

## EVALUATION OF A NEW CERAMIC DIELECTRIC FOR BOTH LOW AND HIGH VOLTAGE APPLICATIONS

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### INTRODUCTION

Miniaturization is a driving need for future power electronics. This need gives rise to the surface Mounting Devices trend which allows to manufacture more and more compact equipment which at last are cheaper to produce and put on orbit.

But this evolution, which is true whatever the application is, implies some modifications linked to a greater difficulty to dissipate the heat generated by the components and the temperature increase of the electrical circuit. Two options can be considered to enable multilayer ceramic capacitors to withstand these new constraints:

- To design capacitors able to work at higher temperature with the same reliability, what means a complete change of the design and/or materials of these components.
- To design alternative components with reduced losses in order to minimize heating. As losses are mainly due to the ceramic dissipation factor, such a choice implies a complete change of the ceramic dielectric.

This second possibility lead up Exxelia Technologies to develop a completely new High Voltage ceramic capacitors range based on a new dielectric material we called “C48X”.

### DIELECTRIC PRESENTATION

#### Technical Constraints

Two classes of dielectric are mainly used to manufacture ceramic capacitors. The first class is mainly composed of NPO ceramics. These ceramics are mainly made of titanium dioxide with a low dielectric constant ( $\epsilon_r \leq 100$ ). These ceramics are very stable with only minor changes under stress of temperature (Figure 1), voltage and frequency.

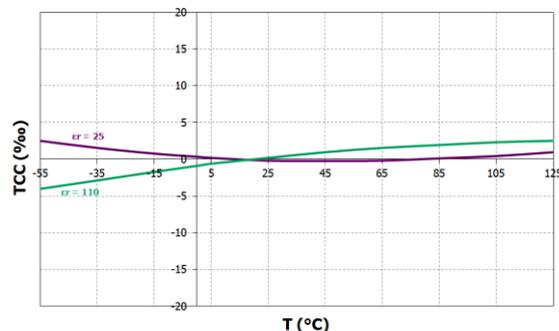
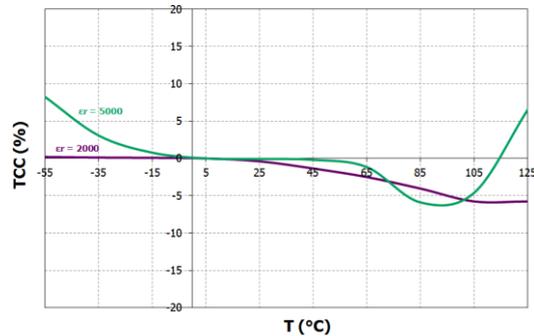


Fig 1 : Typical capacitance variation under temperature for NPO ceramics

The second class is composed of X7R ceramics. These ceramics are mainly made of barium titanate with perovskite structure and have a high dielectric constant ( $1000 \leq \epsilon_r \leq 5000$ ). The counterpart is that these ceramics present some noticeable variations under temperature (Figure 2), voltage and frequency



**Fig 2 :** Typical capacitance variation under temperature for X7R ceramics

With the aim of changing the dielectric material used to manufacture Exxelia high voltage ceramic capacitors, it was obviously necessary to use a ceramic whose performances would allow to:

- Develop ranges with the same capacitance / voltage / volume characteristics than the X7R dielectrics
- Dissipate less energy than X7R materials, what means selecting a dielectric with a dissipation factor much lower than X7R’s dissipation factor –which is typically for high voltage parts equal or greater than  $50 \cdot 10^{-4}$ .

So, we had to find a material which combines most of the dielectric properties of NPO and X7R materials.

Our choice has been a dielectric with an intermediate dielectric constant value (about 450). This material can be processed using a greater voltage gradient (ratio of voltage and dielectric thickness) than X7R dielectrics so that its capacitance per volume could be comparable with the capacitance per volume of an X7R material.

### Dielectric Performances

The main characteristics of the selected material which combines most of the advantages of NPO and X7R materials are summarized in Table 1.

**Table 1 :** Main characteristics of “C48X” material

Dissipation factor at 1kHz, $1V_{eff}$ :	$\leq 10 \cdot 10^{-4}$
Typical DF at 400Hz, $1V_{eff}$ :	$\leq 5 \cdot 10^{-4}$
Insulation resistance at 20°C under $500V_{cc}$ :	$\geq 20\,000M\Omega$ or $500M\Omega \cdot \mu F$
Dielectric withstanding voltage :	$>1.4 U_{RC}$
Temperature coefficient :	$-2200 \pm 500 \text{ ppm}/^\circ C$

The dielectric constant of this ceramic, smaller than the dielectric constant of classical X7R materials, enable to manufacture about half the capacitance of X7R ranges when measured under standardized measurement conditions (Figure 3), what, at a first glance, appears, of course, to be a limitation.

