Simulation

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DESY, MKK
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Outline

1) What is simulation ?

2) Why simulation ?

3) Principles of simulation

4) Types of simulation

- Analog simulation
- Numerical simulation

5) Conclusion

What is simulation?

What is simulation ?

Those who can, do.
Those who can't, simulate.
-- anonymous writer

What is simulation ?

- **Simulation** is a procedure to analyse physical systems
- **Simulation** is an imitation of real-world activities
- Simulation is performed by developing a model
- A model builds a conceptual framing to describe a physical system

What is simulation ?

Physical system

Experiments with physical system

Experimenta with models of physical system

Physical model

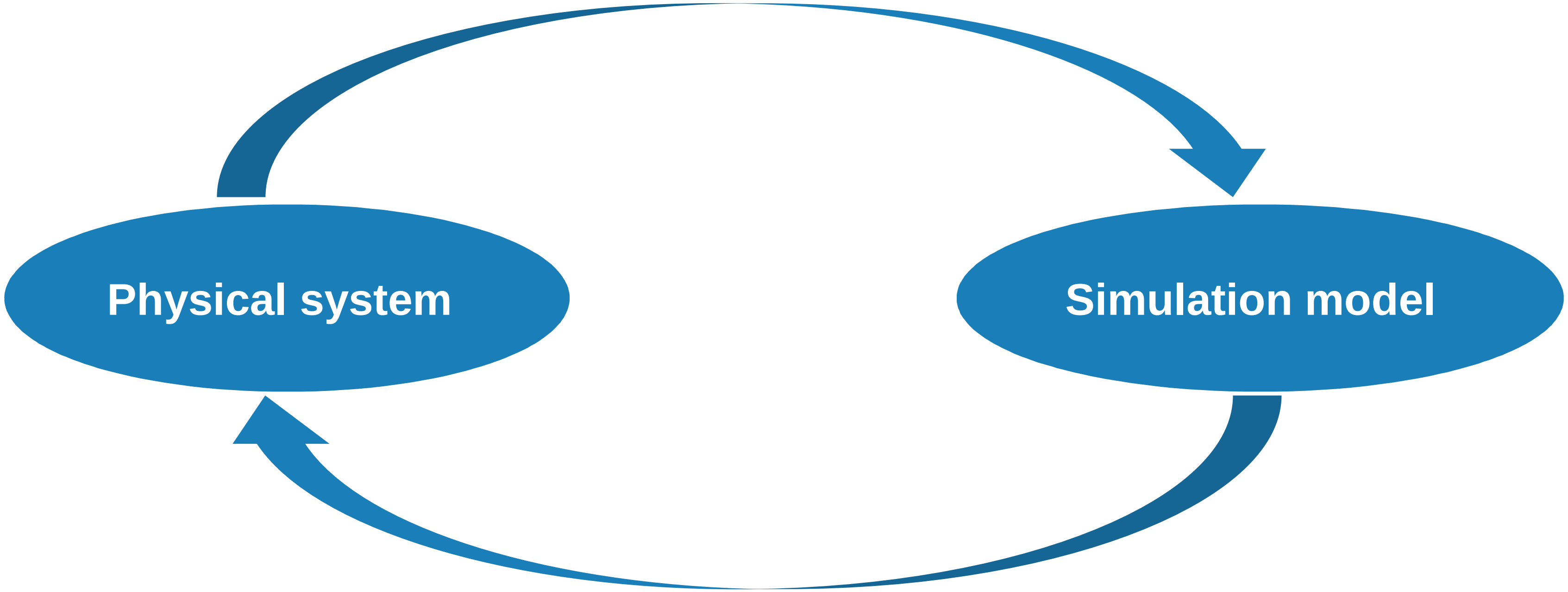
Mathematical model

Analytical method (accurate)

Simulation (approximate)

What is simulation ?

But please never forget!



Simulations are gross simplifications of the reality and are only as good as their underlying assumptions

Why simulation?

Why simulation ?

- A study on the real system could be too dangerous, too complicated, too expensive
- The real system doesn’t exist yet, isn’t understood or is very complex
- The real system is working too fast / too slow or can’t be observed directly
- Nowadays the complexity of physical systems in the power converters world makes the use of simulation unavoidable

Why simulation ?

Fields of application

Simulation →

- Physics
- Astrophysics
- Chemistry
- Biology
- ecomomics
- Engineering
- Social science
- Training
- Education
- Video games
- And more…

→

- Power accelerators
- Power converters

Advantages of simulation

- Saving time and money
- Repeatable and optimizable
- Studying the behavior of a system without building it
- Helps to find un-expected behavior of the physical system

Disadvantages of simulation

- Simulation errors
- Can’t provide easy answers to complex problems
- Can’t solve problems by itself
- Time consuming and expensive

Principle of simulation

Principle of simulation

Simulation

- Input data (Modeling)
- Boundary conditions
- Solution of differential / integral equations

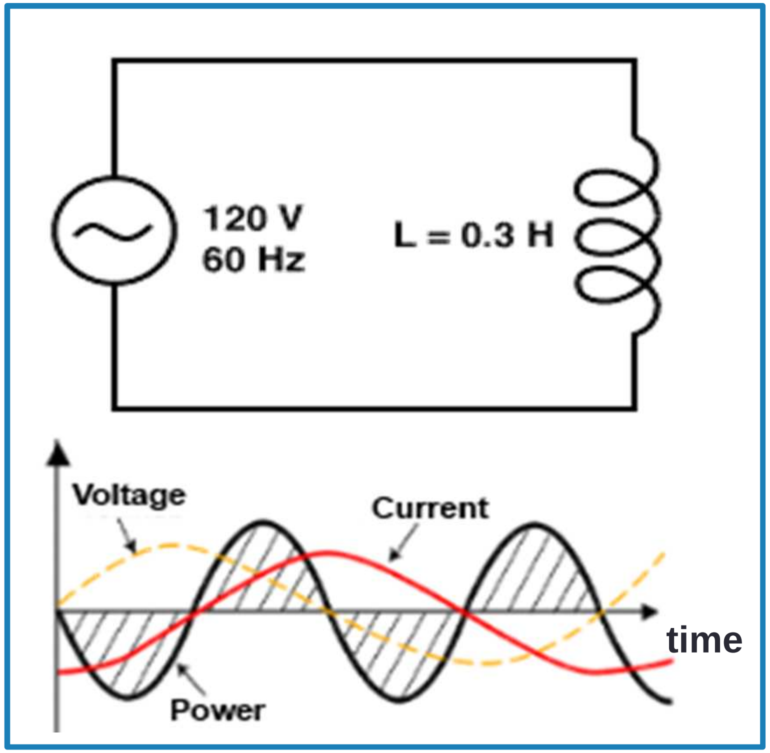
(1) Analog simulation

- Time precisely controllable
- Space less controllable
- Mainly for circuit simulation

(2) Numerical simulation

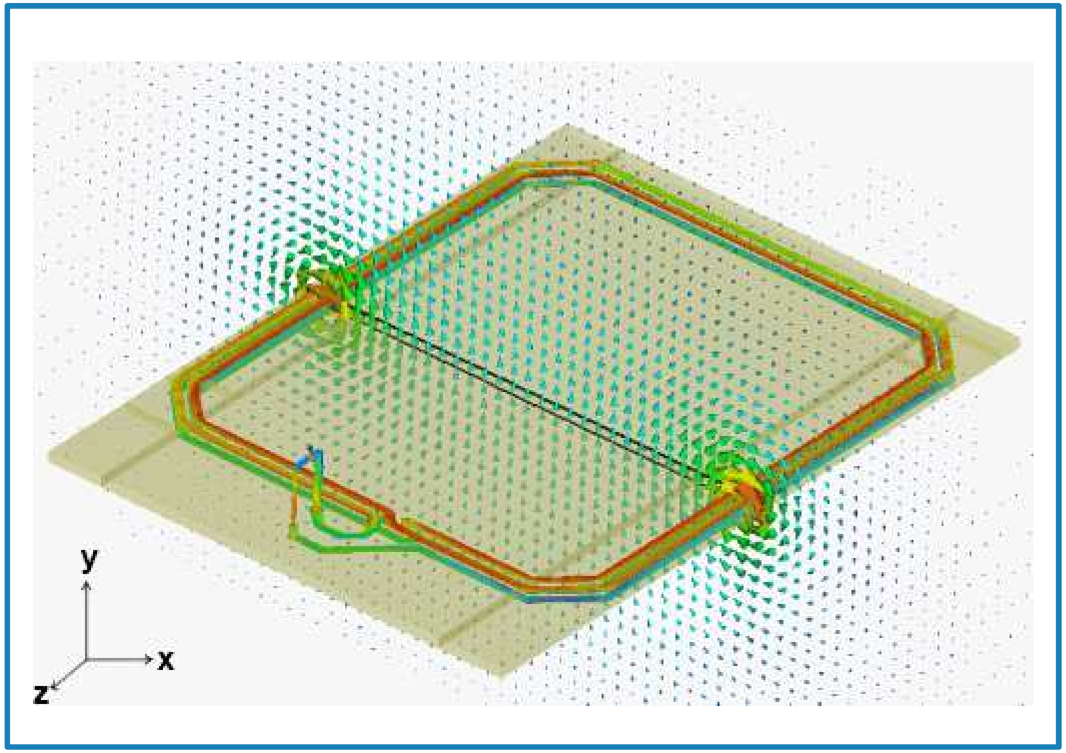
- Space precisely controllable
- Time less controllable
- Mainly for field simulation

(1) Analog simulation



The current and voltage waveforms for a pure inductance circuit

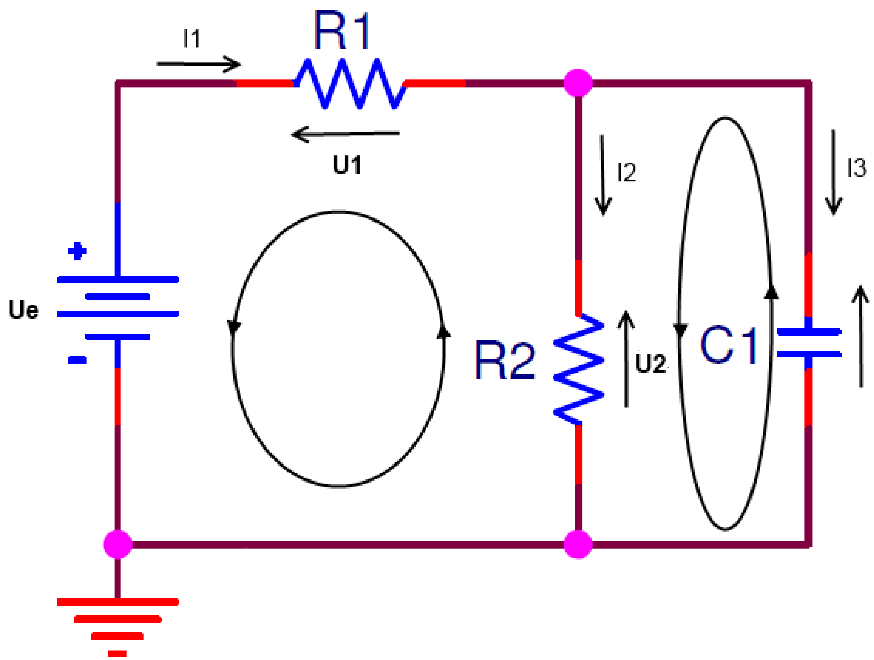
(2) Numerical simulation



Surface current distribution of the coil and magnetic field strength along a vertical cut plane

