High Speed Current Measurement for Ultra Low Inductance Power Modules

The insight into the switching cell.

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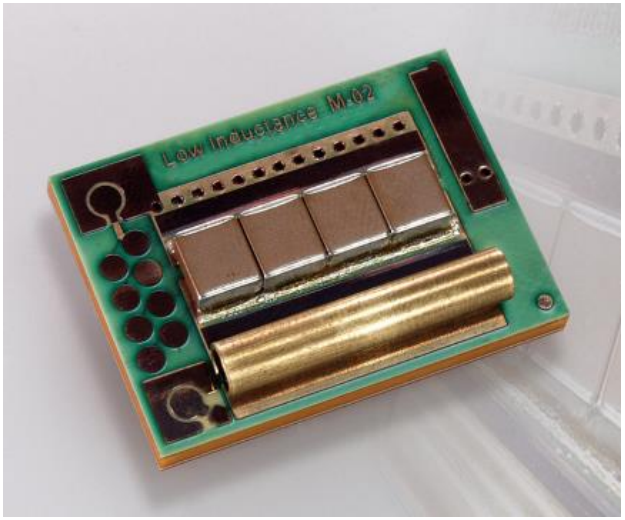
Ultra Low Inductance Power Module

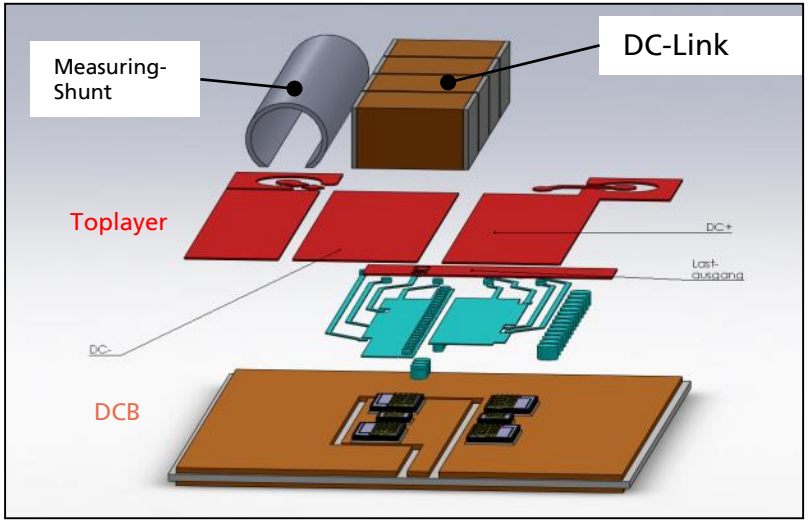
E. Hoene - Award Winner 2013
Ultra-Low-Inductance Power-Module

- PCB Embedded SiC Power module
- Switching cell inductance below **1 nH**

additional inductance: 300pH





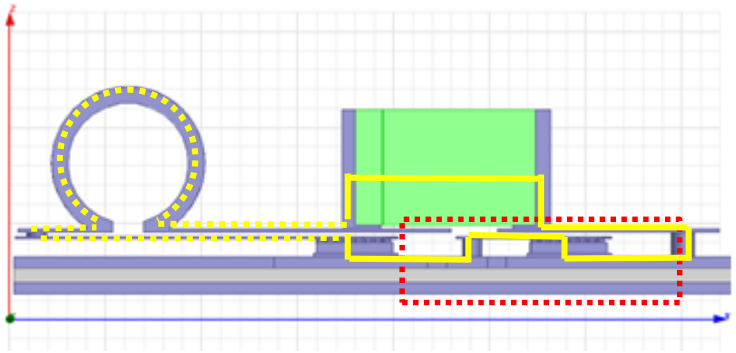


Ultra Low inductance SiC package

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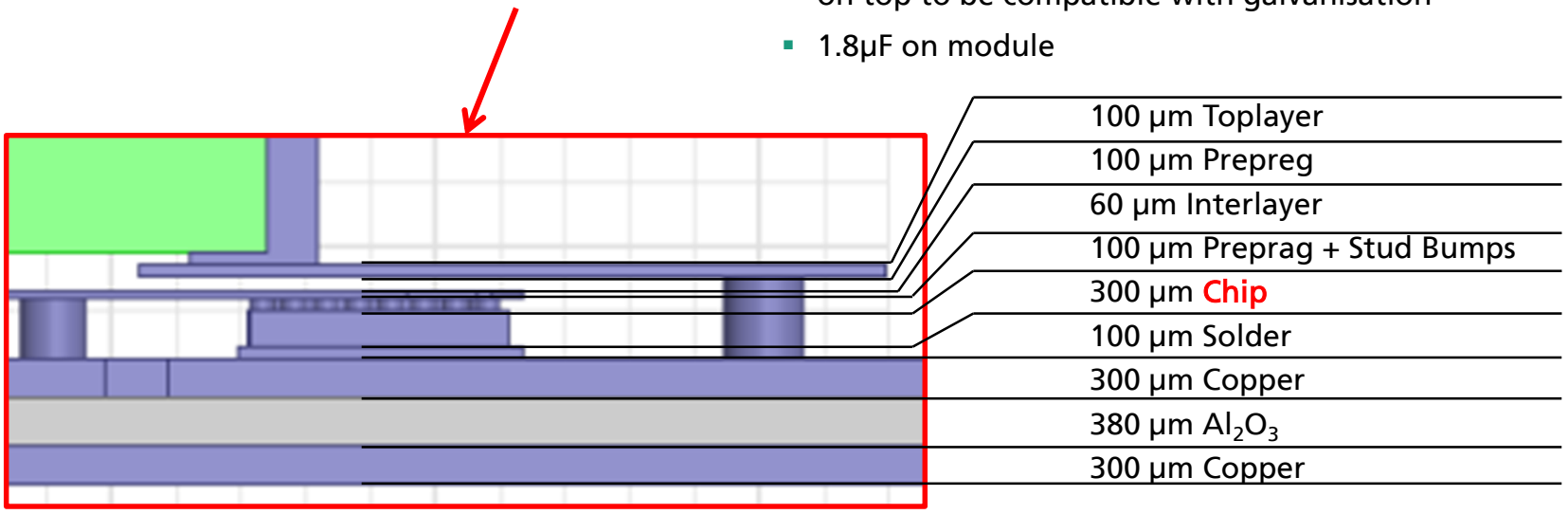
Embedded module



