Estimating Transmission Line Loss by Savage Methods

Tom Wheeler, N0GSG
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To accurately measure feedline loss normally means that test equipment must be connected to both ends of the line at the same time. In the field, this may not be practical or even possible. By terminating a transmission line with various (but known) degrees of mismatch, and reading the resulting VSWR at the transmitter side of the line with an accurate bridge, the loss can be indirectly calculated.

Figure 1 shows the basic setup. The signal source (the transmitter) drives the VSWR indicator (a directional wattmeter), which sends signal down the feedline. The feedline is terminated in a known load; this can be anything from a *short circuit* to a more modest termination of 2 Z_0 or 3 Z_0. The choice of termination is partially dictated by the metering limits of the VSWR indicator. Experimentally, an "SWR Analyzer" such as the MFJ-259B can be substituted for the generator and VSWR bridge.

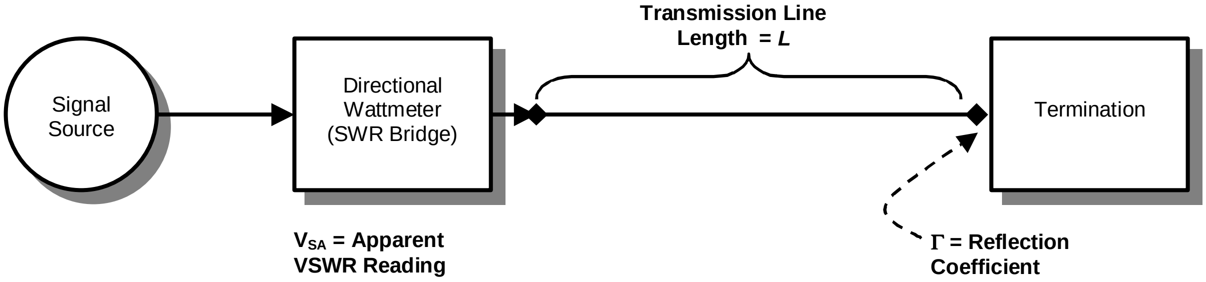

Figure 1: The Test Setup

When a lossless line is terminated with a mismatched load, the VSWR is equal at all points on the line. When a lossy line is introduced, the VSWR gradually approaches unity towards the transmitter. By knowing the termination value, and the "apparent" VSWR at the transmitter, we can solve for the attenuation constant of the line, α.

By following the voltage as it moves from the signal source, to the load, and back towards the signal source, we can gain some insight. The voltage at the load is:

(1) $V_L = V_i e^{-\alpha L}$

Where α is the attenuation constant in Nepers/unit length, and *L* is the length.

The load will reflect a signal back according to its coefficient of reflection, Γ. If the load and characteristic impedance of the line are real, the coefficient of reflection will also be real and can be computed as :

(2) $\Gamma = \dfrac{Z_R - Z_0}{Z_R - Z_0}$ Where Z_R is the termination, and Z_0 is the characteristic impedance.

The signal reflected back at the termination, V_{rL}, will be:

(3) $V_{rL} = V_i \Gamma e^{-\alpha L}$

And this signal will propogate backward down the line, experiencing the line loss again. Therefore, at the transmitter, the reflected voltage will be:

(4) $V_r = V_i \Gamma e^{-2\alpha L}$

The apparent reflection coefficient, S_{11}, as seen by the VSWR indicator will therefore be:

(5) $S_{11} = \Gamma_{apparent} = \dfrac{V_r}{V_i} = \dfrac{V_i \Gamma e^{-2\alpha L}}{V_i} = \Gamma e^{-2\alpha L}$

The VSWR indicator will read the *apparent* VSWR, V_{SA} as:

(6) $V_{SA} = \dfrac{1 + |S_{11}|}{1 - |S_{11}|} = \dfrac{1 + |\Gamma| e^{-2\alpha L}}{1 - |\Gamma| e^{-2\alpha L}}$

Where Γ is the coefficient of reflection for the load, α is the attenuation constant, and L is the length of the transmission line.

Solving equation 6 for α, we get:

(7) $\alpha = \dfrac{\ln\left(\dfrac{V_{SA} - 1}{|\Gamma| + V_{SA}|\Gamma|}\right)}{-2L}$

Equation 7 can be directly applied to find the total transmission line loss, since we know that the incident voltage magnitude at any point on the line can be expressed as:

(8) $|V_i(x)| = V_i e^{-\alpha x}$

The forward gain is expressed by the quantity $e^{-\alpha x}$ from equation 8 above, and is in voltage gain units (V/V). The power gain in decibels can therefore be written as:

(9) $G_{dB} = 20\log(e^{-\alpha x})$

Where the gain *G* will actually be a negative number upon calculation, because the line experiences a loss, and *x* is the length. Substituting equation (8) for α in (9) gives:

(9)

$$G_{dB} = 20\log\left(e^{-\left[\frac{\ln\left(\frac{V_{SA}-1}{|\Gamma|+|\Gamma|V_{SA}}\right)}{-2L}\right]L} \right) = 20\log(e^{\frac{\ln\left(\frac{V_{SA}-1}{|\Gamma|+|\Gamma|V_{SA}}\right)}{2}}) = 20\log\left(\sqrt{\frac{V_{SA}-1}{|\Gamma|+|\Gamma|V_{SA}}}\right) = 10\log\left(\frac{V_{SA}-1}{|\Gamma|+|\Gamma|V_{SA}}\right)$$

Notice how the length *L* is no longer needed. All that is needed to compute the line loss is the reflection coefficient at the load, and the apparent VSWR reading, V_{SA}, as experienced at the generator.

For example, suppose that we terminated a 300' line in a short, and applied a 150 MHz signal. While doing so, we measured an apparent VSWR of 3:1 at the generator. The reflection coefficient Γ is -1 (short), and the line loss is:

$$G_{dB} = 10\log\left(\frac{V_{SA}-1}{|\Gamma|+|\Gamma|V_{SA}}\right) = 10\log\left(\frac{3-1}{1+1(3)}\right) = 10\log\left(\frac{2}{4}\right) = \underline{\underline{-3.01dB}}$$

Many VSWR indicators become inaccurate above a 3:1 VSWR reading. A line loss of less than 3 dB will give a VSWR above 3:1, which is beyond the capabilities of many testers. With a trick, this can be accomodated. The line can be terminated in a value such as 2 Z_0, which will give a lower VSWR reading. Equation 9 will still work in this case, but the value of Γ must be corrected. For $Z_R = 2\ Z_0$, $\Gamma = (Z_R - Z_0)/(Z_R + Z_0) = +0.333333$. For best accuracy, the termination should be a high-quality noninductive resistor, preferably placed within the body of a suitable terminating connector.