

**AUG 7<sup>TH</sup> 2025**



# **ENHANCING ENERGY STORAGE POWER ELECTRONICS DESIGN THROUGH ARTIFICIAL INTELLIGENCE**

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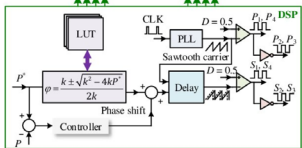
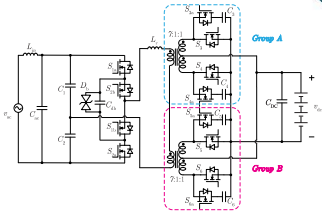
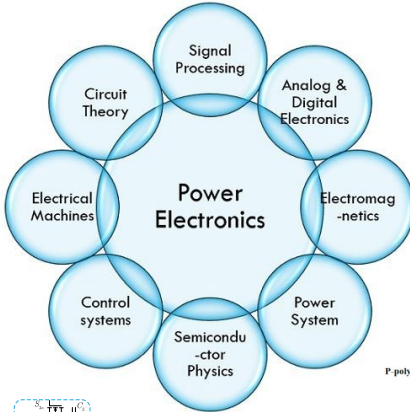
**DR. ALEX Q. HUANG**

Semiconductor Power Electronics Center  
The University of Texas at Austin

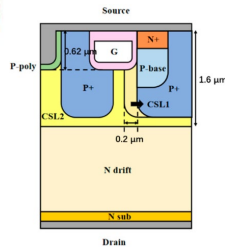
- Key Challenges in Conventional Power Electronics Design
- Background Introduction & Overview
- Case Study: AI enhanced High Power Density BESS Converter Design
  - Multi-Objective Optimization for Circuits
  - PCB Layout for Top-Cooling Power Semiconductor Device
  - Magnetic Components Design
  - AI facilitated Prototype Assembly, Debugging & Testing
- Proposed Future Objectives

- Time Consuming Multi-Physics & Software Tools
- Tools are not well interaction

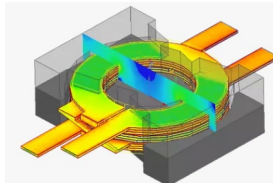
## Power Electronics Multi-Physics[1]



Topology & Control System

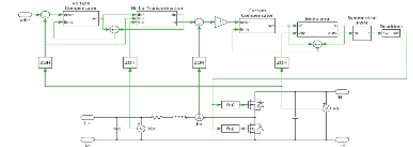
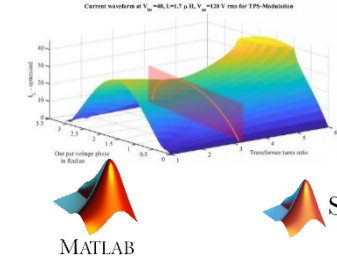