DC link current path

added DC- current path

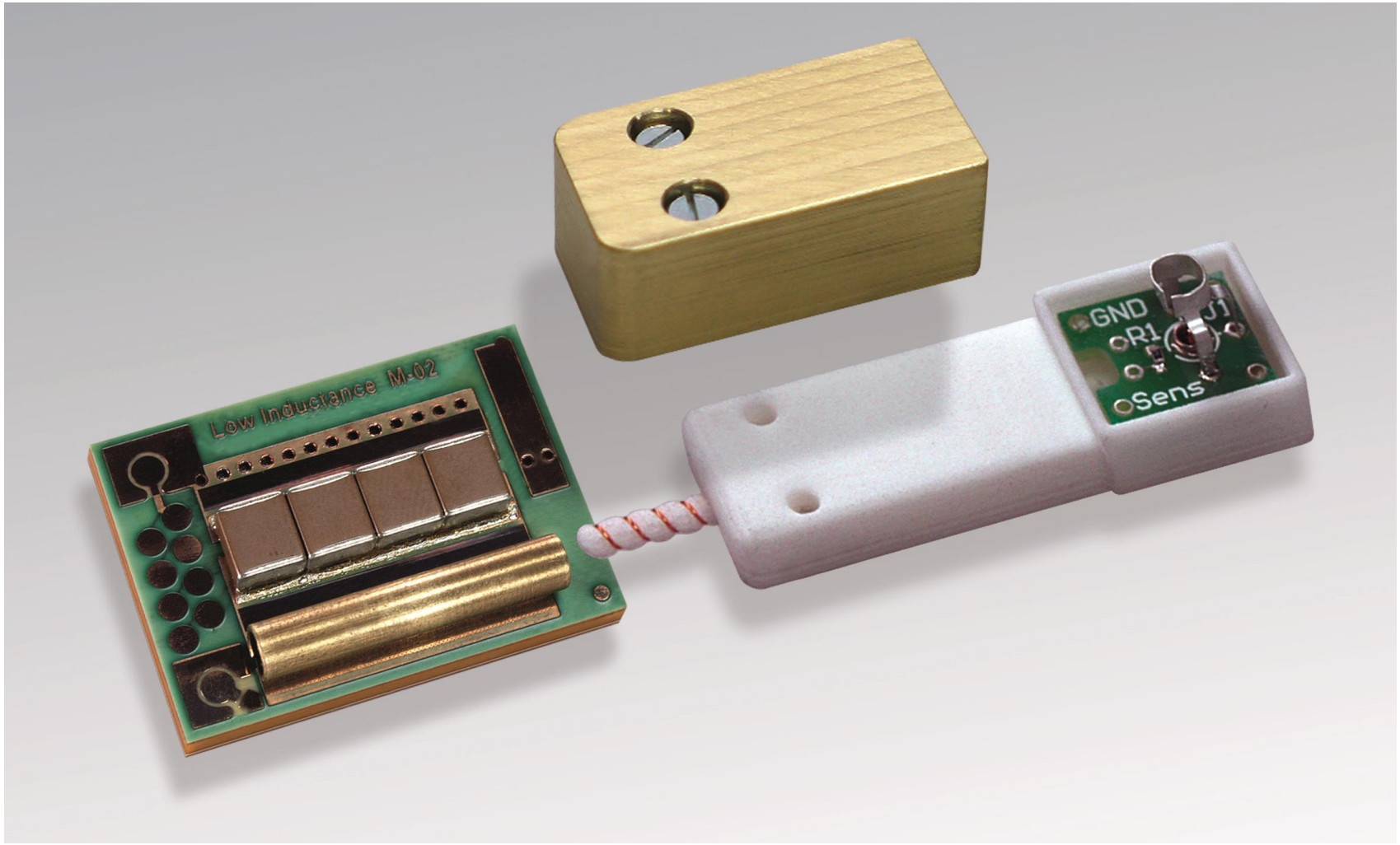
- 3 active layers (DBC, Interlayer 60µm, Toplayer 100µm)
- Semiconductors sintered on bottom and stud bumps on top to be compatible with galvanisation
- 1.8µF on module



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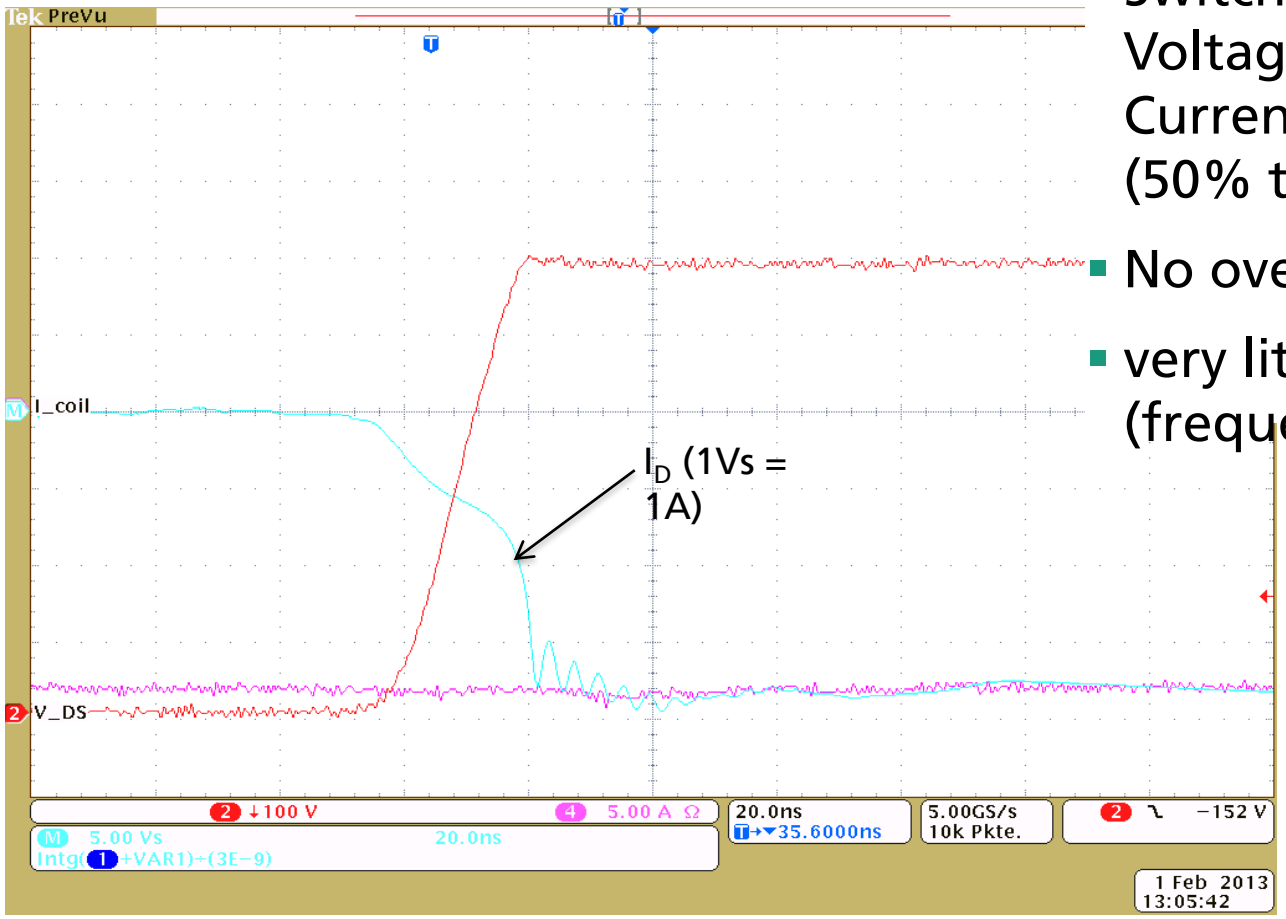
First sensor version



