Rad-Hard Evaluation for Space Applications

19th Workshop "High Performance SiGe BiCMOS Technology Platform for Innovative RF and Photonic ICs"

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Leibniz Association

Outline

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.

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		Dual-gate 0.13µm CMOS → V_{dd}=1.2V and 3.3V	
SGB25V npn-HBTs up to f_t/f_{max}=95/75GHz V_{BCE0} up to 7V **SGB25RH** RadHard variant	**SG25H3** npn-HBTs up to f_t/f_{max}=110/180GHz V_{BCE0} up to 7V	**SG13S** npn-HBTs up to f_t/f_{max}=250/300GHz V_{BCE0} 1.7V f_t/f_{max}=45/120GHz V_{BCE0} 3.7V	**SG13G2** npn-HBTs up to f_t/f_{max}=300/500GHz V_{BCE0} 1.65V f_t/f_{max}=120/330GHz V_{BCE0} 2.5V

Qualif ėd

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 generat ȯn SG13G3** f_t/f_{max}>450/650GHz

Introduction (Status Summary)

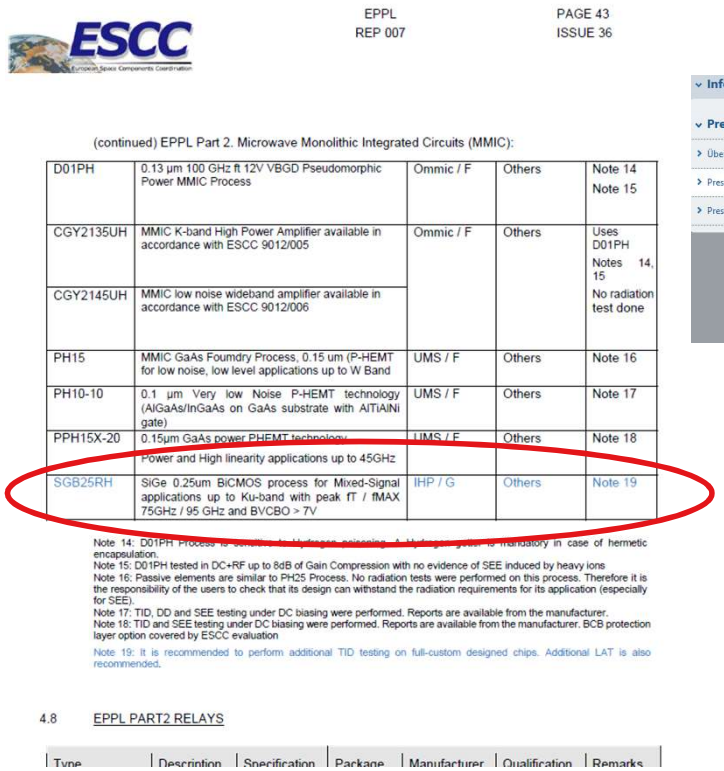
Status on 250nm (SGB25RH)

- 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



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(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
CGY2145UH	MMIC low noise wideband amplifier available in accordance with ESCC 9012/006			No radiation test done
PH15	MMIC GaAs Foumdry Process, 0.15 um (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 AlTiAlNi 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 0.25um BiCMOS process for Mixed-Signal applications up to Ku-band with peak fT / fMAX 75GHz / 95 GHz and BVCBO > 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, DD 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

ESCC European Space Components Coordination

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EUROPEAN PREFERRED PARTS LIST

ESCC/RP/EPPL007-36

July 2018

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

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 (npn-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

