Agenda

- EMC
- Magnetic fields
- Filtering & Signals
- Insertion loss calculation
- Filter topologies
EMC - Definition

- Electro-Magnetic Compatibility

- The ability of electronic equipment and or systems to operate in its environment without causing unacceptable interferences.
EMC - Definition

Transmitter/Receiver

- devices which operate with other devices in one electromagnetic environment

**Source / Transmitter**
- mobile base station
- electro engine
- high power electronic
- mobile device (Laptop, PDA, Mobile phones etc.)
- discharge of static capacity
  → ESD (Electro Static Discharge – “Person”)
  → LEMP (Lighting Electro Magnetic Pulse)

**Load / Receiver**
- receivers (TV, Radio, …)
- white & brown goods
- IT systems
- measurement and control tech. (e.g. sensors)
- medical electronics (e.g. pace maker)
Beginning from definition EMC

• Basic requirement to devices:

1) decreasing of emission
2) prevention of emission
3) existence of noise immunity

effective protection TO AND AGAINST other electronic devices
EMC - Requirement

Electromagnetic Compatibility

- Emission
  - Conducted Emission
  - Radiated Emission

- Immunity
  - Conducted Suscept.
  - Radiated Suscept.
Economical point of view:

- Depends when you will start to design EMC conform
EMC - Norms

Since 1996 it is a must, that in EU all electronic devices are CE conform according to 2004/108/EC

World wide:

IEC 61000-1 - Introduction, terms and conditions
IEC 61000-2 - Classification of electromagnetic environments
IEC 61000-3 - Limits and disturbance levels
IEC 61000-4 - Testing and measurement techniques
IEC 61000-5 - Installation and mitigation guidelines
IEC 61000-6 - Generic standards

European norms

<table>
<thead>
<tr>
<th>Category</th>
<th>Emission</th>
<th>Immunity</th>
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<tbody>
<tr>
<td>Information technology equipment</td>
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<td>EN 55024 (P)</td>
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<td>Industrial plant</td>
<td>EN 50081-2 (FG)</td>
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<td>Industrial, scientific and medical equipment RF equipment</td>
<td>EN 55011 (P)</td>
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<td>EN 50065 (P)</td>
<td>EN 50082-2 (FG)</td>
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<td>Sound and television broadcast receivers</td>
<td>EN 55013 (P)</td>
<td>EN 55020 (P)</td>
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<tr>
<td>Requirements for household appliances, electric tools etc.</td>
<td>EN 55014-1 (P)</td>
<td>EN 55104-2 (P)</td>
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</table>
EMC – General solutions

1) Optimization of the layout:

→ situation:

one Problem but to many “solutions”/opinions

2) Filtering

3) Shielding
EMC – Electromagnetic Wave
1 cycle = 0° to 360°

Period (S) = 0 seconds to 20μS

Frequency (F) = 1 / Period
= 1 / 20μS
= 50 kHz

Wavelength (λ) = Speed of Light (m/s) / Frequency
= 300x10^6 / 50000
= 6000 metres
EMC – Electromagnetic Wave

**Frequency (F) = 500MHz**
Wavelength (λ) = 0.6 metres

**Frequency (F) = 50kHz**
Wavelength (λ) = 6000 metres
EMC – Coupling Paths

1) Conductive
   • Coupling path between source and victim is formed by direct contact.

2) Capacitive
   • Electric field coupling

3) Inductive
   • Magnetic field coupling

4) Radiative
   • Source is the “transmitter” and victim is the “receiver”
EMC – Coupling Paths (Capacitive Coupling)

- Capacitive coupling between conductors cause parasitic currents
- Noise voltage increases with frequency. Higher frequency means more high frequency harmonics flow through the capacitor.
- Two wires with 2 mm diameter and spaced by 1 cm shows about 0.1pF of parasitic capacitance.
Magnetic coupling between conductors causes parasitic induced voltages.
Noise current increases with frequency.
Two wires with 2mm diameter and spaced by 1cm, shows about 10nH/cm of parasitic inductance.
AC “noise” source may “couple” to a DC circuit through mutual inductance ($M_{\text{stray}}$) and capacitance ($C_{\text{stray}}$) along the length of the conductors.
Magnetic Fields
Magnetic Fields - What does frequency mean?

