CABLES AND CROSSTALK

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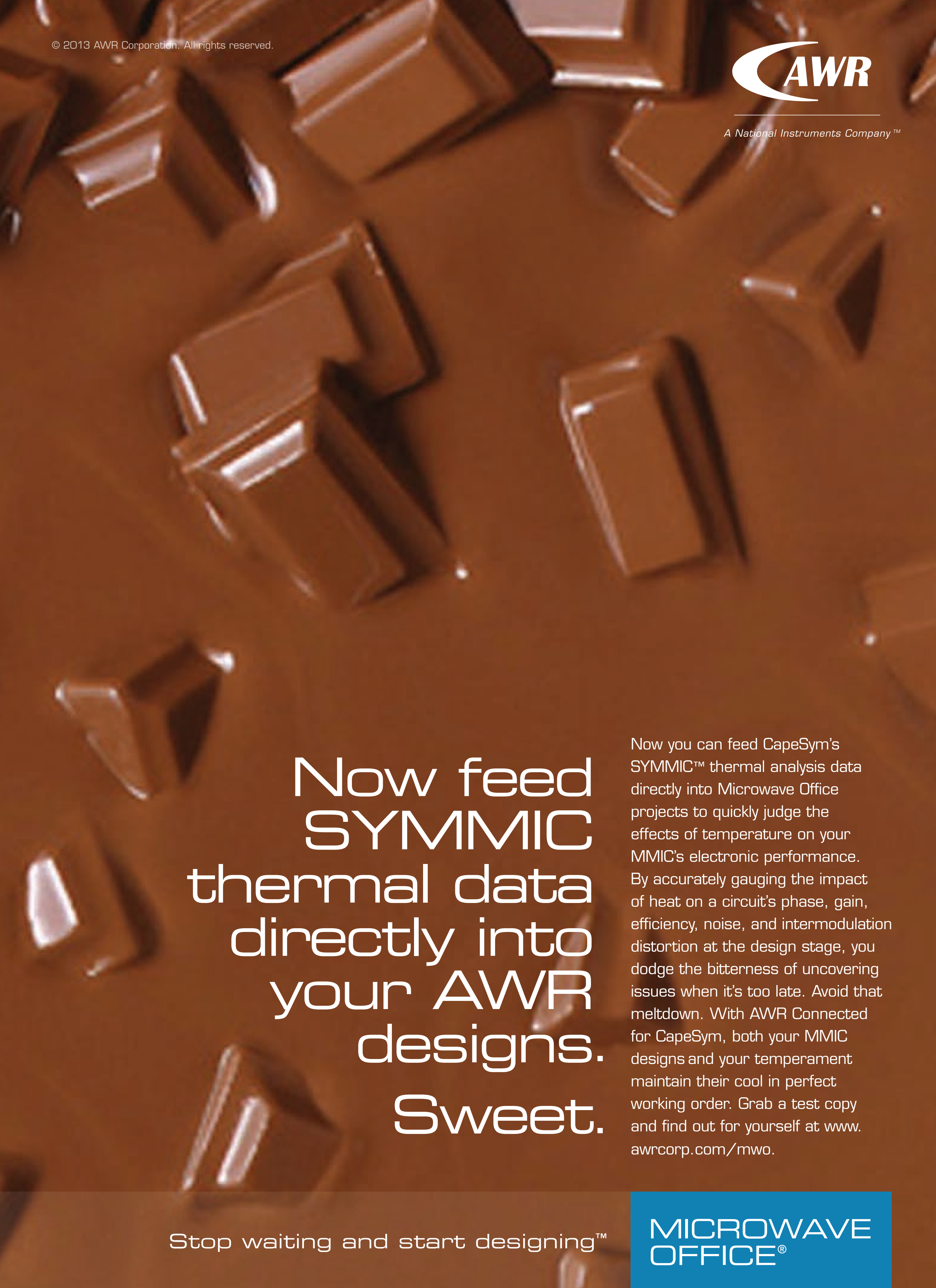
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Cables & Connectors Supplement

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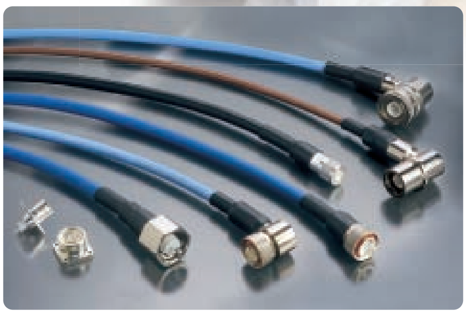

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Simulating Crosstalk and EMI in Cables

Cables not only transfer the power needed to run electrical equipment, but also the data signals needed to operate them. To prevent errors and device failures, the same attention must be paid to the choice and installation of the cabling as is paid to the rest of the system.

Dealing with data means considering signal integrity (SI). Since data signals are modulated electrical pulses, anything that introduces noise into the cable can corrupt the information, causing equipment to lose performance, malfunction or simply fail altogether. Crosstalk and impedance mismatch are common sources of SI problems; cables generally consist of multiple wires travelling together. The fields generated in one wire can, without proper shielding, couple to others and induce currents in them, while signals can be reflected at the interfaces between cables if the impedances do not match. Analyzing these issues uses RF and microwave techniques and expertise.

It is not just interference from other data signals that one needs to worry about, however. Electromagnetic interference (EMI) can come from a range of sources within the system and the wider environment. Switched-mode power supplies generate noise, while lightning strikes and electrostatic discharge (ESD) introduce transients that often cause damaging current surges in devices. Even the interaction between the equipment and its casing can be enough to interfere with data signals. As well as being immune to external radiation, the cables themselves should not radiate either. Electromagnetic compatibility (EMC) is a legal requirement and this means that they must pose little interference risk to other devices.

Every advance in technology pushes cable design requirements further. High-speed devices demand cables capable of handling ever-higher bit-rates. Automotive and aeronautical systems, increasingly reliant on electronic control and communications systems, need cables that are lightweight yet also measure up to stringent safety regulations. Consumer electronics meanwhile are pushing toward standardized multipurpose cables, where one lead might be used for anything from charging a mobile phone to controlling a printer or transferring data to a hard drive.

In light of these developments, designers have turned to cable harnesses, where multiple cables – sometimes a hundred or more – are tied together and travel along the same conduit as well as hybrid cables, which contain both signal and power wires together. The most familiar example of a hybrid cable is probably USB, but custom cables of many configurations are used in industrial applications. For such complex cable designs, traditional design rules to calculate the cable's properties become unwieldy. Simulation offers a way to develop and check an arbitrary cable design and optimize its layout and shielding for better performance.

OVERVIEW OF CABLE SIMULATION

Applying full 3D EM simulation methods to simulate detailed cabling within a large structure such as an automobile is impractical, as shown in ***Figure 1***. Each individual wire might be less than a millimeter in diameter, yet tens of meters long, bending as it carries high frequency signals through an electromagnetically complex environment. A conventional simulation of such a system would need an incredibly fine resolution to capture the fields in the cable, extended over a very large volume, resulting in slow, computationally-intensive calculations. The arbitrary cross sections of cables and changes in the surrounding environment along its path make analytic solutions similarly hard to find.

Specialized cable simulators can model complex cables and cable harnesses far more efficiently. The cable can be divided into segments, each having a constant cross-section. A 2D electromagnetic field solver can then be applied to extract the electrical properties for each segment. The properties of the entire cable may be found by cascading the electrical

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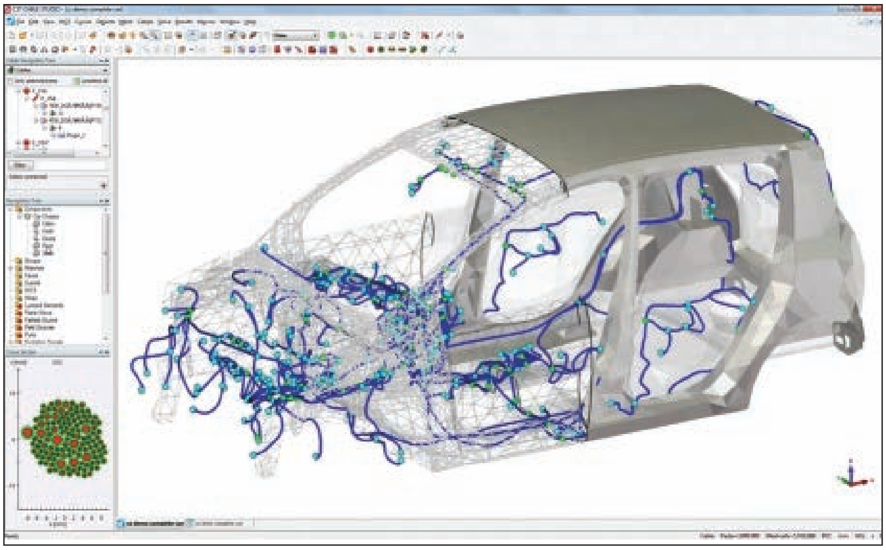

Fig. 1 *The cabling system inside a car.*

TABLE I

VARIOUS APPROACHES TO CABLE SIMULATION

Electrostatic Simulation
Electro- and magneto-static simulations can be used to calculate the L and C contributions to the line impedance. This approach is fast but only accurate at DC.
Full-Wave Simulation
Full-wave 3D simulation lets the frequency dependent effects be taken into account as well, modeling the dispersion of signals as they propagate down the line. This approach is very accurate for broadband signaling, but slower than a specialized cable simulation.
Specialized Cable Simulation
The cable cross-section is analyzed using a 2D field solver and transmission-line network analysis applied to simulate propagation. This approach is both accurate and efficient.

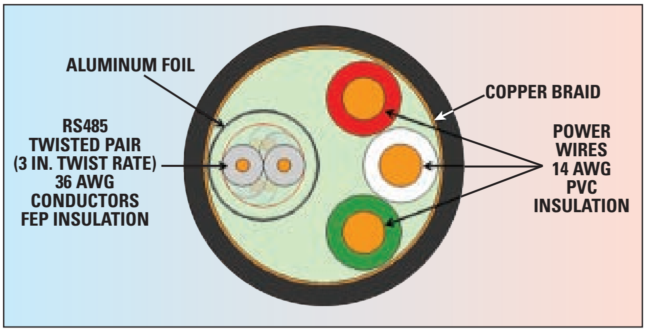

Fig. 2 *A cross section of a hybrid cable carrying five wires.*

models into an equivalent network. The specialized cable solver may also co-simulate with a full 3D field solver to simulate coupling to and radiation from the cable.

The cable shown in ***Figure 2*** carries five wires – two power wires (red and white), two signal wires (gray twisted pair) and a ground (green). The signal wires are shielded from the power wires by foil and the whole cable is shielded by a copper braid. It is an example of a hybrid cable for which an SI and EMI analysis would be important. The signal wires are not only potentially at risk from external interference, they could also pick up noise from the power wires. The shields and the use of twisted pair wires are both meant to reduce noise in the signal; simulation allows the engineer to investigate their performance. The cable is only a few millimeters wide, but could be meters long.

LINE IMPEDANCE SIMULATION

One important property of any data cable is its line impedance. Ideally, the impedance of the data line should match the impedance of the load. If there is a mismatch, signals at the interface between the two will be partially reflected and interfere with the signal, which can lead to SI problems in the connections between the line and components. Reflection is especially problematic for bidirectional cables, where the equipment at both ends acts as both source and receiver.

