High Speed Sensing and Monitoring around GaN devices

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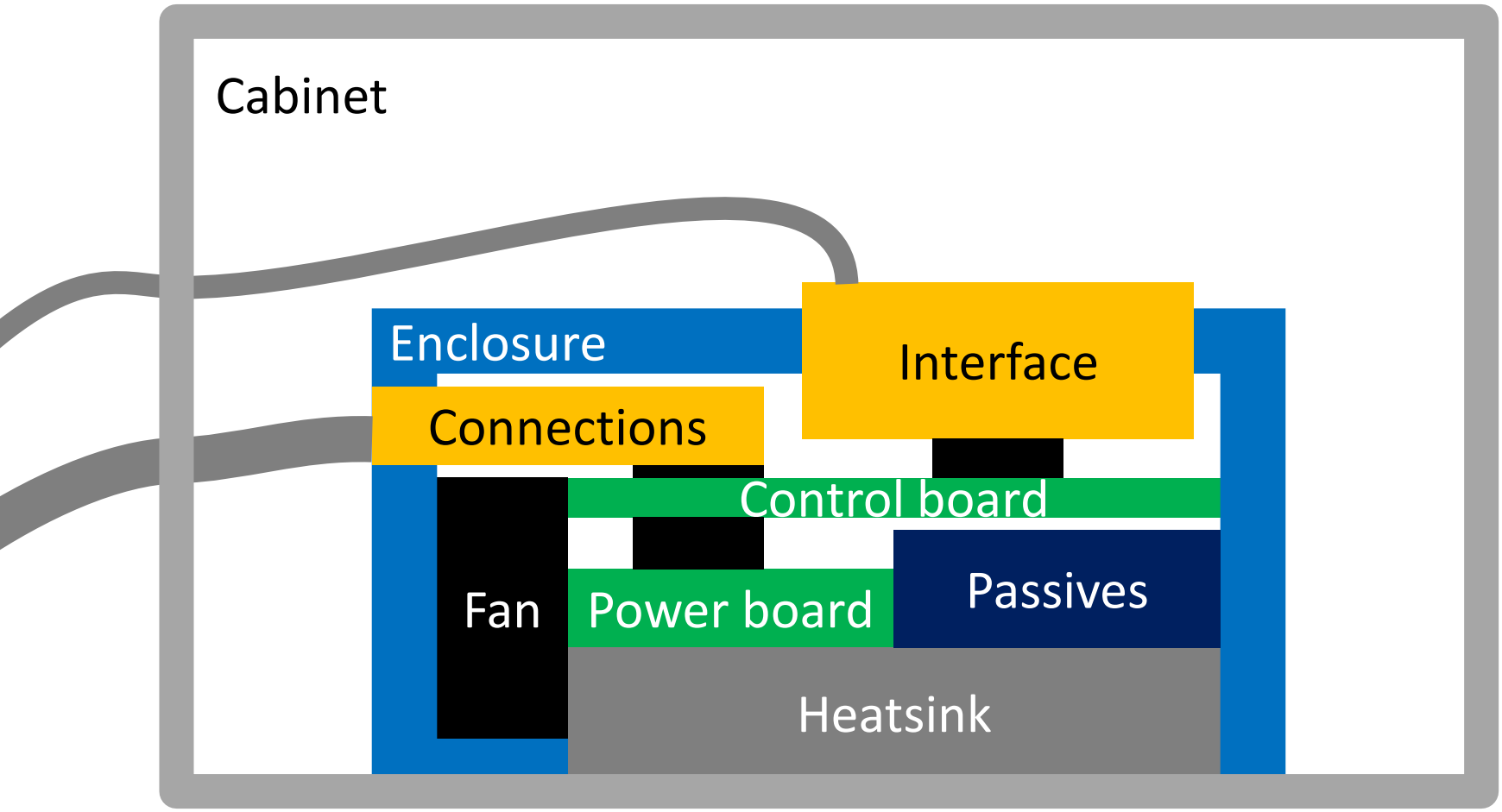
iMAPS-UK Research Showcase: Recent Advances in Reliability and Gate driving of Wide Bandgap Power Electronics
11-12 Jan 2021

Outline

- How do you figure out if it's worth moving from Silicon to GaN?
- New product or modify existing one?
- How get the best from GaN in your power circuit
- Do you need new measurement equipment?
  Maybe. Contact measurement gets harder.
- Does anything get easier?
  Yes! Field-based measurement (e.g. current, voltage, temperature)
- Research into better gate drivers for GaN

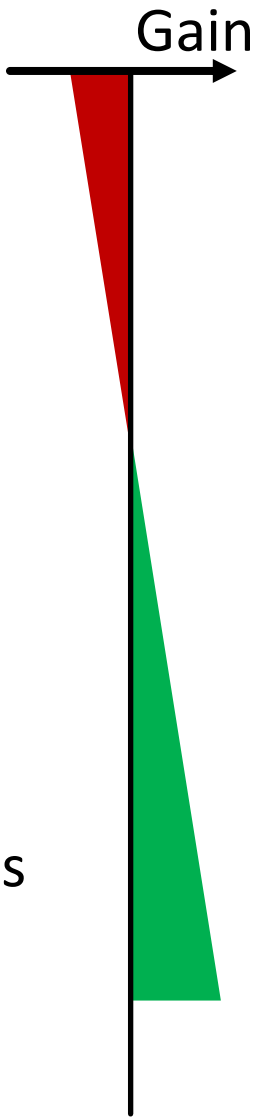
How do you figure out if it's worth moving from Silicon to GaN?



New product or modify existing one?

Silicon-based converter

- Drop in GaN
- Design for SMT Si, then drop in GaN
- Leave control as is, but redesign power core (bridge leg & driving) for GaN.
  - Power daughter boards
  - New power PCB
- Raise sw frequency, smaller passives
- Add extras:
  - Optimum deadtime tracking
  - Multi-level driving for increased robustness
  - Profiling gate signals to reduce loss & EMI
  - Junction temperature sensing
  - Health sensing



⇨ Core needs adapting, incl. gate driving

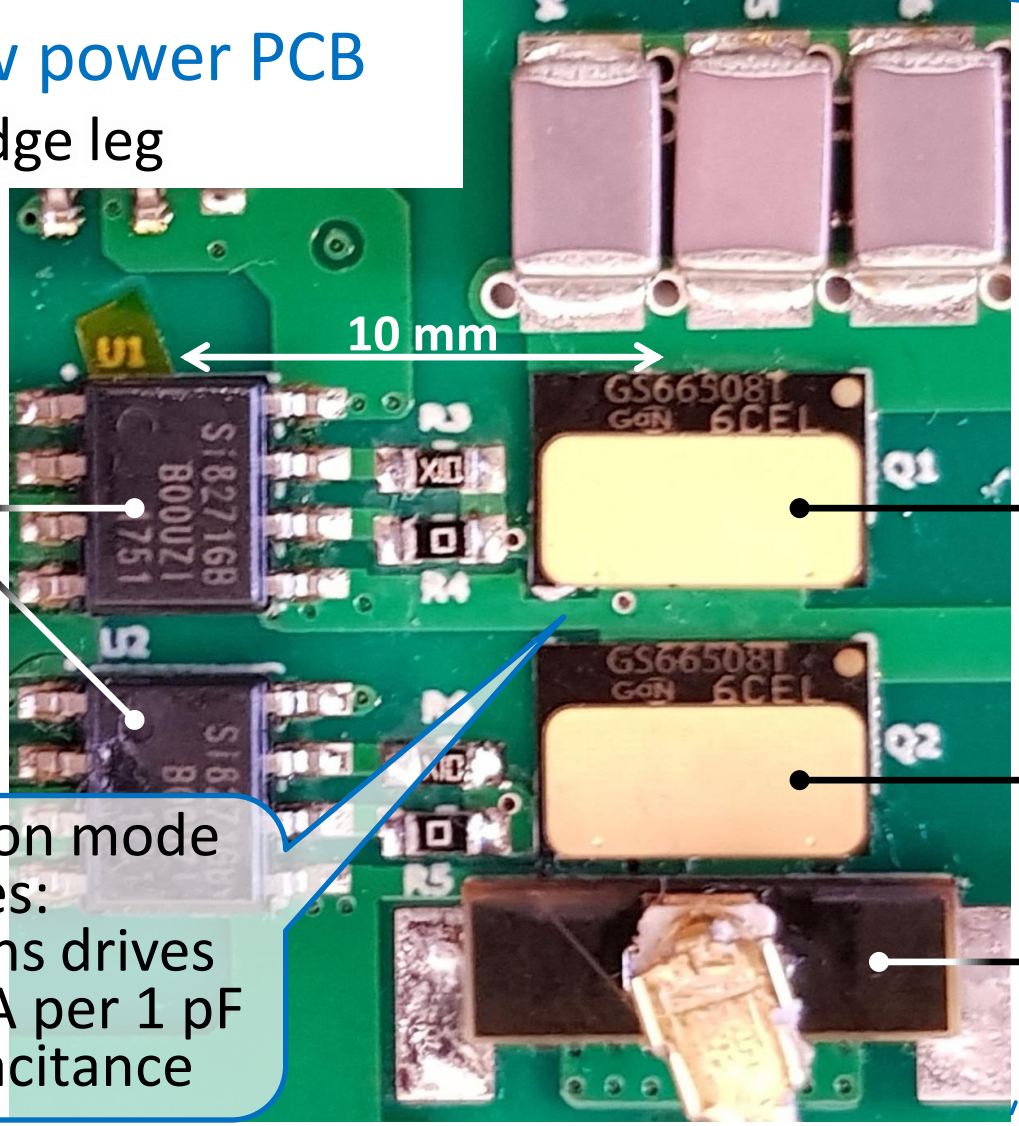
⇨ Probably also fundamental behaviour such as switching frequency

