Rad Hard and Cryo Electronics For Cubesats in Jovian Radiation Environments

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To Be Submitted
Interplanetary Small Satellite Conference: BEYOND LEO
California Institute of Technology, 25-26 April, 2016
Pasadena, CA

Abstract

A Europa mission has been selected by NASA as the next flagship mission, for launch as soon as 2022. A mission to Europa may include cubesats released from the flagship 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.

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. 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). The SiGe will operate over a wide range of temperatures: down to 43 Kelvin (-230 deg C) without "warm boxes", and up to 398 Kelvin (+125 deg C), in normal operation. The performance characteristics of SiGe devices vary gracefully over this extreme temperature range, with no evidence of abrupt "killer" phenomena. The structure of SiGe devices also confers a "free perk" -- multi-Mrad total dose hardness, even with no intentional hardening-by-design. GaN devices are suitable for high voltage and high power circuits, such as needed fields-and-particles instruments and S-Band transmitter.

Designing SiGe chips for these extreme environments, translated into device parameters, require new design rules. Device models in design tools (Cadence) must be extended, calibrated upon experimental data. Packaging design must account for the different thermal coefficients of die, casing and bonding materials, and the variations in physical properties of these materials over the temperature range.

SiGe is obtained by introducing a small (5%-15%) amount of germanium (Ge) in the silicon (Si) lattice. Si and Ge are "almost-but-not-perfect match", and the resulting lattice is stressed. After years of consistent research, semiconductor manufacturers (primarily IBM and TowerJAZZ) have developed a reliable fabrication platform, compatible with standard Si integrated circuits fabrications, which offers low cost and high integration. The lattice stresses in SiGe bring desirable properties to SiGe devices. Higher operating speeds are possible -- SiGe technology is well accepted in high-speed communication circuits. And, important for our applications, SiGe devices can operate reliably in the extreme cold typical of Europa and the other icy satellites of the outer solar system, without carrier freeze-out.

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) local spot-shielding using proven low-Z materials; (3) 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; (4) rad-hard design at the circuit level by including built-in redundancy and a compensating circuit; and (5) error-detecting-and–correcting (EDAC) module and code.

This paper presents the radiation environments for cubesats in orbit or penetrators at the surface of Europa. It presents design characteristics for Silicon-Germanium circuitry for operating low temperature (to 40 Kelvin) and high radiation environments, along with preliminary test results. Further, the paper proposes a radiation testing regime that would expose the electronics to an equivalent radiation dose as would be experienced during a 90-day mission at Europa. This testing regime includes sequential exposure to high energy electrons, protons, and heavy ions, involving combined radiation dosage at cyclotron facilities, and exposure to Van Allen Belt radiation in geosynchronous transfer orbit.

GaN devices are being developed by HRL Laboratories in Malibu, which has a GaN foundry. This project addresses NASA Technology Roadmap Goal 8.1.2 Electronics: Radiation-hardened, extreme environment capable, and data processing electronics with reduced volume, mass, and power.