Switched Mode Power Supply with high efficiency and best EMI design

Speaker:
Lorandt Fölkel M.Eng
Field Application Engineer & Business Development Manager
lorandt.foelkel@we-online.de
!!! Questions ???

- Do you think that ...

  ... a DC/DC converter “generate **Conducted Emission**” ?

  ... the EMC of a DC/DC converter is “affected only by the **PCB layout**” ???

  ... an “**oscilloscope can help you to carry out any EMC tests**” ???
Agenda

- EMC Requirements for DC/DC Converter
- EMI Noise Consideration from Power Source
- Filter Topologies
- Filter design
- PCB layout recommendations
- Shielded vs. Unshielded Inductor
- Storage Inductor selection
- Design tools
- Live EMC Demonstration
- Energy Harvesting
- Wireless Power Charging Live Demonstration
- Power Modules
REQUIREMENTS IN EMC
EMC - Standards

• EN 61000-3-2 Limits for **harmonic current** emissions (equipment input current up to and including 16 A per phase)
• EN 61000-3-3 Limitation of voltage changes, voltage fluctuations and **flicker** in public low-voltage supply systems
• EN 55011 **ISM** Equipment (Industrial, **Scientific** and **Medical**) also known as CISPR-11
• EN 55013 Audio and **Broadcast receiver** equipment
• EN 55014-1 **House hold appliances**, electric tools and similar apparatus
• EN 55015 Limits and methods of measurement of radio disturbance characteristics of **electrical lighting** and similar equipment
• EN 55022 **ITE** (Information **Technology** **Equipment**), also known as CISPR-22
• EN 61000-6-1 **Generic immunity standard** for residential, commercial and light industry environments
• EN 61000-6-2 **Generic immunity standard** for industrial environments
• EN 61000-6-3 **Generic emission standard** for residential, commercial and light industry environments
• EN 61000-6-4 **Generic emission standard** for industrial environments
• EN 61000-4-2 Electrostatic discharge immunity test (ESD)
CE Marking

- With the formation of the single European market, standardization was required to remove technical barriers to trade.
- New Approach Directives were introduced to remove these barriers to trade.
- 20 regulations and directives:
  - LVD - Low Voltage Directive 2014/35/EU
  - EMC - Electromagnetic Compatibility 2014/30/EU
  - MD - Machinery Directive 2014/90/EU
What is the meaning of EMC?
What’s all the fuss about EMC?

- In Europe, we have a mechanism called CE Marking

- It is applicable to any electrical/electronic product

- EMC Directive, regulation to ensure that intentional RF transmission signals are not interfered with

- Ensures that Electrical/Electronic devices continue to operate as intended in a Electro Magnetic Environment

- Failure to comply with the law can be an offence, either criminal, civil or both
What is the meaning of the CE logo?
Other International EMC approval marks

- **Voluntary Control Council for Interference**
- **Australian Communications and Media Authority**

[Images of flags and logos representing the FCC, VCCI, and Australian Communications and Media Authority.]
Conducted Emission

- Conducted emission over wideband
- Caused by ripple current at input lines (common mode - / differential mode noise)
- EMC requirements for “Conducted Emission“ according ETSI, CEN, CENELEC

E.g.: EN 55013 : 2006 (Radio & TV broadcast receivers and associated equipment)

- 66 - 56dBµV @ 150<KHz<500KHz (QP)
- 56 - 46dBµV @ 150<KHz<500KHz (Av)
- 56dBµV @ 0,5<MHz<5 (QP)
- 46dBµV @ 0,5<MHz<5 (Av)
- 60dBµV @ 5<MHz<30 (QP)
- 50dBµV @ 5<MHz<30 (Av)
Radiated Emission

- Radiated emission over wideband
- Caused by:
  - Power traces on PCB
  - Power choke of DC/DC converter
- EMC requirements for „Radiated Emission“ according ETSI, CEN, CENELEC

- EN 61000-6-3 : 2007 (Home)
  30dB @ 30MHz~230MHz µV/m
  37dB @ 230MHz~1GHz µV/m

- EN 61000-6-4 : 2007 (Industrial)
  40dB @ 30MHz~230MHz µV/m
  47dB @ 230MHz~1GHz µV/M
Design phase for EMC

- Economical point of view:
- Depends on you when will start to design EMC conform
How can we check the EMC?
EMC Standards and tests are seen by customers as

HUGE PROBLEMS
EMC – Basic Test

Electromagnetic Compatibility

- Emission
  - Conducted
  - Radiated
- Immunity
  - Conducted
  - Radiated
What causes EMI in a product?

