

Garlock®

WavePro®

Made to order, low-loss dielectric material



Better Antennas with WavePro®

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 80 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

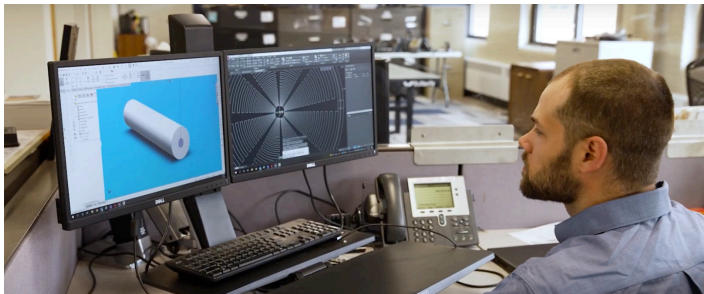
MADE TO ORDER CONFORMAL SURFACES, AND 3D SHAPES

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.

Flat Panels	Suitable for patch antennas and multi-layer PCB designs. Available in 18"x24" panels, thicknesses from 10 mil (0.01") to 375 mil (0.375"). Custom sizes are available upon request.
Curved & Conformal Surfaces	Lenses (plano-convex, convex, concave), dome, disk, rings, and surfaces with non-uniform thickness are available. Custom surfaces are available upon request.
3D Shapes	Cylinders, rectangular tubes, and custom shapes are available.

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.



ANTENNA APPLICATIONS

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.

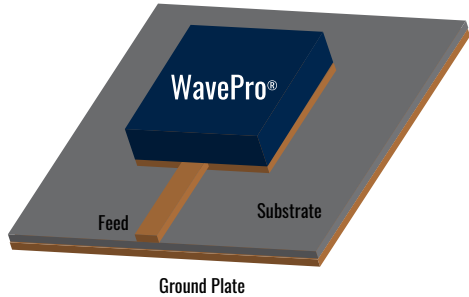
PATCH

In PCB designs, a custom Dk can be used to help achieve the desired bandwidth, antenna size, and impedance matching. Antenna size reduction can be achieved using a higher Dk value [1].



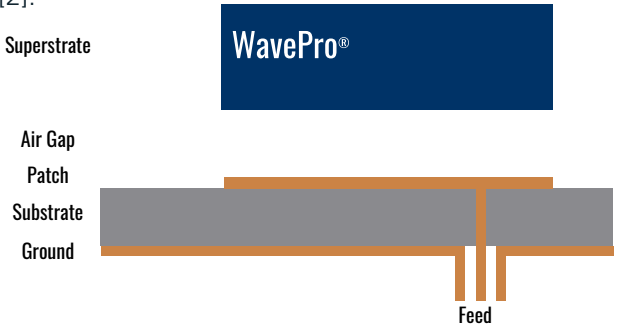
DIELECTRIC RESONATOR ANTENNAS (DRA)

For 5G mmWave applications, 3D shapes (blocks, cylinders, and others) can create compact antennas with wide bandwidths supporting multiple TE modes.



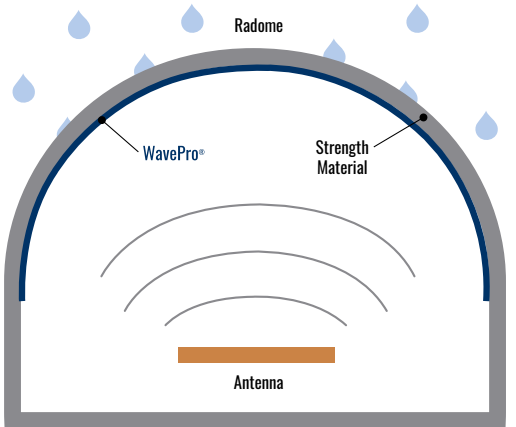
SUPERSTRATE

Using superstrates above patch antennas can increase gain by several dB, improve radiation efficiency, and control beam directivity [2].



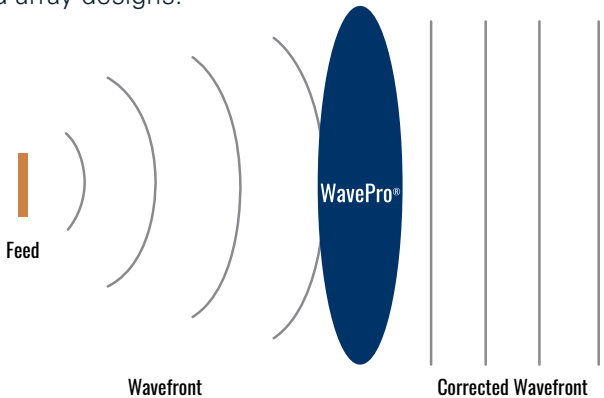
RADOME

A radome protects the antenna from environmental factors, and materials with a low dielectric constant are used to minimize insertion and scattering losses.



