MML technology for film capacitors miniaturization

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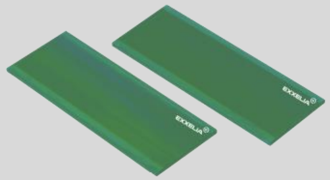
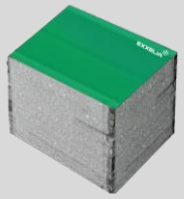
ESA/ESTEC, Noordwijk, The Netherlands

Exxelia MML (Miniature Micro-Layer) Capacitors

Similar to stacked capacitors, the MML are produced in a single step process :



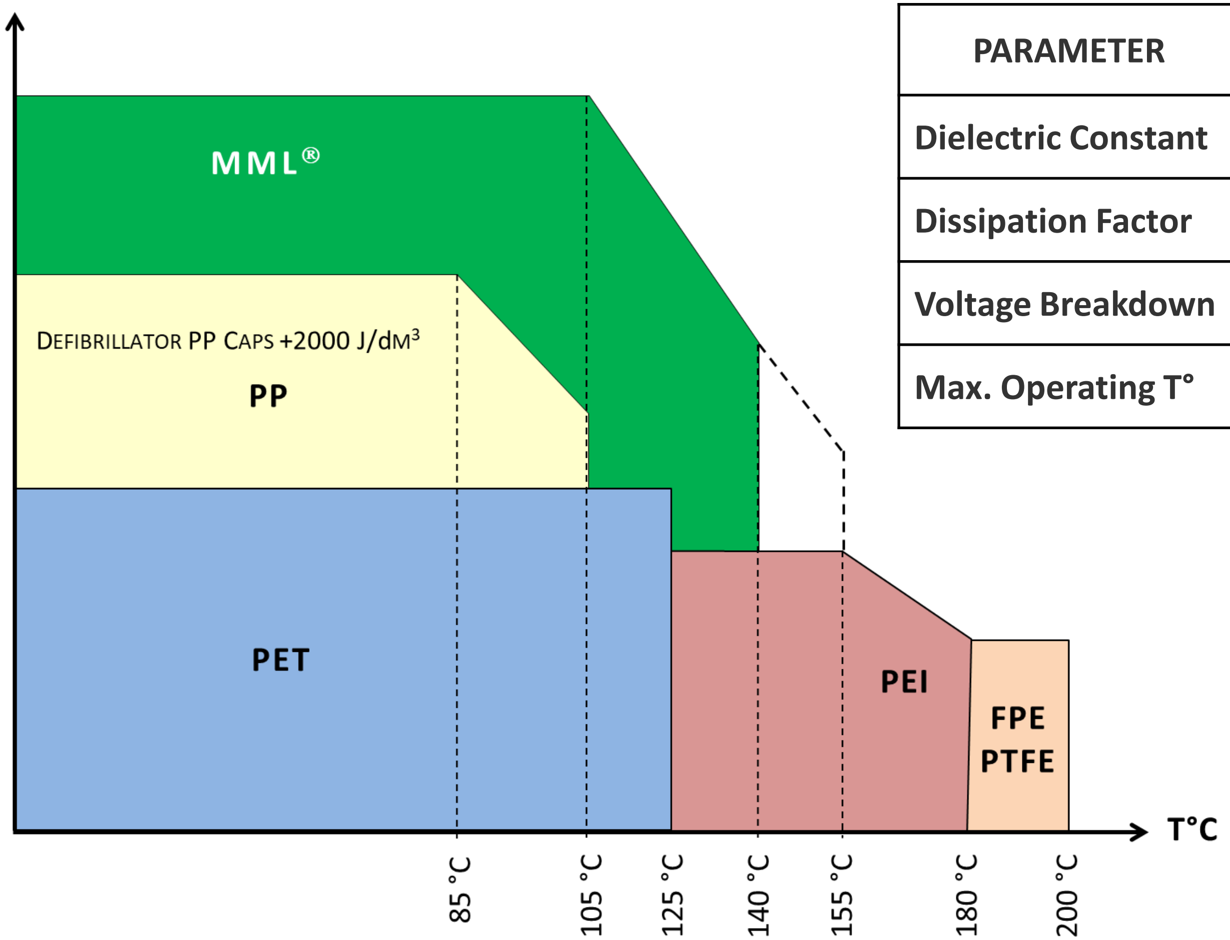
The individual capacitors are stacked in parallel :



The packaging and leads allow to protect the capacitor and adapt it to the application:

Miniaturization ⇨ Energy Density = $\frac{E}{Volume}$

$E = \frac{V^2 C}{2}$ $C = \frac{\varepsilon S}{e}$



PARAMETER	MML	PP	PET
Dielectric Constant	3.2	2.2	3.3
Dissipation Factor	$60 . 10^{-4}$	$2 . 10^{-4}$	$50 . 10^{-4}$
Voltage Breakdown	> 800V/µm	700V/µm	500V/µm
Max. Operating T°	140°C	105°C	125°C

Main MML advantages :

- Miniaturization
- Higher temperature

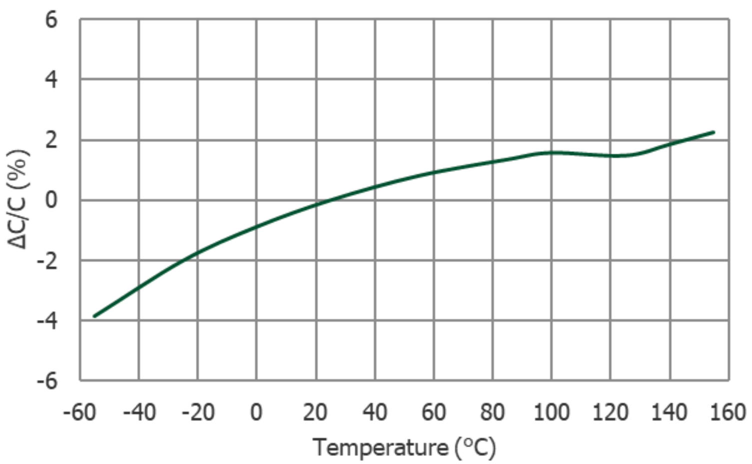
MML is well adapted for DC Filtering

EXXELIA

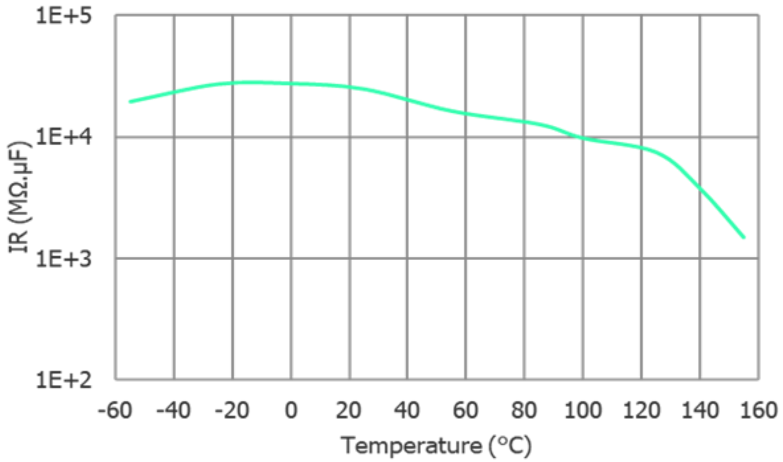
Some MML Characteristics

Main Electrical Characteristics versus Temperature

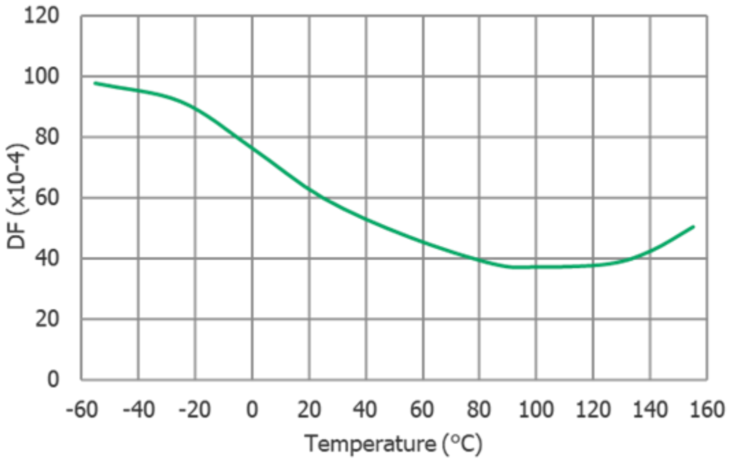
Capacitance drift vs temperature



Insulation Resistance vs temperature



Dissipation Factor vs temperature



- MML present a low capacitance drift for **DC filtering applications**
- There is no capacitance drift under voltage (as for other Film technologies)

