PAUL SCHERRER INSTITUT

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Corrector power supplies for SLS-2

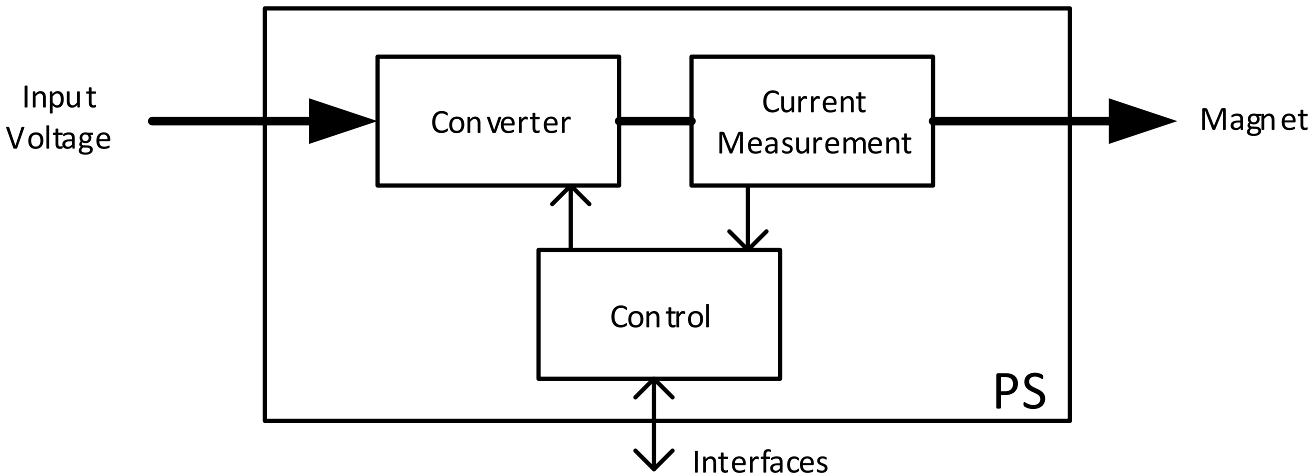
ARIES Workshop 14 November 2018

Outline

- Introduction to Corrector PS (@PSI)
  - Main Components
  - Behavioural Aspects
- SLS2 Storage Ring Magnet & Powersupply Summary
- SLS2 Corrector PS

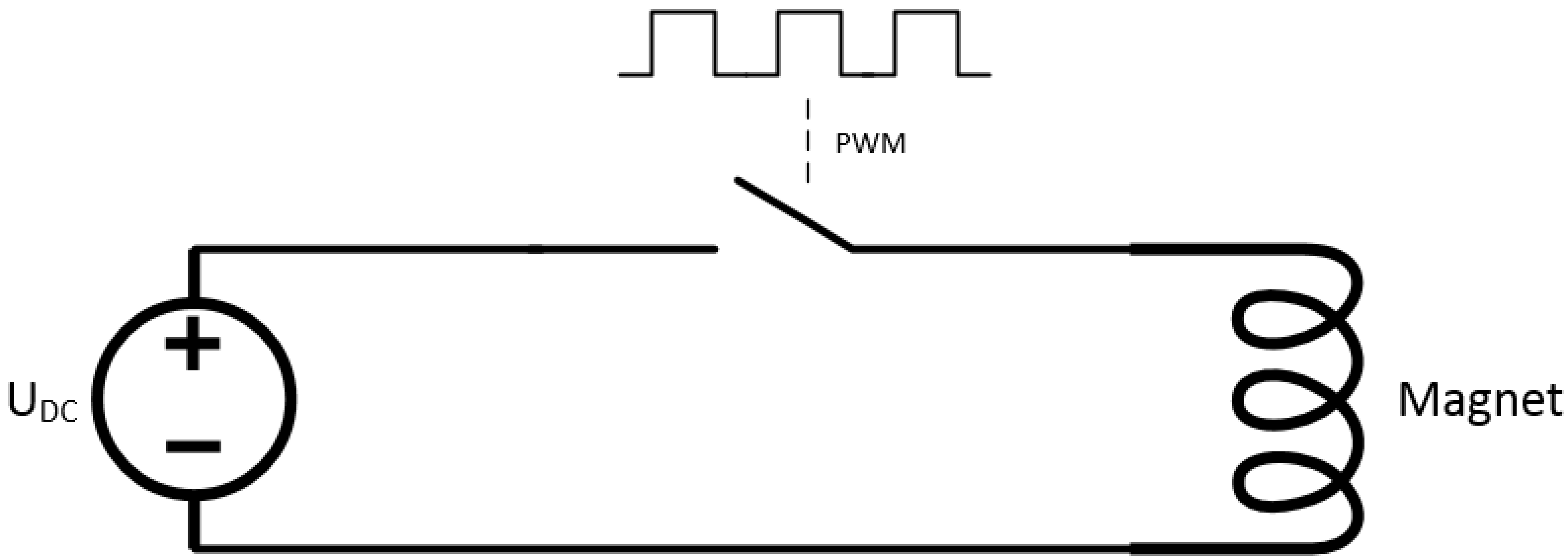
Introduction Powersupply

Main Components



Converter

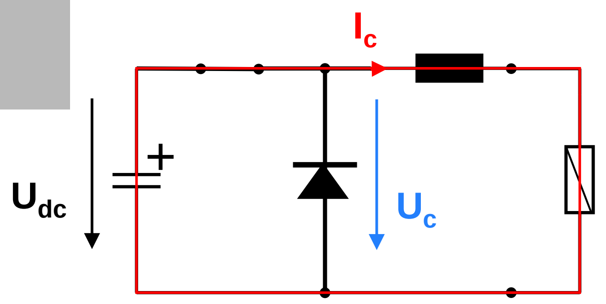
A Converter is basically…



… a switch

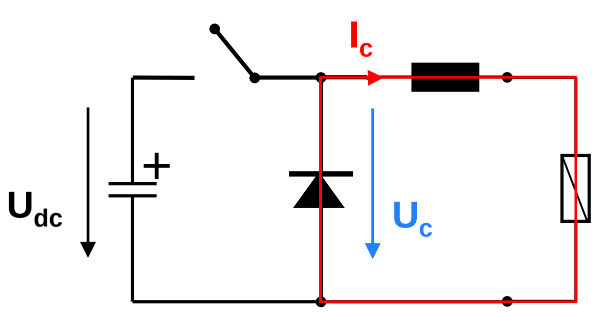
1Quadrant Converter – Principle of operation