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The Results

Embedded module

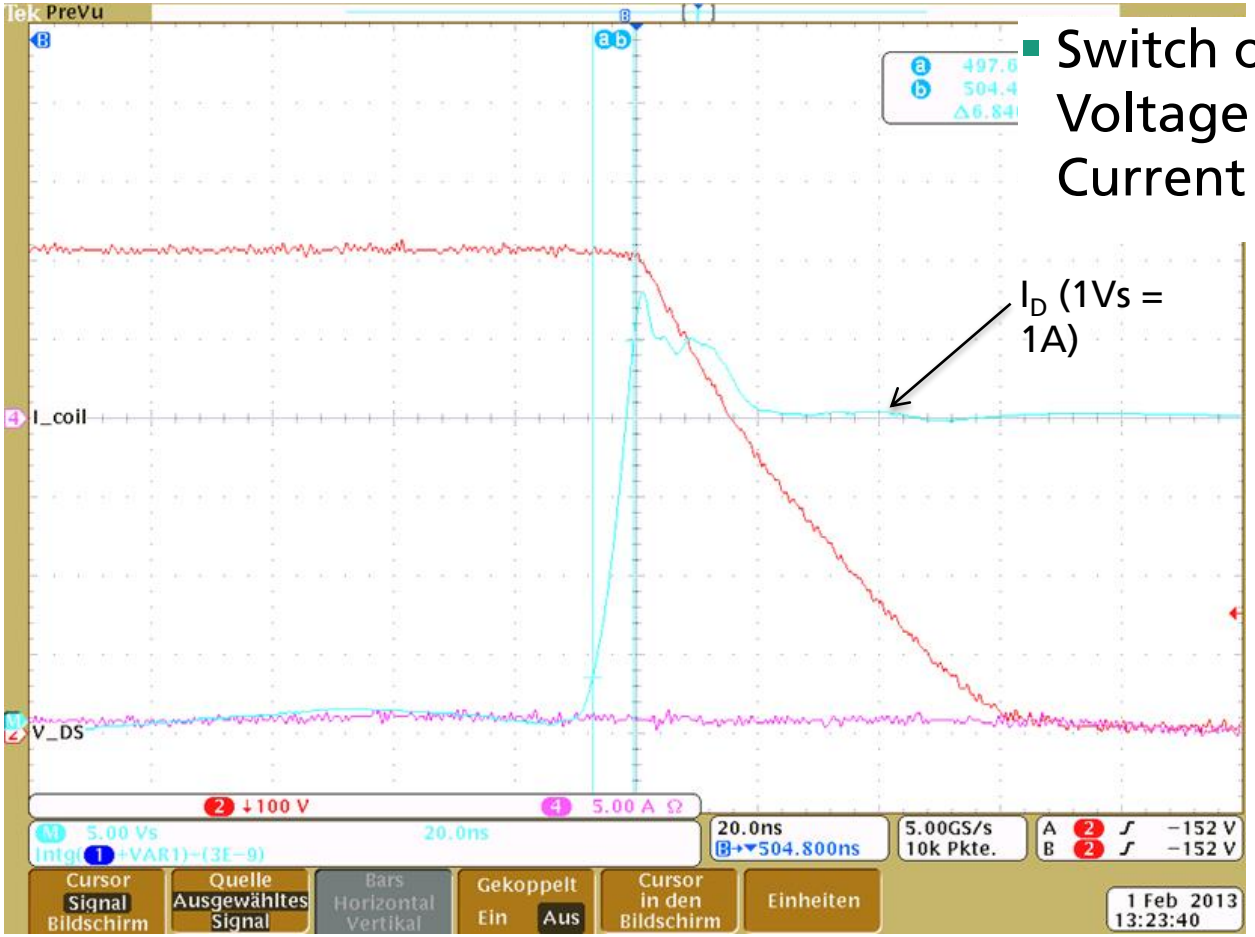


- Switch off at 20A:
  Voltage slope 22V/ns
  Current slope max. 4A/ns
  (50% to 90%)
- No overshot
- very little ringing
  (frequency 240 MHz)

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The Results

Embedded module

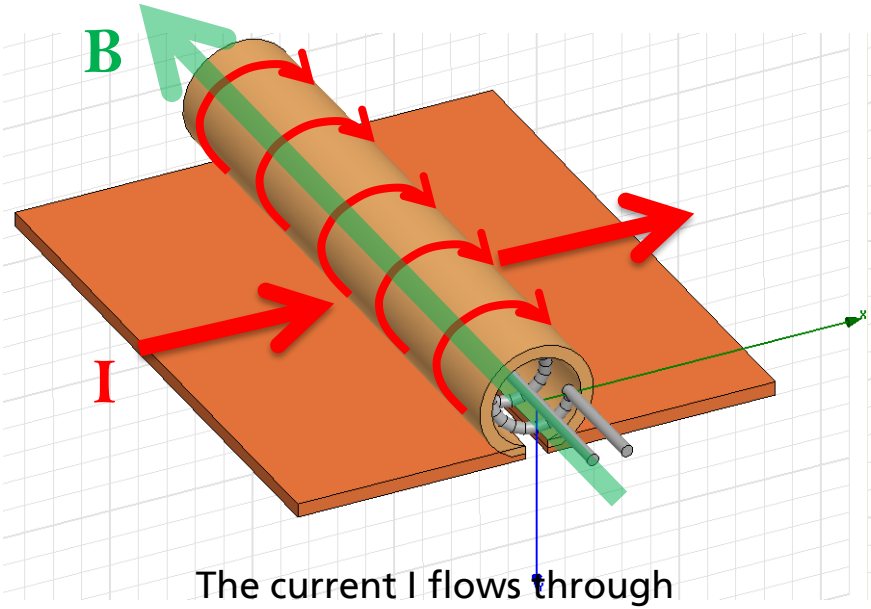


- Switch on at 20A:
  Voltage slope 10V/ns
  Current slope 3.13A/ns

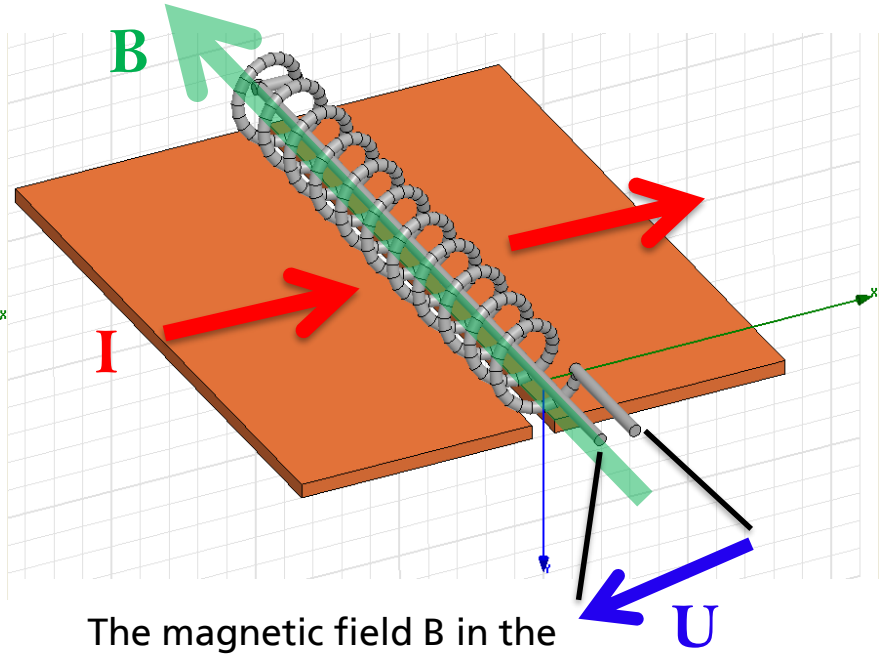
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Principle

- Cutting the low inductive current path (probably a bus bar) and mounting a gapped tube over the slit. This structure originates a magnetic field of 300pH
- A coil surrounding the field will pick up a voltage proportional to the derivative of the current



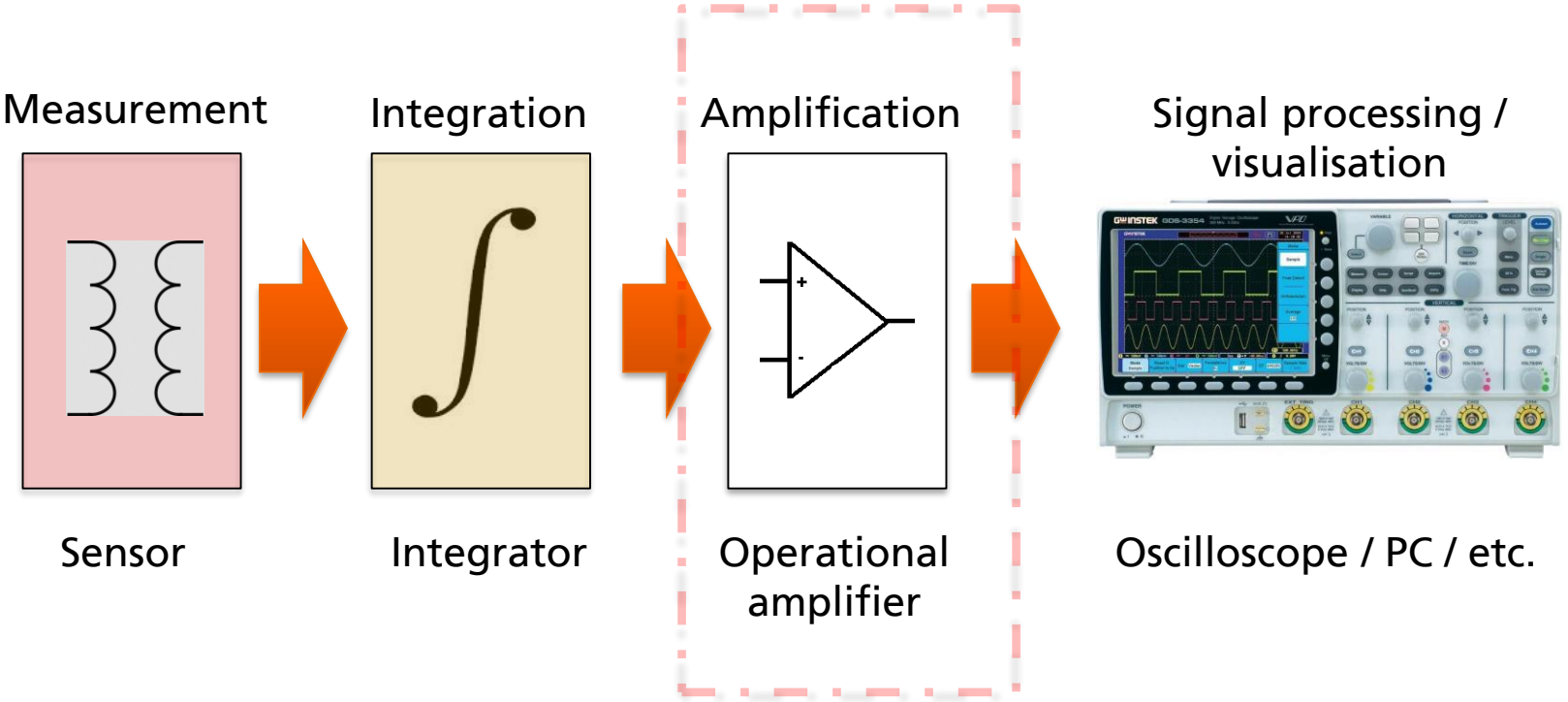
The current I flows through the gapped tube and causes the magnetic field B



