



3-D PEIM 2023  
February 1-3, 2023

# **PCB Based Magnetics Integration - Benefits and Limitations**

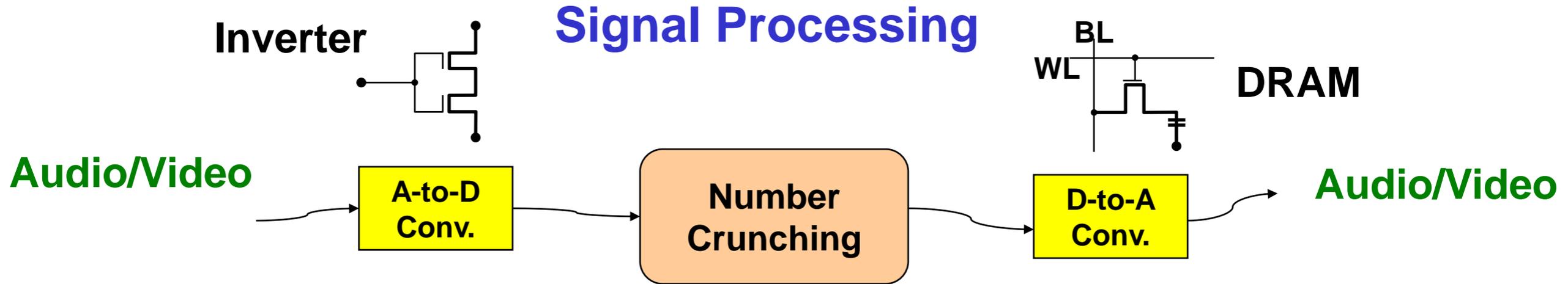
by

Fred C Lee

Center for Power Electronics Systems

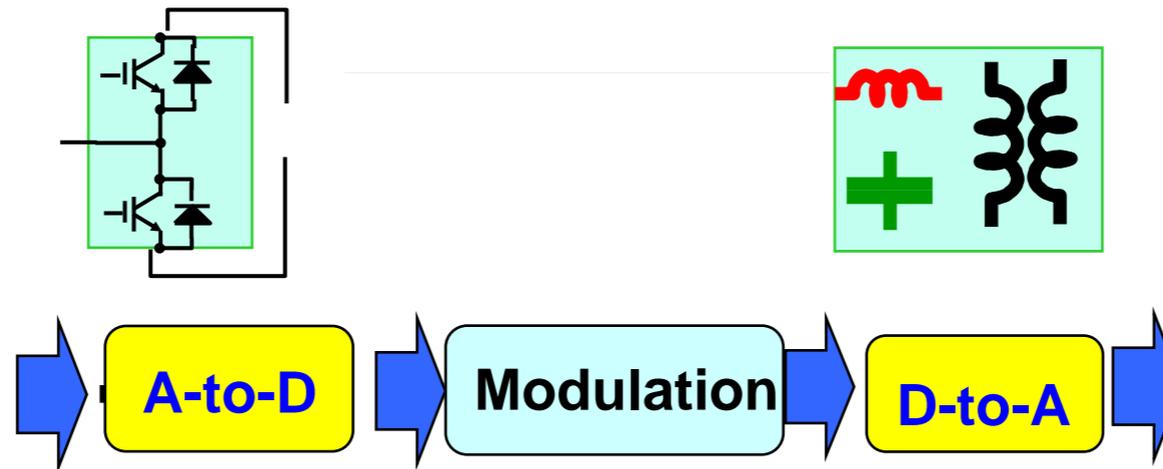
Virginia Tech

# Microelectronics vs Power Electronic



**PV**

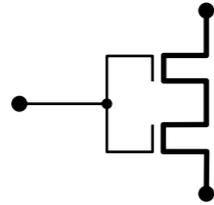
## Power Processing



**60 Hz**

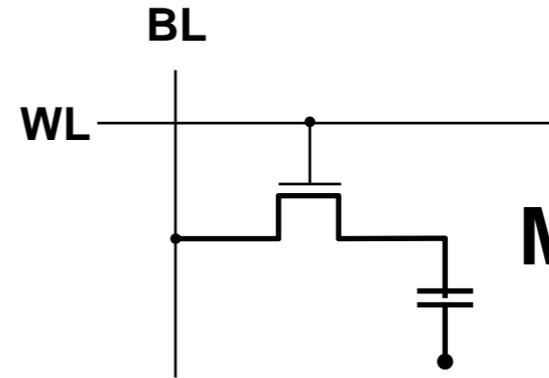
# Micro Electronics & Power Electronics

CMOS  
Inverter



Micro Electronics

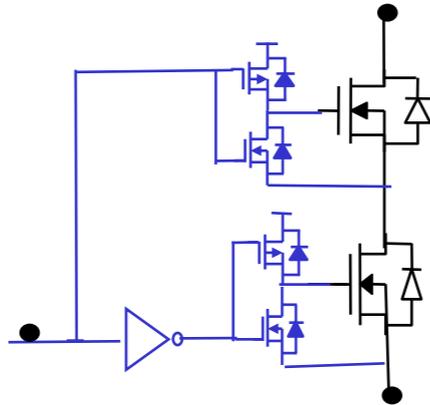
*Building Blocks*  
(1v, mA)  
> GHz



DRAM  
Memory Cell

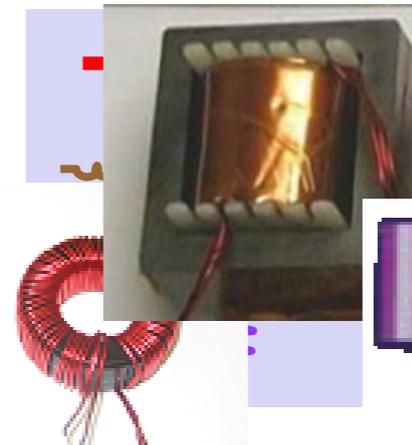
**Monolithic Integration: Moore's Law prevails in 5 decades**

Power Cell  
Inverter



Power Electronics

*Building Blocks*  
(10V - 10,000KV)  
(1A - 10,000A)  
< Mhz



Energy Storage  
Memory Cells

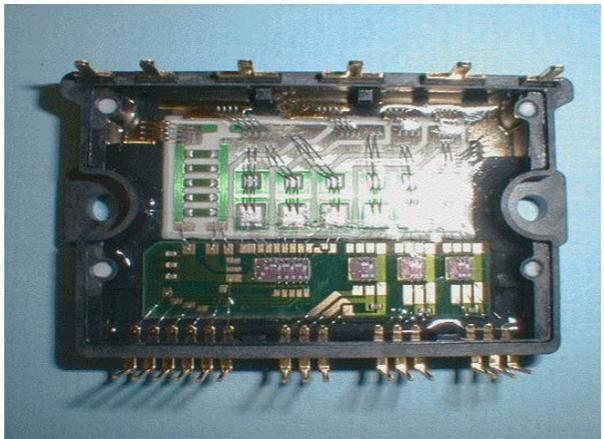
**Barrier: Integration of microelectronics, power devices and passives**

**Heterogeneous Integration** ???

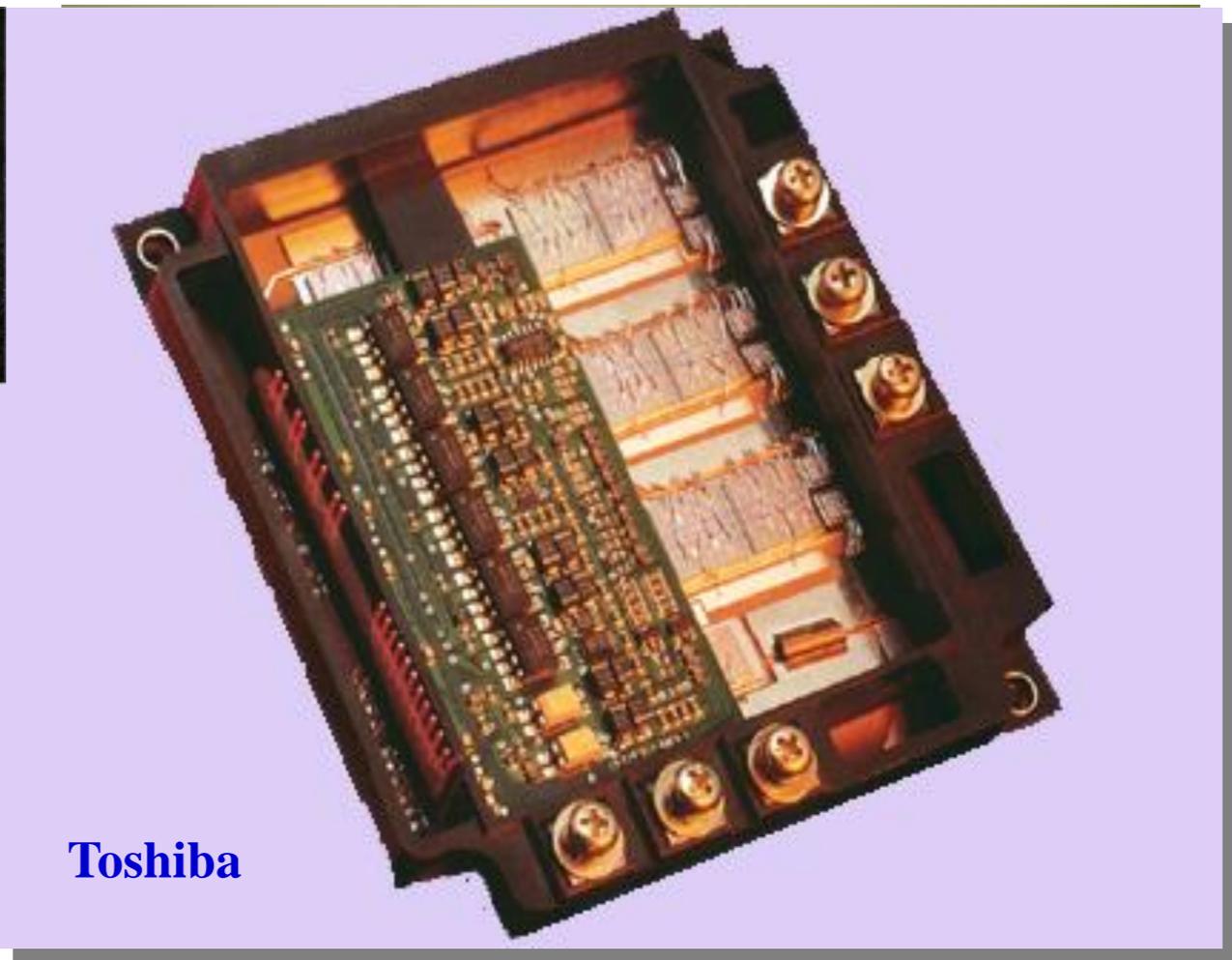
## “*Intelligent Power Module (IPM)*”



