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morEnergy

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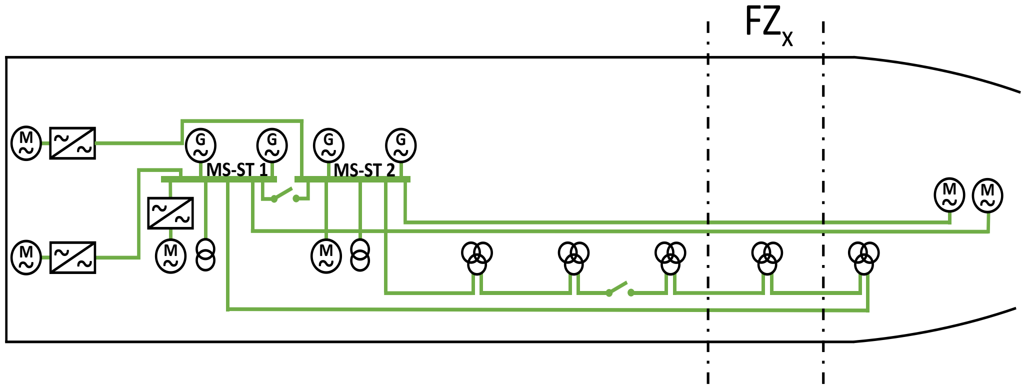
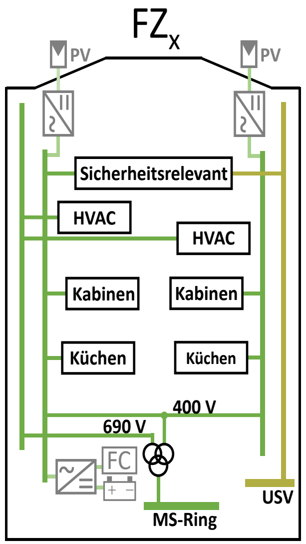
Application of Impedance Measurement in Power Hardware-in-the-Loop Assisted Research

Konferenz Interessenverband Netzimpedanz – C. Klie – 15. Sep. 2022

SuSy: Sustainable DC Systems – Now and Then

Traditional AC ship and firezone:

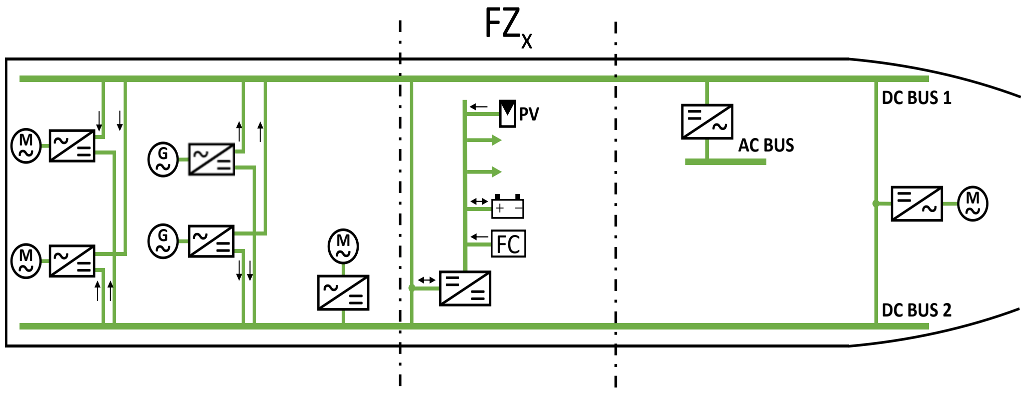


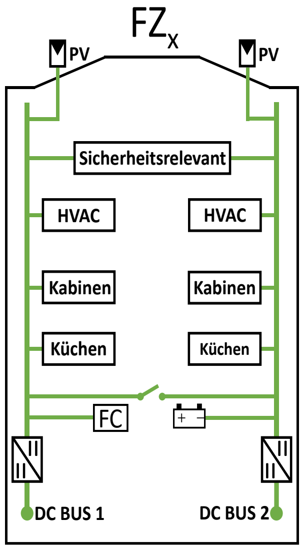


General SuSy goals

- Overall reduction of cabeling while maintaining secure operation
- Direct coupling of DC components to the grid

Proposal for DC ship and firezone:





TUHH goals in SuSy

- Investigation of equipment compatibility
- Investigation of control, stability, reliability and security

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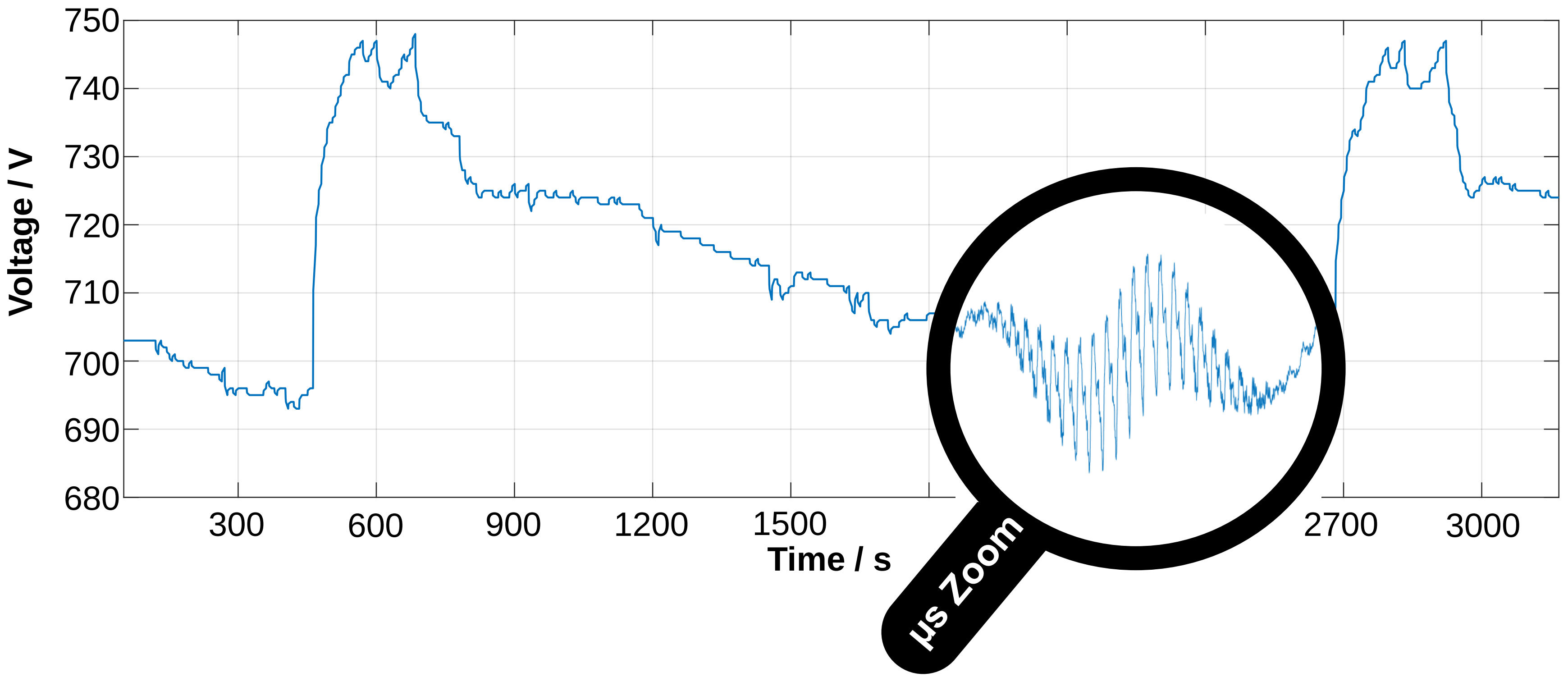
SuSy: Sustainable DC Systems – Now and Then

