POLARIS
SEMICONDUCTOR

Efficient DC Voltage Conversion Without Switching

A Path to Extremely Compact and Low Noise DC Voltage Regulators

Matthew Lumb, Founder

Polaris Background

- Founded late 2018 – based in Northern Virginia
- Fabless semiconductor startup
- Pre-revenue – funding via various non-dilutive grants
- **About me:** Spent 10 years in Optoelectronics and Radiation Effects Branch at NRL
- Optoelectronics and semiconductor device specialist

NSF AFWERX VIPC VIRGINIA INNOVATION PARTNERSHIP CORPORATION

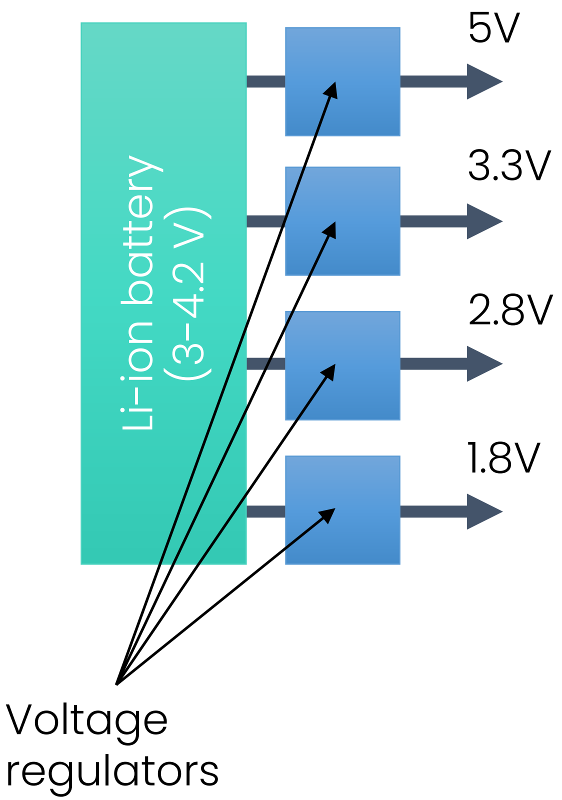
Introduction

DC Voltage Regulator

- Converts unregulated DC input to regulated DC output
- Powers a wide range of digital & analog loads

Requirements for Defense/Space:

- **Low noise** – minimize electromagnetic interference (EMI)
- **SWaP** – minimize footprint and mass
- **Efficient** – minimize heating and maximize battery life
- **Radiation hard** – able to endure harsh space radiation environment



Polaris Technology

Switching Regulator

Advantages

- ✓ Boost and buck voltage
- ✓ High efficiency

Pains

- ✗ Generates EMI
- ✗ Large footprint and component count

Linear Regulator

Advantages

- ✓ No EMI
- ✓ Very compact

Pains

- ✗ Buck voltage only
- ✗ Inefficient for large voltage steps

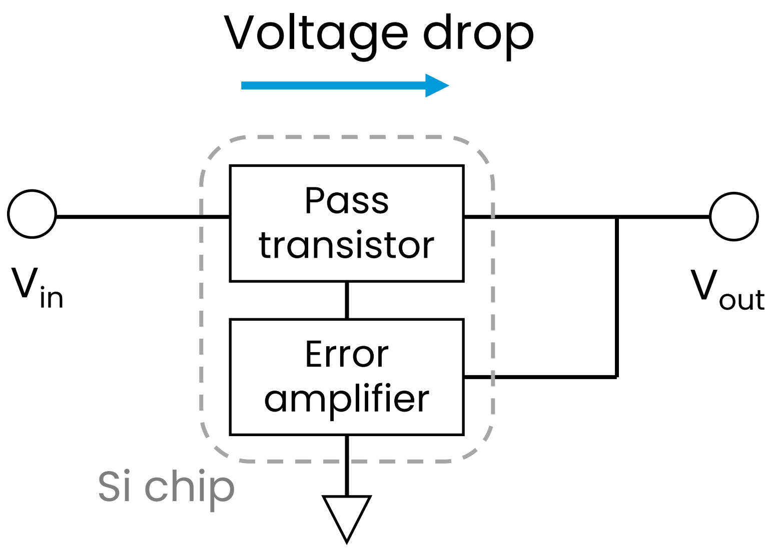
Polaris Semiconductor Technology

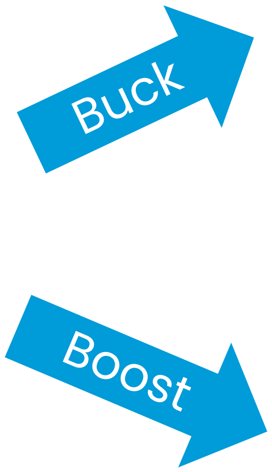
- ✓ Linear regulator with functionality of a switching regulator
- ✓ Boost & buck voltage, no EMI, very compact, high efficiency (65-85%)

