PLASTIC MATERIALS FOR HIGH PERFORMANCE RADOMES

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The expansion of high-frequency and high-power RF systems has increased demand for protective materials with extreme dielectric performance.

Radar systems and telecommunications equipment are often used in harsh outdoor environments. They may have to withstand wind, rain, hail, snow, UV radiation, foreign object impacts, or other adverse environmental factors. Dome-shaped enclosures called radomes are used to protect RF equipment and antennas. They must also allow electromagnetic signals to pass through with minimal attenuation in order to maintain the functionality of the RF system. Examples of technologies that depend on radomes include:

- High-frequency 5G telecommunications
- Chemical tank level indicators
- Coastal and airport surveillance radar
- Global navigation satellite systems (GNSS)
- Advanced driver assistance systems (ADAS)
- High-speed aircraft and spacecraft
- Communications satellites

Radomes are used to protect communication systems.

Marine navigation systems rely on durable radome materials.

The expansion of high-frequency and high-power RF systems has increased demand for protective materials with extreme dielectric performance. The mechanical, thermal, and electronic requirements of radome materials depends on their usage. The primary material considerations are summarized here:

- Electrical properties
- Mechanical strength
- Aesthetics
- Weatherability
- Water absorption, wetting behavior, and rain erosion resistance
- Temperature performance
- Manufacturability

Rigid plastic materials are specified for radome applications due to their outstanding electrical properties, impact resistance, and manufacturability. Tables 1-4 beginning on page 13 list these properties for a wide range of plastic materials.

ELECTRICAL PROPERTIES

The primary tradeoff of radar enclosures is reduced RF performance. The two properties that describe the electromagnetic transparency of a polymeric radome material are its dielectric constant and its dissipation factor.

Dielectric Constant

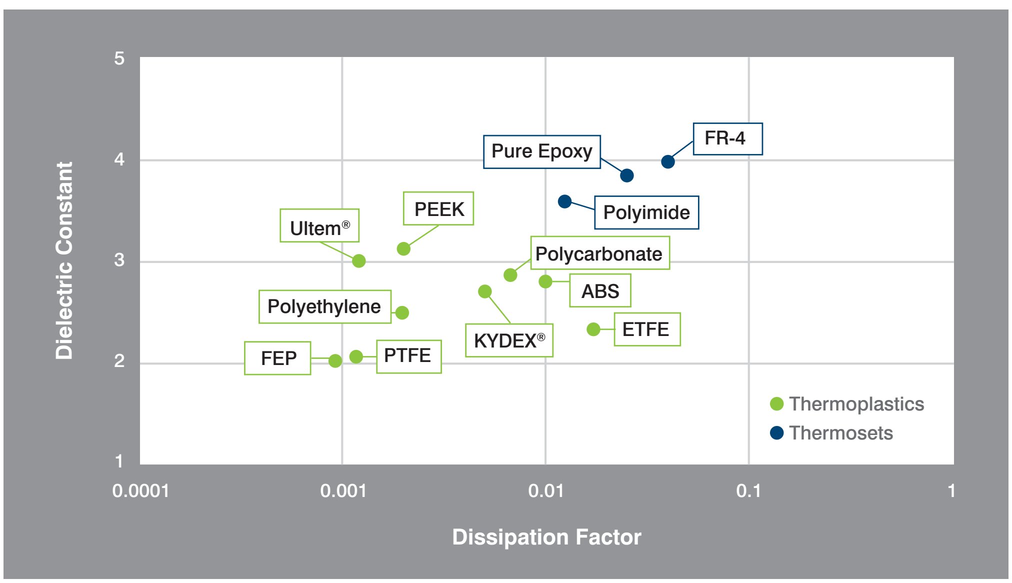
When EM radiation passes through a material, there are two types of losses: *reflection* and *absorption* (Ashby, 2011). The dielectric constant, or relative permittivity, is related to the fraction of the signal that is lost by reflection. It is defined as the ratio of the permittivity of the material to the permittivity of a vacuum. Reflected signals decrease radar performance and can potentially interfere with received signals. The fraction of reflected signals increases with frequency (Ashby, 2011). Materials with low dielectric constants are desirable for radome applications.

Dissipation Factor

The fraction of signals lost by absorption is related to the dissipation factor of a plastic material (Ashby, 2011). Dissipation factor is also referred to as loss tangent, tan δ, or approximate power factor. Materials with lower dissipation factors dissipate electrical energy more efficiently, reducing dielectric losses (e.g., heating). Surface roughness, cracks, or moisture absorbed from the environment typically increases the dissipation factor of plastic materials.

A dielectric constant less than 3.1-3.5 and a loss tangent less than 0.01 is typically desired for radomes. Thermoplastics generally have more favorable dielectric properties (i.e., lower dielectric constants and lower dissipation factors) compared to thermosets, as shown in Figure 1.

Figure 1. Dielectric Constants and Dissipation Factors for Plastic Materials at 1 GHz Frequency near Room Temperature



Adapted from Tonouchi, 2018. Additional data from Apeldorn 2012, Mergos 2010, Triantou 2018, Schramm 1973, Sabic, SEKISUI KYDEX, DuPont

Molecular Polarity
The behavior of plastic materials subject to electric fields is largely determined by their molecular polarity. We can divide dielectric materials into two categories: *polar* and *nonpolar* (Ashby, 2011). Polar materials have permanent electronic dipoles which are present even in the absence of an electric field. This asymmetric charge distribution originates from polar bonds at the molecular level.

