Hands-On Challenges and Solutions in Bidirectional GaN Switch Design

Speaker

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Content overview

High Voltage Switches- Overview

Bidirectional Switches- what is that?

Gate Driving

Placement-Layout

Modern Packages- New Challenges

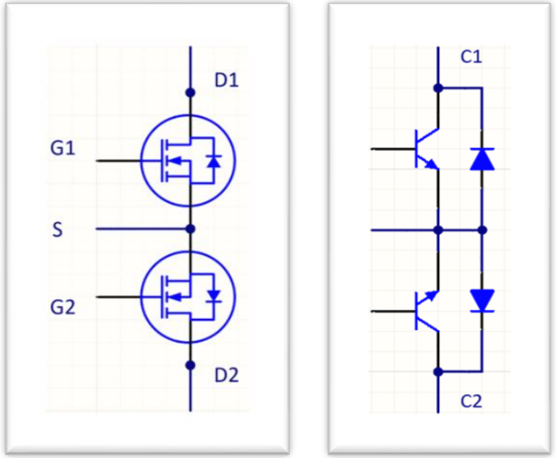
Appendix- Measurements

Detailed Comparison of High-Voltage Power Switch Technologies

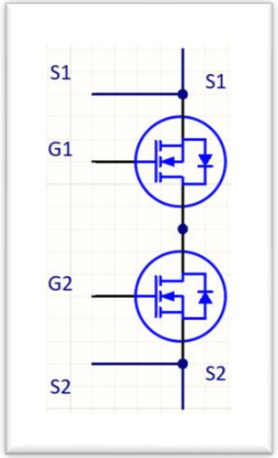
Technology	Key Specs & Features	Technical Pros	Technical Cons
Silicon (SJ / IGBT)	600 – 1700 V Freq < 250 kHz Gate 0 – 15 V JEDEC & AEC-Q101	Mature, low-cost Avalanche/short-circuit robust Easy drive	High switching loss Large die Low frequency efficiency No bi-directional capability
SiC MOSFET	650 – 1700 V Freq up to 500 kHz Gate +15 V to +18 V/–4 V JEDEC & AEC-Q101	High efficiency High immunity: 100 V/ns High Tj (175 °C) No tail current	Costly Needs bipolar voltage bias driver High 3rd quadrant losses (w/o co-diode) No bi-directional capability
Cascode GaN (D-Mode + Si MOSFET)	650 V Gate 0 – 12 V Top-cooled TOLT JEDEC & AEC-Q101	Rugged gate Low Qrr Easy drive Bi-directional operation	Two-chip solution Small Rds(on) penalty No avalanche capability
E-Mode GaN	650 V* p-GaN Gate +6/–2 V Freq ≤ 2 MHz JEDEC & some AEC-Q101	Ultra-fast (+100 V/ns) No Qrr Smallest die Bi-directional operation	Fragile gate (6 V max) No avalanche capability Needs tight layout Lower power density when used on the primary side
Integrated E-Mode GaN	650 V* Built-in driver ~2 MHz Top-cooled JEDEC; AEC-Q101 in progress	Simplifies design OCP/OTP, UVLO Compact	Higher cost Limited scalability – good up to medium power Heat density high Lower power density when used on the primary side No 2nd source
Direct-Drive D-Mode GaN	650 V Integrated driver 150 V/ns adj. slew Top-cooled QFN JEDEC	Direct control (no cascode) ZCD, cycle OC, temp monitor 2 MHz capable	Costly Supply complexity Startup sequencing No 2nd source

Bidirectional Switches- what is that?

- The idea is not new, and there are various ways to build a bidirectional switch.
- Common Drain, Common Source, FET, IGBT, GaN



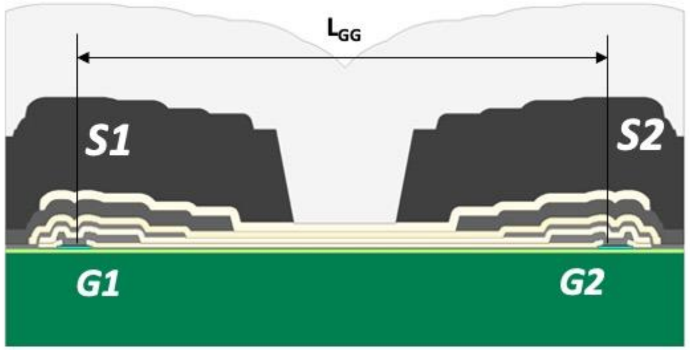
Common Source/Emitter Topology
Control is simpler—the number of isolated AUX supplies is lower.



Common Drain Topology
The control system is more complex and costly.
Integration at chip level is easier.

