Microwave Journal

INVITED PAPER

Challenges Designing 110 GHz Coax Cable Assemblies

Daniel Barnett
Teledyne Storm Microwave, Woodridge, Ill.

While waveguide has been at 110 GHz for a while, the advent of more commercial mmWave applications such as wireless back haul and automotive radar are creating the need for a flexible cable option. Whether used in conjunction with waveguide (e.g., hybrid waveguide-coax-waveguide) or standalone (e.g., a vector network analyzer (VNA) test lead or cable connection between modules), the demand for flexible cable assemblies that operate to 110 GHz is increasing.

This article discusses the technical hurdles and associated decisions to develop a high performance 110 GHz cable assembly, including the 1) cable, 2) connector, 3) test and 4) preparation and resources. These are highly interdependent variables, such that discovering the cause of a problem during development is a combination of science and experience.

CABLE

The flexible cable size chosen for the design is a 0.055 in. (1.4 mm) outside diameter (OD) with jacket, which is a standard size within the industry with an upper frequency above 110 GHz (W-Band). There are other sizes, mostly smaller, that can achieve these frequencies; however, more connector choices are available for the 0.055 in. OD, including 1 mm, SMPS and the proprietary variants of MM4S, G3PO and G4PO.

There are design choices and material challenges for cable construction, depending on which attributes are the primary focus. Is insertion loss more important than ruggedness? Typically, you cannot have both. If loss is important, then a microporous PTFE tape is used, which makes the cable more prone to damage with normal handling. The more rugged choice is an extruded PTFE dielectric, which has an insertion loss penalty. After careful consideration, ruggedness wins, because the target market is test and measurement, where the environment has movement, a fast pace and people are used to a more robust cable. The slightly higher loss is mitigated by the applications that typically use short lengths of cable.

The next design choice is frequency range: should the cable be broadband or one constructed strictly for E-Band (60 to 90 GHz) and W-Band (75 to 110 GHz)? Not knowing how the new E-Band and W-Band applications will use lower frequencies, a broadband cable design is chosen.

Materials and cable constructions that work perfectly well at V-Band and below (i.e., ≤ 70 GHz) sometimes show nonlinear responses above V-Band. When this occurs, there is a diagnostic hunt to identify the problems, with many potential culprits. The factory environment—compressed air and electricity, for example—can introduce intermittent anomalies in the manufacturing process. A fault length resulting in a nonlinear electrical response can be induced either by equipment or materials. Also, a design with tape or wire overlaps can cause periodicity in the electrical performance. Variations in materials from suppliers can be frustrating: one good initial lot of raw material followed by a number of lots of flawed material make the diagnostic hunt more intuitive than scientific.

Once the cable design and construction anomalies have been identified and solved, there is the issue of the test equipment. In a "what came first, the chicken or the egg" conundrum, there is always the nagging doubt about the test setup. Are the test leads good? Is the setup that was used successfully a couple hours ago still in calibration? Someone used the VNA to test at Ka-Band and you changed it back to W-Band; is the recall calibration still valid? The luxury of the time-honored diagnostic method of swapping items when there is a performance anomaly is not an option when there is only one of everything.

CONNECTORS

Choosing the cable design, by definition, narrows the choice of qualified connectors and what connectors to offer, i.e., only those designed in-house, standard connectors offered by outside vendors or a combination. Since this is still a small, evolving market, the choice is to work with all applicable connector suppliers to have the broadest offering.

The size of the component parts and the tolerances needed—while avoiding a skewed tolerance stack-up that results in interference among the component parts—is the shorthand tale of why working at these frequencies is difficult. Depending on the cable dielectric, the wavelength at 110 GHz ranges from 0.083 to 0.100 in. (2.1 to 2.55 mm) and the tolerance of the pin contact below the reference plane is 0.002 in. (0.051 mm). What did not matter at Ka-Band is now the difference between passing and failing.

Are you pursuing a domestic customer base or a global one? If global, then make everything RoHS (Restriction of Hazardous Substances) compliant—a European Union directive—because major customers will demand it, and there is no upside to maintaining two different versions in inventory. Using RoHS solders and processes requires a higher level of assembler attention and skill. When terminating the connector, heat might be a concern with the ferrule/housing if excessive heat transfer causes the dielectric to change or grow. If the design of the connector is point-and-shoot, the length of the center conductor that is inserted into the center contact may change the response curve of the connector. Here, real-time X-ray is invaluable.

