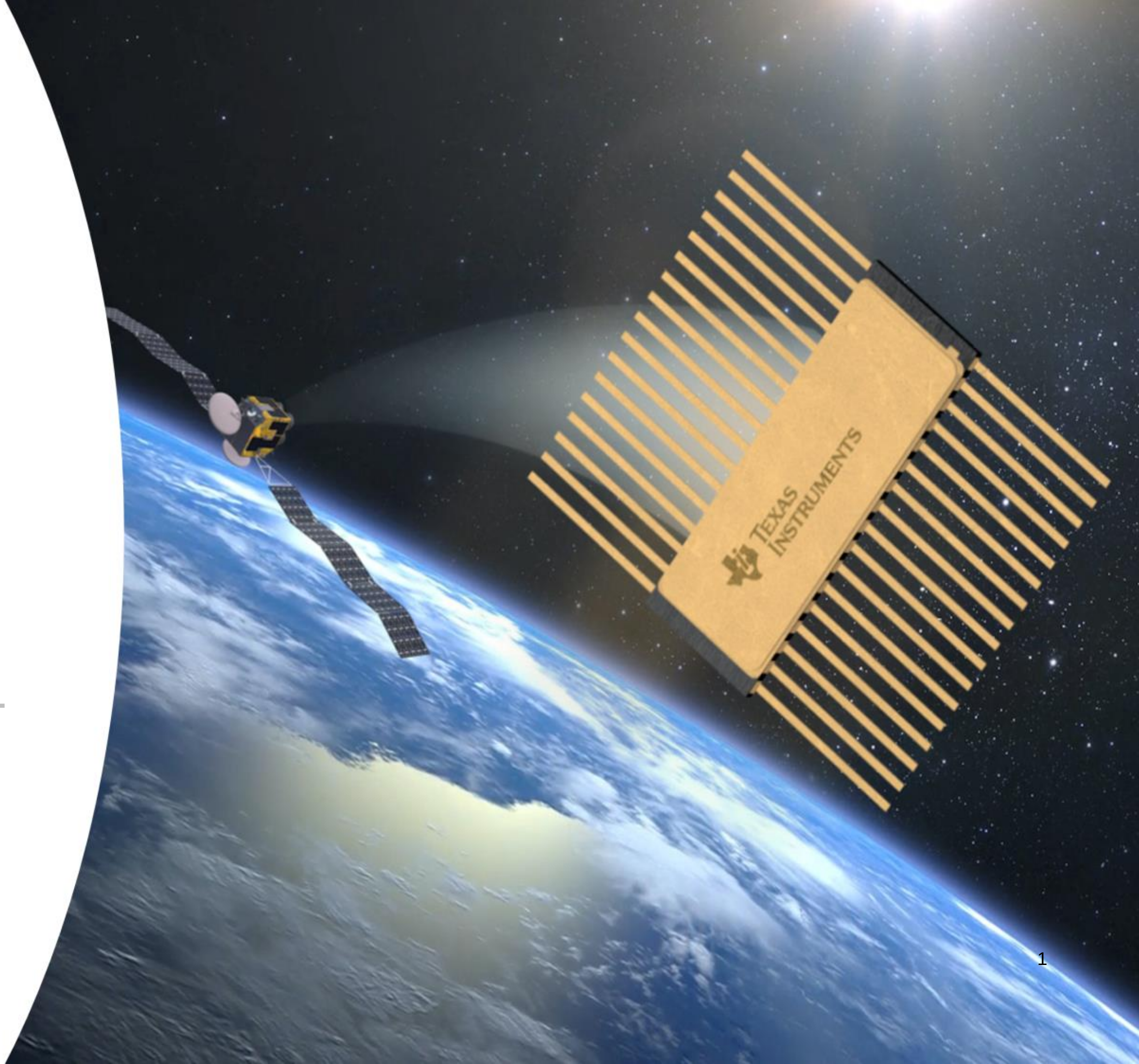
Reduce the Risk in NewSpace with TI's Space Enhanced Plastic Products

