Properties of AIRMAR PiezofLEX™

Piezoelectric Polymer

Polyvinylidene Fluoride (PVDF) (Produced under license from Raytheon)

Properties

Relative dielectric constant (κ')	7.6
Permittivity ($\varepsilon' = \kappa' \varepsilon_0$)	67.3×10^{-12} Farad/meter
Loss tangent (tan δ) @ 1 kHz	0.015
Thickness (t)	515×10^{-6} meter (20 mils)
Electrical capacitance (c)	130×10^{-9} Farad/meter^2 (83×10^{-12} Farad/inch^2)
Density of bare PVDF (ρ)	1.47×10^3 kg/m^3

Output voltage for 20 mil thick PVDF

V_{31}	$+107 \times 10^{-6}$ Volt/Pascal
V_{32}	$+15 \times 10^{-6}$ Volt/Pascal
V_{33}	-260×10^{-6} Volt/Pascal
V_{3h} (hydrostatic)	-138×10^{-6} Volt/Pascal (–197.2 dB re 1 V/µPa)

Intrinsic piezoelectric properties

Charge sensitivity:

d_{31}	$+14 \times 10^{-12}$ Coulomb/Newton
d_{32}	$+2 \times 10^{-12}$ Coulomb/Newton
d_{33}	-34×10^{-12} Coulomb/Newton
d_{3h} (hydrostatic)	-18×10^{-12} Coulomb/Newton

Voltage sensitivity:

g_{31}	+0.21 Volt-meter/Newton
g_{32}	+0.03 Volt-meter/Newton
g_{33}	–0.50 Volt-meter/Newton
g_{3h} (hydrostatic)	–0.27 Volt-meter/Newton
$g_{3h} \times d_{3h}$ (~energy)	4.8×10^{-12} (C/N) (Vm/N) = (Pa)$^{-1}$

Elastic constants

Young's modulus:

Y_{11}	2.5×10^9 Pascal
Y_{22}	2.1×10^9 Pascal
Y_{33}	0.9×10^9 Pascal

For comparison, Young's modulus of copper is:

Y_{11cu}	100×10^9 Pascal

Miscellaneous properties in 3-direction

Thickness coupling constant (k_t)	~0.10
Stiffness (c_{33})	1.05×10^9 Pascal
Speed of sound (v_3)	830 meter/sec

Acoustic impedance

PVDF "3" thickness direction	1.2×10^6 kg/ (sec m^2)
Sea water	1.5×10^6 kg/ (sec m^2)

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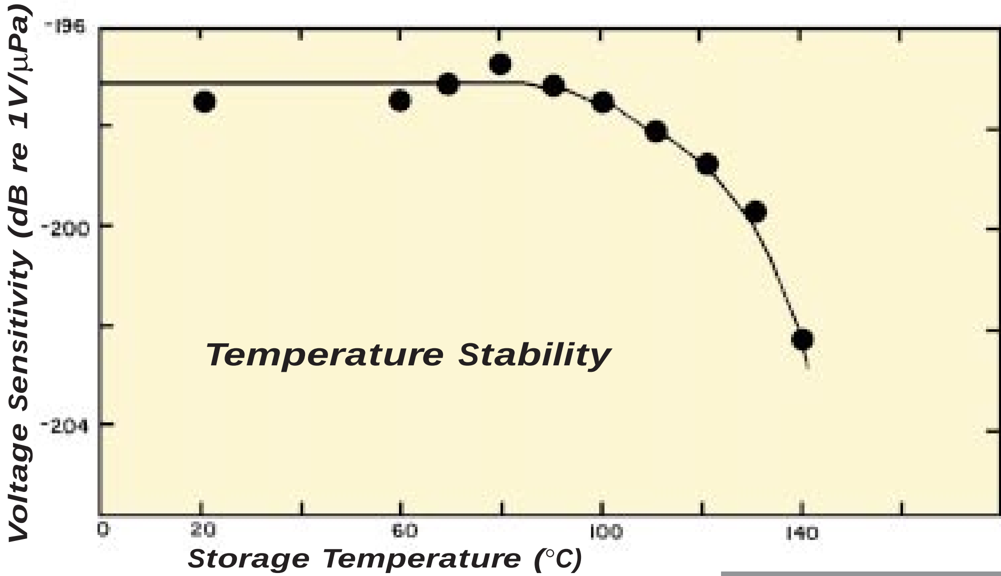
Temperature Stability

This PVDF material can be exposed to 90°C (194°F) without degradation in its piezoelectric properties, when returned to room temperature. (See adjacent figure.) As of this printing, exposure duration has reached nineteen months at 90°C, with no degradation. Also, repeated cycling to 90°C (10 cycles for 2 hour duration) produces no degradation in piezoelectric activity.