- **Clock frequencies.** E.g Crystal 25MHz, CPU 2.6GHz

- **Data rates.** E.g USB 2.0 480Mbps, SATA II 300Mbps

- **DC/DC converters** and Switch mode power supplies (SMPS) E.g 135kHz, 2MHz
Magnetic and Material Basics
The magnetic field – Field Model

Magnetic field H

Current I
Magnetic field- Magnetic field strength

The magnetic field strength is dependent from:

- No. of turns
- current
- dimension
- and

\[ H = \frac{N \cdot I}{2 \cdot \pi \cdot R} \]

\[ H = \frac{N \cdot I}{l} \]

**Straight wire**

**Toroidal core**

**Rod core**
Magnetic field - Magnetic field strength

\[ H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{\text{average}}} \]

\[ R_{\text{average}} = (R_a - R_i) \]

Current I

B_1 \neq B_2
The magnetic field

**Induction in air:**

\[ B = \mu_0 \cdot H \]

linear function, because \( \mu_r = 1 \Rightarrow \) constant!

**Induction in a ferrite:**

\[ B = \mu_0 \cdot \mu_r \cdot H \]

The relative permeability is a: material-frequency-temperature-current-pressure-dependant parameter
Permeability – Core material parameter

Temperature influence

- The magnetization depends from the temperature

\[ \mu_r = ?1 \]

Alignment of elementary magnets

Ferromagnetic change to Paramagnetic

Curie-temperature

Temperature influence diagram:

- T ↑ \text{ therm. movement} \quad \text{Alignment}

Ferromagnetic to Paramagnetic transition

+15% 770
-20% 670
540

500

\( T / ^\circ\text{C} \)

\( \mu_r \)

Temperature range:

-50°C to 540°C

-20% to +15%
Permeability – complex permeability

\[ Z = \sqrt{R^2 + X_L^2} \]
Core materials - Inductors (Energy storage)

Which switching frequency do you use?

- **XL(Fe)**: 1-200kHz
- **XL(MnZn)**: 1-10MHz
- **XL(NiZn)**: 1-40MHz
Core materials - Chokes (filtering)

Noise frequency range must be known

- R (Fe)
- R (MnZn)
- R (NiZn)

Impedance Z / %

- 200kHz-4MHz
- 3-60MHz
- 20-2000MHz

Frequency f/MHz
Core Losses

e.g. electrical energy transformed into \(\rightarrow\) thermal energy

Electro Magnetic energy cannot disappear, it will be just transformed into other energy form

the core losses from ferrite transform the noise energy into heat
Transmission Modes & Filter Topologies
EMC - Coupling

→ Primary procedure
   … to aim at source a low noise

→ Secondary procedure
   … eliminate the noise thru interrupting the coupling way

→ Tertiary procedure
   … increase the noise immunity at load
Recognizing the coupling mode

- common mode noise?

- differential mode noise?
Common mode or differential mode?

Take a Snap Ferrite and fix it on the cable (both lines e.g. VCC and GND)

if noise is reduced or noise immunity increase

you have Common Mode Interference

If not

you have Differential Mode Interference

e.g. Common mode choke

e.g. chip bead ferrite
Snap on ferrite – typical behavior

Increase the no. of turns means:

1 turn
2 turns
3 turns MnZn
2 turns MnZn
1 turn MnZn
3 turns MnZn

Star FIX LFS
Star TEC

2 Turns
Snap on ferrite - Construction

- Snap on ferrite acts as an CMC
- Absorbs common mode Interferences
- Comparable with bifilar winding CMC
Common Mode Filter – How it works

It is a Bi-directional filter

- From device to outside environment
- From outside environment to inside device

Intended Signal - Differential mode

Interference Signal (noise) – Common Mode

Conclusion:

- “almost” no affect the signal - Differential mode
- high attenuation to the interference signal (noise) – Common Mode
Insertion loss – Mathematical Definition

- System attenuation

\[ A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \quad \text{in (dB)} \]

- Impedance

\[ Z_F = \left[ 10^{\frac{A}{20}} \cdot (Z_A + Z_B) \right] - (Z_A + Z_B) \quad \text{in (Ω)} \]
Insertion loss - Definition

- Practical values for source and load impedances:
  - Ground planes: $<1 \ldots 2 \, \Omega$
  - Vcc distribution: $10 \ldots 20 \, \Omega$
  - Video- /Clock- /Data line: $50 \ldots 90 \, \Omega$
  - Long data lines: $90 \ldots >150 \, \Omega$
Check the results in the EMC lab