LENS

As with optical lenses, dielectric lenses focus the beamwidth, increase gain and directivity, and are used in both single-feed and phased array designs.



REFERENCE DIELECTRIC

The tight tolerances of WavePro® dielectric products make it suitable as a reference or calibration material to simulate the dielectric properties of a material being tested.

For example, in medical imaging applications, WavePro can be incorporated into phantoms, or manufactured in the shape of a heart, brain, or other body parts.

THERMAL STABILITY

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.

Figures 2a, 2b, and 2c show the thermal expansion of WavePro® as a function of temperature, indicating approximately isotropic expansion across the X, Y, and Z directions.

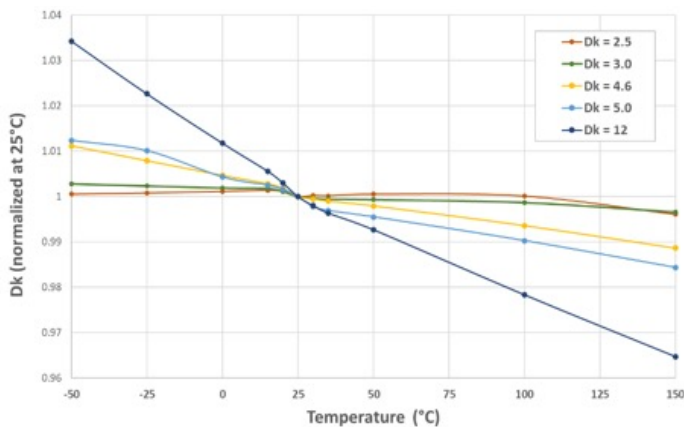


Figure 1: Variation of Dielectric Constant Dk with Temperature

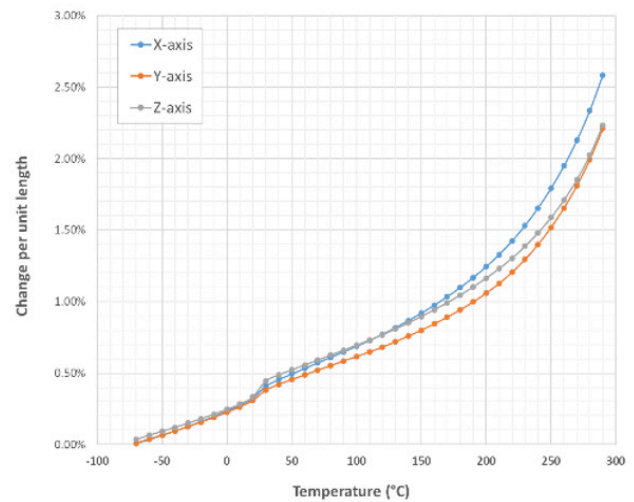


Figure 2a: Thermal expansion vs Temperature
Dk = 3.03

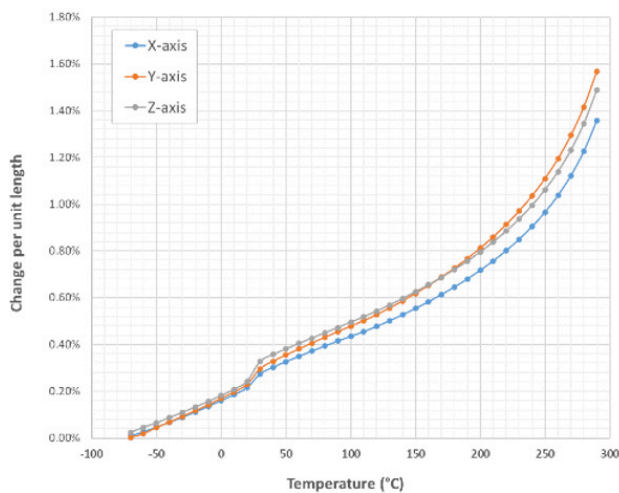


Figure 2b: Thermal expansion vs Temperature
Dk = 5.07

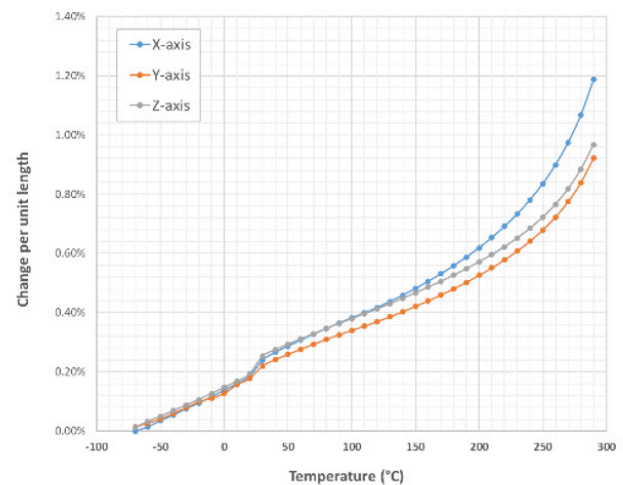
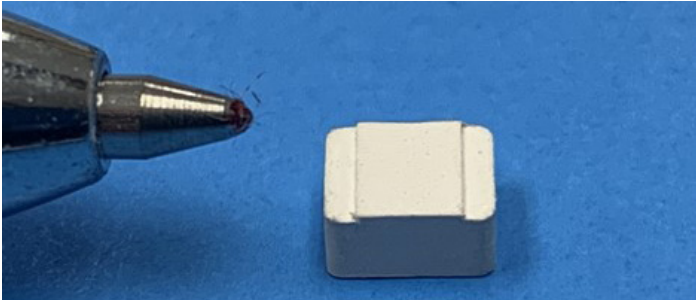


Figure 2c: Thermal expansion vs Temperature
Dk = 10.8

THE WAVEPRO® ADVANTAGE

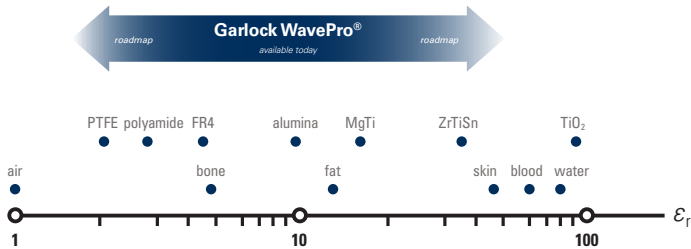
WavePro® is the result of more than 135 years of material science innovations, including 50+ years of modifying and enhancing PTFE to meet industrial needs. The same way that our scientists have altered and improved PTFE to meet the mechanical needs of today, they have now modified and improved PTFE’s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

