EGSTON POWER ELECTRONICS

Welcomes the audience

of

6th grid impedance conference

WORLDWIDE

AUSTRIAN

POWER

From Simulation to Emulation

or

From Digital Twin to Digital Power Twin

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A closer few

on

Power Hardware in the Loop

requirements

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Power Hardware in the Loop

systems & key design factors

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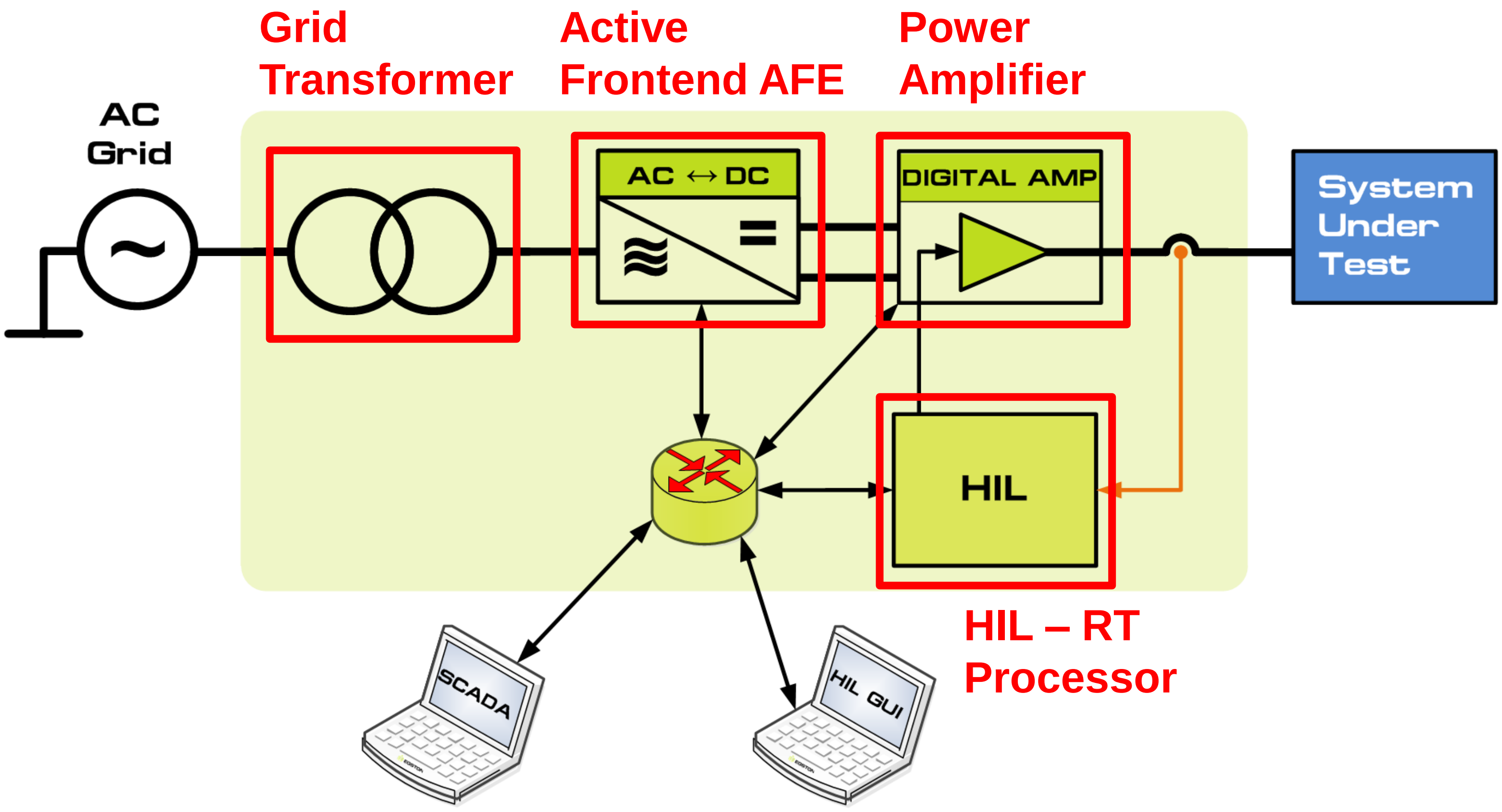
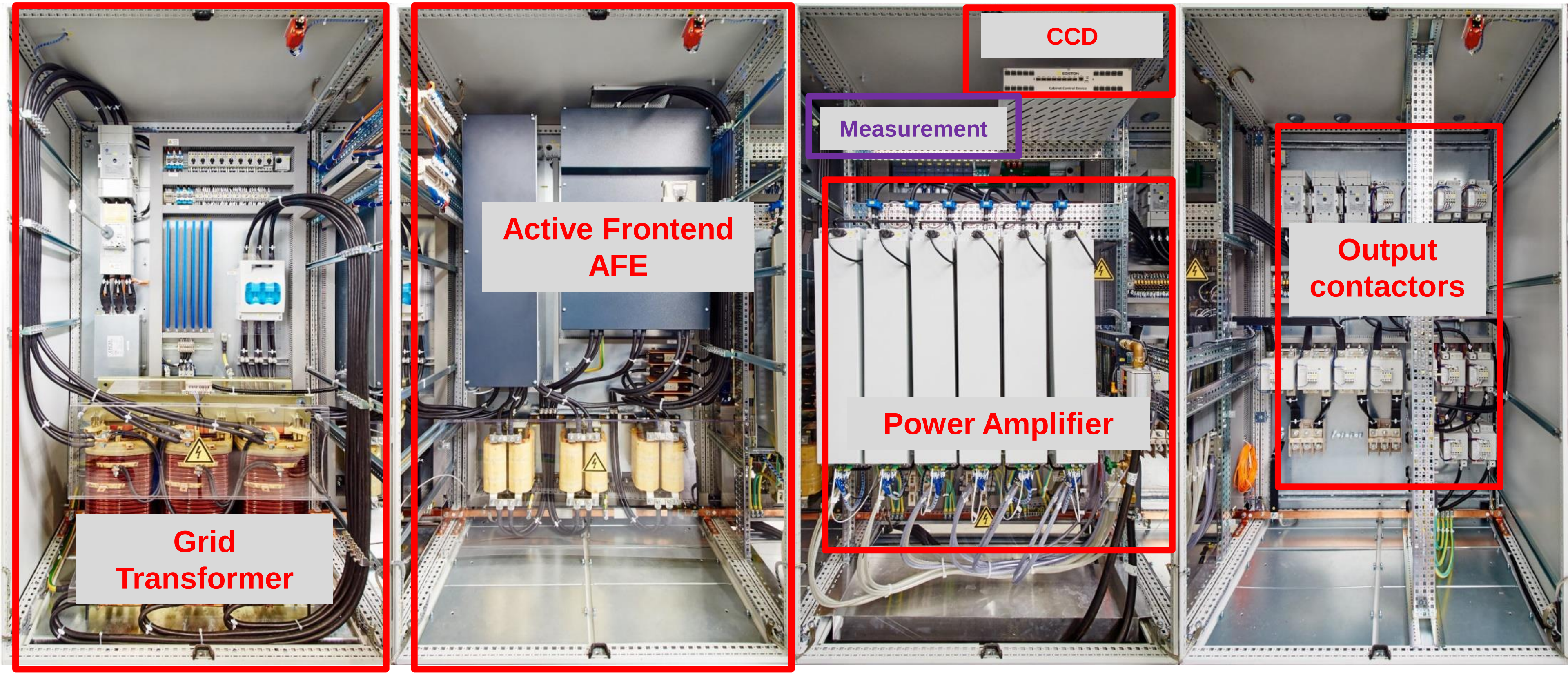
P-HIL – Turn Key System

