ALTER TECHNOLOGY TÜV NORD
SILICON CAPACITORS – DEVELOPMENT AND SPACE PRE-EVALUATION

SPCD OCTOBER 10TH – 14TH,2016

CONTENTS

- **VERY SHORT** INTRODUCTION TO ALTER TECHNOLOGY
- PROJECT **MOTIVATION**
- PRELIMINARY **SURVEY**
- INTRODUCTION TO **IPDIA**
- **TEST** FLOW
- SUMMARY OF **TEST RESULTS**
- **CONCLUSIONS**

ALTER TECHNOLOGY **TÜV NORD**

- 10,000 employees worldwide
- Wide range of expertise
- One of the leading international technology service providers
- Services extend far beyond traditional TÜV activities – now covering IT, **Aerospace**, Natural Resources and many others

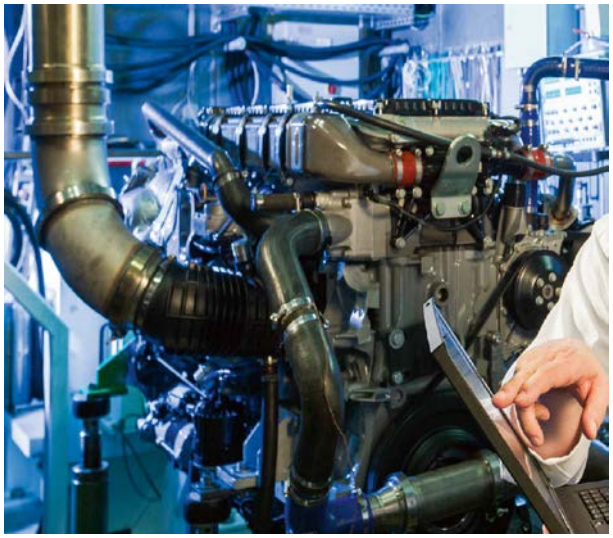
KEY FIGURES

	2014 € million	2013 € million
REVENUE	1,089.5	1,056.4
EBDIT (before non-operating items)	89.5	73.0
EBIT (before non-operating items)	58.8	43.7
EBT	49.2	34.5
EAT	29.4	19.0
TOTAL ASSETS	776.6	745.9

