# *TLW* (Transmission Line for Windows)

## Version 3.24, July 26, 2015

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For those of you who may be familiar with my older transmission-line program *TLA* distributed with the 18th Edition of *The ARRL Antenna Book*, *TLW* is a full-featured upgrade that takes full advantage of the Windows programming environment. Many users during the beta testing phase successfully navigated through all of *TLW*'s many features without the benefit of an instruction manual. Consider the advantage you have, dear reader, since you are now reading the instruction manual! Version 3.24 updates the loss computations for "ladder line" open-wire lines. Thanks to the ARRL Laboratory for precision loss measurements.

## Computer Requirements

The minimum requirements to run *TLW* (and its companion programs *YW,* Yagi for Windows, and *HFTA*, HF Terrain Assessment) are a PC running *Windows 95* or later, including *Windows 98*, *Windows XP* and *Windows 7/8*. You should have a screen resolution of 800 × 600, or even better yet, 1024 × 768.

## A Short History of the *TLW* Program

*TLW*, short for "Transmission Line for Windows" started out life as *TL*, short for just "Transmission Line." *TL* was replaced by *TLA*, short for "Transmission Line Advanced." The core algorithms in *TLW* have been under development, intermittently, for more than 20 years and the program has developed into a sort of "Swiss Army Knife" for transmission lines and antenna tuners.

*TLW* does assume that the user has some technical knowledge about transmission lines and antenna tuners. The user must be familiar with the so-called *rectangular representation* of complex impedance, in the form $Z = R \pm j\, X$. Later in this document there are two tables of typical impedance data for two types of antennas. You can use this data with *TLW* to experiment with realistic situations and to gain familiarity with the program.

## Installing *TLW*

Normally, you would automatically install *TLW* when you use *SETUP.exe* to install the other programs from the CD-ROM included with the 23rd Edition of *The ARRL Antenna Book*. This section describes how to re-install *TLW*, or install it for the first time if you opted not to install it previously.

At the lower left-hand of your Desktop, click **Start**, then **Run**. Click on the **Browse** button and then select the drive corresponding to your CD-ROM. We'll assume here that it is drive D. Select the ***Setup.exe*** program by clicking on it twice and then clicking **OK**. Follow the on-screen instructions to "Modify" your installation. Check the TLW option and click on **Next** to proceed. (Note that clicking on an option that has already been installed will uninstall it. Be careful here.)

### *Possible Problems During TLW Installation*

You may possibly encounter warnings or problems during installation or re-installation of *TLW*. The program uses DLLs (Dynamic Linked Libraries) and other files (such as OCX ActiveX Controls) supplied from Microsoft for *Visual Basic 6*, the language in which *TLW* was written. Microsoft will occasionally update its DLLs and OCXs.

If the installation program finds an older file that must be updated, it will ask your permission to do so. It is OK to allow this updating, since older programs that also use these DLLs and OCXs should still work—in other words, they are backwards compatible. On rare occasions, however, a newer DLL or OCX will not function with older programs. Should this occur, please contact the publisher of the other program, or contact ARRL for problems with *TLW*, using the email address at the end of this document.

We have found that some auxiliary "Uninstall" programs can interact with an installation or re-installation of *TLW* because certain uninstall programs automatically makes DLLs and OCXs "read-only." Consult your operator's manual for such uninstall programs if you see a warning

message about a "read-only" file during *TLW* installation. You will probably have to **Cancel** your *TLW* installation and run the auxiliary uninstall program to update its file inventory. Then you can run the *TLW* installation again.

## TAKING *TLW* FOR A TEST DRIVE

The following procedure assumes that you have not already installed the *TLW* icon during a standard installation from the CD-ROM. From the Desktop Taskbar at the lower left-hand corner of the screen, select **Start**, then **Programs**, followed by scrolling down the list of programs and clicking on *TLW*. You will now see the *TLW* icon to one side. You could start *TLW* immediately by left-clicking on the *TLW* icon if you like. At this point, however, you could also create an shortcut icon on your Desktop by right-clicking on the *TLW* icon and choosing **Create Shortcut**. This creates a shortcut, which you may select by right-clicking on it, dragging it onto your Desktop and then selecting **Move Here**.

So, let's assume you've started *TLW*. You will see the main screen, which contains a lot of information. Note that there are only a small number of places on the main screen where you can choose or enter numeric data. The primary areas are:

1. Choosing the **type of cable**
2. Specifying the **length** of the cable
3. Specifying the operating **frequency**
4. Specifying the **load impedance** (or **input impedance**)

There are default values for each of these data entries when you first boot up *TLW*. When you exit the program, *TLW* stores whatever values you've entered, in the TL.DEF file located in your default subdirectory. This way you can resume operations from where you last stopped.

### *Type of Cable*

First, move the mouse cursor and let it hover over the list box labeled ***Cable Type***. A "tool tip" will show, explaining what is expected for that area. In this case the tool tip says "Choose type of transmission line." You can try this for the other data entry boxes or option buttons.

Now, click the arrow at the right side of the drop-down list box with the label ***Cable Type*.** This is located under the Version number label at the top of the main *TLW* screen. See **Fig 1**. You have a choice of the 34 different types of transmission lines in *TLW*. The first 30 choices are coaxial cables, mainly with "RG" designations and (where available) Belden part numbers. At the end of the list are two-wire balanced transmission lines, such as 300-Ω transmitting line, two types of 450-Ω "window ladder line" or 600-Ω two-wire line.

