Rad Hard and Cryo Electronics For Cubesats in Jovian Radiation Environments

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Robert V. Frampton robert.v.frampton@boeing.com
Boeing – Phantom Works, Huntington Beach, CA

Leora Peltz leora.peltz@boeing.com
Boeing Research & Technology, Huntington Beach CA

Introduction

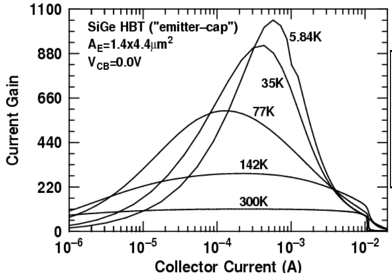
- A Europa mission has been selected by NASA as the next flagship mission. This mission may include cubesats released from the spacecraft. These cubesats would be too small to carry heavy shielding or sufficient batteries for heaters to keep electronics warm. They would be required to have a lifetime longer than a few hours; therefore, the electronics would need to be designed to operate at the extreme cold temperatures and in the Jovian extreme radiation environment.
- These are harsh and challenging environments for electronics circuitry. SiGe and GaN technologies are both particularly suited to meet these demands. Both SiGe and GaN are wide-band-gap materials, giving them inherent radiation tolerance (rad-hard by technology).

Silicon Germanium (SiGe) and Gallium Nitride (GaN) are Suitable for Cryo Environments.

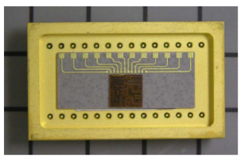
Europa has extreme environmental conditions, with a surface temperature varying from a low of 50 Kelvin up to 125 Kelvin, with a mean temperature of around 100 Kelvin. We can expect similar orbital temperatures. Europa also has an extreme radiation environment, as high as 20 Mrad-Total Ionizing Dose (TID) per month.

SiGe and GaN technologies are both particularly suited to meet these demands. The SiGe will operate over a wide range of temperatures: down to 43 Kelvin (-230^{o} C) without “warm boxes”, and up to 398 Kelvin (+125^{o} C), in normal operation. GaN devices have been tested over a temperature range from 80 K to 500 K (225 C).

Silicon-Germanium (SiGe) Integrated Electronics for Extreme Environments

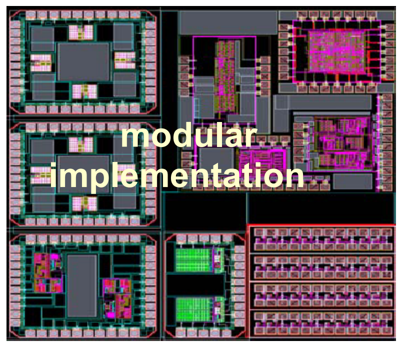


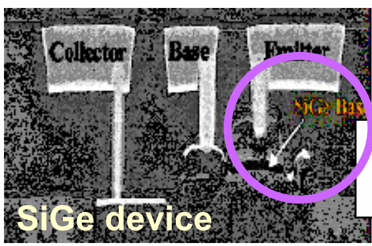
SiGe transistor demonstrated to operate at 5.8 degK



System on a chip

SiGe REU





SiGe transistor is intrinsically RadHard

Silicon-Germanium Electronics for Extreme Environments funded by NASA under the RHESE program.
Managed by NASA MSFC
Dr. M. Watson / Dr. A. Keys

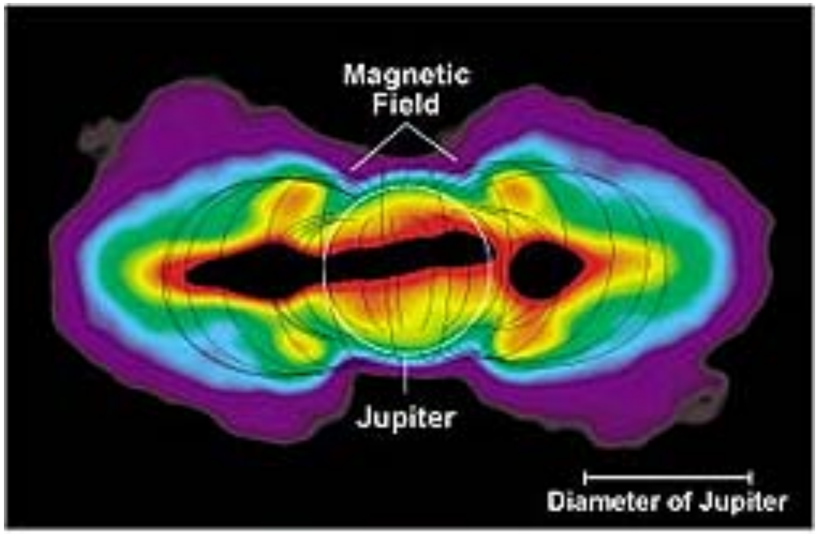
Rationale: There is a 4% difference in the lattice constants of Si and Ge; and so if one is grown on the other, the layer is strained. This strain may be used to vary the semiconductor properties of SiGe (ex: bandgap energy) resulting in a versatile material which is low-cost and compatible with standard Si manufacturing processes.