TÜV NORD GROUP MAIN FIELDS

ENERGY

IT



MOBILITY

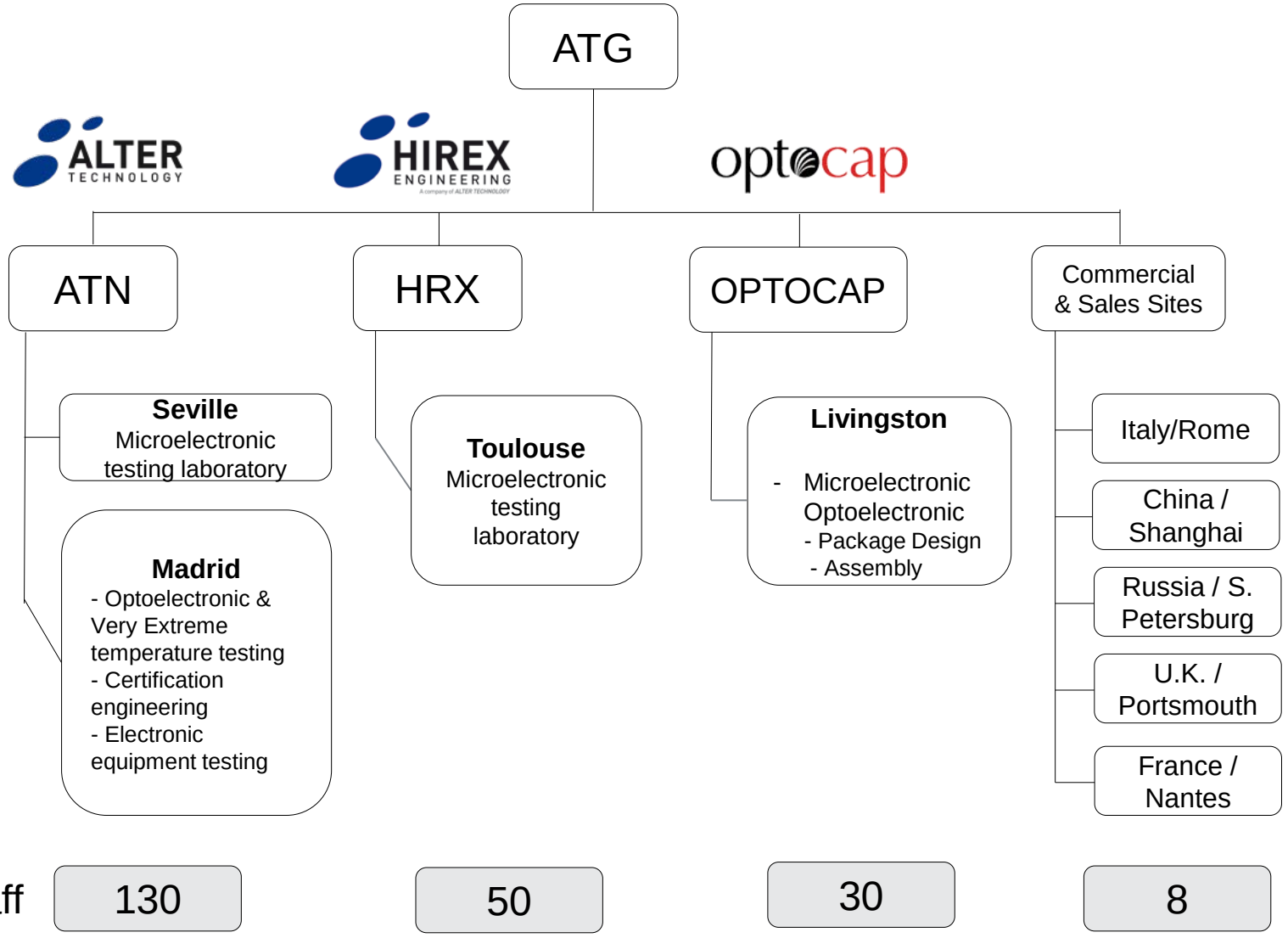
HEALTH AND NUTRITION

NATURAL RESOURCES

AEROSPACE & ELECTRONIC

ALTER TECHNOLOGY TÜV NORD

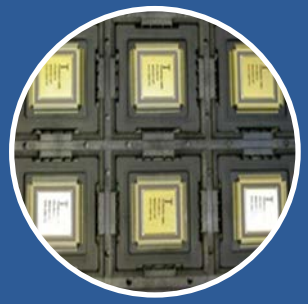
SIMPLIFIED ORGANIZATION



OBJECTIVE

- **To become a single solution provider** for all parts selection, design, procurement, testing and validation activities, including:

- Requirements Definition
- Parts selection



- Procurement
- Product Design
- Packaging

- Test benchs development
- Reliability Testing
- Failure Analysis
- Storage

ATN STRATEGY ON EXTREME TEMPERATURE

New space missions include more extreme requirements of storage and operational temperatures and vacuum conditions exceeding standard -55ºC / +125ºC conditions

Miniaturization implies increase higher power dissipation and hence max junction and PCB temperatures

ALTER TECHNOLOGY ACTIVITIES

- Parts reliability assessment to ensure mission performance
- Characterization of existing technologies under such extreme temperature conditions
- Understanding of failure mechanism
- Development of specific NEW parts for very extreme application
- Assessment on new packages and assembly methods

Name	*Summary*	*YEAR (Contract Signature)*	*Main Program*	*ATN Role*
Characterization of Commecially available SiC JFET	*Full characteerization of SiC JFET & SiC MOSFET to evaluate feasibiity for space application*	2012	ESA -TRP	Prime
1200V Schottky diode	*Development of a 1200V SiC Shotkky diode for Space Applications*	2013	ESA -TRP	Partner
CSP AND MCM-L (NON HERMETIC): LOW TCE HDI SUBSTRATES FOR FLIP-CHIP	*Thermal characterization of new soldering tecquniques for high pin count devices*	2013	ESA -TRP	Prime
Passive parts for extended temperature range	*Upgrading of maxium rating criteria for resistors and capacitors with extended operating temperature for GaN related applications*	2013	ESA - ECI	prime
Development and pre-evaluation of Silicon Capacitors	*Evaluation of current available silicon capacitors to asses feasibility for space application*	2014	ESA -TRP	Prime
Evaluation of SiC MOS structures	*Detailed evaluation of different SiC MOS structures regarding foundry selection and oxidation processes*	2014	ESA -TRP	prime

Motivation (I)

Ref. ESA ITT 7673

It is believed that the **recent improvement in silicon capacitor technology** might provide very **interesting advantages such as stable capacitance value over the operating temperature range (up to 200C-250C)** or small dimensions. In addition, these new types of silicon capacitors might be used in different kind of application (DC/DC converter, power decoupling, RF application, etc.) with quite low voltage.

Silicon capacitor might replace advantageously, due to relative small height, **Ceramic capacitor type I** (low capacitance value), and even **ceramic capacitors type II** (low voltage application, i.e. close to Integrated circuit). GaN application which requires high temperature components would also benefit a high temperature (200C-250C) silicon capacitor range.

However, **relevant data demonstrating the high reliability**, claimed by Silicon capacitor manufacturers shall be provided to **confirm parts suitability for space application.**

Initial survey

Literature survey & Questionnaire details as follows

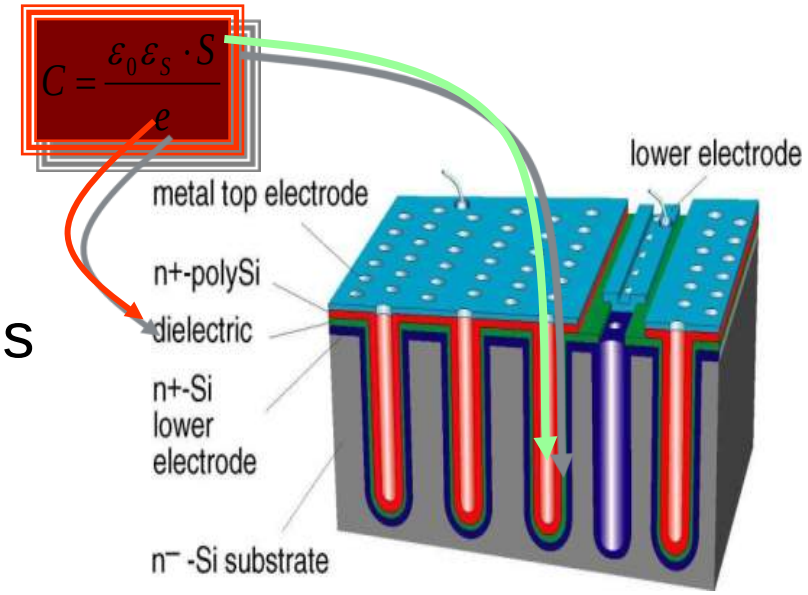
- Potential manufacturers for Silicon Capacitors
- Export license requirement
- Forbidden materials and materials not compliant with outgassing requirements
- Lead & surface termination data
- Availability of specific mounting requirements.

