

## COMMENTS

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

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#### 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

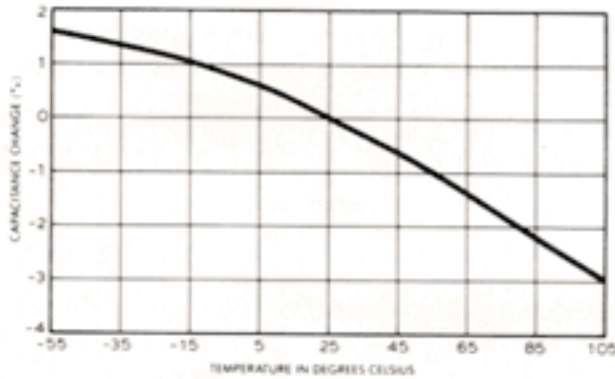
## PERFORMANCE CHARACTERISTICS

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.

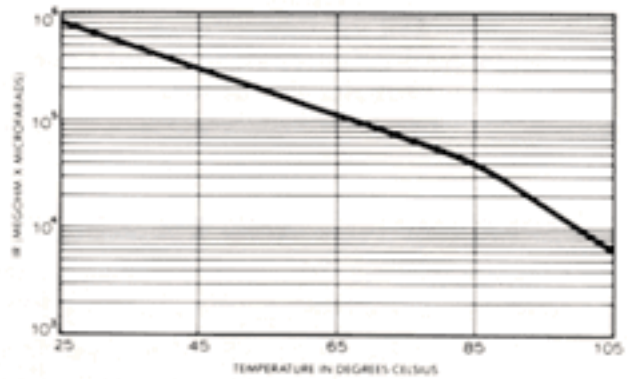
**Table 2**

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

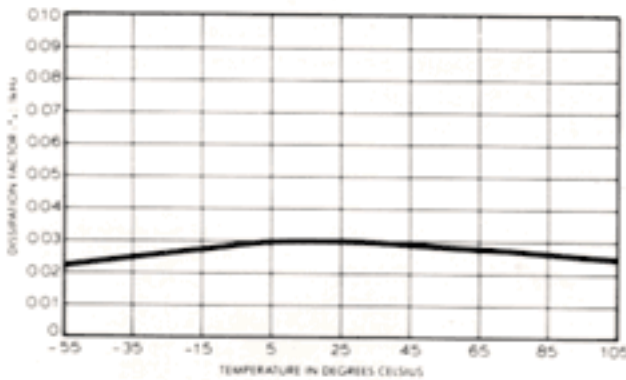
The electrical performance characteristics of metallized-polypropylene tubular metal-case capacitors are described in Figures 1 through 5. The low loss and excellent high frequency characteristics of polypropylene capacitors are fairly well known to component engineers and circuit designers. However, 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.



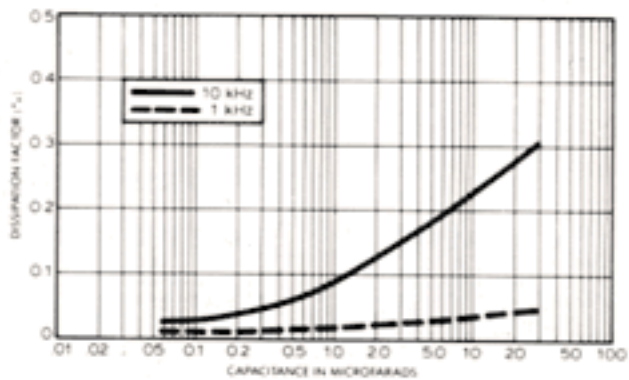
**Figure 1**  
**Capacitance Change vs. Temperature**  
**Metallized-Polypropylene Metal-Case**  
**Tubular Capacitors**



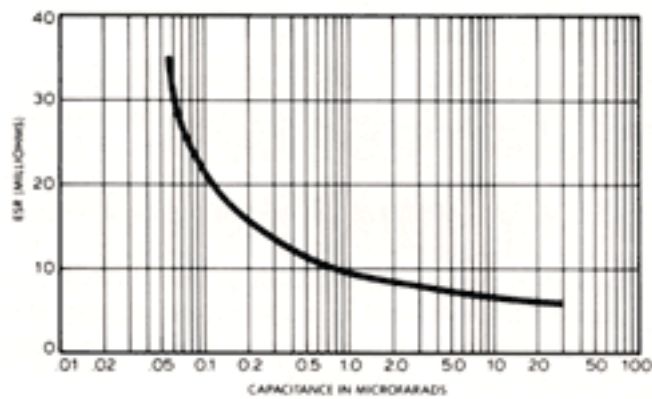
**Figure 3**  
**Insulation Resistance vs. Temperature**  
**Metallized-Polypropylene Metal-Case**  
**Tubular Capacitors**



