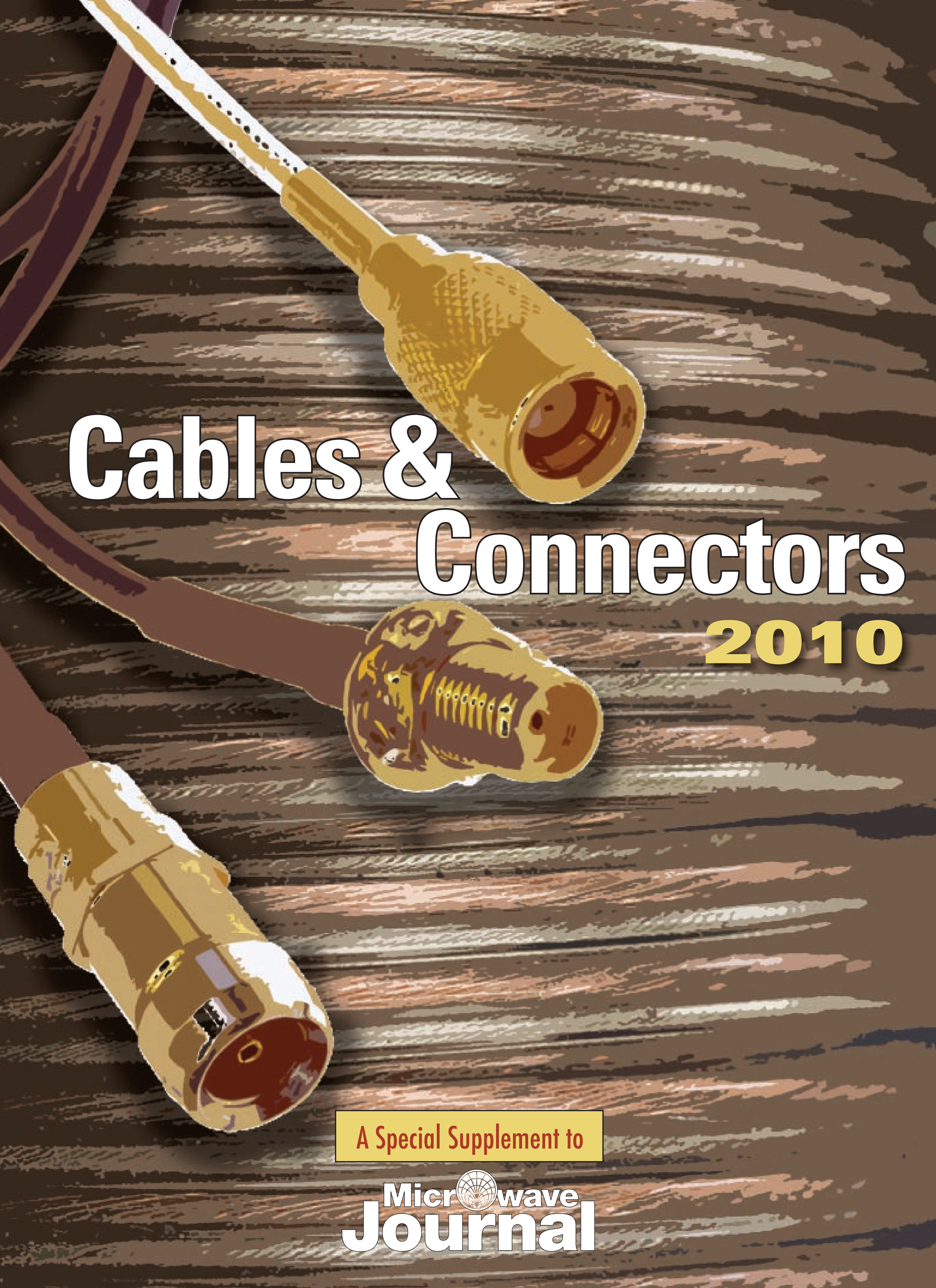

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Cables & Connectors Supplement

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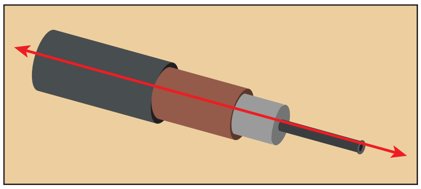
CHOOSING THE OPTIMAL HIGH FREQUENCY COAXIAL CABLE

Operating frequencies for coaxial transmission lines have steadily climbed from below 1 to 110 GHz and beyond over the last few decades. This has caused RF/microwave engineers to search for coaxial transmission lines capable of effectively transmitting at these higher frequencies. The coaxial cable market has responded to these substantial leaps in operating frequencies by offering modern cable designs that far exceed the performance specifications contained in the military's most comprehensive coaxial cable standard, MIL-DTL-17. Many leading cable manufacturers now employ production methods, design innovations and material technologies that optimize the transmission of very high frequency microwave signals. However, no perfect design solution exists to fit all possible applications. This article will discuss the pros and cons of different coaxial cable constructions to help engineers and designers choose the optimal solution for their specific design needs.

Coaxial cable derives its name from the spatial relationship shared between the center conductor and the outer conductor. ***Figure 1*** shows this "co-axial" positioning of conductors. A British engineer and mathematician by the name of Oliver Heaviside first patented the basic design of coaxial cable in 1880 (Patent Number: 1407). Then in 1929, almost 50 years later, Lloyd Espenshied and Herman Affel of AT&T's Bell Labs secured a United States patent for the first modern coaxial cable design (US Patent Number: 1,835,031). Soon afterwards, coaxial cable started gaining popularity with radio engineers and became the preferred choice for connecting antennas to transmitters and receivers. As it turns out, coaxial cable is well suited for running up and down metal antenna towers, along gutters, or around any other metal structures since all electrical energy transmits down the interior of the cable and remains isolated from external influences.



▲ *Fig. 1 Center and outer conductor alignment along a common axis.*

In the late 1920s and early 1930s, Bell Labs set out to determine which coaxial impedance value was optimum. Surprisingly, the optimum impedance changes depending on the primary application. By experimentation Bell Labs found 30 ohms is best for high power, 77 ohms is best for low attenuation, and for high voltage 60 ohms turned out to be the best impedance value. Most modern coaxial cables come in 50, 75 or 93 ohm impedances and 50 ohms is by far

BOB THIELE AND STAN HARDIN
Dynawave Cable Inc., Haverhill, MA

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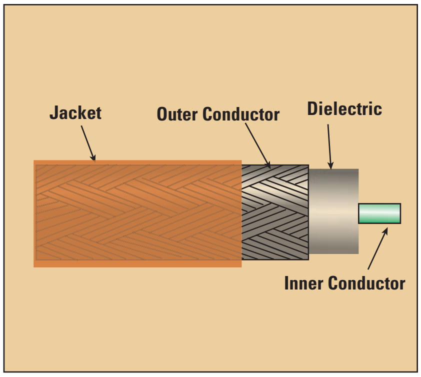

Fig. 2 Basic coaxial cable construction.

the most popular impedance choice for high frequency transmission lines.

Although other industry standards have come and gone since the 1930s, MIL-C-17, now called MIL-DTL-17, has become the most comprehensive and most referenced coaxial cable standard. Three examples of how this military standard impacts our daily lives are:

- Cable Television: The National Cable & Telecommunications Association most recent statistics identify 104.7 million CATV subscribers in the United States. The majority of those households receive their video transmissions through a M17/2 - RG6 cable.
- Vital Emergency Services: M17/28 – RG058 remains one of the most widely used 50 ohm radio antenna cables. It is used on most two-way radio communications systems, such as CB radios, police, fire, ambulance and marine radios.
- A recent GOOGLE web search for "MIL-C-17" produced over seven million references.

We see that many times a day our lives benefit from MIL-DTL-17 cables, but when it comes to transmitting frequencies above 12 GHz, designers must turn to modern cable designs that far exceed the performance specifications of M17 cables. When working at higher and higher frequencies the question we have to ask is, "What is the optimal cable choice for my application?" The following discussion seeks to answer this question by looking at various cable constructions.

OPTIMAL COAXIAL CABLE CONSTRUCTIONS

Coaxial cable design choices include physical size, frequency performance, attenuation, power handling, flexibility, strength, environmental conditions and cost. Today's engineers and designers can choose from a wide variety of design and construction choices, each having their own benefits. The common components found in every coaxial cable include the inner conductor, the dielectric, the outer conductor and the jacket. Each of these components can employ production methods, design innovations and material technologies that optimize specific mechanical and electrical properties, but choosing to boost performance in one area often means reducing performance in another. The following discussion will explain this give and take with regard to performance specification, and provide guidance in making the right choices to successfully match a coaxial cable transmission line to an application.

Inner conductor design choices impact the cable's life span when subjected to dynamic flexure. They also largely influence the attenuation performance (see ***Figure 2***). Basic design choices include the number of strands that make up the conductor and the base metal and surface plating. There are other conductor options, but most high frequency cables use these standard wire constructions for inner conductors including single strand (solid), 7 strands, 19 strands and 37 strands. As a general rule of thumb, the more strands a conductor has the more flexible it will be and the longer its dynamic flexure life will extend. However, the down side to increasing the flexibility of the conductor is that the attenuation caused by the conductor also increases. The designer sacrifices attenuation performance for better flexure performance.

Table 1 lists general data pertaining to the dynamic flexure life of copper conductors with various stranding factors. This data was derived experimentally on a MIL-T-81490 flexure test fixture and is offered for reference only since dynamic flexure life depends on bend radius, angular deflection and the rate of flexures per minute.

In addition to the number of strands contained in the center conductor, the base metal or surface plating conductivity can significantly affect the attenuation of high frequency coaxial cables. A phenomenon known as "skin effect" allows cable designers to take advantage of thin surface layers of highly conductive metals such as silver to minimize cable attenuation. Even though silver is expensive, a relatively thin layer of plating provides significant improvement in loss. ***Figure 3*** shows the effective skin depth of electrical energy traveling in on a copper conductor between 10 MHz and 40 GHz. Above 10 GHz the skin depth is less than 1 micron, which demonstrates a 40 micron thickness of silver plating over the copper will carry all of the electrical energy and reduce the overall conductor losses.

Table 2 shows the conductivity of the most common conductor surface plating used in high frequency cables and coaxial connectors, ranked from best to worst. Although silver plating offers better conductivity, it also costs significantly more than copper

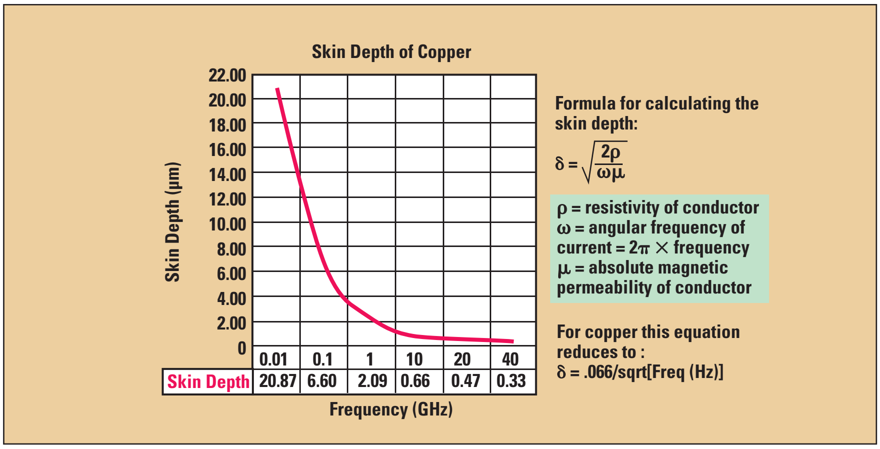

Fig. 3 Skin depth calculations for a copper conductor.

or aluminum; both cost and attenuation performance must be considered when choosing the optimal conductor finish. Taking advantage of skin effect at microwave frequencies, however, means the plating thickness can be relatively thin, which helps control costs.