⇒ **Identification of potential manufacturers**

Introduction to IPDIA technology (I)

KEY FEATURES FOR HIGHLY INTEGRATED CAPACITORS

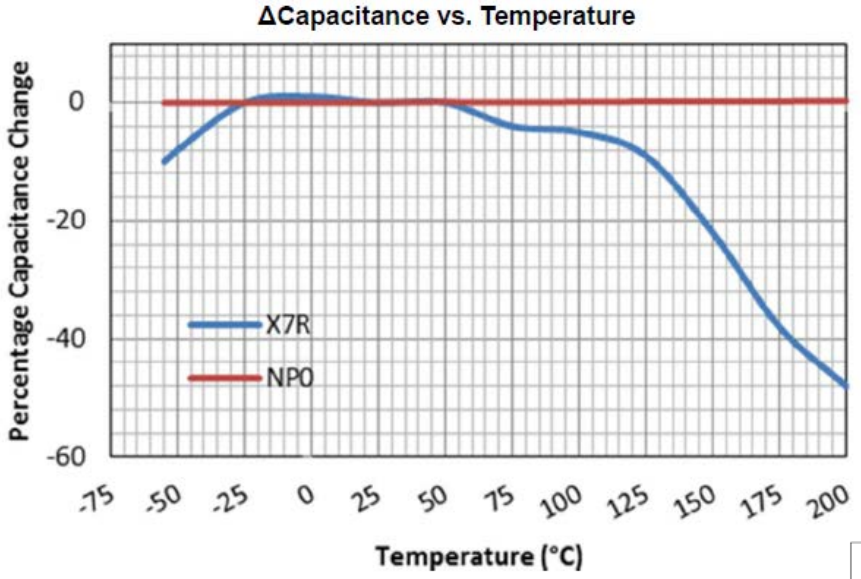
- Increase the effective capacitor surface by etching 3D structures with high aspect ratio.
- Suitable high k material with appropriate deposition techniques
  - High permittivity
  - High breakdown voltage > 10V
  - Low leakage current
  - Excellent linearity vs temperature (62ppm/C°) and voltage (100ppm/V)
  - High reliability

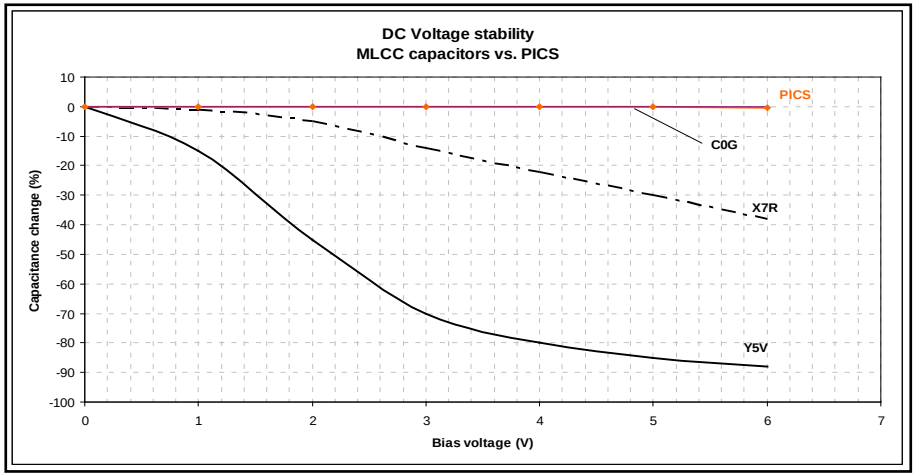


Introduction to IPDIA technology (II)