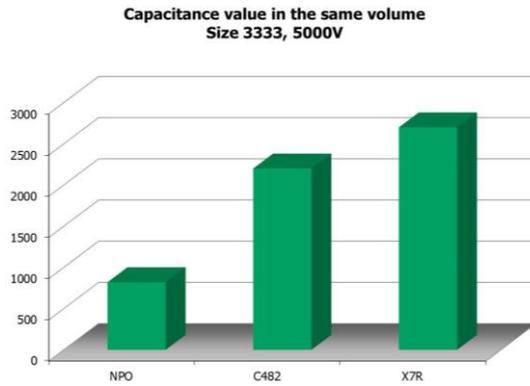


Fig 3 : Comparison of capacitance ranges in the same size package for NPO, C48X and X7R

But this dielectric is very stable under voltage. The loss of capacitance versus dc voltage is only a couple of % (Figure 4) when it's about 60% or more for classical X7R (2R1) ranges.

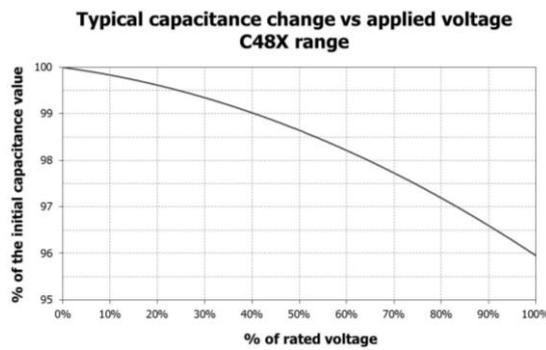


Fig 4 : capacitance change of C48 versus dc voltage

So, when looking at the capacitance value left under nominal voltage (working voltage), a simple calculation demonstrates it's the same when using this ceramic and when using a X7R ceramic dielectric.

Furthermore the dissipation factor is very low, typically less than 0.05% what makes the heat dissipation in use not significant.

Under working conditions the capacitance values of this new range of products are equivalent to X7R values with the unrivalled advantage of no heat dissipation. Figure 5 demonstrates this performance in comparison with X7R material at 400Hz. Opposite to X7R, the C48X capacitors don't suffer a temperature increase, what makes them more reliable.

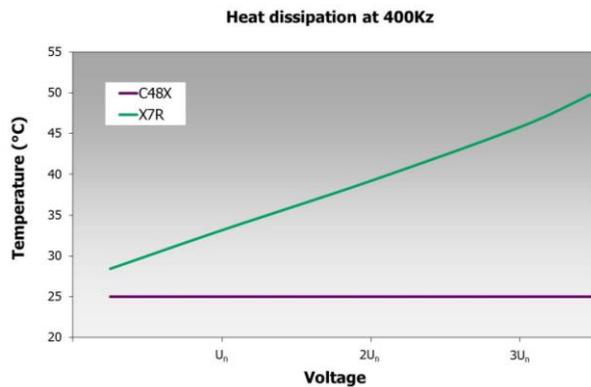


Fig 5 : Temperature increase of capacitors of the C48X range working at 400Hz in comparison with X7R material

## ACCESSIBLE RANGES

### Voltages and Sizes Ranges

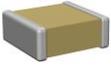
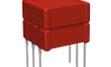
Because of its much lower DF, this ceramic is also much better adapted to low frequencies applications (typically 50Hz and 400Hz) than the X7R materials . That's why it's by now for example widely used in plane electrical network in medium or high voltages applications (typically between 400V and 5kV). So our 1<sup>st</sup> goal was to evaluate high voltage ranges (chips sizes from 1812 to 6560 – voltages from 200V to 5kV) according to space requirements in order to promote a “no heat dissipating” alternative to X7R high voltage parts.

But, in a second step, it appeared obvious that , except for impedance matching applications due to the variations of capacitance with temperature, this dielectric, because of its much higher dielectric constant compared to NPO materials, could be proposed to develop small sizes (0603 to 1210) low/medium voltages ranges (100V to 1kV). The big interest of this choice is that it will allow to propose for a given volume parts with higher capacitance (expected ratio about 3 to 4) and, hence, contribute to equipment miniaturization.

