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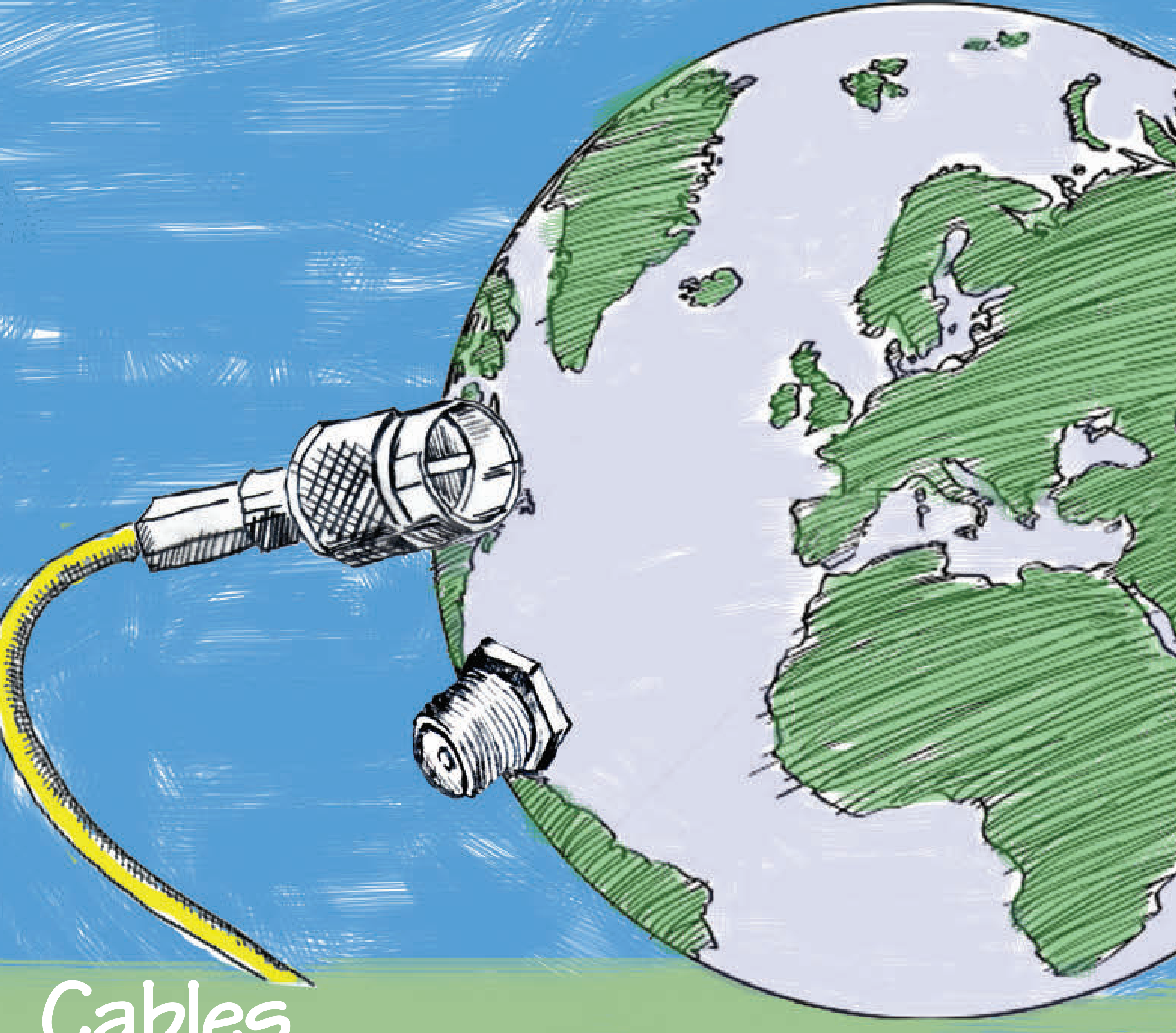

Cables & Connectors 2014

A Special Supplement to

Microwave Journal

Cables and Connectors Supplement

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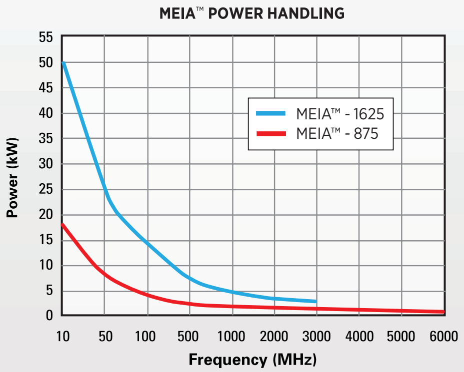

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RF Cable and Connector Outlook

Richard Mumford and Pat Hindle
Microwave Journal *Editors*

To evaluate the cable and connector market on the ground, *Microwave Journal* has taken a snapshot of activity from manufacturers in the U.S. and in Europe who offer a frontline perspective of the outlook for the market in 2014, expectations for growth and drivers impacting product development.

MARKET OUTLOOK FOR 2014

Spectrum Elektrotechnik's view is that in general there will not be significant change compared with recent years, while Huber + Suhner envisages moderate growth. W. L. Gore & Associates (Gore) states, "Uncertainty in the global economy and government cutbacks are affecting the amount of investment in research and innovation, particularly in smaller companies. We believe that this will have an impact in two major areas — the supply chain and innovation. To remain competitive in the market, established suppliers will need to advance the development of new materials, products and technologies."

Gore continues, "Also, we believe that there will be more emphasis on selecting solutions that last longer, therefore, saving time and money over the life of projects or systems. This focus on products that survive the test of time will be the driving force behind innovation, with more customers requesting information about durability testing in their application environments."

SPINNER's focus is primarily related to jumpers (cable assemblies) which are the company's core business and general connectors, with both being predicted to grow in 2014. SPINNER comments, "The tremendous effort to build mobile broadband networks has definitely increased the demand for both connectors and jumpers. We see a rising demand for mid-sized connectors to support more compact housings for BTSs and antennas as well as better PIM that primarily addresses the replacement of N connectors, which has mainly been driven by the U.S. so far."

Mobile communications is also seen as a factor by Molex Inc., which states, "Higher data rates and demand for functionality are major drivers for growth in mobile wireless telecommunications and networking. As an industry, we can expect continued expansion in sales of mobile and wireless devices, in tandem with high rates of technology refresh. Key markets for RF/microwave are growing across the board at a robust pace, including a strong rebound in the automotive industry. The sales pipeline is full across wireless markets, spurred by high volume and high value solutions and tools to make it easier for customers to more quickly bring new products to market."

AREAS OF GROWTH

Concentrating on the company's core markets, SPINNER predicts, "The jumper market

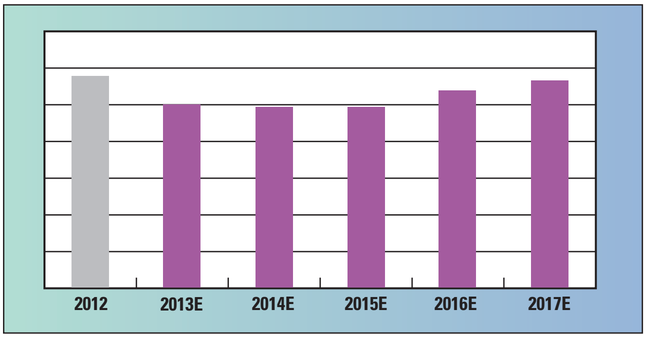

Fig. 1 RF jumper cables for BTS, 2012-2017 (Source: EJL Wireless Research).

will grow and at the same time jumpers will become longer. There is also a tendency for LF1/2" to increase market share compared to SF1/2". The ongoing introduction of BBUs and RRUs will reduce the need for feeder lines, which will be reflected in longer jumpers being used between RRUs and antennas."

EJL Wireless Research also supports that feeder cables are declining in use as they are being replaced by fiber optic cables. The jumper cable stability and future growth is supported by EJL Wireless Research as it sees RF jumper cable demand remaining stable due to remote radio head (RRH) deployments on BTS sites. Its market projection for feeder cables is shown in ***Figure 1*** with flat demand in 2013-15 but some growth expected in 2016-17.

EJL Wireless Research analyzed the feeder and jumper cable size for BTS for 2012. ***Figures 2*** and ***3*** show the size breakdown and total market size for feeder and jumper cables, respectively. About half of the feeder cable diameters are 1¼" or larger with a total market size of $380.7 million. On the other hand, close to half of jumper cables are ½" or less, to provide flexibility, with a total market size of $280.3 million.

With regard to connectors, SPINNER maintains, "From the perspective of quantity, connector growth will be dominated by 7-16 in 2014. Nevertheless, most growth percentage wise (market share) will be with 4.1-9.5 and 4.3-10. The 4.1-9.5 will grow more significantly in North America based on carrier announcements to replace N with 4.1-9.5. 4.1-9.5 based products such as BTS and antennas which have been adapted to 4.1-9.5 and installations have started in Q1 2014.

"While North America is currently primarily focusing on 4.1-9.5 deployments, the rest of the world is looking forward to 4.3-10 with high expectations (and we cannot say North America is not). We have developed 4.3-10 and the system is currently undergoing standardization. Once this is finalized and major carriers/OEMs have introduced them on their equipment, we expect the floodgates to open for this new connector system."

EJL Wireless Research confirms the dominance of 7/16 in as shown in ***Figure 4***. Almost 70 percent of DIN/N connectors for BTS in 2012 were ½" or smaller with a total market of $213.9 million. EJL Wireless Research also analyzed the BTS connectors by type which is shown in ***Figure 5***. This shows the dominance of ½" or smaller DIN straight connectors. EJL Wireless Research also sees a trend that RF connectors are beginning to see mini-DINs and MCIC types for cables/antennas that are driven by TD-LTE deployments in China and the U.S.

Molex sees: "Significant development work to add RF features in everything from appliances to automobiles. In the immediate future, we foresee new technologies such as 4K HDTV and cameras to deliver to savvy consumers the higher resolution experience that will gain mass market appeal as content grows."

With its wide range of cable and connector products, Huber + Suhner sees most growth in the transportation sector, particularly public transport, military and space applications, and to facilitate communication infrastructure changes. In its field of application, Spectrum Elektrotechnik states, "The most growth we expect is for phase matched cable assemblies and hermetically sealed connectors and adapters."

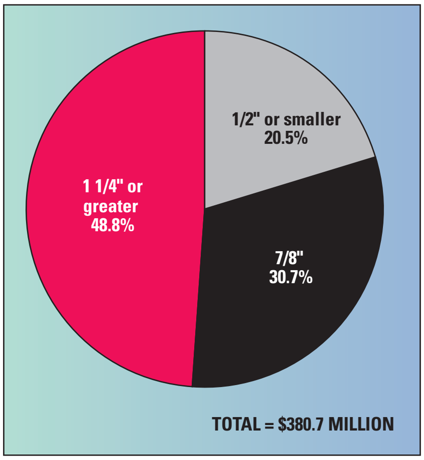

Fig. 2 2012 RF feeder cables for BTS by diameter (Source: EJL Wireless Research).

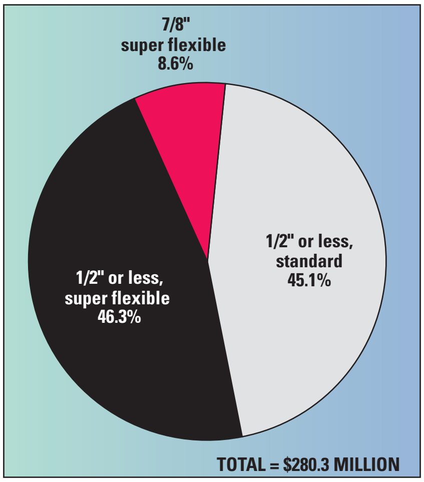

Fig. 3 2012 RF jumper cables for BTS (Source: EJL Wireless Research).

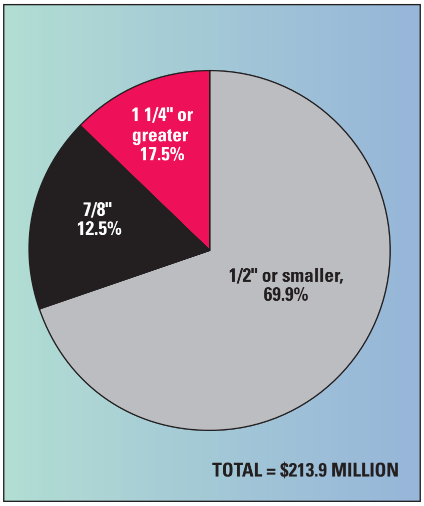

Fig. 4 2012 RF DIN/N connectors for BTS by size (Source: EJL Wireless Research).

Gore envisages environmental factors being important, commenting: "As industries continue to deal with tightening budgets, the biggest area of growth we see for microwave/RF applications is the demand for reliable components — especially cable assemblies — that withstand demanding environments. For example, portable analyzers are increasingly being used in the aerospace and telecommunications industries to facilitate testing out in the field. These analyzers need cable assemblies that can withstand the extreme environmental conditions as well as frequent handling during use. Specific applications that are emerging — and will be a focus for many — include radar systems, millimeter-wave applications, and automotive radar."

With regard to geographical growth, Molex views its global network at the forefront of today's RF/microwave technologies, providing complete support at every phase of the product life cycle. The company says, "Asia represents the fastest regional growth market with proliferation of consumer, networking, cellular mobile products and automotive demand on the rise. In Europe and North America, there is an increasing demand for connectivity across many platforms, driving a need for greater bandwidth to support handheld devices, notebook computers, WiFi access points and other networking activity."

Gore identifies new players in the market, stating, "As the mobile phone and wireless service providers continue to reduce hardware costs and improve system reliability, large underserved markets like Africa may rival China in terms of growth."

Huber + Suhner predicts the potential for growth being in the established markets of North America, Western Europe and APAC. Spectrum Elektrotechnik is concerned that the impact of Germany and several other European companies cutting their military budget, while the "U.S. is stagnating" could mean limited growth. However, SPINNER sees the introduction of 4.1-9.5 in North America as being significant while the rest of the world starts to adapt to LF1/2" jumpers.

DRIVERS FOR PRODUCT DEVELOPMENT

Success is dependent on developing the right product at the right time for the right market. However, achieving that goal is reliant on a multitude of factors.

Gore's current approach is to: "Continue to focus on delivering reliable electrical and mechanical integrity in demanding environments. In the aerospace industry, for example, cables need to withstand abrasion, cut-through, and routing during installation and maintenance as well as vibration, flexibility, and extreme temperatures during operation.

