



RADIATION HARDNESS ASSURANCE TEST GUIDELINES FOR PHOTODETECTORS AND IMAGE SENSORS

CONTENT OVERVIEW

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Acronyms

CCD Charge Coupled Device

CIS CMOS Image Sensor

CMOS Complementary Metal Oxide Semiconductor

COTS Commercial Off The Shelf

CDTI Capacitive Deep Trench Isolation

DDD Displacement Damage Dose

DTI Deep Trench Isolation

ESCC European Space Components Coordination

GSFC Goddard Space Flight Center

IR Infrared

JPL Jet Propulsion Laboratory

JSC Johnson Space Center

LaRC Langley Research Center

MCT Mercury Cadmium Telluride

MOSFET Metal Oxide Semiconductor Field Effect Transistor

RHA Radiation Hardness Assurance

ROIC Read Out Integrated Circuit

STI Shallow Trench Isolation

INDEX

Project Goals & Objectives

Content Overview

Scenario Examples Next Steps & Conclusion

Project Goals and Objectives



Existing Radiation Test Standards

No Radiation Test Standard Dedicated to Photodetectors and Image Sensors

Visible Image Sensor

- Charge Coupled Devices (CCDs)
- CMOS Image Sensor (CIS)
- Commercial Of the Shelf (COTS) CISs

Infrared Detectors

- Detecting Materials (MCT)
- Readout Integrated Circuit (ROIC)
- Cryogenic Temperatures

What degradation and failures are we looking for ?

How do we test those devices?

JEDEC JESD57 Test Procedures for the Measurement of SEE in Semiconductor Devices from Heavy-Ion Irradiation JEDEC JESD234 Test Standard for the Measurement of Proton Radiation SEE in Electronic Devices MIL-STD-750-1 Environmental Test Methods for Semiconductor Devices TM 1017: Neutron irradiation TM 1019: Steady-state total dose irradiation procedure TM 1080 SEB and SEGR MIL-STD-883 Microcircuits TM 1017: Neutron irradiation TM: Ionizing radiation test procedure ESA-ESCC-25100 SEE Test Method and Guidelines ESA-ESCC-22900 Total Dose Steady-State Irradiation Test Method ASTM F1192 Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices ASTM F1892 Standard Guide for Ionizing Radiation Effects Testing of Semiconductor Devices ASTM F1190 Practice for Neutron Irradiation of Unbiased Electronic Components MIL-HDBX-814 Ionizing Dose and Neutron Harness Assurance Guidelines for Microcircuits and Semiconductor Devices Sandia Nat. Lab. SAND 2008- 6983P Sandia Nat. Lab. Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Test Guideline for Proton and Heavy Ion SEE Sandia Nat. Lab. SAND 2008- 6851P Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Radiation Environments, Physical Mechanisms, and Foundations for Hardness Assurance NASA/DTRA Field Programmable Gate Array (FPGA) Single Event Effect (SEE) Radiation Testing	Standard	Title	Date
JEDEC JESD234 Test Standard for the Measurement of Proton Radiation SEE in Electronic Devices MIL-STD-750-1 Environmental Test Methods for Semiconductor Devices TM 1017: Neutron irradiation TM 1019: Steady-state total dose irradiation procedure TM 1080 SEB and SEGR MIL-STD-883 Microcircuits TM 1017: Neutron irradiation TM: Ionizing radiation test procedure ESA-ESCC-25100 SEE Test Method and Guidelines ESA-ESCC-22900 Total Dose Steady-State Irradiation Test Method ASTM F1192 Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices ASTM F1892 Standard Guide for Ionizing Radiation Effects Testing of Semiconductor Devices ASTM F1190 Practice for Neutron Irradiation of Unbiased Electronic Components MIL-HDBX-814 Ionizing Dose and Neutron Harness Assurance Guidelines for Microcircuits and Semiconductor Devices Sandia Nat. Lab. Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Test Guideline for Proton and Heavy Ion SEE Sandia Nat. Lab. Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Radiation Environments, Physical Mechanisms, and Foundations for Hardness Assurance NASA/DTRA Field Programmable Gate Array (FPGA) Single Event Ef- 2012	JEDEC	Test Procedures for the Measurement of SEE in Semicon-	1996
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Semiconductor Devices ASTM F1190 Practice for Neutron Irradiation of Unbiased Electronic Components MIL-HDBX-814 Ionizing Dose and Neutron Harness Assurance Guidelines for Microcircuits and Semiconductor Devices Sandia Nat. Lab. Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Test Guideline for Proton and Heavy Ion SEE Sandia Nat. Lab. Radiation Hardness Assurance testing of Microelectronic Devices and Integrated Circuits: Radiation Environments, Physical Mechanisms, and Foundations for Hardness Assurance NASA/DTRA Field Programmable Gate Array (FPGA) Single Event Ef-2012		conductor Devices	
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NASA/DTRA Field Programmable Gate Array (FPGA) Single Event Ef- 2012	6851P	Physical Mechanisms, and Foundations for Hardness Assur-	
		ance	
fect (SEE) Radiation Testing	NASA/DTRA	Field Programmable Gate Array (FPGA) Single Event Ef-	2012
		fect (SEE) Radiation Testing	