→ Measuring the emission and compare with the solution

![Diagram showing emission levels and frequency comparison]
Insertion loss – recommended filter topology

Choose ferrite bead or inductors L which
= build no resonance with C
= broadband filter

Pay attention to:

SRF of used components

→ small C = higher SRF
Chip bead ferrite – peak current behavior

Ferrite is destroyed due to over current/in-rush current

\[ I_o = \frac{U_o}{(R_{DC \ ferrite} + R_{ESR \ capacity})} \]

\[ = \frac{12V}{0.05\Omega + 0.5\Omega} = 22A \]

11 times higher current

Ferrite can be destroyed, might not fail directly \( \Rightarrow \) “creeping process”
at 22A...you can smell it!
EMI NOISE SOURCES
Representative noise sources

- Input current caused by voltage ripple → „Conducted Emission“
- Power traces and choke radiate EMI → „Radiated Emission“
- Output current caused by voltage ripple → „Conducted Emission“
- Radiated emission will increase by using long input / output lines (cables)
Conducted noise at converter input

- Conducted Emission is generated by voltage drop across \( R_{\text{Sup}} \) and \( ESR_L \)
  \[
  V_{\text{Noise}} = R_{\text{Sup}} \times I_{\text{in}} + ESR \times I_{\text{Cap}}
  \]
- Resonance circuit is formed by \( L_{\text{sup}}, C_{\text{in}} \) and \( ESL_{Cin} \)
  \[
  f_0 = \frac{1}{2\pi\sqrt{(L_{\text{sup}} - ESL)\times C_{\text{in}}}}
  \]
- Different harmonics due to fundamental frequency from \( f_{\text{DC/DC}} \) and \( f_{\text{Resonance Circuit}} \)
Conducted noise at converter output

- Conducted emission is generated by voltage drop at $ESR_C$

  \[ U_{\text{Noise}} = ESR_{\text{Cout}} \times I_{\text{Cout}} \]

- Resonance circuit is formed by $C_{\text{Dconverter}}$, $C_{\text{Out}}$, $L_{\text{Converter}}$, and $ESL_{\text{Cout}}$

  \[ f_0 = \frac{1}{2\pi \sqrt{(ESL_{\text{Cout}}) \times CO_{\text{Out}}}} \]

- Different harmonics due to fundamental frequency from $f_{\text{DC/DC}}$ and $f_{\text{Resonance Circuit}}$
Radiation of PCB traces

- Power and signal loops have antenna characteristics
- Radiation can occur over the entire power and signal loops
- Field strength depends on spanned loop, peak value of alternating current, frequency, distance between noise source and noise receiver

Design recommendations:
- Keep power and signal traces as short as possible
- Keep power and signal loops as small as possible
- Route the trace over GND plane

![Diagram showing radiation of PCB traces with design recommendations](image-url)
FILTER DESIGN
"L" Input filter
(minimal recommend filter)

- Simple L-Filter
  - Input filter reduce current ripple on input line
  - Input filter reduce differential mode noise on input line
  - Input filter reduce radiated emission via input traces

Attention!!! This filter is not efficient to reduce common mode noise on input lines
Calculating input inductance

\[ L_{\text{filter}} = \frac{ESR(DC)(1 - DC)}{f\left(\frac{I_{\text{sup}}}{I_{\text{con}}} - \frac{ESR}{R_f}\right)} \]

ESR = Effective series resistance of input capacitor  
DC = Converter duty cycle  
\( I_{\text{con}} \) = Peak-to-peak input ripple current  
\( I_{\text{sup}} \) = Required peak-to-peak ripple current  
for buck converters \( I_{\text{con}} \approx I_{\text{out}} \)  
\( R_f \) = “Damping” resistor (for lower Q)

For better filter performance choose next higher standard inductance value

Example:

\[ V_{\text{out}} = 5.0V \]
\[ I_{\text{out}} = 4.0A \]
\[ f = 2.5MHz \]
\[ ESR = 0.08\Omega \]
\[ DC = 0.5 \text{(50\%)} \]
\[ I_{\text{con}} \approx I_{\text{out}} \]
\[ I_{\text{sup}} = 0.1A \]
\[ R_f = 0 \rightarrow \infty \]

\[ L_{\text{filter}} = \frac{0.08\Omega \times 0.5(1 - 0.5)}{2.5MHz\left(\frac{0.1A}{4A} - 0\right)} = 320nH \]

