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ECPE Workshop Munich
Electronics around the power switch:
Gate drives, sensors and control
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Power Electronic Systems Laboratory

Case Study: Wireless Voltage Probe for Accurate Voltage Measurement on High and Transient Reference Voltages

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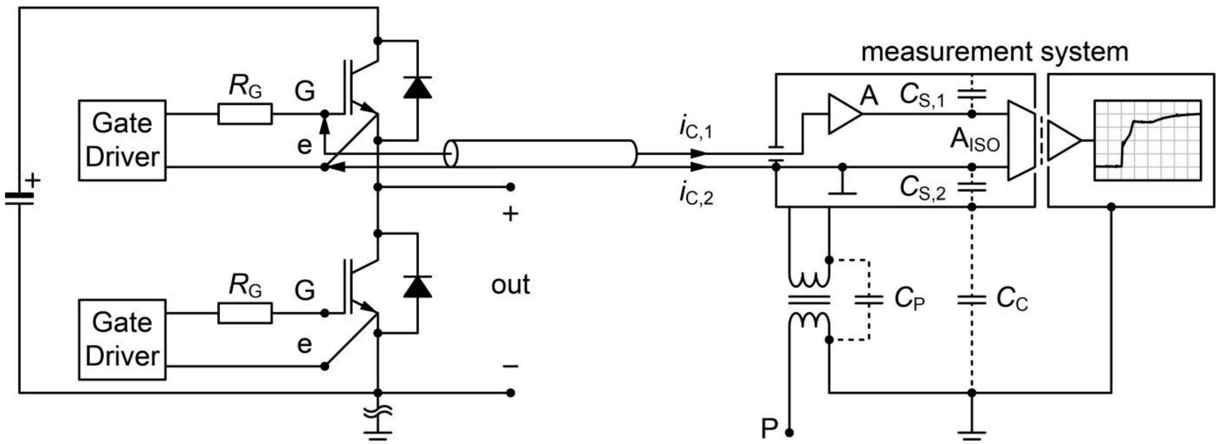
Motivation

Demand for cascaded high power medium voltage converters

- Modular multilevel converters, cascaded H-bridges, series connections of IGBTs

Gate driver requirements

- High voltage isolation: up to few tens of kV
- Immunity to CM voltage transients: up to several tens ok kV/µs



Voltage measurement claims

- Minimally invasive (high impedance and low capacitive coupling)
- High resolution in amplitude and time

Verification measurements

- Gate voltages and currents, logic signals:
  low amplitude (typ. 20 V) on high and transient reference voltage (typ. 10 kV)

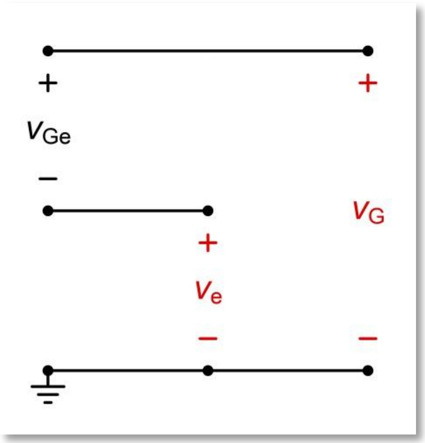
Actual measurement methods

Differential voltage probe / amplifier

- Limited isolation capability of typically few kV due to the isolation amplifier

3-Point (x-y) voltage measurement

- $v_{Ge} = v_G - v_e$
- Low amplitude resolution
- Low CMRR



Floating battery powered oscilloscope

- Large size / limited space in a converter
- Large coupling capacitance to ground
- Relevant to security

How to achieve the needed claims

High accuracy in amplitude

- Floating measurement system attached to the device under test

High CM immunity

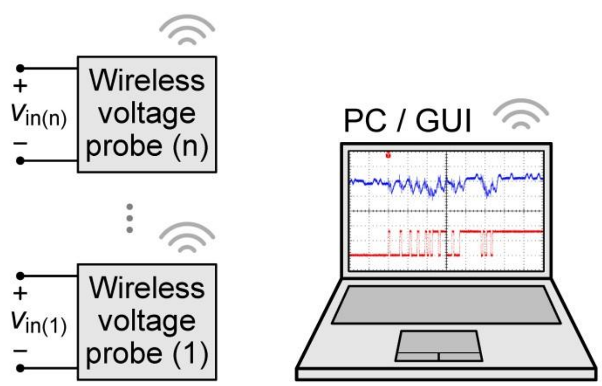
- Shielding of the system to affect the CM current path

