Antennas for Autotuners

How I selected an antenna and feedline for my automatic antenna tuner

Santa left an AT-100Pro[1] automatic antenna tuner under the tree this year and I couldn't wait to try it. After the holiday rush settled down I hooked the autotuner to a resonant 40m dipole in my attic and found that I could tune several bands. However, tuning coax fed dipoles on multiple bands can result in severe losses, so I began a search for a more efficient autotuner-compatible multiband antenna.

Goal

The goal was simple: Using the autotuner, tune the most number of bands with the highest efficiency on a doublet antenna. Getting the highest efficiency mandates the use of ladder line because SWR loss can be very high using coax on multiband antennas. To simplify the search I limited the criteria to center-fed doublets made of #14 AWG insulated wire at lengths of 51 to 135 feet, 35-foot elevation, and ladder line lengths up to 125 feet.

Ladder Line Length

I was intrigued with W5DXP's method of switching in different lengths of ladder line to obtain less than 2:1 SWR for 80m-10m[2]. As an aid to understanding this approach I downloaded a program called TLD, or Transmission Line Details[3]. This utility program shows the impedance and SWR at both ends of a transmission line, details of power loss in the line, and includes characteristics for over 40 transmission line types. I plugged in the W5DXP antenna impedances, observed the 50Ω SWR on 1-125 foot lengths of 450Ω (VF = 0.9) ladder line, and summarized the results in a spreadsheet. I discovered that the minimum 50Ω SWR points (≤ 2:1) for each band coincide with the maximum ladder line currents mentioned in the article.

I reasoned that I could apply this spreadsheet method to the autotuner and expand the SWR ranges to those that fell within the autotuner's specifications. Also, instead of changing the length of the ladder line for each band, I would look for one length that would allow the most bands to be tuned.

Autotuner Specifications

Interpreting the autotuner's specifications turned out to be another problem altogether. The specified range is 6 to 1000Ω loads, and 6 to 4000Ω with the optional 4:1 balun. I didn't know if these ohmic values represented resistive only loads or complex loads. In an effort to understand these specifications more clearly I sent an email to the manufacturer to find out if this range was expressed in impedance, and how it would be represented in terms of $R \pm jX$. Dwayne Kincaid of LDG was kind enough to respond with the following: "The tuning range is specified in impedance at any phase angle. The specification is an average over all the bands. Once you do the math, you will see that the range increases (beyond our spec) on the higher end with higher frequencies and is reduced somewhat (below our spec) on the lower end on the lower frequencies." In order to be able to do the math I began reading everything I could about transmissions lines and tuners[4, 5].

In its simplest form the tuner's load range can be evaluated using purely resistive loads. In fact, the test performed by the ARRL lab used this method in evaluating automatic tuner efficiency[6]. Assuming that the tuner's output load is 50Ω, a 2:1 SWR load is either 25Ω (50/2) or 100Ω (50x2), a 4:1 SWR load is either 12.5Ω (50/4) or 200Ω (50x4), and so on. Remember that the manufacturer stated that the tuner's range is an average: it will tune a lower range on the lower frequencies and a higher range on the higher frequencies. In a follow up question about the SWR range, LDG responded “Since we only spec 10:1 SWR range, the 50/10 comes out to 5 ohms which is very close to our 6 ohm spec.”

In the real world, the antenna and feedline will present a complex impedance load R $\pm$ jX to the tuner, not a purely resistive load. If we input a value of 40 - j30 into the TLD program and specify ideal (lossless) 50Ω transmission line, the SWR will be 2:1 at any frequency. However, the impedance at the other end of the transmission line will vary with frequency and line length. Table-2 is a summary of LDG’s Z-100 autotuner showing estimated tuning ranges and losses for 160m-10m. Although this isn’t the exact autotuner I am using the range and losses should be similar.

Modeling

The next step was to model several doublets using EZNEC[7] for 80m-10m. I chose commercially available ladder line that was listed in the TLD program because all of the specifications (VF, resistance, loss, etc.) were handy. I was tempted to use a 4:1 balun to get a better match from antenna to feedline, but my research revealed that typical 4:1 baluns do not correctly handle the complex impedances required and their efficiency is doubtful. Several experts recommend terminating ladder lines with a high quality 1:1 choke balun and letting the tuner do its job. From there, use low loss coax to connect the feedline to the autotuner.

