



*GORE SPACEFLIGHT MICROWAVE CABLE ASSEMBLIES*



**Reduced Program Risk.** W. L. Gore & Associates, Inc. has developed and proven a wide range of products specifically tailored to the spaceflight industry. With an unmatched history in demanding environments, you may be assured that Gore will provide the reliable products necessary to meet your individual system requirements.

Gore is a quality and service oriented manufacturer of a multitude of high-technology products. Among these products are GORE™ microwave cable assemblies.

GORE microwave cable assemblies were introduced to the microwave community in 1976. A short time later, the first GORE assemblies were used in a spaceflight application. Since then Gore has remained the worldwide leader in providing custom microwave cable assemblies for demanding applications. Typical applications using Gore microwave cable assemblies include: test, aerospace, defense, telecommunication, and general purpose. Gore continues to refine existing products in order to provide the most reliable microwave assembly for your application.

The information contained in this catalog covers the current GORE spaceflight microwave product line. It is accurate and up-to-date as of the time of printing. Continual product advancements, however, virtually assure some information obsolescence. For this reason, all information contained herein is subject to change without notice.

The Microwave Product Team at Gore is committed to the success of your program. If you desire a product or need information not found in this catalog, please contact Gore. Gore's dedicated engineering team stands ready to tailor a microwave cable assembly to meet your needs.



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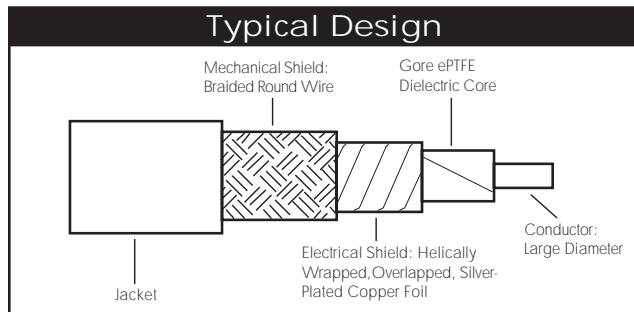
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## Section 1

### Cable

#### Cable Construction

Size for size, GORE™ microwave cable assemblies provide the lowest insertion loss available on the market today. This is accomplished through a unique cable design that exploits the low dielectric constant, low-loss tangent, and conforming nature of expanded polytetrafluoroethylene (ePTFE) dielectric. A basic cable design is shown below.



The low dielectric constant of the ePTFE dielectric core ( $\epsilon_r \approx 1.4$ ) allows the use of center conductors with nearly twice the surface area per unit length as those used in solid PTFE cables of comparable diameter, while still maintaining a characteristic impedance of 50 ohms. This provides a significant decrease in assembly insertion loss and enables higher transmission power. Our low loss tangent further reduces assembly insertion loss, particularly as the frequency of operation is increased. Capacitance is nominally 25 pF/ft (82 pF/m).

The conforming nature of the ePTFE dielectric allows for the use of an electrical shield with 100% coverage. This shield consists of helically wrapped, overlapped, silver-plated copper foil. The overlaps are in intimate contact with each other and with the ePTFE dielectric. The result is minimized signal leakage from the cable and less resistance to signal flow on its inside surface, both of which further reduce assembly insertion loss. Additionally, on some cables a standard braided mechanical shield is placed over the electrical shield to increase crush resistance, torque resistance, and connector pull strength.

A variety of jacket materials are available depending on the environment. Our standard spaceflight assembly jacket is TEFZEL® material from E.I. duPont deNemours and Company Inc.. This material offers superior radiation resistance without compromising flexibility.

In addition, Gore offers materials that improve flexibility, enhance radiation resistance, are nonmagnetic, provide several levels of

crush resistance, or limit the cable's range of motion. These materials can be used in various combinations to align cable performance with your requirements.

#### Selecting the Right Cable

All our assemblies are designed and manufactured for broadband performance. Bandwidth may vary depending on cable/connector configuration. In general, GORE microwave cable assemblies fall into the following basic categories:

- DC through 12.4 GHz
- DC through 18.0 GHz
- DC through 26.5 GHz
- DC through 40 GHz
- DC through 50 GHz
- DC through 65 GHz

Throughout the specified range, our cables are virtually free of moding and narrow band VSWR and insertion loss anomalies. Our broadband performance simplifies specifications, eliminates segregation by frequency, enhances frequency agility, and reduces your stock requirements.

The GORE microwave cable assembly product line is divided into several basic cable diameters from 0.047 in. to 0.320 in. (1.2mm to 8.1mm). As expected, for a given set of conditions, a larger diameter cable will have lower loss than a smaller diameter cable. This comes at the penalty of a heavier weight per length and a larger bend radius.

The physical environment that the cable will experience also affects its final construction. For applications where flex is required, such as in a gimbal, a stranded center conductor should be used. For static applications, a lower loss, solid center conductor is usually the better fit. Lastly, various levels of cable ruggedization are available for custom applications.

#### Customer Specifications

Frequently, Gore works with a customer's specification to develop a unique set of assembly requirements. Gore will maintain customer specifications and drawings for as long as their program remains active. This helps to expedite subsequent orders and ensure consistently high quality products.

#### Gore Guarantee

Unless otherwise specified, every GORE microwave cable assembly is 100% tested, inspected, and certified to meet the acceptance requirements contained in all applicable specifications,

## Section 1

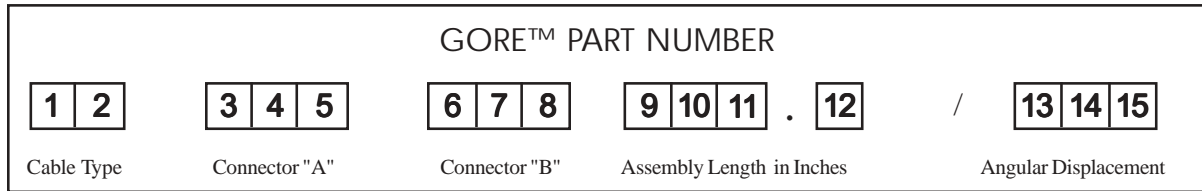
### Cable

whether stated in this catalog or in pre-approved customer contracts. Each assembly is guaranteed to meet those requirements and to be free from defects in materials and/or workmanship at time of delivery. Defect or failure claims may be filed for up to one year beyond the original shipment date.

#### ISO 9001/14001

Gore's microwave manufacturing facilities maintain ISO 9001/14001 certification.

## Section 1 Part Numbering System



### GORE Part Numbering System

GORE part numbers consist of a minimum of 12 and a maximum of 15 alphanumeric characters. Groupings of these characters have a specific meaning, as illustrated above.

Prefix characters 1 and 2 together define the cable type. For assemblies without other options, characters 1 and 2 will designate the basic cable type. For special requirements such as phase match tolerances, hybrid ruggedization, etc., a special part number assignment may be needed. Please contact Gore if you have special requirements.

Characters 3, 4, and 5 define the connector ("A") to be used on one end of the assembly. To determine these characters, refer to the connector configuration drawings for the basic cable type you have selected (see Section 4).

Similarly, characters 6, 7, and 8 define the connector ("B") to be used on the second end of the assembly.

Characters 9, 10, and 11 define the assembly length in inches. Lengths which require only one or two digits (6 or 24 in., for example) should be preceded by zeroes in the unused positions (006, 024).

Character 12 is used to further define lengths which are not in whole-inch increments (24.5 in., for example). Do not use a two-place decimal: round to the most desirable tenth of an inch for your application (keep in mind the length tolerance provided in the assembly specifications). If your length is a whole-inch increment, a "0" should be placed in position 12.

Characters 13, 14, and 15 (preceded by a slash) are used only when an assembly has two angled or "D" mount connectors (or a combination thereof) so that their angular displacement may be specified (see page 38). Angles less than 100° should be preceded by a zero in box 13.

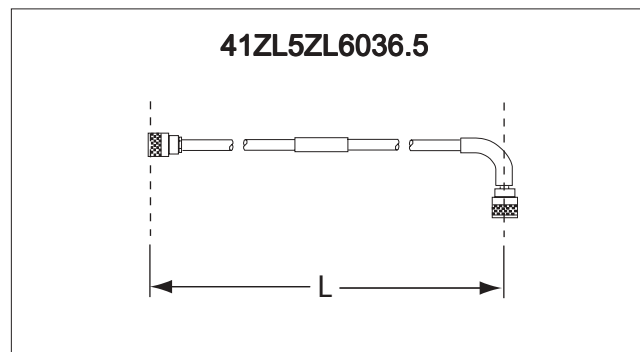
### Special Note:

If characters 13, 14, and 15 are not specified, the assembly will be supplied with an angular displacement of zero degrees. Characters 13, 14, and 15 are required for ordering purposes only, and are not stamped on the assembly I.D. tube unless specified. For more information about angular displacement, see page 38.

### Specifying Assembly Length

Length is measured using the connector reference plane of straight pin connectors, the pin center line of right angle connectors, and the **physical** end of straight socket connectors. As an example, please refer to the assembly shown below, 41ZL5ZL6036.5.

Minimum spaceflight assembly length ranges from 1.5 in. (38.1mm) to 4.0 in. (101.6 mm) depending on connectors and cable type. If a shorter assembly is required please contact Gore.



## Section 1

### Specifications & Standards

#### Gore Solder Workmanship Standard 10001

This specification covers 50-ohm, low insertion loss, flexible coaxial cable assemblies. Cable assemblies conforming to this document are intended for use in high-reliability, spaceflight, and critical ground support applications.

#### Applicable Documents

The following documents, of the issue in effect on the date of invitation for bids or request for proposal, may apply in whole or in part to a finished microwave assembly. Government specifications and standards referenced in this catalog may be changed or eliminated as a part of the government's acquisition streamlining efforts or for other reasons. At such time, industry or company specifications and standards may be substituted.

#### Specifications

##### Federal

AMS-QQ-N-290	Plating, Electro-Deposited Nickel
QQ-B-626*	Brass, One-Half Hard, Composition 360
QQ-C-530*	Beryllium Copper
QQ-P-35*	Passivated Treatments for Corrosion
QQ-S-571*	Solder, Tin Alloy: Lead-Tin Alloy; and Lead Alloy
ZZ-R-765	Rubber, Silicone

##### Military

MIL-C-17	Cables, Radio Frequency, Flexible and Semi-Rigid
MIL-C-26074	Coatings, Electroless Nickel
MIL-C-87104*	Coaxial Assemblies
SAE-AMS-DTL-23053	Insulation Sleeving, Electrical, Heat Shrinkable, General
MIL-G-45204*	Gold Plate, Type II, Grade B (Pins - Class 2; Bodies - Class 1)
MIL-I-45208*	Inspection Systems Requirements
MIL-M-81531	Marking of Electrical Insulation Materials
MIL-P-19468*	Polytetrafluoroethylene (PTFE) Fluorocarbon
MIL-PRF-39012	Connector, Coaxial, Radio Frequency

MIL-R-25988*	Rubber, Fluorosilicone Elastomer, Oil, Fuel Resin, Polyimide, Hot Pressed or Pressed and Sintered
MIL-R-46198*	
MIL-R-83248*	Rubber, Fluorocarbon Elastomer, High Temp. Fluid, and Compression Set Resistant
MIL-T-81490	Transmission Lines, Transverse Electromagnetic Mode

#### Standards

##### Military

MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-348	Radio Frequency Connector Interfaces
MIL-STD-1344	Test Methods for Electrical Connectors
MIL-STD-2000*	Standard Requirements for Soldered Electrical and Electronic Assemblies

##### Other

#### Aerospace Material Specifications

NHB 5300.4(3A-2)*	Requirements for Soldering Electrical Connections
NASA-STD-8739.3	Solder Electrical Connections
SAE/AMS 2404	Plating, Electroless Nickel
SAE/AMS 2405	Electroless Nickel Plating
SAE/AMS 2433	Plating, Nickel-Thallium-Boron or Nickel-Boron
SAE/AMS 3593	Plastic Tubing, Electrical Insulation, Irradiated Polyvinylidene Fluoride, Semi-Rigid, Heat Shrink Marker Sleeving, Grade Low Outgassing
SAE/AMS 3683	Tubing, Irradiated Modified Fluoropolymer Plastic, Electrical Insulation, Flame Resistant, Flexible, Heat-Shrinkable, 2 to 1 Shrink Ratio

#### American National Standards

IEEE STD 287*	Precision Coaxial Connectors
J-STD-004	Requirements for Soldering Fluxes
J-STD-006	Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications

#### Special Note:

\* These standards or specifications are for REFERENCE ONLY. They are obsolete or have been replaced by a new standard (as of publishing date).

## Section 1

### Specifications & Standards

#### American Society for Testing & Materials

ASTM-A-269	Seamless and Welded Austenitic Stainless Steel Tubing for General Services, Class 316L
ASTM-A-582/A582M	Specification for Free Machining Stainless Steel Bars
ASTM-B-16	Free-Cutting Brass Rod, Bar and Shapes for Use in Screw Machines
ASTM-B-194	Copper-Beryllium Alloy Plate, Sheet Strip, and Rolled Bar
ASTM-B-196	Copper-Beryllium Alloy Rod and Bar
ASTM-B-197	Copper-Beryllium Alloy Wire
ASTM-B-298	Silver Coated Soft or Annealed Copper Wire
ASTM-B-488	Electrodeposited Coatings of Gold
ASTM-B-607	Autocatalytic Nickel Boron Coatings for Engineering Use
ASTM-B-656	Autocatalytic (Electroless) Nickel-Phosphorus Deposition on Metals for Engineering Use
ASTM-B-733	Autocatalytic Nickel-Phosphorus Coatings on Metals
ASTM-D-1457	Polytetrafluoroethylene (PTFE) Molding and Extrusion Materials
ASTM-D-1710	PTFE Basic Shapes, Rod, and Heavy-Walled Tubing
ASTM-D-5205	Polyetherimide (PEI) Materials

#### Institute of Printed Circuits

IPC-FC-221 *	Flat-Copper Conductors for Flat Cables
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#### Special Note:

\* These standards or specifications are for REFERENCE ONLY. They are obsolete or have been replaced by a new standard (as of publishing date).



## Section 1

### General Material Characteristics

#### General Material Characteristics\*

The following list covers the majority of our microwave cable assemblies. For a specific list, please contact Gore.

#### Connector Body Shell (SMA, TNC, Type N):

Beryllium Copper per ASTM-B-196, Temper TD04 (H), Alloy C17300 or Stainless Steel per ASTM-A-582/A 582M

*Plating:* Gold Plate per ASTM-B-488, Type II, Grade C, Class 1.25 or MIL-G-45204, Type II, Grade C, Class 1, 0.00005" to 0.00010" thickness; over electrodeposited nickel underplate per AMS-QQ-N-290, Class 1, 0.0001" to 0.0002" thickness; over copper strike

#### Connector Coupling Nut:

Stainless Steel Type 303 per ASTM-A-582/ A 582M  
Passivate per QQ-P-35, Type II

#### Connector Hat:

Copper alloy UNS No. C36000, Temper H02, per ASTM-B-16

*Plating:* Gold Plate per MIL-G-45204, Type II, Grade C, Class 1, 0.00005" to 0.00010" thickness; over electroless nickel underplate per MIL-C-26074, Class 1, 0.0001" to 0.0002" thickness; over copper strike

#### Retaining Nut:

Stainless Steel Type 303 per ASTM-A-582/ A 582M  
Passivate per QQ-P-35, Type II

#### C-Ring:

Beryllium Copper per ASTM-B-196, Temper TD04 (H), Alloy C17300

#### Center Contact:

Beryllium Copper per ASTM-B-196, Temper TD04 (H), Alloy C17300, or Stainless Steel Type 303 per ASTM-A-582/ A 582M

#### Plating:

Gold Plate per ASTM-B-488 Type II, Grade C, Class 2.5 or MIL-G-45204, Type II, Grade C, Class 2, 0.00010" to 0.00015" thickness; over electroless nickel underplate per MIL-C-26074, Class 1, 0.0001" to 0.0002" thickness; over copper strike

#### Dielectric Support Beads:

Ultem® 1000 PEI resin: ASTM-D-5205;

Vespel® polyimide: MIL-R-46198, Type 1, Form M;

PTFE: ASTM-D-1457

Torlon® resin: 4203

#### Jacket Materials:

*Spaceflight Cable:* Extruded TEFZEL® material.

*Ruggedization:* Stainless steel

\* Please consult Gore for specific material usage.

## Section 1 Requirements

### Requirements

Cable assemblies will meet the requirements specified within this catalog.

### Conductor

Standard conductors will be silver-coated copper wire per ASTM-B-298. Silver coating will be 40 microinches minimum per MIL-C-17.

### Dielectric Core

The dielectric core will be tape-wrapped, expanded polytetrafluoroethylene (ePTFE) conforming to the requirements of MIL-C-17, Type F-6.

### Electrical Shield

The inner shield will be helically wrapped, silver coated flat copper conforming to IPC-FC-221. Silver coating will be 40 microinches minimum per MIL-C-17.

### Mechanical Shield

The outer shield will be braided, silver coated round copper wire per ASTM-B-298. Silver coating will be 40 microinches minimum per MIL-C-17. Outer shield coverage will be 90% minimum as determined by MIL-C-17.

### Jacket

The jacket will be extruded TEFZEL® material, conforming to MIL-C-17, type X, tinted black.

### Connectors

Connector type will be as specified. Materials and finishes will conform to the requirements of MIL-PRF-39012, when applicable.

### Gaskets and O-Rings

All connector gaskets and O-rings will be made of VITON® fluoroelastomer per MIL-R-83248, or silicone per ZZ-R-765 or MIL-R-25988.

### PTFE Conditioning

All PTFE connector parts fabricated and supplied by Gore will be conditioned for a minimum of one hour at  $+177^{\circ}\text{C} \pm 16^{\circ}\text{C}$  prior to assembly.

### Solder

All solder used during assembly will be Type SN63, SN96, or other alloys per JSTD-006 as the application requires.

### Pre-Tinning

Prior to assembly the stripped cable center conductor and foil shield ends will be pre-tinned. The pre-tinning will conform to the soldering criteria in Gore Standard 10001, when applicable.

### Soldering

The pin contacts of the connectors will be soldered to the center conductor of the cables and the outer shield of the cable will be soldered to the connector sleeve. Soldered joints will conform to the soldering criteria in Gore Standard 10001, when applicable.

### Shrink Tubing

Shrink tubing will be per SAE/AMS 3593, SAE/AMS 3683, or SAE/AMS-DTL-23053 or other modified polyvinylidene fluoride material.

### Configuration

The configuration of each assembly will be as specified herein and by the procuring activity.

### Length

The completed cable assembly length and tolerances of non-phase matched assemblies will be as specified below:

Nominal Length Tolerance	
Up to 5 ft. (1500mm)	±0.25 in. (6.4mm)
5-15 ft. (1500mm-4600mm)	±0.50 in. (12.7mm)
15-25 ft. (4600mm-7600mm)	±1.00 in. (25.4mm)
> 25 ft. (7600mm)	Consult Gore

### Cable Assembly Identification

Unless specified by the customer, each cable assembly will be supplied with an identification shrink tube. It will contain, as a minimum (if space allows), the following information:

**Gore Part Number**  
**Cage Code (if applicable)**  
**Gore Serial Number**

The tubing will be shrunk to its minimum dimensions, movable for customer's positioning, and be constrained by the connectors. Additional identification markers will be in accordance with, and at the option of, the procuring facility.

## Section 1

### Requirements

#### Marking Ink

Marking ink shall meet the permanency test of MIL-M-81531.

#### Workmanship

Finished cable assemblies shall conform to the requirements specified herein. Nonconforming assemblies shall not be shipped.

#### Visual Inspection

All aspects of material and construction shall be visually examined. The cable outer surface shall be smooth (free from lumps, kinks, abrasions, pin holes, pitted or pocked surfaces). The configuration of each assembly shall be as specified herein and by the procuring activity.

#### Connector Plating Adhesion

On a sampling lot basis the plated connector component shall be crushed. The adhesion of the plating and all underplatings shall then be examined at a magnification of at least 10X. Neither the plating, nor any underplating, on gold-plated connector piece parts shall show blistering, peeling, lifting, or flaking from the base metal or from each other at their interface. Cracks in the base metal or any plating will not be considered failure unless accompanied by flaking, peeling, or blistering.

#### Radiographic Examination

Radiographic examination shall be performed on each completed cable to connector termination. For Gore's examination one view shall be taken perpendicular to the center line of the connector. There shall be no evidence of solder peaks, projections, or loose solder particles in any solder joint. X-ray images, either in wet-film or computer generated graphics, will be retained for procuring activity, source inspection, and/or included with shipment when required.

#### Operating Environment

The coaxial cable assemblies are designed to withstand a normal spaceflight operating environment (-55°C to + 150°C, and pressure less than  $10^5$  torr).

## Section 1

### Electrical Performance

#### Electrical Parameters

When tested by the appropriate method for application, the insertion loss, VSWR or return loss, and phase parameters of each cable assembly will not exceed specified values. Insertion loss, VSWR or return loss, and phase measurements (when applicable) will be made using a scalar or vector network analyzer.

#### Guaranteed (Maximum) Insertion Loss

The guaranteed insertion loss shown on page 18 represents our standard specifications. Please consult Gore before specifying lower values. Typical insertion loss values can be much better than guaranteed insertion loss values as shown on page 16.

#### Guaranteed VSWR

The attached VSWR guarantees, shown on page 15, are our standard specifications. Please consult Gore before specifying lower values. Typical VSWR values can be much better than guaranteed VSWR values as shown on page 15.

#### Characteristic Impedance

The characteristic impedance of the cable will be  $50 \pm 1$  ohm as measured during the manufacturing process by using a time domain reflectometer and a 50-ohm precision air line.

#### Continuity

Continuity will be confirmed based on results obtained from insertion loss and VSWR.

#### Dielectric Withstanding Voltage

The cable assembly will be tested in accordance with MIL-C-17. The voltage will be applied between the inner and outer conductors for a minimum of one minute without breakdown.

When tested, the assembly will be capable of withstanding the following VRMS, with no breakdown, flashover, or sparkover:

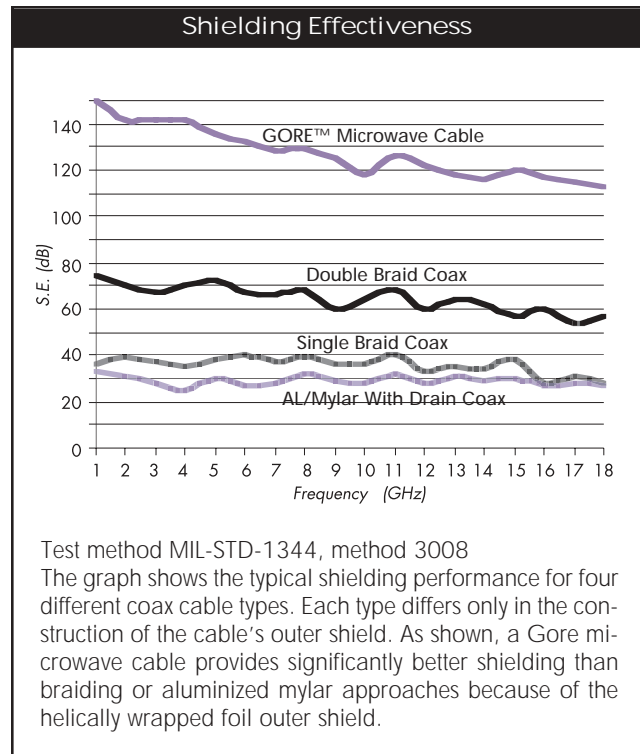
Dielectric Withstanding Voltage		
Part Number	Base Cable O.D. in (mm)	VRMS
5U	0.047 (1.2)	100
8S	0.085 (2.2)	350
26/27	0.120 (3.0)	500
56	0.140 (3.6)	500
21/41/5D	0.190 (4.8)	1000
22/42	0.290 (7.4)	1500
28	0.320 (8.1)	1500

#### Coupling Mechanism Proof Torque

When tested, the coupling mechanism of thread-on connectors will not be dislodged from the connector body when the specified force is applied. The mechanism will rotate freely. The interface dimensions of the socket connector will be compatible with the pin being tested, and will not cause destructive mating.

