Defense Threat Reduction Agency

National Aeronautics
and Space Administration

Point-of-Load DC/DC Converters for Space

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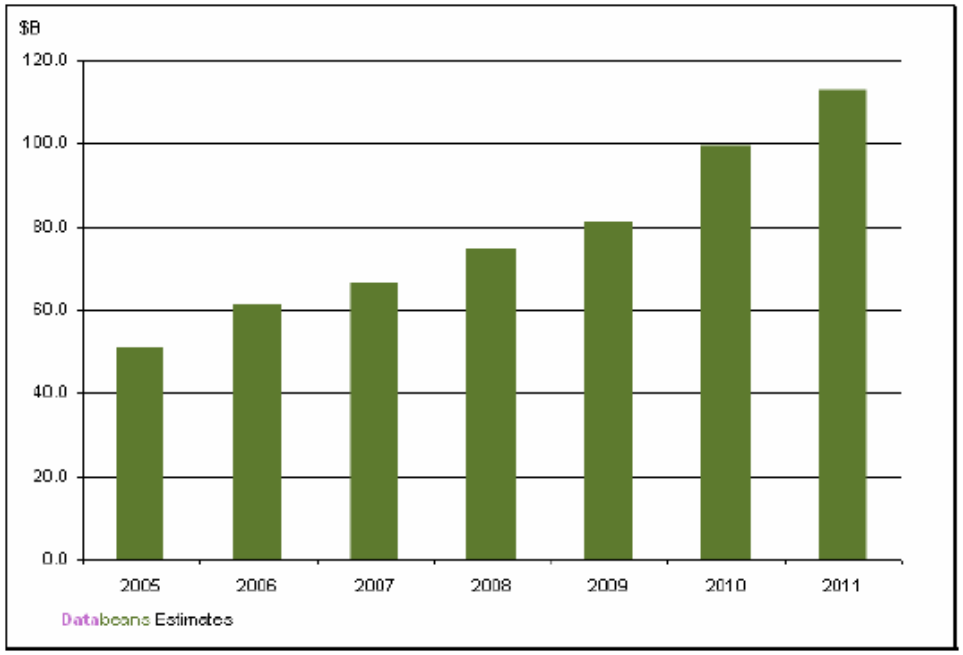
Motivation



S. Inouye, "Real World Signal Management Drives $50 Billion Mixed-Signal Market," A Fabless Semiconductor Association Forum Special Report from Databeans Inc., Reno, NV, May 2006.

- Market for analog and mixed signal ICs continues to increase despite a surge towards digital dominated ICs
- Market for non-isolated point-of-load devices total approximately $10 billion in 2008; estimated growth of 8% by 2013
  - Advancements in ASICs and FPGAs place high demands on power, size, and noise
- CMOS scaling, process designs for bipolar and BiCMOS ICs, and circuit types/designs introduce new challenges for radiation hardness assurance

Market for Point-of-Load (POL) devices continues to grow with new innovations in device process and circuit technology

Objectives

- What are we using?
- Seek out state-of-the-art devices: radiation hardened (Radhard) and commercial-off-the-shelf (COTS)
  - Specifications: Input and output voltage, output power
  - Device types: hybrid or monolithic
  - Technology: CMOS, Bipolar, BiCMOS, SOI, SOS, etc.
- Evaluate radiation response
- Application for current and future NASA missions

Radiation Effects of POL Devices

DTRA Task # 3.2/POLs

- Total ionizing dose (TID) including ELDRS
  - Bipolar and BiCMOS technology vulnerable to ELDRS
- SEGR/SEB/SEL
  - The need for high power outputs drives power MOSFET requirements
  - SEL testing at elevated temperature challenging
- SETs
  - Modern FPGAs demands low noise input from voltage regulators (typically < 200 mV)
  - Switching regulators require fine-tuned circuit layout considerations for output stability (Inductor value, capacitor ESR ratings, etc)
- SEE mitigation adds size (and expense)