Phase A

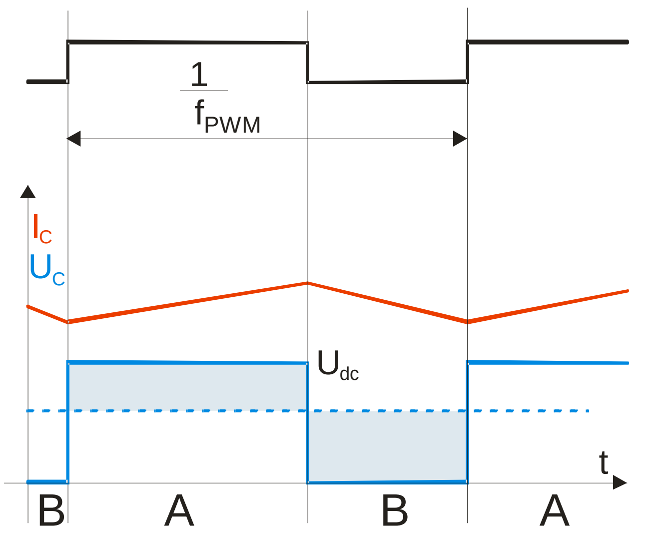


$U_C = U_{dc}$

Phase B



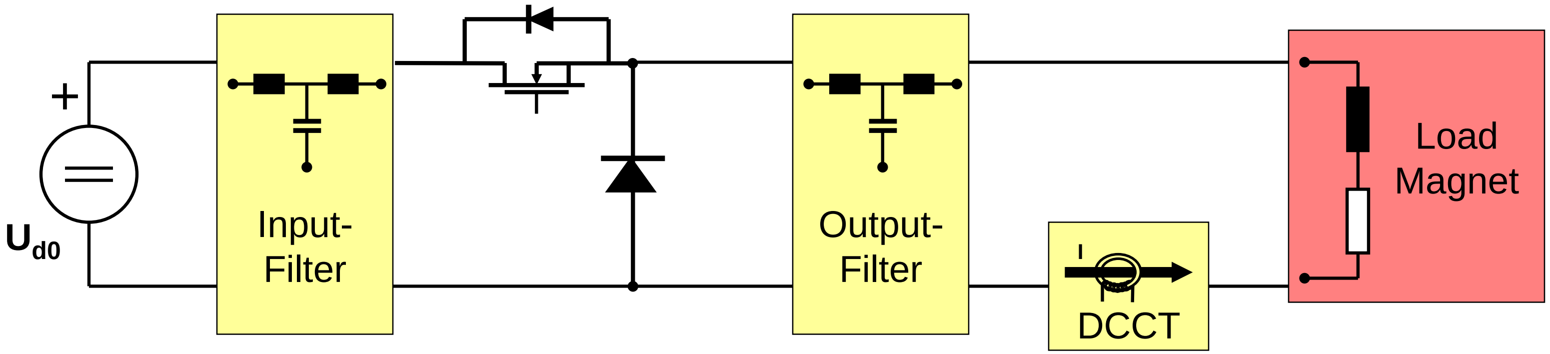
$U_C = 0$



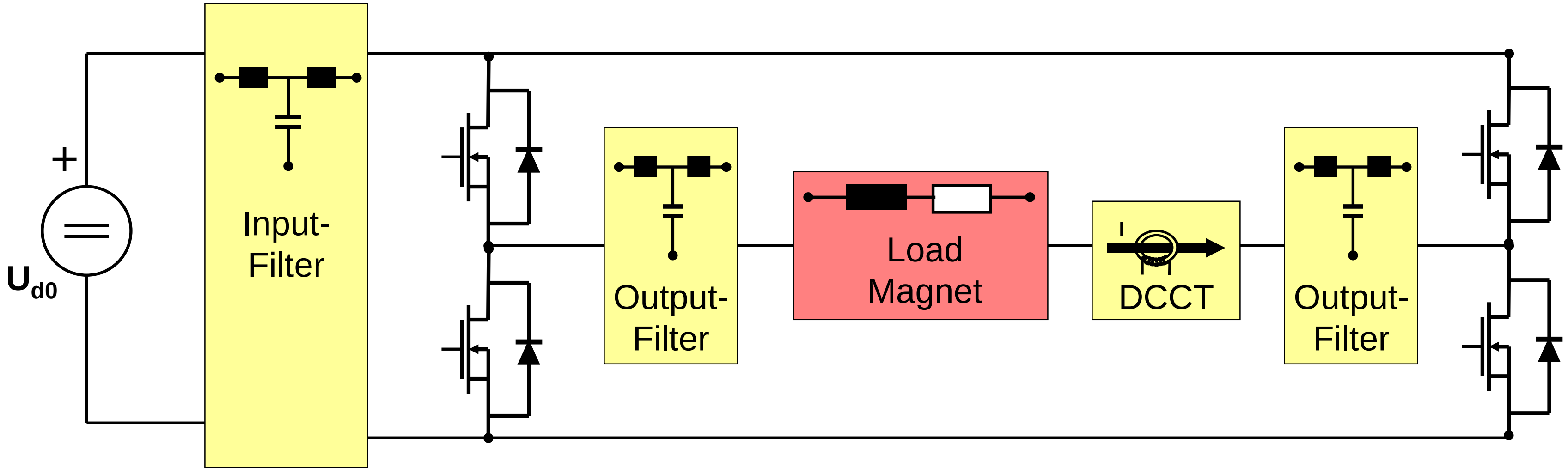
$0 < m < 1$

E.g., $m = 0.6$

a) Buck structure for single quadrant converters

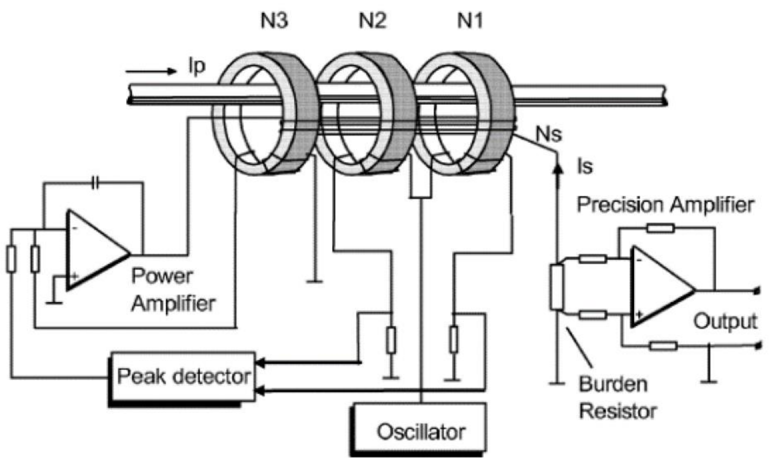


b) Bridge structure for two and four quadrant converters



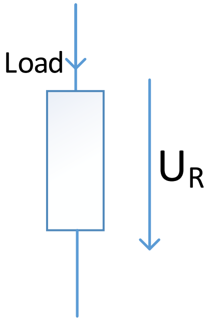
Current Measurement

DCCT



- Zero-flux Detection
- Galvanically isolated
- Usually for currents > 100A

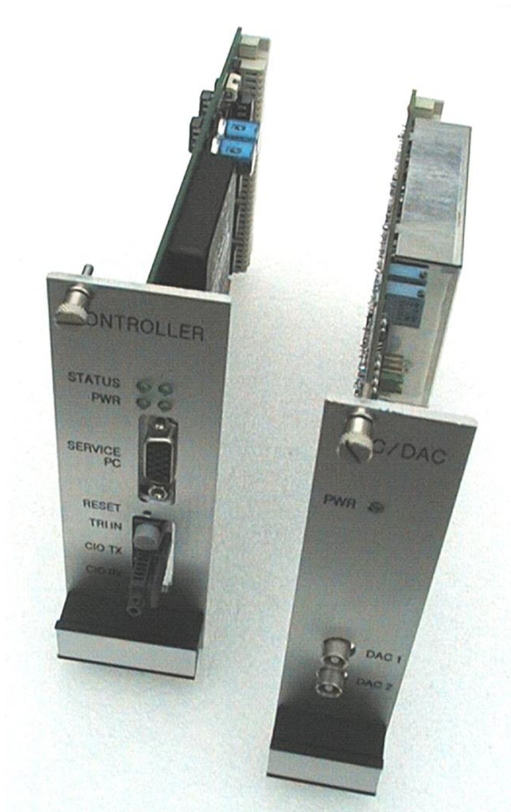
Shunt



- Voltage Drop over Resistor