#### Shielding Effectiveness

In general, our assemblies meet 90 dB/ft (exclusive of connectors) per MIL-STD-1344, Method 3008, Mode Stirred Chamber, (DC-18GHz) or Sniffer-Probe Method (over 18GHz). Any specific method or specification can be supplied by the customer. Connector performance is type-dependent. Please contact Gore for specific details.



#### Time Delay

If required, the time delay will be tested in acceptance with MIL-C-17 using a time domain reflectometer, or a vector network analyzer. The nominal time delay of the cable will be 1.2 ns/ft (3.94 ns/m).

## Section 1

### Electrical Performance

#### Thermal Shock

The assemblies will be capable of withstanding thermal shock requirements when tested in accordance with MIL-STD-202, Method 107, at specified conditions.

#### Quality Assurance Provisions

The quality assurance provisions of ISO 9001 and MIL-I-45208 will apply with exceptions and additions as specified herein. All inspections and tests will be conducted by Gore at our facility or at an approved outside test facility. Gore will allow reasonable access to quality control and test facilities for source inspection purposes. All documentation not considered proprietary will be available for review at the Gore facility.

#### Special Note:

Qualification and Source Inspection, when required, must be specified by the procuring activity at the time of request for quote or proposal.

#### Quality Assurance Verification

Quality assurance will be verified by:

- A. Acceptance Inspection - 100% inspection of all assemblies shipped.
- B. Qualification - When specified by the procuring activity.

#### Acceptance Inspection

Prior to shipment, unless otherwise specified, all cable assemblies will be subjected to, and successfully pass, the following tests:

- Insertion Loss
- VSWR
- Dielectric Withstanding Voltage
- Radiographic Examination
- Visual Inspection
- Phase (When Applicable)

#### Acceptance Inspection Report

Acceptance inspection reports for each shipment lot will be certified by a responsible Gore Quality Assurance Representative. The report will be available for review at Gore's facility, upon request. Insertion loss, VSWR, x-ray, and phase data (when applicable) will be submitted to the procuring activity with the shipment lot. Successful completion of the acceptance inspection for each cable assembly will be indicated by completion of a supplier Certificate of Compliance submitted to the procuring activity with the shipment lot.

#### Qualification

Qualification, when requested, will be per the Gore Standard Spaceflight Specification or customer supplied specifications as defined by customer requirements.

#### Qualification Methods

Qualification may be satisfied either by similarity, analysis, or by actual testing as agreed upon by the procuring activity and Gore.

#### Traceability

Records will be kept by Gore showing all significant manufacturing processes, procedures, and inspection steps that have been performed. Records will indicate the date of the operation and will relate the finished product to the specific production lot. Assembly serial numbers will be the key to the records, and will allow traceability to raw materials. Records will be retained by Gore for seven (7) years.

#### Certificate of Compliance

A Certificate of Compliance, signed by a Gore Quality Representative, will be provided with each cable assembly or group of cable assemblies. This guarantees that each cable assembly has been fully tested in accordance with this document and meets the requirements herein as specified by the procuring activity.

#### Preparation For Delivery

##### Packaging

Cable assemblies will be packaged in antistatic bags. The assemblies will then be packed in boxes and voids shall be filled with shock-absorbent material to prevent damage. Shipping containers may contain multiple assemblies.

##### Labeling

Each cable assembly package will be labeled or tagged to indicate the part number.

#### Spaceflight Hardware Processing

All spaceflight assemblies are manufactured in a Class 10,000 clean room environment. Soldering and inspections are performed by certified personnel. Certifications are granted on successful completion of in-house training conducted by soldering instructors certified to NAS 5300.4, MIL-STD-2000A, and/or J-STD-001.

A visual and mechanical inspection of connector components per MIL-PRF-39012 is performed to verify that critical dimensions are met, thus ensuring both electrical and mechanical in-

## Section 1

### Electrical Performance

egrity on every spaceflight assembly. In addition, all metal parts are degreased prior to assembly integration to ensure maximum cleanliness for the spaceflight environment. One hundred percent x-ray verification of the stringent solder fill criteria, coupled with extensive electrical testing, completes the cycle of producing an extremely reliable GORE™ spaceflight cable assembly.

## Section 1

### Frequently Asked Questions

After choosing your basic cable and connector, there are several additional factors that may influence final assembly construction. Some of the more common factors are discussed below:

#### Q1. Does Gore offer phase matching options?

**A.** Yes, Gore has extensive experience in providing phase matched sets, either to an absolute standard or relative to one another. Discussions of phase performance are provided on page 24-25. The exact phase performance will depend on the particular cable construction.

#### Q2. I have a high power application. What are my options?

**A.** High power applications can affect microwave assembly construction and performance in several ways. For powers over 5-10 watts and frequencies between 400 MHz and 6 GHz, multipaction and ionization breakdown effects must be considered. An overview of these effects is available by request. The second consideration is thermal breakdown. As a rough guide for non-vacuum applications with a service temperature below 70° C and  $f > 3.6$  GHz, thermal breakdown should be analyzed when:

$$\begin{aligned} \rho f &> 60 \text{ for TNC, or} \\ \rho f &> 40 \text{ for SMA} \end{aligned}$$

where  $\rho$ =CW power (Watts) and  $f$ =frequency (GHz)

The exact power rating of each cable and connector configuration will depend on its thermal environment.

#### Q3. Do you offer radiation tolerant designs?

**A.** Yes, Gore offers a wide range of radiation tolerant designs from 5 Mrad to beyond 100 Mrad. The type and intensity of high-energy radiation encountered in space is complex and depends on the trajectory of the spacecraft, the impingement angle of the radiation, and the presence or absence of external shielding.

#### Q4. I have an extreme thermal environment. Do I need to specify different materials?

**A.** Possibly. Our standard construction is guaranteed from -55° C to 150° C. For lower temperatures, special manufacturing procedures are required to stabilize cable performance. At higher extremes, different materials may be required. Gore has qualified several of our cable assemblies to below -180° C. If your environment extends beyond the range of -55° C to 150° C, please contact Gore to specify the appropriate construction.

#### Q5. Do you make cables for flex applications?

**A.** Yes, the GORE™ microwave assembly product line is divided into two separate categories. The first is an ultra low loss solid center conductor construction for static applications. The second is a stranded construction for flex applications. This construction can be optimized for very high flex applications such as found in an antenna gimbal. Stranded cable designs have a slightly higher insertion loss when compared to the same size solid construction. Flex life data on our various constructions can be provided at your request.

#### Q6. What is the lowest loss I can specify?

**A.** Unlimited. The low loss tangent and low dielectric constant of Gore's ePTFE dielectric insulation material allows Gore to offer the industry's lowest insertion loss for any given flexible cable size. Pages 17 and 19 contain two loss curves of the guaranteed and typical loss for each cable type. While insertion loss may be specified between these two formulas, there will be a price premium for specifying loss near the minimum insertion loss line, please consult Gore prior to ordering.

#### Q7. What is the best way to install GORE assemblies?

**A.** There are many options for installing GORE microwave assemblies. Consult Gore with your specific installation requirements to allow us to determine your best installation options. Gore has extensive experience in providing microwave coaxial assemblies for complex applications. Our engineering team is always ready to help you develop the best solution for your application. Gore can provide suggestions regarding the best way to harness assemblies for multi-line configurations. The effects of various clamping technologies on assembly performance have also been studied by Gore.

#### Q8. Do I have to worry about outgassing?

**A.** No, all materials used in GORE spaceflight constructions meet or exceed NASA outgassing requirements. Depending on the cable configuration, there will be a brief period of time required for the dielectric to vent. For some very high power applications, it may be desirable to provide venting in the connector housing.

#### Q9. How much design flexibility do I have?

**A.** Gore offers much design flexibility and spaceflight qualified constructions in a variety of standard configurations. For unique applications, Gore has a dedicated engineering team ready to solve your microwave interconnect problem.

## Section 1

### Frequently Asked Questions

**Q10. What if I need an emergency turnaround on a microwave assembly?**

**A.** Gore recognizes the critical nature of the flight integration schedule and is prepared to meet your needs. We can often turn around small orders within 72 hours.

**Q11. What if I damage a cable after installation?**

**A.** Ideally the cable would be removed for repair or replacement at the Gore plant, however, we recognize that this is not always possible. Gore has a team available to perform repairs at your facility. In most cases we can begin the repair within 48 hours of notification. Gore recognizes the critical nature of the flight integration schedule and is prepared to meet your needs.



## Section 1

### VSWR

#### VSWR

Assembly VSWR or return loss is influenced to a large extent by the particular assembly configuration (length and connector types) in combination with the frequency and bandwidth, and to a lesser extent by the test method and equipment in use. It is impossible, therefore, to provide within this literature a single VSWR specification that would be applicable to all combinations of the variables mentioned above. The following table may be used as a guide. All values apply only to generic connector series SMA,

TNC, Type N, and to Gore's higher frequency versions of these series.

When specific assembly requirements and test methods have been established, it is often possible to guarantee lower VSWR values. Conversely, some connector and/or length combinations (extremely short or extremely long) may result in higher values. To be certain, please contact Gore with your specific requirements.

Cable Assembly VSWR						
Frequency Range (GHz)	Straight Connectors		Two Angle Connectors*		Mixed Connectors*	
	Guar.	Typ.	Guar.	Typ.	Guar.	Typ.
DC to 2	1.15	(1.10)	1.20	(1.10)	1.20	(1.10)
2 to 4	1.20	(1.10)	1.25	(1.20)	1.25	(1.20)
4 to 8	1.30	(1.20)	1.35	(1.30)	1.35	(1.25)
8 to 12	1.35	(1.25)	1.45	(1.35)	1.40	(1.30)
12 to 16	1.35	(1.25)	1.45	(1.35)	1.40	(1.30)
16 to 18	1.35	(1.25)	1.45	(1.35)	1.40	(1.30)
18 to 26.5	1.45	(1.35)	1.55	(1.45)	1.50	(1.40)
26.5 to 65	Call Gore		Call Gore		Call Gore	

\* For box right angle connectors, please consult Gore.

VSWR to Return Loss Conversion	
VSWR	Return Loss
1.06	30.71
1.10	26.44
1.13	24.29
1.15	23.13
1.20	20.83
1.22	20.08
1.25	19.08
1.30	17.69
1.35	16.54
1.40	15.56
1.45	14.72
1.50	13.98

## Section 1

### Typical Insertion Loss

Typical Insertion Loss										
Generic Cable Type	Base Cable O.D. <sup>2</sup> inches (mm)	Nom. Weight <sup>2</sup> g/ft (g/m)	Min. Bend Radius <sup>4</sup> in. (mm)	Insertion Loss Formula <sup>1</sup> Loss (dB)= A + B•f + C•sqrt(f) + L[D + E•f + F•sqrt(f)]						Freq. Max. (GHz)
				A	B	C	D	E	F	
5U	0.047 (1.2)	1.7 (5.6)	0.25 (6.4)	0.02000	0.00000	0.00000	0.00000	0.00184	0.35150	65
8S	0.085 (2.2)	4 (13.1)	0.5 (12.7)	0.02000	0.00400	0.01000	-0.00251	0.00412	0.18925	65
26 <sup>3</sup>	0.120 (3.0)	9 (29.5)	0.5 (12.7)	0.02000	0.00000	0.00000	0.00000	0.00235	0.15720	26.5
21 <sup>3</sup>	0.190 (4.8)	17 (55.8)	1.0 (25.4)	0.02000	0.00000	0.00000	0.00000	0.00219	0.09090	18
22 <sup>3</sup>	0.290 (7.4)	40 (131.2)	1.5 (38.1)	0.02000	0.00000	0.00000	0.00000	0.00242	0.05786	18
27	0.120 (3.0)	9 (29.5)	0.5 (12.7)	0.02314	0.00904	-0.01663	0.00353	0.00270	0.13664	26.5
56	0.140 (3.6)	11 (36.1)	1.0 (25.4)	0.04000	0.00760	-0.00500	0.00450	0.00230	0.10800	50
41/5D	0.190 (4.8)	17 (55.8)	1.0 (25.4)	0.02468	0.01052	-0.01148	0.00077	0.00089	0.07194	18/30
42	0.290 (7.4)	40 (131.2)	1.5 (38.1)	0.00900	0.00500	0.02100	0.00269	0.00093	0.04386	18
28	0.320 (8.1)	44 (144.3)	2.0 (50.8)	0.00900	0.00500	0.02000	0.00248	0.00086	0.04040	18
5V	0.210 (5.3)	19 (62.7)	1.5 (38.1)	0.02468	0.01052	-0.01148	0.00077	0.00089	0.07194	18

#### Notes:

<sup>1</sup> f=frequency in GHz; L=Assembly length in feet.

For non-straight connectors add the following lengths per connector for calculation only: 0.5" (12.7mm) for 8S and 5U cable; 1.0" (25.4mm) for 26, 27, and 56 cable; 1.5" (38.1mm) for 21, 41, and 5V cable; and 2.0" (50.8mm) for 22, 42, and 28 cable. Consult Gore for typical insertion loss for assemblies shorter than 12 inches (304.8mm)

<sup>2</sup> All dimensions and properties are for TEFZEL® jacketed constructions with silver-plated copper center conductors.

<sup>3</sup> Part numbers 21, 22, and 26 use a stranded center conductor; these parts are recommended for applications requiring high flex life.

<sup>4</sup> Minimum bend radius is for multiple bends. Smaller bend radii may be possible for single bend applications.

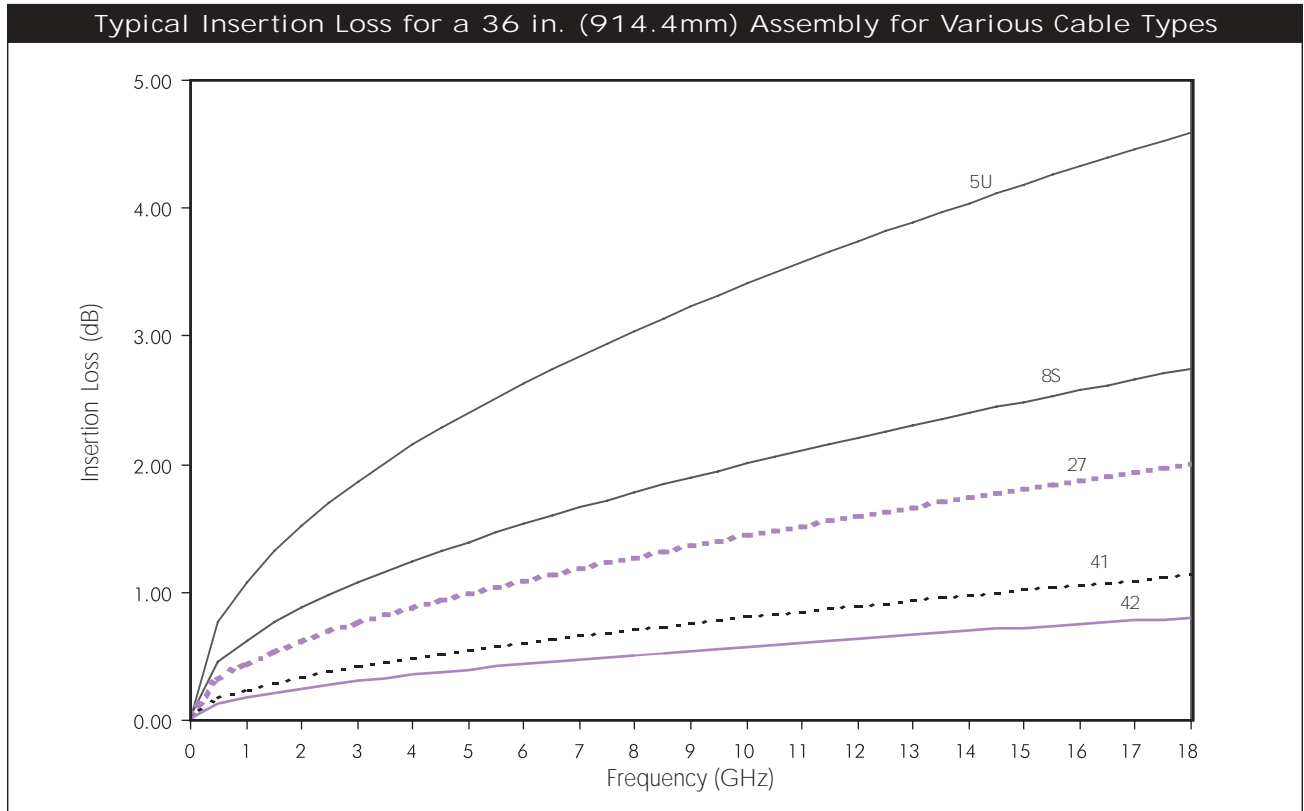
This formula can be used to predict the expected performance of an assembly in a system. It includes connector mismatch error and does account for test error. As such, this information is for reference value only; it cannot be used to specify assembly insertion loss. Length is measured between connector reference planes subject to the aforementioned non-straight connector adds.

For VSWR and Return Loss calculations, use the table on page 15.

## Section 1

### Typical Insertion Loss

Figure 1



#### Calculation Example:

34.5", 0.190" O.D., solid center conductor cable with straight pin TNCA to swept pin connector TNCA:

Part #: 41ZL5ZL6034.5

Length for equation = 34.5" + 1.5" for the swept connector.

Insertion Loss Equation at 4.2 GHz:

$$I_l \text{ (dB)} = 0.02468 + 0.01052 \cdot 4.2 + (-0.01148) \cdot \sqrt{4.2} + (36/12)[0.00077 + 0.00089 \cdot 4.2 + 0.07194 \cdot \sqrt{4.2}]$$

$$= 0.50\text{dB}$$

## Section 1

### Guaranteed (Maximum) Insertion Loss

Guaranteed (Maximum) Insertion Loss										
Generic Cable Type	Base Cable O.D. <sup>2</sup> inches (mm)	Nom. Weight <sup>2</sup> g/ft (g/m)	Min. Bend Radius <sup>4</sup> in. (mm)	Insertion Loss Formula <sup>1</sup> Loss (dB)= A + B•f + C•sqrt(f) + L[D + E•f + F•sqrt(f)]						Freq. Max. (GHz)
				A	B	C	D	E	F	
5U	0.047 (1.2)	1.7 (5.6)	0.25 (6.4)	0.02000	0.00000	0.00000	0.00000	0.00184	0.35150	65
8S	0.085 (2.2)	4 (13.1)	0.5 (12.7)	0.06000	0.00950	0.00500	0.01600	0.00490	0.20350	65
26 <sup>3</sup>	0.120 (3.0)	9 (29.5)	0.5 (12.7)	0.02000	0.00000	0.00000	0.00000	0.00235	0.15720	26.5
21 <sup>3</sup>	0.190 (4.8)	17 (55.8)	1.0 (25.4)	0.02000	0.00000	0.00000	0.00000	0.00219	0.09090	18
22 <sup>3</sup>	0.290 (7.4)	40 (131.2)	1.5 (38.1)	0.02000	0.00000	0.00000	0.00000	0.00242	0.05786	18
27	0.120 (3.0)	9 (29.5)	0.5 (12.7)	0.06000	0.01200	-0.00700	0.00710	0.00330	0.14000	26.5
56	0.140 (3.6)	11 (36.1)	1.0 (25.4)	0.06000	0.00750	0.00900	0.00930	0.00320	0.11250	50
41/5D	0.190 (4.8)	17 (55.8)	1.0 (25.4)	0.04000	0.01230	-0.00412	0.00269	0.00250	0.07360	18/30
42	0.290 (7.4)	40 (131.2)	1.5 (38.1)	0.04000	0.00800	0.02200	0.00541	0.00150	0.04500	18
28	0.320 (8.1)	44 (144.3)	2.0 (50.8)	0.03000	0.00750	0.02000	0.00500	0.00145	0.04140	18
5V	0.210 (5.3)	19 (62.7)	1.5 (38.1)	0.10000	0.01100	0.00000	0.00000	0.00220	0.08014	18

#### Notes:

<sup>1</sup> f=frequency in GHz; L=Assembly length in feet.

For non-straight connectors add the following lengths per connector for calculation only: 0.5" (12.7mm) for 8S and 5U cable; 1.0" (25.4mm) for 26, 27, and 56 cable; 1.5" (38.1mm) for 21, 41, and 5V cable; and 2.0" (50.8mm) for 22, 42, and 28 cable. Consult Gore for guaranteed insertion loss for assemblies smaller than 12 inches (304.8mm).

<sup>2</sup> All dimensions and properties are for TEFZEL® jacketed constructions with silver-plated copper center conductors.

<sup>3</sup> Part numbers 21, 22, and 26 use a stranded center conductor; these parts are recommended for applications requiring high flex life.

<sup>4</sup> Minimum bend radius is for multiple bends. Smaller bend radii may be possible for single bend applications.

