A NEW FILM CAPACITOR—POLYPHENYLENE SULFIDE

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ABSTRACT

In this presentation we will inform you of the inherent, desirable properties and potential advantages of the new high temperature, low loss dielectric film available for capacitors, polyphenylene sulfide (PPS). With the use of sample test data, we will highlight:

1. Possible 150°C operating temperature for DC applications.
2. Low loss at high frequency for AC applications.
3. Size efficiency, particularly vs. polystyrene and polypropylene.
4. Low moisture absorption for non-hermetic capacitors.
5. Low capacitance change vs. temperature for stable capacitance.
6. High insulation resistance through 125°C for minimal leakage of charge.

INTRODUCTION

In this paper we will present a sampling of the initial data collected on capacitors using a new dielectric Film. To quote from Electronic Design' "... capacitor performance has been bolstered by the introduction of the resins for two new films, polyphenylene sulfide (PPS) and polyvinylidene fluoride (PVDF)." Some of us may be familiar with this PPS polymer as "RYTON", the Phillips Petroleum Company high temperature thermoplastic material used for molding. The extruded, biaxially oriented PPS film used in this evaluation has been supplied from Japan by Toray Industries, Inc. This high temperature film is the result of a

We have many high quality plastic film dielectrics— polystyrene (PST), polyester (PET), polypropylene (PP), polycarbonate (PC), Teflon (PTFE)—to name those most commonly used. Why are we looking at another film for capacitors? To confuse the component engineers, circuit designers, or purchasing agents? No. but we continuously look for the ultimate dielectric. which will possess the ideal properties and result in capacitors having small size. high reliability, excellent electrical characteristics, and low cost. Most of the test data and characteristics presented in this paper are based on aluminum metallized film capacitors, although some preliminary data is shown for film-foil capacitors.

THE POLYMER

When we hear of a high temperature dielectric material with a melting point of285°C. and which maintains its excellent properties after exposure to a temperature greater than 150°C. we immediately think of numerous potential capacitor dielectric applications. These include:

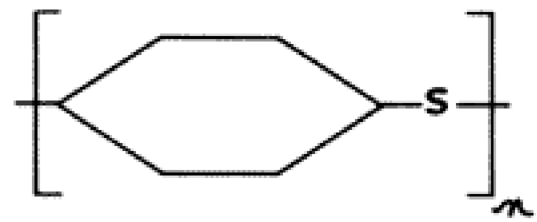
1. High temperature-high frequency AC at 125°C internal temperatures.
2. Surface mount devices for wave or vapor phase soldering at 240°C.
3. Intermittent high temperature, reliable operation at 125°C ambient.

For these applications we require a high temperature material with electrical characteristics similar to polypropylene, but having a higher dielectric constant to obtain size reduction, and an extended operating joint R&D effort by Phillips and Toray begun in 1980. In July 1986 they announced the establishment of a joint venture in Japan to manufacture and market U.S. developed PPS.

Film dielectric capacitors possess many desirable, electrical characteristics. These include low loss factor, good voltage breakdown strength, and high insulation resistance (or low leakage current), which are stable over the normal temperature, voltage and frequency range. These characteristics and the fact that these capacitors are non-polar, together with the use of controlled manufacturing processes, result in film capacitors demonstrating excellent performance in a variety of applications such as DC timing circuits, low to high frequency AC applications, and pulse or energy discharge uses.

temperature to 125°C minimum. The mechanical properties must allow the manufacture and processing of uniform thin gauge film in the 1-2 micron range. PPS film appears to satisfy these requirements.

The structure of polyphenylene sulfide is a crystalline, aromatic polymer. The recurring benzene rings with substituted sulfur are remarkably stable. This is the basis for the PPS outstanding temperature stability, inherent flame resistance, and good chemical resistance. The UL temperature index for PPS molded specimens ranges from 200°C to 240°C depending on the compound, thickness, and end use.



PROPERTIES

Dielectric Constant and Size

A pair of critical parameters relate specifically to the minimum size obtainable for our capacitor. These, dielectric constant and thickness, are obvious in the equation:

$$\text{CAPACITANCE} = \frac{\text{k x DIELECTRIC CONSTANT X AREA}}{\text{(THICKNESS)}}$$

Dielectric constant gives us a measurement of capacitance compared to air. Most plastic film dielectrics have a value in the range of 2 to 3, with only special materials such as the more polar PVDF possessing a dielectric constant of 10. Dielectric film thickness is determined by 1) the minimum thickness required to sustain the operating voltage, and 2) the minimum thickness capable of being produced in a uniform film and able to be processed, such as through a vacuum metallizing operation. Table I compares properties of some dielectric films.

The PPS dielectric constant of 3.0 is equivalent to that of polyester and polycarbonate, and 35% greater than polypropylene. Assuming the PPS can be operated at the same voltage stress level as the other film dielectrics (approx. 35V/um), the size of such capacitors will be equivalent to the polyester and polycarbonate capacitors available today, and will be significantly smaller than polypropylene, polystyrene and PTFE capacitors.

A size advantage will be attained if this high temperature polymer film can be operated at full-rated voltage at 125°C or higher. In contrast the presently available capacitors require a 30%-50% voltage derating for reliable operation at high temperature. See Table II for sizes, and volumetric and board area ratios required for a typical tubular package, with the volumetric and board area factors being equal to one for PPS at 125°C. Figure I is a photo of typical capacitors. With a typical 1.0µF-200VDC capacitor at 125°C. a volumetric size reduction of 55% would be obtained.

