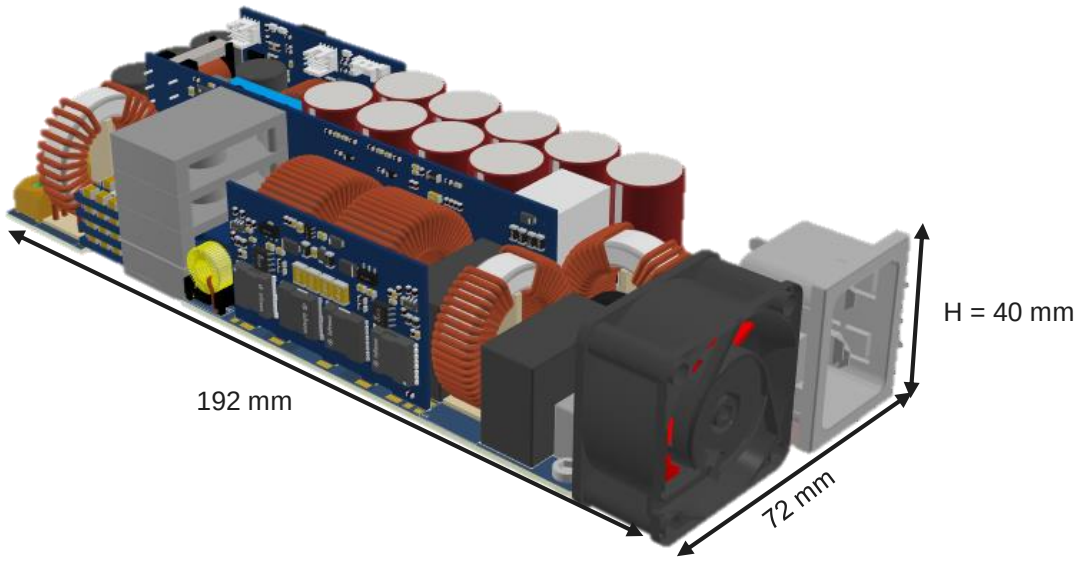
500 kHz high density 3 kW GaN rectifier for server and telecom applications

April 2024

3 kW high frequency and high power density (HF/HD) rectifier REF_3K3W_HFHD_PSU



Parameter	Value
Input voltage range	180 V_{AC} ~ 275 V_{AC}
Output voltage range	51 - 48 V_{DC}
Output current nominal	@ 51 V = 65 A @ 50 V = 66 A @ 48 V = 69 A
Output power maximum	3300 W
Efficiency target	~97.5 % (without fan)
Power factor (load > 10%)	PF > 0.95 @ 180 ~ 275 V_{AC} iTHD < 10 % @ 180 ~ 275 V_{AC}
Ambient temperature	0 °C to 50 °C
LLC Resonant frequency	530 kHz
Learn more	
Infineon components	IMT65R057M1H, IGT60R042D1, IPT60R022S7, IPT60R080G7, IDL10G65C5, 2EDB9259Y, 1EDN8511B, 1EDN8550B, 1EDB8275F, IQE046N08LM5, ICE2QR2280G, BAT46WJ, BAT165, BSS138N, XMC4200, TLS4120D0EPV33, 4DIR1400H
Application	Industrial SMPS, Telecom Rectifier

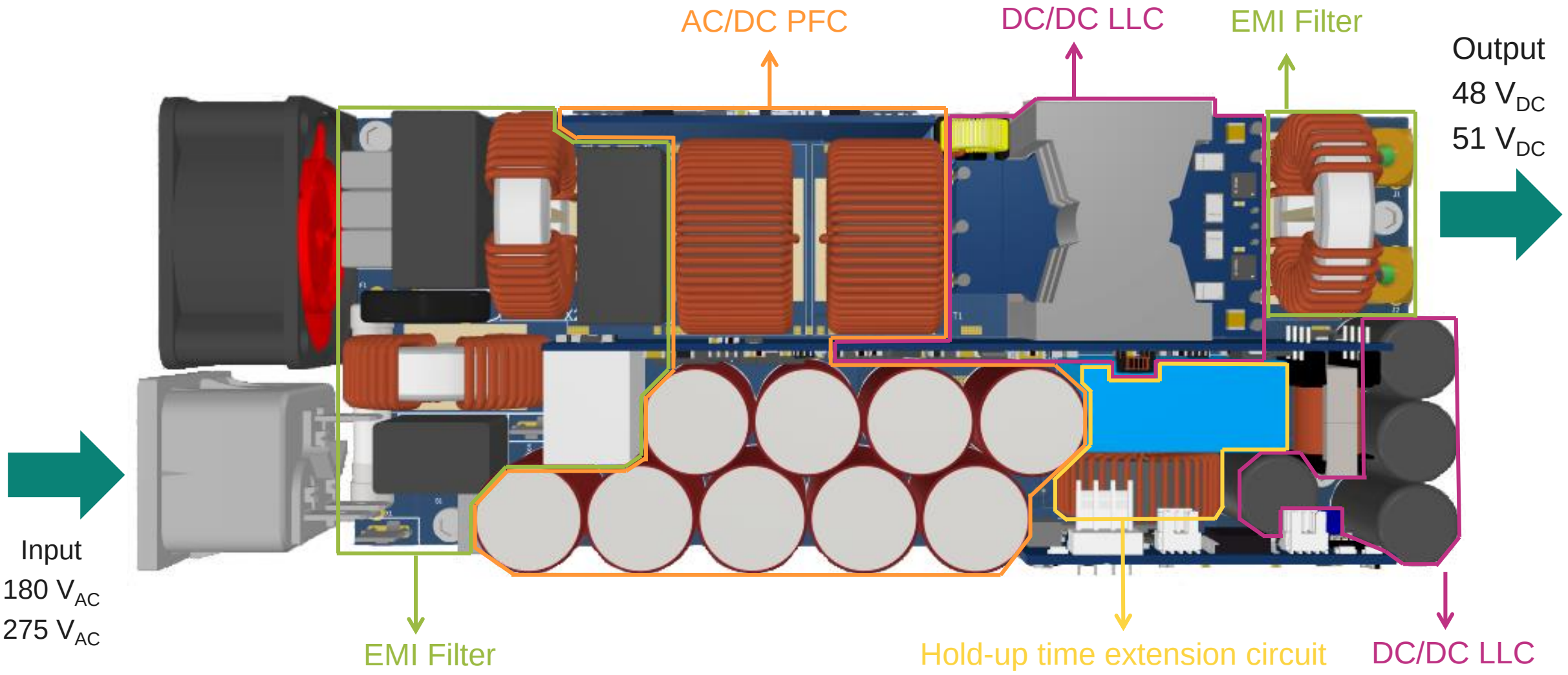
Features

- **Benchmark 97.4% of efficiency:** **~96W/in³** in 1U form-factor
- Highest efficiency & power density with CoolMOS™, CoolSiC ™, CoolGaN™
- Custom integrated planar magnetic construction
- Full digital control (PFC and DCDC)
- Totem-pole SiC PFC + half-bridge GaN LLC

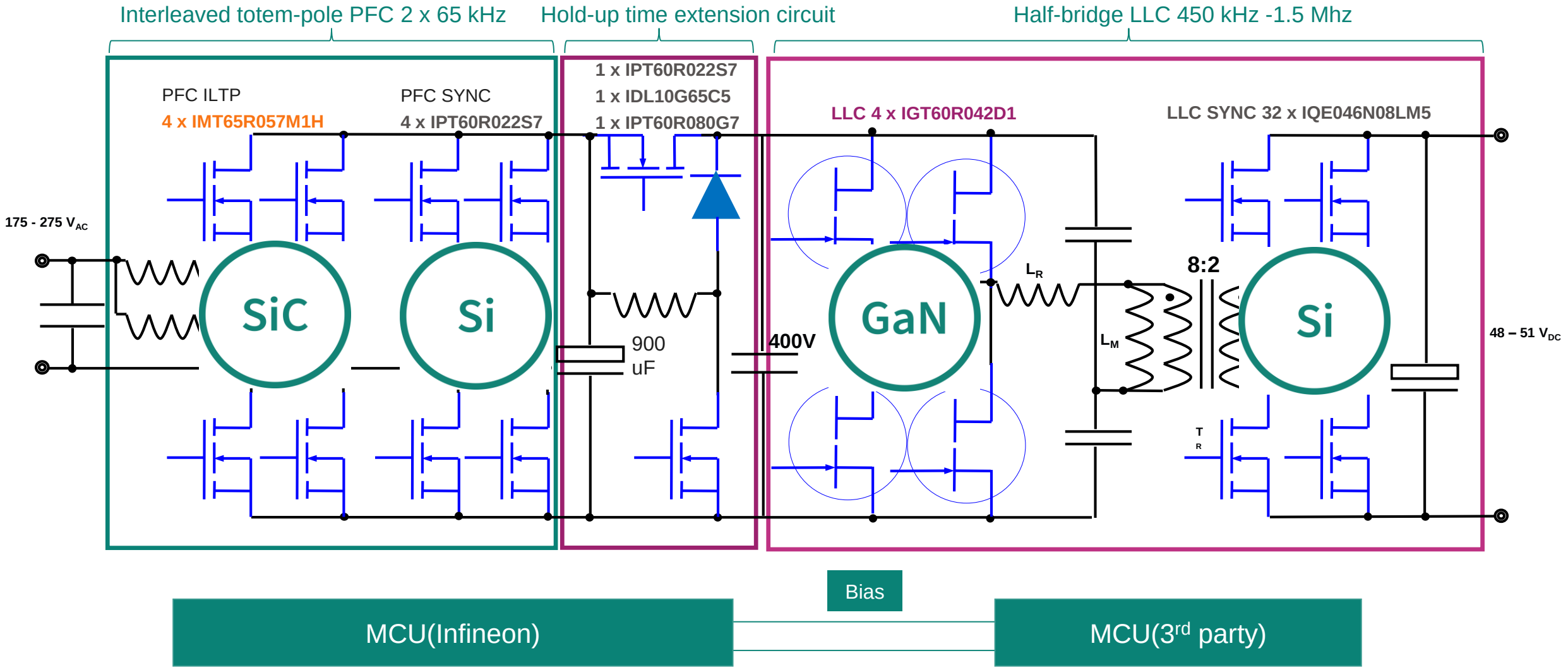
Benefits

- Full Infineon semiconductor solution
- Complete power supply unit (PSU) including PFC + DCDC
- High efficiency, custom and in-house design integrated magnetics
- Hold up time extension circuit