Jason Clark, Michael Seidl

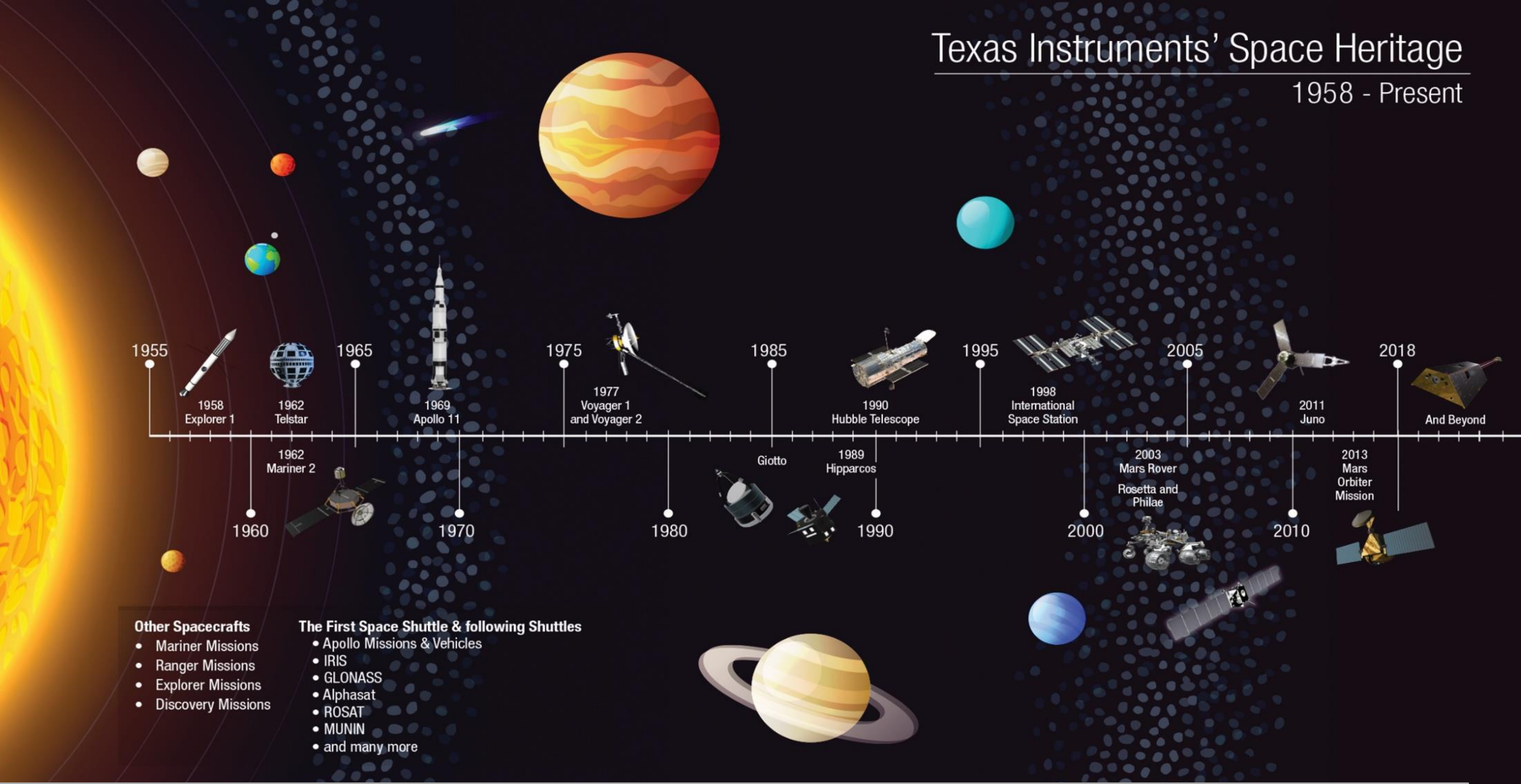
Aerospace Systems



Reduce the Risk in NewSpace with TI’s Space Enhanced Plastic Products

Agenda

- **Impact of cosmic radiation on semiconductors & mitigation techniques**
- **Correct material usage for harsh environments**
- **Quality assurance for space-grade components**
- **TI’s Space-Enhanced Plastic (SEP) Portfolio**


Texas Instruments' Space Heritage
1958 - Present
1955
1958
Explorer 1
1962
Telstar
1965
1969
Apollo 11
1975
1977
Voyager 1
and Voyager 2
1985
1990
Hubble Telescope
1995
1998
International
Space Station
2005
2011
Juno
2018
And Beyond
1962
Mariner 2
1960
1970
1980
Giotto
1989
Hipparcos
1990
2000
2003
Mars Rover
Rosetta and
Philae
2010
2013
Mars
Orbiter
Mission
Other Spacecrafts
• Mariner Missions
• Ranger Missions
• Explorer Missions
• Discovery Missions
The First Space Shuttle & following Shuttles
• Apollo Missions & Vehicles
• IRIS
• GLONASS
• Alphasat
• ROSAT
• MUNIN
• and many more

Sources of Radiation in Space

Radiation Sources

- Ionizing radiation from the sun (solar radiation)
- Particles trapped in the Van Allen radiation belts
- Cosmic rays from outside our solar system, Galactic Cosmic Radiation or GCR

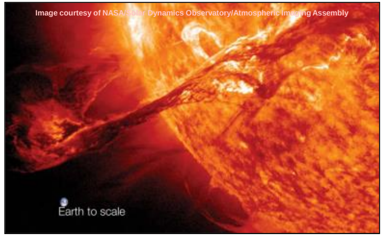
Particles type

- Electrons, Protons, Heavy ions

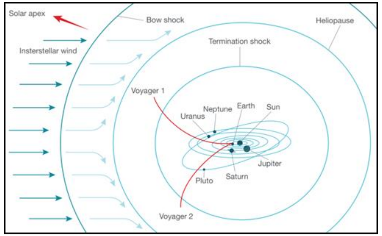
Electron & Proton impact on semiconductors

- Cumulative long term ionizing damage due to protons & electrons can cause devices to suffer threshold shifts, increased device leakage & power consumption, timing changes, decreased functionality, and device failure.

Radiation Sources

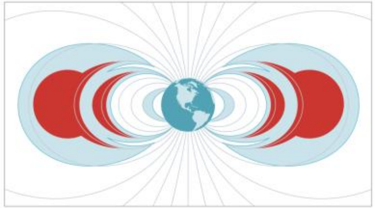


Solar Wind, CME, Flares
Mostly Protons, Electrons, He, and a few Heavier Ions



Galactic Cosmic Rays
Mostly Protons, He, Heavier Ions

Modulator



Van Allen Belts
Earth's Magnetic Field

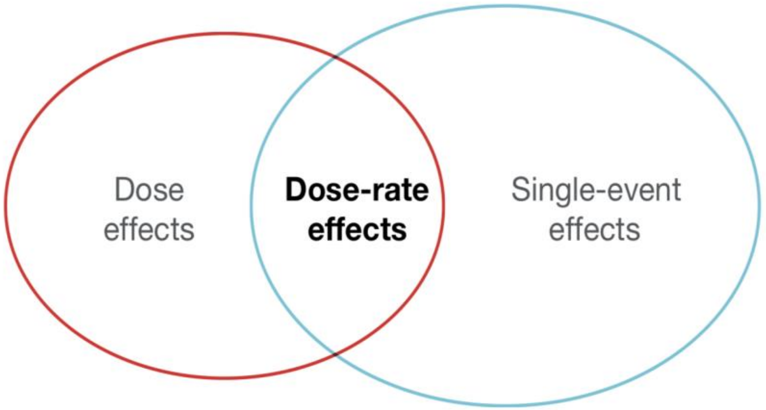
Effects of Radiation on Components

Total Ionizing Dose (TID)