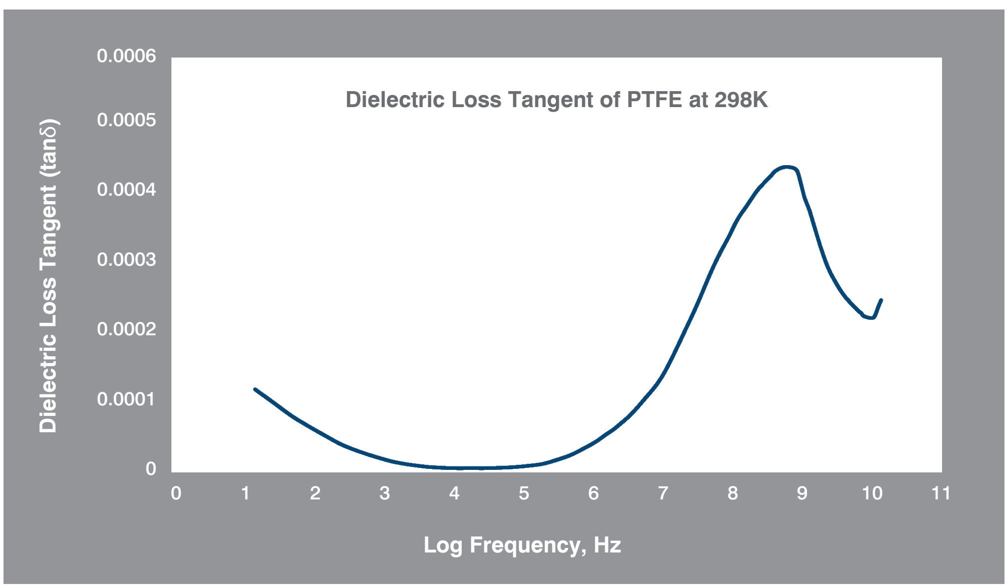
Permanent dipoles increase the polarizability of a material subject to an electric field. This ultimately increases dielectric losses in electrical applications (Geyer, 1990; Bur, 1985). Dipoles attempt to align with the electric field that is alternating at a given frequency. When dipole oscillations are out of phase with the electric field, which is typical at high frequencies, the constantly re-orienting polar molecules cause internal "friction" that generates heat. The heat generated is a form of dielectric loss.

Low-polarity polymers (e.g., PE, PP, PTFE) are only weakly polarized in an electric field. Although PTFE contains highly polar C-F bonds, there are no permanent dipole moments due to the symmetrical orientation of dipoles across the polymer backbone. This results in a nonpolar molecular structure. Similarly, polyethylene is nonpolar due to its structural symmetry. These materials often have low dielectric constants and low loss tangents.

Conversely, the -CH_3-CH_2Cl- repeating unit of PVC contains a polar C-Cl bond that is not canceled by symmetry. The resulting increased polarizability of PVC is manifested by a relatively high loss tangent of over 0.01 at 1 GHz (Mergos, 2010; Bur, 1985).

Temperature and Frequency Dependence of Dielectric Properties
It is important to note that the dielectric properties of plastic materials are dependent on temperature and frequency, and these relationships are typically nonlinear. The dissipation factor and dielectric constant for PTFE at room temperature are shown as a function of frequency in Figures 2 and 3.

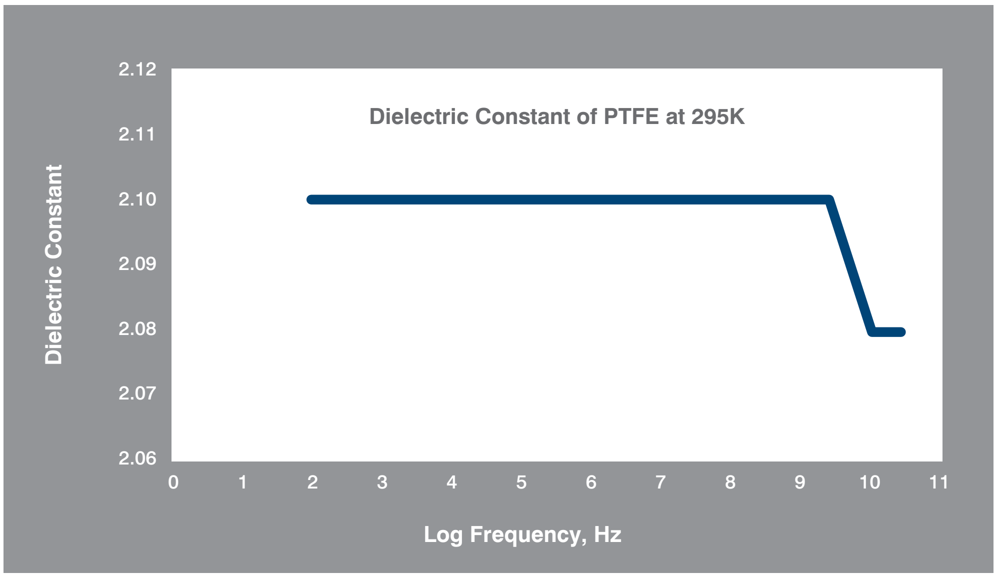
Figure 2. Dielectric Loss Tangent (Dissipation Factor) of PTFE as a Function of Frequency at Room Temperature



Source: Adapted from Schramm, 1973

Note that the frequency dependence of the dissipation factor is typically stronger and less linear compared to the frequency dependence of the dielectric constant. The dielectric constant generally decreases with increasing frequency. This effect is greater in polar polymers (e.g., PMMA, PVC, PA, and PC), especially at high frequencies. However, it is typically constant across low frequencies – especially in nonpolar materials like PTFE, as demonstrated by Figure 3.