**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.

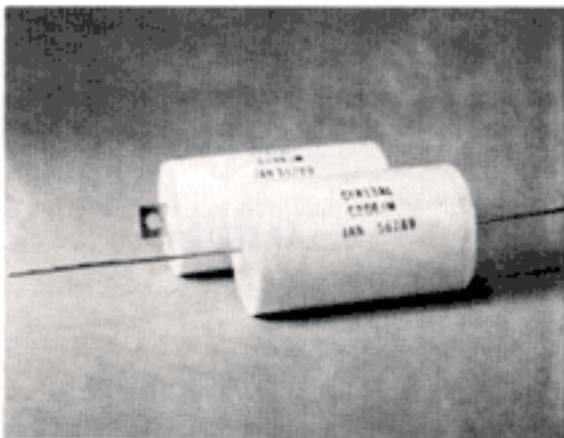
The CFR types include the two MIL terminations as shown in Figure 6, the lead wire for moderate a-c currents and the lug terminal for high a-c currents. Figure 7 depicts hermetically-sealed metal-case tubular capacitors in accordance with the industry standard.

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

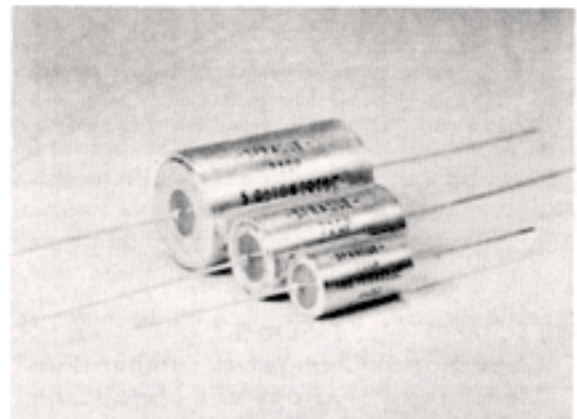
Note the following points from the Tables 4 through 8:

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.

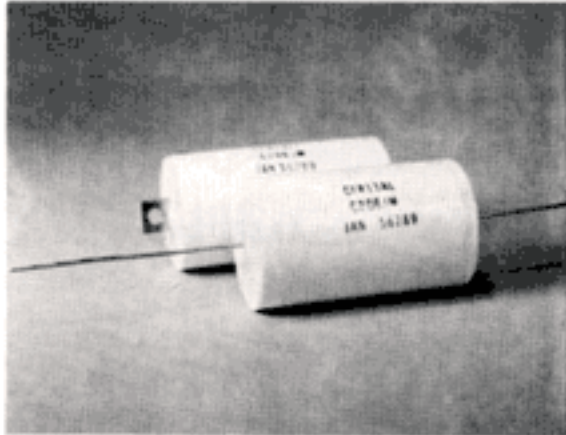
Life test results to date indicate the potential for metallized polypropylene capacitors for reliable performance in both a-c and d-c applications.



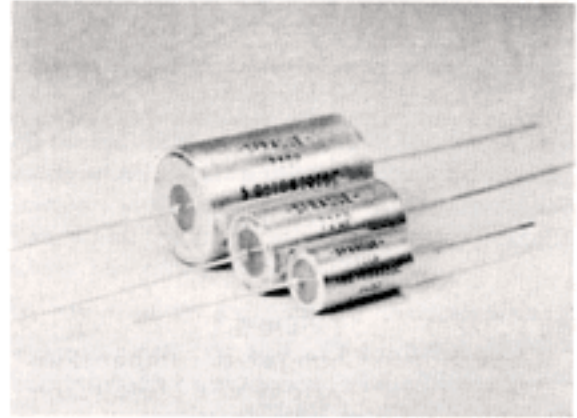
**Figure 6**  
**Polypropylene-Film Capacitors**  
**Wire Lead and Lug Terminal Configurations**



**Figure 7**  
**Type 720P Capacitors**  
**Test Units Showing Size Variations**



**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 - Metalized Polypropylene Film Capacitors**

| <b>Mil Designation</b> | <b>Sprague Designation</b> | <b>Capacitance</b> | <b>D-C Rating</b> | <b>Termination</b> |
|------------------------|----------------------------|--------------------|-------------------|--------------------|
| CFR13ALB306JM          | 735P306X5100               | 30 $\mu$ F         | 100VDC            | LEADS              |
| CFR14LLB306JM          | 735P306X5100               | 30 $\mu$ F         | 100VDC            | LUGS               |
| CFR13ALC206JM          | 735P206X5200               | 20 $\mu$ F         | 200VDC            | LEADS              |
| CFR14LLC206JM          | 735P206X5200               | 20 $\mu$ F         | 200VDC            | LUGS               |
| CFR13ALE106JM          | 735P106X5400               | 10 $\mu$ F         | 400VDC            | LEADS              |
| CFR14LLE106JM          | 735P106X5400               | 10 $\mu$ F         | 400VDC            | LUGS               |
| Metal Tubular          | 720P205X9100               | 2 $\mu$ F          | 100VDC            | LEADS              |
| Metal Tubular          | 720P505X9200               | 5 $\mu$ F          | 200VDC            | LEADS              |
| Metal Tubular          | 720P104X9400               | 0.1 $\mu$ F        | 200VDC            | LEADS              |