Lowest coupling capacitance

- Battery powered
- Optical or wireless signal transfer
- Small dimensions

High bandwidth / sampling rate

- Fast optical fiber link (1 Gbit/s)
- Memory buffer (measurement only during short time interval)



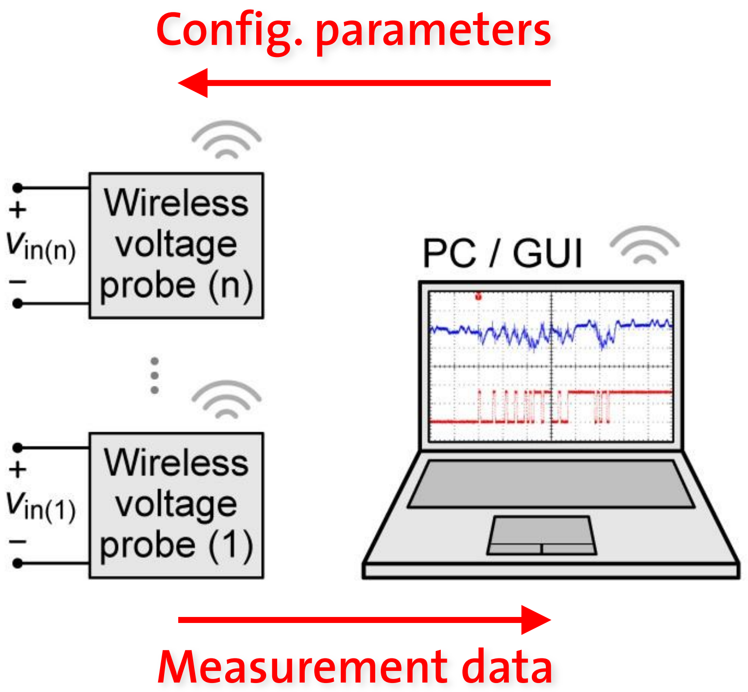
PC / Laptop

- Display
- Computing power
- Signal processing
- Wireless communication

>> Wireless voltage probe

Wireless voltage probe | system overview

Measurement system with WVPs



No conventional oscilloscope needed!

Graphical user interface on the PC to set the individual configuration parameters

- Input voltage attenuation
- AC / DC coupling of the input
- Sampling rate
- Trigger level and slope
- Pre-trigger value
- Trigger activation

>> parameters transmitted to WVPs

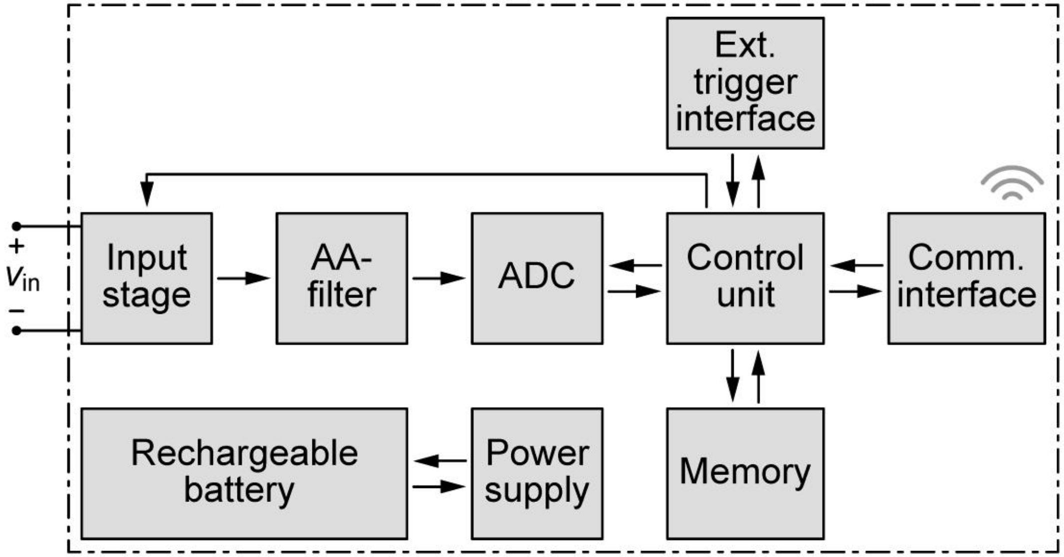
Visualization of the measured voltages in a signal graph

