OCP FUTURE TECHNOLOGIES SYMPOSIUM

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Hybrid and Resonant Switched-Capacitor Converters:

Achieving Ultra-Efficient and Compact 48 V Datacenter Power Delivery

Ting Ge, Rose Abramson, Zichao Ye, Robert Pilawa-Podgurski
EECS
UC Berkeley

Agenda

Background and Motivation

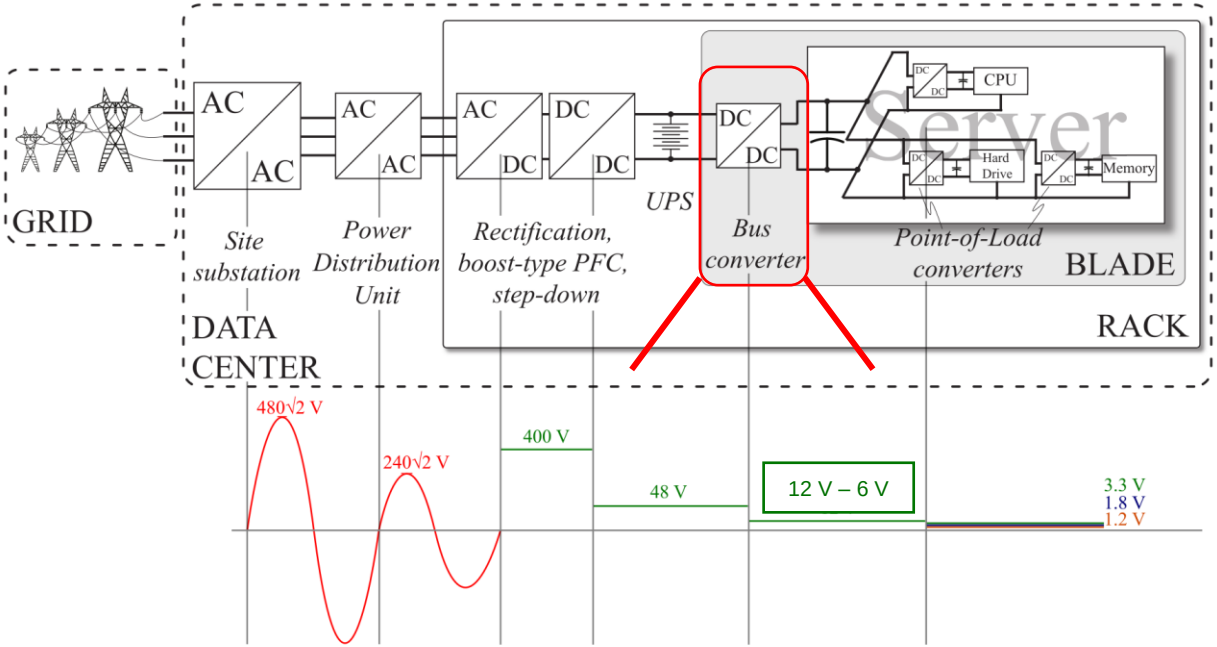
48-to-12 V Cascaded Multi-Resonant Converter

48-to-6 V Cascaded Series-Parallel Converter

Conclusion

Data Center Power Delivery System

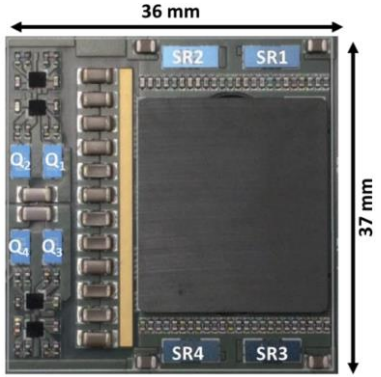
- Focus of this work: Intermediate Bus Converter

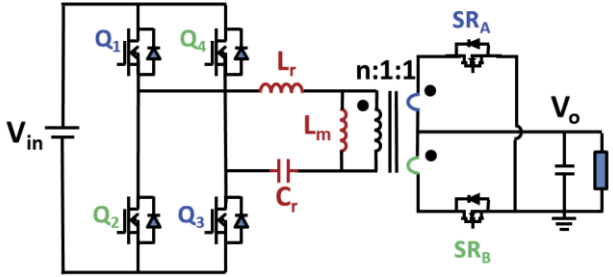


E. Candan, "Improving Data Center Power Delivery Efficiency with Differential Power Processing and Multi-level Power Converters", PhD dissertation, University of Illinois, 2018.

