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Cables & Connectors Supplement

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RF ABLATION: TECHNICAL TRENDS FOR A HOPEFUL FUTURE

A promising new method for the treatment of cancer tumors and metastases is microwave or RF ablation. This minimally invasive treatment makes it possible to operate in areas of the body that are inaccessible using conventional means and alleviates post-traumatic complaints, as well as offering significant cost savings. Such minimally invasive interventions are complemented by constantly improving imaging techniques that make it possible to localize even the tiniest tumors or metastases. All of these advantages mean that this new surgical technique offers excellent potential for growth.

MINIATURE PROBE DISOLATES TUMOURS

The way that ablation works is by releasing electromagnetic energy inside the tumor. This causes water molecules to vibrate, generating heat and destroying the diseased tissue, which is simple but effective. The great challenge, however, is to channel the microwave power required from the generator into the diseased tissue, adding as little loss as possible while keeping flexibility at an optimum, i.e. the cables, connectors, etc. The type of connectivity required is dictated by the specific application.

Although RF ablation is currently used to treat primary tumors and metastases in the lungs, liver, kidneys and bones, the technique is also increasingly being used for treating other organs. As a result, the system frequencies, the ablation time and the applied electromagnetic power vary considerably. These parameters, along with the ergonomic considerations of the operating environment need to be taken into account when deciding what cables/connectors to use.

ATTENUATION IN COAXIAL STRUCTURES

The transmission loss (attenuation), which indicates how much lower the outgoing power is in comparison with the incoming power in a

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cable, is a major consideration. In the equation:

$$\text{Attenuation loss} = \alpha = 10 \log \frac{\text{Power}_{out}}{\text{Power}_{in}} \left[\text{dB}\right] \quad (1)$$

this value is negative; however, to avoid confusion, attenuation is often stated as a positive number. ***Figure 1*** shows the attenuation loss components of a cable, σ_a = conductivity of the inner conductor, σ_b = conductivity of the outer conductor, ε_r = dielectric constant and tangent δ = characteristic of insulator material. The total transmission loss is $\alpha_{total} = \alpha_{conductors} + \alpha_{dielectric}$.

The cable attenuation loss is the sum of the conductor losses (e.g. copper losses) and the dielectric losses. In Equations 2 and 3:

$$\alpha_{Conductor} = \alpha_C = \frac{11.39}{Z}\sqrt{f}\left|\frac{\sqrt{\rho_{rd}}}{d} + \frac{\sqrt{\rho}_{rD}}{D}\right| \left[\text{dB/m}\right] \quad (2)$$

$$\alpha_{Dielectric} = \alpha_d = 90.96 f \sqrt{\varepsilon_r}\, \tan\delta \left[\text{dB/m}\right] \quad (3)$$

f = frequency (GHz) and the diameters d and D are in mm. Z is the characteristic impedance in Ohms [Ω], and ρ_{rd} and ρ_{rD} represent the material resistivities of the conductor in comparison to copper. That is: ρ_{rd} = 1 for a copper inner conductor and $\rho_{rD} \approx 10$ for a steel outer conductor. δ is the loss angle of the insulating material.

Figure 2 shows the attenuation loss as a function of the three cable components. A lower attenuation loss can be achieved by the following:

- Large cable diameter
- High conductivity of the materials
- Low dielectric constant
- Small loss angle

Because the conductor losses increase proportionally to $\sqrt{f}$, whereas the dielectric losses increase directly proportionally to f, the losses from the polymer structures used in applications such as RF ablation are considerable (Equation 2 + Equation 3). The two parameters that need to be influenced are ε_r and tan δ.

Both values are directly linked physically to the presence of material and assume minimum values in a vacuum (ε_r = 1 and tan δ = 0). Furthermore, the polymers used must provide excellent stability in terms of mechanical and thermal loading, dielectric strength and, most importantly, process capability. The values for typical materials are shown in ***Table 1***.

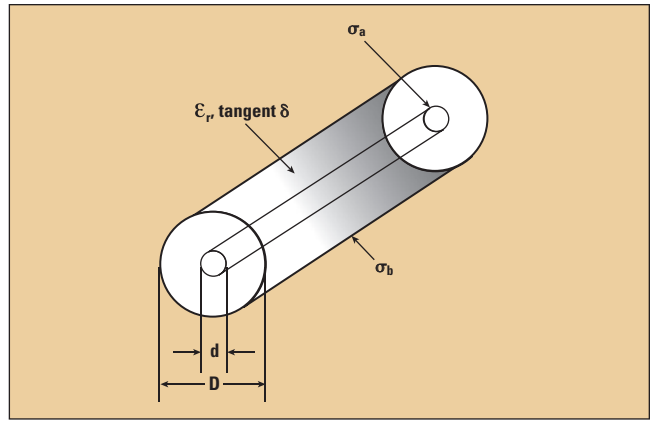

Fig. 1 Attenuation loss components.

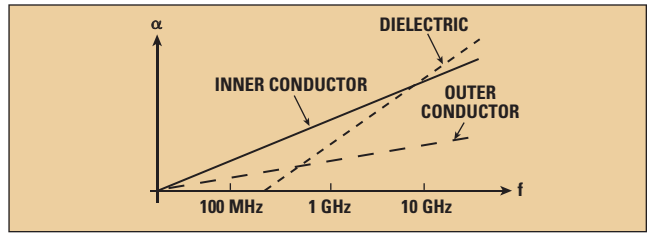

Fig. 2 Attenuation loss as a function of the three cable components.

ERGONOMIC DESIGN

With regards to the surgical environment, many diverse requirements have to be met. For example, if a robust or even crush-resistant connection is required for a cable that is fed to the operating table, then it is desirable to have a cable with the smallest possible dimensions in the operating area. Also, the supply cable to a probe (see ***Figure 3***) for liver tumor ablation should be as flexible as a cord and should remain positioned on the patient without losing its shape, whereas a cable used for intestinal operations should exhibit

TABLE 1

PROPERTIES OF DIFFERENT CABLE MATERIALS

Material	ε_r	tanδ	Glass Temperature (°C)	Operating Temperature (°C)	Density (g/m³)	Dielectric Strength (kV/mm)
Air	1.0	$<10^{-5}$	…	…	0.0013	<1.0
PE	≥2.28	0.0003	<-125	-40…+85	0.91…0.97	>28
SPE	1.25…2.05	<0.0003	…	-40…+80	0.21…0.75	…
XLPE	>2.28	>0.0003	…	-20…+10	0.91…0.97	>25
FEP	2.1	<0.0007	-100	-100…+200	2.15	>50
PFA	2.06	0.0001	<-80	-200…+250	2.14	>50
$PTFE_{sat}$	<2.05	<0.0001	-100	-200…+250	2.2	25…50
$PTFE_{unsat}$	1.4…1.7	<0.0001	…	-200…+250	0.8…1.5	…
PP	2.25	<0.0005	-20	-10…+100	0.9	>25
PEEK	3.2	0.003	143	-250…+250	1.32	20

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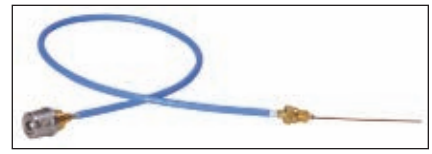
a 'memory effect' and should return to its original position in a controlled manner.