The magnetic field B in the coil causes a voltage U

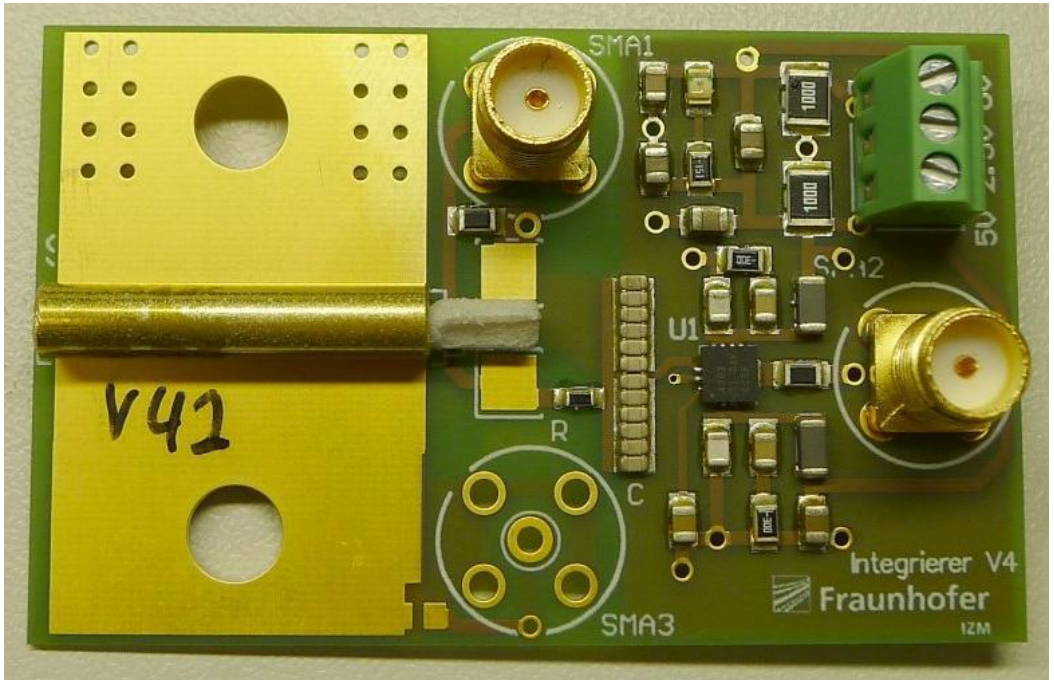
Better usability by directly integrating the signal

First devices with integration by the oscilloscope were not user friendly enough, therefore an analog integrator was developed



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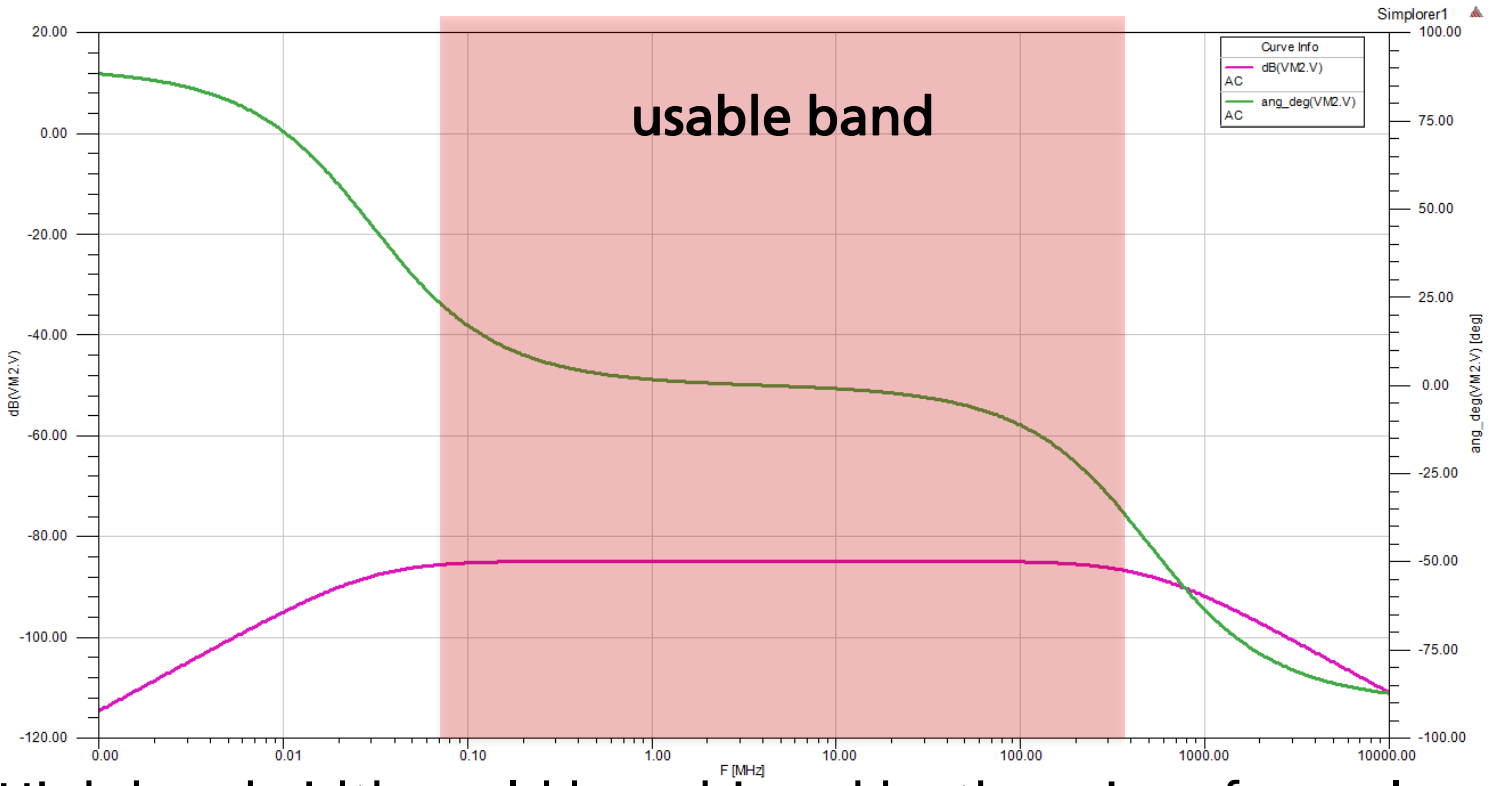
First integrator design



- Main issue are the parasitic effects, that have to be controlled to achieve a bandwidth of 500MHz: ESL of capacitors, parasitic L and C of resistors, capacitive coupling from tube to coil
- Tuning is extremely sensitive

What performance could be achieved?