Transformer-based Solutions

- High current capability and high power density





LLC from CPES: 75 A, 98.4% peak eff. and 1600 W/in^3 [1]

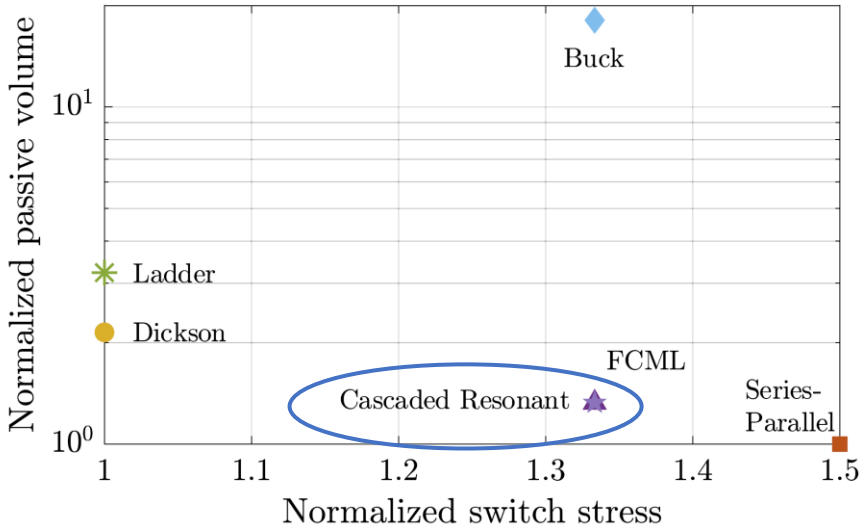
Highly integrated Vicor design: 60 A, 98.0% peak eff. and 4022 W/in^3 [2]

[1] M. H. Ahmed, F. C. Lee, Q. Li, M. de Rooij, and D. Reusch, "Gan based high-density unregulated 48 v to x v llc converters with 98% efficiency for future data centers," in *PCIM Europe 2019*, pp. 1–8.

[2] Vicor Inc., *NBM Non-isolated Bus Converter Module Data Sheet*, 2020.

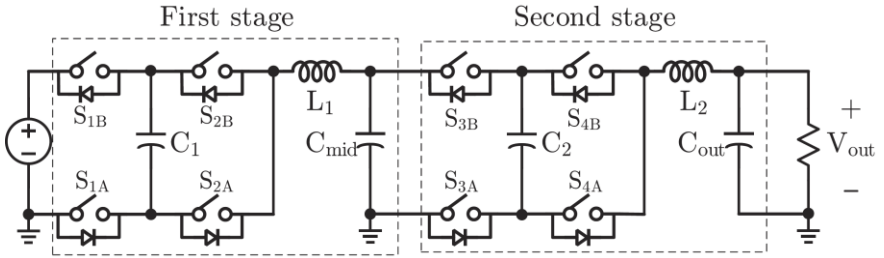
Hybrid Switched-Capacitor Solutions

- Significantly reduced magnetic size



4:1 Hybrid SC topology comparison

Cascaded resonant converter with good balance of active & passive component utilizations