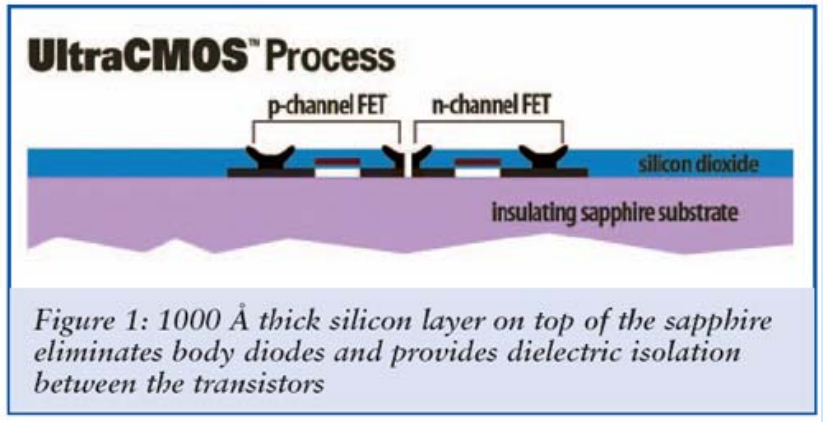
Status

SEE testing activity since 2010

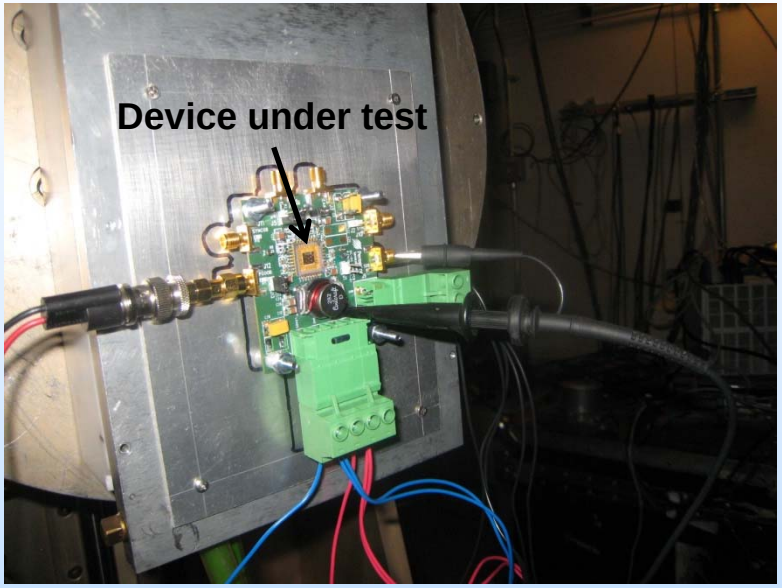
Part Number	Manufacturer	Assurance level	Device type	Input Voltage	Output Voltage	Output Current
MSK5820-2.5RH	MS Kennedy	Radhard	LVDO	2.9 to 6.5 V	2.5 V	3 A
MSK5900RH	MS Kennedy	Radhard	LVDO	2.9 to 7.5 V	Vdo = 0.3 V	4 A
TPS79133	Texas Instruments	COTS	LVDO	-3 to 6 V	3.3 V	0.1 A
ISL70001SRH	Intersil	Radhard	Buck regulator	3V to 5.5V	Adjustable down to 0.8 V	6 A
MSK5810RH	MS Kennedy	Radhard	LVDO	2 - 7.5 V	Adjustable down to 1.5V	5 A
MSK5059RH	MS Kennedy	Radhard	Buck regulator	16 V	Adjustable down to 1.8 V	4.5 A
PE9915X	Peregrine	Radhard	Buck regulator	5 V	3.3 V and 1.8 V	10 A (3.3 V) 2 A (1.8 V)
MFP0507S	Interpoint	Radhard	DC/DC converter	6 V	3.3 V and 0.8 V	7 A (3.3 V) 5 A (0.8 V)
TPS7A4901	Texas Instruments	COTS	LVDO	3 to 36 V	1.2 V	0.15 A
SBB503R3S	International Rectifier	Radhard	DC/DC converter	4.5 to 5.5 V	3.3 V	9.1 A

