Semi-Rigid Cable
Benchmark in RF Performance
Overview

Why use a Semi-Rigid cable?

A coaxial cable is considered "semi-rigid" when the outer conductor is formed from a solid seamless metal tube with a diameter generally less than 0.5 inch. The majority of Semi-Rigid cables have an outer diameter between 0.034 and 0.250 inch. Semi-Rigid cables are available off the shelf to fit almost any application requiring the near perfect transmission of RF/microwave energy.

Semi-Rigid coaxial cable finds applications from very low frequencies through 110 GHz.

Almost any system operating above 500 MHz and in need of good operational performance and total shielding should use Semi-Rigid coaxial cable. Semi-Rigid coaxial cable assemblies are used in defense electronics, test & measurement instrumentation, medical electronics, telecommunications, and space flight systems among other precision applications. In componentry, Semi-Rigid coaxial cable is used in oscillators, amplifiers, printed circuit boards, delay lines, and capacitor sections.

Why Compromise?

There are several principal reasons Semi-Rigid cable is the benchmark by which all other RF/microwave cables are measured:

» No other cable can match the shielding, attenuation, and return loss performance in the compact configuration of a Semi-Rigid cable.

» The availability of connectors from a variety of manufactures along with the ease of connector installation makes Semi-Rigid cable an easy choice for any RF/microwave engineer.

» Semi-Rigid cables do not require bulky bend restrictors or lengthy crimp sleeves behind the connector, allowing the cable to be formed into the tightest configurations without using a lesser performing right angle connector.

» Because Semi-Rigid cable assemblies can be preformed to exacting dimensions, precise cable routing and maximum packaging density is achieved in the system with zero crosstalk issues between lines.

Additionally, electromagnetic interference (EMI) is a growing concern at all levels in any electronic system. A significant contributor to EMI problems can be the cables, especially flexible cables after formed into their final configuration. The solid seamless tube outer conductor of a Semi-Rigid cable creates the near perfect Gaussian surface eliminating any risk of RF leakage in or out of the cable. As shown in Figure 1, actual measurements of Semi-Rigid cable RF leakage indicate performance levels greater than -130 dB to 8 GHz and -100 dB to 18 GHz.

Figure 1 – Typical Semi-Rigid cable RF Shielding
The Center Conductor Selection Guide

How to Select a Semi-Rigid Cable

Coaxial cable attenuation is primarily dependent on the materials and size. Cable construction can contribute negatively, for example, stranded center conductors and braided outer shields have considerably more loss than a solid center and outer conductor.

The Center Conductor

The center conductor is either a solid or stranded metal wire which acts as the primary electrical signal carrier for any coaxial cable. Most attenuation occurs at the surface of the center conductor due to the “skin effect” of microwave signals, making the finish or plating a very important element. Stranded center conductors are generally only used in flexible cable constructions for added flexibility and longer flex life. Since flexibility is not a concern, 99% of Semi-Rigid cables utilize a solid center conductor.

Silver plated copper (SPC) per ASTM B-298 and silver plated copper clad steel, also referred to as silver plated copper weld (SPCW) per ASTM B-501, are the two most common Semi-Rigid cable center conductor materials. Silver plating, besides being an excellent electrical conductor, prevents oxidization during manufacture and improves the solderability of the finished cable. Stainless steel and beryllium copper are also used when low thermal conductivity is a priority. Other materials, including many copper alloys are available on special request.

Table 1 illustrates the advantages and disadvantages of various common center conductor materials.

Table 1 - Center Conductors

<table>
<thead>
<tr>
<th>Center Conductor Material</th>
<th>DC Resistance (Ω·in²/ft)</th>
<th>Microwave Frequency Conductivity Compared to Copper (Ratio)</th>
<th>Thermal Conductivity</th>
<th>Used with “Pin Less” Connector</th>
<th>Magnetic</th>
<th>Ease of Soldering</th>
<th>RoHS Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver Plated Copper</td>
<td>10.4</td>
<td>1.0:1</td>
<td>Very High</td>
<td>No</td>
<td>Yes</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>Silver Plated Copper Clad Steel</td>
<td>93.1</td>
<td>1.0:1</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>464.6</td>
<td>44.8:1</td>
<td>Very Low</td>
<td>No</td>
<td>Slightly</td>
<td>Poor</td>
<td>Yes</td>
</tr>
<tr>
<td>Silver Plated Beryllium Copper</td>
<td>41.7</td>
<td>1.0:1</td>
<td>Low</td>
<td>No</td>
<td>No</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The Dielectric

