PSMA EMC Basics Webinar

Safety & Compliance Committee

Today's Presentation
"Emission of SMPS & Mitigations",
Josefine Lametschwandtner, RECOM Power Inc.

Question & Answer Session:

Submit questions via Questions Window anytime. Questions will be addressed at the end of the presentation.

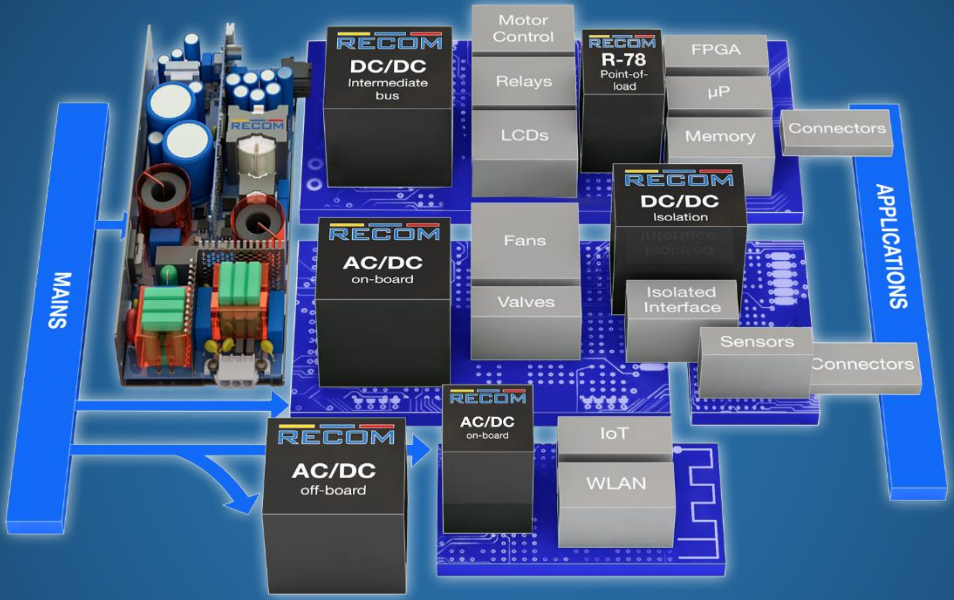
Important Notes

This webinar will be recorded and available on the PSMA web site shortly after the webinar Participant Phone Lines will be muted throughout

Bio – Josefine Lametschwandtner

- BS in Science with an emphasis on Electronics and Technology from FH Joanneum
- Lead EMC Engineer for RECOM Power
  - Joined in 2014
  - Previous experience with GE Medical Systems
- EMC filter development and testing
- Customer consulting around all EMC issues
- Organizes the RECOM EMC Seminar
- Tri-lingual (German, English, Spanish)

MODULES FOR DISTRIBUTED POWER ARCHITECTURE



Emission of SMPS & Mitigations

Josefine Lametschwandtner, BSc

EMC-Webinar, 11. October 2022

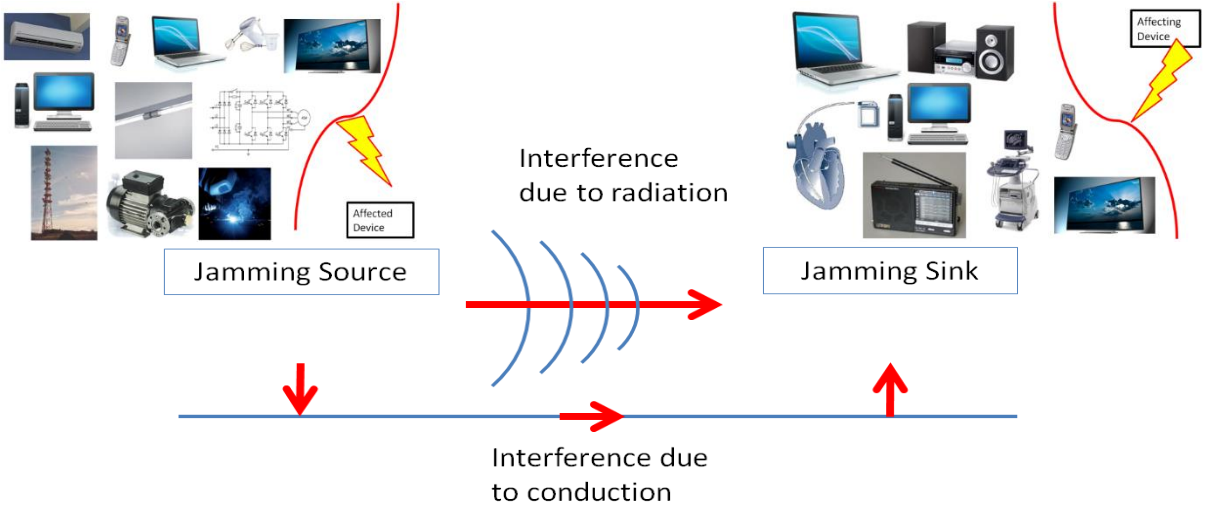
PSMA

RECOM
WE POWER YOUR PRODUCTS

Topics

- „Troublemaker“ SMPS
- Remedial Actions in the Design
  - PFC
  - Snubber
  - Spread-Spectrum
  - Slew Rate Control
  - Layout
- External filtering

General Principle



State-of-the-art SMPS vs. old school PSU

- SMPS Advantages
  - Regulated voltage
  - Lower weight
  - Higher efficiency
  - Wider input range
  - Lower production costs