### Mounting

Many mounting possibilities are offered. Some are compatible with through-hole insertion whereas other are fitted for surface mounting. Table 2 herebelow presents most of these options.

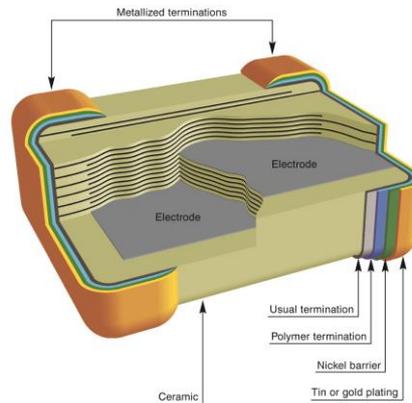
Table 2 : Summary of the different configurations proposed for the C48X ranges

Type	Leads / Finishing	
Chip	Ag/Pd/Pt, Sn, Sn/Pb, Au	
DIL & Ribbons (chips and stacked capacitors)	DIL connections for surface mounting	
	Ribbon leads / varnished	
	DIL connections for through-hole mounting / varnished	
Radial leads	Tinned copper / varnished	
	Tinned copper / dipped	
	Tinned copper / molded	

As already explained, the trend towards miniaturization is linked as much as possible with surface mounting. Of course using chips is the high road (although not always the safest on the reliability point of view) to achieve the biggest compactness and cheapest equipment.

Because of the mounting thermal shocks and the thermomechanical stresses which develop when the equipment are in function and, possibly, lead to the cracking of big sizes chips, some workarounds have to be used:

- The 1<sup>st</sup> one is to use components with shaped DIL or ribbons which absorb the stresses
- The 2<sup>nd</sup> one is to use a flexible termination (see Figure 6 herebelow which present the technology). This termination includes a soft layer which acts as a “stresses buffer” and prevent the chips cracking



**Fig 6:** Flexible termination drawing

Of course all the technologies presented hereabove are of interest and the corresponding ranges are worth testing.

### Examples of Products

In addition to the different advantages, cases, voltages and mounting configurations already presented, this material can also withstand very high dV/dt, up to 10kV/μs what makes it perfectly adapted for pulse and charge/discharge applications.

So the applications of this dielectric, including high reliability uses, are widely spread. Table 3 presents some of these components.

**Table 3 :** Examples of high-reliability products

Electrical characteristics	500nF 400V 400Hz application chips size 6560	1μF 500V Stack of 5 chips size 4040	6,8nF 2000V chips size 1812	250nF 1200V chips size 5440
Presentation	Varnished radial lead	DIL leads for through hole mounting	Single SMD chips	Axial ribbons

## EVALUATION PROGRAM

### Presentation – Main Characteristics

This work is done with the help of the french space agency (CNES). It's based on the classical ESCC2263000 evaluation program completed by several additional investigations which can be summarized as follows:

- Thermal shocks (up to 100) will be performed on mounted components. After completion of the thermal shocks a 85/85/1,5V humidity test will also be performed on the same parts
- Vibrations and shocks according to ESCC3001/3009 recommendations

- A 500 thermal shocks (-55°C,+125°C) test
- Corona testing according to Appendix B of MIL-PRF-49467C. At the end of this characterization a life test will be done on bad capacitors (if any) in parallel with good ones.
- Heating of the components working under ac current (done in parallel with X7R capacitors of same capacitance and rated voltage)

### **Ranges under tests**

It has been chosen to test as many ranges as possible in order to be able to propose components for all mounting processes and applications. These ranges are detailed herebelow.

#### *High Voltage (200V to 5000V)*

- SMD chips with flexible termination, sizes 1812 to 4040
- DIL connections for surface mounting , sizes 1812 to 6560
- Dipped and molded radial leaded capacitors chips size from 1812 to 6560

#### *Low/Medium Voltage Small Sizes(100V to 1000V)*

- SMD chips sizes 0603 to 1210

This program is now running and the results will be accessible in the next months.

### **CONCLUSION**

We have presented in this paper a new dielectric which can, potentially, replace most of the X7R high voltage capacitors which dissipate too much heat in the miniaturized equipment developed nowadays. What is a high road for the future equipment's generations.

This material might also be able to increase by a factor 3 the maximum class1 low/medium voltage small sizes capacitance values, what is also of big interest for the designers .

The evaluation of the low/medium and high voltage capacitors manufactured using this material has been agreed by CNES, the french space agency and this evaluation is now running with the help of this agency.