To summarize, multi strand center conductors offer much better flexure life, but sacrifice attenuation performance compared with a solid conductor. Consideration must be given as to whether attenuation or flexibility is most important before selecting the best cable construction for any given application. Also, most high frequency coaxial cables employ silver plated conductors because the conductivity of silver is better than aluminum or copper, and the skin effect at high frequencies enables thin layers of silver plating to add substantial performance benefit.

Dielectrics provide an insulating layer between two conductors and, in the case of coaxial cables, also perform an important mechanical function by supporting the outer conductor and keeping both conductors fixed along their common axis. Dielectrics used in manufacturing high frequency coaxial cables have two very important characteristics: low dielectric constants and low dissipation factors.

The dielectric constant (k) of a material is used to determine that material's ability to carry alternating current when compared to air in a vacuum. A vacuum provides the most efficient means of transmitting electrical energy and has a k of 1.000. All other materials have higher values for their respective dielectric constants. Values for the most common coaxial cable dielectrics are shown in ***Table 3***. To minimize power losses it is always desirable to have the lowest possible dielectric constant in high frequency coaxial cables.

Dissipation factor is a measure of the inefficiency of a dielectric material. All dielectrics dissipate electric power in the form of heat because of their inefficiencies and the more inefficient a dielectric is, the higher its dissipation factor will be. Table 3 shows comparable dissipation factors for dielectric materials used in high frequency coaxial cables. To minimize power losses, it is always desirable to use materials with the lowest possible dissipation factors.

As shown in Table 3, air in a vacuum provides the optimal dielectric material for transmitting electrical energy. However, air does not provide the mechanical support required to keep the center conductor and outer conductor of a coaxial cable fixed in place. The next best material, which

TABLE I

COMPARISON OF COMMON STRANDING CONSTRUCTIONS FOR INNER CONDUCTORS

Ranking by Best Attenuation Performance	Ranking by Best Dynamic Flexure Life	Number of Strands	Number of Flexures (bend radius = 20x wire diameter)	Approximate Attenuation Increase (% of Single Strand Loss)
1	4	Single Strand	5,000 to 10,000	100
2	3	7 Strand	50,000 to 70,000	107
3	2	19 Strand	150,000 to 200,000	113
4	1	37 Strand	>500,000	122

TABLE II

COMPARISON OF COMMON CONDUCTOR SURFACE FINISHES

Ranking by Best Attenuation Performance	Surface Material	Electrical Conductivity (/ cm Ω)	Reduction in Conductivity (% change from Silver)
1	Silver	$.630 \times 10^6$	100
2	Copper	$.596 \times 10^6$	94
3	Aluminum	$.378 \times 10^6$	60

TABLE III

COMPARISON OF COMMON COAXIAL CABLE DIELECTRICS

Ranking by Dielectric Constant	Ranking by Dissipation Factor	Dielectric Material	Dielectric Constant	Dissipation Factor	Temp. Range (°F)
1	1	Air in Vacuum (for reference)	1.000000		
2	2	Low Density or Expanded PTFE	1.30	<0.00008	-410 / +500
3	3	(PTFE) Polytetrafluoroethylene	2.05	<0.0002	-410 / +500
4	4	(PFA) Perfluoroalkoxy	2.0	<0.0004	-300 / +500
5	5	(FEP) Fluorinated Ethylene Propylene	2.1	<0.0007	-100 / +400
6	3	(PE) Polyethylene	2.25	<0.0002	-30 / +180
7	6	(PVC) Polyvinyl Chloride	3.18	<.016	-40 / +220


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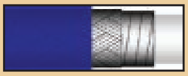
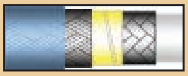
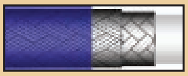
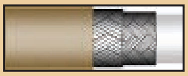
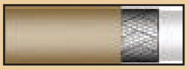
TABLE IV

COMPARISON OF VARIOUS OUTER CONDUCTOR SHIELDING CONSTRUCTIONS

Ranking by Best Atten. Perf.	Ranking by Best Shielding Perf.	Ranking by Best Physical Toughness	Ranking by Flexibility	Outer Conductor Style
1	1 >100 dB	4	3	 Wrapped Foil + Woven Round Braid
2	2 >90 dB	1	5	 Woven Flat Braid + Wrapped Foil + Woven Round Braid
3	3 >80 dB	2	4	 Woven Flat Braid + Woven Round Braid
4	4 >65 dB	3	2	 Two Woven Round Braids
5	5 >40 dB	5	1	 One Single Woven Round Braid

does provide the needed mechanical strength for flexible cables, is a low density Polytetrafluoroethylene (PTFE). Low density PTFE is also referred to as "expanded" or "microporous" PTFE throughout the RF and microwave industry. These terms all describe the same type of material that is standard PTFE with microscopic air spaces distributed throughout. The more air spaces in the material the lower the density and the better the electrical performance of the composite dielectric. This results in a dielectric material, which has a lower dielectric constant and dissipation factor than solid PTFE but still has enough strength to provide a stable mechanical structure to support both conductors.

The top manufacturers of low loss, high performance cables utilize low density PTFE exclusively in their cable constructions for the reasons listed above. GORE™ expanded PTFE and DynaCore™ low density PTFE dielectrics are two examples of how this material technology is applied in coaxial cable products.

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Outer conductor or shield choices impact the attenuation, shielding effectiveness, physical resistance to torque and crushing, and the flexibility of coaxial cables. Basic design choices include braid coverage, application of braid by weaving or wrapping, total number and combination of braid and foil layers, and base metal and surface finish.

There are a variety of ways to design and manufacture shields on coaxial cables. Flexible cables use any combination of braided fine wires and wrapped foils to provide a conductive layer that flexes. ***Table 4*** shows five different variations of outer conductor designs for flexible cables ranked by different design considerations.

Jacket materials serve as a protective covering from the environment. Although cable jackets do not play a role in the electrical performance of a coaxial cable, they are an integral part of the overall cable performance when installed. Some of the environmental conditions cable jackets are designed to protect against include extreme temperature excursions, abrasion, ultra violet radiation, rain, humidity, flame resistance, low smoke and toxicity, resistance to fluids, crushing/bending forces and corrosion. There are various jacket materials offered by manufacturers that are tailored to protect against one or more of these types of environmental conditions. Most manufacturers offer guidance on jacket choices and designers need to consider the service environment their products will experience when choosing the optimal cable for their application.

CONCLUSION

It has been 130 years since Oliver Heaviside first patented the concept of coaxial cable in 1880. Another 80 years have passed since the pioneering work at Bell Labs laid the groundwork for modern coaxial cables to be defined by 50, 75 and 93 ohm impedances and standardized by the military specification, MIL-DTL-17. Today our lives are impacted in many ways by coaxial transmission lines. They are used extensively in two-way communications systems for police and fire departments, rescue personnel, and first responders. The products we consume every day are shipped on carriers who rely on satellite communications systems, GPS tracking and mobile telecommunications technology that all operate with the aid of coaxial cable transmission lines. Our national security is also supported by communication systems, radars, electronic counter measures and target acquisition systems that use coaxial cables.

In the last 30 years a large push to transmit at higher frequencies challenged the manufacturers of high performance coaxial cable to push the technology and introduce new products. These new cables far exceed the performance standards of MIL-DTL-17 and well informed engineers can take advantage of a variety of product designs and innovations to optimize critical performance parameters in their system designs. No single cable offers the best solution for every design application, but by carefully considering the various material and design options related to the inner conductor, dielectric, outer conductor, and jacket and how those options impact the coaxial cable's electrical, mechanical, cost and environmental performance, the optimal product choice can be made. ■

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CBL-10FT-SMSM+	SMA	10	4.8	27	87.95
CBL-12FT-SMSM+	SMA	12	5.9	27	91.95
CBL-15FT-SMSM+	SMA	15	7.3	27	100.95
CBL-25FT-SMSM+	SMA	25	11.7	27	139.95
CBL-2FT-SMNM+	SMA to N-Type	2	1.1	27	99.95
CBL-3FT-SMNM+	SMA to N-Type	3	1.5	27	104.95
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CBL-6FT-SMNM+	SMA to N-Type	6	3.0	27	114.95
CBL-15FT-SMNM+	SMA to N-Type	15	7.3	27	156.95
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CBL-6FT-NMNM+	N-Type	6	3.0	27	112.95
CBL-10FT-NMNM+	N-Type	10	4.7	27	156.95
CBL-15FT-NMNM+	N-Type	15	7.3	27	164.95
CBL-20FT-NMNM+	N-Type	20	9.4	27	178.95
CBL-25FT-NMNM+	N-Type	25	11.7	27	199.95
		Female to Male			
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CBL-2FT-SFNM+	SMA-F to N-M	2	1.1	27	119.95
CBL-3FT-SFNM+	SMA-F to N-M	3	1.5	27	124.95
CBL-6FT-SFNM+	SMA-F to N-M	6	3.0	27	146.95
ARMORED CABLES		Male to Male			
APC-6FT-NM-NM+	N-Type	6	3.0	27	181.95
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Comparison of VNA and TDR Measurement Uncertainty Using Coaxial Cables

Individuals working in digital applications tend to prefer the Time Domain Reflectometer (TDR), while those involved in traditional RF applications consider the Vector Network Analyzer (VNA) to be a laboratory staple. The push for ever-faster data rates has fueled an analytical re-thinking of high-speed digital signaling. Contemporary wisdom views high-speed digital systems as high-frequency applications, where more traditional microwave analysis techniques apply. Once this concept is embraced, engineers often exploit the strengths of both the TDR and VNA, combining time and frequency domain analysis to accelerate design and development cycles. Both instruments can measure impedance, time delay, phase delay and reflection coefficient so they are often thought of as equals. This begs the question: Is there a quantifiable difference in measurement uncertainty between the TDR and VNA?

Characterizing the time delay of a passive device, such as coaxial cable assembly is a common use for the TDR and VNA. It is therefore an ideal vehicle for a performance comparison. How do the two compare under ideal test conditions, and the less-than-ideal environment of production testing? Do both instruments possess similar levels of measurement precision? This article answers these questions by examining the measurement uncertainty and repeatability of the TDR and VNA.

Description of Experiment

To understand the capabilities of any measurement system, it is important to test the system's response to a variety of inputs to avoid erroneous conclusions. For this discussion, the term "input" refers to a "Device Under Test" (DUT), which in this experiment were different cable assemblies from a variety of manufacturers, having a range of insertion loss and VSWR characteristics. In a manner consistent with commonly used production test practices, measurements of the time delay of the cable assemblies described above were measured with a TDR and a VNA. The resulting measurement uncertainty of the two instruments under these conditions was then compared.

