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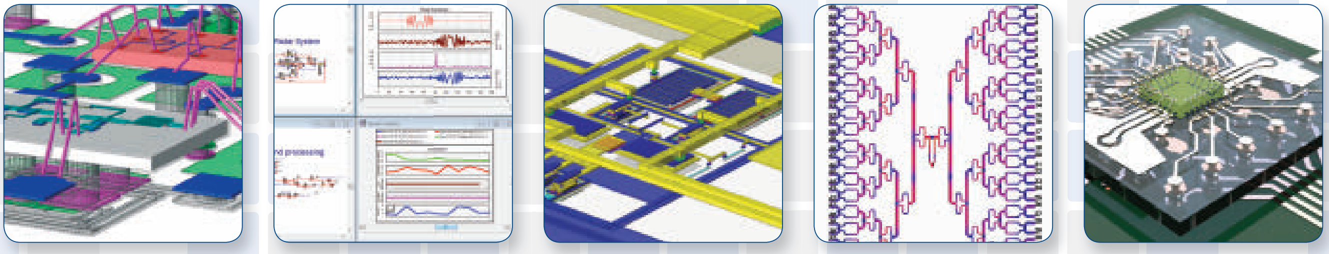

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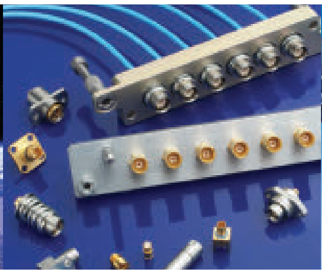

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INVITED PAPERS FROM
CST – COMPUTER SIMULATION TECHNOLOGY
&
W. L. GORE AND ASSOCIATES (GORE)

"Leaky" Cables Make Fine Broadband Antennas

Editor's Note: A cable that leaks electromagnetic energy sounds like a defective cable. Yet, ironically, it makes an excellent broadband antenna. To avoid confusion, antennas based on this approach are called leaky feeders. They are typically used in environments that mirror the cylindrical shape and length of the cable: tunnels, mines, aircraft, railroad tracks and skyscrapers.

CST provides a tutorial explaining the basic theory and electromagnetic performance. Turning theory into practice, with assistance from W. L. Gore, we examine their use enabling Wi-Fi and cellular service on commercial airlines and corporate jets.

PRINCIPLES OF LEAKY FEEDER ANTENNAS

Franz Hirtenfelder and Stephen Murray
CST – Computer Simulation Technology

The leaky feeder antenna is an adaptation of the standard coaxial cable, with one key difference: the outer conductor is slotted or punctured, allowing the cable to radiate. Based on cables, leaky feeders are strong, flexible and robust against environmental conditions. Together, these characteristics make leaky feeders a good candidate for providing mobile connectivity and RF sensor coverage in confined, challenging environments such as tunnels, underground facilities, mines, factories, ships and aircraft.

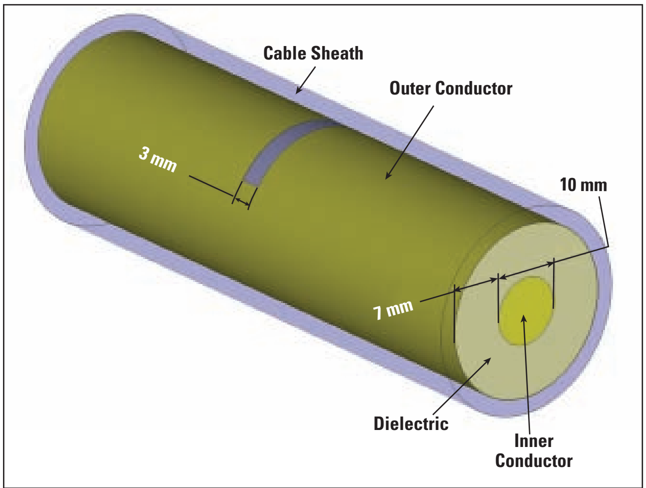
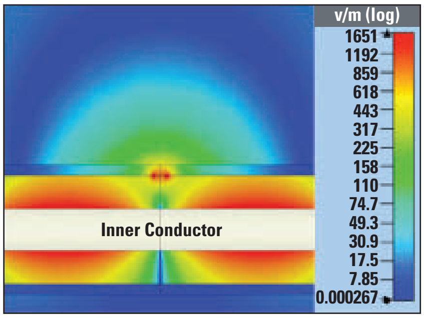


Fig. 1 A simulation model of a coaxial cable with a single slot.

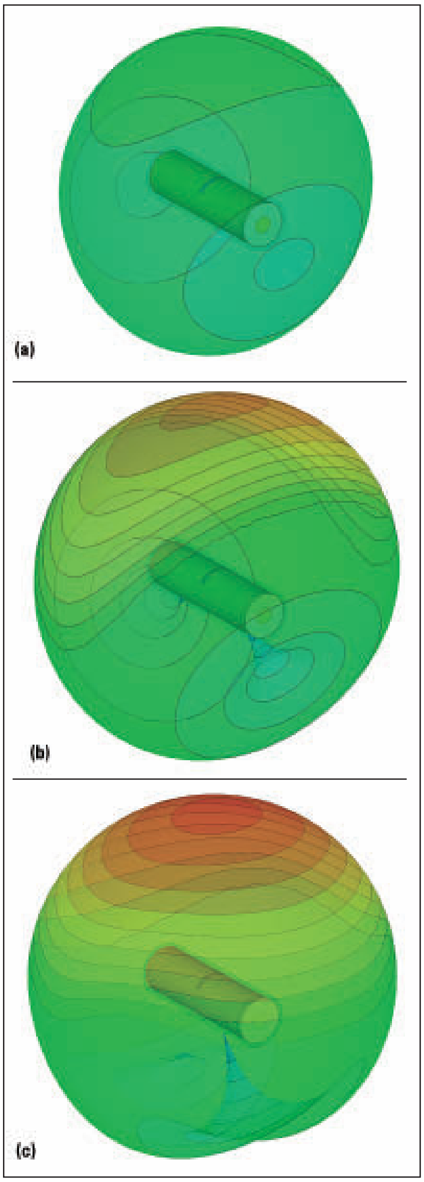
The leaky feeder doubles as both a transmission line and an antenna. Waves propagate through the dielectric, with currents running along the inner and outer coaxial conductors. These waves can "leak" through gaps in the outer conductor. In a normal coaxial cable this is, of course, unintended behavior, however this is what allows the cable to act as an antenna.

A leaky feeder antenna is effectively an array, with numerous radiating slots along its length. There are several classes of leaky feeders, which depend on the shape of the slots. This explanation of the antenna characteristics will focus primarily on the simple case where the slots are rectangular, regular and run circumferentially perpendicular to the axis of the cable. The same principles apply to a wide range of leaky feeder antennas.

The first step in understanding how a leaky feeder antenna operates is to examine the behavior of a single slot (see ***Figure 1***). Although radiation from leaky feeders is described in layperson's terms as the fields "leaking" through the shield, there are really two distinct modes: radiated and coupled.



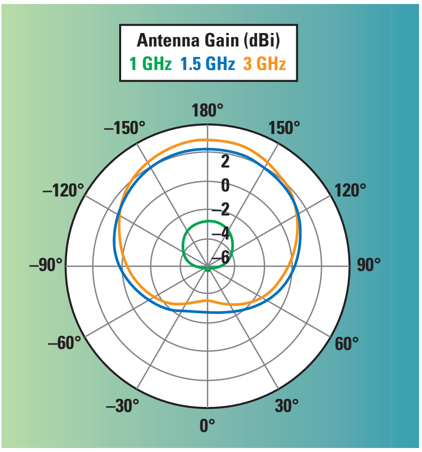
▲ *Fig. 2 Simulated E field at 3 GHz, inside the cable and around a slot.*



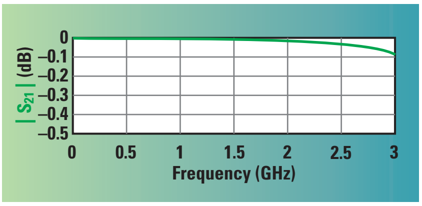
▲ *Fig. 3 Simulated 3D far field radiation pattern for a single slot on a short length of cable at 1 GHz (a) 1.5 GHz (b) and 3 GHz (c).*

RADIATED MODE

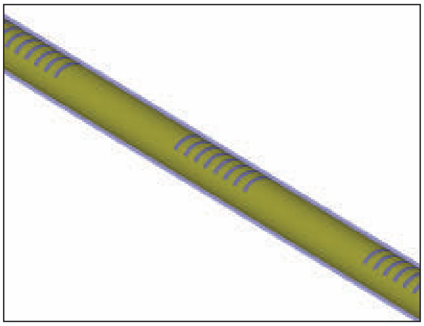
In radiated mode, each slot behaves as a magnetic dipole antenna. The slot will interrupt the current lines running along the outer conductor of the coaxial cable, which causes the slot to radiate as simulated[1] in ***Figure 2***. The radiation pattern for the slot is directional, but the width of the main lobe is very large, as shown in ***Figures 3*** and ***4***. This offers good coverage within the tightly enclosed spaces in which leaky feeders are used. For this simple slot design, the radiation efficiency increases with frequency, as the wavelength of the radiation becomes comparable with the length of the slot. More complex designs can be used to adjust the electrical size of the slot to tune its radiation properties more finely.[2] Individually, a single slot is not a very effective radiator. By design, the slots are not usually resonant, which would improve the radiation.[3]



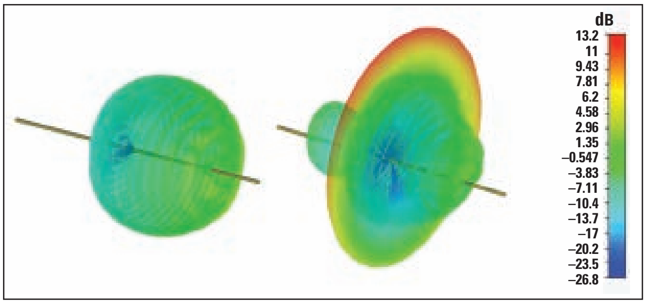
▲ *Fig. 4 Simulated 2D far field radiation patterns vs. frequency (plane midway through the slot and perpendicular to the cable length).*



▲ *Fig. 5 Loss vs. frequency for a short cable section with a single slot.*



▲ *Fig. 6 A length of leaky feeder with alternating leaky and shielded sections.*



▲ *Fig. 7 Comparison of the simulated radiation patterns for 2 m of continuously slotted cable (left) and periodically slotted cable (right) at 1.5 GHz.*

Analyzing the loss through the cable, ***Figure 5*** shows the simulated S_{21} for a short section with a simple slot (Figure 1) is only -0.097 dB at 3 GHz. However, a 100 meter run of a leaky feeder may include thousands of slots, and the losses will quickly accumulate resulting in significant attenuation of the signal. In applications with long cable runs – a tunnel or mine, for example – booster amplifiers will be installed at regular intervals to compensate for the losses.

As a compromise between maximizing antenna efficiency and minimizing coaxial mode attenuation, leaky feeders are often designed with leaky sections interspersed with shielded sections (see ***Figure 6***). This also improves the directionality of the antenna by suppressing higher-order harmonics outside the cable, as shown in ***Figure 7***.

When multiple slots are combined, they behave as an array. This significantly affects the performance of the leaky feeder, compared to individual dipole slots. The phase difference between the slots, proportional to the distance between the slots relative to the wavelength in the dielectric, causes constructive and destructive interference. This interference results in beam steering, meaning the maximum gain is not normal to the cable; rather, it is directed at an angle that varies with frequency (see ***Figure 8***).

The leaky feeder resembles a conventional slotted waveguide antenna with one key difference: in leaky feeder antennas, the n = 0 harmonic does not radiate. This means that it is not necessary to alternate the placement or alignment of the slots to cancel this harmonic.[3]

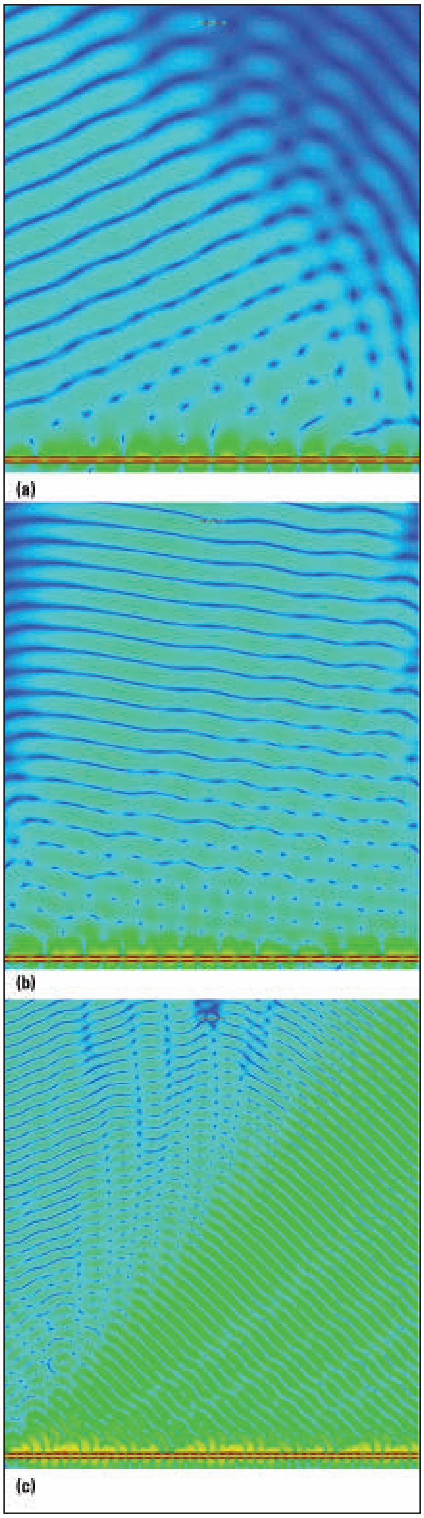


Fig. 8 Simulated E field around a 2 m length of periodically slotted leaky feeder at 1 GHz (a) 1.5 GHz (b) and 3 GHz (c). The changes in beam orientation with frequency reflect the cumulative phase interference from the individual slots.