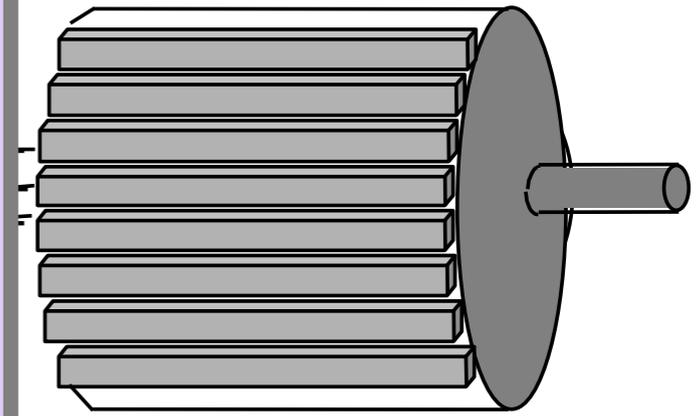
**Semikron**



**Fuji**



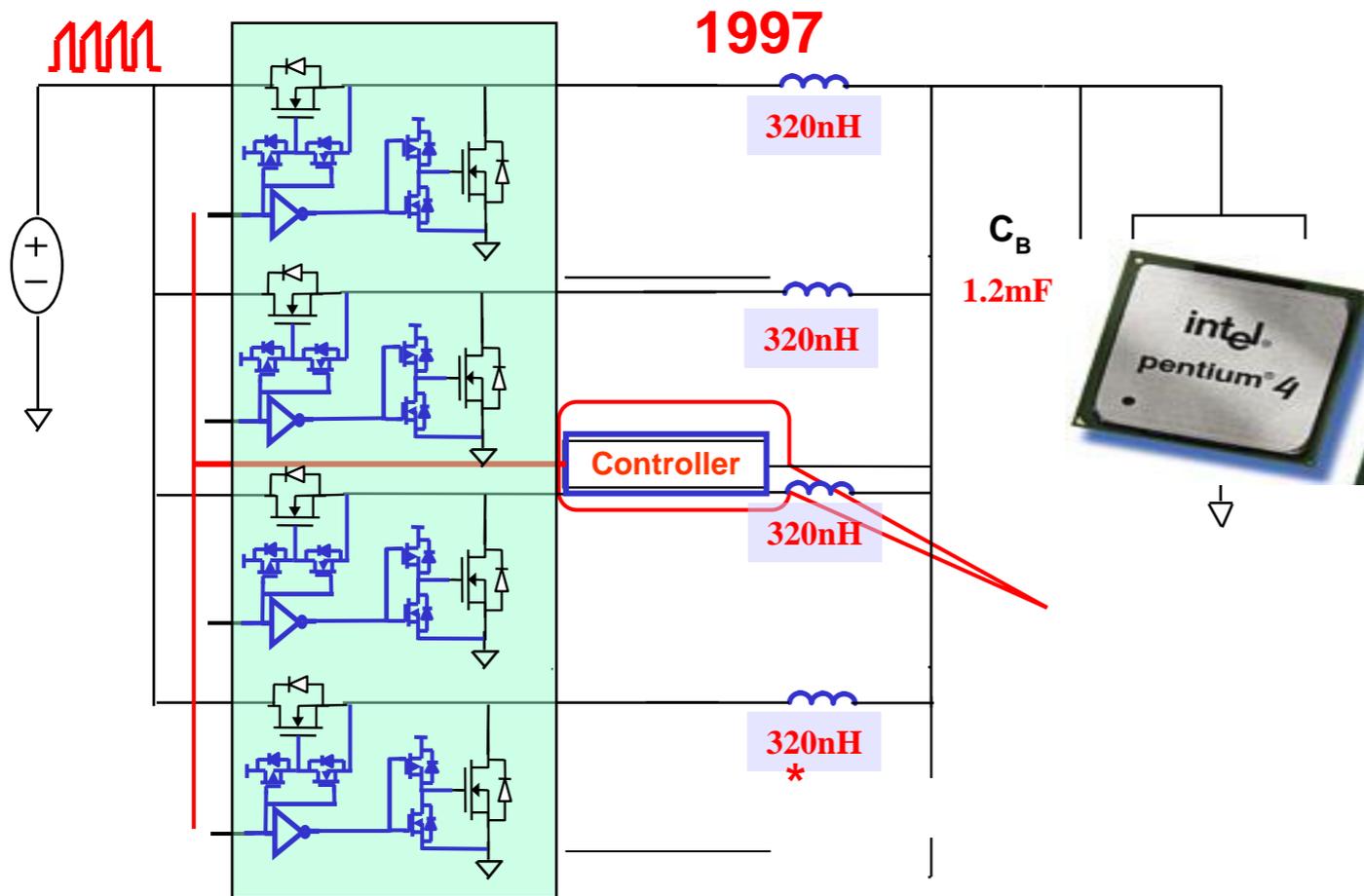
**Toshiba**



**Today, more than 60% of standard drives using IPM**



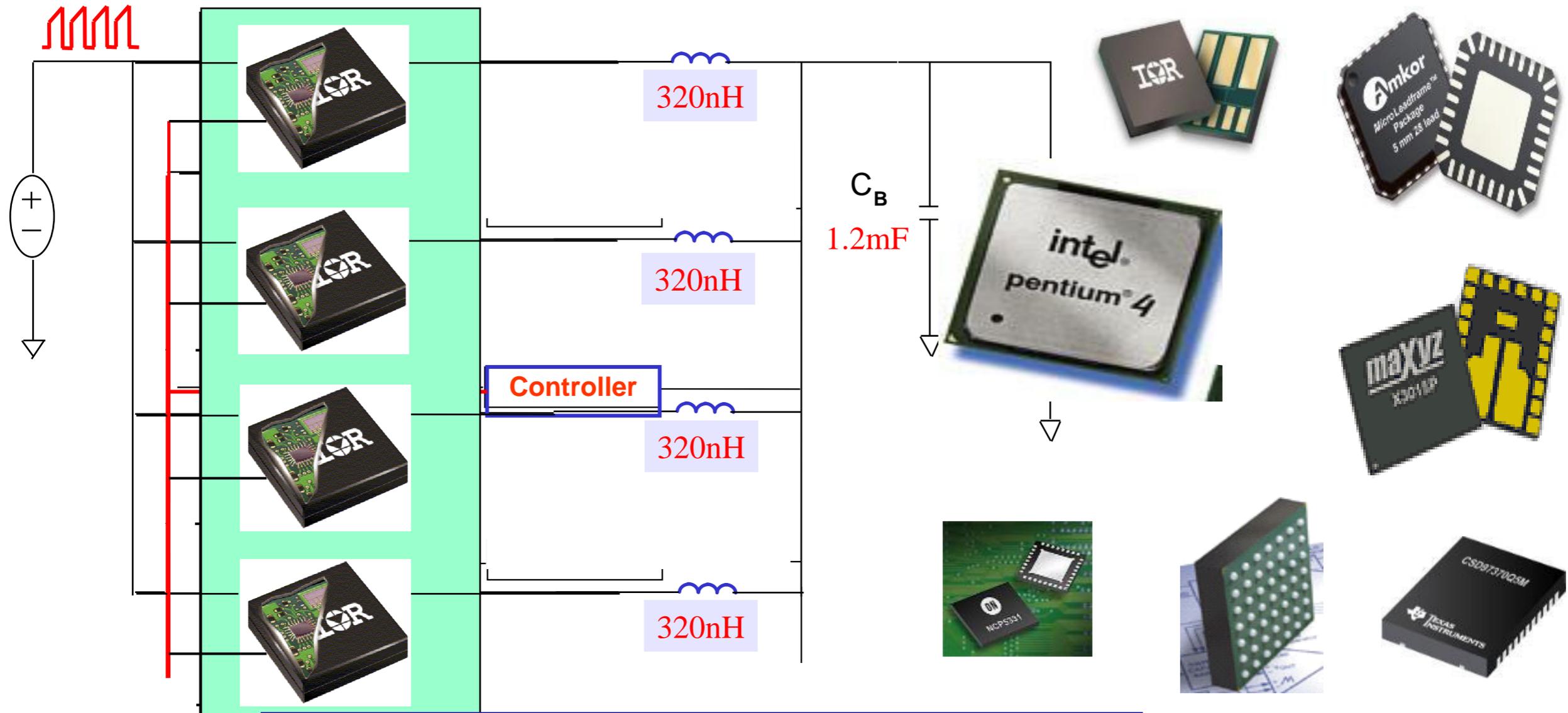
# Integration of Multi-Phase Controllers



**Integrated Controller: cost effective**

**FAIRCHILD SEMICONDUCTOR®**

# Integration of Voltage Regulation Modules



**Power Modules: performance enhancement**

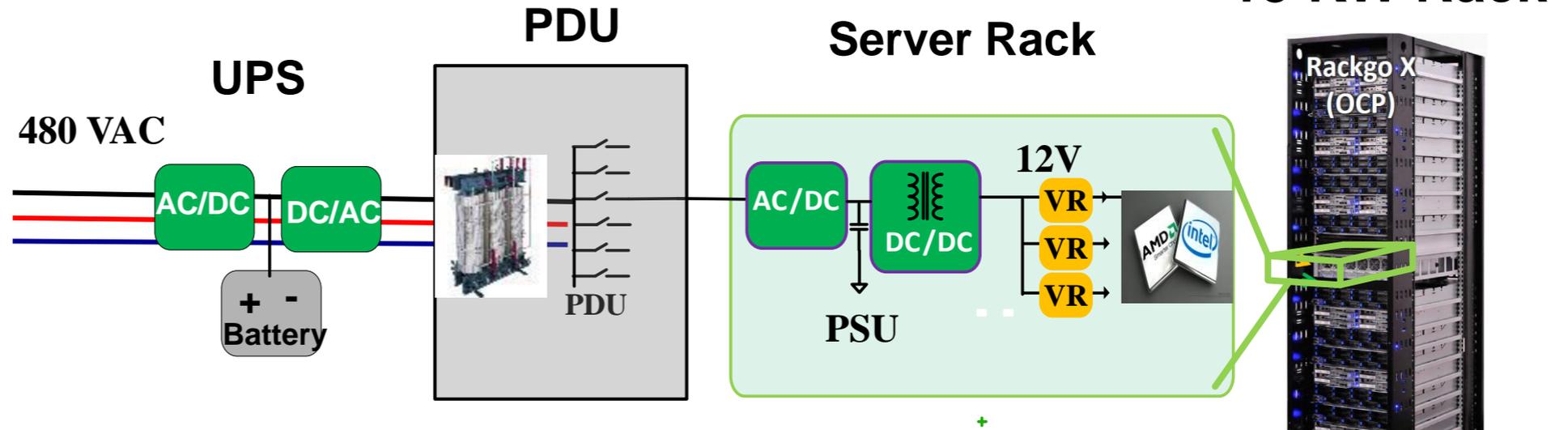
# Gen.1 Data Center Power Architecture



Medium voltage  
13.8KV



Transformer  
Cable  
**98%**



UPS  
**95%**

PDU  
**98%**

PSU  
**96%**

VRs  
**92%**

**≈ 80%**

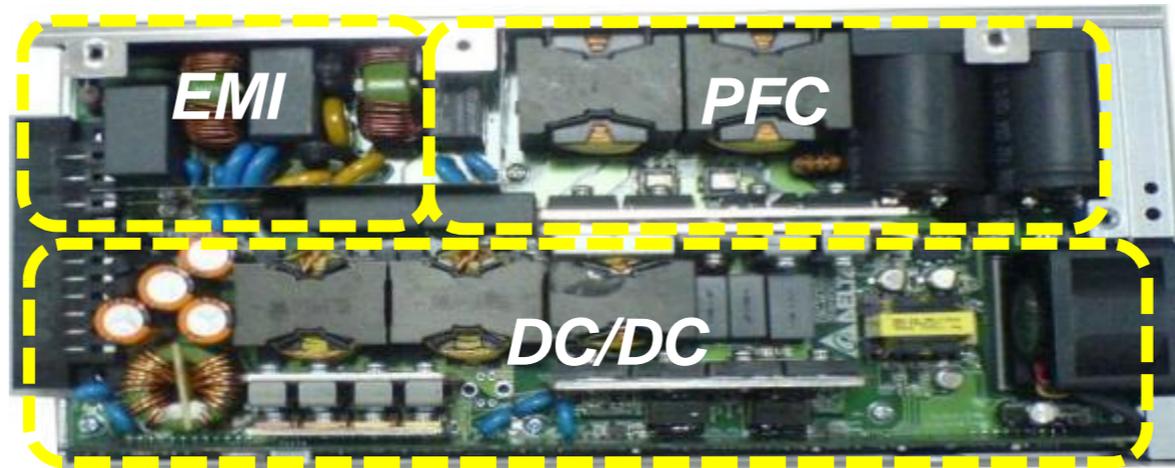
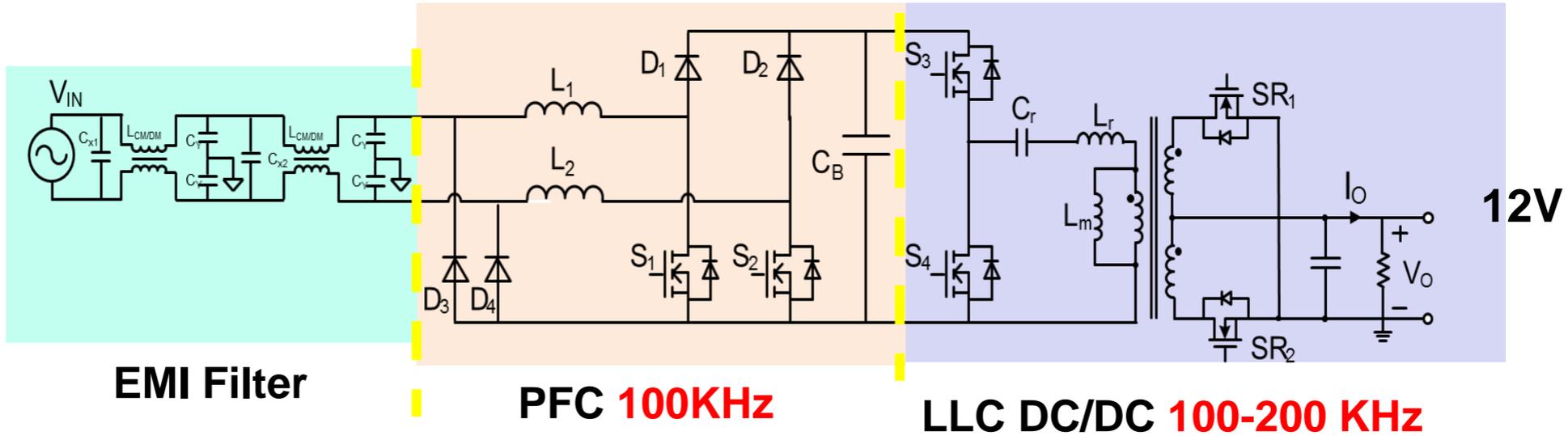
**Data centers consume 7% of electricity (1400TWH worldwide)**

**1% efficiency improvement = 14TWH**

**≈ 2 Nuclear Power Plants each @ 1GW Capacity**

# SOA Data Center Server Power Supply

208VAC

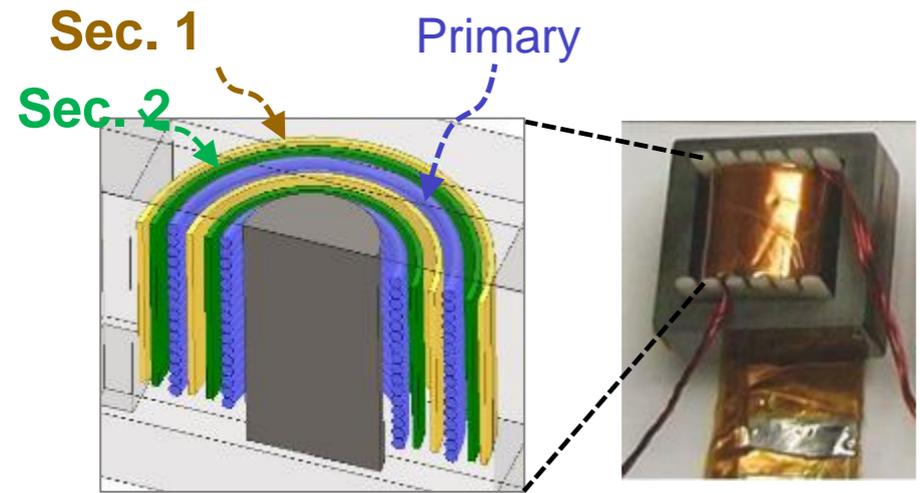
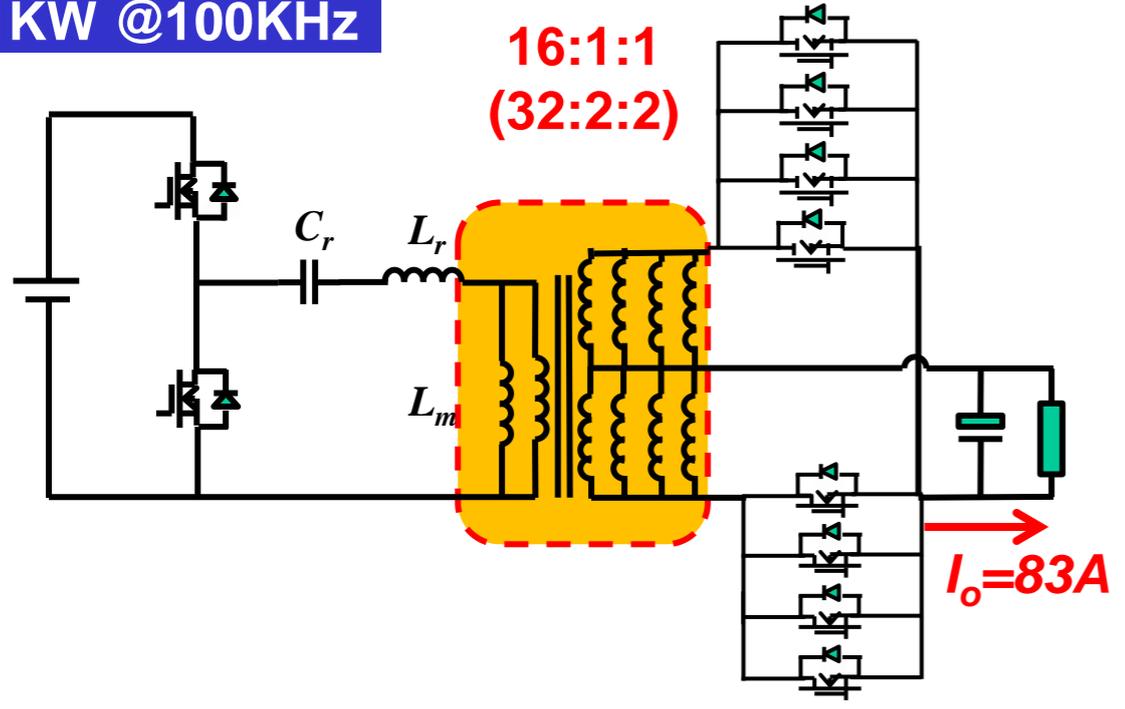