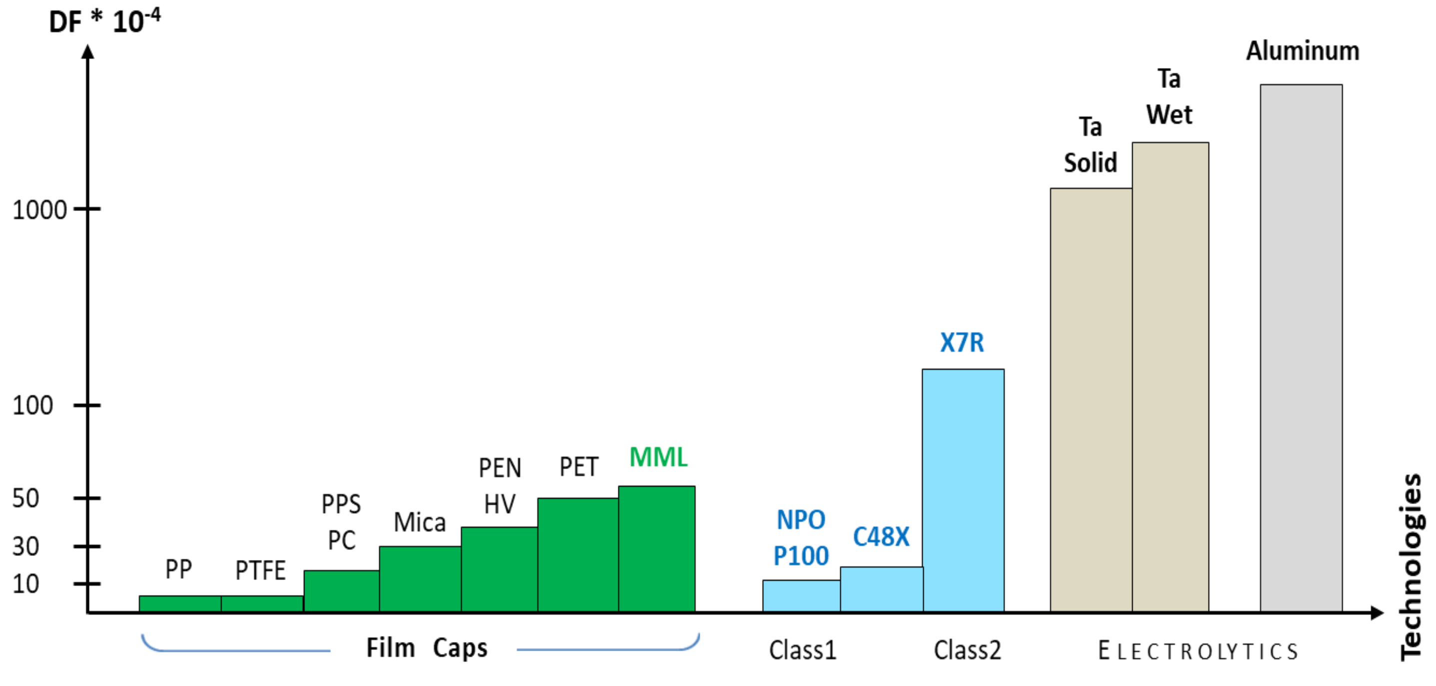
- Stable Insulation Resistance up to 125°C
- Decreasing of the IR upper 125°C (increasing of the leakage current)
- Voltage derating between 125°C / 140°C

Dissipation factor presents dielectric losses and **power behavior** of the technology

- Relatively low Dissipation Factor
- DF decreases for higher temperatures

MML power behavior versus other technologies

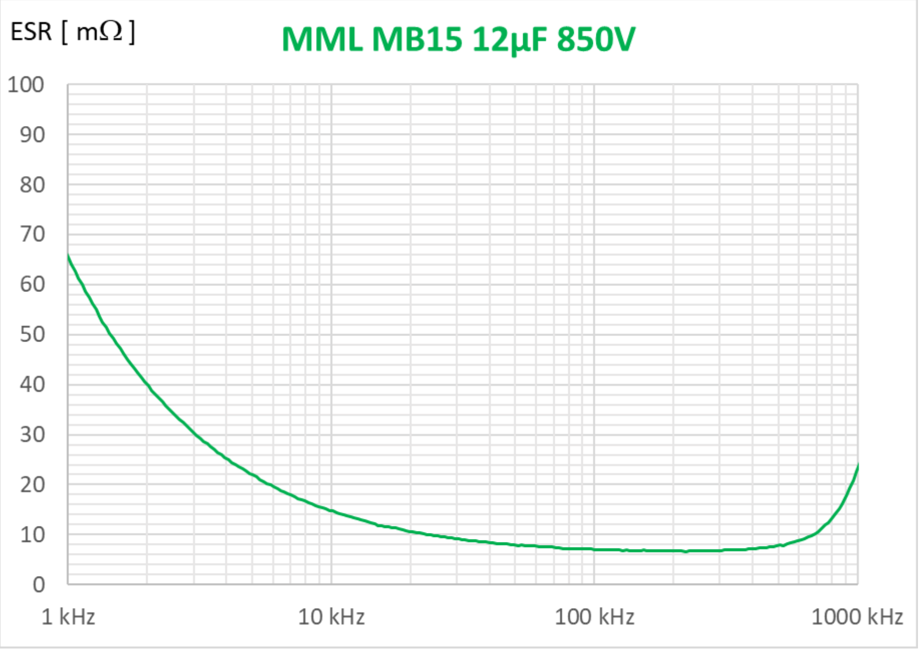
Dissipation Factor for Main Capacitor Technologies



$$P_{LOSSES} = I^2_{RMS} \cdot ESR$$

$$ESR = R_S + \frac{DF}{2\pi f C}$$

The DF, presenting dielectric losses, limits MML power behavior for low frequency AC filtering



