Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Power Electronic Systems Laboratory

ECPE Double Workshop
II. Electrical Testing of Power Electronic Systems
26–27 March 2014,
Ismaning-Munich, Germany

Enertronics GmbH

On The Benefits of Floating Electrical Measurement

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Concept and Experimental Evaluation of a Novel DC – 100 MHz Wireless Oscilloscope

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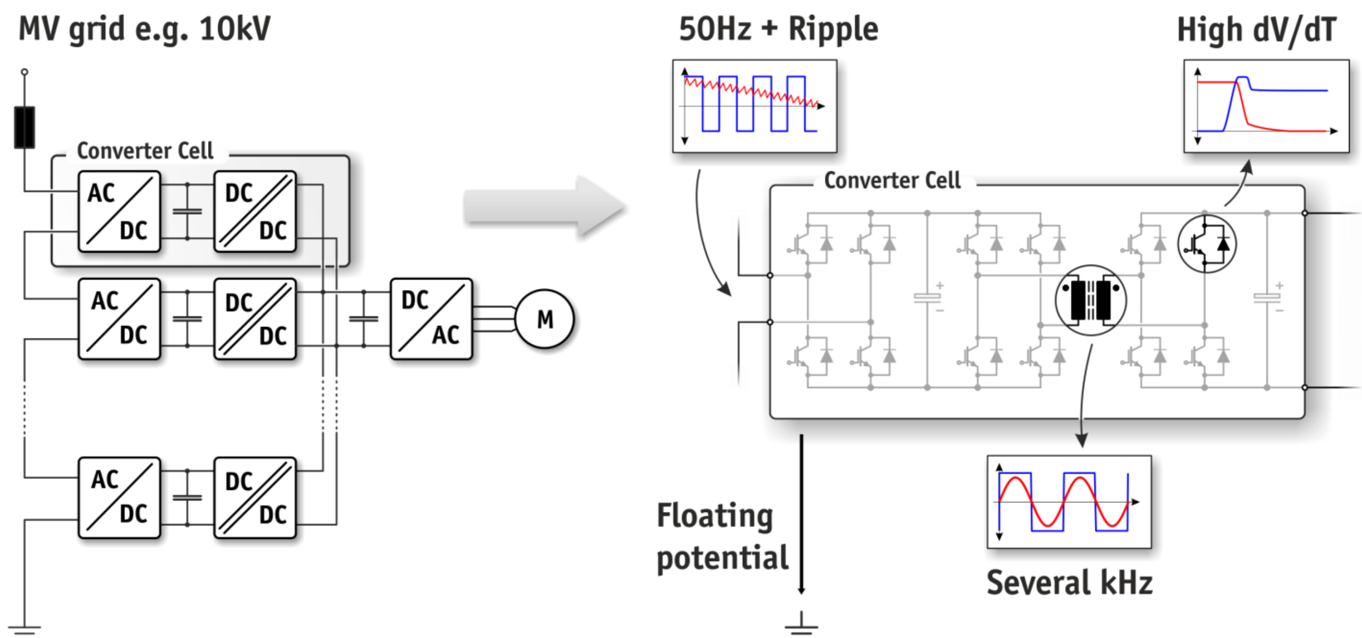
Outline

- Typical Testing of Power Electronics
- State of the Art Isolated Measurement Principles
- New Concept: Wireless Oscilloscope
- Experimental Verification
- Summary

Typical Situation at Testing of Power Electronic Systems

- **Measurements during bringing into service of converters**



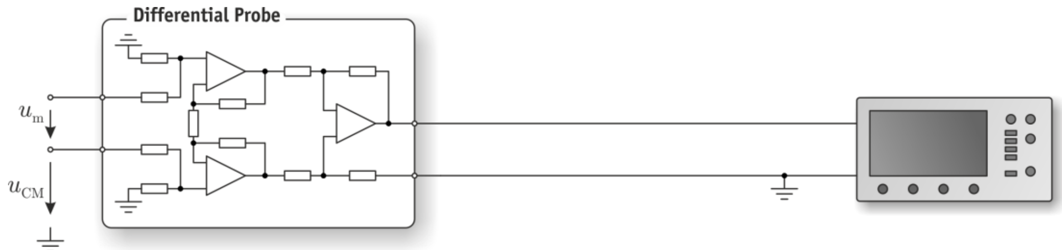
- **Floating Potential(s)!**
  - Up to tens of Kilovolts
  - Up to tens of Kilovolts/Microsecond

- **Voltages / Currents**
  - Millivolts to Kilovolts
  - Ampères to Kiloampères
  - DC to Tens of Megahertz

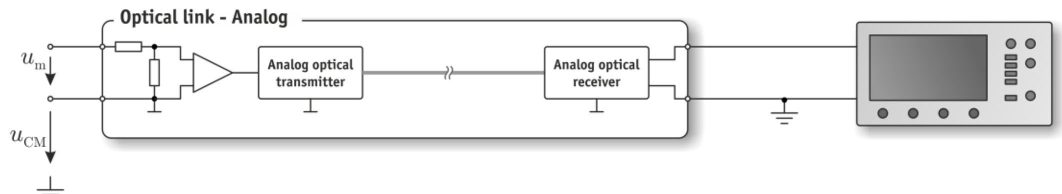
Outline

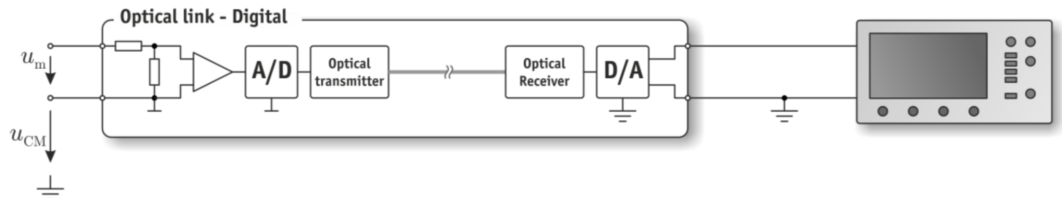
State of the Art Isolated Voltage Measurement

- **Basic Types**
  - Differential Probes



  - Optically Isolated Systems (analog link / digital link)

