Next Generation of Power Supplies

- Design for Manufacturability

Presented to

PEAC 2018

Nov 5-7, 2018

by

Fred C Lee

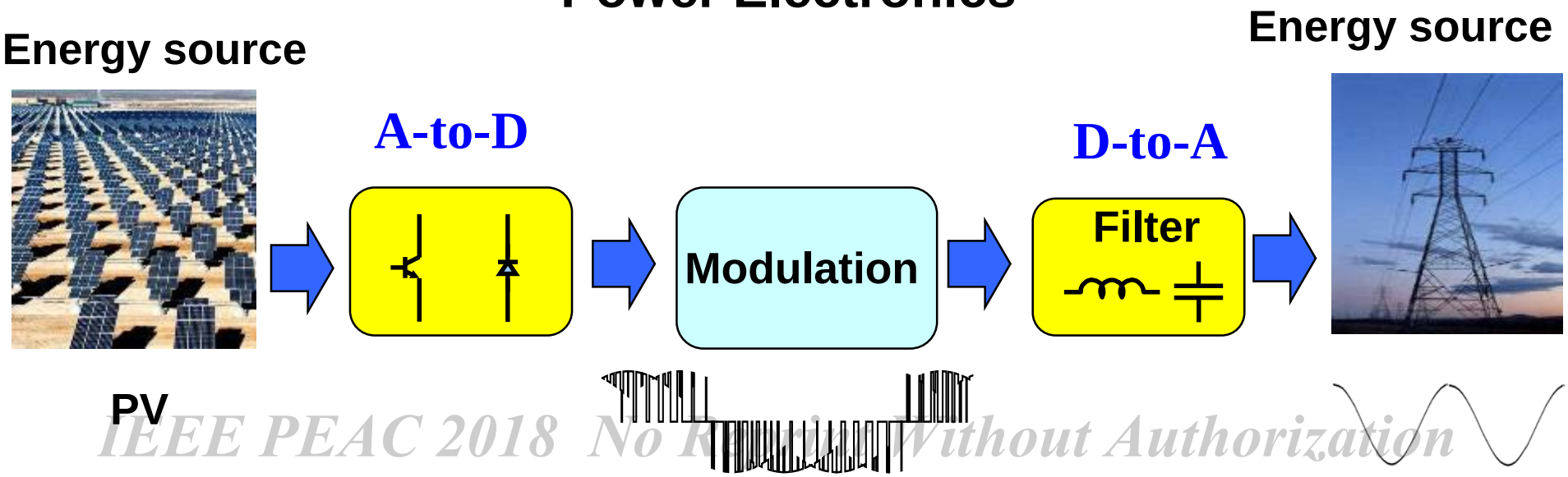
Virginia Tech

Micro Electronics vs Power Electronics

Micro Electronics

Signal Processing

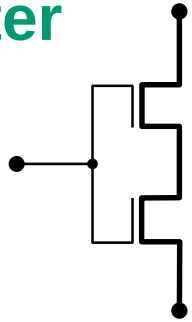
Power Electronics



2 Building Blocks

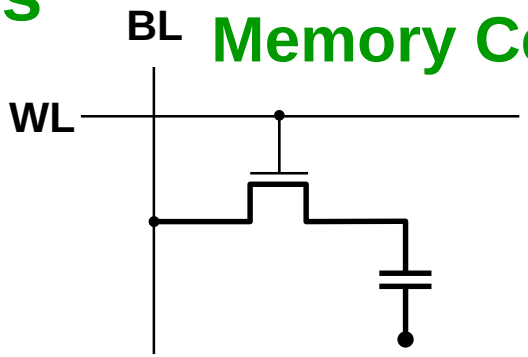
Micro Electronics

CMOS Inverter



Building Blocks (1v, mA)

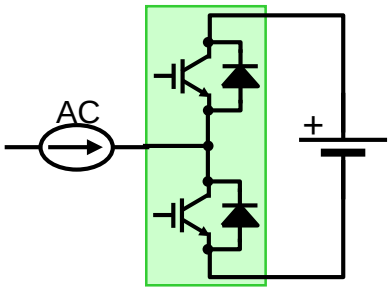
DRAM Memory Cell



Moore's Law prevails in 5 decades

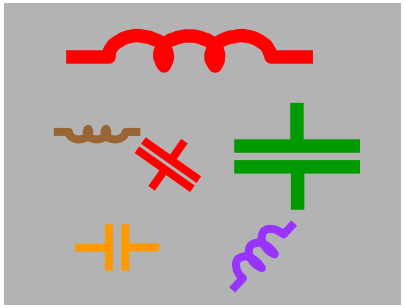
Power Electronics

Power Cell Inverter



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

Energy Storage Cell



KPI: frequency, efficiency & power density

Evolution of Power Devices

BI-POLAR
(60-70)

10X

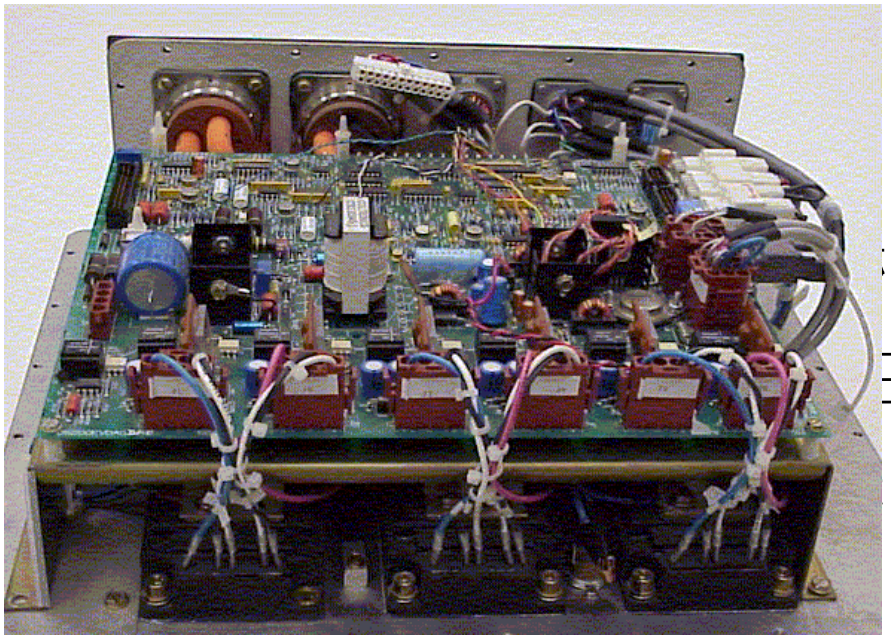
Switching Frequency

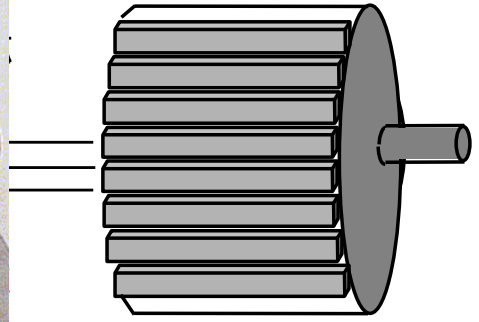
Efficiency

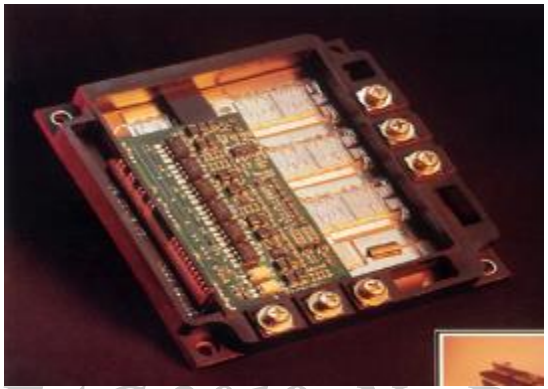
Power Density

MOSFET/IGBT
(80- present)

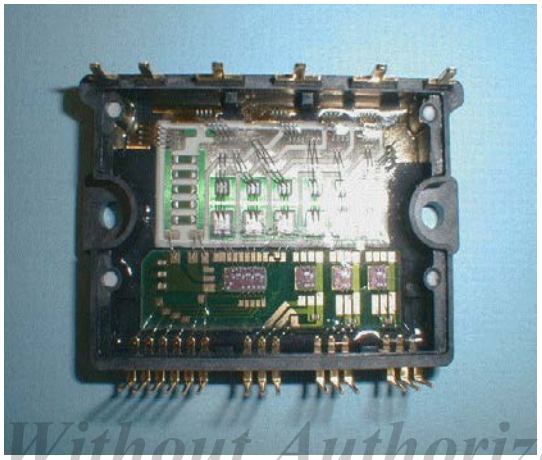
Power Module Integration







Toshiba

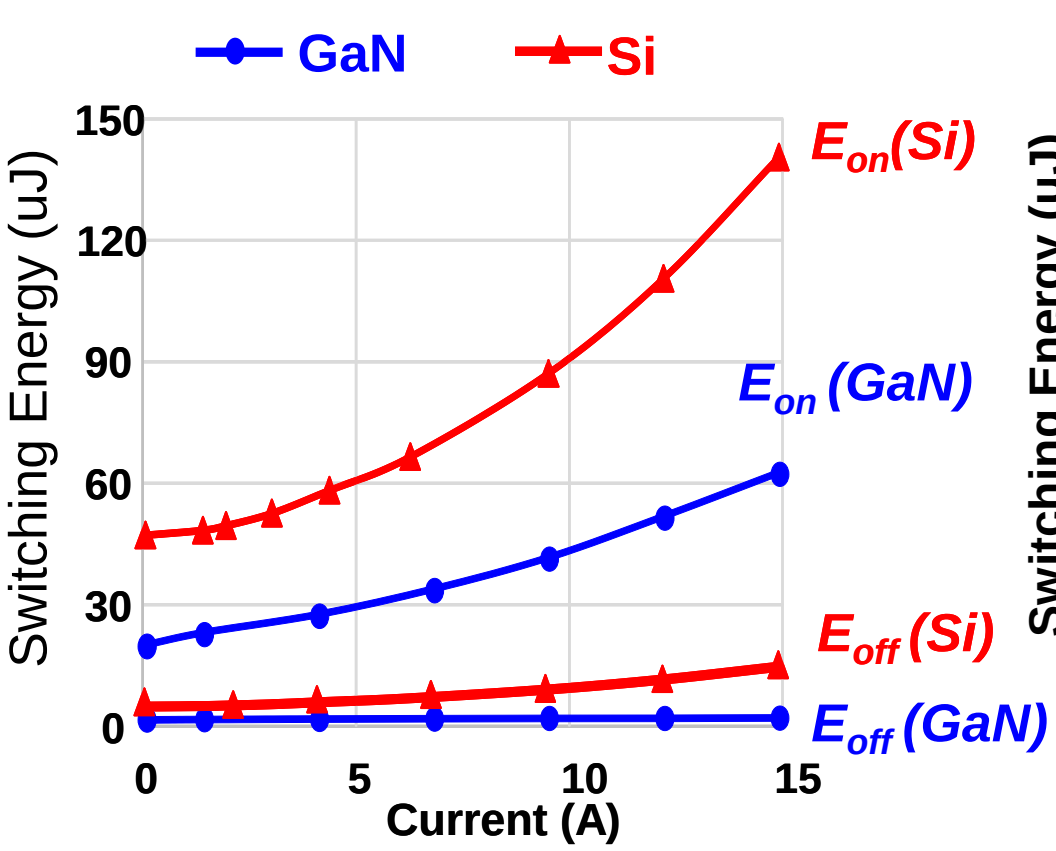


Fuji

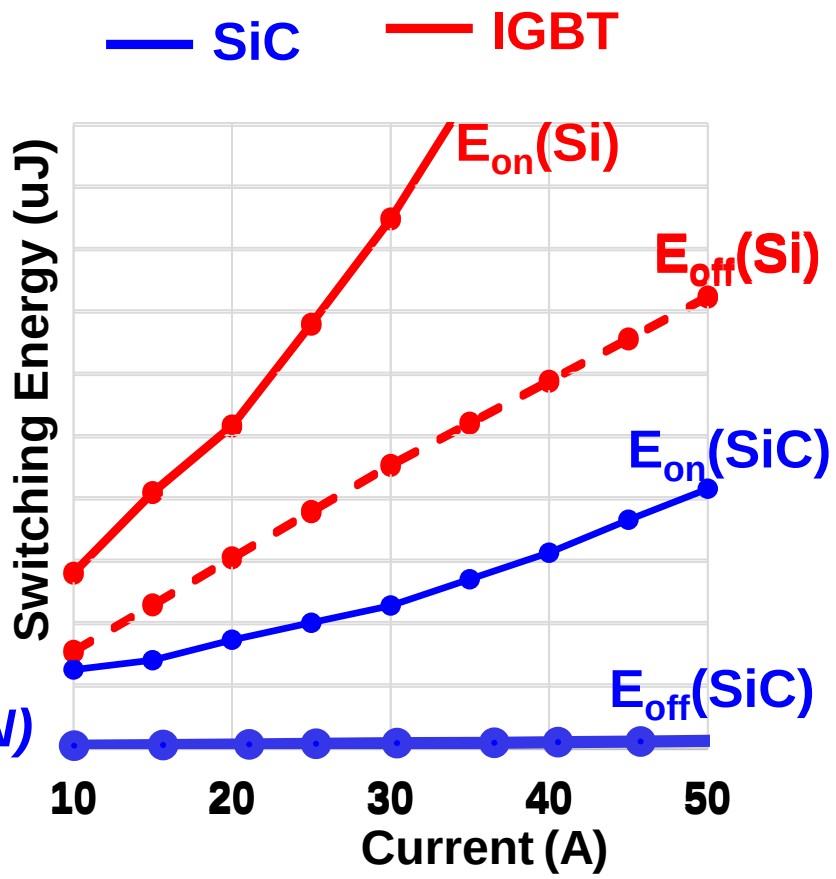
Switching Loss Comparison

WBG and Silicon

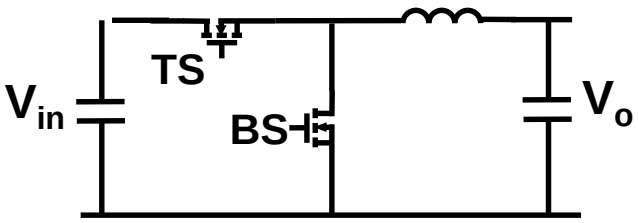
GaN v.s. Silicon (MOSFET)



