A Resonant Switched-Capacitor based 48-to-12 V Bus Converter Achieving 2500 W/in^3 Power Density and 99.0% Peak Efficiency

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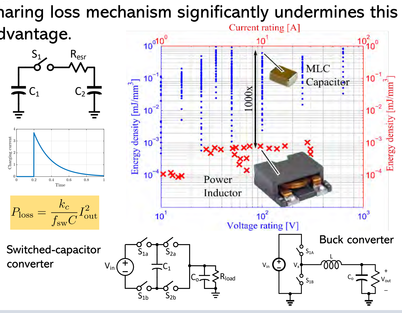
Introduction

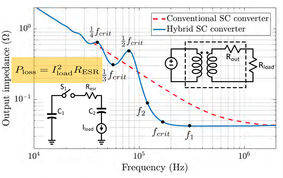
This work presents a new type of hybrid switched-capacitor based power converter, named cascaded resonant converter, which can have significantly higher efficiency than the state-of-the-arts. This disruptive technology has the potential to greatly reduce the energy loss in the power delivery system of data centers.

Why Hybrid Switched-Capacitor Converter

Capacitors have a energy density that is up to 100x higher than inductors. However, the inherent charge sharing loss mechanism significantly undermines this advantage.



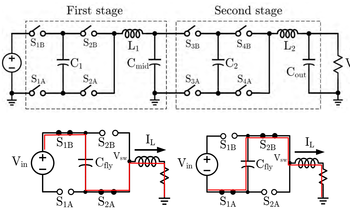
$$P_{loss} = \frac{k_c}{f_{sw} C} I_{out}^2$$

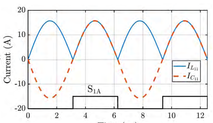


$$P_{loss} = I_{load}^2 R_{ESR} \frac{1}{2} f_{crit}$$

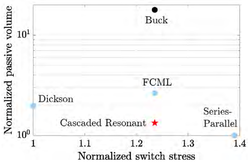
Hybrid switched-capacitor converters use both capacitors and inductors in the power transfer process. The inductor behaves like a current source and can help recover the charge sharing loss, through an operation called *soft charging*.

Cascaded Resonant Converter

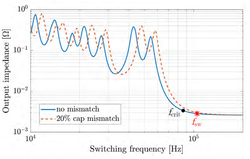




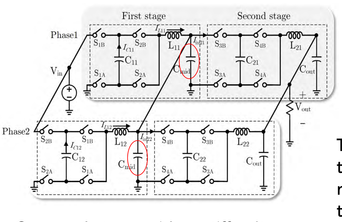
Cascading basic 2-to-1 ReSC converters to achieve higher conversion ratio.



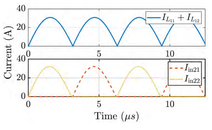
Good balance of active and passive components.



Good component tolerance, repeatability and reliability.

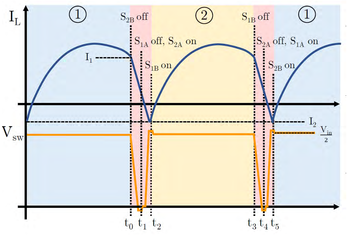


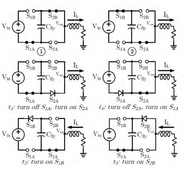
C_{mid} needs to provide a stiff voltage.



The combined input current of the second stage closely matches the inductor current of the first stage. This way C_{mid} can be reduced dramatically.

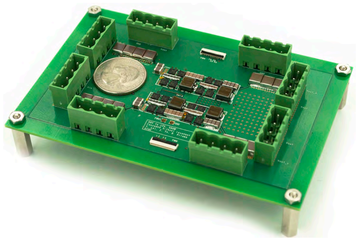
Two-phase interleaved design



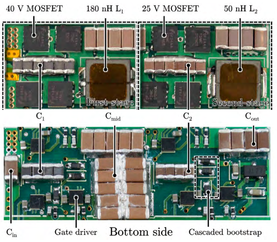


Help improve light-load efficiency by up to 50%.