Choose 1µH (closest standard value)

e.g.: WE-LQ “744 045 001”  
or: WE-PD2 “744 773 0”
Calculating rated current $I_L$

- $I_L = \frac{(V_{out})(I_{out})}{(V_{in})(E)}$
- $V_{out}$ = Output Voltage
- $I_{out}$ = Output Current
- $V_{in}$ = Input Voltage
- $E$ = Efficiency (/100)

For Example:

- $I_L = \frac{(5V)(4A)}{(20V)(0.8)} = 1.25A$

- To avoid overload considerations choose a choke with higher rating current
- To avoid losses in efficiency choose a choke with low DCR
Wideband input filter
(recommended filter solution)

- **T-filter recommend for wideband filtering**
  - $L_{\text{in}}$ for low frequency filtering (DC/DC converter switching frequency)
  - Ferrite for high frequency filtering
  - $C_{\text{filter}}$ shorting ACnoise to GND ($220\text{pF} < C_{\text{filter}} < 1\text{nF}$, low ESR)

**Attention!!!** This filter is not efficient to reduce common mode noise on input lines
„L / C“ output filter
(minimal recommended filter)

- Simple L/C Filter
  - Output filter reduce voltage ripple on output traces (Conducted Emission)
  - Output filter reduce radiated emission via output traces (Radiated Emission)
  - No optimal solution for radio power devices

Attention!!! This filter is not efficient to reduce common mode noise on output lines
Calculating „L / C“ output inductor

\[
f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \leftrightarrow \quad L_{\text{filter}} = \frac{1}{(2\pi \frac{1}{10} f_0)^2 C_{\text{filter}}}
\]

- Example:
  1. Choose capacitor e.g. 1\(\mu\)F, Electrolytic, low ESR
  2. Determine switching frequency of DC / DC converter
  3. Calculate inductor
  4. Choose next larger inductance value

\[
L_{\text{filter}} = \frac{1}{(2\pi \frac{1}{10} f_0)^2 C_{\text{filter}}} \quad \leftrightarrow \quad L_{\text{filter}} = \frac{1}{(2\pi \frac{1}{10} 1.6MHz)^2 \times 1\mu F} = 989.5nH
\]

\[
L = 1.0\mu H
\]
„T“ - output filter
(recommended filter solution)

- **T-filter** recommend for wide bandwidth filtering
  - **L\textsubscript{filter}** for low frequency filtering (DC/DC converter switching frequency)
  - Ferrite for high frequency filtering
  - This kind of output filter is for powering radio devices high recommended

**Attention!!!** This filter is not efficient to reduce common mode noise on output line
Decoupling common mode noise

- For common mode rejection use common mode chokes
- For supplying over long distance common mode chokes are recommended
- Additional capacitor reduce differential mode noise
  - Small value for ceramic capacitor is recommended
  - Capacitor and common mode choke act as a LC - filter for differential mode noise
- Can be used for input and output lines
PCB - LAYOUT RECOMMENDATIONS
PCB-Layout recommendations

- Keep PCB traces as short as possible
- Avoid indirect trace routing
- Avoid any kind couplings \(\rightarrow\) “capacitive”, “inductive”
- AC-current should flow across capacitor
- Short way for AC-current direct to GND (place double vias to GND)
PCB-Layout recommendations

- Avoid indirect routing of power traces
- Avoid any kind of couplings → “capacitive”, “inductive” … etc …
- AC-current should flow across common mode choke
- Route power traces on component layer
- Do not use vias
PCB-Layout recommendations

DC/DC buck converter

- Avoid GND planes under inductor (between inductor pads)
- Don’t route any kind of signals (analog, clock) under the inductor
- Fill out unused space on PCB with GND (flood)
PCB-Layout recommendations

- PCB-design of at least 4 layers is recommended
- Place a solid ground plane below the power component layer
- Minimize loops for power components
- Keep power traces as short as possible
- Establish good GND connections using low impedance vias
SHIELD VS. UNSHIELD
Magnetic field leakage

Shielded

Unshielded

Marking
Magnetic Field – Shielded vs. Unshielded

- Magnetic field

shielded

unshielded
Radiation by inductor

WE - PD2 unshielded
10µH, 2MHz Clock, 1A

WE – PD shielded
10µH, 2MHz Clock, 1A

19dBm difference
Magnetic leakage  shielded vs. unshielded
Magnetic Fields – Conducted Emission Measurement

Power supply V 1.0

Buck Converter ST L4960/2.5A/fs 85-115KHz
Magnetic Fields – Conducted Emission Measurement

Power supply V 1.1

PCB

Schematic
Magnetic Fields – Be Aware!

