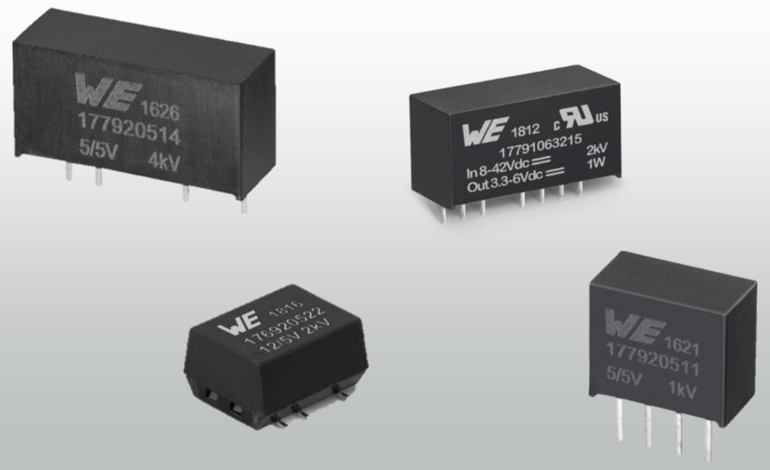
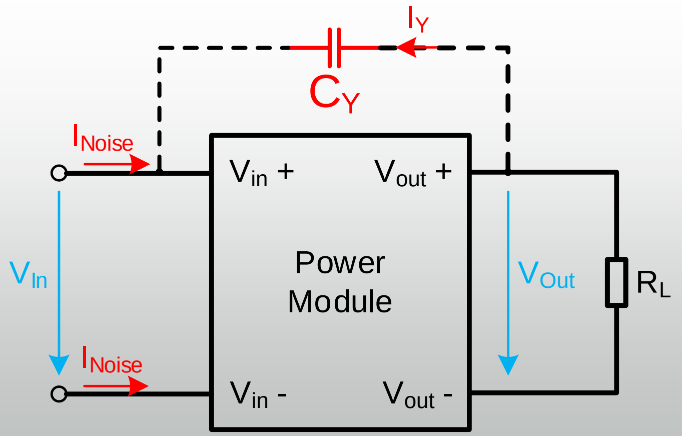
Improving the EMI performance of isolated power modules





MagI³C Power Modules

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28 April 2021

Agenda

- Introduction
- EMI Basics
- EMI Meets Kirchhoff
- Real EMI measurement
- Application specific filters

INTRODUCTION

Common Mode Myths

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Myths around EMI:

- Common mode interference suppression <u>only</u> works with <u>common mode chokes</u>

- Common mode interference suppression is more of a <u>try and error process</u>

- Common mode interference suppression are rather <u>difficult to understand</u>

WRONG!

INTRODUCTION

Common Mode Truth

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Truth!

Common mode interference suppression is not rocket science,

It´s just using basic electrical facts and Kirchhoffs law

But how to realize?

With the right setup of tools and a different view to emi

it´s just as easy as riding a bicycle……

INTRODUCTION

Typical application in automation technology

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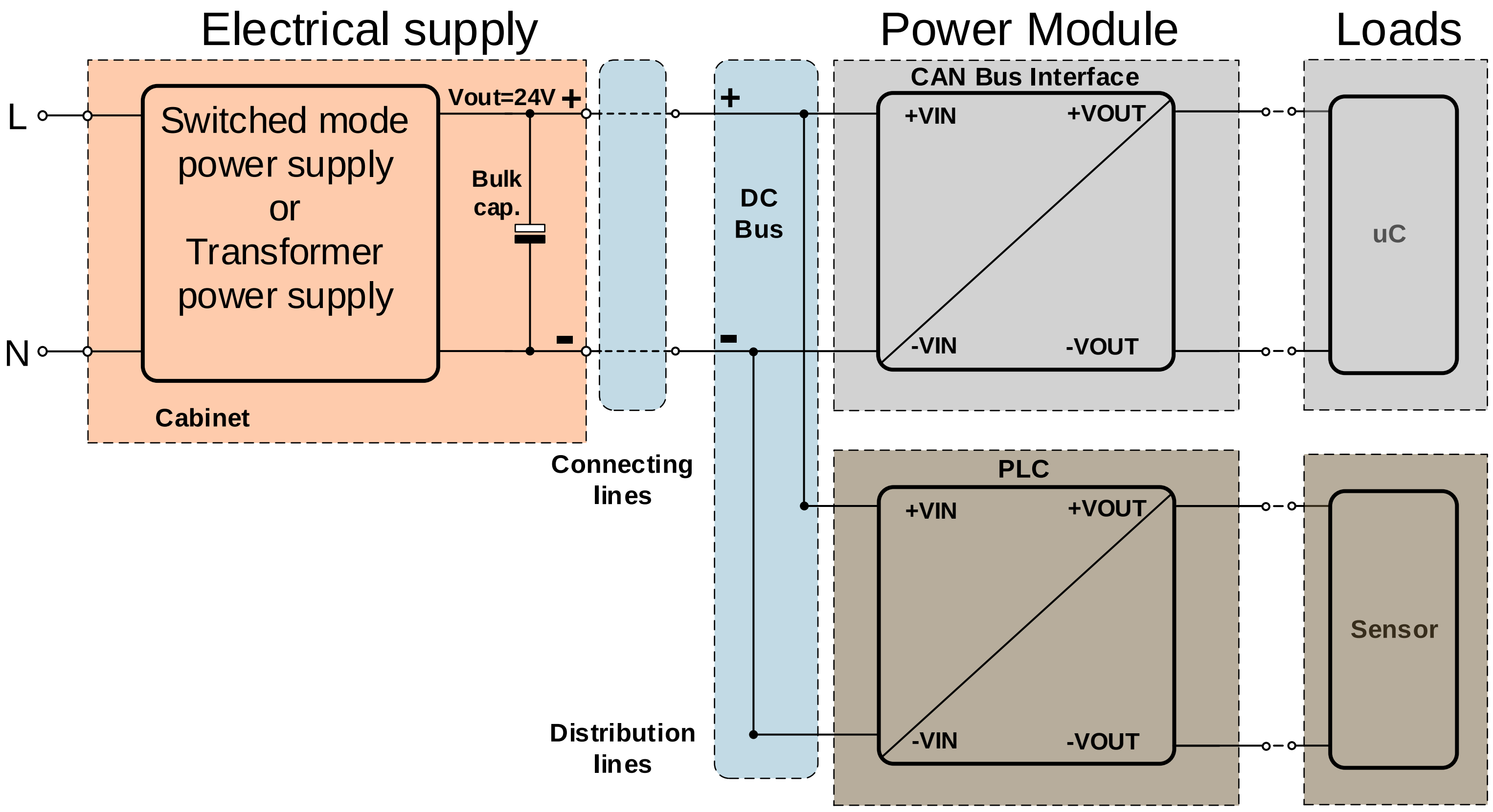


Description:

- Electrical supply is realized through cabinets with switched mode power supplies or transformer power supplies
- The separated parts of the applications are supplied through a dc bus
- On site, every separated electrical load is connected via a sub distribution with 24V.

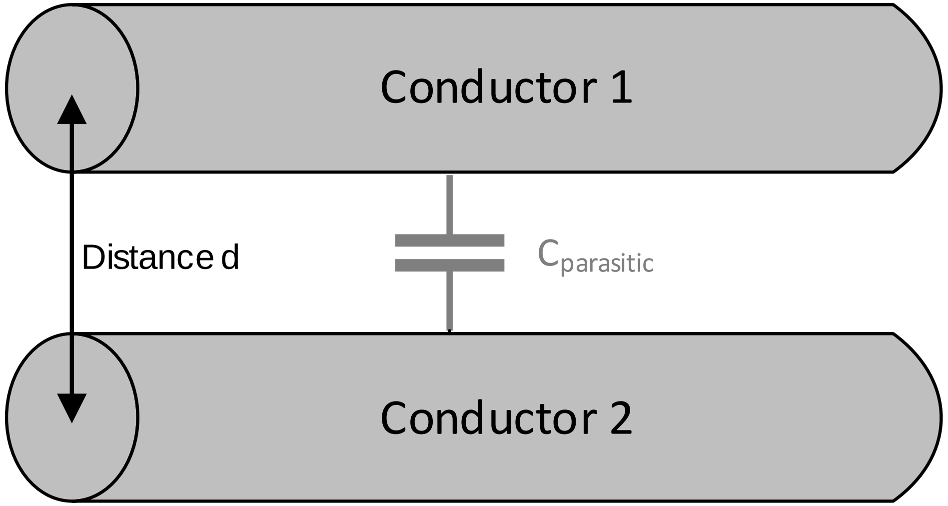
GENERAL BASICS

Parasitics, parasitics and again parasitics

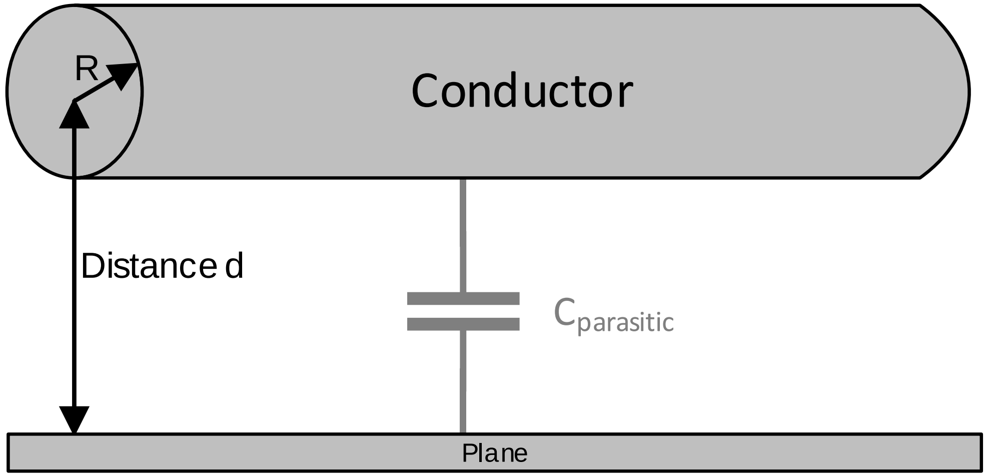
Keep in mind:

In every circuit, parasitic capacitances are present between different elements with different potentials.

