

**Garlock**

# WavePro®

Low-loss dielectrics and laminates  
for RF & mmWave applications



## HIGH-PERFORMANCE DIELECTRIC MATERIAL

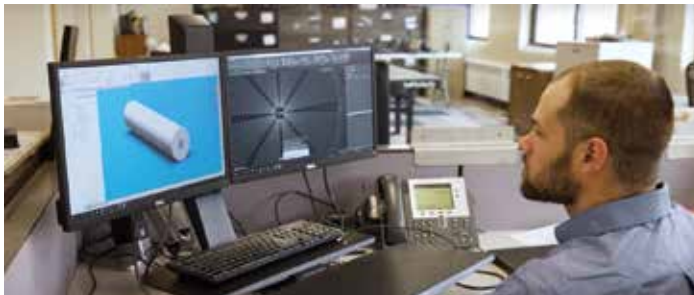
WavePro® is a ceramic-filled PTFE dielectric, engineered for use in antennas, lenses, and discrete components such as phase shifters, couplers, and more for RF and mmWave applications. Its precise formulation provides a low loss factor, superior mechanical and thermal stability. It exhibits minimal phase shift with frequency and temperature, and its highly consistent characteristics within and across panels improve quality control and result in higher production yields. WavePro® is an excellent choice for reliable, high-performance wireless applications up to 110 GHz.

### KEY SPECIFICATIONS

	WP025LDf	WP025	WP030	WP050	WP108	WP120	WP156	WP204
Dk dielectric constant	2.50	2.55	3.03	5.07	10.80	12.10	15.60	20.40
Df loss tangent	0.0007	0.0021	0.0009	0.0009	0.0015	0.0014	0.0010	0.0100

### MADE TO ORDER DIELECTRIC CONSTANT (Dk)

A proprietary PTFE formulation combined with advanced manufacturing techniques allows for precise, tunable dielectric properties. WavePro®'s unique materials and manufacturing processes allow you to tune the dielectric constant and layer multiple dielectric constants within a single panel or part. This means that RF designers can specify the Dk(s) needed to optimize their designs instead of being limited to a small set of commercially available standard options.



### MADE TO ORDER CONFORMAL SURFACES AND 3D SHAPES

Thanks to an innovative, precision manufacturing process, WavePro® is available in custom shapes and sizes while maintaining its superior dielectric and structural properties. This can reduce product cost and complexity by eliminating etching, machining, or molding steps during the manufacturing process.

<b>Flat Panels</b>	Available in 18"x24" panels, thicknesses from 10 mil (0.25mm) to 394 mil (10.0mm). Pre-cut shapes and custom dimensions are available upon request.
<b>Laminates</b>	Suitable for patch antennas, dielectric components that require metallization, and multi-layer PCB designs. Available in 18"x24" panels, thickness from 10 mil (0.25mm) to 394 mil (10.0mm). Custom sizes are available upon request.
<b>Curved &amp; Conformal Surfaces</b>	Metasurfaces with a periodic or non-repeating pattern, as well as contoured/conformal surfaces can be produced.
<b>Single Dk 3D Shapes</b>	Cylinders, rectangular tubes, large blocks, disks, and build-to-print components are available.
<b>Multilayered Dk 3D Shapes</b>	Ideal for Gradient-Index (GRIN) lenses, reflection reduction surfaces, and other designs.

## BUILD-TO-PRINT MANUFACTURING

WavePro® is a versatile material that is available as a pure dielectric substrate or as a copper-clad laminate for PCB designs. As a pure dielectric substrate, WavePro® is compatible with metallization processes including metallic ink, printing, screen printing, cladding, plating, and vapor deposition. The structural strength and stability of WavePro® also make it ideal for attaching elements such as stampings.



