System Level Modeling of Smart Power Switches using SystemC-AMS for Digital Protection Concept Verification

Hans-Peter Kreuter, Vladimir Košel, Michael Glavanovics, Robert Illing

KAI – Center of Competence for Automotive and Industrial Electronics,

Infineon Technologies Austria AG, Villach, Austria

BMAS

2009 IEEE International Behavioral Modeling and Simulation Conference

KAI

Infineon

Overview

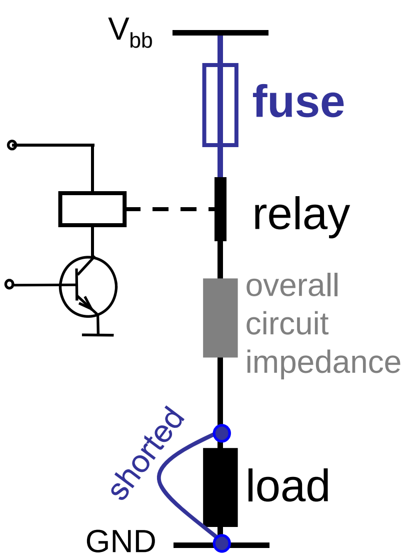
- Automotive & Smart Power devices
- Stress caused by inappropriate protection strategies
- System level model for a short circuit scenario
  - electro-(non-linear) thermal MOSFET model
  - controller model
- Simulation results and verification on HIL testbench using a test chip
- Conclusion

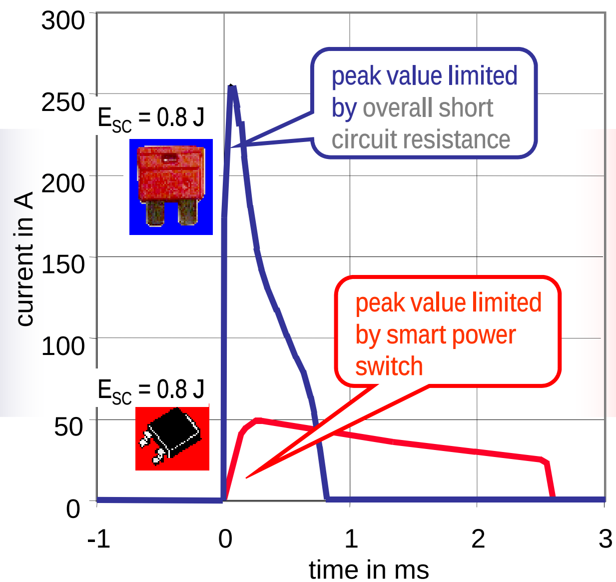
Smart Power switch application

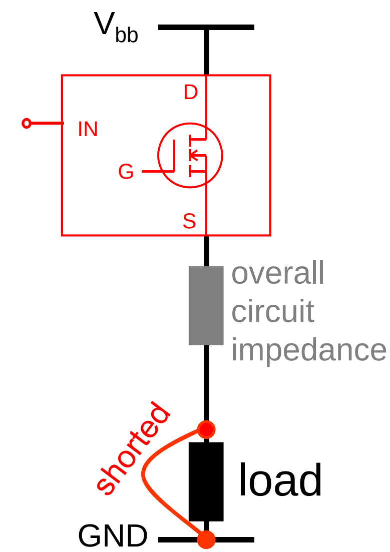
Mechanical power switch application

versus

Electronic Smart Power switch application







- Low cost & complexity
- Separate fuse required
- High peak current

- Integrated protection function
- Overcurrent limited
- Fault diagnosis available