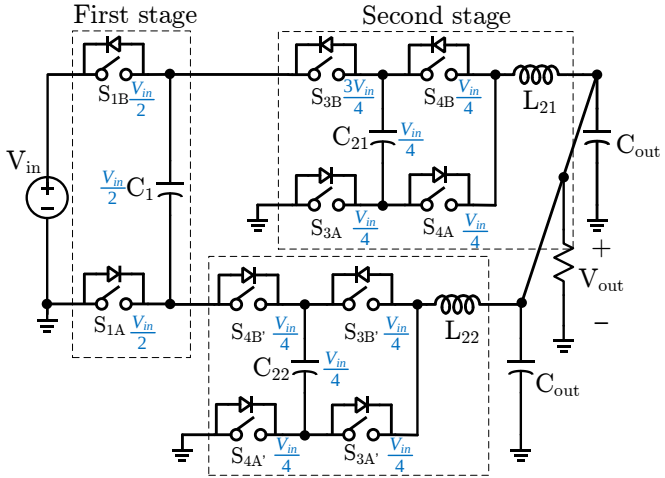


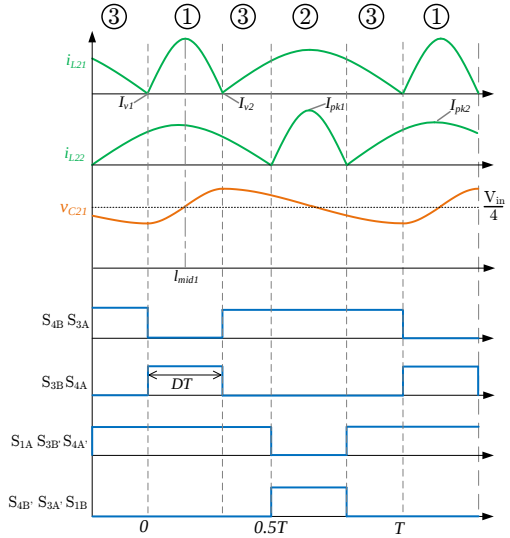
99.0% peak eff. and 2500 W/in^3

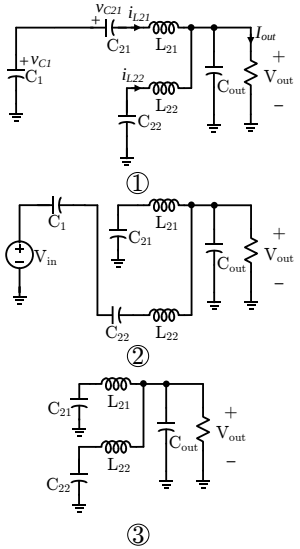
Z. Ye, Y. Lei, and R. C. N. Pilawa-Podgurski, "The cascaded resonant converter: A hybrid switched-capacitor topology with high power density and efficiency," *IEEE Transactions on Power Electronics*, vol. 35, no. 5, pp. 4946–4958, 2020.

Cascaded Multi-Resonant Converter

- 2nd stage uses two phases for higher power and small C_{mid}
- 1st stage uses only two switches to realize 2:1 step down ratio and shares resonant inductors with the 2nd stage



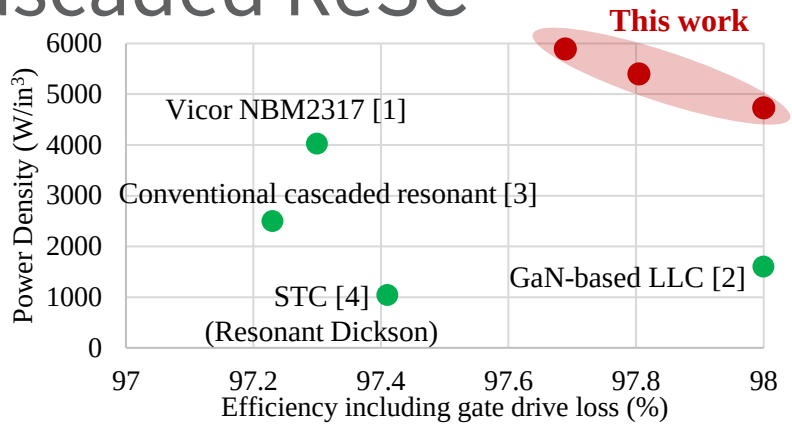


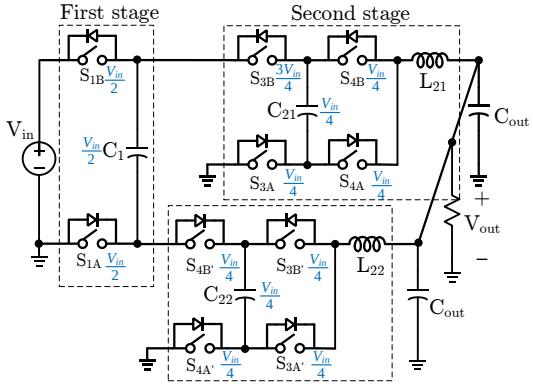


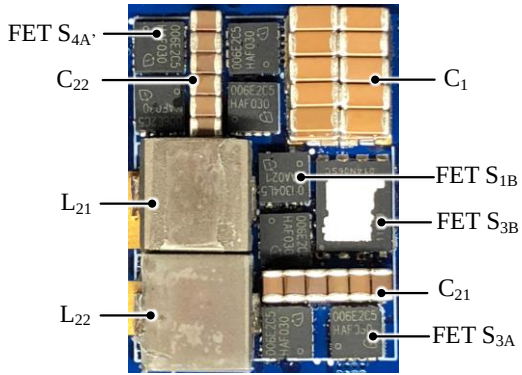
T. Ge, et. al., "A 48-to-12 V Cascaded Multi-Resonant Switched-Capacitor Converter Achieving 4700 W/in³ Power Density and 98.9% Peak Efficiency," 2021 ECCE.

