PhaseTrack®

Phase Stable Cable Assemblies

- *Phased Array Systems*
- *All Phase Sensitive Systems*
- *All Phase Sensitive Platforms*
- *All System Platforms*
  (Ground, Sea, Airborne, Space)

TIMES MICROWAVE SYSTEMS
An Amphenol Company

INTRODUCTION

Phase stable interconnects are essential to the performance of many radio frequency and microwave systems. Until now, most solutions utilized PTFE based dielectric medium. The well documented problem with PTFE is a drastic change that occurs at a temperature of approximately 19 degrees C. This change is steep enough to cause significant phase difference between cables that are only fractions of a degree apart in temperature.

Over the last several years Times has developed a product line with a proprietary fluorocarbon material named TF4™ that has completely eliminated the knee.

The product was launched in 2004 with the selection of our PT210 and PF402 for a radar mapping satellite requiring over 2000 phase critical assemblies. The success of the technology has led to the expansion of the product to cover a wide range of applications.

The Phasetrack (PT) line of flexible cables now available in sizes ranging from .110” to an 18 GHz .318” optimized design which addresses a wide range of interconnect applications.

Phaseflex (PF) and Phasetrack semi-Rigid (SR) are available in sizes commonly used in most in box applications and are compatible with existing connectors.

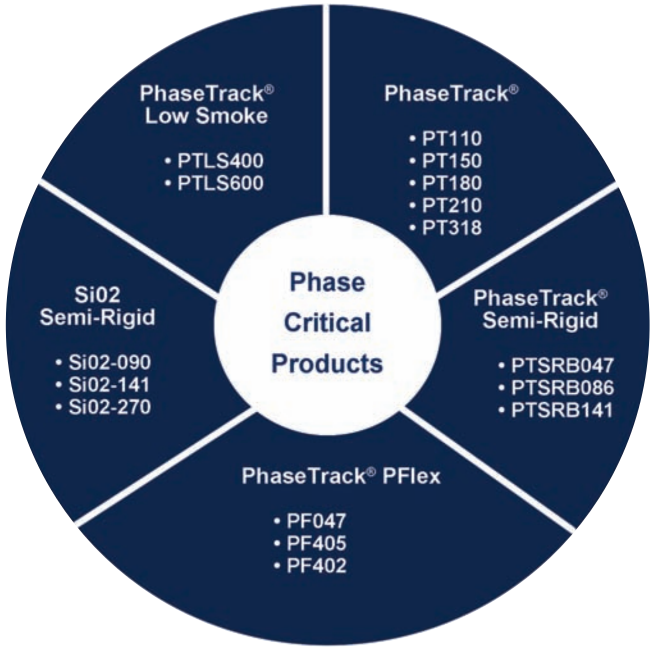
Phasetrack LSLT have been developed with a specially blended and processed foam polymer dielectric for longer lower frequency runs that demand a larger cable to minimize loss. Jacketed with our proprietary M17 zero halogen jacket this product is ideal for shipboard and other applications which are required to meet the stringent requirements of MIL-DTL-17.

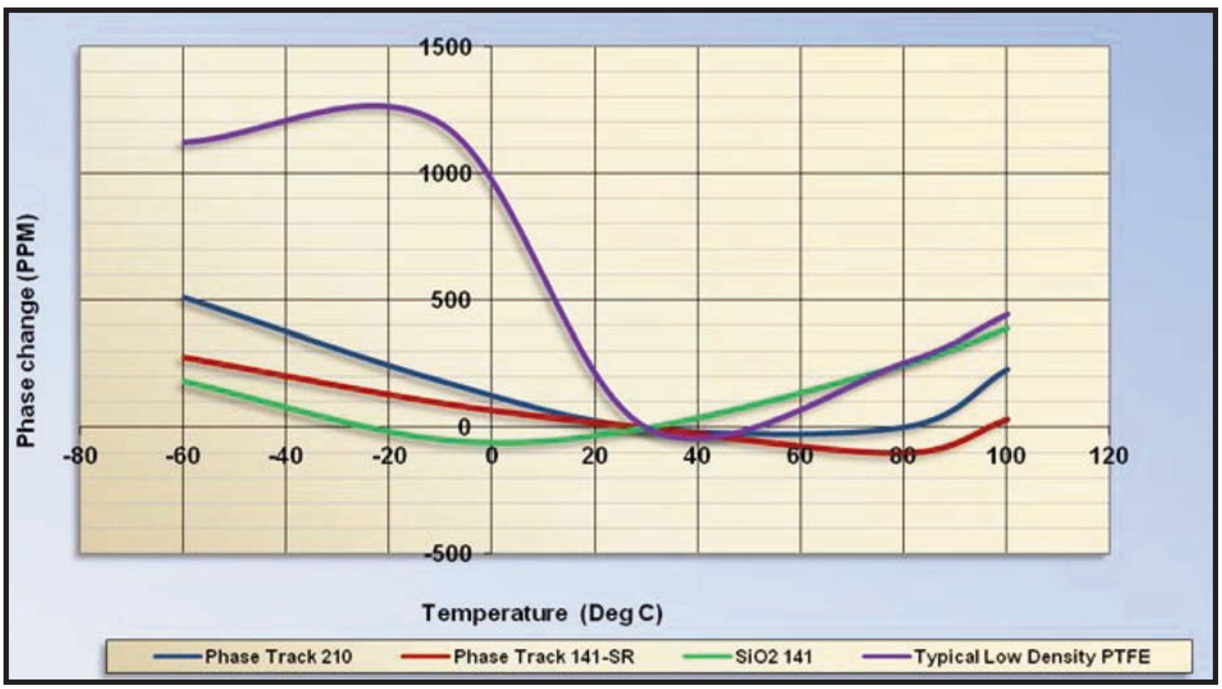
The phasetrack product line is rounded out with our Si02 dielectric cables that provide the ultimate in performance from cryogenic temperatures to those exceeding 1000 degrees C.

PhaseTrack® Legacy

Programs:	Applications:
• *Terra SAR-X*	• *Phased Array Antennas*
• *Tandem X*	• *Precision Differential Timing*
• *EA 18-G*	• *Synthetic Apertures*
• *Galactica*	• *Microwave Interferometry*
• *F35*	• *Direction Finding*
• *TPS-80 G/ATOR*	• *Test and Measurement*

PhaseTrack® Cable

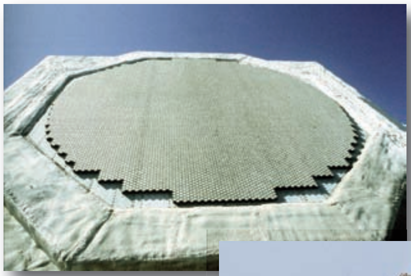




PhaseTrack®

Phase Stable Cable Assemblies For:

- *Phased Array Systems*
- *System Interconnects*
- *Phase Stable Test Cables*
- *All System Platforms*
  (Ground, Sea, Airborne and Space)

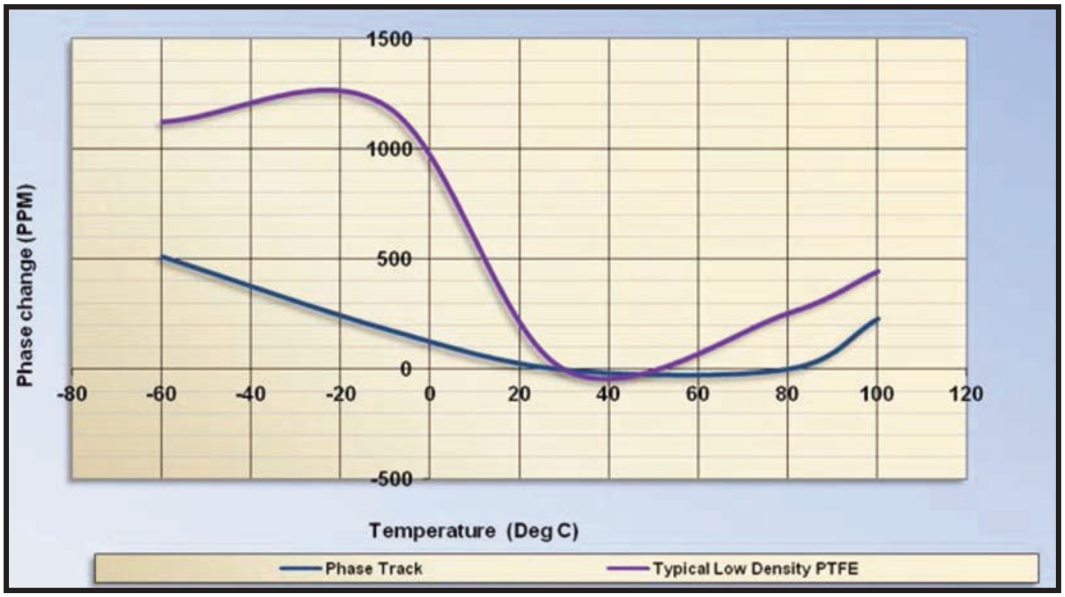


PhaseTrack® cable assemblies are designed for applications demanding minimal phase change over temperature. All PhaseTrack cables use proprietary TF4™ dielectric that does not have the abrupt shift in the phase that occurs with solid or tape wrapped PTFE based products under normal room ambient temperature conditions.