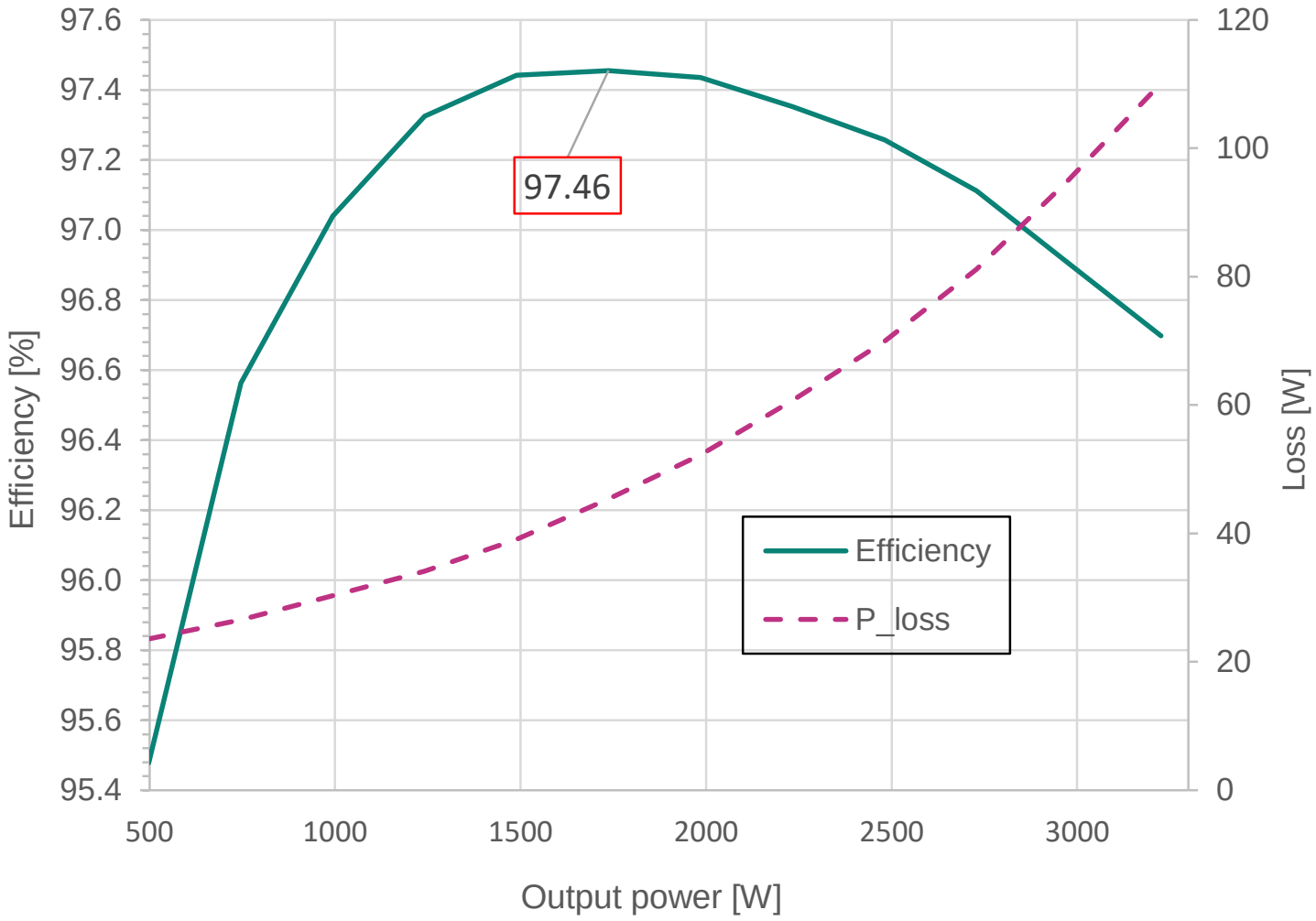
Board hardware overview

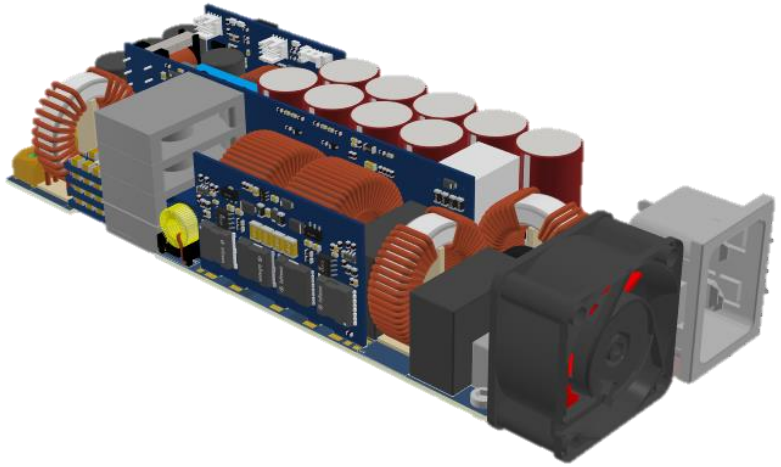


Basic schematic of the HF/HD rectifier



Measured efficiency of the full PSU

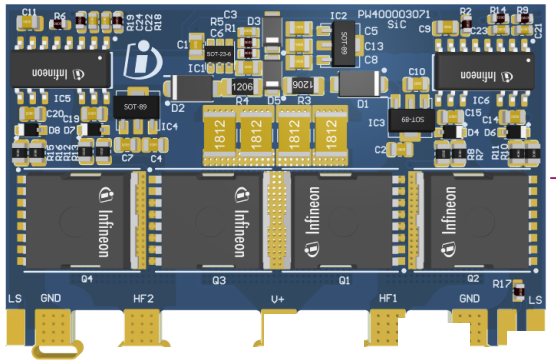




- Measurement conditions:
- V_{in} = 230 V_{AC}
- V_{out} = 50 V_{DC}
- I_{out} up to 65 A

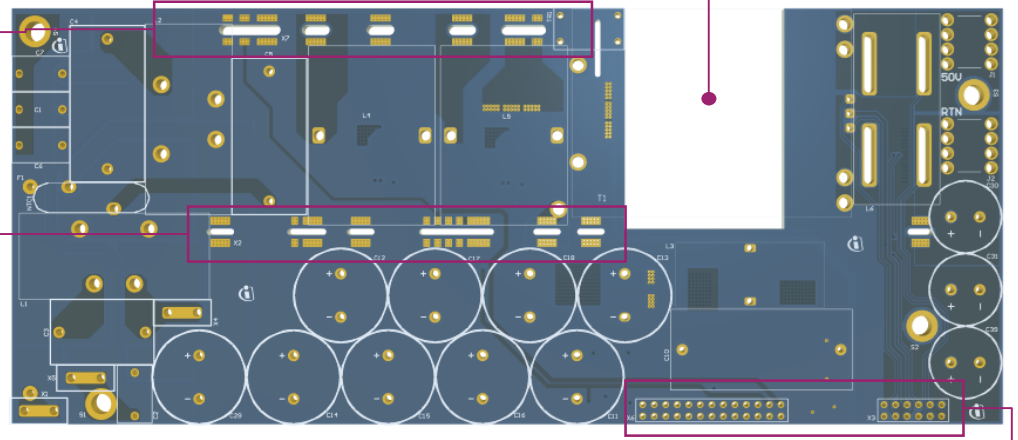
Sub-assembly

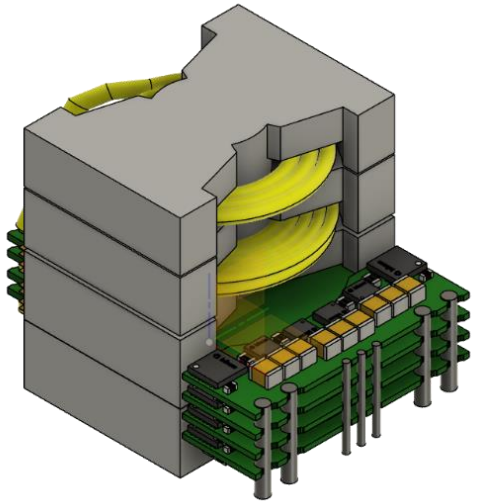
Overview of the sub-assembly



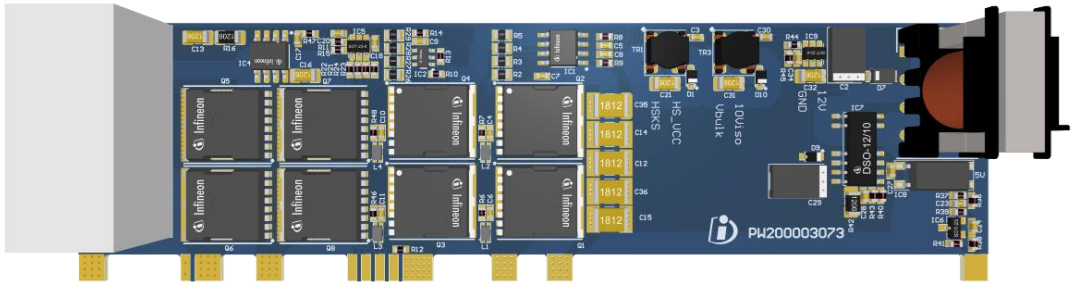
Interleaved totem-pole PFC

Main board, input and output EMI filters, electrolytic capacitors, hold up time circuit.

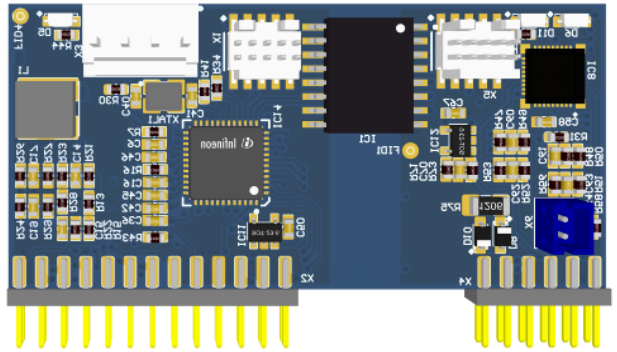




Main transformer, series inductor, parallel inductor and including rectifiers.



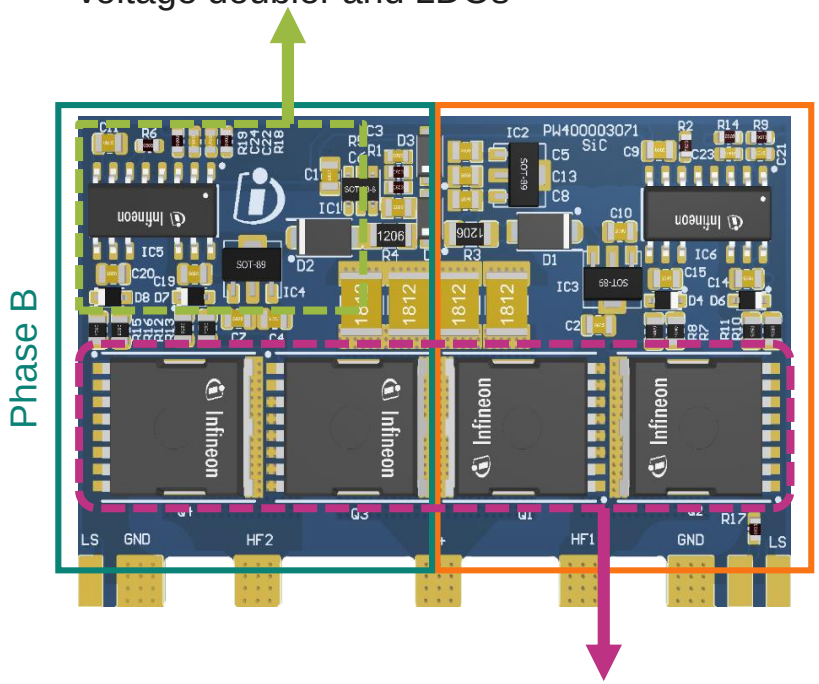
Half Bridge LLC, auxiliary fly-back and totem-pole grid rectifiers