How it Works

Standard Linear Regulator

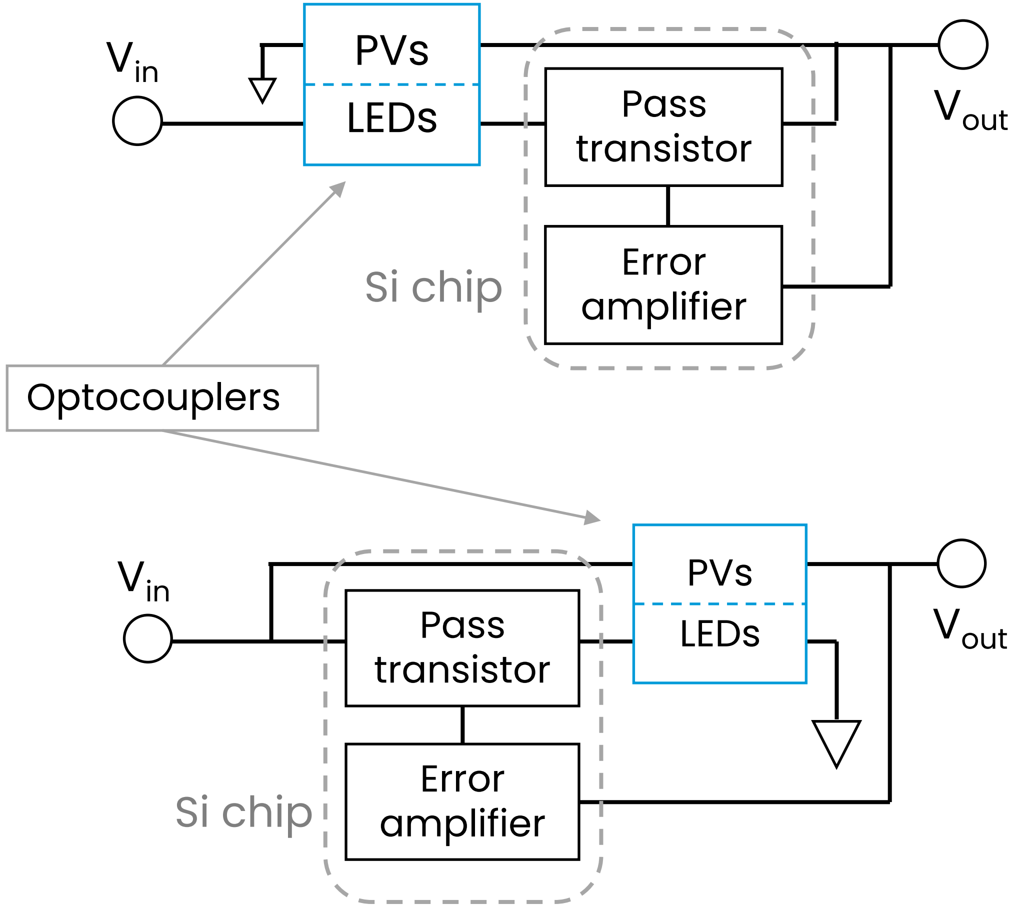
- Controlled voltage drop across pass transistor





Polaris Semiconductor Regulator

- Uses photons to raise or lower voltage

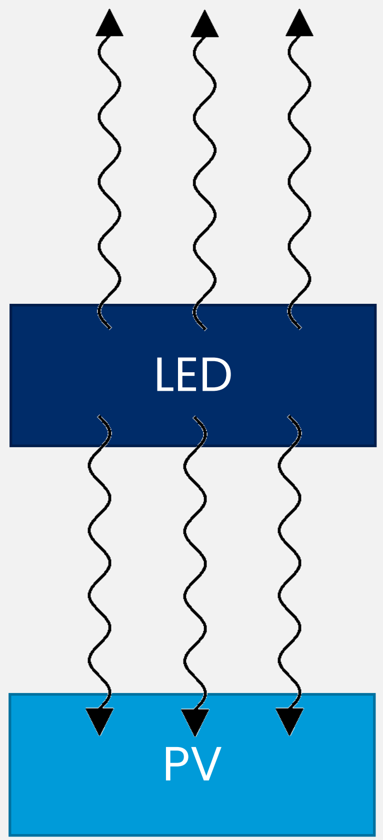


US patents 11,137,784 and 11,307,601

High Efficiency

- **A problem:** typical optocoupler is 1-2% efficient
- Three main losses:
  - Undirected emission
  - Reflection and escape cone losses
  - Spectral mismatch of LED and PV