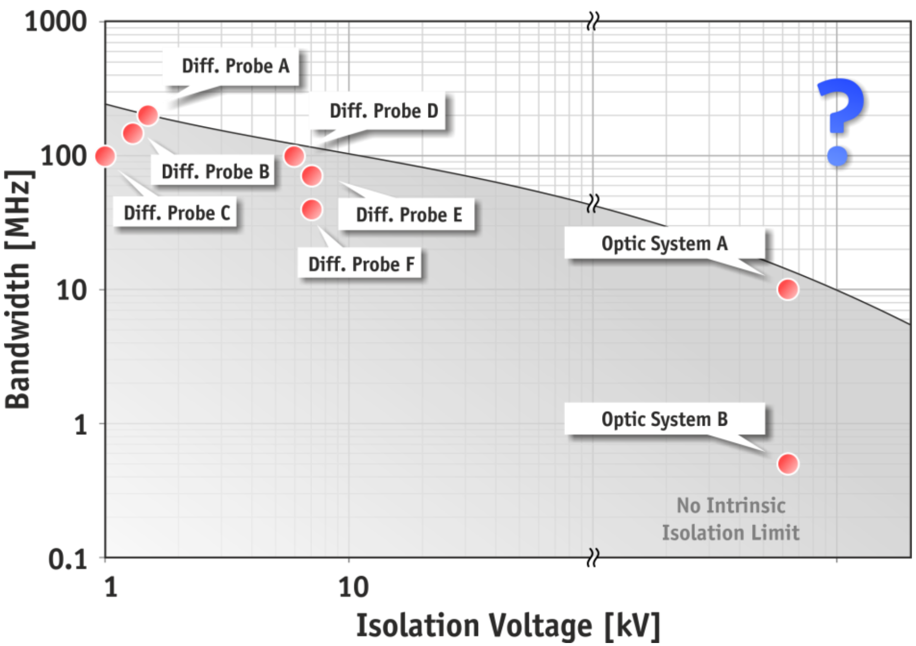




- **Drawback: Probe Combines Isolation and Measurement**
  - Differential probe: strong attenuation of input voltage
  - Optical systems: high bandwidth / data rate real time signal transmission

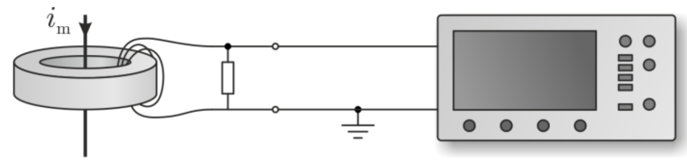
State of the Art Isolated Voltage Measurement

- Trade-Off: Voltage Isolation vs. Measurement Bandwidth of Commercially Available Measurement Systems

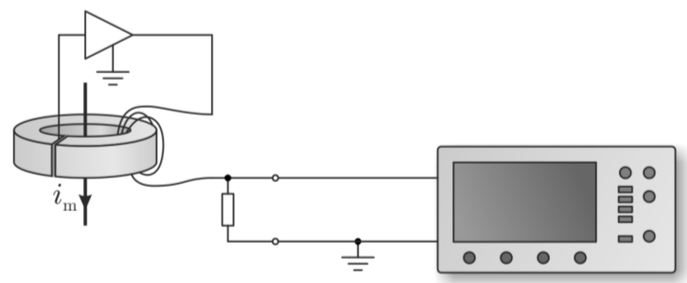


State of the Art Isolated Current Measurement

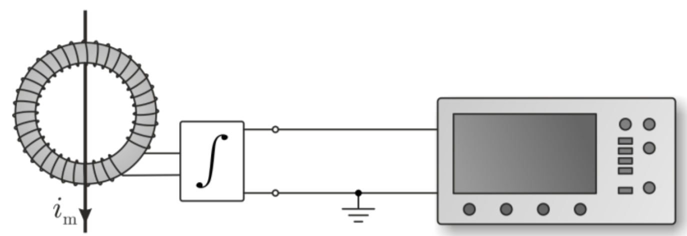
- **Basic Types**
  - Current Transformers



  - Current Compensated Transformers (clamp-on current probes)



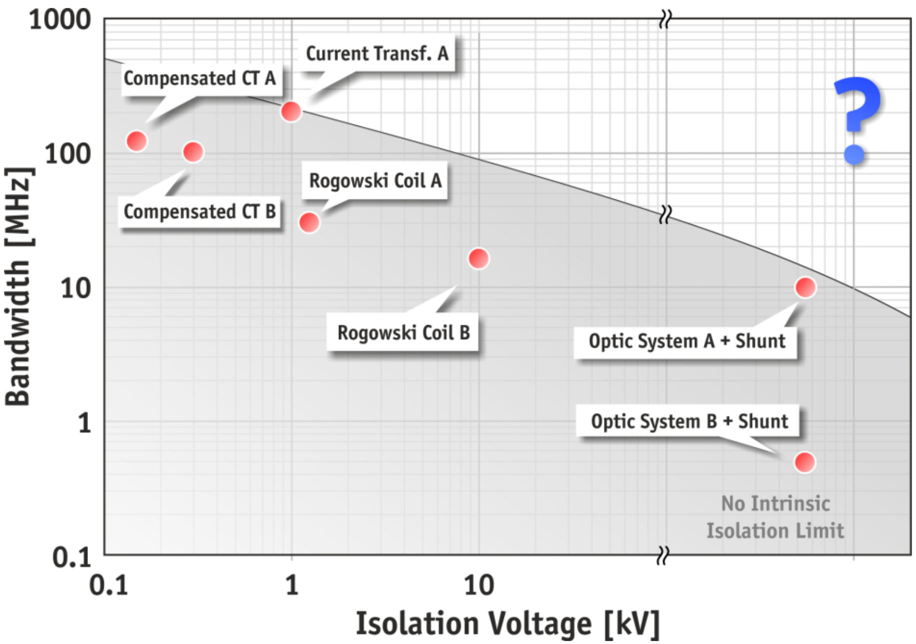
  - Rogowski Coils



- **Drawback: Combination of Isolation and Measurement**
  - Parasitics scale with geometrical dimensions
  - Large size – high isolation – low bandwidth

