Exxelia's Path to RoHS: Ensuring Reliability in Next-Generation Space capacitors

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1.Introduction

The space industry is transitioning to RoHS standards to align with global environmental protection regulations. This paper outlines the methodology and roadmap aimed at defining and validating accurate mounting and soldering profiles (time, temperature), as well as the surface treatment of the capacitors terminals enabling the transition to lead-free alloys while keeping at least the same electrical and mechanical performances of the capacitors without any impact on their lifetime and reliability. Additionally, improving energy density remains a key target.

To maintain flight safety standards during this industrial transition, compliance with established ESCC qualification frameworks is required. The qualified film capacitor series summarized below serve as the technical baseline for this upcoming evaluation campaign.

2.Background of the company

For over 50 years, EXXELIA has manufactured capacitors across multiple technologies (film, mica, ceramic, tantalum, and aluminum). Our extensive expertise in metallized film capacitor production allows us to manage more than 10 different dielectrics, enabling the selection of optimal film technology for design and process optimization. Recognized as a high-reliability passive component supplier for space applications, our company is an ESCC and MIL Qualified Manufacturer. Within the space sector, EXXELIA features over 30 product series listed in the EPPL and QPL, including 4 metallized film capacitor series qualified (QPL) by ESA, as detailed in Table 1:

Table 1. ESA qualified film capacitor series (QPL)

Reference	ESCC Qualification Number	Date of Qualification	Detailed ESCC specification
Ref1	353	06/2020	3006/020
Ref2	353 (ex. 270)	03/2002	3006/024
Ref3	353 (ex. 338)	03/2016	3006/025
Ref4	353 (ex. 338)	03/2016	3006/026

While this qualified baseline provides a foundation for our test vehicles, moving from traditional SnPb solder to lead-free alloys introduces severe physical constraints that must be thoroughly addressed.

3.Critical technical challenges

This transition faces several critical challenges, starting with the significant thermal gap during the reflow process, a peak temperature increase of around 30 °C (reaching up to 245 °C–250 °C) between traditional SnPb soldering and lead-free alloys. This increase in peak reflow temperature could induce thermal stress or degradation in the metallized polyester (PET) dielectric film, potentially impacting the electrical and mechanical characteristics of the capacitors. Beyond thermal sensitivity, a second challenge is the growth of Intermetallic Compounds (IMC) which is accelerated by lead-free soldering. Furthermore, the process window narrowing requires a precise balance between wetting optimization (to ensure a strong bond) and the control of voiding (gas bubbles) within the solder joints. These factors define the strict boundaries of the new assembly process to prevent mechanical failure during launch vibrations. Overcoming these limitations requires a dual strategy involving material benchmarking and precise soldering profile control.

4.Proposed methodology

To address these issues, the adapted methodology integrates a market survey of alternative dielectrics (PPS, PEN, PP) and the use of an internal database for multiphysics modeling to simulate thermal distribution. Experimental validation involves specialized tinning lines and high-purity solder formulations. Evaluation is performed through SEM : scanning electron microscopy equipped with an EDS detector, alongside proprietary vibration and thermal shock tests to verify the robustness of the new RoHS-compliant design. In parallel, for solder joint reliability under space environments, tests will be conducted (thermal cycling, vibration, mechanical shock, long-term life tests) on soldered capacitor samples according to ESCC standards. A detailed failure analysis on any failed units will be performed.

Building on this dual approach, Exxelia proposes to develop optimized lead-free soldering profiles that will be thoroughly evaluated and validated through a full test protocol on PCB reflowed SMD capacitors.
This activity defines the technical baseline for the ESCC qualification of downsized RoHS range. It ensures that lead-free PET capacitors meet the high-reliability standards required for next-generation satellite constellations, providing a safe path for the industry's ecological transition. As detailed in the 24-month project execution roadmap in Appendix A (Figure A.1), the first operational step focuses on dielectric screening and market benchmarking.

5.Material screening and benchmarking

5.1.Market survey and literature review

A market survey was conducted to analyze current offerings for SMD film capacitors, focusing on suppliers targeting industrial or non-space applications. Table 2 compares representative series and their technical specifications across various dielectrics (PET, PET-HT, PEN, PPS), manufacturing technologies (stacked vs. wound), and construction types (encapsulated vs. bare). These commercial offerings mainly focus on lower capacitance values. To complement this market survey, a targeted literature review has been initiated to assess lead-free soldering risks and long-term joint in high-reliability environments [1–3].