Calculating the line impedance of a cable is an obvious application of simulation. Multiple approaches exist for impedance calculations: the static approach, a full-wave simulation and a specialized cable simulation. Each has its advantages and disadvantages, as shown in ***Table 1***.

A full-wave simulation also permits one to model the connectors at the end of the cable. Impedance matching and EMI analysis are very important when designing or choosing a connector. This is especially true if the connector differs from the cable in some way – for example, if a twisted wire terminates in a straight pin, or if the connector is shielded in a different manner to the cable. The connectors are critical in impedance matching, since they provide the transition between the cable and the load. Often one wants to know which cable dimensions will give suitable cable characteristics to minimize reflection and improve data transmission. To do this, an optimizer is used. The optimizer simulates multiple possible values for model parameters – for instance, the thickness of an insulator or the position of a wire – using sophisticated algorithms to reduce the amount of guesswork involved in finding the best configuration.

CALCULATING LOSSES

Losses in the cable cause signals to be attenuated, with the degree of attenuation depending on the frequency. High frequencies typically suffer from greater loss, which has the effect of rounding the sharp edges of data pulses, limiting the data transmission rate.

The AC resistance (skin effect) of the wires is one obvious contribution to losses. Another is the loss tangent of the dielectric insulation materials. Signals may also leak through non-

perfect shields, introducing additional losses into the circuit. Full-wave and specialized cable simulation both allow designers to calculate the losses for a cable. Full-wave simulations of short cable sections can be cascaded, allowing losses over the whole length to be found without having to solve a full model of the structure.

Simulation can also calculate the scattering parameters (S-parameters), which describe the cable's characteristics concisely and show how the losses vary with respect to signal frequency. Standard measurements used in the lab such as the eye diagram, shown in ***Figure 3***, can also be replicated with simulation. To produce an eye diagram, a series of random bits are fed into the cable, and the output at the other end captured and graphed. Layering the output signals gives a useful illustration of the rounding of the pulses caused by attenuation.

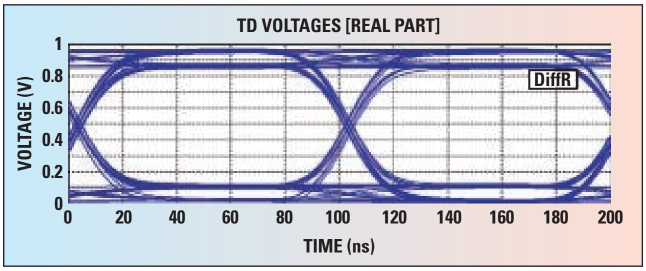

Fig. 3 Eye pattern of a 20 m long cable carrying a 10 Mb/s signal.

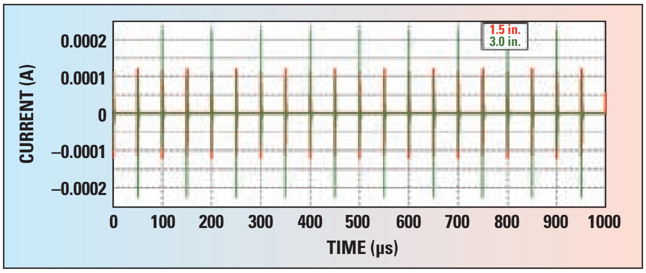

Fig. 4 Induced differential mode currents for twist length of 1.5 in. (red) and 3 in. (green) of the hybrid cable, assuming no shielding.

CROSSTALK SIMULATION

The potential for crosstalk arises whenever two or more wires are coupled. In the example, the power conductors can couple with the signal lines. This sort of broad spectrum noise may be difficult to filter out of signals. Instead, the best option for reducing crosstalk is to shield the wires well and make sure the coupling is minimized.

Since the data is carried by differential signaling, it is the difference between the two wires (the differential mode) that matters. If the cable system is perfectly balanced, the noise coupled to each conductor in the differential pair will be equal and the receiver will be able to reject the noise when the voltage signals are subtracted.

Simulating Twisted-Pair Wire

Twisted-pair cabling, commonplace in communication systems for over a century, winds wires around each other in sets of two. This minimizes the loop area between the wires to reduce mutual inductive coupling. It also helps to maintain balance in the line, equalizing the exposure of each conductor to external fields. Coupling is reduced as long as the twist length is small compared to the wavelength of the interference. The precise choice of twist length can make a big difference to how immune the cable is to crosstalk; for cables carrying several pairs of signal wires, such as the ubiquitous Cat-5, giving each set of wires a slightly different number of twists per meter can reduce the crosstalk between them significantly.

With simulation, the cable designer can examine the interference experienced by the wires and test how different wire configurations affect the signal characteristics. Cable simulation lets one easily adjust the distance between twists (twist rate) in the computer model, and simulate the induced currents caused by switching noise in each case (see ***Figure 4***). For this cable, making the twists shorter makes a big improvement to the differential mode noise rejection characteristics of the line. These simulations are performed without a shield around the twisted pair to study the noise rejection due to twisting alone.

Wire twisting is most effective if the two wires are well-balanced. In

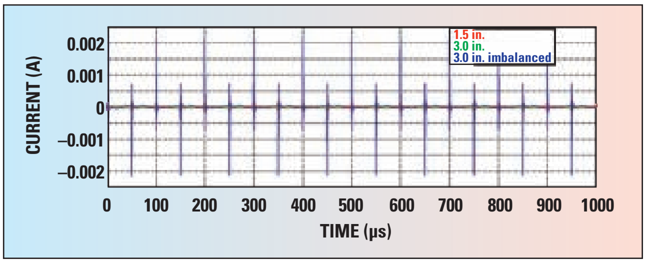

Fig. 6 Differential mode crosstalk in the imbalanced system (blue) massively outweigh the crosstalk in the balanced system.

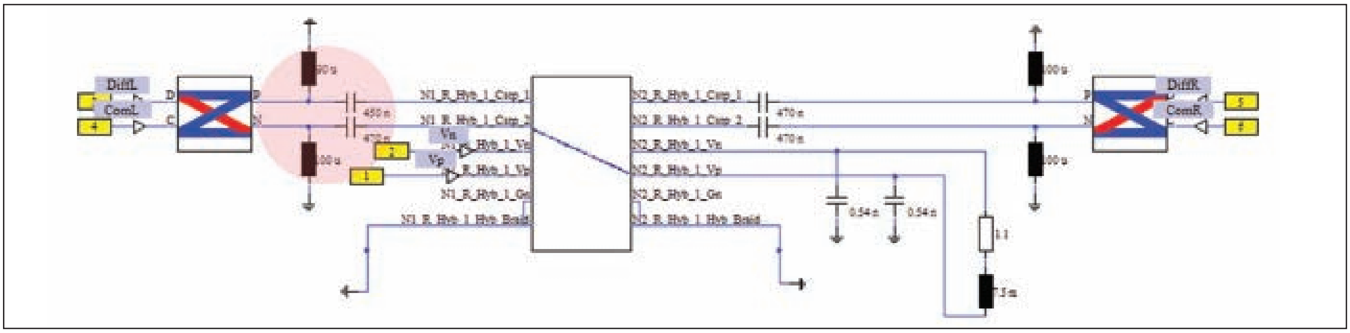

Fig. 5 A length of the cable is attached to a lumped element circuit in CST DESIGN STUDIO™. The imbalanced section is highlighted.

a real system, with varying loads and imperfectly manufactured components, this will not always be the case. The cable model can be attached to a circuit made up of lumped elements to replicate the equipment at either end and one can see how well the cable performs when the manufacturing tolerances are taken into account. In this example, shown in ***Figure 5***, a 10 percent imbalance is introduced in the shunt inductance (a drop of 10 µH) and a 4 percent imbalance in the series capacitance (a 20 nF decrease).

This proves to have a huge impact on the coupling. The peak induced current in the imbalanced system is ten times greater than in a perfectly balanced system, leaping from 0.2 to 2 mA – a 20 dB increase in the intensity of the crosstalk (see ***Figure 6***).

Shielding

For an extra layer of protection, which should guard against crosstalk and interference even if the cable terminations are not balanced, the wires can be shielded. Different shield types exist for different applications: the main two are foil shields, consisting of a thin sheet of metal such as aluminum, and braided shields, which are made up of many thin wires woven into a tube. Shields can either go around the entire cable to keep out external interference, or they can be placed within the cable to reduce crosstalk.

However, shielding not only adds bulk and weight to the cable, it can also decrease its flexibility and drive up the manufacturing costs. With many types of shielding available, each with different properties and suited toward different types of interference, it is not always easy to balance a cable's noise characteristics against the design requirements.

The performance of a shield is measured by its transfer impedance, as derived by Schelkunoff.[1] The transfer impedance Z_T is given by:

$$Z_T = \frac{1}{I_0}\frac{dV}{dx}$$

where I_0 is the current flowing on one side of the shield and dV/dx is the voltage per unit length along the opposite side. The transfer impedance effectively provides a measure of to what extent the shield's construction prevents fields passing through. The environment does not affect the transfer impedance – it is solely an intrinsic characteristic of the shield itself. The lower the transfer impedance, the better the shielding.

In a foil shield, the skin effect improves shielding performance at high frequencies as shown in ***Figure 7***. Current diffuses through the shield at low frequencies, but is confined to the surface at high frequencies. This


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means that external fields cannot penetrate the shield at high frequencies, provided that the shield is perfectly closed and has no apertures. However, in a real shield, fields can also pass through the seam formed where the layers of foil overlap, and for a more accurate simulation, this seam can also be taken into account.

Braided shield, by contrast, behaves the opposite way. The transfer impedance of a braided shield, as described by Kley,[2] depends on a number of effects. The skin effect still plays a role, but more significant at high frequencies are the small apertures between the strands and the mutual inductive coupling, as well as an inductive interaction, known as "porpoising," when strands cross each other. These drive up the transfer impedance, so that a braided shield is most effective at low frequencies. ***Figure 8*** shows the transfer impedance curve for a braided shield across the frequency spectrum.

Because mathematical models exist to describe the behavior of shields based on their properties, they are ideal candidates for designing and testing with cable simulation software. Arbitrary shields, whose properties are found experimentally, can also be used in simulations, simply by importing their transfer impedance profile.

If there are multiple shields, their combined transfer impedance can be found analytically by taking into account the internal impedance of each shield and the inductance between them.[3] Cable simulation software incorporating such calculations is capable of simulating multi-layer shielding arrangements. Because foil and braided shields work best at different frequencies, combining the two in the cable gives it a good broadband noise rejection profile. The crosstalk analysis can now be repeated, but with shields in place – in this case, either a foil shield or a combined foil and braid shield around the signal wires – to see how this affects the noise characteristics of the cable.

The combined two-shield cable has far better coupling rejection than the cable with just a foil shield. In fact, the common mode noise is so low on this cable that it is too small to see in ***Figure 9*** – the peak current is less than 4 μA.

