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CAPACITORS
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Guide for

Replacing Electrolytic Capacitors with Polypropylene Film Capacitors

I. Summary

For many years after the development of metallized polypropylene, the film was not being produced in thicknesses that made it beneficial for Power Electronic Inverter designers to effectively use film capacitors as the DC Link capacitors.

Over the past several years advancements in polypropylene production in thicknesses less than three microns combined with metallizing techniques has allowed film capacitors to become an effective, reliable replacement for electrolytic capacitors in specific applications namely DC Link Capacitors for inverter applications.

II. Electrolytic Technology

Electrolytic capacitors have a high dielectric constant typically ranging 8 to 8.5 versus film technology which is typically around 2.2 for polypropylene. As a result electrolytic capacitors gain more capacitance per given area.

Electrolytic capacitors are processed by the formation of an insulating metal oxide referred to as "alumina" through corrosion. Due to limitations of the thickness of this formation, voltages on electrolytic capacitors do not exceed 600V (typically 550V or less).

For voltages exceeding 600V electrolytic capacitors are placed in series to increase the voltage handling capability. As a result the capacitance is halved. Electrolytic capacitors are voltage sensitive and not necessarily equal in their capability. Consequently voltage divider resistors are applied to maintain equal voltage distribution.

Other limitations with electrolytic capacitors are the dielectric withstanding voltage which is generally limited to a maximum value of 1.2 x the Undc rating. Electrolytic capacitors are also polarized meaning that they require negative and positive connections to be correctly applied. Failure to do so results in a potential explosion of the capacitor.

Where bulk capacitance is needed for systems such as UPS's, some motor drive applications and other "off grid" technologies, electrolytic capacitors are utilized.

III. Film Technology

Film technology for power electronic applications is nearly exclusively metallized polypropylene. The metallized layer is created by applying metal either zinc, or aluminum through vacuum deposition to the surface of the polypropylene. This technology has allowed film capacitors to withstand very high voltages per given thicknesses. Minor imperfections in the film are "cleared" out during electrical processing allowing the capacitor to continue functioning. This process is also referred to as "self-healing".

Metallized polypropylene has very low losses (2 x 10-4) and is very stable over the full temperature range being -40 to +85C as a general rule. Higher temperature ratings have been achieved through the use of high crystalline polypropylene which has a higher transition point for shrinkage typically around 110C. Special processing allows use up to 105C, however voltage de-rating should be practiced.

Film capacitors are not polarized and may be connected to positive or negative posts without the explosion risk of reverse voltage, experienced by electrolytic capacitors.

Because of advanced technologies in polypropylene processing, the capacitors withstand very high over voltages 1.5 times the rating (Undc) routinely per IEC standard 61071. As a result, film capacitors may be applied at the full rating without concern of slight overages over the life of the capacitor. Voltage is typically increased by varying the dielectric thickness in film capacitors, as a result series connections are not typically used in the voltage ranges of 600V to 3000V.

IV. Comparative Data

Capacitors for study:

- 5000uF 450V Electrolytic – 2 connected in series for 900V rating
- 500uF 1150V ASC IFP

Table 1: Comparison between film and electrolytic capacitors

Electrical Characteristic	***Electrolytic Capacitor***	***Film Capacitor***
Rated Voltage	450 V (single) 900 V (2 in series)	1150V (single)
Capacitance	5000 μF (single) 2500 μF (2 in series)	500μF (single)
Withstand Voltage	550 V (single) 1100 V (2 in series)	1725V (single)
Size	75 x 145 mm (single) 341.5 cm³ (single) 683 cm³ (2 in series)	85 x 175 mm (single) 467 cm³ (single)
Reverse Voltage handling	No	Yes
Storage – reforming	Yes	No
Maximum RMS Current	20 mA/μF (ex: 100 A for 5000 μF)	1000 mA/μF (ex: 500 A for 500 μF)
Dry Construction	No	Yes
High Peak Currents	No	Yes
Cost	\$28 (single) \$56 (2 in series)	\$57 (single)

