Simulation of the Destruction Effects in CMOS-Devices after Impact of Fast Transient Electromagnetic Pulses

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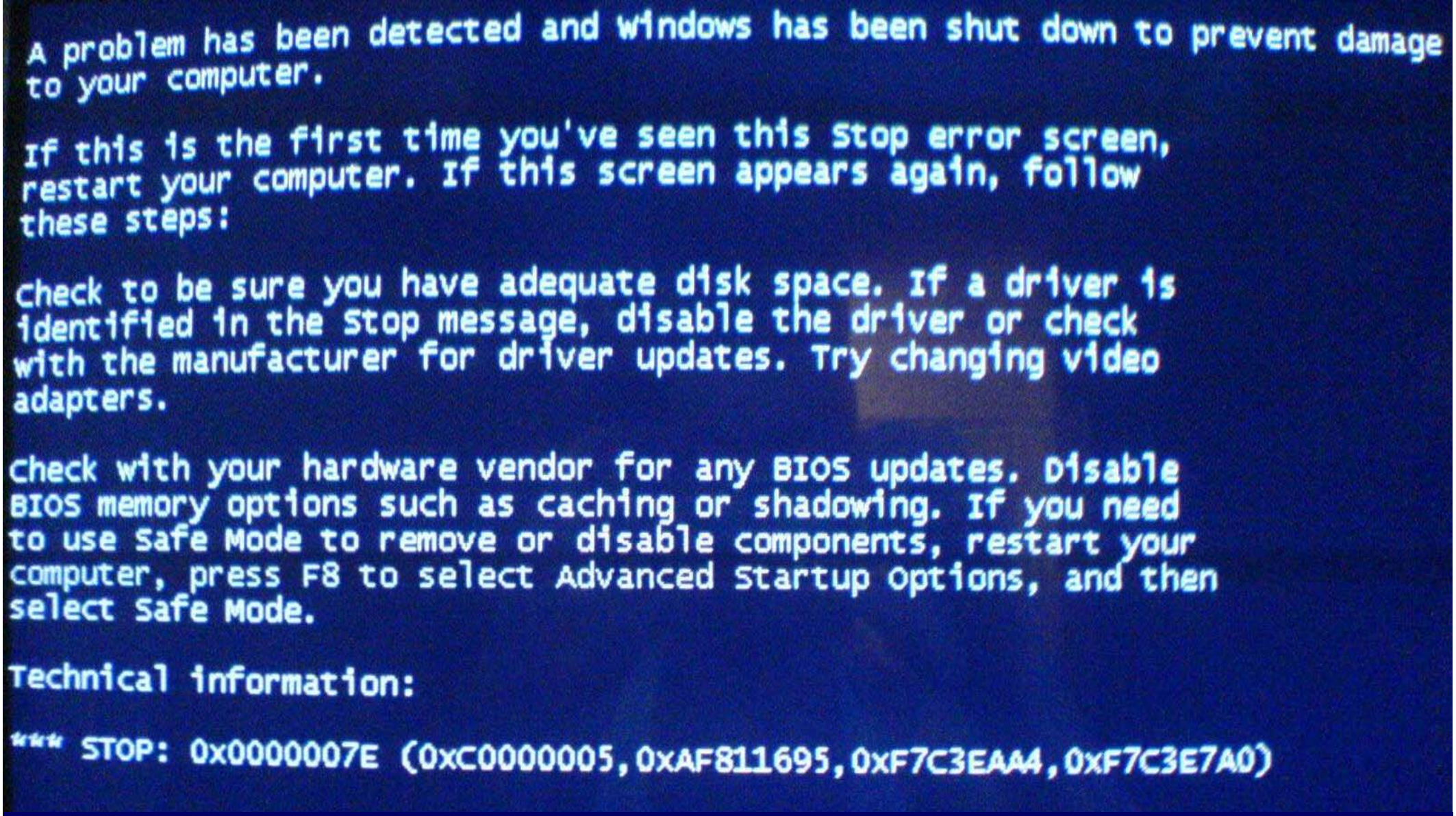
Overview

- Motivation
- Threats
- Disturbing Signals
- Microscopical Analysis
- Simulation of Breakdown
- Simulation of Melting Process
- Time Behavior of Electric Field and Temperature
- Summary



What do you think at this moment, when these error message appears on your screen ?

What does a flight controller think about ?

. . .or a pilot?

And which consequences will it have, if this happens on an intensive care unit ?

Motivation

Meaning of electronic systems for the world in the 21st century

- ***safety systems***
- medicine
- economy
- traffic
- forces

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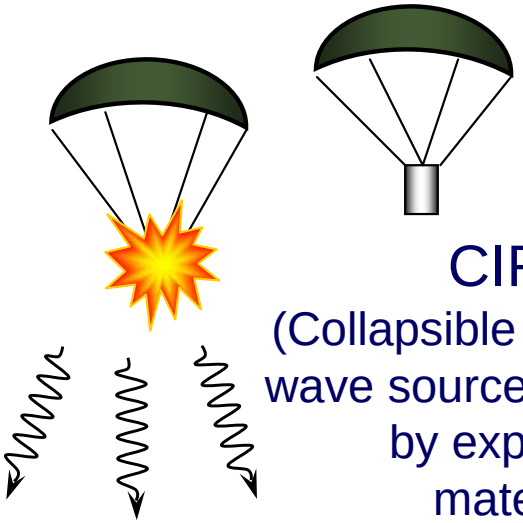
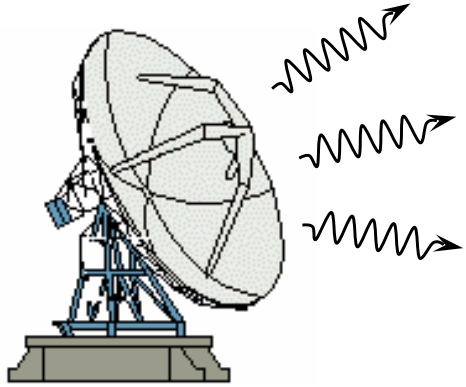
Threats

