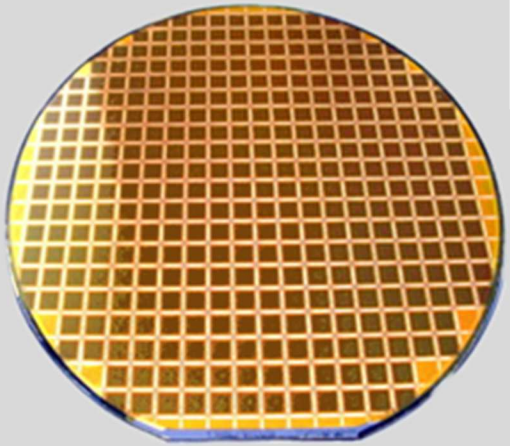
Active, All-Cell Reconfigurable Strings for Long, High Efficiency Missions

Reconfigurable Photovoltaic (PV) Arrays



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Concept & Motivation

Mitigate Voltage Variation By PV Array Reconfiguration

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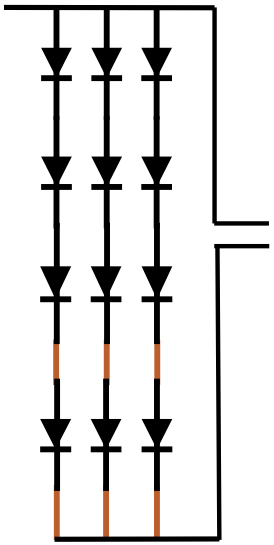
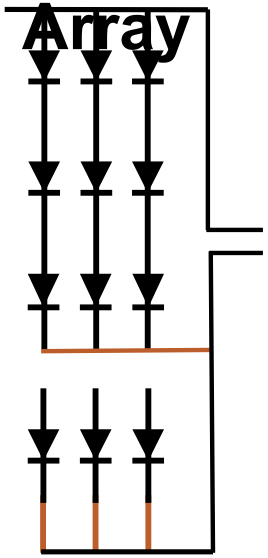
3 x 4 PV Cell Array



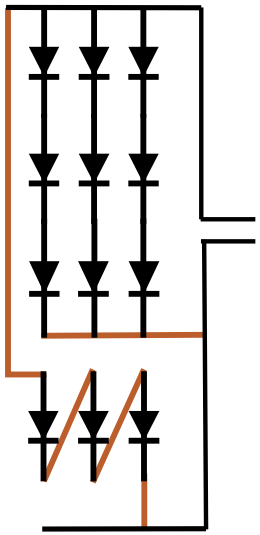
V=4*Vmp_lowT
> optimal

3 x 3 PV Cell Array



Vmp reduced with power loss

4 x 3 PV Cell Array, Reconfigured



Vmp reduced with no power loss

Reconfigurable strings: n x (n+1)