"Aircraft manufacturers are continuing to look for solutions that lower the total weight and cost of cable assemblies and improve their installation process, all without compromising signal integrity over the life of the aircraft. This translates to a demand for lighter, tougher, more durable cable technologies that minimize the need for frequent cable replacements."

SPINNER takes the view that, "The jumper market is developing more and more into a project driven installation business, which is driving us to offer the highest possible flexibility to our customers, facilitated by focusing on fast and customized manufacturing. Flexible means, manufacturing different jumper types with individually configured connectors and cable length within a few days. To achieve this, the focus is not just on product development, but also the development of our manufacturing plants and processes to ensure quick turnaround time while maintaining high quality."

The company also believes that with the introduction of LTE, low PIM has become even more critical alongside the increasing need for miniaturization since BTS and antenna housings are quite often dominated by the size of the connector system. SPINNER says, "Our customers see most of the problems in the field going back to incorrect installation or inappropriate material usage; this is why we developed a more robust and less error-prone 4.3-10 connector system. Basically, SPINNER is committed to 4.3-10 that support the key factors of PIM, size and reliability."

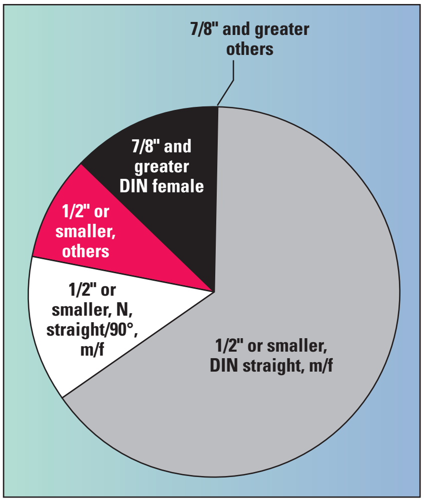

Fig. 5 2012 RF connectors for BTS by type (Source: EJL Wireless Research).

Low PIM requirements have been a growing concern over the last few years as system requirements have tightened up as the industry learned more about its effects. System integrators are now requiring very low PIM specifications and might move to even lower levels that could push many cable/connector manufacturers out of the this market. Current industry standards require PIM levels of about -150 dBc or better, but some in the industry have hinted that they might require levels as low as -160 dBc in the future. This will also impact testing as designing test systems that are capable of accurately measuring down to the level will be difficult. Read "Passive Intermodulation Characteristics" by Murat Eron of the Wireless Telecom Group in this issue for more specifics about PIM and how it affects cable design and systems.

Focusing on the specific needs of its customers and its product offering, Spectrum Elektrotechnik sees a key driver being "phase adjustable self-locking connectors with a wide adjustment range, e.g., 280° at 18 GHz."

Huber + Suhner identifies key drivers being to provide energy ef-

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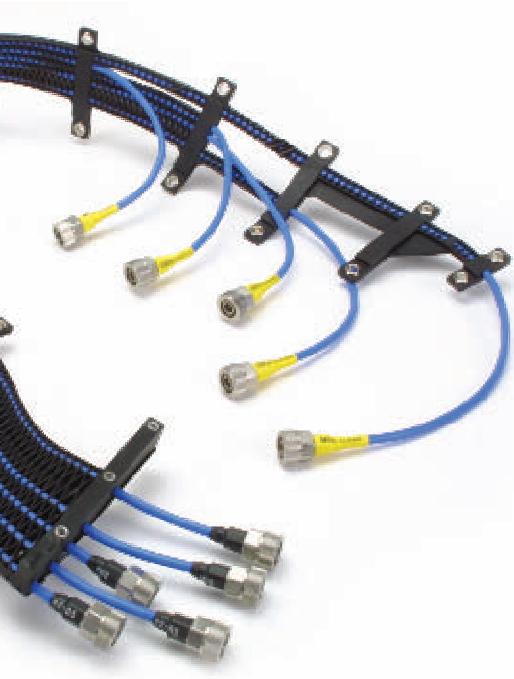

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ficiency and the production of environmentally friendly product with the elimination of hazardous substances and the adherence to safety standards. It also sees increased bandwidth and the subsequent demand for higher frequencies being significant, along with the need to reduce weight and size, requiring miniaturization.

Miniaturization is also a consideration for Molex as are the requirements of OEMS. The company states, "Based on proven connector technologies, specialty ganged, stacked, backplane and other multi-port I/O solutions that group connectors in a common housing are gaining traction among OEMs looking to streamline designs and save space in many different systems. Miniaturization has enabled better designs in smart products, earbuds, music players, streaming video and audio devices.

"Low frequency microcoaxial RF solutions represent a high volume market, especially for ultra-miniature stamped connectors. Microcoaxial RF connectors are a low-profile (available down to 1 mm mated height) wire-to-board solution – ideal for embedding in small, handheld wireless devices such as mobile phones, radio-communication equipment, GPS systems, tablet computers and a plethora of content streaming consumer applications."

SUMMARY

Most companies see the BTS cable assembly market being stable with flat to moderate growth in the coming years. There seems to be a shift away from feeder cables due to the ongoing introduction of BBUs and RRUs plus some replacement by fiber optical cables. The jumper cable market is expected to experience moderate growth due to the deployment of remote radio heads. There seems to be a market push for higher quality cables that are more durable and have lower PIM. As more LTE networks are deployed, PIM becomes more important and requirements are likely to become even more stringent forcing cable assembly manufacturers to improve quality and testing procedures. While the 7/16 RF connector dominates the current BTS market, other connector types are being introduced and are expected to grow in popularity. RF connectors are beginning to see the use of mini-DINs and MCIC types for cables and antennas driven by TD-LTE deployments in China and the U.S. ■

ACKNOWLEDGMENT

Thanks to EJL Wireless Research who provided the data and graphics for the market analysis and projections in addition to inputs on market trends (www.ejlwireless.com, info@ejlwireless.com).

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NEW Precession Test 75Ω (CBL)	DC-3	N, F	2-6	-55/+105
Armored (APC)	DC-18	N	6.0-15	-55/+105
Low Loss (KBL-LOW)	DC-40	2.92	1.5-6.6	-55/+85
Phase Stable (KBL-PHS)	DC-40	2.92	1.5-6.6	-55/+85

All models 50Ω except as noted.

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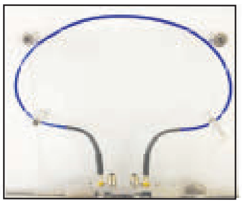

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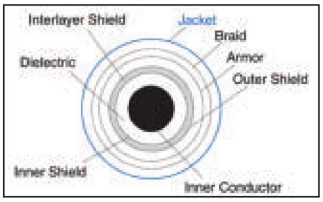

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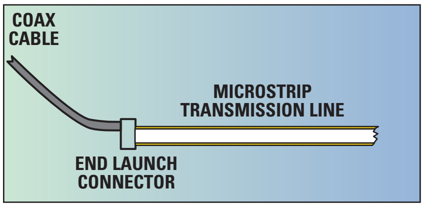
Signal Launch Methods for RF/Microwave PCBs

John Coonrod
Rogers Corp., Chandler, AZ

Transferring high frequency energy from a coaxial connector to a printed circuit board (PCB) is often referred to as a signal launch and it can be difficult to characterize. How efficiently energy is transferred can vary a great deal from one circuit structure to another. Factors such as the PCB material, its thickness and the operating frequency range affect performance, as well as the connector design and its interaction with the circuit material. With an understanding of the issues, including the differences in signal-launch configurations, and by reviewing some examples of ways to optimize RF/microwave signal launches, performance can be improved.

Achieving an effective signal launch is design dependent, with broadband optimization typically more challenging than narrowband. Design of a high frequency launch usually grows in difficulty with increasing frequency, and can be more problematic with thicker circuit materials and more complicated circuit constructions.

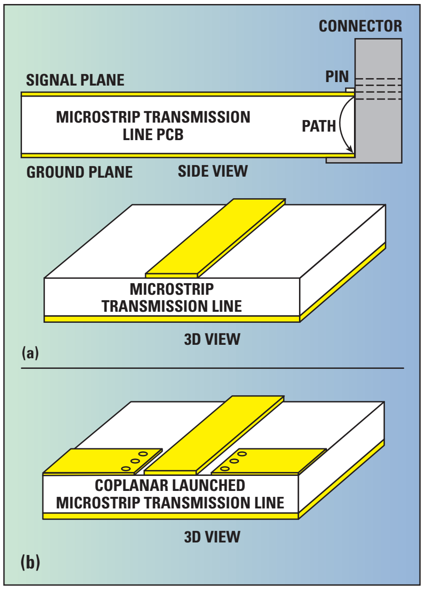


▲ *Fig. 1 Signal launch from a coaxial cable and connector to a microstrip.*

SIGNAL LAUNCH DESIGN AND OPTIMIZATION

A signal launch from a coaxial cable and connector to a microstrip PCB is illustrated in ***Figure 1***. The electromagnetic (EM) fields traveling through the coaxial cable and connector have a cylindrical orientation while the EM fields in the PCB have a planar or rectangular orientation. When the fields transition from one propagating medium to another, they change orientation to accommodate the new environment, causing anomalies. The transition depends upon the type of medium; whether a signal launch is being made, for example, from a coaxial cable and connector to microstrip, grounded coplanar waveguide (GCPW), or stripline. The type of coaxial connector also plays an important role.

Optimization may involve several variables. Understanding the EM field orientation within a coaxial cable/connector can be useful, but the ground return path must also be considered as part of the propagating medium. It is often beneficial to achieve smooth impedance transitions from one propagating medium to another. Knowing the capacitive and inductive reactances at impedance junctions can provide

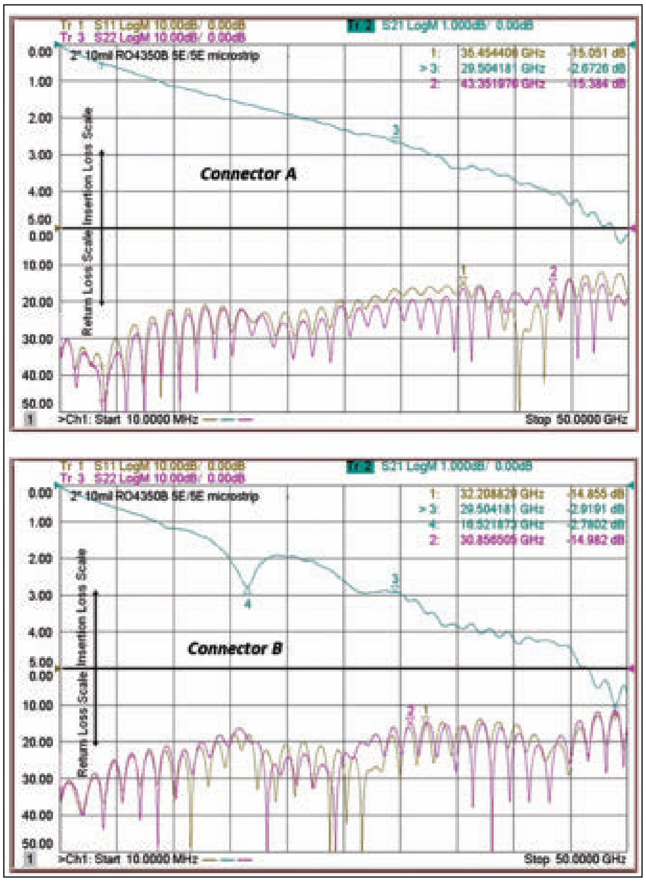


▲ *Fig. 2 Representation of a thick microstrip transmission line circuit and the lengthened ground return path back to the connector (a), a grounded coplanar launched microstrip circuit (b).*

insights into the expected behavior. When three-dimensional (3D) EM simulation is available, current-density mapping can be used. In addition, best practices associated with radiation loss can serve as guidelines.

Although the ground return path between a signal launch connector and a PCB may not appear to be an issue, the ground return path from the connector to the PCB are ideally continuous and uninterrupted; this may not always be the case. There is typically some small surface resistance between the metal of the connector and the PCB. There may also be small conductivity differences between the solder that joins the different parts and the metal of those parts. These small differences usually have minor effects at lower RF and microwave frequencies, but they can significantly affect performance at higher frequencies. The actual length of the ground return path can play a role in the quality of launch that is achieved with a given connector and PCB combination.

As ***Figure 2a*** illustrates, when EM energy transitions from a connector pin to the signal conductor of a microstrip PCB, the ground return path back to the connector housing can be lengthy for a thick microstrip transmission line. Using a PCB material with a relatively high dielectric constant can exaggerate the problem by leading to a longer electrical length in the ground return path. Any lengthening of this path can result in frequency-dependent issues typically linked to a localized difference in phase velocity and capacitance. Both are related and affect the impedance in the transition area and cause differences in return loss. Ideally, the length of a ground return path should be minimized, with no impedance anomalies in the signal launch area. Note that the grounding point of the connector in Figure 2a is shown only on the bottom of the circuit. This is a worst-case scenario. Many RF connectors have grounding pins on the same layer as the signal. In that case, the PCB will have ground pads there, as well.



▲ *Fig. 3 Coplanar launch microstrip circuit tested with similar end launch coaxial connectors having different ground separations.*

Figure 2b represents a coplanar launched microstrip circuit, where the body of the circuit is microstrip but the signal launch area is a grounded coplanar-waveguide (GCPW). Coplanar launched microstrip is advantageous because it minimizes the ground return path and has other beneficial properties. When using a connector with ground pins on both sides of the signal conductor, the ground pin separation distance can have a significant impact on performance. It has been demonstrated that this distance impacts the frequency response.[1]

In an experiment with a coplanar launched microstrip on 10-mil-thick RO4350B™ laminate from Rogers Corp., similar connectors are used, but with different ground spacings at their coplanar launch interfaces (see ***Figure 3***). Connector A has a ground separation of approximately 0.030", while Connector B has a ground separation of 0.064". The connectors launch onto the circuit the same in both cases.

The x-axis shows frequency, with each division representing 5 GHz. Performance is comparable at lower microwave frequencies (< 5 GHz), but above 15 GHz, performance of the circuit with wider ground separation degrades. The connectors are similar, although there is a slight difference in pin diameters between the two models, Connector B has a larger pin diameter and is designed for use with a thicker PCB material. This may also have contributed to the performance differences.