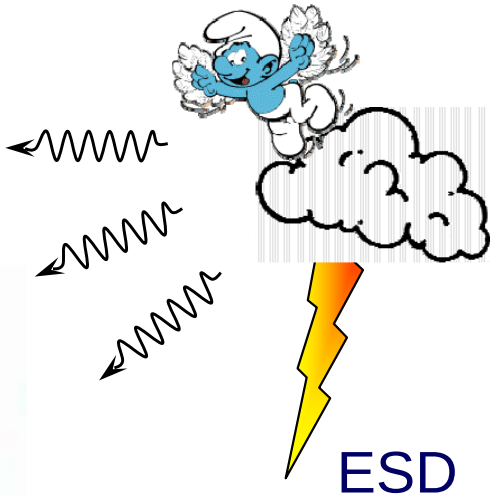
NEMP
(Nuclear electromagnetic pulse)



CIRA
(Collapsible IRA; micro-wave source embossed by explosive material)



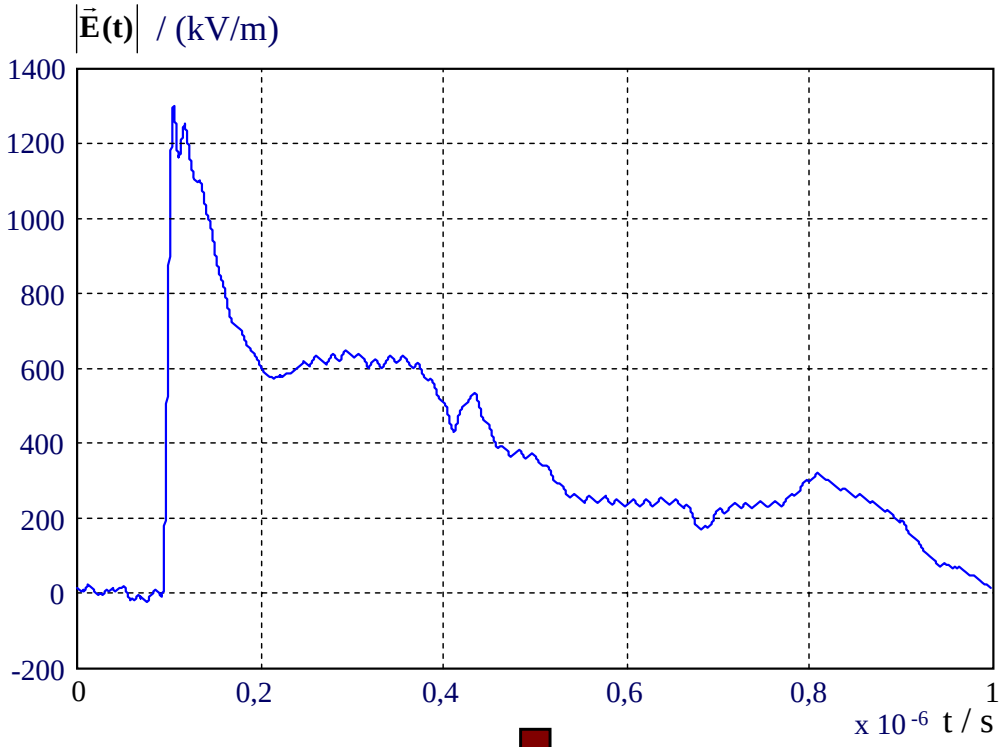
IRA
(Impulse radiating antenna)



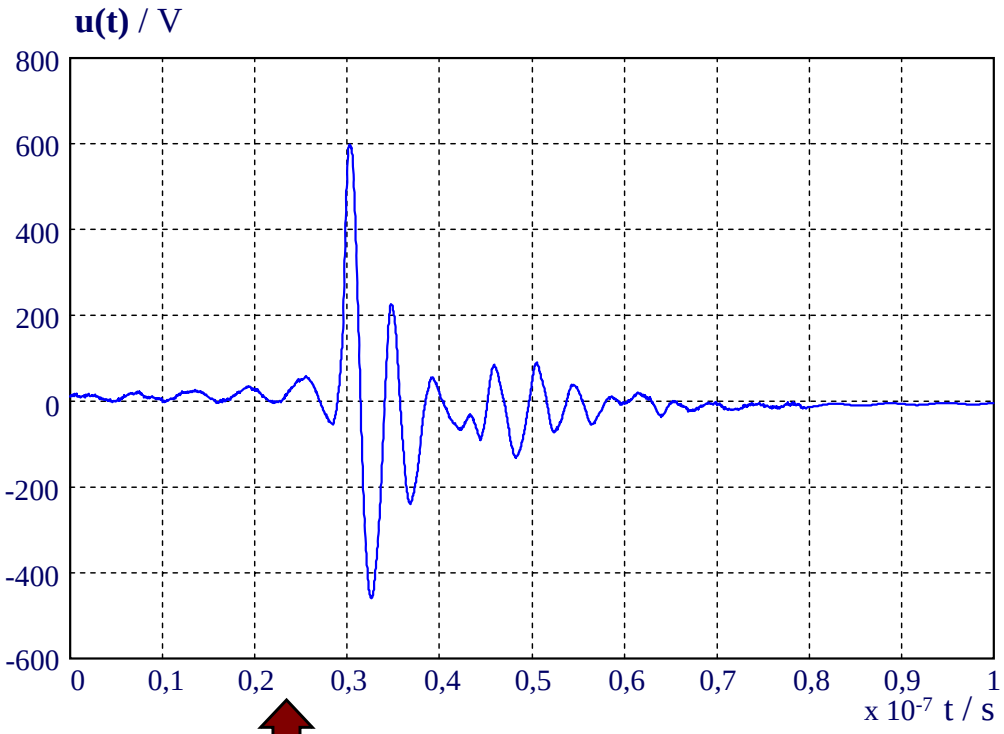
ESD
(Electrostatic discharge)