The last choice in the list is for a "User-Defined Transmission Line." For this choice, the user manually enters the matched-line attenuation (in dB/100 feet or dB/100 meters), the velocity factor, the resistive part of the characteristic impedance, and the maximum RMS voltage for which its manufacturer rates the line. The program then allows you to compute the value of the reactive part of the characteristic impedance. (You may override the reactance-calculation feature if you like, although it doesn't make a lot of sense to do so, since the first transmission-line characteristics determine the reactive portion.)
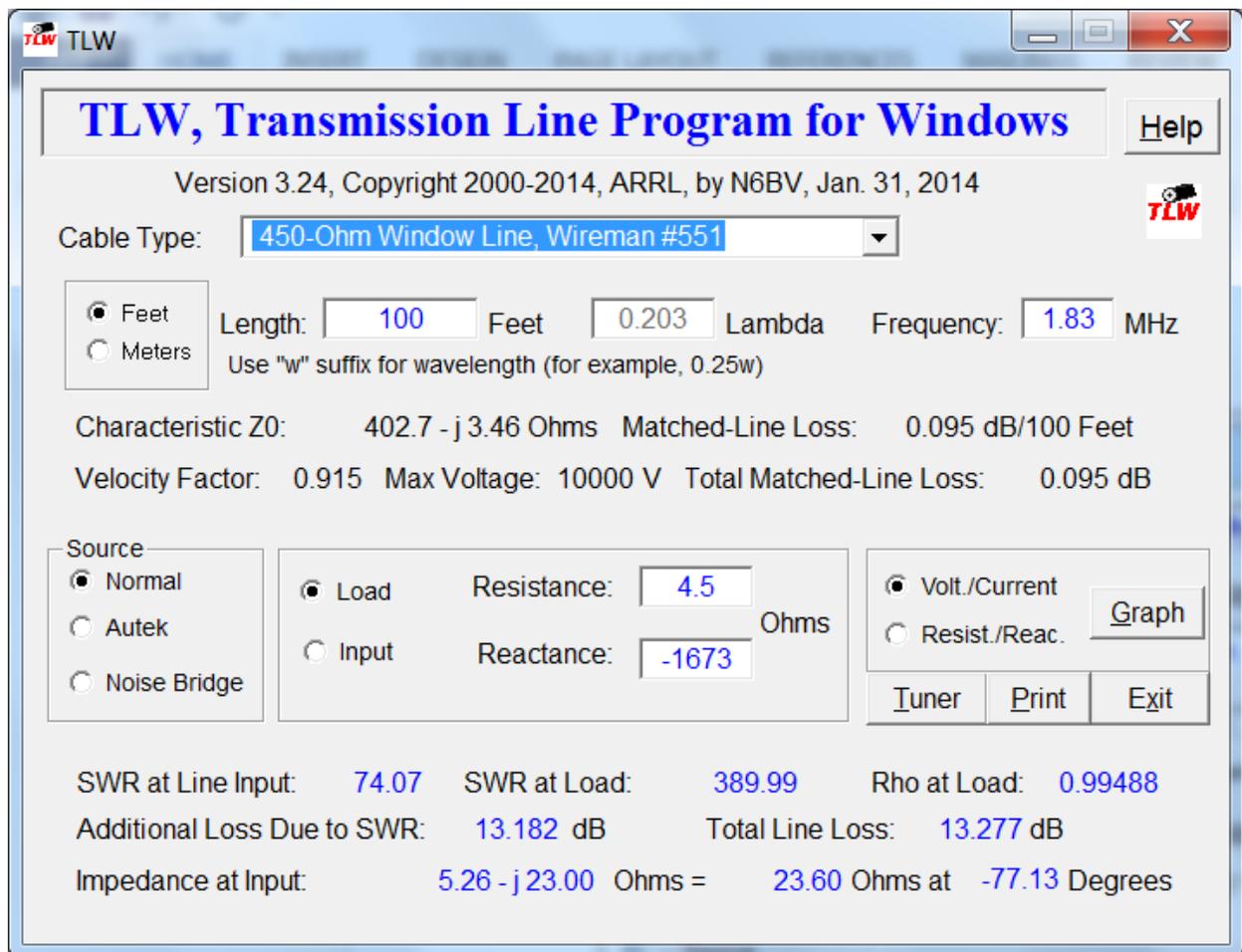
**Fig 1—Selecting the type of transmission line.**

If *TLW* requires an updated computation for a user-defined cable (for example, when you change frequency), *TLW* will show a highlighted red warning on screen next to the arrow in the **Cable Type** list box. The values for the user-defined cable are stored in the TL.DEF file, so that once you enter your own values for a particular type of transmission line, you needn't manually enter them the next time you open the program.

All cables in *TLW* use the parameters listed in Chapter 23 of the 23rd Edition of *The ARRL Antenna Book*. The default value for the type of transmission line is RG-8A (Belden 8237), nominally 50-Ω cable solid-dielectric cable. For our test drive, choose the "450-Ohm Window Ladder Line, Wireman #551" selection. The #551 designation refers to the part number for window-line products sold by The Wireman. The characteristics of either #551 or #554 are represented here. Wireman #551 uses solid 18 AWG copper-clad wire and #554 uses stranded 14 AWG wire.

*Setting the Cable Length*

The default value for the length of the transmission line is 100 feet. Note that you can force *TLW* to work in metric units by clicking the **Meters** option button in the frame next to the

*Length* box. The fact that you are working in meters will also be stored in the TL.DEF file so that *TLW* boots up in metric mode the next time you start it.

Go ahead and specify a length of, say, 120 feet. The easiest way to do this is simply to double-click on the 100 and then type in 120. Or you can edit the 100 manually, using the right/left arrow keys and the Delete key, plus the keyboard numeric keys.

One very convenient feature is that you may enter the transmission-line length in *wavelengths*. The program automatically converts the value to either feet or meters, taking into account the velocity factor of the chosen line at the operating frequency. To enter a length in wavelengths, append a "w" immediately after the length. For example, to specify a quarter wavelength, type:

**.25w** or **0.25w**

Once you press the "w" key, *TLW* will instantly compute the physical length of an electrical quarter-wave of line (in feet or meters). This will be used by the program for all subsequent computations. The physical length will remain constant even if you change frequency. This makes it easy to evaluate the effects of shorted quarter-wave stubs, for example, at twice the fundamental frequency. After you have finished exploring what length changes do, respecify a length of 100 feet to continue our example using the #551 450-Ω line.

*Changing the Frequency*

The default frequency is 3.5 MHz. You can enter any frequency as high as 5999 MHz (6 GHz), or as low as 0.02 MHz (20 kHz). As you enter each digit of the frequency you will see that *TLW* automatically computes all other parameters. It's fascinating to watch the **Total Line Loss** change when you start out at 1 MHz and add zeroes one at a time to the end — first 10 MHz, then 100 MHz and finally 1000 MHz. Note how the reactive portion of the **Characteristic $Z_0$** also changes subtly with changes in frequency. [Note: *TLW* uses a more-rigorous algorithm to compute the $R_0$ than the older DOS-based *TLA* program. There will be subtle differences between *TLW* and *TLA* computations for this reason.]

For now, type in a frequency of 1.83 MHz. Note that at this frequency a 100-foot piece of 450-Ω line is 0.204 λ long electrically. (The symbol λ is the Greek letter "lambda," an abbreviation for wavelength.)