A simple and effective method for optimizing signal launch is to mini-

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Excellent Phase Stability vs. Flexure	± 3.6° @ 18 GHz (When wrapped 360° around a 1.95" radius mandrel)	± 3.6° @ 18 GHz (When wrapped 360° around a 2.35" radius mandrel)	± 5.4° @ 18 GHz (When wrapped 360° around a 3.0" radius mandrel)
Amplitude Stability vs. Flexure	⩽ ± 0.2 dB @ 18 GHz		
Good Phase Stability Over Temperature	250 ppm max. @ + 22 ~ + 100°C		
Operating Temperature for Cable Assembly	- 50 ~ + 125°C		
Common Features	Ultra low loss, higher power handling capacity & lighter weight compared with other similar size cables		
Application	Commercial System, Test&Measurement, Military, Aerospace,		

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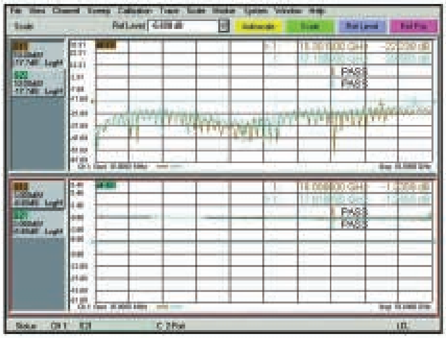
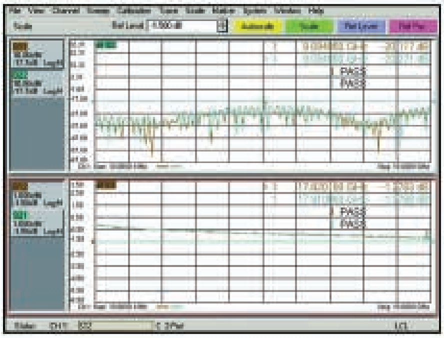
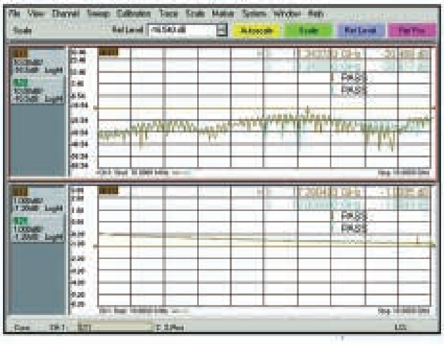
Insertion Loss and Return Loss for LL142, SMA M-SMA M, 18GHz (Typ.)



Insertion Loss and Return Loss for LL235, SMA M-SMA M, 18GHz (Typ.)



Insertion Loss and Return Loss for LL335i, SMA M-SMA M, 18GHz (Typ.)



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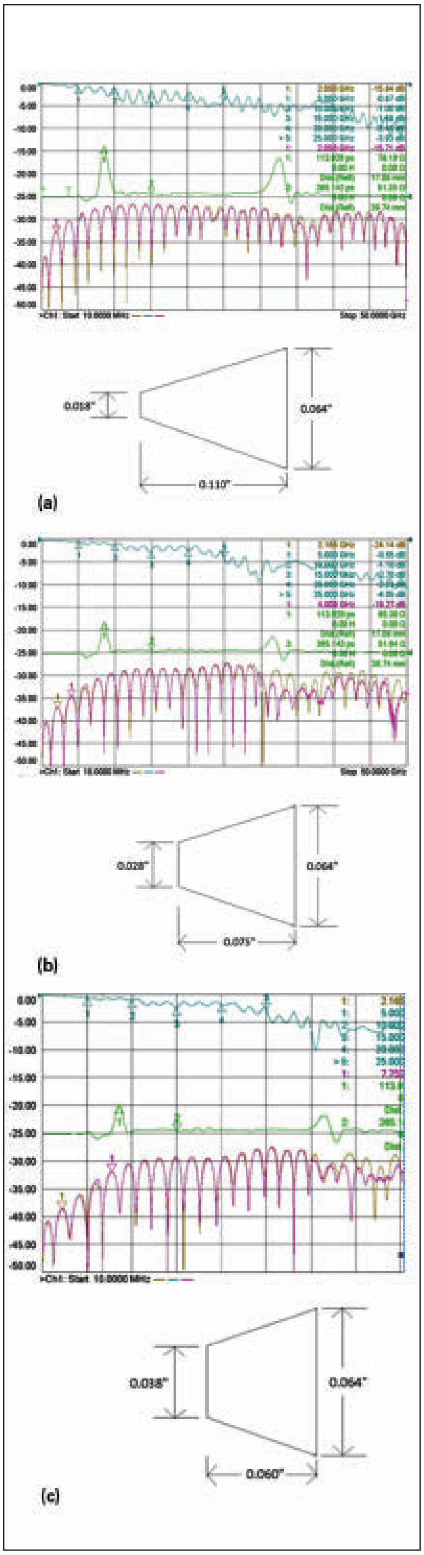
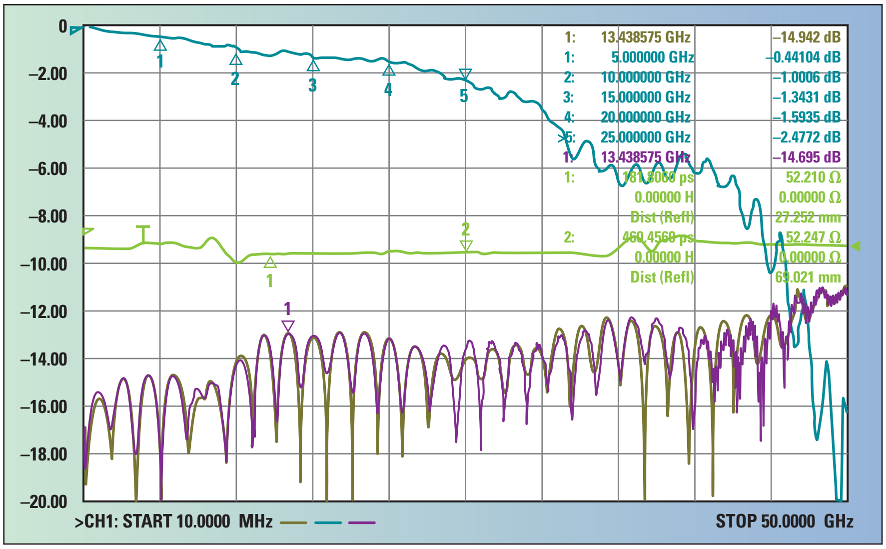


▲ *Fig. 4 Performance of three microstrip circuits with different tapers; the original design having a long narrow taper (a), the taper length reduced (b), and the taper length reduced still further (c).*



▲ *Fig. 5 Performance that is further optimized.*

mize impedance mismatches in the signal launch area. A rise in the impedance curve is basically due to an increase in inductance while a dip in the impedance curve is due to an increase in capacitance. For the thick microstrip transmission line shown in Figure 2a (assuming a PCB material with a relatively low dielectric constant of about 3.6), the conductor is relatively wide – much wider than the connector's center conductor. With a large dimensional difference between the circuit's conductor and the connector's conductor, there is a strong capacitive spike at the transition. This can often be reduced by tapering the circuit's conductor to form a more narrow transition where it joins with the coaxial connector pin. Narrowing the PCB conductor makes it more inductive (or less capacitive), offsetting the capacitive spike in the impedance curve.

Frequency-dependent effects must be considered. A taper occurring over a long distance provides a greater inductive effect at lower frequencies than a shorter taper. For example, in the case of a signal launch with poor return loss at lower frequencies and having a capacitive impedance spike, a longer taper may be suitable. Conversely, a short taper has a greater effect on higher frequencies.

For a coplanar-launched geometry, the adjacent ground planes can increase the capacitance when they are close to the signal conductor. Frequency-dependent adjustments are often made through the combinations of signal taper and ground plane spacing to modify the inductance and capacitance of the signal launch as required. In some cases, the coplanar spacing is wide over a certain distance of the taper, correlating to some band of lower frequencies. The spacing then narrows at a wider portion of the taper and over a short distance to affect higher frequencies. In general, narrowing the conductor taper adds inductance. The length of the taper affects the frequency response. Altering the adjacent coplanar ground spacing changes the capacitance and the distance of the adjacent spacing influences the frequency band over which the change in capacitance is most effective.

EXAMPLES

Figure 4 provides a simple example. Figure 4a is a thick microstrip transmission line with a long and narrow taper. The taper is 0.018" (0.46 mm) wide starting at the edge of the circuit and over a length of 0.110" (2.794 mm), it transitions to the width of a 50 Ω conductor, 0.064" (1.626 mm). The taper is reduced to shorter lengths in Figures 4b and c. Field-serviceable, pressure-contact, end-launch connectors are used and

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not soldered, so the same connector is used in each case. The microstrip transmission line is 2" (50.8 mm) in length and fabricated on a 30 mil (0.76 mm) thick RO4350B™ microwave circuit laminate, with a dielectric constant of 3.66. In Figure 4a, the blue curve represents insertion loss (S_{21}), with many ripples in the response. In contrast, S_{21} in Figure 4c has the least number of ripples. As these curves reveal, the trend is for improved performance with shorter taper.

Perhaps the most telling curves in Figure 4 show the impedance of the cables, connectors and circuit (the green curves). The large positive peak in Figure 4a represents the connector on the circuit attached to a cable at port 1. The peak on that same curve to the right is the connector at the other end of the circuit. The large impedance peak is reduced with a reduction in taper length. The improvement of the impedance match in the signal launch areas is due to the taper becoming wider as it is shortened, the increase in taper width correlating with a reduced inductance.

An excellent reference on signal launch,[2] which uses this same material and material thickness in its examples, offers some further insight into circuit dimensions in the signal launch area. A coplanar launched microstrip built with its recommendations (see ***Figure 5***) yields performance superior to that of Figure 4. The most obvious improvement is elimination of the inductive spike in the impedance curve, which is actually a mix of a slight inductive spike and a slight capacitive dip. Having the correct taper minimizes the inductive spike, while additional capacitance is provided by the coupling of the coplanar line adjacent grounds in the launch area. The insertion loss curve for Figure 5 is smoother than shown in Figure 4c and the return loss curve is also improved. The example in Figure 4 will have a different outcome for a microstrip circuit on a PCB material with higher dielectric constant, or different thickness, or using a different connector style.

Signal launch is a complex issue and can be influenced by many different factors. This example and these guidelines are intended to assist designers in understanding some of the basic principles. ■

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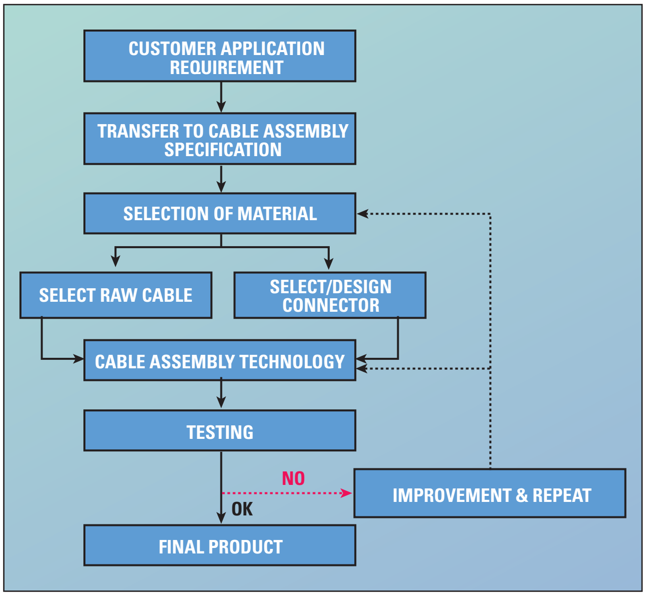
Optimizing Cable Assemblies per Application Requirement

Wei Liu and Da Wenpen
MICable Inc., Fuzhou, Fujian, China

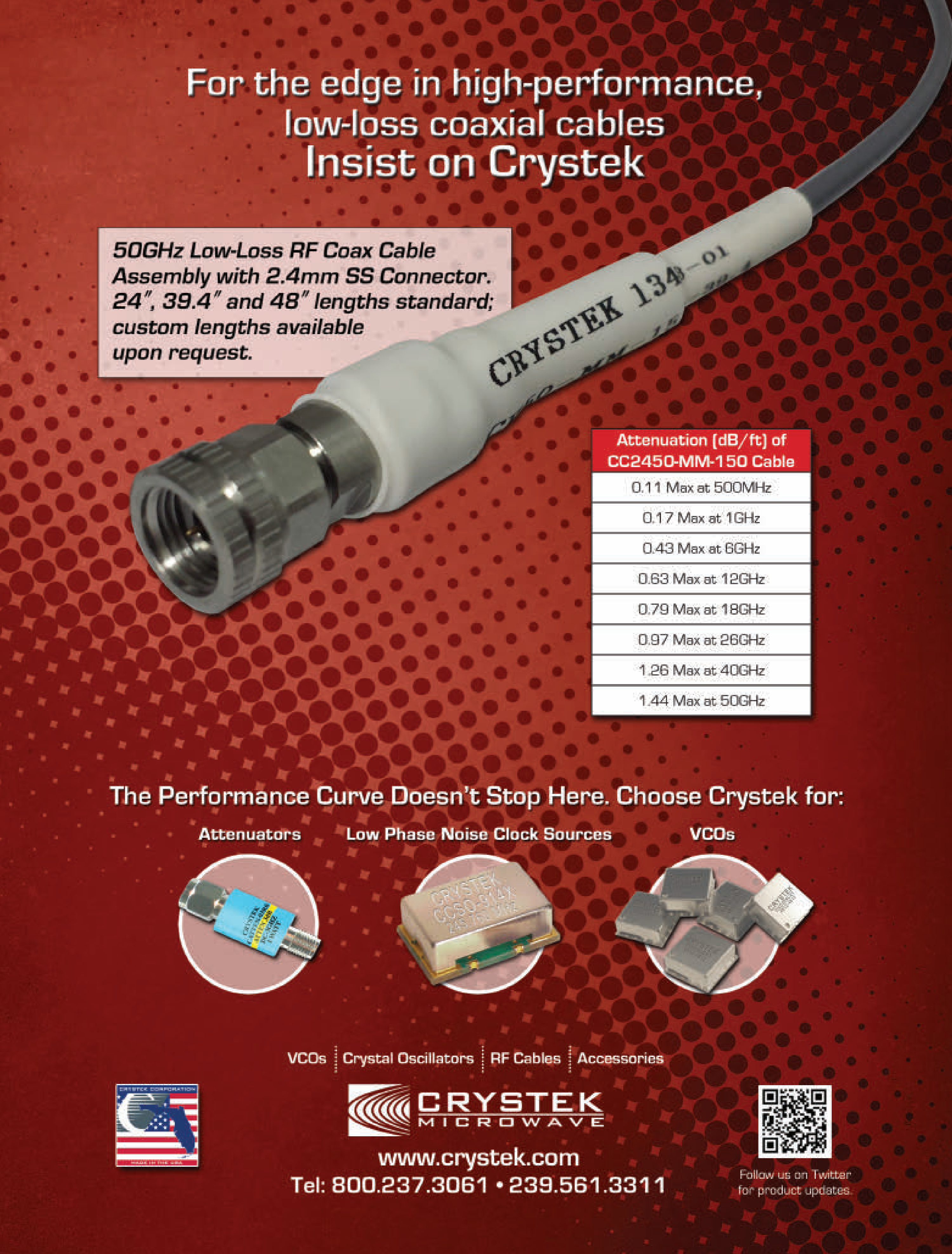
Cable assemblies are some of the most widely used components in military and commercial electronic systems. They are used as connections between components within racks, subsystems, antenna feeds and various test platforms, among many others. Although a cable assembly looks like a very simple component, consisting of just coaxial cable and connectors, in many situations it can be the critical factor determining system performance, reliability and cost. Developing the most suitable and effective cable assembly for a particular application with a reasonable cost can be a challenge to the system or subsystem designer. Good communication between customer and vendor is necessary for the proper choice of cable, connector and assembly technique.

