



# Rad-Hard Evaluation for Space Applications

19<sup>th</sup> Workshop “High Performance SiGe BiCMOS Technology Platform for Innovative RF and Photonic ICs”

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# Outline

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IHP works on radhard technologies in space and extreme harsh environments

SGB25RH is already fully evaluated against ESCC standards and the technology is EPPL listed. The evaluation of SG13RH supported by the ESA component group consists of different activities and this overview gives an overall status of the progress.

1

Introduction

2

Ongoing Evaluation of SG13RH – Test structures developed by IHP

3

IHP Processes and PDKs for Space Applications

4

Representative Results, Future Plans and Roadmap

## Introduction (General Information)

- E.g. space : temperature stress, radiation, long time missions
- Other possible fields: Medicine, Nuclear physics, Filling logistics

### Our Key benefits

- Strong need for high performance RF ASICs for Space applications
- Niche Market (Low Volume Production)
- European Technology - Strategic - Non Dependency/EU Value Chain – ITAR Free
- Extreme environmental conditions

### Goals

- ESA/DLR evaluation of SGB25RH and SG13RH SiGe BiCMOS technologies
- IHP Rad-Hard SGB25RH and SG13RH Design Kit availability for industry partners
- Inclusion of IHP technologies in ESA EPPL (ESA Preferred Parts List)
- Offer access to other radhard technologies, modules and devices for research cooperations

# Introduction (Commercially available IHP Technologies (MPW))



## Baseline CMOS technologies

0.25μm CMOS →  $V_{dd}=2.5V$

### SGB25V

nnp-HBTs up to  
 $f_t/f_{max}=95/75GHz$   
 $V_{BCE0}$  up to 7V

### SGB25RH

RadHard variant

### SG25H3

nnp-HBTs up to  
 $f_t/f_{max}=110/180GHz$   
 $V_{BCE0}$  up to 7V

### SG13S

nnp-HBTs up to  
 $f_t/f_{max}=250/300GHz$   $V_{BCE0}$  1.7V  
 $f_t/f_{max}=45/120GHz$   $V_{BCE0}$  3.7V

### SG13G2

nnp-HBTs up to  
 $f_t/f_{max}=300/500GHz$   $V_{BCE0}$  1.65V  
 $f_t/f_{max}=120/330GHz$   $V_{BCE0}$  2.5V

**Qualified**

### SG25H5-EPIC

$f_t/f_{max}=220/290GHz$   
 Ge-PD, MZM, WG, GC,...

**Stable/  
Early access**

LBE, TSV

### SG13RH

SG13S  
 RadHard variant

### SG13SCu

SG13S with  
 Cu-BEOL

### SG13G2Cu

SG13G2 with  
 Cu-BEOL

### SG25H5Cu-EPIC

SG25H5\_EPIC with  
 Cu-BEOL

**Under  
development**

W2W bonding  
 Backside RDL  
 RadHard MOS devices

### Next generation SG13G3

$f_t/f_{max}>450/650GHz$

# Introduction (Status Summary)



## Status on 250nm (SGB25RH)



- Radiation Hardening by Design (RHBD) on standard qualified process
- Evaluation of capability domain through specific test vehicles (TCV, DEC, RIC)
- Successfully listed on EPPL since Aug. 2018
- Maintaining Process Identification Document (PID)

## Status on 130 nm (SG13RH)

- Radiation assessment (Analog) completed
  - HBT npn (all devices), PMOS, NMOS (WG=1μm), ELT-NMOS (RHBD Device)
- Radiation assessment (Digital) completed
- Evaluation project with DLR/ESA is starting
- Assess the technology limits and possible failure modes
- Demonstrate technology absolute maximum ratings

# EPPL Listing of SGB25RH



EPPL  
REP 007

PAGE 43  
ISSUE 36

(continued) EPPL Part 2. Microwave Monolithic Integrated Circuits (MMIC):

