Understanding Eaton's film capacitors (Safety, DC-Link, Pulse & AC-filtering)

Overview

What are DC link capacitors?

Eaton's DC link capacitors are constructed of metallized polypropylene film encapsulated with epoxy resin in a plastic case with 2 or 4 pin tinned copper wire terminals. These capacitors act as the intermediate stage between a rectifier (DC-DC converter) and an inverter (DC-AC), filtering the high-frequency components, smoothing the low-frequency ripple, and sinking currents from the load side that may return to the first stage side.

Compared to electrolytic types, polypropylene film capacitors typically have a lower capacitance density, which may be considered a limitation. However, in high-performance applications, film capacitors offer significant advantages over electrolytic capacitors in several aspects; improved performance in terms of stability, voltage handling, lower losses, and longer lifetime. Moreover, key manufacturing advancements have reduced the size and weight of film capacitors, making them suitable for use even in space-constrained applications.

While the initial cost of film capacitors may be higher than electrolytic capacitors, their reliability and longevity can lower the total cost of ownership over time. Thus, DC link capacitors need not be viewed merely as an alternative, but as a potentially superior solution in applications where their specific advantages are required.

Eaton's automotive grade family includes THB Grade IIIB and AEC-Q200 qualified products for automotive, high reliability, and harsh environment applications.

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How DC link capacitors are used

The primary function of a DC-link capacitor is maintaining steady DC voltage levels by absorbing and releasing energy. This process helps to smooth out any fluctuations in the DC link caused by the rectification of AC power or by the switching operations of power electronic devices.

Another important function is filtering out unwanted electrical noise and smoothing the rectified voltage. In a typical power conversion process, AC power is rectified to DC, which often results in a pulsating voltage with a frequency that is twice the AC supply frequency. Voltage ripples can cause performance issues in electronic circuits. DC-link capacitors filter out ripples by charging during the peaks and discharging during the troughs, providing a stable voltage across the load.

Capacitor selection

When selecting a DC-link capacitor, engineers must consider factors such as voltage rating, ESR, ripple current rating, and sel-healing properties to match the capacitor to the application's specific needs.

Voltage rating

The voltage rating of a DC-link capacitor is the maximum continuous voltage it can handle without significant degradation or failure. It is crucial to select a capacitor with a voltage rating higher than the maximum expected DC link voltage to ensure reliability and longevity.

Equivalent series resistance (ESR)

A lower ESR is preferable as it allows the capacitor to charge and discharge more quickly, which is essential for responding to rapid changes in power demand. Additionally, a lower ESR reduces the amount of heat generated within the capacitor, which can affect its performance and lifespan.

Ripple current

DC-link capacitors are usually subjected to ripple currents resulting from the rectification process and the switching of power electronics. These capacitors must be able to handle the expected ripple current without overheating.

Self-healing properties

DC-link capacitors containing metalized film dielectrics offer self-healing properties, which can be beneficial in electronic applications. If a dielectric breakdown occurs due to a voltage spike, the metal around the breakdown area evaporates, restoring the insulation and preventing catastrophic failure.

Benefits of Eaton's EFDKx DC link capacitors

- **High capacitance density** - A higher capacitance value means a lower ripple thus allowing for a smaller form factor saving board space
- **High contact reliability** - Ensures the capacitor remains attached to the PCB during vibrations, preventing potential terminal/lead failures.
- **Self-healing property** - Recovers from temporary dielectric breakdowns under extreme voltage, extending service life and reducing field failures.
- **Suitable for high frequency applications** - Power supplies benefit from high-frequency DC link capacitors for better efficiency.
- **Low ESL and ESR** - Enables the DC link capacitor to operate more efficiently.
- **High ripple current** - Gives the DC link capacitor the ability to tolerate larger ripple currents, allowing more design flexibility.

What are safety film capacitors?

Eaton's Class X1/X2 products come in various sizes, lead lengths, and terminal configurations. The standard and automotive grade families are available for each class **(Table 1)**. Automotive grade family are THB Grade IIIB and AEC-Q200 qualified products for automotive, high reliability, and harsh environment applications.