Cumulative Effects

krad

Drift-Like



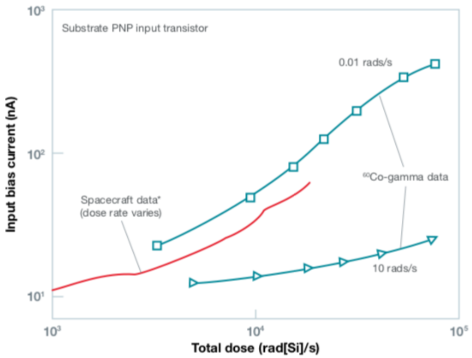
Single-Event Effects (SEE)

Transient Effects

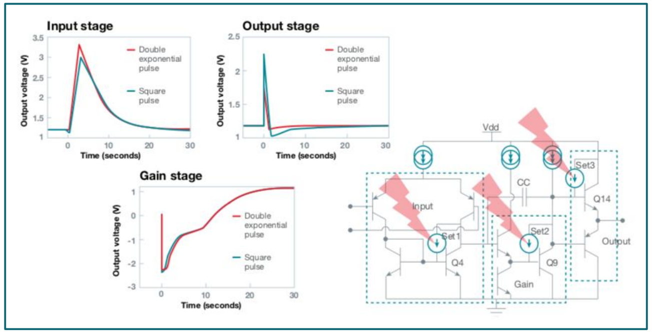
MeV·cm²/mg

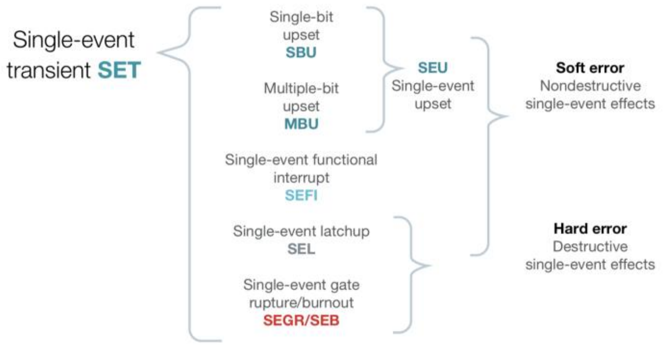
Surge-Like

Dose Effects



Sigle-Event Effects





TI Radiation Hardening and Test Capability

Rad Hard by Process (RHBP)

- Process technology development
- Process improvements on existing IP and designs

Rad Hard by Design (RHBD)

- Design and layout changes on existing IP
- Radiation hardened design library on key process technologies
- Focus on key technologies like Power and Data Converters

25+ Years of Radiation Testing - Centralized Team for Radiation Testing and Debugging

Dose Effects

Total Ionizing Dose (TID) Testing Based on Process Technology

- Bipolar - Low Dose Rate (LDR) [10 mrad/sec or below]
- CMOS - High Dose Rate or HDR [50-300 rad/sec]
- BiCMOS - Both LDR and HDR

Neutron Displacement Damage (NDD) for Bipolar and BiCMOS

Test Facilities: TI Owned HDR Testing, External HDR/LDR Testing

Single-Event Effects

SEL Immunity, SET, SEB, SEGR, SEU, and SEFI Testing

- Single Event Latch-up (SEL) Immunity Characterization
- Cross-Section Characterization of SET, SEB, SEGR, SEFI, SEU depending on device function and process technology

Test Facilities: TAMU, LBNL, and other facilities

Radiation Reports can be found in the Product folder → Technical Documents → Radiation & Reliability Reports on TI.com

Reduce the Risk in NewSpace with TI's Space Enhanced Plastic Products

Agenda

- **Impact of cosmic radiation on semiconductors & mitigation techniques**
- **Correct material usage for harsh environments**
- **Quality assurance for space-grade components**
- **TI's Space-Enhanced Plastic (SEP) Portfolio**

TIN Whisker Problem

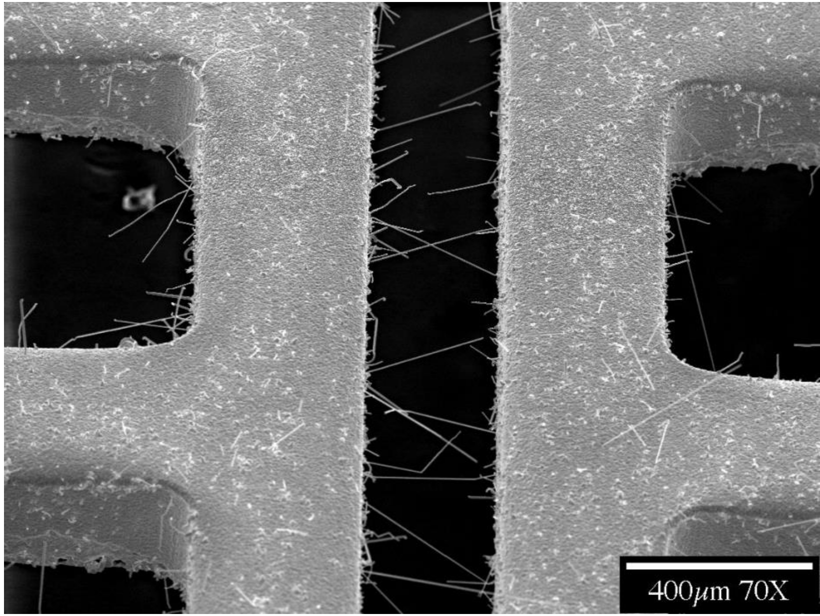
Tin whiskers are conductive, crystalline structures that grow from surfaces where tin (especially electroplated tin) is used as a final finish.