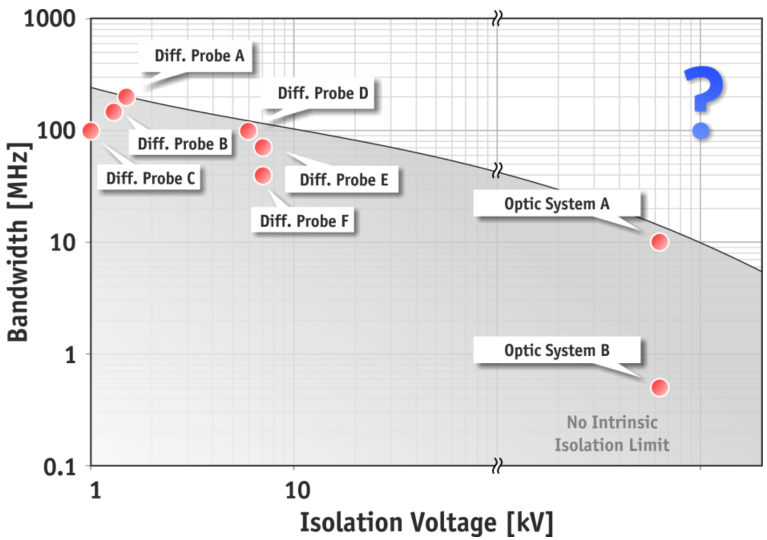
State of the Art Isolated Current Measurement

► Trade-Off: Voltage Isolation vs. Measurement Bandwidth of Commercially Available Measurement Systems

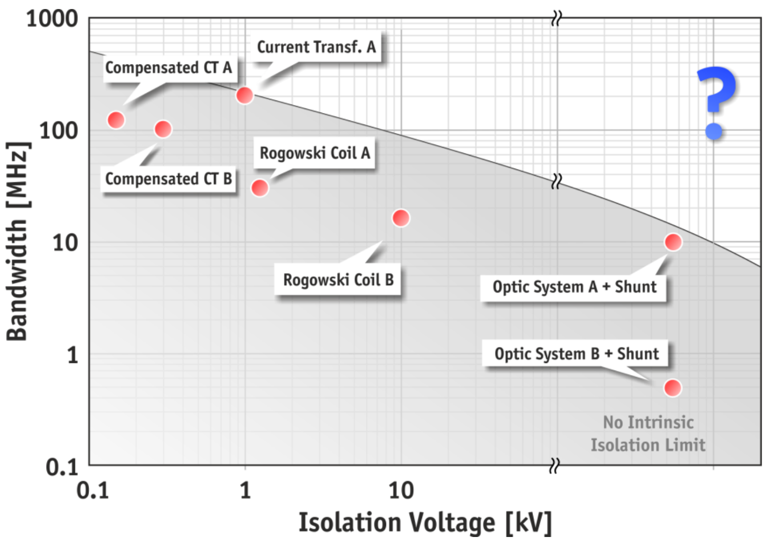


State of the Art Isolated Voltage / Current Measurement

Voltage



Current



- **Goal: New Measurement Concept!?**
  - Reaching no intrinsic isolation voltage
  - Reaching at least 100 MHz bandwidth

Outline

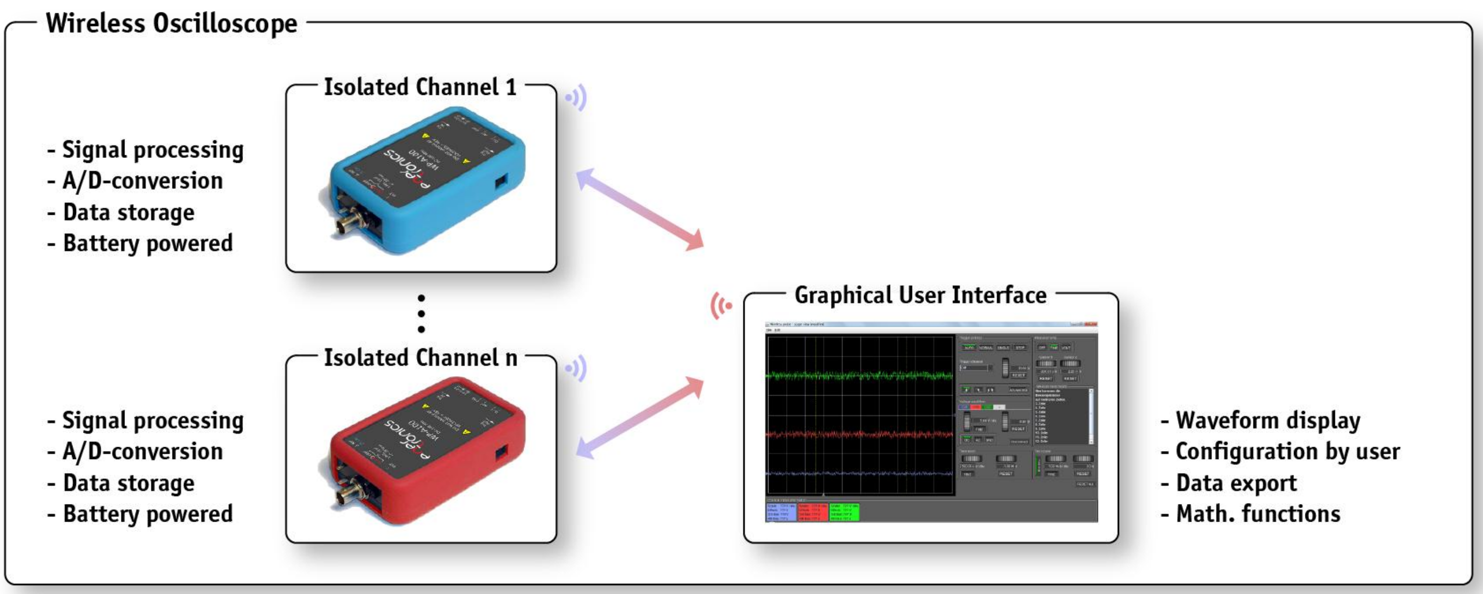
- Typical Testing of Power Electronics
- State of the Art Isolated Measurement Principles
- New Concept: Wireless Oscilloscope
- Experimental Verification and Comparison
- Summary

