RF Connector Selection for Higher Frequencies

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Selection of the proper RF connector, and proper attachment of connectors, can affect transmission line performance as much or more than choosing the right coaxial cable

When designing an RF system, an engineer will frequently be very careful in the selection of the coaxial cable, basing any decision on the cable's ability to meet system requirements such as return loss or VSWR, insertion loss, shielding effectiveness, velocity factor, passive intermodulation, power handling capability, bend radius, bending moment, diameter and other characteristics. It's a wise decision to spend this "up front" time on cable selection, because choosing the optimal cable for the application will help to insure that system design parameters are met.

Unfortunately, the design engineer will frequently pay much less attention to the selection of the RF connector, even though the selection of an appropriate connector and ensuring proper attachment of that connector to the cable are equally critical to achieving required performance. More often than not, transmission line problems can be traced back to improper design or installation of the cable connectors. The focus of this article is the effect of connector design and termination on voltage standing wave ratio (VSWR) and insertion loss (IL).

Selecting the Right Cable Construction

The primary consideration in selecting a coaxial cable is usually the loss budget for the run. Times Microwave Systems' LMR family of cables offers a wide range of sizes and constructions that can satisfy the requirements of a broad range of systems and is generally very cost effective, so we will consider termination issues with respect to this range of cables.

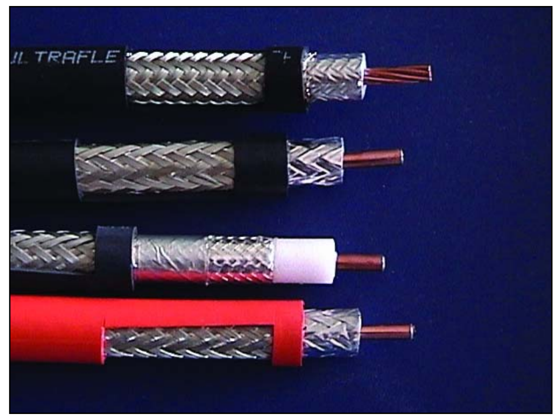

Figure 1 · Different types of coaxial cable construction.

The construction of the basic LMR cable consists of a copper or copper-clad aluminum center conductor or copper tube that is coated with an adhesive over which a closed cell polyethylene foam dielectric is extruded. Bonded adhesively to the outside of the dielectric is an aluminum-mylar-aluminum composite tape that serves as the outer conductor of the cable. Covering the tape is a tinned copper, round wire braid. A heavy-wall black, UV-protected polyethylene jacket is extruded over the braid. This construction is low-loss, flexible and cost effective, suitable for many different applications.

There are many variations on this construction in the LMR family that may be used with the same standard connectors. Each is optimized for specific requirements or applications. A few of these constructions are shown in Figure 1.

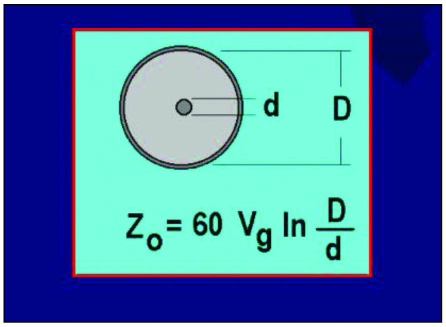

Figure 2 · Impedance is a function of the conductor diameters and the propagation velocity (V_g).

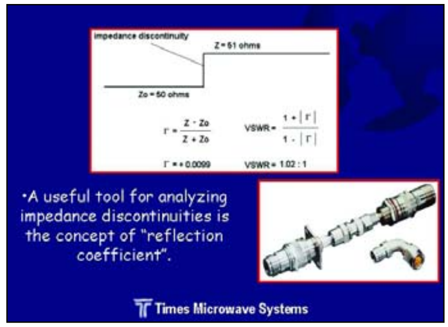

Figure 3 · The relationship between impedance non-uniformity and the VSWR.