The leaky feeder is typically used in an enclosed space, such as a tunnel or aircraft fuselage. Since the frequency of operation is much greater than the cutoff frequency of the enclosure, propagation of the radiated mode through the enclosure is mainly by reflection. ***Figure 9*** shows the propagation in a concrete tunnel, simulated with a ray-tracing asymptotic solver.[1]

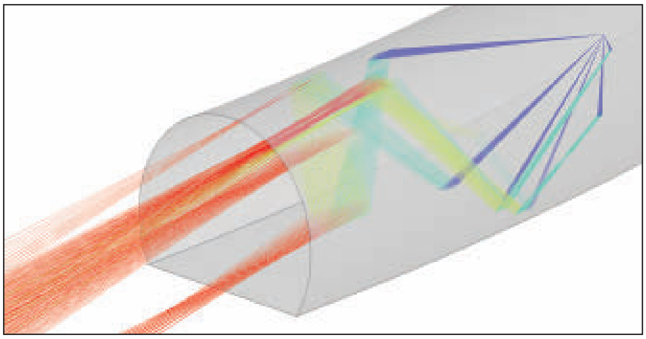


Fig. 9 Simulated propagation from a short length of leaky feeder cable (not shown) in a concrete tunnel at 3 GHz. The colors distinguish the direct signal from the various reflections.

COUPLED MODE

While radiated mode can operate in free space, coupled mode relies on the interaction between the cable and its environment – typically enclosures that act like waveguides. Consider a leaky feeder running through a tunnel. The outer conductor of the leaky feeder can be considered the inner conductor of a much larger coaxial cable, where the walls of the tunnel form the outer conductor (see ***Figure 10***). The leaky feeder is a mode convertor between the coaxial mode (in which the coaxial cable is the waveguide) and the monofilar mode (in which the tunnel itself is the waveguide).[2] Coupled mode dominates at low frequencies, where the wavelength is much greater than the slot spacing.[5] In this mode, the antenna radiates at discontinuities, such as irregularities in the wall and interactions with the cable mounts. The radiation increases when the cable is close to the wall, where the interaction between the coaxial mode and the discontinuities is stronger.

The performance of the leaky feeder in a waveguide enclosure will also be improved by alternating leaky and shielded sections. Currents propagate along the outside shielded sections, allowing the cable to radiate without significant attenuation in these regions.[2,5] Although the requirement for an outer wall restricts the use of coupled mode to specific applications, reducing attenuation allows the distance between amplifiers to be increased, which improves the performance of the leaky feeder.[6]

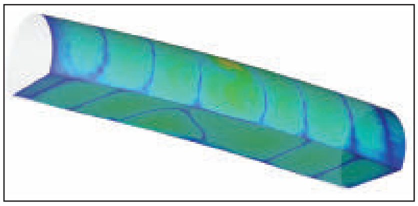


Fig. 10 The simulated E field from a short section of leaky feeder cable (not shown) in a 5 m diameter concrete tunnel at 60 MHz. The tunnel acts as a waveguide.

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LEAKY FEEDERS ENABLE AIRLINE Wi-Fi

W. L. Gore and Associates (Gore)

Major airlines are offering Wi-Fi access to the Internet on many of their flights and moving quickly to deploy the service to virtually all aircraft. Some airlines outside the U.S. — Emirates, for example — also offer cellular connections, allowing passengers to text and make calls using their mobile phones. Within just a few years, Wi-Fi has moved from a unique feature to attract flyers, to a frustration when connections are slow or it is not offered on the flight. The growth in demand has service providers such as Global Eagle, Gogo and ViaSat upgrading their systems to increase data rates and provide global coverage.

If you fly frequently, none of this is news. What you may not know, though, is that leaky feeder antennas are an important part of the system.

Whether the aircraft is connected to the Internet with a radio link to the ground or to a satellite (and then back to earth), the onboard equipment is similar (see ***Figure 11***). A Wi-Fi access point routes data back and forth between the passengers and an onboard processor, using a leaky feeder as the antenna. If the airline also offers cellular service, a separate picocell connects to the same leaky feeder antenna through a diplexer. The size of the aircraft determines the number of access points and picocells, which defines the number of leaky feeder runs in the cabin. For a wide-body aircraft like the Airbus 330 or Boeing 777, each aisle will have a leaky feeder, as illustrated in ***Figure 12***.

While uniform RF coverage throughout the cabin is important to passengers, the leaky feeder must also be airworthy, meeting requirements for flame and smoke toxicity. The antenna must be strong mechanically to withstand vibration and abrasion, ensuring it does not fail during the lifetime of the aircraft.

W.L. Gore and Associates is the leading manufacturer of leaky feeder antennas for aircraft applications and one of few suppliers certified, according to Gore product specialist, Adrian Milne. He estimates that Gore's antennas are flying on more than 1000 commercial aircraft, including Airbus and Boeing. Dassault Aviation selected their leaky feeders for the Falcon 7× corporate jet, as part of a system that provides cellular service during flight.

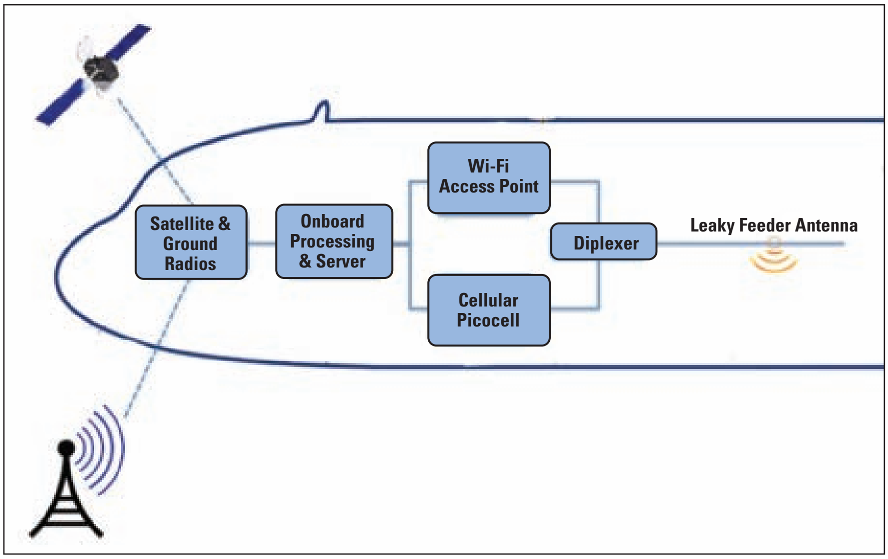


Fig. 11 Simplified block diagram of system for providing inflight Wi-Fi and cellular service.

Fig. 12 The leaky feeder antennas are mounted in the aircraft ceiling above the aisles.

Fig. 13 GORE Leaky Feeder Antennas look like a traditional RF cable.

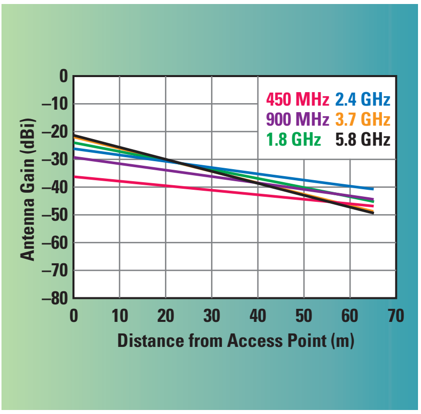
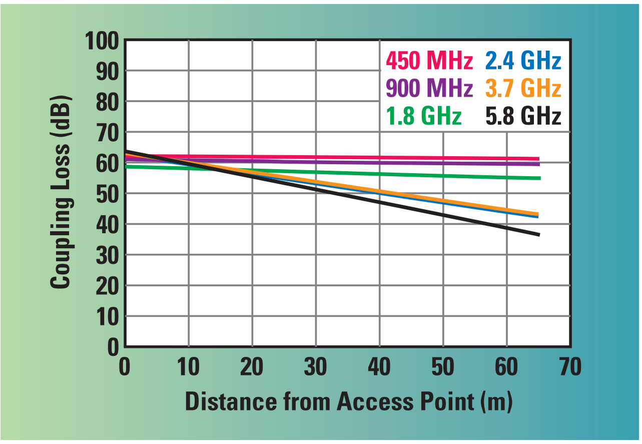


Fig. 14 Antenna gain vs. frequency and distance from the access point.



▲ *Fig. 15 Antenna coupling loss vs. frequency and distance from the access point.*

The frequency response of GORE™ Leaky Feeder Antennas (see ***Figure 13***) covers 400 MHz to 6 GHz, so a single antenna run handles all cellular and Wi-Fi bands. The antennas are manufactured in three diameters, from 6.5 to 11.7 mm, with the smaller diameter cable lighter and with a tighter bend radius. The trade-off with the smaller diameter is lower gain.

Figure 14 shows the measured gain of the smallest diameter leaky feeder as a function of frequency and distance from the access point. The measured coupling loss for the same antenna versus frequency and distance is plotted in ***Figure 15***. For reference, the length of the cabin in an Airbus 330-300 is 50 m.

Both the antenna gain and coupling loss were measured according to the free space method specified by the International Electrotechnical Commission (IEC) in standard IEC-61196-4. The leaky feeder is elevated to 2 m above the ground, held by non-metallic posts, and the measurement antenna is positioned at the same height and 2 m from the leaky feeder. The data reflects only the radiated mode of the leaky feeder, not any interaction that the antenna would have with the metal fuselage of the aircraft.

Airline flights used to offer harried travelers a few hours of isolation and thoughtful reflection, disconnected from the world by the limitations of technology. No longer. The leaky feeder antenna is playing a part in the encroachment of 24/7 connectivity — even in the skies. ■

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INVITED PAPER

Realistic Shielding Effectiveness Measurements of Coaxial Cable Assemblies

Gerald Womer and John Lewis
Micro-Coax, Pottstown, Pa.

Shielding effectiveness is the ability of a cable assembly to either reject interference from the surrounding environment or to prevent the signal in the cable assembly from 'leaking' into the surrounding environment and causing interference to other nearby systems or subsystems. While there have been a number of measurement techniques and standards established over the years for the individual components of a cable assembly (i.e., cable and connectors),[1-3] it is desirable to know the shielding effectiveness of the entire cable assembly so the designer can have confidence that overall system performance will not be compromised.

The mode-stirred method is invaluable in establishing the shielding effectiveness of an entire cable assembly. This is performed in accordance with IEC International Standard 61000-4-21[4] and detailed in Annex F of this standard.[5] The most significant aspect of performing the shielding effectiveness test to IEC 61000-4-21, Annex F is the use of a reverberation chamber (as opposed to an anechoic chamber). An advantage to using a reverberation chamber is stated in IEC 61000-4-21 and is cited here: "Realistic environments for propagation of electromagnetic waves are often characterized by multiple reflections and multipath effects. Reverberation chambers go some way to simulate such complex environments in an extreme manner (worst-case effect) and may be more representative than other EMC test methods in this respect. An advantage of reverberation chambers is the ability to generate a statistically, isotropic, homogeneous, unpolarized and uncorrelated interior field, through the action of the tuner/stirrer."[4]

For this reason, Micro-Coax has installed and operates a mode-stir test facility at its factory in Pottstown, Pa. This facility enables real time characterization of shielding effectiveness on microwave cable assemblies from 1 to 18 GHz.

The broad frequency range for this testing dictates the physical size of the chamber since a particular number of 'modes' must be present at all frequency points within the chamber

▲ *Fig. 1 Internal view of reverberation chamber.*

to have a statistically uniform RF field within the test volume. As such, a physically larger chamber than might otherwise be expected is required to accommodate lower frequency measurements. A mode stirrer (or tuner) in the chamber then ensures that the internal EM field boundaries of the chamber are constantly changing in order to prevent standing waves. During the measurement cycle, the mode stirrer rotates at a slow uniform rate. The dimensions of the mode stirrer must provide changing boundary conditions across the chamber's useable frequency range.