Measured DC-Bus voltage on ship type: „waterbus“ (DAMEN SHIPYARDS)



Hardware-in-the-Loop – The why and how

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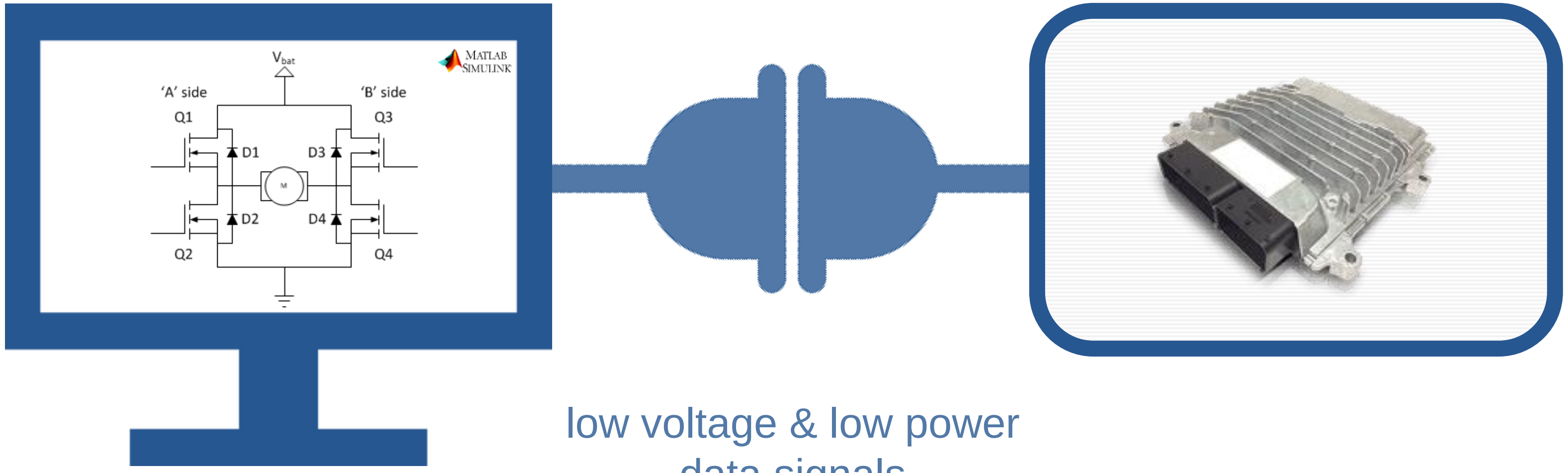
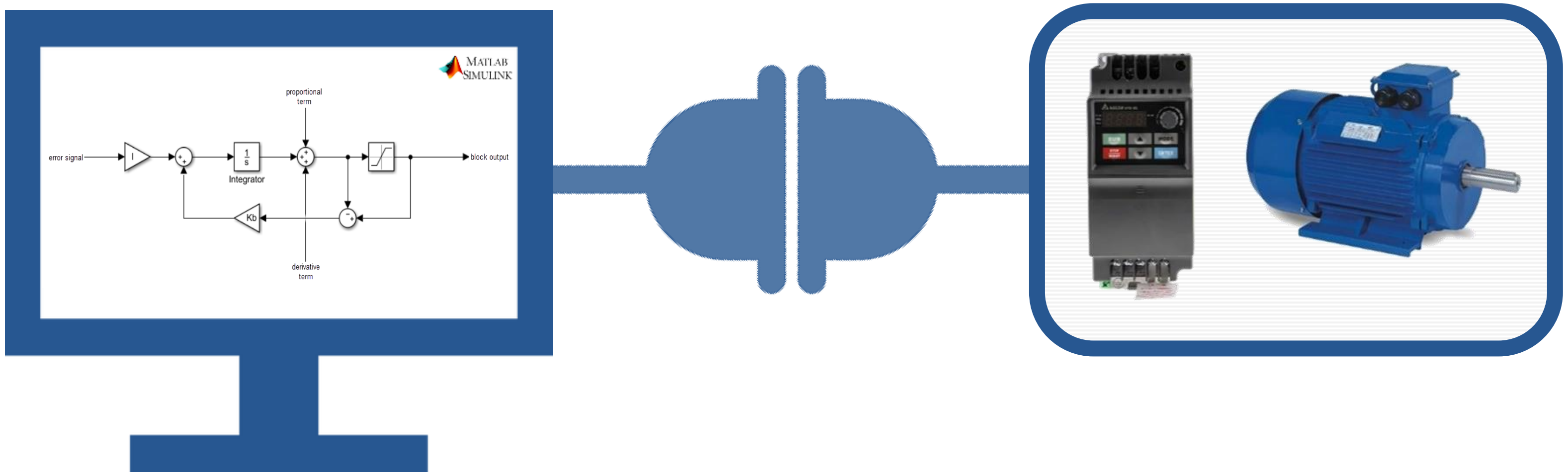
Realtime simulation
of
hardware components



Real controller

low voltage & low power
data signals

Realtime simulation
of
controller algorithms



Real hardware

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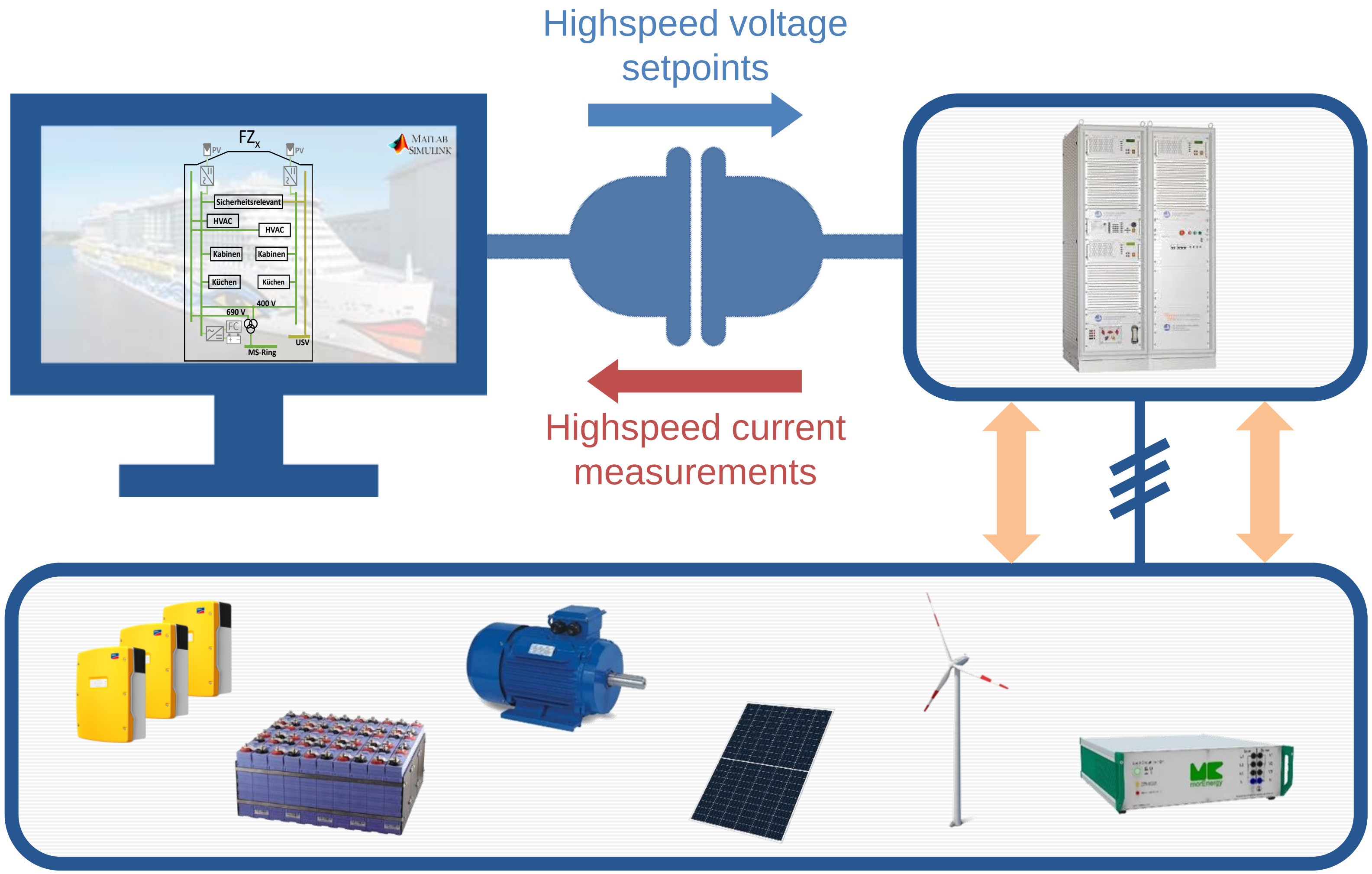
Power Hardware-in-the-Loop – The next leap in HiL

