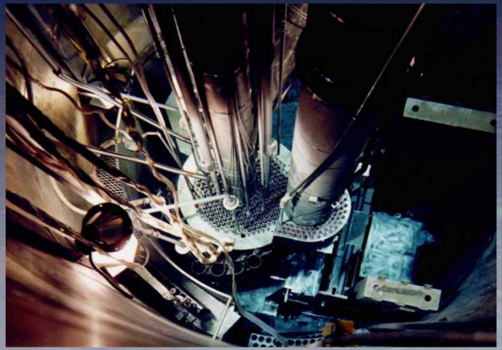

SAND2018-10152PE

Sandia 2018/19 Rad-Hard Little-Bus Challenge

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Sandia National Laboratories

Albuquerque, NM

Exceptional service in the national interest

Sandia National Laboratories

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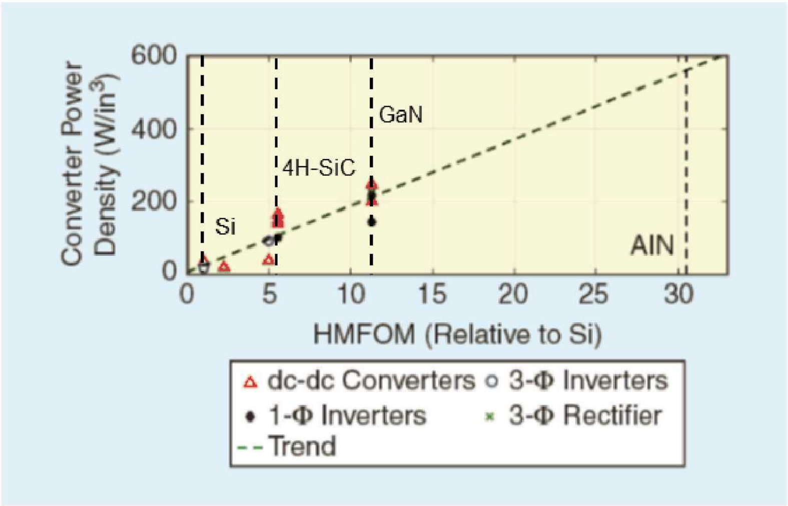
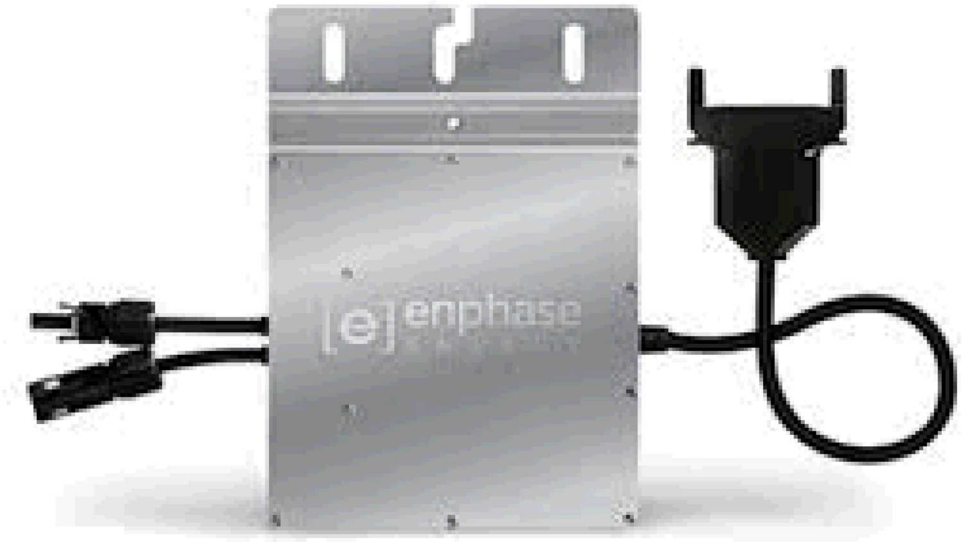
Semiconductor Material Properties Dictate Power Conversion System Size and Weight

- Recent developments in wide bandgap (WBG) semiconductors, have enabled a new generation of devices, resulting in power electronics with unprecedented power density and efficiency (recall the Google Littlebox Challenge)
- WBG materials also have some properties that may enable superior resilience to radiation environments