D01PH	0.13 µm 100 GHz ft. 12V VBGD Pseudomorphic Power MMIC Process	Ommic / F	Others	Note 14 Note 15
CGY2135UH	MMIC K-band High Power Amplifier available in accordance with ESCC 9012/005	Ommic / F	Others	Uses D01PH Notes 14, 15 No radiation test done
CGY2145UH	MMIC low noise wideband amplifier available in accordance with ESCC 9012/006	Ommic / F	Others	
PH15	MMIC GaAs Foundry Process, 0.15 µm (P-HEMT for low noise, low level applications up to W Band	UMS / F	Others	Note 16
PH10-10	0.1 µm Very low Noise P-HEMT technology (AlGaAs/InGaAs on GaAs substrate with AlTiAlN gate)	UMS / F	Others	Note 17
PPH15X-20	0.15µm GaAs power PHEMT technology Power and High linearity applications up to 45GHz	UMS / F	Others	Note 18
SGB25RH	SiGe 0.25µm BiCMOS process for Mixed-Signal applications up to Ku-band with peak fT / fMAX 75GHz / 95 GHz and BVCEO > 7V	IHP / G	Others	Note 19

Note 14: D01PH Process is sensitive to Hydrogen poisoning. A Hydrogen getter is mandatory in case of hermetic encapsulation.  
Note 15: D01PH tested in DC+RF up to 8dB of Gain Compression with no evidence of SEE induced by heavy ions.  
Note 16: Passive elements are similar to PH25 Process. No radiation tests were performed on this process. Therefore it is the responsibility of the users to check that its design can withstand the radiation requirements for its application (especially for SEE).  
Note 17: TID, DO and SEE testing under DC biasing were performed. Reports are available from the manufacturer.  
Note 18: TID and SEE testing under DC biasing were performed. Reports are available from the manufacturer. BCB protection layer option covered by ESCC evaluation.  
Note 19: It is recommended to perform additional TID testing on full-custom designed chips. Additional LAT is also recommended.

## 4.8 EPPL PART2 RELAYS

Type	Description	Specification	Package	Manufacturer	Qualification	Remarks
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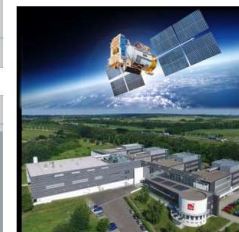
▼ Infocenter

▼ Presseportal

► Übersicht

► Pressemitteilungen

► Pressespiegel



IHP-Technologie darf in den Weltraum fliegen  
20.06.2018  
Europäische Raumfahrtbehörde ESA zertifiziert SiGe BiCMOS Technologie  
► Mehr  
Vollständige Pressemitteilung (PDF 637 kB)



Page 1 of 45

## EUROPEAN PREFERRED PARTS LIST

ESCC/RP/EPPL007-36

July 2018

<https://escies.org/webdocument/showArticle?id=166>

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1 Introduction

**2 Ongoing Evaluation of SG13RH – Test structures developed by IHP**

3 IHP Processes and PDKs for Space Applications

4 Representative Results, Future Plans and Roadmap



# Baseline of the Evaluation of SG13RH

## PDK SG13RH based on :

- Qualified SG13S Standard Commercial SiGe:C BiCMOS Dual Oxide
  - BEOL 5 thin + 2 thick (TM1:2μm TM2:3μm) Al metal layers + MIM Capacitor Layer
  - SiGe HBTs npnVp ( $f_{MAX}/f_T/BV_{CEO}$ ) : 340GHz/250GHz/1.7V ; npnV1 : 220GHz/180GHz/3.7V
  - CMOS Library Core Voltage +1.2V; IO Library +3.3V
- RHBD Libraries
  - Analog Devices (nnp-HBT, MOS devices incl. ELT- RHBD version)
  - Digital Standard Cell Core and IO Libraries RHBD special cells (80 cells)