(1) Analog simulation

Modeling (Schematic) + Kirchhoff's circuit laws + System of DE / IE



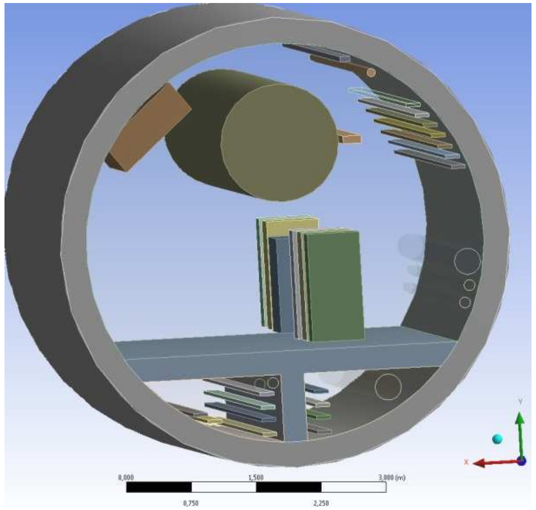
$$\sum_k \vec{I}_k = 0$$ Current law

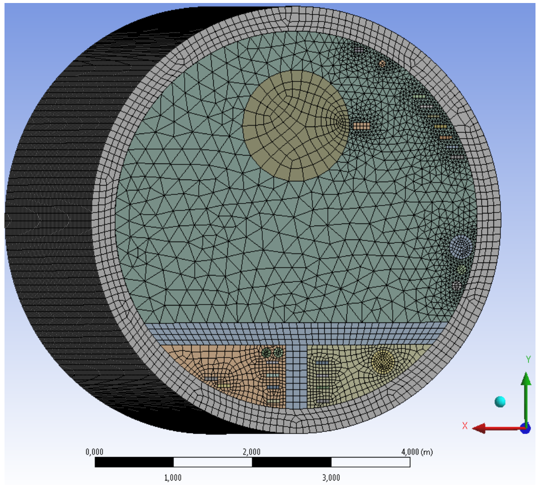
$$\sum_k \vec{U}_k = 0$$ Voltage law

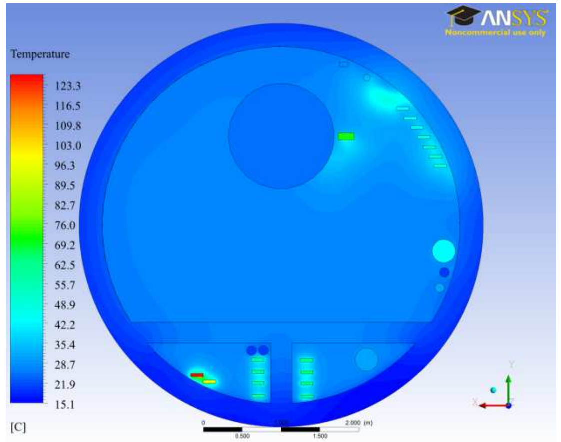
Principle of simulation

(2) Numerical simulation

Modeling (Geometric) + Meshing and Boundary conditions + System of DE / IE







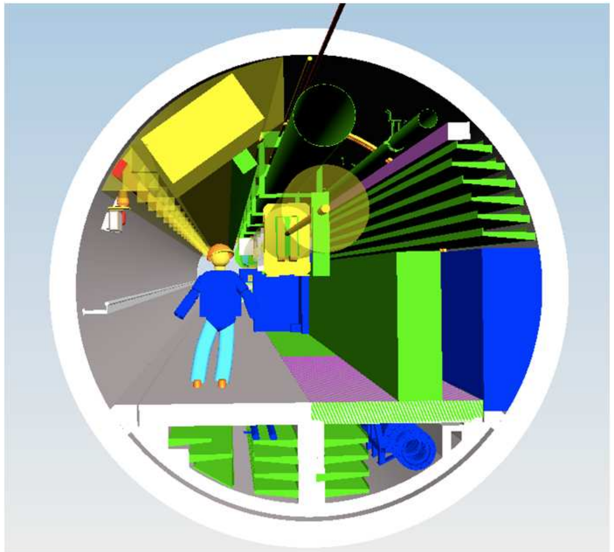
Analog simulation

Some simulation tools

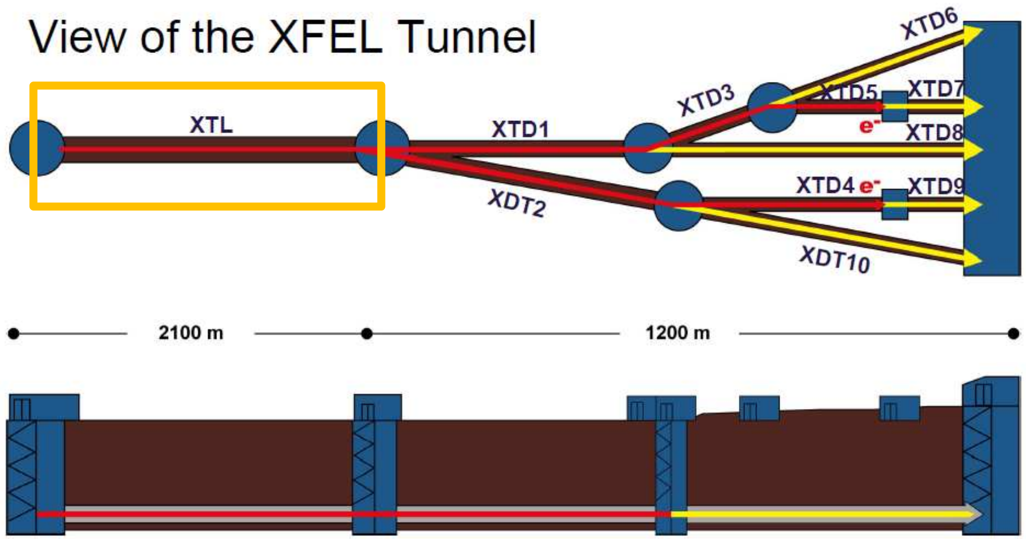
- Pspice
- Psim
- Matlab / Simulink / SimPowerSystems / PLECS
- LTSpice
- CASPOC
- **ANSYS Simplorer**

Example(1): temperature simulation for European XFEL at DESY

Tunnel design



View of the XFEL Tunnel



- Total length: about 3.4 km
- Underground tunnels
- Depth : 6 -38 m
- Diameter
  - XTL, XTD1, XTD2 → 5.2 m
  - XTD2 …XTD10 0 → 4.5 m

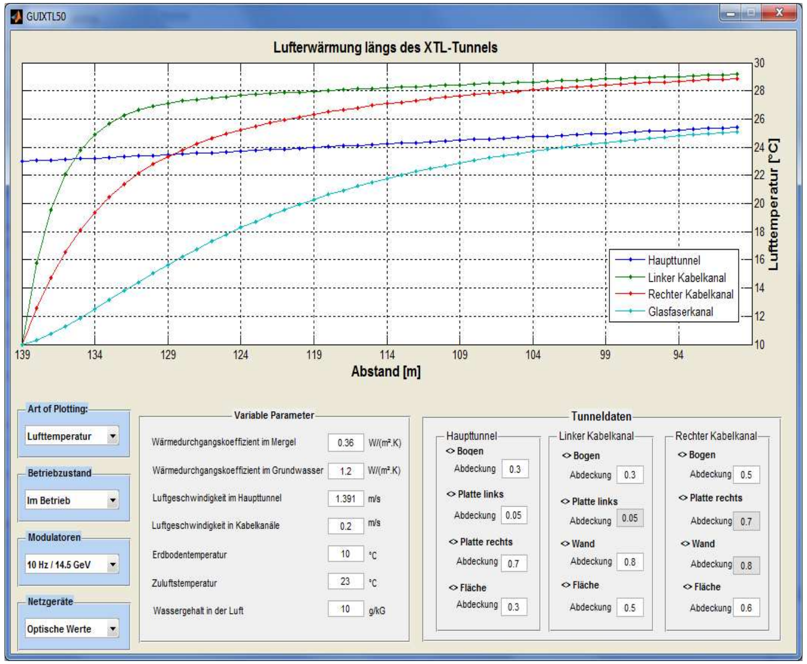
Example(1): temperature simulation for European XFEL at DESY

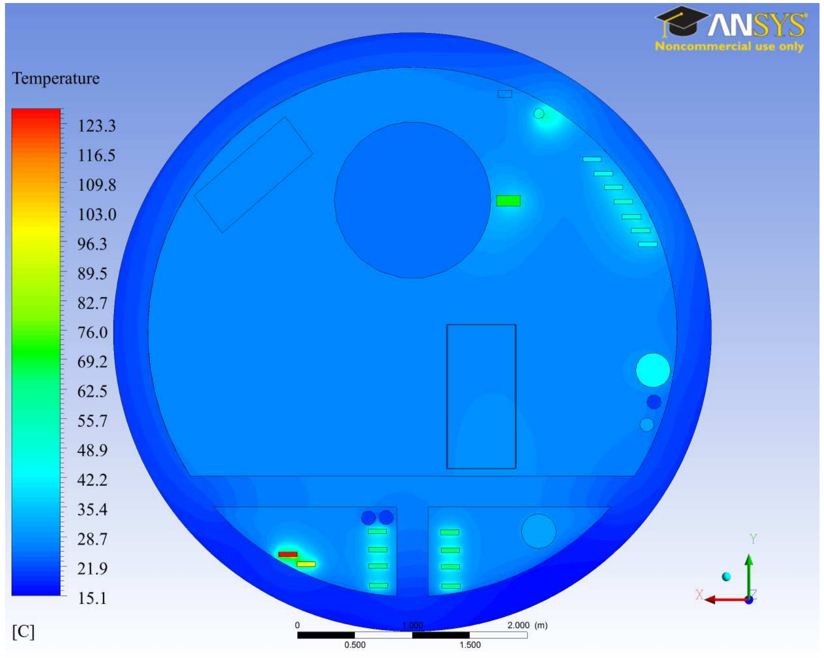
- Motivation
  - Overview of temperature profile along the XTL-tunnel
  - Stable temperature profile (max. ΔT of +/- 0.5 K) during operation modes
- Goal
  - Analyze the transient thermal processes in the XTL tunnel
- Input parameters
  - Heat sources / Heat sinks (dependent on a position)
  - Geology of the ground
  - Experience and temperature measurement in HERA

Example(1): temperature simulation for European XFEL at DESY

1) Analyses with Matlab were limited to steady state calculation

2) Analyses with ANSYS CFD would have cost too much computing time & capacity





Example(1): temperature simulation for European XFEL at DESY

ANSYS Simplorer als simulation tool

- Complex multiphysics circuit analysis:
  electrical, power electronic, electromagnetic, thermal, electromechanical and hydraulic
- AC, DC and TR analysis
- Based on numerical methods of mathematics
- Non linear Multidomain-System simulation
- Very stable simulation algorithm
- Enough user licenses in our department