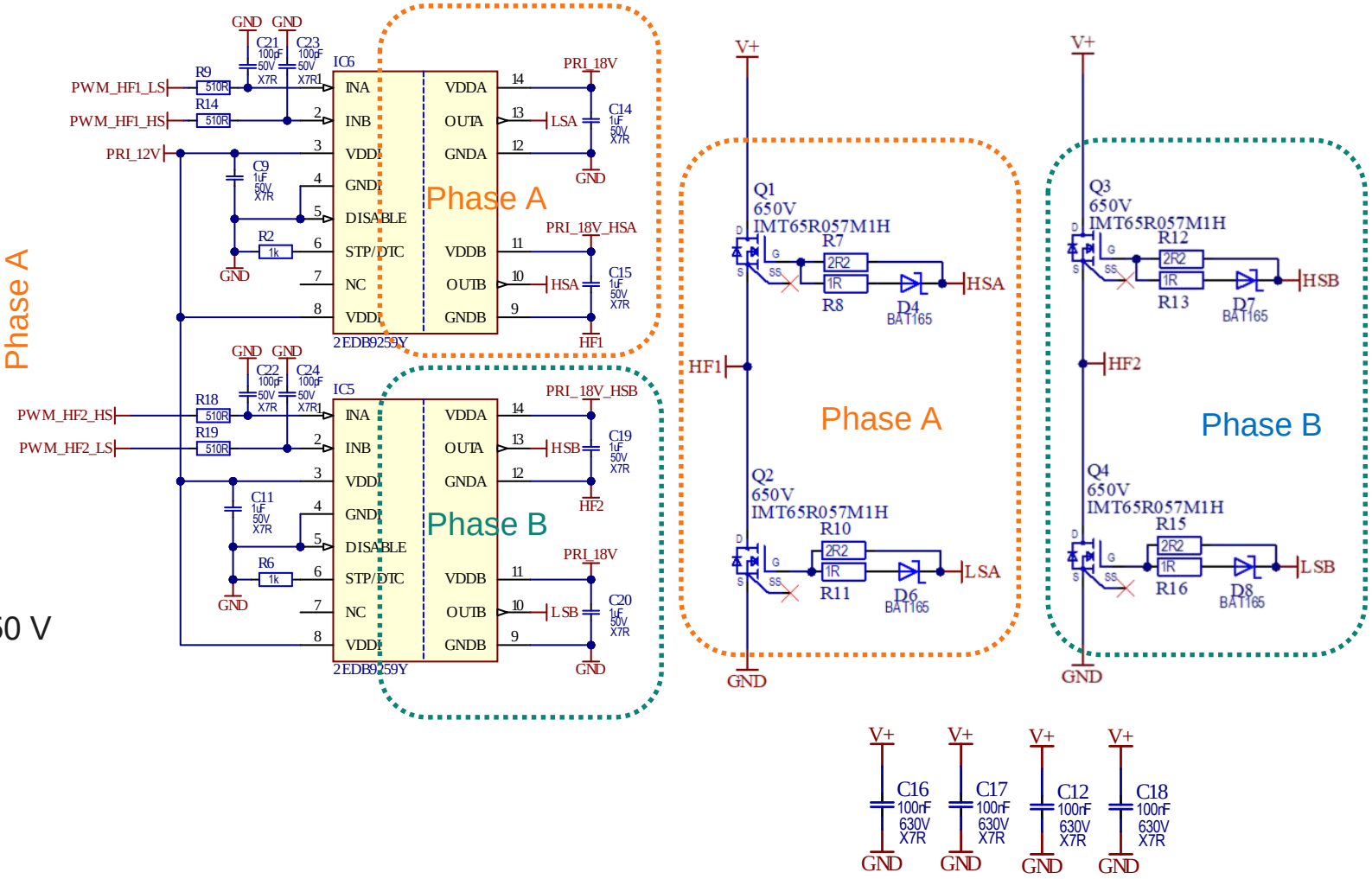
PFC and LLC control card

Interleaved totem-pole daughter card

EiceDRIVER™ 2EDB9259Y,
voltage doubler and LDOs



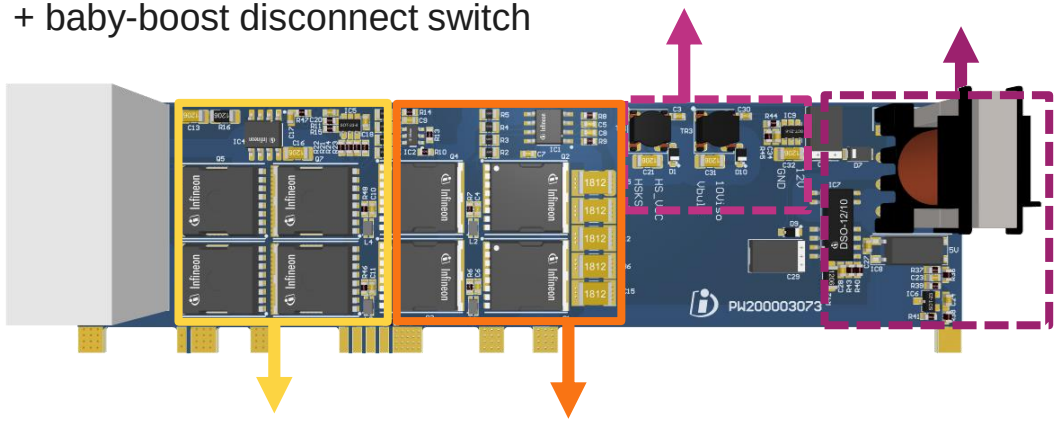
57 mΩ CoolSiC™ MOSFET 650 V
IMT65R057M1H