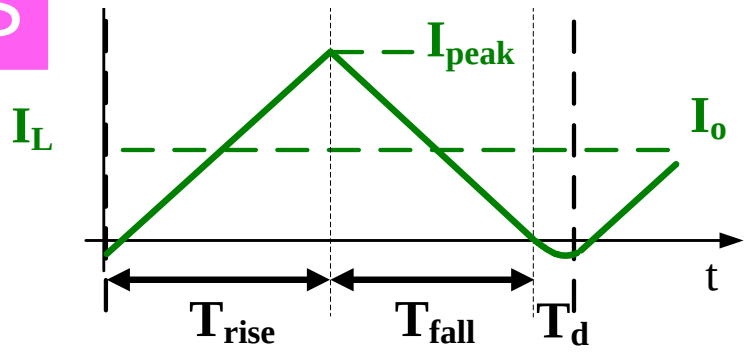
SiC v.s. Silicon (IGBT)



GaN: Loss Breakdown

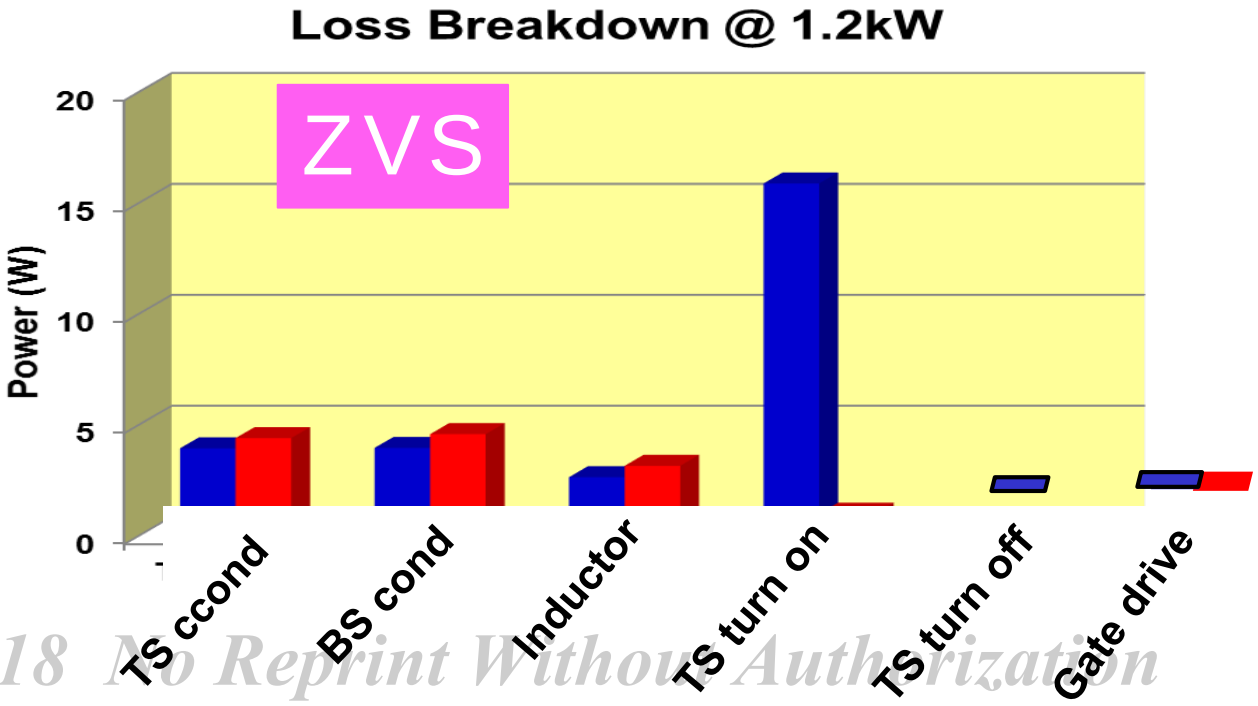


ZVS



1.2 KW @ 1MHz

Switching losses are negligible



What Do You Do?

If you are given a device without switching losses,

what would you do ?

“Figure of Metrics ”

Is it a meaningful metrics ?

Shall we re-assess our design approach

and trade off criteria ?

Challenges for WBG

Low threshold voltage & breakdown voltage

dv/dt (>6X)

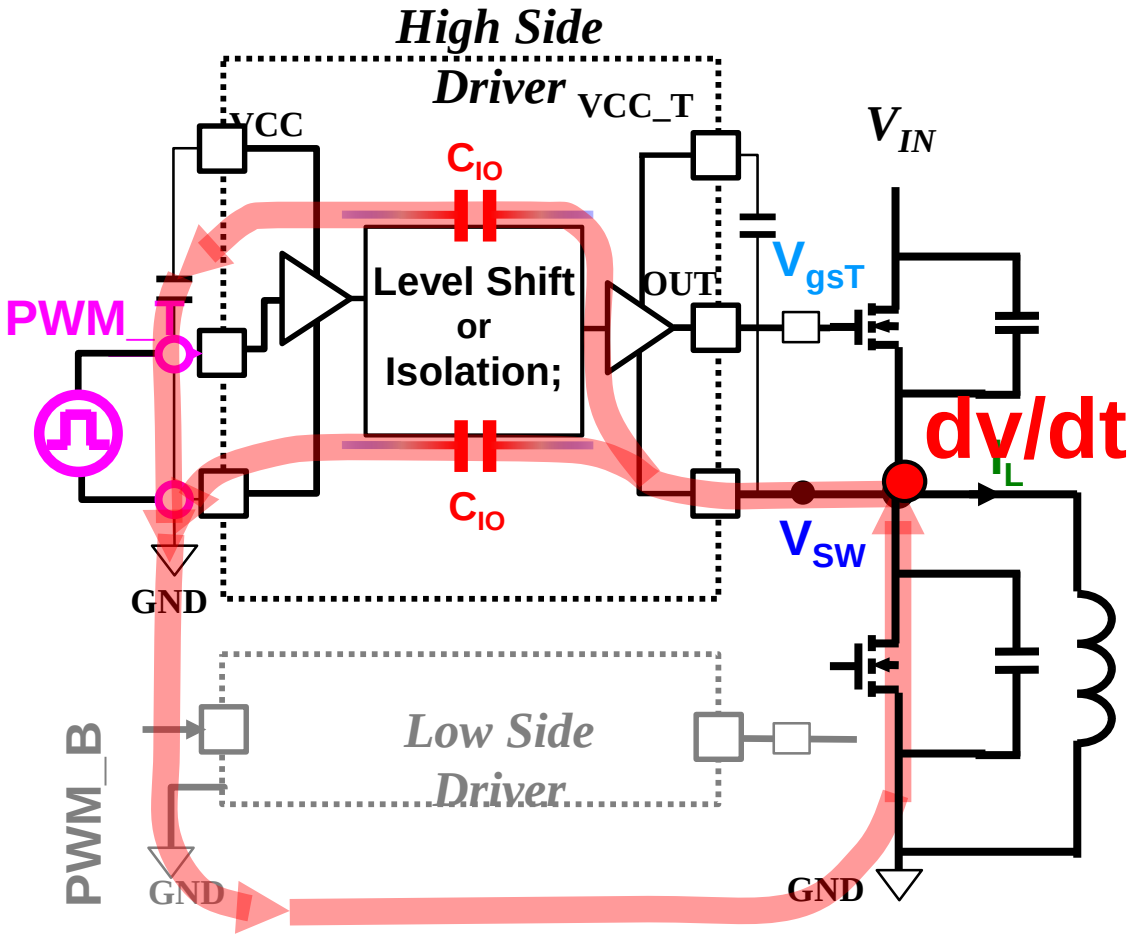
di/dt (>3X)

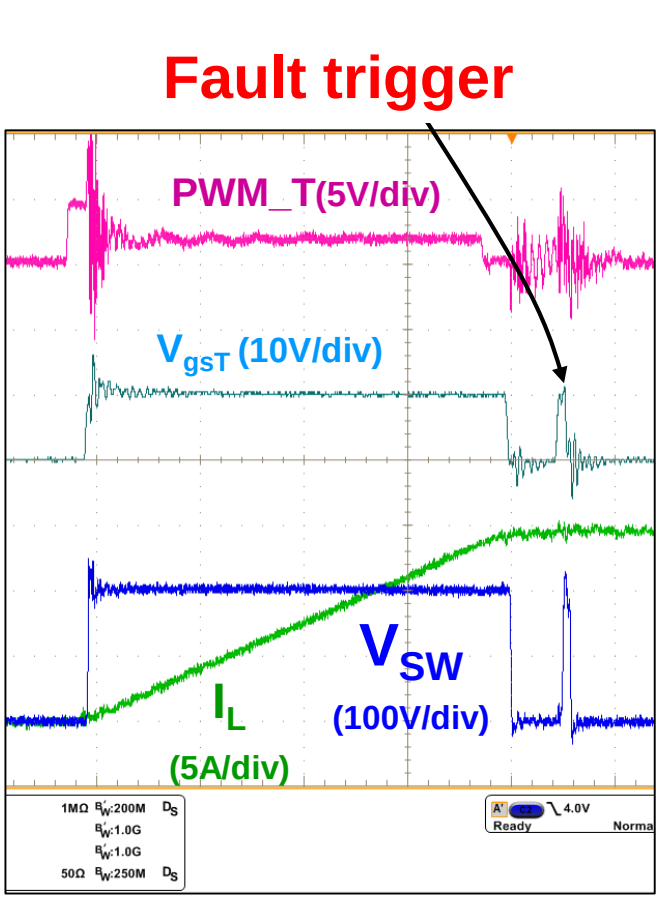
Packaging consideration

TO220

GAN/SiC

dv/dt Deteriorates Input PWM Signal





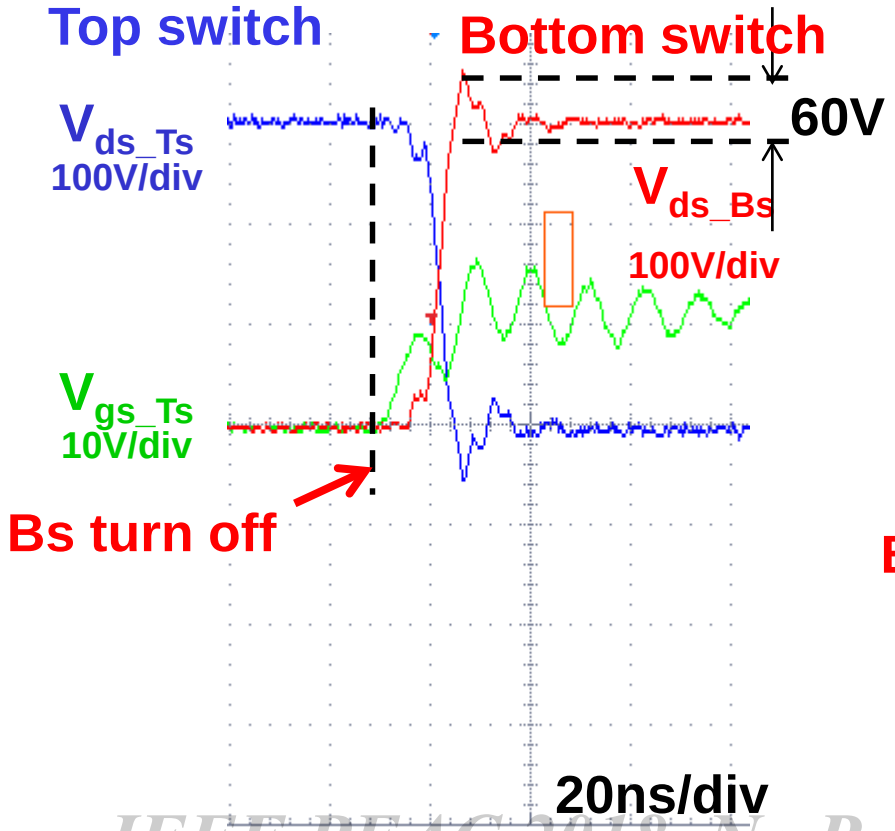
- High dv/dt noise deteriorates the input PWM signal through parasitic capacitance path.