Example 1: Two parallel conductors



Example 2: One conductor parallel over a flat surface

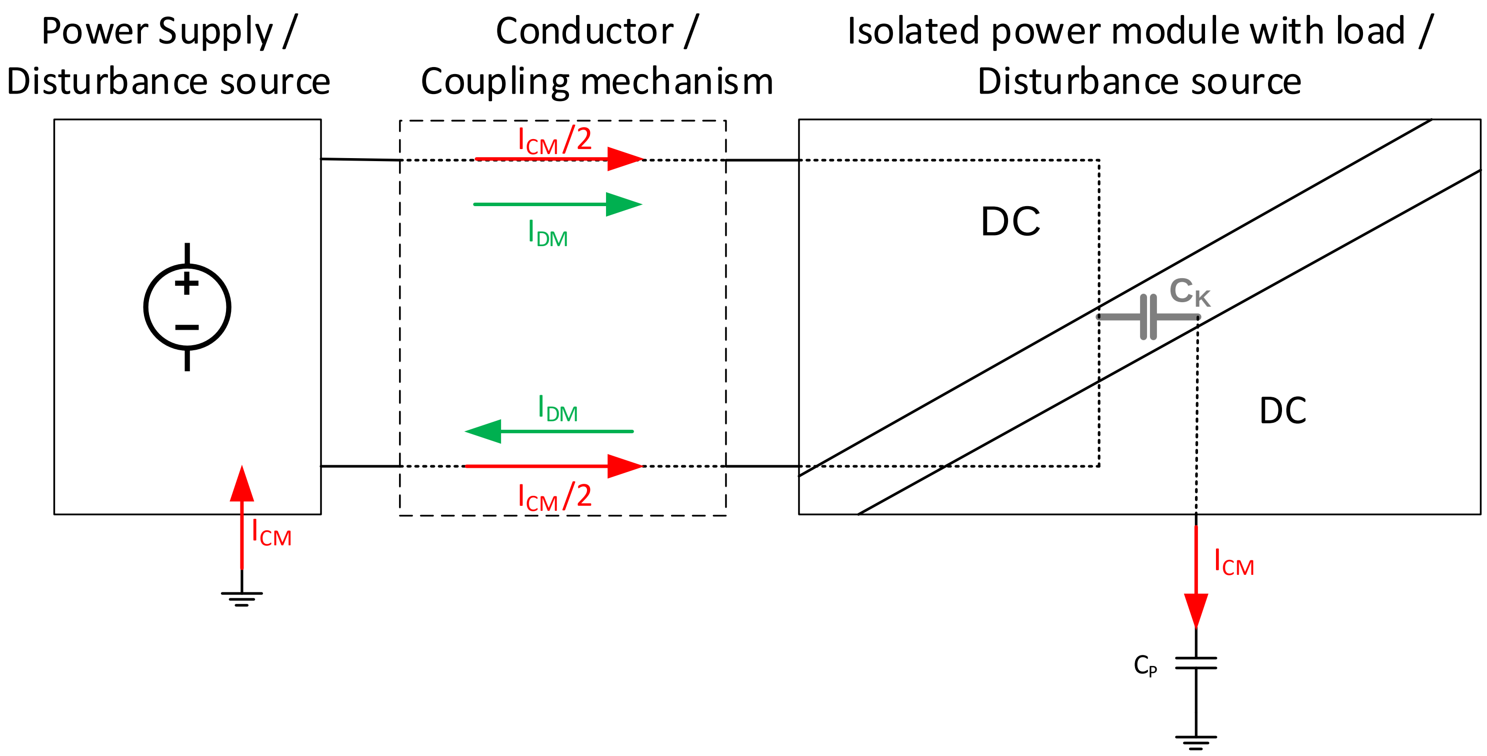


EMI BASICS

Differential Mode & Common Disturbances

Differential Mode Disturbances

- Current in the supply lines in the opposite direction
- Input current from power module
- Dominant in non-isolated power modules



Common Mode Disturbances

- Current in the supply lines in the same direction
- Mainly due to a high dv/dt of the switching elements
- Dominant for isolated modules

EMI BASICS

Defined EMI Test Setup

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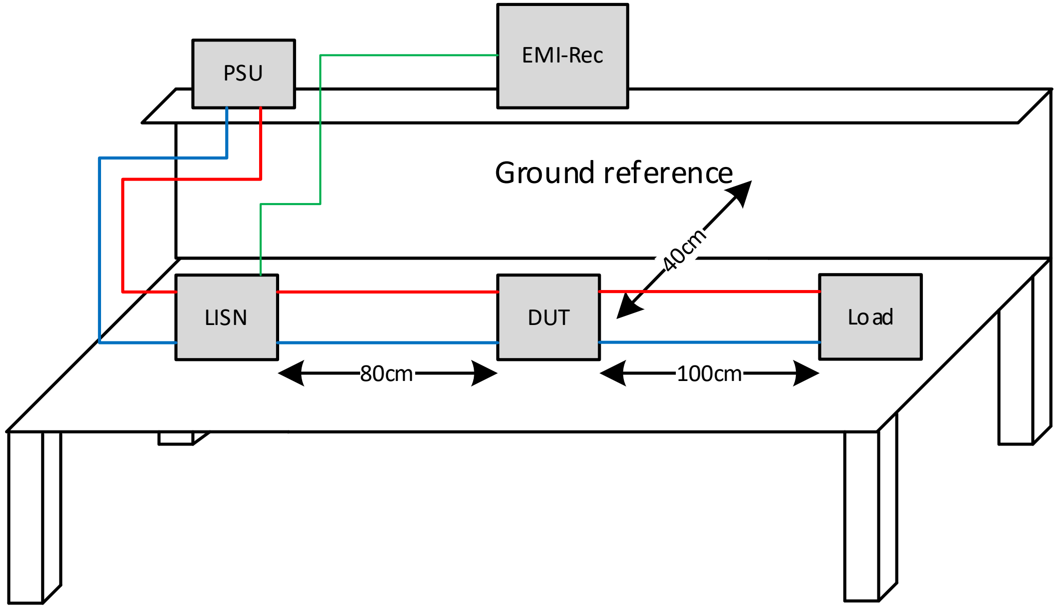
Basic considerations:

- Each application reshuffles the common mode cards
- That is why no general recipe can work
- For the time being, the consideration must be decoupled from the application
- Structure according to CISPR32 is a sufficiently good compromise for the following considerations

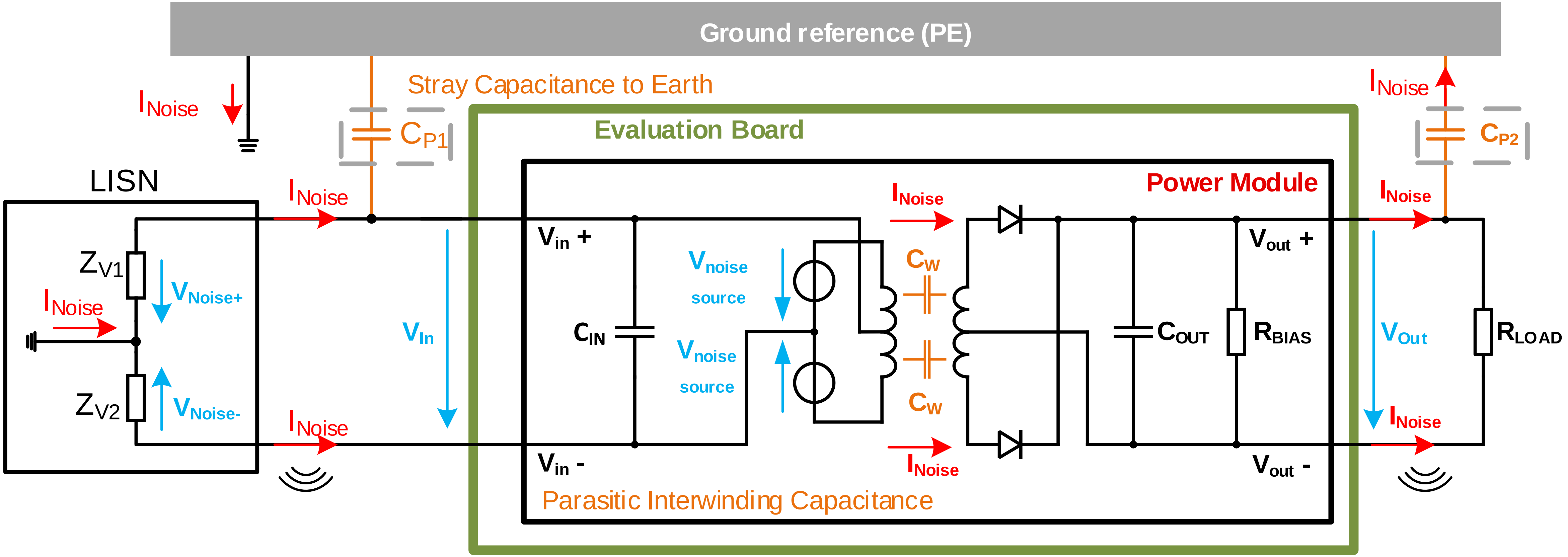


EMI test setup structure based on CISPR-32:

- Power supply unit (PSU)
- EMI-Receiver
- Power Module with load (DUT)
- Line Impedance Stabilisation Network (LISN)