An internal view of a typical reverberation chamber showing the mode stirrer (bent structure at top of picture), transmit antenna (red double-ridged horn antenna) and cable assembly under test on the EM field transparent table is shown in ***Figure 1***. The chamber's internal dimensions are 4.83 × 3.61 × 3.05 m with a lower useable frequency of 200 MHz.[6] Ancillary equipment used to generate the RF field within the chamber can restrict the useable frequency range from 1 to 18 GHz.

SETUP

During initial chamber calibration, it is important to determine the location of the 'working volume' within the chamber. This is where the E-field of the RF signal is uniform within 3 dB regardless of the direction from which the RF field enters the working volume. This is verified by a series of measurements using directional E-field probes at each corner as well as the center of the working volume (9 locations in all). At each of these locations, individual measurements are made with the directional E-field probes oriented in the 'X', 'Y' and 'Z' directions. This assures that any device under test placed within the working volume is uniformly illuminated by the RF field from every direction. Once uniformity of the E-field is verified, technicians lock down the position of the transmit antenna within the chamber so that the generated fields within the working volume are always uniform.

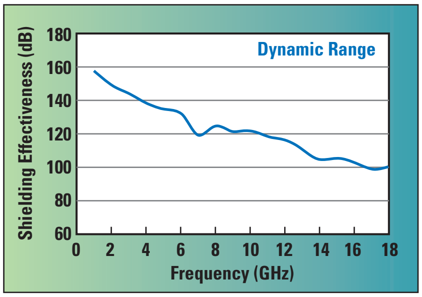
Using this equipment (see the Associated Equipment Requirements section of this article), typical average E-field values present in the chamber during testing are between 75 and 100 volts/meter in the 1 to 4 GHz frequency range. The average E-field from 4 to 18 GHz falls off linearly from roughly 90 volts/meter at 4 GHz to about 58 volts/meter at 18 GHz. This follows the expected chamber loss documented by the manufacturer and is thus deemed typical for a chamber of that size.

CALIBRATION AND VERIFICATION

The periodic calibration performed consists of two major steps. The first is to make a measurement of the strength of the RF field within the chamber. This is done by using a receive antenna as the DUT. The receive antenna is the same make and model as the transmit antenna so it exhibits the same gain characteristics. The receive antenna is placed at several random positions within the working volume and at various orientations to provide unbiased measurements. Averaged together, these measurements create the overall chamber 'baseline'.

The second step is known as the 'leakage' measurement. Here the DUT is a well-shielded load. The purpose of the leakage measurement is to determine the minimum signal which can be detected within the chamber. The transmit antenna delivers the same power level to the chamber as during the baseline measurement and the resultant detected signal level shows any flaws in the interconnect cabling present in the chamber as part of the test setup.

The dynamic range of the chamber is the difference between the 'baseline' and 'leakage' values. One can think of this dynamic range as being the chamber's 'noise floor'. The dy-



▲ *Fig. 2 Dynamic range of reverberation chamber.*

namic range is typically greatest at the lower frequencies and decreases as the RF frequency increases. MicroCoax normally achieves no less than 100 dB dynamic range across the entire 1 to 18 GHz frequency range. When a cable specification calls for 90 dB of RF shielding, the 100 dB dynamic range allows a 10 dB margin in the measurement range. This is a typical margin recommended by various industry specifications. A plot of the chamber's dynamic range is shown in ***Figure 2***.

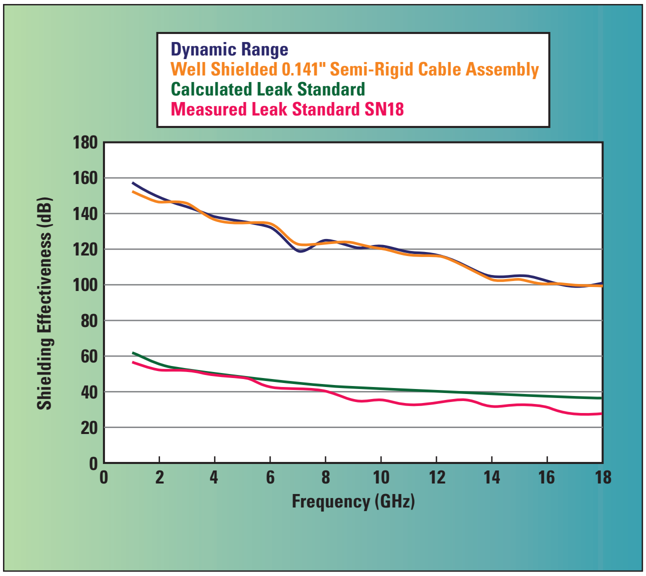
To verify the periodic calibration, two gold standards are employed. One is a cable assembly fabricated from 0.141" diameter semi-rigid cable. This cable has a solid copper outer conductor and uses well-shielded fully soldered SMA connectors. This standard is used to represent a fully shielded cable assembly. From a practical perspective, nothing is fully shielded, but when RF shielding measurements are performed on this device, the resulting measurements are expected to track the dynamic range curve shown in ***Figure 3***. Note that it has been questioned on occasion as to why this standard gives results that are sometimes better than the dynamic curve. The dynamic range is also close to the noise floor of the measurement equipment and the randomness of noise within the equipment can often give these types of readings. This is one reason why the dynamic range of the chamber must be at least 10 dB better than the expected RF shielding measurement.

The second gold standard is known as a 'leak standard'[7] designed to provide a known amount of RF shielding. The leak standard is patterned after that described in IEC-61726, Annex C and is similar in construction to the fully shielded standard but with a single 0.1" diameter hole drilled in its outer conductor at approximately the midpoint of the assembly. The equations in this IEC specification and the actual RF shielding measurements made with a 'leak standard' have been validated to correlate nearly identically to the results shown in Figure 3.

Use of both the well shielded cable assembly and the leak standard cable assembly provides a high degree of confidence in the accuracy of shielding measurements made on cable assemblies, since these assemblies normally fall between the RF shielding values of the two gold standards.

The actual value for RF shielding of a cable assembly is then the difference between the measured RF signal of the cable assembly when placed in the working volume of the chamber and the 'baseline' value obtained during the periodic calibration.

Note that verification of the measurement of the leak standard as well as sample cable assemblies has been performed in similar (but not identical) reverberation chambers at test laboratories in the United States as well as



▲ *Fig. 3 Gold standards measurements.*

in Europe. The close correlation of these independent measurements indicate that the mode-stirred reverberation chamber method of performing shielding effectiveness provides consistent and valid data.

ASSOCIATED EQUIPMENT REQUIREMENTS

The entire RF shielding test is controlled by a proprietary software program developed specifically for this purpose. The signal fed into the chamber is produced by a microwave signal generator driving a switchable power amplifier. The output of the amplifier feeds a securely mounted double ridged horn antenna. RF energy coupled into the DUT is then fed out of the chamber to a spectrum analyzer and converted by the software program into tabular and graphical reports. The internal reference oscillators of the signal generator and the spectrum analyzer are frequency locked.

The spectrum analyzer is set to zero span mode with a very narrow bandwidth. In this configuration, it is essentially a single frequency receiver locked to the same frequency as the signal generator, and displays the signal strength as a function of time. The mode stirrer in the chamber is set to a rotational speed such that in a single sweep on the spectrum analyzer (7 seconds), it will rotate approximately $1\frac{1}{2}$ times. The signal detected by the spectrum analyzer has peaks and valleys and the software program commands the spectrum analyzer to place and read a marker at the peak of the response for each measured frequency.

EXTENDED CAPABILITY

A physically smaller mode-stirred chamber is used to perform shielding measurements from 18 to 40 GHz. This chamber measures 0.4 × 0.5 × 1.1 m. Pre-measurement calibrations are the same as described for the larger 1 to 18 GHz chamber. Dynamic range is at least 100 dB across the entire 18 to 40 GHz frequency range. Chamber performance is verified by using both the well shielded 0.141" diameter semi-rigid cable assembly as well as the known leak standard.

PRACTICAL MEASUREMENTS

In order to obtain accurate and meaningful shielding effectiveness measurements of a cable assembly, certain practices must be observed. The first is to ensure that the cable assembly is positioned correctly within the working volume of the chamber. No part of the assembly should be allowed outside the working volume as the EM field values have not been measured and verified during chamber calibration and will not fall within the established statistically uniform EM field limits.

Next, it is critical that the connectors on the cable assembly under test be properly mated to the interconnect leads within the chamber. For threaded type connectors, this involves making sure that the proper torque specifications are observed. For push-on and blind-mate connectors, it is necessary that the correct force be used to hold the mating connectors together. If adapters are required, they may be sources of unintended signal leakage and must be validated. Wrapping connections and/or adapter bodies with some form of shielding material may also be required to reduce or eliminate leakage. Typical materials for shielding include bronze and copper wool and copper tape. It is important that any additional shielding material be properly grounded to the cable assembly, otherwise it may become an additional receptor of the EM field surrounding the cable under test and allow extraneous EM energy to be coupled to the inside of the cable assembly.

If the shielding effectiveness measurements appear to be uncharacteristically poor, and all connectors are properly torqued and shielded, any solder joints between the connectors and cable may be suspect. A cable assembly which measures electrically good in terms of insertion loss and VSWR as measured on a network analyzer may still have small voids in the connector to cable solder joint which can allow EM fields at certain frequencies to pass through with little or no attenuation.

Once connectors and solder joints have been validated, the next source of leakage may be the cable itself. A poorly constructed coaxial cable with minimal braid coverage cannot be expected to yield high values of shielding effectiveness. A damaged cable may also leak.

Troubleshooting these types of failures is normally accomplished by trial and error. One approach is to shield various sections of the assembly until the leak is found. Another is to employ methods such as real time X-ray. At the measurement stage, there is little that can be done to correct the effects of using a damaged cable and typically requires replacement. If replacement is impossible, additional shielding may be added over the entire cable in the form of an external braid or sock. This will add weight and cost to the cable assembly, and unless the additional braid is grounded properly to the rest of the cable assembly, could actually cause the shielding effectiveness to deteriorate.

CONCLUSION

RF shielding measurements have been found to be an effective tool in helping to determine the quality and more importantly, the long term reliability of microwave cable assemblies. The mode-stirred method is invaluable in establishing the shielding effectiveness of an entire cable assembly and can be performed in accordance with IEC International Standard 61000-4-21. ■

References

1. Military Standards, MIL-STD-1344A (Method 3008), MIL-STD-461F (RS 103).
2. Military Specifications, MIL-PRF-39012, MIL-C-85485.
3. Industry and International Standards, EIA-364-66A, IEC 60096-1.
4. IEC International Standard 61000-4-21:2011, "Testing and Measurement Techniques – Reverberation Chamber Test Methods."
5. IEC International Standard 61000-4-21:2011 Annex F, "Shielding Effectiveness Measurements of Cable Assemblies, Cables, Connectors, Waveguides and Passive Microwave Components."
6. ETS-Lindgren SMART™ 200 Chamber, www.ets-lindgren.com/SMART200.
7. IEC International Standard 61726:2001 Annex C, "Example of a Calibrator."

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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		
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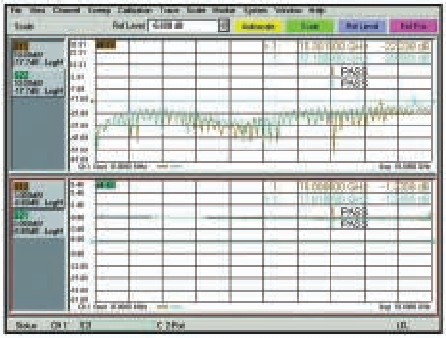
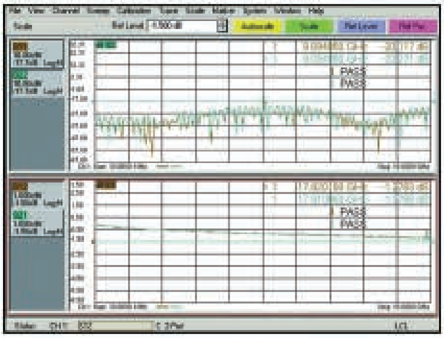
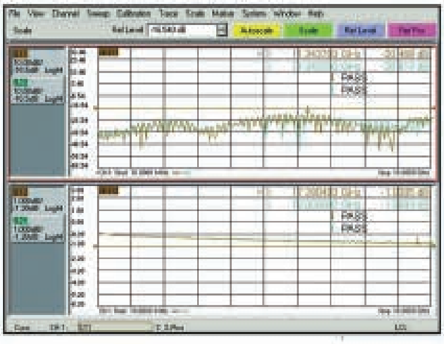


Insertion Loss and Return Loss for LL235, SMA M-SMA M, 18GHz (Typ.)



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



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INVITED PAPER

RF Stability of Cable Assemblies – More Than Meeting IEC or MIL Standards

Fred Hull
San-tron Inc., Ipswich, Mass.

