Measuring Cable Loss

Improving measurement accuracy when low-power analyzers are used.

By Frank Witt, AI1H

The matched loss of a cable with a characteristic impedance, Z_0, is the loss of the cable when it is terminated in Z_0. A well-publicized way of measuring the matched loss of a cable is to measure the magnitude of the reflection coefficient, $|\rho|$, *SWR*, or return loss, *RL*, at one end when the other end of the cable is either shorted or open. The formula for matched loss (in decibels) for either shorted or open cables is:

$$L_C = -10\,log|\rho| = 10\,log\left(\frac{SWR+1}{SWR-1}\right) = \frac{RL}{2} \quad \text{(Eq 1)}$$

This is an expanded version of Eq 29 on page 24-26 and Eq 35 on page 24-27 of *The ARRL Antenna Book*, 19th and 20th editions, respectively.

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This method has two problems when the measuring instrument is a low-power analyzer like the MFJ Model MFJ-259B and similar analyzers. The first is that shorting or opening the circuit at the far end gives different answers. For electrically short cables, these answers can be very different. Eq 1 assumes that the reference impedance of the measuring instrument equals the complex characteristic impedance of the cable. However, the nominal reference impedance of the analyzer is 50 + *j*0 Ω, rather than the complex characteristic impedance of the cable. The second problem is that the values of $|\rho|$, *SWR*, or return loss do not fall in favorable parts of most analyzers' measurement ranges.

The problem of different answers can be overcome by making a measurement for *both* the shorted *and* open cases. We can then find the cable loss (in decibels) from:

$$L_C = -5\,log|\rho_S||\rho_O| = 5\,log\left(\frac{SWR_S+1}{SWR_S-1}\right)\left(\frac{SWR_O+1}{SWR_O-1}\right) = \frac{RL_S+RL_O}{4} \quad \text{(Eq 2)}$$

where the subscripts "S" and "O" refer to the short- and open-circuited cases, respectively.

Examination of Eq 2 reveals that it is essentially the same as Eq 1, except that the value of $|\rho|$ used is the *geometric* average of the $|\rho|$ values found for the two cases. The value of return loss used is the *arithmetic* average of the *RL* values found for the two cases. However, this does not solve the second problem (that is, non-optimum measurement ranges).

Let's look at a specific example:

Assume that we have 25 feet of RG-58A (Belden 8259), and we want to measure the matched loss of the cable at 10 MHz. The Belden catalog shows this to be 1.4 dB/100 ft, so the matched loss of our cable segment should measure 1.4/4 = 0.35 dB. The nominal characteristic impedance is 50 Ω, and the electrical length of this cable segment is 0.385 wavelength.

I used *TLMan.mcd*, the *Mathcad* worksheet that is a part of Note 1, to simulate a measurement with an analyzer. *TLMan.mcd* is a transmission-line simulator that uses manufacturers' data to derive transmission-line properties. The matched loss of 100 feet of cable calculates to be 1.39 dB. This rounds to the value given by Belden (L_C = 1.4 dB/100 ft). The worksheet provides a cable model that very accurately matches Belden's published matched-loss data from 1 to 1000 MHz. The worksheet also uses the manufacturer's velocity factor and capacitance-per-foot specifications. To obtain an accurate simulation, the worksheet calculates and uses the complex characteristic impedance. I modified the worksheet to use an analyzer reference impedance of 50 + *j*0 Ω, rather than the complex characteristic impedance of the cable.

Now, back to the 25-foot example: For the shorted case, $|\rho_S|$ = 0.937 (SWR_S = 30.8; RL_S = 0.564 dB), and the calculated matched loss using Eq 1 is 0.282 dB. For the open-circuit case, $|\rho_O|$ = 0.909 (SWR_O = 21.0, and RL_O = 0.829 dB) and the calculated matched loss is 0.414 dB. These are clearly very different results. Geometrically averaging the $|\rho|$s and arithmetically averaging the *RL*s give a matched loss of 0.35 dB, which is the correct value.

Although the results found from short- and open-circuited cables are different, the difference is inconsequential in many practical cases. Either case will reveal whether a cable is usable. My aim here is to show that the two results are different and how we can account for and correct those differences.

The values of $|\rho|$, *SWR*, and return loss do not lie in a favorable part of the instrument's measurement range. This was recognized by Dan Wanchic, WA8VZQ, and published in Hints and Kinks.[2] Dan suggested "moving" the measurement to a more favorable range, *SWR* between 1 and 2.3, by inserting a 4-dB 50-Ω attenuator between the analyzer and the cable being measured.