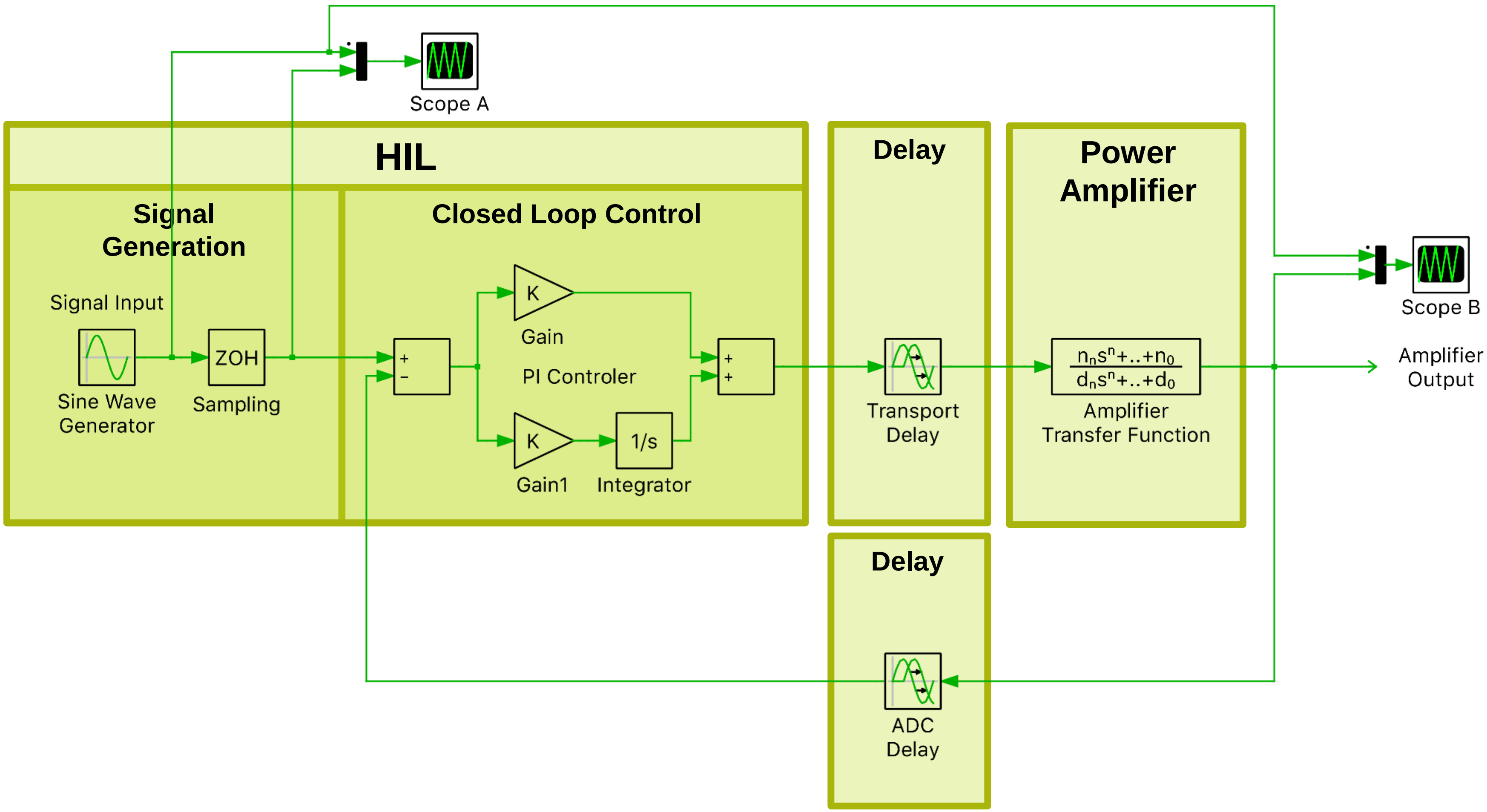


COMPISO P-HIL Solutions – 200 kVA



Example: 200kVA – 6 Amplifiers

Simplified Simulation Model



Power Hardware in the Loop

Requirements

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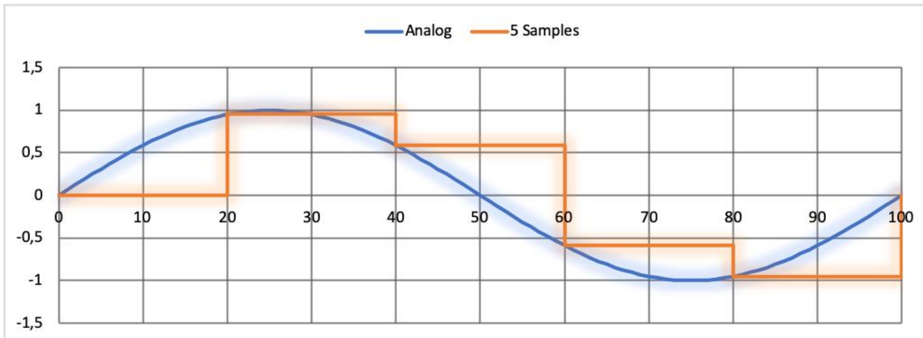
REQ 1: Model Bandwidth

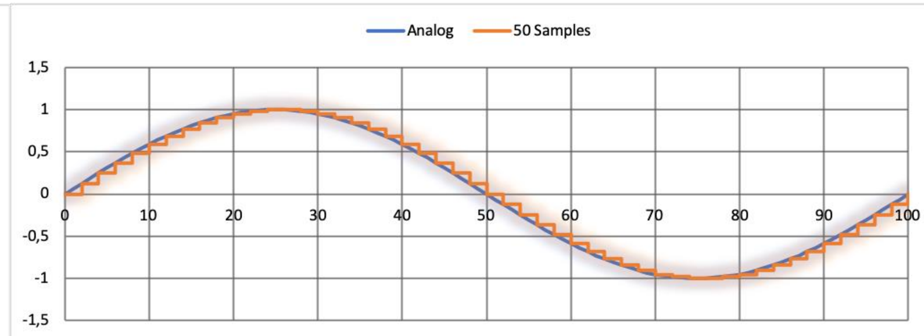
- Definition: Model Bandwidth
  - What is the highest frequency (f_{Model_Max}) in the model that has to be controlled in a closed loop application in the P-HIL System

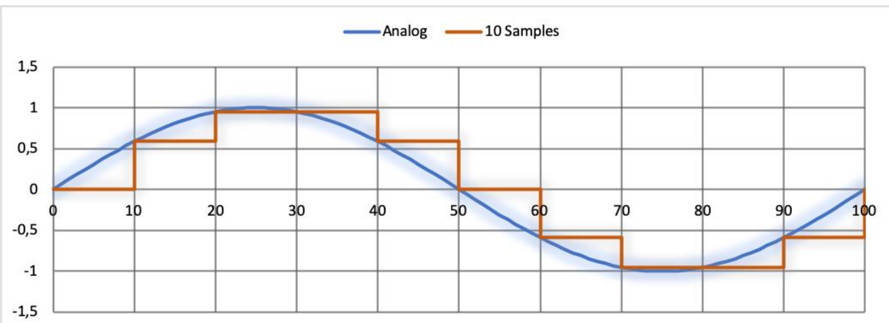
  - **REQ 1: f_{Model_Max} : Maximum Model Frequency**

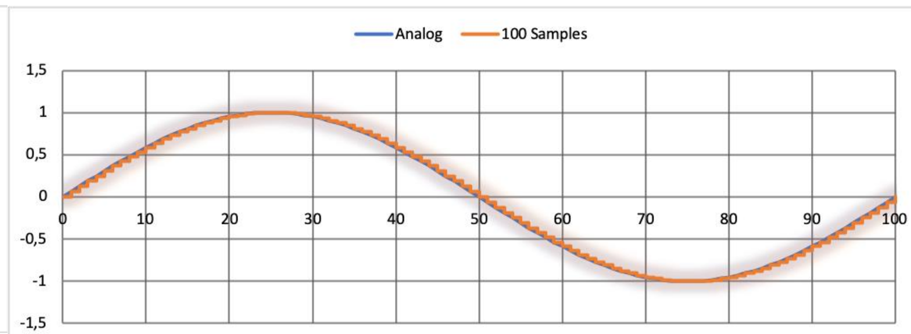
  - Remarks:
    - It is not the fundamental frequency!
    - It can be
      - the highest harmonic you want to model
      - The highest „modulation“ frequency (eg impedance spectroscopy) you want to model