When discussing RF coaxial cable assemblies, we frequently hear "What is the RF stability of the assembly?" The trouble is, depending on the application, a variety of answers may apply. With this article, we intend to illustrate the value of employing a conservative methodology that closely aligns with published International Electrotechnical Commission (IEC) documents and is tailored to environmental conditions to arrive at test procedures that will absolutely ensure performance in the field. By comparing and contrasting our own San-tron test procedures with those published by the IEC, we hope to demonstrate how a different perspective and approach nets optimal results in the field. We note, however, that the evolution of test protocols that originated within the U.S. military procurement agencies (MIL-STD) and were adopted and updated by the IEC may still develop into more improved practices.

In the process of implementing test procedures, it is essential to first identify the true intent of the testing. One may be to characterize the limiting performance characteristics of the assembly. As a result, the test protocol will require manipulation of the cable to its actual limiting parameters, as opposed to those outlined by the "standard." For example, these would include dynamic minimum bend radius, maximum torque and the operational thermal limits of the components. Another intent may be to characterize the cable performance within the scope of an operational deployment, such as avionics, outdoor cellular communications or test and measurement. In so doing, it becomes easier to compare alternative solutions and how they will support the intended application.

In this article, we will demonstrate the characterization of test port cables used for vector network analyzer (VNA) and passive intermodulation (PIM) testing. The typical test port cable will range in length from 40 inches (1 m) to 13 feet (4 m). Access to the device under test (DUT) varies: it can be located on a test bench, within an environmental chamber, a rack-mounted subsystem, tower mounted system or an aircraft installation. In all of these applications, a test cable will be subjected to repeated bending and twisting. Therefore, we generalize that the cable deployment can be characterized by three basic activities: folding and twisting the cable about a mandrel and low frequency vibration. Regardless of the cable size, it will be subjected to these realistic stresses and strains.

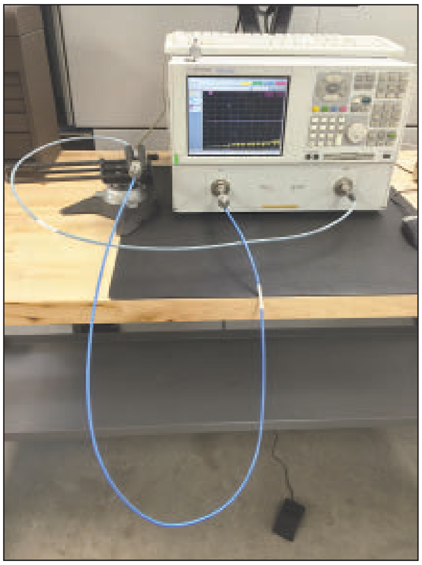

Fig. 1 The baseline performance data for the cable being tested (blue outer sheath) is taken with the cable in a U shape.

TABLE 1

WORST-CASE TEST RESULTS

Cable Test	Freq (GHz)	$\|S_{21}\|$ (dB)	dB/GHz	S_{21} Phase (deg)	deg/GHz
Baseline	10	-0.024	-0.0024	-0.30	-0.03
Clockwise	10	-0.010	-0.0010	-1.61	-0.16
Unfold	10	-0.027	-0.0027	0.81	0.08
Counter-Clockwise	10	-0.003	-0.0003	-0.90	-0.09
Unfold	10	-0.042	-0.0042	2.64	0.26
Positive Twist	10	-0.004	-0.0004	5.42	0.54
Untwist	10	-0.048	-0.0048	7.09	0.71
Negative Twist	10	-0.004	-0.0004	4.54	0.45
Untwist	10	-0.049	-0.0049	7.40	0.74
Maximum		0.00	-0.0003	7.40	0.74
Minimum		-0.05	-0.0049	-1.61	-0.16
Range		0.05	0.0049	9.01	0.90

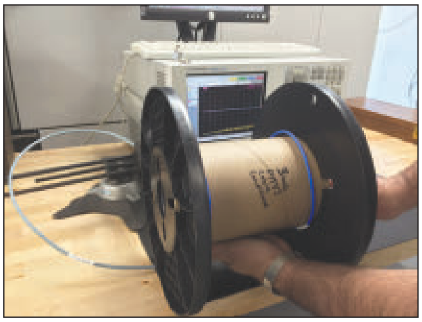

Fig. 2 Test setup for the cable folding test.

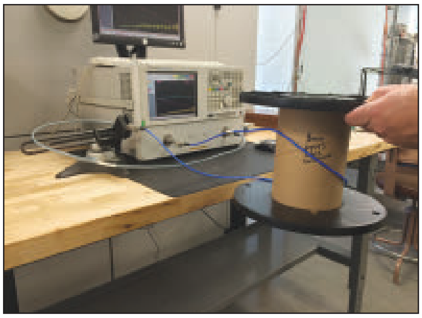

Fig. 3 Test setup for the cable twist test.

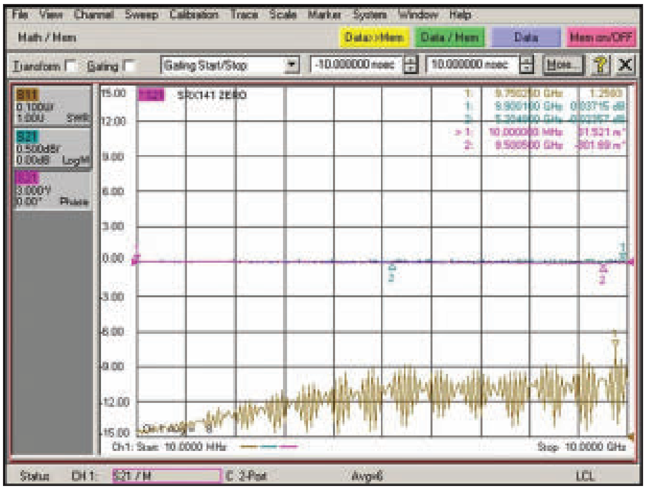

Fig. 4 Baseline performance of the test cable.

ASSESSING PHASE STABILITY

To illustrate stability characterization, we use a SRX141™ coaxial cable with eSeries™ connector terminations, the most widely used product from San-tron's SRX™ series of assembly solutions for both system integration and test and measurement.

The original prototype for this cable was a fluorinated ethylene propylene (FEP) jacketed cable with silver (Ag) clad copper (Cu) wire braid, Ag clad Cu foil helix, polytetrafluoroethylene (PTFE) dielectric, and Ag clad solid Cu center conductor. Using the cable fold test outlined in the standard for STI 8.2.4-14 A1, the prototype functioned very well. During the cable twist test (STI 8.2.4-14 B1), however, measurements showed instabilities in both insertion loss and PIM performance. Applying the vibration test of STI 8.2.4-14 C2, we saw catastrophic degradation of the cable's performance over time. The root cause was the physical makeup of the cable loosening under the weave of the braid, generating PIM signals and varying insertion loss. The failure mode prompted a design review and process upgrade, and we ultimately developed a cable structure that maintains its performance through harsh environments and test protocols.

For this demonstration, the test cable was an SRX141 cable assembly, rated for PIM applications, that was 60 inches long and terminated with straight eSeries Type N male connectors. The VNA was setup with one test port cable and a full two-port calibration from 10 MHz to 10 GHz using a Type N calibration kit. After calibration, the test port cable was secured with a 10 lb table vise to prevent the test setup from introducing variation. The test cable was then mated to the VNA and laid out in a U shape, as shown in ***Figure 1***. The test cable was first subjected to five cycles of the cable fold test (see ***Figure 2***) and then five cycles of the cable twist test (see ***Figure 3***). The worst-case results are summarized in ***Table 1***.

The initial phase baseline measurement, shown in ***Figure 4***, established the "zero" line between -0.30 and +0.03 degrees. Folding the sample

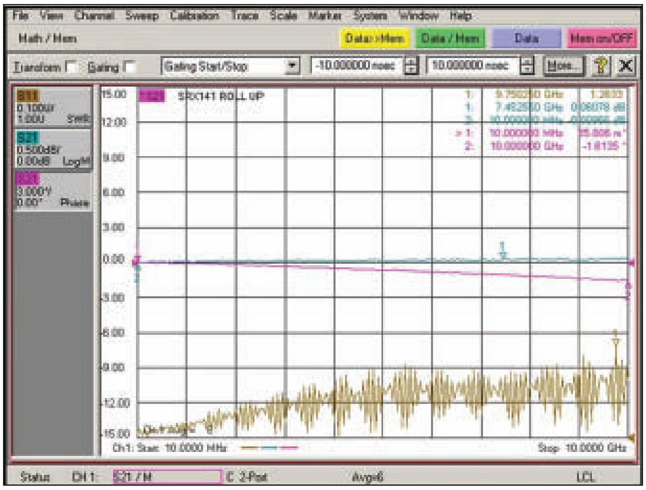

Fig. 5 The S_{21} phase change after the test cable is folded clockwise.

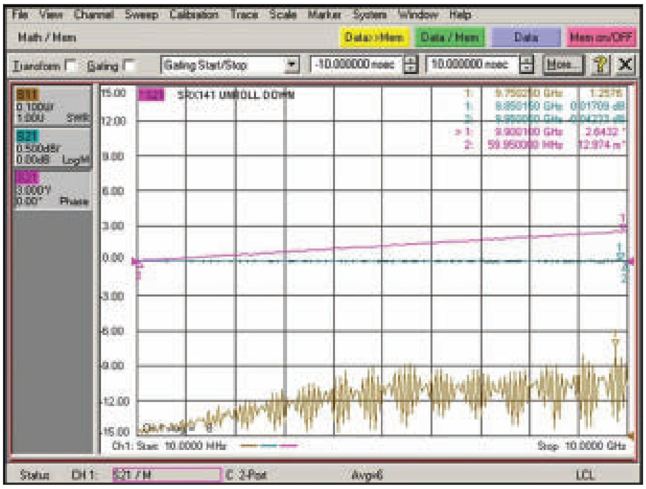

Fig. 6 The S_{21} phase after the test cable is unfolded. Note that the phase response does not return to the baseline.

cable assembly for five repeated cycles in both directions about the 5 inch diameter mandrel resulted in phase shifts with the extreme readings shown in Table 1. The electrical length increased to -0.16 degrees/GHz with clockwise folding (see ***Figure 5***). Unfolding the sample decreased the electrical length to +0.08 degrees/GHz, which is a 0.11 degrees/GHz offset from the baseline measurement. Next, counter-clockwise folding of the sample expanded the electrical length to -0.09 degrees/GHz. Unfolding the sample resulted in +0.26 degrees/GHz (see ***Figure 6***), a 0.29 degrees/GHz offset from the initial condition. The measurements show an asymmetrical variation in phase shift from randomly folding the sample, between -0.16 and +0.26 degrees/GHz. From this data, we can consider the phase stability with folding to be 0.42 degrees/GHz.

Traditionally, the cable twist test causes greater degradation and is, therefore, performed after the cable fold test. Applying a positive 180 degree physical twist to the test sample yielded a decrease in electrical length to +0.54 degrees/GHz. Relaxing the twist back to the neutral position shifted the phase to +0.71 degrees/GHz. Then applying a negative 180 degree physical twist expanded the electrical length to +0.45 degrees/GHz. Finally, relaxing the twist

TABLE 2

SAN-TRON (STI) TEST METHODS

STI 8.2.4-14 Setup 1: Network Analyzer Setup

1. Port 1 is the primary test port and will be selected for the least performing component.
2. Port 2 will be terminated through a high performance test cable.
3. Select upper frequency.
4. Set number of test points to a minimum of 25 × frequency range in GHz.
5. Set Transform to "Low Pass Step" with window set to minimum rise time.
6. Set Averaging = 6.
7. Perform a full two-port calibration based upon test port 1.
8. Display test parameters such as VSWR, S_{21} log magnitude and S_{21} phase.
9. After calibration, the test port cable may be secured with a 10 lb table vise to help prevent test data variation.

STI 8.2.4-14 Test-A1: Cable Fold Test, Insertion Loss, Phase and PIM Stability

The subject cable assembly is formed into a U-shaped loop with a 6" radius. The static test parameter is recorded in this neutral position. The test parameter is then recorded at each step of this test protocol as follows:

1. Wrap the loop 360 degrees about a 5" diameter mandrel.
2. Unwrap the loop to the neutral position.
3. Wrap the loop a negative 360 degrees about the 5" mandrel.
4. Unwrap the cable to the neutral position.
5. Repeat five times.

System stability is asymmetrical and is published as a range/GHz.
Note: The 6" loop and 5" mandrel may be adjusted for larger sized cables or specific deployment scenarios.

STI 8.2.4-14 Test-B1: Cable Twist Test, Insertion Loss, Phase and PIM Stability

The subject cable assembly is formed into a U-shaped loop using the 5" mandrel as the base of the U-shape. The static test parameter is recorded in this neutral position. The test parameter is then recorded at each step of this test protocol as follows:

1. Rotate the loop mandrel 180 degrees about its symmetrical axis.
2. Rotate the loop mandrel back to its neutral position.
3. Rotate the loop mandrel a negative 180 degrees.
4. Rotate the loop mandrel back to its neutral position.
5. Repeat five times.