Power Semiconductor Design

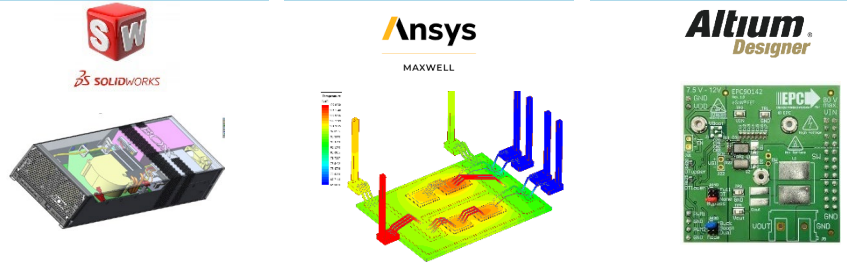


Magnetics Design

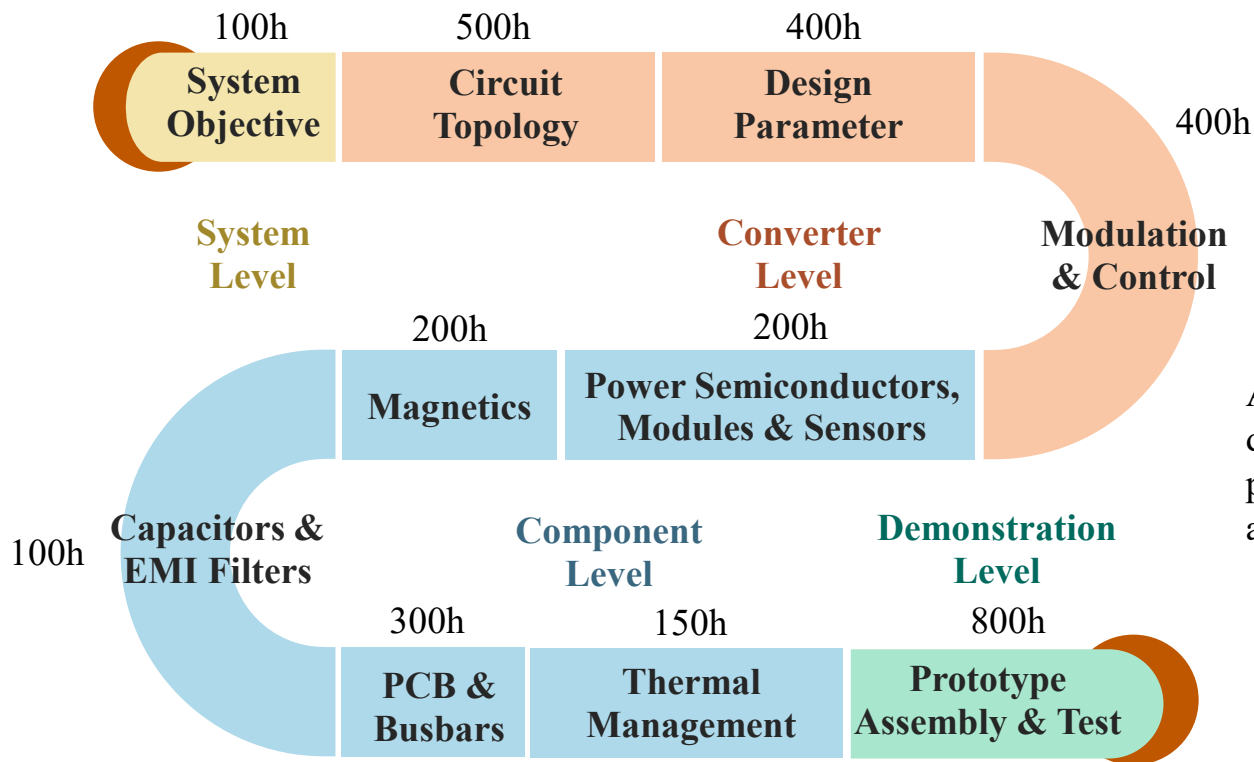
## Power Electronics Design Tools



<b>Circuit Optimization</b>	<b>Topology Simulation</b>	<b>Critical Loop Simulation</b>
<b>Package &amp; Mechanical</b>	<b>Magnetics &amp; Thermal</b>	<b>PCB Layout</b>



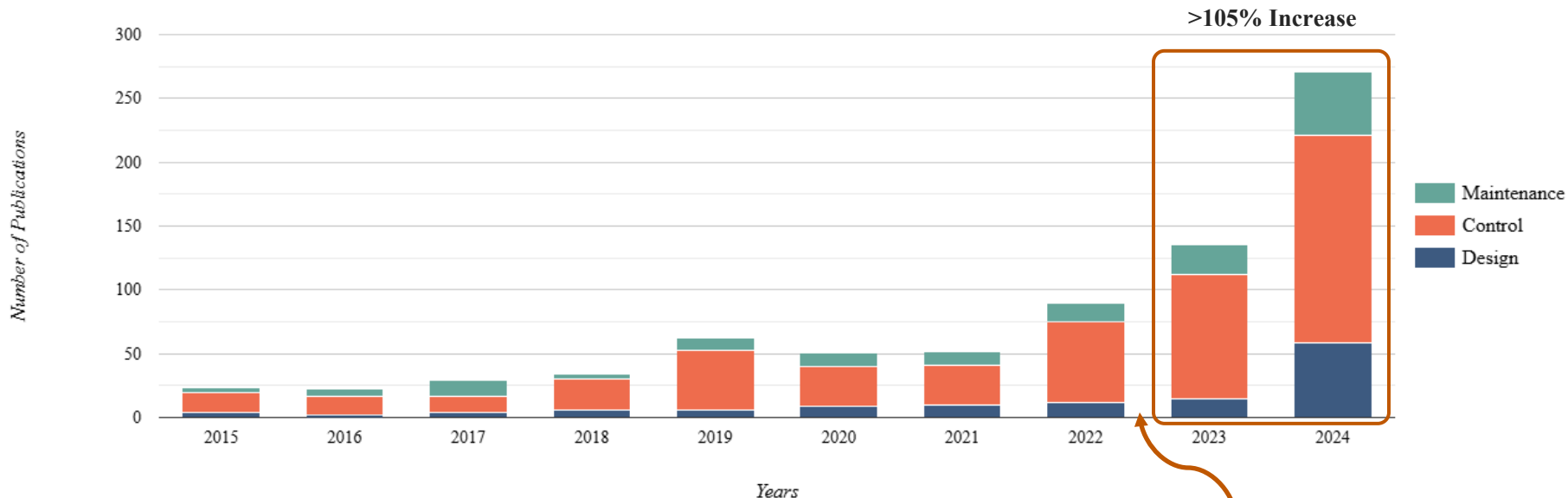
- How long does an experienced engineer successfully build one BESS converter?