Realtime simulation
of
large and complex
grid structures



Power amplifier

Bidirectional
powerflow

Real devices

Three-phase
device-under-test (DUT)
connection

PHiL Usecase: Impedance Replication of AIDAcosma

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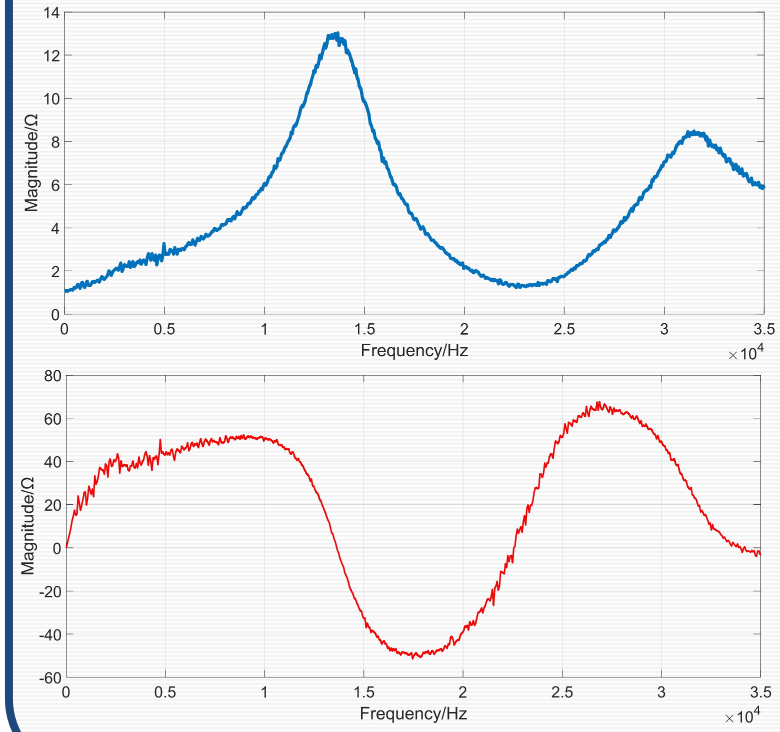
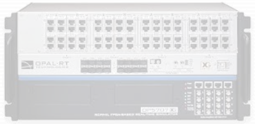
ONIS measurement on AIDAcosma



Simulink measurement of equivalent circuit on OP5707XG



PHiL measurement with ONIS on Spitzenberger

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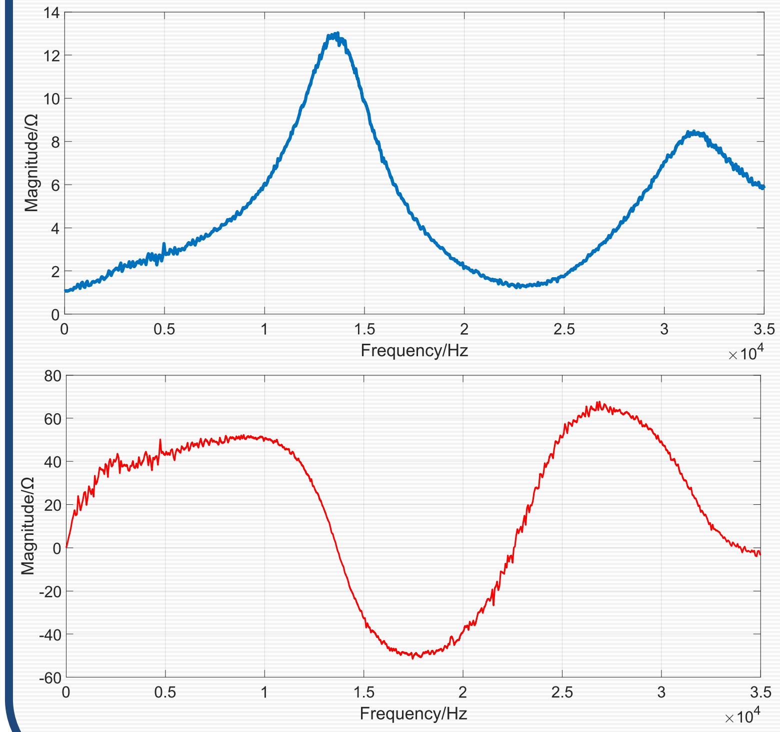
PHiL Usecase: Impedance Replication of AIDAcosma

ONIS measurement on AIDAcosma



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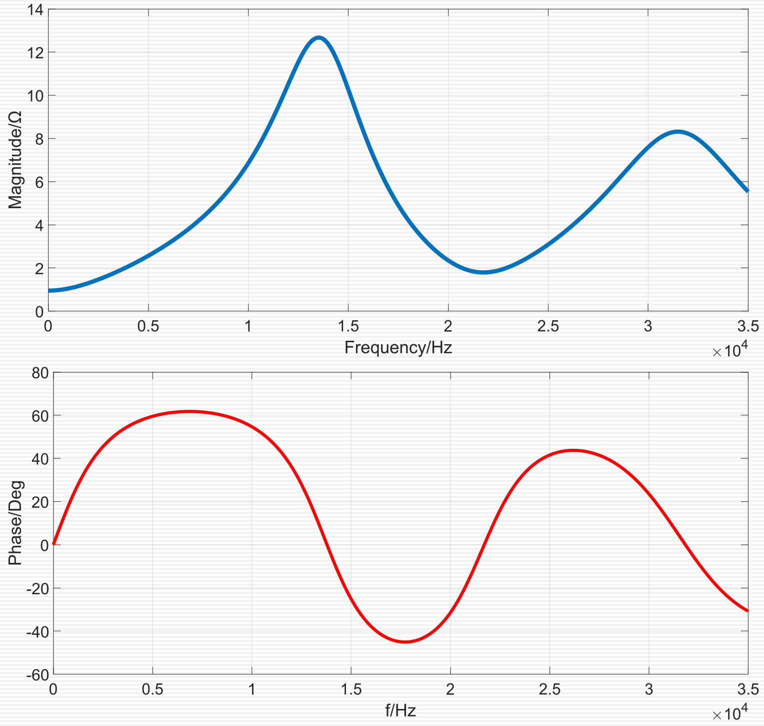