Wireless Oscilloscope – Basic Idea

▶ Provide the Isolation at a Different Position in the Measurement Chain

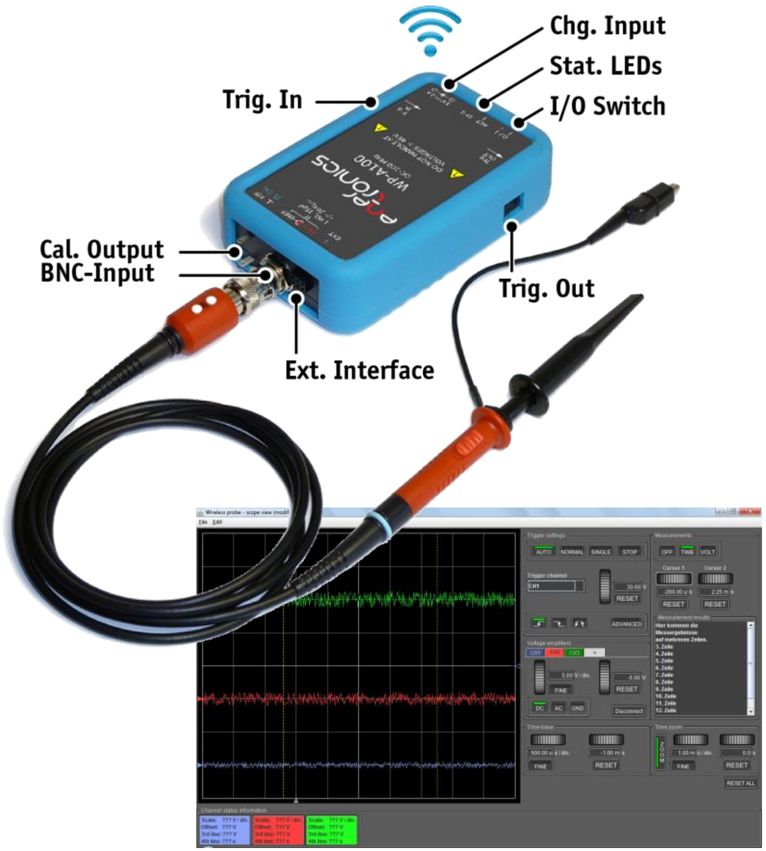
– Separate data acquisition (channels) and user interface!
– No need for isolated probes / sensors
– No need for an additional oscilloscope

▶ System Overview



Wireless Oscilloscope – Overview

▶ Isolated Channel(s) and GUI



▶ Specifications of Prototype

Analog Bandwidth	DC – 100 MHz
Sampling Rate	400 MS/s
Memory Depth.	200’000 S
Resolution	8 Bit
Input Voltage	±80 mV … ±20 V ±800 mV … ±200 V (1:10 passive probe) …
Input Impedance	1 MΩ
Input Capacitance, Differential	15 pF
Input Capacitance, Common Mode	26 pF
Battery	Li-Ion, Rechargeable
Battery Runtime (typ.)	>8 h
Communication	Bluetooth, Class 1
Trigger	Wireless & Optical
Physical Dimensions	141 mm x 81 mm x 32 mm
Weight	350 g

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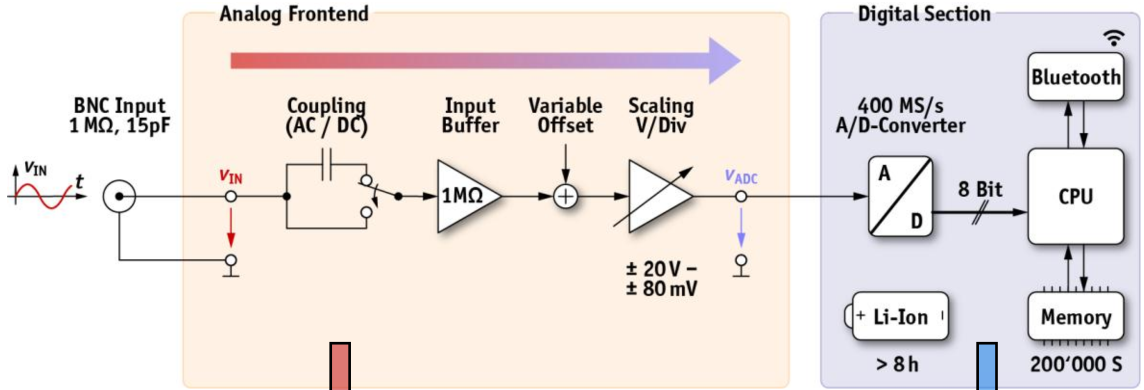
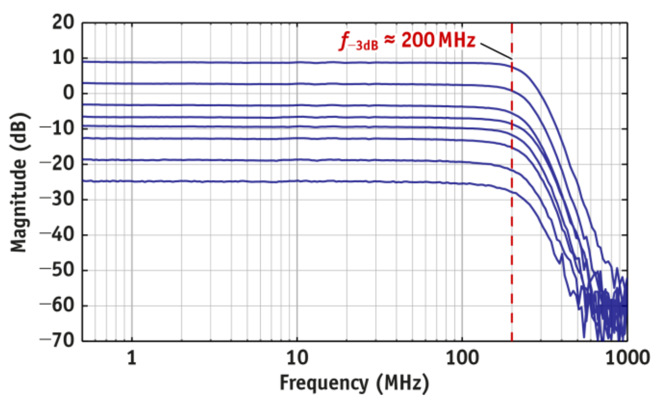
Analog Bandwidth