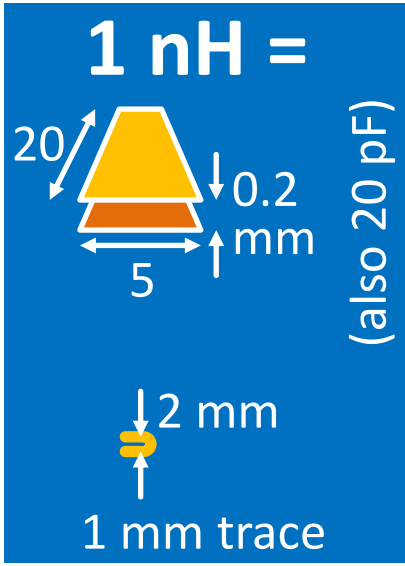
The new power PCB

2 kW bridge leg

100 V/ns

10 A/ns



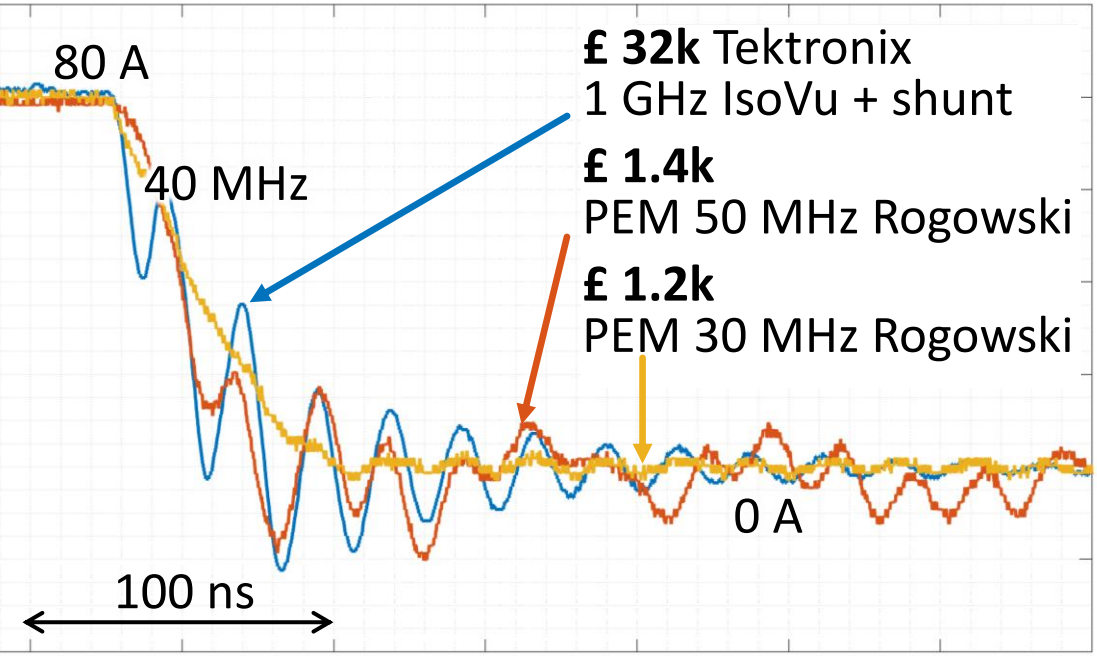


- Crucial: Layout, packages, pinouts, com. mode transient immunity CMTI.
- For same voltage overshoot, loop inductances need to reduce 10×.
- For same current overshoot, parasitic capacitances need to drop 10×.
- Resonances are now 100s of MHz.

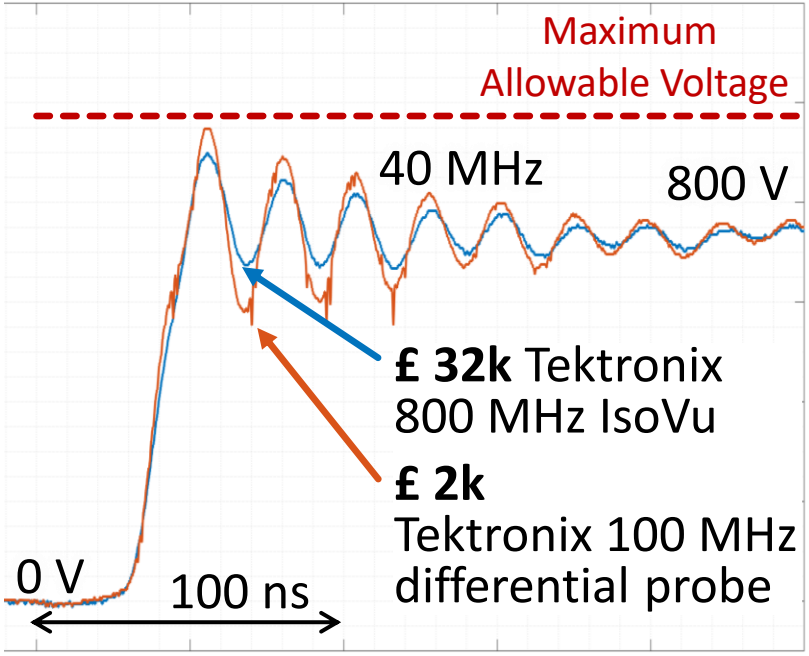
Do you need new measurement equipment?

Using slower **SiC** as an example:

Current measurement



High-side voltage measurement

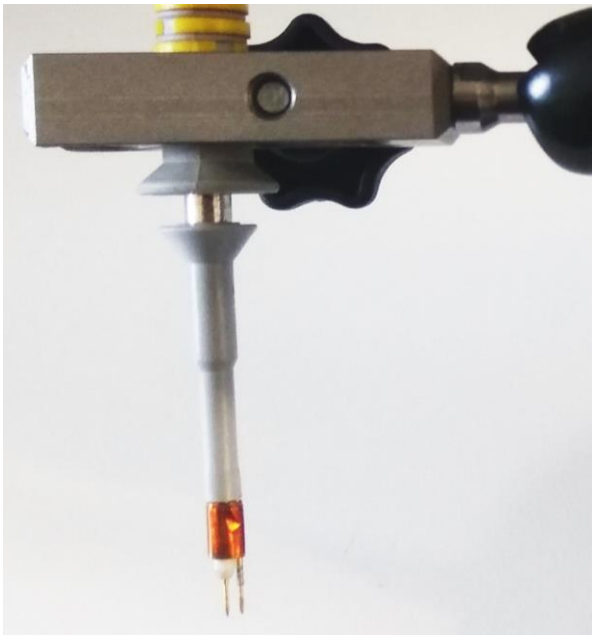


- With **GaN**, the slopes and ringing frequencies are **10× higher**
- 1 GHz single-ended probes for the low side, optically isolated measurement for the high side, due to common mode voltages
- Consider switching from contact sensing to field sensing.