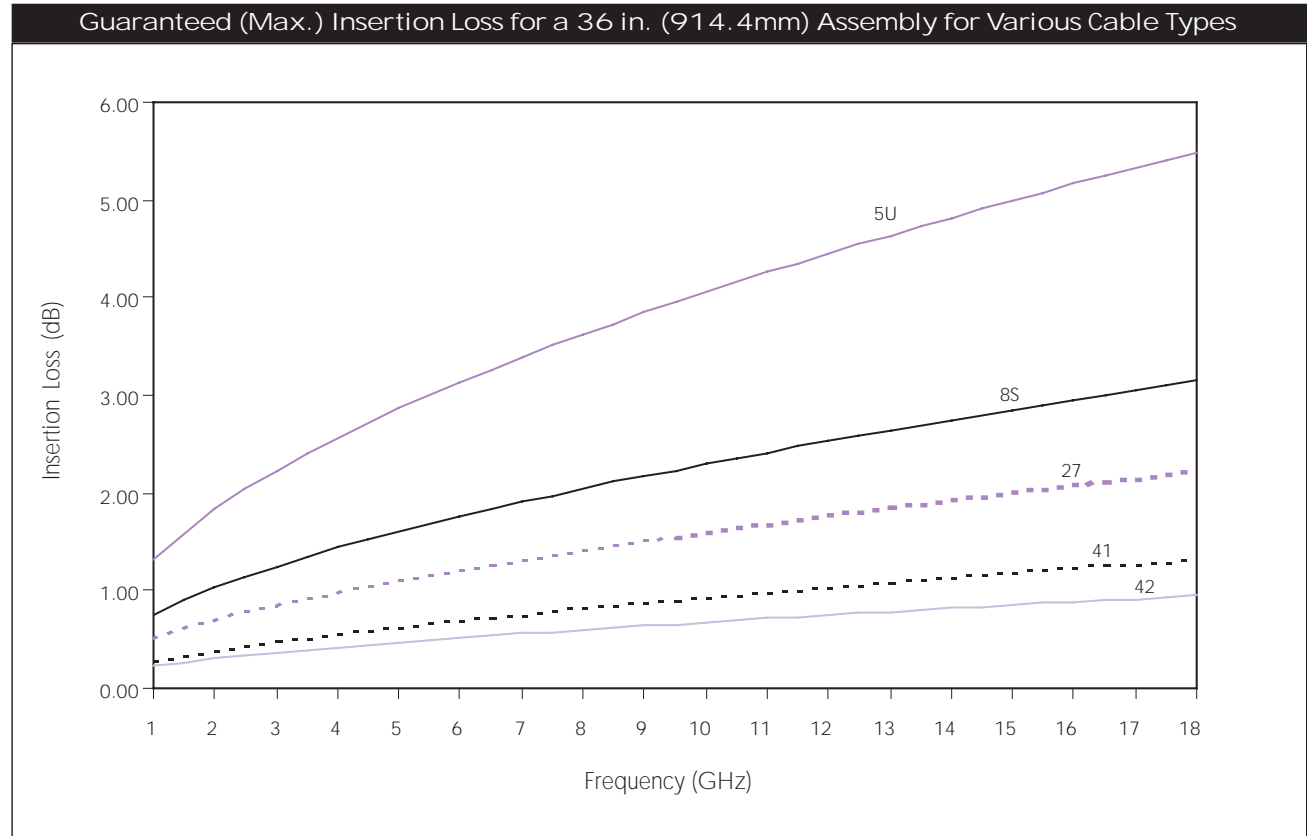
Tighter guarantees may be possible on some cable types, consult Gore.

The insertion loss figures represented by this table may be used to calculate the maximum allowable assembly insertion loss value. This calculation includes test error, measurement error and connector effects. Length is measured between connector reference planes subject to the aforementioned non-straight connector adders. For VSWR and Return Loss calculations, use the table on page 15.

## Section 1

### Guaranteed (Maximum) Insertion Loss

Figure 2



**Calculation Example:**

34.5", 0.190" O.D., solid center conductor cable with straight pin TNCA to swept pin connector TNCA:

Part #: 41ZL5ZL6034.5

Length for equation = 34.5" + 1.5" for the swept connector.

Insertion Loss Equation at 4.2 GHz:

$$I_l(\text{dB}) = 0.04 + 0.01230 \cdot 4.2 + (-0.00412) \cdot \sqrt{4.2} + (36/12)[0.00269 + 0.00250 \cdot 4.2 + 0.07360 \cdot \sqrt{4.2}]$$

$$= 0.58 \text{ dB}$$

## Section 1

### Insertion Loss and Phase Variation

#### Changes in Insertion Loss With Temperature

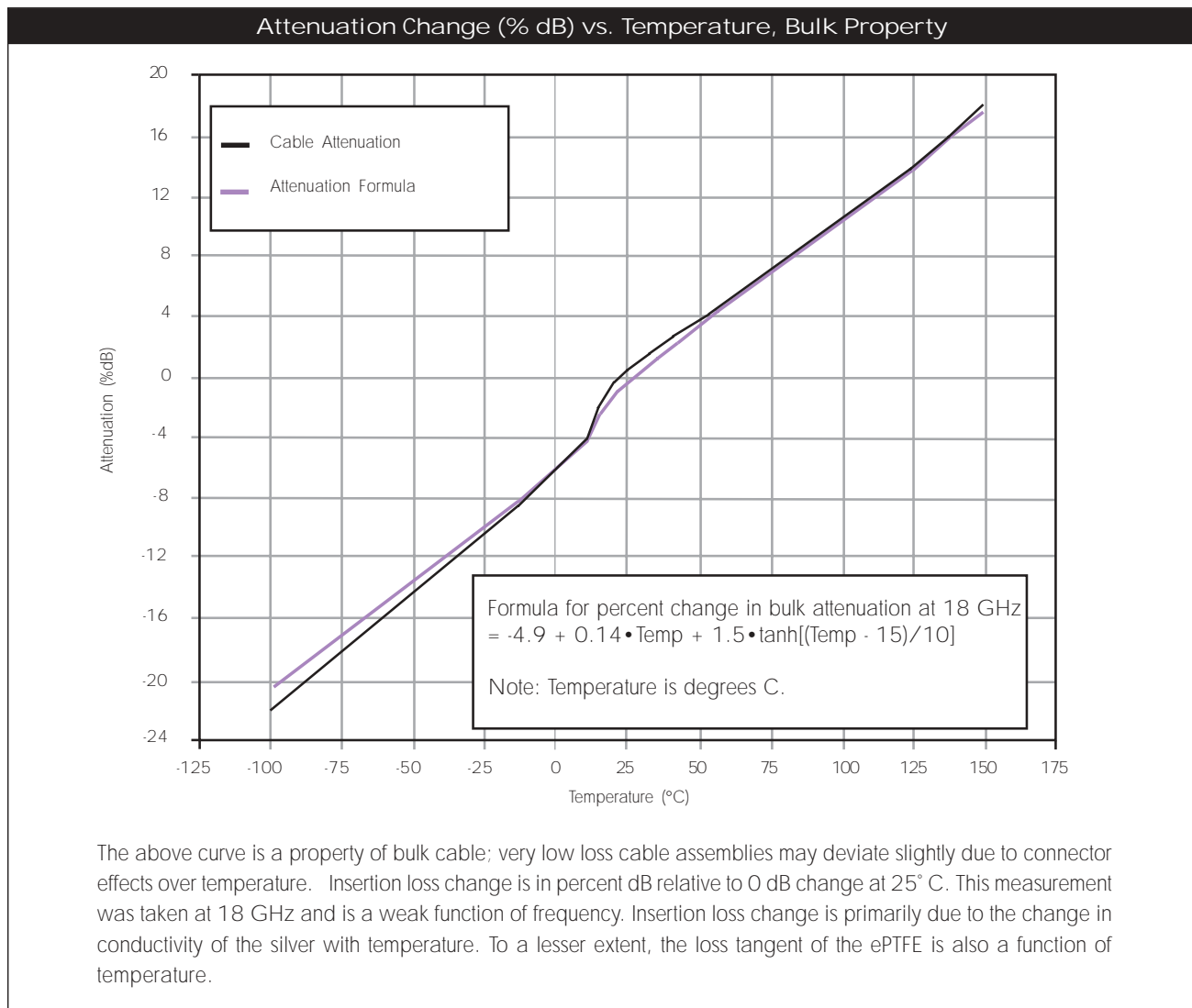
Insertion loss tracking is the ability of different assemblies of the same type and length to closely reproduce, with changing temperature, their inherent loss characteristics. As with phase tracking, the closer the assemblies track, the lower the residual systemic error, and the more consistent the beamwidth, sidelobe suppression, and beam steering will be. System range, jamming and clutter resistance, and overall accuracy are ultimately superior. Poor insertion loss tracking is generally attributable to poor control over materials and processes during cable manufacturing, or by use of a mix of different assemblies with different characteristics.

Figure 3 is a plot of data which illustrates typical insertion loss tracking of GORE™ microwave cable assemblies over the temperature range of -100°C to +150°C. Typical insertion loss will track within two percent for a given cable type, depending on the assembly length. Tighter insertion loss tracking may be achieved by selecting cables from the same material batch. Please consult Gore for details.

#### Changes In Phase Length With Temperature

GORE microwave cable assemblies offer the opportunity to improve the performance and reliability of a phase sensitive system while also reducing its complexity and cost. The low loss and

Figure 3



## Section 1 Insertion Loss and Phase Variation

VSWR characteristics of our products are well known. Perhaps not so well known is our exceptional electrical length stability under various environmental conditions. The purpose of this information is to familiarize you with that stability.

The key to this enhanced stability is our well-known cable dielectric, ePTFE. The ePTFE used is manufactured exclusively by Gore, and is used in no other manufacturer's microwave assemblies. It is, in essence, the key component of our microwave cable assembly.

The information presented herein was extracted from a variety of actual qualification tests and applications. However, due to extensive variations in system requirements, it may or may not be applicable to your requirements, and should not be directly specified without our consultation. Gore routinely provides performance guarantees for specific requirements. With our unique vertical integration, we have an unmatched capability to define the phase performance of our assemblies. For additional information, please contact Gore.

### Temperature Change (Phase vs. Temperature)

The extent of electrical length change over temperature range is referred to as phase-temperature response. The flatter the response curve, with reference to a specified temperature (usually

25° C), the better. In addition to the flatness of the phase-temperature response curve, the extent of hysteresis is of great concern. Hysteresis is the change in electrical length measured at a particular temperature, when cycling toward a temperature extreme, and upon return to that particular temperature from the extreme. It is very difficult to apply error correction techniques to a system using transmission lines which exhibit hysteresis characteristics since their electrical lengths, when returning to a temperature from cold versus returning to it from hot, are different.

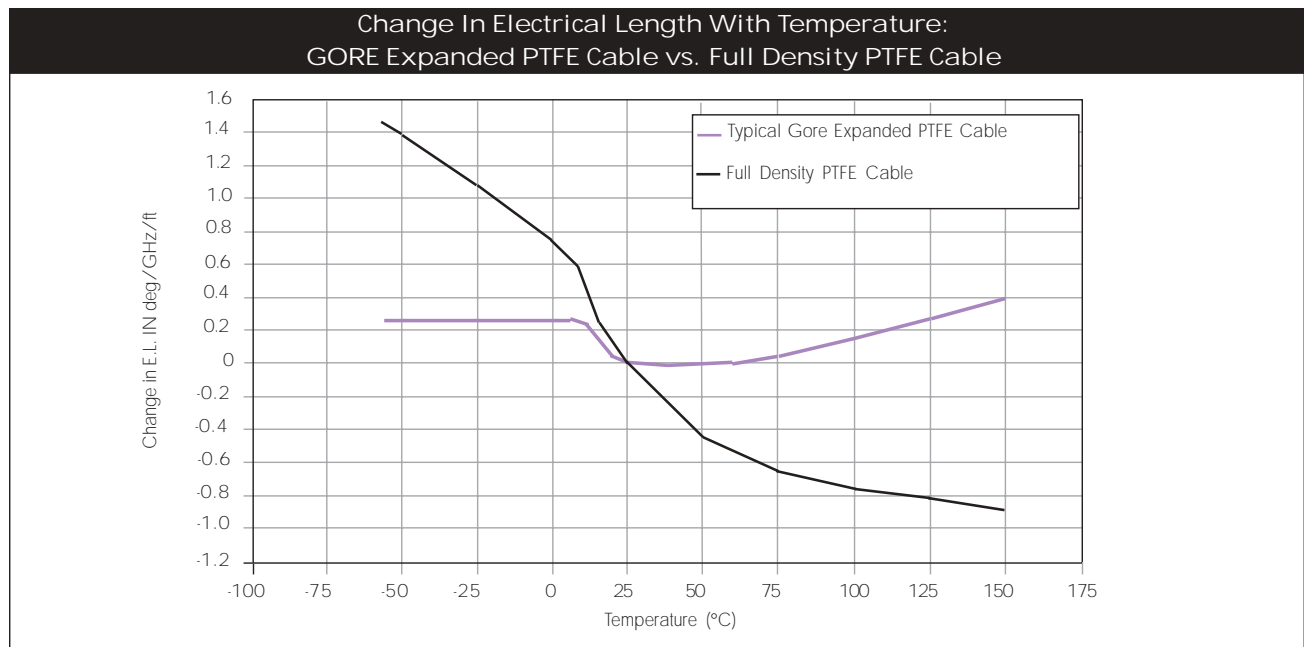
### Assembly Fingerprints (Phase vs. Temperature)

When considered together, the phase/temperature response and the hysteresis characteristics of a particular microwave transmission line assembly type constitute its "fingerprint." The fingerprint for each assembly type is unique, within limits. Some assembly types have wide limits, usually due to a lack of control over materials and the manufacturing processes.

GORE™ microwave cable assemblies have very tight limits of variation on their fingerprint, because Gore has total control over variables. We can and do guarantee limits, if requested.

The fingerprints for full-density PTFE semirigid type assemblies and for GORE™ ePTFE type assemblies are very different, and are used to illustrate the differences you will encounter between

Figure 4



## Section 1

### Insertion Loss and Phase Variation

assembly types. Figure 4 shows the difference between solid PTFE and Gore's ePTFE. Electrical length is normalized to 0 degrees electrical length at 25°C. All data is relative to this value.

Figure 5 is the fingerprint for one of our most common cable types, 41. The data shows the mean phase performance value and expected lower and upper phase performance windows. The vertical scale is shown in units of phase change in degrees/GHz/ft. These measurements do not include measurement error.

#### Fingerprints and Your System

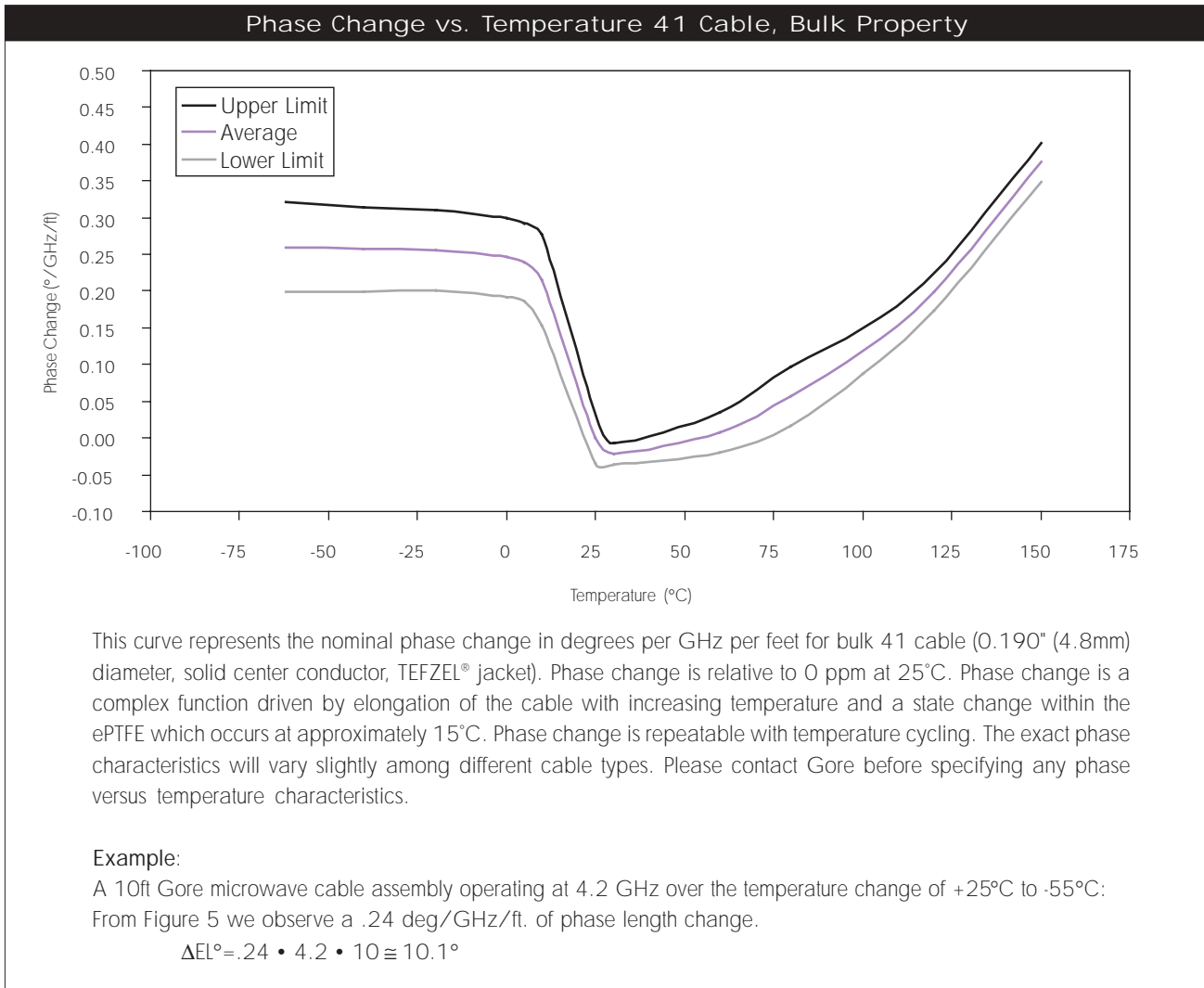
In order to compare the impact on your system of the fingerprints shown in Figure 5, you must first define certain requirements of

your application: operating frequency, assembly length, operating and nonoperating temperature ranges, and the tolerance of your system for phase change with changing temperature. The latter is dependent on your system performance specifications, and the complexity of error correction (and its associated cost) that you can live with. Values achieved by these calculations are nominal; actual assembly characteristics will vary based on a variety of design characteristics and requirements. Contact us for specific data relating to your particular needs.

#### Phase Tracking

Phase tracking is the ability of multiple assemblies of the same type and length to closely reproduce, with changing tempera-

Figure 5





## Section 1

### Insertion Loss and Phase Variation

ture, their inherent fingerprint. The closer assemblies track to one another the better, since error-corrected systems are generally designed to operate at the mean of the tracking window. The larger the window, the larger the residual systemic error. In military applications such errors affect, for example, beamwidth, sidelobe suppression, and beam steering, which in turn affect system range, clutter and jamming resistance, and overall accuracy. In digital applications such errors will increase signal skew.

The failure of assemblies to phase track adequately is most often due to poor materials and process control during manufacturing of the cable and assembly, or to the use of a mix of assemblies, constructed of components produced by different manufacturers.

#### Phase Stability with Bending

The phase stability of coaxial assemblies with bending or flexure is of great importance in phase sensitive systems, since there are very few applications in which the assemblies will not be subjected to bending during installation, routine maintenance, or actual use. It is important that phase changes with bending be minimal and predictable. Only then can the impact of those changes on system performance be assessed during the system design phase. Predictability is particularly important for systems such as phase arrays, where many paths must ultimately be matched in electrical length within tolerances.

Also of importance, but often overlooked, are phase changes which are induced during system maintenance. If cables are temporarily moved to achieve access, it is highly improbable that they will be returned to their exact original position. And, even if they are, changes of electrical length will almost certainly occur. It is very important that these changes be minimized; otherwise, system performance will suffer.

Unfortunately, phase changes with flexure cannot be totally avoided, since coaxial cable is a cylindrical component. When a cylindrical component is bent, the circumference of the outside of the bend must be larger than that of the inside of the bend. This modifies the geometry of the cylinder and the stresses within it due to extension and compression.

Coaxial cable consists of multiple concentric, cylindrical components. Since their diameters, materials and actual construction differ, modification of their geometries and stresses with bending and torque differ accordingly. These differences ultimately translate into changes in electrical length. GORE™ microwave coaxial assemblies offer the best phase stability with bending, due

to the extreme flexibility and resilience of our dielectric and also due to Gore's shielding technology.

This shielding technique was introduced by Gore in 1975 and has demonstrated its superior flexibility, shielding effectiveness, and phase stability over the years.

This proven design, when used in combination with Gore's ePTFE dielectric, eliminates many of the bend-induced stresses which are found in other assemblies. The end result is far less phase change when our assemblies are bent or flexed.

Of course, it is important to establish the stability characteristics of the assembly in the actual system environment. Unfortunately, this is not always possible or practical, so a test which will provide an indication of relative phase stability must be used.

One such test consists of a check in which the "median" conditions of occasional bending, medium bend radius, and single, reversed bend plane are simulated. To make the test more stringent, a large bend angle (a worst-case condition) is incorporated. In this test, a mandrel having a radius equal to one and one half times the minimum recommended cable bend radius is used.

Four measurements of electrical length are made: first with the assembly relaxed (in a straight position); then with the assembly wrapped 360° clockwise on the mandrel to provide a large bend angle; then with the assembly wrapped 360° counterclockwise on the mandrel to simulate a reversed bend plane; and finally, again in the relaxed state.

#### Electrical and Mechanical Stability in Severe Environments

Assemblies used in microwave systems are exposed to many environmental conditions in addition to temperature change. Among these are vibration, shock, humidity, flexure, and torque.

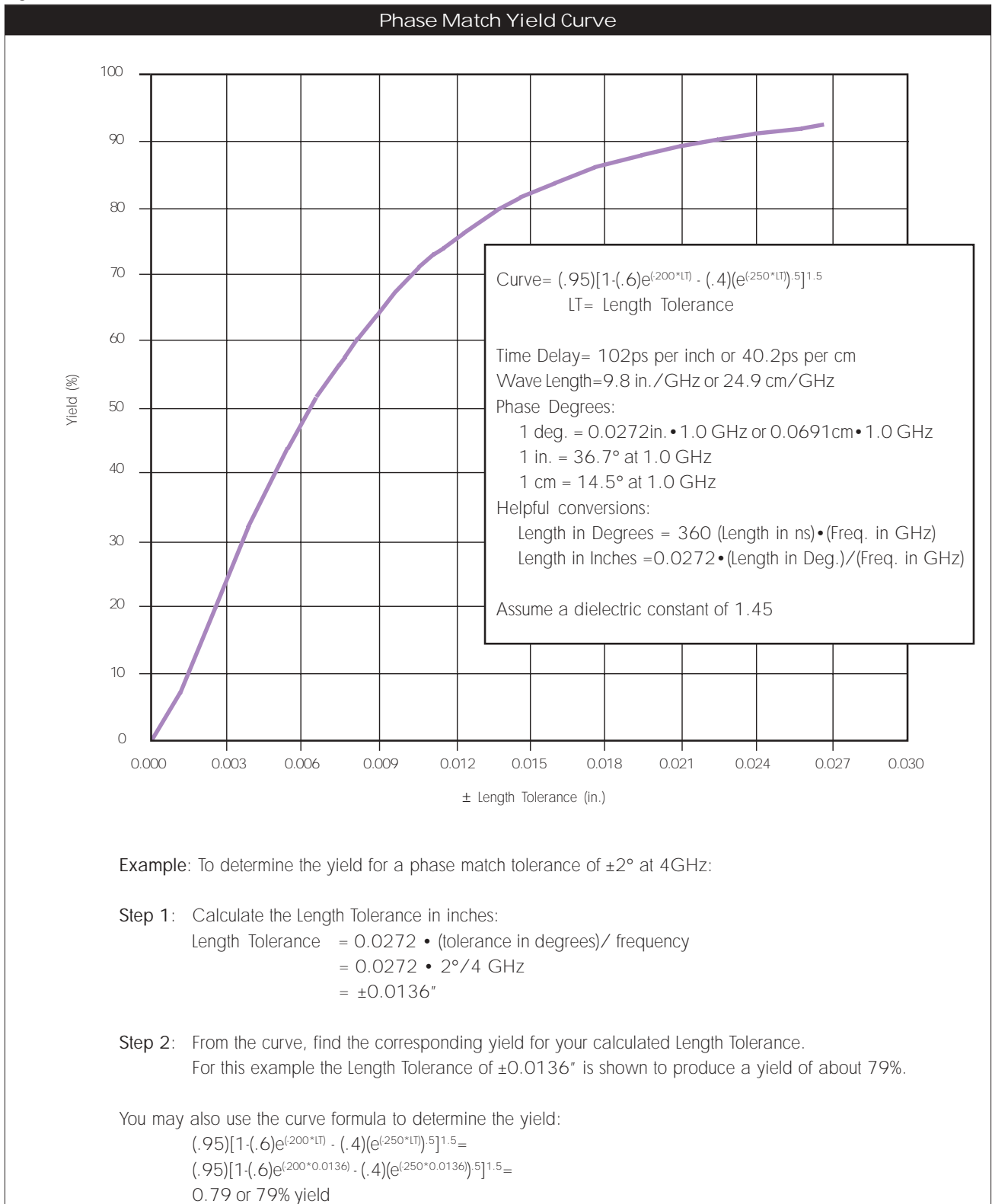
GORE microwave cable assemblies subjected to vibration and shock environments over long periods of time are not destined to fail mechanically and electrically due to metal fatigue or cracking of solder joints, as is the case with semirigid assemblies. Further, they do not exhibit self-generated noise or microphonism during vibration. And, last but not least, they retain their electrical characteristics: electrical length, phase and loss stability, insertion loss, and VSWR.