- **T**echnology **C**haracterization **V**ehicle

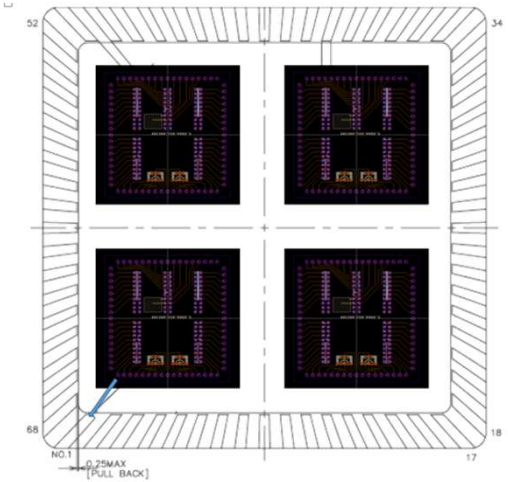

Figure 3-2: SG13RH_TCVPASS chips in PGA68 package

-> 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

- **D**ynamic **E**valuation **C**ircuit

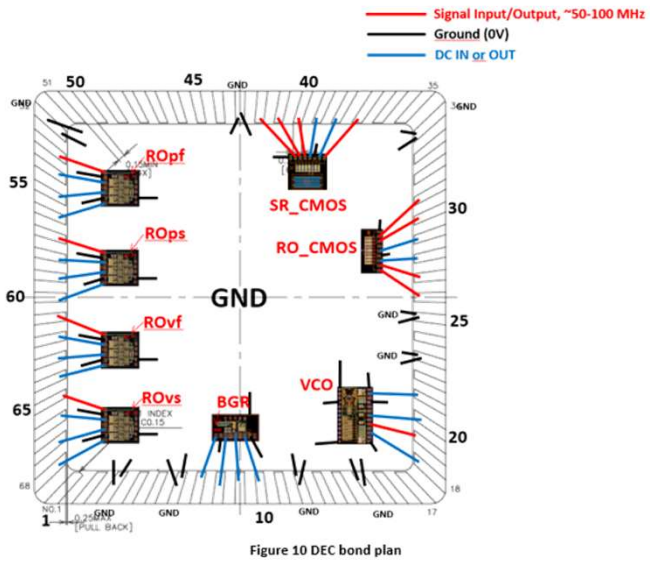

Figure 10 DEC bond plan

-> 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

- **R**epresentative **I**ntegrated **C**ircuit

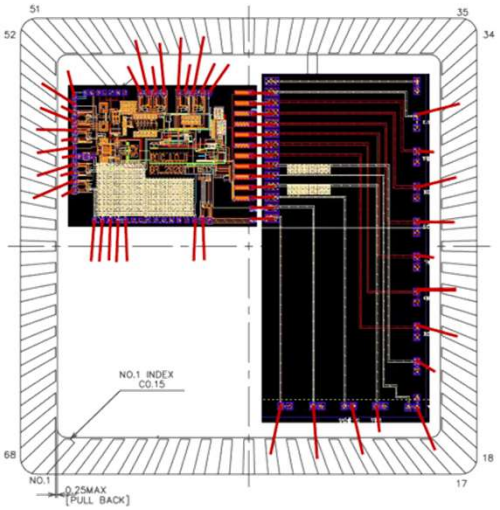

Figure 11. The proposed boding plan with the 52 lead gull wing package and imposer (dimensions not in accurate proportion with respect to each other)

-> 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

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IHP Processes and PDKs for Space Applications

Summary I of III

Status : Jan 2021

	SGB25V/RH	SG13S/RH
■ **Process Description**	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)
■ **Applications**	Mixed-Signal MMIC/ASICs up to Ku Band	Mixed-Signal MMIC/ASICs up to W-Band
■ **Commercial Qualification** – Based on JEDEC Standard JP001.01 – QML/QPL (ESCC QPL, ESCC QML, MIL QPL, JAXA QPL)	**Re-Qualified 2010** **active & stable > 10 years (2005)** No QML/QPL	**completed 2014** No QML/QPL
■ **Radiation Assessment (Analog)** ■ HBT npn (all devices) ■ PMOS ■ NMOS (WG=1µm) ■ ELT-NMOS (RHBD Device)	**completed** PASS TID 800krad(Si) no ELDRS TID > 550krad(Si) PASS TID 100krad(Si) Characterized up to 500krad(Si) TID > 550krad(Si)	**completed** 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
■ PDK Availability ■ Access Status	Completed Special digital libs, Replacement of cell with radhard IP, Aging modeling NDA/EXPORT License	In development -Early Access Special digital libs, Replacement of cell with radhard IP, Aging modeling in preparation NDA/EXPORT License
■ CMOS Std Cell Core and IO Libraries	Dolphin SESAME2-LP core cells + special RHBD cells (IHP) (80 cells) Saphyrion SAGL (25 cells) (Tested for SEU/SEL only)	IHP IXC013RH (~ 90 cells)
■ Radiation Assessment (Digital) ■ TID ■ CMOS Libraries	100krad(Si) – 300krad(Si) SEU/SEL completed SEL Threshold > 65MeV/cm²/mg (RHBD IHP cells) SEU Threshold > 30MeV/cm²/mg (IHP FF)	100krad(Si) – 300krad(Si) SEU/SEL completed SEL Threshold > 65MeV/cm²/mg (RHBD IHP cells) SEU Threshold > 65MeV/cm²/mg (IHP FF)