PHiL measurement with ONIS on Spitzenberger

PHiL Usecase: Impedance Replication of AIDAcosma

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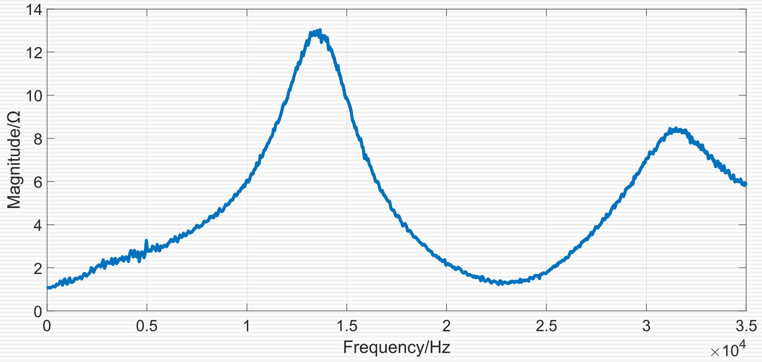

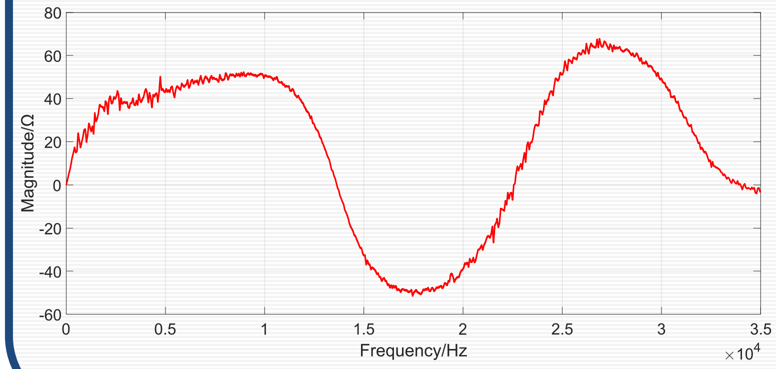

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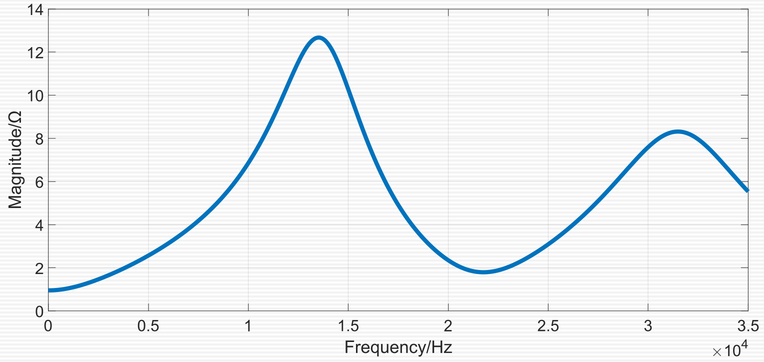
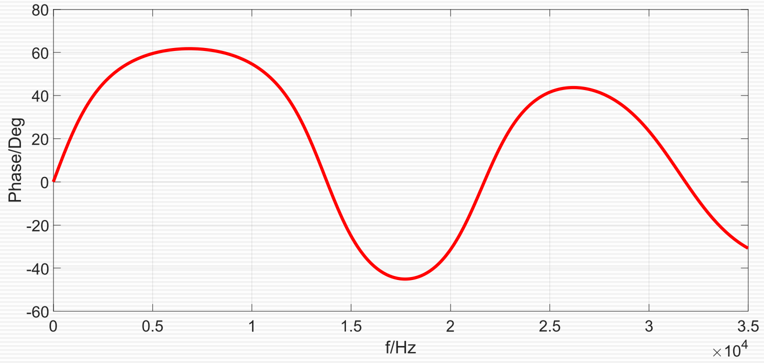
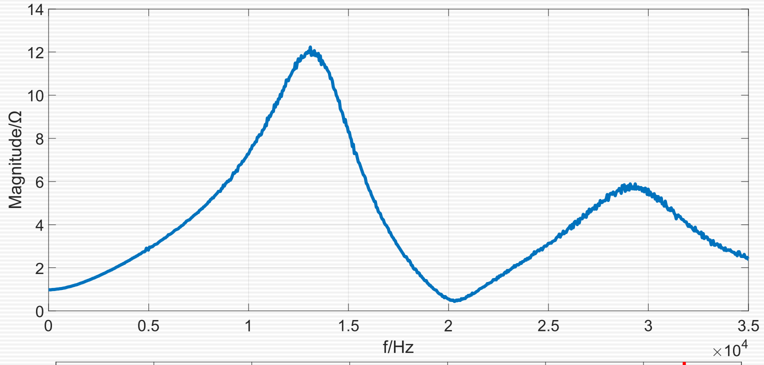
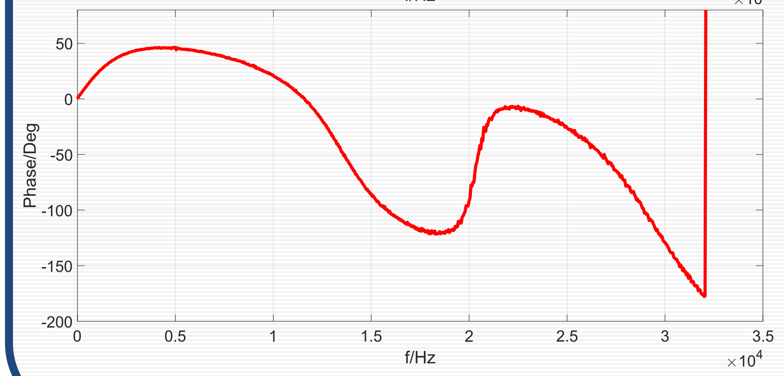




PHiL measurement with ONIS on Spitzenberger





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Importance of Impedance Measurement in the Future