Soft v.s.Hard Switching

DuringTurn On

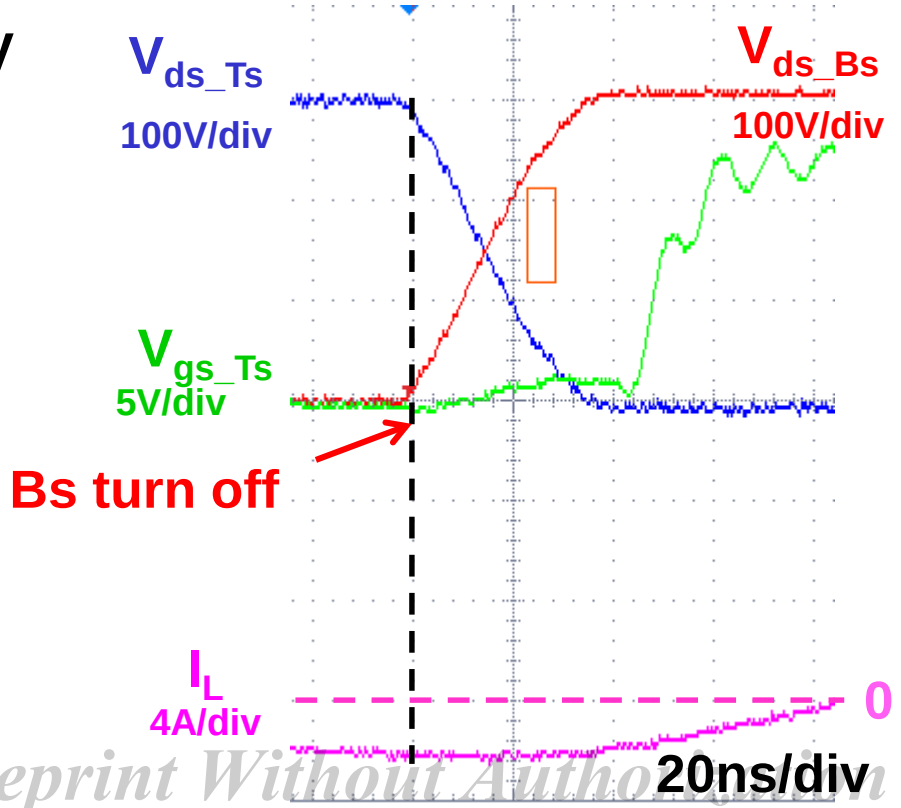
Hard Switching

CCM: L= 250uH, ΔI_{LL}= 0.4A



Soft Switching

CRM: L= 6uH, ΔI_{LL}=14A



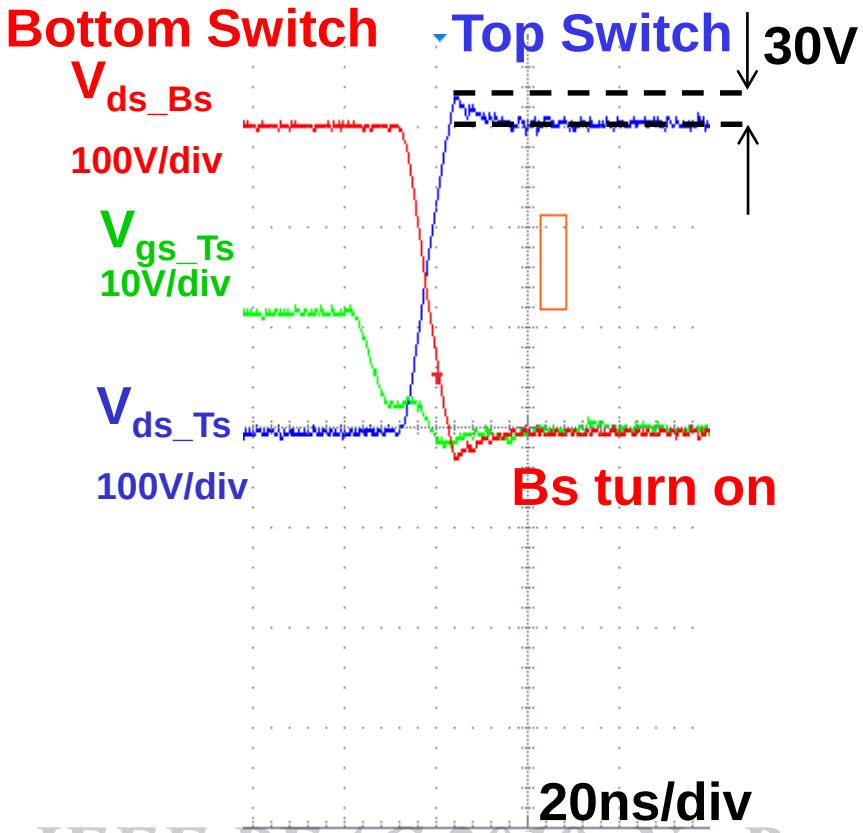
F=500kHz, Vin=300V, Vout = 48V, Iout = 5A