All Cells Are Used In All Cases

Maintain Full PV Array Electrical Output With Reduced ΔV

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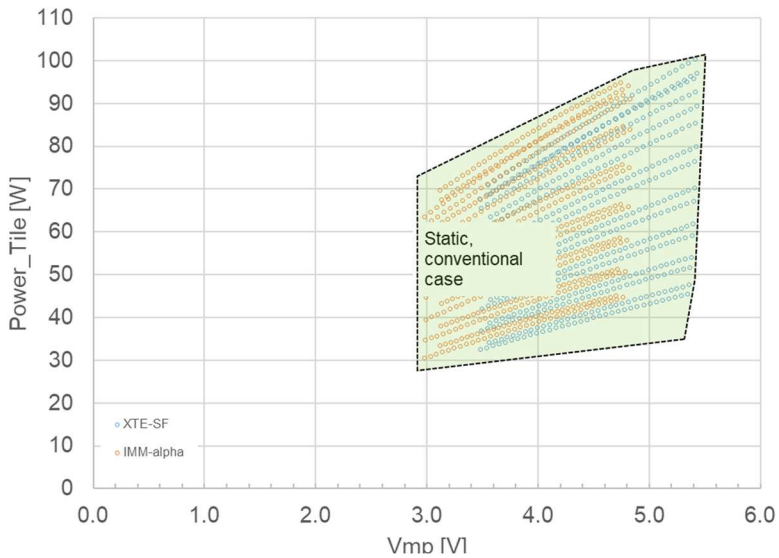
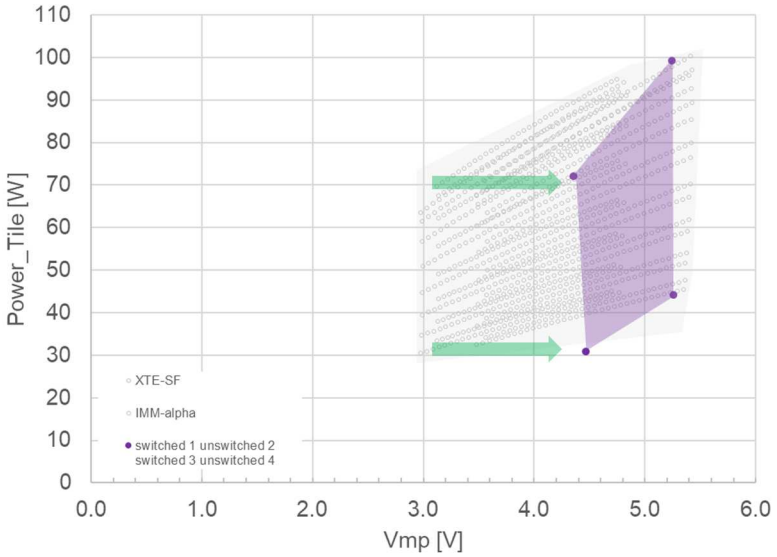
Without Switching



