

Please note that the links in the PEARL logotype above are “live” and can be used to direct your web browser to our site or to open an e-mail message window addressed to ourselves.

To view our item listings on eBay, [click here](#).

To see the feedback we have left for our customers, [click here](#).

This document has been prepared as a public service . Any and all trademarks and logotypes used herein are the property of their owners.

It is our intent to provide this document in accordance with the stipulations with respect to “fair use” as delineated in Copyrights - Chapter 1: Subject Matter and Scope of Copyright; Sec. 107. Limitations on exclusive rights: Fair Use.

Public access to copy of this document is provided on the website of Cornell Law School (<http://www4.law.cornell.edu/uscode/17/107.html>) and is here reproduced below:

Sec. 107. - Limitations on exclusive rights: Fair Use

Notwithstanding the provisions of sections 106 and 106A, the fair use of a copyrighted work, including such use by reproduction in copies or phonorecords or by any other means specified by that section, for purposes such as criticism, comment, news reporting, teaching (including multiple copies for classroom use), scholarship, or research, is not an infringement of copyright. In determining whether the use made of a work in any particular case is a fair use the factors to be considered shall include:

- 1 - the purpose and character of the use, including whether such use is of a commercial nature or is for nonprofit educational purposes;
- 2 - the nature of the copyrighted work;
- 3 - the amount and substantiality of the portion used in relation to the copyrighted work as a whole; and
- 4 - the effect of the use upon the potential market for or value of the copyrighted work.

The fact that a work is unpublished shall not itself bar a finding of fair use if such finding is made upon consideration of all the above factors

Polypropylene-Film Capacitors for Military and Industrial A-C Applications

By
Leonard Adelson
And
Herbert H. Farr
Dearborn Electronics, Inc.
Longwood, FL 32750

INTRODUCTION

There are less than a dozen plastic films currently used as capacitor dielectrics, and polypropylene is by far the most widely used of these. Significant quantities are employed in commercial applications such as entertainment, motor run, power factor correction ballast, microwave, and other appliance uses. Capacitors manufactured for these applications use a film that is of comparatively low cost, however, this film has excellent dielectric strength, extremely low dielectric loss, and worldwide availability.

To put film usage into perspective, we refer to information published by Kalle. Worldwide use of plastic film for capacitors for 1983 by weight, was estimated as follows:

Table 1

<u>Film</u>	<u>Total Weight (%)</u>
Polypropylene (PP)	70.0
Polyester (PETP)	27.0
Polycarbonate (PC)	2.3
All Others	0.7

Polyester and polycarbonate film capacitors presently dominate in applications serving military and industrial requirements. Utilization of these two films includes product types specified in MIL-C 19978, MIL-C-55514, MIL-C-39022, and MIL-C-83421.

The use of films listed as "All Others" is comparatively small, and generally directed toward

specialty applications, with no significant changes, expected unless breakthroughs are made in cost, quality, available thickness, and performance.

We will examine performance characteristics of polypropylene capacitors to provide a frame of reference from which this type of film capacitor can be selected for specific applications for military, industrial and instrumentation market segments. These capacitors should be excellent candidates for a variety of a-c devices including switched-mode power supplies, high frequency inverters, and snubber applications.

Polypropylene capacitors are now included in MIL-C-55514, and will shortly be added to MIL-C-39022. The performance data and related information obtained from these programs constitute a major portion of this paper. Sprague Technical Paper TP83-4, "A-C Applications of Plastic-Film Capacitors" is also used as a basic reference. The data used to generate tables, curves and graphs was obtained from actual measurements, and should not be interpreted as maximum/minimum values or limits for use in specifications.

Discussions are presented on the following subjects:

1. Performance Characteristics
2. Reliability
3. ESR
4. A-C Heating
5. Polypropylene-Foil Characteristics

PERFORMANCE CHARACTERISTICS

Polypropylene has a relatively high dielectric strength compared to polycarbonate and polyester films, as shown in Table 2. This property can be translated into fewer "clearings" of dielectric faults, with enhanced prospects for the manufacture of high quality, high performance, capacitors.

Table 2

Film (48ga - 12um)	Volts/Mil
Polycarbonate	7,600
Polyester	14,000
Polypropylene	16,500

The electrical performance characteristics of metallized-polypropylene tubular metal-case capacitors are described in Figures 1 through 5. The low loss and excellent high frequency characteristics of polypropylene capacitors are fairly well known to component engineers and circuit designers. However, these capacitors exhibit additional performance advantages such as extremely high insulation resistance, excellent capacitance stability, and an essentially linear, negative capacitance change as a function of temperature.

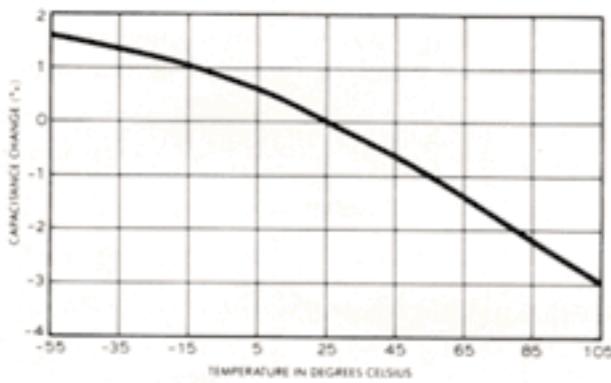


Figure 1
Capacitance Change vs. Temperature
Metallized-Polypropylene Metal-Case
Tubular Capacitors