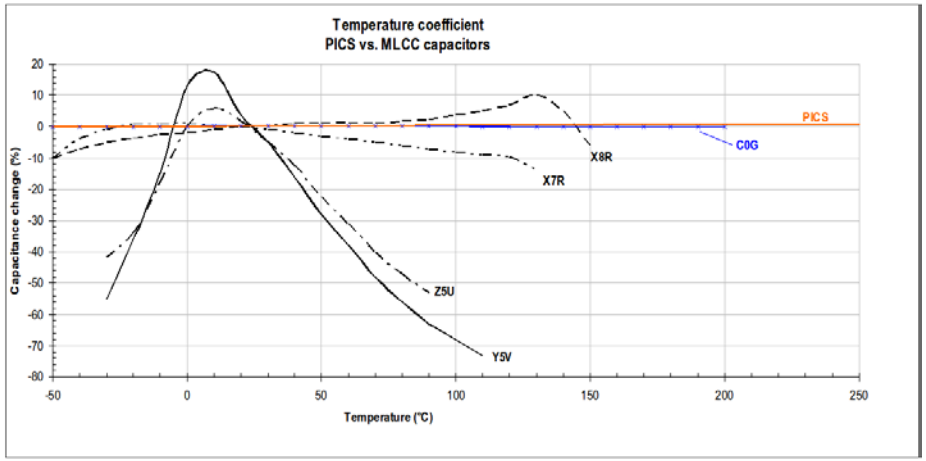
STABILITY UPON TEMPERATURE

MLCC performances up to 200°C





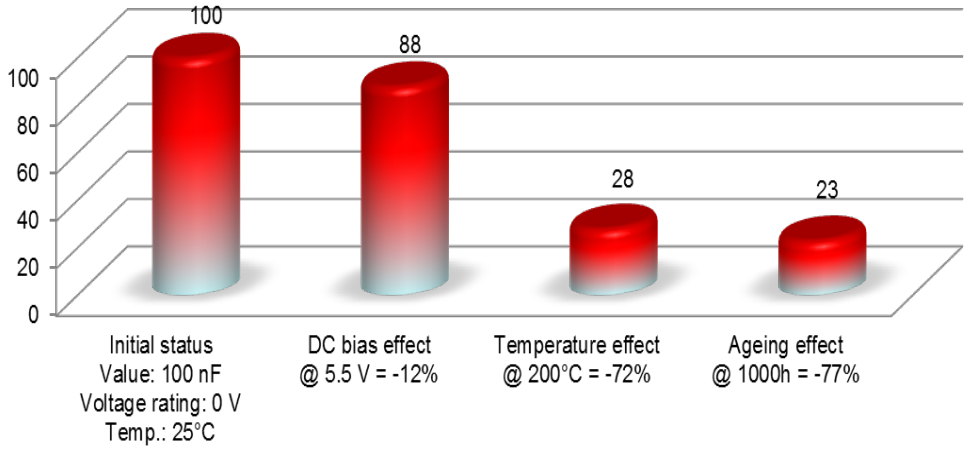
SiCap performances up to 250°C



Introduction to IPDIA technology (III)

Really need 100nF ?

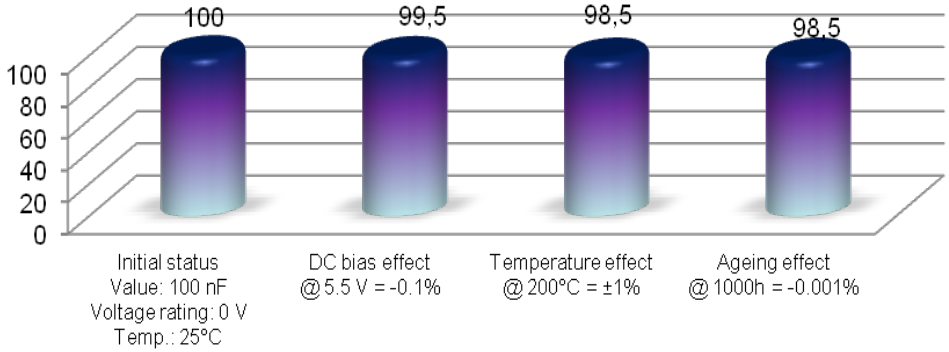
For X8S 0402 100nF capacitors the cumulated derating @ 200° C is -77 %



Unique low derating:

100nF SiCap in **0402** instead of :
-470nF X8S MLCC (**0805**)
Or
-100nF NPO in **1206**

SiCaps stability performances

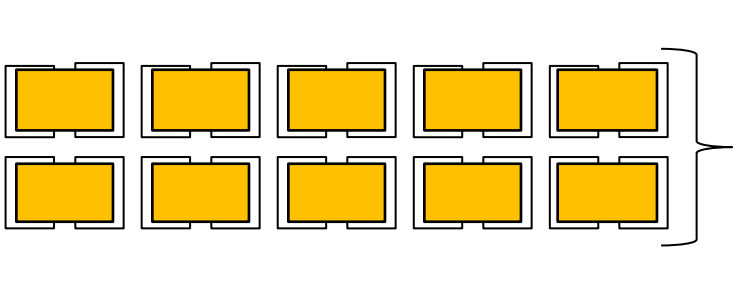


Introduction to IPDIA technology (IV)

Space saving on boards thanks to PICS capacitor density

100 nF : PICS vs. C0G/NPO capacitors

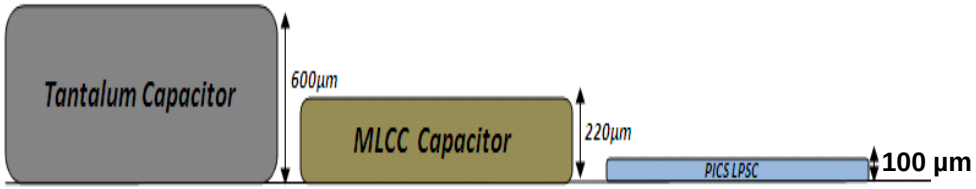
1 IPDiA capacitor
100 nF
« 0402 »



10 0603 10nF NPO

Surface at least 10 times smaller

The lowest profile: PICS vs. MLCC and tantalum capacitors

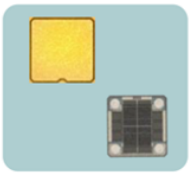


Silicon Capacitors – Development and Space Pre-evaluation

Selected technology for evaluation tests

Wirebound & Embedded Silicon Capacitors

Styles	Dimensions	Op. Temp.	Range	Br. V	Tem. Coeff.
EMSC	0202 to 2016	-55 to +150	100nF – 4.7uF	11V	<+/- 0.5%
EMSC	0202 to 2016	-55 to +150	10nF – 1uF	30V	<+/- 0.5%
ETSC	0202 to 2016	-55 to +200	10nF – 1uF	30V	<+/- 0.5%
ETSC	0202 to 2016	-55 to +200	10nF – 1uF	30V	<+/- 0.5%
EXSC	0202 to 2016	-55 to +250	10nF – 1uF	30V	<+/- 0.5%
EXSC	0202 to 2016	-55 to +250	10nF – 1uF	30V	<+/- 0.5%