*Entering Load Impedance*

The default method of specifying impedance is at the **load** end of a transmission line. To continue our example using 100 feet of 450-Ω line at 1.83 MHz, assume that we are simulating the load of a 100-foot long dipole, 50 feet above flat ground. The feed-point impedance of this electrically short antenna at 1.83 MHz is 4.5 − *j* 1673 Ω. This shows that this antenna is extremely short at this frequency! Enter 4.5 into the input box labeled **Resistance** and −1673 in the input box labeled **Reactance**.
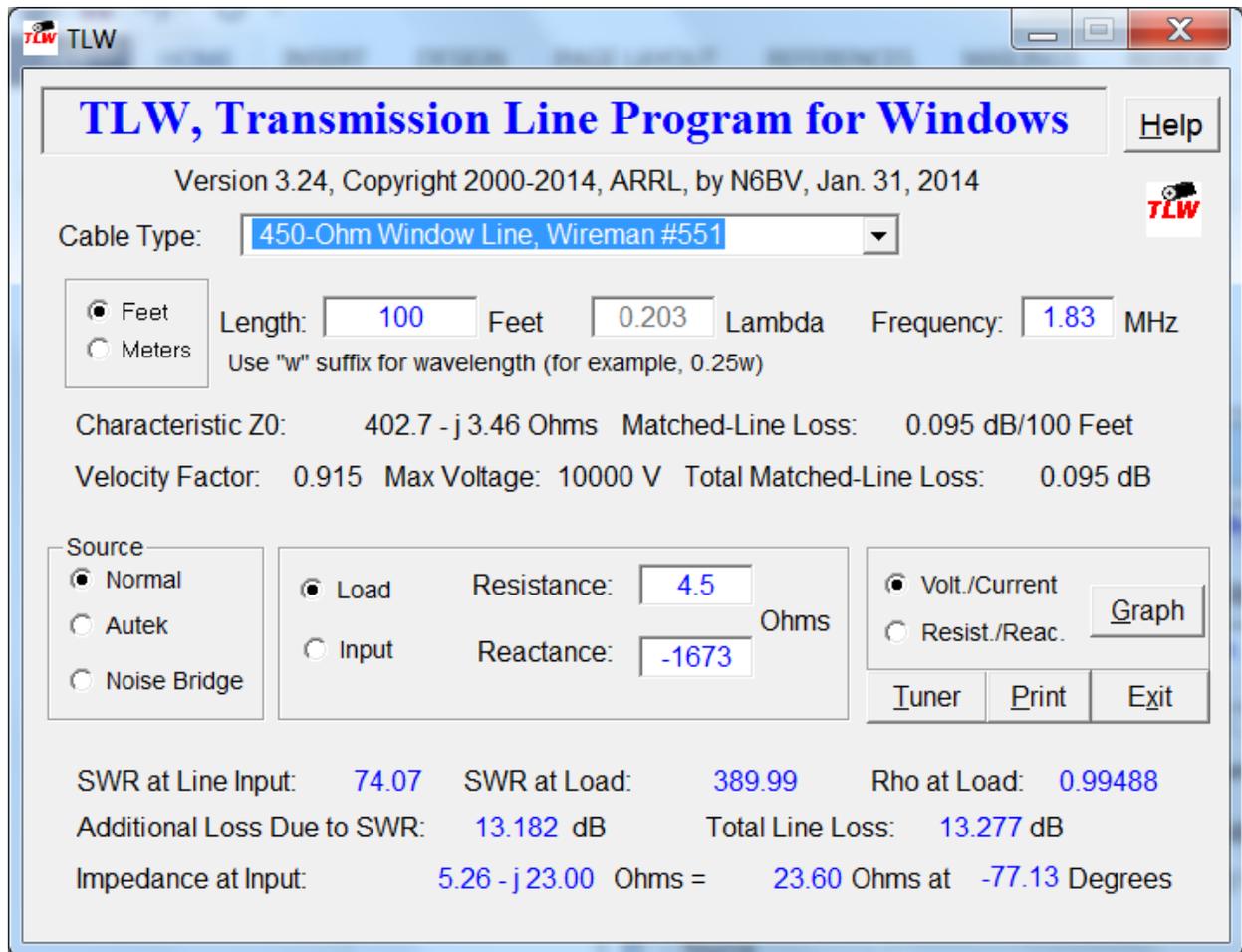
**Fig 2—An extreme load at 1.83 MHz!**

Now look at what *TLW* computes for this severe load condition. Despite the fact that the transmission line is a "low loss" line (with just 0.095 dB/100 feet of loss), under these conditions where the SWR at the load is 389.99, the additional loss due to this high SWR is an astounding 13.182 dB! This brings the total loss in the line alone up to 13.277 dB. Because of this loss, the SWR at input end of the transmission line is "only" 74.07. The losses in the line have masked the true level of SWR at the load.

The impedance looking into the input end of the cable under these conditions is quite low, at $5.26 - j\,23.00\ \Omega$. In polar coordinates this is $23.60\ \Omega$ at a phase angle of $-77.13°$. See **Fig 2**. We'll find out later that this very low impedance makes the job of the antenna tuner feeding this line much more difficult.

Some extreme combinations of load resistance and reactance can result in a computed load SWR that is negative—try a load of $1.5 + j\,1900$ in the example above. *TLW* warns you by highlighting the output SWR in red text. A negative value for SWR happens only under exceptional circumstances, with loads that you'd never actually connect to a real-world transmission line because of the severe losses involved. Rest assured, however, that the math is correct.

Select the **Volt./Current** option button and then click on the **Graph** button. These are located towards the bottom right of the screen. *TLW* generates a graph showing how the current and the voltage vary along this transmission line, for an input power of 1500 W at the input of the 450-Ω line with the 100-foot long dipole at 1.83 MHz. The maximum RMS voltage, which occurs at the load end of the line, is more than 6607 V, while the maximum RMS current is 16.7 A, occurring at the input end of the line. Clearly this line is in danger of arcing over under these extreme conditions. See **Fig 3**.

You can use the mouse cursor to see the exact values at points along the line. A "tool tip box" will display the value of current or voltage as you move it along the curves. *TLW* computes the current and voltage at 200 points along the line, so you will see this degree of granularity as you move the mouse cursor.

If you want to see what happens at a different power level at the input of the line, you can go back to the main *TLW* screen and select **Tuner**. Try entering 100 W in the input box labeled **Transmitter Power, W** in the ***Tuner Selection, TLW*** form that comes on-screen. Now click on **Back** to return to the *TLW* main screen, and select **Graph** again to see the graph. The maximum RMS voltage has decreased to 1,995 V and the maximum RMS current goes down to 5.1 A. The line probably won't arc over at this power level.
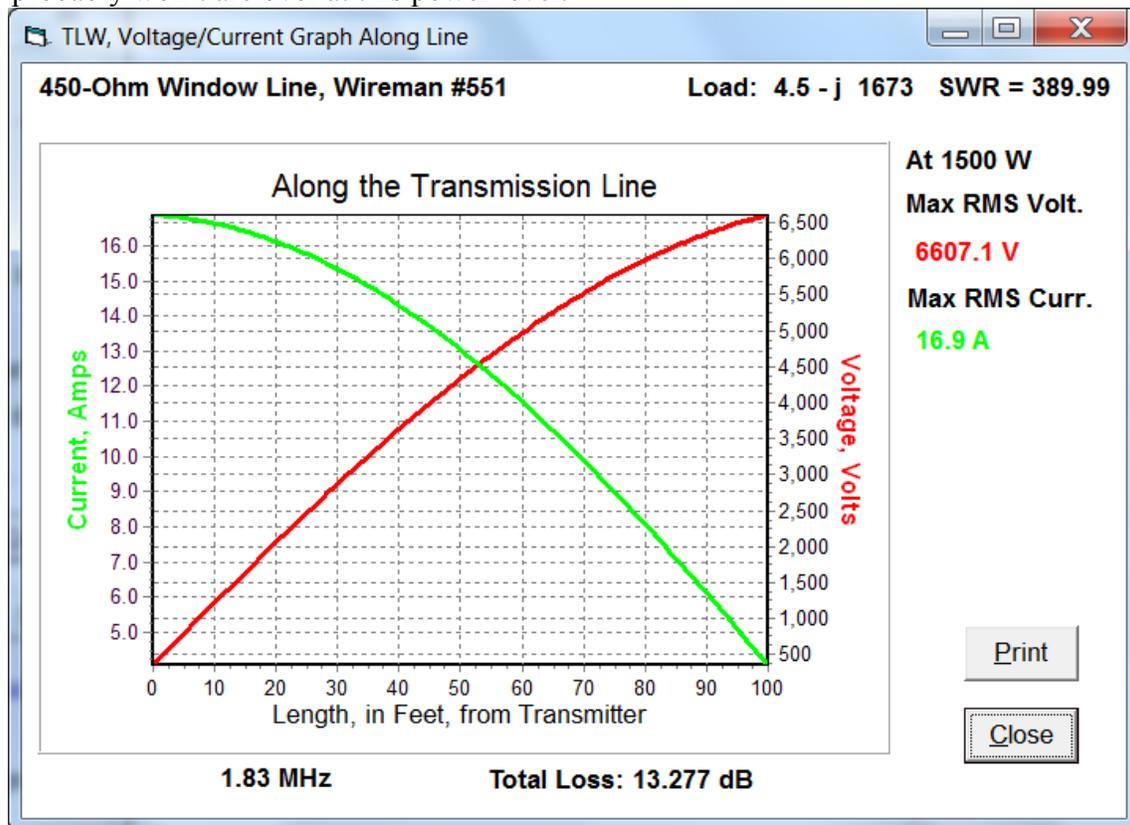