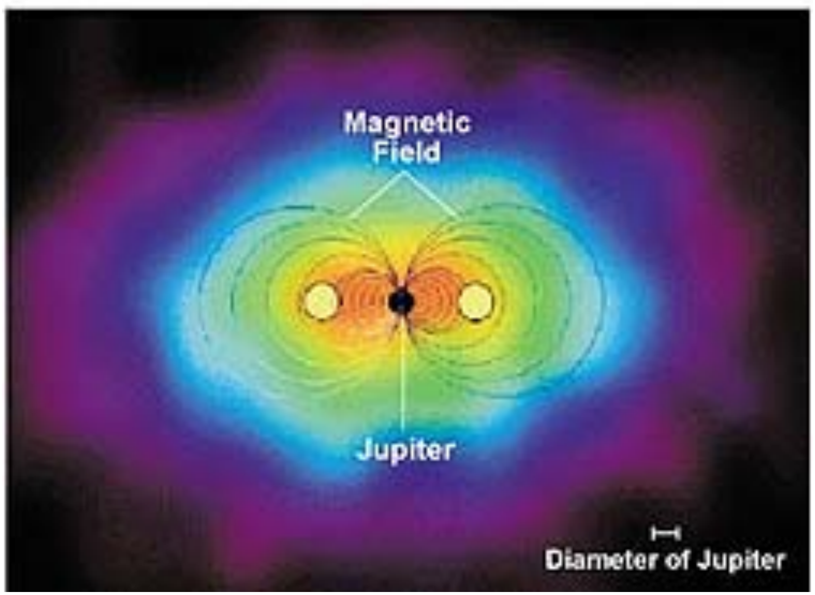
Objective: Develop and demonstrate SiGe Electronics for Extreme Environments for distributed architecture for Moon and Mars.

SiGe REU is a System-on-a-Chip that can operate at 43K without heaters. Also, SiGe HBTs are intrinsically Rad-Hard for TID.

Applications:
- distributed sensor and IVHM modules.
- adaptive control for MAGGI motors and actuators.
- penetrators.