Measurement of V and I

Some options shown here →

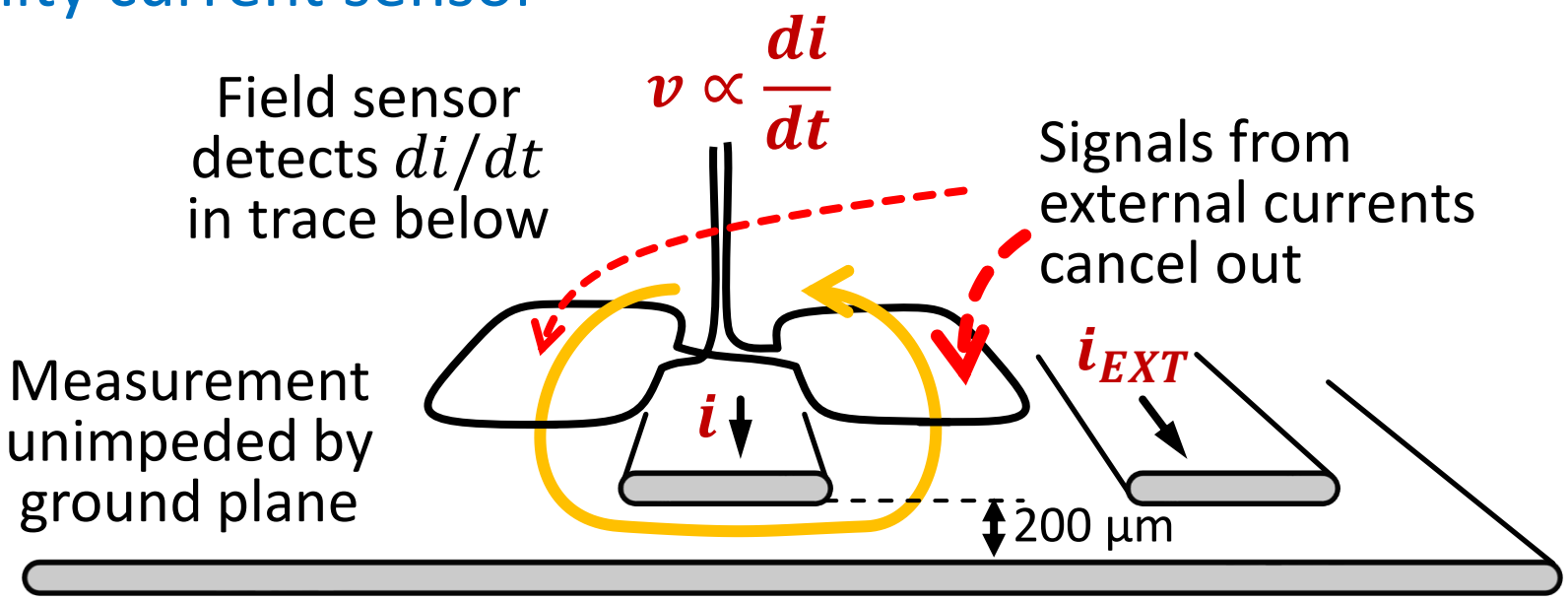
Cut down parasitic coupling

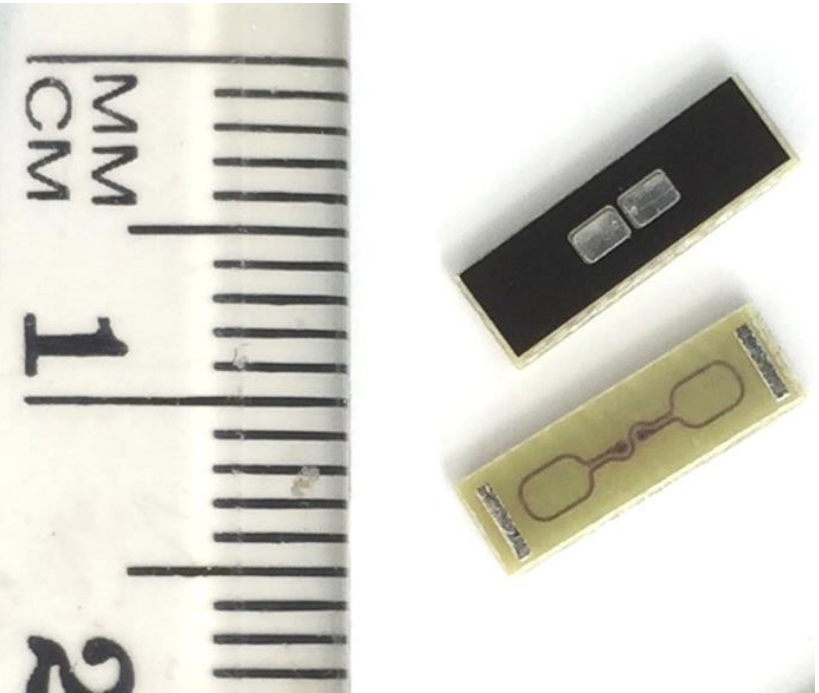


Don’t stretch power loop to make space for current probes

Optical isolation: 120 dB rejection of common mode

Infinity current sensor



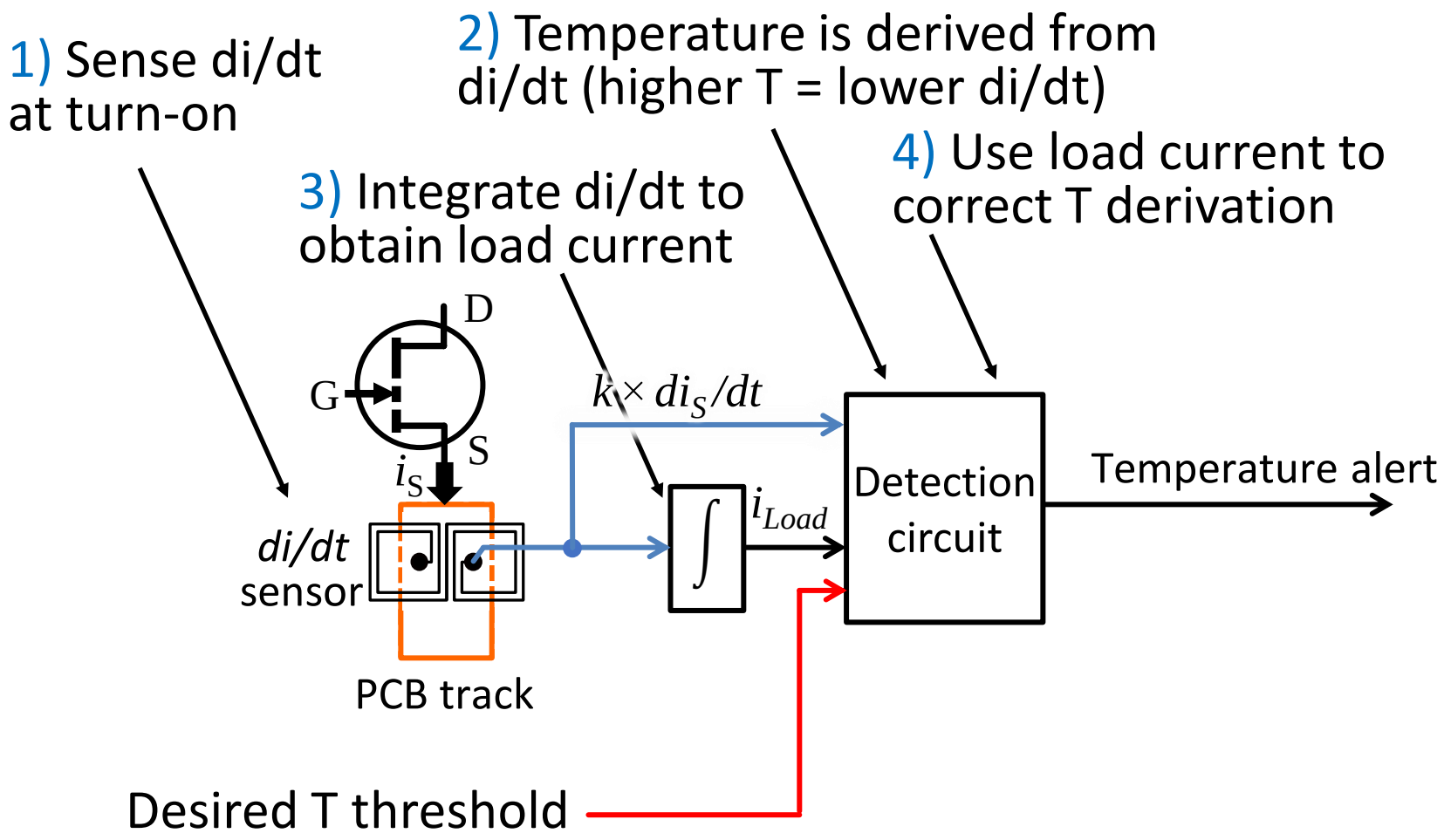


10×3mm
Around 200 mV per A/ns
500+ MHz (work in progress)
0.2 nH insertion inductance

More info at
Infinity Sensor: Temperature Sensing in GaN Power Devices using Peak di/dt, 2018 IEEE Energy Conversion Congress and Exposition (ECCE)

