Wurth Electronics (UK) Ltd

Practical EMI Filter Design Considerations – Part 1

19th September 2017

Presented by

Mohamed AlAlami
Field Application Engineer - UK

Agenda

- **Magnetics and Materials**
- **EMI Transmission Modes and Filter Topologies**
- **REDEXPERT**
- **Practical EMI Filter Design Considerations**

MAGNETICS AND MATERIALS

What is an Inductor ?

… technical aspect

- a piece of wire wrapped on something

We also see inductance …

- as parasitic effects

THE INDUCTOR IS USED TO STORE THE ENERGY

- **DC/DC converter topology**
  - **Buck**
  - **Boost**
  - **Sepic**

- **What are the main difference between these inductors?**










Inductors/Ferrites

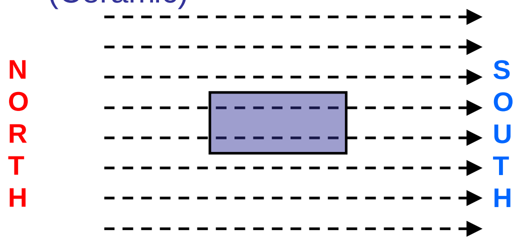
- **Shape & size : Different construction**
  - **THT, or SMT**
  - **Toroidal , Solenoidal (Rod core), Multilayer**
  - **Shielded or not shielded**
  - **Wire (Round, Flat, Multi-wire,..)**

- **Different material**
  - **NiZn**
  - **MnZn**
  - **Iron alloy**
    - **Superflux**
    - **WE-Perm**
    - **WE-Perm2**
  - **Iron Powder**

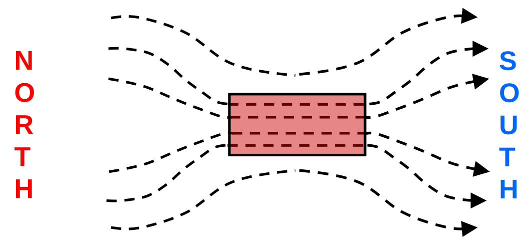
Core Material - Permeability

Air

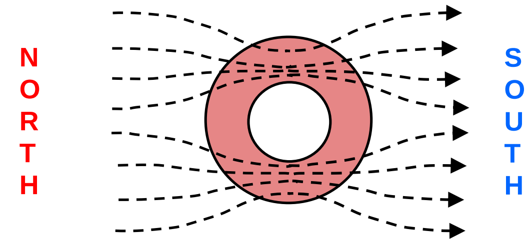
(Ceramic)



Rod core ferrite



Ring core ferrite



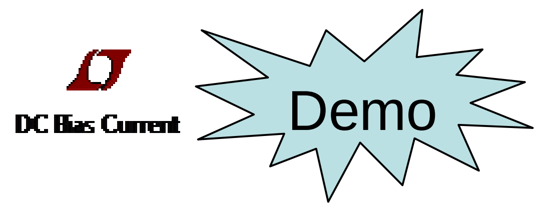
Induction in air:

$$B = \mu_0 \cdot H$$

linear function, because μr = 1 = constant!

Induction in a ferrite:

$$B = \mu_0 \cdot \mu_r \cdot H$$



The relative permeability is a: **material- frequency- temperature- current- Pressure-** **-dependent parameter**

