Film Capacitors for DC-Link Application in Industrial Converters

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Abstract

Nowadays, new converter technologies demand higher performance to all involved components from semiconductors to passive components, in terms of both electrical and climatic operating conditions. DC-Link Capacitors are not an exception and challenging standards are being set to all technologies available, in which the reliability of the product is becoming more and more critical.

In this sense, film capacitors offer lots of advantages against other capacitor types. High current capability, low inductance, flexible design, different mounting possibilities, thermal stability, reliability and long service life make film capacitors a suitable solution for these applications. In addition, wherever much higher currents are required, 4-pin configurations are available, improving further the current handling capability of the standard 2-pin capacitors.

EPCOS understood that new trend and offered a wide range of MKP Capacitors [1], in different operating voltages, fulfilling the typical requirements of these applications.

However, based on our continuous research and development activities, that series has been complemented in two aspects: by means of using also polyester as a dielectric material, the maximum capacitance value has been enlarged up to 100 µF; in addition to that, maximum operating voltages have also been increased, based on the product enhancement that we have achieved with the improvements that have been introduced.

Basic requirements for DC Link capacitors

Technically, the basic roll that DC Link capacitors play in the circuit is to stabilize the DC voltage after a rectifier. At that position in the circuit, superimposed to a DC voltage that those capacitors have to deal, a high frequency ripple voltage is also present.

As a consequence of that, the main features that DC Link capacitors have to offer are the following:

- Low ESR and ESL, in order to reduce the circuit losses.
- High ripple current capability at high frequencies.
- Very high insulation resistance, in order to ensure that the DC voltage level is kept constant.
- High capacitance values, which will be useful for smoothing the voltage.
- Thermal and electrical stability of the capacitor.

- High reliability, in terms of capacitor performance during the product life time.

Up to now, electrolytic capacitors used to be the most common solution for this application. Basically this was due to the high capacitance values that can be achieved with that technology.

Nevertheless, reliability and stability are requirements that increasingly become more and more important, leading film capacitor technology to be a more convenient solution.

Therefore, designers are working on optimizing their circuit in order to reduce the weight of the capacitance value –by means of increasing the voltage after the rectifier, increasing the switching frequency of the inverter,…-, which was the limiting factor to use film capacitors [2].

Concerning the operating conditions, in most of the cases these capacitors are used in power electronic devices, which work in industrial environments. Therefore, climatic operating conditions are usually controlled and more stable than in other application fields.

In this sense, a standard operating temperature is 70ºC, with 85ºC as maximum. Only in some rare applications it could be above 100ºC, like in the case of some DC-Link capacitors for HEV [3].

Dielectric and construction

Taking into consideration the requirements for those capacitors, in terms of electrical performance, it is clear that high ripple current and low ESR and ESL are factors that dictate the capacitor internal construction.

Initially, polypropylene becomes the best choice with respect to the dielectric material, due to its low dielectric loss factor. Furthermore, this characteristic displays a low dependency with the frequency, which is also important for this application [4].

In addition to that, we are successfully working with polyester, being also able to produce capacitors that feature low ESR and low ESL values and, therefore, low self-heating while operating with high frequency ripple current. The advantage of using polyester is that higher capacitance value can be produced with reasonable sizes, since its dielectric constant is higher than in the case of polypropylene and, therefore, it offers a more competitive volumetric efficiency.

The thickness of the dielectric film depends on the capacitor rated voltage and thus it is a parameter that has been analyzed deeply to optimize the relation among the capacitor sizes, its electrical performance and the product costs.

Film metallization is also an important design factor that has been developed in order to enhance the electrical behavior of our product. The metallization profile has been optimized to increase the dielectric strength of the plastic film, enhance the self-healing properties and keep low values for ESR and ESL parameters.

Regarding the capacitor construction, wound technology is the chosen one for these products. With this construction, capacitors feature a good contact length that offers a good path for the current to flow into the capacitor, reducing the potential self heating that the ripple current might provoke.