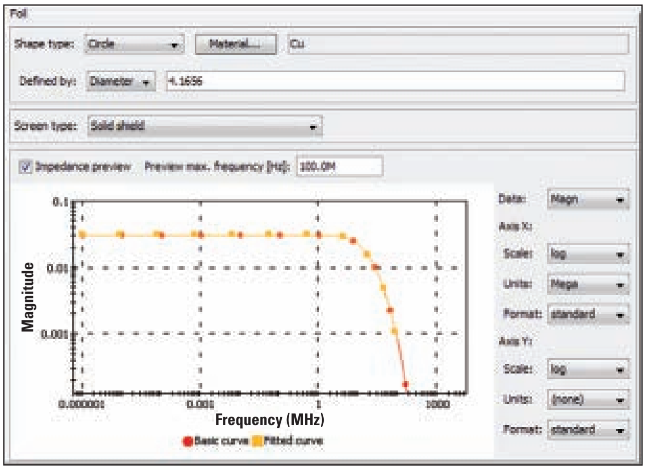


Fig. 7 Creation tool box for a foil shield in CST CABLE STUDIO™, showing the transfer impedance curve over a range of frequencies.

Fig. 8 The same dialog for a braided shield. The transfer impedance rises dramatically at high frequencies.

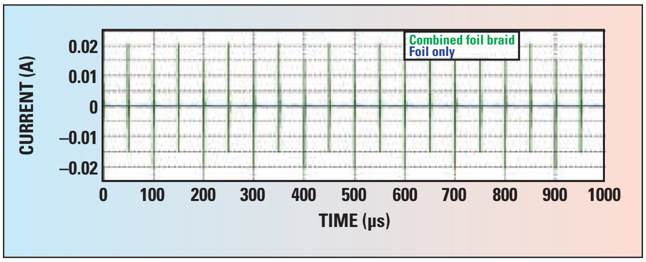


Fig. 9 Common mode noise for different shield arrangements. The induced current when both shields are used is too small to see.

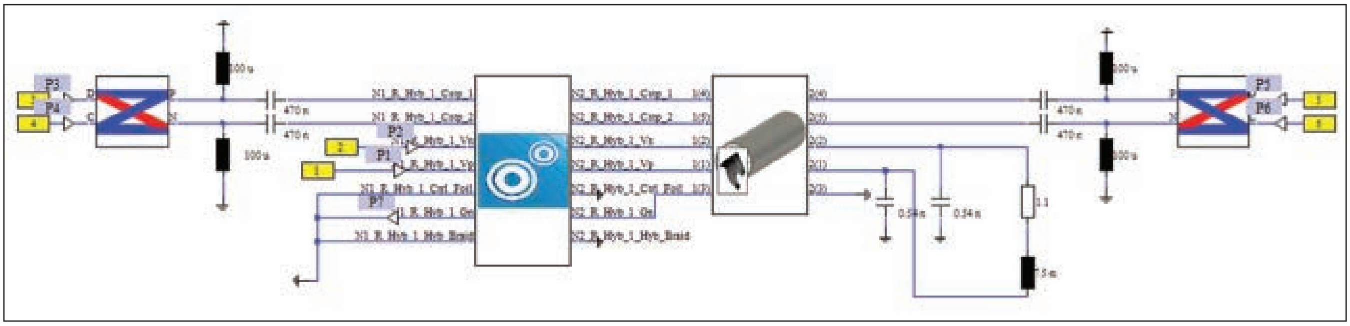
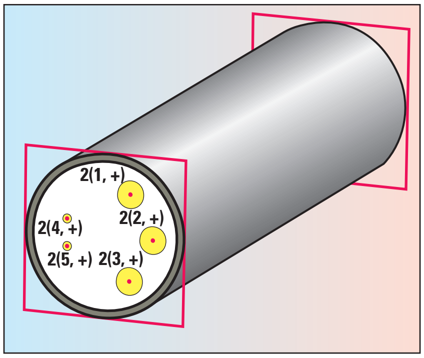


Fig. 10 A circuit for testing a cable linked to the load by a shielded connector.

The cable and the connector can also be combined together in one simulation. Circuit co-simulation, combining results from multiple full-wave and cable simulations, connects components so they can be simulated as a system. ***Figure 10*** shows a circuit for one such simulation: the power lines are driven by a periodic switching voltage and the load is modeled by lumped elements. The output from the cable – the blue box on the middle-left – is simply linked to the input of the connector from ***Figure 11*** – the gray tube on the middle-right. Because the S-parameters of the connector have already been calculated, the circuit solver can run very quickly; there is no need to rerun the entire 3D full-wave calculation.

EXPERIMENTAL VERIFICATION

As a demonstration of the effects of grounding and shielding on EMC, and to show the accuracy of cable simulation, multiple cables – standard RG58 coax with a braid, RG6 coax with a combined foil/braid shield, twisted pair with a foil and drain wire, shielded twisted pair (STP) with a braid, and the unshielded versions of the cables – had their EMI properties studied, both experimentally and using computer modeling. These cables were terminated in TNC connectors, which contain a metal shell or shield, enabling an ideal 360° connection between the cable and connector shield. To provide a further comparison, an additional length of twisted pair wire was terminated in a non-shielded connector with a "pigtail" connection from the cable shield to the inside of the enclosure housing (see ***Figure 12***).



▲ *Fig. 11 A shielded connector compatible with the hybrid cable showing the ports for simulation.*

The interference source was a wire loop radiating across a range of different frequencies. This loop can couple to the signal wires in the cable – the extent to which the cables reject this interference enables the shielding effectiveness to be assessed. The system would be difficult to solve accurately in full 3D due to the small details in geometry and the specialized cable simulator makes it possible to solve the problem in a fraction of the time (see ***Figure 13***).

Figure 14 shows the results of the study, where increasingly negative coupling corresponds to higher shielding effectiveness. The unshielded results serve as a reference. The spiral/drain cable with a pigtail termination provides an additional 20 dB or so of shielding at low frequencies, but its effectiveness degrades at higher frequencies. The same cable was simulated with a TNC termination (dashed blue line) for comparison, and provides further improvement in shielding, as expected. The STP, RG58 and RG6 cables show good shielding effectiveness at all frequencies. Unlike a 360° shield termination, which provides a low impedance connection from the shield to the ground, the pigtail connection adds inductance and the corresponding frequency-dependent impedance. Furthermore, the aperture in the enclosure is no longer closed and may leak electromagnetic fields to the interior of the load box, coupling noise to the exposed signal wires.

▲ *Fig. 12 The experimental setup showing the pigtail connector (left) and the signal cable (right).*

The measurements all agree closely with the simulation. With highly shielded cables, the coupling is very small and the induced signals may be below the noise floor of the experimental equipment. This explains some differences for coupling levels below –90 dB. Although it only used a very simple representation of the system, cable simulation was able to model the results very accurately – the simulation even identified a significant resonance at approximately 65 MHz that was subsequently seen in the experiment.

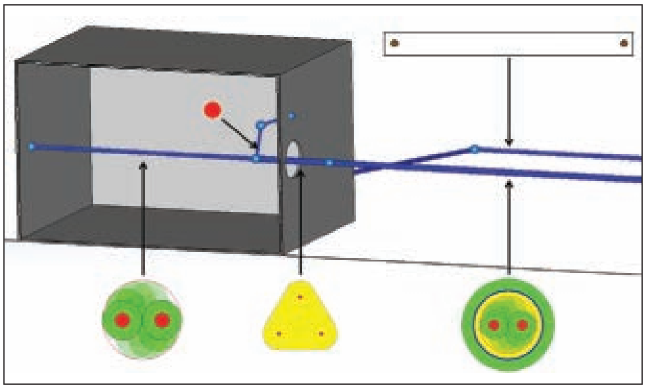
TRANSIENT CO-SIMULATION

Calculating the properties of a cable gives a good idea of its intrinsic characteristics, but in the real world, cables are rarely if ever completely isolated from the environment. Nearby structures, external fields and the route of the cable can all have an effect on signals within the cable. The transient nature of many interference effects, however, means that a full-wave simulation is necessary to model the precise behavior of many potential sources of interference, such as ESD and electromagnetic pulses (EMP).

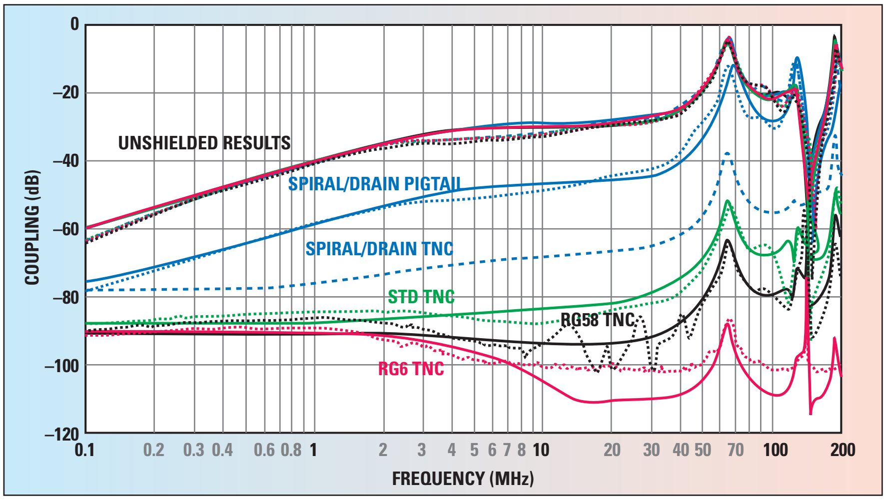
Simulation is therefore a useful tool for full system design, but neither specialized cable simulation nor full 3D simulation alone is ideal for giving a complete picture of how a cable behaves in a complex system. Combining them into a hybrid co-simulation task means that the advantages of both – the fast, accurate cable models and the versatility of full-wave – can be brought to the fore.

Two types of cable co-simulation exist: unidirectional and bidirectional. In unidirectional simulation, the cable is assumed to be either a transmitter or a receiver, while in bidirectional simulation, it is both. Bidirectional simulation is therefore most useful for examining how the coupling between a cable and its surroundings affects signals on the cable itself.

Figure 15 shows a typical application of bidirectional co-simulation. The helicopter contains a number of cables, carrying both power and signals, following complex curved routes. The cables may directly couple if routed too closely together, and radiated



▲ *Fig. 13 Model of the same system in CST CABLE STUDIO™ showing the wire cross section for each segment.*



▲ *Fig. 14 Coupling between the shield and the transmitter for different types of cables, simulated (solid lines) and measured (dotted lines).*

fields may excite resonances inside the vehicle, which can lead to increased coupling. Transient co-simulation allows a number of different scenarios to be modeled. One example would be the potential susceptibility due to an electromagnetic pulse (EMP). A pulse striking the aircraft may couple to the inside through imperfectly conducting panels and seams inducing current in the cabling.