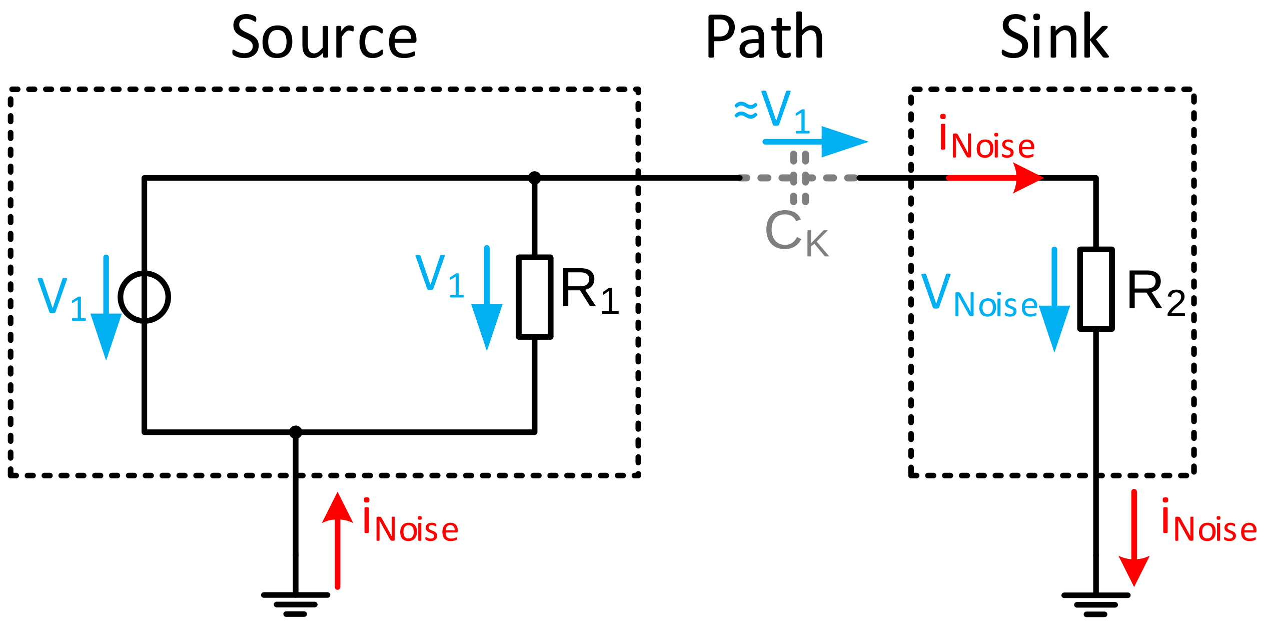
EMI Basics

Disturbance Source & Disturbance Path – Real Power Module



EMI BASICS

Simplified Electrical Equivalent Circuit – Disturbance



Equation for common mode noise current:

$$i_{noise} = C_K \cdot \frac{dv_1}{dt}$$

i_{noise} depends on:

- For example parasitic interwinding capacitance between primary & secondary

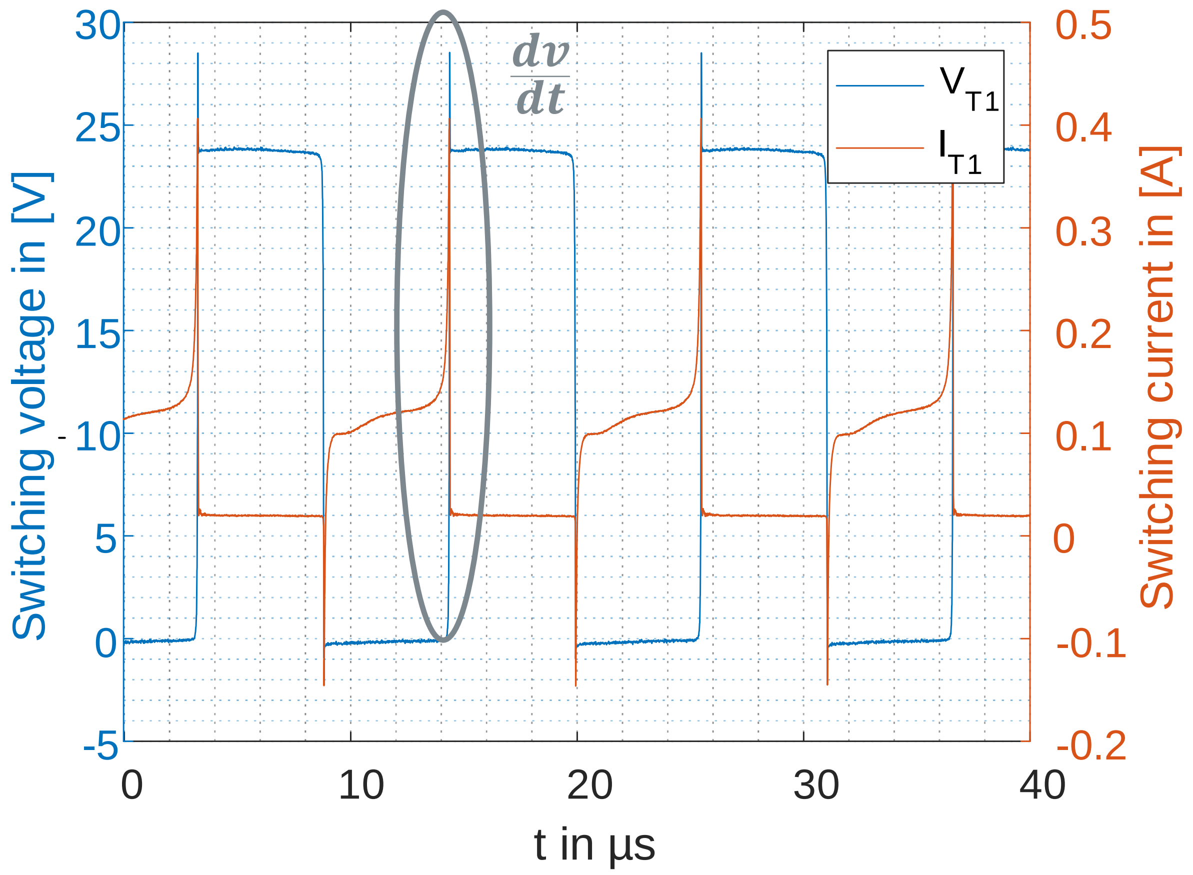
  C_K

- Voltage change over time ratio

  $\frac{dv_1}{dt}$

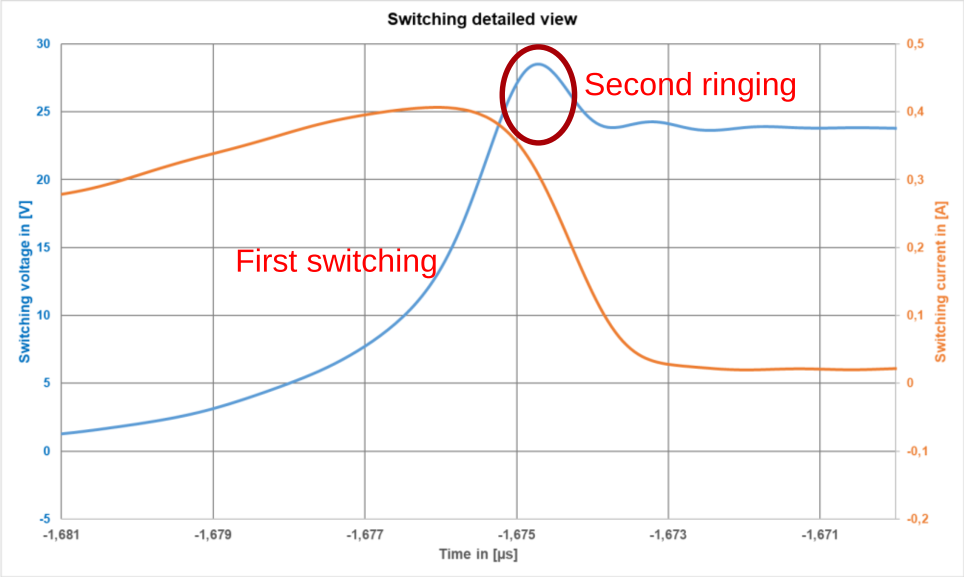
EMI BASICS

Noise Source



Description:

- Self oscillating push pull topology
- Switching is related to saturation of transformer core
- Due to switching topology high dv/dt
- Higher dv/dt leads to more harmonics



EMI BASICS

Noise Path

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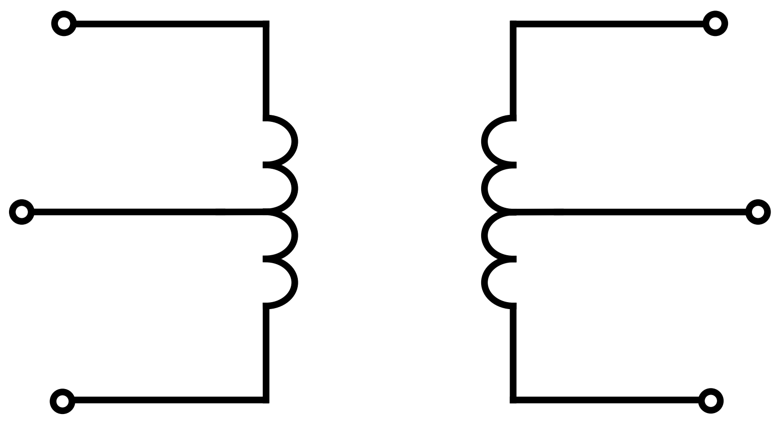
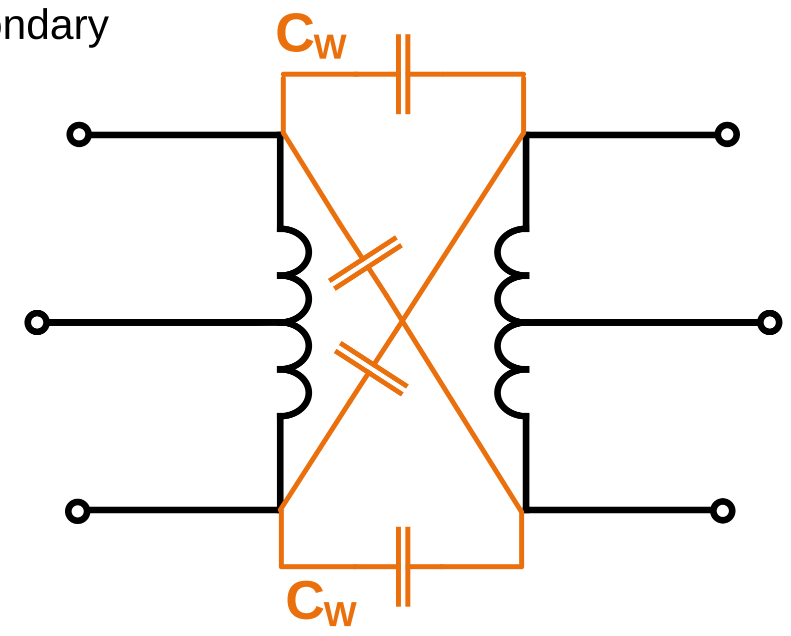
Ideal transformer:

- Separation between primary & secondary



Real transformer:

- Parasitic interwinding capacitance between primary & secondary



EMI BASICS

General Methods to pass EMI

Solve the noise problem inside the power module.
→ Transformer shielding layer for CM noise

Don´t let the noise reach the LISN.
→ Y-Cap CM noise

Minimize the noise that reaches the LISN.
→ L-C Filter, common mode choke

EMI BASICS

Techniques for CM Noise Reduction

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Possible ways to get rid of the common mode at PCB level:

1. Chip Bead Ferrite – low attenuation, extremely cheap, additional series resistance → losses
2. Bridging (Y) -Cap – good attenuation, cheap → critical in safety applications
3. Common Mode Choke – high attenuation, cheap → losses

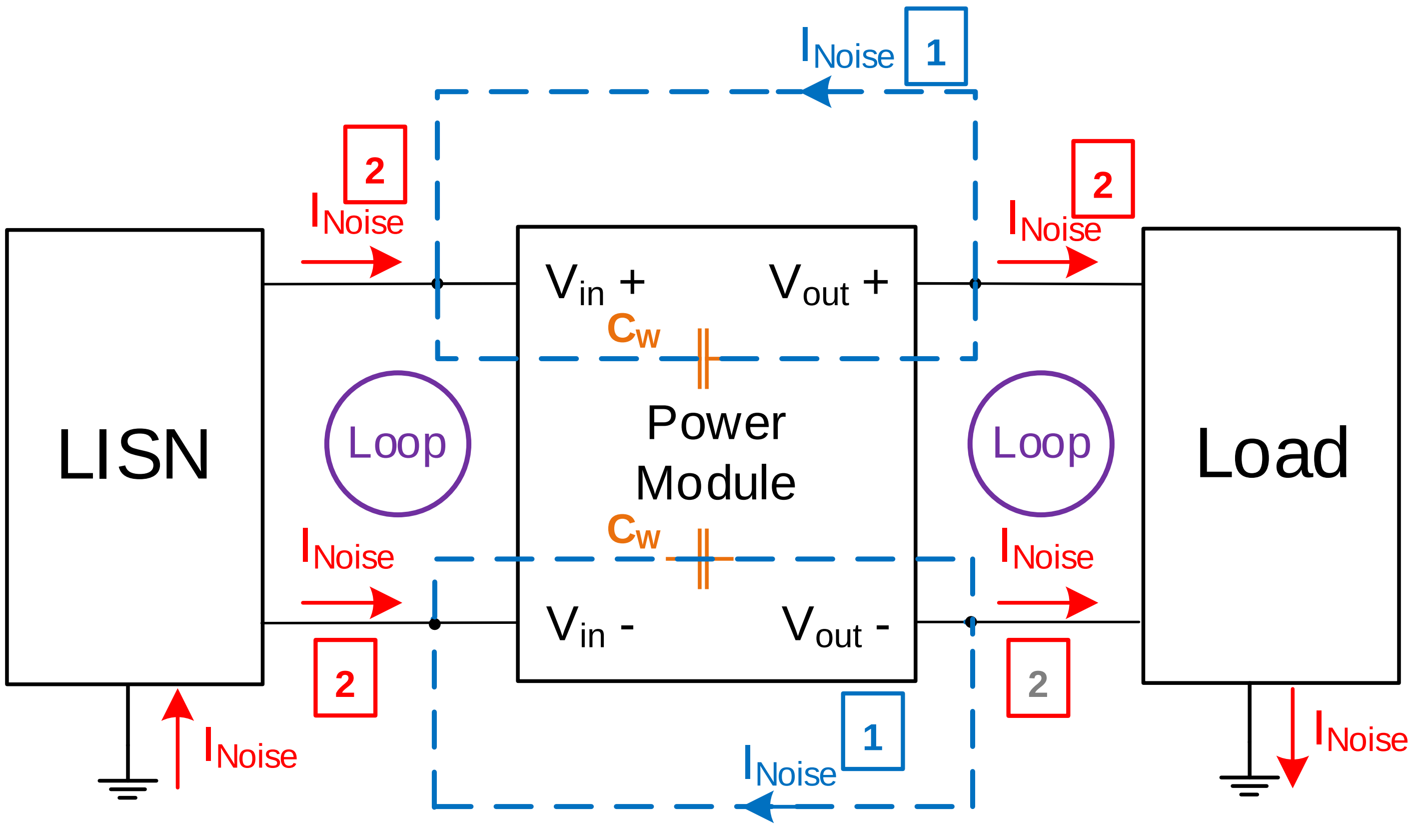
Alternative ways on system level:

1. Snap ferrite
2. Ferrite cores

EMI BASICS

Don´t let the Noise reach the LISN

Simplified electrical equivalent circuit



Circuit description

- The interference current is diverted
- Interference current circulates within the power module / through the power module
- No interference current through the LISN means no dBµV
- Smaller current loop means less radiation

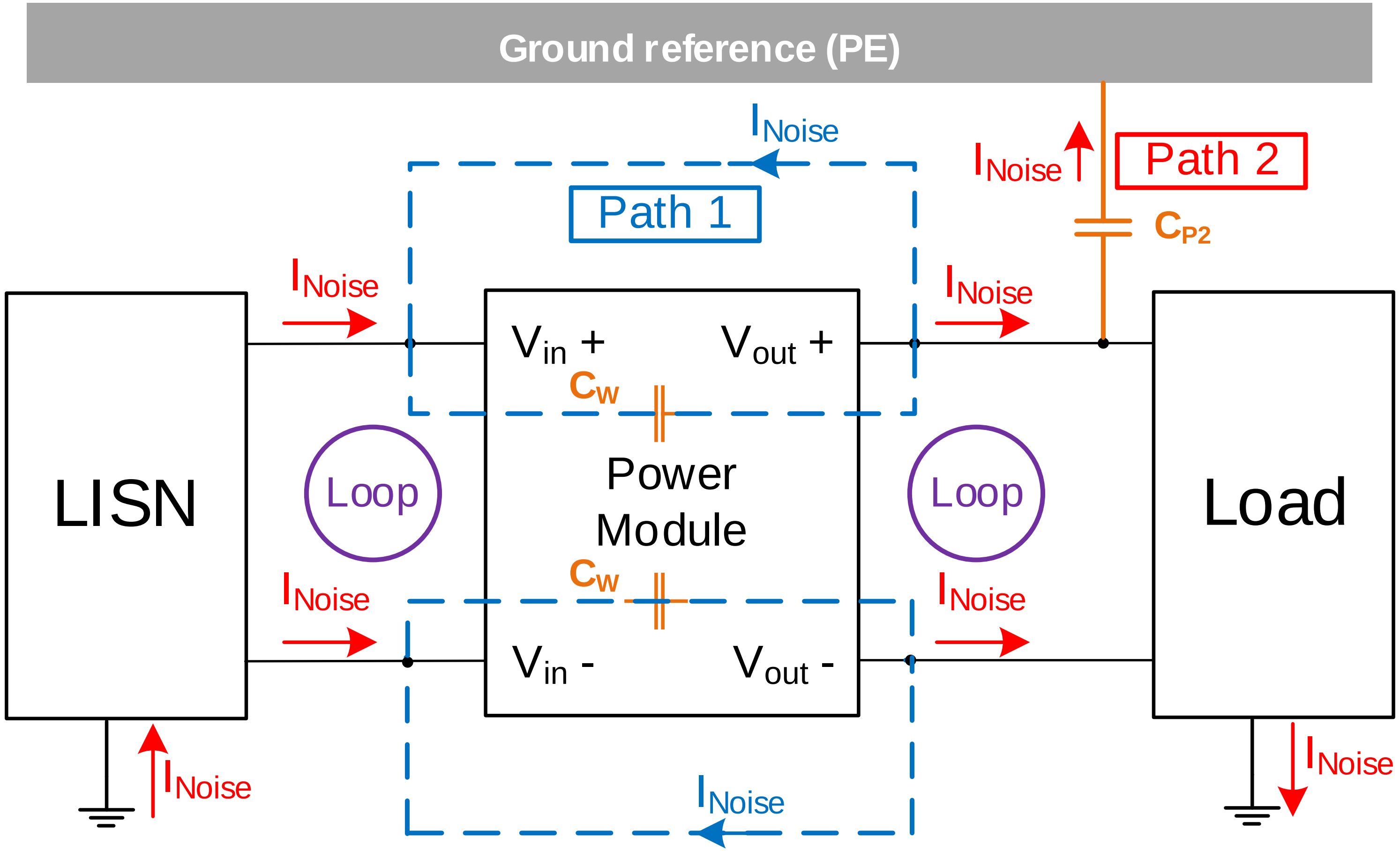
1 **Common mode current with diversion**