Core Material - Permeability

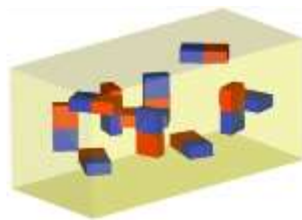
Relative permeability

- describes the capacity of concentration of the magnetic flux in the material

$$\mu_r = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H}$$

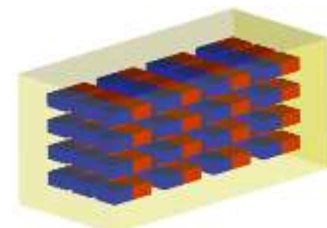
Ferrite material

- unordered (random position)
- soft magnetic



Permanent magnet

- ordered
- hard magnetic

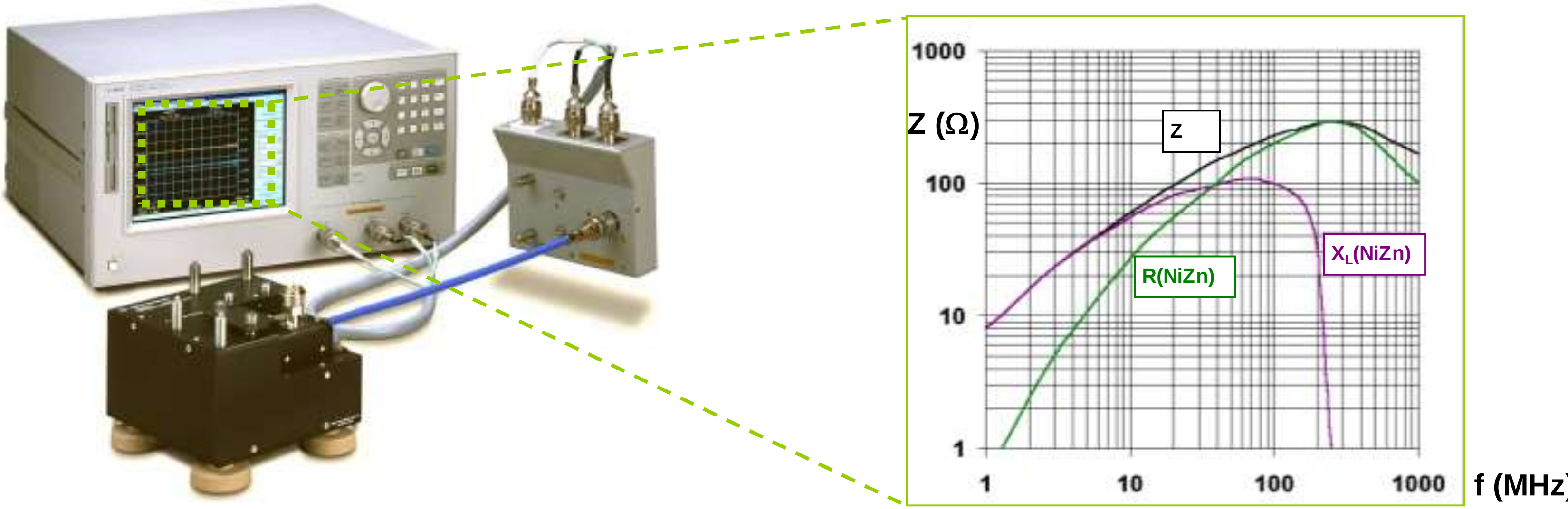


Typical permeability μ_r:

- Iron Powder/ Superflux: 50 ~ 150
- Nickel Zinc (NiZn): 40 ~ 1500
- Manganese Zinc (MnZn): 300 ~ 20000