The most important advantages of these capacitors could be summarized as follows:

- Low ESR values [5]. It helps the capacitor to minimize the power generated by working under high frequency AC voltages. ESR will lie between 2mW and 16mW (at 100KHz).

- High I_{rms} handling capability. Due to the long contact length, they are able to withstand high I_{rms} values at the high frequencies demanded. Maximum I_{rms} could be above 25A (at 100KHz).

- High reliability due *Self-healing* [6] properties. Self-healing is an advantage of metallised film capacitors and can be defined as the capacitor ability to clear faults (such as pores or impurities in the film) under the influence of a voltage. If the dielectric breakdown field strength is exceeded locally at a weak point, a dielectric breakdown occurs. At that point, high temperatures are reached (up to 6000 K) and the dielectric is transformed into highly compressed plasma that forces its way out. In addition, the metallization in the vicinity of the channel is evaporated and finally the region becomes insulated. This process causes the capacitor to regain its full operation ability and, therefore, enhances the product reliability during its life time.

- Safe failure mode. Electrical parameters drift and final open circuit are the standard failure modes for film capacitor, while for other technologies an eventual failure might lead the capacitor to a short circuit putting into risk the integrity of the whole equipment.

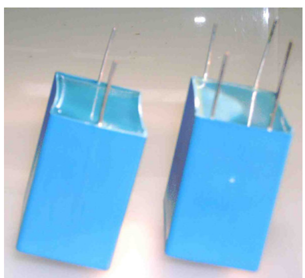

Fig. 1: 2-pin and 4-pin LS37.5 capacitors

Lead configuration

In terms of capacitor construction, lead configuration is one of the parameters that can be modified to further improve the ratings in terms of ESR and maximum I_{rms}, in case the application requirements demand it.

Different lead diameters can be offered, as a solution to modify the ratings of the capacitors in regards to the self heating behavior and the current handling capability.

