MINIBEND® CTR – PHASE INVARIANT CABLE ASSEMBLIES

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ABSTRACT

Polytetraflouroethylene (PTFE), or Teflon™, has widely been considered an industry standard dielectric material for microwave and radio frequency cable assemblies. It has very low attenuation and the capability to operate in harsh environments with extreme temperature requirements. However, at approximately 18°C, PTFE undergoes a structural transition resulting in a substantial change in the delay of transmitted signal. This phenomenon, known as the "Teflon™ knee" (see fig. 1), creates a decrease in the dielectric constant and the expansion of the material, which leads to a change in the electrical length of the cable and phase of the transmitted signal. The "Teflon™ knee" phenomenon is a property of the molecular structure of the material and cannot be eliminated regardless of advancements in dielectric manufacturing technology. Despite this limitation, the coaxial cable market has seen accelerated trends toward increasingly phase sensitive applications in dynamic thermal environments, amplifying the importance of a material that meets these stringent performance demands.

In response to this trend, HUBER+SUHNER has applied its extensive heritage in plastic foaming technology to develop phase versus temperature stable Perfluoroalkoxy alkane (PFA) dielectrics. The foaming process modifies the existing melt extrusion by continuously injecting high-pressure nitrogen gas into the molten resin, creating a distribution of gaseous bubbles throughout the insulation. Formation of large bubbles can lead to inconsistent performance around the center conductor, so the extruder is specifically designed to control the size and distribution of the nitrogen bubbles. Upon exiting the extruder, the polymer-gas mixture solidifies, resulting in a PFA foam structure. A lower dielectric constant (ε_r), lower capacitance (C), and increased relative velocity (v_r) are all benefits of foamed PFA, but the most significant advantage is a much more constant electrical length over a wide operating temperature range when compared to PTFE.

HUBER+SUHNER has harnessed this extrusion technology as a way to meet these new market demands and has incorporated the cutting-edge PFA dielectric into the world-renowned minibend® product family. The phase invariant minibend® CTR line of cable assemblies maintains the bend-to-the-end solderless connector termination technology and introduces industry-leading phase versus temperature performance with an absolute phase change of <300 ppm over a temperature range of -50°C to +125°C. By synergizing our heritage and qualification of the solderless connector attachment technology and combining it with a MIL-DTL-17 qualified foamed PFA coaxial cable, HUBER+SUHNER is able to provide a phase stable minibend® CTR interconnect solution suited for space flight applications for up to 40 GHz.

THE TEFLON™ KNEE

For many years, Polytetraflouroethylene (PTFE), or Teflon™ has been widely used in coaxial lines and is considered the best dielectric material due to its low attenuation and excellent electrical and mechanical properties. As the market demanded enhanced performance at increasing frequencies, the manufacturing technologies of PTFE dielectrics started to evolve to achieve the lowest dielectric constant (ε_r) by striving for maximal air content and unsintered PTFE. The low density PTFE offered an even lower attenuation and increased velocity of propagation (v_p). Another method used tape-wrapping technology, instead of the typical extrusion process, to offer a more phase stable material. Even after the tremendous advancements in PTFE manufacturing technology, the one limiting factor of PTFE was not resolved. At approximately 18°C, PTFE undergoes a structural transition altering the dielectric constant of the material and resulting in a substantial change in the delay of the transmitted signal. This non-linear phenomenon, known as the Teflon™ Knee [See Figure 1], is a property of the molecular structure of the PTFE material and cannot be eliminated regardless of advancements in dielectric manufacturing technology. Coaxial cable manufacturers have made many efforts to minimize this effect while designers of phased array radar systems have been struggling to overcome the Teflon™ Knee due to the lack of options. In order to meet the demands of increasingly phase-sensitive applications, an alternative material must be considered.