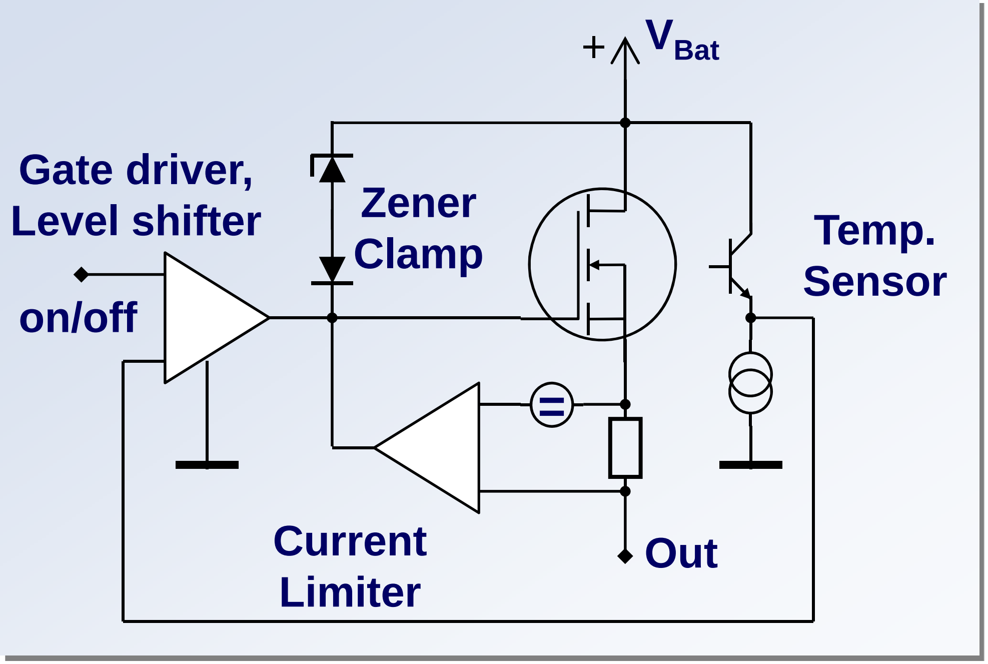
Smart Power stage protection

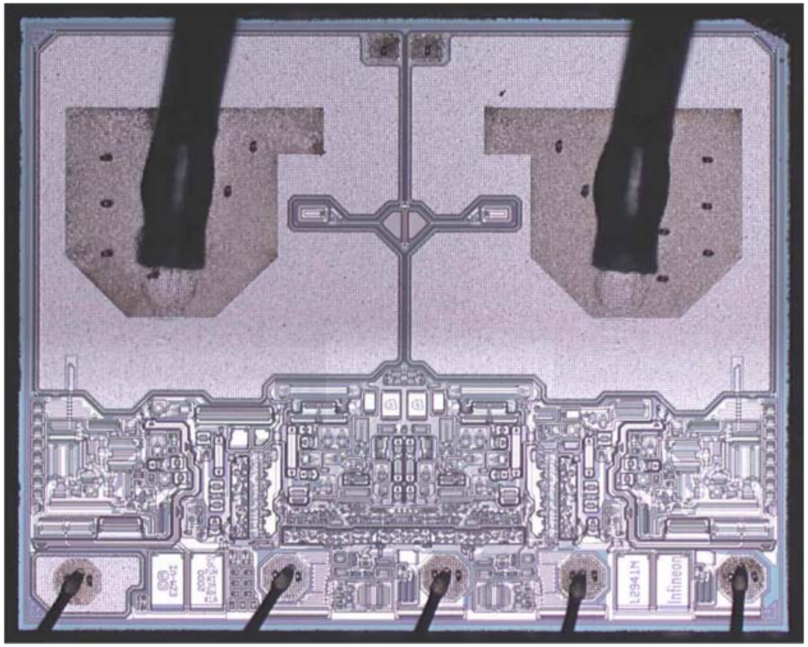
Protection mechanisms:

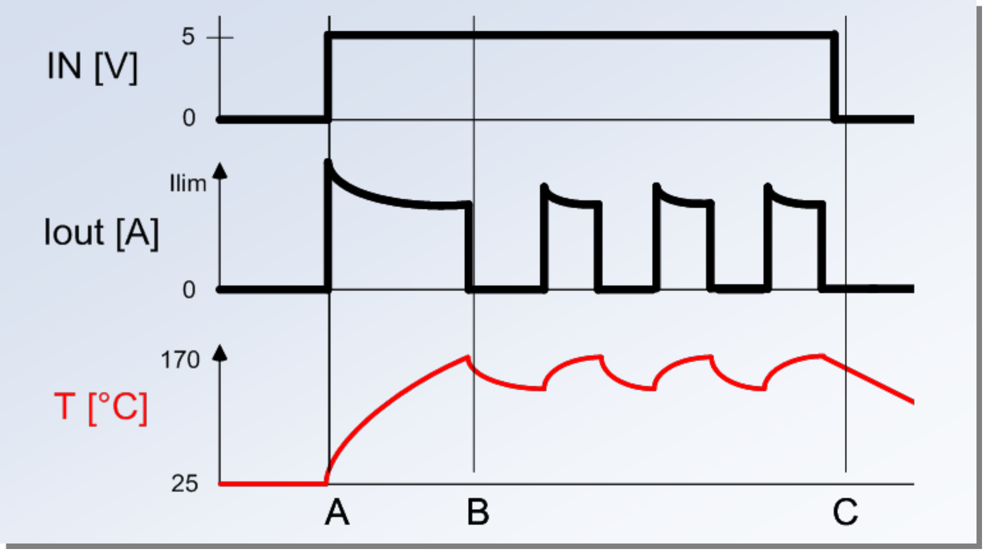
Current limitation .... 10 x I_{Load}

Thermal shutdown .... 170°C

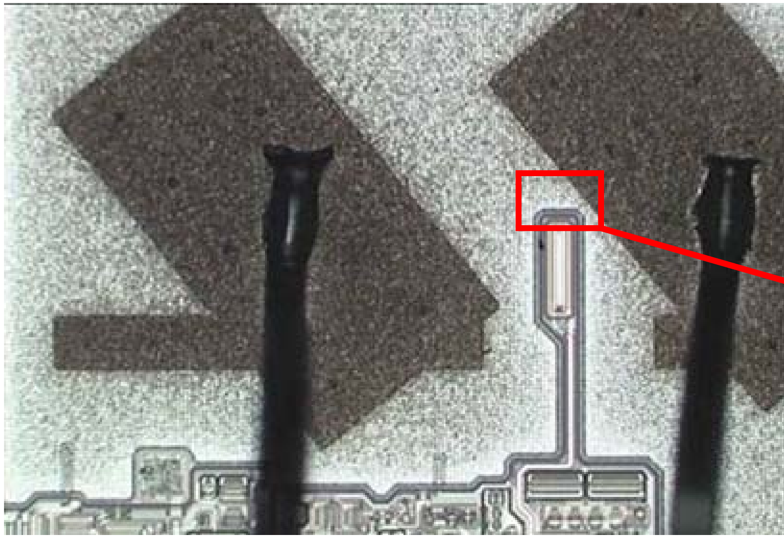
Voltage clamping ...... 50 V





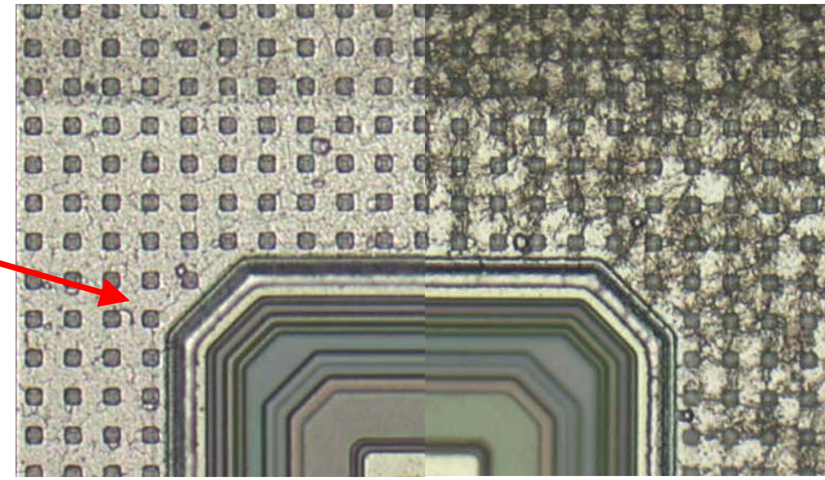


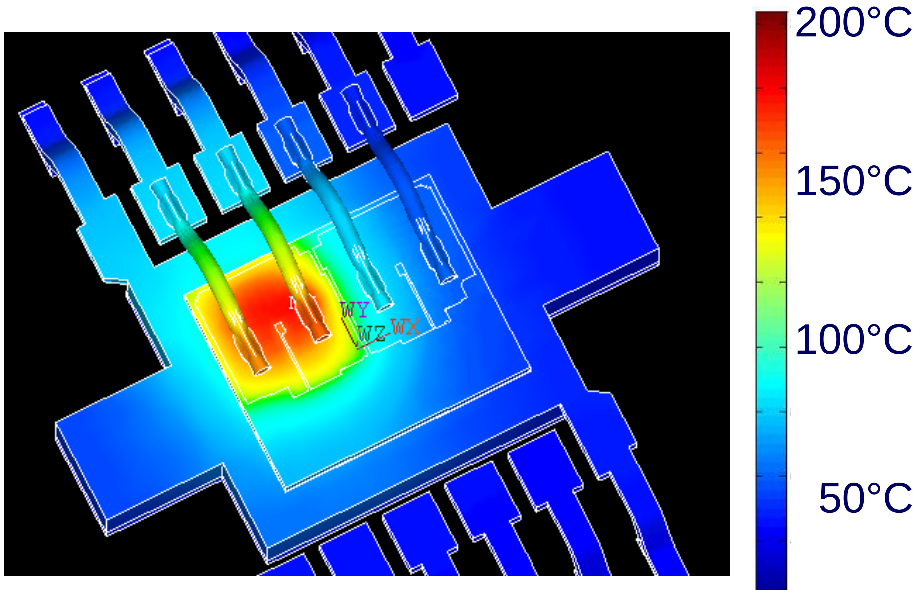
Protection strategy influences realiblity



ORIGINAL (new device)

DEGRADED (after 10k cycles)





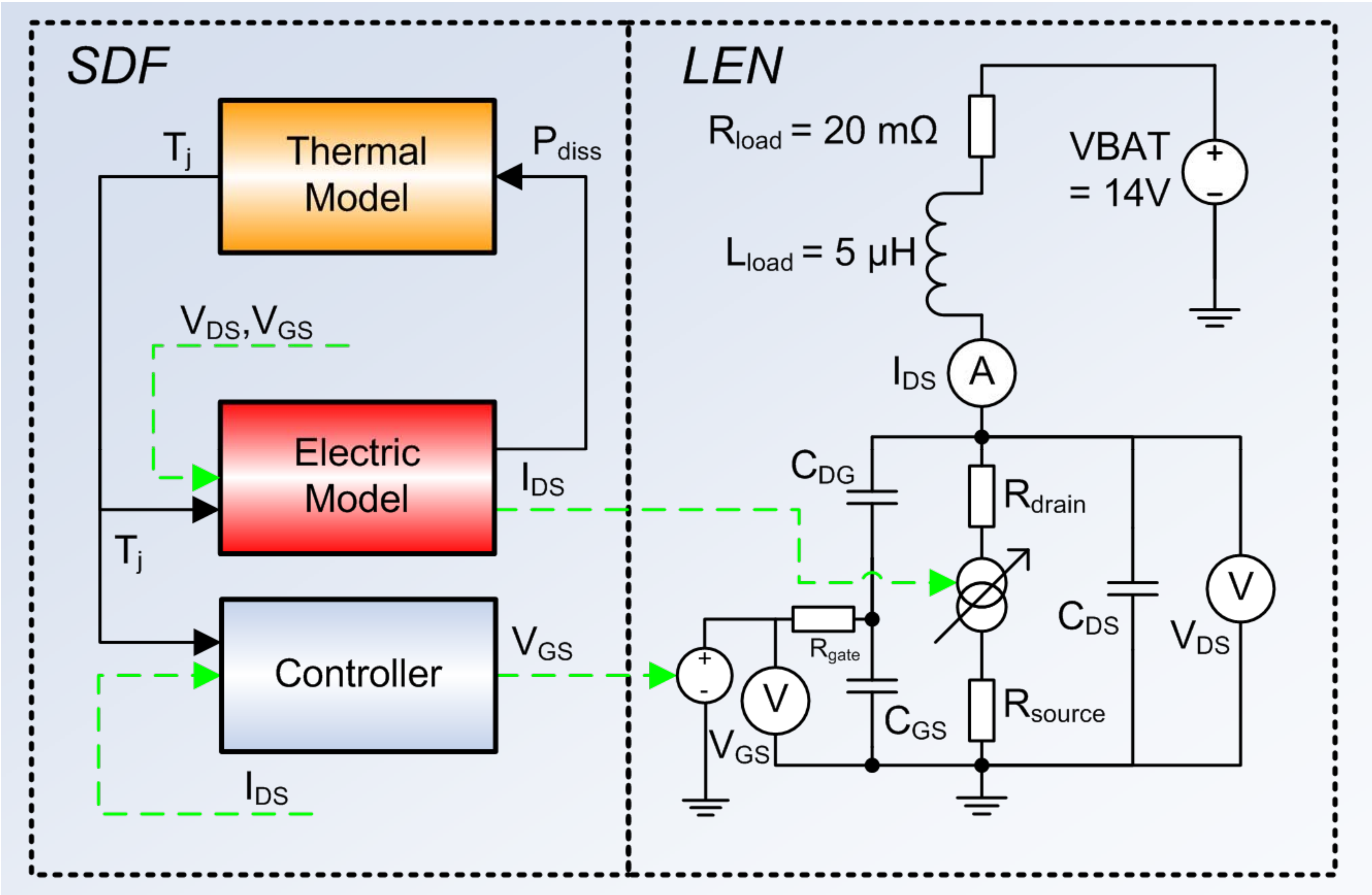
Design affects

RELIABILITY!