Surface properties regarding sterilization and 'coolability' as well as the choice of color in order to ensure visibility in the operating area and system matching are further examples of parameters that have to be considered when selecting the most suitable cable.

SELECTIVITY

A bent coaxial cable may, depending on the structure and material, develop forces and become deformed over time. Although in most cases this effect should be completely avoided, it can be desirable in certain special catheter applications. For such individual circumstances it is vital for the cable and connector manufacturer to work closely with the end user to select the right choice of connectivity products and develop test procedures to simulate the end-user applications.



▲ *Fig. 3 Supply cable and probe.*

INTERDISCIPLINARY APPROACH

Just as today's doctors are expected to be familiar with the use of state-of-the-art equipment, in order to supply and fit the right cables and connectors, engineers must have an understanding of how medical practitioners work and the environment in which they have to function. It is essential to select RF connectors that provide true and easily achievable connection.

This is a major consideration, for example, with the microwave-compatible connectors that an operating team would use, as partial or insecure mating could have serious consequences given the high power levels used in these applications. In such circumstances a push-pull connector that clicks audibly into place, reliably remains connected even when subjected to radial movements and is waterproof, would be the type of connector that should be considered.

CONCLUSION

RF ablation is a technique being increasingly used in the medical field. These applications are diverse, requiring a variety of cables and connectors to deliver the high power demanded. In order to provide effective, efficient and safe systems, engineers must calculate the attenuation loss of the cable and be aware of the specific characteristics of the cable/connector options on the market in order to be able to meet the specific demands of the medical environment. ■

Following a four-year apprenticeship as an electrician, **Reto Germann** *gained an engineering degree in mechatronics from FHS St Gallen, Switzerland, and a management diploma from the Chinese-European International Business School (CEIBS), Shanghai, China. He joined HUBER+SUHNER as an Applications Engineer in 2000, became Application Engineering Manager, China, in 2005, and Distribution Manager, APAC a year later. Since 2008 he has been Market Manager Medical, Radio Frequency Division.*

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REDUCING COSTS WITH FLEXIBLE CABLES AND IMPROVED CONNECTORS

Semi-rigid cables have long been the backbone of the US Military interconnection technology for RF and microwave applications. These cables provide a robust means of interconnection supporting high power, low loss and high frequency applications with extremly good shielding characteristics. With no fear of sand and abrasion, these cables provide armor to military electronics on land, sea and air. Today, however, is semi-rigid really the best solution for high reliability?

San-tron believes that Times Microwave has developed an ideal alternative to semi-rigid cables that should be seriously considered for system integrations. Below is a discussion of the apparent differentials that Times TFLEX-402 and TFLEX-405 provide to technical performance, costs of design-in, cost of manufacturing, and to the logistics chain and maintenance operations. This is followed by a discussion of the connector designs that fully leverage the capabilities of flexible cables.

TABLE I

COMPARISON OF ATTRIBUTES OF TFLEX AND SEMI-RIGID CABLES

Parameter	TFLEX-402	RG-402
jacket	FEP	n/a
shield	Ag/Cu	Cu
core	PTFE	PTFE
conductor	Ag/Cu	Ag/Cu/Steel
mass (kg/m)	0.049	0.051
Vo (kVrms)	1.9	1.9
Temp max C	125	125
Temp min C	-65	-40
Min Bend Radius (mm)	12.7	6.4
|S21| k1	0.330	0.318
|S21| k2	0.0012	0.0012
|S21| @ 18 GHz (1 meter)	-2.16 dB	-2.11 dB
P (watts) @ 18 GHz	48	65

TECHNICAL ATTRIBUTES & DIFFERENTIALS

The technical performance of semi-rigid cables and TFLEX are extremely similar. A brief decision matrix is helpful in identifying the major characteristics. Due to the solid copper outer shield of semi-rigid cable, these assemblies are superior at diffusing heat, insuring low attenuation and thus providing higher power handling abilities. The TFLEX series provides better support for corrosive environments due to its FEP jacket and silver clad metals. TFLEX also supports low attenuation, full shielding and further offers multiple cable bending. ***Table 1*** provides a close look at some of these differentials in attributes.

The standard semi-rigid RG-402 cable is composed of a solid copper shield and a silver clad steel center conductor. Thus, the operating environment needs to be considered in choosing these materials. Will the assembly be exposed to corrosive agents that will attack the copper shield? Will the steel center conductor generate PIM products within frequencies of interest? This cable does support tight bend radii of 6.4 mm; however, the cable can only be bent once. Repeated bending will fracture the solid copper shield.

TFLEX cables are composed of a FEP jacket and silver clad copper metals. The FEP jacket provides excellent protection from corrosive environments. This TFLEX shielding is a composite of a helical wrap and braid, and like semi-rigid, the RF leakage is beyond the range of measurable limits. The silver clad helical wrap further provides temperature phase stability, loss stability and low insertion loss. A one meter length of the two cables perform within 0.05 dB of each other at 18 GHz. From the technical profile of these cables, the only parameter that favors semi-rigid cable is power handling; at 18 GHz the semi-rigid nudges out TFLEX at 65 versus 48 W.

COSTS OF DESIGN-IN

Within system integration, each semi-rigid cable requires predetermined geometries. Just as a civil engineer designs bridges, entrance ramps and clover leafs into our highways, a mechanical engineer takes on the task of designing bend radii, segment lengths, over and under locations, etc. Each cable becomes a customized part number with exacting requirements to rigidly lie within the constraints of various barri-

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San-tron Inc., Ipswich, MA

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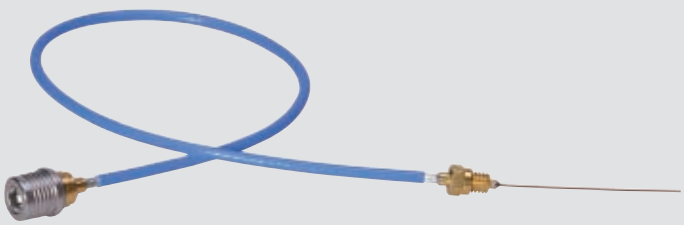

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ers: amplifiers, filters, mixers and other cables. When subsystems are modified and upgraded, so too are the cable assemblies, which effects fit, form and function between new versus legacy deployments. With the typical semi-rigid cable being composed of ~5 bends and total lengths of 8 to 30 inches, a simple problem just became a documentation dilemma. All of these custom cables can be supported with standard TFLEX assemblies supplied in incremental lengths. One can simplify the documentation and focus on engineering creativity and solving technical issues.

COSTS OF MANUFACTURING

The manufacturing processes for semi-rigid is a bit more involved than the TFLEX methodology. Below is a cost comparison just in the required capital equipment for both processes (see ***Table 2***).