The designer/customer must first be able to transfer the requirement and specification for a cable assembly to the vendor/manufacturer. Cable and connector selections are the next steps, possibly with assistance from the manufacturer, to ensure that all requirements are met within cost and delivery constraints. In some situations, existing cable and connectors are not suitable, and custom design may be necessary to meet the specifications. Assembly techniques must also be examined as they may dictate the use of alternative cable or connectors, due to manufacturing issues such as availability, time, cost or quality. Finally, testing must be done at all stages to ensure that the assemblies meet electrical, environmental and reliability requirements. ***Figure 1*** shows a typical development cycle for cable assemblies.



▲ *Fig. 1 Flowchart of cable assembly development.*

Customers often ask why some vendors make better cable assemblies than others, even though they use identical cable and connectors. Experience and knowledge of proper assembly techniques can be the answer. Modern electronic systems are expensive and complex and need to be dependable so cables should not be a source of any problems with proper selection of components and manufacturers.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Below are two successful examples showing how cable assemblies were developed for a commercial and military application.

DC TO 26.5 GHz TEST CABLE ASSEMBLIES

Test cable assemblies are among the most difficult to make of all cable assembly demands. In many production situations, test cable assemblies are used multiple times daily and their performance and reliability will directly affect the customers' product performance and cost.

Performance requirements that customers expect for test cable assemblies:

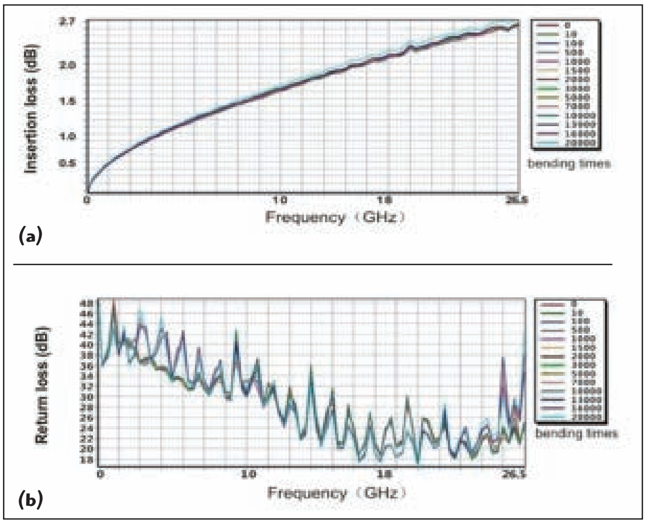
1. Very flexible with small bending radius for convenient use
2. Very small phase change versus flexure
3. Low amplitude/insertion loss change with movement and bending
4. Consistent good performance over time and frequent use
5. Low cost

A good test cable assembly, therefore, needs to be ultra flexible and amplitude/phase stable with a long life and low cost.

The first step in developing a new product is making the decision about product requirements and specifications. For test cable assemblies, the most important specification is phase and amplitude stability with flexure. ***Table 1*** lists the market specifications found in various published materials for test cables.

Considering that the new product should be competitive in the market, the cable assembly should have the following specifications:

1. Equal or better than the best electric performance in the market, better than the specifications listed in Table 1.
2. The cable should have a small bending radius and be very flexible. For this example, it was decided to select 0.195" as the outer diameter of the cable and 1.95" radius mandrel instead of the Table 1 2.25" radius as the test condition for phase and amplitude stability.
3. The assembly should have better reliability and longer life compared to presen- products in the market.
4. The assembly should have a competitive cost compared to present products in the market.



▲ *Fig. 2 Insertion loss change (a) and return loss (b) measured over 20,000 flex cycles (C041 cable, 1 m).*

TABLE I

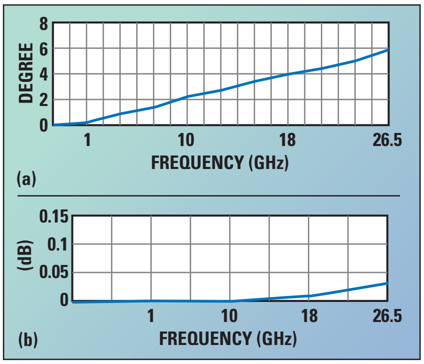
IDEAL SPECIFICATIONS FOR TEST CABLE ASSEMBLIES

Specifications	Typical @ 18 GHz	Max @ 18 GHz	Typical @ 26.5 GHz	Max @ 26.5 GHz
Phase stability with flexure (degrees)	±2	±4.7	±3	±6.6
Amplitude stability with flexure (dB)	±0.05	±0.15	±0.05	±0.15
Note: the above assemblies are 36" long with the cable wrapped 360 degrees around a 2.25" radius mandrel.				

In the process of developing the example test cable assembly, the following steps were taken:

1. Work with the cable manufacturer for special custom designed cables according to the requirements.
2. Improve connector design to a more rugged and easily assembled configuration, so the cable is well protected.
3. Use a stronger connector strain release design so the life of the cable assembly can be extended and the assembly can have a shorter bend radius.
4. Improve assembly techniques to counteract the differential expansion coefficient of the dielectric and center conductor, for better mechanical reliability and electric performance.
5. Develop a complete test method to check the performance as well as the long term reliability.

The example DC to 26.5 GHz test cable assembly uses a custom designed cable with 0.195" outer diameter, soft and flexible PVC jacket, solid PTFE dielectric and improved braid layer design. The rugged connectors, special strain release design and improved assembly technique were used in the new cable assembly. This process of cable assembly design and manufacturing produced a new cable that meets all of the requirements. Listed in ***Table 2*** is the test data of the new cable assembly and ***Figure 2*** is a plot of the change in insertion loss and return loss over 20,000 bend cycles showing little change over the entire frequency range to 26.5 GHz.



▲ *Fig. 3 Phase stability (a) and amplitude stability (b) versus flexure.*

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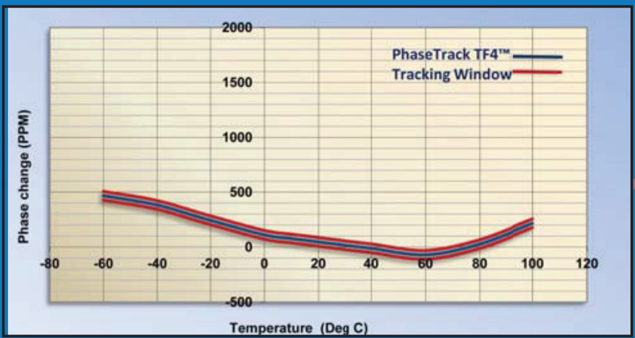

Typical Low Density PTFE Performance

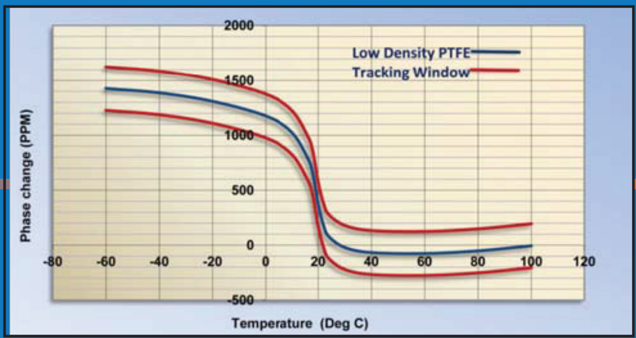

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TABLE II

DATA FOR C041-01-01-1M CABLE ASSEMBLY DURING BENDING UP TO 24,000 TIMES

# of Bending Times	S11/S22	S12/S21	Insertion Loss Change*	Phase Change*
0	18.56/19.13	2.63/2.65	0.04	4.63°
1500	18.38/19.97	2.61/2.61	0.03	4.89°
3000	18.43/18.57	2.58/2.63	0.03	4.45°
4500	17.92/18.78	2.58/2.63	0.03	4.51°
6000	19.13/17.85	2.64/2.68	0.04	4.77°
7500	18.91/17.66	2.67/2.69	0.04	4.58°
9000	17.72/19.12	2.61/2.63	0.03	4.64°
10500	18.83/17.74	2.69/2.69	0.05	4.95°
12000	18.83/17.67	2.68/2.67	0.04	4.44°
13500	19.00/17.20	2.64/2.66	0.05	4.85°
15000	19.21/17.24	2.69/2.69	0.03	4.72°
16500	19.18/17.66	2.61/2.62	0.04	4.77°
18000	18.93/17.71	2.70/2.68	0.05	4.46°
19500	19.20/17.57	2.67/2.75	0.05	4.81°
21000	19.21/17.49	2.75/2.71	0.04	4.50°
22500	19.22/17.57	2.73/2.75	0.03	4.39°
24000	18.93/17.67	2.67/2.73	0.05	4.75°

* The above data is from a 36" long assembly with the cable wrapped 360° around a 1.95" radius mandrel.

TABLE III

PERFORMANCE OF C04I-01-01-1M AFTER TEMPERATURE CYCLES (-55° TO +85°C, DC TO 26 GHz)

	No. 1 Cable Assembly		No. 2 Cable Assembly	
Number of Cycles	Insertion Loss (dB)	Return Loss (dB)	Insertion Loss (dB)	Return Loss (dB)
0	2.67	18.9	2.78	19.6
25	3.11	18.5	3.18	19.60

Phase and amplitude stability plotted in ***Figure 3*** show that a 36" long cable has phase stability less than 4° and 6° with the cable wrapped around a 1.95" radius mandrel at 18 and 26.5 GHz, respectively, with amplitude stability of 0.03 dB max. The data shows that after up to 20,000 bending cycles, the return and insertion loss plus the phase and amplitude stability exhibit little change. The cable also shows good electrical performance with the same tests after 25 temperature cycles between -55° and +85°C (see ***Table 3***). The bending machine used for exercising the cables is shown in ***Figure 4***.

PHASED ARRAY RADAR APPLICATION

Phased array radar has become an important product around the world but has inherent problems for cable assembly manufacturers. Large numbers of assemblies are needed with close phase matching, making the specifications difficult to consistently reproduce.

When system engineers select cable assemblies for phased array systems, the following requirements are needed:

1. The cable needs to have low loss, high power capability and close tolerances.
2. The cable must meet excellent phase matching specifications, with little phase change while bending, during vibration, and with temperature fluctuation.
3. Phase matching requirements are needed for large quantities.

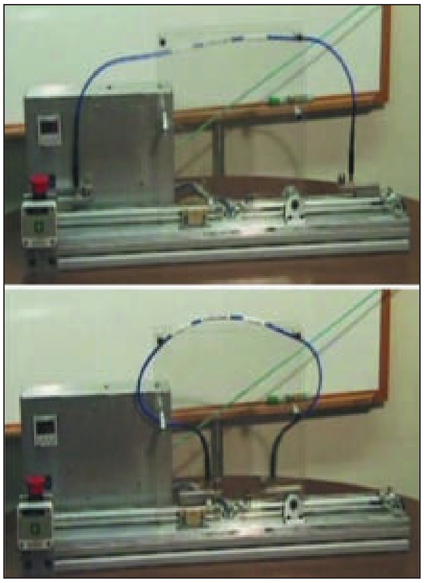
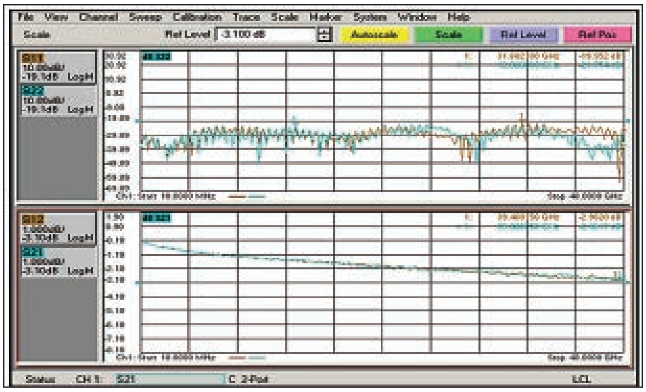


Fig. 4 Bending machine for performing cable flexure.

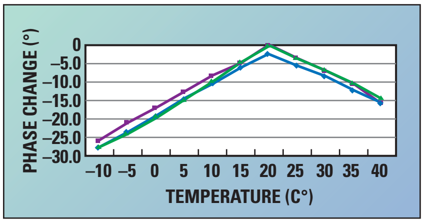
Airborne phased array system manufacturers state that their biggest problem is phase mismatching during rapid altitude change. Calibration will not correct this issue and cable assembly manufacturers have had a hard time correcting this problem. In addition, phase tracking over temperature is an equally important specification that the system engineers should require for the product. Many system engineers incorrectly emphasize the cable's phase stability over temperature instead of phase tracking. A tight phase tracking specification is the correct goal to achieve good phase matching over wide altitude and temperature variations. Making good phase tracking cable assemblies is a big challenge, requiring strict consistency in materials and manufacturing techniques.

Cable assembly manufacturers should have the following capabilities to properly address the problems in phased array systems:

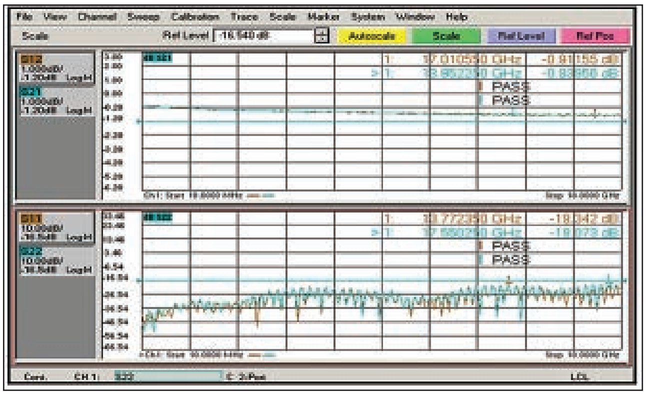
1. Helping the customer select the cable that is most suitable to the application.



