OCP FUTURE TECHNOLOGIES SYMPOSIUM

OCP Global Summit

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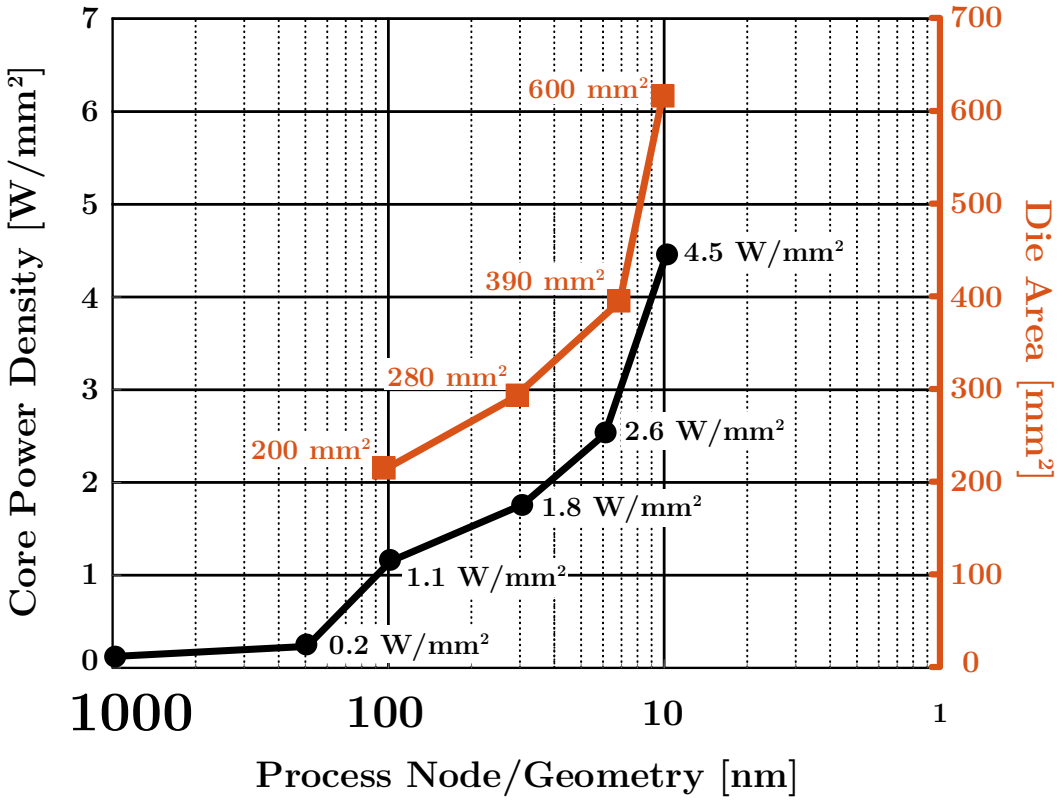
PRINCETON UNIVERSITY