A sample of six new cable assemblies were used in the experiment, each equipped with SMA pin connectors. ***Table 1*** details their loss, VSWR and physical length characteristics. The electrical data in Table 1 was acquired through VNA analysis. The experiment consisted of two rounds of testing. Within a round, each sample was connected to the TDR or VNA and measured five consecutive times, without being disconnected or disturbed ("repeat testing"). After five measurements, the sample was

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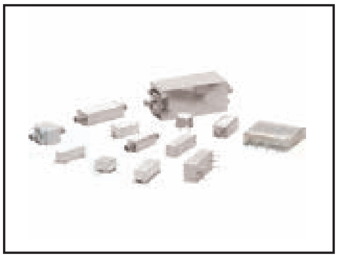

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TABLE I

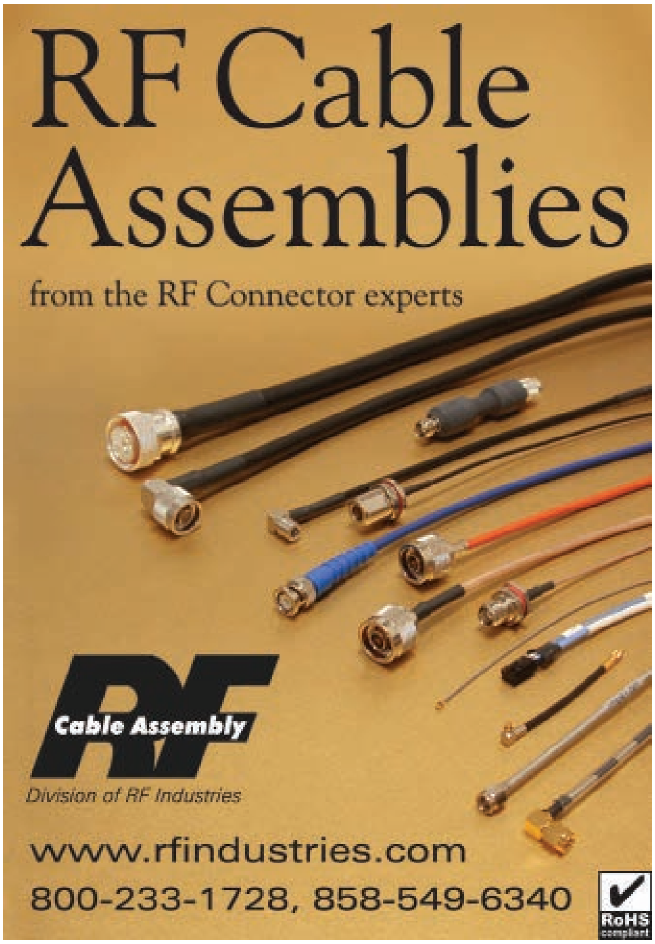
ELECTRICAL/PHYSICAL CHARACTERISTICS OF SAMPLE CABLE ASSEMBLY

	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*
Length	39.4 in	96.0 in.	30.0 in.	36.0 in.	120.0 in.	8.0 in.
Max. loss @ 18 GHz	1.13 dB	5.02 dB	2.66 dB	1.32 dB	4.26 dB	0.46 dB
Max. VSWR thru 18 GHz	1.13:1	1.27:1	1.13:1	1.13:1	1.28:1	1.10:1

removed from the instrument and not reconnected until the next round of testing ("round testing"). The sample assemblies were labeled 1 through 6 and their test order within each round was randomized to reduce test bias. Repeat testing reflects instrument uncertainty, while round-to-round testing reflects measurement reproducibility or test uncertainty.

TEST CONFIGURATIONS

During the TDR portion of testing, the sample assemblies were connected directly to the TDR sampling head while the opposite end was terminated with a 3.5 mm precision open standard. This was done to ensure a well-defined and controlled termination. In the VNA portion of testing, the sample assemblies were connected between ports 1 and 2. In both TDR and VNA testing, standard RF cable assembly care and handling practices were exercised. ***Figure 1*** shows the cable sample assemblies.

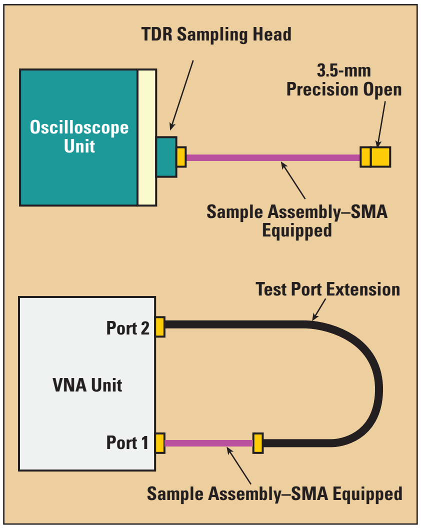


EQUIPMENT AND TEST CONDITIONS

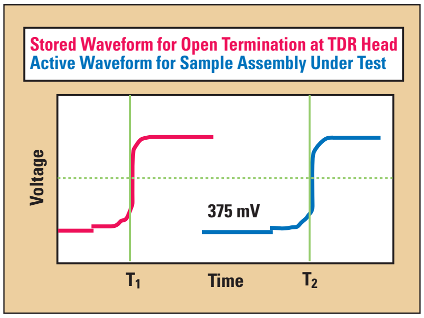
For the TDR time delay measurement, a sample assembly, fitted with precision open termination, was connected to the TDR and the round-trip time delay value was recorded using the instrument's built-in time delay measurement algorithm. The round trip time delay is taken as the difference in time between the active waveform (T_2), representing the precision open circuit at the end of the sample assembly, and the stored waveform (T_1), representing the open circuit at the TDR head. The time delay was recorded at a 375 mV level. The actual sample assembly time delay is one half the measured round-trip time delay, as shown in ***Figure 2***.

$$\text{Device time delay}_{TDR} = (T_2 - T_1)/2$$

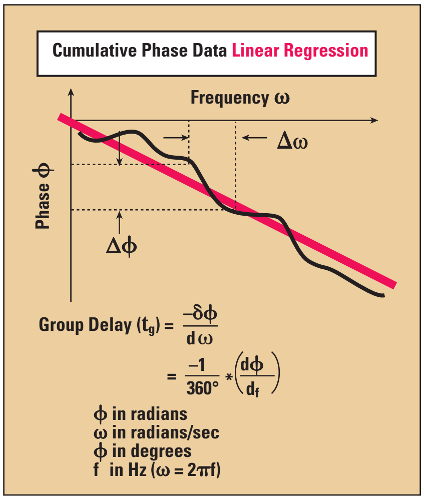
For the VNA time delay measurement, the sample assembly was connected to VNA ports 1 and 2 and stimulated through a swept frequency range. Using proprietary software, cumulative phase information over the swept frequency range was extracted from the S_{21} data. The time delay was calculated by perform-



▲ *Fig. 1 Sample assemblies.*



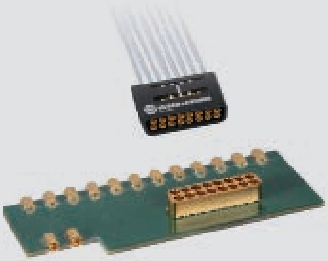
▲ *Fig. 2 TDR waveform display for time delay measurement.*



▲ *Fig. 3 Group delay calculation as applied to S-parameter data.*






ing a least-squares curve fit, linear regression of the cumulative phase. The slope of the linear regression is the change in phase with respect to the change in frequency or the group delay (t_g). The group delay value returned from this process is taken as the device time delay (see ***Figure 3***).

RESULTS OF EXPERIMENT

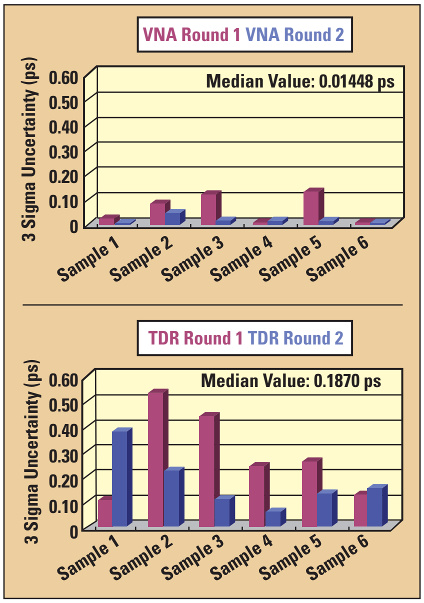
Figure 4 illustrates the ± 3 sigma measurement uncertainty by sample for the TDR and VNA measurements. The following observations were made: measurement uncertainty for both instruments appeared to be device-under-test dependent; the median uncertainty across rounds was considerable; and the overall values for the VNA were significantly lower than those of the TDR. The figure also illustrates the instrument repeatability: the variability associated with measuring the same DUT repeatedly, while not disturbing it or the measurement system. This gives a window into the uncertainty of the instrument itself under the prevailing test conditions. It is predicated on the assumption that the DUT and any related fixtures are stable.

Rounds 1 and 2 were intended to capture the measurement system variability stemming from connect/disconnect cycling of the DUT, referred to as "measurement reproducibility." Connectors can affect measurement reproducibility, but SMA connectors, when new and in good condition, possess sufficient repeatability such that a significant influence on reproducibility was not anticipated. All six sample assemblies were equipped with SMA pin connectors. During the experiment each was thoroughly cleaned before every round and tightened to the appropriate torque value.

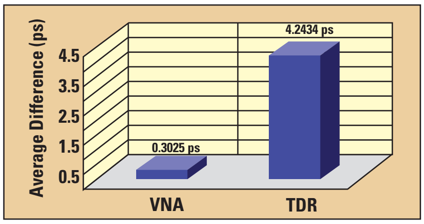
In a production test scenario, it is often necessary to re-measure a device for re-classification. ***Figure 5*** shows that between rounds 1 and 2, the measured time delay of a sample differed, on average by 0.3 ps for the VNA and 4.2 ps for the TDR.

ANALYSIS OF BEST-CASE PERFORMANCE

An initial review of the experiment indicated that one sample out of the six performed consistently better than the others in both TDR and



▲ *Fig. 4 "Repeat testing", ±3 sigma uncertainty by test sample.*



▲ *Fig. 5 Average difference in measured time delay across six test samples from round 1 to round 2.*

VNA testing. The assembly, Sample 6, was identified as a best-case scenario for both instruments and selected to undergo additional analysis. A second experiment, similar to the first, was created to gather information on measurement uncertainty under best-case conditions. With identical instruments, test conditions and configurations, a new experiment consisting of the following was performed:

- Repeat testing consisted of 22 consecutive measurements without disconnecting/disturbing the DUT and test system
- Reproducibility testing consisted of 22 connect/disconnect cycles of the DUT, with measurements taken at each connect/disconnect cycle
- To ensure VNA/TDR test parity, VNA measurements were made using S_{11} reflection techniques as well as the more conventional S_{21} transmission method

The objective was to observe measurement uncertainty under more closely controlled conditions. Towards that end, during TDR testing the 3.5

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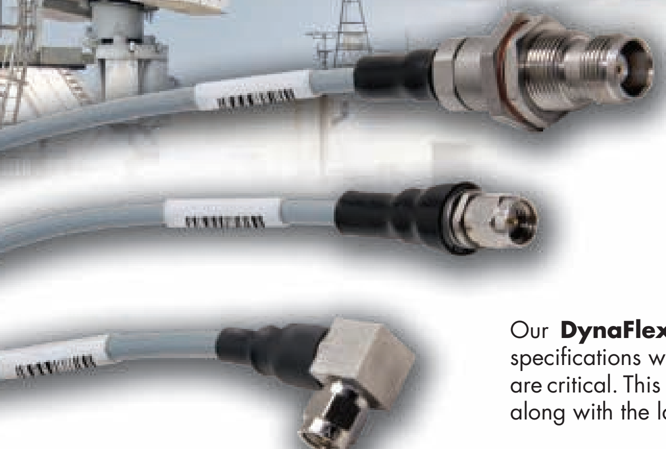

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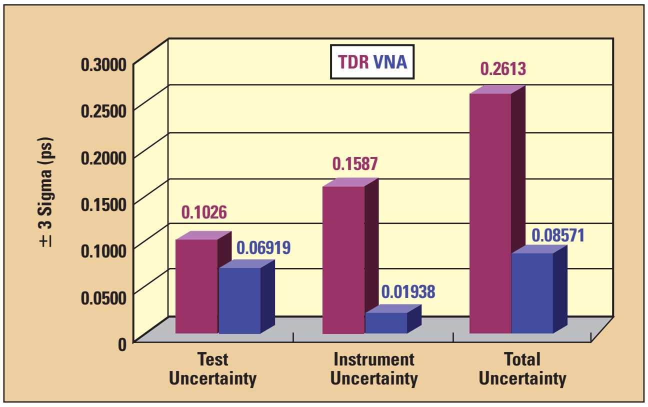
mm precision open was left in place during all 22 connect/disconnect measurements; the sample assembly connection was cycled at the TDR sampling head only. Likewise during VNA testing, the sample assembly connection was cycled at port 1 only. This strategy, although not representative of production testing, does introduce a disturbance into the test system such that the outcome can be observed.