TABLE 1. FILM CAPACITOR SPECIFICATIONS

DC Link capacitor specifications

Product number	Capacitance range	Voltage rating	Operating temperature
EFDKS and EFDKA*	1 µF ~ 200 µF	450 Vdc ~ 1200 Vdc	-40/55 °C ~ +105 °C

Film safety capacitor specifications

Product number	Capacitance range	Voltage rating	Operating temperature
EFX1S (X1)	0.01 µF ~ 5.6 µF	480 Vac/1000 Vac	-40 °C ~ +110 °C
EFX1A* (X1)	0.01 µF ~ 1.8 µF	480 Vac/1000 Vac	-40 °C ~ +110 °C
EFX2S and EFX2A* (X2)	0.1 µF ~ 15 µF	305 Vac/630 Vac	-40 °C ~ +110 °C

Film pulse capacitor specifications

Product number	Capacitance range	Voltage rating	Operating temperature
EFXLS and EFXLA*	0.001 µF ~ 4.7 µF	630 Vdc ~ 2000 Vdc	-40/55 °C ~ +105 °C

Film AC-filtering capacitor specifications

Product number	Capacitance range	Voltage rating	Operating temperature
EFACA*	0.1 µF ~ 60 µF	180 Vac ~ 760 Vac	-55 °C ~ +105 °C

* Product numbers ending in A are THB Grade IIIB and AEC-Q200 qualified for automotive grade series.

How safety film capacitors are used

Power lines can experience high-voltage transients alongside their standard sine wave voltage (e.g., 117 Vac at 60 Hz in the US, 240 Vac at 50 Hz in Europe, 100 Vac at 60 Hz in Japan). The main objective of power supply line filters is to manage conducted emissions

TABLE 2. IEC 60384-14 SUBCLASS RATINGS

Protection	Capacitor type	Peak voltage pulse	Peak impulse before endurance test
Line-to-Line, Line-to-Neutral (Protects against differential mode noise)	X1	> 2.5 kV ≤ 4.0 kV	4 kV when C ≤ 1 µF 4 /√(C/10^{-6}F) kV when C > 1µF
	X2	≤ 2.5 kV	2.5 kV when C ≤ 1 µF 2.5 /√(C/10^{-6}F) kV when C > 1 µF
Protection	**Capacitor type**	**Peak voltage pulse**	**Peak impulse before endurance test**
Line-to-Earth (Protects against common mode noise)	Y1	≤ 500 Vac	8 kV
	Y2	150 Vac ≤ V < 300 Vac	5 kV when C ≤ 1 µF 5 /√(C/10^{-6}F) kV when C > 1 µF

comprising both common mode and differential mode noise. Still, safety remains a primary concern for these EMI suppression filters. For instance, an X-Class capacitor failure might lead to fires, while a Y-capacitor failure can result in electrocution. Hence, safety standards and approvals (e.g., UL/cUL, VDE/ENEC, CQC and KC) exist to safeguard users. EMI noise suppression in safety-critical applications uses two capacitor subclasses: Class-X and Class-Y. Class-X capacitors connect line to line, whereas Y-Class capacitors typically connect from line to ground. They are generally classified based on their rated voltage and the peak impulse voltage they can safely endure **(Table 2)**.

Benefits of Eaton's EFXx film safety capacitors

- **High capacitance stability** - Offers consistent performance across temperature, voltage, and time.
- **Self-healing property** - Recovers from short-term dielectric breakdowns under extreme voltage, ensuring longer service life and fewer early field failures.
- **Overvoltage stress resistance** - An essential parameter for selecting a safety capacitor.
- **Flame-retardant plastic case and resin** - Minimizes safety hazards related to component failure.
- **Approvals: UL/cUL, VDE/ENEC, CQC, KC** - These certifications confirm the capacitors' compliance with standards organizations' requirements.