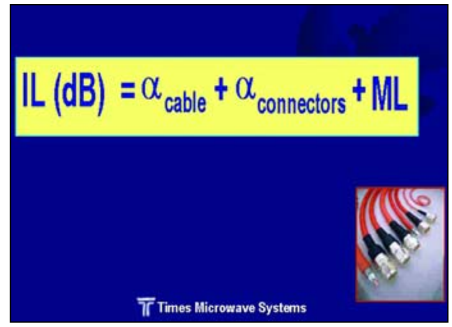

Figure 4 · IL is the sum of all contributing losses—cable loss, connector loss and mismatch loss.

How Connector Quality Impacts Performance

The preparation of the cable can greatly affect the overall performance of the assembly or jumper. Improper workmanship can readily result in poor performance of the finished cable assembly.

The efficiency of a transmission line is partly a function of impedance uniformity. Impedance is a function of the center conductor ("d" in Figure 2), the outer conductor ("D" in Figure 2) and the dielectric constant (ε) or velocity of propagation (V_g), where $\varepsilon = 1/V_g$.

An ideal RF transmission line has uniform impedance along its length and matches the impedance of the system itself. In practice, however, this will never be the case. But over the years cable manufacturing processes have improved to the point that the cable is seldom the culprit when impedance non-uniformities are detected. Due to the line size transitions that are taking place and the mechanical techniques that are required to secure the connector to the cable, the connector and the junction between the connector and the cable will exhibit impedances that are different than the cable impedance.

In a well-designed connector, proper design of the transition between the different line sizes of the cable and the connector interface will minimize the deviation of the impedance from the nominal value. However, many connector designs have less than optimal design of these transition sections. We will look at a few examples below. Another contributor to impedance non-uniformity is the termination process. There are many opportunities to alter the impedance constant during the termination process. Figure 3 shows the relationship between impedance non-uniformity and the VSWR. The VSWR value can be used to express the level of impedance non-uniformity within a cable or cable assembly. A cable assembly having perfect impedance uniformity will have a VSWR of 1.00:1. Increased levels of impedance non-uniformity will be represented by increasingly higher levels of VSWR.

Mismatch loss (MML) is an often overlooked factor in system planning. The formula of Figure 4 shows how the MML value is a component of the overall IL . MML is the additional loss experienced by reflected waves as they travel through the cable/connector system and, therefore, is a function of both matched loss and VSWR. Figure 5 is a table showing the MML number for a range of VSWR values in a system with a fairly high matched loss (not unusual at microwave frequencies). It also lists the reduction in transmission efficiency that is a function of the impedance mismatches in the system. In this example, you will lose an additional 25 percent of your incident signal with a 3.0:1 VSWR.

How the Termination Process Can Impact VSWR

Many steps in the termination process can impact the VSWR. Figure 6 shows a properly prepped and soldered cable end; in Figure 7 the cable end is properly crimped. The length of the various strip backs from the end of the cable should be in accordance with the manufacturer's recommendations. In addition, care must be taken to cut the dielectric and outer conductor square. It should be cut with a sharp instrument so as not to form an indentation in (or deforming of) the dielectric or to produce a jagged outer conductor. Commercially available cable stripping tools are great for obtaining the proper strip length, as well as assuring a square cut of the dielectric. Make sure that the tool is sharp.

The soldering of the pin is another step in the termination process that can have a great impact on the final performance of the transmission line. Aside from cold solder joints and the risk of opens, the pitfalls that are present during the pin soldering process are (1) excess solder and flux, (2) improper pin-to-core gap, (3) melting of the dielectric and (4) the actual pushing of the solder cup of the pin into the dielectric material. All of these mistakes will create impedance mismatches and higher overall values of (IL).

