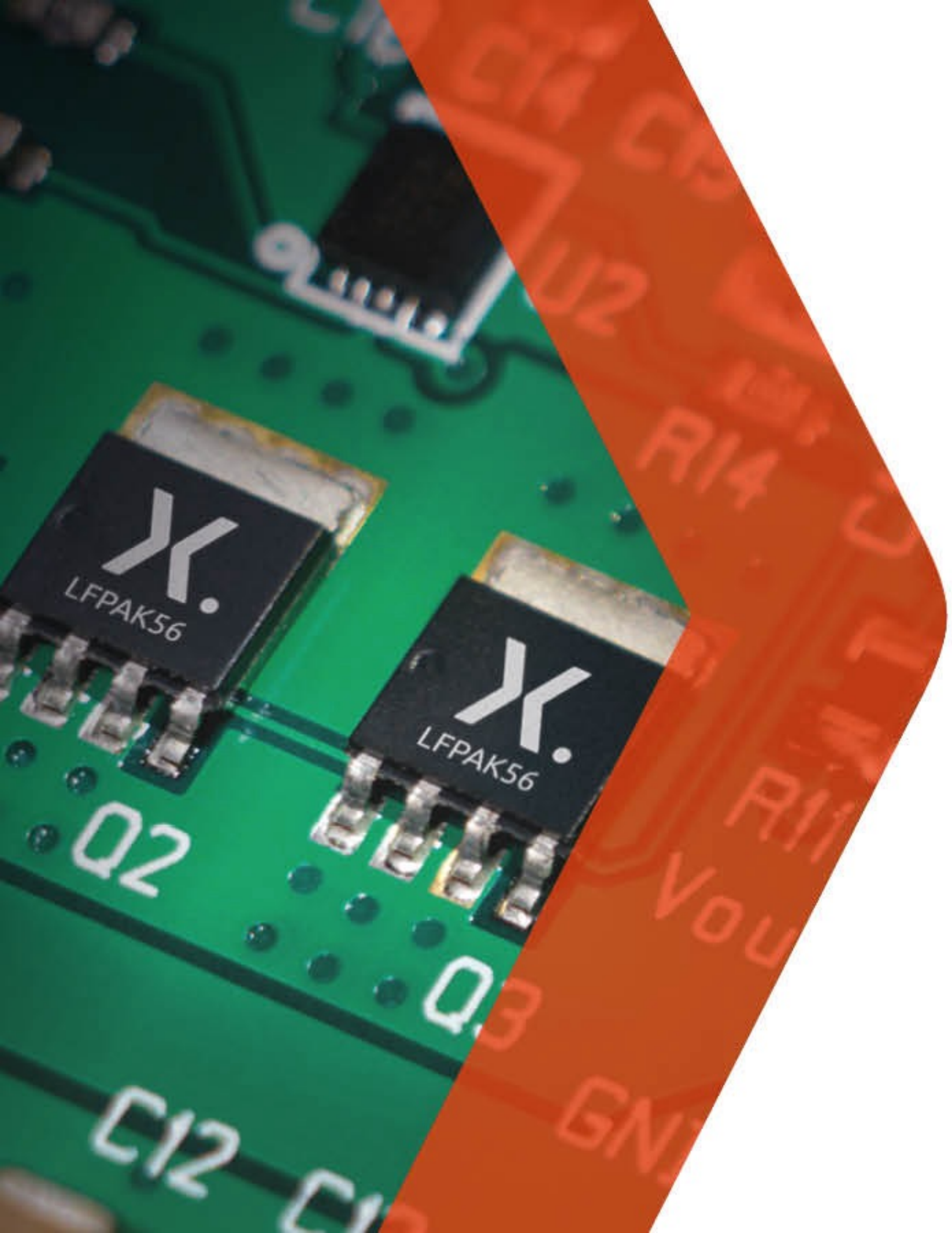

nexperia

Switching evaluation of fast GaN devices

Power GaN FETs

September 2021

Introduction

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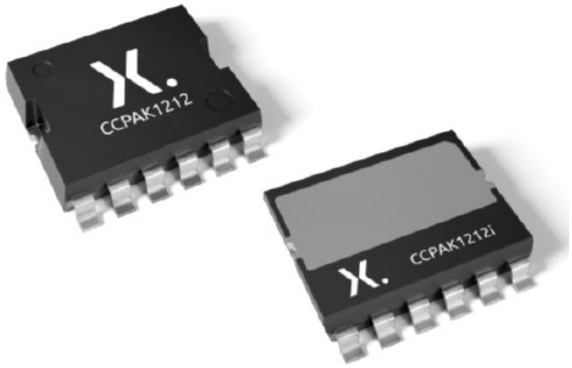
- Principal Application Engineer

- Giuliano Cassataro
- GaN Marketing & Commercial Director

Outline

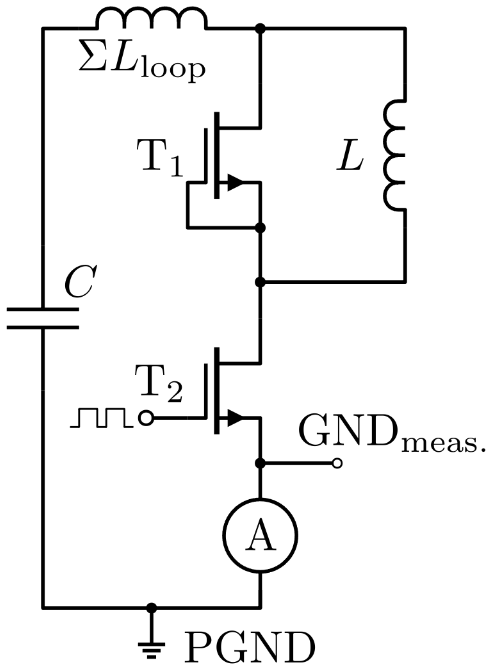


- Modern GaN devices in low-inductance SMD packages such as the CCPAK enable fast and clean switching transients