CONCLUSION

Simulating cables requires careful consideration. Specialized cable simulation software can be incorporated into the cable design workflow to speed up the process and give the designer an idea of how the cable will behave once connected to the system. These calculations can give not only the electrical properties of the cable itself, but also permit to observe how fields propagate along the cable and interact with the environment. Properly set-up, cable simulations can replicate real-world situations very accurately, with the results of simulations agreeing very closely with measurements in the laboratory or field. ■

▲ *Fig. 15 A simple wiring system inside a helicopter, showing cables for the control system, antenna (center) and rotor (right).*

ACKNOWLEDGMENTS

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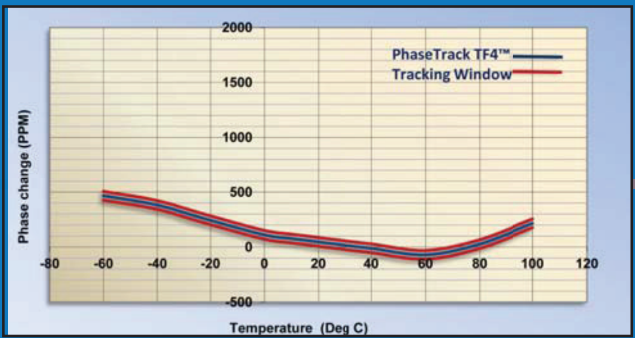

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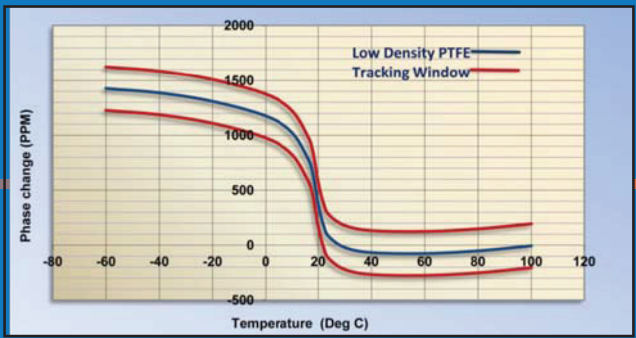

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Making the Connection at EDI CON 2013

The Connectivity Workshop and Expert Panel, to be held as a special event within the Electronic Design Innovation Conference (EDI CON 2013) in Beijing this month, will give Chinese RF/microwave engineers an opportunity to learn about various cable, connector and cable assembly technologies in the context of overall high frequency electronic component design and system integration. The combined workshop and panel session will feature individual presentations from some of the world's leading cable/connector vendors followed by a group panel discussion on the capabilities of today's RF, microwave and high-speed interconnects and the challenges of the systems they support.

Speakers from Mitron, Insulated Wire (IW), Times Microwave, Maury Microwave and Southwest Microwave will present various connector technologies and their corresponding electrical and mechanical characteristics. These talks will concentrate on connector performance, examine how cable/connector attributes align to high-frequency application requirements and guide engineers who require help in selecting the appropriate interconnect solutions for the systems and instrumentation equipment they are developing.

SOME OF THE CHALLENGES

Cables are often the last detail considered during system designs and yet as a ubiquitous component in the signal path of any communication system, their performance is critical to the overall health and performance of the system. The ideal cable system must consider factors such as weight, durability, performance and cost. To avoid being the source of a failure, interconnect systems must be engineered to last the life of the product in any environment. Today's cable systems are increasingly being used in hostile environments, exposed to extreme temperatures, chemicals, abrasion and extensive flexing. Meanwhile, today's high-frequency applications call for smaller, lighter packaging, that last longer and cost less, especially in satellite communications and navigation systems.

To help workshop attendees better understand how to select the best connector/cable for their application, workshop presenters will discuss the constraints that affect performance, including electrical, mechanical, environmental, and application-specific factors. Presenters will share information regarding the materials and construction used in their cable/connector products, emphasizing the engineering and manufacturing technology behind achieving specific performance requirements. Attendees will learn how manufacturers use testing and data analysis to qualify their existing products and enhance future ones.

PERFORMANCE CRITERIA

Electrical performance is often the leading consideration in cable/connector selection. The workshop presenters will discuss the various ways in which cables may impact signal integrity and thus the overall system performance including impedance mismatch (VSWR), which lead to reflections of microwave energy between modules and devices (reducing signal strength and power added efficiency), insertion loss, which ultimately determines the maximum length of a signal cable, electromagnetic interference (EMI) and crosstalk, which results from unwanted coupling of signals between two transmission circuits.

While the electrical performance may be reliable under ideal conditions, environmental factors such as temperature can play a significant role in impacting how connectors behave

David Vye
Microwave Journal *Editor*

in the real-world. For instance, the electrical properties of the material used to support the inner connector of a coaxial cable is subject to change with temperature and mechanical stress. Presenters will discuss this phenomenon, known as the "Teflon-knee," and its impact on phase stability over temperature. The workshop will also consider the impact of mechanical stress when cable systems operating at high speeds in tight spaces are exposed to movement, such as in handheld devices or automation and aerospace applications. Random, rolling and torsion type motion can cause severe damage if not properly managed. Presenters will discuss some of the real-world problems that can degrade performance, how to avoid such mishaps through installment best practices and/or better cable selection.

Environmental stress will have a different impact on performance depending on where cables are used and exposed. Extreme temperatures affect cable materials, with low temperatures making them brittle while high temperatures will cause them to become very soft. Like extreme temperatures, extreme pressures can also have a significant impact on cables. Cables operating in a vacuum may leach oils and additives, which could lead to contamination of a work surface such as a clean manufacturing process for semiconductor chips. Conversely, hydrostatic pressure causes gas or liquids to permeate insulation or cable jackets and can destroy some cable materials. Workshop presenters will look at how these environmental factors and others can significantly shorten the life of a cable, and how to factor such considerations into designing a cable system with the proper technology.

HANDLING TIPS

RF cable assemblies are designed to operate at the highest electrical performance level. High performance cables require special handling procedures to ensure optimum electrical performance. Many of these handling procedures will be discussed by a speaker from Insulated Wire (IW) in the presentation "How to Get the Best Performance Out of Your Cable Assembly." By taking a few basic preventative measures during cable handling, installers and system assembly technicians can significantly extend the life of their assembly and avoid system failures. The expert from IW will provide tips on how to prevent some common problems such as internal damage caused by compression and how to prevent the cable from bending below its minimum bend radius which would cause the cable to kink and also results in internal damage. To maximize connector performance and lifetime, the presenter will discuss proper torque down procedures, connector orientation and how to avoid assembly twisting, proper cable tie down methods, providing adequate drip loops, weather proofing and working with short cable assemblies.

Connector Types

In addition to integrating modules and subsystems, connectors are also used to launch signals from coax to planar substrates where the surface mount ICs and discrete devices that provide radio functionality reside. With pressure to reduce circuit size and increase functionality, engineers are working with thinner PCB materials often at higher frequencies. Design and test engineers need to be aware of the quality of their electrical interface between planar substrate (microstrip, stripline, etc.) and the connector launch. Poor choice in connector size and shape can lead to undesirable parasitics and unacceptable VSWR, resulting in non-optimal performance, power loss and inaccurate device characterization (when being used as part of a test fixture). For example, substrates that are thinner than 8 mil have line widths that are too small to optimize the launch with a taper for even the smallest connector pin. For substrates that are thicker than 30 mil, line structures can be created that achieve a good match and bandwidth to 50 GHz, but the loss of these lines starts to increase significantly at higher frequencies.

In addition to developing better performing products, innovation can also target usability and convenience for the user. Maury Microwave, a leading test solutions provider that also develops interconnect products, will be discussing an innovation that does both. The company's new China country manager, Nian-min Zhang, will present the new ColorConnect™ precision adapters, which are designed for lab and field use addressing the need for quality, performance, ease-of-identification and ease-of-use. New manufacturing techniques have resulted in improved VSWR specifications bridging the gap between calibration-grade metrology adapters and daily-use lab adapters. Following the proposed IEEE high-frequency connector/adapter color convention, the components are the first commercially available products to offer clear indications of compatibility and intermatability. Zhang will discuss how the product makes it a simple matter to avoid and eliminate damaged equipment, degraded equipment reliability, degraded performance and lengthy maintenance times due to improper mating (and attempted mating) of incompatible adapters.

Addressing Various Applications

Technology trends in circuit miniaturization, wide bandwidths, increased circuit density and functionality, linearity and passive intermodulation requirements are forcing evolution in connector technology. The physical and electrical attributes of connectors are constantly improving, supported by advanced design/analysis capabilities (3D EM simulation such as CST or HFSS) and precision machining.

Cable assemblies and connectors have become specialized for test applications, aircraft, spaceflight, defense and commercial communication applications. Clarifying the specific requirements of these different applications and aligning them to a particular interconnect technology will be a common theme of this special EDI CON workshop/panel. The workshop will allow presenters to educate attendees with regard to some of these advances and the panel session will allow attendees to ask the experts about their own particular needs and challenges. ■

PIM Test Power Levels For Mobile Communication Systems

In 1999, the International Electro-technical Commission (IEC) released Standard 62037 providing the wireless industry a consistent test method for measuring Passive Intermodulation (PIM) in RF components and systems. Over the next 12 years, wireless technology evolved from 2G systems serving primarily voice traffic to 4G systems serving high-speed data users. These 4G systems require new network architectures with broadband modulation schemes to achieve the required increase in network capacity. This article reviews the applicability of IEC 62037 for qualifying components, subsystems and systems used in today's commercial telecommunications infrastructure and specifically addresses whether or not there is technical merit in increasing PIM test power levels from 20 to 40 W.

WHY DO WE MEASURE PIM?

PIM occurs when two or more high power RF signals encounter nonlinear electrical junctions or materials in an RF path. These nonlinear junctions behave like a mixer causing new signals to be generated at mathematical combinations of the original RF inputs. If these signals fall in a network operator's receive band, the noise floor rises causing reduced data rates and decreased service quality.

PIM is often caused by inconsistent metal-to-metal contacts in high current density regions such as inside transmission lines, inside RF components, or outside the system but in the main beam of an antenna. Common sources of PIM are:

- Contaminated or oxidized RF surfaces
- Inadequately torqued RF connectors
- Loose screws or rivets inside RF components caused by transportation shock and vibration
- Metal flakes or shavings inside RF connections
- Poorly prepared RF terminations due to improper tooling, or incorrect assembly procedures
- Metal flashing or rusty vent pipes in front of antennas on roof-top sites

PIM testing identifies the presence of these defects using RF transmission as the stimulus and highly sensitive receivers to detect and measure the response. PIM testing is the ultimate measure of construction quality of RF components, subsystems and systems. It will identify mechanical, as well as material defects in workmanship that may go undetected by more conventional techniques such as visual inspection or S-parameter measurement.

LACK OF STANDARDS

In the early days of commercial telecom, it was understood, based upon experiences of other communications systems and most particularly satellite communications, that PIM could produce interference conditions that were performance impacting. Recognizing this, mobile operators and OEMs impressed upon their component suppliers (manufacturers of antennas, cables, connectors, filters, lightning protectors, etc.) the need to provide "Low PIM" solutions. However, there was very little guidance of what "Low PIM" meant.

Left to their own devices, component manufacturers around the world began specifying the PIM performance of their products using varying and inconsistent parameters. Some manufactures only conducted PIM tests in their engineering laboratories claiming that their products were "Low PIM" by design. Others conducted PIM tests on each unit produced to verify not only the design but also assembly workmanship. Some certified higher order PIM products such as IM5 or IM7 depending on the end-user's band of operation. Finally, some manufacturers specified peak PIM while applying mechanical stimulus (dynamic testing) while others measured the best case PIM achieved with the DUT at rest (static testing).

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This arbitrary and haphazard approach made it impossible to compare products and performance. To establish consistency, IEC Technical Committee 46, Working Group 6 was formed to create an industry standard for Passive Intermodulation testing. The PIM Working Group was comprised of OEMs, component manufacturers, universities and national standards organizations.

DEVELOPING THE RECOMMENDED TEST STANDARD

There were many energized debates among the working group constituents that ranged from academic, to practical, to sometimes political. There were arguments about how many carriers should be used, how much power was needed, what IM products to measure, how to define repeatable and meaningful dynamic tests, and whether PIM testing was even necessary since only high order IM products could land in the operator's own receive band.

