WHAT DO WE DO WHEN POLYCARBONATE ISN'T AVAILABLE ANYMORE?

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Three plastic dielectrics, polyester, polypropylene, and polycarbonate, have been the mainstays of the film capacitor industry for many years. Other dielectrics, such as tetrafluoroethylene, polyimide, polystyrene, polyethylene napthalate, and polyvinylidene fluoride, have also been used for some applications. The use of these other dielectrics was only a small percentage of the "big three". In most high performance applications, polycarbonate has been the dielectric of choice, particularly in "military applications".

In mid-July of this year the sole supplier of base polycarbonate dielectric film (PC) announced that they would stop producing the film by year-end. The announcement also indicated that a replacement might be available in the future. What action should we, Dearborn Electronics and our customers who specify polycarbonate, take with this news?

Should film capacitor manufacturers stockpile large quantities of PC film? Eventually this inventory is going to run out. Might it be possible that someone else would pick up the manufacture of PC film? We have been down this road before with very poor results. Just when will the replacement film be available? Even if it were available tomorrow, will it have exactly the same performance characteristics and be available in the same thickness? Finally there is the consideration of cost impact. How will this PC replacement compare to current PC film prices? Can the film capacitor industry and its customers afford to wait and see what will happen?

Rather than dealing with so many questions that none of us can answer, a more appropriate question might be: Is there a dielectric available today that can be used as a replacement for polycarbonate? The answer is: YES, There is a dielectric, available right now, that can replace polycarbonate. It is polyphenylene sulfide (PPS).

Polyphenylene sulfide is not a "new kid on the block". Film development began in 1980. In 1986 PPS became available as a film dielectric. In 1987 Dearborn Electronics presented a paper at the Capacitor and Resistor Technology Symposium (CARTS) on PPS dielectric and its performance characteristics in capacitors as a prelude to announcing two new product families, the Type 880P and the Type 882P. The Type 880P capacitor is an axial leaded, wrap and fill construction based on metalized PPS. The Type 882P is also an axial leaded, wrap and fill construction, but is based on discrete, extended foil electrodes with plain, unmetalized PPS.

Dearborn also manufactures a metalized PPS version in the classic, tubular hermetic package, the Type 871P. The Defense Supply Center Columbus (DSCC) recently approved this construction for military applications formally using MIL-PRF-83421/01. The new specification is MIL-PRF-83421/06. We have submitted a request to DSCC to have other military versions available in PPS. They agreed and Dearborn is currently seeking approval to MIL-PRF-55514/13. This will be a direct replacement using PPS for MIL-PRF- 55514/7 PC devices.

INTRODUCTION TO PPS

The PPS polymer is crystalline in nature and is based on an aromatic structure of repeating benzene rings substituted with sulfur atoms. It is a remarkably stable structure resulting in a material with high operating temperature capabilities (UL temperature index of +200ºC), inherent flame resistance, and good resistance to attack by solvents and moisture.

Like PC, the PPS film is available from only one source of supply, Toray of Japan, but with one very important difference. Toray is a film manufacturing company, not a chemical company like Bayer who has decided to discontinue PC. They have never vacillated on the availability of their PPS film trademarked as Torelina. Since its introduction the supply of Torelina film has never been interrupted. At this writing the cost of PPS film is comparable to PC film. We have had direct communications with Toray and they are quite excited about the prospect of replacing PC. They also let us know that if the demand for PPS were to increase dramatically they would add PPS film production capacity.

Now let's discuss the specifics of replacing PC with PPS. Polypropylene (PP) and polyester (PE) won't be included in these discussions since they have there own specific, time-honored applications. If you could have used PP or PE in your application, you probably did, and making comparisons to these two dielectrics as well doesn't add anything to solving the problem of finding a replacement for PC.