Figure 3. Dielectric Constant of PTFE as a Function of Frequency at Room Temperature



Source: Adapted from Schramm, 1973

MECHANICAL PROPERTIES

Suitable mechanical properties for a radome depend on the application and the operating environment. For example, in aerospace applications, bird impacts pose a serious threat to critical radar systems so dielectric materials with high impact resistance are required to protect sensors and electronics. Radomes for spacecraft and military vehicles may also require high toughness and impact resistance. As shown in Table 2, plastic materials such as ABS, KYDEX® Thermoplastics, and TUFFAK® SL polycarbonate are good options for radomes that require high impact strength.

For some applications, strength and modulus (stiffness) may be required for part performance. As shown in Table 4, polyaryletherketone plastics including PEEK and PEKK, polyimides such as DuPont™ Vespel® SP-1, and reinforced thermoset composites such as FR-4 glass-reinforced epoxy have high strength and modulus values. These materials are often specified for radomes when load bearing properties are important.

High-performance thermoplastics such as polyaryletherketones, fluoropolymers, and DuPont™ Vespel® are used in aerospace applications for their low outgassing characteristics, high-purity, and broad chemical resistance. They also have good dielectric properties which qualifies them for radome applications in the most demanding environments.

Large repair costs on radio towers can be mitigated with durable radomes designed for long-term outdoor service.

AESTHETICS

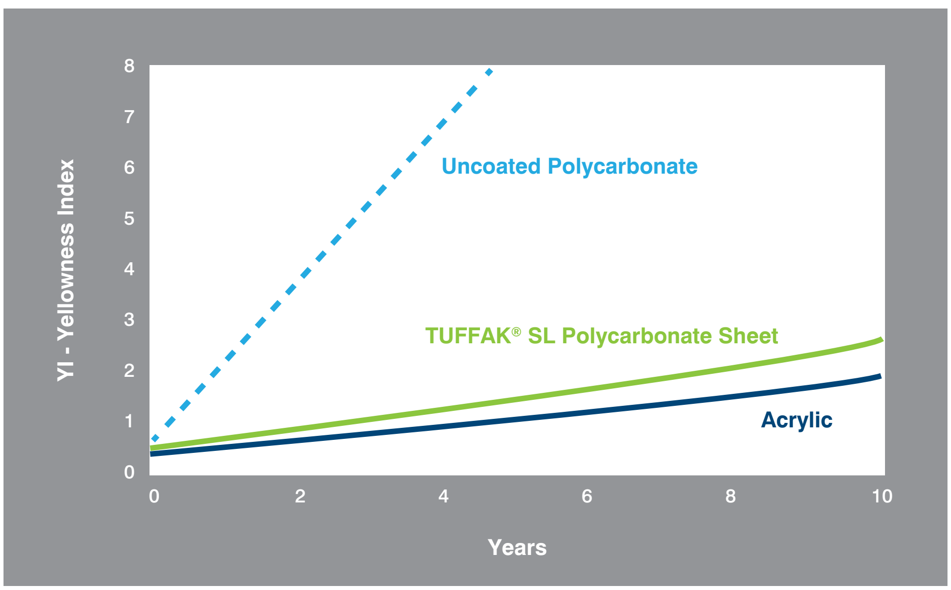
Applications such as 5G cellular antennas must be placed in population centers to best utilize their capabilities. The radomes for these transmitter/receiver systems are visible on rooftops, the sides of buildings, and street benches. Inconspicuous and aesthetically pleasing radome designs will facilitate acceptance of telecommunication equipment in residential communities. A number of plastic materials that are suitable for radomes including ABS, KYDEX® 510, and TUFFAK® SL polycarbonate sheets are available in a wide range of colors and textures, which allows the devices to achieve the desired appearance.

WEATHERABILITY / UV RESISTANCE

Weatherability is important for radomes that are exposed to challenging environmental conditions including intense sunlight, extreme temperatures, rain, ice, hail, and snow. Many plastics discolor and become brittle from UV exposure. Electrical properties also tend to degrade over time. Plastic materials used outdoors need to have good UV resistance to maintain the desired aesthetics and functionality. Some thermoplastics are inherently UV stable. Notable examples are acrylic, PTFE, and Ultem®. PTFE is virtually unaffected by weather and is resistant to extreme heat, cold, and UV irradiation commonly encountered in radar and other electronic components and enclosures (DuPont, 1996). For example, after 10 years of outdoor exposure only a minor change in the dissipation factor (on the order of 10^{-4}) of PTFE is expected (McKeen, 2019).

UV stabilized grades, UV cap layers, and protective coatings are commercially available for many polymer sheet materials that are not inherently UV stable. For example, TUFFAK® SL polycarbonate sheet is formulated with an enhanced UV resistance technology that allows it to retain color for a long service life in outdoor applications. Figure 4 shows the UV resistance of TUFFAK® SL compared with uncoated polycarbonate and also with acrylic, which is inherently UV stable.

