Empowering the EMI Filtering Industry- Development of a Capacitor series up to 45µF with X2 safety classification for high density filters

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Abstract

The extensive use of power electronic converters in a wide range of electronic systems can increase the harmonic interferences into the grid, mainly due to the use of diode rectifiers or IGBT bridges configurations. Also the use of new systems of power generation, like windmills and solar panels, is varying the nature and conditions of the Electromagnetic (EM) disturbance. Therefore, Filters and Drives Industry is asking for higher capacitance components to handle these increasing interferences, amplified by the rising demand of power.

These components shall be able to comply with the EM requirements and safety regulations, but reducing size and weight at the same time. Film Capacitor Technology is the safest technology in case of overload operation, and commonly used for EM Interference Suppression.

EPCOS research efforts have resulted in a new film capacitor series that is able to satisfy this need. The electrical and mechanical parameters are compared and evaluated in this paper in order to prove that this new series can cover the capacitance density and performance requirements from the Industry.

Origin, need of this series

The use of filter circuits in all the electronic equipment is a must. Electromagnetic Interferences (EMI) feeding the equipments through the network shall be blocked in order to assure the correct handling of the input signal and avoid damage to the equipment itself but also operators and users. In parallel, the internal interference generated by these equipments must be minimized outside by these filter stages according to the EM Compatibility regulations. For example, the extensive use of power electronic converters contaminates the net with harmonics coming from the switching of IGBTs.

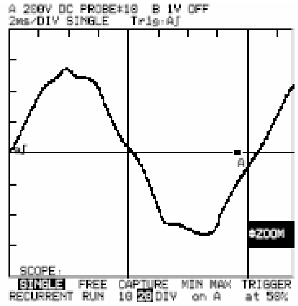

Figure 1: Example of a disturbed signal from the net.

Total Harmonic Distortion (THD) [1], or the contribution of the individual harmonics to the fundamental RMS voltage, is therefore, the enemy to beat.

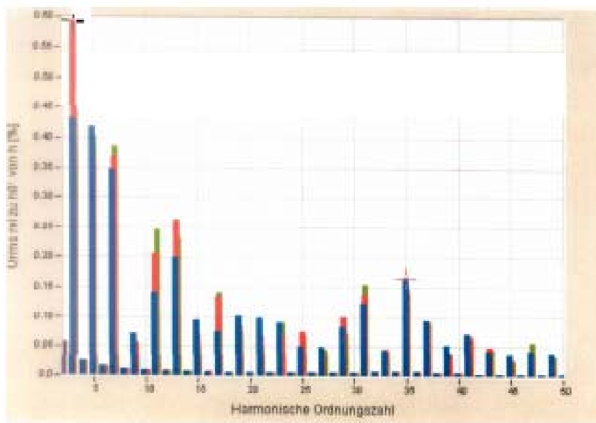

Figure 2: Example of frequency Spectrum with high THD

Electronic designers are facing the challenge to block these interferences with filters that use Inductors, chokes and X and Y capacitors. X for line to line and Y for line to ground capacitors, according to the nomenclature of the most used standard IEC 60384-14 for EMI capacitors. Also, this standard includes different safety class: 1 (the safest), 2 or 3, being 2 the most extended in the market (X2 and Y2 Capacitors). Moreover, the capacitors approved under this standard, shall be able to withstand transients (over-voltages up to 1000Vrms and high voltage impulses up to 2500V) and also a significant level of flammability immunity (Category B).

The use of high capacitance values is mandatory for filtering the high frequency harmonics joined to the significant power of these ones.

The way to achieve these high capacitance values is by the parallel connection of capacitors, where total capacitance value will be the sum of individual capacitance values. The inconvenience of doing parallel connection is the parasitic inductance and the losses associated to the wires used for these connections, joined to the higher labour and material cost, together with the use of a bigger area on the PCB.

In the last century, the biggest X2 single capacitor was 2.2µF. Five capacitors in parallel were required to reach up to 10µF in the filter. In 2004 EPCOS presented a 10µF X2, which offered significant advantages for those applications. Now, in 2007, EPCOS is again launching into the market a new series of X2 capacitors, with a maximum capacitance value of 45uF, which will help our customers to optimize their products.

