More on Transmission Lines and SWR – Part IV

By Don Steinbach, AE6PM

Standing waves on the transmission line occur when the characteristic impedance of the transmission line is not the same as the antenna impedance at the point where the two are connected. In that case, not all of the incident (forward) power from the transmission line is accepted by (and radiated by) the antenna and the difference is reflected back down the transmission line toward the source. It's commonly assumed that the reflected power is lost forever, but that's not the case. The reflected power is reflected again when it reaches the source, this time back toward the antenna, because the source impedance is not exactly equal to the transmission line impedance. Now, practical transmission lines always have some loss, so the wave being reflected back and forth becomes smaller with each round trip. The energy bounces back and forth inside the transmission line until it's all radiated by the antenna or absorbed by losses in the transmission line. The bottom line is that the power lost due to SWR is directly related to the loss in the transmission line. This is why antennas having a very high SWR, but fed with low-loss transmission line (such as open-wire line) can be very efficient and highly effective.

Excessive Reactance

Remember, though, that if the antenna feed-point impedance consists of reactance as well as resistance (which it undoubtedly does) any capacitive reactance can result in high currents and any inductive reactance can result in high voltages. Unfortunately, these reactive parts of the antenna impedance do not absorb or radiate power (remember AC Circuits 101?), but they do result in these undesirable side effects. If your antenna system tries to self-destruct, is arcing, or your balun explodes, look for a significant reactance term in the antenna impedance that could result in unusually high voltages or currents.

Transmission Line Loss SWR Masking Effect

Loss in the transmission line manifests itself in other ways such as masking the true SWR at the antenna. Specifically, the SWR seen at the transmitter end of the transmission line will appear to be lower than it really is at the antenna because of the increased return loss. For example, if the loss in the transmission line is 3 dB, a SWR of 2 at the transmitter translates to a SWR of 5 at the antenna and a SWR of 3 at the transmitter translates to a SWR of over 100 at the antenna. These examples are admittedly extreme, but they serve to illustrate my point, which is that a lossy transmission line makes the impedance match at the antenna appear better than it really is.

The relationship between the SWR at the input (transmitter) end of the line and the SWR at the load (antenna) end of the line is:

SWR at input = $(a + |\rho|) / (a - |\rho|)$

Where:

$a = 10^{ML/10}$ = 10 ^ (ML/10)
$|\rho| = (SWR - 1)/(SWR + 1)$

ML = Matched-line loss of the transmission line in dB
SWR = SWR at the load (antenna)
(Ref: ARRL Handbook for Radio Communications, 82nd Edition, page 21.6)

See Table 1 for some calculated values. Note that as the transmission line loss (matched-line loss) increases, the SWR as measured at the transmitter becomes vastly different from the SWR that would be measured at the antenna.

Table 1 – SWR at the antenna for various matched-line loss and SWR at the transmitter.

	Matched-Line Loss						
SWR at Antenna	0.5 dB	1 dB	2 dB	3 dB	4 dB	5 dB	6 dB
	SWR at Transmitter						
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.43	1.38	1.29	1.22	1.17	1.14	1.11
2	1.85	1.72	1.53	1.40	1.31	1.24	1.18
2.5	2.24	2.03	1.74	1.55	1.41	1.31	1.24
3	2.61	2.32	1.92	1.67	1.50	1.38	1.29
4	3.30	2.82	2.22	1.86	1.63	1.47	1.35
5	3.93	3.25	2.45	2.00	1.72	1.53	1.40
6	4.50	3.62	2.64	2.12	1.79	1.58	1.44
7	5.03	3.95	2.80	2.20	1.85	1.62	1.46
8	5.52	4.23	2.93	2.28	1.90	1.65	1.49
9	5.97	4.49	3.04	2.34	1.93	1.68	1.50
10	6.39	4.71	3.13	2.39	1.97	1.70	1.52

Determining the Transmission Line Loss

In order to calculate the SWR at the antenna from the SWR measured at the transmitter end, the matched-line loss of the transmission line at the frequency of interest must be known. This can be estimated from the manufacturers' published data or it can be determined experimentally (i.e., measured). Regardless of method, the matched-line loss should be determined at the frequency at which the antenna is going to be used. An actual measurement the matched-line loss of the transmission line is preferred, but that requires that both ends of the transmission line be accessible. If that's not possible, then an estimate based on the manufacturers' published data plus knowledge of the actual physical length of the transmission line is the only other alternative.