- Trade off:
  Signal Amplitude vs Dissipated Power

PS Controller at PSI

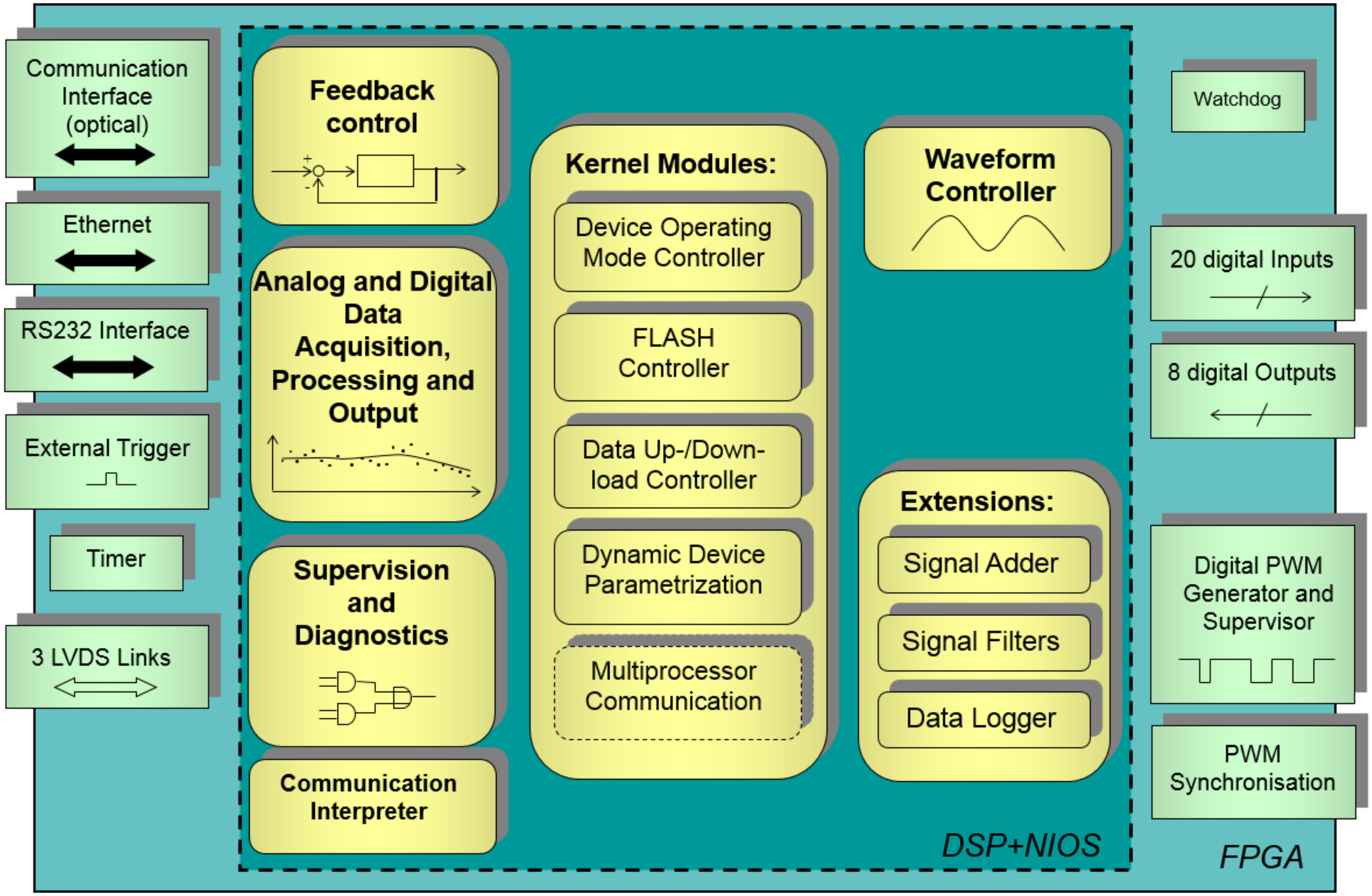
1. Generation (2000)
SLS



2. Generation (2010)
SwissFEL

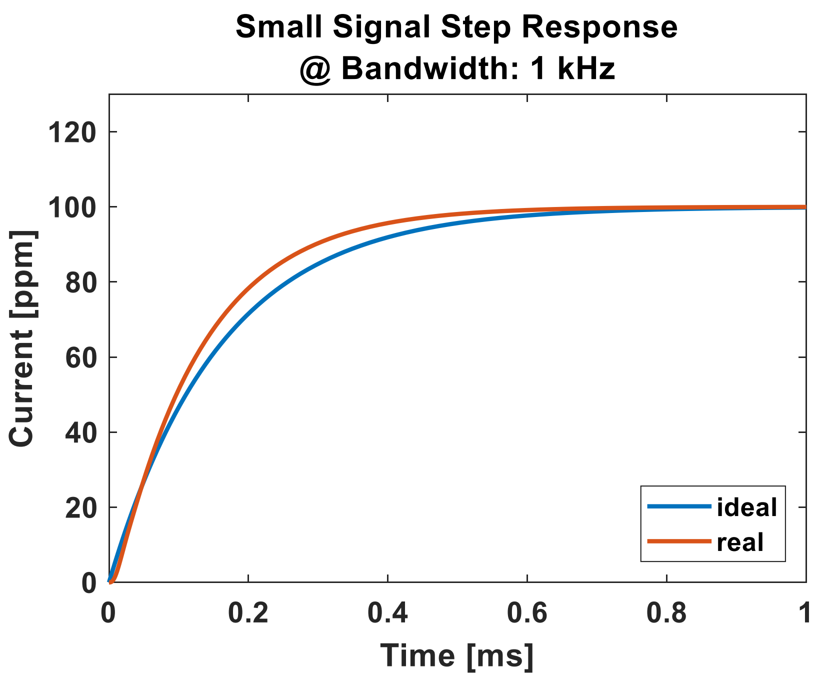
3. Generation (>2020)
SLS2

Control

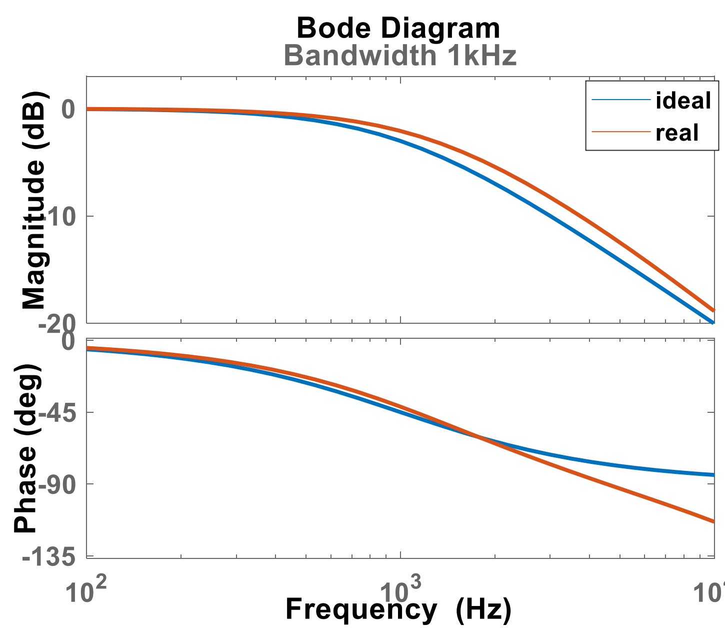


Communication Interface (optical)
Ethernet
RS232 Interface
External Trigger
Timer
3 LVDS Links
Feedback control
Analog and Digital Data Acquisition, Processing and Output
Supervision and Diagnostics
Communication Interpreter
Kernel Modules:
Device Operating Mode Controller