System stability is asymmetrical and is published as a range/GHz.

STI 8.2.4-14 Test C2: Cable Vibration Test, Insertion Loss and PIM Stability

1. The subject cable assembly is relatively straight. The static test parameter is recorded in this neutral position.
2. Vibration: 0.2" double amplitude, 17 Hz, 3 minutes.
3. System stability is reported as the initial, dynamic worst case and post-test parameter values.

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Model Family	Freq. (GHz)	Connectors (male)	Lengths† (ft)	Temp (°C)
NEW Extra Flexible (FLC)	DC-26	SMA	1.5-6	-55/+85
Precession Test (CBL)	DC-18	SMA‡, N	1.6-50	-55/+105
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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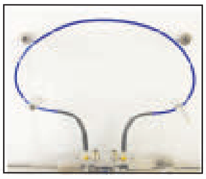

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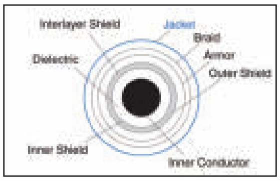

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TABLE 3

CURRENT RF STANDARDS PER IEC PUBLICATIONS

IEC-60966-1 Radio Frequency and Coaxial Cable Assemblies, General Specification
1. Insertion Loss Stability, paragraph 8.4
2. Stability of Electrical Length, paragraph 8.6
• Bending
• Twisting
3. Phase Variation with Temperature, paragraph 8.8
IEC-62037-2 Measurement of Passive Intermodulation in Coaxial Cables
1. Dynamic axial offset of 1 cable diameter +10 mm, 3 revolutions about the central axis, 5 seconds/ revolution
IEC-62037-4 Measurement of Passive Intermodulation in Coaxial Cable Assemblies
1. Clamped Cable Loop, paragraph 5.2, dynamic displacement ±20 mm, 3 cycles/orthogonal plane, 5 seconds/cycle
2. Flexing Tool, paragraph 5.3

TABLE 4

EARLY METHODOLOGIES PER MIL-STANDARDS

MIL-STD-202, Vibration, High Frequency per Method 204, Condition B
MIL-PRF-39012, 15g, 10 to 2000 Hz, 20 minute exposure, 12 times/3 orthogonal planes
MIL-T-81490A(AS) Transmission Lines: Transverse Electromagnetic Mode
• Insertion Loss and VSWR Stability
• Vibration
• Flexure
• Torque
• Tensile Load

back to the neutral position decreased the electrical length to +0.74 degrees/GHz.

Notice that when the cables are relaxed, the phase shift does not revert back to zero; we see a range between +0.08 (for the fold test) and +0.74 (for the twist test) degrees/GHz. The fold and twist tests exhibited phase shifts of -0.16 to +0.26 and +0.45 to +0.74 degrees/GHz, respectively. Combining these variations, from -0.16 to +0.74, specifies a phase stability range of 0.90 degrees/GHz.

Multiple mechanisms generate instability. Twisting a cable causes different changes than simply folding the cable. We also see that the effect of twisting decreases the electrical length, where folding can both elongate and constrict phase length. By modeling the intended application and applying tests in a progressive protocol, we can develop a test flow and parameter, such as degrees/GHz, to estimate the measurement uncertainty and cable variation and how the product will perform in the field.

COMPARING CABLE ASSEMBLY TEST METHODS

The above example showed that no single test can identify all latent failure modes. With the initial cable design described previously, the prototype passed the fold test, yet the twist test surfaced an anomaly. The vibration test confirmed that the assembly possessed a latent defect that would manifest failures in the field. By defining a test protocol to evaluate and qualify the design and assembly processes, the SRX™ product line was deployed with performance characteristics never before realized in fully flexible cable assemblies.

The San-tron test methods are summarized in ***Table 2***. These tests require multiple cycles of physical stress, at least five times to determine if the measured parameters vary over the repeated cycles. If variation is observed, personnel can decide if additional testing is warranted. San-tron has found these tests to be extremely cost effective. Other than the VNA, they require a minimum investment in test fixtures, apparatus and training. They are easily duplicated and can be implemented in the field for on-site testing and validation.

For comparison with the San-tron test methods, ***Table 3*** summarizes the IEC publications. These test methods are also economical and require a minimum of tooling. They are an excellent source for training engineers and test technicians, especially the General Specifications of IEC-60966-1. It offers an overview of RF cable assemblies and performance parameters. However the IEC methodology only requires a single test cycle for the stability validations (paragraphs 8.4 and 8.6) and could be improved by requiring multiple cycles of the physical stresses. More development in the processes of IEC-62037-2 and IEC-62037-4 is warranted.

The U.S. military standards (see ***Table 4***) were the genesis of the IEC and San-tron test methods. However, many of the tests are ineffective in identifying potential failure modes, and the required Qualified Products List (QPL) methodology is expensive. It requires significant investments in personnel, test samples, test equipment and the supporting fixtures. Nevertheless, the MIL-STDs define the most comprehensive characterization and are justified for military deployments where lives are at risk.

CONCLUSION

Adequately testing and qualifying a cable assembly design and assuring product quality in manufacturing requires a test methodology that is tailored to the application and will identify potential failure modes before they can occur in the field. The methodology must subject the cable assembly to multiple cycles of physical stress, including folding, twisting and low frequency vibration. The tests and flow developed by San-tron have proven to achieve these goals – it is cost effective and can be performed in the field. ■


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INVITED PAPER

Coax Connector Design Above 110 GHz

Anritsu Co.
Morgan Hill, Calif.

Historically, coaxial connectors have had two methods for center conductor mating, the hermaphroditic contact and the male pin/slotted female contact. The non-sexed connectors have many advantages, the main being that only one connector type is required. As frequencies got higher, connectors became smaller in order to remain single mode. The success of the SMA connector foretold the end of the non-sexed connectors. Mechanically it is difficult to make butt type connectors. The pin depth tolerances are very critical and the small size makes it difficult to make a resilient contact. These factors raise the cost of the connectors well above the simple male pin/slotted female contact.

As connectors became smaller and reached higher frequencies, the male/female contact design became the standard. A slotless female design was introduced for metrology applications, but this became impractical above the 50 GHz, 2.4 mm connector. A four-slotted contact is much more resilient. The 3.5 mm connector, designed to mate with SMA, incorporates a four-slot female contact and an air interface. This results in a higher precision design, but with a problem. Since they have to be compatible with the SMA connector, the size of the male pin was set at 0.914 mm (0.036"). The center conductor size of the 3.5 mm connector is 1.52 mm (0.060"). Therefore, the wall thickness of the female fingers is 0.3 mm (0.012"); this is quite thick for such a small diameter. After slotting, the fingers are closed and the part is heat treated. If they are closed too little, the contact will be unreliable. If they are closed too far, the insertion force required to mate the connectors will become quite high. This introduces excess wear and may even distort the support beads holding the center conductors in place. The large wall thickness also introduced more pin gap reflection. The impedance of the gap section is 80 ohms.

The 40 GHz, 2.92 mm K connector, introduced in 1985, addressed many of these problems. A short male pin ensures that the outer conductor parts align the two connectors before the center conductors engage, so the male pin will not damage the female by being inserted at an angle. The center conductor diameter of the K connector is 1.27 mm (0.050") leading to a finger wall thickness of 0.18 mm (0.007"). This means that the fingers are more flexible and the insertion pressure is greatly reduced. As a result, K connectors are rated for 4000 connections.

The 50 GHz, 2.4 mm and the 65 GHz, 1.85 mm connector interfaces were introduced by HP/Agilent (now Keysight). The 2.4 mm connector was required with introduction of their 50 GHz VNA. With improvements of V connector bead design, the VNA frequency moved up to 65, then 67, and now 70 GHz.

The 110 GHz, 1 mm connector was introduced by Agilent (now Keysight). Anritsu introduced the 110 GHz W connector with the introduction of their 110 GHz broadband VNA. Anritsu has also introduced a 0.8 mm connector as part of the 70 kHz to 145 GHz VNA and is working on even higher frequency connectors.

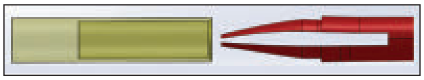

Fig. 1 "Lobster claw" high frequency connector design.

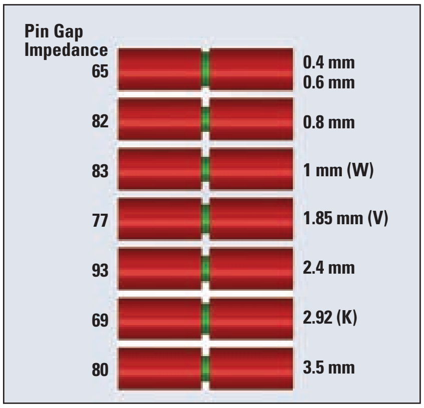

Fig. 2 Pin gap impedance values.

TABLE 1

MECHANICAL AND ELECTRICAL PROPERTIES OF VARIOUS CONNECTORS (# and* SHOWS COMPATIBLE CONNECTORS ** SHOWS DESIGNS UNDER DEVELOPMENT)

Connector	Air Frequency Cutoff F_{co} (GHz)	Max Rated Frequency (GHz)	Pin Gap Impedance	Size of Center Conductor (mm)	Size of Bead (mm)
TYPE N	19.4	18		3.04	
SMA #	N/A	18	N/A	1.27	N/A
3.5 mm #	38.8	33	80	1.52	3.6
2.92 mm K #	46	40	69	1.27	3.05
2.4 mm*	56	50	93	1.042	2.1
1.85 mm V*	73	70	77	0.803	1.5
1 mm W	133	110	83	0.434	1.15
0.8 mm	166	150	82	0.347	0.559
0.6 mm	TBD**	TBD**	65	0.26	0.406
0.4 mm	TBD**	TBD**	63	0.174	0.28

THE SLOT PROBLEM

If the dimensions are reduced by 50 percent for a higher frequency connector, the slotted female contact would be very fragile. If a thin walled design was used, the insertion force would be very slight, but so would the contact pressure. If a thick walled design was used, the contact pressure would be greater but the finger flexibility would be minimal. So a slotted female contact seems out of the question. An out of the box comment supplied the answer. "Don't slot the female, slot the male pin. What would that look like?"

We can make the female wall very thin so there are no slots. Therefore the male pin could be large, closer to the main center conductor size, as shown in ***Figure 1***. This pin could be made with a 0.05 mm slot. Also since the slotted portion is contained inside the un-slotted hole, it would be quite robust with no tendency to spread out like the standard slotted female contact. The impedance of the pin gap is 65 ohms, much less than lower frequency designs. This makes the connector less sensitive to pin depth reflections (see ***Figure 2***). ***Table 1*** provides information on existing connectors and those in design. The current plan is to use the new slotted male design (called the "lobster claw") in the sub-0.8 mm connector designs. Notice that the center conductor of these connectors quickly approach 1/20th the size of the N connector center conductor.

CONNECTOR SIZES AND IDENTIFICATION

Traditionally, connectors moving up in frequency get smaller. Anritsu decided to keep the coupling nuts of new connectors the same size as the 1 mm connector. Smaller than that makes the connectors difficult to work with. Also, the threads are different. The 1 mm connector has a course thread and the higher frequency connectors have a fine thread. It is critical that all of the sub-1 mm connectors cannot be connected in a destructive manner.

The connectors are identified by a laser engraved number that shows the connector size. The number is also etched on the coupling nuts. The 1 mm male coupling nut is plain, the 0.8 mm coupling nut has a single groove and smaller connectors have sequentially additional grooves.

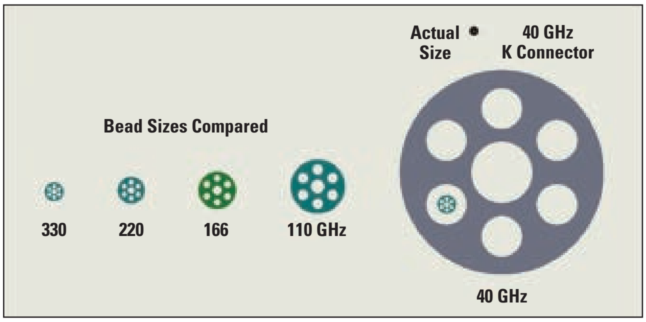

Fig. 3 A comparison of sizes of the beads since the K connector.

SUPPORT BEADS

The connectors above the 1 mm connector have a maximum rated frequency that is the same as the F_{co}, the air dielectric cutoff frequency. The lower frequency connectors have support beads that are larger than the air outer conductor size. This means that they have an F_{co} that is substantially lower than the air F_{co}. The cutoff frequency is inversely proportional to the square root of the dielectric constant of the material between the center conductor and the outer conductor. The new designs have support beads that are substantially smaller than the size of the air outer conductor. They are designed to have an F_{co} that is the same frequency as the air F_{co}. They are also much smaller, as shown in ***Figure 3***.