PhaseTrack cable has the same triple shield construction used in Times popular SF®, SFT®, SilverLine® and MT cables.

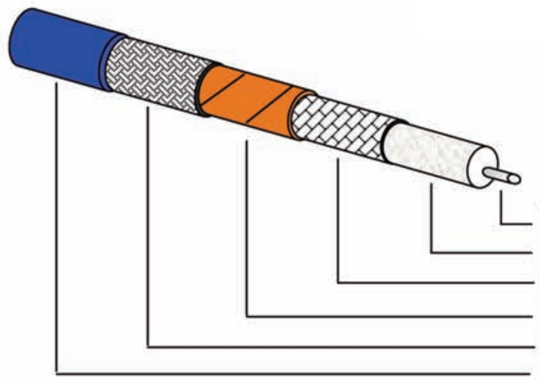
Features:

- Superior Stability (vs LD PTFE)
- PTFE "Knee" is Nonexistent
- TF4™ Dielectric Technology



PhaseTrack®

PhaseTrack® Construction



Center Conductor	Silver Plated Copper*
Dielectric	TF4 Dielectric
Shield	Silver Plated Copper
Interlayer	Metalized Polyimide Tape
Outer Braid	Silver Plated Copper Braid
Jacket	Blue FEP

Part Number	PT110	PT150	PT180	PT210	PT318
Dielectric Technology	TF4™	TF4™	TF4™	TF4™	TF4™
Diameter (in)	0.108	0.145	0.180	0.220	0.315
Minimum Bend Radius	0.550	0.750	1.000	1.125	1.750
Mass (lbs/1000 feet)	14.0	24.0	36.0	46.0	90.0
Temperature Rating	-55C to +150C				
Center Conductor	Silver Plated Copper Clad Steel	Silver Plated Copper			
Outer Conductor	Silver Plated Copper Strip Braid				
Jacket	Blue FEP				
Characteristic Impedance	50 Ohms				
Velocity of Propagation	82.5%	82.5%	83.0%	83.5%	83.5%
Cutoff Frequency (GHz)	80.0	52.4	38.7	29.0	18.9
Delay (nS/foot)	1.23	1.23	1.23	1.23	1.22
Capacitance (pF/foot)	24.7	24.7	24.6	24.4	24.0
Shielding	-90 dB Minimum				
Loss @ 6 GHz (db/100 feet)	64.0	38.4	30.5	24.6	16.7
Loss @ 18 GHz (db/100 feet)	121.0	70.5	58.5	48.4	34.7
K1	0.72391	0.4532	0.33627	0.25971	0.15565
K2	0.0013239	0.00055605	0.00074129	0.00075526	0.00076725

*PT110 uses silver plated, copper clad steel as a center conductor.

PhaseTrack® SR

Phase Stable Cable Assemblies For:

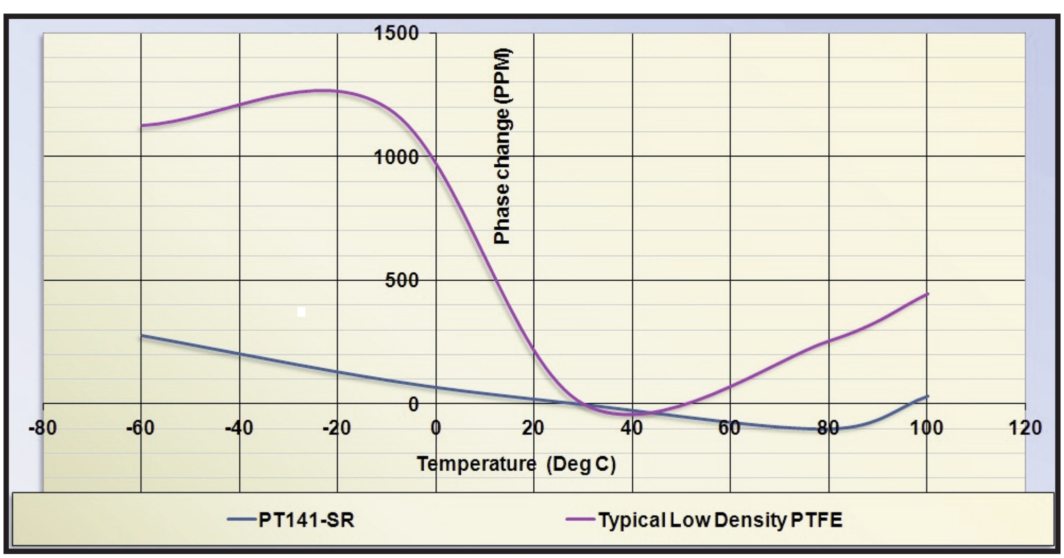
- *Phase-Optimized*
- *Semi-Rigid Cables*
- *All Phase Sensitive Systems*
- *All System Platforms*
  (Ground, Sea, Airborne and Space)

PhaseTrack® SR cable assemblies are designed for applications demanding minimal phase change over temperature.

PhaseTrack® SR cable assemblies are a classic semi-rigid-style cable with optimized phase performance.

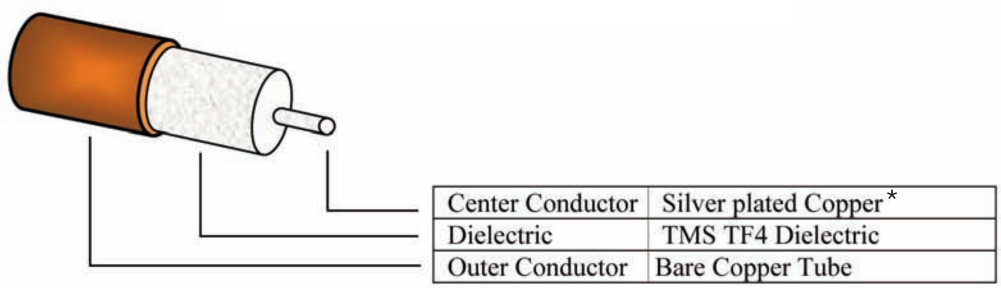
PhaseTrack® SR cables use proprietary TF4™ dielectric that does not have the abrupt shift in phase that occurs with solid or tape wrapped PTFE based products under normal room ambient conditions.

Features:
- Superior Stability (vs LD PTFE)
- PTFE "Knee" is Nonexistent
- TF4™ Dielectric Technology



PhaseTrack® SR

PhaseTrack®-SR Construction



Part Number	PTSRB047	PTSRB085	PTSRB141
Dielectric Technology	TF4™	TF4™	TF4™
Diameter (in)	0.047	0.085	0.141
Minimum Bend Radius	0.15	0.25	0.425
Mass (lbs/1000 feet)	4.5	14.2	29.0
Temperature Rating	-55C to + 125C		
Center Conductor	Silver Plated Copper Clad Steel		Silver Plated Copper
Outer Conductor	Bare Copper		
Jacket	NA		
Characteristic Impedance	50 Ohms		
Velocity of Propagation	82.5%	82.5%	82.5%
Cutoff Frequency (GHz)	138.5	80.2	38.4
Delay (nS/foot)	1.23	1.23	1.23
Capacitance (pF/foot)	24.6	24.6	24.6
Shielding	-110 dB Minimum		
Loss @ 6 GHz (db/100 foot)	96.3	55.2	28.2
Loss @ 18 GHz (db/100 foot)	173.8	102.9	54.8
K1	1.17249	0.63712	0.30382
K2	0.00091751	0.0009676	0.00077836

*PTSRB047 and PTSRB085 use silver plated, copper clad steel as a center conductor.

