A 99.7% Efficient Series-Stacked Architecture for Rack-Level Power Delivery in HDD Storage Servers

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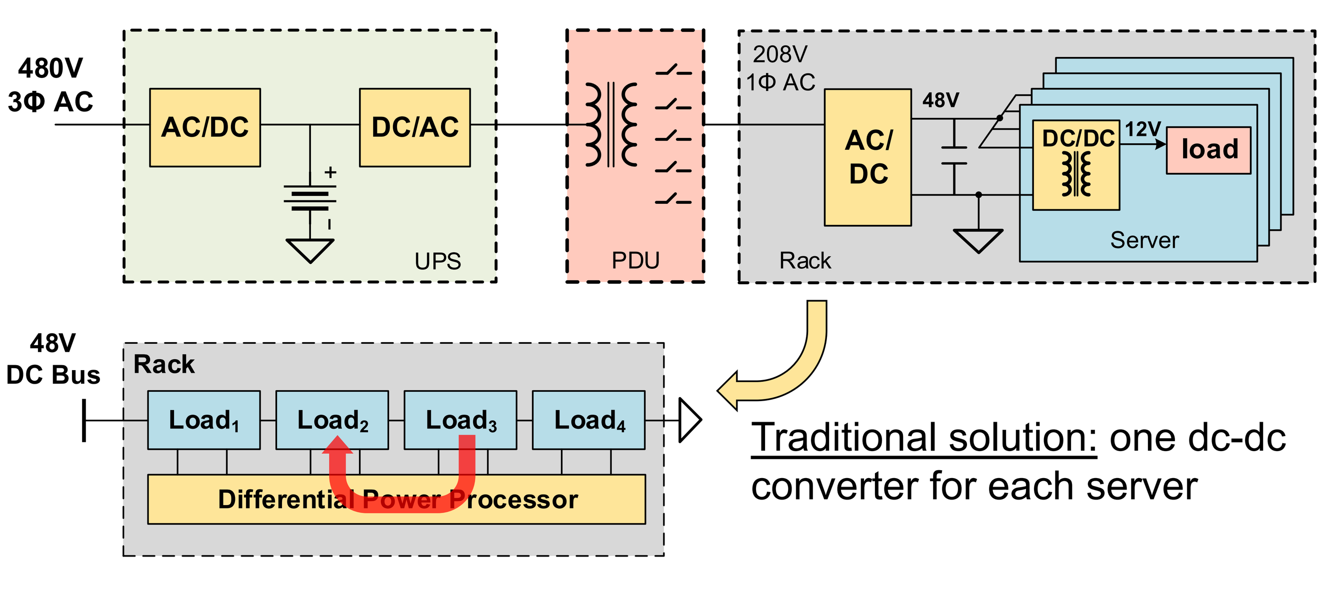
Motivation

Power Delivery Architecture in Data Center



Traditional solution: one dc-dc converter for each server

A 50V to 5V solution with 10 series-stacked voltage domains:

- Series-stacked architecture which can step down voltage by nature and support a large number of loads
- Differential power processing (DPP) for extreme efficiency
- Multi-port ac-coupled (MAC) converter