**Fig 3—The voltages and currents along a highly mismatched open-wire line feeding a 100-foot long, 50-feet high dipole at 1.83 MHz.**

*Graphing Resistance/Reactance Along the Line*

After you select Resistance/Reactance and click the **Graph** button you will see a graph of how the resistance and reactance vary along the transmission line. For the example we've been working with, the resistance goes from a maximum of 4.5 Ω at the load end of the line, to a minimum of about 1.75 Ω at about 70 feet from the input end of the line. This puts a really severe strain on any antenna tuner trying to match the line to 50 Ω. In fact, *any* length of line with such a severe load will severely tax an antenna tuner! Click on the **Cancel** button to close the graph and get back to the main *TLW* window.
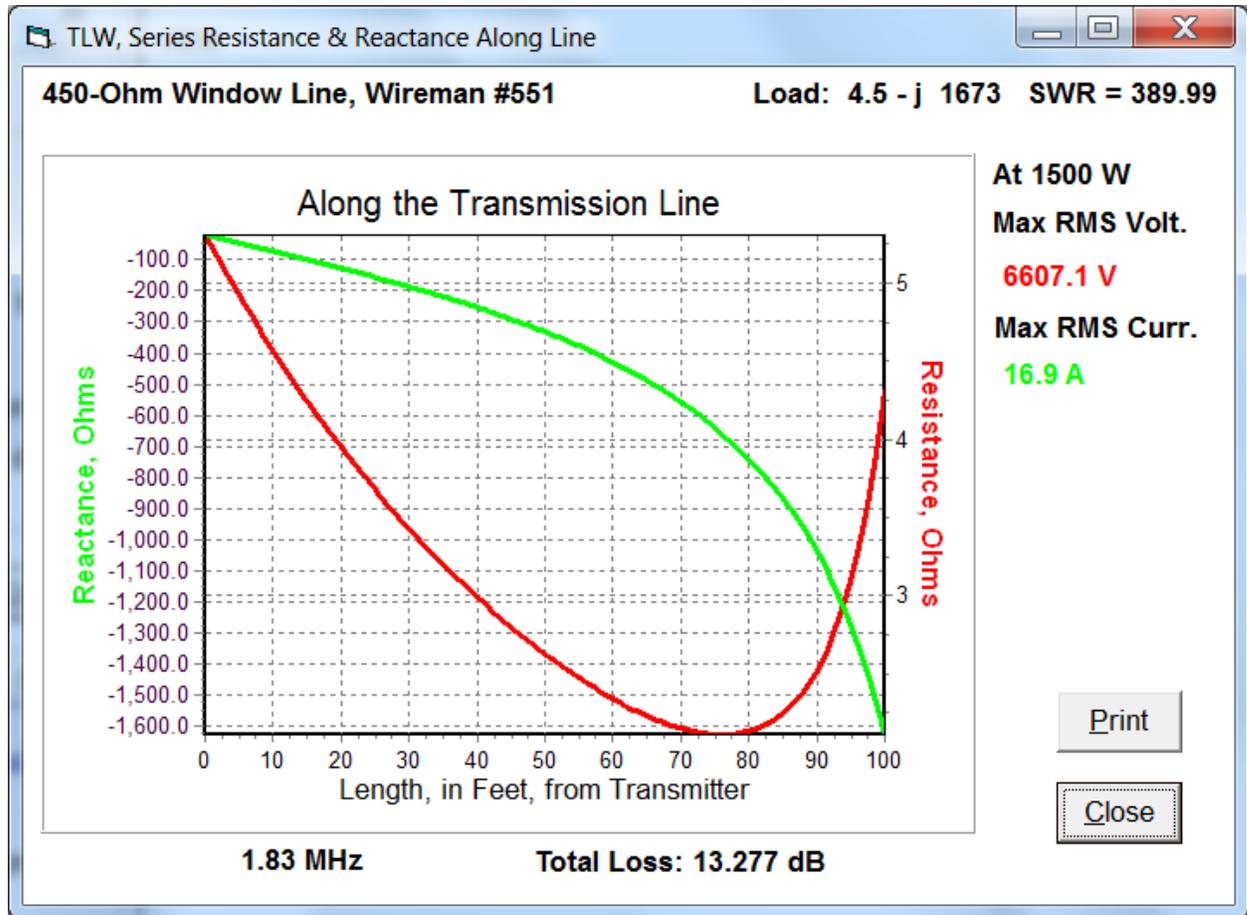


**Fig 4—The impedance along the highly mismatched line in Fig 2.**

*Zooming and Scrolling the Graph*

You can zoom or scroll about the graphs in *TLW* by using the left or right mouse button while dragging the mouse cursor. Hold down the left mouse button while dragging downwards from left to right to zoom the area outlined in the resulting rectangular box when you release the left-button. Reverse the procedure (dragging upwards from right to left) to unzoom. By holding down the right mouse button and dragging you can scroll the graph around.

*Specifying Impedance at the Line's Input*

If you measure the complex impedance at the input of a transmission line from the comfort of the operating shack, you can use *TLW* to compute the load impedance at the end of that line. Simply click on the option **Input** (rather than **Load**) in the frame containing the entries for resistance and reactance.

For example, for the 100-foot of #551 450-ohm window ladder line at 1.83 MHz, enter for **Resistance** 35 ohms, with a **Reactance** of −10 ohms, after clicking **Input**. *TLW* computes that the impedance at the load is $392.30 - j\,1353.12\,\Omega$. As opposed to the previous example using an electrically short 100-foot dipole as a load for the same ladder line, the SWR now is much more reasonable with this load (at 13.12), and as a consequence, the total loss on the line is only 0.703 dB.

There are combinations of input resistance and reactance that result in a negative value for the resistance at the load end of the line. This condition is flagged by *TLW* by highlighting the computed load impedance in red. While the mathematics are correct, this is a very special circumstance and you should exercise caution interpreting such results. What *TLW* is in effect telling you is that you would never actually measure such an impedance at the input end of a real transmission line!