Whisker growth has been attributed to stress, surface morphology, thermal mismatch, etc. – no conclusive single cause. It can occur during operation or on the shelf.

Observed to grow to lengths of several millimeters (mm) to lengths in excess of 10 mm. Numerous system failures have been confirmed due to short circuits caused by tin whiskers bridging closely-spaced circuit elements (NASA)

Alloying tin with a second metal can reduces the propensity and size of whisker growth. Alloys of tin and lead are generally considered to be acceptable (≥ 3% lead by weight).

Tin Whiskers growing on a MATTE tin-plated copper lead frame after a few years of ambient storage…



Photos Courtesy of Peter Bush (State University New York at Buffalo)

See: http://nepp.nasa.gov/Whisker/background/index.htm

Fixing the TIN Whisker Problem

Solder dip tin-plated surfaces with a tin-lead solder to alloy the tin.
Issues: expensive additional processing, special precautions required to prevent thermal shock damage, loss of hermeticity, and thermal degradation. Difficult to ensure that the entire surface is properly reflowed and alloyed.

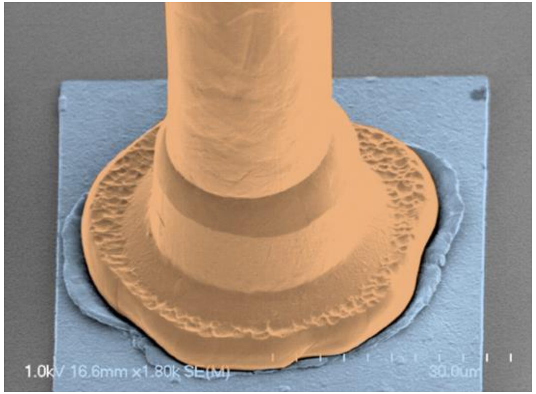
Re-plate the whisker-prone areas with plating material such as tin/lead or Nickel.
Issues: expensive additional processing, whiskers may still form and protrude through thin plating.

Conformal encapsulation over the whisker prone surface
Can contain whisker growth while providing resistance to penetration by external whiskers.
Issues: expensive additional processing and must qualify encapsulant for stress/curing/react. etc.

BEST SOLUTION – Eliminate pure Tin from process/packaging
Works for ceramic/plastic – EP, Space EP, and SP products contain no pure tin.

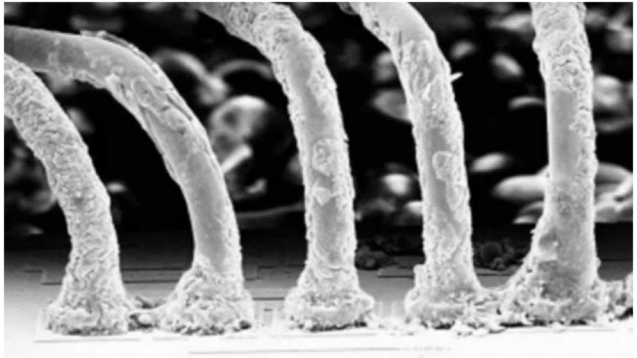
Cu Bond Wire Concerns

Commercial product is using more and more copper (Cu) bond wire to replace more expensive gold wire. Reliability has been optimized for the commercial operating environment and the customer generally does not know what bond wire is used (unless the product is running 100% Cu)



Potential risks identified by the industry include:

- Bond integrity (Cu bonding to aluminum requires much tighter process controls and environments)[1]
- Sporadic DPPM level corrosion due to mold compound interaction[2]
- Bondwire neck breaks during temperature cycling (The coefficient of thermal expansion [CTE] of Cu is higher than Au, resulting in a higher failure rate in the presence of delamination compared to Au)[3]



Sources:

[1] Luke England and Tom Jiang. "Reliability of Cu Wire Bonding to Al Metallization". Electronic Components and Technology Conference. 2007.

[2] Hui Teng, et al. "Effect of Moisture and Temperature on Al-Cu Interfacial Strength". International Conference on Electronic Packaging Technology & High Density Packaging, 2008.

[3] Bart Vandevelde and Geert Willems. "Early fatigue failures in Cooper wire bonds inside packages with low CTE Green Mold Compounds". 4th ESTC Conference. 2012, Amsterdam, The Netherlands.

Plastic Outgassing and Moisture Absorption

- **Organic mold compound** that can **absorb moisture** and **outgas organic compounds**.
- **Moisture absorption** can result in **reduced reliability and lifetime** of a product.
- **Outgassing constituents** can condense on **other components**, **contaminating** them and **impacting** their **performance** (e.g. imaging sensors).
- TI's **Space EP** products use **enhanced mold compounds** and go through extended qualification testing**.**
- Space EP products **exceed the NASA** driven **outgassing requirements** (ASTM E-595)