The jacket strip back and the crimping of the connector can also have ramifications in terms of VSWR. The length of the jacket strip back must be in accordance with

VSWR (:1)	Return Loss (dB)	Reflection Coefficient	Mismatch Loss (dB)	Match Efficiency(%)
1.011	45	0.006	0.000	100.00
1.020	40	0.010	0.000	99.99
1.036	35	0.018	0.001	99.97
1.065	30	0.032	0.004	99.90
1.074	29	0.035	0.005	99.87
1.08	28	0.040	0.007	99.84
1.09	27	0.045	0.009	99.80
1.11	26	0.050	0.011	99.75
1.12	25	0.056	0.014	99.68
1.13	24	0.063	0.017	99.60
1.15	23	0.071	0.022	99.50
1.17	22	0.079	0.027	99.37
1.20	21	0.089	0.035	99.21
1.22	20	0.100	0.044	99.00
1.25	19	0.112	0.055	98.74
1.29	18	0.126	0.069	98.42
1.33	17	0.141	0.088	98.00
1.38	16	0.158	0.110	97.49
1.43	15	0.178	0.140	96.84
1.50	14	0.200	0.176	96.02
1.58	13	0.224	0.223	94.99
1.67	12	0.251	0.283	93.69
1.78	11	0.282	0.359	92.06
1.92	10	0.316	0.458	90.00
2.10	9	0.355	0.584	87.41
2.32	8	0.398	0.749	84.15
2.61	7	0.447	0.967	80.05
3.01	6	0.501	1.256	74.88
3.57	5	0.562	1.651	68.38
4.42	4	0.631	2.205	60.19
5.85	3	0.708	3.021	49.88

Figure 5 · MML numbers for a range of VSWR values.

the manufacturer's directions. Removal of too much jacket will have an impact on torsional pull strength (which we are not addressing in this article). Removal of too short a piece of jacket can have serious impact on VSWR. It will almost certainly cause a piece of the jacket to be crimped underneath the ferrule. If the jacket is compressed, it has nowhere to go but to compress the foam dielectric and create a section of lower impedance by altering the value of (D) and (V_g). Basically, the connector should be crimped so that it is optimally connected to the cable in mechanical terms without impacting (D) or (V_g). Figure 8 shows a connector where the ferrule has been pushed away from the connector due to protruding braid, plus the ferrule has been double-crimped. A termination such as this would likely have a very high VSWR value.

Figure 9 shows a comparison of VSWR for an assembly using good workmanship vs. one of poor workmanship

Figure 6 · Properly soldered cable end.

Figure 7 · Properly crimped connector.

Figure 8 · Improperly attached connector.

(i.e., melting of dielectric, improper pin gap, jagged cutting of dielectric and outer conductor, double crimping, etc. Keep in mind that we are using high-quality cable and connectors in this demonstration and that the degradation of performance portrayed by the red curve is strictly due to errors in termination. This demonstration is not an exaggeration. The author has evaluated many cables and cable assemblies both in the lab and in the field and assures you that these errors are commonplace.

Selecting the Right Connector

The overall performance and reliability of the transmission line can be greatly impacted by impedance mismatches within the connector. Connectors that look iden-

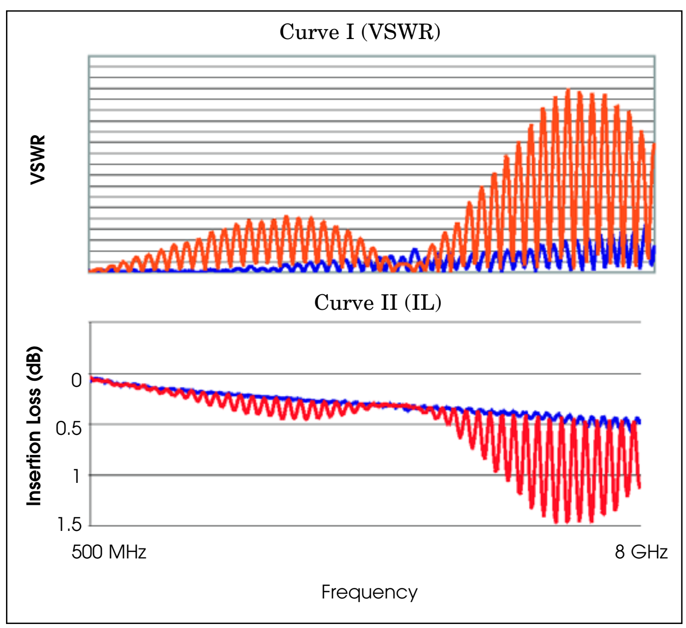

Figure 9 · VSWR for proper vs. improper assembly.