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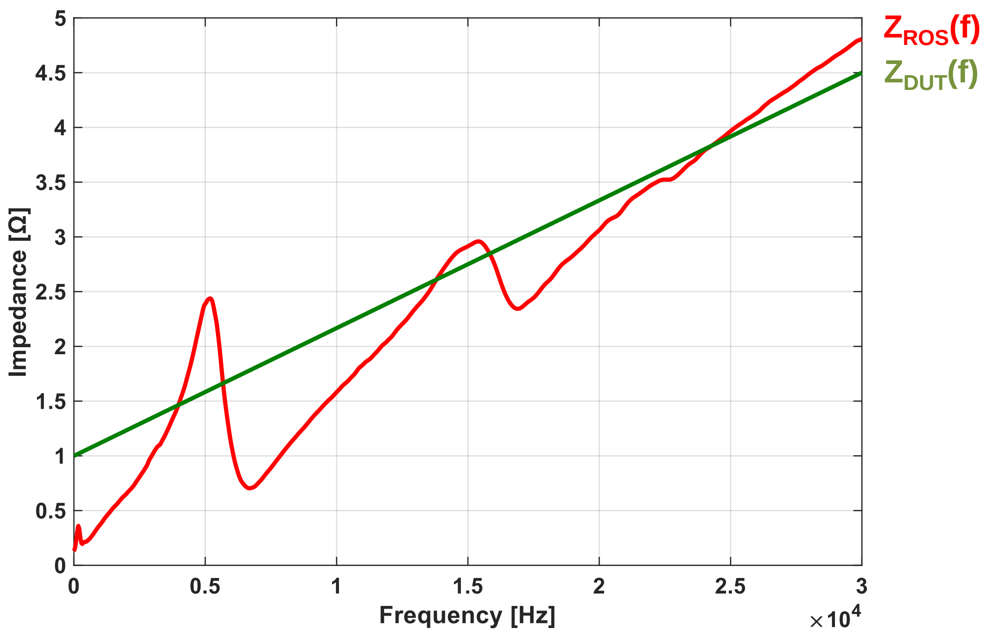
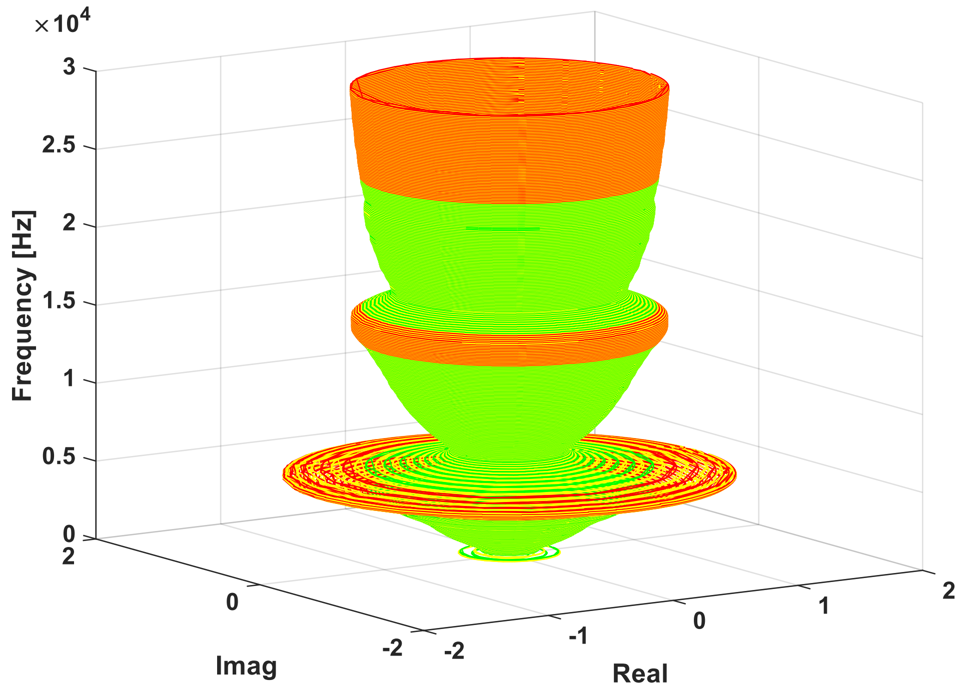
Exemplaric impedance of DUT and ROS in PHiL



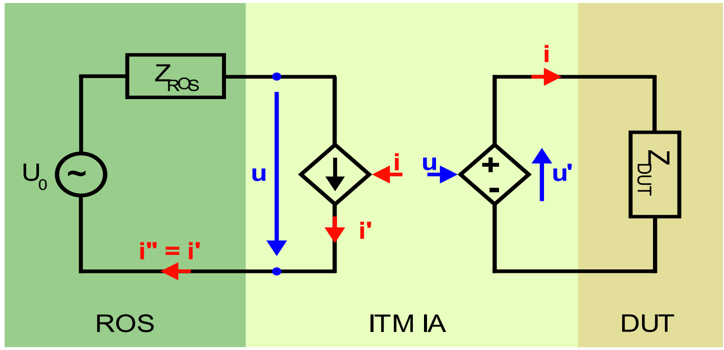
Visualization of unstable frequency regions of PHiL



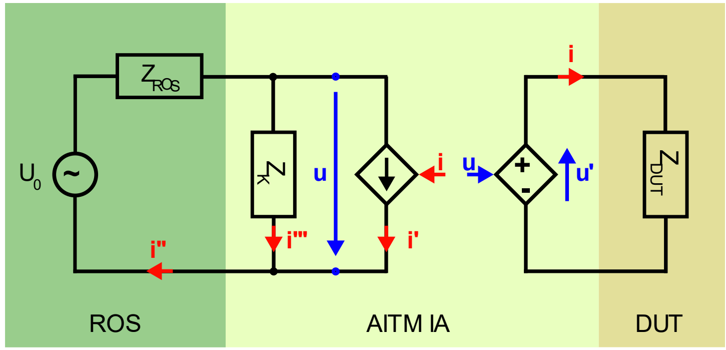
- PHiL gets unstable for $Z_{ROS}(f) > Z_{DUT}(f)$ due to delays (Nyquist) → Interface Algorithm (IA) for compensation
- Online impedance measurement of ROS and DUT with OP5707XG and Spitzenberger
  - ✓ Current state: Online impedance measurement from 100 Hz – 30000 Hz in 0.3 s (realtime capable)
  - ✓ Implementation of a custom interface algorithm which allows for full-bandwith PHiL simulation

Thank you for participating!

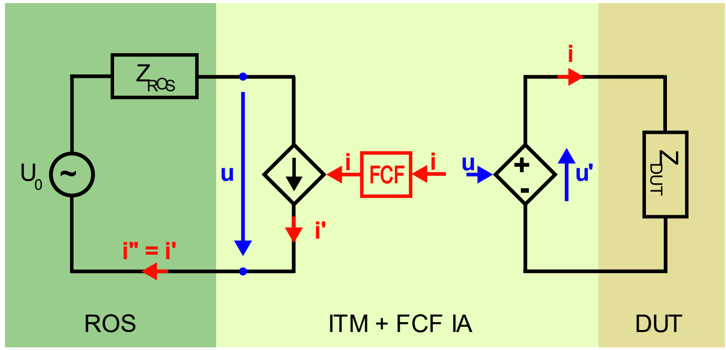
Stability criterion for PHiL – Interface Algorithms (IA)



- Ideal Transformer Method (ITM)
  - Direct coupling of u from simulation to hardware
  - Direct coupling of i from hardware to simulation

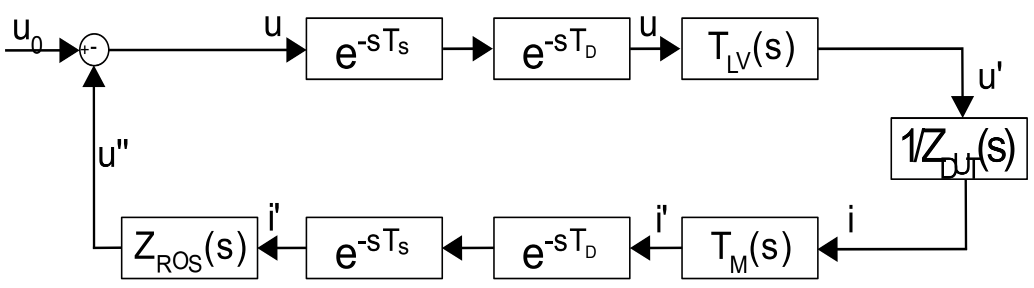


- Advanced Ideal Transformer Method (AITM)
  - Direct coupling of u fom simulation to hardware
  - Direct coupling of i from hardware to simulation
  - Additional stabilization impedance



- Ideal Transformer Method (ITM) with Feedback Current Filter (FCF)
  - Direct coupling of u from simulation to hardware
  - Filtered signal i from hardware to simulation