REQ 2: Signal Quality @ f_{Model_Max}

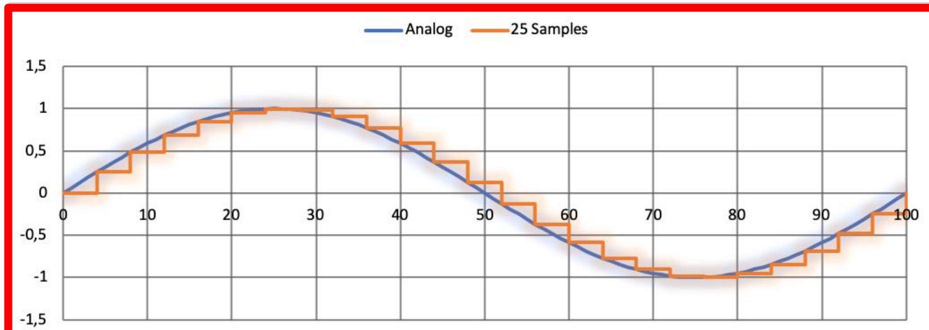








at least 25 set points per period @ f_{Model_Max}



REQ 2: Signal Quality @ f_{Model_Max}

- Signal quality of generated signals
  - At f_{Model_Max} a curve shall be represented by at least 25 (better 50) samples for a full sine wave period

REQ 2: at least 25 set points per period @ f_{Model_Max}

REQ 3: Model Cycle Time

- Requirement Model Cycle Time:

- **REQ 3**: $$T_{Model\_Cycle\_Time} = \frac{1}{25 \cdot f_{Model\_Max}}$$

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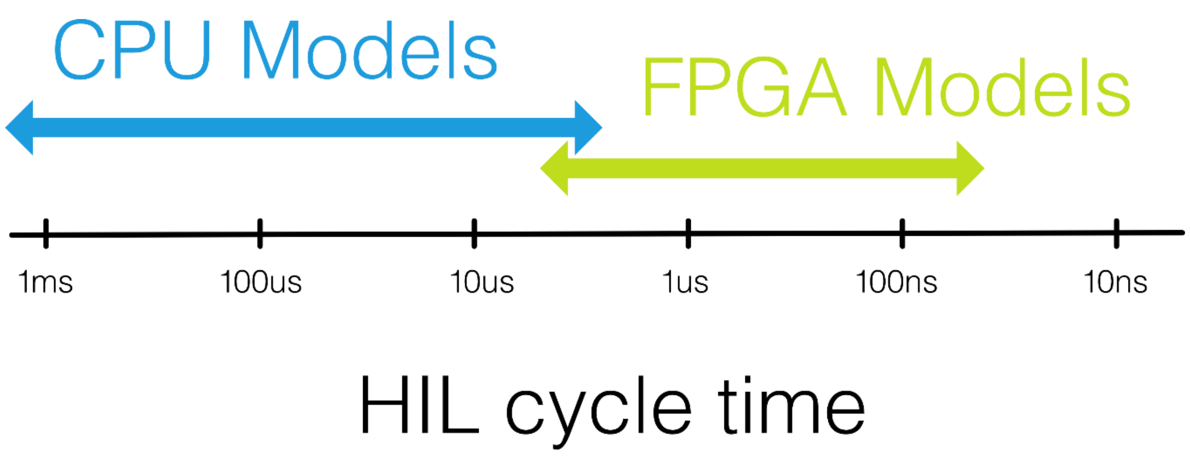
REQ 4: HIL CPU vs FPGA Technology

- Cycle time step size of the HIL real-time simulator: $T_{HIL\_Cycle\_Time}$

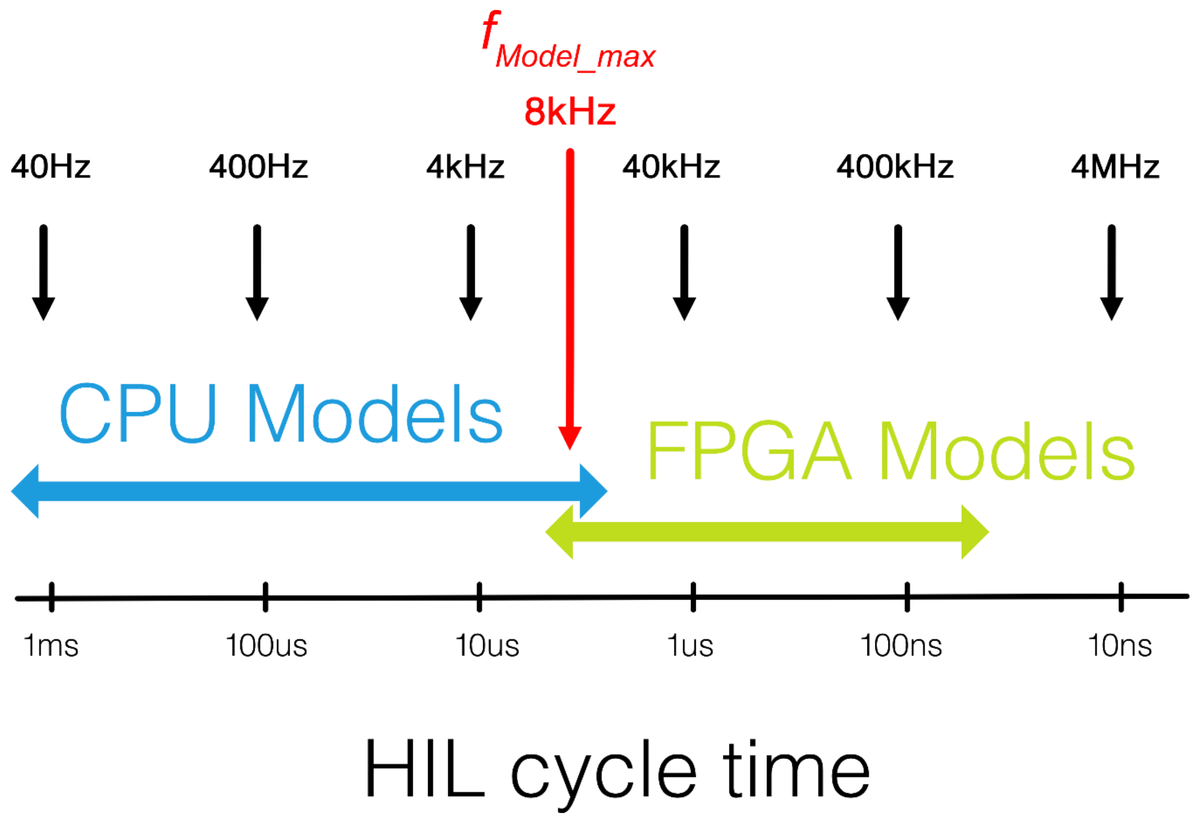
REQ 4: $T_{HIL\_Cycle\_Time} \leq T_{Model\_Cycle\_Time}$