A major problem with making the bead size smaller than the air dielectric outer conductor size is how to captivate the bead. The old designs, where the bead is larger than the air outer conductor, allowed a mechanical capture in both directions. The solution was a sleeve that contained the bead and had an outer diameter about the same size as the air outer conductor. The sleeves have very thin lips on both ends and are swaged to hold the bead in place (see ***Figure 4***). The as-

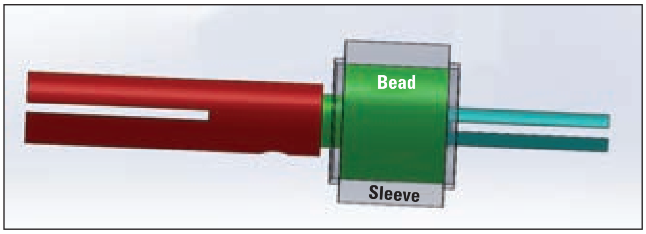

Fig. 4 *Swaged bead sleeve drawing.*

sembly can then be soldered in place, due to the use of high temperature plastics.

ASSEMBLY DETAILS

Figure 5 shows a 0.8 mm connector and does not have the lobster claw design. The backside of the connector is a Coplanar Waveguide (CPW) design similar to a wafer probe. The center conductor is common, but the outer conductor end cap can be configured to accommodate different CPW designs. Figure 5 also shows how the bead sleeve is soldered into the outer conductor.

A feature of the design is the ability to adjust the position of the back side CPW interface. Correct positioning of the connector to the substrate is critical to performance. Holes are centered at the edges of the flange. A tapered pin allows the flange to be moved up and down as well as left and right. When the connector is properly connected to the CPW substrate, the flange screws are tightened.

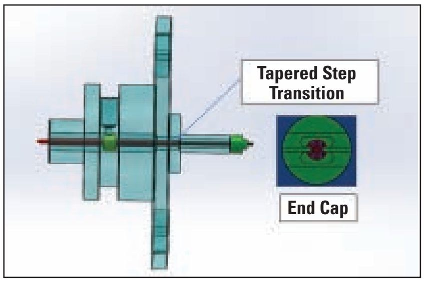

Fig. 5 *0.8 mm connector design.*

These types of connections are mostly used to connect high frequency VNA modules to a wafer probe that in turn will be used to measure CPW substrates over a very large bandwidth. VNA technology is now available from 70 kHz to 145 GHz using 0.8 mm connectors. Waveguide modules extend that coverage to 1.1 THz. These "lobster-claw" connectors are intended to extend the broadband coverage from 70 KHz to 332 GHz.

CONCLUSION

What will be the last connector in a long string of higher and higher frequency connectors?

In 1983, a 40 GHz coax connector was considered unlikely. Today we are designing a connector that reaches almost 10 times higher in frequency. Circuit designers seem to be able to create devices that operate at ever-higher frequencies, and some kind of connection is always needed to make these devices useful. Let's not limit our imagination. ■

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Spring-Mounted Measurement Adapter Saves Costs

SPINNER GmbH
Munich, Germany

The mobile industry is under cost pressure. What can be done to reduce product cost beyond R&D and product design? Manufacturers have not fully tapped into savings from RF fine-tuning during product assembly or test and measurement during product qualification.

When tested, RF products are usually mated manually. Traditional push-pull adapters cannot be used for automated testing, as they are not self-centering and require manual feeding. SPINNER's EasyDock can significantly reduce costs by automating RF measurement and quality tests, testing faster without sacrificing quality or measurement precision.

For conventional push-pull mechanisms, the measurement adapters are manually fed to the test device. This is unsuitable for automated movement processes, since the positioning of the test device to the adapter is not guaranteed to be 100 percent aligned. A certain amount of tolerance cannot be avoided, which the measurement adapter has to reliably compensate for.

These requirements are met entirely by the EasyDock, a spring-mounted measurement adapter that guarantees perfect contact and reliable operation, even when the axes of the test device and the adapter are not perfectly aligned. Also, the precision of the measurement process is not affected by mechanical tolerances.

PRECISION MATING

The EasyDock tolerates deviations in all planes and directions. The conical intake ensures that the adapter and the test device slide together reliably, even if they are not centered and aligned. Moreover, they do not have to meet each other at a right angle, since the adapter compensates for tilt, and the spring-loaded mounting evens out variances in distance. These mechanical compensations are crucial for automated testing, as they protect the devices and measurement interfaces.

When testing, the EasyDock first centers itself within the test device. Then the devices are tightened together for mating. Over the entire mating process, the EasyDock ensures a constant contact pressure of 80 N, which maintains a correct and reproducible electrical contact for the measurement and ensures consistent data.

The ability to compensate for misalignment enables the EasyDock to test RF products with

▲ *Fig. 1 The EasyDock portfolio includes 7-16, 4.3-10, 4.1-9.5 and N measurement interfaces.*

more than one interface. Devices such as couplers, diplexers, base stations and antennas can be tested within one stroke, provided multiple EasyDock adapters are installed on a dedicated measurement frame.

The EasyDock is available for all common mobile industry interfaces. The portfolio (see ***Figure 1***) includes 7-16, 4.3-10, 4.1-9.5 and N interfaces and hosts 7-16, 4.3-10, N and 3.5 mm interfaces on the rear, contacting the measurement cable or device. The adapter can be mounted on a front panel or housing, either as a bulkhead or four-hole flange.

PIM MEASUREMENT

Since passive intermodulation (PIM) is one of the most crucial aspects for the mobile communication industry, SPINNER has designed the EasyDock 7-16 and 4.3-10 measurement interfaces for PIM measurements. While a contact pressure of 80 N is sufficient for PIM measurements on a 4.3-10 interface, it is not sufficient for a typical 7-16 interface. To address this, the 7-16 EasyDock interface was adapted to ensure proper PIM measurement with 80 N contact pressure. This allows simultaneous PIM tests of devices with many connectors and is also suitable for products with a high connector density, such as antennas.

An EasyDock adapter featuring either a 7-16 or 4.3-10 measurement interface (front or rear) supports PIM measurements up to -162 dBc IM3. The EasyDock can be combined with SPINNER's low PIM switch and low PIM rotary joint for automating test systems where movement and rotation are required or where test procedures switch between PIM and VSWR measurements.

COST SAVINGS

Tests with the EasyDock have shown significant savings – up to 80 percent compared to manually mated test procedures. Design to cost measures have improved the CAPEX position of manufacturers. Now, EasyDock adds OPEX savings to significantly reduce production costs.

VENDORVIEW

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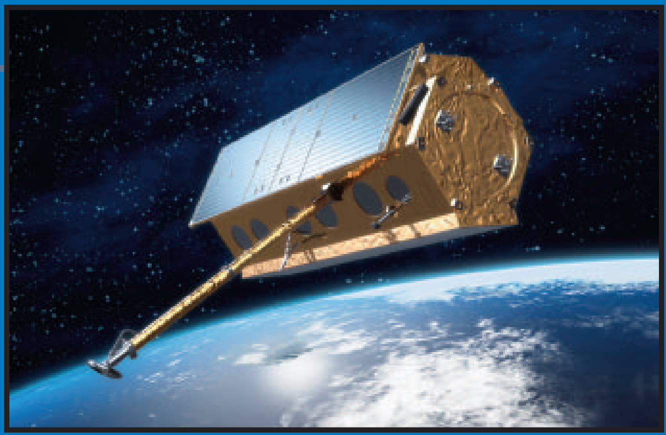
info@spinner-group.com
www.spinner-group.com

Instantly Improve the Performance of Your Phased Array Radar!

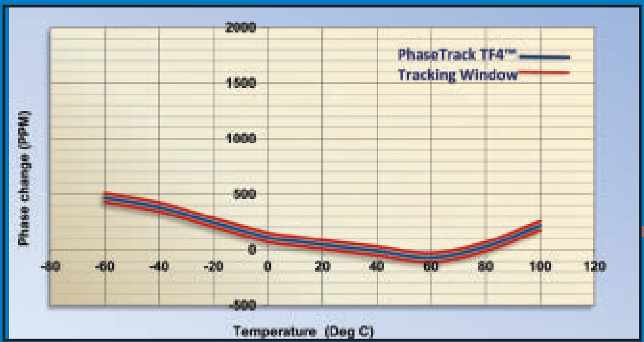


Phased Array Radar system performance has long been limited by the phase change over temperature of coaxial cables.

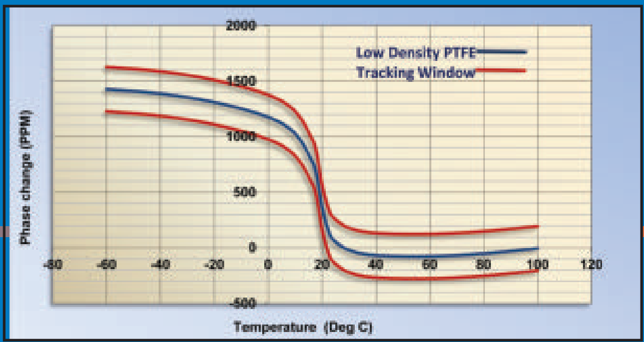
Not anymore!

TF4™ - our proprietary, ultra stable dielectric material significantly improves Phased Array Radar system performance by reducing the phase change of the interconnecting coaxial cables.

Typical PhaseTrack TF4™ Performance



Typical Low Density PTFE Performance



- Available NOW in various flexible coaxial cable and semi rigid coaxial cable assembly sizes
- Perfect for all Ground, Naval, Airborne or Spaceflight Phased Array Radar applications
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- Wide range of connector types available
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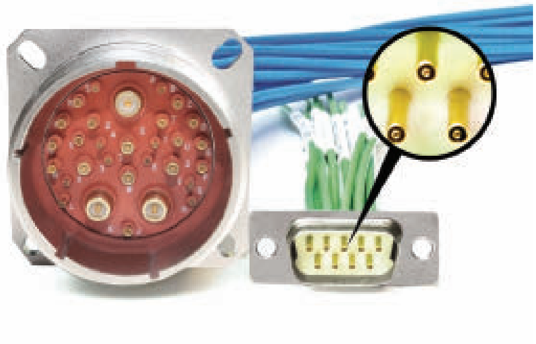


Next Generation Interconnect Cabling

Southwest Microwave Inc.
Tempe, Ariz.

Electronic equipment has evolved significantly over recent decades, both in terms of performance and packaging. A myriad of advancements in device engineering in the commercial, military and scientific sectors have contributed to components and end systems that are more sophisticated and much smaller than their predecessors. For example, today's unmanned vehicles have greater range as a result of optimized energy sources and reduced craft size. Satellites that communicate from deep space are constructed from compact, lightweight materials to reduce launch costs. Surgical procedures are more minimally invasive through robotics and microscopic tools.

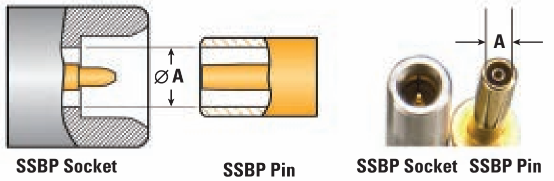
Yet as end solutions evolve in function and form, microwave coaxial connector solutions have been slow to keep pace with the complex interconnect cabling requirements to support these new generation technologies. In an age of miniaturization, legitimate concern exists relative to the heavy weight and extensive space needed for individual connector mounting, between-connector spacing, and manual mating of each connector and cable. If intricate harnesses are developed to organize a maze of interconnections, system cost grows. If not, field maintenance is extensive and expensive. Finally, the range of connectors commonly needed to address the varying frequency demands of today's electronic products further increase PCB or panel area and project budget.

There are also interconnect quality issues that can negatively affect reliability. Standard push-on RF connectors can separate under the vibration or shock of a harsh environment. Poor connector grounding equals poor RF performance and shorter system mean time between failures (MTBF). Similarly, without a built-in stress release, a soldered center conductor is a failure point for many of today's coaxial cable assemblies. In a spec where the potential for mismating of cables is prohibited, reverse-sex plug-jack combinations, polarized (keyed) connectors or pairing of dissimilar connectors can solve the problem, but at high cost.

As systems expand in capability but shrink in size, there is a distinct need for multifunctional microwave interconnect solutions that support higher RF frequencies, greater bandwidth, improved survivability, easier servicing and a more compact footprint.

THE SSBP ADVANTAGE

To provide a reliable alternative to the packaging challenges of traditional interconnect cabling, Southwest Microwave has developed a family of SSBP RF and microwave coax contacts. SSBP coax contacts conveniently seat in cavities designed for signal (non-coax) contacts



SSBP Size:	SSBP-20	SSBP-20HD	SSBP-16	SSBP-12	SSBP-8
"A" Diameter: (reference only)	0.9 mm	0.9 mm	1.2 mm	1.7 mm	3.3 mm
Max Frequency: (calculated)	150 GHz	150 GHz	108 GHz	76 GHz	40 GHz

Fig. 1 SSBP size (using signal contact sizing terminology) vs. millimeter wave transmission line diameter "A". The maximum frequency depends on contact size and cable application.

