UNIVERSITÄT BONN

SI LAB
Silizium Labor Bonn

PXD WORKSHOP – 22.05.2023

SIMULATION OF POWER LINES FOR THE INVESTIGATION OF THE EMERGENCY SHUTDOWN SYSTEM OF THE DEPFET PIXEL DETECTOR

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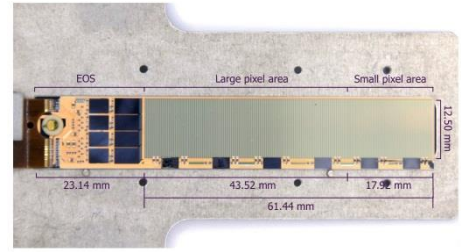
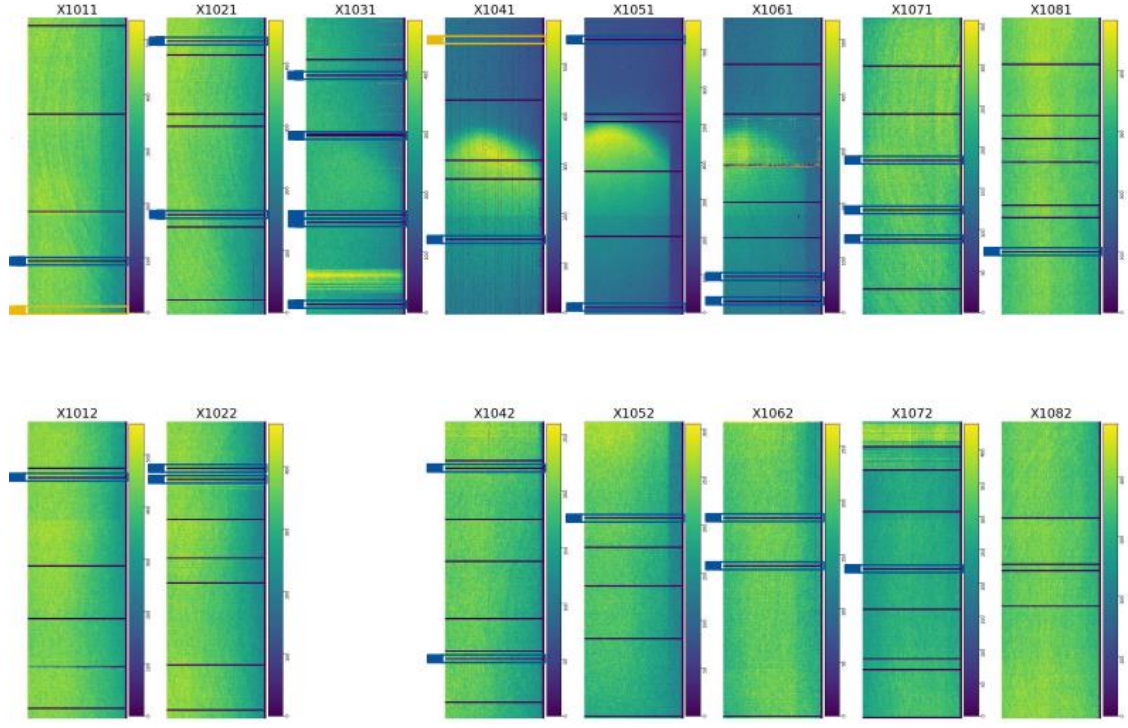
MOTIVATION

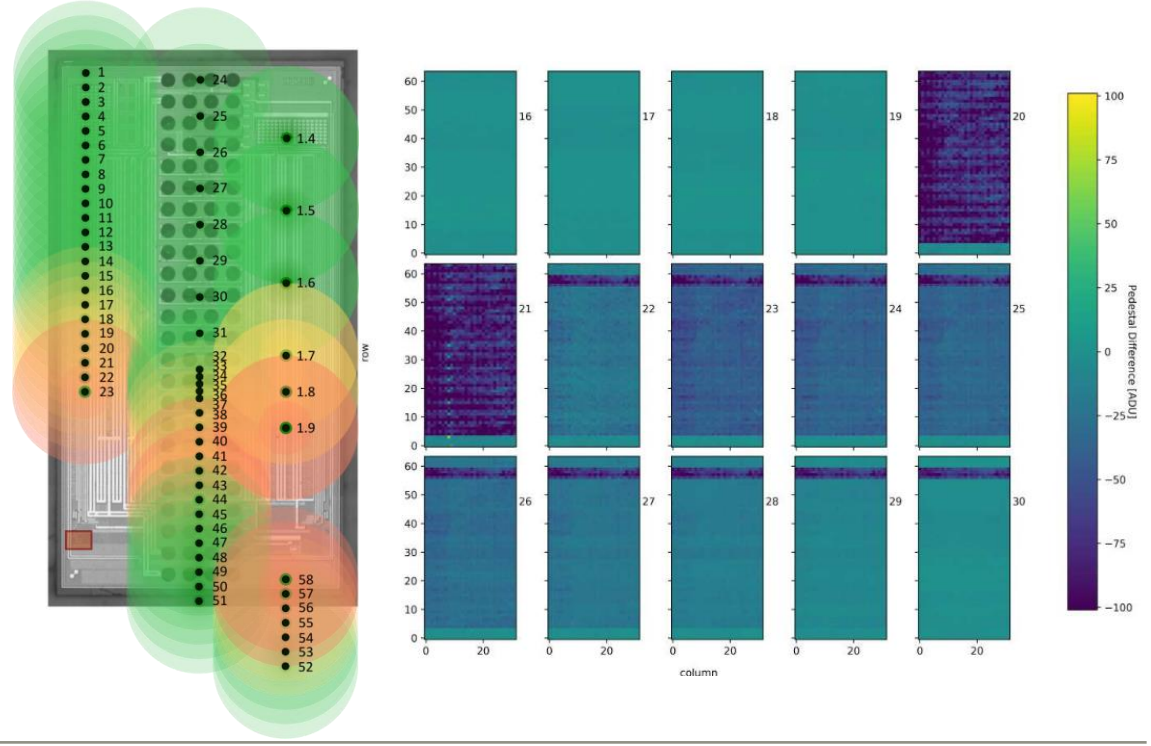


- Switchers **vulnerable** to large radiation ➔ shutdown as fast and safe as possible
- Example: Beam loss event in 2020
  - Estimated dose: 500 rad for PXD in 40µs
  - Increased number of **inefficient rows**
    - In total 89 inefficient rows ➔ efficiency drop of 3%
    - blue flags: freshly emerged inefficient rows
  - Increase of Switcher (Clear and Substrate) currents



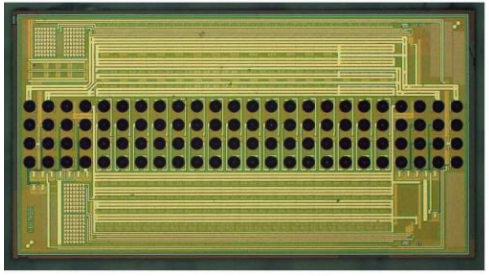
CONFIRMATION OF RESULTS

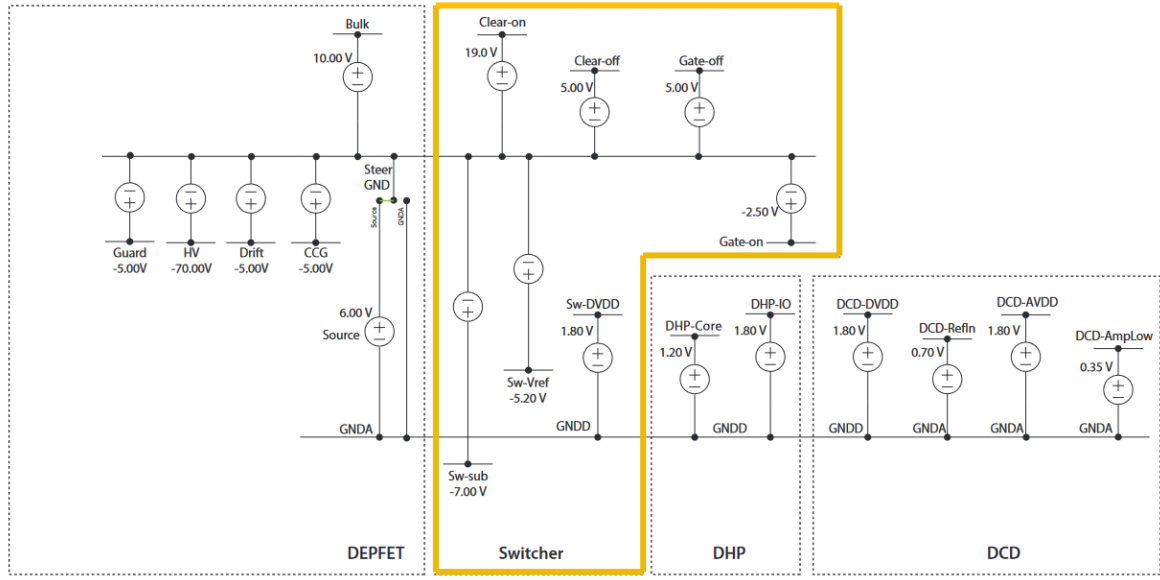
- Irradiation with electron beam
- Fine scan of ASIC area
  - July 2020 with H5029
  - Colour coded measurement points
  - red => permanent damage
- Raw data difference of 15 raw frames during injection
  - Second to last Switcher channel is damaged permanently
- Switcher only vulnerable when turned on



