PSMA EMC Basics Webinar
Safety & Compliance Committee

Today’s Presentation

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)
Emission of SMPS & Mitigations
Josefine Lametschwandtner, BSc
EMC-Webinar, 11. October 2022
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
Example: 150 kHz, 400V/50ns

Switching frequency $\approx 150$kHz

Emissions in the MHz range

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

Fig.: Rising edge of an SMPS switch
Frequency Response

**Fig.:** Switching signal of a SMPS[1]

**Fig.:** Frequency response of trapezoidal waveforms [1]

\[ T = \text{the period of the repetitive waveform} \]
\[ \tau = \text{pulse width at the 50\% points} \]
\[ A = \text{pulse amplitude} \]
\[ t_r = t_f = \text{pulse rise and fall times} \]
Ringing

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 \([4]\)

\[
Z = \frac{R + j\omega L}{\sqrt{G + j\omega C}}
\]
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)
■ Ratio of active power (W) to apparent power (VA)

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

■ 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

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

  \[ I = \frac{211\text{VA}}{230V} = 0,92\text{A} \]

- **Without PFC**

  
  P=200W  
  PF=0,8

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

  \[ I = \frac{250\text{VA}}{230V} = 1,09\text{A} \]
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 $\frac{di}{dt}$ 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

- **Critical Conduction Mode (CRM)**
  - Fig.: Critical Conduction Mode CRM [5]

- **Discontinuous Conduction Mode (DCM)**
  - Fig.: Discontinuous Conduction Mode DCM [5]

- **Continuous Conduction Mode (CCM)**
  - Fig.: Continuous Conduction Mode CCM [5]
# PFC – Modes of Operation Comparison

![Fig.: Overview of modes of operation [5]](image)

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>CRM</th>
<th>DCM</th>
<th>CCM</th>
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<td>Frequency</td>
<td>Variable</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>Peak Current</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Recovery loss</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>Typ. Power range</td>
<td>50W - 500W</td>
<td>50W – 500W</td>
<td>100W - …</td>
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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
RC Design rules (ignoring power dissipation):

\[
R \leq \frac{V_o}{I} \quad C_S = \frac{1}{V_o^2 f_s}
\]

- \( R \) = snubber resistor
- \( V_o \) = off voltage
- \( I \) = on current
- \( f_s \) = switching frequency
- \( C_S \) = snubber capacitor
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]
Determination of the resistor value

\[ R = \sqrt{\frac{L_p}{C_p}} \]

\( X_p \) = parasitic element

\[ P_s = CV^2 f_{Sw} \]
Fig.: Oscilloscope traces without RC snubber and with RC snubber [7]
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
Fig.: Slew rate comparison [1]
Layout - Flyback Converter

**Fig.:** Typical schematic [9]

**Fig.:** Current and voltage waveforms [9]
Layout - Flyback-Converter – EMC Analysis

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

Fig.: EMC-improved schematic [9]
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.: Without parasitic path to ground

Isolated Substrate

Fig.: With parasitic path to ground
Common Mode Interference in a Class II Power Supply

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

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

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<th>( Z_G )</th>
<th>( Z_L )</th>
<th>Simple Filter</th>
<th>Advanced Filter</th>
<th>Amplification possible</th>
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<td><img src="image8" alt="Advanced Filter" /></td>
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</table>

**Fig.:** Filter topologies [4]
Practical Example of Unwanted Signal Amplification

Fig.: Without Filter

Fig.: C1 and L fitted

Fig.: C1, L and C2 fitted

Fig.: Optional Filter Components
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: $Z_{\text{out,filter}} \ll Z_{\text{in,converter}}$
CM Capacitor

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

Fig.: Filter Suggestion from RECOM datasheet
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]
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.
1. Understanding Noise Spreading-Techniques and their Effects in Switch-Mode Power Applications
   John Rice, Dirk Gehrke and Mike Segal; http://www.smps.us/Unitrode.html


3. Elektromagnetische Verträglichkeit in der Praxis;
   Dieter Stotz; Springer Verlag, 2013

4. EMV für Geräteentwickler und Systemintegratoren
   Gonschorek, K. H.; Springer, 2005

5. Schaltnetzteile und ihre Peripherie
   Schlienz, Ulrich; Vieweg Praxiswissen, 3. Auflage, 2007


10. Elektromagnetische Verträglichkeit; Adolf J. Schwab; Springer Verlag 2011; 6. Auflage

11. Application Note: Line Filter- The last barrier in the switch mode power supply Stefan Klein, Würth Elektronik;
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Live Measurement
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Thank You

Please take the survey

We appreciate any ideas or suggestions for improvement.
Thank You and hope you have enjoyed the webinar

“Wisdom is not a product of schooling but of the lifelong attempt to acquire it.” – Albert Einstein

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