FLASH Controller
Data Up-/Down-load Controller
Dynamic Device Parametrization
Multiprocessor Communication
Waveform Controller
Extensions:
Signal Adder
Signal Filters
Data Logger
DSP+NIOS
Watchdog
20 digital Inputs
8 digital Outputs
Digital PWM Generator and Supervisor
PWM Synchronisation
FPGA

Small Signal – Medium Bandwidth

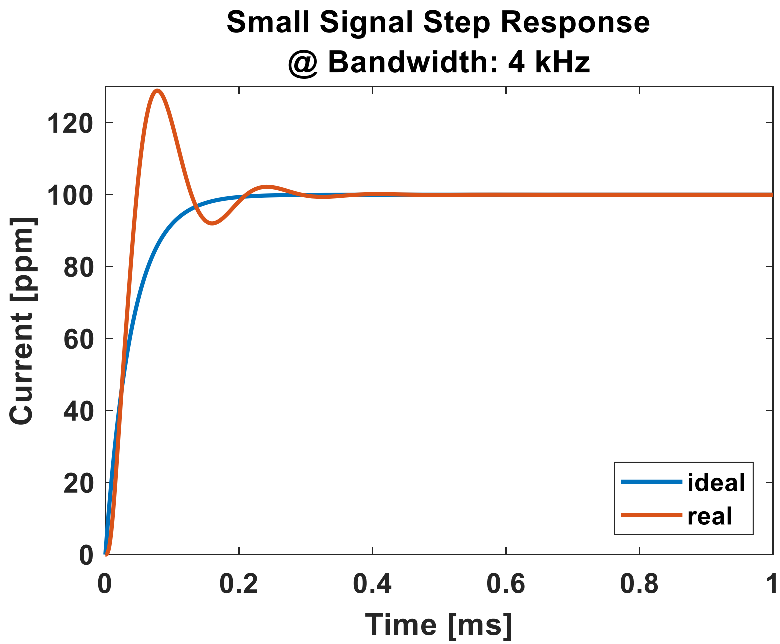


Generic example for illustration

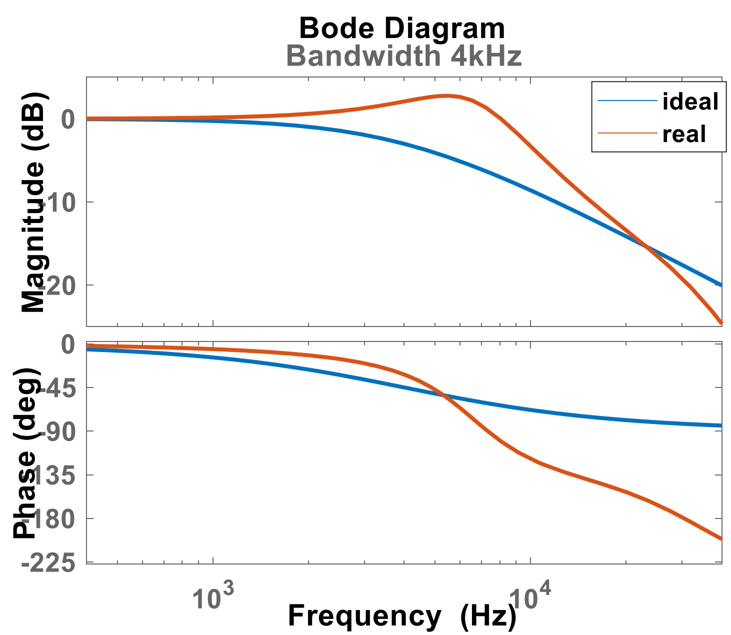


For moderate Bandwidths, the small signal behaviour can be modeled as a first order lowpass filter (LPF1)