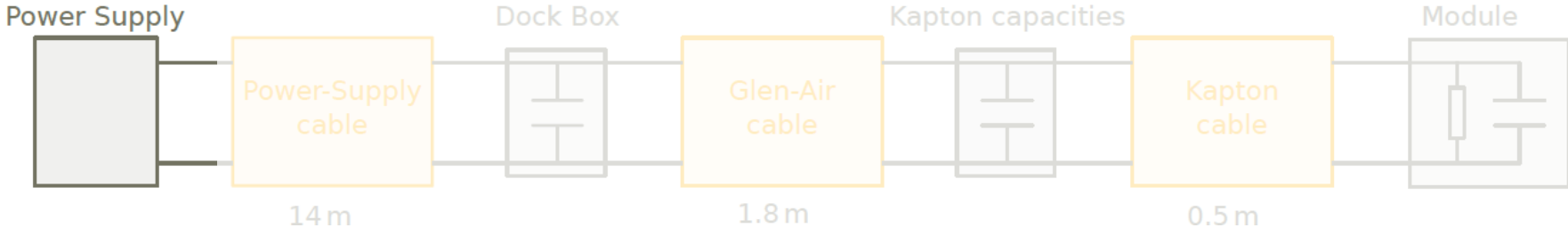
POWERING SCHEME

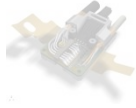
- Dedicated power-up and power-down sequence
- Range between +19V and -7V
- Switcher switches between high voltages

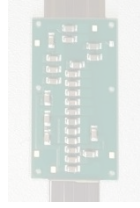


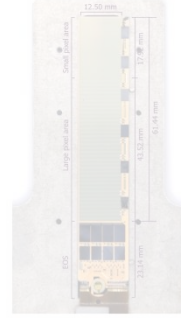


SIGNAL PATH


Power Supply
Dock Box
Kapton capacities
Module
Power-Supply cable
Glen-Air cable
Kapton cable
14 m
1.8 m
0.5 m







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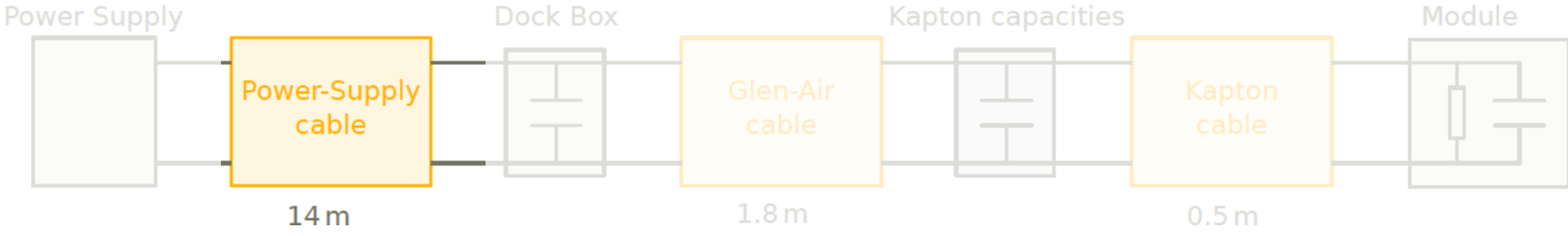
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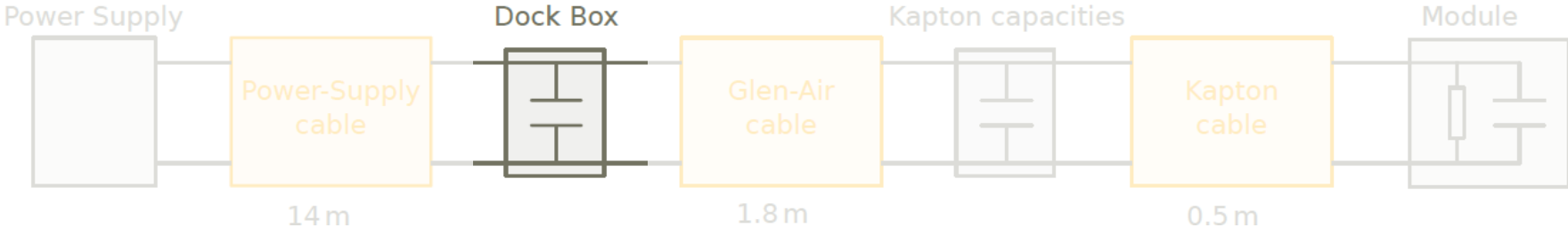
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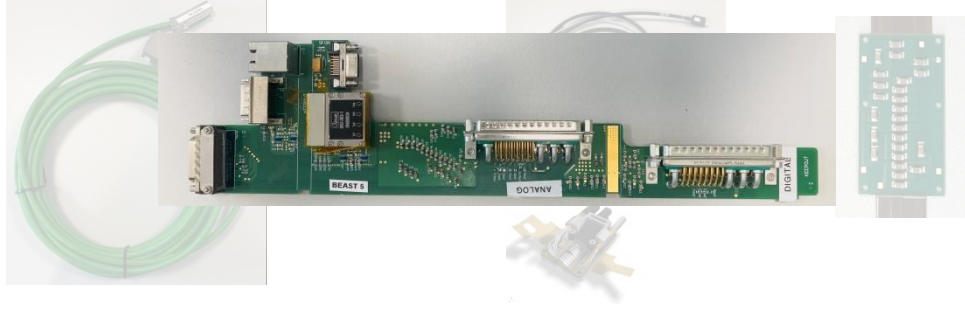
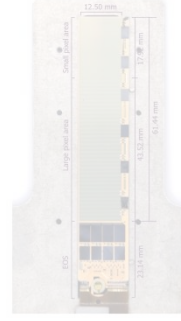

BEAST 5
ANALOG
DIGITAL



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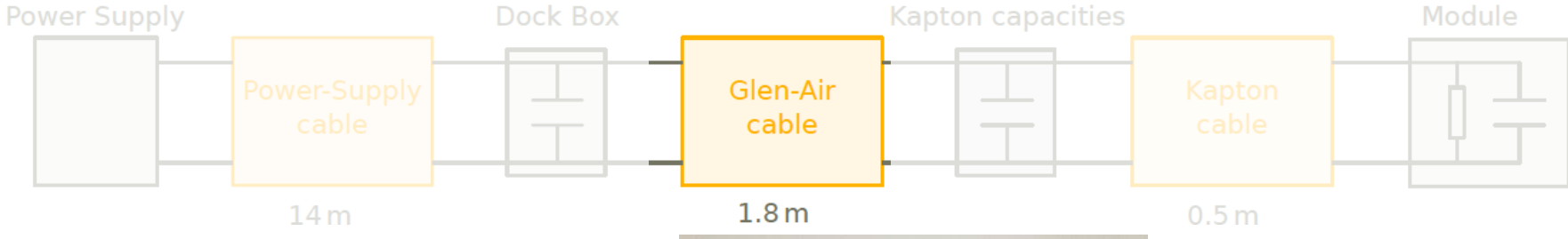
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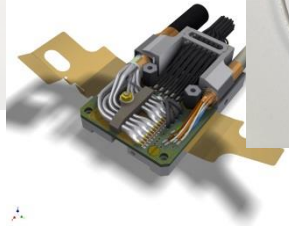

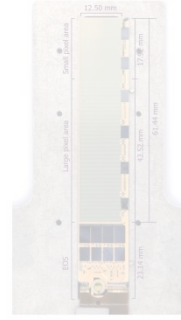

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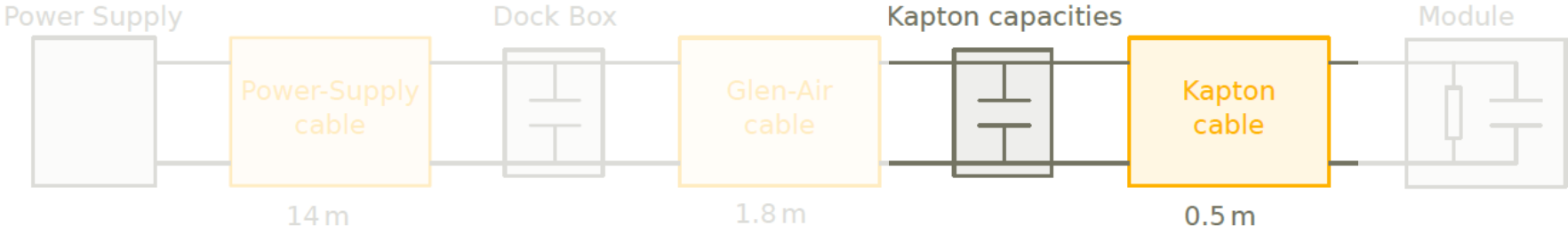
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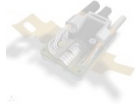