To manufacture semi-rigid cables there is a common process requiring $77,300 in estimated costs:

- Cable is supplied in straight 8-foot lengths
- Cut the cable to developed length
- Process the cable through a bending machine
- Verify position of bends within tolerances via a quad-axis machine
- Thermal cycle the cable to relieve stresses within the PTFE core
- Strip the cable ends for connector termination
- Solder both the center contacts and bodies to the cab

Comparatively, the process for TFLEX only requires $18,400 of costs:

- Cable is supplied in continuous spools
- Cut the cable to developed length
- Strip the cable ends for connector termination
- Solder bodies to the cable

EFFECTS ON LOGISTICS & MAINTENANCE

Imagine all the costs associated with producing these unique semi-rigid cable assemblies and every dimension is within specification; every segment length, every bend radius, and even the tolerance stack-up from connector end to connector end has been minimized. These cables are not simply going into a plastic bag and shipped to the customer. Each cable assembly part number will have unique cut foam inserts and these cables will be carefully placed into expensive custom boxes. Then a set of these boxes will be placed into a larger shipping box. If the customer requires five different cables for a deployment then the manufacturer will provide five different sets of cut foam inserts. Each assembly will be custom packaged to prevent dimensional changes during shipping and handling.

The customer will receive different crates of semi-rigid cable assemblies with each assembly packaged in a box that measures 12" × 18" × 6". How do they place these crates within your work flow? And how quickly can they remove the empty boxes from the production floor and store or dispose of them?

The alternative could be as simple as a couple of cable lengths of TFLEX supporting all of the semi-rigid applications. Then just a couple of part numbers of flexible TFLEX cables are needed. These are bulk package as 20 pieces into a plain plastic bag and dropped into the mail. No need for foam inserts, pallets, specialized work flow and packaging removal.

For maintenance operations this advantage is greatly multiplied. Consider TFLEX to be the "duck tape" of the 21st century for microwave applications. Regardless of the OEM, the frequency range and the performance parameters, standard lengths of TFLEX cable assemblies can be stocked for a full array of upkeep and retrofits. The concern

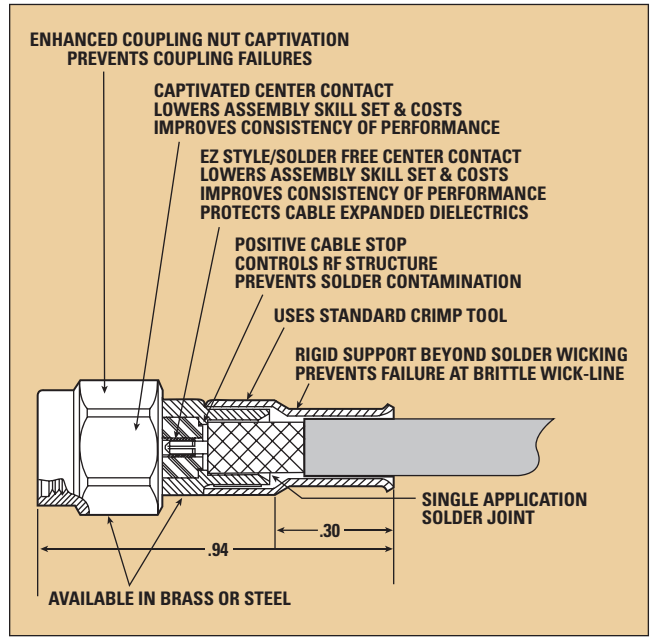

Fig. 1 e Series improvements made to SMA connector.

Field Replaceable SMA


2 Hole, .625", with Ground Plane


4 Hole, .500", with Ground plane


2 Hole Diamond with Ground Plane


2 Hole, .550" with EMI Gasket


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2 Hole, .625", Male, with EMI Gasket


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Male Thread Mount

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Voltage Rating:	335 V RMS (sea level)
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DWV:	1000 V RMS @ 60 Hz (sea level)
Insulation Resistance:	10,000 megohms
Temperature Range:	-65°C to +165°C

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EMI gaskets:	Silver filled Fluorosilicone rubber

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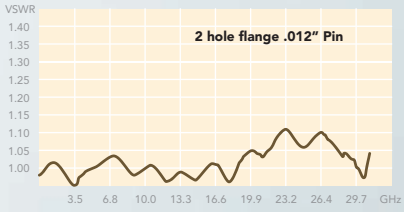

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is shifted from exacting geometries to only the need for minimum length assemblies. And with the minimum of tooling required it is even possible to produce retrofit cable assemblies on site.

eSERIES: CONNECTOR DESIGNS THAT LEVERAGE FLEXIBILITY

Now that TFLEX cable has been offered as a drop-in substitute for semi-rigid cables, there is a need to take a look at connectorization. What attributes can the connector bring to the overall reliability and performance of these assemblies?

The San-tron eSERIES product line was initiated with the SMA interface as this is the most prevalent connector for intra-system integrations, the connection of sub-systems within an OEM package. The company wanted to design advance features into the connector to remedy issues that were common with conformable cable assemblies. By combining experiences of both semi-rigid and conformable cable assemblies, the new eSERIES is a positive step in the enhancement of performance and survivability in the field. The following features were implemented into the eSMA series (see ***Figure 1***):

- Enhanced coupling nuts that will not "walk-off" brass bodied connectors
- Captivated factory-set center contacts for no worry interface dimensions
- EZ style, solder free center contacts
- Integral positive cable stops that control RF structure and limits solder contamination
- Rigid cable support beyond the solder wick line
- Cable assembly performance with VSWR < 1.22 (DC-20 GHz)
- PIM performance < -150 dBc

The enhanced coupling nut is a far reaching improvement beyond the e-SERIES product line. It is a natural occurrence that brass bodied SMAs coin with each successive torque application of the coupling nut. As this coining continues to progress, the retaining ring eventually fails to capture both the body and the coupling nut. The brass SMA connectors have implemented a feature that prevents this failure mode. All of these SMA connectors exceed the military specification of 15 in-lbs of coupling proof torque. It typically requires ~80 in-lbs of torque to cause fracture. The captivated, factory-set center contacts provide controlled interface dimensions that reduce the opportunity for mechanical collisions within mating connectors.

The EZ style, solder free contacts prevent heat disruption of the core dielectric helping to maintain the 50 ohm structure. It is the combination of heat disruption and controlled solder spacing of the center contact that contributes most to variation in RF performance. These EZ style contacts negate these limitations.

Integral positive cable stops control the resultant geometry of the prepared cable into the connector. The cable stop also limits the flow of solder to the braided cable zone preventing solder flow forward into the connector cavity. This helps give the cable assembly technician a repeatable process to support the higher 20 GHz performance.

As solder is applied to the cable it naturally wicks up the cable braid. The further it wicks, the more problems that will ensue. The wick line is a very distinct characteristic in that the braid is solid on one side of the line and is flexible on the other. Thus, this wick line becomes a fulcrum plane at which cable failure is prone. By controlling heat and dwell time it is easy to limit this solder wicking to 0.33 inches. Then the application of the optional crimp ferrule provides mechanical support to 0.49 inches. This extended ferrule provides the mechanical support that prevents braid failure under multiple cable flexing. Additional support can then be augmented with heat shrink strain relief.

The ultimate goal of these enhancements is to provide a consistent, reproducible process to fabricate low cost SMA cable assemblies with strong RF performance through 20 GHz. As a result, the required skill set of the cable assembly technician has been simplified. These features with 20 GHz performance were implemented into SMA plugs, jacks, panel mounted jacks and weather sealed bulkhead mounted jacks. Recently the SMA right angle plug was added to this product line with performance to 12.4 GHz.