Small Signal – Higher Bandwidth



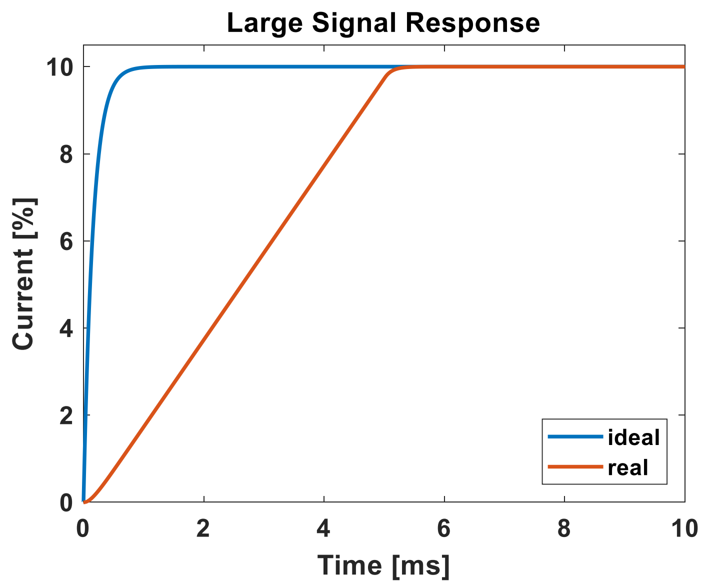
Generic example for illustration



Still LPF1 behaviour if:

$$f_{BW\_OFB} \ll f_{BW\_PS}$$

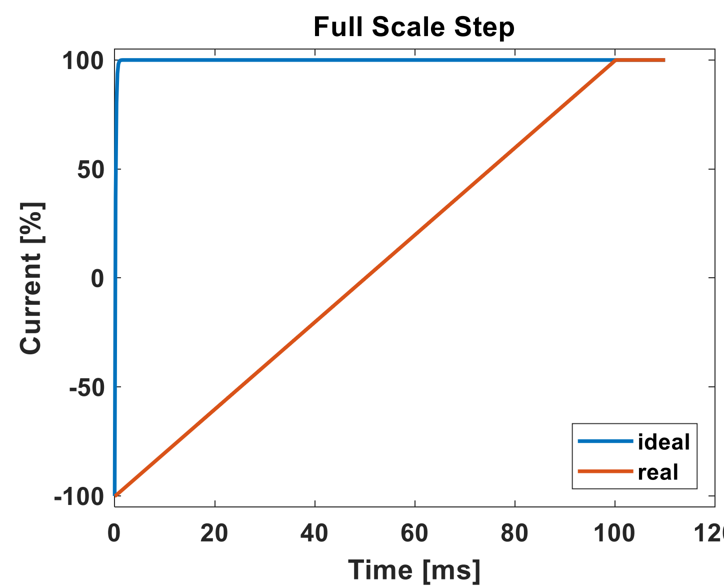
Large Signal Behaviour



Often, the controller limits the rate of change (dI/dt) of the reference value

Ramp can be made faster with:

- Higher input voltage
- Lower magnet inductance



Noise & Ripple (Main Sources)

Current Measurement Noise

- Scales with Closed Loop Bandwidth

PWM (Switching) Ripple

- Harmonics (e.g. 3MHz) & Subharmonics (e.g. 5kHz) of f_{PWM} = 500kHz

Ripple & Noise from Input Voltage

- 100Hz, kHz & MHz
  - Example: 10mV 100Hz Input Ripple with 20V Input Voltage on 1Ohm load
    -> @5A 2.5mA (500ppm) Ripple

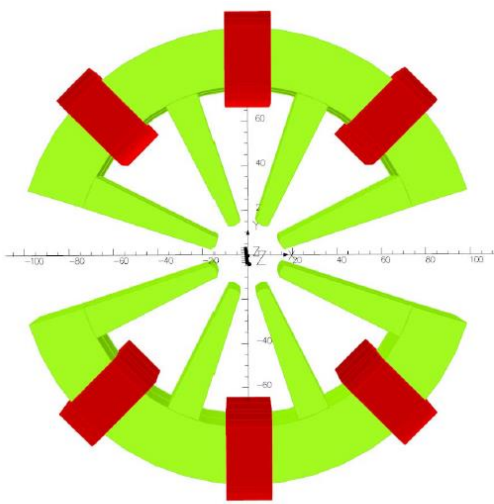
➢ Input Voltage Ripple is attenuated by:
- Feedforward
- Magnet inductance
- Current Closed Loop

