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**

- e.g. PV Inverter

- **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 Slides
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

\[
\begin{align*}
  v_a &= v_{CM} + v_{DM,a} \\
  v_b &= v_{CM} + v_{DM,b} \\
  v_c &= v_{CM} + v_{DM,c} \\
  v_{CM} &= \frac{(v_a + v_b + v_c)}{3} \\
  v_{DM,a} + v_{DM,b} + v_{DM,c} &= 0
\end{align*}
\]

► 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

\[
CMTF = \frac{v_{CM,\text{out}}}{v_{CM,\text{LISN}}}
\]

\[
DMTF = \frac{v_{DM,\text{out}}}{v_{DM,\text{LISN}}}
\]

\[
CMRR = \frac{v_{DM,\text{out}}}{v_{CM,\text{LISN}}}
\]

\[
DMRR = \frac{v_{CM,\text{out}}}{v_{DM,\text{LISN}}}
\]

- 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

3-Φ LISN

- Matching of Passive Components
- Active Realization preferred

Source: Heldwein et al. 2009

Hardware Demonstrator
Passive Noise Separator

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

Matching of Passive Components

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Passive Noise Separator

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Source: Heldwein et al. 2009
Active Noise Separator

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

**Hardware Demonstrator**

- **Realization on PCB → Controlled Parasitic Elements → Influence?**
- **Reproducible and Simple Manufacturing**
Active Noise Separator

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Hardware Demonstrator

Realization on PCB → Controlled Parasitic Elements → Influence?
Reproducible and Simple Manufacturing
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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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
Influence of Parasitic Elements (II)

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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**
Influence of Parasitic Elements (III)

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Almost at Amplifier Limit for f > 10MHz

Very Simple Trimming Procedure Results in Superior CMRR
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
Three-Phase Conducted EMI Noise Separation

Active CM/DM Separator Circuit

Flat CMTF and DMTF

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► Consider Impact of LISNs, Cables, Etc. !
Thank You!

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