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Active Electromagnetic Interference (EMI) Filter for Conducted Noise Reduction

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Hong Kong Applied Science and Technology Research Institute Company Limited

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Outline

I. What is conducted EMI noise

II. Noise source and propagation path

III. Noise measurement and extraction

IV. Mitigation techniques for conducted EMI

V. A proposed active EMI circuit

VI. Conclusion

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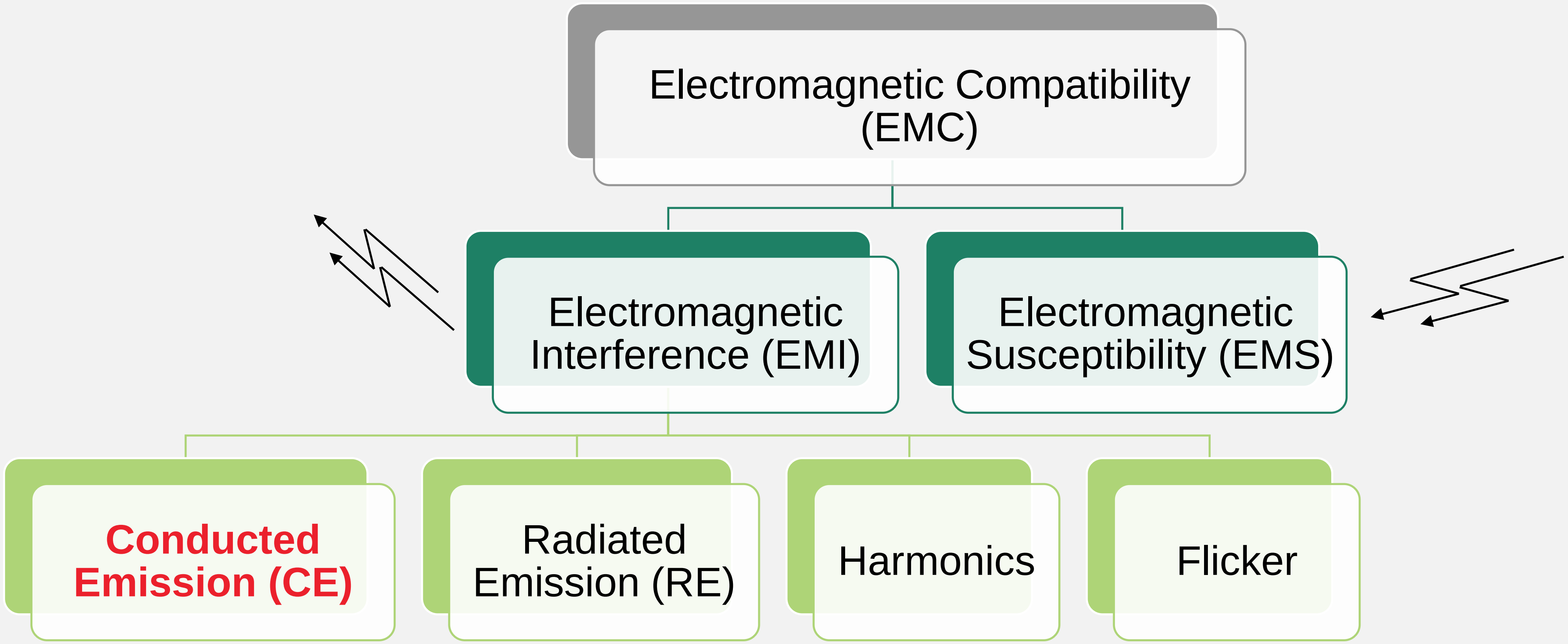
What is conducted EMI noise (1/3)

❑**Conducted EMI:** propagates along conductors

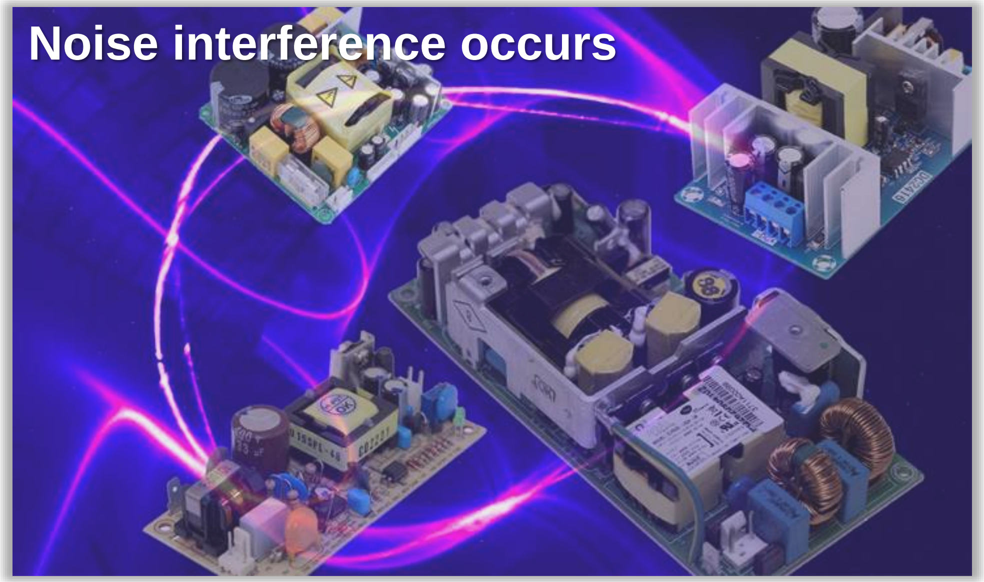


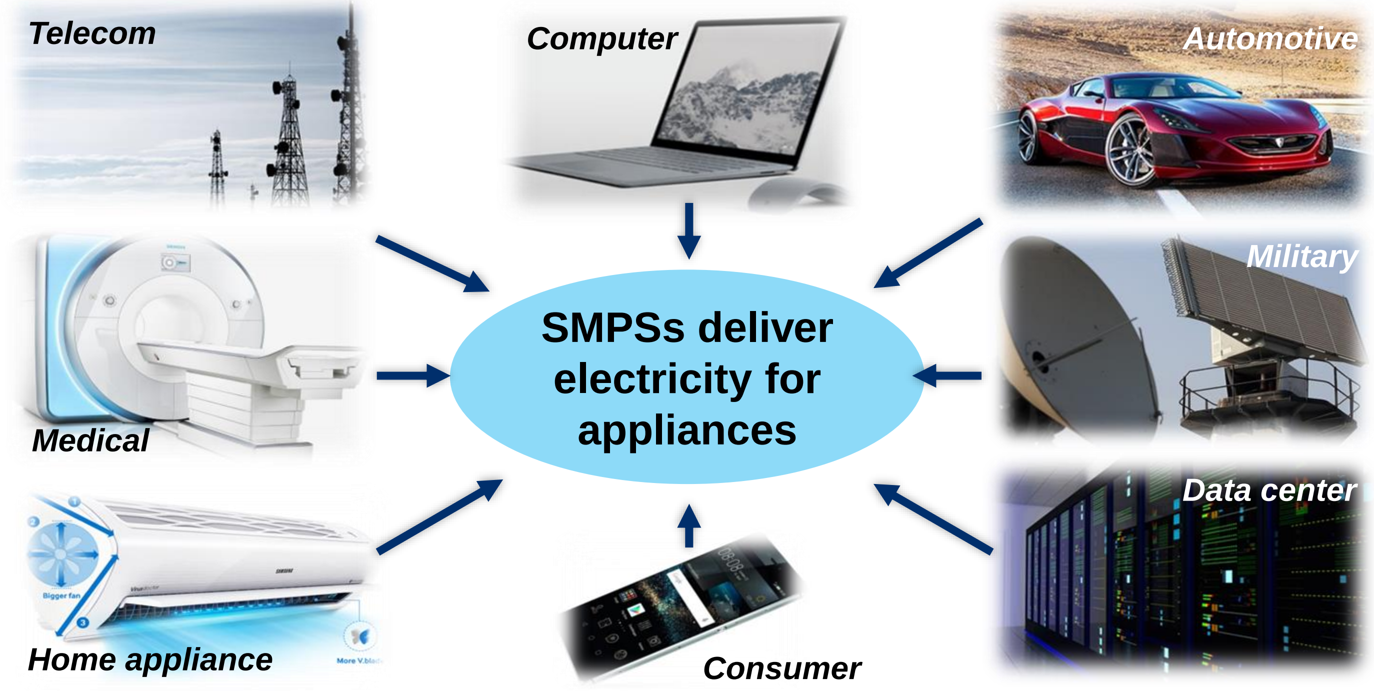
Definition: noise that are generated by a device or a circuit and transferred to another device or circuit **via cabling, PCB traces, power/ground planes, or parasitic capacitance**.

