GaN Systems

TRANSFORMING THE WORLD

WITH SMALLER, LOWER COST, MORE EFFICIENT POWER ELECTRONICS

Parasitics Optimization for GaN HEMTs in Conventional Housing-Type Power Modules

GaN Systems company overview

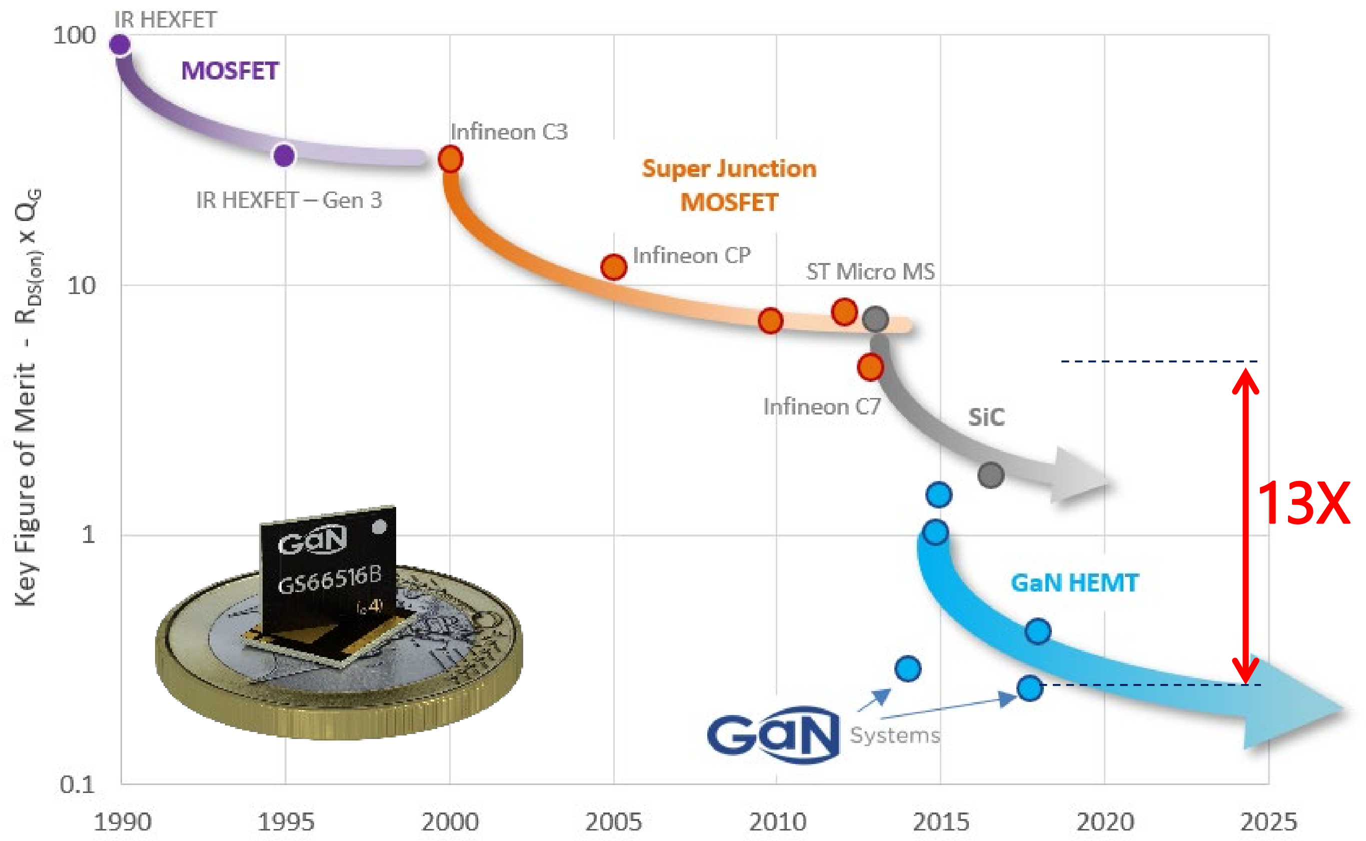
Market leader for GaN power transistors

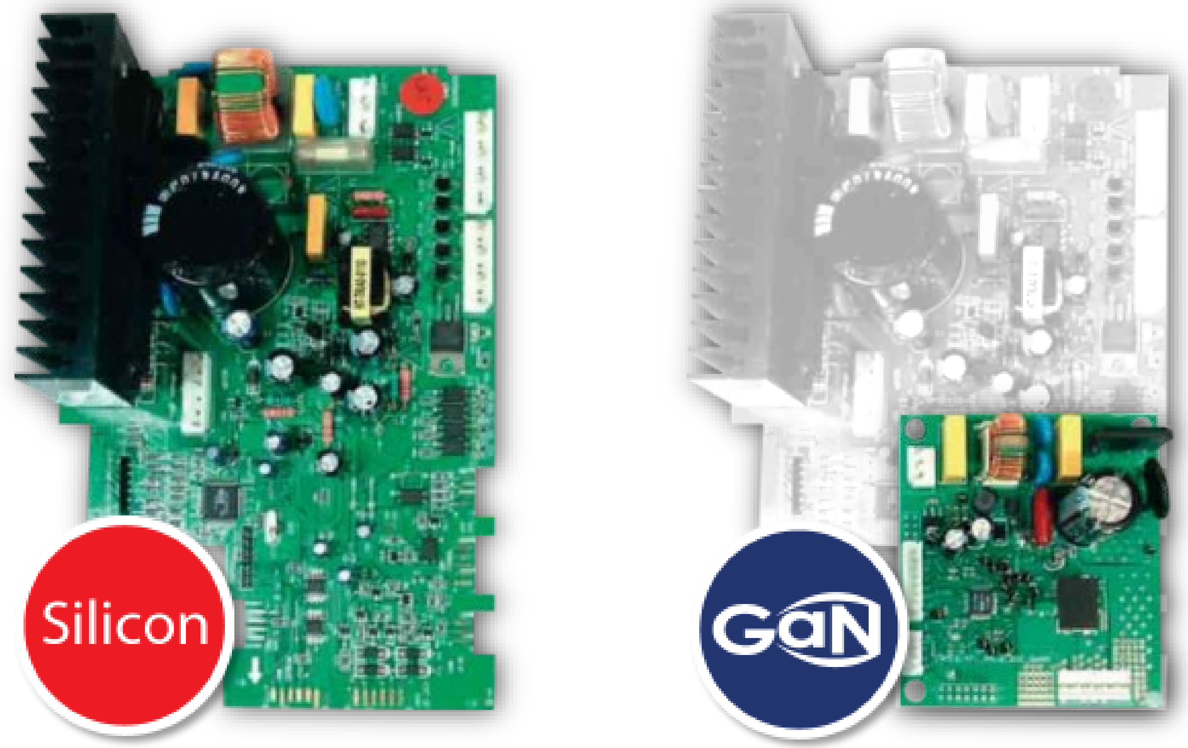
- GaN-on-Silicon transistors for the power conversion market
- Industry's most extensive & highest-performance products
  - Enhancement mode devices
  - 100V & 650V devices; industry-best performance

Global company with decades of experience in GaN

- Parts shipping overnight from Mouser since 2014
- World-class fabless manufacturing and advanced packaging
- HQ and R&D in Ottawa, Canada
- Sales & Applications Engineering globally

GaN leads the shift in power electronics





Power Supply with Silicon

Power Supply with GaN

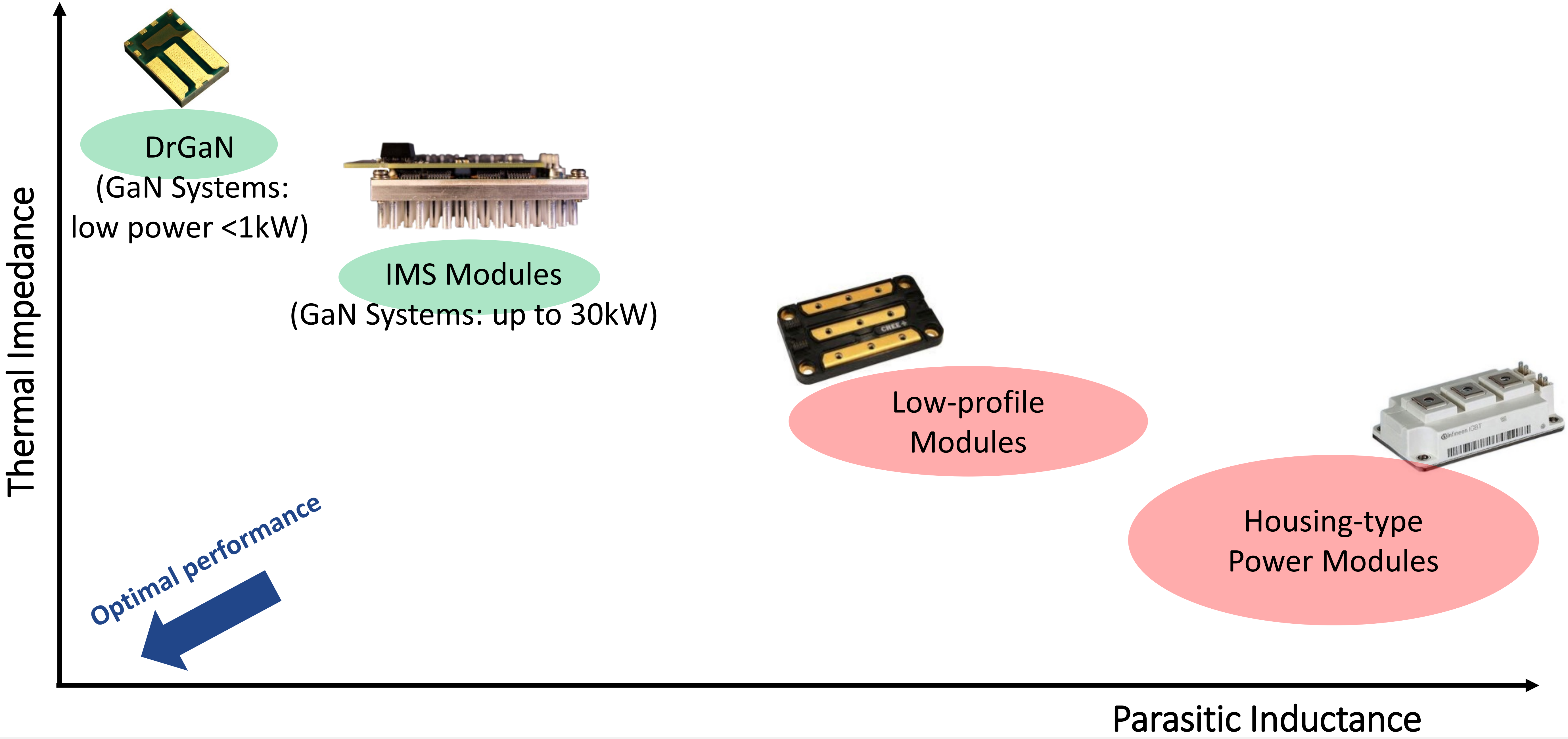
GaN SYSTEMS OUTPERFORMS OTHER TRANSISTORS

- ↑ 13X better than best Silicon
- ↑ 6X better that best SiC
- ↑ 3X better than other GaN

CUSTOMERS ACHIEVE IMPROVED SYSTEMS

- More efficient *1/4 the losses*
- Smaller *1/4 the size*
- Lighter *1/4 the weight*
- Lower system cost

High Performance vs. Legacy Packaging Technologies



DBC housing-type modules: excellent thermal performance, cost effective, available and mature; but high circuitry parasitics