Experimental temperature stability of Airmar's PVDF. Each data point represents exposure to a given temperature for one hour. Values of sensitivity were measured upon return to room temperature. No further degradation occurs for longer exposure.

Pressure Stability

This PVDF material operates with less than 1 dB degradation in sensitivity at a static pressure of 1,000 psi.

Repeated cycling to 1,000 psi (10 cycles) produces no degradation in piezoelectric sensitivity.

After exposure to static pressure for 24 hours, this PVDF shows the following degradation (upon return to atmospheric pressure), which represents a (one-time) permanent loss. The material can be cycled to a given pressure repeatedly without additional degradation.

Pressure	One-time Loss
1,000 psi (2,200 feet)	0 dB
2,000 psi (4,400 feet)	–1.0 dB
3,000 psi (6,700 feet)	–2.5 dB

Stability Exposed to Liquids

Piezoflex™ polymer has shown no degradation of its properties (to within experimental accuracy) after immersion under water (unprotected) for eight months. Also, no degradation was observed after immersion under Isopar-L kerosene (unprotected) for nineteen months.

Stability Under High Voltage

This PVDF has been electrically stressed under dc high voltage (in a direction opposite to its original poling) with no degradation in piezoelectric properties for voltages up to 45 x 10^3 Volts (87 X 10^6 Volt/meter). Dielectric breakdown through the material begins to occur when voltage exceeds approximately 75 x 10^3 Volts (150 x 10^6 Volt/meter).

Shelf Storage

This PVDF has retained its original properties after seven years (84 months) shelf storage at room temperature, as of this printing. This long-term evaluation was conducted in real time (not accelerated testing).

Electrodes

PVDF can be supplied with or without copper electrodes. Electrodes are deposited by electroplating copper, typically 10 µm (0.40 mils) thick on each side. Other electrode thicknesses (from 7 to 50 µm) on special order.