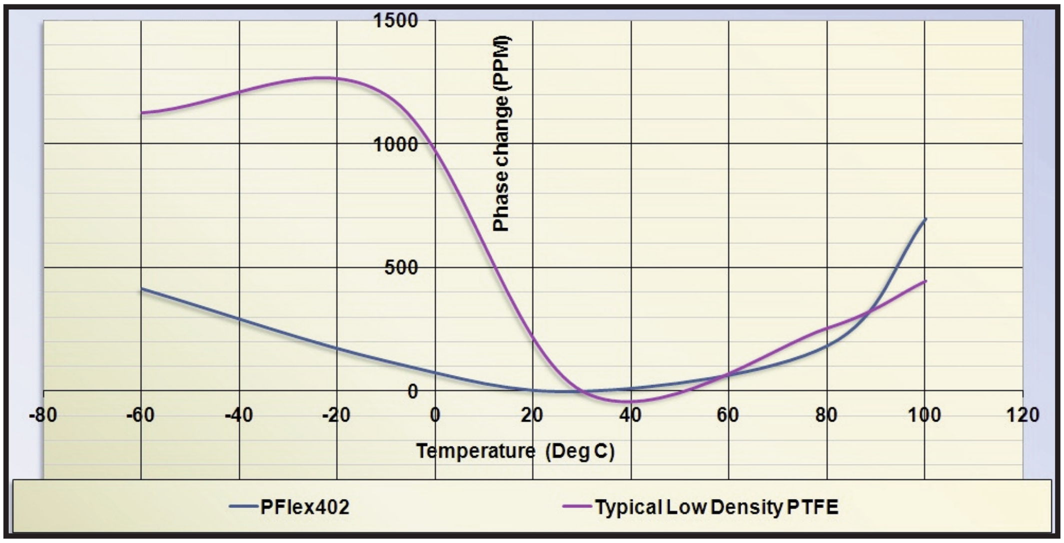
PhaseTrack® PFlex

Phase Stable Cable Assemblies For:

- *All Phase Sensitive Systems*
- *Phase Optimized Flexible Alternative to Semi-Rigid*
- *All System Platforms*
  (Ground, Sea, Airborne, Space)

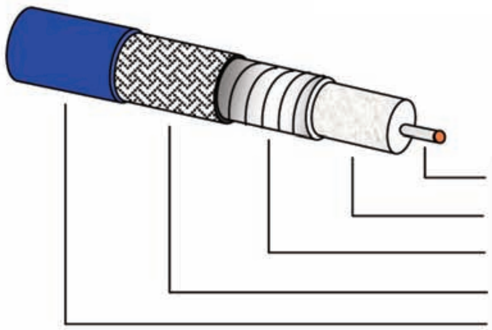
PhaseTrack PFlex cable assemblies are designed for applications demanding minimal phase change over temperature. PFlex cable assemblies are a flexible interconnect-style cable often used as a semi-rigid replacement. PFlex cables use proprietary TF4™ dielectric that does not have the abrupt shift in phase that occurs with solid or tape wrapped PTFE based products under normal room ambient conditions. PFlex cable uses the same shield construction as Times popular TFlex® cables.

Features:
- Superior Stability (vs LD PTFE)
- PTFE "Knee" is Nonexistent
- TF4™ Dielectric Technology



PhaseTrack® PFlex

PhaseTrack® PFlex Construction



Center Conductor	Silver Plated Copper*
Dielectric	TMS TF4™ Dielectric
Outer Conductor	Silver Plated Copper
Outer Shield	Silver Plated Copper Braid
Jacket	Blue FEP

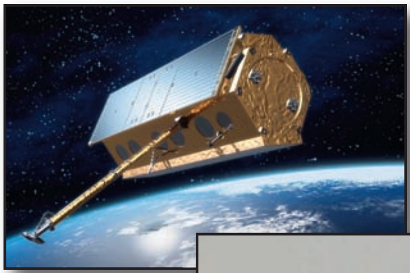
Part Number	PF047	PF405	PF130	PF402
Dielectric Technology	TF4™	TF4™	TF4™	TF4™
Diameter (in)	0.064	0.094	0.130	0.160
Minimum Bend Radius	0.250	0.500	0.625	0.750
Mass (lbs/1000 feet)	4.5	11	18	28.0
Temperature Rating	-55C to + 125C			
Center Conductor	Silver Plated Copper Clad Steel		Silver Plated Copper	
Outer Conductor	Silver Plated Copper Strip			
Jacket	Blue FEP			
Characteristic Impedance	50 Ohms			
Velocity of Propagation	82.5%	82.5%	82.5%	82.5%
Cutoff Frequency (GHz)	142.3	79.9	52.3	38.7
Delay (nS/foot)	1.23	1.23	1.23	1.23
Capacitance (pF/foot)	24.4	24.4	24.4	24.4
Shielding	-90 dB Minimum			
Loss @ 6 GHz (db/100 foot)	102.74	59.34	37.96	30.92
Loss @ 18 GHz (db/100 foot)	185.95	110.16	71.61	59.36
K1	1.24487	0.69102	0..43043	0.3399
K2	0.0010516	0.0009697	0.00077	0.0007645

*PF047 and PF405 use silver plated, copper clad steel as a center conductor.

SiO2

SiO2 Phase Stable Cable Assemblies

- *Ultimate in Phase Tracking*
- *All Phase Sensitive Systems*
- *Semi-Rigid Style*
- *Extreme Environments*
- *All System Platforms*
  (Ground, Sea, Airborne and Space)

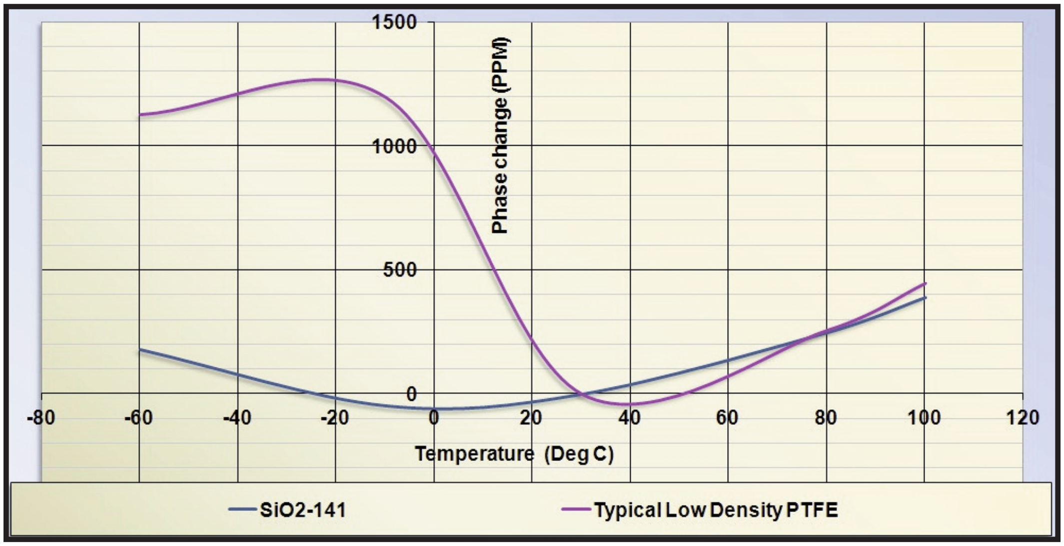


Times SiO2 cable assemblies are used in applications demanding the ultimate in phase tracking performance. SiO2 semi-rigid cable assemblies use a proprietary Silicon Dioxide dielectric material allowing use in extreme environments.

As with other products in the PhaseTrack® product line, the dielectric formulation does not have the abrupt shift in phase that occurs with solid or tape wrapped PTFE based products under normal room ambient conditions.

