWR's of only about 2:1 from 3.5 to 4.0 MHz. A compact vertical dipole for 80 meters provides excellent low elevation angle radiation for DX, and it has a height of only 33 feet with 2 sloping tophat wires and 2 elevated counterpoise wires at 8 feet. It can be tuned across the entire 80 meter band with good results. Other systems such an inverted L antennas for 160 meters with radials or a K2AV Folded CounterPoise (FCP) are possible with the tuner for 160 and 80 meter antennas. A number of possibilities are in the list below with EZNEC models and results and arrangements for the tuner. Compact antennas with bent legs, tophats or similar methods of achieving resonance have wider SWR bandwidths than compact antennas with inductive loading and also avoid the need for large and generally lossy inductors. Bent leg and tophat type antennas to achieve small footprint implementations work well with this tuner. The 80 and 160 meter inverted vees with legs bent under the elements result in especially small footprints, and they are fairly simple to build. This tuner enables full band coverage with them.

EZNEC models are included and results for low and high dipoles and inverted vees; dipoles with bent legs; and dipoles with legs bent under on 160 and 80 meters. Also verticals with and without tophats are included. The results for average soil are in an Excel spreadsheet, but it is straight forward to change the models for ground conditions and run additional simulations. Inductor values and T200-2 turns for some configurations are listed.

Antenna EZNEC list for the 3 inductor integrated antenna tuner

1. 160 m Inverted Vee at 40 feet center and 15 feet ends
2. 160 m Inverted Vee at 80 feet center and 40 feet ends
3. 80 meters Inverted Vee at 40 feet center
4. 80 meters Inverted Vee at 80 feet center
5. 80 meters dipole at 30 feet with bent legs
6. 160 meters dipole at 30 feet with bent legs
7. 80 meters inverted vee at 30 feet with legs bent under
8. 160 meters inverted vee at 30 feet with legs bent under
9. 160 m full size vertical 32 buried radials
10. 80 m full size vertical 32 buried radials
11. 160 m compact vertical dipole at 65 feet
12. 80 m compact vertical dipole at 36 feet
13. 160 m 43 feet vertical 4 tophat wires 32 buried radials
14. 80 m 33 feet vertical 4 tophat wires 32 buried radials
15. 160 m 43 feet inverted L 32 buried radials
16. 160 m 33 feet inverted L 32 buried radials
17. 160 m inverted L at 43 feet with FCP
18. 160 m inverted L at 33 feet with FCP
19. 80 m 33 feet inverted L 32 buried radials
20. 80 m inverted L at 33 feet with FCP
21. 160-80-40 m fan dipole at 30 feet with bent legs

For full sized 160/80 meter inverted vees, dipoles, dipoles with folded ends for small lots,…. The inductance required to tune the antenna from 2/4 to 1.8/3.5 MHz is about 16.5/10.25 uH and has very small variation for different soil types, antenna height,…. However, the radiation resistance will vary with soil and antenna height, so the inductors can be specified the same for a wide range of conditions but the BALUN impedance ratio will vary a bit depending on radiation resistance. Verticals generally only require about ½ the total inductance of dipoles to tune across the band, but compact verticals require higher total inductance and tophat loaded verticals require less total inductance. Verticals using a FCP require total inductance similar to a dipole (the antenna behaves a bit like a vertical dipole).

Many of the antennas will support a worst case SWR of about 1.5 to 1 or so across the desired band including the dipoles, inverted vees and verticals after adjustments providing excellent matching and very low loss in the connecting coax. The dipoles and inverted vees with bent legs have a bit more narrow SWR bandwidth and worst case SWR's may be about 2 to 1. The multiband antenna in case 21 makes several compromises and worst case SWR may be about 3 to 1, but it should support full-band operation with final tuning using built in tuners in the rig or amplifier which usually can handle 3 to 1 SWR, so there may be a bit higher loss in connecting coax, but it will be much better than using the antenna without remote integrated tuning.

Toroid Inductors

The toroid inductors do not require added insulation for the enameled wire. Enameled 14 gauge copper wire is a good choice for the toroids. The inductors are arranged with L2 2x the inductance of L1 and L3 2x the inductance of L2 to support tuning in a binary sequence. L3 should have 2x the number of turns of L1 since L3 is 4x the inductance of L1, and the inductance is proportional to the number of turns squared. In case of a fractional turn, the fraction can be dropped and if needed, a few turns of ½ inch to 1 inch diameter hand-wound air coil added in series. L2 should have about 1.4x the number of turns of L1. During testing, the toroid inductors can be tweaked so that L2 changes the frequency about 2x the change caused by L1 and L3 changes the frequency about 4x the change caused by L1. They can also be adjusted if the total frequency span is too small or too large.