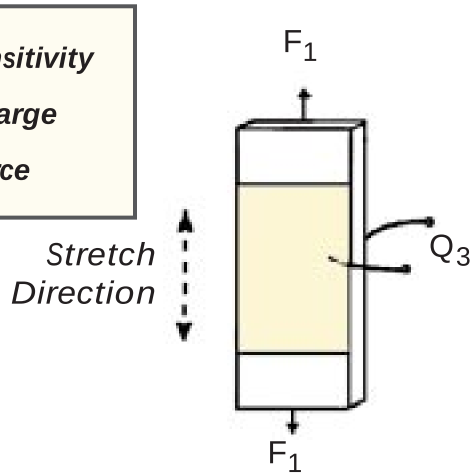
PVDF Piezo-Tensors

***d* = Charge sensitivity**

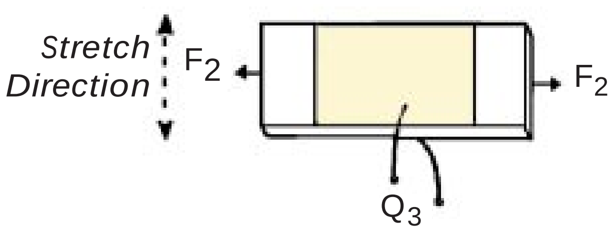
***Q* = Output charge**

***F* = Applied force**

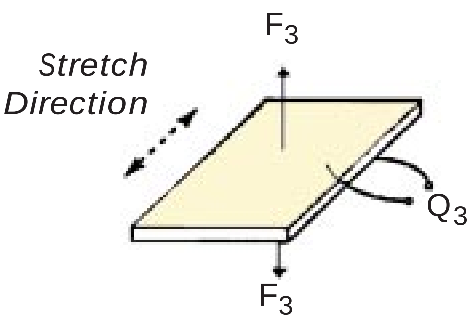
Typical Values



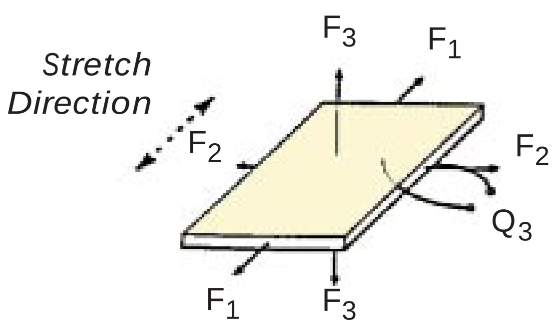
$d_{31} \propto \frac{Q_3}{F_1}$ — *+14 pC/N*



$d_{32} \propto \frac{Q_3}{F_2}$ — *+2 pC/N*



$d_{33} \propto \frac{Q_3}{F_3}$ — *-34 pC/N*



$d_h = d_{31} + d_{32} + d_{33}$ — *-18 pC/N*

(Hydrostatic mode)

Illustration of the technique used to measure the piezoelectric matrix coefficients. The value of d_{33} is deduced from the equation given for d_h. Numerical values listed are for AIRMAR 500 micron PVDF. The hydrostatic mode, shown at the bottom, is the typical operation of PVDF in a hydrophone. Yellow shaded regions represent areas coated with metal electrodes.

Dielectric Properties of Piezoflex™ Piezoelectric Polymer

The accompanying graphs show the temperature and frequency dependence of the dielectric properties of Piezoflex™ piezoelectric polymer. Engineers often find this information useful for calculating electrical impedance, designing preamplifiers, and for determining Johnson noise levels. Specifically, data are shown for:

- ***Capacitance:** from 100 Hz to 5 MHz (measured in picofarads per square centimeter)*
- ***Loss tangent:** from 100 Hz to 5 MHz (This parameter is a ratio of impedances and has no units.)*
- ***Temperature:** 5°C, 20°C, and 30°C*
- ***Electrodes:** Thin copper*
- ***Polymer thickness:** 20 mils (500 microns)*

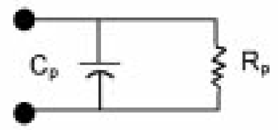
As is well known, the dielectric properties of most polymers change with temperature and with frequency. The objective of these graphs is to quantify the changes across a broad frequency range. Change in the polymer's dielectric loss is more pronounced than the small change in capacitance across this range of temperature and frequency.

It may be helpful to review common terminology for dielectric materials. In the technical literature, "dielectric loss" is often referred to as "dissipation". The mathematical symbol "D" is often used to represent "dissipation". Another common mathematical notation for this loss is "tan δ" (which means the "tangent of delta", where delta is the phase angle of the material's capacitance). "D" and "tan δ" are equivalent.

We offer a word of explanation of the "bump" in the dissipation curves around 800 kHz. The increase in loss at this frequency represents mechanical loss at the acoustic resonance of the polymer sheet (i.e., at the sheet's thickness resonance). The "bump" arises from a rapid increase in mechanical motion at resonance due to piezoelectric coupling.

An equivalent circuit model is often useful for circuit analysis, and is shown below. The quantity C_p is the polymer's parallel capacitance (in Farads) and R_p is the parallel loss resistance (in Ohms). The quantities are related by the equation shown below for a frequency f (in Hertz).