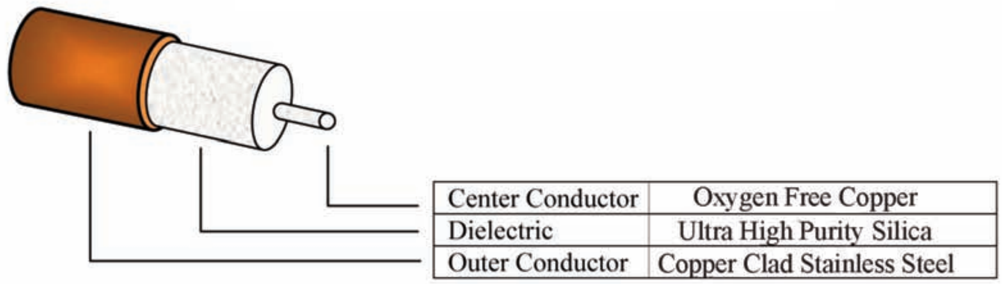
Features:

- Ultimate Phase Tracking Performance
- PTFE "Knee" is Nonexistent
- SiO2 Dielectric Technology
- Semi-Rigid Construction
- Withstands Extreme Environments



SiO2

SiO2® Construction



Part Number	SiO2-090	SiO2-141	SiO2-270
Dielectric Technology	Silica Paste	Silica Paste	Silica Paste
Diameter (in)	0.090	0.141	0.270
Minimum Bend Radius	0.360	0.564	1.080
Mass (lbs/1000 feet)	15.0	24.0	75.0
Temperature Rating	(Available)	-273C to + 1000C	Standard (-80 to +300)
Center Conductor	Oxygen Free Copper		
Outer Conductor	Oxygen Free Copper		
Jacket	304 Stainless Steel		
Characteristic Impedance	50 Ohms		
Velocity of Propagation	80%	80%	80%
Cutoff Frequency (GHz)	60	50	18
Delay (nS/foot)	1.27	1.27	1.27
Capacitance (pF/foot)	25	25	25
Shielding	-120 dB Minimum		
Loss @ 6 GHz (db/100 foot)	41.25	27.3	14.8
Loss @ 18 GHz (db/100 foot)	80.6	56.4	34.8
K1	0.439557	0.259307	0.098031
K2	0.0012	0.0012	0.0012
Product Code	AA9790	AA9789	AA9779
Stock Code	25090	25141	25270

PhaseTrack® LS

Phase Stable Cable Assemblies

- *Low-Smoke Phase-Optimized Flexible Cable*
- *All Phase Sensitive Systems*
- *Low Smoke Formulation*
- *All System Platforms*

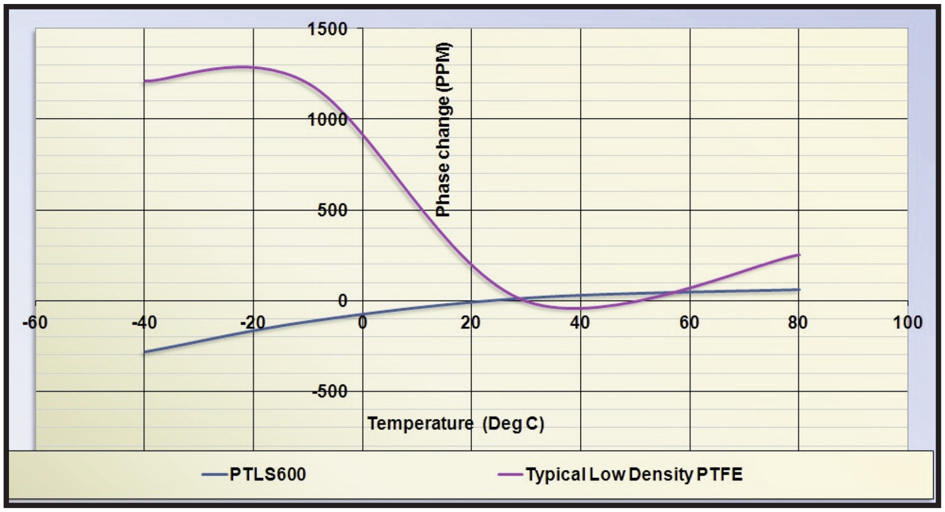
(Ground, Sea, Airborne and space)

PhaseTrack® LS cable assemblies are designed for applications demanding minimal phase change over temperature.

PhaseTrack® LS cable assemblies are a phase performance optimized version of the Times-exclusive low-loss flexible Low Smoke cables.

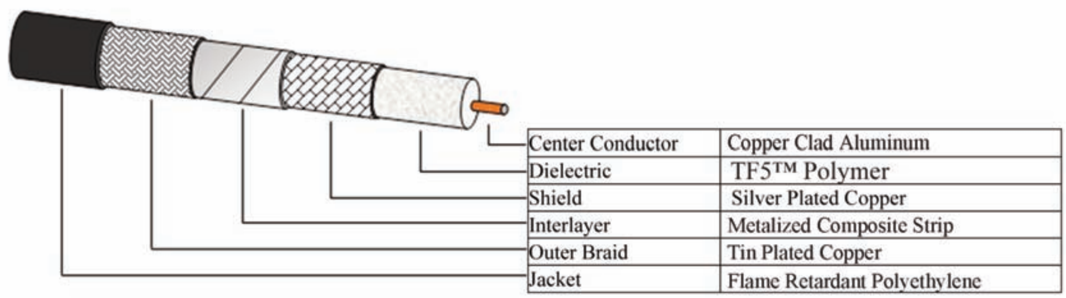
PhaseTrack® LS cables use proprietary TF5™ dielectric that does not have the abrupt shift in phase that occurs with solid or tape wrapped PTFE based products under normal room ambient conditions.

Features:
- Superior Stability (vs LD PTFE)
- PTFE "Knee" is Nonexistent
- TF5 Dielectric Technology



PhaseTrack® LS

PhaseTrack®- LS Construction



Part Number	PTLS400	PTLS600
Dielectric Technology	Polymer Foam	Polymer Foam
Diameter (in)	0.400	0.600
Minimum Bend Radius	4.000	6.000
Mass (lbs/1000 feet)	100.0	160.0
Temperature Rating	-40C to +85C	
Center Conductor	Copper Clad Aluminum	
Outer Conductor	Silver plated Copper Strip Braid	
Jacket	Flame Retardant Polyethylene	
Characteristic Impedance	50 Ohms	
Velocity of Propagation	84.0%	84.0%
Cutoff Frequency (GHz)	16.2	10
Delay (nS/foot)	1.21	1.21
Capacitance (pF/foot)	23.4	23.4
Shielding	-90 dB Minimum	
Loss @ 6 GHz (db/100 feet)	13.2	8.7
Loss @ 10 GHz (db/100 feet)	17.6	11.3
K1	0.150138	0.092086
K2	0.000262	0.000256

Notes:

Notes:

Our Mission

TIMES MICROWAVE SYSTEMS designs and manufactures high performance RF transmission lines. These products consist of flexible coaxial cable, connectors, accessories and cable assemblies.

We are committed to understanding the needs and requirements of our customers and providing highly engineered, cost effective products. TIMES MICROWAVE SYSTEMS is dedicated to total customer satisfaction and superior results for our shareholders in all we do.

TIMES MICROWAVE SYSTEMS
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Phase Track® Cable - TF4™ Dielectric: The "Knee Replacement"

by Michael Brewster, Director of Business Development, Times Microwave Systems

Thermal Vacuum & Space Flight Applications

In our continuing pursuit for excellence, Times Microwave Systems has developed the Phase Track® line of phase stable, low loss cable products. These products are designed for use on many application platforms, but are particularly well suited for thermal vacuum test and space flight cable requirements. These cables incorporate a revolutionary new dielectric composition that eliminates the infamous non-linear "knee" exhibited by Polytetrafluoroethylene (PTFE) based dielectrics. A brief summary of the history of cable dielectric materials will further illustrate this dramatic breakthrough in microwave transmission line technology.

