ETH zürich

Measurement of Conducted EMI using a Three-Phase Active CM/DM Noise Separator

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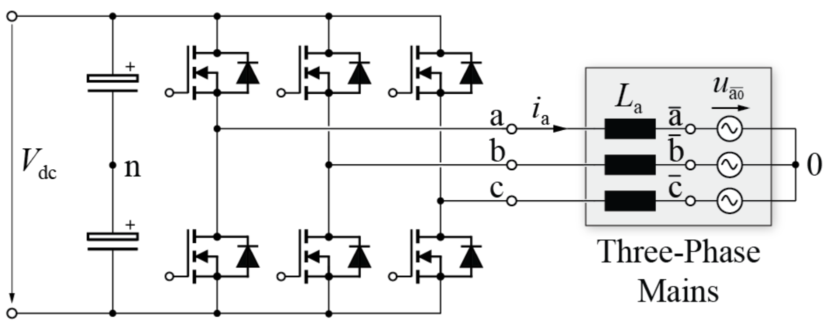
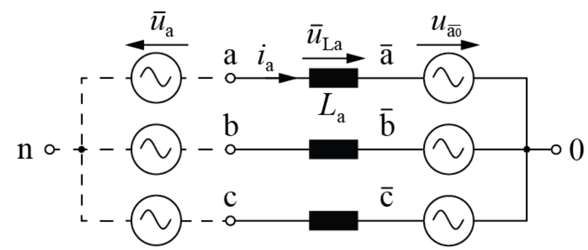
Motivation

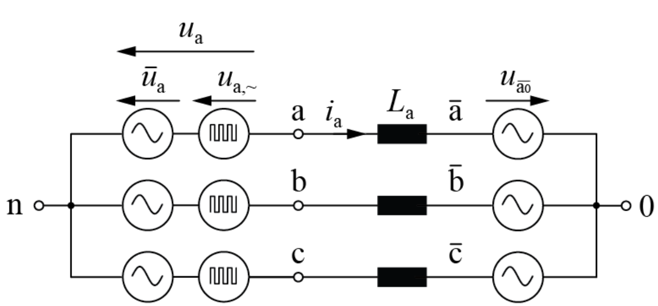
- Switched-Mode Converters must comply with CISPR Standards for Conducted EMI
- Fundamental Component + Switching Harmonics / Noise → CM and DM



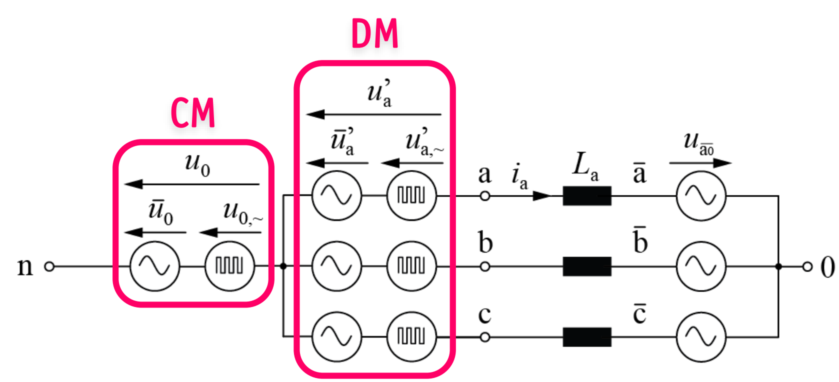
▶ Three-Phase PV Inverter



▶ Fundamental Frequency



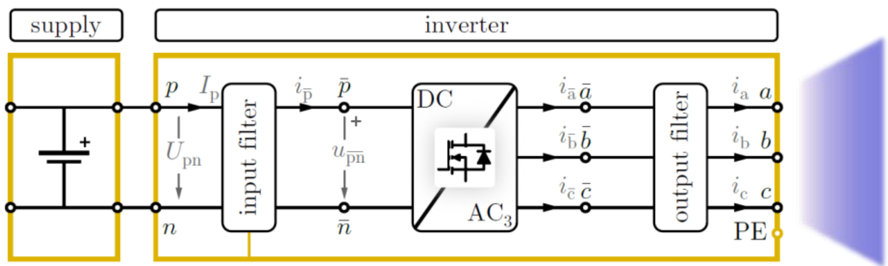
▶ Fundamental + Switching Frequency



▶ EMI Equivalent Circuit

▶ Motivation

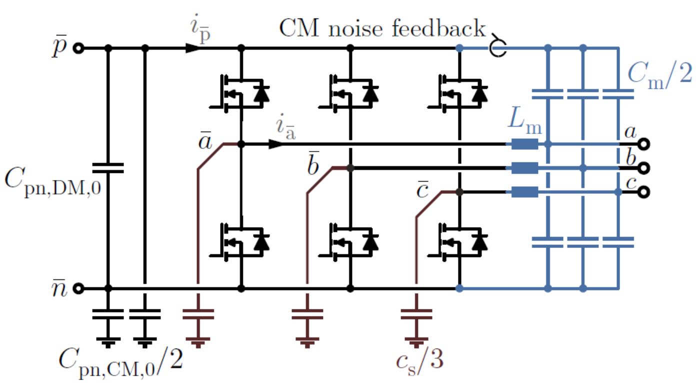
- Switched-Mode Converters must comply with CISPR Standards for Conducted EMI
- Output Filter to reduce Switching Harmonics / Noise



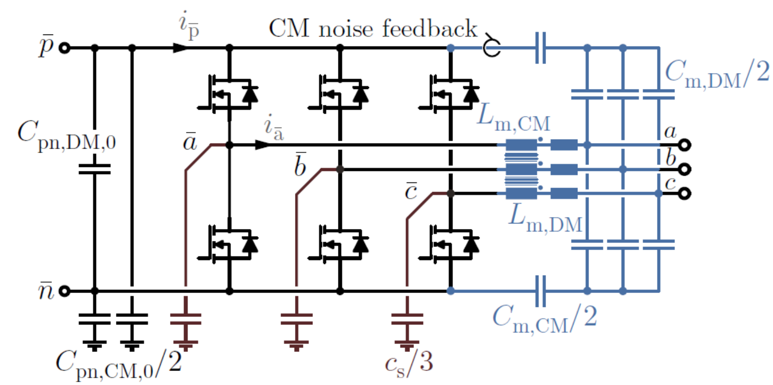
CM Noise

DM Noise

▶ e.g. PV Inverter



▶ Combined CM/DM Filter



▶ Separate CM and DM Filter

▶ *Optimize* for Minimum Volume, Cost, Losses, Weight, ...

Agenda

Measurement Setup
5 Slides

Realization
7 Slides

Design Considerations
5 Slides

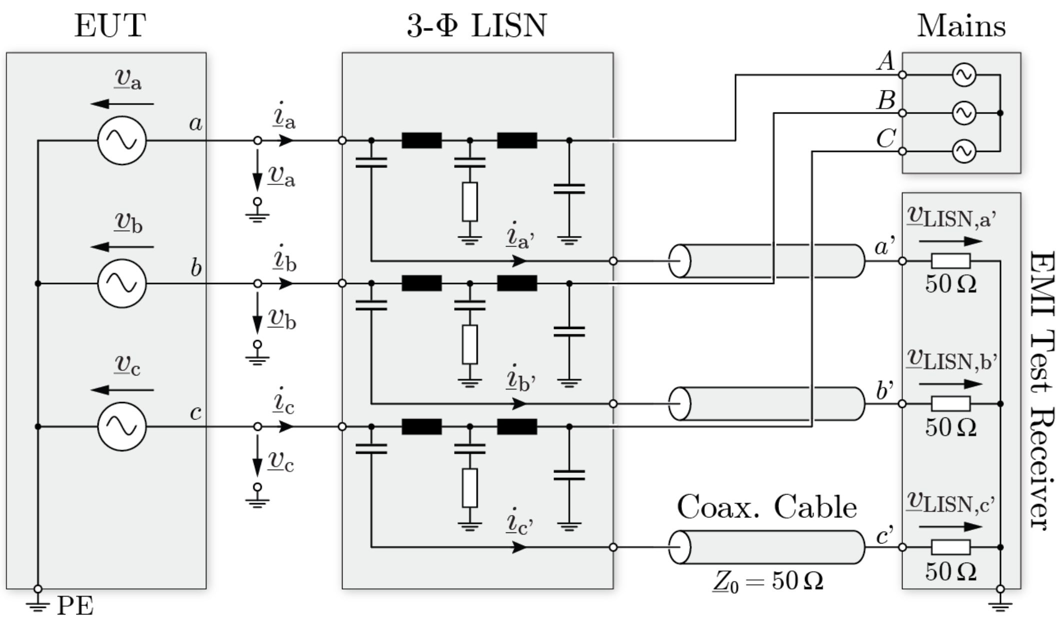
Performance Evaluation
3 Slides

Conclusions
2 Sl.