- To evaluate the performance of these devices, careful setup is required:
  - Optimized test platform
  - Suitable measurement setup
  - Proper preparation and post-processing

- Good technique is required for all switching investigations but:
  GaN is less forgiving since devices can switch faster and more efficiently than most Si and SiC transistors

Basic setup



Half-bridge with current measurement for double pulse test

Main focus of this presentation: double pulse analysis

Direct measurement in a double pulse setup is suitable for most tasks:

➢ characterize most applicated related parameters:

- voltage & current slopes (dv/dt, di/dt)
- reverse recovery (Q_{rr})
- gate drive performance

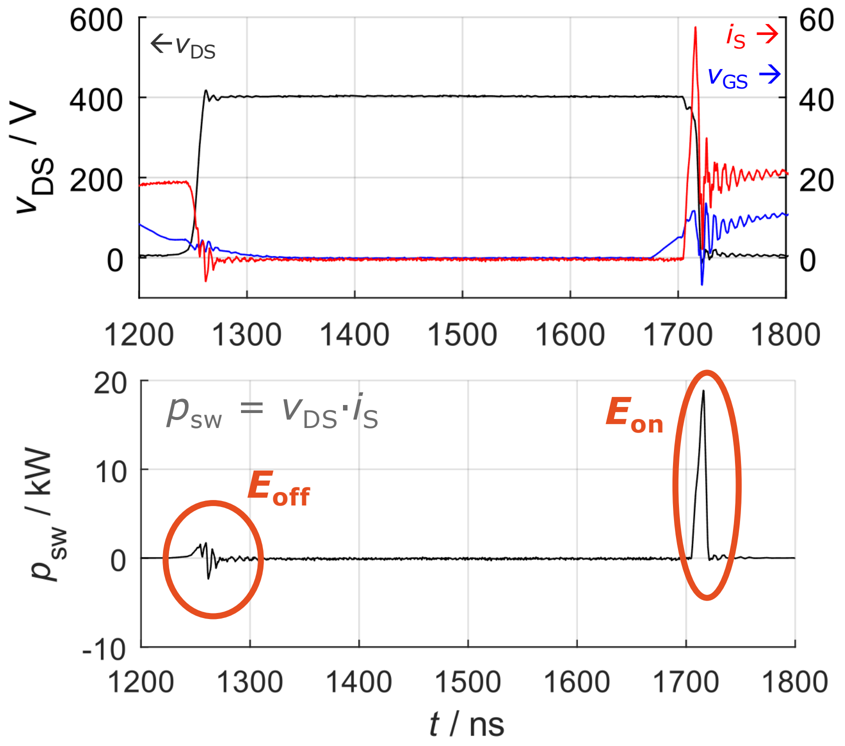
at different voltage, current, temperature etc.

➢ High precision for hard-switching loss analysis (E_{on} and E_{off})

➢ Low precision for resonant (soft) switching loss evaluation
→ Indirect measurement methods required

Why double pulse only for hard-switching

Hard-switching



➢ E_{on} and E_{off} can be determined with direct measurement

For 650V GaN:

- $E_{on} \gg E_{off}$ usually
- At low to medium current, channel can be turned off before v_{DS} can rise significantly
  → $E_{off} \approx E_{oss}$
  → Nearly lossless in this time instant, but E_{oss} is dissipated at next hard turn-on

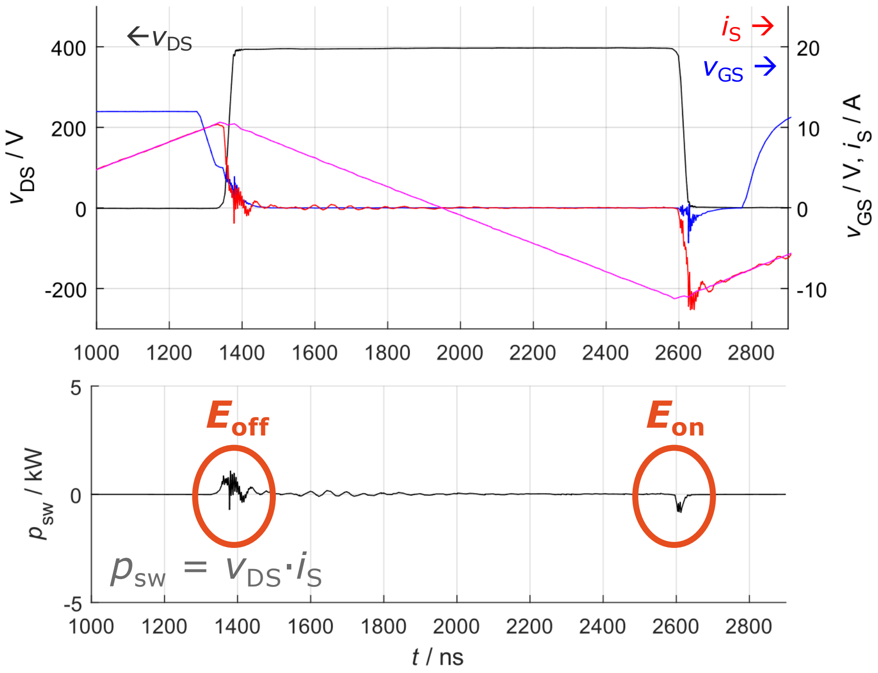
➢ **$E_{tot} = E_{on} + E_{off}$, total: 10s … 100s of µJ**