▲ *Fig. 6 ±3 sigma uncertainty analysis based on measurements of Sample 6.*

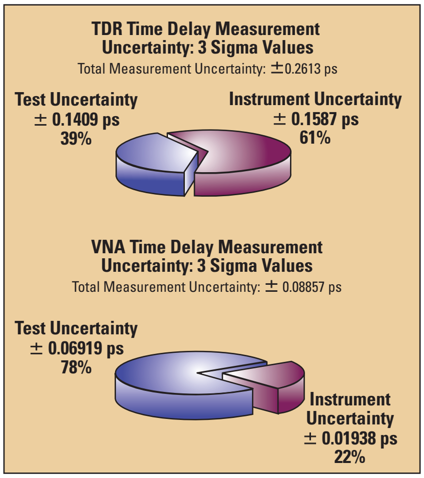
The number of measurements (22) was determined through a confidence interval calculation. Twenty-two measurements assure a 98 percent confidence that the sample mean in the experiment will be within ± 0.08 ps of the actual population mean. This is based upon an estimated standard deviation of 0.16 ps.

For this portion of the analysis, TDR and VNA measurement uncertainty was divided into three categories:

- Instrument uncertainty: Uncertainty associated with the instrument platform itself, measured through repeat testing.
- Total uncertainty: Uncertainty resulting from the cumulative effects of instrument characteristics, test fixture, test conditions and operator influences. Measured through connect/disconnect cycling, includes instrument uncertainty.
- Test uncertainty: Resulting from operator error, test fixture influences and prevailing environmental conditions at time of test, measured indirectly.

Figure 6 shows best-case uncertainty for Sample 6. Test uncertainty values were expected to be similar in the TDR and VNA due to similarities in test configurations. With this information, the best-case uncertainty associated with each instrument platform can be assessed.

The pie graphs in ***Figure 7*** reveal that 22 percent of the total measurement uncertainty for the VNA is associated with the instrument itself, as compared to 61 percent for the TDR. This was a repeating theme throughout the experiment. This significant difference means that even under ideal test

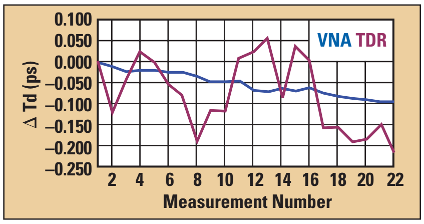


▲ *Fig. 7 Total measurement uncertainty broken down by test and instrument uncertainties.*

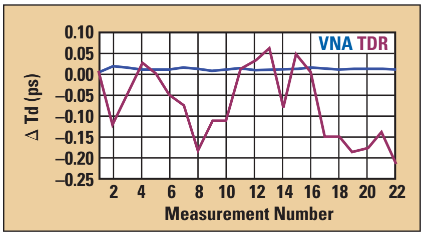
conditions, that is minimal test fixture, operator and environmental influences, the gap in TDR/VNA measurement uncertainty will remain, as it is inherent to the instrument performance.

Figure 8 compares the 22 connect/disconnect delta time (T_d) delay measurements of Sample 6 relative to the first measurement using the TDR and VNA. The VNA measurements have a range spanning 0.0983 ps as compared to the TDR's range of 0.275 ps. Both data clearly show a trend downward, that is a progressively shorter device delay. Although the TDR data suggests a repeatability issue with the 3.5 mm connector on the TDR sampling head, it was determined that the variability is associated not with the connector, but the instrument itself.

The downward-trending behavior noted may be attributed to burnishing of the SMA/3.5 mm mated interfaces. A 3.5 mm connector was used as the calibrated reference plane to which the test sample's SMA was mated. Connecting and disconnecting the



▲ *Fig. 8 Twenty-two connect/disconnect measurements in sequence.*



▲ *Fig. 9 Twenty-two connect/disconnect measurements of Sample 6 in sequence.*

SMA interface in succession (without cleaning between cycles, as was done in the experiment) has the potential to burnish the mated connector interface components. It was theorized that over the course of 22 test cycles, the mated interfaces were sufficiently abraded to experience improved electrical contact, as evidenced by a reduction in insertion loss and electrical length.

It is of some interest to compare the absolute time delay values for Sample 6 as measured by the TDR and VNA. An examination of repeat testing produced an average time delay of 0.817364 ns for the VNA and 0.849754 ns for the TDR; a difference of 32.5 ps. This discrepancy was unexpected and an attempt was made to obtain closer agreement between the two instruments.

The average time delay value of 0.849754 ns was referenced to an open circuit at the TDR sampling head, meaning the connection at the head was not terminated. The reflection from the resulting open circuit was stored as a reference waveform. Measurements of Sample 6 were taken with respect to this reference. To improve the agreement between TDR and VNA measurements, the sampling head was fitted with a 3.5 mm pin to 3.5 mm socket precision adapter ("connector saver") from a VNA calibration kit. The adapter provides a precise reference plane and sufficient electrical length to establish a new reference plane well away from the sampling head's 3.5 mm panel connector.

To define a new reference plane, a 3.5 mm (pin) precision open from a VNA calibration kit was used. The open was connected to the sampling head and the resulting waveform was stored as the new reference. TDR measurements of Sample 6 were conducted as described under Equipment and Test Conditions. The above-mentioned method of reference plane calibration was applied to the primary TDR used in this experiment as well as a second TDR of the same manufacturer.

TDR/VNA ONE-PORT MEASUREMENT COMPARISON

To ensure TDR/VNA test parity, the VNA was re-configured from a two-port to a one-port calibration and best-case performance testing was repeated. DUT time delay data was extracted from the resulting S_{11} reflection data. Findings indicate virtually no change in VNA instrument uncertainty, as compared to two-port S_{21} data, and a decrease measurement uncertainty associated with connect/disconnect DUT testing.

Figure 9 compares the 22 connect/disconnect performance of the TDR with that of the VNA, when using S_{11} reflection measurement techniques. As with earlier testing, the VNA's uncertainty is approximately an order of magnitude below that of the TDR under similar measurement conditions.

CONCLUSION

The findings suggest that before making critical production measurements with either a TDR or VNA, an understanding of DUT and measurement system interaction is necessary. Each has its strengths and weaknesses, but in the hands of a properly trained and experienced user, both are formidable tools. Data has been presented indicating that the VNA operates with a significantly lower level of measurement uncertainty under specific conditions. It is left to the reader to decide which best suits his or her needs given the application requirements. ■

ACKNOWLEDGMENT

The author extends his thanks to Jose G. Ramirez, Industrial Statistician, and Harmon Banning, Technologist, and W.L. Gore & Associates Inc. for its guidance and kind assistance in the writing of this technical note.

COAXIAL CABLE POWER HANDLING

This application note covers power handling capability of coaxial cables. The matrix of average power over frequency provided for each example cable type is to be used as a guideline.

PEAK AND AVERAGE POWER

There are two potential failure modes in cables used to transmit high peak power. One is voltage breakdown; the other is overheating. The major concern associated with application of peak power is breakdown due to high potential. By themselves, the cable and the connectors may break down under high voltage due to peak power. However, the cable-to-connector junction is the one location on the cable assembly most sensitive to high potential breakdown. Prudent design of overlapping dielectrics and proper selection of connector type, combined with actual high potential or severe requirements testing, ensures that breakdown will not occur. Another consideration in pulsed systems is overheating due to CW power.

TABLE I

CONNECTOR CENTER CONDUCTOR DIAMETERS

Connector	"a" (center conductor diameter)
ETNC	0.085 inch
N	0.120 inch
SC	0.120 inch
SMA	0.050 inch
TNC	0.085 inch

AVERAGE (CW) POWER HANDLING CAPABILITY

The major effect of average power in cable assemblies is the generation of heat from power dissipation and the resultant temperature rise. Many factors are involved in determining this effect for a particular cable assembly, but a short discussion may help distinguish the many facets of the problem.

In all cases, the limit of CW power level is reached when the hottest surface temperature (measured anywhere on the cable assembly) has reached a predetermined temperature, T_{max}. For most high performance high power cable assemblies, T_{max} is on the order of 400°F (204°C). This temperature is chosen based on explosive atmosphere mil spec requirements and also because higher temperature starts to soften the dielectric used in most cables. The temperature T_{max} usually occurs near or on the connector nearest the source. For different types of cables, the tolerance temperature unit that a component within that cable will withstand determines T_{max}. Expressed differently, one may allow T_{max} to increase up to the limit of initial damage to the most sensitive component within the cable.

CONNECTORS AS A LIMITING FACTOR

Heat generation in a connector is analyzed by examining the center conductor diameter "a" of the connector involved (see ***Table 1***). Generally, if the diameter of the center conductor of the cable is approximately the same

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AND PETER WALTZ
Cobham Antenna Systems, Microwave Components, Exeter, NH

as the dimension "a" of the connector, the surface temperature at the connector and of the cable next to it will be about the same with power applied. Choice of a small connector for use with a large cable will make the connector hotter than the cable.

The data presented includes a safety margin (SM). This SM will allow operation of cable assemblies at the stated average power levels for the length of time called out in the appropriate mil specs.

Aging is a process dependent on many variables; among them are ambient temperature, mechanical vibration or flexure, and handling. If one could isolate the aging effect due to the application of power only, the following applies (as for all microwave components): there is a time limit, after which continuing the application of CW power will accelerate the aging of the cable assembly. Power application eventually will affect cable performance. These time limits will vary, depending on consideration of all stresses.