Introduction: Measurement Setup

▶ Motivation

- Standard Meas. Setup only gives Total Conducted EMI Noise from EUT
- Total EMI Noise composed of CM and DM Parts

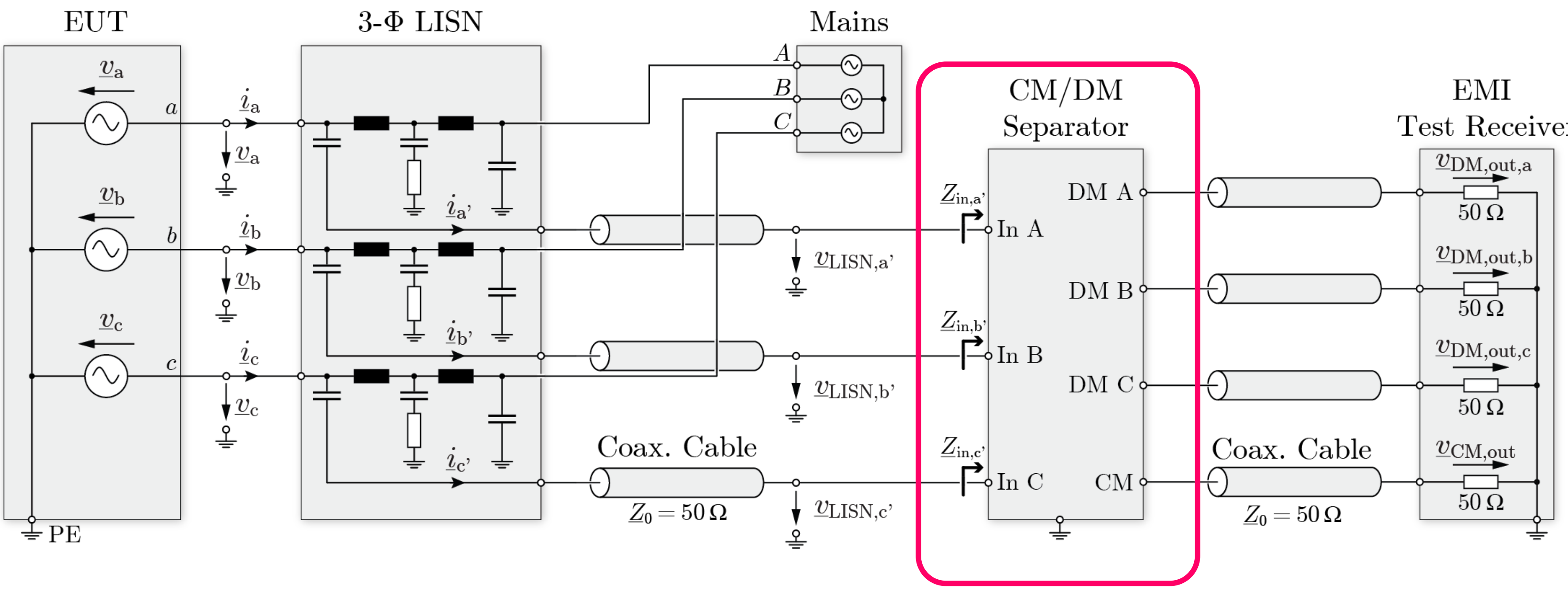


▶ *Optimize Each Filter Stage* for Minimum Volume, Cost, Losses, Weight, ...

▶ *Separation of Total Noise into CM and DM Part*

▶ Motivation

- Three-Phase CM/DM Separator between LISN and Test Receiver
- Attribute Exceeding to CM and/or DM Noise

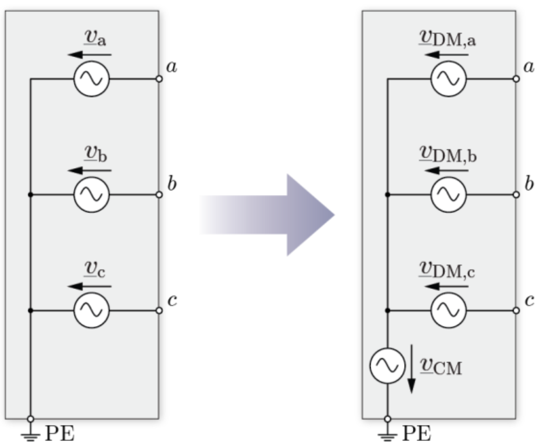


▶ *Optimize Each Filter Stage* for Minimum Volume, Cost, Losses, Weight, ...

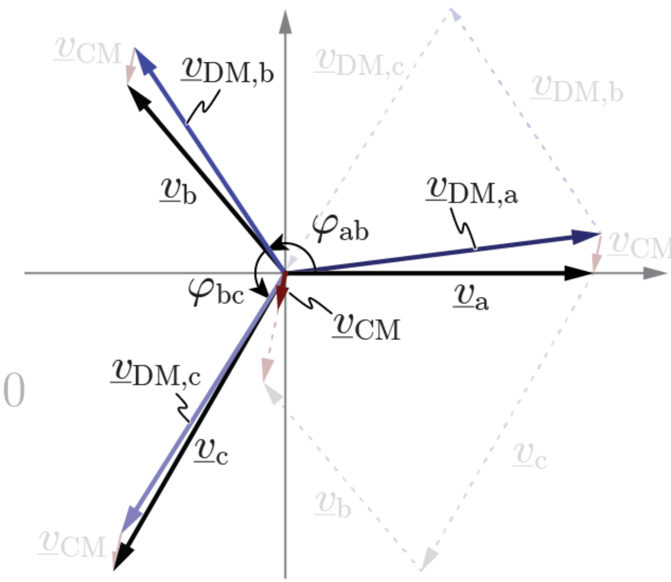
▶ *Separation of Total Noise into CM and DM Part*

▶ Three-Phase CM/DM Decomposition

- CM Component Common to all Phases → Geometric Mean
- DM Component = "Not CM" → Add up to zero



$$\underline{v}_a = \underline{v}_{CM} + \underline{v}_{DM,a}$$
$$\underline{v}_b = \underline{v}_{CM} + \underline{v}_{DM,b}$$
$$\underline{v}_c = \underline{v}_{CM} + \underline{v}_{DM,c}$$
$$\underline{v}_{CM} = (\underline{v}_a + \underline{v}_b + \underline{v}_c)/3$$
$$\underline{v}_{DM,a} + \underline{v}_{DM,b} + \underline{v}_{DM,c} = 0$$



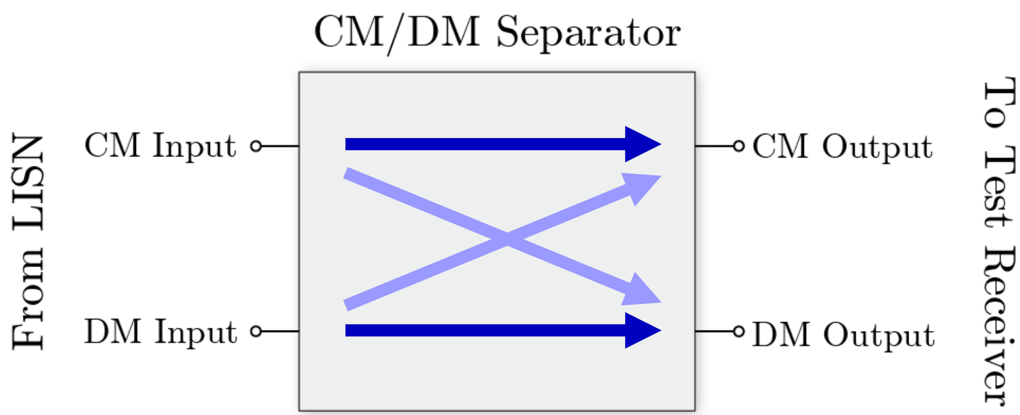
▶ Phasor Representation

▶ Derive CM Component and therefrom DM Components

▶ *Circuit Representation for these Operations*

▶ Performance Metrics

- Transfer from each Input to each Output → Direct and Cross Coupling
- General Multi-Port Notation



$$CMTF = \left| \frac{v_{\mathrm{CM,out}}}{v_{\mathrm{CM,LISN}}} \right|$$

$$DMTF = \left| \frac{v_{\mathrm{DM,out}}}{v_{\mathrm{DM,LISN}}} \right|$$

$$CMRR = \left| \frac{v_{\mathrm{DM,out}}}{v_{\mathrm{CM,LISN}}} \right|$$

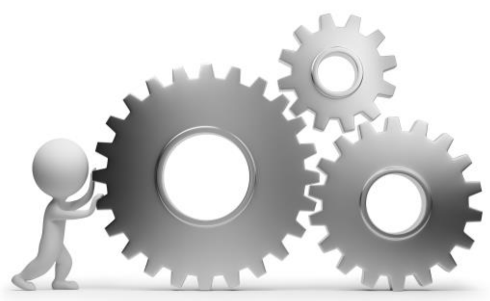
$$DMRR = \left| \frac{v_{\mathrm{CM,out}}}{v_{\mathrm{DM,LISN}}} \right|$$