## Section 1

### Phase Matched Assemblies

Figure 6



## Section 1

### High Power Applications

#### High Power Applications

During spaceflight operation, one or more mechanisms may limit the operational power of a coaxial assembly. Perhaps the most common limiting mechanism is thermal breakdown. This is caused by heating within the cable and connector due to power dissipation. Less common, but equally important in a spaceflight environment, are multipaction and ionization breakdown effects.

The intent of this technical notice is to provide a brief overview of these effects and how they relate to a coaxial transmission system. Actual environments include additional factors that may affect the conclusions presented herein.

#### Thermal Breakdown

Thermal breakdown is a fairly complex interaction of heating within the cable, connector, source, and load. To determine the power dissipation of a cable, a simple calculation that takes into account the loss per unit length of the cable plus connector losses can be used. This yields the total cable power loss. Power dissipation can be assumed to be uniform provided the assembly does not operate in high VSWR/Return Loss conditions. In this case, localized heating due to a current standing wave may also need to be calculated.

Given a certain level of heat generation within an assembly, thermal dissipation occurs through three primary mechanisms.

The first mechanism is longitudinally along the cable center conductor. Since approximately 50% of the heat is dissipated along the center conductor, and the center conductor is almost 1,000 times better a thermal conductor than the surrounding ePTFE, the ability of the source and load to dissipate heat will play a significant role in power handling.

The second mechanism is radial conduction. Inside the cable a percentage of the heat generated within the center conductor will pass through the ePTFE insulation and out through the cable exterior. Within the connector, a similar process takes place through the dielectric support beads. These thermal dissipation mechanisms may be enhanced by using conductive tie downs along the cable and conductive strapping at the connector interface.

The third mechanism, radiant emission, is the weakest. Gore uses a high emissivity (0.92) black jacket material to promote thermal dissipation; however, the use of the other two mechanisms provides the greatest ability to reduce the assembly temperature.

Given these complex characteristics, it is impossible to define one set of curves to predict the power handling of a coaxial assembly. The curves shown in Figure 7 represent estimates of a few select assembly types.

In a nominal 50 ohm system, multipaction and ionization breakdown mechanisms may occur in an air section between conductors in the presence of a periodic RF/microwave field. Even in a dielectric filled coaxial transmission line, air sections may exist between the inner and outer conductor at the connector interface.

At atmospheric pressures below  $10^{-5}$  torr (approximately equal to an altitude above 100 miles (160 km)), multipaction breakdown is the limiting mechanism. At higher atmospheric pressures, multipaction cannot exist and ionization breakdown is the limiting breakdown mechanism. Because both breakdown mechanisms are harmonic in nature, breakdown will only occur under a limited set of circumstances. Breakdown can be expressed in terms of the product between the conductor gap ( $d$  in mm), and the fundamental frequency ( $f$  in GHz). Referring to Figure 8, multipaction is the dominating factor for  $f \cdot d$  less than  $0.7 \text{ GHz} \cdot \text{mm}$ . Above  $2 \text{ GHz} \cdot \text{mm}$ , ionization breakdown limits power handling. Between  $0.7$  and  $2 \text{ GHz} \cdot \text{mm}$  both mechanisms may be present.

#### Multipaction Breakdown

Multipactor breakdown arises from a resonant secondary electron emission in the conductor wall. This mechanism requires a high vacuum condition, where the mean free path of an electron is greater than the distance between the inner and outer conductors.

Under this condition, free electrons are accelerated by the electric field component of the microwave signal and strike conductor surface, thus producing additional electrons. This electron cloud increases in intensity by being swept by half wave ( $N=\text{odd}$ ) cycles between conductor surfaces.

When the gap distance, microwave frequency, and electronic field support a resonant mode, the process will be sustained and an electron avalanche condition will exist. This mobility limited event will increase until the mutual repulsion of the electrons limits the peak density of the electron cloud. The end result is discharge between the conductor surfaces, with an associated power density typically less than  $10 \text{ mW}/\text{cm}^2$ . Usually, a venting mechanism is provided at the connector interface to prevent destructive pressure buildup during discharge. However, even nondestructive power

## Section 1

### High Power Application

Figure 7

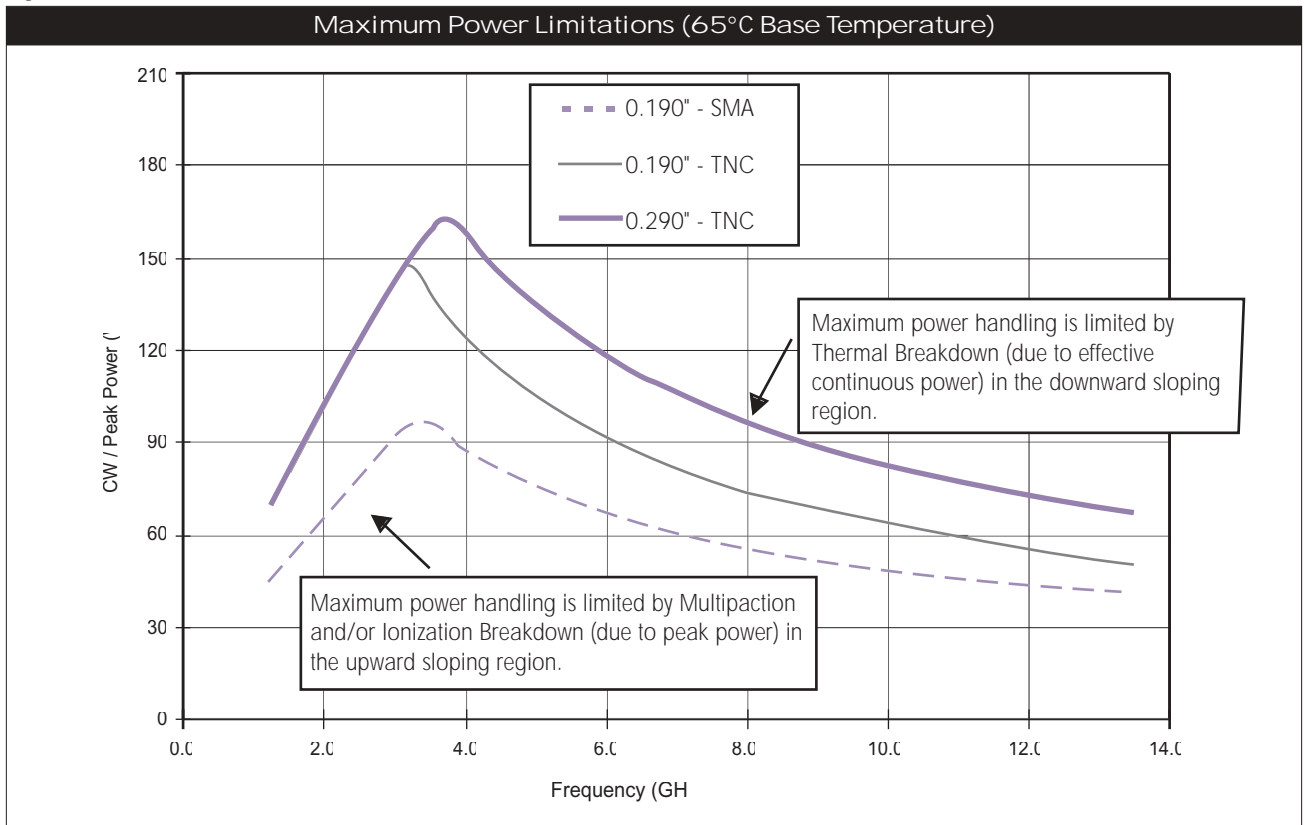
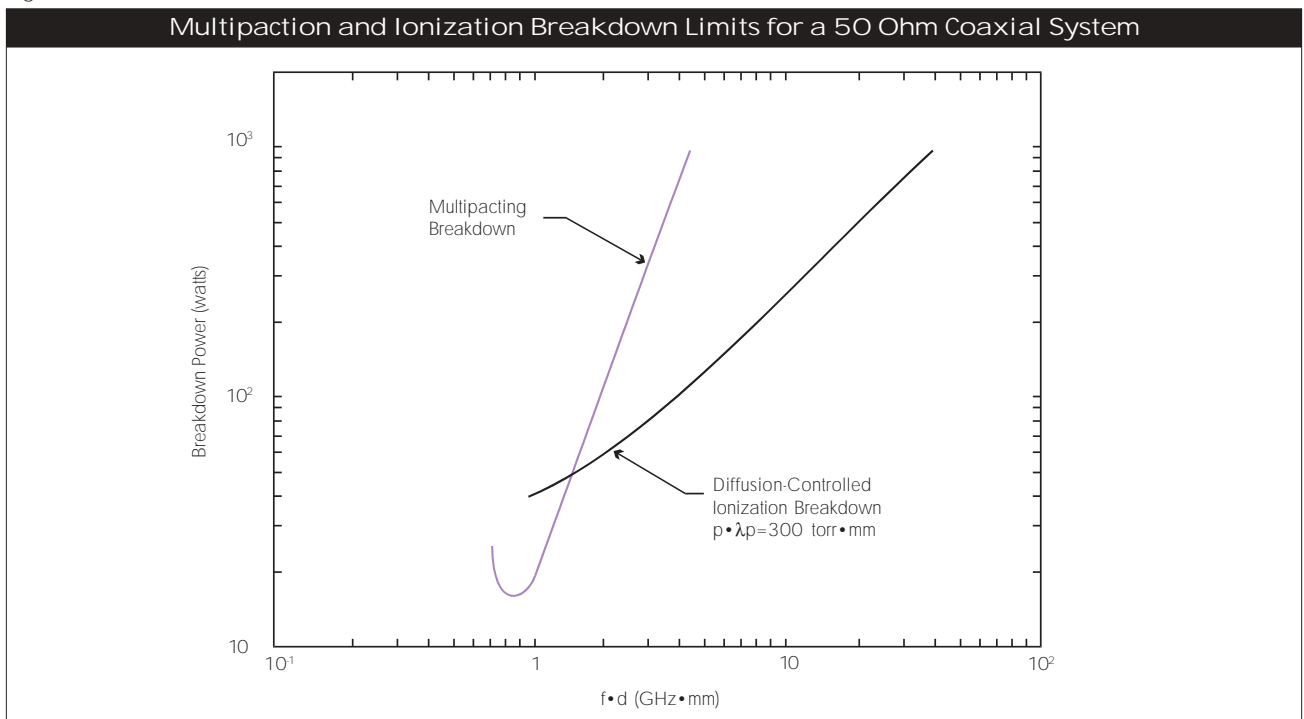


Figure 8



## Section 1 High Power Applications

levels can lead to data transmission loss, excess noise, and eventual connector failure.

Figure 9 shows the extent of experimental multipactor data taken on a coaxial geometry conductor surface. Normalized to an  $f \cdot d$  product, this demonstrates the comparatively tight set of conditions required for multipactor. In fact, multipactor is a unique mechanism in that it is possible to transmit at power *above* the multipactor region.

Although total available power is the usual desired result, multipactor stems from the electric field present. Potential limits on the power are adjacent electric fields which can reduce or increase multipactor effects and VSWR effects due to poor matching conditions. Power handling is stated in an ideal 50 ohm system, and must be derated for  $VSWR > 1$ .

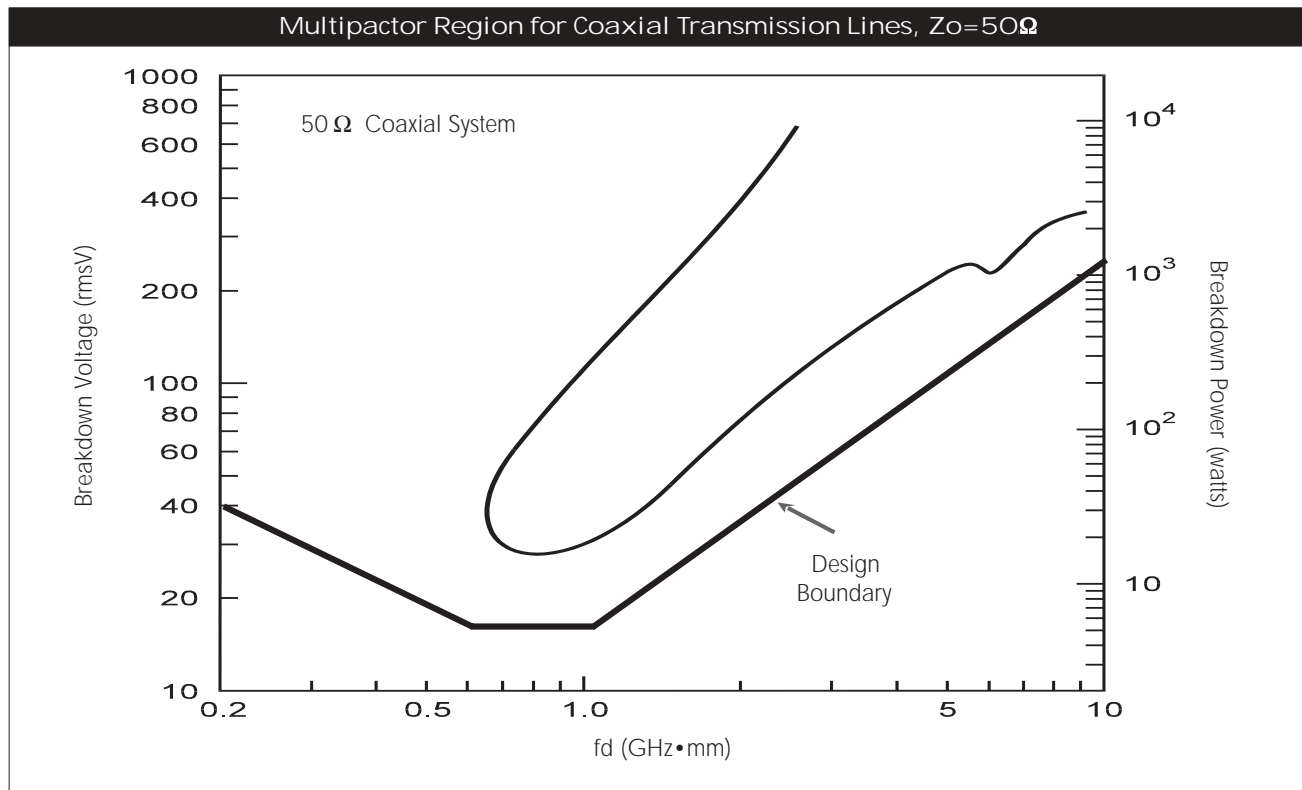
As noted, a resonant condition must exist between the conductor surface to sustain multipactor breakdown. In addition to the primary power and  $f \cdot d$  product constraints, four additional conditions should be considered when analyzing a system for multipactor:

1. A vacuum greater than approximately  $10^{-3}$  torr must be present between the inner and outer conductor to enable electron transport. Thus the interposition of a dielectric material in the air gap or reconfiguration of the connector dimensions can be used to prevent multipactor.

2. The electron generation at the conductor surface must be multiplicative to induce avalanche. In other words, for every incident primary electron, an additional fraction of secondary electrons must be produced. The measure of this effect can be represented as  $\delta$ , where  $\delta > 1$  is sufficient for multipactor to exist. Because  $\delta$  is strongly dependent on surface conditions, studies have shown the effect of contaminants and methods of reducing  $\delta$ . Dust, fingerprints, and volatile substances resulting from outgassing have been found to reduce power handling between 0 to 6 dB. This points out the need to have a safe margin between the onset of multipactor shown in Figure 9 and the design criteria. As yet, no lasting substance has been found to significantly increase power handling through a decrease in  $\delta$ .

3. Multipactor is an electric field driven event. As such, conductor geometry, the presence of external fields, and VSWR all must be

Figure 9



## Section 1

### High Power Application

considered before power handling can be determined. For ease in theoretical calculations, most multipactor power rating curves presented in literature apply to parallel plate conductors. While these can provide a "ball park" guide to the  $f \cdot d$  region where multipactor can occur (parallel plate models offer conservative projections), E-field concentration at the center conductor of a coaxial line can significantly alter parallel plate rating curves.

4. A common misconception is that multipactor breakdown requires both the inner and outer surfaces to be conductive. This is incorrect; one or both surfaces may be insulated by dielectric. Although this will reduce the applied electric field across the gap, such regions must still be analyzed for multipactor.

#### Ionization Breakdown

Ionization breakdown occurs when a concentration of free electrons is generated through resonant collisions between electrons and gas molecules. This effect is less common than multipactor breakdown as it requires partial pressure conditions that are unlikely to occur in space.

Unlike multipactor breakdown, which is a surface phenomenon, ionization breakdown is initiated in the air gap between the inner and outer conductor. During ionization, a high energy short is realized between inner and outer conductors. Since there is no upper power limit to ionization, either the connector interface or an unprotected transmitter can be permanently damaged during the event.

In ionization breakdown, either the frequency is too large or the air gap distance is too small to allow the electrons to significantly interact with conductor surfaces. Thus the electrons accumulate in a charge cloud that is swept between the conductor surfaces. With each pass of the electric field, the electrons interact with the molecules causing additional charge accumulation and thermal dissipation. Limited by diffusion, this process will continue until the energy density is sufficient to form a plasma arc between conductors.

Breakdown reaches a minimum when the energy transfer from the microwave field to the electrons is at a maximum. This point is referred to as the collision-frequency transition point. Below this pressure, the collision decrease, the mean free path increases and proportionally less energy is imparted to the electrons. At higher pressures, collisions increase, the mean free path is decreased, and the breakdown voltage increases.

In Figure 10, the ionization and multipactor power limit for a set of  $f \cdot d$  contours is plotted against a normalized pressure-wavelength axis. In a spaceflight mission with continuous transmit, it is useful to calculate the worst case pressure for ionization. Referring to Figure 10, the  $f \cdot d$  contours for most useful geometries go through a minimum at:

$$(1) p/f = 1 \text{ torr/GHz}$$

where  $c=f\lambda$  and where  $p$  is pressure in torr and  $f$  is the fundamental frequency in GHz. As a simple example, suppose  $f$  equals 4 GHz and  $d$  equals 2.5 mm. Then, the  $f \cdot d$  product is 10 GHz\*mm and a minimum breakdown occurs at:

$$(2) p/4 \text{ GHz} +/ -1 \text{ torr/GHz} \Leftrightarrow p +/ -4 \text{ torr}$$

Working across to the power axis, the maximum transmit power is 260 watts.

As depicted in Figure 10, there is a slight negative slope to the minima of points on  $f \cdot d$  contours such that  $f \cdot d = 25 \text{ GHz} \cdot \text{mm}$ ,  $p/f = .9 \text{ torr/GHz}$  and for  $f \cdot d = 2.5 \text{ GHz} \cdot \text{mm}$ ,  $p/f = 1.5 \text{ torr/GHz}$ .

As a practical matter, the ionization phenomenon is constrained to a very narrow set of pressures and  $f \cdot d$  products. In most circumstances, thermal dissipation, rather than ionization will limit the peak transmit power.

#### Acknowledgments:

The data used to generate Figures 8, 9, and 10 is largely based in measurements obtained from Reference 1.

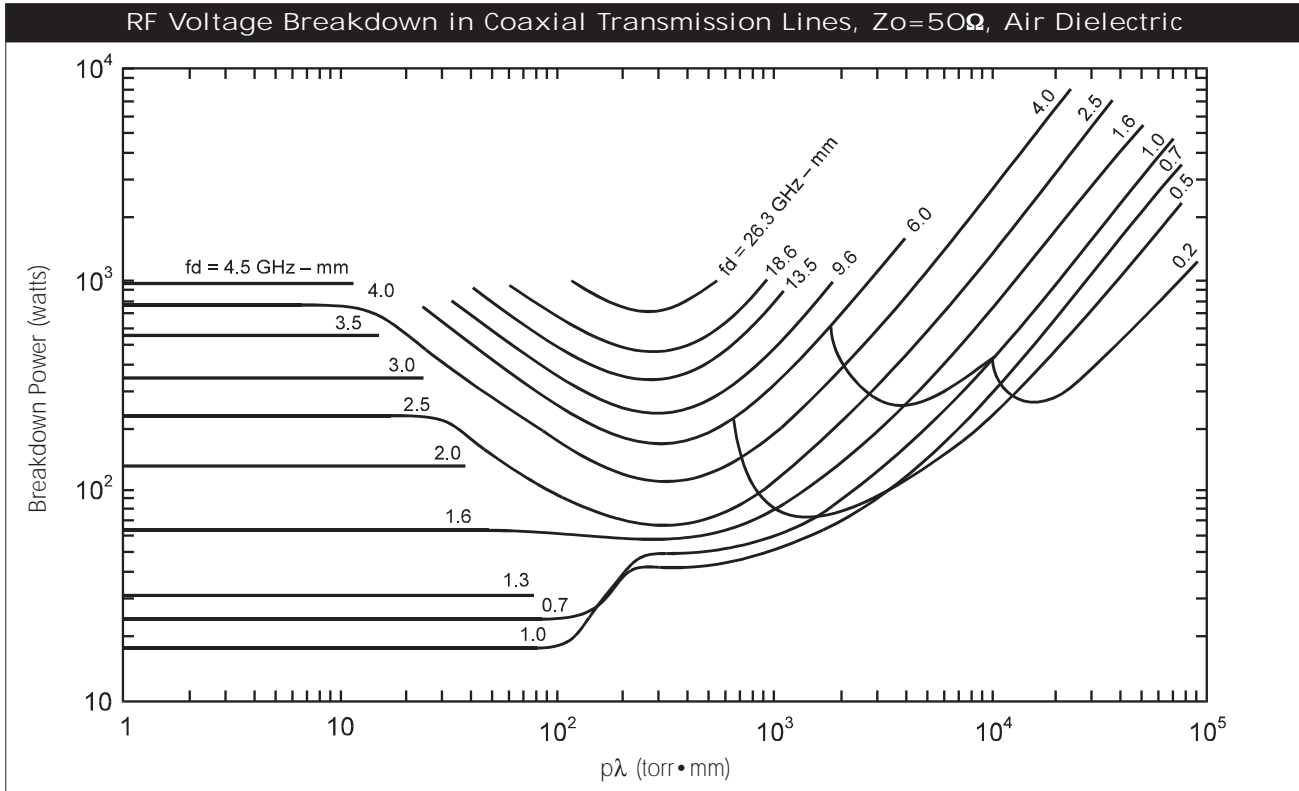
#### References:

1. R. Woo, "Final Report on RF Breakdown in Coaxial Transmission Lines," NASA Report 32-1500, October, 1970.
2. P. F. Clancy, "Multipactor Control in Microwave Space Systems," Microwave Journal, March 1978, pp 77-78, 81-83.
3. D. Woode and J. Petit, "Design Data for the Control of Multipactor Discharge in Spaceflight Microwave and RF Systems," Microwave Journal, January 1992, pp 142-155.
4. J. Rodney and M. Vaughn, "Multipactor," IEEE Trans Ed., Vol. 35, No. 7, July 1988, pp 1172-1180.
5. N. Rozarion, et al. "Investigation of Telstar 4 Spacecraft Ku-Band and C-Band Antenna Components for Multipactor Breakdown," IEEE Trans Ed., Vol. 42, No. 4, April 1994, pp 558-572.