The next series of solutions focused on inter-system integrations—how to get the signals to the outside world. The type N and 7/16 connectors have a

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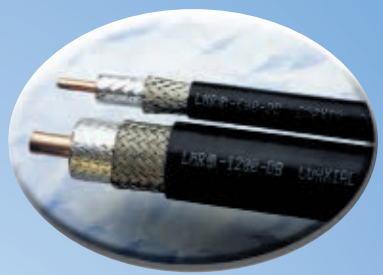

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TABLE II
COST COMPARISON TO PROCESS TFLEX VERSUS SEMI-RIGID CABLES

Equipment	TFLEX-402	RG-402
Bending Fixture: #HB1	N/A	$700
Q/C Orthogonal	N/A	$100,000
Thermal Cycling: Blue-M	N/A	$19,000
Cable Strip: #CS5400	$18,000	N/A
Cable Strip: #SR1000	N/A	$57,000
Soldering	$400	$600
Total Capitalization	$18,400	$177,300

TABLE III
eSERIES CONNECTORS FOR TFLEX-402

Frequency	PIM	Part Number	Part Description
18 GHz	no	0401-257-AH	N Plug
18 GHz	yes	0401-257-AS	N Plug
18 GHz	no	0405-72-AH	N Bulkhead Jack
18 GHz	yes	0405-72-AS	N Bulkhead Jack
6 GHz	no	0501-75-AH	RPTNC Plug
6 GHz	no	0502-17-AH	RPTNC Right Angle Plug
20 GHz	no	1201-28 M1-GJP	SMA Plug Quick Mate
20 GHz	no	1201-28-GJP	SMA Plug
20 GHz	yes	1201-33-BWA	SMA Plug Solder Contact
20 GHz	yes	1201-33-GWP	SMA Plug Solder Contact
20 GHz	no	1201-45-VJP	RPSMA Plug
12.4 GHz	no	1202-24-VJP	SMA Right Angle Plug
20 GHz	yes	1203-08-AG	SMA Jack
20 GHz	no	1203-08-VH	SMA Jack
20 GHz	no	1204-06-VJ	SMA Panel Jack
20 GHz	no	1205-06-VJ	SMA Bulkhead Jack
20 GHz	no	1205-07-VJ	SMA Bulkhead Jack Weather Seal
8 GHz	yes	1904-05-SS	7/16 Panel Jack
8 GHz	yes	1905-06-SS	7/16 Bulkhead Jack Weather Seal

strong market position for external connectivity. Therefore, these features were implemented into an 18 GHz type N bulkhead mounted jack and into an 8 GHz 7/16 panel jack and bulkhead mounted jack. The RPTNC and RPSMA were also added specifically for wireless LAN customers. The product offering of eSERIES for TFLEX-402 is shown in ***Table 3***.

Re-thinking the use of high performance flexible cable and connector designs shows that semi-rigid cables may not be the best choice in many demanding applications. The traditional semi-rigid cables may actually be increasing manufacturing costs, reducing design flexibility, increasing maintenance costs and impacting operational costs that could be avoided in many cases with flexible cable options. ■

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IEEE P1785: A NEW STANDARD FOR WAVEGUIDE ABOVE 110 GHz

The Microwave Theory and Techniques Society (MTT-S) of the IEEE has recently launched an activity to develop an international standard to define waveguides used at frequencies of 110 GHz and above—specifically, rectangular metallic waveguides. The standard's Working Group (P1785) has already met several times and is looking to define both the dimensions of the waveguides (and associated frequency bands) and their interfaces (that is flanges).

There are many applications that are presently being researched in the high millimeter-wave/low terahertz frequency range. These applications are supporting many areas, including astronomy, remote sensing, communications, radar systems and homeland security. This standard is being developed to make sure that all of these applications have a commonality and can interface easily with other technologies that are being developed.

FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS

To date, much of the work of the Working Group has concentrated on establishing the frequency bands and waveguide dimensions. It was agreed early on that, for the waveguide aperture, the ratio of the width to height of the waveguide would be 2:1. The waveguide sizes and frequency bands that have been chosen to be included in the standard are shown in ***Table 1***.[1] The waveguides in the shaded region of Table 1 correspond closely to waveguides given in existing standards (References 2 and 3, for example). The main difference is that the IEEE waveguide sizes are being specified using metric units (that is micrometers, rather than mils that were used, for example in Reference 2). The waveguides will also be named according to their metric size: the letters WM indicate that the size refers to waveguide using metric dimensions, followed by a number indicating the size (in micrometers) of the broad wall dimension of the waveguide. For example, WM-570 refers to a waveguide with a broad wall dimension of 570 µm. Another difference with the IEEE standard is that it will use tighter tolerances for specifying the critical dimensions of the waveguide (that is those dimensions that directly affect electrical performance).

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TABLE I

PROPOSED FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS FOR THE IEEE STANDARD

Waveguide Name	Aperture Width (μm)	Aperture Height (μm)	Cut-off Frequency (GHz)	Minimum Frequency (GHz)	Maximum Frequency (GHz)
WM-2540	2540	1270	59.014	75	110
WM-2032	2032	1016	73.767	90	140
WM-1651	1651	825.5	90.790	110	170
WM-1295	1295	647.5	115.75	140	220
WM-1092	1092	546	137.27	170	260
WM-864	864	432	173.49	220	330
WM-710	710	355	211.12	260	400
WM-570	570	285	262.97	330	500
WM-470	470	235	318.93	400	600
WM-380	380	190	394.46	500	750
WM-310	310	155	483.53	600	900
WM-250	250	125	599.58	750	1100
WM-200	200	100	749.48	900	1400
WM-164	164	82	913.99	1100	1700
WM-130	130	65	1153.0	1400	2200
WM-106	106	53	1414.1	1700	2600
WM-86	86	43	1743.0	2200	3300

For information, ***Table 2*** gives a comparison between the new IEEE waveguide names[1] and the names of related waveguides in the existing MIL standard,[2] and the nearest waveguides that have been proposed previously to extend the MIL series of waveguides.[4]

The series of waveguides shown in Table 1 have been chosen so that they can be easily extended, when necessary, to cover higher frequencies. The following procedure should be followed to extend the waveguide series:

- Select a waveguide size from the unshaded region of Table 1;
- Divide the mechanical dimensions by 10;
- Multiply the frequency values by 10;
- Rename the waveguide accordingly.

For example, the next two sizes in this series (derived from WM-710 and WM-570) are shown in ***Table 3***.

The part of the standard covering frequency bands and waveguide dimensions has now been drafted and is likely to be circulated for public comment in the coming few months.