Stability criterion for PHiL – ITM theory



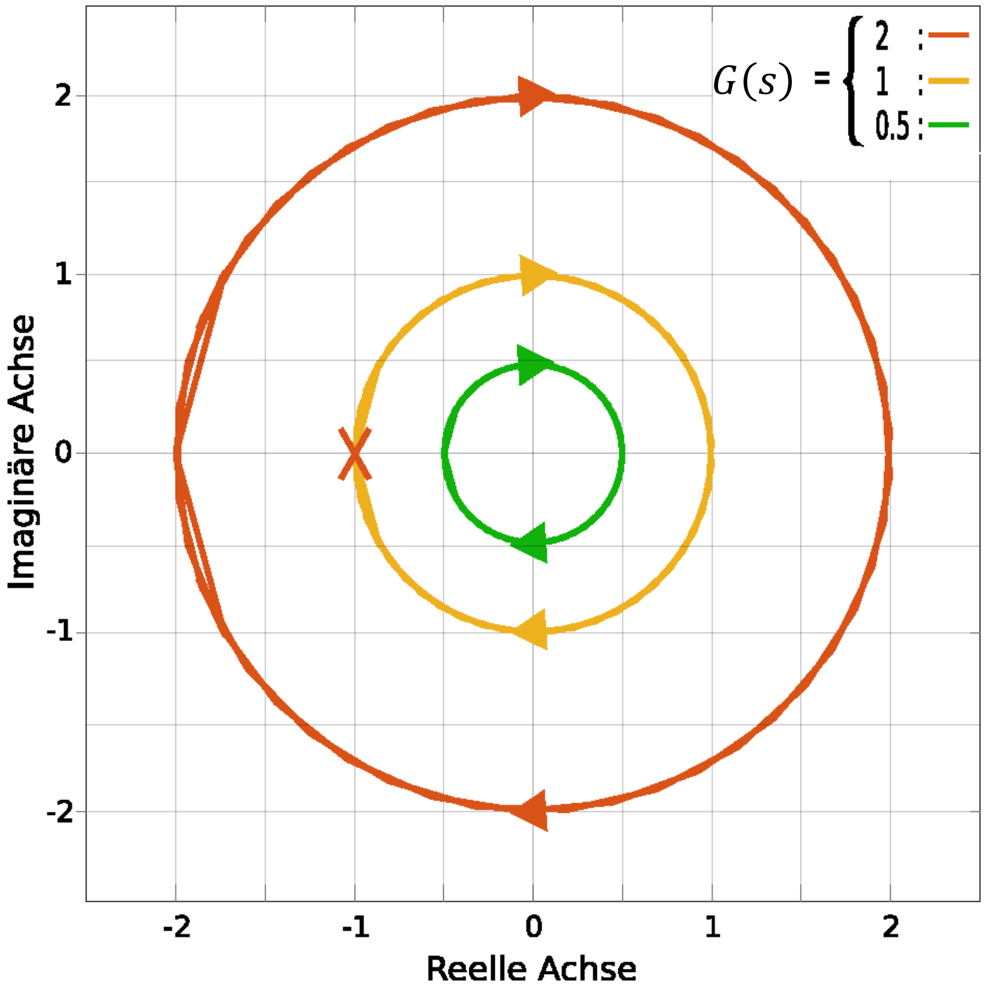
Open-loop is stable as $T_{LV}(s)$ is always stable

Closed-loop stability:

$$\rightarrow G(s) = e^{-sT_G} \cdot T_{LV}(s) \cdot T_M(s) \cdot \frac{Z_{ROS}(s)}{Z_{DUT}(s)}$$

$$\rightarrow G(s) \approx \frac{Z_{ROS}(s)}{Z_{DUT}(s)} \overset{!}{\leq} 1$$

$$\rightarrow Z_{DUT}(s) \geq Z_{ROS}(s)$$



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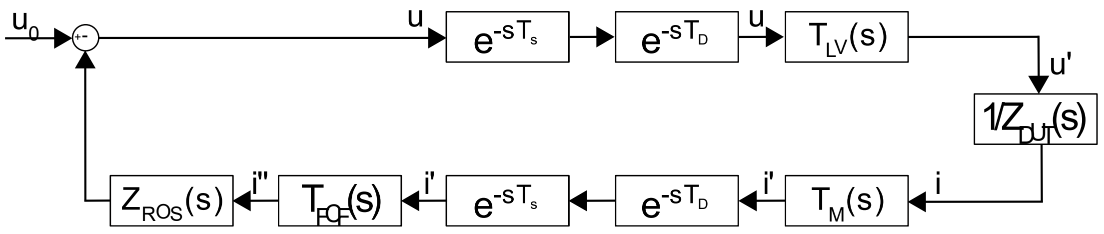
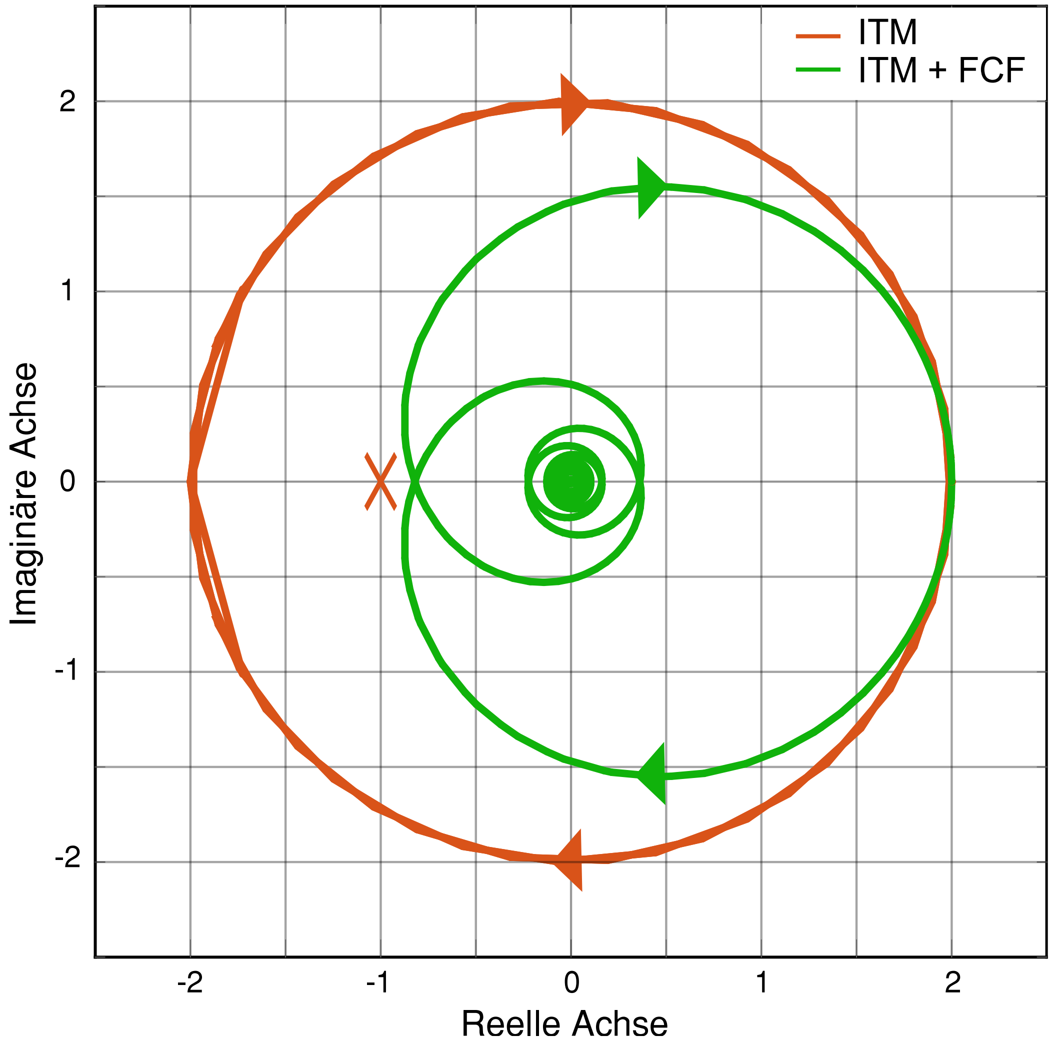


$$G(s) = e^{-sT_G} \cdot T_{LV}(s) \cdot T_M(s) \cdot T_{FCF}(s) \cdot \frac{Z_{ROS}(s)}{Z_{DUT}(s)}$$

$$\rightarrow G(s) = T_{FCF}(s) \cdot \frac{Z_{ROS}(s)}{Z_{DUT}(s)} \overset{!}{\leq} 1$$

$$\rightarrow \textit{choose matching } T_{FCF}(s) \textit{ to } \frac{Z_{ROS}(s)}{Z_{DUT}(s)} \textit{ and } T_G$$