- With comparison to other Film technologies, MML presents similar characteristics to Polyesters and is well adapted for DC filtering and energy storage
- MML technology has much lower dielectric losses compare to Ceramic capacitors and other technological families

MML miniaturization versus X7R ceramics

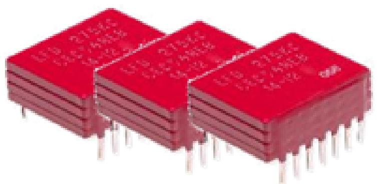
TYPICAL CHARACTERISTICS		FILM MML®	CERAMIC X7R
RELIABILITY	Self-Healing	Excellent	NO
	Failure Mode	Open Circuit	Short-Circuit
CAPACITANCE DRIFT	T° = -55°C / +125°C	-4% / **+2%** (typical)	+15% / **-15%**
	Under Rated Voltage	**No Drift**	**-30% to -50%**
	Operating Life	± 5%	± 12.5%
POWER BEHAVIORS	DF (Tg **d**)	$< 100 \cdot 10^{-4}$ ($60 \cdot 10^{-4}$ typical)	$< 250 \cdot 10^{-4}$ ($150 \cdot 10^{-4}$ typical)
	RMS Current	Low ESR for HF	Higher Dielectric Losses
	Discharging	High dV/dt & i^2t	Fragile -> Cracks
MASSE	for same Size	Low (~ 4 times lower)	Heavy
ThermoMech.	withstanding	Flexible Structure	Fragile, T° shock Sensitive
CASING	type	Case packaging needed	**Chips available**
Voltage Range	Low voltages	adapted for > $50V_{DC}$	**low voltage available**

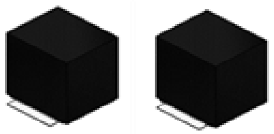
Example of MML capability to replace some big stacked Ceramic capacitors

Criteria	Ceramic X7R (1, 2, 3)	MML® (1, 2)
Total Capacitance	3*47µF = 141µF	2 * 50 µF
Total Cap requirement	> 100 µF	> 100 µF
Operating temp	-55°C / 125°C	-55°C / 140°C
DF (typical) at 25°C	$150 \cdot 10^{-4}$	$60 \cdot 10^{-4}$
Total Volume	121 cm^3	40 cm^3
Energy Density (after drift)	145 J/dm^3 ~ 100 J/dm^3	250 J/dm^3
Total Weight	~ 650 g	~ 65 g
Failure Mode	Short Circuit	Open Circuit

X7R Ceramic
47µF 500V

MML®
50µF 450V





Technological Evaluation vs Product Qualification

ESA STANDARDS SYSTEM IS THE ONLY HAVING A REAL TECHNOLOGICAL APPROACH

EVALUATION -> to demonstrate the technological limits, acceleration factors, EOL characteristics, failure mode, reliability level

QUALIFICATION -> to qualify Design / Product / Process -> demonstrate it periodically