After considerable analysis, experiments and discussion, IEC Standard 62037 was finalized and released in the fall of 1999. The specification defined technical requirements for PIM testing apparatus as well as provided key recommendations to enable consistency in PIM performance comparisons. Two key recommendations from the original specification were:

- PIM comparisons should be conducted at the same power level: 2 × 20 W recommended for mobile communications applications
- Third order IM products typically represent the worst case condition of unwanted signals; therefore measuring IM3 characterizes the DUT

An update to IEC-62037 was published in May 2012 with more specific instructions for testing of antennas, connectors, cables, cable assemblies and filters. This new revision contains the same fundamental recommendations as the original specification: measure IM3 using 2 × 20 W test tones and adds clarity regarding a third key requirement for PIM tests:

- Devices should be subjected to impact or movement while PIM testing

TESTING AT HIGHER CARRIER POWERS

Some PIM test equipment manufacturers have claimed that PIM testing should be conducted at 40 W rather than the IEC recommended 20 W level in order to "spot problems that cannot be seen on a 20 W PIM tester." Further claims are made that 40 W is the correct power level to use since it is more representative of "real world" BTS operating conditions.

To determine whether or not there is validity to these arguments, first consider the claim that PIM testing should represent "real world" BTS conditions. As seen in ***Table 1***, PIM test parameters have very little to do with the particular air interface, number of carriers, or power level deployed at a site. Rather, the test parameters were selected to define an accurate method to measure the degree of nonlinearity present in an RF path. Presented further in this document, 20 W is more than enough power to accurately measure nonlinearity in RF components as well as in completed feed systems.

If the goal was to simulate the actual BTS environment, the required test equipment would need to transmit hundreds of watts to capture the full range of base station transmit levels. Test equipment would need to transmit multiple carriers rather than just two and would need to transmit GSM, wideband CDMA or LTE waveforms rather than CW test tones. The resulting test equipment would be significantly larger, heavier and more expensive and would pose safety risks to technicians performing the test. In addition, this equipment would need to be replaced every few years to keep up with the ever changing wireless industry (2G, 3G, 4G, etc.). This is not a practical solution for RF equipment manufacturers, or network operators forced to continually invest additional CAPEX to keep up with a continuously changing specification.

These are exactly the same issues that the IEC working group faced back in 1999. Their challenge was to develop a test that was "fit for purpose" and not constantly changing based on individual manufacturer's claims. The IEC team analyzed this problem over several years and produced the test specification that the industry has relied on ever since.

To address the claim that higher test power will unveil PIM problems that cannot be seen using the industry standard 20 W test, one must understand how PIM behaves with increasing test power as well as consider the test as a whole rather than by its individual components. The magnitude of PIM produced by a given defect is dependent on the physical characteristics of that defect. Looking at the data in ***Figure 1***, one can conclude that the Spinner PIM standard (produced using a diode in its construction) creates the highest level of PIM and that the corrugated jumper cable (constructed with solid copper conductors with soldered connections) produces the lowest level of PIM at any given test power. Some observations from Figure 1 are the more severe the defect, the higher the PIM for a given test power, the PIM level increases linearly on a dB scale with increasing test power and the rate of PIM level increase versus test power is different for each PIM source. One will also notice that as the test power changes over the range of 2 to 40 W, the magnitude of the PIM produced

TABLE I

COMPARISON OF PIM MEASUREMENTS AND ACTUAL BASE STATION OPERATING PARAMETERS

	PIM Measurement	*Typical BTS*
Carrier Modulation	CW	Various: GSM, UMTS, CDMA, LTE
Number of Carriers	2	1, 2, 3, 4 or more
Bandwidth per Carrier	5 kHz	> 5 MHz for LTE
Carrier Power	20 W	20, 40, 60, 80 W and higher
IM Product of Concern	IM3	IM5, IM7, IM9 and higher


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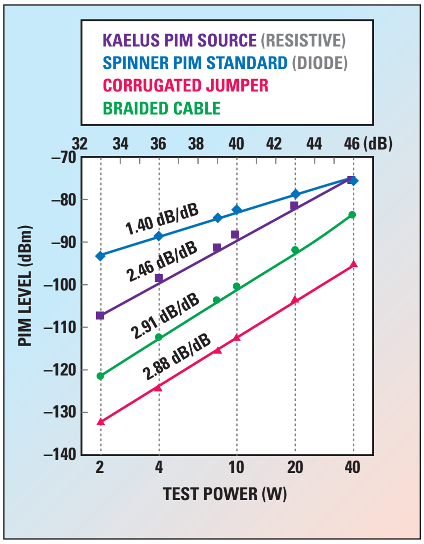


▲ *Fig. 1 IM3 change vs. test power.*

by each defect also changes. In theory, IM3 is expected to change 3 dB for every 1 dB change in test power and is expected to be linear over a wide range of test powers. In practice, this rate of change is typically lower and varies based on the physical characteristics of the defect causing the PIM. In the example, the "PIM slope" varies between 1.4 and 2.9 dB/dB for the components tested and, as expected, remains very consistent over the full range of powers tested.

This means that if we know the magnitude of PIM produced by a defect at one test power level and we know the PIM slope, we can accurately estimate the magnitude of the PIM that will be generated at a different test power. Using this knowledge, we can see that nothing new or unexpected is revealed by increasing the test power. The PIM magnitude is higher at 40 W than it is at 20 W, but it is higher by a predictable amount.

In order for the claim to be true that 40 W PIM testing will "spot problems that cannot be seen on a 20 W PIM tester," either the test instrument does not have sufficient receiver sensitivity to yield a 10 dB signal to noise ratio for the PIM signal being measured or the PIM level increases in a nonlinear fashion (on a dB scale) as the test power level increases. High quality PIM test instruments manufactured today typically achieve a receiver noise floor level on the order of –130 dBm. Since the IM3 level that is required to measure is on the order of –150 dBc (–107 dBm) for factory tests and –140 dBc –97 dBm) for field tests, the typical signal-to-noise ratio achieved is between 23 and 33 dB. This means the PIM signal level is already 20 to 200 times stronger than the 10 dB minimum signal to noise ratio required for an accurate measurement. Increasing the test power does not create a useful benefit in measurement accuracy and may increase the personal safety risk to test personnel.

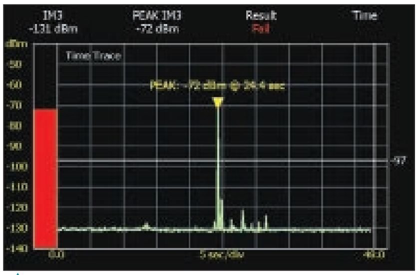
The data presented in this paper shows that IM3 increases linearly on a dB scale with increasing test power. This is true for the vast majority of defects found in RF components and in typical cell site installations. Similar results have been demonstrated across a wide range of test powers and test frequencies by other investigators.[1,2]

THE IMPORTANCE OF DYNAMIC TESTING

It is important to emphasize that all elements of a PIM test are important and must be used together to ensure the quality of the system under test. Accurately controlling the test power alone does not ensure a trouble free system, regardless of the test power level used.

To demonstrate the importance of dynamic testing, metal flakes (see ***Figure 2***) were inserted inside an RF connection and the system was

▲ *Fig. 2 Metal flakes used to demonstrate the need for dynamic testing.*



▲ *Fig. 3 Results of dynamic testing showing jump in PIM level.*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tested using the required 20 W power level. Without mechanical movement (static testing) the PIM performance appeared to be very good. When the connection was lightly tapped (dynamic testing) the PIM level jumped more than 50 dB clearly indicating that a problem exists (see ***Figure 3***).

Dynamic testing identifies loose metal-to-metal connections as well as contact surface defects that might cause arcing at higher power levels. Without dynamic testing, these defects could go unnoticed until activated by wind loading, tower vibration or stresses caused by temperature changes.

Claims have been made by test equipment manufacturers that using 40 W of power rather than 20 W eliminates the need for dynamic testing. There is no single test power that by itself will sufficiently stress a system to identify defects. Applying mechanical stress while the PIM test is in process is the only way to ensure that the system is robust. If simply increasing the test power would have eliminated the need for dynamic testing, the IEC working group would not have spent the last 10 years fine tuning dynamic PIM test requirements for RF components such as jumper cable assemblies, RF connectors, filters and antennas. Details of this work can be found in the newly released versions of the IEC 62037 PIM test specification.

CONCLUSION

The existing PIM test standard was developed through a lengthy process of analysis, measurement and debate by a respected group of engineers, scientists and managers from the commercial telecommunications market: OEMs, component manufacturers and standards organizations. The test standard produced has been used globally for more than a decade. Component manufacturers, OEMs and network operators have built their quality procedures and performance requirements around measuring IM3 with 2 × 20 W test tones while applying dynamic stimulus. As shown by the example of the metal flakes inside a connector, dynamic stimulus is a critical component of the PIM testing process for identifying faults that are not visible under static conditions. There is no technical justification for changing the power level used for PIM tests to 40 W or any other power level (higher or lower). Nothing has changed since the specification was first released in 1999 to invalidate the IEC's original, well considered recommendations. ■

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2. M. Bayrak and F. A. Benson, "Intermodulation Products from Nonlinearities in Transmission Lines and Connectors at Microwave Frequencies," *Proceedings of IEEE*, Vol. 122, April 1975, pp. 361-367.

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200	1.22	1.3
225	1.28	1.3

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Connect with Confidence: Color-Coded Interconnects

We all know of engineers and technicians who have at times been unsure whether two adapters mated, whether cable assemblies could be connected and what torque wrench to use. With this uncertainty comes an underlying fear of damaging equipment, reducing measurement accuracy and wasting precious time. If only these interconnects, which are so similar, could be easily labeled and identified.

John Bies of Redstone Arsenal certainly did; he lobbied for the establishment of a "standardized method to rapidly identify high frequency coaxial connectors." His report included a short list of possible results from misidentifying connectors and attempting to mate two incompatible connectors, including damaged equipment, degraded equipment reliability, degraded performance, degraded mission readiness, increased maintenance time, increased maintenance actions and lost efficiency. Additionally, even if two connectors could mate, their operational frequencies might differ, as is the case with mechanically compatible 3.5mm and 2.92mm connectors where the highest common operational frequency may only be 26.5 GHz.

Bies went on to state that the benefits of color-coding high frequency coaxial connectors would include the elimination of damage to equipment, a greater confidence in connector identification and use, a financial saving in training time and costs (he estimated $5.8 million and 5000 man-hours per year in the U.S. military/government agencies alone), an increase in efficiency, reliability and readiness, and an improvement in personnel safety.

An Institute of Electrical and Electronics Engineers (IEEE) Coaxial Connector Rapid ID Working Group was established in June 2008 and a proposed color code scheme was developed in August 2008. The IEEE project authorization request P1802 was submitted for review in January 2009 and approved in May 2009. The working group is now referred to as IEEE P287 with mandate to review the 287-2007 standards for coaxial connectors. With no other reason than selecting a familiar color scheme known to engineers across the globe, the standard resistor color-code BBROYGBVGW was proposed for high frequency coaxial connectors (increasing resistor value compared to increasing frequency) and is shown in ***Figure 1***.

Maury Microwave has used color bands for more than twenty years to identify 75 Ω Type N connectors, and in 2012 decided to extend its offering with the launch of ColorConnect™

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ColorConnect™ Precision Adapters are designed for lab or field use where quality, performance, ease-of-identification and ease-of-use are critical. ColorConnect™ Precision Adapters are the first commercially available products to offer clear indications of compatibility and intermatability by employing the proposed IEEE high-frequency connector/adapter color convention, making it easy to avoid and prevent equipment damage, degraded equipment reliability, degraded performance and lengthy maintenance times that result from improper mating (and attempted mating) of incompatible adapters.