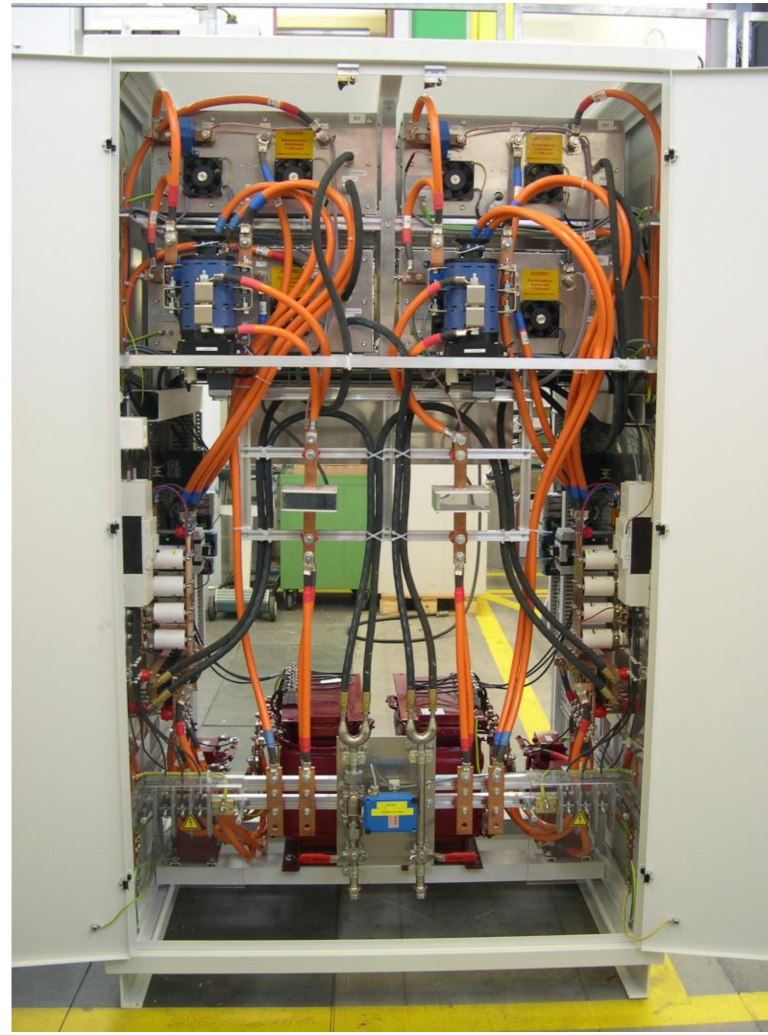
➢ Magnet Inductance also helps with PWM Subharmonics

Other non-ideal behaviour

- Drift (Temperature & Ageing)
- Gain, Offset, Accuracy Error, INL,…
- EMI Susceptibiliy
- Other environmental influences

SLS2 Storage Ring Magnets & PS





SLS2 storage ring magnets

Magnet	#	Magnet excitation
Bending magnets	228	Permanent magnet
Quadrupoles QC	96	electrical
Sextupole SX	288	electrical
Octupole OC	288	electrical
Aux. Quadrupoles QA	288	electrical
Skew quad windings	96	electrical
Corrector magnets	240	electrical
Total	**1524**	

Rating and number of power supplies

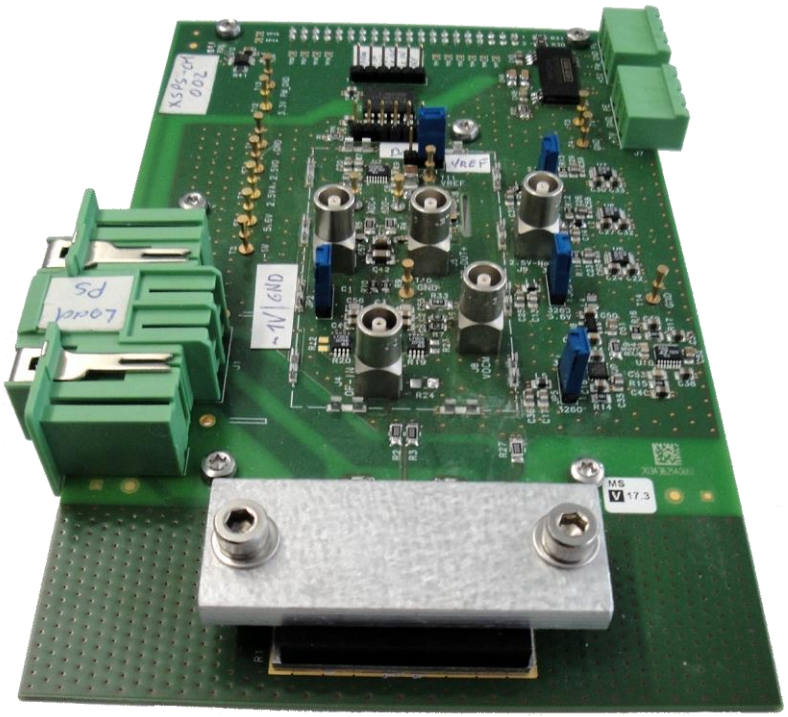
PS rating	1Q /4Q	#	Magnets / connection
5 A, 24 V	4Q	864	Corrector magnets Aux Quadrupoles Skew Quadrupoles
70 A, 24 V	1Q	96	Quadrupoles
150 A, ?V or 50A, 50V	1Q 4Q	12 - 36 12 / 24	Sextupoles, n groups & 288/n in series Octupoles, m groups & 288/m in series
400 A, 50 V?	2Q	3	Superconducting, with Quench circuit
Total (appr.)		**1000**	

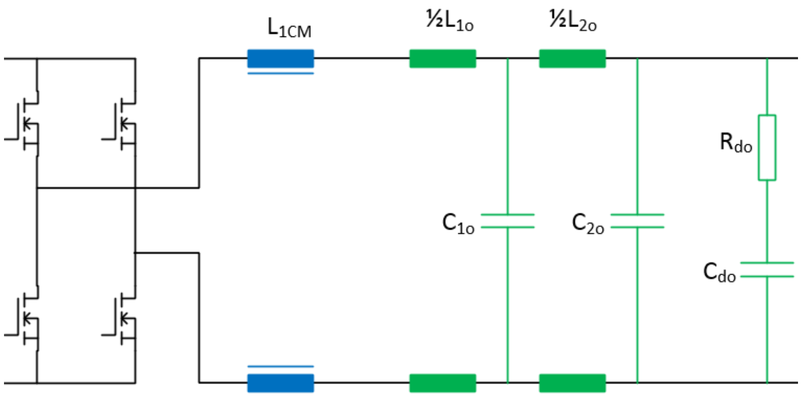
- 4 PS Types for 6 Magnet Types
- Specification not yet completed

For comparison: # Power supplies in SLS storage ring: 391

(although many magnets in SLS2 are permanent magnets)