- Signal processing
- Calculations

>> data received from the WVPs

Wireless voltage probe | operating principle

Integral functional units of the WVP

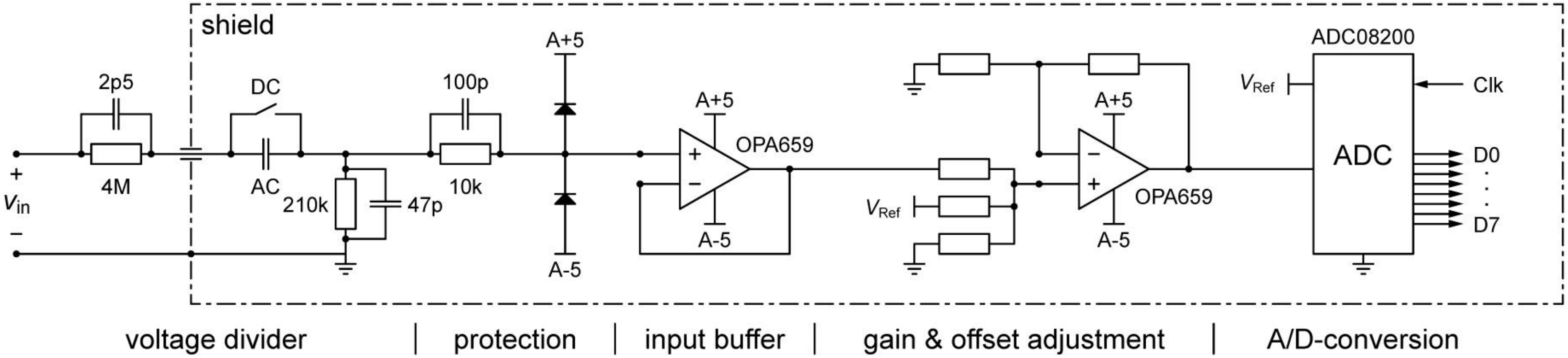


- Wireless communication channel to the PC is established
- Config. parameters are received from the PC
- Control unit configures the input stage

- After the activation signal received from the PC, the control unit activates the ADC and stores the data to the memory (only the amount of pre-trigger values)
- On a trigger event (int. or ext.), the memory is filled up. The data stored in the memory are then transferred wireless to the PC.

Wireless voltage probe | analog input stage

Schematic of the WVP's analog input stage



- Passive voltage divider (single-ended) with AC / DC coupling
- Shielded case (comm. antenna outside shield)
- Overvoltage protection

- Op-amp with JFET-input stage to provide decoupling from the voltage divider
  - Low bias current (10 pA)
  - Low offset voltage (1 mV)

- Adjustment of input voltage to the range of the A/D-converter
- Parallel bus to the FPGA for fastest data transfer rate

Wireless voltage probe | performance constraints

Analog bandwidth: > 1 GHz

- Limited by the operational amplifier used for the input buffer

Sampling rate: few 100 MS/s

- ADCs are available of to several 100 MS/s
- Digital control units (FPGAs) can operate up to few 100 MHz, limited by the software
- FPGA internal memory or external FIFO memory units (no addressing needed)

Memory size / depth

- Cost and addressing of the memory are typically the limiting factors

Data transfer rate: up to few Mbit/s

- For systems with low power consumption < 100 mW (like Bluetooth, ZigBee)