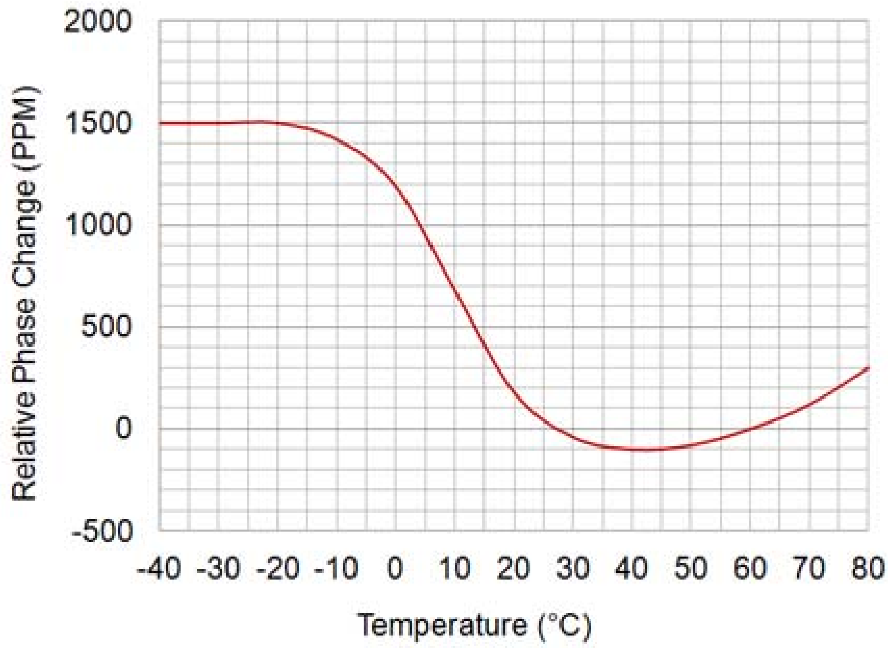

Figure 1 – Relative Phase Change (ppm) vs. Temperature (°C) for low density PTFE (76% v_p)

PERFLUOROALKOXY ALKANE (PFA)

One of the primary reasons for lack of alternate material options and why PTFE has been the industry standard dielectric material is because not many materials can offer loss tangent on the same low level as PTFE. If a new dielectric material can provide a more phase stable cable, then the loss tangent should not be sacrificed. One such material is Perfluoroalkoxy alkane (PFA), which does not exhibit a substantial structural change over broad temperature ranges. PFA is a fluoropolymer with similar properties to PTFE. Before PFA can effectively displace PTFE, the dielectric constant and loss tangent of the material has to be lowered to guarantee similar attenuation to that of PTFE. One major difference between the two is that PFA can be pressure and melt extruded while PTFE has to be pressure extruded [1]. This property of PFA allowed HUBER+SUHNER to leverage its vast experience in extrusion and foaming technology. Employing a very precisely controlled process to inject nitrogen gas during the melt extrusion of PFA creates a foamed structure. The importance of a well-controlled foaming process is the key to extrude a stable homogeneous material and cannot be overstated. A typical extrusion line [Figure 2] feeds the barrel with pre-formed material while the screw generates flow through a steady rotational speed inside the barrel. Additional heaters are placed along the barrel to properly melt the polymer. During the extrusion process, highly-pressurized nitrogen gas is injected into the melted polymer, creating the foamy solution. The pressure at which nitrogen is injected forms bubble-like voids in the material as it exits the crosshead and cools onto the surface of the cable center conductor. The extruder must be designed to precisely control the mixture of nitrogen in solution to facilitate a uniform distribution of the gaseous bubbles, consistent electric performance, and proper adhesion along the surface of the center conductor [2].

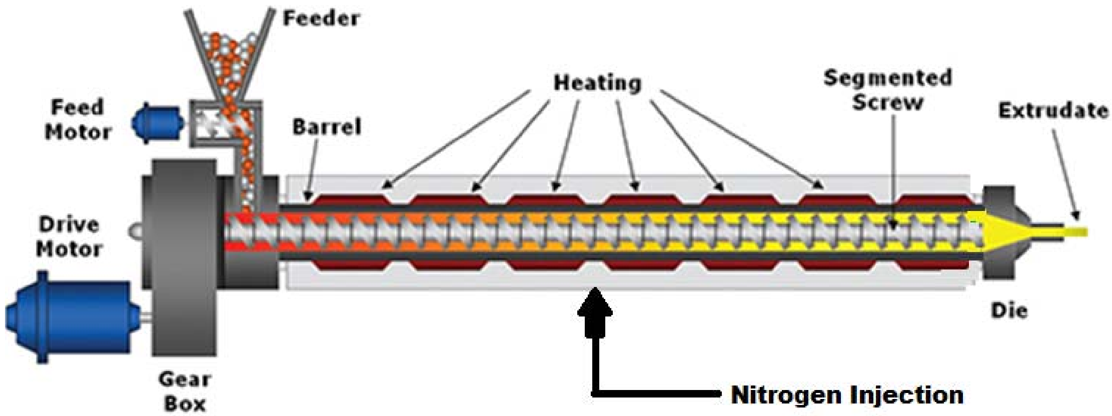

Figure 2 – Typical extrusion line[3]

With the addition of nitrogen injection, HUBER+SUHNER is able to produce distinct advantages over the traditional melt extrusion processes. By foaming PFA during melt extrusion, its dielectric constant and capacitance is lowered, velocity of propagation is increased, all while retaining the mechanical properties of a solid PFA. Aside from these, the single most important characteristic of the foamed PFA is phase stability versus temperature [Figure 3]. With foamed PFA as the insulator, a cable assembly can achieve industry leading typical phase variation values of 200 ppm over the entire temperature range of -50°C to +125°C. In addition, the ambient temperature range of most applications is between 18°C and 25°C, where the phase versus temperature curve of foamed PFA is almost flat. This is also where the Teflon™ Knee occurs. Design engineers no longer have to adjust their processes to re-calibrate the system due to temperature fluctuations in their test and work environment.