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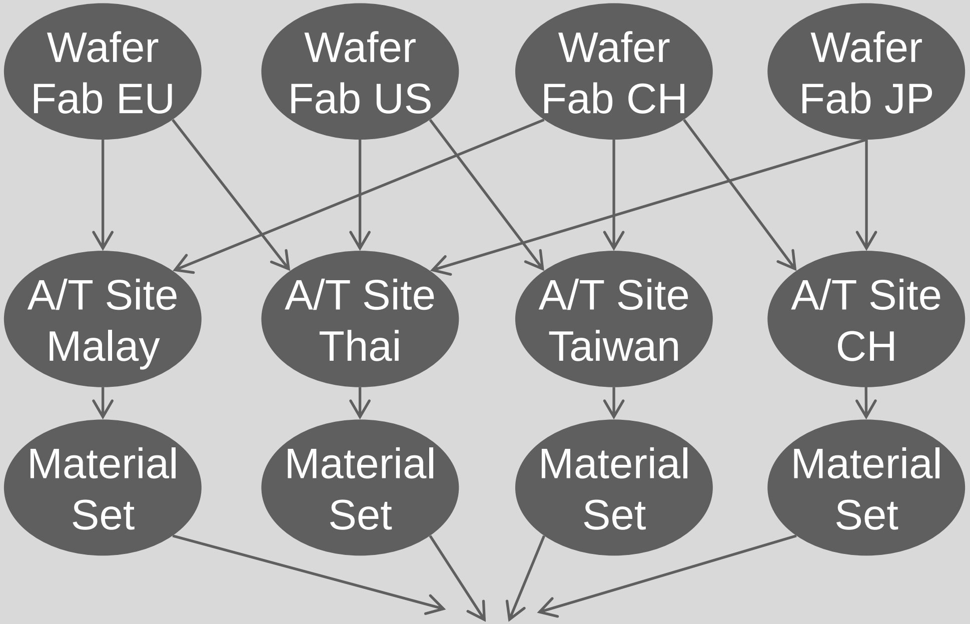
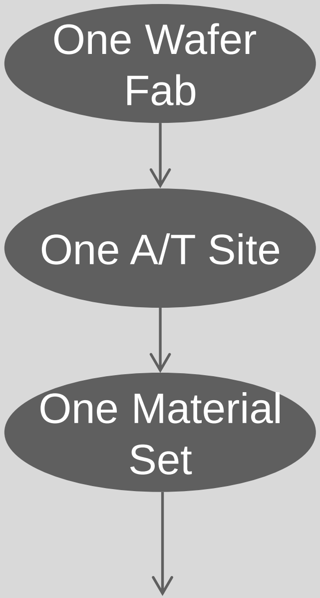
Space EP Baseline Controlled Flow

Commercial/Automotive Flow



Commercial product builds = multiple FABs, A/T sites and may use various material sets

Space EP Flow



EP product build = one FAB, one A/T site, and one material set

Commercial Flow (real example: SN74HC138)

3-Line To 8-Line Decoders/Demux

Commercial Process Variables

3 active wafer fabs

- TI SFAB in Sherman, Texas
- ATC (subcontractor) in Hsinchu, Taiwan
- ASMC (subcontractor) in Shanghai, China

Each wafer fab runs a similar BUT NOT identical baseline

- Glassivation (protective overcoat)
- Base silicon wafers (vendor and doping spec)
- EPI versus non-EPI (doping profile/yield)
- Diffusion and metal profiles
- Process equipment
- Process recipes
- Process control limits

Commercial Assembly Baseline Flows

3 assembly/test sites

- TI Mexico
- TI Taiwan
- ALP (subcontractor) in Thailand

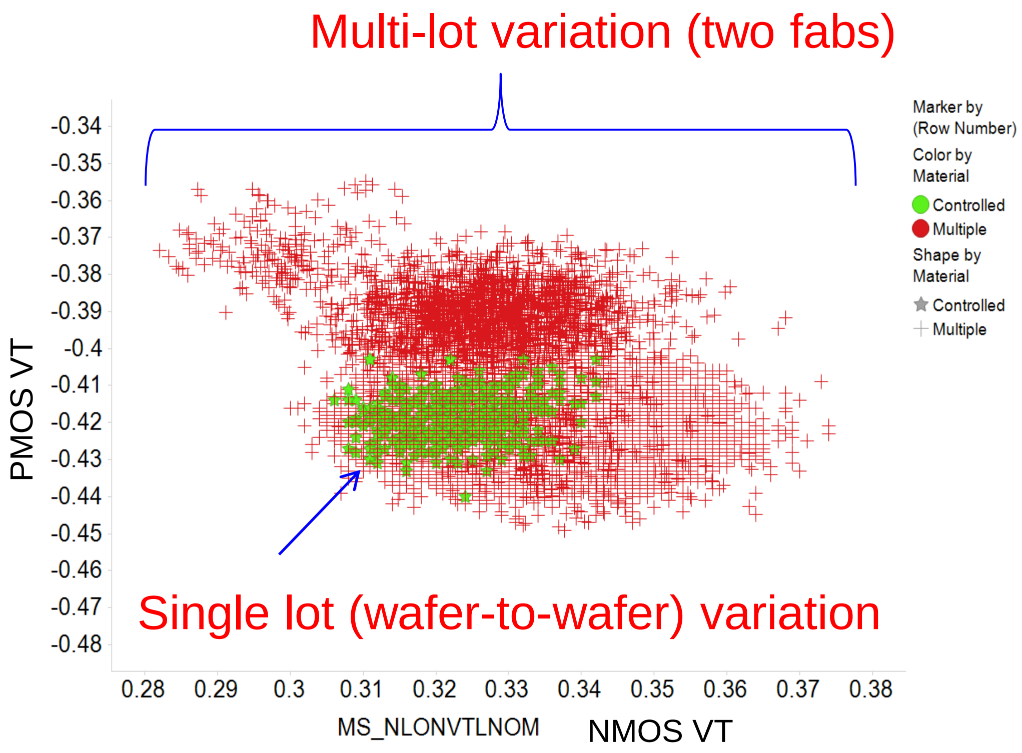
Each assembly site runs a similar BUT NOT identical baseline

- Lead-frame source and geometries
- Mold compound (encapsulant)
- Mount compound (die attach)
- Wire bonder type and profile
- Wire type and other materials
- Injection mold press type and profile

Sources of Variability

- **Intrinsic Process Sensitivity**
- **Impact is component-specific**
- **Optimized for electrical perf./rel.**

- **Fab-to-Fab**
  - Fab equipment set
  - Fab recipe/starting material
  - Fab controls/methods
  - Revisions/shrinks
  - Design sensitivity/component choice
- **Lot-to-Lot**
  - Process has a natural variation
  - Processes drift over time
  - Process tweaks to boost yield