What is conducted EMI noise (2/3)

❑Switch-Mode Power Supply (SMPS):

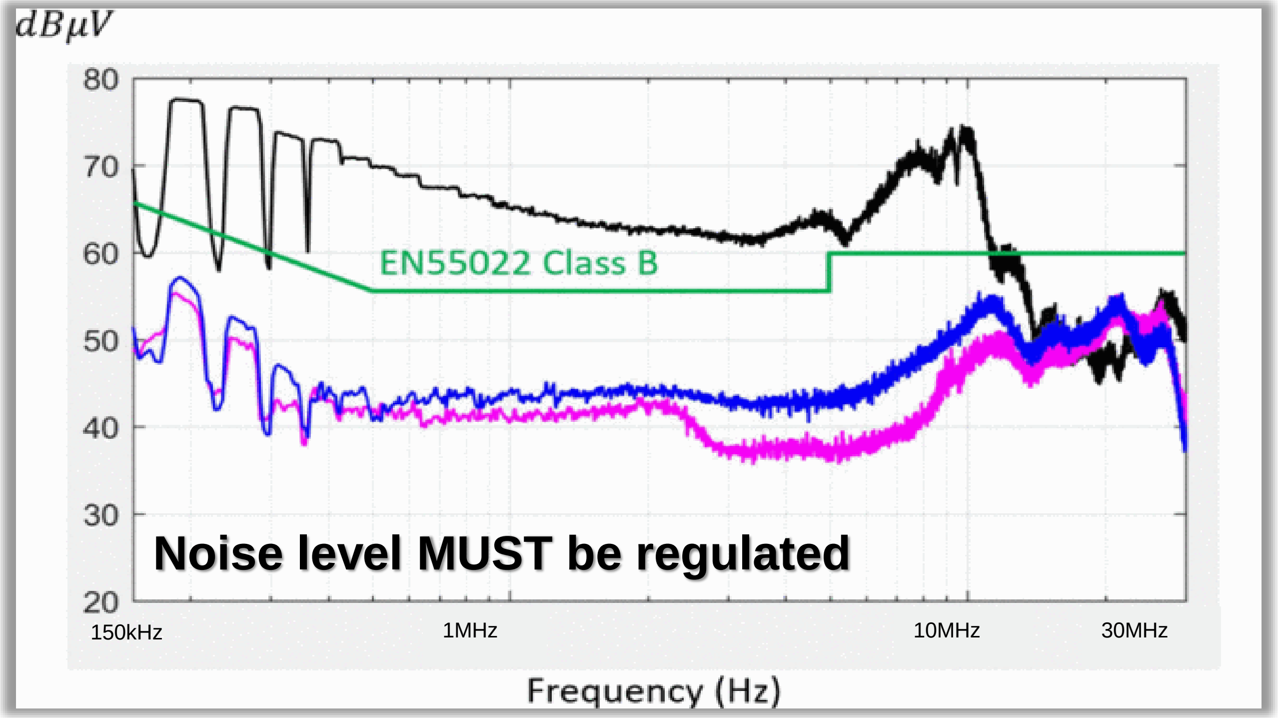
- Light, small, efficient
- Power MOSFETs work in **fast on/off operation**, e.g. hundred kHz





What is conducted EMI noise (3/3)

- **Dangers of conducted EMI:**
  - Affecting internal sensitive circuits of SMPS: e.g. feedback pins, frequency settings, compensation networks, sensing paths
  - Affecting operation of external devices and pollute power network
- **A product must pass the related EMI standard in that region**
- **Frequency range:**
  - **Start**: depends on different EMI standards, e.g. 150kHz for CISPR 22; 450kHz for FCC part15; 9kHz for CISPR 15
  - **Stop**: 30MHz
- **Noise mode:**
  - Common mode (CM)
  - Differential mode (DM)



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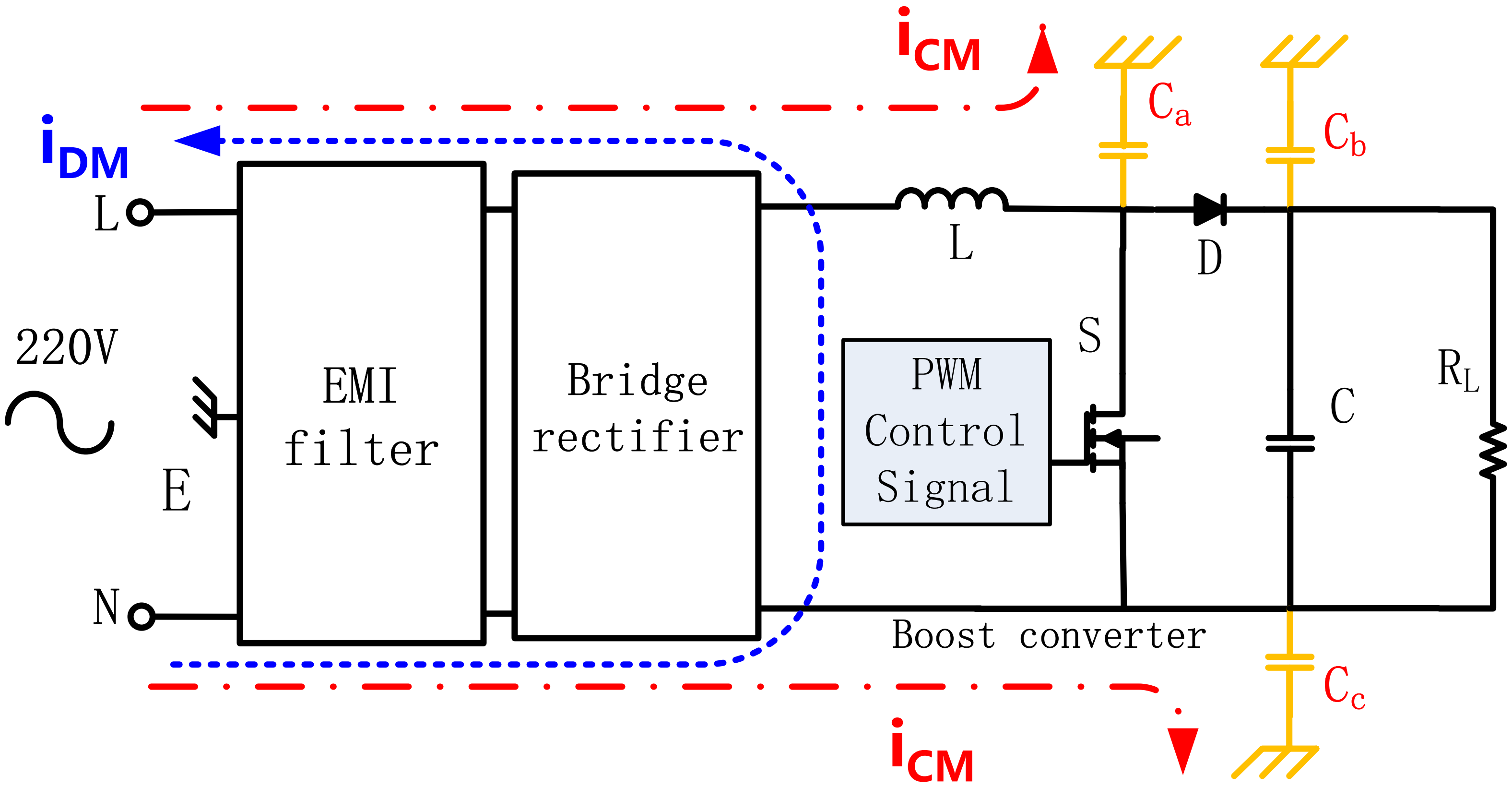
Noise Source and Propagation Path (1/3)

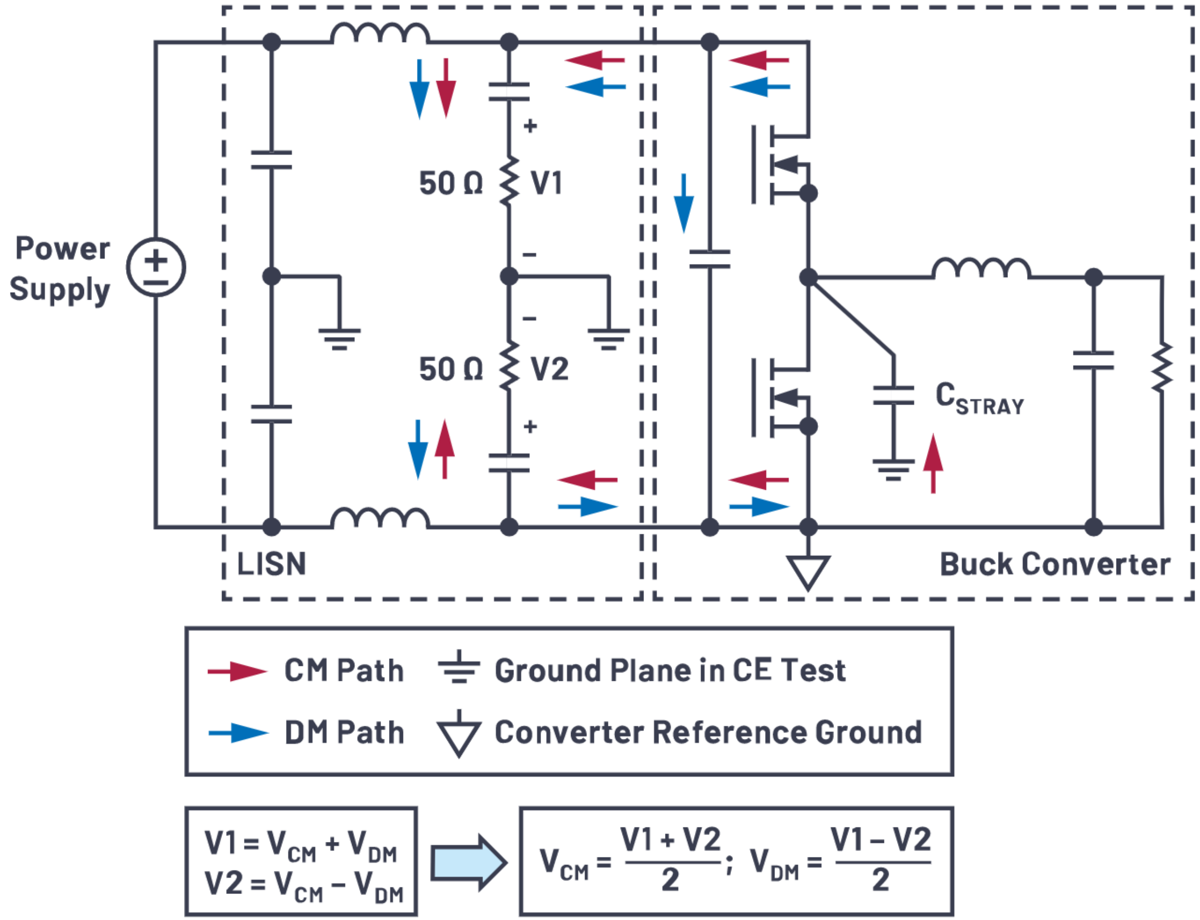
❑Example 1: boost converter



The CM noise path and DM noise path in a boost converter

Noise Source and Propagation Path (2/3)