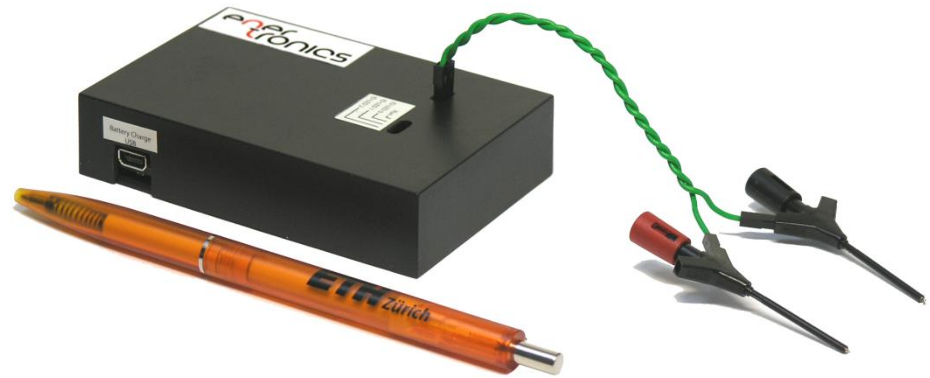
Runtime: up to 4 hours

- For a power consumption of 1 W and small battery dimensions: 5 x 4 x 0.5 cm

Prototype of the WVP

PCB of the WVP prototype

Outside view of the WVP prototype



Performance

▪ Sampling rate	100 MS/s
▪ Analog bandwidth	
▪ sin(x)/x interp.	≈ 25 MHz
▪ Linear interp.	≈ 10 MHz
▪ Resolution	8 Bit
▪ Memory depth	8’192 S
▪ Runtime:	4 h (4.6 Wh)

Specifications

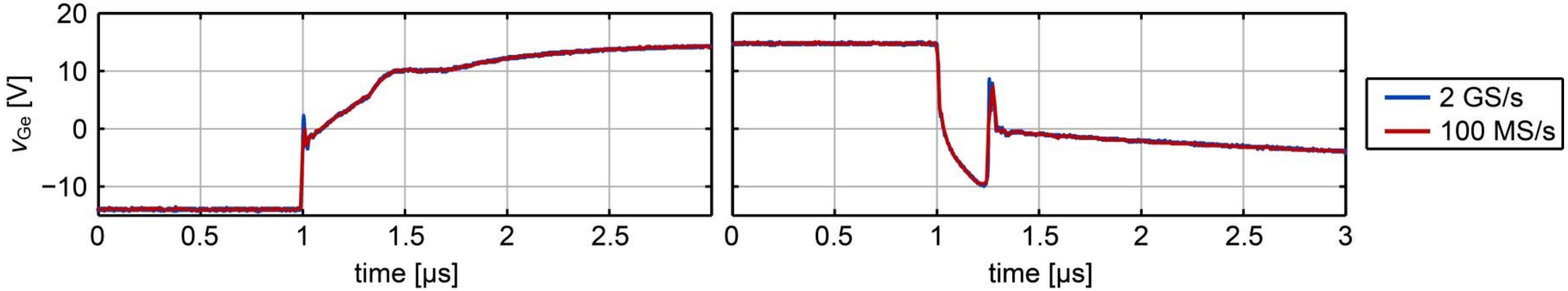
▪ Input voltage	+/- 20 V (1:1 Probe) +/- 200 V (10:1 Probe)
▪ Communication:	Bluetooth, 115 kbit/s