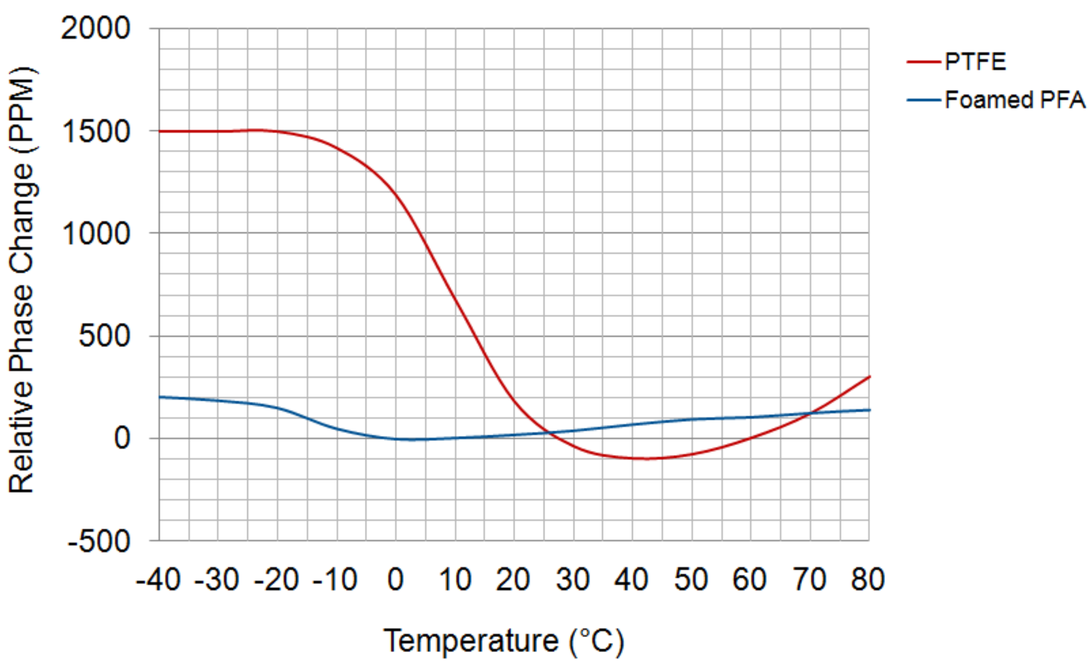

Figure 3 – Relative Phase Change (ppm) vs. Temperature (°C) PTFE and Foamed PFA

MINIBEND® CTR

HUBER+SUHNER's minibend® family of truly flexible coaxial cable assemblies, with a patented bend-to-the-end solder-less connector termination technology has been widely installed in low- profile, point-to-point interconnections between radio frequency (RF) modules for over 20 years.

The conventional method of attaching connector requires solder on the outer conductor with a strain relief on the cable to protect the solder joint, therefore increasing the distance from the connector at which the cable can be bent. minibend® products use a solderless clamped outer conductor, allowing ±90° bends of the cable immediately behind the connector with a very tight bend radius without any degradation in electrical performance for up to 30 bends [Fig 4]. A reduced mass and geometric footprint of the cable and the connector are both achieved by using a minibend® cable assembly. This high reliability technology not only eliminates the risk of any solder wicking in to the braid, but also eliminates the failure modes associated with solder joints. The solderless design is rated higher than a soldered connector design for reliability per the Parts Count Reliability Prediction of MIL-HDBK-217 [4].

$$\lambda_e = \sum_{i=1}^{i=n} N_i \left(\lambda_g \pi_Q\right)_i \quad (1)$$

In equation (1), failures per million hours (λ_e) is calculated using the sum of the quantity of individual parts (Ni), different part categories (n), base failure rate for each part (λ_g), and the quality factor for each part (π_Q). The model predicts the mean time between failures in a space-flight environment for a soldered junction is 0.0028 failures/106 hours, which is four times higher than that of a solderless junction [5]. The mean time between failures under the same conditions for a solderless junction predicted by the reliability model is 0.0007 failures/106 hours. Due to the lack of solder on the outer conductor, minibend® cables are constructed with stainless steel braids to provide excellent mechanical robustness which prevents kinking and allows up to 1,000 flexes. The performance limiting, bulky, and expensive right angle or swept connectors can also be eliminated with the bend-to-the-end feature, allowing simplified installations in tightly congested subsystems. Manufacturers' goals of miniaturization and cost reduction, without sacrificing performance and robustness, are achieved with the minibend® product portfolio.