Soft v.s.Hard Switching

During Turn Off

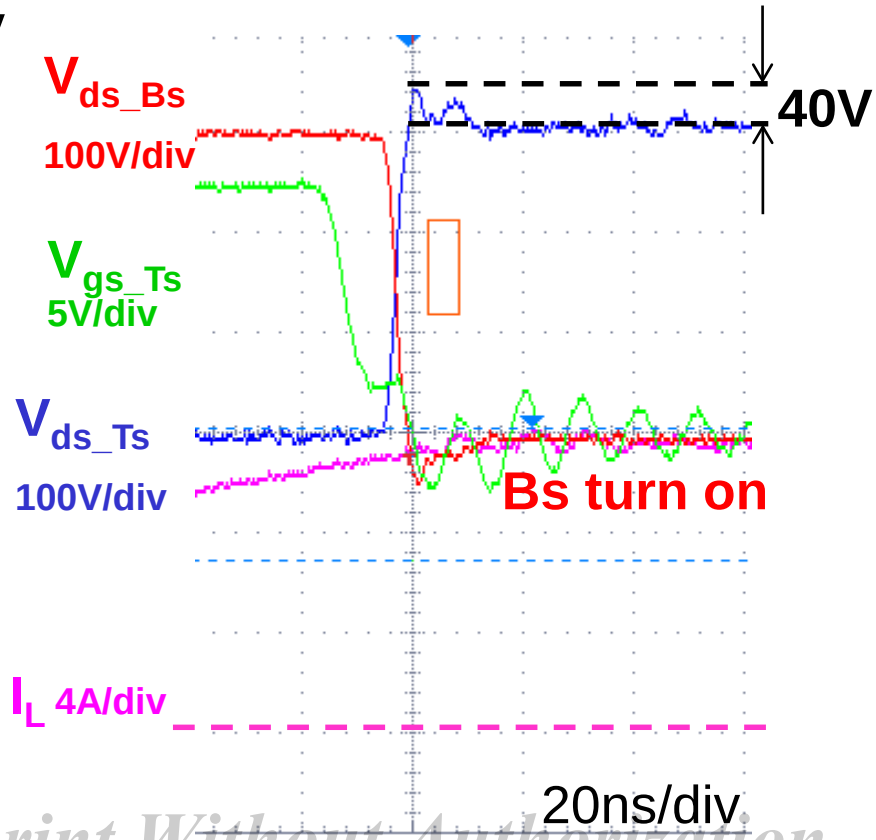
Hard Switching

CCM: L=250uH, ΔI_{LL}=0.4A



Soft Switching

CRM: L=6uH, ΔI_{LL}=14A



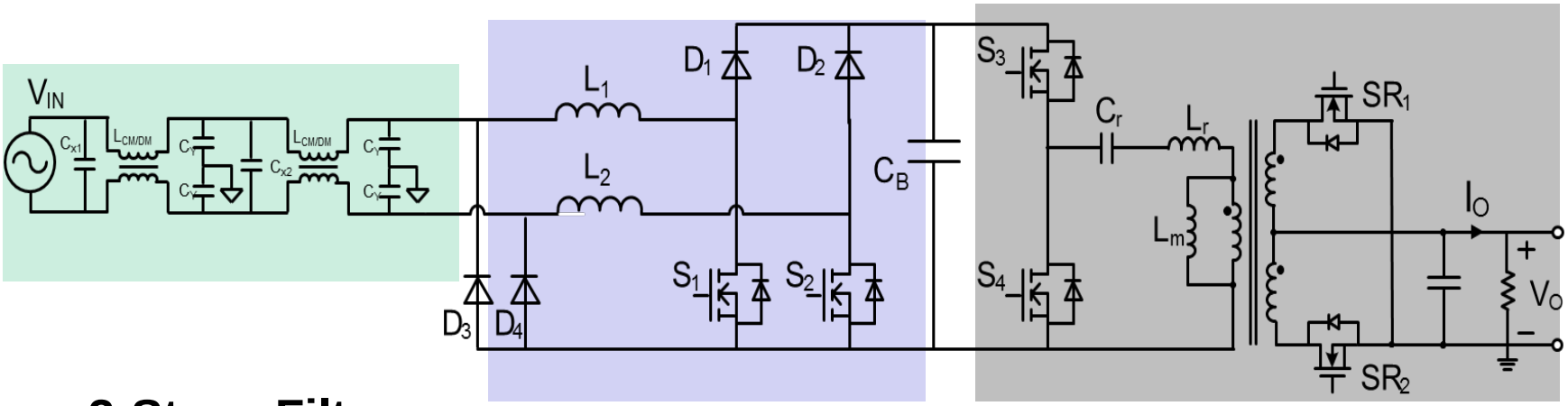
F=500kHz, Vin=300V, Vout=48V, Iout=5A

Demonstrations

1. Server power supplies (1 KW)

2. EV chargers (6.6 KW)

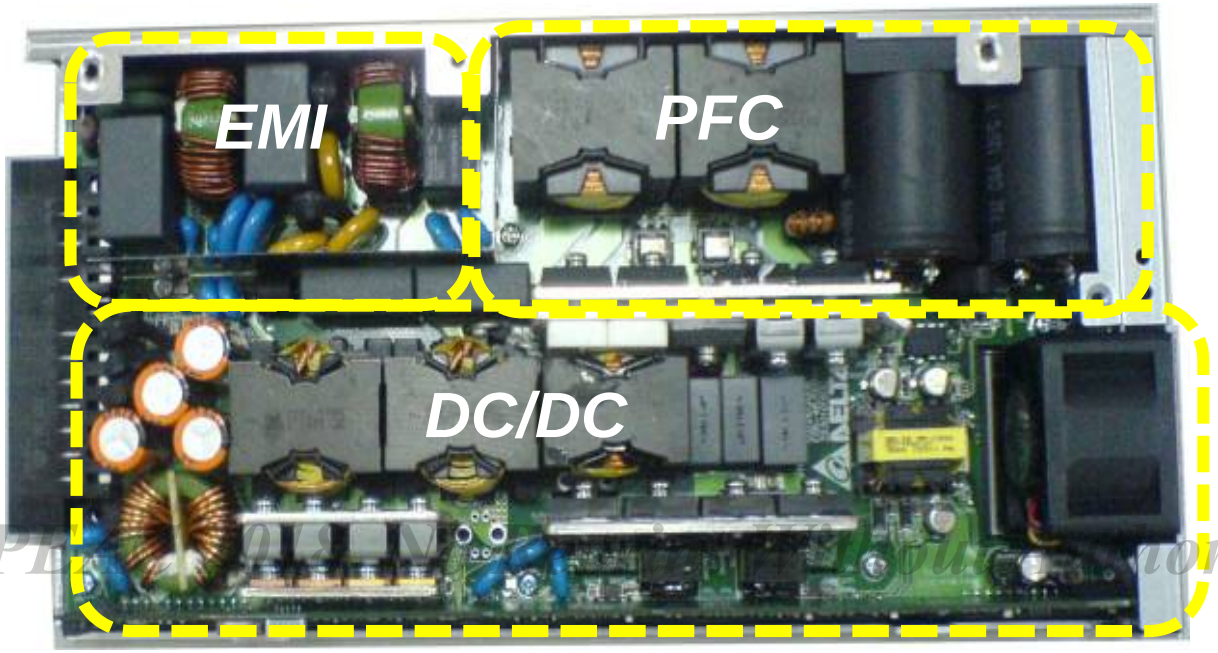
Today's Server Power Supply



2-Stage Filter

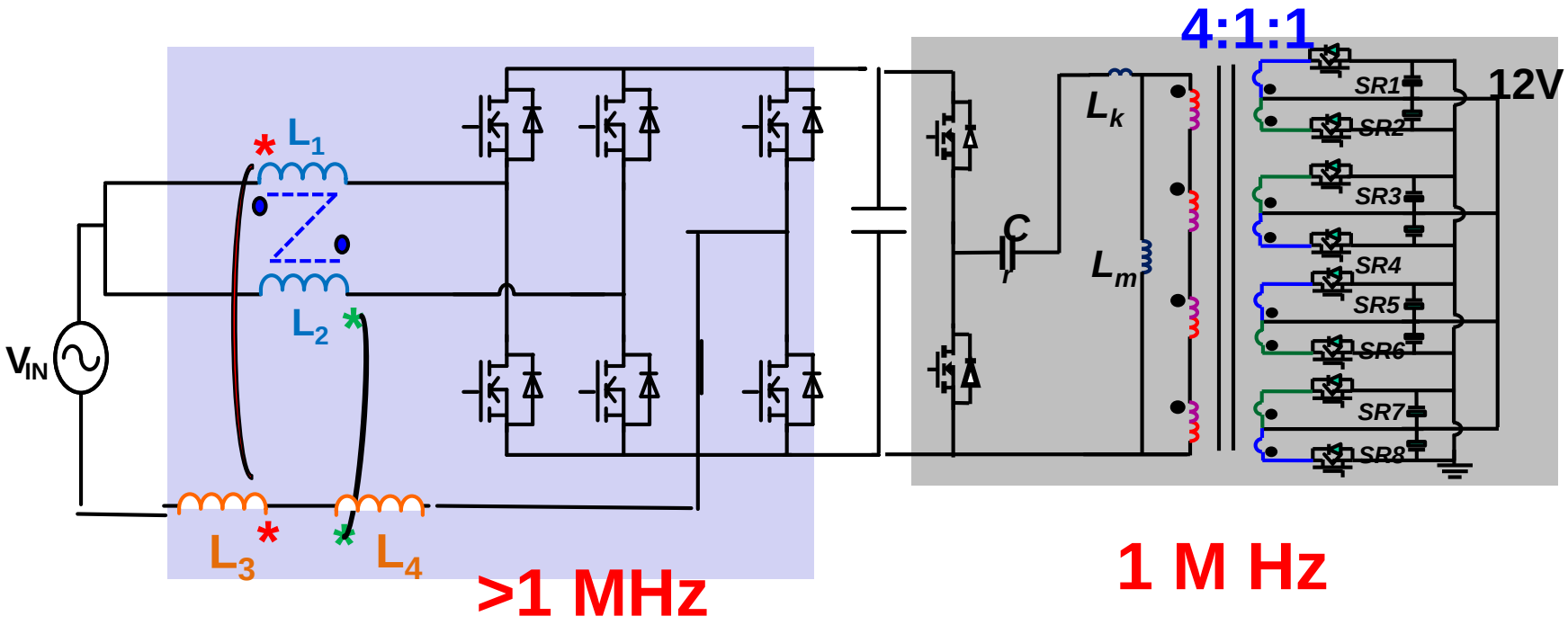
Bridgeless PFC
100KHz

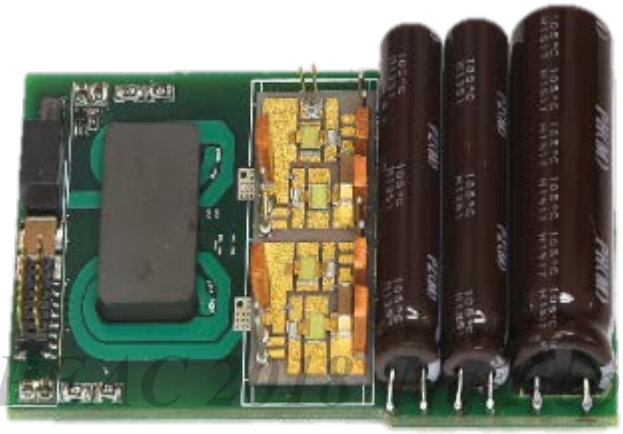
LLC DC/DC
100-200 KHz

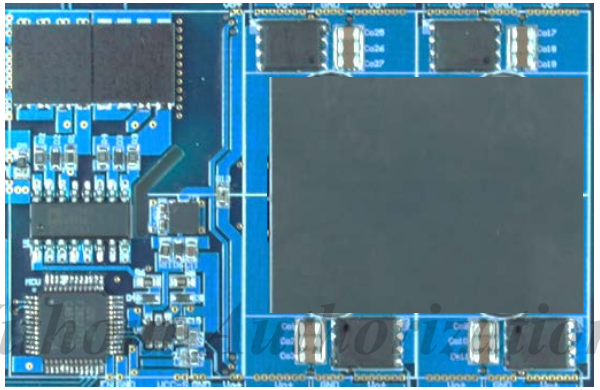


96%
30-40 W/in³

GaN Based Server Power supplies

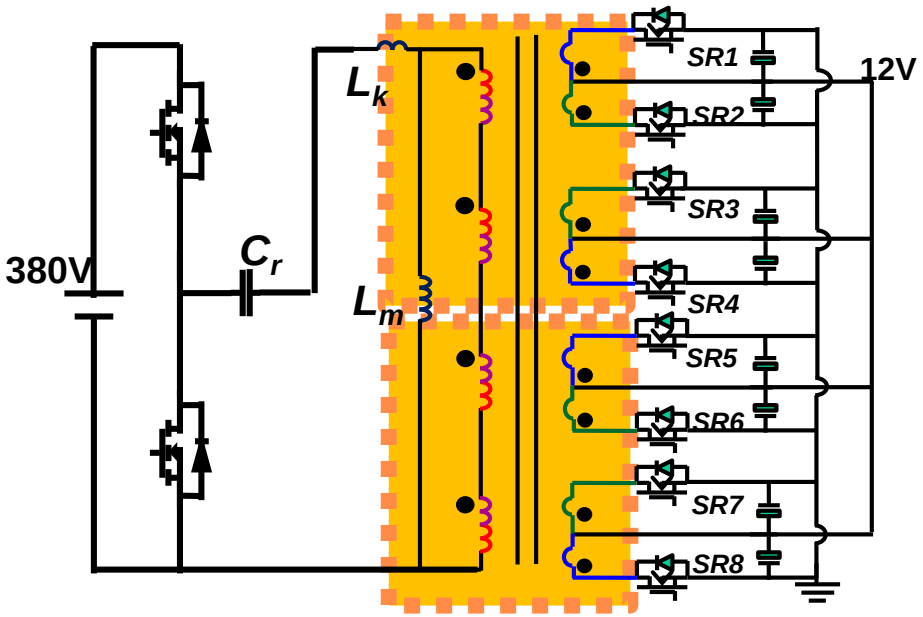


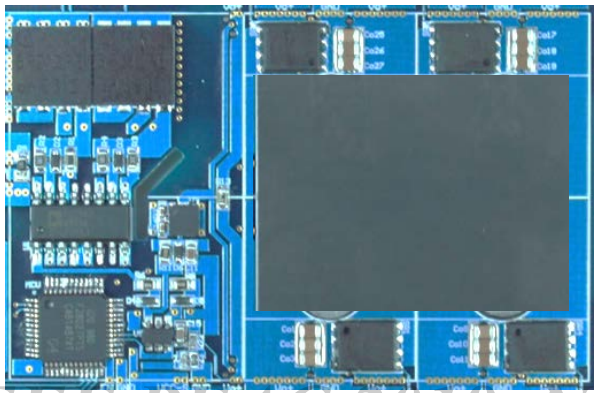




1MHz LLC Converter

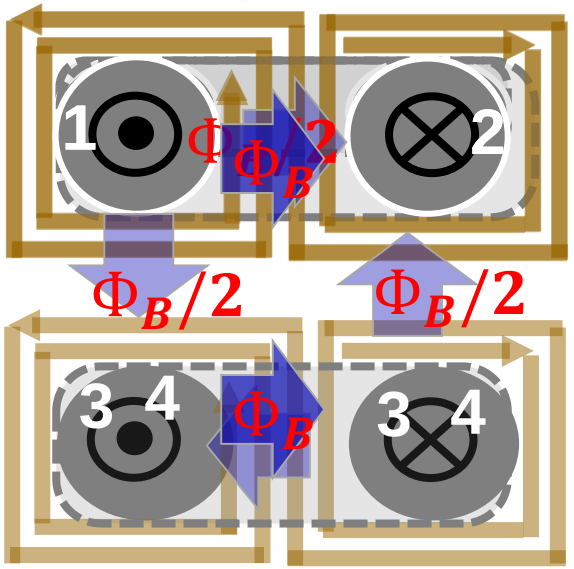
1MHz, 800W



