TECH TIME

Helpful tips for the Avionics Technician

BY AL INGLE

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Transmission Lines- Continued

Last month the fundamental theory of transmission lines was discussed and we expand and explore further here.

A perfect transmission line may be thought of as a series of small inductors (in the center conductor and shield), and as a series of small capacitors (the gap between the inner and outer shield). In this perfect, idealized line, this scenario repeats into infinity. The inductance and capacitance values per unit of line are dependent upon the size of the conductors and the spacing between them. The smaller the spacing between the conductors, and the greater their diameter, the higher the capacitance and the lower the inductance. As the wave propagates down the line, each series inductor limits the rate at which current can charge the following shunt capacitor and in so doing establishes that transmission line's *surge impedance* or, as it is more commonly known, *characteristic impedance* or Z_0. As previously discussed, the aircraft environment almost exclusively uses 50 ohms as the characteristic impedance.

Aircraft are not infinitely long (although they seem to break down in an infinite number of ways!) so we must deal with real world transmission lines that exhibit some power loss. In use they are connected or terminated into a load. Some unavoidable losses are due to resistance from the copper conductors, and leakage from the dielectric material separating the inner and outer conductors. If the load is purely resistive and matches the characteristic impedance of the line, the line is said to be *matched*. If the line is terminated into an impedance not equal to Z_0 it is considered to be *mismatched*. RF energy reaching the end of the mismatched line will not be fully absorbed by the load and will be reflected back toward the source. The amount of reflected energy depends upon the degree of mismatch between Z_0 and the load impedance. The two extremes would be a short at the terminating end, or an open at the terminating end. In both cases no energy would be dissipated by the load and the entire wave would be reflected back to the source. Upon reaching the source it would be reflected back towards the load and this process would repeat until the losses in the line have reduced the wave to zero.

If a continuous wave is applied to a transmission line, an equilibrium will be established between the *forward* or *incident* wave and the *reflected* wave returning from the mismatched load. *The ratio of the maximum peak voltage anywhere on the line and the minimum voltage found anywhere on the line is called the VSWR.* Because the ratio of maximum to minimum current is identical to that of voltage, the abbreviation SWR is commonly used for *S*tanding *W*ave *R*atio.

In our industry, a numerical value for SWR is used often in technical specifications. The VSWR of the Comant CI-209 *top* mount communications antenna is 2.0:1 max, while the VSWR for the Comant CI-122 *bottom* mount communications antenna is 3.0:1 max. Why the difference? Because the radiating element on the CI-122 is bent for the inevitable low clearances required of underside mounting. Remember that all compromises come at a cost! And what of the increased VSWR? How much is the efficiency degraded? We will soon see.

In the IIMorrow GX50/60/65 Installation manual, it states that the installing coaxial cable and antenna must not have a VSWR in excess of 3.0:1. If you use a CI-122 antenna, your coax and connectors better be *perfect* or you have exceeded design requirements the day that the customer takes delivery of the aircraft! Add *any* sharp bends to the coaxial cable, tight ty-raps that deform the diameter of the cable, water intrusion into the antenna or poor RF bonding of the antenna to the fuselage and you are staring at a marginal communications system that will never work as intended.

Having stated how important SWR is, let us now find a simple way to measure it. The SWR is related to the magnitude of the reflection energy as shown in the equation below:

$$SWR = \frac{1 + |\rho|}{1 - |\rho|}$$

Where $|\rho|$ is expressed as the ratio of forward and reflected waves as:

$|\rho| = \sqrt{Pr / Pf}$ Where Pr is reflected power, Pf is forward power

Example: Let us examine the previously referenced Apollo GX50/60/65 GPS/Com installation manual. The recommended VSWR is 2:1, maximum is 3:1. Taken from the manual, a 2:1 SWR corresponds to approximately 88% efficiency with 12% reflected or absorbed. If the unit produces 10W total power, *Pf* is then 10 watts as shown on a wattmeter, and the reflected power *Pr* is 1.2 watts.

$|\rho| = \sqrt{1.2 / 10}$ or 0.346. $SWR = (1 + 0.346) / (1 - 0.346) = 2.03 \approx 2:1$.

Again taken from the manual, a 3:0 SWR corresponds to approximately 75% efficiency with 25% reflected or absorbed. If the unit produces 10W total power, *Pf* is 10 watts and the reflected power *Pr* is 2.5 watts.

$|\rho| = \sqrt{2.5 / 10}$ or 0.50. $SWR = (1 + 0.50) / (1 - 0.50) = 3.0:1$.

Below is a table of efficiencies for easy reference:

Pr/Pf	SWR	Pr/Pf	SWR	Pr/Pf	SWR	Pr/Pf	SWR
0	1:1	0.2	2.62:1	0.40	4.4:1	0.7	11.3:1
0.05	1.57:1	0.25	3:1	0.45	5.1:1	0.8	17.9:1
0.1	1.92:1	0.3	3.42:1	0.5	5.8:1	0.9	38.2:1
0.15	2.26:1	0.35	3.88:1	0.6	7.9:1	1.0	∞

One last issue. If you have a lossy transmission line, it can make a high VSWR look completely normal. This is because the forward wave is being reduced in amplitude as it travels to the discontinuity, then the reflected wave is also being attenuated during its return to the source (and your wattmeter). It is possible to have a 6:1 VSWR look like 2:1 in this instance. Beware that whatever you measure, the actual value is higher. I believe that many transponder problems are due to inadequate transmission lines, but how to accurately measure them?

Next Month: We go to the aircraft.