UNUN's and BALUN's

The compact antennas discussed with this tuner such as the verticals with tophats, have low real impedances of 9 to 12 Ohms (assuming that any reactance is matched to near zero with the tunable inductive loading). These are best matched with UNUN's at the input of the tuner providing a 2:1 turns ratio (the impedance ratio is the turns ratio squared). A good source of information on building appropriate UNUN's can be found at:

https://ia601609.us.archive.org/17/items/fe_Ham_Radio_Transmission_Line_Transformers_Handbook/Ham_Radio_Transmission_Line_Transformers_Handbook.pdf

Jerry Sevick, W2FMI (SK) also has books published on BALUN and UNUN design which can be purchased

Starting on page 24, Jerry details several UNUN's with multiple impedance outputs and 50 Ohm inputs. The first is a trifilar design and the second is a quadrifilar design (3 or 4 wires in parallel wound on the cores and connected together in specific ways). Jerry uses 1.5 inch or FT150 type K cores in these designs. For 160 to 40 meters combined with high power, more power margin may be provided by using 2.4 inch FT240-43 cores, but this may reduce the performance on 15 and 10 meters. Enameled #14 copper wire or magnet wire placed in Teflon tubing is recommended (#12 is possible but hard to handle and may crowd the toroid). McMaster-Carr carries high temperature teflon tubing for insulating wire (0.066" ID for #14 wire or 0.095" ID for #12 wire).

For dipoles or inverted vees or the compact vertical dipoles, with balanced inputs and impedances lower than 50 Ohms, an RF transformer with separate input and output windings may be used. For balanced antennas with impedances near 50 Ohms, a current or Guanella BALUN (see page 29 in Sevick's online book) works well, but for lower impedances a simple RF transformer is convenient although it may have slightly lower efficiency than a multi-core design such as an UNUN followed by a Guanella BALUN. For an RF transformer, the primary and secondary windings should be interleaved which minimizes the magnetic fields in the toroid and heating of the core. For 160 and 80 meter antennas that are only 30 feet high or so, the impedance may be 20 to 40 Ohms (160 and 80 meters), and impedance matching is

important. The 80 meter inverted vee tuner detailed earlier used an 8 to 7 interleaved turns ratio and insulated #12 stranded wire providing 50 to 38 Ohms impedance match.