Disturbing Signals

Electromagnetic pulse



Voltage on connecting line

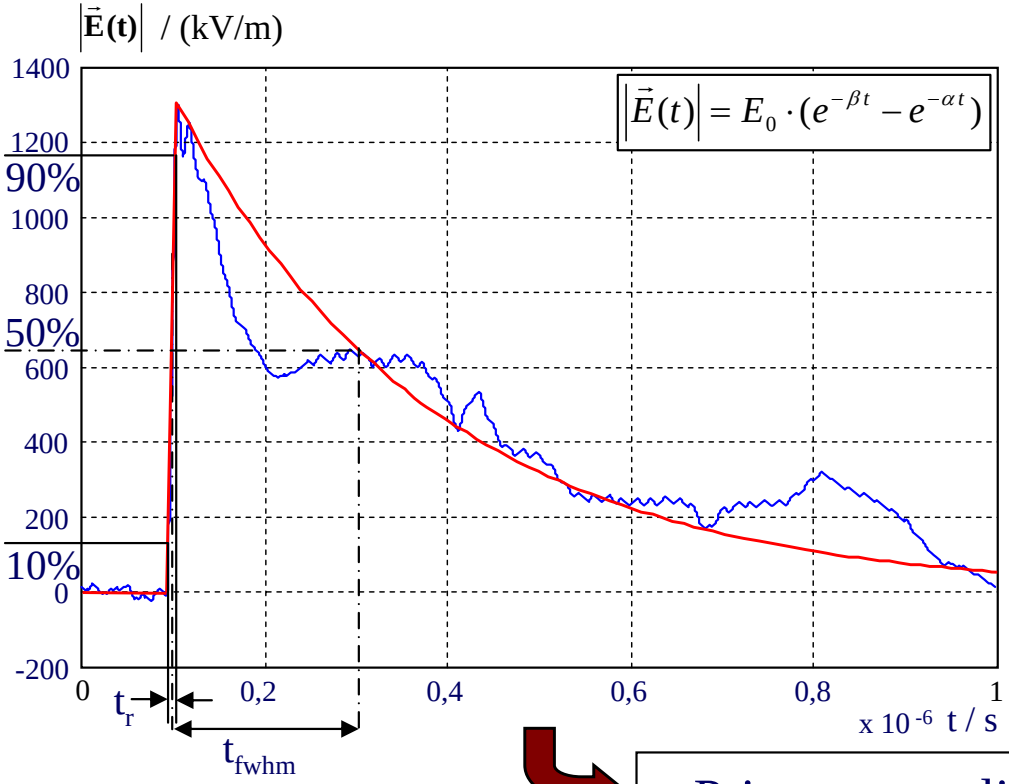


Primary coupling path:
Connecting lines

Disturbing Signals

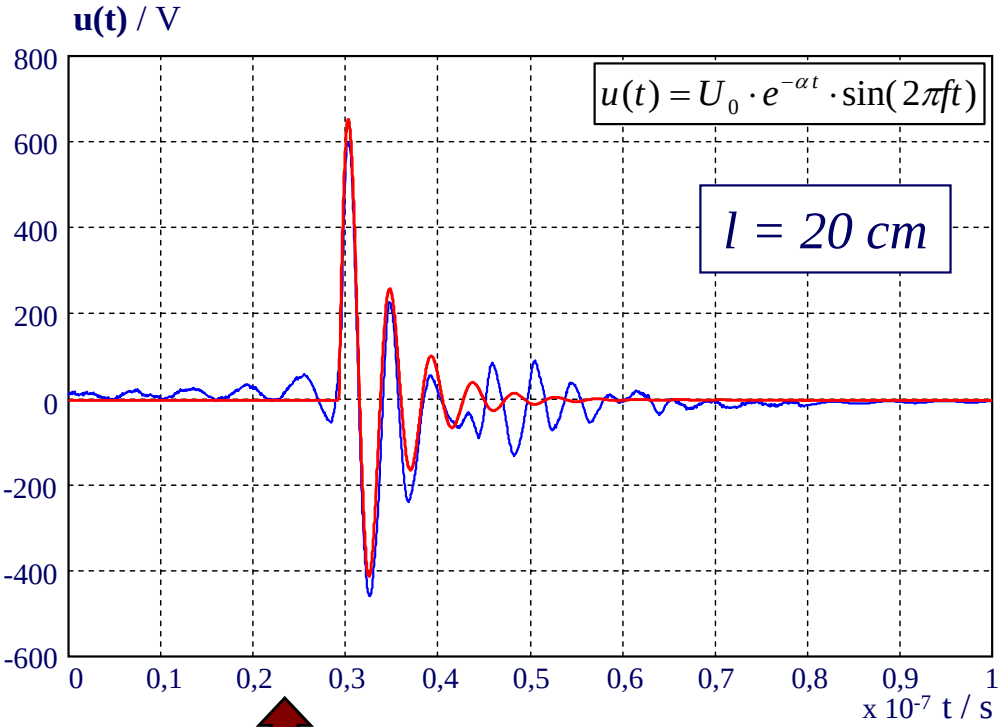
Electromagnetic pulse

➡ double-exponential form



Voltage on connecting lines