## APPLICATIONS

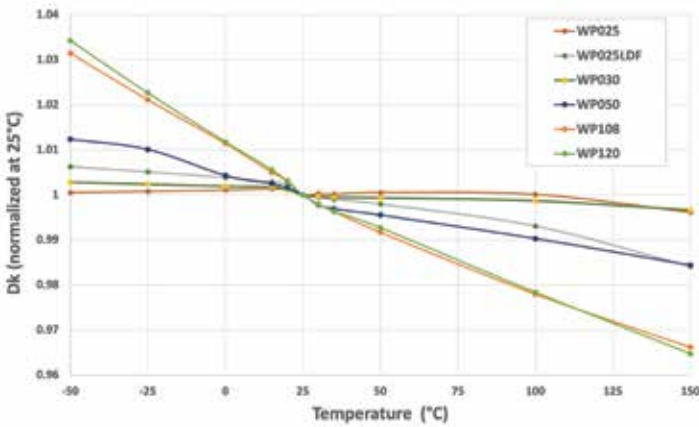


## STABLE PERFORMANCE ACROSS A WIDE TEMPERATURE AND FREQUENCY RANGE

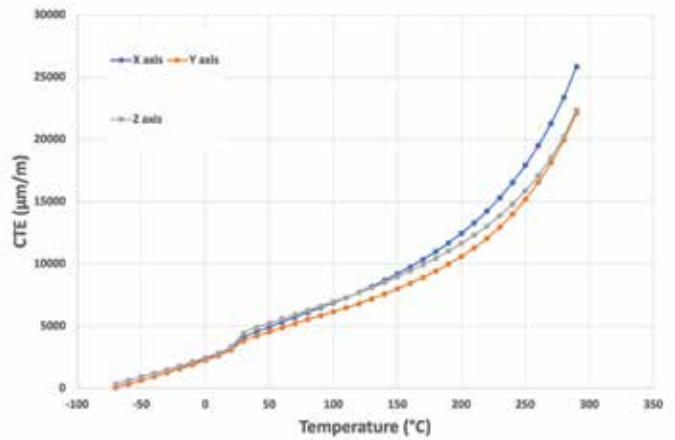
WavePro® offers excellent thermal stability as shown in **figure 1**, which illustrates the variation of the dielectric constant Dk as a function of temperature. Lower Dk substrates (Dk = 2.5 and 3.0) maintain their Dk within 0.3% of their specified value across the tested range of -50°C to 150°C. As Dk increases, so does the variation of Dk with temperature.

**Figure 2** shows the thermal expansion of WavePro® WP030 as a function of temperature, indicating approximately isotropic expansion across the X, Y, and Z directions from -50°C to 150°C.

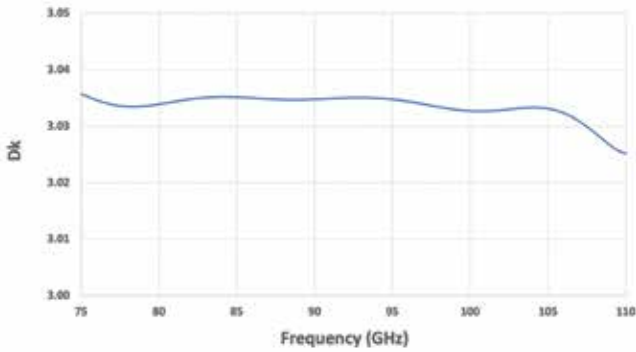
Frequency dependence of WP030's dielectric constant and loss tangent in the 75-110 GHz range are shown in **figures 3 and 4**.



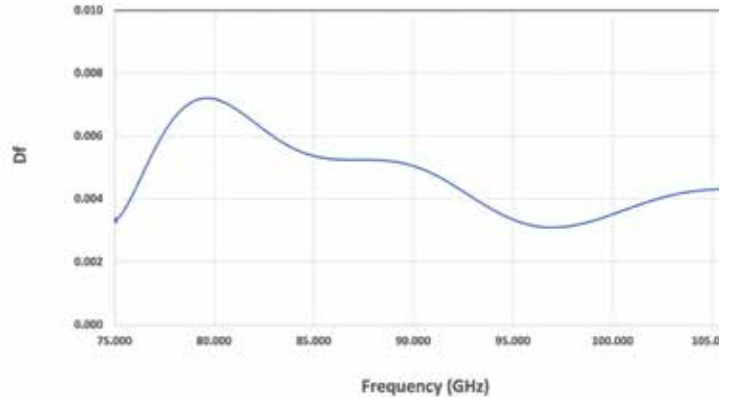
**Figure 1:** Variation of Dielectric Constant Dk with Temperature