*Available in Type N, SMA, 3.5mm, 2.92mm, 2.4mm and 1.85mm. See website for details.

Maury Microwave's Stability™ Microwave/RF Cable Assemblies set the standard for high-performance ruggedized cable assemblies. Designed specifically for phase-stable, amplitude-stable applications, Stability™ offers excellent measurement repeatability even after cable flexure.

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COLORCONNECT™ PRECISION ADAPTERS

ColorConnect Precision Adapters are currently the only commercially available adapters to employ the IEEE working group color-coding scheme. These adapters offer improved VSWR specifications bridging the gap between calibration-grade metrology adapters and daily-use lab adapters. Compensated beads maintain an accurate 50 Ω transmission line for improved VSWR performance. Compensated female contacts extend the usable lifetime to more than 500 matings. Critical pin-depth and position-tolerance prevents performance degradation (due to “gap-fit”) and component damage (due to “interference-fit”). Inner and outer conductor’s finish and materials ensure high conductivity with reduced signal loss. Mating surface flatness and finish minimizes signal loss. Orbital consistency and concentricity ensure proper alignment and best repeatability. ColorConnect Precision Adapters are available in SMA, Type N, 3.5mm, 2.92mm, 2.4mm and 1.85mm in-series and between-series and are selectively shown in ***Figure 2***.

STABILITY™ CABLE ASSEMBLIES

Cable assemblies are used in a wide range of applications and by a user-base with varying degrees of experience and training. As with the adapters, how can one be certain that the cable assembly about to be connected is in fact compatible, and that damage to both the assembly and system will not occur? Listening to its customers, Maury implemented its ColorConnect color-coding to its Stability line of cable assemblies.

Designed specifically for phase-stable and amplitude-stable applications, Stability offers excellent measurement repeatability even after cable flexure. With a ruggedized, durable construction, Stability will outperform other typical assemblies resulting in a reduced total cost-of-test. Stability’s light weight, flexibility and small form factor make it ideal for daily use with VNAs, test instruments, bench-top testing and ATE systems.

Stability assemblies are offered with 2.92mm connectors to 40 GHz, 3.5mm connectors to 26.5 GHz and Type N connectors to 18 GHz, and have respectable insertion losses of 0.84, 0.67 and 0.54 dB/foot, respectively (at F_{max}). Designed specifically for phase- and amplitude-stability, these assemblies offer a typical phase-stability after bending of 5, 3.5 and 2 degrees, respectively, and an amplitude-stability after bending of 0.05, 0.02 and 0.0015 dB, respectively. Phase stability with temperature is less than 4°/m/GHz between –55° and +125°C. Stability achieves a crush resistance of > 260 lb/inch (44 kN/m) by employing additional ruggedizing layers, including a crush protection layer, a braided strength member and braided outer jacket.

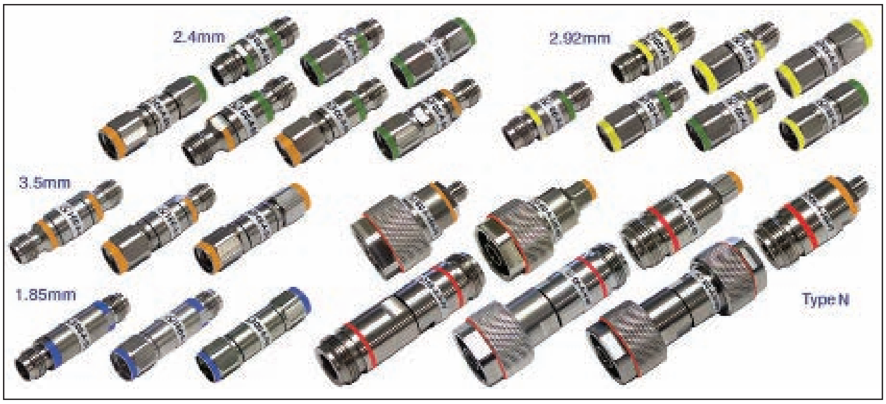
BLACK	—	DC–18 GHz	—	Type N Connector
Brown	—	DC–18 GHz	—	SMA Connector
Red	—	DC–20 GHz	—	Precision Type N Connector
Orange	—	DC–26.5 GHz	—	3.5mm Connector
Yellow	—	DC–40 GHz	—	2.92mm (K) Connector
Green	—	DC–50 GHz	—	2.4mm Connector
Blue	—	DC–67 GHz	—	1.85mm (V) Connector
Violet	—	DC–18 GHz	—	GPC-7 Connector
Gray	—	DC– <Reserved for future use>		
White	—	DC–110 GHz	—	1.0mm (W) Connector

▲ *Fig. 1 Proposed color coding scheme.*

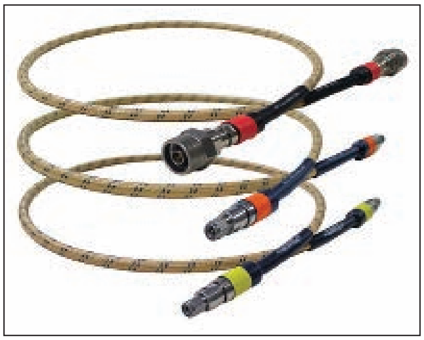
The assemblies have a minimum bend radius of 1 in (25.4 mm) making it flexible and versatile. With a flex life-cycle over 20,000, Stability offers one of the lowest cost-of-ownership of most any phase-stable assembly. 2.92mm, 3.5mm and Type N color-coded Stability Cable Assemblies are shown in ***Figure 3***. ColorConnect Precision Adapters and Stability cable assemblies have been specifically designed so that the color identification bands are visible when connected, making identification and verification simple without the need to disconnect any piece of the interconnect chain.

TW-SERIES TORQUE WRENCHES

Most, if not all, 5/16"-hex high-frequency connecters look similar from the outside but vary greatly in performance and design. Sub-Miniature version A (SMA) connectors use a polytetrafluoroethylene (PTFE) dielectric which contacts along the mating plane, that along with the



▲ *Fig. 2 Assortment of in-series and between-series color-coded adapters.*



▲ *Fig. 3 2.92mm, 3.5mm and Type N color-coded cable assemblies.*

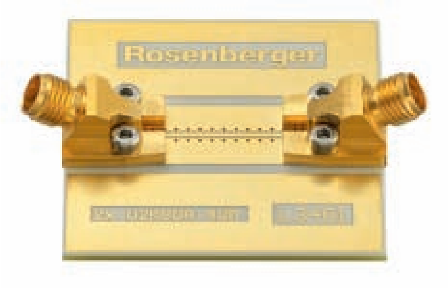
variances in design and construction can cause mating uncertainties and introduce a possible air gap. Because of the possible variances in materials used (i.e., brass versus stainless steel) and the possibility of the thin outer wall (conventional SMA design), it is generally accepted that SMA connectors require a torque value of 5 in-lb in order to limit possible damage.

Other 5/16" hex high-frequency connecters implement an air-dielectric and are named after the diameter of said dielectric; 3.5mm, 2.92mm, 2.4mm and 1.85mm. 3.5mm and 2.92mm employ center pins of equal size and are thereby mechanically mateable, along with the SMA. However, due to the design and specifications of the connector which includes a stronger wall (0.021 inches in the case of the male versions), 8 in-lb torquing is recommended.

With a common 5/16" hex interface, how does one tell the difference between 5 in-lb torque wrenches designed for SMA connectors, and 8 in-lb wrenches designed for the rest? Maury offered a color-coded handle, black for 5 in-lb and blue for 8 in-lb, but it was often confusing to remember which was which. Maury's new line of TW-series torque wrenches employ color-banded handles, with the 5 in-lb handle striped with a brown band, and the 8 in-lb handle striped with orange, yellow, green and blue stripes, as shown in ***Figure 4***. TW-series wrenches employ a "break" design making it difficult to over-torque a coupled junction. Each torque wrench is factory preset to the proper in-lbs value and have a variance of ± 10 percent. With its high quality, low cost and color code, engineers can match up the paint stripes on the wrench handle with the color bands on the ColorConnect adapters and Stability cable assemblies and be guaranteed a proper torque each and every time.

▲ *Fig. 4 Color-coded torque wrenches.*

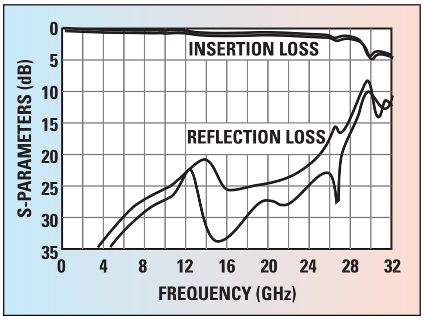
Color-coded connectors, cable assemblies and torque wrenches give engineers and technicians the confidence that the proper interconnections are being made. No more doubt or concerns about damaging equipment or inaccurate measurements due to mis-matched connections or improper torquing. They reduce costs, improve testing relibility and reduce setup time. ■



Solderless PCB Mount Connectors

A significant trend is the ever-increasing bandwidth requirements of high frequency electronics and modern data-transmission circuits, alongside a strong push toward integrated modules, is cost and performance. This means that classical coax connectors do not have an important role to play in large volume assemblies at high frequencies. However, connectivity solutions for test and measurement applications are required for frequencies up to 110 GHz and beyond in the design phase. To address these issues, the Solderless PCB Mount Rosenberger Precision Connectors (RPC) were developed.

Surface mount connectors are typically realized as right angle or edge mount types. Both of these types are used throughout the communication industry where impedance control and good shielding properties are required. They are reliable, exhibiting excellent and reproducible results. However, with the move to very high frequencies, where the wavelength of the transmitted signals is comparable to the dimensions of the connector, care has to be taken not to couple resonant structures to the signal path.



▲ *Fig. 1 Calculated insertion (S_{12}, S_{21}) and reflection loss (S_{11}, S_{22}).*

This means that careful control of potential resonances and radiation at the interface from the connector to the circuit board is essential for a predictable performance. The wavelength in vacuum is 3 mm at 100 GHz and quarter (0.75 mm) and half wave (1.5 mm) resonances have to be managed. Voids and gaps have to be small compared to these dimensions, keeping in mind that the wavelength is much smaller in the PCB dielectric.

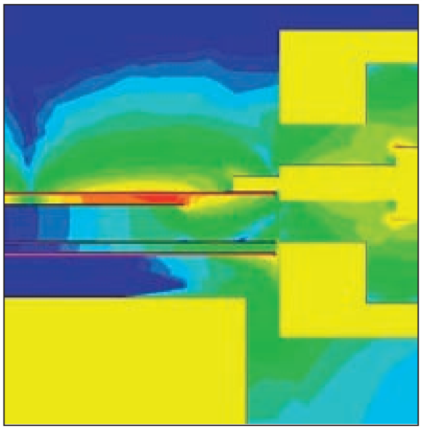
SUBSTRATE THICKNESS

The substrate thickness also has to be kept well below a quarter wavelength for mode-free operation. The ratio of the width of a microstrip line and the substrate thickness is constant for a given substrate material. The sizes of millimeter-wave circuits are thus no more than a few tenths of a millimeter and have to be connected electrically by the center pin of the surface mount connector.