*Using the Autek RF-1 to Compute the Impedance at the Input*

You can use an Autek RF-1 antenna analyer to measure the magnitude of the impedance and the SWR at the input of a transmission line. Then you can use *TLW* to compute the complex input impedance and then the impedance at the load end of the line. These two scalar quantities of the magnitude of impedance and SWR give enough information to compute the resistive and reactive portions of the impedance at the line input, but you can't determine from them directly the *sign* of the reactance. You must choose the sign of the reactance based on your knowledge of what the load actually is. Note that certain lengths of line will reverse the sign — this includes any odd multiple of a quarter wavelength of line.

Let's try another line: an RG-213 coax that is 128 feet long at 3.8 MHz. Assume that the load at the end of this line is an 80 meter dipole, resonant at 3.7 MHz. In the frame labeled *Source*, click on **Autek**. A new form will appear on-screen labeled ***Calculation of Impedance from Autek***. Let's assume that the Autek RF-1 shows the magnitude of Z to be 34 ohms, with an SWR of 2.0. Enter these values and *TLW* computes that the complex impedance at the input of the line is $29.3 \pm j\,17.3\,\Omega$. You must determine the sign of the reactance.

In this example we are using 128 feet of RG-213 to feed an 80 meter dipole, which is resonant at 3.700 MHz. (The electrical length of the line is very close to $\frac{3}{4}\,\lambda = 0.75 \times 984\,/\,3.8$ MHz $\times\,0.66$, where the 0.66 is the velocity factor.) The feed-point impedance of a typical 80 meter dipole is somewhere about 60 $\Omega$, with no reactance at resonance. At frequencies higher than resonance can expect to see an inductive reactance at the dipole's feed point. Since the coax is a multiple of $\frac{1}{4}\,\lambda$, the sign of the reactance will be reversed at the input compared to what it is at the load. This means that we should expect to see a capacitive (negative) reactance at the input of this line, not the true inductive reactance. Yes, it sounds complicated, but you'll get the hang of it.

Now click the **Negative** option in the frame labeled *Choose sign of reactance*. Notice that there is another piece of information showing on the form, labeled *Minimum SWR for Z chosen*. This shows that you must enter an SWR value of at least 1.5 in order for *TLW* to make sense of the magnitude of impedance you specified at 34 Ω. (For a 50-Ω line, the SWR would be 50/34 = 1.47 minimum if there is no reactance.)

Now, click **OK** to return to the *TLW* main screen, where you can see that the *Impedance at the load* (that is, the impedance at the dipole's feed point) is 64.72 + *j* 41.67 Ω, just as you'd expect. Note also that *TLW* has clicked the **Input** option automatically for you, with the **Autek** option encircled by a dotted box.

You can see that it's a good idea to check the sign of the reactance at the input of a transmission line by manually entering expected resistance and reactance values using the **Load** option. Then you can see the effect that the transmission line has on transforming that load impedance to another impedance at the input of the line.

Let's continue with this example, but at 3.5 MHz, a frequency lower than the resonance of the 80 meter dipole. At this frequency we can expect the dipole to exhibit a feed-point impedance that is on the order of 40 Ω, with a capacitive reactance of around −100 Ω.

Assume that your Autek RF-1 shows Z = 10 and SWR = 5.1 at the shack end of the line. See **Fig 5**. When you enter these values into *TLW* at 3.5 MHz, *TLW* computes the impedance at the input of the line as 9.8 ± *j* 1.9 Ω. In this case, you would choose "+", since again you must reverse the sign of the reactance due to the impedance inversion of that length of line, which *TLW* shows you is 0.690 λ long. Now, *TLW* computes that the load at the antenna is 38.15 − *j* 100.31 Ω up at the antenna, very close to what we would have expected.

You should see that the number of decimal points that *TLW* computes (two) are not justified by the amount of decimal points (one) that the Autek RF-1 computes SWR or Z. Computers programs are wonderful, but they are only as good as the data fed to them!



**Fig 5—Sample Autek input box.**

*Using a Noise Bridge to Determine the Impedance at the Input*

If you click on Noise Bridge, you will open a new form entitled *Input from Parallel-Form Noise Bridge*. You will enter values for the shunt resistance and then the shunt capacity (in pF)

that you read from the Noise Bridge. If the shunt capacity is negative (meaning that the unknown impedance is inductive), enter the capacity value preceded with a minus sign, since "negative picoFarads" indicates inductance on these types of bridges. A capacitive reactance need not be preceded with a "+" (plus) sign, although you may enter one if you wish.

Not all Noise Bridges are calibrated in shunt values. For example, the units in recent editions of the *ARRL Handbook* are calibrated in series impedance at 10 MHz. However, I built the Noise-Bridge function into *TLW* because my own homebrew unit uses shunt values.

The Noise Bridge routine in *TLW* also can compensate for the series resistor I must sometimes use to bring the unknown impedance into the range of the noise bridge's shunt capacitor, particularly on the lower frequencies. I often must use a series 100-Ω adapter on 80 or 40 meters, where the range of capacitive reactance of the variable capacitor in the noise bridge is small.

## CAVEATS

I must caution you at this point. *TLW* displays results out to two, or even three, decimal places. Internally, computations are carried out to even more decimal places. In the real world, the one factor that varies the most in actual transmission lines is the Velocity Factor. This may easily vary plus or minus 10% for typical lines — in fact, the velocity factor may even vary slightly for two pieces of cable cut from the same bulk roll! Along with the Velocity Factor, the exact value for the characteristic impedance $Z_0$ also varies.

*TLW* will give you a good indication of what you can expect in the real world, but only plus or minus the velocity factor and the actual impedance at the antenna feed point! Please remember: *TLW* is fundamentally an educational tool. It can also be used very effectively as a design tool, provided that you know the exact parameters of your transmission lines and your antennas. If *TLW* helps open your eyes about transmission lines and antenna tuners, particularly the losses associated with each, then I will have achieved my goal in writing it.

*TLW* can show a negative value for SWR when the load impedance is very highly reactive and inductive: for example, a $1.5 + j\ 1800$ ohm load on a 95-foot long, 450-ohm line at 1.9 MHz yields a computed SWR of −864.18. This is certainly non-intuitive, but it is correct and it has no physical significance. What is happening is that *TLW* computes that the reflection coefficient is larger than 1.0, yielding the negative value for SWR. *TLW* flags a negative SWR computation by highlighting it in red, to warn the operator that something unusual is afoot.

## EVALUATING ANTENNA TUNER CONFIGURATIONS

Return to a frequency of 1.83 MHz, with 100 feet of #551 450-Ω ladder line, terminated in a load of $4.5 - j\ 1673\ \Omega$. Now, select **Tuner**, and *TLW* will display the ***Tuner Selection, TLW*** form. You should always remember that *TLW*'s antenna tuner is assumed to be located in the shack, at the input end of the transmission line feeding the load. Presumably, the load at the end of the transmission line is an antenna. (After all, putting the antenna tuner out at the antenna would result in a trivial computation for *TLW*, since the tuner would match the $Z_0$ of the transmission line going to the shack, yielding a 1:1 SWR!)

You may choose one of four different *Tuner Network Types*:

- Low-Pass L-Network (shunt capacitance, series inductance)
- High-Pass L-Network (shunt inductance, series capacitance)
- Pi-Network (shunt capacitances, series inductance)
- Tee-Network (series capacitances, shunt inductance)

Choose one of the antenna-tuner configurations. For either high-pass or low-pass L-networks, *TLW* will immediately compute all values, using default unloaded Qs of 200 for any inductor and 1000 for any capacitor. (You may alter these values if you like.) The inductor is usually, but not always, the most lossy component in an antenna tuner. The default value of Q = 200 is pretty typical for a practical inductor mounted in a metal case.