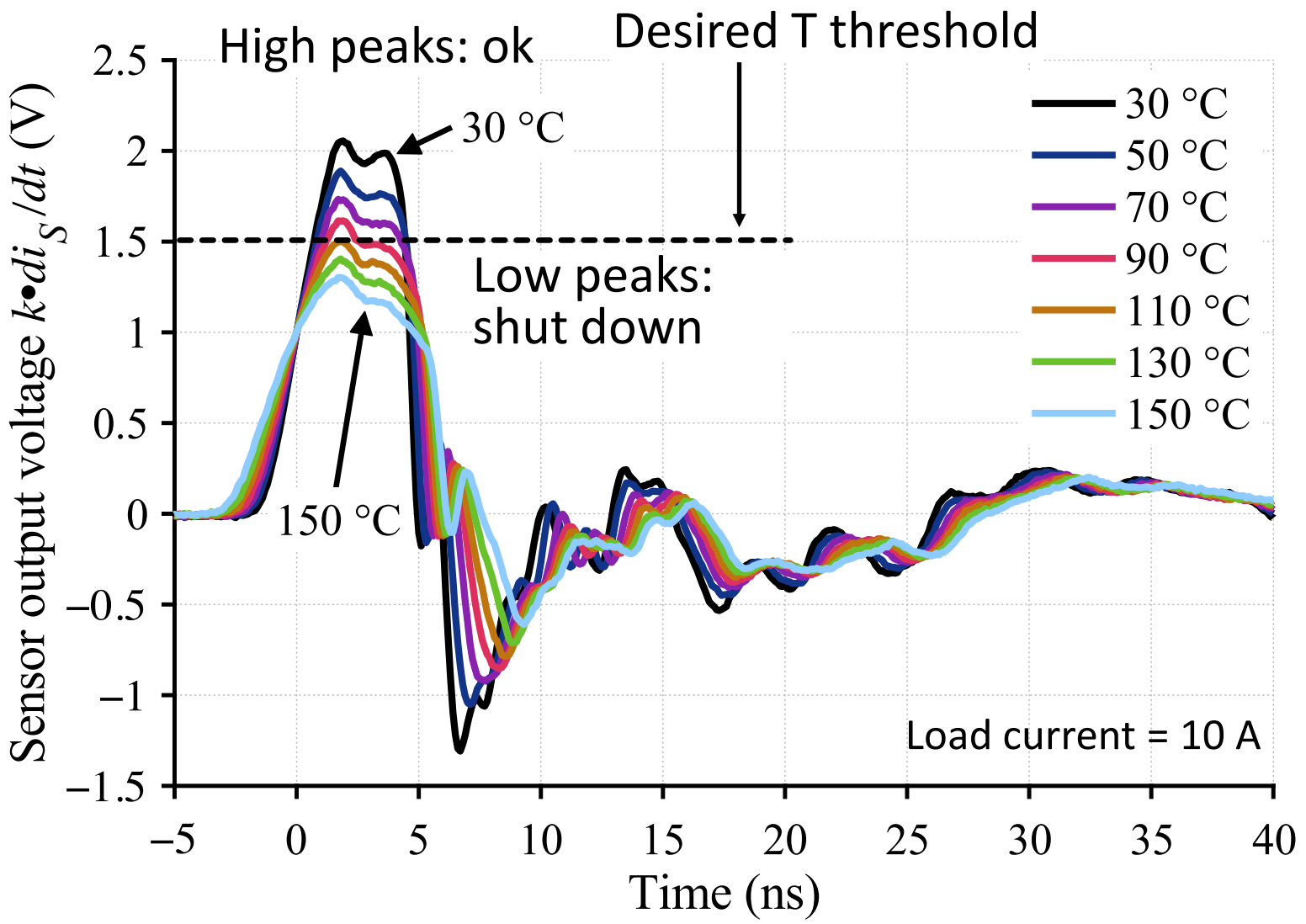
For samples, contact bernard.stark@bristol.ac.uk

Junction temperature monitoring using di/dt sensor



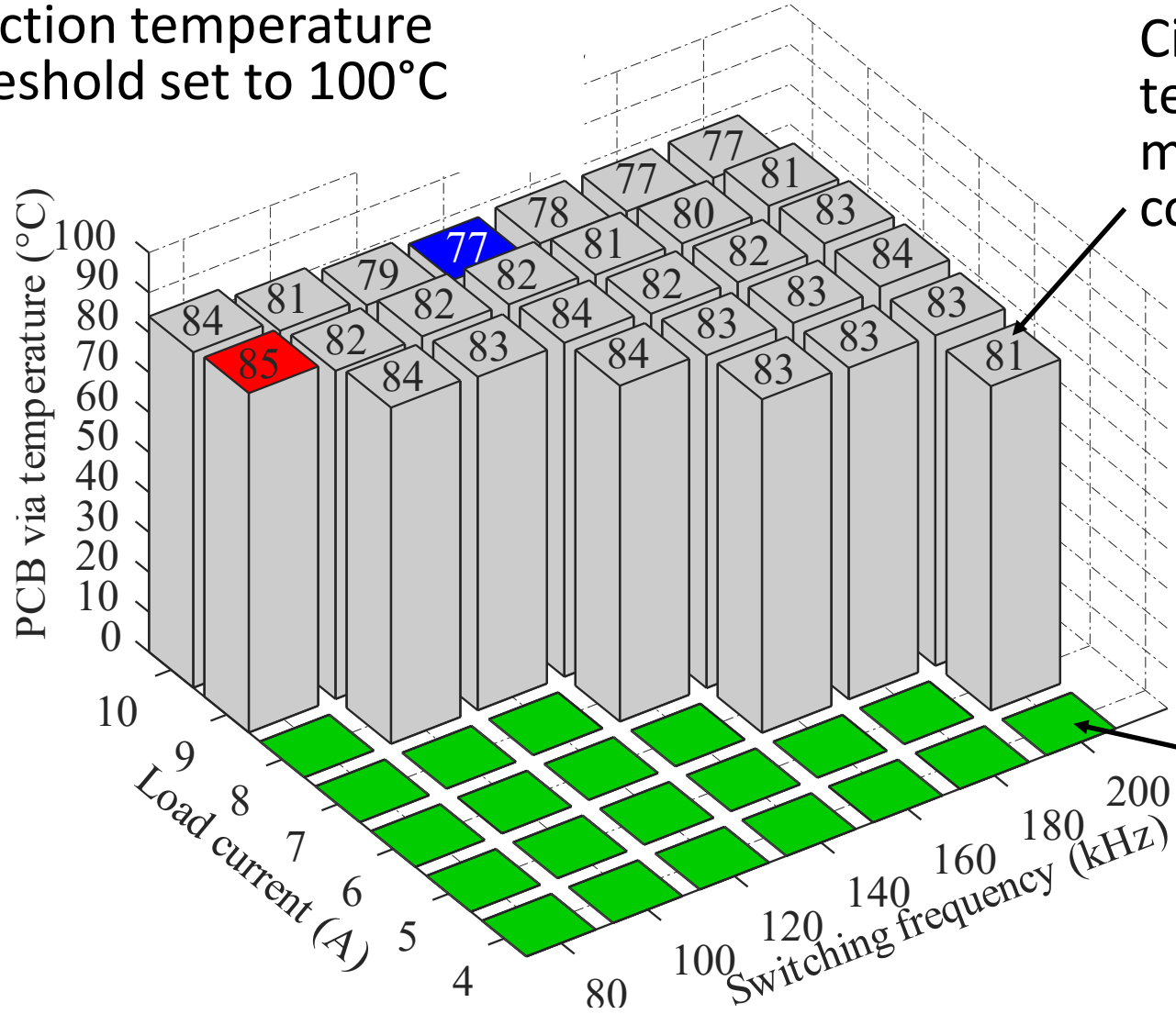
More info in
Over-Temperature Protection Circuit for GaN Devices Using a di/dt Sensor,
in IEEE Transactions on Power Electronics, 2021.