$$R_p = \frac{1}{2 \pi f C_p D}$$



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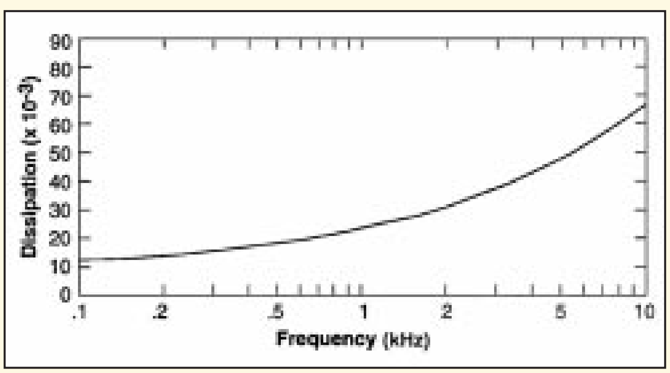
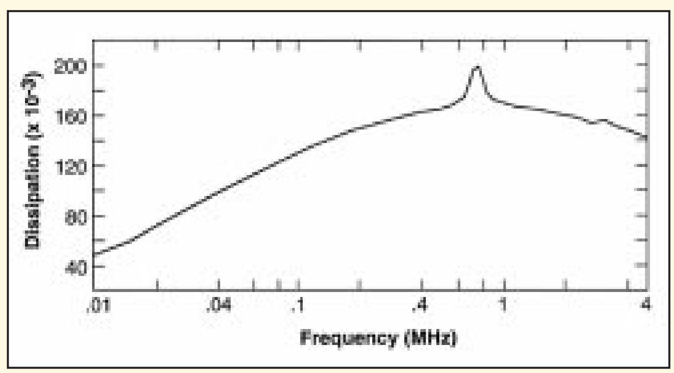
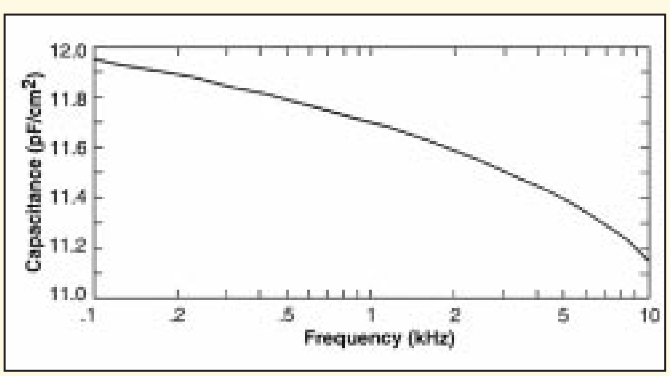
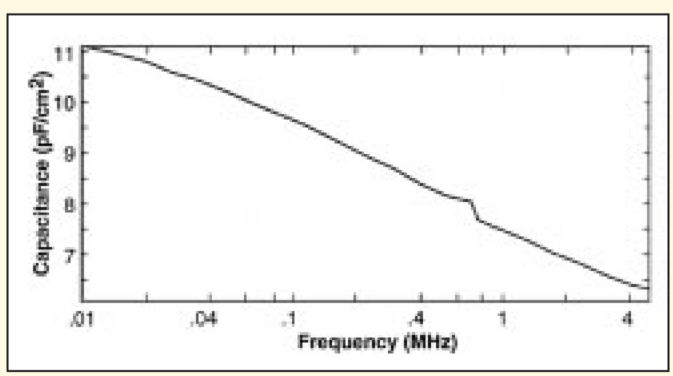
Measurement Temperature 5°C