Over the years, many materials have been used for transmission line dielectrics. These materials have ranged from paper to a variety of Polyethylene (PE) and PTFE materials. There have been many variations for these materials; efforts have been made to reduce the dielectric constant by injecting air, or gases into the material to achieve better performance. There are advantages that some materials have over others, but it became clear that the best overall dielectric material for transmission lines and many other microwave components was PTFE.

The major application of PTFE, consuming about 50% of production, is for wiring in aerospace and computer applications, e.g. hookup wire, coaxial cables. These applications exploit the fact that PTFE has excellent dielectric properties. This is especially true at high radio frequencies, making it suitable for use as an insulator in cables and connector assemblies and as a material for printed circuit boards used at microwave frequencies. Combined with its high melting temperature, this makes it the material of choice as a high-performance substitute for the weaker and lower melting point PE dielectrics, which are commonly used in low-cost applications.

There is one major issue with PTFE based dielectrics; they exhibit an inherent, non-linear change in phase when the material passes through the 15-25° Celsius temperature range. This material hysteresis has caused major issues for phased array radar antenna designers for many years. There have been attempts to minimize this non-linear effect by thermal cycling cables and components, as well as, efforts to introduce other materials to help minimize this condition. One of the more successful efforts was to add glassine materials to the dielectric. This did help to reduce the hysteresis effect, but was not conducive to good electrical performance. The added glass increased the dielectric constant and loss tangent of the material, thereby increasing attenuation. The other major disadvantage was the effect the glassine materials had on extrusion dies used to produce the material. The cost of manufacturing these materials went up greatly, as the dies used for manufacturing had to be replaced often and the material had to be run at much slower rates.

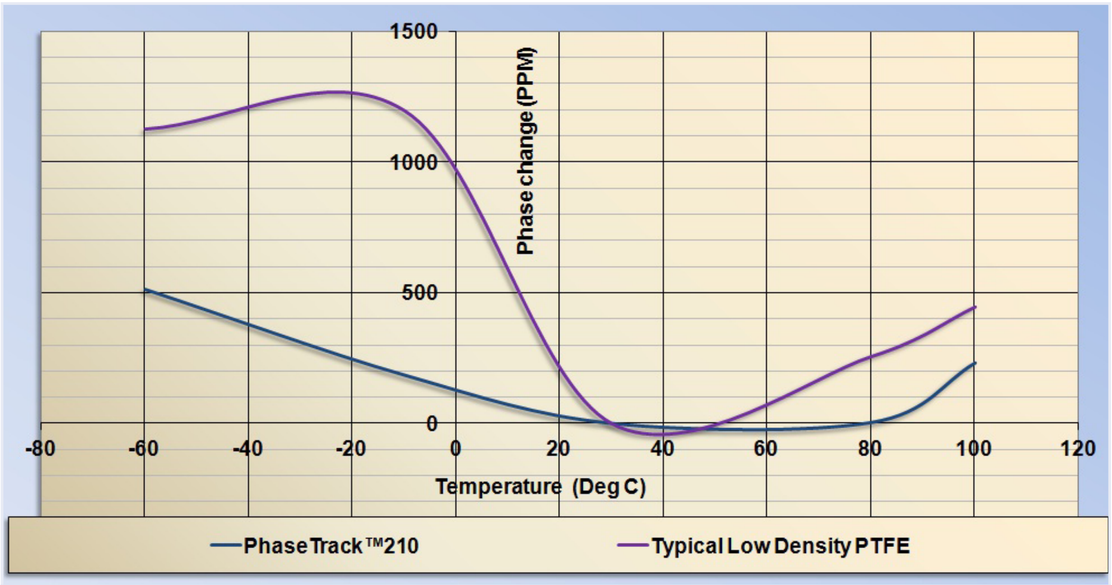

Figure 1

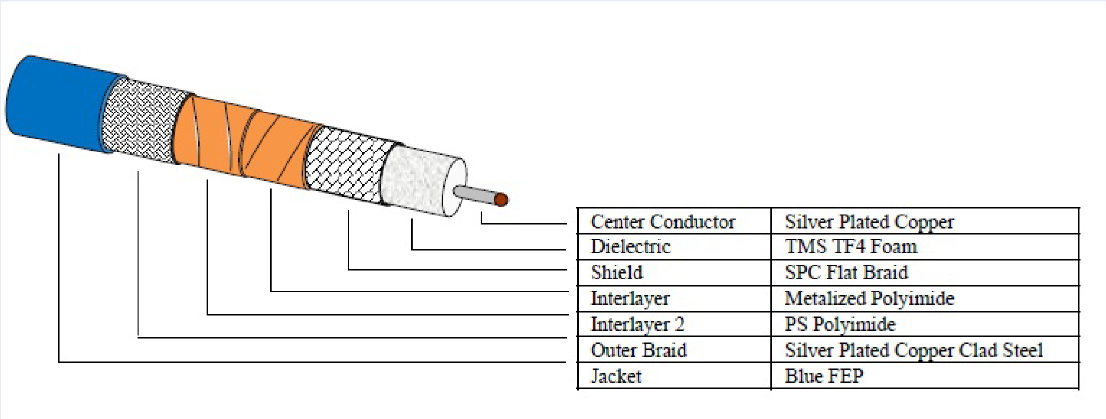

Figure 2

In the 1970s, an engineer experimenting with cable dielectrics made a significant breakthrough when he took a PTFE rod, heated it and stretched it. The stretching process pulled the material apart on a micro-physical level, thereby trapping air between interconnecting fibrils of the PTFE rod. After electrical testing, it was apparent that the air had lowered the dielectric constant and a new, low density PTFE dielectric was discovered. This low density material lowered attenuation, increased the velocity of propagation, power handling and allowed for smaller transmission lines. These were all very significant factors in moving to the next level in coaxial cable performance. However, one aspect does not change, the non-linear phase characteristics of the dielectric. It was better than the solid, sintered performance of the original PTFE compositions, but the non-linear phase change, although somewhat smaller, is still present.

There have been other breakthroughs in dielectric science utilizing Silicone Dioxide (SiO_2) materials that have greater thermal capabilities than PTFE and do not exhibit the non-linear performance in phase, but have other serious concerns. The SiO_2 product, like the old paper dielectrics are very susceptible to moisture ingression, with serious absorption qualities and must be encapsulated within a completely hermetic cable system. This requires the use of semi-rigid outer conductors that requires special bending dies The SiO_2

cables are very well suited to very severe environments, such as extreme heat and radioactive applications, but are not practical, or economical for the bulk of microwave applications that require flexible cables.

Many companies, including TMS have utilized Polyethylene (PE) for dielectric cores in coaxial cables, as it does not exhibit the phase hysteresis effect that PTFE does. It is a low temperature dielectric by comparison and does not yield many of the overall benefits that PTFE does for high temperature and electrical performance. There have been many attempts to improve the PE electrical characteristics by injecting air, or gas during the extrusion process to lower the dielectric constant and achieve better attenuation performance, but one detail always remains the same, one cannot improve the temperature handling capability of PE. This limits the power handling of the cable and prevents the use of fully soldered connector attachments.

The Breakthrough: TF4™ Dielectric...The "Knee Replacement"

Times Microwave Systems has addressed these issues through a very scientific and detailed process and has made the breakthrough our industry has been waiting for in PTFE based dielectric science. We have achieved a complete "knee replacement" for PTFE. TMS has achieved what was once considered impossible, we have eliminated the non-linear phase performance of PTFE through the 15-25C temperature range. This achievement has been accomplished without any detrimental electrical, or mechanical performance degradation. As can be seen in Figure 1, the phase performance of the Times TF4™ dielectric exhibits linear characteristics when compared to the best and typical low density PTFE dielectrics.