Stabilitätskriterium für PHiL – ITM Stabilitätsbereich

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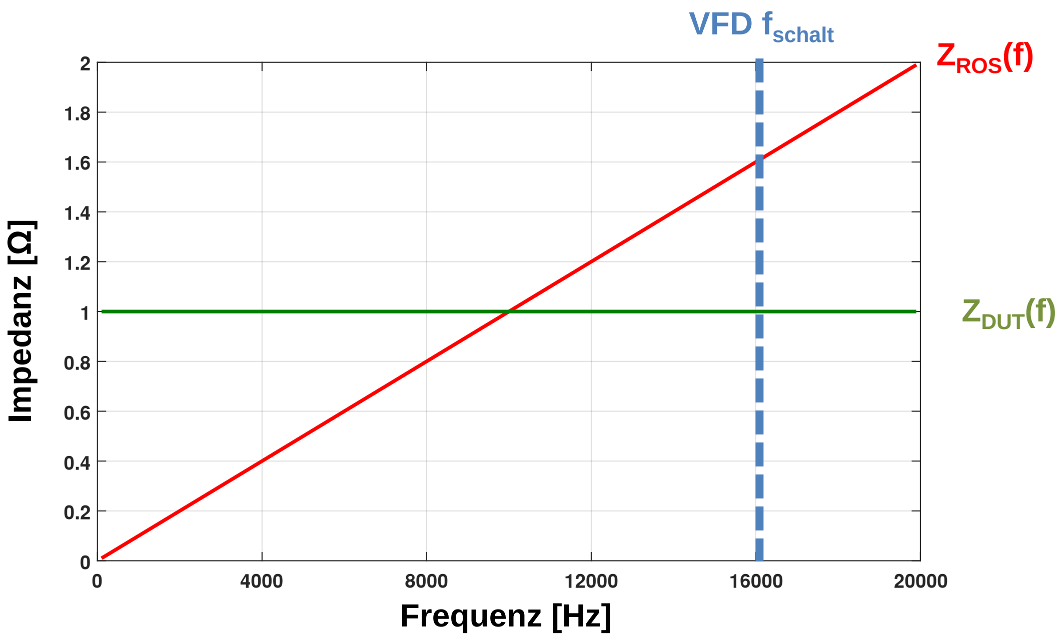
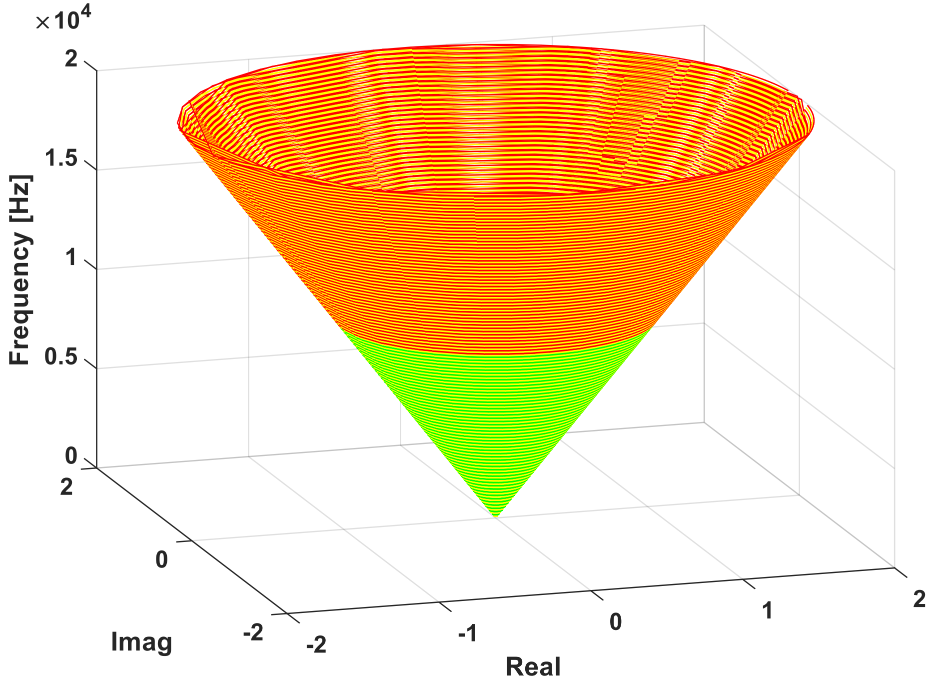
Exemplarische frequenzabhängige Impedanzen bei PHiL



Stabilitätsbereiche für frequenzabhängige Impedanzen bei PHiL



- Berücksichtigung frequenzabhängiger Impedanzen $\{Z_{DUT}(f), Z_{ROS}(f)\}$: f = [0; 20] kHz
- Anregung von Frequenzen aufgrund der Vielzahl schaltender Elemente im Netz (VFD, DC/DC,...)

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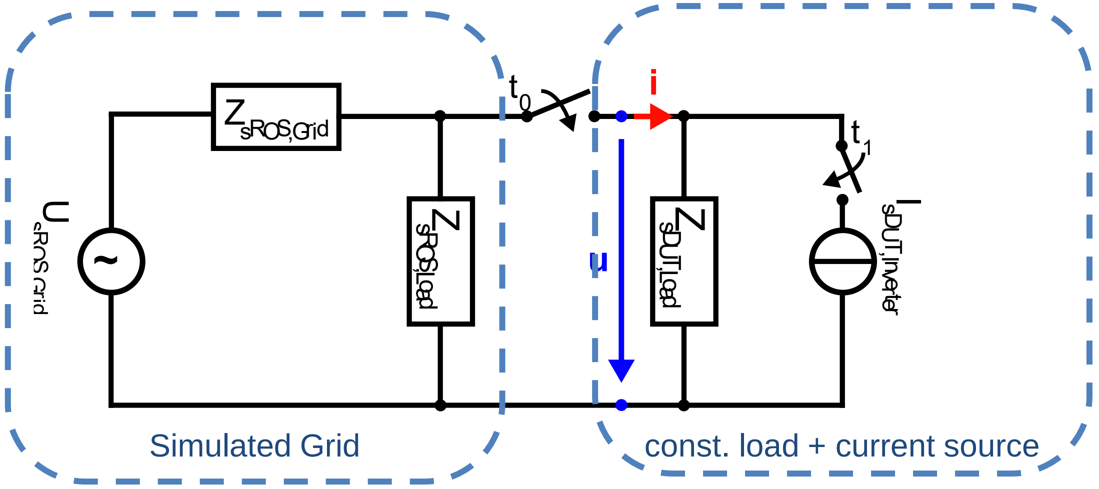
Stability criterion for PHiL - Examples

Simulated grid expansion with constant load and variable current source

- $Z_{sROS,Load} = Z_{sDUT,Load}$ = 31,36 Ω (marginally stable)
- constantly increasing current $I_{sDUT,Inverter}$ from battery inverter starting from $t = t_1$
- $Z_{sDUT} < Z_{sROS}$ @ $t = t_1$