## Section 1

### High Power Application

Figure 10





## Section 2

### Passive Intermodulation Tech Note

#### Introduction

Passive Intermodulation (PIM) is an interference phenomenon attributable to the many sources of non-linearity within a communication system. In high power, multichannel systems, these nonlinear sources generate higher order harmonics of the fundamental frequency. The fundamental signal plus the harmonic products then "mix" together to generate a predictable set of new frequencies. The end result is that certain parts of the frequency spectrum become unusable for the receiving portion of the communication system. While careful allocation of receive and transmit frequencies can be used to avoid this problem, spectrum crowding and assigned frequency allocation may make this impossible.

If it is determined that your system may be affected by PIM distortion, there are a few basic guidelines that may be used to minimize PIM generation. The following sections describe in more detail the generation of PIM products and different material constructions as they pertain to coaxial cable systems.

#### Background

One of the major sources of PIM in a coaxial cable assembly results from the contact resistance of metals within the cable and connector surfaces. These surfaces behave like diodes that cause a nonlinear current voltage trace. These nonlinearities generate harmonic frequencies that can be represented as:

$$F_n(\omega t) = A_0 + A_1 \cos(\omega t + \phi_1) + A_2(\cos 2\omega t + \phi_2) + \dots$$

$$\leftrightarrow F_n = F_n \pm 2F_n \pm 3F_n \dots$$

In a system with two or more transmission frequencies, these harmonics can mix together to form multiple frequencies. For example, in a two-tone system, with carriers at  $F_1$  and  $F_2$ , the output spectrum could equal:

$$F_{out} = F_1 + F_2 + 2F_2 \cdot F_1 + 2F_1 \cdot F_2 + 3F_2 \cdot 2F_1 + 3F_1 \cdot 2F_2 \dots$$

In general, these mixing products can be referred to by their order, such that:

$$F_n = 1^{st} \text{ order}$$

$$2F_2 \cdot F_1 = 3^{rd} \text{ order}$$

$$3F_2 \cdot 2F_1 = 5^{th} \text{ order} \dots \text{etc.}$$

Fortunately, the power content of the higher order harmonics, beyond the 5<sup>th</sup>, drops dramatically. Also, your system may employ either filters or other devices that further reduce higher order harmonics. Nevertheless, the potential for a significant power

content in the 3<sup>rd</sup> through 9<sup>th</sup> order equations is still quite real. If these frequencies fall within your receive path, your system's noise figure will degrade.

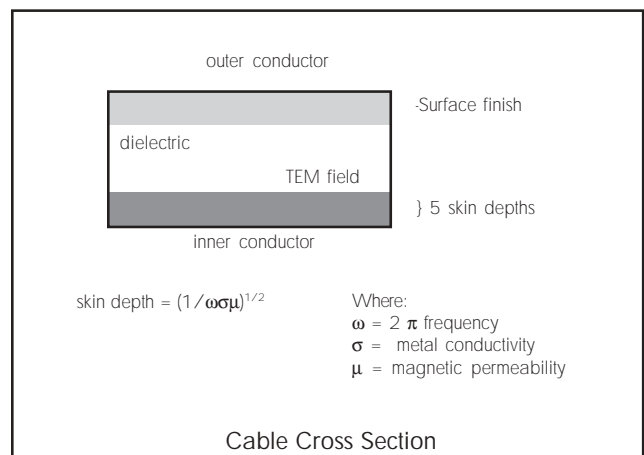
#### Options

After determining that your system may be affected by PIM, you still have several cable options that may reduce or eliminate your problem. Several papers have been written on the subject of PIM (see references on page 32) and the use of different contact materials. Again, since each surface and metal-to-metal contact point within the coaxial RF field may generate PIM products, it is in these areas where care must be taken. These surfaces may be broken into three major categories: cable, cable-to-connector junction, and connector-to-connector junction.

#### Cable

The cable itself is probably the easiest factor to control. In general, a solid center conductor reduces the number of point contacts versus a stranded center conductor. However, studies have shown that by using metals with low contact resistance, such as silver or gold, the problem can be virtually eliminated. The second source of PIM is surface oxides on either the inner or outer conductor. These semiconducting oxides are one of the greatest factors in the generation of PIM. Thus, two very common center conductor materials, aluminum and copper, should not be used without an overplate of nonoxidizing metal. Lastly, conductor surface finishes should either prevent the formation of oxides at the metal to finish junction, or be of sufficient depth that they extend at least five "skin depths" normal to the TEM field.

This is illustrated in the figure below:



## Section 2

### Passive Intermodulation Tech Note

#### Cable to Connector Termination:

The single most important concern is the degree of contact between the cable and connector. Since a partial contact will result in a nonlinear device, only 360° solder attachment of the connector to the cable should be used. However, when using solder, care must be taken to prevent excess solder from extending beyond the connector to cable joint.

#### Connector:

Due to the many mating surfaces found within a standard connector interface, particular care must be taken to prevent PIM. In general, all metals that exhibit magnetic properties, paramagnetic properties, or possess surface oxides should be eliminated along the signal path.

#### References:

1. M. Bayrak, M. Eng and F. A. Benson, "Intermodulation Products from Nonlinearities in Transmission Lines and Connectors at Microwave Frequencies," Proc. IEEE, Vol. 122, No. 4, April 1975.
2. M. Bani Amin and F. A. Benson, "Coaxial Cables as Sources of Intermodulation Interference at Microwave Frequencies," IEEE Trans. ed., Vol. EMC-20, No. 3, August 1978, pp 376-384.
3. F. Arazm and F. A. Benson, "Nonlinearities in Metal Contacts at Microwave Frequencies," IEEE Trans. ed., Vol. EMC-22, No. 3, August 1980, pp 142-149.

## Section 2

### Radiation Resistance Tech Note

#### Radiation Resistance

Until now, high-radiation environments presented microwave system designers with a difficult coaxial cable choice: semi-rigid cable or externally shielded flexible cable. The problems associated with configuring and routing semi-rigid cables are well-known. Standard flexible cables with fluorocarbon jackets and dielectrics deteriorate when exposed to high levels of radiation. External shields add weight and complexity to flexible cable runs.

#### Designed-in Radiation Resistance

GORE™ spaceflight cables are engineered to withstand the severe levels of radiation found in many satellite applications. The use of radiation resistant materials, along with our proven basic constructions, provides a truly practical choice for flexible cable in high radiation environments. Gore's radiation resistant cable retains the basic construction and performance of our standard microwave cable.

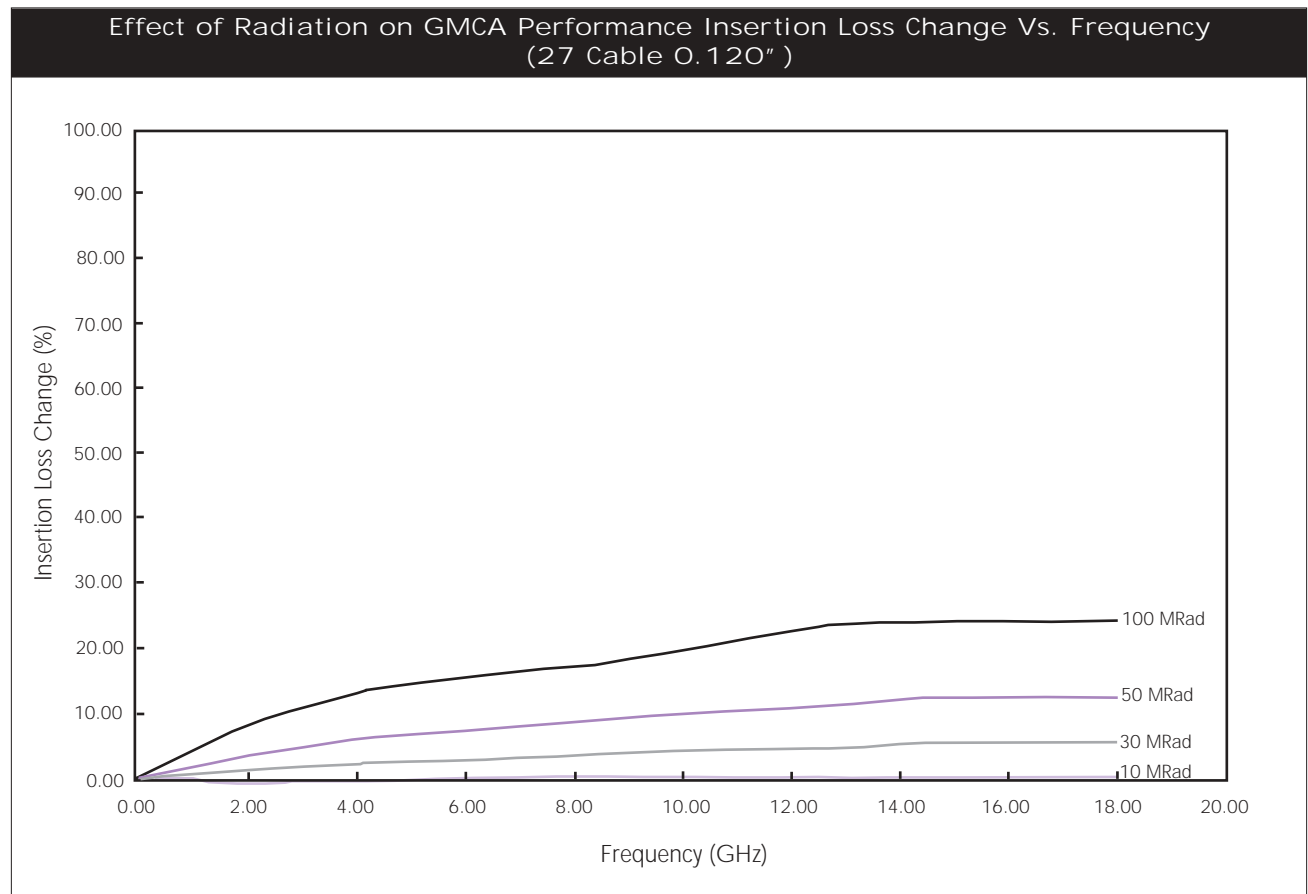
#### Standard Spaceflight Construction

Our standard spaceflight product line, for radiation environments up to 100 Mrad, is our most common spaceflight construction. This assembly differs from our baseline ground cable in that it is manufactured with a TEFZEL® radiation resistant jacket material. This material ensures that the cable remains structurally sound during radiation exposure.

#### Microwave Assembly Specifications

GORE spaceflight microwave assemblies use dielectric cores identical to those found in our basic cable types. Naturally, all GORE spaceflight cable types meet the generally accepted maximum vacuum outgassing rates for spacecraft of 1.0% TML and 0.10% CVCM. The low or ultra-low attenuation of these cable types is retained and the same insertion loss and VSWR guarantees apply.

Figure 11



## Section 2

### Radiation Resistance Tech Note

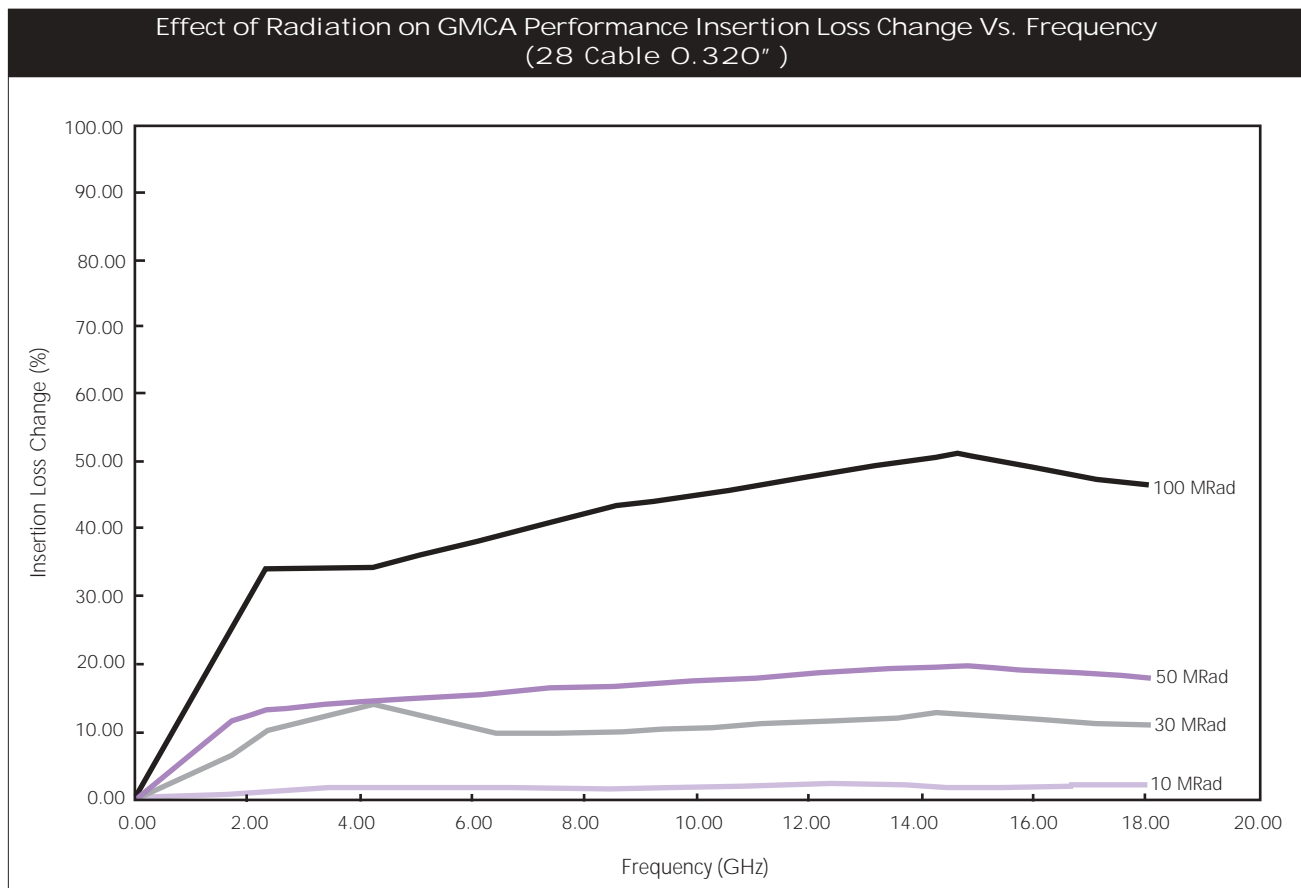
#### Radiation Resistance Over a Wide Exposure Range

The type and intensity of high-energy radiation encountered in space is complex and depends on the trajectory of the spacecraft, the impingement angle of the radiation, and the presence or absence of external shielding.

Gore's standard spaceflight assemblies withstand a 30 megarad ( $10^6$  rads) dose of Cobalt 60 gamma radiation with only a slight change in electrical performance. After 100 megarads ( $10^7$  rads) the jacket remains pliable and the mechanical performance is only slightly affected.

Figures 11 and 12 show the effects of radiation on insertion loss performance for two different cables, Gore part numbers 27 and 28. For more information on radiation resistant GORE™ microwave coaxial assemblies, please contact Gore.

Figure 12



## Section 3

### Ordering Guidelines

#### Areas to Consider When Ordering GORE™ Microwave Cable

GORE microwave coaxial assemblies are ready to meet the challenge of your system. From initial concept stage to prototype development to field testing, Gore engineers are available to assist in reducing your system risk. The information from this questionnaire will aid in specifying the most appropriate GORE microwave assembly.

Special Note: It is important when placing your order to identify it as spaceflight. This will ensure you receive spaceflight qualified materials and processes.

For quicker service please have the following information available when calling:

Application: \_\_\_\_\_ Number of assemblies: \_\_\_\_\_

Length: \_\_\_\_\_ in Connector Interface: \_\_\_\_\_ End A: \_\_\_\_\_  
End B: \_\_\_\_\_

Max. Cable O.D.: \_\_\_\_\_ in Profile Restrictions: \_\_\_\_\_

Min. Bend Radius: \_\_\_\_\_ in Wiring Restrictions: \_\_\_\_\_

Weight Restrictions: \_\_\_\_\_ Maximum Operating Frequency: \_\_\_\_\_

Temperature Range: \_\_\_\_\_

Electrical Length, Time Delay, and/or Phase Matching Requirements: \_\_\_\_\_ (Absolute/Relative)

Insertion Loss of \_\_\_\_\_ dB per \_\_\_\_\_ ft at \_\_\_\_\_ GHz

VSWR/Return Loss: \_\_\_\_\_

Expected Shock/Vibration: \_\_\_\_\_

Other Environmental Requirements (ex. radiation, etc.) \_\_\_\_\_

Other items to consider:

High Power (Including CW or peak/average power levels)

Routing Restrictions

Mate-Demate Cycles

Phase with Temperature and/or Flexure

Insertion Loss with Temperature

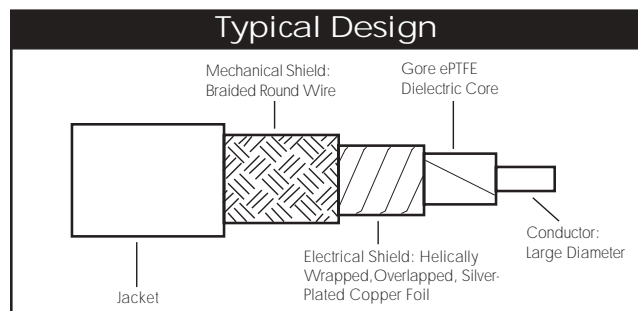
Temperature Cycling/Thermal Shock

## Section 3

### Basic Cable Options

#### Cable Construction

Size for size, GORE™ microwave coaxial cable assemblies provide the lowest insertion loss available on the market today. This is accomplished through a unique cable design that exploits the low dielectric constant, low loss tangent, and conforming nature of expanded polytetrafluoroethylene (ePTFE) dielectric. A basic cable design is shown below.



The low dielectric constant of the ePTFE dielectric core ( $\epsilon_r \cong 1.4$ ) allows the use of center conductors with nearly twice the surface area per unit length as those used in solid PTFE cables of comparable diameter, while still maintaining a characteristic impedance of 50 ohms. This provides a significant decrease in assembly insertion loss and enables higher transmission power. Our low loss tangent further reduces assembly insertion loss, particularly as the frequency of operation is increased.

The conforming nature of the ePTFE dielectric allows for the use of an electrical shield with 100% coverage. This shield consists of helically wrapped, overlapped, silver-plated copper foil. The overlaps are in intimate contact with each other and with the ePTFE dielectric. The result is minimized signal leakage from the cable and less resistance to signal flow on its inside surface, both of which further reduce assembly insertion loss. Additionally, most cables have a braided mechanical shield placed over the electrical shield to provide torsional and tensile strength.

A variety of jacket materials are available depending on the use environment. Our standard spaceflight assembly jacket is TEFZEL® material from E.I. duPont deNemours and Company Inc. This material offers superior abrasion and moisture resistance without compromising flexibility.

In addition, Gore offers materials that improve flexibility, enhance radiation resistance, are nonmagnetic, provide several levels of crush resistance, or limit the cable's range of motion. These

materials can be used in various combinations to align cable performance with your requirements.

The cable option chart on the following two pages lists all of the standard cables with their Gore part number and respective technical information.

#### Light Weight Cable Options

Gore's unmatched quality and performance are now available in a light weight version. Our newest cable constructions provide a significant decrease in weight while continuing to provide the lowest insertion loss available on the market today. These light weight cables provide the superior electrical and mechanical performance you expect from Gore's spaceflight microwave cable assemblies.

For specific information about the available cable sizes and connector options for our light weight space-qualified cables, please contact Gore .

## Section 3

### Cable Options

	<b>Base Cable</b>	<b>Max.</b>	<b>Nom.</b>	<b>Min Bend</b>	<b>Restricted</b>	<b>Nom. Cable</b>		
<b>Gore</b>	<b>in. (mm),</b>	<b>Freq.</b>	<b>Center</b>	<b>Radius *</b>	<b>Bend</b>	<b>Outer Dia.</b>		
<b>P/N</b>	<b>Special Attribute</b>	<b>GHz</b>	<b>Conductor</b>	<b>in. (mm)</b>	<b>Radius</b>	<b>in. (mm)</b>		
				<b>g/ft (g/m)</b>				
Standard Spaceflight Cable	5U	0.047 (1.2)	65	Solid	2 (6.5)	0.25 (6.4)	No	0.054 (1.4)
	8S	0.085 (2.2)	65	Solid	4 (13.1)	0.5 (12.7)	No	0.089 (2.3)
	27	0.120 (3.0)	26.5	Solid	9 (29.5)	0.5 (12.7)	No	0.123 (3.1)
	26	0.120 (3.0)	26.5	Stranded	9 (29.5)	0.5 (12.7)	No	0.123 (3.1)
	41	0.190 (4.8)	18	Solid	17 (55.8)	1.0 (25.4)	No	0.191 (4.9)
	21	0.190 (4.8)	18	Stranded	17 (55.8)	1.0 (25.4)	No	0.191 (4.9)
	5V	0.210 (5.3), Phase Stable	18	Solid	19 (62.7)	1.5 (38.1)	No	0.215 (5.5)
	42	0.290 (7.4)	18	Solid	40 (131.2)	1.5 (38.1)	No	0.286 (7.3)
	22	0.290 (7.4)	18	Stranded	40 (131.2)	1.5 (38.1)	No	0.286 (7.3)
	28	0.320 (8.1)	18	Solid	44 (144.4)	2.0 (50.8)	No	0.318 (8.1)
	5D	0.190 (4.8), High Frequency	30	Solid	17 (55.8)	1.0 (25.4)	No	0.191 (4.9)
	56	0.140 (3.6), High Frequency	40	Solid	10 (32.8)	1.0 (25.4)	No	0.138 (3.5)

\* Minimum bend radius is for multiple bends.

## Section 3 Connector Options

### Choosing the Connector

After the cable size is determined, connectors can be selected. For general applications, Gore offers several styles of miniature "push-on" and blindmate connectors as well as the standards: SMA, TNC, and Type N. For test applications, we offer 7 mm, 3.5 mm, 2.92 mm (K), 2.4 mm, 1.85 mm test connectors and other specialty adapters. Many of these connectors may be specified as either pin, socket, with a right angle, as a bulkhead, or flange mount. While the connector options are diverse, it is important to note that not all connectors are available with all cable styles. In general, the smaller connectors are configured for smaller diameter cables. Similarly, the larger connectors mate with the larger diameter cables. The table below provides a rough guide. Some of the more common connector configurations may be found in this section.