**TABLE 4**

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

| MIL<br>DESIG. NO. | NO. PARTS<br>TESTED | TEST<br>VOLTAGE | CAP $\mu$ F (1kHz) |               |                  | % DF (1kHz)     |               |                | IR (megohms)        |                     |
|-------------------|---------------------|-----------------|--------------------|---------------|------------------|-----------------|---------------|----------------|---------------------|---------------------|
|                   |                     |                 | INITIAL<br>AVG.    | FINAL<br>AVG. | AVG. %<br>CHANGE | INITIAL<br>AVG. | FINAL<br>AVG. | AVG.<br>CHANGE | INITIAL<br>AVG.     | FINAL<br>AVG.       |
| CFR13ALE100JM     | 50                  | 400             | 9.98               | 9.98          | 0                | .046            | .041          | -.005          | 1.1x10 <sup>5</sup> | 7.9x10 <sup>4</sup> |
| CFR14LLE106JM     | 50                  | 400             | 9.97               | 9.96          | -.10             | .056            | .057          | +.001          | 1.1x10 <sup>5</sup> | 8.1x10 <sup>4</sup> |
| CFR13ALC206JM     | 25                  | 200             | 20.76              | 20.69         | -.30             | .033            | .036          | +.003          | 9.6x10 <sup>4</sup> | 7.9x10 <sup>4</sup> |
| CFR14LLC206JM     | 25                  | 200             | 19.84              | 19.82         | -.10             | .044            | .067          | +.023          | 3.7x10 <sup>4</sup> | 2.7x10 <sup>4</sup> |
| CFR13HLB306JM     | 25                  | 100             | 29.99              | 29.89         | -.30             | .038            | .038          | 0              | 9.7x10 <sup>4</sup> | 7.8x10 <sup>4</sup> |
| CFR14LLB306JM     | 25                  | 100             | 29.09              | 29.09         | 0                | .043            | .057          | +.014          | 3.8x10 <sup>4</sup> | 3.1x10 <sup>4</sup> |

**TABLE 5**

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

| MIL<br>DESIG. NO. | NO. PARTS<br>TESTED | TEST<br>VOLTAGE | CAP $\mu$ F (1kHz) |               |                  | % DF (1kHz)     |               |                | IR (megohms)        |                     |
|-------------------|---------------------|-----------------|--------------------|---------------|------------------|-----------------|---------------|----------------|---------------------|---------------------|
|                   |                     |                 | INITIAL<br>AVG.    | FINAL<br>AVG. | AVG. %<br>CHANGE | INITIAL<br>AVG. | FINAL<br>AVG. | AVG.<br>CHANGE | INITIAL<br>AVG.     | FINAL<br>AVG.       |
| CFR13ALE106JM     | 30                  | 560             | 9.97               | 9.98          | +.10             | .036            | .037          | -.001          | 9.7x10 <sup>4</sup> | 7.7x10 <sup>4</sup> |
| CFR14LLE106JM     | 30                  | 560             | 9.95               | 9.96          | +.10             | .059            | .048          | -.011          | 1.1x10 <sup>5</sup> | 9.2x10 <sup>4</sup> |
| CFR13ALC206JM     | 15                  | 280             | 20.75              | 20.70         | -.24             | .030            | .071          | +.041          | 9.6x10 <sup>4</sup> | 7.6x10 <sup>4</sup> |
| CFR14LLC206JM     | 15                  | 280             | 19.61              | 19.71         | +.51             | .042            | .031          | -.009          | 3.9x10 <sup>4</sup> | 3.0x10 <sup>4</sup> |
| CFR13ALB306JM     | 15                  | 140             | 30.02              | 29.97         | -.17             | .041            | .044          | +.003          | 9.6x10 <sup>4</sup> | 7.0x10 <sup>4</sup> |
| CFR14LLB306JM     | 15                  | 140             | 29.15              | 29.11         | -.10             | .050            | .027          | -.023          | 3.6x10 <sup>4</sup> | 3.4x10 <sup>4</sup> |