Physical sizes

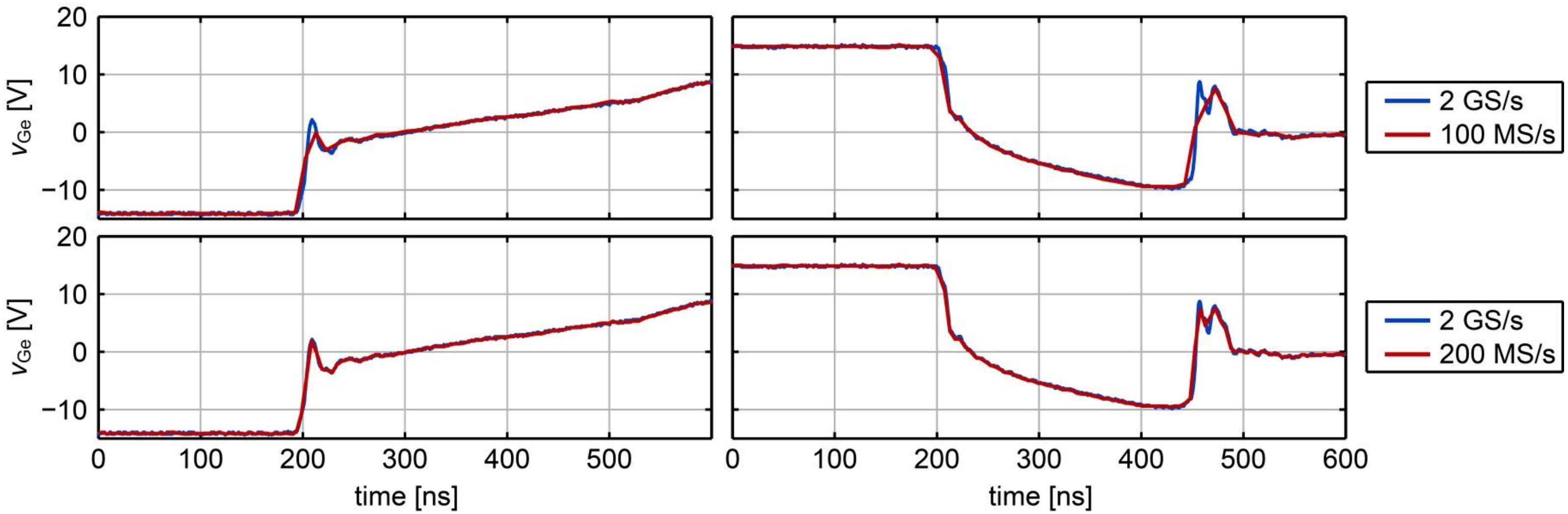
▪ Ext. Dimensions:	90 x 60 x 20 mm
▪ Weight:	95 g

Impact of the sampling rate in practice

Typ. application: measurement of an high power IGBT's gate-emitter voltage

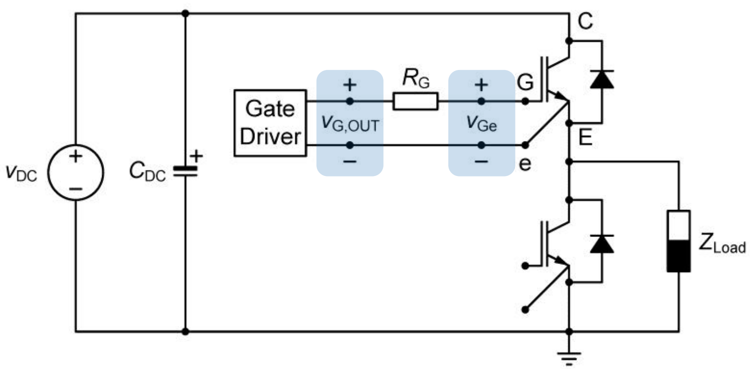


Zoom view: the sampling rate of 100 MS/s affects the measured signal observably; at 200 MS/s, the impact of the sampling rate gets negligible



Experimental verification | measurements 1

Measurement situation



Measurements on the high-side IGBT:

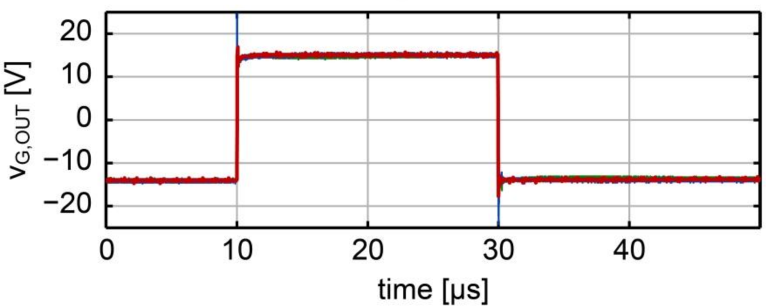
- Output of the voltage source gate driver: $v_{G,OUT}$
- Gate-emitter voltage of the IGBT at the gate driving terminals: v_{Ge}