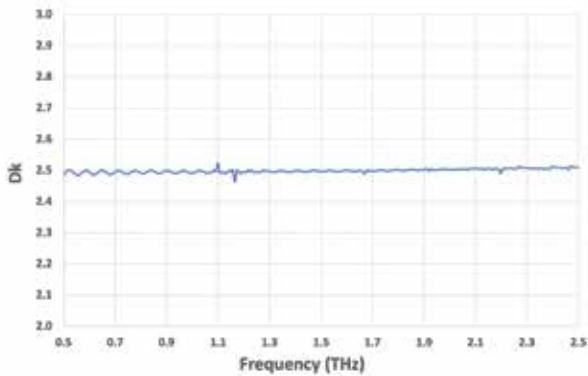
**Figure 2:** Thermal expansion vs Temperature  
Dk = 3.03



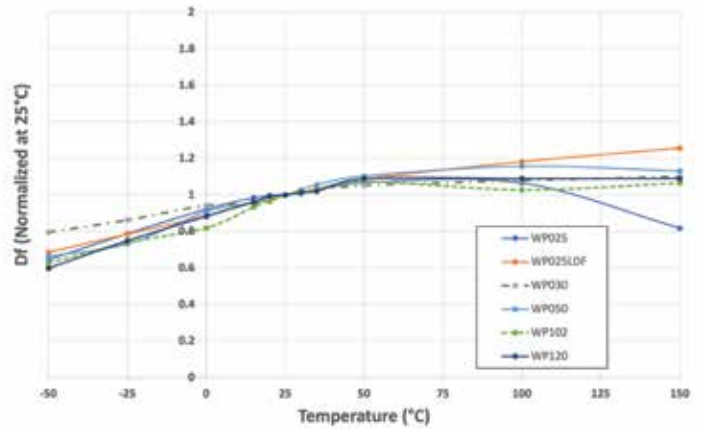
**Figure 3:** Dielectric constant at mmWave frequencies  
WPO30: Dk = 3.03 @ 5 GHz



**Figure 4:** Loss tangent at mmWave frequencies  
WPO30: Df = 0.0009 @ 5GHz



**Figure 5:** Dielectric constant at Terahertz frequencies  
WPO25: Dk = 2.5 @ 5 GHz



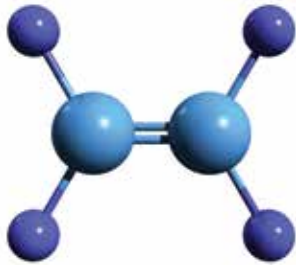
**Figure 6:** Thermal Coefficient of Loss Tangent

## THE WAVEPRO® ADVANTAGE

WavePro® is the result of more than 135 years of material science innovations, including 50+ years of modifying and enhancing PTFE to meet industrial needs. The same way that our scientists have altered and improved PTFE to meet the mechanical needs of today, they have now modified and improved PTFE's electrical properties for the needs of tomorrow.

### POLYTETRAFLUOROETHYLENE (PTFE): A VERSATILE POLYMER

The PTFE monomer consists of carbon flanked by fluorine atoms. Polymerization creates long chains from this building block.



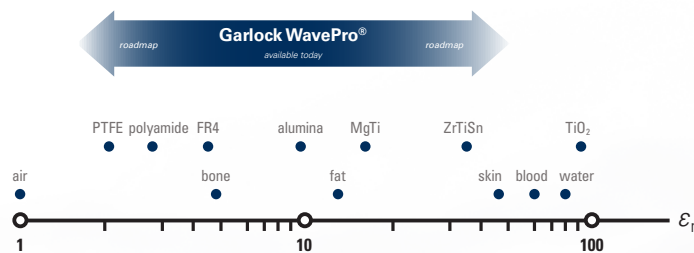
The strength of the carbon-fluorine bond gives rise to many of the desirable properties of PTFE.