Half-bridge LLC daughter card

2 x isolated bias for GaN LLC high-side primary + baby-boost disconnect switch

3 x V_{out} fly-back

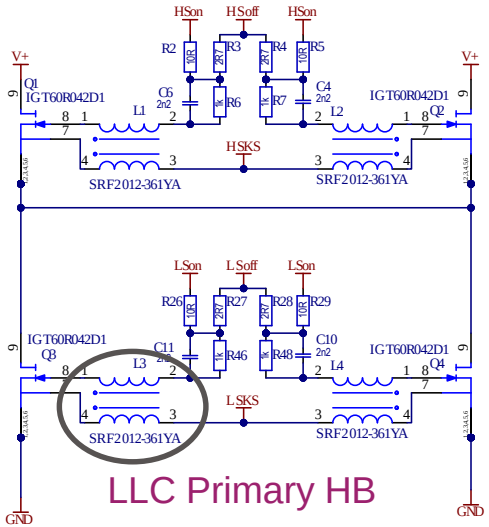


PFC LF SRs

LLC primary HB

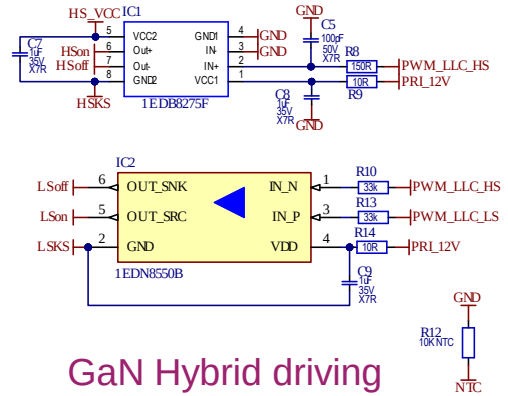
CoolMOS™ SJ MOSFET S7 IPT60R015S7

42 mΩ CoolGaN™ power transistor 600 V IGT60R042D1

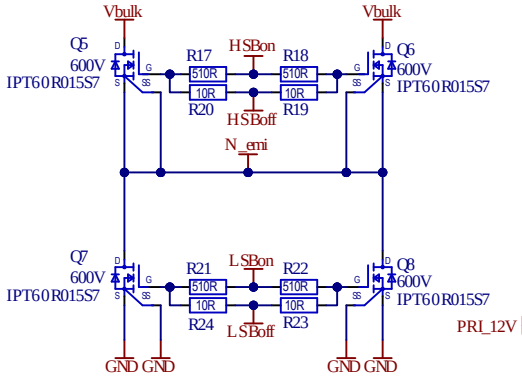


LLC Primary HB

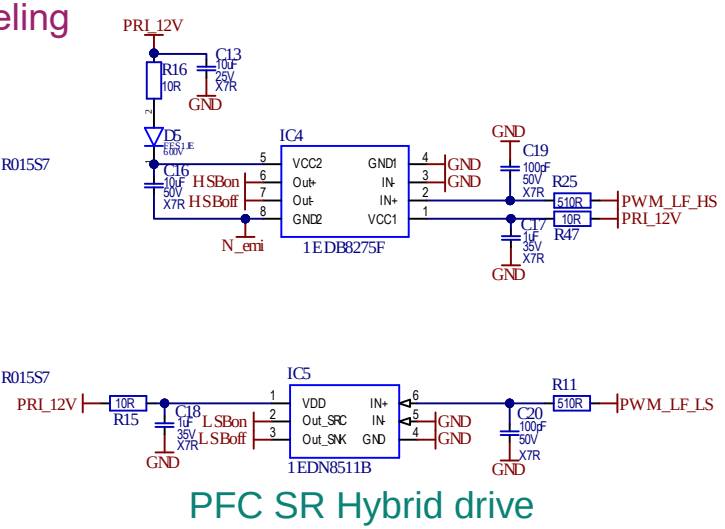
→ CoolGaN™ paralleling



GaN Hybrid driving



PFC SR



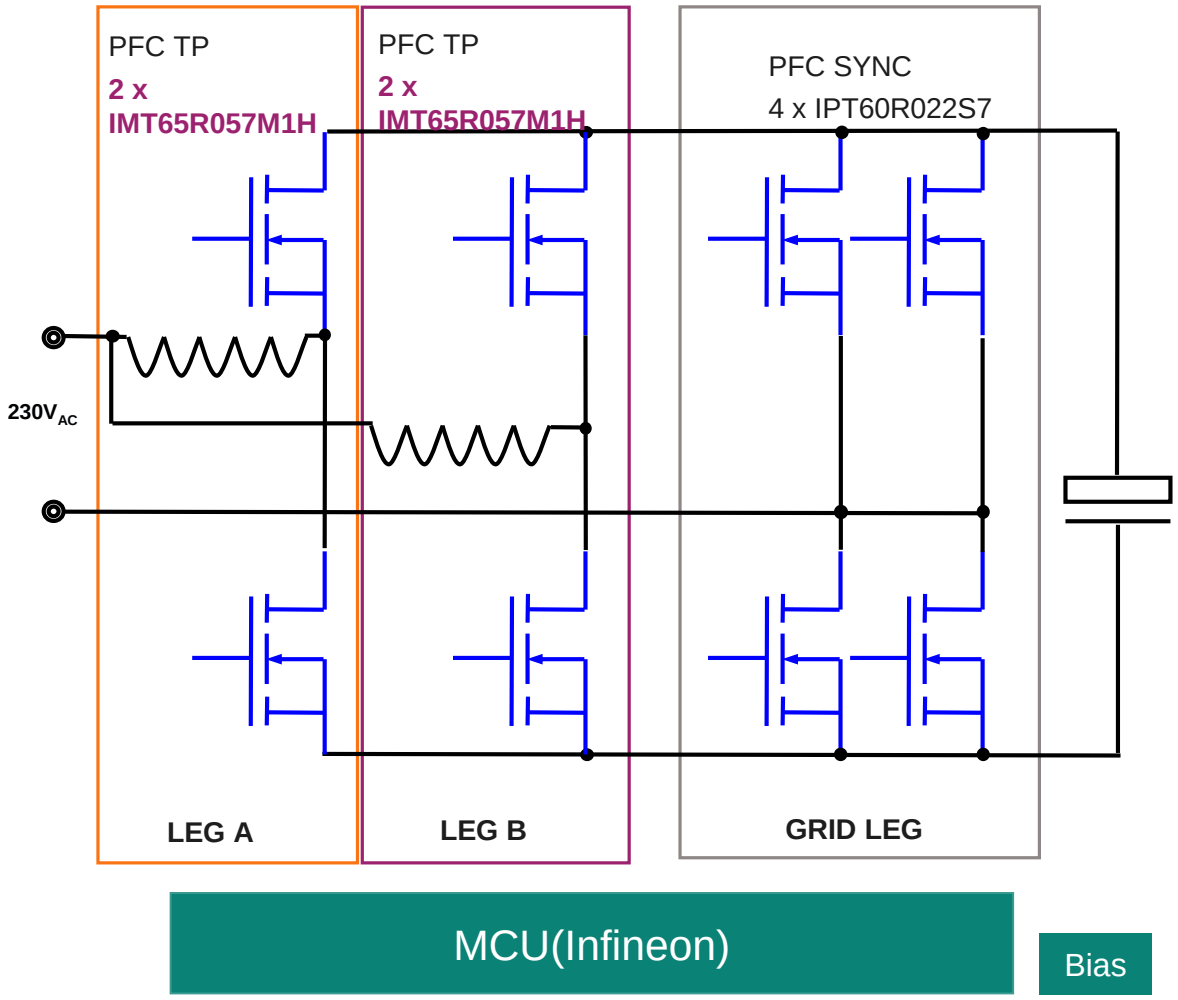
PFC SR Hybrid drive

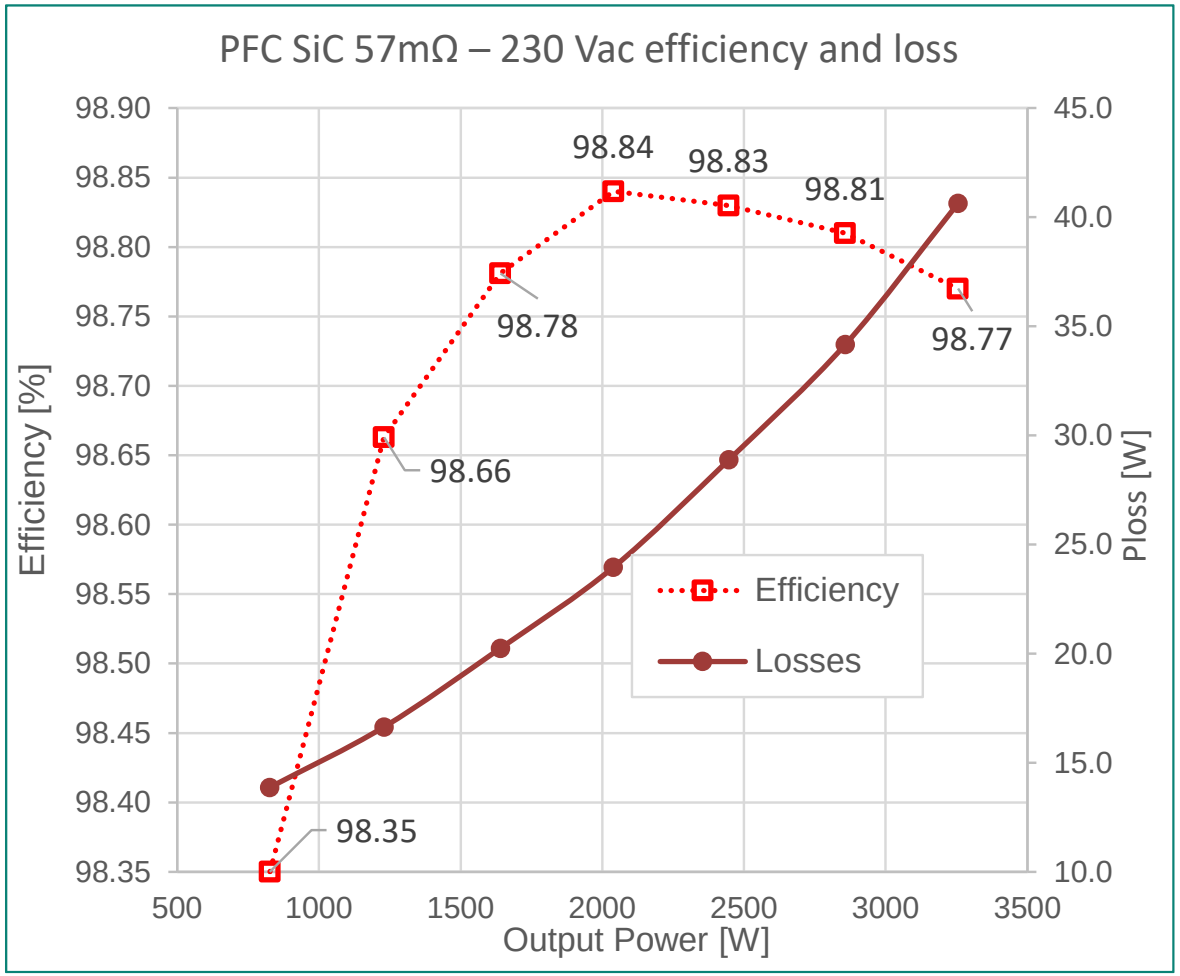
"How to parallel CoolGaN 600V HEMT in half-bridge configurations for higher-power applications"