- SMPS Disadvantages
  - Wide spectrum EMI

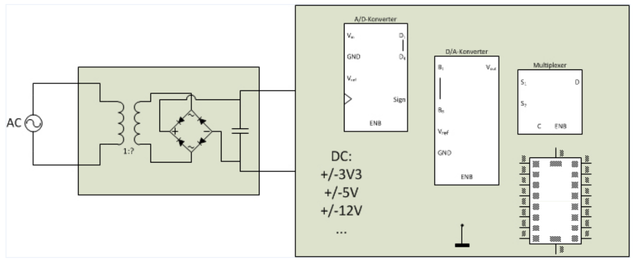


Fig.: Old-school

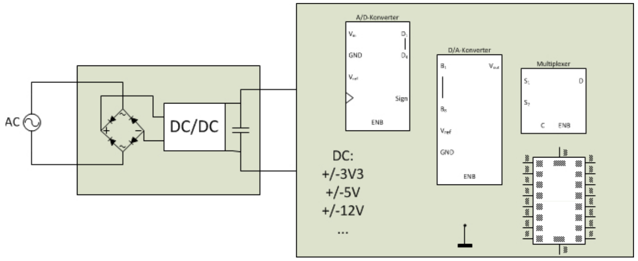


Fig.: State-of-the-art

Example: 150 kHz, 400V/50ns

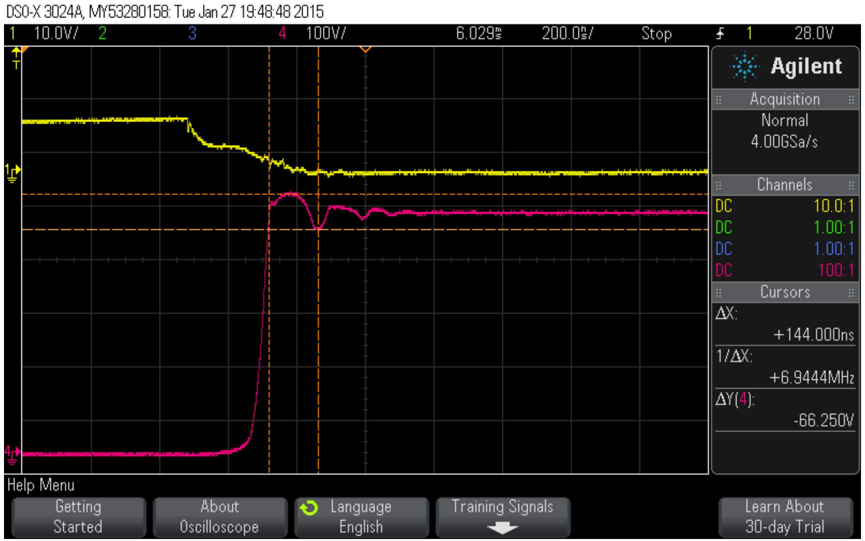


Fig.: Rising edge of an SMPS switch

Switching frequency ≈ 150kHz

Emissions in the MHz range

$$f = \frac{1}{2\,\pi\,t}$$

Frequency Response

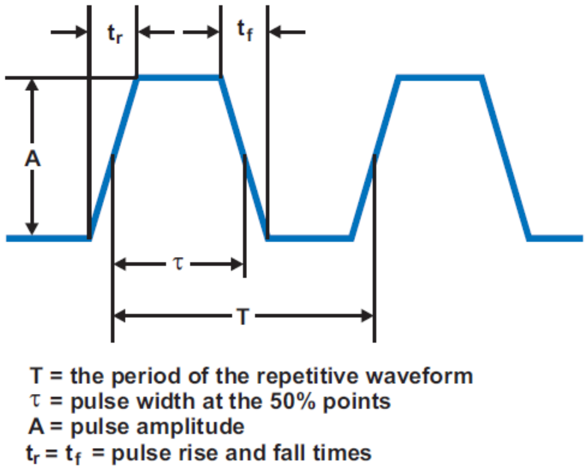


Fig.: Switching signal of a SMPS[1]

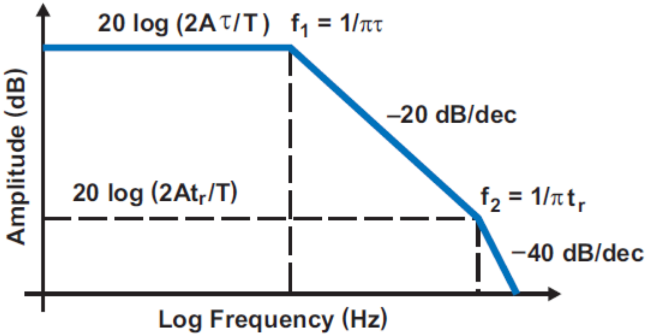


Fig.: Frequency response of trapezoidal waveforms [1]

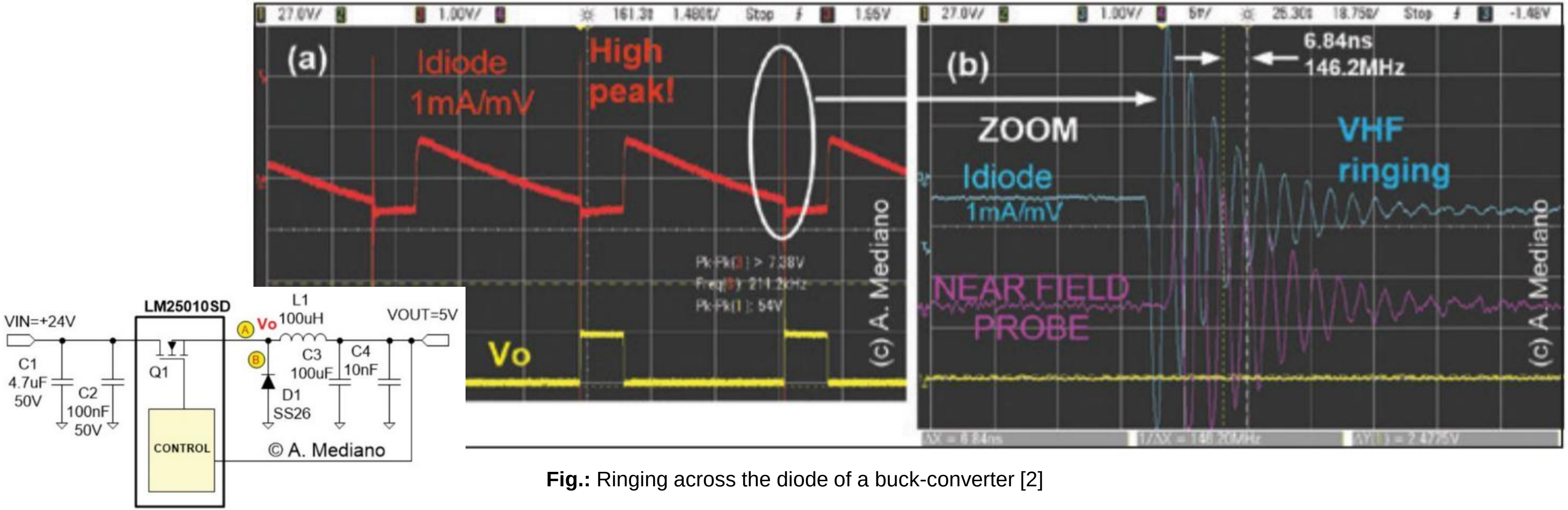


Fig.: Ringing across the diode of a buck-converter [2]

Proximity Effect

Return current takes the path with the lowest impedance, which need not be the path of the lowest DC resistance.

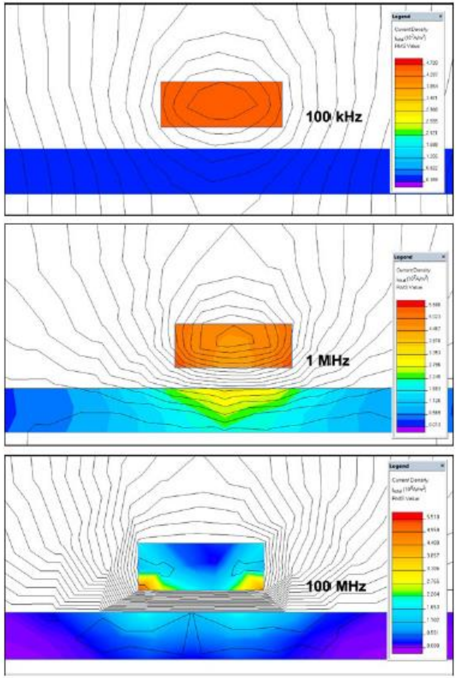


Fig.: Current density related to frequency [3]

Equivalent Circuit for PCB Tracks

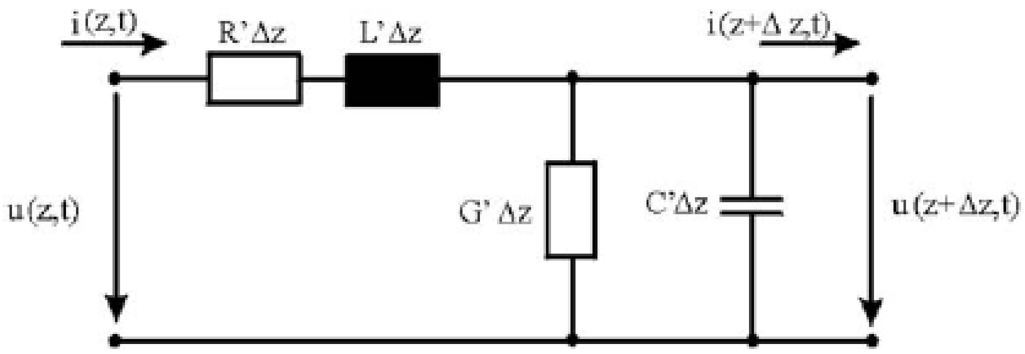


Fig.: Impedance per unit length [4]