## Activity promoted by DLR and IHP – Radiation Assessment

### Project successfully finished!

#### Goal :

- Design of Test Vehicles TCV, DEC
- Process Radiation Assessment i.a.w. :
  - ESCC N°. 25100 (SEE Testing)
  - ESCC N°. 22900 (Total Dose Steady State Irradiation Test Method) & MIL-STD-750E TM1019, MIL-STD-883H TM1019 Condition A and/or ESCC 22900 Window1
- Draft Definition of Capability Domain i.a.w. ESCC 24300
- Process Identification Document (PID) i.a.w. ESCC 22700

**Further activities :** [proceeding into Evaluation Testing i.a.w. 2269010 \(Endurance\)](#)

Started in 2019 within ESA project



# Ongoing Evaluation of SG13RH – Test structures developed by IHP



- Technology Characterization Vehicle

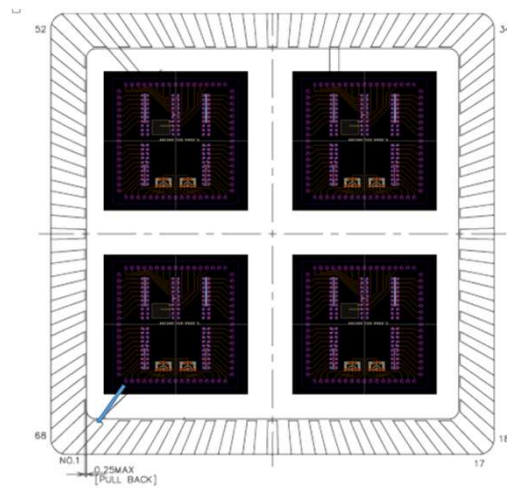


Figure 3-2: SG13RH\_TCVPASS chips in PGA68 package

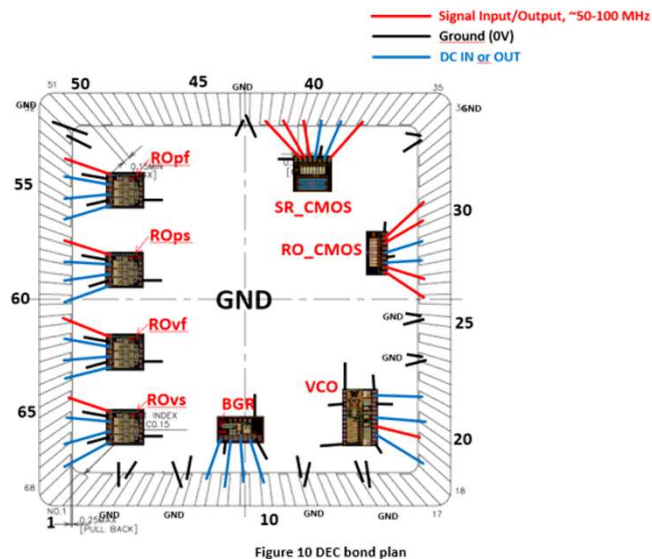
-> Selected active/passive components from standard IHP SG13S process control and monitor test structures

e.g. resistors, CMOS/bipolar transistors, metal lines with via connections

# Ongoing Evaluation of SG13RH – Test structures developed by IHP



- Dynamic Evaluation Circuit



-> Selected circuit structures,  
MOS/bipolar ring oscillators, MOS  
shift register, band-gap reference,  
voltage-controlled oscillator and  
HBT amplifier

## Ongoing Evaluation of SG13RH – Test structures developed by IHP



- **Representative Integrated Circuit**

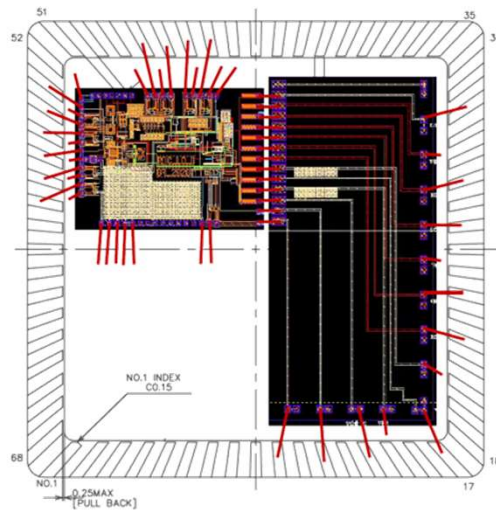


Figure 11. The proposed bonding plan with the 52 lead gull wing package and imposer (dimensions not in accurate proportion with respect to each other)