▶ Three-Phase System → Three DM Inputs and Outputs

▶ *Three DMTFs and CMRRs*

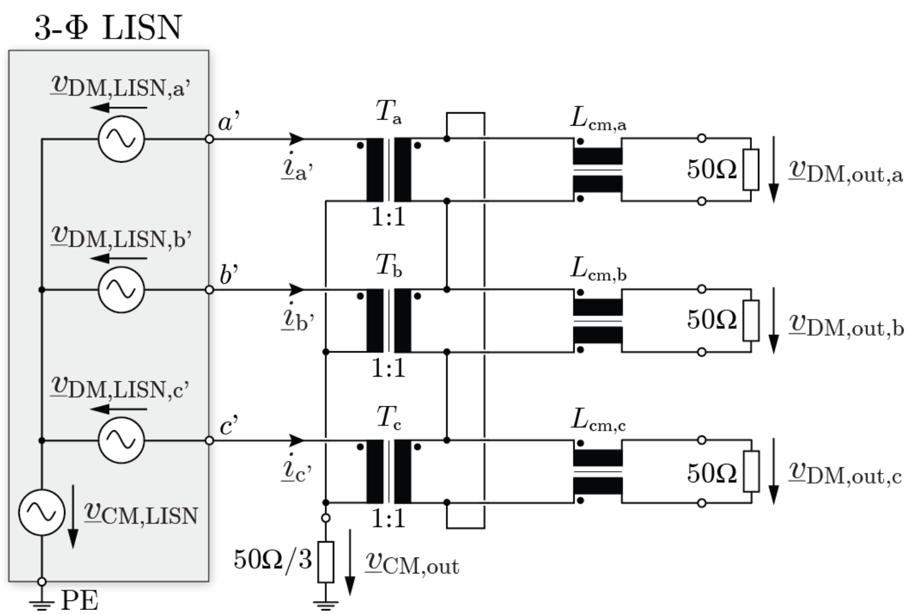
Realization

1. *Passive Separator*
2. *Active Separator*



▶ Passive Noise Separator

- Y/Δ Transformer → Flux Addition / Cancellation
- Very High Coupling Factor Required



Source: Heldwein et al. 2009

▶ Hardware Demonstrator

▶ *Matching of Passive Components*

▶ *Active Realization preferred*

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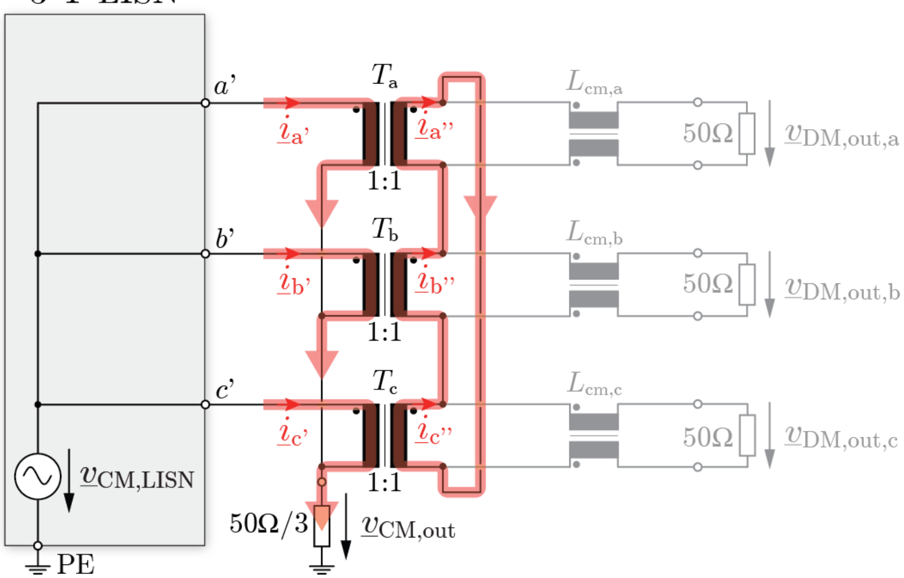

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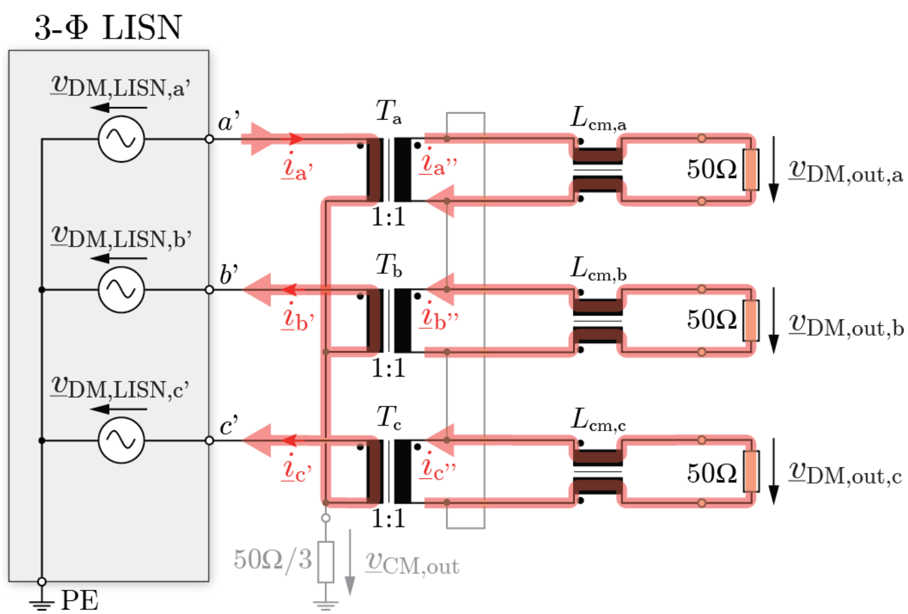

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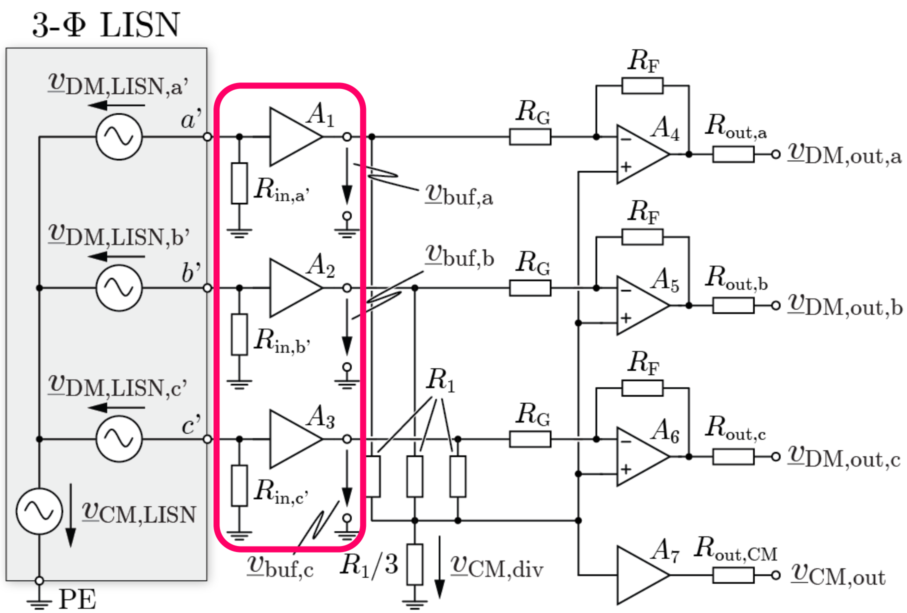
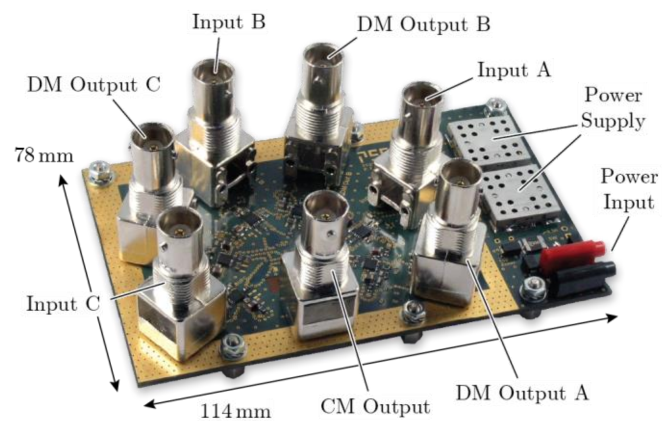
▶ Active Noise Separator