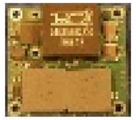


Huang Material FOM = $E_C \mu_n^{1/2}$



SOA commercial microinverter
250 W in 59 in^3 → 4.2 W/in^3

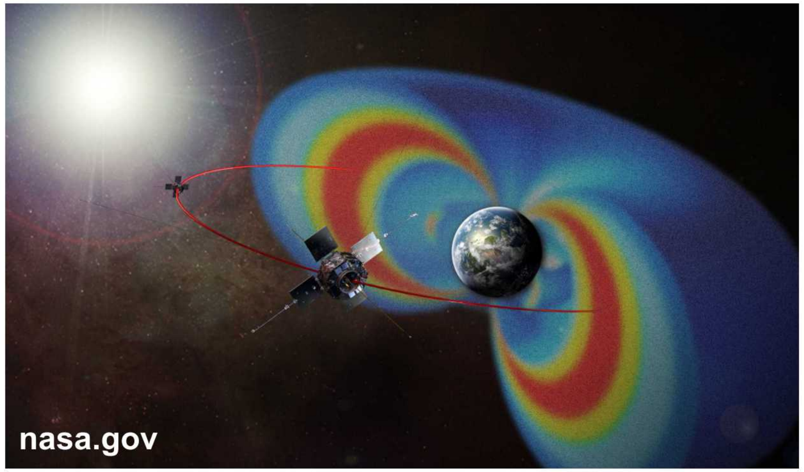
SNL GaN HEMT microinverter
400 W in 2.4 in^3 → 167 W/in^3

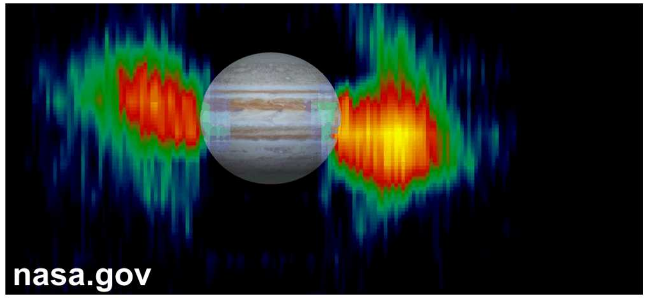


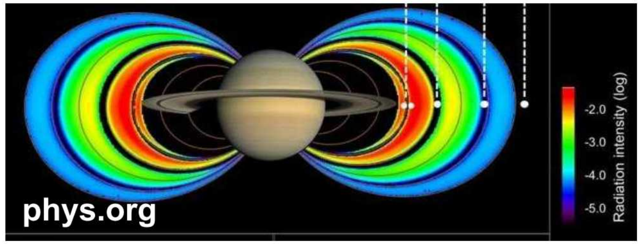
R. J. Kaplar, J. C. Neely, et al., *IEEE Power Electronics Magazine (March 2017)*

Rad-Hard Power Electronics May Enable Extended Space Missions

- Energetic charged particles from solar wind and cosmic rays are present in the solar system
- High concentrations of charged particles exist around Earth
  - Inner Van Allen belt: 1,000 – 6,000 km above Earth
    - 100s of keV electrons
    - Up to 100 MeV protons
  - Outer Van Allen belt: 13,000 – 60,000 km above Earth
    - 100 keV – 10 MeV electrons
    - Protons and ions (alpha particles and heavy elements)
    - For protons of energy 1.0 MeV and higher, flux is as high as $2x10^7$ p/sec·cm^2 (magnetic equator at ~3 Earth radii, normal conditions)
- Radiation belts exist around outer plants as well, e.g. Jupiter and Saturn
- Radiation exposure of space craft components influences design, flight plans, and mission time