Vertical Stacked 48V-1V Voltage Regulator for Ultra High Current Microprocessors

Jaeil Baek, Youssef Elasser, and Minjie Chen

Princeton University

Higher Power Consumption of Processor

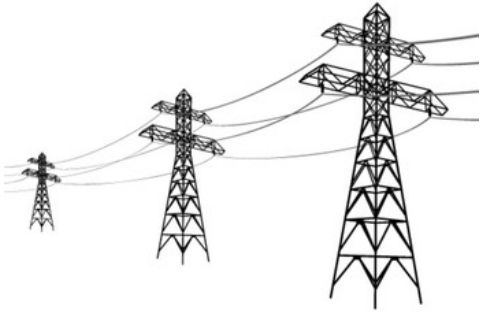


Power Density ↑

Die Area ↑

Higher Power Consumption of Processors

Data Center Power Delivery



48V Power Delivery

Rack Level

48V

48V / 50A

48V-1V

48V-1V

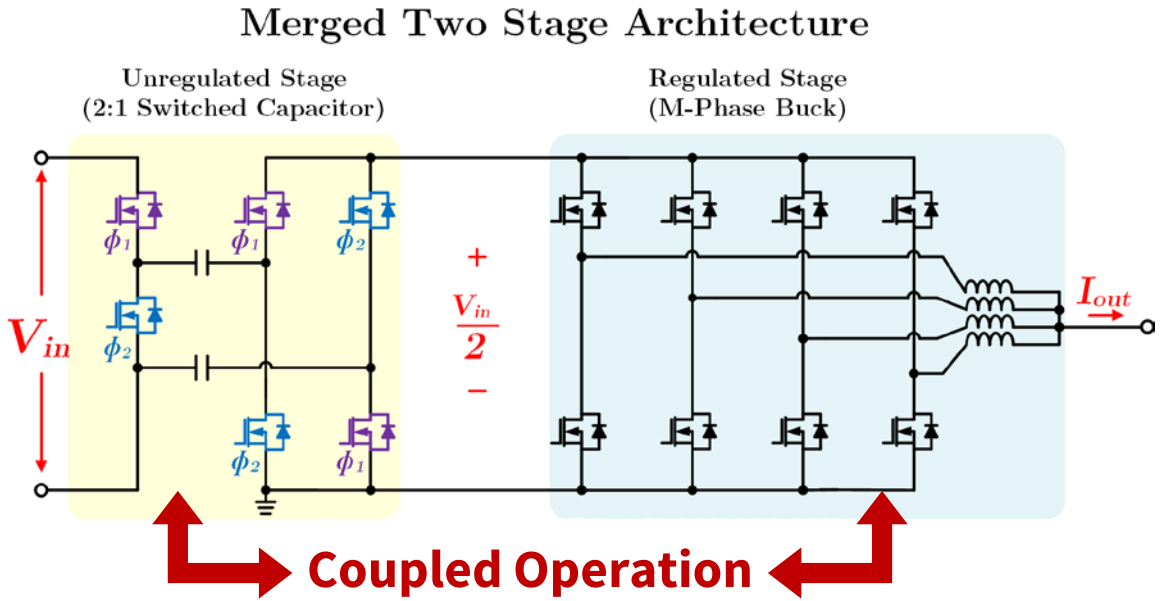
Challenge

- High step down
- High current
- High power density

48V-1V