HEAT REMOVAL

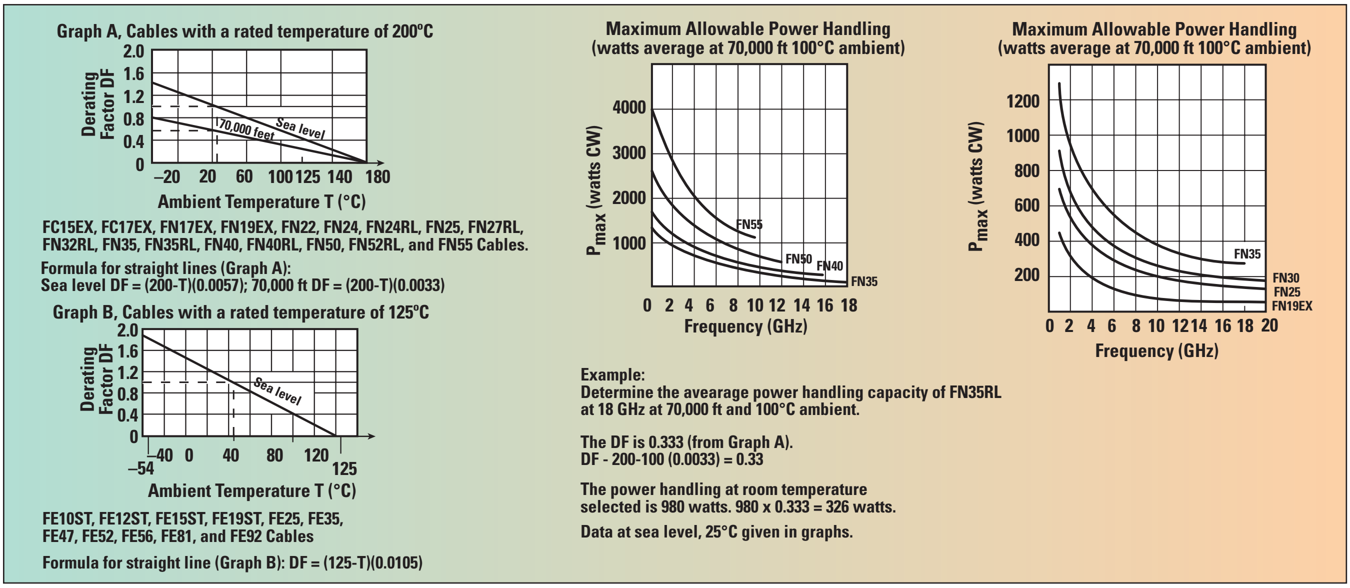
The following is a discussion of heat removal and experimental results obtained at Cobham. Exact mathematical description of the hot cable assembly in terms of heat flow analysis is almost impossible.

Under steady state conditions (typically achieved after about 20 minutes of continuous CW power application), a cable assembly has a unique temperature distribution. This distribution is heavily influenced by the installed environment. As in all heat transfer problems, the hot cable assembly gets rid of its heat by conduction, convection and radiation. Conduction could be the most effective of the three, especially at high altitude where the air is thin. However, because the geometry of bulkheads and mounting plates in general cannot be predicted, this most effective means of heat removal is not included in the power handling data. In fact, the power handling data relates to a cable that is allowed only convection and radiation for heat removal. While conduction might improve significantly the power handling characteristics of cable assemblies, this note treats any benefit resulting from conduction as an increased safety margin.

Of the two means left for removing heat, convection remains as the more effective, even at high altitude. Cobham has empirical data based on extensive testing of many cable assemblies in the company's temperature-altitude chamber, while varying the chamber's ambient temperature and altitude. These tests were performed on a variety of cable types to generate the power handling and derating the data. The matrix data are a good guide to choosing the right cable for a particular frequency and average power level (see ***Figure 1***).

PRACTICAL CONSIDERATION

A system application may require all cable assemblies to use ETNC connectors. In addition, the cable chosen may have a center conductor considerably larger than that of the connector. When this is true,



▲ *Fig. 1 Power handling and derating factors for sample cables.*

the connector will be hotter, perhaps considerably hotter, than the cable. Under these conditions, heat sinking of the connector is recommended; bulkhead connectors or finned heat-sunk connectors are examples of such connectors. Usually, heat sinking is sufficient since conduction is very effective at removing heat. However, if power levels and predicted temperatures are very high, tests should be conducted to verify the design.

APPROXIMATE DERATING CURVES

To determine the Derating Factor (DF) at different altitudes or at different ambient temperatures, see Figure 1. Based on the listed groups, select the appropriate derating curve. Multiply the average power handling data at the frequency of interest. The resultant number is the maximum average power handling capability of the selected cable at the selected ambient temperature and altitude (Derated Average Power = DF × Average Power from data section). ■

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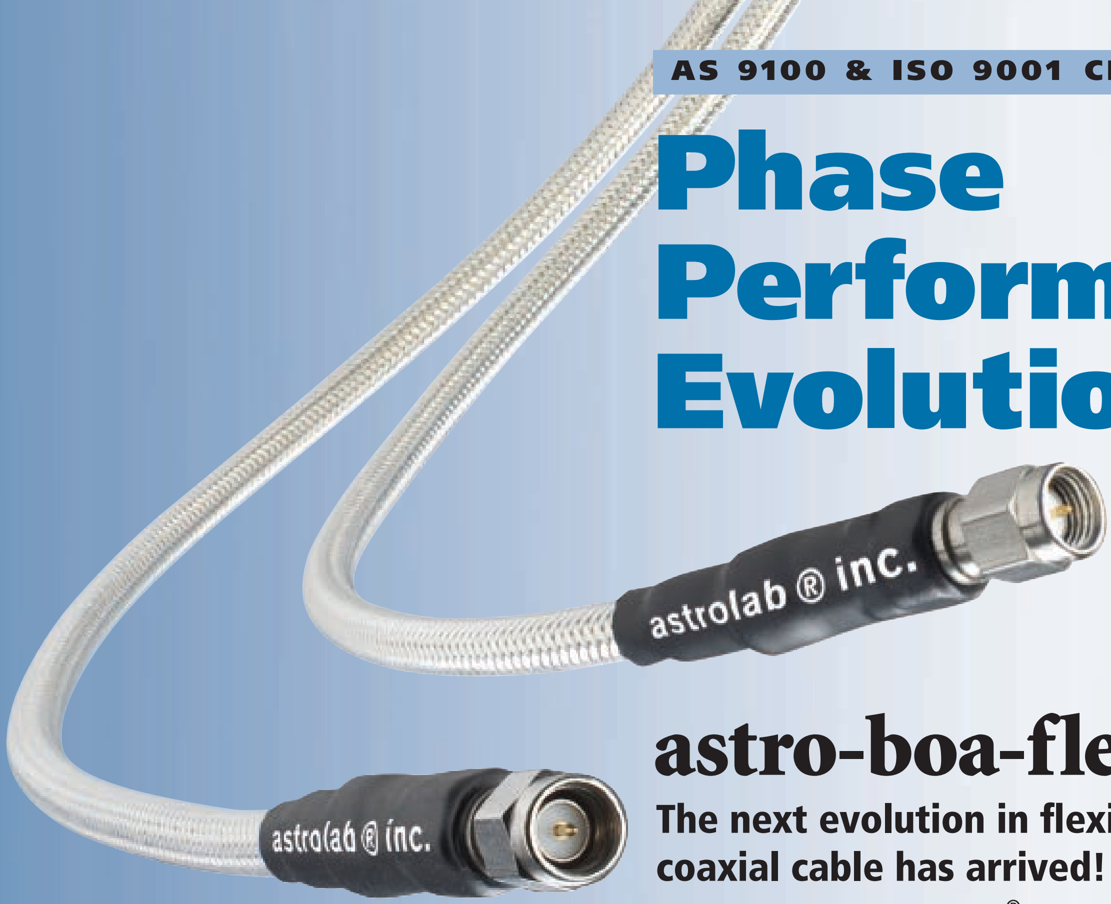
Phase Performance Evolution



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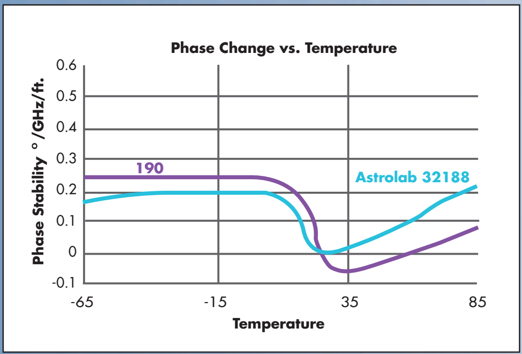

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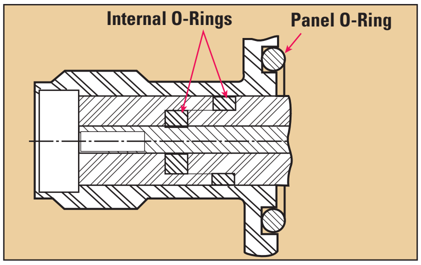
SEALED FLOATING BLINDMATE CONNECTOR

With modern electronic warfare trending toward the use of portable electronic systems in the field of battle, the environmental sealing qualities of interconnects are under scrutiny now more than ever. Conditions ranging from driving rain to dust storms can wreak havoc on the performance and longevity of electronic components without sufficient sealing. Many component engineers are choosing to use threaded connectors where blindmates would be the preferred choice because they cannot tolerate the possibility of foreign object mitigation into their enclosures. SV Microwave has developed a solution to address this concern.

CURRENT TECHNOLOGIES

SV Microwave currently carries a line of waterproof, threaded, rigid mounted connectors (SMA, TNC among others) that provide environmental sealing using a series of o-rings. As shown in ***Figure 1***, the dielectric is sealed to the connector body by an internal silicone rubber o-ring; the connector body is sealed against the enclosure by a panel o-ring. This design is effectively used to seal connectors in the mated and un-mated condition to IP67 standards, including full immersion in water. This is a field-tested, standard product for SV Microwave.



▲ *Fig. 1 Waterproof RF connector sealed with o-rings.*

SV Microwave also offers a full product suite of floating blindmate connectors (BMA, BMMA, BZ, BMZ, ZMA) that are ideal for box to box mating where axial and radial misalignment must be compensated for without sacrificing RF performance. Blindmate connectors are useful when simultaneously mating multiple RF connections because of their low engagement forces. A spring mechanism is used to provide the radial and axial float, as shown in the BMA connector in ***Figure 2***. This is standard technology and has been used extensively on airborne, ground-based and maritime platforms.

The floating mechanism used in the blindmate connector separates the connector line from the enclosure, thus allowing the connector to pivot in the axial and radial directions. While an effective method of generating float, this design does not protect the enclosure from the environment.

NEED FOR A BETTER SOLUTION

SV Microwave customers asked for a connector that has the float of a blindmate and the sealing capabilities of a rigid mounted connector. This product simply does not exist in the high performance RF connector market. RF designers need a connector that can be used in

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applications where box to box mating is required outside a sealed enclosure such as in Line Replaceable Units. Radial and axial float are critical in these applications in order to ensure that any misalignment generated during manufacturing or install can be compensated for by the interconnect. Given the high cost and complexity of inside the box electronic components, introducing the potential for water damage or electrical failure caused by foreign object mitigation is not an option.

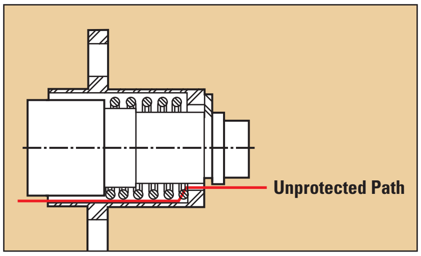
SV Microwave's goal was to design a connector that provides a solution to this problem by offering a high performance interconnect that is both sealed against the environment and has the floating characteristics of a blindmate connector. SV Microwave now offers the Sealed Floating Blindmate connector (SFB connector).

ELECTRICAL/MECHANICAL SPECIFICATIONS OF THE SFB CONNECTOR

The SFB connector utilizes the physical dimensions and electrical/mechanical performance characteristics of SV's BMZ connector line. These are defined as:

- VSWR less than 1.3:1 at 18 GHz
- Insertion Loss less than 0.3 dB at 18 GHz
- Dielectric Withstanding Voltage = 1000 V RMS
- Axial Float = 0.06"
- Radial Float = 0.02"
- Engage/disengage forces = 12 oz (max)/2 oz (min)

The BMZ interface offers a few distinct advantages over conventional BMA (OSP) and BMMA (OSSP) connector interfaces. The first advantage is the use of splayed fingers and a recessed contact to ensure that the connector is fully grounded before the male and female contacts are mated. This is clearly shown in the cross sectional image of the BMZ connector in ***Figure 3***.