AI can accelerate the 18+ month development cycle for innovative power electronics hardware at advanced level.

\*Based on findings from a small-scale survey of students within SPEC research center.

## Annual Number of Publications of AI in Power Electronics from 2015 to 2024[2]



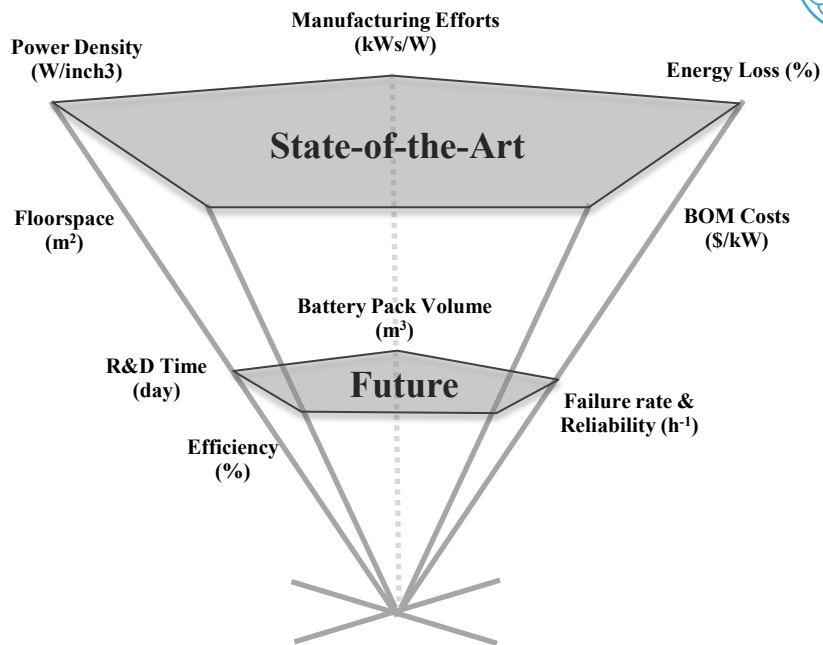
AI Agents went mainstream starting in late 2022



ChatGPT



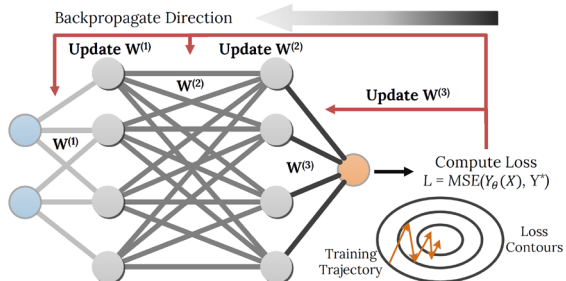
\*Searched on IEEE Xplore w/ metadata “Artificial Intelligence” or “AI” or “Machine Learning” or “Deep Learning”.