SIZE

In general, since PPS and PC have the same dielectric constant the size of a PPS and a PC capacitor will be the same. One difficulty in making this general statement is that PPS film is not available in the same thickness as PC. One thing to keep in mind is that the theoretical **breakdown strength of PPS is higher** than that of PC. PPS has a reported breakdown strength of 400V per micron thickness compared to 350V for PC. The following table compares the available thickness of the two films.

AVAILABLE FILM THICKNESS (µm)
(* = Unavailable)

PC	PPS
2.0	2.0
*	2.5
3.0	3.0
3.5	3.5
*	4.0
5.0	*
6.0	6.0
8.0	*
*	9.0
10.0	*
12.0	12.0

What if you had a design based on 5.0µm thick PC, what do you do? For PC designs based on 5.0µm thick PC you can use series wound 2.5µm PPS with no increase in overall voltage stress. For PC designs based on 8.0µm thick PC you can go to series wound 4.0µm thick PPS and actually decrease the voltage stress by 12%! If you had a design based on l0µm PC you can replace it with 9.0µm thick PPS and actually decrease the voltage stress by 3%. Obviously, the differences in available film thickness do not pose a problem and DEI has collected data on these types of film replacement strategies.

ELECTRICAL CHARACTERISTICS

We've already discussed the fact that PPS has higher theoretical voltage breakdown strength than PC, but what about some of the other characteristics?

Capacitance Stability with Temperature

PPS has a superior, overall capacitance stability with temperature over PC from -55ºC to +125ºC, 80 ppm/C for PPS compared to 150 ppm/ºC for PC, as shown in Figure 1. If you are looking for **extreme capacitance stability** from -55C to +85ºC, PPS is virtually flat over this temperature range with a ppm/ºC of only seven!

Voltage Stress

As we have already said, PPS has a higher voltage break down strength than PC. We life tested PPS at 140% of the nameplate or rated voltage at +150ºC. Typically, established PC designs are limited to +125ºC operation and many PC specifications stipulate that the voltage be de-rated by 50% at +125ºC. UNLIKE PC, **PPS REQUIRES NO VOLTAGE DE-RATING AT +125ºC** AND CAN OPERATE AT TEMPERATURES AS HIGH AS +150ºC.

Table I provides a summary of data collected on a Dearborn 1.0µF Type 880P metalized PPS capacitor rated at 50VDC and life tested at +150ºC with 70VDC applied for 2,000 hours.

TABLE I: MPPS Life Test Data At +150ºC and 140% RVDC DEI P/N 880P105X5050 25 units tested				
INITIAL VALUES		2,000 Hr. FINAL VALUES		
1kHz D.F. (%)	25ºC I.R. (Megohms)	1kHz Cap. Chg. (%)	1kHz D.F. (%)	25ºC I.R. (Megohms)
0.05	1,600,000	+1.1	0.05	1,200,000
±	±	±	±	±
0.01	800,000	0.5	0.01	700,000

This is a fairly standard life test. Dearborn, known for manufacturing capacitors that are not ordinary, performed life testing at some extreme conditions. The conditions were 240% to 400% of the rated or nameplate voltage at a temperature of +125ºC. The test capacitors ranged in age from one (1) to eight (8) years old. Twenty five (25) units of six (6) different 880P Type part numbers were tested for a total of 500 hours each. The results of these tests are summarized in Table II.

TABLE II: EXTREME LIFE TESTING OF MPPS

Case 1: 880P 0.10µf, 50VDC rated/Date Code 9826
Tested at 400VDC (4X Rated VDC) & +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. *(%)*	n/a	-0.61
Max. +25ºC 1kHz D.F. *(%)*	0.04	0.05
Min. +25ºC I.R. (megohms)	1,100,000	840,000

Case 2: 880P 2.2µF, 50VDC rated/Date Code 9903
Tested at 160VDC (3.2X Rated VDC) & +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. (%)	n/a	+4.8
Max. +25ºC 1kHz D.F.	0.04	0.06
Min. +25ºC I.R. (megohms)	120,000	350,000