→ Measurement errors have limited impact on E_{tot}

Why double pulse only for hard-switching

Soft-switching

Soft turn-on, zero voltage switching (ZVS)



- E_{on} and E_{off} can be determined with direct measurement
- E_{on} is nearly lossless due to ZVS. Output energy ≈-E_{oss} is transferred instead of dissipated.
- **$E_{tot} = E_{on} + E_{off}$ can be in the single digit µJ range:**
  - $E_{on} \approx -E_{oss}$
  - $E_{off} \approx E_{oss}$, (but $E_{off} > E_{on}$)
- Output charge transfer dominates in direct V/I measurement
- Sources of error (limited bandwidth, amplitude error, offset, deskew, parasitics, etc.) have extreme impact

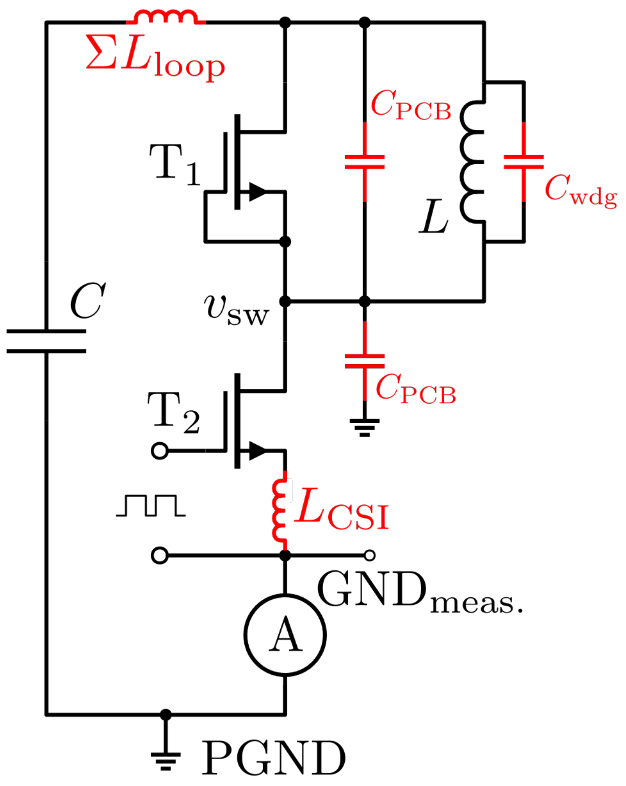
Basic requirements: Test platform

➢Should be similarly built as a real application circuit → half-bridge is a good choice

➢Needs to enable precise voltage and current measurement without introducing extra parasitics

<u>Main parasitics to minimize:</u>

- Commutation loop inductance ΣL_{loop}
  →Adds overshoot, ringing, can be a stability issue
- Capacitances of switch-node and inductor winding
  → Increases switching losses and measured Q_{rr}
- Common source inductance
  → Slows down switching transients, can be a stability issue



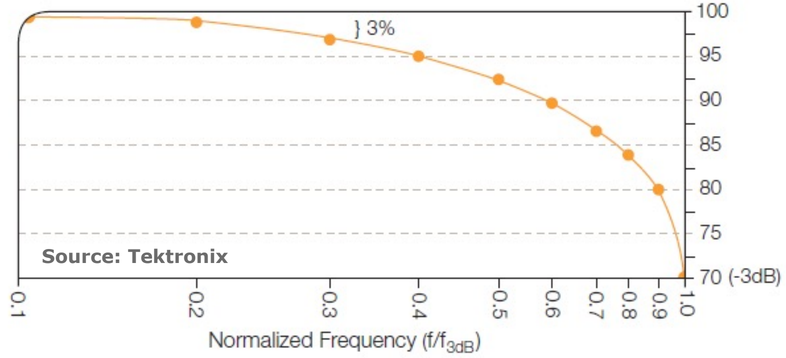
Basic requirements: Measurement setup

- High sample-rate oscilloscope and probes with sufficient bandwidth required
- Measured signal is attenuated by $^{1}/_{\sqrt{2}}$ at the system bandwidth: $BW_{sys} = \frac{1}{\sqrt{\frac{1}{BW_{scope}^2}+\frac{1}{BW_{probe}^2}}}$ *

*some manufacturers specify probe BW as system BW

Rules of thumb:

- System bandwidth ≥ 3-5x highest frequency component of signal f_{max}
- Sample rate at least 10 times f_{max} (for linear interpolation)



Estimation for GaN:

- For up to 100 V/ns at 400Vdc:

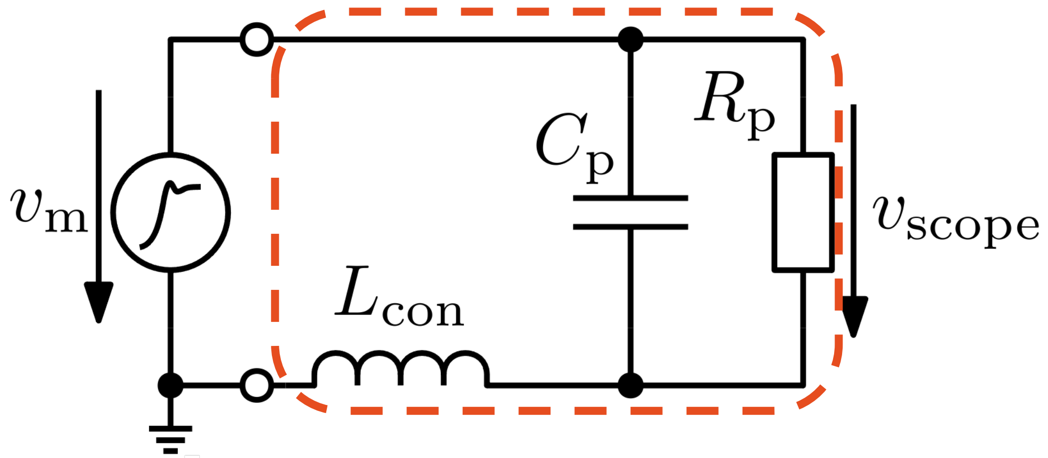
  t_{rise} (10%-90%) = 3.2 ns → equivalent f_{max} ca. 0.35/3.2ns = 109 MHz
- Oscillations at gate or drain can contain much higher frequency components

BW_{scope}	BW_{probe}	BW_{sys}	Error
1 GHz	1 GHz	707 MHz	1.1%
500 MHz	500 MHz	353 MHz	4.7%
350 MHz	200 MHz	174 MHz	18%

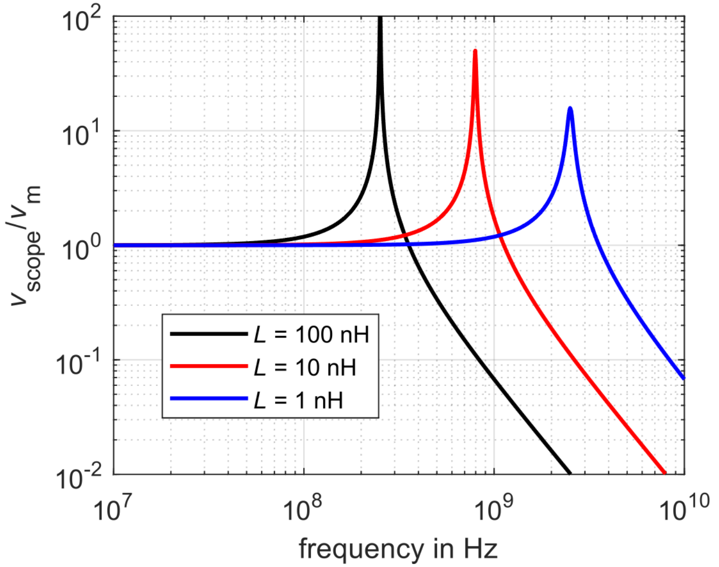
Basic requirements: Measurement setup

Voltage probes:

- Passive probes are preferred for low-side measurement
  - High bandwidth (e.g. 1 GHz for low voltage, 800 MHz for HV)
  - Widely available
  - Small ground loop possible → Less ground inductance, less parasitic induction



Probe equivalent circuit



Example:
C_p = 4 pF
R_p = 10 MΩ

Basic requirements: Measurement setup

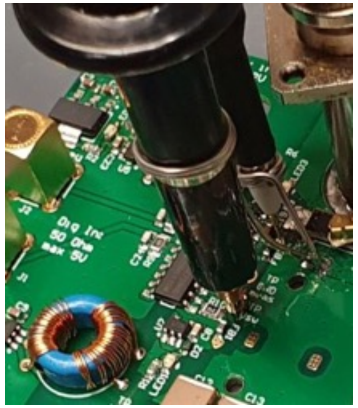
Voltage probes:

- Passive probes are preferred for low-side measurement
  - High bandwidth (e.g. 1 GHz for low voltage, 800 MHz for HV)
  - Widely available
  - Can be connected with very small ground loop → Less ground inductance, less parasitic induction

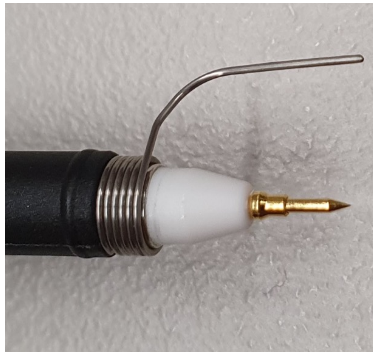
worse — Ground loop → **better**

Ground lead

Ground lead (twisted)



Hand wound wire



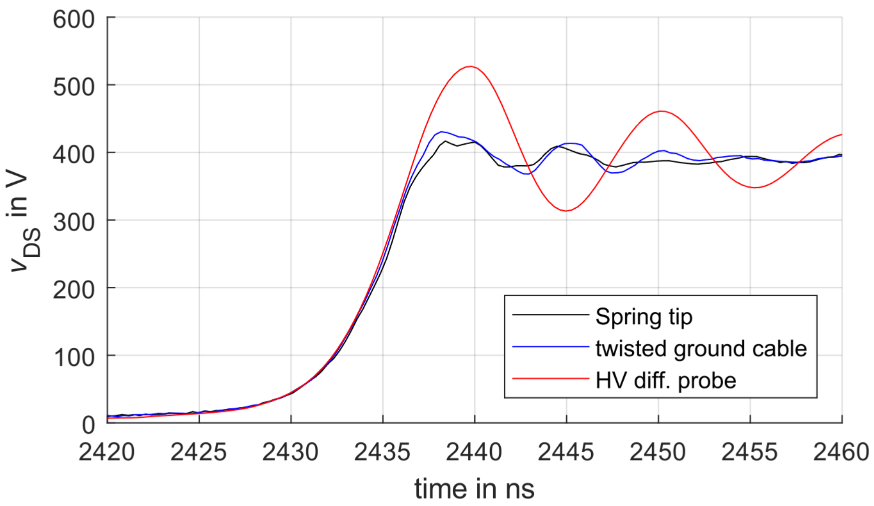
Ground spring

Fixed coax/pin connector

Basic requirements: Measurement setup

Are HV differential probes suited, e.g. for high-side measurement?