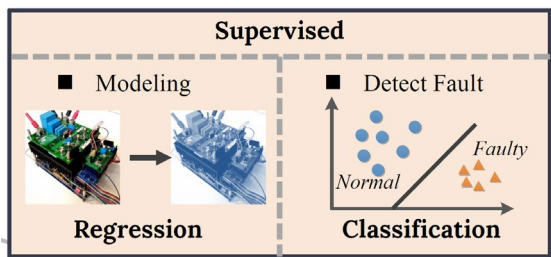
## AI Duties[3]

- **Autonomous Design:** AI generating full schematics from system requirements.
- **Multi-Objective Optimization:** Interactively balancing cost, efficiency, and reliability.
- **Proactive Reliability:** Integrating safety and aging models into the initial design.
- **Holistic Co-Optimization:** Designing the battery, BMS, and converter as one unified system.
- **Application-Centric Design:** Tailoring the entire system for its specific end-use and grid needs.
- **Digital Twin Lifecycle:** Using a real-time model for predictive maintenance and future design feedback.

## Traditional NN Models



Neural Network Structure[4]



Modeling and Fault Detection

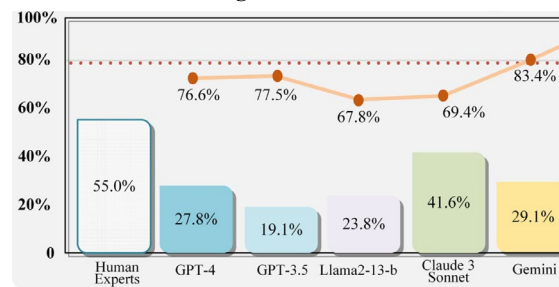
## Dialog Based AI Agent

I want to design a dual active bridge converter with wide soft switching range across the entire operating range. What specific modulation strategy you would like to recommend to me? It also needs to be easy for implementation.

For designing a dual active bridge (DAB) converter with a wide soft switching range across the entire operating range, Phase Shift Modulation (PSM) would be an effective and relatively simple strategy to implement. Here are the key considerations and steps for implementing PSM in your DAB converter:

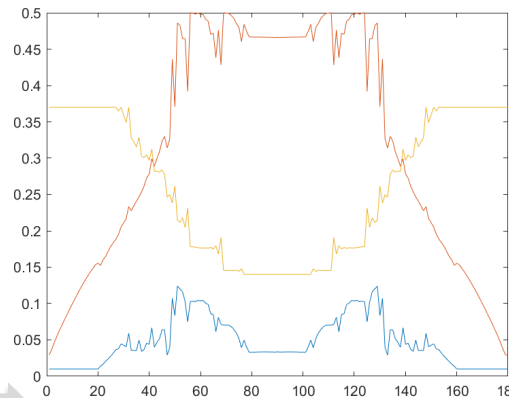
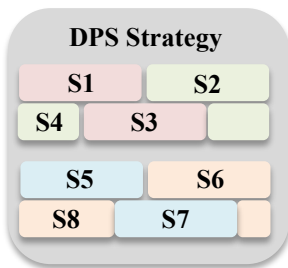
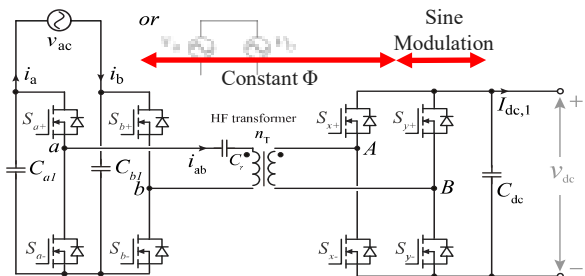
- Basic Concept:** In PSM, the switching of the primary and secondary bridges is controlled by shifting the phase angle between their gating signals. This phase shift controls the power flow between the primary and secondary sides of the converter, enabling efficient operation and minimizing switching losses.
- Wide Zero Voltage Switching (ZVS) Range:** To achieve a wide ZVS range, you can implement an extended phase shift strategy. This involves adjusting the phase shift beyond the typical range of 0 to 180 degrees to potentially up to 360 degrees, allowing for greater control over the converter's operation and improving ZVS across varying load conditions.