PTFE exhibits good temperature characteristics, is inert to virtually all chemicals, and is the only known surface that a gecko cannot stick to. It possesses many dielectric and mechanical properties that make it attractive for use in a broad range of RF designs – including high-performance applications and harsh environments:

- Low loss tangent Df
- Low moisture absorption (hydrophobic)
- High operating temperature

In 1967, Garlock introduced filled PTFE sealing products. The expertise required for designing and formulating PTFE-based composites forms the basis of the WavePro® dielectric material.

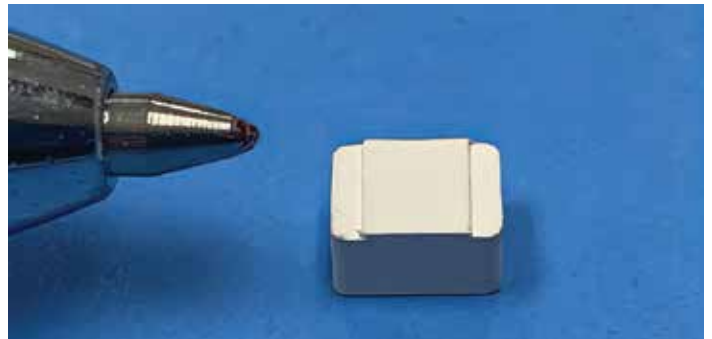
### ENGINEERING MATERIAL PROPERTIES



As a ceramic-filled PTFE composite material, WavePro® combines attributes of PTFE and ceramics. Pure PTFE acts as the host substrate, to which micro-particles of a ceramic are added. Depending on the ceramic(s) used, the dielectric constant, loss tangent, thermal coefficient of expansion, and other properties can be substantially altered and engineered for a desired outcome.

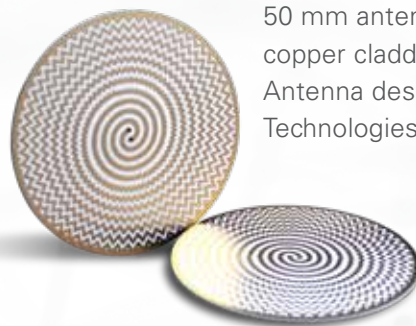
To attain a specific property value, the right filler materials and exact manufacturing processes are needed.

### PRECISION MANUFACTURING



At mmWave frequencies, the physical dimensions and tolerances of components are much tighter. WavePro can create precise, high-yield components for mmWave frequencies using techniques from our polymer-based product manufacturing in the sealing, chemical, and biomedical sectors.

### REMARKABLE RESULTS



50 mm antenna on 30mil thick copper clad WP030 substrate. Antenna design by Black Art Technologies.

## MATERIAL PROPERTIES

Parameter	WP025Ldf	WP025	WP030	WP050	WP108	WP120	WP156	WP204	Condition	Test Method
Dk (dielectric constant permittivity)	2.50	2.55	3.03	5.07	10.80	12.10	15.60*	20.40*	5 GHz @ 23°C	IPC-TM-650-2.5.5.5 *ASTM D2520
Df (loss factor, tan δ)	0.0007	0.0021	0.0009	0.0009	0.0015	0.0014	0.0010*	0.0100*	5 GHz @ 23°C	IPC-TM-650-2.5.5.5 *ASTM D2520
Moisture absorption	0.02%	0.09%	0.03%	0.03%	0.10%	0.10%	-	-	24 hrs/23°C	IPC-TM-650-2.6.2.1
CTE (coefficient of thermal expansion) ppm/°C	-	-	X: 42 Y: 36 Z: 40	X: 25 Y: 29 Z: 28	X: 22 Y: 19 Z: 21	-	-	-	-55 to 150°C	IPC-TM-650-2.4.41
Volume Resistivity MΩ-cm	-	-	2.66 x 10 <sup>9</sup>	1.94x 10 <sup>8</sup>	0.62 x 10 <sup>8</sup>	-	-	-	1.5hr/25°C/90%RH	IPC-TM-650-2.5.17.1
	-	-	2.43 x 10 <sup>9</sup>	2.05 x 10 <sup>8</sup>	0.37 x 10 <sup>8</sup>	-	-	-	96hr/35°C/90%RH	
Tensile Strength (MPa)	26.0/3776	18.4/2675	16.0/2316	12.5/1816	10.8/1560	10.7/1558	-	-	X-axis	ASTM D1708
	25.1/3565	17.2/2501	14.9/2166	11.4/1657	9.7/1413	9.4/1359	-	-	Y-axis	
Flammability	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	-	UL-94V
Density (g/cm3)	2.17	1.96	2.17	2.49	2.89	2.98	3.02	3.57	23°C	ASTM D792