96% and 30 W/in<sup>3</sup>

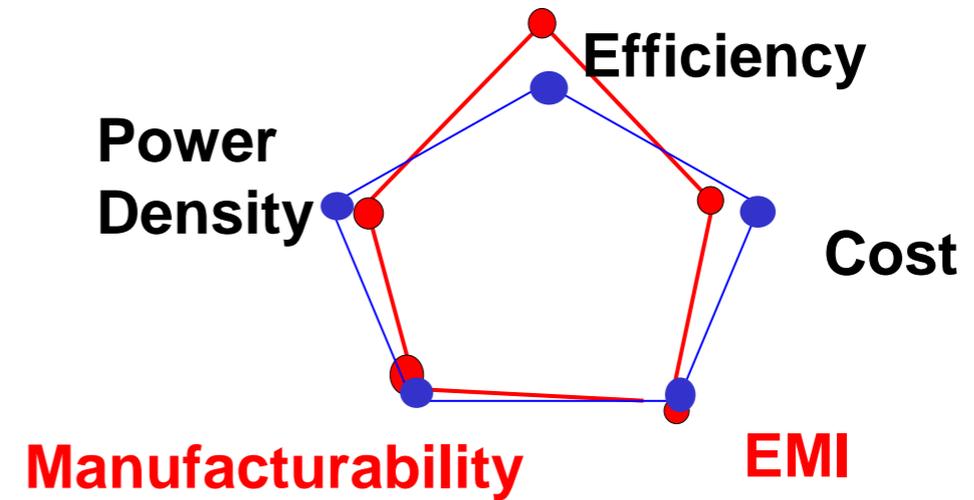
Large variation of Topologies & deemed as competitive advantage

# Manufacturing Challenge @ *Component level*

1KW @100KHz

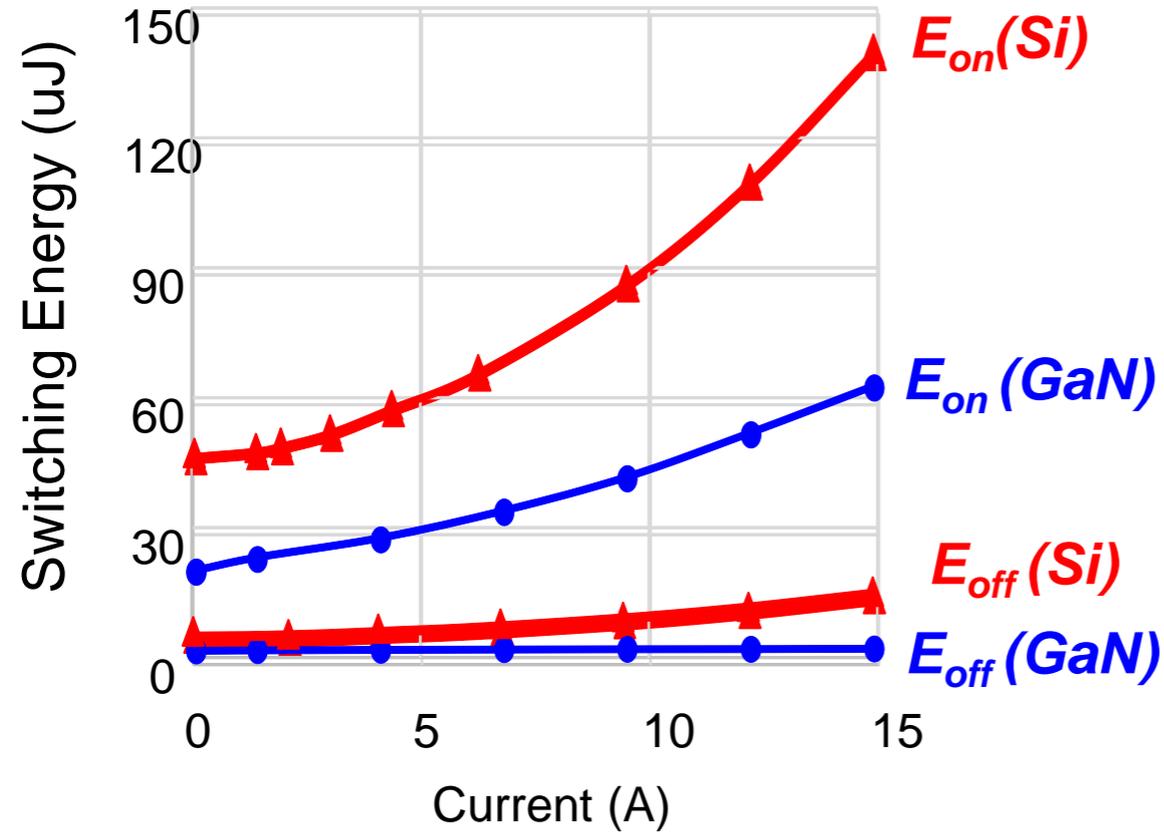


# Manufacturing Challenge @ *System level*



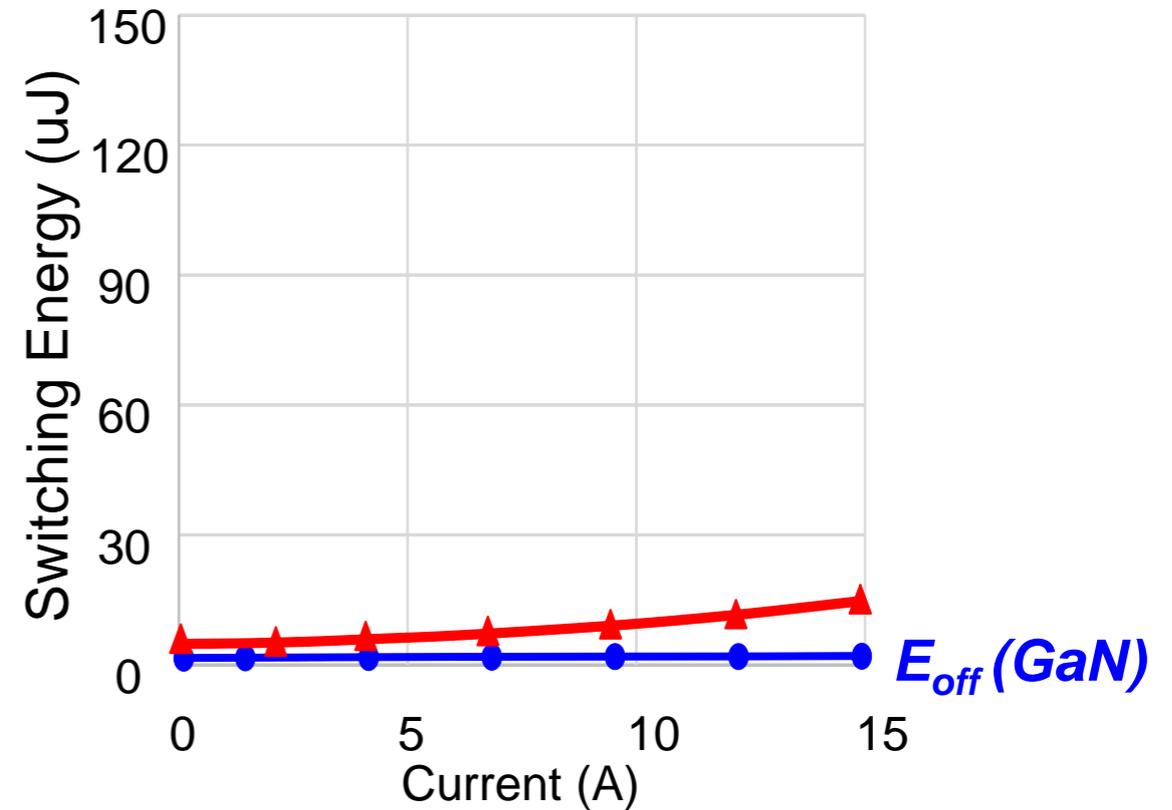
# Wide-Band-Gap Power Semiconductor Devices

GaN. vs Si MOSFET



**GaN: 3X better**

“Zero-voltage Switching”



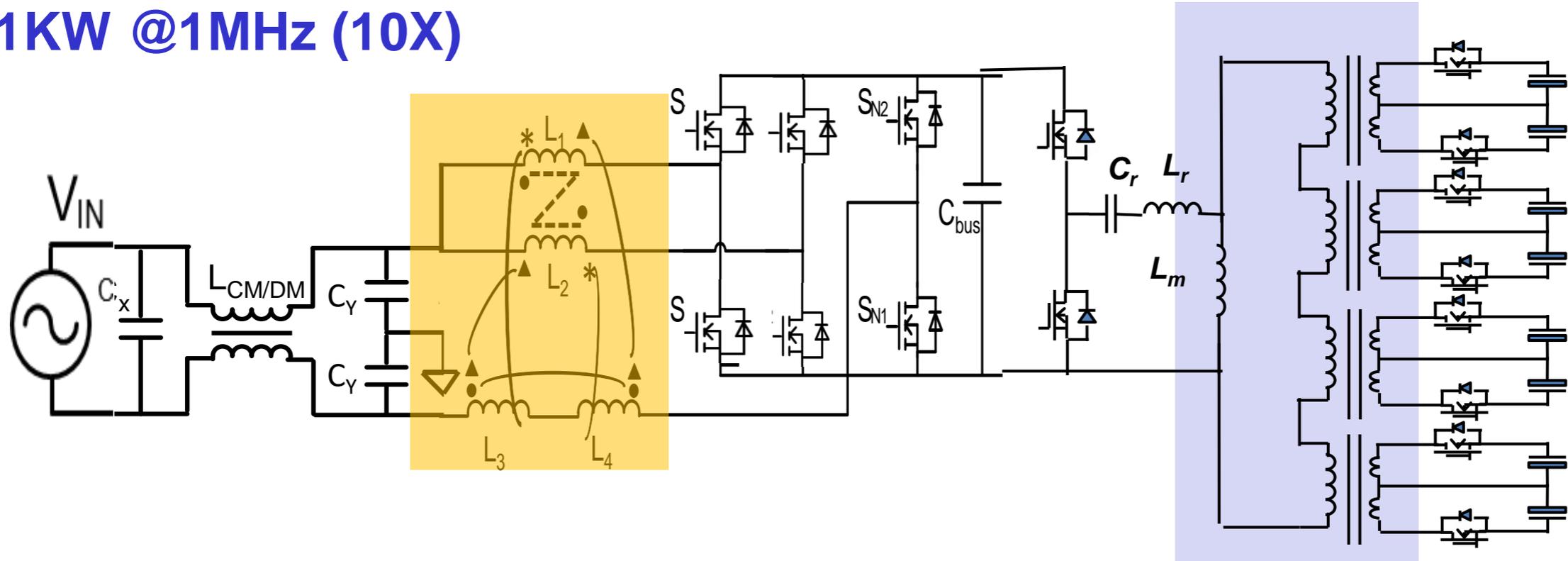
**GaN: 10-20X better**

# GaN Based Server Power Supplies

Standard topology

4:1:1

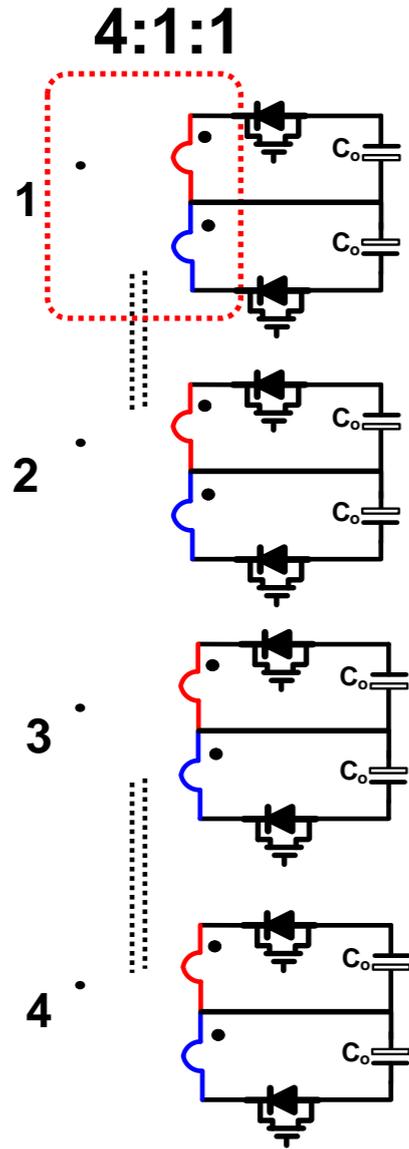
1KW @1MHz (10X)