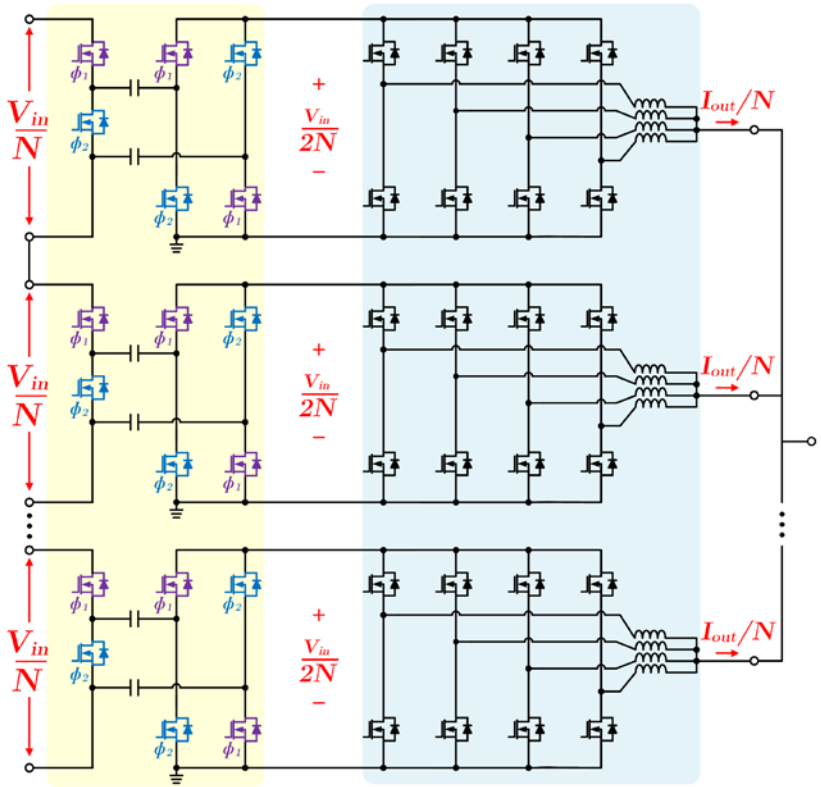
48V-1V

LEGO Point of Load (LEGO-PoL) Architecture



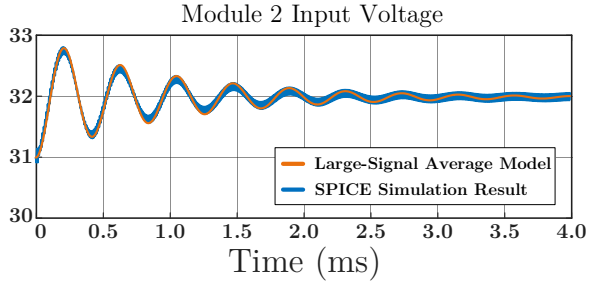
High Power Density	High Efficiency	High Speed

LEGO Point of Load (LEGO-PoL) Architecture

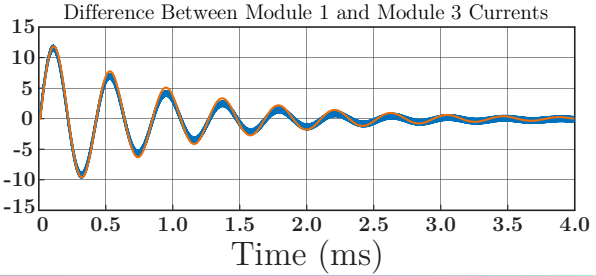


Linearly
Extendable
Group
Operated

Automatic Voltage Balancing



Automatic Current Sharing



Vertical Power Delivery

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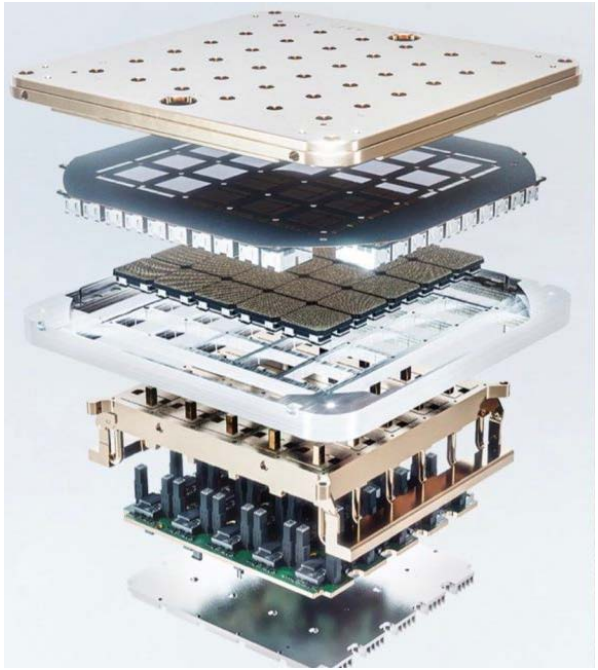
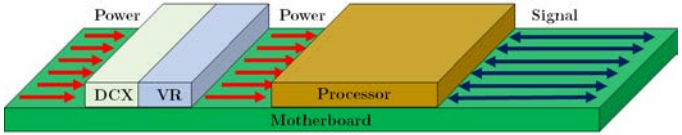
Intel PowerVia