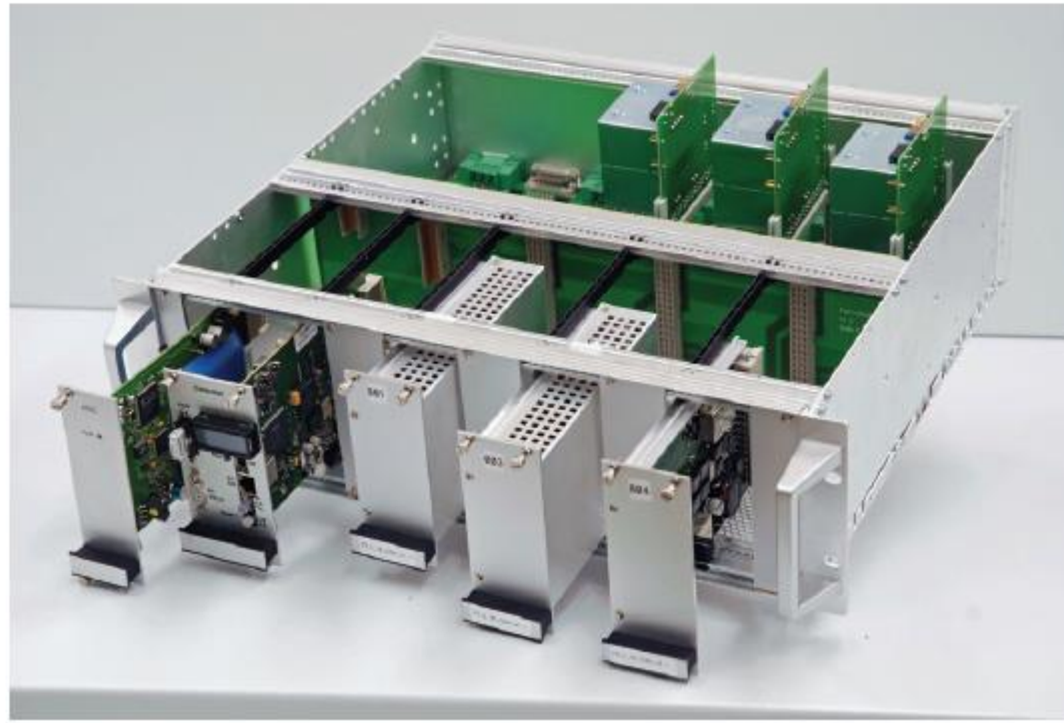
Corrector PS for SLS2





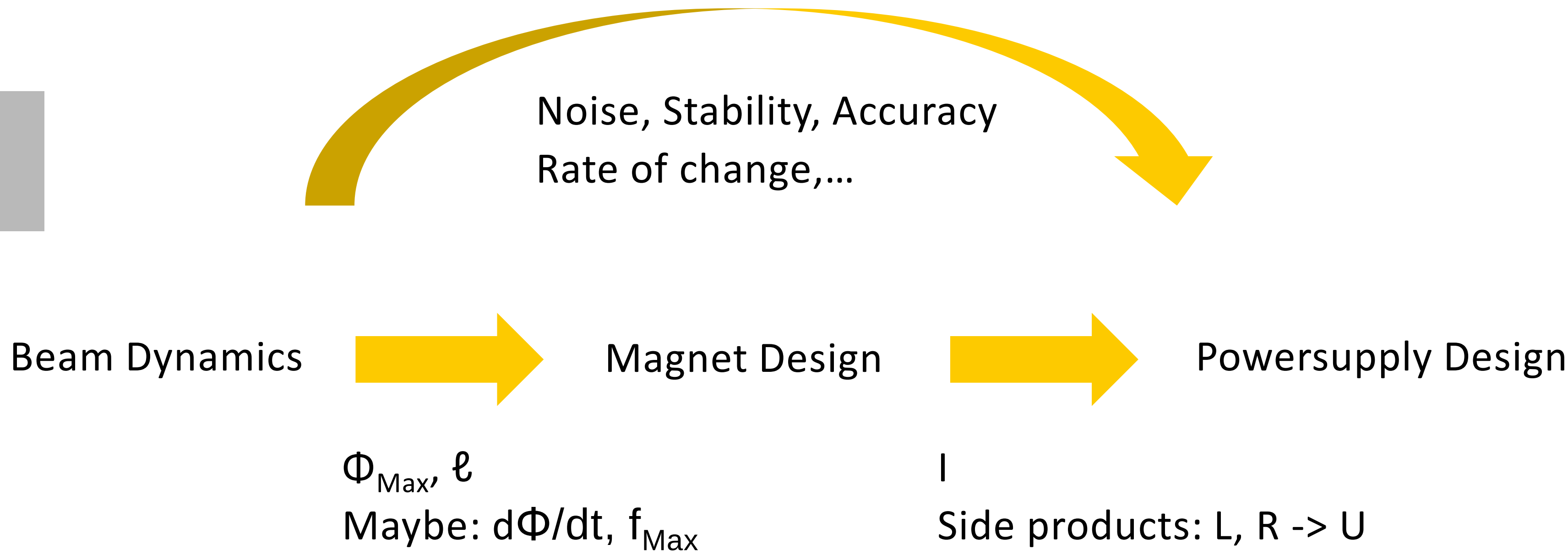
SwissFEL Corrector PS

One controller board controls 3 10A converters, with a PCB DCCT



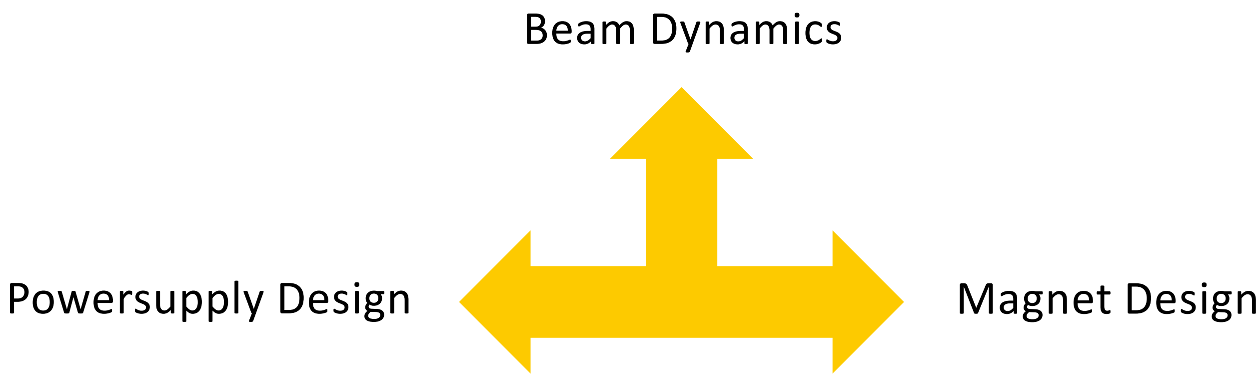
Not ideal for SLS2 because:
- Noise > 5ppm
- DCCT is for 12.5A and expensive
- Only 3 Converters in one crate
- Shared Link (Latency)

How do we get the requirements?