Turn-on di/dt measured at different junction temperatures



Over-temperature protection, experimental results

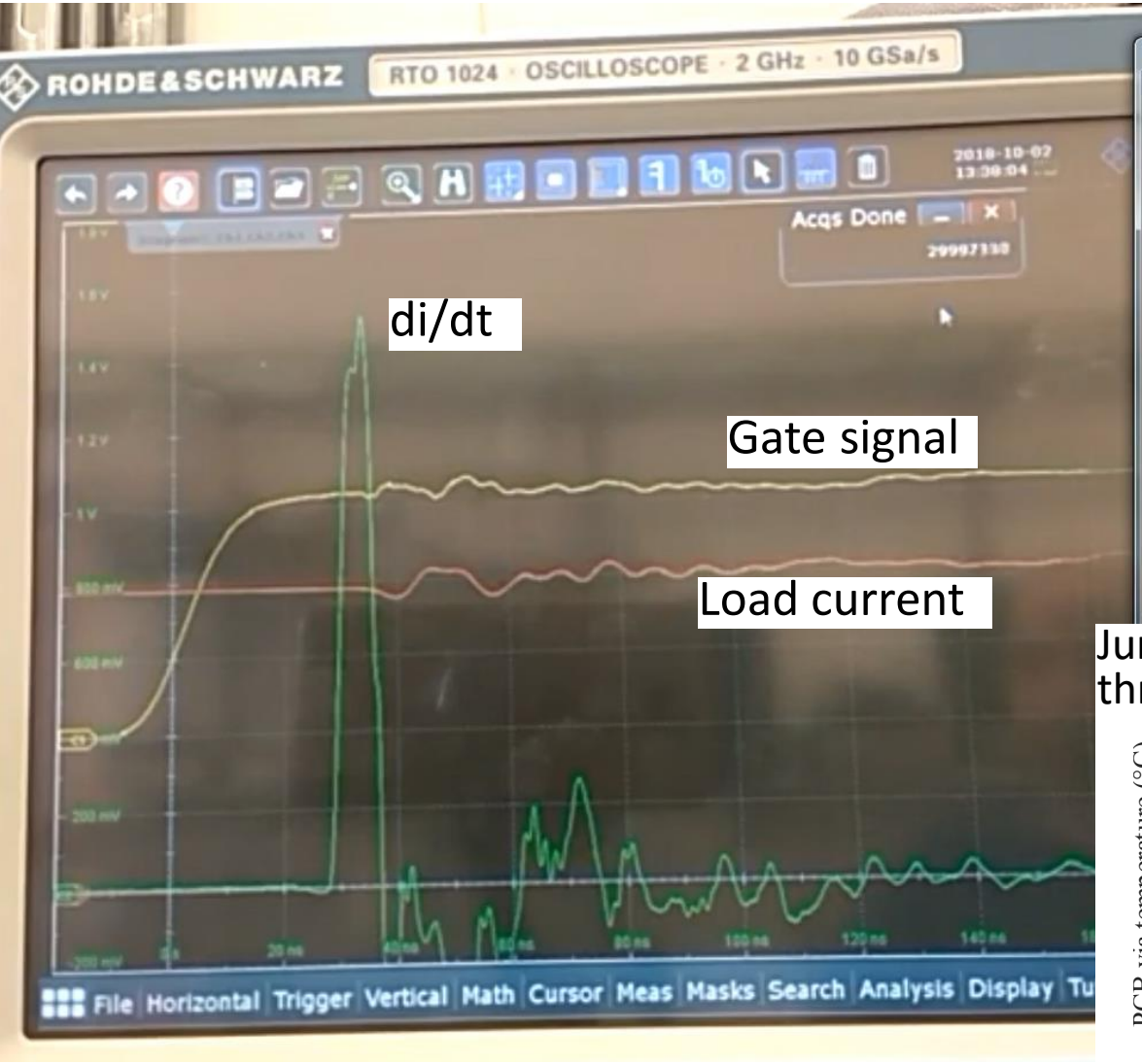
Junction temperature threshold set to 100°C