- Active Components (Operational Amplifiers) + Passives → No Magnetics!
- Subtract Phase Voltage from CM Voltage → $-v_{DM}$ at Outputs





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▶ Realization on PCB → Controlled Parasitic Elements → *Influence?*

▶ *Reproducible and Simple Manufacturing*

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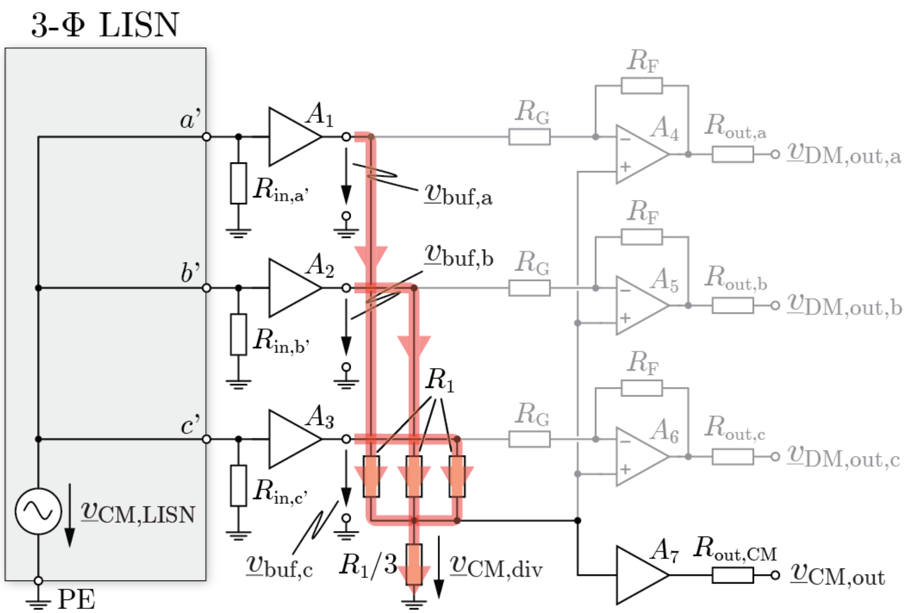

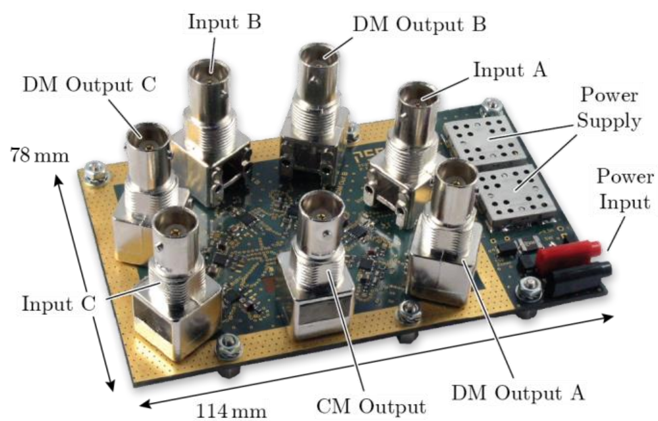

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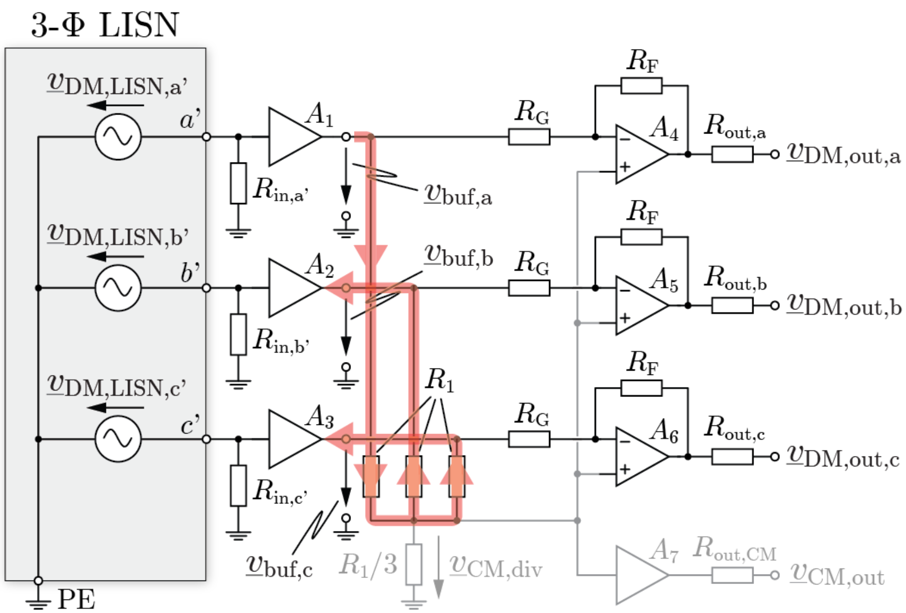

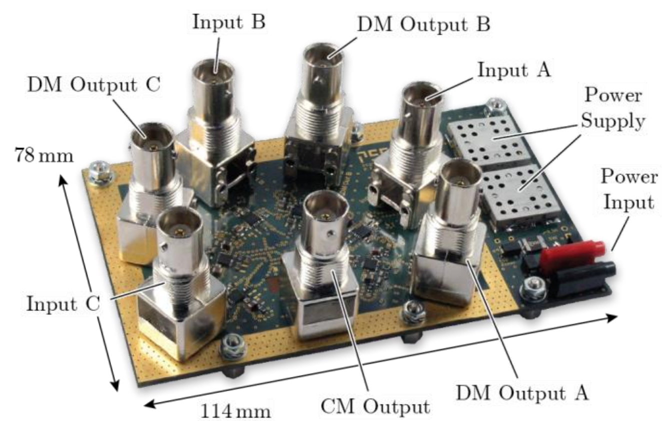

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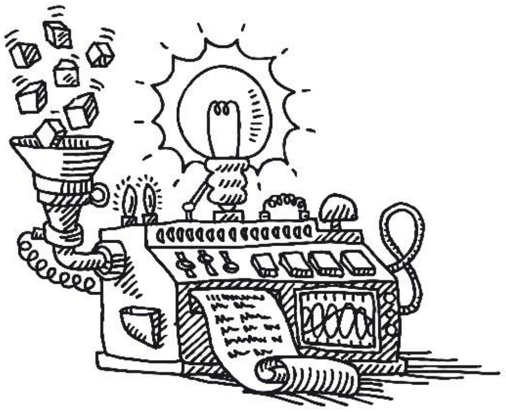
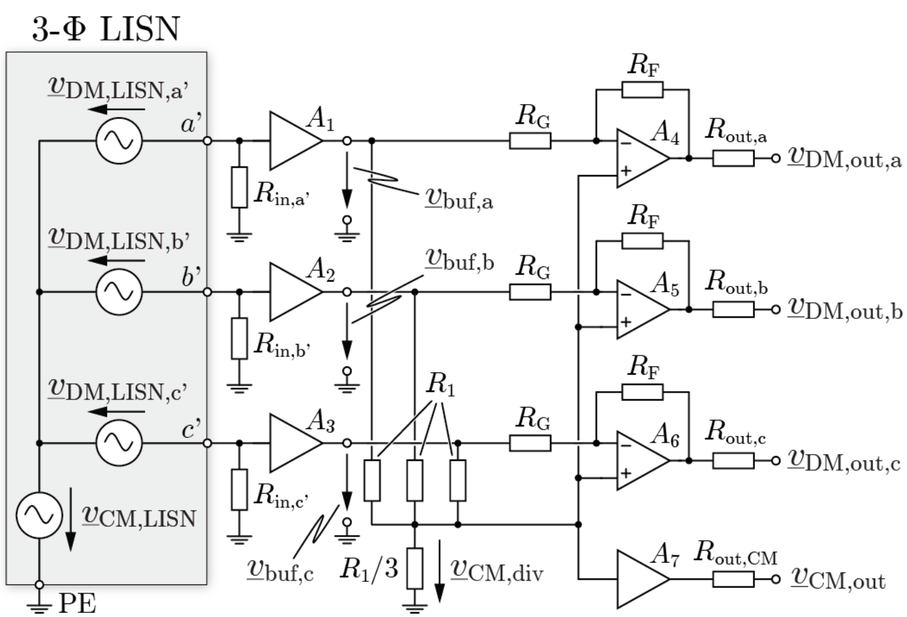
Design Considerations