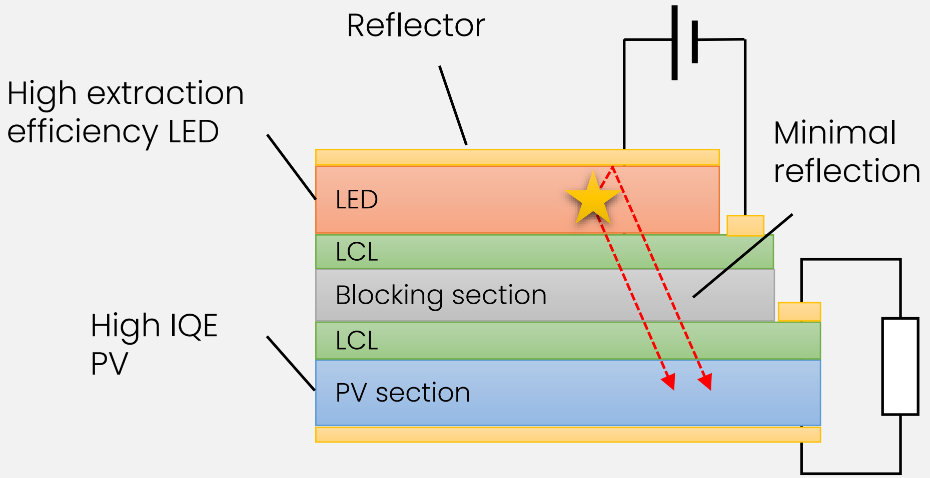
PV Output Optocoupler Device



High Efficiency

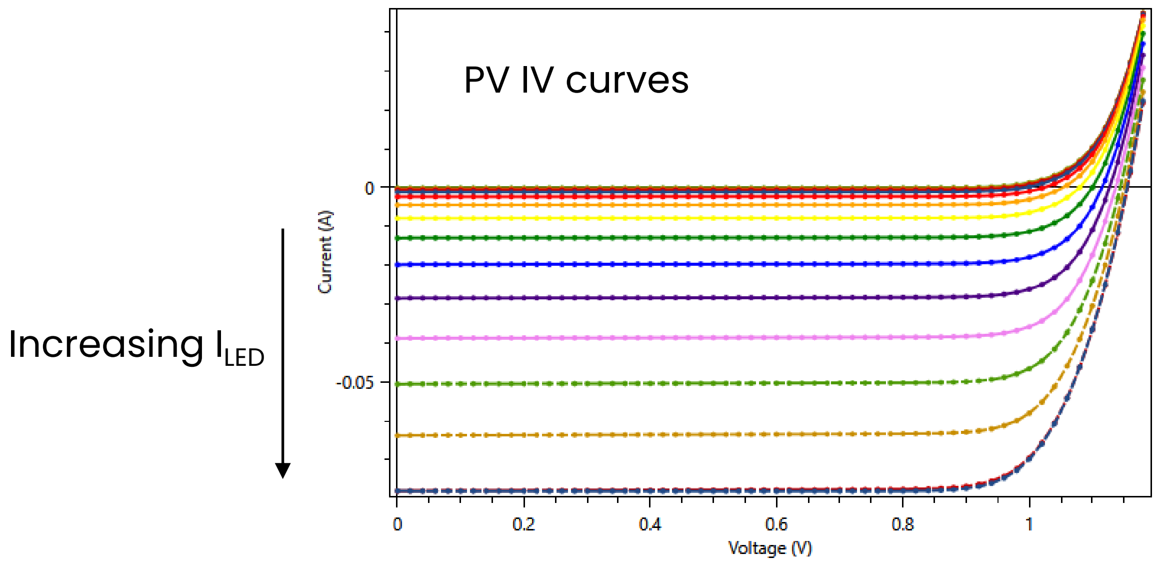
- **A problem:** typical optocoupler is 1-2% efficient
- Three main losses:
  - Undirected emission
  - Reflection and escape cone losses
  - Spectral mismatch of LED and PV
- **Our solution:** novel GaAs-based monolithic optocoupler device
- Manufacture identical to GaAs LEDs, VCSELs etc.

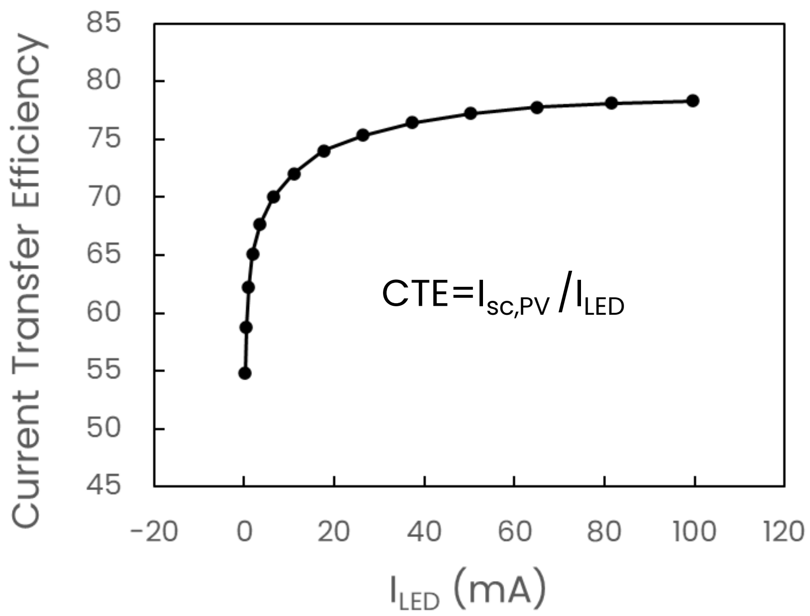
PV Output Optocoupler Device

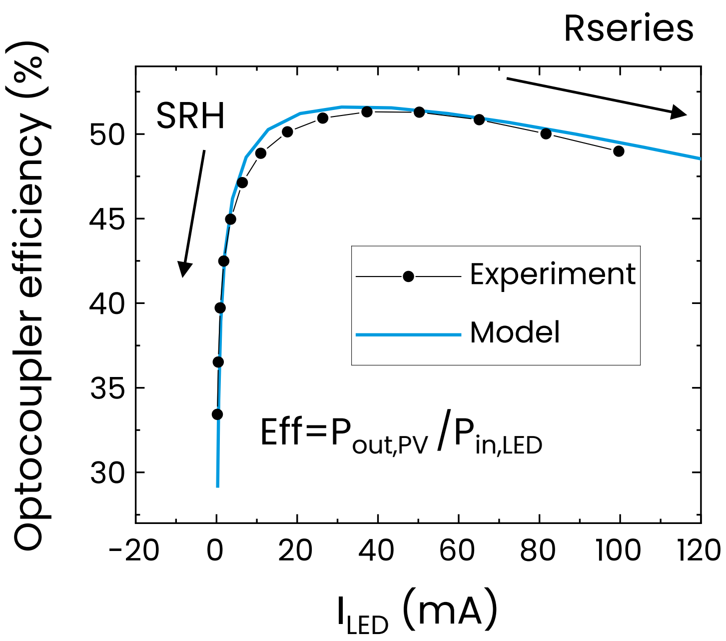


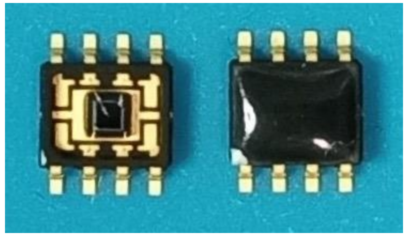
Optocoupler Performance

- Peak efficiency of optocoupler is 52%
- Close to 80% current transfer at high forward bias
- Future efficiency improvements, clear path to 60%









SOIC-8 packages

52% optocoupler efficiency

(NSF Phase I data)