2 **Common mode current with out diversion**

EMI BASICS

Don´t let the Noise reach the LISN

Simplified electrical equivalent circuit



Requirements:

- Path 1 has to be more attractive for I_{Noise} than Path 2
- Path 1 has to be less impedant than Path 2
- Path 1 is the noise loop in the power module

EMI MEETS KIRCHHOFF

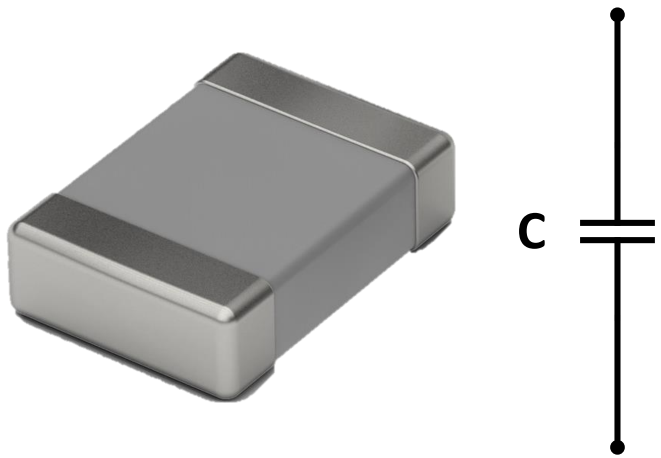
Electrical Equivalent Circuit - Simplified

WÜRTH ELEKTRONIK

Requirements for the branch:

- With increasing frequency it becomes less impedant
- It must ensure a separation between primary and secondary
- It must be easy to implement

➢ The answer…… a capacitor



Equation for X_c:

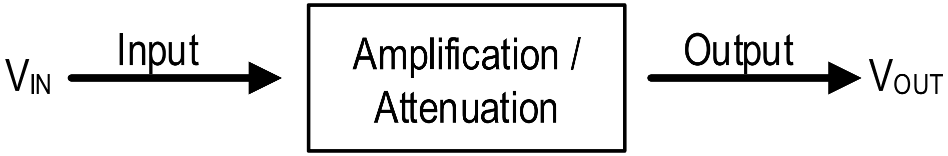
$$Xc = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

EMI MEETS KIRCHHOFF

Electrical Equivalent Circuit - Simplified

WÜRTH ELEKTRONIK

Basic considerations for attenuation



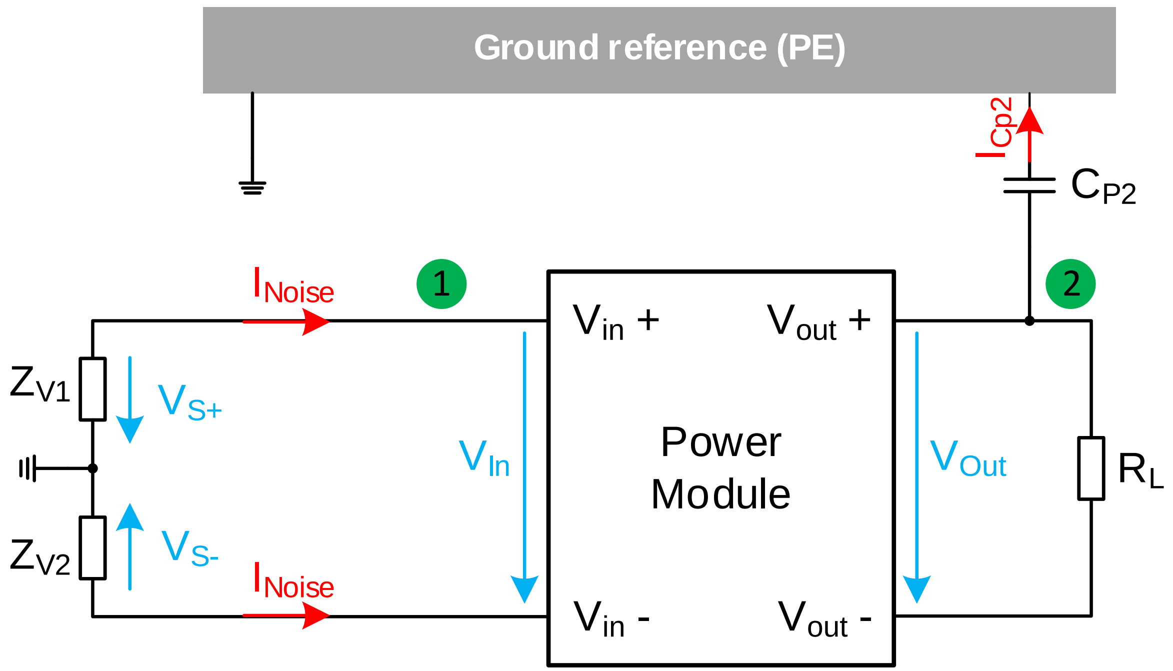
In this case we compare two systems:
1st system without Y-Cap (attenuation A1)
2nd system with Y-Cap (attenuation A2)

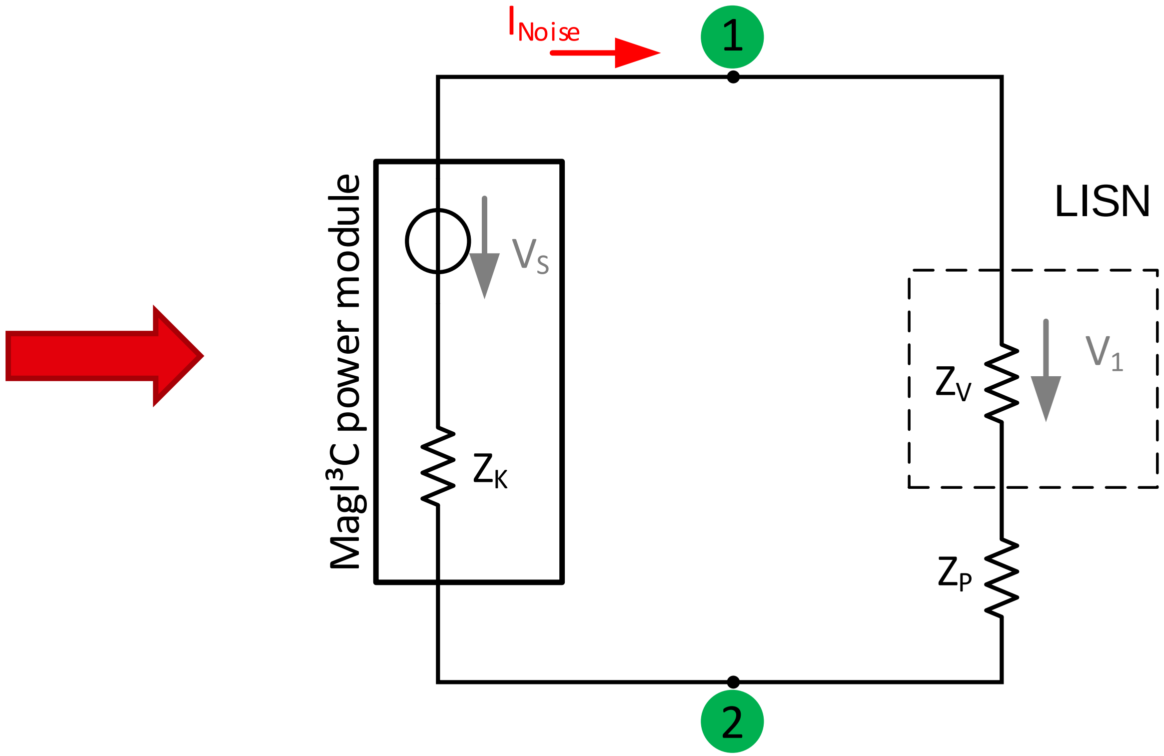
→ Attenuation A = A2 – A1

$$Attenuation\ A = 20 \cdot Log\left(\frac{Voltage\ drop\ LISN\ with\ Y - Cap}{Voltage\ drop\ LISN\ with\ out\ Y - Cap}\right) dB$$

EMI MEETS KIRCHHOFF

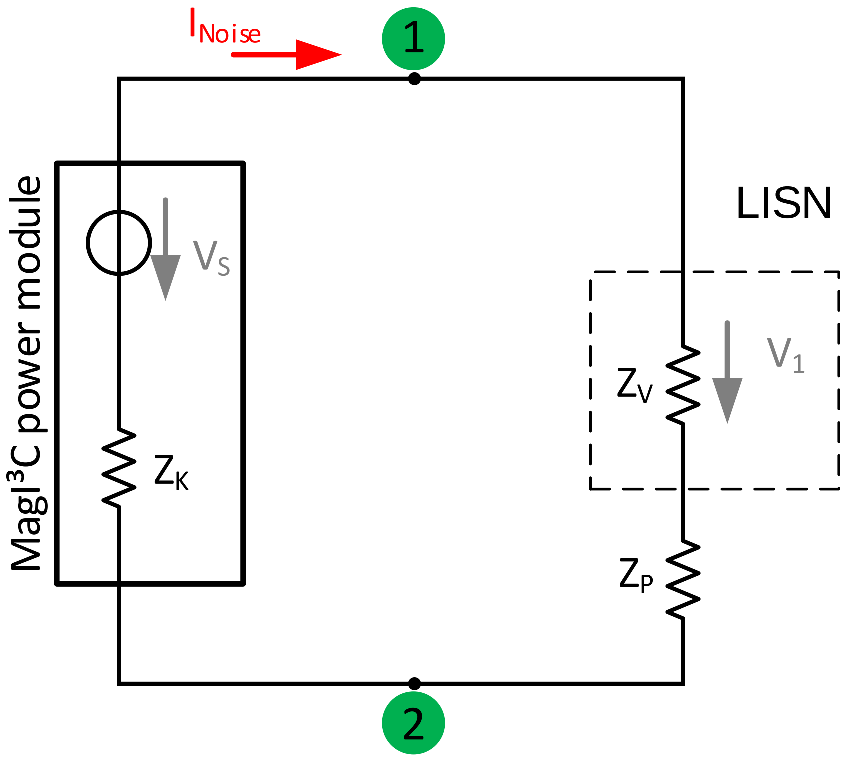
Electrical Equivalent Circuit - Simplified