Jupiter Magnetic Field

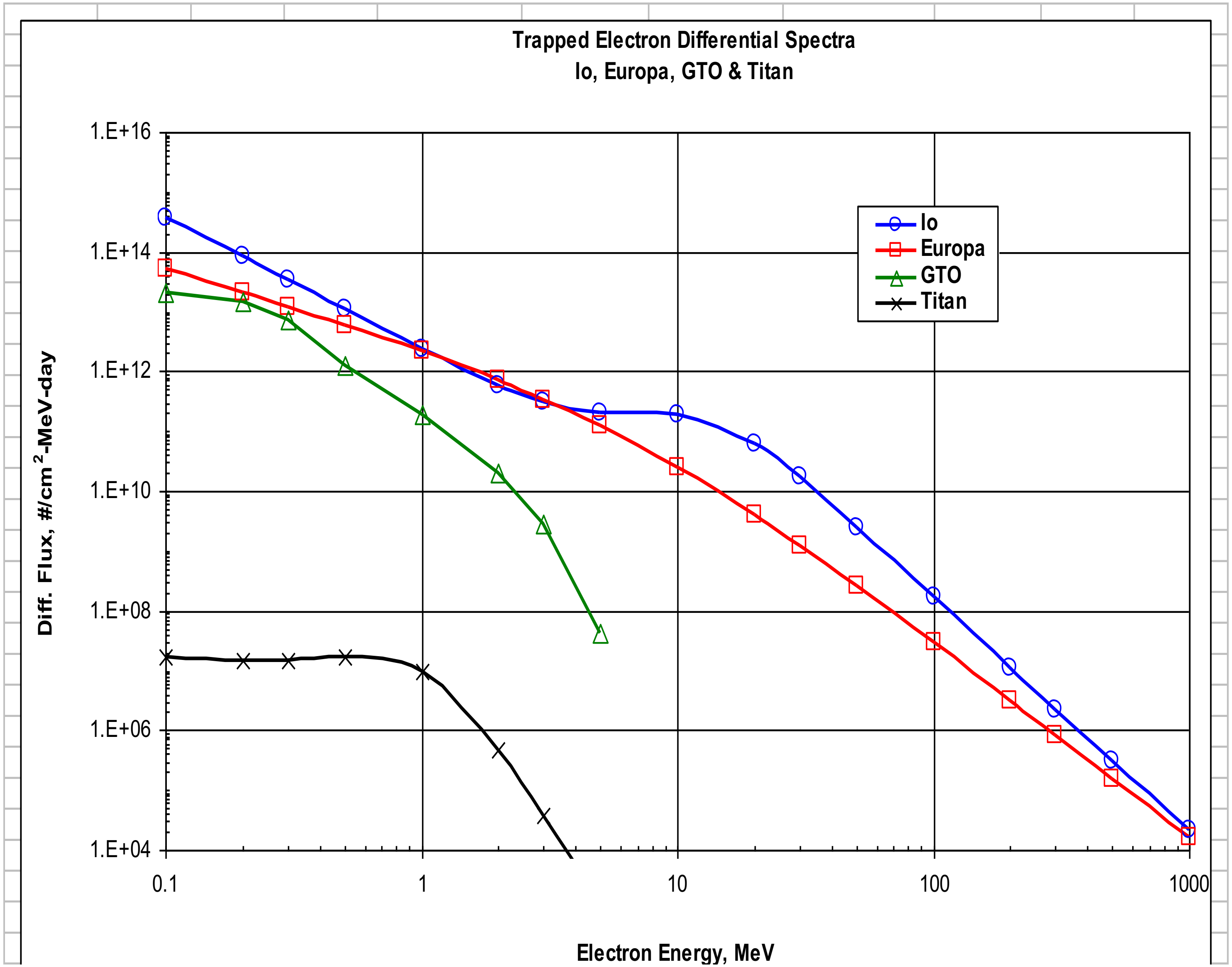




The magnetosphere of Jupiter is the largest "object" in the Solar System. Europa orbits within this radiation belt, bombarded by energetic particles accelerated by the flowing magnetic field lines that rotate with the planet.

This arrangement is not unusual for satellites of giant planets, and it has already led to the discovery of an induced magnetic field in Europa, most likely generated in a liquid ocean beneath the ice.

Electron Radiation Environment at Europa, compared to Van Allen Belts (GTO)



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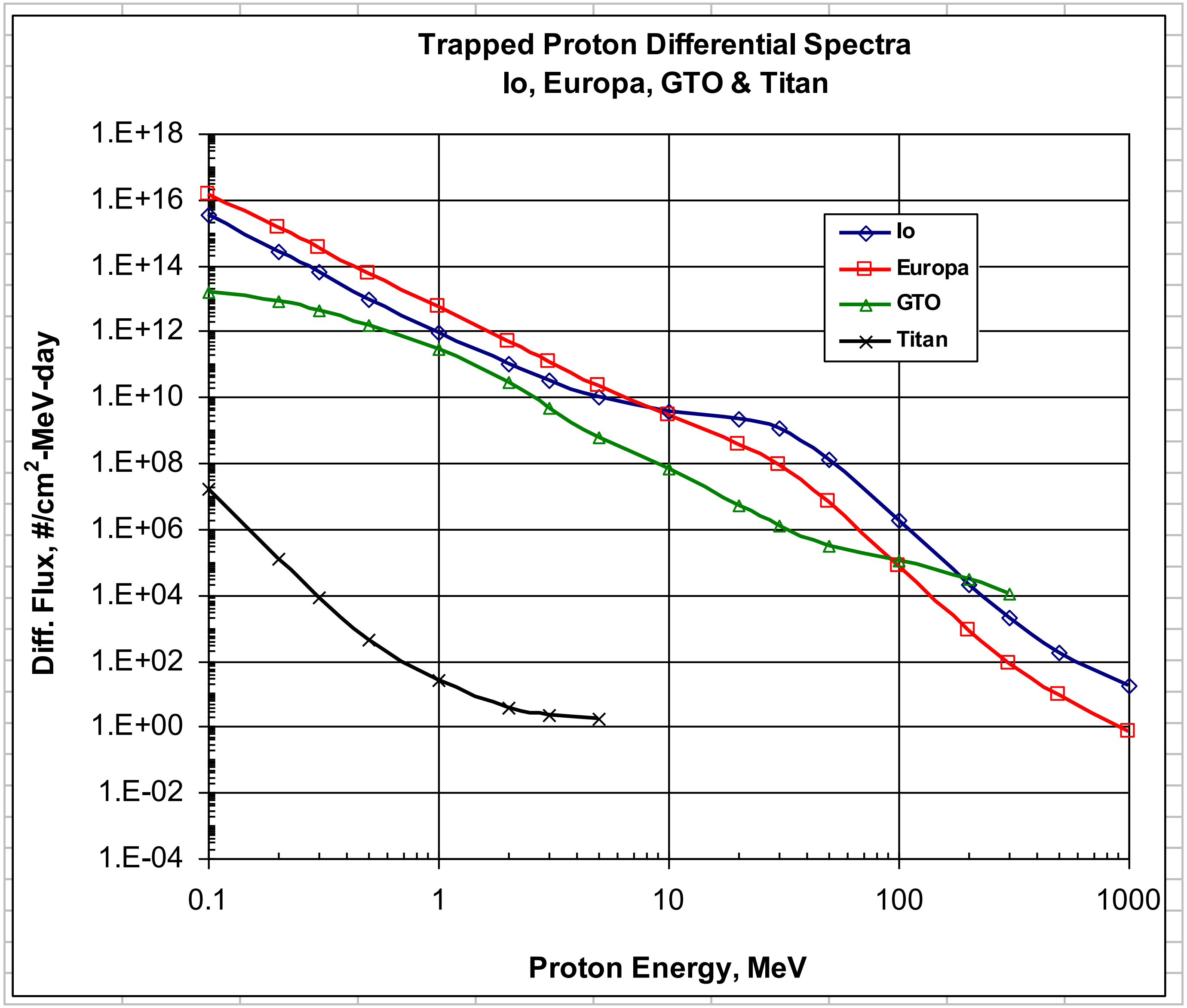
Proton Radiation Environment at Europa, compared to Van Allen Belts (GTO)