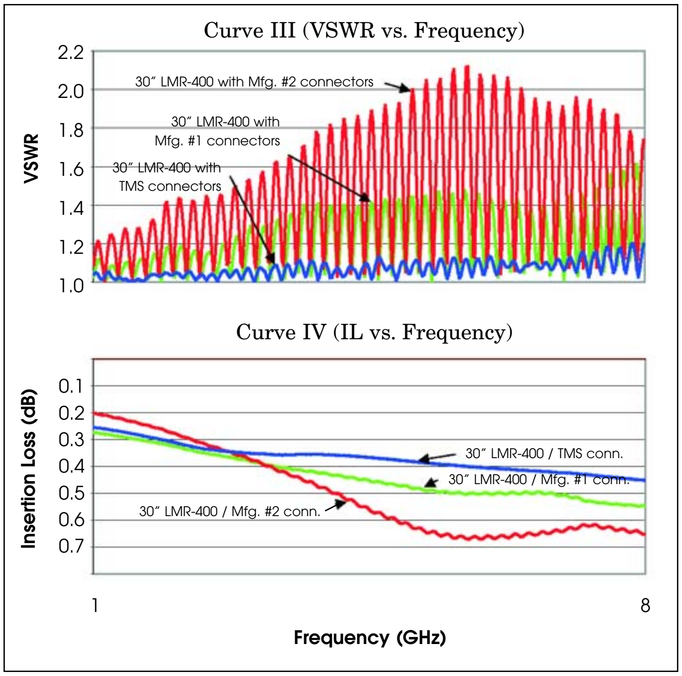

Figure 10 · Electrical performance for three 50 ohm flexible coaxial cable assemblies.

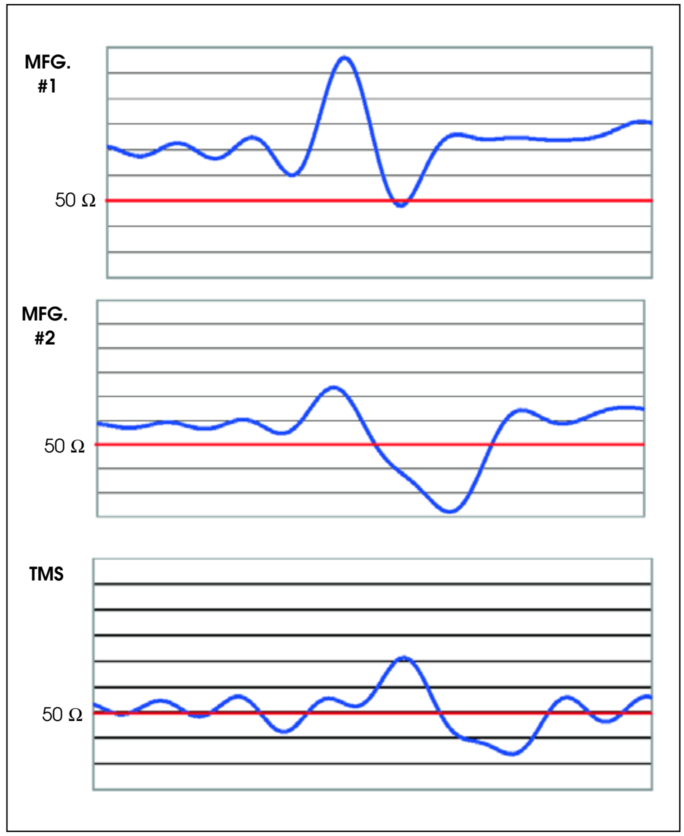

Figure 11 · TDR plots showing impedance deviations through the connectors.