The model for a lossy inductor is a lossless inductive reactance in series with a loss resistance. For example, if the unloaded Q is 200 and the inductive reactance at the chosen frequency is +400 ohms, then the loss resistance is 2 ohms in series with the +400 ohms reactance (Q unloaded = 200 = 400/2).

*TLW* assumes a default value of 1000 for the unloaded Q of any capacitor, although you can change this too. Again, the model for a lossy capacitor in *TLW* is a lossless capacitive reactance in series with a small loss resistance. (This is the series equivalent of a parallel combination of a perfect capacitor and a high-resistance loss resistor. See *The ARRL Handbook* for details about unloaded Q and series/parallel equivalent circuits.) The default value of unloaded Q = 1000 is typical of transmitting air-variable capacitors with wiping contacts.

If you choose either the Pi-network or Tee-network, you will be prompted to enter the value (in pF) of the output capacitor in the network. For the Pi-network the default value is 500 pF, and for the Tee-network configuration the default value is 100 pF. These values will not necessarily yield the most efficient tuner!
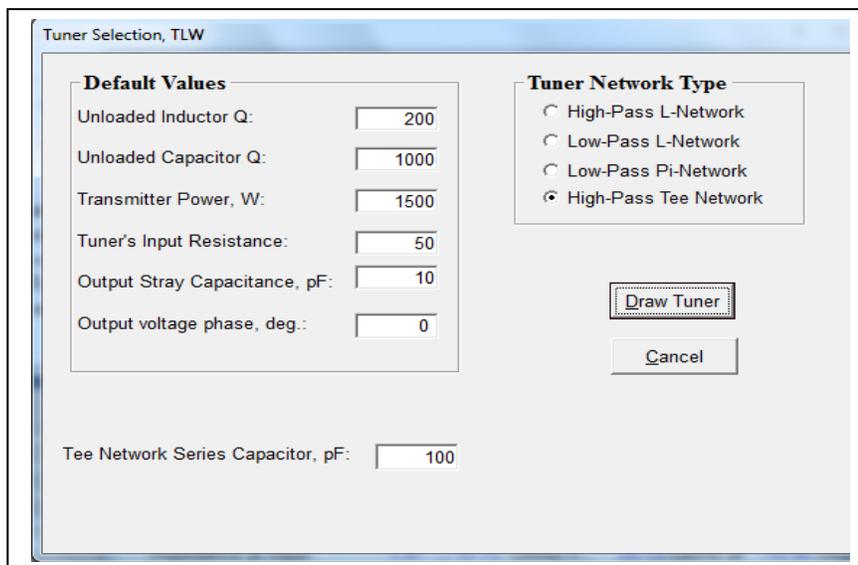


**Fig 6—Setting up an antenna tuner.**

See **Fig 6**. For now, click on the **High-Pass Tee Network** using the default values, then click on the **Draw Tuner** button. Click **OK** and *TLW* will compute all component values needed to transform the impedance at the antenna tuner output to 50 Ω (or to any value of resistance you choose) and will change to a schematic-diagram page. You may need to move the window with your mouse to see all parts of it, depending on your screen resolution. See **Fig 7**.

If the chosen network configuration cannot perform the desired transformation, an audible alarm will sound, and *TLW* will either recommend another network or another output capacitor value to try.

### The Antenna Tuner Schematic Screens

Examine the antenna tuner schematic screen carefully — a *lot* of information is displayed there. At the top of the display, there is a summary of the transmission line parameters chosen: the frequency, the type of line, and the length of the line. The next line shows the impedance at the load end of the line, in both rectangular and polar forms, as well as the SWR at the load end of the line. This SWR is usually computed for a default value of 50 Ω, although if you change the input impedance at the tuner's input, let's say to 200 Ω, the SWR shown on this line will change appropriately.



High-Pass Tee-Network

450-Ohm Window Line, Wireman #551     Length:   100 feet              Frequency:   1.83 MHz
At load:  4.5 - j 1673 ohms = 1673 ohms, at -89.8 degrees    Load SWR = 389.99
Eff. Q = 101.2    1.5:1 SWR BW = 7.4 kHz (0.4%) and 2:1 SWR BW = 12.8 kHz (0.7%)
Estimated power lost in tuner for 1500 W input:   911 W (4.06 dB = 60.8% lost)
Transmission-line loss = 13.28 dB.  Total loss = 17.34 dB.  Power into load = 27.7 W

| At 1500 W: | C1 | L2 | C3 |
|---|---|---|---|
| Unloaded Q | 1000 | 200 | 1000 |
| Reactance | -1728.458 | 588.806 | -869.699 |
| Peak Voltage | 13389 V | 13394 V | 13049 V |
| RMS Current | 5.5 A | 16.1 A | 10.6 A |
| Est. Pwr Diss. | 52 W | 762 W | 98 W |

RMS Vin:   273.86 V at -100.73 deg.        RMS Vout:   249.72 V at 0.00 deg.

50.3 pF     100.0 pF

50.0 Ohms          L2          CStray          5.26 - j 23.00 Ohms

51.21 uH          10 pF

Print

Main Screen

Cancel

**Fig 7—Antenna schematic screen for tuner configuration in Fig 6.**

Look carefully at the on-screen schematic of the Tee-network you chose. The impedance at the output terminals of the tuner (that is, at the input end of the transmission line) is shown at the right side of the schematic drawing. (This is a departure from earlier versions of *TLA* or *TL* and I changed it because I sometimes became confused using the old method.)

*TLW* shows something called the "Effective Q," also known commonly as the "loaded Q" of a network. This is the loaded Q in the network at the specified load impedance, and is an indication of how *touchy* the tuning will be. The higher the effective network Q, the more carefully you must tune the variable capacitor(s) and/or variable inductor in the tuner in order to achieve the desired transformation.

Thanks to an algorithm developed by Frank Witt, AI1H, this line also shows the computed 1.5:1 and 2:1 SWR bandwidths for the tuning network itself, calibrated both in kHz and in percentage of the tuned frequency. Here, the load is assumed to be constant and the frequency is shifted internally to compute the bandwidth numbers. If the computed bandwidth is greater than 30% of the center frequency, *TLW* will display "Large" rather than a value in kHz. Note that real-world antennas are very often narrowband devices, and the antenna — not the tuner — sets the limits for how far you can change your frequency without retuning the antenna tuner.

The loss in an antenna tuner is also closely related to the effective network Q — the higher the effective network Q, the higher will be the loss. Efficiency in an L-C network is defined as:

Efficiency (%) = $100 \times (1 - (Q_L/Q_U))$

where $Q_L$ is the loaded Q, and $Q_U$ is the unloaded Q of the network components. See the *ARRL Handbook* for more details on this subject.

For a given network loaded Q ("effective network Q" in *TLW*), components with higher unloaded Qs will result in lower tuner losses. This makes intuitive sense, especially if you recall that "Q" stands for "Quality Factor," and higher unloaded Qs mean higher quality, less lossy components.