Case 3: 880P 2.0µF, 50VDC rated/Date Code 9722
Tested at 160 VDC (3.2X Rated VDC) & +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. *(%)*	n/a	+3.1
Max. +25ºC 1kHz D.F. *(%)*	0.07	0.09
Min. +25ºC I.R. (megohms)	60,000	170,000

Case 4: 880P 0.47µF, 200VDC rated/Date Code 9512
Tested at 480 VDC (2.4X Rated VDC) & +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. *(%)*	n/a	+1.0
Max. +25ºC 1kHz D.F. *(%)*	0.04	0.04
Min. +25ºC I.R. (megohms)	530,000	1,400,000

Case 5: 880P 0.047µF, 400VDC rated/Date Code 9913
Tested at 960 VDC (2.4X Rated VDC)& +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. *(%)*	n/a	+0.62
Max. +25ºC 1kHz D.F. *(%)*	0.04	0.05
Min. +25ºC IR. (megohms)	2,200,000	7,900,000

Case 6: 880P 7.8µF, 300VDC rated/Date Code 9150
Tested at 720 VDC (2.4X Rated VDC)& +125ºC

PARAMETER	INITIAL	FINAL
Max. Cap. Chg. *(%)*	n/a	+1.4
Max. +25ºC 1kHz D.F. *(%)*	0.05	0.09
Min. +25ºC I.R. (megohms)	57,000	110,000

You can see that the quality of PPS film has remained unchanged for a long period of time and that capacitors made with metalized PPS can withstand extreme test conditions even after sitting "on the shelf" for years and years. These test conditions represent approximately a 5X increase over the test conditions that would have been used for PC capacitors of similar designs. You might ask why we didn't rate PPS at these levels before. The simple reason is that we were merely replacing PC in some customer designs. It seems that we have just begun to understand the true capabilities of this dielectric.

Dissipation Factor & E.S.R. Performance

Figures 2 and 3 plot the D.F. and E.S.R. performance at room temperature over the frequency range from 100Hz to 100,000Hz for a sampling of capacitance values with metalized electrodes. <u>In every case the performance of PPS is superior to PC.</u>

At elevated temperatures the loss characteristics of PPS differ than those exhibited by PC. As shown in Figure 4, above +100ºC PPS experiences an increase in D.F. that PC does not. This means that it is possible that a PPS device may run hotter than a PC device in some particular ac applications. It is important to remember, however, that PPS, unlike PC, can operate without degradation at higher temperatures as shown in the life test data in Tables I and II.

To see just what effect this increasing D.F. would have we ran a series of ac heat rise studies on a PPS capacitor design. The capacitor we selected was the same design used in Case 6 of the extreme life test evaluations in Table II. It was the 880P 7.8µF, 300VDC device that is an 18 AWG copper axial leaded wrap-and-fill configuration with a diameter of 1.250 inches and a length of 2.250 inches.

The tests were performed in an air-circulating oven stabilized at +125ºC. To prevent convection cooling of the capacitor surface, the unit under test was placed inside a pressboard box of approximately 5” X 3” X 2”. Thermocouples were fitted to the unit body, to the inside surface of the box, and freestanding in air in the oven as a reference. A sinusoidal ac signal was then applied to the unit and the heat rise of the capacitor body monitored compared to the temperature of the oven chamber after all three (3) reference thermocouples had stabilized for at least three (3) hours.
The results of these tests are provided in Table III.

TABLE III: PPS AC HEAT RISE EVALUATION

Test Frequency (Hz)	AC Current Applied (Amps)	Oven Temp. (ºC)	Cap. Body Temp. (ºC)	Heat Rise (ºC)
400	3	+125	+130	+5
1,000	8	+125	+136	+11
10,000	16	+125	+133	+8
40,000	14	+125	+135	+10

These tests show that the increasing D.F. behavior PPS exhibits with temperature above +l00ºC does not limit this dielectric in ac applications. In fact, none of the post electrical characteristics of the capacitors subjected to these tests degraded. It was as if they had never been tested at all. All of these tests resulted in capacitor temperatures exceeding the +125ºC accepted maximum operating temperature of PC capacitors in dc applications and are well above polycarbonate’s +100ºC maximum temperature rating for ac operation. A PC of similar size and rating was used to replace the PPS capacitor in the 40,000Hz test. Shortly after the ac signal was applied the ends of the PC melted off.