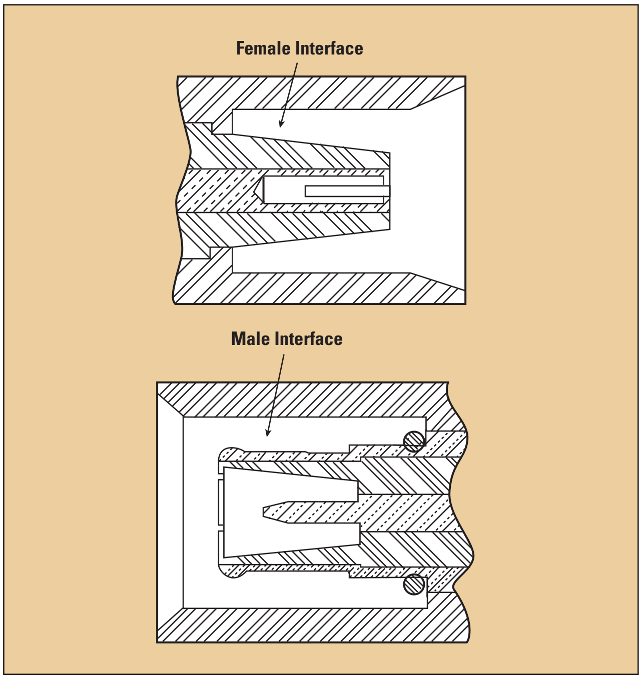
▲ *Fig. 2 Floating blindmate connector (not sealed).*

Another advantage is the tapered dielectric, which allows higher peak power handling than the similarly sized BMMA connector by reducing the air gap between the dielectrics when mated. This design allows the BMZ connector to operate with the highest power to line size ratio in its class.

The SV Microwave SFB connector is ideal in situations where a threaded connector is unacceptable. These situations include field deployed electronic units where a quick disconnect is necessary and applications where tensile ability is restricted by protective gloves or other equipment. The blindmate connector also eliminates the potential for over-torquing the connector and damaging the interface or conversely under-torquing the connector, which could result in sub-optimal mating and decreased electrical performance.

ENVIRONMENTAL SEALING OF THE SFB CONNECTOR

The SFB environment utilizes a sealing method similar



▲ *Fig. 3 BMZ male and female interfaces.*

to the internal and external o-ring seals discussed earlier, but with an additional proprietary mechanism that allows the connector to be fully sealed against the panel while permitting radial and axial float to the levels previously defined. The SFB connector was designed to be compliant with the International Standard for Ingress Protection per IEC 60529. This standard requires the connector to withstand ingress of foreign materials (solid particles) and the harmful effects of water.

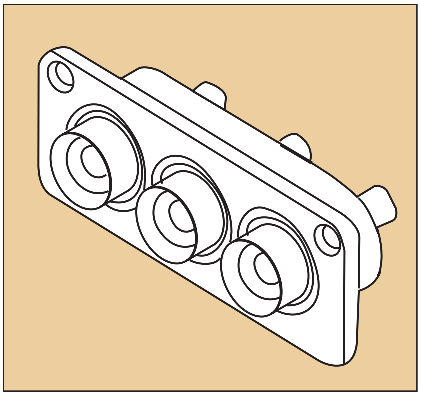
SV's target IP requirement for the first iteration of the SFB is IP56. The first digit in IP56 (5) determines the ability of the interconnect (when sealed to an enclosure) to withstand the harmful effects of solid object ingress. Level 5 is the protection level at which the connector is guaranteed to seal against dust such that dust shall not penetrate in a quantity that interferes with satisfactory operation of the connector. This standard applies to the enclosure both in a static un-mated condition and in a dynamic field operation environment.

The second digit in the IP56 rating (6) defines the ability of the interconnect to protect against the harmful effects of powerful water jets projected against the enclosure from any direction. This product is also compliant to this specification in static and dynamic environments. This specification is designed to simulate the exposure of the interconnect to marine and intensely humid and wet environments.

SAMPLE APPLICATION OF THE SFB CONNECTOR

The initial design of the SFB connector consisted of a multiport block incorporating three connector lines. The footprint of this block was designed to minimize the center-to-center spacing of the connectors and the overall dimensions of the multiport block. Schematics of the male and female 3 port block are shown below in ***Figures 4*** and ***5***.

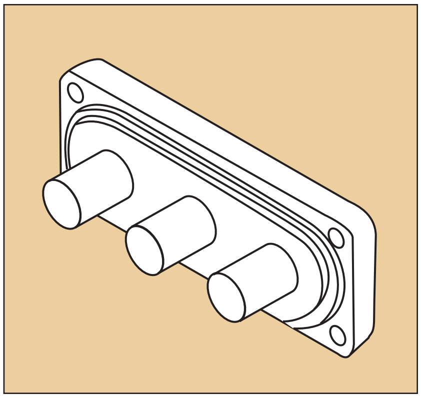
The female multiport block consists of a panel mounted bracket sealed against the panel by a silicon o-ring and



▲ *Fig. 4 Multiport male block.*

three press-in SFB connectors. These SFB connectors are cabled on the inside of the enclosure. The female connector, having no float, is fully sealed to the IP67 standard in the unmated condition making this an ideal interconnect for applications where the outside of the enclosure experiences extreme environmental conditions.

The male multiport block consists of a panel mounted bracket and three snap-in SFB connectors. These connectors are also cabled on the inside of



▲ *Fig. 5 Multiport female block.*

the enclosure. The SFB male connectors contain the radial and axial float and are sealed to the IP56 standard in the unmated and mated conditions.

This is just one example of how this connector line can be tailored to a specific requirement. These connectors can be custom made to fit any application including:

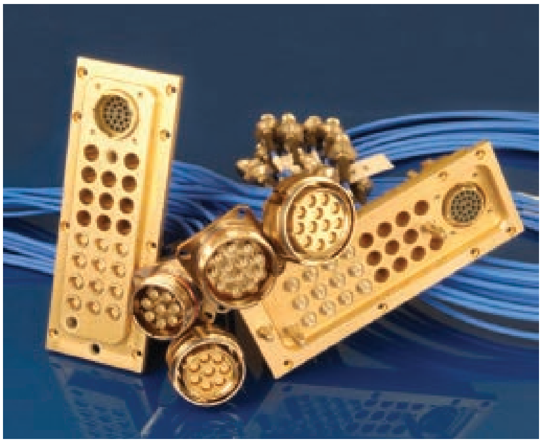
- Multiport blocks in various configurations
- Termination to standard and non-standard cables
- Individual panel mounted connectors

In the case shown in Figures 4 and 5, the cable on the inside of the enclosure (for the male connector) must be flexible cable in order to accommodate the radial and axial float of the connector. The female connector can be terminated to semi-rigid cable as this connector is rigidly mounted.

The SFB connector offers a unique solution to a common problem encountered in field applications. With the electrical and mechanical performance of a floating blindmate connector and the sealing performance of a rigid mounted connector, RF design engineers now have a suitable alternative when float is required in environmentally sensitive design applications.

SV Microwave,
West Palm Beach, FL
(561) 840-1800 x152,
www.svmicrowave.com.

RS No. 301



MULTIPIN CONNECTORS FOR A WIDE VARIETY OF ENVIRONMENTS

Peter von Nordheim, Managing Director of Spectrum Elektrotechnik GmbH.

Executive Interviews

Visit www.mwjournal.com to read this in-depth interview.

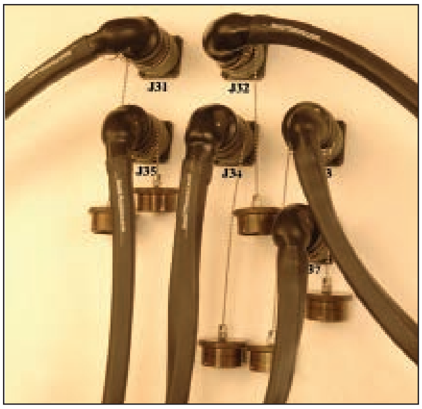
In microwave systems coaxial microwave links often have to be regularly connected and disconnected, which means threading and unthreading, torquing and untorquing. As a result, it is not possible to densely pack regular connectors as room is needed for threading and for the use of a torque wrench. Also, in helicopters, airplanes and vehicles, connectors usually have to be safely secured, normally using safety wire through the wire holes in the coupling nuts of the connectors, which is time-consuming.

An alternative is to use multipin connectors to connect microwave signals between two parts of a system. Standard circular blind mate series MIL-DTL-38999 connectors are designed and approved by the military and aerospace industry to meet the most stringent requirements in severe environments and are used for cable-to-panel applications in military, aerospace and other demanding situations.

Originally these connectors were designed to connect up to 128 wires for electronic equipment, but the necessity arose to incorporate coaxial cable contacts for high frequency or microwave applications and the requirement to combine simple electronic wire contacts and microwave coaxial contacts. The disadvantage is the dependence on the contact layouts offered for size 8, size 12 or other coaxial contacts. There is often the need to package numerous microwave links in a connector and to use different coaxial cables, e.g. a fairly thin and flexible cable for higher frequency applications or shorter leads, or a thicker cable for low loss applications and longer assemblies. Size 8, size 12 or other contacts are only available for some coaxial cables and might not be ideal for the application it is intended for. In addition, most standard coaxial contacts are not designed for higher frequency applications.

To address this issue, Spectrum Elektrotechnik has introduced multipin connectors beginning with the SQ-8 (shown in ***Figure 1***), which uses a 4.3 mm high performance low loss coaxial cable and is supplied with eight coaxial inserts for applications up to 24 GHz, using the size 21 MIL-DTL-38999 series III shell. For applications in harsh environments the assem-

PETER VON NORDHEIM
Spectrum Elektrotechnik GmbH
Munich, Germany



▲ *Fig. 1 SQ-8 multipin connectors can be fitted in compact areas.*

▲ *Fig. 2 The SQ-8 has eight RF contacts.*

blies are supplied armored and water protected.

The need for circular connectors using more coaxial assemblies in a connector and different cables has resulted in Spectrum designing a whole family of multipin connectors that are fully compliant with the MIL-DTL-38999 standard, Series I with a bayonet coupling and Series III with a threaded coupling. Both series are rugged, designed to operate in harsh environments and are available in five different keyed versions, ensuring proper and fool-proof connection.

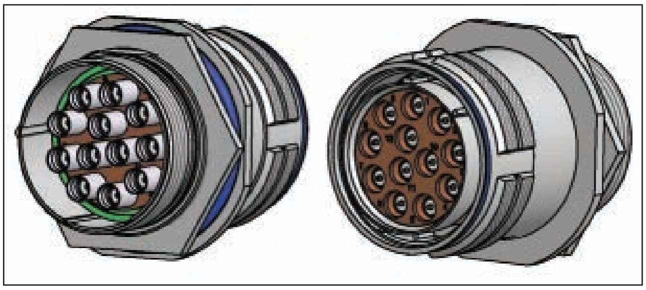
The original SQ-series uses eight RF contacts (an example is shown in ***Figure 2***) in a size 21 shell; the cable assemblies terminated with spring loaded bayonet catch connector inserts. The TQ-Series and IQ-Series offer size 21 and size 25 shells, with threaded coupling and 4, 7, 8 or 12 (shown in ***Figure 3***) coaxial inserts, and are available for four different cables: spring loaded, limited spring loaded, fixed and pressurized. They are available for DC to 24 GHz and DC to 40 GHz frequency ranges, although the cable used may limit the

▲ *Fig. 3 The TQ-12 has 12 coaxial inserts.*

frequency range. For example, if Spectrum's Type 141 cable is favored, a low loss high performance cable with a jacket diameter of 7.8 mm and an insertion loss of 0.64 dB/m, the frequency range is limited to 18 GHz.