Highlights

PE9915X Radhard monolithic buck regulator from Peregrine



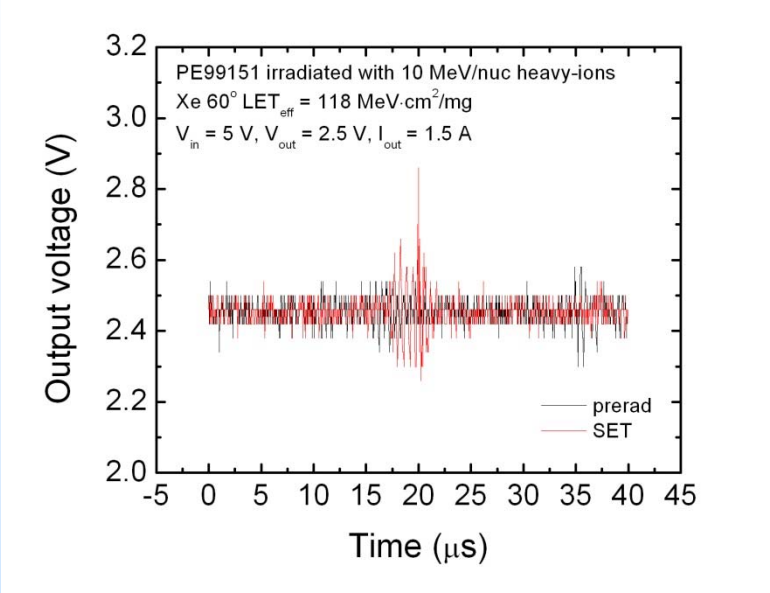
http://www.mpdigest.com/issue/Articles/2009/may/peregrine/Default.asp

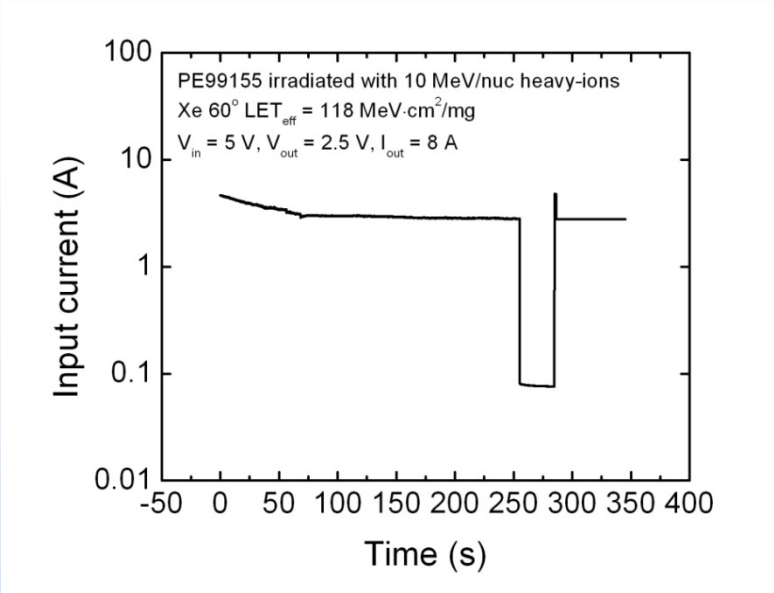


- 180 nm Silicon-on-Sapphire process, monolithic design
- V_{in} = 4.5 to 6 V, V_{out} = 3.3 to 1 V, I_{out} = 10 A or 2 A continuous
- Irradiated with 10 MeV/amu Xe at normal incidence in vacuum at LBNL
  - Tested with V_{in} = 5 V, V_{out} = 3.3 and 1.8 V, I_{out} up to 8 A
  - 1000 µF capacitor at output

