Power Film Capacitor Application Guide

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DC FILM CAPACITORS FOR POWER ELECTRONICS AN OVERVIEW

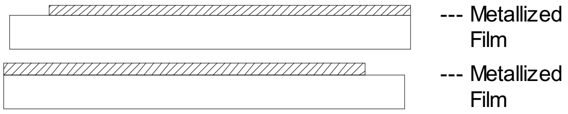
Film capacitors are widely used in power electronics applications including but not limited to DC Link, DC output filtering, and as IGBT snubbers. The dielectric most often used is polypropylene because it has low dissipation factor (DF) that permits high AC currents with low self heating, and it performs well over the temperature range and frequencies in power electronics applications. Other materials such as polyester (PET) may be used for light duty filtering but its high dissipation factor makes it a poor selection where high AC current or high peak current at high rep rates are encountered. Materials such as polycarbonate and PPS have desirable characteristics for power electronics applications but they are in scarce supply and are therefore relatively expensive and exotic materials.

This catalog features only polypropylene types which cover the vast majority of power electronics applications.

CONSTRUCTION

The capacitor's electrode system is an important design consideration. There are three basic options for electrodes used with polypropylene capacitors. A description of each follows:

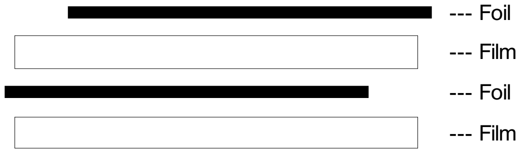
Metallized Capacitors



Metallized capacitors use a thin layer of vapor deposited aluminum, zinc or alloy (aluminum/zinc) blend as the electrode system. The metallized layer is only hundreds of angstroms thick, so it takes up little space in the capacitor winding relative to the dielectric thickness, measured in microns. Metallized capacitors offer the highest energy density of all of the available film constructions. Metallized capacitors also self heal. A fault in the dielectric system vaporizes the metal deposit in the area of the fault, a process known as clearing. The result of "clearing" is a tiny amount of capacitance loss while allowing the capacitor to continue to operate without any adverse effects. If a condition arises that causes multiple clearings, such as overvoltage, or dielectric aging at end of life, the capacitor will continue to self heal and lose capacitance. The capacitor is considered to have failed when it loses 3% or more of its capacitance.

Changing the metallized electrode thickness alters the properties of the capacitor. Lighter metallization, higher ohms per square, result in higher energy density designs. While light metallization improves the voltage capabilities, it compromises the rms and peak current carrying capabilities of the capacitor. Patterned metallized layers add another dimension to the mix of options. Metallized patterns have built in fuses that further enhance the self healing capabilities and dielectric voltage withstanding properties of the system.

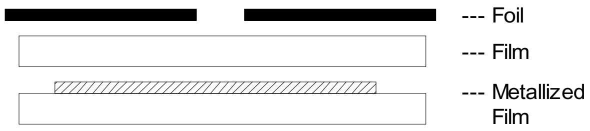
Film / Foil Capacitors



Aluminum foil electrodes are used where very high peak and rms currents are required. IGBT snubbers, for example, are designed to handle the high peak currents encountered during IGBT switching. Typical IGBT applications, such as those encountered in high power inverters, have voltage rise times exceeding 1000 V/µs with switching rates of 10 kHz or more. The end connections of a capacitor employing a simple metallized electrode system would deteriorate with repeated exposure to these conditions. Foil capacitors use electrodes that are about 5 microns thick to handle the high current pulses.

Foil electrodes are also used where the capacitor will see high rms current, especially where the capacitor size is small. As an example, tank circuits for induction heating devices typically require capacitors less than 100 µF that must handle hundreds of amperes. The main benefit of the foil electrodes is to reduce the heat rise by reducing ESR. Cooler operation prevents thermal runaway and dielectric failure from self heating. The main disadvantages of foil electrode capacitors are their inability to self heal and low energy density relative to metallized types.

Hybrid Capacitors



One scheme that combines the benefits of metallized and foil electrode types, is the hybrid series capacitor. It has foil electrodes that connect to the external leads of the capacitor and afree-floating metallized electrode wound in a series configuration. The result is a self healing capacitor that handles high current pulses.

With all of these variables at play, the choice of dielectric, electrode metals, electrode thickness and metallized pattern must be considered to optimize the capacitor's performance for a specific application.

CUSTOM DESIGNED FILM CAPACITORS

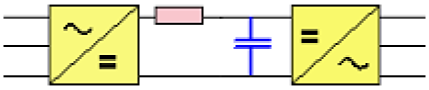
This catalog offers standard capacitor products for use in common power electronics applications. Inverter design engineers are often challenged with finding a capacitor that takes them out of the realm of standard catalog items. Packaging a capacitor to accommodate a physical bus structure is a common design challenge. Designing for a specific ripple current rating and life expectancy at a given ambient temperature is another consideration that usually requires custom solution. CDE is highly experienced in custom capacitor design and manufacturing. Where possible, we "repackage" standard materials to meet specific customer requirements.