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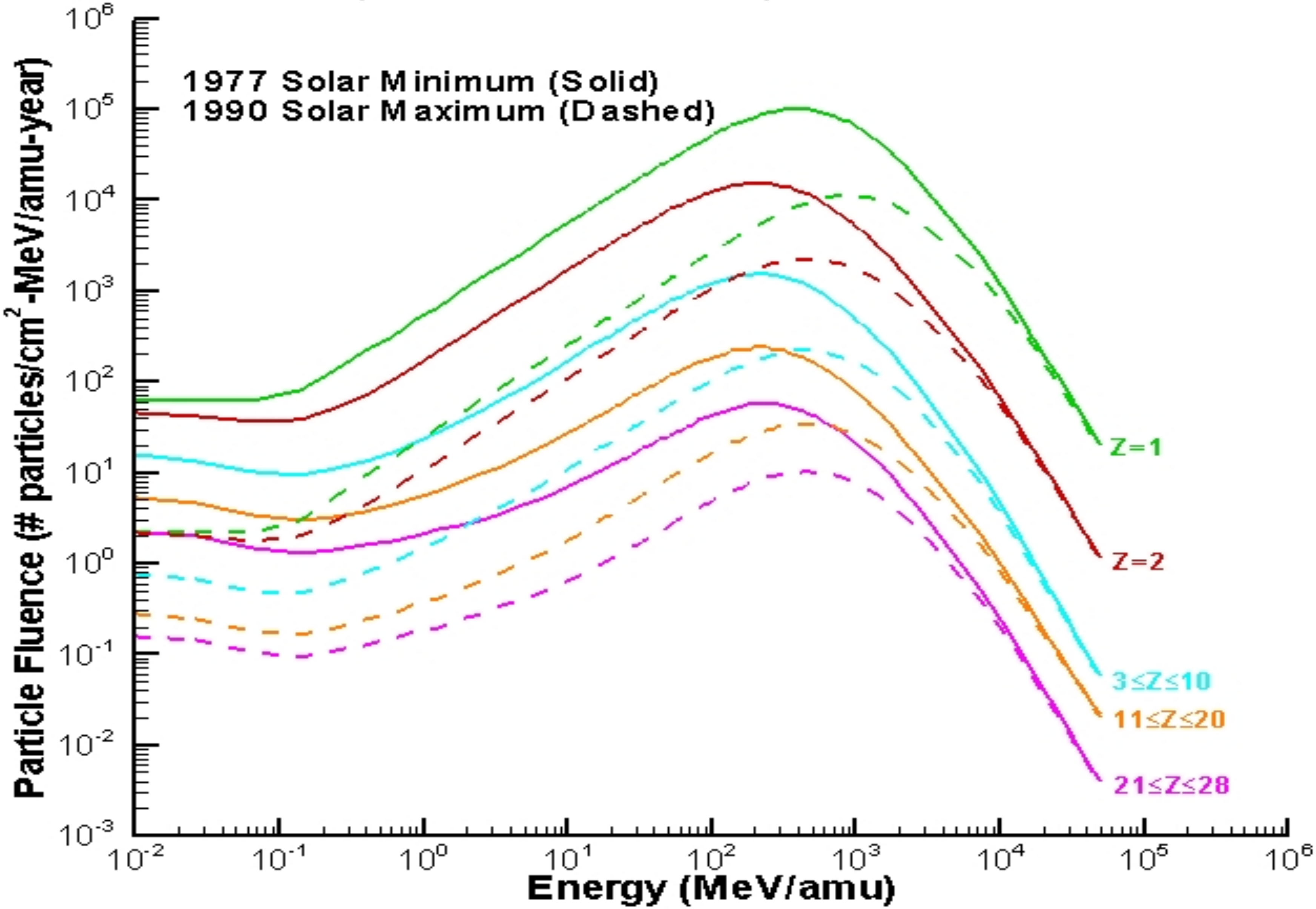
FREE-SPACE GALACTIC COSMIC RADIATION (GCR) ENVIRONMENT
Background Radiation During Cruise to Jupiter