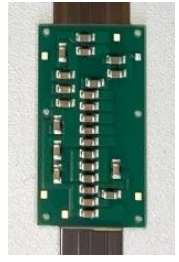

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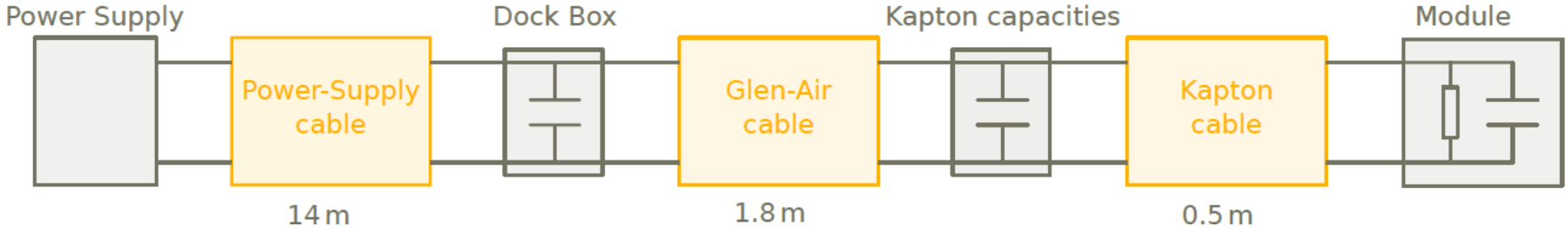
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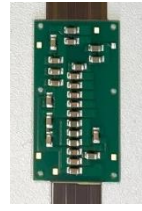
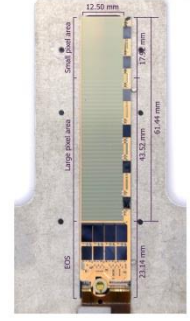
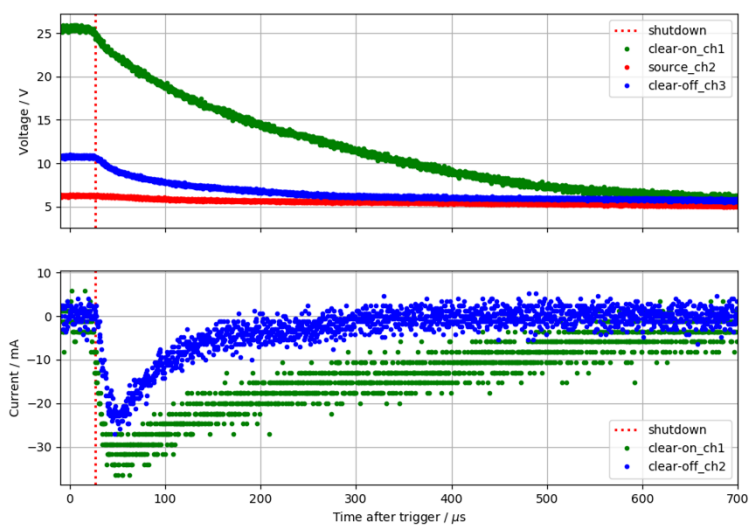
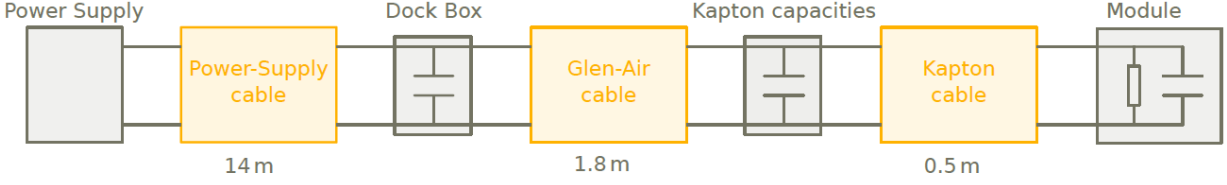



12.50 mm
Small pixel area
Large pixel area
17.0 mm
61.44 mm
43.52 mm
23.14 mm
EOS

REGULAR SHUTDOWN

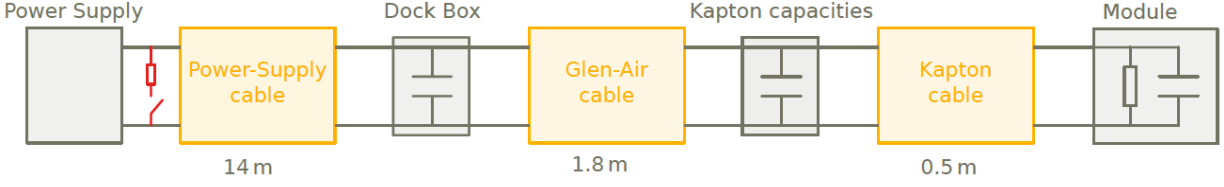
- System consists of segmented cable with additional capacitors (Patch Panel, Dock Box)
- Regular shutdown:
  - Switch off power
  - Long discharge due to capacitors
  - Shutdown time in ms-range

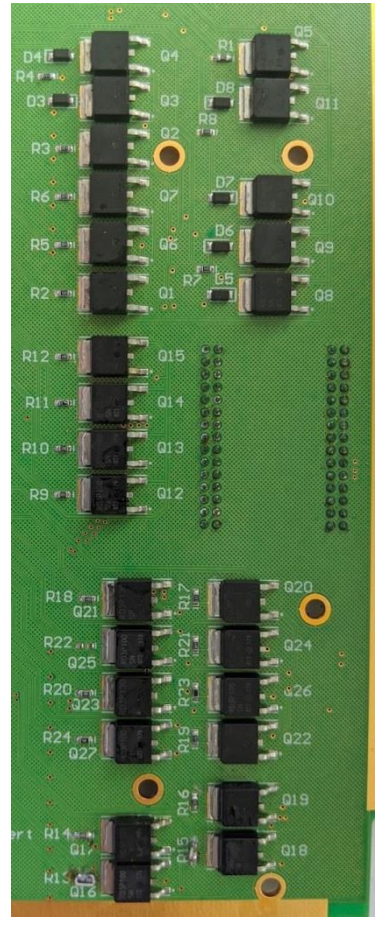




FAST SHUTDOWN BOARD

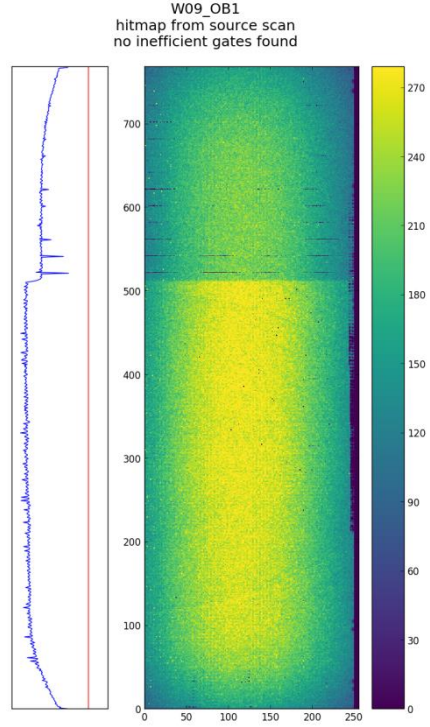
- Idea:
  - Short all channels with FET to respective ground
    - ➔ **Active pull-down**
  - Add resistor to influence pull-down time
- Problem: Required resistor values unclear yet



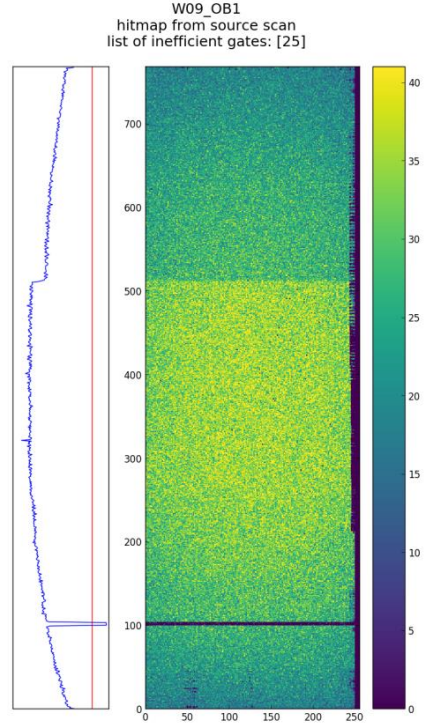


RESULTS FROM FAST SHUTDOWN

- Testing of **fast shutdown** board resulted in high Switcher currents
- Example:
  - Compare hitmaps before and after using fats shutdown board
  - Detected **inefficient rows**
- If done wrongly:
  - fast shutdown has **same effects** as a beam loss event



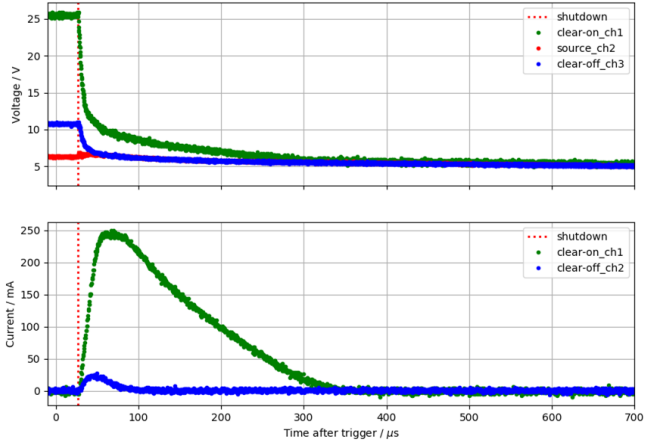
Before fast shutdown

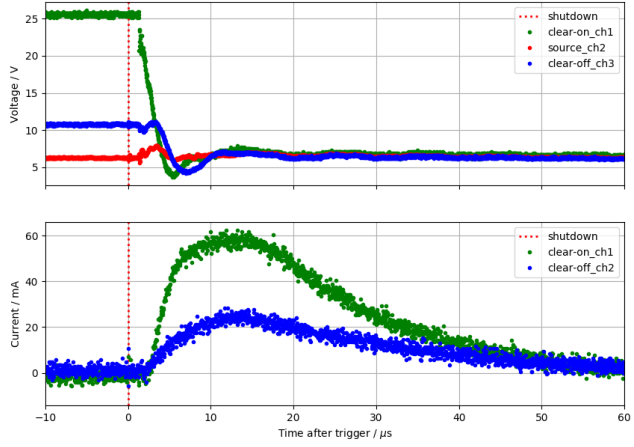


After fast shutdown

FAST SHUTDOWN MEASUREMENT

- Example: shutdown of voltage required for Switcher (Clear-on/ Clear-off), measured at Power Supply