PRECISION MANUFACTURING



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

CUSTOM Dk & ENGINEERED 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.

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.

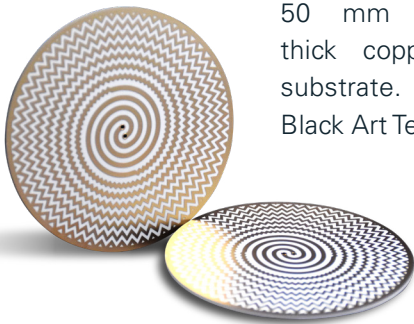
The dielectric material of WavePro® is based on polytetrafluoroethylene (PTFE), commonly known as Teflon™.

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.

REMARKABLE RESULTS



50 mm antenna on 30mil thick copper cladded 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)	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
Thermal Coefficient of Dk ppm/°C	-111	-22	-31	-140	-327	-348	-	-	5 GHz -50 to 150°C	IPC-TM-650-2.5.5.5
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 ⁸	1.94x 10 ⁸	0.62 x 10 ⁸	-	-	-	1.5hr/25°C/90%RH	IPC-TM-650-2.5.17.1
	-	-	2.43 x 10 ⁸	2.05 x 10 ⁸	0.37 x 10 ⁸	-	-	-	96hr/35°C/90%RH	
Surface Resistivity MΩ	-	-	9.50 x 10 ⁷	6.43 x 10 ⁷	2.78 x 10 ⁷	-	-	-	1.5hr/25°C/90%RH	IPC-TM-650-2.5.17.1
	-	-	9.33 x 10 ⁷	7.87 x 10 ⁷	7.03 x 10 ⁷	-	-	-	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
Panel size	18" x 24" (457 x 610 mm) Custom sizes made to order									
Panel thickness	10 to 394 mil (0.25 to 10 mm) Custom thicknesses made to order									
Conformal surface	Made to order									
3D shape	Made to order									