Performance of 48-to-12 V Cascaded ReSC

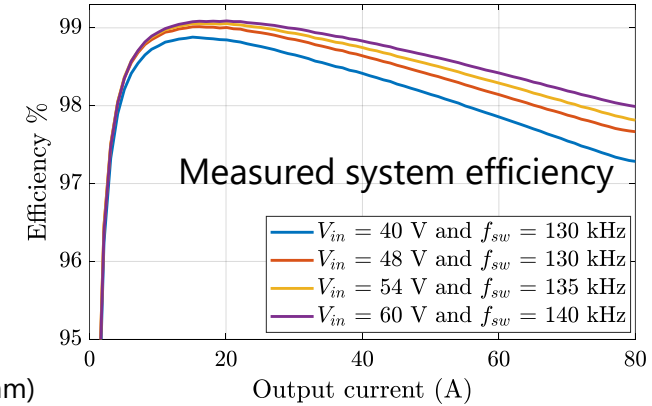
- Customized one-turn powder-iron inductors
- 4-to-1 fixed ratio (unregulated)
- Maximum I_{out} = 80 A
- 6000 W/in^3 power density
- 99.0% peak and 97.7% full-load system efficiency







Dimensions: 0.681 × 0.905 × 0.26 in (17.3 × 23 × 6.6 mm)



[1] Vicor Inc., *NBM Non-isolated Bus Converter Module Data Sheet*, 2020.
[2] M. H. Ahmed, et. al., "Gan based high-density unregulated 48 v to x v llc converters with 98% efficiency for future data centers," in *PCIM Europe 2019*, pp. 1–8.
[3] Z. Ye, et. al., "The cascaded resonant converter: A hybrid switched-capacitor topology with high power density and efficiency," IEEE Transactions on Power Electronics, 2020.
[4] S. Jiang, C. Nan, X. Li, C. Chung, and M. Yazdani, "Switched tank converters," in 2018 IEEE APEC.

Lower Intermediate Bus Voltage

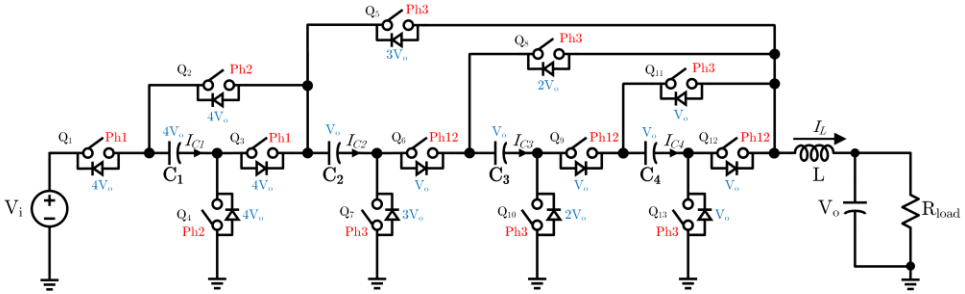
- Lower intermediate bus voltage for better overall efficiency
- In need of high performance bus converters with higher conversion ratio

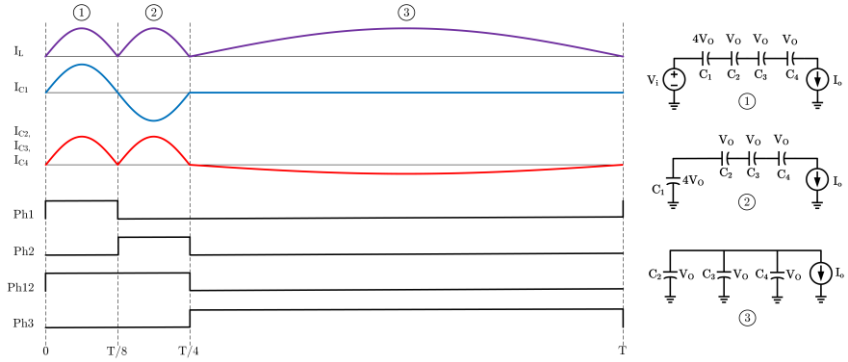
Vin (V)	Eff (%)	Manufacturer	Part Number	Frequency
5	94.0	TI	TPS543C20	500 kHz
5	93.5	TI	TPS543C20	500 kHz
8	91.2	Murata	MYMGK00504ERSR	250 kHz
10	89.2	TI	PMP20023 TPS544C25	386 kHz
12	88.5	TI	PMP20023 TPS544C25	386 kHz
12	89.0	CUI	NDM2Z-25	320 kHz
12	89.2	Murata	MYMGK00504ERSR	250 kHz
12	89.9	EPC	EPC9059	1000 kHz