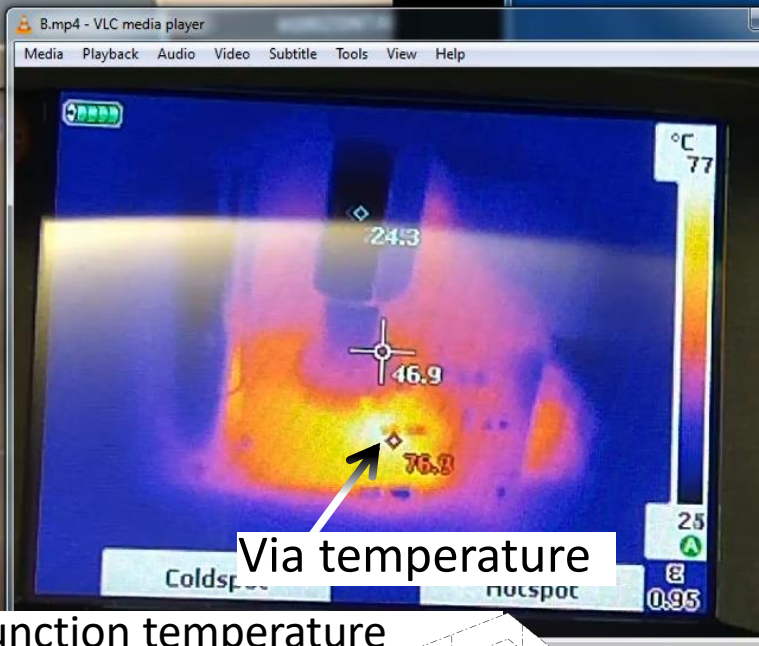


Circuit trips at this temperature, measured on via connected to case

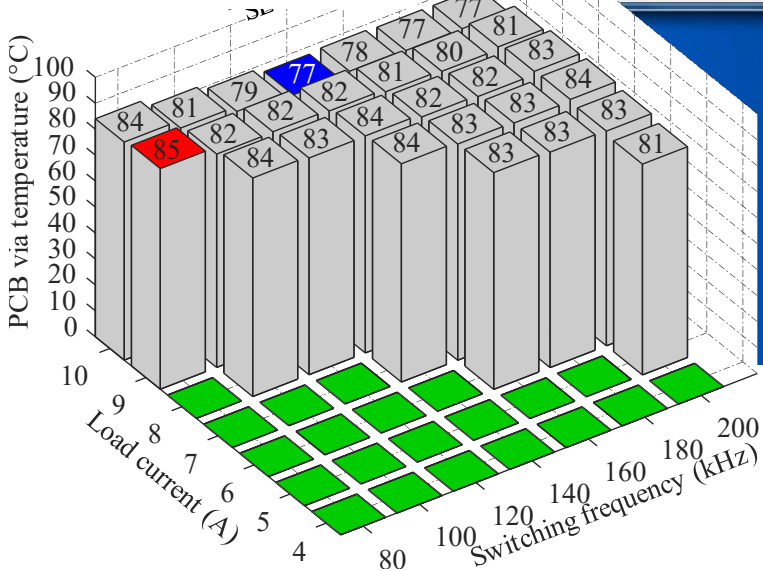
No trip

Demo

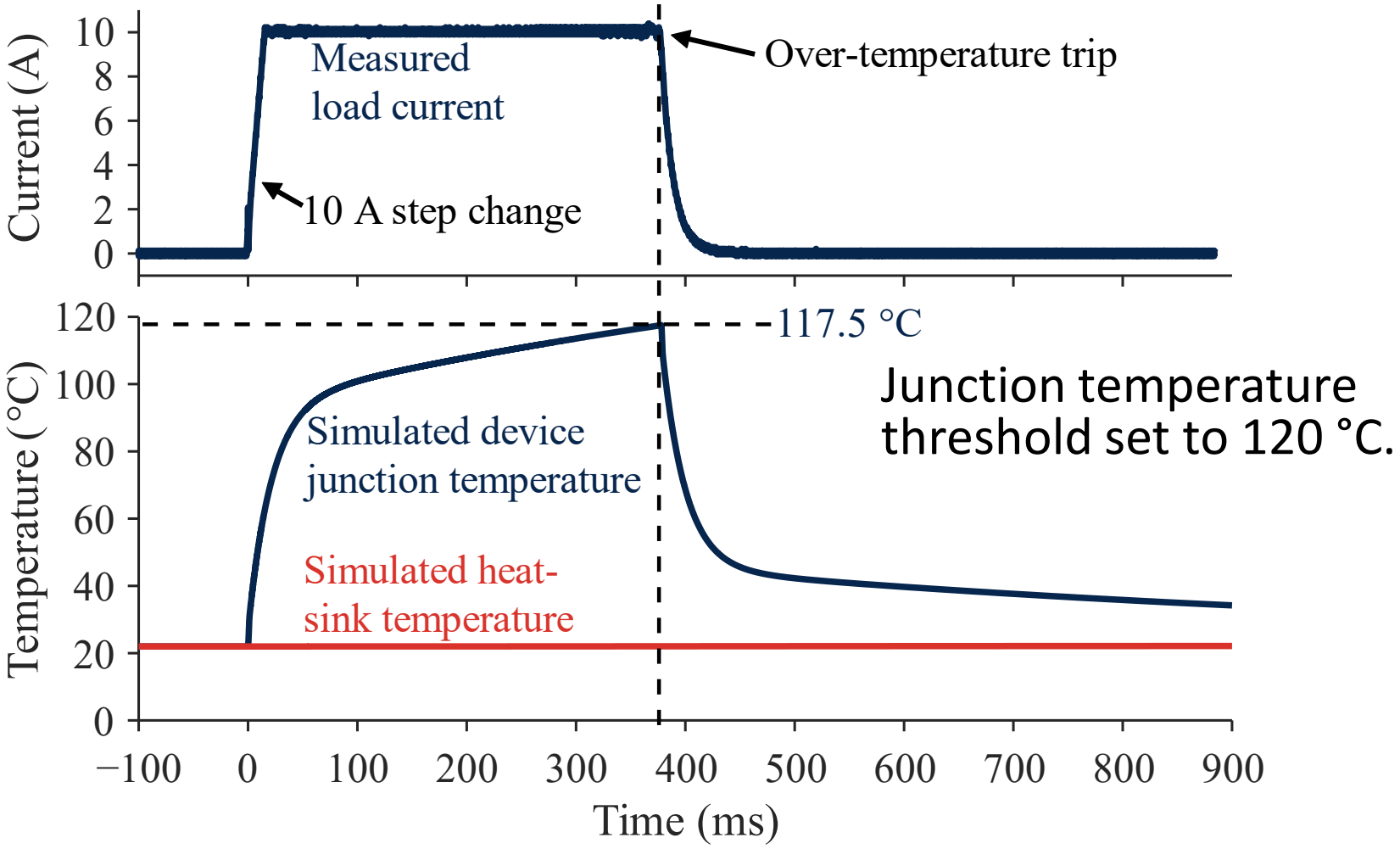




Junction temperature threshold set to 100°C



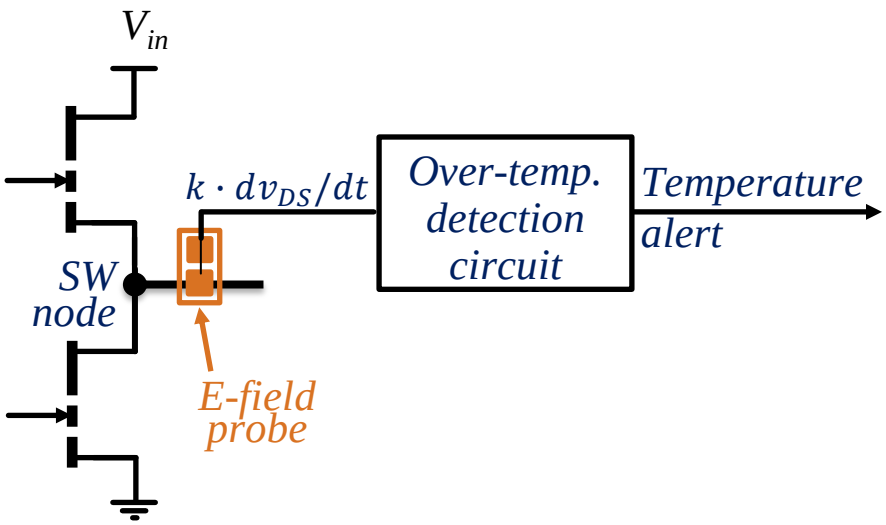
How fast does the protection circuit act?



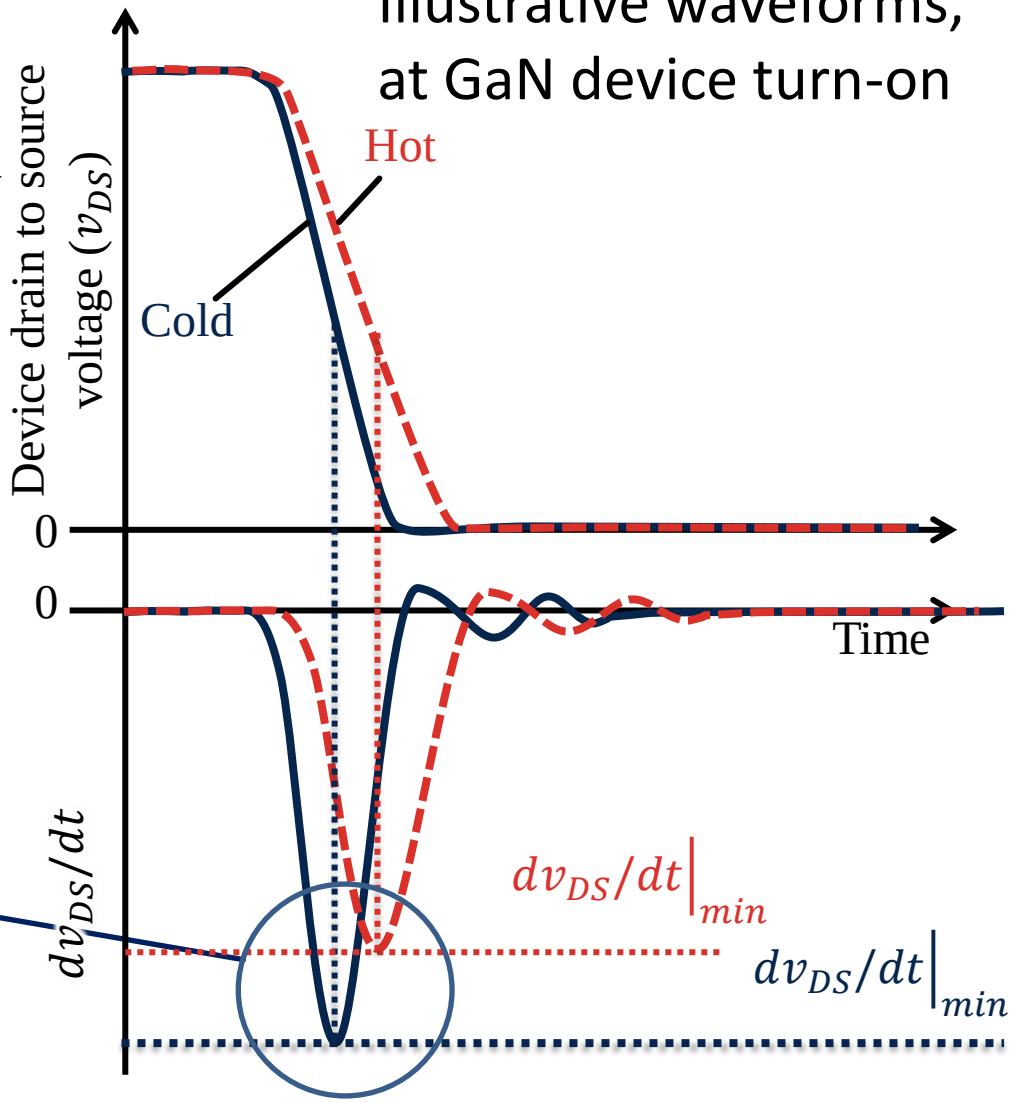
Demonstration of safe shutdown on highly overloaded GaN bridge-leg converter, operating at 10 A, 2 kW, and 500 kHz.

More info in
Over-Temperature Protection Circuit for GaN Devices Using a di/dt Sensor,
in IEEE Transactions on Power Electronics, 2021.

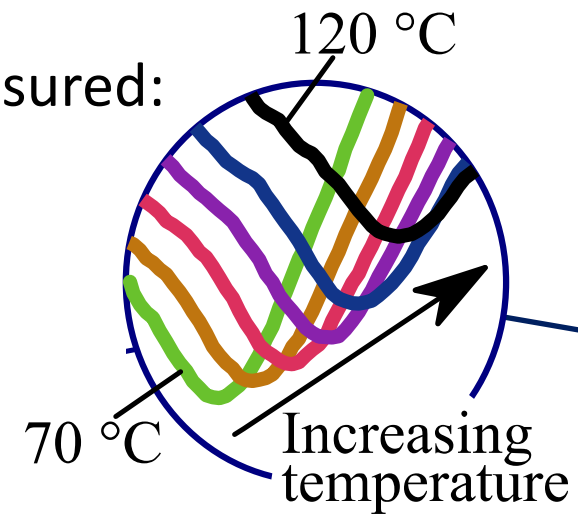
Voltage and temperature sensing using E-field (dV/dt)



Illustrative waveforms, at GaN device turn-on

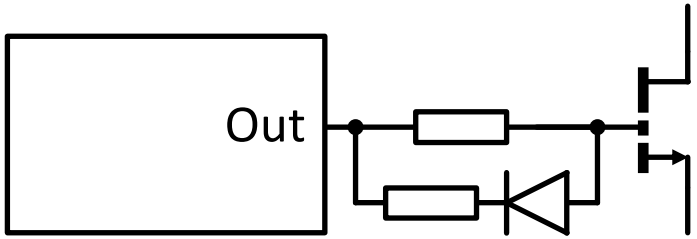


Measured:

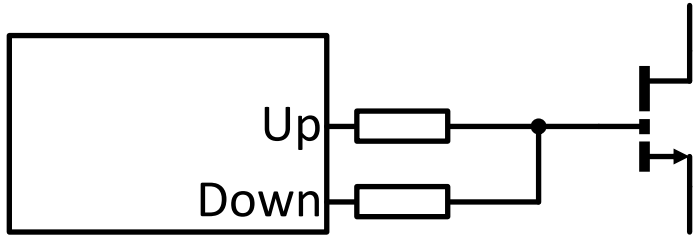


More info in
Fast temperature sensing for GaN power devices using E-field probes,
2020 IEEE Workshop on Control and Modelling for Power Electronics (COMPEL)