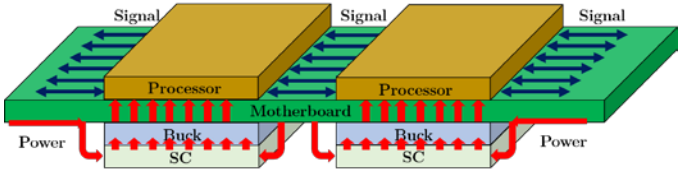
Tesla Dojo



Lateral



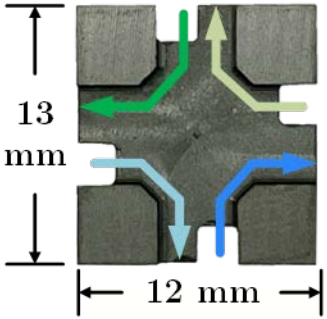
Vertical

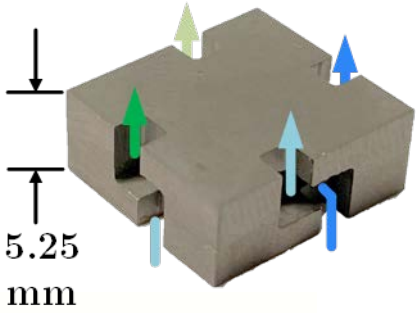


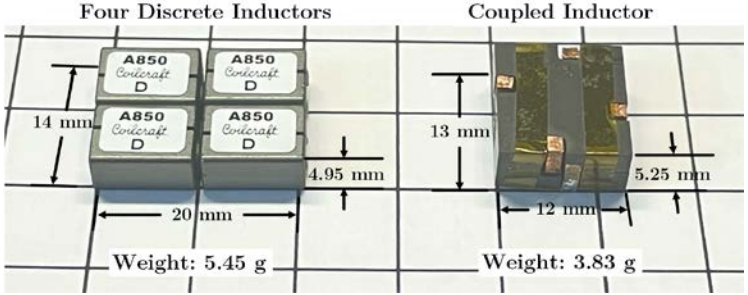
- **Reduced power delivery loss**
- **More area for signal routing (Multiple processors)**

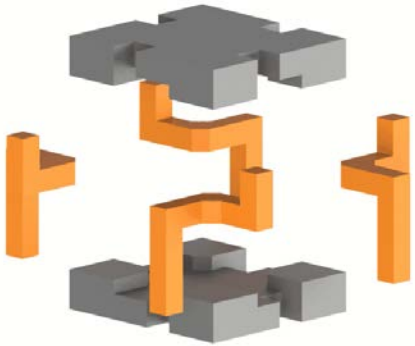
Sources- Intel PowerVia: https://www.youtube.com/watch?v=t6Y41zdO3Pc
- Tesla Dojo: https://www.youtube.com/watch?v=DSw3IwsgNnc

Custom Four Phase Coupled Inductor









Benefits of Multiphase Coupling

Reduced Energy Storage Requirements	**Lower Phase Current Ripple**	**Fast Transient Speed**