Example1: temperature simulation for European XFEL at DESY

- Duality principle
- 50 m XTL tunnel section

$$R_{s1} = \frac{d_1}{\lambda_{s1} * \frac{4*\pi}{3} * r_1 * l} \quad [\tfrac{K}{W}]$$

$$R_B = \frac{d}{\lambda_B * \frac{4*\pi}{3} * ra * l} \quad [\tfrac{K}{W}]$$

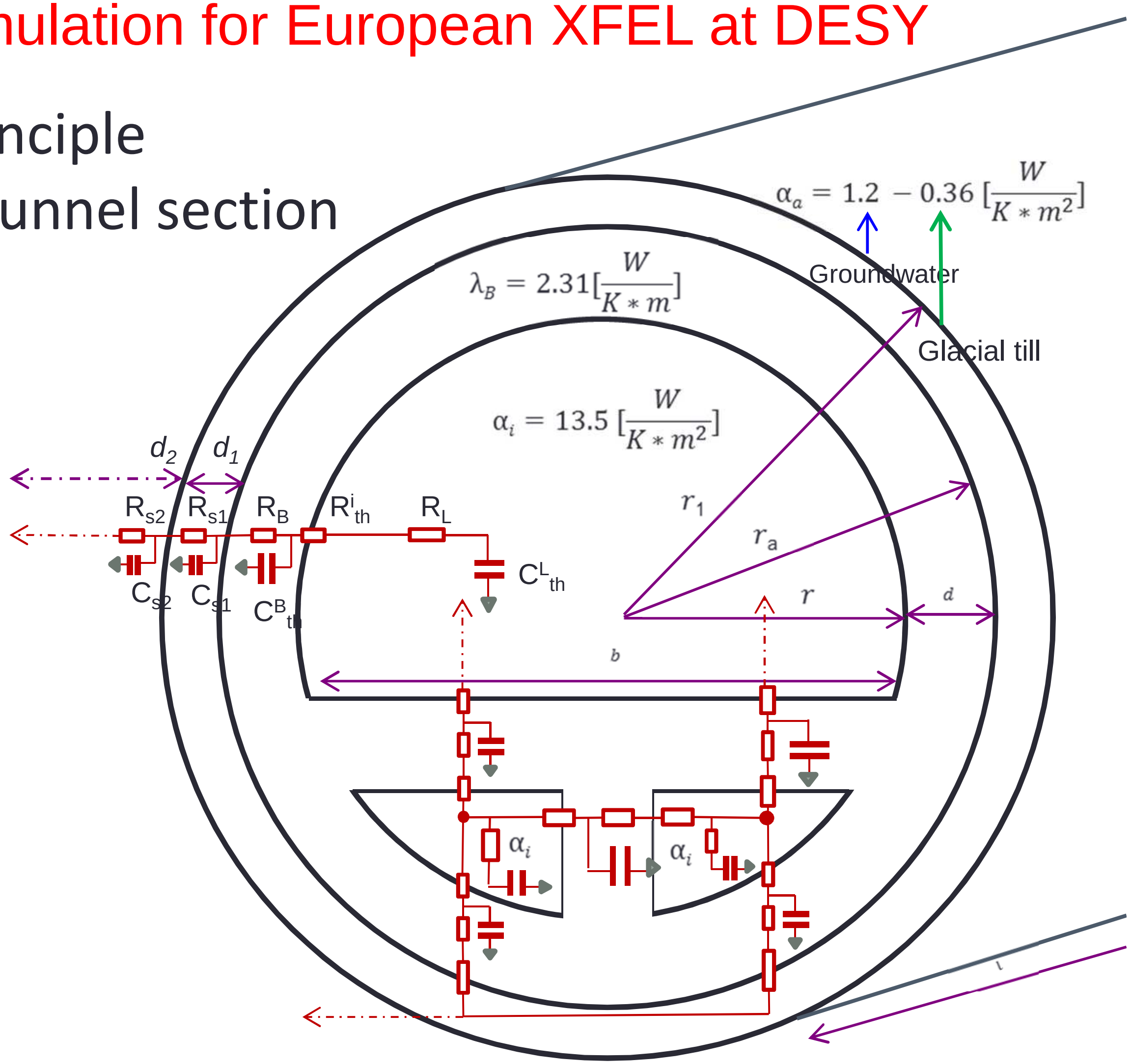
$$R^i{}_{th} = \frac{1}{\alpha_i * \frac{4*\pi}{3} * ri * l} \quad [\tfrac{K}{W}]$$

$$R_L = \frac{0.5 * ri * \frac{4*\pi}{3}}{\lambda_L * (\frac{4*\pi}{3} * ri + b) * l} \quad [\tfrac{K}{W}]$$

$$C^L{}_{th} = c_L * \rho_L * \frac{4*\pi}{3} * r_i{}^2 * l \quad [\tfrac{J}{K}]$$

$$C^B{}_{th} = c_B * \rho_B * \frac{4*\pi}{3} * (r_a{}^2 - r_i{}^2) * l \quad [\tfrac{J}{K}]$$

$$C_{s1} = c_1 * \rho_1 * \frac{4*\pi}{3} * (r_1{}^2 - r_a{}^2) * l \quad [\tfrac{J}{K}]$$



Analog Simulation: Simplorer

Example(1): temperature simulation for European XFEL at DESY

Start values

- Ground water: 10ºC
- Concrete: 10ºC
- Inlet temperature: 23ºC

ICA:

T_Grundwasser := 283.15

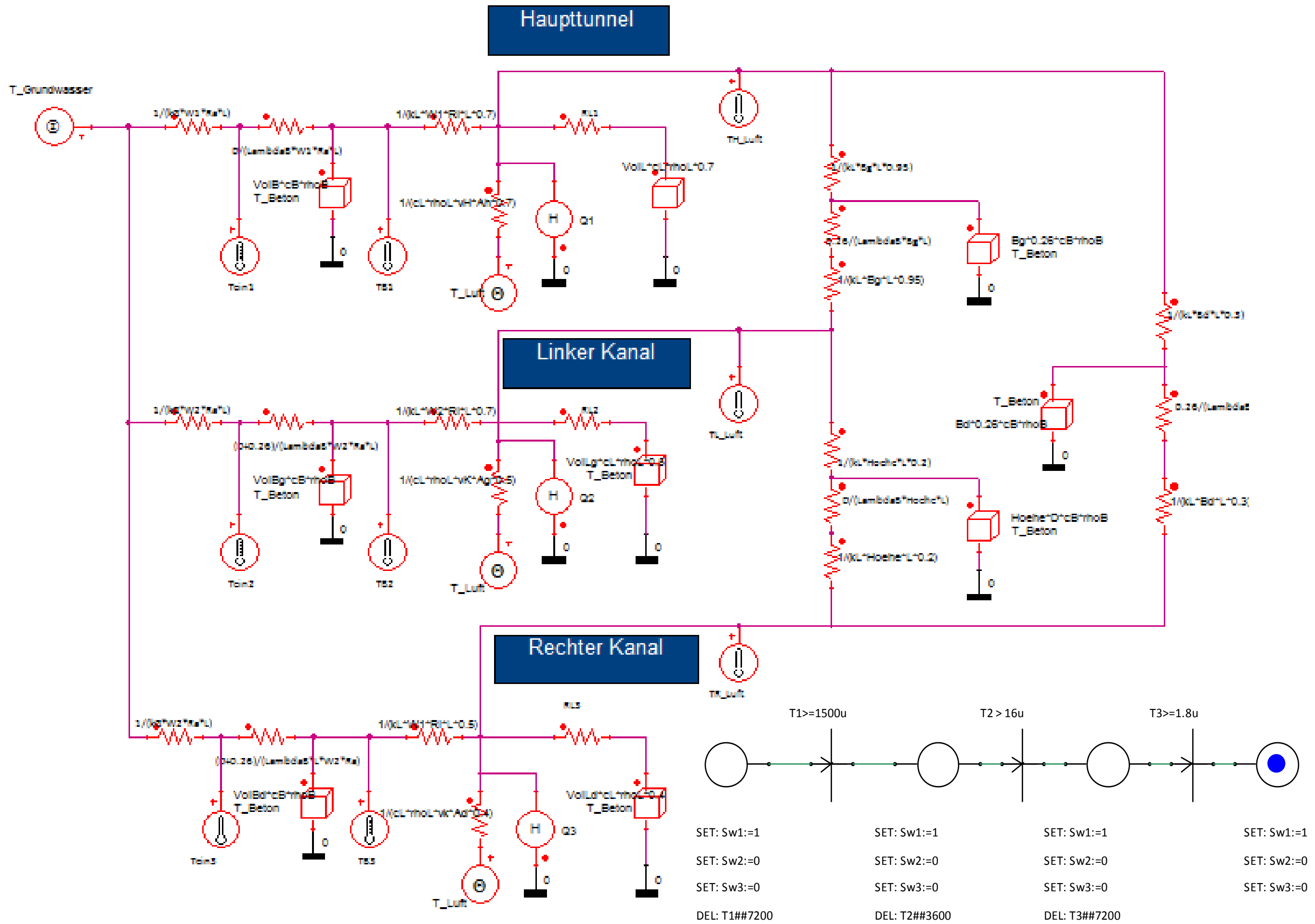
T_Luft := 296.15

T_Beton:=273.15

Twr_10:=313.15

Twr_21:=293.15

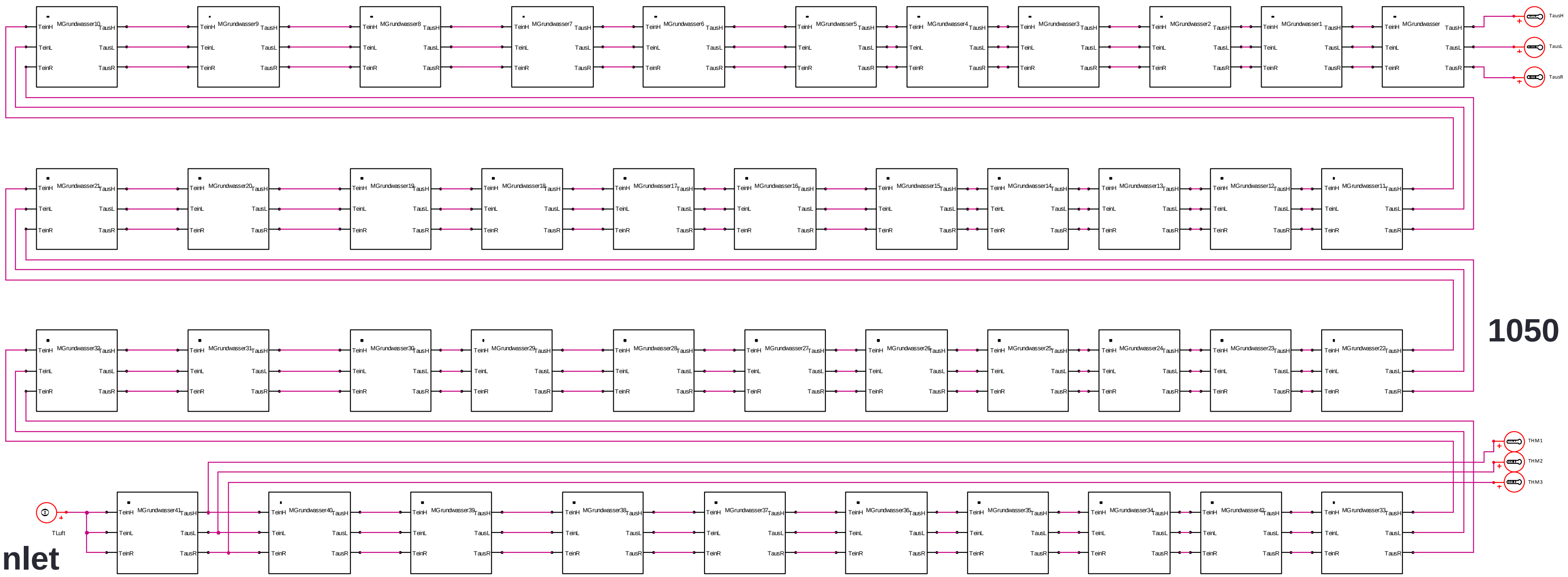
Twr_22:=303.15



Example(1): temperature simulation for European XFEL at DESY

- Tunnel length: 2100 m
- 43 submodels

Outlet: 2150 m



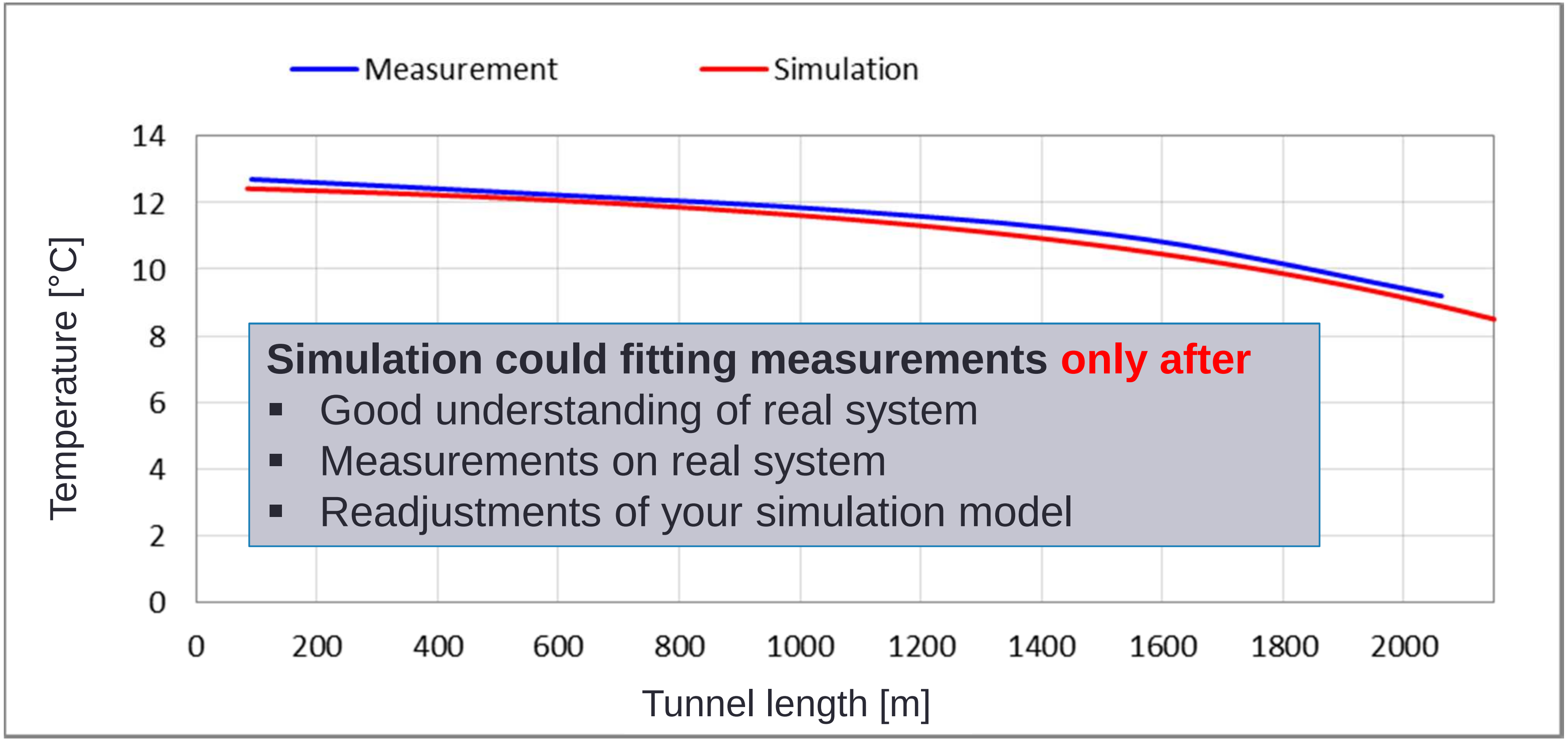
1050 m

Inlet

50m

Example(1): temperature simulation for European XFEL at DESY

12.03.2013: Temperature in the empty main tunnel



Simulation could fitting measurements only after

- Good understanding of real system
- Measurements on real system
- Readjustments of your simulation model

Example(1): temperature simulation for European XFEL at DESY

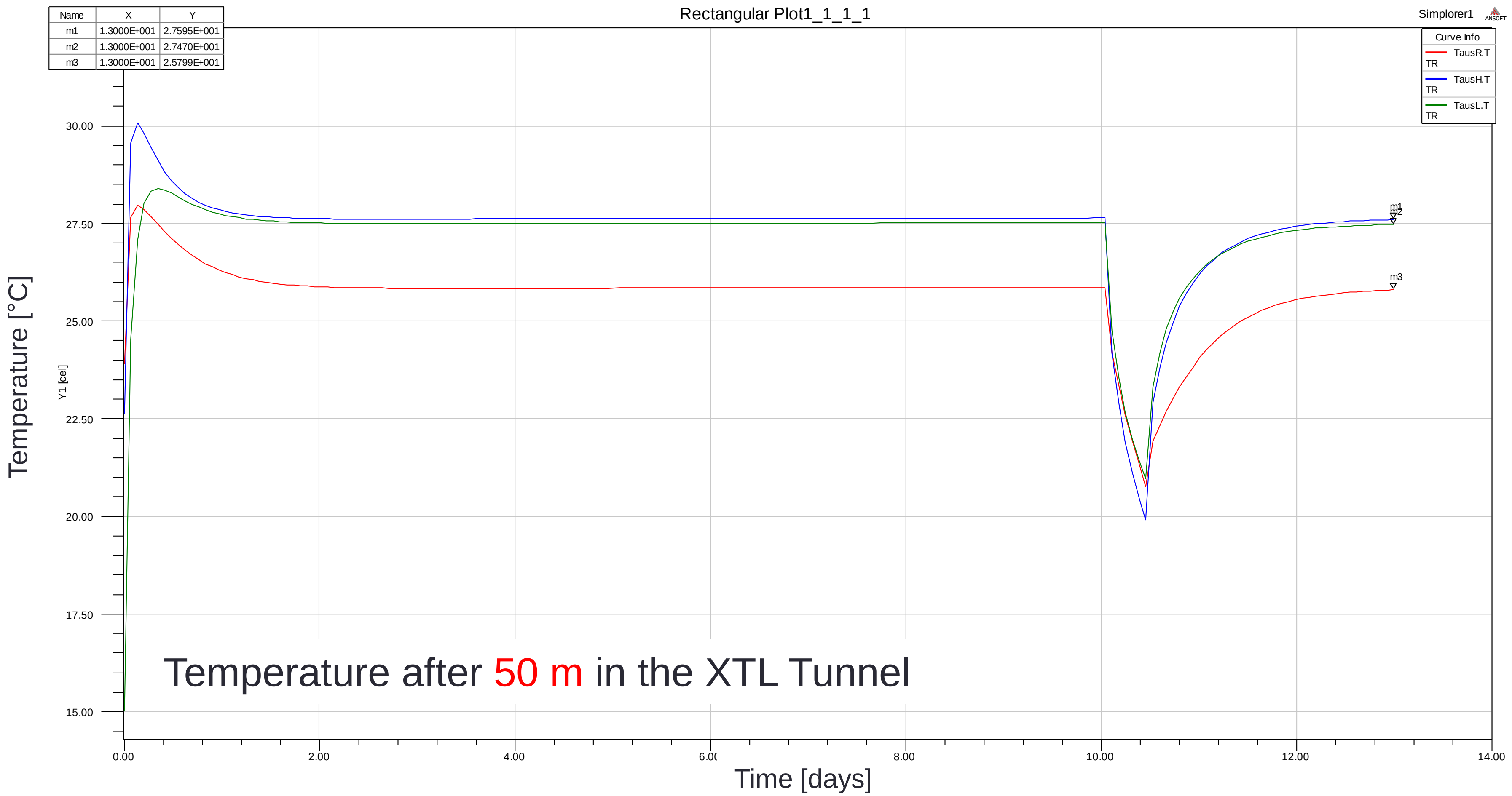
Two operating modes of the XFEL

Heat sources in the XTL tunnel	Tunnel section	In operatation	Service day
Pulse cables left	LK	ON	OFF
Pulse cables right	RK	ON	OFF
MV power cables	HT	ON	ON
LV Power cables	LK	ON	ON
DC power cables	LK	ON	OFF
Pulse Transformators	HT	ON	OFF
Impedance matching network	HT	ON	OFF
Magnets	HT	ON	OFF
30℃ water pipe 1 (VL)	RL	ON	ON
40℃ water pipe 1 (RL)	HT	ON	ON
20℃ water pipe 2 (VL)	HT	ON	ON
25℃ water pipe 2 (RL)	HT	ON	ON
20℃ water pipe 3 (VL)	HT	ON	ON
20℃ water pipe 4 (VL)	RKG	ON	ON
20℃ water pipe 5 (VL)	LK	ON	ON
Elektronic racks	HT	ON	ON
Waveguides	HT	ON	OFF
Lighting	HT	OFF	ON

- Inlet temperature: 23°C
- Temperatur after 50m in the tunnel?
- Temperature after 2100m at the end of the tunnel ?
- Temperatur behavior in the XTL tunnel after 10 days of machine operating and a service day(~10 h) ?

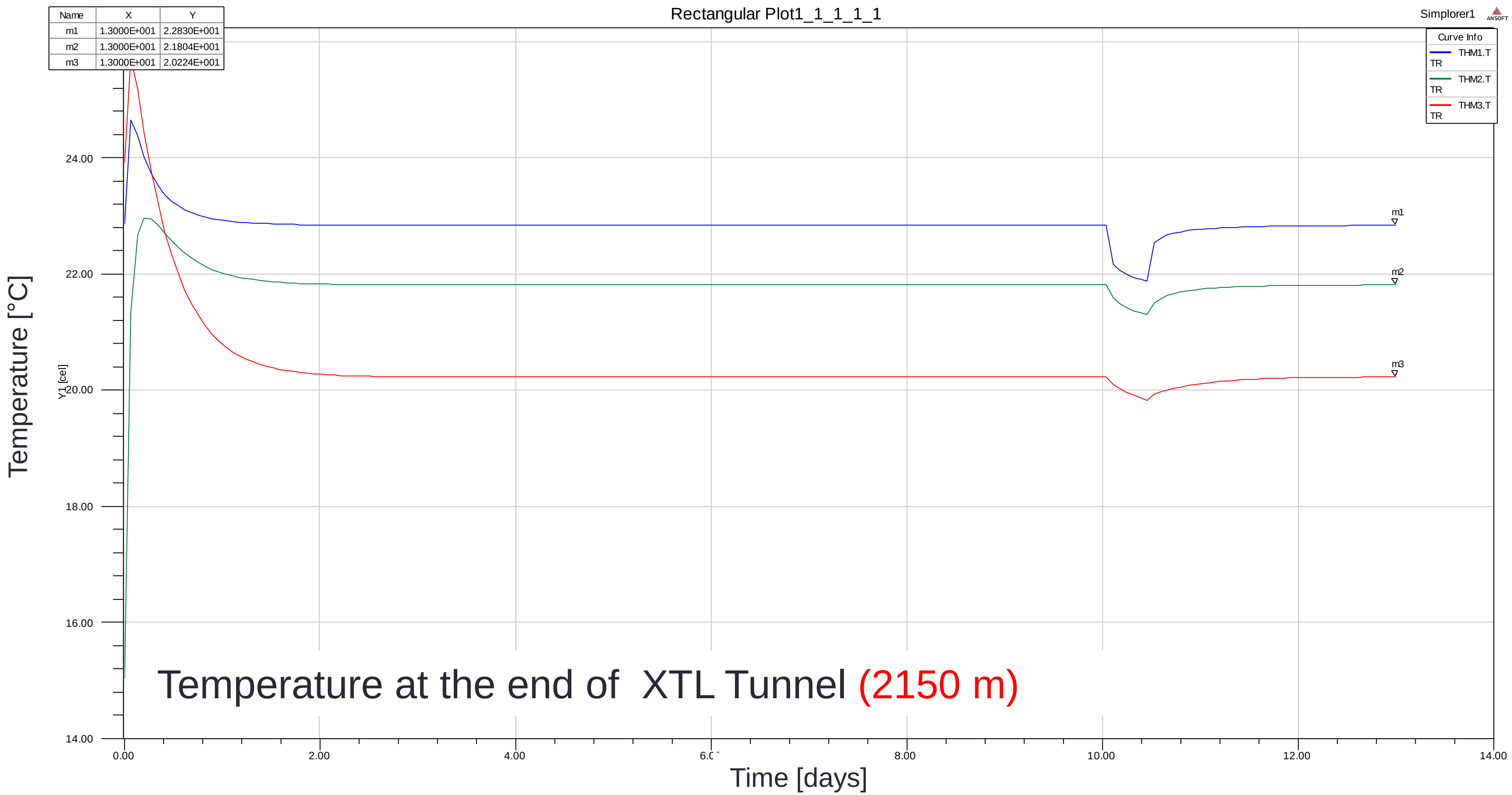
Example(1): temperature simulation for European XFEL at DESY