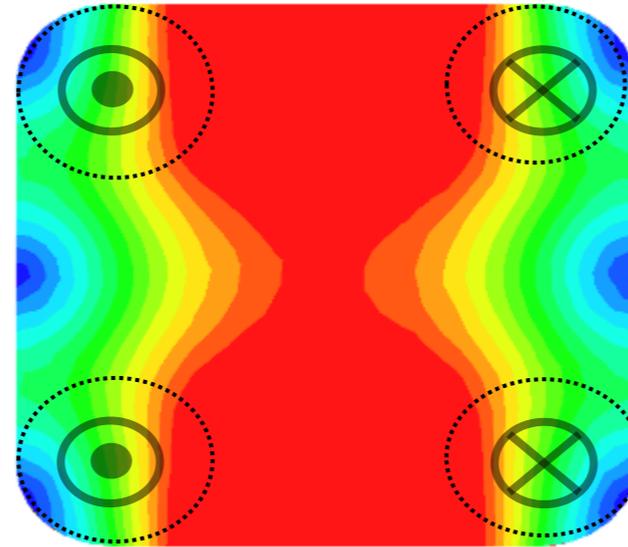
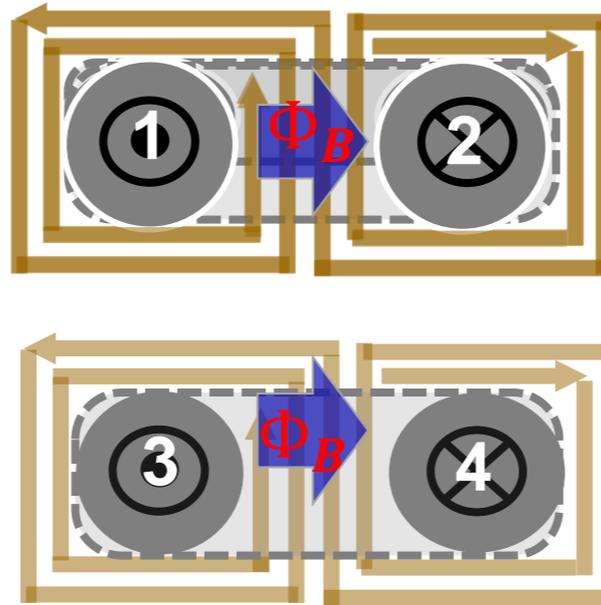
**PFC**  
**ZVS @1-2 MHz**

**LLC Resonant**  
**ZVS @ 1MHz**

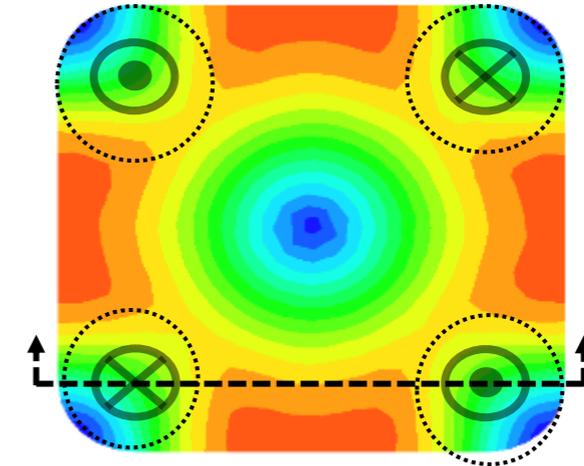
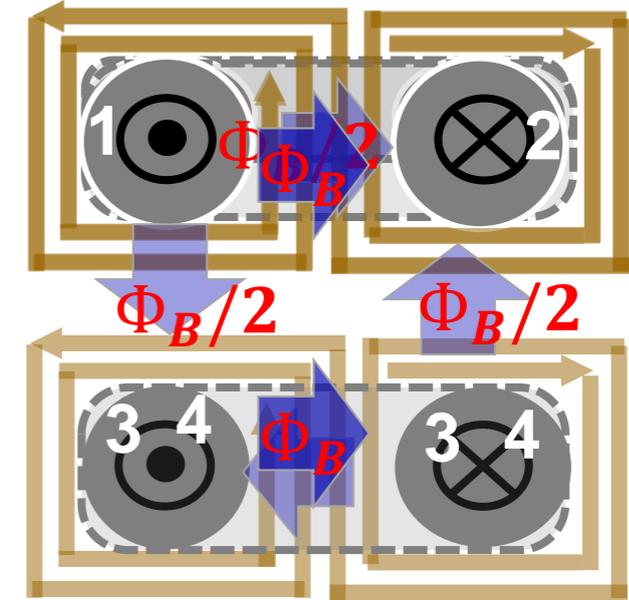
# PCB-Based DC/DC Converter



4-layer PCB



60% volume reduction

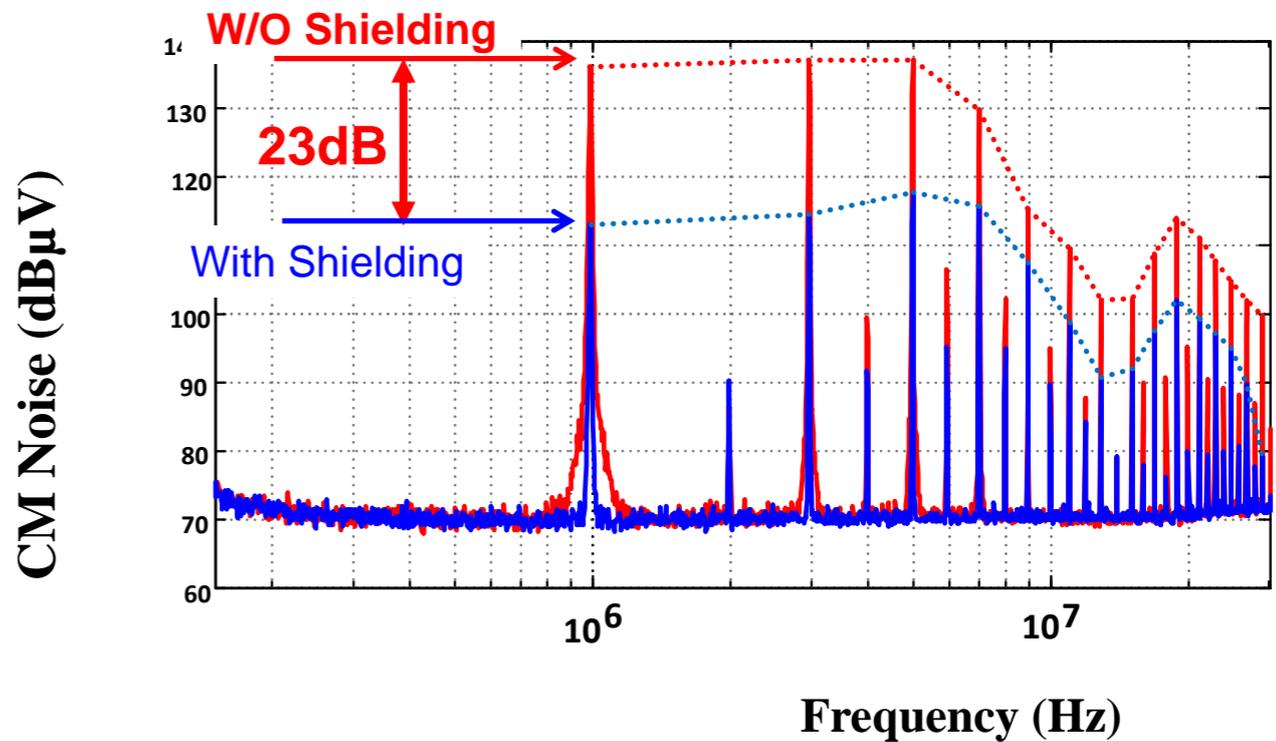
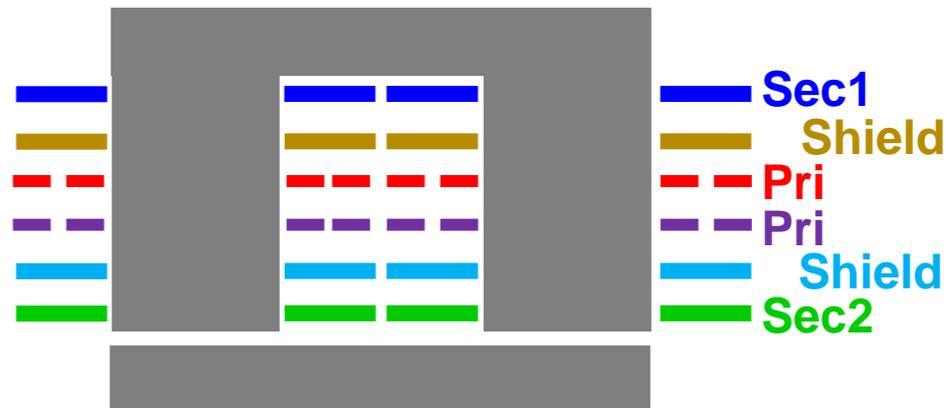
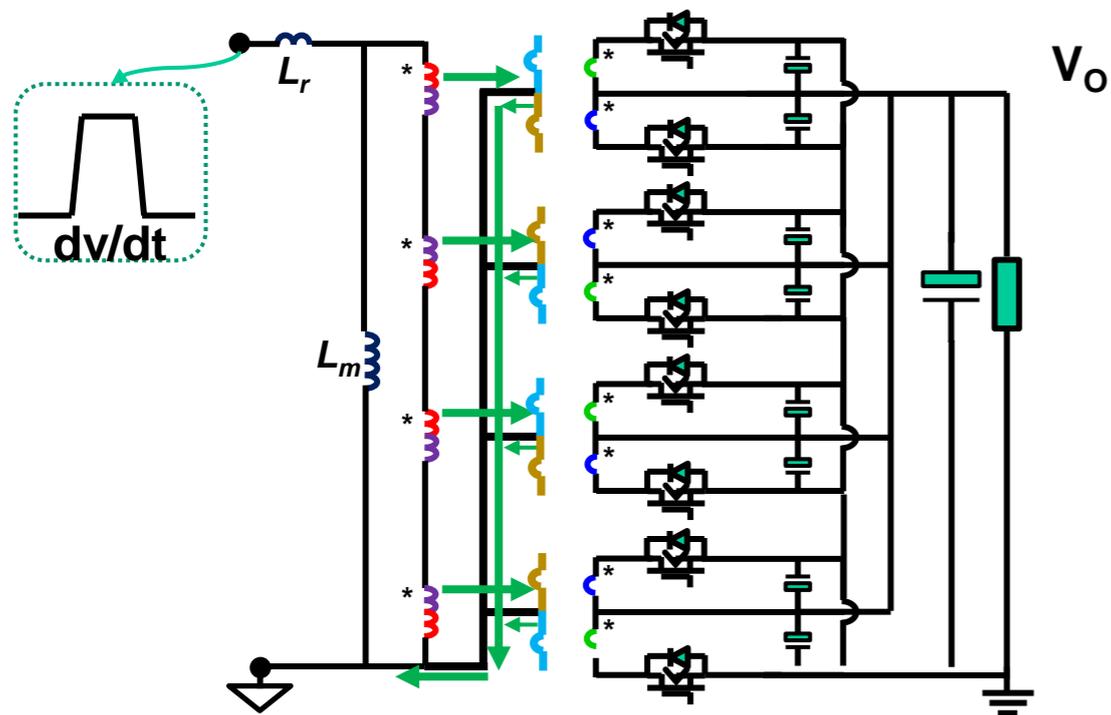