3 different voltage probes:

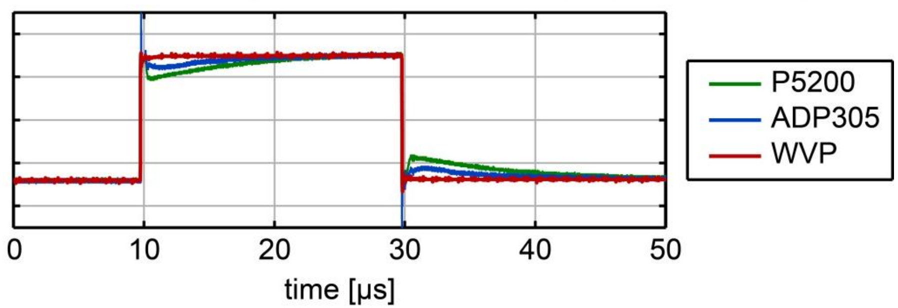
- Tektronix diff. probe P5200, 25 MHz
- LeCroy diff. probe ADP305, 100 MHz
- Prototype of the WVP, 10 MHz

Gate driver output voltage $v_{G,OUT}$

without CM voltage



with CM voltage (600 V; on: 4 kV/µs | off: -1.7 kV/µs)

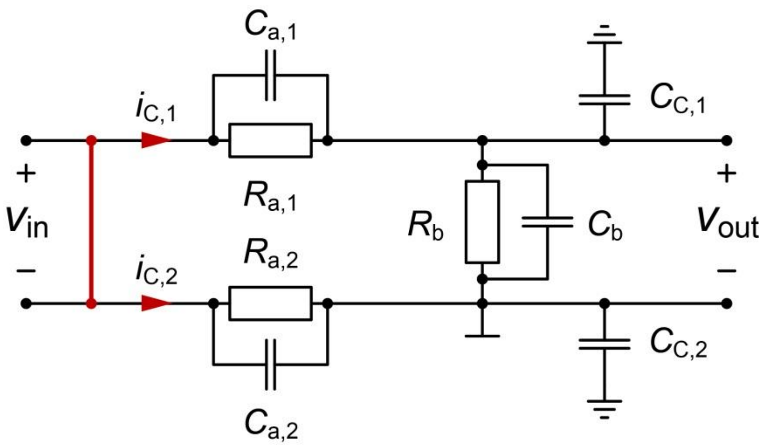


No CM disturbance for all probes

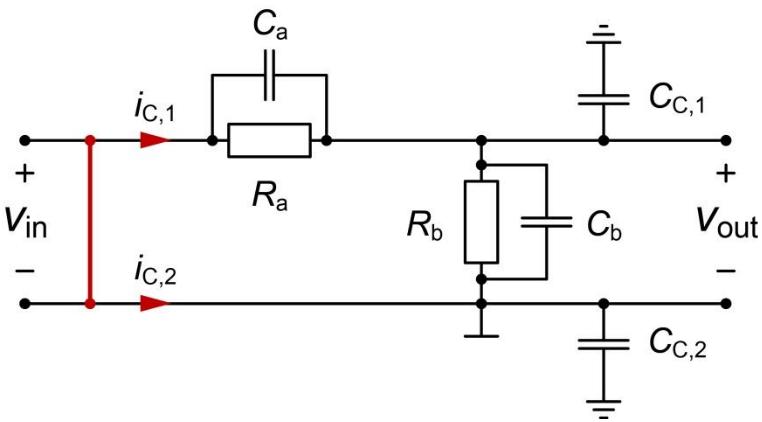
No CM disturbance only for the WVP

Common mode equivalent circuit

Symmetrical input voltage divider



Asymmetrical input voltage divider



Non-symmetrical $C_{C,1}$ and $C_{C,2}$ cause a common mode current in C_b

- Charche / discharge of $C_{a,1}$ $C_{a,2}$ and C_b
- CM disturbance results in v_{out}