• lat. frequentia = frequency, commonness

• …describes some events within a dedicated space of time

• Mostly we talk about recurrent events - periodic

• All waveforms are based on a basic wave (sin or cos)
  → fourier-series expansion

• Unwished superposition of these signals results in disturbance signals
  → e.g. noise (a random signal/waveform with a constant amplitude)

• One target of EMC: suppressing / filtering these interferences
Magnetic Fields - What is an Inductor? What is a coil?

…technical aspect:

→ a piece of wire wound on something

What is the difference between Coil and Inductor?

Coil = Inductor

(many shapes) (just inductance)

As a function:

• A filter
• An energy-storage-part (short-time)
Magnetic Fields - What is an EMC ferrite?

……..technical aspect:

→ sintered ferrite material applied to a wire

As a function

• RF-Absorber

• frequency dependant filter

Shapes:

Split ferrite

Toroid / sleeve ferrite

flat cores

ferrite plates

chip bead ferrite

multi hole ferrite

ferrite beads
Magnetic Fields - The magnetic field

Each electric powered wire generates a magnetic field

Field model

current I

Magnetic field H
Magnetic Fields - The magnetic field

Field model

Magnetic field $H$

Current $I$

NORTH

SOUTH
Magnetic Fields - The magnetic field

Field model
Magnetic Fields - The magnetic field

Coil or Loop
S-pole
N-pole
Lines of Magnetic Flux produced around a Coil
Coil or Loop
S-pole
N-pole
Lines of Magnetic Flux produced around a Coil
Coil or Loop
S-pole
N-pole
Lines of Magnetic Flux produced around a Coil
Magnetic Fields – Permeability (Core material parameter)
Magnetic Fields - The magnetic field

**Straight wire**

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

**Toroidal**

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

**Rod choke**

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

The magnetic field strength depends on:

- Dimensions
- No. of turns
- Current

but

**NOT FROM MATERIAL**
Magnetic Fields - The magnetic field

Induction in air:

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

\[ B = \mu_0 \cdot H \]

linear function because \( \mu_r = 1 = \text{constant} \)!

The relative permeability is:

Induction in Ferrite:

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

Material-
Frequency-
Temperature-
Current-
Pressure-

-dependent parameter
Magnetic Fields - What is permeability?

Relative Permeability

→ describe the capacity of concentration of the magnetic flux in the material
→ is a factor of energy needed to magnetize

\[ \mu_r = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H} \]

Ferrite material
- un ordered
- soft magnetic

Permanent magnet
- ordered
- hard magnetic

Typical permeability \( \mu_r \):
- Iron power / Superflux : 50 ~ 150
- Nickel Zinc : 40 ~ 1500
- Manganese Zinc : 300 ~ 20000
Magnetic Fields - Magnetic Domains Simulation

- Linear hysteresis loop
- Rectangular hysteresis loop
- Magnetostriction
Magnetic Fields – Permeability (Core material parameter)

Domain limits in a magnetic field
- the domain limits are melting together with higher magnetic flux
Magnetic Fields – Permeability (Core material parameter)

Domain limits in a magnetic field
- the domain limits are melting together with higher magnetic flux
Magnetic Fields – Permeability (Core material parameter)

**Dependence on temperature**
-the magnetizing are influenced from the heating energy

\[ T \uparrow \sim \text{thermal motion} \uparrow \sim \text{degree of order} \downarrow \sim \]

\[ \mu_r \]

![Graph showing the dependence of permeability on temperature](image)

Alignment of elementary magnets
Para magnetism
reached at Curie-Temperature
\[ \mu_r = ?1 \]
Magnetic Fields – Permeability (Complex permeability)