### Changing the Tuner Defaults

Once you have changed any default values, they will remain in effect until you either reboot *TLW* or respecify the values from within *TLW*. Just for your information, I've limited the maximum amount of power from the transmitter to 5 Megawatts. I suspect that limit won't affect too many of you.

The ability to specify the resistance seen at the tuner's input terminal when it is tuned allows you to experiment with other tuner configurations. You might, for example, use a wideband impedance transformer, such as a 50:200-Ω balun at the input of a tuner. You access this feature in the **Tuner Selection, TLW** form using the **Tuner's input resistance** input box.

You may find that the physical component values for various loads are more practical for a different impedance at the tuner's input than for 50-Ω, the default value. Another use is given in detail below — evaluating a Pi-network tank circuit in a transmitter.

### Tuner Losses, Details

Examine the line showing the estimated power loss in the tuner. The loss shown is computed for the level of transmitter power you have specified. The loss is expressed in watts, in dB, and

also as a percentage of the power at the input. For example, a particular tuner configuration might lose 114 W out of 1,500 W put into it, yielding a loss of 0.34 dB, or 7.6% of the input power. If the input to the tuner is 100 W, rather than 1,500 W, the loss would still be 0.34 dB, or 7.6% of 100 W = 7.6 W.

The next line on-screen summarizes the system losses: the loss in the transmission line itself and the total loss in the line and the antenna tuner, both expressed in dB. The final entry at the end of the line is how many watts actually make it to the load. This can be sobering to see!

*Stressing the Tuner*

Now examine carefully the table for the individual components in the antenna tuner. The reactances for each element are shown first, followed by the peak voltage, the RMS current, and the power lost. Each is computed for the value of transmitter power you specify. (Note that the reactances are displayed to three decimal points, so that the purists among you may take these numbers and manually verify that the program is working the way it should. I too used this data to validate the program during development.)

Note that the voltage shown by *TLW* is the peak voltage across each component. Pardon the pun, but this is potentially a little confusing, especially where a series element is concerned. What is shown is not the voltage from the element to "ground" (the common terminal); it is the voltage across the component itself. In addition, the current shown is that flowing through each component, but here the current is the RMS value, because this is what heats up a component.

Exceeding the peak voltage rating across any component in a tuner will probably cause an arc. This may or may not be disastrous, depending on whether the arcing component develops a permanent "carbon track" or not. Exceeding the RMS current-carrying ability for a component will often result in smoke, due to the excessive amount of power dissipated in that element. The inductor in a tuner will sometimes melt because of excess power dissipation.

Inductor damage occurs most frequently with low-resistive loads, with or without a high reactive component. For example, you can simulate a stressful situation by specifying a load impedance for the tuner of $3 + j\,0\ \Omega$ at 3.5 MHz (Hint: use a length of 0 feet for the transmission line), for a high-pass Tee-network configuration having a 100 pF output capacitor. For the full amateur legal power level of 1500 W, the insulation of the shunt inductor will not only have to withstand almost 10,000 V peak, but worse yet, it will have to dissipate almost 700 W of power at more than 20 A of circulating current. This level of current will toast the coil, if it doesn't arc first.

Next on the screen is a line showing the voltages at the input and output of the tuning network chosen. The RMS input voltage is determined by the power fed into the tuner at the input resistance of the tuner (usually 50 Ω). The phase angle of the output voltage is assumed to be zero degrees, although you can change it if you wish. The magnitude and phase of the RMS output voltage are shown to the right. The magnitude and phase angle of the output voltage are particularly interesting to people designing networks for phased antenna arrays.

*TLW* allows you to play around with various impedances, unloaded Qs and different network configurations, without having to endure the smoke and arcing that occurs in many tuners, even ones supposedly rated to handle a "full gallon" of RF. Now, for fun, increase the size of the output capacitor in the Tee-network and/or increase the unloaded Q of the inductor to help

unstress the beleaguered antenna tuner in the example above — or change to a lower-loss configuration than the Tee-network.

Now, let's try something really dramatic. At a frequency of 3.5 MHZ for a transmission-line length of 0 feet, enter a value of 0.001 Ω for the resistive part of the load, with a reactance of 0 Ω. Then select the Tee-network, with an output capacitor of 100 pF. The tuner will absorb all 1500 W of input power — in other words it tunes up wholly into itself, given a short at the output!

In general, L-networks will exhibit the least loss among the various network configurations, but they often require awkward values for inductance and capacitance. The Tee-network configuration is often used because it can accommodate a wider range of impedances with practical values of variable capacitors and inductors, albeit with sometimes-disastrous internal losses. The Pi-network configuration is flexible, but it too will often require very large values for capacitors.

### *TLW* and Transmitter Output Pi-Networks

*TLW* also allows you to evaluate the capabilities and losses in a Pi-network used at the output of a vacuum-tube power amplifier. You can change the default input resistance seen at the input of the network from the 50 Ω most commonly used for an antenna tuner to the desired loadline resistance needed for a tube or transistor. For example, an 8877 power tube wants to see a load of about 2200 Ω for a plate voltage of 3100 V. You would change the default from 50 to 2200 Ω in *TLW*.

Now, following the recommendations in the *ARRL Handbook*, you want to achieve an effective network Q between 12 to 15 in order to ensure adequate suppression of harmonics. At a frequency of, let's say, 29.7 MHz, with a 50-Ω load at the output of the Pi-network tank, *TLW* tells you that an output capacitor of 500 pF (the default value) yields an effective network Q of 33.1. This will result in good harmonic suppression, but it will also result in excessive losses, burning up 290 W in the tank circuit at 1500 W into the tank circuit. It's obvious that we need to lower the network Q somehow.

An output capacity of 200 pF at 29.7 MHz will lower the network Q to 15.2, but now the required value of the capacity at the input of the Pi-network is only 32.6 pF. The plate capacity of the 8877 is about 15 pF, and there will inevitably be stray capacitance of at least 10 pF. This means that the minimum value of the tuning capacitor must be less than 7.6 pF in order to achieve the desired overall capacity of 32.6 pF. This is a tough requirement, especially for an air-variable capacitor that is used on 80 or even 160 meters too. Further trials with *TLW* will result in a compromise, although you may still find it necessary to use an expensive vacuum-variable capacitor to achieve a low minimum value.

**See Fig 8**, which again uses a zero-length cable to simulate just the tuning network by itself. The load at the output of the Pi-network is 50 Ω in this case.