75% volume reduction

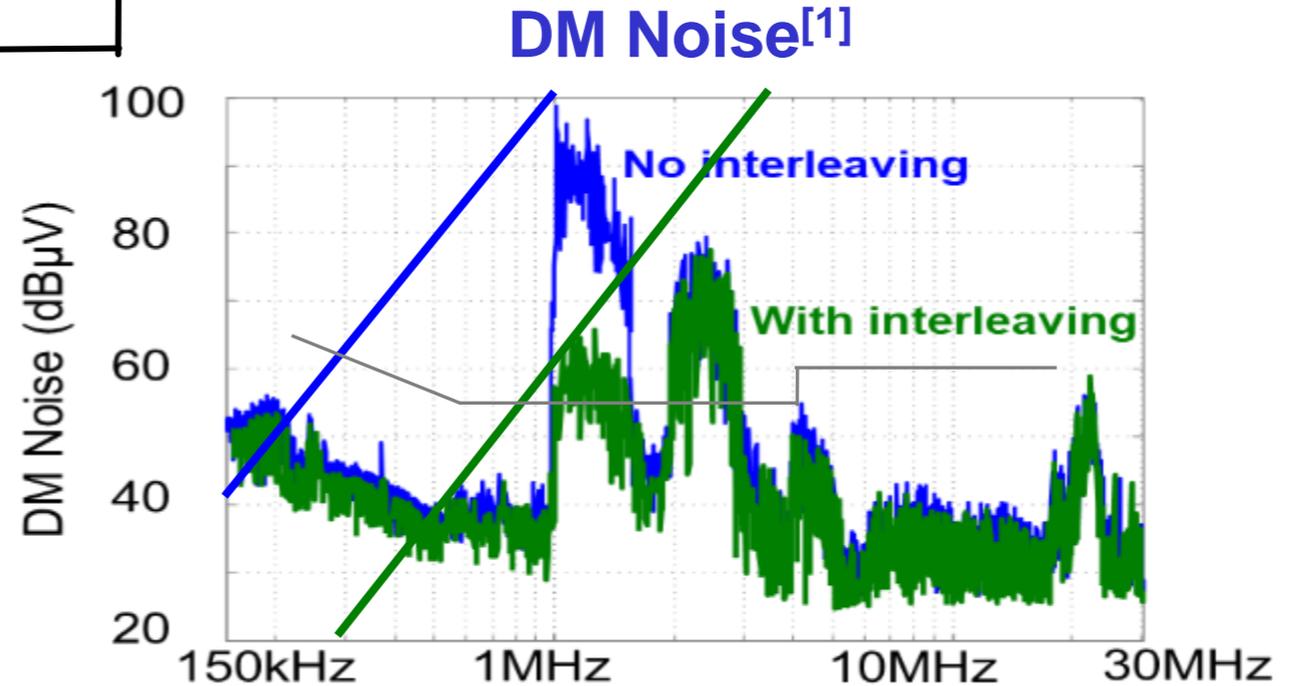
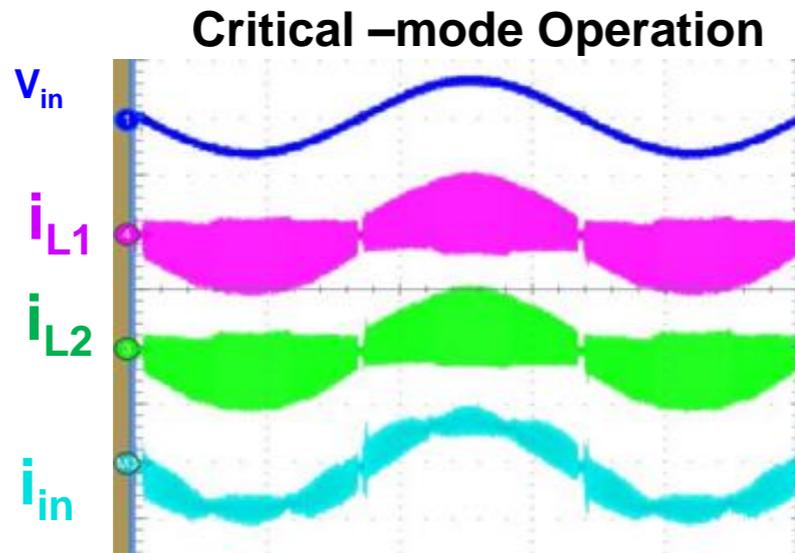
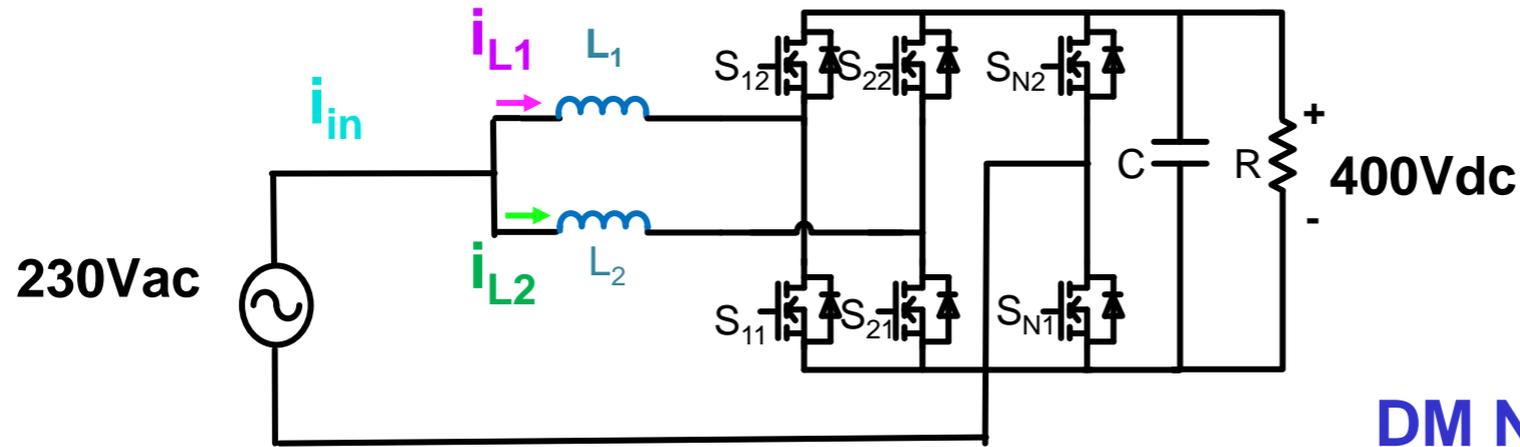
Core1

Core2

# CM Noise Reduction by Shielding



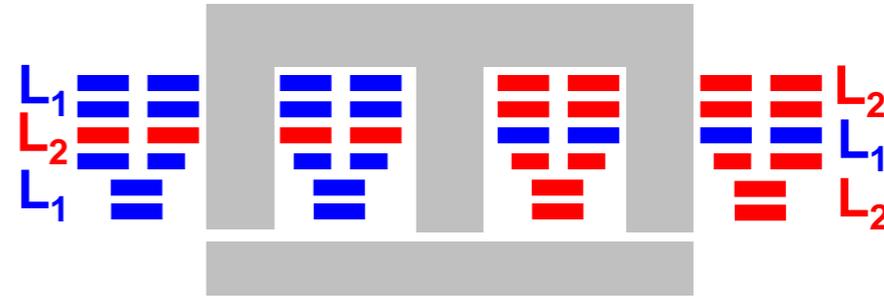
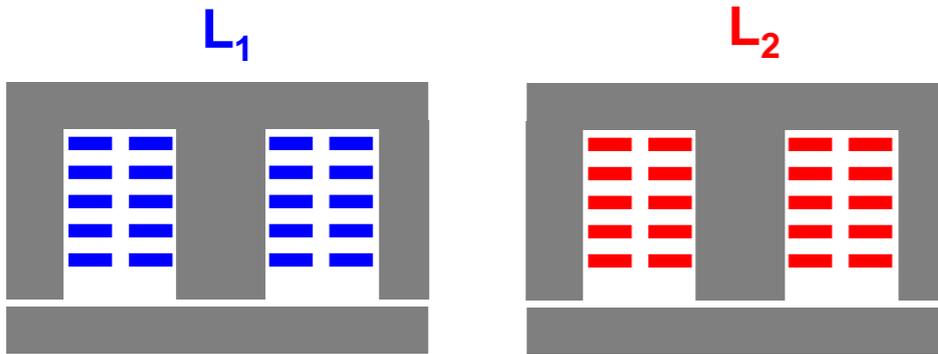
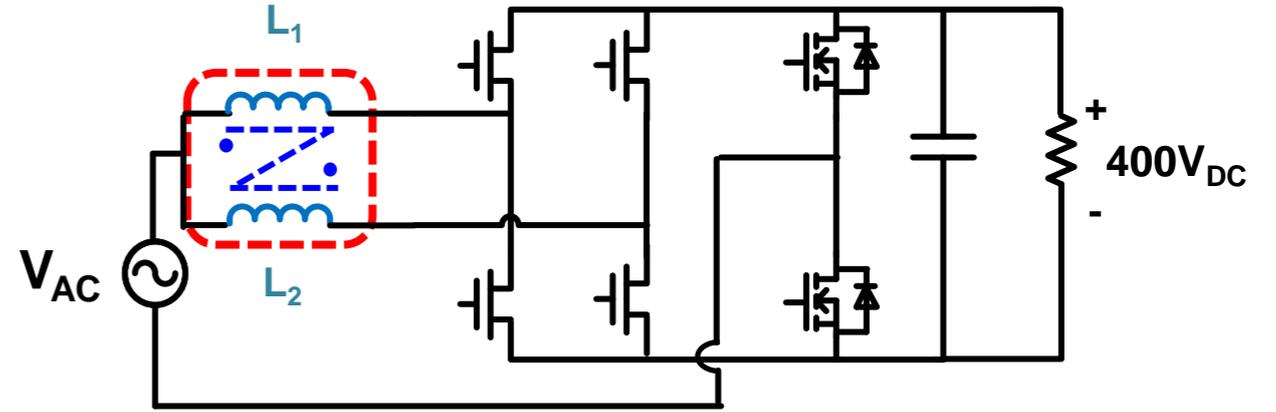
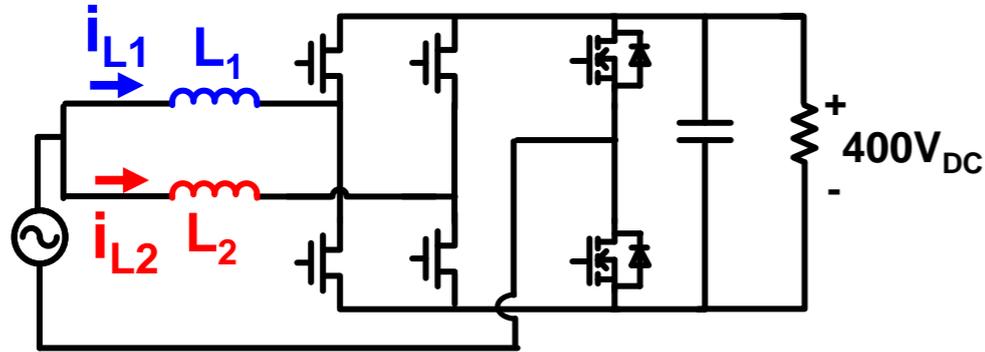
# PFC: Reducing DM Noise with Two-Phase Interleaving

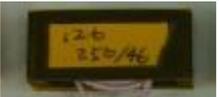


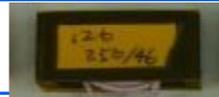
- Interleaving for ripple cancellation

- DM noise and filter size reduced by 3 times

# Winding Loss Reduction by Interleaving Winding



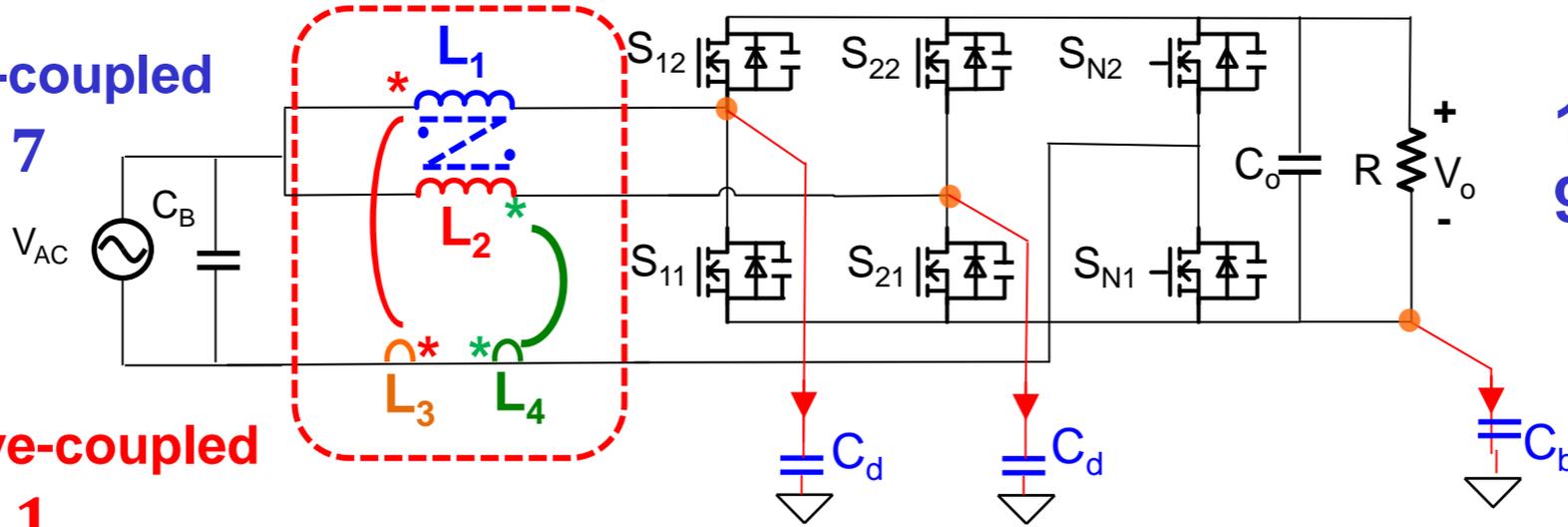
	Winding Loss	Core Loss	Total Loss
PCB w/o interleaving	<b>4.5W</b>	2.3	<b>6.8</b>
	2.3	2.3	4.6