- Select the right parts for your application.
- Do not always look on cost.

Very easy solution with a dramatic result!

Choke before

or

Choke after
Boost converter Bad Example

Bad Example:
- Standard Alu-Electrolyte Cap Input/Output > ESR
- Power Inductor is not shielded
- Bad Layout with large Current Loops
- Power and Analog GND not separated
- No MOSFET Gate Resistor
- No Input&Output Filter
- Feedback Trace bad routing

A Boost Converter is critical at the Output!!
Boost converter Bad Example
Boost converter Bad Example no filter
Boost converter Bad Example with filter
Boost converter Good Example

Good Example:
- Low ESR Input Caps
- Low ESR Output Caps
- Input&Output Filter
- Low Impedance Layout
- Small Current Loops
- Fully shielded Power Inductor
- Signal GND is separated and quiet

Vin 5V/4.5A

Vout 12V / 2A

A Boost Converter is critical at the Output!!
Boost converter Good Example
Boost converter Good Example
STORAGE INDUCTOR SELECTION
Inductor selection

Example: Step down converter

1. $\frac{U_{out}}{U_{in}} = \frac{5V}{15V} \approx 0,33$

2. $I_{rated} \equiv I_{out} = 1A$

3. $I_{ripple} \approx 20\%...40\% \cdot I_{out} = 0,2...0,4A$ (practical values)

4. $L = \frac{DC \cdot (U_{in} - U_{out})}{f_{\text{switch}} \cdot r \cdot I_{out}} = \frac{0,33 \cdot (15V - 5V)s}{200E3 \cdot 0,2 \cdot 1A}$

$L = 83....33\mu H$ ⇒ choose average value 56$\mu$H to begin optimization

\[ U_{\text{in}} = 15V \]
\[ f_{\text{switch}} = 200kHz \]
\[ U_{\text{out}} = 5V \]
\[ I_{\text{out}} = 1A \]
Definition of saturation currents

Definition
Würth Elektronik: e.g. WE-PD

- the saturation current always refers to a certain inductance drop and is individually
What is saturation current?

![Inductance vs. Current (typ.)](image)
LIVE EMC DEMONSTRATION
AC/DC CONVERTER EMI
Transformers for EMC – What to choose?
Transformers for EMC – No external gaps

- Center leg gap only
  - Windings shield
- No gaps in outer legs
  - Nothing to shield
Transformers for EMC – No drum cores

- Drum core style
- Very large gap
- Much radiation

Not a good solution!
Transformers for EMC – No rod cores

- Rod core style
- Huge gap – much radiation
- This is an AM antenna

So where is the gap?
What is this?

Not a good solution!
Transformers for EMC – No EI core

- EI core style
- Mylar or tape used for gap
- Three unshielded gaps

Not a good solution!
Transformers for EMC – Gap

- **Gap must be perpendicular to flux lines**
  - Here only one side is gapped
- **Uneven gaps are inefficient. => Why?**
  - Core saturates at minimum gap.
  - Requires a larger gap
- **Also larger gap – More potential EMI**
Transformers for EMC – Internal shields

- Shield both conducted and radiated noise
- Copper foil or wound magnet wire?
- Copper foil shields – Expensive, => Why?
  - Must build shield
  - Must be covered with tape
  - Winding machine stopped to apply
- All shields take away space from winding area
Transformers for EMC – External shields

- How do external shields differ from internal shields?
- Shield radiate noise only!
- As expensive as internal shields
Transformers for EMC – Y-Cap termination

- Noise couples through the transformer via $C_{ww}$
  - Noise seeks path to primary circuit
  - Without path, noise may become conducted emissions
- Y-Cap across transformer reduces noise
  - Tune the capacitor for optimum loss vs. noise reduction
  - Capacitor usually in the 470pF to 4.7nF range
  - Y-Caps to transformer terminals not on switch nor on diode
  - Close to transformer as possible

What Can We Do?

What Else Can We Do?

Decrease $C_{ww}$?
Transformers for EMC – Reducing $C_{ww}$

- High $C_{ww}$ causes conducted emissions
- **May reduce** $C_{ww}$, but what happens?
- Leakage inductance increases
- $L_{LKG}$ can be controlled by Snubber but efficiency and cost suffer
- Balance between $C_{ww}$ and $L_{leak}$
Transformers for EMC – No varnish or potting

Radiated Emissions

With potting material fails at three different frequencies
Transformers for EMC - Small designs

Why build smaller designs?