Core Material – Permeability

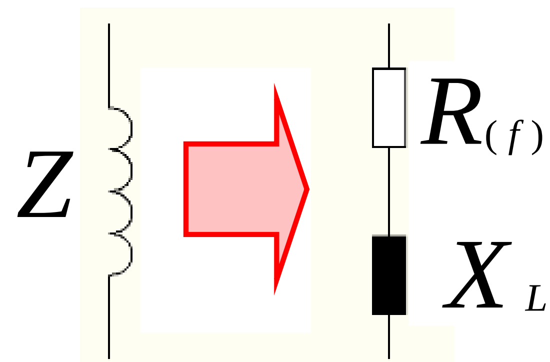
=1 turn



NiZn
MnZn
Iron Powder

Core material-Parameter

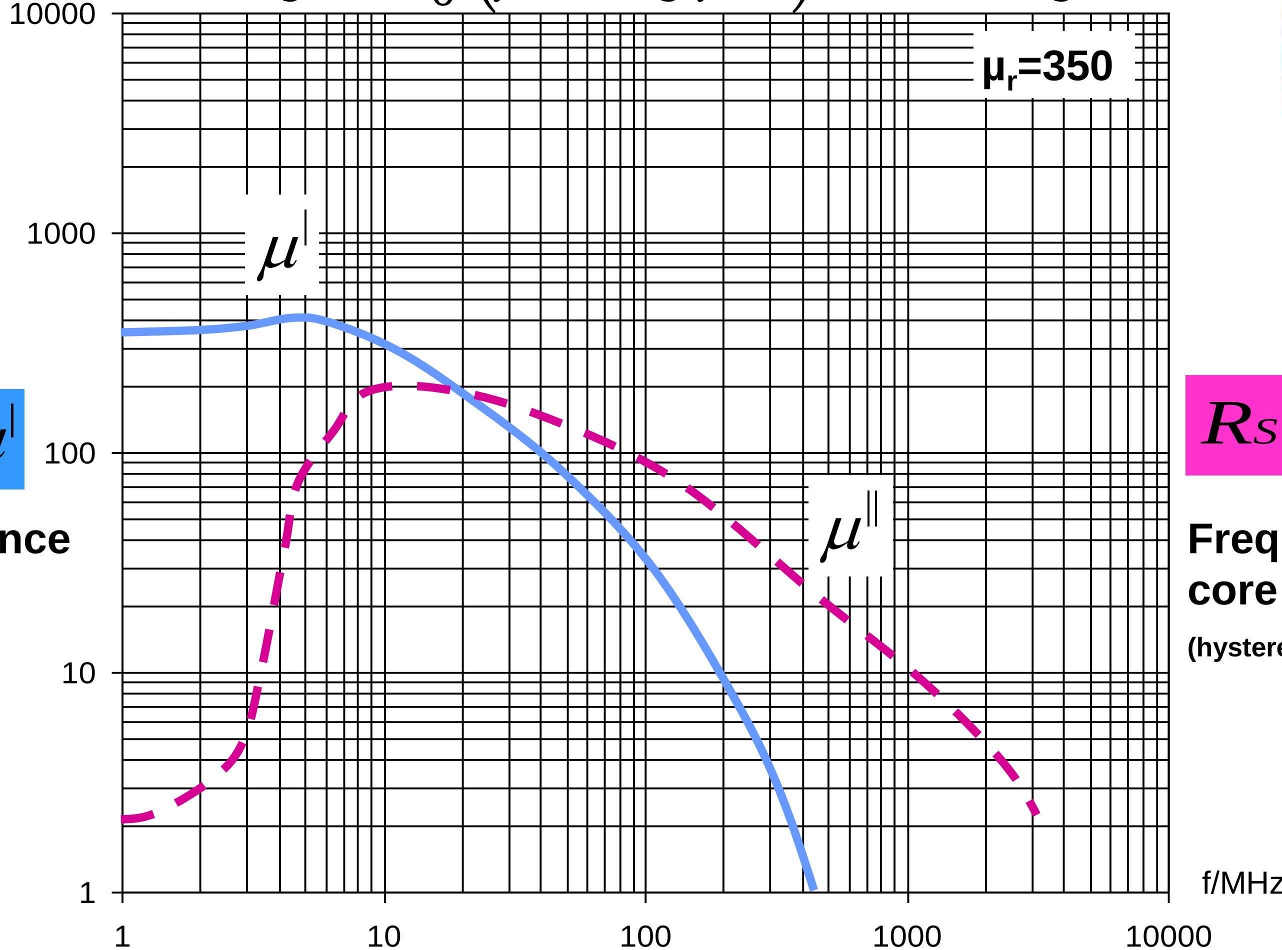
<u>Replacement circuit</u>



$$Z = \sqrt{R_{(f)}^{2} + X_{L}^{2}}$$