The insulating material between the center and outer conductor maintains the spacing and geometry of the cable and ensures mechanical integrity during forming and bending. A significant portion of the transmission losses are caused either directly or indirectly by the dielectric. Cables with a low dielectric constant, while offering lower bulk dielectric losses, also require a larger center conductor diameter to maintain the same characteristic impedance. The larger center conductor can substantially lower the overall cable attenuation. In addition, the dielectric determines the velocity of propagation, temperature range, power rating, phase and amplitude stability, and contributes to cable flexibility.

The most commonly used dielectric for Semi-Rigid cable is Polytetrafluoroethylene (PTFE), in both full density and low density (a.k.a. low loss or micro-porous) forms. PTFE is an excellent choice for a cable dielectric due to its low reactivity to chemicals, an operating temperature that can withstand the heat of soldering, and low dielectric constant that is stable at microwave frequencies.

Full density PTFE meets all the requirements of MIL-DTL-17, Type F-1. Most Semi-Rigid cables utilize full density PTFE in the solid form, however, larger Semi-Rigid cables are also available in a spline configuration. Spline dielectrics have a thin layer of material around the center conductor with 3 to 5 spokes projecting radial outward. A majority of a spline insulator is air which yields an effective relative dielectric constant as low as 1.3. It should be noted that spline dielectrics are generally considerably more expensive than their solid PTFE counterparts.

Low density PTFE utilizes the same base material as the full density version, but processed differently. As a result of the lower density, both the dielectric constant and dissipation factor are reduced, leading to an overall lowering of the cable attenuation. Low density PTFE is also more thermally stable when compared to solid PTFE. The trade-off being that anytime the dielectric density is reduced, the mechanical integrity is also reduced. As a result, cables employing a low density or spline dielectric will have larger minimum bend radii when compared to the solid full density versions.

Fluorinated Ethylene Propylene (FEP) and Perfluroalkoxy (PFA) are two other dielectrics that are sometimes used when very thin walls are required like those on low impedance cables. Both FEP and PFA have properties that are similar to PTFE.

Other materials, including polyethylene are available on special request.

Table 2 summarizes the performance of the common Semi-Rigid cable dielectric materials.

<table>
<thead>
<tr>
<th>Dielectric Material</th>
<th>Dielectric Constant</th>
<th>Dissipation Factor</th>
<th>Phase Stability vs. Temperature</th>
<th>Max Service Temp. (°C)</th>
<th>Typical Max Cable Operating Temp. (°C)</th>
<th>Thermal Stability</th>
<th>RoHS Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid PTFE</td>
<td>2.03</td>
<td>0.0002</td>
<td>Good</td>
<td>260</td>
<td>125</td>
<td>Good</td>
<td>Yes</td>
</tr>
<tr>
<td>Spline PTFE</td>
<td>1.35</td>
<td>0.0001</td>
<td>Very Good</td>
<td>260</td>
<td>250</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>Low Density PTFE</td>
<td>1.70</td>
<td>0.0001</td>
<td>Very Good</td>
<td>260</td>
<td>250</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>FEP</td>
<td>2.05</td>
<td>0.0010</td>
<td>Good</td>
<td>204</td>
<td>125</td>
<td>Good</td>
<td>Yes</td>
</tr>
<tr>
<td>PFA</td>
<td>2.06</td>
<td>0.0033</td>
<td>Good</td>
<td>260</td>
<td>125</td>
<td>Good</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The Outer Conductor

The outer conductor serves many purposes. It is the electrical shield which contributes to cable attenuation and controls RF leakage. Through precision mechanical tolerances, the outer conductor minimizes return loss (VSWR) by maintaining a constant characteristic impedance. The outer conductor is the primary strength member that keeps connectors firmly attached to the cable. It provides environmental protection and determines the flexibility or how easy the cable can be formed or bent.

The most commonly used materials are copper and aluminum due to their low DC resistance. These materials can be in many forms such as tube for Semi-Rigid cable, tin coated braid for conformable cable, or a foil in high performance flexible cables. Material selection typically involves trade-offs between electrical performance, size, and flexibility.