Interleaved totem-pole

Efficiency of PFC stage stand-alone

Interleaved totem-pole PFC 2 x 65 kHz

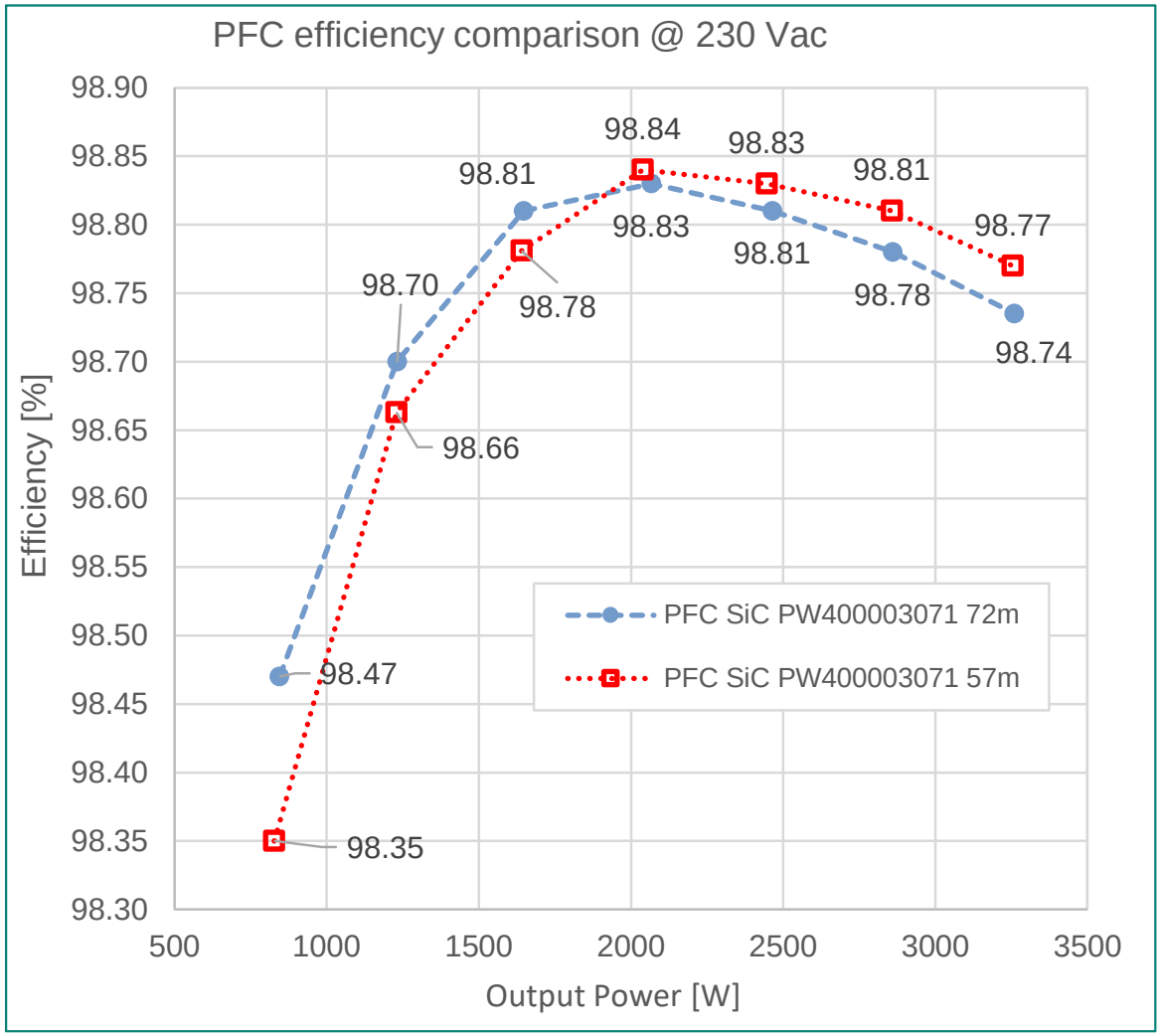


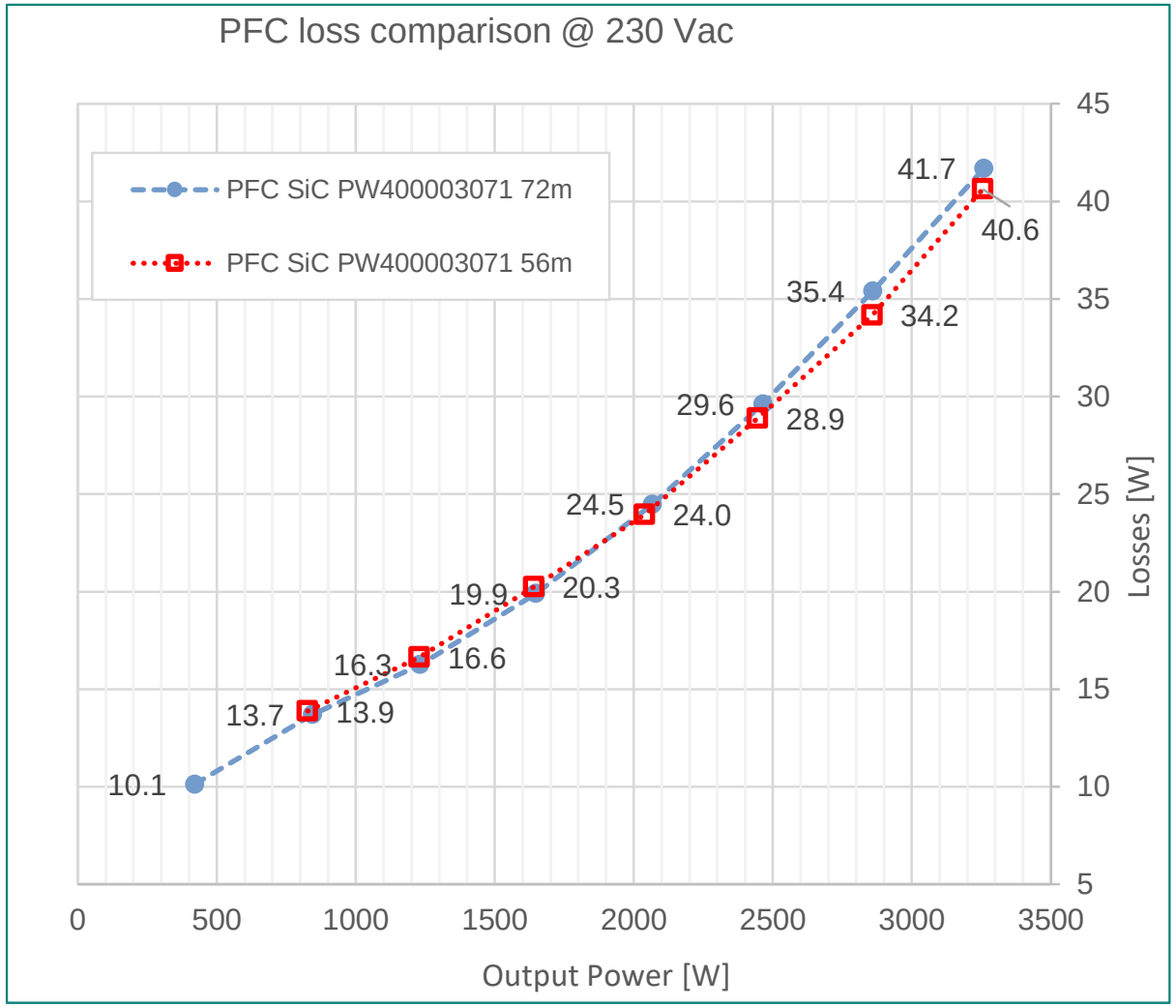


Settings WT3000: 64AVG – line filter: input 500 Hz, output 1 kHz

*Fan supplied externally, no enclosure

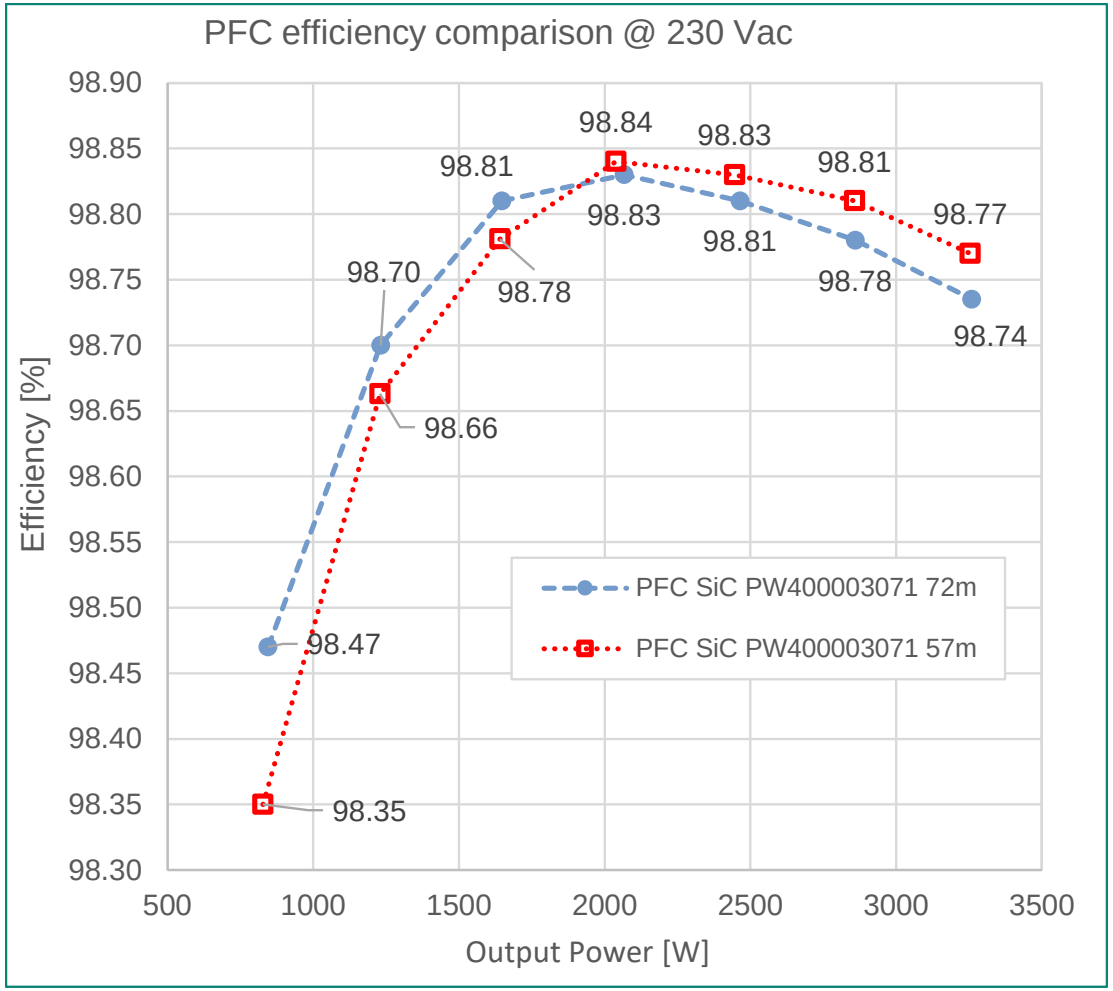
Efficiency PFC stage stand-alone SiC 72 mΩ vs 57 mΩ $R_{DS(on)}$ (1/2)





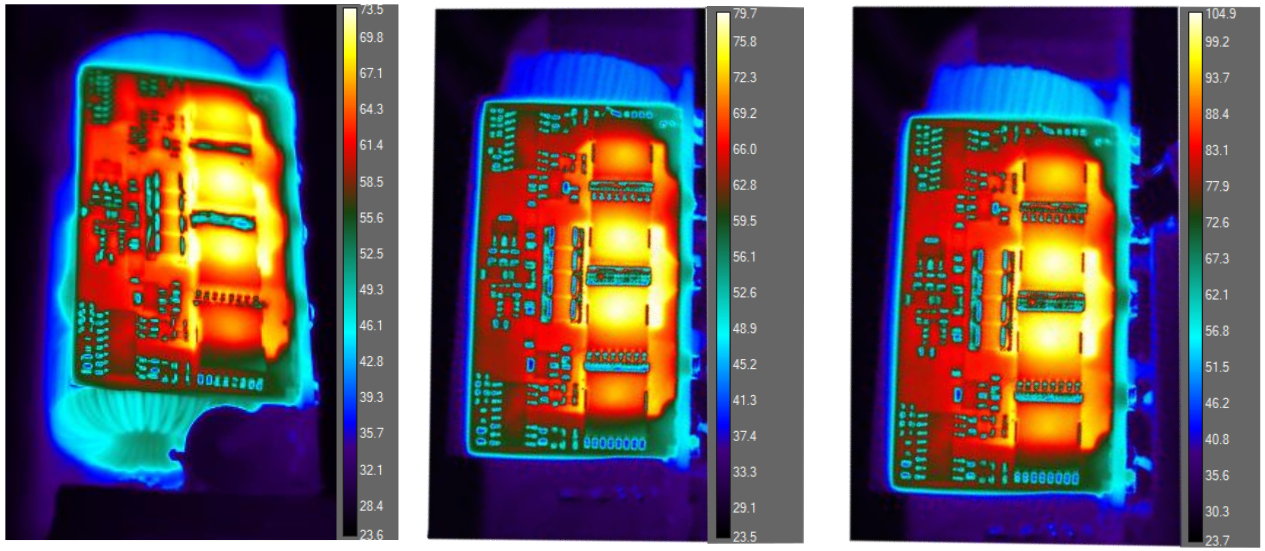
Settings WT3000: 64AVG – line filter: input 500 Hz, output 1 kHz

Efficiency PFC stage stand-alone. SiC 72 mΩ vs 57 mΩ $R_{DS(on)}$ (2/2)



Settings WT3000: 64AVG – line filter: input 500 Hz, output 1 kHz

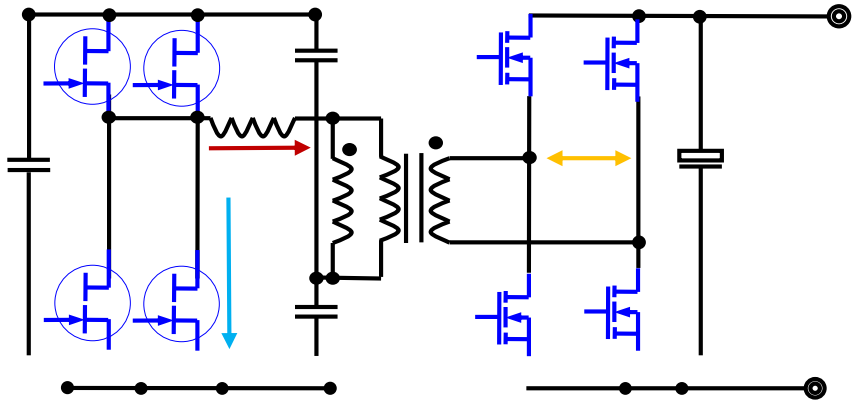
57 mR – 230 V	72 mR – 230 V	72 mR – 180 V

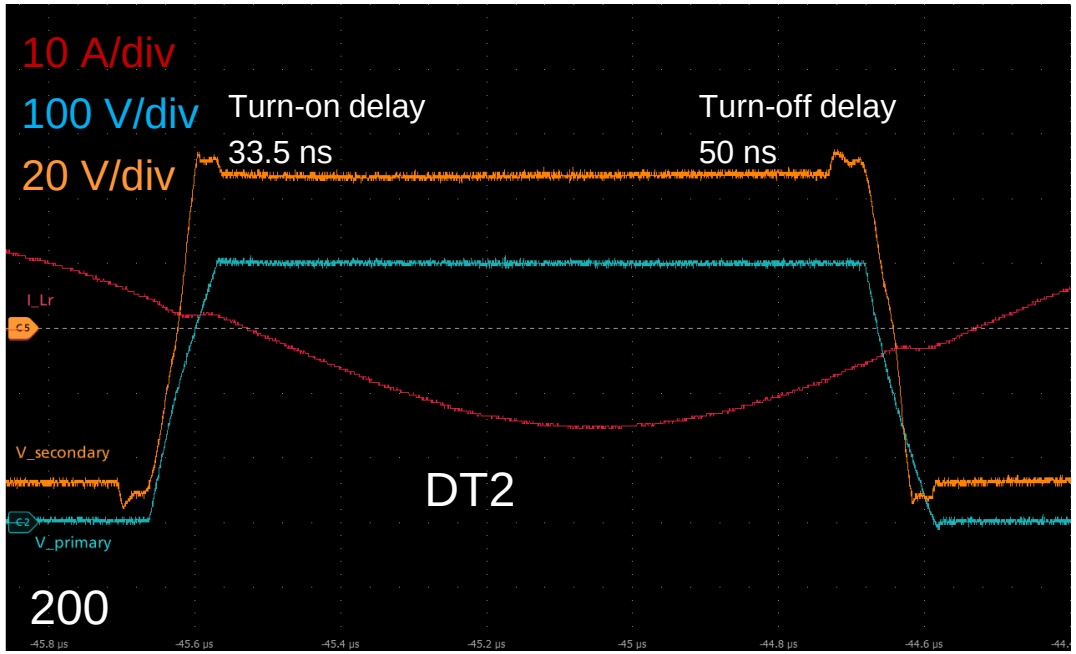


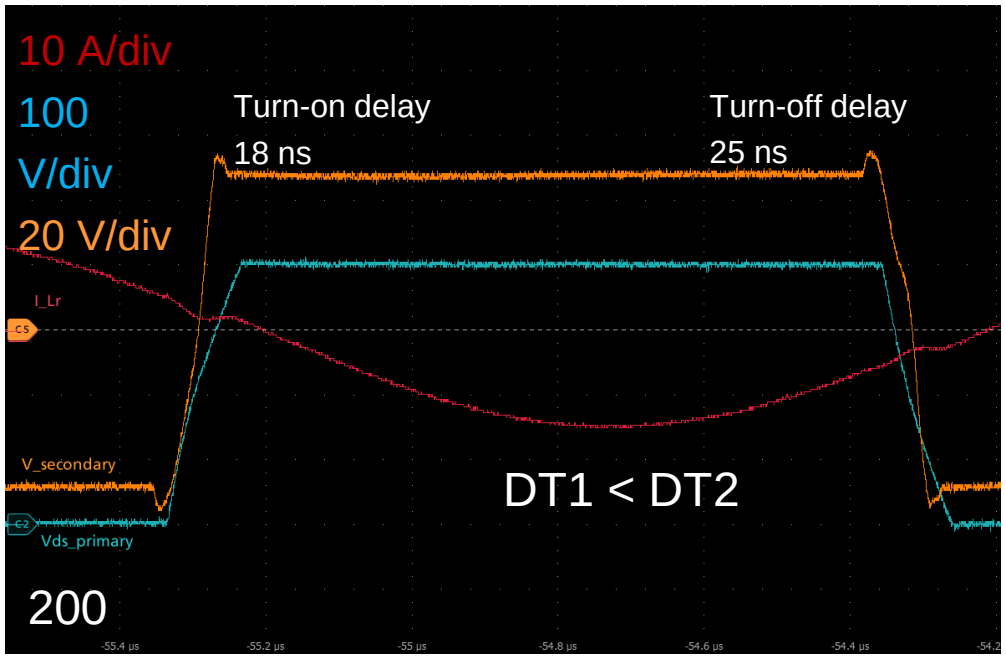
* Infrared camera measurement at open frame