Figure 4. UV Weather Resistance of Select Plastics Based Upon Xeon WOM Accelerated Weathering for UV Dose at a Mid-latitude Location



Source: Adapted from Plaskolite TUFFAK® SL Data Sheet 2018

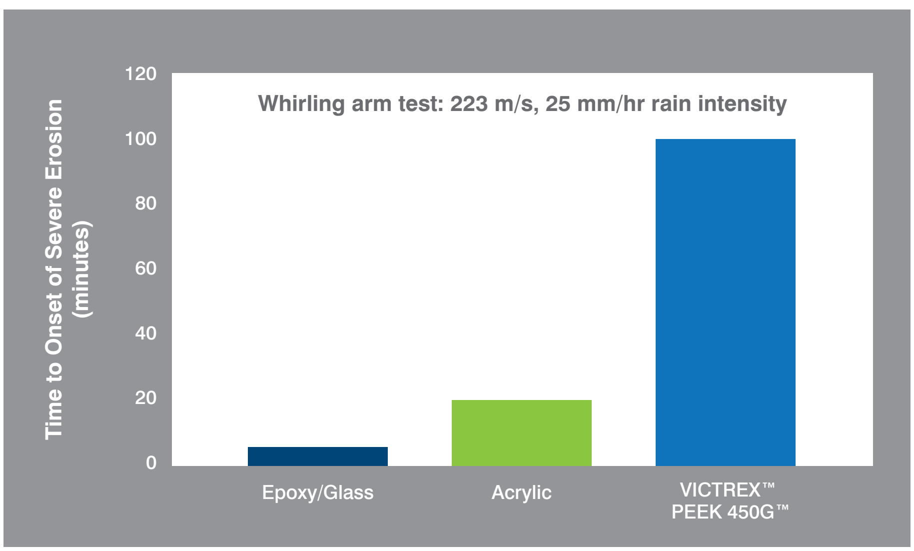
WATER ABSORPTION, WETTING BEHAVIOR, AND RAIN EROSION RESISTANCE

Water absorption typically reduces the electrical and mechanical performance of polymeric radome materials. For instance, the dielectric constant of PEEK at 1 GHz increases from approximately 3.11 in dry conditions to 3.27 at 50% relative humidity (Apeldorn, 2012). Additionally, the creation of a thin water film on radomes during heavy rainfall can result in severe signal losses due to reflections (Weigand, 1973; Griffiths, 2008). For these reasons, plastics with hydrophobic (water-hating) surfaces and low moisture absorption are often specified for radomes. Hydrophobic materials have low surface energy and a receding (minimum) water contact angle greater than 90° (Law, 2014). Water will tend to bead and roll off of these surfaces rather than forming a thin film. It is also more difficult for ice to adhere to hydrophobic surfaces.

Fluoropolymers are inherently hydrophobic plastic materials. PTFE, FEP, and PFA are perfluorinated (i.e., fully fluorinated) polymers that have advancing (maximum) water contact angles of approximately 120°. On the other hand, partially fluorinated polymers contain surface dipoles that enhance wettability (Lee, 2008). For instance, ECTFE and ETFE have advancing water contact angles of approximately 99° and 108°, respectively – making them less hydrophobic than their fully fluorinated counterparts (Lee, 2008). HDPE and PP are inherently hydrophobic owing to their nonpolar chemical structures (Extrand, 2004; Ryntz, 1990). Conversely, acrylic and polycarbonate are hydrophilic and contain dipoles in their chemical structures (Rios, 2007). Note that surface roughness (topology) can have an effect on the wettability of polymeric surfaces. Tables 1-4 include water contact angles for a number of plastic materials with smooth surfaces.

Rainfall erodes radome surfaces, contributing to long-term structural degradation. It is important to select plastic materials with sufficient rain erosion resistance for radomes subject to outdoor conditions. Figure 5 shows the rain erosion resistance of various plastics under laboratory conditions.

Figure 5. Rain Erosion Resistance of an Epoxy/Glass Composite, Acrylic, and PEEK



Source: Adapted from Gentilcore, 1992

TEMPERATURE PERFORMANCE

The temperature that a radome can experience may be influenced by the environment, heat generated by electronics, or in the case of devices traveling at high velocities, frictional heating from movement through air. The electrical and mechanical properties of radome materials should not degrade in normal operating temperatures. Continuous use temperatures, creep characteristics, dynamic modulus behavior, and thermal expansion characteristics should all be considered when selecting plastic materials for radome applications that involve elevated temperatures.

As shown in Tables 2-4, certain plastic materials including polyaryletherketones, Ultem®, fluoropolymers, and DuPont™ Vespel® have high service temperatures. DuPont™ Vespel® is a high-performance polyimide thermoplastic that maintains consistent mechanical properties across temperature extremes. The continuous use temperature is 500 °F in air, with allowable excursions up to 900 °F (DuPont, 1993; Wingard, 2013). The ability to withstand extreme aerodynamic heating has resulted in DuPont™ Vespel® polyimide being considered as a radome material for smart munitions that travel at supersonic speeds (Hollis, 2001).

Radomes used for aircraft, spacecraft, and ground vehicles may experience extremely low temperature conditions. Polymers generally become more brittle at cold temperatures. However, some plastic materials such as ultra-high molecular weight polyethylene, PCTFE, and DuPont™ Vespel® maintain some degree of ductility even at cryogenic temperatures (McDonald, 1987; Weihan, 1992).

MANUFACTURABILITY

Manufacturability is a key consideration of an effective and economical plastic solution. All thermoplastics can be machined into complex geometries. Some thermoplastics can also be thermoformed into hollow shapes which allow them to be manufactured into radomes at relatively low cost. Thermoforming involves preheating plastic sheet stock in a frame and applying vacuum pressure, or mechanical forming techniques, to conform the pliable plastic sheet to a preheated mold. Positive pressure can also be applied to the opposite, non-mold, side to achieve greater detail or molded-in textures that resemble an injection molded part.