Method 1 (Estimated from Published Data): The matched-line loss varies with frequency and the published data will probably not be at the frequency of interest so a correction is required. If the frequency at which the loss is specified is F_1 and the matched-loss at that frequency is A_1, then the matched-loss (A_0) at the frequency of interest (F_0) is approximately equal to:

$A_0 = A_1 \text{ sqrt } (F_0/F_1)$

The product of A_0 times the transmission line physical length equals the loss. The published data probably has units of dB per 100 feet, so scale the loss for the length of your transmission line accordingly.

Method 2 (Direct Measurement): Direct measurement of the matched-line loss is accomplished by measuring the magnitude of the reflection coefficient, or alternatively, the SWR at one end of the transmission line while the other end is either open- or short-circuited. Since all of the power that reaches the short- or open-circuit will be reflected back toward the source, the matched-line loss of the cable will be half the return loss resulting from this measurement.

Method 2 is best done with an antenna analyzer that reports the reflection coefficient or the return loss rather than the SWR since the theoretical SWR will be infinite whereas the reflection coefficient (ρ) will be about 1 or the return loss will be about zero. An SWR meter or SWR bridge will simply read full-scale. See Table 1 of Part III for examples.

For best accuracy, the impedance of the analyzer should be equal to the complex characteristic impedance of the transmission line. Most analyzers have a choice of 50 or 75 ohms, resistive (mostly, since there will always be some reactance present), and we'll live with that even though it may not perfectly match the transmission line. After all, we're not trying to land a man on the moon. Also, make two measurements: one with the far end open-circuited and one with the far end short-circuited and use the arithmetic average of the two (i.e., add them up and divide by two).

"My Feedline Tunes My Antenna"

This is the title of an article in the March 1956 issue of QST where the author (Byron Goodman, W1DX) addresses the possible impedance transforming effect of the transmission line, much as has been done here, and how changing the length of the transmission line can affect the SWR, leading to the misconception that this has somehow "tuned" the antenna. His objective is to dispel that incorrect notion (among others).

Keep in mind that the antenna is a fixed physical object with predictable and measurable electrical characteristics that can only be changed by modifying its physical properties or its environment. No magical twisting of knobs or adding networks at the station-end can alter the characteristics of the antenna proper. Adding an impedance transforming network between the transmission line and the antenna or between the transmitter and the transmission line, or both, is the only way to alter the perceived electrical characteristics of the antenna.

Transmission Line Properties (More)

In Part 3 under “Transmission Line Properties”, I listed five transmission line properties of interest. I should have included a sixth:

The magnitude of the impedance measured at the free end of a one-eighth wavelength transmission line is almost exactly the magnitude of its characteristic impedance when the line is terminated with a resistance of any value.

Errata:

Three of the equations in Part 3 in the August 2011 SCCARA-GRAM took a hit in the publishing process. Specifically, the letter “r” was substituted for the greek letter rho (•). So, where you see r = , or |r| =, in the August issue, replace the r with •.

The corrected equations are:

$\rho = E_R/E_F = I_R/I_F = \text{sqrt}(P_R/P_F) = (Z_L – Z_0) / (Z_L + Z_0)$

$|\rho| = \text{sqrt}[((R_L – R_0)^2 + X_L^2) / ((R_L + R_0)^2 – X_L^2)]$

$|\rho| = \text{sqrt}[((50 – 50)^2 + (-j50)^2) /((50 + 50)^2 – (-j50)^2)]$

More next month … stay tuned.