E-Mode FQS: GaN-on-QST

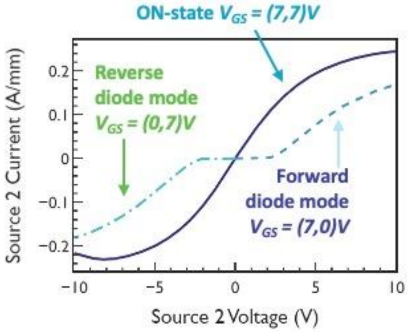
Dual-Gate Bidirectional Switch (BDS)



Depending on the bias at the two gates, four operation modes can be defined:

Mode	Current direction	G1	G2
ON-state	S1 ⇄ S2	ON	ON
Frw. diode mode	S1 ← S2	ON	OFF
Rev. diode mode	S1 → S2	OFF	ON
OFF-state	S1 ✕ S2	OFF	OFF

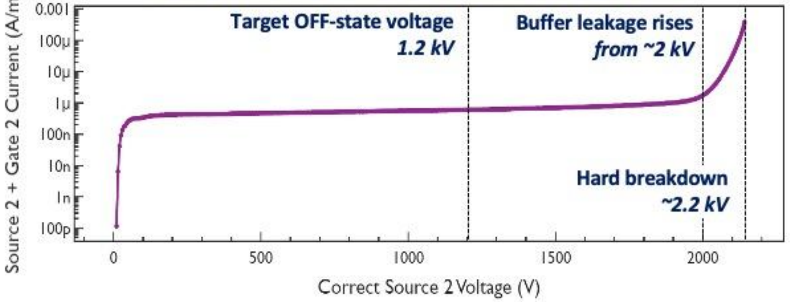
ON state



Typical values for reference L_{GG}	
V_{TH} (gate 1 and 2)	2 V
R_{ON}, ON-state	18 Ωmm
R_{ON} diode modes	34 Ωmm
V_{offset} diode modes	2.5 V

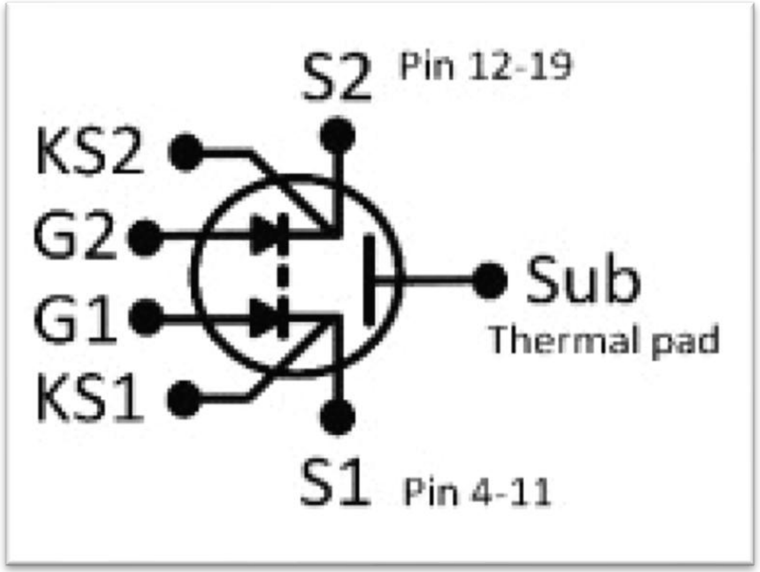
OFF state

ON-wafer measurement: S2 and G2 are shorted together as only one HVSMU is available in current configuration of Keysight B1505



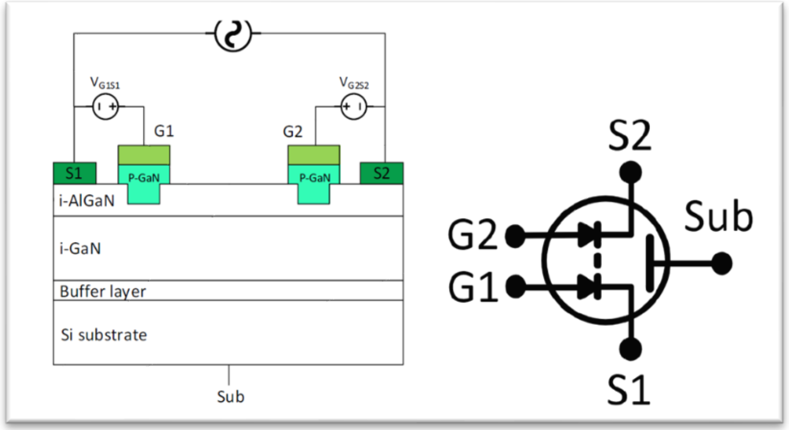
Bidirectional GaN Switches?

- Bidirectional GaN switches are very new to the market.
- Manufacturers: very few on the market



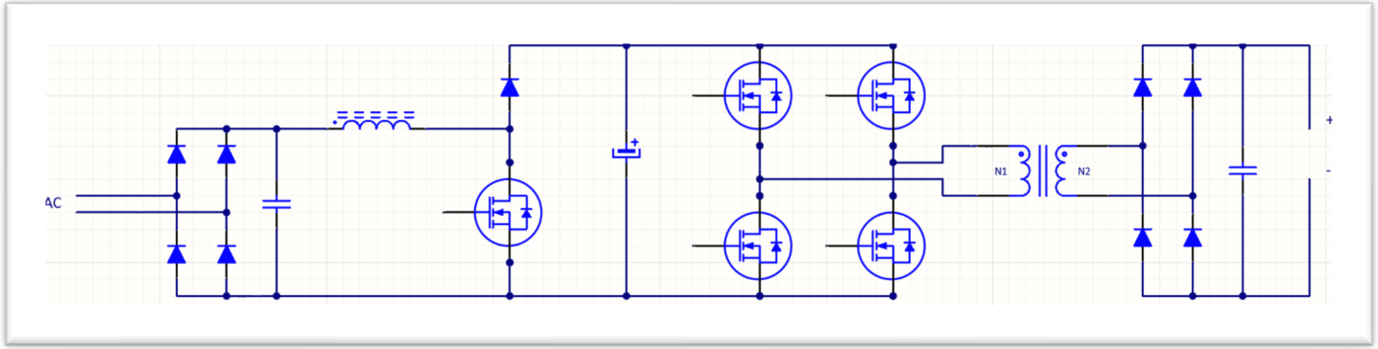
Bidirectional GaN Switches?