APPLICATIONS for POWER FILM CAPACITORS

The most common applications for DC film capacitors in power electronics are DC Link, DC Filtering and snubbers for IGBT modules. A brief description of each application follows:

DC Link for Inverter Applications

Large value capacitors are used as the energy storage element or DC-Link at the DC input to the inverter. The size of the DC Link depends on the amount of AC energy it must absorb to maintain required ripple current at the DC line and the level of rms current it can handle because of ESR heating.



DC Link Capacitor

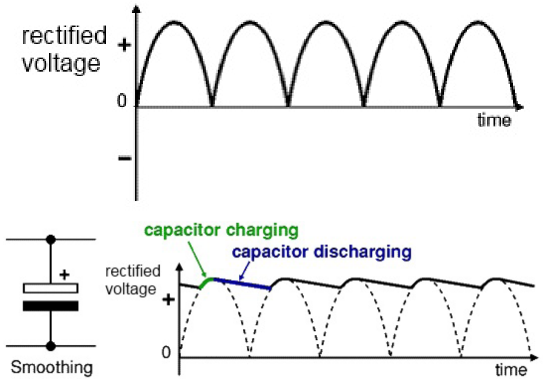
Aluminum Electrolytic capacitors offer greater capacitance per unit volume and higher energy densities compared with film. The trade-off is that the much higher ESR of aluminum electrolytic capacitors often results in capacitor banks that are oversized to handle the ripple current requirements. Polypropylene film capacitors have much lower ESR to handle the AC ripple without overheating. Film technology advantages over electrolytics are listed below.

Advantages of Film Capacitors versus Aluminum Electrolytics for DC Link Applications

- Two times the voltage capability frees you from series capacitors and voltage balancing resistors.
- Three times the ripple current capability frees you from needing excess cap to handle ripple.
- Dry construction frees you from the explosive failures with liquid electrolyte.
- Solid encapsulation delivers higher shock and vibration withstanding.
- Non-polar dielectric delivers reverse-proof mounting and AC withstanding.

DC Output Filtering

Film capacitors are widely used for DC filtering in power supplies. Their function is to smooth out the DC voltage waveform after rectification.



IGBT Snubber

As with all switching devices, IGBTs are subjected to voltage transients during turn-off operation. Voltage transients result from energy trapped in the circuit's stray inductance. The amount of voltage overshoot is dependent on the amount of stray inductance and the switching speed (dV/dt) of the IGBT. Fortunately, there are ways to protect IGBTs and other switching devices from over voltage; the most common is to use a snubber capacitor across the switch to divert the inductive current. IGBT snubbers may be terminated with lugs for direct mount across the IGBT to minimize added inductance.

DEFINITIONS

Capacitance (C)

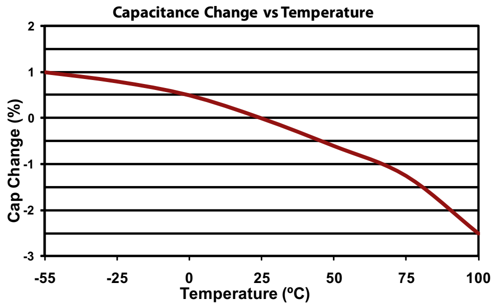
Nominal capacitance typically given at 25 ºC and 1 kHz in units of microfarad (µF)

Capacitance Tolerance

Range in percent for which the capacitance may differ from rated capacitance as measured at 25 ºC and 1 kHz. This range results from variances in materials and manufacturing processes rather than from temperature and or frequency characteristics. The standard manufacturing tolerance for polypropylene capacitors is ± 10% or "K" tolerance. Tighter tolerance of ± 5%, "J" tolerance, can be achieved for polypropylene, usually at a slightly higher cost.

Temperature Coefficient

The temperature coefficient is the average capacitance change per ºC over a specified temperature range.



Capacitive Reactance (X_c)

The reactance is the capacitor's opposition to passing AC current. It is inversely proportional to frequency and capacitance.

$$X_c = \frac{1}{2 \cdot \pi \cdot f C}$$

Equivalent Series Resistance (ESR)

The total ohmic resistance that contributes to power loss, represented by a single resistance in series with the ideal capacitor. Typically given at 25 °C at 10 kHz and 100 kHz in units of milliohms (mΩ)