Table 2. SMD film capacitors : Comparative matrix of competitor offerings

Manufacturer	Dielectrics	Key Series	Technology	Capacitance Range	Voltage Range (V_{DC})	Re-flow soldering T_{max}°C
C1	PET	Serie C1.1	Wound/Box encapsulated	0.01µF – 6.8 µF	63 V – 1000 V	220° - 250°
	PPS	Serie C1.2		0.01µF – 2.2 µF		250°
C2	PEN	Serie C2.1	Stacked/Bare	0.001µF – 4.7 µF	50 V – 1000 V	250° - 255°
	PPS	Serie C2.2		3,3nF – 0.1 µF	16 V – 50 V	250° - 260°
C3	PEN	Serie C3.1	Stacked/Bare	0.001µF – 1 µF	100 V - 630 V	240° - 250°
	PPS	Serie C3.2		1nF – 0.22 µF	16 V – 50 V	260°
C4	PET-HT	Serie C4	Stacked/Bare	10nF – 4.7 uF	63 V – 630 V	240° - 245°
	PEN			1nF – 4.7 nF	25 V – 630 V	250° -255°
	PPS			1nF – 180 nF	16 V – 50 V	260°

Lead-free soldering presents significant manufacturing risks for space electronics due to higher reflow temperatures, increased surface tension, and potential thermal shock defects [1, 2]. However, literature shows careful optimization of the reflow process profile enables lead-free joints (such as Sn Ag-Cu) to exceed 2,000 thermal cycles under severe aerospace conditions, matching or exceeding traditional SnPb endurance [3]. Consequently, selecting lead-free compatible components combined with with custom-tailored thermal profile is essential to guarantee long-term performance for space-qualified designs.

5.2.Dielectric property trade-off analysis

While multiple film types are used across the market, a specific choice must be made regarding which film will be suitable for our requirements. The following decision matrix evaluates the intrinsic properties of various dielectrics to identify the most suitable candidate for our application :

Table 3. Film Dielectric Property Comparison

Property	**PP (Standard)**	**PPHT**	**PET (Standard)**	**PET-HT**	**PEN**	**PPS**
Polarity	Non-Polar	Non-Polar	Slightly Polar	Slightly Polar	Slightly Polar	Non-Polar
Relative Permittivity	2,2	2,2	3,2	3,2	3	3
Lab Breakdown	600 V/µm	700 V/µm	350 V/µm	350 V/µm	300 V/µm	350 V/µm
Operating voltage stress	200-250 V/µm	200-250 V/µm	125 V/µm	125 V/µm	100 V/µm	80 V/µm
Melting point Temperature	168°C	173°C	255°C	255°C	265°C	285°C
Max operating Temperature	105°C	140°C	125°C	145°C	150°C	180°C
Self-Healing	Excellent	Excellent	Good	Good	Moderate	Poor
Min, Thickness (µm)	2,2	1,9	0,9	1,7	1,4	1,2
Dissipation Factor (ESR)	Very Low	Very Low	High	High	Moderate	Low
Conclusion	**(-) :** Melting point (168°C) is too low for reflow. Low relative permittivity prevents miniaturization. **REJECTED**	**(-) :** Melting point (168°C) is too low for reflow. Low relative permittivity prevents miniaturization. **REJECTED**	**(-) :** Melting point and Max temperature low for lead-free reflow. **CANDIDATE**	**(-) :** Lower gradient requires thinner films, limiting miniaturization. (Availability) **CANDIDATE**	**(-) :** Limits high-gradient designs. **CANDIDATE**	**(-)** Poor self-healing; limits miniaturization. **REJECTED**

PET, PET-HT and PEN emerge as the primary candidates, offering a better balance between high-temperature resistance, self-healing capability, and dielectric thickness for component miniaturization.

6.Soldering profile optimisation and thermal control

Existing industry reflow recommendations provide a useful baseline; however, studying and adapting these profiles to high-reliability space constraints is required. Dedicated thermal tests will subsequently be performed to guarantee long-term component reliability. As shown in the reflow curve in Figure. 1, the soldering process is divided into three main phases: pre-heating, soldering (reflow), and cooling.

Optimization focuses on controlling key critical parameters across each phase:

- Pre-heating phase: Adjusting temperature, duration, and ramp rate to prevent thermal stress, specifically respecting the dielectric's glass transition temperature T_g.
- Soldering phase: Optimizing reflow slope, peak temperature, and duration above liquidus to ensure proper wetting and minimal voiding while protecting the capacitor core.
- Cooling phase: Controlling the cooling ramp-down rate to eliminate micro-cracking risks from thermal shock.

Temperature regulation ensures that the component's hotspot accurately tracks the target profile without overshoot. Furthermore, the component's internal heat treatment during manufacturing will be optimized, as it is a critical lever for thermal endurance against lead-free reflow peaks.