The current and proved X2 series from EPCOS, B3292-CD, goes from 10nF to 10µF with a rating of 305VAC and 105ºC. Next generation B3292-EF, will go from 2µF to 45µF, focused on filters which requires a higher capacitance value joined to a high density (capacitance per volume), holding the same rated voltage (305V), but allowing even higher operation temperatures (up to 110ºC).

The design of this new series B3292-EF satisfies also the market requirements in terms of size optimization, which will help filter designers to develop more compact filters. In this sense, a comparison between existing EPCOS series and the new one is shown in Figure 4.

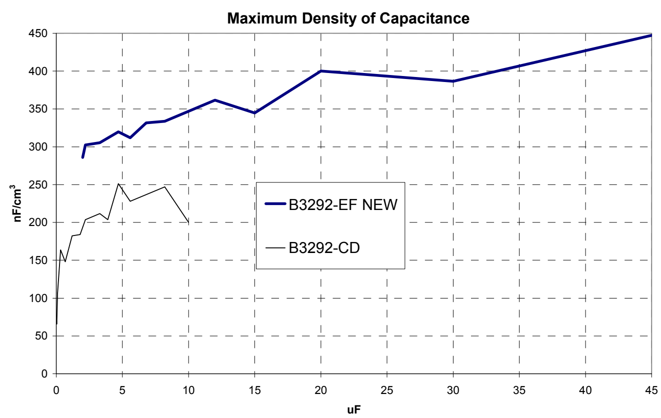

Figure 3: Density of capacitance in nanofarad per unit of volume: comparison between new and current series.

Technology

As well as the existing X2 series, the new EPCOS series B3292-EF is based on our wound capacitor technology, with polypropylene as a dielectric material.

By means of using special metallization profiles for the film, and the specific process parameters for this new construction, we are able to offer a new series of capacitors with such high capacitance values, which also comply with the extremely high safety requirements that every X2 capacitors have to meet.

Plastic metallized film capacitor is the safest capacitor technology because of the well known *self-healing* property [4], which allows the clearing of weak dielectric areas when over-voltages appear. And nowadays, it is the only suitable technology when capacitors with high capacitance values, high peak voltages, high temperature levels (105ºC) and X2 safety levels –which means the capability to withstand for example, over-voltages up to 1000Vrms– are needed.

Impedance versus frequency.

For the design of filters, it is basic to know the impedance curve with respect to the frequency for the capacitor element. This curve will provide the typical resonant frequency (F_R), that is to say, the frequency at which inductive (L) and capacitive (C) components are equal (but with opposite sign), reactive part is null, and therefore the whole impedance has the minimum value:

$$Z = R_S + j * \left(\frac{-1}{C\omega} + L\omega \right) = R_S$$

$$X = \frac{-1}{C\omega} + L\omega = 0$$

And $$F_R = \frac{1}{2\pi\sqrt{LC}}$$

At F_R the capacitor behaves as a very low resistance (R_s). For frequencies lower than F_R, capacitive part is more significant than inductive part, and beyond this frequency, there is a change in the sign of the reactive part, and the component behaves as an inductor:

- $f<F_R$, $X<0$, component is capacitive
- $f>F_R$, $X>0$, component is inductive.

The parasitic elements are then, L and R_s. For the same capacitance value (C), a lower resonant frequency will involve a greater parasitic inductance, and vice versa. Therefore, the resonance frequency can give a measurement of the parasitic inductance of the component.

This parasitic inductance could be the origin of circuit instabilities or electromagnetic incompatibilities of the equipment which use capacitors, and therefore it is convenient that main operation frequency of the application is far below the resonance frequency of the capacitors, in order to consider them as pure components as possible.

The series B3292-EF brings higher capacitance values joined to a high density of capacitance, respect of already miniaturized series full available in the market (for example, B3292-CD). Let us compare the elements showed in figure 5 and 6:

Figure 4: One capacitor of 20µF from new B3292-EF, compared to five capacitors of 4µF connected in parallel, with total capacitance 20µF.