*Table 3 highlights the attributes of the most common Semi-Rigid cable outer conductors.*

<table>
<thead>
<tr>
<th>Outer Conductor Material</th>
<th>DC Resistance (Ω·in²/ft)</th>
<th>Microwave Frequency Conductivity Compared to Copper (Ratio)</th>
<th>Thermal Conductivity</th>
<th>Weight</th>
<th>Magnetic</th>
<th>Ease of Soldering</th>
<th>RoHS Compliant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>10.4</td>
<td>1.0:1</td>
<td>Very High</td>
<td>Very High</td>
<td>No</td>
<td>Excellent</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum</td>
<td>18.3</td>
<td>1.8:1</td>
<td>High</td>
<td>Low</td>
<td>No</td>
<td>Poor</td>
<td>Yes</td>
</tr>
<tr>
<td>Stainless Steel 304</td>
<td>464.6</td>
<td>44.8:1</td>
<td>Very Low</td>
<td>High</td>
<td>Slightly</td>
<td>Poor</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Plating and Finishes

Copper and aluminum conductors are often plated for additional corrosion protection and solderability. The most common plating materials are tin and silver. Both materials are very soft and ductile.

Silver has superior electrical conductive properties along with being very corrosive resistant to atmospheric oxygen, although vulnerable to tarnish by atmospheric sulfides and nitrates. Silver plating is the preferred plating anytime the material is part the conductive path inside the cable. For Semi-Rigid cables, silver plating the outer conductor is not recommended for high humidity or salt water environments due to its susceptibility to galvanic corrosion (red plague).

Tin is economical, corrosion resistant, has excellent solderability, and is the preferred plating for Semi-Rigid cable outer conductors. Tin plating can be prone to tin whiskers. Tin whiskers are electrically conductive, crystalline structures of tin that sometimes grow from surfaces where tin is used as a final finish. Tin whiskers have been observed to grow to lengths of several millimeters. Tin whiskers have the potential to cause short circuits by bridging closely-spaced circuit elements maintained at different electrical potentials. The risk of tin whiskers can be eliminated by adding a small amount of lead to the plating, referred to as electro-deposited solder (EDS).

Other plating and finishes are available by special request.

<table>
<thead>
<tr>
<th>Table 4 – Plating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plating Material</td>
</tr>
<tr>
<td>Silver</td>
</tr>
<tr>
<td>Tin</td>
</tr>
<tr>
<td>Tin-Lead (90/10)</td>
</tr>
</tbody>
</table>
White Paper

How Does Semi-Rigid cable Deliver Maximum Power Transfer?

In a coaxial cable, the characteristic impedance is the result of the center (d) and dielectric (D) diameters along with the dielectric constant (e) of the insulator as expressed in the following equation:

\[ \text{Impedance} = \frac{138}{\sqrt{e}} \times \log \left( \frac{D}{d} \right) \]

Since Semi-Rigid cables use solid center and outer conductors, diameter control is easily maintained. Both are typically held to less than ± 0.001 inch. This translates into an overall impedance tolerance of less than ± 1.0 ohm and not varying more than ± 0.5 ohm within a given cable length. Of course, this is important since any change in impedance will translate directly into additional return loss of the final cable assembly.

Beyond gross diameter control, Semi-Rigid cables are not plagued with the small periodic dimensional discontinuities found in flexible cables. These discontinuities typically result from the stranding or braiding processes. As a result, the VSWR spikes that are often found in other cables are nonexistent in Semi-Rigid cables.

In addition, connectors designed for Semi-Rigid cable do not require exotic center contact captivation techniques since the cable will not be flexed, enabling better impedance control inside the connector ultimately leading to better return loss for the final cable assembly. The reduction in connector complexity also lends itself to easier installation and less overall cost.

Impedance control is important for maximum power transfer, but what about non 50 ohm cables? No other cable type offers more “odd” impedance cables than Semi-Rigid. Semi-Rigid cable with 5, 10, 12, 15, 18, 25, 35, 70, 75, 93, 95, and 100 ohm characteristic impedance are available off the shelf for immediate delivery.

Why is Semi-Rigid cable Better for Precision Phase Matching?