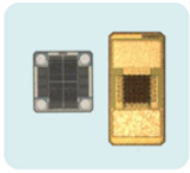


Wirebond Silicon Capacitors

- Vertical Silicon Capacitors (WBSC)
  Broadband and RF communication modules
- Wirebond & Embedded Silicon Capacitors (EMSC)
  Bypass capacitor applications

High Stability & Reliability Silicon Capacitors

Styles	Dimensions	Op. Temp.	Range	Br. V	Tem. Coeff.
HSSC	0201 to 1812	-55 to +150	100nF – 3.3uF	11V	<+/- 0.5%
HSSC	0201 to 1812	-55 to +150	10nF – 47nF	30V	<+/- 0.5%



High Temperature Silicon Capacitors

- High Temp. Silicon Capacitors 200 °C (HTSC)
  Downhole equipment, avionics
- Xtreme Temp. Silicon Capacitors 250 °C (XTSC)
  Downhole equipment, avionics

Low Profile Silicon Capacitors

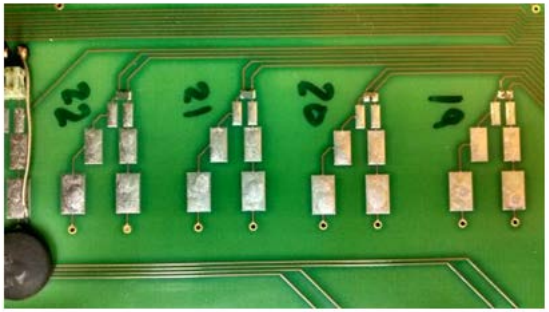
Styles	Dimensions	Op. Temp.	Range	Br. V	Tem. Coeff.
LPSC	0105 to 1812	-55 to +150	100pF – 1uF	11V	<+/- 0.5%
LPSC	0101 to 1812	-55 to +150	10nF – 47nF	30V	<+/- 0.5%

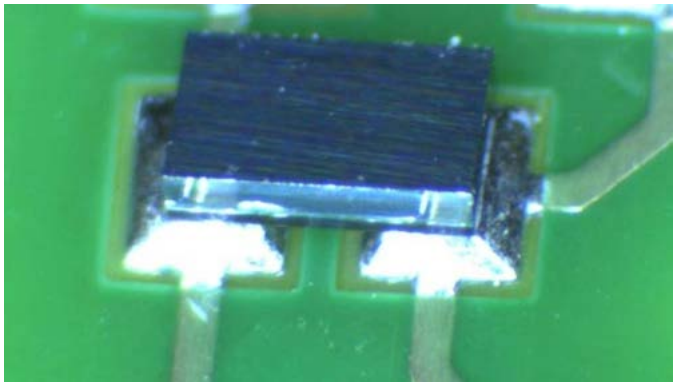
STYLE	Value	Case size	BV (V)
HSSC	100 nF	0603	11
	1 µF	1206	11
	47 nF	0402	30
LPSC	100 nF	0603	11
	1 µF	1206	11
	33 nF	0402	11
EXSC	3.7 µF	1616	11

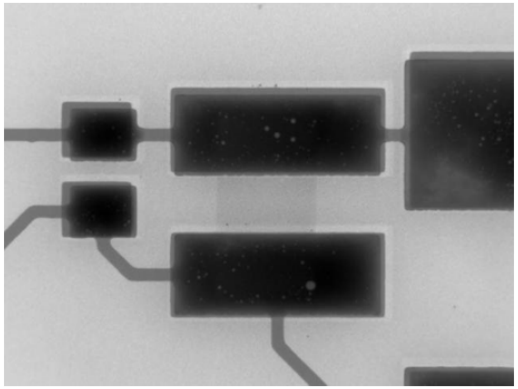
Proposed Test Flow & Test Setup

STEP STRESS TEST	ENVIRONMENTAL TESTS	ENDURANCE TESTS	RADIATION TESTS

Reliability and environmental tests such as **V-T step stress, life endurance, thermal and vibration tests** were carried out with HSSC and LPSC components. Regarding radiation tests, HSSC and LPSC capacitors were irradiated up to **300 krad gamma radiation** dose
Furthermore, **SEE (single event effect)** test was carried out with EXSC capacitors