- This REQ defines the required HIL RT-Processor technology



REQ 4: HIL CPU vs FPGA Technology

$$f_{Model\_max} = \frac{1}{25 \,.\, T_{HIL\_Cycle\_Time}}$$



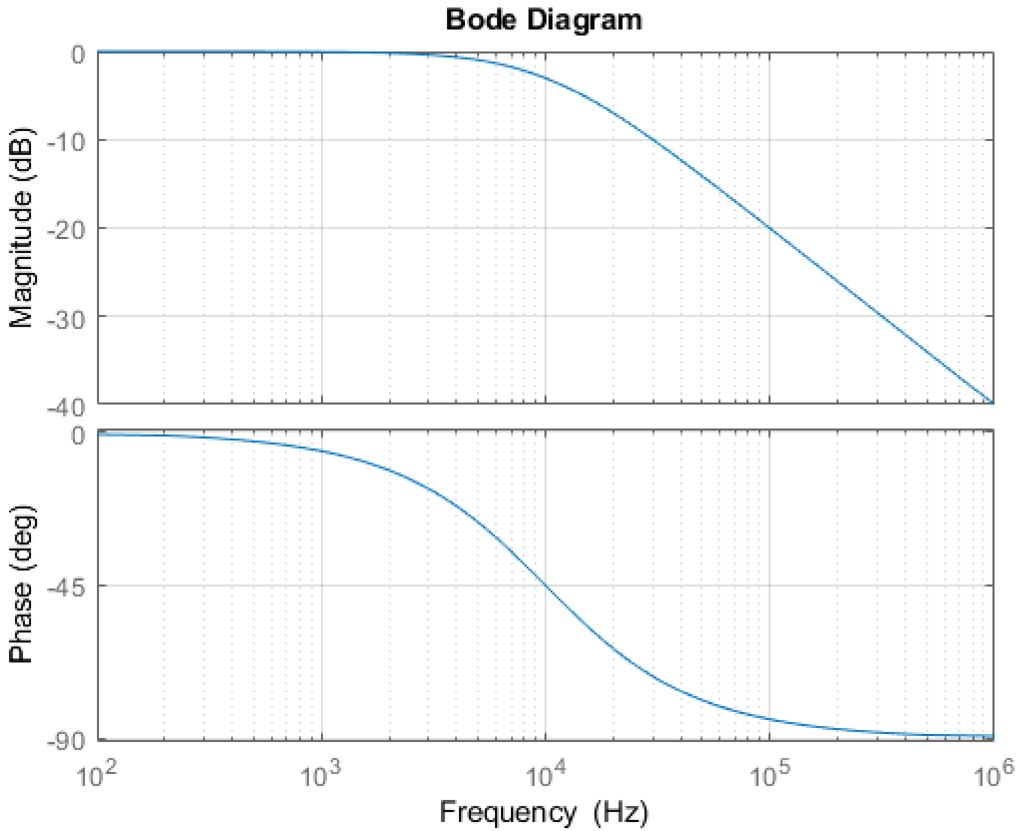
REQ 5: Power Amplifier Bandwidth

- At frequency: f_{Model_Max}
  - Amplifier Gain: < -1,5 dB
  - Amplifier Phase Shift: < -30°

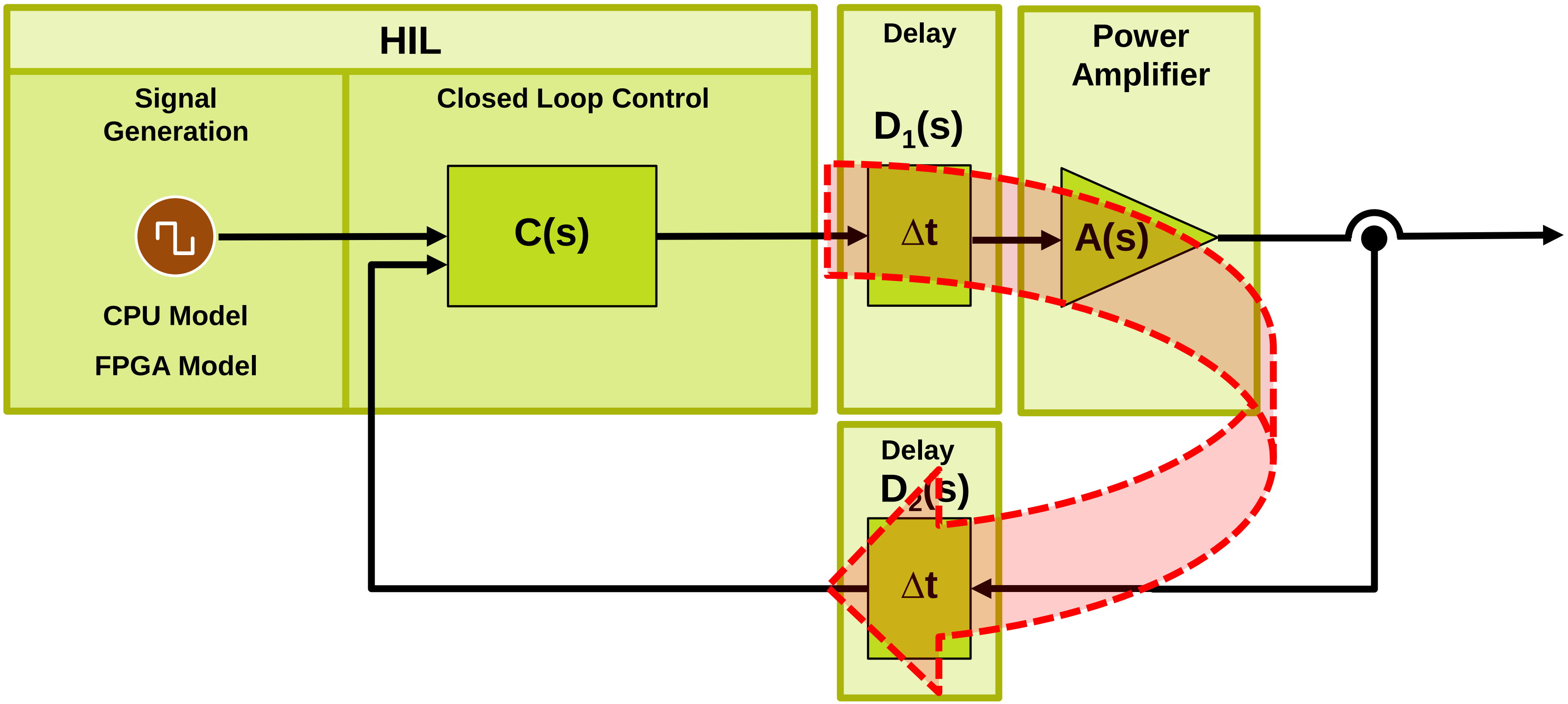
- **REQ 5: Amplifier Bandwidth (-3dB)**
  - $\boldsymbol{f_{-3dB} > 1,5 \cdot f_{Model\_Max}}$
    - Amplifier Gain: -3 dB
    - Amplifier Phase Shift: < -45°

Amplifier Transfer Function

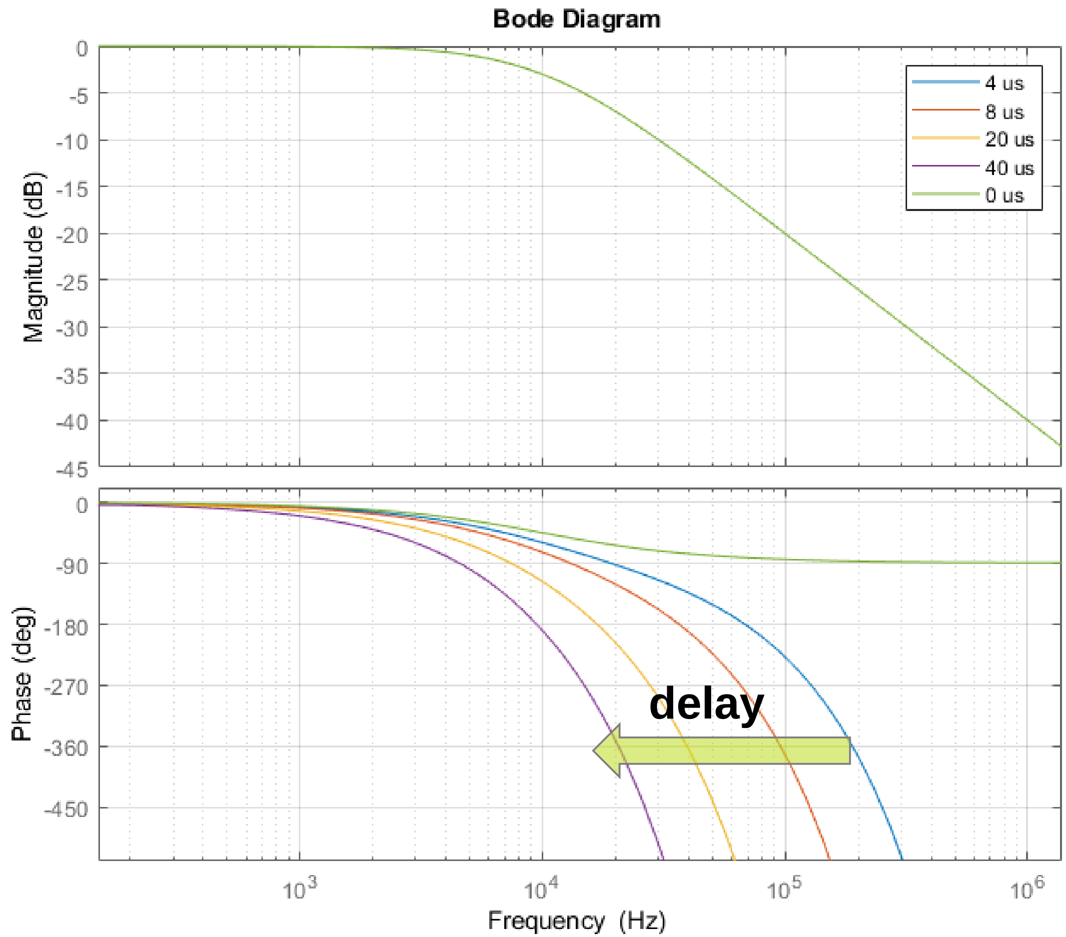
- Model requirement
  - For simple investigation:
    1st order transfer function is sufficient to start investigation