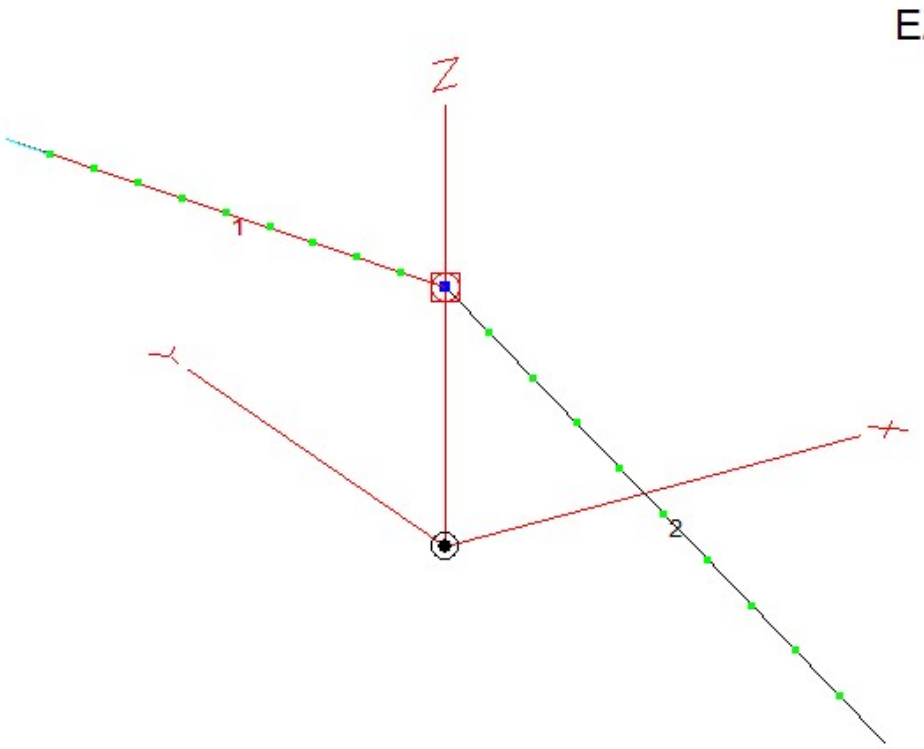
Relays

The SPST AZ7555 relays are rated with open contact breakdown voltages of at least 1000 VAC for 60 Hz. However several factors combine to result in measured test results for these relays of about 2000 VAC or about 2x the rated value. First some margin is built into the design, secondly, the rating must also be met at high altitude, but for operation closer to sea level, the value will increase by about 20%, and thirdly, there are both SPDT and SPST versions of this relay, and the SPST appears to achieve a larger contact gap. However, for RF frequencies between 2 and 10 MHz, the open contact breakdown voltages must be reduced by about 20% or to about 1600 VAC for these relays based on measurements for 60 Hz.

The voltages on the relay open contacts can be calculated by looking at the largest inductors that are used (the relay contacts are open at some point in the band to activate the inductor). Then calculate the inductive impedance at that frequency, calculate the peak RF current and multiply these 2 values to find peak RF voltage. Looking at antenna case 21 which is multiband, it has the largest inductors in the list of antennas, and the largest inductors are used at a highest frequency of about 3.75 MHz. With an antenna impedance of only about 30 Ohms, the RF current at 1500 Watts is about 7Amps. So, the impedance of the inductor (7 uH) is (2 x pi x frequency x inductance) is 165 j Ohms and at 7Amps can generate 1154 volts. This results in modest margin for the relays, so operation in this case should be fine at 1500 watts, but the margin on relay open contact voltages is modest. Case 21 causes much higher voltages on the inductors than the single band cases since tuning 80 meters requires increased inductance due to the fan dipole arrangement, and cases 1 to 20 should have good margin with full 1500 watts operation. It is important in case 21 for the fan to be wide spaced as shown in the model to minimize interaction between the tuning of the bands and the required loading to tune across each band.

The relays are subject to failure due to overheating during soldering. The suggested soldering is with a 375 degree C setting on a temperature controlled soldering iron for a maximum of about 5 seconds. A small chisel tip is appropriate. If too much heat is applied, the plastic mounts for the relay contacts may deform and the relay may not operate properly. The relay coil filter caps do not require strong soldering heat. The toroid and BALUN/UNUN connections will require significantly more heat (higher temperatures and/or longer time) since the large wires tend to conduct heat away from the solder area, but they are very robust to strong heat. The traces on the PCB though can be damaged at some point with strong heat. It makes sense to install the relays after the toroids and capacitors are installed to minimize any chance of heat overload for the relays.

Antenna Examples



Figure; Case 1 – A simple inverted vee on 160 meters with a 30 to 50 feet center support

A simple inverted vee on 160 or 80 meters can provide full-band coverage with the tuner and only require a single center support. The worst case SWR may be about 1.5 to 1 to about 2 to 1 depending on the configuration and various factors. The tuner is placed at the apex of the antenna.