Motivation

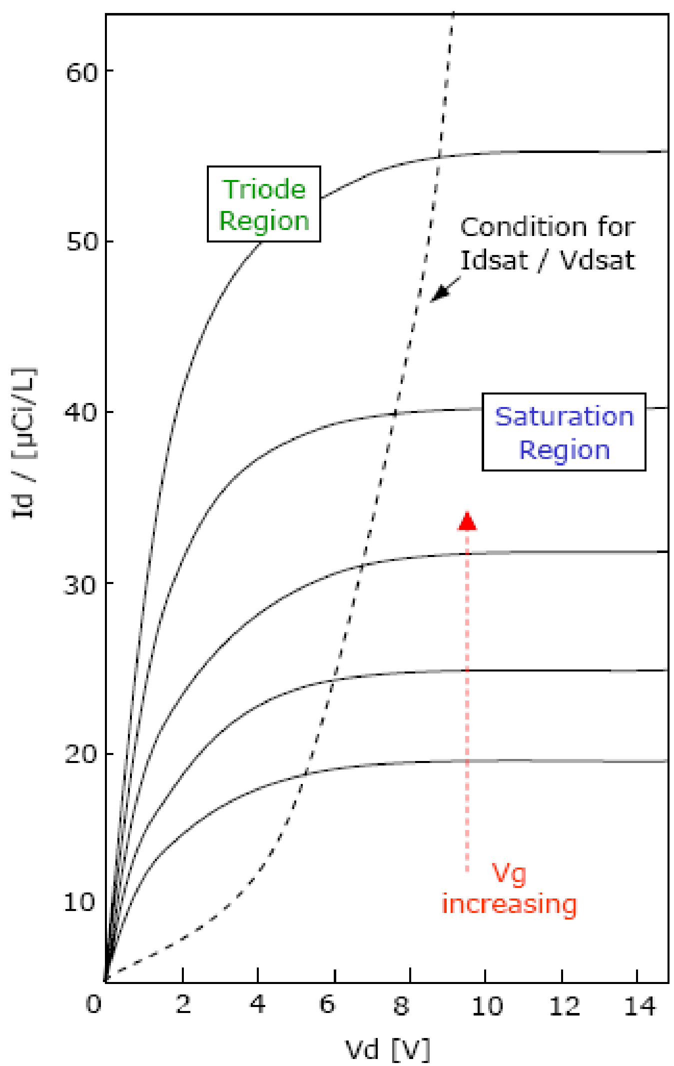
- Provide system level models of a SPS
  - Electro thermal model for the power stage
  - Description of gate driving unit (protection concept)
  - Load model – worst case scenario >>shorted load<<
  - Be ready to model more DIGITAL functionality (PWM …)
- Verify the models on a HIL testbench

System level model for short circuit scenario

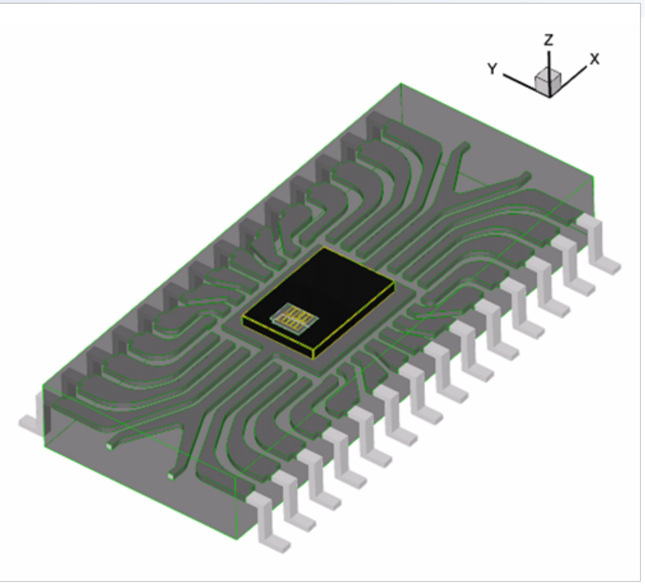


Electric MOSFET model

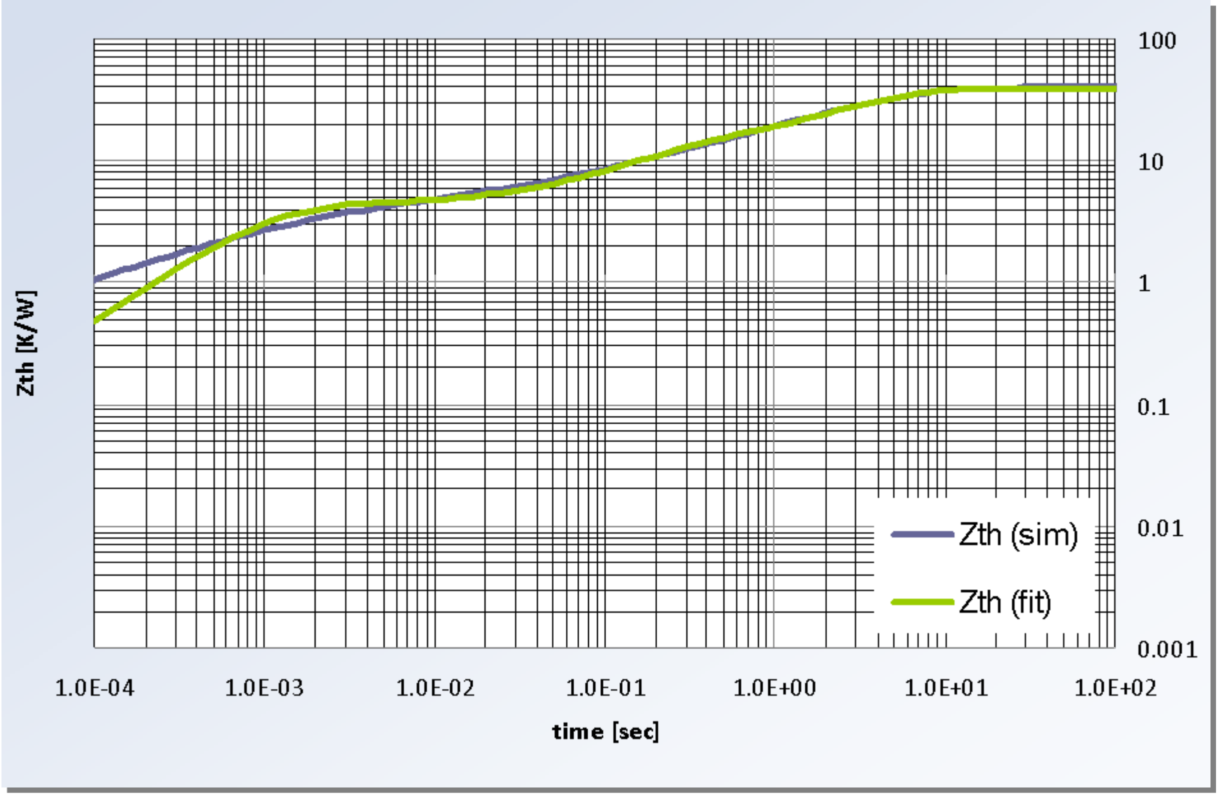
- Grove-Frohman channel equation including thermal effects
- Meyer-Cap model
- Fitted for power MOSFET based on measurements and technology parameters