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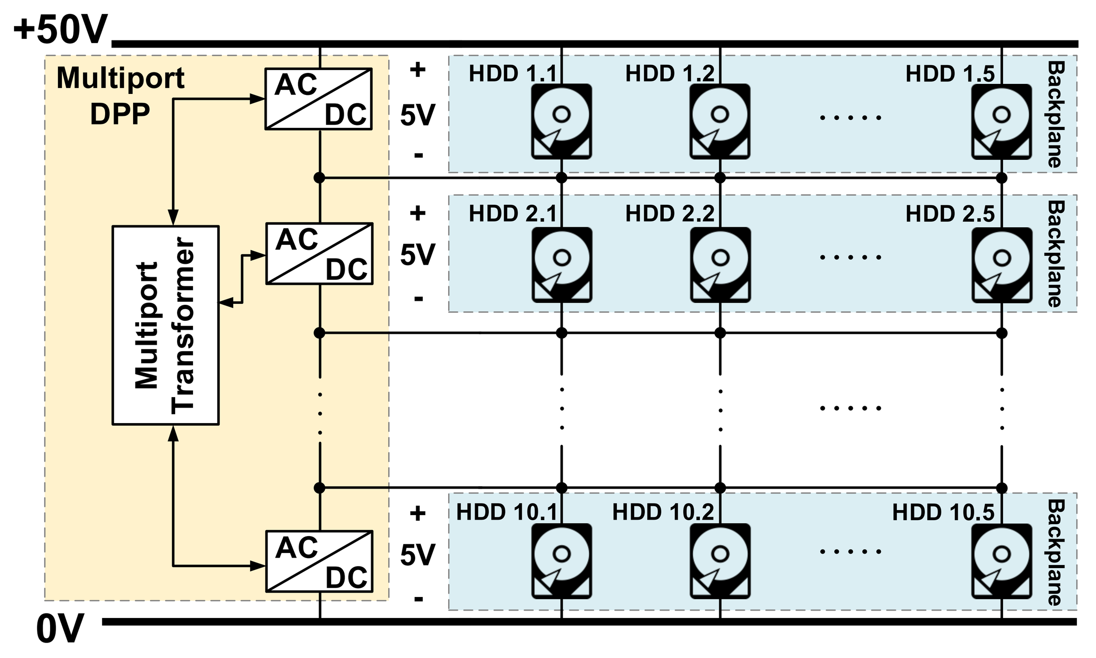
HDD Storage Server

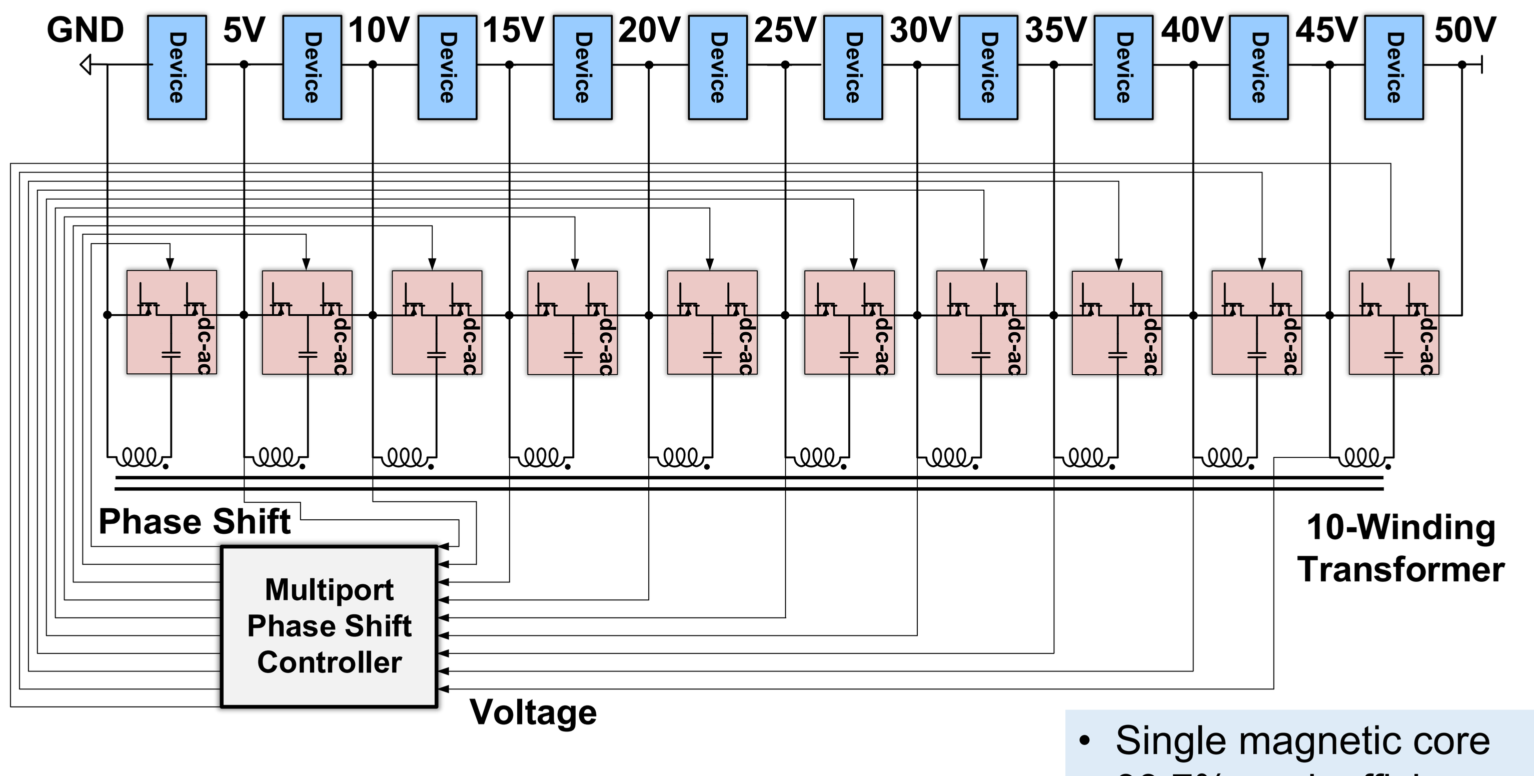
Overall DPP Architecture for HDD Storage Server