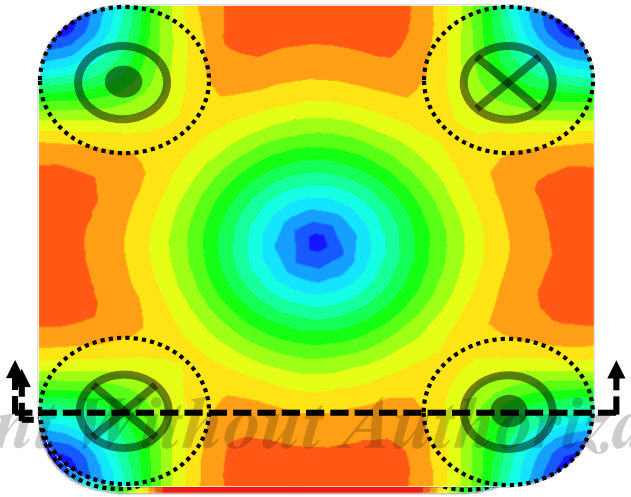


900W/in³ @ 97.6%

4-layer PCB

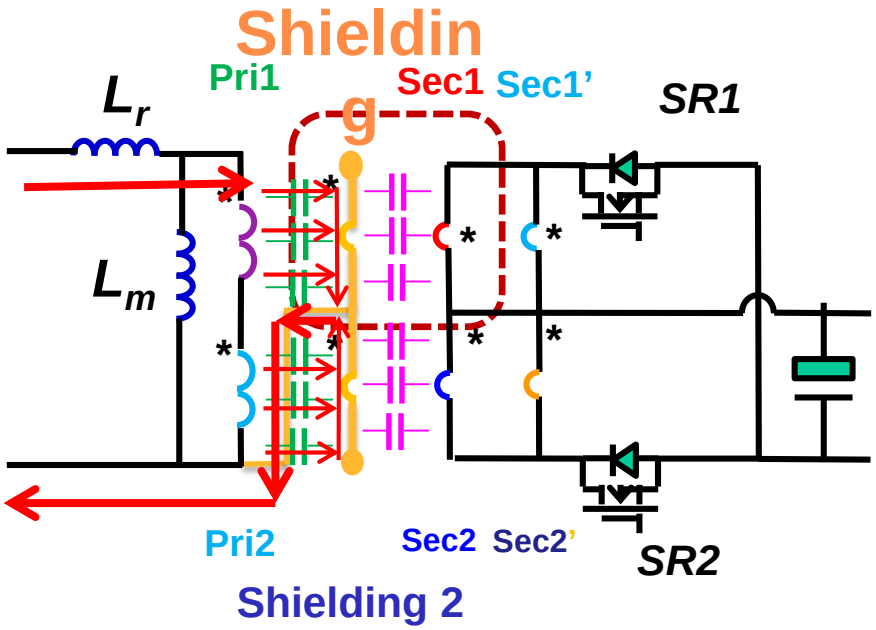


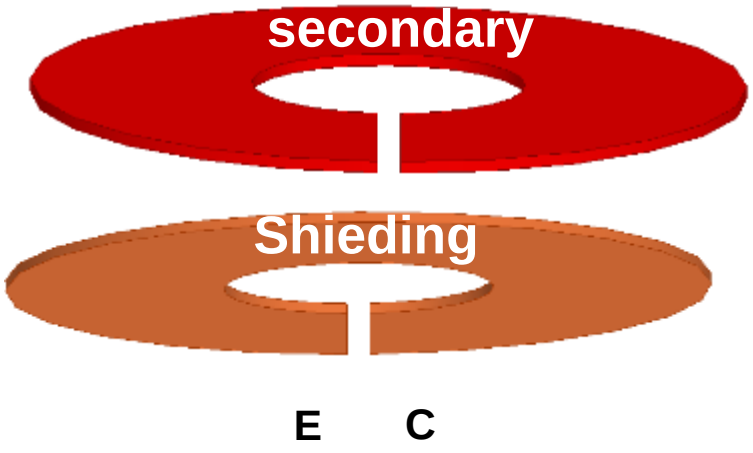
Flux Distribution



Shielding for CM Noise Reduction

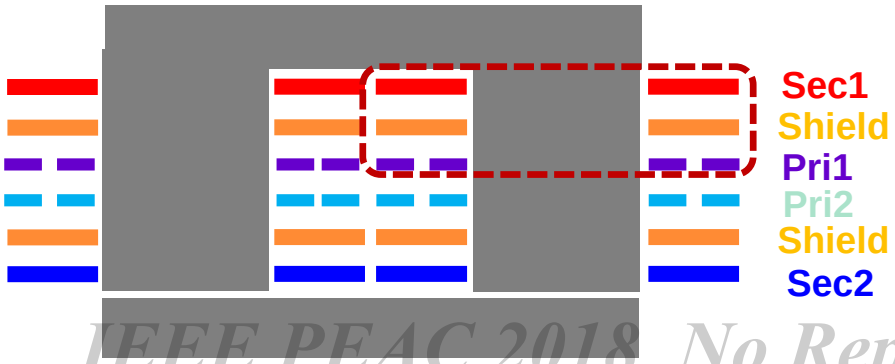
US patent



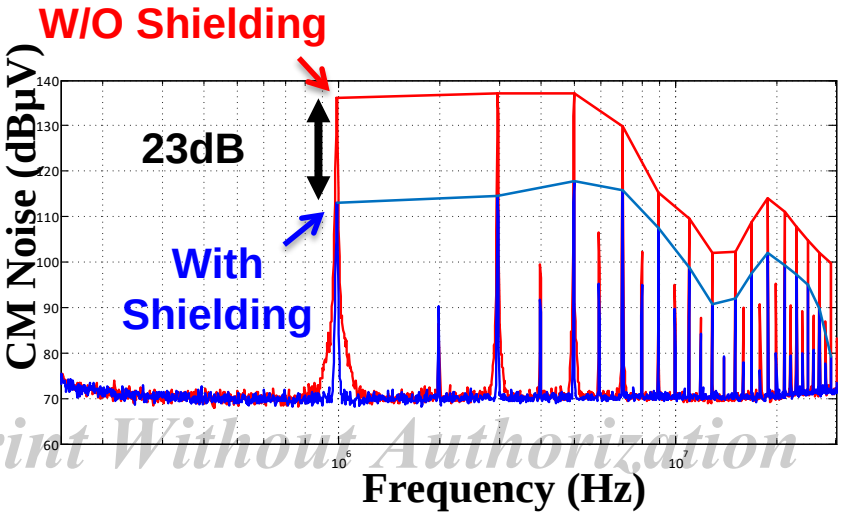


No displacement current

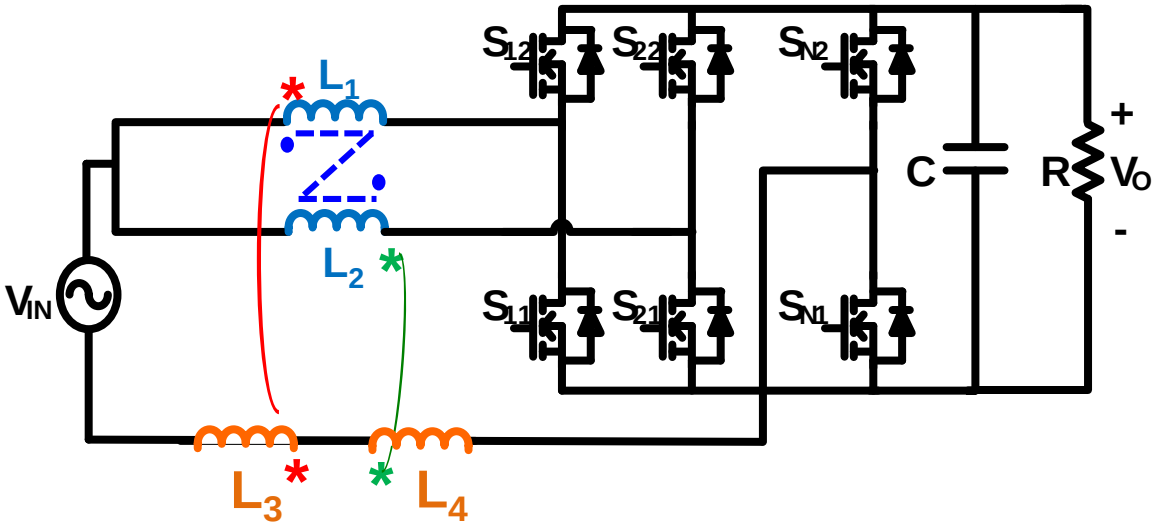
4:1:1

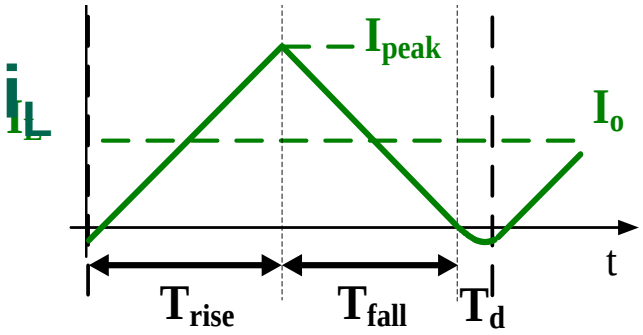


6 layers PCB

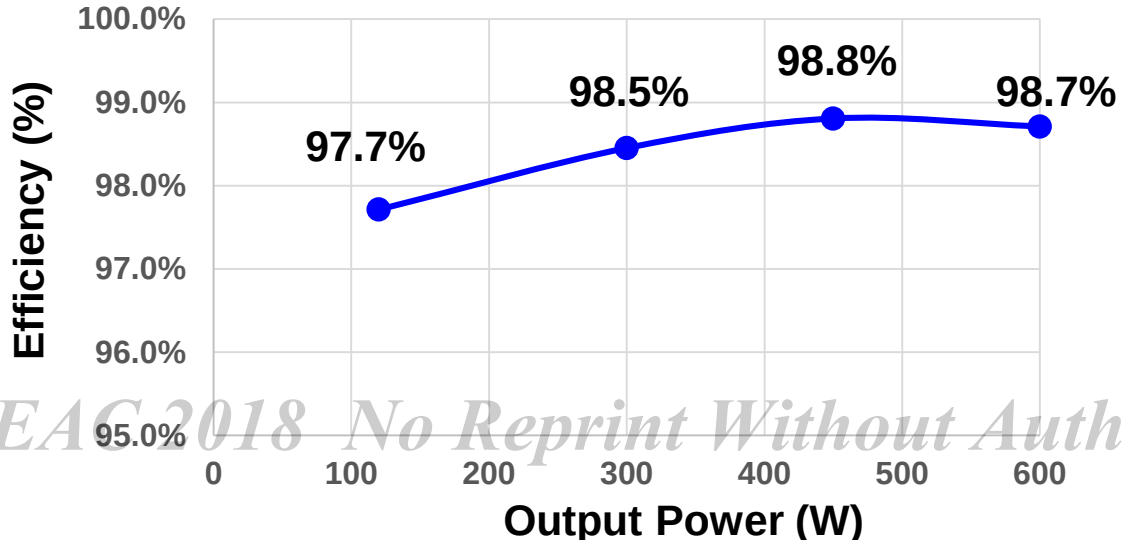


1-3 MHz, 1KW PFC

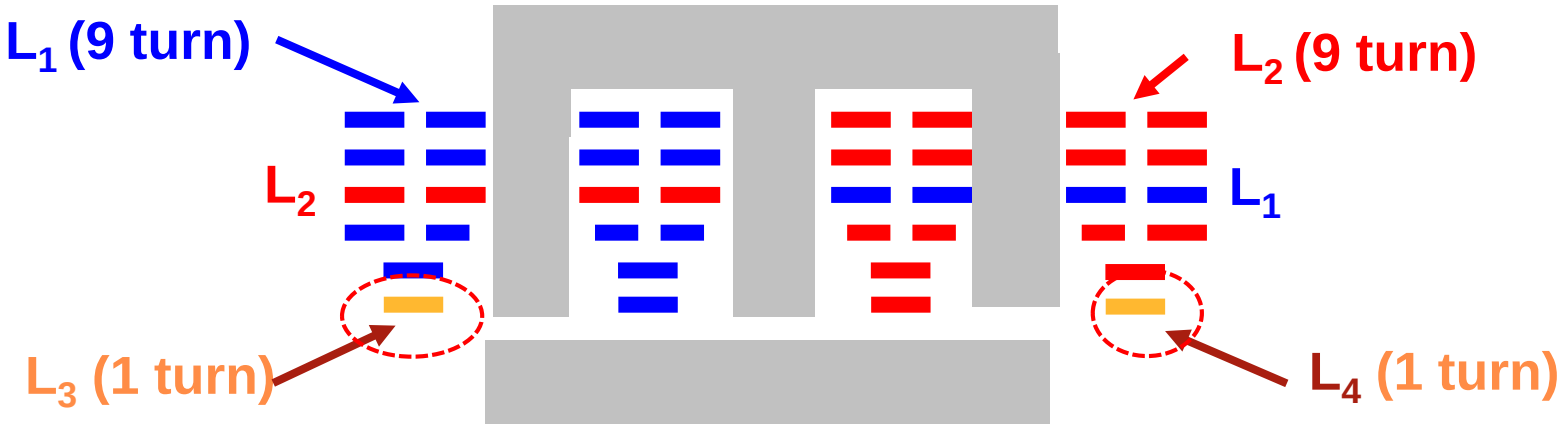




Balance Technique: L_3 & L_4 for CM reduction

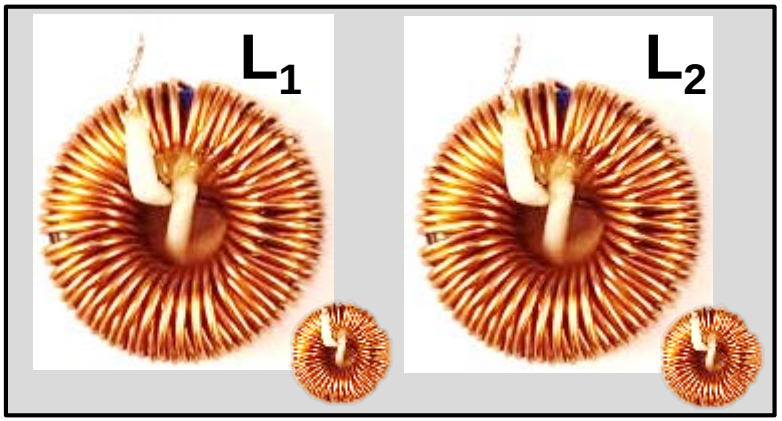


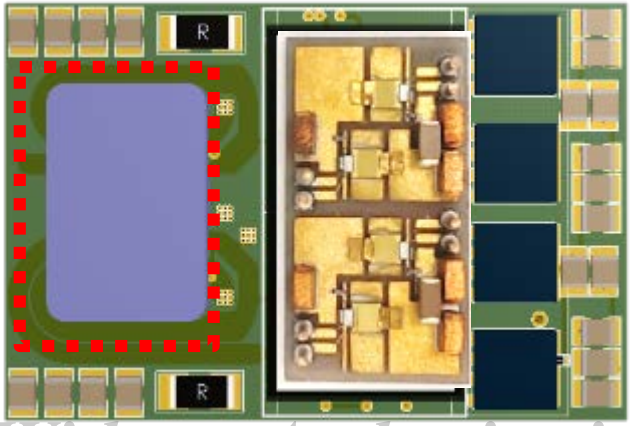
“Balance” for CM Noise Reduction



6 layer PCB

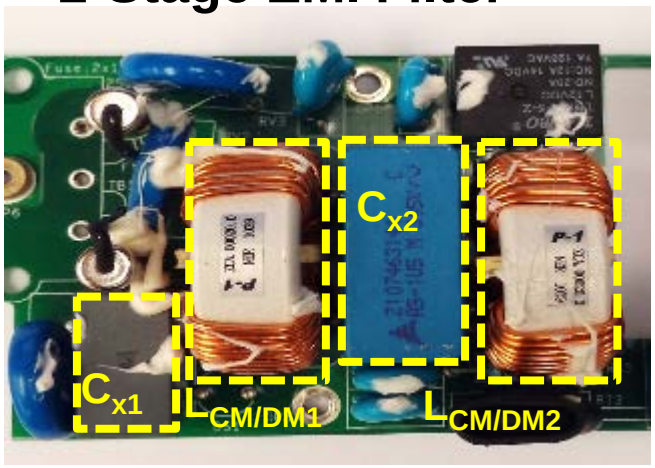
700W/in³ (without cap)