1 turn

$$Z = \sqrt{R^2 + X^2}$$

Equivalent circuit

Core material-Parameter

$$X = X_L - X_C$$

Reactance

$$Z = \sqrt{R^2 + X^2}$$
Magnetic Fields – Permeability (Complex permeability)

\[ Z = j \omega L_0 \]

\[ R = \omega L_0 \]

\[ \left( \mu^I - j \mu^\parallel \right) \]
Magnetic Fields – Permeability (Complex permeability)

\[ Z = j \omega L_0 \left( \mu^\prime - j \mu^\| \right) = R + jX \]

**Inductance reactance**

\[ X_L = j \omega L_0 \mu^\prime \]

(energy storage)

**Frequency dependent core losses**

\[ R = \omega L_0 \mu^\| \]

(hysteresis & eddy current losses)

\[ \mu_r = 350 \]
Magnetic Field - Core material (Inductors {Storage})

knowledge of operating frequency

- $X_L(\text{Fe})$
- $X_L(\text{MnZn})$
- $X_L(\text{NiZn})$

Impedance

- „0“-200kHz
- „0“-10MHz
- „0“-40MHz

f/MHz

EMC  Magnetic fields  Filtering & Signals  Insertion loss calculation  Filter topologies
Magnetic Fields - Core material (Choke \{Filter\})

knowledge of noise frequency range

- Core material (Choke {Filter})
  - Impedance
    - 200kHz - 4MHz
    - 3-60MHz
    - 20-2000MHz

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

f/MHz
Magnetic Fields - Core material (Inductor / EMC Ferrite)

- Compare the $Q$
1. **Application**: *Storage inductor*
   
   Request: - lowest possible core losses at switching frequency

   **HIGH Q**

2. **Application**: *Absorber / Filter*
   
   Request – highest possible core losses at application frequency

   **LOW Q**
Magnetic Fields - Shielded vs. Unshielded power inductor
Magnetic Fields - Shielded vs. Unshielded power inductor

- **Magnetic field**

  **shielded**

  **unshielded**

  [Diagram showing comparison between shielded and unshielded power inductors]
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
# Magnetic Fields - Core materials (Application)

## Filter

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<tr>
<th>Frequency Band</th>
<th>1 kHz</th>
<th>10 kHz</th>
<th>100 kHz</th>
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## Storage Inductor

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<td>W29</td>
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</table>

## Core materials

- **Fe** (Eisenpulver): Nickel-Zink
- **MnZn** (Mangan-Zink): Keramik
- **NiZn**: Keramik
Filter and Signal
Filter and Signal - Basics

The energy can not disappear it will be just transformed into other energy form → law of conservation of energy

- e.g. electrical energy transformed into → thermal energy
- the core losses from ferrite transform the noise energy into heat

**MAIN TARGET:**

Noise energy should not occur at all!
Filter and Signal - Basics

What is filtering?

- Useful to reduce coupling of noise from device A to device B
- Reduce noise emission
- Increase noise immunity
- The signal should be not affected

Efforts?

→ Filtering can be very difficult if signal and noise frequency are close to each other

→ if signal and noise frequency are far away from each other, then a filter design is very easy
Filter and Signal - Structured interference suppression

• Recognize the coupling mode:
  • Common mode noise
  • Differential mode noise
Filter and Signal – Determining type of interference

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 is increased

Common Mode interferences

if not

Differential Mode interferences

e.g. Common mode choke

e.g. chip bead ferrite
Filter and Signal - Common Mode Filter

The DIFFERENTIAL Mode Signal creates a Flux in opposite directions – Thereby canceling.