On each EZNEC model I noted the antenna terminal's impedance at each band frequency. I then plugged each frequency and corresponding impedance value from EZNEC into the TLD program (see Figure-1). The final step in each case was to select the desired transmission line type and length. In an effort to make the data easier to read, all information is color-coded and presented in Table-1 which depicts data for five antenna and feed line combinations:

Antenna 1: 130-foot doublet at 37 feet elevation fed with generic 450Ω ladder line (0.9 VF). The blue squares indicate 50Ω SWR less than or equal to 2:1 for ladder line lengths of 1 to 125 feet. The blue squares with an ‘X’ indicate switched lengths of ladder line as built by W5DXP.

Antenna 2: 135-foot doublet at 35 feet elevation fed with Wireman 552 ladder line (450Ω, 0.917 VF). The red squares indicate 50Ω SWR less than or equal to 10:1 for ladder line lengths of 1 to 125 feet. A ladder line length of 51 feet implies six tunable bands.

Antenna 3: 102-foot doublet at 35 feet elevation fed with Wireman 552, ladder line (450Ω, 0.917 VF). The red squares indicate 50Ω SWR less than or equal to 10:1 for ladder line lengths of 1 to 125 feet. Ladder line lengths of 30-31 and 64-65 feet imply five tunable bands.

Antenna 4: 65-foot doublet at 35 feet elevation fed with 600Ω ladder line (0.92 VF). The red squares indicate 50Ω SWR less than or equal to 10:1 for ladder line lengths of 1 to 125 feet. A ladder line length of 121 feet implies four tunable bands.

Antenna 5: 51-foot doublet at 35 feet elevation fed with Wireman 552, ladder line (450Ω, 0.917 VF). The red squares indicate 50Ω SWR less than or equal to 10:1 for ladder line lengths of 1 to 125 feet. A ladder line length of 113 feet implies six tunable bands.

Field Testing, Part One

The 102-foot Doublet was chosen because it offered the most number of bands with the smallest footprint and shortest length of ladder line. The antenna was assembled using 30 feet of Wireman 552 ladder line, 102 feet of #14 AWG insulated wire, one Ladder-Loc, two end insulators, and a 1:1 choke balun as illustrated in Figure 2. During a recent camping trip, the antenna was suspended between two trees and pulled tight to minimize the sag in the middle. A 50-foot length of RG-8X coax connected the choke balun to the AT-100Pro. I began at 80m and worked to 10m with tuned SWRs no worse than 2:1. This included frequencies in the 60m, 30m, 17m, and 10m bands, which, according to Table-1, were outside of the autotuners range. At first I was stumped, but I then realized that the 50 feet of RG-8X coax must be the culprit. I had intended to use a shorter length of RG-8 instead of the RG-8X. Going back to the TLD program, I entered the impedances for each frequency at the *end* of the ladder line and selected 50 feet of RG-8X as the next length of transmission line. My suspicions were confirmed, as the average line loss (due to ladder line plus coax) for 80m through 10m was 48.3 watts (Table-3A). Rerunning the calculations using 25 feet of RG-8 reduced the average line loss to 26.5 watts (Table-3B). Due to these losses, the 50Ω SWR for each frequency at the end of the 50 feet of RG-8X was reduced to values that the autotuner could handle, thus explaining why I could tune so many bands.

Not having a 25-foot length of RG-8, I continued with an on-the-air assessment. Near HF blackout conditions hindered testing but contacts were made on 80m, 40m, 20m, 17m, and 15m using digital and SSB modes, thanks in part to the Armed Forces Day Military/Amateur Crossband Communications Test. Even with the losses, the antenna was definitely getting out, as I logged several 59 reports from Portugal and the Canary Islands on 17m.

Field Testing, Part Two

On a subsequent camping trip, I installed the antenna in the same location. I installed a newly fabricated 25 foot coax cable (from Wireman #106 RG-8) to replace the 50 foot RG-8X cable. The system now behaves exactly as predicted in Table-1, and the autotuner will not tune 60m, 30m, 17m, or 10m.