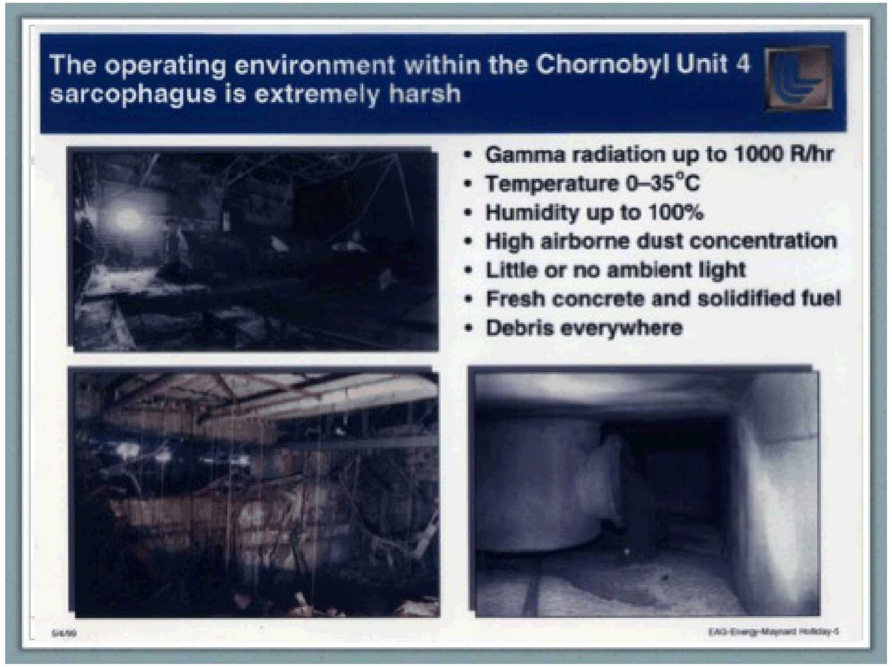


Rad-Hard Power Electronics May Enable Improved Nuclear Disaster Response

- Nuclear reactor incidents are low probability, but high consequence when they do occur
- The Fukushima Dai-ichi reactor incident demonstrated that response crews may be unprepared to handle such a crisis, with environments too hazardous for humans to enter
- Robotics technology is critical to respond to these types of incidents, but is often used in an ad-hoc scenario with whatever is available.
- Rad-hard power electronics may be an important component for extending the operational time of robots in harsh radioactive environments (as high as 1000 Rad/hour gamma)

Dai-ichi Reactor Buildings – Post Incident

Work at Dai-ichi – Post Incident



Radiation Damage Depends on Several Factors

- ***Radiation damage*** **depends on:**
  - **Dose**
  - **Dose rate**
  - **Damage mode**

- ***Radiation damage modes*** **depend on:**
  - **Type of particle**
  - **Particle energy**
  - **Initial condition or bias of the material**

- **Particle flux ϕ is specified in units of particles/s·cm^2**

- **Particle fluence Φ is the flux integrated over total exposure time, specified in units of particles/cm^2**

- **The dose is the energy deposited per gram of material**
  - **1 rad = 0.01 J/kg = 6.24×10^{13} eV/g**
  - **Dose rate is the deposited dose per unit exposure time, specified in units of rad(mat)/s**

Sandia Facilities Enable the Testing of Radiation Effects and Damage Modes: Gamma Irradiation Facility

- **The *Gamma Irradiation Facility (GIF)* simulates gamma radiation environments for materials and component testing**
  - **GIF produces a wide range of gamma radiation environments (from 10^{-3} to over 10^{3} rad/s) using cobalt-60 sources**
  - **GIF can irradiate objects as small as electronic components and as large as a satellite**
- **GIF is used for:**
  - **Testing for electronic-component hardness**
  - **Materials-properties testing**
  - **Investigations of various physical and chemical processes**
  - **Testing and radiation certification of satellite system electronic components**
  - **Investigations of radiation damage to materials**

The Project

- This is a competitive project between two or more teams to develop a power electronic converter design that is suited for use in a candidate cube-sat power system architecture.
- The goal is to realize power converter designs that are power dense (i.e. small), reasonably efficient, and hardened against ionizing radiation.
- Two power converter prototypes (per team) will be operated in a gamma irradiation cell to determine their resilience to long term radiation exposure.
- The team with the best design (determined by a weighted performance measure) will be acknowledged.
- Scoring will follow these guidelines
  - 50% - Mean Converter Radiation Dose before first failure (in kRad(Si))
  - 25% - Mean Converter Efficiency (in %)
  - 25% - Mean Converter Power Density (W/in^3)