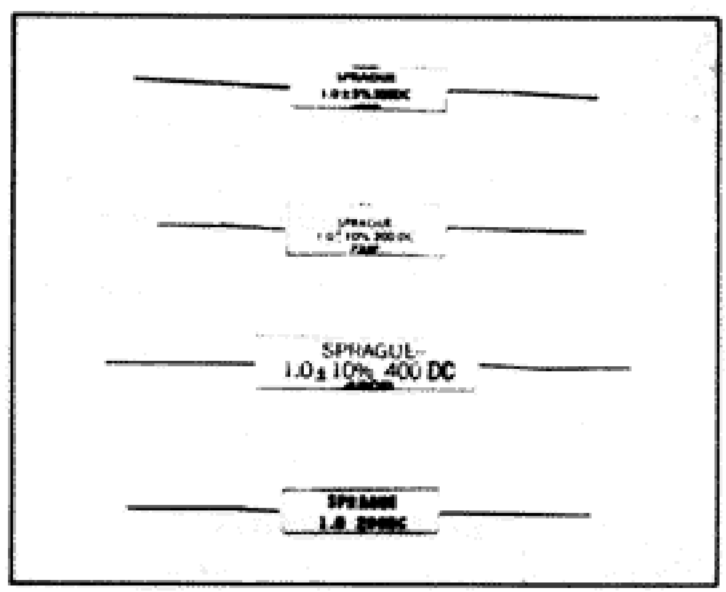


Figure I

TABLE I
Properties of Dielectric Films

		PPS	PET	PC	PP
Dielectric Constant	1KHz, 25°C	3.0	3.2	3.0	2.2
Dissipation Factor (%)	1KHz, 25°C	.06%	.45%	.10%	.02%
	1KHz, 100°C	.06%	1.0%	.15%	.015%
	1MHz, 25°C	.18%	1.4%	.80%	.02%
Dielectric Strength (V/um) DC		400	500	350	600
Film Thickness (urn)		2-10	1.5-23	2-20	3.5-23
Recommended Max. Temp (°C)		160	125	125	105
Moisture Absorption *{%)*		.05	.4	.3	.01
Solvent Resistance		exc.	good	fair	exc.

TABLE II
Size Comparison—Met. Film Capacitors

FILM	0.1µF-200VDC			1.0µF-200VDC		
	D x L	VOL	AREA	D x L	VOL	AREA
PET at 85°C PP at 105°C PET at 125°C PPS at 125°C	.200" x .750" .260" x .750" .280" x .750" .200" x .750"	1.0 1.7 2.0 1.0	1.0 1.3 1.4 1.0	.350" x 1.25" .480" x l.25" .440" x l.75" .350" x 1.25"	1.0 1.9 2.2 1.0	1.0 1.4 1.6 1.0

Loss and ESR

Film capacitors are desirable for high frequency, high current switcher power supplies due to the characteristic low losses at high frequencies. The temperature resistance of PPS becomes even more of an asset for high frequency AC applications, where internal capacitor heating added to the ambient operating temperature often results in dielectric degradation and eventual early wear-out at high temperature. Most often internal heating is the major limitation in this type of AC application. We calculate this heating by determining the power loss, and from this we can calculate the internal heat generated.

$P_D = I^2R$ P_D - Power Dissipated
I = Current (RMS)
R = Effective Series Resistance

The ESR varies with frequency and is dependent on the losses of the dielectric, the electrode, and the resistance at the lead connection.

From the Kowalsky and Rice paper presented at CARTS '83, we have taken a plot of dissipation factor vs frequency for dielectric film and added the PPS data. As is evident in Figure II, the DF of PPS film lies between the extremely low loss polypropylene dielectric film and the polycarbonate dielectric film. At low frequencies we may use the DF measurement to calculate the R (ESR) in the power dissipated equation by using:

$$\text{ESR} = \frac{\text{DF}}{\text{2-T pi fC}}$$

For higher frequencies all losses must be considered, and the actual ESR should be measured.

The low loss of PPS results in an ESR value which is less than that obtained with polycarbonate, and only slightly higher than that for polypropylene. This is shown in Figures III and IV. DF vs frequency and ESR vs frequency for three capacitance values tested. At the high frequencies (100KHz) the loss due to the dielectric becomes a smaller contributor, and the major loss or resistance is due to the electrode and connection. The DF and ESR for the PPS remains constant, or decreases slightly, with temperature up through 100°C. Above 100°C it starts to increase, resulting in additional dissipated power. This is shown in Figure V, which is data from a 0.0068µF PPS-foil capacitor.