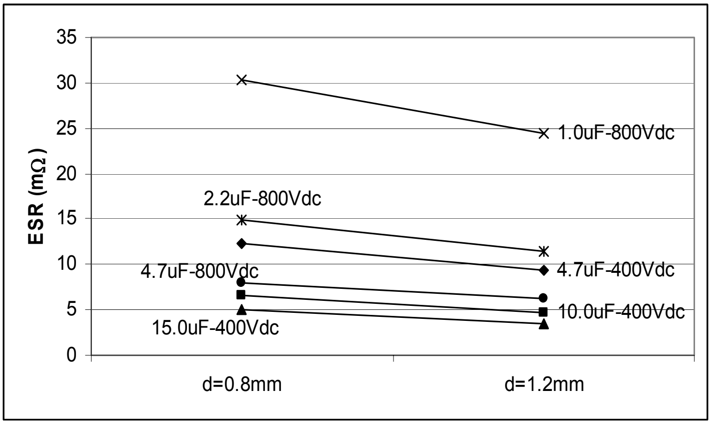

Fig. 2: ESR vs. lead diameter for LS37.5 capacitors

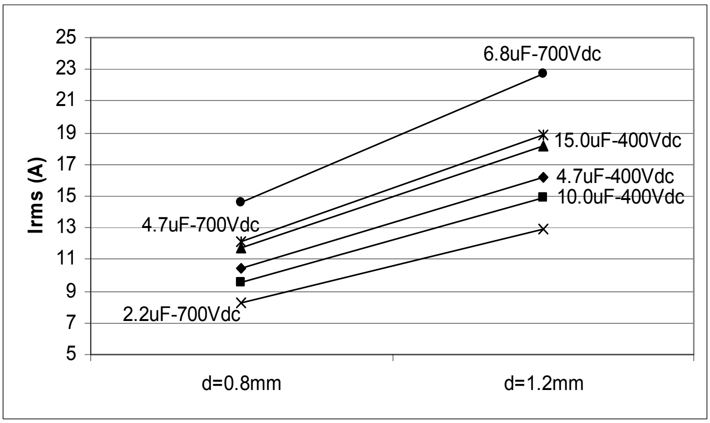

Fig. 3: I_{rms} vs. lead diameter for LS37.5 capacitors

Additionally, traditional 2-pin capacitors can also be produced with a 4-pin configuration (figure 1), improving ESR and I_{rms} ratings further. As a reference, and keeping lead diameter as a fixed parameter, 4-pin configuration can help to reduce ESR in 20% (figure 4). Obviously, this option also allows to increase the maximum admissible I_{rms} (figure 5) becoming the right solution for high demanding applications.

Apart from this, 4-pin configuration also gives a higher mechanical stability for those capacitors, which could be needed in certain situations where mechanical vibrations play a major role.

Taking into consideration that the polyester construction covers the upper part of the spectrum, in terms of capacitance sizes ($V \geq 33.200$ mm^3) and values, it has been decided that those capacitors exclusively feature 4-pin configuration, in order to enhance the mechanical stability of the product.

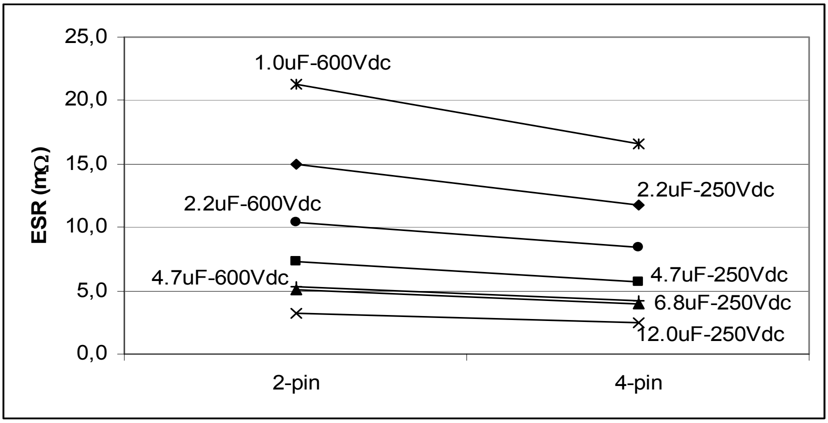

Fig. 4: ESR vs. number of pins for LS27.5 capacitors (lead diameter is 1.2mm)

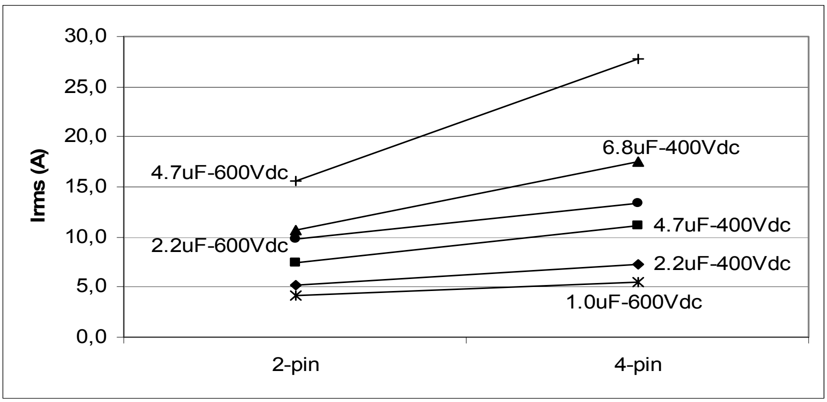

Fig. 5: I_{rms} vs. number of pins for LS27.5 capacitors (lead diameter is 1.2mm)

Evaluation tests

In order to evaluate the performance of these capacitors, several tests have been designed according to the general requirements of the application.

To ensure the capacitor reliability in the product life time, long endurance tests have been carried out under the following conditions:

- Voltage. Since the thickness of the dielectric material changes for every capacitor based on its rated voltage, the voltage levels during the tests have been defined according to that thickness: from 112.5 volts per µm up to 180 volts per µm.

