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Using Single-Frequency Antenna Analyzers

This material originally appeared in the *ARRL Antenna Book*, 23rd and prior editions.

Antenna or SWR analyzers that employ a low-level variable frequency signal source and wideband RF detectors have become very popular for antenna and transmission line measurements, largely displacing the noise bridge and dip meter as the preferred tool for antenna system measurements. The basic operation of the instrument is well-covered by the instrument user's manual and supplemented by descriptions of its use in several measurement techniques described in this chapter.

Peter Shuch, WB2UAQ contributes methods for the first three common analyzer tasks. The Sep 1996 *QST* article by George Badger, W6TC, and others, "SWR Analyzer Tips, Tricks and Techniques: SWR Analyzer Hints" provides other interesting applications of SWR analyzers and the *QST* article by Frederick Hauff, W3NZ, "The Gadget — An SWR Analyzer Add-on" describes a useful test accessory. (Articles are included on this book's CD-ROM and listed in the Bibliography.)

Amateur antenna analyzers are not intended to be precision instruments — values for impedance and reactance should be considered to have accuracy of a few percent. If precision measurements are required use calibrated, laboratory-grade test instrumentation.

Common-mode currents and load imbalance can also cause errors in measurements involving lengths of cable. Use a good-quality choke balun when measuring antenna characteristics so that the outside surface of the cable does not influence the measurement. It may also be necessary to use RF choke techniques if the cable is long enough to pick up significant levels of RF from any nearby transmitters, such as broadcast stations or paging transmitters.

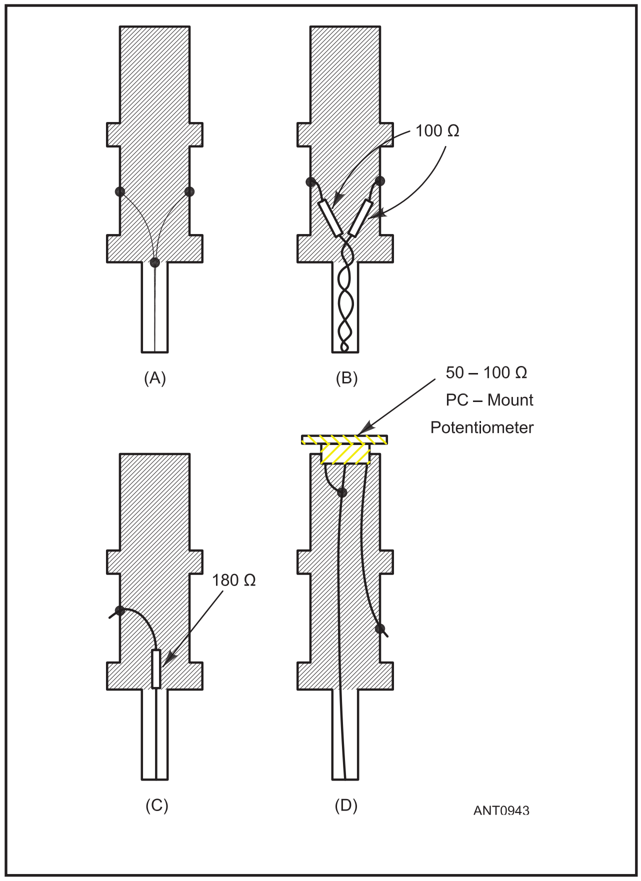

Figure 27.31 — Construction details of the resistive loads used to check and calibrate the noise bridge. Each of the loads is constructed inside a coaxial connector that matches those on the bridge. (Views shown are cross-sections of PL-259 bodies; the shells are not shown.) Leads should be kept as short as possible to minimize parasitic inductance. A is a 0-Ω load; B depicts a 50-Ω load; C is a 180-Ω load; D shows a variable-resistance load used to determine the loss in a coaxial cable. Use noninductive carbon-film or metal-film resistors.

MEASURING LINE LENGTH

In addition to the analyzer, you'll need a coaxial tee adaptor and a 50-Ω load (see **Figure 27.31**). Connect the tee adapter to the analyzer. To one arm of the tee, connect the 50-Ω load. Connect the cable under test (CUT) to the other arm. Short the far end of the line with the minimum length connection. Starting at a frequency too low for the line to be $\lambda/4$ long, slowly tune the analyzer frequency upward until the SWR decreases to a minimum or reaches 1:1. (The lossier the cable, the higher SWR will be at the minimum.) At that frequency the CUT will be $\lambda/4$ long because a shorted $\lambda/4$ line is an open-circuit at the other end and the analyzer will only see the 50-Ω load, regardless of the line's characteristic impedance.

MEASURING VELOCITY FACTOR

Start by determining the frequency at which the line is $\lambda/4$ long as described above. To find the velocity factor, divide the line's physical length by the free-space wavelength at the frequency at which the line is $\lambda/4$ long. For example, if an 86-foot piece of line is $\lambda/4$ long at 7.58 MHz, the velocity factor (VF) = 86 / (984 / 7.58) = (86 × 7.58) / 984 = 0.662.