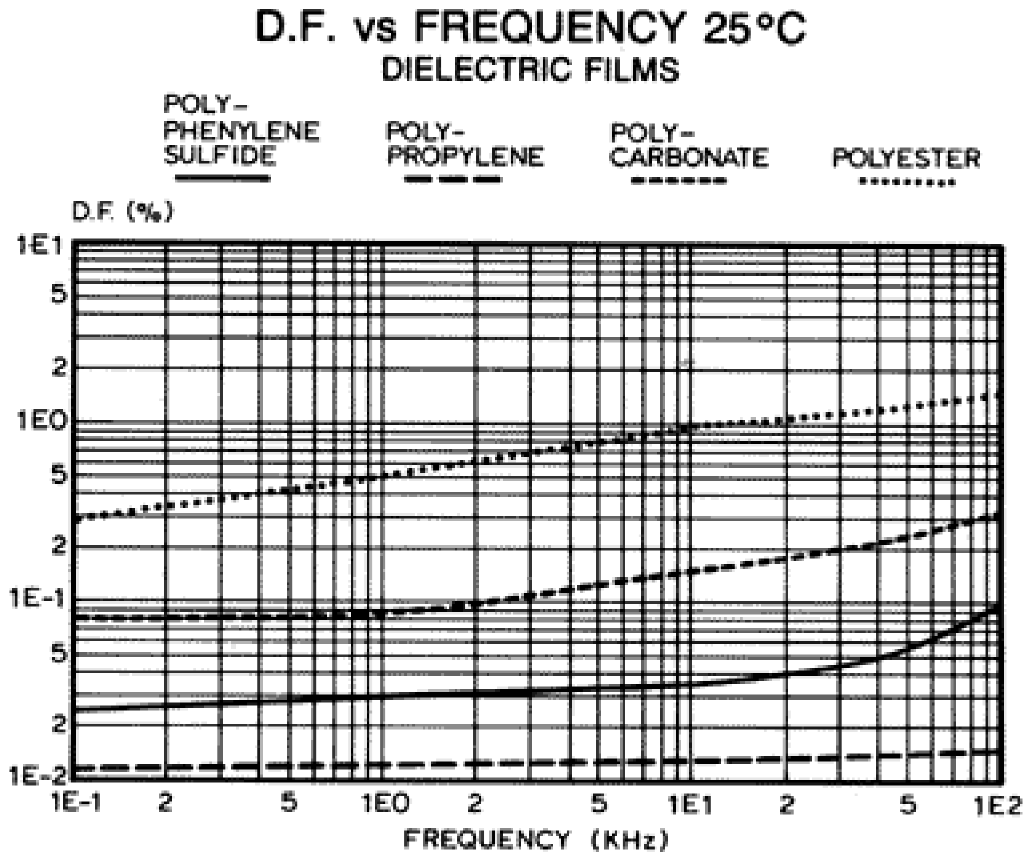


Figure II

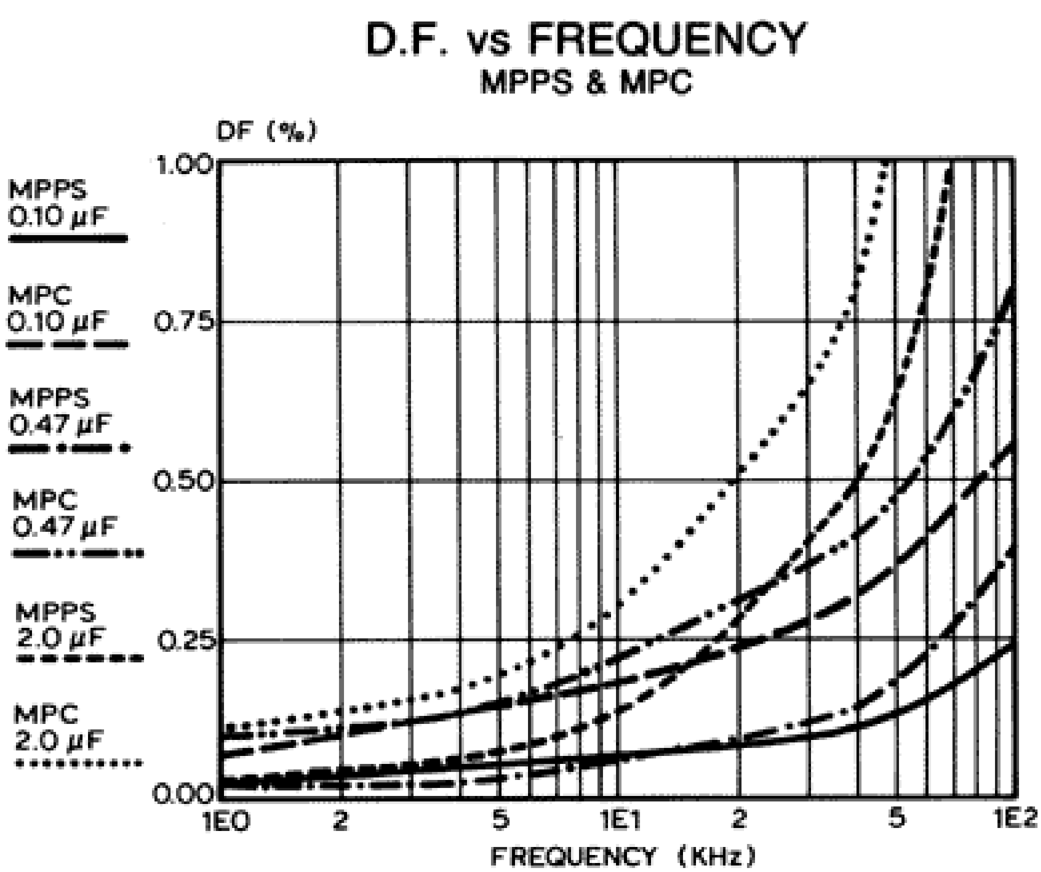


Figure III

ESR vs FREQUENCY
MPPS & MPC

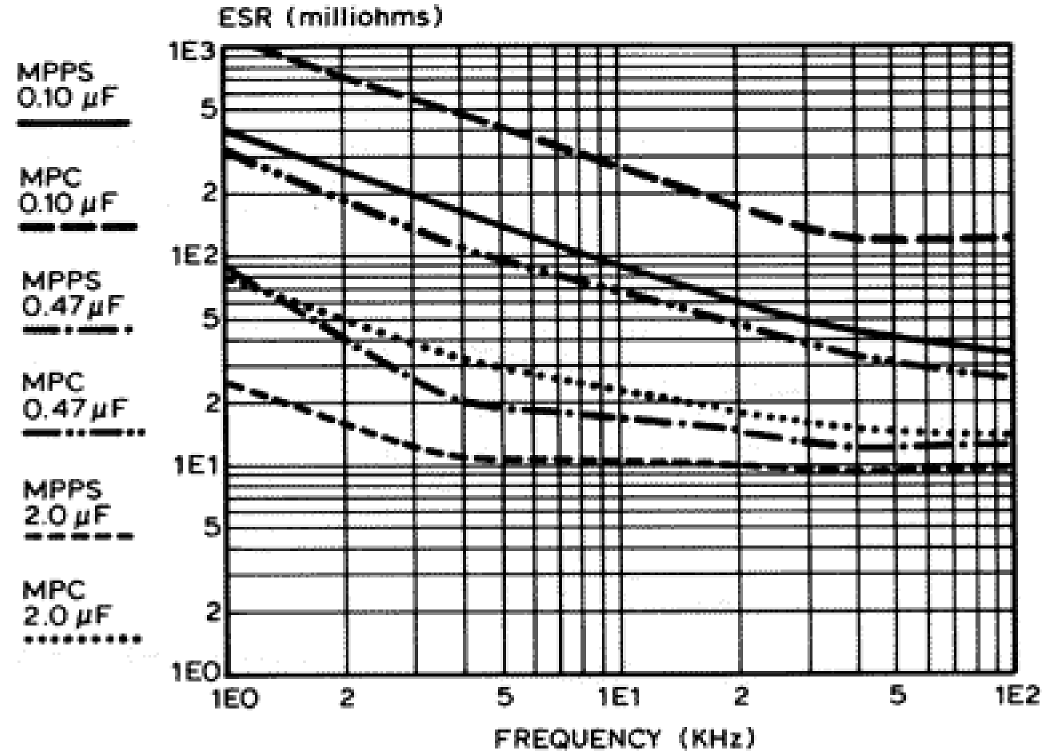