▶ Isolated Channel – Schematic Overview



▶ Analog Frontend: f_{-3dB} = 200 MHz

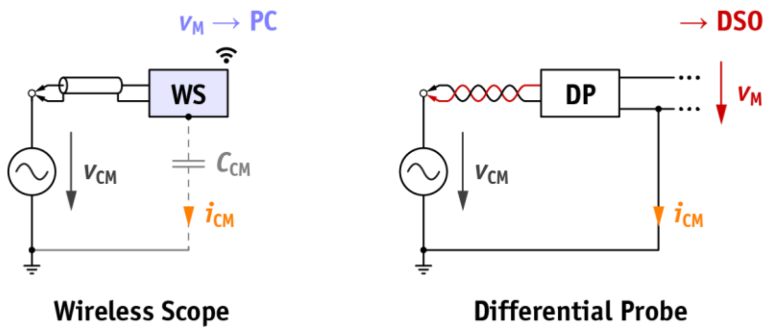


▶ Limitation by Sampling Rate

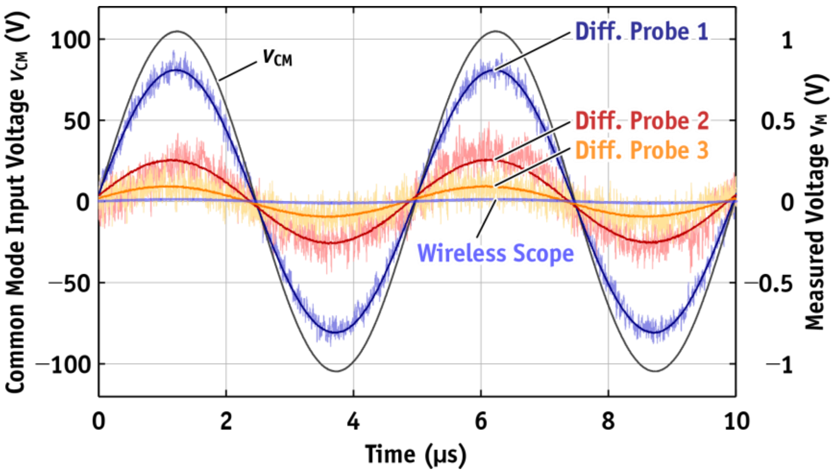
- 400 MS/s sampling rate
- Reconstruction of periodic signals with f_{max} = 200 MHz (Nyquist-Shannon)
- Rule of thumb: $f_{-3dB} \cdot t_{rise} \approx 0.35$
  Sampling rate limits bandwidth to $f_{-3dB,max} \approx 140$ MHz

Common Mode Rejection @ f = 200 kHz

▶ Measurement Setup



▶ Measurement: Differential vs. Wireless



Differential Probes (State of the Art)

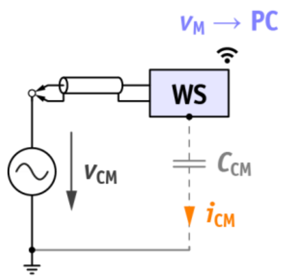
	CMRR
– Diff. Probe 1 (25 MHz)	≈ 42dB
– Diff. Probe 2 (100 MHz)	≈ 54dB
– Diff. Probe 3 (100 MHz)	≈ 61dB

Wireless Oscilloscope

	CMRR
– Direct Connection	≈ 100 dB
– 1:1 Passive Probe	≈ 100 dB
– 1:10 Passive Probe	≈ 80 dB

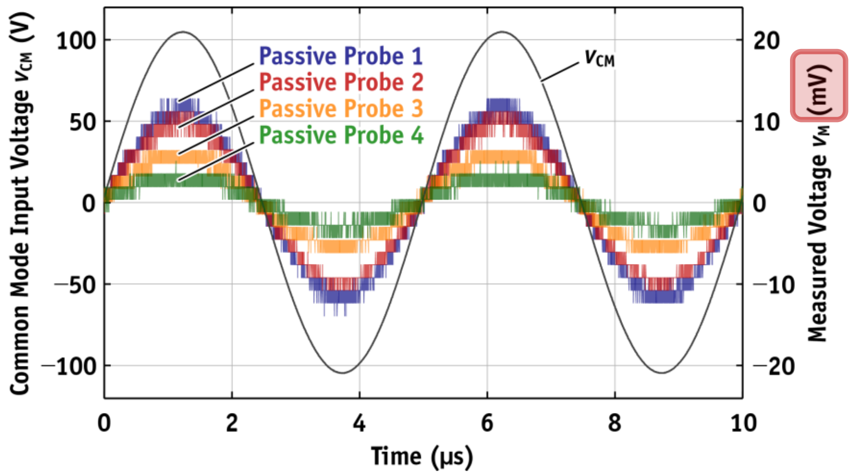
Common Mode Rejection @ f = 200 kHz

▶ Measurement Setup



Wireless Scope

▶ Wireless with Different Passive Probes

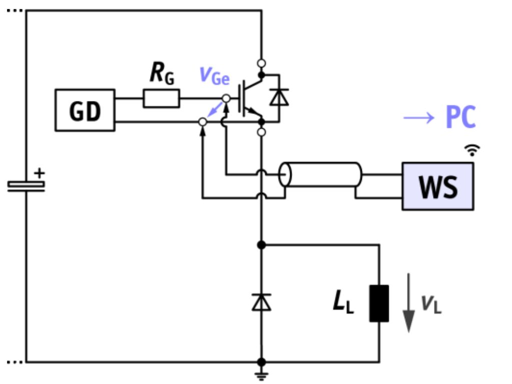


Wireless Oscilloscope:
Influence of Passive Probe (1:10)

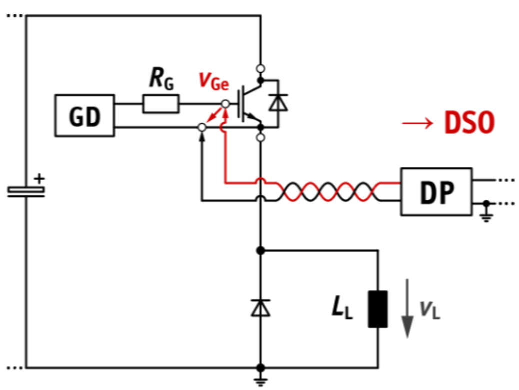
	CMRR
– Passive Probe 1	≈ 79 dB
– Passive Probe 2	≈ 80 dB
– Passive Probe 3	≈ 85 dB
– Passive Probe 4	≈ 90 dB