Project Goals and Objectives



Existing Documents and Main Contributions

Outdated Technologies	{
Simulation Oriented	1
Focused on CCDs	1
Test Report	{
Expand the content	{
Not Applied to Detectors	

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Contribution	Title	Date
Sira Electro-Optics	Radiation Effects in 2-D IR Sensors [3]	1997
for ESA		
ESA	Predicting Displacement Damage Effects in Electronic	2002
	Components by Method of Simulation: Literature Sur-	
	vey and Pre-Assessment of Methods [4]	
NASA	Proton Test Guideline Development-Lessons Learned	2002
	[1]	
NASA	CCD Radiation Effects and Test Issues for Satellite	2003
	Designers [2]	
Sira Electro-Optics	Radiation Testing of CCD and APS Imaging Devices	2003
for ESA	[5]	
SURREY	Displacement Damage Guidelines [6]	2014
Ref: 0195162		
ONERA	Displacement Damage Test Guideline Development [7]	
for ESA		
ESA-ESCC-22500	Guidelines for Displacement Damage Irradiation Test-	2019
	ing [8]	

Project Goals and Objectives

Capture and Sustain NASA Expertise and Capability in Photodetector and Image Sensor RHA



What do we value?

Best practices, Past Research, Lessons-Learned



From Where?

Across NASA centers: GSFC, JPL, Ames, LaRC, JSC...



Main objectives:

- Support Photodetector RHA activities
- Maximize the utility of the guidelines for all



How?

 Collaborate to shape the content of the guidelines document to meet current and future needs

1.

Project Goals and Objectives



RHA Guidelines

- 1. Pragmatic
- 2. Scientific
- 3. Flexible
- 4. Collaborative



RADIATION HARDNESS ASSURANCE GUIDELINES FOR PHOTODETECTORS AND IMAGES SENSORS

— Version 1.0 —



Alexandre Le Roch Jean-Marie Lauenstein

Supported by: NASA Electronic Part and Packaging Program (NEPP)

April 18, 2023

Context and Future Needs of RHA Tests on Photodetectors and Image Sensors

 Positions Photodetectors in Microelectronic Trends and Foresees Future Needs in RHA

Fundamentals on Radiation Effects on Semiconductor Devices

~ 60 pages

 Focus on DDD and Ongoing Research Activities

Test Method for CCDs and CMOS Image Sensors ~ 120 pages

Test Setup Requirements and Test Method

~ 250 pages

Guidelines Content Overview

01

Context and Future Needs of RHA Tests on Photodetectors and Image Sensors

What's the content?

- Overview of the context of photodetectors and image sensor development trends
- Evolving needs for RHA testing
 - COTS CMOS Image Sensors
 - SPAD Imagers
 - Hybrid Infrared Detectors

Who is this for?

- Junior RHA & Detector System Engineers
- Senior RHA Engineers
- Management

Why is this useful?