Hardware Implementation



	Nominal	Range
Input voltage	48 V	36 – 60 V
Output voltage	12 V	9 – 15 V
Output current	60 A	60 A
Power level	720 W	540 – 900 W
Switching frequency	100 kHz	91 – 111 kHz

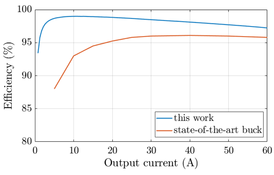


Dimensions (one phase):
1.38 x 0.46 x 0.22 inch
(3.5 x 1.17 x 0.56 cm).
Note: limited C_{in} and C_{out} are included

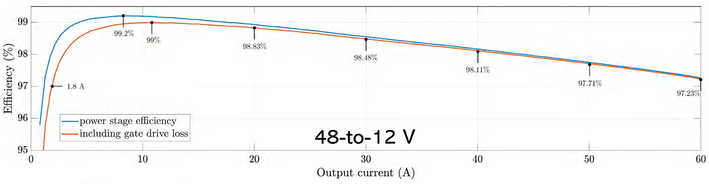
Component	Parameters
1st stage MOSFET	40 V, 2.5 mΩ
1st stage flying cap (C_1)	35 V, 22 μF x 12 0805 X5R
1st stage inductor (L_1)	180 nH, XAL6030-181
1st stage output cap (C_{mid})	50 V, 10 μF x 20 0805 X5R
2nd stage MOSFET	25 V, 1.3 mΩ
2nd stage flying cap (C_2)	16 V, 10 μF x 16 0805 X5R
2nd stage inductor (L_2)	50 nH, SLC7530S
Gate driver	LM5113
Bootstrap diode	40 V Schottky

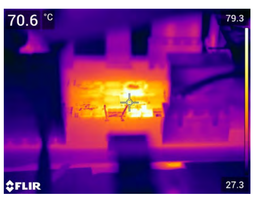
Note: the capacitance is the nominal value before dc derating

Experimental Results

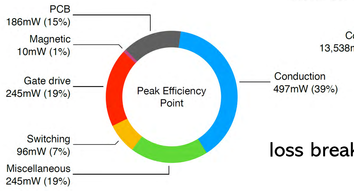


Comparison with buck converter

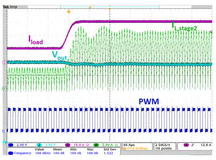




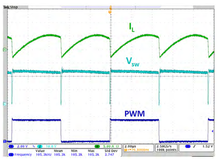
Full load with fan cooling only



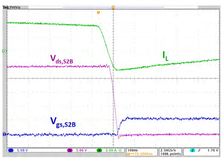
loss breakdown



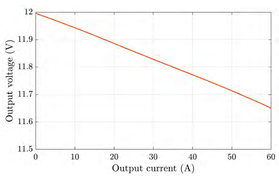
10 A to 30 A load step



resonant operation



zero voltage switching



Open-loop load regulation

Reference	Topology	Output current (A)	Power Density (W/inch^3)	Efficiency	Notes
this work	cascaded resonant	60	2500	full load: 97.23%, peak: 99.0%	calculated based on 48:12V conversion, gating loss included
Linear Technology LTC7820 application design	cascaded pure 2:1 switched-capacitor	40	up to 1500	full load: ≤97.0% peak: ≤98.6%	highly integrated 48:12 V design detailed data unavailable (use conservative estimate)
EPC9130	5-phase interleaved buck	60	> 1000	full load: 95.8%, peak: 96.2%	48:12V, GaN switches, **regulated**
Google Switched Tank	modified Dickson	50	500 (power stage only: switches and passives)	full load: 97.41%, peak: 98.61%	54 V input, 4:1 fixed ratio, components are not densely populated