Name	X	Y
m1	1.3000E+001	2.7595E+001
m2	1.3000E+001	2.7470E+001
m3	1.3000E+001	2.5799E+001



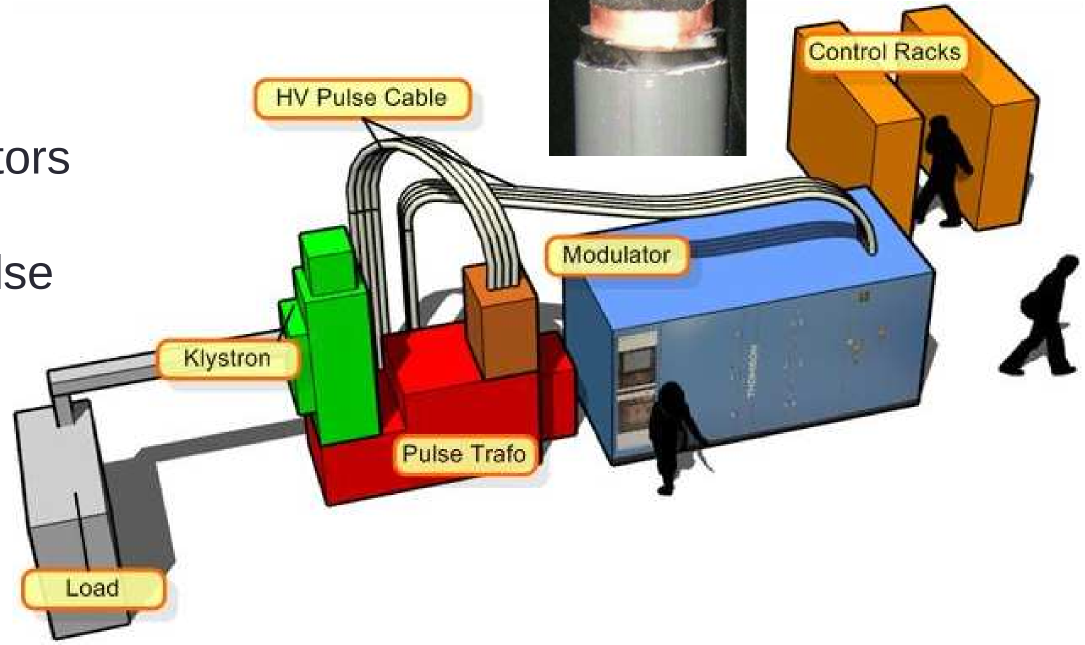
Example(1): temperature simulation for European XFEL at DESY

Name	X	Y
m1	1.3000E+001	2.2830E+001
m2	1.3000E+001	2.1804E+001
m3	1.3000E+001	2.0224E+001

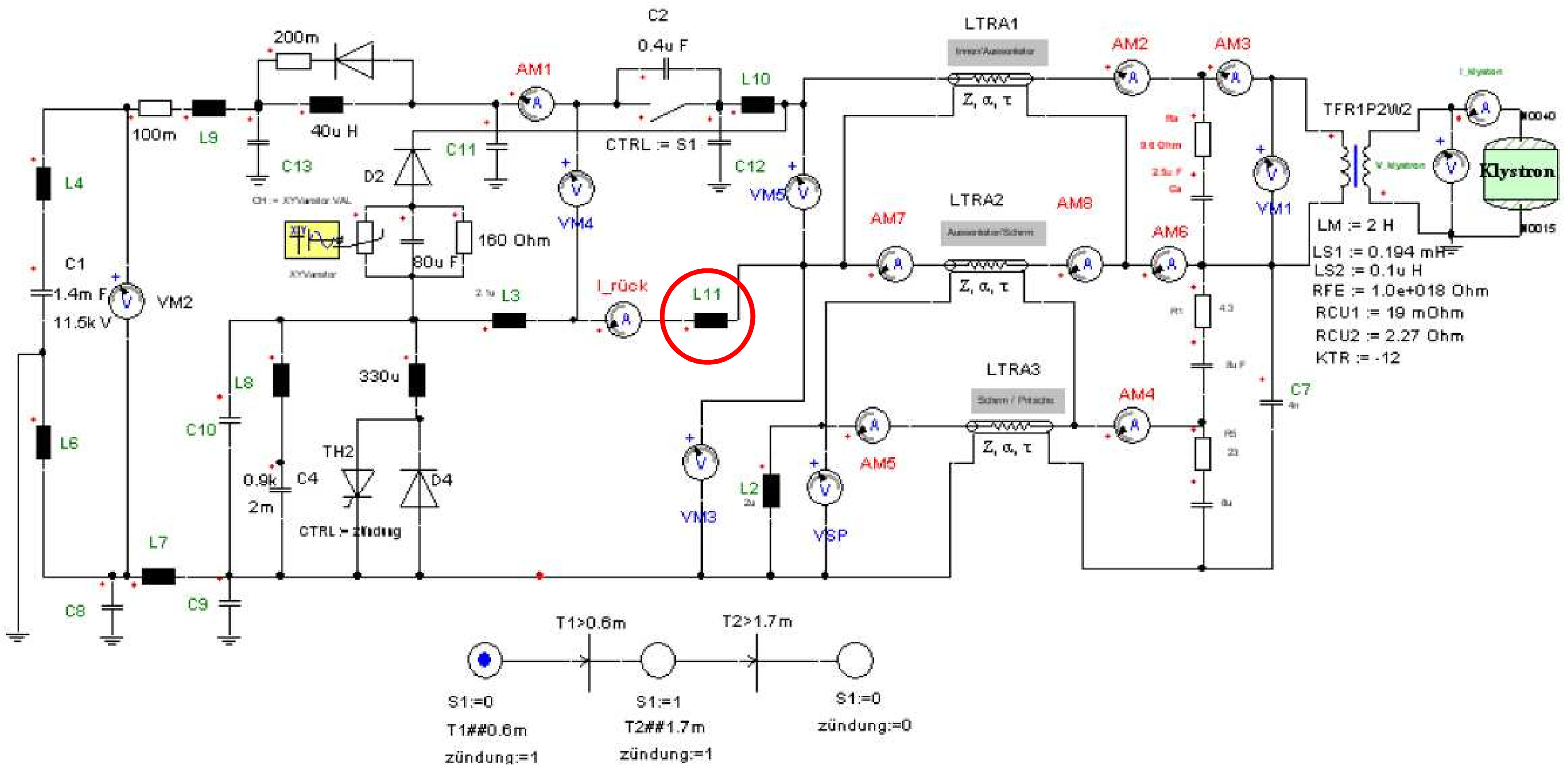


Example(2): EMI behavior of XFEL modulators with pulse cables

- 29 HV pulse power supplies (modulators) of 10MW RF station each in a central modulator hall (XHM)
- RF stations(klytrons & pulstransformers) in the accelerator tunnel (XTL)
- Up to 1.5 km long triaxial cables between RF stations and modulators
- Analyses of EMI behavior with pulse cables and modulators