HALF-BRIDGE LLC

Impact of the synchronous rectifiers' body diode conduction time (1/2)

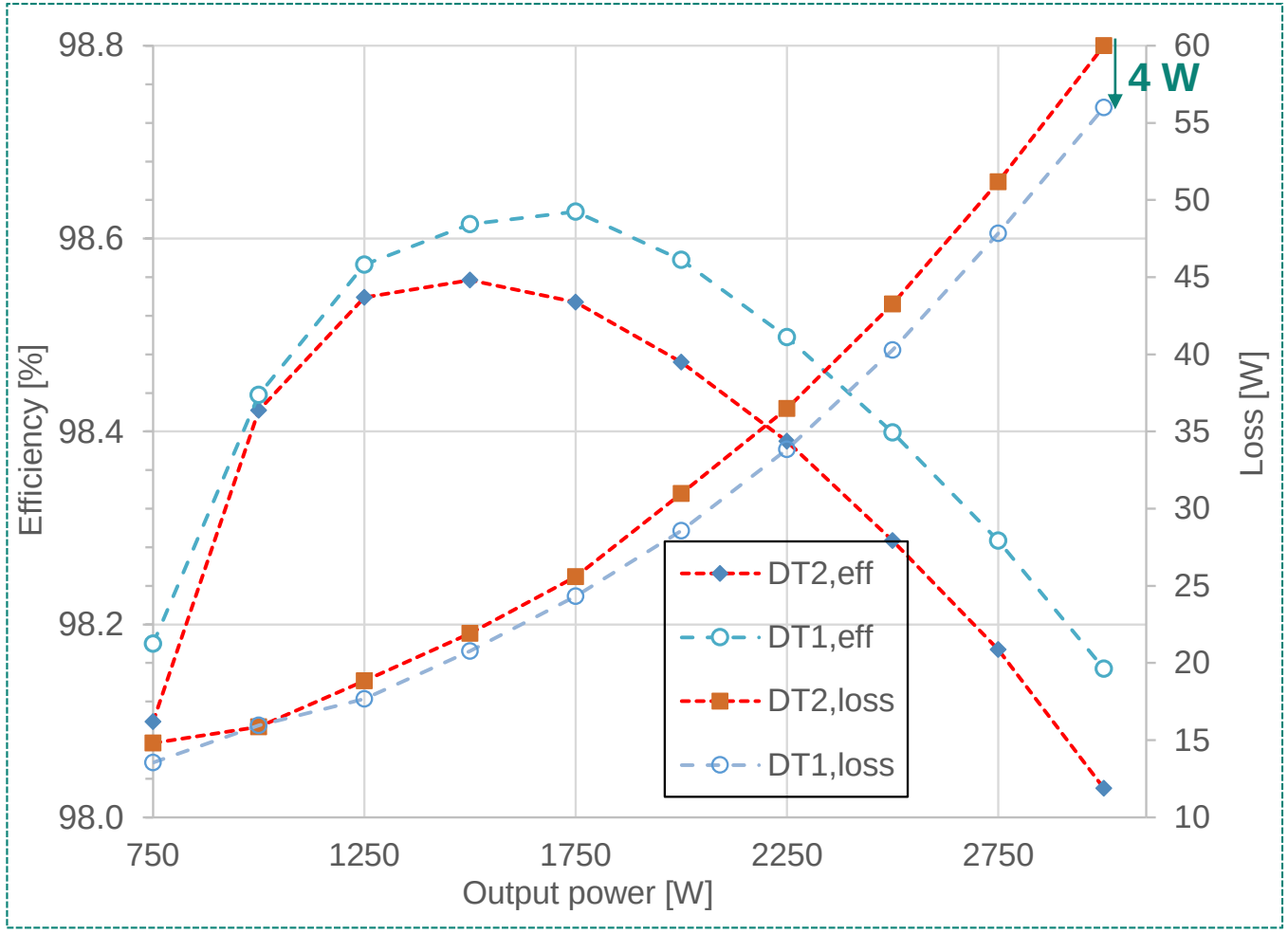




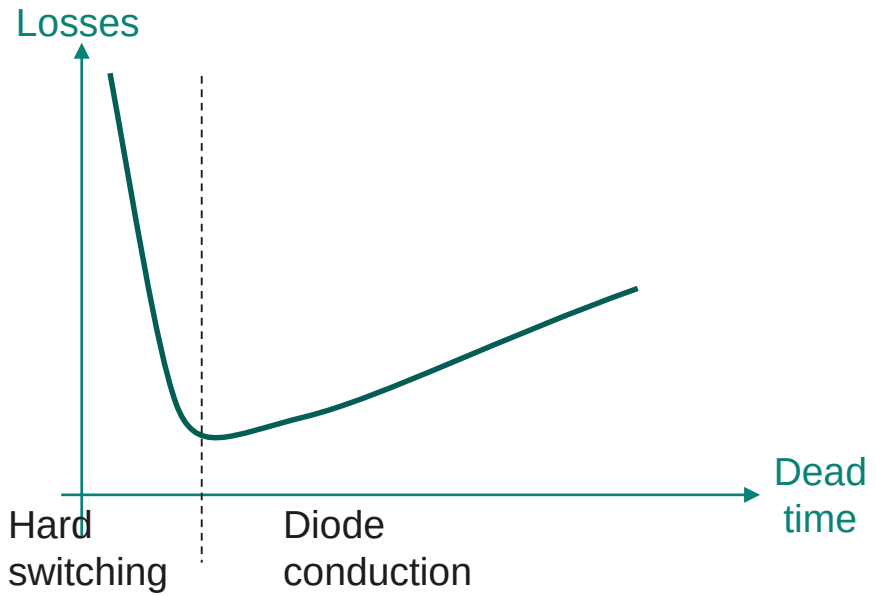


Impact of the synchronous rectifiers' body diode conduction time (2/2)

LLC with DT1<DT2 (DT secondary side dead times)



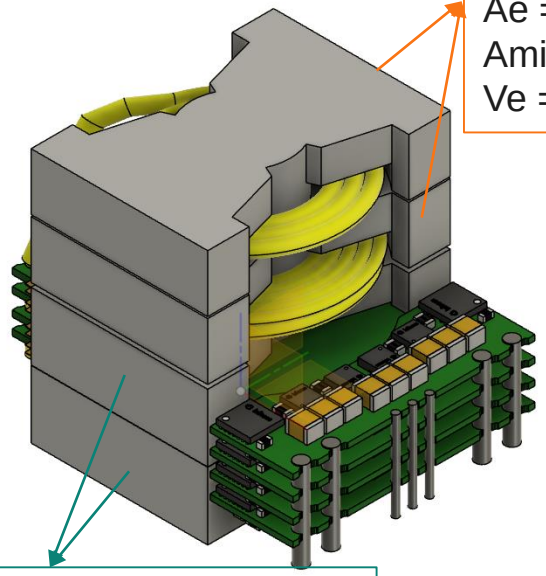
- In high frequency LLC design, dead times play a fundamental role in order to obtain high efficiency → **Minimized DT**
- Hard switching needs to be avoided, even if WBG devices would be used and only low voltage is hard switched. With the high frequency the impact is not negligible → **Minimum DT**



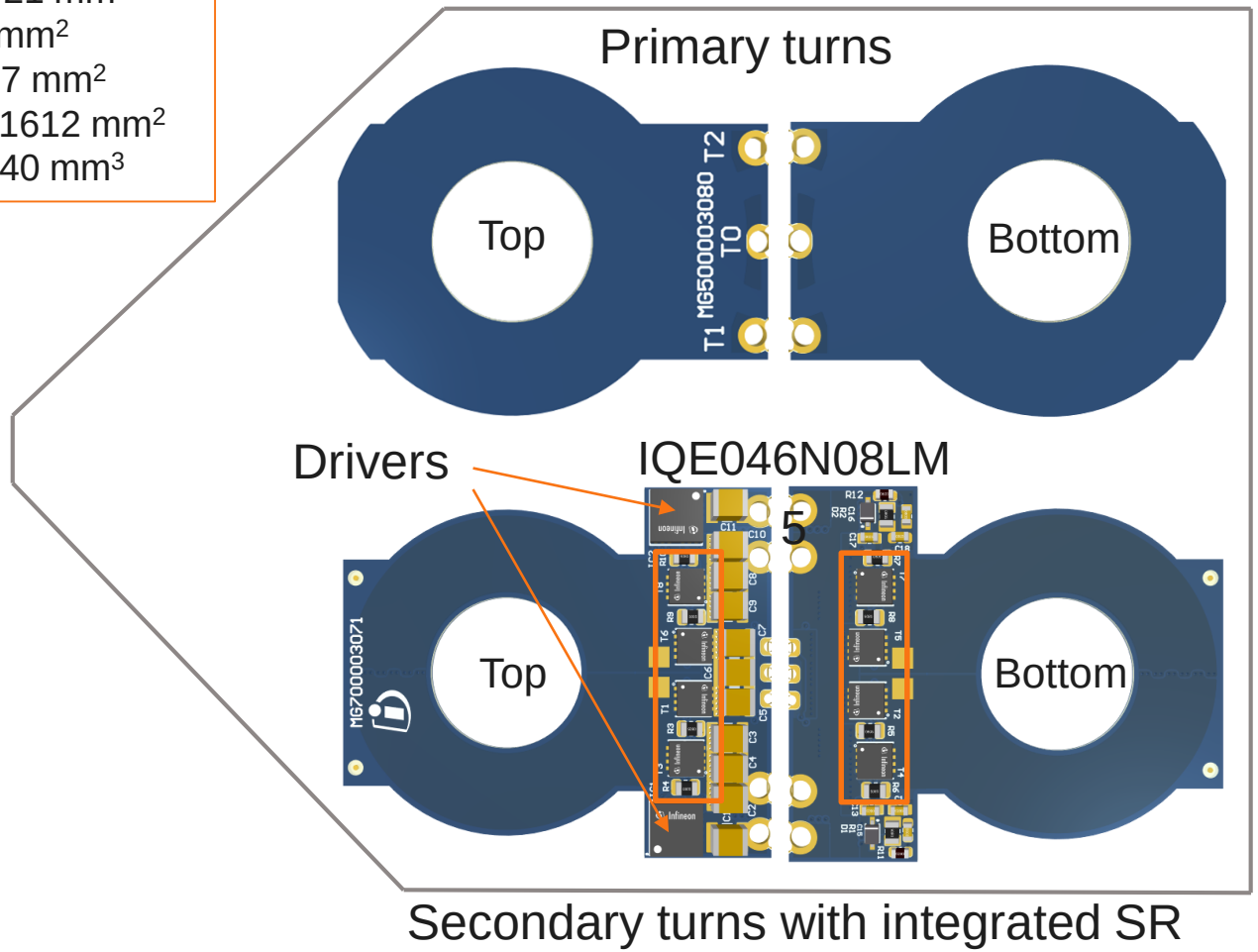
Planar transformer

Transformer assembly stack (1/2)

PQ35
ΣI/A= 0.21 mm^{-1}
le = 37 mm^2
Ae = 177 mm^2
Amin = 1612 mm^2
Ve = 6540 mm^3