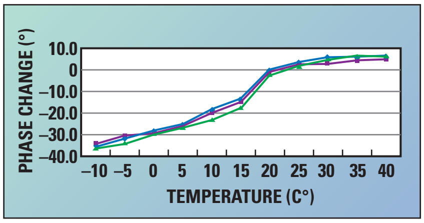
▲ *Fig. 5 B01-40-40-1M test data from DC to 40 GHz.*



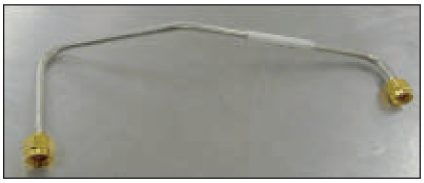
▲ *Fig. 6 B01-40-40-1M phase tracking versus temperature.*



▲ *Fig. 7 A04I-01-01-1M test data from DC to 18 GHz.*



▲ *Fig. 8 A04I-07-07-1.5M phase tracking versus temperature at 18 GHz.*



▲ *Fig. 9 Semi-rigid phase matching and tracking cable assembly.*

2. Producing high performnce phase matching and tracking cable assemblies, with the ability to produce large numbers of consistent assemblies.
3. Strictly controlling the consistency of the materials and manufacturing techniques so that the specifications of phase and amplitude can be met during variations in environmental conditions.

A set of comprehensive methods was developed, including cable evaluation, connector design, manufacturing and assembling techniques, and inspection and testing procedures, in order to produce products that met this type of application's requirements. Cable was chosen from a well known supplier, QPL approved, that previous experience had shown high standards. Connectors were designed and tested thoroughly. To control quality and consistency, inspection after every process was emphasized and workers trained to IPC J-STD-001 and IPC/WHMA-A-620 standards. Rapid phase correcting techniques were developed and computerized semi-rigid bending machines, fast and precise stripping equipment and PNA vector network analyzers were utilized. Quality management systems according to MIL-I-45208 and MIL-STD-2219 were used, along with ISO 9001 and China GJB-9001B-2009 standards.

Figure 5 shows the test data for three phased array cable assemblies (B01-40-40-1M) from DC to 40 GHz with insertion loss of 2.97 dB max., VSWR of 1.23:1, phase stability vs. flexure of ±8° at 40 GHz (bend radius: 51 mm), and phase stability vs. temperature of 500 ppm max. @ -40° to ~+85°C. ***Figure 6*** shows the measured phase tracking plots for these cables' phase tracking with a max. phase change inconsistency of 1.6° for every 5°C from -10° to 40°C for three different cable assemblies.

Figure 7 shows the test data for 3 DC to 18 GHz cable assemblies (A04I-01-01-1M) with insertion loss of 0.91 dB max., VSWR of 1.25:1, phase stability vs. flexure: ±5.4° at 18 GHz (bend radius of 76 mm), phase stability vs. temperature 250 ppm max. @ +22° ~+100°C, and power handling of 600 W at 10 GHz. ***Figure 8*** shows the phase tracking data for (A04I-07-07-1.5M) at 18 GHz with a max. phase change of 3.8° for every 5°C from -10° to 40° for three different cable assemblies.

Finally, bent phase matching and tracking semi-rigid cable assemblies were manufactured with a minimum bending radius of 6 mm with phase match ≤1° at 2.3 GHz, phase tracking ≤1° at 2.3 GHz. Manufacturing was able to deliver 1400 pieces in two weeks (see ***Figure 9***). As the data shows, the temperature tracking performance of the cable assemblies was tightly controlled. The cable assemblies have good consistency, proving the capability to offer good temperature tracking performance over volume production.

CONCLUSION

As the commercial and military markets demand higher performance and more reliable cable assemblies, a good combination of cable design and assembly techniques are more important than ever before. The cable assembly designer/engineer must understand the customer's application and know how to transfer the application demand to the requirement of the cable assembly. The cable assembly manufacturer must then be able to source the proper components, assemble them with advanced techniques and equipment and be alert for changes to meet the specifications and requirements of the project. Good communication between all is absolutely necessary – good teamwork is a must. ■

Reliable Cable Assembly Performance Over Time

Robert John
W. L. Gore & Associates Inc., Landenberg, PA

In today's competitive electronics industries, reliability is essential for applications that use microwave/RF cable assemblies to ensure consistent, repeatable measurements and to maintain electrical performance over time. Therefore, cable assemblies must be durable enough to withstand continuous movement, flexing and exposure to environmental conditions while still maintaining reliable electrical performance.

A recent study[1] showed that globally more than 75 percent of microwave/RF cable assemblies are replaced frequently (see ***Figure 1***). These assemblies were replaced for a variety of reasons, including damage during installation or use, poor quality construction, connector termination issues or failure when exposed to outdoor environmental conditions. However, the most common reason by far was damage during installation or use. The study found that overall, 36 percent were replaced once a year and 20 percent were replaced at least twice a year. As a result, equipment manufacturers are experiencing delays in production schedules, increased troubleshooting and maintenance, more frequent calibration, additional retesting, compromised system performance, and higher overall costs to purchase replacement assemblies.

Cable Replacement Frequency
Do you know how often you are replacing your Microwave/RF cables?

More than 75% of microwave cables fail
- **36% replaced one time a year**
- **20% replaced more than once a year**

IT ADDS UP

Only 24% of cables are never replaced!

▲ *Fig. 1 Summary of cable replacement study.*[1]

In addition, the impact of replacing cable assemblies varied in different regions. The study showed that in the United States, 70 percent of equipment manufacturers are replacing their cables frequently, with 35 percent being replaced at least once a year and 12 percent being replaced once a quarter. In Europe, 49 percent of equipment manufacturers had to replace their cables once a year. However, the most significant impact was in Asia Pacific with 32 percent of cables replaced once a year, 21 percent replaced once a quarter, and 11 percent replaced at least monthly. The study further indicated that the industry expects

microwave/RF cable assemblies to last a very long time — years rather than months, even lasting longer than the life of their system.

DURABILITY TESTING

W. L. Gore & Associates (Gore) evaluated the durability and performance over time of several microwave/RF cable assemblies typically used in the industry. The cable assemblies selected were described as having a ruggedized construction (including GORE® PHASEFLEX® Microwave/RF Test Assemblies). While many cable assemblies perform well out-of-the-box (see ***Figure 2***), the study wanted to evaluate how cables with similar specifications performed after repeated use, and whether their performance changed or remained stable.

When tested under the same criteria, the results[2] showed that the failure rate of cables across the industry varied significantly. For example, in an accelerated life test simulating real-world conditions such as flexure and handling, some cables failed in less than 25 days, but others continued to perform after seven years. The testing also showed that the internal construction of some cable assemblies physically changed (i.e., stretched and distorted) after repeated use, which compromised their electrical performance. However, others performed significantly better over time without any physical changes, which means that these cable assemblies maintained electrical integrity in environments where the others failed (see ***Figures 3*** and ***4***).

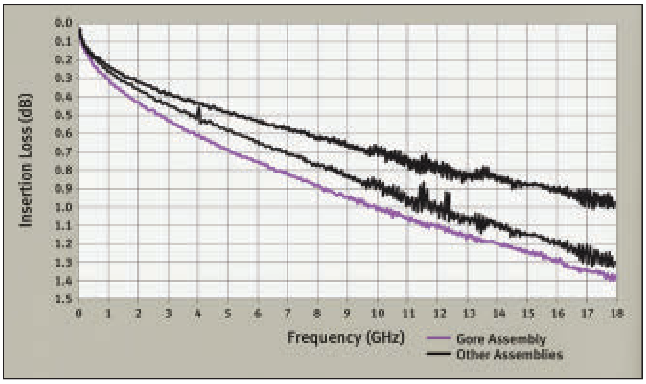


Fig. 2 Out-of-the-box cable assembly performance comparison at 18 GHz.

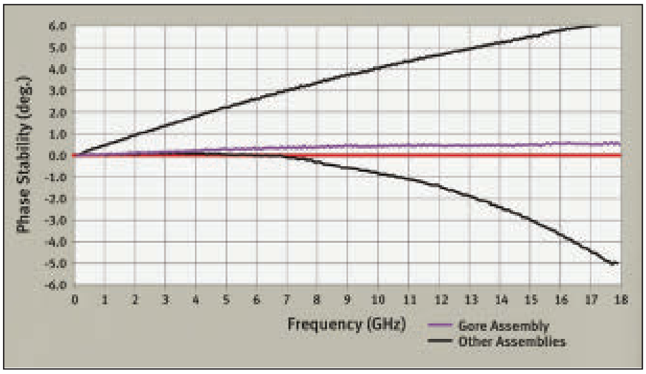


Fig. 3 Cable assembly phase stability with flexure comparison at 18 GHz.

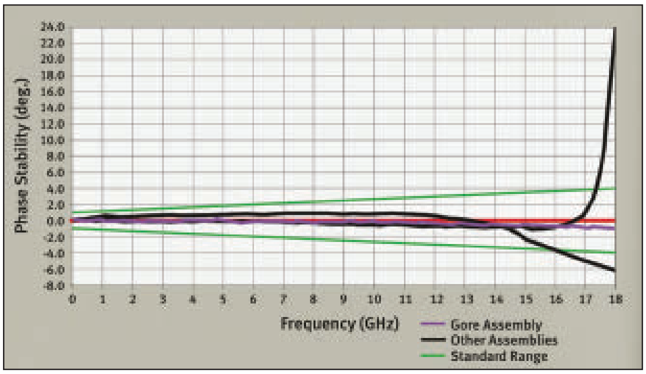


Fig. 4 Cable assembly phase stability over time comparison.

TOTAL COSTS OVER TIME

It is important to consider the cost implications when selecting the right cable, as the consequences of cable failure and replacement can be quite high. The total cost of ownership should include installation, maintenance, manufacturing downtime and replacement cables. So, how much money can you really save by making purchasing decisions based solely on the initial price of a microwave/RF cable assembly?

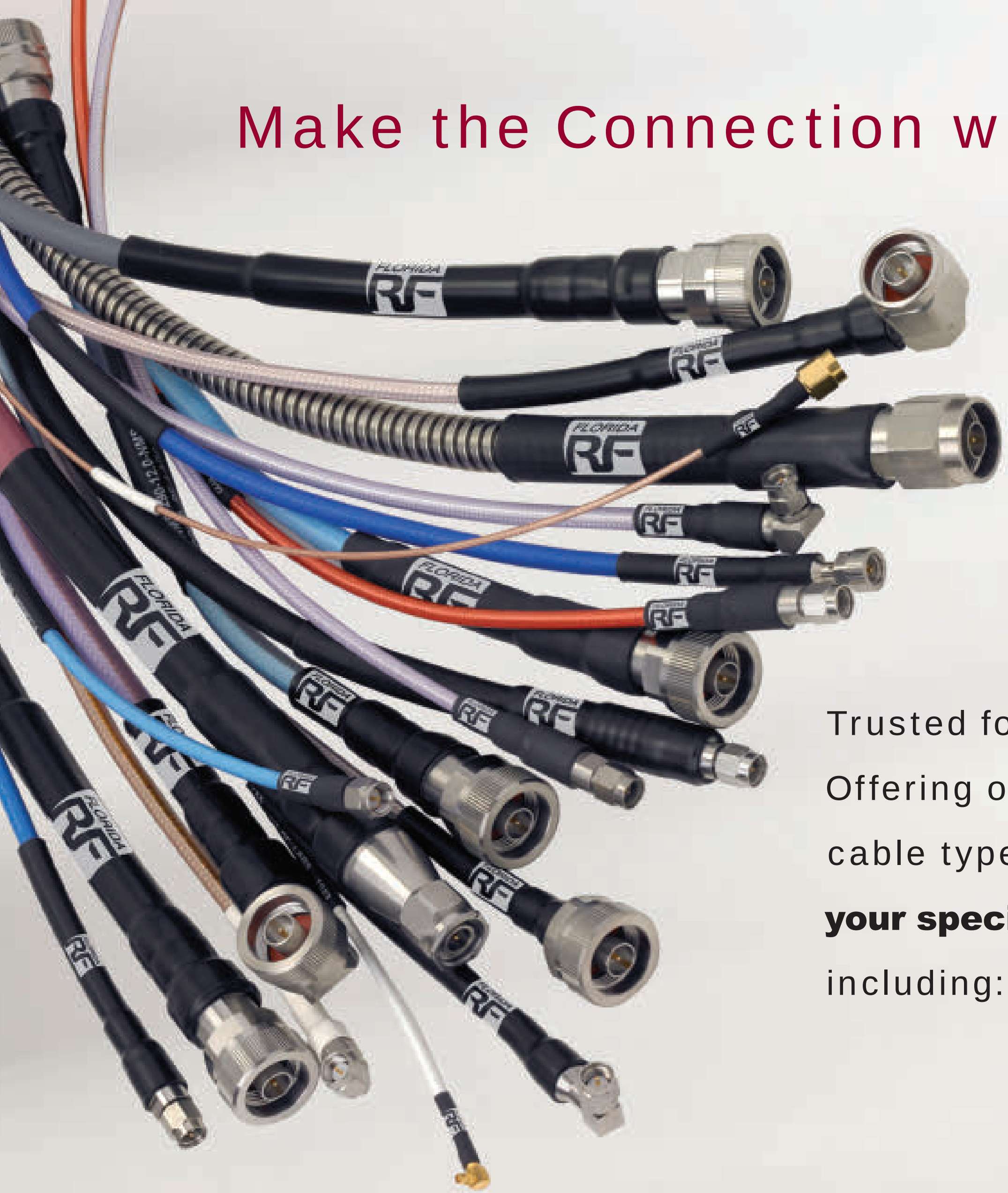
Based on this testing, one could spend more money and resources in replacing lower-cost cables that do not survive the test of time. Using a real-world example, assume a system requires four cables, and you are using cables that are replaced every 25 days. Over the ten-year life of the system, you will be purchasing approximately 600 new cables. If the average cost of a cable is between \$200 and \$400, it will cost between \$120,000 and \$240,000 to replace the cables over 10 years. However, if the cables used last more than seven years, then they would only need to be replaced once.