- Temperature. The temperature of these tests has been 85ºC, which is the maximum operating temperature for these capacitors.

- Duration. The duration of these tests has been fixed in 1.000 hours.

In the case of our polypropylene construction, tested capacitors have displayed the typical behavior when they are submitted to temperature for a long period of time (figure 6 and 7): the wound element becomes more compact and the capacitance value slightly increases. Afterwards they remain stable for the rest of the test, confirming their capability to withstand those conditions.

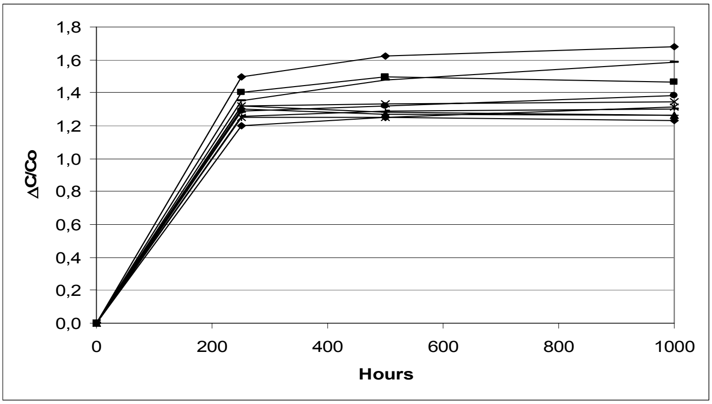

Fig. 6: 25µF/450Vdc/LS27.5/PP
PLD 112Vµm at 85ºC/1000h

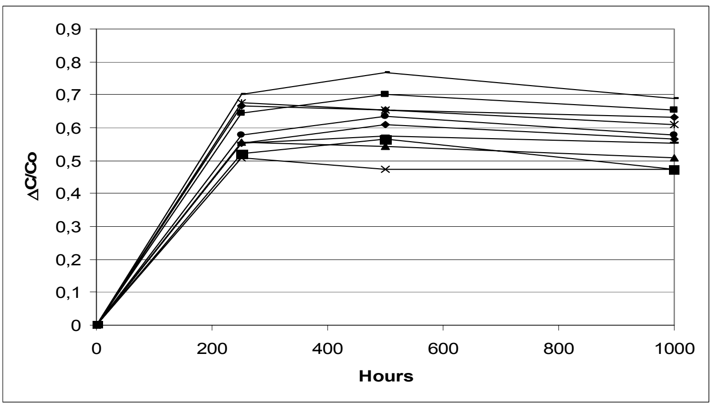

Fig. 7: 10µF/900Vdc/LS27.5/PP
PLD 180V/µm at 85ºC/1000h

In regards to the tests that we have conducted with our polyester capacitors the results show the expected performance for this film material. After the first hours, temperature removes the humidity that is inside the capacitor and, therefore, the capacitance value decreases, being stable until the end of the test.

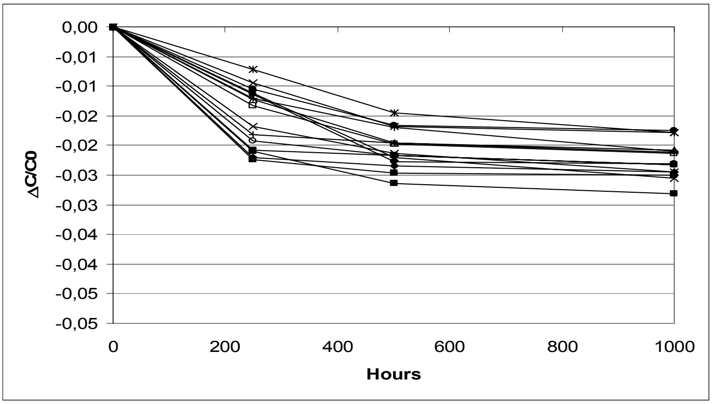

Fig. 8: 40µF/450Vdc/LS37.5/PET
PLD 135Vµm at 85°C/1000h

On the other hand, neither tg δ nor R_{ISO} values have shown any significant degradation, which confirms that those designs are suitable to fulfil the application requirements.