The COMMON MODE signal does not cancel and an Inductive Impedance is created thereby acting as a filter.
Filter and Signal - Common Mode Filter (Signal theories)

Reduction of noise

• from device to environment
• from environment to device

Conclusion:

• “almost” no influencing of the signal ➔ Differential mode
• high attenuation of noise ➔ Common mode
different kinds of noise:

- Common mode noise
- Differential mode noise
Filtering

Common mode

Source

Signal path

Load

e.g.: USB

VCC

D+

D−

GND

WE-CNSW Type 0805

<table>
<thead>
<tr>
<th>Order Code</th>
<th>Impedance (Ω @ 100 MHz)</th>
<th>Rated voltage (V)</th>
<th>DCR (Ω)</th>
<th>Rated Current (mA)</th>
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</table>
When will the signal be attenuated?

• the Differential mode impedance will also attenuate the signal

• The Common mode impedance will attenuate just the noise
What is the best solution to filter noise close to signal frequency?
Filter and Signal - Common mode choke (Construction)

### bifilar

\[ L_s \sim 0.01 \ldots 0.1\% \times L_R \]

### sectional

\[ L_s \sim 0.5 \ldots 2\% \times L_R \]

< ? Advantage ? >
Filter and Signal - Common mode choke (Construction)

**bifilar**
- Less differential impedance
- High capacitive coupling
- Less leakage inductance

**sectional**
- Low capacitive coupling
- High leakage inductance

- Data lines
  → USB, Fire-wire, CAN, etc.
- Power supply
- Measuring lines
- Sensor lines

- Power supply input/output filter
  → CMC for mains power
- High voltage application
- Measuring lines
- Switching power supply decoupling

- WE-CNSW
- WE-SLM
- WE-LF
- WE-SLx-Series
- WE-CMB
- WE-VB / VB2
Filter and Signal - Common mode choke (Construction)

**WE-SL2 744227S**  
**sectional winding**

**WE-SL2 744227**  
**bifilar winding**
Filter and Signal - Common mode choke (Construction)

WE-split ferrite – Is it a CMC?

- Yes, CMC with one winding

  e.g. 74271712

  comparable with bifilar winding CMC

- both will absorb Common Mode interferences
Increase the number of turns means:

![Graph showing the relationship between number of turns and frequency response of a common mode choke (Ferrite core).]
Filtering with two inductors or chip beads

Signal before filtering

Signal after filtering

Rise time of the signal is affected, which could cause problems for fast data signal lines.
Filter and Signal - Common mode choke (Advantages)

Filter with a common mode choke

No affect on the signal rise time, because of magnetic field compensation
Filter and Signal - USB 2.0 Filtering for common mode noise
Filter and Signal – USB 2.0 Filtering with WE-CNSW

Too much differential mode impedance distorts the USB 2.0 eye pattern.
Filter and Signal – CMC (Multiple usage “5in1”)

• WE-MLS

→ can be easy designed at PCB layout connection
1 component for 5 application

Optimal for power supply filtering (U < 60VDC); charger, sensors, etc.
Filter and Signal – CMC (Multiple usage “5in1”)

- Application WE-MLS: power supply filtering
Filter and Signal - Common mode chokes (Line card)

**CMC from Würth Elektronik eiSos**

**For mains power**
- 250VAC / max. 35A

**Wire wound with sectional windings**
- SMD
  - WE-LF SMD
  - WE-CMB

- THT
  - WE-UKW

**For signal and low voltage**
- $U_{\text{max.}} = 80\text{VDC} / \text{current up to 5A}$

**THT**
- WE-MLS
- WE-VB

**SMD**
- WE-SLx Series
  - WE-VB2
  - WE-CNSW
  - WE-CMS

**sectional**
- WE-SLx Series
  - WE-CNSW

**bifilar**
- WE-VB
Appearance of *differential noises* on the input line of a Flyback Converter

mostly high Cap Values >100uF; \( X_c = \frac{1}{(\omega C)} \)

**differential interference**

Switch (e.g. Transistor)

**differential interference**

PE

Earth ground

**differential interference occurs mainly at *lower* frequencies**
Appearance of **common mode noises** on the input line of a Flyback Converter

- mostly high Cap Values $>100\mu F$; $X_c=1/(\omega C)$
- common mode interference occurs mainly at higher frequencies
- parasitic capacities; in the lower pF/nF (e.g. VCC layer to GND layer (coupling))
Filter and Signal - Usual mains power filter