The TF4™ dielectric allows systems and design engineers the luxury of not requiring any extra calibration process-

Table 1

NASA-ESA Outgassing Qualified Products – Test Results
Materials Tested: PTFE, FEP, PVDF/Kynar, TEFZEL
Test Procedures: ESA: PSS-01-792; NASA: ASTM E595-90
Test Conditions: 125C for 24 hours @ 10-3 Pa (<10-5 Torr)
Acceptability: Total Mass Loss (TML) <1%
Volatile Condensable Materials (CVCM) <0.1%

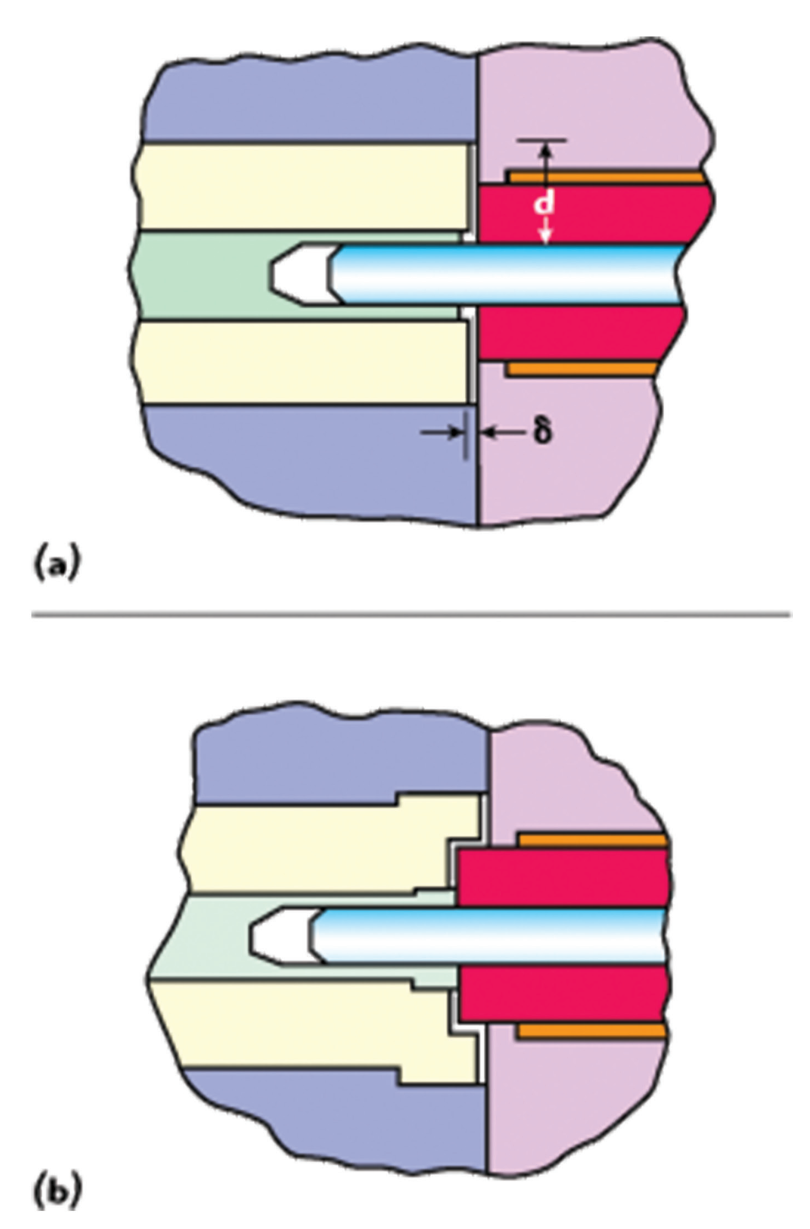

Figure 3: (a) shows a very simple interface that is more susceptible to ionization breakdown, when compared to (b) which utilizes overlapping dielectrics

ing to level the system after thermal changes. This problem is a particular concern because the change in phase can be simply caused by an air conditioner, or heating system turning on during, or after the calibration process, thereby introducing potential measurement errors into the calibration setup. In Figure 2, the Phase Track® materials are detailed. These products can be used for many applications and all utilize the TF4™ dielectric core. This cable design utilizes only the best available materials that yields the most superior phase versus temperature performance available in a coaxial cable.

Space... Thermal Vacuum Test & Space Flight Cables

It has been noted in several marketing studies that space exploration will continue to exhibit significant growth over the next ten years. In the past, the US and Russia (former Soviet Union) were the only major players in the space market. Today, many countries are now developing robust and tangible space programs. The net result of these global efforts are a significant and growing market for space qualified, flight level, test and measurement cable assemblies.

One of the biggest areas for growth are in test and measurement cable assemblies. These products are necessary for testing components and sub-systems in a vacuum environment before launch to insure proper product adherence in the vacuum environment of space. TMS is producing cable assemblies utilizing its standard microporus dielectric products, as well as, our Phase Track® cables, with our revolutionary TF4™ dielectric material.

TMS has supplied thousands of cable assemblies for space and thermal vacuum applications. The Phase Track® product is currently in use for thermal test cable applications at a wide variety of space related component and system level manufacturers. This test cable product is very phase and amplitude stable and has been designed for the best possible VSWR and attenuation performance. All connector designs incorporate rugged connector bodies and are tuned for optimum electrical performance.

There are several critical aspects of this type of cable assembly. These assemblies must use non-outgassing materials in a vacuum environment and TMS takes great care in selecting only the best available materials to meet this requirement. Most of the TMS products available for vacuum applications utilize a FEP outer jacket, other materials include PVDF (Kynar) and TEFZEL®. See below for outgassing test results for standard materials used by TMS for vacuum environments. It is imperative that no polymeric materials are used for these vacuum requirements, as the standard materials, such as polyolefin, commonly used for heat shrink strain relief systems in cable assemblies will outgas. TMS uses PVDF (Kynar) for strain relief systems.

The above tested materials meet, or exceed all the requirements noted for outgassing per ASTM E595-90 and ESA-PSS-01-792. These materials are listed in the NASA-ESA databases for low outgassing materials acceptable for use in vacuum environments.

Another very important aspect of operating within a vacuum environment is the potential for ionization breakdown of the connector dielectric. In most cases, multipactor in a coaxial line is a high power condition in that occurs when the power level reaches the peak power capacity of the component. In fact, the multipaction discharge within a coaxial line is usually not the mode of failure. However, the discharge can vaporize some of the dielectric material within the coaxial line and create ionized gas particles. If the coaxial line is not properly vented, these collected gas particles can initiate an ionization breakdown within the structure. The ionization breakdown is the typical mode of failure. TMS designs and manufactures a wide variety of connectors designed to withstand high peak power levels. These connectors are designed with overlapping dielectrics, see **Figure 3**, to minimize the potential for ionization breakdown of the dielectric and are vented to allow for the controlled relief of gaseous ionized pressure.

Many space level testing applications may include the cable's ability to survive in a radiation environment. In this case, TMS will apply the proper external materials on the cable to withstand a radiation active environment. These cables are protected by multiple layers of materials that allow for excellent microwave operation in the most difficult and highly radioactive environment. The standard cable jacketing materials used on coaxial cable, PE, PFA and FEP will not stand up to significant radiation. The best thermoplastic material for radiation resistance in flexible cables is TEFZEL®, manufactured by DuPont. They produce several grades of this product that have varying degrees of radiation resistance. TMS will also use PVDF (Kynar) for heat shrink strain relief systems because it also has excellent radiation resistant properties. The cable is extremely well shielded by multiple layers of silver plated secondary conductors served over the TF4™ dielectric core.

TMS is currently working with several large satellite manufacturers to supply low loss, phase stable cable assemblies for use on space flight applications. The Phase Track® products are leading the way in these efforts and provide our customers with the best possible cable performance available in our industry. All of the above noted benefits make these assemblies reliable and electrically superior for these very demanding applications. We have instituted a very robust and disciplined process control system to manufacture these cable assemblies with the utmost concern for quality and schedule adherence. TMS understands the need for reliable products, delivered on-time, with the highest degree of quality control.

The Phase Track® products are also extremely well suited for phased array radar, high power antenna and other applications requiring precise phase stability. Times manufactures a wide variety of cable products with specialized processes that include the extrusion of PTFE and PE in both, sintered and foamed versions. We also manufacture tape wrapped, low density PTFE dielectrics that have an excellent velocity of propagation, low loss and very high power handling capabilities. These cables incorporate high levels of shielding to prevent intermodulation and have outstanding RF leakage qualities. We want to emphasize that TMS has the largest product selection available in our industry and we have a cable available for any of today's most demanding microwave applications.