- Get the big picture
 - Anticipate trainings
 - Orient the work force
 - Justify funds
- Align visions among main RHA actors
- Bring expertise to decision-making

1	Rising interests and specific needs for Radiation Hardness Assurance (RHA) tests dedicated to photodetectors and images sensors operating in space environments				
	envi	ITOIIIIE	ents	1	
	1.1	Defini	tions and scope of the guidelines	2	
		1.1.1	External Photoelectric Effect: Phototubes and Photomultipliers	3	
		1.1.2	Internal Photoelectric Effect: Semiconductor Photodetectors	4	
	1.2	Micro	electronics and photodetectors development tends	4	
		1.2.1	Understanding the International Roadmap of Devices and Systems (IRDS) $$	7	
		1.2.2	Understanding major trends in devices and systems	12	
	1.3	Positio	oning photodetectors and images sensors into the microelectronics trends	20	
		1.3.1	Photodetectors interact with the real world	20	
		1.3.2	Single Structure Photodetectors	31	
		1.3.3	Images sensors and Focal Plane Arrays (FPA)	38	
		1.3.4	Commercial and custom photodetectors	46	
	1.4	Conclu	usion	66	
	Bibli	iograph	y	79	

2.

Guidelines Content Overview

1.3.3	Images s	sensors and Focal Plane Arrays (FPA)
	1.3.3.1	Charge Coupled Devices (CCD)
	1.3.3.2	CMOS Image Sensor (CIS)
	1.3.3.3	Avalanche photodiode (APD) arrays and Single Photon Avalanche
		Diode (SPAD) Imager
	1.3.3.4	Infrared Focal Plane Array (FPA)
	1.3.3.5	Ultraviolet Focal Plane Array (FPA)
1.3.4	Commen	cial and custom photodetectors
	1.3.4.1	Commercial sub-micrometer pixel pitch CMOS image sensors 47
	1.3.4.2	Custom CMOS Image Sensors
	1.3.4.3	Visible image sensors in space applications 59
	1.3.4.4	Other image sensors in space applications: Infrared, UV, X-ray 65

Covers a wide range of technologies and applications from custom to commercial detectors

1		Rising interests and specific needs for Radiation Hardness Assurance (RHA) tests dedicated to photodetectors and images sensors operating in space		
environments			ents	1
	1.1	Definit	cions and scope of the guidelines	2
		1.1.1	External Photoelectric Effect: Phototubes and Photomultipliers	3
		1.1.2	Internal Photoelectric Effect: Semiconductor Photodetectors	4
	1.2	Micro	electronics and photodetectors development tends	4
		1.2.1	Understanding the International Roadmap of Devices and Systems (IRDS) $$	7
		1.2.2	Understanding major trends in devices and systems	12
	1.3	Positio	oning photodetectors and images sensors into the microelectronics trends	20
		1.3.1	Photodetectors interact with the real world	20
		1.3.2	Single Structure Photodetectors	31
		1.3.3	Images sensors and Focal Plane Arrays (FPA)	38
		1.3.4	Commercial and custom photodetectors $\ \ldots \ \ldots \ \ldots \ \ldots$	46
	1.4	Conclu	ısion	66
	Bibl	iograph	у	79

Ouidelines Content Overview

02

Fundamentals of Radiation Effects on Semiconductor Devices

What's the content?

- Overview of radiation effects in semiconductor devices (Silicon)
- Focus on displacements
 - Responsible for hot pixels
 - Dynamics of Defect Creation
 - Damage Factor & NIEL Scaling

Who is this for?

- Jr. RHA Engineers → Training
- Sr. RHA Engineers → Updated references
- Instrument/FPA Designers → Understand Limitations

Why is this useful?

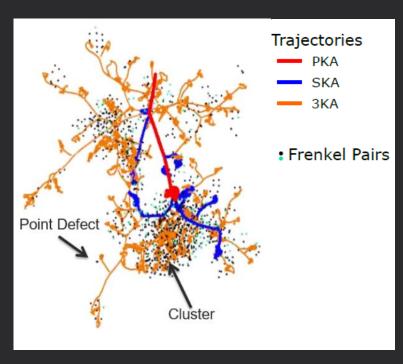
- Get the big picture
 - Physics behind the degradation
 - Understand foundations of test methods and standards
 - Enable new ideas and contributions
- Update on ongoing research activities

2	Fundamentals of space radiation environment and radiation-induced degradations on semiconductor devices	81
	2.1 Main space radiation sources and characteristics	82



		· ·		
2.2	Radiation-matter interactions			
	2.2.1	Interaction with electromagnetic radiation		
	2.2.2	Interaction with corpuscular radiation		
	2.2.3	Electronic and nuclear stopping power		
	2.2.4	Ionizing Dose and Displacement Dose Concepts		
2.3	Effect	s of radiation on electronic devices		
	2.3.1	Effects of ionization in electronic devices		
	2.3.2	Effects of Atomic Displacements		
	2.3.3	Radiation-induced degradation on photodetectors and image sensors 125		
Bibl	Bibliography			