- 50×2.5-inch HDDs are grouped into 10 series voltage domains
- Each domain supplies 25W peak power (5 HDDs)
- Support "hot-swap" of an entire domain (30W differential power)

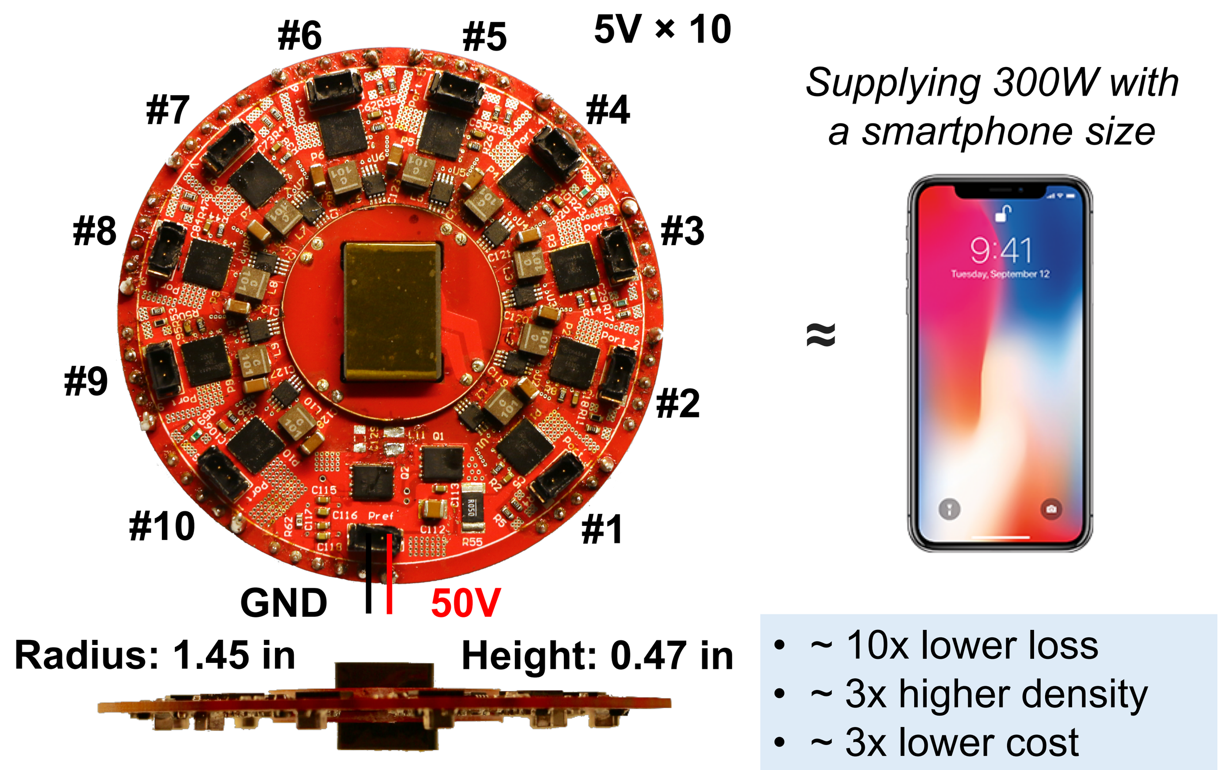
Multiport Ac-Coupled (MAC) Differential Power Processing