- Build smaller more compact transformers
- Smaller transformers have less parasitic
  - Less capacitance
  - Smaller leads (e.g. smaller antennas)
  - Smaller gaps
  - Less leakage inductance
- Less conducted and less radiated noise
Transformers for EMC – Power Supply

CMC WE-FC

Snubber

Y-Cap Transformer

Output filter WE-TI

Switch

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Transformers for EMC – Example 1

- Without common mode choke
- With adjusted Snubber
- Without adjusted Y-Cap

**EMC- Test Failed**

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<th>Pegel [dBμV]</th>
<th>Frequenz [Hz]</th>
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Transformers for EMC – Example 2

- With common mode choke
- With adjusted Snubber
- Without adjusted Y-Cap

QPeak
Avg.
Peak
Avg.
Transformers for EMC – Example 3

- With common mode choke
- With adjusted Snubber
- With adjusted Y-Cap

**EMC- Passed**

---

**Pegel [dBµV]**

**Frequenz [Hz]**

- 0
- 150k
- 300k
- 500k
- 1M
- 2M
- 3M
- 5M
- 7M
- 10M
- 30M

- 0
- 20
- 40
- 60
- 80
- 100

**QPeak**

**Avg.**

**Peak**

**Avg.**
Transformers for EMC – Example 4

- With common mode choke
- Without adjusted Snubber
- With adjusted Y-Cap

EMC- Passed

QPeak
Avg.
Peak
Avg.

Pegel [dBμV]

Frequency [Hz]

150k 300k 500k 1M 2M 3M 5M 7M 10M 30M
Transformer for EMC – Conclusion for this power supply

- Necessary to pass EMI:
  - Common Mode Choke (CMC)
  - Y-Cap
- Not necessary to pass EMI
  - Optimized Snubber
Common Mode Noise Suppression

WE-SAFB

WCAP-FTXX

C_X

N

WCAP-FTXX

C_Y

C_Y

C_Bulk

L

PE
Radiated Emissions made by AC-DC Converter
No Filter- no Y -Cap

- Uin: 230Vac
- Iout: 1,5A
- Polarization: Horizontal
- Norm: EN55022A

Uout: 24Vdc
fsw: 100kHz
Radiated Emissions made by AC-DC Converter
No Filter- using Y -Cap

- Uin: 230Vac
- Iout: 1,5A
- Polarization: Horizontal
- Norm: EN55022A

Frequency (MHz)

0 100

dBµV/m

-30 30MHz

3GHz

w/o Y-Cap

with Y-Cap
Radiated Emissions made by AC-DC Converter
Use Input Filter & Y-Cap

![Diagram of Input Filter and Y-Cap](image)
Radiated Emissions made by AC-DC Converter
With Input Filter & Y-Cap

- Uin: 230Vac
- Iout: 1.5A
- Polarization: Horizontal
- Norm: EN55022A

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<th>Frequency (MHz)</th>
<th>30MHz</th>
<th>3GHz</th>
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<td></td>
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<tr>
<td>with Input filter</td>
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- Uout: 24Vdc
- fsw: 100kHz
- Polarization: Horizontal
- Norm: EN55022A
Conducted Emissions made by AC-DC Converter without Input Filter with Y-Cap

- **Uin**: 230VAC
- **Iout**: 1,5A
- **Measured**: L to PE
- **Norm**: EN55022A

- **Uout**: 24VDC
- **fsw**: 100kHz

**Frequency (MHz)**: 150kHz - 30MHz

**Conducted Emissions** made by AC-DC Converter without Input Filter with Y-Cap.
Conducted Emissions made by AC-DC Converter with Input Filter & Y-Cap

- Uin: 230VAC, Uout: 24VDC
- Iout: 1.5A, fCLK: 100kHz
- Leitung: L nach PE
- Norm: EN55022A
OTHER EMC SITUATION FOR AC/DC CONVERTER
Radiated Emissions made by AC-DC Converter without Ferrite bead and without Y-Cap

- Uin: 230VAC
- Uout: 12VDC
- Iout: 4.16A
- fsw: 90kHz

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**Graph:**

- **Top**
  - Frequency (MHz) from 30MHz to 1GHz
  - Radiated Emissions made by AC-DC Converter
  - Without Ferrite bead and without Y-Cap
  - Comparison between no Shielding and With Input Filter