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

Remedial Actions in the Design

- PFC (AC/DC)
- Snubber
- Spread-Spectrum
- Slew Rate Control
- Layout

The Need for Power Factor Correction

- EN 61000-3-2 standard for grid quality
  - Reduction of phase shift & distortion
- Energy Star compliance
- Efficiency
  - Reduction of impulse loading on components (lifetime, rating)

PFC

- Ratio of active power (W) to apparent power (VA)

$$PF = \frac{\frac{1}{T}\int_0^T vi\,dt}{\sqrt{\frac{1}{T}\int_0^T v^2\,dt \times \frac{1}{T}\int_0^T i^2\,dt}} = \cos(\varphi)$$

- Valid for:
  - Sinusoidal sources
  - Linear loads

PFC – Voltage & Current Waveforms

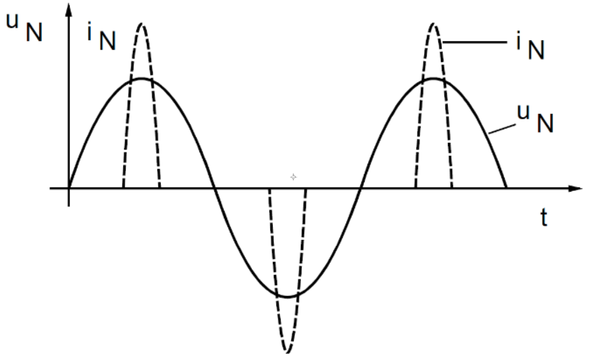


Fig.: Voltage and current waveform without PFC [5]

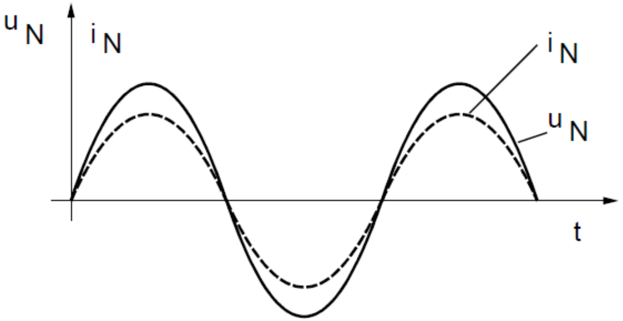


Fig.: Voltage and current waveform with PFC [5]

PFC – Comparison with a 230V, 1A rated System.

- With PFC

P=200W
PF=0,95

$$S = \frac{200W}{0,95} = 211\text{VA}$$

$$I = \frac{211VA}{230V} = 0,92A$$

- Without PFC

P=200W
PF=0,8

$$S = \frac{200W}{0,8} = 250\text{VA}$$

$$I = \frac{250VA}{230V} = 1,09A$$

PFC – E-Cap

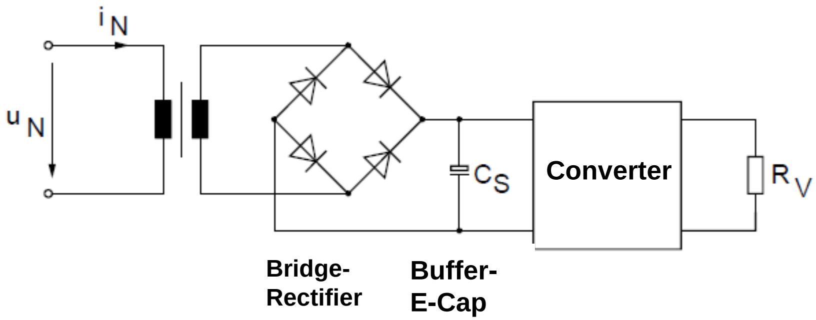


Fig.: Circuit without PFC [5]

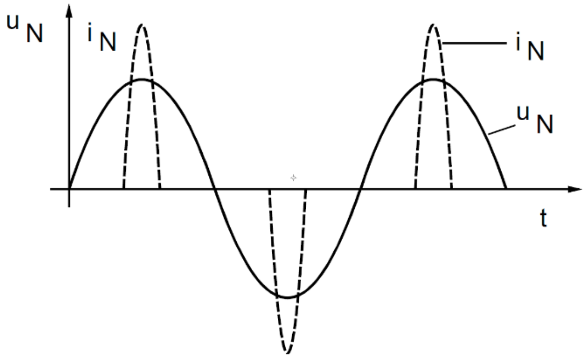


Fig.: Voltage and current waveform without PFC [5]

Active PFC

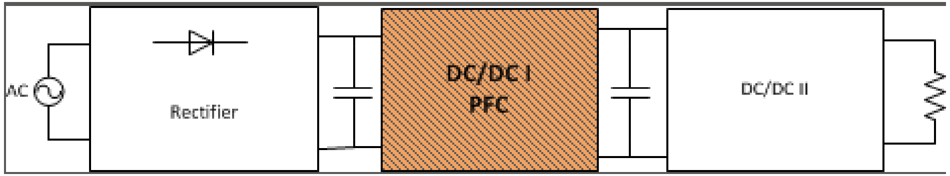


Fig.: Principle circuit of a PFC stage

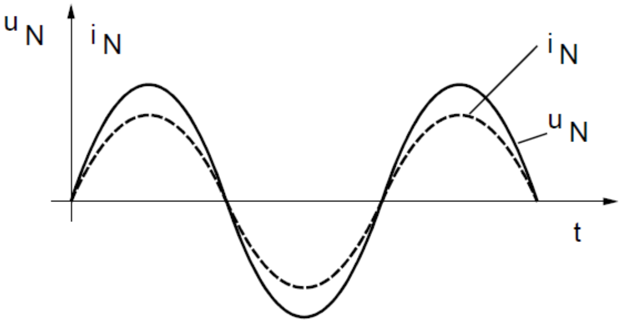


Fig.: Voltage and current waveform with PFC [5]

Advantages of Active PFC

- Input peak current is limited
- E-Cap di/dt current is lower – capacity can be reduced
- More efficiency in distributed systems – lower conduction losses due to lower RMS current
- Reduced VA Rating
- Lower stress for both L-N and Y-caps

Influence of an active PFC on efficiency

Losses are dependent on the ratio of output voltage to input voltage (Boost Factor)

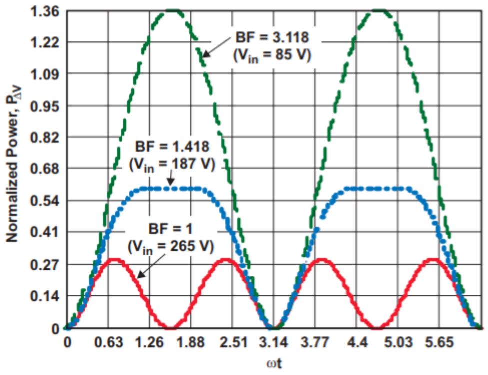


Fig.: Power at different BF [6]