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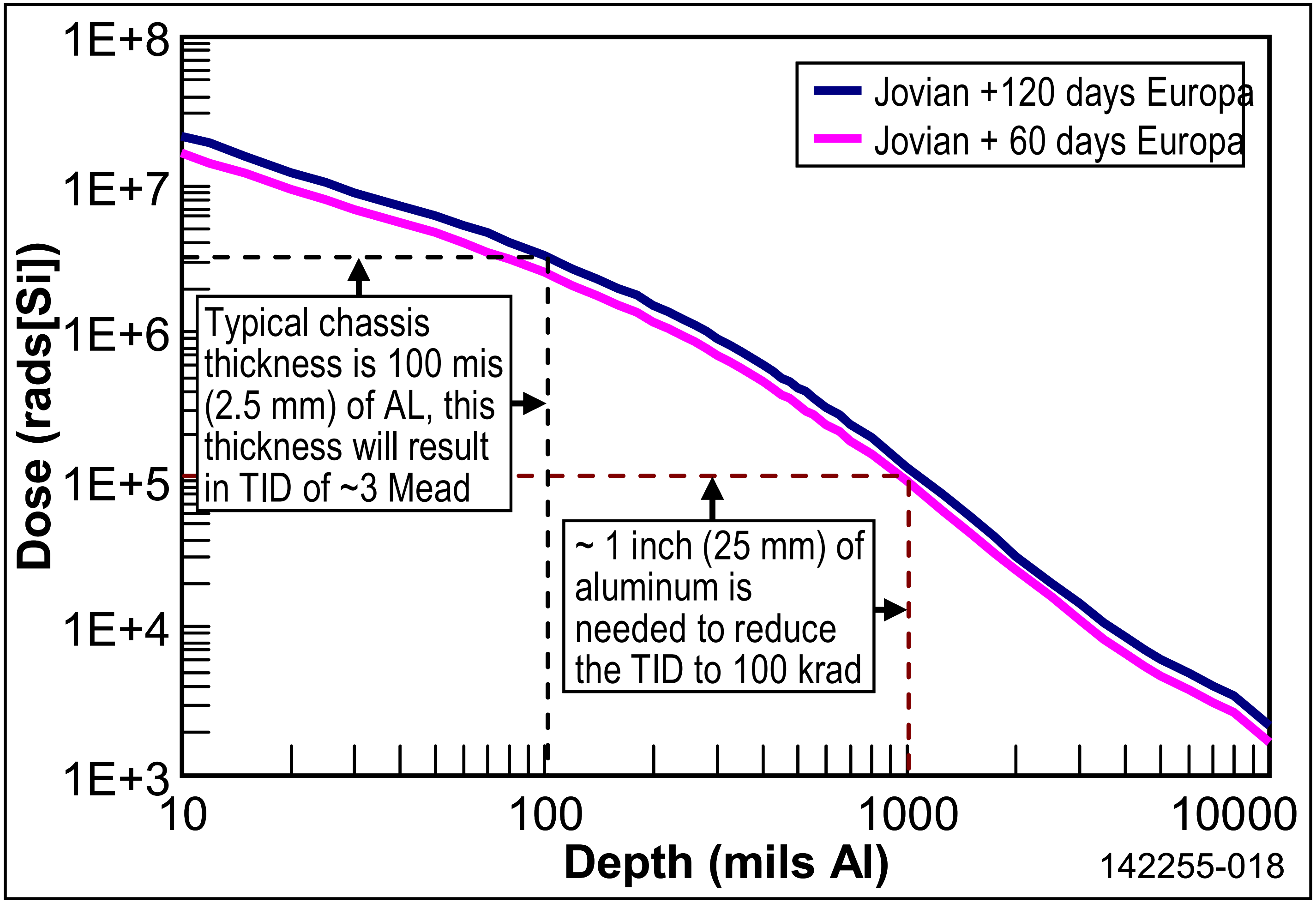
. Dose Depth Curve for a Europa Mission



Shielding alone to protect electronics, to 100 Krad level, is much too heavy and bulky, and unpractical, for a Cubesat for Europa.

SiGe and GaN Electronics are able to meet Europa Total Dose Requirement

The previous Figure indicates that ~25 mm (1”) of aluminum is needed to shield the dose to 100 krad, the typical radiation capability of parts in the current technology LP. For a 10 cm cube electronic box, 25 mm of aluminum will result in a mass of 1.1 kg for current instrument technologies.