- Bandwidth up to 400 MHz
- Limited common-mode rejection ratio (CMRR): Current models: 26…45 dB @ 100 MHz
  → Common mode voltage shift will be visible in high-side differential measurement
  26 dB: 20V @ 400V!   45 dB: 2.25V @ 400V
- Connected with long leads → high inductance



→ Not suitable for analysis

Good but expensive alternative for high-side measurement: Optical isolated probes (IsoVu)

Basic requirements: Measurement setup

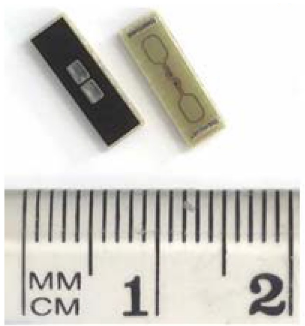
Current probes:

- Needs to be part of the measurement system, retrofitting of very high bandwidth solutions usually not possible w/o compromising performance
- »100 MHz Bandwidth at minimal insertion inductance desirable
- Standard Rogowski coil can not capture d*i*/d*t* of unrestricted GaN devices

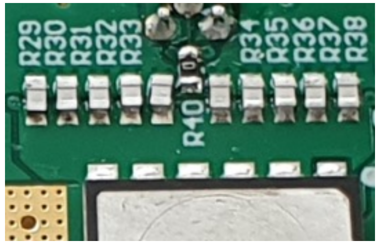
10s MHz — Bandwidth → **GHz**

Rogowski coil

Current transformer



Spec. field sensor



Spec. SMD shunt design

Coax Shunt

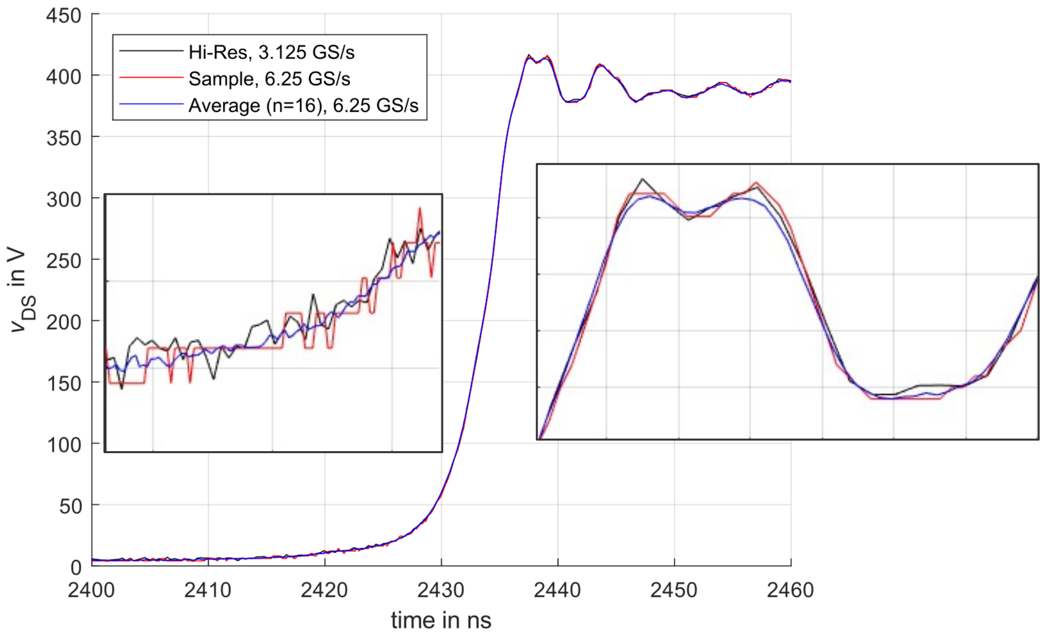
public

Measurement Preparation

Might sound obvious but is extra important at low switching losses:

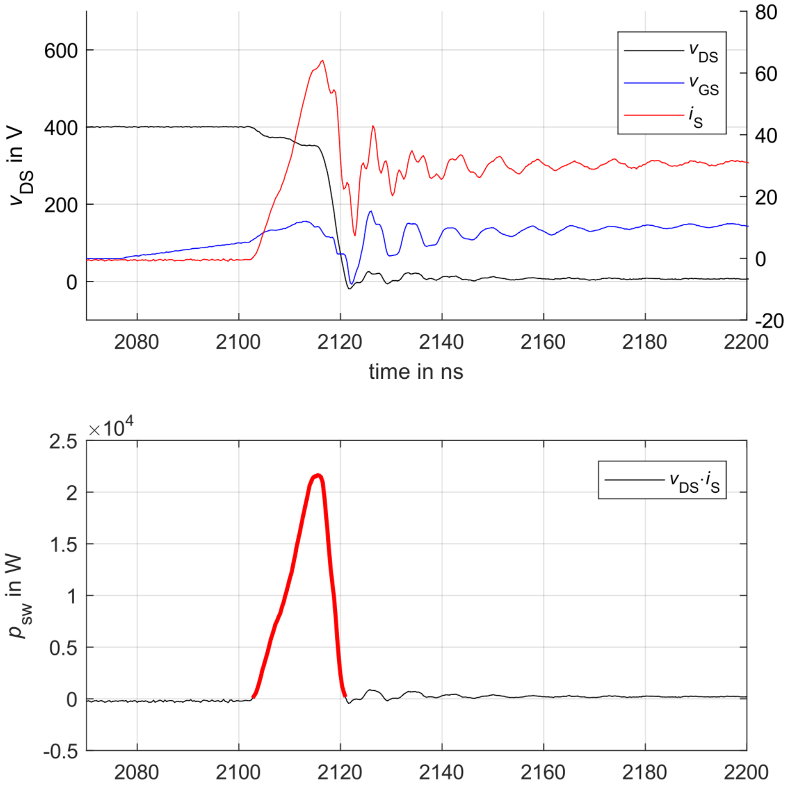
- Probe compensation to prevent amplitude errors
- Custom de-skewing between current and voltage probe
- Removal of offset
- Running at max. bandwidth
- Using the full vertical scale

- Acquisition mode:
  Either can work but Hi-Res or averaging can help increase precision at low amplitudes

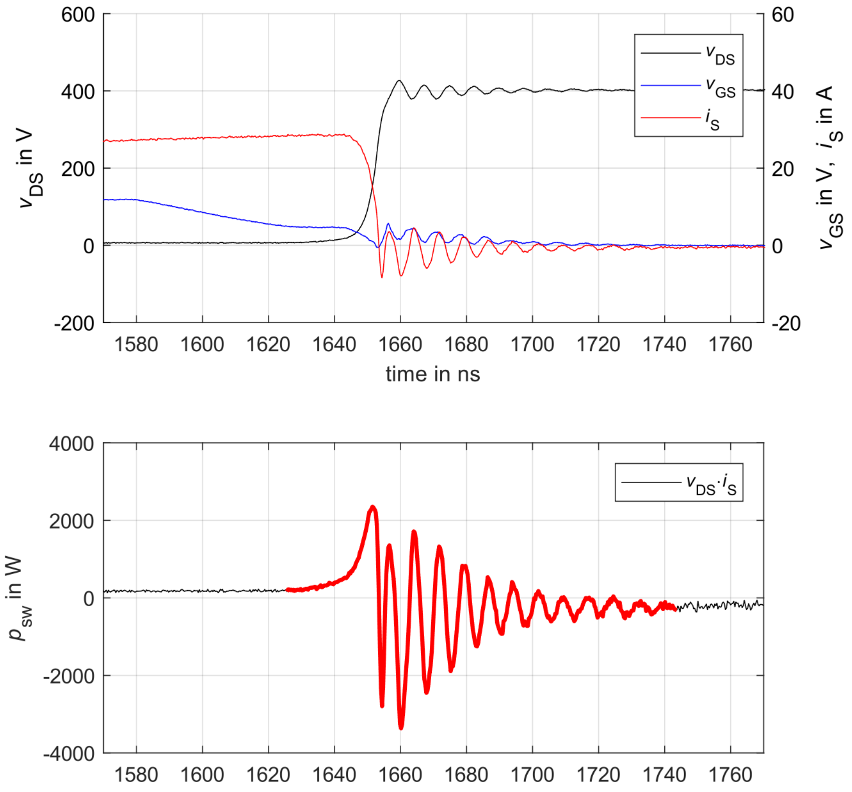


Determination of E_{sw}

- Direct measurement (low-side) of voltage and current → compute $E = \int v \cdot i \, \mathrm{d}t = \int p_{sw} \, \mathrm{d}t$



Turn-on transient:
Relatively large compared to E_{off} in hard-switching, even for GaN