**TABLE 6**

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

| MIL<br>DESIG. NO. | NO. PARTS<br>TESTED | TEST<br>CURRENT | CAP $\mu$ F (1kHz) |               |                  | % DF (1kHz)     |               |                | IR (megohms)        |                     |
|-------------------|---------------------|-----------------|--------------------|---------------|------------------|-----------------|---------------|----------------|---------------------|---------------------|
|                   |                     |                 | INITIAL<br>AVG.    | FINAL<br>AVG. | AVG. %<br>CHANGE | INITIAL<br>AVG. | FINAL<br>AVG. | AVG.<br>CHANGE | INITIAL<br>AVG.     | FINAL<br>AVG.       |
| CFR13ALE106JM     | 6                   | 14.1            | 9.98               | 9.97          | -.10             | .04             | .04           | 0              | 9.8x10 <sup>4</sup> | 1.0x10 <sup>5</sup> |
| CFR14LLE106JM     | 6                   | 14.7            | 9.93               | 9.92          | -.10             | .065            | .038          | -.027          | 1.0x10 <sup>5</sup> | 8.2x10 <sup>4</sup> |
| CFR13ALC206JM     | 3                   | 12.8            | 20.76              | 20.74         | -.09             | .03             | .023          | -.013          | 9.7x10 <sup>4</sup> | 8.1x10 <sup>4</sup> |
| CFR14ALC206JM     | 3                   | 15.4            | 20.01              | 19.92         | -.40             | .05             | .043          | -.013          | 4.4x10 <sup>4</sup> | 3.2x10 <sup>4</sup> |
| CFR13ALB306JM     | 3                   | 11.4            | 30.00              | 29.87         | -.43             | .037            | .02           | -.017          | 1.0x10 <sup>5</sup> | 8.1x10 <sup>4</sup> |
| CFR14ALB306JM     | 3                   | 11.9            | 29.50              | 29.50         | 0                | .037            | .033          | -.044          | 4.7x10 <sup>4</sup> | 6.3x10 <sup>4</sup> |

**TABLE 7**  
**METALLIZED POLYPROPYLENE METAL TUBULARS**  
**D-C LIFE TEST: 2000 Hrs. 105°C 140% RVDC**

| CAPACITOR RATING   | NO. PARTS TESTED | TEST VOLTAGE | CAP $\mu$ F (1kHz) |            |               | % DF (1kHz)  |            |             | IR (megohms)        |                     |
|--------------------|------------------|--------------|--------------------|------------|---------------|--------------|------------|-------------|---------------------|---------------------|
|                    |                  |              | INITIAL AVG.       | FINAL AVG. | AVG. % CHANGE | INITIAL AVG. | FINAL AVG. | AVG. CHANGE | INITIAL AVG.        | FINAL AVG.          |
| 0.1 $\mu$ F 400VDC | 20               | 560          | .099               | .099       | 0             | .006         | .015       | +.009       | 1.1x10 <sup>7</sup> | 2.4x10 <sup>7</sup> |
| 2.0 $\mu$ F 100VDC | 20               | 140          | 1.96               | 1.95       | -.51          | .019         | .024       | +.005       | 9.4x10 <sup>5</sup> | 1.4x10 <sup>6</sup> |
| 5.0 $\mu$ F 200VDC | 20               | 280          | 5.13               | 5.12       | -.20          | .030         | .136       | +.106       | 3.0x10 <sup>5</sup> | 9.1x10 <sup>5</sup> |

**TABLE 8**  
**METALLIZED POLYPROPYLENE METAL TUBULARS**  
**A-C LIFE TEST: 500 Hrs. + 85°C, 40kHz**

| CAPACITOR RATING   | NO. PARTS TESTED | TEST CURRENT | CAP $\mu$ F (1kHz) |            |               | % DF (1kHz)  |            |             | IR (megohms)        |                     |
|--------------------|------------------|--------------|--------------------|------------|---------------|--------------|------------|-------------|---------------------|---------------------|
|                    |                  |              | INITIAL AVG.       | FINAL AVG. | AVG. % CHANGE | INITIAL AVG. | FINAL AVG. | AVG. CHANGE | INITIAL AVG.        | FINAL AVG.          |
| 0.1 $\mu$ F 400VDC | 15               | 2.0          | .098               | .098       | 0             | .006         | .006       | 0           | 1.0x10 <sup>7</sup> | 2.6x10 <sup>7</sup> |
| 1.0 $\mu$ F 100VDC | 15               | 5.3          | 1.96               | 1.95       | -.51          | .019         | .022       | +.003       | 8.1x10 <sup>5</sup> | 1.1x10 <sup>6</sup> |
| 5.0 $\mu$ F 200VDC | 15               | 8.5          | 4.84               | 4.84       | 0             | .030         | .036       | +.006       | 1.4x10 <sup>5</sup> | 1.5x10 <sup>6</sup> |

## 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

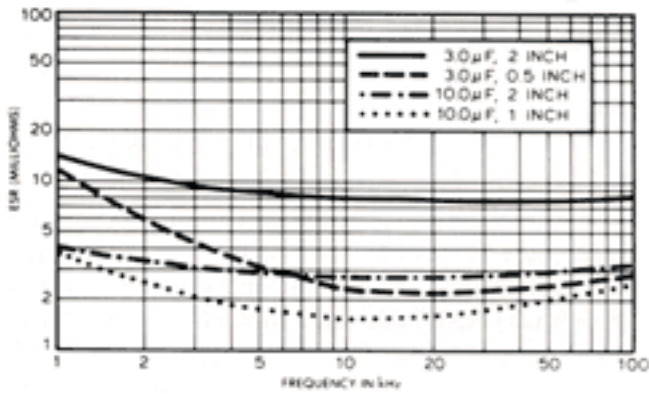
ESR values measured for 10  $\mu$ F, 3  $\mu$ F and 1.5  $\mu$ F capacitors made with two different film widths show significant improvements in ESR may be obtained by reducing film width. For example, the 3  $\mu$ F capacitors, each using approximately 760 sq. in. of electrode surface, show a three-fold 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.