### Printing Out a Graph or Screen

If you wish to print out a particular graph or *TLW* screen, simply select the **Print** button while that graph or screen window is on-screen. Note that if you try to print a full-screen graphic, parts of it may be cut off towards the edges of the print. Resize the graphic to print it fully on

your particular printer. You can also copy the entire screen to the Windows Clipboard using the <Print Screen> key on your keyboard or you can use the <Alt><Print Screen> combination to copy only the active window to the Windows Clipboard. Once a graphic is on the Windows Clipboard, you can bring it into other Windows programs.
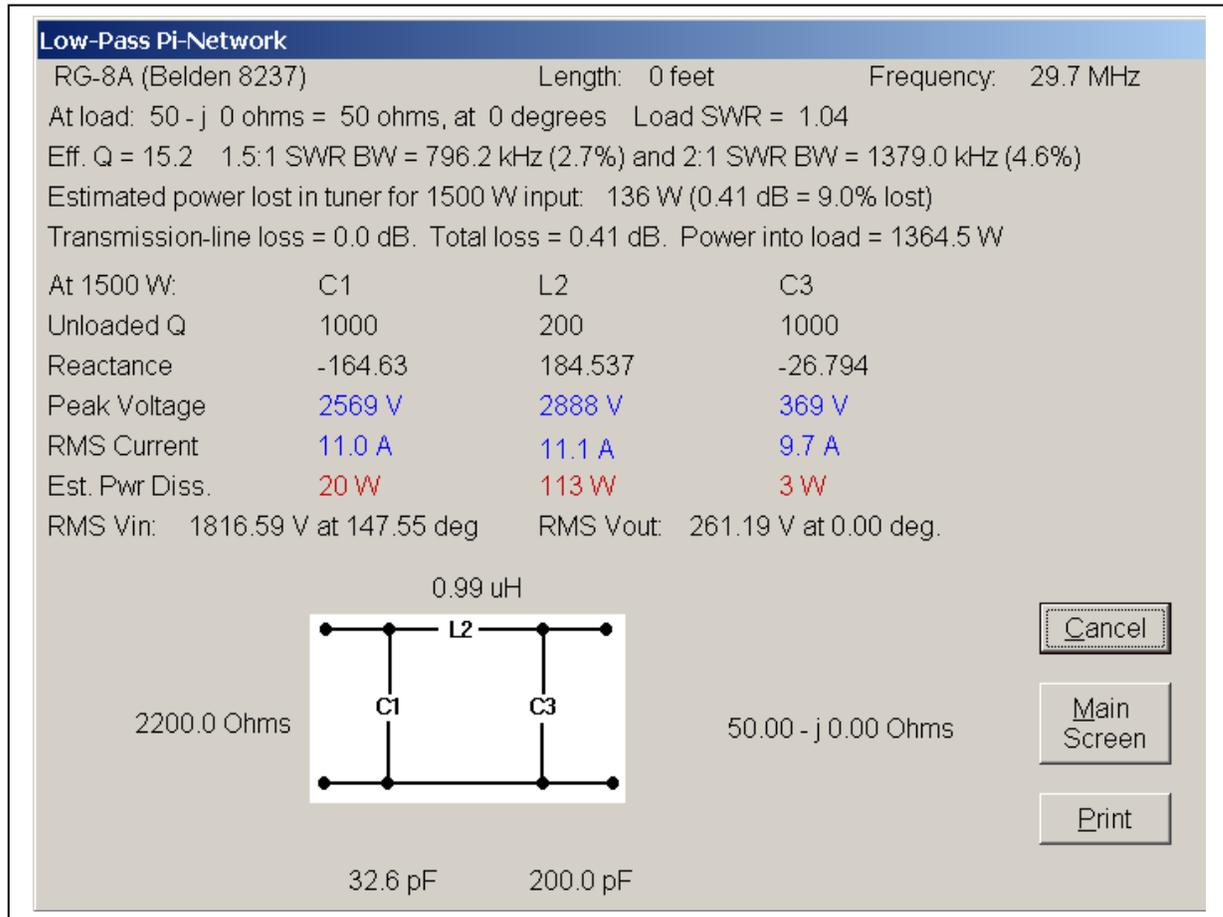


**Fig 8—A Pi-network for a tube-type transmitter.**

### FEEDBACK, PLEASE!

This is where *TLW* stands. In a very complex program like this, I'm sure people will find bugs. I'd really appreciate detailed feedback concerning any problems found. My email address at ARRL HQ is n6bv@arrl.net.

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## APPENDIX A — TRANSMISSION-LINE LOSSES

Several years ago I wrote sidebars to two *QST* "New Ham Companion" articles by Steve Ford, WB8IMY. These dealt with the stresses on transmission lines used with multiband center-fed dipoles. The computed losses, for both RG-213 coax and for open-wire transmission lines, raised some eyebrows — and some hackles. Some people were astonished at how high the transmission-line losses could be when an extremely high SWR was involved — such as when an 80 meter dipole was used on 160 meters, an octave lower than its resonant frequency.

After much debate and correspondence, I revised the loss algorithm in several versions of the older program *TL*. In October, 1995, Frank Witt, AI1H, and Scott Townley, NX7U, kindly provided me with more information on the true nature of the complex characteristic impedance. This was incorporated into *TL*, *TLA* and now *TLW*. After all the changes, the losses for severe SWR cases are close to what the original *TL* computed, but they are more exact nonetheless.

Now, the loss computations very closely match the calculated examples for truly severe mismatches in the book *Reference Data for Radio Engineers*, published by Howard W. Sams and Co. The examples, on page 22-11 of the Fifth Edition, were for RG-218 (old type RG-17), terminated at 2.0 MHz with a $0.4 - j\,2000\ \Omega$ load. This is about what an unloaded mobile whip would look like in the absence of ground-related losses. A 124-foot long RG-17 line would have more than 35 dB of loss with this load, and a 24-foot long piece would dissipate almost 20 dB.

# APPENDIX B — SOME DATA TO PLAY WITH

Below are listed some sample impedance data you may use to play with using *TLW*.

Feed-point impedances for 100-foot long, center-fed dipole, 50 feet over ground with dielectric constant (relative permittivity) of 13, conductivity of 5 mS/m. Computed by *NEC2* for flat-top configuration.

| Freq.<br>MHz | Feed-Point<br>Impedance |
|---|---|
| 1.83 MHz: | $4.5 - j\,1673\ \Omega$ |
| 3.8 MHz: | $39 - j\,362\ \Omega$ |
| 7.1 MHz: | $481 + j\,964\ \Omega$ |
| 10.1 MHz: | $2584 - j\,3292\ \Omega$ |
| 14.1 MHz: | $85 - j\,123\ \Omega$ |
| 18.1 MHz: | $2097 + j\,1552\ \Omega$ |
| 21.1 MHz: | $345 - j\,1073\ \Omega$ |
| 24.9 MHz: | $202 + j\,367\ \Omega$ |
| 28.4 MHz: | $2493 - j\,1375\ \Omega$ |

Feed-point impedances for a 66-foot long, center-fed inverted-V dipole, apex at 50 feet high over ground with dielectric constant of 13, conductivity of 5 mS/m.

| Freq.<br>MHz | Feed-Point<br>Impedance |
|---|---|
| 1.83 MHz: | $1.6 - j\,2257\ \Omega$ |
| 3.8 MHz: | $10.3 - j\,879\ \Omega$ |
| 7.1 MHz: | $64.8 - j\,40.6\ \Omega$ |
| 10.1 MHz: | $21.6 + j\,648\ \Omega$ |
| 14.1 MHz: | $5287 - j\,1310\ \Omega$ |
| 18.1 MHz: | $198 - j\,820\ \Omega$ |
| 21.1 MHz: | $103 - j\,181\ \Omega$ |
| 24.9 MHz: | $269 + j\,570\ \Omega$ |
| 28.4 MHz: | $3089 + j\,774\ \Omega$ |