Isolated Voltage Measurement 1/2

▶ Measurement Setup



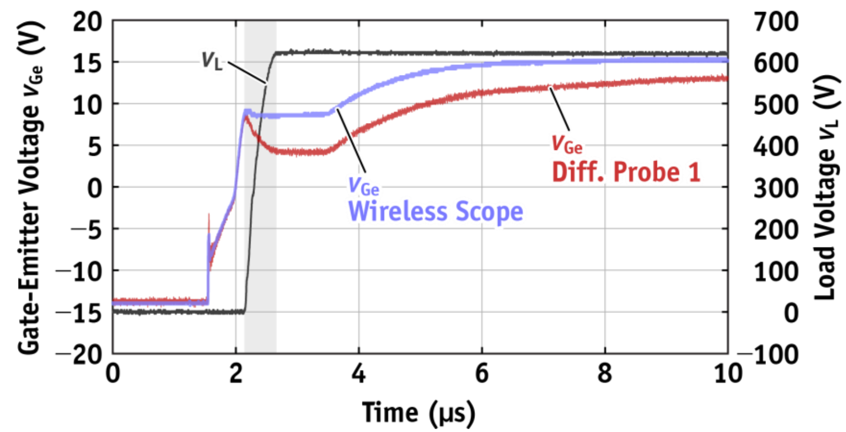
Wireless Scope



Differential Probe

▶ High-Side Gate-Emitter Voltage

– Small amplitude of ca. ± 15 V with respect to the floating load voltage v_L of ca. 0/600 V



Differential Probe 1

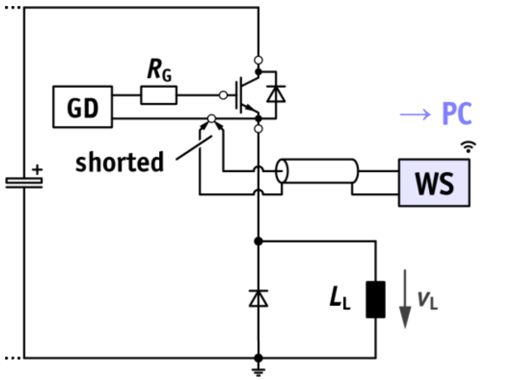
– Strong CM error of the measurement during the high dv/dt of the load voltage v_L

Wireless Scope

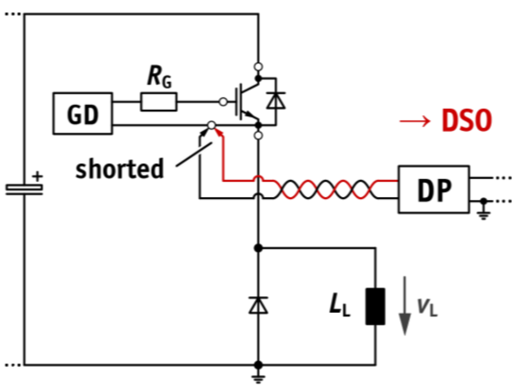
– No visible CM error of the measurement (Miller plateau is flat as expected)

Isolated Voltage Measurement 2/2

▶ Measurement Setup



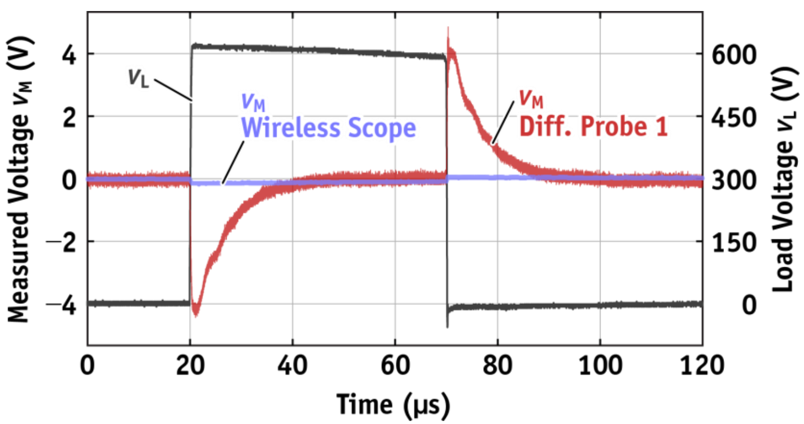
Wireless Scope



Differential Probe

▶ Shorted Probe Leads on Floating Load Voltage

- Differential input signal = 0 V!
- Floating load voltage v_L of ca. 0/600 V

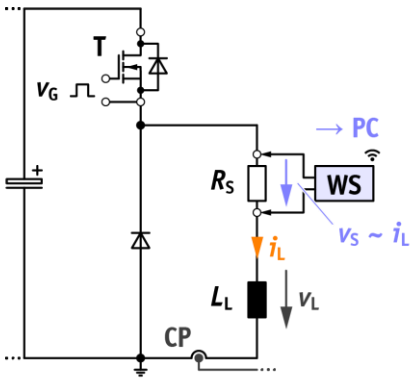


Differential Probe 1
- Strong CM error during d*v*/d*t* transients of ca. 4 V!
- Error decays only with a time constant of ca. 7 µs!

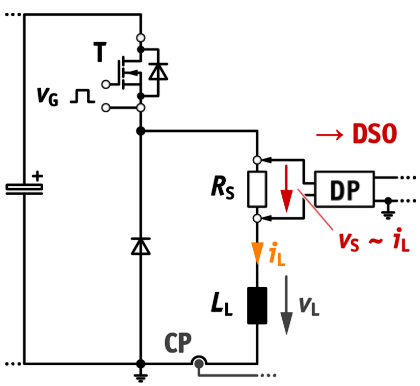
Wireless Scope
- Only very small CM error
- Low noise level