Guidelines Content Overview



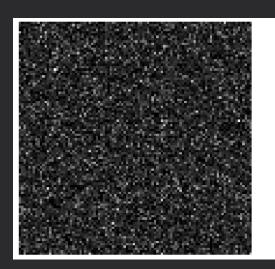
Courtesy of Antoine Jay, NSREC 2016

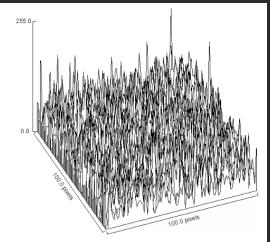
Focuses on the physics of displacements and associated damage factor & NIEL scaling concepts

2	Fundamentals of space radiation environment and radiation-induced degradations on semiconductor devices			81
	2.1	Main s	space radiation sources and characteristics	82
	2.2	Radiat	ion-matter interactions	91
		2.2.1	Interaction with electromagnetic radiation	92
		2.2.2	Interaction with corpuscular radiation	94
		2.2.3	Electronic and nuclear stopping power	98
		2.2.4	Ionizing Dose and Displacement Dose Concepts	108
	2.3	Effects	of radiation on electronic devices	114
		2.3.1	Effects of ionization in electronic devices	114
		2.3.2	Effects of Atomic Displacements	119
		2.3.3	Radiation-induced degradation on photodetectors and image sensors	125
	Bibli	iograph	у	140

2.

Guidelines Content Overview





Focuses on the main performance degradation mechanisms in all photodetectors and image sensors

2	Fundamentals of space radiation environment and radiation-induced degradations on semiconductor devices			81
	2.1	Main s	space radiation sources and characteristics	82
			•	
			· · · · · · · · · · · · · · · · · · ·	
	2.2	Radiat	cion-matter interactions	91
		2.2.1	Interaction with electromagnetic radiation	92
		2.2.2	Interaction with corpuscular radiation	94
		2.2.3	Electronic and nuclear stopping power	98
		2.2.4	Ionizing Dose and Displacement Dose Concepts	108
	2.3	Effects	s of radiation on electronic devices	114
		2.3.1	Effects of ionization in electronic devices	114
		2.3.2	Effects of Atomic Displacements	119
		2.3.3	Radiation-induced degradation on photodetectors and image sensors $$	125
	Bibl	iograph	у	140

Guidelines Content Overview

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03

Test Method for CCDs and CMOS Image Sensors

What's the content?

- Image sensor working principle
- Test method
- Focus on CIS
 - Growing interest
 - Specificities & Vulnerabilities
 - Testing methodology

Who is this for?

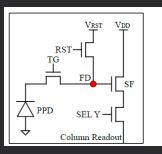
- RHA Engineers → Test Method
- RHA Engineers → Identify Vulnerabilities
- Instrument/FPA Designers → Understand Limitations

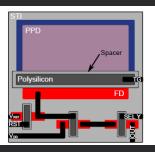
Why is this useful?

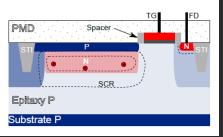
- Guide test design & Raise awareness
 - Setup & Equipment & Best Practices
- Understand the origin of the degradation
 - More adaptable to actual needs
 - Enabling new ideas and contributions
- Updated references and ongoing research

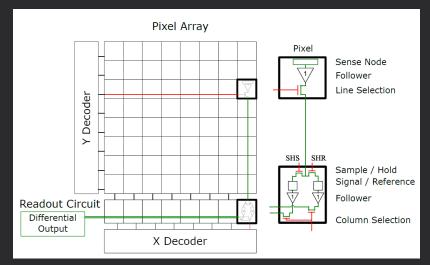
3	Charge Coupled Devices (CCD) and Complementary Metal Oxide Semi- conductor (CMOS) images sensors 141		
	3.1	Funda	amentals on CCD and CIS
	3.2	Funda	amentals on images sensors figures of merits
	3.3	Paran	neters extraction method and radiation-induced degradations 192
		3.3.1	Charge to Voltage Factor - CVF
		3.3.2	Dark Current
		3.3.3	Dark current activation energy
		3.3.4	Dark Current Random Telegraph Signal - DC-RTS
		3.3.5	Electro-optical transfer function
		3.3.6	Dynamic Range
		3.3.7	Quantum Efficiency
		3.3.8	Annealing Effects
		3.3.9	Radiation-induced degradation in advanced pixel architectures
	Bibl	iograph	ıy