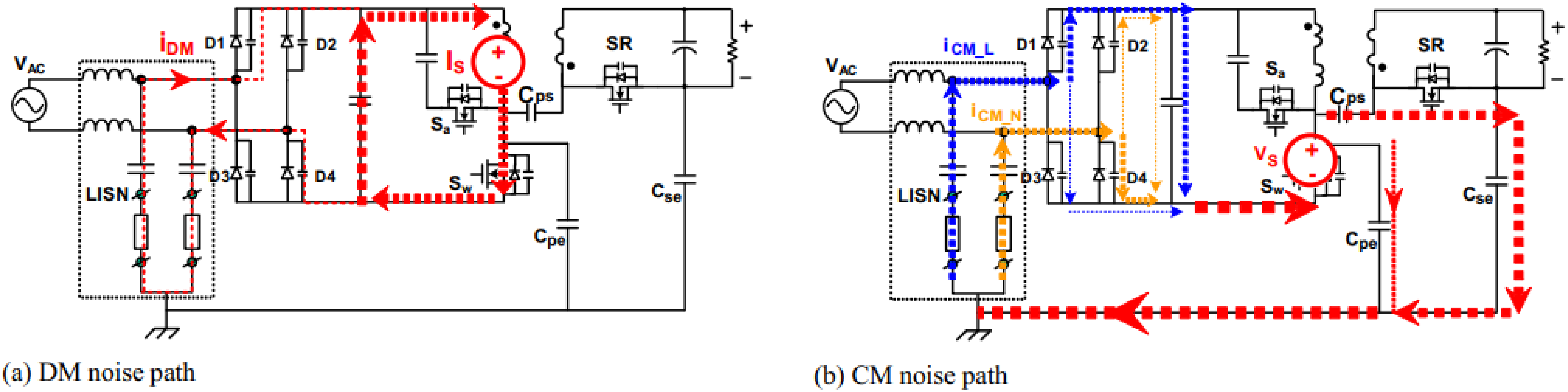
❑Example 2: buck converter



The CM noise path and DM noise path in a buck converter

Noise Source and Propagation Path

❑Example 3: active clamp flyback converter



EMI noise path of active clamp flyback converter

Ref: Huanng X. al, Conducted EMI analysis and filter design for MHz active clamp flyback front-end converter, APEC 2016

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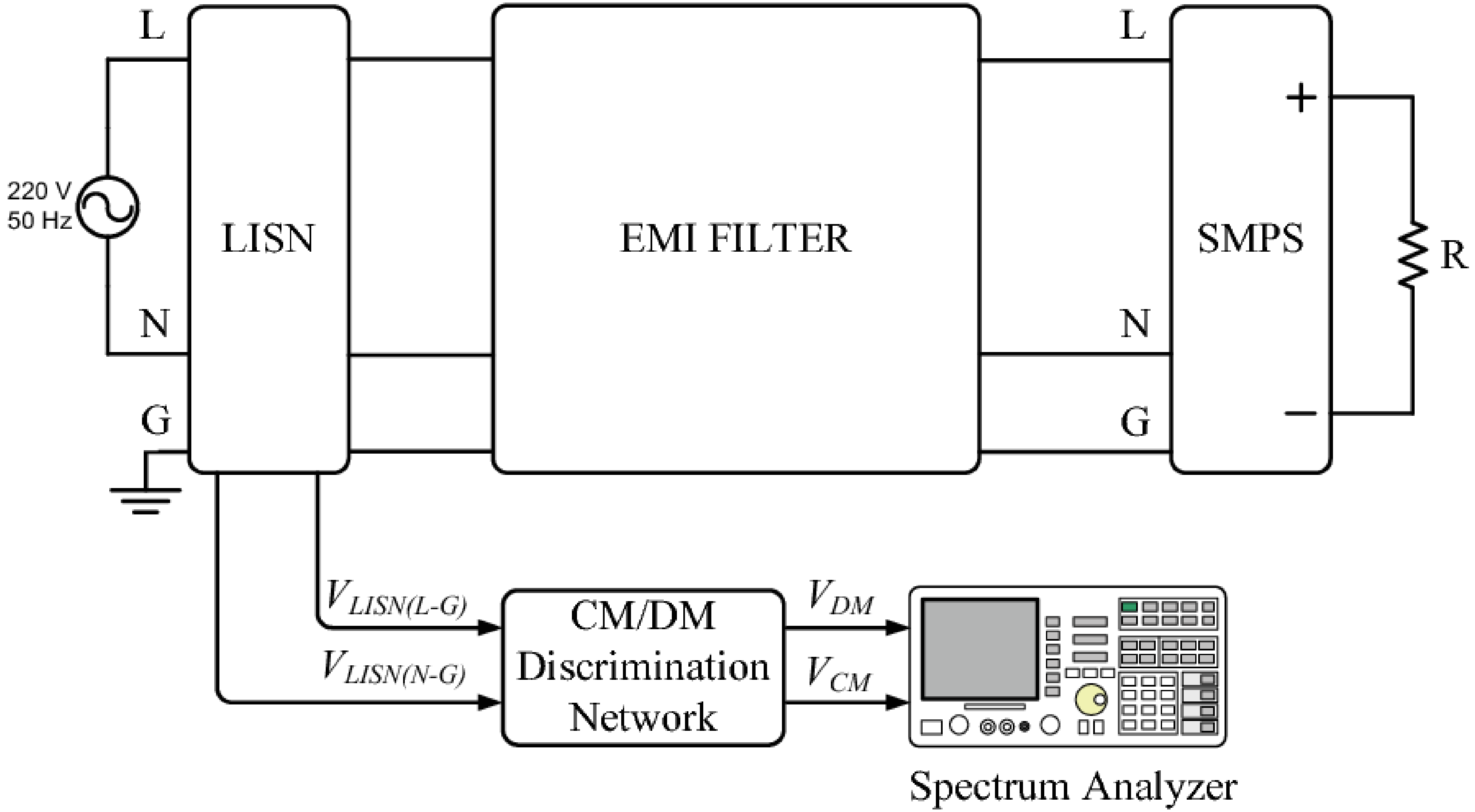
Noise Measurement and Extraction (1/4)

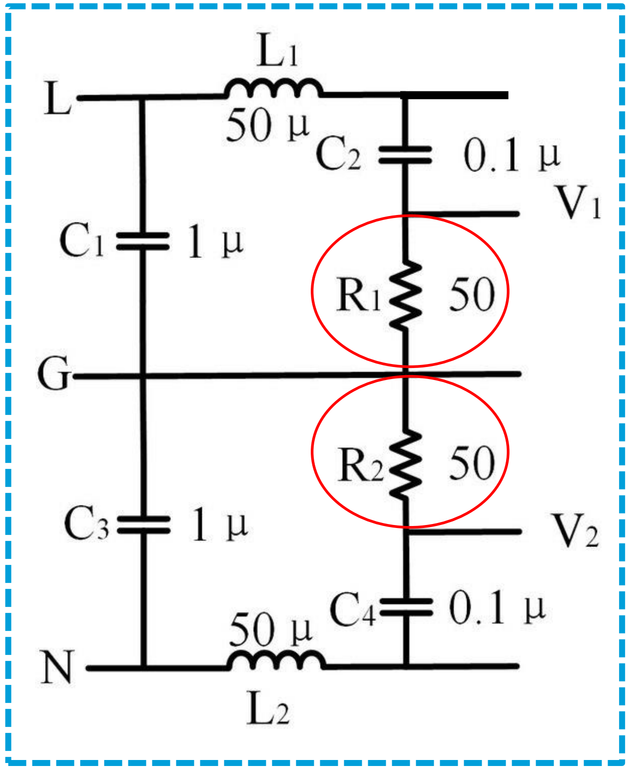
❑Conducted EMI measurement setup



Noise Measurement and Extraction (2/4)

❑LISN: Line Impedance Stabilization Network

- A device widely used in conducted emission and susceptibility tests
- To provide a stable power line impedance so that the measurement results can be repeatable.



- **R_1 & R_2:** 50 ohms impedance in EMI receiver
- C_2 & C_4: form a high pass filter with R_1 & R_2
- L_1 & L_2: filter inductors in LISN
- C_1 & C_3: filter capacitors in LISN

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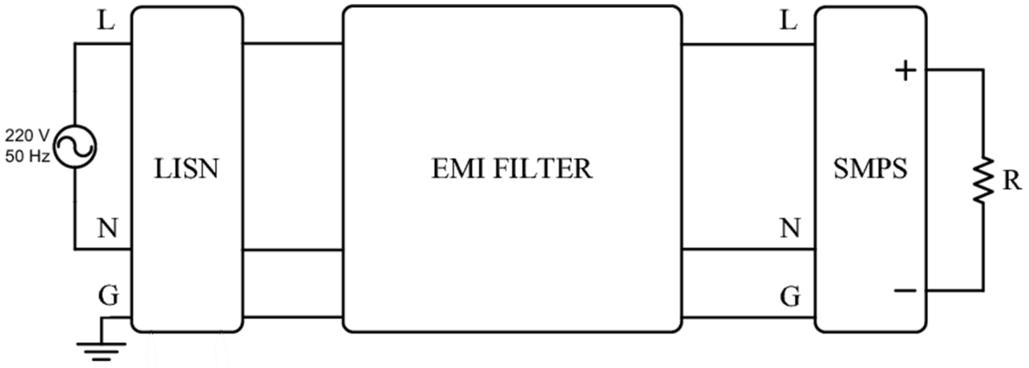
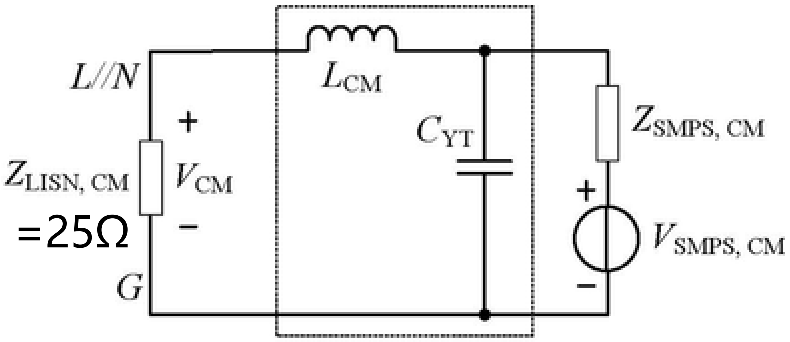
Noise Measurement and Extraction (3/4)