MML Rated Limits and Evaluation Tests

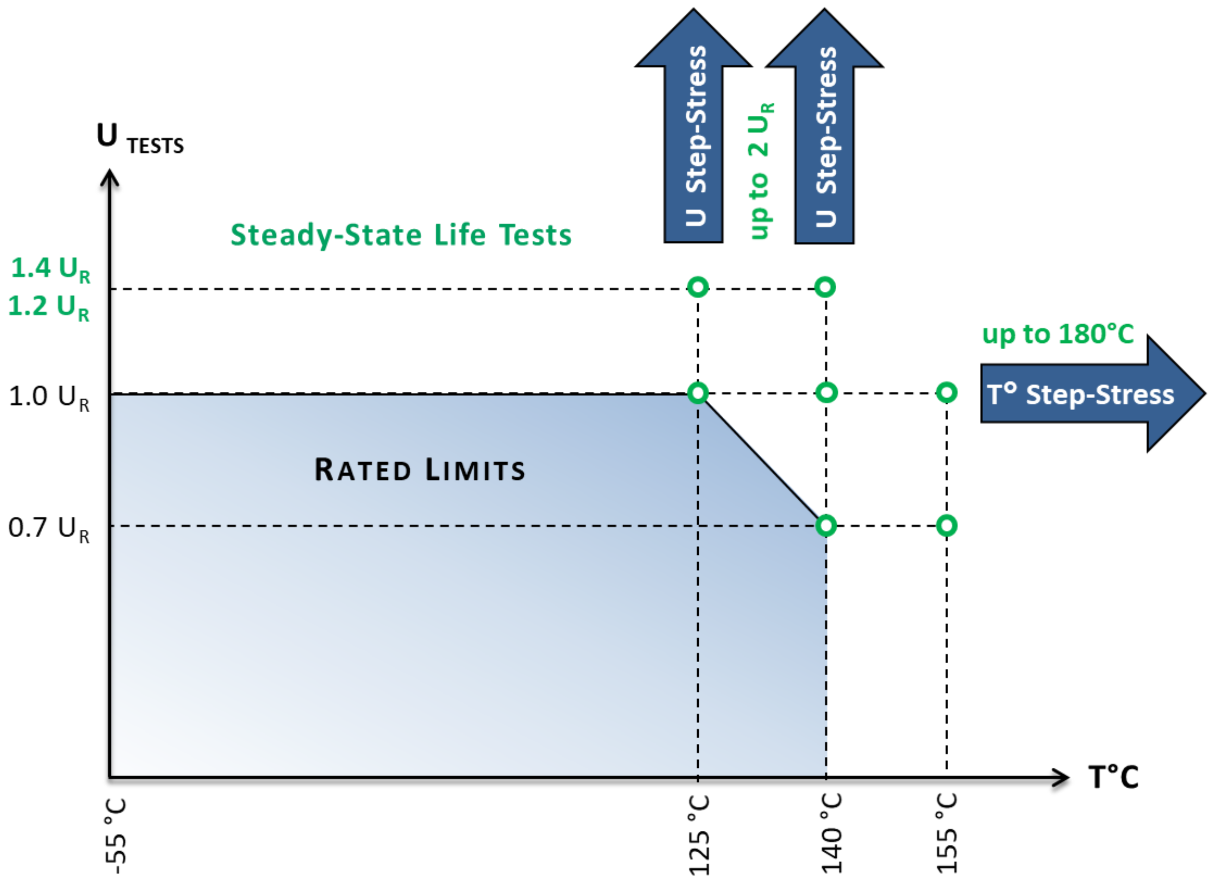
MML capacitor testing with Technological Evaluation Approach

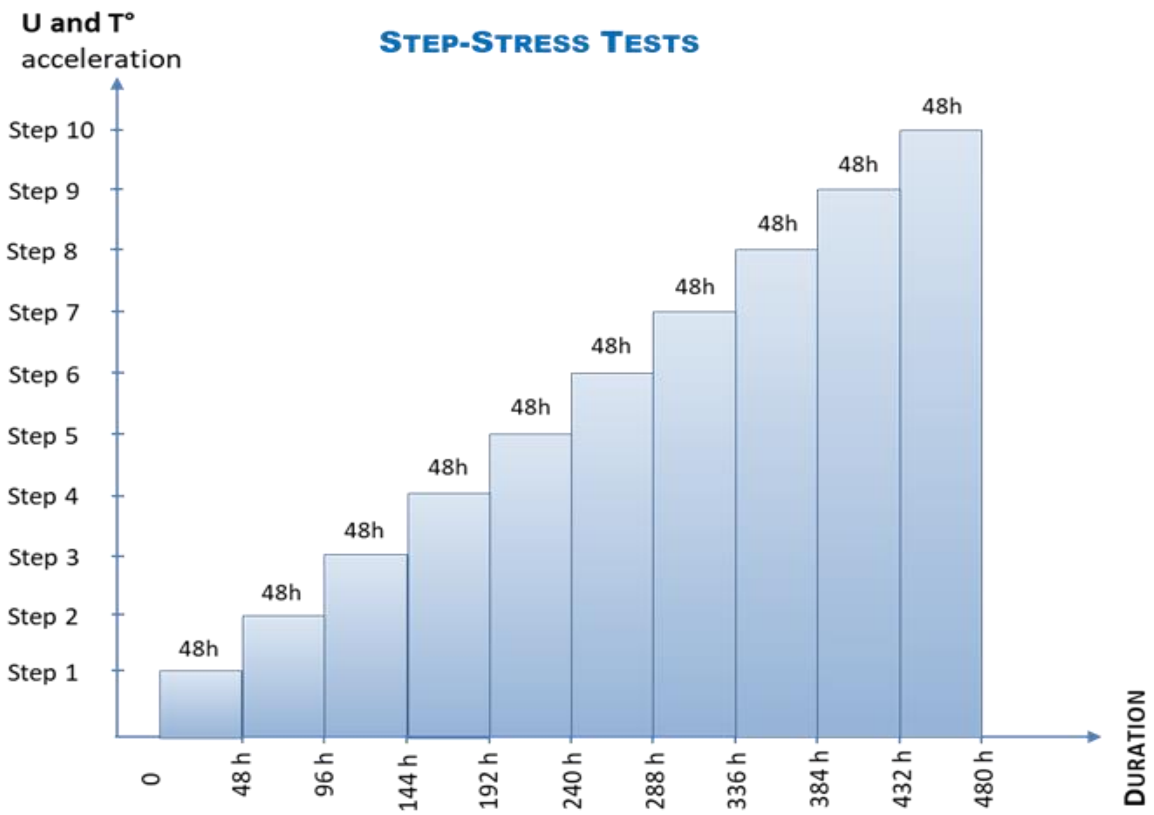
Goals : to define acceleration factors, EOL characteristics, demonstrate the open circuit failure mode, reliability level