The outer conductors of the cable assemblies in the TQ-Series use the common ground of the MIL-DTL-38999-shell, while the assemblies of the IQ-Series are isolated from each other and also from the ground of the MIL-DTL-38999-shell. Both the BQ-Series and the CQ-Series are identical to the TQ-Series with the exception that they employ the MIL-DTL-38999 standard, Series I with bayonet coupling. They differ from each other because the assemblies of the CQ-Series do not use the same ground, but are isolated from each other and from the ground of the MIL-DTL-38999-shell.

Also, all circular designs, the SQ, TQ, IQ, BQ and CQ-Series are available in pressurized versions, meeting the EIA364_02C test specifications, replacing MIL-STD 1344 and with the capacity to withstand 0.6 bar (8 PSIG) for 35 minutes. These connectors, which are usually bulkhead feed-through or are four-hole flanged versions, are required in airplanes where cable assemblies are installed in walls separating pressurized and unpressurized areas.



▲ *Fig. 4 Drawing of the 8TQB-Z2ID-29 multipin adapter.*

Alternatively, multipin adapters (shown in ***Figure 4***) are designed for applications where bulkhead multipin connectors cannot be installed in the wall separating pressurized and unpressurized areas, as male multipin connections need to be used on both sides for disconnection purposes. These adapters are also available in pressurized versions to meet the EIA364_02C test specifications. In addition, hermetically sealed connectors and adapters are designed to be installed in the walls of vacuum test chambers.

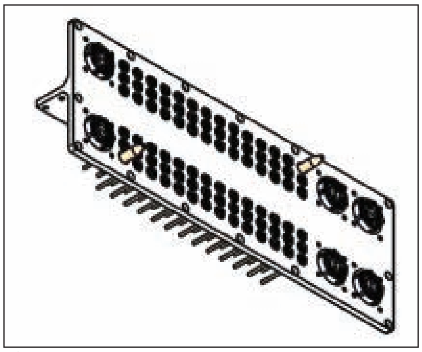
The RQ-Series has been developed to address the need for even more cable assemblies to be packaged into one shell, taking up as little room as possible. They are designed for those applications where many more microwave coaxial connections are needed than circular designs can accommodate (where limited space is available) and where many DC and driver signals using AWG wire also have to be connected.

For example, the RQ23-DC26 (shown in ***Figure 5***) connects and disconnects 23 coaxial RF lines and 26 signal and supply lines at once and in seconds, while being as small as possible for such a complex design. When connecting such a high number of assemblies the insertion and withdrawal force is particularly significant. For the RQ23-DC26 a maximum of 150 N is specified for the insertion and withdrawal of all 23 coaxial lines plus the 26 signal and supply lines. The 23 coax inserts use the standard Type 11 or Type 43 high performance cable and are grouped in four to eight assemblies, secured by mounting bolts for easy replacement in the shortest time. Its maximum operating frequency is specified as 25 GHz, but higher frequency designs are available on request.

For applications where even more connections are needed, the newest design, the RQ80-DC120 (see ***Figure 6***), features 80 coaxial connectors operating to 40 GHz and 120 signal lines, all in a unit measuring 107 × 304 mm. Designs are also available that operate up to 65 GHz.

Modern systems also require accurate phase matching of the cable assemblies in multipin har-

▲ *Fig. 5 The RQ23-DC26 connector.*



▲ *Fig. 6 Drawing of the RQ80-DC120 connector.*

nesses and Spectrum achieves phase matching through the latest cable manufacturing processes, interface cutting techniques and advanced adjustable connector designs. Also, the adjustable matching mechanism can meet the most serious shock and vibration requirements.

Selecting the proper materials and aging techniques is important as well as ensuring that the cable assemblies and harnesses operate effectively in the standard temperature range of -54° to +115°C or the extended temperature range of -72° to +200°C. All the Spectrum connectors are RoHS compliant and meet the conditions and corrosion requirements of MIL-STD- 202, method 101, condition B. The multipin connectors are compliant with thermal shock to MIL-STD-202, method 107, condition B, vibration to MIL-STD-202, method 204, condition D, and shock to MIL-STD-202, method 213.

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Munich, Germany,
Tel: +49 89 3548 040,
info@spectrum-et.com,
www.spectrum-et.com.

RS No. 304

Phase Matched Microwave Cable

One thing that the test and measurement, sensors, radar and wireless markets all have in common is the need for robust, high performance microwave cable assemblies. A major attribute of such cables is electrical stability, which has been achieved through the development and advancement of cable technology over many years of manufacturing and applications experience.

The ability of a cable to deliver a signal in good condition with the minimum of loss and delay is the essence of microwave cable design. This is a specific attribute of the new Teledyne Storm 190E Phase Master microwave cable, which is an enhanced version of the 190 Phase Master that has been a standard in the engineers' tool kit for many years. The 190E provides enhanced performance in a number of areas that are becoming increasingly important as signal frequencies increase and the performance requirements, both mechanical and electrical, are becoming more demanding.

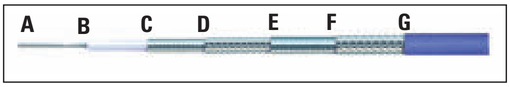
In particular it addresses the need for a high level of phase stability versus temperature and cable flexure, reduced insertion loss, increased amplitude stability, improved shielding effectiveness, greater connector retention, and additional mechanical durability focusing on torsion resistance. The result is an amalgamation of Teledyne Reynolds' cable design technology and experience, taking into account customer demands, to bring higher performance cables to the market. The 190E is specified up to 26.5 GHz, dependant on the connector used, the industry standard SMA connector is specified to 18 GHz and the 3.5 mm connector is specified up to 26.5 GHz.

Cable Construction

The cable construction (shown in ***Figure 1***) is a proprietary combination of a silver plated copper (OFHC) centre conductor [A], a MicroForm™ PTFE tape wrapped dielectric [B], four screening layers, alternate helically wrapped silver plated copper foil [C and E] and silver plated copper braid [D and F], with a blue FEP unarmored jacket (5.05 mm diameter) [G] as standard.

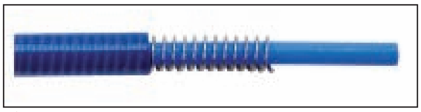
Additional armored jackets to enhance the robustness of the cable include:

Ruggedized - Polyurethane Jacket (see ***Figure 2***), which is for applications where weight, flexibility and abrasion resistance are critical, and moderate compression resistance

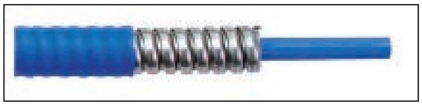


▲ *Fig. 1 Construction of the 190E Phase Master microwave cable.*

Teledyne Reynolds
Newbury, UK



▲ *Fig. 2 Cable with ruggedized, polyurethane jacket.*

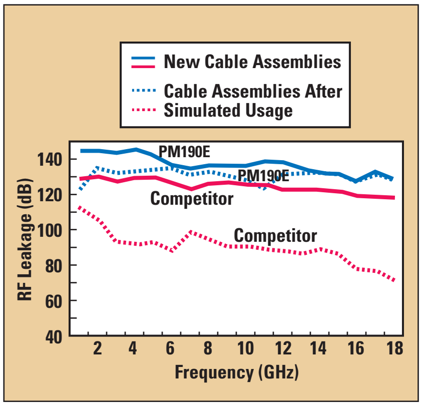


▲ *Fig. 3 Hard armored cable.*

is required (300 lbs/in). The cable is covered with a flexible wound helix of passivated stainless steel wire and an extruded polyurethane jacket. Its temperature range is -54° to +100°C.

Hard Armored (see ***Figure 3***) is suitable for both inside and outside environments where the application requires the ultimate in cut and crush resistance (500 lbs/in), and flexibility and weight are not as critical. The cable is covered with stainless steel interlocked armor and its temperature range is -54° to +135°C.

The complete cable specifications for the 190E Phase Master Cable are shown in ***Table 1***. The exceptional shielding effectiveness, high levels of phase stability with temperature and flexure, and the much improved cable retention capabilities are all products of engineering development driven by market demands.



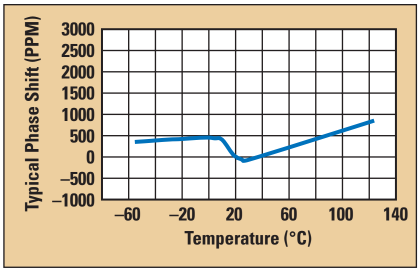
▲ *Fig. 4 Graph of shielding effectiveness.*

The shielding effectiveness is a capability that enables cables to be located in close proximity to other cables and equipment. ***Figure 4*** shows the shielding effectiveness by comparison with a competitor's cable in both new and used conditions. Although there is some reduction in shielding effectiveness with use, the 190E shield construction effectively minimizes that reduction. The effect is a more stable, longer lived cable.

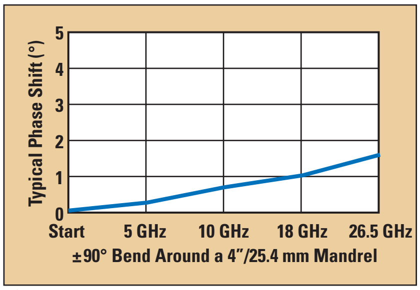
Phase stability performance is affected by both temperature and flexure during use. The 190E is designed to minimize phase shift for both temperature and flexure. ***Figure 5*** demonstrates the minimal effects of both those environmental conditions. The temperature range is -55° to +125°C with a <800 ppm phase shift at the maximum temperature. ***Figure 6*** demonstrates the phase shift due to flexure. The phase shift with the cable in a 90° bend around a 4.0 in (100 mm) mandrel is nominally 1° at 18 GHz.

TABLE I 190E PHASE MASTER CABLE SPECIFICATIONS	
Diameter (in/mm)	0.199/5.05
Operating Frequency (Max, GHz)	26.5
Attenuation-Nom @ 2 GHz (dB/ft)	0.112
Attenuation-Nom @ 10 GHz (dB/ft)	0.261
Attenuation-Nom @ 18 GHz (dB/ft)	0.36
Power Handling Average Power in Watts @ 1 GHz	700
Phase Stability vs. Temperature (ppm, nom, °C)	<500 from -55 to +85*
Phase Stability vs. Flexure† (degrees @ 18 GHz, nom)	1
Shielding Effectiveness-Minimum‡ (dB @ 1 GHz)	-120
Typical VSWR (2 straight connectors)	1.35 @ 18 GHz 1.40 @ 26.5 GHz
Min Bend Radius (in/mm)	1/25.4 static 2/50.8 dynamic
Connector Retention up to 18 GHz, straight pull (lbs/kg)	40/18.14
Weight (grams/ft)	21
Velocity of Propagation (%)	82.4
Operating Temperature Range (°C)	-55 to +125

*<800 up to +125
† ±90 degree bends around a 4" mandrel
‡ Subject to connector choice



▲ *Fig. 5 Phase Master 190E phase vs. temperature.*



▲ *Fig. 6 Phase Master 190E phase vs. flexure.*

CONCLUSION

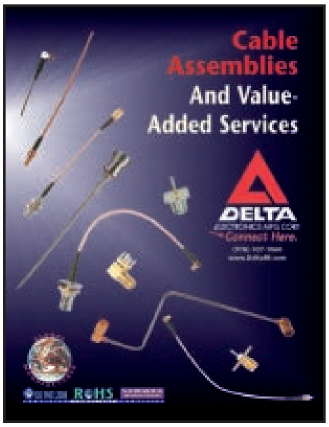
The 190E Phase Master microwave cable is aimed at test and measurement, radar, wireless communications, electronic warfare and antenna systems applications. The overall cable stability and specifically the phase stability, leakage shielding and rugged construction are ideally suited to applications in semiconductor test and measurement where repeated use of the test equipment and the high throughput of the device under test require the performance repeatability and environmental ruggedness to work and survive over long periods of use.