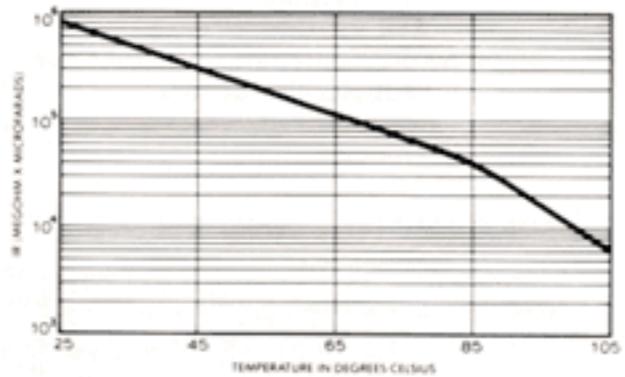


Figure 3
Insulation Resistance vs. Temperature
Metallized-Polypropylene Metal-Case
Tubular Capacitors

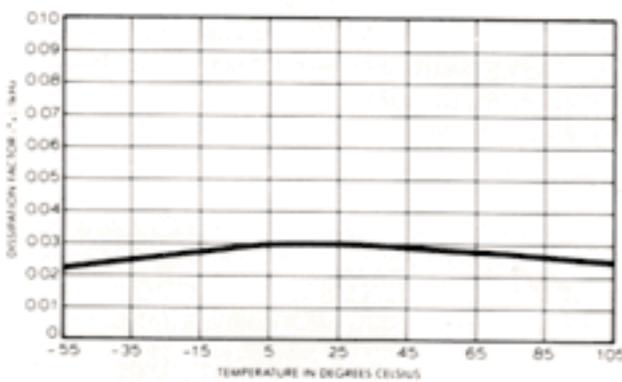


Figure 2
Dissipation Factor vs. Temperature
Metallized-Polypropylene Metal-Case
Tubular Capacitors

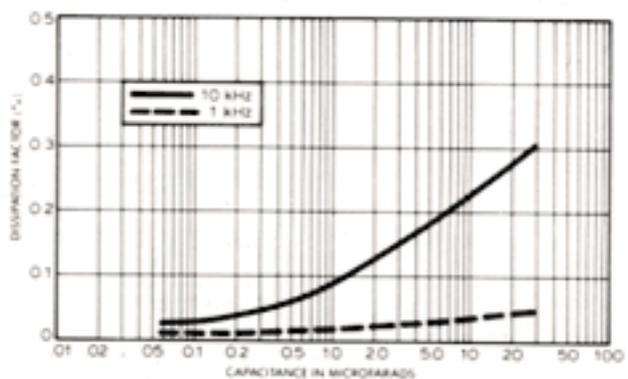


Figure 4
Dissipation Factor vs. Capacitance
Metallized-Polypropylene Metal-Case
Tubular Capacitors

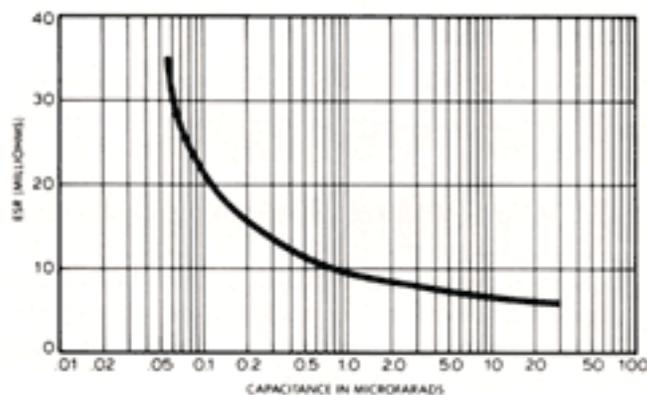


Figure 5
ESR vs. Capacitance
Metallized-Polypropylene Metal-Case
Tubular Capacitors

PERFORMANCE AND RELIABILITY

Capacitor types and ratings used to generate a-c and d-c life test data are listed in Table 3.

The CFR types include the two MIL terminations as shown in Figure 6, the lead wire for moderate a-c currents and the lug terminal for high a-c currents. Figure 7 depicts hermetically-sealed metal-case tubular capacitors in accordance with the industry standard.

Results of life tests are summarized in Tables 4 through 8.

Note the following points from the Tables 4 through 8:

1. Sixty-nine (69) capacitors totaling 540 μF were tested at MIL specified a-c currents at 40 kHz and +85 degrees C for a total of 28,260 unit-hours of operation –with no failures.
2. One hundred eighty (180) capacitors totaling 2260 μF were tested at 140% of rated d-c voltage and +105degrees C for a total of 260,000 unit-hours of operation. One unit failure occurred after 600 hours of the 2000 hour test.
3. Two hundred (200) capacitors totaling 3100 μF were tested at rated d-c voltage and +105degrees C for 400,000 unit-hours of operation with no failures.

Life test results to date indicate the potential for metallized polypropylene capacitors for reliable performance in both a-c and d-c applications.