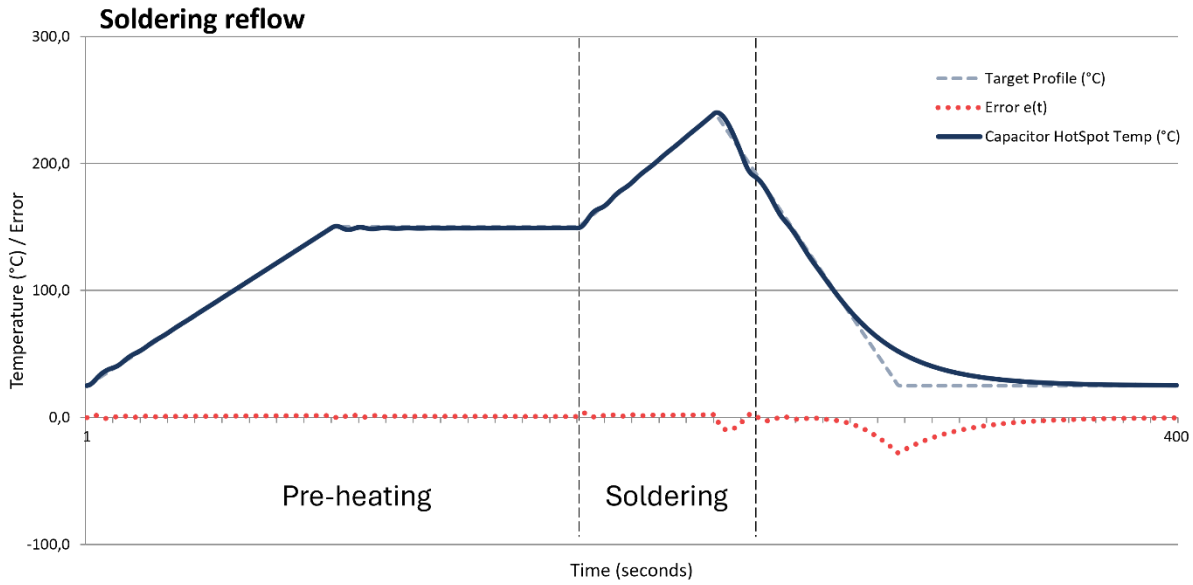


Figure 1. Reflow Soldering Profile

7.Scope of the work

Based on the trade-off evaluation and heritage baseline, the primary test campaign focuses on Exxelia PM series film capacitors, which feature a PET dielectric commonly employed in space applications. Particular emphasis is placed on surface-mount device (SMD) variants suitable for reflow soldering. The manufactured test vehicles encompass a capacitance range from 0.82 µF to 15 µF and rated voltages between 50 Vdc and 630 Vdc, as detailed in Table 4

Table 4. Test vehicles to be manufactured

Reference	Quantity	Capacitance (µF)	Voltage (Vdc)	Terminals	Dimensions (mm)
Ref1 0.82µF 400V	100	0.82	400	R1	20x6.5x20
Ref3 10µF 250V	75	10	250	R2	20x20x20
Ref2 15µF 63V	75	15	63	SMD	16,5x14x15,5
Ref4 1,2µF 630V	100	1,2	630	SMD	18,5x17x17
Ref4 10µF 50V	75	10	50	SMD	18,5x6x17
Ref4 12µF 170V	75	12	170	SMD	18,5x17x17

8.Conclusion

This paper outlines the strategic roadmap for qualifying Exxelia's RoHS-compliant SMD film capacitors for space applications. While currently at its inception, the project sets a rigorous framework across six Work Packages to overcome lead-free soldering challenges and demonstrate that space-grade performance is maintained . The immediate next steps focus on initial sample tinning and reflow profile optimization, paving the way for comprehensive thermal and endurance evaluations to secure full ESCC compliance.

References

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[2] BRIGGS, Ed et LASKY, Ron. Best practices reflow profiling for lead-free SMT assembly. In : SMTA International. Surface Mount Technology Association, 2009. p. 639-645.

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Appendix A : Project schedule

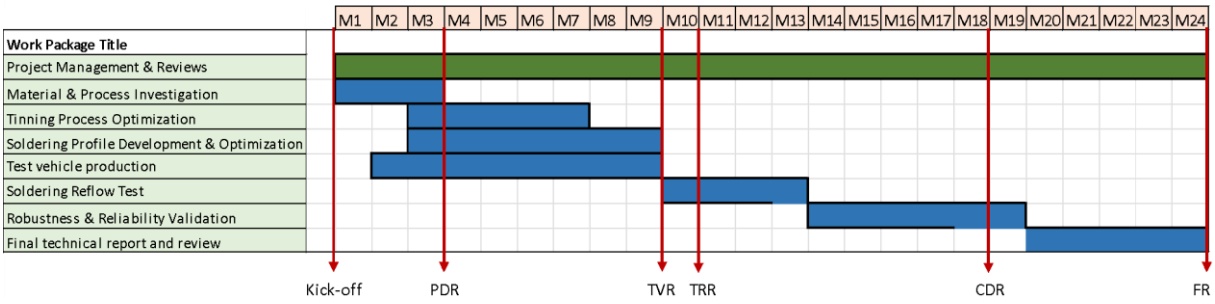


Figure. A.1 — 24-Month project roadmap and ESA key milestones.