- It is a common drain tap with a double gate structure based on Infineon's gate injection transistor (GIT) technology. The CoolGaN™ BDS is a five-terminal device with two gates, two sources, and one substrate. There are four operating modes:
- the traditional on/off modes
- two diode modes in which the switch can be actively controlled to behave like a diode that can block voltages in both directions

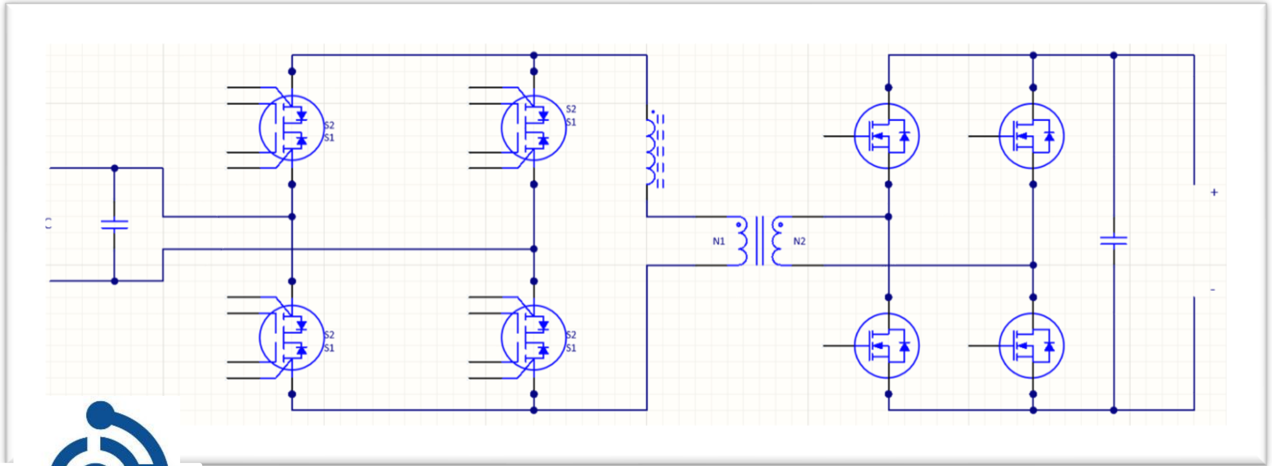


What is this good for?

- Standard Topologies- PFC+DC/DC
- Single stage topology: AC/DC without intermediate circuit capacitor

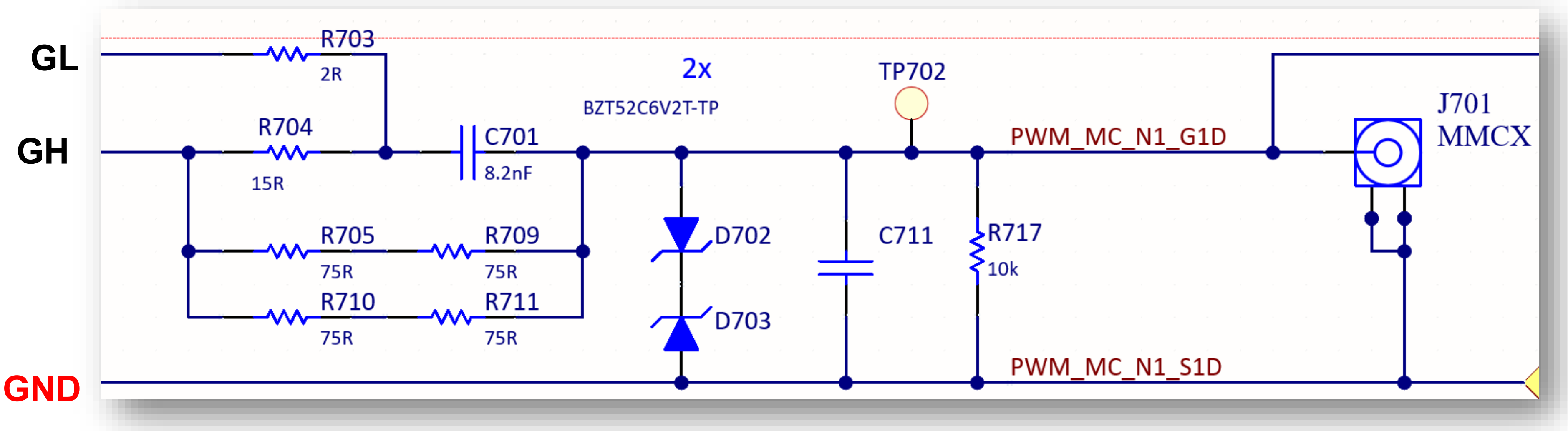


- Standard Topologies
- Analog/Digital Control
- Availability
- Number of components
- Efficiency
- Electrolytes, service life
- Operating temperatures