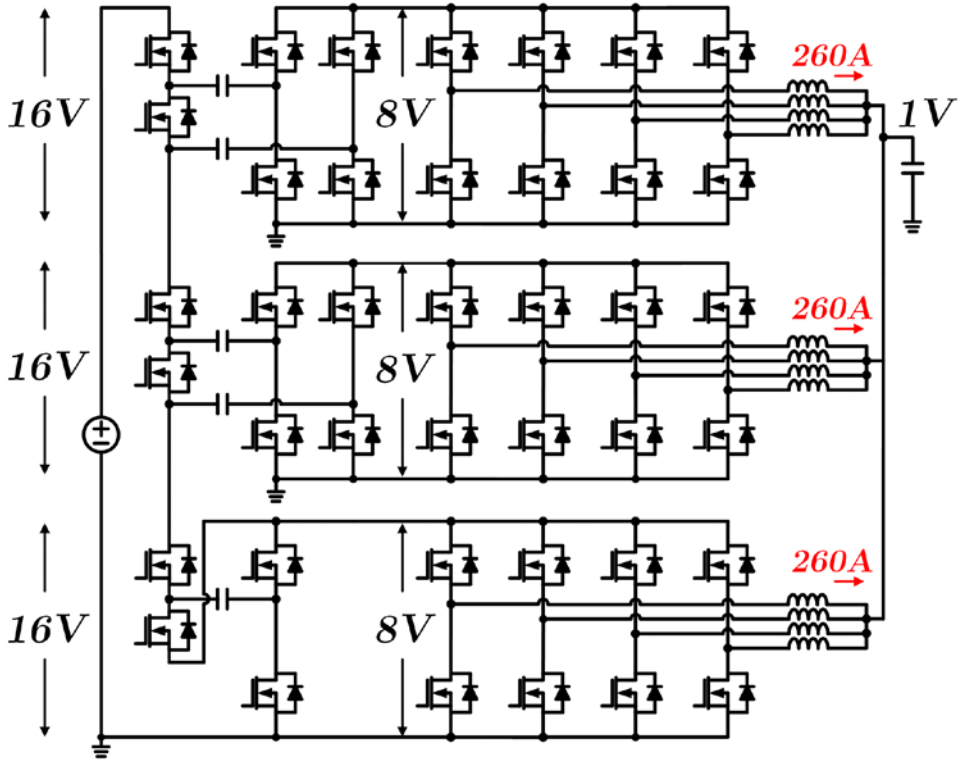
Further Reading

Unified Models for Coupled Inductors Applied to Multiphase PWM Converters

M. Chen and C. R. Sullivan

IEEE Transactions on Power Electronics, vol. 36, no. 12, December 2021

Assembled Vertical Stacked Prototype



3 SUBMODULES

- Three Series 2:1 Switched Capacitor

48 V → 8 V

- Three Parallel Four-Phase Buck

260 A
260 A
260 A
} **780 A**

Assembled Vertical Stacked Prototype

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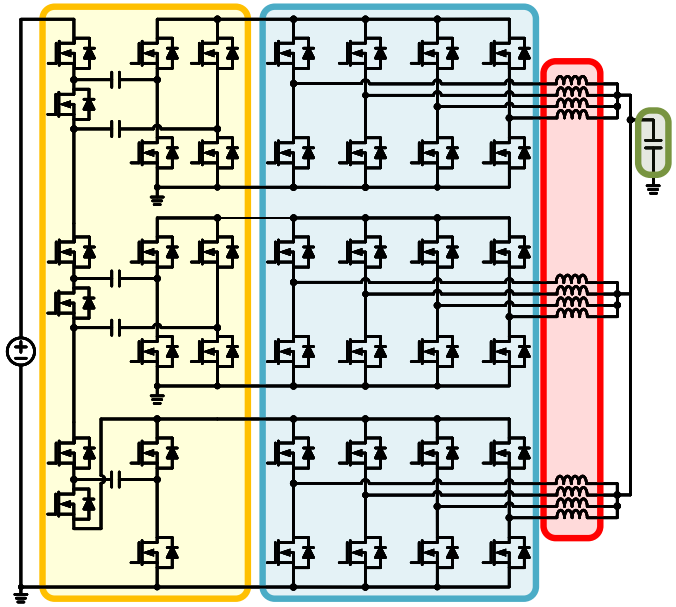
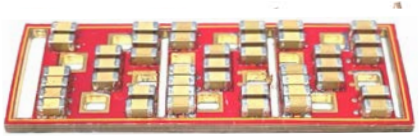
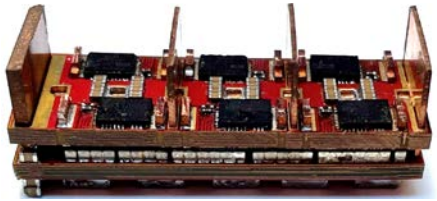




Output Capacitors
42 × 220 µF
X7R, 1206

3

2



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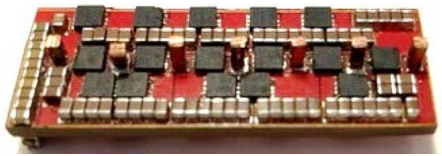