- **10-Port MAC DPP Converter Circuit Topology**



- Single magnetic core
- 99.7% peak efficiency

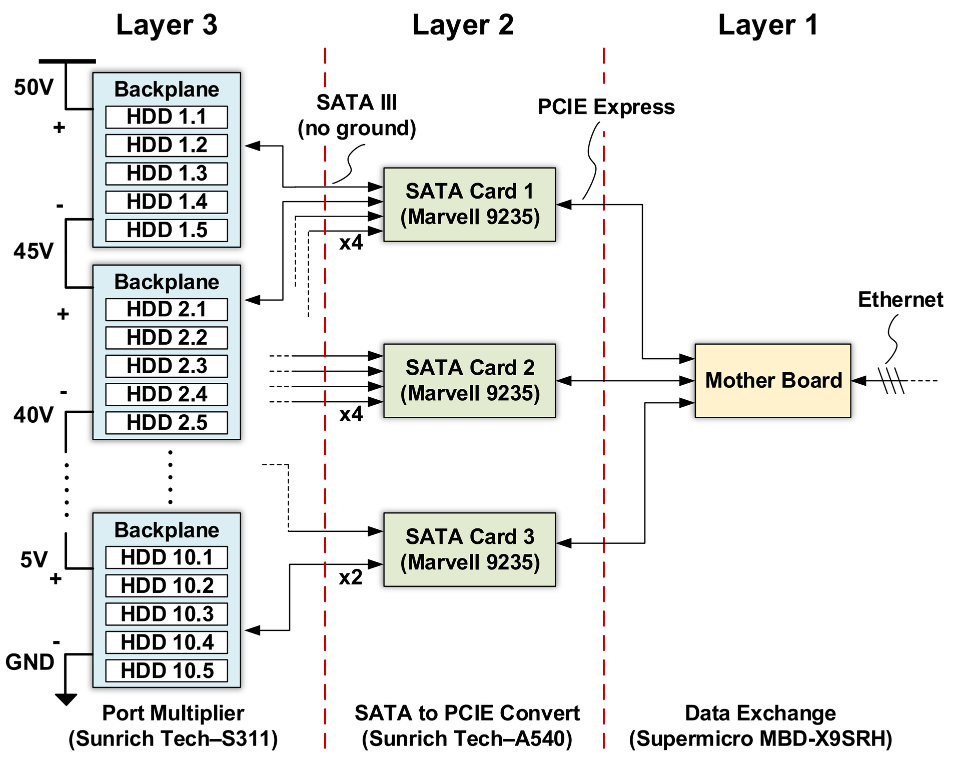
- **MAC DPP Prototype (100 W/in³ Power Density)**



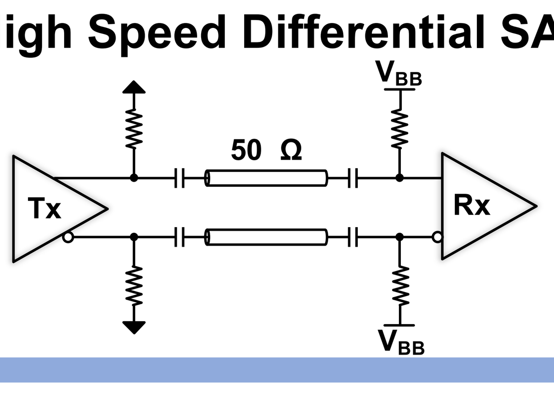
- ~ 10x lower loss
- ~ 3x higher density
- ~ 3x lower cost
- Read, write, hot swap