If parts with capability $\geq$ 3 Mrad are used inside the electronics, only 2.5 mm of aluminum is needed to shield the radiation to the desirable level. The mass for the aluminum10 cm cube electronic box with this thickness is 0.15 kg. Therefore, the use of 3 Mrad parts in the cubesat electronics will result in a mass saving of 0.95 kg. Additional mass savings on batteries is available, and battery power for heaters is not needed.

Components fabricated from SiGe and GaN technologies have been shown to have TID capabilities in excess of 3 Mrad.

Radiation Vs. Cryo Environments

- Cryo temperature affects the response of SiGe to incident radiation, and this effect has been investigated under the SiGe extreme environments project under the RHESE program.
- Single-event effects are more challenging for SiGe designs. The choice of SiGe-on-Insulator helps mitigate this.
- Boeing has successfully employed a combination of layout, device geometry, circuit topology, increasing node capacitance, and system-level approaches to mitigate SEUs in silicon electronics, and these will be applied to SiGe and GaN designs.

Radiation hardening of electronic circuits can be accomplished by a combination of five methods:

(1) radiation hardening by technology is achieved utilizing wide band-gap materials such as SiGe, SiC, and GaN, which have innate radiation tolerance (use of SiGe-on-Insulator provides further radiation tolerance);

(2) rad-hard-by-design at the device level, by using design techniques that involve employing unique geometries of the device and isolation trenches in the device to contain charge-bursts created by the radiation;

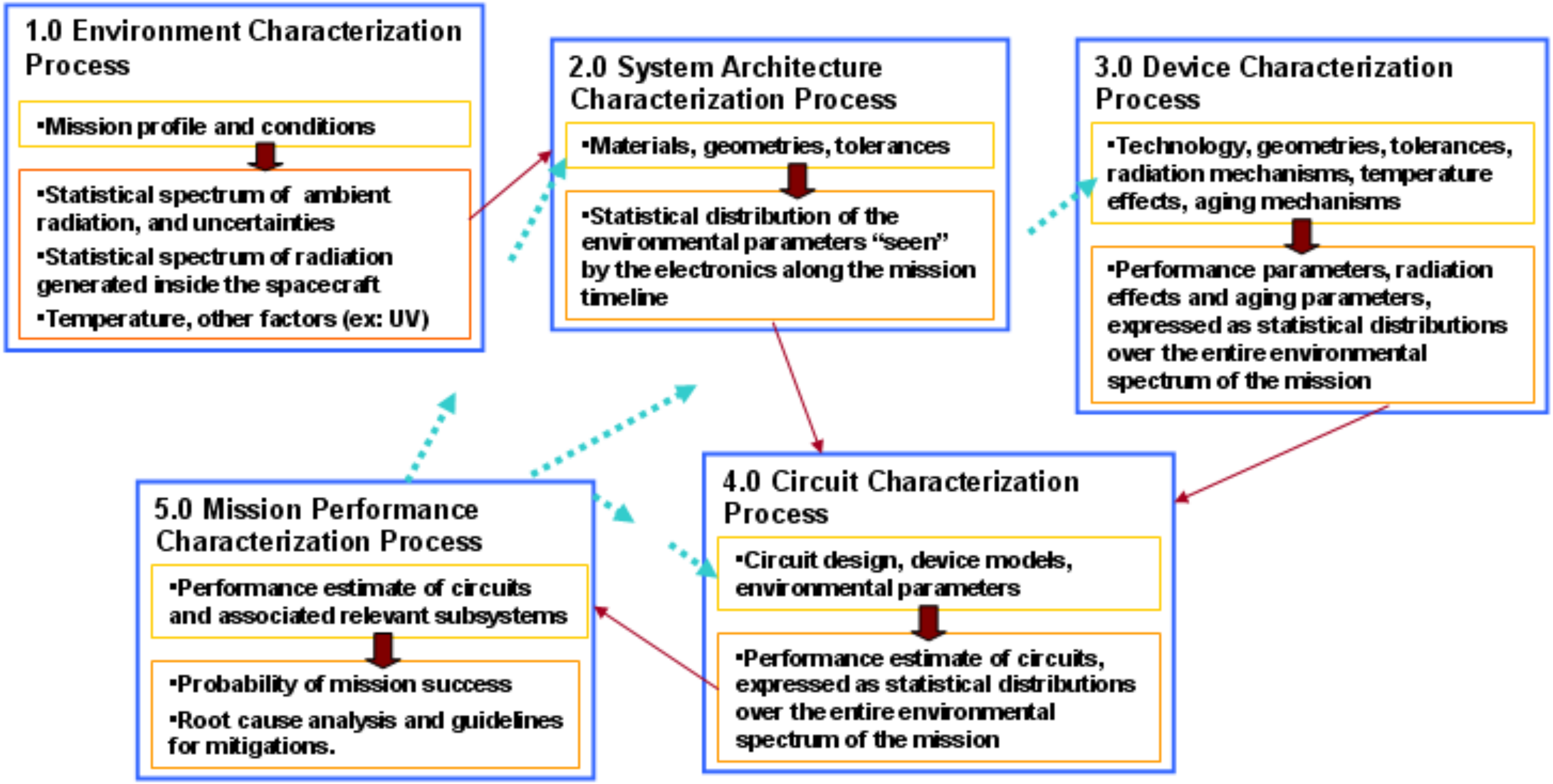
(3) local spot-shielding using proven low-Z materials;