The thermoformability of plastic materials is variable. Plastics with the right melt strength and sufficiently wide processing windows thermoform more easily. In general, amorphous polymers such as KYDEX® Thermoplastics, Ultem®, Tuffak® SL polycarbonate, and ABS can be thermoformed more easily.

With material expertise and sophisticated tooling, semi-crystalline polymers including HDPE, PP, PEEK, and PEKK can also be thermoformed, but generally with more difficulty than with amorphous thermoplastics. DuPont™ Vespel® polyimide and thermoset materials such as FR-4 glass-reinforced epoxy cannot be thermoformed.

Tables 1-4 list the plastic materials commonly used for radomes that are easy to thermoform and easy to machine.

In summary, material properties to consider for radome applications include:

- Low dissipation factor
- Low dielectric constant
- High strength and modulus
- High impact resistance
- Low water absorption
- Weatherability
- Rain erosion resistance
- UV resistance
- Surface hydrophobicity
- Machining and fabrication characteristics

PLASTIC MATERIAL FAMILIES

The following is an overview of plastic materials that are used for radomes.

Polyolefins (Polyethylene and Polypropylene)
Polyethylene and polypropylene are low-cost thermoplastics that have good chemical resistance, good dielectric properties, and limited thermoformability. They are available in a wide range of colors. Both materials have poor UV resistance, however they can be formulated with carbon black or other additives to improve their weatherability for outdoor use. High molecular weight grades of polyethylene have excellent cold temperature toughness.

Amorphous Thermoplastics (ABS, KYDEX® Thermoplastics, TUFFAK® SL polycarbonate, Noryl® (PPO), and Ultem® (PEI))
Amorphous thermoplastics have excellent thermoformability. ABS, KYDEX® Thermoplastics, Boltaron®, and TUFFAK® SL polycarbonate are available in many different colors and surface textures. Amorphous thermoplastics tend to have limited resistance to many industrial chemicals.

Thermoplastic Polyolefins (PMC® TPO)
TPOs are blends of an olefinic thermoplastic (typically PP or PE), an elastomer, and usually a filler. They have decent thermoforming characteristics and high toughness. PMC® TPOs are available in monolithic form or in coextruded sheet systems with cap layers engineered for enhanced weatherability, scratch and mar resistance, and gloss levels.

Fluoropolymers (PTFE, ECTFE (Halar®), ETFE, FEP, PFA, and PCTFE)
Unique properties including inherent surface hydrophobicity, wide service temperature ranges, high purity, low moisture absorption, and extraordinary chemical resistance are consequences of the carbon-fluorine chemistry in fluoropolymers. Many fluoropolymers have good electrical properties including a low dielectric constant and dissipation factor. Fluoropolymers are also generally resistant to weathering and UV irradiation.

Polyaryletherketones (PEEK and PEKK)
Polyaryletherketones are semi-crystalline thermoplastics containing varying ratios of ketone and ether groups in the repeating polymer unit. These materials are stable at elevated temperatures and have high mechanical strength and good dielectric properties. Polyaryletherketones also have outstanding chemical resistance.

Thermoset Laminates (FR-4)
Thermoset laminates have exceptional load-bearing properties but have a more brittle character than most thermoplastics. They are suitable for applications that do not require very low dielectric constants or dissipation factors. Wall thickness is often sacrificed to achieve suitable electrical properties, especially for high-frequency applications. They have excellent flammability characteristics. Thermoset laminates can be somewhat challenging to machine.

DuPont™ Vespel® Polyimide
DuPont™ Vespel® polyimide is unique in that it has fairly consistent mechanical properties from cryogenic to extremely high temperatures (DuPont, 1993; Lewis, 2015; Wingard, 2013). It is often specified in applications where dimensional stability and performance at extreme temperatures is required.

MATERIAL SELECTION PROCESS

The following process can be used to select among plastic materials for a radome application. Tables 1-4 beginning on page 13 provide useful reference information.

1. Determine the required dielectric constant and dissipation factor at the application frequency and operating temperature range.
2. Quantify service temperatures (continuous use and excursion), mechanical loads, and flammability requirements.
3. Consider the operating environment including wind, rain, ice, hail, water exposure, chemical exposure, threat of foreign object impact (e.g., birds, vandalism), importance of aesthetics, and service life.
4. Consider manufacturability. All thermoplastics can be machined. This process is suitable when the part geometry can be easily yielded from a sheet or rod, or when thermoforming is not possible. Thermoforming can be used to form deep-draw radome structures in an economical way.
5. Conduct empirical testing of the radome in simulated application conditions. A wide range of tests for plastic materials is available from independent laboratories.

Tough and ductile thermoplastics like polycarbonate withstand foreign object impacts and rain erosion more effectively than traditional thermoset composite materials, allowing for thinner skins and superior dielectric performance.

The expansion of high-frequency communication systems requires innovative and economical manufacturing methods for costly components like radomes.