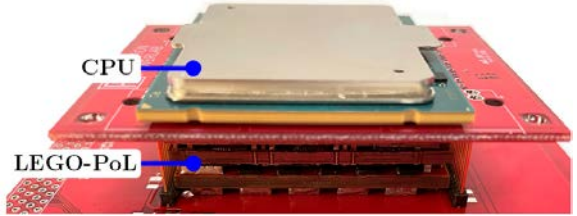
Assembled LEGO-PoL Prototype

46.5 mm × 16.5 mm × 16.65 mm

Area: 767 mm^2

Volume: 0.78 in^3

Mechanical Demonstration



Liquid Cooling for 780A Operation

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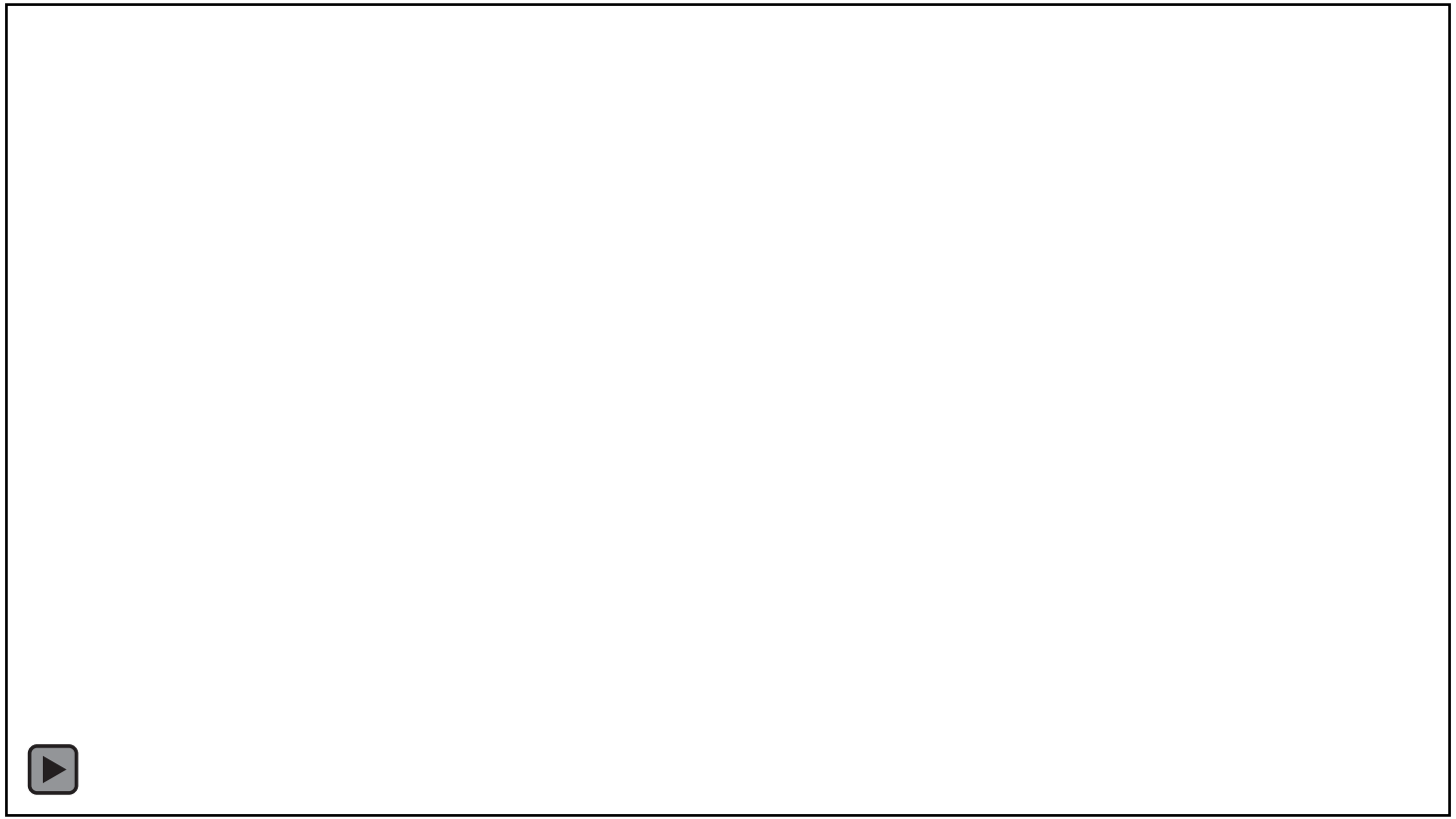