Figure 5: One capacitor of 40µF from new B3292-EF, compared to five capacitors of 7µF and one cap of 4µF in parallel connexion, also 40µF.

A first comparison between each group in terms of *impedance versus frequency* can be found in Figure 7. The curves of 40uF and 20uF of both series (B3292-CD and B3292-EF) follows the same trend up to 30KHz in case of 40uF and 70KHz in case of 20uF. Starting at these frequencies, the inductive component is more significant for the series B3292-CD than for the series B3292-EF.

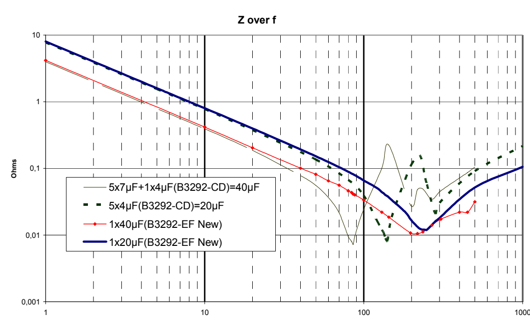

Figure 6: Impedance versus frequency. Existing X2 series (B3292-CD, dashed lines) compared to new X2 series (B3292-EF, continuous lines).

Therefore, the resonant frequency of B3292-EF is higher than the resonant frequency of B3292-CD series, which provides a better behaviour, in special when high frequency harmonics have to be filtered.

The origin of this improvement on the resonant frequency is achieved by the increment of density of capacitance. The size reduction, holding the same or even higher capacitance value, involves a shorter path for the current, which brings a lower parasitic inductance, a higher resonant frequency, and thus a very high electromagnetic frequency noise range suppression:

	5x4uF(B3292-CD)=20uF	1x20uF(B3292-EF-New)
fr (KHz)	137	245
L (nH)	81	21.0
V(cm^3)	121	57
nF/cm^3	170	351

	5x7uF+1x4uF(B3292-CD)=40uF	1x40uF(B3292-EF-New)
fr (KHz)	86	226
L (nH)	106	14
V(cm^3)	188	101
nF/cm^3	213	380

Validation of the design: Long Endurance Tests

In order to evaluate the performance of the capacitors of this new series, and ensure their reliability along the product life time, long endurance tests have been carried out under the conditions that are defined in the reference international standards. In this case, the tests have been done during 1050 hours at the maximum rated temperature (110ºC), with 380VAC (1.25 times Vr).

The results of the tests for our 2.7µF and our 20µF capacitors are shown in Figure 8 and 9. The evolution of the capacitance value follows the typical behaviour of polypropylene capacitors when they are submitted to this kind of tests. The capacitance value decreases slightly at the end of the test, in a level which is far away from the maximum variation of 10% that is defined in the international standards.

Concerning the dissipation factor, it remains almost constant during the whole test.

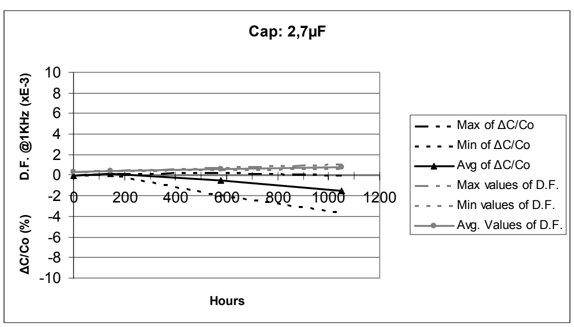

Figure 7: Evolution of the capacitance value and (C) and the dissipation factor (D.F.) of the new B32924-E3275-M, during the Long Endurance Test.