$C_{C,1}$ causes CM current in C_b and C_a

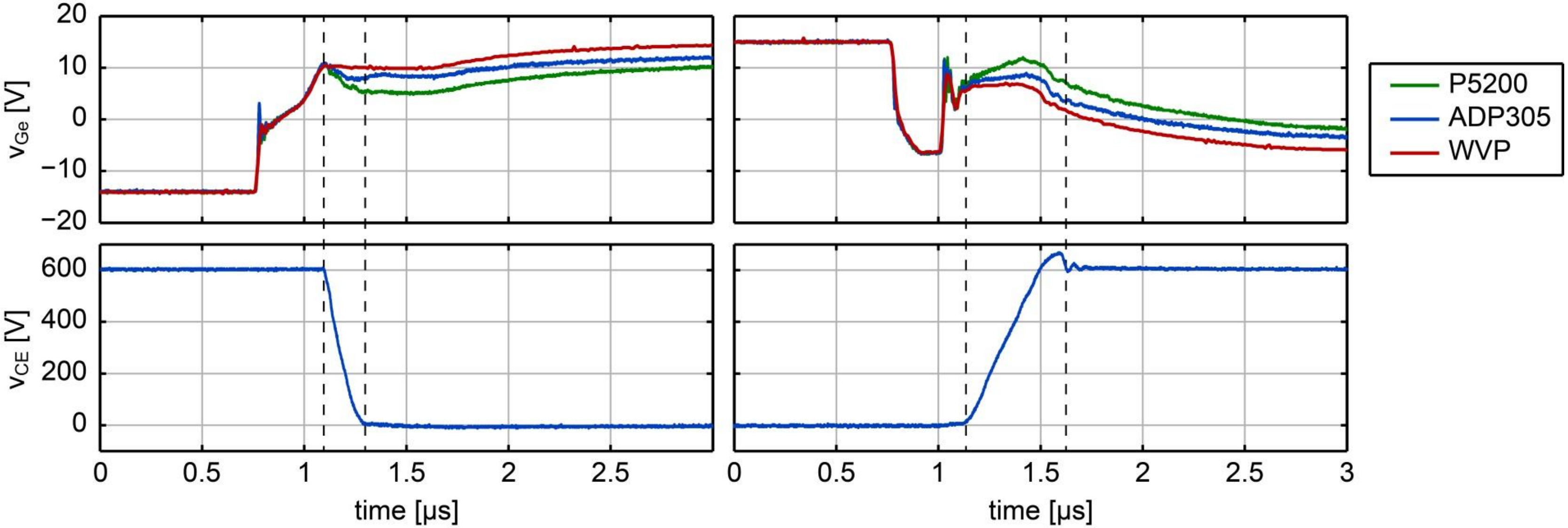
- Inverse charge / discharge of C_a, C_b
- CM disturbance results in v_{out}

CM disturbance discharge time constant is rather high: $\tau = R_i \cdot C_i \approx$ 10us (typ.)

Gate-emitter voltage v_{Ge} and collector-emitter voltage v_{CE} of high-side IGBT