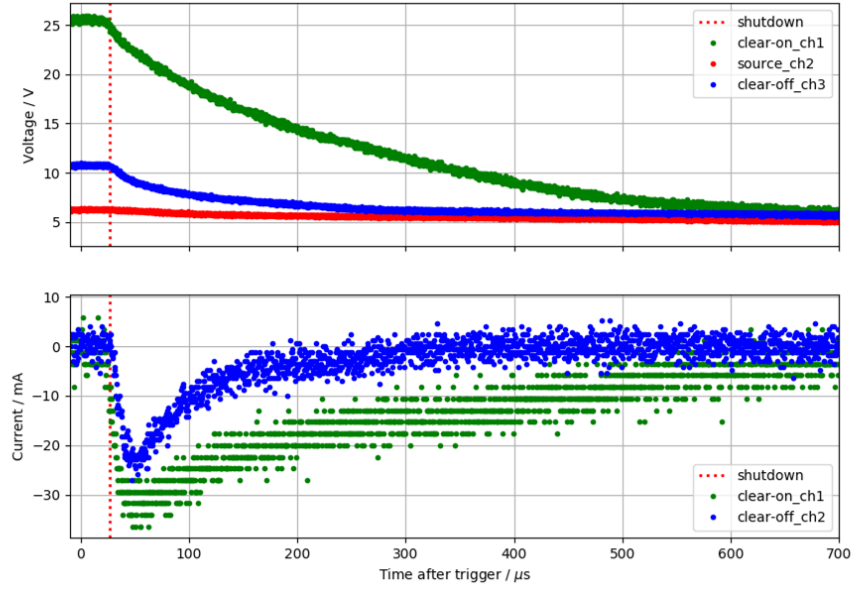


- $R_{clear\text{-}on}$ = 10 Ω, $R_{clear\text{-}off}$ = 10 Ω
- Decreased shutdown time
- Influence of FET visible

- $R_{clear\text{-}on}$ = 0 Ω, $R_{clear\text{-}off}$ = 0 Ω
- $V_{clear\text{-}on}$ drops below $V_{clear\text{-}off}$ ➔ violation of shutdown sequence

FAST SHUTDOWN MEASUREMENT

- Example: shutdown … t Power Supply



- $R_{clear\text{-}on}$ = 10 Ω, $R_{clear\text{-}c…}$ … 0 Ω
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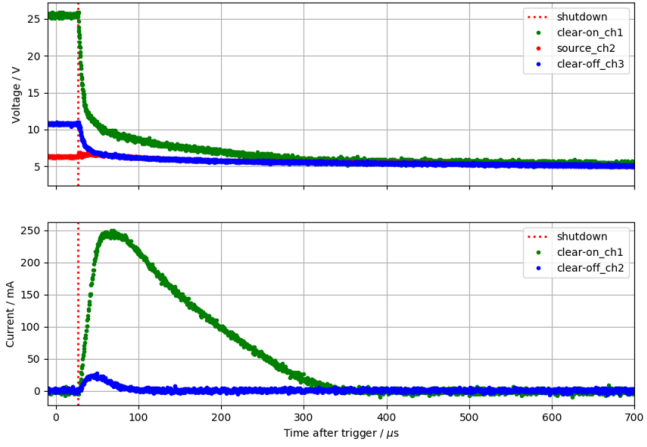

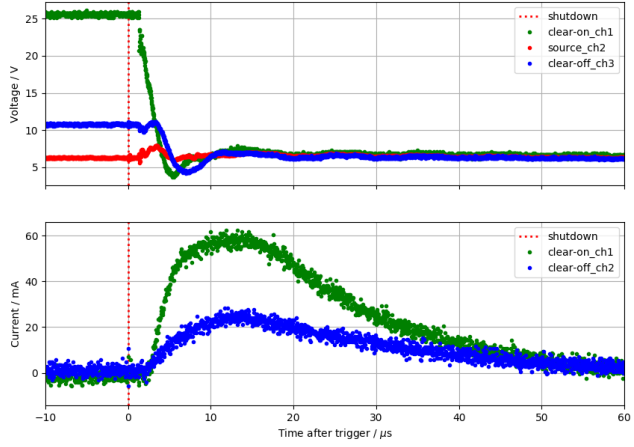

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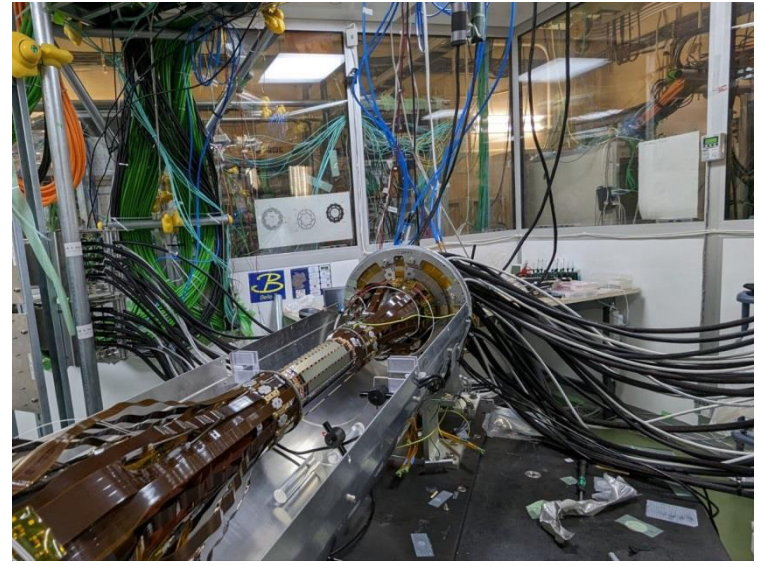
SYSTEM SIMULATION

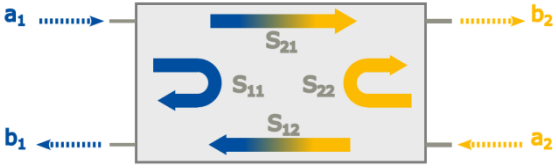
➔ Simulate powering scheme of single module
- understand limitations
- find hardware modifications

- Influence of cables on fast shutdown unknown: in total **>15m**
- Measure S-Parameters to characterize cable
- Use cable characteristics in simulation
- Different simulation approaches
  - LTspice s2spice-Program
  - LTspice lossy transmission line (LTRA)model
  - HyperLynx S-Parameter model



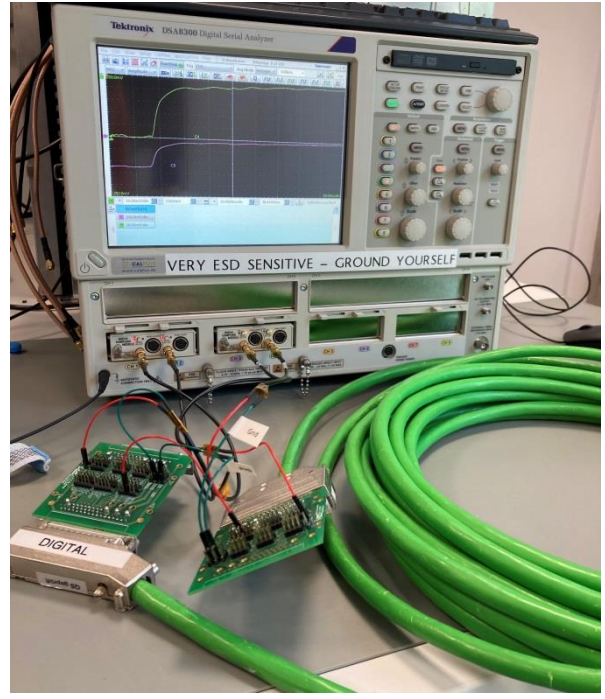
MEASURE S-PARAMETERS

- Describe electrical behaviour of cable
- Measure incoming and outgoing wave for various frequencies
- Deduce information about L and C-values within cable



$$S_{11} = \frac{b_1}{a_1} \qquad S_{12} = \frac{b_1}{a_2}$$

$$S_{21} = \frac{b_2}{a_1} \qquad S_{22} = \frac{b_2}{a_2}$$



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SIMULATION METHODS

LTspice: LTRA-model	LTspice: s2spice-model	HyperLynx: S-Parameter-model
• Lumped RLC-circuit • Takes frequency-independent values for R, L and C • Use S-Parameters to deduce L and C-values • R-values: four-terminal-sensing	• Transform S-Parameter file into frequency-response-table for voltage dependent voltage sources • Add as subcircuit into simulation	• Uses S-Parameters directly • Enforces symmetry and passivity in S-Parameters
• Fast simulation possible	• Frequency dependent values • LTspice very versatile	• Easy to use • Frequency dependent values
• Less accurate • Very high standard deviation for R, L and C-values	• Takes long to simulate • Unreliable, as voltage sources are simulation duration dependent	• Takes some time to simulate • Simulation duration is limited to 500 µs