DC link and safety film capacitor applications and use cases

Switching power supplies can generate noise at their switching frequency and its harmonics, posing interference risks for nearby equipment. As a result, they must adhere to EMC and safety regulations, especially for devices like medical power supplies. **Figure 1** illustrates a mains filter circuit where the filter suppresses both common mode and differential mode noise between the switching circuits and the line.

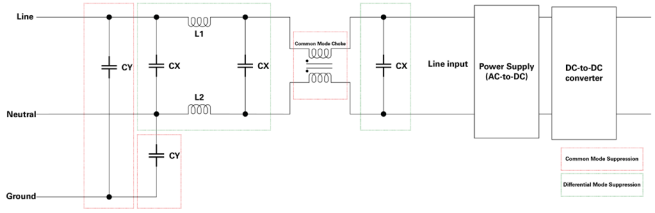

Figure 1: Input supply with EMI suppressing, safety capacitors.

Safety capacitors are used in the input supply before rectification (AC-DC) to prevent EMI. In contrast, the DC link capacitor is positioned before the DC-AC inverter. Examples include its use between a battery and an inverter for an AC motor drive circuit in an EV **(Figure 2)** or between a solar panel and a solar inverter **(Figure 3)**.

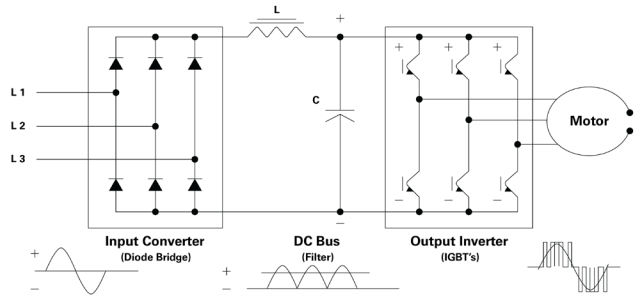

Figure 2: AC motor drive circuit with a DC link capacitor between the input converter and output inverter.

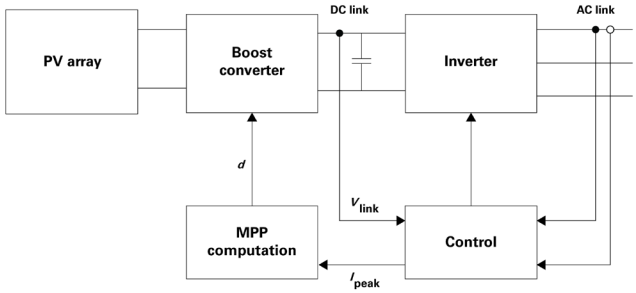

Figure 3: Maximum power point tracking technique with a DC link capacitor for droop control.

While safety film and DC link capacitors offer solutions for EMI suppression and voltage ripple reduction, the EFPLS, EFPLA, and EFACA families cater to specialized needs of pulse handling and AC filtering. Their robust construction, combined with critical certifications, ensures these products meet the stringent demands of electronic applications, from automotive to industrial.

What are film pulse capacitors?

Eaton EFPLS and EFPLA film pulse capacitors incorporate metallized polypropylene film with double-sided metallized polyester film as electrodes. Their construction features radial leads made of tinned wires, encapsulated within plastic cases and sealed with epoxy resin. These capacitors excel in applications demanding high dV/dt and high current handling. Eaton's EFPLA series, in particular, is compliant with THB Grade IIIB and AEC-Q200, making them an ideal choice for automotive or high-reliability applications.

How film pulse capacitors are used

Film pulse capacitors are designed to protect sensitive electronics from rapid voltage changes (dV/dt). In power electronics, they are vital in circuits where swift voltage transitions occur, such as those found in pulse applications and power conversion systems (**Figure 4**). The robust design of these capacitors ensures they effectively reduce voltage spikes and ripples in these applications. Film pulse capacitors, such as the EFPLS and EFPLA series, are useful in applications requiring high transient stability, such as high-frequency power supplies or motor drives. Eaton also offers an automotive-grade EFPLA suitable for automotive and high-reliability applications.

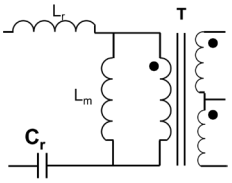

Figure 4: Resonant tank.