Delay & Phase Shift



Delay & Phase Shift



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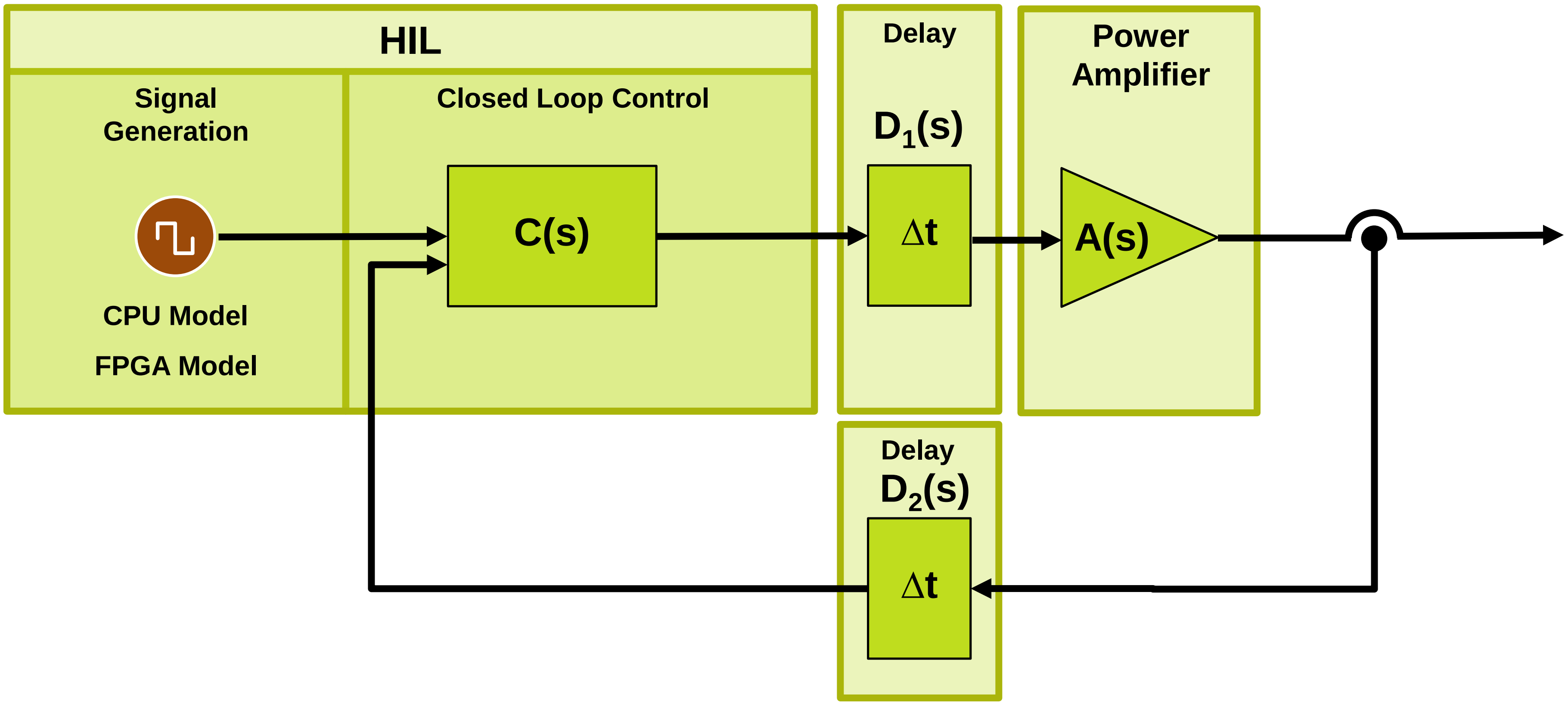
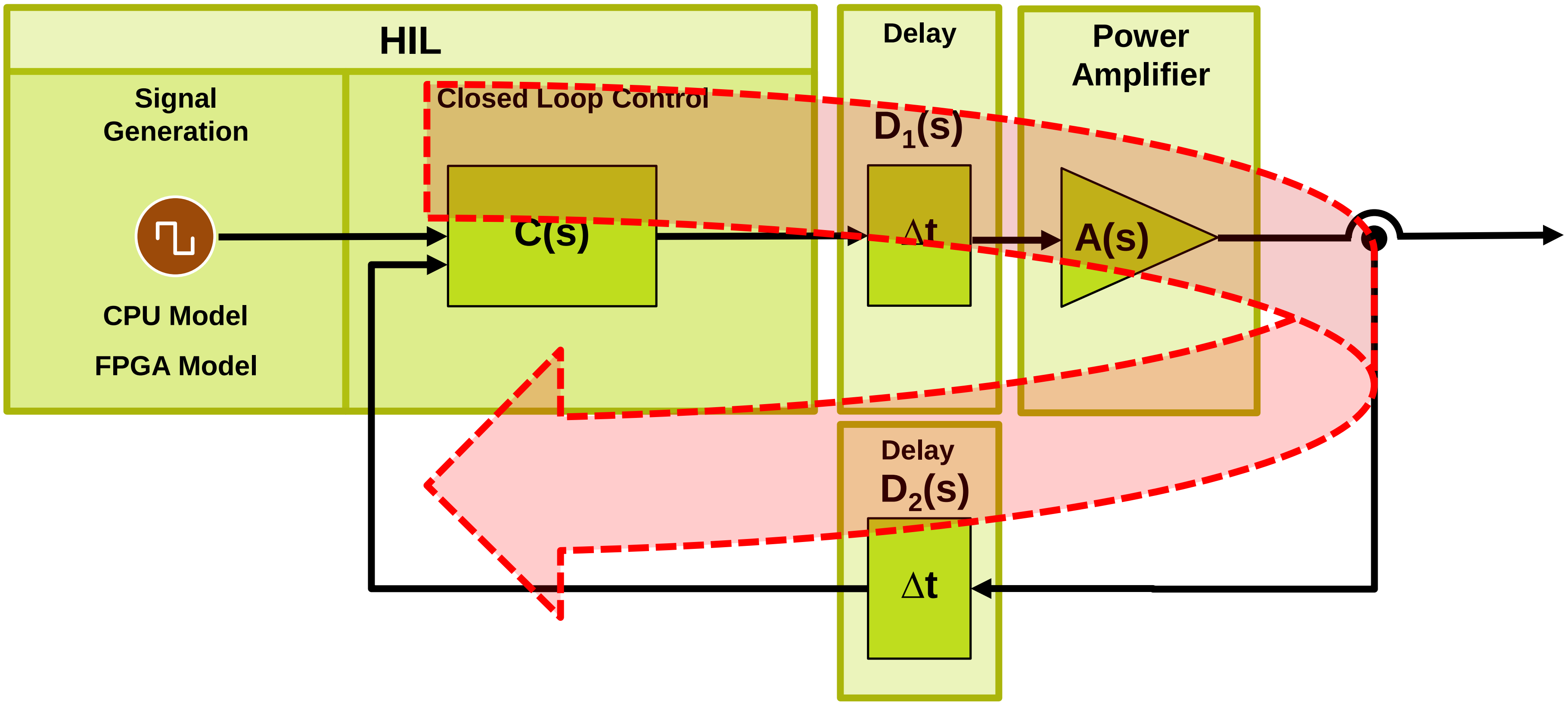
Stability Analysis

$$\frac{Y(s)}{X(s)} = \frac{C(s).D_1(s).A(s)}{1 + C(s).D_1(s).A(s).D_2(s)}$$



Stability Analysis – Open Loop Analysis



Stability Analysis

- Transfer Function

$$\frac{Y(s)}{X(s)} = \frac{C(s).D_1(s).A(s)}{1+\ C(s).D_1(s).A(s).D_2(s)} = \frac{Z(s)}{1+N(s)}$$