Reconfigurable Switching



Simulated Temp Effects

2.8V < Vmp < 5.3V

3 x 2 Array

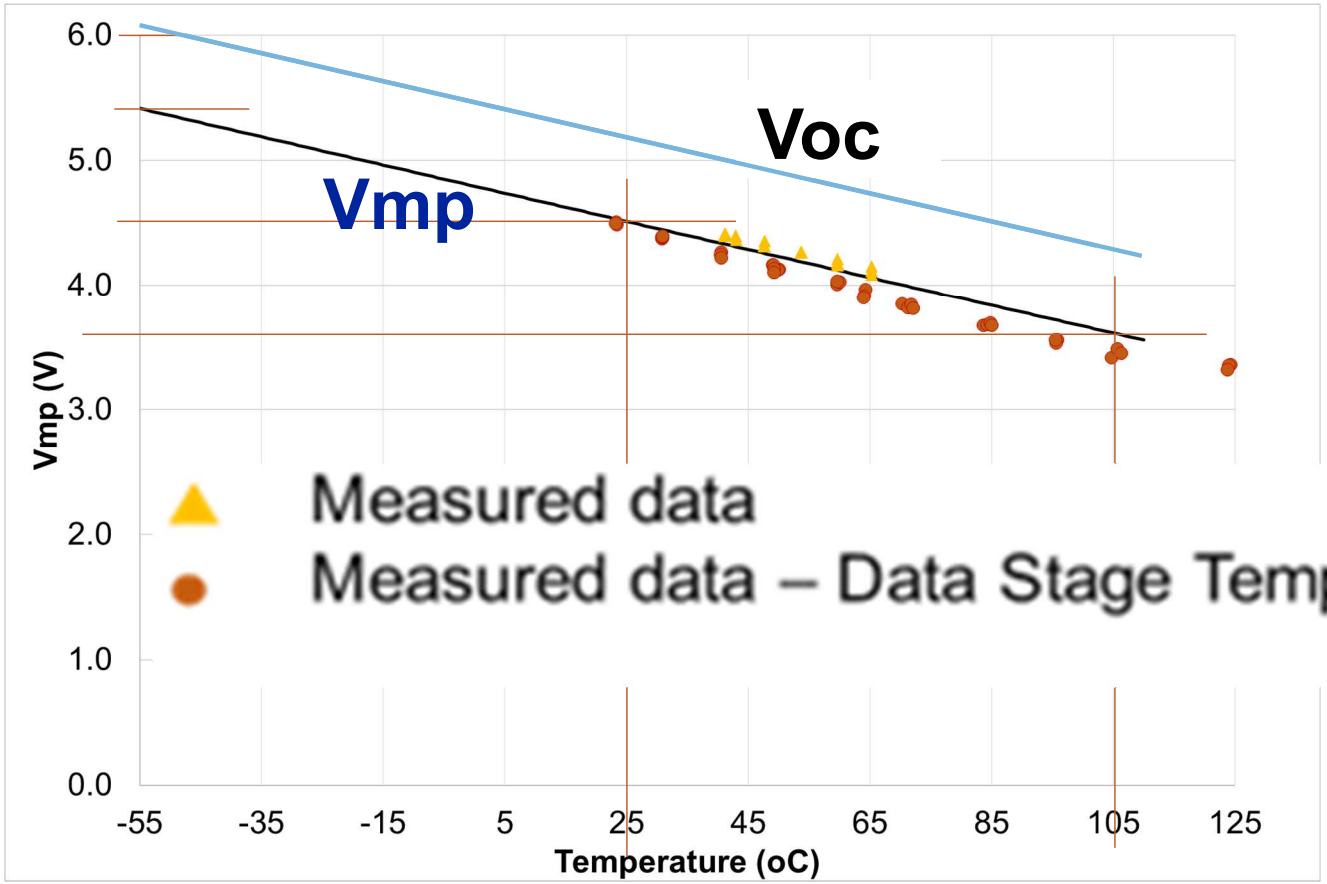
Simulated Temp Effects

4.3V < Vmp < 5.2V.

3 x 2 ⇔ 2 x 3 Switching

Reduced ΔV => Greater Efficiency

PV Cell Modeled Vmp & Voc Plots



Voltage differential Voc – Vmp is relatively constant over temperature.