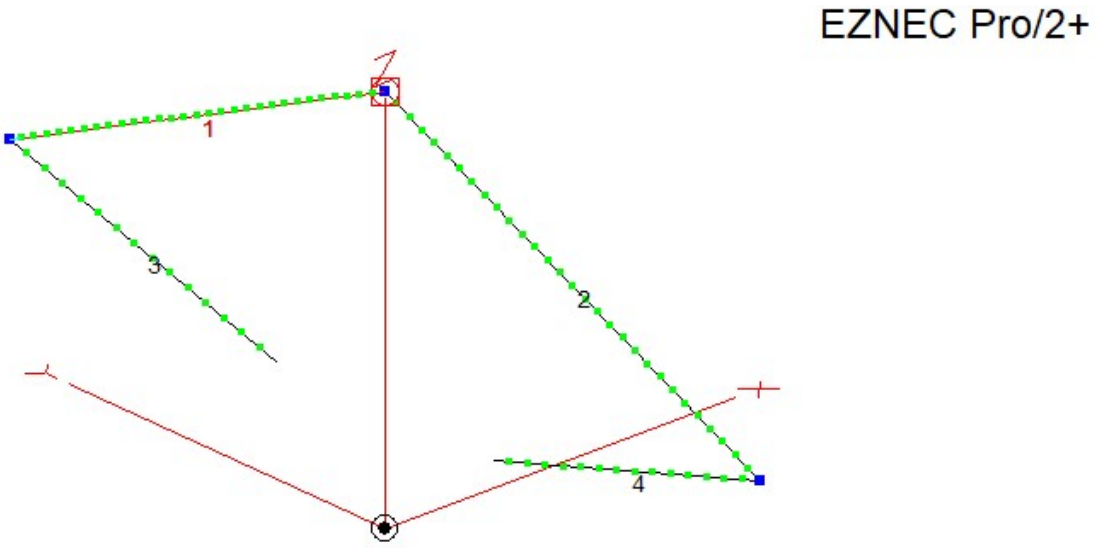


Figure: Case 7 – An 80 meter inverted vee with legs bent under

This antenna requires only a single 30 feet support in the center and two 15 feet supports space +- 35 feet. With the simple tuner, it can cover 3.5 to 4 MHz with a worst case SWR of about 2 to 1 operating at full 1500 watt power levels. The tuner is placed at the apex of the antenna.

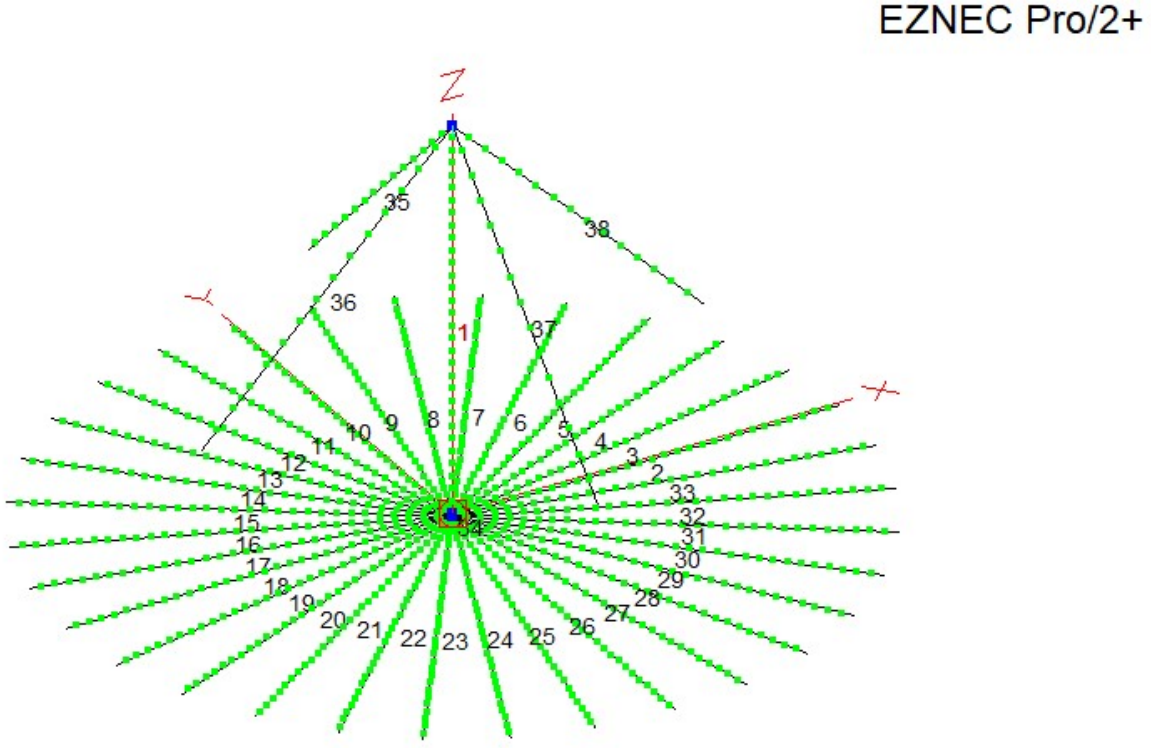


Figure: Case 13 – A high performance vertical for 160 meters DX'ing with a vertical only 43 feet tall.

The 32 radial vertical with 4 tophat wires with a 43 feet vertical element results in a high performance antenna which can provide full band coverage at low SWR with the tuner. The DX Engineering Thunderbolt for 160 meters is similar to this antenna but with a higher vertical element at 55 feet. The 2 to 1 SWR bandwidth of case 13 or the DX Engineering Thunderbolt is about 50 KHz. The tuner can provide full band coverage from 1.8 to 2.0 MHz. For average ground conditions, this antenna can perform at only about 3 dB lower signal levels compared to a full height vertical on 160 meters (120 feet or so) or about ½ S unit for total radiated power and at 10 degrees in elevation. The tuner is placed at the base of the vertical element for this system and it is wired for verticals with an UNUN at the input.