Core Material – Permeability

$$\underline{Z} = j\omega L_0\left(\mu' - j\mu''\right) = R + jX$$



$$X_{LS} = \omega L_0 \mu'$$

Inductive reactance

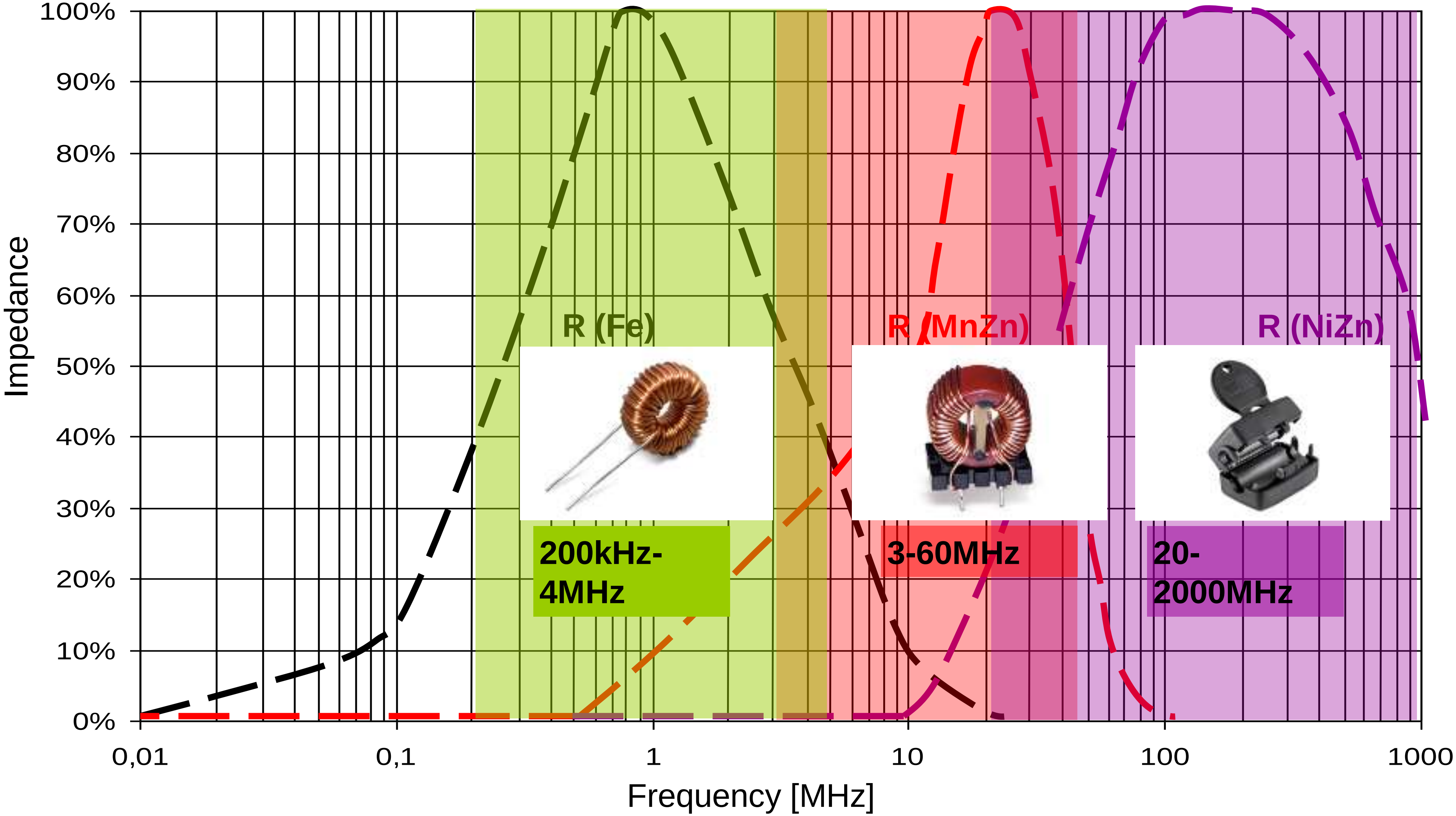
(Magnetize ability)