High-pass and Low-pass in series



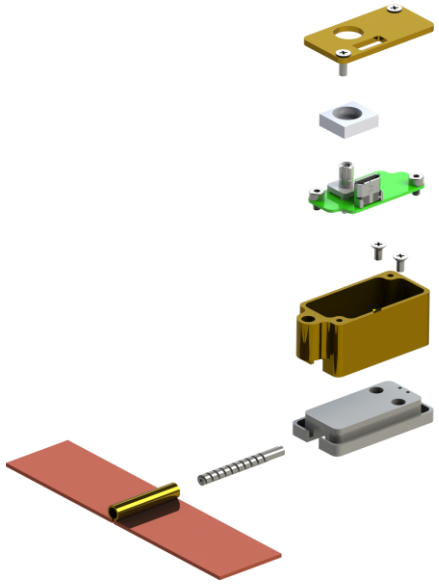
- High bandwidth could be achieved by the price of poor low frequency behavior. Therefore the sensor is only good for measuring switching events (but this better than anything else)

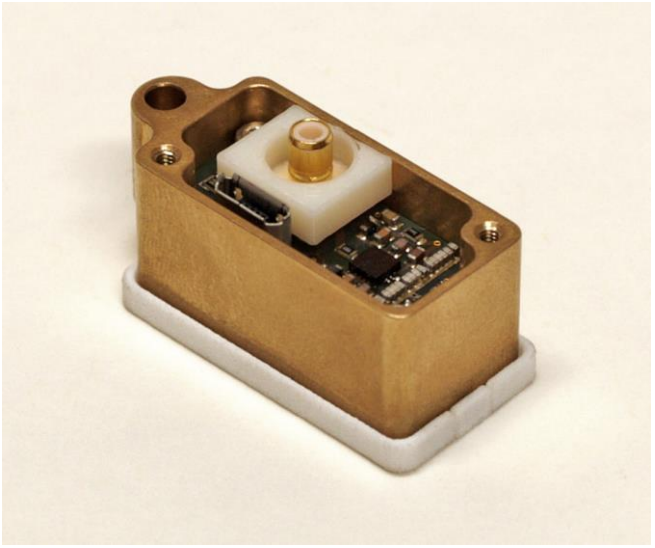
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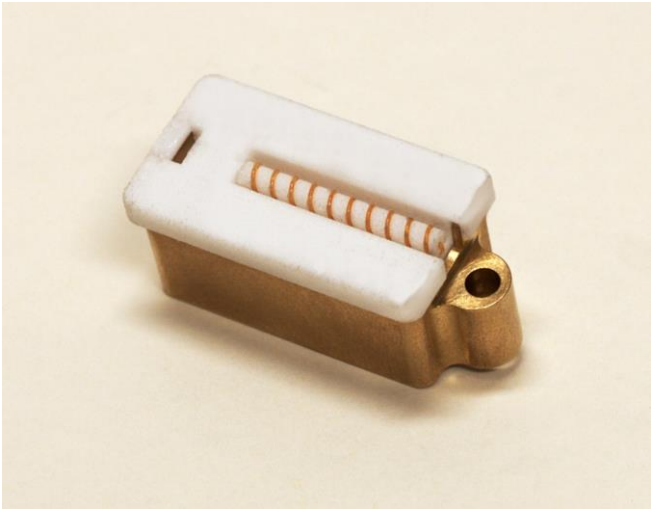
Second sensor version

Two main types were developed

- 480kHz…500Mhz : 80A
- 160kHz…300MHz: 200A
- Isolated up to 3kV







Further developments forced by demands from customers

SiC

- more current (200…1000A)
- Bandwidth of 300MHz is enough

IZM Sensor V3

GaN

- smaller
- less current (max. 80A)
- Bandwidth of >500MHz

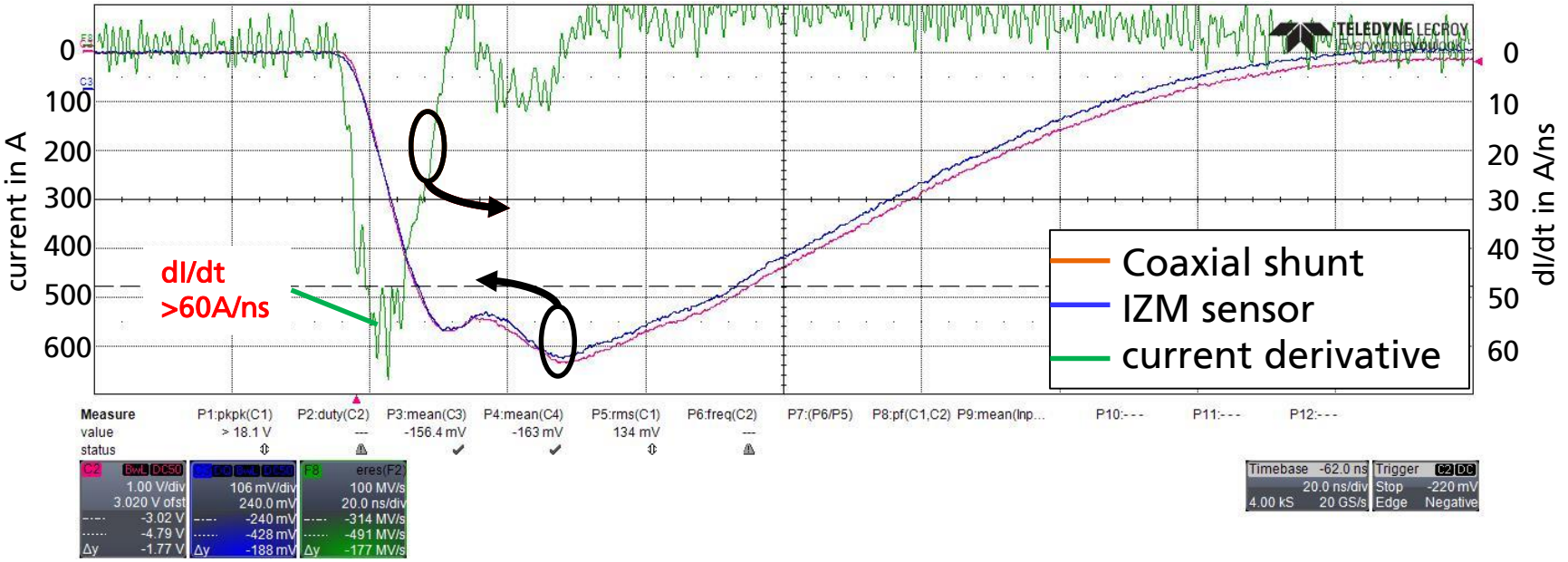
IZM Sensor V4 ?

⇒ double f_{low}: 70kHz…300MHz
⇒ I_{peak} ~ 750A
⇒ Improved CM and EMI behavior



Comparison of Sensor with coaxial shunt

Comparison to 400MHz T&M Coaxial ohmic current sensor (min. 2.4nH)



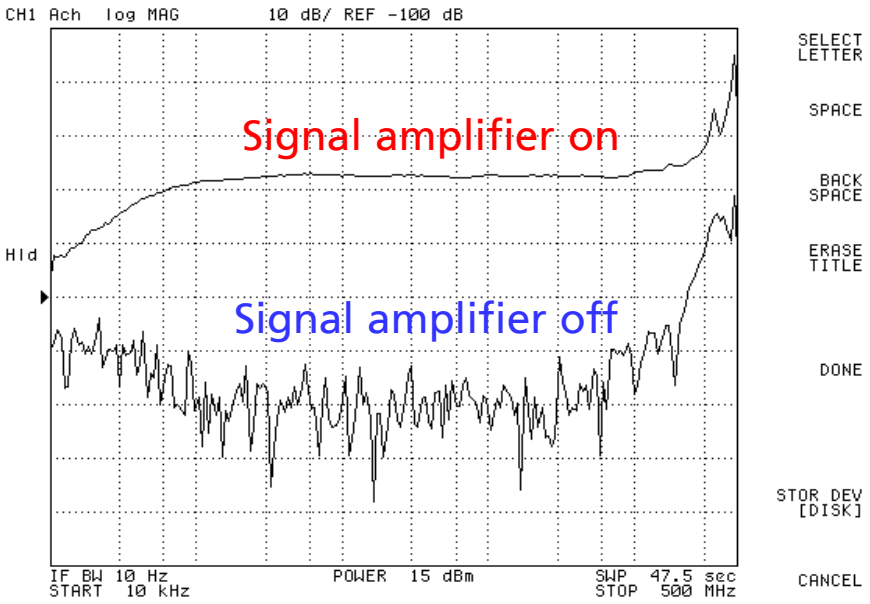
- The burst generator test shows perfect matching with the only measurement device of the same bandwidth and the capability to measure at least 60A/ns