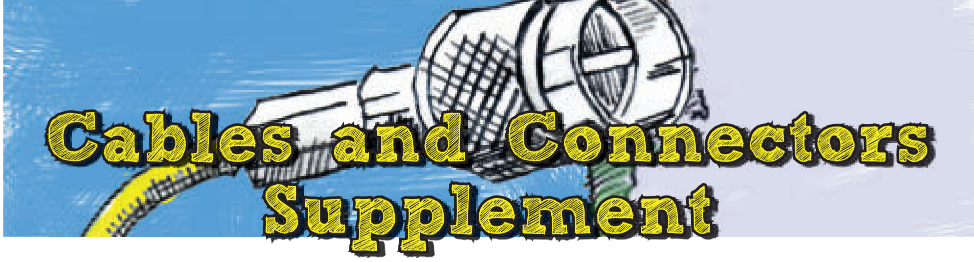
And these totals do not include the additional costs due to downtime, maintenance, recalibration and retesting. In some industries, these additional costs can far exceed the direct purchase cost. For example, a chip manufacturer has estimated that its downtime costs can exceed \$50,000 per hour. Therefore, one should complete a similar cost analysis to consider the full impact of cable failure and replacement before selecting microwave/RF cable assemblies.

SELECTING THE RIGHT CABLE

It is critical to select a cable manufacturer that understands the challenges of the application, because demanding environments can easily compromise a cable assembly's signal integrity, reliability and performance over time. Therefore, it is important to evaluate the electrical, mechanical, and environmental challenges that will affect an assembly's performance in the specific application. Some key things to consider when selecting microwave/RF cable assemblies include:

- **Reliable Performance** — The user should consider electrical performance first because various factors can compromise signal integrity, such as electromagnetic interference, crosstalk, attenuation and conductor resistance. Mechanical





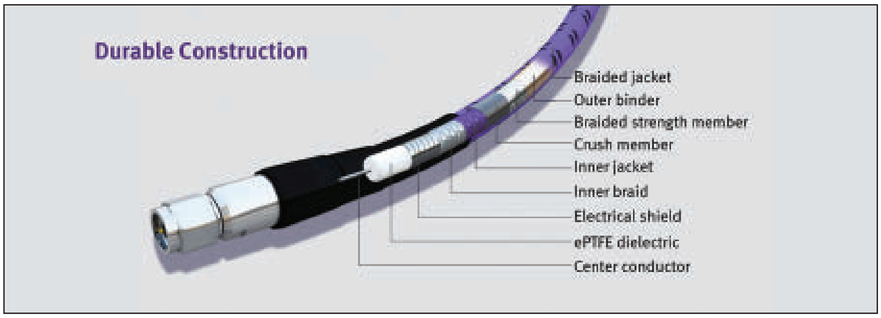


Fig. 5 Example of durable cable construction.

stress is also important to consider; factors such as vibration, frequent flexing and potential damage during installation and maintenance can physically change the cable and affect electrical integrity. The cables must also maintain reliable performance in environments in which they will operate, such as extreme temperatures, radiation, exposure to harsh chemicals, and even rapid altitude changes encountered during take-off and landing of an aircraft. The most important consideration is having the cable manufacturer evaluate electrical performance while simulating mechanical and environmental stress similar to that in your application.

- **Durable Construction** — To reduce cable replacements, be sure to choose cables that withstand installation and handling, provide low insertion loss, ensure phase and amplitude stability, and maintain electrical and mechanical integrity during use. Materials used in microwave/RF cable assemblies are key to their electrical and mechanical performance. For example, internally ruggedized cables that have a small bend radius and enhanced tensile strength are more flexible and easier to route without damage. In addition, engineered fluoropolymers can enhance the durability of microwave/RF cable assemblies in a variety of challenging environments as shown in ***Figure 5***.
- **Application Specific Constraints** — Cable assemblies should also be evaluated for the constraints within your specific application, such as the need for small, lightweight cables that reduce mass and increase fuel efficiency in the aerospace industry. In the test and measurement market, portable analyzers are increasingly being used to facilitate testing out in the field. These analyzers need microwave/RF cable assemblies that can withstand extreme environmental conditions, as well as frequent handling during use. Cables that have a longer service life can reduce the need for maintenance and equipment downtime, resulting in lower costs for testing in laboratory, production and field test environments.

Having to replace cable assemblies frequently is costly. Not only does the overall purchasing cost increase, but companies can often experience a much greater impact from delayed production schedules, compromised system performance and additional retesting and calibration. The out-of-the-box performance of microwave/RF cable assemblies does not necessarily ensure reliable performance over the lifetime of a system. Choosing a cable assembly with a durable construction that has been tested to survive real-world conditions is the key to reducing replacement costs and the only way to ensure reliability over time. ■

References

1. This study was compiled and published by the Penton Design Engineering & Sourcing Group.
2. For more information, visit www.gore.com/test to download a white paper describing the test methods and results.

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Microwave cable assemblies are quite often exposed to a wide range of hostile environments including extreme temperature, abrasion, compressive forces, high pressure fluids, solvents, chemicals, salt water, UV, vibration, and mechanical stress just to name a few. IW offers a wide range of materials and processes designed to protect the integrity of our cable assemblies. These include:

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Passive Intermodulation Characteristics

Murat Eron
Wireless Telecom Group, Parsippany, NJ

The art and science of radio hardware design has been to some degree about minimizing, avoiding and, if possible, altogether eliminating unwanted spurious signals that find their way into the receive path of a radio. Typical sources of such signals are usually the multitude of two or more terminal devices that contain active semiconductor junctions such as diodes, transistors and ICs made up of them. These junctions with their nonlinear current voltage characteristics can be a rich source of harmonics and various intermodulation products, especially if more than one signal is present across them. Though magnetic materials commonly encountered in electronic circuits of most kinds are also a potential source of such nonlinearities, these components are usually used in blocking low level, low frequency ripples and occasional spikes in voltage or current and rarely interfere with communication signals unless poorly designed and selected.

One exception is the RF ferrites in the form of isolators and circulators. Such components, usually preceded by amplifiers, will generate and contribute to the harmonic and intermodulation content present in the outputs of such circuits. In a typical telecommunication system, such unwanted spurious signals will be eliminated and blocked before they have a chance to leak back into the receiver. Voluminous standards exist to ensure that such interferers are always well controlled and contained. Most RF engineers are usually well aware of these issues. These effects can be modeled and the theory behind them is well understood, so such nonlinear signal products can be analyzed and managed relatively easily.

There is another type of signal distortion that has become a great concern in wireless applications recently and that is passive intermodulation (PIM). This is the kind of intermodulation that is generated by passive components and interfaces. It is counterintuitive for most engineers and designers that totally passive components can produce intermodulation products, but they do and can degrade operation of advanced wire-

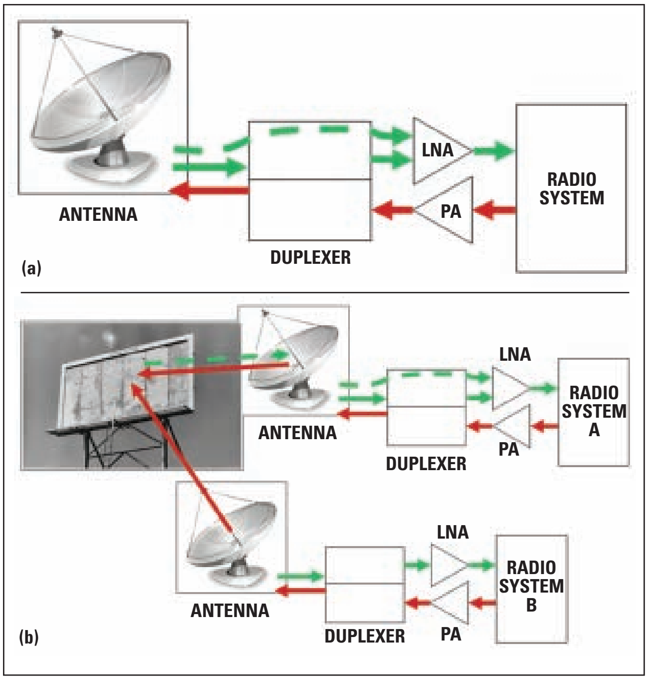


Fig. 1 Shared apertures with multiple carriers can cause PIM to appear in the receiver of a duplex system (a) and external PIM generated beyond the antenna, either in combination with another transmitter or by reflection of the mixed transmit signal of the same transmitter by a nearby PIM generating object/obstacle (b).

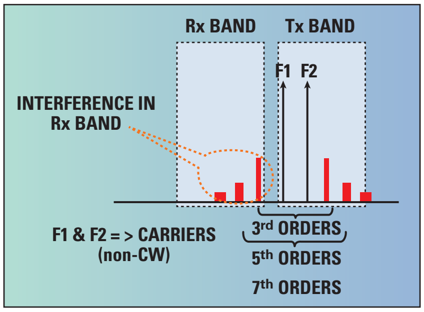


Fig. 2 Odd-order IM products fall near the carriers themselves, sometimes within the Rx band of the same or another operator and cannot be filtered (note that IM bandwidth is n times the bandwidth of the fundamental tones for non-CW signals).

less services and even block radio links altogether if not controlled and managed properly.

WHAT CAUSES PIM?

It is important to understand that typically there is no single and unique source of PIM and this is a general term for a whole category of intermodulation phenomena caused by passive elements in the path of an RF signal. It is also true that at the microscopic level, the actual process of PIM generation is still poorly understood. We know, for example, that poor contacts are the most common source of PIM. Poor contact may mean connectors not torqued to proper limits or poor quality of mating surfaces which may be the result of poor surface finish as well as presence of any contaminants such as flux, oxidation or loose particles. These result in mildly nonlinear contacts as opposed to clean ohmic ones. Dissimilar metals in contact may create diode-like effects also. Ferromagnetic material or coatings as well as certain types of PCB designs, metallization schemes and certain dielectric materials and coatings can generate PIM too.

Electro-thermal effects can cause PIM as well. Electro-thermal conductivity modulation in resonant structures like filters and antennas is very different in nature than other types of PIM since there are no dissimilar metals or even junctions or contacts involved.

When the antennas are also part of the consideration, then “external” PIM that is produced and introduced beyond the transmit antenna when single or multiple antennas reflect strong signals from nearby metallic structures is also a possibility. This is true for both indoor and outdoor installations.

As can be surmised from above, there are a wide variety of causes for PIM, from basic component design to quality of assembly and installation, and all will exist and contribute to total PIM at some level. It is important to realize that it may be unnecessary or even impossible to eliminate PIM altogether but it is critical that it stays below a certain level at locations where it may impact the receiver sensitivity.

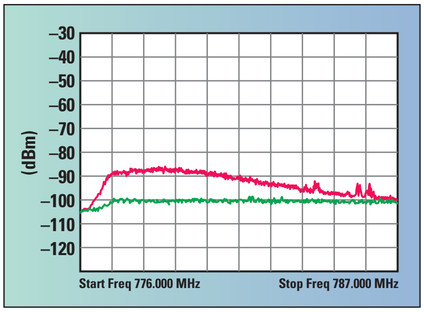


Fig. 3 Rise in the noise floor of an LTE receiver due to PIM when the transmitter is turned on.

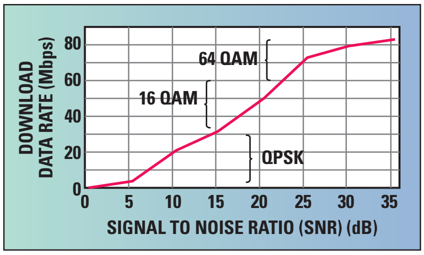
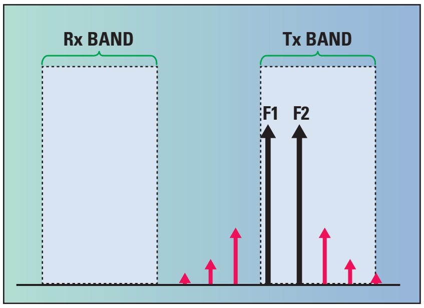


Fig. 4 Downlink data rate in modern wireless systems is dependent on the signal to noise ratio at the receiver.

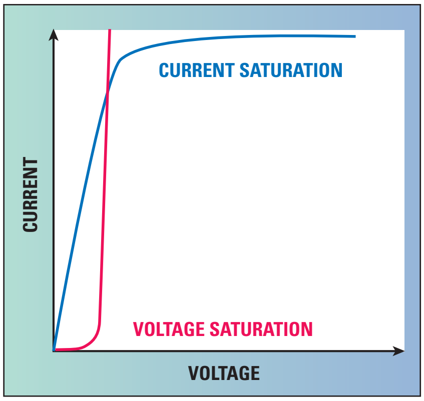
WHAT IS THE PROBLEM?

The detrimental nature of PIM to radio reception has been well known for a long time by radar and satellite earth station engineers due to the shared antenna apertures for very strong transmit and very weak receive signals (see ***Figure 1***). This also explains why PIM is typically a concern for infrastructure equipment and not for the user equipment.

At the point or points of PIM generation along a transmit chain, the generated intermodulation products and energy will travel in both forward and reverse directions. If there is a path back to the receiver and if PIM has components in the passband of the receive chain (see ***Figure 2***), then some of this energy will be mixed in with the actual receive signal as excess noise, as shown in ***Figure 3***. In essence, PIM is always present in any RF system but the degree of it and where it ends up is the concern for good radio operation.

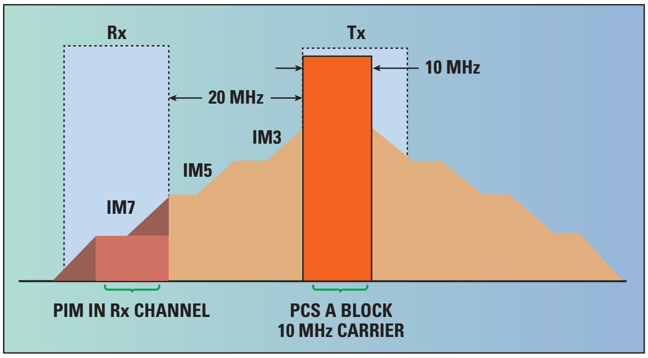


▲ *Fig. 5 Many times the IM products generated will not fall into the Rx band, or those that do will have very high orders and negligible power.*



▲ *Fig. 7 Unlike an amplifier where the source of nonlinearity is the current saturation, most of the nonlinearities that generate PIM are caused by voltage saturation due to imperfect contacts.*

Use of an increasing variety of wireless bands and the need to share antennas to minimize non-recurring as well as recurring cost of wireless antenna installations, not to mention esthetic concerns, have exasperated PIM-related problems in recent years. In addition to shared antenna and other infrastructures, proliferating in-building wireless (IBW) systems, mainly distributed antenna systems (DAS), which also combine and consolidate high power macro base stations, small cells or repeaters create more opportunities for PIM problems. Also contributing to the problem are the higher data rates and the complex modulation schemes that enable them. High data rates are achieved only under good SNR conditions, where either the desired signal is strong with respect to all other noise and interference, or such noise is very small (see ***Figure 4***). So while coverage is critical, good signal quality is just as critical now.