Figure IV

D.F. vs TEMP. & FREQUENCY
(PPS-FOIL .0068 MF)

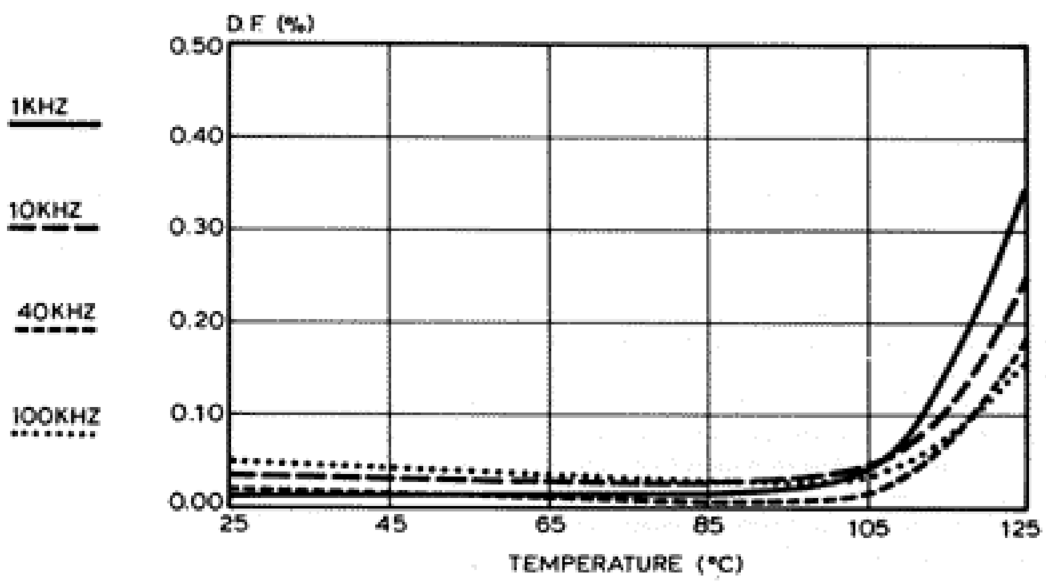
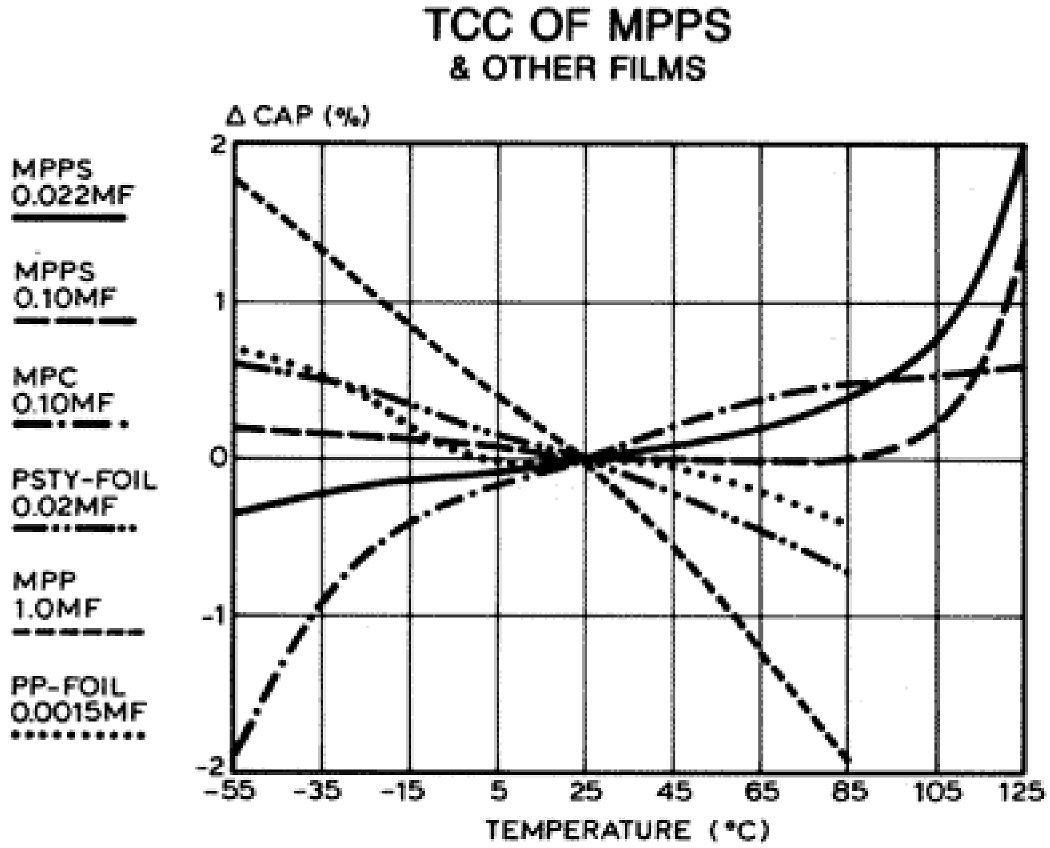