EMI MEETS KIRCHHOFF

Electrical Equivalent Circuit - Simplified



Circuit description:

$$V_1 = V_S \cdot \frac{Z_V}{Z_K + Z_P + Z_V}$$

V_1 / V_2 – voltage drop LISN

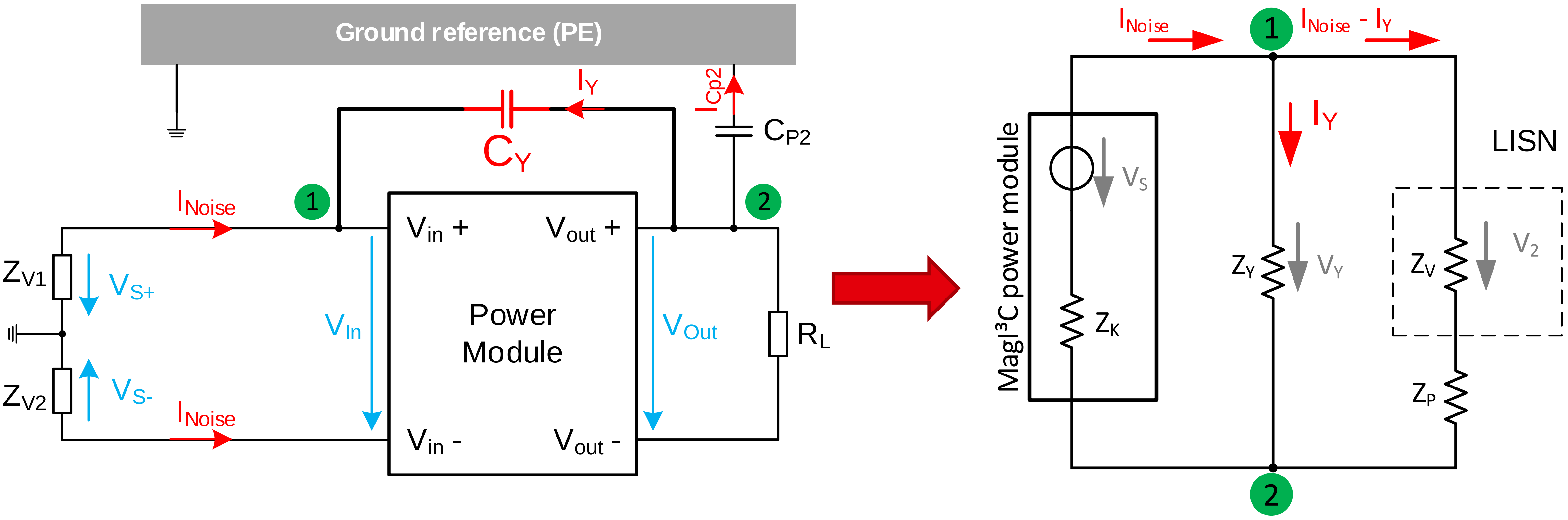
Z_K – impedance interwinding coupling capacity

Z_P – impedance parasitic coupling capacity

Z_V – impedance LISN

EMI MEETS KIRCHHOFF

Electrical Equivalent Circuit - Simplified



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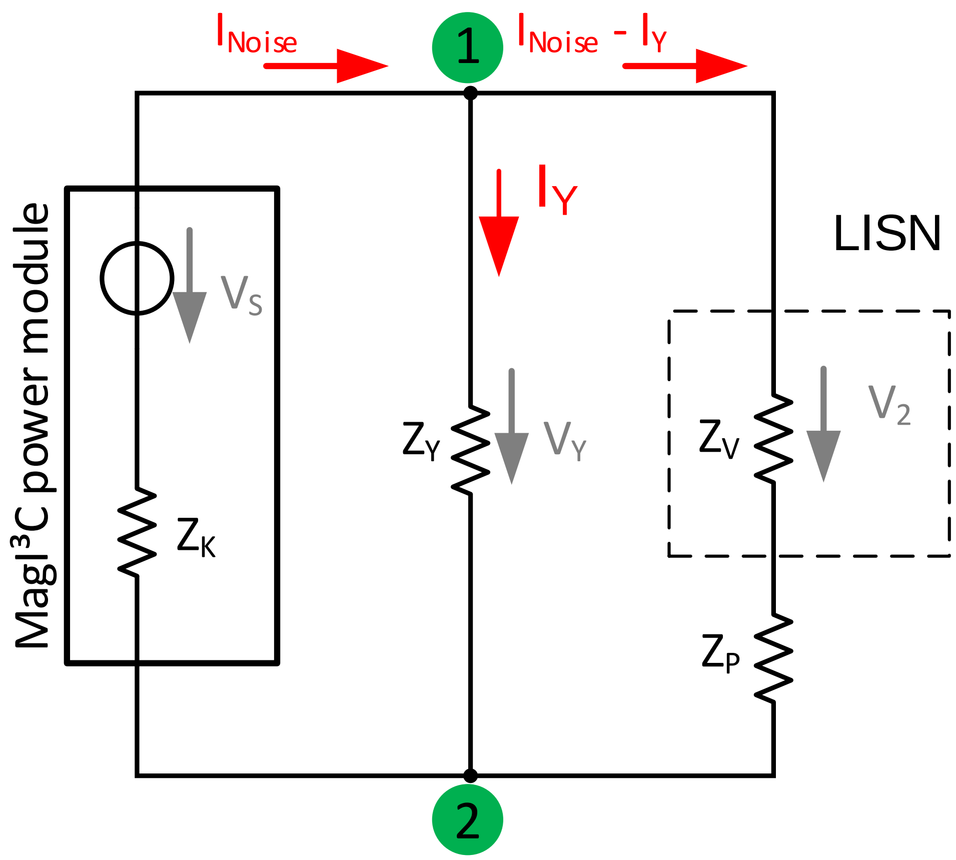
Electrical Equivalent Circuit - Simplified

WÜRTH ELEKTRONIK



Circuit description:

$$V_2 = V_S \cdot V_Y \cdot \frac{Z_V}{Z_P + Z_V}$$

$$V_Y = V_S \cdot \frac{Z_Y||(Z_P + Z_V)}{Z_K + Z_y||(Z_P + Z_V)}$$

V_Y – voltage drop Y-capacitor

Z_Y – impedance Y-capacitor

Equation for attenuation A

$$A = \frac{Z_K + Z_P + Z_V}{Z_K + Z_P + Z_V + \frac{Z_K}{Z_Y} \cdot (Z_P + Z_V)}$$

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Electrical Equivalent Circuit - Simplified

WÜRTH ELEKTRONIK

Example calculation for simplification of the equation:

$$C_P = 20pF \rightarrow 795\Omega \,@10MHz$$

$$C_Y = 470pF \rightarrow 34\Omega \,@10MHz$$

$$C_K = 75pF \rightarrow 212\Omega \,@10MHz$$

$$Z_V = 25\Omega$$

$$A = \frac{212\Omega + 795\Omega + 25\Omega}{212\Omega + 795\Omega + 25\Omega + \frac{212\Omega}{34\Omega} \cdot (795\Omega + 25\Omega)}$$

$$A = \frac{1032\Omega}{1032\Omega + \frac{212\Omega}{34\Omega} \cdot 820\Omega} = 0.1679 = \mathbf{0.168}$$

Further simplification:

$$A = \frac{\overset{(\approx 1000\Omega)}{1032\Omega}}{\underset{(\approx 1000\Omega)}{1032\Omega} + \frac{212\Omega}{34\Omega} \cdot \underset{(\approx 1000\Omega)}{820\Omega}} = \frac{34\Omega}{212\Omega} = \mathbf{0.160}$$