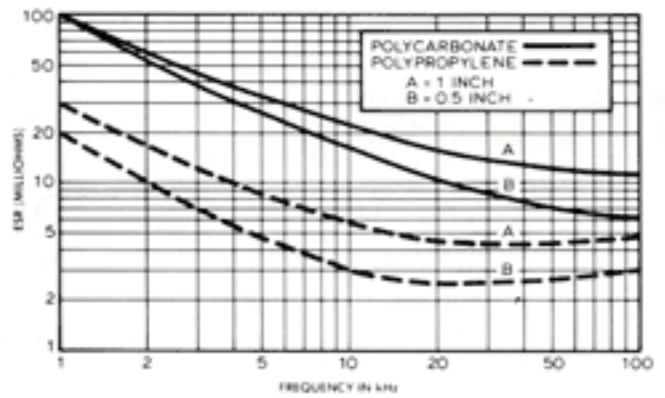
A reduction in film width(requiring an increase in capacitor diameter)is a design consideration where the objective is to minimize the contribution for the electrodes and termination to the total ESR.

**Table 9**  
**Metallized Polypropylene Section Design vs. 100kHz ESR**

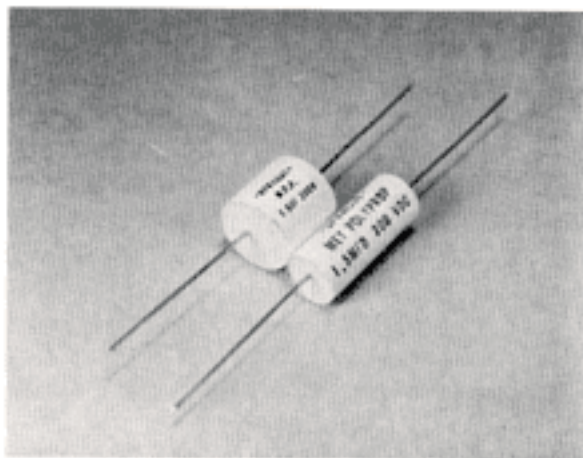
| CAP (μF) | Film Width (inches) | Film Length (inches) | Electrode Surface (sq. inches) | 100kHz ESR (milliohms) |
|----------|---------------------|----------------------|--------------------------------|------------------------|
| 20       | 2                   | 2700                 | 5020                           | 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**

