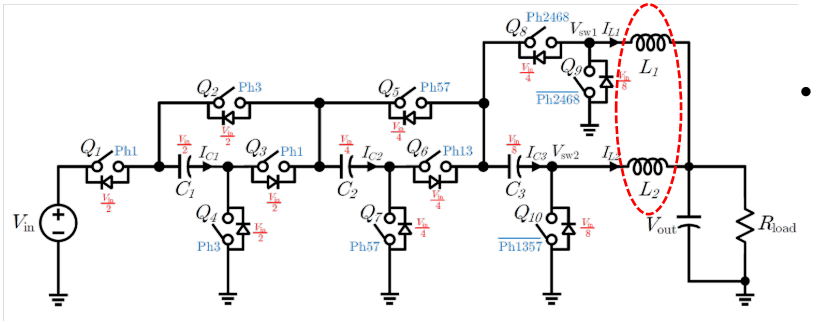
# Core Size Scaling Law of Two-Phase Coupled Inductors – Demonstration in a 48-to-1.8 V MLB (Multi-Level-Binary)-PoL Converter

Berkeley Power and Energy Center

## Motivation and Applications

Multi-Level Binary (MLB) hybrid switched-capacitor converter for 48 V to PoL conversion

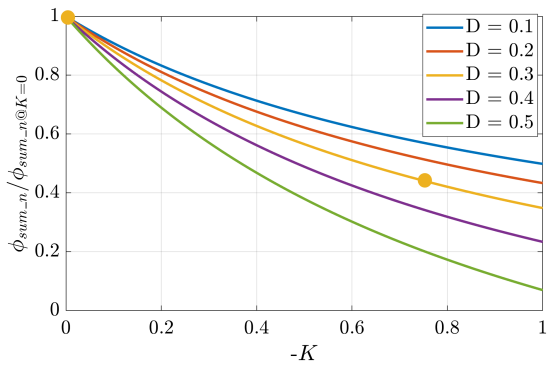



Zichao Ye, 2020 COMPEL

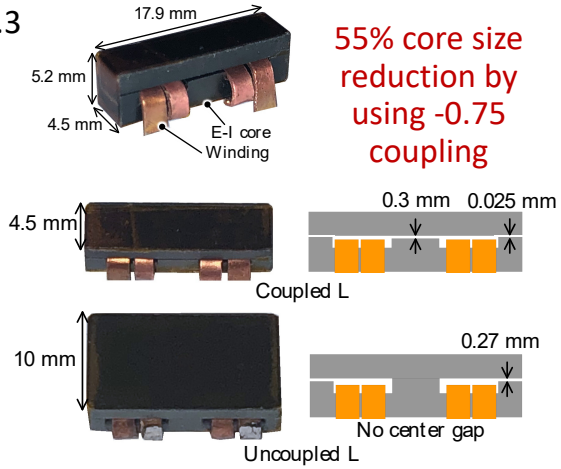
- In Point-of-Load (PoL) applications, inductors usually occupy >50% total volume
- **A general core-size model** is desired to evaluate the duty-ratio advantage of hybrid converters and guide magnetic design

## Hardware Implementation

Modeled $\Phi_{sum\_n}/\Phi_{sum\_n@K=0}$ versus −K at α = 0.3



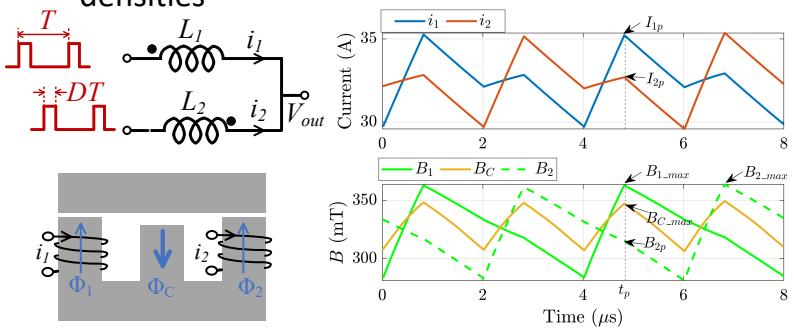

K: coupling coefficient




55% core size reduction by using -0.75 coupling

## Proposed Method and Result

- 2-phase coupled inductors: schematic, core structure, current waveforms, and flux densities




- Total flux is proportional to core size and calculated by:

$$\begin{bmatrix}\Phi_{1\_max}\\ \Phi_{2p}\end{bmatrix}=\begin{bmatrix}L_s & KL_s\\ KL_s & L_s\end{bmatrix}\begin{bmatrix}I_{1p}\\ I_{2p}\end{bmatrix}/N$$

$$\Phi_{sum\_N}=\frac{\Phi_{sum}f_{sw}N}{V_{out}}=\frac{4}{\alpha(1-K)}-\left(\frac{4}{\alpha}+2\right)D+\frac{3}{2}$$

α: ripple factor, defined by the peak-to-peak inductor current over the maximum dc current

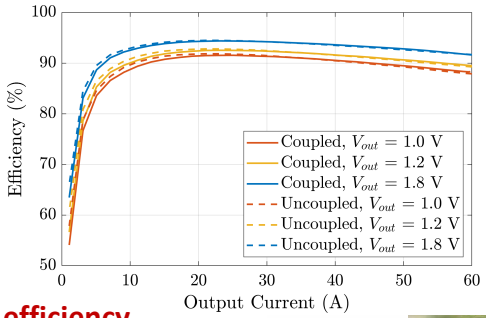
## Experimental Results

| Converter specifications | |
|---|---|
| $V_{in}$ | 48 V |
| Max. $V_{out}$ | 1.8 V |
| Max. D | 0.3 |
| Max. $I_{out}$ | 65 A |
| $f_{sw}$ | 250 kHz |
| $\alpha$ | 0.3 |
| **Design 1: coupled inductors** | |
| $K$ | -0.75 |
| $L_s$ | 800 nH |
| **Design 2: uncoupled inductors** | |
| $L$ | 517 nH |

Converter performance summary

| | Efficiency at 48 V input and 1.8 V output | Power density & Dimensions |
|---|---|---|
| **Coupled L (This work)** | **Peak: 94.4% Full load: 91.5%** | **474 W/in³ 26×18.4×7.8 mm** |
| Uncoupled L (This work) | Peak: 94.5% Full load: 91.6% | 391 W/in³ 31.5×18.4×7.8 mm |
| [1] using commercial discrete L | Peak: 94.0% Full load: 91.3% | 329 W/in³ 29×18.4×10.1 mm |

Measured efficiency including gate drive loss




The converter with coupled L achieves **0.4% higher peak efficiency** and **44% higher power density** compared to the discrete counterpart.

**Reference:** T. Ge, R. Abramson, Z. Ye, and R. C. N. Pilawa-Podgurski, "Core Size Scaling Law of Two-Phase Coupled Inductors – Demonstration in a 48-to-1.8 V Hybrid Switched-Capacitor MLB-PoL Converter," 2022 APEC.

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