Experimental Results

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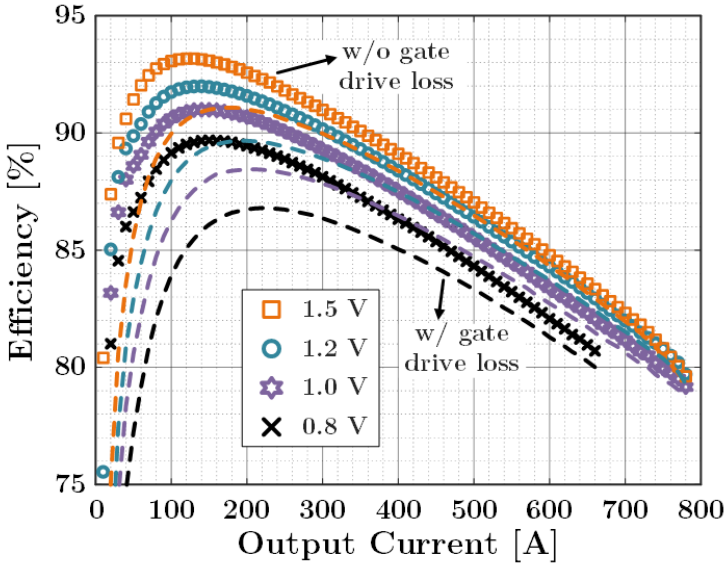
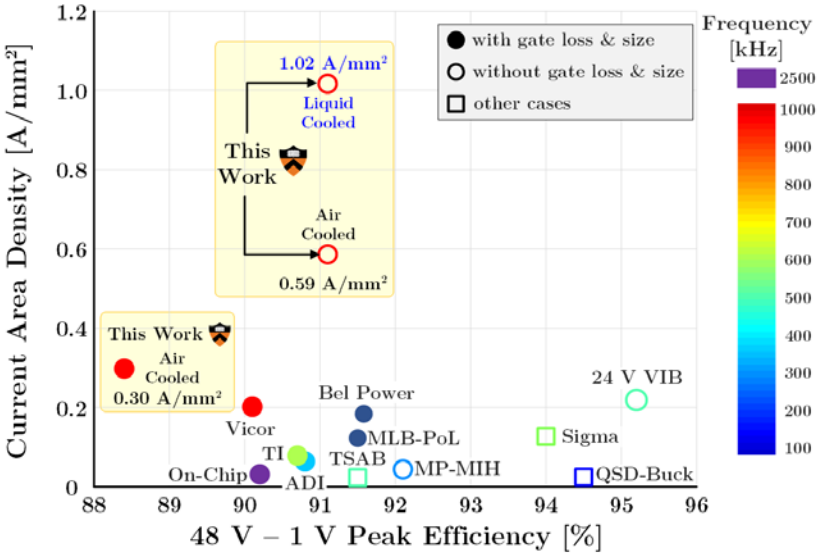
Measured Efficiency: 48V to 0.8V-1.5V



Performance Comparison



- 91.1% peak efficiency and 79.2% full load (780A) efficiency at 48V to 1V (without gate driving loss)
- Very high current area density of 0.59 A/mm^2 with fan cooling and 1.00 A/mm^2 with liquid cooling

* Disclaimer: The compared numbers are obtained from published papers as well as datasheets. Power densities are calculated box density based on the information provided in these documents. Refer to the original papers and datasheets.

Summary & Further Works

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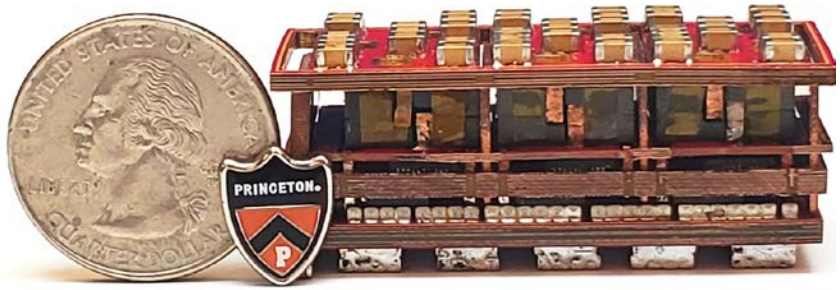
Vertical Power Delivery