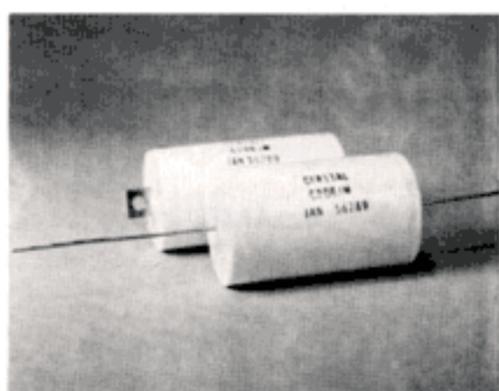


Figure 6
Polypropylene-Film Capacitors
Wire Lead and Lug Terminal Configurations

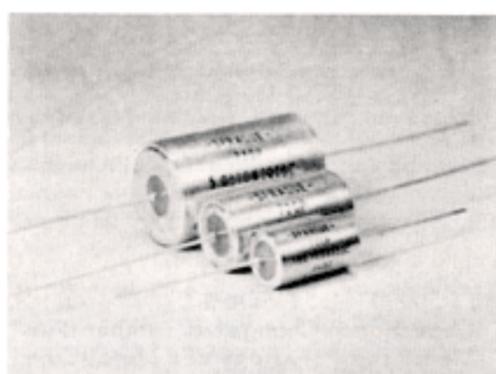


Figure 7
Type 720P Capacitors
Test Units Showing Size Variations

Table 3

Life Test - Metallized Polypropylene Film Capacitors

Mil Designation	Sprague Designation	Capacitance	D-C Rating	Termination
CFR13ALB306JM	735P306X5100	30 μF	100VDC	LEADS
CFR14LLB306JM	735P306X5100	30 μF	100VDC	LUGS
CFR13ALC206JM	735P206X5200	20 μF	200VDC	LEADS
CFR14LLC206JM	735P206X5200	20 μF	200VDC	LUGS
CFR13ALE106JM	735P106X5400	10 μF	400VDC	LEADS
CFR14LLE106JM	735P106X5400	10 μF	400VDC	LUGS
Metal Tubular	720P205X9100	2 μF	100VDC	LEADS
Metal Tubular	720P505X9200	5 μF	200VDC	LEADS
Metal Tubular	720P104X9400	0.1 μF	200VDC	LEADS

TABLE 4

METALLIZED POLYPROPYLENE TO MIL-C-55514/9 D-C LIFE TEST: 2000 Hrs. + 105°C 100% RVDC

MIL DESIG. NO.	NO. PARTS TESTED	TEST VOLTAGE	CAP μF (1kHz)			% DF (1kHz)			IR (megohms)	
			INITIAL AVG.	FINAL AVG.	AVG. % CHANGE	INITIAL AVG.	FINAL AVG.	AVG. CHANGE	INITIAL AVG.	FINAL AVG.
CFR13ALE100JM	50	400	9.98	9.98	0	.046	.041	-.005	1.1x10 ⁶	7.9x10 ⁶
CFR14LLE106JM	50	400	9.97	9.96	-.10	.056	.057	+.001	1.1x10 ⁶	8.1x10 ⁶
CFR13ALC206JM	25	200	20.76	20.69	-.30	.033	.036	+.003	9.6x10 ⁶	7.9x10 ⁶
CFR14LLC206JM	25	200	19.84	19.82	-.10	.044	.067	+.023	3.7x10 ⁶	2.7x10 ⁶
CFR13HLB306JM	25	100	29.99	29.89	-.30	.038	.038	0	9.7x10 ⁶	7.8x10 ⁶
CFR14LLB306JM	25	100	29.09	29.09	0	.043	.057	+.014	3.8x10 ⁶	3.1x10 ⁶

TABLE 5

METALLIZED POLYPROPYLENE TO MIL-C-55514/9 D-C LIFE TEST: 2000 Hrs. + 105°C 140% RVDC

MIL DESIG. NO.	NO. PARTS TESTED	TEST VOLTAGE	CAP μF (1kHz)			% DF (1kHz)			IR (megohms)	
			INITIAL AVG.	FINAL AVG.	AVG. % CHANGE	INITIAL AVG.	FINAL AVG.	AVG. CHANGE	INITIAL AVG.	FINAL AVG.
CFR13ALE106JM	30	560	9.97	9.98	+.10	.036	.037	-.001	9.7x10 ⁶	7.7x10 ⁶
CFR14LLE106JM	30	560	9.95	9.96	+.10	.059	.048	-.011	1.1x10 ⁶	9.2x10 ⁶
CFR13ALC206JM	15	280	20.75	20.70	-.24	.030	.071	+.041	9.6x10 ⁶	7.6x10 ⁶
CFR14LLC206JM	15	280	19.61	19.71	+.51	.042	.031	-.009	3.9x10 ⁶	3.0x10 ⁶
CFR13ALB306JM	15	140	30.02	29.97	-.17	.041	.044	+.003	9.6x10 ⁶	7.0x10 ⁶
CFR14LLB306JM	15	140	29.15	29.11	-.10	.050	.027	-.023	3.6x10 ⁶	3.4x10 ⁶

TABLE 6

METALLIZED POLYPROPYLENE TO MIL-C-55514/9 A-C TEST: 240 Hrs. + 85°C 40kHz

MIL DESIG. NO.	NO. PARTS TESTED	TEST CURRENT	CAP μF (1kHz)			% DF (1kHz)			IR (megohms)	
			INITIAL AVG.	FINAL AVG.	AVG. % CHANGE	INITIAL AVG.	FINAL AVG.	AVG. CHANGE	INITIAL AVG.	FINAL AVG.
CFR13ALE106JM	6	14.1	9.98	9.97	-.10	.04	.04	0	9.8x10 ⁶	1.0x10 ⁶
CFR14LLE106JM	6	14.7	9.93	9.92	-.10	.065	.038	-.027	1.0x10 ⁶	8.2x10 ⁶
CFR13ALC206JM	3	12.8	20.76	20.74	-.09	.03	.023	-.013	9.7x10 ⁶	8.1x10 ⁶
CFR14ALC206JM	3	15.4	20.01	19.92	-.40	.05	.043	-.013	4.4x10 ⁶	3.2x10 ⁶
CFR13ALB306JM	3	11.4	30.00	29.87	-.43	.037	.02	-.017	1.0x10 ⁶	8.1x10 ⁶
CFR14ALB306JM	3	11.9	29.50	29.50	0	.037	.033	-.044	4.7x10 ⁶	6.3x10 ⁶