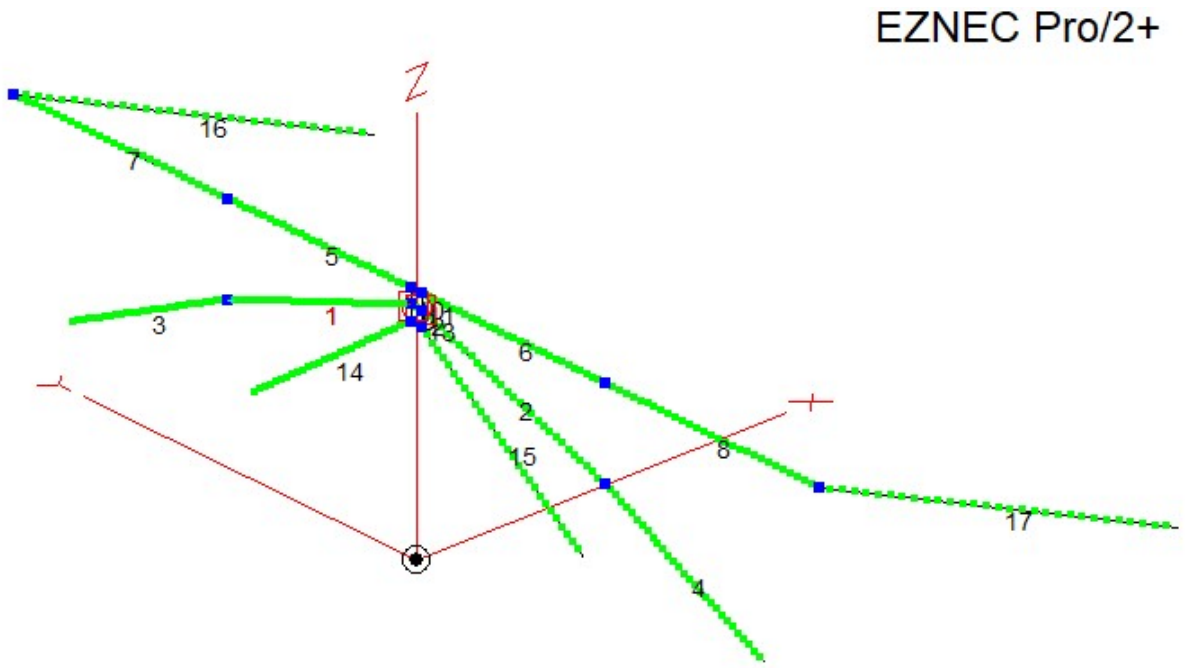


Figure: Case 21 A 160-80-40 meter fan dipole with bent legs on 160 meters

This antenna has a center support of 30 feet and 2 corner supports of 30 feet. The endpoints of each element are at about 10 feet each. The center unit uses a 2 feet by 4 feet PVC pipe spacer to spread out the elements. Full coverage of the 3 bands is possible with the simple tuner (with worst case SWR of about 3 to 1) and at full 1500 watt power levels. The tuner is placed at the bottom middle of the 2 x 4 feet PVC center spacer and it drives the wire set on one side with one output and it drives the opposite wire set with the second output.

Testing and Adjustments

A nanVNA is convenient to measure antenna complex impedance and to adjust the antenna elements to resonant near the top of the band as well as to determine the antenna resistance. It can also be used to test the antenna system for tuning steps of the tuner and the BALUN or UNUN impedance ratio. EZNEC simulation of a specific antenna's configuration is also desirable.

If the tuner turns out to have a larger frequency span or smaller frequency span than optimal or the steps are not reasonably uniform, then the toroid inductors can be adjusted. One convenient trick is to remove or add turns in the middle/top of the toroids to avoid removing the PCB from the enclosure, although this requires splicing the wires of the inductor. If the impedance match of the BALUN/UNUN turns out to be lower or higher than is optimal, then adjusting the number of secondary turns in the case of an RF transformer is possible or in the case of an UNUN, the tap for the output can be adjusted.

Once the tuner and antenna system are working well under testing with a nanoVNA or similar device, then testing can proceed to lower TX power across the band, then 100 Watt levels and finally high power.