IHP Processes and PDKs for Space Applications

Summary III of III

Status : Jan 2021

	SGB25V/RH	SG13S/RH
■ **Evaluation Testing** ■ **in acc. ESCC No. 2269010**	**completed**	**ongoing**
■ **Operation Temperature (max rated T_J)**	**-55°C to +125°C**	**-55°C to +125°C (TBC)**
■ **Test Vehicles** ■ in acc. ESCC No. 2269010	**TCV, DEC-I/-II, RIC**	**TCV,** **DEC –I DEC-II(CMOS, Bipolar)** **RIC**
■ **Radiation Tests** ■ TCV (Devices, analog) ■ DECs (Digital, Analog BiCMOS) ■ RIC (Mixed-Signal IC)	**completed** „ DEC-I (SEU/SEL), Early structures TID + SEE LO RIC	**completed** „ DEC-I (SEU/SEL), Early structures
■ **Endurance Testing HT & RT** ■ HBT npn- devices ■ HBT lifetime determination ■ CMOS devices ■ CMOS Core & IO Std Cell Library	**passed** very stable : no or low drifts characterization available drifts are mesured and defined lifetime determination ~ 20 years	**Planned 2021**
■ **Additional Tests (Reliability)**	**SiGe HBT HCI & Lifetime Estimation**	**SiGe HBT HCI & Lifetime Estimation**

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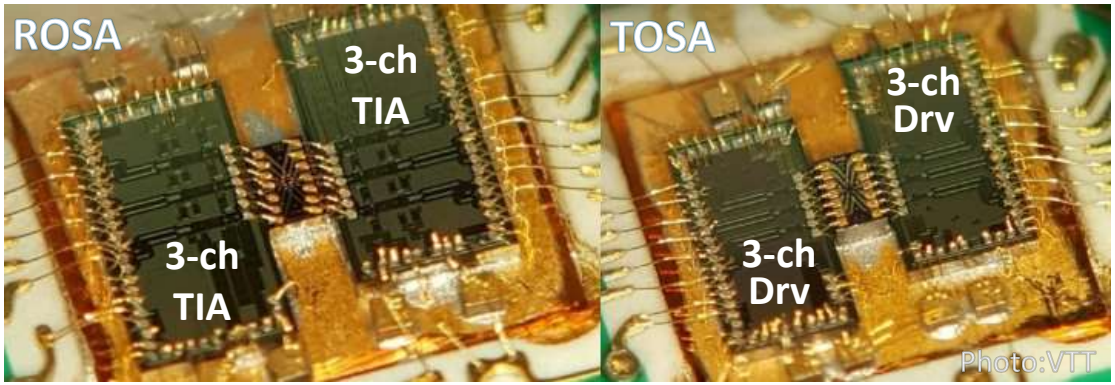
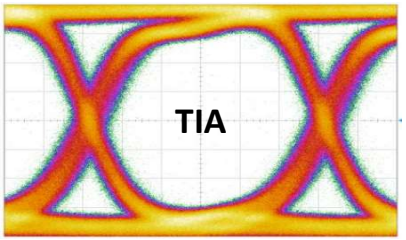
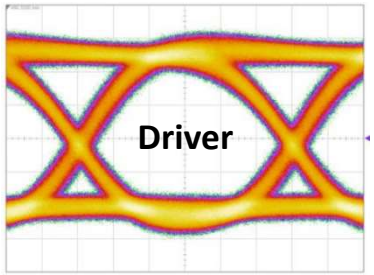
25 Gb/s TIA & 40 Gb/s VCSEL Driver ICs