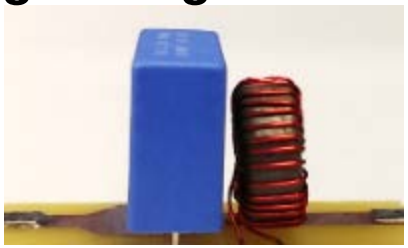


Inductor Integration

2-Stage EMI Filter

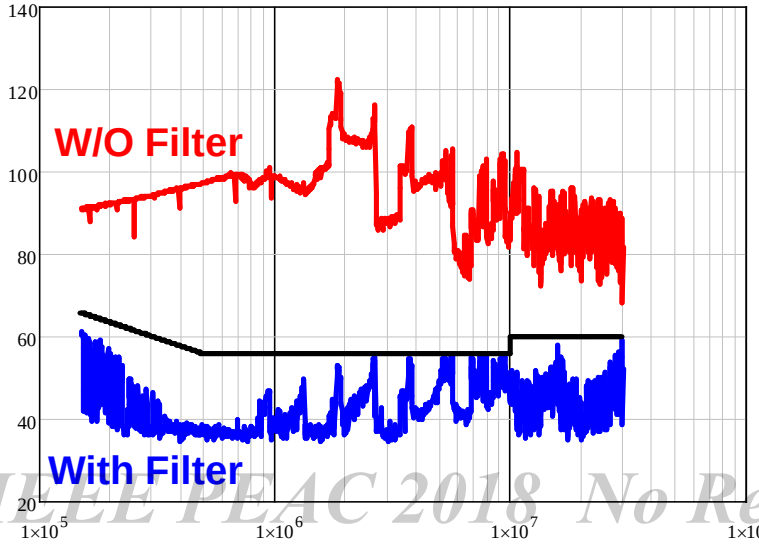


Single-Stage EMI Filter

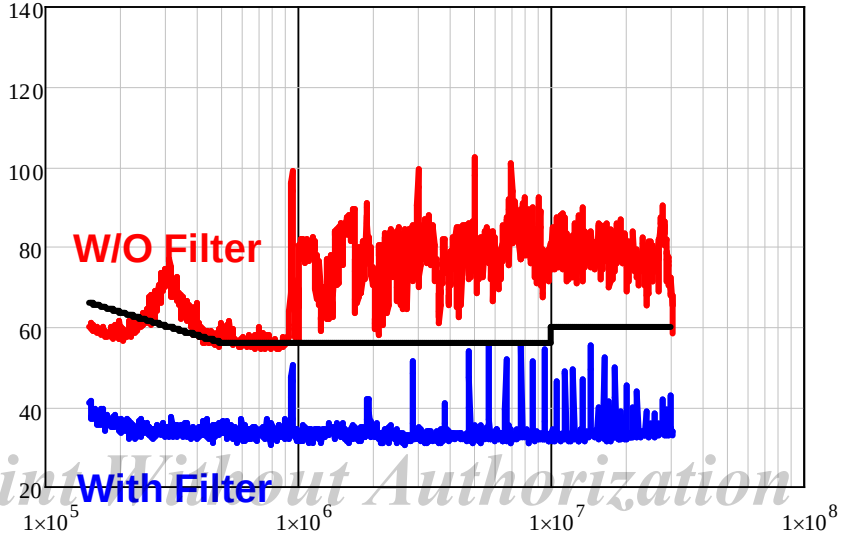


75% volume reduction

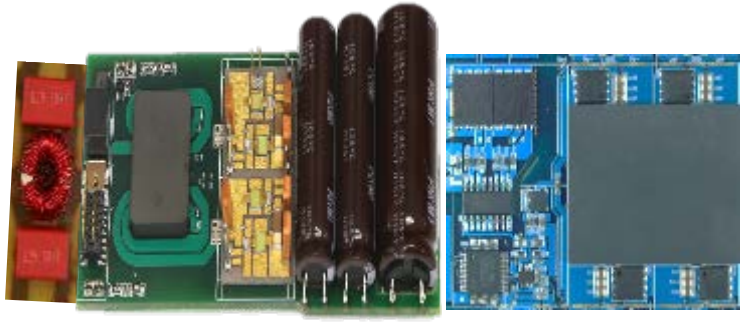
DM Noise



CM Noise



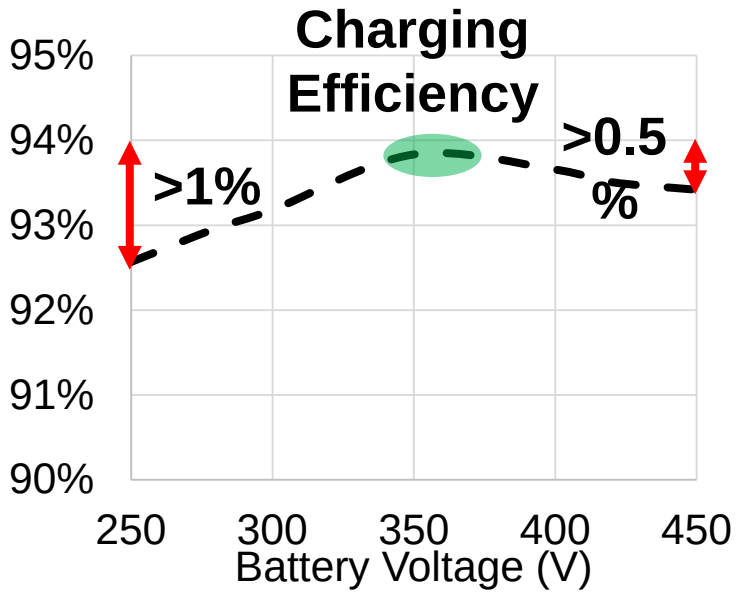
Manufacture Paradigm

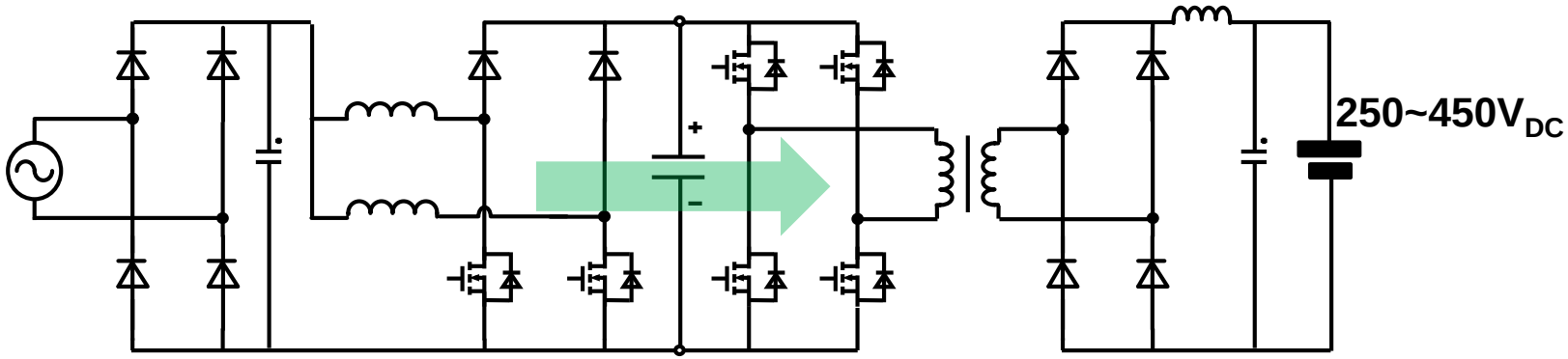


Automated Manufacturing

Conventional On-Board Charger

6.8KW Bidirectional OBCl



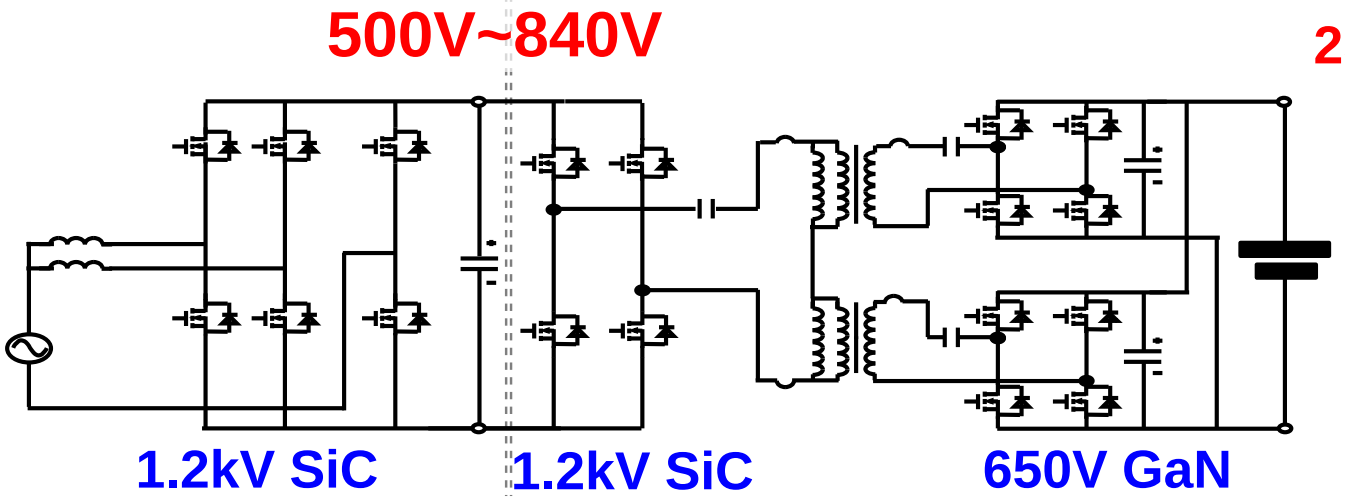


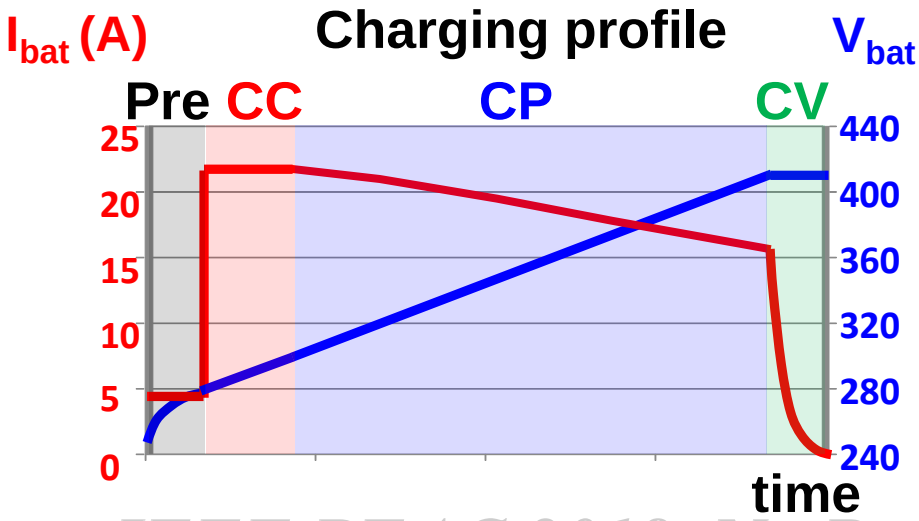
Dual Boost PFC (CCM) **20-50kHz 96% peak eff.**

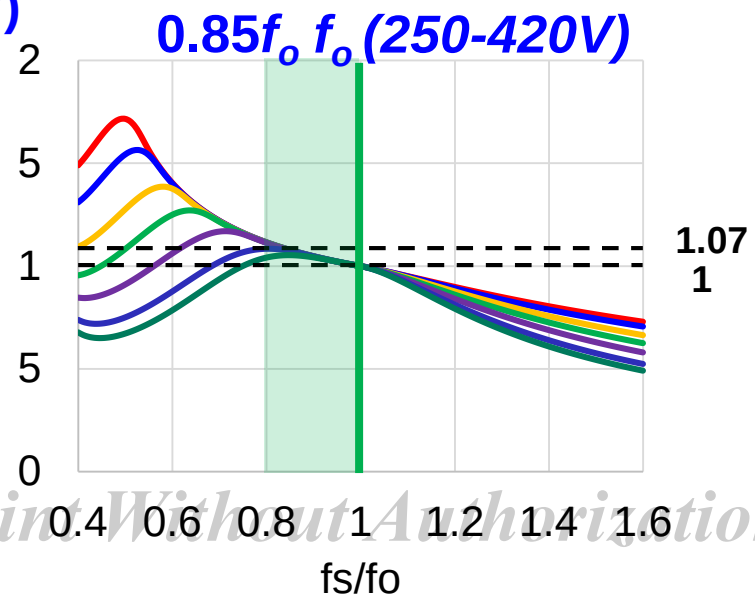
Phase Shift Full Bridge **20-50kHz 96% peak eff.**

Proposed On-Board Charger

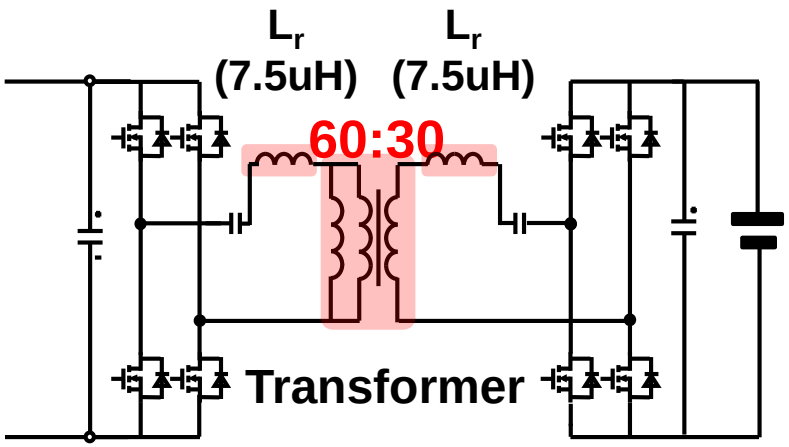
Proposed Design: Variable DC-Link Voltage

