RF transmission line tips

By Harold Kinley, C.E.T.

There are a few techniques that all technicians should know in order to work and deal with RF transmission lines more effectively. Some myths have been perpetuated over the years. Some are taken as fact without question. The following tips should help to clear up some of the murky water surrounding RF transmission lines.

Trim the coax!

I remember, back during the heyday of CB radios, hearing some of the "experts" on CB telling their friends how to reduce the VSWR on their rig. Almost invariably the advice was *"Trim the coax!"* Seldom did I hear *"Tune the antenna!"* If the antenna is properly tuned it will present a 50Ω impedance to the transmission line. If the transmission has the proper 50Ω characteristic impedance, the length of the line will not matter as long as the antenna is properly tuned.

Non-resonant lines

A transmission line is *non-resonant* when it is *terminated in an impedance that is equal to the characteristic impedance of the line.* Changing the length of non-resonant transmission lines does not change the impedance at the input. It can be 50 feet or 100 feet, but the input impedance will remain unchanged. The only degrading factor will be the loss of the line as the length increases.

Resonant lines

When a transmission line is terminated by an impedance that is *not* equal to the characteristic impedance of the line, it is said to be *resonant.* The length of a resonant transmission line is critical. *Changing the length of the line will change the impedance of the line,* looking from the source. When an antenna impedance is other than the characteristic impedance of the transmission line, the line length can be adjusted to present a better matching impedance at the output of the transmitter.

Line length vs. impedance

This discussion assumes a 50Ω system impedance and thus the use of 50Ω transmission line—that is, transmission line with a characteristic impedance of 50Ω.

In Figure 1 above, a transmission line is terminated into a 50Ω load. The impedance 1/8λ from the load is 50Ω. The impedance 1/4λ from the load is 50Ω. The impedance 3/8λ from the load is 50Ω. The impedance 1/2λ from the load is 50Ω.

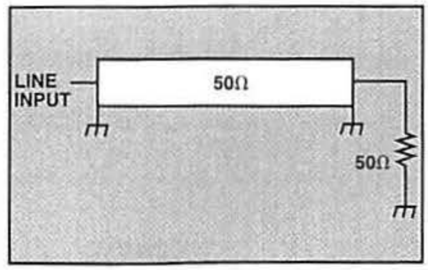

Figure 1. A transmission line terminated into a load equal to the characteristic impedance of the line—50Ω. The impedance will be the same at all points along the line.

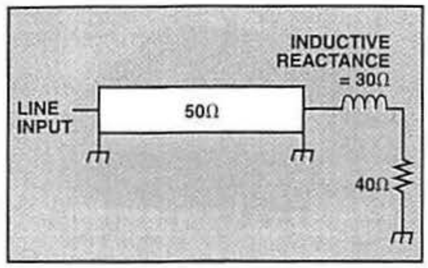

Figure 2. A 50Ω transmission line terminated by a load with the complex impedance of 40 + j30. The impedance will vary along the length of the line and will repeat at every 1/2λ.

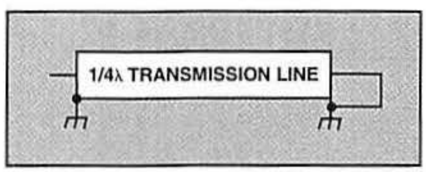

Figure 3. A 1/4λ transmission line shorted on one end produces an open circuit on the other end.

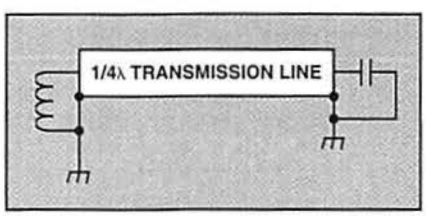

Figure 4. A 1/4λ transmission line can be used to transform an inductive reactance at one end of the line into a capacitive reactance at the other end of the line.

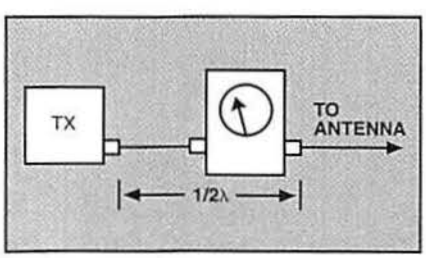

Figure 5. If a transmitter must be tuned into a resonant line, be sure to use a 1/2λ cable (including wattmeter section). Include velocity factor in cable length calculations.