- Powersupply Design can only start after coarse magnet design is completed
- Might result in unreasonable U / I, L, R
- Might lead to one PS type per magnet type

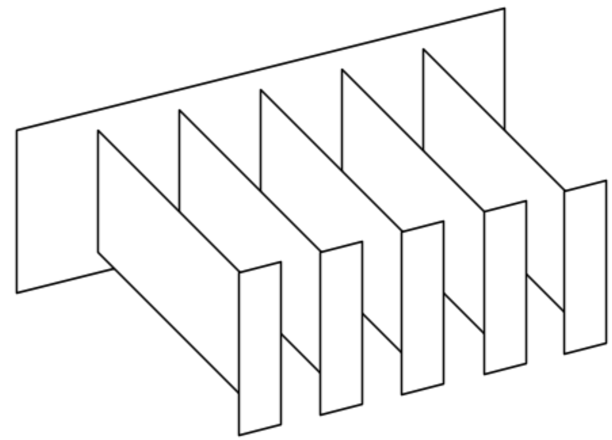
How do we get the requirements?



- Start discussions with other groups early
- Cannot wait for specifications, start work based on assumptions

Early Assumptions & Design «Decisions»

5A Shunt Measurement
- SLS1: 7A, expected the same or less for SLS2
- Good compromise:
  - Signal Amplitude vs Dissipated Power



Buy Module for Control part
- Saves development time
- Reduces risks (Tradeoff: perfect fit)
- Module based on Xilinx Zynq MPSoC
  - SLS2 Standard (?)

Single Board
- Do not use the General Purpose Controller card, not enough commonalities
- Converter, current measurement & control on a single board

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Constraints & Challenges

- Same PS for Correctors types: Dipole, Quadrupole, Skew Quadrupol Correctors
  - E.g Drift no issue for dipole correctors, cannot be ignored for others

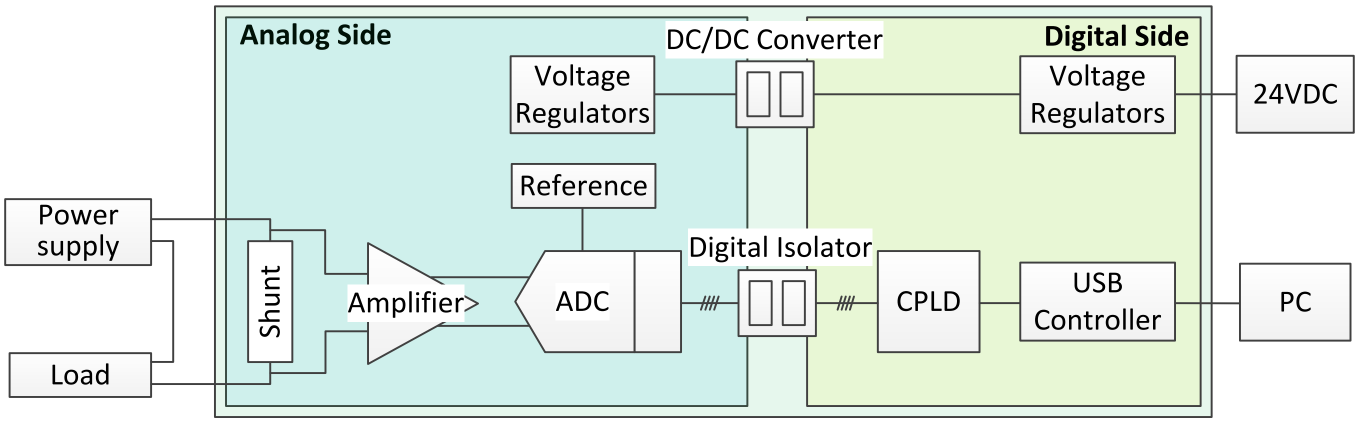
- Conflicting Goals, Constraints & Challenges:
  - Noise vs
    - Dynamic Range
    - Bandwidth
    - Drift
  - Power Dissipation & Heat Removal
    - Shunt resistor (1.25W)
    - Converter (< 4W)
    - Module (> 5W)
  - Space (3x PS, available space?)
  - Costs, Manpower, Time, Know-How
  - Simplicity vs Flexibility vs Performance

Plan

- Build a current measurement prototype
- Build a converter prototype
- Build the PS prototype with current measurement, converter & control on one board

Current Measurement Prototype

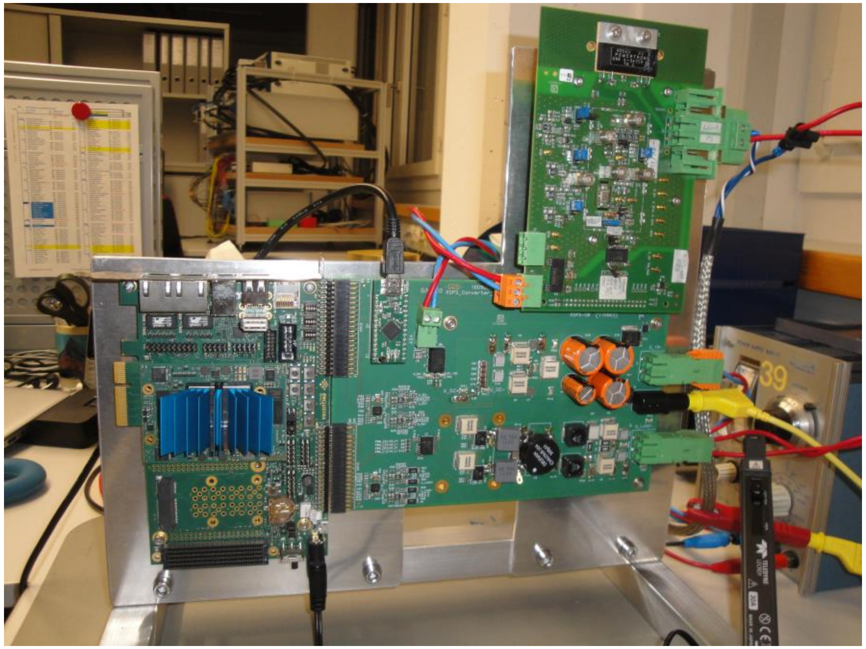
Isolated High-Side Shunt measurement
20bit ADC @ 1MSps with Gain = 20



Total Noise:	< 10ppm RMS
Noise (10Hz – 1kHz):	1.7ppm RMS
Noise (10Hz – 10kHz):	3ppm RMS
Temperature Drift:	< 5ppm / °C

Converter Prototype

500kHz PWM, GaN FET Switches
-> High PWM Frequency
- keeps components small
- allows for lower latency



Thank you for your attention!