	Winding	Core Loss	Total Loss
PCB Winding	<b>2.4</b>	1.9	<b>4.3</b>
	2.3	2.3	4.6

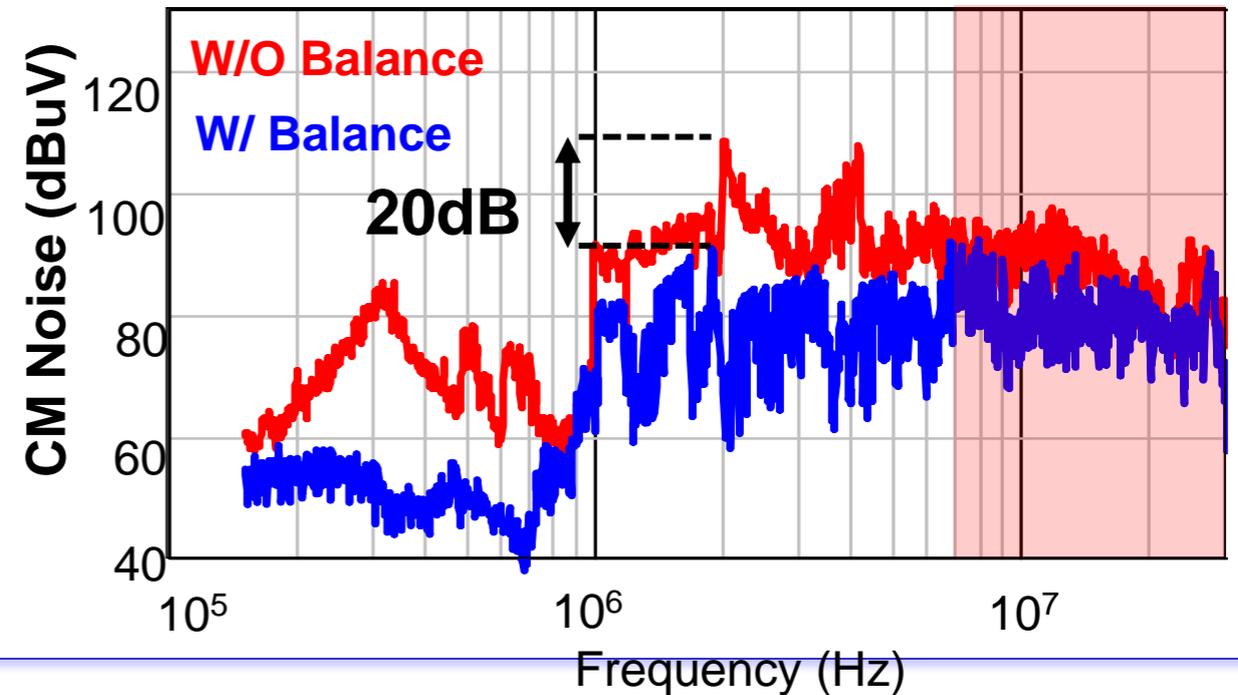
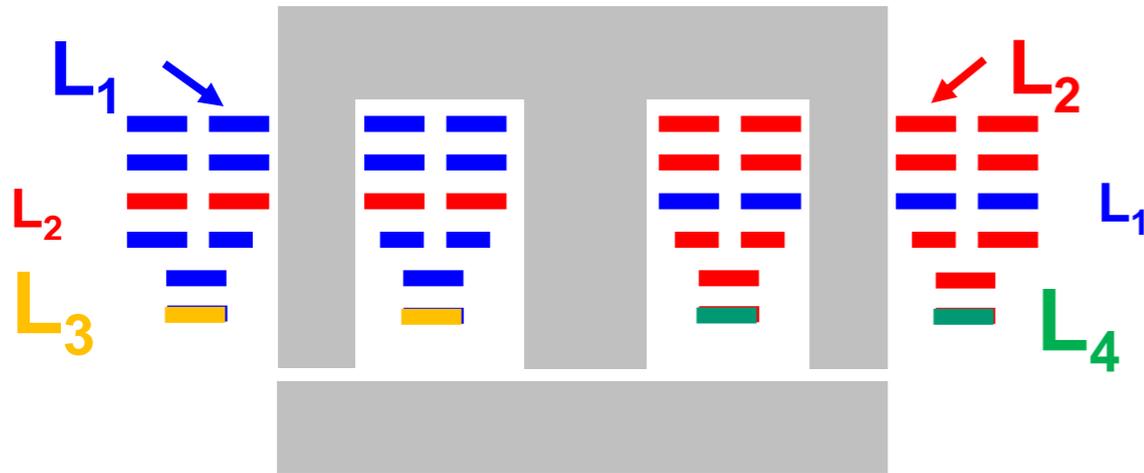
# CM Noises Reduction *using "Balance Principle"*

$L_1$  &  $L_2$  Negative-coupled  
 $\alpha \approx 0.7$

$L_1$  &  $L_3$   
 $L_2$  &  $L_4$  Positive-coupled  
 $\alpha \approx 1$



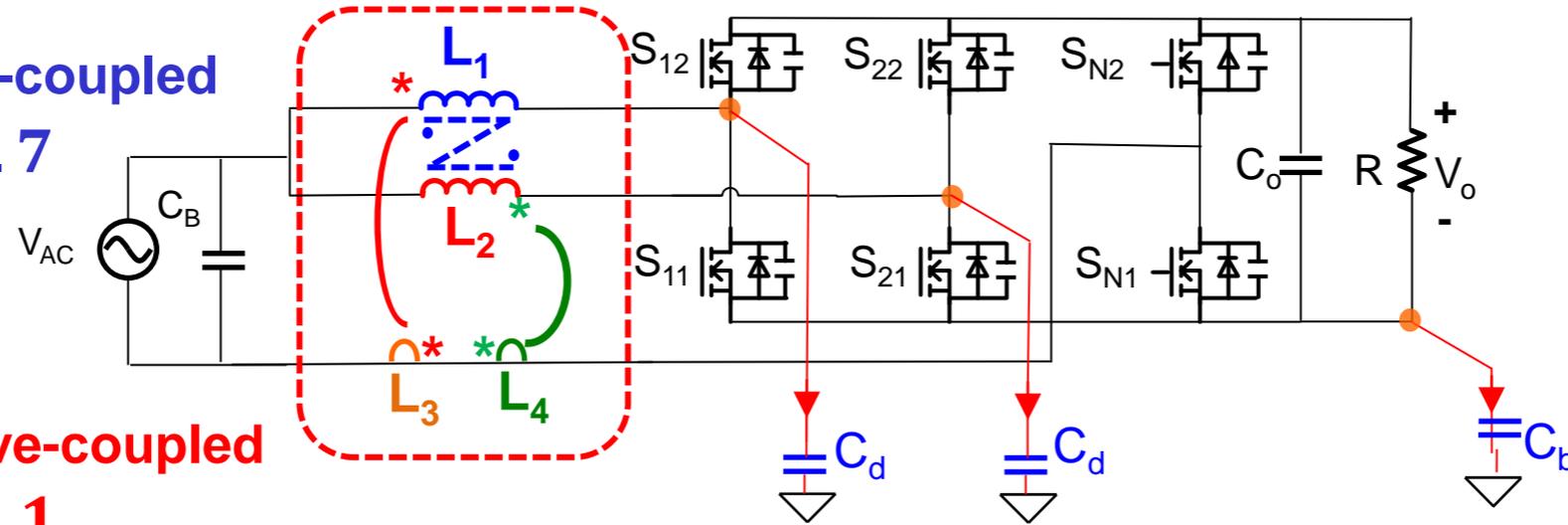
1KW @1-2MHz  
 99% efficiency



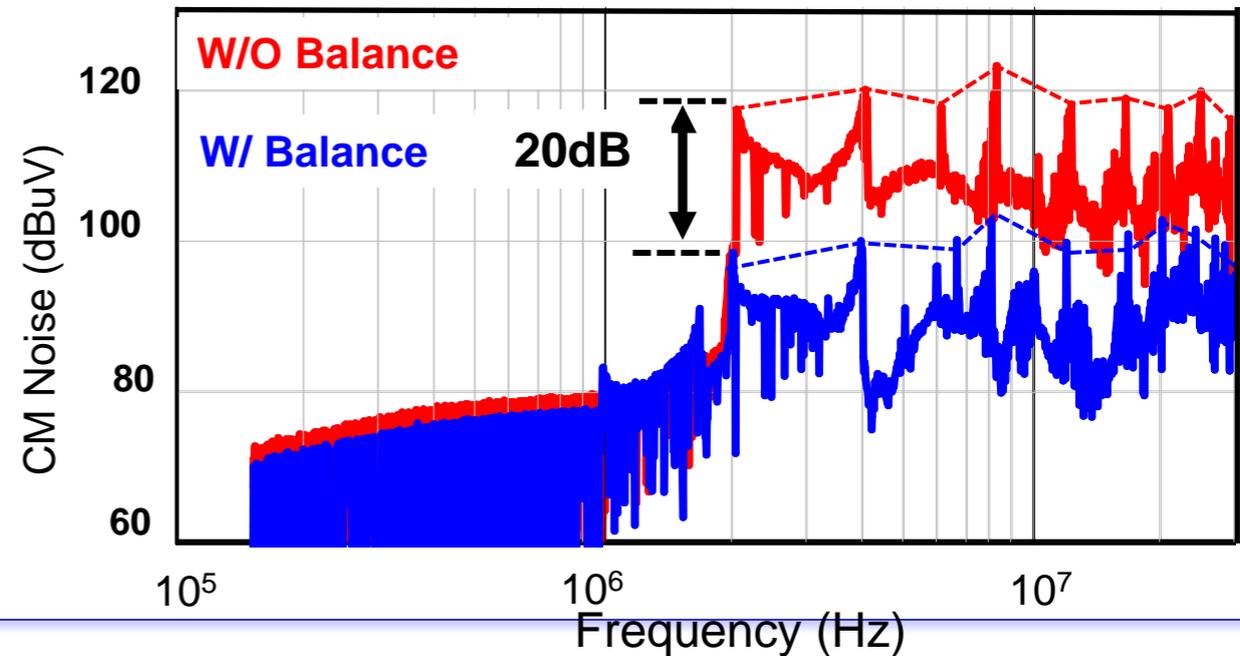
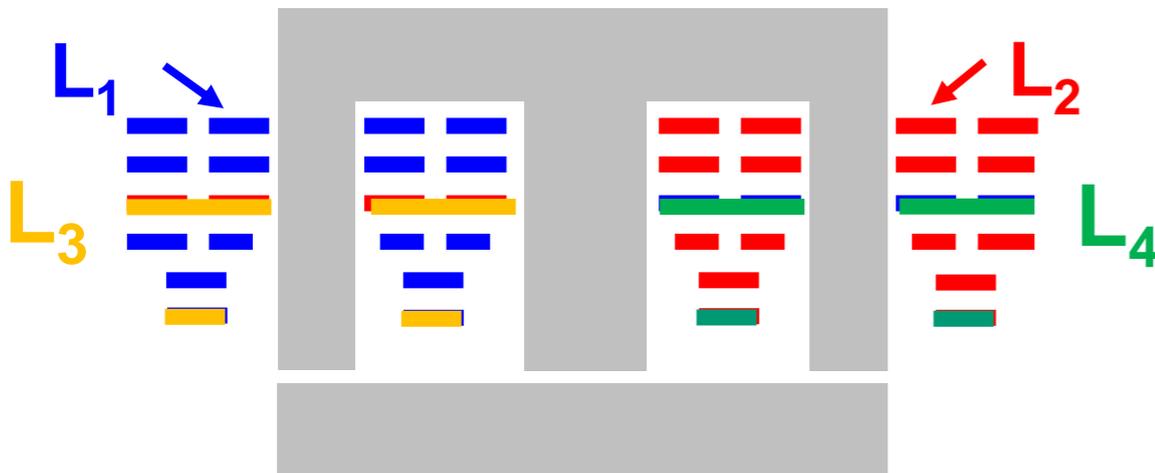
# CM Noises Reduction *using Balance Principle*

$L_1$  &  $L_2$  Negative-coupled  
 $\alpha \approx 0.7$

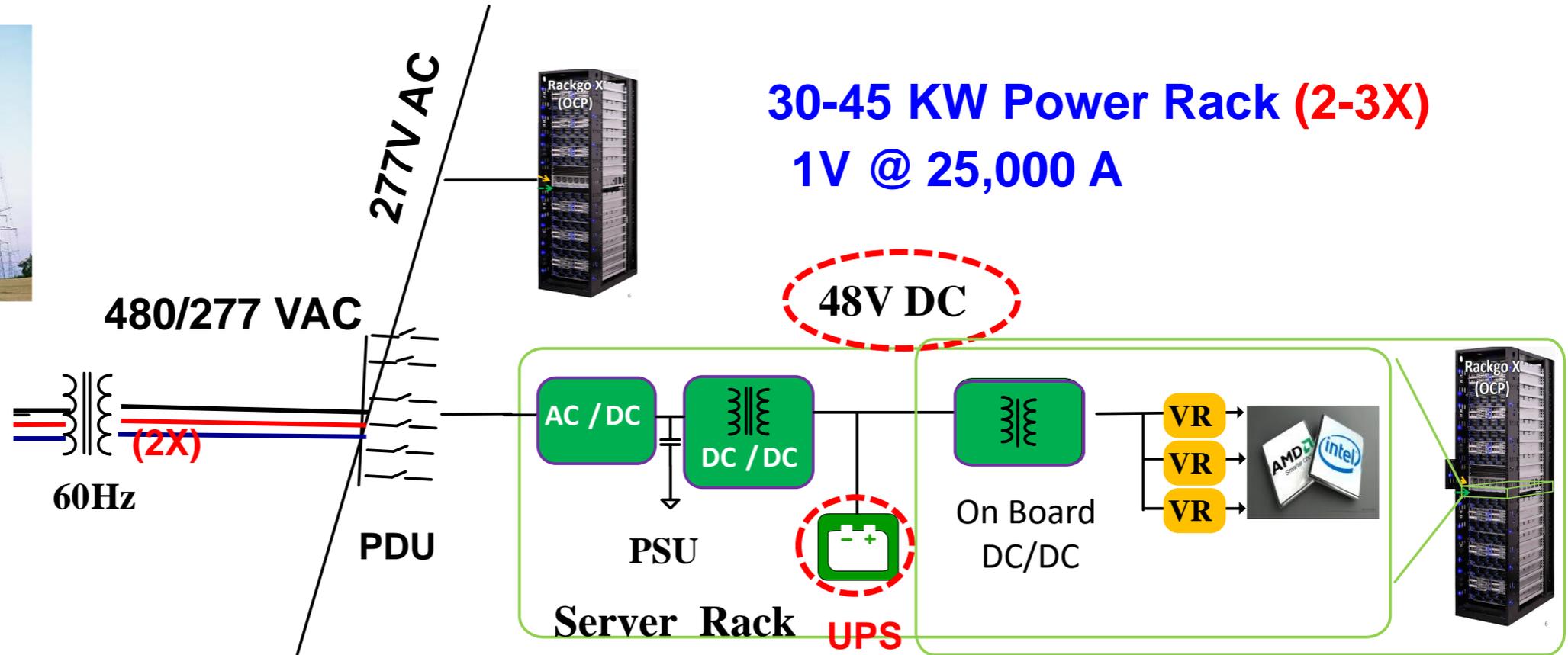
$L_1$  &  $L_3$   
 $L_2$  &  $L_4$  Positive-coupled  
 $\alpha \approx 1$