❑ CM model:



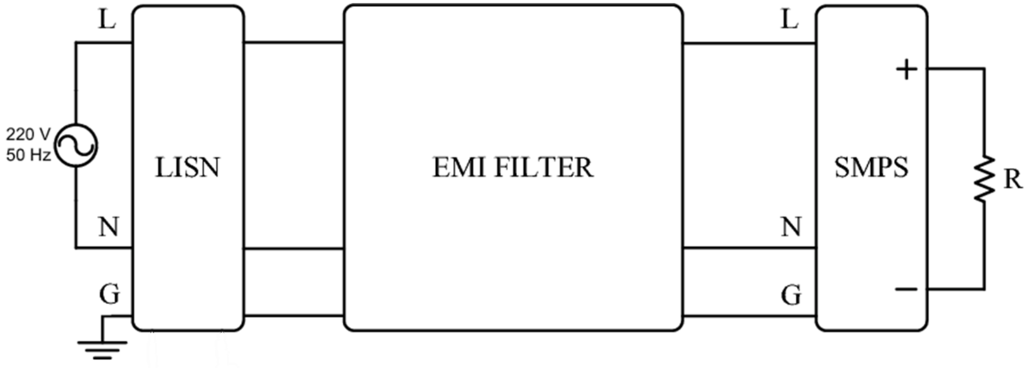


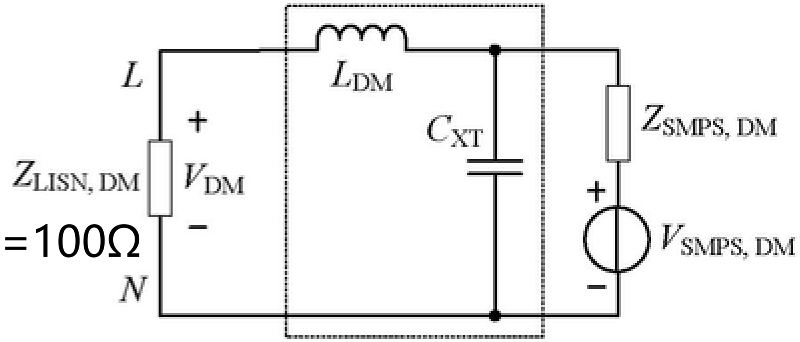
$=25\Omega$

$$|Noise|_{dB\mu V} = 20log_{10}(V_{CM})$$

$20log_{10}(1mV)$ = 60dbμV

❑ DM model:



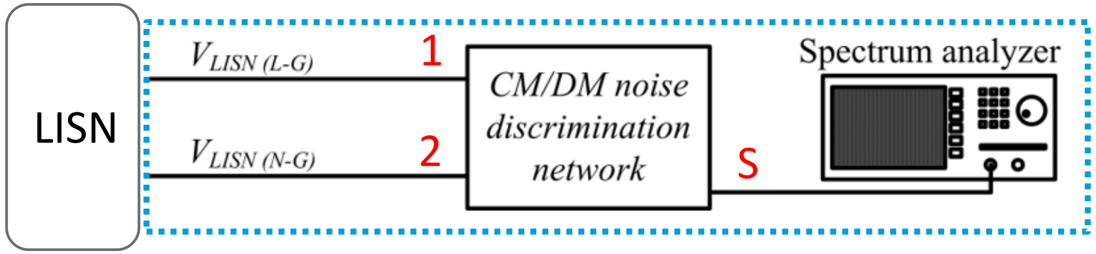


$=100\Omega$

$$|Noise|_{dB\mu V} = 20log_{10}(V_{DM})$$

Noise Measurement and Extraction (4/4)

❑CM/DM extraction network



$$I_{L1} = \frac{|I_{CM} + I_{DM}|}{2}$$

$$I_{L2} = \frac{|I_{CM} - I_{DM}|}{2}$$

$$I_{CM} = \frac{|I_{L1} + I_{L2}|}{2}$$

$$I_{DM} = \frac{|I_{L1} - I_{L2}|}{2}$$

- Mini Circuits power splitter

ZFSC-2-6+

Coaxial

Power Splitter/Combiner

2 Way-0° 50Ω 0.002 to 60 MHz

Maximum Ratings

Operating Temperature	-55°C to 100°C
Storage Temperature	-55°C to 100°C
Power Input (as a splitter)	1W max.*
Internal Dissipation	0.125W max.

* At low range frequency band (f_L to 10 f_L), linearly derate maximum input power by 13 dB typ.

Permanent damage may occur if any of these limits are exceeded.

Coaxial Connections

SUM PORT	3

Features
- low insertion loss, 0.3 dB typ.
- excellent isolation, 30 dB typ.
- excellent amplitude unbalance, 0.1 dB typ.
- excellent phase unbalance, 0.2 deg. typ.
- rugged shielded case

Applications
- HF
- ham radio
- defense communications

ZFSC-2-6+

BNC version shown

CASE STYLE: K18

Connectors	Model
BNC	ZFSC-2-6+
SMA	ZFSC-2-6-S+
N-TYPE	ZFSC-2-6-N+
BRACKET (OPTION "B")	

+RoHS Compliant
The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications

ZSCJ-2-2+

Coaxial

Power Splitter/Combiner

2 Way-180° 50Ω 0.01 to 20 MHz

Maximum Ratings

Operating Temperature	-55°C to 100°C
Storage Temperature	-55°C to 100°C
Power Input (as a splitter)	1W max.
Internal Dissipation	0.125W max.

At low range frequency band (f_L to 10 f_L), linearly derate maximum input power by 13 dB.

Permanent damage may occur if any of these limits are exceeded.

Features
- low insertion loss, 0.2 dB typ.
- high isolation, 30 dB typ.
- rugged shielded case

Applications
- HF
- radio communication
- instrumentation

ZSCJ-2-2+

CASE STYLE: M22

Connectors	Model
BNC	ZSCJ-2-2+
BRACKET (OPTION"B")	
BRACKET (OPTION"BR")	

+RoHS Compliant
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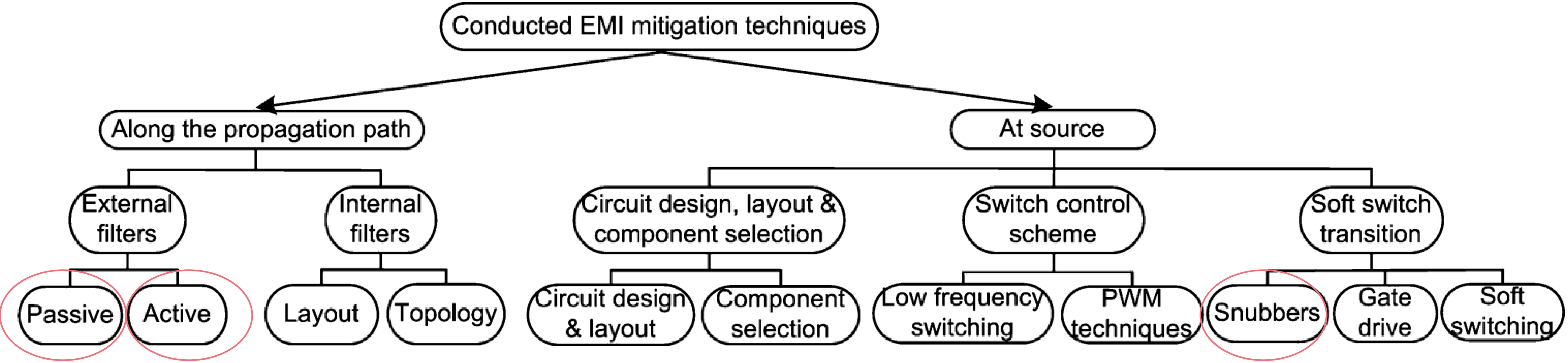
Mitigation techniques for conducted EMI (1/4)

❑Classifications of mitigation techniques for conducted EMI



: **Suppression techniques for a finish good design/product**

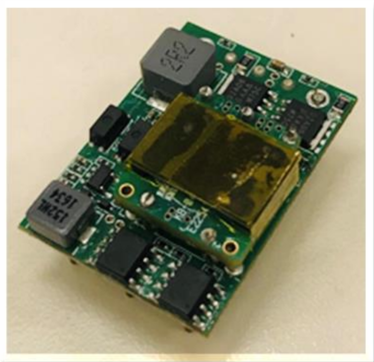
Ref: K. Mainali. al, Conducted EMI Mitigation Techniques for Switch-Mode Power Converters: A Survey, 2010

Mitigation techniques for conducted EMI (2/4)

❑Traditional solution 1:

- Passive EMI filters (PEFs), e.g. inductors & X/Y capacitors

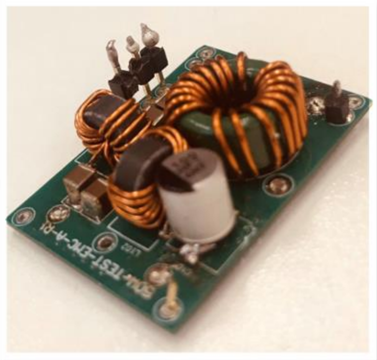
1/16 brick converter (50W)