There are some common problems when designing a connector in-house or troubleshooting with a trusted outside supplier. Initially, when making the transition from simulated data provided by CST, HFSS or home-brew software to empirical data, the cable or connector will not perfectly match the model. Be prepared for many iterations of design improvement, as the empirical data informs the design software. Whether using in-house design expertise or relying on a trusted external vendor, the ability to precisely machine component parts (e.g., a ferrule or a dielectric bead) is quite useful and cuts down the development time dramatically, as shown below.

The difference in equipment (e.g., VNA and related adapters) can make a difference in the shape of insertion loss and the VSWR or return loss curves. What you see may differ from what your customer or supplier sees due to the age of the calibration, age and condition of the adapters or settings used on the VNA. The importance of listening, graciously receiving feedback, providing samples and trying to re-create a problem are opportunities to learn.

Figure 1 shows a real example of iterative design and the utility of having a precision machine shop in-house. Early in the design, it was clear that the transition from cable to connector had an impedance mismatch which severely affected performance. The time domain reflectometry (TDR) function on the network analyzer highlighted this, and the most promising design change was adjusting the dimension on one of the component parts by either 0.001 or 0.002 in. (0.025 or 0.051 mm). Having a machine shop onsite made the decision easy: make two parts. Figure 1a shows "before" and Figure 1b "after." Having two parts with one dimension being a thousandth of an inch (0.025 mm) different made the fine tuning process easy. From Figure 1a, the design had a 54 Ω inductive hump; slightly modifying a component part reduced the inductive hump to 52 Ω, as shown in Figure 1b. There is also a corresponding improvement, although less dramatic, in the capacitive dip in the connector, by 0.5 Ω. This is an example of the tuning process, as improvement leads to change, which leads to compromise, which leads to iteration. Fixing one section of the connector changes the response of another section, making design modifications a series of compromises.

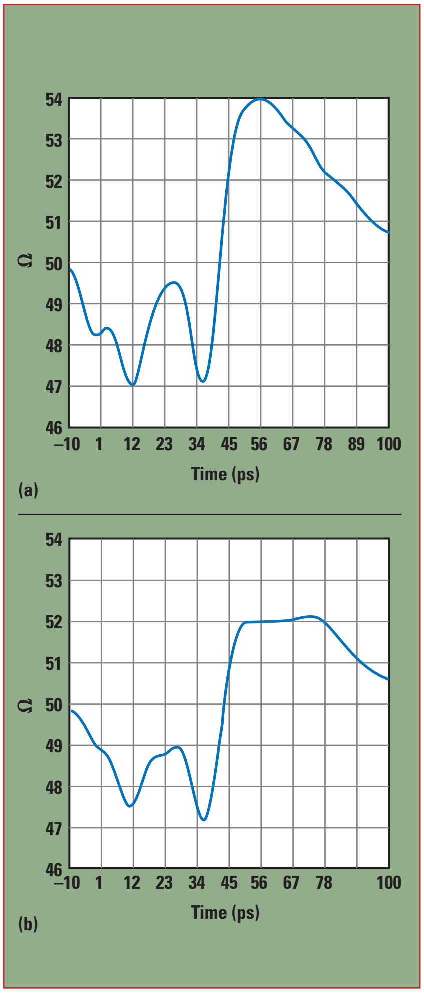


Fig. 1 TDR response of the initial connector design (a) and after tuning to reduce the inductive hump (b).

While all of these problems apply to the development and testing of the 1 mm thread-on connector, there are additional perils with push-on connectors (e.g., SMPS and proprietary variants). These connectors have the theoretical capability of reaching 100 GHz into an air section, but most of the vendors have not tested them to that frequency because they do not have the equipment. This market segment is small, and the capital expense of a 110 GHz VNA cannot be justified. There are very few 1 mm to SMPS or proprietary variant adapters that are available for testing; the ones that are available are very

expensive and, normally, you need two. There may not be any calibration kits for the push-on connectors. This means gating is used to get a realistic reading, which is somewhat interpretive. The concept of allowable axial and radial misalignment can lead to non-repeatable measurements.

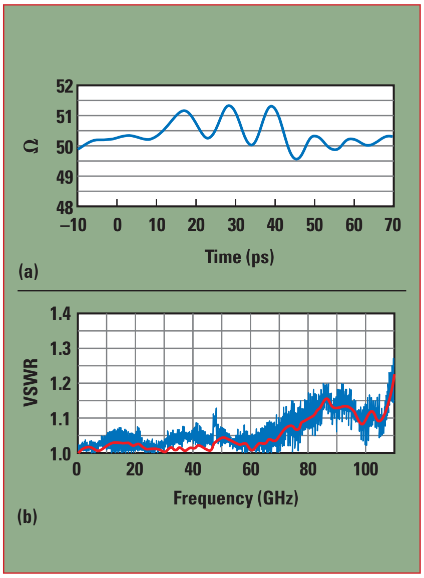
TEST

The first hurdle with testing is the cost of the equipment and creating and approving the business case. This effort is not for the faint of heart: a VNA capable testing up to 110 GHz costs more than $400,000, the calibration kit is over $30,000 and adapters are $1,500 apiece (cheaper by the dozen). There is no way around this expense if you want to develop or manufacture E- and W-Band cable assemblies.