$$R_S = \omega L_0 \mu''$$

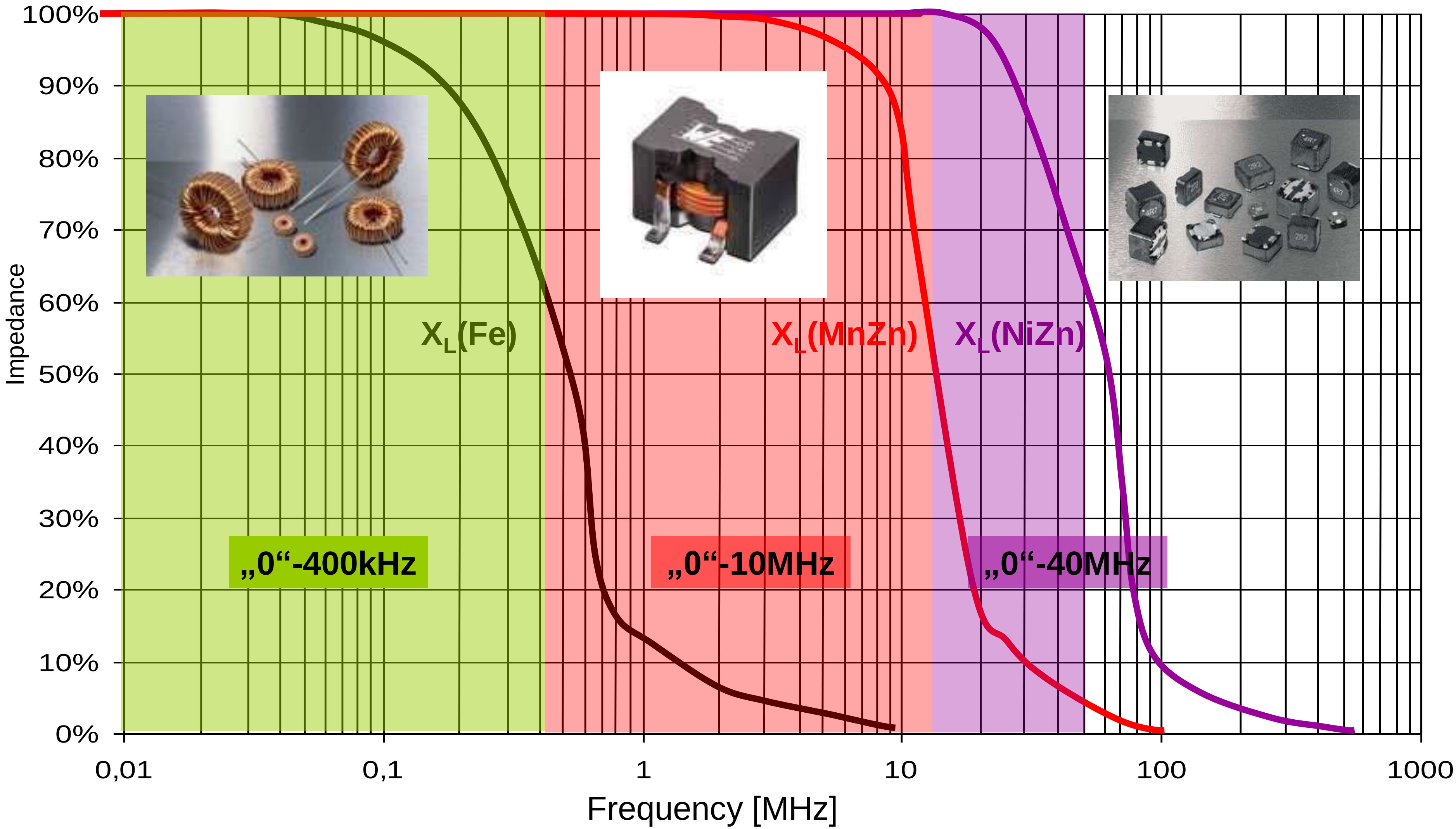
Frequency dependent core losses

(hysteresis loss)

Core Material – Resistance



Core Material – Inductance



Core Material – Saturation/Frequency

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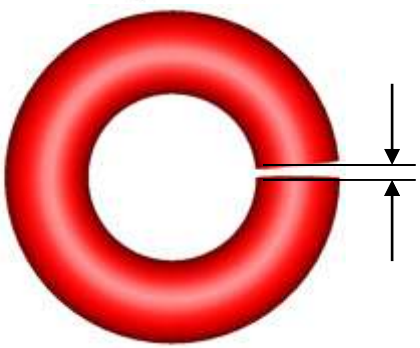
Core Materials	Core Loss	Perm f(DC bias)	Relative Cost	Frequency Range	Saturation Flux density (B_{sat})	Temp Stability
Iron Powder	Highest	-	Lowest	200kHz	15.000 Gauss (1,5 Tesla)	-
Ni Zn	Lowest	-	Low	10MHz	4.500 Gauss (0,45 Tesla)	-
WePerm	Low	+ +	Low	3 MHz	10.000 Gauss (1.0 Tesla)	++
SuperFlux	Medium	+++	Medium	1.0 MHz	12.000 Gauss (1,2 Tesla)	+++