1KW @1-2MHz  
 99% efficiency



# Gen.2: Data Center Power Architecture



Eff 98%

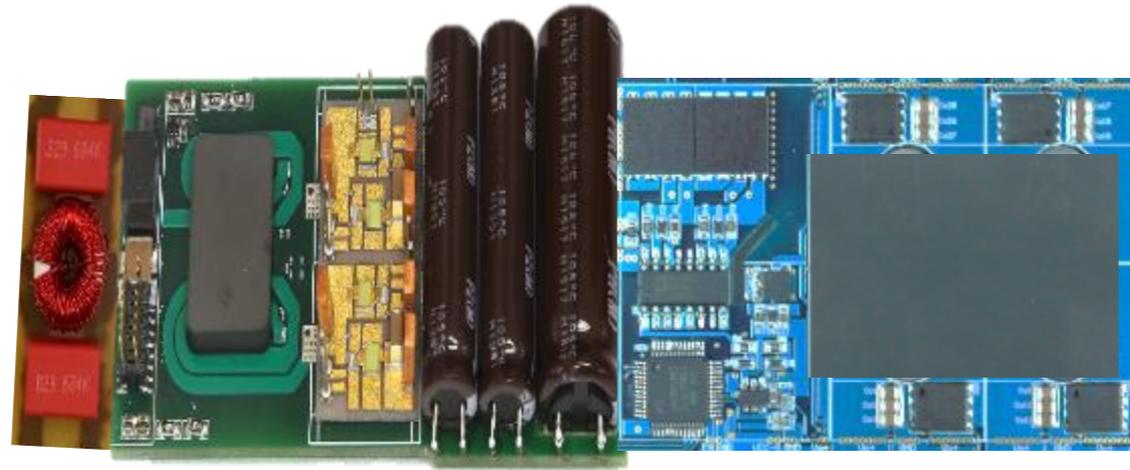
99%

98%

90%

≈ 85%

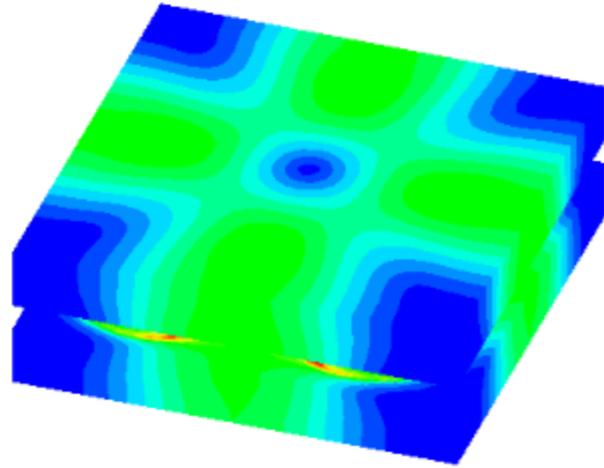
*Energy saving ≈ 10 Nuclear Power Plants each @ 1GW Capacity*



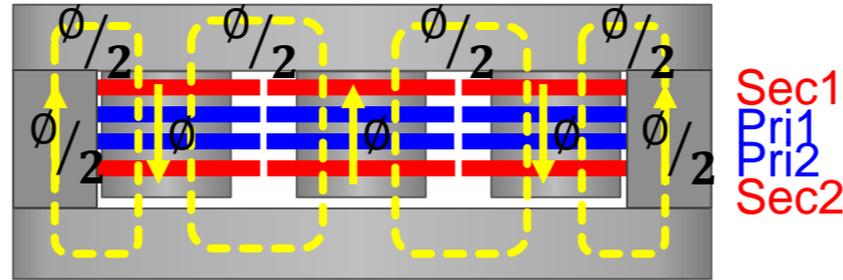
1KW Sever Power

**Can we extend this level of heterogeneous integration  
to 3KW, 6KW and beyond??**

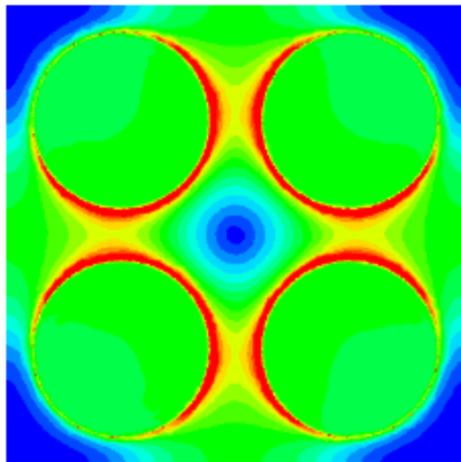
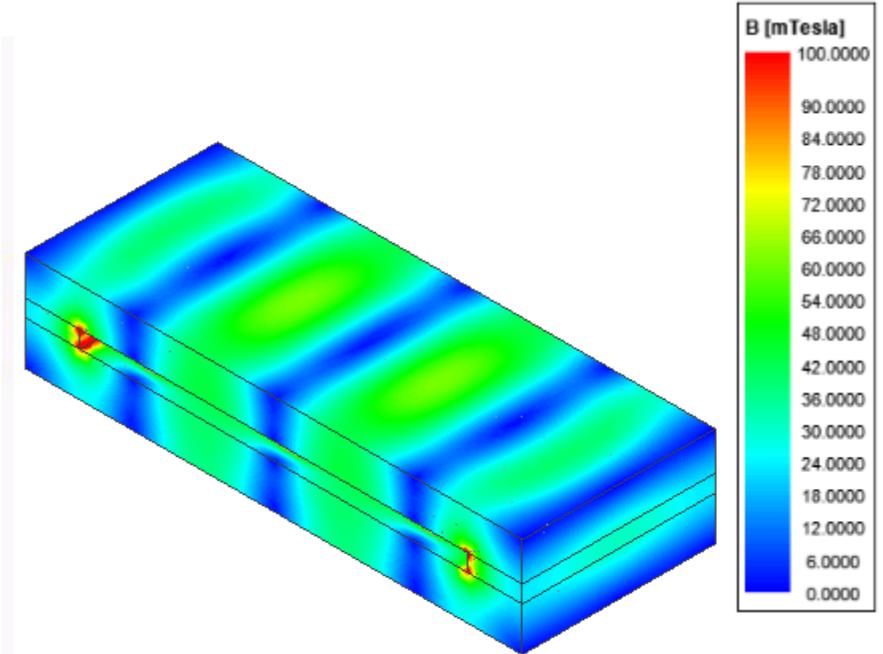
# Transformer Design From 1 KW to 3 KW



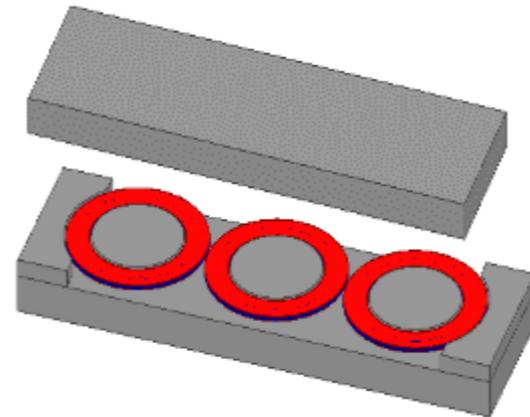
Side View



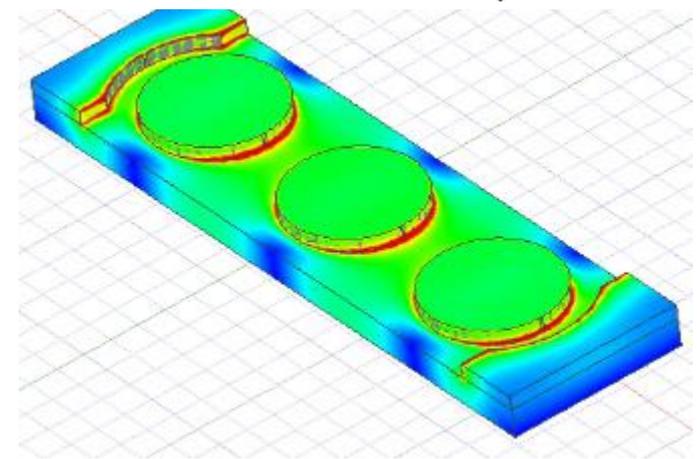
Flux in the plates = 0.5 Bm



Core Loss = 9.7W

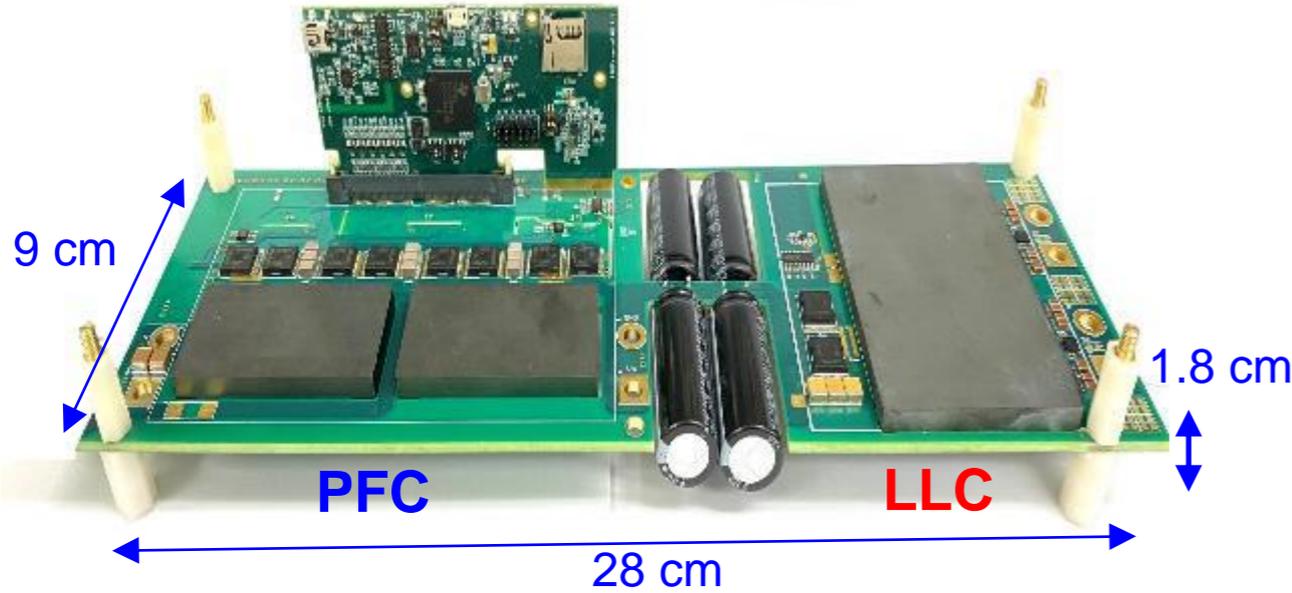


1KW per transformer

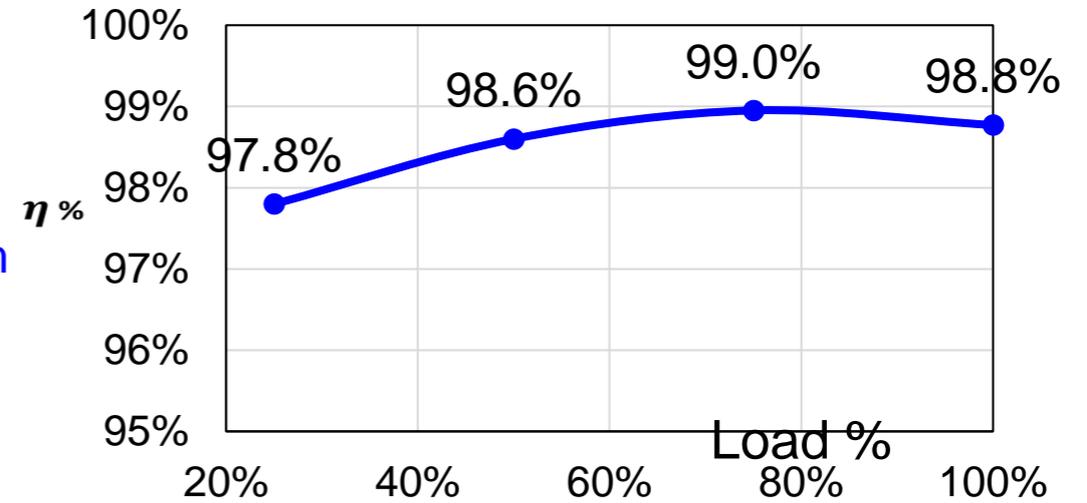


Core loss = 4.8w

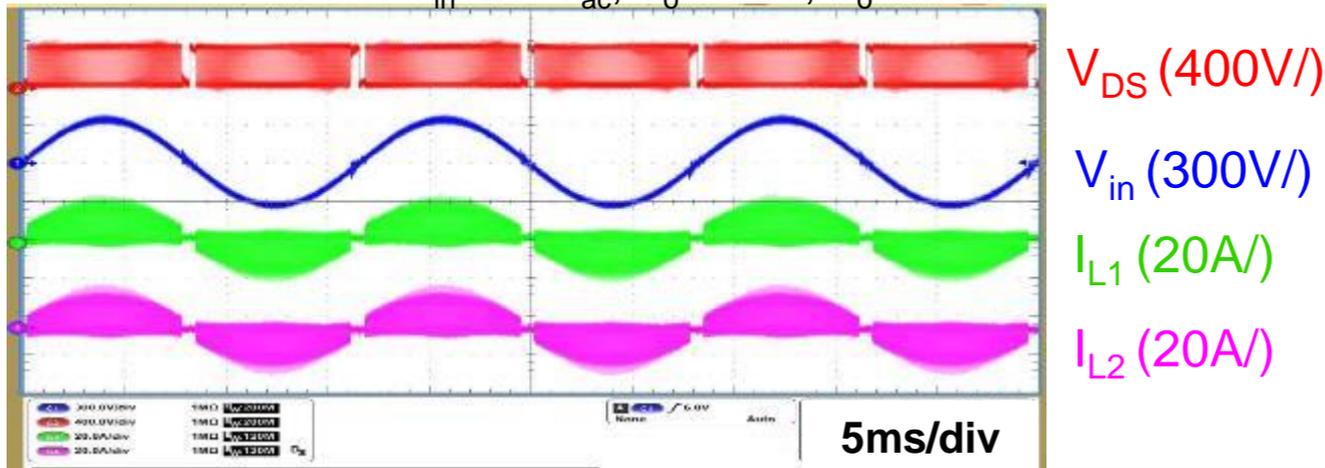
# 3KW Power Supplies for Gen 2 Data Center