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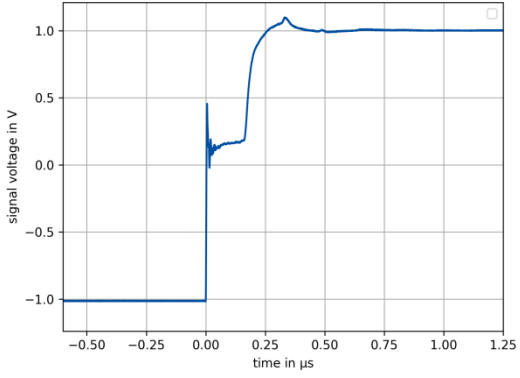
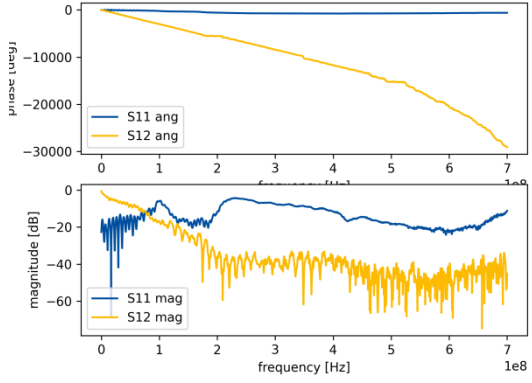
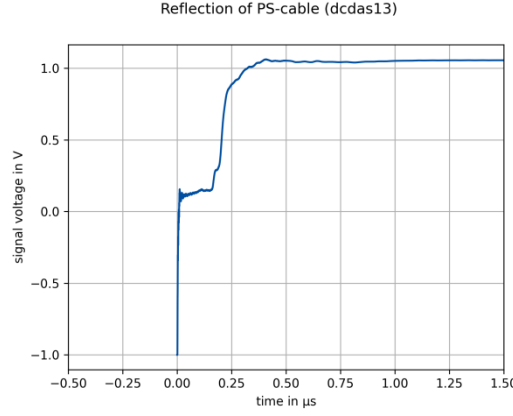
SIMULATION PROCESS

➔ Example: Reflection at open cable end (HyperLynx and s2spice-model)







Measure with **time domain** reflectometer

→

Fourier transformed into **frequency domain**

➔ Scattering Parameters

→

Use S-parameters in **time-domain** transient simulation

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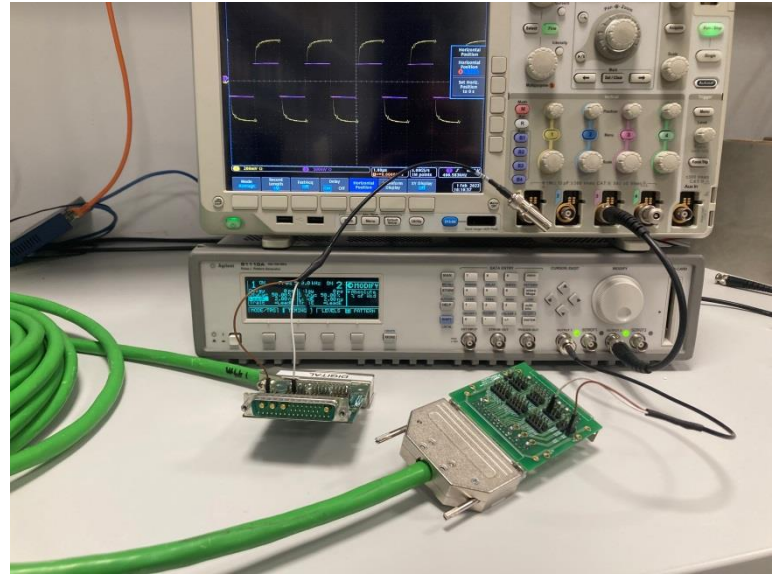
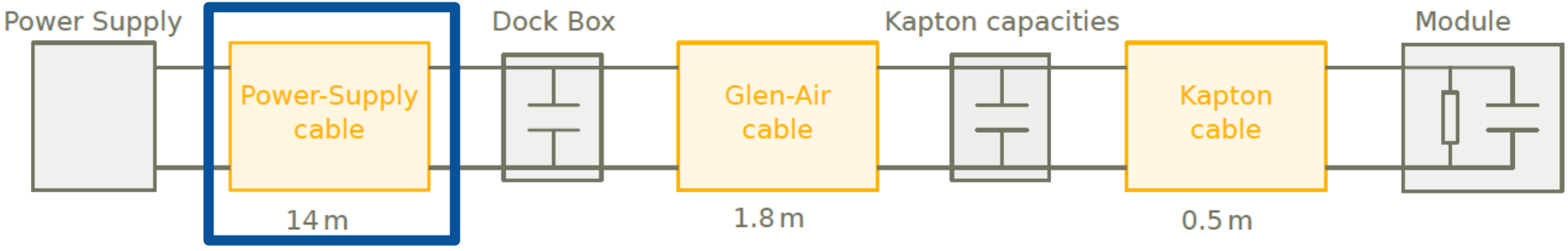
VERIFY SIMULATION

- Examine **falling edge** of square pulse
- To **verify** simulation compare with measurement
  - Function generator used for creating squared pulse
  - View transmitted signal on oscilloscope
- Verify each cable segment **individually**
- For quantification:
  - Compute **difference in voltage** between simulation and measurement data
  - Both data sets are interpolated linearly



CABLE MODEL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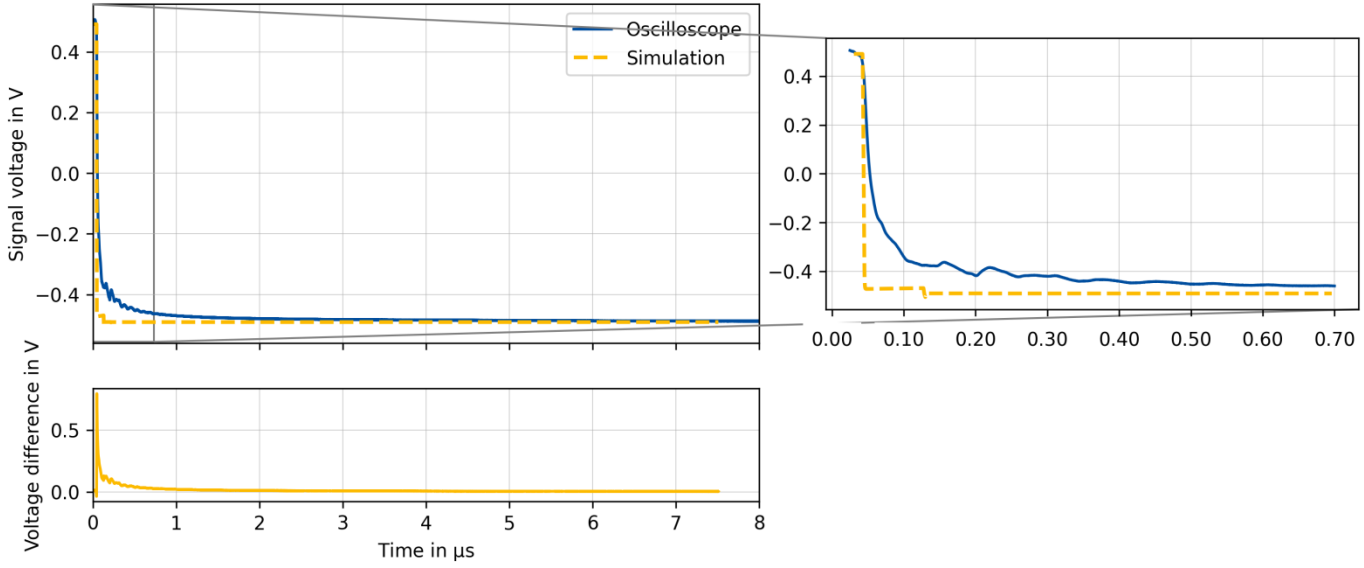
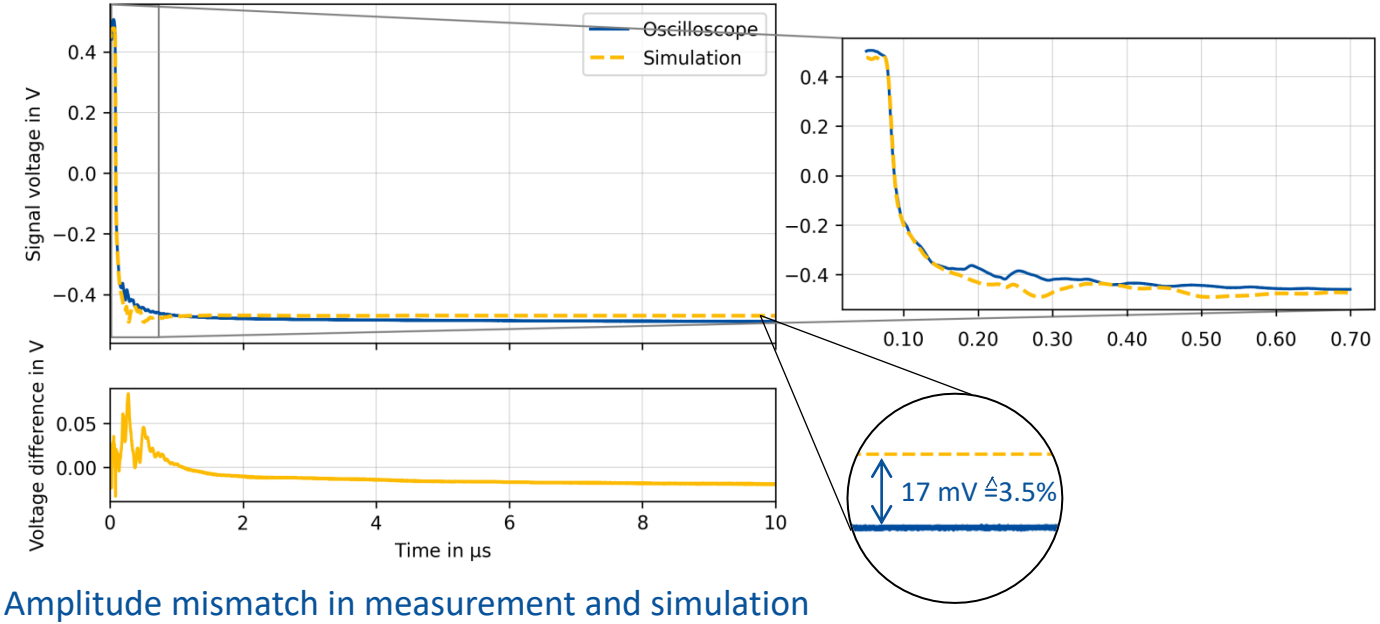
SIMULATION RESULTS: LTSPICE- LTRA MODEL