### Dialog Box with ChatGPT



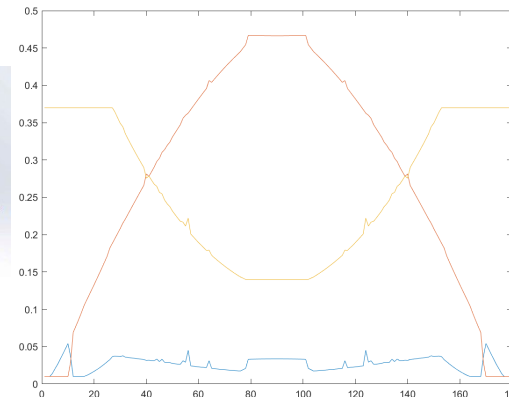
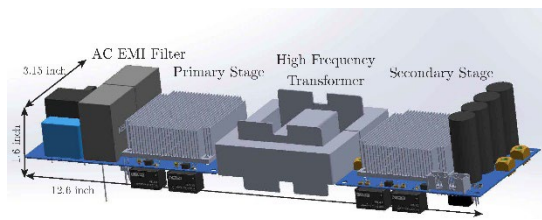
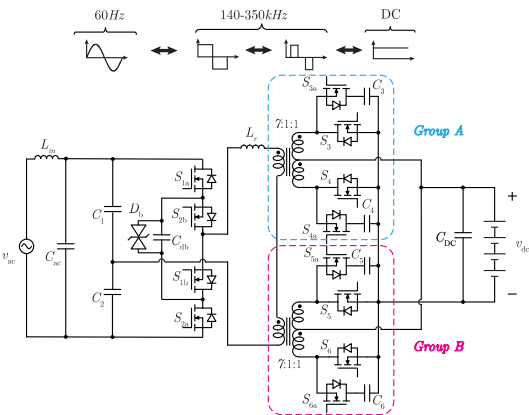
Comparison between Human and LLM models[6]

- Opportunity 1: LLM enhanced Multi-Objective Optimization for SR-DAB Modulation[7][8]



- W/o AI suggested solver:**
- result falls into local optimum
  - Bad THD quality
  - **156 seconds** Calculation time

**Optimization Goal:**  
Fmincon( $\Phi 1, \Phi 2, fsw$ )



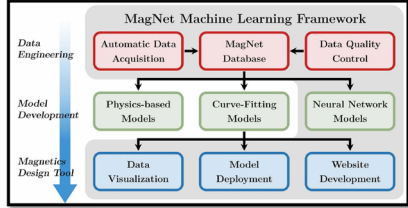
- W/ AI suggested solver :**
- result falls into global optimum
  - Great THD quality
  - **11 seconds** Calculation time

**Proposed AC-DC SR-DAB Topologies**

- Opportunity 2: AI based High Frequency Magnetics design for bidirectional converter

## AI based Magnetic Modeling

MagNet ML Framework for Modeling Magnetic Materials



Ferrite B-H and Loss Curves Modeling[9]



## LLM based XFMR Design

Basic Converter Inputs

Dual Active Bridge

Input Voltage (Nominal or range, specify AC or DC)  
240Vac

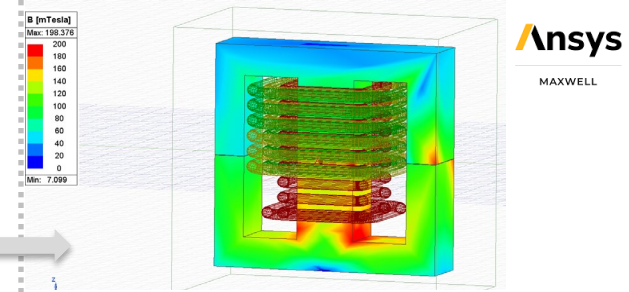
Output Voltage (Nominal or range)    Output Power  
100Vdc                                    5000w average

Additional design requirements (Optional)  
fsw=100khz

Input Dialog Box



## Magnetic Simulation & Prototype

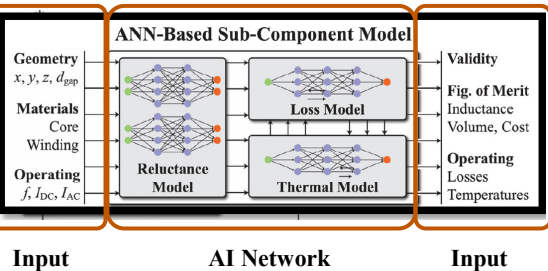


Magnetic Simulation in Ansys Maxwell



Built Transformer Prototype[14]

Magnetic R&D Time:  
From >200h to 100h



Transformer Design w/ Material, Core, Winding Selection[10]