A. Lidow, “Powering graphics processors from a 48-V bus,” 2019.

Multi-Resonant Cascaded Series-Parallel (CaSP) Converter

- 2-to-1 series-mode cascaded with 4-to-1 parallel-mode step-down
- Multiple operating phases → reduced component count
- Operated above resonance for soft charging and reduced conduction loss

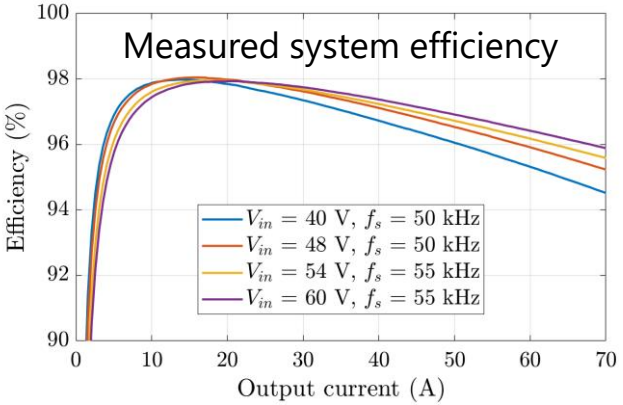


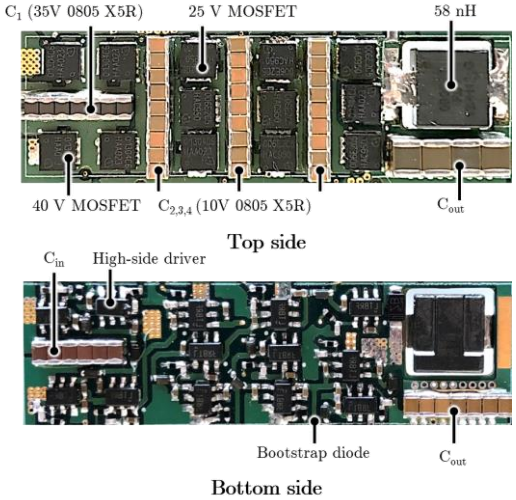


R. Abramson, et. al., "A High Performance 48-to-6 V Multi-Resonant Cascaded Series-Parallel (CaSP) Switched-Capacitor Converter," 2021 APEC.

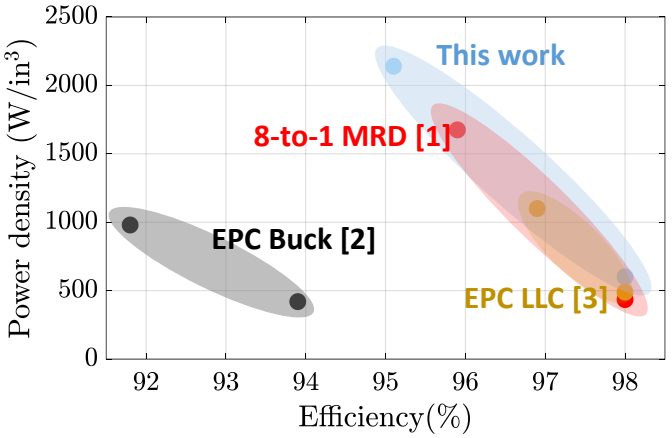
Performance of 48-to-6 V CaSP Converter

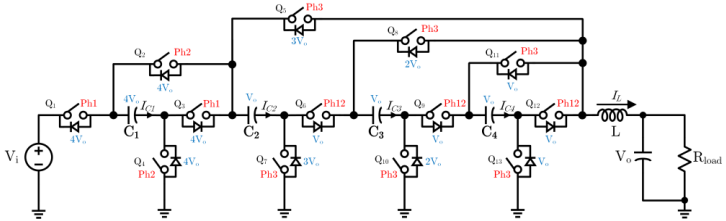
- 8-to-1 fixed ratio (unregulated)
- 2140 W/in^3 power density
- 98.1% peak and 95.3% full-load system efficiency
- Maximum I_{out} = 70 A