Figure V



TCC OF MPPS
& OTHER FILMS
Δ CAP (%)
MPPS
0.022MF
MPPS
0.10MF
MPC
0.10MF
PSTY-FOIL
0.02MF
MPP
1.0MF
PP-FOIL
0.0015MF
2
1
0
-1
-2
-55
-35
-15
5
25
45
65
85
105
125
TEMPERATURE (°C)

Figure VI

Characteristics vs Temperature

Basic characteristics we specify for component applications and specifications include Capacitance, Dissipation Factor, and Insulation Resistance vs Temperature. The capacitance vs temerature (temperature coefficient of capacitance) is reported as % change, or ppm/°C. In Figure VI is shown typical capacitance curves for Film capacitors, including PPS. This data is summarized in Table III.

Basically, polycarbonate capacitors demonstrate a positive TCC and are described as stable capacitors through 125°C. The data obtained on metallized PPS (MPPS) capacitors from -55°C to 105°C indicates less of a capacitance change than with metallized polycarbonate (MPC). It is only when we exceed the transition point at 105°C, does the MPPS dielectric exceed the capacitance change obtained with MPC. A note of caution, we have observed a higher level of capacitance change after temperature cycling with these PPS capacitors than is seen with the so-called stable dielectrics - polystyrene, polypropylene, and polycarbonate. This may be due to a larger air layer being present, which was not removed during the heat treatment or shrinkage of the PPS in these capacitors. Additional heat shrinkage of this film may be difficult to accomplish, but efforts in this area will be pursued.

We also produced some PPS-foil capacitors, primarily looking to replace a polystyrene dielectric design. The results are shown in Figure VII. Our experience with this foil design is very limited, and we will be verifying the reproducibility of this data.

The subject of DF has been previously discussed, and its relationship to ESR and its importance in AC applications is well covered in Sprague Electric technical papers by Kowalsky and Rice and by Adelson.

Another parameter used to determine suitability of a capacitor for the application is insulation resistance (IR). This is sometimes measured or specified as leakage current rather than as a resistance values. One can be converted to the other as long as the test voltage is specified.