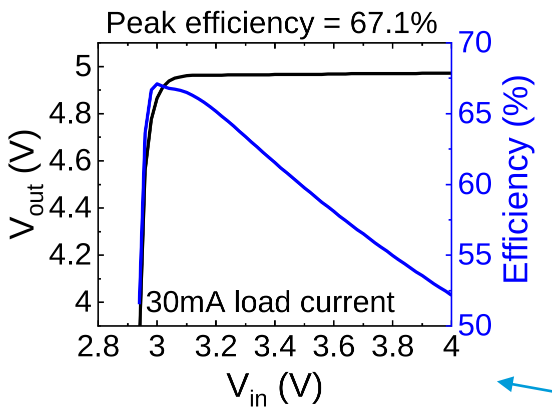
Path to >60%

Non-rad-hard prototypes

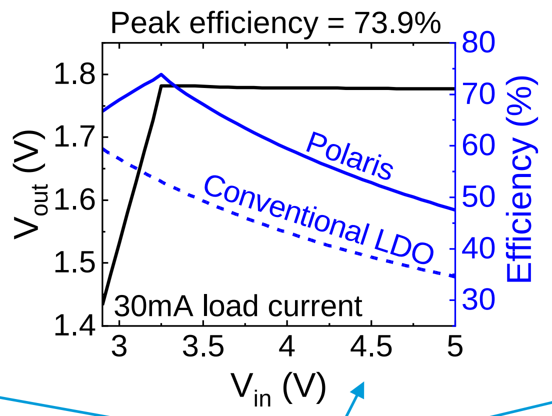
- Built a range of proof-of-concept chips, some packaged, some at breadboard level
- Possibility for bypass operation
- Can also achieve galvanic isolation

Voltage in / Voltage out	Polaris regulator efficiency	Linear regulator efficiency	Relative improvement
3.3V/5V (boost)	67%	N/A	N/A
4V/2.5V	77%	66%	17%
3.3V/1.8V	74%	53%	40%
5V/1.8V	66%	36%	80%