Effect of Mode Switching at 30°C
3 x 2 Array

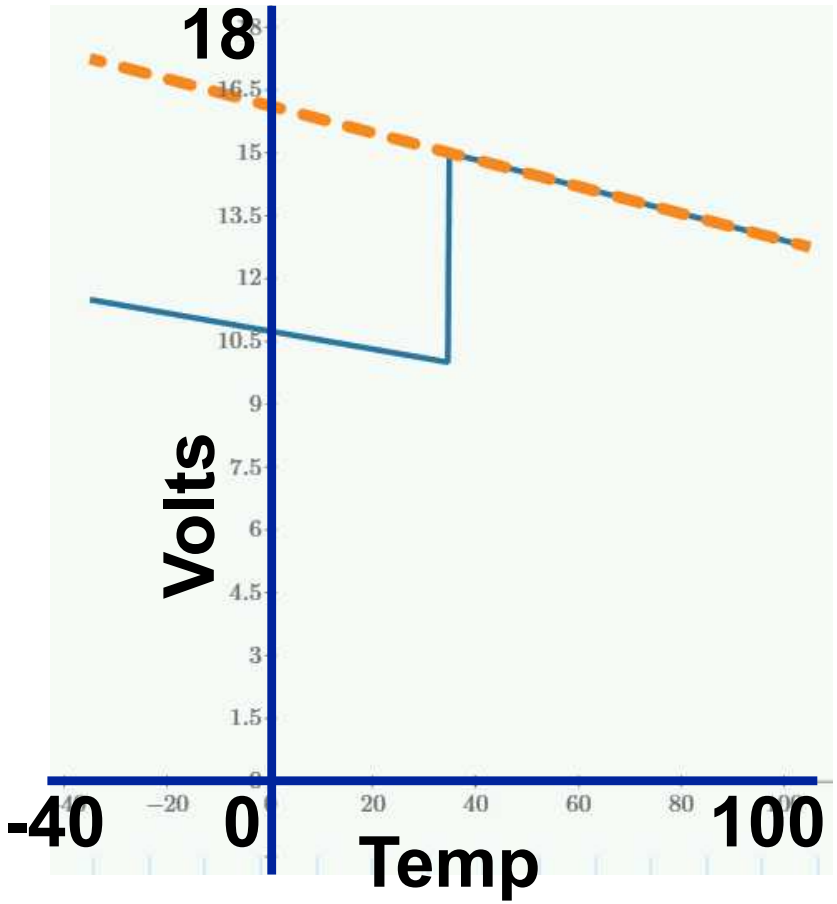


Image at left is a 2 x 3 PV cell array

Maximum Voc reduced by ~2.2V

Allows use of lower voltage switches leading to higher efficiency

This conservative analysis ignores the effect of aging, AOI, and cell type

Effect of Mode Switching at 30°C 8 x 9 Array

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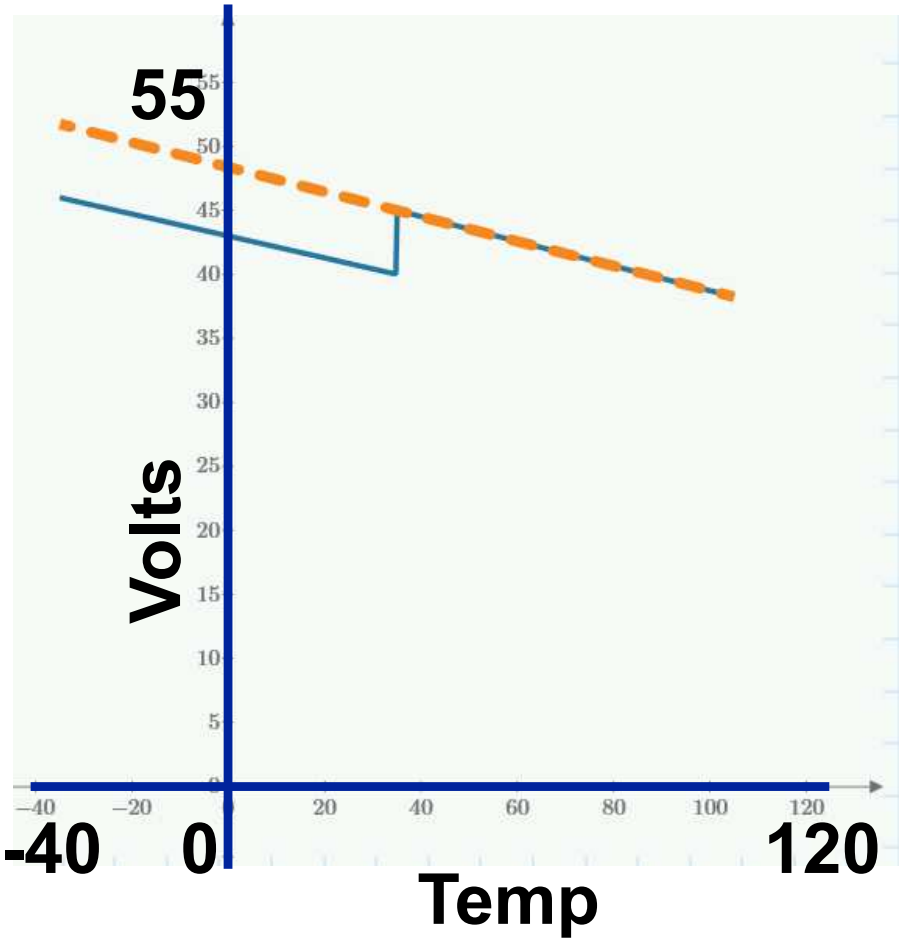
Image at right is an 8 x 9 PV cell array

Illustrates that there is an optimum ΔV configuration

A function of PV cell type, temperature, load, and the environment

This is a conservative analysis



ΔV ÷ 2

Reasons to Implement Reconfigurable Switching

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- **Maximize power output at all temperatures**
- **Limit maximum voltage**
  - Allow use of lower rated converter devices with lower Rds (on)
    - Improves converter efficiency
- **Limit minimum voltage**
  - Allows more flexibility in component choice
  - Prevents brownout issues
- **Improve overall system efficiency by reducing PV array voltage variation**
  - LLC converters prefer a limited Δvin, for example
- **Compensate for PV cell aging and radiation effects**