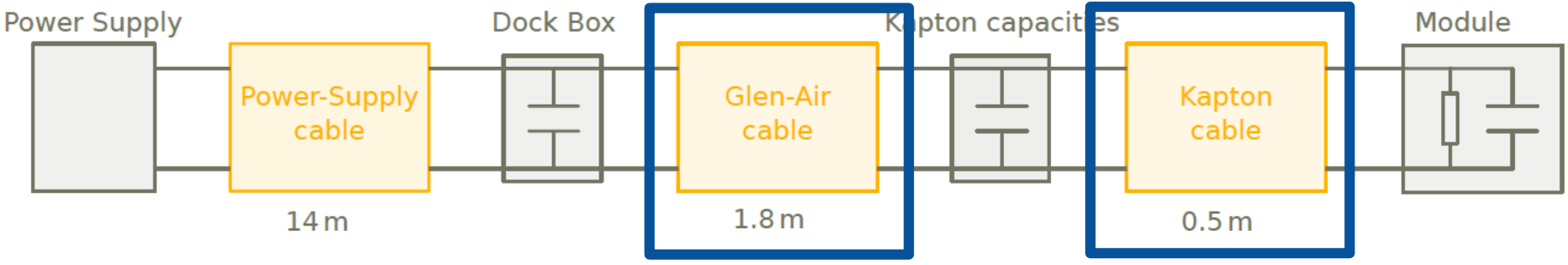


- Amplitude of voltage signal fits
- Falling edge not captured well

SIMULATION RESULTS: HYPERLYNX

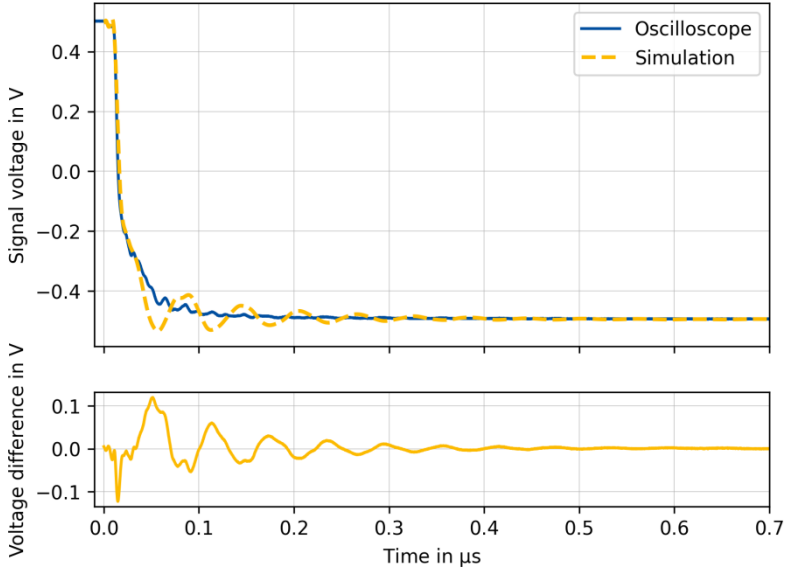


- Amplitude mismatch in measurement and simulation
- Good agreement in falling edge

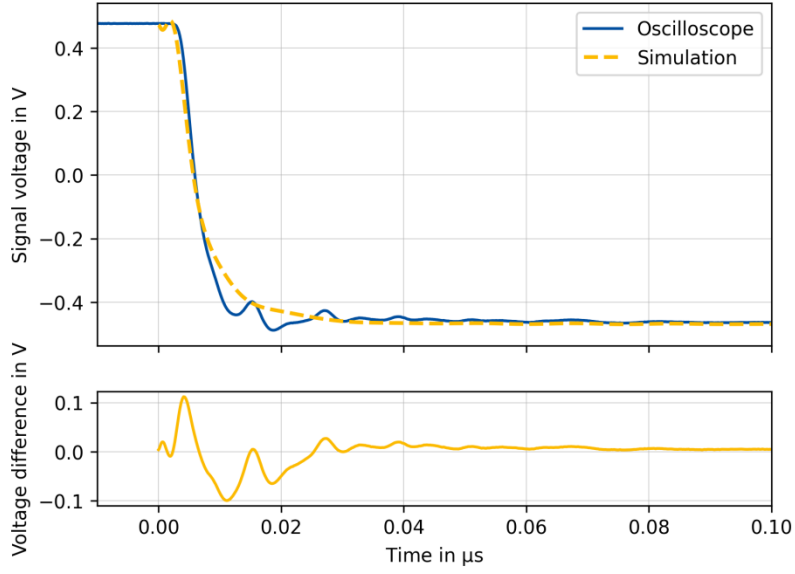

Power Supply
Power-Supply cable
14 m
Dock Box
Glen-Air cable
1.8 m
Kapton capacitors
Kapton cable
0.5 m
Module

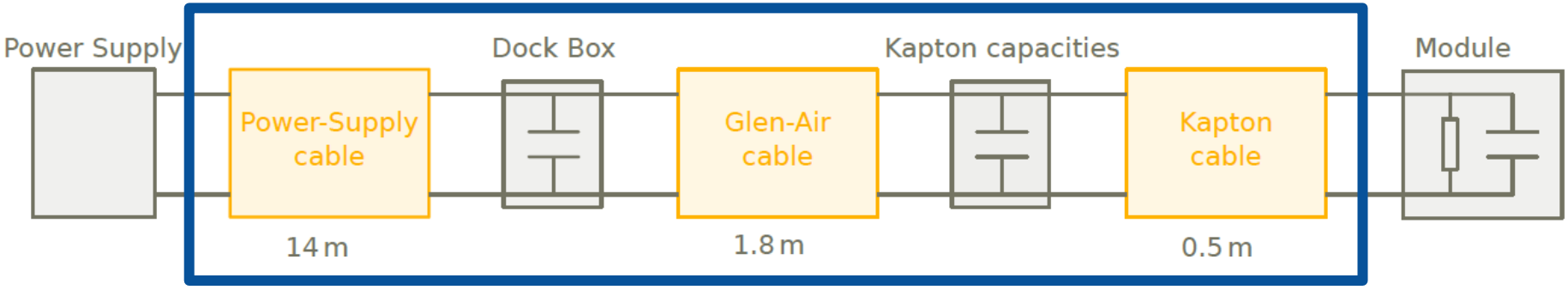
GLEN-AIR-CABLE AND KAPTON-CABLE

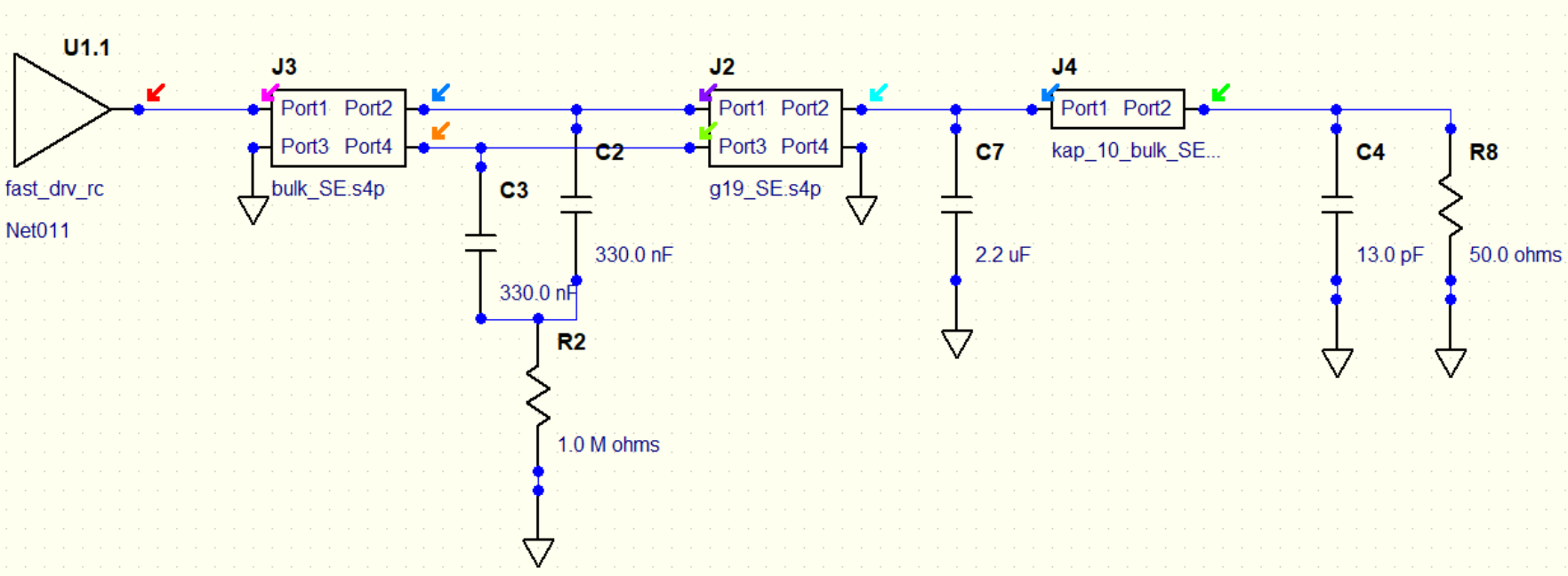
- Example of single **Glen-Air-cable Bulk-line** with Steer GND/ Source as reference using HyperLynx