Ongoing tests since 2019

Voltage Step-Stress
$U_{n+1} = U_n + 0{,}2 \, . \, U_{RC}$
at constant temperature

Temperature Step-Stress
$T_{n+1} = T_n + 10°C$
under constant voltage



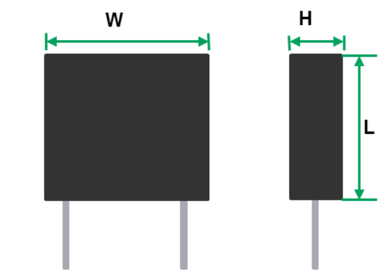


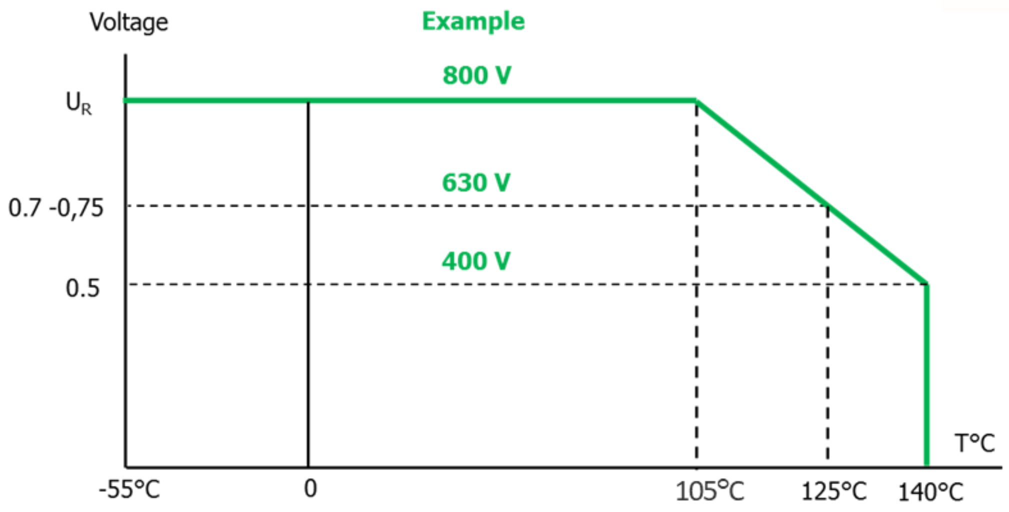
MML Evaluation Tests – Example of Step-Stress testing

MML cap Element

Dimensions (mm)	L = 55	W= 21,3	H = 4

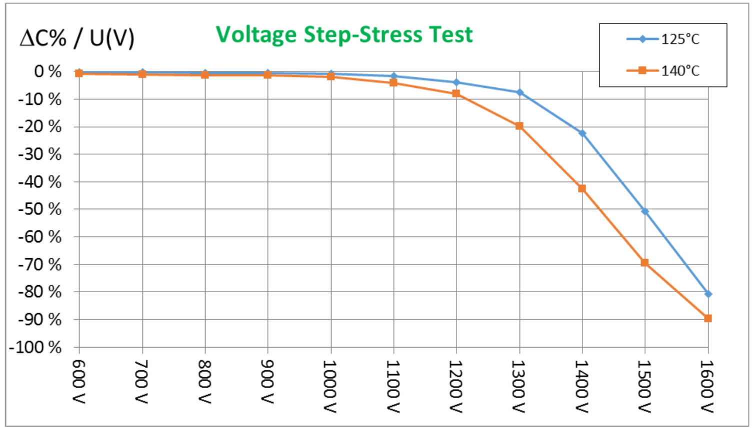
C @ 1 kHz	7,25 µF ± 10%		
U_R	800 V_{DC}		
Operating temperature	-55 °C / +140 °C		
DF @ 1 kHz	≤ 70 .10^{-4}		
IR @ (500V- 1min)	≥ 2200 MΩ		
Dimensions*	L = 60 mm	W = 30 mm	H = 9 mm