Ongoing research in gate driving: Gate driver output options



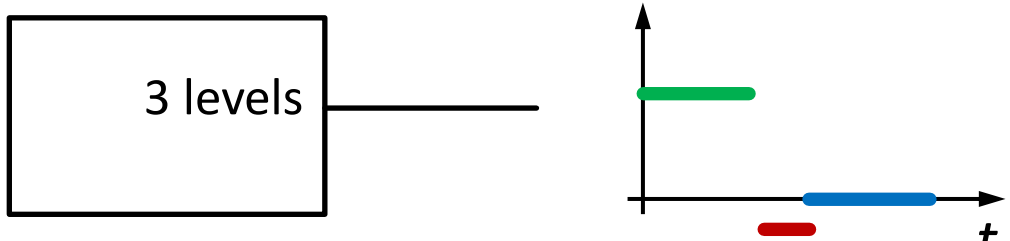
Problematic



Preferred

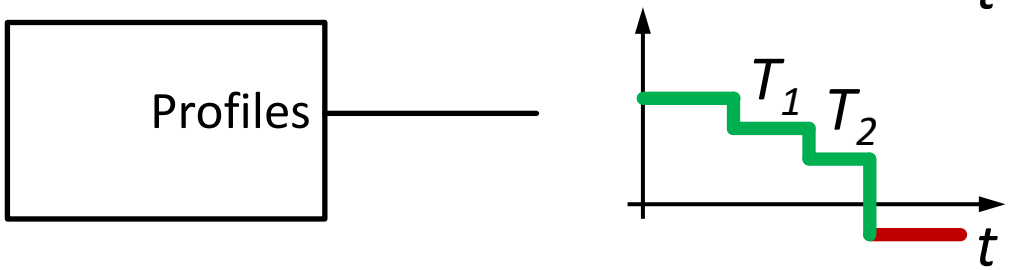
Manufacturer-recommended gate resistors

	GaN Systems	EPC
Off	0 – 2 Ω	0 Ω
On	10 – 20 Ω	2 Ω

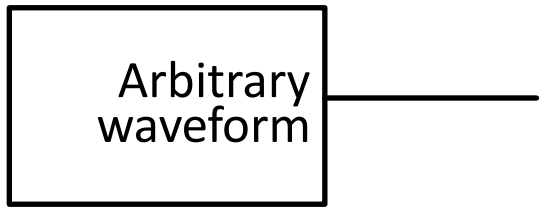


Available

Infineon EiceDRIVER 1edf5673k

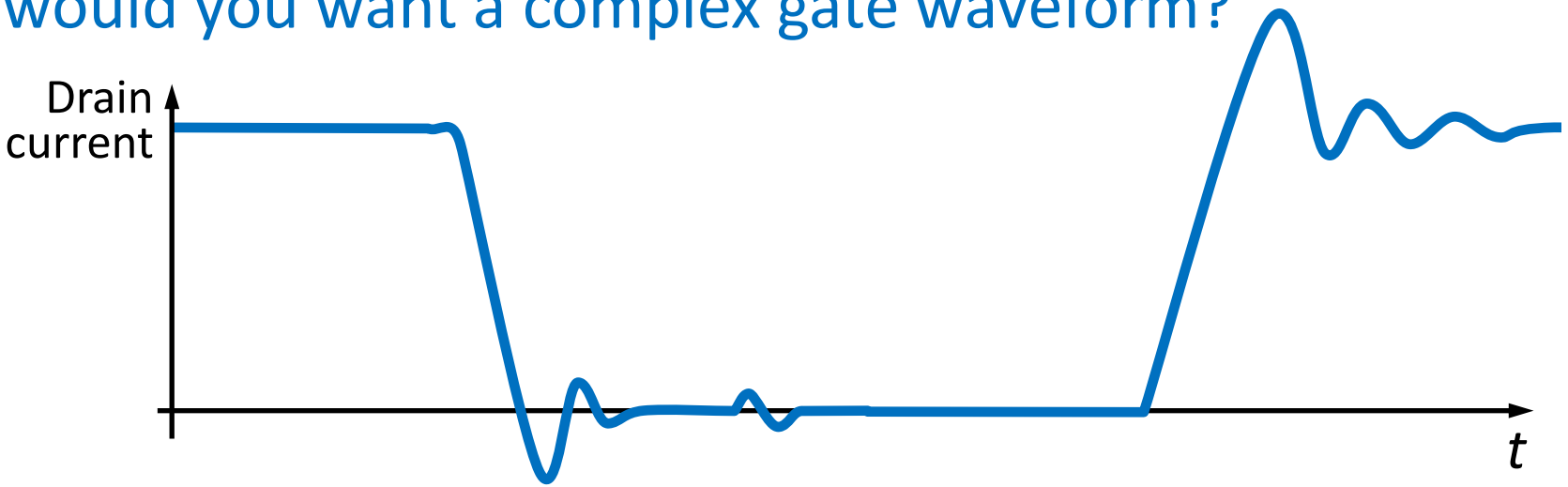


Becoming available

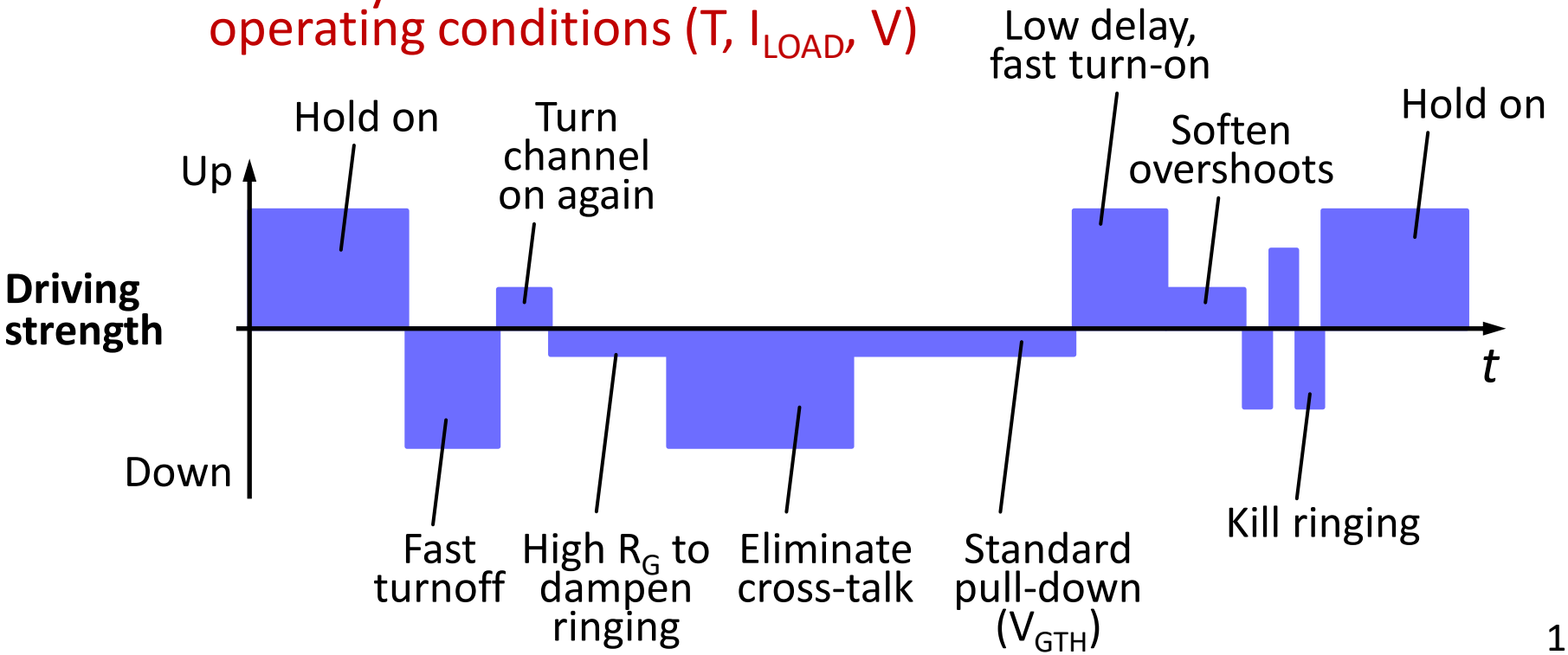


Research

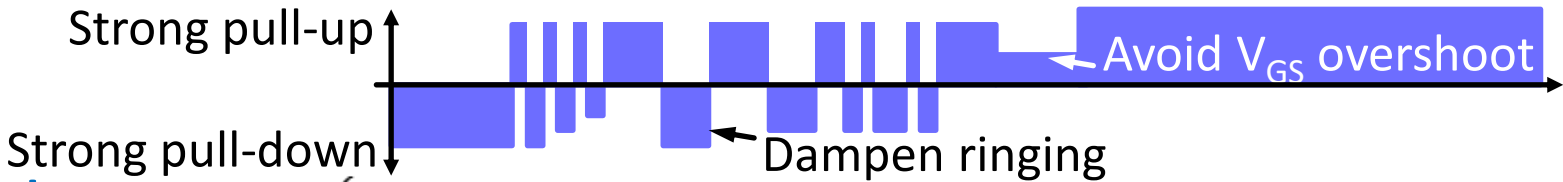
Why would you want a complex gate waveform?