➡ damped harmonic oszillation

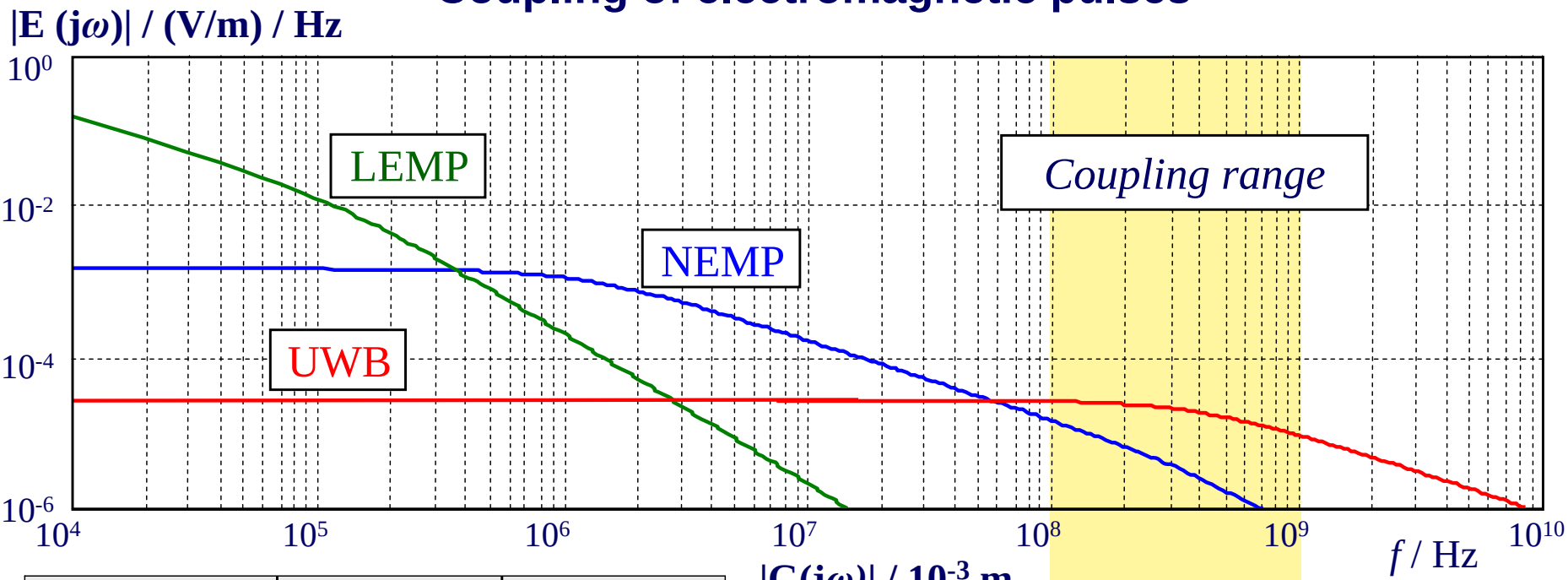


Primary coupling path:
Connecting lines

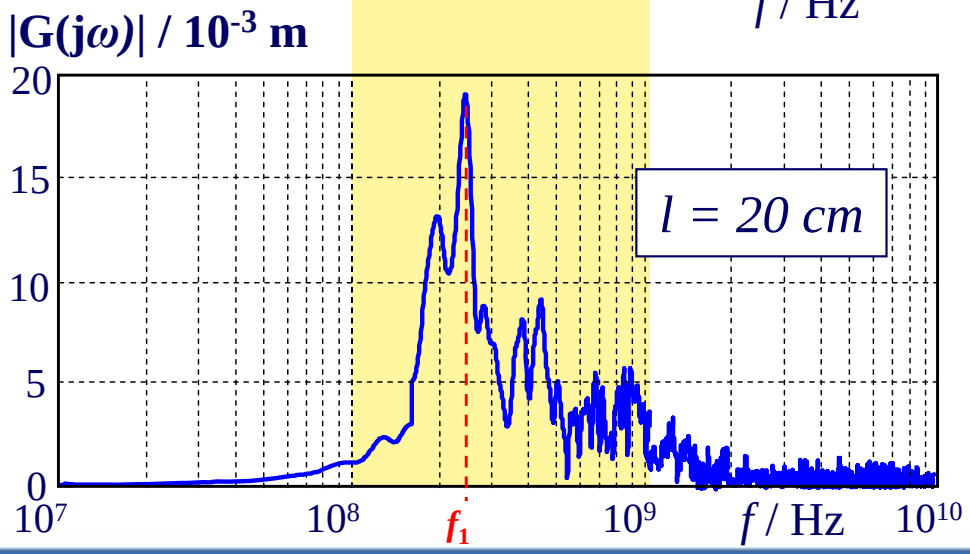
Pulse parameter:
t_r = 7,5 ns
t_{fwhm} = 180 ns
E_{max} = 1290 kV/m

Parameter of the coupled-in signal:
α = 2,1· 10^8 s^{-1}
f_1 = 230 MHz
U_0 = 821 V