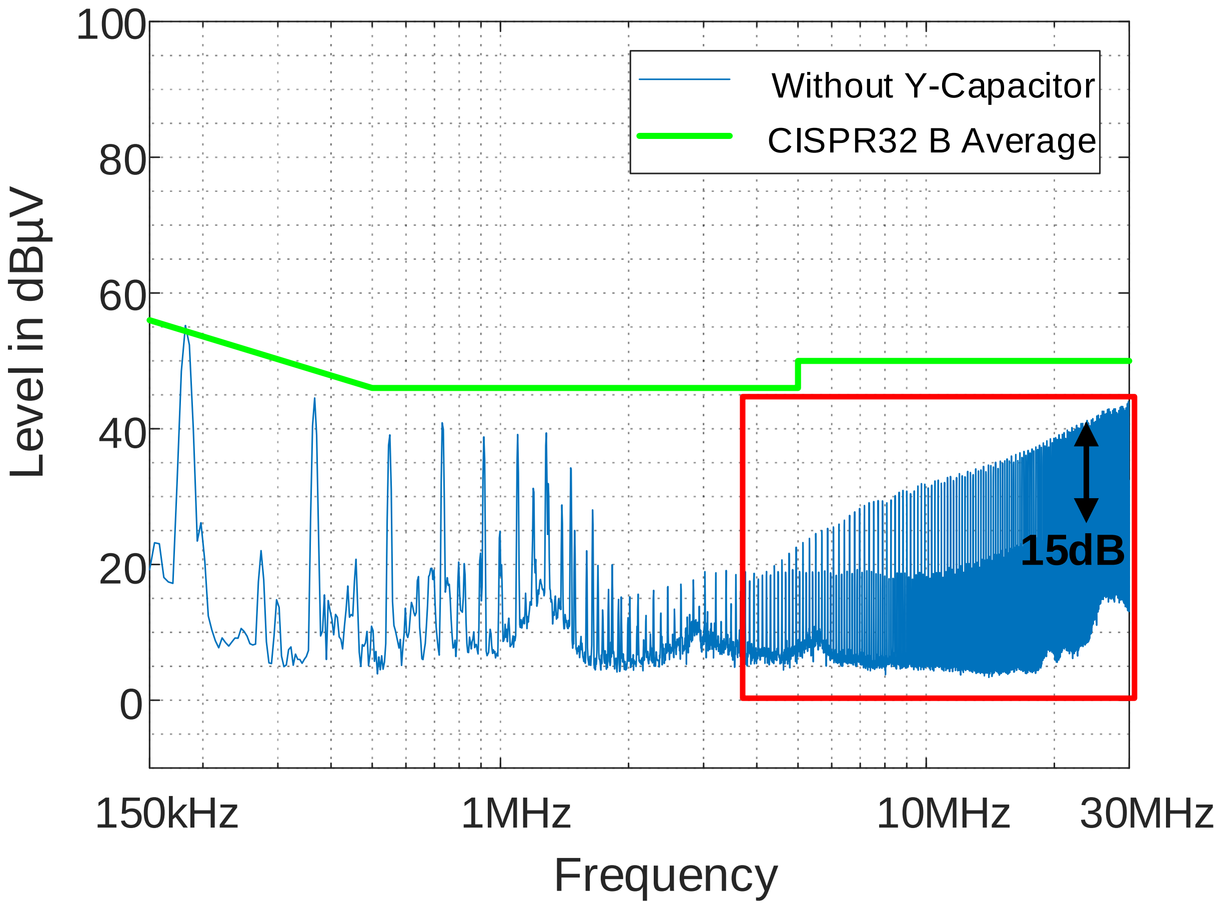
$$0.168 \approx 0.160$$

Simplified equation:

$$A = \frac{Z_Y}{Z_K}$$

EMI MEETS KIRCHHOFF

Finding Good Starting Values for the Bridging Capacitor – Numerical Example



Conditions:

- SIP-4 V_{IN} = 12V V_{OUT} = 5V I_{OUT} = 0.2A (PN:177920521)
- Conducted EMI measurement
- Scope of the example noise between 4MHz to 30MHz

  Peak value at 30MHz ca. 12 dBµV margin to class B

Step 1:

Desired attenuation from 4MHz to 30MHz of 15dB

EMI MEETS KIRCHHOFF

Finding Good Starting Values for the Bridging Capacitor – Numerical Example

WÜRTH ELEKTRONIK

Step 2:
Determination of the interwinding coupling capacitance of the transformer of the power module.

Screenshot datasheet SIP-4 V_{IN} = 12V V_{OUT} = 5V I_{OUT} = 0.2A (PN:177920521):

Isolation characteristics						
C_{ISO}	Isolation capacitance		-	-	75	pF
R_{ISO}	Isolation resistance		1	-	-	GΩ

- C_k = 75pF as a max value
- Typically measured at 100kHz
- C_k can expected as stable up to beginning GHz

EMI MEETS KIRCHHOFF

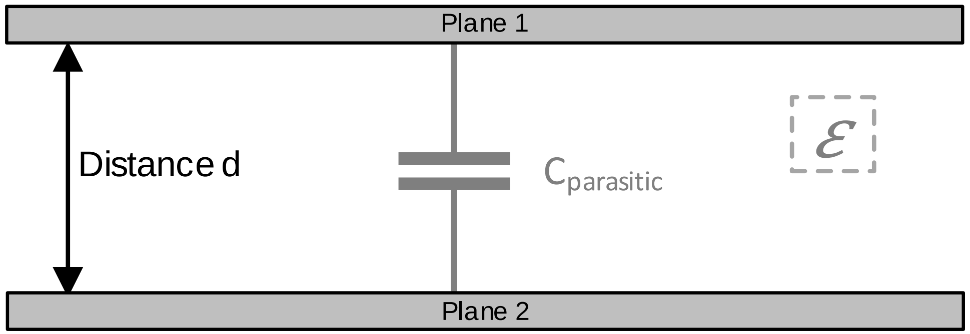
Finding Good Starting Values for the Bridging Capacitor – Numerical Example

WÜRTH ELEKTRONIK

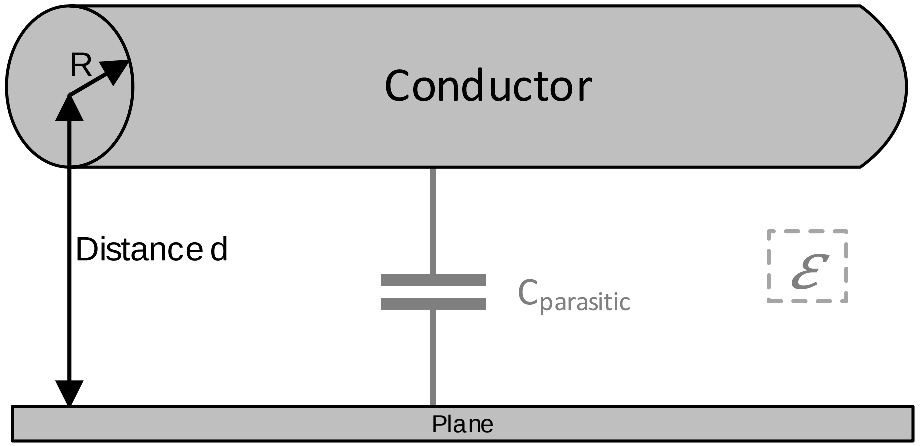
Step 3:

Determination of the parasitic coupling capacitance C_p of the DUT to the ground reference

Two parallel planes



One conductor parallel over a flat surface



$$C_p = \varepsilon \cdot \frac{A}{d} = 8.85 \cdot 10^{-12} \cdot \frac{1m^2}{0.4m} = \mathbf{2.2 \cdot 10^{-11} F}$$

$$C_p = \frac{2 \cdot \pi \cdot \varepsilon \cdot l}{arcosh\left(\frac{d}{R}\right)} = \frac{2 \cdot \pi \cdot 8.85 \cdot 10^{-12} \cdot 0.8m}{arcosh\left(\frac{0.4m}{0.001m}\right)} = \mathbf{6.65 \cdot 10^{-12} F}$$

EMI MEETS KIRCHHOFF

Finding Good Starting Values for the Bridging Capacitor – Numerical Example

WÜRTH ELEKTRONIK

Step 4:

Conversion logarithmic to linear

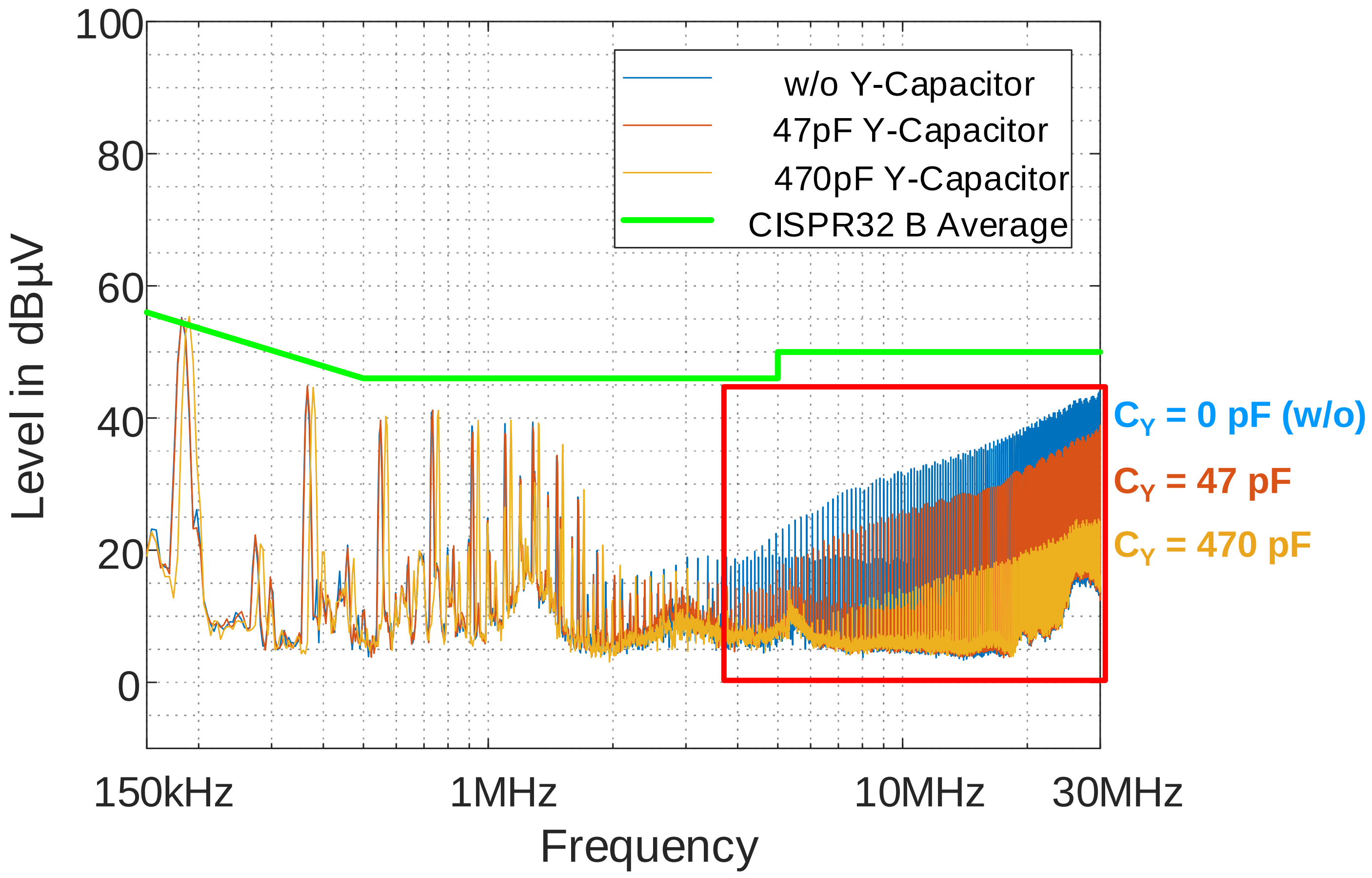
$$A = 10^{\left(\frac{xdB}{20}\right)} = 10^{\left(\frac{-15dB}{20}\right)} = \mathbf{0.177}$$