Isolated Current Measurement 1

▶ Measurement Setup

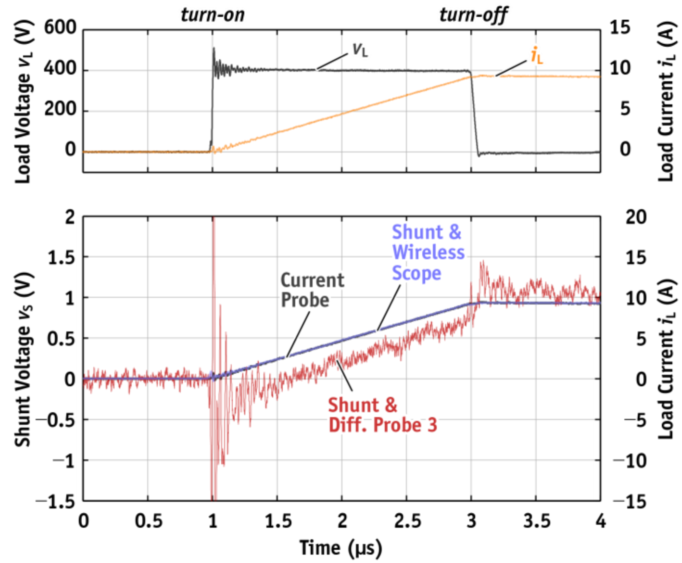


Shunt & Wireless Scope



Shunt & Differential Probe

▶ Load Current on Floating Voltage



0.1 Ohm Coaxial Shunt + Diff. Probe 3
- Strong CM error
- High noise level

0.1 Ohm Coaxial Shunt + Wireless Scope
- Identical to clamp-on current probe, no errors

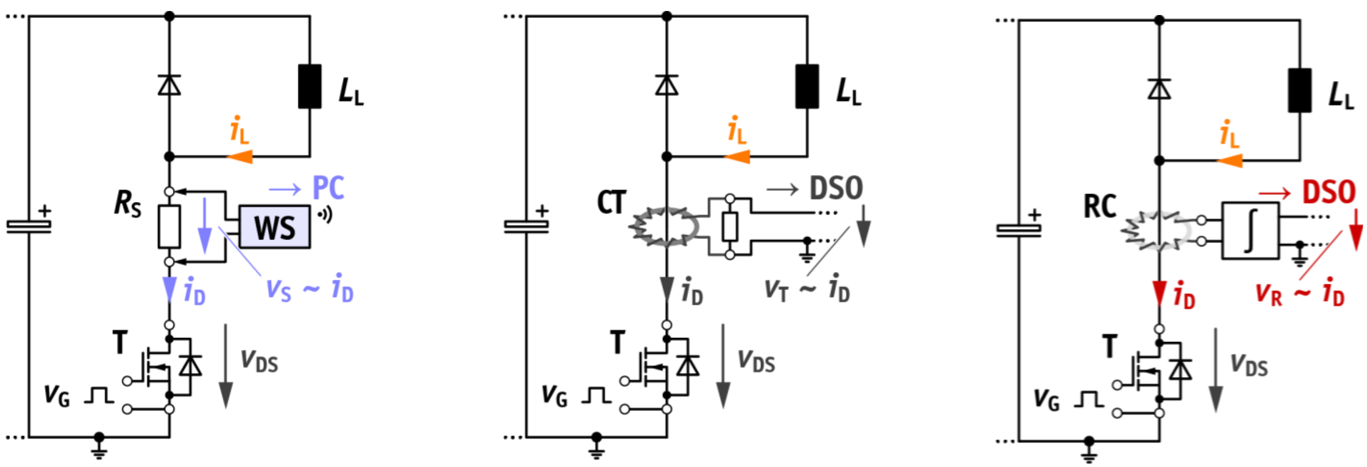
Isolated Current Measurement 2 – Overview

▶ MOSFET Drain Current

- Floating Reference Voltage
- High Bandwidth Current Transients (turn-on / turn-off)

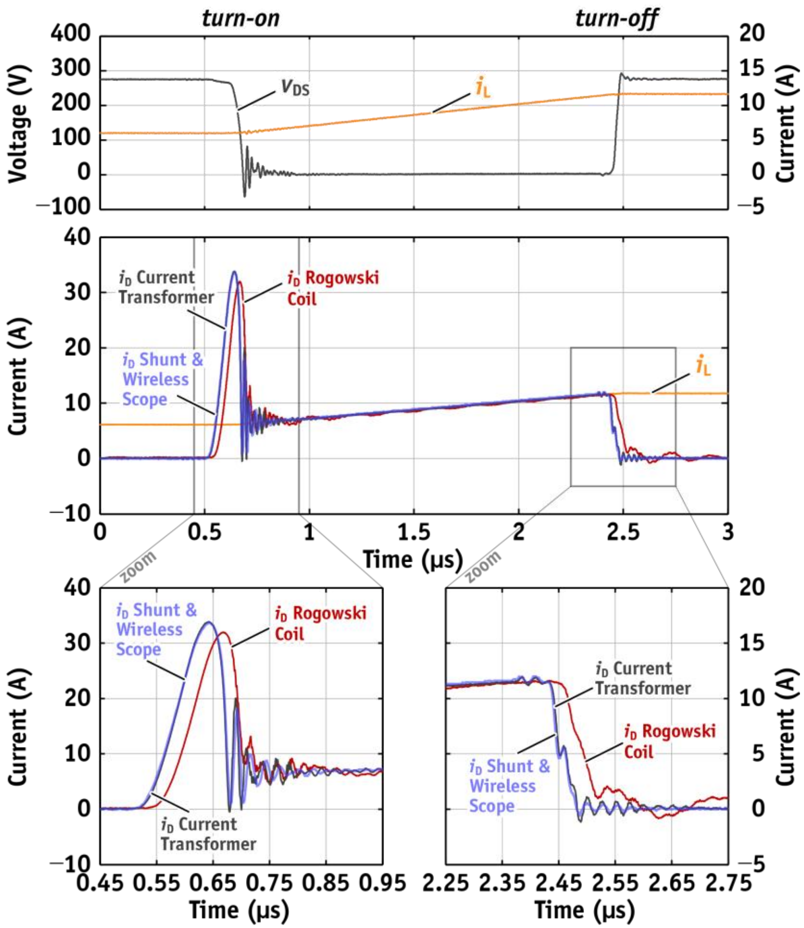
▶ Measurement Setup

- 0.1 Ohm Shunt & Wireless Scope
- Current Transformer
- Rogowski Coil



Shunt & Wireless Scope   Current Transformer   Rogowski Coil

Isolated Current Measurement 2 – Results



- **Rogowski Coil**
  - Delay
  - Limited bandwidth
  - Ringing due to CM transients
  - Limited isolation voltage
- **Current Transformer**
  - High bandwidth
  - No apparent CM error
  - High-pass characteristic (no DC)
  - Limited isolation voltage
- **Shunt & Wireless Scope**
  - High bandwidth
  - No apparent CM error
  - DC – 100 MHz
  - No intrinsic limitation on isolation voltage