Thus, the impedance anywhere along the length of a transmission line will remain the same as long as the line is terminated into a load equal to its characteristic impedance. To further qualify this statement, the load must be a *purely resistive load* equal to the characteristic impedance of the line. This means that the load must not contain a reactive component. Written in complex form, the load must be equal to 50 ± j0.

To illustrate the preceding point, the formula for impedance is:

$$Z = \sqrt{R^2 + X^2}$$

Now, if the load impedance in the complex form is 40 + j30, then the resultant impedance is 50Ω. (See Figure 2 at the left.) However, because a reactive component is in the load, a mismatch will result. The actual VSWR at the load will be 2:1. The same VSWR will be seen at all points along the transmission line, assuming a lossless line. However, the actual impedance along the line will vary, and will repeat every 1/2λ.

At a distance of 1/8λ from the load, the impedance is 100 ± j0. At 1/4λ, the impedance is 40 − j30. At 3/8λ, the impedance is 25 ± j0. And, again, at 1/2λ, the impedance repeats the load impedance—40 + j30. The cycle repeats every 1/2λ on the line moving away from the load and toward the generator.

Impedance transformation

From the preceding information, it follows that a transmission line can be used to transform impedance. In fact, a 1/4λ line can transform an open circuit at one end into a short circuit at the other end. Or, it can transform a pure inductive reactance into a pure capacitive reactance. (See Figures 3 and 4 at the left.) Open or shorted stubs are used to match impedances using the Smith chart. (Smith is a registered trademark of Analog Instruments, P.O. Box 808, New Providence, NJ 07974.)

Normally, any mismatch at the antenna

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should be corrected so that the antenna presents a proper 50Ω impedance to the transmission line, which, in turn, will present the 50Ω impedance to the transmitter. Because the transmitter is designed to work into a 50Ω load impedance for optimum performance, every effort should be made to make the impedance at the transmitter equal to 50Ω.

If this is not possible, and the transmitter must be operated into a line with moderate VSWR, the following technique should be used. An in-line wattmeter is connected between the transmitter and the transmission line using a length of coax, such that the length of coax plus the in-line section of the wattmeter are exactly 1/2λ at the operating frequency. Be sure to take into account the velocity factor of the connecting line. (See Figure 5 on page 8.) With the wattmeter connected through a 1/2λ section of line (plus wattmeter section), the transmitter is loaded and tuned for proper power output. Then, the wattmeter and connecting line are removed, and the transmission line is reconnected. The transmitter output should see the same impedance it saw during the tuning procedure.

Line loss masks true VSWR

When you check the forward and reflected power at the transmitter output, you are not getting the actual reflected and forward readings that exist at the antenna, unless the line loss between the transmitter and antenna is quite small. For example, suppose that a catastrophic failure occurs at the antenna transmission line connection—either open or short circuit. Theoretically, this represents a VSWR of infinity. However, if the line has a loss of 3dB, the actual VSWR seen at the transmitter will be about 3:1. Obviously, high VSWR levels can go virtually undetected by measurements made at the transmitter when line loss is high. The line loss acts like a pad to smooth impedance bumps. Such padding is desirable on low-level signal generators but not on high-power transmitters.

Lightning protection?

An old practice among many technicians is to use a shorted transmission line stub to provide a degree of lightning protection. A shorted 1/4λ stub is placed on the transmission line using a "tee" connector. The length of the stub is 1/4λ at the operating frequency with the velocity factor of the line included. The stub has negligible effect on the system at the operating frequency but puts a dc short across the line to offer some measure of protection against lightning. I won't argue for or against the merits of such a lightning protection scheme.

Similarly, 1/4λ stubs can be used as notch filters to notch out interfering signals. Good-quality cables with high velocity factors are generally more effective for such purposes.

I hope this has provided some insight into working with transmission lines and avoiding some pitfalls along the way. The RF transmission line is more than just a conduit through which RF energy is passed. It is a complex electronic circuit with many features that can be used to great advantage.

Until next time, *stay tuned!*