-> Fractional-N phase-locked loop (PLL) working around 31 GHz

# SG13RH Evaluation: Test Program



## TCV (Technology Characterization)

- Thermal Characterization of electrical parameters at -55, 27, 125°C
- Temperature Storage Testing
  - 250, 275°C
  - 2000hrs with intermittent measurements
- Endurance Testing under electrical stress
  - passive DUTs: 125, 170, 190°C; active DUTs: 27, 85, 125°C
  - 2000hrs with intermittent measurements

## DEC (Dynamic Evaluation Circuits)

- Thermal Analysis (Temperature Distribution, Local power loss)
- Endurance Testing under electrical stress
  - 27, 85, 125°C;
  - 2000hrs with intermittent measurements
- Constructional Analysis

## RIC (Representative IC)

- Endurance Testing with standard biasing
  - 27, 85, 125°C;
  - 2000hrs with intermittent measurements

- 
- 1 Introduction
  - 2 Ongoing Evaluation of SG13RH – Test structures developed by IHP
  - 3 IHP Processes and PDKs for Space Applications**
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# IHP Processes and PDKs for Space Applications



## Summary I of III

Status : Jan 2021

	SGB25V/RH	SG13S/RH
<b>■ Process Description</b>	SiGe HBTs npn Peak $f_T / f_{MAX}$ 75/95GHz 250nm CMOS ( $V_{DD}=+2.5V$ ; $T_{OX} = 5.8nm$ )	SiGe HBTs npn Peak $f_T / f_{MAX}$ 220/340GHz 130nm Dual Gate –Oxide CMOS ( $V_{DD}=+1.2V, +3.3V$ ; $T_{OX} = 2nm / 7nm$ )
<b>■ Applications</b>	Mixed-Signal MMIC/ASICs up to Ku Band	Mixed-Signal MMIC/ASICs up to W-Band
<b>■ Commercial Qualification</b> – Based on JEDEC Standard JP001.01 – QML/QPL (ESCC QPL, ESCC QML, MIL QPL, JAXA QPL)	<b>Re-Qualified 2010</b> <b>active &amp; stable &gt; 10 years (2005)</b>  No QML/QPL	<b>completed 2014</b>  No QML/QPL
<b>■ Radiation Assessment (Analog)</b> <ul style="list-style-type: none"> <li>■ HBT npn (all devices)</li> <li>■ PMOS</li> <li>■ NMOS (WG=1<math>\mu</math>m)</li> <li>■ ELT-NMOS (RHBD Device)</li> </ul>	<b>completed</b> PASS TID 800krad(Si) no ELDRS TID > 550krad(Si) PASS TID 100krad(Si) Characterized up to 500krad(Si) TID > 550krad(Si)	<b>completed</b> PASS TID >1210krad(Si) no ELDRS TID > 200 (HV) / 500 (LV) krad(Si) PASS TID 50krad(Si) (LV) Characterized up to 500krad(Si) TID > 900krad(Si)