Guidelines Content Overview









Covers all the basics to understand the device, its vulnerabilities, and the parameters of interest

3		Charge Coupled Devices (CCD) and Complementary Metal Oxide Semi- conductor (CMOS) images sensors 141		
	3.1	Funda	mentals on CCD and CIS	
	3.2	Funda	mentals on images sensors figures of merits	
	3.3	Parameters extraction method and radiation-induced degradations 192		
		3.3.1	Charge to Voltage Factor - CVF	
		3.3.2	Dark Current	
		3.3.3	Dark current activation energy	
		3.3.4	Dark Current Random Telegraph Signal - DC-RTS	
		3.3.5	Electro-optical transfer function	
		3.3.6	Dynamic Range	
		3.3.7	Quantum Efficiency	
		3.3.8	Annealing Effects	
		3.3.9	Radiation-induced degradation in advanced pixel architectures 250	
	Bibl	iograph	265	

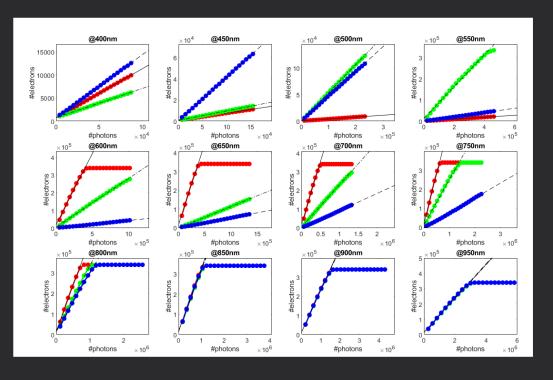
Guidelines Content Overview

Questioning Wor	rkflow	Corresponding Section		
What's it for ?		1.	Objective	
What do I need?		2.	Setup & Equipment	
How to do it?		3.	Method	
How to deal with	data ?	4.	Data Processing	
Is that normal?		5.	Examples	
What does radiati	on do?	6.	Radiation Impacts	
What's that thing	?	7.	Common Artifacts	
Provides guidance for conducting				

Provides guidance for conducting
tests and adaptable solutions to
the user's own needs

3		Charge Coupled Devices (CCD) and Complementary Metal Oxide Semi- conductor (CMOS) images sensors 141		
	3.1	Funda	mentals on CCD and CIS	
	3.2	Funda	mentals on images sensors figures of merits	
			•	
	3.3	Param	eters extraction method and radiation-induced degradations 192	
		3.3.1	Charge to Voltage Factor - CVF	
		3.3.2	Dark Current	
		3.3.3	Dark current activation energy	
		3.3.4	Dark Current Random Telegraph Signal - DC-RTS	
		3.3.5	Electro-optical transfer function	
		3.3.6	Dynamic Range	
		3.3.7	Quantum Efficiency	
		3.3.8	Annealing Effects	
		3.3.9	Radiation-induced degradation in advanced pixel architectures	
	Bibliography			

Guidelines Content Overview



Provides real data figures and analysis to present how it looks

3	Charge Coupled Devices (CCD) and Complementary Metal Oxide Semi- conductor (CMOS) images sensors 141		
	3.1	Funda	amentals on CCD and CIS
	3.2	3.2 Fundamentals on images sensors figures of merits	
	3.3	Paran	neters extraction method and radiation-induced degradations 192
		3.3.1	Charge to Voltage Factor - CVF
		3.3.2	Dark Current
		3.3.3	Dark current activation energy
		3.3.4	Dark Current Random Telegraph Signal - DC-RTS
		3.3.5	Electro-optical transfer function
		3.3.6	Dynamic Range
		3.3.7	Quantum Efficiency
		3.3.8	Annealing Effects
		3.3.9	Radiation-induced degradation in advanced pixel architectures 250
	Bibliography		

Scenario Example

Detector RHA Typical Workflow

1

2

3

4

5

Mission Details

Life duration & Orbital parameters & Radiation environment

Detector

Irradiative environment at detector level after shielding

Ground Test Design

Energy & Dose & Dose rate

Performance Degradation Measurements

Performance-driving parameters (ex: Dark Current, Dynamic Range, Sensitivity)

Test Report and Actions

- End of life detector performance
- Impacts on mission's goals
- Modifications: Shielding / Operating Temperature / Others...