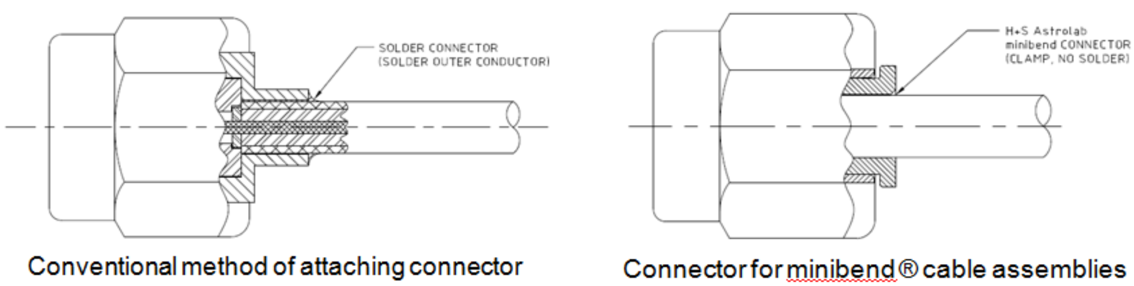

Figure 4 – Connector attaching methods

The phase invariant minibend® CTR cable assemblies combine the cutting-edge foamed PFA dielectric with the world-renowned minibend® product family to offer an industry-leading phase versus temperature performance in addition to the mechanical and electrical performance described in Table 1. The foamed PFA dielectric also provides superior phase stability versus flexure equivalent to an extruded to PTFE dielectric.

Table 1 – minibend® CTR specifications

Electrical specifications	
Impedance (nominal)	50 Ohm
Operating Frequency	DC – 40 GHz
Return Loss (min)	-32 dB @ 18 GHz -25 dB @ 40 GHz
Insertion Loss (typical)	3.67 dB @ 18 GHz 5.83 dB @ 18 GHz
RF leakage	100 dB
Phase variation vs. temperature	< 300 ppm
Mechanical specifications	
Diameter	2.49 mm
Minimum Bend Radius	5.08 mm
Weight	15.6 g/m
Environmental specifications	
Outgassing according ECSS-Q-ST-70-02 and NASA Reference Publication 1124	TML < 1% CVCM < 0.1%

HERITAGE AND QUALIFICATION

The minibend® family comes with a proven spaceflight heritage of 20 years various commercial and scientific research projects. Upon incorporating the minibend® CTR into the existing space qualified minibend® portfolio, a full MIL-DTL-17 qualification was performed on the cable to further add to the integrity of the product. The connector termination technology of minibend® has been qualified to meet ESA, NASA, and MIL standards. By combining the existing connector termination and the MIL-DTL-17 qualification of the cable, minibend® CTR cable assembly is suitable for space flight application without requiring any additional qualification expense to the customer. Table 2 lists the standards to which all HUBER+SUHNER products are certified by testing or similarity.

Table 2 – Qualification Summary

Cable Qualification	MIL-DTL-17
Connector Qualification	MIL-PRF-39012 MIL-PRF-31031
Cable Assembly Qualification	MIL-PRF-55427
Space Qualification	MIL-STD-1547 MIL-STD-790 NASA EEE-INST-002 LEVEL 1 ESA 3902 ESA 3402
Mechanical Shock	MIL-STD-202, method 213, 12,000 g peak MIL-STD-883, method 2002, 1500 g peak

The phase invariant minibend® CTR are already being used in the performance radar satellite for a satellite-based reconnaissance system by a major satellite manufacturer to interconnect the highly-sensitive phased array antenna modules of the satellite.

CONCLUSION

With over 20 years of flight heritage of the minibend® products, combined with a full MIL-DTL-17 cable qualification, the phase stable minibend® CTR interconnect solution is suitable for all space flight applications.

NOTES

minibend® is a registered trademark of HUBER+SUHNER Astrolab, Inc.

REFERENCES

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[3] Dr. Sampada Upadhye, *HOT MELT EXTRUSION – OptiMelt™ Hot Melt Extrusion Technology to Improve Bioavailability of Poorly Soluble Drugs*, http://www.drug-dev.com/Main/Back-Issues/HOT-MELT-EXTRUSION-OptiMelt-Hot-Melt-Extrusion-Tec-983.aspx, August 31, 2015

[4] United States. Dept. of Defense. *MIL-HDBK-217 (Military Handbook), Reliability Prediction of Electronic Equipment*. Revision F, Notice 2. February 28, 1995. Print.

[5] Andrew Weirback. *High Density Coaxial Interconnect Solution for Space Applications Requiring High Electrical Stability*. September, 2013.