Losses

The use of antenna tuners will introduce losses in addition to those incurred by the transmission line, and automatic tuners are no exception. Lacking the equipment to measure these losses, I expanded on the ARRL autotuner tests and listed the results in Table-2. System losses for the 102-foot Doublet were computed and are listed in Table-3A, 3B, and 3C.

Table-3A: Illustrates losses for (30 feet of ladder line) + (50 feet of RG-8X) + (Autotuner loss), yielding an average system loss of 58.3 watts for all bands, and 45.5 watts for tunable bands.

Table-3B: Illustrates losses for (30 feet of ladder line) + (25 feet of RG-8) + (Autotuner loss), yielding an average system loss of 36.5 watts for all bands, and 21.5 watts for tunable bands.

Table-3C: Illustrates total system loss for the 102-foot Doublet without a ladder line segment, (50 feet of RG-8X) + (Autotuner loss). The average system loss is 77.9 watts for all bands, and 66.6 watts for tunable bands. This is over double the loss shown in Table-3B, and illustrates the severe losses (> 3dB) incurred when using 100% RG-8X coax on a multiband antenna.

Autotuner Operation

Operating the AT-100Pro is straightforward once you understand the controls and displays. It can tune automatically whenever the SWR exceeds a set value, or you can set it to tune in semi-automatically when you start a tuning cycle by pressing the Tune button. In the semi-automatic mode, the tuner uses stored settings from internal memory, reducing tuning time down to a fraction of a second. I found the LED bargraph to be very accurate at power levels from 5 to 100 watts, and the SWR indications were very close to my analog SWR meter. One problem did surface, however, when I attempted to tune a band that was outside of the autotuner's range. After indicating a high SWR the autotuner appeared to lock up and would not tune previously tuned bands until I executed a reset. Reset is performed by simultaneously pressing the "Func+Ant+Tune" buttons during power up.

The following is taken from the AT-100Pro manual: "You can tune while transmitting up to 125 watts if your transceiver has a "roll-back circuit" to protect it from high SWR. If it does not have a roll-back circuit, limit power when tuning to 25 watts to avoid damage to your transmitter or transceiver." It is *extremely* important to heed this advice.

Conclusion

This project has taken some of the mystery out of the process of selecting transmission lines, and I now understand why the ubiquitous G5RV is a popular multiband antenna. However, I discovered that the coax connecting the ladder line/balun to the autotuner plays a very important role. By decreasing this coax loss, the system efficiency will improve but at a cost of less tunable bands. For most bands, the autotuner's ability to tune exceeded the guaranteed SWR range of 10:1. In spite of the losses, the autotuner is happy with the setup and the antenna radiates better than expected.

Amateurs with automatic antenna tuners can choose their bands of interest and refer to Table-1 to select an antenna and ladder line length. Or, by following the methods presented here, develop an antenna and feed line to meet their needs. Although not as efficient as tuning by adjusting ladder line length, multiband capability with automatic antenna tuners *is* feasible for doublets fed with one length of ladder line.

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[1] AT-100Pro, LDG Electronics, Inc., http://www.ldgelectronics.com/at-100pro.html
[2] *W5DXP's No-Tuner, All-HF-Band, Horizontal, Center-Fed Antenna*, C.A. Moore, W5DXP, http://www.qsl.net/w5dxp/notuner.htm
[3] *Transmission Line Details*, Dan Maguire, AC6LA, http://www.qsl.net/ac6la/tldetails.html
[4] *Transmission Lines*, Dean Straw, N6BV, 2005 ARRL Handbook, Chapter 21
[5] *How to Evaluate Your Antenna Tuner-Part 1*, *How to Evaluate Your Antenna Tuner-Part* 2, F. Witt, AI1H, QST April and May 1995,
http://www.arrl.org/members-only/tis/info/pdf/9504030.pdf
http://www.arrl.org/members-only/tis/info/pdf/9505033.pdf
[6] *Automatic Antenna Tuners - A Sample of the Field*, J. Hallas, W1ZR, QST May 2004, http://www.arrl.org/members-only/prodrev/pdf/pr0405.pdf
[7] EZNEC Antenna Software, Roy Lewallen, W7EL, http://www.eznec.com/