Realization of Mode Switching

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Switching Network Implementation Goals

- **Minimize number of switches**
  - Reduce cost and footprint
  - Maximization of PV cell packing factor reduces open area available for circuitry
- **Use all N-channel switches**
  - For maximum efficiency
- **Implement control circuit in ASIC to minimize footprint**
- **Use inherently rad-hard components**
- **Accommodate reverse current protection**
  - Control switches to prevent reverse current
  - Or, add a separate ideal diode circuit

Reconfigurable Circuit Implementation 3 x 2

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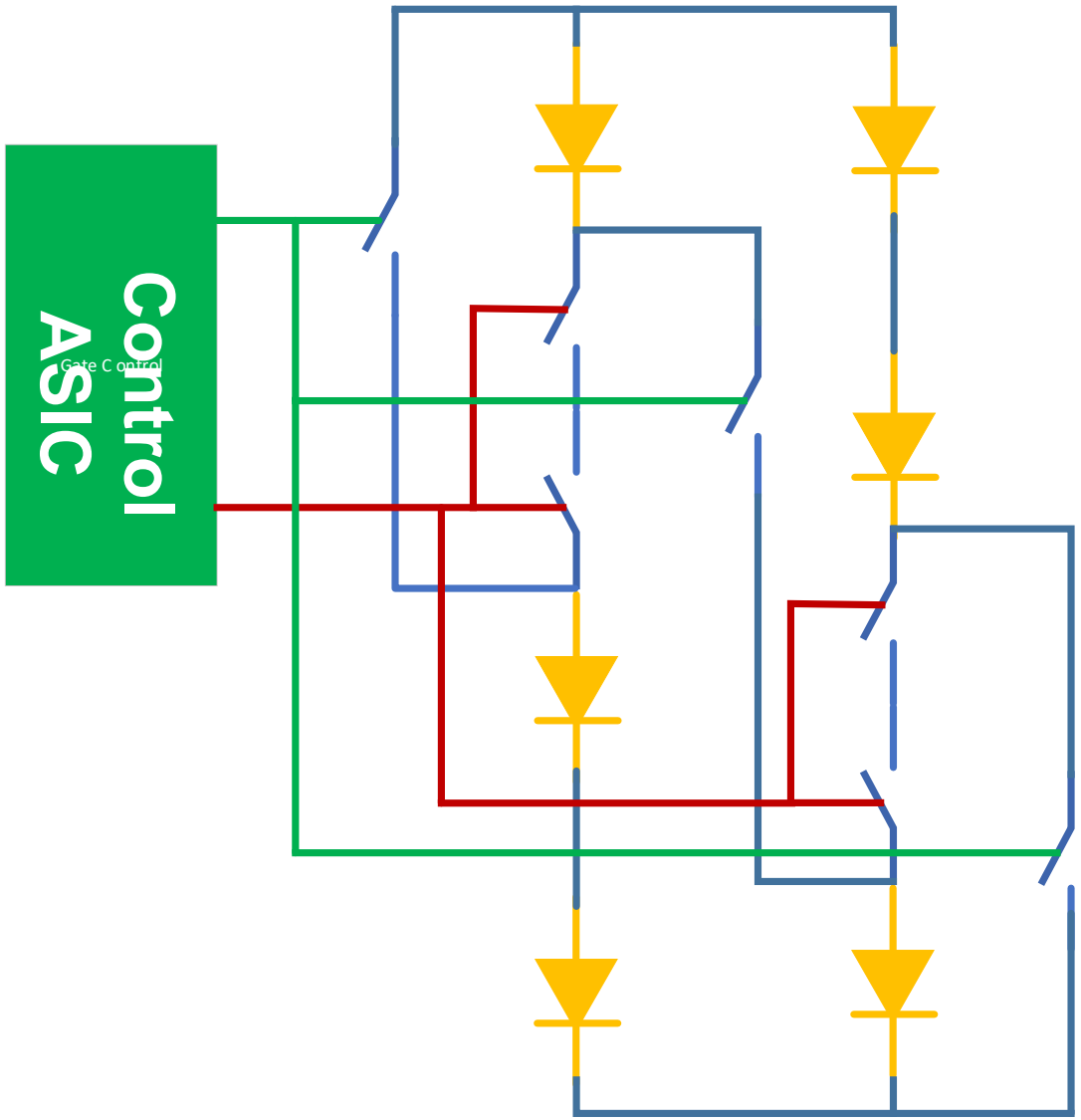
- **Red – 3 x Vcell**
- **Green – 2 x Vcell**
- Switches are N-channel GaNFETs
- Yellow diodes represent PV cells
- < 1mA gate drive needed
- Bootstrap supply needed for gate drive