(4) rad-hard design at the circuit level by including built-in redundancy and a compensating circuit;

(5) error-detecting and -correcting module and code (software).

(6) lastly, shielding to “close the gap” not met by the above.

Rad Hard Electronics Design Philosophy

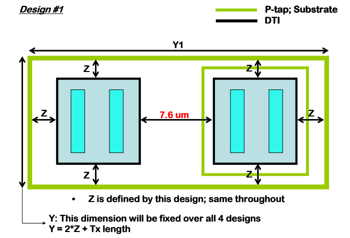


Ground testing of combined radiation + low temperature effects.

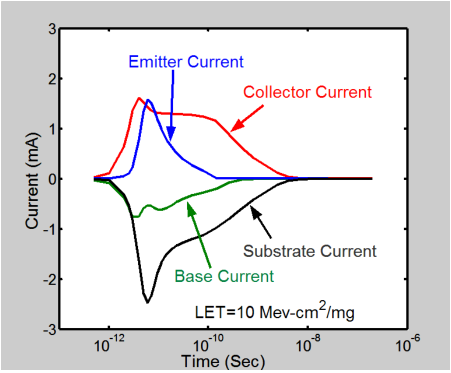
Tolerance of combined radiation + (cold) temperature environment

- Modeling/simulation provides initial evaluation of significance; motivates need for testing
- Device and test-circuit level testing to validate modeling trends, allows calibration of models for circuit designs
- Models allow design optimization for radiation tolerance and provide required inputs for estimation of event / error rates.
- Full circuit level testing procedure supports pre-flight part qualification

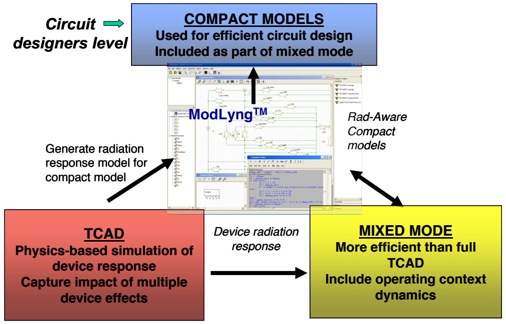
CIRCUIT LAYOUT



TCAD "ION STRIKE" SIMULATION



INTEGRATED DESIGN



Cubesat for Europa
(from JPL Mission Concept Study Report, May, 2012)

Potential Cubesat Science

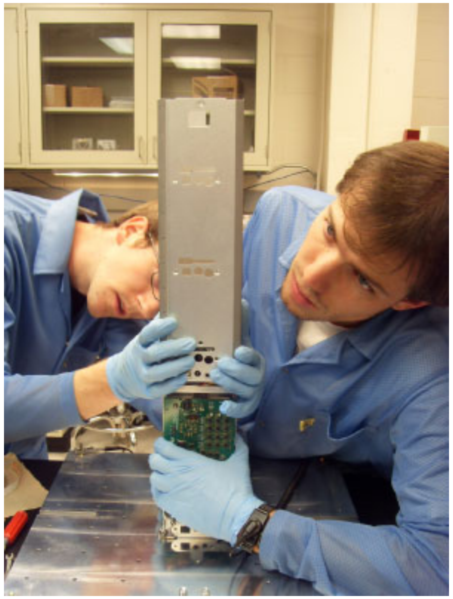
- Ocean conductance measurement
- Radio Science
- High resolution descent imagery
- Magnetometry
- Radiation measurements

Cubesat Development

- University competition, selected on the basis of science, risk, and cost
- 6-12 Cubesats at max. 15kg
- Deployed during flyby
- Project could provide rad-hard parts as required

Univ. of Colorado 3U Cubesat for Space Weather CSSWE: Colorado Student Space Weather Experiment.

CSSWE was launched Sept. 2012 to complement the measurements of the Radiation Belt Storm Probes (aka Van Allen Probes) larger satellites that were launched a month earlier as part of the Sun-Earth connection. The CSSWE houses an energetic particle telescope. Its primary objective is to measure the directional differential flux of Solar Energetic Protons (SEPs) and Earth's radiation belt electrons.