TABLE 7

METALLIZED POLYPROPYLENE METAL TUBULARS D-C LIFE TEST: 2000 Hrs. 105°C 140% RVDC

CAPACITOR RATING	NO. PARTS TESTED	TEST VOLTAGE	CAP μF (1kHz)			% DF (1kHz)			IR (megohms)	
			INITIAL AVG.	FINAL AVG.	AVG. % CHANGE	INITIAL AVG.	FINAL AVG.	AVG. CHANGE	INITIAL AVG.	FINAL AVG.
0.1 μF 400VDC	20	560	.099	.099	0	.006	.015	+.009	1.1x10 ⁷	2.4x10 ⁷
2.0 μF 100VDC	20	140	1.96	1.95	-.51	.019	.024	+.005	9.4x10 ⁶	1.4x10 ⁶
5.0 μF 200VDC	20	280	5.13	5.12	-.20	.030	.136	+.106	3.0x10 ⁶	9.1x10 ⁶

TABLE 8

METALLIZED POLYPROPYLENE METAL TUBULARS A-C LIFE TEST: 500 Hrs. + 85°C, 40kHz

CAPACITOR RATING	NO. PARTS TESTED	TEST CURRENT	CAP μF (1kHz)			% DF (1kHz)			IR (megohms)	
			INITIAL AVG.	FINAL AVG.	AVG. % CHANGE	INITIAL AVG.	FINAL AVG.	AVG. CHANGE	INITIAL AVG.	FINAL AVG.
0.1 μF 400VDC	15	2.0	.098	.098	0	.006	.006	0	1.0x10 ⁷	2.6x10 ⁷
1.0 μF 100VDC	15	5.3	1.96	1.95	-.51	.019	.022	+.003	8.1x10 ⁶	1.1x10 ⁶
5.0 μF 200VDC	15	8.5	4.84	4.84	0	.030	.036	+.006	1.4x10 ⁶	1.5x10 ⁶

EQUIVALENT SERIES RESISTANCE

Low equivalent series resistance (ESR) is a most desirable characteristic for capacitors used for high-frequency/high-current a-c applications. Heat generated during a-c operation is directly related to capacitor ESR. While the dielectric loss for polypropylene is very low, the electrode resistance contributes significantly to the effective ESR, and must be considered in optimizing the capacitor design.

In order to analyze ESR and the effect of various changes in capacitor geometry, we produced several different capacitors using 24 gauge metallized-polypropylene film with 1/16-inch wide unmetallized margins. These parts are shown in Figures 8,9, and 10. We additionally used metallized polycarbonate capacitors for reference.

Metallized-polycarbonate capacitors used for reference are shown in Figure 11 along with metallized-polypropylene capacitors of the same ratings. Note the sizes are virtually identical for the same ratings of each type of capacitor.

ESR measurements referenced in this section were made on a Hewlett-Packard 4274A LCR meter using a fixture designed with fixed dimensions for minimum resistance. Equipment calibration effectively removed the fixture resistance from the test circuit.

Pertinent design features, metallized-polypropylene film width, film length, effective electrode areas, capacitance at 100kHz ESR figures are listed in Table 9. (The effective electrode areas are the total metallized surface areas.)

Length and Diameter

ESR values measured for 10 μF , 3 μF and 1.5 μF capacitors made with two different film widths show significant improvements in ESR may be obtained by reducing film width. For example, the 3 μF capacitors, each using approximately 760 sq. in. of electrode surface, show a three-fold improvement in ESR for units made with 1/2 inch wide film as compared to the ESR for units made with 2-inch wide film. The same relationship holds for other units tested.

Figures 12 and 13 are plots of ESR vs. frequency for the tested capacitor pairs. Figure 13 also provides ESR data for equivalent metallized-polycarbonate capacitors for reference. Figures 14,15 and 16 show the length to diameter variations for these capacitor pairs.

A reduction in film width (requiring an increase in capacitor diameter) is a design consideration where the objective is to minimize the contribution for the electrodes and termination to the total ESR.

Table 9
Metallized Polypropylene Section Design vs. 100kHz ESR

CAP (μF)	Film Width (inches)	Film Length (inches)	Electrode Surface (sq. inches)	100kHz ESR (milliohms)
20	2	2700	5020	2.1
10	2	1350	2510	3.2
10	1	2900	2500	2.4
5	1	1450	1250	3.3
3	2	400	750	7.8
3	1/2	2150	770	2.7
1.5	1	440	385	4.7
1.5	1/2	1075	390	3.0
.75	1/2	540	195	4.3