- Build your own one – possibility for above ~ 30 MHz as well

![Diagram of mains power filter components]

- **6-hole-Ferrite bead** (I<3 to 5A)
  - 742 750 1 – 742 750 46
  - WE-LF
  - 744 612 002 7

- **Sleeve choke** (I<1A)
  - 742 760 3 – 742 760 6
  - WE-CMB
  - 744 821 039

- **Rod core inductor** (I >= 30A)
  - 744 710 1 – 744 716 0
  - WE-FC
  - 744 864 040 4
Insertion Loss
**Insertion loss - Definition**

![Diagram of insertion loss](image)

**Impedance =>**
\[ Z_F = 10 \log \left( \frac{P_{in}}{P_{out}} \right) \]

**System Attenuation =>**
\[ A = 20 \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \text{ in } (dB) \]
Insertion loss - Definition

The real world - equivalent circuit

- practical values for source and load impedance

- Grounding planes 1 ... 2 Ω
- Vcc distribution 10 ... 20 Ω
- Video-/Clock-/Data line 50 ... 90 Ω
- long data lines 90 ... >150 Ω
Insertion loss - Example

• Original measurement
Insertion loss - Example

→ Application: Power supply
→ 20dB @ 200 MHz

• system impedance = 10 Ω

→ catalogue: WE-CBF 742 792 61
**Insertion loss - Example**

**WE-CBF 742 792 61**

![Typical Impedance Curve](image)

- **Impedance / Impedance [Ohm]**
- **Frequency / Frequency [MHz]**
- **Insertion loss - Example**

- **IF BW 10kHz**
- **START 1 MHz**
- **POWER 0 dBm**
- **STOP 1,8 GHz**
- **SWP134,5 msec**

**200Ω**

**200MHz**
Insertion loss - Example

• Check the results

→ Measuring the emission and compare the attenuation
Insertion loss - Example

- Choosing different system impedance
- Effect on video/clock/dataline system impedance (50Ω)

--- : With 50 Ω system impedance, it still fails

--- : With 10Ω system impedance it passes

Example

• Choosing different system impedance
• Effect on video/clock/dataline system impedance (50Ω)
Insertion loss - Example

• **Possibility: Attenuation too low**

→ could be because of wrong system impedance estimation
→ increase the impedance of ferrite ($Z_F \sim 1000\,\Omega$)
**Insertion loss - Example**

- **Dependency** of system impedance (Source/Load) vs. attenuation

  - high system impedances results in a low attenuation

  ![Graph showing the relationship between system impedance and attenuation](image)

  - Increased system impedance

  - Filtering just to a certain system impedance possible

  → Filtering just to a certain system impedance possible
Filter Topologies
Filter Topologies - Recommended filter topologies

<table>
<thead>
<tr>
<th>Source Impedance</th>
<th>Load Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>high or unknown</td>
<td>high or unknown</td>
</tr>
<tr>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>low or unknown</td>
<td>low or unknown</td>
</tr>
</tbody>
</table>

- **LC circuit (Induct/Cap)**
- **Capacitor Filter**
- **Pi Filter (low pass filter)**
- **Inductor Filter**
- **Tee Filter (low pass filter)**
Filter Topologies – Test Board

Filter circuit 1uF; Ferrite; 1uF

IC 74LS132

$R_L = 220\Omega$

$R = 470\Omega$

$5.1V_{DC}$

$C_L = 47pF$

Trimmer 10K
Filter Topologies – Test Board (Vcc Decoupling)

![Graph showing filter topologies](image)
Filter Topologies – Test Board (Vcc Decoupling) [C Filter]

Step 1: 1uF Cap.