Connectors are available in three options: pin, socket, and hermaphroditic. These connectors can be referred to by several different names. Pin connectors are also known as male or plug. Socket connectors are also known as female or jack, while hermaphroditic connectors are referred to as sexless.

Base Cable O.D. in. (mm)	Miniature (See Notes)	SMA/ 2.92mm	TNC	Type N
0.047 (1.2)	■	■	□	□
0.085 (2.2)	■	■	□	□
0.120 (3.0)	■	■	■	□
0.150* (3.8)	□	■	■	□
0.190 (4.8)	□	■	■	■
0.290 (7.4)	□	■	■	■
0.320 (8.1)	□	■	■	■

■ Recommended    ■ Available    □ Not Recommended

#### NOTES:

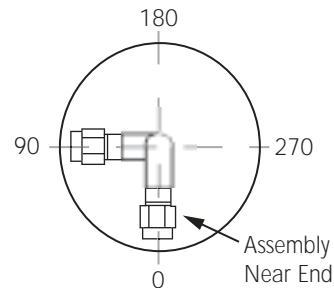
\* 0.150 in. (3.8mm) diameter cable is primarily designed for high frequency (>26.5 GHz) applications. 2.92 mm connectors are also available.

Miniature connectors encompass SMPM, SMP, MSSS® connector, and other similar types.

### Specifying Displacement of Angular Terminations

On assemblies with two angled connectors, two "D" hole panel mount connectors, or a combination thereof, the relative angular displacement of the two connectors must be specified to avoid the application of excessive torque to the assembly during installation. The shorter the assembly, the more important the correct specification becomes.

Angular displacement should be specified per the following drawing:



Position the assembly so that the near-end (end A) right angle connector (or "D" mount flat) faces downward (0° position per drawing). Sight along the assembly to determine the angular displacement of the far end (end B) right angle connector (or "D" mount flat), as compared to the near-end connector.

The standard manufacturing tolerance on a specified angular displacement is  $\pm 10^\circ$  for assembly lengths to 24 in. (609.6mm), and  $\pm 20^\circ$  for lengths longer than 24 in. (609.6mm). If relative angular displacement is not specified, we will assume that a zero degree displacement (connectors and connector flats in the same plane) is desired.



## Section 3

### Connector Options

Notes:

\* Connector drawing not available in this catalog, call Gore for specifics about the connector.

<sup>1</sup> SMP connectors are compatible and intermateable with GPO™ connectors.<sup>2</sup> GS3 connectors are compatible and intermateable with MSSS® connectors.

#### Cable Type 5U: 0.047" (1.2 mm) O.D., solid center conductor, 65 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMP <sup>1</sup>	Straight Socket	ZEM	20	43
SMP <sup>1</sup>	Right Angle Socket	ZF6	20	43
SMA	Straight Pin	S01	20	43
GS3 <sup>2</sup>	Straight Socket	ZMS	20	*
GS3 <sup>2</sup>	Right Angle Socket	ZMM	20	*

#### Cable Type 8S: 0.085" (2.2 mm) O.D., solid center conductor, 65 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin	S01	18	44
SMA	Box Right Angle Pin	S71	18	44
SMA	Clip Right Angle Pin	ZF8	18	44
SMA	Straight Bulkhead Mount Socket	R42	18	*
SMP <sup>1</sup>	Right Angle Socket	ZF6	18	44
SMP <sup>1</sup>	Straight Socket	ZEM	18	44
GS3 <sup>2</sup>	Straight Pin, Limited Detent	ZNF	22	44

#### Cable Type 27: 0.120" (3.1 mm) O.D., solid center conductor, 26.5 GHz max. freq. 26: 0.120" (3.1 mm) O.D., stranded center conductor, 26.5 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin	S01	18	45
SMA	Swept Right Angle Pin	S11	18	45
SMA	Elbow Right Angle Pin	S21	18	*
SMA	Box Right Angle Pin	S71	18	45
SMA	Clip Right Angle Pin	ZF8	18	45
SMA	Straight Bulkhead Mount Socket	R42	18	*
TNCA	Straight Pin	C01	18	45

#### Cable Type 56: 0.140" (3.6 mm) O.D., solid center conductor, 40 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
2.92 mm	Straight Pin	ZMQ	40	46
2.92 mm	Right Angle Pin	ZMR	40	46

## Section 3

### Connector Options

Notes:

\* Connector drawing not available in this catalog, call Gore for specifics about the connector.

#### Cable Type 21: 0.190" (4.8 mm) O.D., stranded center conductor, 18 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin, Vented	ZN1	18	47
SMA	Swept Right Angle Pin, Vented	ZN2	18	47
SMA	Box Right Angle Pin, Vented	ZSK	18	47
TNCA	Straight Pin, Vented	ZL5	18	47
TNCA	Swept Right Angle Pin, Vented	ZL6	18	48

#### Cable Type 41: 0.190" (4.8 mm) O.D., solid center conductor, 18 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin, Vented	ZN1	18	47
SMA	Swept Right Angle Pin, Vented	ZN2	18	47
SMA	Straight Pin, High Power	ZH8	5	47
SMA	Box Right Angle Pin, Vented	ZSK	18	47
SMA	Straight Bulkhead Mount Socket	ZL7	18	*
TNC	Straight Pin, High Power, Vented	ZLK	5	47
TNCA	Straight Pin, Vented	ZL5	18	47
TNCA	Swept Right Angle Pin, Vented	ZL6	18	48
TNCA	Elbow Right Angle Pin, Vented	ZS2	18	48

#### Cable Type 5D: 0.190" (4.8 mm) O.D., solid center conductor, 30 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
2.92 mm	Straight Pin	ZMQ	30	48
2.92 mm	Right Angle Pin	ZMR	30	48

#### Cable Type 5V: 0.210" (5.3 mm) O.D., solid center conductor, 18 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin	ZA8	18	49
SMA	Right Angle Pin	ZSK	18	49

## Section 3

### Connector Options

Notes:

\* Connector drawing not available in this catalog, call Gore for specifics about the connector.

#### Cable Type 42: 0.290" (7.4 mm) O.D., solid center conductor, 18 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin, Vented	ZN1	18	50
SMA	Swept Right Angle Pin, Vented	ZN2	18	50
SMA	Straight Pin, High Power	ZH8	5	50
SMA	Box Right Angle Pin, Vented	ZSK	18	50
TNC	Straight Pin, High Power, Vented	ZLK	5	50
TNC	Swept Right Angle Pin, High Power, Vented	ZLV	5	50
TNC	Straight Socket, High Power, Vented	ZLL	5	*
TNC	Straight Socket, High Power, Vented, Bulkhead Mount	ZPC	5	*
TNCA	Straight Pin, Vented	ZL5	18	51
TNCA	Swept Right Angle Pin, Vented	ZL6	18	51
TNCA	Elbow Right Angle Pin, Vented	ZS2	18	51
TNCA	Box Right Angle Pin, Vented	ZMB	18	51
TNCA	Straight Bulkhead Mount Socket	ZSD	18	*

#### Cable Type 22: 0.290" (7.4 mm) O.D., stranded center conductor, 18 GHz max. freq.

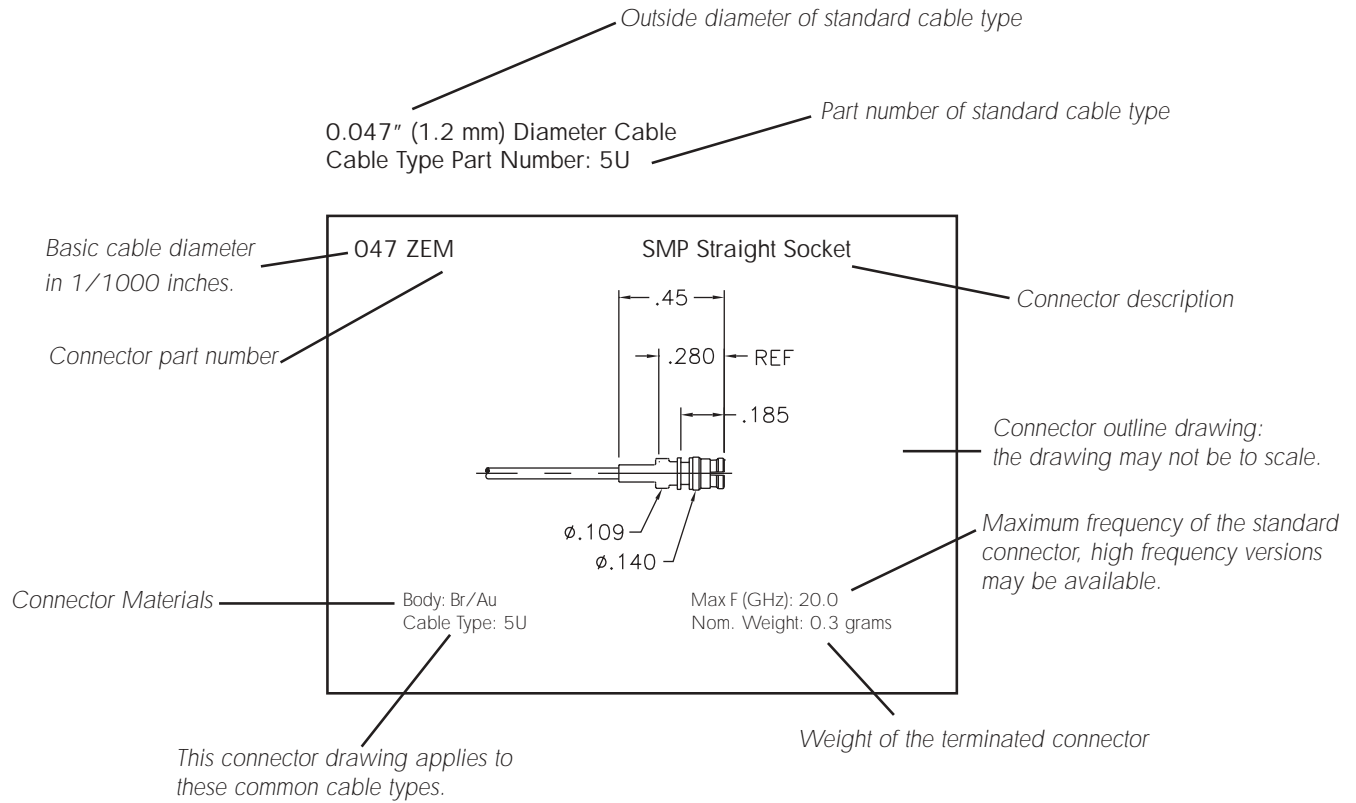
Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin, Vented	ZN1	18	50
SMA	Swept Right Angle Pin, Vented	ZN2	18	50
TNCA	Straight Pin, Vented	ZL5	18	51
TNCA	Swept Right Angle Pin, Vented	ZL6	18	51
TNCA	Elbow Right Angle Pin, Vented	ZS2	18	51
TNCA	Box Right Angle Pin, Vented	ZMB	18	51

#### Cable Type 28: 0.320" (8.1 mm) O.D., solid center conductor, 18 GHz max. freq.

Connector Type	Configuration	Gore Part Number	Max. Freq. (GHz)	Catalog Page Number
SMA	Straight Pin, Vented	ZN1	18	52
SMA	Box Right Angle Pin, Vented	ZSK	18	*
TNCA	Straight Pin, Vented	ZL5	18	52
TNCA	Box Right Angle Pin, Vented	ZMB	18	*
TNC	Box Right Angle Pin, High Power, Vented	ZLW	5	*
TNC	Straight Pin, High Power, Vented	ZLK	5	*

## Section 4

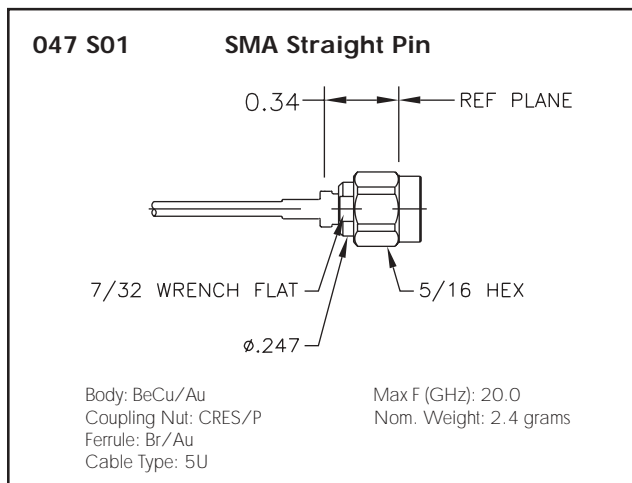
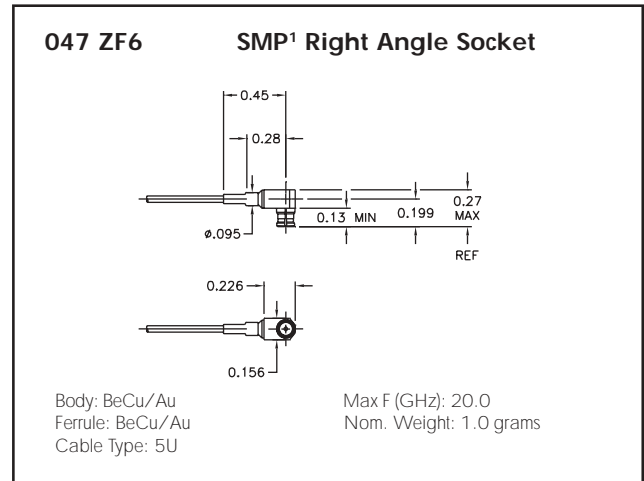
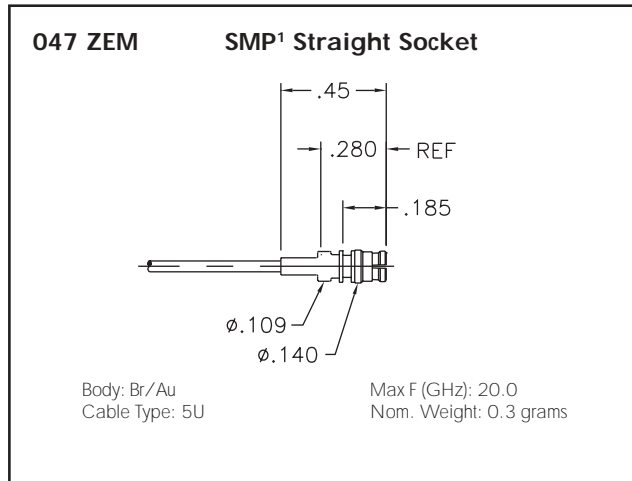
### Connector Drawings-Example



## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:  
 0.047" (1.2 mm) Diameter Cable  
 Cable Type Part Number: 5U



<sup>1</sup> SMP connectors are compatible and intermateable with GPO™ connectors.

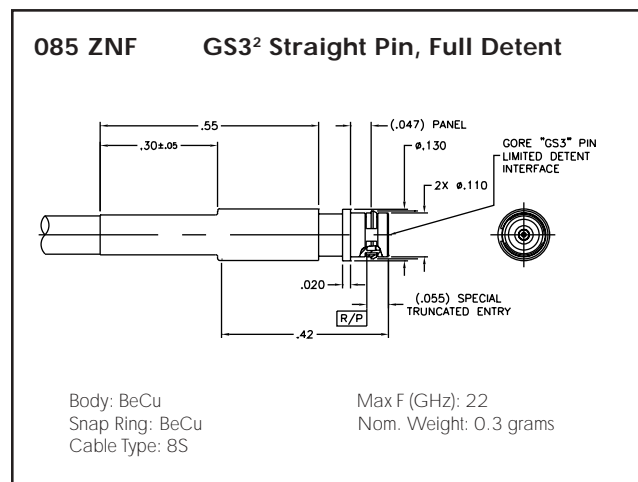
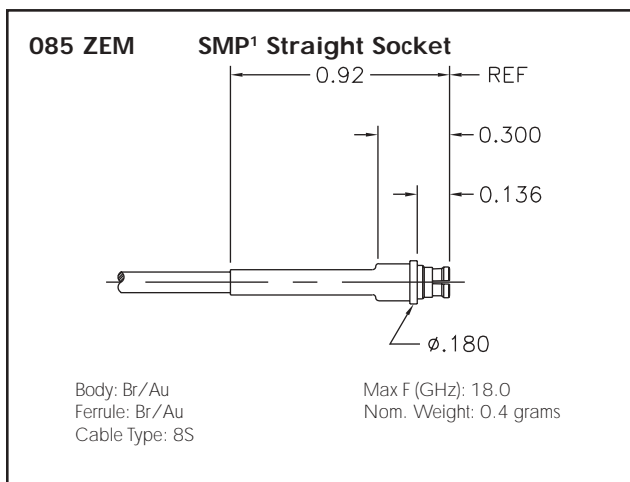
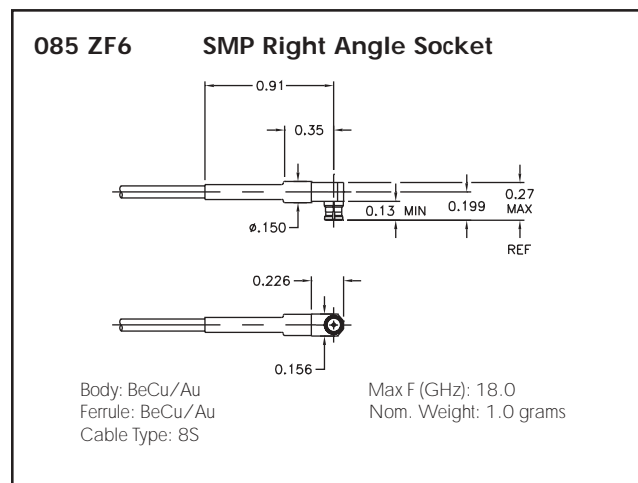
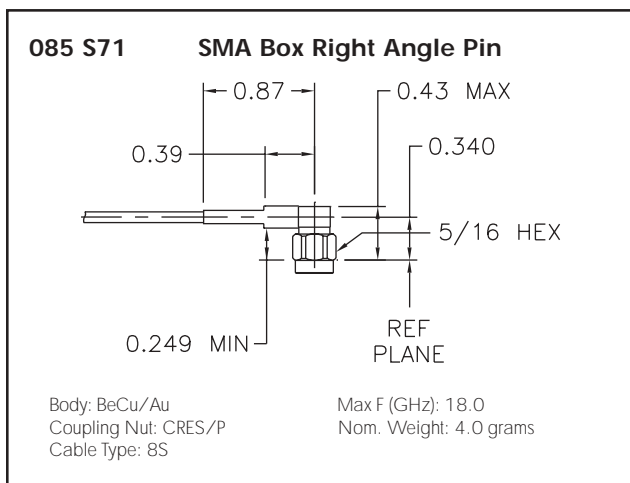
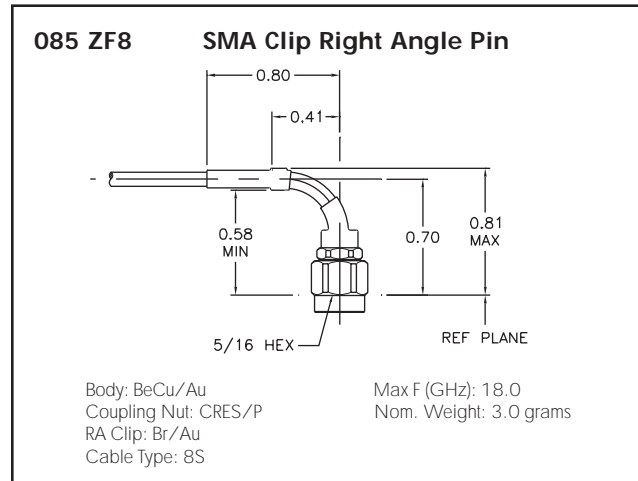
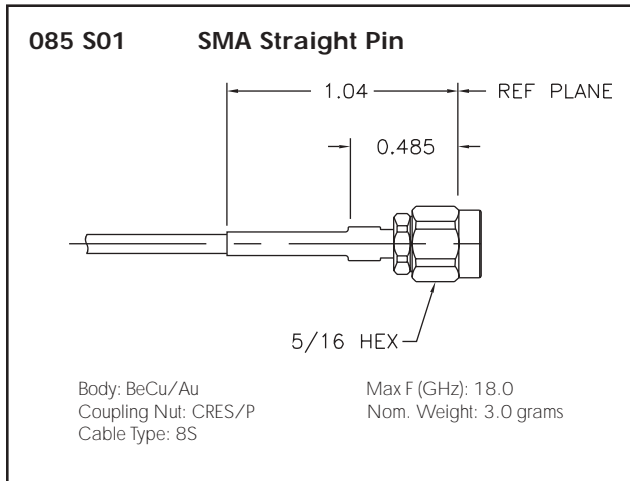
## Section 4

Note: All dimensions are nominal unless specified.