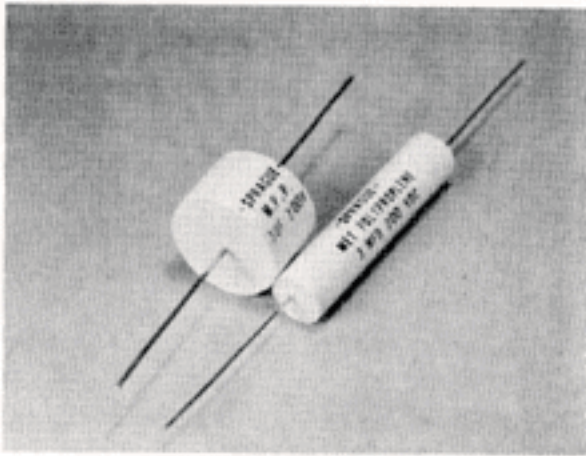


**Figure 13**  
**ESR vs. Frequency**  
**1.5 μF Polypropylene and**  
**Polycarbonate Capacitors**

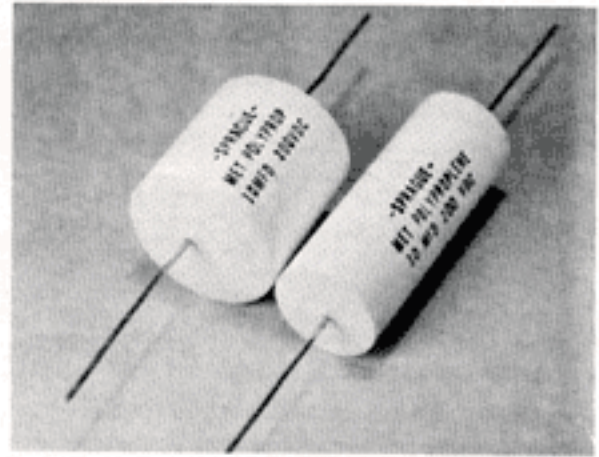


**Figure 14**  
**1.5 μF Capacitor Sections — 2 Sizes**  
**Metallized-Polypropylene Capacitors**





**Figure 15**  
**3  $\mu$ F Capacitor Sections — 2 Sizes**  
**Metallized-Polypropylene Capacitors**



**Figure 16**  
**10  $\mu$ F 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.

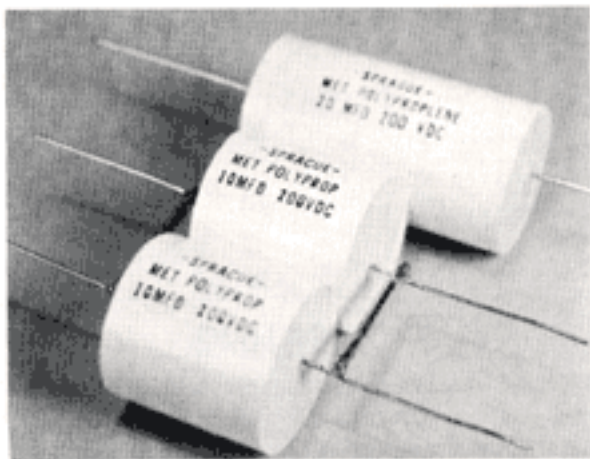
Frequency plots, Figures 21 and 22 compare these parallel configurations and single capacitors made with wider film.

The ESR values are compared in Table 10.

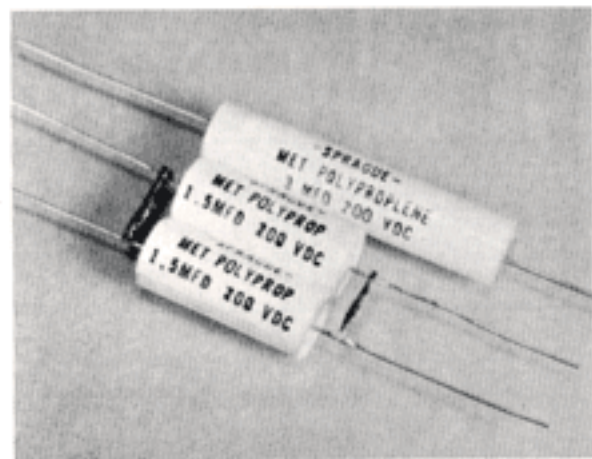
The test results demonstrate that capacitor sections designed with relatively narrow film widths and connected in parallel offer a viable design option for a-c applications requiring exceptionally low ESR. The "parallel" design approach would use a rectangular or "bathtub" case with the added advantage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

**Table 10**

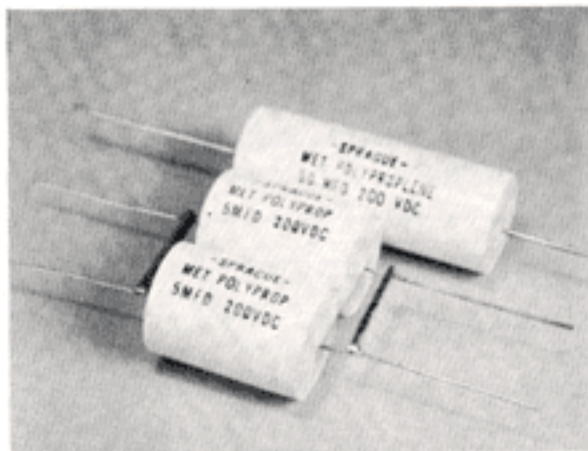
| Total CAP<br>( $\mu$ F) | Film Width<br>(inches) | # Parallel<br>Parts | ESR 100kHz<br>(milliohms) |
|-------------------------|------------------------|---------------------|---------------------------|
| 20                      | 2                      | -                   | 2.1                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



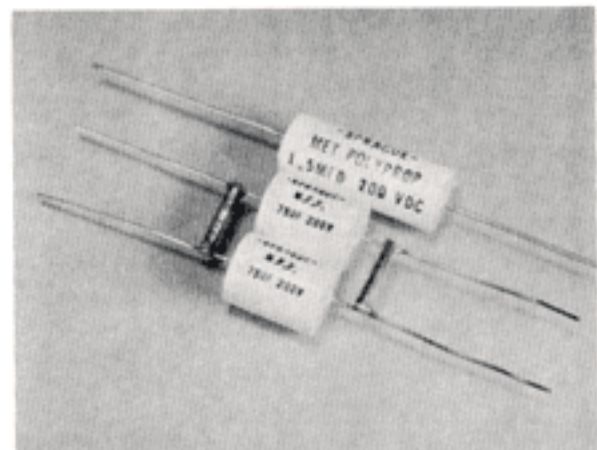
**Figure 17**  
 2 x 10  $\mu$ F (1" Wide Film)  
 1 x 20  $\mu$ F (2" Wide Film)  
 Parallel and Single Capacitor Sections