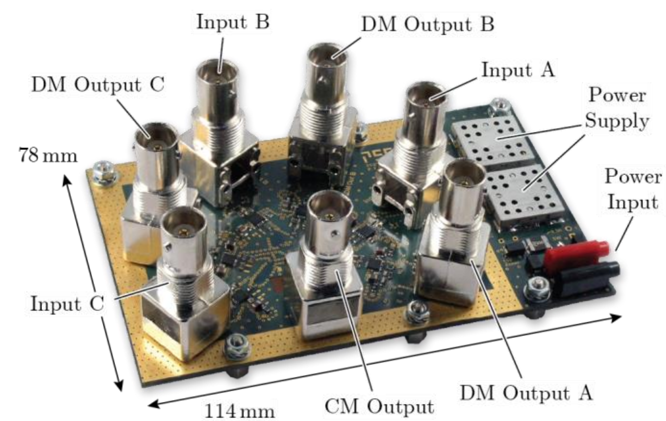


- *Influence of Parasitic Elements*
- *Length Matching*
- *Trimming*

▶ Influence of Parasitic Elements (I)

- Assume pure CM Input Signal
- Parasitic Capacitances due to Layout + Components





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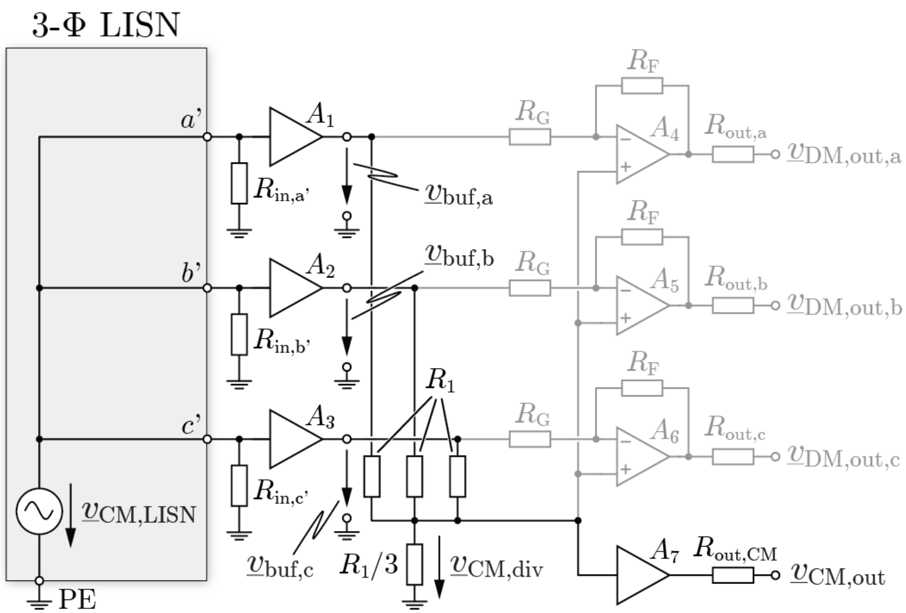

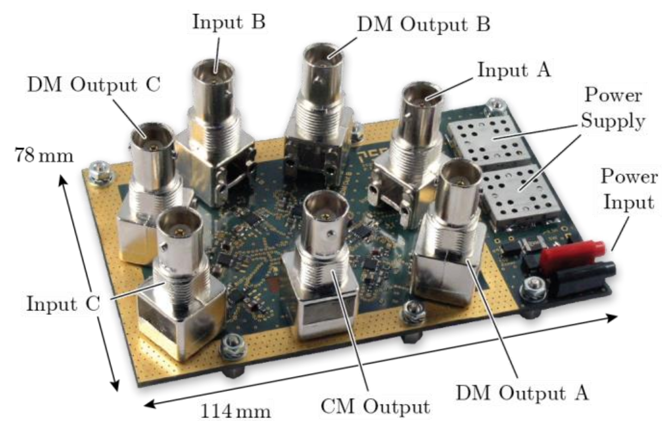

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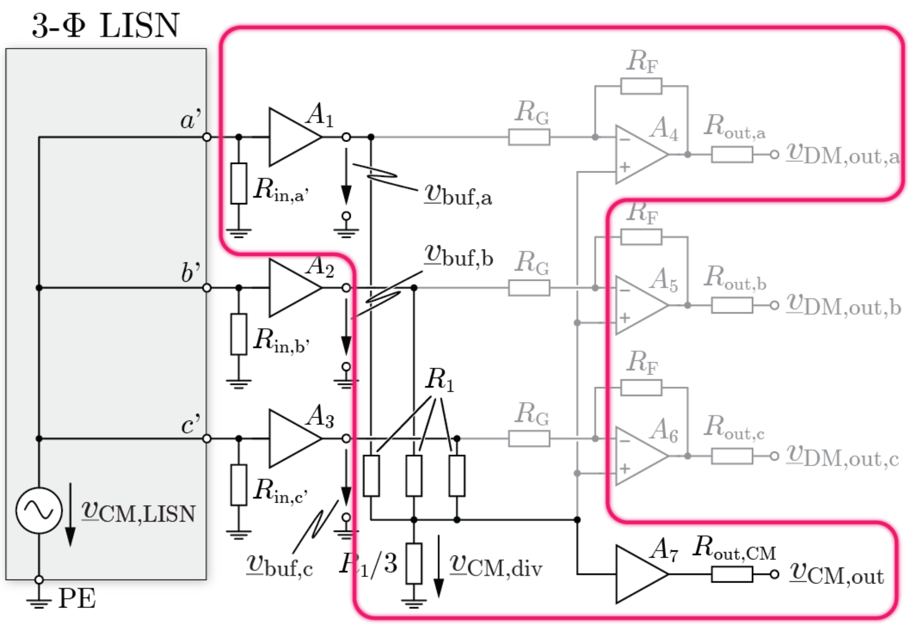
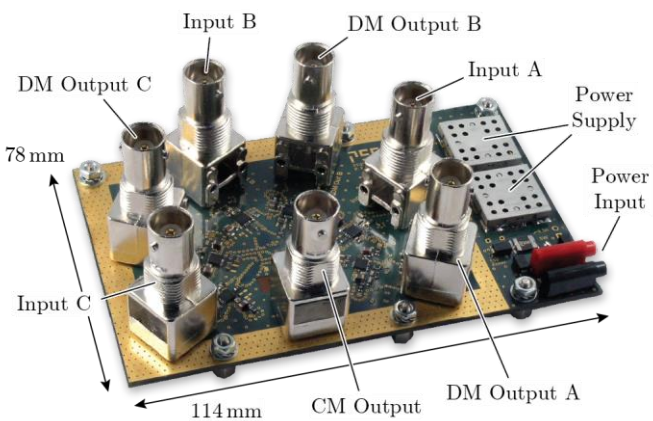
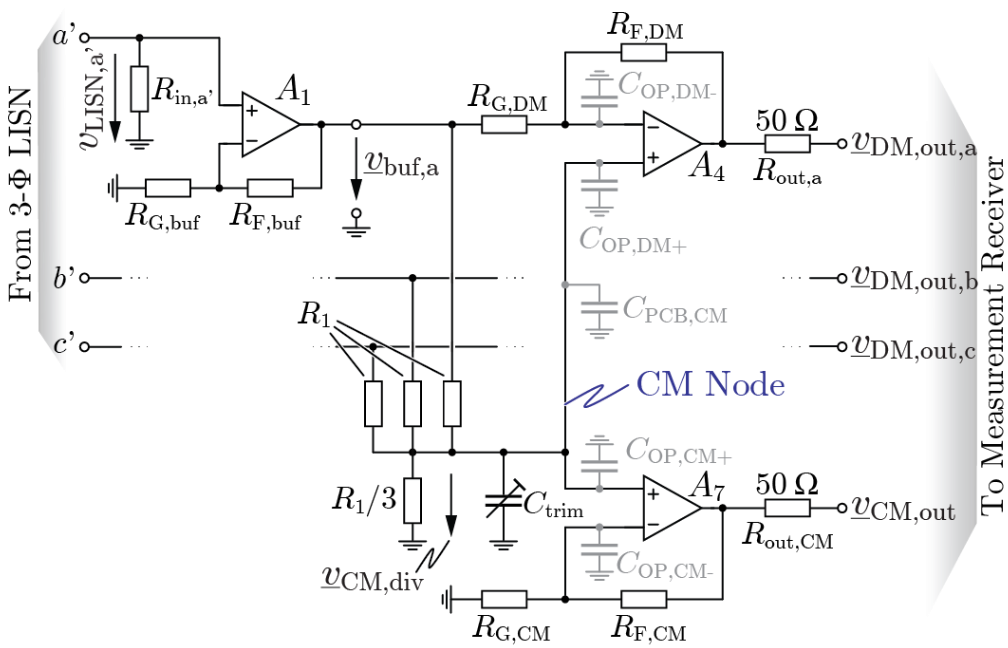