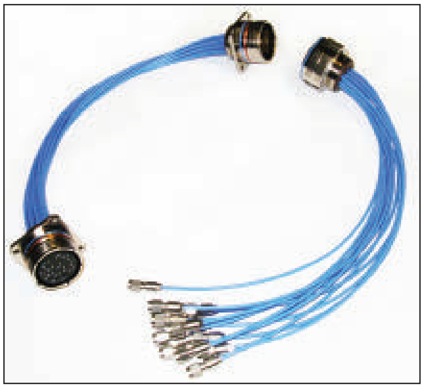


Fig. 2 SSBP high performance coax contacts for use in standard MIL-DTL-38999 and other multiport connectors solve the space, weight and performance challenges of standard interconnect cabling.

in off-the-shelf multiport connectors that use M39029 contacts. For maximum design flexibility, SSBP contacts for special applications, including discrete coax installations, can be arrayed in custom envelopes. Seating or removal of SSBP contacts is achieved using standard MIL-I-81969 insertion and extraction tools.

SSBP coax contacts achieve a single, high performance connection to device cabling that can be easily connected and disconnected as needed, rather than mating an array of individual RF connectors. This simplifies interconnections and cabling, especially in tight or hard to reach spaces, dramatically reducing field maintenance or system test requirements and contributing to reductions in end-system cost. The miniaturized SSBP RF packaging format enables significant space and weight savings, versus discrete connectors and cables, by reducing the necessary area and volume of interconnections.

SSBP solutions offer higher RF performance and greater bandwidth than a corresponding array of individual connectors. Coax contacts of varying frequencies can easily be housed in one multiport connector or mixed with DC power, signal and fiber optic contacts to optimize multi-functionality, packaging design flexibility and project cost savings.

For circular connector applications, SSBP size 20, 16, 12 and 8 contacts are available to seat in standard MIL-DTL-38999 connectors with size 20, 16, 12 and 8 contact cavities. In rectangular connector applications, SSBP size 20HD coaxes seat in size 20 contact locations in standard MIL-DTL-24308 D-Subminiature connectors. SSBP 20HD assemblies used in D-Sub applications are also used in low profile, ruggedized, board-launchable MIL-DTL-83513 Micro-D type connectors in 3, 6 or 9-pin configurations. ***Figure 1*** shows the SSBP size versus millimeter wave transmission line diameter "A". The maximum frequency depends on contact size and cable application.

For miniaturized applications, SSBP contacts retrofit into Glenair Mighty Mouse® Series 79 and 80 connectors, and can be designed for use in other types of multi-pin connectors. SSBP high performance coax contacts for use in standard MIL-DTL-38999 and other multiport connectors (see ***Figure 2***) solve the space, weight and performance challenges of standard interconnect cabling.

SSBP coax design ensures exceptional RF performance and longevity, particularly in harsh environments. Pin and socket construction offers built-in contact stress relief during mating, as does a positive, three-step mating sequence in the host connector that accurately aligns the contact's outer conductor prior to engaging the center conductor, which guarantees matched impedance and EMI-tight, repeatable mating. Spring-loaded contacts maintain a constant ground path through shock or vibration and have no exposed spring fingers or slots that could be damaged or allow EMI emissions. Termination of SSBP contacts does not involve soldering of the cable center conductor to the socket contact, preventing breakage due to cable movement.

MIL-HDBK-217F, Notice 2 outlines that coaxes in multi-pin connectors are predicted to have higher reliability, or longer MTBF, than groups of equal numbers of discrete coaxes. Coupling this data with the highly positive outcomes of SSBP coax testing for vibration, shock, mating/unmating durability, EMI shielding effectiveness and typical microwave performance reinforces the viability of these solutions for hi-rel or harsh environments.

BROAD-RANGING APPLICATIONS

Systems with complex signal generation and routing requirements – such as communications, radar or missile defense systems – call for a high volume of RF interconnects. The higher the volume of RF interconnects, the more applicable the SSBP solution. The small footprint and reduced weight of numerous SSBP coax contacts housed in a multiport connector also make this solution ideal for interconnect applications where weight and space are concerns, such as the tight spaces of on-board computers, landing gear, microsurgical equipment or unmanned systems.

With the environmentally sealed, ruggedized packaging of the D38999 connector housing, SSBP contacts will withstand the shock and vibration inherent in aerospace or military applications. By facilitating instant and reliable mating of a complex array of interconnections with a single multiport connector, SSBP coaxes reduce the potential for mating error and connector damage, and add efficiency to highly-regulated electronic system performance testing applications, such as aircraft system testing, where the manipulation of individual interconnections adds extensive data logging and cost to the testing process.

Southwest Microwave Inc.
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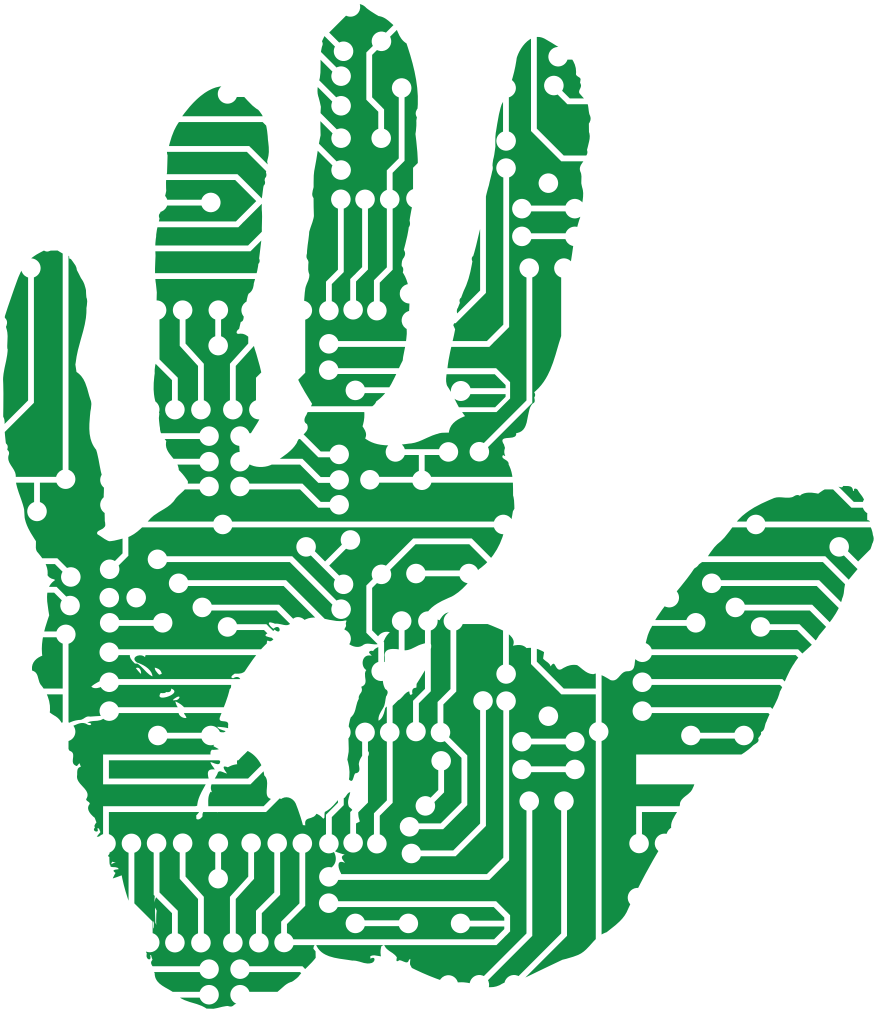


RF/Microwave Cable Assemblies

Maury Microwave's Stability™ series RF/microwave cable assemblies are designed specifically for phase- and amplitude-stable applications, offering excellent measurement repeatability even after cable flexure. With a ruggedized, durable construction, Stability results in a reduced total cost-of-test. Stability's light weight, superior flexibility and small form factor make it ideal for daily use with VNAs, test instruments, bench-top testing, probe station integrations and ATE systems.

Stability low-profile cable assemblies are designed for high-density applications such as switch matrices and PXI/PXIe/AXIe cards, as well as wafer probe applications where traditional cable assemblies might cause interference due to cable and connector size. Stability low-profile cable assemblies offer the same electrical performance as Stability RF/microwave cable assemblies in a configuration that is 44 percent smaller and 66 percent lighter, and are available with 3.5 and 2.92 mm connectors.

For thermal vacuum applications, Stability TVAC cable assemblies have been designed for measurements in a thermal vacuum environment for space product testing. Stability TVAC cable assemblies offer the same electrical and mechanical performance as Stability RF/microwave cable assemblies with specialized vented 2.92 mm connectors that meet low outgassing requirements of ESA-PSS-01-702 with a TML < 1 percent and CVCM < 0.1 percent.

Stability Swept 90° cable assemblies are designed for applications requiring a fixed and stable bend where traditional cable assemblies may be inconvenient. With a bend radius of 1.43" and a cable-to-connector length of 3.3", Stability Swept 90° cable assemblies retain the electrical and mechanical specifications of the traditional assembly while removing stresses related to hand-formed bends.

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

Low Loss Hermetic Cable Assembly

GLA & GULA cable assemblies have been developed and produced for aircraft and cover the broad frequency range from DC to 18 GHz. These high quality, low loss cable assemblies deliver a low VSWR of 1.35:1, feature a self-locking connector and are protected by a Nomex and Kevlar jacket, which offers abrasion resistance.

MIL-T-81490 COMPLIANCE

As required by the aircraft sector, the GLA & GULA cable assemblies must be lightweight, small in size and not sacrifice performance. All cables are designed to meet statutory aircraft requirements and are in compliance with MIL-T-81490, which enables the cable to withstand harsh environments over a long period of time.

The GLA & GULA cable assemblies have been developed to meet stringent communication standards with a cable design that is crushproof and hermetically sealed. Another advantage is that the cable assemblies also enable the connection of an anti-rotation connector which is used in high vibration environment applications.

APPLICATIONS

GLA & GULA cable assemblies are also applicable to helicopter, trainer, UAV, military, communication, aircraft antenna systems, radar system, air reply system and satellite communication systems.

GigaLane Co. Ltd.
Gyeonggi-do, South Korea
(82)31-370-3517
sales@gigalane.com
www.gigalane.com

Self-Contained, Computer Controlled Measurement System

In-Phase Technologies announced availability of their Model PCT306 Microwave Vector Test System. The self-contained, computer controlled measurement system is used for testing RF and microwave passive devices utilized in helicopters, aircraft, ships, submarines and militarized vehicles. The 50 Ohm system, covering the frequency range of 30 KHz to 26.5 GHz, accurately measures all S-parameters, scalar insertion loss, VSWR and distance to fault (DTF) of RF and microwave cable assemblies under harsh environments. It is designed to withstand vibration, shock and varied temperature and humidity conditions. The system is packaged within a small transit case and is capable of running off its own internal battery supply, or can be connected to any AC outlet. The portable test set is ideal for rapid integrity checks or for troubleshooting coaxial cable runs, antennas and other passive devices on the flight line or in depot and field maintenance facilities.

The design of Model PCT 306 is based on field proven In-Phase cable test systems used over a decade within the CH-47 Chinook and V-22 Osprey rotorcraft production facilities. Each test set can be pre-programmed with scores of antenna, coaxial cable and other device performance specifications. These specifications are used by a test operator to test and verify the performance of critical cables and devices used in C5ISR avionic systems.

In-Phase Technologies
Bordentown, N.J.
(609) 298-9555
www.in-phasetech.com

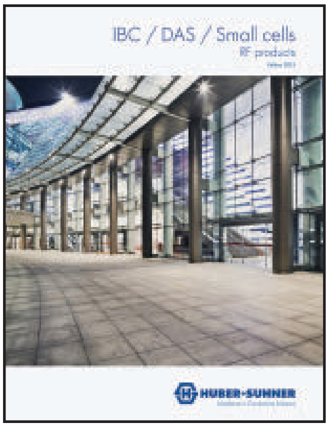
Cables and Connectors

Literature Showcase

RF/Microwave Signal Transmission

Cinch Connectivity Solutions offers a wide range of connectors and cable assemblies suited for RF/microwave signal transmission. Their products support wireless communications, data networking, test and measurement, broadcast, military and aerospace applications. Johnson offers a wide variety of RF connector types and board interfaces. Semflex offers a high performance, low attenuation bulk cable and custom, fixed length and semi-rigid cable assemblies to satisfy the most demanding requirements. Learn more at www.cinchconnectivity.com or call (800) 247-8256.

Cinch Connectivity Solutions
www.cinchconnectivity.com

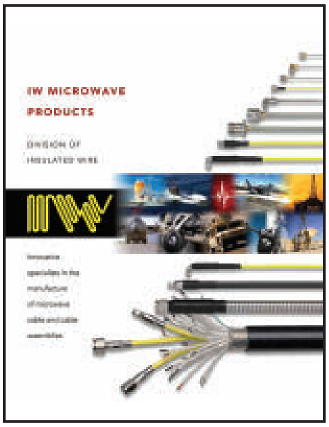


IBC/DAS/Small Cells Catalogue

VENDORVIEW

When it comes to availability and quality of wireless data communication services, the high coverage requirements apply equally both outside and inside buildings. With the implementation of dedicated solutions like distributed antenna systems (DAS), additional capacity for voice and data channels can be created as required. The new HUBER+SUHNER IBC/DAS/Small cells product catalogue contains a wide range of radio frequency solutions that support all applications in the deployment of the mobile communication network in urban environments. Visit HUBER+SUHNER's microsite at www.wireless-infrastructure.com/solutions for a closer look.