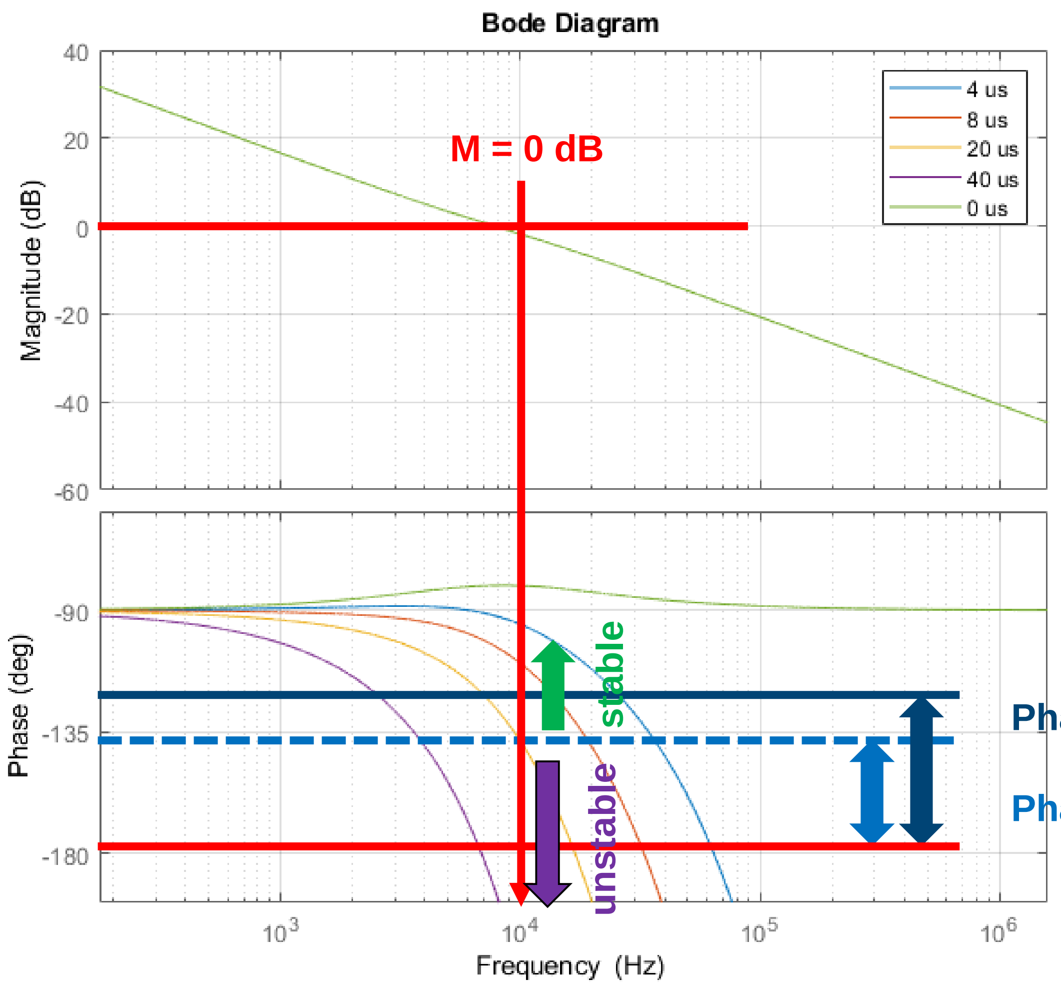
Instability: $1 = \ C(s).D_1(s).A(s).D_2(s) = N(s)$

$$Abs\big(N(s)\big) = 1\ \rightarrow 0dB$$

$$\varphi =\ 180^o$$

Stability Criterion (Nyquist): Phase Reserve $\phi >\ 45^0$

Stability Analysis



Phase Reserve Optimal: $\phi \geq 60^0$

Phase Reserve Min: $\phi \geq 45^0$

REQ 6: Open Loop Delay

- Phase Shift & delay time: $\Delta \boldsymbol{t}(\boldsymbol{f}, \boldsymbol{\varphi}) = \frac{\boldsymbol{\varphi}}{\mathbf{360}\ .\ \boldsymbol{f}}$
- Nyquist: Open loop stability: At $\boldsymbol{f}_{\boldsymbol{Model\_Max}}$ Phase reserve $\phi > 45^{o}$

Suggestion: **Phase Reserve: $\boldsymbol{\phi} \geq \mathbf{60^{o}}$**

$$\varphi = 180^{0} - \phi = 120^{0}$$

$$\boldsymbol{T}_{\boldsymbol{Open\_Loop\_Delay}}\,(\boldsymbol{f}_{\boldsymbol{Model\_Max}}, \mathbf{120^{o}}) = \frac{\mathbf{120}}{\mathbf{360}\ .\ \boldsymbol{f}_{\boldsymbol{Model\_max}}} = \frac{\mathbf{1}}{\mathbf{3}\ .\ \boldsymbol{f}_{\boldsymbol{Model\_max}}}$$

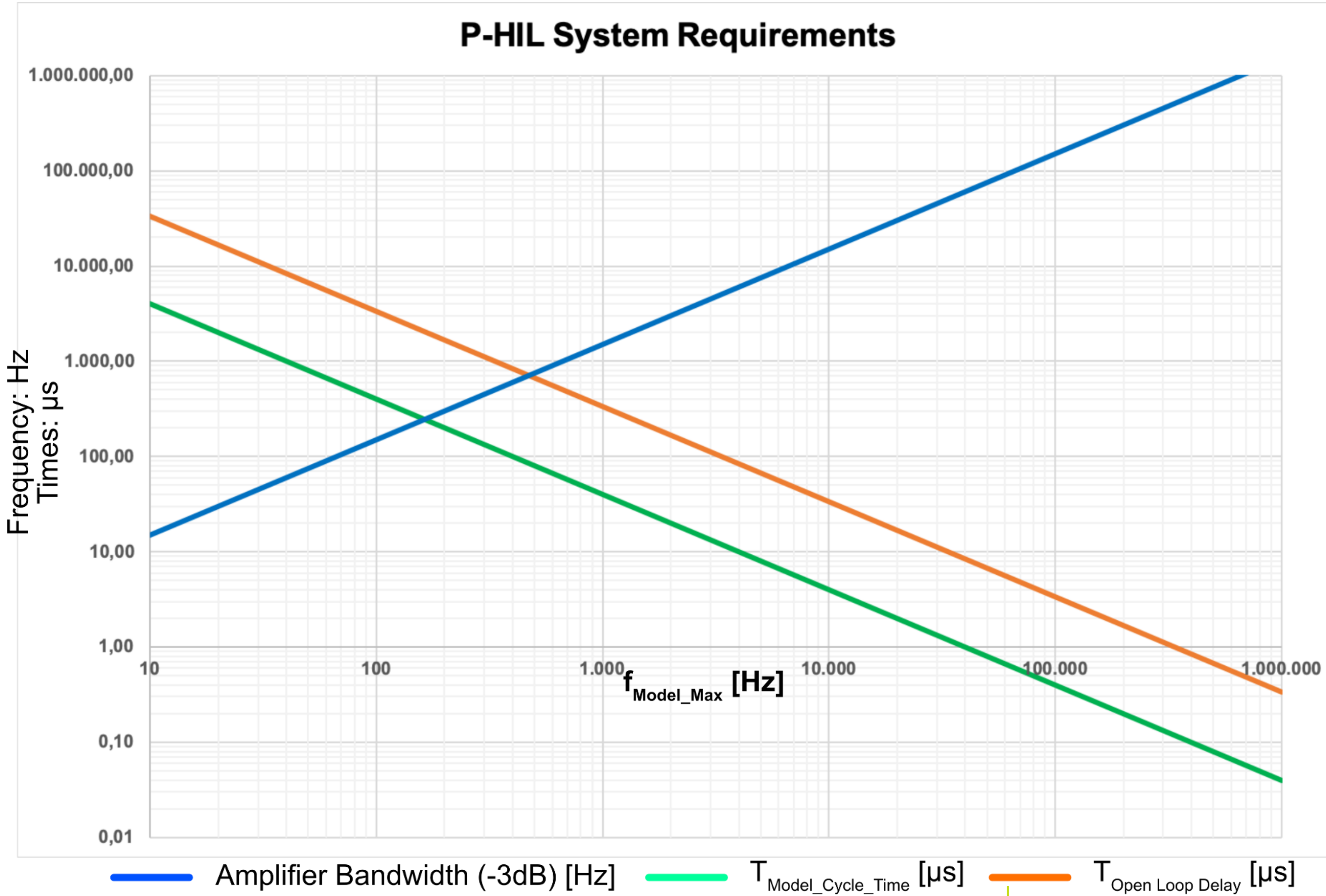
$$\boldsymbol{T}_{\boldsymbol{Open\_Loop\_Delay}} = \boldsymbol{T}_{\boldsymbol{Transport\_HIL_{Amp}}} + \boldsymbol{T}_{\boldsymbol{Amplifier}} + \boldsymbol{T}_{\boldsymbol{Transport\_ADC\_HIL}}$$