# IHP Processes and PDKs for Space Applications



## Summary II of III

Status : Jan 2021

	SGB25V/RH	SG13S/RH
<ul style="list-style-type: none"> <li>■ PDK Availability                             <ul style="list-style-type: none"> <li>■ Access Status</li> </ul> </li> </ul>	<p><b>Completed</b></p> <p>Special digital libs, Replacement of cell with radhard IP, Aging modeling NDA/EXPORT License</p>	<p><b>In development -Early Access</b></p> <p>Special digital libs, Replacement of cell with radhard IP, Aging modeling in preparation NDA/EXPORT License</p>
<ul style="list-style-type: none"> <li>■ CMOS Std Cell Core and IO Libraries</li> </ul>	<p>Dolphin SESAME2-LP core cells + special RHBD cells (IHP) (80 cells)</p> <p>Saphyrion SAGL (25 cells) (Tested for SEU/SEL only)</p>	<p>IHP IXC013RH (~ 90 cells)</p>
<ul style="list-style-type: none"> <li>■ Radiation Assessment (Digital)                             <ul style="list-style-type: none"> <li>■ TID</li> <li>■ CMOS Libraries</li> </ul> </li> </ul>	<p>100krad(Si) – 300krad(Si) SEU/SEL completed</p> <p>SEL Threshold &gt; 65MeV/cm<sup>2</sup>/mg (RHBD IHP cells)</p> <p>SEU Threshold &gt; 30MeV/cm<sup>2</sup>/mg (IHP FF)</p>	<p>100krad(Si) – 300krad(Si) SEU/SEL completed</p> <p>SEL Threshold &gt; 65MeV/cm<sup>2</sup>/mg (RHBD IHP cells)</p> <p>SEU Threshold &gt; 65MeV/cm<sup>2</sup>/mg (IHP FF)</p>

# IHP Processes and PDKs for Space Applications



## Summary III of III

Status : Jan 2021

	SGB25V/RH	SG13S/RH
<ul style="list-style-type: none"> <li>Evaluation Testing                             <ul style="list-style-type: none"> <li>in acc. ESCC No. 2269010</li> </ul> </li> </ul>	completed	ongoing
<ul style="list-style-type: none"> <li>Operation Temperature (max rated T<sub>J</sub>)</li> </ul>	-55°C to +125°C	-55°C to +125°C (TBC)
<ul style="list-style-type: none"> <li>Test Vehicles                             <ul style="list-style-type: none"> <li>in acc. ESCC No. 2269010</li> </ul> </li> </ul>	TCV, DEC-I/-II, RIC	TCV, DEC –I DEC-II(CMOS, Bipolar) RIC
<ul style="list-style-type: none"> <li>Radiation Tests                             <ul style="list-style-type: none"> <li>TCV (Devices, analog)</li> <li>DECs (Digital, Analog BiCMOS)</li> <li>RIC (Mixed-Signal IC)</li> </ul> </li> </ul>	completed ” DEC-I (SEU/SEL), Early structures TID + SEE LO RIC	completed ” DEC-I (SEU/SEL), Early structures
<ul style="list-style-type: none"> <li>Endurance Testing HT &amp; RT                             <ul style="list-style-type: none"> <li>HBT npn- devices</li> <li>HBT lifetime determination</li> <li>CMOS devices</li> <li>CMOS Core &amp; IO Std Cell Library</li> </ul> </li> </ul>	passed very stable : no or low drifts characterization available drifts are mesured and defined lifetime determination ~ 20 years	Planned 2021
<ul style="list-style-type: none"> <li>Additional Tests (Reliability)</li> </ul>	SiGe HBT HCI & Lifetime Estimation	SiGe HBT HCI & Lifetime Estimation