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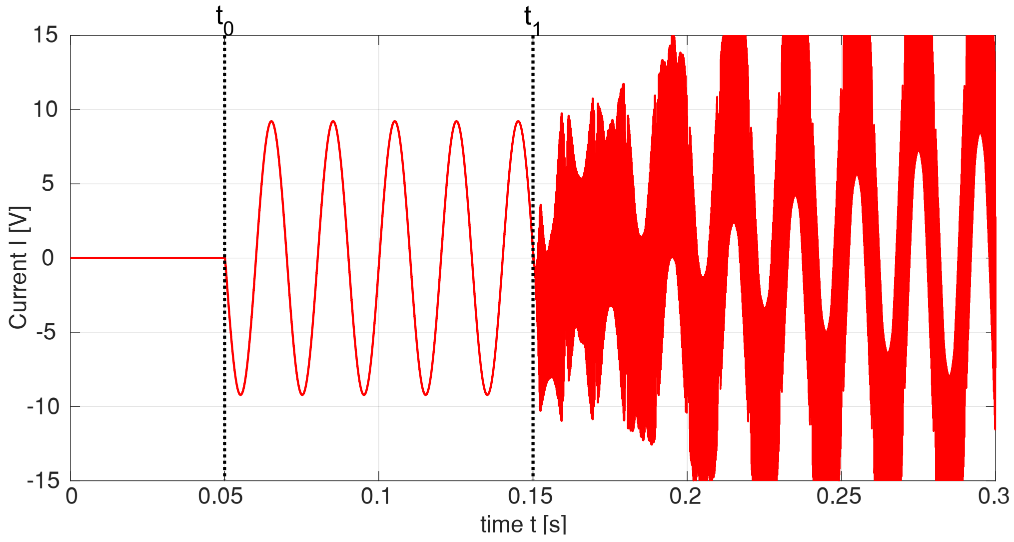
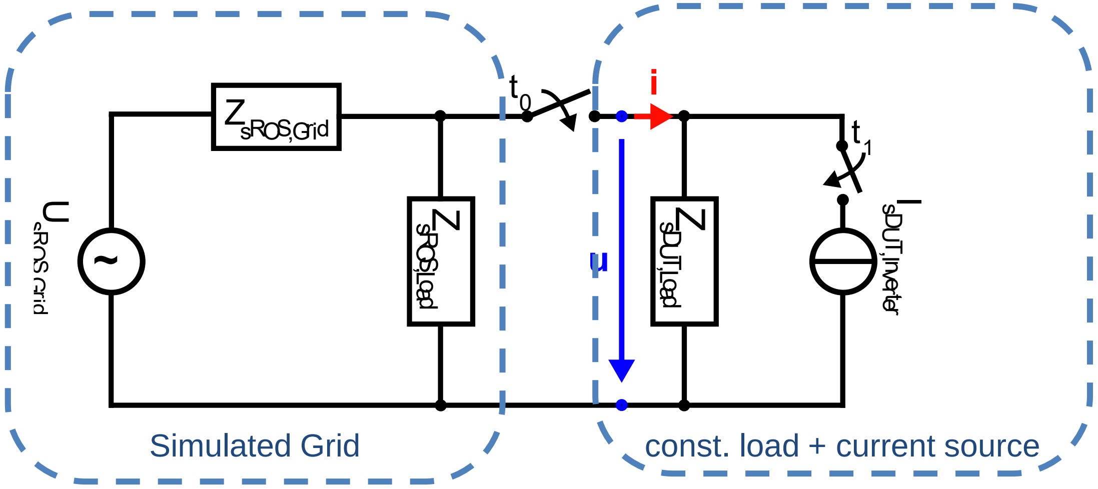
- constantly increasing current $I_{sDUT,Inverter}$ from battery inverter starting from $t = t_1$
- $Z_{sDUT} < Z_{sROS}$ @ $t = t_1 \rightarrow$ instability with ITM

ITM





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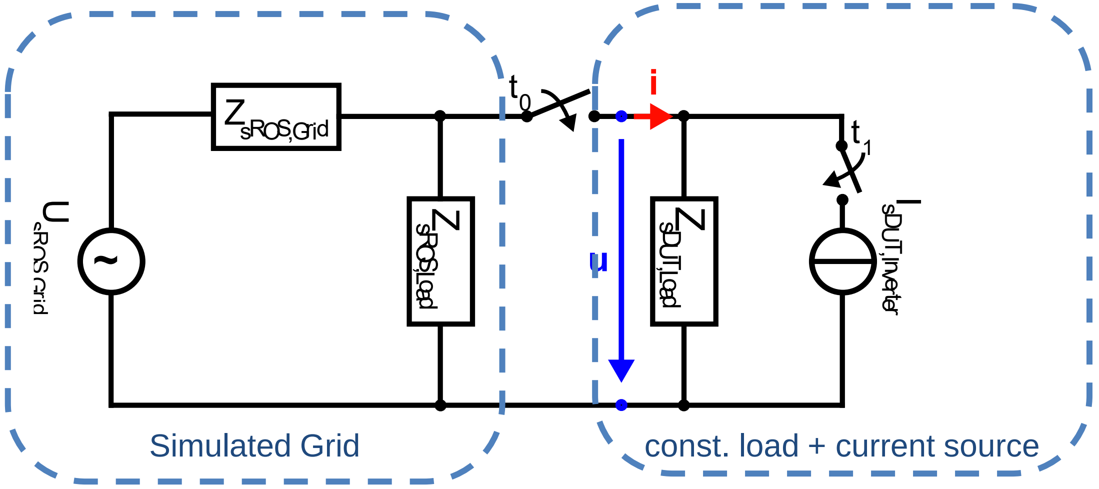
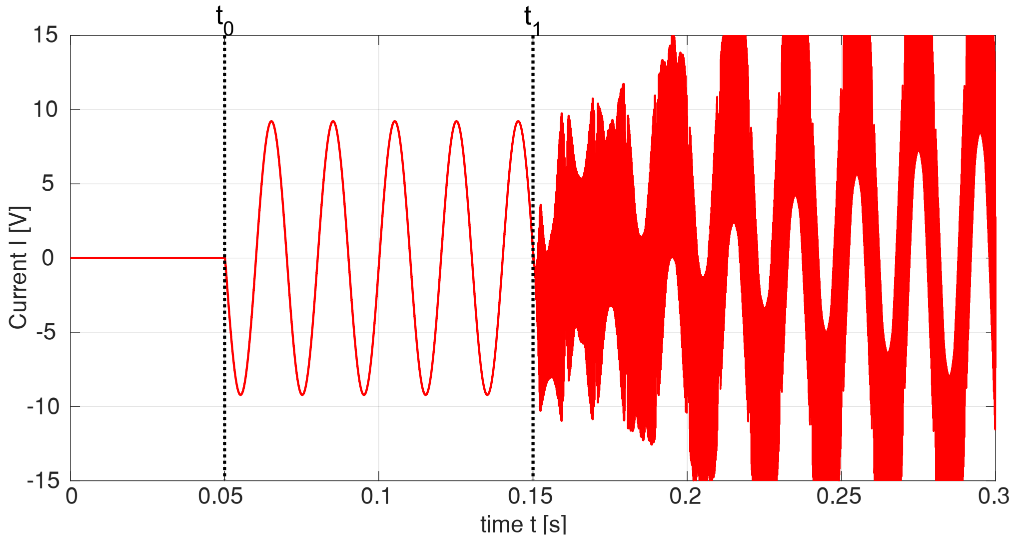
- constantly increasing current $I_{sDUT,Inverter}$ from battery inverter starting from $t = t_1$
- $Z_{sDUT} < Z_{sROS}$ @ $t = t_1$ → instability with ITM
  → stable with ITM + FCF



ITM



ITM + FCF