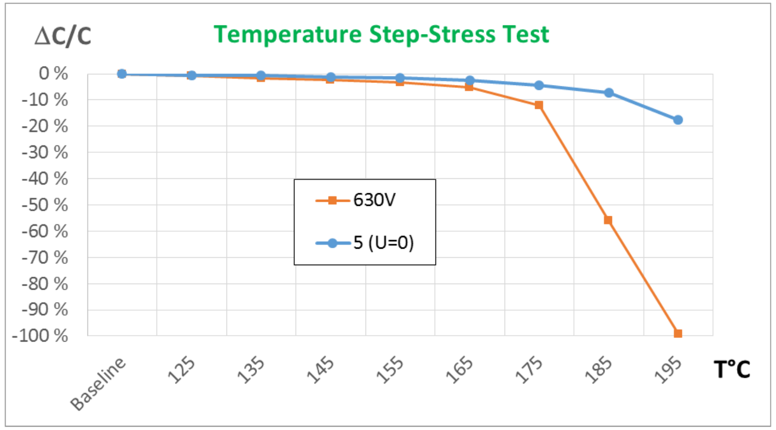


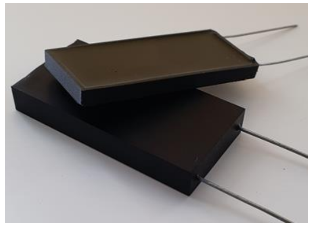


Voltage Step-Stress up to 2*Ur without any short-circuit failure thanks to selfhealing behavior (step 48h at 125°C and 140°C).

T° Step-Stress (step 48h under 630V) validated up to 180°C with stable characteristics and no short-circuit failure.