WAVEGUIDE INTERFACES

The attention of the standard's Working Group is now turning to the waveguide interfaces, often called

TABLE II

COMPARING THE IEEE[1], MIL[2] AND 'EXTENDED' MIL[4] WAVEGUIDE NAMES

MIL name	New IEEE Name	fmin (GHz)	fmax (GHz)
WR-10	WM-2540	75	110
WR-08	WM-2032	90	140
WR-06	WM-1651	110	170
WR-05	WM-1295	140	220
WR-04	WM-1092	170	260
WR-03	WM-864	220	330
'Extended MIL' name	**New IEEE Name**	**fmin (GHz)**	**fmax (GHz)**
WR-2.8	WM-710	260	400
WR-2.2	WM-570	330	500
WR-1.9	WM-470	400	600
WR-1.5	WM-380	500	750
WR-1.2	WM-310	600	900
WR-1.0	WM-250	750	1100

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TABLE III

EXTENDED FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS FOR THE IEEE STANDARD

Waveguide Name	Aperture Width (μm)	Aperture Height (μm)	Cut-off Frequency (GHz)	Minimum Frequency (GHz)	Maximum Frequency (GHz)
WM-71	71	35.5	2111.2	2600	4000
WM-57	57	28.5	2629.7	3300	5000

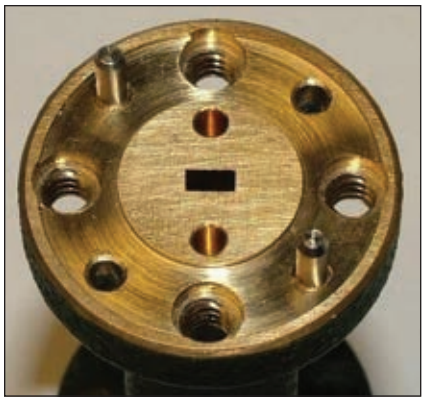

Fig. 1 A precision version of the so-called "UG-387" flange, showing the two additional dowel holes, immediately above and below the rectangular waveguide aperture.

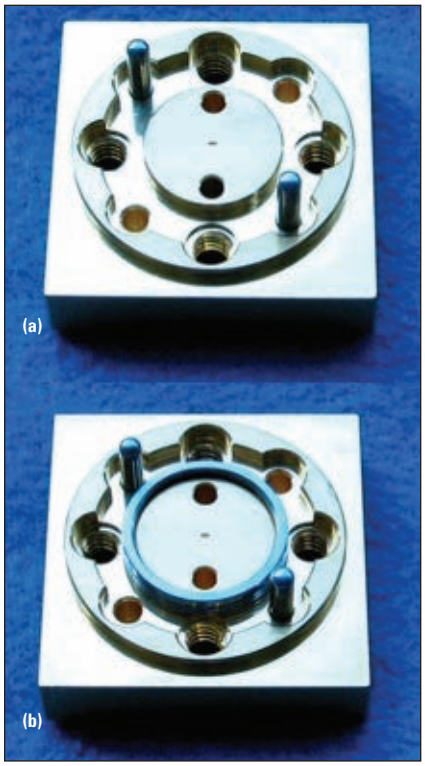

Fig. 2 Ring-centered waveguide flange: (a) with dowel holes and pins and (b) with the coupling ring in place.

"flanges". The Working Group is keen to ensure that it considered all flange designs that are used regularly at these frequencies (that is at 110 GHz and above). Therefore, a subgroup is being set up to investigate this matter further. Advice is also being sought from the entire millimeter- and submillimeter-wave communities to help identify any such candidate flange designs. *If you are aware of any flange design that you consider should be included in this standard, please contact the authors of this article.* The plan is that the standard, when published, will contain all appropriate flanges that will be used routinely in this frequency region.

For example, one such flange that is likely to be considered for inclusion in the standard is a precision version of the MIL-F-3922-67D flange (often called UG-387) that has been described[5] and is shown in ***Figure 1***. Compared to the conventional UG-387 flange,[6] this precision version contains two additional alignment dowel holes immediately above and below the waveguide aperture. These additional holes (and the associated dowel pins) are specified to a tighter dimensional tolerance than the dowel holes and pins found on the conventional UG-387 flange. This leads to better mechanical alignment of the waveguide interfaces and hence lower electrical reflection from a mated pair of flanges.

Another type of flange that is likely to be considered for inclusion in the standard is a newer design—a ring-centered flange,[7] as shown in ***Figure 2***. This design is compatible with both the UG-387 and precision UG-387 flange designs, but also uses a coupling ring to significantly improve the alignment of the flange interfaces.

It is expected that the IEEE standard, when published, will contain several flange designs, allowing end-users (such as customers, suppliers, etc.) to chose a design that best meets their given requirements. The role of the standard, in this context, is to provide the information needed for this choice to be made reliably.

CONCLUSION

The IEEE is well on its way to publishing a standard for defining rectangular metallic waveguides for use at frequencies above 110 GHz. Already, there are many applications emerging for the use of this part of the electromagnetic spectrum—millimetre-wave, submillimeter-wave, terahertz, etc.[8] Therefore, the publication of this standard is timely, and should serve our industry well for many years to come. ■

Nick Ridler and Ron Ginley are chair and vice-chair, respectively, of the EEE P1785 working group (http://grouper.ieee.org/group/1785).

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NEW HYBRID JUMPER FOR REMOTE RADIO HEADS

Against a background of expansion of the LTE network, worldwide operators are increasingly relying on amplifiers installed close to the antenna, known as remote radio heads (RRH), especially for smaller antenna systems mounted in towers or on roofs. Previously, the transmission distance between the RRH and the antenna was usually bridged by ½ inch jumpers. However, operators have met with increased difficulties due to the maximum allowable insertion loss of such links, which is why the ½ inch jumpers have been deemed to be unsuitable for certain cable lengths. This is why the larger 7/8 inch feeder cables, which have better attenuation properties, often need to be used.

The downside is that their diameter is almost twice as large. This makes them rigid in comparison to ½ inch jumpers and their relatively large bending radius and high bending torque are obstacles to easy installation, particularly on the last meter before the antenna or the RRH. In reality, for installation purposes, users have often had to resort to the far more flexible ½ inch jumpers again, at least where close-coupled connections need to be made. However, this approach requires quite a lot of effort to cut the 7/8 inch feeder cables to length on site, strip them and attach the necessary connectors. Furthermore, assembling the cables on site is critical, given that conditions are not always ideal and that the RF parameters and durable resistance to environmental influence are essential.

COMBINED BENEFITS

SPINNER has addressed these issues by offering the market a product that combines the benefits of both cable types, thus ensuring easy assembly. The Hybrid Jumper features the good attenuation performance of the feeder cable as well as the desirable flexibility of the jumper cable. The specifications for the Hybrid Jumper are shown in ***Table 1***.