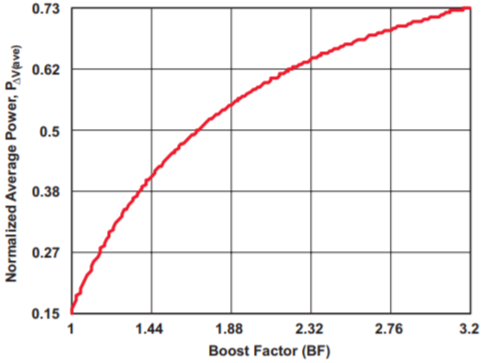


Fig.: Average Power vs BF [6]

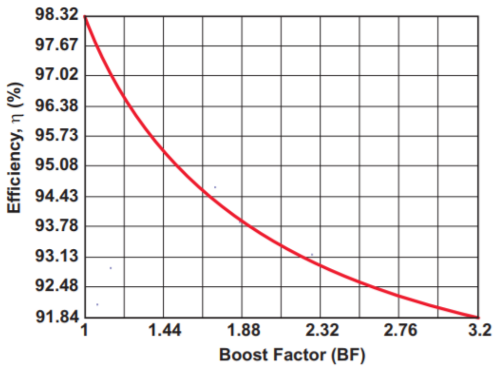


Fig.: Efficiency vs BF [6]

PFC – Modes of Operation

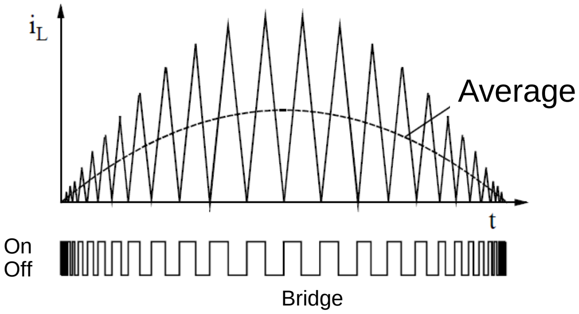


Fig.: Critical Conduction Mode CRM [5]

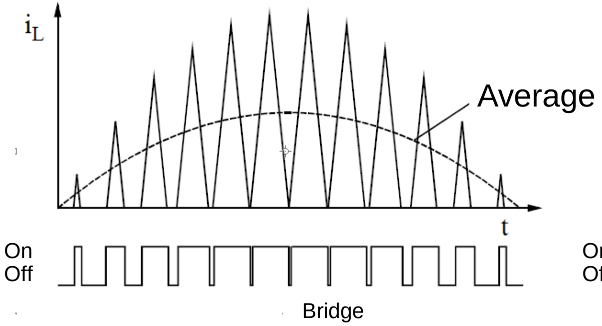


Fig.: Discontinuous Conduction Mode DCM [5]

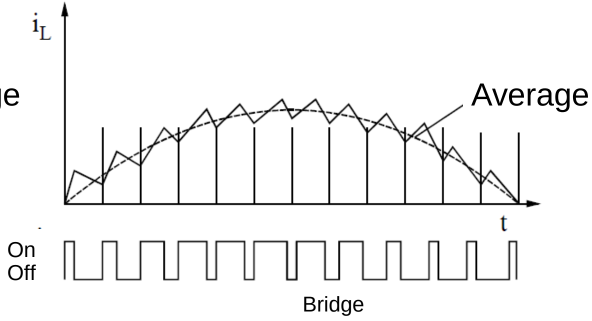


Fig.: Continuous Conduction Mode CCM [5]

PFC – Modes of Operation Comparison

Mode of Operation	CRM	DCM	CCM
Frequency	Variable	Constant	Constant
Peak Current	High	High	Low
Recovery loss	None	None	Yes
Typ. Power range	50W - 500W	50W – 500W	100W - …

Fig.: Overview of modes of operation [5]

Action of a Snubber

- Reduced ringing in both frequency and amplitude
- Peak current and voltage limiting during switching
- Side effects:
  - Reduced temperature of the PN-junction of the switching transistor, as the energy is dissipated by external resistor.
  - Reduction of peak voltage across the switching transistor for safer operation

Snubber RC-Design (quick)

- RC Design rules (ignoring power dissipation):

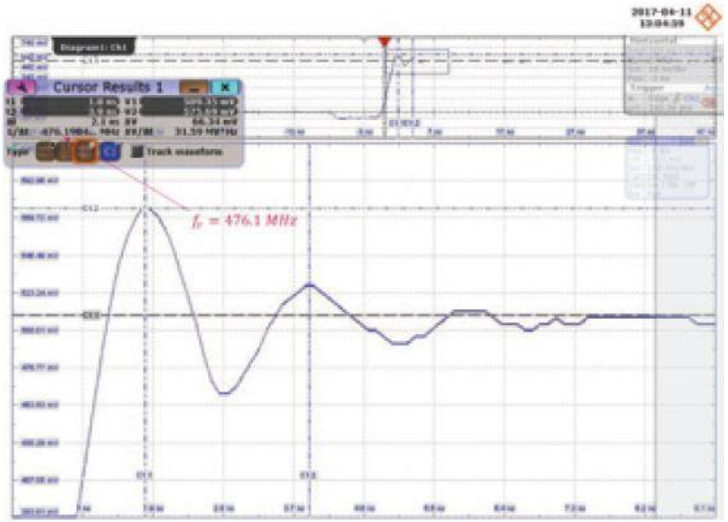
$$R \leq \frac{V_o}{I} \qquad C_S = \frac{1}{V_o^2 f_S}$$

R = snubber resistor
V_o= off voltage
I = on current
f_s = switching frequency
C_s = snubber capacitor

Snubber RC-Design (1)

- Identifying the parasitic capacitance and inductance
  - Add capacitance until the turn off ringing frequency halves.
  - Parasitic capacitance is then equal to a third of the value of the external capacitor.
  - Parasitic Inductance can be derived from $L_p = \frac{1}{C_p(2\pi f_0)^2}$

Waveforms (1)



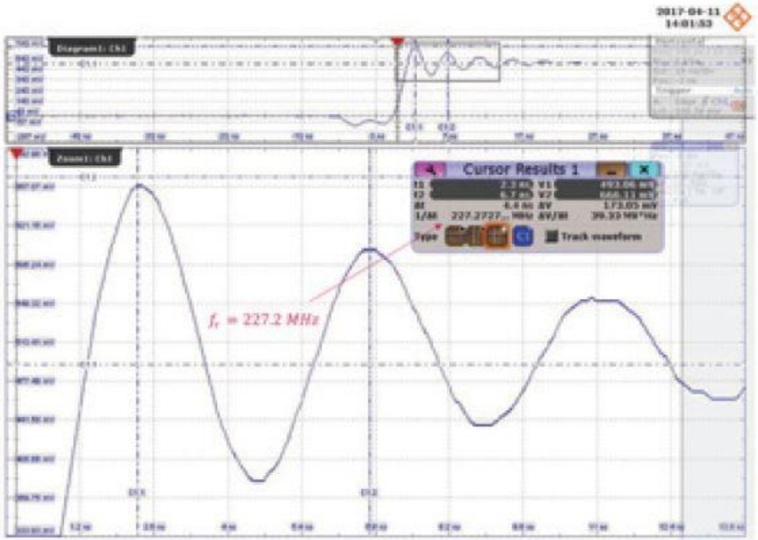


Fig.: Oscilloscope traces without snubber and with snubber capacitor [7]

Snubber RC-Design (2)

- Determination of the resistor value
  - $R = \sqrt{\frac{L_p}{C_p}}$ X_P= parasitic element
  - $P_s = CV^2 f_{Sw}$

Waveforms (2)