▶ Hardware Demonstrator

▶ Influence of Parasitic Elements (II)

- Assume pure CM Input Signal
- Parasitic Capacitances due to Layout + Components



▶ **Difference Amplifier Crucial for CMRR**

→ Equal Source Impedances

→ Equal Source Path Lengths

→ Finite CMRR of Amplifier

▶ **Selection of High Performance Amplifiers**

▶ ***Symmetric Layout absolutely Essential! → < 0.06° Phase Mismatch for 60dB CMRR***

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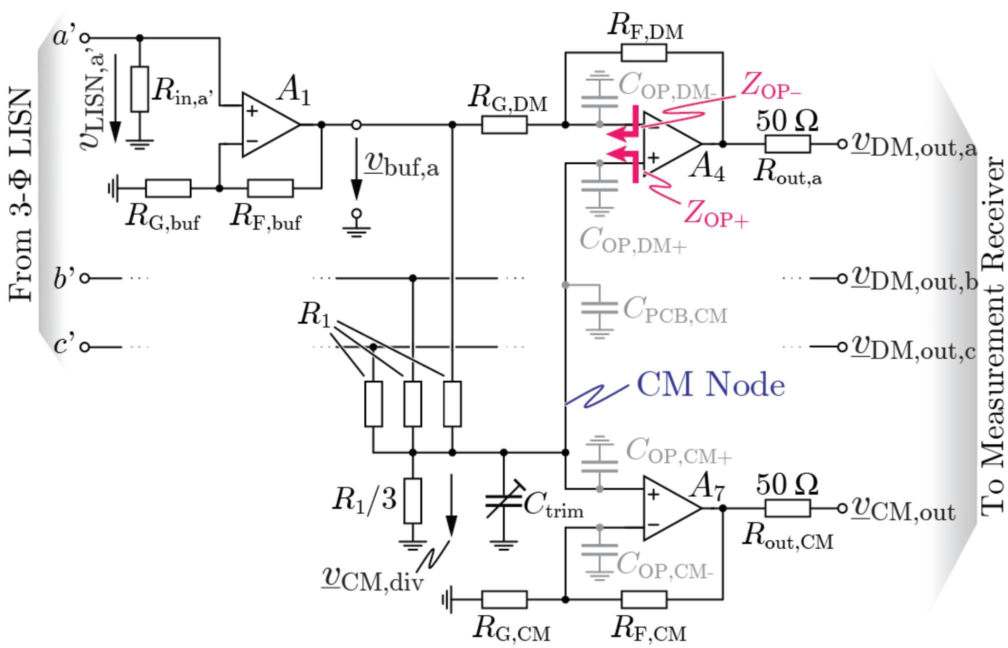

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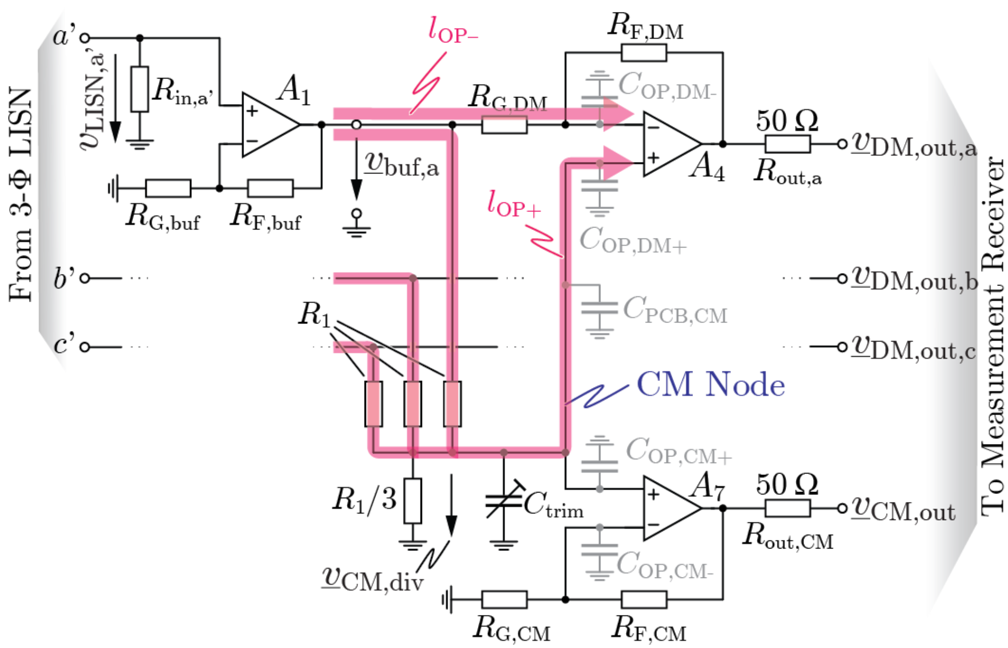

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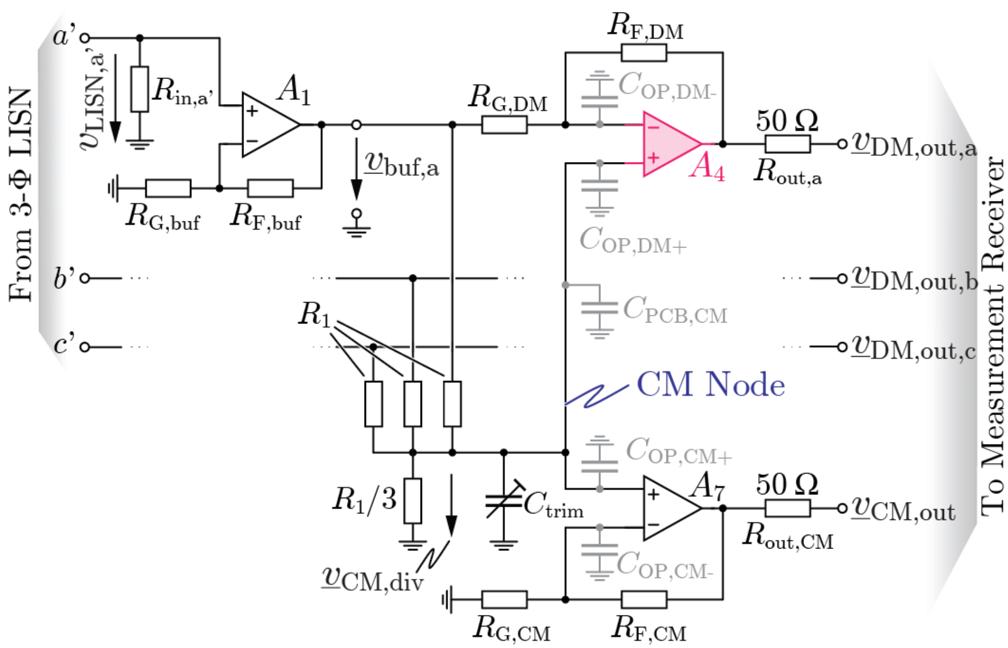