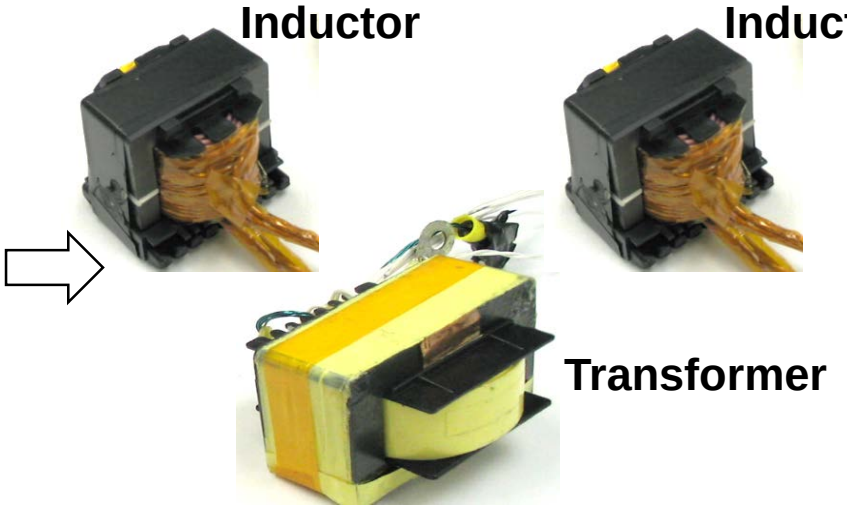




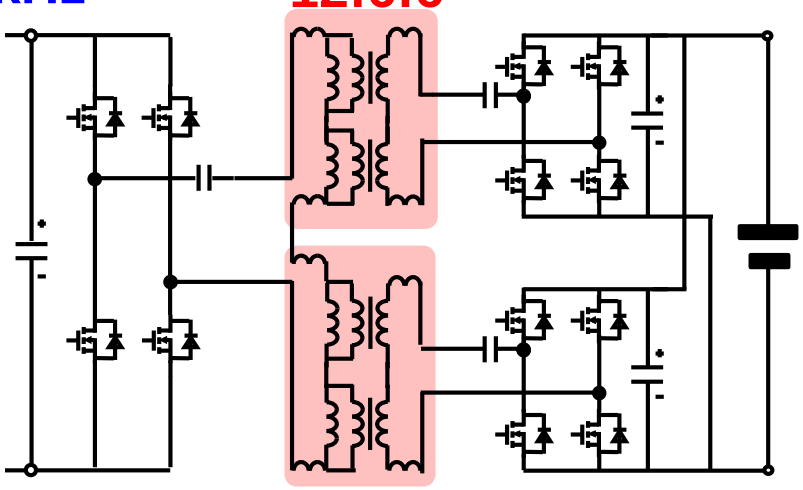


PCB Based Magnetic Integration





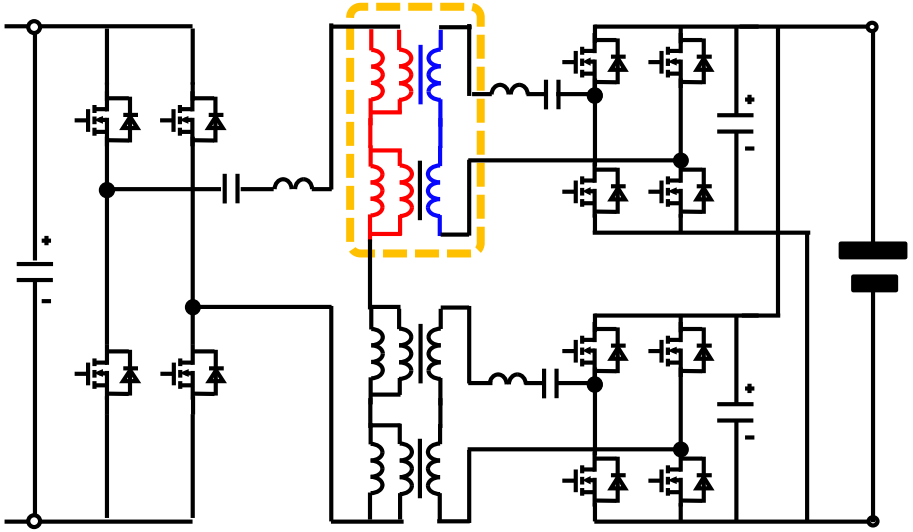
500kHz

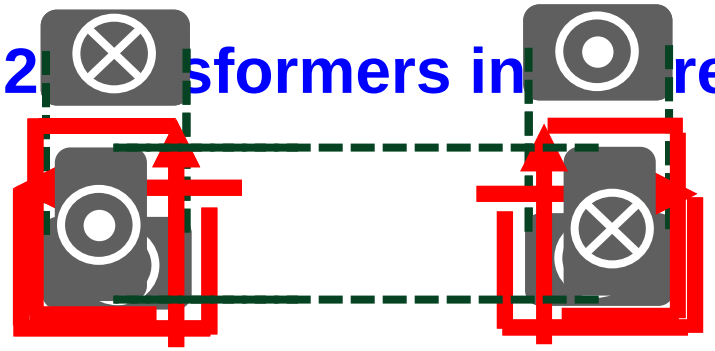


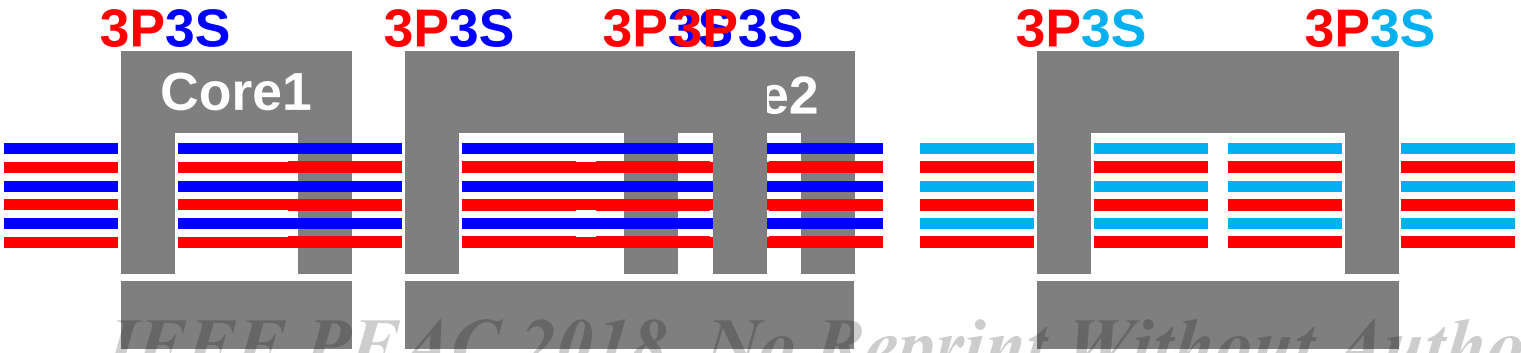
Transformer
+ L_r(1.5uH)

Magnetic Integration

w/ Flux Cancellation

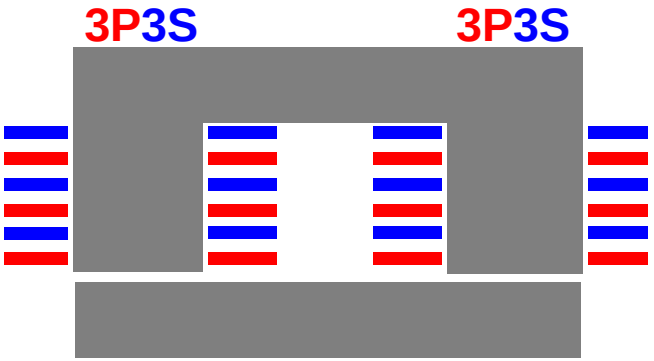


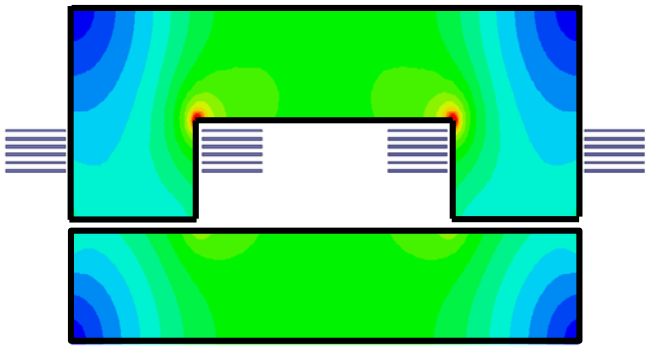




Built-in Leakage Inductors

UI Core



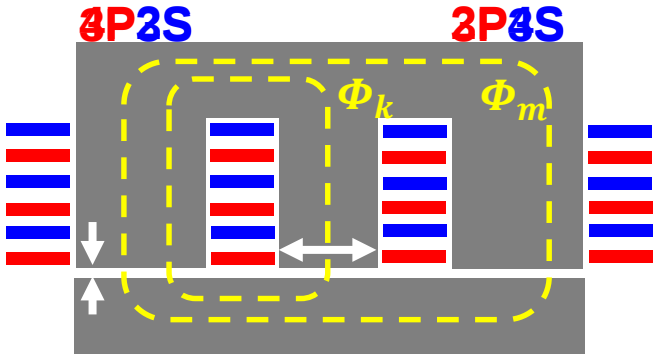


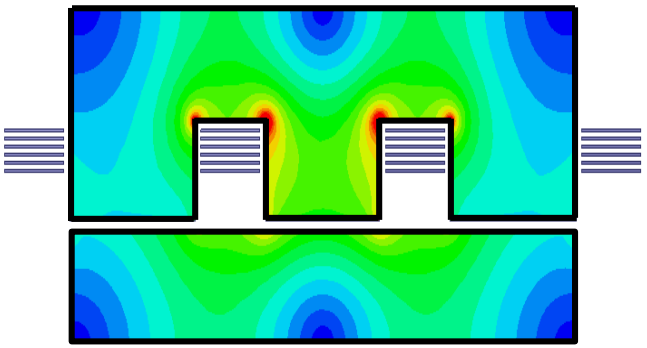
L_m= 17uH

L_r = 103nH << 1.4uH

Leakage inductance is too small to be useful

Built in Leakage Inductance



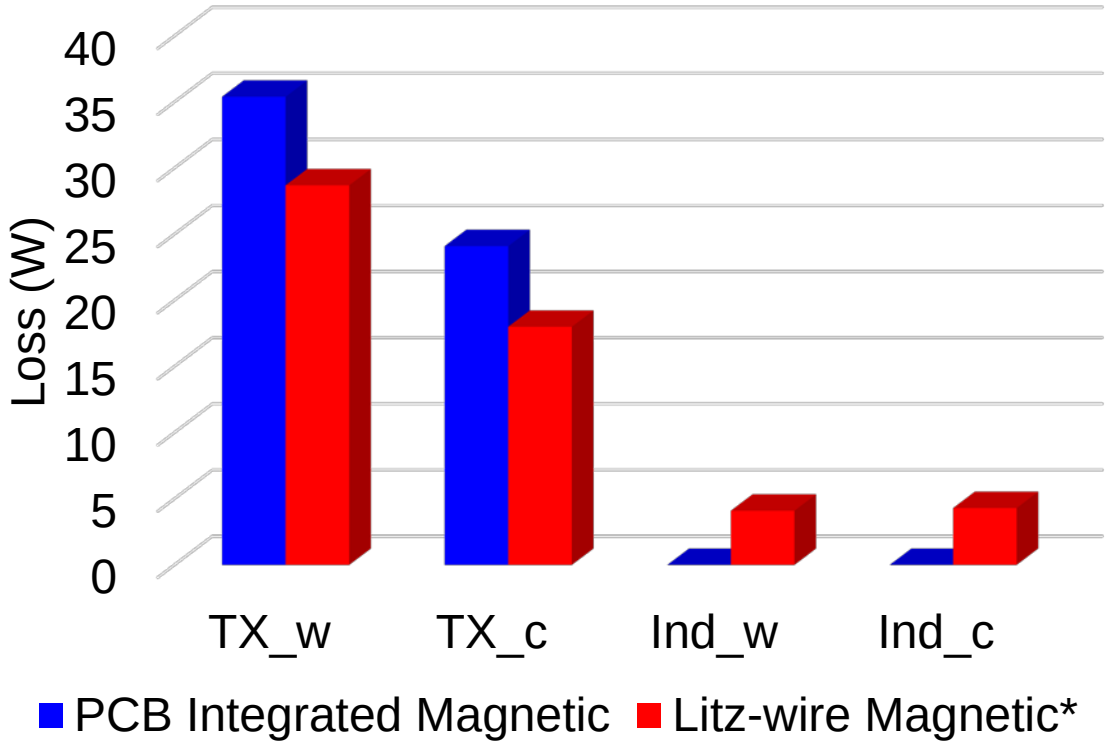


L_m= 17uH L_r = 1.4uH

- L_m is controlled by air gap.
- L_k is controlled by center leg area.