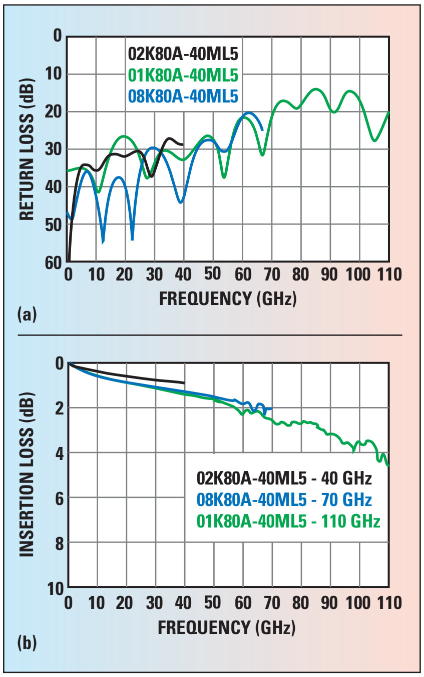
For illustration, we calculated the S-parameters of an edge mount connector that is shown in ***Figure 1***. It shows excellent signal properties up to 25 GHz. However, a very strong resonance is observed at 30 GHz. This is caused by a parasitic resonant structure that is coupled to the transmission line via the gap between the connector body and the PCB ground. It sucks out a significant part of the signal, causing a deep narrowband dip in the order of several dBs in the insertion loss while causing a spike in the reflection loss.

A significant part of the signal is radiated into free space where it may potentially interfere with adjacent circuits. The logarithmic field plot of ***Figure 2*** illustrates the resonant fringing field as it escapes through the void in the ground plane. Stressing a physical model, it

ROSENBERGER HOCHFREQUENZTECHNIK GMBH
Fridolfing, Germany



▲ *Fig. 2 Field plot of the resonant fringing fields at 30 GHz.*



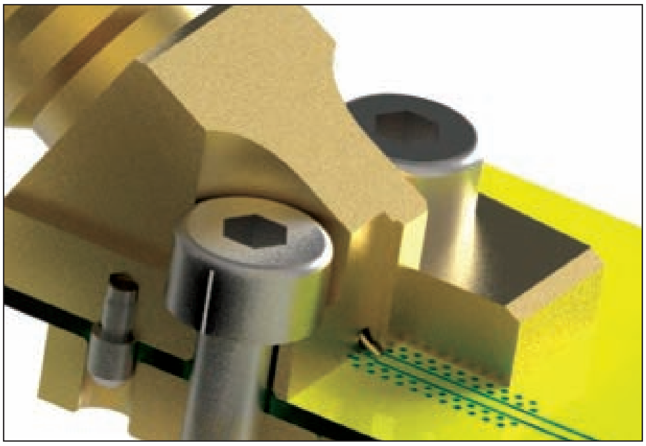
▲ *Fig. 4 Measured reflection loss of solderless PCB mount connectors (a) and measured insertion loss (b).*

behaves similarly to a waveguide transition with the signal pin acting like an inductive post. Let us consider how we mastered the challenges.

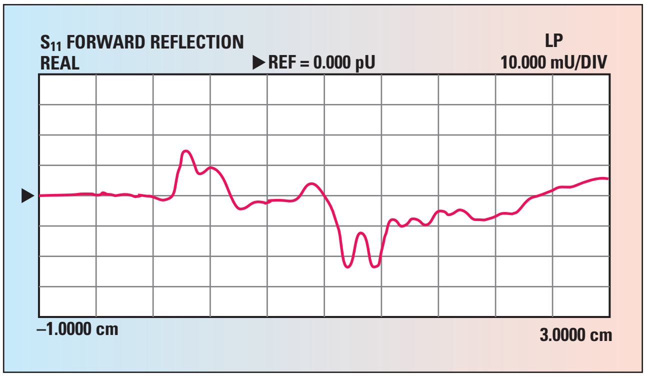
TECHNICAL FEATURES

The structure of the connector topology that was chosen is depicted in ***Figure 3***. The RF-ground plane and the top ground are connected by many vias that keep the PCB mode-free. The connector block is placed on top of the ground plane. This helps keep the footprint for this connector very simple and easy to design while no resonances may be excited in the transition.

The 'pencil point'-like signal contact causes only a very low capacitive loading to the stripline, which is essential for minimum reflections at high frequencies. No voids are required in the ground plane that would otherwise make the design cumbersome. As the signal pin protrudes from the mounting face of the connector, a spring force is applied to the signal pad once the connector is mounted, providing a stable and vibration-proof connection.



▲ *Fig. 3 Detailed view of the PCB contact area with cut-out.*



▲ *Fig. 5 Gated S_{11} in TD of the 110 GHz connectors 01K80A-40ML5.*

FEATURES

- Connectors are available in: RPC-2.92 (40 GHz) 02K80A-40ML5, RPC-1.85 (70 GHz) 08K80A-40ML5 and RPC-1.00 (110 GHz) 01K80A-40ML5
- No soldering required
- Prepositioning enforced by dowel pins
- Clamping mechanism accommodates a wide range of board thicknesses while providing a continuous ground connection between contact area and circuit board
- Universal, robust and reusable

As expected from the simulations, test results confirm the excellent RF-properties of the new connector series with connectors available up to 40, 70 and 110 GHz. Reflection loss and insertion loss of the three products are plotted in ***Figures 4a*** and ***4b***, respectively. The frequency response is mode-free up to 110 GHz. The insertion loss represents 50 percent of the GCPW-losses on the PCB. The actual insertion loss of the connectors is considerably lower. The 70 and 110 GHz versions have been tested on the same substrate. A separate design was chosen for the 40 GHz version.

This explains the lower loss of the 02K80A-40M at lower frequencies. It may be attributed exclusively to the different PCB layouts. The TDR response of the 110 GHz type of connector is shown in ***Figure 5***. The coaxial interface is on the left. It confirms the excellent impedance control along the signal path. There is a wide field for the application of this connector family in the ultra high frequency test and measurement applications and also in situations where minimum radiation and coupling to adjacent circuitry is mandatory.

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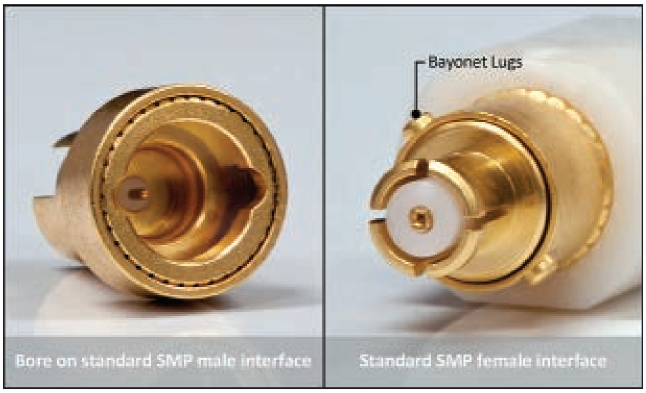
Locking Push-On RF Connector for Harsh Environments

Carlisle Interconnect Technologies has advanced the design of traditional push-on RF connectors with a new line of locking push-on connectors, the SMP-L™ series. This new series of connectors addresses the needs of RF system designers who are looking for a blindmate interconnect solution that can withstand harsh mechanical stress, primarily in rugged military/defense applications such as radars, missiles, handheld radios, avionics and UAVs, as well as for a growing number of commercial uses. The SMP-L connectors are available in cable, PC board or panel configurations for use within microwave modules and subsystems.

DESIGN

The introduction of push-on blindmateable connectors, such as the Sub Miniature Push-on (SMP), galvanized the RF/microwave industry as their use enabled designers to increase package density by stacking PC boards and thus reducing their form factor, while also simplifying the assembly and test of these designs. Since then, SMP and other push-on connector types have become the interconnect system of choice within RF/microwave systems.



▲ *Fig. 1 Secure-Lok connectors.*

Generally, push-on connectors utilize a push-on or friction-fit mating, or sometimes a snap-on mating to ensure a suitable connection. While a number of factors contribute to the overall performance of these systems, signal integrity issues at the connector level typically arise from any coupling or de-mating problems at the interface, including any alignment issues with respect to the socket (female)/pin (male) components. Under somewhat vigorous use, including harsh environments that are subject to significant movement or vibration at the connector interface, such conventional push-on architectures may not perform well. Furthermore, there are certain applications where push-on connectors are required to remain mated even under the tensile strain of the cable coupled to the connector.

The SMP-L series adds a patent pending positive-locking mechanism referred to as Secure-Lok™ onto a standard SMP interface

Carlisle Interconnect Technologies
Cerritos, CA

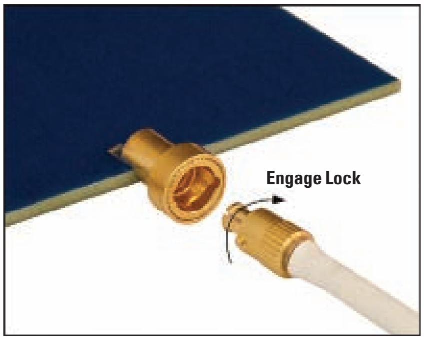


Fig. 2 *SMP-L locking mechanism.*

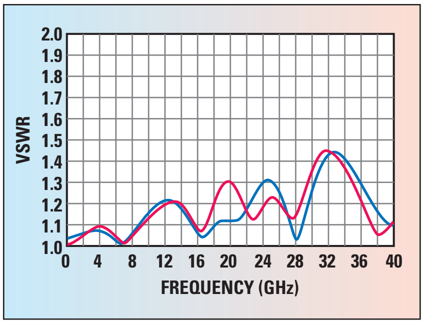


Fig. 3 *Typical performance of P657SL-3CC (cable connectors) measured on Accuphase TLL40-1111A flexible cable.*

to improve upon the ruggedness and repeatability. The female SMP-L connector interface adds a movable collar onto and rearward of the push-on socket, which includes a pair of bayonet pins. The male SMP-L connector interface adds a second bore onto and in front of the push-on plug, which includes a latch to accept the bayonet pins of the female interface (see ***Figure 1***).

When the female interface is inserted in the male interface and rotated clockwise, the bayonet pins slide along the inclined latch surfaces to axially drive the collar into the receiving bore to secure the female connector onto the male connector (see ***Figure 2***). To disengage the locking mechanism, the collar on the female interface must be pressed in and rotated anti-clockwise to de-mate the connectors. Consequently, the retention mechanism of this design improves upon a push-on connector's ability to resist unintentional de-mating forces, and to maintain signal integrity under adverse operational conditions such as heavy vibration.

TABLE I

SMP-L SPECIFICATIONS

Parameter	Specification
Impedance	50 Ω
Frequency Range	DC to 40 GHz
VSWR	1.3:1 (DC to 26 GHz) 1.5:1 (26 to 40 GHz)
Insertion Loss	.06 X √f GHz
DWV @ Sea Level	500 Vrms
Insulation Resistance	1000 MΩ min
RF High Pot. @ 5MHz	325 Vrms
Corona Level @ 70,000'	190 Vrms
Inner Conductor Resistance	6.0 MΩ
RF Leakage	–80 dB (DC to 3 GHz) –65 dB (3 to 18 GHz)
Force to Engage	
Smooth Bore	1.5 lbs
Force to Disengage	
Smooth Bore	1.0 lbs
Coupling Nut Retention Force	>100 lbs
Temperature Range	-55° to +165°C
Environmental	
Thermal Shock	MIL-STD-202, Method 107, Cond B
Moisture Resistance	MIL-STD-202, Method 106, except step 7b
Corrosion	MIL-STD-202, Method 101, Cond B
Vibration	MIL-STD-202, Method 204, Cond D
Shock	MIL-STD-202, Method 213, Cond I

PERFORMANCE

The SMP-L connectors retain the electrical performance characteristics of their SMP equivalents, and thus are an excellent fit for RF/microwave systems operating up to 40 GHz. The coupling retention mechanism, Secure-Lok, improves the retention force to > 100 lbs when measured on a 0.085" cable. This ensures that a reliable connection is maintained between the male and female interfaces even in harsh environments where a standard SMP interface with detent can possibly lose mating. The SMP-L interface specifications are listed in ***Table 1*** and typical VSWR performance to 40 GHz is shown in ***Figure 3***. In addition, durability tests were performed during the qualification phase to ensure that repeatability is maintained over 500 mate/de-mate cycles.