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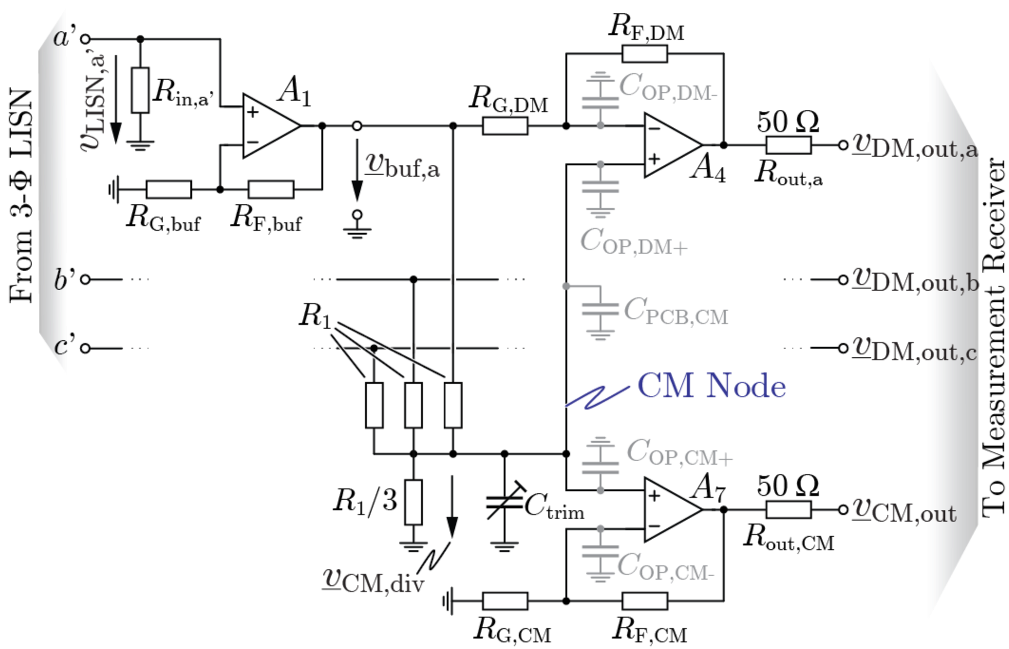
▶ Influence of Parasitic Elements (III)

- Simplified Test Circuit for Initial CMRR Test
- Single Channel with Trimming Capacitor at CM Node



▶ Almost at Amplifier Limit for f > 10MHz

▶ *Very Simple Trimming Procedure Results in Superior CMRR*

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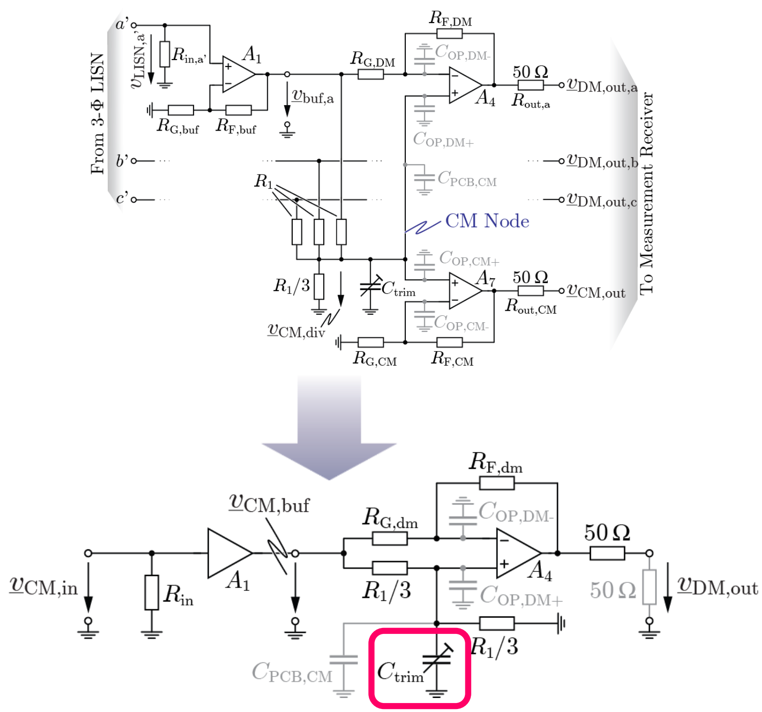

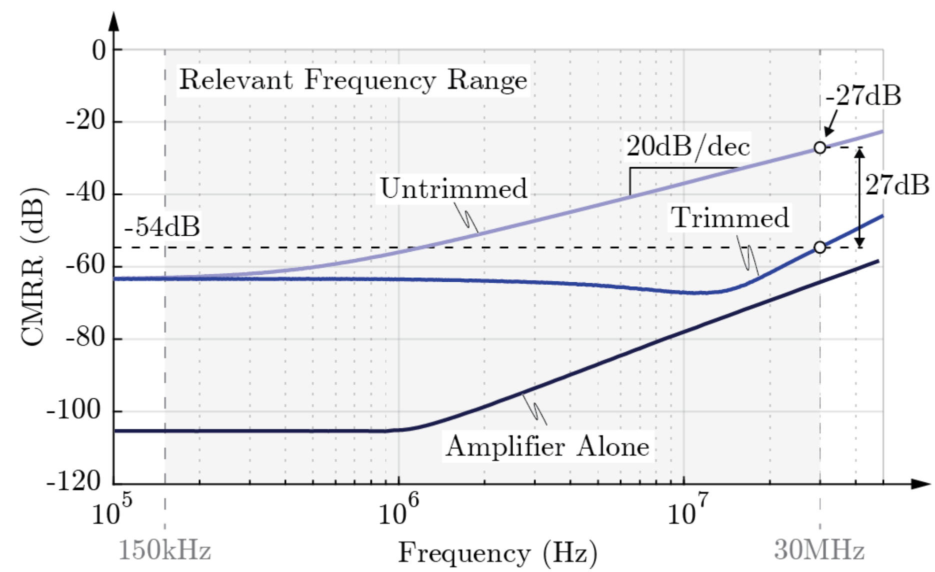

- ▶ Almost at Amplifier Limit for f > 10MHz
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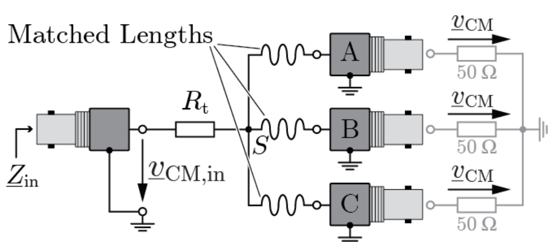
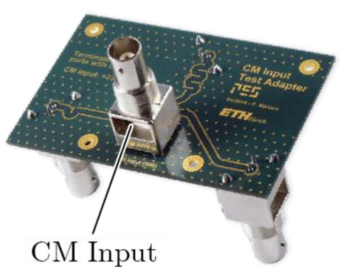
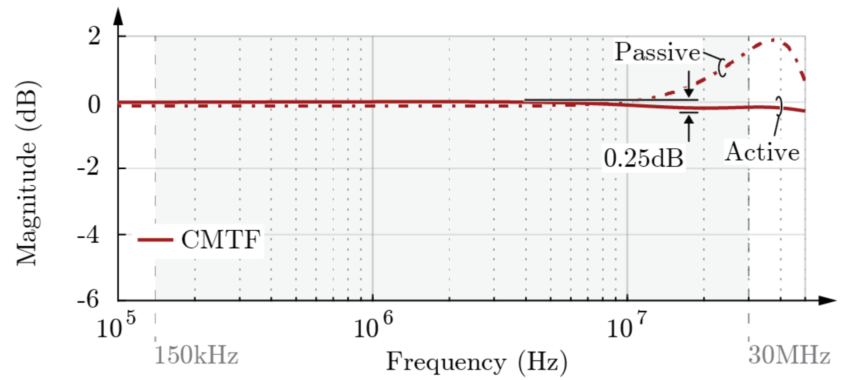
Results:
Performance Evaluation

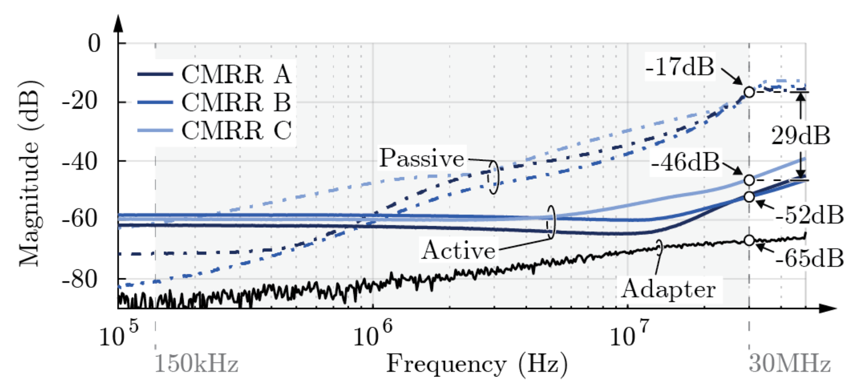
▶ Common-Mode Excitation

- Evaluation of Transfer Functions and Rejection Ratios
- Dedicated CM Input Signal Adapter