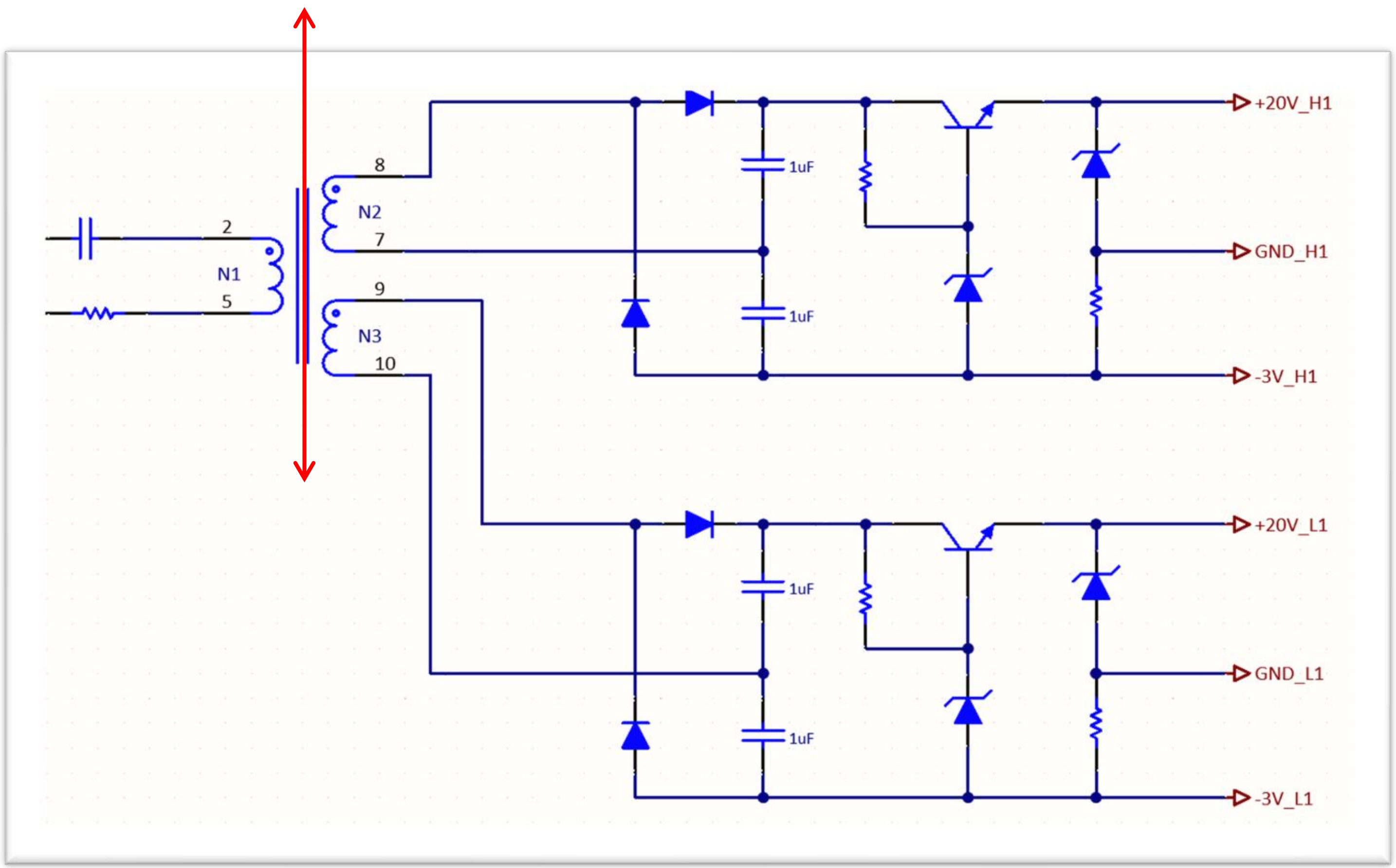
- New topologies
- Complex [digital] control
- Availability
- Number of components
- Efficiency
- Service life
- Operating temperatures

Gate Driving?



Gate Driving?

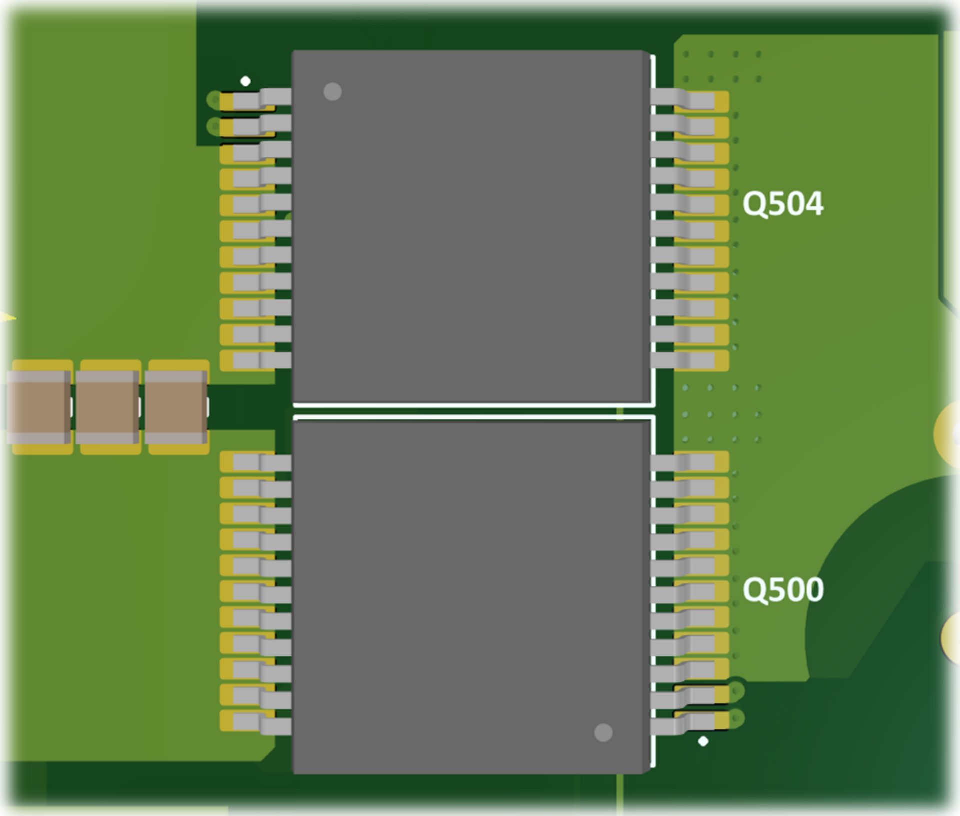
- Component selection
- Gate Drivers,
- Isolation,
- Placement, Layout