V. Total Cost consideration

When considering film capacitors for an application the extended cost of using electrolytic capacitors should be considered. This includes but is not limited to:

- Cost of series and parallel connections
- Cost of balancing resistors
- Cost of reverse voltage diode protection
- Reliability of more components used
- Suitability for use across the entire temperature range
- Lifetime of film capacitors is longer (>150K hours typically, depending on application), resulting in less field service and component replacement
- Safety- film capacitors are available with fusing mechanisms
- Film capacitors have lower inductance resulting in a less costly snubber circuit
- Film capacitors have higher allowable ripple currents allowing downsizing of the inverter in some instances

VI. Property/ Performance Curves

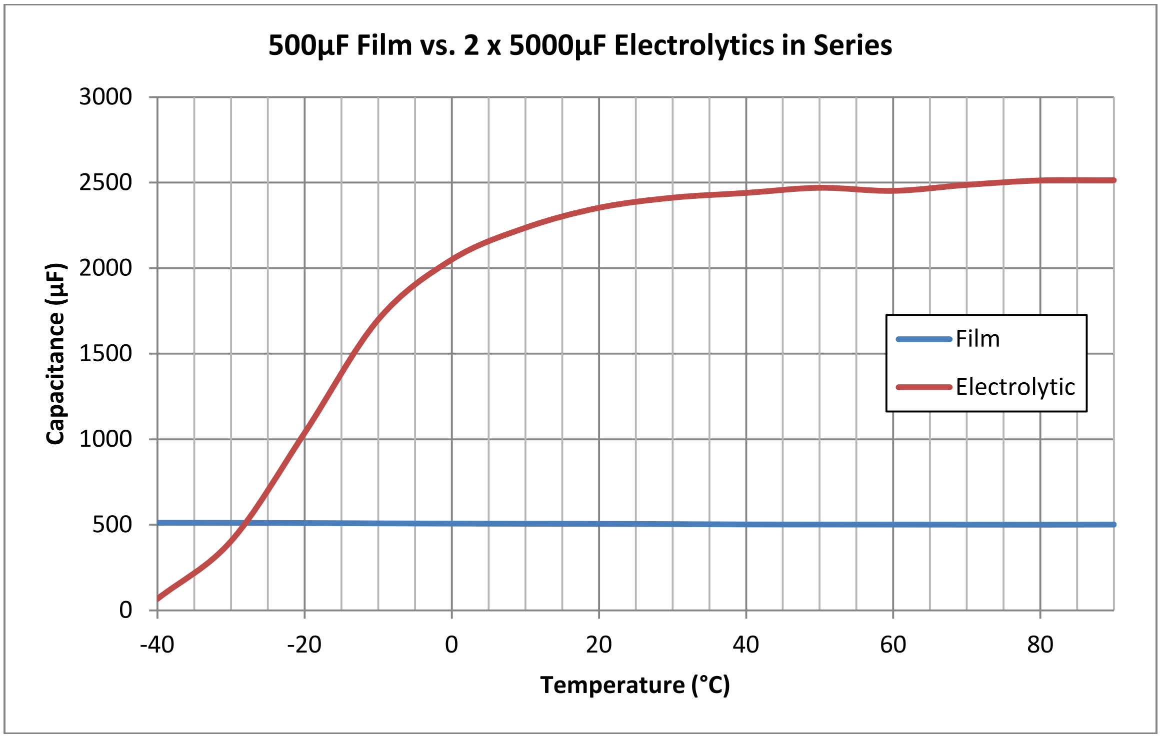

Figure 1: Capacitance versus Temperature

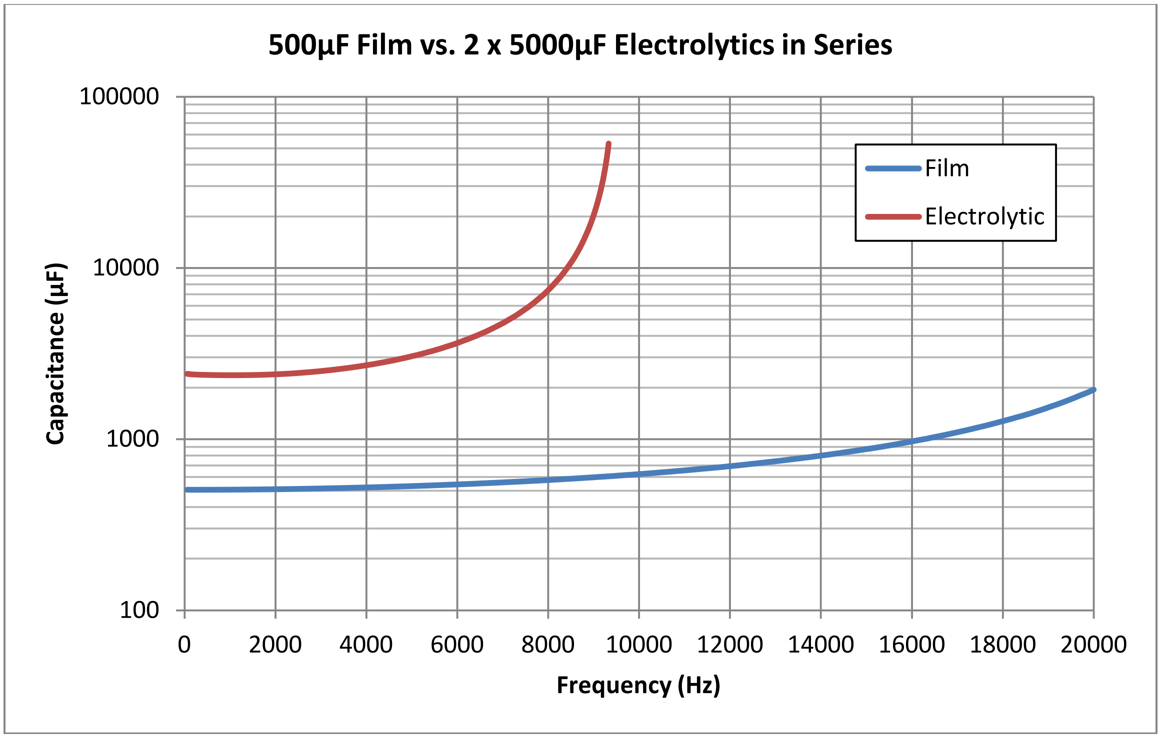

Figure 2: Capacitance versus Frequency

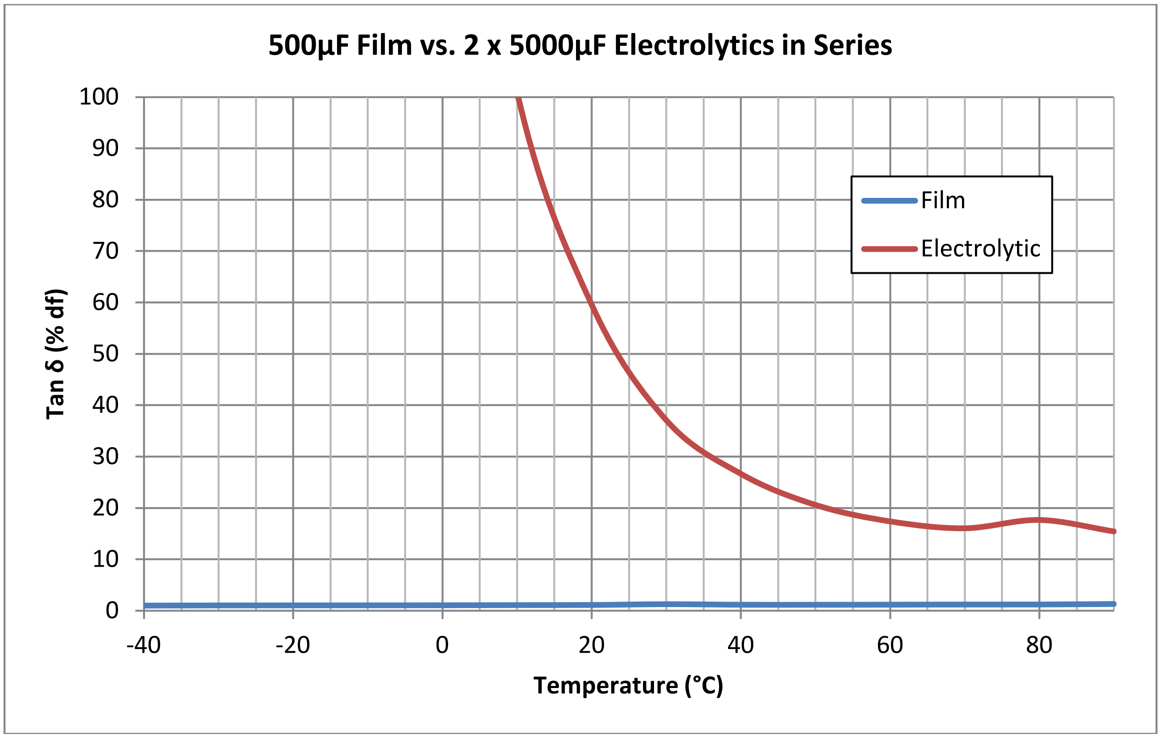

Figure 3: Tan δ (% df) versus Temperature

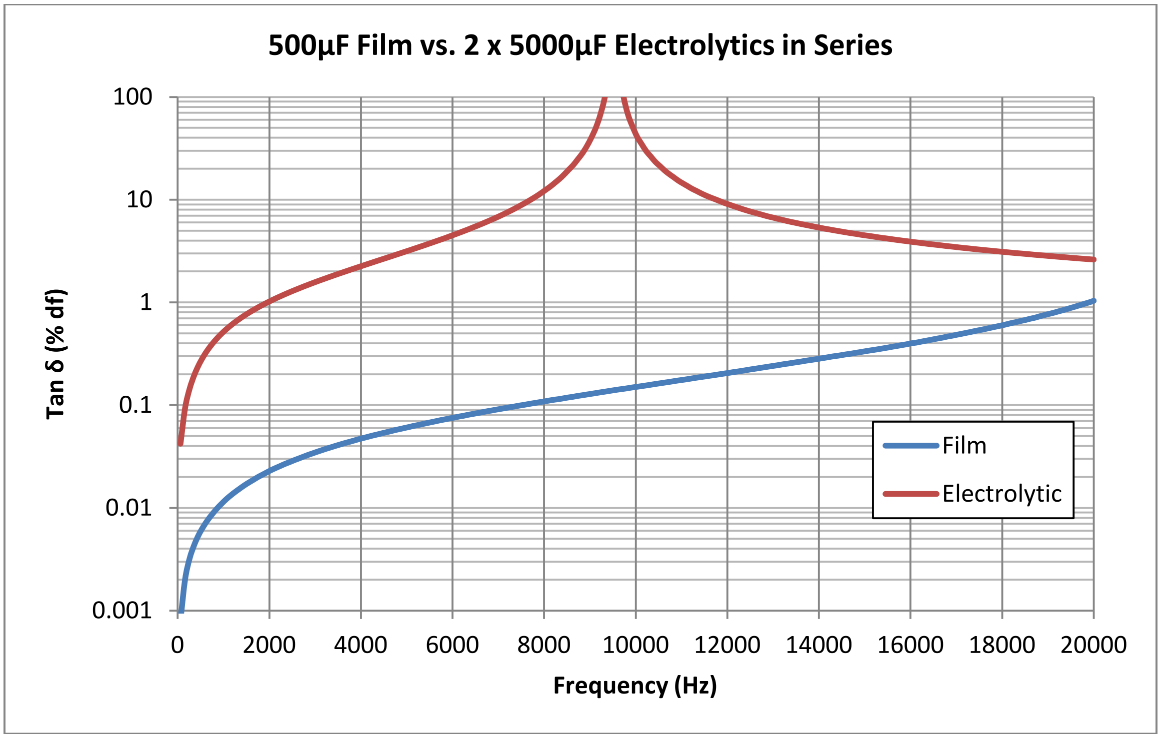

Figure 4: Tan δ (% df) versus Frequency