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**Table:**

- Frequency (MHz): 30MHz to 1GHz
- Radiated Emissions: dBµV/m

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www.we-online.com
Radiated Emissions made by AC-DC Converter with Ferrite bead and without Y-Cap

- Ferrite bead selection:
  - Check noise frequency
  - NiZn Ferrite bead
  - use WE-SAFB 4x2 mm, 250Ohm @ 90 MHz

![Ni-Zn Ferrite bead](image1)

![Ni-Zn Ferrite bead](image2)
Radiated Emissions made by AC-DC Converter with Ferrite bead and without Y-Cap

- **Uin:** 230VAC, **Uout:** 12VDC
- **Iout:** 4.16A, **fsw:** 90kHz
- **Polarization:** Horizontal
- **Norm:** EN55022A

![Graph](attachment:image.png)
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y-Cap

- **Selection of Y Cap**
  - High freq. type
  - High Voltage
  - Low ESR
  - Small package
  - Example: WCAP-CSSA 1nF

- **Selection of Ferrite bead**:
  - NiZn Ferrite bead
  - Small size bead
  - Example: WE-SAFB 4x2 mm, 250Ohm @ 90 MHz

Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y-Cap
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y-Cap

- Uin: 230VAC, Uout: 12VDC
- Iout: 4.16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A

![Graph showing radiated emissions with and without Y-Cap and Ferrite bead.]
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y –Caps + Snap Ferrite

- Uin: 230VAC,
- Iout: 4,16A,
- Polarization: Horizontal
- Norm: EN55022A

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>dBμV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>30MHz</td>
<td>0</td>
</tr>
<tr>
<td>1GHz</td>
<td>100</td>
</tr>
</tbody>
</table>

w/o Snap Ferrite
with Snap Ferrite
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y-Caps + Shielding

- Uin: 230VAC,
- Iout: 4.16A,
- Polarization: Horizontal
- Norm: EN55022A

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>w/o Shielding</th>
<th>with Shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td>30MHz</td>
<td>-30 dBµV/m</td>
<td>-30 dBµV/m</td>
</tr>
<tr>
<td>1GHz</td>
<td>0 dBµV/m</td>
<td>0 dBµV/m</td>
</tr>
</tbody>
</table>

Uout: 12VDC
fsw: 90kHz
OTHER EMC SITUATION FOR A DC/DC CONVERTER
DC/DC Converter with galvanic separation

Vin 18V-36V

K1 s110171002

K3 61300211121

K4

K5 61300211121

PWS2 +IN +OUT

+IN +OUT

Bad

IN -OUT

Tes3-2412

C1 10nF

C2 10nF

L1

C4 10nF

C5 10nF

L2

L3

L4

C6

C7

WE-ALPHAS

Alu-Elektrolyt

9623843064

WE-CSSP

Keramik

87511582004

fsu=300kHz

Vout 12V/250mA

GND 691101710082

GND

GND

Jumper

Jumper

Jumper
DC/DC Converter with galvanic separation

Bad Example

Good Example
DC/DC Converter with galvanic separation 18V input
no filter
DC/DC Converter with galvanic separation 24V input no filter
DC/DC Converter with galvanic separation 32V input no filter
DC/DC Converter with galvanic separation 24V input with input filter

### Receiver

<table>
<thead>
<tr>
<th>Level</th>
<th>dBµV</th>
<th>Frequency</th>
<th>30,000,000,000 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Peak</td>
<td>19.36</td>
<td>20  40  60  80  100</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>4.23</td>
<td>20  40  60  80  100</td>
<td></td>
</tr>
</tbody>
</table>

**RBW (CISPR) 9 kHz MT 100 ms**

**Input DC Att 10 dB Preamp OFF Step LIN**

### Scan

- **Limit Check**
  - Line 55022-QP
    - 50 dBµV: PASS
    - 40 dBµV: PASS
    - 30 dBµV: PASS
    - 20 dBµV: PASS
    - 10 dBµV: PASS
    - 0 dBµV: PASS
    - 1 MHz PASS
  - Line 55022-AV
    - 50 dBµV: PASS
    - 40 dBµV: PASS
    - 30 dBµV: PASS
    - 20 dBµV: PASS
    - 10 dBµV: PASS
    - 0 dBµV: PASS
    - 1 MHz PASS

**Start 150.0 kHz Stop 30.0 MHz**
MEASUREMENT TECHNIQUES
Measuring voltage ripple

Example:

\[ U_{\text{Drop}} = R_{\text{GND}} \times I_{\text{GND}} = 20mV \]