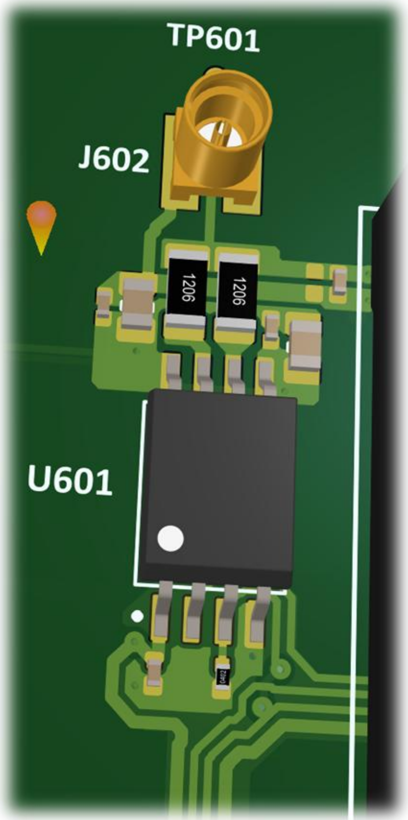


- *Important- Very good decoupling Cp~1pF*
- *Gate drivers with high CMTI , >100V/ns*

Placement- Layout?

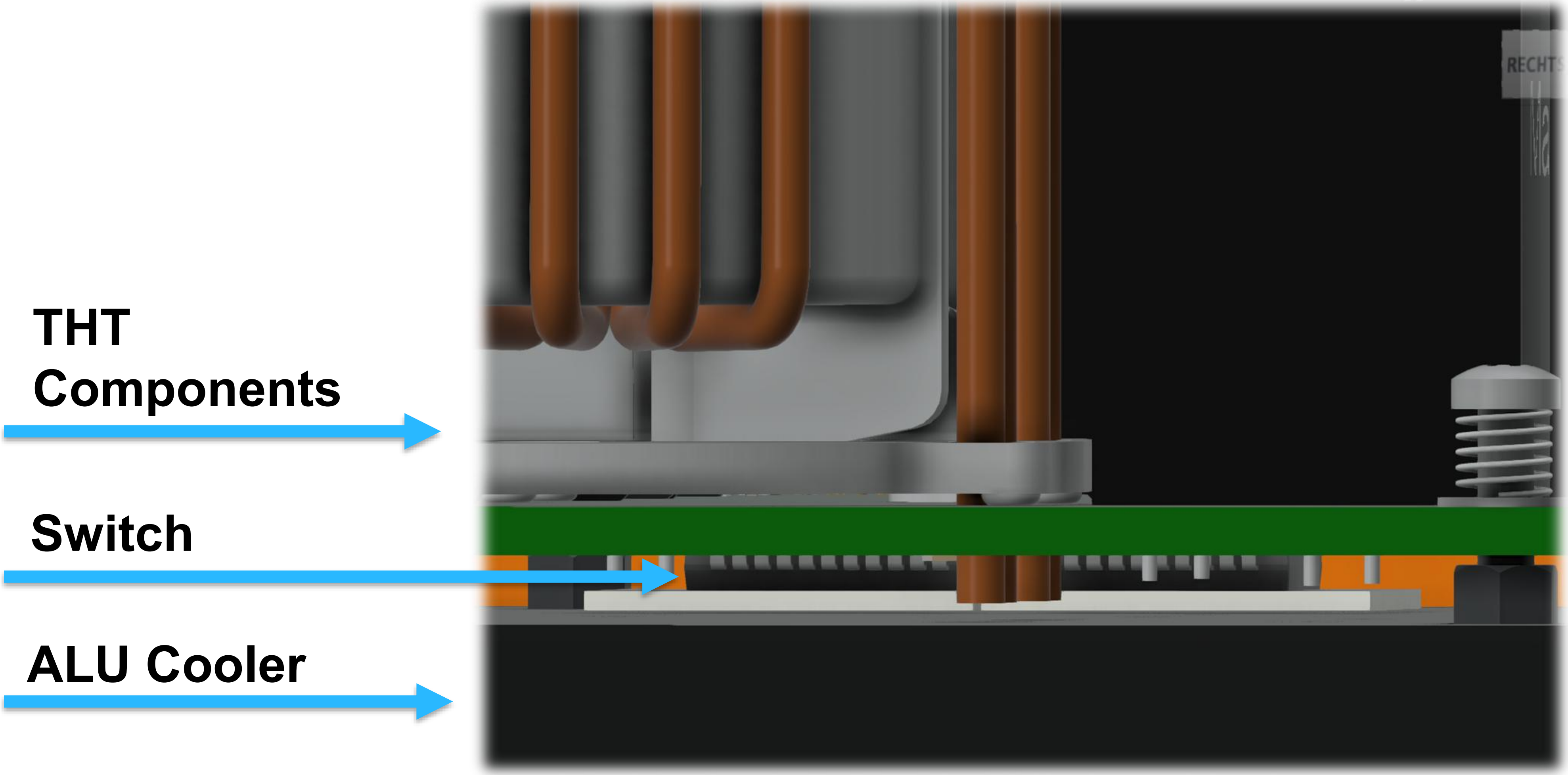
- Placement
- Layout
- Component selection
- Measurement Techniques