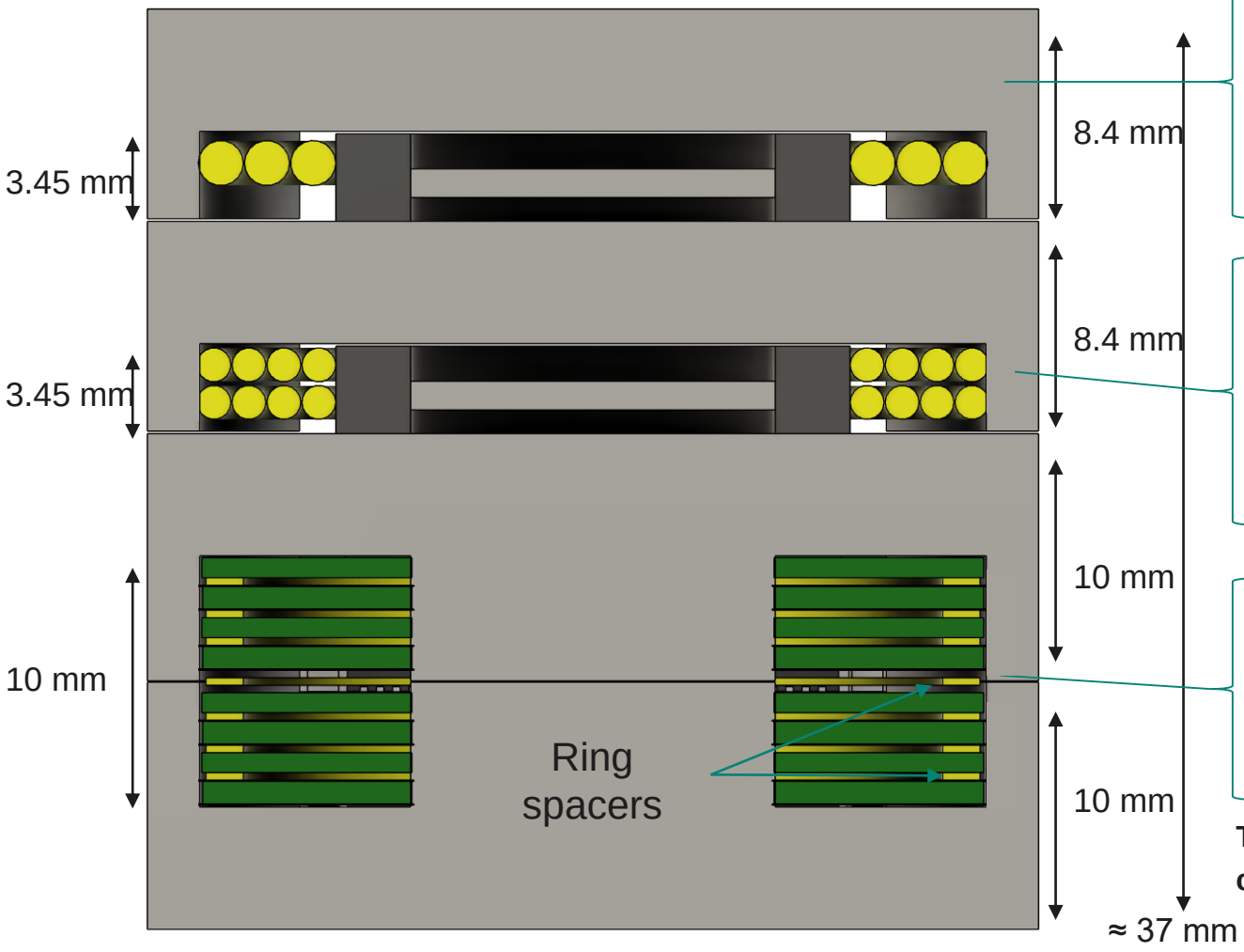


PQ35
ΣI/A= 0.285 mm^{-1}
le = 49.8 mm^2
Ae = 174 mm^2
Amin = 162 mm^2
Ve = 8680 mm^3



Total estimated volume = 0.055 dm^3 = 3.36 in^3
Estimated power density ≈ 54 kW/l ≈ 893 W/in^3

Transformer assembly stack (2/2)



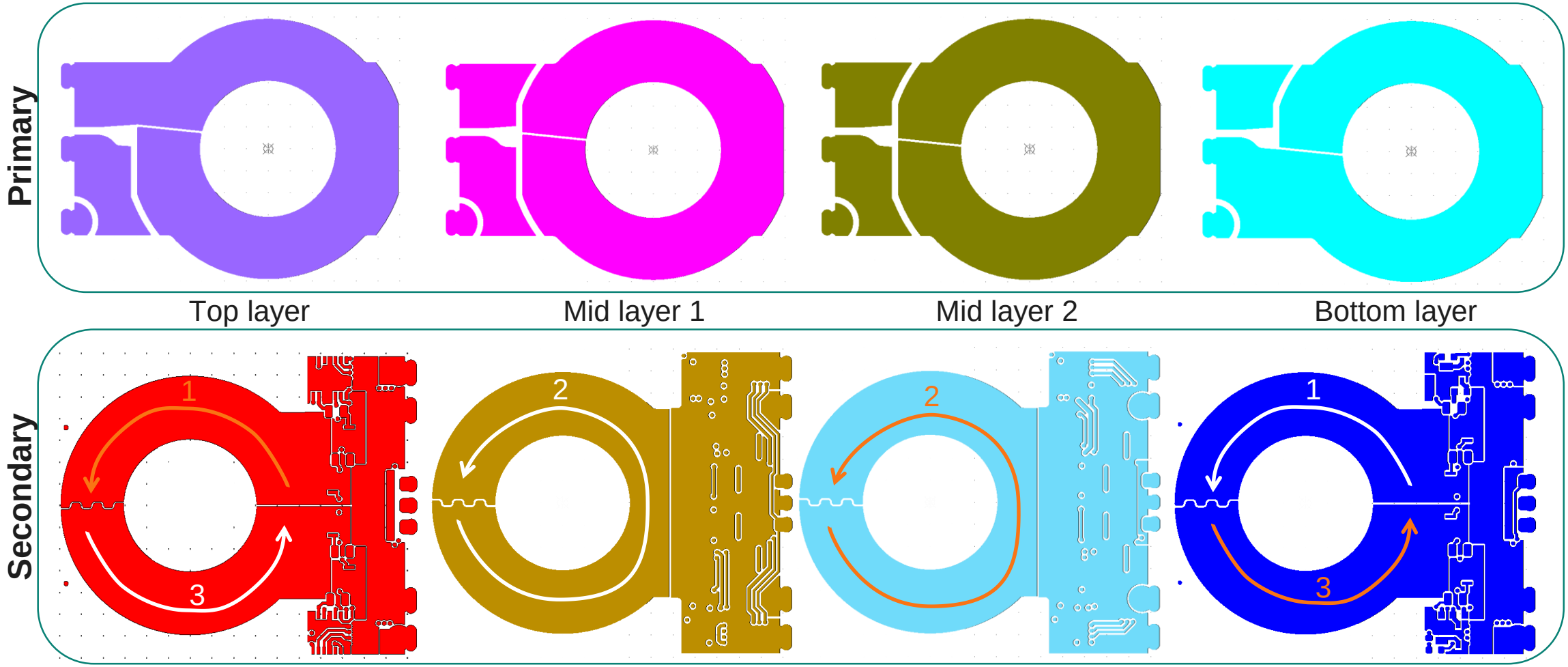
- Series inductor (1.2 µH) core PQ35/16.8/G1500-3F36-G800.
- Series inductor triple isolated Litz wire, 3 turns with 1000, 50 µm diameter strands.

- Magnetizing inductor (10 µH) core PQ35/16.8/G1500-3F36-G800.
- Magnetizing inductor triple isolated Litz wire, 8 turns with 300, 50 µm diameter strands

- Main transformer cores PQ35/20-3F36.
- Modular PCB assembly.

The ring spacers between PCBs decrease the inter-winding capacitance from circa 140 pF to near 60 pF!

Layout of the transformer‘s PCBs

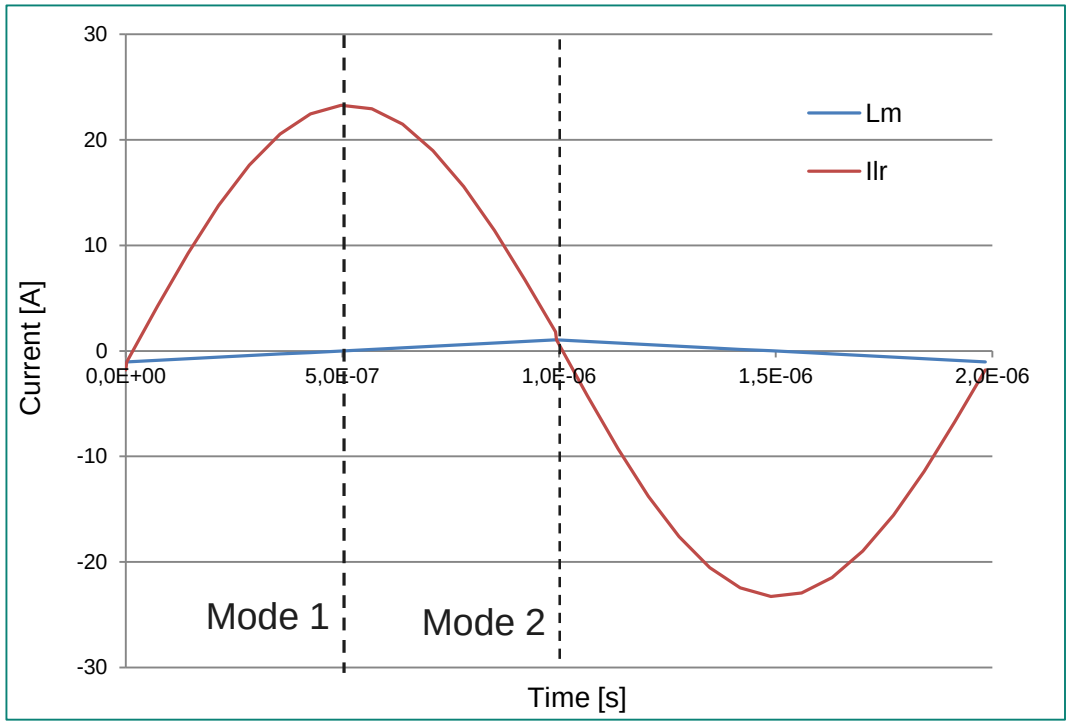


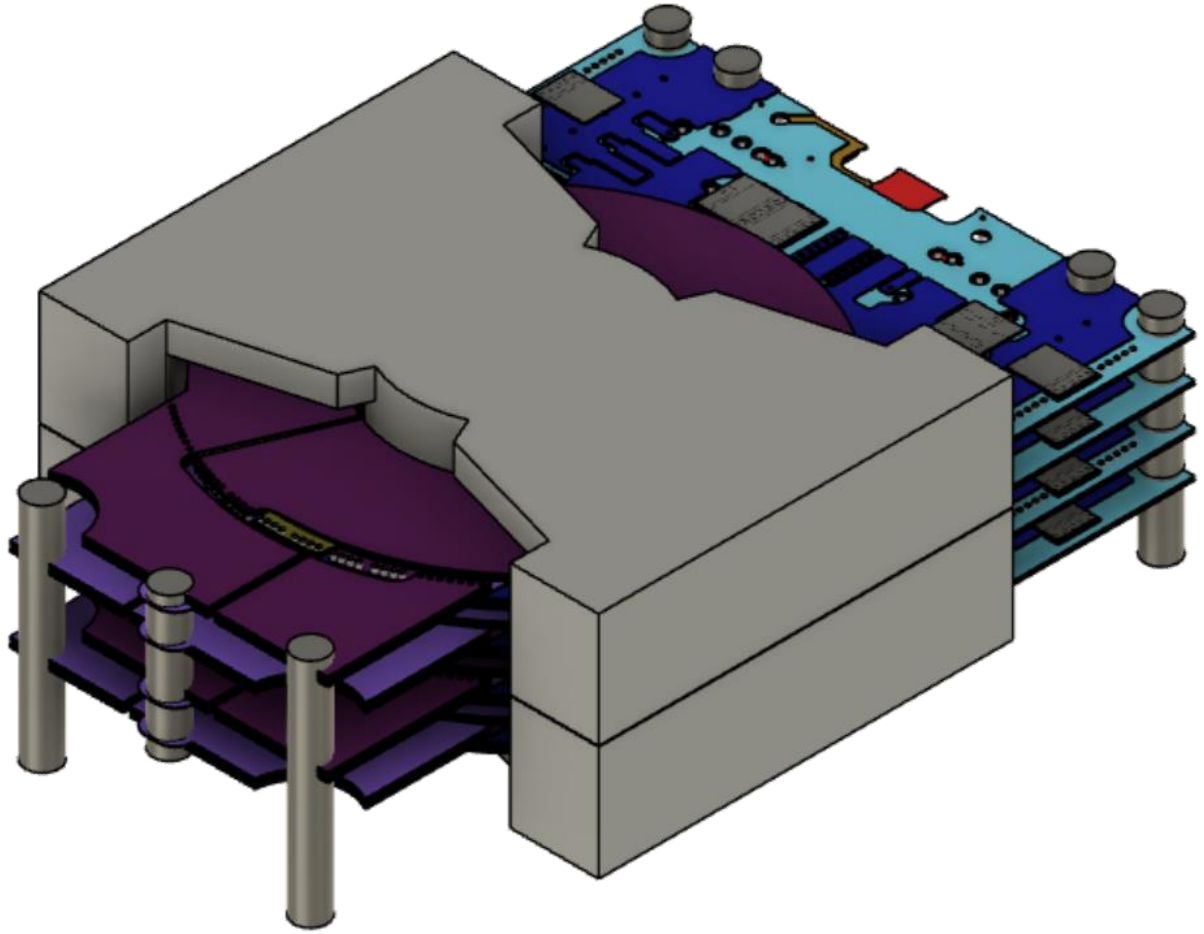
Secondary-side PCB has exchange of layers from bottom to top to balance the copper usage in a non-sandwiched PCB (Litz wire like exchange of layers).