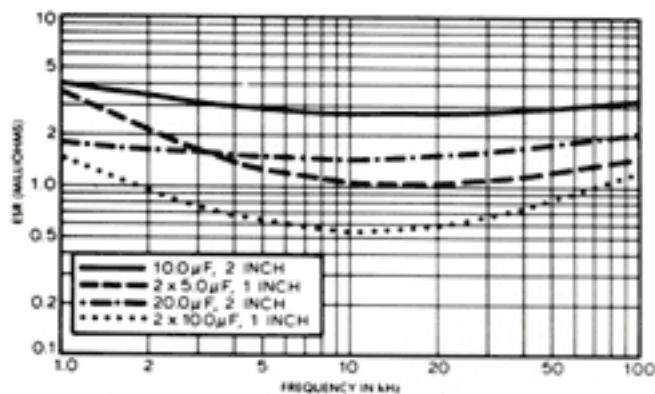
**Figure 19**  
 2 x 1.5  $\mu$ F (1" Wide Film)  
 1 x 3.0  $\mu$ F (2" Wide Film)  
 Parallel and Single Capacitor Sections



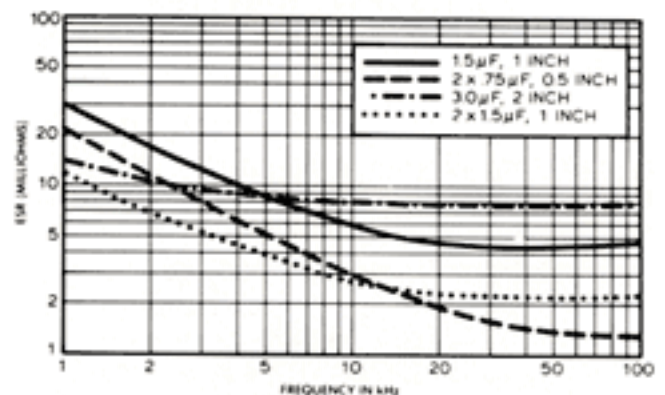
**Figure 18**  
 2 x 5  $\mu$ F (1" Wide Film)  
 1 x 10  $\mu$ F (2" Wide Film)  
 Parallel and Single Capacitor Sections



**Figure 20**  
 2 x 0.75  $\mu$ F (0.5" Wide Film)  
 1 x 1.5  $\mu$ 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

## 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**

| <b>Capacitance<br/>(F)</b> | <b>Film Width<br/>(inches)</b> | <b>40kHz RMS Current<br/>(amperes)</b> |
|----------------------------|--------------------------------|--|
| 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.

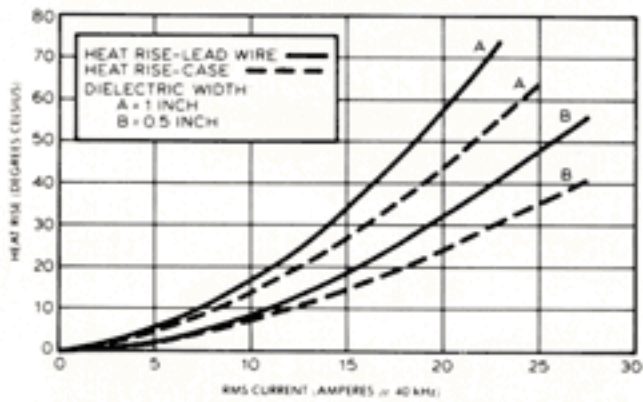
While the differences in heat rise between short, stubby capacitors and long, small diameter capacitors are significant, the stubby configuration should also provide better heat dissipation.

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.

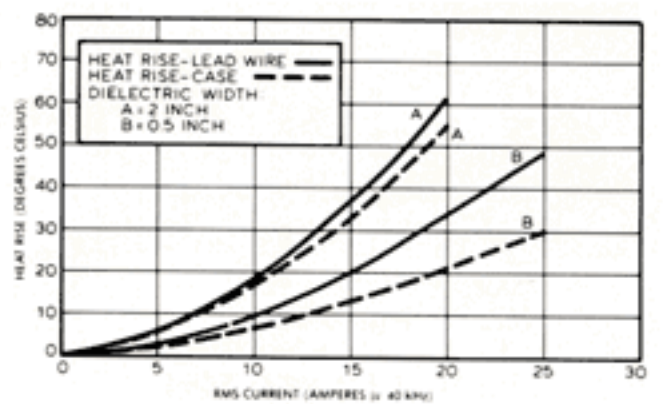
The capacitor lead wire or terminal should be large to increase heat dissipation from the capacitor body and to prevent the wire from becoming a heat generator at high current levels. This latter condition could produce a situation where heat would be pumped back into the capacitor. The heat rise graphs 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.