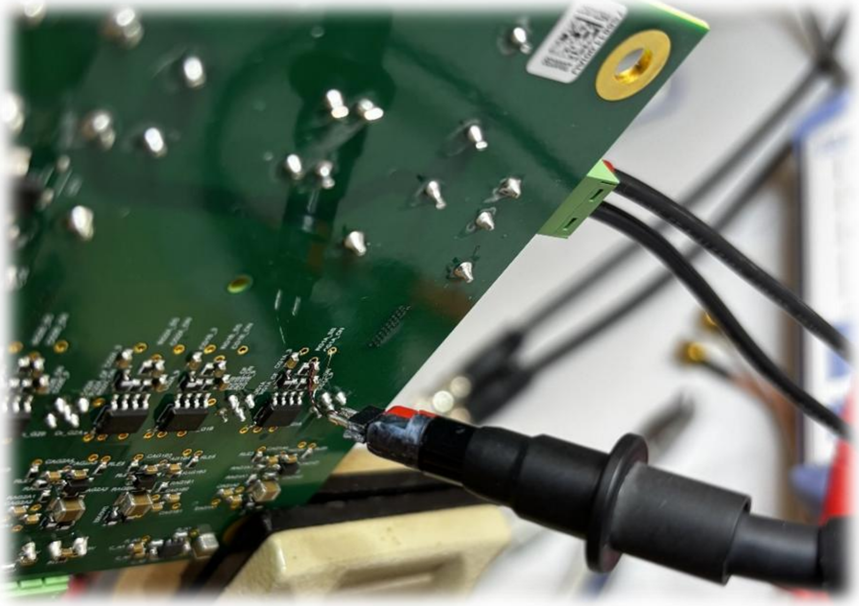
Cooling- System integration?

- Placement
- Layout
- Mechanics



Practical challenges- Measurement

- Modern high-speed Scopes, 1GHz
- Probes and probing techniques
- HF connectors (MMCX and compensated tips)
- There's no room for improvisation with the tips anymore.



- 8CH Scopes, Optical Isolated Probes, HV Diff Probes, High speed current probes

Practical challenges- Control

Virtual validation with C-HIL and P-HIL de-risks every step from model to a HW design.

Speedgoat Performance
Simulink Real-Time target

Plexim RT Box 3
PLECS C-HIL / P-HIL

Typhoon HIL 404
Ultra-high-fidelity C-HIL

OPAL-RT OP4510
FPGA + CPU real-time sim

dSPACE SCALEXIO
Modular automotive HIL

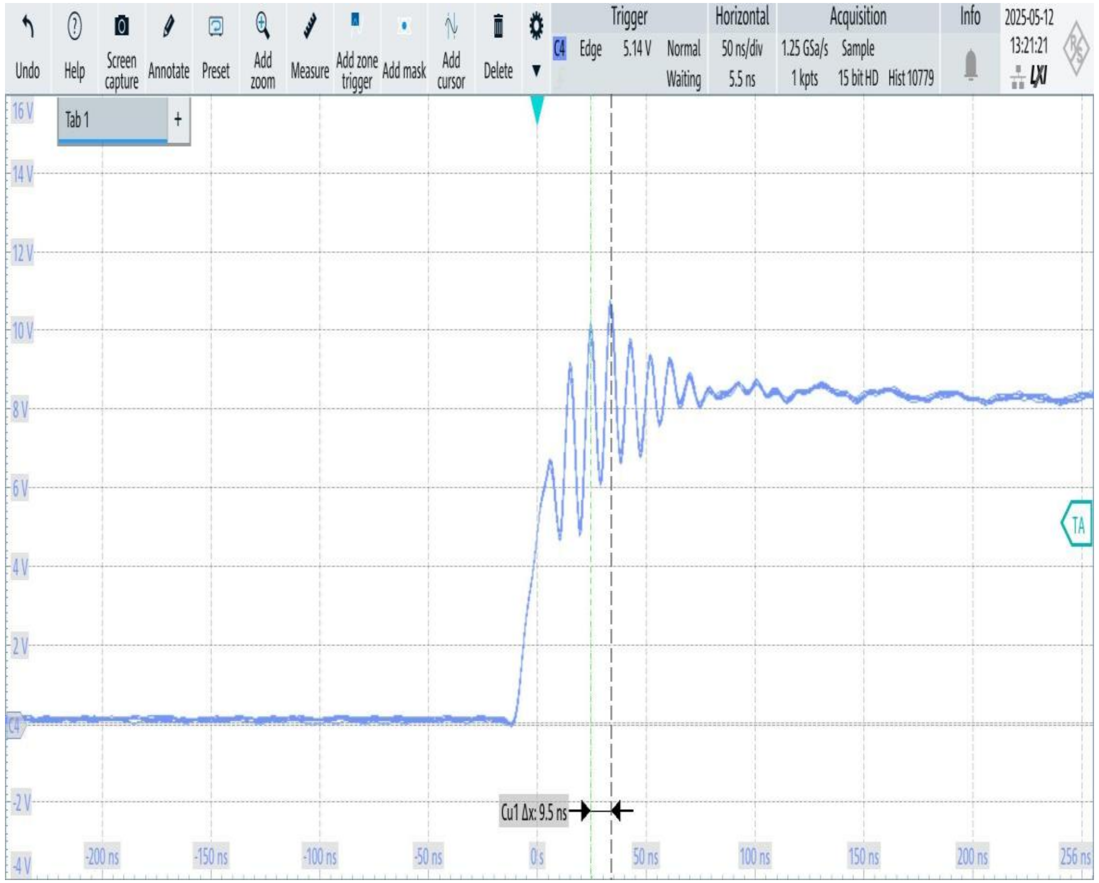
Concept & Model – System-level design → **C-HIL** – Controller in the loop, signal-level I/O → **P-HIL** – Power stage in the loop, real currents & voltages → **Prototype** – Validated HW + FW