Magnetic Design

Design Summary

Total losses (W)	44.06	Dimensions (mm)	
Core losses (W)	19.53	Width (mm)	87.00
Winding losses (W)	24.53	Depth (mm)	101.00
Max. temp (°C)	108.08	Height (mm)	70.00

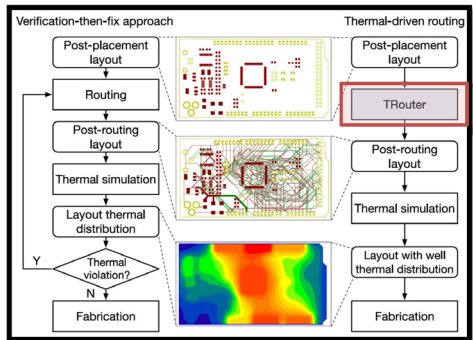
Core & Winding

Core Shape	PM8770
Number stacks	1
Material	3C95
Gap (mm)	1 × 0.2

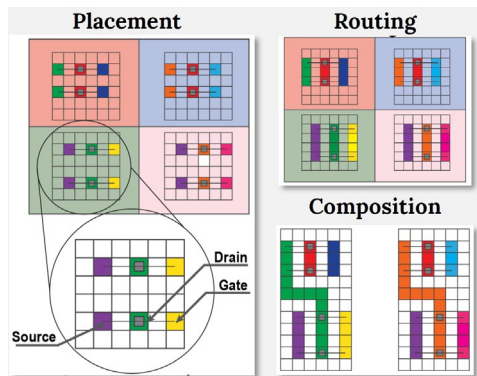
Figure of Output[11]

- Opportunity 3: Power Stage PCB Layout Design aided by AI

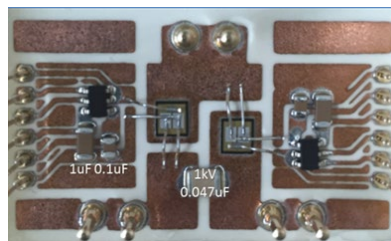
## AI based PCB Signal Layout



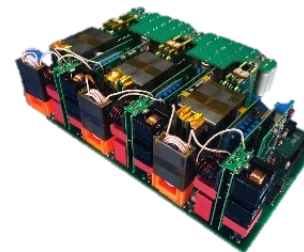
Automation Flowchart[12]



## PCB Power Stage Layout



[13]



[8]



[14]

**Altium**  
Designer

### Key Challenge for PCB Layout

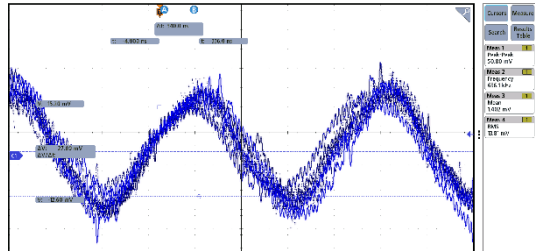
- Minimize Power Loop Inductance
- Minimize Gate Loop Inductance
- Adjust Transistor Package (TO247-3, TO247-4, QFN, TOLL, TOLT, D3PAK, etc.)
- Gate Driver circuit design
- Thermal Management
- Assembly Difficulty
- Sensor & Aux Power Supply
- Etc.

**No Power Stage PCB Layout Automation Tool Available**

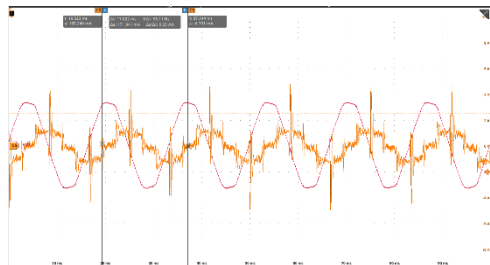
Parameters	Value
Rated Power	5kw each
DC Voltage	72-108Vdc
Dimension (L*W*H)	12.6*3.15*1.6 inch 32*8*4 cm
Switching frequency	100kHz
Power Density	220W/inch <sup>3</sup> or 13.4kW/L