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München, Germany

TABLE I

SPECIFICATIONS OF THE HYBRID JUMPER

Electrical Specification					
Frequency range (MHz)	380 ... 470	698 ... 960	1710 ... 1990	2000 ... 2200	2200 ... 2700
VSWR	1.07 max.	1.09 max	1.11 max	1.13 max	1.16 max.
	1.05 typ.	1.06 typ.	1.08 typ.	1.08 typ.	1.10 typ.
IM3	≤ -160 dBc max./-165 dBc typ. (@ 2 × 43 dBm)				
Environmental Specification					
Ingress protection	IP 68 (0.1 bar/24 hours/unmated) IP 68 (1 bar/1 hour/mated)				
Recommended temperature range	-70°C to +85°C | -94°F to+185°F Storage -40°C to +60°C | -40°F to+140°F Installation -55°C to +85°C | -67°F to+185°F Operation				
Types (Extracted Examples)					
Article	LF 7/8" Feeder length "L"	Assemply weight	Nominal insertion loss @		
			800 MHz	1800 MHz	2700 MHz
Cable Sizes: SF 1/2" /LF 7/8" Connectors: both ends 7-16 male					
JFJ-S12L78-7M7M-6	4000 mm	2.9 kg | 6.4 lb	0.36 dB	0.56 dB	0.72 dB
JFJ-S12L78-7M7M-8	6000 mm	3.9 kg | 8.6 lb	0.42 dB	0.68 dB	0.86 dB
JFJ-S12L78-7M7M-10	8000 mm	4.9 kg | 10.8 lb	0.50 dB	0.80 dB	1.00 dB
JFJ-S12L78-7M7M-12	10000 mm	5.9 kg | 13.0 lb	0.58 dB	0.92 dB	1.16 dB

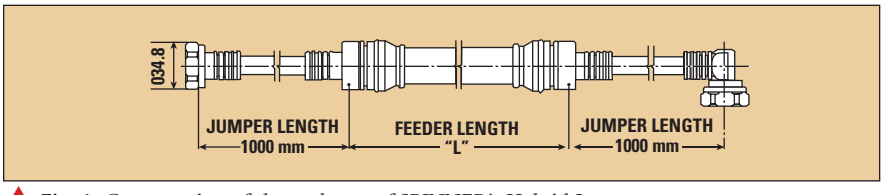

Fig. 1 Cross-section of the make-up of SPINNER's Hybrid Jumper.

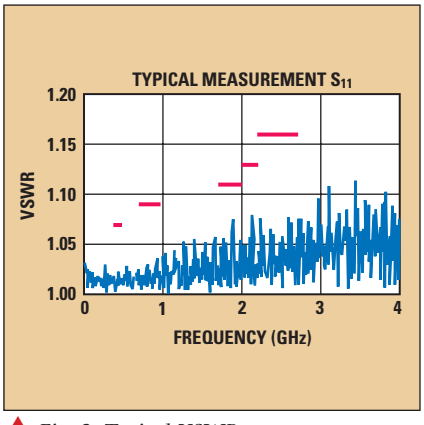

Fig. 2 Typical VSWR measurement graph.

The newly designed Hybrid Jumper includes a 7/8 inch feeder cable as the main line, the length of which can be freely determined. On each end, it has a one meter long ½ inch jumper that is assembled on the main line with specially developed and optimized connection elements. ***Figure 1*** shows the configuration. These connection elements are tightly soldered on the outer conductors of the cables, thus ensuring high stability and excellent intermodulation properties over the whole service life and under any environmental conditions.

COMPLETE ASSEMBLED UNITS

The traditional approach has been to join the feeder cable and jumper with a combination of connector and coupler, with at least one of them (usually the connector of the feeder cable) being assembled on site. Instead, the Hybrid Jumper is delivered as one completely assembled unit that is ready for use. The transition points are exactly matched and ensure superior VSWR values under repeatable manufacturing conditions. Typical measurements are shown in ***Figure 2***.

The Hybrid Jumper, as a complete line, has an IM3 ≤ -160 dBc, which meets the stringent intermodulation requirements of individual pre-assembled ½ inch jumpers over the whole service life. Furthermore, the cables go through a 100 percent test before dispatch; upon request the test log is available to the customer. The product also fully meets the requirements of the IP68 protection rating, thus ensuring resistance against environmental effects.

By harnessing the company's technical competence and long-standing experience in order to find the optimum solutions for its customers, SPINNER's new Hybrid Jumper is a cable that is flexible where flexibility is needed, while also featuring low insertion loss. Repeatable manufacturing conditions and 100 percent testing of all relevant technical parameters guarantee high operational reliability. An additional benefit is that complete pre-assembly makes the Hybrid Jumper very easy to install and ready for immediate use. It is currently available in standard lengths from 6 to 12 m and special lengths can be manufactured and supplied upon request. Besides the most common connector combination with 2 × 7-16 connectors, the Hybrid Jumper is also available in the standard version 7-16 connector/7-16 angled connector.

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BRAIDED OUTER-CONDUCTOR LOW PIM TEST LEADS

Competition in the cellular industry continues to drive the need to not only attract but keep subscribers. However, subscribers increasingly view cell service as a commodity driven in part by laws requiring cell phone numbers to be portable. Providers attempt to differentiate themselves with new services, but poor call reception remains a major reason subscribers change providers so the race to eliminate dropped calls remains a very high priority.

Passive Intermodulation Distortion (PIM) has been identified as a leading source of dropped calls in cell systems; therefore, it is understandable that providers view eliminating PIM sources as a high priority. PIM concerns have been raised for years, but are a relatively recent cell test criteria and still not completely understood by test technicians. Passive Intermodulation Distortion is caused by the presence of multiple transmit signals in a single transmission line or other components. The RF signals interact with each other at nonlinear junctions and create unwanted signals at frequencies that are the sum or difference of the transmit frequencies. If these signals fall in the receive band and are at high enough levels they can interfere with call quality and cause dropped calls. The levels that can cause problems in the receive band are more than 130 dB below the level of the carrier signal meaning that they can be generated by very small nonlinearities created by loose connections, the presence of non-ferrous metals or other reasons. They are difficult to measure and difficult to find and fix.

Independent contractors report finding the source of PIM frustratingly elusive and time consuming. Identifying the root cause is many times trial and error with a body of knowledge being generated from individual experiences. However, predicting the source in unique situations remains a challenge. For example, multiple systems now compete for space on the same or nearby towers and high PIM levels may only show up sporadically. The nearby landscape may have changed. Metal grates or large pieces of metal-encased equipment may have been added to a rooftop generating unacceptable PIM levels where none existed when the system was deployed. Tower vibrations can loosen any number of hundreds of connections. Individual components that exhibited acceptable PIM levels when first installed sometimes degrade with time, from antennas at the top to lightning protection devices down to internal radio components and jumpers. Even temperature changes may contribute to poor PIM performance.

Accepted practices to reduce PIM levels include using only non-ferrous metals and eliminating nickel under-plating in components used particularly in the transmit paths. Plating finishes must be smooth and are limited to silver or preferably non-tarnishing tri-metal (tin, copper, zinc). Reducing the number of pressure contacts between two pieces of metal within the primary RF path is desirable. When metal-to-metal contact is required (usually in a

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mated pair of connectors), clean, uniform, undamaged interfaces and high contact pressure is crucial. Specific torque values must be maintained. For 7-16 connectors, 21 ft-lbs is required. This brings us to the issue of how to get from the PIM tester to the DUT without introducing additional sources of PIM generated from the test lead itself.

Corrugated cable is typically used to achieve low PIM in the test lead. This eliminates the countless contact points found in the braided outer conductor of flexible coax, but the trade off is the lead can be difficult to handle and tends to kink mid-span or break more easily at the connector attachment area. Flexible coax makers historically have not focused on making low PIM, long flex life cable regardless of the application because of the high barrier to entry in this market.