$$I_{DC} = V/R \text{ or } R = V/I$$

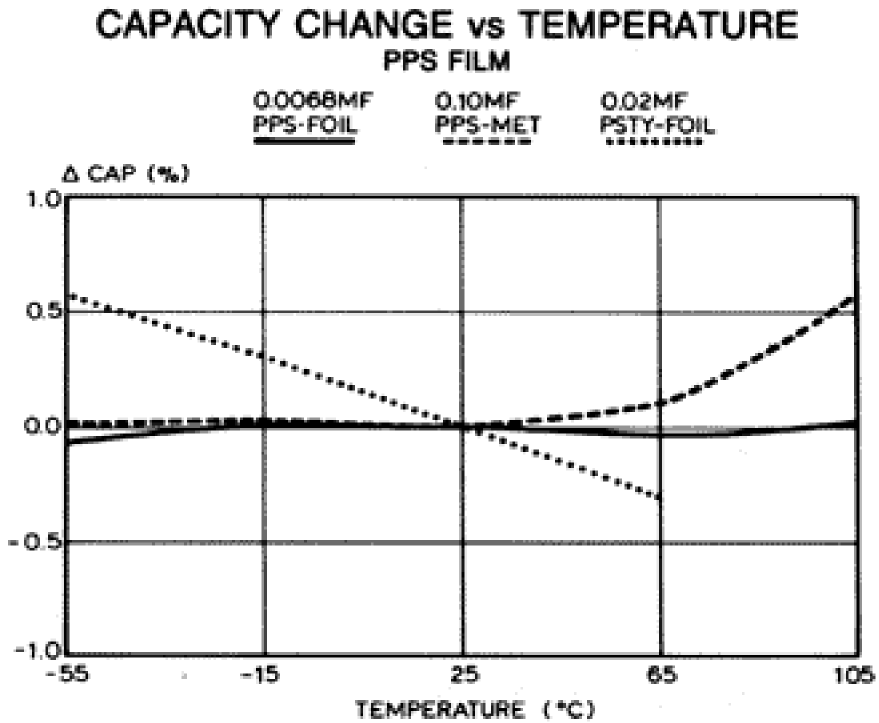


Figure VII

TABLE III
Capacitance Change vs Temperature

TYPE OF CAPACITOR	A CAP RANGE	TEMPERATURE RANGE	COMMENT
Polystyrene-Foil	±½%	-55°C/+ 85°C	Negative, linear TCC; constant slope.
Polypropylene-Foil Met	± ½%	-55°C/+ 85°C	Less negative at high temperature.
Polypropylene Met.	±2%	-55°C/+ 105°C	More negative due to metallized electrodes
Polycarbonate Met.	-2%/ +1%	-55°C/+ 125°C	Flat TCC 0°C to + 125°C.
Polyphenylene Sulfide	±½%	-55°C/+ 105°C	Abruptly increase to 1 ½% at 125°C.

This property is also used to determine quality level of the capacitor. It is used as a basic measurement after various tests (thermal shock, life test, moisture exposure) to determine degradation due to the test condition, as well as a measurement of initial quality of the dielectric film. Flaws, contamination, or physical damage to the film result in decrease insulation resistance, particularly noticeable at elevated temperatures, such as 125°C.

In addition to its usefulness as a quality indicator, insulation resistance is important in timing circuit and energy storage applications, calling for the storage of charge or energy over long periods of time. The leakage is a measure of the charge not held by the dielectric. Polystyrene and polypropylene films have exhibited the highest insulation resistance values over their temperature ranges. For temperatures greater than 85°C, polycarbonate film is used where high insulation resistance values are required. As shown in Figure VIII, the PPS exhibits insulation resistance levels comparable with polycarbonate up through 125°C. and has the potential advantage of being capable of operation at 150°C.