▲ *Fig. 6 When broadband signals are involved, it does not take two carriers to generate PIM. A single broadband carrier will generate its own PIM also.*

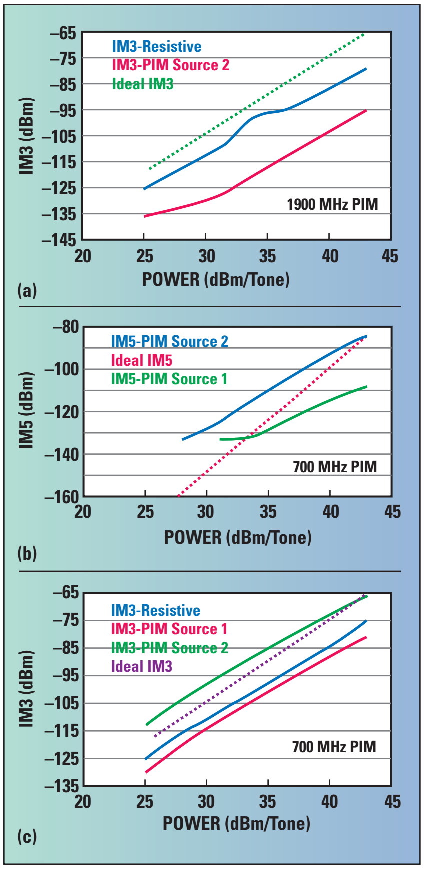
Consequently, any PIM in the receive band that will raise the noise floor, especially in a 4G receiver, and will be detrimental to receiver operation and achievable data rates. Note that not all PIM, even high levels, presents a problem for the receiver if it is blocked or out of the band of operation, as shown in ***Figure 5***. It is also possible for a single broadband carrier to generate its own PIM due to self-mixing without a second carrier present (see ***Figure 6***).

PIM CHARACTERISTICS

The very presence of PIM points to a nonlinearity in the signal path, of course. Thus we have to reach in our tool box of nonlinear analysis to understand, quantify and, most importantly, specify acceptable PIM levels in a system and for individual components used. Similarities to other types of nonlinearities, that we are all so familiar with in the RF world, can be misleading if relied on beyond the basics. Where the nonlinear theory is very precise and helpful is identifying where to expect the PIM signals to appear given the presence of the interacting high power signals/carriers. Regardless of the type and source of nonlinearity present, there will be odd- and even-order intermodulation products when anything other than a single CW tone is forced into the system. Thus we can precisely determine where the PIM will appear given a knowledge of the carrier frequencies. In a typical telecommunication application, it would be the third and other odd-order products that would be of interest.

The problem is our trusted non-linear analysis and methods would be of little use in predicting typical PIM amplitudes. The sources of nonlinearities that cause PIM are not the semiconductor junction types we are more familiar with as previously discussed. Sources of nonlinearity may be a poor interface and ohmic contact. Current flow through such surfaces may involve tunneling type conduction. This is a very mild type of nonlinearity, closer to ohmic than a usual semiconductor junction (see ***Figure 7***). There may be millions of such contacts in parallel with true ohmic contact points present in two contacting surfaces, thus creating a collective nonlinearity that is highly dependent on pressure, temperature, signal amplitude itself and maybe even time. It would be hard to expect such a system to follow a single power law. Note that the mechanism is not one of saturation either. To make matters worse, while some PIM sources are point sources, well localized, some are distributed. Various orders also add and cancel as a function of frequency and tone/carrier separation. Consequently, one cannot and should not make extrapolations that are typically made with better behaved nonlinearities, such as quantifying the nonlinearity and PIM by an IP3 of the system. Due to combined effects described above, it is not very unusual to observe 5^{th} or 7^{th} order PIM to have a higher observed power level than 3^{rd} for example.

Data clearly indicates that PIM rarely follows the typical odd-order power law. For each dB increase in incident RF (tone) power, one rarely observes a 3 dB increase, or a 3:1 slope for IMD3, which nominally would be the strongest component (see ***Figure 8***). More commonly, the observed slope lies somewhere between 1.5:1 to 2.7:1. It is also likely to be very frequency dependent. So, IP3 turns out



▲ *Fig. 8 IM3 vs. power for two different devices compared with ideal at 1900 MHz (a), IM5s do not follow 5:1 slope either (b) and typical PIM IM3 rises 1.5-2.5:1 (c) (most set-ups are limited to near –140 dBm measurement by noise floor).*

to be a rather meaningless parameter in quantifying and specifying PIM. Similarly, one should not expect PIM to decrease by 30 dB (IMD3 component) because the RF excitation is 10 dB lower and vice versa. It rarely works that way in practice. The same applies to higher orders too, as seen in Figure 8b.

AVOIDING PIM

The best method of assuring good PIM performance is to obviously start with guaranteed low-PIM components in the first place. Second, try to specify PIM as close to working conditions and power as possible to avoid needlessly expensive solutions. Given the infinite variety of conditions these components, subsystems and systems are used in, it is difficult to make up an all-encompassing standard. The closest we have to a standard is the IEC 62037-1 and -4 that specify the conditions for testing PIM and specifically in cables and connectors. These documents "recommend" the use of 2 × 20 W CW tones leaving the choice of frequencies and separation to the user per the needs of the system in use. These standards make no mention of the allowed maximum PIM level either. Again this is left to the discretion of the system designer or maintenance engineering since depending on the application and location, the requirements may vastly vary.

Meanwhile industry has developed ad hoc specifications for PIM, mostly based on field tests and trial and error. A maximum PIM level of –110 dBm in the receive band is usually what is desirable in many cases, especially when BTS interfaces are involved. Many component vendors aim for –118 dBm or better depending on the type of component. Given the standard test level of 43 dBm per tone (CW), this corresponds to a –153 dBc of PIM level. Note that it may be hard to relate this analytically to an ideal state-of-the-art receive sensitivity of around –120 dBm since these are defined for specific bandwidths and for CDMA/OFDM type signals that resemble anything but CW.

One of the drawbacks of a fixed power testing per IEC is its unsuitability to lower power applications. Designing and manufacturing a passive component or assembly for a 2 × 20 W test when, let's say, the application is only 2 W, results in a costly and heavier solution than required. In the absence of a standard and accepted guideline, some users are inclined to stick with the 2 × 20 W test requirement which results in significant cost increase for the product. Even when the test requirement is pulled back to 2 × 2 W for example, the false expectation is for the PIM performance to be 30 dB better, around –140 dBm based on traditional IP3 analysis. This level is about –173 dBc from the test tone, the reliable measurement limit of many of the state of the art test instruments. It gets even worse if the PIM of specific interest is 5th or 7th order and one tries to apply textbook power laws. Then the requirement exceeds what is physically measurable. In Figure 8b, when reducing power down to 1 W per tone for example, the actual IM5 measured is about 25 dB higher than what a simple 5:1 extrapolation would predict. It is possible to lower PIM for a component to such low levels by careful design, numerous iterations and very well controlled manufacturing process, but it is unlikely to obtain a reasonable yield for commercial applications, in addition to being unnecessary for proper system operation. So there is an obvious need to rethink the PIM specifications as the base stations get smaller and power outputs get lower.

Some of the confusion can directly be traced to the convention of specifying PIM as a relative measure in dBc rather than an absolute. This has become a defacto standard method of PIM measure. In reality and practice, a radio receiver responds to power, not dBc. Sensitivity of the radio does not typically change with PIM or other low-level interference. Since in practice, power levels impinging on an aperture may vary from system to system or for different installations, one could, in theory, adjust the required dBc value based on 2 × 20 W measurement and establish the requirement appropriate for the actual power levels. This would be straightforward only if PIM behaved according to a known power law. It does not, as shown in Figure 8. So while higher power level components and systems are tested with a standard level of 20 W tones, which is likely to be a good figure of merit, lower power system specs still remain open to interpretation and requires better knowledge of specific operating conditions and receiver sensitivity requirements. Otherwise, trying to extrapolate from 2 × 20 W tests to lower power levels, without considering the actual absolute power levels involved and required, will result in unrealistic component and subsystem requirements which will drive the costs up and yields down. ■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Compact and Reliable 4.3-10 Connector

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Herisau, Switzerland

The choice between classical interfaces such as 7/16, N or 4.1/9.5 connectors and the new 4.3-10 interface can make a significant impact on how a particular network will perform. There are several considerations to make when choosing a connector, including the network design and the choice of the mobile telecommunications system used.

Because Long Term Evolution (LTE) networks feature an increased mobile data rate of 100 Mb/s, this higher transmission rate will expose PIM vulnerabilities in today's networks with frequency division duplexing. 4G networks require superior network transmission fidelity, higher than previous generations. Network operators also face the challenge of maintaining customer loyalty in an unforgiving competitive arena. As such, good network PIM performance and PIM testing are now imperative. Indeed, the 4.3-10 connector satisfies the requirement of very low PIM performance and compactness, fitting into a 1" (25.4 mm) flange and being up to 60 percent lighter than some RF interfaces.

FEATURES AND BENEFITS

A key feature of this connector is the separation of the electrical from the mechanical plane. This implies another way of contacting the outer contact. The front contact force that is needed for interfaces like 7/16, N or 4.1/9.5 is not needed for the 4.3-10. That is because the contact is realized radially, which requires a lower force for the maximization of the contact points.

The decoupling of the electrical from the mechanical plane means there is no need for a high torque value to achieve high electrical performances. Besides the screw version, the design can offer a hand-screw solution or a push pull design because of this feature. The coupling mechanism does not influence the PIM or return loss performance and all the three configurations – screw, hand-screw or push pull connectors (shown in ***Figure 1***) perform the same. For better handling during installation, the hand-screw or push pull versions make it possible to rotate the cable and still have a secure connection.

The 4.3-10 connector interface is characterized by protected contact surfaces, thus making the connector more robust and even if not handled with the greatest care, it is possible to have optimal PIM performance. All three coupling mechanisms can meet the same universal jack (female), giving absolute flexibility to the end user to install the plugs (male) in the most convenient way. For those customers who prefer tool-less solutions, the hand-screw or push pull connectors are the best choice. The installation is very simple and intuitive and is espe-

Fig. 1 The 4.3-10 connector is available in hand-screw, screw and push pull versions.

cially suitable for multiple installations in very tight spaces.

As mentioned, the dimensions of the 4.3-10 connector enable the coupling to fit in a 1" flange, thus offering the opportunity to design high density modules. Also, the fact that the hand-screw and push pull type require no torque wrench renders possible the option to reduce the pitch itself to 1". Since only low or no torque is required, the board panel can be designed to be lighter and thinner.

APPLICATIONS

Due to its properties, the 4.3-10 connector is suitable for numerous applications. For instance, in new base stations, the 4.3-10 can be used for interconnections in the remote radio head as well as an interface on the antenna and on the jumpers. The connectors can be used in multi-operator, multiband distributed antenna systems (DAS) where RF signals have to be combined, terminated or distributed to the antenna, as well as in small cell applications where it is particularly suitable for meeting the challenging space restrictions and electrical performance requirements.

With wireless data use increasing rapidly, network infrastructure, both in-building and outdoors, must support good coverage and bandwidth in order to handle and transport such large amounts of data. Also, signals of different wireless operators with different frequencies have to be accommodated and re-distributed to provide the best coverage without mutual interference. Therefore, signal quality and reliability is becoming a feature of differentiation for operators.

With today's requirements for RF connectors such as compactness, robustness, easy installation and very reliable electrical performance, the 4.3-10 connector, with its excellent electrical performance independent of the torque applied, innovative and multiple coupling mechanism and compactness, provides significant customer benefits and therefore competitive advantages in communication systems.

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The Next Generation in High Power RF Transmission

TRU Corp.
Peabody, MA

TRU Corp. has introduced the latest innovation in high power connector design with the MEIA™ series interface. MEIA connectors and cable assemblies provide an innovative solution to common issues experienced in coaxial high power RF transmission. Higher power applications exceeding 5 kW begin to eliminate practical use of standard 7-16 and LC connector interfaces that do not have the required power handling or design margin in frequencies above 100 to 200 MHz. MEIA-1625 will handle approximately three times more power than a 7-16 interface and two times greater than an LC, up to an operating frequency of 3 GHz (see ***Figure 1***). Traditionally, engineers have turned to EIA 7/8 or EIA 1-5/8 connectors to handle these high power requirements but were faced with a set of different challenges regarding size, weight and the difficulty of hand fastening the flanged interface with bolts and nuts.

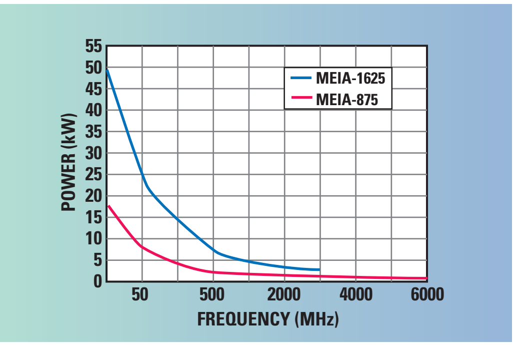

Fig. 1 Power handling of MEIA-1625 (blue) and MEIA-875 (red) connectors (interface only, 25°C, sea level, matched load).

The MEIA interface provides equivalent kW power handling compared to similar EIA connector line sizes but provides a 30 percent smaller and 40 percent lighter form factor with a high efficiency, threaded coupling mechanism as shown in ***Figure 2***. This threaded cou-

pling eliminates the issues inherently found in mechanically aligning and fastening a flanged EIA interface with individual bolts. MEIA offers greater ease of installation and coupling while providing superior power handling characteristics.

Operating over the frequency of DC to 3 GHz, the MEIA connectors have a voltage rating of 5100 V rms and dielectric withstanding voltage of 10400 V rms. The connectors offer a durability of 500 cycles minimum and meet various environmental testing standards.

The MEIA series is available with TRU Corp.'s flexible TRU-560 and TRU-500 coax cables to create an unmatched combination of high power and flexibility to suit your challenging applications. MEIA series high power panel mount receptacles can be designed with a variety of back-end launch geometries to optimize your equipment for performance and safety. MEIA to EIA adapters are available to allow transformation of existing EIA connections to the more efficient MEIA interface coupling.

TRU Corp.'s long heritage in high power design has made it a premier supplier in high power markets including critical safety applications in the industrial equipment segment. The company's experienced technical staff is available to personally answer application questions.