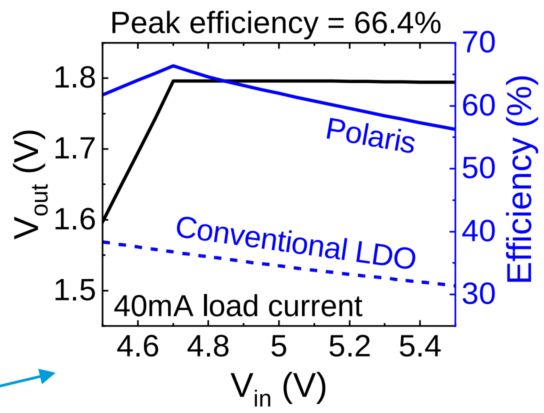
3.3V/5V boost



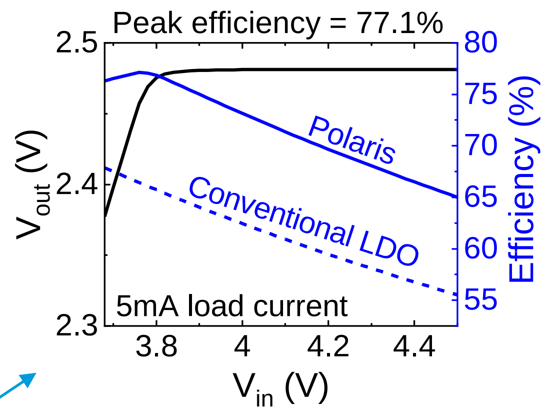
3.3V/1.8V buck



5V/1.8V buck



4V/2.5V buck

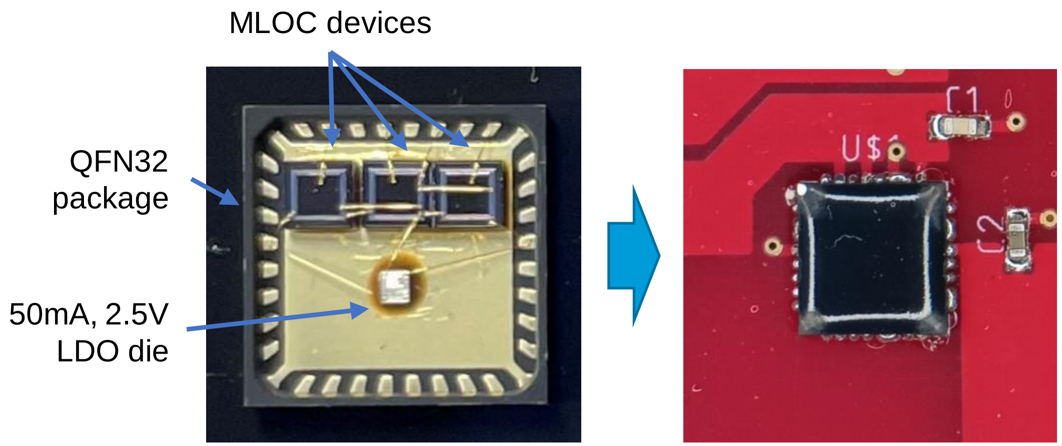


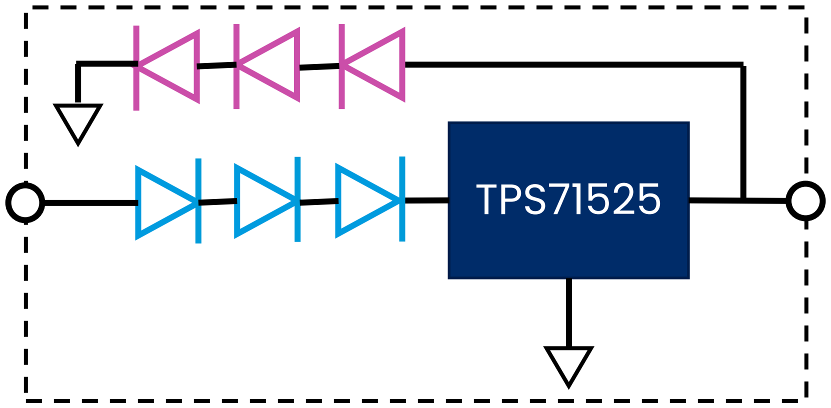
Using LT1963 LDO

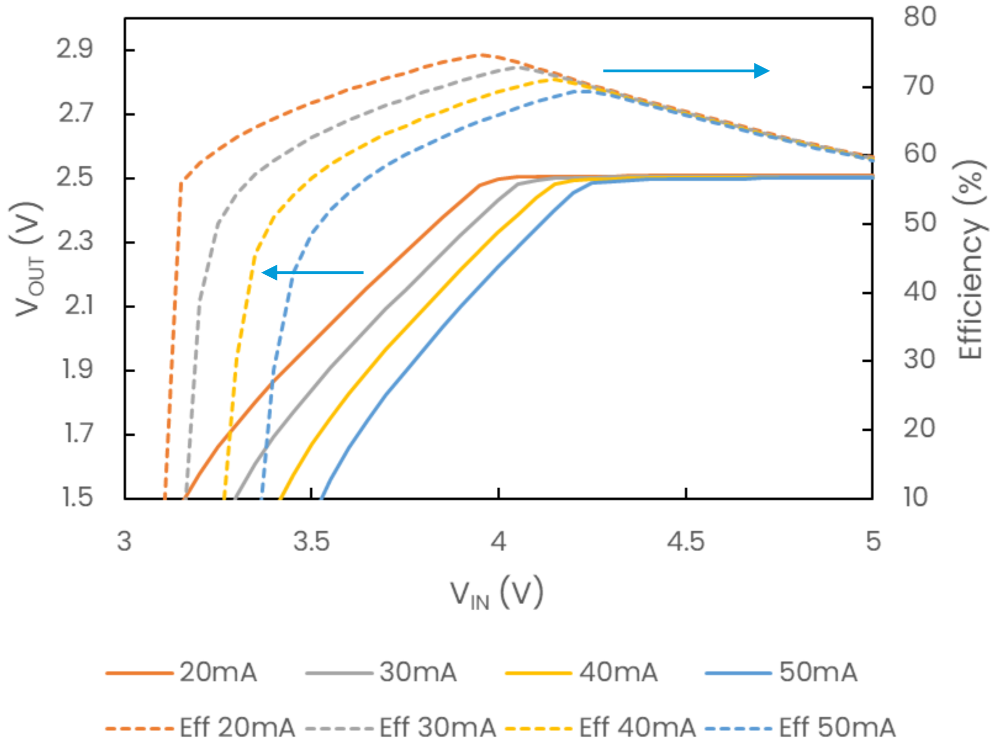
Using TPS71525 LDO

Performance – 2.5V buck

- Texas Instruments TPS71525 LDO co-packaged with optocouplers
- TPS71525: 50mA, 2.5V fixed output LDO
- Co-packaged with optocouplers in 7mm QFN32 plastic packages
- Not optimized for size!



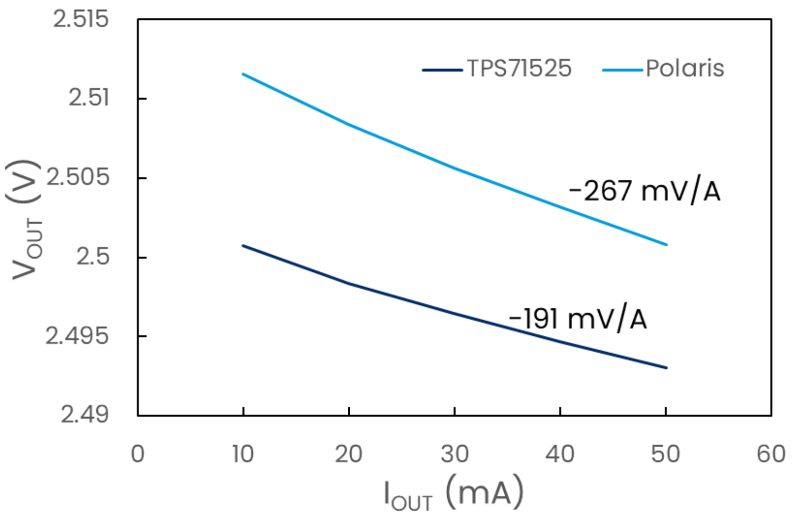




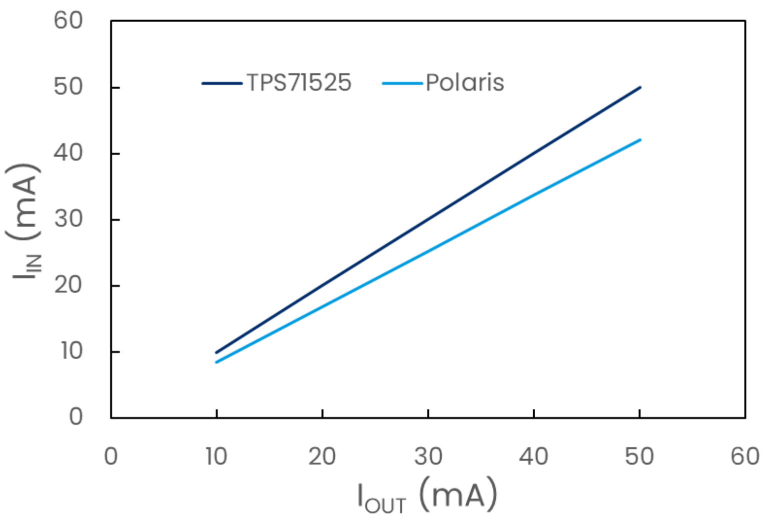
Comparison - 2.5V buck

- Comparison of standard TPS71525 to Polaris device at V_{IN} = 5V, V_{OUT}=2.5V
- Comparable load regulation - within datasheet specs of 440 mV/A
- Lower input current for Polaris device – optocoupler effect
- ~20% rel. higher efficiency at V_{IN}=5V – efficiency advantage increases for larger V_{IN}/V_{OUT} ratios