Switching Frequency ⬄ Core Material

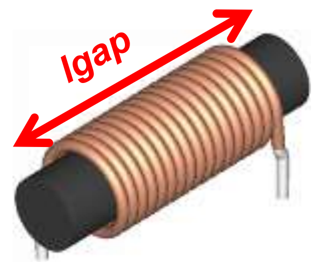
INDUCTOR / inductance

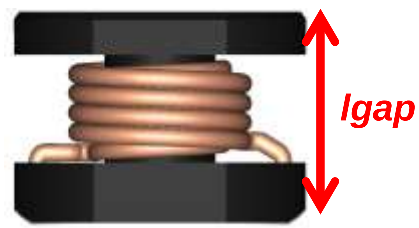
$$L = \frac{(\mu_0 * \mu_r * A_{eff} * N^2)}{l_{eff}}$$



$$l'_{eff} \sim l_{eff} + l_{gap} \mu_r$$

μ_r = relative permeability
N = No. of turns
A_{eff} = effective magnetic area
l_{eff} = effective magnetic length





Higher l_{eff} ↑ Lower L ↓

Core Material – Shielding

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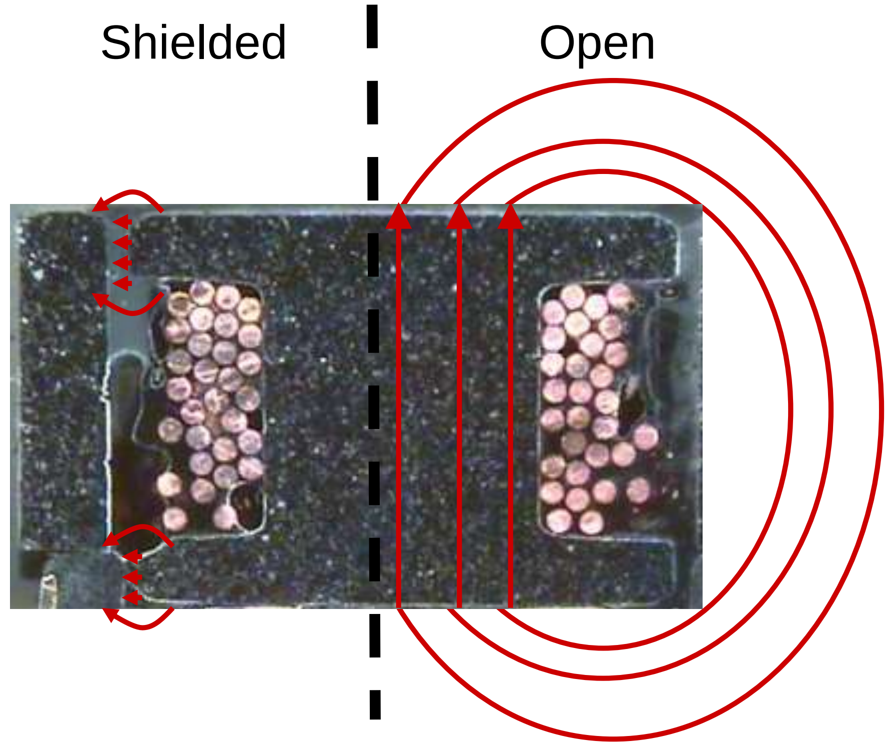