REQ 6 Open Loop Delay: $\boldsymbol{T}_{\boldsymbol{Open\_Loop\_Delay}} < \frac{\mathbf{1}}{\mathbf{3}\ .\boldsymbol{f}_{\boldsymbol{Model\_Max}}}$

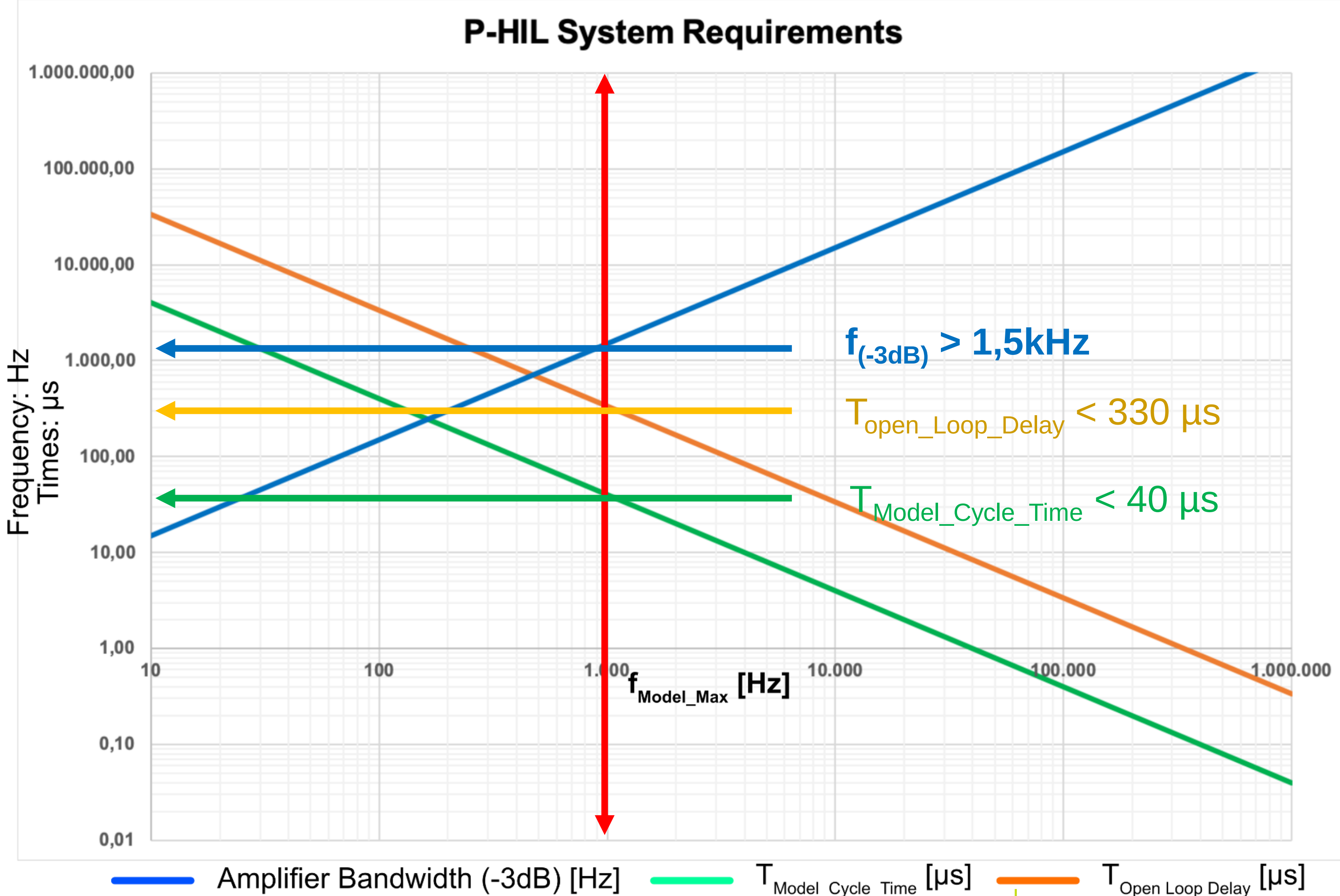
REQIREMENTS Summary

- **REQ 1: define Maximum Model Frequency** f_{Model_Max}
- **REQ 2: at least 25 set points per period @** f_{Model_Max}
- **REQ 3**: $$T_{Model\_Cycle\_Time} = \frac{1}{25 \cdot f_{Model\_Max}}$$
- **REQ 4:** $T_{HIL\_Cycle\_Time} \leq T_{Model\_Cycle\_Time}$
- **Select Simulation Technology**
  - $T_{HIL\_Cycle\_Time}$ **> 4µs ➔ CPU Model**
  - $T_{HIL\_Cycle\_Time}$ **< 4µs ➔ FPGA Model**
- **REQ 5: Amplifier Bandwidth (-3dB)**
  - $f_{-3dB} > 1,5 \cdot f_{Model\_Max}$
- **Phase Reserve:** $\phi \geq 60^o$
- **REQ 6 Open Loop Delay:** $T_{Open\_Loop\_Delay} < \frac{1}{3 \cdot f_{Model\_Max}}$