High Performance vs. Legacy Packaging Technologies

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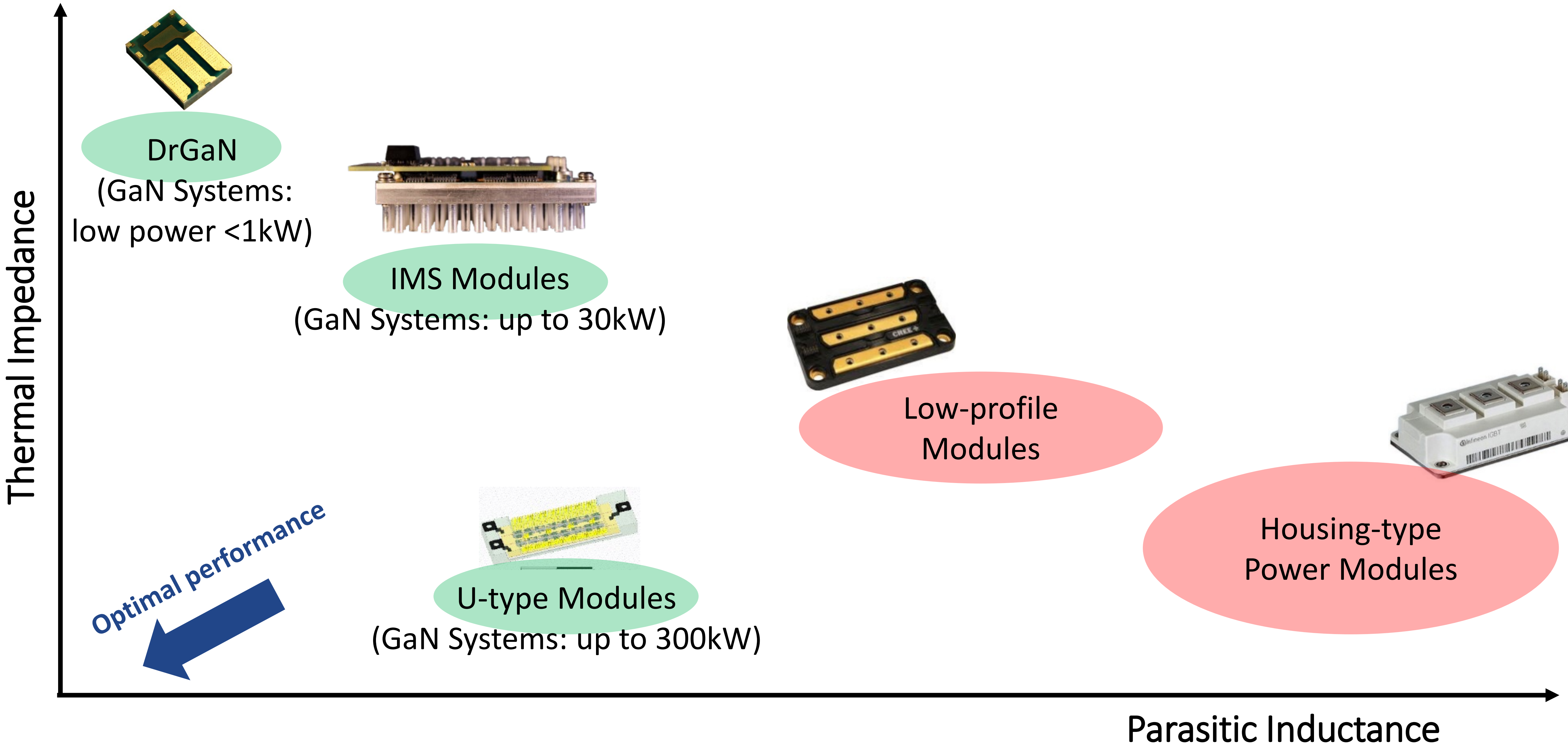

U-type minimizes the parasitics with proven packaging technology for high power systems

Agenda

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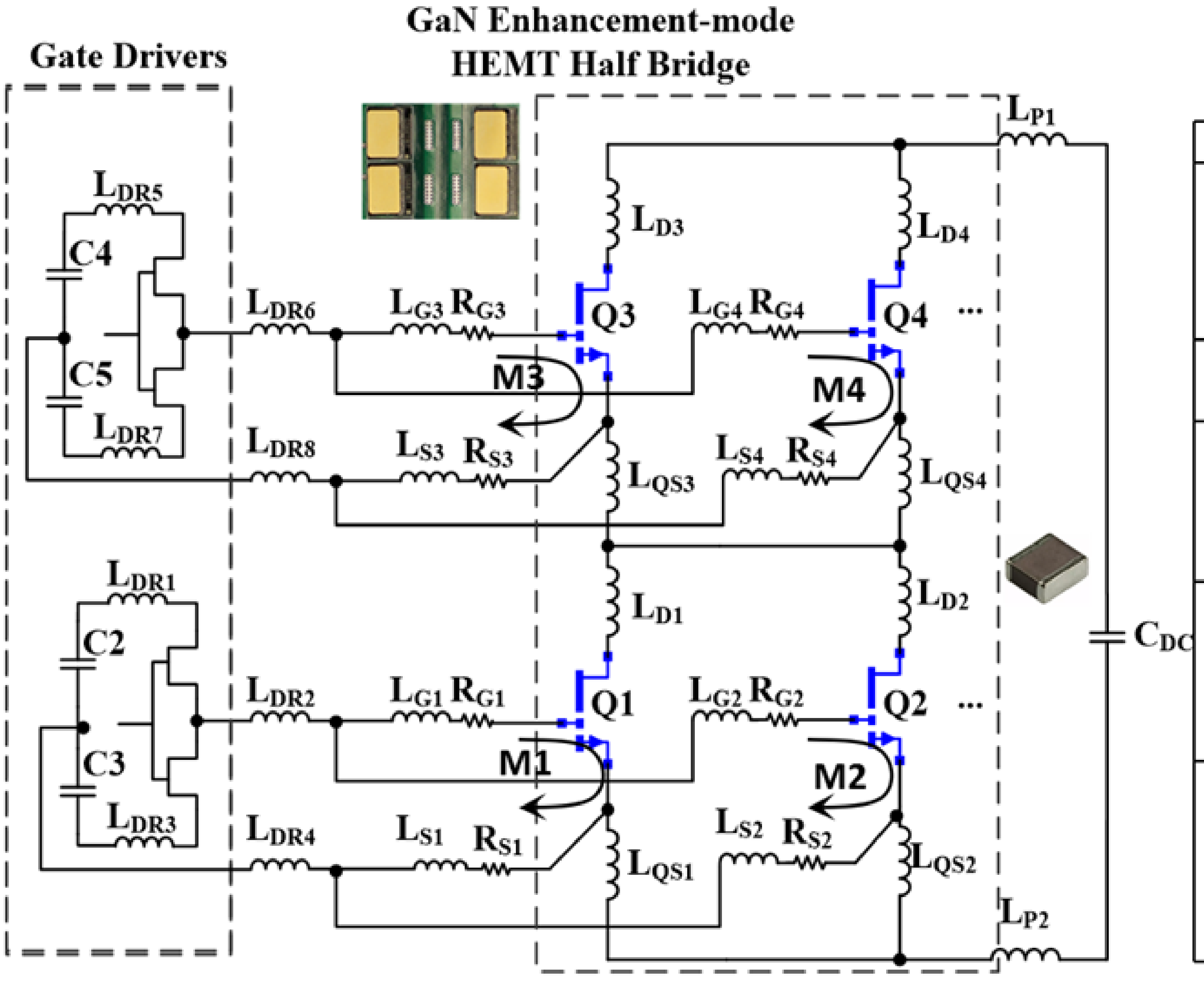
- **Effect of circuit parasitics on GaN switching performance and module design considerations**
- Experimental verification with IMS-based modules
- Proposed U-type Module

Parasitic inductance effects



Two GaN devices in Parallel

Effects of Parasitics

Parameter	Description	Effect	Priority	Design Rules
L_{P1},L_{P2} L_{D1-4}	Commutation Loop Inductance	Cause/participate in isolation/ringing	No.2	As small and symmetric as possible
L_{DR1}-L_{DR8}	Gate drive loop inductance		No.3	
L_{G1}-L_{G4} L_{S1}-L_{S4}				
M1-4	Mutual Inductance between power loop and gate loop		No.1	
L_{QS1-6}	Quasi-common source inductance			

The effect of parasitics have been thoroughly discussed in existing works [1][2][3].

[1] J. Lu, H. K. Bai, S. Averitt, D. Chen and J. Styles, "An E-mode GaN HEMTs based three-level bidirectional DC/DC converter used in Robert Bosch DC-grid system," WiPDA *2015*, pp. 334-340.
[2] J. L. Lu, D. Chen and L. Yushyna, "A high power-density and high efficiency insulated metal substrate based GaN HEMT power module," *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*,
[3] J. L. Lu and D. Chen, "Paralleling GaN E-HEMTs in 10kW–100kW systems," *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Tampa, FL, 2017, pp. 3049-3056.

Common Source Inductance

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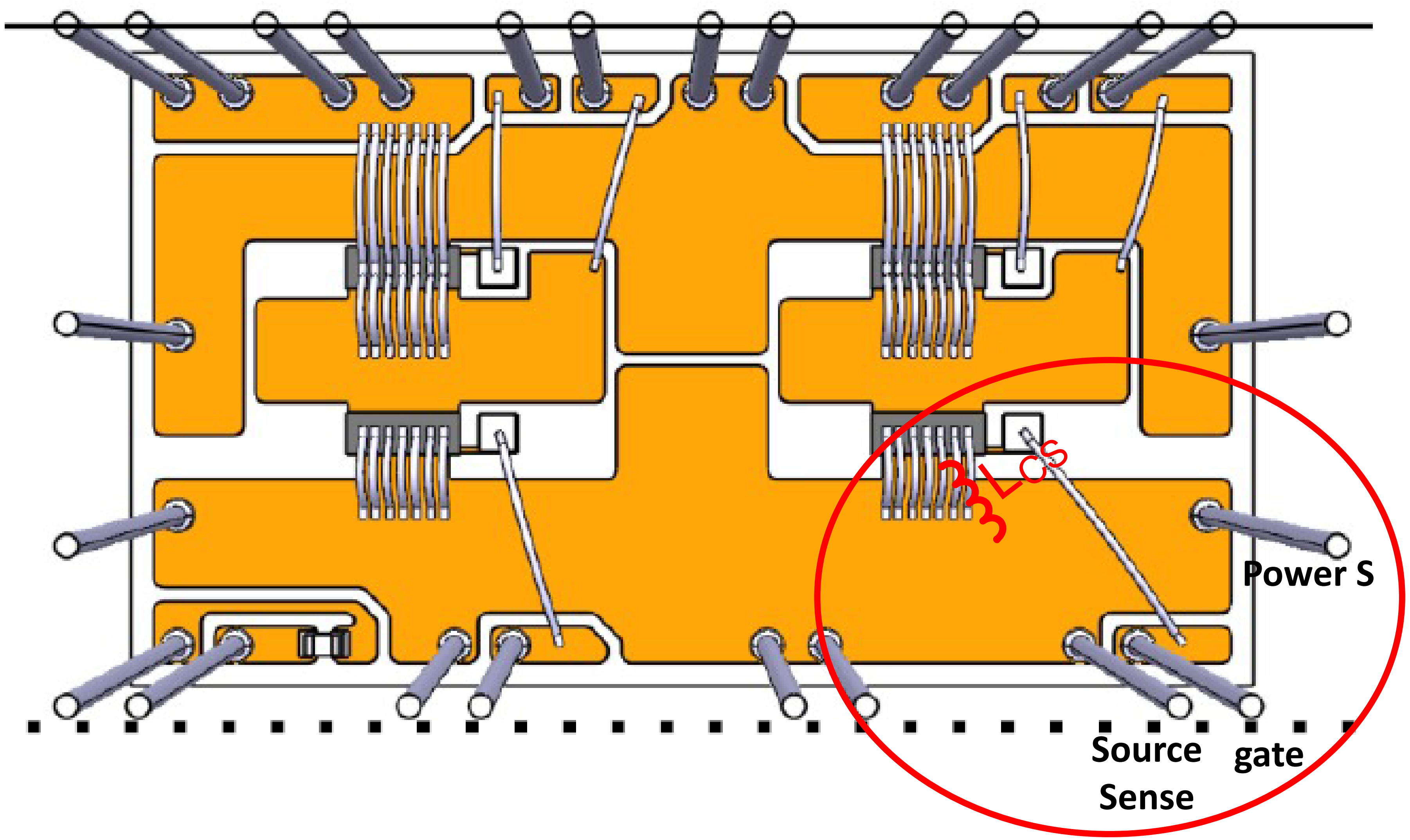
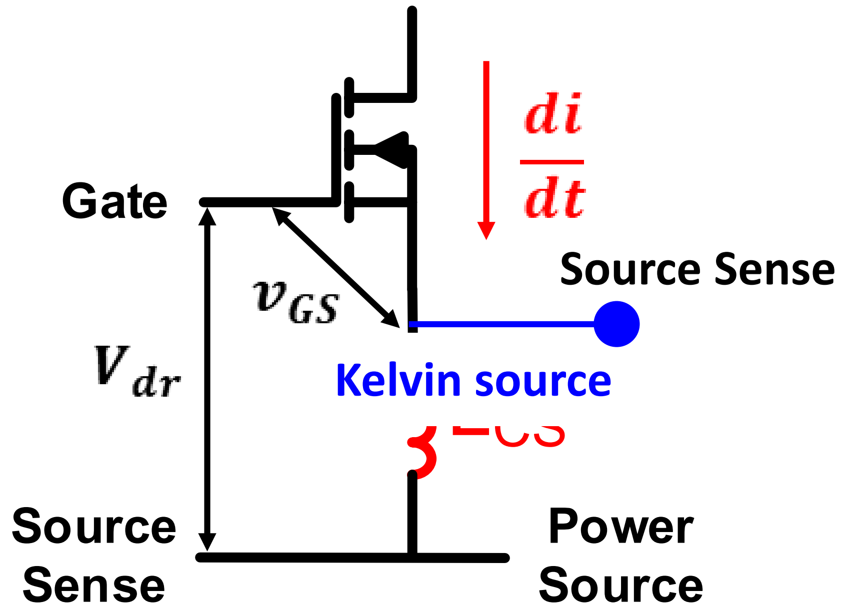