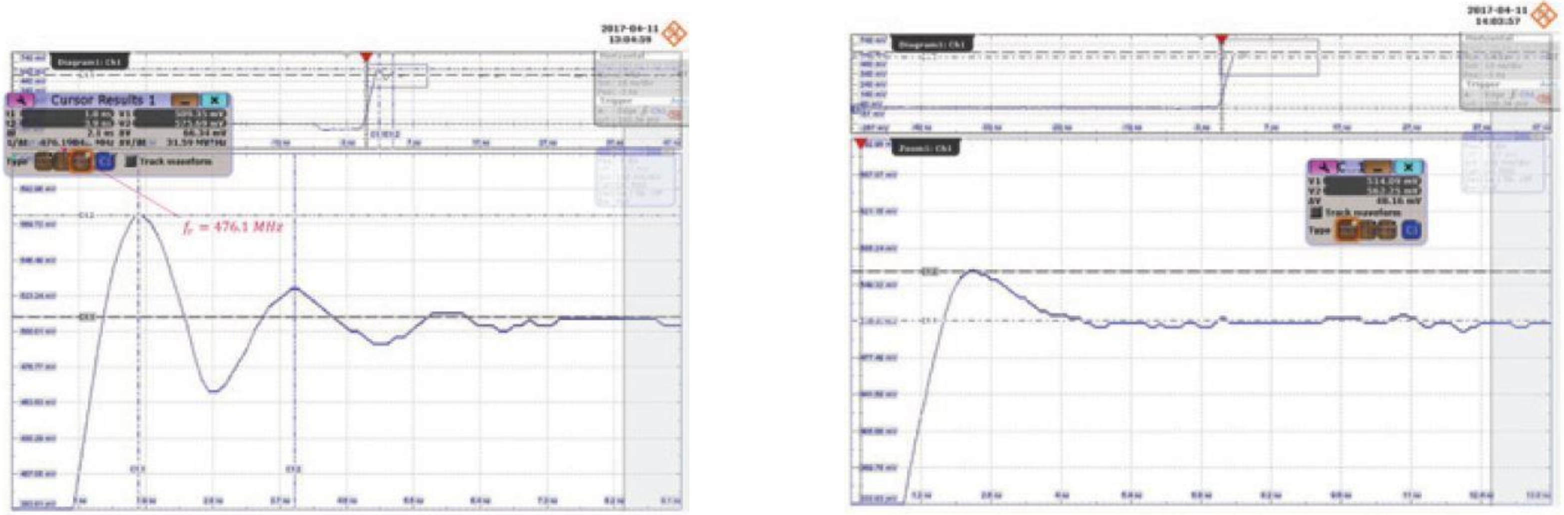


Fig.: Oscilloscope traces without RC snubber and with RC snubber [7]

Spread-Spectrum – General Principles

Peak amplitude can be reduced by spreading the RF energy over a wider frequency range.

Origin: digital communication systems

The overall power remains the same but due to the frequency spread, it decreases in amplitude and interference signals can be reduced to signal noise levels.

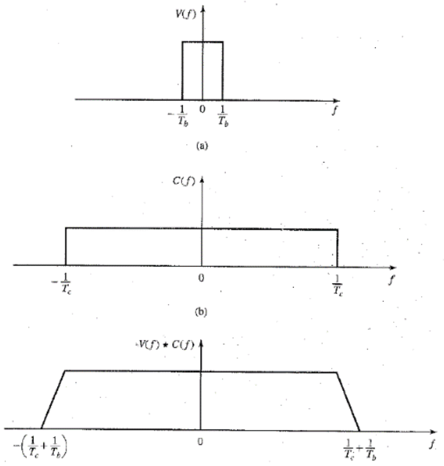


Fig.: Principle of Spectrum Spreading [8]