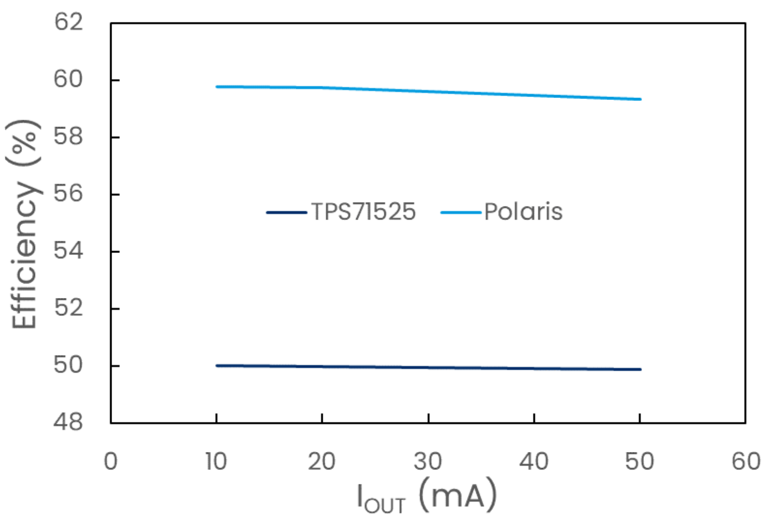
Load regulation V_{IN}=5V



Input current V_{IN}=5V

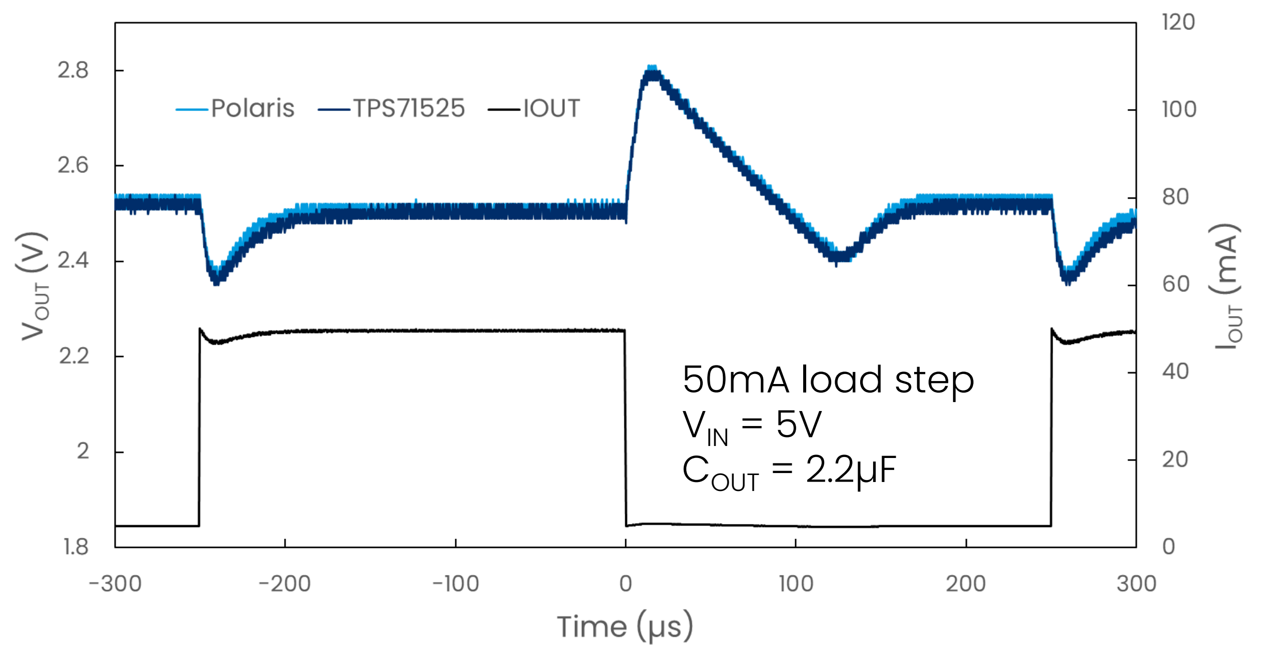


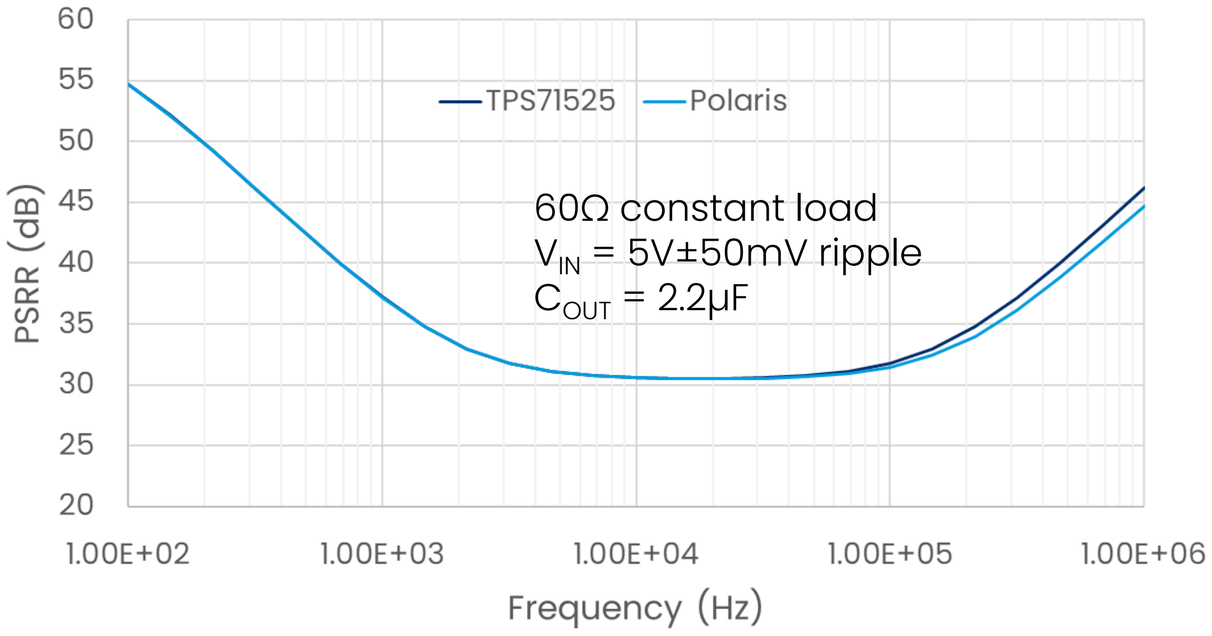
Efficiency V_{IN}=5V



Transient Response - 2.5V buck

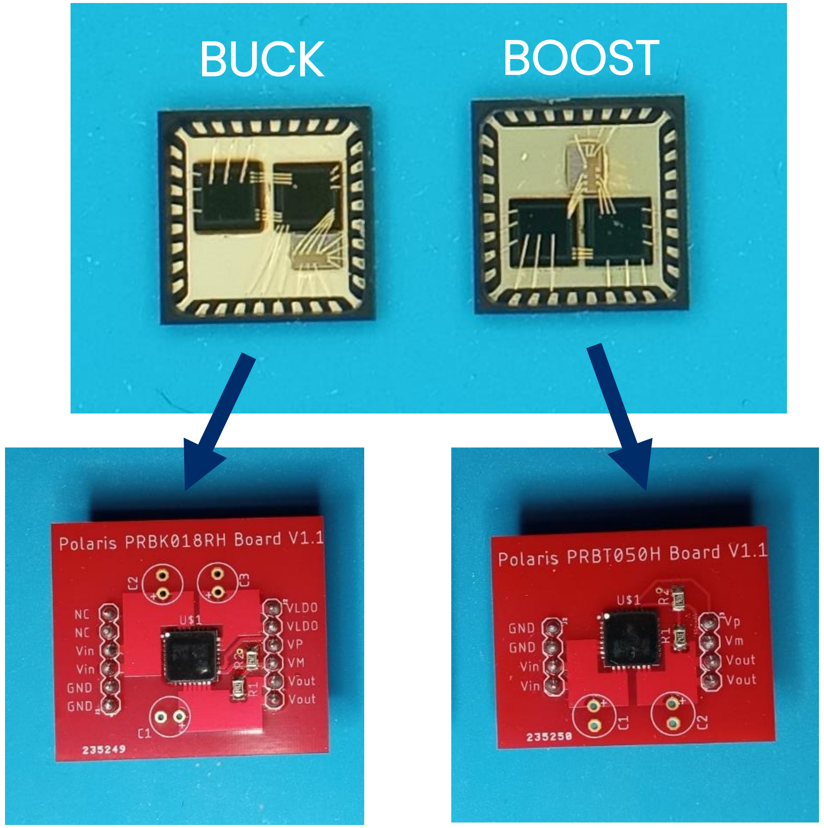
- Load step measurements of 2.5V buck regulator containing TPS71525
- Compared to TPS71525 LDO