Automatic Voltage Balancing Current Sharing

Custom Vertical Coupled Inductor

Merged-two-stage Operation

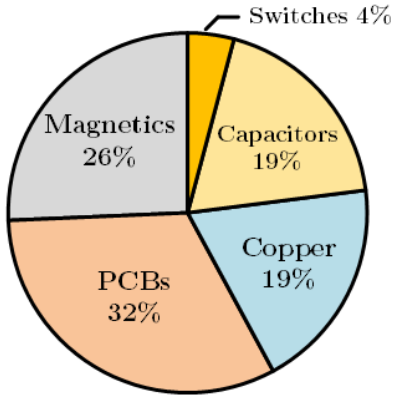
Liquid Cooling



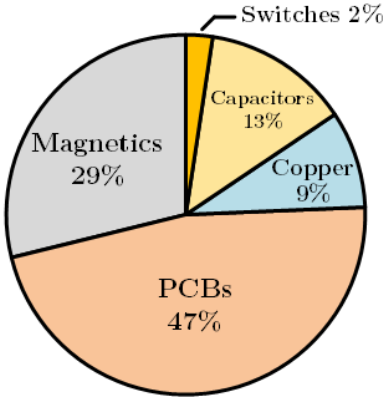
1.0 A/mm² Current density	1000 W/in³ Power density	91.1% peak efficiency

Toward Better Performance

Weight Breakdown



Volume Breakdown



- Reduce energy storage components
- Advanced packaging techniques

References

[Sigma] M. H. Ahmed, C. Fei, F. C. Lee, and Q. Li, “Single-Stage HighEfficiency 48/1 V Sigma Converter With Integrated Magnetics,” *IEEE Trans. on Ind. Electronics*, vol. 67, no. 1, pp. 192-202, January 2020.

[TI] “Using the LMG5200POLEVM-10 48V to Point of Load EVM,” Texas Instruments, 2017 [online]. Available: https://www.ti.com/lit/ug/snvu520b /snvu520b.pdf

[MP-MIH] R. Das, G.-S. Seo, D. Maksimovic, and H.-P. Le, “An 80-W 94.6%- ´ Efficient Multi-Phase Multi-Inductor Hybrid Converter,” *IEEE Applied Power Electronics Conference and Exposition*, Anaheim, CA, USA, 2019.

[QSD-Buck] M. Halamicek, T. McRae, and A. Prodic, “Cross-Coupled Series- ´ Capacitor Quadruple Step-Down Buck Converter,” *IEEE Applied Power Electronics Conference and Exposition*, New Orleans, LA, USA, 2020.

[MLB-PoL] M. Halamicek, T. McRae, and A. Prodic, “Cross-Coupled Series- ´ Capacitor Quadruple Step-Down Buck Converter,” *IEEE Applied Power Electronics Conference and Exposition*, New Orleans, LA, USA, 2020 **.**

[Bel Power] “Main & Satellite Power Stamp 48V-to-PoL Isolated DC-DC Converters,” Bel, 2020 [online]. Available: https://www.belfuse.com/resources/datasheets/powersolutions/ds-bps-48-v-to-pol-power-stamp.pdf

[TSAB] J. Zhu and D. Maksimovic, “48 V-to-1 V Transformerless Stacked Active ´ Bridge Converters with Merged Regulation Stage,” *IEEE Workshop on Control and Modeling for Power Electronics (COMPEL)*, Aalborg, Denmark, 2020.

[Vicor][PRM] “PRM Regulator PRM48BH480T250A00,” Vicor, 2020 [online]. Available: http://www.vicorpower.com/documents/datasheets/PRM48BH480T 250A00 ds.pdf

[Vicor][VRM] “VTM Current Multiplier VTM48MP010x107AA1,” Vicor, 2017 [online]. Available: http://www.vicorpower.com/documents/datasheets/VTM 48M 010 107AA1.pdf

[On-Chip] X. Yang et al., “An 8A 998A/inch 3 90.2% Peak Efficiency 48V-to-1V DC-DC Converter Adopting On-Chip Switch and GaN Hybrid Power Converter,” *IEEE International Solid-State Circuits Conference (ISSCC)* , San Francisco, CA, USA, 2021.

[ADI] “LTM4664 54VIN Dual 25A, Single 50A µModule Regulator with Digital Power System Management,” Analog Devices, 2021 [online], Available: https://www.analog.com/media/en/technicaldocumentation/data-sheets/ltm4664.pdf.

[24 V VIB] Y. Chen, H. Cheng, G. Szczeszynski, S. Allen, D. M. Giuliano, and M. Chen, “Virtual Intermediate Bus CPU Voltage Regulator,” *IEEE Trans. on Power Electronics*, Under Review.

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