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Common mode rejection

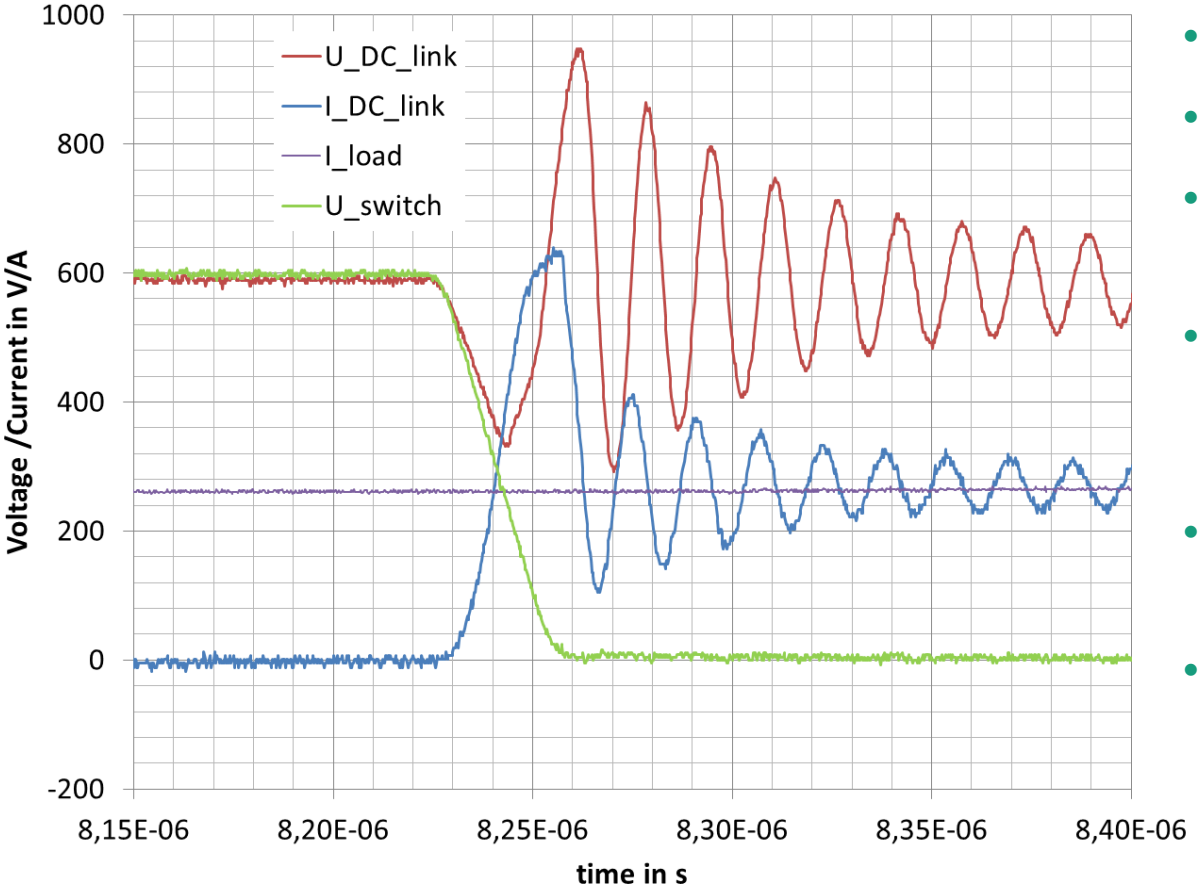
Under the conditions of fast switching interference is a great challenge

Common mode rejection



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SiC half bridge module with 4 Cree 25mΩ MOSFETs in parallel

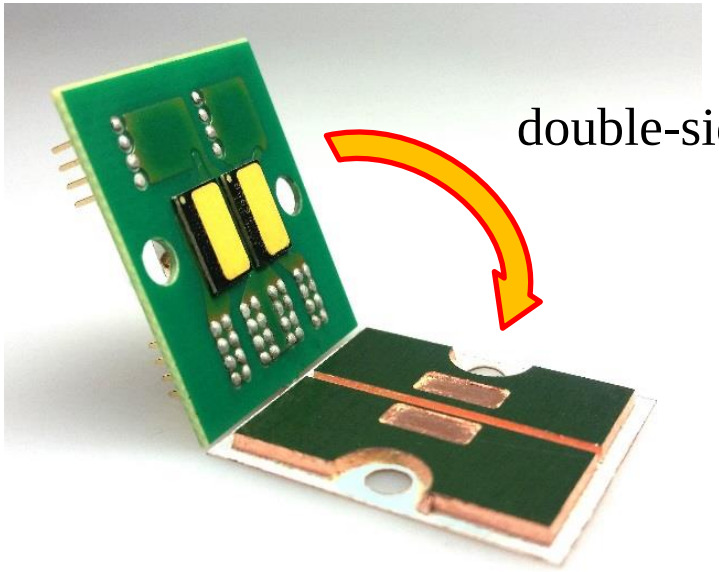


- $Rg_{external}$=0 Ohm,
- $L_{DC\ link}$=8 nH
- Revers recovery of the body diode (15ns)
- Reloading of semiconductor capacitance (10ns)
- Huge current with ringing
- => consequence for semiconductor: first improvement is the revers recovery!

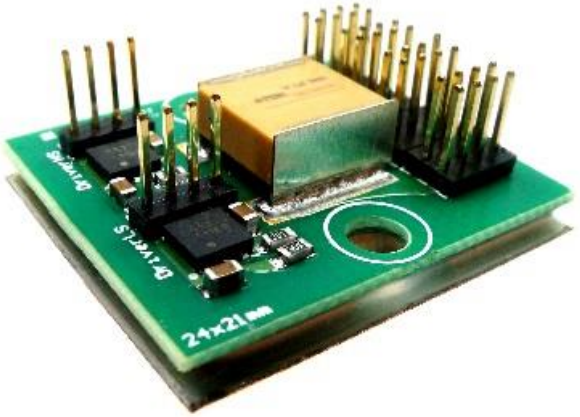
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Example for a GaN switching cell module

- half-bridge with 2 GaN Systems GS66508T
- 650V, 55mOhm GaN HEMTs
- DC link inductance **2.8nH**
- Mounting on IMS substrate for cooling



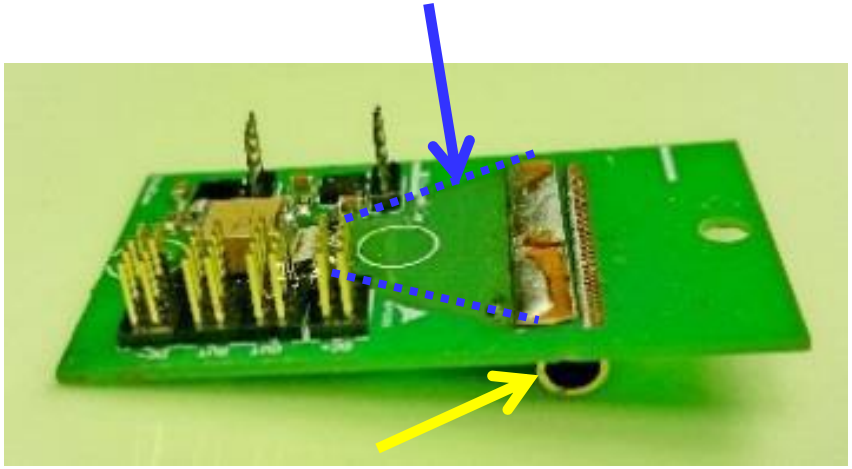
double-sided soldering



Size: 24x21mm

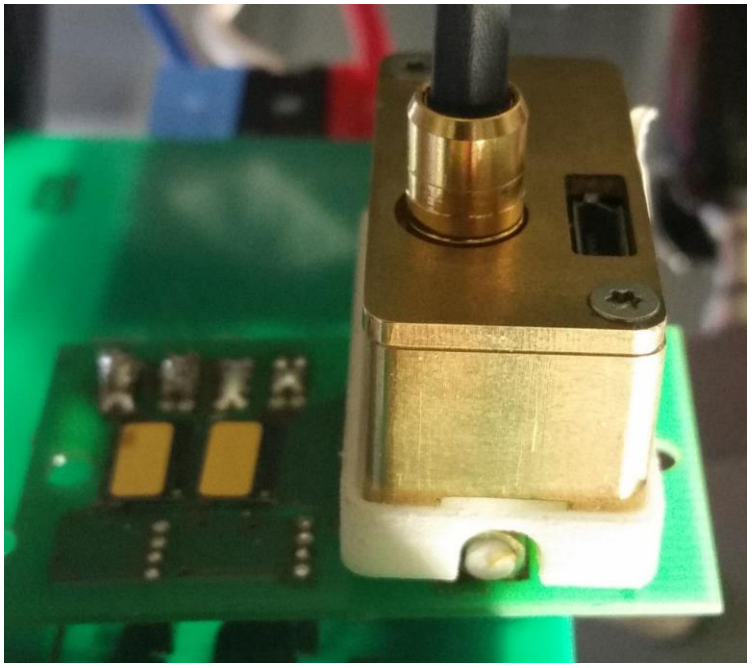
“GaN Module Preparation”