Insulation Resistance

This characteristic is used to determine a capacitor’s quality that might result from dielectric flaws, contamination or capacitor manufacturing defects. It is also a useful measurement to determine the potential degradation of a device after life testing, extended thermal cycling or exposure to moisture for long periods. It is of particular concern in applications such as timing and sample & hold circuits.

As shown in Figure 5, the PPS exhibits insulation resistance levels comparable with polycarbonate to +125ºC and has the advantage of being capable of operation at +150ºC.

CONCLUSION

Dearborn Electronics has been producing PPS capacitors for over ten years. During this time we have learned to handle and process the film to manufacture quality capacitors with excellent yields. We are currently in the process of obtaining qualifications for PPS to replace PC in all the popular military specifications (MIL-PRF-83421, MIL-PRF-83439, MIL-PRF-19978, MIL-PRF-39022 and MIL-PRF-55514) and have already been approved to MIL-PRF-83421/06, the PPS to MIL-PRF-83421/01 PC devices.

Polyphenylene Sulfide can directly replace polycarbonate, at about the same cost, in almost all applications without requiring a change in size. From a specification standpoint, it will, in some cases, require the customer to alter device drawings to allow for minor changes in capacitance changes with temperature. With all the testing we have performed and the data presented here, I wonder why we didn’t replace polycarbonate with polyphenylene sulfide years ago.