25 Gb/s at 64 mW/channel

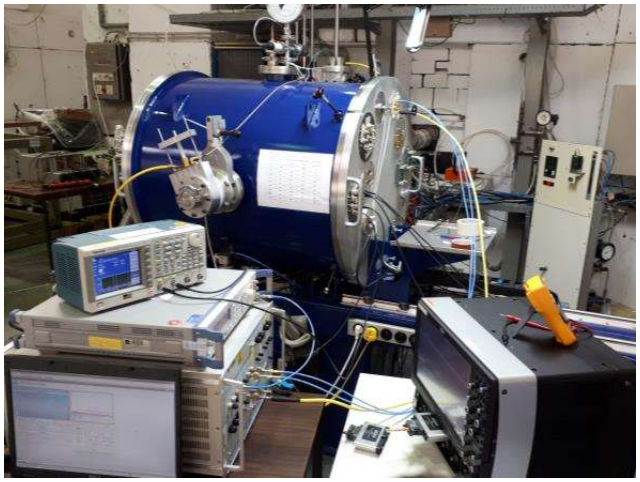
- 3- and 4-channel power efficient ICs
  - resulted from the EU MERLIN/ROBIN Project
- Channel-independent digital control via SPI
  - gain, noise optimization, pre-emphasis, output amplitude adjustments, channel on/off switching
- Power-on-reset (PoR) circuit for autonomous start-up
- Non-zero preset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

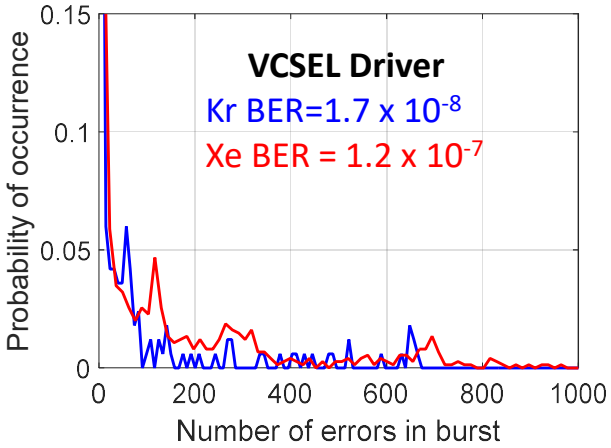


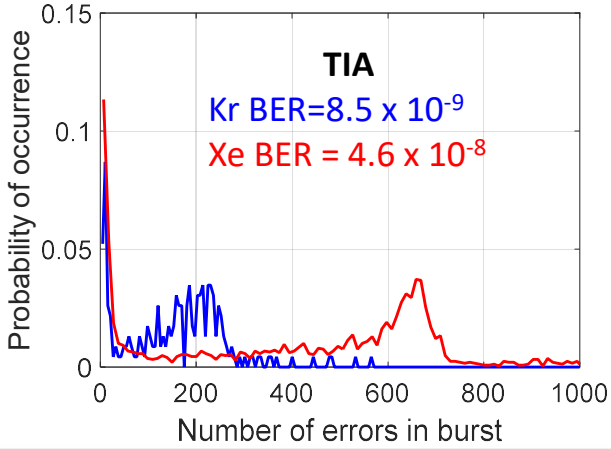
40 Gb/s at 40 mW/channel

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^2/mg
  - Xe ions LET = 62.5 MeV·cm^2/mg
- No SEL (latch-up) detected





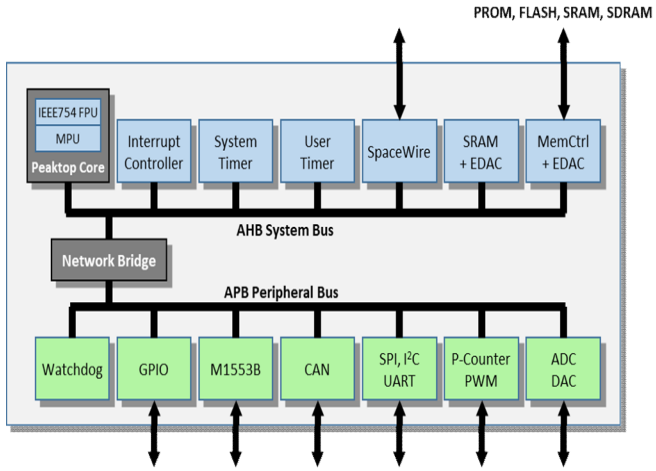


Space Networks and ongoing Projects

- 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 µcontroller for space apps (H2020)
- **Develop a completely European, ITAR-free µcontroller 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

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!

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