TEFLON® is a registered trade mark of DuPont

TEFZEL® is a registered trade mark of DuPont

Kynar® is a registered trade mark of Arkema

Phase Track® is a registered name to Times Microwave Systems

TF4™ is a registered trade mark of Times Microwave Systems

MPD MICROWAVE PRODUCT DIGEST

Current Innovations In Phase Stable Coaxial Cable Design

by Times Microwave Systems

Why Are Phase Stable Cables Important?

Radio frequency and microwave systems have become increasingly sensitive to phase variations of their sub assemblies and components. Cable assemblies, that form the interconnecting backbone of these systems, can be a significant source of poor system performance unless proper choices are made when selecting and designing these components. The development of a new Dielectric material, TF4™, now gives the system designer a previously unavailable option with far better phase performance than PTFE, SiO_2 or other conventional cables. For many applications this is critical to achieving required system performance.

Satellite and military aircraft often deploy Synthetic Aperture RADAR (SAR) systems that use multi-element co-planar arrays and interferometry techniques. Lower magnitude of phase change and better phase tracking with changing temperatures result in lower residual errors and uncertainties. This contributes to very controllable and consistent beam steering, beamwidth and sidelobe suppression. Antenna gain, minimum discernable signal levels, system range, jamming and clutter resistance are all enhanced. In short, overall system performance and accuracy will be significantly improved.

Many wireless applications use switched beam and adaptive array antenna systems. Bit error rates; especially on signals close to the receiver noise floor will be better, effectively increasing range. These systems can greatly increase their coverage area and make most efficient use of available bandwidth when stable components are used.

The test and measurement community benefits from highly phase stable cable assemblies as well. One of the largest contributors to measurement uncertainty is temperature-related drift of the systematic errors. Interconnections that are highly phase stable, as a function of changing temperature, can greatly extend the length of time between calibrations and can minimize the amount of drift between calibrations. This is of particular benefit to people who are making measurements in hangars, on flightlines or outdoors; anywhere that temperature are fluctuating. This could allow cellular base station maintenance personnel the option of

Figure 1: Times Microwave's PhaseTrack Cable

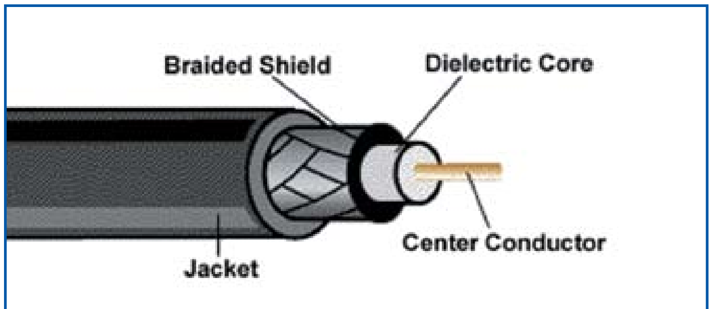

Figure 2: Typical Coaxial Cable

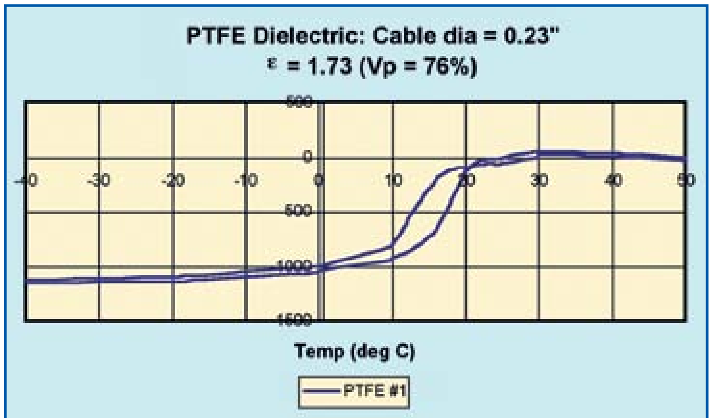

Figure 3: Phase vs. Temperature Performance of Typical Cable

calibrating inside the equipment shelter and then going outside, into the weather, to make their measurements. Vector Network Analyzers (VNAs) and Vector Signal Analyzers (VSAs) are both highly phase sensitive instruments. Test personnel should use the most phase stable cables obtainable when making measurements with these sensitive devices.

What is the Current State of Technology?

In the 1970s and 1980s, before RF and microwave systems became phase sensitive, Polytetroflourethelene (PTFE) became widely used as the dielectric propagation medium in high performance coaxial cable assemblies. PTFE, or Teflon™ as it is more commonly known, is a very good choice of material for this application. It has very low attenuation at microwave frequencies and its electrical and mechanical properties are relatively constant over a wide range of temperatures.

As the quest for lower attenuation progressed, and frequency ranges were increased, cables were constructed of lower dielectric constant, expanded PTFE materials. Systems became increasingly sensitive to phase changes in their sub-systems and components. Cable designers carefully optimized their constructions and processes to minimize the electrical length changes of the cable and cable assemblies. Due to the physics inherent in PTFE the stability of PTFE based cable can only be reduced to finite limits.

Silicon Dioxide dielectrics have also been used with great success. It is impossible to manufacture flexible cable using SIO_2 as the dielectric. This type of cable must be manufactured as a rigid, or semi-rigid, construction.

The search is on for a flexible alternative that has extremely low phase change with temperature and yet maintains all of the benefits of a lightweight, flexible cable.

What is "Electrical Length?"

A single frequency, step function stimulus, when launched into a cable assembly, can be thought of as a rotating voltage vector whose angular velocity (deg/sec) is equal to 360 times the frequency. This voltage vector rotates at this angular velocity for an amount of time equal to the propagation delay of the cable assembly. The product of the propagation delay and the angular velocity of the applied voltage vector are known as the electrical length of the cable assembly.

Consider a case of an X Band SAR transmitter feeding an antenna element. The frequency of the applied signal is 9.5 GHz and the propagation time delay of the cable assembly is 3 nano-seconds. The electrical length of the cable, in degrees, can be calculated by, what is essentially, a simple "distance equals rate times time" formula:

$$\Phi = 360\ f_0\ td$$

$$\Phi = 360 \times 9.5 \times 10^{9} \times 3 \times 10^{-9}$$

$$\Phi = 10{,}260 \text{ degrees}$$

The propagation delay of the cable assembly is a function of the physical length, velocity of light and the net dielectric constant of the propagation medium.

If we assume that our antenna cable has a dielectric constant of 2.04 and the physical length is 24.8 inches the propagation delay can be calculated by:

$$td = \frac{l \times \sqrt{\varepsilon_r}}{c}$$

$$td = \frac{24.8 \times \sqrt{2.04}}{11.8029 \times 10^{9}}$$

$$td = 3.0 \times 10^{-9} \text{ sec}$$

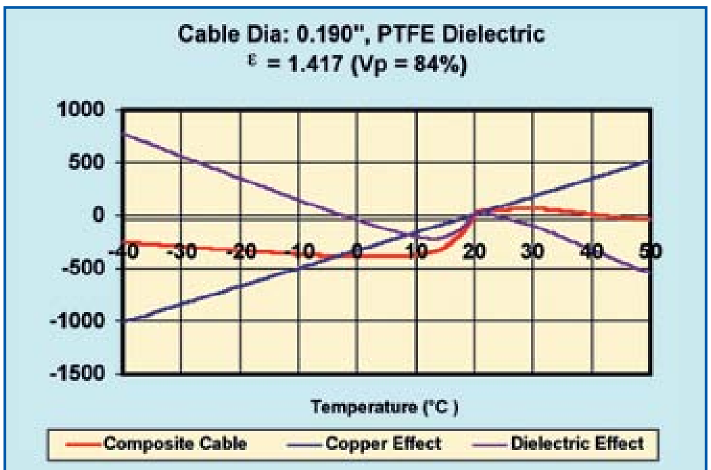

Figure 4

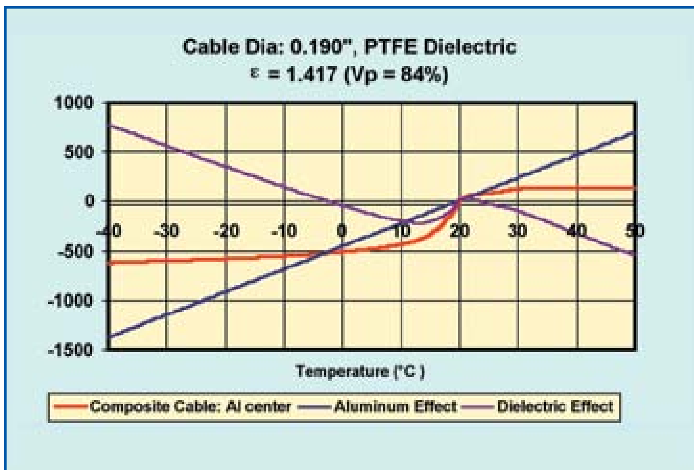

Figure 5

Substituting the time delay calculation into the electrical length formula provides the complete relationship between electrical length and the appropriate electrical and physical properties of the cable.

$$\Phi = \frac{360\times f_0\times l\times\sqrt{\varepsilon_r}}{c}$$

The frequency is held constant and the velocity of light is constant. The only variables in the electrical length equation are physical length and net dielectric constant of the propagation medium.