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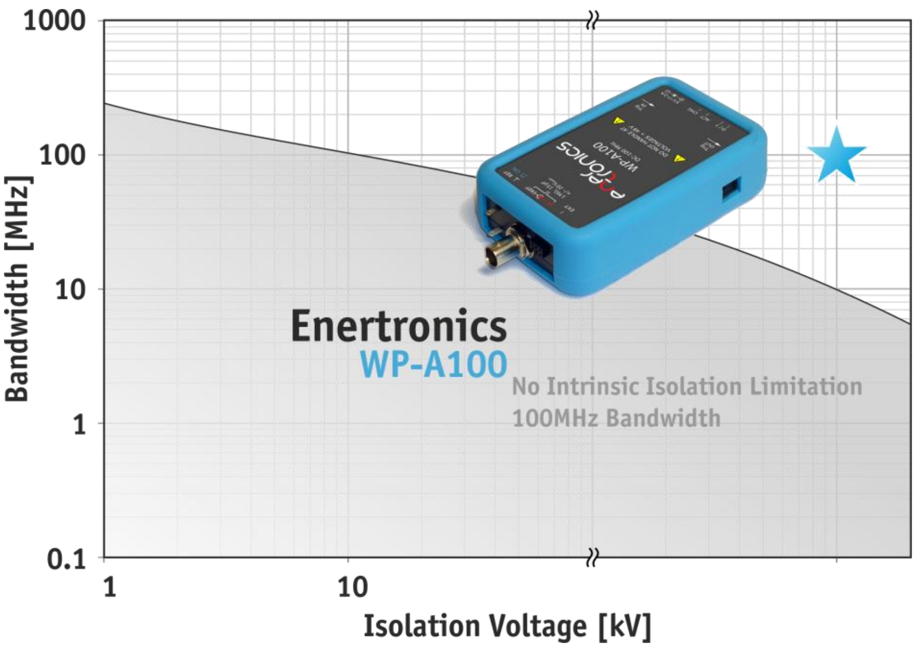
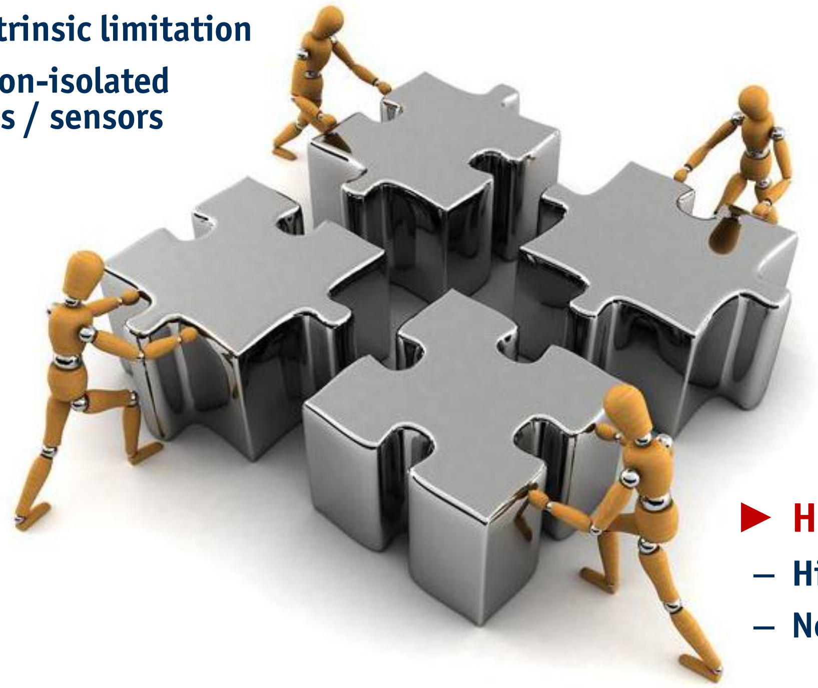
Wireless Oscilloscope – Isolated Measurement

- High Bandwidth (DC – 100 MHz)
- No Intrinsic Limitation on Isolation Voltage



Summary

- **Wireless Oscilloscope**



- **Isolation**
  – No intrinsic limitation
  – Use non-isolated probes / sensors
- **Analog Bandwidth**
  – DC – 100 MHz
  – Variable attenuation
  – Variable offset
- **Accuracy**
  – High CMRR
  – Low Noise
- **Handling**
  – Highly secure
  – No cabling needed

Summary

- **Wireless Oscilloscope**

- **Isolation**
  - No intrinsic limitation
  - Use non-isolated probes / sensors

- **Analog Bandwidth**
  - DC – 100 MHz
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References

[1] **Y. Lobsiger, G. Ortiz, D. Bortis, and J. W. Kolar,** "Concept and Experimental Evaluation of a Novel DC – 100 MHz Wireless Oscilloscope," to be published in *Proc. of the 7th Int. Power Electronics Conf. (IPEC / ECCE-Asia)*, Hiroshima, Japan, May 2014.

[2] **Y. Lobsiger, D. Bortis and J. W. Kolar,** "Case Study: Wireless Voltage Probe for Accurate Voltage Measurement on High and Transient Reference Voltages," in *Proc. of the ECPE Workshop "Electronics around the Power Switch: Gate Drivers, Sensors and Control", Ismaning-Munich, Germany, June 29-30, 2011*.

[3] **Y. Lobsiger, D. Bortis and J. W. Kolar,** "100 MS/s 10-25 MHz Wireless Voltage Probe," in *Proc. of the Power Conversion Intelligent Motion Conf. (PCIM Europe)*, Nuremberg, Germany, May 2011.

Questions ?