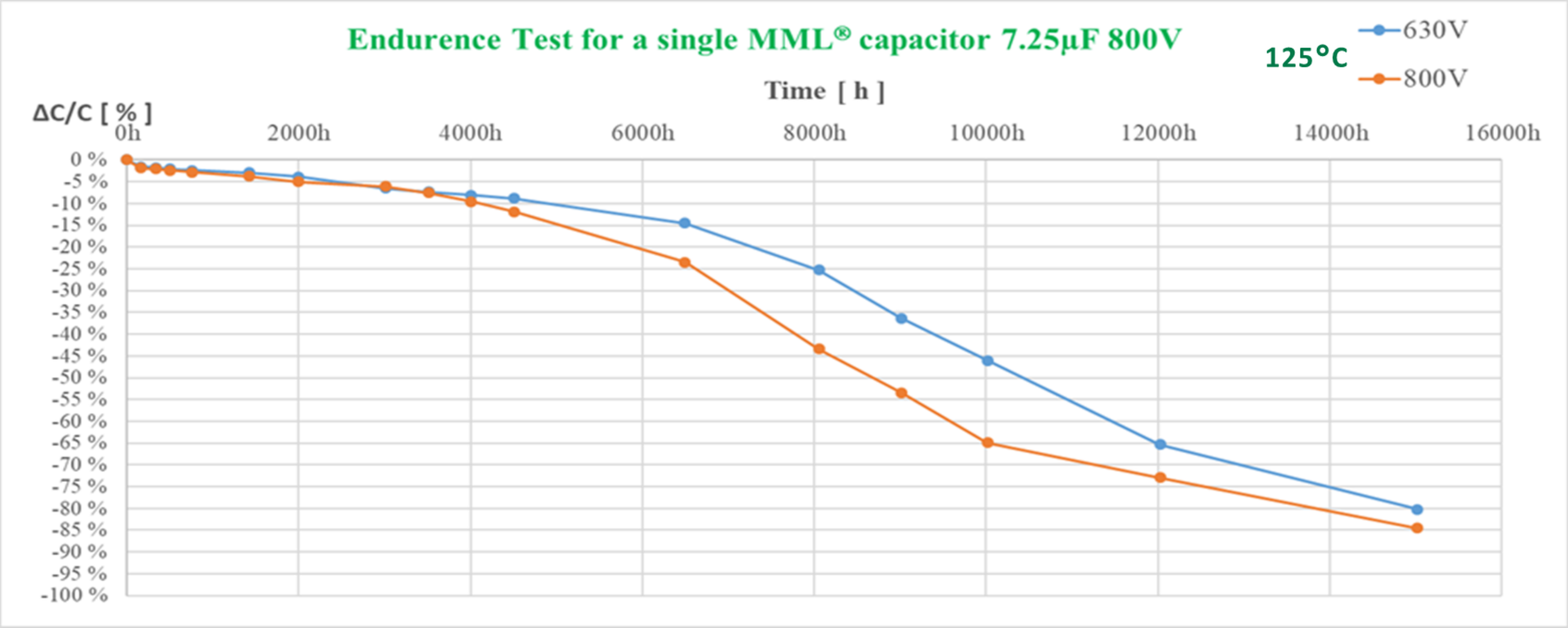




MML Evaluation – Steady-State Accelerated Life Tests

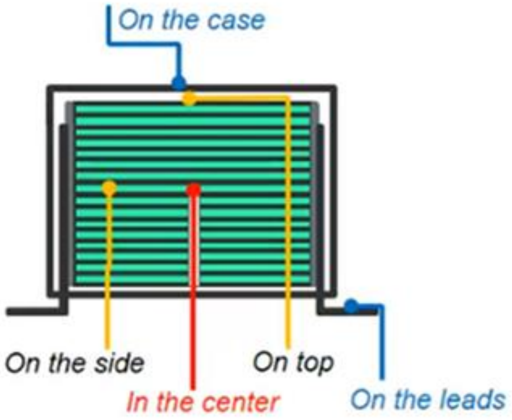
Example of MML capacitor long endurance testing at 125°C

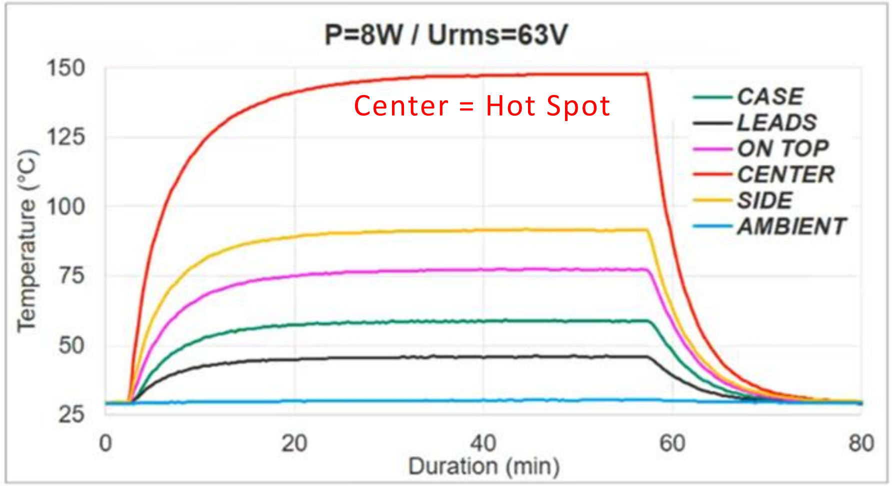
More than 15 000 hours testing for Open-Circuit Failure Mode demonstration



MML Thermal Management Evaluation

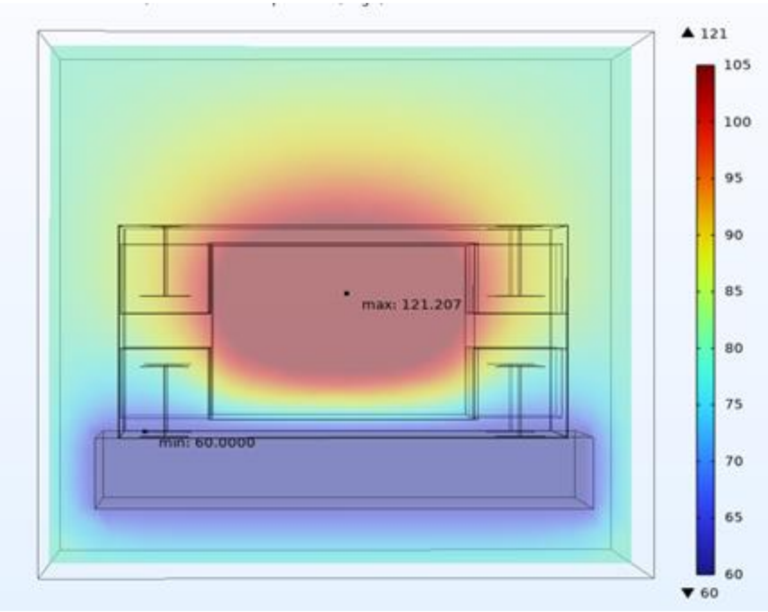
Example of R_{TH} evaluation





The size reduction of the MML capacitors has the consequence of decreasing the external surface needed for the thermal exchange.

For high-power filtering, a compromise must be made between size reduction and capacitance value in order to limit the ripple current and internal heating.



Multiscale modeling for a capacitor integrated on cooled base plate