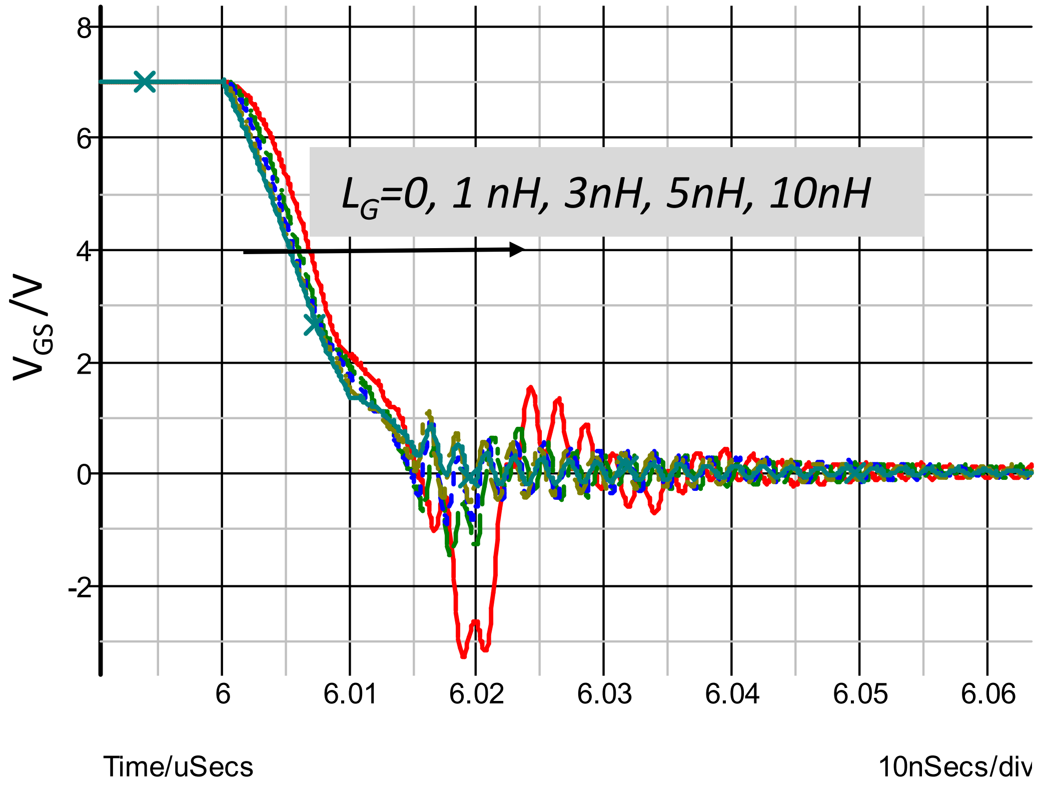


$$v_{GS} = V_{dr} - L_{CS} \cdot \frac{di}{dt}$$

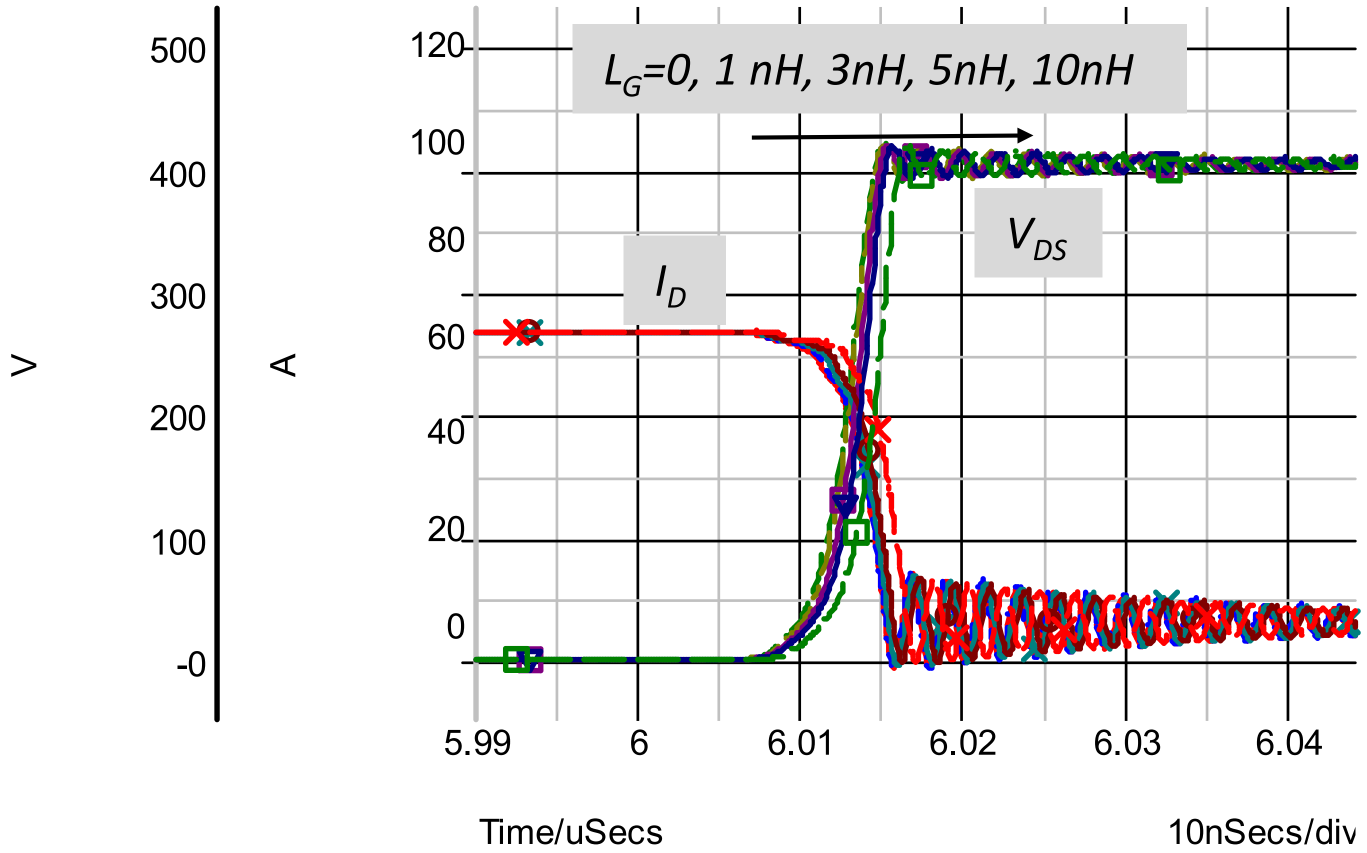
- The common source inductance will **feedback di/dt** of the power loop into the gate loop.
- The **mutual inductance** between the power loop and the gate loop is part of L_{CS}.
- **Kelvin source** is usually employed to bypass the common source inductance.

L_G Effect on Switching Performance of GaN HEMT

Condition: GS66516T, Rg=0 Ohm, L_G is varying from 0 to 10nH, V_{BUS}=400V, I_D=60A.



V_{GS} Waveforms with Different L_G



Drain-Source I/V Waveforms with Different L_G

- **L_G can cause overshoot on V_{GS}, however ≤ 10nH L_G will not cause mis-trigger of HEMTs**
- **L_G does NOT cause "Gate Loop Losses"**
- **Integrated gate driver will not reduce switching loss**

Power Commutation Loop Inductance

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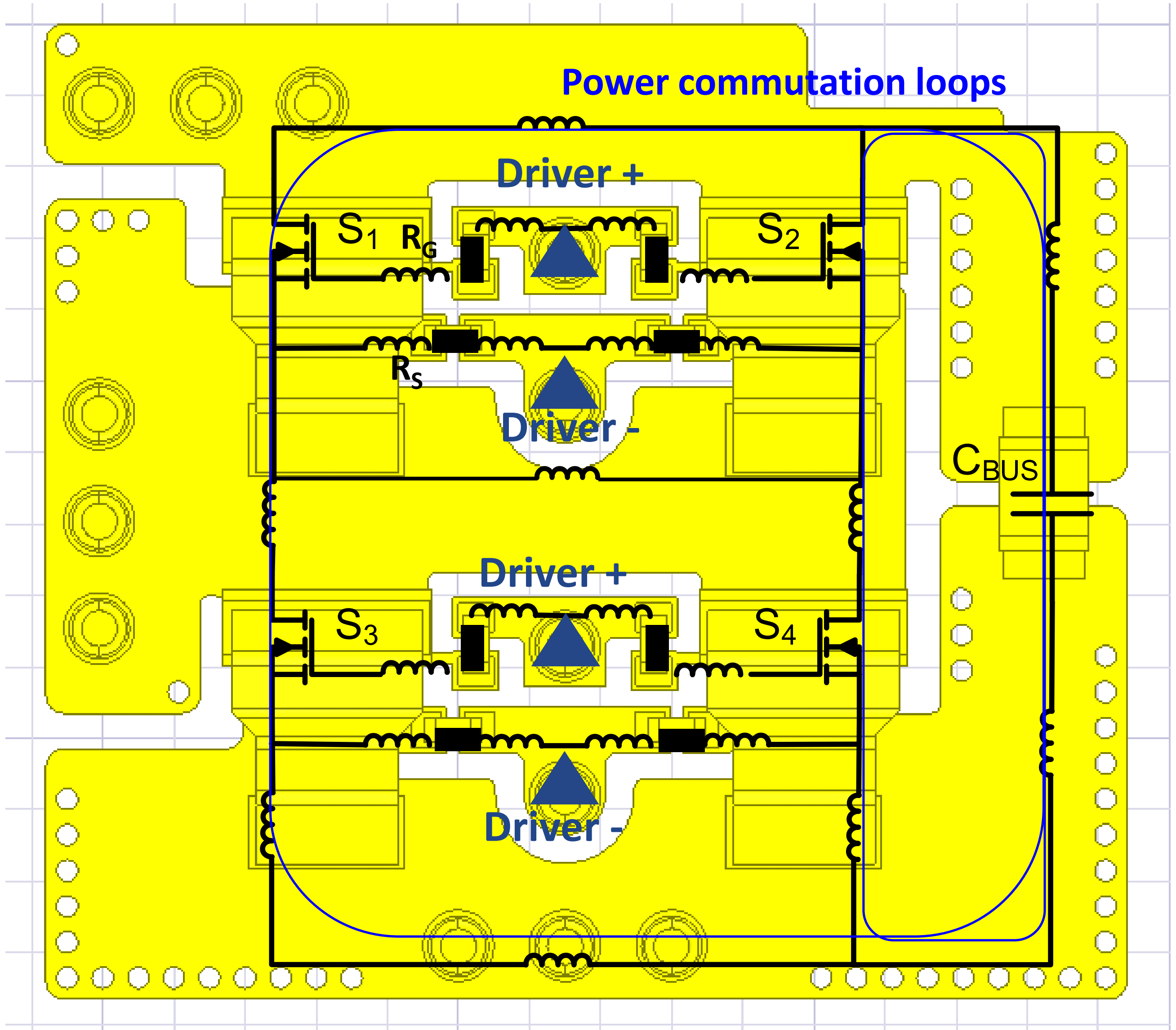
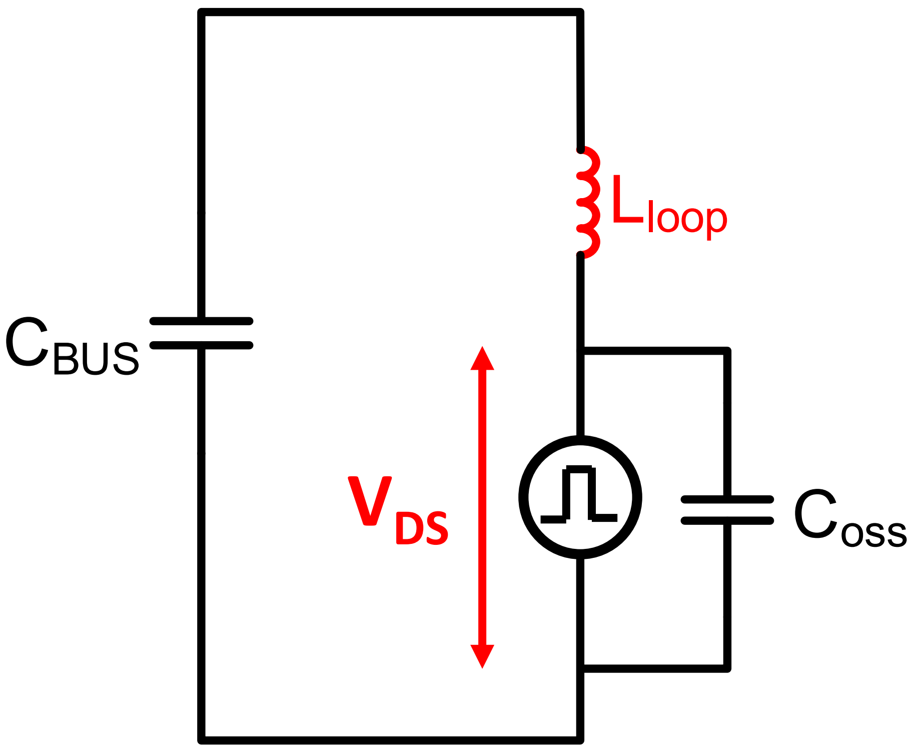