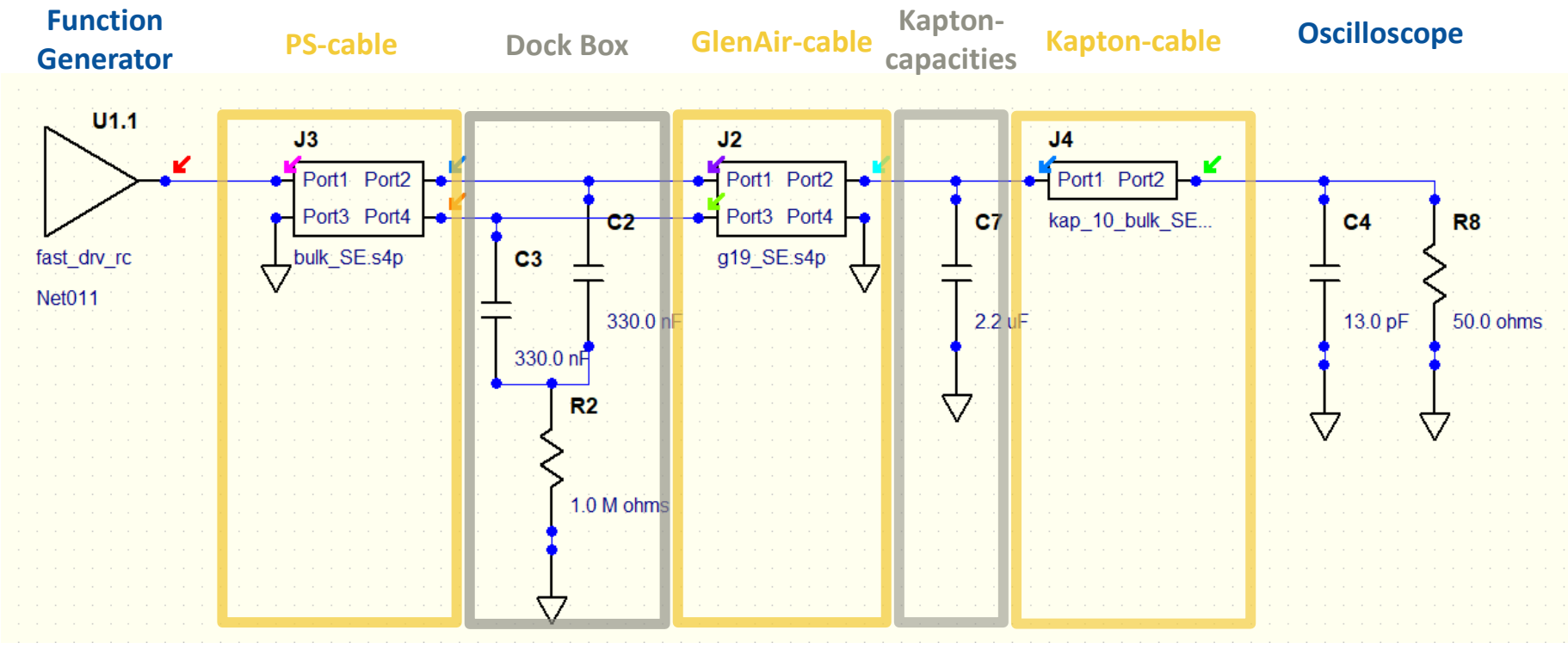


Single **Kapton-cable Bulk-line**



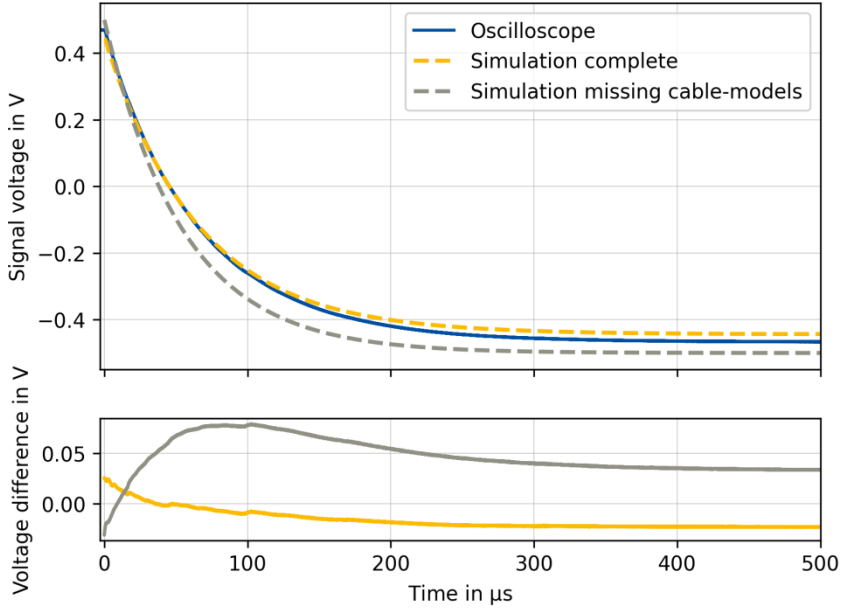

Power Supply
Power-Supply cable
14 m
Dock Box
Glen-Air cable
1.8 m
Kapton capacities
Kapton cable
0.5 m
Module


U1.1
fast_drv_rc
Net011
J3
Port1 Port2
Port3 Port4
bulk_SE.s4p
C3
330.0 nF
C2
330.0 nF
R2
1.0 M ohms
J2
Port1 Port2
Port3 Port4
g19_SE.s4p
C7
2.2 uF
J4
Port1 Port2
kap_10_bulk_SE...
C4
13.0 pF
R8
50.0 ohms


Function Generator
PS-cable
Dock Box
GlenAir-cable
Kapton-capacities
Kapton-cable
Oscilloscope
U1.1
fast_drv_rc
Net011
J3
Port1 Port2
Port3 Port4
bulk_SE.s4p
C3
330.0 nF
C2
330.0 nF
R2
1.0 M ohms
J2
Port1 Port2
Port3 Port4
g19_SE.s4p
C7
2.2 uF
J4
Port1 Port2
kap_10_bulk_SE...
C4
13.0 pF
R8
50.0 ohms

PS-CABLE + DB + GLEN AIR-CABLE + KAPTON

- Example of single Bulk-line with Steer GND/ Source as reference using HyperLynx



- Compare:
  - Simulation including cable-models and capacitors
  - Simulation without cables but only considering capacitors
- Influence of cables is not negligible
- Amplitude of simulation still off

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CONCLUSION

- Goal is prevention of switcher damage in beam loss events
- Fast shutdown ➔ avoid power-down sequence violation
- Complex system due to many voltages
- Simulation as a tool to better understand the system
- Good agreement for falling edge but unresolved amplitude problem

➔ Add load to simulation and measurement

➔ Create complete system simulation

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THANK YOU!