60% of the volume

+

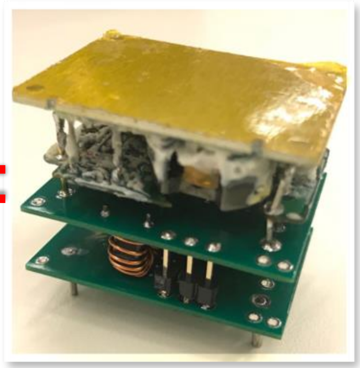
Its EMI filter board



40% of the volume

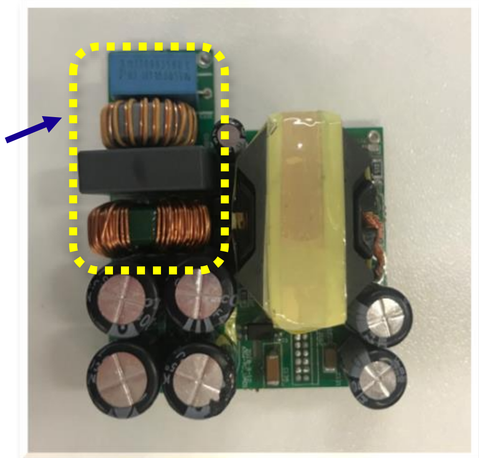
=

Assembly photo



100% of the volume

Its EMI filter
(30% of the PCB footprint)



65W AC-DC power adapter

❑ Pros:
- Simple
- Effective

❑ Cons:
- Bulky
- Heavy
- Power loss
- Low power density

- The footprint and volume of PEFs are large.

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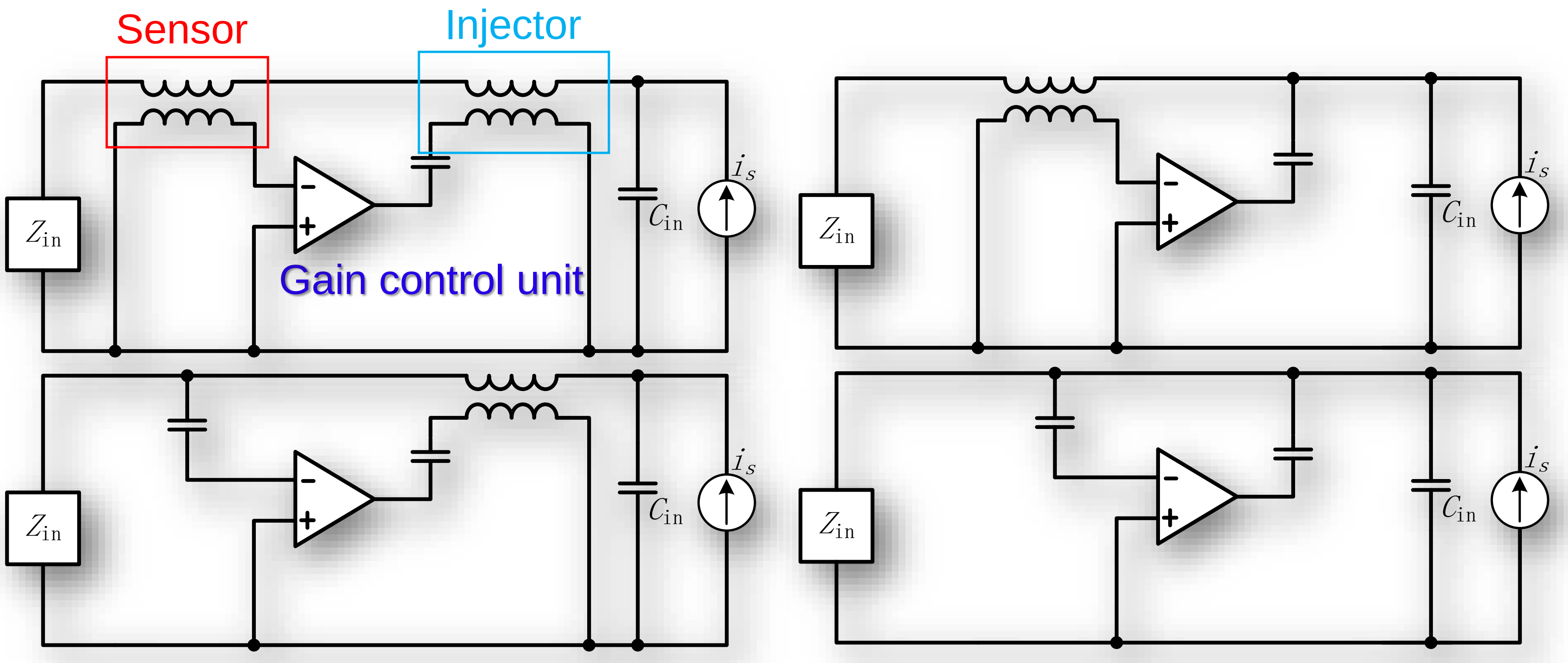
Mitigation techniques for conducted EMI (3/4)

❑Traditional solution 2:

- Active EMI filters (AEFs)



- Design complexity of AEFs is high

❑ Pros:

- **Effective**
- **Small**
- **Integration**

❑ Cons:

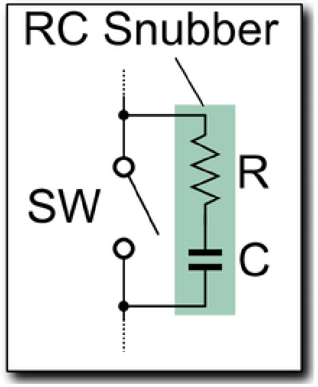
- **Design complexity**
  - Current/voltage sensor
  - Current/voltage injector
  - Gain control
  - Feedforward/feedback
- **Bulky magnetics**

Mitigation techniques for conducted EMI (4/4)

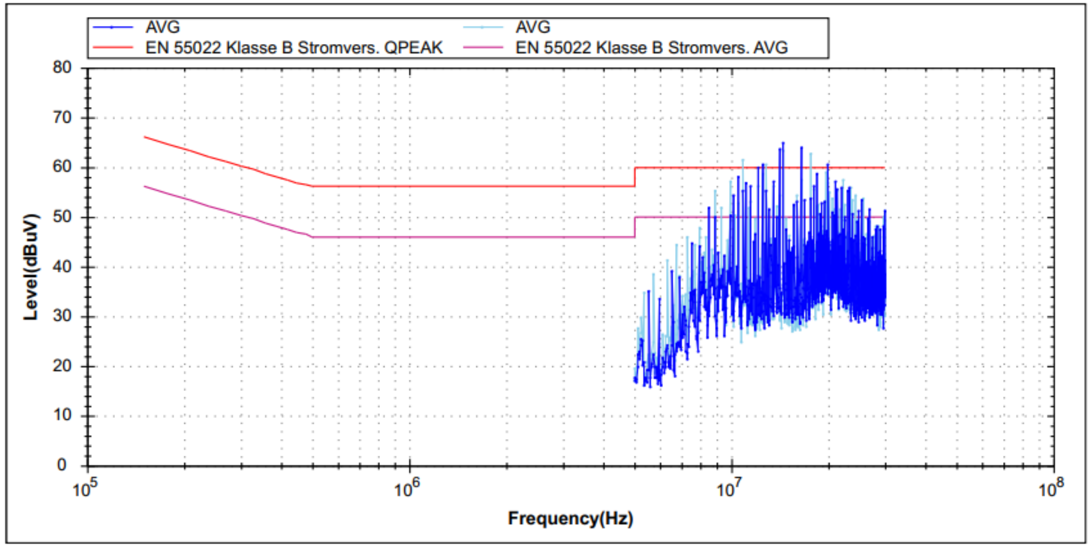
❑Traditional solution 3:

- ➢ Snubber circuit
  - ➢ RC circuit, RCD circuit
  - ➢ Related to SW frequency
  - ➢ Trade-off between efficiency and EMI

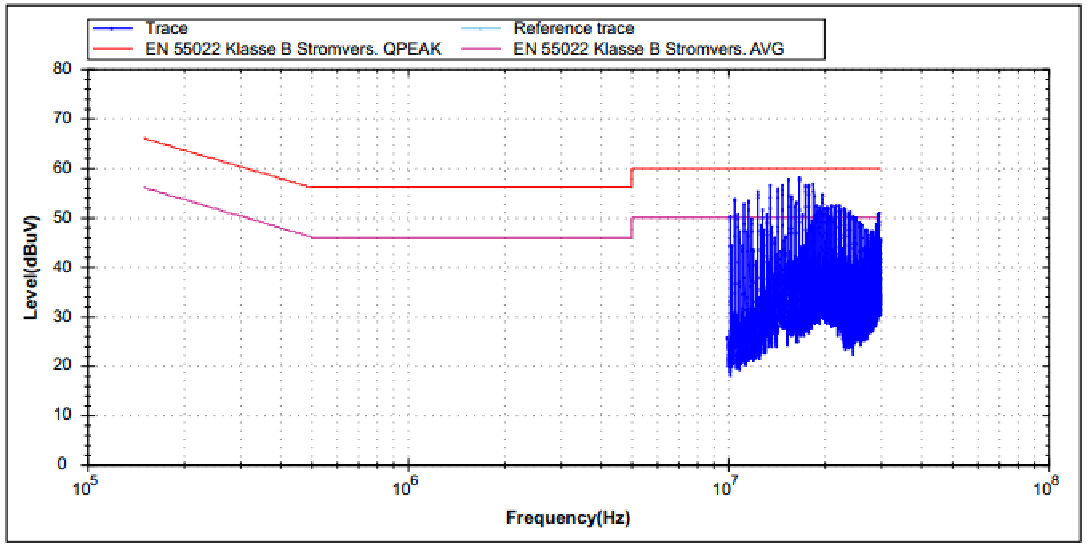
- ➢ R: limit current
- ➢ C: limit dv/dt
- ➢ D: reduce I^2R loss