COMPATIBILITY

The SMP-L family comprises of female cable connectors and their male PCB and panel receptacles. These SMP-L connectors are fully compatible with the standard SMP connector line, which includes bullets, adapters, panel mounts and field replaceables. Thus, a complete interconnect system is available for new designs that also maintains compatibility with the existing SMP standard interface that is commonly employed in RF/microwave systems. Additionally, Carlisle has designed a variety of SMP-L connectors, including IP67 compliant configurations, specifically for its customers' application needs.

Hence, SMP-L connectors are an ideal solution for applications that require the performance and density of a push-on connector with the ruggedness of a locking feature. Their superior performance under vibration and other harsh environmental factors allows designers to overcome the historical limitation of using only threaded connectors such as the SMA or Type N in their designs. Moreover, the compatibility of the SMP-L connectors with the standard SMP interface enables the use of a single interconnect system throughout the design.

Carlisle Interconnect Technologies, Cerritos, CA (562) 498-0901, www.CarlisleIT.com.

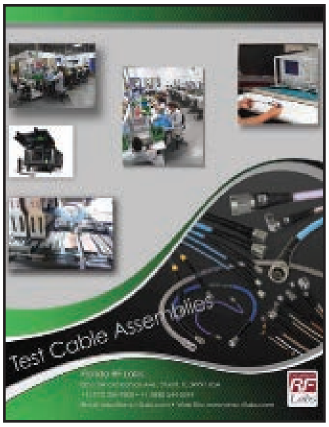
Cables & Connectors Supplement

LITERATURE SHOWCASE

Locking Push-On Connectors

CarlisleIT advances the design of traditional push-on connectors with its new line of SMP-L™ connectors by adding a patent-pending locking mechanism called Secure-Lok™ to the standard SMP interface. SMP-L connectors are ideal for rugged military and commercial applications where susceptibility to vibration and other environmental factors is an issue.

Carlisle Interconnect Technologies, www.CarlisleIT.com.

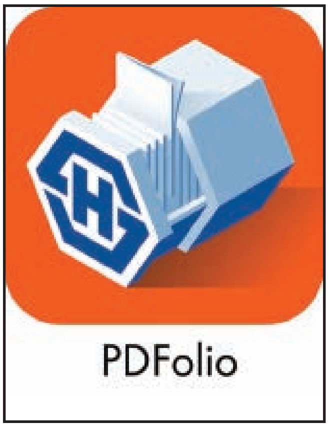


Test Cable Assembly Brochure

VENDORVIEW

Continuing its commitment to "Excellence in Interconnect Solutions," Florida RF Labs has released a brochure highlighting its dedication to providing durable, high-performance test cable assemblies for lab, production and test equipment applications. The brochure features Lab-Flex®, Lab-Flex S, ASR and Mini-Flex product families and introduces the new Titan-Flex test assemblies.

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



App for iPads

As of now Huber+Suhner provides the "PDFolio" app for the iPad showing all brochures and catalogues. The documents are arranged according to technologies and markets and can be downloaded as and when required. All content of the app is always updated. This app is available for free in the iTunes Store.

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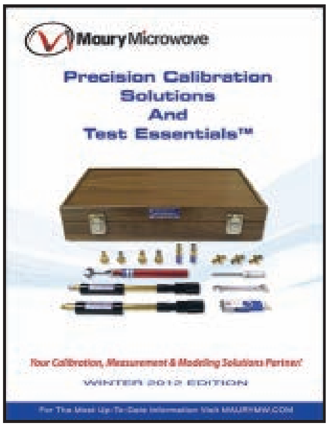


Precision Calibration Solutions and TestEssentials Catalog

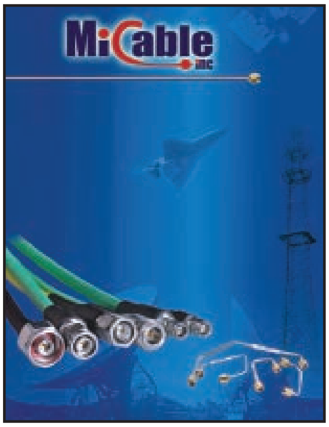
A complete listing of Maury's cal kits/cal standards for accurate calibration of Agilent, Anritsu, Rohde & Schwarz and other network analyzers (DC to 110 GHz). Maury's cal kit configurations include all popular coax and waveguide connector types. Other items include Maury's metrology-grade adapters, TestEssentials™ lab adapters, and ColorConnect™ precision adapters, Stability™ microwave/RF cable assemblies, connector gage kits and much more, with a full section on Maury's complete line of thermal/cryogenic noise calibration systems and equipment.

Maury Microwave Corp., www.maurymw.com.

Connectors, Cable Assemblies and Components Catalog

Mesa Microwave since 1995 has been manufacturing connectors, cable assemblies and components for the RF and microwave industry in frequency ranges from DC to 110 GHz for commercial and military applications. Mesa is the source for standard and custom designs for unique applications. Contact the company at (480) 890-1612 or sales@mesamicrowave.com. "Live chat" is available. Request a catalog online at www.mesamicrowave.com.

Mesa Microwave, www.mesamicrowave.com.

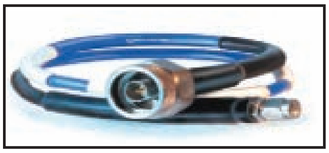


Coaxial Cable Assemblies

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 test cable assemblies, hand-flex cable assemblies, and semi-rigid cable assemblies. In addition, the company also designs and produces various precise coaxial stainless and copper connectors and adapters. Custom designed cable assemblies are also available. MIcable Inc. is your quality fast and low cost solution. Please email sales@micable.cn.

MIcable Inc., www.micable.cn.

LITERATURE SHOWCASE

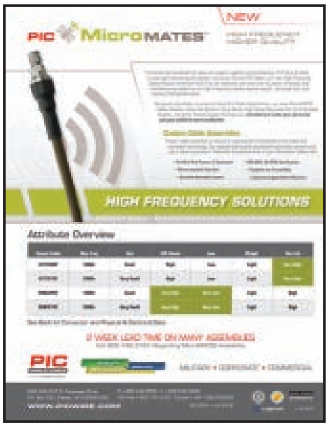


Six-Month Cable Guarantee

VENDORVIEW

Mini-Circuits offers a six-month product guarantee for CBL series RF cable. Test cables traditionally undergo tremendous strain due to many connections which are a normal part of nearly every test lab application. Furthermore, a test environment often results in stress on the cable and cable-to-connector interface due to the high number of bends and flexures required during testing processes. Mini-Circuits will repair or replace your test cable at its option if the connector attachment fails within six months of shipment.

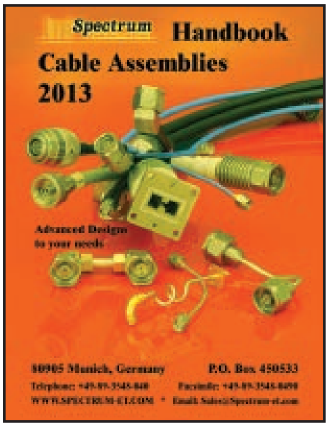
Mini-Circuits, www.minicircuits.com.



MicroMATES Assemblies

PIC Wire & Cable's MicroMATES™ were introduced in 2012 for Ku- and X-Band assemblies. Learn more about these 50 Ω microwave assemblies engineered with minimum 200°C rating on all materials plus superior components including: Inner flat braid or strip braid, high temp polyimide foil, dual braided shields and silver-plated copper throughout.

PIC Wire & Cable, www.picwire.com.



Cable Assembly Handbook 2013

Spectrum Elektrotechnik GmbH has a new comprehensive handbook with detailed information on such products as high performance cable assemblies, operating to 65 GHz; phase matched cable assemblies, showing also phase adjustable connectors to 40 GHz; multipin/multiport cable assemblies: circular connectors with up to 12 coaxial cable assemblies, operating to 18, 26 and 40 GHz, and rectangular connectors with 23 coaxial connectors and 26 DC lines; phase king assemblies with limited phase shift over temperature; phase stable assemblies to 26 GHz; and many more.

Spectrum Elektrotechnik GmbH, www.spectrum-et.com.

Connector Series Application Note

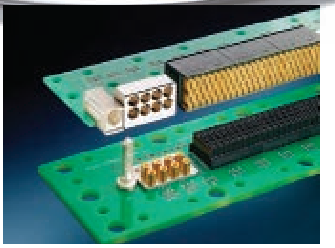
SV Microwave has released a new application note for the QuarterBack™ connector series. The line utilizes a quarter turn bayonet style coupling nut with a locking feature for standard SMP/SMPM interfaces. The QuarterBack connectors are ideal for high vibration and test applications that require a large number of mating cycles.

SV Microwave, www.svmicrowave.com.

dB Miser Brochure

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

Teledyne Storm Microwave, www.teledynestorm.com.



VITA 67 Standards for Connector Modules

The VITA 67.0, 67.1 and 67.2 standards, which define the RF connector modules for implementation within the OpenVPX™ architecture, have been ratified by the American National Standards Institute (ANSI). TE Connectivity's RF connector modules, which meet these new standards, have been designed for high-reliability, high-density aerospace and defense applications that meet the vibration, environmental and corrosion resistance requirements of VITA 47.

The new VITA 67 standards enhance the ability to add RF capabilities in VITA 46 VPX board-to-board connections. The modules provide a convenient and standardized microwave interface and also meet the needs of C4ISR applications such as ground base stations and communication systems, land and sea antiballistic signal processing, avionics and ground-based radar systems, and electronic countermeasures.

The modular design allows application-specific configurations with high contact counts in VPX systems. The RF connector modules are compatible with VITA 65 OpenVPX specification, which defines standard profiles for various configurations at the chassis, backplane, slot and module levels.

RF modules are available with standard 4 positions (VITA 67.1) or 8 positions (VITA 67.2) of high-frequency coaxial contacts for blind-mate daughtercard to backplane applications. The SMPM based contacts are on a 0.240" centerline, and the module interface is designed to maintain excellent channel-to-channel isolation, over 100 dB at 30 GHz.

The jacks are designed with float on the daughter-card side to accommodate mating tolerances and confirm that the RF interface is bottomed through the full board-to-board tolerance range, maintaining a positive RF ground and supporting frequencies up to 40 GHz. The modules offer a contact float of 0.079", radial misalignment of ±0.010", and a design that provides reliable blind-mating. Contacts are available for a wide range of flexible and semi-rigid cable.

TE Connectivity, Harrisburg, PA (800) 522-6752, www.te.com.

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