### Connector Drawings:

0.085" (2.2 mm) Diameter Cable

Cable Type Part Number: 8S



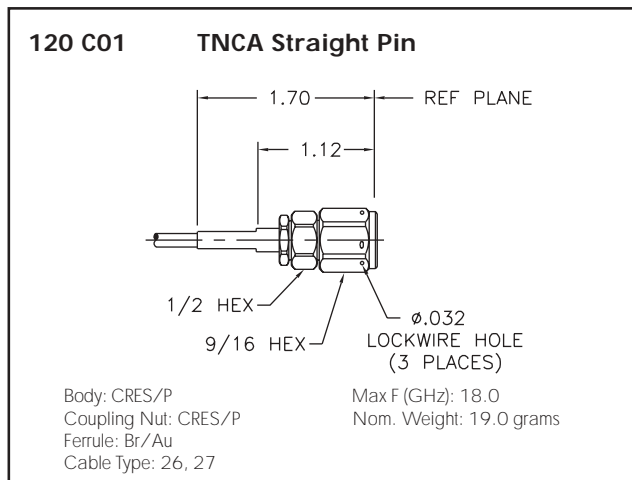
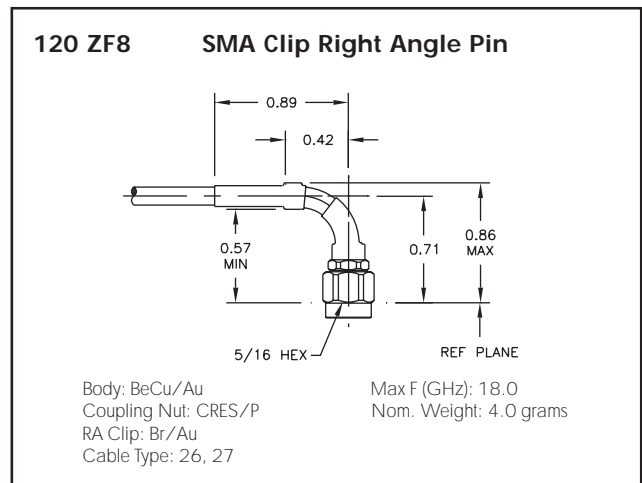
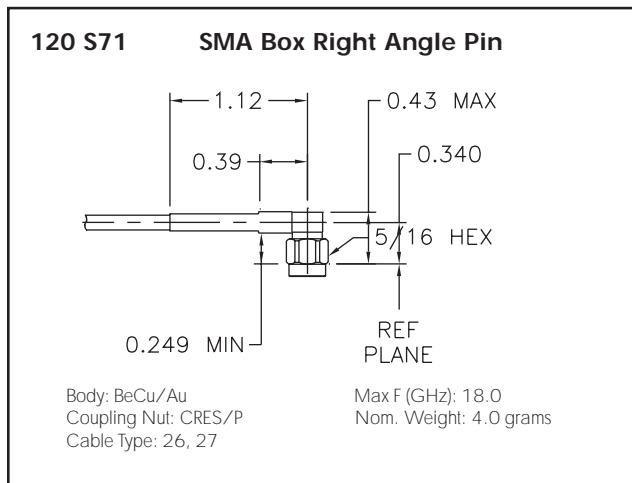
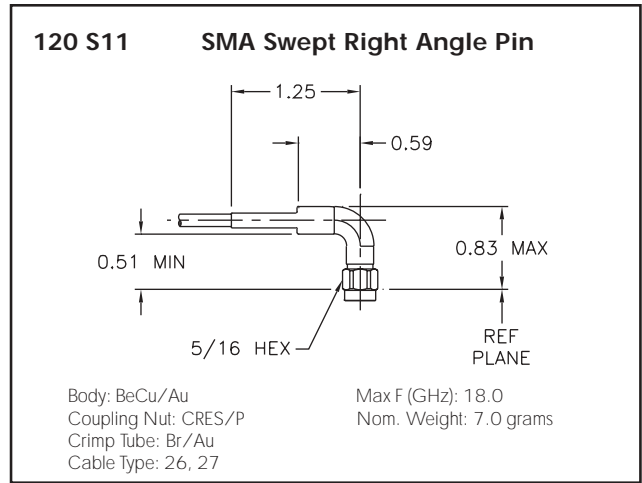
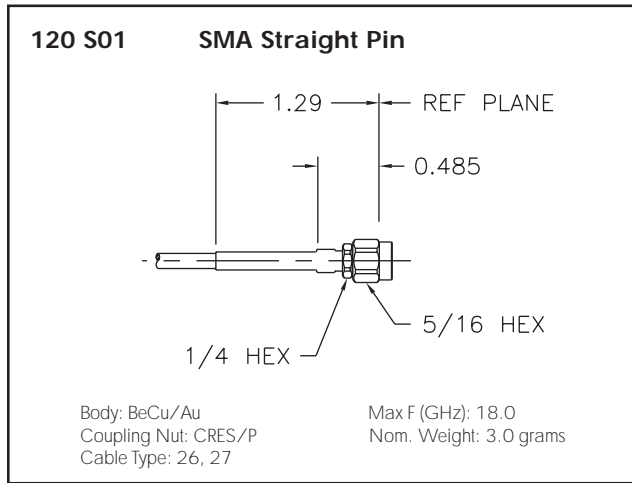
<sup>1</sup>SMP connectors are compatible and intermateable with GPO™ connectors.

<sup>2</sup>GS3 connectors are compatible and intermateable with MSSS® connectors.

## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:  
0.120" (3.1 mm) Diameter Cable  
Cable Type Part Number: 26/27



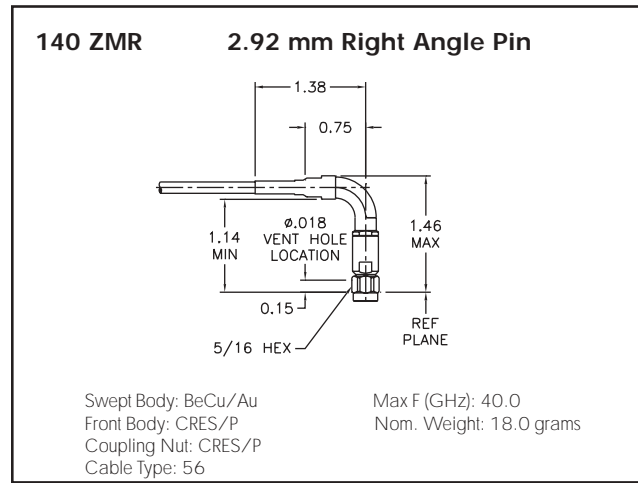
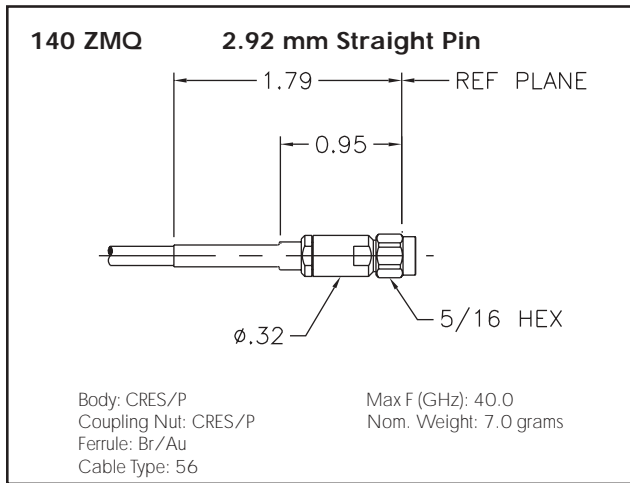
## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:

0.140" (3.6 mm) Diameter Cable

Cable Type Part Number: 56

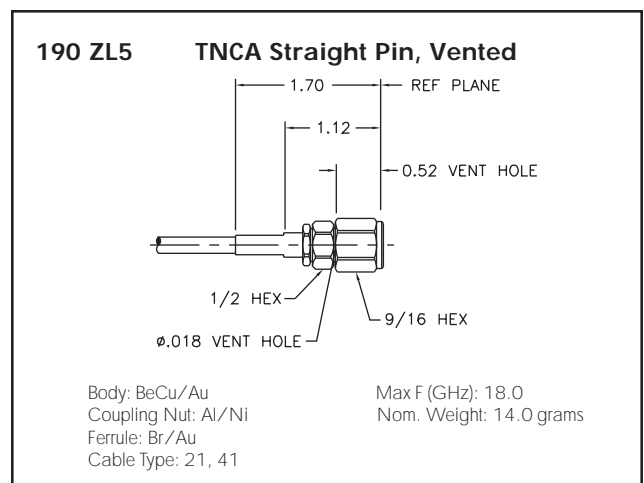
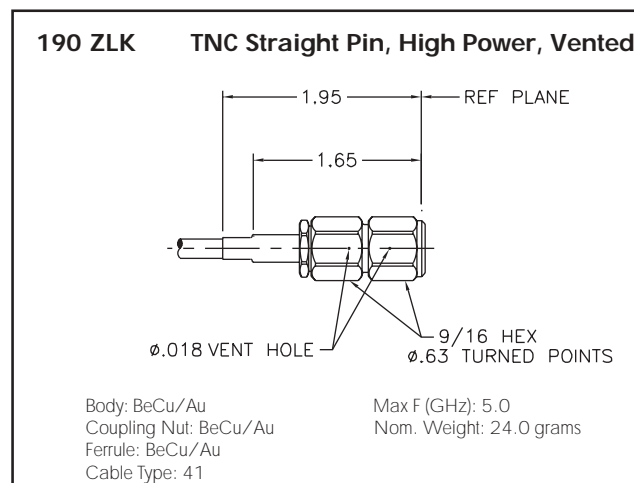
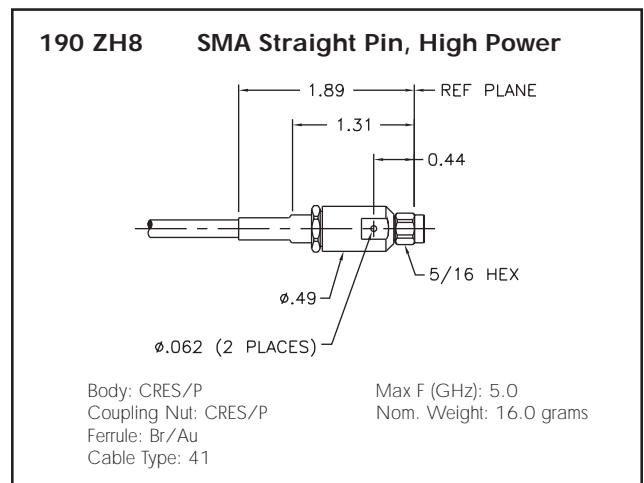
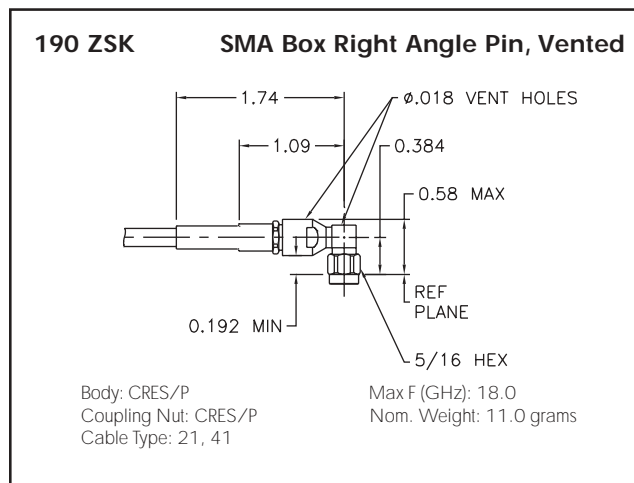
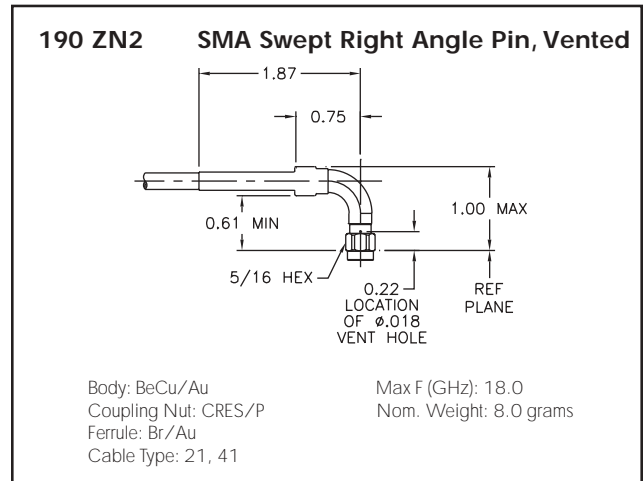
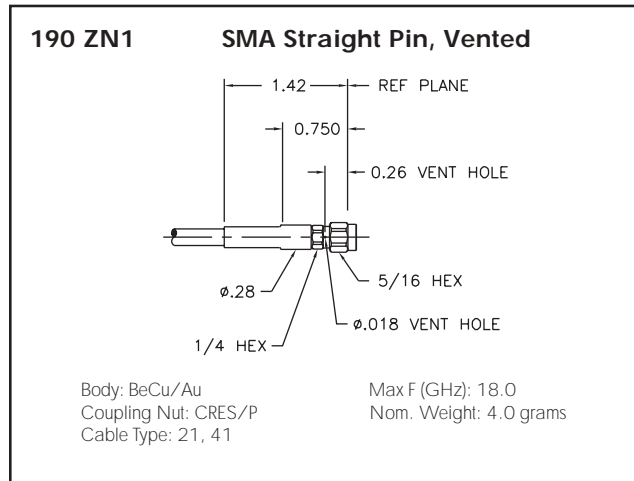




## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:  
0.190" (4.8 mm) Diameter Cable  
Cable Type Part Number: 21, 41



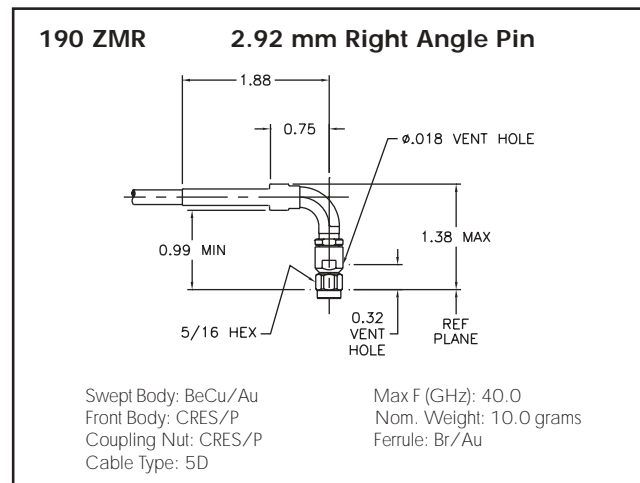
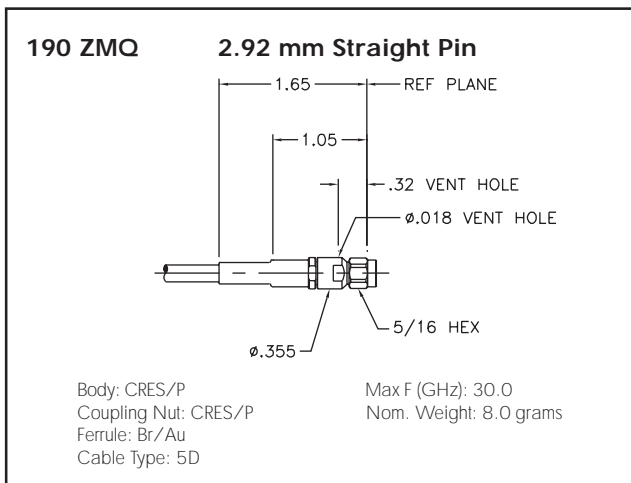
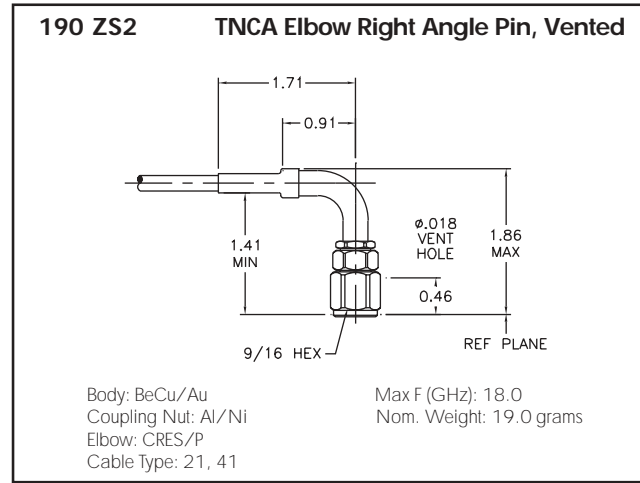
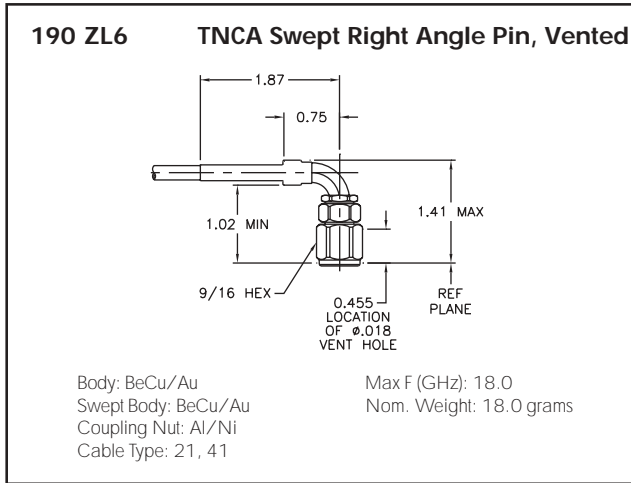
## Section 4

Note: All dimensions are nominal unless specified.

### Connector Drawings:

0.190" (4.8 mm) Diameter Cable

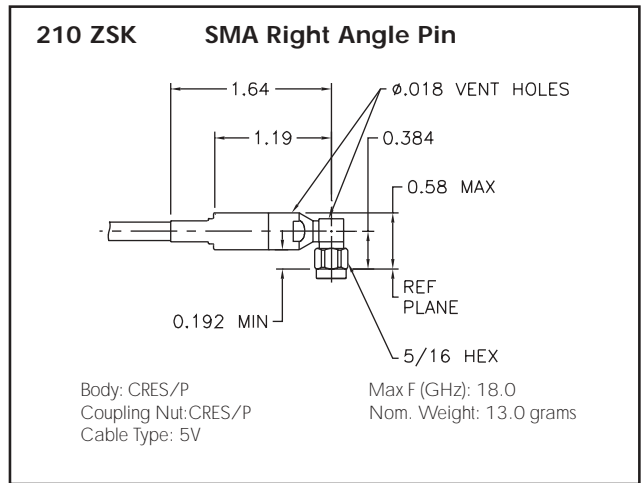
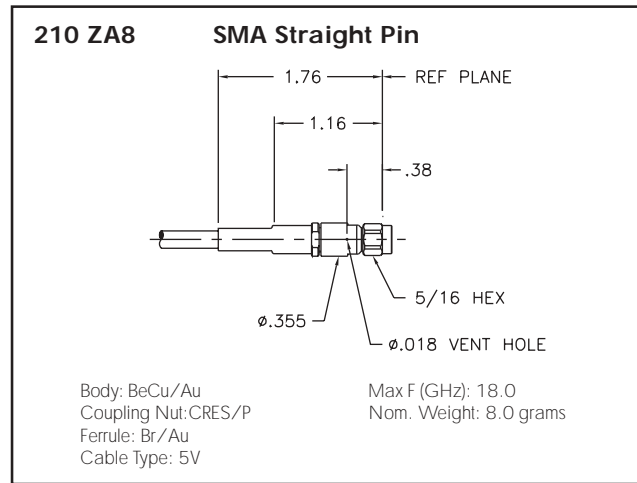
Cable Type Part Number: 21, 41, 5D



## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:  
 0.210" (5.3 mm) Diameter Cable  
 Cable Type Part Number: 5V



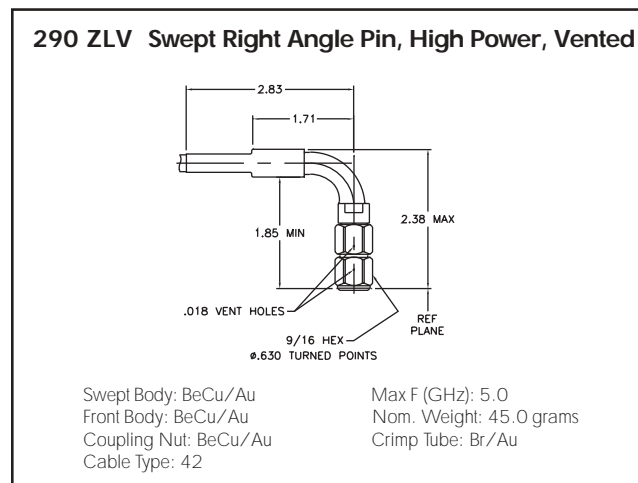
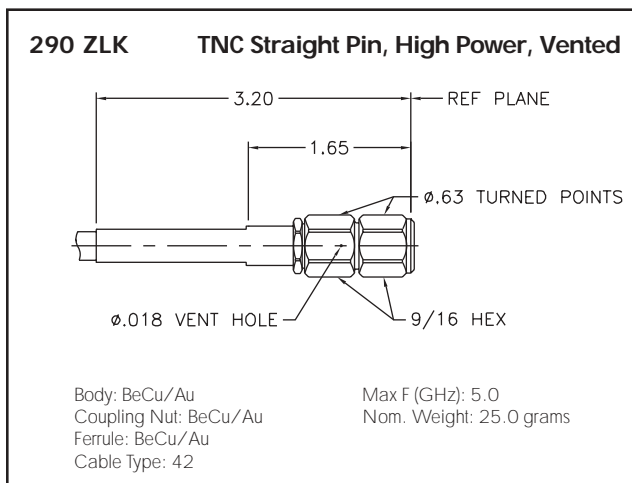
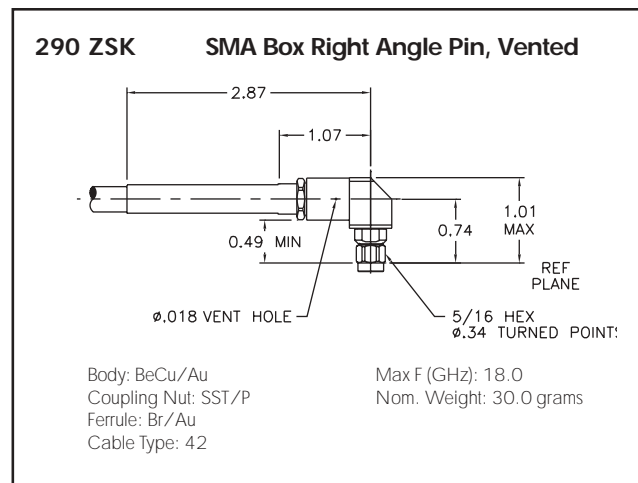
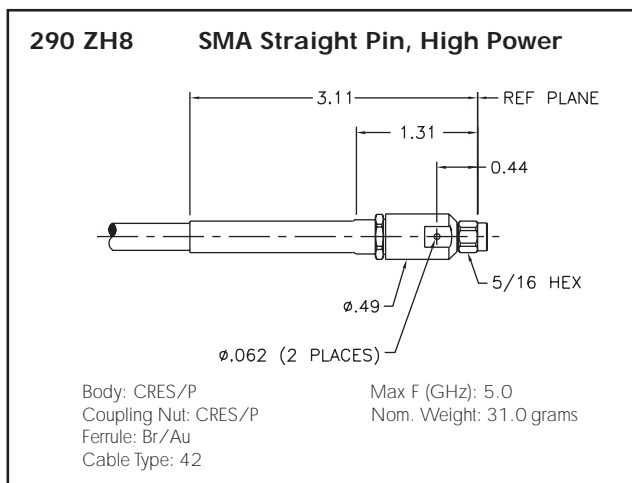
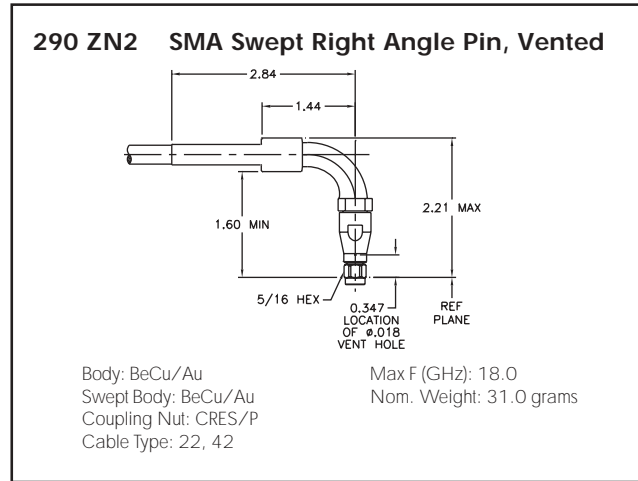
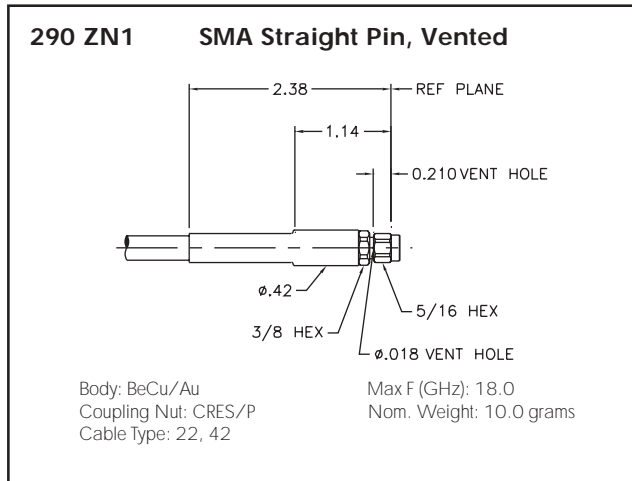
## Section 4

### Connector Drawings:

0.290" (7.4 mm) Diameter Cable

Cable Type Part Number: 22, 42

Note: All dimensions are nominal unless specified.