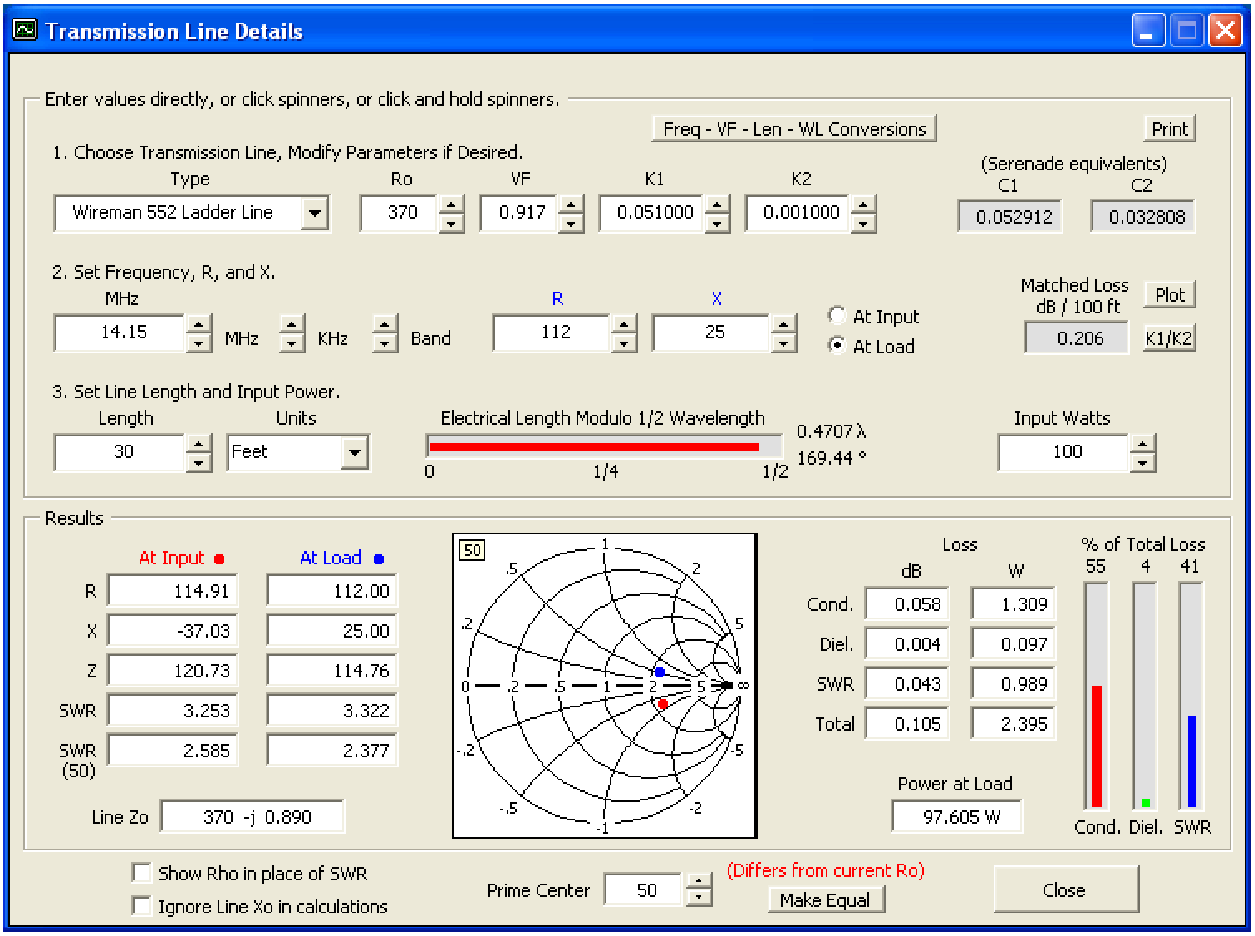

Figure 1

A typical TLD window for the 102-foot Doublet at 14.15 MHz using 30 feet of Wireman 552 ladder line. The values under At Load refer to the antenna's impedance at the antenna terminals and the values At Input list the impedance at the end of the ladder line.