Coupling of electromagnetic pulses

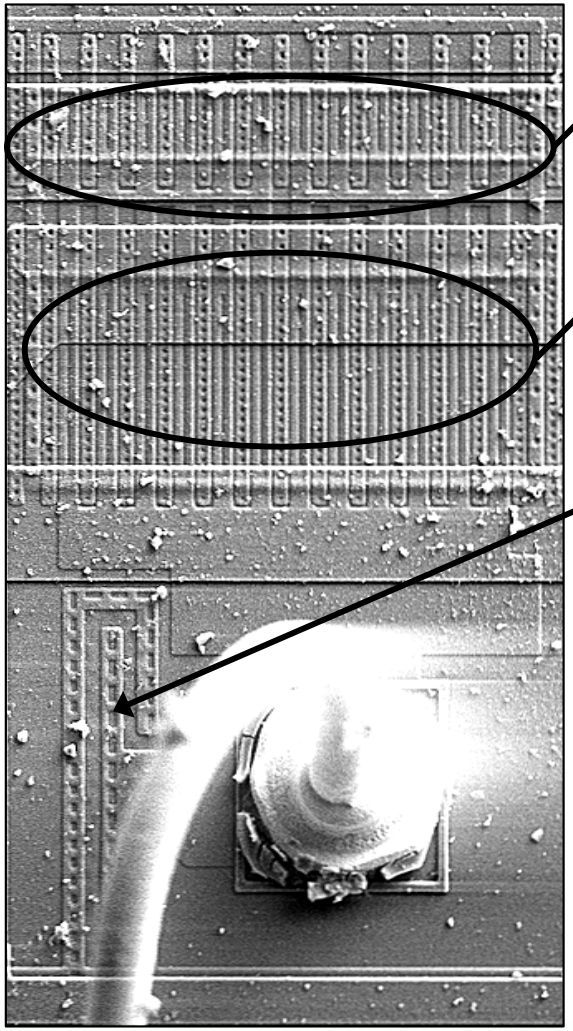


Source	Rise time	Pulse duration
UWB	t_r = 100 ps	t_{fwhm} = 2.5 ns
EMP (fast)	t_r = 1.5 ns	t_{fwhm} = 80 ns
Nuclear explosion (NEMP)	t_r = 1ns – 5 ns	t_{fwhm} > 100 ns
EMP (middle)	t_r = 5 ns	t_{fwhm} = 300 ns
EMP (slow)	t_r > 10 ns	t_{fwhm} = 500 ns
Lightning (LEMP)	t_r = 1 µs – 2 µs	t_{fwhm} ≈ 50 µs



Microscopical Analysis

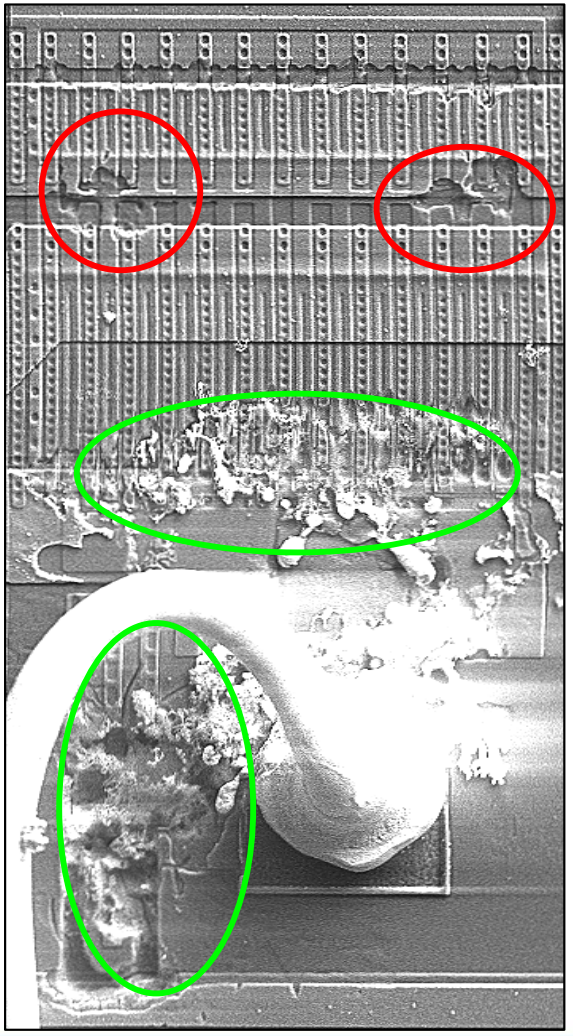
(rear section of an AC-/ACT-Inverter)