TID variation examples

- **Fab to Fab Variation** – Example: UC18xx-SP
  - 50 krad to 5 krad
    Solution: process recipe improvement, single fab
- **Lot to Lot Variation** – Example: LM108
  - Lot 1 = 100 krad, Lot 2 = 30 krad, Lot 3 = 10 krad
    Solution: Radiation Lot Acceptance Test (RLAT)
- **Design to Design** – Examples: LM124 and LM139-SP
  - LM124AQML-SP and LM139AQML-SP – 100 krad
  - LM124-SP and LM139-SP – 40~50 krad

Lot-to-Lot variation impact on HDR TID

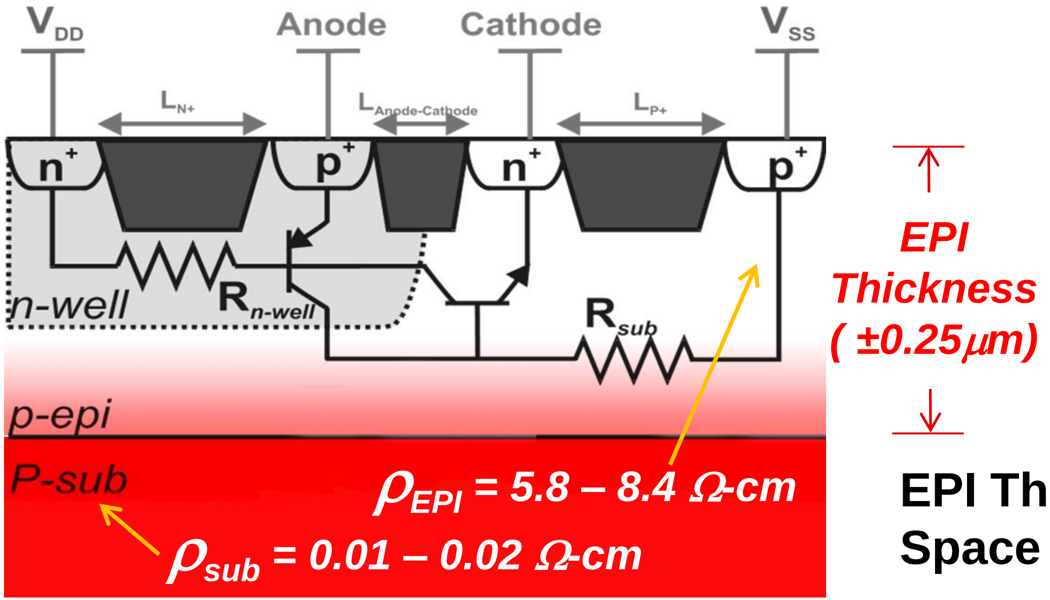
LM108	HDR TID (krad)	Status
Lot #1	100	Pass
Lot #2	30	Pass
Lot #3	10	Fail

Wafer-to-Wafer impact on LDR TID

LM108	LDR TID (krad)	Status
Wafer #2	80	Pass
Wafer #3	50	Pass
Wafer #15	30	Pass

Key Sources of Variability for SEL

- EPI thickness (±3%)
- EPI doping (±20%)
- Substrate doping (±33%)



SN65HVD233-SP EPI example

CAN Exhibits SEL based on 0.5um variation

EPI (um)	Temp	LET	SEL
Commer.	25	60	Yes
9.5	25	85	No
9.5	125	85	No
10	25	85	Yes
10	125	60	Yes

Commercial device has high resistivity substrate With baseline EPI thickness of 8 um. SP version uses highly doped substrate.

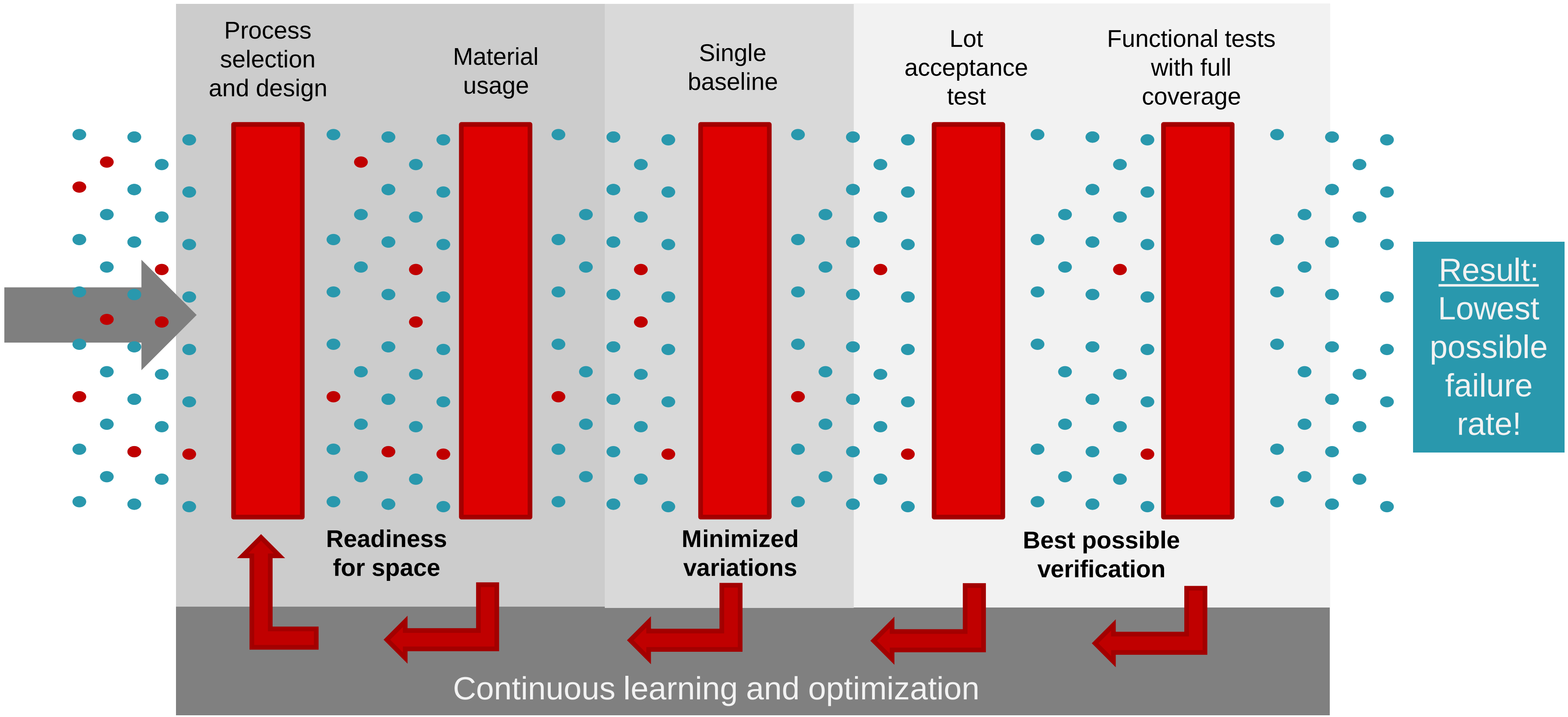
EPI Thickness controlled tightly for Space flow