HUBER+SUHNER
www.hubersuhner.com



More Technical Content

IW's new 2015 catalog features a new data sheet format with increased technical content. Tabulated and graphical data for all cables includes stranded center conductor, expanded Re-Flex™ options, attenuation values in dB/m, plus useful cable handling instruction and new product specifications. IW introduces 0471, 170 series and RF250 following customer demand for smaller diameter cable, improved attenuation and extended frequency range for SATCOM applications, and the most versatile RG401 replacement available. IW–we're flexible!

Insulated Wire (IW)
www.iw-microwave.com

Kappa 331 UX

The Kappa 331 UX is a modular wire cut and strip machine capable of processing coaxial and triaxial cables with cross sections from AWG 24 to AWG 2. The Kappa 331 UX comes equipped with the TopTouch user interface that is extremely operator friendly and easily programmable. The Kappa 331 UX can be changed over quickly to increase efficiency and production rates. For more information, please contact your local Komax Wire sales representative or visit the company's homepage.

Komax Wire
www.komaxwire.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 assemblies are available in stock in standard lengths.

Maury Microwave Corp.
www.maurymw.com

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, handflex 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.

MIcable Inc.
www.micable.cn

Cables and Connectors

Literature Showcase

Custom Rack Mount Test Equipment Guide

VENDORVIEW

Mini-Circuits' Custom Rack Mount Test Equipment Guide is a 52-page, full color brochure showcasing a wide selection of custom test solutions ranging from DC to 18 GHz including amplifiers, signal generators, routing and distribution systems, and more. The brochure highlights Mini-Circuits' ability to deliver affordable, reliable custom test solutions with turnaround times as fast as two weeks and also introduces the company's user-friendly control software, programming support and test accessories. To request a copy, email sales@minicircuits.com.

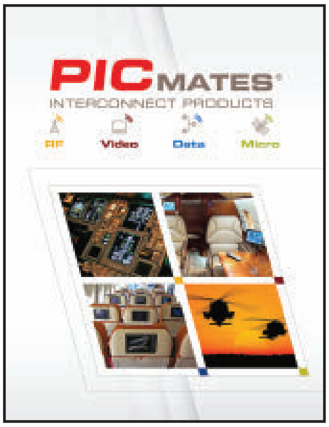
Mini-Circuits
www.minicircuits.com

V11.03 Update

VENDORVIEW

NI AWR Design Environment™ introduced new antenna measurement capabilities and a ready-built 3D parts library within its Analyst 3D FEM EM simulator, as well as user-configurable 3D PCells for custom parts creation. NI AWR software provides an intuitive use model that delivers an exceptional user experience and open design flow that supports third party tools, resulting in more compelling solutions. These unique aspects of NI AWR software solutions maximize user productivity by eliminating errors and design redundancies and quickening the pace to market. Learn more about additional enhancements for V11.03 at www.awrcorp.com/whatsnew.

National Instruments
www.ni.com



PICMATES Interconnect Products

The PICMATES family of cables and connectors offers solutions for high frequency/microwave applications plus network/communications, data transfer and entertainment demands. The company's brochure highlights their broad selection of specialized coaxial, triaxial, high speed data and custom cable options. In particular, MicroMATES are designed to advance interconnect technology for Ku- and X-Band assemblies supporting satellite communications and onboard connectivity in aircraft. Visit www.picwire.com/pdfs/PIC_Overviews/pic_wire_picmates_overview.pdf for more in-depth information.

PIC Wire & Cable
www.picwire.com

Precision Coaxial Connectors

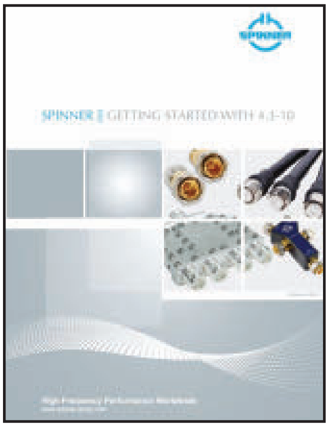
SGMC Microwave is a registered ISO 9001:2008 manufacturer of precision coaxial connectors including cable connectors, receptacles and adapters. The company's product catalog along with their newly revamped website showcases their extensive line of readily available products which includes these series: 1.0 mm, 1.85 mm, 2.4 mm, 2.92 mm, 3.5 mm, SMA, N, TNC and SSMA. Quality, performance, and reliability you can count on.

SGMC Microwave
www.sgmcmicrowave.com

Hermetically Sealed Adapters

Spectrum's new brochure features numerous updates to their product line. 2.4 and 1.85 mm units were added to their N, TNC, and 2.92 mm series. The standard Hermeticity specifies 10^{-8} atm. cm^3/s minimum. As several applications do not need this high class Hermeticity, more economical priced products with Hermeticity of 10^{-5} atm. cm^3/s were also added. All adapters use fused in glass seals between center contact and outer conductor. The adapters are normally used at vacuum chambers testing products that are undergoing tests for outer space applications.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com



Getting Started with 4.3-10

VENDORVIEW

SPINNER GmbH's 4.3-10 portfolio is consistently growing. New offerings include calibration kits and easy dock for test & measurement; connectors, adapters and jumpers; loads and attenuators; plus couplers and splitters. The SPINNER Group has been setting standards with its RF technology products for more than 65 years. The company's high quality standards of design, material and manufacturing ensure the best possible connectivity, optimized installation and failure-free operation, even under the toughest environmental conditions. For more information visit the company's website at www.spinner-group.com.

SPINNER GmbH
www.spinner-group.com

Cables and Connectors
Literature Showcase

DAS Coaxial Cable Products

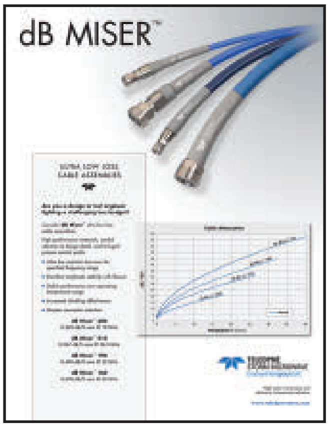
Superior Essex offers a broad portfolio of cable products and accessories for the modern wireless heterogeneous (HetNet) network, including coaxial, fiber, power, hybrid and category cables, as well as connectors and jumpers used for both cell towers and Distributed Antenna Systems (DAS). Superior Essex DAS coaxial cable products offer industry-leading electricals, with low attenuation across 30 to 4000 MHz, guaranteed voltage standing wave ratio (VSWR) less than 1.25 dB, and passive intermodulation (PIM) less than -155 dBc. With manufacturing facilities throughout the U.S., Superior Essex offers short lead times to help meet your wireless installation needs faster.

Superior Essex
www.superioressex.com

Comprehensive Product Catalog

SV Microwave released their latest, most comprehensive product catalog that features all of their distribution items categorized by series. Additionally, every part number in SV Microwave's digital copy has a hyperlink to its own landing page on the company's website with series information, data sheets and inventory availability. Please visit www.svmicrowave.com/resources/catalogs to download your copy today.

SV Microwave
www.svmicrowave.com



dB MISER Brochure

The clear choice for engineers facing challenging system gain or signal-to-noise requirements, dB Miser™ assemblies exhibits ultra low loss, excellent amplitude stability with flexure, stable performance over temperature and exceptional connector retention. Teledyne Storm Microwave's recently updated brochure provides data for the full line of dB Miser™ cables (0.160", 0190", 0.210" and 0.299" diameters) including cable specifications, construction, connector options, armoring and ruggedization options, plus full ordering information. Visit the resource center on the company's website to view and download a copy.

Teledyne Storm Microwave
www.teledynestorm.com

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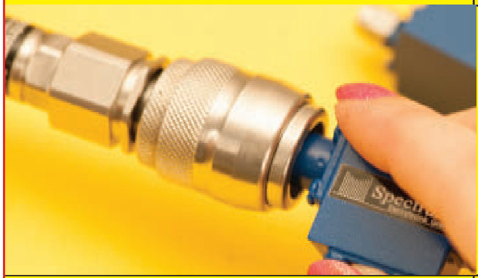
Procedure for how to use the N, TNC and 7/16 Push-On male. Push-On Connectors mate with any standard female connector of the same connector style.

1. Convert your standard Assembly into a Push-On Assembly using the Nf to Nm Push-On Adapter.

2. Put your fingers firmly onto the knurls of the “Lock Nut”.

3. Push “Lock Nut” forward and engage the Push-On end of the Adapter with the mating female. Back nut must be released.

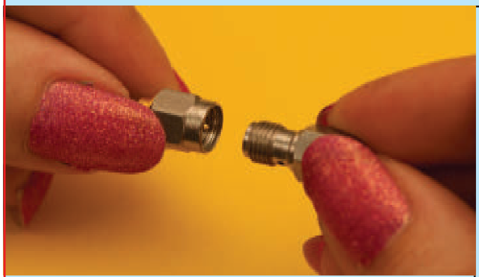


4. The Connection has been completed, easy and fast. The connector has been locked on safely.

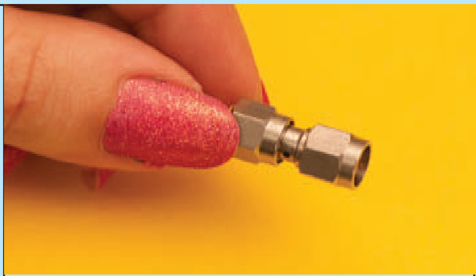
5 . To unlock (when “Back Nut” is in unlocked mode) push the “Lock Nut” forward and stop reverse movement by setting your fingers onto the “Back Nut”.

6. Keep fingers on “Back Nut” to ensure that “Lock Nut” cannot slide back and pull the connector off.

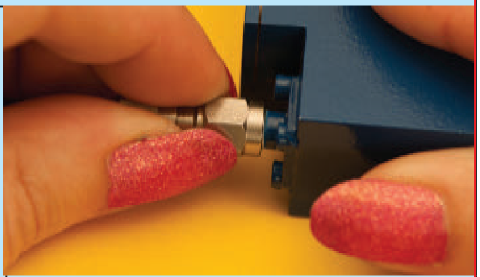
Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.



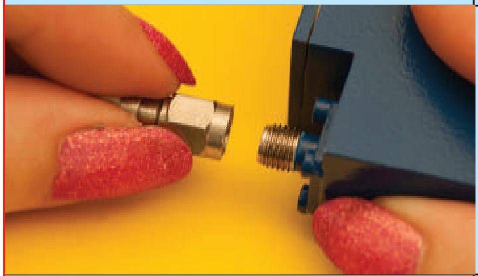
1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted into an SMA male Push-On Assembly.



3. Just slide the Push-On SMA male Connector onto any standard SMA female. The connection is securely completed in seconds.



4. To disconnect, just pull the connector off.

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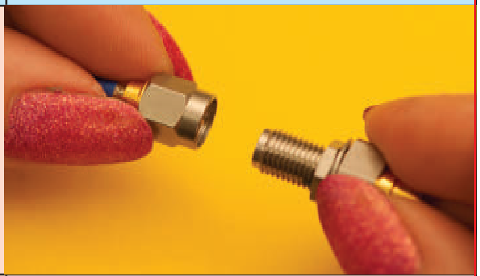
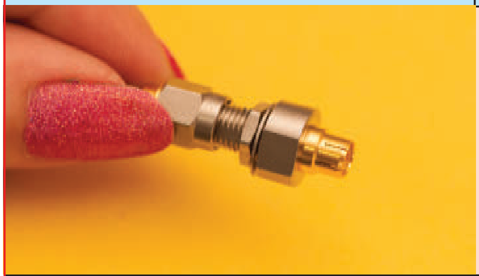
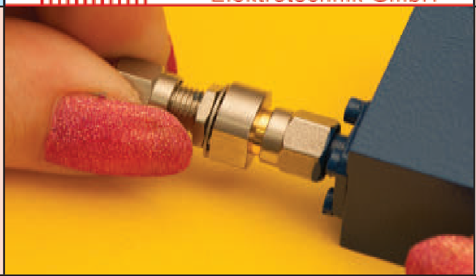


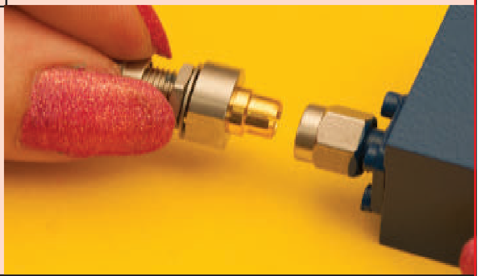
1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted to a Push-On SMA female Cable Assembly.



3. Just slide the Push-On SMA female Connector onto any standard SMA male. The connection is securely done in seconds.



4. To disconnect, just pull the connector off.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