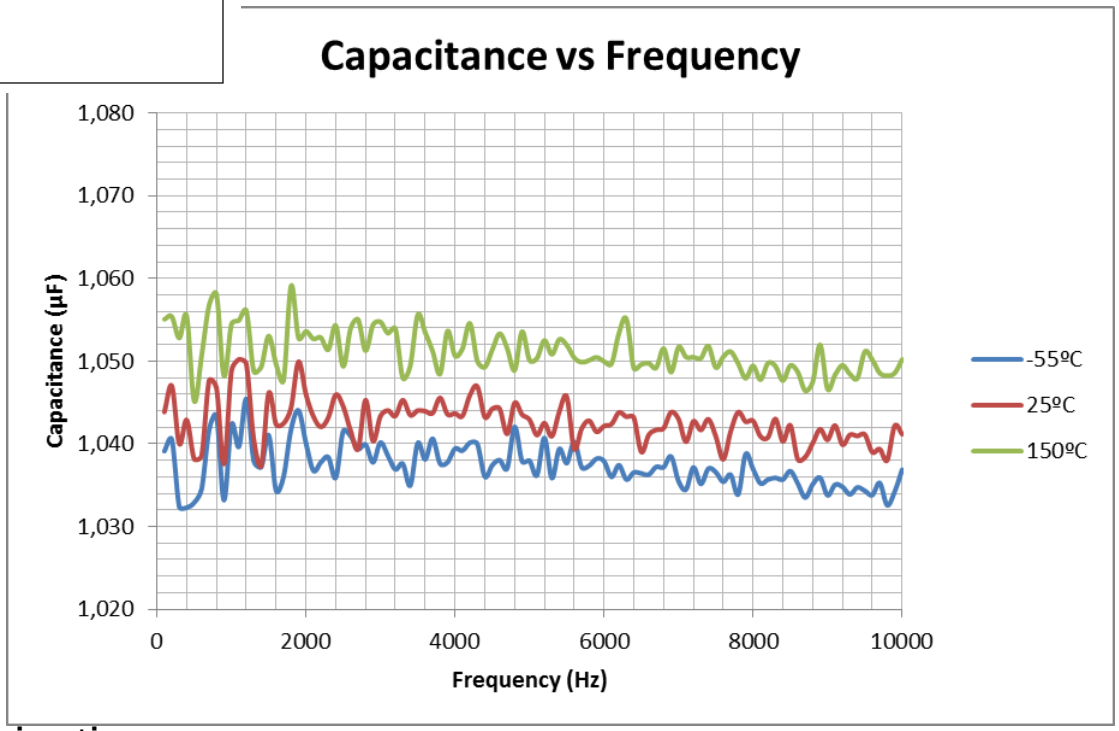
Summary of tests results

- Electrical Characterization
- Step Stress
- Endurance test
- Radiation test

Summary of tests results

- **Electrical Characterization**

Parameters	Test conditions and Limits
- Capacitance - Equivalent Series Resistance - Equivalent Series Inductance - Insulation Resistance - Voltage Proof – Dielectric - Voltage Proof – Body Insulation - Tangent of Loss Angle - Leakage current	Min - Ambient and Max temp as per applicable data sheet



Example of preliminary characterization:
1 µF HSSC silicon capacitors capacitance values for frequencies up to 10 kHz at temperature values of T=-55ºC, 25ºC and 150ºC

Summary of tests results

- **Step Stress**

Step	Voltage (V)	Voltage (V) (Only HSSC 47 nF)	Temperature (ºC)
1	5.5	15	125
2	5.5	15	135
3	5.5	15	145
4	5.5	15	155
5	5.5	15	165

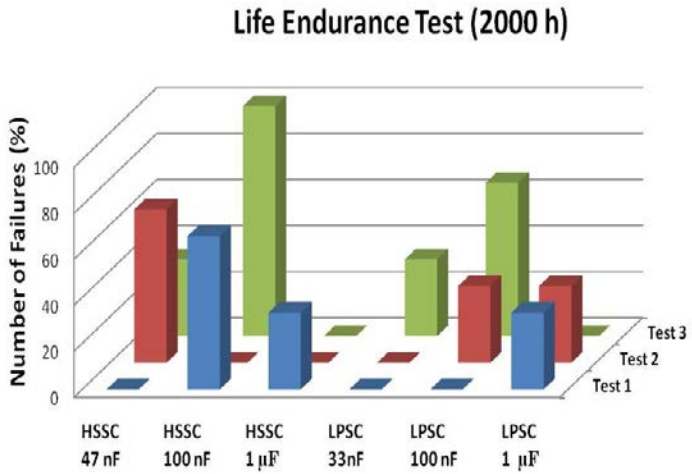
Step	Voltage (V)	Voltage (V) (Only HSSC 47 nF)	Temperature (ºC)
1	5.5	15.0	150
2	6.6	18.0	150
3	7.9	21.6	150

Type of component	Step 1	Step 2	Step 3	Final test result
HSCC 47nF	0/3	1/3	0/2	1/3
HSCC 100nF	0/3	0/3	2/3	2/3
HSCC 1uF	0/3	0/3	0/3	0/3
LPSC 33 nF	0/3	0/3	2/3	2/3
LPSC100 nF	0/3	1/3	1/2	2/3
LPSC1 uF	0/3	0/3	0/3	0/3

Summary of tests results

- **Endurance test**

Test	Temperature (°C)	Voltage (V)	Expected Lifetime (MTF) (*)
1	T_0= 150ºC	V_0= 5.3V/14.45V for HSCC 47nF	94.4 days 2264 h ± 400 h
2	T_0 = 150ºC	V_0=5.5V/15V for HSCC 47nF	59.1 days 1410 h ± 376 h
3	T_0 = 170ºC	V_0=5.5V/15V for HSCC 47nF	46.7 days 1121.76 h ± 319.15 h