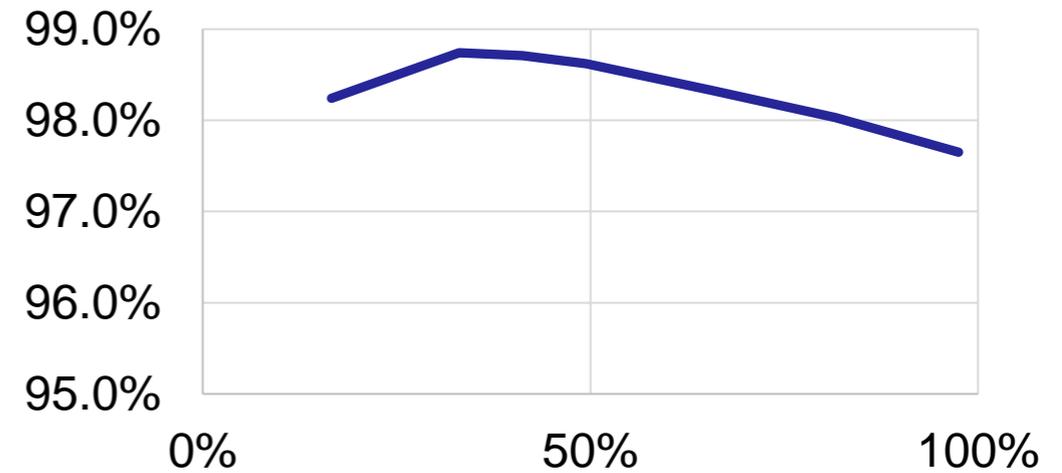
### PFC Efficiency



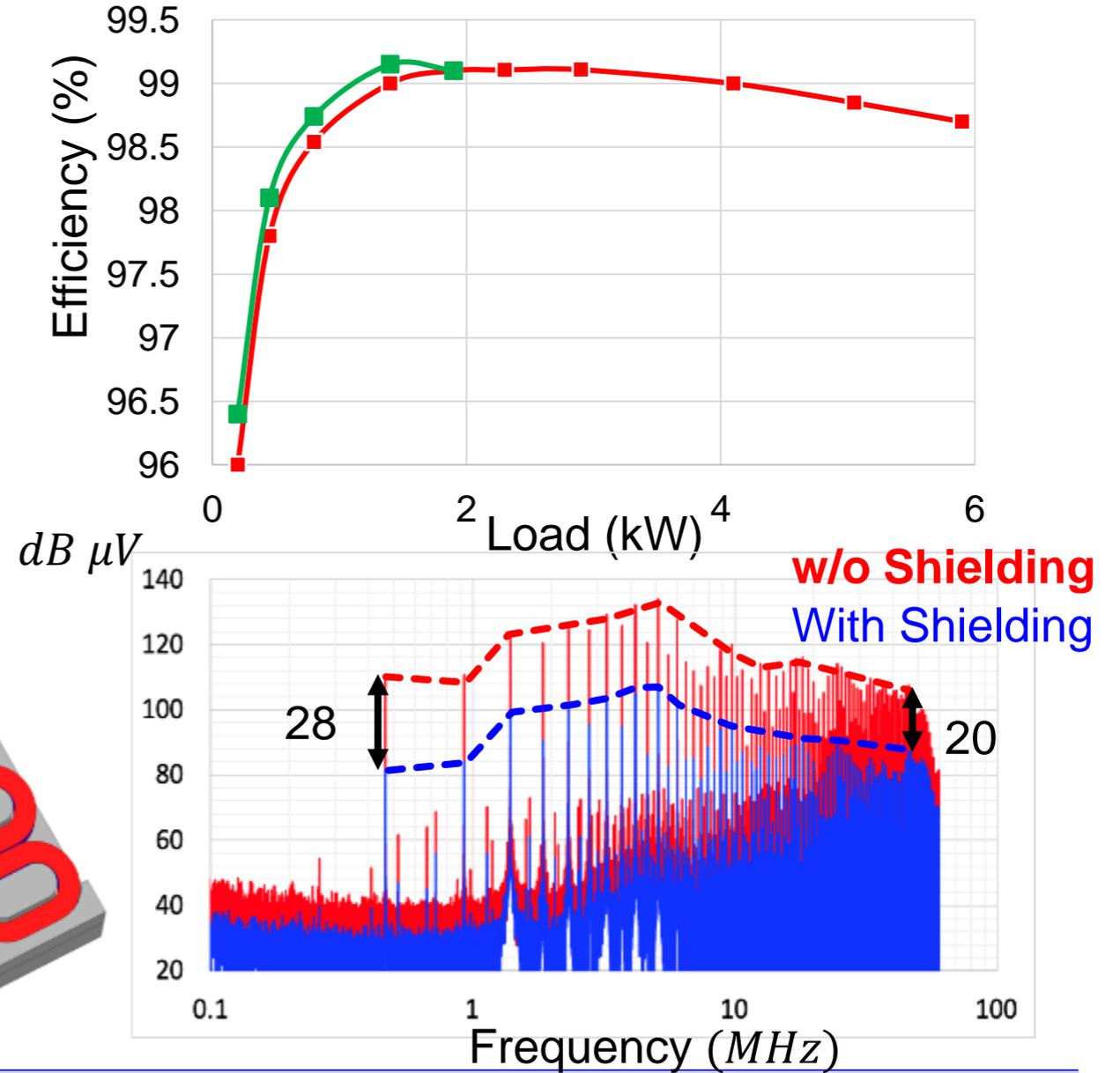
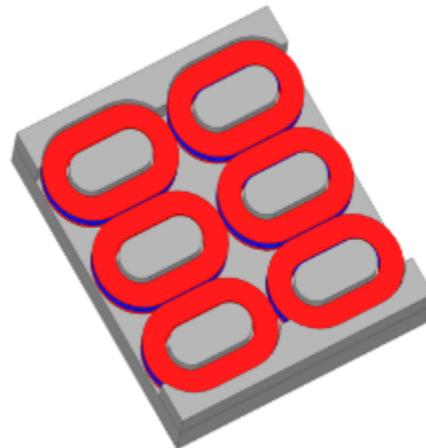
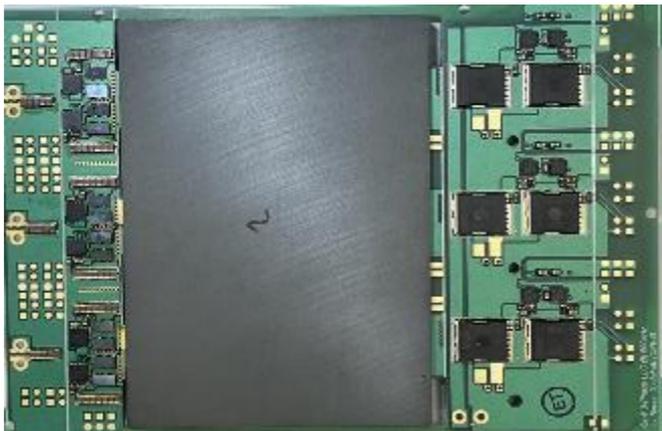
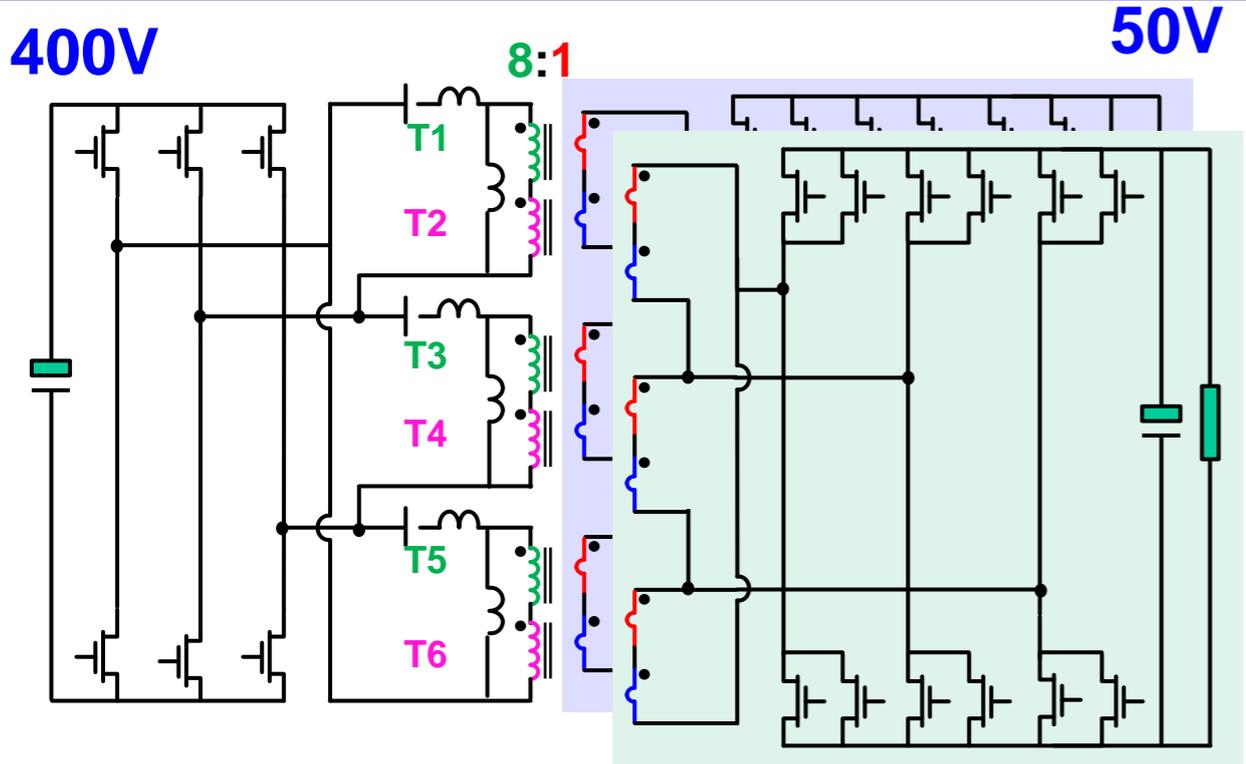
PFC:  $V_{in}=230V_{ac}$ ,  $V_o=400V$ ,  $P_o=3.0kW$



### D2D Efficiency



# Proposed Topology for 6-9 KW: 3-phase LLC



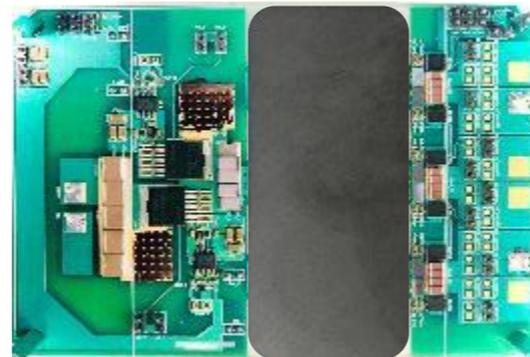
# “Heterogeneous Integration”



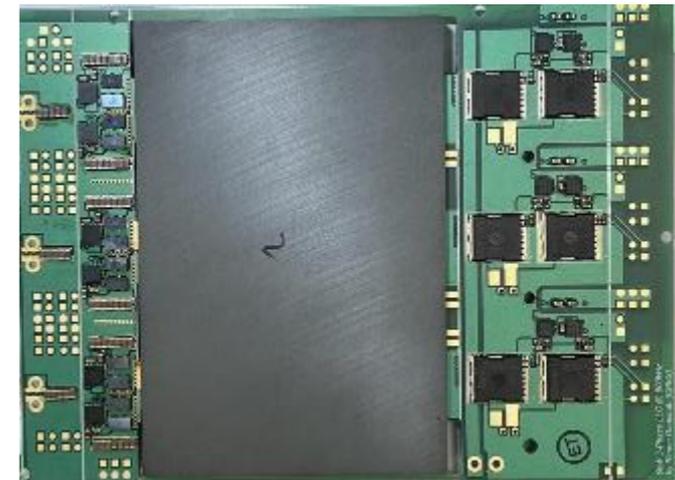
**Product Specifications**



1KW Server Power



3KW Server Power



6-9 KW Server Power

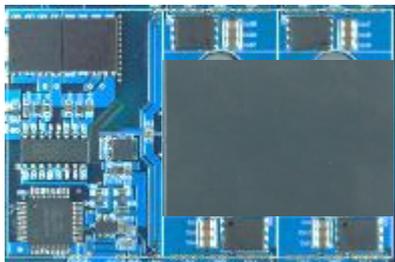
# Summary

**Silicon**

**100KHz**



**WBG**



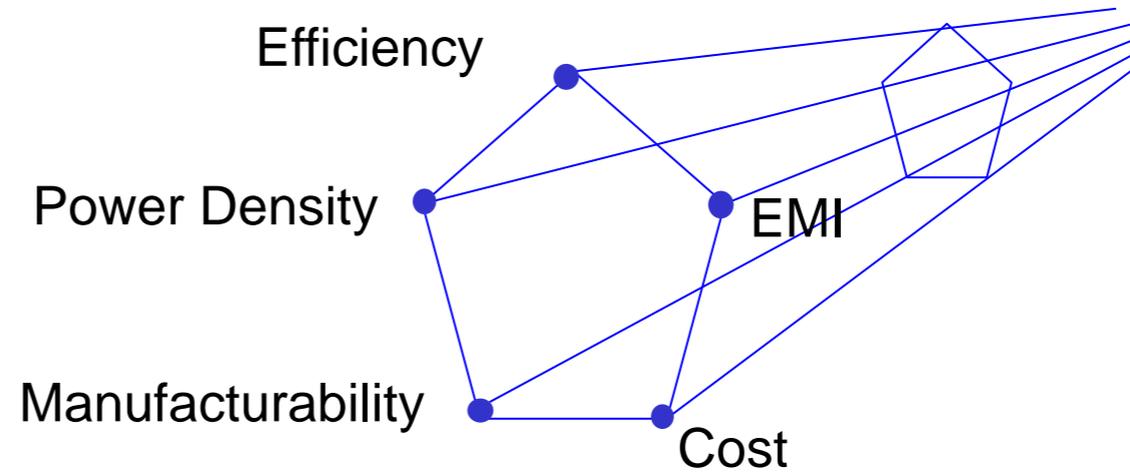
**1KW**



**6-9 KW**

**Silicon**

**WBG**



Eff  $\approx$  98%

Power density  $>$  3 – 5X

Improved EMI  $\approx$  20dB

Manufacturability

Low Cost

## A Game Changer

**Thank You**