Comprehensive functional test of every unit with best possible coverage

Best possible testing capabilities

- Leveraging test programs & experience from parenting devices
- Best knowledge of design and potential failures
- Culture of excellence: TI has achieved a number of industry certifications including ISO 9001, ISO14001, IATF16949, OHSAS18001 and the Underwriters Laboratories (UL) rating.

Space-grade quality assurance



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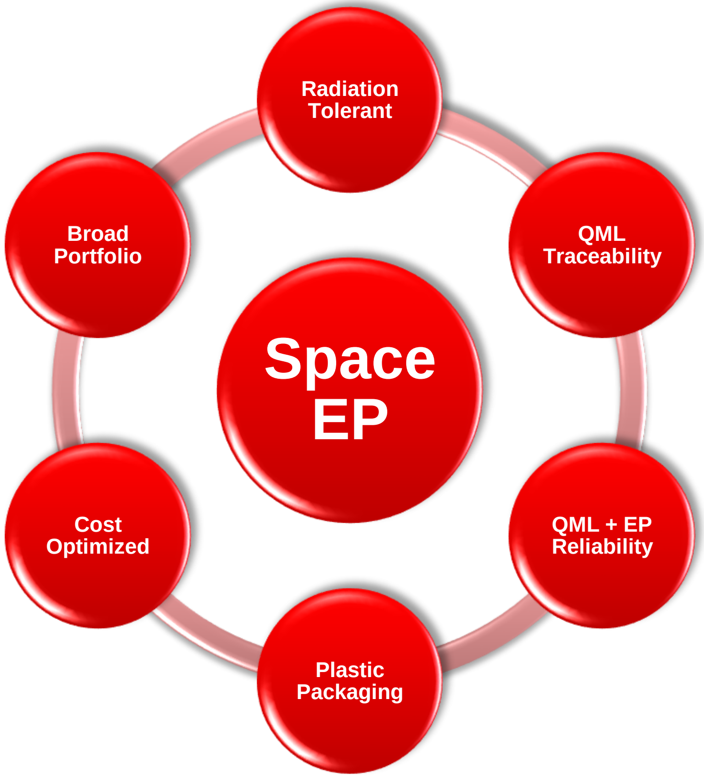
What is Space EP?

- Cost effective radiation **tolerant** solution for **shorter** duration **high volume** small satellites

- **Space EP = Traceability + Reliability + Radiation**
  - QMLV like flow
    - Wafer lot accept
    - Traceability
  - Radiation
    - RHA Qualification: **20k rad**
    - SEL Characterization : **43MeV**
  - Enhanced Products Reliability
    - Robust material set (lead frame, mold compound, bond wire, etc..)
    - Enhanced qualification (HAST, extended temperature, meets MIL-PRF 38535 Class N)



TI's space products

Similarities in SEP and SP
Similarities in SEP and EP

Space Products

	Commercial Industrial	Automotive Q100	EP (Military)	QML-Q (Military)	Space Enhanced Plastic (SEP)	QML-V (Space) QMLV	QML-V (Space) QMLV-RHA
Packaging	Plastic	Plastic	Plastic	Ceramic	Plastic	Ceramic	Ceramic
Single Controlled Baseline	No	No	Yes	Yes	Yes	Yes	Yes
Bond Wires	Au/Cu	Au/Cu	Au	Al	Au	Al	Al
Is Pure Sn used?	Yes	Yes	No	No	No	No	No
Production Burnin	No	No	No	No	No	Yes	Yes
Typical Temperature Range	-40ºC - 85ºC	-40ºC - 125ºC	-55ºC - 125ºC (majority)	-55ºC - 125ºC	-55ºC - 125ºC (majority)	-55ºC - 125ºC	-55ºC - 125ºC
Radiation (SEL/SEE)	No	No	No	No	Yes (43 MeV)	Yes (>60 MeV)	Yes (>60 MeV)
Radiation (TID)	No	No	No	No	Yes (30 krad)	Yes (50~300 krad)	Yes (50~300 krad)
Radiation (TID) Lot Acceptance (RLAT)	No	No	No	No	Yes (20 krad)	No	Yes
Outgassing tested per ASTM E595	No	No	No	N/A	Yes	N/A	N/A
Lot Level Temp Cycle	No	No	No	Group D	Lot Level	Group D	Group D
Lot Level HAST	No	No	No	N/A	Yes	N/A	N/A
Multiple wafer lots per reel possible	Yes	Yes	Yes	No	No	No	No
Life Test Per Wafer Lot	No	No	No	No	No	Yes	Yes