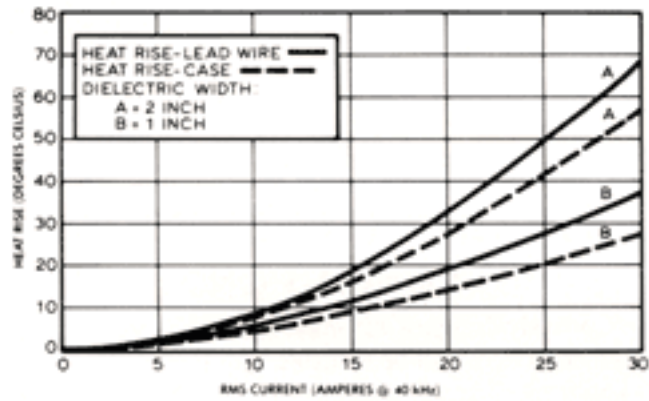
There are a number of valid reasons why capacitor geometry may not always be fully optimized, including: capacitor manufacturing limitations, encapsulation problems, volume efficiency, mounting requirements and available space in chassis.



**Figure 23**  
**Heat Rise vs. RMS Current**  
**1.5  $\mu$ F Metallized-Polypropylene Capacitors**



**Figure 24**  
**Heat Rise vs. RMS Current**  
**3.0  $\mu$ F Metallized-Polypropylene Capacitors**



**Figure 25**  
**Heat Rise vs. RMS Current**  
**10.0  $\mu$ 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/ $\mu$ F), 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.

## **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:

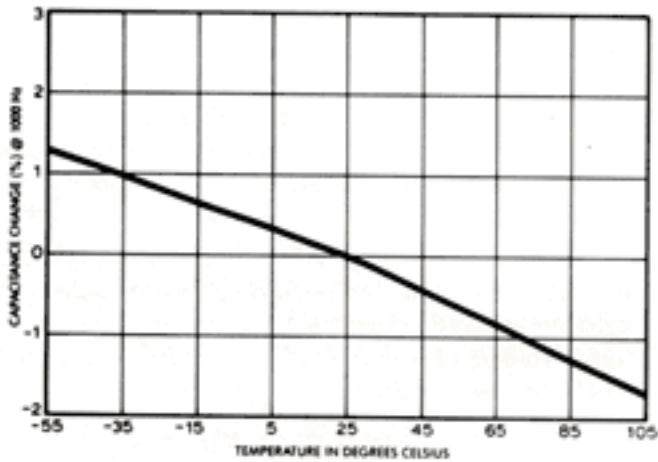
1. Excellent polypropylene film quality is available and a high reliability capacitor design is achievable.
2. Very low ESR may be obtained by combining the low loss characteristics of polypropylene film and optimized section geometry.
3. A properly designed polypropylene-film capacitor can be used to 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**

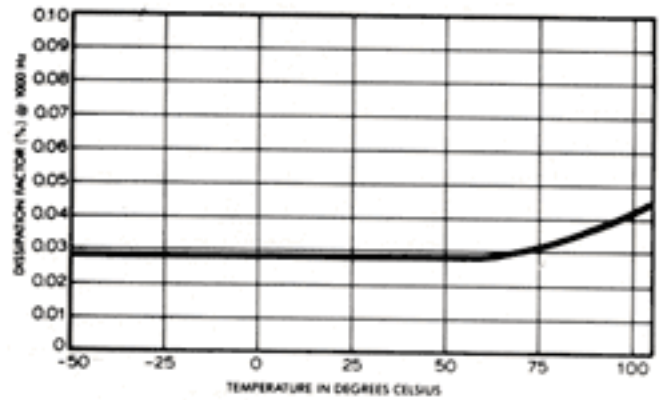
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## **REFERENCES**

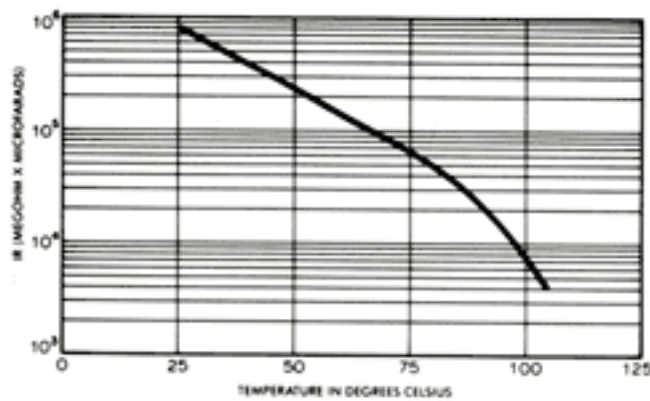
- "CAPACITOR FILMS" Klaus Schubring, Kalle (Presented at CARTS 1984)
- "A-C APPLICATION OF PLASTIC-FILM CAPACITORS", Jerold D. Kowalsky and Herbert L. Rice, Sprague electric Co. (Presented at CARTS 1983)



**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**