RC：470pF + 10R



RC： 3.3nF + 10R



EMI performance at high frequency band (10MHz-30MHz) using different RC

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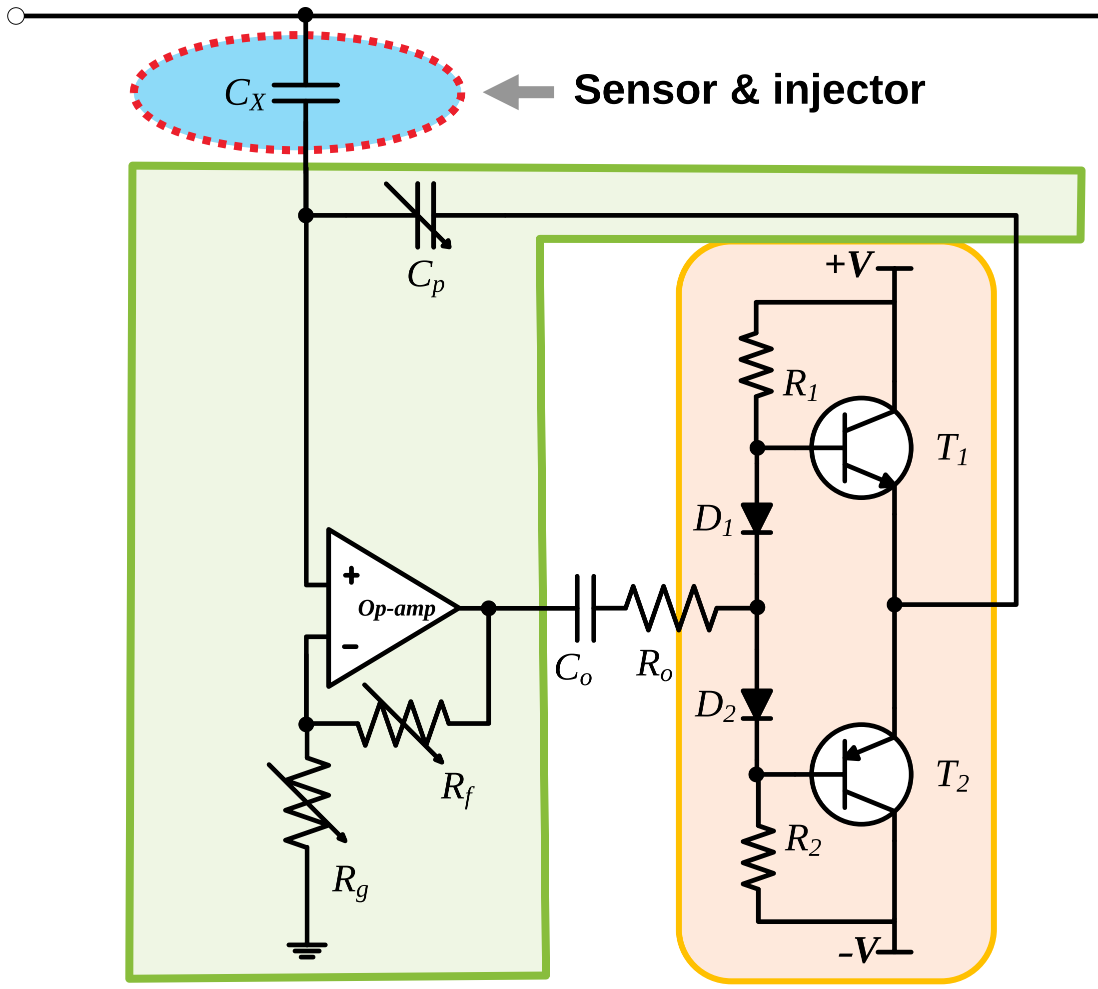
A proposed active EMI circuit (1/7): circuit topology

❑ Proposed active circuit



1st stage: gain control

2nd stage: PA circuit (optional)

❑ Description of the circuit:

- C_x → To sense noise current and inject a compensation voltage.
- Operational amplifier (Op-amp) → To provide an output voltage which is in phase with the input.
- R_g, R_f → To provide a voltage gain.
- Cp → To serve as a transfer unit to transfer sensed current into voltage.
- Power Amplifier (PA) Circuit → To generate sourcing current and further provide a higher current capability.

❑ Novelty:

- Sensor & injector at same point (C_X)
- Simplified design methodology using negative capacitance concept
- Variable resistor & capacitor for gain compensation (temperature/bandwidth)

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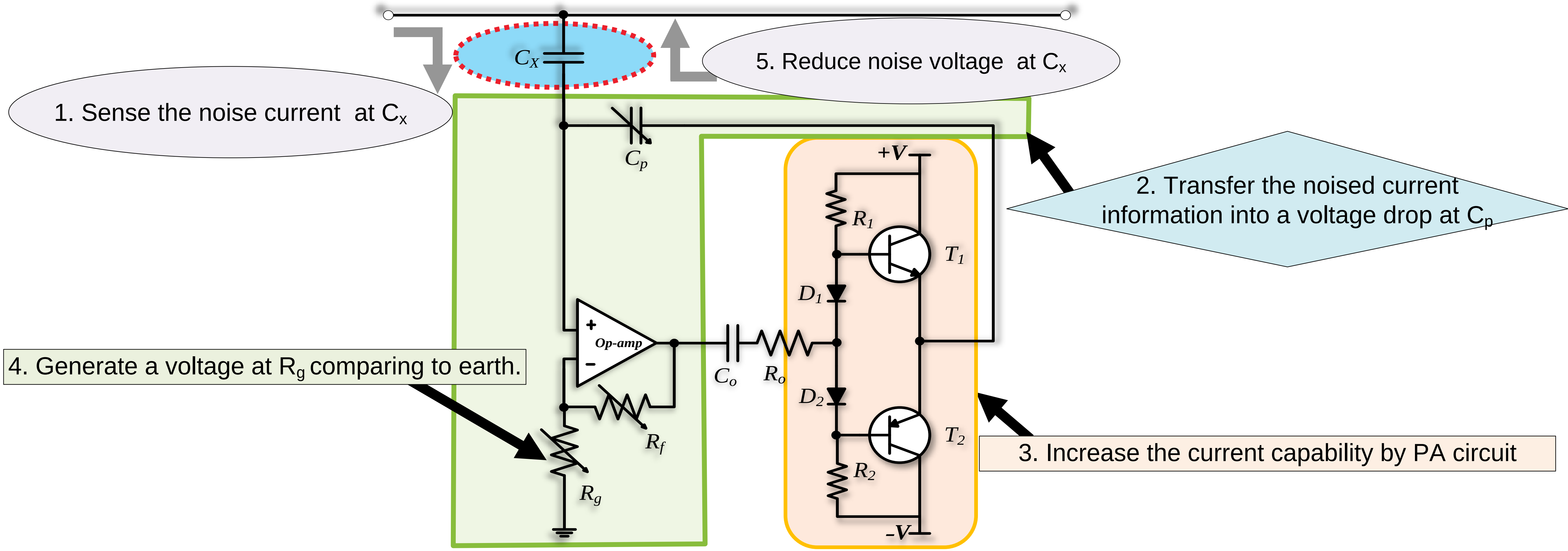
A proposed active EMI circuit (2/7): operation principle

❑ Operation principle - current controlled voltage source (VCCS)

➢ **Equivalent input impedance** would be in the form of a negative capacitance below Cx