Table 1. Properties of Polyolefins and Thermoplastic Polyolefin Materials Used for Radomes

				POLYOLEFINS Low dielectic constants, low strength and stiffness, not suitable for elevated temperature applications, difficult to thermoform, good chemical resistance, low cost		**THERMOPLASTIC POLYOLEFINS** Low dielectric constants, moderate mechanical properties, decent thermoforming characteristics
	Property	**Test Method**	**Units**	**HDPE**	**Polypropylene**	**PMC® 750**
ELECTRICAL PROPERTIES	Dissipation Factor (at 60 Hz)		Hz	0.002	0.00019 @ 1 MHz	-
	Dielectric Constant (at 60 Hz)		Hz	2.35	2.4 @ 1 MHz	-
	Dissipation Factor (at GHz frequencies)		GHz	0.002 @ 1 0.001 @ 11.3	0.00008 @ 9.4	0.006 @ 2.5 0.002 @ 5 0.004 @ 6, 18 0.001 @ 10, 30 0.004 @ 18 0.003 @ 39
	Dielectric Constant (at GHz frequencies)		GHz	2.5 @ 1 2.4 @ 11.3	2.26 @ 9.4	2.55 @ 2.5 2.59 @ 5, 6 2.60 @ 10 2.59 @ 18 2.58 @ 24, 28, 39 2.57 @ 30
	Dielectric Strength	ASTM D149	V/mil	1000	1140	-
MECHANICAL PROPERTIES	Tensile Strength at Break (or at yield, when noted)	ASTM D638	psi	4000	4700 @ yield	3090 @ yield
	Tensile Elongation at Break (or at yield, when noted)	ASTM D638	%	600	>50	–
	Flexural Modulus	ASTM D790	kpsi	140	225	290
	Notched Izod Impact Resistance (unless otherwise noted)	ASTM D256	ft-lbs/in	1.9	1.0	44 Joules (Mulit-Axial Impact)
THERMAL PROPERTIES	Heat Deflection Temperature @264 psi	ASTM D648	°F	147	210	134
	Continuous Service Temperature		°F	170	180	–
	Coefficient of Thermal Expansion	ASTM D696	in/in/°Fx10^{-5}	9.0	6.0	3.3
OTHER PROPERTIES/MFG NOTES	Outdoor Weatherability*	–	–	Good	Poor	Good
	Moisture Absorption (24 hours)	ASTM D570	%	0.10	<0.10	–
	Water Contact Angle	–	°	104 (advancing) 96 (receding)	97 (static)	–
	Flammability	UL-94	–	HB @ 0.118", 0.236"	HB @ 0.125"	–
	Availablity in a wide variety of colors and surface textures	–	–	✓	✓	✓
	Easy to Machine	–	–	✓	✓	✓
	Easy to Thermoform	–	–			✓

All data originates from manufacturer datasheets, manufacturer product literature, test reports, or published academic literature. Material datasheets are available upon request.

All statements and technical information contained in this table are for informational purposes only. Curbell does not guarantee the accuracy or completeness of any information contained herein and it is the customer's responsibility to conduct an independent review and make its own determination regarding the suitability of specific products for any given application. **Flammability**: Some manufacturers' do not indicate the thickness associated with the listed UL-94 rating.

Property data ranges: In this table, material properties are indicated either by a range of values or as one average value. All material properties are dependent on a number of factors and the listed ranges and values are intended to serve as general comparative guidelines only. The information provided does not imply the suitability of a material for any particular application. *Outdoor weatherability depends on a number of material and environmental factors. The specfic grade, color, and presence of UV stabilizers in a material will have a significant effect on weatherability.

Table 2. Properties of Amorphous Thermoplastic Materials Used for Radomes

				AMORPHOUS THERMOPLASTICS Moderately low dielectric constants, good mechanical properties, excellent thermoforming characteristics, moderate chemical resistance					
	Property	Test Method	Units	ABS	Boltaron® 4550	KYDEX® 510	TUFFAK® SL Polycarbonate	Noryl® PPO	Ultem® 1000 PEI
ELECTRICAL PROPERTIES	Dissipation Factor (at 60 Hz)		Hz	0.02	–	0.011	0.0009	0.0007	0.0005
	Dielectric Constant (at 60 Hz)		Hz	3.3	–	2.9	3.17	2.69	2.9
	Dissipation Factor (at GHz frequencies)		GHz	0.01 @ 1 0.0051 @ 2.44	0.005 @ 2.5 0.006 @ 5 0.012 @ 10 0.008 @ 18 0.009 @ 28 0.010 @ 39	0.005 @ 1	0.0066 @ 1 0.0005 @ 11	0.0050 @ 38.2 0.0013 @ 57.3 0.0017 @ 75.8 0.0050 @ 95 0.0043 @ 113.35	0.0012 @ 1.1 0.0024 @ 5 0.0027 @ 10 0.0052 @ 38 0.0034 @ 63.25 0.0069 @ 76 0.0082 @ 114
	Dielectric Constant (at GHz frequencies)		GHz	2.8 @ 1 2.74 @ 2.44	2.90 @ 2.5 2.96 @ 5 2.95 @ 10 2.93 @ 18 2.92 @ 28, 39	2.7 @ 1 2.6 @ 1.9, 2.5, 5 2.5 @ 20	2.86 @ 1 2.70 @ 10	2.56 @ 38.2, 57.3 2.60 @ 75.8 2.59 @ 95 2.62 @ 113.35	3.01 @ 1.1 3.02 @ 5, 10 2.99 @ 38 3.02 @ 63.25 3.02 @ 114
	Dielectric Strength	ASTM D149	V/mil	450	–	500	380	500	830 @ 0.063"
MECHANICAL PROPERTIES	Tensile Strength at Break (or at yield, when noted)	ASTM D638	psi	5100	5000 - 5400	6100	9500	9200	15200
	Tensile Elongation at Break (or at yield, when noted)	ASTM D638	%	20	–	–	110	25	40
	Flexural Modulus	ASTM D790	kpsi	265	300 - 330	360	345	370	480
	Notched Izod Impact Resistance (unless otherwise noted)	ASTM D256	ft-lbs/in	6.6	15 - 18	15.0	18.0	3.5	1.0
THERMAL PROPERTIES	Heat Deflection Temperature @264 psi	ASTM D648	°F	177	161	168	270	254	394
	Continuous Service Temperature		°F	160 (long term) 210 (intermittent)	–	–	–	–	–
	Coefficient of Thermal Expansion	ASTM D696	in/in/°Fx10^{-5}	5.6	–	3.8	3.8	3.3	2.9
OTHER PROPERTIES/MFG NOTES	Outdoor Weatherability*	–	–	Fair	Good	Good	Good	Good	Good
	Moisture Absorption (24 hours)	ASTM D570	%	0.13	–	–	0.15	0.07	0.25
	Water Contact Angle	–	°	94 (static)	–	–	81 (static)	-	75 (static)
	Flammability	UL-94	–	HB	V-0 @ 0.118"	V-0	HB @ 0.060"	V-0 @ 0.236" V-1 @ 0.059"	V-0 @ 0.03" 5VA @ 0.118"
	Availablity in a wide variety of colors and surface textures	–	–	✓	✓	✓	✓		
	Easy to Machine	–	–	✓	✓	✓	✓	✓	✓
	Easy to Thermoform	–	–	✓	✓	✓	✓	✓	✓