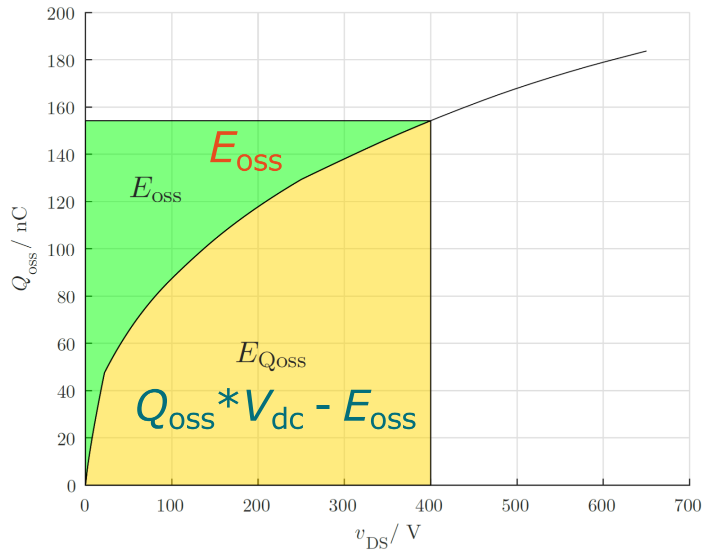


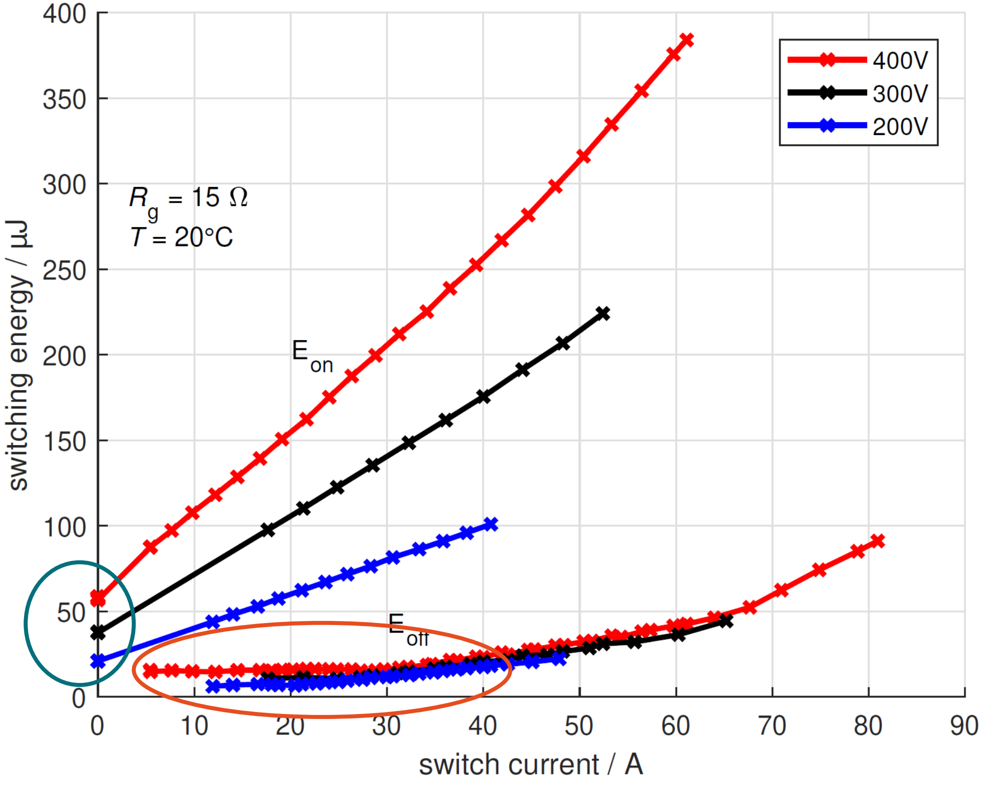
Turn-off transient:
$E_{off} \approx E_{oss}$ at low…medium currents → very low

Post-processing optimization:

- **Current calculation from measured signal (if required)**
- **Offset correction (e.g. LF oscillation of power supply circuit)**
- **Integration limits (start&stop at steady state values?)**
- **Bandwidth optimization (e.g. apply inverse)**

E_{sw} for GAN039:





Switching loss overview

Plausibility checks:

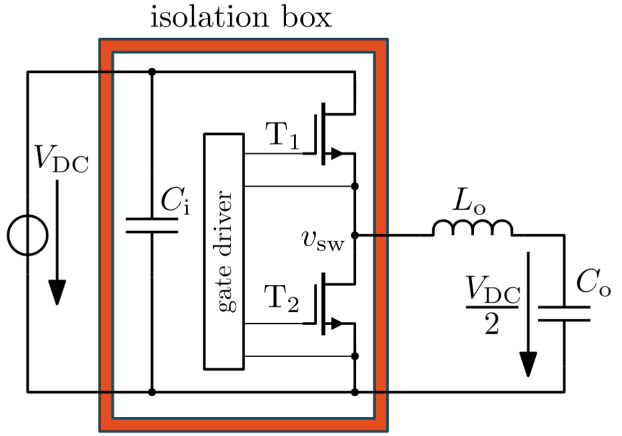
E_{on} at 0A: ≈ $Q_{oss}*V_{dc} - E_{oss} + \Delta E$

(ΔE: energy in parasitic capacitance)

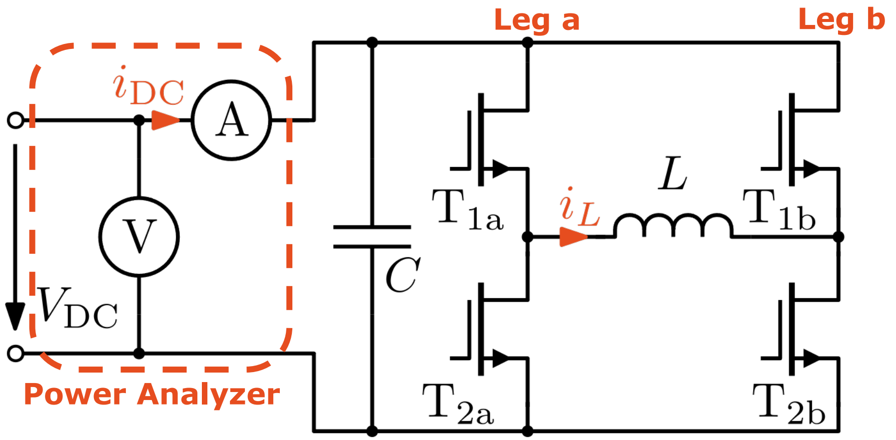
E_{off} at low currents: ≈ E_{oss}

Soft-switching (zero-voltage-switching, ZVS)

Indirect methods offer much higher precision for soft-switching, e.g.:



Calorimetric method: „Bridge-leg-in-the-box“



„Opposition method“

- Determination of losses via change of temperature in the box

Requirements:

- Thorough calibration
- Knowledge about other loss components

- Two bridge legs produce circulating current, losses can be measured precisely on DC side

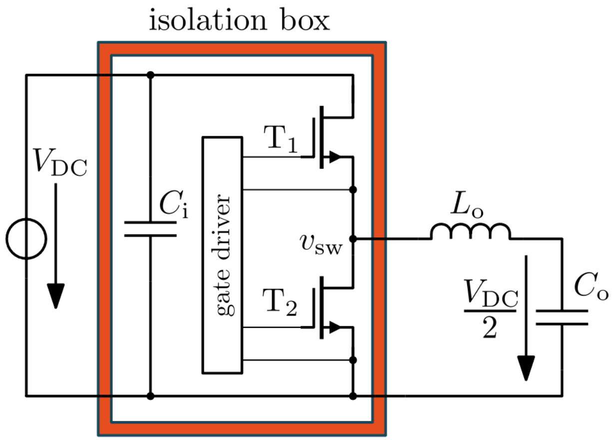
Requirements:

- 2nd bridge leg and low loss inductor
- Knowledge about other loss components

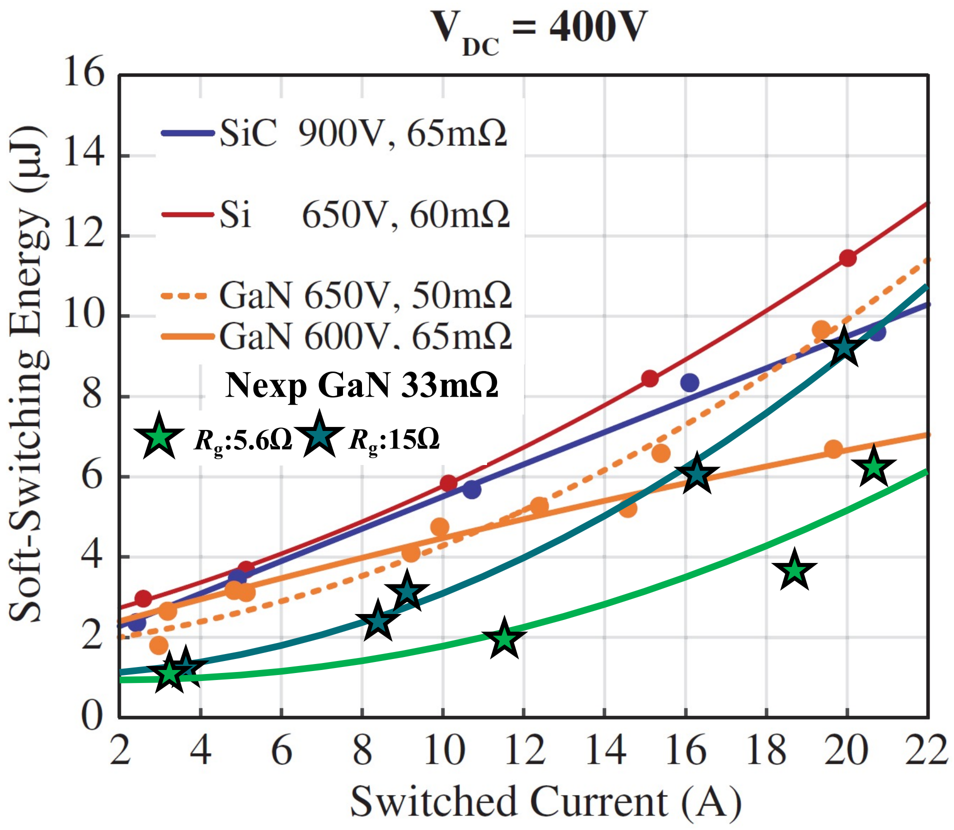
→ **Higher complexity but sub µJ precision can be achieved with both methods**

Soft-switching (zero-voltage-switching, ZVS)

Test results for using calorimetric setup



Calorimetric method: „Bridge-leg-in-the-box"



Further information

Please visit Nexperia.com/GaN-FETs

GaN FETs

Efficient and effective high-power FETs

Details | Parametric search | Packages | Documentation | Datasheets | Technology Hub | Cross reference

Datasheets (6)

Type	Title	Date	Download
Data sheet	650 V, 33 mOhm Gallium Nitride (GaN) FET in a CCPAK1212 package	2021-04-19	GAN039-650NBBA
Data sheet	650 V, 33 mOhm Gallium Nitride (GaN) FET in a CCPAK1212i package	2021-04-19	GAN039-650NTBA
Data sheet	650 V, 33 mOhm Gallium Nitride (GaN) FET in a CCPAK1212i package	2021-04-19	GAN039-650NTB
Data sheet	650 V, 33 mOhm Gallium Nitride (GaN) FET in a CCPAK1212 package	2021-04-19	GAN039-650NBB
Data sheet	650 V, 35 mΩ Gallium Nitride (GaN) FET in a TO-247 package	2021-01-12	GAN041-650WSB
Data sheet	650 V, 50 mOhm Gallium Nitride (GaN) FET	2020-07-31	GAN063-650WSA

Nexperia GaN FETs - Performance, efficiency, reliability brochure

MOSFET and GaN FET Application Handbook

Focus package: CCPAK

Application notes & white papers

Understanding Power GaN FET data sheet parameters

AN90005

Circuit Design and PCB Layout Recommendations for GaN FET Half Bridges

AN90006

GaN FET technology and the robustness needed for AEC-Q101 qualification

White paper

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