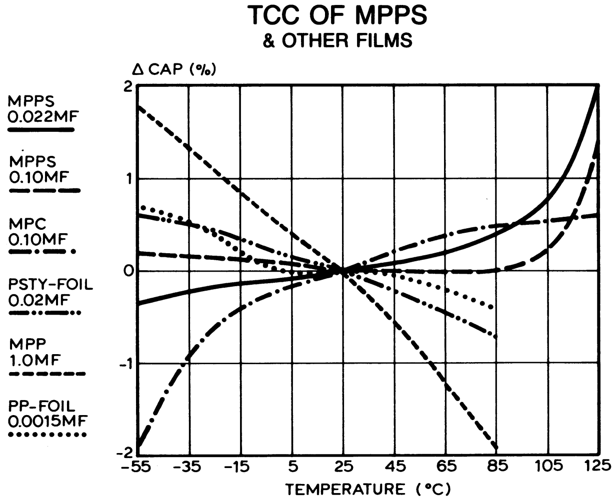

FIGURE 1

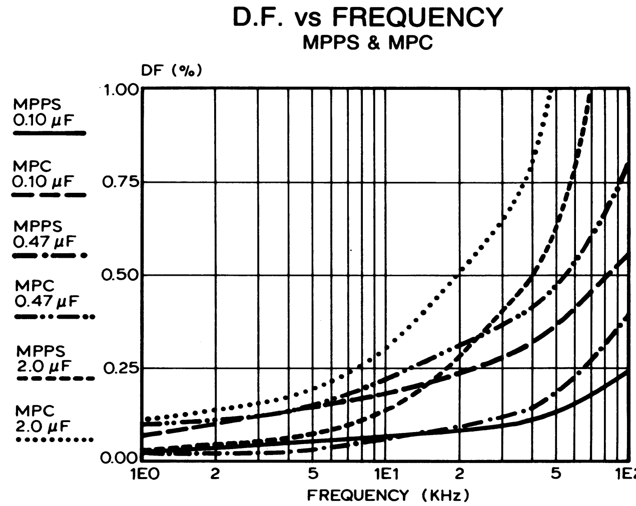

FIGURE 2

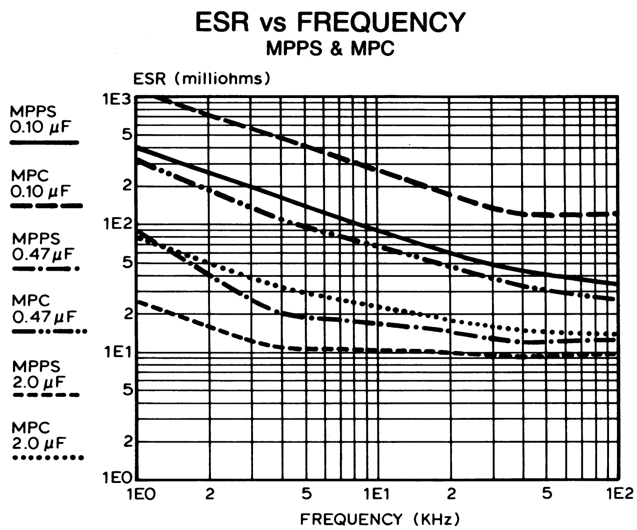

FIGURE 3

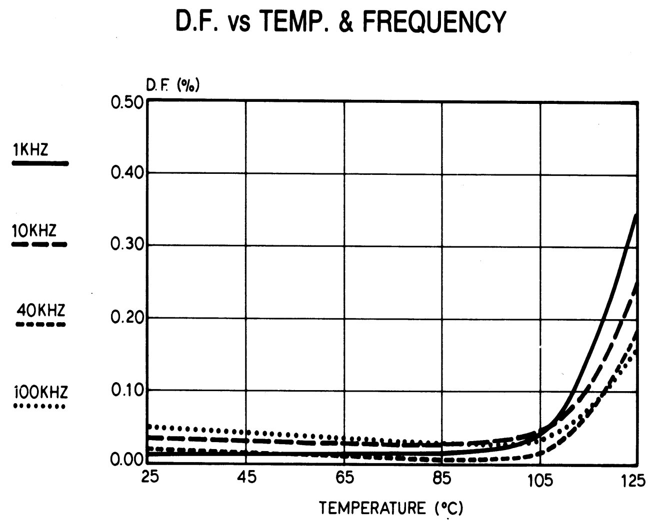

FIGURE 4

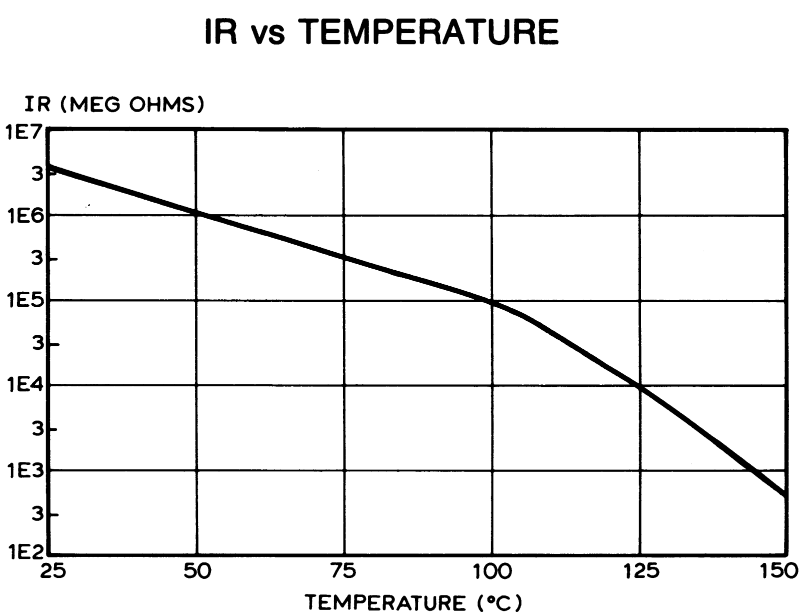

FIGURE 5