## ORDERING INFORMATION

Part Number	Required (panels and laminates)										For laminates only						
	WP	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Permittivity (Dk): WP025, WP120, etc.																	
Panel Thickness (mm)																	
Panel Width (inches)																	
Panel Length (inches)																	
Surfaces clad: DC (dual clad) or SC (single clad)																	
Copper type: ED (electro-deposited) or RL (rolled)																	
Copper weight: 050 (0.5 oz / 35µm thick) or 100 (1 oz / 70µm thick)																	

The following examples illustrate the part numbering schema.

Part Number	Description
WP030-0151824	WavePro flat panel, Dk = 3.03, Df = 0.0009, 1.5mm x 457mm (18" x 610mm (24"))
WP025Ldf-0401824	WavePro flat panel, Dk = 2.50, Df = 0.0007, 4mm x 457mm (18" x 610mm (24"))
WP025-1001824-SC-RL-050	WavePro laminate, D = 2.55, Df = 0.0021, 10mm x 457mm (18" x 610mm (24")) Single-clad, rolled, 0.5 oz (35µm) copper cladding
WP156-0801824-DC-ED-100	WavePro laminate, Dk = 15.6, Df = 0.001, 8mm x 457mm (18" x 610mm (24")) Dual-clad, electro-deposited, 1 oz (70µm) copper cladding

### BUILD-TO-PRINT SHAPES AND SURFACES

For custom shapes and sizes, including designs with multiple or a gradient dielectric constant, please visit <https://waveproantenna.com/pages/custom-products> and send us your drawings. We accept all standard CAD file formats.

# ABOUT GARLOCK & ENPRO INDUSTRIES

Garlock, a division of Enpro Industries, has formulated and processed filled PTFE for more than 50 years. As experts in PTFE and polymers, we continually explore new applications for our product and process expertise. We take pride in engineering materials and developing innovative processing techniques to deliver high-quality, high-performance products to meet exacting requirements.

## MATERIALS SCIENCE & MANUFACTURING INNOVATION

### PRECISION MANUFACTURING

Ultra-narrowband interference filters (down to  $\sim 0.1$  nm linewidth) for LIDAR imaging are made by depositing alternating layers with contrasting refractive indices onto a substrate. Layers are typically  $\frac{1}{4}$  wavelength thick. Our optical filters are also used in non-linear optical systems with high-intensity femtosecond pulse lasers.



### RELIABILITY IN EXTREME ENVIRONMENTS

We went to Mars! Well, our products did. The Mars Rover traveled 54 million miles through space to explore a rocky, hostile planet. The Rover's robotic arm drill spindle incorporates our metal-PTFE bearing segments – which are self-lubricating and are capable of functioning from  $-328^{\circ}\text{F}$  to  $+536^{\circ}\text{F}$  ( $-200^{\circ}\text{C}$  to  $+280^{\circ}\text{C}$ ).



### DELIVERING UNDER PRESSURE

An extensive, two-year testing phase preceded the requirements definition and design of a sealing system for protecting vital electronics in a subsea oil and gas environment. Our seal consists of a close-wound helical spring core and ductile outer jacket for maximum sealing integrity.



### QUALITY WITHOUT COMPROMISE

When it comes to vaccines and gene therapies, the unwanted introduction of contaminants at any point in the production process can have disastrous consequences. Our sterile fluid transfer solutions for critical environments make sure injections and fluids remain clean and sterile.



WavePro, a Garlock Brand  
1666 Division Street  
Palmyra, New York 14522 USA

Email: [WavePro@Garlock.com](mailto:WavePro@Garlock.com)

[WaveProAntenna.com](http://WaveProAntenna.com)

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