Spread Spectrum – Example

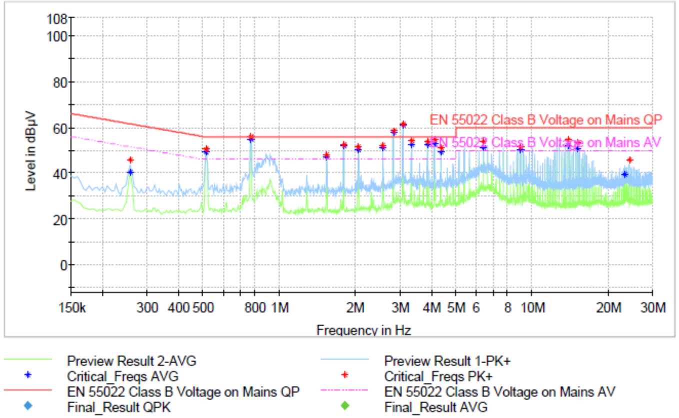


Fig.: @ Normal operation

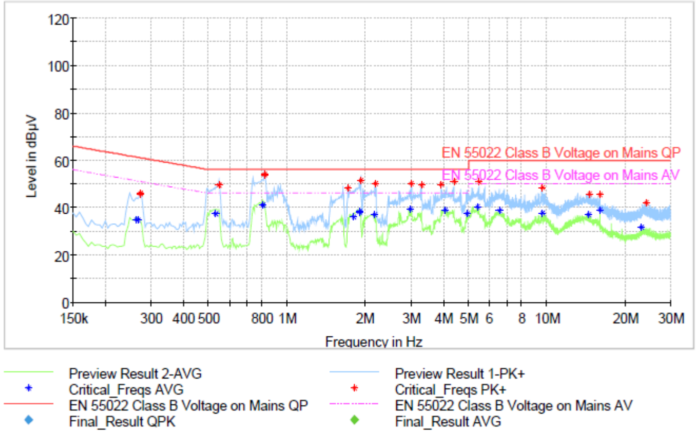


Fig.: With 10% spreading factor

Slew Rate Control with Gate Resistors

- R1 influences the rising edge
- R2 influences the falling edge

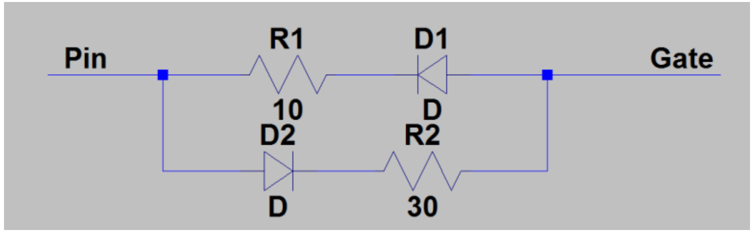


Fig.: Control circuit for the FET

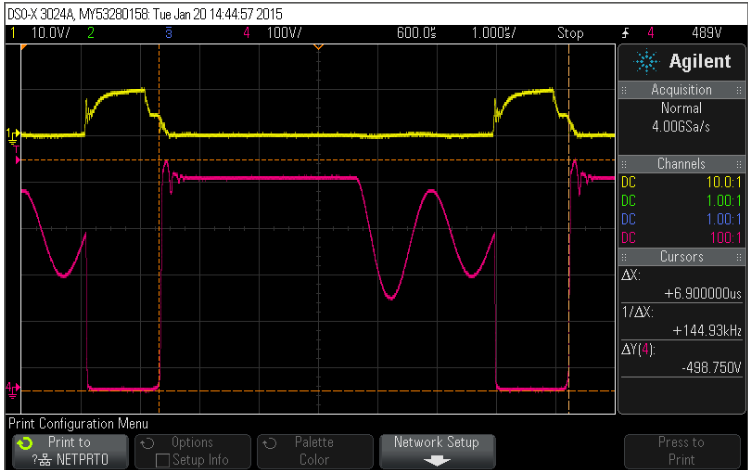


Fig.: Ringing and excursion in a flyback QR waveform

Slew Rate Control

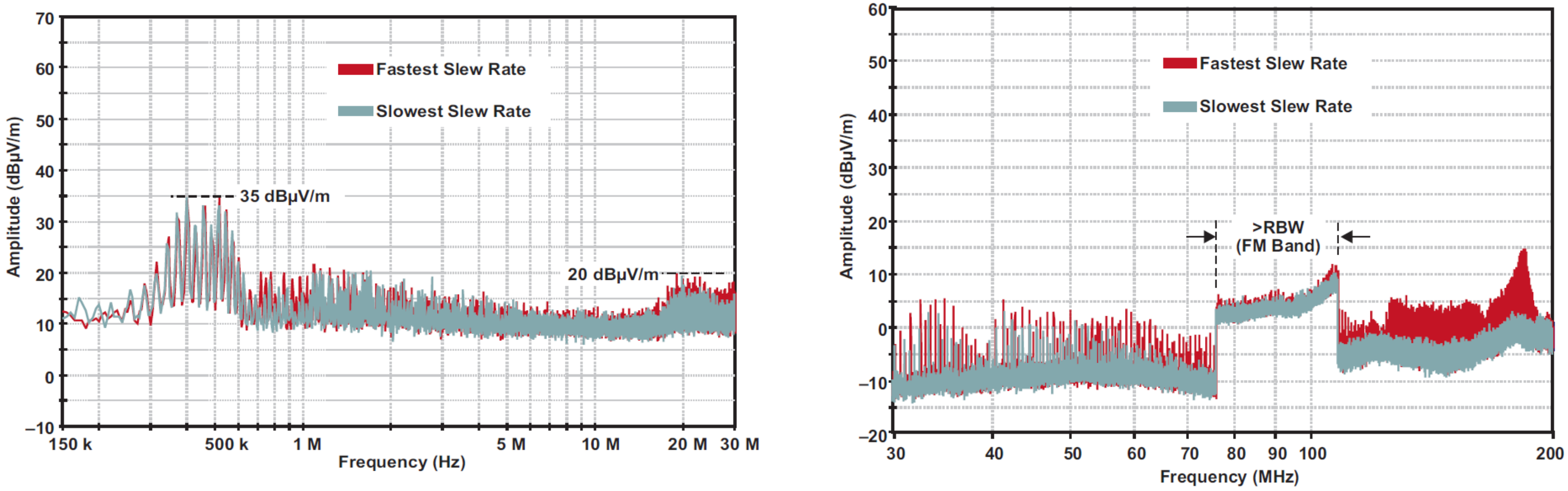


Fig.: Slew rate comparison [1]

Layout - Flyback Converter

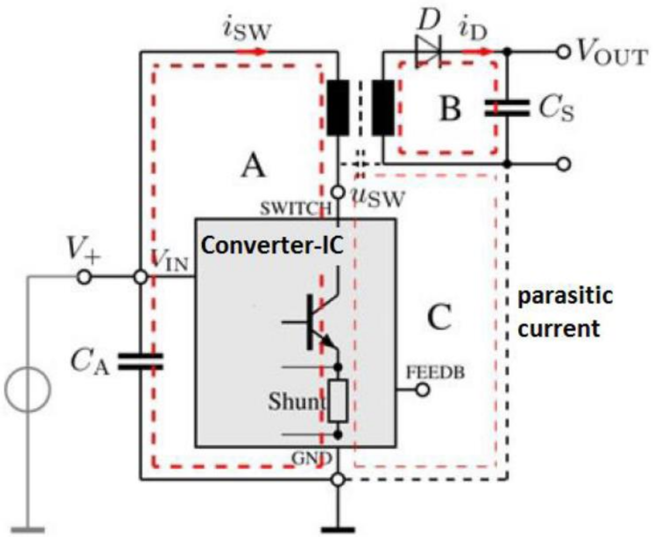


Fig.: Typical schematic [9]

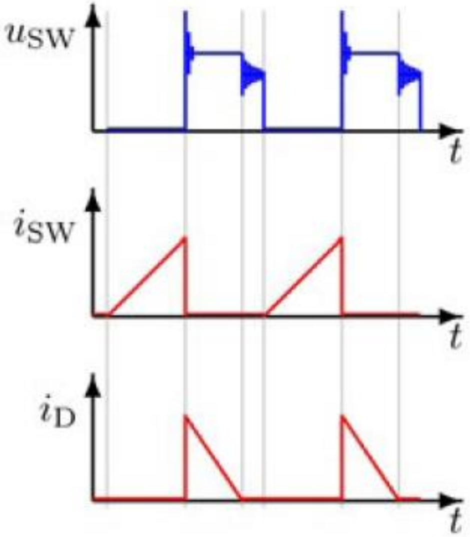


Fig.: Current and voltage waveforms [9]

Layout - Flyback-Converter – EMC Analysis

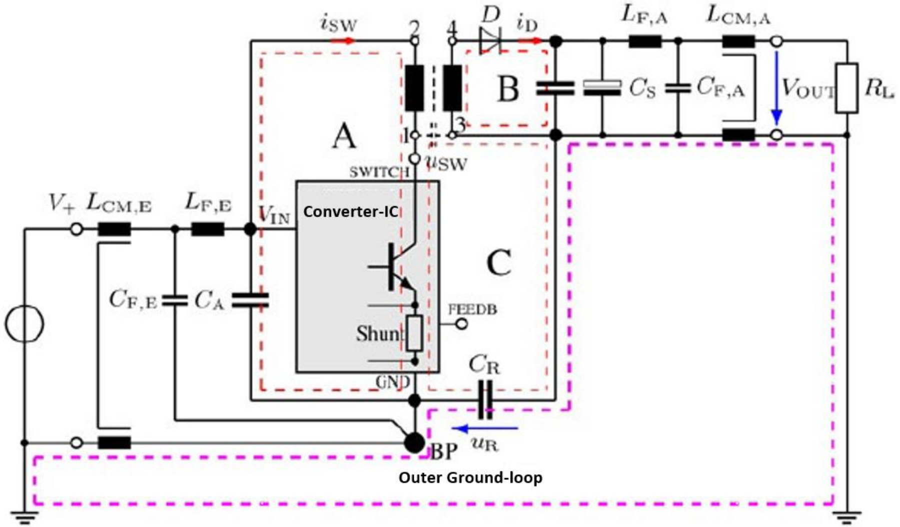


Fig.: EMC-improved schematic [9]

- Critical loops
- Multiple output capacitors
- Input side filtering
- CM capacitor
- Star grounding

Filters for a Switched Mode Power Supply

- Differential/Common Mode distortion
- Common Mode noise in two-wire-systems
- Filter topologies
- Stability of SMPS with filtering
- CM-Capacitor