Many applications require cable assemblies to be an exact electrical or phase length. Phase matching cable assemblies is typically accomplished by manufacturing the cable assembly slightly longer than required, measuring the electrical length, and then mechanically trimming a small amount. As one could imagine, precisely trimming back the Semi-Rigid cable solid copper tube a few thousands of inch is much easier to control than a messy wire braid might be on the equivalent flexible cable. However, the hidden advantage of a phase matched Semi-Rigid cable is that it can be matched in its final bend configuration. All coaxial cables will change phase length when bent or flexed. It is highly unlikely that the phase length of a flexible cable assembly will remain unchanged after the rigors of shipping and system integration. While some view the idea of a preformed Semi-Rigid cable as an inconvenience, it is the only way to guarantee precision phase matching before and after installation.
What is MIL-DTL-17?

No discussion on Semi-Rigid cable is complete without mentioning MIL-DTL-17, the governing military specification for RF cables. MIL-DTL-17 lists five Semi-Rigid cables sizes ranging from 0.034 to 0.250 inch diameter. Within each size group, there are multiple part numbers covering different center and outer conductor materials along with tin, silver, and solder plating.

Semi-Rigid cables purchased from the MIL-DTL-17 Qualified Products List (QPL) are guaranteed to meet certain minimal performance requirements aimed at the typical military applications regardless of the Semi-Rigid cable supplier. At CarlisleIT, all Semi-Rigid cables are designed and manufactured in accordance with the stringent requirements of MIL-DTL-17, whether standard commercial grade or on the QPL. This ensures our customers the same quality and reliability across all cables, without the need to call out special requirements on the purchase order.

Are Final Assembly Drawings Necessary?

The knock on Semi-Rigid cable has always been the cost and hassle of creating final assembly configuration drawings. While there is no denying the need for these drawings, it does not have to be the burden that it once was. For example, modern CAD systems and the use of bend tables can greatly simplify the process. In addition, the Semi-Rigid cable assembly business is highly competitive with numerous companies scattered around the world hungry for your business. Many will create the drawings for you at minimal to no charge depending on the potential amount of business.

While forming the Semi-Rigid cable assembly to reasonable tolerances is important, especially in the case of the larger cables in short runs, the cable is “semi-rigid”, not “rigid”. Most Semi-Rigid cables can be adjusted during installation to make up for any gaps in tolerances. Over specifying the mechanical tolerances will require unneeded additional fine tuning and inspections by the cable assembly manufacturer, potentially adding cost without adding value. This is important to keep in mind when pursuing affordability.

### Table 5 – M17 Cables

<table>
<thead>
<tr>
<th>MIL-DTL-17 Specification</th>
<th>Cable Part Numbers in Group</th>
<th>Cable Diameter (inch)</th>
<th>Attenuation @ 10 GHz (Copper Jacketed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M17/129</td>
<td>2</td>
<td>0.250</td>
<td>33 dB/100 ft</td>
</tr>
<tr>
<td>M17/130</td>
<td>16</td>
<td>0.141</td>
<td>45 dB/100 ft</td>
</tr>
<tr>
<td>M17/133</td>
<td>19</td>
<td>0.0865</td>
<td>80 dB/100 ft</td>
</tr>
<tr>
<td>M17/151</td>
<td>2</td>
<td>0.047</td>
<td>130 dB/100 ft</td>
</tr>
<tr>
<td>M17/154</td>
<td>2</td>
<td>0.034</td>
<td>180 dB/100 ft</td>
</tr>
</tbody>
</table>
Why Carlisle Interconnect Technologies?

Why Specify a Carlisle Interconnect Technologies-Manufactured Semi-Rigid cable?

In 1936, Precision Seamless Tube Company received an inquiry involving an insulated wire in which the customer wanted to be encased in a solid metal tubular sheath for mechanical protection. A sample was produced which worked well for the application, and an order was received. Thinking that the design might be unique, the company applied for, and, in due course, received a patent. The product was called “Metal Shielded Wire”.

In 1940, the two partners that owned Precision Seamless Tube Company separated to form Uniform Tubes and Precision Tubes. Both parties retained the rights to the Metal Shielded Wire patent.

It was not until the 1960’s that Metal Shielded Wire became known as Semi-Rigid cable. The industry grew and both Uniform Tubes and Precision Tubes continued to manufacture Semi-Rigid coaxial cable, each eventually creating their own cable divisions. Uniform Tubes called their company Micro-Coax Components, later shortened to just Micro-Coax and Precision Tubes named their division Coaxitube. Ironically, the companies were reunited in 2002 when Micro-Coax, now a stand-alone company, purchased the assets of Coaxitube from Precision Tubes.