Radiation Test Standards Software Tools Experience

Overlap



RHA Guidelines



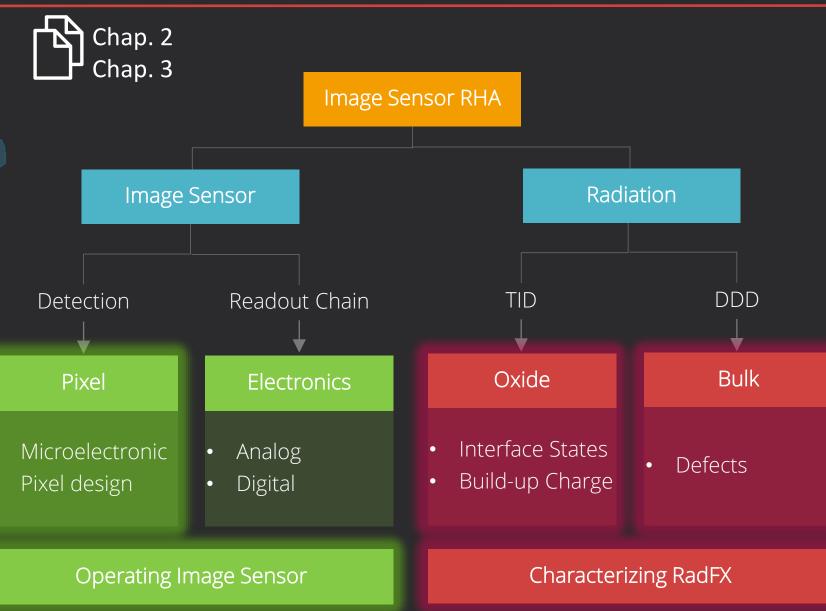
Scenario example

Who: Junior RHA engineer



Competencies:
Background in electronics

Tasks:
Collaborate with detector s
ystem engineer in
designing radiation testing
of a commercial CMOS
Image Sensor



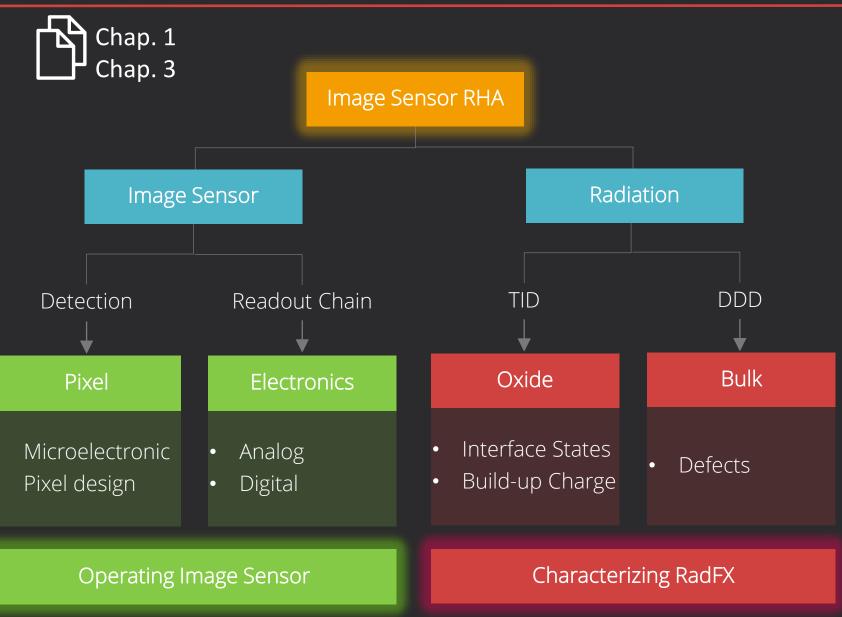
Scenario example

Who: Senior RHA engineer



Competencies: Expertise in electronics and radiation effects

Tasks:
Collaborate with detector s
ystem engineer in
designing radiation testing
of a commercial CMOS
Image Sensor