By paying strict attention to the braiding process and materials, Times Microwave has developed several cable designs that exhibit reasonable flexibility, flex life and PIM performance (see ***Figure 1***). PIM performance is better than -160 dBc at full PIM test equipment RF power levels. A three meter assembly exhibits approximately 1.25 dB of attenuation at 1 GHz. Drawing on its extensive experience supplying SilverLine-TG™ (TuffGrip) phase stable test cables for cell site DTF measurements, Times outfits SilverLine-LP™ (Low PIM) products with a large armor and strain relief system that is another industry first. The armor withstands 1500 lbs per inch crush resistance. Connector retention exceeds 500 lbs. All pressure contact areas are eliminated in the assembly design in favor of full induction soldering for both center and outer conductors—not a trivial process when the entire product is heavily armored. As an added value, Times offers a set of three low PIM adaptors in a heavy duty protective nylon case and a limited-time test lead refurbishment program with every purchase of SilverLine-LP (part number SLS03-76M76M-02.75MK).

SilverLine-LP flexible low PIM test leads are also suitable for high volume production test. Beta site tests of

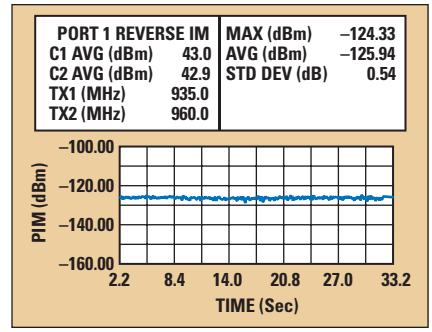

Fig. 1 Typical PIM performance.

SilverLine-LP with a maker of cellular antennas show SilverLine-LP lasts for up to six months in regular production use. As with any high performance test lead it is recommended to flex the product as little as possible for the longest life.

PIM testing also requires a PIM load suitable for the application. For tower testing, the most popular load on the market today is designed primarily for weight savings. If left under full power, it burns out quickly. Other designs that can handle full power are extremely heavy and cumbersome. Times portable PIM loads strike the ideal balance between weight (approximately three lbs) and full power handling. Times part number 67019 can handle full test equipment output power continuously for as long as is needed to troubleshoot a system. It comes equipped with both male and female 7-16 connectors eliminating the need for adaptors under certain test conditions or jumper configurations. Metal protective connector caps secured with metal chains, a frame-mounted lanyard loop, heavy-duty protective nylon case and wide wrench flats to assure proper torque are standard features not found in competing products.

For production or lab environments, Times also offers part number 67020 bench PIM load. The company's bench model includes similar features to the portable model with the addition of an easy-to-use folding handle. For those more comfortable with traditional corrugated test leads, Times offers part number SLCOR03-76M76M-03.00M, 3/8" super flex corrugated cable test leads.

Times Microwave Systems,
Wallingford, CT
(800) 867-2629,
www.timesmicrowave.com.

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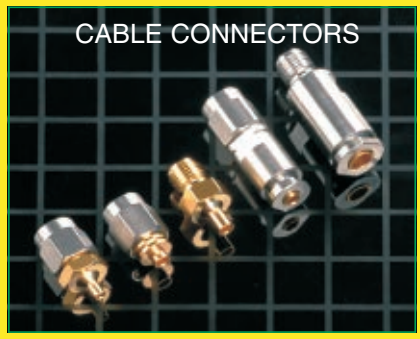

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LIGHTER-WEIGHT RG COAXIAL CABLE

W.L. Gore & Associates has introduced a new, lighter-weight RG coaxial cable for aircraft communication and navigation systems, providing significant weight savings without compromising performance. When compared to standard RG coaxial cables, these new cables reduce operating costs because they are over 25% lighter and the diameter is more than 15% smaller. This smaller and lighter profile coaxial cable still meets the stringent electrical and mechanical requirements of MIL-T-81790 and EN 3475-503. The cables engineered for electrical impedance of 50 and 75 Ω also exceed the electrical requirements of MIL-C-17G.

Although weight is a crucial factor for the aerospace industry, the performance of cables cannot be compromised to reduce mass. Gore's experience in developing fluoropolymer-based materials for the rugged environments encountered by aircraft has enabled them to consistently deliver high-performance, light-weight cables that meet RG specifications. These new lightweight RG coaxial cables are ideally suited for both newly designed systems and retrofit applications because their standard range of RF connectors can be terminated using standard tooling and processes.

The special cable design of Gore's new RG coaxial cables facilitates easier routing and improved abrasion resistance for the cables. The unique jacketing material used in the cable's construction significantly reduces size while maintaining shielding effectiveness, controlling impedance and withstanding operating temperatures ranging from -65° to 150°C.

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

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ARMORED FAMILY OF 18 GHz LOW-LOSS CABLE ASSEMBLIES

Crystek has ruggedized its LL142 low-loss RF cable assemblies by incorporating a spiraled stainless steel casing, along with extra fortification provided by heavy-duty adhesive strain relief with a Neoprene jacket. This added measure of protection eliminates the failures commonly caused by cable flexion and compression. At 18 GHz, the new Armored LL142 assemblies feature attenuation of 0.36 dB/ft and VSWR characteristics of <1.3.

Crystek's Armored LL142 Series cables offer shielding effectiveness of greater than -110 dB with an operating temperature range of -55° to +85°C (extended range of -55° to +125°C available through special order). The cables feature rugged stainless-steel solder-clamp construction and a minimum bend radius of 1.5 inches with minimal spring-back. The Armored LL142 Series cables are available in four standard lengths—24, 36, 48 and 60 inches—with SMA male to SMA male connectors. Custom lengths and configurations (Type N and TNC connectors) and electrically matched pairs are also available.

Crystek has been providing frequency products since 1958 and operates two divisions dedicated to frequency control. Crystek Crystals and Crystek Microwave are dedicated to the development and manufacture of frequency products using quartz-based resonators and frequency control products for the microwave industry.

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sales@crystek.com,
www.crystek.com.

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Email: sales@astrolab.com
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Cables & Connectors Supplement

Product Brochure

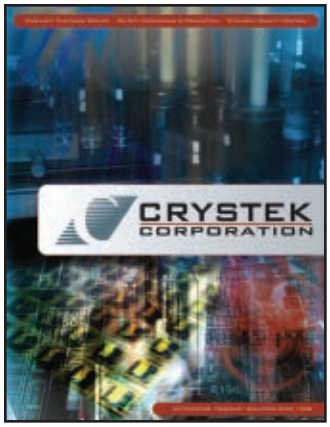
Amphenol RF introduced its latest innovation, the Mini Lock 7 (ML7) RF connector for wireless infrastructure markets. The ML7 combines proven advantages of the 7/16 interface with a new, low torque, quick coupling mechanism that speeds installation and reduces connector size up to 25 percent while delivering the same high performance quality and electrical performance users expect from Amphenol RF products. The ML7: lower costs and improved performance from the leader in RF technology.

Amphenol RF,
Danbury, CT (800) 627-7100, www.amphenolrf.com.