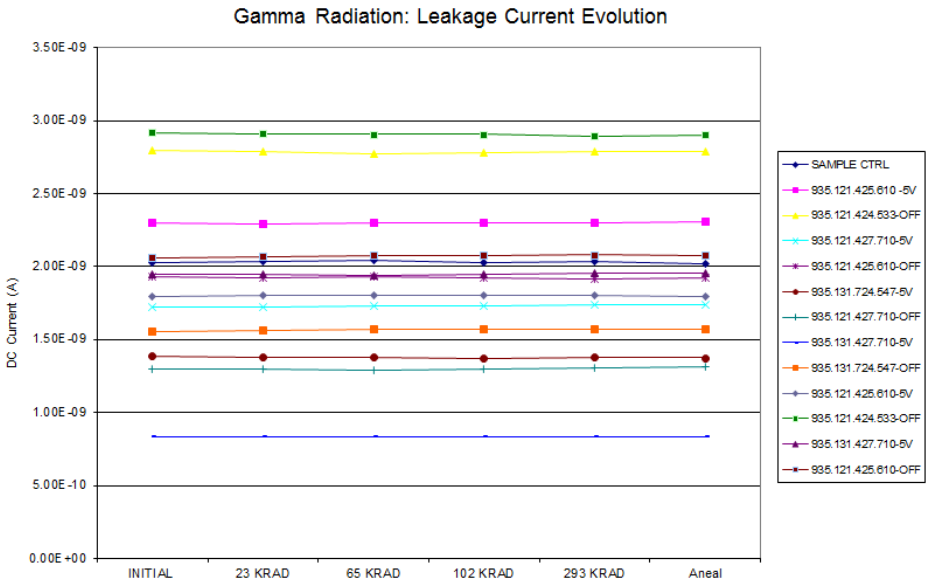


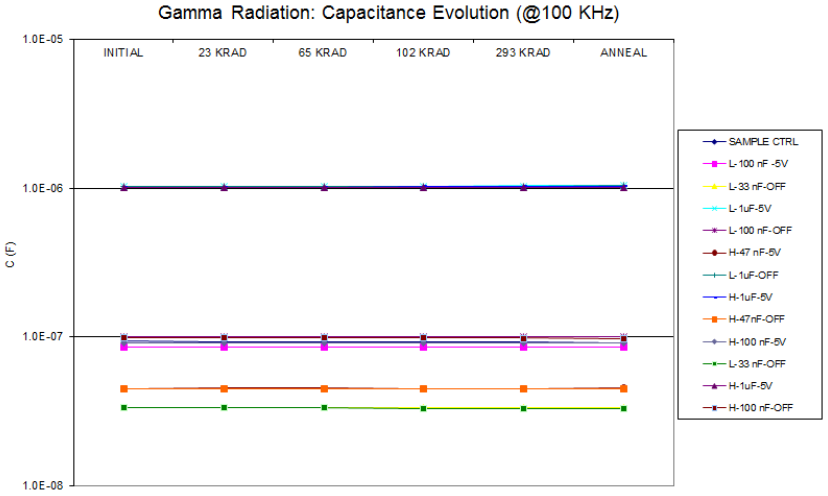
(*) Based on initial simulations

Summary of tests results

- **Radiation Tests:**

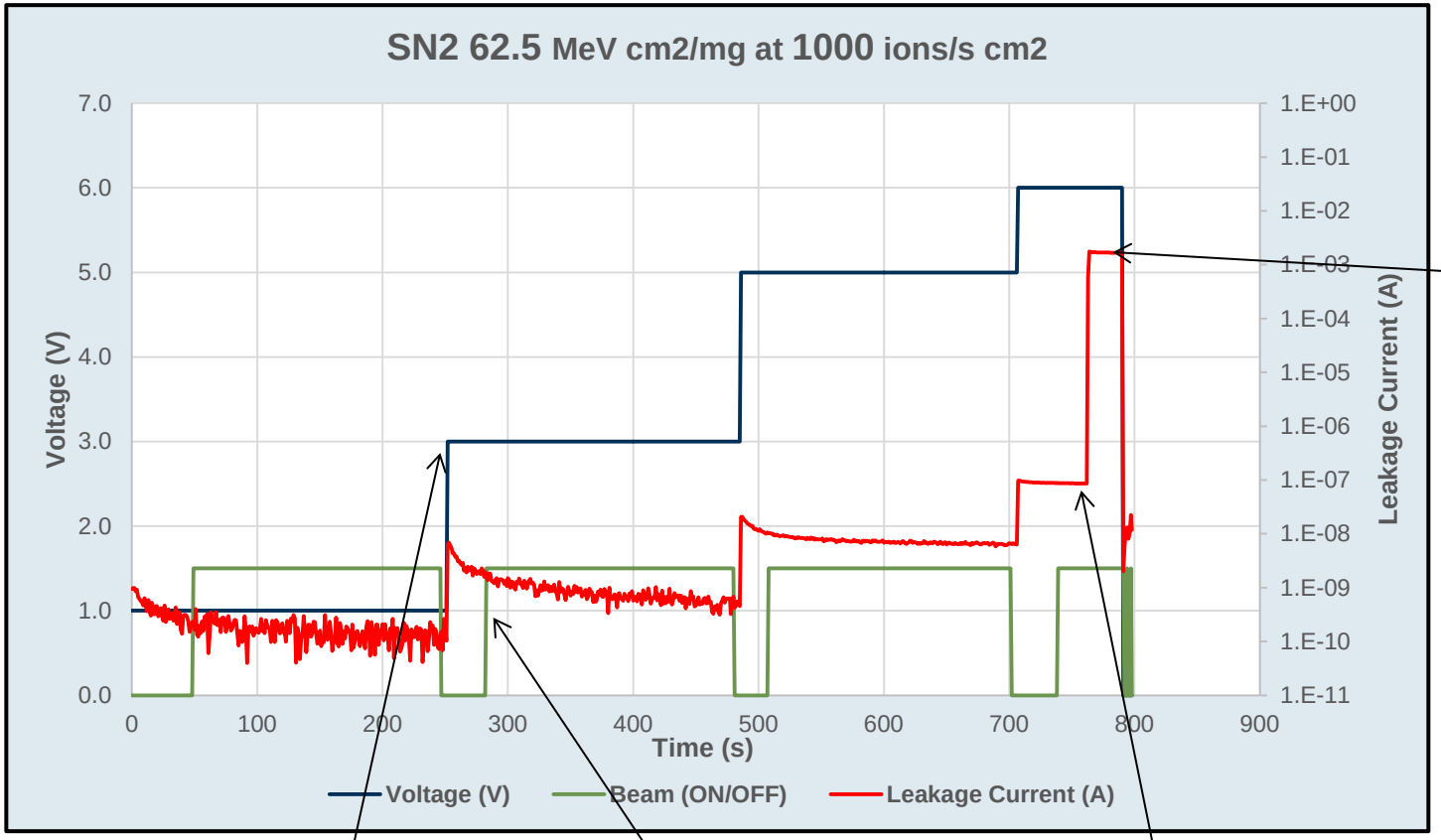
  Gamma Radiation (TID) -> No significant drift observed up to 300KRAD