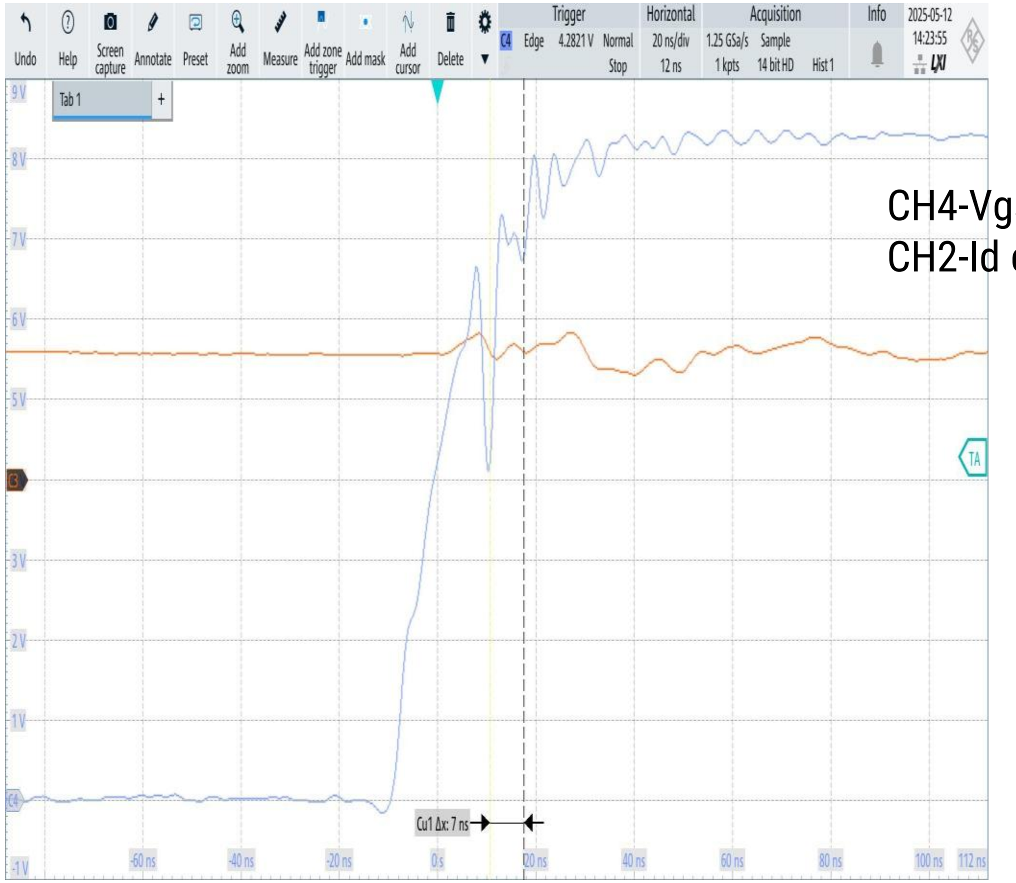
- **Switched / sampled models** — resolve every switching event; verify PWM, dead-time, protection, and control bandwidth at sub-μs time steps.
- **Averaged models** — abstract the switching action; ideal for slow outer loops, system-level dynamics and long simulations with larger time steps.
- **Pick per objective** — averaged for architecture exploration, sampled for firmware-accurate HIL validation.
- **Hybrid flow** — move from averaged to sampled inside the same environment to keep the model investment.

- **Find bugs before physical prototype** — firmware, protections, and fault handling are exercised without risking real power hardware.
- **Shorter debug cycles** — deterministic, repeatable tests beat one-off bench sessions.
- **Safer commissioning** — hardware arrives with a controller already battle-tested against representative plants.
- **Automation & coverage** — regression suites on HIL cover corner cases real HW rarely reaches.
- **Seamless handoff** — same model reused from concept → C-HIL → P-HIL → field prototype.