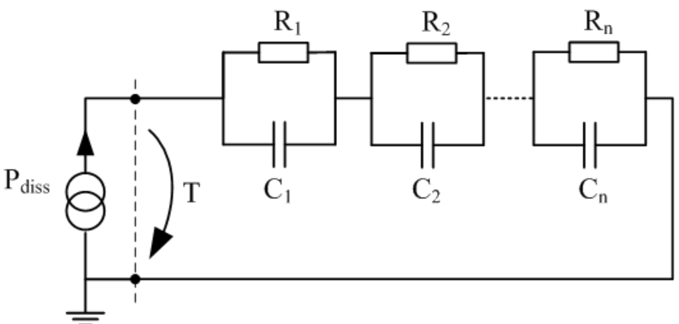
Thermal MOSFET model



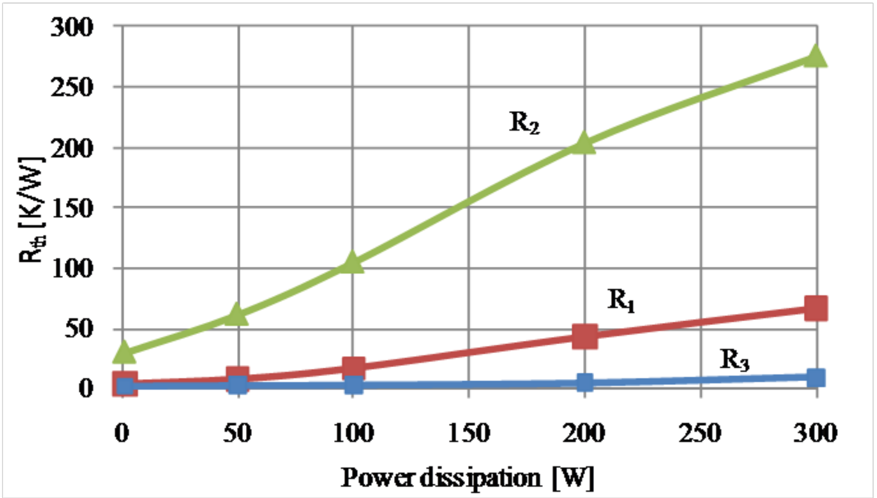
$$Z_{th}(t) = \sum_{i=1}^{n} R_i \left(1 - e^{-\frac{t}{R_i C_i}}\right)$$

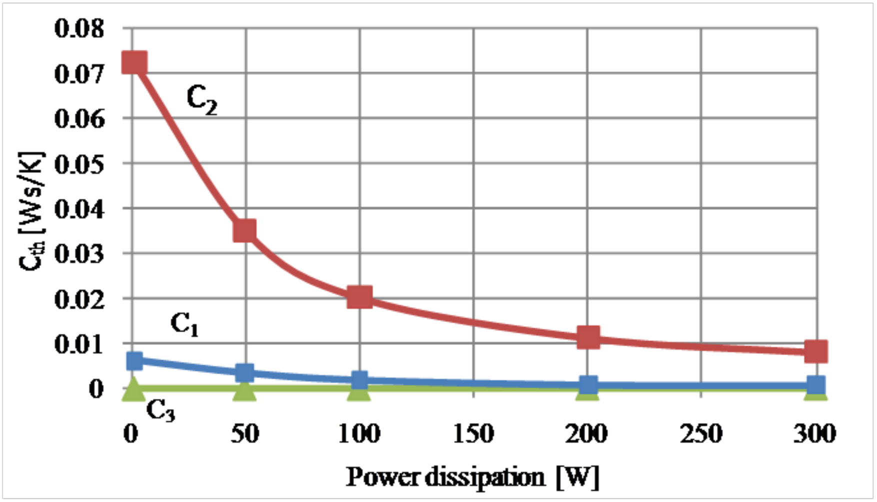


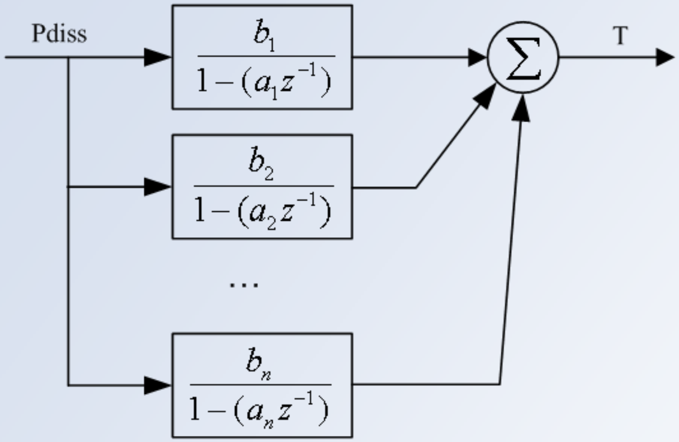
- Obtain Z_{th} curve using FEM simulations
- Fit R_i/C_i with thermal step response of a Foster network in time domain