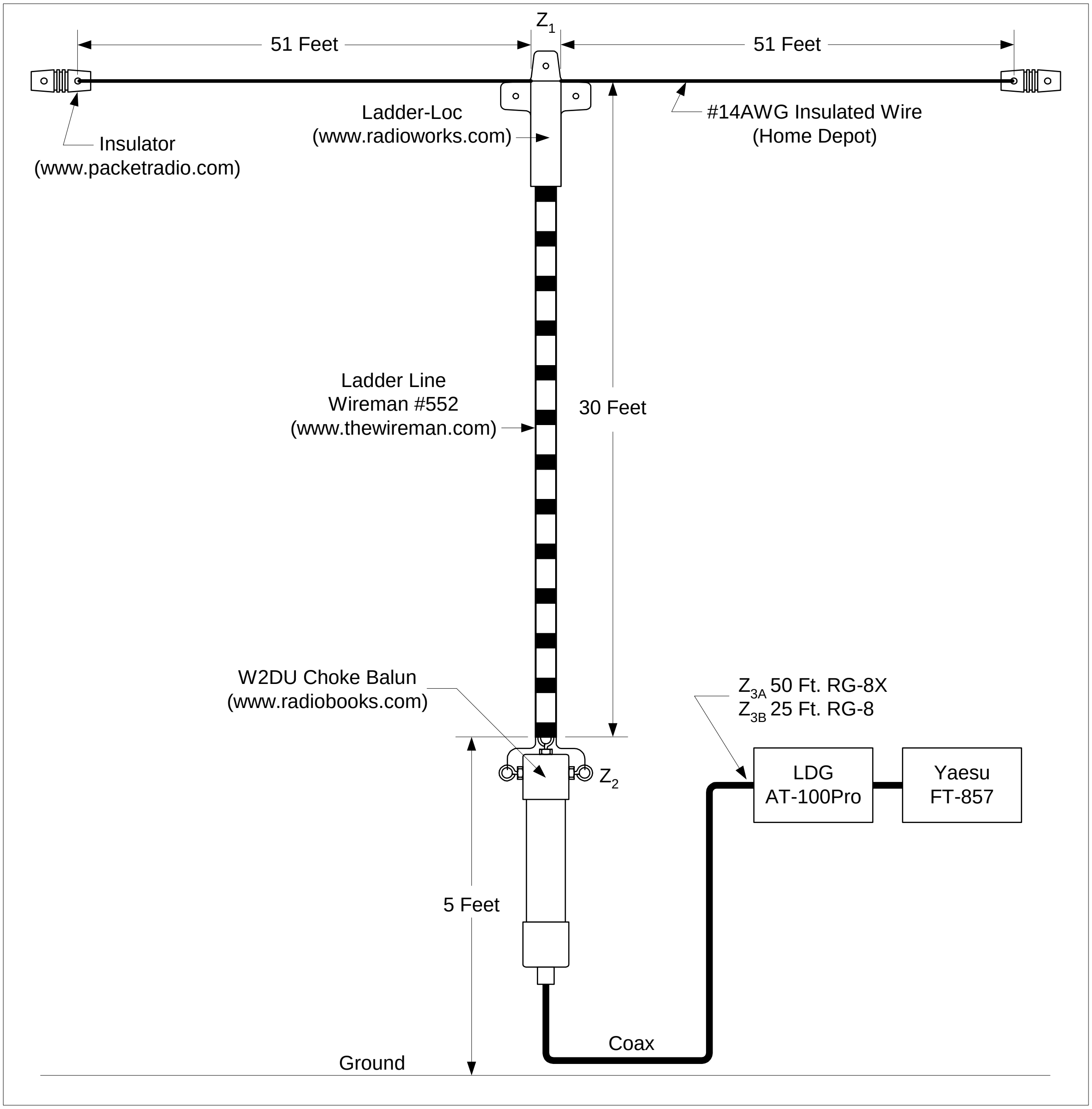

Figure 2

Layout of the 102-foot Doublet
See Table-3 for Z_1, Z_2, Z_{3A}, and Z_{3B} impedance and SWR values.

Z_1 = impedance at the antenna terminals
Z_2 = impedance at the end of the ladder line
Z_3 = impedance at the end of the coax