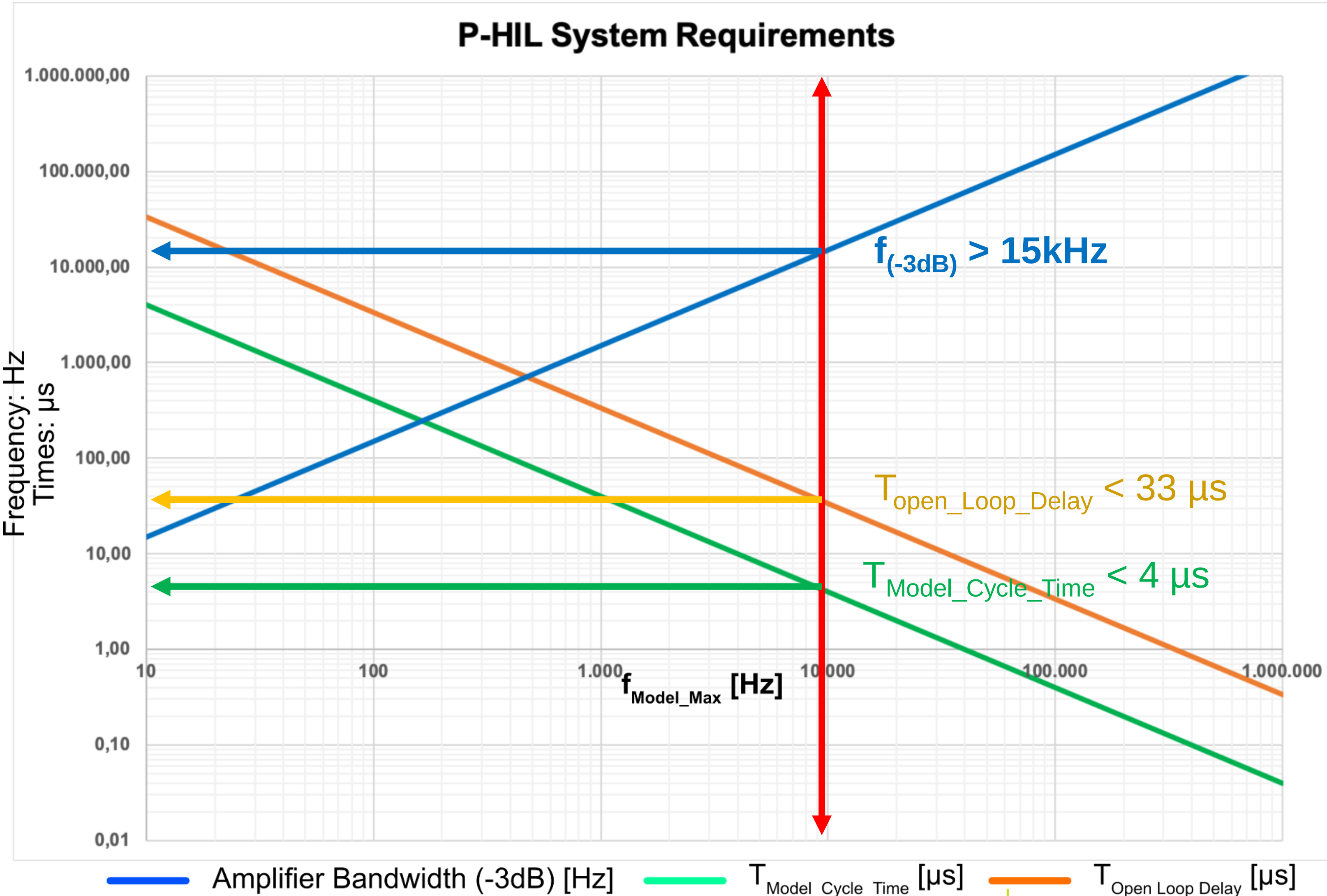
P-HIL Selection Table



Example: f_{Model_max} = 1 kHz



Example: $f_{Model\_max} = 10$ kHz



EGSTON POWER ELECTRONICS
PROVIDES YOU
WITH

HIGH POWER AND
HIGH END
AMPLIFIERS

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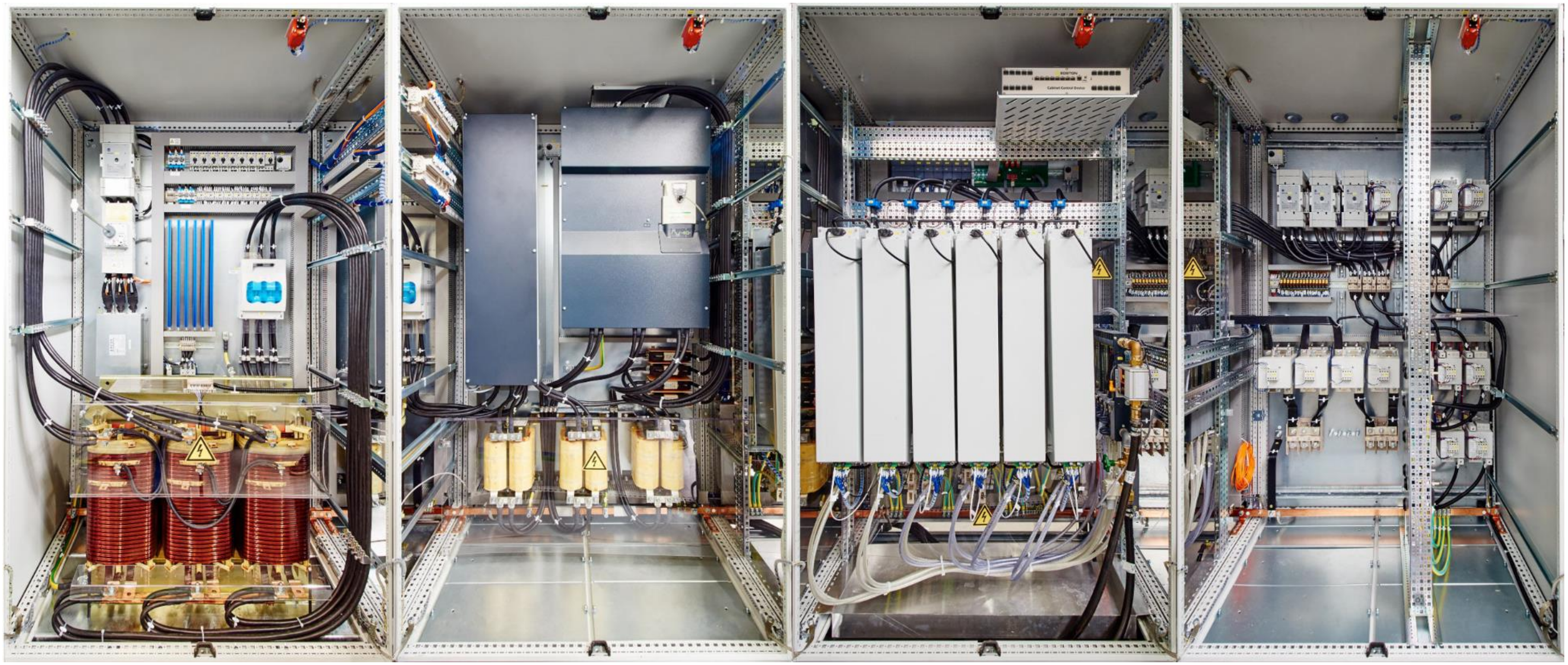
Key Features of COMPISO Amplifiers

- **Provides DC and / or AC**
- **Source and /or Sink**
- **Up to 820VDC at full load**
- **Cascadable up to 1500VDC**
- **Up to 485V AC Line-Line**
- **Up to 5kHz full span and 15kHz -3dB harmonics**
- **Groups of 4 or 6 Amplifiers can be used ultra flexible**

COMPISO 100 kVA P-HIL Solutions

COMPISO 200 kVA P-HIL Solutions



HIL Partner

High Speed Fibre Optic Interface implemented

OPAL-RT TECHNOLOGIES

RTDS Technologies

NATIONAL INSTRUMENTS™

speedgoat
real-time simulation and testing

dSPACE

Typhoon HIL

MARKETS & APPLICATIONS

SMART GRID

Applications

- Grid Emulator (50, 60, 400 Hz)
- Grid Load
- PV-Inverter Emulation
- Wind-Generator Emulation
- Impedance Spectroscopy
- UPS (Uninteruptible Power Supply) Emulation
- Grid Inverter Emulation
- Grid Motor / Generator Emulation

AUTOMOTIVE & TRANSPORT

Applications

Electrical drive train emulation

- Battery Emulator
- Drive Inverter Emulator
- Motor Emulator

eVehicle Applications

- eVehicle charging station emulator
- Test Bench for charging

Test Benches for combustion engine drive train

- Drive Inverter for electrical machines connected to combustion machines, wheel, gear boxes

Transportation

- Grid Emulator
- Machine Emulator
- Inverter Emulator
- Electrical drive train emulation

AEROSPACE & DEFENSE

Applications

- 400 Hz Supply Grid Emulator
- DC-Supply emulation
- 400 Hz Aerospace device emulator
- AC-DC Coupling Emulator
- Generator / Motor Emulator
- 400 Hz Inverter Emulator

OTHERS

- Motor / Generator Emulator
- Motor Drive Inverter Emulator
- Motor Frequency Inverter Emulator

Thank you…

…for your attention

for further dicussions please feel free to contact me

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