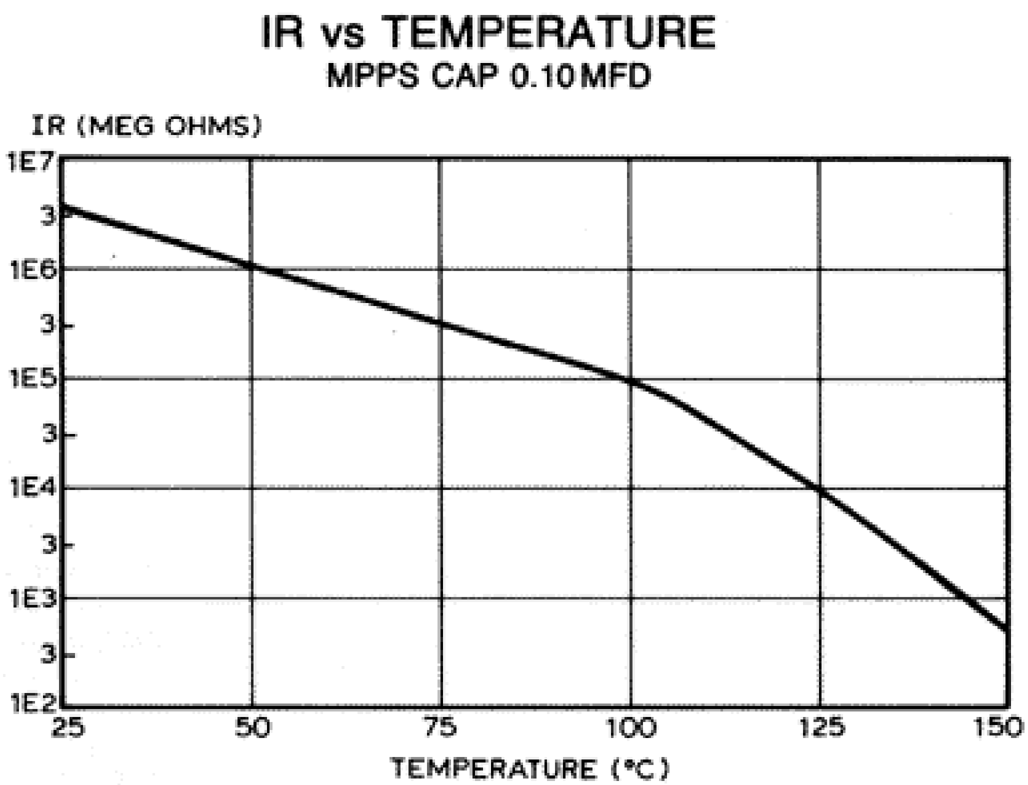


Figure VIII

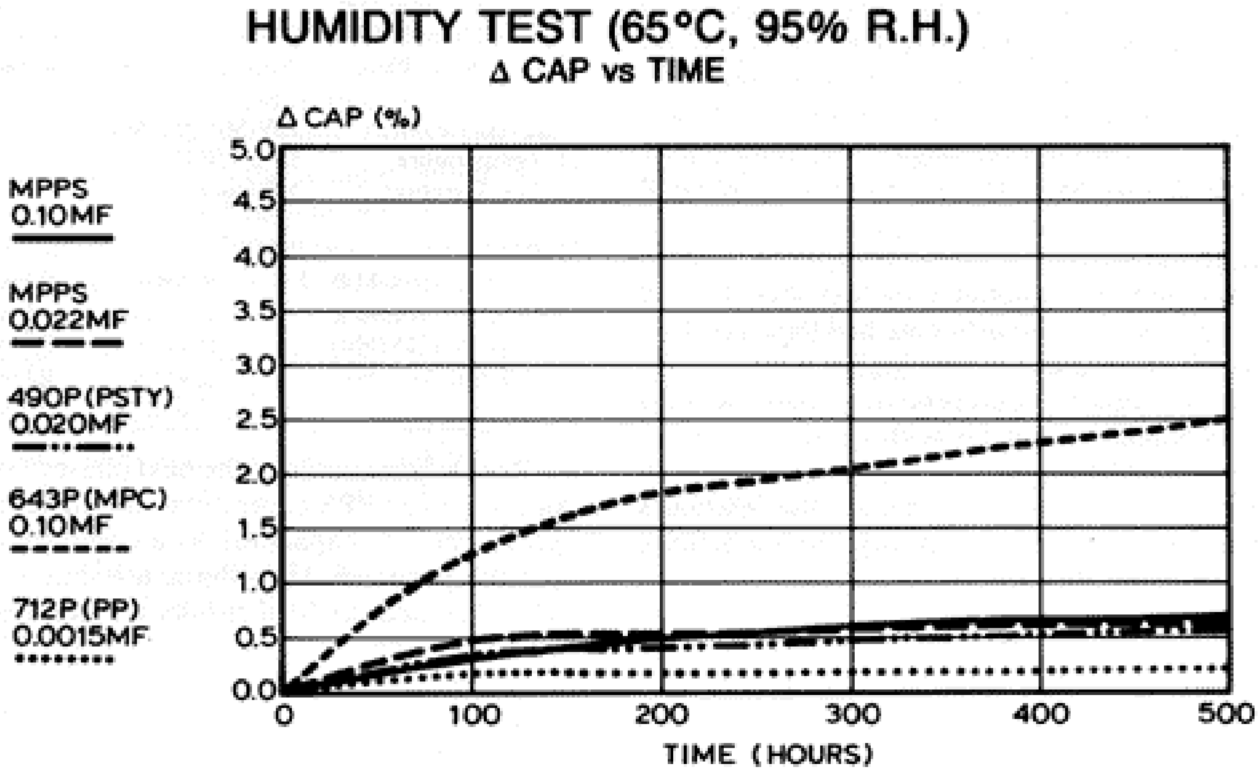

HUMIDITY TEST (65°C, 95% R.H.)
Δ CAP vs TIME
Δ CAP (%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
TIME (HOURS)
MPPS
0.10MF
MPPS
0.022MF
490P (PSTY)
0.020MF
643P (MPC)
0.10MF
712P (PP)
0.0015MF

Figure IX

Moisture Absorption

The PPS Film offers possible advantages for nonhermetic sealed capacitors. In hermetic sealed metal-cased capacitors we are not concerned with the moisture absorption and solvent resistance of the dielectric film, except during the manufacturing process.

For the non-hermetic capacitor, the most popular being the tape wrap and epoxy end fill construction, no matter how good the sealing process, over the long haul, and when briefly exposed to extreme conditions and materials such as wave soldering and cleaning, there is the probability of moisture and/or solvent vapors entering the capacitor section. Polystyrene Film is very sensitive to solvent attack, while polycarbonate and polyester exhibit unstable capacitance and decreased insulation resistance due to moisture absorption.

The PPS is similar to polypropylene with its low moisture absorption and excellent solvent resistance. Combining these properties, along with a low hygroscopic coefficient of expansion, results in a low change of capacitance due to moisture exposure. Encapsulated in the standard polyester tape wrap and epoxy end fill construction, these units were exposed to the 65°C, 95% RH steady-state moisture test for total of 21 days (500 hours). Typical data for small, low capacitance capacitors with various dielectric systems is shown in Figure IX.

All units, except the metallized polycarbonate (MPC), increased in capacitance by less then 1%. Of the dielectrics tested, polycarbonate had the largest increase. which correlates with its higher moisture absorption (0.3%), and the polypropylene had the least change, which again correlates with its minimal moisture absorption (0.01%). The PPS is comparable with polystyrene at 0.5% capacitance change after 500 hours of exposure. This low moisture absorption is a definite advantage of using PPS film in non-hermetic sealed capacitors.

LIFE TESTS

We perform life tests at increased voltage and temperature conditions for various purposes.