Scenario example

Who: Instrument/FPA Designers

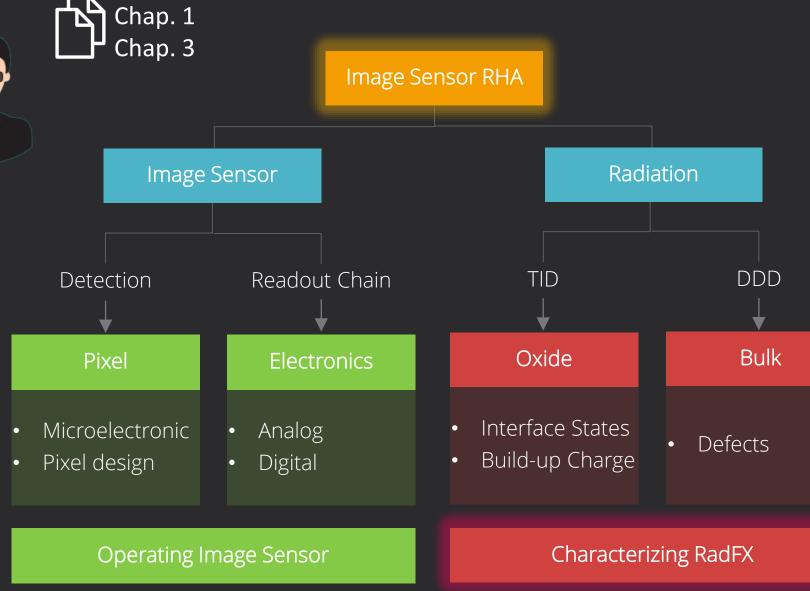


Competencies:

Expertise in image sensor characterization and development

Tasks:

Design of a camera based on a commercial CMOS Image Sensor



Scenario example

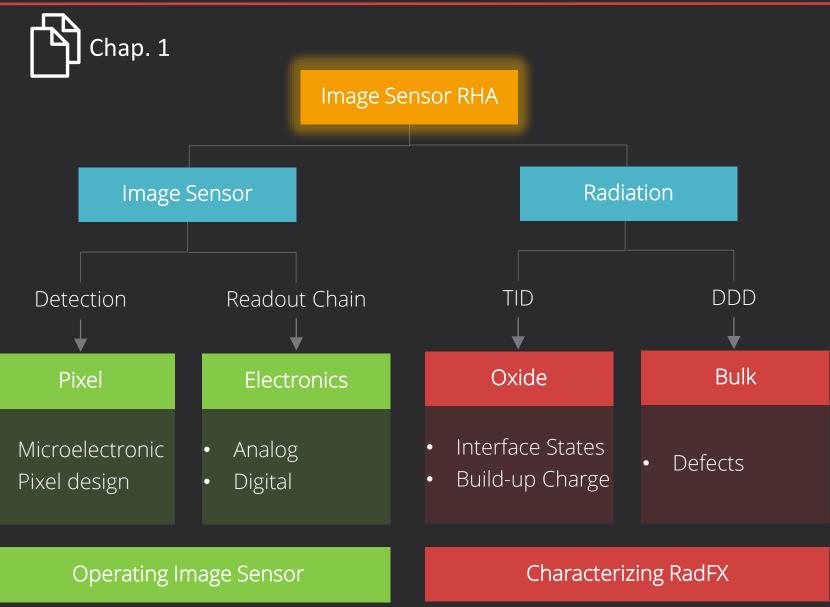
Who: Radiation Team Manager



Competencies: Knowledge of electronics and radiation effects

Tasks:

Orient radiation engineers, support test platform development, anticipate RHA needs



Next Steps and Conclusion

01

Rising interests and specific needs for Radiation Hardness Assurance (RHA) tests dedicated to photodetectors and image sensors operating in space environments



- Definition & Scope
- Positioning Photodetectors in Microelectronic Trends
- Future Needs in RHA

02

Fundamentals of space radiation environment and radiation-induced degradations on semiconductor devices



- Basic Knowledges & Key Concepts
- Focus on DDD
- Updated References
- Updates on Ongoing Research Activities

03

Charge Coupled Devices (CCD) and Complementary Metal Oxide Semiconductor (CMOS) images sensors



- Identify and Estimate the Radiation Vulnerabilities
- Parameters of Interest
- Test Setup Requirements and Test Method