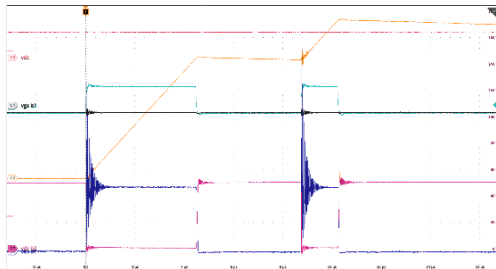
• Opportunity 4: AI facilitated Prototype Assembly, Debugging & Testing



Abnormal 630kHz Noise on AMC3330 Output



Abnormal current Noise on EMI Filter



DPT: 140V overshoot @ 50V, 10A

Waveforms

Description

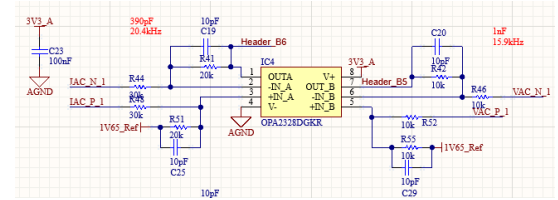
**AI Agent**

- Understand waveforms and user questions.
- Link to previous set Power Electronics Design Database & knowledge.
- Implement Chain-of-thought and think like power electronics engineer with expertise.
- Analyze question and give the answer.