Communication Structure

- **A Three Layer Solution with SATA Extension Boards**



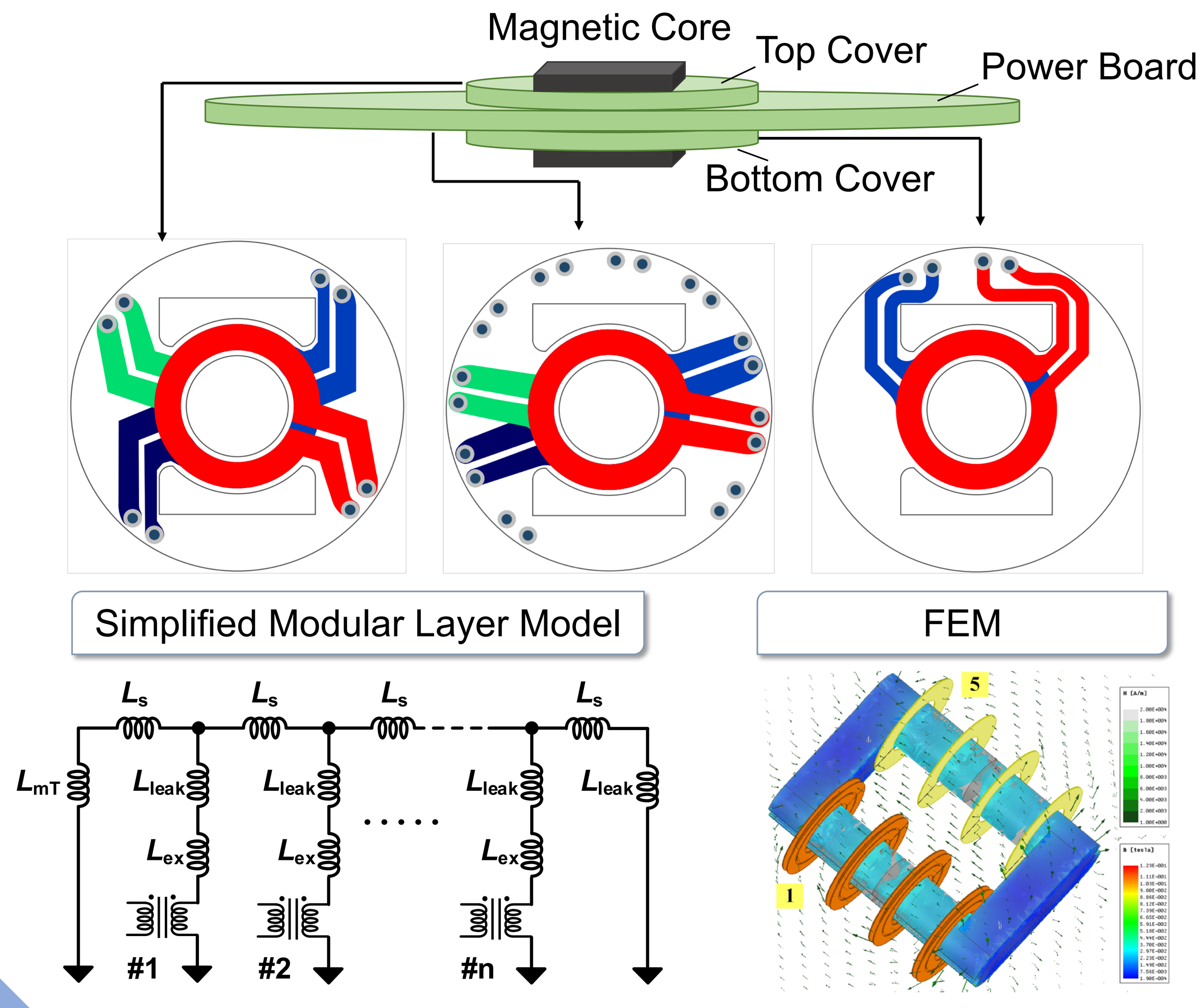
- **High Speed Differential SATA Signal**



- HDDs at different voltage domains transmit information through standard SATA
- Verified reading, writing and hot-swapping