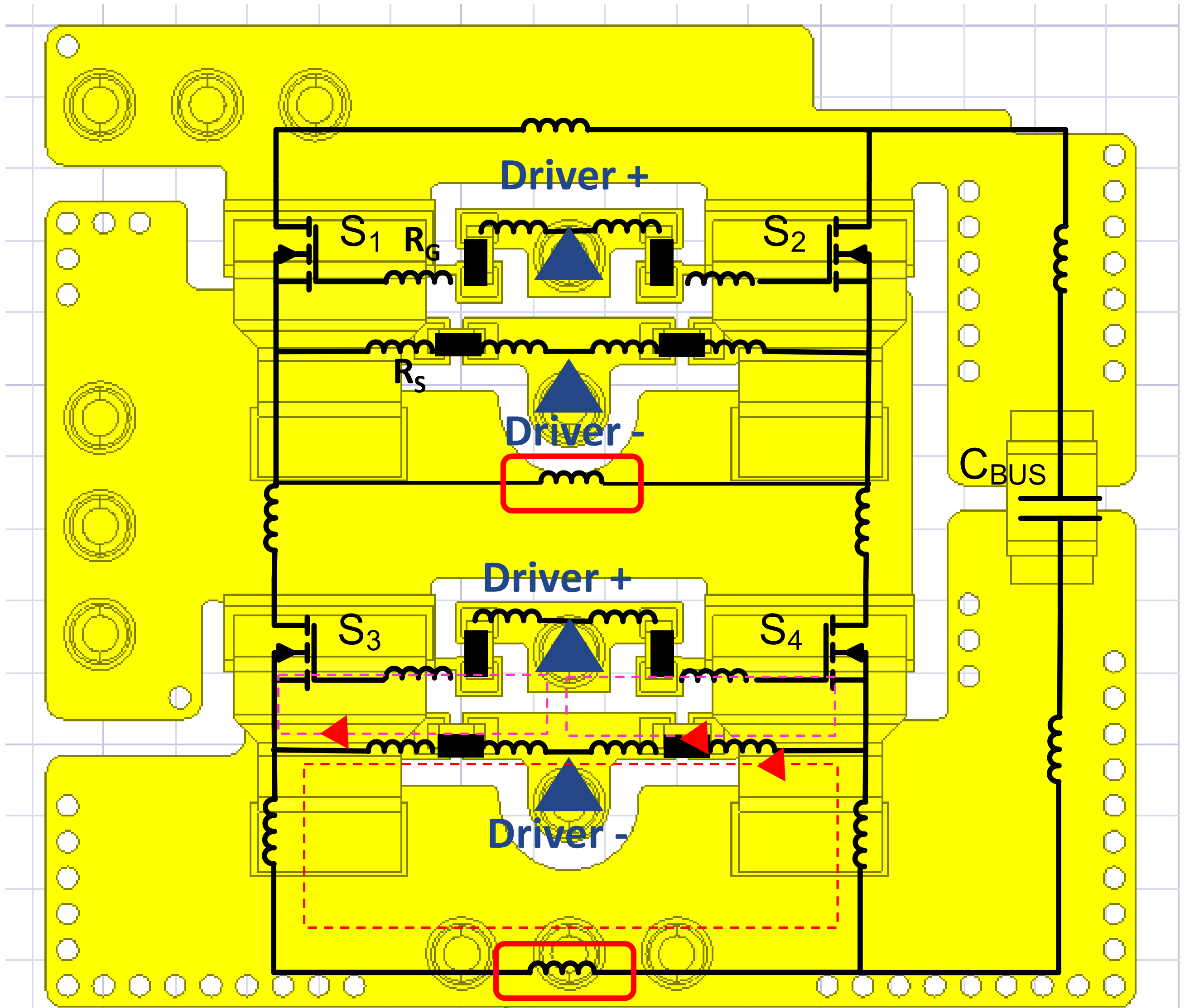
Stray inductance



Similar to a step response

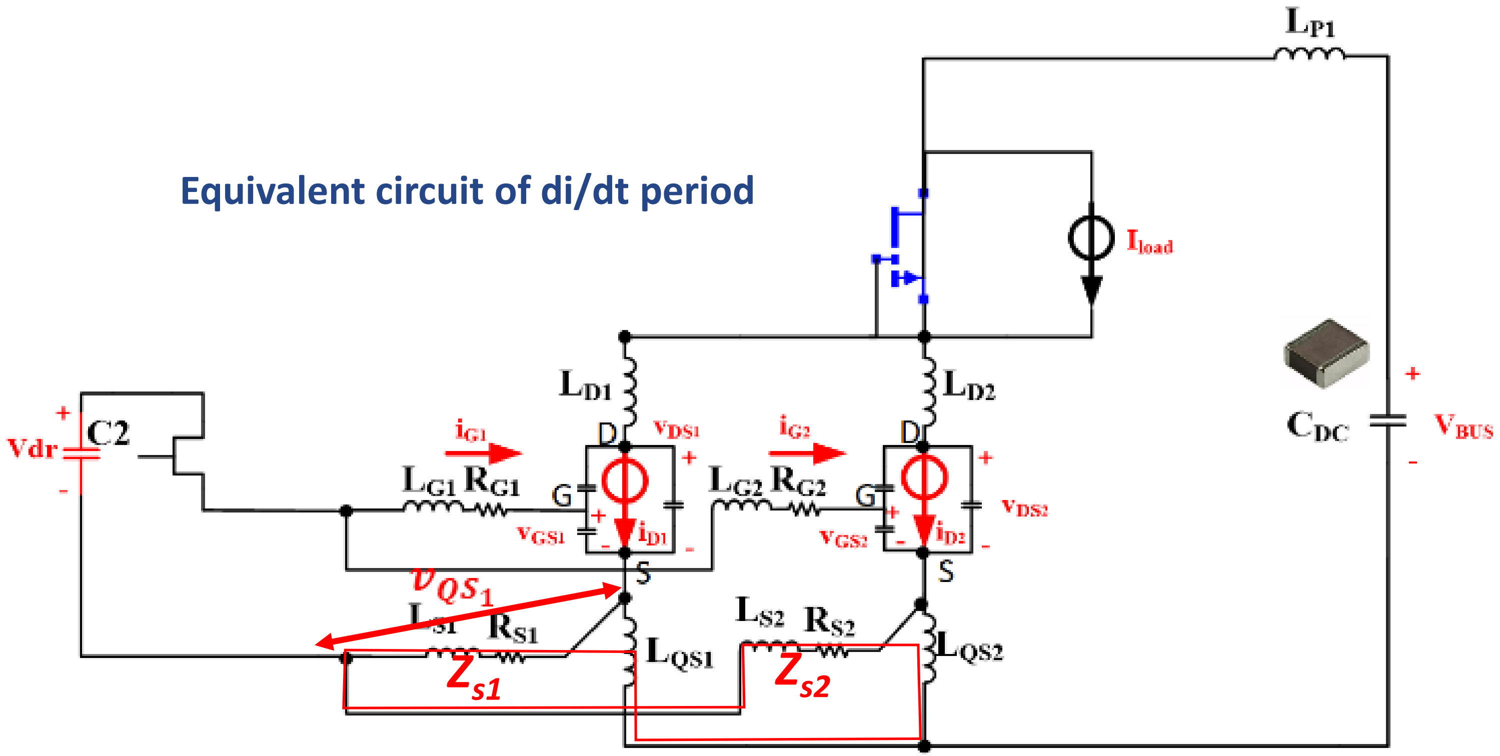
The voltage spike across the drain and source increases with the power commutation loop inductance

Quasi-Common Source Inductance



Quasi-common source inductance (L_{QS})

Stray inductance



When any of the $V_{GS} > V_{GS(th)}$, $i_D = g \cdot (v_{GS} - V_{th})$

$$v_{GS_1} = V_{dr} - v_{QS_1} - M_1 \cdot \frac{di_{D1}}{dt} - R_{G1} \cdot i_{G_1} - L_{G1} \cdot \frac{di_{G1}}{dt}$$

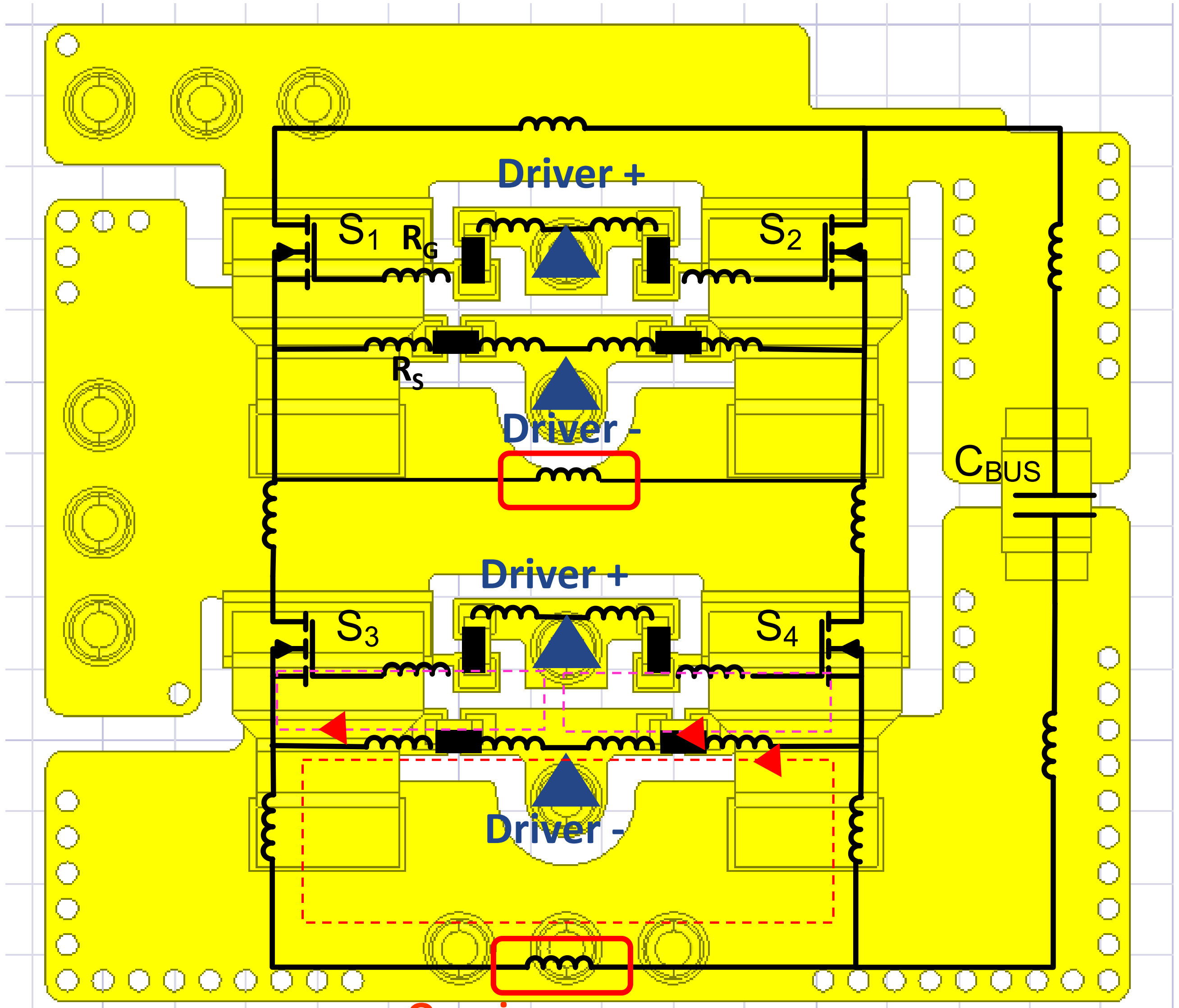
$$v_{DS_1} = V_{BUS} - L_{P1} \cdot \left(\frac{di_{D1}}{dt} + \frac{di_{D2}}{dt}\right) - M_1 \cdot \frac{di_{G1}}{dt} - (L_{D1} + L_{QS1}) \cdot \frac{di_{D1}}{dt}$$

Where, R_{G1} and L_{G1} are the total resistance and inductance of the gate loop