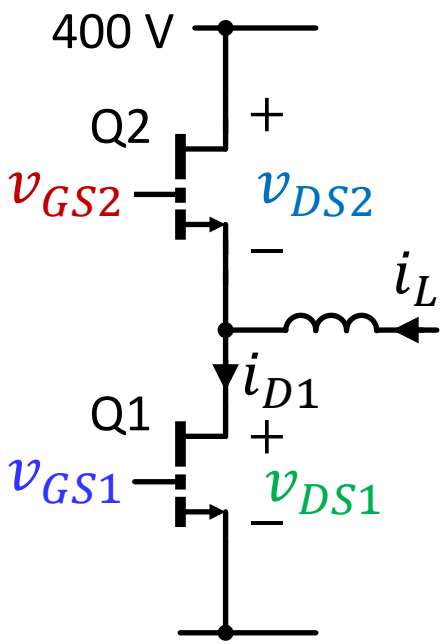


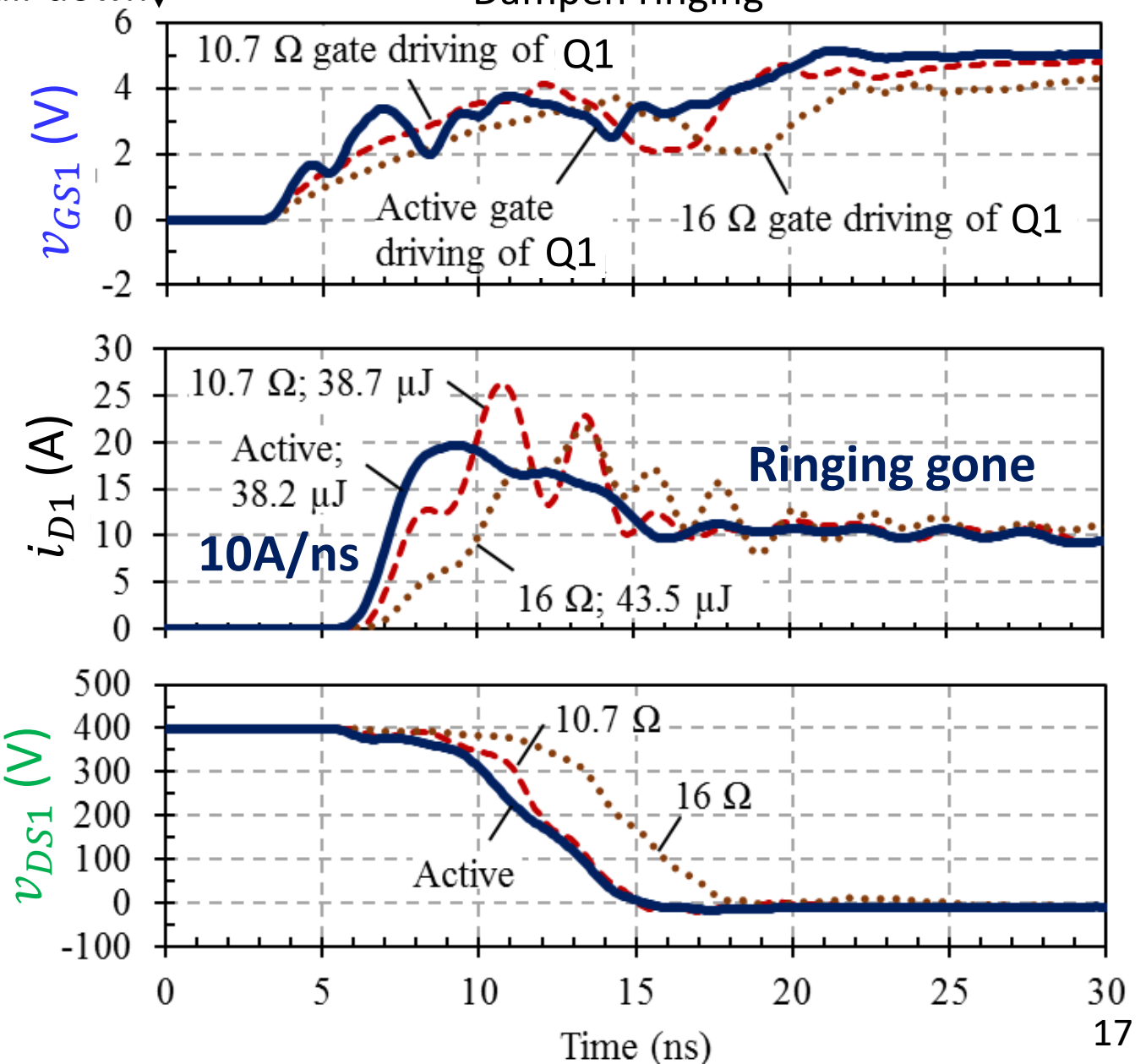
Vary some of these with operating conditions (T, I_{LOAD}, V)



Speed up turn-on to 10A/ns to reduce loss, protect gate, and dampen current ringing

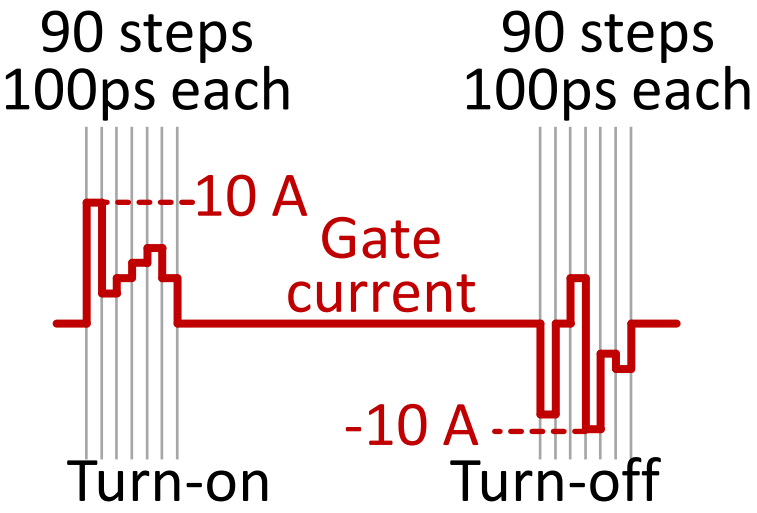






Arbitrary waveform driver

Approximate capability:



Steps every time light travels 3cm!

⇨ Useful tool for developing gate drivers.

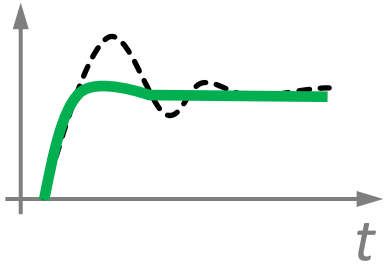
More info in

Gen 3: **Full custom design of an arbitrary waveform gate driver with 10 GHz waypoint rates for GaN FETs**, in IEEE Transactions on Power Electronics, 2021

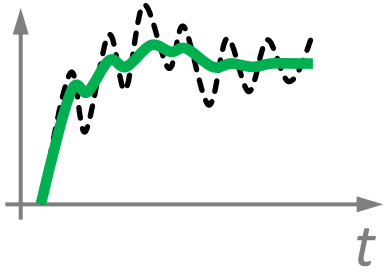
Gen 2: **A 6.7-GHz Active Gate Driver for GaN FETs to Combat Overshoot, Ringing, and EMI**, IEEE Trans. Power Electronics, 2018.

Demonstrated on hard-switched GaN at 100 V/ns

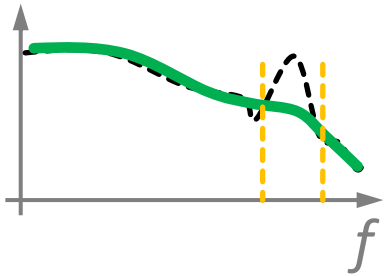
Reduce V & I overshoot



Reduce V & I ringing



Target a spectral EMI range



Online health tests?

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