Fig. 2 MEIA-1625 is 30% smaller and 40% lighter than the comparable EIA 1-5/8 (a) and has a shorter form factor and more efficient threaded coupling than the EIA 1-5/8 (b).

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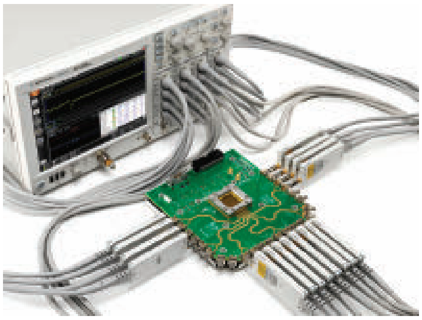

TDR/TDT Solution with Electronic Calibration

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Agilent Technologies Inc. has introduced the Agilent N1055A 35/50 GHz (8 ps) time-domain reflectometry and transmission module for the Agilent 86100D DCA-X platform. The 86100D DCA-X oscilloscope mainframe can be configured with one to four N1055A TDR/TDT plug-in modules to provide a 2- to 16-channel TDR/TDT measurement system that is both economical and accurate.

The 2/4 port TDR/TDT remote heads can be configured with a sampler bandwidth of 35 or 50 GHz, providing single-ended and differential measurement capability, including True-Mode stimulus functionality. With TDR step edge speeds as fast as 8 ps and receiver bandwidths of 50 GHz, the DCA-TDR solution resolves the magnitude and location of impedance discontinuities with unmatched performance.

With Agilent 86100D Option 202 enhanced impedance and S-parameter analysis software, scattering parameters (S-parameters) are generated in real time within the oscilloscope and simultaneously displayed with time domain results. The N1055A's fast rise time enables calibrated S-parameter measurements to 50 GHz and above. The high-channel-count capability of the DCA-TDR solution also helps to minimize cable reconnections and facilitate more efficient near-end crosstalk and far-end crosstalk measurements in both R&D and high-volume test applications.

The DCA-TDR solution achieves a significant breakthrough for accuracy and ease-of-use with its support for electronic calibration (ECal) modules, leveraging an advanced calibration technique originally developed for vector network analyzers and recognized as the "gold standard" in S-parameter measurements. A special Agilent N4694A DC-67 GHz ECal module was developed for the DCA-TDR to let users calibrate and de-skew channels and TDR modules quickly.

VENDORVIEW

Agilent Technologies Inc., Santa Clara, CA, www.agilent.com/find/N1055A.

Spaceflight Cable Assemblies and Connectors

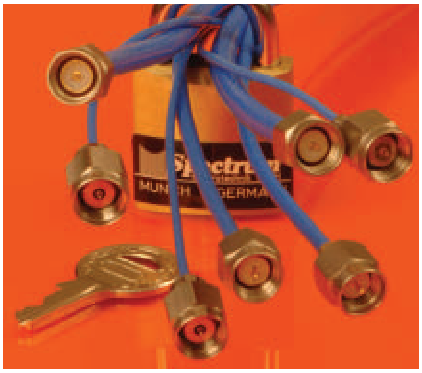
W. L. Gore & Associates has introduced a line of GORE® Spaceflight Microwave/RF Assemblies that have been optimized for Ka-Band uplink and downlink satellite applications. The durable construction of the Type 5G Series provides good shielding effectiveness and ensures reliable signal integrity with good insertion loss and return loss performance up to 32 GHz. They have been qualified for spaceflight applications in three separate phases – integration, launch and in-orbit – to ensure consistently reliable performance for the duration of the mission.

The assemblies can be terminated with either 2.92 mm straight-pin connectors (ZMQ) or 2.92 mm right-angle pin connectors (ZQA). These connectors withstand the harsh environment experienced during satellite launch and orbit without compromising signal performance. Additionally, the low-profile of these connectors will increase flexibility during the layout process of satellite design.

The ZQA connector features a non-bifurcated swept contact design for use with low-loss microwave coaxial cable qualified for 32 GHz spaceflight applications. Traditional box right-angle connectors are often associated with poor VSWR performance, particularly at frequencies approaching 18 GHz. This is because many box right-angle designs employ a bifurcated (two-part) internal contact. While the bifurcated configuration allows for easy assembly and low cost, its shape does not lend itself to good internal impedance control or to a robust solder connection.

W. L. Gore & Associates Inc., Landenberg, PA, www.gore.com/zqaconnector.

Flexible Cables Offer Replacement for Semi-Rigid



SpectrumFlex is a flexible cable that can be terminated with any standard semi-rigid cable connector. There are three versions available: Series 47F, which is a replacement for 0.047" semi-rigid cable, Series 89F that can replace 0.085" semi-rigid cable, and Series 169F, which is a replacement for 0.141" semi-rigid cable.

SpectrumFlex 47F and 89F are miniature assemblies with 0.055" (1.40 mm) and 0.096" (2.44 mm) diameters, durable construction and low profiles in SMA configuration. They offer excellent electrical performance in a trouble-free, compact assembly. They are especially suitable for situations where: the development of complicated semi-rigid cable drawings is prohibitive from a time or cost perspective; the installation of other miniature cable assemblies has caused expensive or hard-to-find failures; high density devices require stable, miniature cable assemblies for connection during test; and the cost of SMA right-angle connectors may be prohibitive.

Combining flexibility and durability with a larger diameter – 0.160" (4.06 mm) SpectrumFlex 169F maintains excellent electrical characteristics and performance through multiple flexures and offers a high strength replacement for RG 402 semi-rigid cable.

The SpectrumFlex 47F comprises a solid silver-plated copper-clad steel center conductor, solid PTFE dielectric, high coverage, silver-plated copper ribbon braid, high coverage, silver-plated stainless steel braid and extruded FEP jacket. Both the SpectrumFlex 89F and the 169F are made up of the same center conductor and dielectric, helically wrapped silver-plated copper foil shield, high coverage, silver-plated high strength alloy braid and extruded FEP jacket. The robust construction of all three versions ensures high compression resistance and durability and eliminates cable breakage associated with repeated bending and handling.

Spectrum Elektrotechnik GmbH, Munich, Germany +49 89 3548040, www.spectrum-et.org.

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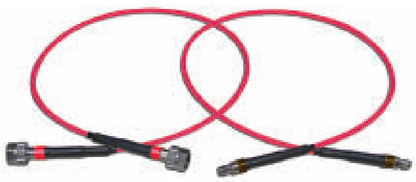
All-Purpose Test & Measurement Cables



Maury Microwave's Utility™ series sets a new standard for high-end all-purpose test and measurement cable assemblies. Designed for general testing applications, Utility offers excellent value with its low cost, low insertion loss, excellent return loss, flexibility, and amplitude and phase stability. Typical insertion loss is 0.64 dB/ft (cable only), VSWR maximum of 1.30 (up to 18 GHz, Type N connector) and 1.25 (up to 20 GHz, SMA connector), typical phase stability versus bending of ±3.0° and typical amplitude stability versus bending of ±0.015 dB. Utility is the ideal interconnection for reliable and repeatable measurements when mated with test instruments, including bench-top testing, on-wafer characterization and ATE systems.

Utility cable assemblies are now part of the ColorConnect™ family. Following the proposed IEEE high frequency connector/adapter color convention, Utility cable assemblies are among the first commercially available assemblies to offer clear indications of compatibility and intermatability. ColorConnect makes it a simple matter to avoid and eliminate damaged equipment, degraded equipment reliability, degraded performance and lengthy maintenance times due to improper mating (and attempted mating) of incompatible interconnects. Utility RF/microwave cable assemblies are available with N-Type connectors to 18 GHz and SMA connectors to 20 GHz in 24", 36", 48" and 60" lengths (custom lengths are available).

Maury Microwave, Ontario, CA (909) 987-4715, www.maurymw.com.

Cables and Connectors Supplement

LITERATURE SHOWCASE

Florida RF Labs,
www.emc-rflabs.com.

Test Cable Assemblies Catalog

VENDORVIEW

Florida RF Labs has a new catalog detailing an extensive selection of test cable assemblies for precision measurements. The assemblies include Lab-Flex®, Titan-Flex™, ASR and ASR-F. Florida RF Labs has provided assemblies delivering consistent performance and robust interfaces that can be used in static and dynamic conditions for many years.

HUBER+SUHNER,
www.hubersuhner.com/4310.

4.3-10 Connector Brochure

HUBER+SUHNER, a leading global supplier of RF product, is an active partner of a developing group designated to provide an innovative solution for the telecom market. The new 4.3-10 connector system is designed to meet the rising performance needs of mobile network equipment and at the same time reducing its size supporting the ongoing space reduction requirements. This brochure details the full connector and adapter range of HUBER+SUHNER for the 4.3-10 connector system.

Maury Microwave Corp.,
www.maurymw.com.

Cable Assemblies

Maury Microwave is a worldwide leader in interconnect solutions with three families of cable assemblies to meet your every need. Test Port cable assemblies offer the highest accuracy for VNA measurements. Stability™ cable assemblies consistently deliver high performance for phase-stable applications. Utility™ cable assemblies have been designed for price/performance and everyday lab use. Stability and Utility cable assemblies are available in stock in standard.

Mesa Microwave,
www.mesamicrowave.com.

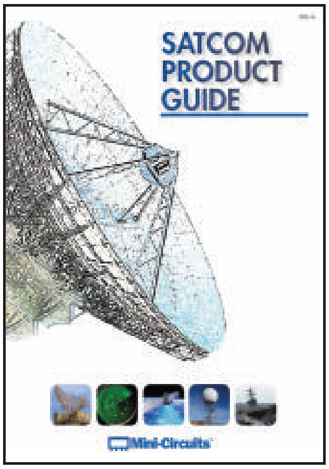
Connectors and Cables

Offering DC to 110 GHz connectors and cables: 1 mm, K, 2.92, SMA, N, BNC and TNC. Offering power dividers, couplers, amplifiers, isolators, circulators, switches DC to 40 GHz. Contact: sales@mesamicrowave.com or (480) 890-1612.

MIcable Inc.,
www.micable.cn.

Coaxial Cable Assemblies

MIcable Inc. is a leading designer and manufacturer of high performance microwave coaxial cable assemblies for a variety of applications, including DC to 50 GHz flexible cable assemblies, hand-flex cable assemblies, semi-rigid cable assemblies and VNA test cable assemblies. MIcable also designs and produces various precise coaxial stainless steel and copper connectors and adapters. Custom designed cable assemblies are also available. Please email sales@micable.cn for more information.



Mini-Circuits,
www.minicircuits.com.

SATCOM Product Guide

VENDORVIEW

Mini-Circuits is pleased to release its new SATCOM Product Guide featuring a full survey of components and assemblies for satellite and earth station systems. With selected models from over 20 different product types to 40 GHz, the guide provides key performance parameters for each product and serves as a handy reference for engineers evaluating parts for their design needs. Request your copy from the literature section of Mini-Circuit's website or email apps@minicircuits.com.

Cables and Connectors Supplement

LITERATURE SHOWCASE

PIC MicroMATES

PIC Wire & Cable's MicroMATES® line of cables and connectors was designed to advance interconnect technology for Ku- and X-Band assemblies. Learn more about these 50 Ω high frequency/microwave assemblies engineered with minimum 200°C rating on all materials plus superior components including: Inner flat braid or strip braid, high temp polyimide foil, dual braided shields and silver-plated copper throughout. Just two weeks lead time on most assemblies.

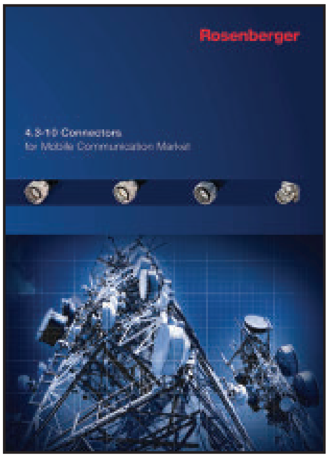
PIC Wire & Cable,
www.picwire.com.

T&M Instruments

VENDORVIEW

Whatever your job is, you are not always performing complex measurements and do not always need the ultimate high-end T&M equipment. What you need are precise, reliable, universal measuring instruments. That is exactly what you get with value instruments from Rohde & Schwarz: they combine practical features with excellent measurement characteristics; they are easy to use and easy on the budget. Find out more in the Value Instruments Catalog 2013 from Rohde & Schwarz.

Rohde & Schwarz GmbH & Co. KG,
www.rohde-schwarz.com.



4.3-10 Connectors

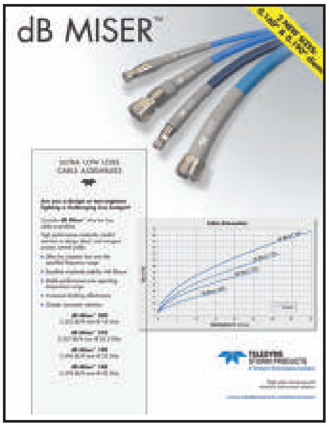
Rosenberger presents a new brochure for its 4.3-10 connector series. The new 4.3-10 connector series, developed together with the renowned RF suppliers Huber + Suhner, Spinner and Telegärtner, has been designed to meet the rising performance needs of mobile network equipment. Outstanding product features include best electrical performance and very low passive intermodulation, very small connector dimensions and easy installation. Plug types are available as screw-on, hand-screw and quick-lock types – installation failures are limited by torque independency.

Rosenberger Hochfrequenztechnik GmbH & Co. KG,
www.rosenberger.com.

MM-Wave Connector Assembly

Successfully launching an RF connector to a PCB at millimeter wave frequencies requires a carefully engineered plan for design, simulation and installation. SV Microwave is now offering the design services and assembly tools needed to optimize your high frequency connector launch.

SV Microwave,
www.svmicro.com.



dB Miser Brochure

The clear choice for engineers facing challenging system gain or signal-to-noise requirements, dB Miser™ cables exhibit ultra low loss, excellent amplitude stability with flexure, stable performance over temperature and exceptional connector retention. This expanded brochure introduces two new cables in the dB Miser line of assemblies: a 0.160" diameter cable (0.678 dB/ft nom. at 40 GHz) and a 0.190" diameter cable (0.496 dB/ft nom. at 32 GHz), as well as new connector offerings.

Teledyne Storm Microwave,
www.teledynestorm.com.

GORE PHASEFLEX Microwave/RF Test Assemblies

For test applications that require precise, repeatable measurements, GORE® PHASEFLEX® Microwave/RF test assemblies provide excellent phase and amplitude stability with flexure. The rugged, lightweight construction of these assemblies delivers reliable performance with longer service life and reduced equipment downtime, which results in lower costs for testing in laboratory, production, and field test environments.

W. L. Gore & Associates,
www.gore.com/test.

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