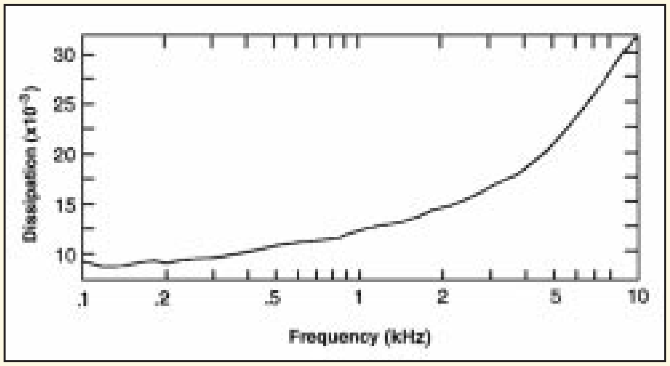


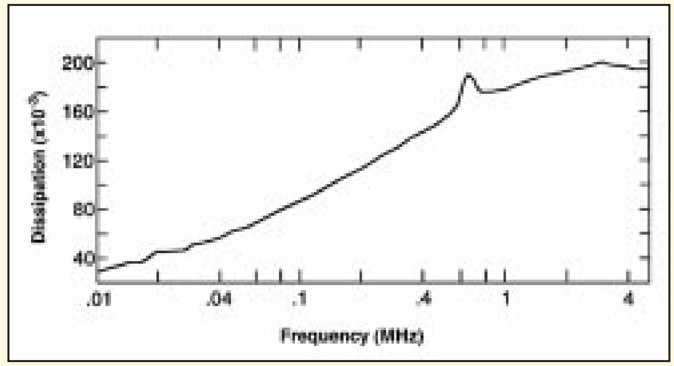


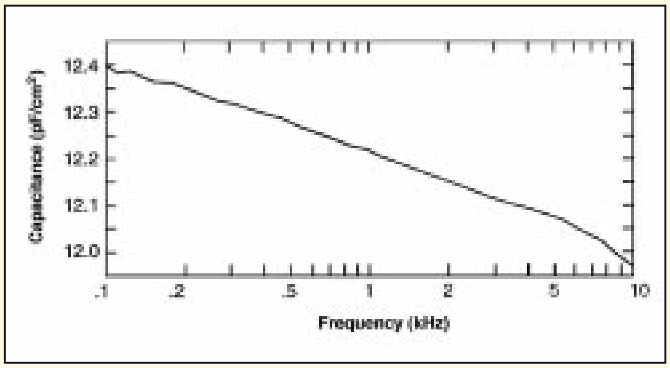


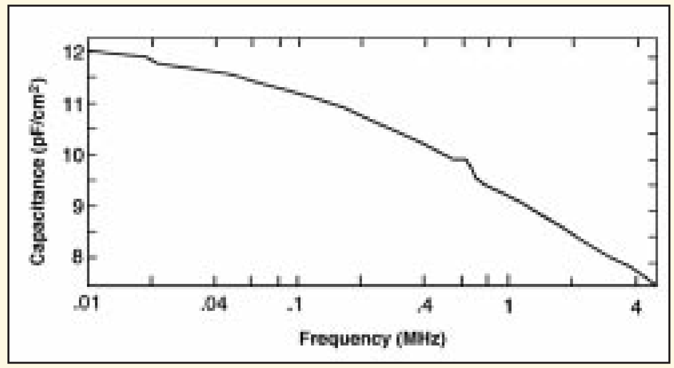


Measurement Temperature 20°C

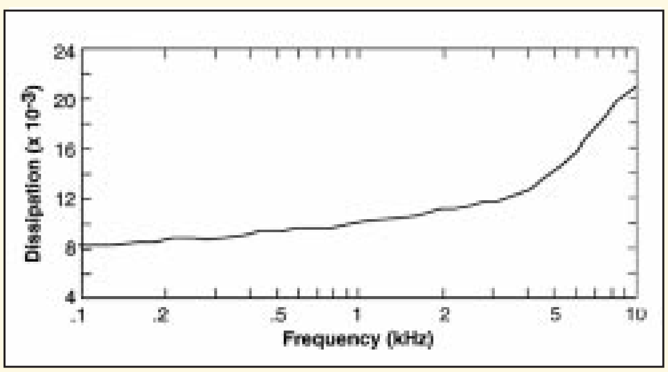


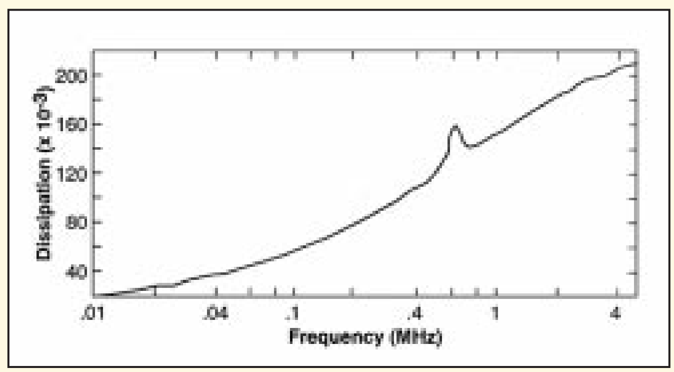


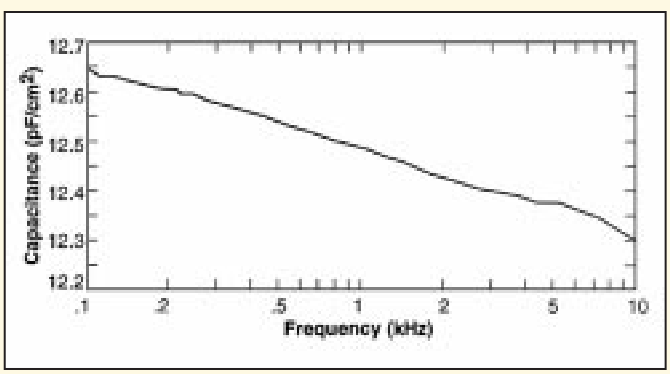


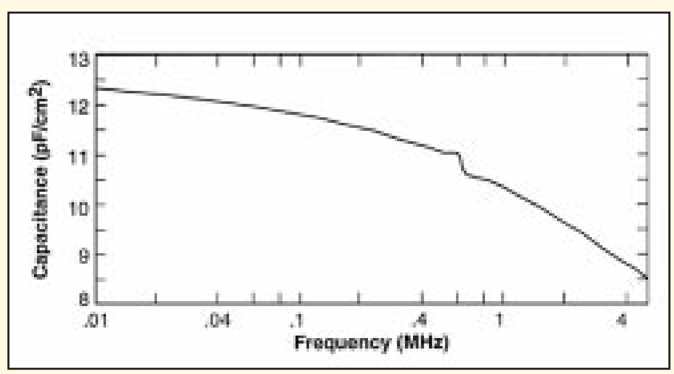


Measurement Temperature 30°C









APPENDIX

Useful Relationships

1 Pascal = 1 Newton/square meter

1 psi = 6,895 Pascals

1 Pascal = 145 x 10^{-6} psi

1 meter = 39.4 inches

1 inch = 25.4 x 10^{-3} meters

$\varepsilon_o = 8.854 \times 10^{-12}$ *Farad/meter*

$d = g \times (\kappa' \varepsilon_o)$

$V = g \times t$

g x d = Figure of Merit for piezoelectric materials

SUMMARY

Piezoflex™ Performance Specifications

Property	Value	Notes
Hydrostatic voltage sensitivity (M_o)	-197.2 dB re 1V/mPa	1
Hydrostatic charge sensitivity (d_h)	-18 pC/N	
Charge sensitivity in stretch direction (d_{31})	+14 pC/N	2
Charge sensitivity in orthogonal direction (d_{32})	+2 pC/N	2
Charge sensitivity in thickness direction (d_{33})	-34 pC/N	2
Relative dielectric constant (κ')	7.6	3
Dielectric loss tangent (tan δ)	0.015 at 1kHz	4
Capacitance (C)	130 nF/m^2 (83 pF/$inch^2$)	
Thickness (t)	0.50 mm (0.020 inches)	
Density (ρ)	1.47 x 10^3 kg/m^3	
Young's modulus ("3" direction) (Y_{33})	900 MPa	5
Maximum exposure temperature (T_{max})	90°C (194°F)	6