- Virtually identical load step response!
- SPICE simulation of PSRR – slightly lower PSSR at high frequency with optocouplers
- Presently arranging testing of PSSR





Rad-hard Prototypes

- RF Micropower supplied LDOs, I_{OUT} < 300mA
- Two configurations – 5V/1.8V buck, 3.3V/5V boost
- No external caps required



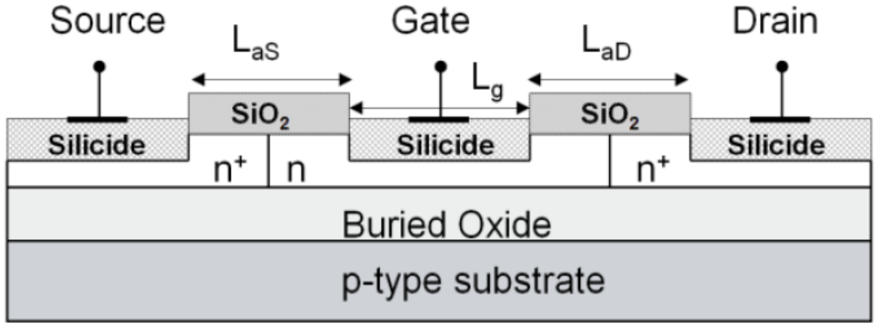
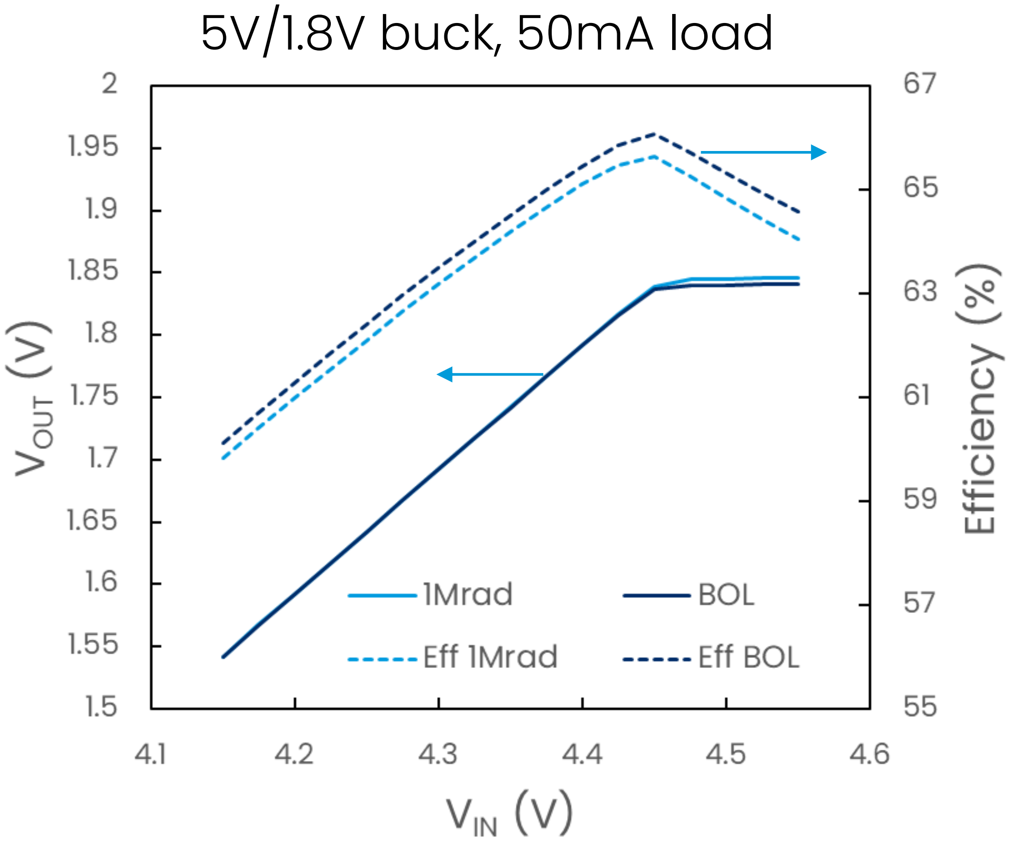