Type of Distortion: Differential Mode

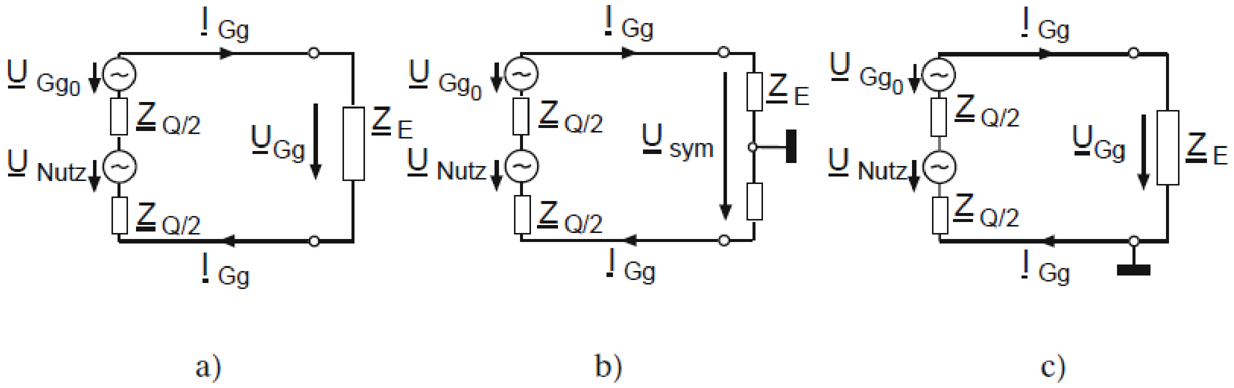


Fig.: Variations in differential mode interference [10]

a: Circuit without grounded connection
b: Circuit operated symmetrically
c: Circuit operated unsymmetrically

Type of Distortion: Common Mode

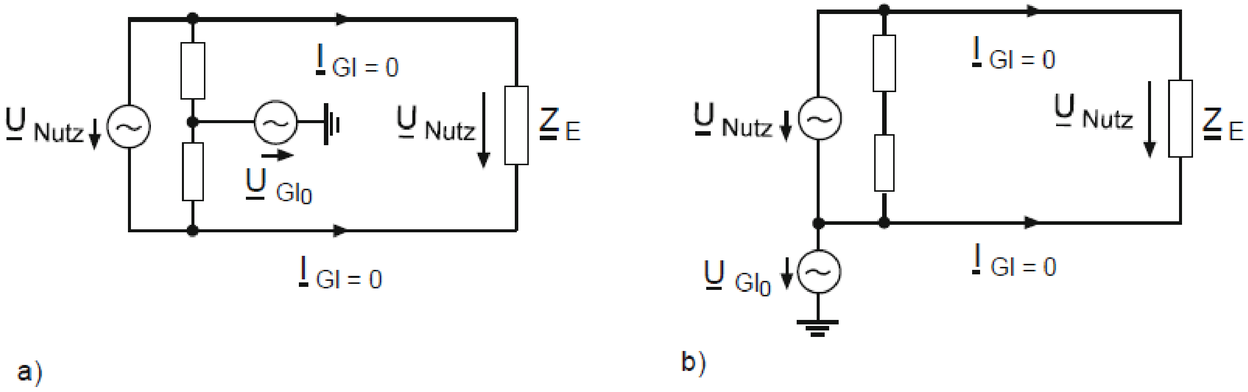


Fig.: Variations of common mode interference [10]

a: Circuit operated symmetrically
b: Circuit operated unsymmetrically

Practical example – DC/DC Converter with/without PE

Earthed Substrate

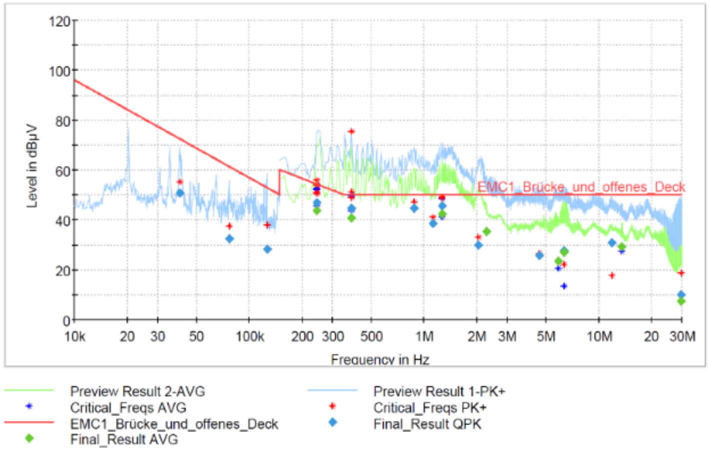


Fig.: With parasitic path to ground

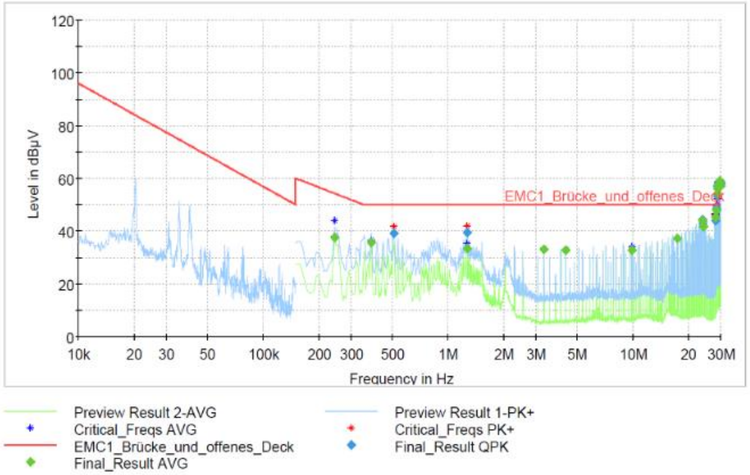


Fig.: Without parasitic path to ground

Isolated Substrate

Common Mode Interference in a Class II Power Supply

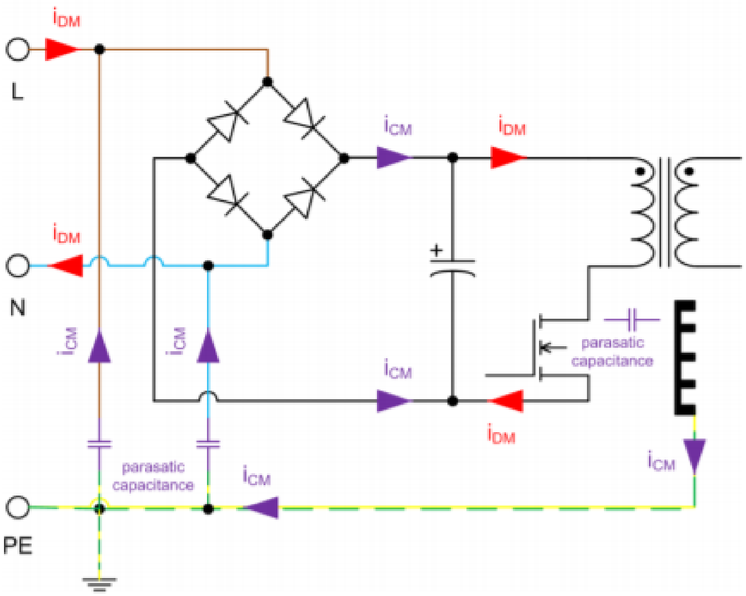


Fig.: Parasitic path to protective earth (PE) [11]

Coupling Capacitance:
directly proportional to area and indirectly proportional to gap distance

Filter

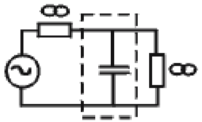
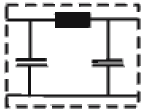
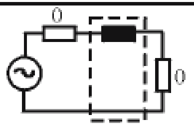
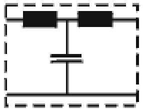
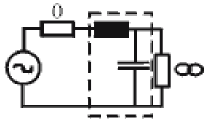
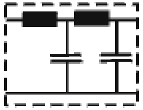
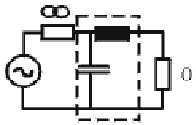
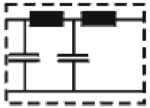
Z_G	Z_L	Simple Filter	Advanced Filter	Amplification possible
∞	∞			No
0	0			No
0	∞			Yes
∞	0			Yes