Another way to "move" the measurement to a more favorable range is to use a method based on the *indirect method* for evaluating antenna tuners and baluns.[3,4] A comparison of the two methods follows in the next section.

Here is a summary of how the indirect method is used for measuring the loss of an antenna tuner. Connect the analyzer to the input of the tuner and the load resistance R_L to its output. Measure the loss of the antenna tuner by first terminating it in the desired load resistance, R_L. Adjust the tuner so the input impedance of the tuner is 50 + *j*0 Ω ($|\rho|$ = 0, and *SWR* = 1). Then terminate the tuner with $R_L/2$ and $2R_L$, in sequence. Use the analyzer readings to compute the loss of the tuner.

To measure 50 Ω cables, connect the analyzer directly to one end of the cable as in the cases cited above. No tuner is required. As a check, first terminate the cable in 50 Ω; the *SWR* reading should be very close to 1. Then terminate the cable in 25 Ω and 100 Ω and measure $|\rho|$, *SWR* or *RL* for each load. Calculate the loss (in decibels) from:

$$L_C = -5\log|\rho_1\|\rho_2| - 4.77\,dB = 5\log\left(\frac{SWR_1+1}{SWR_1-1}\right)\left(\frac{SWR_2+1}{SWR_2-1}\right) - 4.77\,dB = \frac{RL_1+RL_2}{4} - 4.77\,dB \qquad \text{(Eq 3)}$$

where the subscripts "1" and "2" refer to the 25 Ω and 100 Ω termination cases, respectively.

The nice aspect of this approach is that the analyzers are used in regions where they have good accuracy, where the factory personnel calibrate them. For a lossless cable, $\rho_1 = \rho_2 = 1/3$; $SWR_1 = SWR_2 = 2.0$; and $RL_1 = RL_2 = 9.54$ dB. For cables with loss, the reflection-coefficient magnitude, *SWR* and return-loss values stay within the range where the analyzer has its best accuracy and resolution.

Let's look at our specific example: 25 feet of RG-58A (Belden 8259) cable. Again, "measure" the cable with *TLMan.mcd*. We find that $|\rho_1|$ = 0.316; SWR_1 = 1.93; RL_1 = 10.00 dB); $|\rho_2|$ = 0.299; (SWR_2 = 1.85, and RL_2 = 10.48 dB), which from Eq 3, gives L_C = 0.35 dB. Not only is this in agreement with the actual loss, but the quantities measured are in the range where most analyzers shine. In this case, instead of *SWR* values over 20, the analyzer must measure *SWR* values just under 2.

When measuring cables of other characteristic impedances, insert an antenna tuner between the analyzer and the cable. Terminate the cable with a load resistance, R_L, which equals the nominal characteristic impedance of the cable, and adjust the tuner so that the input impedance of the tuner is 50 + *j*0 Ω ($|\rho|$ = 0 and *SWR* = 1). Use resistors of values $R_L/2$ and $2R_L$ to obtain the values for use in Eq 3. The loss measured will be the loss of the tuner-cable combination. Measure the loss of the tuner by terminating the tuner in R_L and use the indirect method to find the tuner loss. The indirect method is described in the references of Notes 3 and 4. Subtract the tuner loss from the total loss to obtain the matched loss of the cable.

A Comparison of Methods

The method described in Hints and Kinks (Note 2), which we will call the WA8VZQ method, involves adding a 4-dB pad to move the measured data to a more favorable part of the analyzers' measurement range. We will call the method described above, which uses resistive terminations with values above and below the nominal characteristic impedance of the cable, the AI1H method. It turns out that the two methods are equivalent in concept and potential accuracy. Let's look first at the formula for computing the loss for the WA8VZQ method:

$$L_C = -5\log|\rho_S\|\rho_O| - 4\,dB = 5\log\left(\frac{SWR_S+1}{SWR_S-1}\right)\left(\frac{SWR_O+1}{SWR_O-1}\right) - 4\,dB = \frac{RL_S+RL_O}{4} - 4\,dB \qquad \text{(Eq 4)}$$

where the subscripts S and O refer to the short- and open-circuited cases, respectively.

This equation was not explicitly mentioned in the Hints and Kinks article, but it is appropriate use for the WA8VZQ method. Notice that it takes advantage of the averaging technique described earlier.