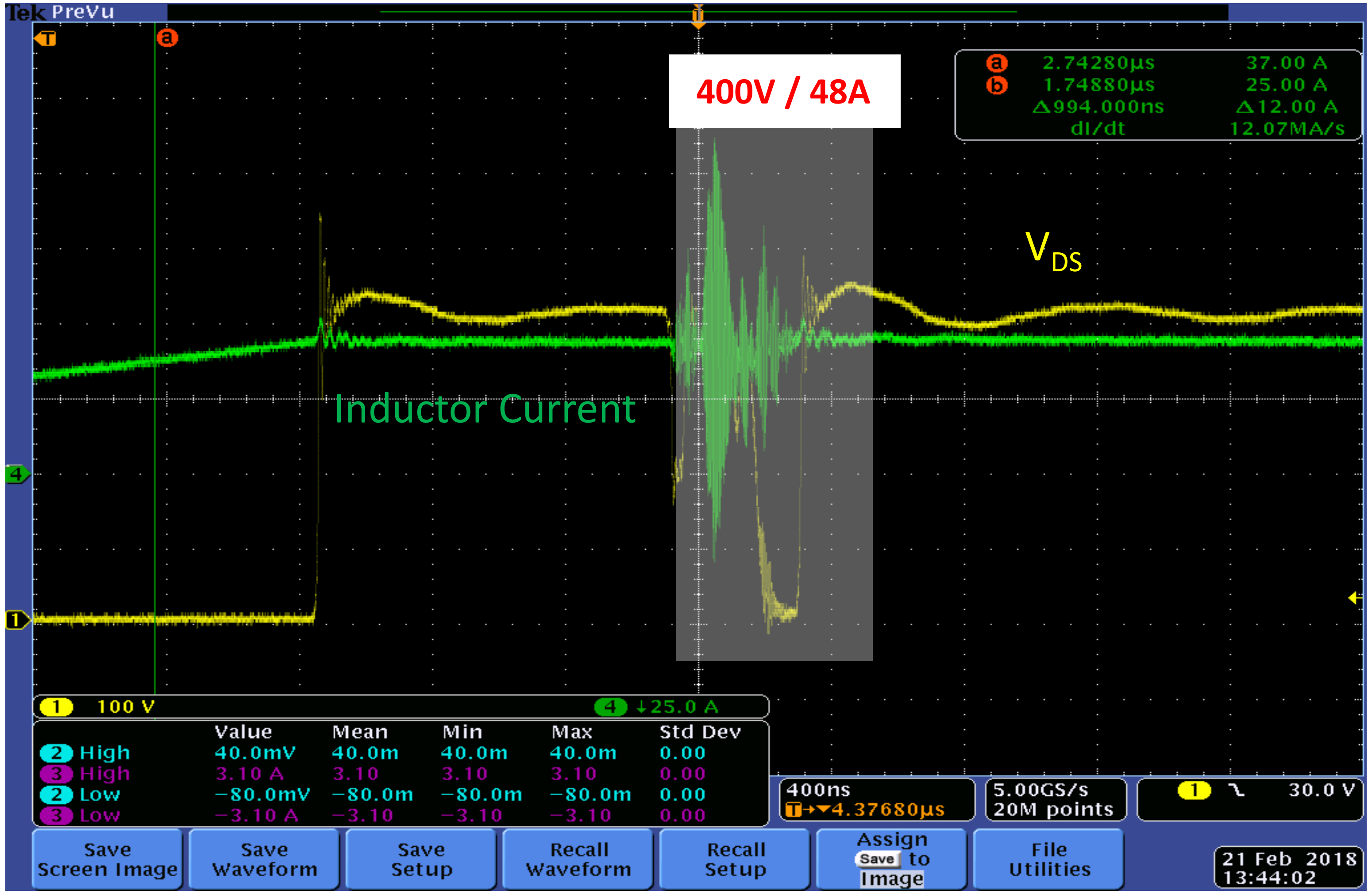
$$v_{QS_1} = \left(L_{QS_1} \cdot \frac{di_{D_1}}{dt} - L_{QS_2} \cdot \frac{di_{D_2}}{dt}\right) \cdot \frac{Z_{s2}}{Z_{s1} + Z_{s2}}$$

di/dt difference causes voltage drop across L_{QS} affecting the gate voltage

Quasi-Common Source Inductance Effects



Quasi-common source inductance



Double Pulse Test@400V/48A

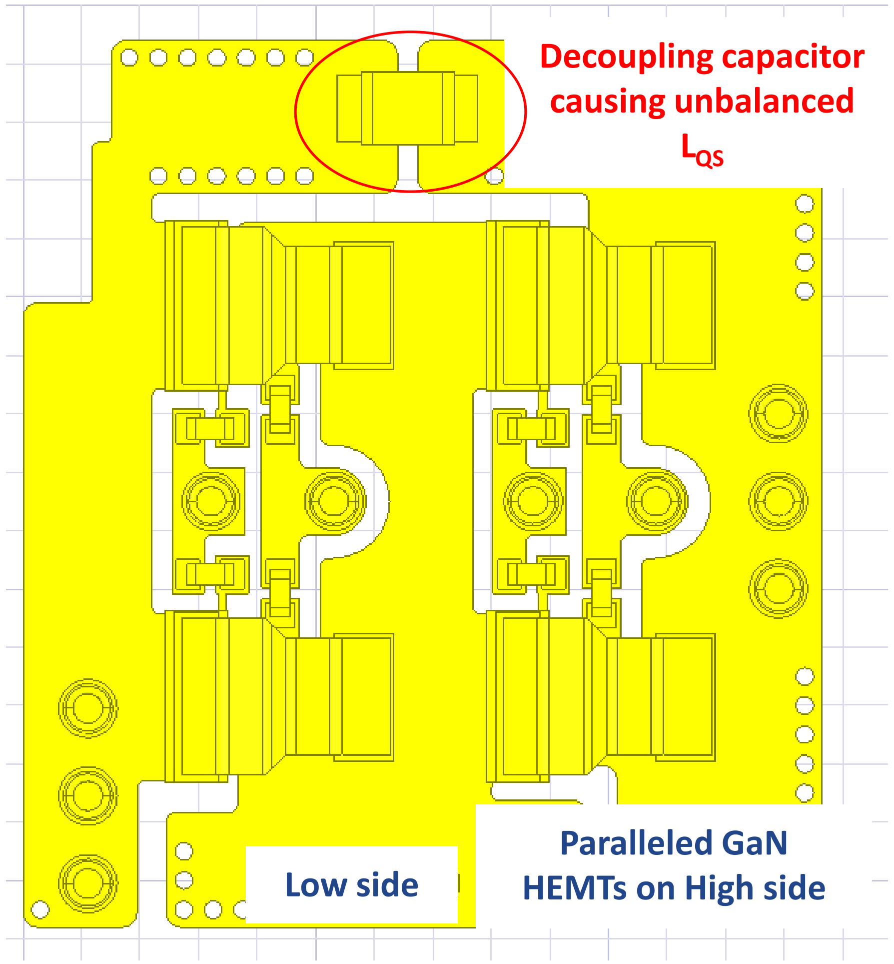
Stray inductance

di/dt difference causes voltage drop across L_{QS} affecting the gate voltage

Agenda

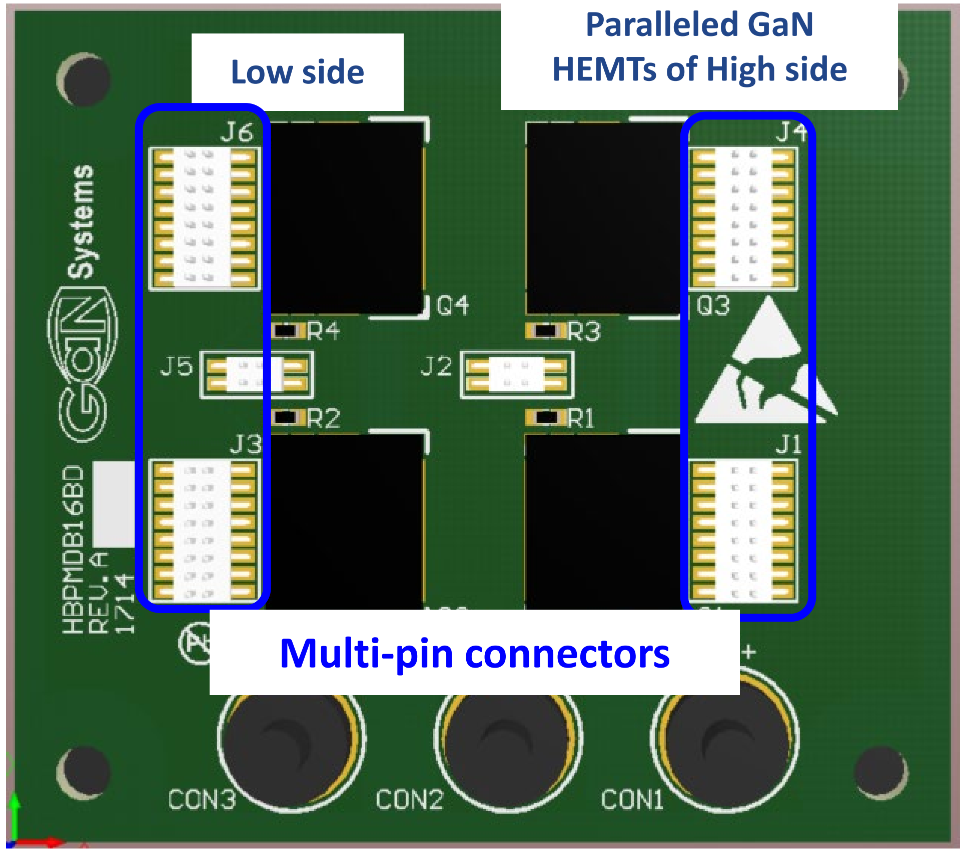
- Effect of circuit parasitics on GaN switching performance and module design considerations
- Experimental verification with IMS-based modules
- Proposed U-type Module

Module experimental setup – balancing L_{QS}



Module with unbalanced L_{QS}

VS.

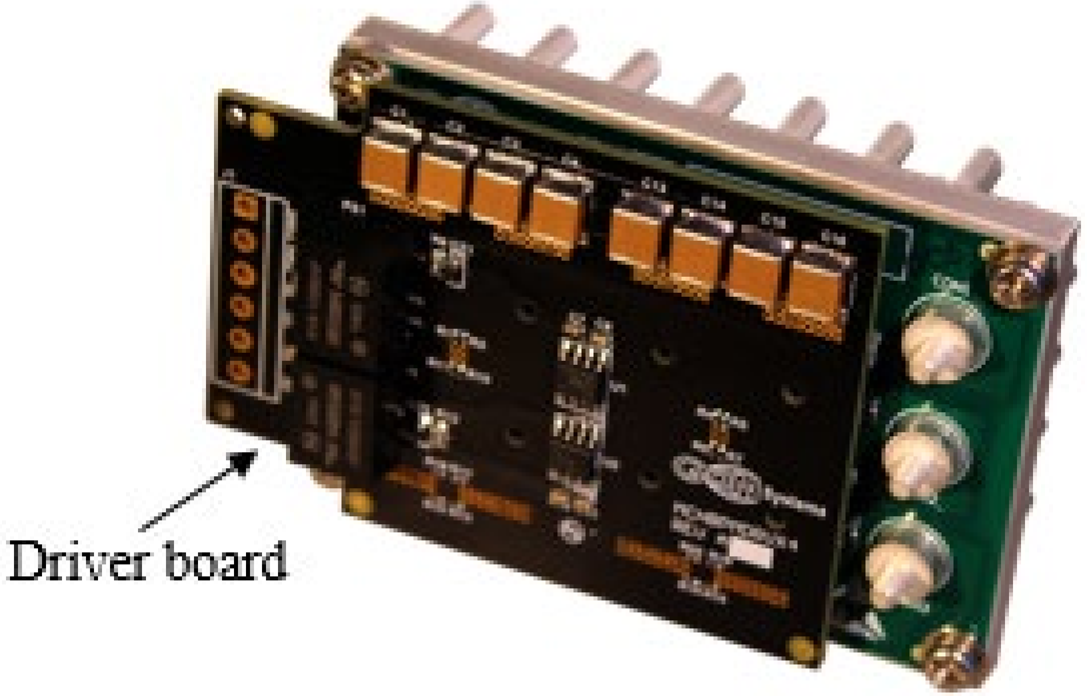


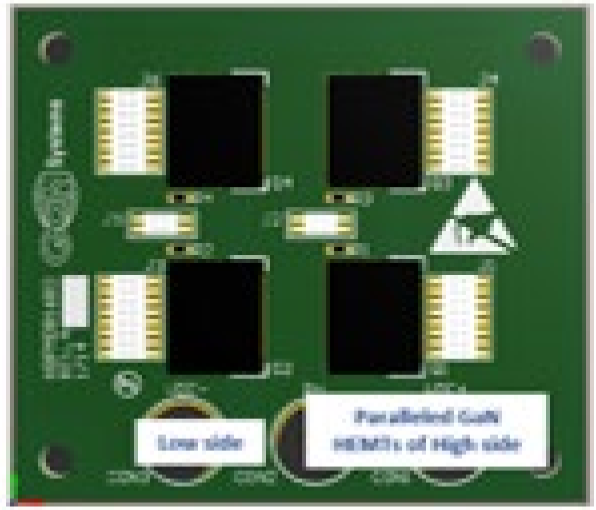
IMS module with balanced L_{QS}

* Insulated metal substrate (IMS) is a high-performance, low cost material for prototyping modules.

