MKP Capacitors for DC-Link application in modern converters.

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1. 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 has understood the new trend and offers a wide range of MKP capacitors in different operating voltages, whose design and performance are described in this paper.

2. 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. However, the rest of the requirements can be better fulfilled by film capacitors.

Nevertheless, as reliability and stability are increasingly becoming the most important requirements for those capacitors, and film capacitor technology becomes the preferred solution. Therefore, designers are working on optimizing their circuit in order to reduce the weight of the capacitance value, which was the limiting factor to use film capacitors [1].

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.

In this sense, 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 [2]. 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.

Regarding the capacitor construction, the 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 [3]. It helps the capacitor to minimize the power generated by working under high frequency AC voltages. ESR will lie between 4mΩ and 20mΩ (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* [4] 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 a 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.

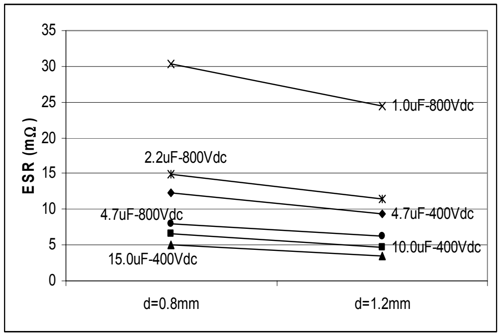

Fig. 1: ESR vs. lead diameter for LS37.5 capacitors

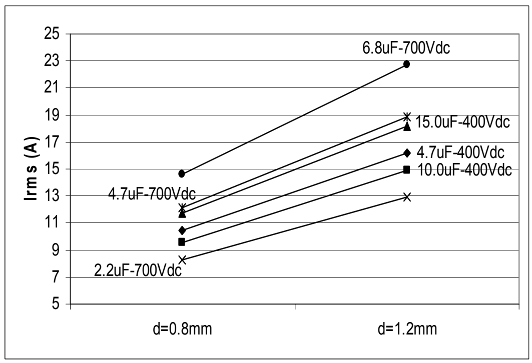

Fig. 2: I_{rms} vs. lead diameter for LS37.5 capacitors

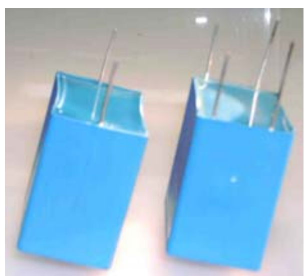

Fig. 3: 2-pin and 4-pin LS37.5 capacitors

Additionally, traditional 2-pin capacitors can also be produced with a 4-pin configuration (figure 3), further 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.

4. 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 of customer's requests.

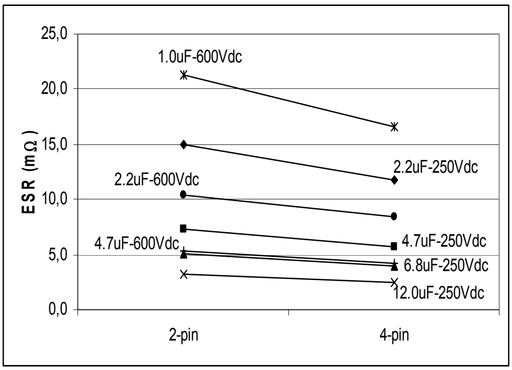

Fig. 4: ESR vs. number of pins for LS27.5 capacitors (lead diameter is 1.2mm)

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.

5. 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. The voltage levels during the tests have been calculated according to 1.8 times the rated voltage of the tested capacitor.

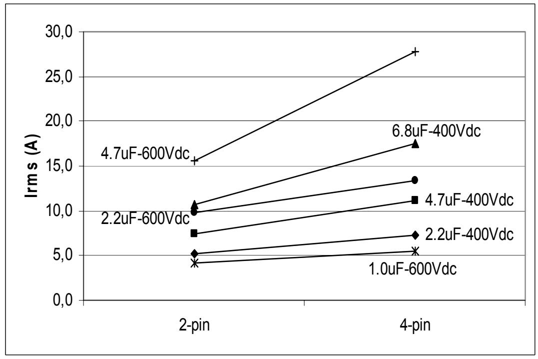

Fig. 5: I_{rms} vs. number of pins for LS27.5 capacitors (lead diameter is 1.2mm)

- 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.

With the conditions just described, those tests allow us to simulate the capacitor performance for more than 200.000 hours under standard operation conditions (Vr and 40ºC). Results are shown in figures 6 and 7

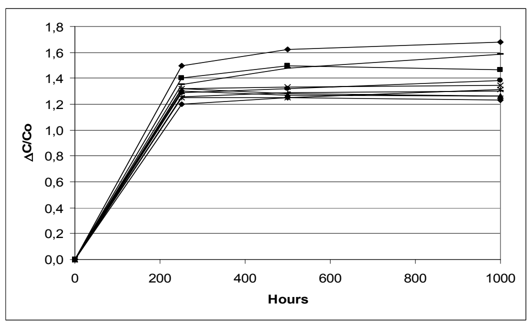

Fig. 6: 25µF/250Vdc/LS27.5. PLD 1.8xVr /85ºC/1000h

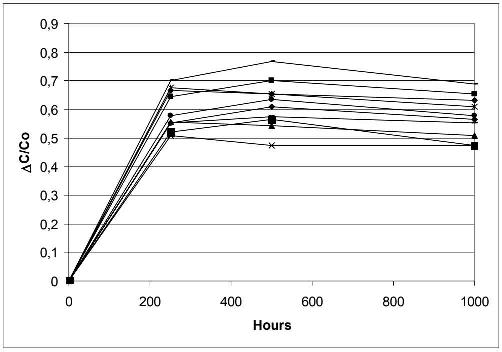

**Fig. 7: 10µF/200Vdc/LS27.5.
PLD 1.8xVr /85ºC/1000h**

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).

6. 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.

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.

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

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
250	2.0µF … 12.0µF	17.5 … 4.6	5 … 12
400	1.5µF … 7.5µF	18.6 … 5.3	8 … 14
600	1.0µF … 4.7µF	22.5 … 6.4	8 … 14
700	0.68µF … 3.0µF	28.3 … 8.0	7 … 14
800	0.47µF … 3.0µF	35.5 … 7.2	6 … 14

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

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
250	3.3µF … 25.0µF	19.1 … 4.3	6 … 17
400	2.0µF … 17.0µF	24.6 … 4.7	5 … 14
600	3.3µF … 12.0µF	13.1 … 5.1	7 … 16
700	2.2µF … 8.0µF	17.1 … 6.1	8 … 16
800	0.68µF … 7.0µF	47.3 … 6.1	8 … 16

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

Voltage	**Capacitance value**	**ESR (mΩ) 100KHz**	**Irms (A) 100KHz**
250	30.0µF … 60.0µF	4.3 … 3.9	12 … 16
600	10.0µF … 25.0µF	4.5 … 3.0	14 … 18

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

7. 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 [1].

8. References

[1] Namho Hur, Jinhwan Jung, Kwanghee Nam: A Fast Dynamic DC-Link Power-Balancing Scheme for a PWM Converter-Inverter System. IEEE Transaction on Industrial Electronics, Vol. 48, No. 4, 2001.

[2] Vetter H.: Hostaphan and Trespaphan for Capacitors. Hoechst Daifoil, Edition 1, 1995.

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[4] EPCOS Film Capacitor Data Book. Edition 08/2004