Compare Equations 3 and 4. The differences are that the AI1H method involves the sequential connection of 25 Ω and 100 Ω load resistors and the WA8VZQ method involves shorting and opening the circuit at the end of the cable. Also, different values are subtracted, 4.77 dB for the AI1H method and

4 dB for the WA8VZQ method. If a 4.77-dB attenuator had been used for the WA8VZQ method, Equations 3 and 4 would have been identical, except for the terminations used.

The AI1H method uses terminations that are half and twice the nominal characteristic impedance (25 Ω and 100 Ω, respectively, for 50 Ω cables). If the terminations had been 1/2.323 times and 2.323 times 50 Ω (21.5 Ω and 116.2 Ω, respectively), a 4-dB term would be used instead of the 4.77-dB term in Eq 3. In general, for the AI1H method, if k is the multiplier for the load resistors (Z_0/k and kZ_0, where Z_0 is the nominal characteristic impedance of the cable), the value to be subtracted (in decibels) is

$$10\log\left(\frac{k+1}{k-1}\right).$$

The main difference between the two methods is that for the WA8VZQ method attenuators are used, and for the AI1H method resistive terminations are used instead of a short and an open circuits. In most cases, suitable resistors are more available than a calibrated attenuators, so the AI1H method is easier to implement. Also, when attenuators are used, they must have the same design impedance as the nominal characteristic impedance of the cable being measured. Both methods require an antenna tuner when the cable characteristic is not 50 Ω, since most analyzers have a reference resistance of 50 Ω.

Accuracy and Resolution

Reflection-coefficient magnitude, *SWR* and return loss are shown in the above equations. This was done because various analyzers that are used for measuring cable loss provide best accuracy when a particular one of these three parameters is measured. The equations are useful only if the analyzer accuracy is adequate. For a simple check of the accuracy, test a zero length cable. For the AI1H method using $Z_0/2$ and $2Z_0$ loads, a perfect analyzer would read $|\rho| = 1/3$, $SWR = 2.0$ and $RL = 9.54$ dB. For the WA8VZQ method with a 4 dB attenuator, the analyzer would read $|\rho| = 0.40$, SWR = 2.3 and $RL = 8.0$ dB. This does not guarantee that the intermediate readings are accurate, but this is a good start.

Accuracy is the degree to which the instrument provides the correct result. Resolution is the granularity to which the measured result can be displayed. In many cases, resolution is the controlling factor in the measurement process. *A perfect measuring instrument is limited by the resolution of the displayed result.*

As an example, let's look at the popular MFJ-259B when used to measure cable loss. This instrument measures $|\rho|$ directly and displays it on an LCD panel. It also displays *SWR* and return loss, which are computed internally from the $|\rho|$ data. All three parameters are displayed as two decimal digits. The reference of Note 3 shows how to calibrate the MFJ-259B for use in this application.

The loss versus $|\rho|$ behavior for the AI1H method is shown in Fig 1. The graph is based on Eq 3, where $Z_0/2$ and $2Z_0$ terminations are used. In this case, it is assumed that ρ_1 and ρ_2 are equal. The individual dots in the graph are the only values possible because of the two-digit display characteristic of the MFJ-259B, which controls the resolution of the instrument. To take full advantage of the displayed result, interpret a reading that alternates between two adjacent values as a value half-way between the two values. For example, interpret a reading of $|\rho|$ that "bounces" between 0.22 and 0.23 as 0.225. This leads to a resolution of cable loss as shown in Fig 2.

Fig 2 clearly demonstrates that the resolution of loss for $|\rho|$ measurements is better than that for SWR or Return Loss measurements and is better than 0.05 dB for cable losses up to 2 dB. Comparable graphs to Fig 1 for SWR and Return Loss are not shown because the algorithms that convert measured $|\rho|$ values to SWR and Return Loss introduce errors. The use of $|\rho|$ for this application of the MFJ-259B is clearly preferred because of both accuracy and resolution considerations.