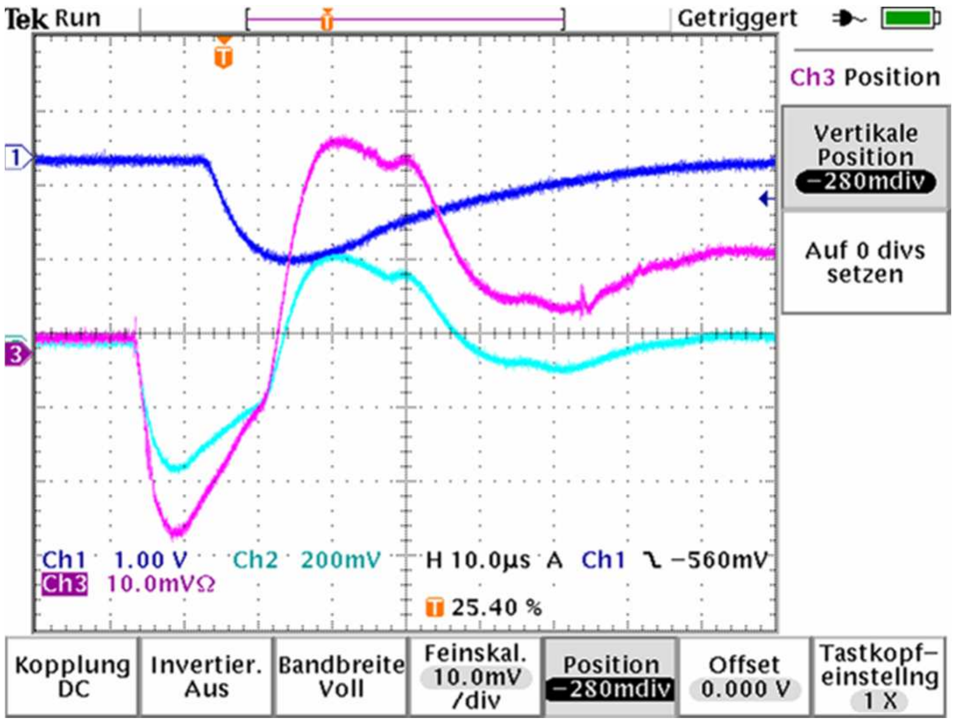


Example(2): EMI behavior of XFEL modulators with pulse cables

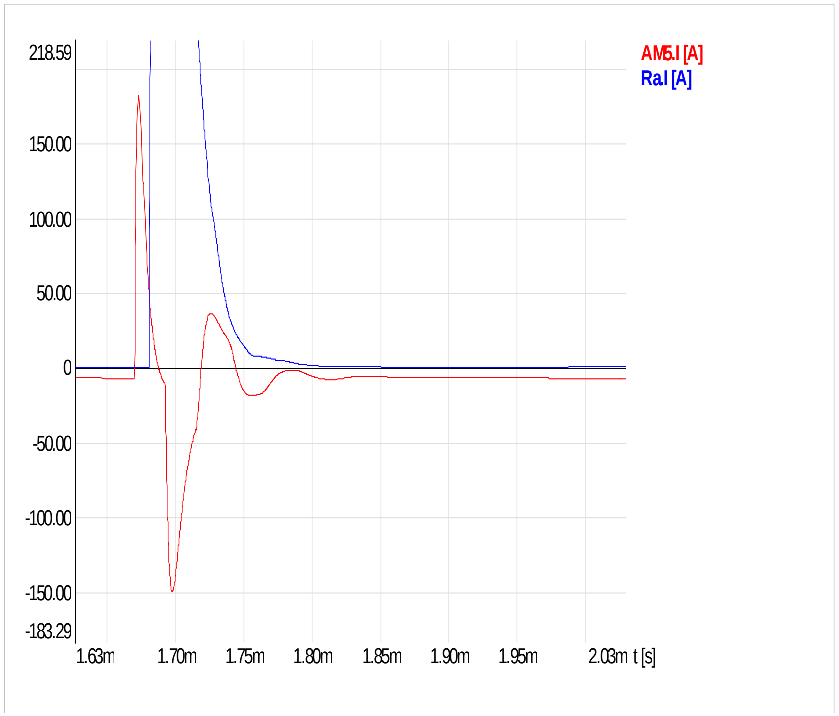


Example(2): EMI behavior of XFEL modulators with pulse cables

Measurement



Simulation

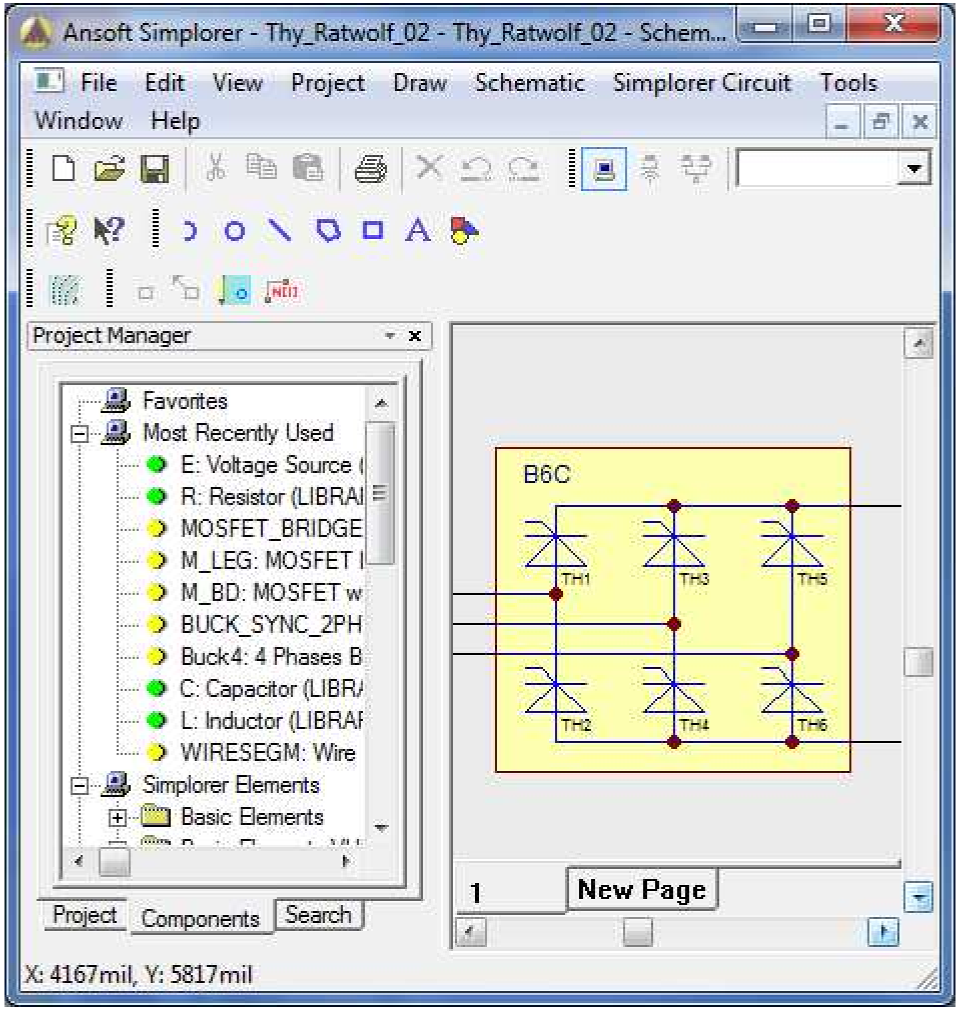


Ansys Simplorer vs LTSpice IV

ANSYS Simplorer	LTSpice IV
▪ Limited student version / not free	▪ **Free** & **popular**
▪ Analog & digital circuits simulation	▪ Mainly analog circuits simulation
▪ Idealized / accurate model of components	▪ Accurate model of components
▪ Schematic draw(comfortable)	▪ Schematic draw(not comfortable)
▪ Multiphysics simulation	▪ Electrical circuit simulation

Roundup

- Basic understanding of physical system for a good simulation model
- Simulation model as simple as possible
- Simulation model as complex as needed
- Measurement of physical model to optimize the simulation model

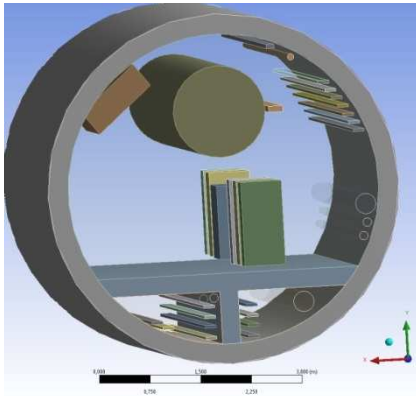


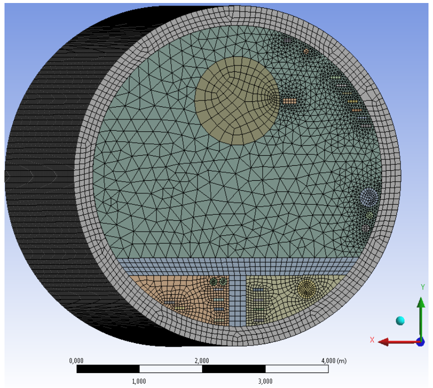
Types of simulation

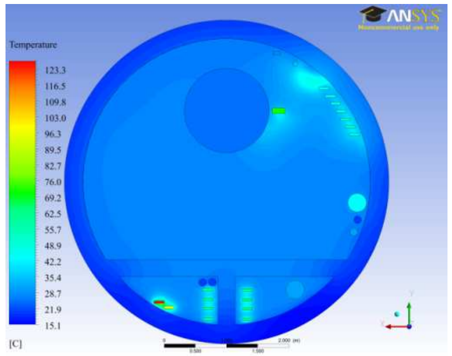
Numerical simulation

Numerical simulation

Models (geometric)	+	Meshing and Boundary conditions	+	System of DE / IE







Numerical Simulation splits the problem into smaller pieces, solves those separately with numerical methods, and finally merges the partial results into the solution for the entire problem.

Some numerical methods

- finite difference method
- method of weighted residuals
- moment method
- finite element method
- transmission-line modeling
- Monte Carlo method
- method of lines

Some simulation tools

- ANSYS CFD
- ANSYS HFSS
- CST Microwave studio
- ANSYS Maxwell 2D
- FEKO
- CONCEPT-II
- Quickfield

Example: grounding of XFEL modulators for RF stations at DESY

- Motivation
  - EMI during the commissioning of Modulators
  - Measurement of high inducted current on PE conductor
  - Source of high inducted current not clear (50Hz / up to 50App)
- Suspicion
  - Insulation fault
  - Inducted current from power cables
- Goal
  - Theoretical analysis and measurement to confirm the suspicions
  - Optimization of the grounding system of modulators

Example: grounding of XFEL modulators for RF stations at DESY

Quickfield as simulation tool

- Easy to learn / Easy to use
- Mainly for EM fields simulation
- Coupled multiphysics
- Various analysis types
  AC, DC and transient electromagnetics, electrostatics, DC, AC and transient electric analysis, steady-state and transient heat transfer, Stress analysis)
- Electrical circuit combined with fields simulation
- Only basic components for electrical circuit analysis

Example: grounding of XFEL modulators for RF stations at DESY

View of modulators hall

- 29 HV pulse power supplies (Modulators) capable of 10MW RF station each
- Modulators in a central modulator hall (XHM)
- RF stations in the accelerator tunnel

Transformer

HV racks

Power & PE cables

Modulator

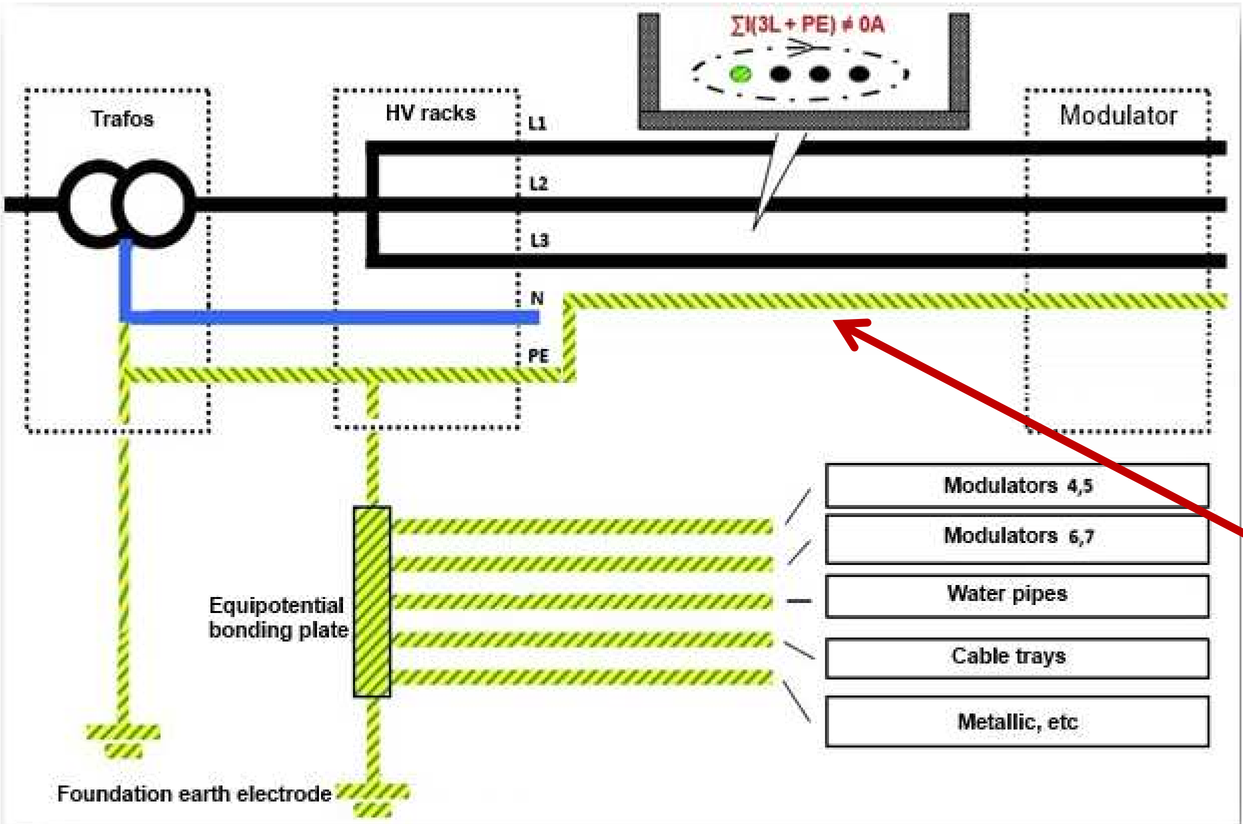
Example: grounding of XFEL modulators for RF stations at DESY