Why Does Electrical Length Change With Temperature?

Most high quality, high performance coaxial cables are made using dielectric materials whose dielectric constant is very stable across a relatively wide range of temperatures. The dielectric constant, of the base material (i.e. PTFE or Silicon Dioxide), is constant for all practical purposes. As the environmental temperature changes around the cable the metal conductors of the coaxial structure undergo a well-understood thermal expansion/contraction. Copper expands at a rate of 17 PPM per degree Celsius. The physical length of the cable will change directly proportional to the thermal coefficient of expansion. It is self evident that the electrical length will change in proportion to the physical length change.

From the simplified diagram of a typical coaxial cable it is clear that the center conductor's expansion and contraction directly effects the physical length and thus the electrical length. The effects of the expansion and contraction of the braided outer conductor is a bit more interesting and complex. The individual conductors, that comprise the braid, are wrapped around the circumference of the dielectric core. When they expand and contract they do not lengthen and shorten the physical length of the cable assembly. Instead they tend to tighten and loosen themselves upon the core.

A coaxial structure, when stabilized at room ambient temperature (about +25° C), will have a certain amount of constrictive force imparted into the dielectric core by the braids and subsequent outer layers within the cable. When measuring electrical length stability, as a function of dynamic temperature, it is common to use this condition as a basis against which phase stability is measured. The relative net dielectric constant of the core, and its relative density, can be normalized to 1 at this starting point. As temperature changes the amount of constrictive force imparted into the dielectric increases or decreases. This causes the relative density of the dielectric (and therefore the net dielectric constant) of the propagation medium to change.

For example: When temperature is decreasing the physical length is decreasing. The physical length of the braids are decreasing as well causing the relative density of the dielectric to increase and the dielectric constant to increase. The net effect on electrical length is that the effects of the changing physical length are opposite to the dielectric constant changes. In typical cable the effects of the dielectric are much greater than the effects of the physical length changes.

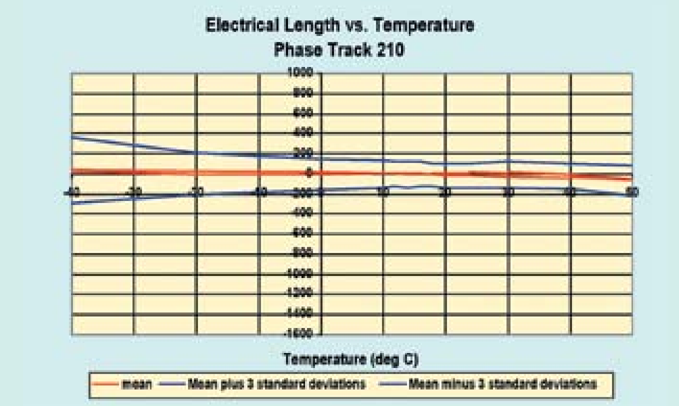

Figure 6

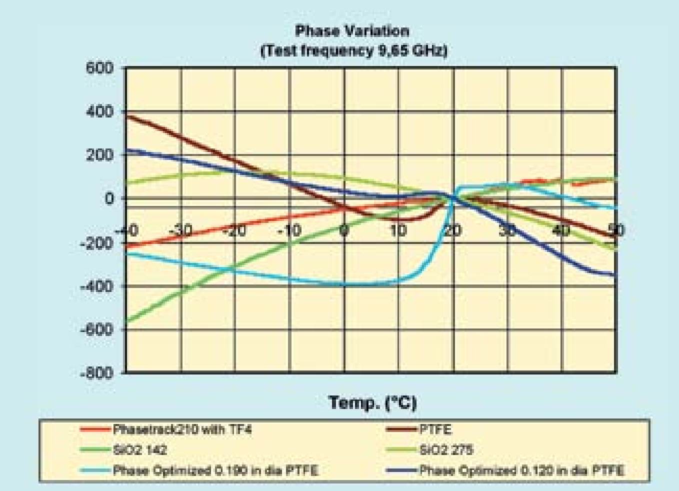

Figure 7

Phase Vs. Temperature Performance of Typical Cable

Traditional high performance cables, for non-phase critical applications, are typically made of expanded PTFE dielectric. The relative dielectric constant of this class of cable is about 1.73. This cable is relatively dense and undergoes significant phase change as a function of temperature. It is common for these types of cables to have maximum phase changes of over 2500 PPM. These cables were designed without regard to phase stability. They were optimized to have the lowest attenuation possible.

The phase vs. temperature response of a representative high performance expanded PTFE dielectric cable is illustrated in **Figure 3**.

How to Overcome These Problems

As radio frequency and microwave systems became increasingly phase sensitive it became clear to cable manufacturers that designs would have to be significantly improved to meet the performance demanded by the industry. Since the metal and dielectric effects have opposite temperature slopes it stands to reason that a balance should be possible. Through mechanical and process design the typical balance illustrated below is commonly achieved.

It is absolutely imperative that the design, materials and processes be considered simultaneously. Changing materials, without changing the mechanical design will no longer yield optimum results. Using the best materials for a particular design is no guarantee of success unless the processes are optimized and monitored closely. When the exact design and process used to make the cable whose response is illustrated in **Figure 4** is constructed by replacing the copper center conductor with an aluminum center conductor the results are clear. Phase stability has been significantly degraded.

What About That "Knee?"

PTFE, in many ways, is the perfect material for RF and microwave dielectrics. It has a very low loss tangent and the electrical properties are virtually constant across a wide range of temperatures. Unfortunately, this material has one very significant shortcoming. At around +18 degrees C (65 F) the material undergoes a molecular phase transition. When transiting through this band of temperatures the material undergoes a "step function" change in dielectric constant. Along with this change in dielectric constant is an abrupt change in electrical length. This is commonly known as the Teflon™ "knee".

The dielectric and metal effects on electrical length can be balanced above and below this phase transition band of temperatures. But the laws of physics are irrefutable. The knee will always be present in PTFE dielectric cable.

The Only Option Is To Find Another Material

For many years the best material on the market was Silicon Dioxide. SIO_2 is a very good cable. It has reasonable attenuation characteristics, although significantly higher than PTFE. It has a very high temperature rating and has an essentially linear phase vs. temperature slope.

Problem Solved, Right?

SIO_2 is a ceramic material that is quite brittle. The only practical coaxial cable that can be made with this material is a semi-rigid cable. Semi-rigid cable has many deficiencies in that it is difficult to make in long lengths and precise bend data must be supplied when making cable assemblies.

Another avenue was needed to achieve linear phase stability in a flexible coax structure.

Phase Stable and Flexible

TF4 is a proprietary flouropolymer material process, developed by Times Microwave Systems, to specifically address this issue.

This is a plastic material that has an extremely linear phase-temperature characteristic. By employing this material, and the correct design and process measures, a very good balance between dielectric and metal effects has been achieved.

How Does TF4 Technology Compare?

Figure 7 compares the phase vs. temperature characteristics of a variety of cable options. There are several phase optimized PTFE constructions, two silicon dioxide constructions and the PhaseTrack 210 using TF4 technology. The PhaseTrack cable offers the system designer the option of using a flexible cable with much better phase stability than previously available options, resulting in enhanced system performance.

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