Benefits of EFPLS and EFPLA film pulse capacitors

- **High dV/dt handling** - These capacitors can withstand rapid voltage changes, making them suitable for applications that require quick voltage transitions.
- **High current capacity** - Eaton's film pulse capacitors can handle substantial currents, making them ideal for fluctuating conditions.

- **Self-healing property** - Like Eaton's DC link capacitors, these film pulse capacitors possess the self-healing property due to their metallized structure.
- **Reliability** - Encased in plastic and sealed with epoxy resin, pulse capacitors are designed to withstand challenging conditions.
- **Automotive grade certification (EFPLA)** - With THB Grade IIIB and AEC-Q200 qualifications, the EFPLA series is optimized for automotive applications with high reliability requirements.

What are film AC filtering capacitors?

Eaton's EFACA film AC filtering capacitors utilize a metallized polypropylene film encapsulated with epoxy resin in a plastic case, complemented by 2 or 4 pin tinned copper wire terminals. Primarily designed for high ripple harmonic content filtering, these capacitors are crucial for the inputs of AC/DC converters and outputs of DC/AC inverter systems. The EFACA family is THB Grade IIIB and AEC-Q200 qualified for automotive or high-reliability applications.

How film AC filtering capacitors are used

In power electronics, filtering capacitors play a pivotal role in eliminating unwanted harmonic frequencies (**Figure 5**). Eaton's EFACA film AC filtering capacitors minimize high ripple harmonic content, ensuring cleaner power is delivered to connected systems, especially crucial for the inputs of AC/DC converters and outputs of DC/AC inverter systems in a wide range of applications.

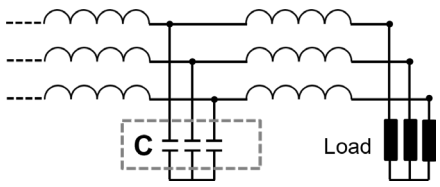

Figure 5: AC filtering capacitors placed in three-phase AC power lines.

Benefits of Eaton's EFACA film AC filtering capacitors

- **High harmonic filtering capacity** - These capacitors are designed to minimize high ripple harmonic content, leading to a more stable power supply.
- **Durable construction** - The use of epoxy resin and a plastic case ensures longevity and reliable performance.
- **Qualified for harsh environments** - With certifications such as THB Grade IIIB and AEC-Q200, they are suitable for demanding applications, including automotive and industrial settings.

Final notes

Eaton's range of film capacitors, including safety, DC-link, pulse, and AC filtering capacitors, offer a comprehensive suite of solutions for various electronic applications. Each capacitor type is designed with specific features to meet the stringent demands of their respective functions.

Safety film capacitors are integral in suppressing EMI and withstanding overvoltage surges, ensuring compliance in safety-critical applications like automobiles and medical devices. Their high capacitance stability, self-healing properties, and flame-retardant construction make them a reliable choice for protecting against electrical noise and potential hazards.

DC-link capacitors, known for their high capacitance density and self-healing metallized film construction, offer a robust alternative to electrolytic capacitors. They are suitable for smoothing voltage ripples and managing current flow in rectifiers and inverters, crucial for high-frequency power circuits.

Eaton's film pulse capacitors, including the EFPLS and EFPLA, offer high dV/dt handling and current capacity, self-healing capability, and ensure reliable performance in high-frequency power supplies and motor drives, with products meeting automotive reliability standards.

The EFACA film AC filtering capacitors are suitable for minimizing high ripple harmonic content, ensuring a stable power supply for power converters and inverters. Their durable construction and qualification for harsh environments make them suitable for a broad range of applications, including those in the automotive and industrial sectors.

Eaton's portfolio of capacitors demonstrates a commitment to quality and reliability, addressing the needs of energy storage, filtering, and pulse power in various electronic applications. Each capacitor family offers unique benefits, ensuring that designers can find the right component for their specific application.

Eaton
Electronics Division
1000 Eaton Boulevard
Cleveland, OH 44122
United States
www.eaton.com/electronics

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