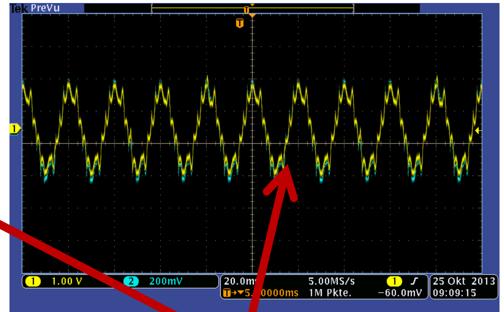
Technical data of a modulator

Nbr. of modulators	29
Output Voltage	0 – 12kV
Output current	0 – 2 kA
Ave. Output power	max. 380kW
Max. pulse power	16,8 MW
Pulse duration	0,2 – 1,7 ms
Pulse repetition rate	1 – 30 Hz

Example: grounding of XFEL modulators for RF stations at DESY

View of grounding system in the hall: PE conductor near power cables

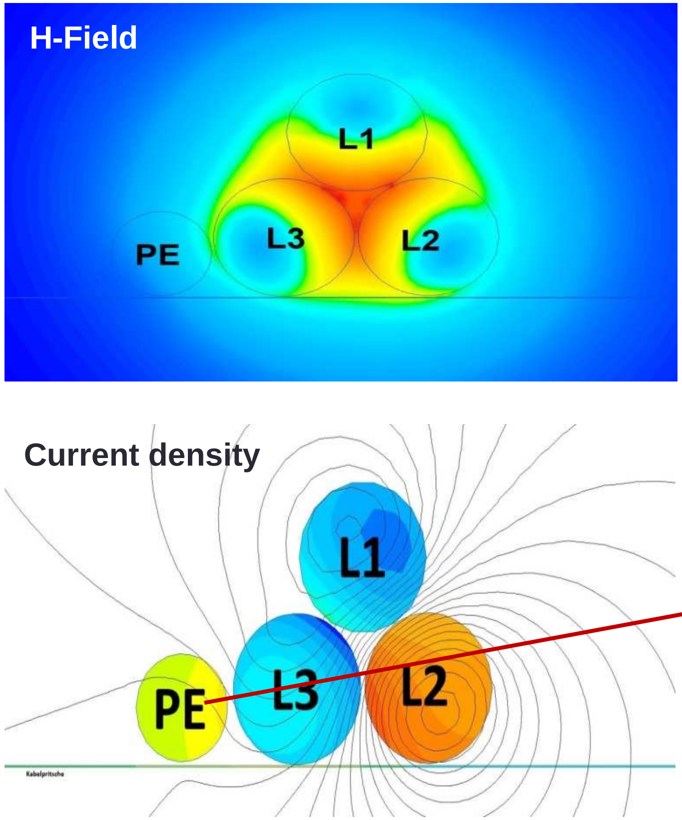


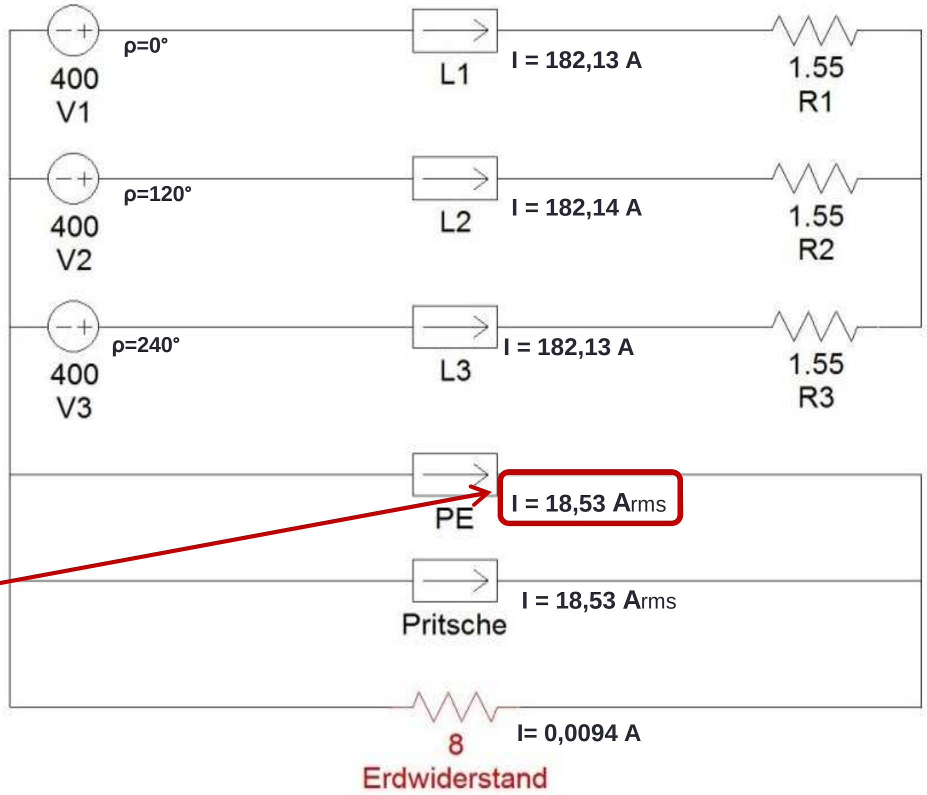


Measure of 21 Arms / 50Hz Interference current on PE-conductor

Example: grounding of XFEL modulators for RF stations at DESY

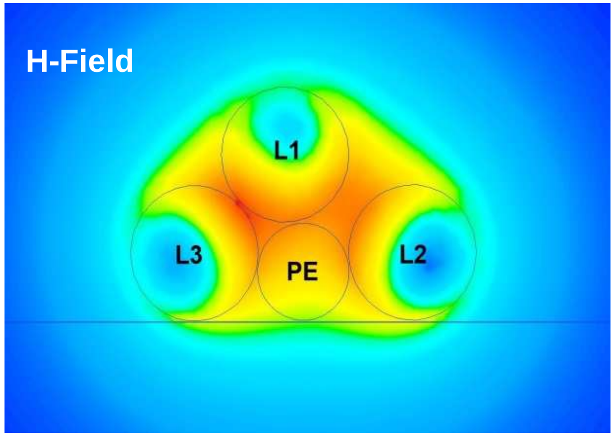
Simulation results of PE conductor near power cables