Turn-on. CM voltage: 600V; 4 kV/µs

Turn-off. CM voltage: 600 V; -1.7 kV/µs



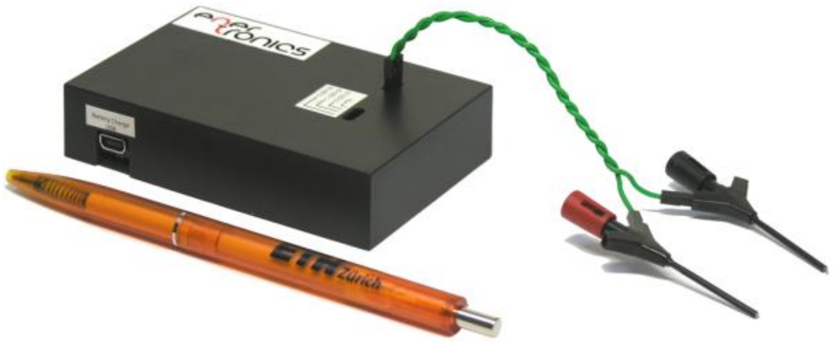
Results

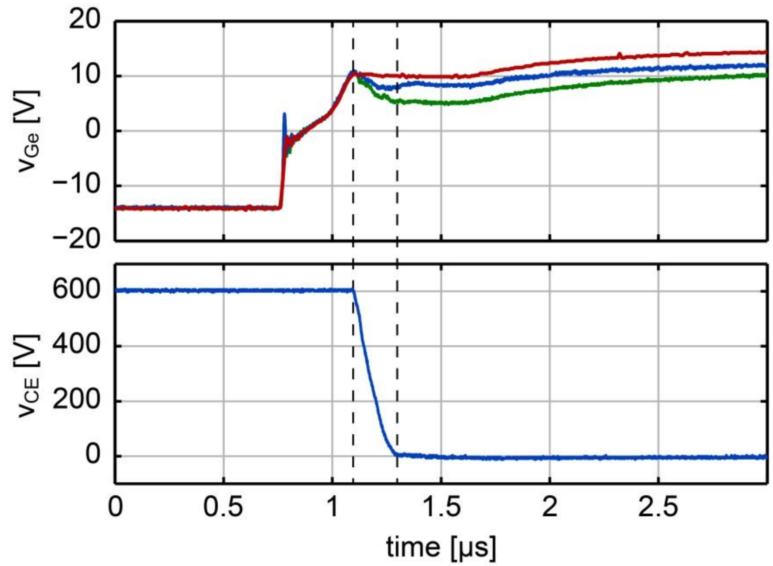
- Measurements of WVP don't get disturbed by CM and the Miller plateau of the gate-emitter voltage is flat in accordance to the actual system behavior.
- CM disturbance not dependent on CM voltage derivative

Conclusion

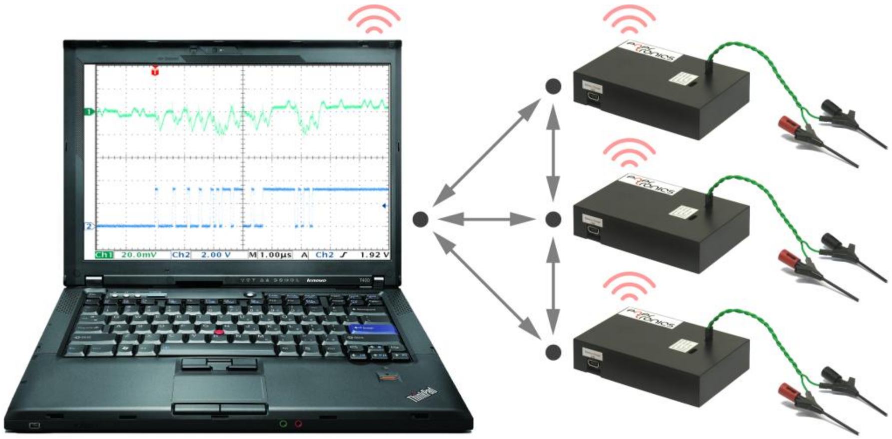
Prototype of a WVP

- Accurate voltage measurements on arbitrary reference voltages possible (100 MS/s, 10-25 MHz)
- Lower sensitivity to transient CM voltage noise compared to differential voltage probes
- Minimal impact to circuit under test due to low coupling capacitance
- Small ext. dimensions allowing to measure in narrow / compact converters
- No cabling needed, simple handling
- No commercial oscilloscope needed





Outlook



Higher sampling rate

- 200 MS/s

Smaller ext. dimensions

Lower energy consumption

- Low power idle mode
- Communication via IEEE 802.15.4 standard

Implementation of a wireless trigger

- Synchronized voltage measurements

Literature

Y. Lobsiger, D. Bortis, H. Ertl and J. W. Kolar, "100 MS/s 10-25 MHz wireless voltage probe," Proc. of the Conf. for Power Electronics, Intelligent Motion, Power Quality (PCIM Europe), pp. 627—633, 2011.