Highlights

PE9915X Radhard monolithic buck regulator from Peregrine

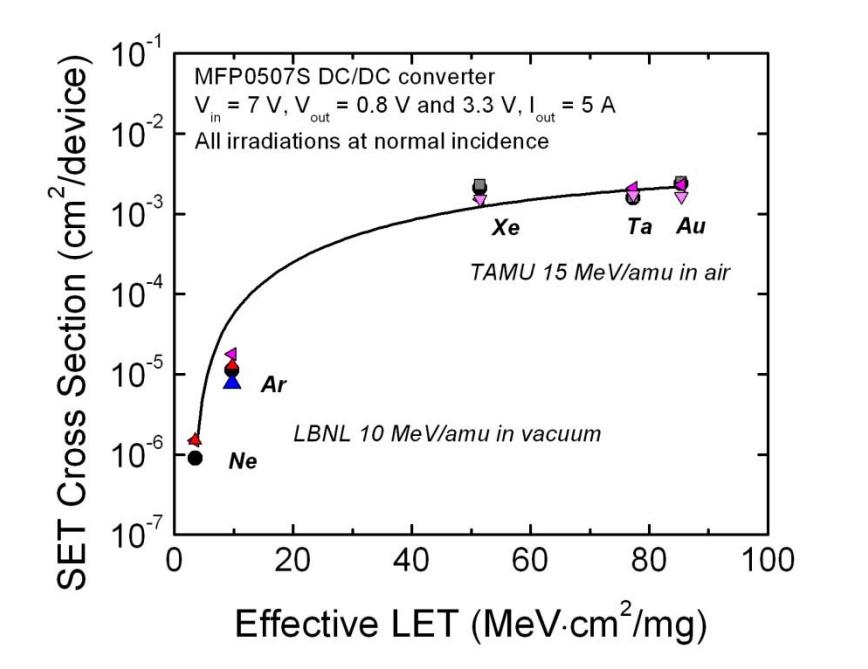




- Voltage transients with short duration and recurring with frequency
  - Noise from external facility equipments
- SEB/SEGR LET threshold > 118 MeV·cm^2/mg
- The output voltage dropped out of regulation during a run with high output load at LET = 118 MeV·cm^2/mg
  - Parametric degradation from TID/DD and/or over-heating
  - Observed similar event during recent TAMU test

Highlights

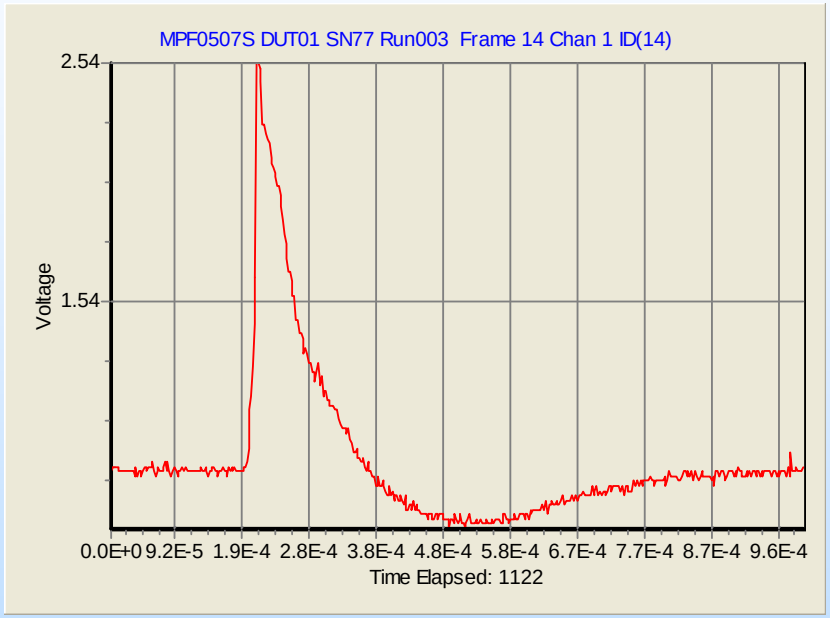
MFP0507S Radhard hybrid DC/DC converter from Interpoint