For applications in military markets, the ruggedness of the cable is as important as the repeatability of the electrical specification of the cable. For all RF applications the need for insertion loss repeatability and VSWR stability are a given, but the addition of phase stability, especially where the cable is used in harsh environments, becomes a matter of paramount importance. The combination of the design features and the interlocking electrical and environmental performance capabilities delivered by the design provide the robust, high performance cables required to meet today's customer demands.

Teledyne Reynolds,
Newbury, UK
Tel: +44 (0)1635 262200,
www.teledyne-europe.com.

RS No. 300

Cables & Connectors Supplement
Literature Showcase

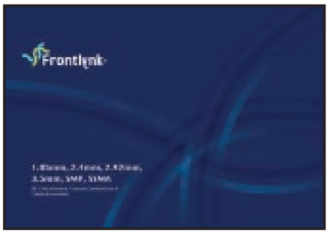


Product Brochure

To assist customers who have a need to streamline their supply chain and logistics, Delta Electronics Manufacturing now offers a broad range of coaxial cable assemblies and other connector-related, value-added component subassemblies. Delta's cable assemblies, incorporating flexible, semi-rigid and hand-formable cables, range in size from micro-miniature to large, high-power types. They cover the spectrum of market needs from high-volume, low-cost assemblies to high-performance, low-volume categories.

Delta Electronics Manufacturing Corp.,
Beverly, MA (978) 927-1060, www.deltarf.com.

RS No. 310



RF/Microwave Connectors

As well as giving details and in-depth specifications of the company's extensive range of 1.85 mm, 2.4 mm, 2.92 mm, 3.5 mm, SMP and SSMA RF/microwave coaxial connectors and cable assemblies, this 50-page catalog also offers an introduction to Frontlynk and explains its capabilities. It explains that the products are developed as the result of extensive research involving critical factors: operating frequency, characteristic impedance, skin effect, cut-off frequency, intermodulation, voltage and power rating, leakage, etc. and emphasizes the company's commitment to quality, testing and supply.

Frontlynk Technologies Inc.,
Tainan, Taiwan +886-6-3562626, www.frontlynk.com.

RS No. 311

Defence Connections

Promoting 'Excellent Connection', this brochure takes the approach that whether in the air, on land or at sea, quality in modern defence technology solutions permits no compromise. The 2010 issue of the defence brochure features solutions for cables, connectors, antennas, and connection-ready cable systems that comply with international standards such as MIL, IEC and Lloyds Register.

HUBER+SUHNER AG,
Herisau, Switzerland, +41 71 353 4111, www.hubersuhner.com.

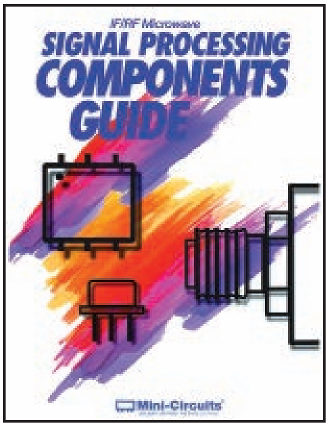
RS No. 319

Product Catalog

MIcable Inc. produces a wide variety of high quality coaxial cable assemblies with flexible, conformable, and semi-rigid cable and customer specified connectors. The company offers prototypes or volume quantities, all fully tested up to 40 GHz and delivered on time. The product brochure highlights a few of the company's products along with providing performance data. For more information, call 86-591-87382855 or e-mail: sales@micable.cn.

MIcable Inc.,
Fuzhou, Fujian, China +86-591-8738 2855, www.micable.cn.

RS No. 312

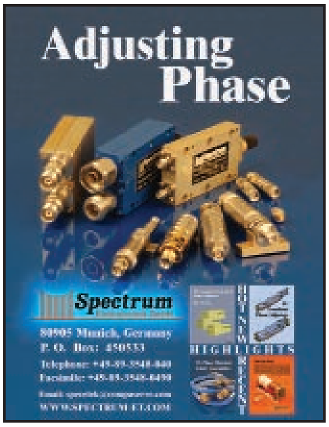


IF/RF Microwave Signal Processing Components Guide

Mini-Circuits' new 164-page catalog includes over 750 new products and is the industry's most comprehensive listing of RF/IF and microwave components and subsystems with more than 4100 products and over 25 product lines, including state-of-the-art amplifiers, mixers, VCOs, synthesizers, filters, test accessories and USB Power Sensors. Mini-Circuits' website provides additional data, application notes, design tools and its powerful YONI search engine, which searches actual test data on over thousands of units.

Mini-Circuits,
Brooklyn, NY (718) 934-4500, www.minicircuits.com.

RS No. 313



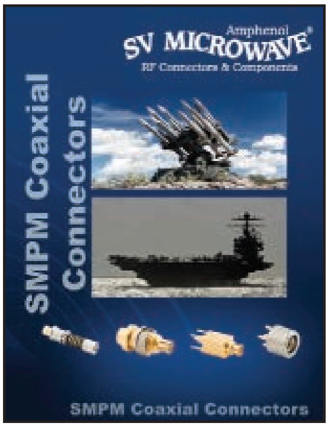
Adjusting Phase

This 52-page catalog focuses on precision phase shifters or phase adjusters that enable the adjustment of the electrical separation between components. It outlines how a precision mechanical movement provides for smooth and accurate adjustment over the frequency ranges from DC to 2 GHz, DC to 3 GHz, DC to 12.4 GHz, DC to 18 GHz, DC to 26.5 GHz, DC to 40 GHz, DC to 50 GHz and DC to 65 GHz, with a secure locking mechanism furnished with every unit. The publication shows the wide selection of components available.

Spectrum E.T. GmbH,
Munich, Germany +49 89 3548 040, www.spectrum-et.com.

RS No. 314

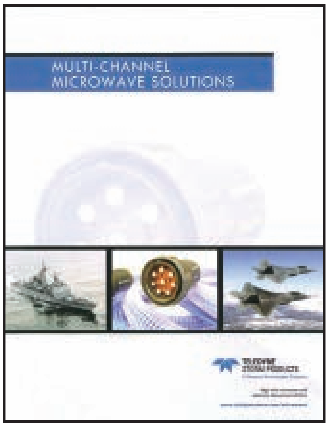
CABLES & CONNECTORS SUPPLEMENT
Literature Showcase



SMPM Catalog

SV Microwave released its new SMPM catalog. The revised catalog features detailed information on SV's entire collection of SMPM coaxial connectors, including technical specifications, applications, drawings and part numbers. SV Microwave SMPM connectors, a push-on design, provide microwave performance through 65 GHz.

SV Microwave,
West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.
RS No. 315



Capabilities Brochure

Teledyne Storm Products' new Multi-channel Microwave Solutions brochure details the company's capabilities in the design and manufacture of both standard and custom multi-channel microwave harness assemblies. The harnesses, found in a wide range of airborne, ground and sea-based military and commercial applications, are backed by Teledyne Storm's more than 30 years of microwave cable design and manufacturing expertise. Includes a case study.

Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.
RS No. 316

Product Brochure

PhaseTrack II™ is a significant breakthrough in coaxial cable technology. PhaseTrack II is based on the unique, thermally stable Times Microwave Systems' proprietary TF5™ dielectric material. A proprietary engineered material and process combine to make TF5 dielectric the most stable dielectric material available, virtually eliminating the changes of phase with temperature characteristic of other high performance expanded PTFE dielectric flexible RF and microwave coaxial cable assemblies.

Times Microwave Systems,
Wallingford, CT (203) 949-8400, www.timesmicrowave.com.
RS No. 317

Interactive Product Catalog

Trilithic's interactive flip-book catalog is now available online. From custom filters and passive components to subsystems design, this new easy-to-use catalog features an overview of the company's complete line of attenuators, terminations, switches, custom-designed filters, diplexers and subsystems.

Trilithic,
Indianapolis, IN (317) 895-3600, www.trilithic.com.
RS No. 318

Cables & Connectors Supplement

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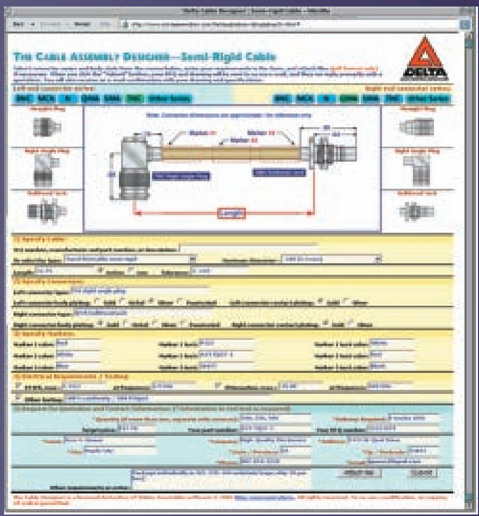

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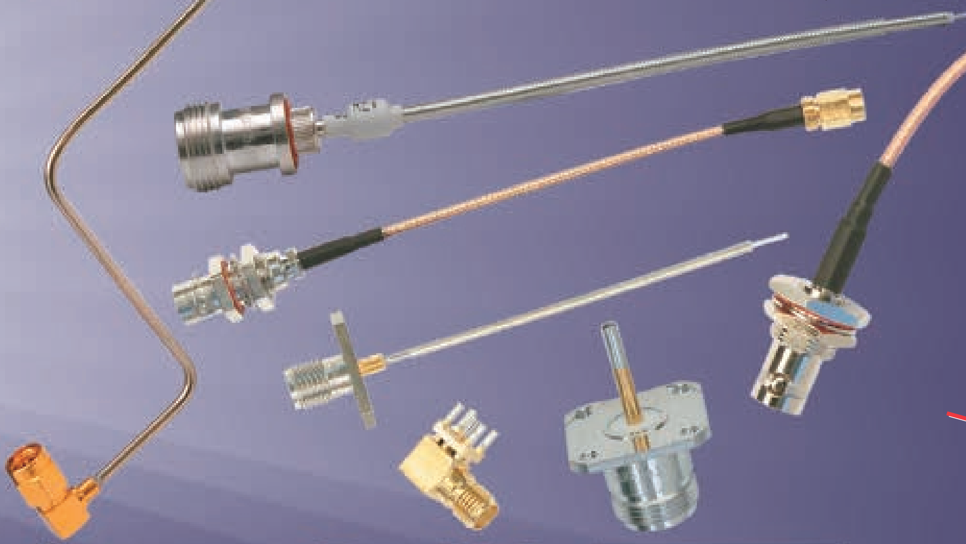

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