- DC link path splitted and connections extended to the side (+~0.9nH)



- brass cylinder added (+0.3nH)

- mounted on system board
- Sensor inserted



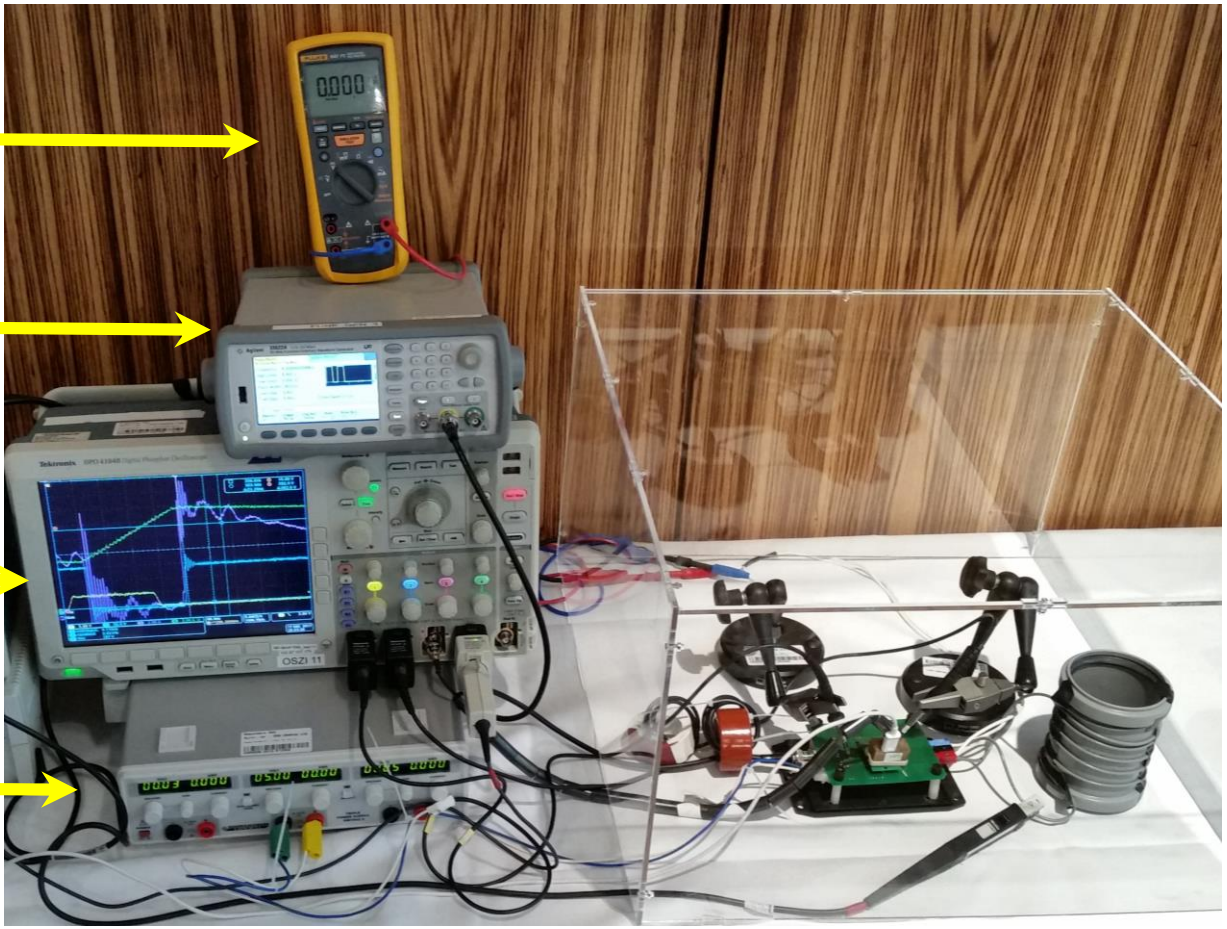
Demonstrator

HV Power supply =
DC link Voltage

Double pulse
signal generator

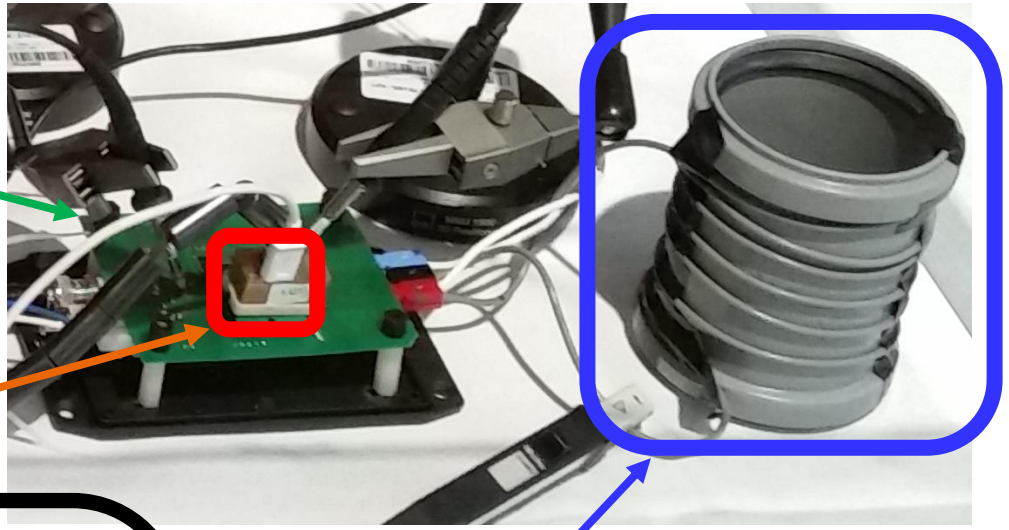
Oscilloscope

Driver power
supply



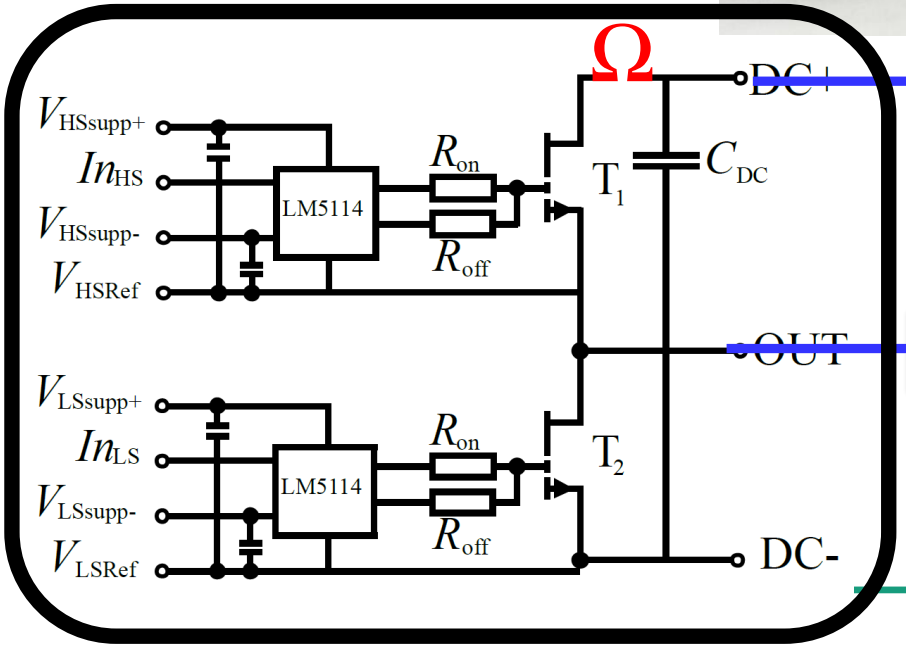
Demonstrator (made asap. specially for the Workshop)