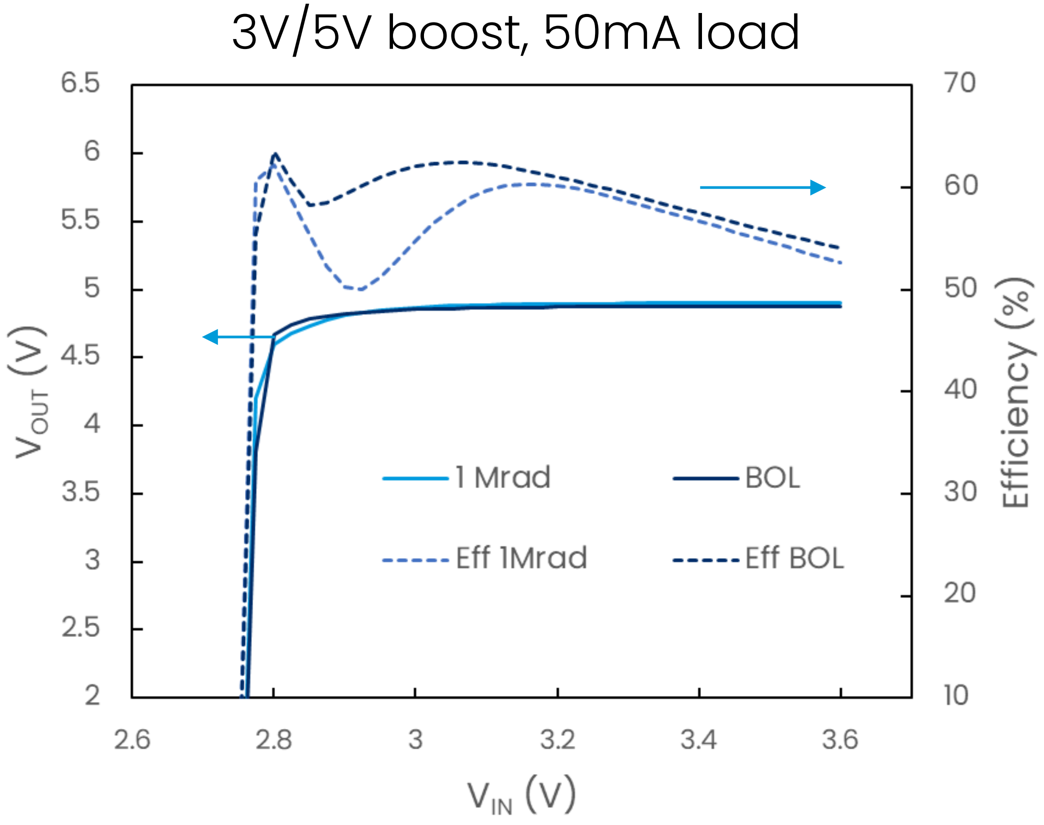
Fig. 1. Schematic cross-section of the SOI MESFET. The Schottky gate of the MESFET is formed using the silicide step that creates the low resistance source drain contacts. Spacer regions of length L_{aS} and L_{aD} are used to isolate the gate silicide from the source/drain silicides. For the MESFET used as the output pass transistor of the linear regulator $L_g = L_{aS} = L_{aD}$ =200nm, W_g=152.2nm and the device had a soft breakdown voltage of >5V.

T. Thornton *et al.*, 2013 IEEE Radiation Effects Data Workshop (REDW), July 2013

Device data

- TID irradiation using cobalt-60, up to 1 Mrad(Si) (50, 100, 300, 500, 1000 krad)
- Slight degradation in efficiency, but very little change in either device
- Optocouplers sensitive to displacement damage – rad hard optocouplers under development





Radiation & test sponsored by VIPC CCF grant

Next Steps

Present activities

- New program to develop next gen optocouplers
  - Lower R_{series}
  - Improved quantum efficiency
  - High radiation tolerance
- Develop advanced packaging – 2.5D and 3D schemes to reduce footprint, Hi-rel packages
- Able to provide prototypes for evaluation – or custom builds for particular specs

Acknowledgements

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  - Prof T. Thornton at ASU/RF Micropower
  - S. Buchner, radiation effects consultant

Thank you

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