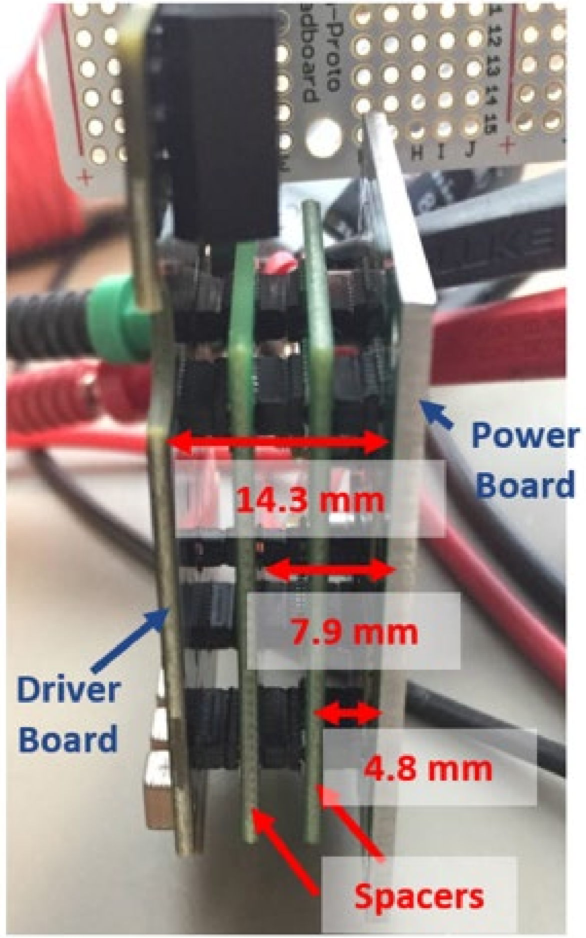
Multi-pin connectors (highlighted in blue) are employed on the IMS module to minimize and balance quasi-common source inductance

Module experimental setup – IMS spacing





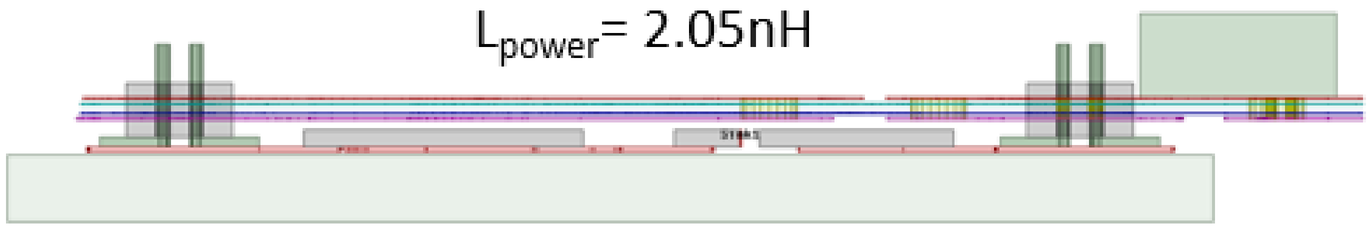
GaN IMS Module



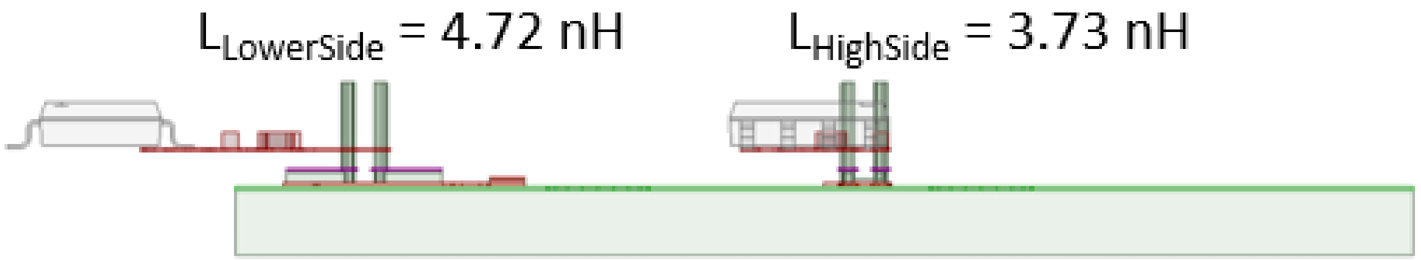
IMS GaN Module with adjustable distance between power board and driver board

The distance can be adjusted to modify the power commutation loop and gate driver loop inductance for experiments

Parasitics Extraction with Different Distances

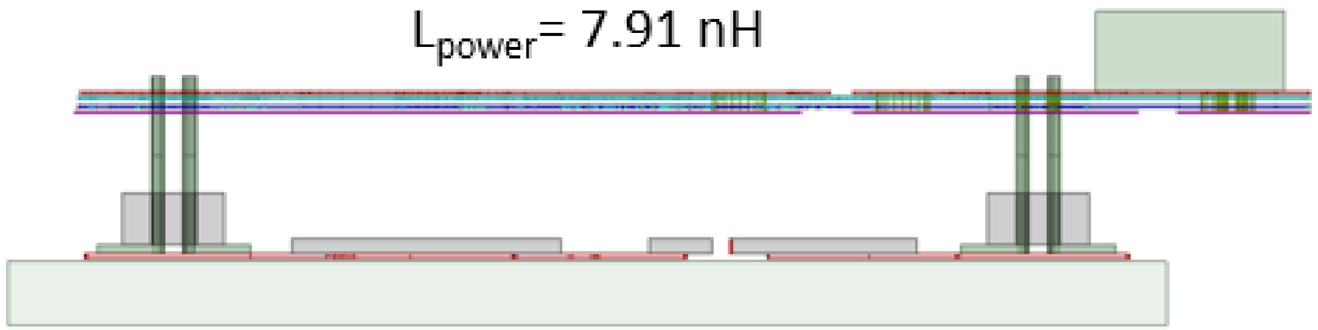


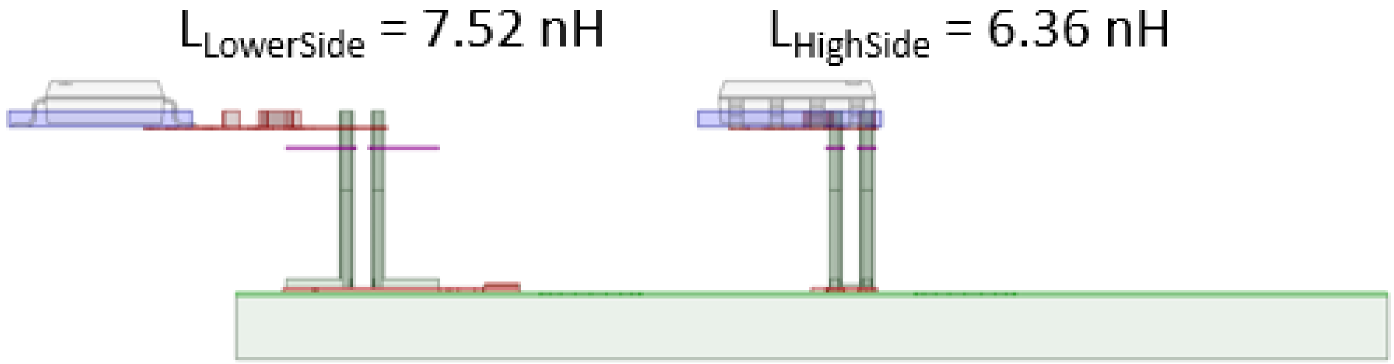
Power Commutation Loop



Gate Driver Loops

0.6 mm distance between GaN board & gate driver board





4.1 mm distance(due to the female sockets) between GaN board & gate driver board (what GW uses for debug)

The power commutation loop and gate driver loop inductances increase as the distance increases

Experimental Verification I

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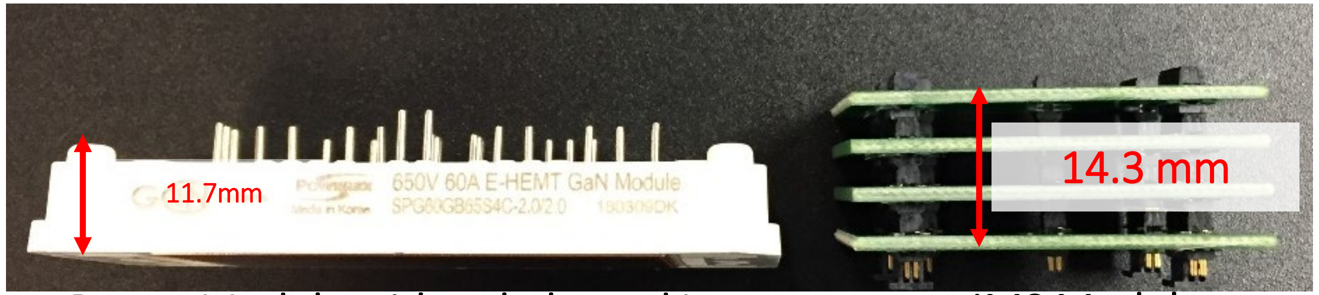
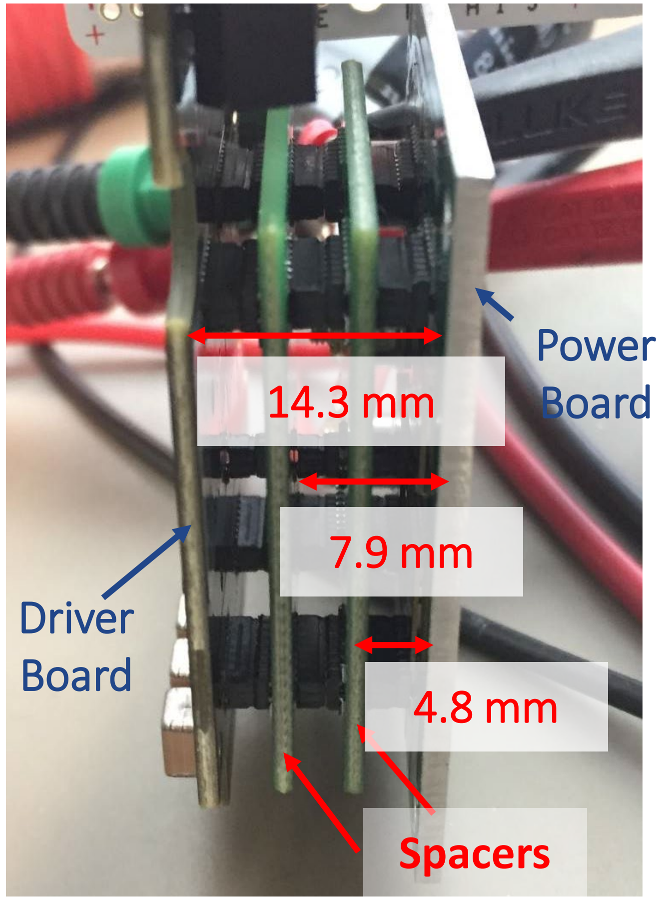
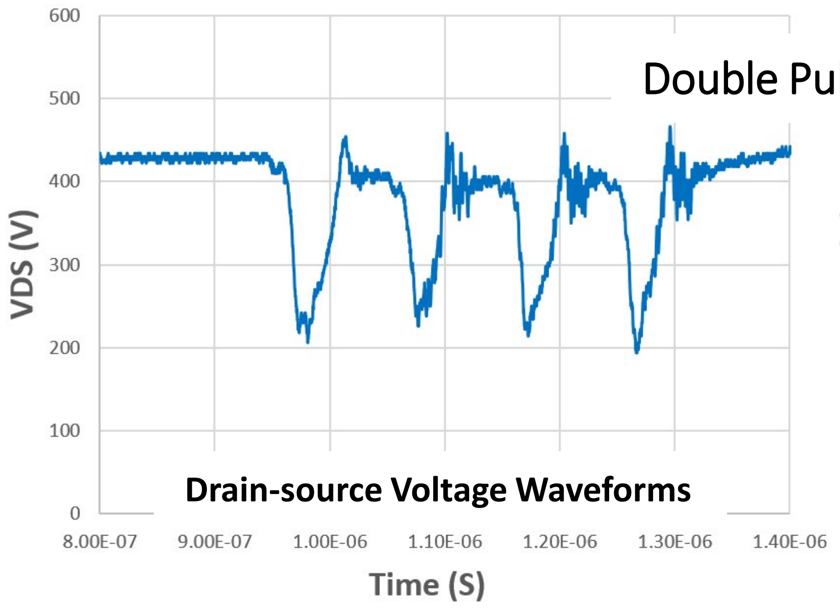