Summary of tests results

- **Heavy Ions Radiation Sensitivity: Test Explanation**



Leakage current limited by the setup (device damaged)

Increase bias is applied while the ion Beam is OFF

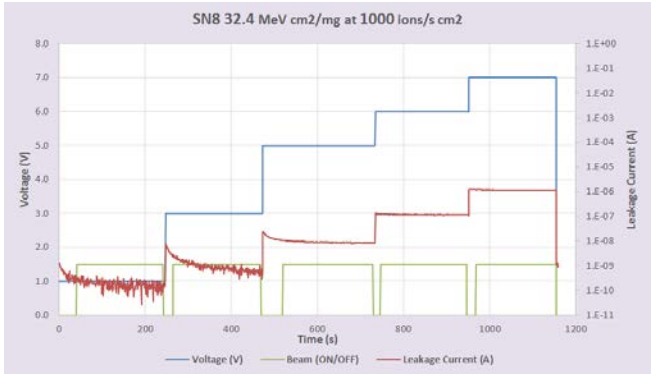
Ion Beam activated again after a few seconds of stable leakage current

Abrupt increase in leakage current

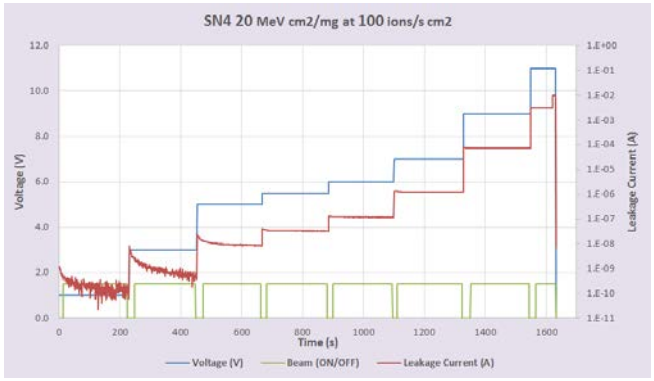
Silicon Capacitors – Development and Space Pre-evaluation

Summary of tests results

- **Heavy Ions Radiation Test Results**



Passed test example



Failed test example

LET (MeVcm2/mg)	Flux (ion/s cm2)	Biased Conditions Capacitor (V)							
		1	3	5	5.5	6	7	9	11
3.3 (Ne)	10000 up to 1e7	OK	OK	OK	OK	OK	OK	OK	OK
10.0 (Ar)	10000 up to 1e7	OK	OK	OK	OK	OK	OK	OK	OK
0.4 (Ni)	100 up to 1e5	OK	OK	OK	OK	OK	OK	OK	FAIL
	1000 up to 1e6	OK	OK	OK	OK	OK	OK	OK	FAIL
	10000 up to 1e7	OK	OK	OK	OK	OK	OK	OK	FAIL
32.4 (Kr)	100 up to 1e5	OK	OK	OK	OK	OK	OK	FAIL	FAIL
	1000 up to 1e6	OK	OK	OK	OK	OK	OK		
	10000 up to 1e7	OK	OK	OK	OK	OK	OK		
62.5 (Xe)	100 up to 1e5	OK	OK	OK	OK	OK	FAIL		
	1000 up to 1e6	OK	OK	OK	OK	FAIL			
	10000 up to 1e7	OK	OK	OK	OK [1]	FAIL			

Failures occurred for bias values above 5V, maximum recommended working voltage by Ipdia

Project Status

All technical activities already completed. Final deliverables and contract closure under preparation

Doc. No.	Title	Notes
TN 1.1	Technical Survey and Requirements Critical Review	Completed
TN 1.2	Procurement Specification	Completed
TN 2.1	Characterisation Plan	Completed
TN 2.2	Characterisation report	Completed
TN 3.2	PID	Completed
Tn 4.1	Evaluation Test plan	Completed
Tn 5.1	Evaluation batch manufacturing synthesis	Completed
TN 6.1	Evaluation Test Results and analysis	Completed
TN 6.2	Workmanship standard	Completed
TN 6.3	QTP Quotation and schedule	In progress
SR	Summary Report	In progress

Conclusions

Due to these excellent characteristics for Space applications and with the aim of a possible qualification for Space commercial use, an evaluation of different family IPDIA silicon capacitors such as HSSC, LPSC and EXSC IPDIA silicon capacitors was carried out by ALTER TECHNOLOGY.
Experimental results of these tests are presented and some conclusions such as their good response to heavy ions and gamma radiation exposure will be shown. It is concluded that these capacitors are ideal for space applications.

⇒ **Next STEPS**

- ⇒ Parts to be proposed for EPPL part 2 (EAPL under preparation
- ⇒ Commercial agreement IPDIA / ATN under preparation to promote technology word wide for space application

Acknowledgments

The authors acknowledge the technical and economic support received by IPDIA and ESA under the framework of the ESA contract 4000110740/14/NL/SFe.

Specific thanks to:

Mr. Denis Lacombe & Leo Farhat — European Space Agency
Mrs Charlotte Jennequin & Laurent Lengignon — IPDIA

TÜV NORD GROUP

Thank you!!!

Contact: Demetrio López
Demetrio.lopez@altertechnology.com