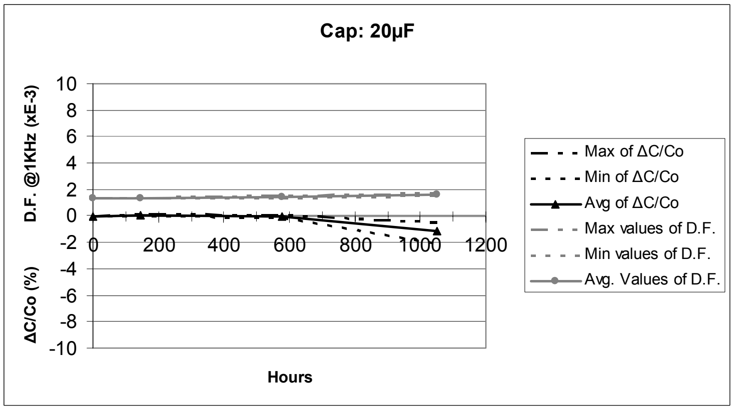

Figure 8: Evolution of the capacitance value and (C) and the dissipation factor (D.F.) of the new B32926-E3206-M, during the Long Endurance Test.

Electrical parameters: loss factor and insulation resistance

The use of metallized polypropylene technology, allows extremely low losses, which makes this series perfect for operation in AC applications [5]. The following graph shows results of the loss factor (Tan δ) at 1KHz as function of the capacitance:

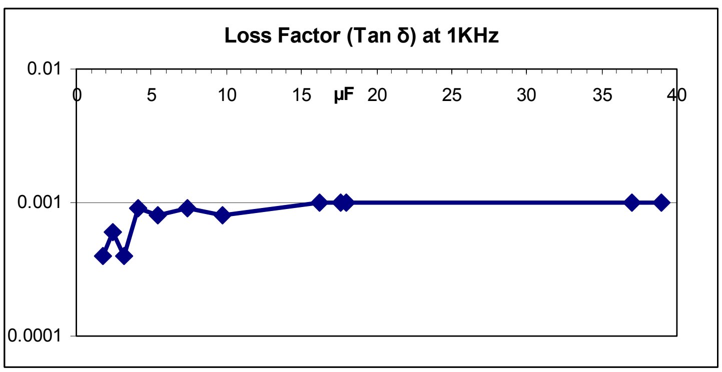

Figure 9: Typical Loss Factor in function of the capacitance value for the new B3292-EF series.

The technology and the construction of the capacitor and the parameters of the manufacturing process have a significant influence on the insulation resistance of film capacitors.

This electrical parameter has been measured after charging the capacitors during 60 seconds at 100V (acc. to IEC 60384-14 [2]). Taking into consideration the high capacitance values of the capacitors of this new series, the values that we have obtained are far above the limits that are defined by the reference international standards. In this sense, some representative values are shown in figure 9.

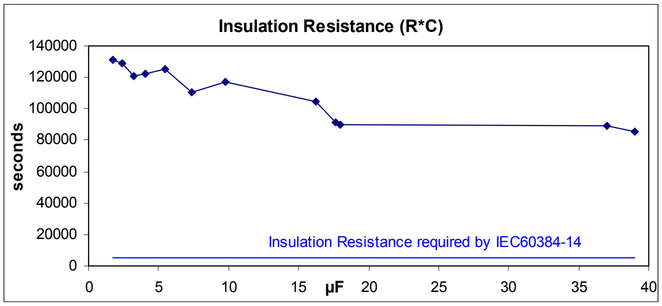

*Figure 10: Typical Insulation Resistance (=R*C) as function of the capacitance value for the new B3292-EF series.*

Safety and approvals.

In terms of safety, since these capacitors are connected directly to mains, they must be able to withstand over-voltages (transients) that might be provoked by interferences coming from other equipments.

The result in the Breakdown Voltage Test (BVT), that is to say, the peak voltage at which the capacitor breaks, is one criterion to evaluate the suitability of the design to meet this requirement. In this sense, Figure 10 shows the behaviour of some capacitors when submitted to this test.

The following graph shows the results in the breakdown voltage test, that is to say, the peak voltage at which the capacitor breaks.

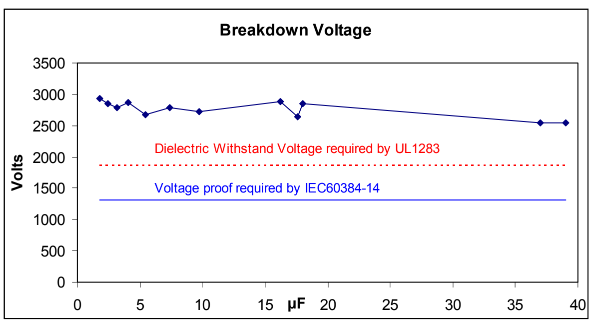

Figure 11: Average Breakdown Voltage in function of the capacitance value for the new B3292-EF series.