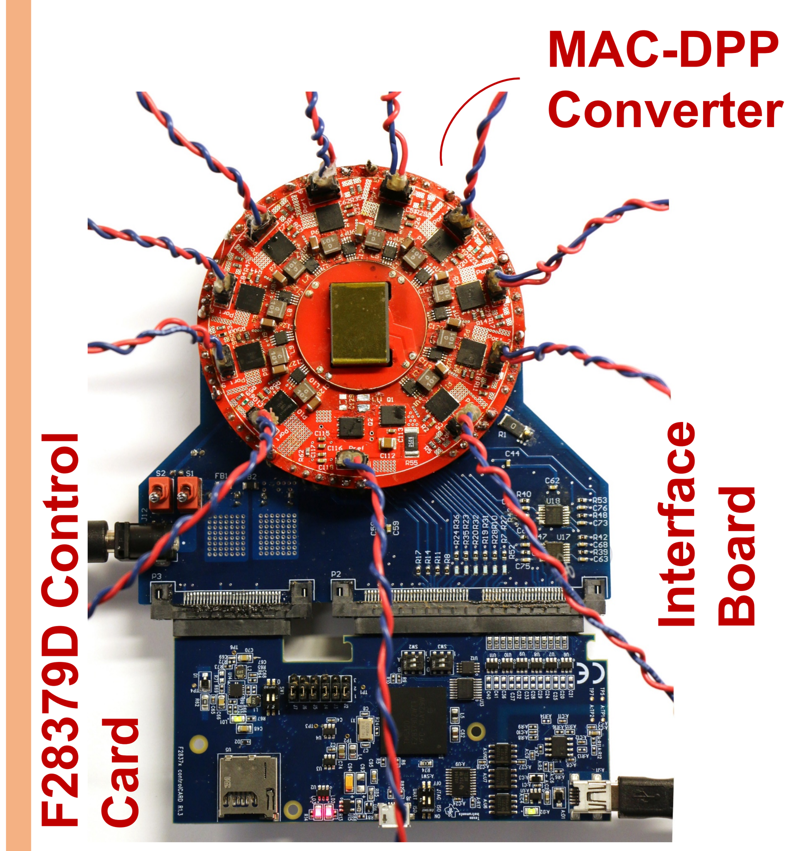
Multi-Winding Transformer

- **Planar PCB Structure**

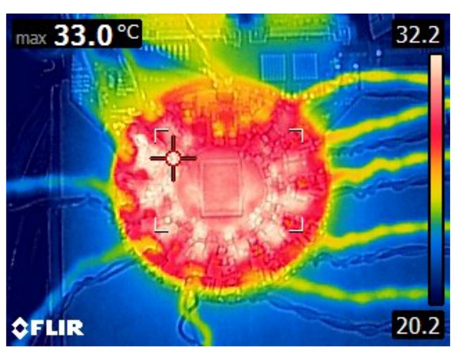


Experiment Results

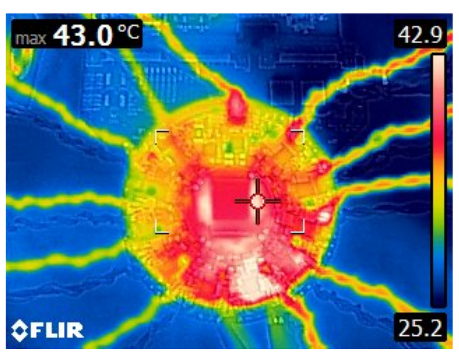
- **Prototype Overview**



- **Thermal Images**

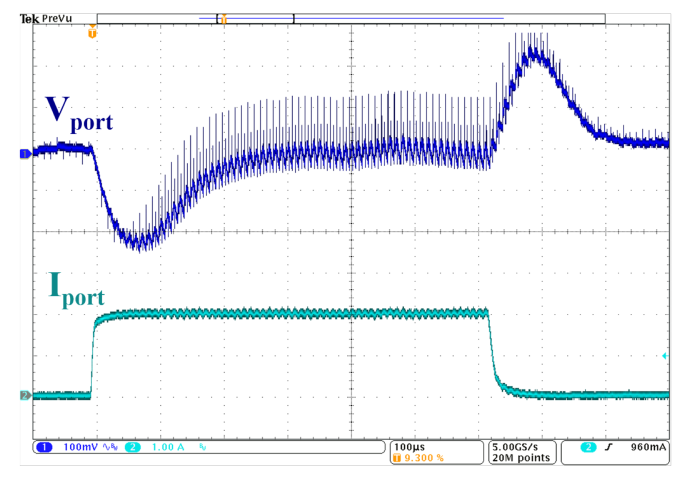


(a) Balanced Load



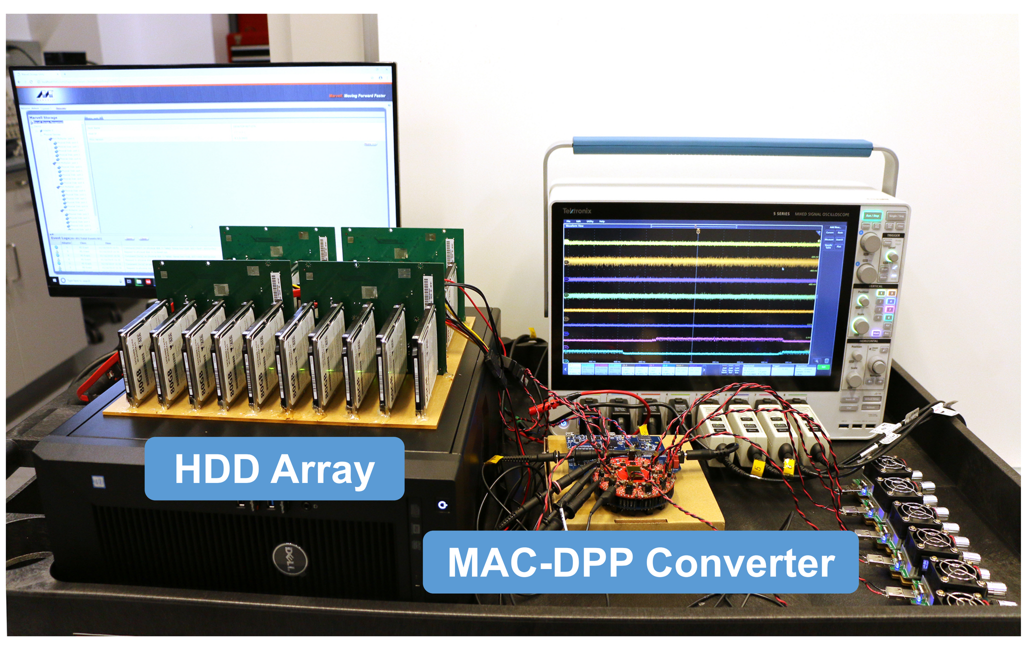
(b) 30W Unbalanced Load

- **Transient Response (2A Step Load at One Port)**

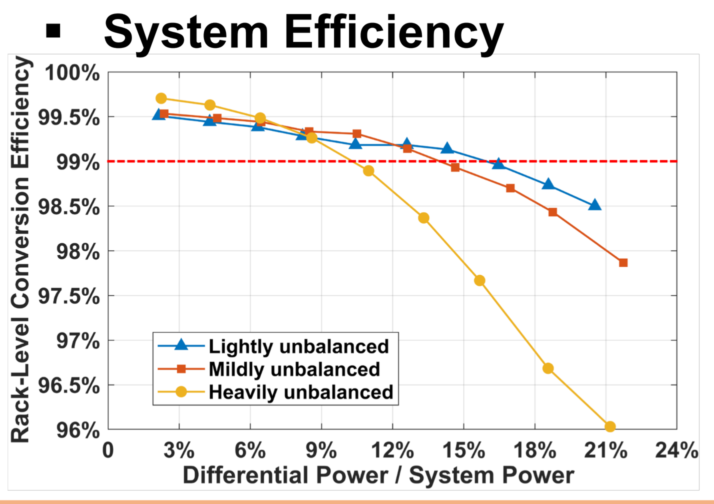


- 700 uF output capacitance.
- Transient overshoot : <230 mV.
- Settling time: <200 us.
- Meet the hot-swap requirement of typical HDDs (5% of VDD)

- **HDD Storage System Testbench**



- **System Efficiency**



$$\eta = \frac{\textit{Power Consumed by HDD}}{\textit{System Power}}$$

- Peak efficiency: **99.7%**
- Efficiency: **>99%** for differential power ratio <10%.

MAC-DPP Demo Video

References

[1] P. Wang and M. Chen, "Towards Power FPGA: Architecture, Modeling and Control of Multiport Power Converters," *2018 IEEE 19th Workshop on Control and Modeling for Power Electronics (COMPEL)*, Padua, 2018, pp. 1-8.

[2] E. Candan, P. S. Shenoy and R. C. N. Pilawa-Podgurski, "A Series-Stacked Power Delivery Architecture with Isolated Differential Power Conversion for Data Centers," *IEEE Transactions on Power Electronics*, vol. 31, no. 5, pp. 3690-3703, May 2016.