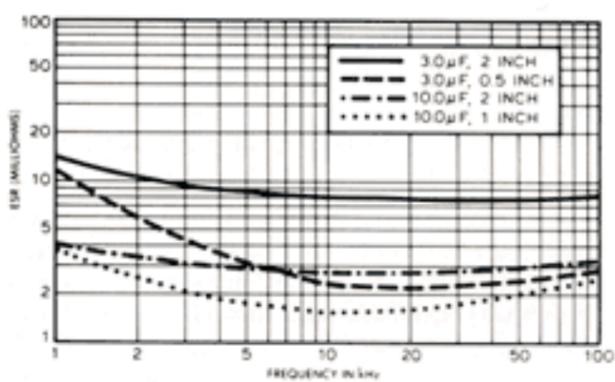


Figure 12
ERS vs. Frequency
Metallized-Polypropylene
Tubular Capacitors

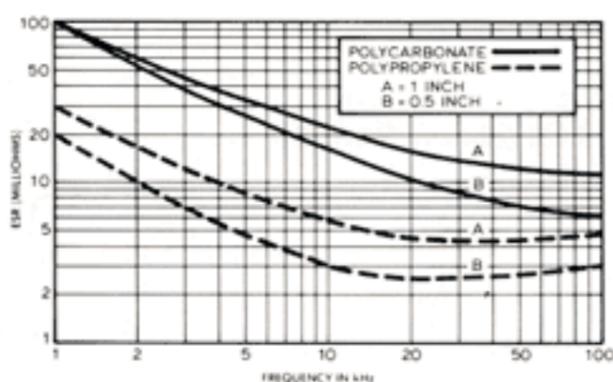


Figure 13
ESR vs. Frequency
1.5 μF Polypropylene and
Polycarbonate Capacitors

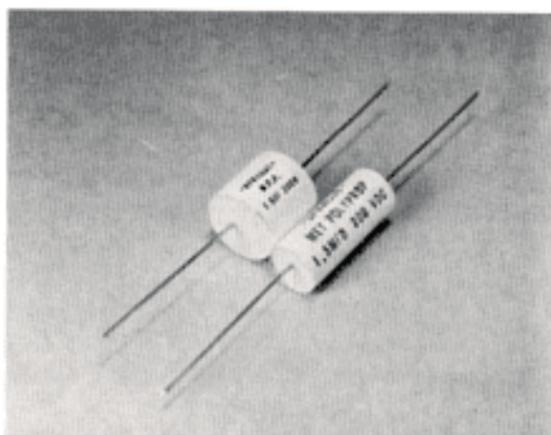


Figure 14
1.5 μF Capacitor Sections — 2 Sizes
Metallized-Polypropylene Capacitors

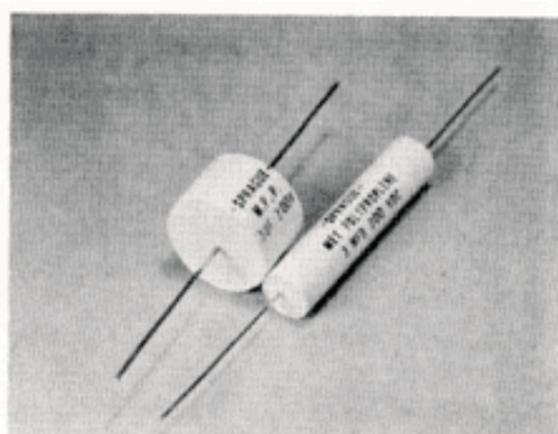


Figure 15
3 μF Capacitor Sections — 2 Sizes
Metallized-Polypropylene Capacitors

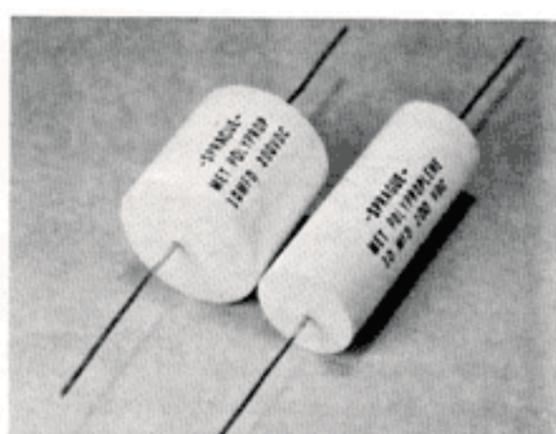


Figure 16
10 μF Capacitor Sections — 2 Sizes
Metallized-Polypropylene Capacitors

Parallel Sections

We also studied an alternative approach to reducing ESR using capacitor sections connected in parallel shown in Figures 17,18, 19 and 20.

Frequency plots, Figures 21 and 22 compare these parallel configurations and single capacitors made with wider film.

The ESR values are compared in Table 10.

The test results demonstrate that capacitor sections designed with relatively narrow film widths and connected in parallel offer a viable design option for a-c applications requiring exceptionally low ESR. The "parallel" design approach would use a rectangular or "bathtub" case with the added advantage of reduced inductance, a definite "plus" for applications in the frequency range of over 50kHz. The rectangular parts additionally offer easier fit and mounting.

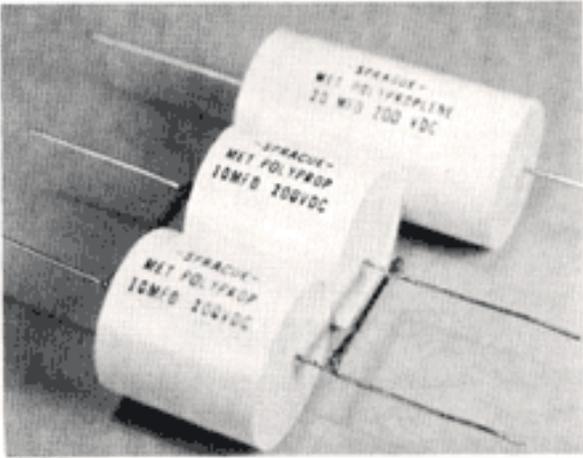


Figure 17
 2 x 10 μ F (1" Wide Film)
 1 x 20 μ F (2" Wide Film)
 Parallel and Single Capacitor Sections