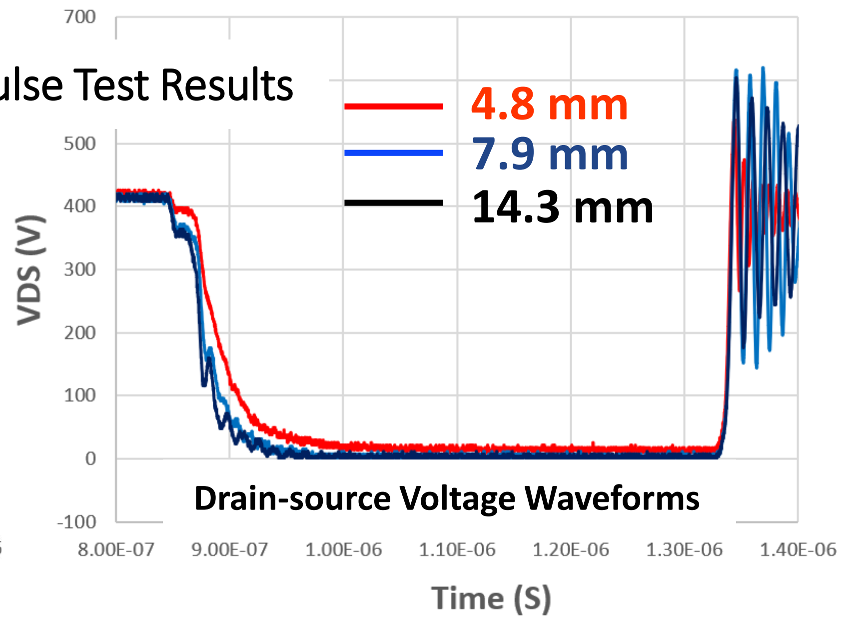
Power Module with unbalanced L_{CS} IMS Module

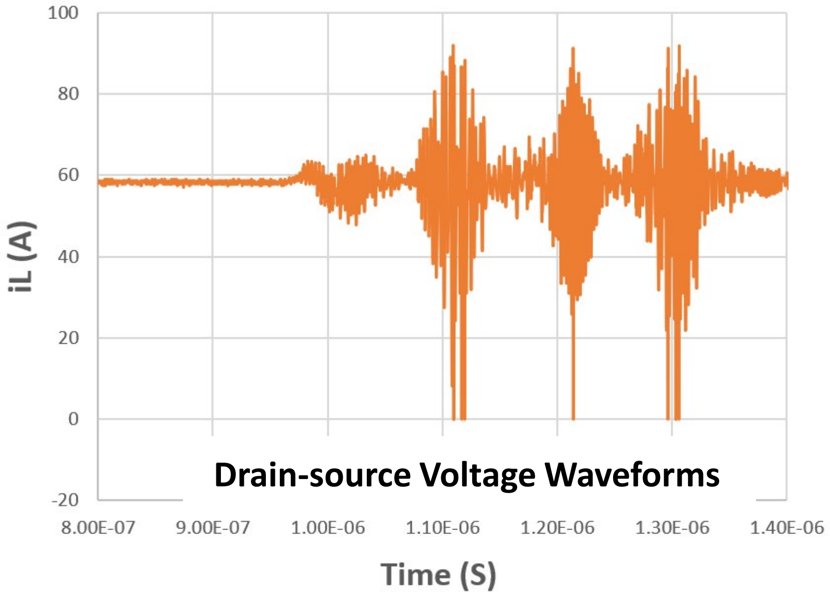
- Spaces to enlarge L_G in IMS Module
- 14.3mm (a worse case) and 7.9mm is tested
- Decoupling caps are on the driver board



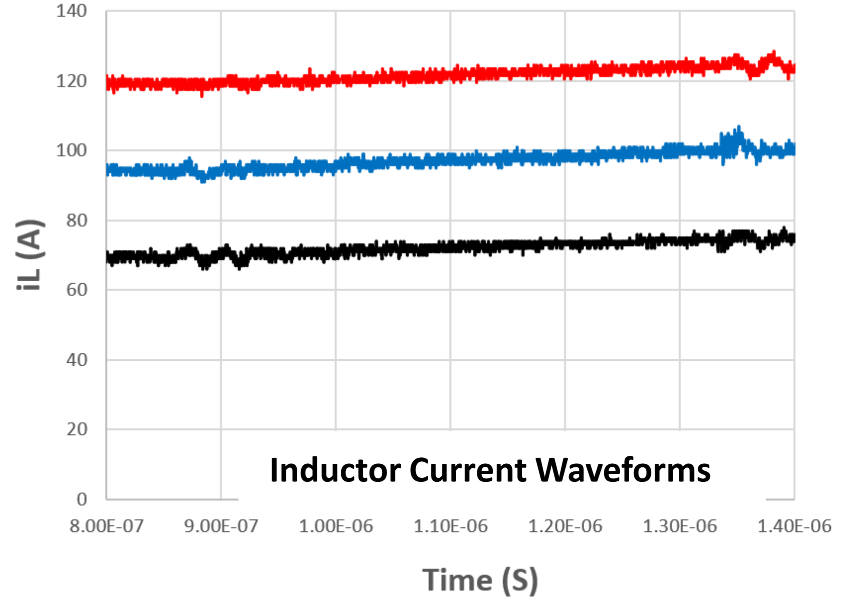
Spacer for IMS Module







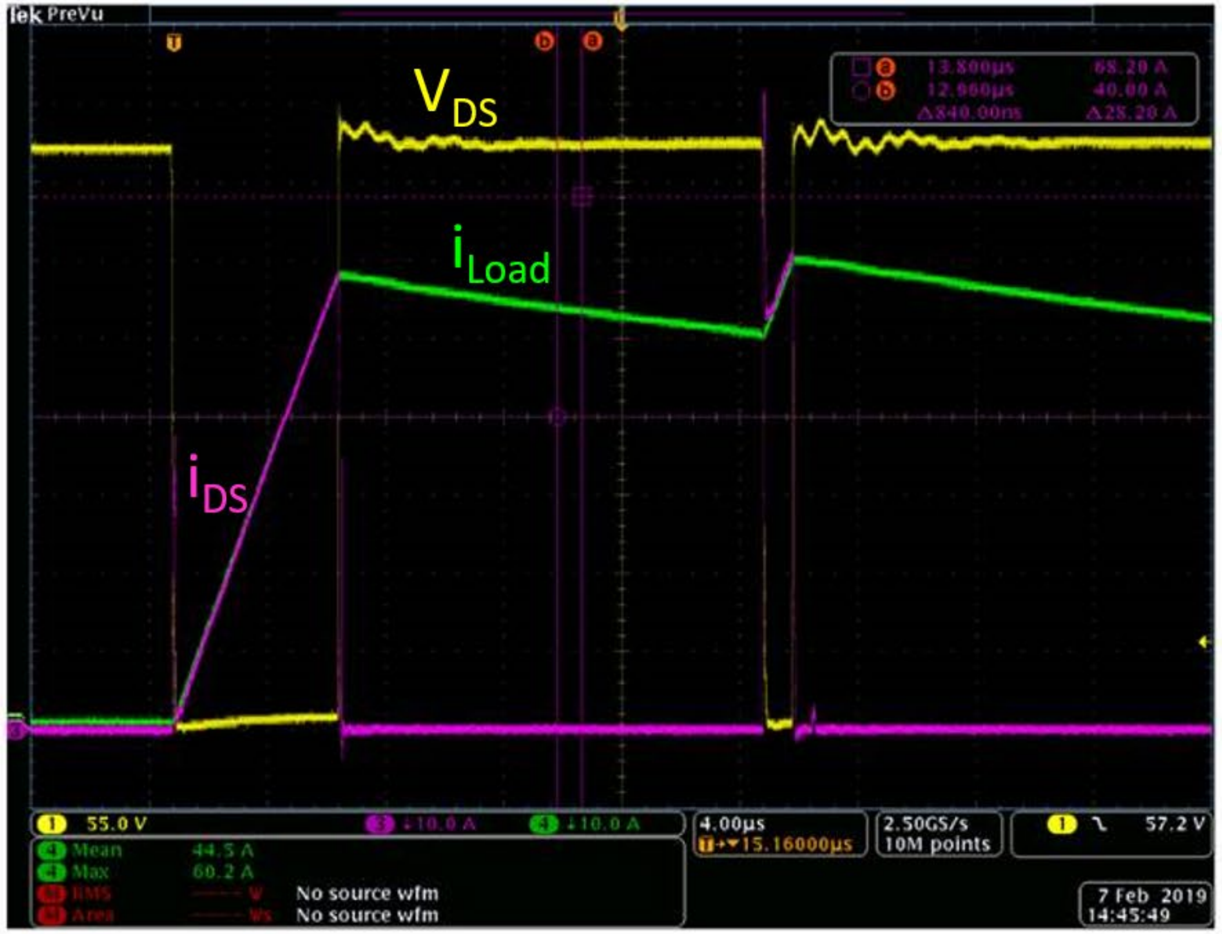
Power Module with Unbalanced L_{QS}



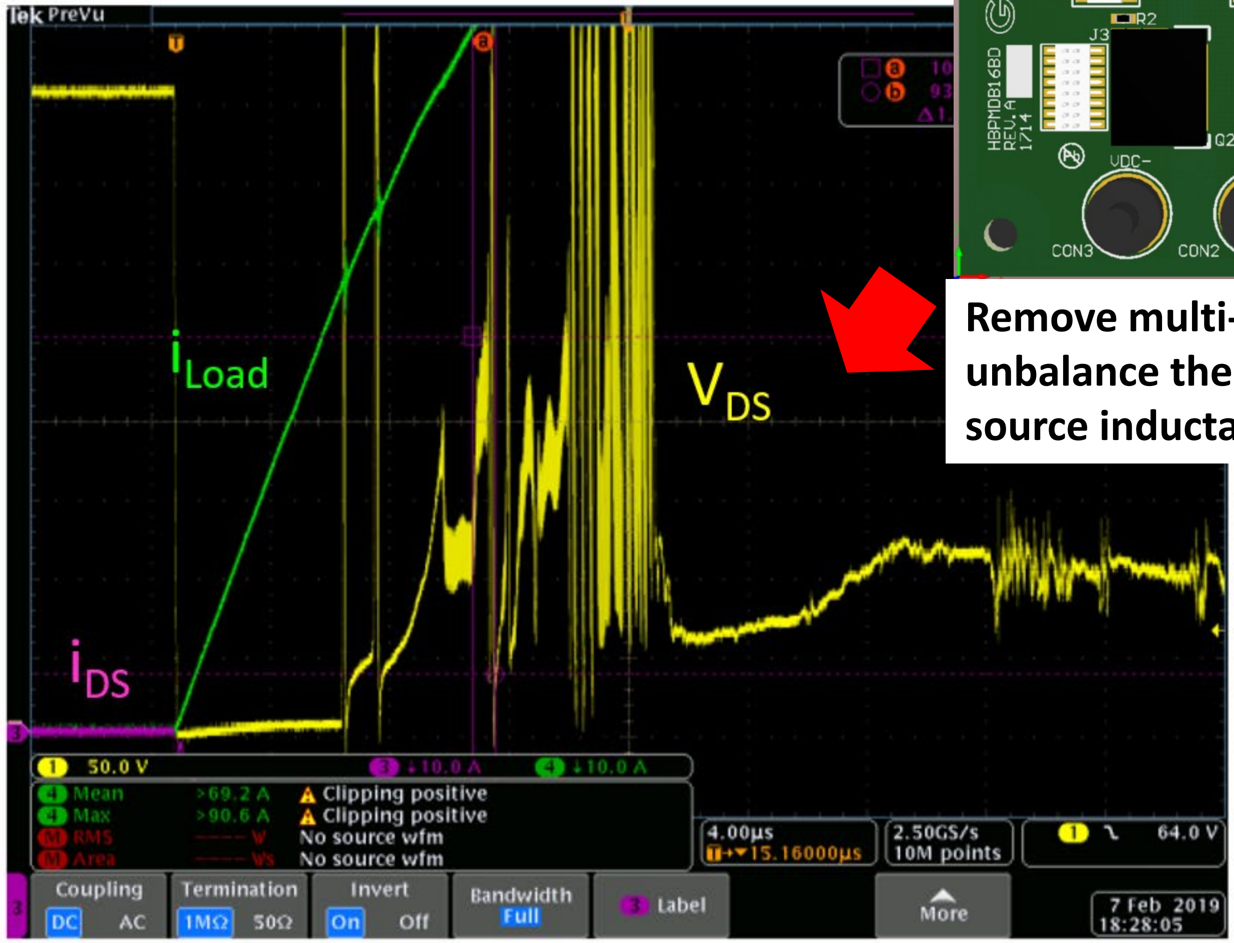
IMS modules with balanced L_{QS} and different Height