C-Filter with 1uF

\[ V_{CC} \]

\[ GND \]

\[ C \]

**Attenuation**

-140 -120 -100 -80 -60 -40 -20 0

\[ 1 \ 4 \ 10 \ 100 \ 1000 \]

**Frequency [MHz]**

-140 -120 -100 -80 -60 -40 -20 0

**Attenuation**

-140 -120 -100 -80 -60 -40 -20 0

**Frequency [MHz]**

-140 -120 -100 -80 -60 -40 -20 0

**Frequency [MHz]**

50dB
Filter Topologies – Test Board (Vcc Decoupling) [C Filter Results]

Step 1:
1uF Cap.

C-Filter with 1uF

![C-Filter with 1uF Diagram](image)

**Attenuation**

- without filtering
- C-Filter 1uF
- C-Filter Simulation
Filter Topologies – Test Board (Vcc Decoupling) [LC Filter]

Step 2: 1uF Cap. & Ferrite

LC-Filter: 1uF-742792093

main attenuation done by the ferrite

Attenuation

Frequency [MHz]

dB

LC-Filter-Simulation
C-Filter Simulation
Filter Topologies – Test Board (Vcc Decoupling) [LC Filter Result]

Step 2:
1uF Cap. & Ferrite

LC-Filter: 1uF-742792093

![Attenuation Graph]

- C-Filter 1uF
- LC-Filter 1uF_742792093
- without filtering
- LC-Filter-Simulation
Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

Step 3: 1uF//1uF Cap. & Ferrite

\[ \pi \text{-Filter: } 1 \mu F-742792093-1 \mu F \]

\[ \begin{array}{c} \cap \\ \hline \text{GND} \\ \hline \text{VCC} \end{array} \]

\[ \begin{array}{c} \cap \\ \hline \text{GND} \end{array} \]

![Attenuation Graph](image)
Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

Step 3: 1uF//1uF Cap. & Ferrite

\[ \pi \text{-Filter: } 1\text{uF-742792093-1\text{uF}} \]

![Diagram of \( \pi \) filter with 1uF capacitors and ferrite beads]

**Attenuation**

- C-Filter-Simulation
- C-Filter 1uF
- LC-Filter 1uF_742792093
- PI-Filter 1uF//1uF_742792093
- without filtering

**Frequency [MHz]**
- 1
- 10
- 100
- 1000

**DB**
- -140
- -120
- -100
- -80
- -60
- -40
- -20
- 0
Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

\[ \pi \text{-Filter: } 1\mu F-742792093-1\mu F \]

No filtering on Vcc

Filtering on Vcc

---

**Agilent** 17:31:42 28 Sep 2005

**Agilent** 17:39:10 28 Sep 2005

---

<table>
<thead>
<tr>
<th>Marker</th>
<th>Trace</th>
<th>Type</th>
<th>X Axis</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1)</td>
<td>Freq</td>
<td>1 MHz</td>
<td>-37.35 dBm</td>
</tr>
<tr>
<td>2</td>
<td>(1)</td>
<td>Freq</td>
<td>5 MHz</td>
<td>-17.1 dBm</td>
</tr>
<tr>
<td>3</td>
<td>(1)</td>
<td>Freq</td>
<td>30 MHz</td>
<td>-22.9 dBm</td>
</tr>
<tr>
<td>4</td>
<td>(1)</td>
<td>Freq</td>
<td>200 MHz</td>
<td>-41.94 dBm</td>
</tr>
</tbody>
</table>
Simulation – Conducted Emissions without filter (Example 1)

LT3481EMSE Demo Board
24V to 3.3V @2A
fsw=800kHz
CEM 0.15 – 30 MHz

Test without EMC filter:
Peak 82dBµV
→ 26dB above limit
Simulation – Conducted Emissions with filter (Example 1)

Ferrite bead
High ESR Elco to damp cable

Test with additional $L = 10\mu\text{H}, \ C = 3.3\mu\text{F}$ 50V 1210 input filter

Peak = $42\text{dB}\mu\text{V/m}$
$\varnothing = 32\text{dB}\mu\text{V/m}$

Peak & $\varnothing$ 14dB below limit
Simulation – Conducted Emissions (Example 2)