N-Channel-MOSFET

P-Channel-MOSFET

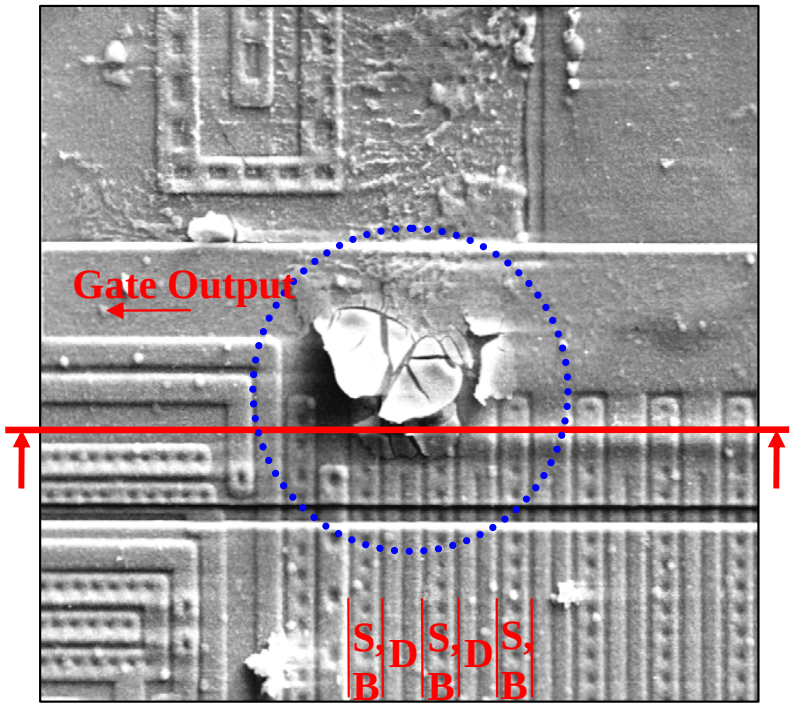
Diode

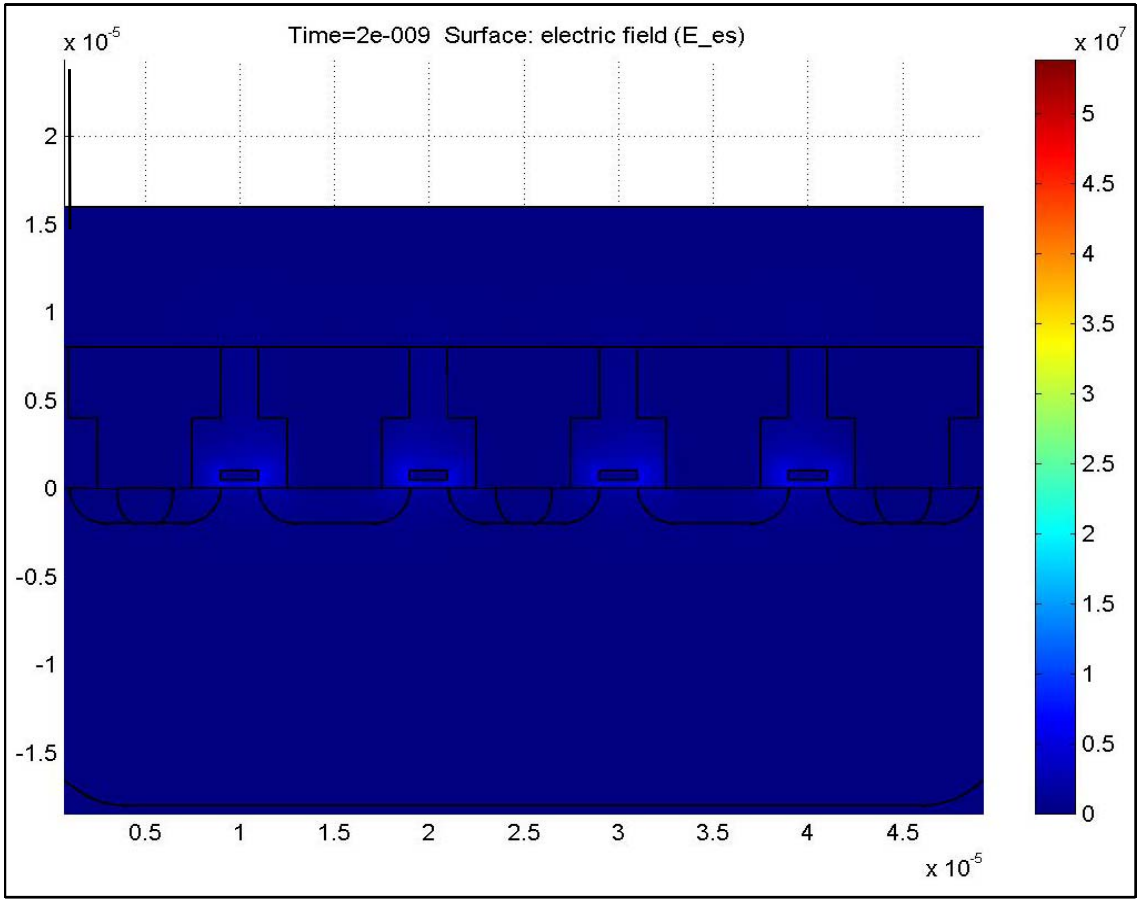


Breakthrough

Melting Process

Simulation of Breakthrough (CMOS)





Criterion of breakthrough:

$E_{BR,SiO2} \approx 10^8$ V/m

$E_{BR,Si} \approx 2 \cdot 10^7$ V/m

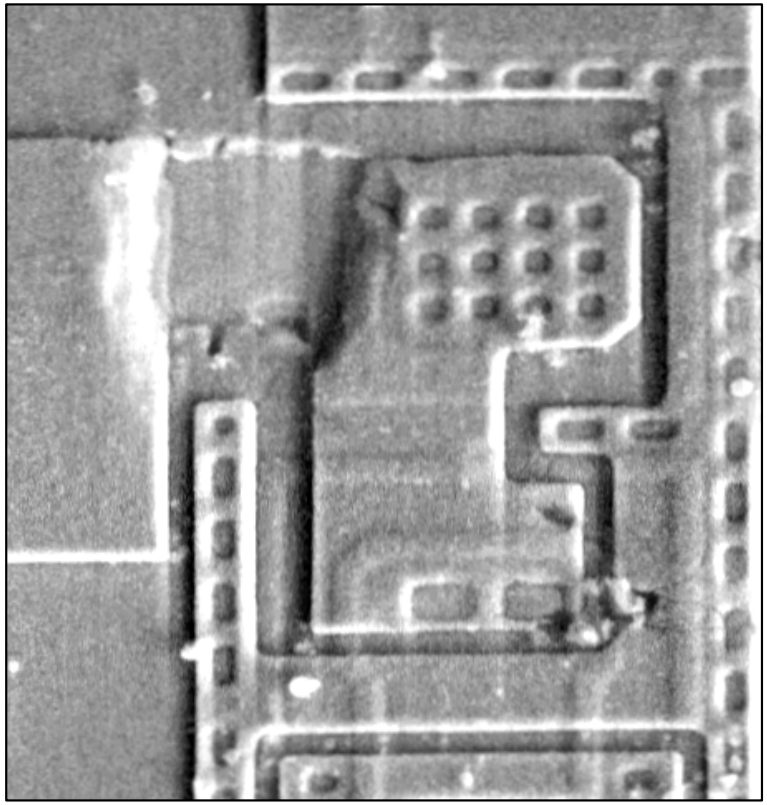
Simulation of the field strength characteristic:

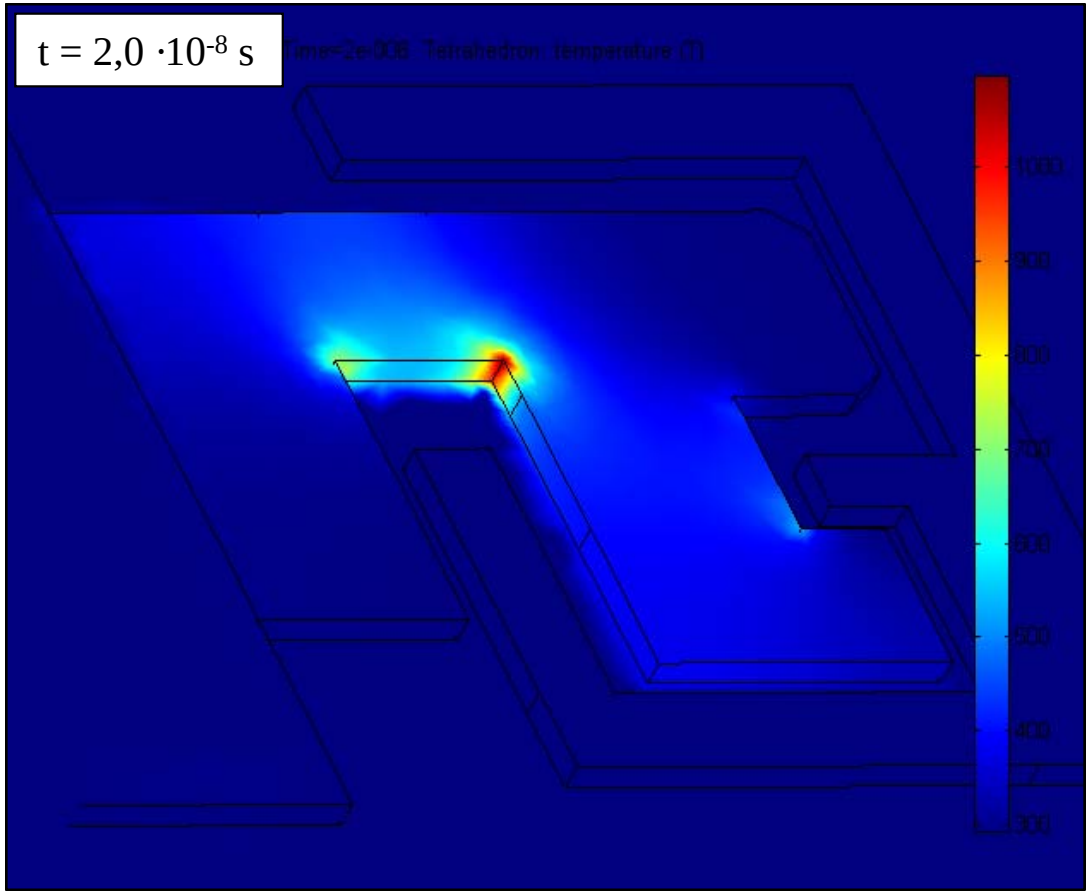
$E_{max} = 5{,}38 \cdot 10^7$ V/m $< E_{BR,SiO2}$ ⇨ no breakthrough over the whole period of time

$E_{max,Si} = 2{,}04 \cdot 10^7$ V/m $> E_{BR,Si}$ ⇨ Drain-Gate-Breakthrough at time $t = 1 \cdot 10^{-9}$ s

- but note, that there is no information about the depth → faulty simulation results

Simulation of Melting Process





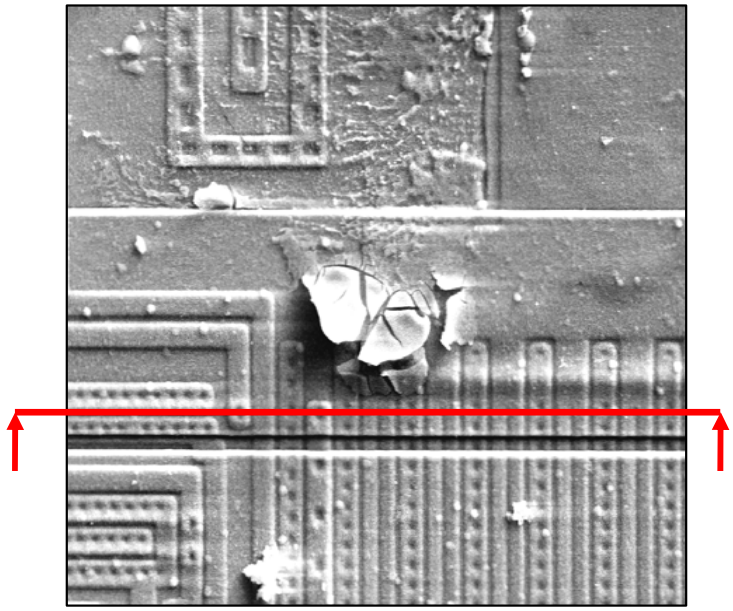
Criterion of melting:
$T_{Melting,AlSiCu} = 933$ K