Fig.: Filter topologies [4]

Practical Example of Unwanted Signal Amplification

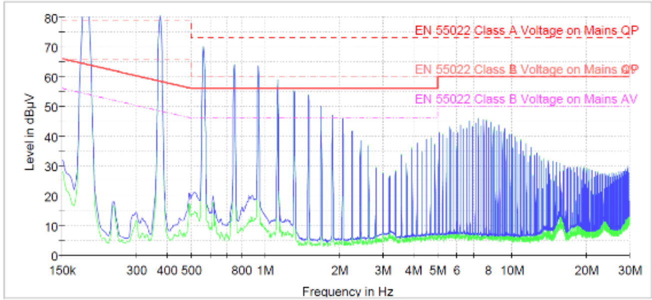


Fig.: Without Filter

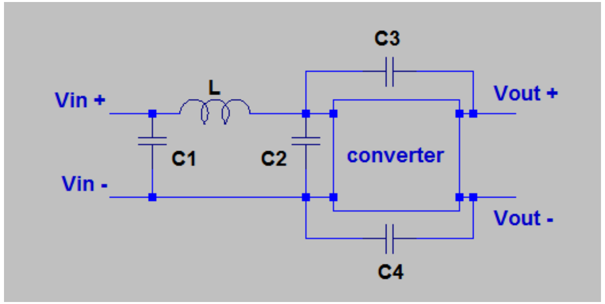


Fig.: Optional Filter Components

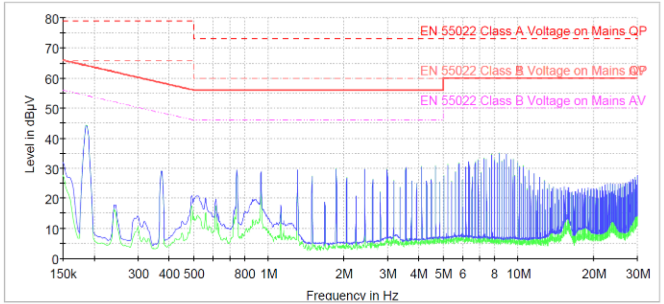


Fig.: C1 and L fitted

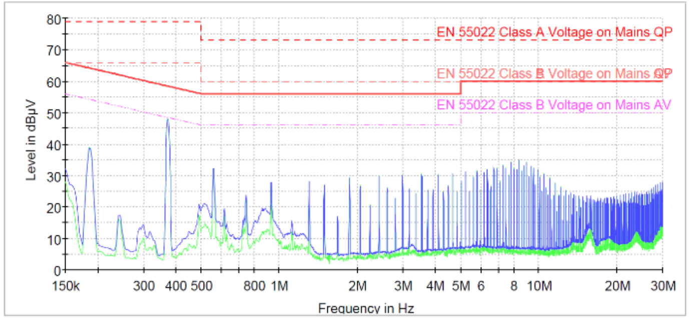


Fig.: C1, L and C2 fitted

Instability despite Input Filter

- Affects regulated converters
- AC instability seen at the input
- Acoustical noise (whining, whistling, …)
- Input filter interferes with the converter loop gain
- Middlebrook Criterion: $Z_{out,filter} \ll Z_{in,converter}$

CM Capacitor

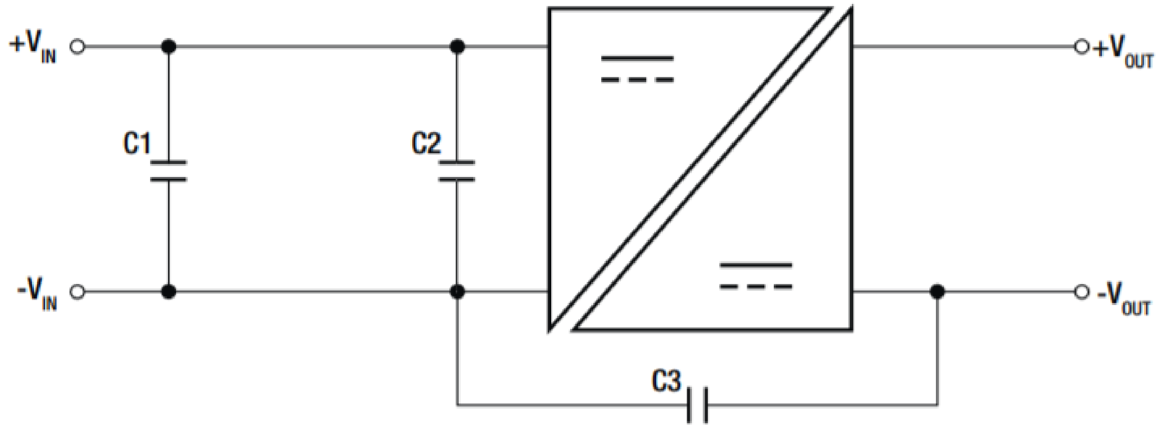


Fig.: Filter Suggestion from RECOM datasheet

C3 is required in many cases to reduce the CM interference emissions

CM Capacitor

- Mainly used with isolated converters
- For example: Flyback

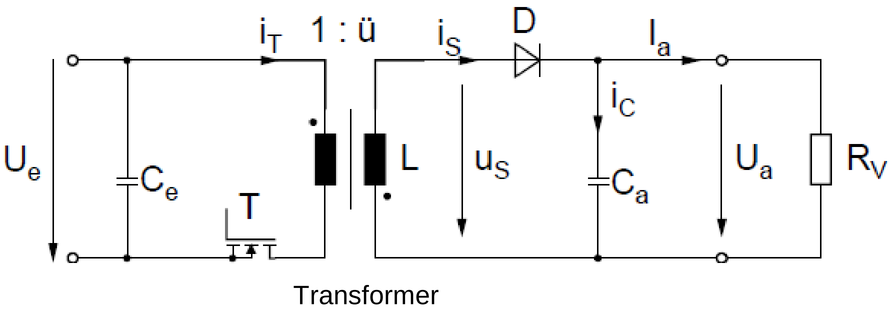


Fig.: Principle of a flyback converter [5]

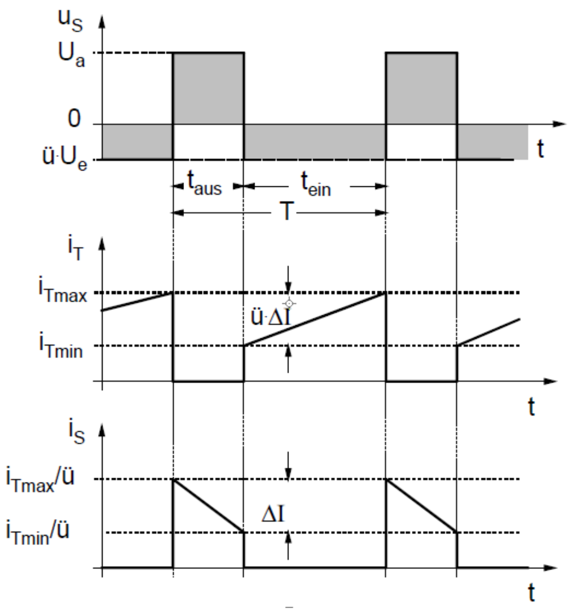


Fig.: Current and voltage waveforms of a flyback [5]

Overview

- Power supplies are a serious source of HF noise interference
- EMC countermeasures start at the draft stage
- The earlier EMC is considered in the design, the more time, cost and space efficient the countermeasures will be.

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Q & A

Live Measurement
Presented by Maximilian Bichler

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