1

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2

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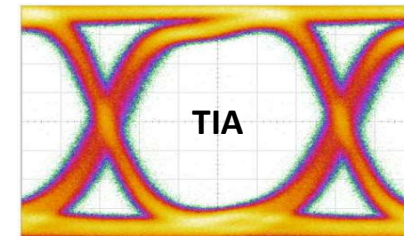
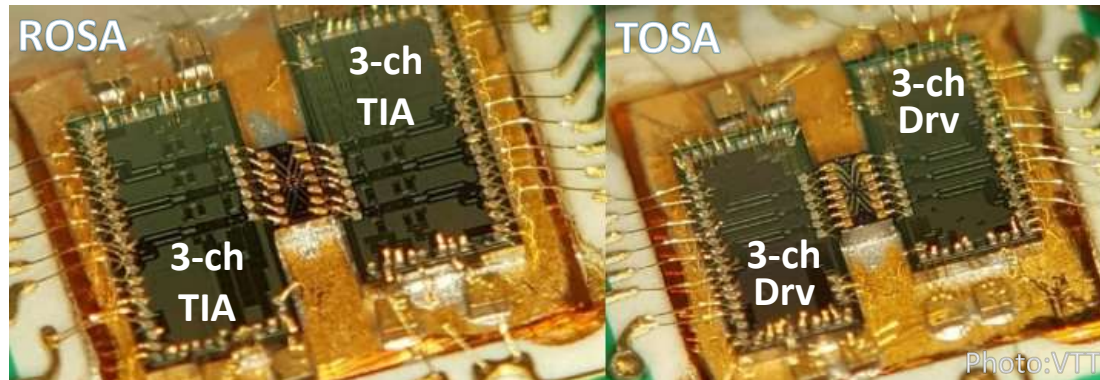
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IHP Processes and PDKs for Space Applications

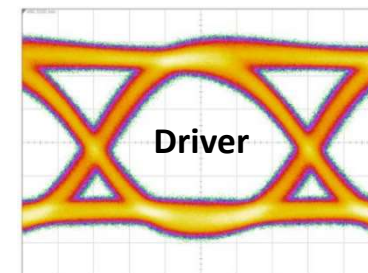
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Representative Results, Future Plans and Roadmap

## 25 Gb/s TIA & 40 Gb/s VCSEL Driver ICs



25 Gb/s at 64 mW/channel

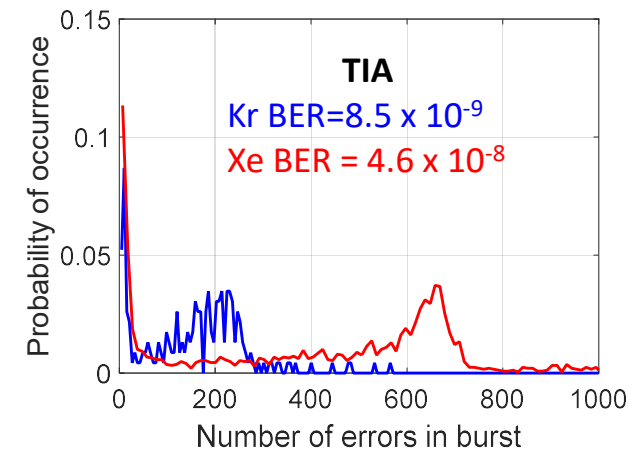
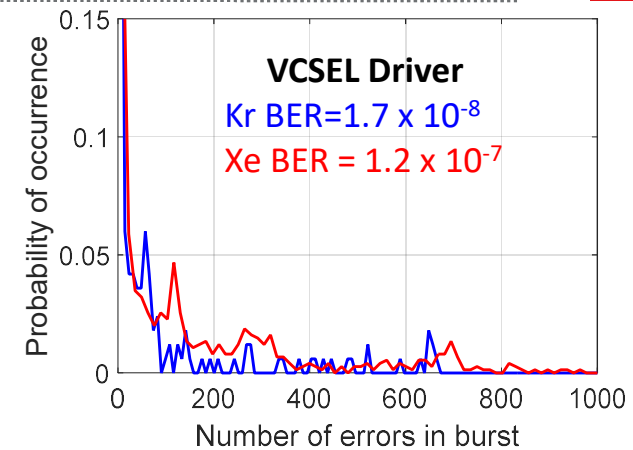
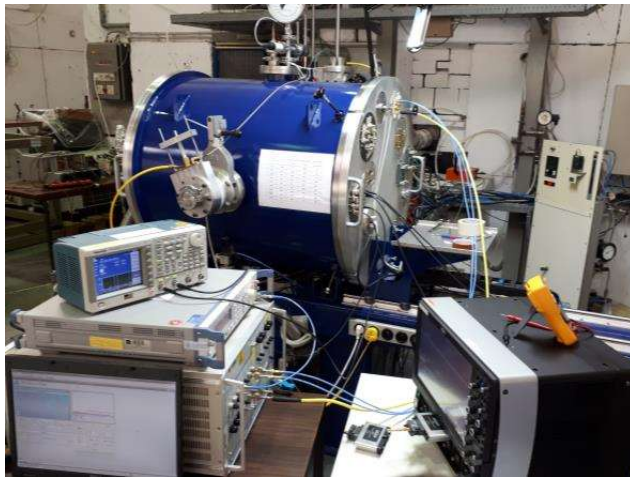