- Chip Bead
- Differential Choke
- Bifilar wound CMC
- Sectional wound CMC
Simulation – Conducted Emissions Test Setup (Example 2)

- No load
- 1.5A load at 300KHz fsw
Simulation – Conducted Emissions Test Setup (Example 2)

Line Impedance Stabilization Network (LISN)

- Isolates DUT (device under test) from Power Source (typically mains) Noise
- Provide characteristic impedance to DUT (50 Ohms in this case)
- Path for conducted noise from DUT to spectrum analyzer

The 1 μF in combination with the 50 μH inductor is the filter that isolates the mains from the EUT. The 50 μH inductor isolates the noise generated by the EUT from the mains. The 0.1 μF couples the noise generated by the EUT to the EMC analyzer or receiver. At frequencies above 150 kHz, the EUT signals are presented with a 50-Ω impedance.
Simulation – Conducted Emissions Test Setup (Example 2)
Simulation – Conducted Emissions Test Setup (Example 2)

- DC/DC Converter
- Input Voltage 20V-25V
- Output Voltage 12V/6.25A
- Fsw: 300KHz

Testcondition:
- no load
- max. load 1.5A
Simulation – Conducted Emissions Example 2 Chip Bead Ferrite

Chip Bead 530Ω / 3A
Simulation – Conducted Emissions Example 2 Chip Bead Ferrite Result

Chip Bead 670Ω at 3A

load 1.5A>
Simulation – Conducted Emissions Example 2 Chip Bead Ferrite Result

742 792 515
Simulation – Conducted Emissions Example 2 Differential Choke

744 743 221 (220uH)
Simulation – Conducted Emissions Example 2 Differential Choke Result

744 743 221 (220uH)
Simulation – Conducted Emissions Example 2 Bifilar CMC

4.7mH Bifilar winding Common Mode Choke
Simulation – Conducted Emissions Example 2 Bifilar CMC Result

Load is 1.5A
And...CMC

4.7mH Bifilar winding Common Mode Choke

Warning: Don’t try this at home!
For Demonstration Purposes Only!

IDC 350mA Max

Warning: Don’t try this at home!
For Demonstration Purposes Only!

IF BW 10kHz
START 1 MHz
POWER 0 dBm
SNR 12.5 mV
STOP 1.2 GHz

744 272 472
4.7mH Bifilar winding Common Mode Choke
Sectional common mode choke 47mH
Simulation – Conducted Emissions Example 3 CMC Sectional

CMC 47mH Sectional Winding
Leakage Inductance $L_s \sim 250\mu H$ (5% of $L$)

Sectional common mode choke 47mH
Simulation – Conducted Emissions Example 2 CMC Sectional Result

Sectional common mode choke 47mH

no load >

load 1.5A>
Simulation – Conducted Emissions Example 2 Conclusion

• High frequency noise appears under load (Noise is differential mode)

• **Chip Bead Ferrite**
  - Without a load there is some affect at high frequencies, but with a load the bead pre-magnetizes and there is no effect at all.

• **Differential Choke**
  - Attenuates low frequency noise because of SRF

• **Bifilar common mode choke**
  - Does not attenuate because of very low leakage inductance

• **Sectional common mode choke**
  - Attenuates both high and low frequencies because of leakage inductance and high SRF
**Filter topologies – LC-Filter**

**design tip:** avoid over current (low dump)

\[ U_{\text{in}} \quad \text{e.g. 12V DC} \]

![LC Filter Diagram](image)

\[ U_{\text{max}} \quad U(t) \]

\[ I_{\text{max}} \quad I(t) \]

\[ \tau \quad 2\tau \quad 3\tau \quad 4\tau \quad 5\tau \]
at 15A.....
at 15A.....
Filter topologies – LC-Filter

design tip: avoid over current (low dump)

- SMD-Ferrite safe from low dump current
- not a PI-Filter
  → capacitor C1 is just for stabilization
L Filter SMD-Ferrite WE-CBF