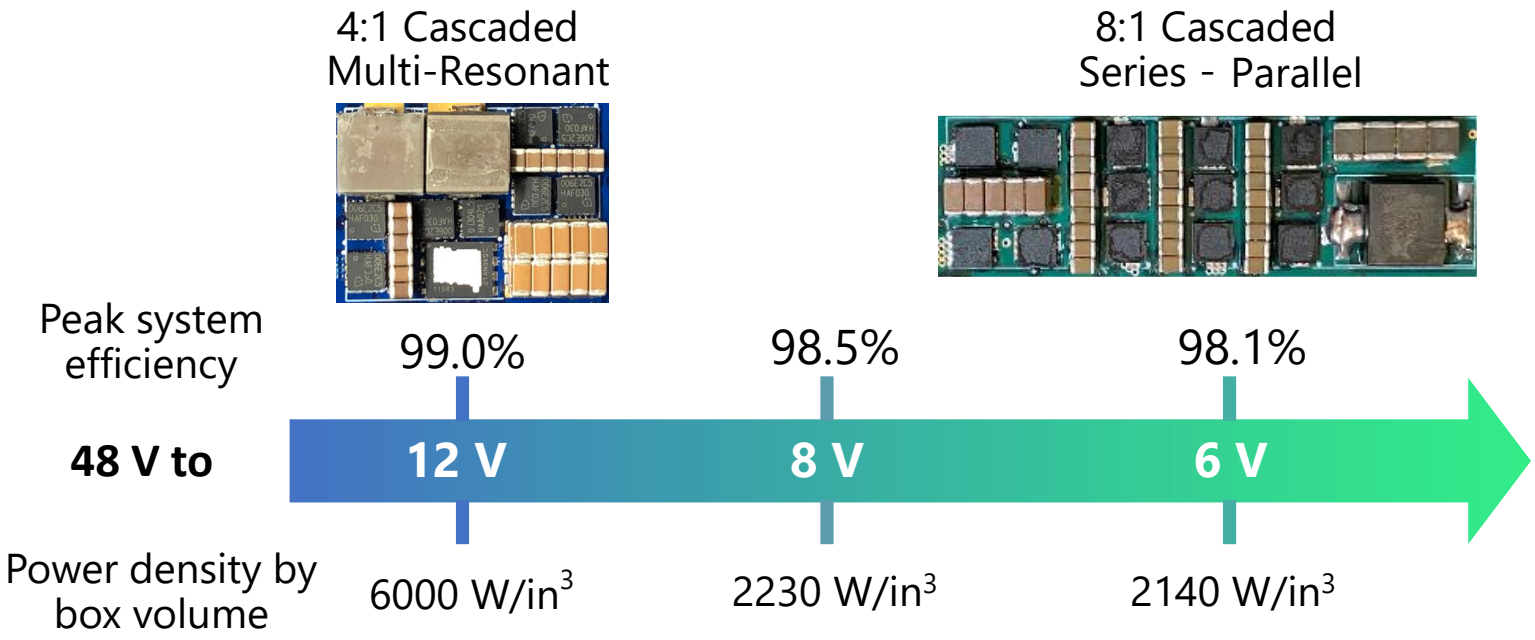
Dimensions: 1.76 x 0.51 x 0.21 inch
(4.47 x 1.30 x 0.53 cm)





[1] Z. Ye, et. al., "A 48-to-6 v multi-resonant-doubler switched-capacitor converter for data center applications," in 2020 IEEE APEC.
[2] E. Inc., "Building the Smallest and Most Efficient 48 V to 5 - 12 V DC to DC Converter using EPC2045 and ICs," 2018.
[3] EPC Inc., How to Exceed 98% Efficiency in a Compact 48 V to 6 V, 900 W LLC Resonant Converter Using eGaN FETs, 2018.

Conclusion


4:1 Cascaded
Multi-Resonant
8:1 Cascaded
Series - Parallel
Peak system efficiency
99.0%
98.5%
98.1%
48 V to
12 V
8 V
6 V
Power density by box volume
6000 W/in3
2230 W/in3
2140 W/in3

Acknowledgment

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