It is observed enough safety margins (600-700V) between the requirements of the reference standards [2] [6] (IEC 60384-14 and UL1283) and the results obtained for this capacitor series.

However, the basic and necessary indication of the safety level of any EMI capacitor series is given by the approval tests to obtain the certificate according to the international reference standard IEC60384-14, “Fixed capacitors for electromagnetic interference suppression and connection to the supply mains”.

Tests like:

- Electrical parameters testing,
- High voltage proof tests,
- Impulse testing,
- 1000 hours life test at maximum temperature (110ºC) and 125%Rated voltage (305Vac), with impulses of 1000Vrms of .1seconds every hour.
- And Flammability tests,

must be passed by any EMI capacitor series approved under this standard. This B3292-EF is not an exception, and the corresponding certification was obtained after the success in all these tests. Approval testing has been carried out by the very well know and prestigious German Institute, VDE.

Product ratings.

Series B3292-EF is the solution that EPCOS has presented into the market, to offer X2 capacitors with capacitance values up to 45uF, 305ºC rated voltage and 110ºC rated temperature, which is an excellent product to enlarge the spectrum of X2 capacitors that are nowadays in our portfolio.

In the following table the most important parameters are shown, together with the mechanical dimensions of some relevant capacitors within this series.

	E/F Version
Dielectric Material	PP
Capacitance Range	10nF … **45.0**µF
Lead Space	10mm … **52.5**mm
Rated AC Voltage	305 V
Rated Temperature	110 ºC
Maximum Continuous VAC	310 V
Climatic Category	40/105/56/B

	Cap Val.	Dimensions (mm)
LS27.5	4.7µF	18.0x27.5x31.5
	6.8µF	21.0x31.0x31.5
	8.2µF	22.0x36.5x31.5
LS37.5	10.0µF	20.0x39.5x42.0
	15.0µF	28.0x37.0x42.0
	20.0µF	28.0x42.5x42.0
LS52.5	15.0µF	21.0x38.0x60.0
	20.0µF	21.0x40.0x58.5
	45.0µF	35.0x50.0x57.5

Conclusions.

Nowadays, handling Electromagnetic Interferences is becoming a critical subject for the designers of electronic devices, who are looking for capacitors with higher capacitance values that help them to improve and optimize the design of the EMI filters.

With the new series B3292-EF, EPCOS is offering a new range of X2 film capacitors with capacitance values from 2uF up to 45uF, and 305VAC and 110ºC as rated voltage and temperature. This series is perfectly in line with the new requirements of the market and, in summary, offers the following main advantages:

- No need of large parallel connections as cap values up to 45uF are included.
- A reduced volume, achieving low parasitic inductance and higher resonant frequencies, with higher EM frequency noise range suppression.
- High voltage testing required by safety standards is possible.
- Approvals for Filters and other end Products possible, as the capacitors are already approved according to the basic standard for capacitors: IEC60384-14.

The electrical performance of these capacitors has been evaluated by means of different electrical tests (i.e., LET, BDV). Furthermore, additional tests according to IEC60384-14 have been conducted to get corresponding X2 approvals, which confirm the robustness of the design and the reliability of this new series B3292-EF.

References.

[1] IEC 61000-3-4 3rd Edition: Electromagnetic compatibility
[2] IEC 60384-14, 3rd Edition: Fixed capacitors for use in electronic equipments.
[3] EPCOS Film Capacitor Data Book. Edition 08/2004
[4] Fägerholt P.: CLR Handbook on Passive Components, Chapter C. CLR Consult, 1999
[5] Hostaphan and Trespaphan for Capacitors. Hoechst Daifoil, Edition 1, 1995.
[6] UL 1283, 5th Edition: Safety standard for electromagnetic interference filters