With the conditions just described, those tests allow us to simulate the capacitor performance for more than 200.000 hours under standard operation conditions.

Concerning the ESR and the maximum admissible I_{rms} for those capacitors, we have also evaluated those parameters by performing many different measurements (please refer again to figures 1 to 4). In order to carry out this analysis, many different configurations have been evaluated (different lead diameters, and 2 or 4 pin configurations).

Product ratings

The range of product that EPCOS offers as a high reliable solution for new converter technologies covers a wide spectrum of capacitance values and rated voltages.

In particular for the rated voltage, improvements in our designs and the tests that we have carried out in the last months have provided us with enough information to increase the voltages that were initially defined for these series.

ESR values and maximum admissible I_{rms} are also defined for those capacitors, giving to converter designers the basic information to select the right product according to their needs.

In this extend, also the optimization of the metallization profile has allowed us to confirm that these capacitors feature lower losses and, therefore, are able to handle higher RMS current than the confirmed one at the beginning of this project.

A rough summary of those parameters is included in table 1 and table 2.

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
450	2.2µF … 12.0µF	12.0 … 4.0	7 … 12
630	1.5µF … 7.5µF	7.9 … 2.8	8 … 14
800	1.0µF … 5.0µF	10.5 … 3.4	7 … 14
900	0.68µF … 4.0µF	12.0 … 3.5	7 … 14
1050	0.47µF … 3.0µF	14.0 … 3.6	7 … 14

Table 1: Summary of ratings for LS27.5 capacitors, with 1.2mm lead diameter

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
450	3.3µF … 30.0µF	13.1 … 2.6	7 … 22
630	2.2µF … 20.0µF	14.0 … 1.4	9 … 29
800	2.0µF … 14.0µF	12.5 … 1.7	10 … 29
900	1.5µF … 10.0µF	15.2 … 2.3	9 … 29
1050	1.0µF … 7.5µF	14.1 …2.9	10 … 29

Table 2: Summary of ratings for LS37.5 capacitors, with 1.2mm lead diameter

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
450	30.0µF … 100µF	4.0 … 2.6	29
630	20.0µF … 35.0µF	2.2 … 1.4	29
800	15.0µF … 25.0µF	2.7 … 1.8	29
900	15.0µF … 20.0µF	2.7 … 1.9	29
1050	10.0µF … 15.0µF	2.5 … 2.0	29

Table 3: Summary of ratings for LS52.5 capacitors, with 1.2mm lead diameter

Other technical data for those capacitors is listed in the following table:

Working temperature	-40ºC…+85ºC
dV/dt	up to 150 V/µs
Tan d (at 20ºC and 1KHz)	< 1·10-3
Riso (25ºC, 65%r.h.)	>10 000 sec.
Test voltage between terminations	1.6 x Vr for 2sec.

Table 4: Technical data of DC-Link capacitors

Conclusions

Jumping from the traditional electrolytic capacitor towards film technology is now possible.

New design criteria allow a reduction of the capacitance value, which was the main argument to use electrolytic capacitors.

Low ESR values, high ripple current capability, electrical and thermal stability, long term reliability and safe failure mode give EPCOS' DC-Link series B32674…B32678 a good opportunity to improve capacitor performance in state-of-the-art converters [2].

Further improvements in our definition of the film metallization profile and dielectric materials have given us two main advantages: firstly, ratings in regards to the operating voltages have been upgraded; secondly, the spectrum of capacitance values has been enlarged in order to achieve up to 100 μF.

Future activities will be focused on new products that are able to operate under unfriendly ambient conditions, using the knowledge that we have obtained with our developments.

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