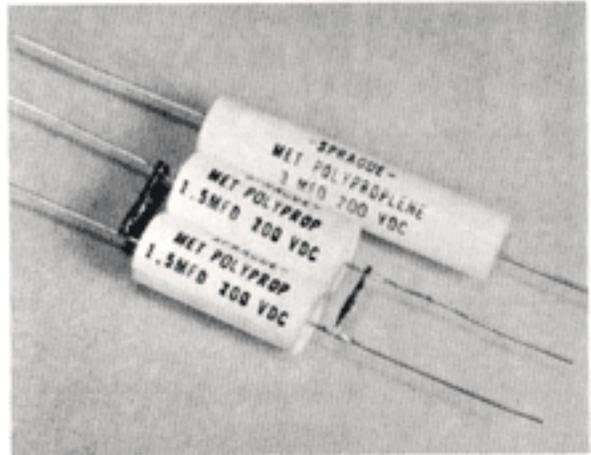


Figure 19
 2 x 1.5 μ F (1" Wide Film)
 1 x 3.0 μ F (2" Wide Film)
 Parallel and Single Capacitor Sections

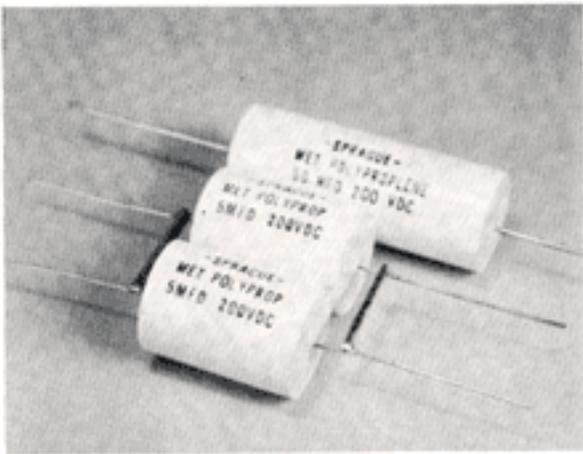


Figure 18
 2 x 5 μ F (1" Wide Film)
 1 x 10 μ F (2" Wide Film)
 Parallel and Single Capacitor Sections

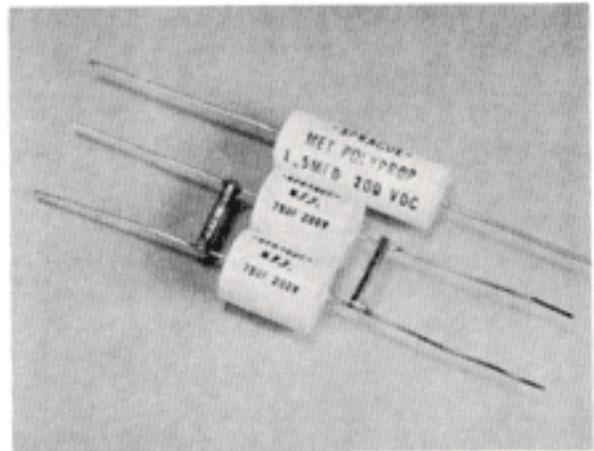


Figure 20
 2 x 0.75 μ F (0.5" Wide Film)
 1 x 1.5 μ F (1.0" Wide Film)
 Parallel and Single Capacitor Sections

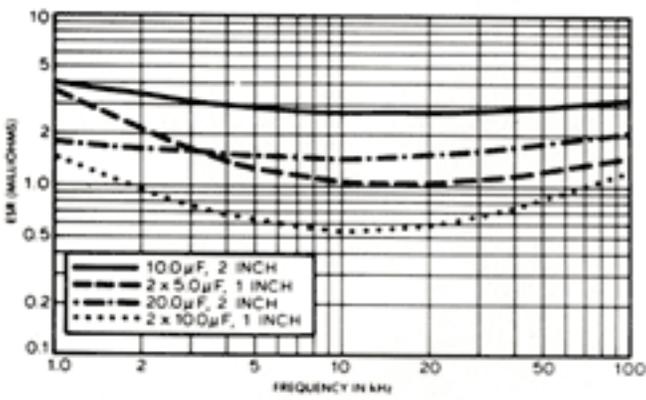


Figure 21
 ESR vs. Frequency
 Parallel Section
 Metallized-Polypropylene Capacitors

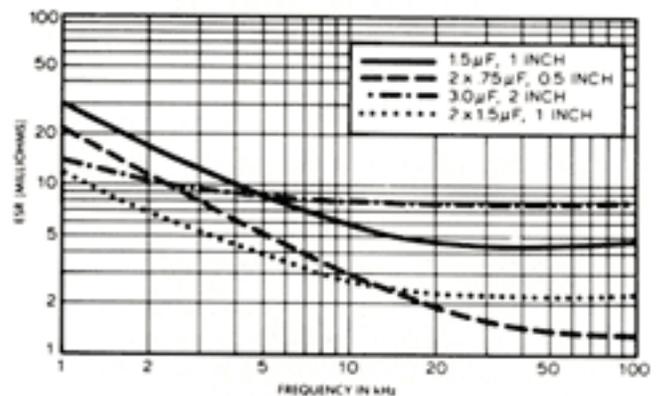


Figure 22
 ESR vs. Frequency
 Parallel Section
 Metallized-Polypropylene Capacitors

Table 10

Total CAP (μ F)	Film Width (inches)	# Parallel Parts	ESR 100kHz (milliohms)
20	2	-	2.1
20	1	2x10 μ F	1.2
10	2	-	3.2
10	1	2x5 μ F	1.6
3	2	-	7.8
3	1	2x1.5 μ F	2.3
1.5	1	-	4.7
1.5	1/2	2x.75 μ F	1.5

A-C HEATING

We have demonstrated that the geometry of a capacitor can be modified to reduce ESR. The practical result of reduced ESR is reduced heating, and we have examined the effect of lower ESR on heating for the capacitor pairs described in Table 3.