Carlisle Interconnect Technologies (CarlisleIT) now represents over 100 years of combined experience between the two original Semi-Rigid coaxial cable companies. The “UT” prefix in our part numbers is recognized around the world for its legacy of quality and reliable performance.

CarlisleIT is highly vertically integrated. Besides manufacturing all the cable it sells, CarlisleIT also extrudes the PTFE dielectric, draws down and plates the metal tubing for the outer conductor, straightens, and marks the cable all in-house. This vertical integration gives CarlisleIT more control over the raw material quality needed to make a high performance microwave cable, provides quick turn capability, and allows CarlisleIT to be the Semi-Rigid cable cost leader. In addition, CarlisleIT is the only Semi-Rigid cable manufacturer that marks its cable with the manufacturer, part number, and lot number for ease of traceability1.

Unlike some Semi-Rigid cable manufacturers, CarlisleIT Semi-Rigid cable is built in straight lengths (not coils)2. Building cable in straight lengths allows better mechanical tolerance control, and more importantly, better control of the adhesion between the conductors and the dielectric. This is true even when secondary operations such as bending, temperature cycling, soldering, or stripping the outer conductor are performed. A coiled Semi-Rigid cable requires significant flexing through a series of rollers to make straight. The smaller the coil, the more flexing required.

This process will change the residual stress in the metal tube outer conductor causing it to “spring” off the dielectric core leading to serious reductions in adhesion between the outer conductor and dielectric. Because of this, cable straightness must be balanced against the potential loss of adhesion. As a result, a truly straight Semi-Rigid cable that started as a coil is very difficult to achieve. The challenge of forming a Semi-Rigid cable assembly to tight mechanical tolerances is only compounded when starting with a bent or warped cable. More and more customers have begun specifying a minimum level of straightness on their Semi-Rigid cable for this exact reason.

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1 For cable diameters of 0.085 inch and larger only.
2 For lengths under 21 feet only.
With the largest selection of Semi-Rigid coaxial cables in the industry, CarlisleIT has a solution for almost any transmission line problem. Our extensive line of Semi-Rigid coaxial cables include:

**MIL-DTL-17 Qualified Cables**
A full range of MIL-DTL-17 qualified cables. These cables undergo additional testing to ensure they are fully capable of satisfying the most demanding military applications.

**Standard 50 Ohm Cables**
Diameters from 0.013 to 0.390 inch in lengths up to 150 feet on select cables. Many standard connectors are available from numerous suppliers.

**Dimensionally Stable “DS” 50 Ohm Cables**
CarlisleIT’s newest addition to its Semi-Rigid cable product line utilizes a unique solid PTFE dielectric that provides significantly improved thermal stability when compared to traditional solid PTFE Semi-Rigid cables. The improved thermal stability reduces the need for temperature preconditioning and virtually eliminates the dielectric protrusion when soldering. All other mechanical and electrical performance is equal or better than the traditional solid PTFE equivalents.

**Low Loss 50 Ohm Cables**
When even better performance is required, specify CarlisleIT Low Loss Semi-Rigid coaxial cables. These cables typically lower the attenuation by another 20% and extend the operating temperature to 250° C.

**Aluminum 50 Ohm Cables**
Available in both standard and low loss versions, aluminum jacketed cables offer easier bending and significant weight reduction.

**Stainless Steel 50 Ohm Cables**
Stainless steel cables for cryogenic or medical applications where low thermal conductivity or hypo allergenic properties are required.

**Odd Impedance Cables**
Impedances from 5 to 100 ohms ranging in diameters from 0.020 to 0.250 inch.

**Custom Made-To-Order Cables**
Semi-Rigid cables have been built from a large spectrum of materials, every size imaginable, almost any impedance, and tested to the toughest requirements. Semi-Rigid cables can be insulated with an FEP or other polymer jacket as required by special request. If you cannot find the Semi-Rigid cable you need, contact Micro-Coax, we may already have it in stock.

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Accept NO Imitations!

If your application requires the near perfect transmission of an RF/microwave signal under the harshest conditions, demand CarlisleIT “UT” Semi-Rigid cable. Accept nothing less from your cable assembly supplier.