Maximum operating pressure (P_{max})	7 MPa (1,000 psi)	7
Maximum drive voltage (V_{max})	±45 kV	8

Notes

1. *The term "hydrostatic" indicates that acoustic pressure is exerted on all sides of PVDF (without pressure release or clamping on any side).*
2. *These tensor coefficients represent charge collected on the electrodes when PVDF is stressed along a single direction. The "1" direction is the process (or so called "stretch") direction. The "2" direction is the in-plane direction orthogonal to the process direction. The "3" direction is the thickness direction. The first subscript indicates that the charge is collected on the large surface area (perpendicular to the "3" direction). The second subscript indicates the direction of the applied stress.*
3. *Equal to an absolute dielectric constant of 67.2 picoFarads per meter.*
4. *Loss tangent changes with frequency, gradually increasing as frequency is raised. Contact Airmar for detailed graphs.*
5. *Young's modulus is anistropic. In-plane directions have higher moduli than the thickness "3" direction. In the stretch direction: 2.5 GPa; orthogonal to stretch direction: 2.1 GPa.*
6. *PVDF can be exposed to this temperature for an indefinite length of time without degradation in properties.*
7. *In addition, PVDF survives pressure to 14 MPa with 1 dB (permanent) reduction in sensitivity.*
8. *Dielectric breakdown begins to occur for voltages above 70 kV (150 MV per meter).*