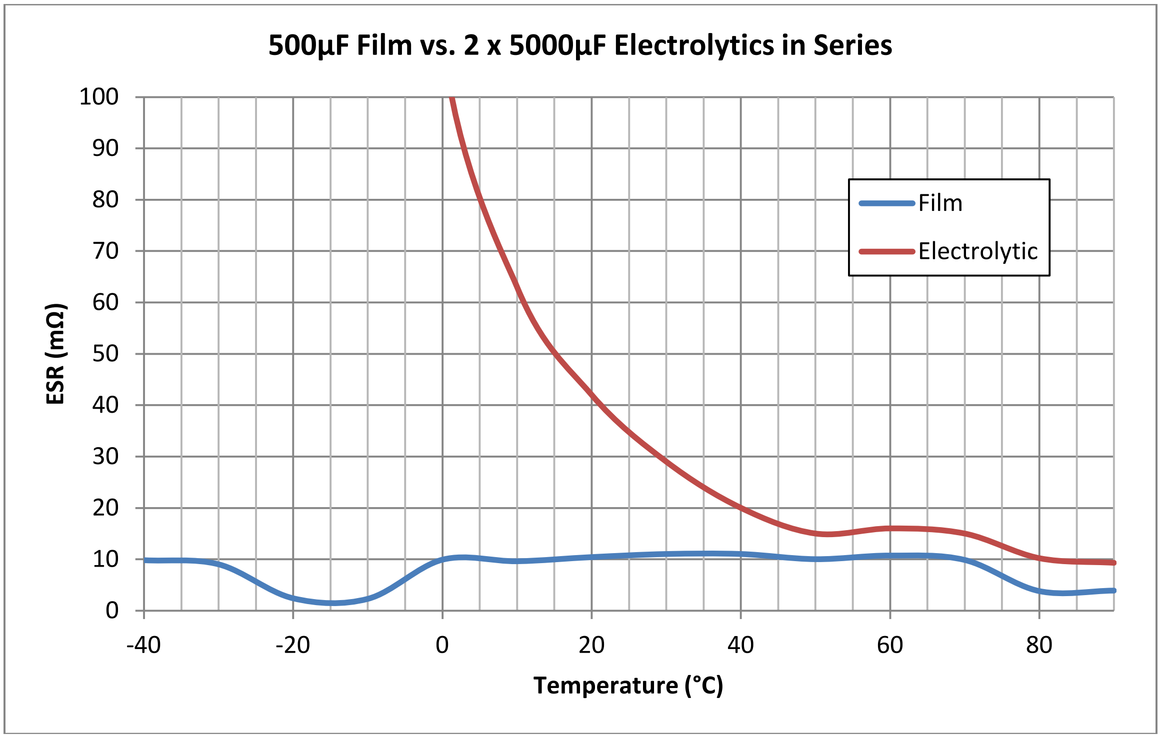

Figure 5: ESR versus Temperature

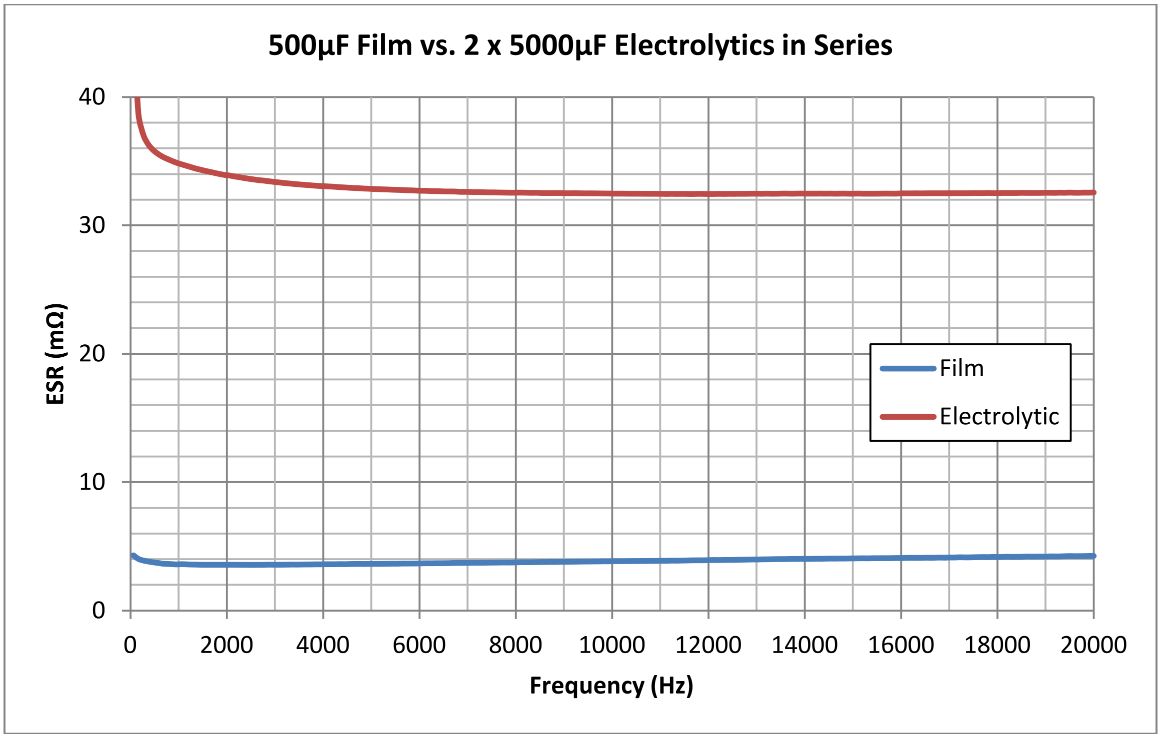

Figure 6: ESR versus Frequency

VII. Formulas and Terms

Definition of Terms:

U_{Ripple}:	Ripple Voltage (Volts RMS) – Peak to peak alternating component of the unidirectional voltage
I_{RMS}:	Rated Current (Amps RMS) – The maximum r.m.s. alternating current which the capacitor can sustain for a given time in specified conditions
P_{Load}:	Load Power (Watts) – The rated power of the system
U_{Max}:	Max Voltage (Volts) – Maximum voltage for which the system is designed