Nonlinear thermal MOSFET model



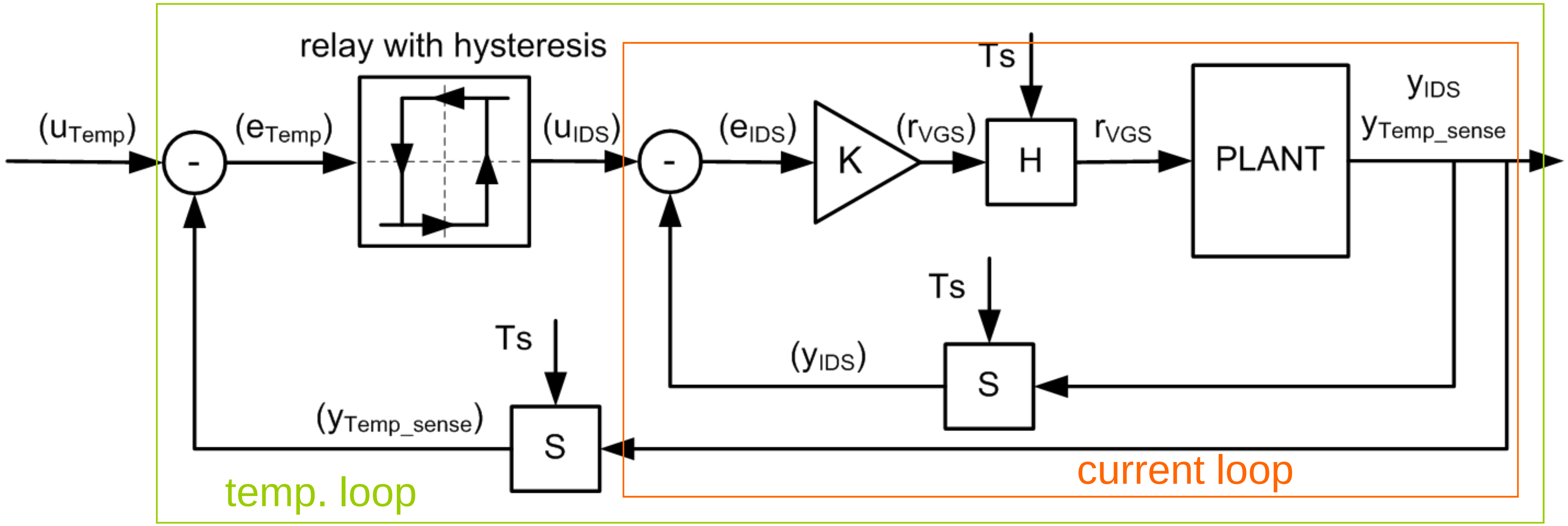




$$a_n = Ts \cdot \frac{f_{Rn}(P)}{1 + \frac{f_{Rn}(P) \cdot f_{Cn}(P)}{Ts}}$$

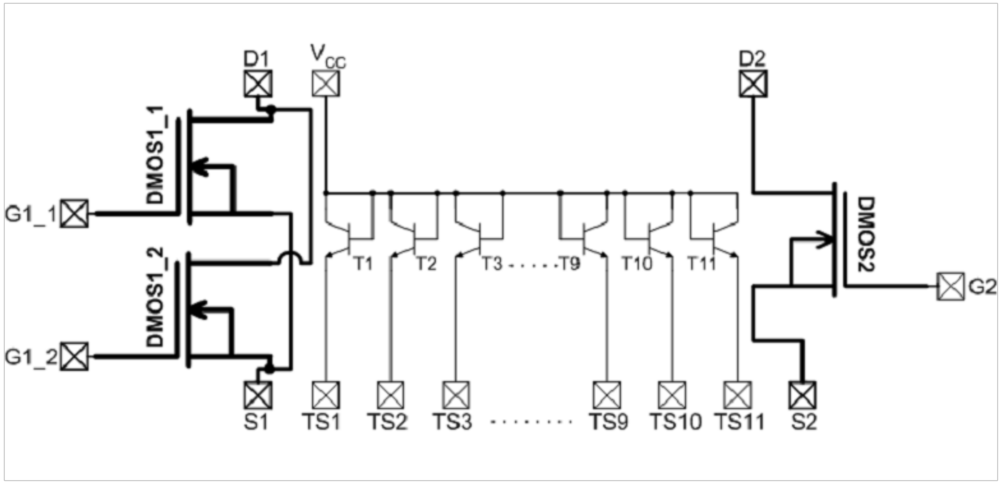
$$b_n = \frac{f_{Rn}(P) \cdot f_{Cn}(P)}{Ts + f_{Rn}(P) \cdot f_{Cn}(P)}$$

Controller Model

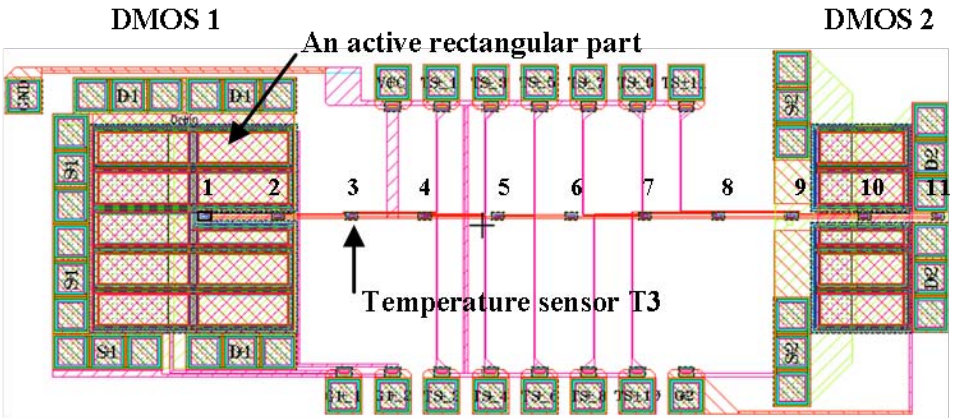


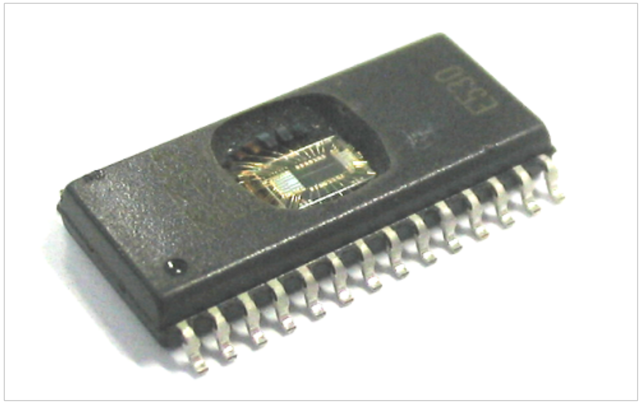
- Over temperature protection – thermal relay with hysteresis
- P-controller for current regulation