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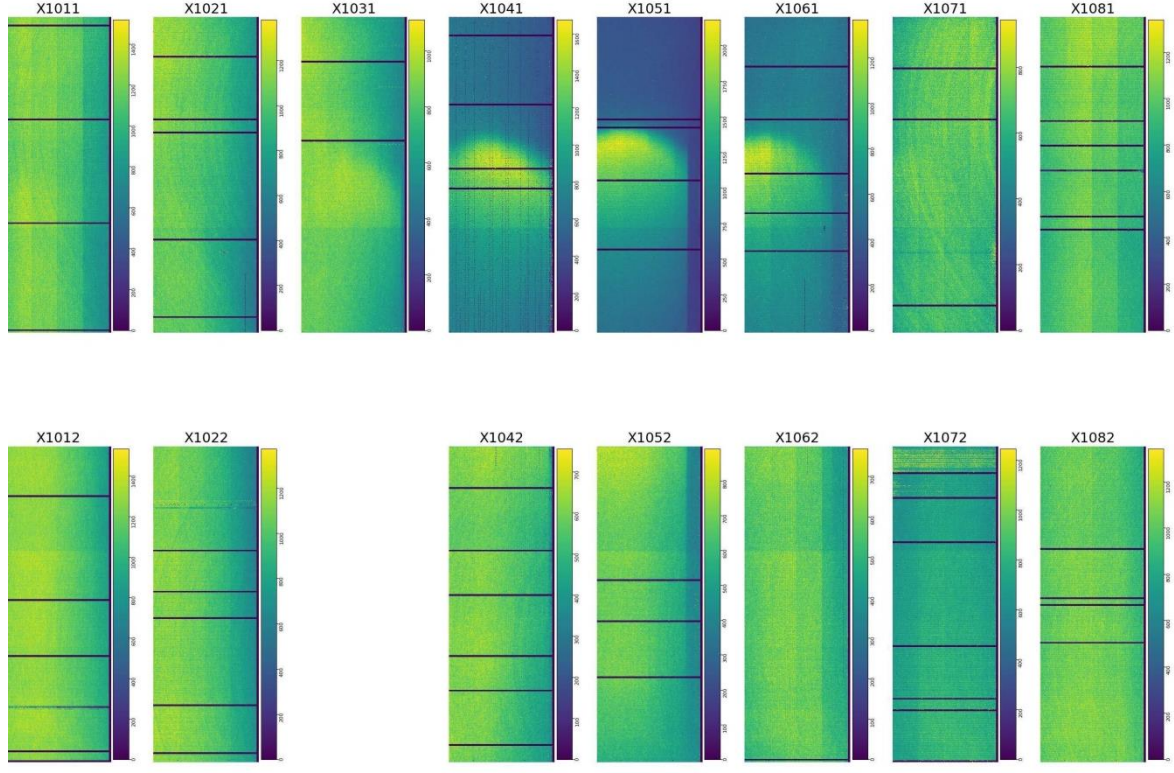
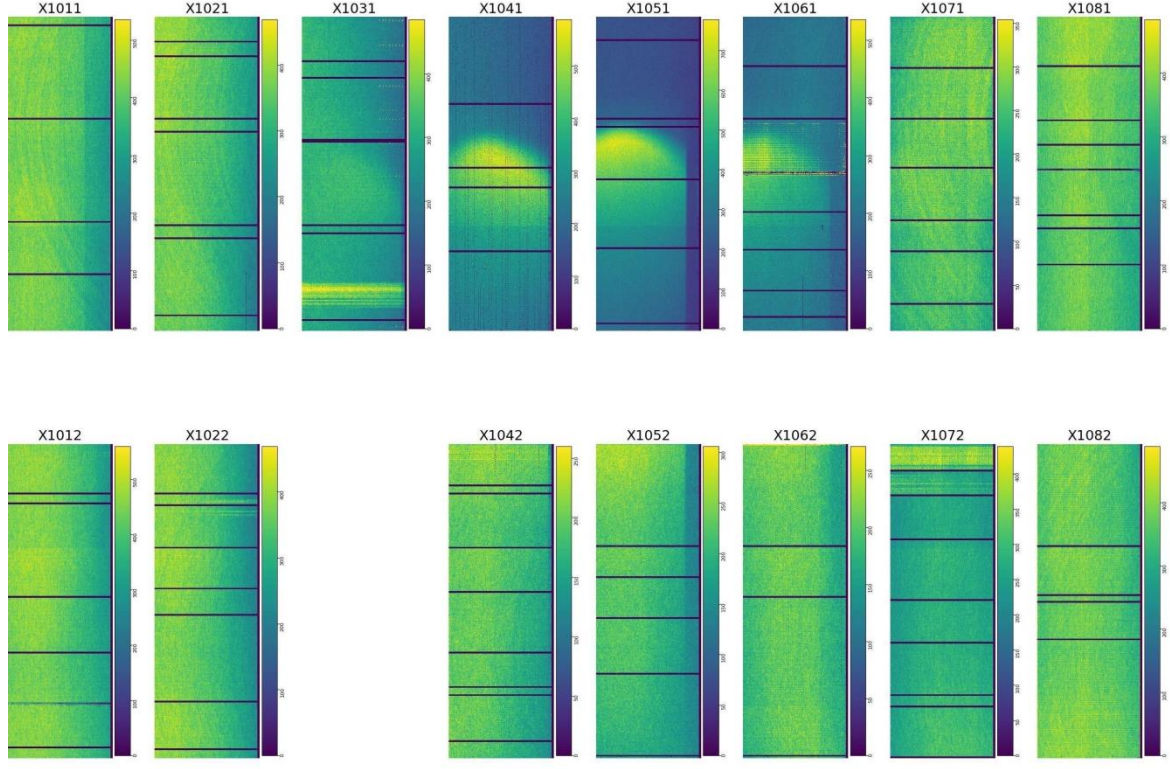
BEFORE BEAM LOSS EVENT



AFTER BEAM LOSS EVENT

- 89 inefficient Switcher channels (➔ 89x4 matrix rows)
- 15 modules of inner layer: 192x15=2880 Switcher channels



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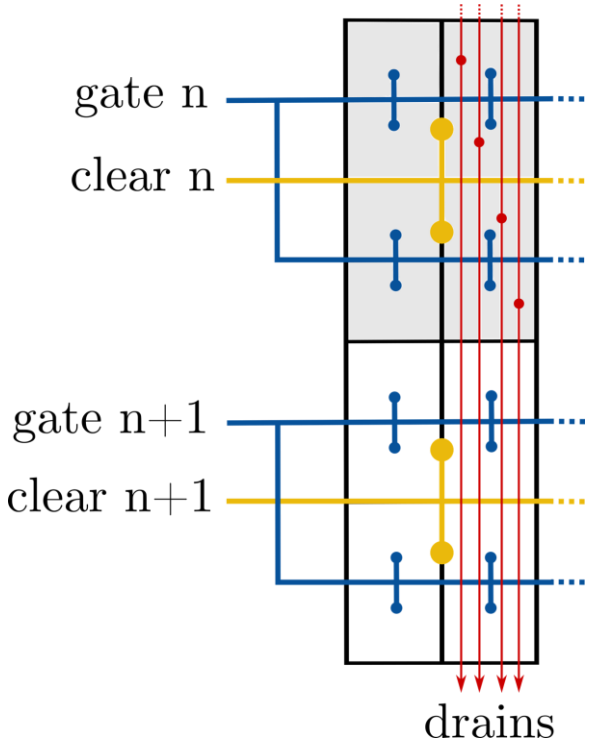
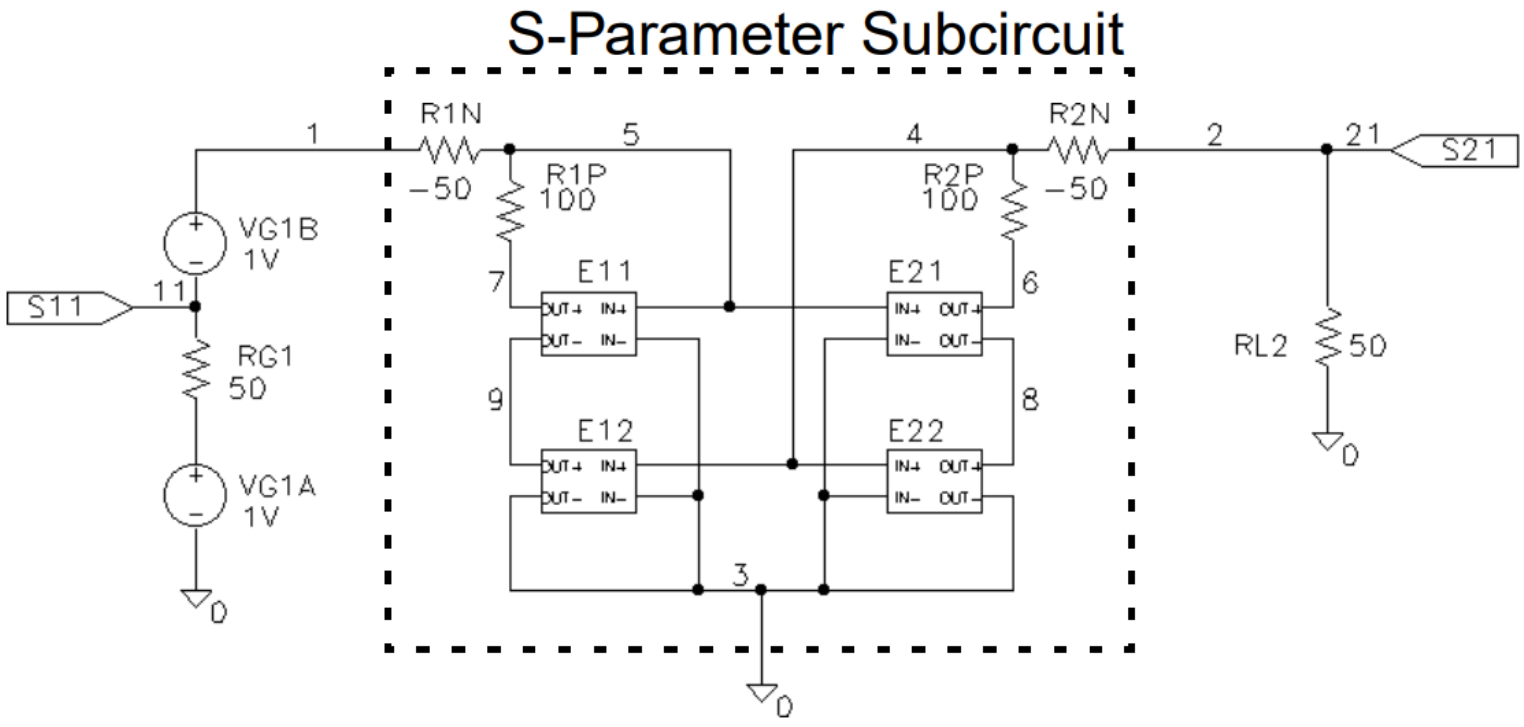
SIMULATION METHODS

LTspice: LTRA-model	LTspice: s2spice-model	HyperLynx: S-Parameter-model
• Lumped RLC-circuit • Takes frequency-independent values for R, L and C • Use S-Parameters to deduce L and C-values • R-values: four-terminal-sensing	• Transform S-Parameter file into frequency-response-table for voltage dependent voltage sources • Add as subcircuit into simulation	• Uses S-Parameters directly • Enforces symmetry and passivity in S-Parameters
• Fast simulation possible	• Frequency dependent values • LTspice very versatile	• Easy to use • Frequency dependent values
• Less accurate • Very high standard deviation for R, L and C-values	• Takes long to simulate • Unreliable, as voltage sources are simulation duration dependent	• Takes some time to simulate • Simulation duration is limited to 500 µs


gate n
clear n
gate n+1
clear n+1
drains


S-Parameter Subcircuit
1
R1N
−50
5
R1P
100
4
R2P
100
R2N
−50
2
21
S21
VG1B
1V
11
S11
RG1
50
VG1A
1V
0
7
E11
6
E21
9
E12
8
E22
3
0
RL2
50
0