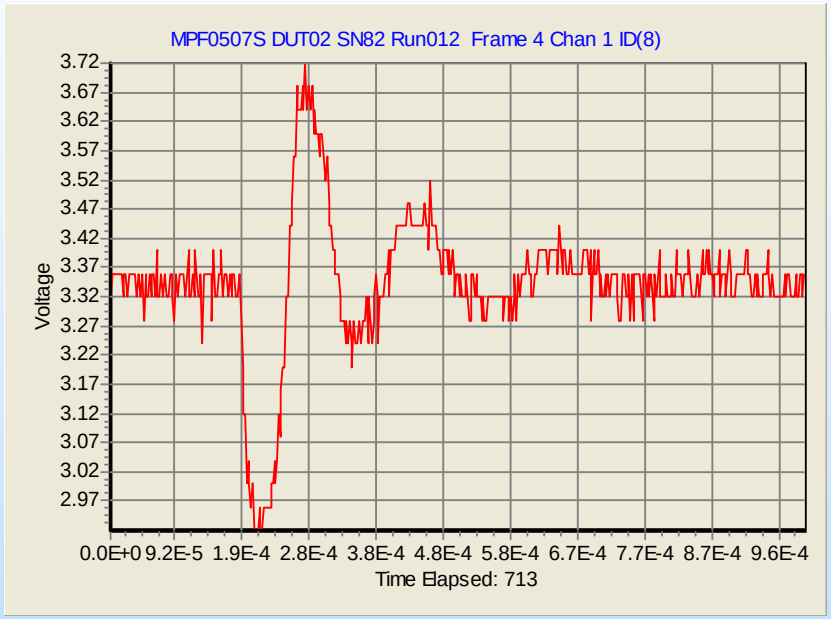


- Irradiated at TAMU and LBNL
- Tested with V_{in} = 6 V, V_{out} = 3.3 and 0.8 V, I_{out} up to 4.2 A (3.3 V) and 1.4 A (0.8 V)
- SEL/SEGR/SEB > 85.4 MeV·cm^2/mg
- SET characteristics
  - SET cross-section ~ 2.65 × 10^{-3} cm^2 at LET = 85.4 MeV·cm^2/mg
  - SET LET_{th} < 3.49 MeV·cm^2/mg (max load)
  - SET threshold sensitive to output load

Highlights

MFP0507S Radhard hybrid DC/DC converter from Interpoint

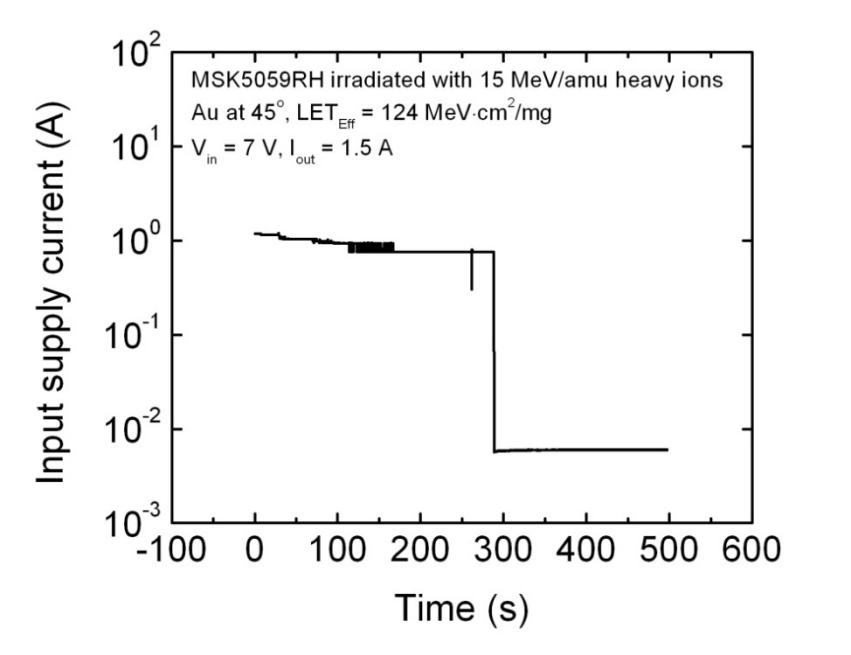




- Worst case transients (V_{out} = 0.8 V): amplitude ~ 1.7 V and FWHM ~ 100 µs
- Typical transients (V_{out} = 3.3 V): positive and negative spike, each with amplitude ~ 200 mV and FWHM ~ 50 µs