Complete model for FEA (Ansys Electromagnetic) simulation

Starting from top of right hand side figure: P-S-P-S-P-S-P-S
Core 3F36 with B-H curve and 60 um gap
Simulation conditions:

- 500 KHz
- Primary sinewave 30 A peak (0 A magnetizing)
- Secondary sinewave 120 A peak





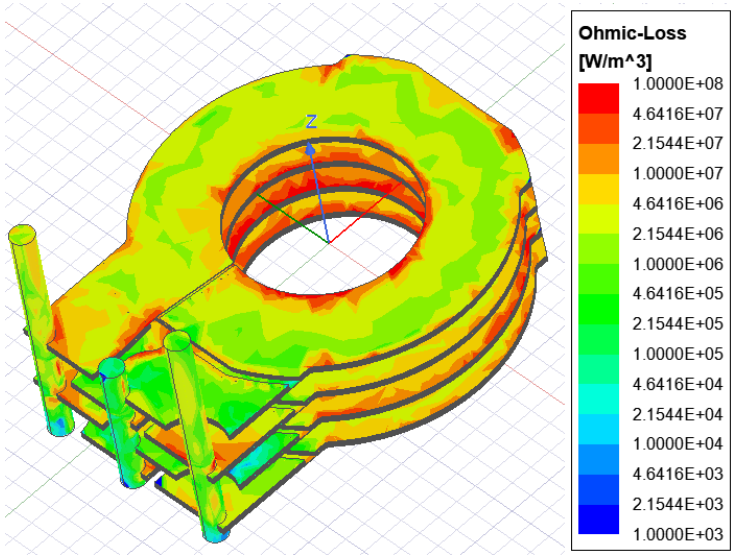
Transformer ohmic loss at full load. 4 PCBs of final layout.

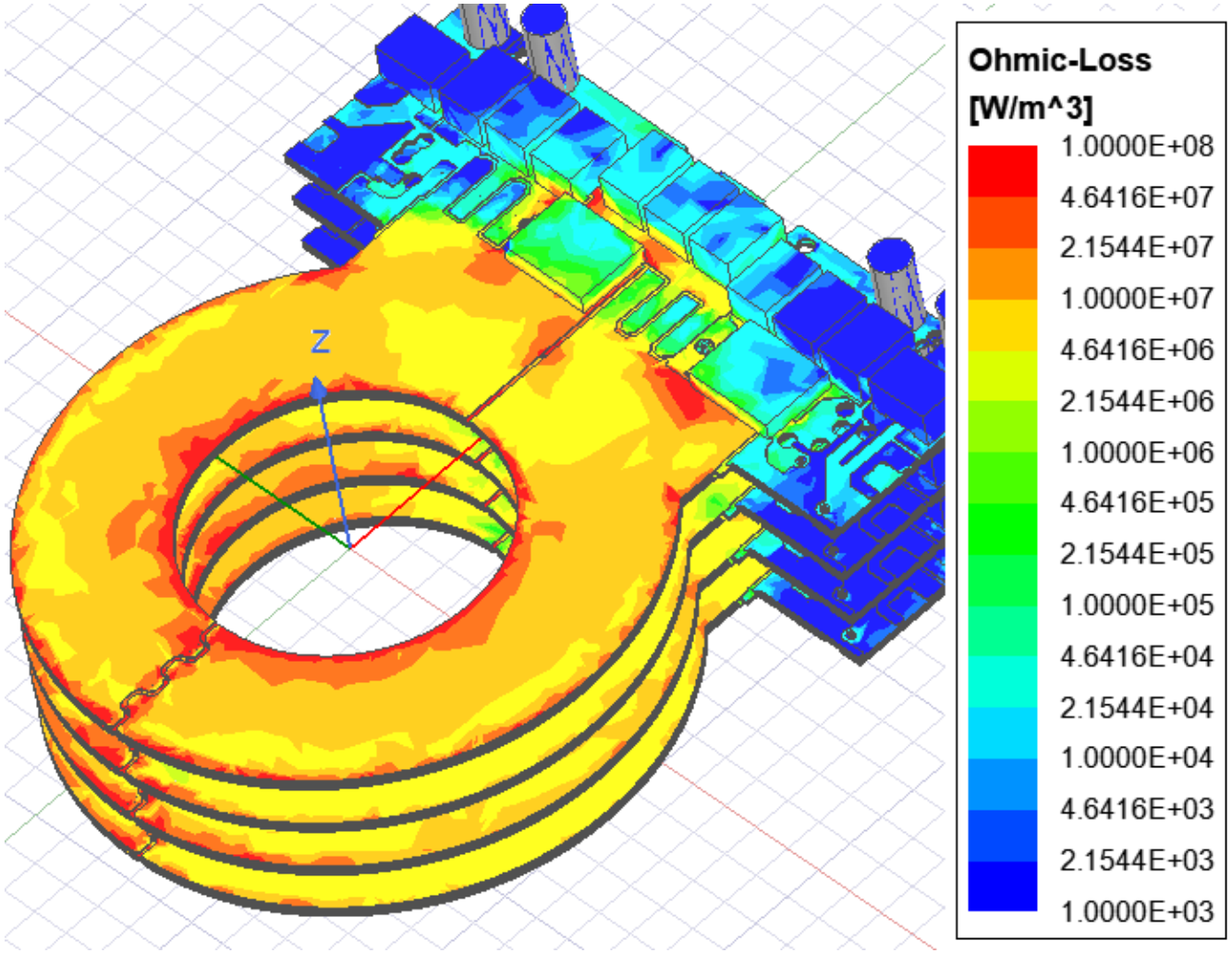
Simulation conditions:

- 500 kHz
- Primary sinewave 30 A peak (Mode 1)
- Secondary sinewave 120 A peak

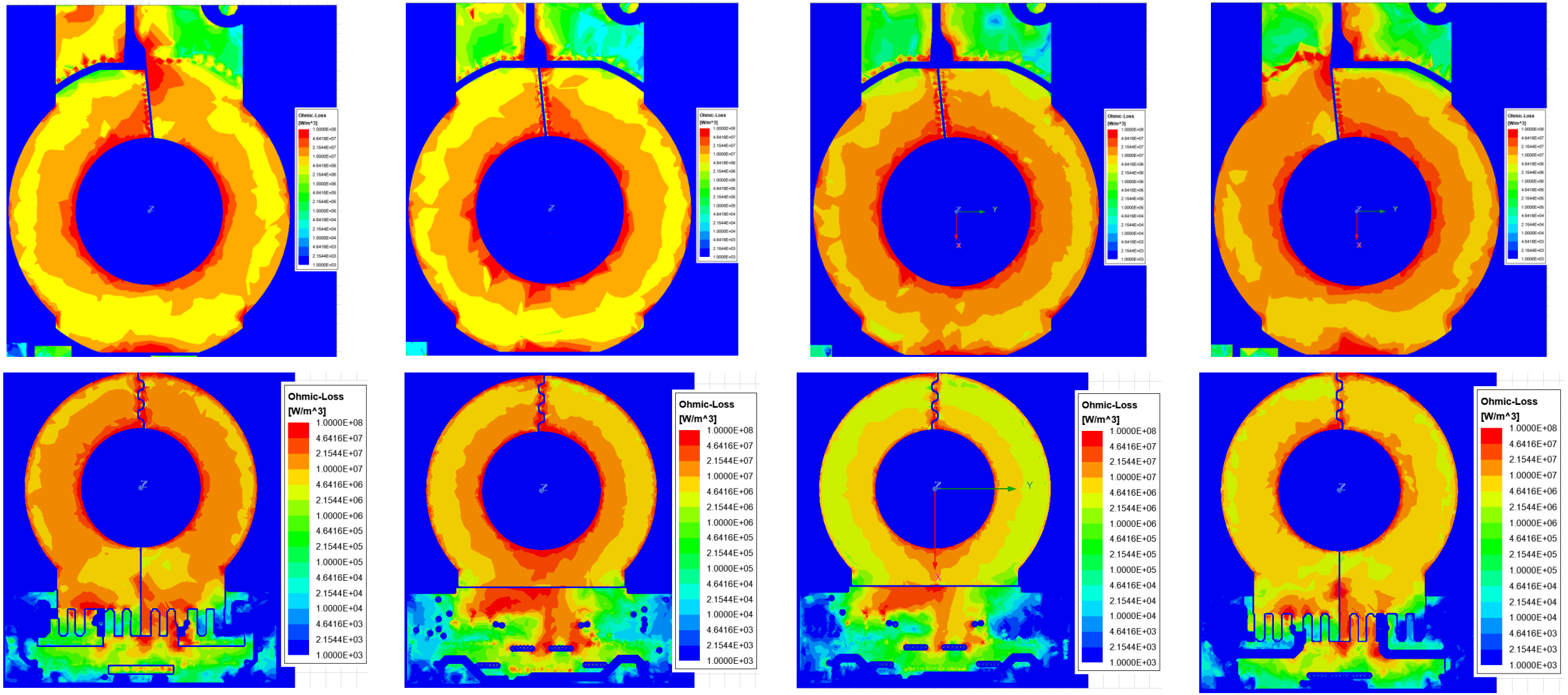
Results:

- Primary: 6.01 W, 13.36 mΩ
- Secondary: 7.83 W, 1.09 mΩ
- Total: 13.84 W





Transformer ohmic loss at full load



Summary

Summary

Full Infineon system solution for server and telecom applications

- CoolGaN™ + CoolSiC™ + CoolMOS™ + OptiMOS™

High power density and efficiency: 3 kW – 96 W/in³ – η_{peak}=97.5%

- Interleaved PFC (EMI – PFC choke)
- High-freq LLC (transfomer + Lm + Lr)
- Hold-up time extension (bulk capacitance)

Modular design

- Power boards: SMD TOLL

Interleaved Totem-pole PFC, η_{peak} > 98.8%

- 57 mΩ CoolSiC™ / 72 mΩ CoolSiC™ with power derating at 180 V

High-frequency LLC (f_{res} = 530kHz) with CoolGaN™ and OptiMOS™, η_{peak} > 98.6%

- Dead time high impact on performance at high-freq
- SR integrated in transformer PCB
- Planar transformer: FEA for design optimization


Infineon