Appendix

Vgs- Emode GaN- direct vs. compensated





CH4-Vgs ZISO Probe
CH2-Id current probe

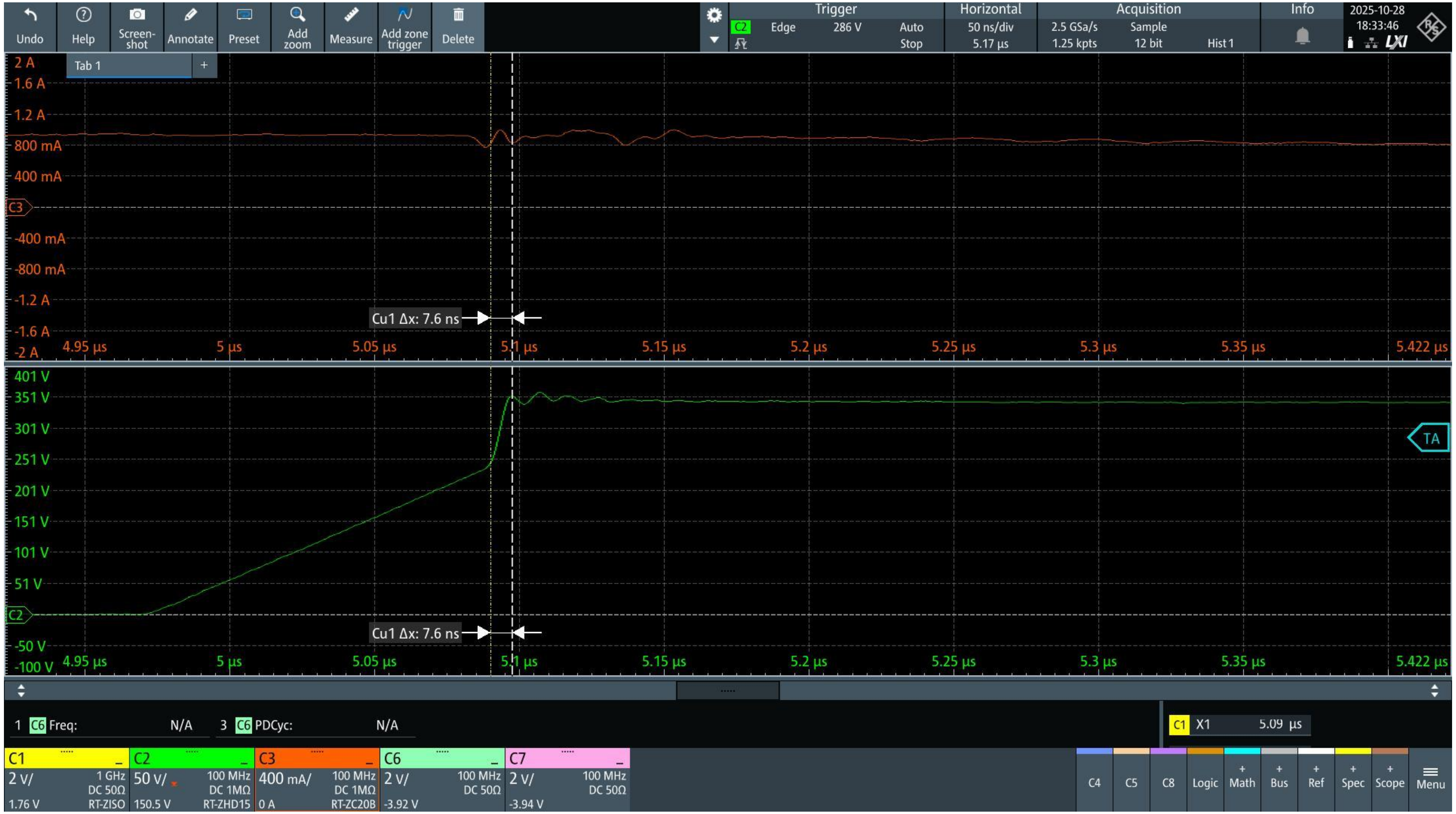
Vgs- Comparison measurement using different probe techniques

CH1-ZISO Probe
CH2-ZHD probe

Efficient AC-AC Power Conversion measurement

CH2- Vss Voltage
CH3- Choke current

Efficient AC-AC Power Conversion- Measurement at ZVS



CH2- Vss Voltage
CH3- Choke current

Gate driving performance

CH1-Vgs
CH2-Vss voltage
CH3-Switch current

Conclusion

- Bidirectional GaN switches are emerging as a notable innovation in modern power electronics,
- They are offering a more compact and efficient alternative to traditional back-to-back unidirectional MOSFET/IGBT configurations.
- Current market offerings: medium-voltage devices (e.g., ~40 V), high-voltage types (e.g., 650 V devices suitable for converters, inverters, EV charging, and renewable systems)
- They actively block voltage and current in both directions and simplify designs while improving efficiency and reducing component count and PCB area.
- Although commercial bidirectional GaN products are still concentrated around established vendors.
- Research and advanced prototypes (e.g., 1200 V GaN bidirectional switches) indicates ongoing development toward higher blocking voltages and broader adoption in grid, EV, and industrial applications.

- Overall, **bidirectional GaN switches represent a growing class of power devices** that are helping designers to achieve:
- **higher power density,**
- **lower losses,**
- **simpler topologies across a range of markets.**

Q&A

Thank You!

For more information, please visit our website

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