All data originates from manufacturer datasheets, manufacturer product literature, test reports, or published academic literature. Material datasheets are available upon request.

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Property data ranges: In this table, material properties are indicated either by a range of values or as one average value. All material properties are dependent on a number of factors and the listed ranges and values are intended to serve as general comparative guidelines only. The information provided does not imply the suitability of a material for any particular application. *Outdoor weatherability depends on a number of material and environmental factors. The specfic grade, color, and presence of UV stabilizers in a material will have a significant effect on weatherability.

Table 3. Properties of Fluoropolymer Materials Used for Radomes

				FLUOROPOLYMERS Low dielectric constants, good outdoor weatherability, can be used at elevated temperatures, outstanding chemical resistance					
	Property	Test Method	Units	PTFE	Halar® 901 ECTFE	ETFE	FEP	PFA	PCTFE
ELECTRICAL PROPERTIES	Dissipation Factor (at 60 Hz)		Hz	0.0001	0.0006	0.0007 @ 1 kHz	0.00007 @ 1 kHz	0.0002 - 0.0007 @ 100 Hz - 1 MHz	0.02 @ 1 kHz
	Dielectric Constant (at 60 Hz)		Hz	2.1	2.6	2.60 @ 1 kHz	2.0 @ 1 kHz	2.0 @ 100 Hz - 1 MHz	2.6 @ 1 kHz
	Dissipation Factor (at GHz frequencies)		GHz	0.0004 @ 1 0.0030 @ 47.2 0.00001 @ 61, 76, 89.5, 104.5	-	0.0172 @ 1 0.0119 @ 3 0.01 @ 10 0.0073 @ 13.6	0.001 @ 1 0.00085 @ 10	0.0008 @ 1 0.0009 @ 10	0.0052 @ 1 0.0060 @ 10
	Dielectric Constant (at GHz frequencies)		GHz	2.07 @ 1 2.03 @ 10 1.88 @ 47.2 1.99 @ 61, 76 2.07 @ 89.5, 104.5	-	2.33 @ 1 2.31 @ 3 2.3 @ 10 2.28 @ 13.6	2.04 - 2.05 @ 1 kHz - 13 GHz	2.05 @ 1 - 10	2.30 @ 1 2.29 @ 10
	Dielectric Strength	ASTM D149	V/mil	600	355	1800 @ 0.0098" 760 - 890 @ 0.0394" 370 @ 0.126"	1800 @ 0.197"	2030 @ 0.984" 6500 @ 0.001"	500
MECHANICAL PROPERTIES	Tensile Strength at Break (or at yield, when noted)	ASTM D638	psi	4500	4500 @ yield	6500	2900 - 4900	3000	4900 - 5700
	Tensile Elongation at Break (or at yield, when noted)	ASTM D638	%	400	255	150 - 300	325	300	100 - 250
	Flexural Modulus	ASTM D790	kpsi	50 - 90	245	170	80 - 95	80	185 (amorphous) 238 (crystalline)
	Notched Izod Impact Resistance (unless otherwise noted)	ASTM D256	ft-lbs/in	3	no break	no break	no break	no break	2.5 - 3.5
THERMAL PROPERTIES	Heat Deflection Temperature @264 psi	ASTM D648	°F	115	160	123	124	-	259
	Continuous Service Temperature		°F	-328 - 500	-40 - 302	-150 - 302	-400 - 400	-400 - 500	-400 - 379
	Coefficient of Thermal Expansion	ASTM D696	in/in/°Fx10^{-5}	7.0	5.0	7.3 (32 - 212°F)	7.5	6.7	2.8
OTHER PROPERTIES/MFG NOTES	Outdoor Weatherability*	–	–	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	Moisture Absorption (24 hours)	ASTM D570	%	< 0.01	< 0.01	0.007	< 0.01	< 0.03	0
	Water Contact Angle	–	°	122 (advancing) 112 (static) 94 (receding)	99 (advancing) 78 (receding)	108 (advancing) 84 (receding)"	119 (advancing) 98 (receding)	121 (advancing) 90 (receding)	84 (static)
	Flammability	UL-94	–	V-0	V-0	V-0	V-0	V-0	V-0
	Availablity in a wide variety of colors and surface textures	–	–						
	Easy to Machine	–	–	✓	✓	✓	✓	✓	✓
	Easy to Thermoform	–	–						

All data originates from manufacturer datasheets, manufacturer product literature, test reports, or published academic literature. Material datasheets are available upon request.