Highlights

MSK5059RH Radhard hybrid buck regulator from MSK



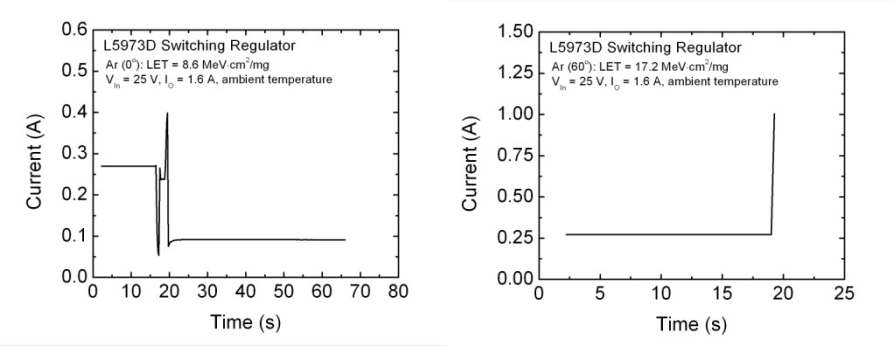
- 400 µm high speed bipolar process, hybrid design
- Irradiated with 15 MeV/amu cocktail heavy-ions at various incident angles at TAMU cyclotron facility
  - Tested with V_{in} = 7 V, V_{out} = 3.3 V, I_{out} = 100 mA to 1.5 A
- SEB/SEGR threshold > 88 MeV·cm^2/mg
- Output dropped when loading to 1.5 A
  - Thermal shutdown?
- Pre-irradiation noise (300 to 500 mV peak-to-peak) affected SET characterization
  - No classical example of SET
  - Events are voltage fluctuations that originate from the output ripple noise
- Plan to investigate with laser

Highlights

- ISL70001 Radhard monolithic buck regulator
- ISL75051SRH Radhard LVDO
  - Tested at TAMU with 15 MeV cocktail heavy-ions (on May of 2010)
  - No destructive events observed (SEL LET_{th} > 86 MeV·cm^2/mg) up to 125°C case temperature
  - SETs observed

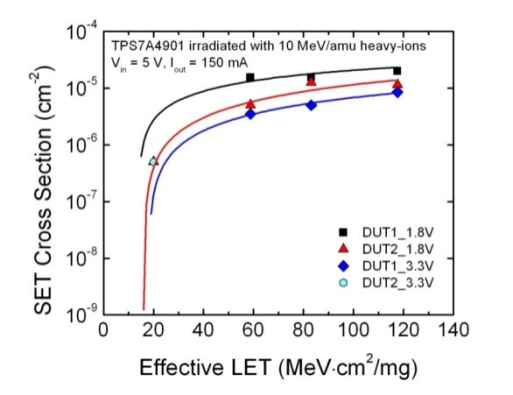
Highlights

L5973D COTS monolithic switching regulator from STM



- 0.55 µm BiCMOS process, integrated DMOS power MOSFET, Monolithic design
- V_{in} = 4 to 36 V, V_{out} down to 1.235 V, I_{out} up to 2.5 A
- Destructive events
  - High current state (Ar at 60º) may be caused by SEL or SEB
  - Dropout event (Ar at 0) may be the result of SEGR

TPS7A4901 COTS Low-voltage dropout regulator from TI



- BiCOM3 SiGe SOI BiCMOS process
- V_{in} = 5 V, V_{out} = 3.3 and 1.8 V, I_{out} = 5 and 150 mA
- SET LET threshold: $10 < LET_{th} < 20$ MeV·cm²/mg
  - Worst case SETs were rail-to-rail dropouts that lasted hundreds of milliseconds

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Conclusion

- SEE characterization becoming more challenging
  - Low output voltage (< 1 V), high output current (up to 10 A), small size, and low noise margins
  - Electrical stability – selection of passive circuit elements (capacitor ESR ratings) and board layout considerations (placing output capacitors close to device terminals, good ground plane, proper heat sinking)

- SEE response
  - Power MOSFET vulnerable to SEGR and SEB
  - Output dropouts caused by accumulated TID or part self-heating
  - Difficult to test SEL susceptibility at elevated temperature
  - SET characteristics influenced by circuit stability, output filtering elements, and test conditions