Autonomous Temperature Switch

Autonomous Local Electronic Temperature Switch

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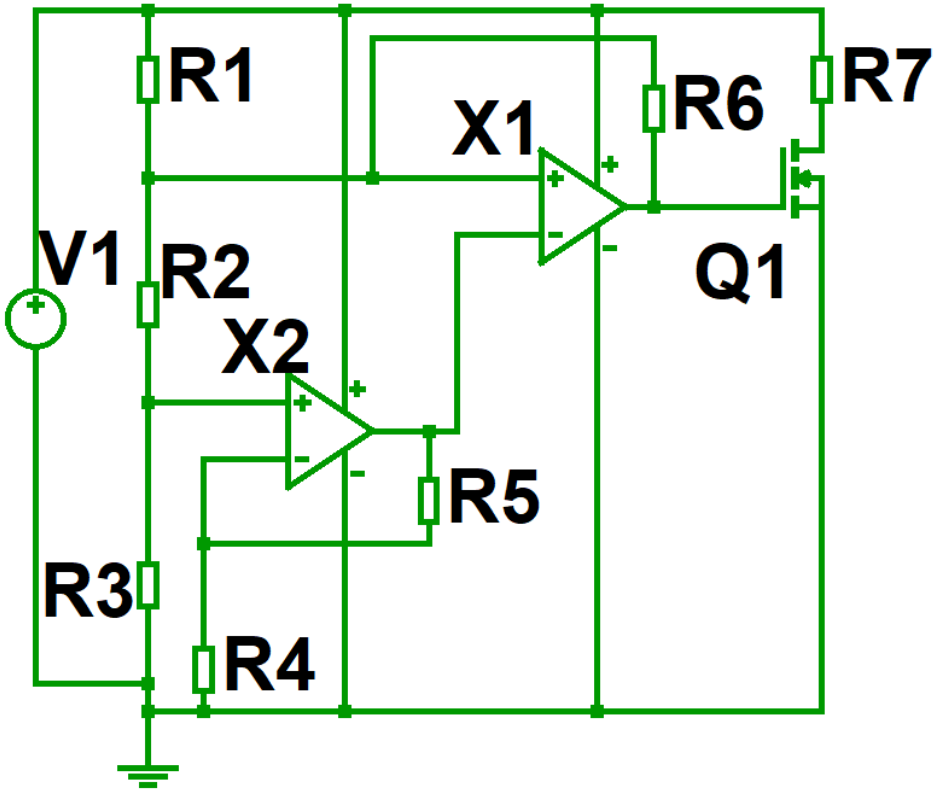
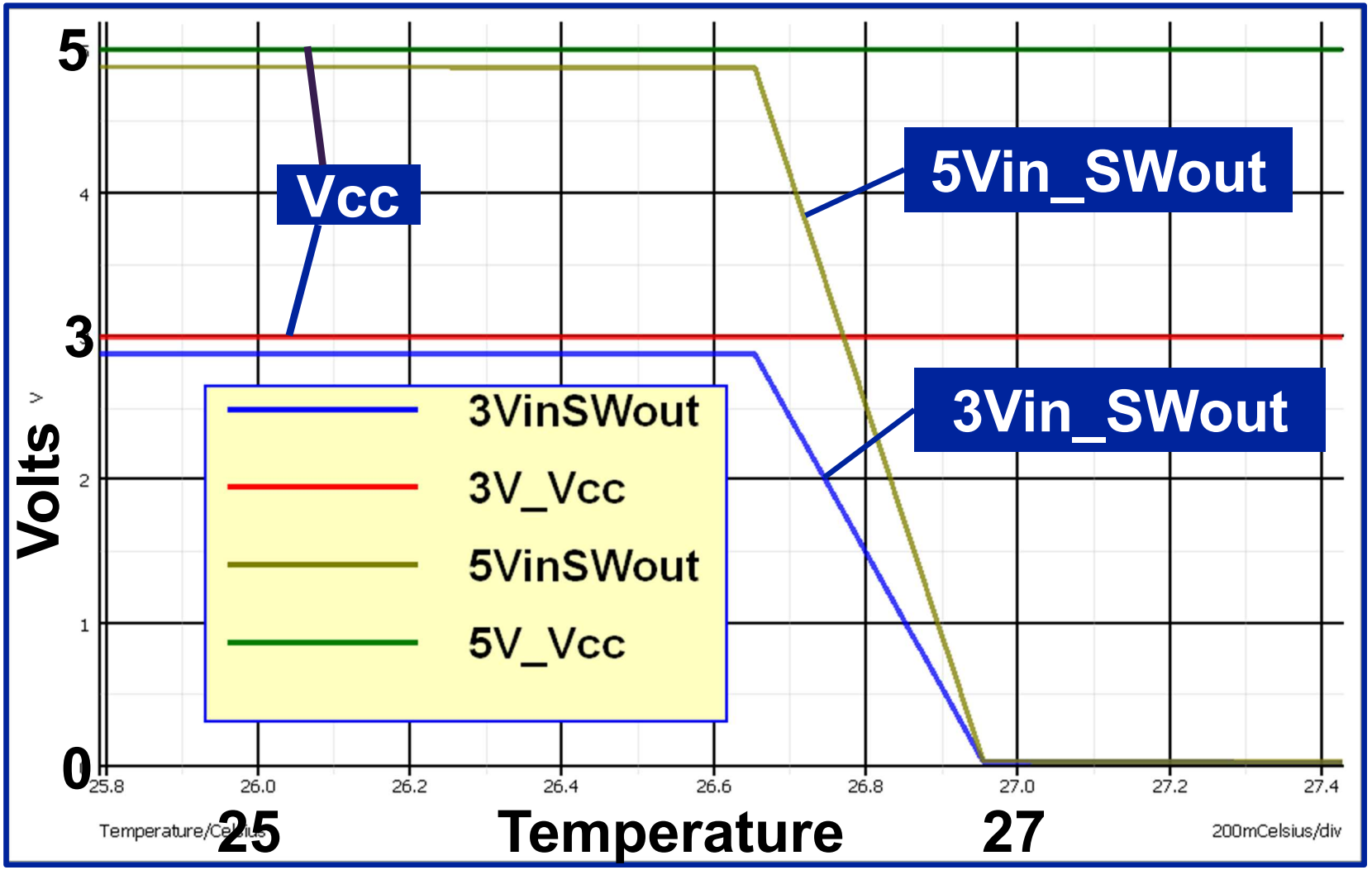
- R3 is a PTC temperature sensor, can be < 100 ohms
- No voltage reference or current source needed
- Switching temperature independent of V1 voltage
- V1 can be from PV cells
- Minimal footprint



Substantial Wiring Reduction Compared to Array-Level Control

Temperature Switch Simulation Plots



Mode Switch Temp is independent of Vcc

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Summary

- **A method of stabilizing a PV array output voltage while producing 100% of available power has been realized**
  - Reduced ΔV increases downstream efficiency
  - Can bound array output voltage without power loss
- **Readily extensible to n x (n+1) array sizes**
- **Minimal footprint maximizes packing factor**
- **Designed with radiation hardness as a requirement**
- **A minimal footprint autonomous temperature switch reduces wiring complexity**
- **Can be implemented with all N-channel devices**