Model Verification - the test chip

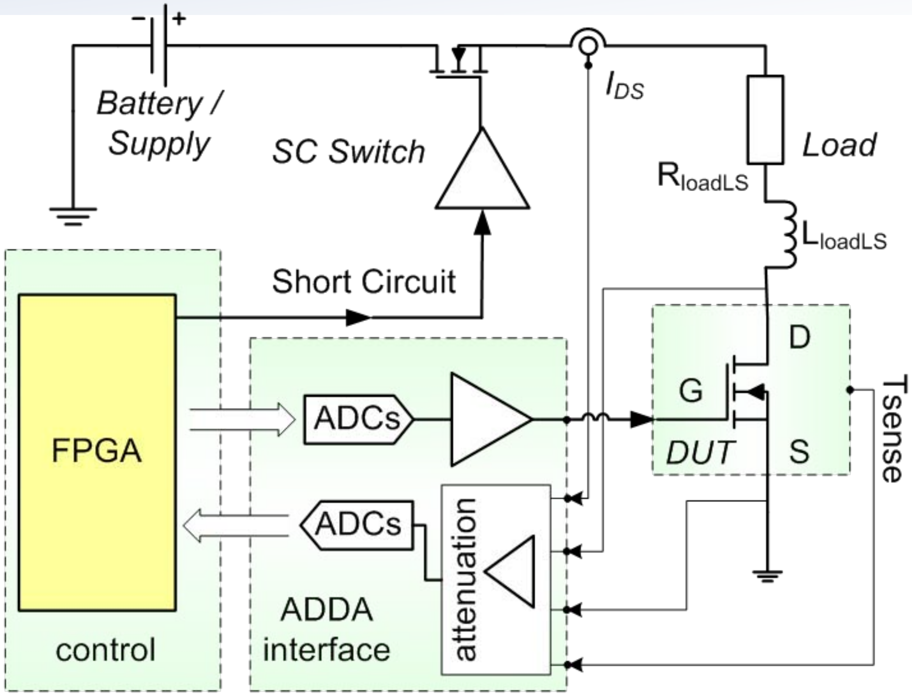


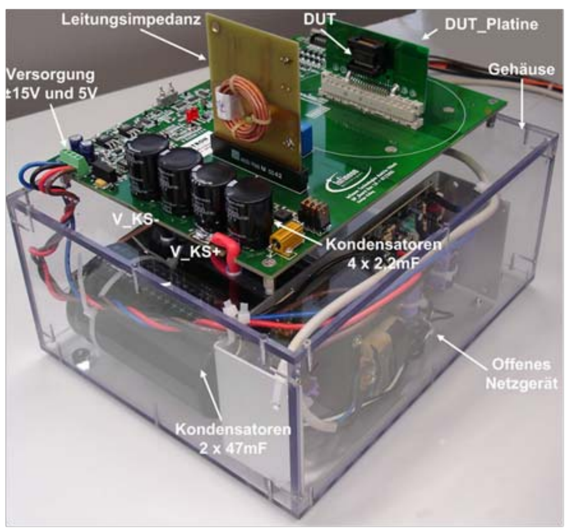
- 2 power MOSFETs
- 11 temperature sensors
- BCD technology
- assembled in P-DSO-28 plastic package