All statements and technical information contained in this table are for informational purposes only. Curbell does not guarantee the accuracy or completeness of any information contained herein and it is the customer's responsibility to conduct an independent review and make its own determination regarding the suitability of specific products for any given application. **Flammability**: Some manufacturers' do not indicate the thickness associated with the listed UL-94 rating.

Property data ranges: In this table, material properties are indicated either by a range of values or as one average value. All material properties are dependent on a number of factors and the listed ranges and values are intended to serve as general comparative guidelines only. The information provided does not imply the suitability of a material for any particular application. *Outdoor weatherability depends on a number of material and environmental factors. The specfic grade, color, and presence of UV stabilizers in a material will have a significant effect on weatherability.

Table 4. Properties of Polyaryletherketones, Thermoset Laminates, and Polyimide Materials Used for Radomes

				POLYARYLETHERKETONES Low dielectric constants, high strength and stiffness, can be used at elevated temperature applications, outstanding chemical resistance, good dimensional stability		THERMOSET LAMINATES Moderate dielectric constants, good mechanical properties, can't be thermoformed, challenging to machine	POLYIMIDE Moderately low dielectric constant, broad operating temperature range, widely used for spacecraft applications, excellent dimensional stability, expensive
	Property	**Test Method**	**Units**	**PEEK**	**KEPSTAN® 7001 PEKK**	**FR-4 Glass Reinforced Epoxy**	**DuPont™ Vespel® SP-1**
ELECTRICAL PROPERTIES	Dissipation Factor (at 60 Hz)		Hz	0.003 @ 1 MHz	0.002 @ 1 kHz	0.025 @ 1 MHz, 0.062"	0.0018 @ 100 Hz
	Dielectric Constant (at 60 Hz)		Hz	3.2	2.6 @ 1 MHz	4.8 @ 1 MHz, 0.062"	3.62 @ 100 Hz
	Dissipation Factor (at GHz frequencies)		GHz	0.002 @ 1	0.0072 @ 28.6 0.0079 @ 39.4	0.03 @ 1	0.0034 @ 1 MHz 0.021 @ 10 GHz
	Dielectric Constant (at GHz frequencies)		GHz	3.11 @ 1 3.2 @ 10	3.21 @ 28.6 3.20 @ 39.4	4.6 @ 1	3.55 @ 1 MHz 3.1 @ 10 GHz
	Dielectric Strength	ASTM D149	V/mil	630 @ 0.1"	2100	650	560
MECHANICAL PROPERTIES	Tensile Strength at Break (or at yield, when noted)	ASTM D638	psi	8900	16000 @ yield	40000 (crosswise) 50000 (lengthwise)	10500 - 12500
	Tensile Elongation at Break (or at yield, when noted)	ASTM D638	%	30	> 20 5 @ yield	-	7.5
	Flexural Modulus	ASTM D790	kpsi	600	550	2400 (crosswise) 2700 (lengthwise)	450
	Notched Izod Impact Resistance (unless otherwise noted)	ASTM D256	ft-lbs/in	1.0	2.95 (Charpy Impact Strength)	12.0 (crosswise) 15.0 (lengthwise)	0.8
THERMAL PROPERTIES	Heat Deflection Temperature @264 psi	ASTM D648	°F	320	312	-	680
	Continuous Service Temperature		°F	480 (long term) 572 (short term)	-	260	500 (long term) 900 (very short term)
	Coefficient of Thermal Expansion	ASTM D696	in/in/°Fx10^{-5}	2.5	0.13	0.67 (crosswise) 0.56 (lengthwise)	3 (73 - 572°F) 2.5 (-80 - 73°F)
OTHER PROPERTIES/MFG NOTES	Outdoor Weatherability*	–	–	Fair	Fair	Good	Good
	Moisture Absorption (24 hours)	ASTM D570	%	0.02	0.05	0.10	0.24
	Water Contact Angle	–	°	87.5 (advancing) 78 (static) 70 (receding)	87 (static)	40 (static)	-
	Flammability	UL-94	–	V-0 @ 0.057"	V-0 @ 0.032"	V-0 @ 0.062"	V-0
	Availablity in a wide variety of colors and surface textures	–	–				
	Easy to Machine	–	–	✓	✓	✓	✓
	Easy to Thermoform	–	–				

All data originates from manufacturer datasheets, manufacturer product literature, test reports, or published academic literature. Material datasheets are available upon request.

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Property data ranges: In this table, material properties are indicated either by a range of values or as one average value. All material properties are dependent on a number of factors and the listed ranges and values are intended to serve as general comparative guidelines only. The information provided does not imply the suitability of a material for any particular application. *Outdoor weatherability depends on a number of material and environmental factors. The specfic grade, color, and presence of UV stabilizers in a material will have a significant effect on weatherability.

CONCLUSION

This paper provided an overview of the critical-to-quality properties of plastic materials used for radomes. For technical assistance with a plastic radome application, please contact Curbell Plastics via the Ask a Plastics Expert link at www.curbellplastics.com.

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TECHNICAL EXPERTISE

Curbell white papers are intended to provide engineers and designers with basic information about the engineering polymers available as sheet, rod, tube, and film stock from Curbell Plastics. We invite you to contact Curbell via e-mail at **technicalsupport@curbellplastics.com** to discuss applications in detail.

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