40 Gb/s at 40 mW/channel

- 3- and 4-channel power efficient ICs
  - resulted from the EU MERLIN/ROBIN Project
- Channel-independent digital control via SPI
  - gain, noise optimization, pre-emphasis, output amplitude adjustments, channel on/off switching
- Power-on-reset (PoR) circuit for autonomous start-up
- Non-zero preset value for each control register

# Heavy Ion Test

- BER measurements at 25 Gb/s for both ICs
- Irradiation with ion flux of 5000 particles per second
  - Kr ions LET= 32.4 MeV·cm<sup>2</sup>/mg
  - Xe ions LET = 62.5 MeV·cm<sup>2</sup>/mg
- No SEL (latch-up) detected



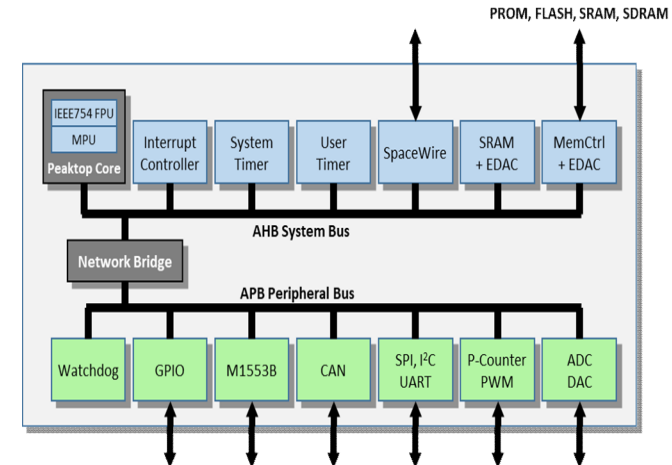
## Space Networks and ongoing Projects



- Space Region
- Trans Border Integration of the Space Sector Partners
  - IHP (Germany)
  - CBK PAN (Poland)

- ELICSIR – Enhancement of Scientific Excellence and Innovation Capacity in Electronic Instrumentation for Ionizing Radiation Environments (H2020)
- Electronic instrumentation for ionizing radiation environments
- Partners
  - University of Nis (Serbia) – coordinator
  - IHP (Germany)
  - Tyndall Institute (Ireland)
  - University of Granada (Spain)

- MORAL - Export-free rad-hard  $\mu$ controller for space apps (H2020)
- Develop a completely European, ITAR-free  $\mu$ controller for space apps
- Based on the novel Peaktop architecture (incl. novel ISA)
- Formally-verified C compiler, RTOS and toolchain
- Demonstrator board



## Future Plans and Roadmap

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Immediate goal is finalization of ESA evaluation project for 130 nm SG13RH

The project should be followed with EPPL listing of this technology (~2022)

Further IHP technologies could be considered for evaluation depending on demand

Provide Technologies modules and devices for research and development.

High interest in VCSEL Driver qualification (results of EU project MERLIN/ROBIN)

Ongoing development: radhard Microcontroller (EU project MORAL), radhard ADC (>13 Bit, >10 Msps), radhard SERDES (> 2 Gbps)

Several projects under qualification/qualified from the industry partners using IHP technology



# Thank you for your attention!

Milos Krstic

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