HIL test bench

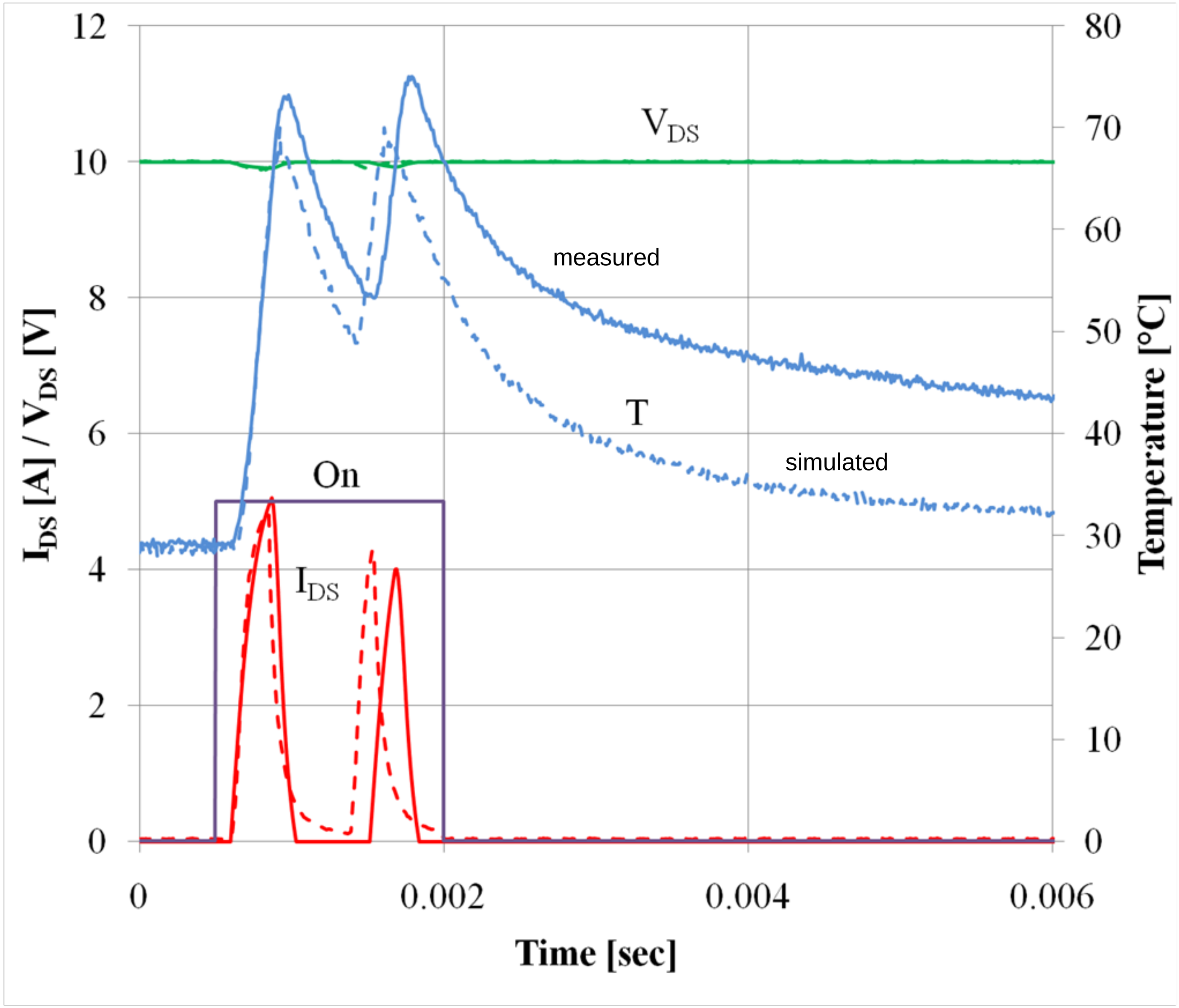




- switch up to 100 A
- over temperature and over current shutdown
- battery/supply up to 60 V
- R_{load}/L_{load} configurable
- FPGA for control and data aquisition
  40 MHz clock
  8 x AI@200 kS
  8 x AO@1 MS

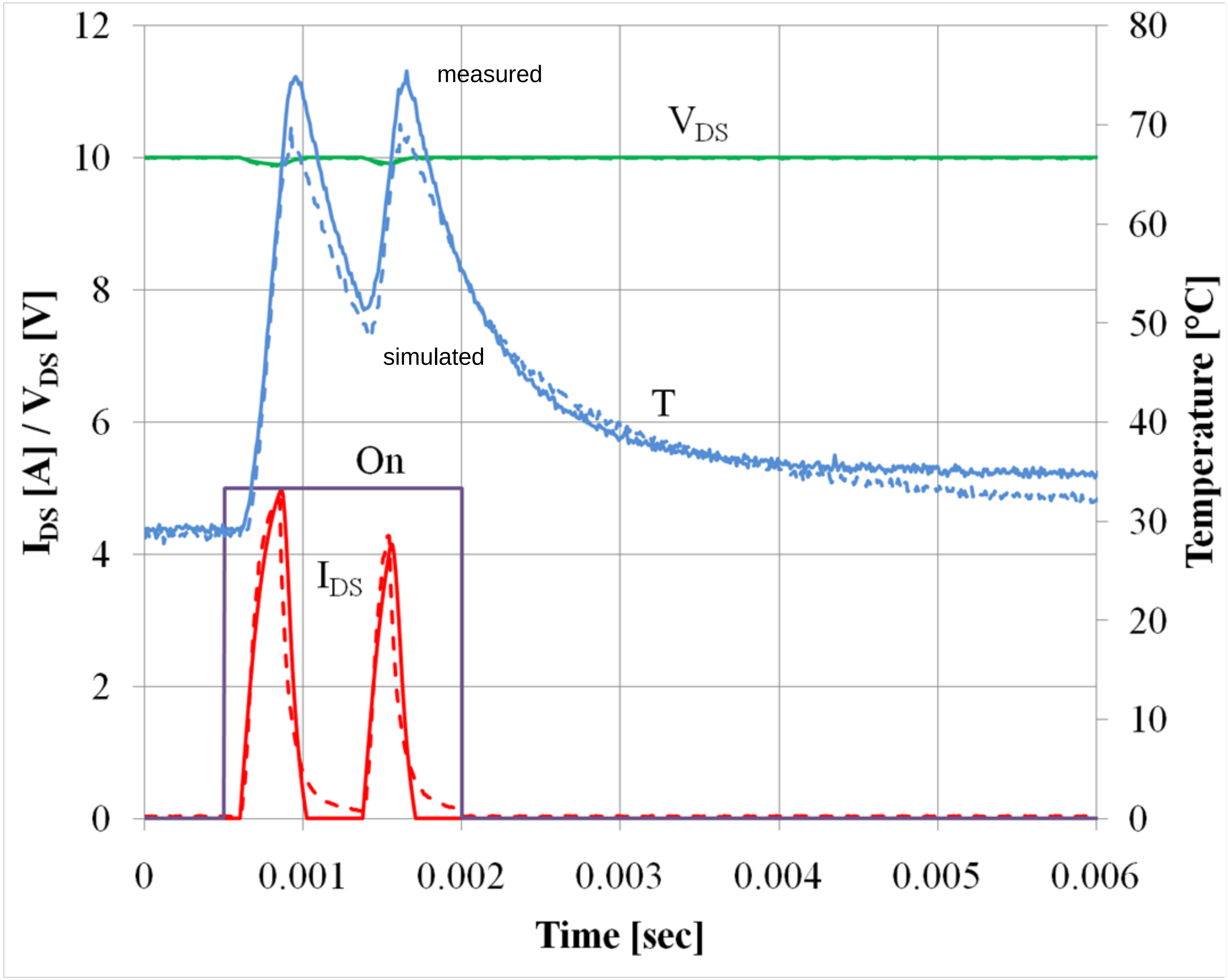
[Master thesis Robert Illing]

Measurement and Simulation Result (1)



- Linear temperature model leads to realively large deviations

Measurement and Simulation Result (2)



- Using the non-linear temperature model results in better accuracy!

Conclusion

- An electro-thermal SystemC-AMS MOSFET model was developed
- Non-linear thermal Foster network was introduced
- SystemC-AMS testbench presented; power MOSFET, load (short circuit) and protection concept
- Successful verification using a HIL testbench was presented








Thank You for Your Attention!