Testing was performed in still air at room temperature. Test parts were subjected to incremental increases in 40 kHz sinusoidal current. The case (capacitor bodies) and lead wire temperatures were continuously monitored. Temperature increases as functions of rms current are shown in Figures 23, 24, and 25.

The differences in heat rise are dramatic. To demonstrate this the 40 kHz sinusoidal current values required to produce a 20°C rise in lead wire temperatures were extracted and tabulated in Table 11.

Table 11

Capacitance (F)	Film Width (inches)	40kHz RMS Current (amperes)
1.5	0.5	16
1.5	1.0	11
3	0.5	15
3	2.0	11.5
10	1.0	21
10	2.0	16

By reducing capacitor length (and increasing capacitor diameter) we cut the heat rise by almost 50%.

Conversely, we could increase the operating current by perhaps 50% by using a capacitor geometry with a lower ESR.

While the differences in heat rise between short, stubby capacitors and long, small diameter capacitors are significant, the stubby configuration should also provide better heat dissipation.

The surface area of the metal end-spray termination is increased with an increase in section diameter thereby improving heat dissipation. Additionally, there is a reduction in "hot spot" temperature, an important factor in overall capacitor performance.

The capacitor lead wire or terminal should be large to increase heat dissipation from the capacitor body and to prevent the wire from becoming a heat generator at high current levels. This latter condition could produce a situation where heat would be pumped back into the capacitor. The heat rise graphs show the change in temperature for lead and body diverge as the rms current is increased. This is undoubtedly due to increased body heat being transmitted to the lead wire in addition to the lead wire heating due to its own ESR losses.

One frequently overlooked factor that can restrict the use of metallized film capacitors in high current a-c applications is the ability of the metallized-film electrode/metal end-spray interface to withstand high peak currents. If the situation arises where the current is limited for this reason, a simple solution is to change the geometry of the section, decreasing the capacitor length and increasing the diameter until the safe current value has been reached. If this is not possible with a single section, use of parallel sections would be considered.

There are a number of valid reasons why capacitor geometry may not always be fully optimized, including: capacitor manufacturing limitations, encapsulation problems, volume efficiency, mounting requirements and available space in chassis.

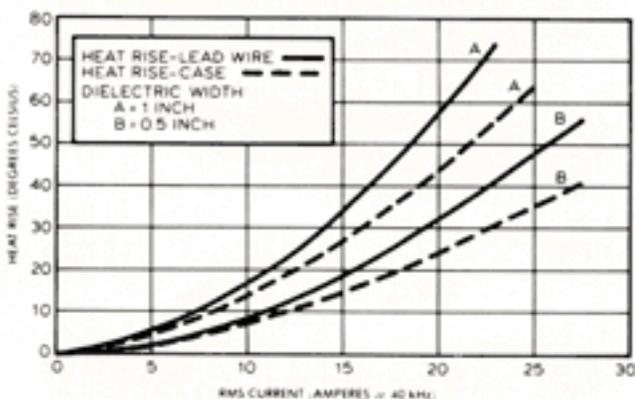


Figure 23
Heat Rise vs. RMS Current
1.5 μ F Metallized-Polypropylene Capacitors

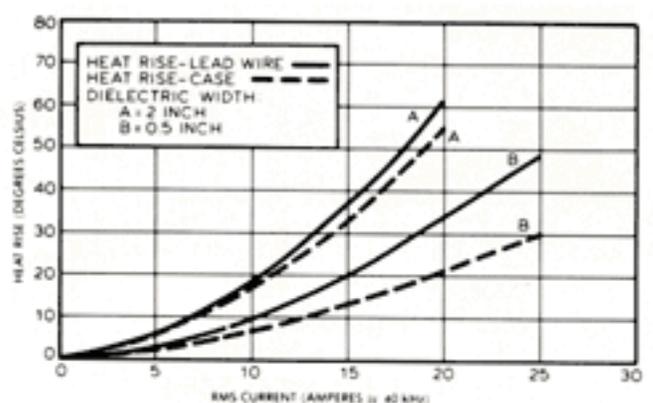


Figure 24
Heat Rise vs. RMS Current
3.0 μ F Metallized-Polypropylene Capacitors

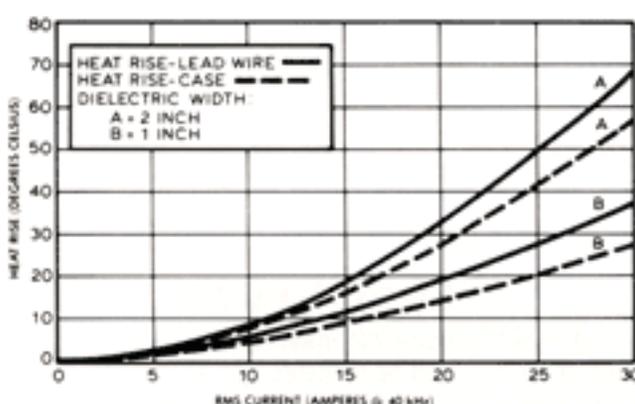


Figure 25
Heat Rise vs. RMS Current
10.0 μ F Metallized-Polypropylene Capacitors

POLYPROPYLENE-FILM/FOIL CAPACITORS

Any discussion of polypropylene film capacitors must cover polypropylene film/foil as well as metallized-film capacitors. There are a-c applications for which a metallized film capacitor cannot be used effectively. Deterioration of the connection between the film metallization and the metal end-spray can occur when metallized-film capacitors are subjected to extremely high peak currents. Increasing the metallized-film electrode length can help, but the use of film/foil capacitors may be a preferable option, particularly in the case of low microfarad values.