1. Determine a suitable nameplate rating for a capacitor design, particularly for a new dielectric such as PPS.
2. Determine performance capability at specific conditions, for specific customer applications.
3. Obtain reliability and failure rate levels, particularly for MIL specification capacitors.
4. Verify life vs. voltage and temperature relationship, to estimate life expectancy at various conditions.
5. Determine parameter changes and observe degradation and possibly wearout, during extended operation.

Preliminary DC life test data has been obtained on PPS capacitors, primarily those with metallized electrodes. A summary is shown in Table IV. The 152 capacitors were tested for 500 hours, and we observed zero shorts and two units with low insulation resistance at the completion of the test. Failures were defined as insulation resistance less than IOOK megohm x microfarad. The two failures were in the group of 1.0 mfd. units made with the initial shipment of nine micron metallized PPS film. The 100°C life test data is based on the 0.0068 mfd. PPS-foil capacitors tested at 250VDC and 100°C.

TABLE IV
Life Test of PPS Film Capacitors

FILM LOTS		**CAP VALUES**
9µ x 1.5" Met		1.0µF
2.5µ x 4.5mm Met		0.15µF
6µ x 12mm Met		0.10µF & 0.022µF
6µ x 10mm Plain		0.0068µF
Stress Level:	12V/Mil-50V/Mil	
Temperature:	85°C-150°C	
Test Duration:	500 Hours	
RESULTS:		
85°C (50V/Mil)	56 units	0 Fail
100°C (40V/Mil)	28 units	0 Fail
125°C (35V/Mil)	59 units	0 Short; 2 Low IR
150°C (20V/Mil)	9 units	0 Fail
totals:	152 units	0 Shorts; 2 Low IR

TABLE V
Metallized Polyphenylene Sulfide
Metallized Polycarbonate
DC Life Test at 200VDC and 150°C

	INITIAL AVERAGE AVERAGE			AFTER 96 HOURS				
CAPACITOR	%DF (1KHz)	ESR (100KHz) milliohms	IR (200V) megohms	%^ CAP	%DF (1KHz)	ESR (100KHz) milliohms	IR (200V) megohms	#FAIL/ #TEST
0.47µF MPPS	.03	10	$5.0x10^5$	+0.70	.03	16	$5.0x10^5$	0/6
0.47µF MPC	.10	22	$3.8x10^5$	+2.4	.11	38	$3.5x10^5$	1/6
2.0µF MPPS	.04	9.0	$2.5x10^5$	+0.90	.04	13	$1.6x10^5$	0/6
2.0µ MPC	.11	14	$1.5x10^5$	+2.0	.11	20	$0.8x10^5$	2/6

Recently we initiated the next phase of the evaluation of metallized PPS capacitors, and included metallized polycarbonate capacitors as a control group for comparison purposes. Only initial test data shown in Table V is included, as final results are not available at this time. The DC life tests are being conducted at 125°C and 150°C to verify the capability of the new Film at the higher temperature.

This test verifies the lower dissipation factor and higher insulation resistance of the PPS, compared with the polycarbonate. After 96 hours of 150°C life test we see a substantial advantage of the PPS capacitors. Three of the twelve polycarbonate units failed insulation resistance, while the twelve PPS capacitors meet the original limits of IOOK megohm x microfarad. The 2% capacitance change for the polycarbonate is probably due to additional film shrinkage, since the capacitors had been manufactured as standard 125°C capacitors.

An AC life test program has been started to determine capability of metallized PPS capacitors at various frequencies and current levels. Initial test conditions are based on two MIL specifications for metallized polycarbonate capacitors, MIL-C-83421/1 and

1. High power, high temperature AC—where the combination of low dissipation factor, or ESR, and capability to withstand high ambient temperature, makes PPS a natural for military power applications.

2. Surface mount circuits—where its resistance to solvents, low moisture absorption; and high temperature resistance make PPS an ideal dielectric system for this next generation package. Evaluation of PPS Film in capacitors is continuing. Additional experience and test data are required prior to releasing and recommending such a product for electronic circuits.

REFERENCES

1. Biancomano, V., Film Capacitors, Electronic Design. November 13,1986.
2. Kowalsky, J.D., and Rice, H.L., A-C Application of Plastic-Film Capacitors, Sprague Technical Paper TP-83-4 (presented at CARTS 1983).
3. Adelson. L., and Farr. H.H., Polypropylene-Film Capacitors For Military and Industrial A-C Applications,

MIL-C-55514/7. Capacitors are being tested at 100°C and 400 Hz, and 40KHz, and if performance is satisfactory at. 100°C, the ambient test temperature will be increased to 125°C to determine capability at this temperature.

CONCLUSION

Based on this initial evaluation, polyphenylene sulfide should find a position in the film dielectric capacitor market. There are many applications where its desirable properties will allow it to replace other presently used dielectrics. This will certainly depend on its availability, consistent quality and reliability, experience and prove-out, and last but not least, its cost.

Two specific areas of application for PPS capacitors are:

Sprague Technical Paper TP-85-1 (presented at CARTS 1985).

ACKNOWLEDGEMENT

I would like to express my appreciation to Toray Industries Plastics and Film Group for supplying the new film used in these capacitors. I would also like to thank Mr. Charles Heinrich and Mr. Leo Lamore of Sprague Electric Company for performing the tests and obtaining the data used in this presentation.

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