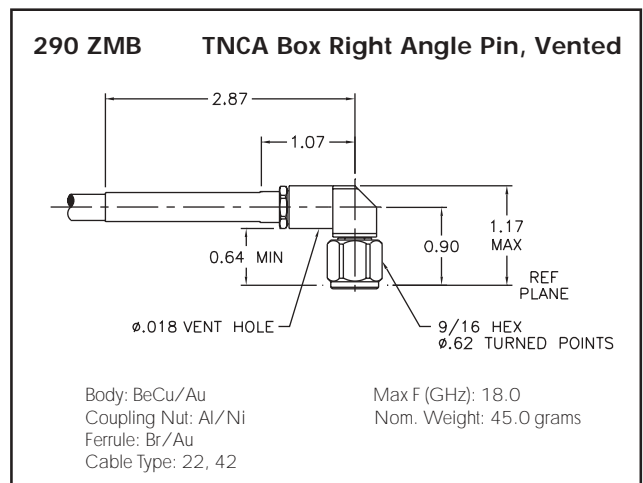
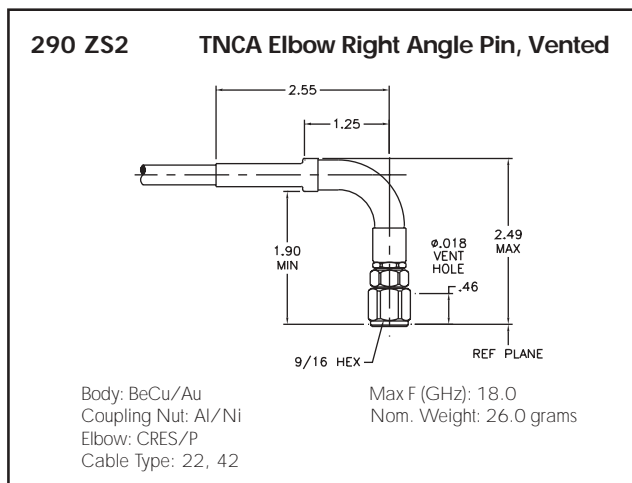
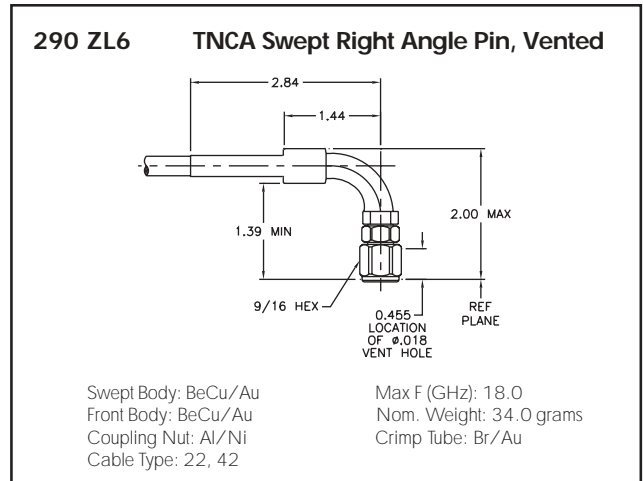
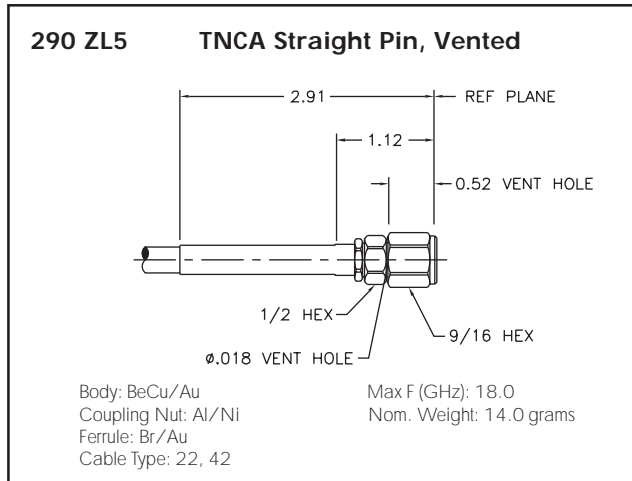
## Section 4

Note: All dimensions are nominal unless specified.

### Connector Drawings:

0.290" (7.4 mm) Diameter Cable

Cable Type Part Number: 22, 42



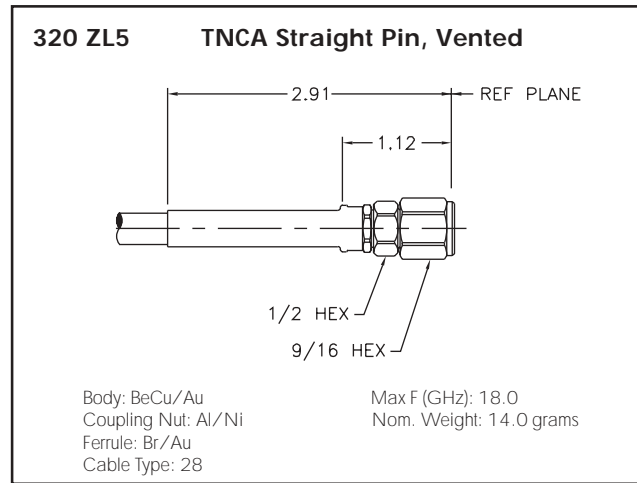
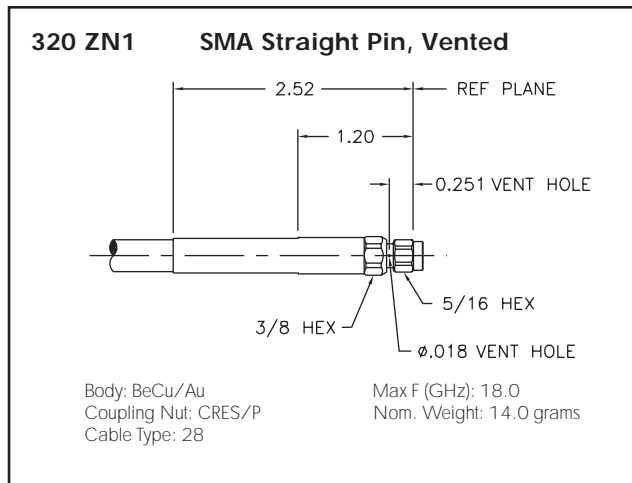
## Section 4

Note: All dimensions are nominal unless specified.

Connector Drawings:

0.320" (8.1 mm) Diameter Cable

Cable Type Part Number: 28



## Section 5

### Mating and Retention Characteristics

#### Mating and Retention Characteristics

Interface dimensions shall meet the requirements of MIL-PRF-39012 and MIL-STD-348A for connectors listed in those specifications. For connectors not listed therein, connectors shall conform with MIL-T-81490, MIL-C-87104, IEEE STD 287, or special counterparts, as applicable. Interface dimensions and tolerances for connectors not listed in MIL-PRF-39012 or MIL-STD-348A are available upon request. The characteristics listed in the table below are valid when tested per MIL-PRF-39012.

Mating and Retention Characteristics							
Characteristic (Per MIL-PRF-39012)	SMP <sup>1</sup> SMPM <sup>2</sup>	2.92 mm	SMA	TNC	TNCA	Type N	Precision N
Recommended mating torque lbf-in (N-m):							
without gasket	NA	7-9 (0.8-1.0)	7-9 (0.8-1.0)	4-6 (0.5-0.7)	7-9 (0.8-1.0)	6 (0.7)	12-15 (1.4-1.7)
with gasket*	NA	7-10 (0.8-1.1)	7-10 (0.8-1.1)	12-20 (1.4-2.3)	12-20 (1.4-2.3)	12-20 (1.4-2.3)	12-20 (1.4-2.3)
Max. torque to engage/disengage lbf-in (N-m)	NA	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	6 (0.7)	6 (0.7)
Min.coupling proof torque lbf-in (N-m)	NA	15 (1.7)	15 (1.7)	20 (2.3)	20 (2.3)	30 (3.4)	30 (3.4)
Min. cable retention force lbf (N)							
Type 5U	10 (44.5)	NA	NA	NA	NA	NA	NA
Type 8S	15 (66.8)	NA	15 (66.8)	NA	NA	NA	NA
Type 26, 27	NA	NA	30 (133.5)	30 (133.5)	30 (133.5)	30 (133.5)	30 (133.5)
Type 21, 22, 41, 42, 28	NA	NA	50 (222.5)	50 (222.5)	50 (222.5)	50 (222.5)	50 (222.5)
Type 56, 5D	NA	30	NA	NA	NA	NA	NA

\* Lower torque values should be used for static applications, while higher values are suggested for more dynamic applications, e.g., with vibration and thermal cycling.

<sup>1</sup> SMP connectors are compatible and intermateable with GPO™ connectors.

<sup>2</sup> SMPM connectors are compatible and intermateable with GPPO™ connectors.

## Section 5

### Care & Handling

#### Care and Handling

##### Introduction

Microwave cable assemblies, regardless of manufacturer or type, will provide you with better service when proper care and usage are maintained. Your equipment will perform better, last longer, and your measurements will be more accurate and repeatable.

Microwave cable assemblies are precision components. Proper use, routine inspection of the complete assembly, and cleaning of the connectors are extremely important.

##### Initial Connector Mating

Never attempt to mate connectors before first aligning their center lines when applicable. Due to necessary play in the coupling nut mechanism, or coupling arrangement, it is often possible to mate without connector pins aligned. This can result in bent pins and destroyed dielectric inserts.

Depending on the connector type, it is often possible to "feel" whether or not the pins are aligned. If you are reasonably sure that they are, proceed by gently mating the coupling nut until it bottoms. If during this process the nut is difficult to turn, it may be due to one of the following:

- The pins are not aligned
- The coupling nut is cross-threaded
- The connector (or its mate) has been damaged by excessive torque

Stop and determine the reason. To proceed without doing so will risk destruction of the assembly and/or the mating connector.

Never hold a pin connector coupling nut stationary while screwing the socket counterpart into it. This will ultimately destroy both connectors, as such rotation will wear away plating and score both the outer interface rim and the pin. If the pins lock up, serious damage can be induced within the device and/or the assembly. This is a very common form of damage, since it is a natural way to mount an adapter to an assembly.

##### Connector Torque

Prior to tightening a connector to the proper torque, grasp the body of the connector firmly to keep it from rotating. As the pin coupling nut becomes tighter, frictional forces will increase and the nut and body will tend to lock up, which in turn will cause the body to rotate with the nut. If allowed, this rotation will wear away

plating and score both the outer interface rim and the pin of both connectors.

Additionally, unwanted torque will be transferred to the cable assembly.

Always use a torque wrench that is permanently set to the correct torque value to mate a connector with wrench flats. Tighten slowly until the wrench "snaps" (fast tightening overrides the torque-limiting capability of the wrench). Resist the urge to snap the wrench more than once; this can be likened to an uncontrolled impact wrench and can cause over torque.

To mate connectors with knurled nuts, use only your fingers. If you feel that this does not provide sufficient tightness, you should use hex-nut connectors and torque wrenches. Never use pliers to tighten any connector.

Depending upon the connector, over-torque can cause damage to connectors in a variety of ways:

- Mushroomed outer interface shells
- Mushroomed pin shoulders
- Recessed or protruding pins
- Recessed or protruding dielectrics
- Bent pins
- Chipped plating
- Coupling nut retaining ring damage
- Damage to coupling threads

When an assembly connector is over-torqued, not only is it damaged, but so is the connector to which it is mated.

Once a connector has been damaged, it will continue to damage each and every connector to which it is mated. In most cases, it will also give you poor system performance, erroneous data, etc.

##### Push-On and Blindmate Connectors

Self-sustained coaxial connectors have a mechanism which provides the necessary mating force to bring and hold the connecting surface together. Some self-sustained connectors use either a screw thread or a bayonet to provide the mating force. Push-on coaxial connectors use a self contained latching or detent mechanism to provide positive mating force. A simple push is all that is required to mate the connection. Removal is facilitated by a special pry bar-like tool.



## Section 5

### Care & Handling

Push-on connectors are well suited for high density applications where small diameter, smaller than 0.100" (2.5 mm), coax cables are used. Examples of push-on connectors are the MSSS® interface and the full and partial detent versions of the SMP and SMPM.

Blindmate coaxial connectors utilize an external structure to provide proper location and mating force. These structures are often referred to as rack and panel connectors. In some cases a spring mechanism provides axial force and a float mechanism provides radial positioning for the blindmate connector. Typical applications for blindmate connectors are multiple coaxial lines or rack and panel. Examples of blindmate connectors are the smooth bore SMP and SMPM.

## Section 5

### Cable Handling and Assembly Inspection

#### Cable Handling

Failure to observe the minimum bend radius specified for the cable will destroy it. Be alert to tight bends where they are not necessarily obvious, for example, at the end of connector strain relief tubing, or at the end of marker tubing. Remember, although the angular displacement of the cable may be slight, the bend radius at the point of angular departure may be far smaller than that recommended.

Cable assemblies are normally stored in a coiled configuration. Cable "set" can be minimized by using large coil diameters (1 or 2 ft (304.8mm or 609.6mm)). When you are ready to use them, unroll them; never just pull the loops out. Similarly, re-roll them when you put them away.

Cable Type	Single Bend Radius in. (mm)	Multiple Bend Radius in. (mm)
5U	0.125 (3.2)	0.25 (6.4)
8S	0.25 (6.4)	0.50 (12.7)
26/27	0.30 (7.6)	0.50 (12.7)
56	0.50 (12.7)	1.00 (25.4)
21/41	0.50 (12.7)	1.00 (25.4)
22/42	0.75 (19.1)	1.50 (38.1)
28	0.90 (22.9)	2.00 (50.8)

Avoid pinching, crushing, or dropping objects on assemblies. Dragging cable over sharp edges will tend to flatten one side. Additionally, it is highly likely that the minimum bend radius will be exceeded.

Never pull equipment around by the assemblies and never expect the assemblies to support equipment or devices.

For holding cable in place, the use of toothed, rubber-lined "P-clamps" is recommended. If tie-wraps must be used, use the widest possible wrap and the lowest setting on the gun to reduce pressure to the lowest possible level.

#### Inspection of Assemblies

First, inspect the cable itself for dents, twists, flattening, abraded jacket, or other signs of abuse.

Wrinkles in the jacket are an indication that the minimum bend radius has been exceeded. This may occur at or near the connectors and marker tubes.

Next, inspect the connector interfaces using magnification for

the following:

- Bent pins
- Bent or missing pin tines
- Worn or chipped plating
- Damaged or displaced dielectric inserts
- Thread damage
- Folded or mushroomed outer interface rims
- Mushroomed pin shoulder or tine ends
- Score lines on pins and outer interface rims
- Recessed or protruding pins

If any of the above damage is noted, the assembly should be replaced before its further use results in equipment damage.

If, during the preceding inspection, debris is found in the interface, clean it as directed. (It may be helpful to clean the connectors prior to inspection to make subtle damage more apparent.)

Debris may take the form of:

- Plating chips or other metal particles
- Dust or dirt
- Oily films
- Other of unknown character or origin

Do not forget to inspect the mating connectors.

#### Connector Interface Cleaning

Do not use chlorinated solvents, particularly those in pressurized cans. These solvents are extremely penetrating and sometimes ruin otherwise good devices and assemblies.

Moisten a lint free synthetic material swab, such as polyester, with isopropyl alcohol. Roll the swab on a paper towel to remove excess (the swab should only be dampened). Use the dampened swab to wipe away debris (do not try to dissolve debris by over wetting the swab).

Repeat the cleaning process using additional swabs as necessary. If metallic particles are embedded in the dielectric, use an eyeglass and a sharp pick to dislodge them.

When satisfied that the interfaces are clean, blow them dry with dry compressed air or, preferably, dry nitrogen (pressurized spray cans work well). Do not use your breath: it is moisture-laden and alcohol absorbs moisture.

Do not forget to clean the mating connectors. They may be the source of the debris.

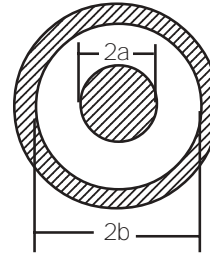
## Section 6

### Constants & Formulas

$\mu$	=	Permeability
$\epsilon$	=	Dielectric Constant
$c$	=	Speed of Light $2.9979 \times 10^8 \text{m/s}$
$C$	=	Capacitance
$L$	=	Inductance
$L_E$	=	Electrical Length
$Z_0$	=	Characteristic Impedance
$R_L$	=	Return Loss
VSWR	=	Voltage Standing Wave Ratio
$V_p$	=	Phase Velocity
$\lambda$	=	Wavelength = $\frac{c}{f}$ (Free Space)
$f$	=	Frequency
$\Gamma_L$	=	Reflection Coefficient
$\epsilon_0$	=	$\frac{1}{\mu_0 c^2} = 8.85 \times 10^{-12} \text{F/m}$ (Free Space)

$\mu_0$	=	$4\pi \cdot 10^{-7} \text{H/m}$ (Free Space)
$Z_0$	=	$\sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$ (Free Space)
$\epsilon_r$	=	1.45 for ePTFE
	=	2.1 for solid PTFE (TEFLON®)
	=	$\frac{\epsilon}{\epsilon_0}$

Conventional Coaxial Line:



2a is the OD of the center conductor.  
2b is the ID of the outer conductor.

Thermal Conductivity & Expansion Coefficient				
Material	W/cmK	Density (g/cm <sup>3</sup> )	Thermal Coefficient of Linear Expansion (ppm/°C)	Electrical Resistance (ρ)
ePTFE	≈ 0.0015	0.7	*	N/A
Copper (cu)	4.01	8.9	17	1.5
Aluminium (Al)	2.37	2.7	23	2.0
Silver (Ag)	4.29	10.5	19	1.5
Gold (Au)	3.17	19.3	14	1.5
TEFZEL® Material	0.0019	2.12	140	N/A

\* The thermal expansion coefficient of ePTFE is a function of its boundary conditions.

W/cmK=Btu/(hr•ft•°F)•1.729

Emissivity for TEFZEL material = 0.85 to 0.92

## Section 6

### Constants & Formulas

Voltage Standing Wave Ratio	$VSWR = \frac{1 +  \Gamma_L }{1 -  \Gamma_L } = \frac{E_{max}}{E_{min}} \quad  \Gamma_L  = \frac{VSWR - 1}{VSWR + 1}$
Insertion Loss	$I_L(dB) = P_{in} (dBm) - P_{out} (dBm) = 10 \log_{10} \frac{P_{in}}{P_{out}}$
Return Loss	$R_L(dB) = P_{in} (dBm) - P_{refl} (dBm) = 20 \log_{10} \left( \frac{1}{ \Gamma } \right)$
Reflection Coefficient	$ \Gamma ^2 = \frac{P_{refl}}{P_{in}}$
Skin Depth	$\delta = \sqrt{\left( \frac{\rho}{\pi f \mu_0 \mu_r} \right)}$

### Coaxial - Line Characteristics

Parameter	Expression	Units
Capacitance	$C = \frac{55.556 \epsilon_r}{\ln(b/a)}$	pF/m
Inductance	$L = 200 \ln b/a$	nH/m
Characteristic Impedance	$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln(b/a) = \sqrt{\frac{L}{C}}$	$\Omega$
Phase Velocity	$V_p = \frac{3 \cdot 10^8}{\sqrt{\epsilon_r}} = \frac{1}{\sqrt{LC}}$	m/s
Delay	$\tau_d = 3.33 \sqrt{\epsilon_r}$	ns/m
Dielectric Attenuation Constant	$\alpha_d = 27.3 \sqrt{\left( \epsilon_r \frac{\tan \delta}{\lambda_0} \right)}$	dB/unit length
Conductor Attenuation Constant s for silver = $6.17 \times 10^7$ mho/m	$\alpha_c = \frac{8.686}{Z_0} \sqrt{\left[ \frac{\mu_r f}{16\pi} \left( \frac{1}{a \sqrt{\sigma_a}} + \frac{1}{b \sqrt{\sigma_b}} \right) \right]}$	dB/unit length
Cutoff Wavelength for TE <sub>11</sub> mode	$\lambda_c \approx \pi \sqrt{\epsilon_r (a+b)}$	unit of a or b

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## Section 7

### Spaceflight Heritage

GORE™ microwave assemblies are used in spaceflight applications for guidance control, data links, telemetry, and other purposes. These assemblies withstand the extraordinary stresses of launch and the harsh environment of space. Along with many classified programs that cannot be identified, GORE assemblies are used or specified on the following programs with 100% flight history success.

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AUSSAT	INDOSTAR	SPACENET
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ECHOSTAR	MARS OBSERVER	UARS
EMBRATEL	MMS	UHF FOLLOW-ON
ENVISAT	MORELOS	WESTAR
EOS	MSG	WHITETAIL
ERS	NAHUEL	WIDEBAND GAPFILLER
EURECA	NATO	WIRE
EUROSAT	OLYMPUS	
EUTELSAT	PALAPA	
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## 100% Flight History Success

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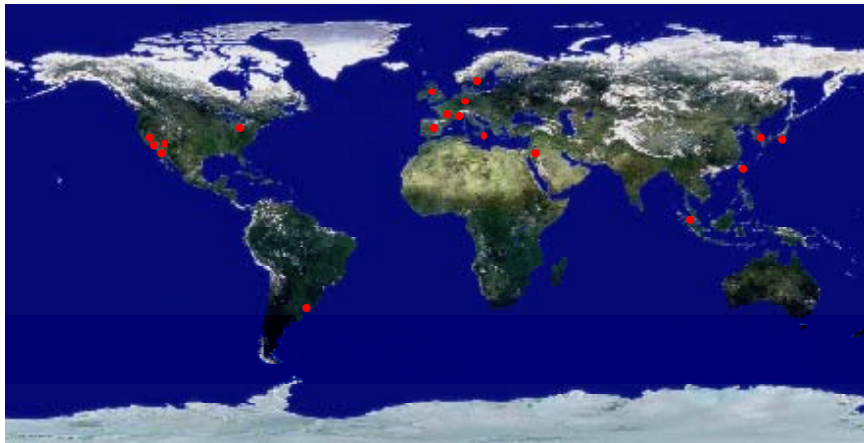
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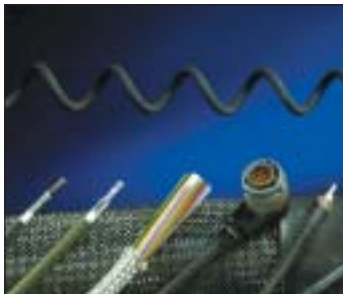
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