- **Increased power loop inductance will increase the V_{DS} voltage spike**
- **However, unbalanced quasi-common source inductance will cause switching failure**

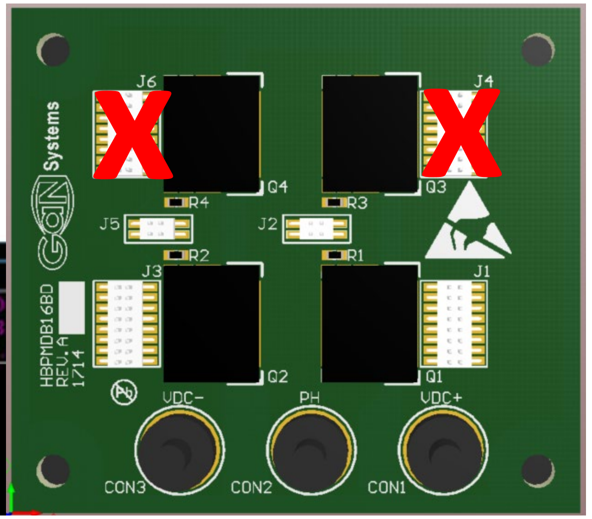
Experimental Verification II



120A/400V double pulse waveform with balanced L_{QS}



120A/400V double pulse waveform with unbalanced L_{QS}



Remove multi-pin connectors to unbalance the quasi-common source inductance

Unbalanced quasi-common source inductance causes switching failure

Agenda

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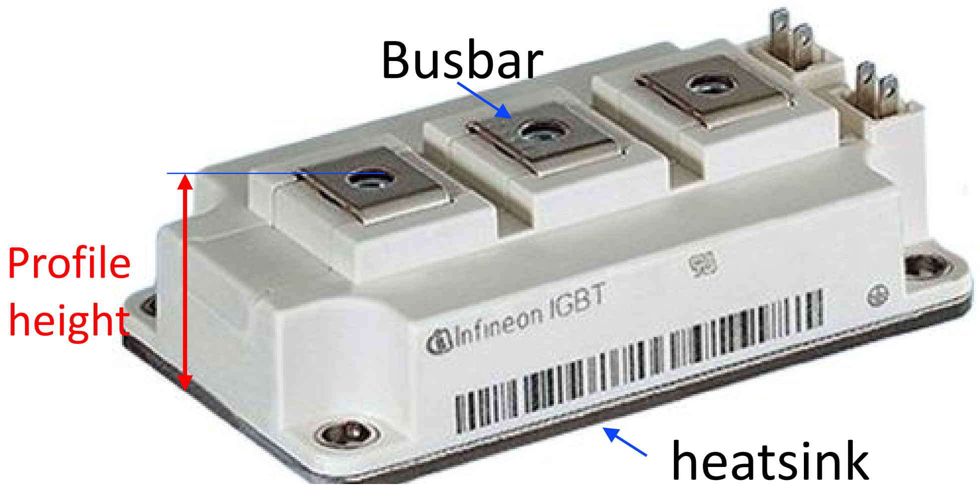
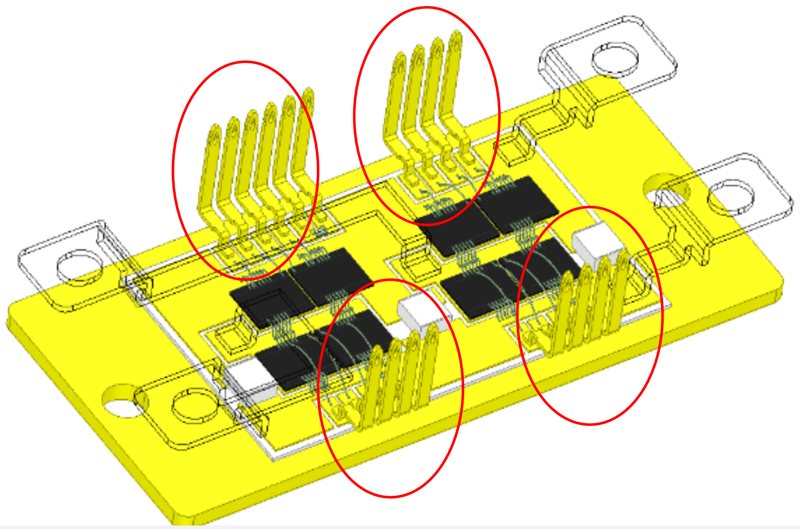
- Proposed U-type Module

The Limitations of Typical Designs

A Typical Housing-type IGBT module





- **Profile height increases the power commutation loop and gate loop inductance.**

An obvious solution: Low-profile module?

- **Violates the creepage and clearance requirements of many power electronic systems.**

GaN works in both designs. And additional performance improvement available

U-Type Module

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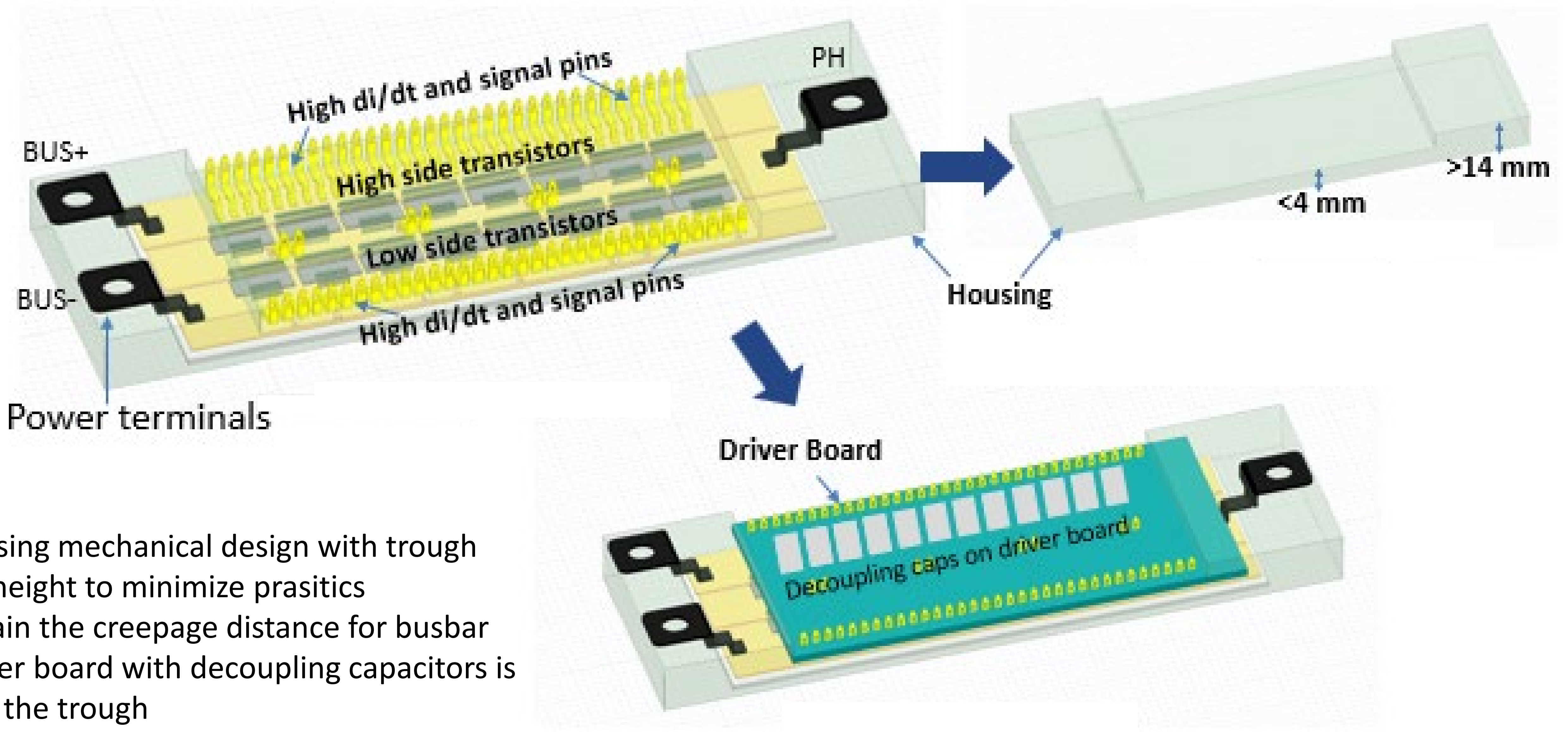


- New housing mechanical design with trough
  - Short height to minimize prasitics
  - Maintain the creepage distance for busbar
- Gate driver board with decoupling capacitors is placed in the trough

FEM simulation shows the gate loop inductance can be controlled to <5nH and power loop inductance can be reduced to <2nH, resulting in excellent EMI and Switching performance with GaN

Conclusions

- Power Modules are important for high-power systems
- Critical for high performance modules are
  - Layout and profile height are the most critical aspects of a GaN module design
  - For layout: minimized and symmetric quasi-common source inductance maximizes the performance
  - For profile height: a U-Type module is proposed that combines creepage distance and compatibility while demonstrating exceptionally low inductance
- Recommendations
  - Existing modules work with GaN, but don’t deliver the highest performance
  - Use IMS for medium power … a low-cost, simple module for systems up to 30kW
  - Use U-type for high power … a big step-up in performance for up to 200kW systems

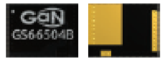
Join the wave - revolutionize your power electronics

GaN Systems

Broadest line of Products

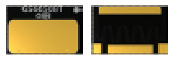
650 V GaN

GS66502B
7.5 A, 200 mΩ
6.6 x 5.0 mm

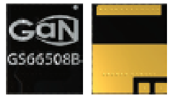


GS66504B
15 A, 100 mΩ
6.6 x 5.0 mm

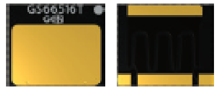
GS66506T
22 A, 67 mΩ
5.6 x 4.5 mm



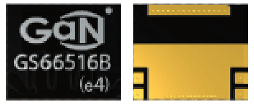
GS66508T
30 A, 50 mΩ
7.0 x 4.5 mm



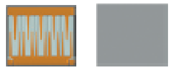
GS66508B
30 A, 50 mΩ
8.4 x 7.0 mm



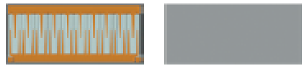
GS66516T
60 A, 25 mΩ
9.0 x 7.6 mm



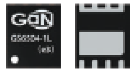
GS66516B
60 A, 25 mΩ
11.0 x 9.0 mm



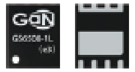
GS-065-080-1-D1
80 A, 18 mΩ
6.6 x 5.6 mm



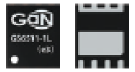
GS-065-150-1-D1
150 A, 10 mΩ
12.7 x 5.6 mm



GS-065-004-1-L
3.5 A, 500 mΩ
5.0 x 6.0 mm



GS-065-008-1-L
8 A, 225 mΩ
5.0 x 6.0 mm



GS-065-011-1-L
11 A, 150 mΩ
5.0 x 6.0 mm

100 V GaN

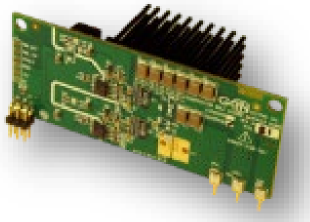
GS61004B
45 A, 15 mΩ
4.6 x 4.4 mm

GS61008P
90 A, 7 mΩ
7.6 x 4.6 mm

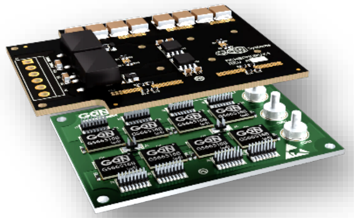
GS61008T
90 A, 7 mΩ
7.0 x 4.0 mm

GS-010-120-1-P
120 A, 5 mΩ
7.6 x 4.6 mm

Many Eval Kits & Reference Designs



Half bridge power stage



High power Paralleling

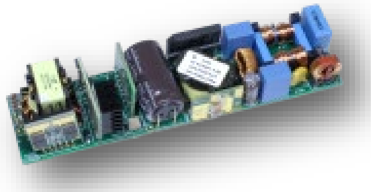
3 kW bridgeless totem pole PFC

650 V test kit

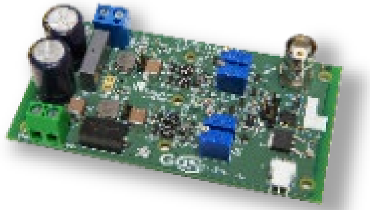
1.5 kW bridgeless totem pole PFC

300 W wireless power transfer

EZDrive™ Eval Kit



High density PFC/LLC



Full Bridge Class D Amplifier

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