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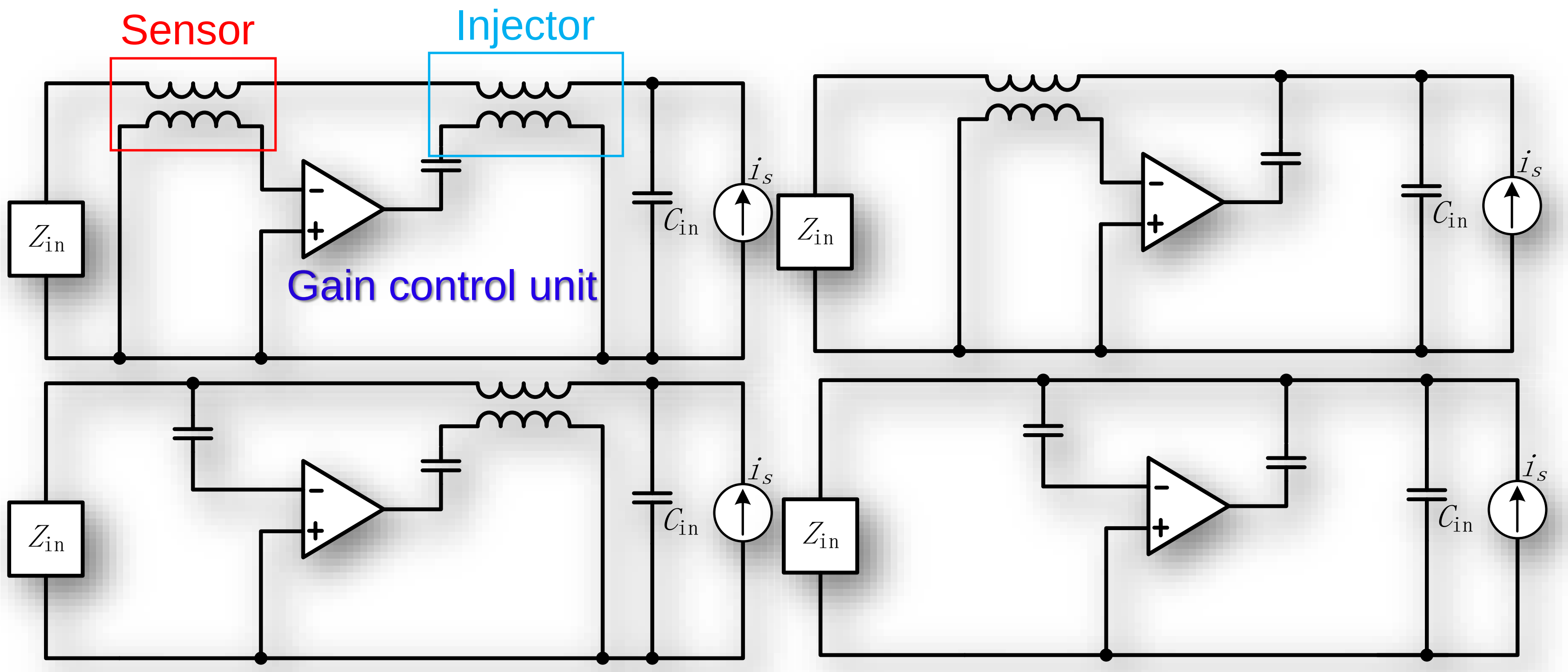
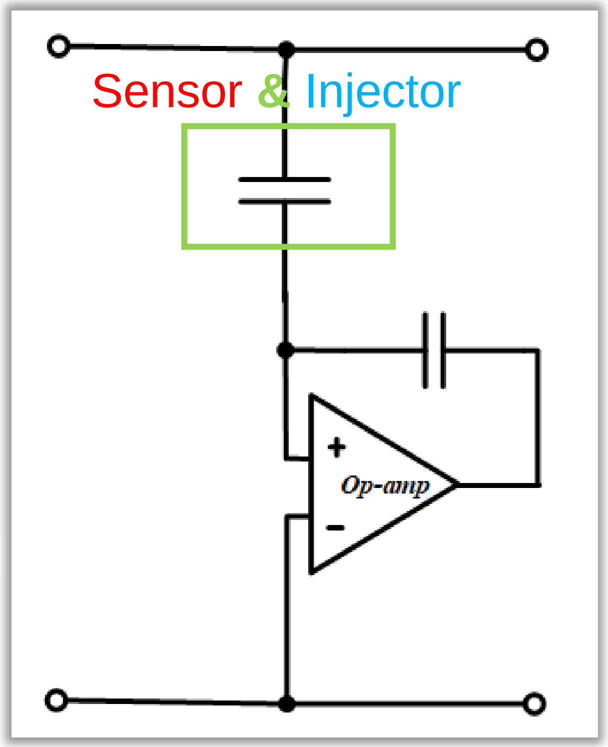
A proposed active EMI circuit (3/7): comparison

❑Comparing with traditional solution 2:

➢ Existing AEFs



➢ The proposed AEF



➢ Design complexity is reduced
➢ Higher bandwidth

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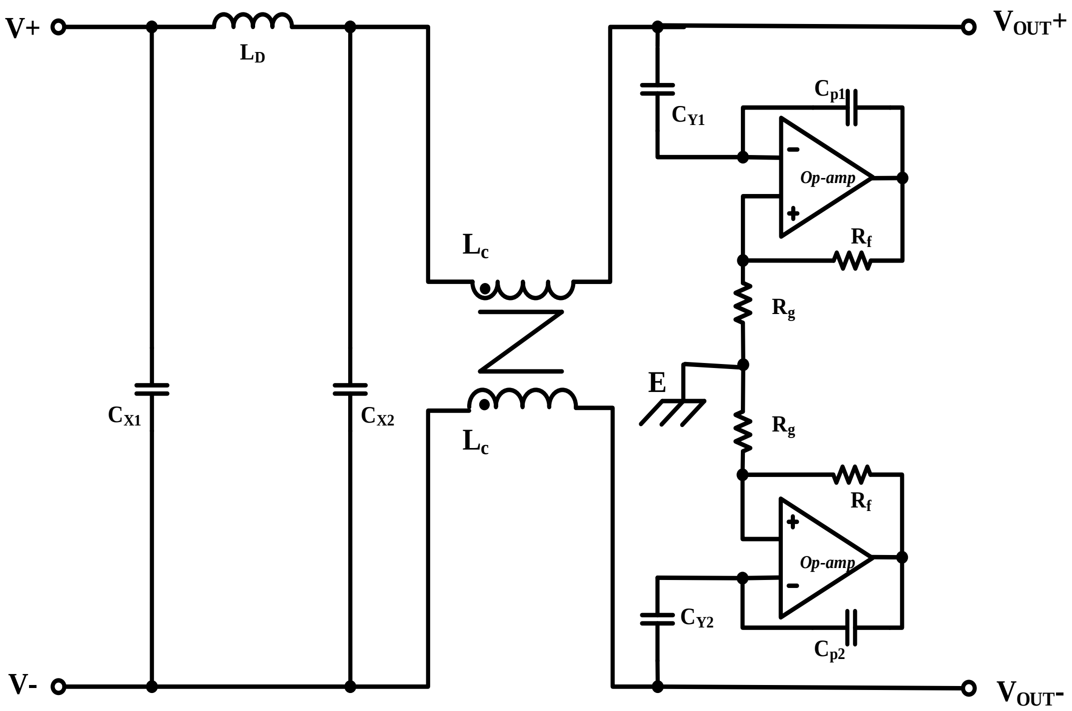
A proposed active EMI circuit (4/7): implementation

❑ Hybrid EMI filter (HEF) schematic and photo



A hybrid EMI filter (HEF) adopting the proposed AEF

Left: top view Right: bottom view

45uH CM choke

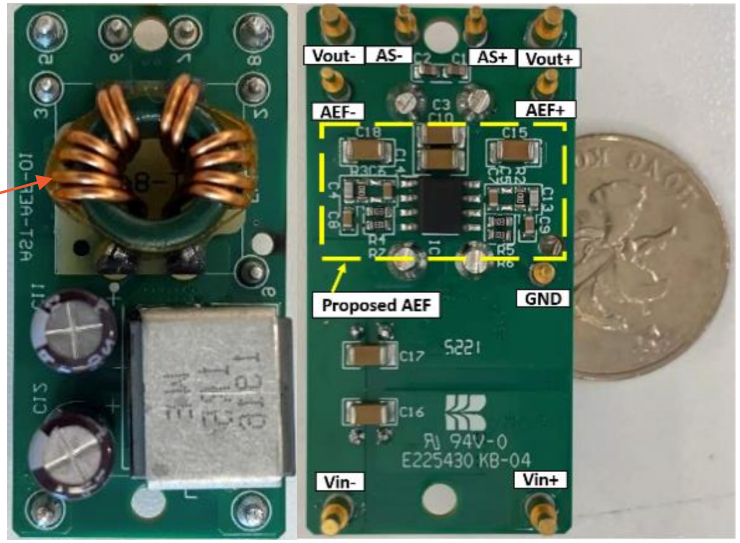
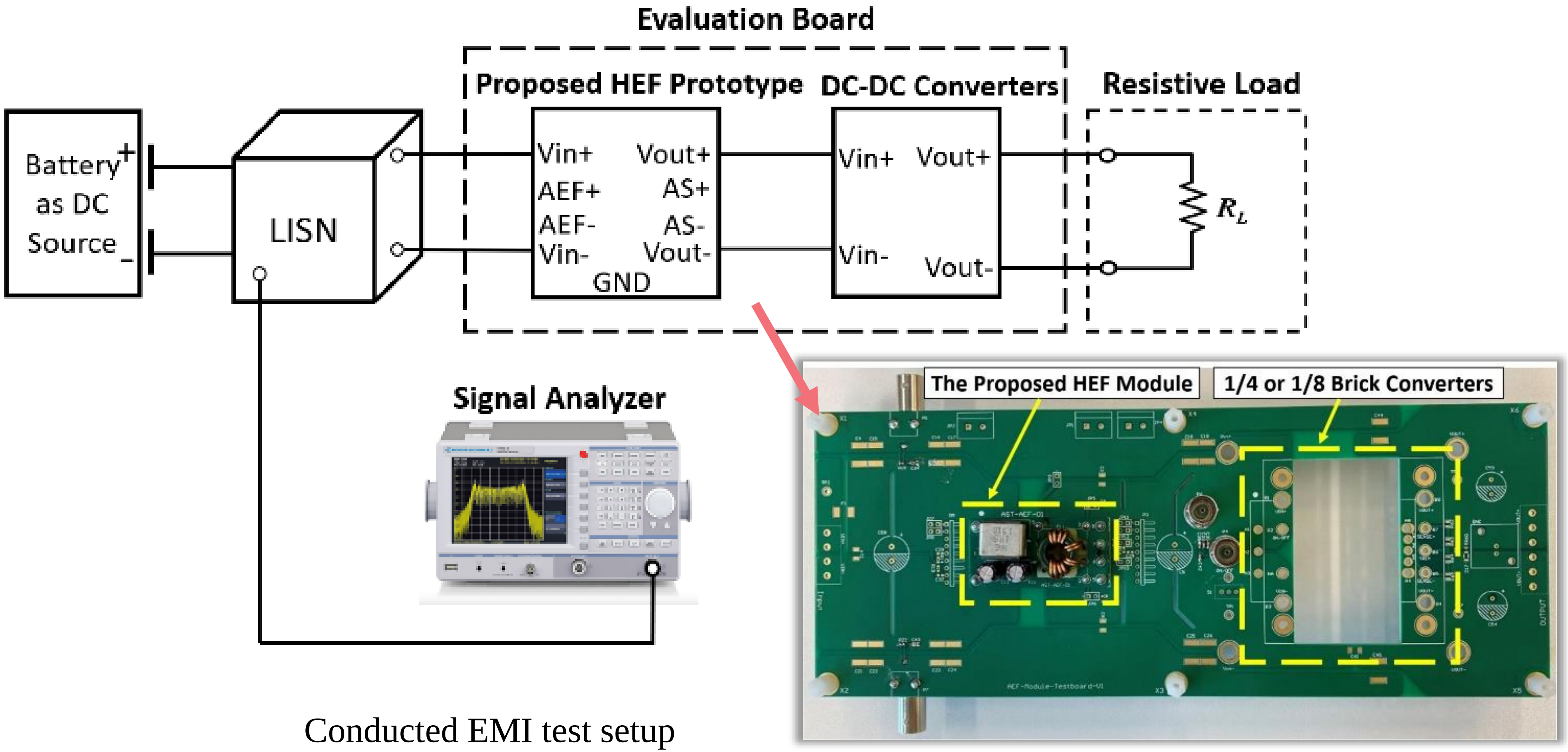