Product Catalog

This brochure features the company's SMPM-T, the smallest threaded open source connector on the market. Its unique and innovative combination of a MIL-STD-348 SMPM Female Interface connector together with a retractable threaded nut provides an integrated solution offering unprecedented electrical and mechanical performance.

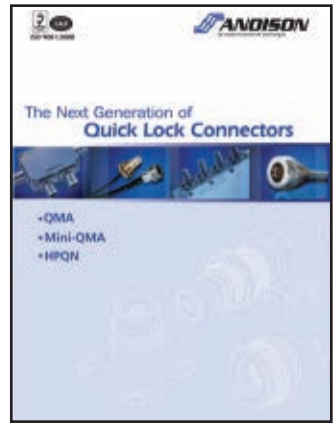
Astrolab Inc.,
Warren, NJ (732) 560-3800, www.astrolab.com.



Frequency Control Solutions

Crystek specializes in providing high frequency, low-phase-noise solutions to the microwave and RF wireless industries. Crystek's custom engineering solutions, manufacturing capabilities and quality control have been unmatched in the industry. The Crystek frequency control lineup features VCOs, VCXOs, PLLs, XOs, TCXOs and quartz crystals, along with a full line of accessories such as RF coax cable assemblies, attenuators and filters.

Crystek,
Fort Myers, FL (239) 561-3311, www.crystek.com.



Coaxial Connectors

Anoison Electronics offers a full range of QUICK LOCK coaxial connectors in three series: QMA, Mini-QMA and HPQN. The QMA offers comparable electrical performance to an SMA, DC to 18 GHz, and is inherently waterproof to IP 68. The Mini-QMA offers the same advantages of the QMA in a smaller package. The HPQN is designed to replace N connectors, where a quick connect/disconnect application is desired, DC to 18 GHz.

Anoison Electronics LLC,
Portsmouth, NH (603) 431-1414, www.anoison.com.

Corporate Capabilities Brochure

VENDORVIEW

This Carlisle Interconnect Technologies brochure is a high level overview of all the company offers as a global provider of RF/microwave, specialty and filtered connectors, cable/cable assemblies, complex harnesses, integrated installation kits and ARINC trays, racks and shelf assemblies, to engineering/certification services with DER, DAR and DMIR personnel on staff.

Carlisle Interconnect Technologies,
St. Augustine, FL (800) 458-9960, www.CarlisleIT.com.

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.

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Herisau, Switzerland, info@hubersuhner.com.

Product Catalog

This 204-page catalog covers the entire Maury Metrology-Grade Precision Calibration Standards product line, including coaxial and waveguide VNA calibration kits, opens, shorts, loads, coaxial adapters, waveguide-to-coaxial adapters, coaxial connectors and cables, connector gage kits, torque wrenches and manual tuners. It is available in the original 2006 printed edition, and as a revised and updated 2010 PDF edition that can be downloaded from the Maury website at: www.maurymw.com.

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

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.

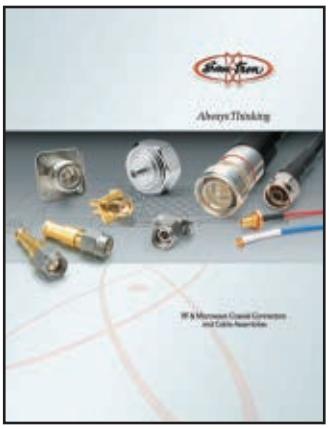
MIcable Inc.,
Fuzhou, Fujian, China +86-591-8738 2855, www.micable.cn.

IF/RF Microwave Signal Processing Components Guide

VENDORVIEW

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.



Coaxial Connectors and Cable Assemblies

VENDORVIEW

The brochure features several innovative high performance designs, including: S292™ connectors offering VSWR of <1.18 through 40 GHz; solderfree Type N right angle adapters; Type N panel receptacles featuring rugged single piece body construction; eSMA™ cable assemblies that replace semi-rigid; field-replaceable SMAs that minimize loss from DC to 26.5 GHz; and a 7/16 panel receptacle featuring -175 dBc intermodulation.

San-tron Inc.,
Ipswich, MA (978) 356-1585, www.santron.com.

Cable Assembly Handbook

The company's new Cable Assembly Handbook will be available shortly. The company has been designing and manufacturing coaxial cable assemblies for 30 years. Spectrum has a complete RF and microwave design capability, developing and manufacturing 100 percent in-house the wide range of connectors for its cable assemblies and offers customized solutions.

Spectrum Elektrotechnik GmbH,
Munich, Germany +49 89 3548 040, www.spectrum-et.org.

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141-5SM+	5	0.19	37	8.69
141-6SM+	6	0.25	39	8.69
141-7SM+	7	0.33	37	8.69
141-8SM+	8	0.30	38	8.69
141-9SM+	9	0.38	38	8.69
141-10SM+	10	0.39	37	8.69
141-12SM+	12	0.46	38	9.70
141-14SM+	14	0.52	37	9.70
141-15SM+	15	0.54	37	9.70
141-18SM+	18	0.62	37	9.70
141-24SM+	24	0.77	37	11.70
.086" Diameter				
086-3SM+	3	0.20	33	8.95
086-4SM+	4	0.23	33	8.95
086-5SM+	5	0.29	33	8.95
086-6SM+	6	0.34	34	8.95
086-7SM+	7	0.42	32	8.95
086-8SM+	8	0.46	36	8.95
086-9SM+	9	0.54	33	8.95
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Product Catalog

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

Short Form Catalog

This new short form catalog presents an overview of Teledyne Storm Products' microwave cable assembly lines, as well as its manufacturing and test & measurement capabilities for build-to-print assemblies, and its multi-channel microwave harness solutions. This Line Card can be viewed or downloaded at www.teledynestorm.com; click on the Resource Center link.

Teledyne Storm Products,
Woodridge, IL (630) 754-3300, www.teledynestorm.com.

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.

RF and Microwave Interconnects

TRU Corp. has created a short form capability catalog that outlines a wide variety of RF and microwave interconnect solutions. The catalog utilizes easy to use matrices to specify TRU brand cable and connector interface options for general purpose, commercial wireless and high performance test cable assemblies. A complete outline of RF receptacle design options as well as a full range of precision test and quick change adapters are included. This capability catalog discusses additional application driven design capabilities available from TRU Corp.

TRU Corp.,
Peabody, MA (978) 532-0775, www.trucorporation.com.

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Complete RF/Microwave Solutions

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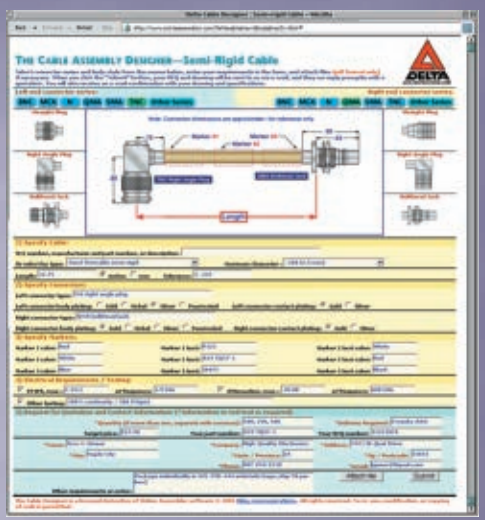

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