- Avoid incorrect voltage amplitude caused by GND / PE loops
  - Higher currents causes higher voltage drop
- Use isolation transformer
- Don’t use probes with ground clips to reduce spikes
  - Inductive coupling by ground clip
Conducted Emission test setup

- **LISN**: „Line Impedance Stabilization Network“
  - Create known impedance on power lines for DUT
  - Filter mains voltage and cut higher frequency
  - Transfer conducted emission noise to EMC-Receiver
- EMC-chamber is recommended but not required
DC-LISN

- DC-LISN allow measurement of conducted emission at DC/DC converters
- Decouple the DC from the EMC receiver
- Creates 50Ω impedance for EMC-receiver
- Just differential noise measureable
Ripple-Measurement

• for a clean external connection
EXAMPLES FOR BAD DESIGN
Example for Bad Design

- Schematic for AC/DC converter
- No Input Filter
- Bad Layout
Example for Bad Design

- High Emissions for Conducted
- QP & AV limits exceed
Example for Bad Design

- No Input Filter
- Simple Pi Filter → Layout mistake!
- Wrong positioned Filter
- Simple 2 Layer
- Bad routing
Example for Bad Design

- Un insolated DC/DC converter
- No input filter
- Bad Layout
Example for Bad Design

- High emissions for radiated
- Limits over shoted
Example for Bad Design

- No input filter
- Simple 2 layer
- Wrong position for output capacity
- Bad Ground routing
DESIGN TOOLS
WE Component Selector
Simulation – WEBENCH

- http://www.we-online.de/web/de/electronic_components/toolbox_pbs/webench.php
Simulation – LTSpice IV

- http://www.linear.com/designtools/software/#LTSpice
Energy Harvesting to Go kit

- Environment energy captured and converted into electricity for small autonomous devices making them self-sufficient.

- Thermo Electric Generator (heat)
- Piezo Electric (vibration/strain)
- Photovoltaic (light)
- Galvanic (chemical)
- Induction (motion)

Energy Management & Storage

Regulated Voltage
WE WPCC Demo Kit
Wireless Power Coils WE-WPCC- Tx/Rx coils

- Fully compliant to WPC Qi standard
- Efficiency up to 85%
- Supreme shielding characteristics for low leakage inductance
- Outstanding performance due to usage of Litz wire:
  - lowest $R_{DC}$
  - highest $Q$ values
MagI³C Power Module
DC/DC Step Down Converter with integrated inductor

- **Branch:**
  - Industrial
  - Communication
  - Audio/Video equipment
  - Test & Measurement equipment
  - Medical

- **Application area:**
  - Voltage supply
  - Multi-Voltage Systems
  - Software developers with no hardware knowledge

5 types with variable output voltage

2 types with variable output voltage
MagI³C Power Module
DC/DC Step Down Converter with integrated inductor

Power Module Concept

Controller IC

V_IN

I_SWITCH 1

I_LOAD

V_OUT

I_SWITCH 2

Lead frame
MagI³C Step-Down Regulator Power Module Family

**Output Range:**

- 5-24V
- 0.8-6V
- 2.5-15V
- 0.8-3.6V
- 3.3V / 5.0V @0.5A

**V\textsubscript{IN} [V]**

- QFN
  - 171 021 501
  - 171 012 401
  - 171 020 601
- TO263
  - 171 050 601

**I\textsubscript{OUT} [A]**

- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 4
- 5
- 6

**SIP 7.5 6**

- 171 020 302
- 171 040 302
- 171 060 302
Trilogy of Magnetics

1. LTspice Book
   → How to use and build spice models
2. Trilogy of Magnetics
   → Design Guide for EMI Filter Design, SMPS & RF Circuits
3. Trilogy of Connectors
   → Basic Principles and Connector Design Explanations
4. ABC of Power Modules
   → Functionality, Structure and Handling of a Power Module
5. ABC of Capacitors
   → Basic principles, characteristics and capacitor types
!!! Questions ???

- Do you still think ...

  ... that a DC/DC converter “does not generate Conducted Emission” ???

  ... that the EMC of a DC/DC converter “isn’t affected by the PCB layout” ???

  ... that an “oscilloscope can’t help you to carry out any EMC tests” ???
If you still have questions?

Just call us: we try to help you

Don’t give up !!!
Globally available. Locally present!

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- Own offices
- Distribution
- Factories
Technical support needed?
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we-online.com/askLoranldt

or contact me directly:
askLoranldt@we-online.com