Figs 1 and 2 apply for the AI1H method, but similar results are obtained with the WA8VZQ method. In fact, if a 4.77 dB attenuator is substituted for the 4 dB attenuator used

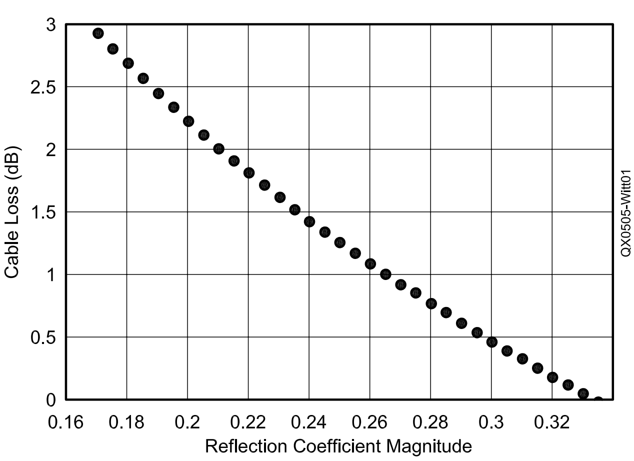

Fig 1—Cable loss versus reflection coefficient magnitude for the MFJ-259B Analyzer using the AI1H method.

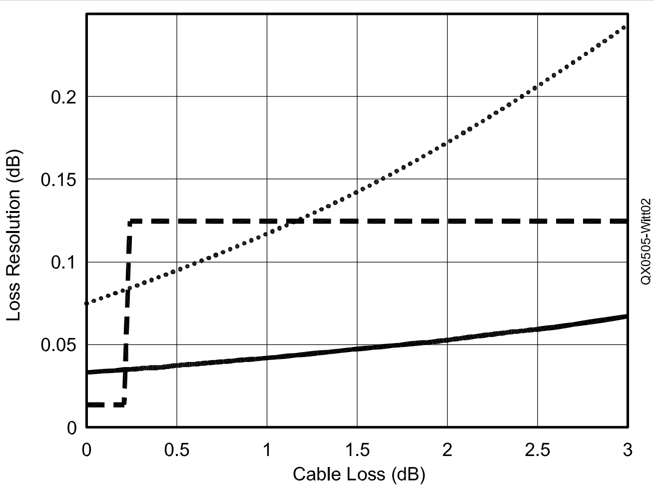

Fig 2—Loss resolution versus cable loss for the MFJ-259B Analyzer using the AI1H method. Solid line: Using reflection coefficient magnitude readings. Dotted line: Using SWR readings. Dashed line: Using return loss readings. The resolution is controlled by the two decimal-digit display of the results.

by WA8VZQ, the graphs would be the same for the two methods.

MFJ offers an analyzer of "improved accuracy," the MFJ-269. How does it perform in this application? It has A/D converters with greater resolution (more bits) than the A/D converters in the MFJ-259B. This would be very helpful if the MFJ-269 displayed three decimal digits for $|\rho|$, *SWR* and return loss, and the *SWR* and return loss algorithms were improved. Unfortunately, for the MFJ-269 I tested, the $|\rho|$, *SWR* and return loss displays show only two decimal digits. Also, the *SWR* and return-loss algorithms were the same as those for the MFJ-259B. In fact, the displayed resolution of the MFJ-269 is worse by a factor of two (twice the values displayed in Fig 2) than those of the MFJ-259B. This is true because the higher-bit A/D converters eliminate the bounce referred to above, so values between the two-digit values displayed on the LCD are not available. These comments apply for this application of the MFJ-269. For other applications, the improved A/D converters in the MFJ-269 are useful and do result in accuracy improvement. I hope that future versions of the MFJ-269 will provide three-digit decimal display for $|\rho|$, SWR and Return Loss and improved algorithms to convert $|\rho|$ data into *SWR* and return-loss data.

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Notes

[1] F. Witt, AI1H, "Transmission Line Properties from Manufacturers' Data," *The ARRL Antenna Compendium*, Volume 6, (Newington: ARRL, 1999), pp 179-183. *TLMan.mcd* is on the CD-ROM that is included with Volume 6.

[2] Dan Wanchic, WA8VZQ, "Better Feedline-Loss Measurements with Antenna Analyzer," *QST*, Mar 2004, "Hints & Kinks," pp 67-68.

[3] F. Witt, AI1H, "Evaluation of Antenna Tuners and Baluns—An Update," *QEX*, Sep/Oct 2003, pp 3-15, and *QEX*, Nov/Dec 2003, p 62, on the Web at: **www.arrl.org/tis/info/pdf/030910qex003.pdf**.

[4] F. Witt, AI1H, "Improved Accuracy in Antenna Tuner Evaluation," *QST*, Oct 2003, "Technical Correspondence," pp 73-74.