tical may actually perform very differently. The best way to demonstrate this is by reviewing the data of an experiment run to test our suppositions. Figure 10 shows electrical performance of three 50 ohm flexible coaxial cable assemblies. The cable used in the demonstration is TMS LMR-400. The assemblies are the same length and terminated with the same interfaces, however each connector is from a different manufacturer, built and marketed for LMR cable. Since each of the assemblies was built from the same cable lot and terminated by the same person under the same conditions, the steadily increasing VSWR of the assemblies from Manufacturer 1 and Manufacturer 2 can be attributed to reflections because of impedance and mismatches within the connectors. These three curves demonstrate how the size and material transitions within a particular connector will affect performance. The VSWR curves on the right show how the ratio of reflected signal increases with an increase in frequency. The lower curve displays the associated insertion loss for the assemblies. Notice that at some frequency, the mismatch loss attributed to the higher VSWR creates a noticeable divergence in the insertion loss curves. It's conceivable that a short jumper assembly can actually have more than twice the theoretical insertion loss due to the use of inferior connectors or connectors that are not properly compensated for higher frequencies.

Causes of VSWR Variation in Different Connectors

In the next section of the experiment, we ran Time Domain Reflectometry (TDR) plots on the same connectors used in the preceding section. We then sliced them open to better understand the TDR plots and the reason for the high levels of VSWR. (Though it's not the focus of this article, it is almost impossible to ignore the variation in mechanical robustness between the three connectors. While the general wall thickness and ability to withstand coupling nut torquing of the connector from Manufacturer 2 appear to be marginal, the connector from Manufacturer 1 looks downright fragile. There are also many other mechanical parameters that may or may not impact electrical performance. Dimensional tolerances, plating and plating thicknesses, pull strength and pin captivation are just a few.)

Figure 11 demonstrates how easily the performance of the transmission line can deviate from the optimal. The vertical scale is 2 ohms per division. The connectors were swept across 400 ps on an HP8510 at 18 GHz. What we see is frequency-dependent and not an exact representation of the impedance, but at 18 GHz we get a very good idea of what is going on. Some of the things that are noticeable are: (1) how the different manufacturers compensated the diameter of the pin where it is encapsulated by dielectric. The pin diameter of the Times connector

Figure 12 · Pin without compensation.

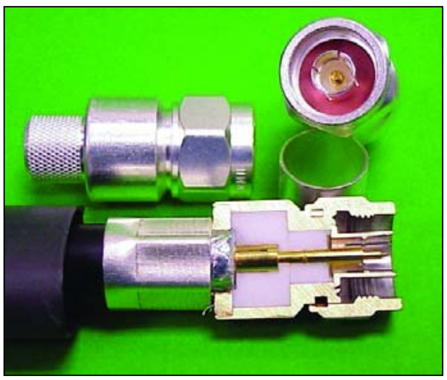

Figure 13 · Pin with large diameter compensation.

increases slightly in the dielectric whereas the pin in the connector in Figure 12 doesn't use any compensation. There is a large diameter compensation in the back of the pin in Figure 13 (over-compensation) and its impact can be seen in the TDR trace as a very large area of lower impedance. This is the primary cause of this connector's high VSWR. It is also possible to detect the impact of the various means of captivating the pins (i.e., slight protrusion or indentation). The impedance mismatch caused by these captivation points is minimal, but if the connector is properly designed, it is possible to actually have the impact work in favor of the connector in terms of VSWR.

How to Minimize Variables in the Field

Using a spring finger or "EZ" connector in the field is a good means of minimizing the variables that will affect performance, because each employs a gold-plated, beryllium copper center pin. Using these connectors in concert with a sharp strip tool, a simple de-burr tool and the proper crimp die can make the termination process almost foolproof.

When possible, such as in the case of cable assemblies that are of standard length or configuration, it is wise to purchase pre-terminated assemblies that have been factory-tested for VSWR and IL across the frequency band of the application.

Conclusion

The connector and and its termination process can have a large impact on the overall performance of a cable assembly. A little extra effort in planning, workmanship and training at this point will pay dividends in system reliability for years to come. You should always be aware of the VSWR vs. frequency performance of the connectors that you are using. Remember, a connector or method of termination may perform satisfactorily at lower frequencies, but cause problems at higher frequencies.

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