Calculating the starting value for C_Y

$$C_Y = \frac{C_K}{D} = \frac{75pF}{0.177} = \mathbf{421pF \approx 470pF}$$

REAL EMI MEASUREMENT

Example SIP-4 12V to 5V Isolated Power Module



Graph description

- Without any y-cap 12 dB to Class B limit
- With 47 pF y-cap nearly 7 dB damping
- With 470 pF y-cap nearly 19 dB damping

Result:

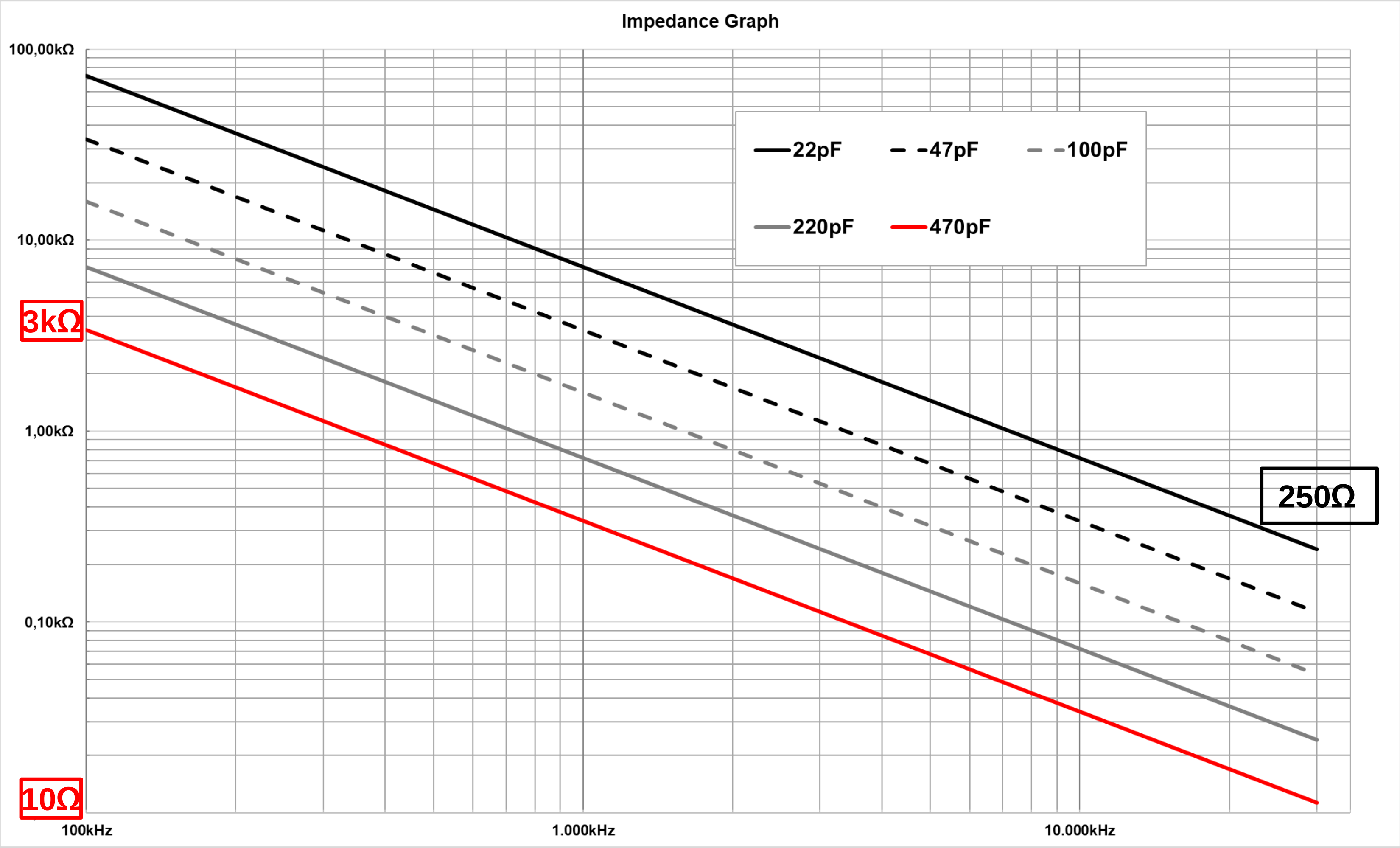
Damping with real cap is higher than calculated value.

→ C_k is lower than stated in the datasheet

→ 19 dB results in nearly 60pF interwinding capacitance instead of 75pF according to datasheet

REAL EMI MEASUREMENT

Impedance Graphs for the Bridging Capacitor – Ideal

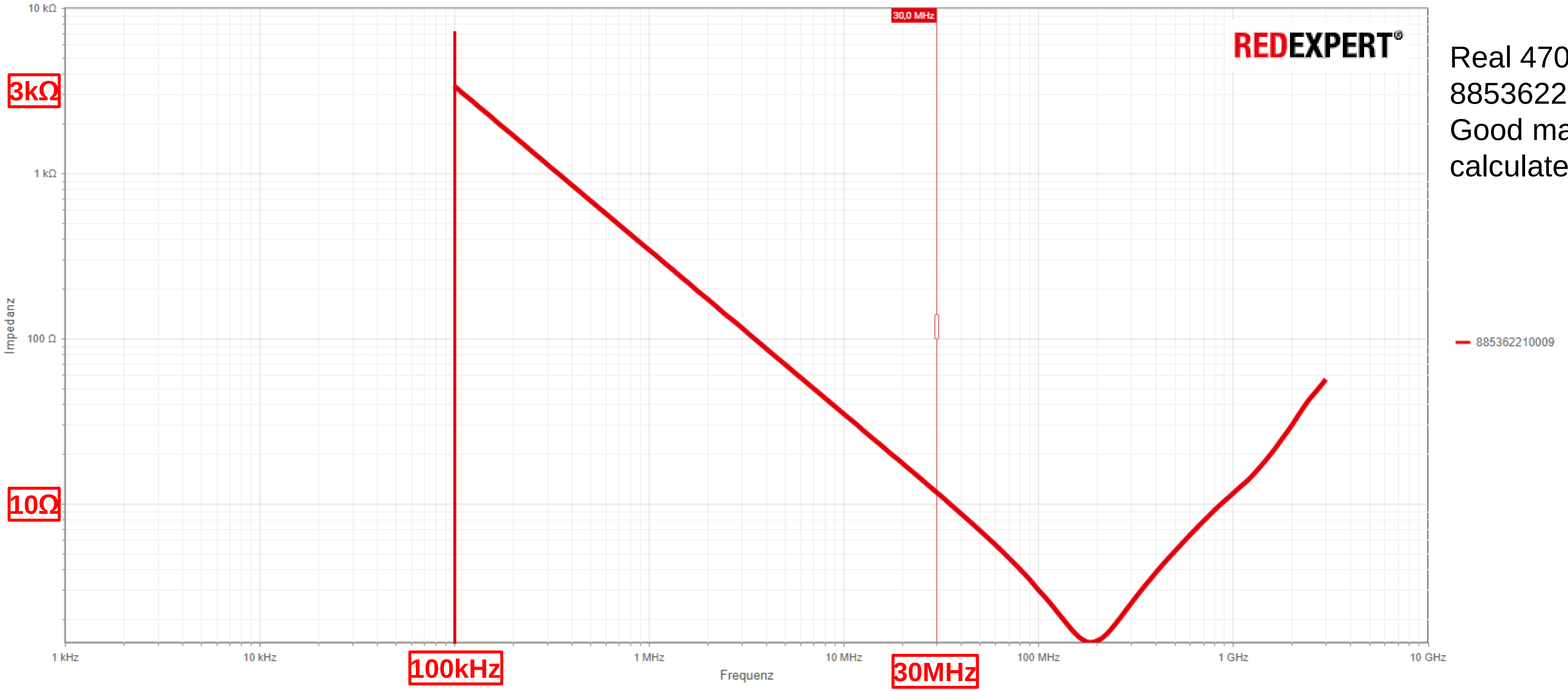


Description:

- Theoretical consideration without inductive component & ESR
- High impedance delta

REAL EMI MEASUREMENT

Impedance Graphs for the Bridging Capacitor – Real



Real 470pF MLCC
885362210009
Good match to
calculated values

APPLICATION SPECIFIC EMI FILTERS

Service of MagI^{3}C Power Modules

EMI Filter Support / Filter Bags

- Separate part number for filter bag
  → *easy sampling*
- Picture of the filter bag
  → *clear visualisation of what is included*
- Characteristics and Applications
  → *capabilities and what for*
- Bill of materials (BOM) with all included parts
  → *for copy and paste in application BOM*
- Links to related MagI^{3}C power module datasheet included
  → *complete description of filter implementation and measurement results*
- Links for all included filter parts datasheet included
  → *quick access to discrete components specification*

Find all available Filter Bags on https://www.we-online.de/katalog/en/APPLICATION_SPECIFIC_FILTER

Thank you for your Attention!

→ Support request to our hotline: powermodules@we-online.com

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Contacts:

Design-In Support

EMC Filter Design Support

Layout Review Support

Thermal Design Support

Questions
& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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