System board
- signal isolation
- driver supply +6/-3V
- el.-mech. Interface



IZM Sensor

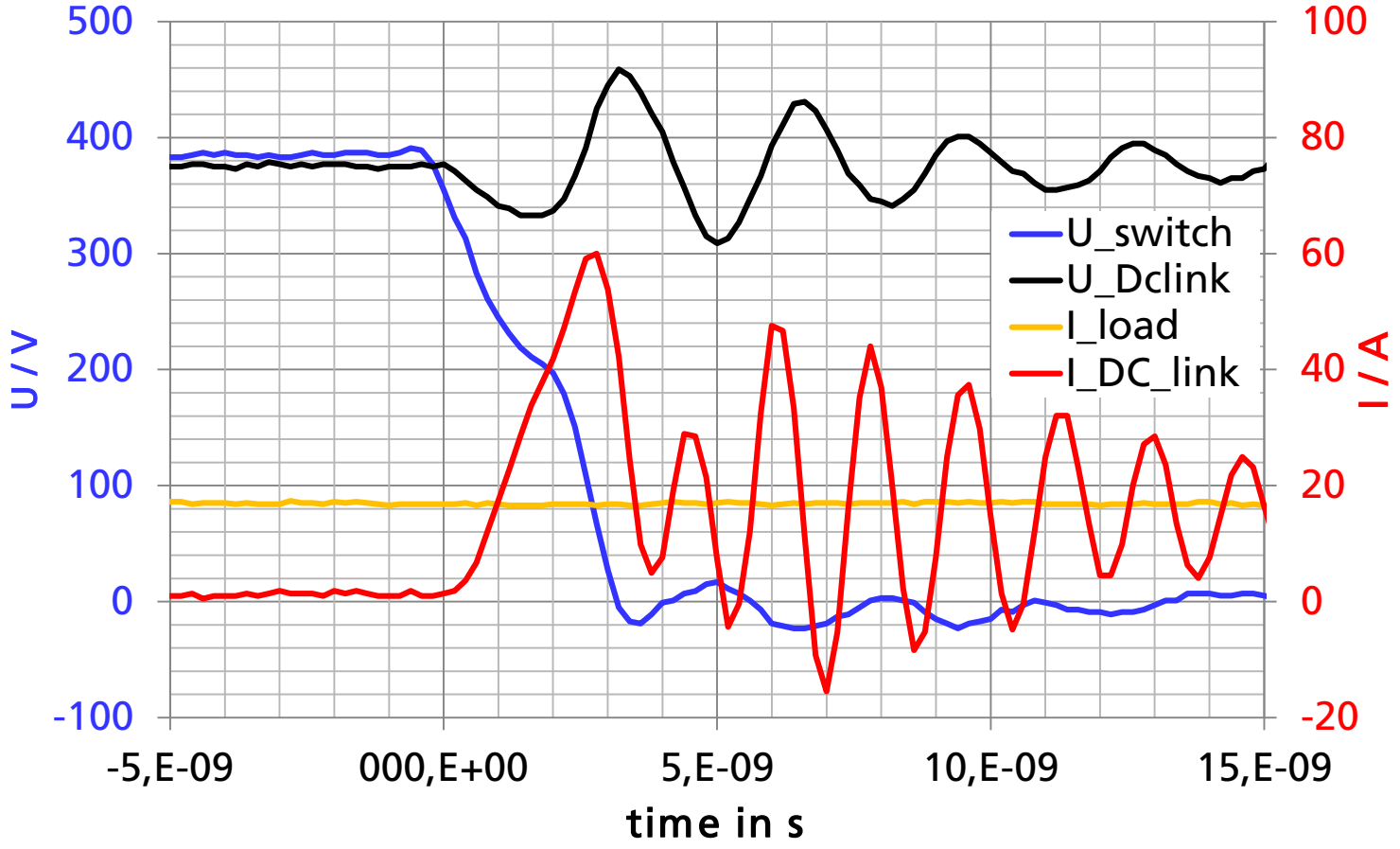
GaN IPM



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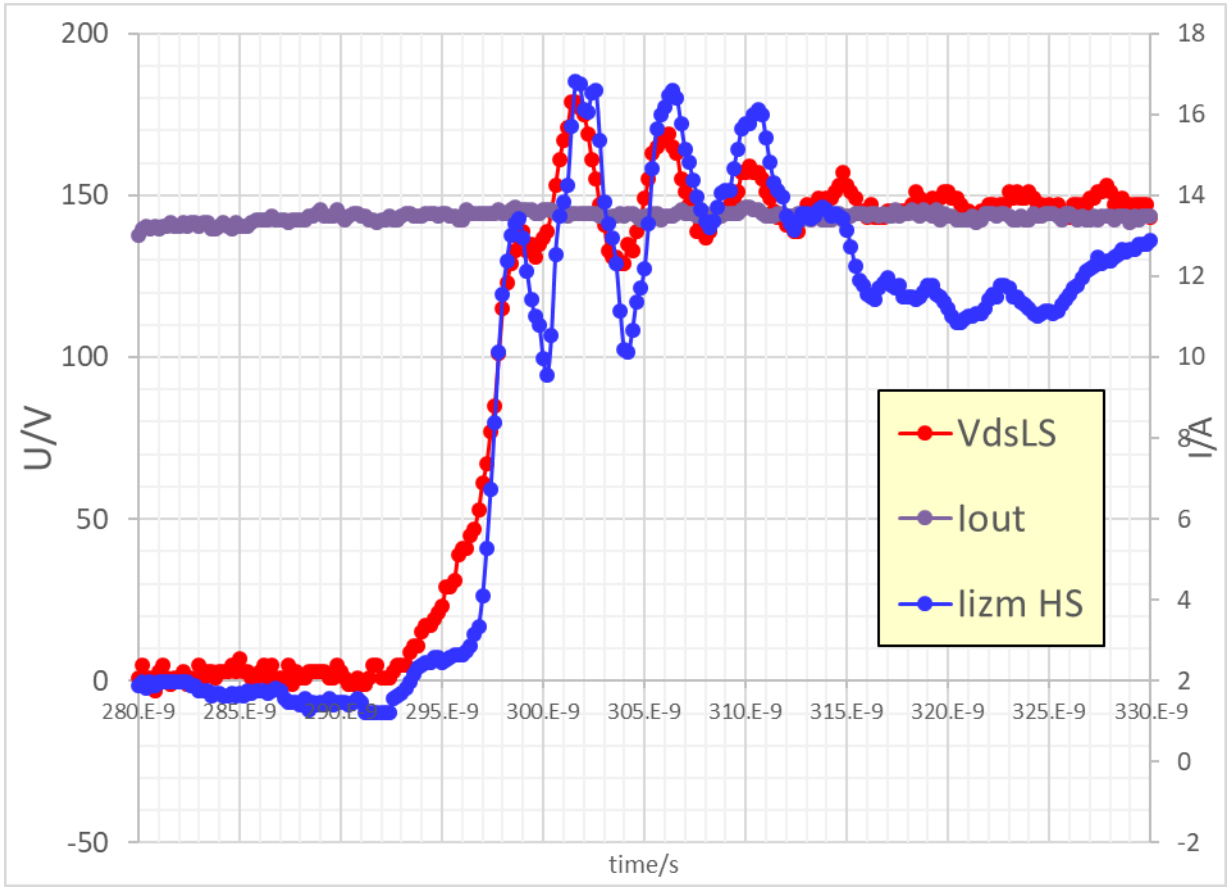
Switch on of GaN HEMT (R_g=10ohm, $L_{DC\ link}$=4nH)

- Reloading of semiconductor capacitance (3ns)
- Huge current with ringing



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Measurement from 17.10.17 (commutation to HS)



- dI/dt: ~10A/ns
- ~250MHz ringing of the current within the switching cell

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Resume

- IZM Current Sensor gives a possibility to perform low invasive current measurements and thereby allows first time insights into fast switching cells
- Ready for research on SiC
- Low current GaN requires a geometrically smaller and HF optimized design => Sensor v4?

Thank you for your attention!