$\mathrm{F}_{Rectifier}$:	Rectifier Frequency (Hz) – Operational frequency of the rectifier

To determine capacitance using RMS current:

Film Capacitor Formula

$$C(\mu F) = \frac{\mathrm{I}_{RMS}}{\mathrm{U}_{Ripple} * \ 2\pi * \ f(Hz)}$$

Example:

$$318 = \frac{50}{5 \ * \ 2\pi * \ 5000}$$

Electrolytic Capacitor Formula

$$C(\mu F) = \frac{\mathrm{I}_{RMS}}{0.02}$$

Example:

$$2500 = \frac{50}{0.02}$$

To determine DC link capacitance using max voltage, ripple voltage and frequency:

DC Link Capacitance Formula

$$C(\mu F) = \frac{P_{Load}}{U_{Ripple} * \left[U_{Max} - \frac{U_{Ripple}}{2}\right] * \ F_{Rectifier}}$$

Example:

$$1136 = \frac{50{,}000}{200 * \left[1200 - \frac{200}{2}\right] * 200}$$

To determine RMS current through capacitor using ripple voltage:

Capacitance & Frequency Formula

$$I_{RMS} = \frac{U_{Ripple}}{2 * \sqrt{2}} * C(F) * 2\pi * F_{Rectifier}$$

Example:

$$100.9 = \frac{200}{2 * \sqrt{2}} * .001136 * 2\pi * 200$$

Max Voltage & Power Formula

$$I_{RMS} = \frac{P_{Load} * \pi}{\left[U\,max - \frac{U\,ripple}{2}\right] * \sqrt{2}}$$

Example:

$$100.9 = \frac{50{,}000 * \pi}{\left[1200 - \frac{200}{2}\right] * \sqrt{2}}$$