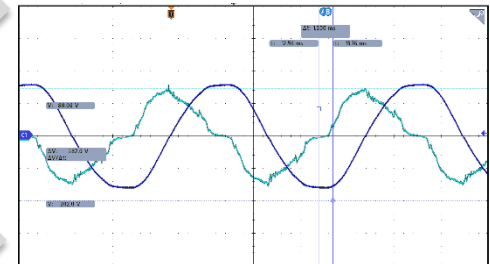


Reason

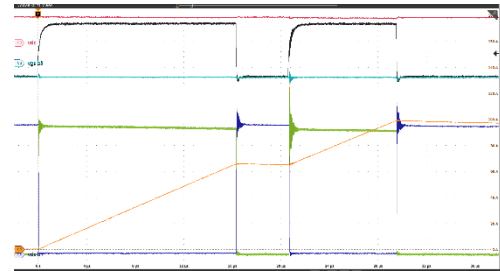
Solutions



CM Noise Filtered, Sensing Circuit Works

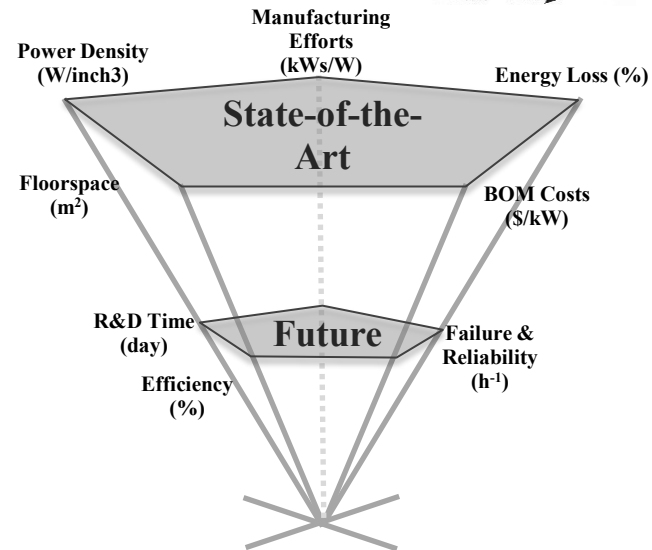
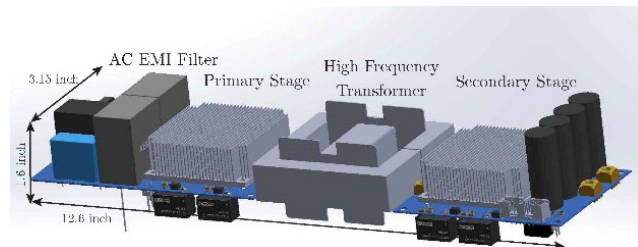
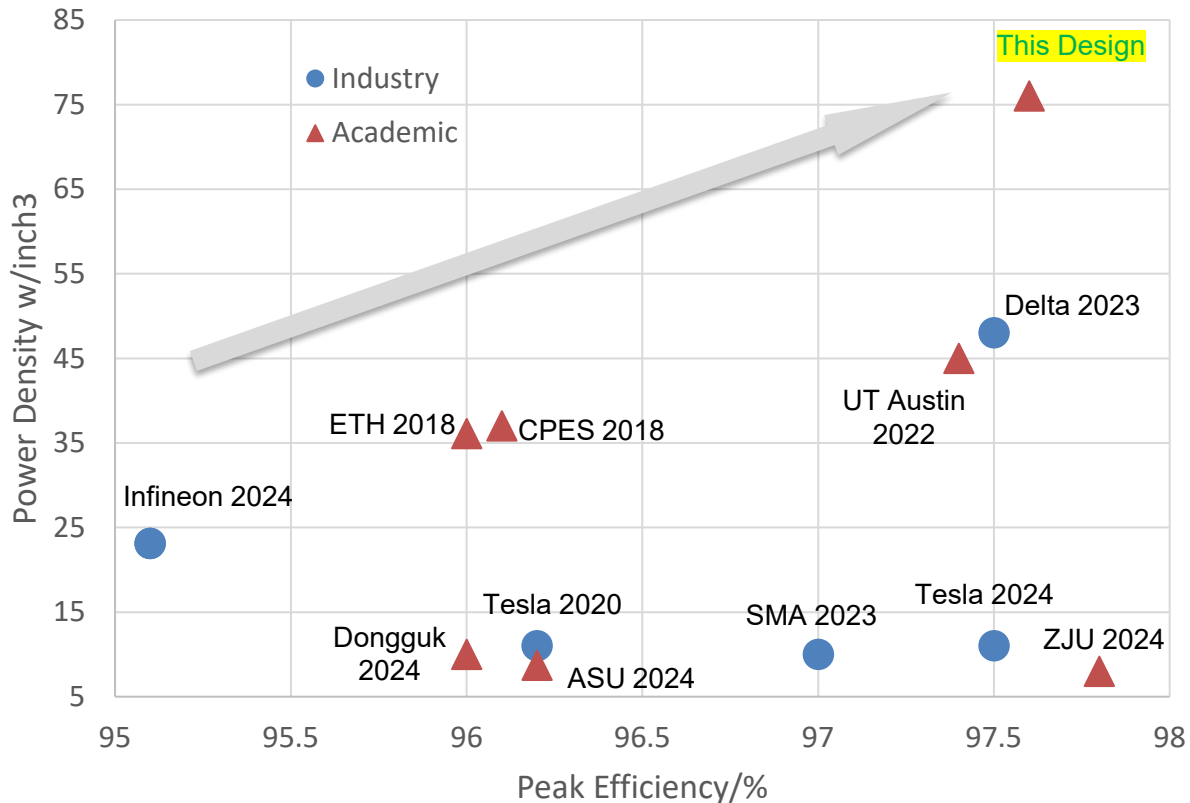


Current Noise Disappeared



DPT: 120V overshoot @ 100V, 100A

## Comparison among Hardware Prototypes for Power Density & Peak Efficiency





- **Build and Validate the Foundational AI Enhanced PE Design Acceleration Tool**
  - Establish validated Physics-Informed AI models.
  - Integrate AI models into a unified simulation environment.
  - Enable AI-driven multi-objective optimization.



- **Execute Autonomous Co-Design to Generate a Digital Blueprint**
  - Define system-level specifications as AI inputs.
  - Autonomously generate and co-optimize the complete converter design.
  - Produce a full set of manufacturing-ready layout files.



- **Fabricate, Test, and Benchmark the Physical Prototype**
  - Accelerate hardware testing and debugging with AI assistance..
  - Validate performance against state-of-the-art benchmarks.

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- [12] T. Chen, S. Xiong, H. He, and B. Yu, "TRouter: Thermal-Driven PCB Routing via Nonlocal Crisscross Attention Networks," *IEEE Trans. Comput.-Aided Des. Integr. Circuits Syst.*, vol. 42, no. 10, pp. 3388–3401, Oct. 2023, doi: 10.1109/TCAD.2023.3243544.
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- [14] H. Zou and A. Q. Huang, "Design and Optimization of PCB Layout for paralleled Top-Side-Cooling Package MOSFETs in High-Power Converters"

# THANK YOU FOR ATTENTION

*For further information, please contact:*

**Dr. Alex Q. Huang**

[aqhuang@utexas.edu](mailto:aqhuang@utexas.edu)

[spec@utexas.edu](mailto:spec@utexas.edu)