A VNA of this type is much like our brains; we only harness about 10 percent of the capability of the machine. While, in rare instances, some esoteric functions will be used, the same setup is normally used all the time. This means the test setup and test technician are critical to successful cable and connector development and subsequent manufacturing. Since these machines are used in various applications and organizations (e.g., universities, electronic hardware testing), your Anritsu, Keysight or Rohde & Schwarz applications engineer may not be familiar with the eccentricities of the 110 GHz coaxial cable assembly. Your test technician might provide the needed perspective to solve a problem. Allow him or her to get training from your VNA vendor, just a little bit at a time. With so many equipment functions to learn, it takes time to digest the initial training, spend time on the unit, test, make mistakes, test again and come up with the next set of questions.

Different brands of adapters perform differently, and while price is normally predictive of performance, this is not always the case. When figuring out what adapters work best in your environment, do not buy enough to hit the first price break. Buy a couple and see how they work before committing. Because of the price of the adapters, proper interface care and handling of the connectors is a must. Inspect the connector interface under magnification to insure no damage.

These are sensitive machines that are affected by temperature shifts. A 0.5°C change in temperature, which is quite normal in a loosely temperature-controlled test environment from the morning to the afternoon, can affect performance. The calibration may not last long and, if the measurements are critical, it is safer to do a new calibration. An indication of an old calibration is a nonlinear response at the frequency where the VNA extender takes the signal to 110 GHz or accelerated degradation at the upper frequency limit.



▲ Fig. 2 TDR response (a) and VSWR (b) of the final connector design.

While the natural tendency for mating an SMA or 2.4 mm connector to a test lead of a VNA is to snug it twice with the torque wrench, doing that with these connectors will not improve performance and will damage the threads and internal components of the adapter. Always use a calibrated torque wrench when mating the thread-on connectors; 4 in./lb (0.45 Nm) is not much, but it is tighter than finger-tight.

Finding the source of a poor performing cable assembly is always difficult, especially with new technology. Is it the cable or connector or test setup going south—when it was fine just minutes ago? Having a gold standard that has been tested and verified for stable performance over several months is helpful in these instances.

PREPARATION AND RESOURCES

These are called the mmWave frequencies for good reason. Everything is small, tolerances are tight, equipment is sensitive, you blink and the dielectric bead has disappeared. How each company prepares the cable for terminating is specific, and each manufacturer has unique tricks. The important point for an excellent result is adherence to a set of processes that are repeatable and can be audited. Whether you trim the cable using a blade, a saw or a laser, whether you tin and wick the contact, if applicable, or meter the solder, the adherence to these processes and acceptance of the processes by the manufacturing personnel is paramount.

Another paradigm shift pertains to manufacturing. Cable manufacturers are used to making L- through V-Band cables, with certain expectations for the time to manufacture and test and yields. The E- and W-Band cables are different; everything is slower by at least an order of magnitude: the time to prep and inspect the cable, terminate the connectors, identify where a problem resides (e.g., cable, connectors, termination, test setup) or when to accept failure and move on. Making this transition is easier if the manufacturing personnel are dedicated to the product rather than switching back and forth between high and low frequency cable assemblies.

SUMMARY

Compare Figure 1, which shows the connector's performance at the beginning of the development process, to ***Figure 2***, which shows the performance of the finished design, now in production. Connector discontinuities that were in the 7 Ω range, inductive to capacitive, are now in a 2 Ω range, and the VSWR confirms a cable assembly performing well to 110 GHz.

This article is a primer discussing some of the common problems encountered when designing and developing 110 GHz cable assemblies, rather than an in-depth, technical, cause-solution explanation. Users of these cables will find information to help select a supplier and some shortcuts to diagnose problems. The discussion highlights some of the reasons why a 110 GHz cable assembly that looks identical to a Ka-Band cable assembly and whose SMPS connector looks very similar to the SMPM connector, costs 3 to 5× more than the Ka-Band cable assembly.

The 110 GHz cable assembly market is growing and, as more commercial systems become available, demand will rise. After the initial use in automotive radar and wireless backhaul, there is interest in other communications services, including the soon-to-be launching satellite constellations such as OneWeb and Telesat.■