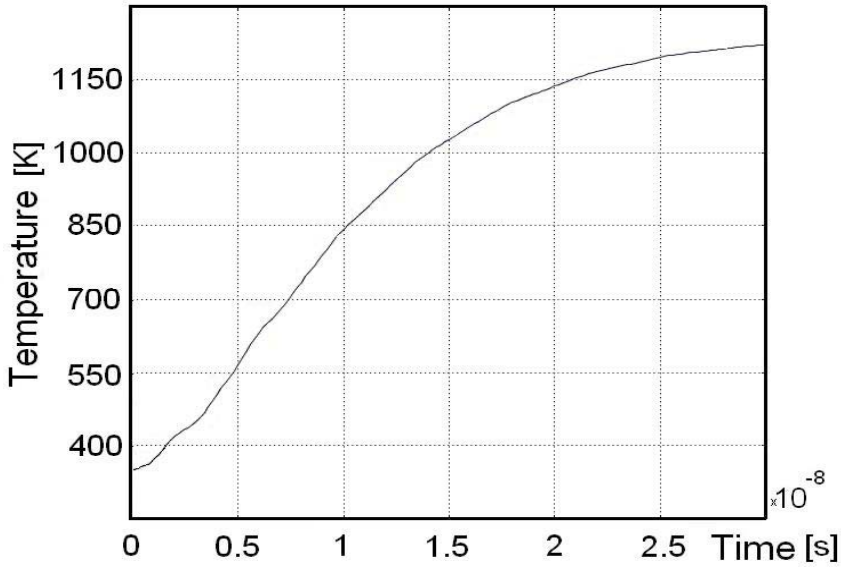
Simulation of the temperature characteristic:

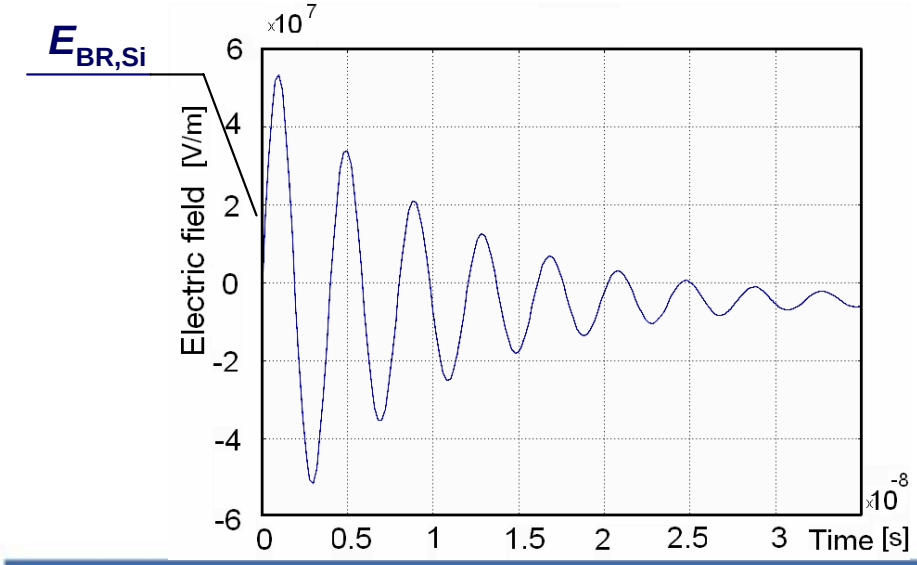
$T_1 = 720$ K $< T_{Melting,AlSiCu}$ ⇨ no destruction

$T_{max} = 1092$ K $> T_{Melting,AlSiCu}$ ⇨ melting of the conductor line at time $t \approx 0{,}8 \cdot 10^{-8}$ s

Time behavior of electric field strength and temperature







- determination of the time of breakthrough is possible
- the destruction field strength can be determined → modifying the input variable until $E_{max} = E_{BR}$
- determination of the time of melting process is possible

Summary

- Microscopical analysis shows breakthroughs and melting processes → both processes can be simulated
- Information got by the simulations:

  * time of breakdown

  * location of the position of the destruction

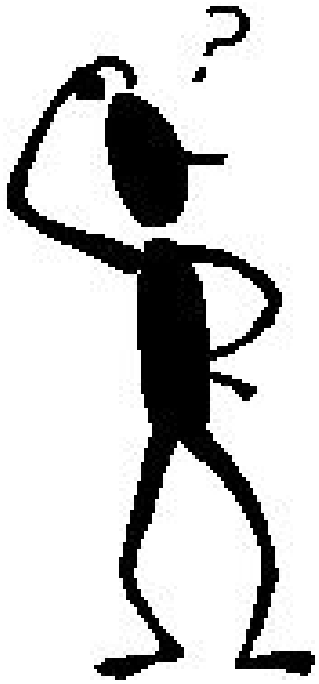
  * field strength required for destruction

- Simulation reproduces the measured results
- Problems:

  * only a part of the whole structure could be simulated, because the models are very complex

  * thin and large structures → problems with mesh

Thank you for your attention!



Questions?