Polypropylene-film capacitors using foil electrodes are appropriate for non-sinusoidal applications with very high peak currents such as snubber applications. Rugged electrode terminations produce the ability to handle high peak currents. These capacitors can also handle higher average current as a result of low dielectric loss, lower electrode resistance, and greater heat conduction reducing potential hot spot problems.

The type 710P polypropylene-film/foil capacitor is qualified to MIL-C-55514/10 as MIL Style CFR 15. This document specifies the maximum allowable peak current capacity, expressed as dV/dt (Amps/ μF), for each capacitor listed. These limits are an order of magnitude greater than those for equivalent metallized-film capacitor ratings (for example, 300 $v/\mu s$ vs. 40 $v/\mu s$ for 200-volt rated parts).

The performance characteristics (Figures 26, 27 and 28) of polypropylene-film/foil capacitors are also of interest because of the extremely high insulation resistance. In addition, the temperature coefficient of capacitance is negative and typically 150ppm/degrees C, a characteristic suitable for matching with positive TCC components where circuit stability is a requirement.

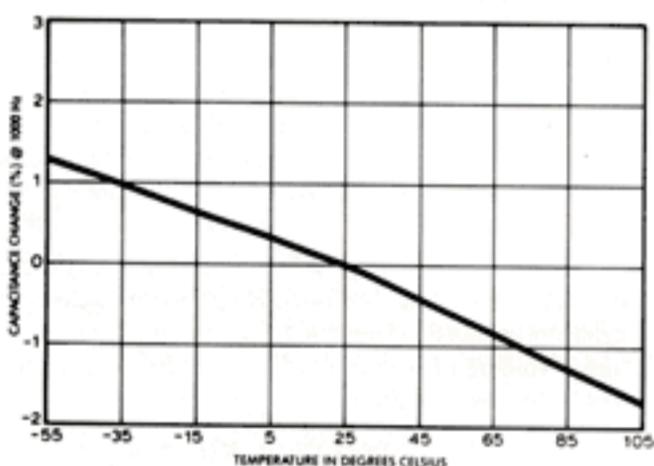


Figure 26
Capacitance vs. Temperature
Polypropylene-Film/Foil Capacitors

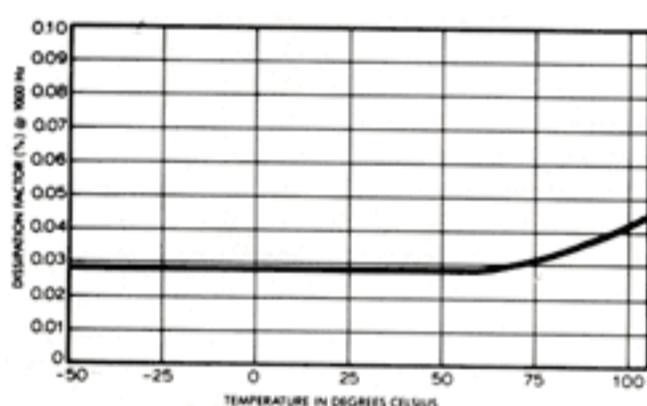


Figure 27
Dissipation Factor vs. Temperature
Polypropylene-Film/Foil Capacitors

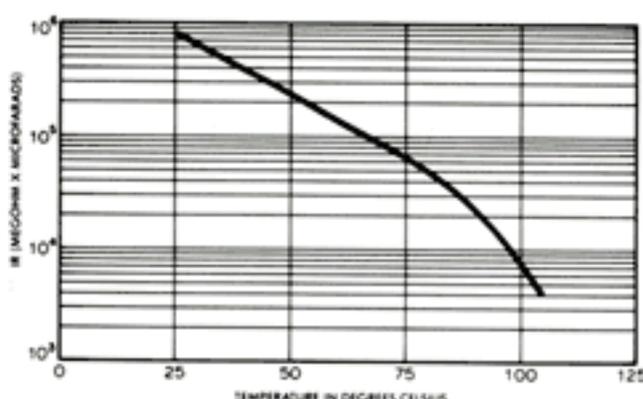


Figure 28
Insulation Resistance vs. Temperature
Polypropylene-Film/Foil Capacitors

CONCLUSIONS

Correctly designed and manufactured polypropylene-film capacitors will be valuable additions to those film capacitors currently covered by active MIL specifications. The following considerations apply:

1. Excellent polypropylene film quality is available and a high reliability capacitor design is achievable.
2. Very low ESR may be obtained by combining the low loss characteristics of polypropylene film and optimized section geometry.
3. A properly designed polypropylene-film capacitor can be used to good advantage in high-frequency, high-current applications.
4. Performance characteristics are excellent, suggesting possible uses beyond the a-c applications mentioned here.
5. Polypropylene-film/foil capacitors are good choices for non-sinusoidal applications where the metallized capacitor may not effectively handle high peak current (dV/dt) requirements.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Mark Rumler for obtaining much of the data used as a basis for this paper.

REFERENCES

"CAPACITOR FILMS" Klaus Schubring, Kalle (Presented at CARTS 1984)

"A-C APPLICATION OF PLASTIC-FILM CAPACITORS", Jerold D. Kowalsky and Herbert L. Rice, Sprague electric Co. (Presented at CARTS 1983)