The Relativistic Electron and Proton Telescope integrated little experiment (REPTile) will provide directional differential flux measurements of high-energy electrons and protons. The CSSWE mission goals are:

- Develop a student-designed CubeSat system for space weather investigation;
- Understand the relationships between solar energetic protons (SEPs), flares, and coronal mass ejections (CMEs);
- Characterize the variations of the Earth's radiation belt electrons.

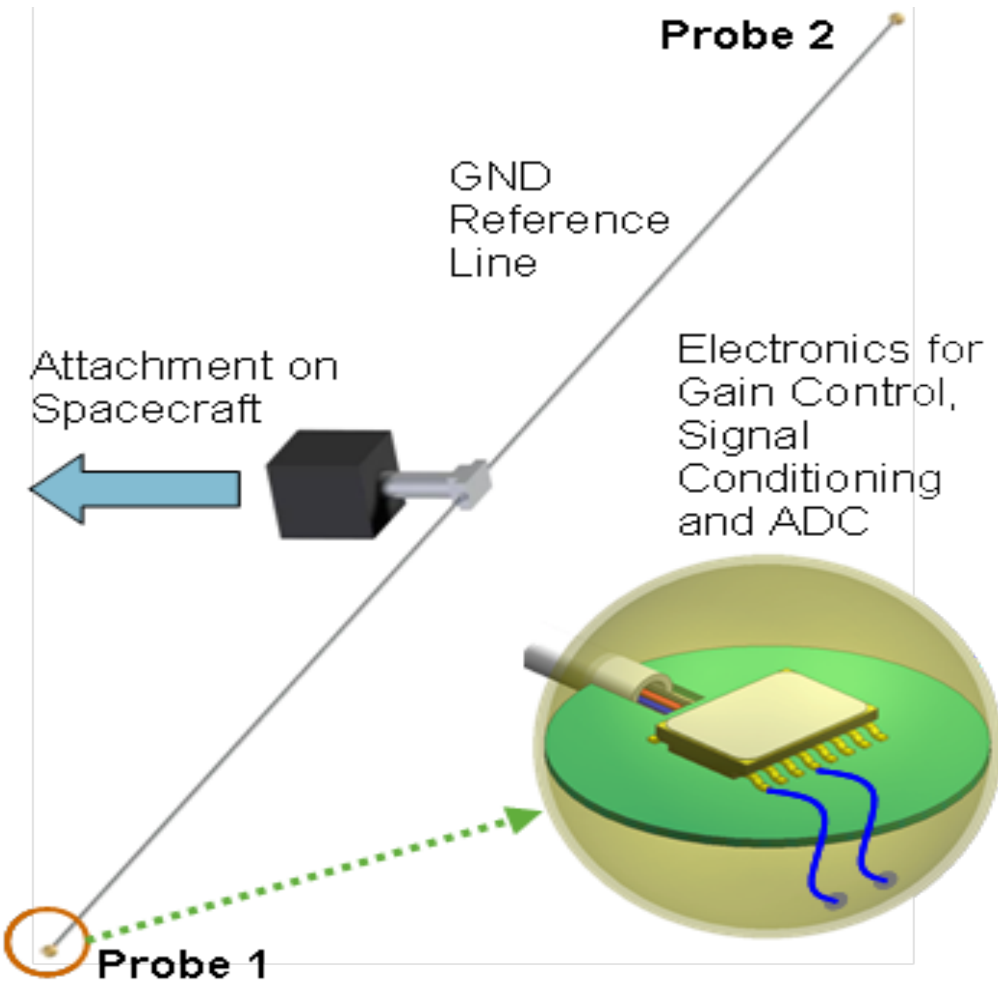
University of Iowa: FLEXI Plasma Wave Instrument

The Jovian magnetosphere is the largest and probably the most complex in the solar system. Unfortunately there have been only eight spacecraft (five with plasma wave instruments) to visit this complex system. Of these eight, only the Galileo spacecraft actually went into orbit around Jupiter and obtained measurements over a range of parameters in the Jovian equatorial magnetosphere (Juno will spend about one year in a polar orbit in 2017).

The University of Iowa has recently developed a cubesat sized plasma wave instrument called "FLEXI", for FLEXible ELF-VLF Plasma Wave Instrument.

As a baseline mission at Jupiter, University of Iowa suggests that a number of FLEXI CubeSats deployed at key positions in the Jovian system to obtain wave magnetic amplitudes and for the first time wave normal angle measurements of the Jovian chorus to provide input to the various simulations and models of the Jovian wave-particle interactions.

Concept for a Langmuir Probe Sensor Electronics for Europa Cubesat



Langmuir Probe could measure Electric Field and low-energy electron density near Europa.

Langmuir Probe Sensor Electronics (pre-amplifier, A-to-D Conversion, Signal Conditioning, and perhaps voltage sweep circuit) are on the boom, exposed to the intense background radiation.