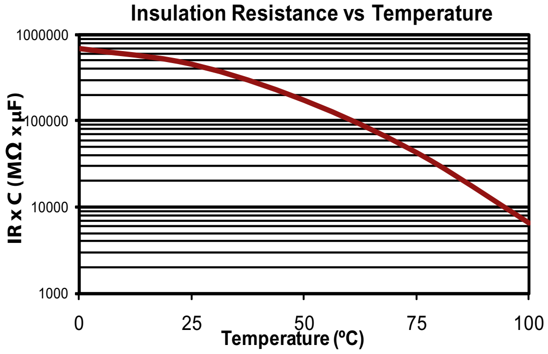
Equivalent Series Inductance (ESL)

The total series inductance of the capacitor winding including any internal connections, typically low and given at 25 °C in units of nanohenries (nH)

Insulation Resistance (IR)

The ratio of the applied voltage to leakage current (DCL), typically given in megohms (MΩ) or in the discharge time constant format MΩ x µF. The formula for insulation resistance:

$$IR = \frac{V_{dc}}{DCL}$$

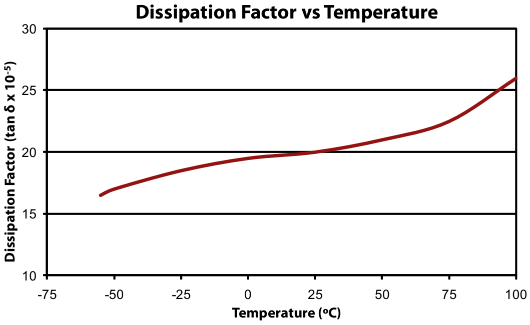

Insulation Resistance vs Temperature

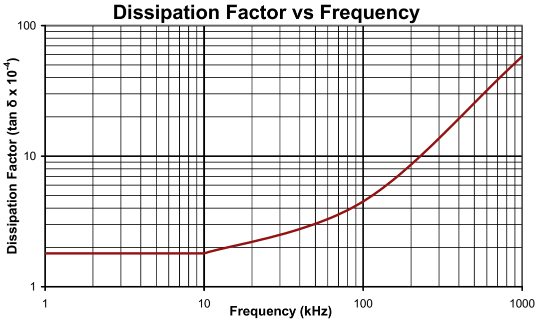
Dissipation Factor (DF, tanδ)

The ratio of the capacitor's ESR to capacitive reactance X_c, the DF of a capacitor is frequency and temperature dependent and is usually specified at 25 °C and 1 kHz.

$$DF = \frac{ESR}{X_c}$$

DF change with temperature and frequency are given for polypropylene in the curves below.


Dissipation Factor vs Temperature


Dissipation Factor vs Frequency

Rated DC Voltage (V_{dc})

The maximum operating peak voltage for which the capacitor has been designed for continuous operation at rated temperature.

Rated AC Voltage (V_{RMS})

The maximum operating AC rms voltage for which the capacitor has been designed for continuous operating at rated temperature, typically given at 60 Hz.

Peak Current (I_{pk})

The peak current amplitude for which the capacitor is designed, given in units of amperes (A). The Peak Current is related to dV/dt by the formula:

$$I_{pk} = C \cdot dV / dt$$

Where C is rated capacitance.

RMS Current / Ripple Current (I_{RMS})

The maximum operating rms current, typically given at a specific reference frequency and temperature in units of amperes rms (A_{RMS})

Thermal Resistance (θ_{cc} , θ_{ca})

The total thermal resistance from core to case (θ_{cc}) and case to ambient (θ_{ca}) defined as the temperature change per dissipated power (°C/W)

The formula for thermal resistance:

$$\theta_{ca} + \theta_{cc} = \frac{\Delta T}{I_{rms}^2 \cdot ESR}$$

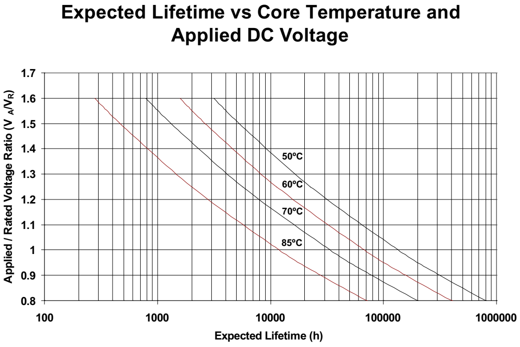
Where ΔT is temperature rise in °C.

Life Expectancy

The life expectancy formula for the power film capacitors in this catalog* is given in terms of applied voltage and temperature.

$$Life_S = Life_R \cdot \left(\frac{V_R \cdot F}{V_A}\right)^8 \cdot 2^{\frac{T_R - T_A}{10}}$$

$Life_S$ = Service Life
$Life_R$ = Rated Life
V_R = Rated Voltage
V_A = Applied Voltage
F = Voltage Acceleration Factor
T_R = Rated Temperature
T_A = Ambient Temperature


Expected Lifetime vs Core Temperature and Applied DC Voltage

* Life Expectancy curves for the DC Link types 944U and 947C are given on their datasheets.