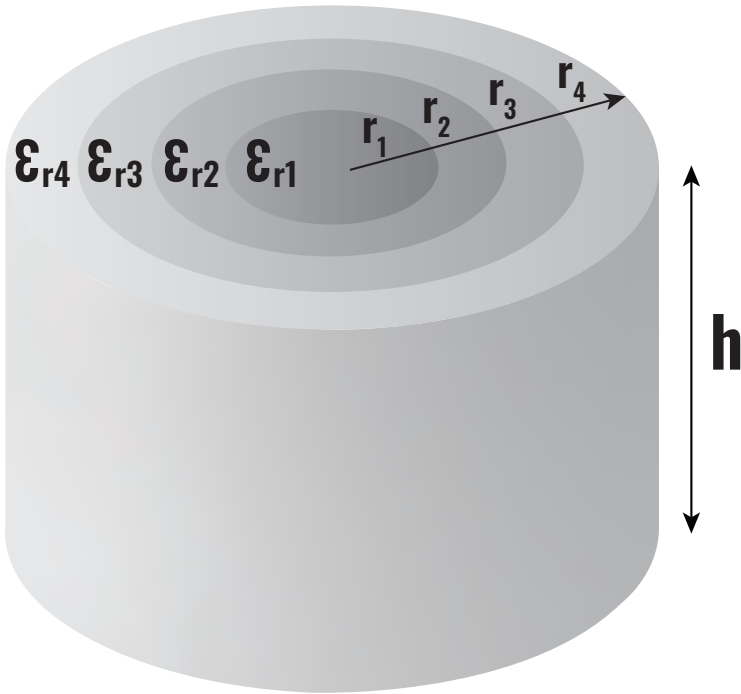
ORDERING INFORMATION

FLAT PANELS

Panel Length		610 mm / 24"				
Panel Width		457 mm / 18"				
Panel Thickness		1.5 mm / 0.059"	2 mm / 0.079"	4 mm / 0.157"	8 mm / 0.315"	10 mm / 0.394"
Dk	Df					
2.50	0.0007	WP025LDf-0151824	WP025LDf-0201824	WP025LDf-0401824	WP025LDf-0801824	WP025LDf-1001824
2.55	0.0021	WP025-0151824	WP025-0201824	WP025-0401824	WP025-0801824	WP025-1001824
3.03	0.0009	WP030-0151824	WP030-0201824	WP030-0401824	WP030-0801824	WP030-1001824
5.07	0.0009	WP050-0151824	WP050-0201824	WP050-0401824	WP050-0801824	WP050-1001824
10.80	0.0015	WP108-0151824	WP108-0201824	WP108-0401824	WP108-0801824	WP108-1001824
12.00	0.0014	WP120-0151824	WP120-0201824	WP120-0401824	WP120-0801824	WP120-1001824
15.60	0.0010	WP156-0151824	WP156-0201824	WP156-0401824	WP156-0801824	WP156-1001824
20.40	0.0100	WP204-0151824	WP204-0201824	WP204-0401824	WP204-0801824	WP204-1001824

SHAPES AND SURFACES

For custom shapes and sizes, including designs with multiple or a gradient dielectric constant, please visit waveproantenna.com and send us your drawings.



For custom orders, please visit waveproantenna.com and send us your specifications.

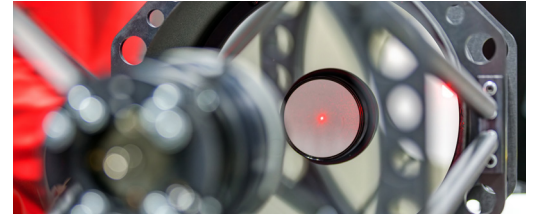
ABOUT GARLOCK & ENPRO INDUSTRIES

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

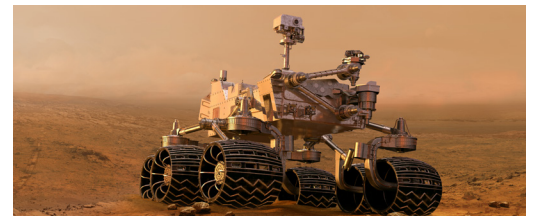
PRECISION MANUFACTURING

Ultra-narrowband interference filters (down to ~0.1nm 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°F to +536°F (-200°C to +280°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.



Garlock Family of Companies

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