• Using the core losses $R = f(f)$

• Transform differential noise energy into heat
L Filter SMD-Ferrite WE-CBF

IMPORTANT:

• Check equivalent circuit
Filter topologies – Inductor / SMD-Ferrite

• Parasitic capacities
  → Inductors: 10 pF … 500 pF
  → SMD-Ferrite: 5 fF … 5 pF

• Losses
  → Inductors: up to 30 kΩ
  → SMD-Ferrite: 10 Ω … 3 kΩ
Filter topologies C-Filter

- Expand the filter with an additional frequency dependent component
  - with a Capacitor
- Series inductance \( L_s \)
  - SMD-typical: \( 1 \text{ nH} \ldots 5 \text{nH} \)
- Losses (ESR) \( R_s \)
  - SMD-typical: \( 20 \text{ mΩ} \ldots 300 \text{ mΩ} \) (1 Ω)

\[
\begin{align*}
Z &= \frac{1}{\omega C_s} \\
\varphi &= \omega L_s \\
\log(Z) &= \log(f) \\
SRF &= R_s
\end{align*}
\]
Filter topologies – LC-Filter

R

L

Cp

Lr

C

ESR

L trace/L via

1 mm ~ 1 nH
1 via ~ 0.5 nH
0.5 nH @ 100 MHz = 0.314 Ω
0.5 nH @ 1 GHz = 3.14 Ω!

Zges: ESR+Lr (2nH)+Lvia(0,5nH)
100nF= 0,2Ω+1,2Ω+0,3Ω= 1,7Ω@100MHz
Size: 0603/X7R
Filter and Signal - Low pass filter

...are most popular used filter for EMI

**LPF 1. order**

\[
U_E \quad R \quad \frac{1}{\omega C} \quad U_A
\]

Frequency \( f \) decreases as \( Z_C \) increases.

**LPF 2. order**

\[
U_E \quad \omega L \quad \frac{1}{\omega C} \quad U_A
\]

Frequency \( f \) decreases as \( Z_L \) increases. Frequency \( f \) also decreases as \( Z_C \) increases.
Low pass filter - insertion loss

\[ \frac{1}{LC} \quad \frac{1}{RC} \quad 1 \quad 10 \quad 100 \quad \text{[log } w\text{]} \]

- \( a \text{ [dB]} \)
- \( \log |F_p| \)

- \( \text{Shifting from } RC \)
- \( \text{20dB/dec} \)
- \( \text{Shifting from } LC \)
- \( \text{40dB/dec} \)
- \( \text{LPF } p_1 \)
- \( \text{LPF } p_2 \)
Grounded filter

- most important condition for an LC filter
  → extremely good connection from capacitor to ground

- the filter efficiency will be depreciated from additional impedances
  → parasitic from capacitor connection (long legs)
  → layout design (to long trace)
  → from construction (ground pins, or bolts for PCB mounting)

\[ \begin{align*}
\omega L & \quad \frac{1}{\omega C} \\
E & \quad U_A
\end{align*} \]

- low space required
- good grounding
- well arranged
Grounded filter

**bad design**

- Inductive coupling from filter input to capacitor ground
- Capacitive coupling – will increase for higher frequencies
- Parasitic inductance from to long traces
  - 1mm trace means approx. 1nH
  - per via 0.5 nH
- No connection to chassis/case
- Bad position of filter output

**Improved design**

- Double via to GND
- Connection to chassis
- Contraction for RF
Bonus - More information online....

www.we-online.com
Unexpected effects – who smile more?

• …if the application is **not** EMC conform?
Headquarter in Germany, office: USA, UK, Sweden, France, Ireland, Italy, Austria, Spain, Switzerland, Nederland, Czech Rep., Hungary, Singapore, China and Taiwan

Production plant in: China, Taiwan, Mexico, USA, Bulgaria, Czech Rep. and Germany

Distribution rest World:
RS-Components, Farnell, Digikey

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