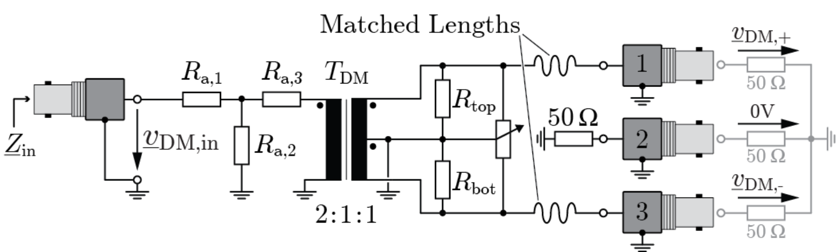


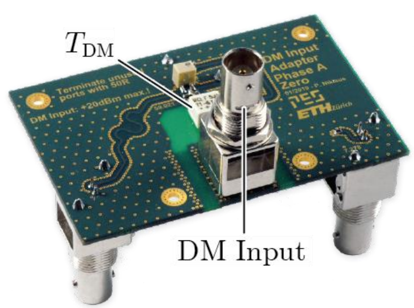
▶ >50dB CMRR for CE EMI Range

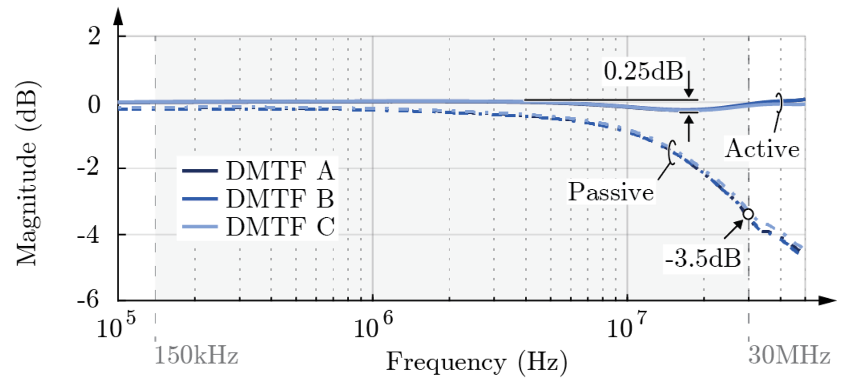
▶ *Significantly Better Compared to Passive Realization*

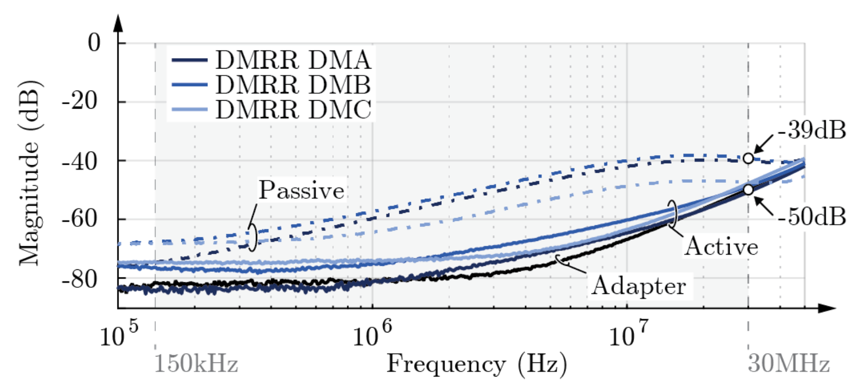
▶ Differential-Mode Excitation

- Evaluation of Transfer Functions and Rejection Ratios
- Dedicated DM Input Signal Adapters









▶ >50dB DMRR for CE EMI Range

▶ *HF DMRR Limited by Adapter*

Conclusions

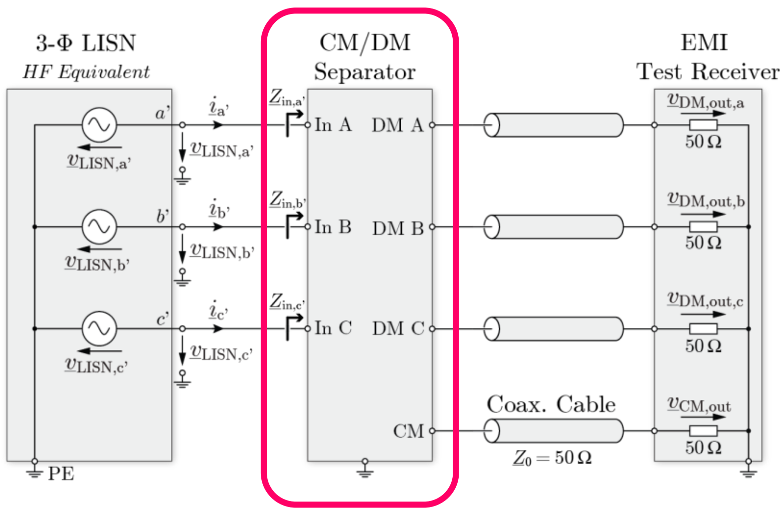
Three-Phase Conducted EMI Noise Separation

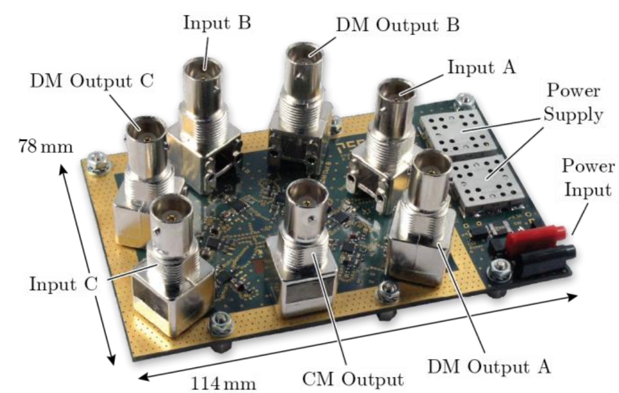
Active CM/DM Separator Circuit

Flat CMTF and DMTF

CMRR & DMRR > 50dB up to 30MHz

No Magnetic Components





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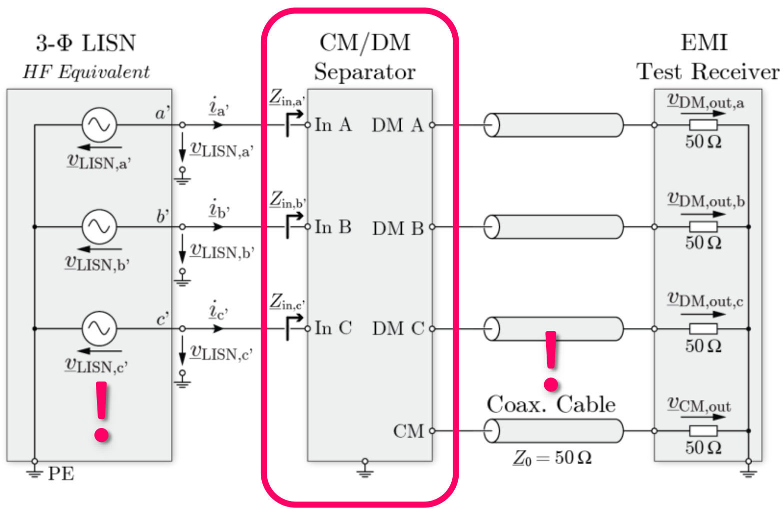

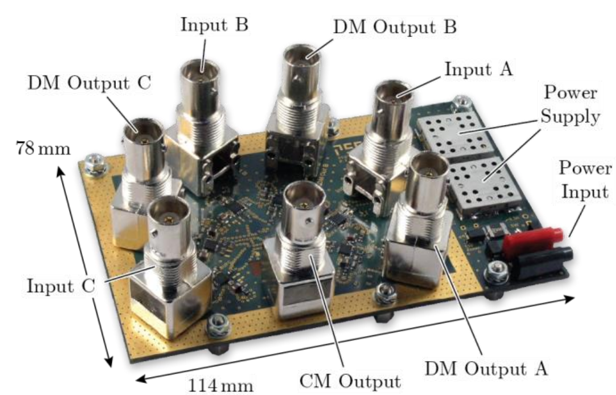

► *Consider Impact of LISNs, Cables, Etc. !*

Thank You!

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