MEASURING CHARACTERISTIC IMPEDANCE

Characteristic impedance changes slowly as a function of frequency, so this measurement must be done near the frequency of interest, f_λ. The characteristic impedance of the coaxial cable is found by measuring its input impedance at two frequencies separated by ¼ f_λ. This must be done when the cable is terminated in a resistive load.

If your analyzer can measure the magnitude of impedance, a $\lambda/4$ line's characteristic impedance, Z_0, can be measured by using the formula

$$Z_0 = \sqrt{Z_i \times Z_L}$$

where

Z_i = the input impedance to the line

Z_L = the load impedance.

Terminate the line with a 50-Ω load. At the frequency for which the line is λ/4 long, measure input impedance, Z_i. If the input impedance is 50 Ω, so is the line's characteristic impedance. If the input impedance is some other value, use the equation above. For example, if Z_i = 100 Ω, then

$$Z_0 = \sqrt{100 \times 50} = 70.7\Omega$$

The preceding procedure yields only the magnitude of the characteristic impedance which actually includes some reactance. The measurement procedure to determine complex characteristic impedance follows.

1) Place the 50-Ω load on the far end of the coaxial cable and connect the near end to the analyzer. (Measurement error is minimized when the load resistance is close to the characteristic impedance of the cable. This is the reason for using the 50-Ω load.)

2) Tune the analyzer approximately ⅛ f_λ below the frequency of interest. Call this frequency f1. Read R_{f1} and X_{f1}. Remember, the reactance reading must be scaled to the measurement frequency.

3) Increase the frequency by exactly ¼ f_λ. Call this frequency f2 and note the readings as R_{f2} and X_{f2}.

4) Calculate the characteristic impedance of the coaxial cable using Eqs 8 through 13. A scientific calculator or spreadsheet is helpful for this.

$$R = R_{f1} \times R_{f2} - X_{f1} \times X_{f2} \quad \text{(Eq 8)}$$

$$X = R_{f1} \times X_{f2} + X_{f1} \times R_{f2} \quad \text{(Eq 9)}$$

$$Z = \sqrt{R^2 + X^2} \quad \text{(Eq 10)}$$

$$R_0 = \sqrt{Z} \cos\left[\frac{1}{2}\tan^{-1}\left(\frac{X}{R}\right)\right] \quad \text{(Eq 11)}$$

$$X_0 = \sqrt{Z} \tan\left[\frac{1}{2}\tan^{-1}\left(\frac{X}{R}\right)\right] \quad \text{(Eq 12)}$$

$$Z_0 = R_0 + jX_0 \quad \text{(Eq 13)}$$

where Z_0 is the characteristic impedance of the transmission line.

Let's continue with the example used earlier for cable length. The measurements are:

f1 = 29.000 – (9.883/8) = 27.765 MHz

R_{f1} = 64 Ω

X_{f1} = –22 Ω × (10/27.765) = –7.9 Ω

f2 = 27.765 + (9.883/4) = 30.236 MHz

R_{f2} = 50 Ω

X_{f2} = –24 Ω × (10/30.236) = –7.9 Ω

When used in Eqs 8 through 13, these data yield:

R = 3137.59 Ω

X = –900.60 Ω

Z = 3264.28 Ω

R_0 = 56.58 Ω

X_0 = –7.96 Ω

Remember the limitations on accuracy for inexpensive test equipment and be skeptical of data or calculations beyond two significant figures. The level of precision implied here is for illustration purposes only.

CABLE ATTENUATION

Cable loss can be measured once the cable electrical length and characteristic resistance are known. The measurement must be made at a frequency where the cable presents no reactance. Reactance is zero when the cable electrical length is an integer multiple of λ/4. You can easily meet that condition by making the measurement frequency an integer multiple of ¼ f_λ . Loss at other frequencies can be interpolated with reasonable accuracy. This procedure employs a resistor-substitution method using the test loads in Figure 27.31 that provides much greater accuracy than is achieved by directly reading the resistance from the analyzer. (You can also measure loss directly by using a wattmeter to measure power into and out of the line.)

1) Determine the approximate frequency at which you want to make the loss measurement by using

$$n = \frac{4f_0}{f_\lambda} \quad \text{(Eq 14A)}$$

where f_0 is the nominal frequency.

Round n to the nearest integer, then

$$f1 = \frac{n}{4} f_\lambda \quad \text{(Eq 14B)}$$

2) If n is odd, leave the far end of the cable open; if n is even, connect the 0-Ω load to the far end of the cable. Attach the near end of the cable to the analyzer and read resistance and reactance.

3) Disconnect the cable from the analyzer and connect the variable-resistance calibration load in its place. Without changing analyzer frequency, adjust the load resistor to obtain the same resistance and reactance.

5) Remove the variable-resistance load from the analyzer and measure the load resistance using an ohmmeter that's accurate at low resistance levels. Refer to this resistance as R_i.

6) Calculate the cable loss in decibels using

$$\text{loss} = 8.69 \frac{R_i}{R_0} \quad \text{(Eq 15)}$$

To continue this example, Eq 14A gives n = 11.74, so measure the attenuation at n = 12. From Eq 14B, f1 = 29.649 MHz. The input resistance of the cable measures 12.1 Ω with 0-Ω load on the far end of the cable; this corresponds to a loss of 1.86 dB.

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