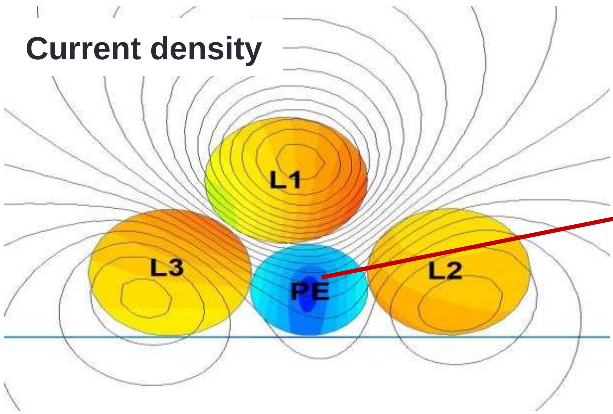


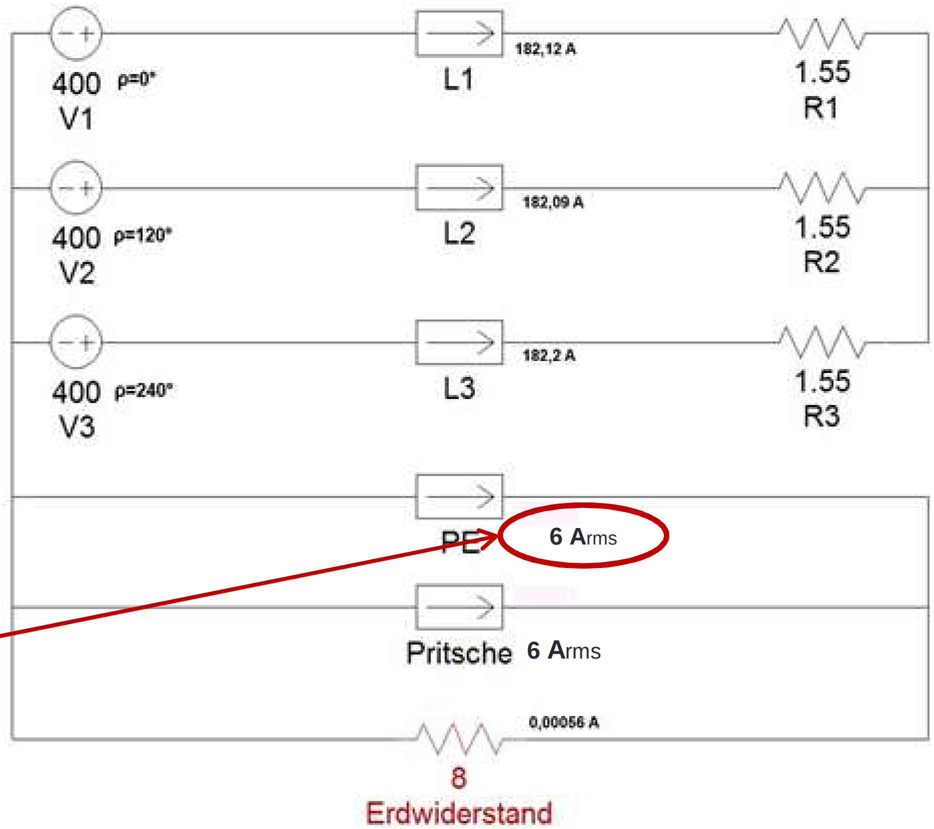


Example: grounding of XFEL modulators for RF stations at DESY

Simulation results with PE conductor between power cables

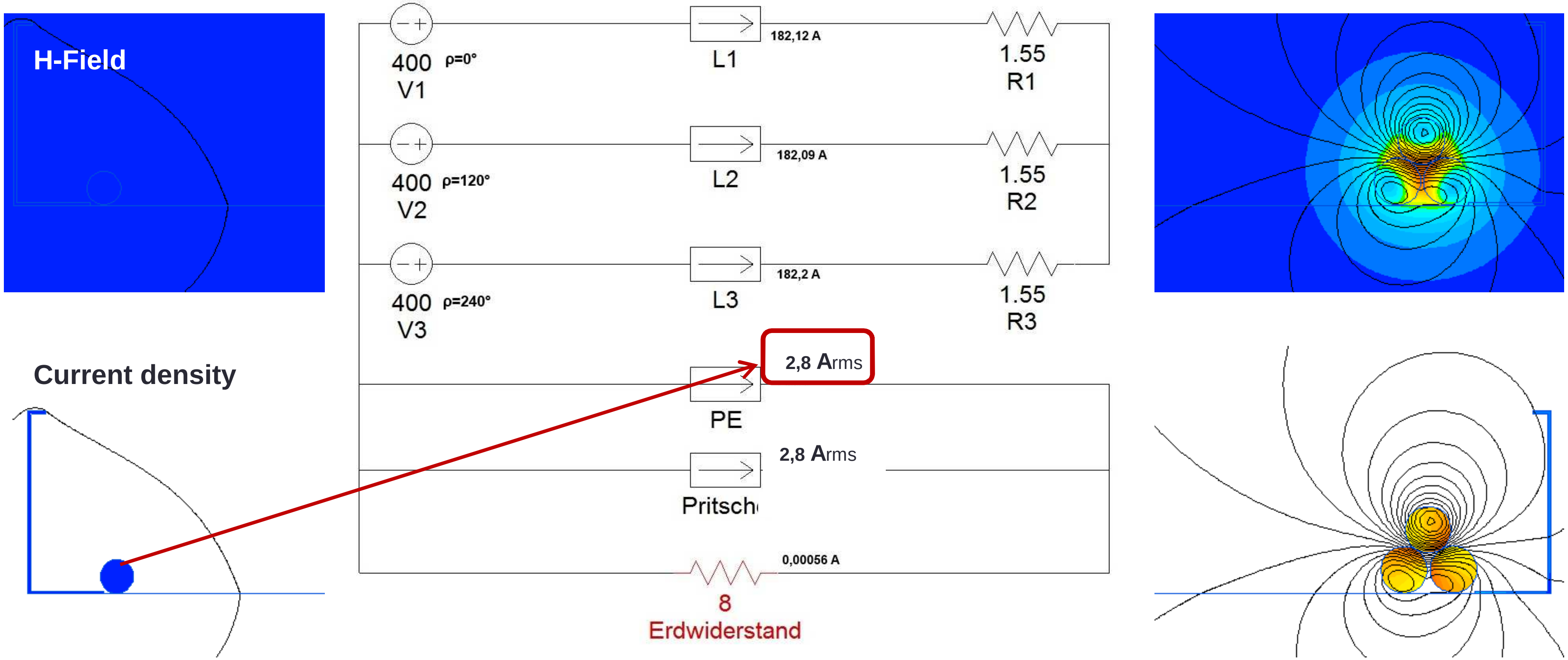






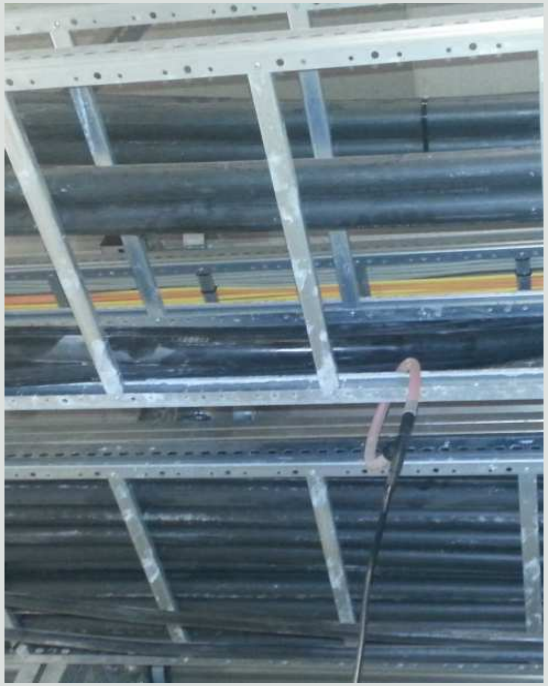
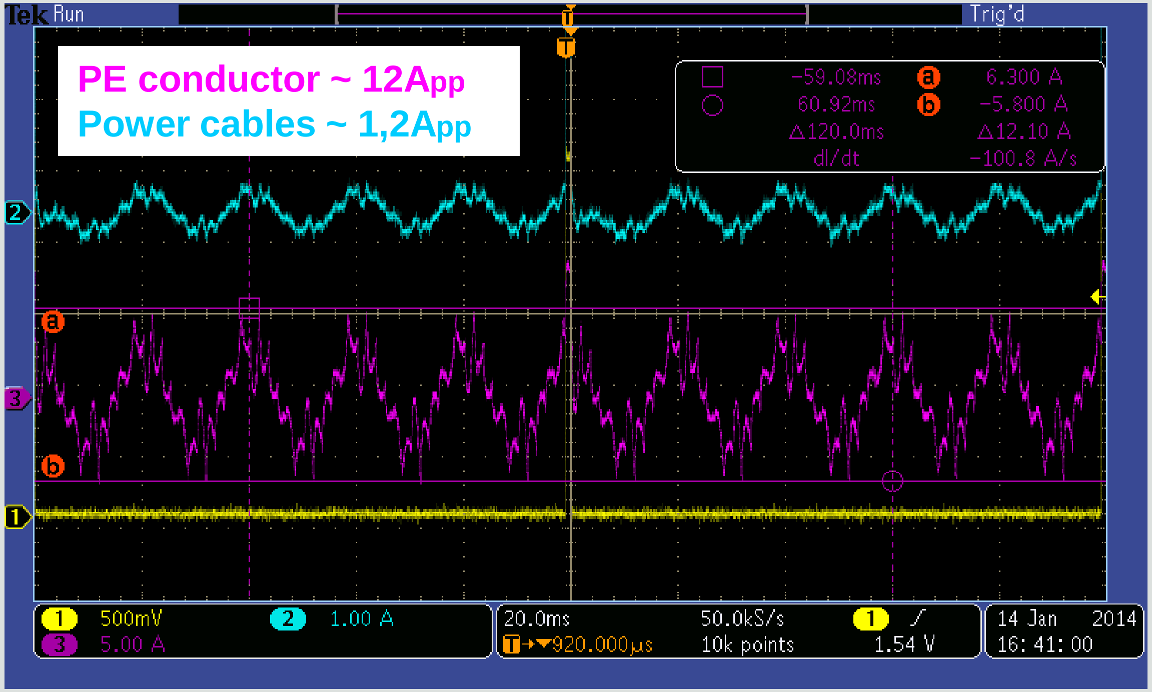
Example: grounding of XFEL modulators for RF stations at DESY

Simulation results of PE conductor at ~25cm from power cables



Example: grounding of XFEL modulators for RF stations at DESY

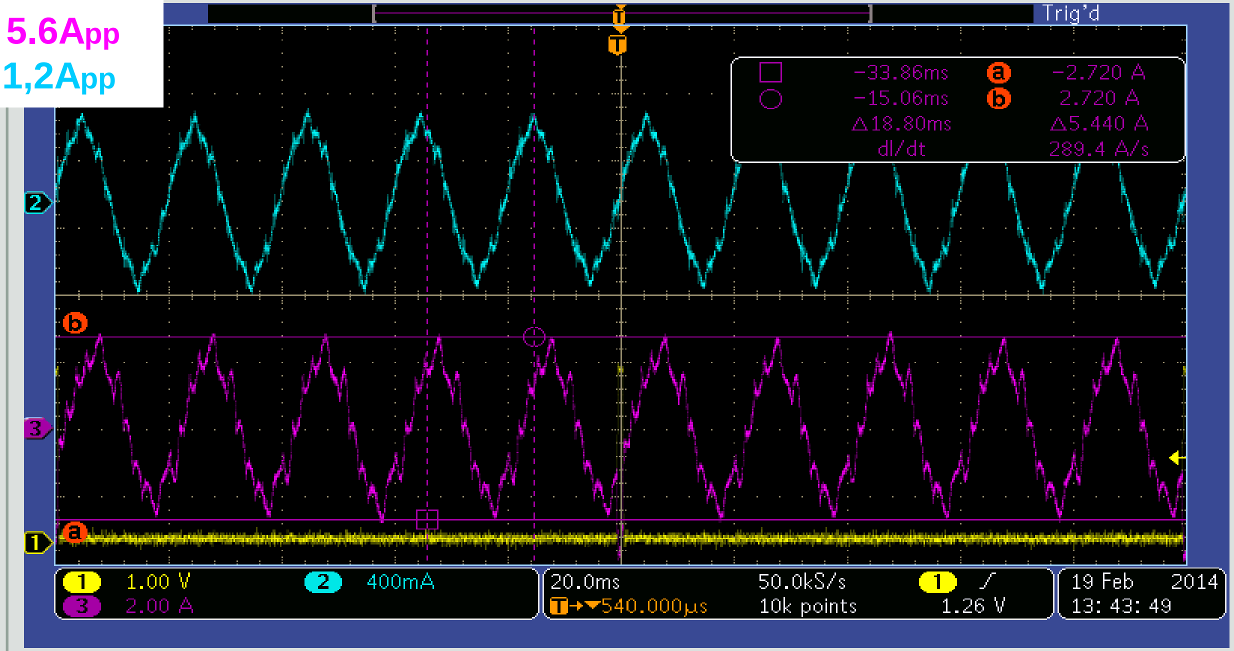
Measurement with PE conductor between power cables

Picture	Measurement
	

Umod =10kV; Pulse repetition =10Hz; Pulse length =1000us

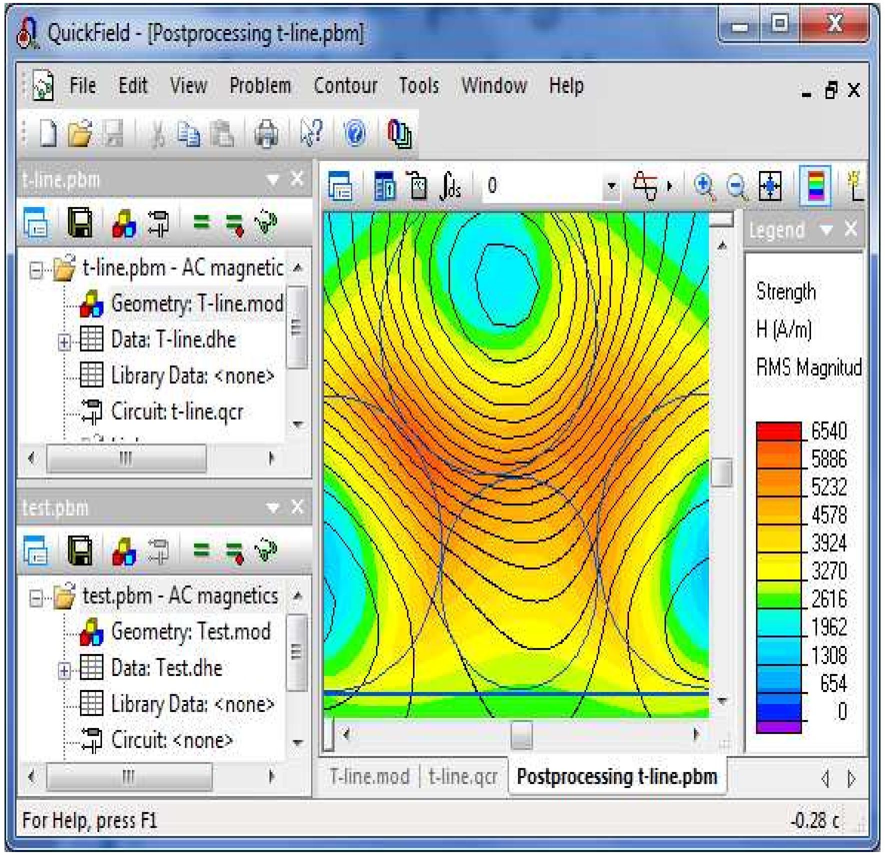
Example: grounding of XFEL modulators for RF stations at DESY

Measurement with PE conductor at ~25cm from power cables

Picture	Measurement
 PE conductor ~ 5.6App Power cables ~ 1,2App	
Umod =10kV; Pulse repetition =10Hz; Pulse length =1000us	

Roundup

- Simulation to investigate a best solution for modulators grounding system
- Simulation for better understanding of real system
- Simulation to reduce the installation time of physical system



Conclusion

Expectations for a good simulation tool

- Comfortable, intuitive input of the circuit model
- Correct error messages
- Robust execution of the simulation
- Output data to be used in other softwares
- Good user support
- Portability of models in software update

Challenges in world of simulation

- More intuitive usage
- Lower simulation time
- Models & results transfer
- Better user support & extended online help
- Various models of components

Checklist to opt for a simulation tool?

1) Investment in time and money
2) Clearly state the problem to solve
3) Determine the general type of simulation tool
4) Check the functional requirements
5) Select the most appropriate Tool

Conclusion

Important points to perform a good simulation

1) Basic understanding of your real system

2) Simulation model as simple as possible

3) Simulation model as complex as necessary

4) Interaction between simulation and physical system

Conclusion

Those who can, do.
Those who can't, simulate.
-- anonymous writer

Those who can, simulate.
Those who can't, don’t simulate.

Thank you for attention!