Quality / Reliability / Cost →

Upscreening Risks

- **Space EP** minimizes many sources of process variation
  - Process variation can effect both Single Event Performance and Total Ionizing Dose Performance
- **Space EP** is a fully warrantied device by TI for small sat applications
  - Warranty is not supported if up screening is suspected on any TI device
- **Space EP** utilizes extensive production test capability
  - Upscreeners do not have access to production test vectors
- **Space EP** absorbs any yield hits
  - Must acquire many extra commercial devices to cover yield/screen loss
- **Space EP** manages a controlled baseline to minimize electrical performance drift
  - Commercial devices come from multiple FABs and A/Ts
- **Space EP** addresses radiation effects upfront and guarantees them
  - Unknown what radiation levels you will receive based on process

Space EP Devices

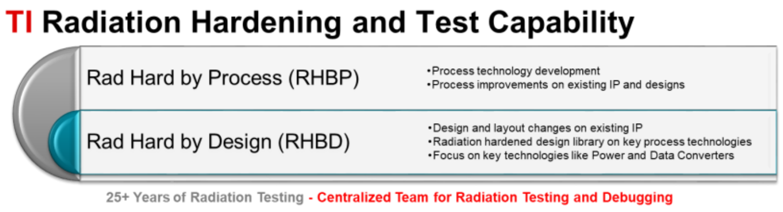
Function	Device	Package	RTM	Description
RF	LMX2694-SEP	48-pin QFN	Released	40 MHz to 15GHz Synthesizer
MCU	MSP430FR5969-SP	48-pin QFN	Released	Mixed-Signal MCU w/FRAM
Interface	ISOS141-SEP	16-pin SSOP	Released	100 Mbps, 4-Ch (3/1)Digital Isolator
Interface	SN55HVD233-SEP	8-pin SOIC	Released	CAN Transceiver
Interface	SN65C1168E-SEP	16-pin TSSOP	Released	Dual differential RS-422 drivers and receivers
Comparator	TLV1704-SEP	14-pin TSSOP	Released	Quad, 2.2-V to 36-V, microPower Comparator
Sensor	INA240-SEP	8-pin TSSOP	Released	Hi/Lo Side (-4 to 80V), 20V/V, Bi-Directional Current Sense Amp
Supervisor	TL7700-SEP	8-pin TSSOP	Released	Supply-Voltage Supervisor
LDO	TPS73801-SEP	SOT-223	Released	2.2-20V Vin, 1A, 0.24V dropout
POL (DC-DC)	TPS7H4010-SEP	30-pin QFN	Released	3.5V to 36V, 6A Synchronous Step-Down Voltage Converter

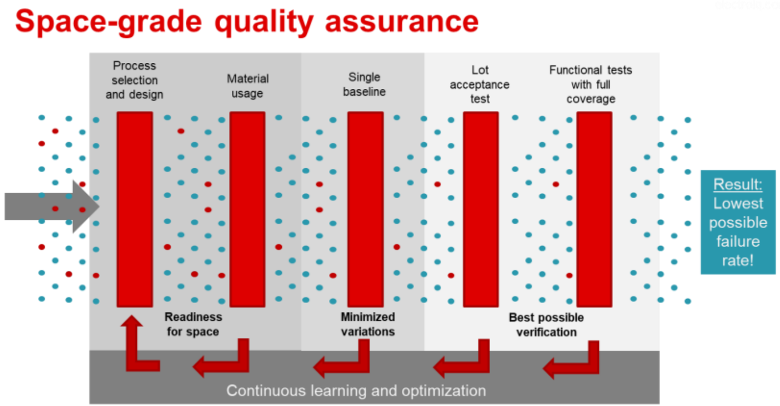
Space EP Collateral

- Overview Video: learn how Space Enhanced Plastic ICs address New Space design requirements
- Overview Article: Space EP products Overview
- App Note: Reduce the risk in NewSpace with Space Enhanced Plastic products
- Technical Article: Space Enhanced Plastic gives designers a new solution for emerging low-Earth orbit commercial applications
- Archived Webinar: Reduce design risk for Low Earth Orbit satellites and other New Space applications

Summary

- TI has a long heritage and strong expertise in space-grade component design
- TI's Space EP portfolio bridges the gap between Full Space Grade and Q100/Commercial
- Space EP reduces the risk of component failures in various aspects
  - Space readiness by design and material usage
  - Single base line to minimize variations
  - Verification
    - Radiation (TID) Lot Acceptance (RLAT)
    - Functional test with full coverage
- 10 Space EP parts released already. Many more to follow across all product categories with strong support:
  - collaterals on ti.com
  - via e2e forum





It takes a lot more to call a semiconductor component 'space-grade' than a single radiation test

Thank You - Q&A

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Reducing the Risk in New Space

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TI Space Products Guide

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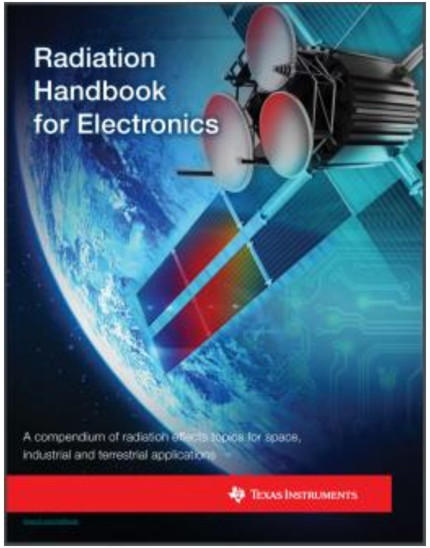

Radiation Handbook for Electronics

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