B (Tesla)
0.1
0.08
0.06
0.04
0.02
0

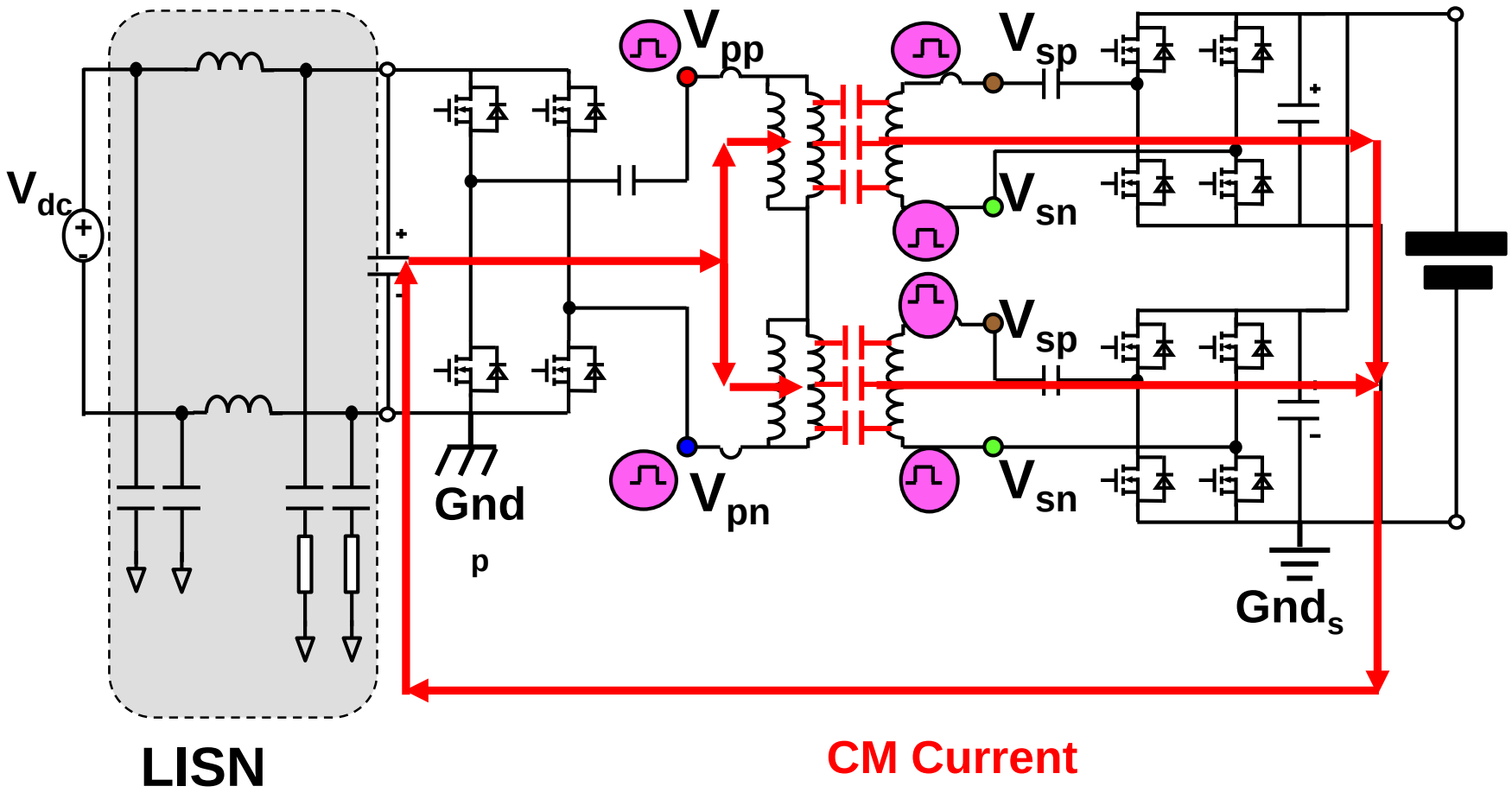
PCB Transformer Trade off



Total Loss	59.5W	55.1W
Total Volume	135cm^3	140cm^3

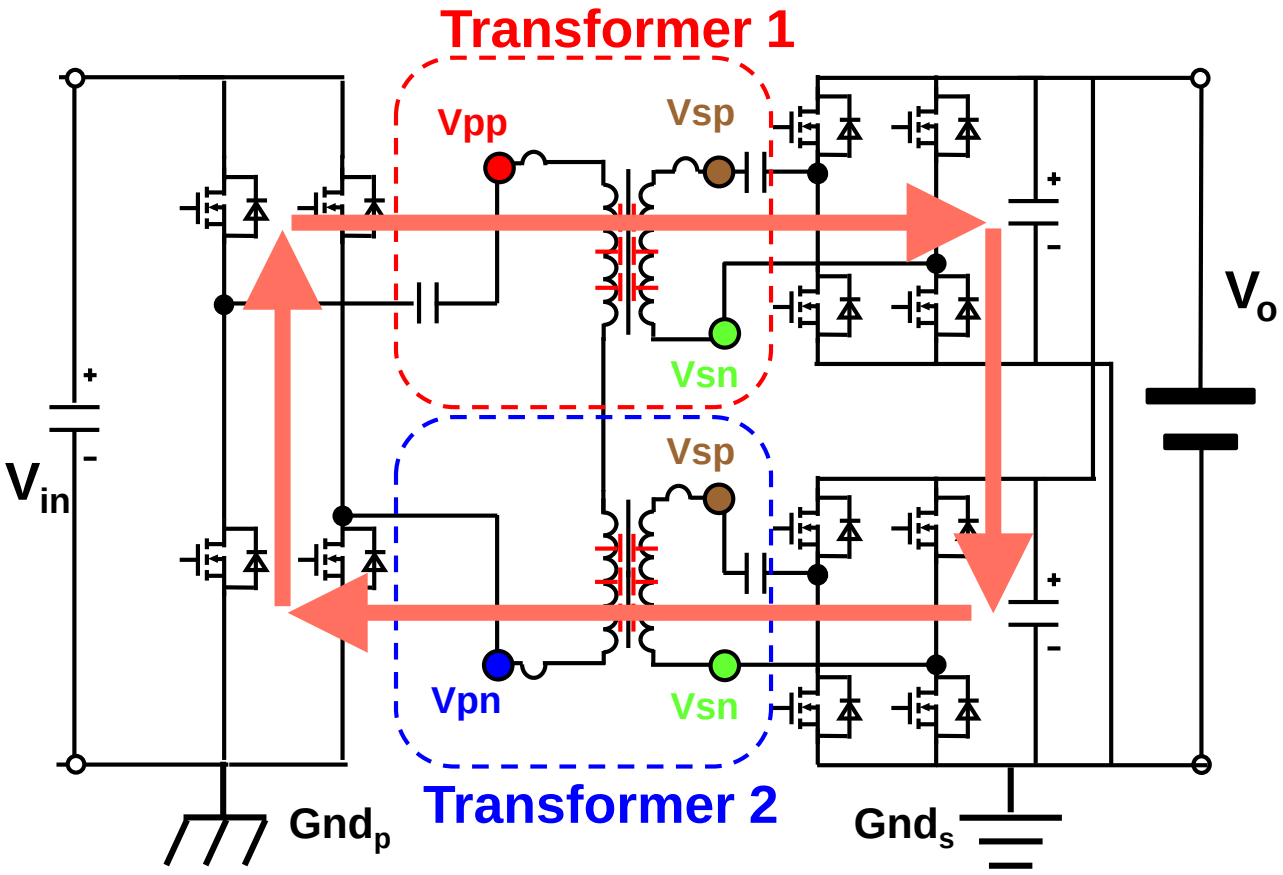
***AWG48/2000 for litz-wire design**

CM Current



CM Noise Suppression

Using Cancellation Concept

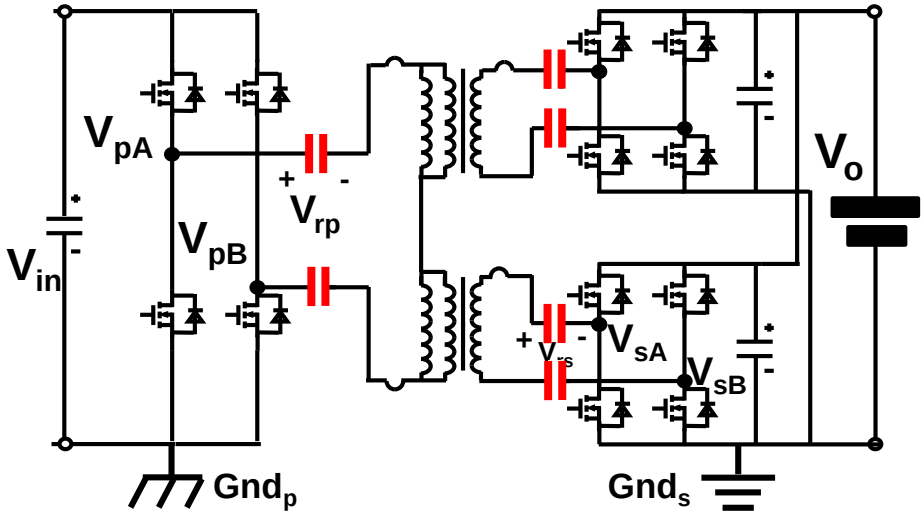


If Tr1 and Tr2 have

- **Complimentary noise sources**
- **Complimentary noise path**

CM current will circulate only within the two transformers

Complimentary Noise Sources



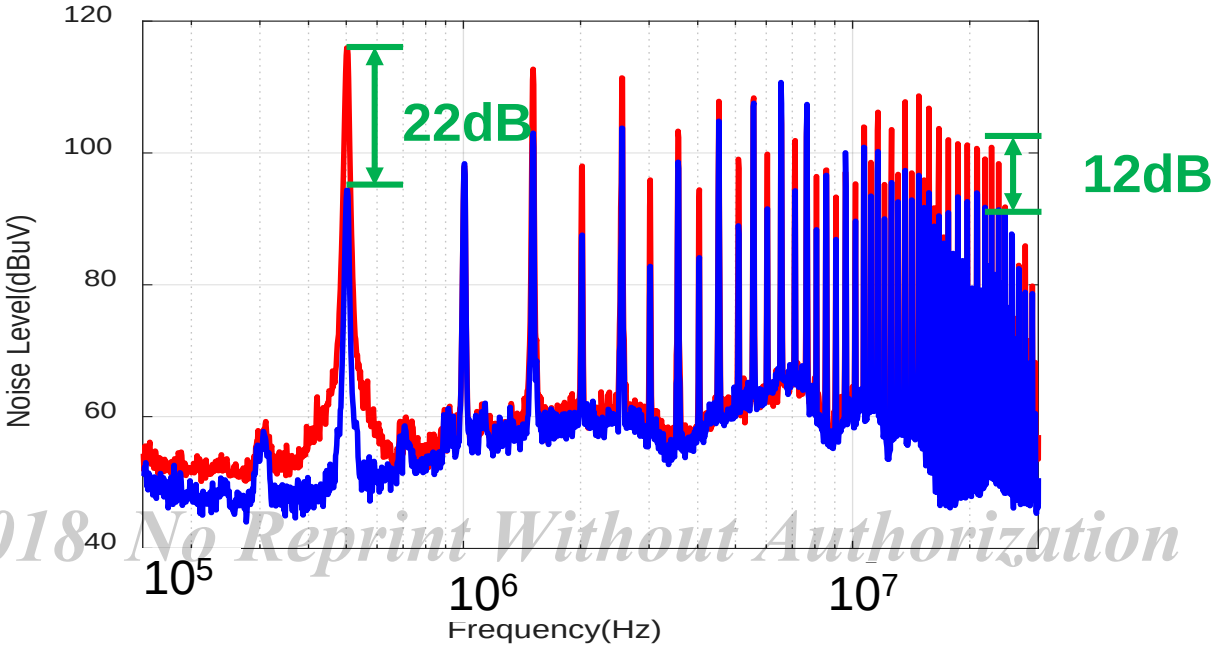
Noise sources are complimentary

Also need complimentary noise paths

Unsymm TX

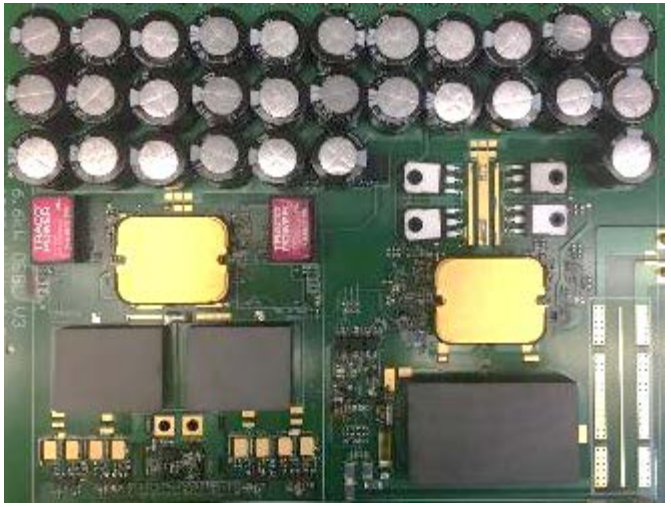
Single Cap

Symm TX
Split Cap

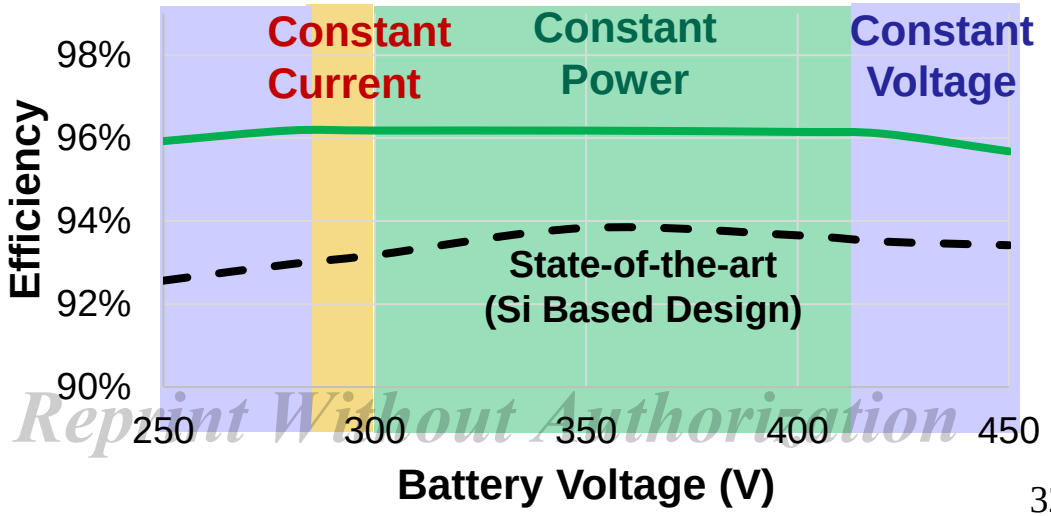


On-Board Charger

IGBT Version @ 20kHz



SiC/GaN; 43W/in^3 **3X**



40% energy saving per charging cycle

Summary

GaN to Replace Silicon

- Improvement of Efficiency (1%-2%)
- Improvement of Power Density (5X-10X)
- Improvement of EMI/EMC (20dB)
- Improvement of Manufacturability
  - Paradigm shift
- Cost ???

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Thang You