Photo of the HEF prototype
(size: 50mm x 27mm)

A proposed active EMI circuit (5/7): testing platform



Conducted EMI test setup

Photo of evaluation board

Working condition of the DC/DC converter: V_{in} = 12V, V_{out} = 5V and I_{out} = 10A (full load)

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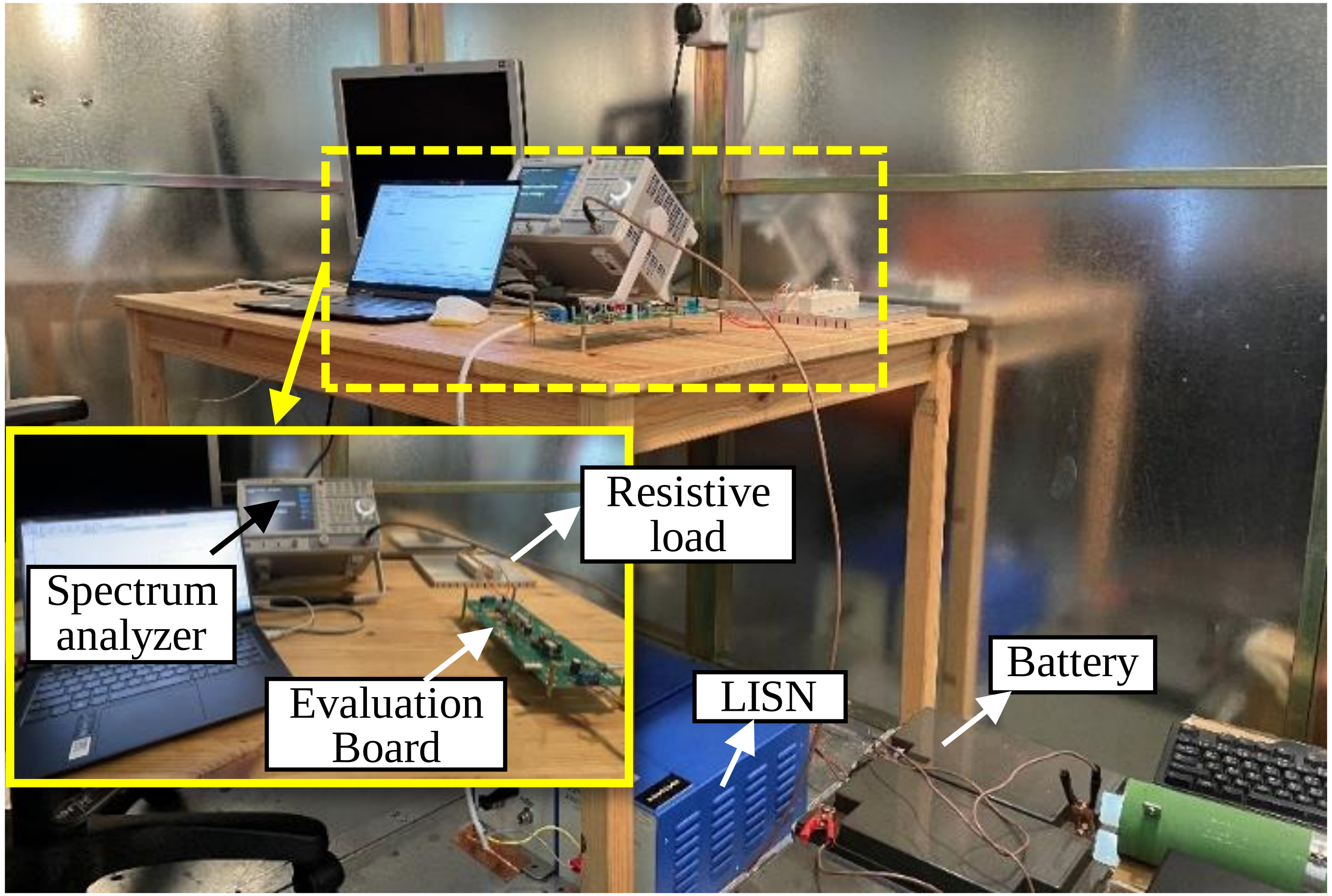
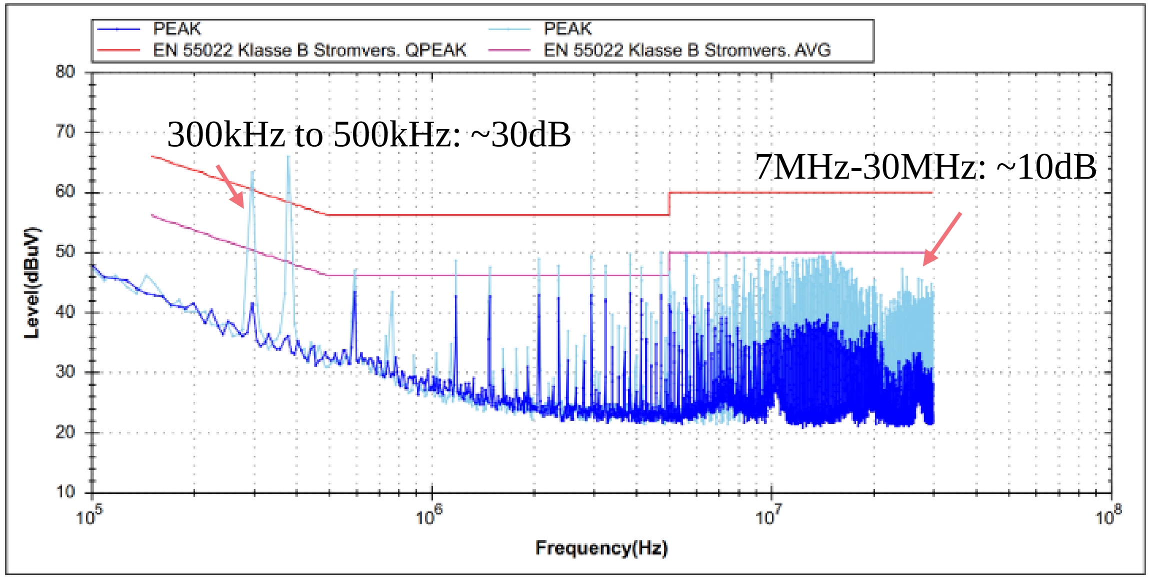
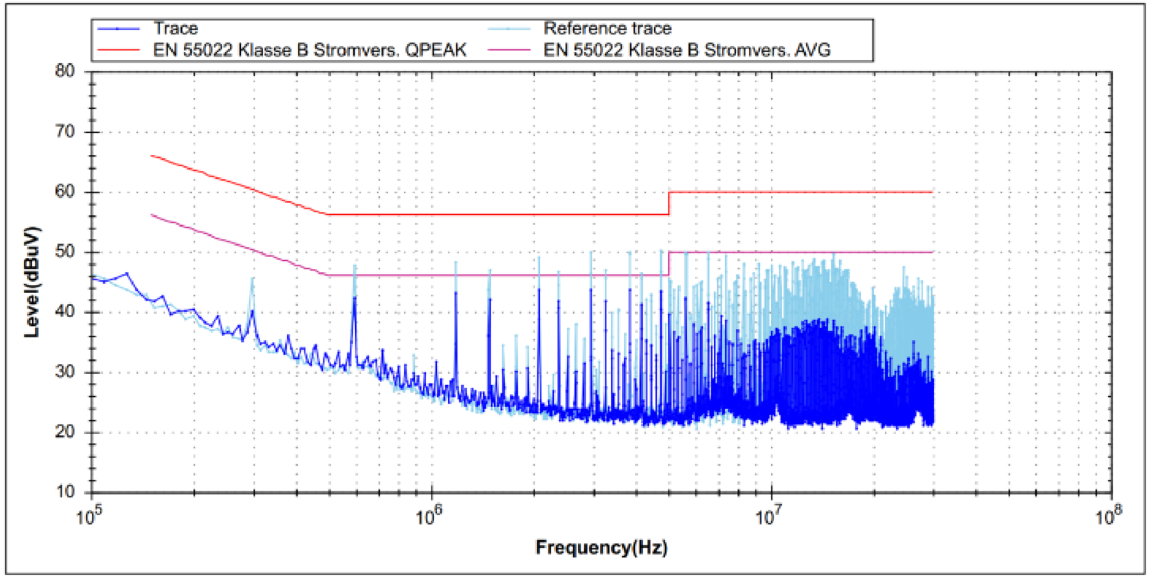
A proposed active EMI circuit (6/7): testing setup



Conductive EMI test in the shielding room

A proposed active EMI circuit (7/7): testing results





- Bare noise of the converter
- With the proposed HEF

- With PEF only
- With the proposed HEF

PEF: better performance at low frequency band
AEF: better performance at midrange and high frequency band

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Conclusion

- ✓The reduction of conducted EMI noise at its source is more desirable than reduction along the conduction path
- ✓After finishing the design, passive EMI filters and active EMI filters are both good solutions to suppress noise
- ✓Active EMI filtering technique is promising both on noise reduction of SMPS and the size reduction of EMI filter

Thank You

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