04

Photodetector Array for UV & Infrared Applications



- Identify and Estimate the Radiation Vulnerabilities
- Parameters of Interest
- Cryogenic Test Setup
- Test Setup Requirements and Test Method

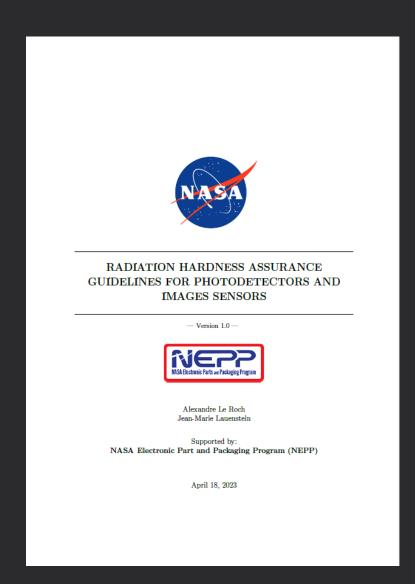
4.

Next Steps and Conclusion

Gather useful information in one document.

Covers central aspects of Image sensor RHA.

Available on the NEPP website shortly.





Best Practices



THANKS FOR YOUR ATTENTION





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JEAN-MARIE LAUENSTEIN Radiation Engineer — NASA GSFC Jean.m.lauenstein@nasa.gov





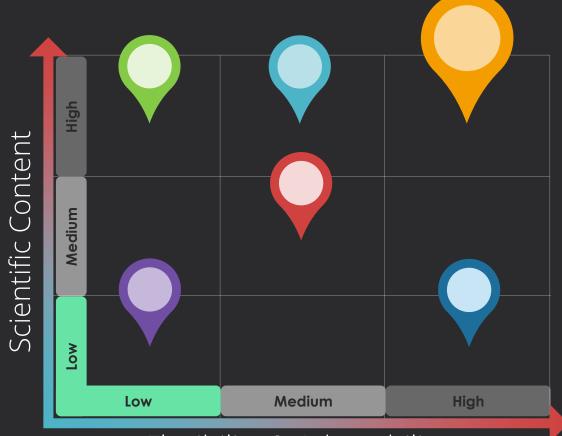




1 Backup slide: Project Goals and Objectives



Radiation Hardness Assurance Guidelines



Flexibility & Adaptability

Documentation

- Literature Review
- Scientific Report
- Test Report
- Mil & ESCC Standards
- Best Practices & Lesson-Learned
- RHA Guidelines

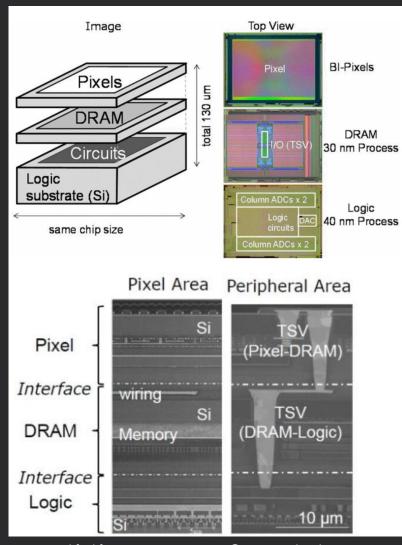
Backup slide: Testing COTS Image Sensors

Commercial Of The Shelf (COTS) CMOS Image Sensor

- Even more complex 3D pixel structures

 Multilayers, Vertically Pinned Photodiodes, Anti Blooming, Pixel Binning, Dark

 Current Mitigation...
- Advanced oxide processes:
 Shallow Trench Isolation (STI), Deep Trench Isolation (DTI), Capacitive Deep
 Trench Isolation (CDTI), High-k oxide...
- Stacking technologies
 Readout Integrated Circuit (ROIC), Memory DRAM, Logic
- Increased interest in flying COTS CIS
 OSIRIS REX instrument, Mars Perseverance's landing sequence



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Backup slide: What makes photodetectors different?

Analog detector

- Large in-pixel structures
- Double gate oxide (GO2) MOSFETs
- High voltage swing 2 3.3V

Adapted CMOS process for imaging

- GO2 In-pixel MOSFETs
- Photodiode implant
- Doping profile
- Oxides (liner oxides)

Mixed-mode device

Analog and digital signals

Include optical features

- Antireflecting coating
- Microlens & Color filters