Advantage of the shielded inductor => smaller Gap

⇒ Less turns to reach the L value => Lower DCR compare to a open version

⇒ With big air gap the inductance is less dependent of the core material

EMI TRANSMISSION MODES AND FILTER TOPOLOGIES

EMC Impact

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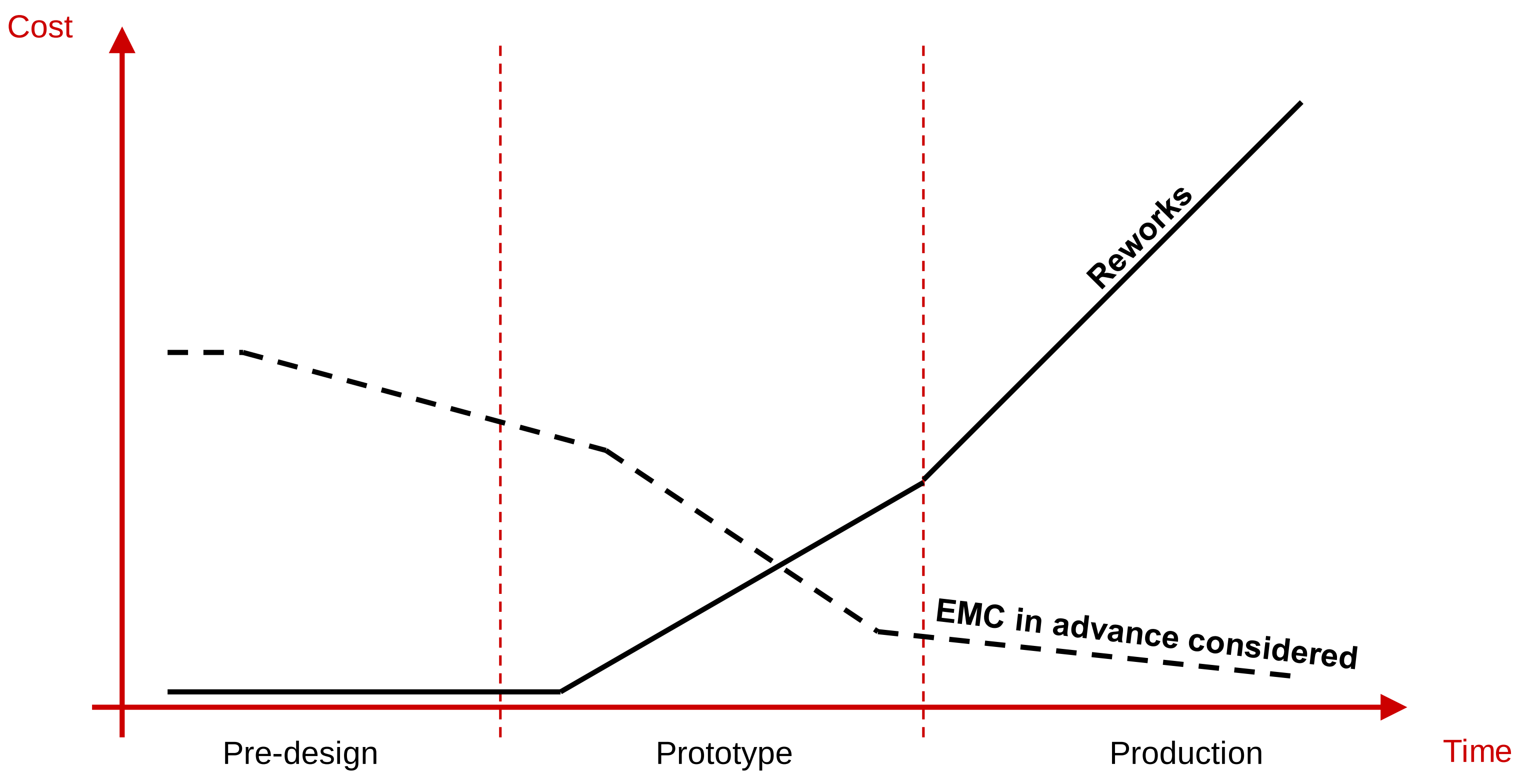
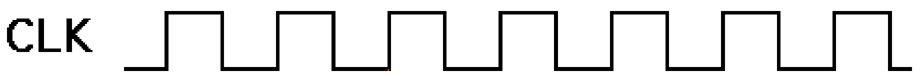
Economical point of view:

- Dependent on when EMC conformity is considered in a design phase

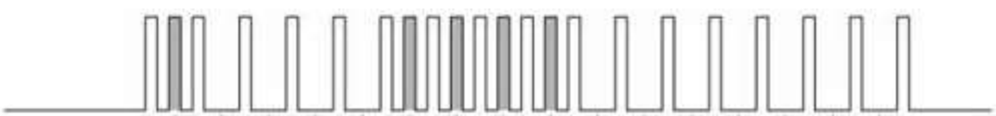


What causes EMI in a product?

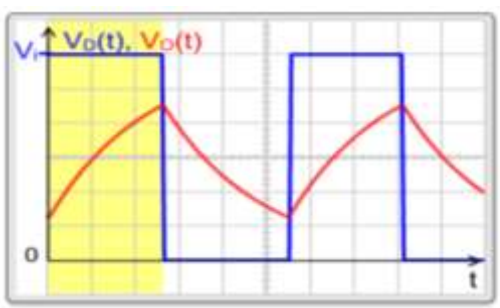
- **Clock frequencies.** **E.g Crystal 25MHz, CPU 2.6GHz**

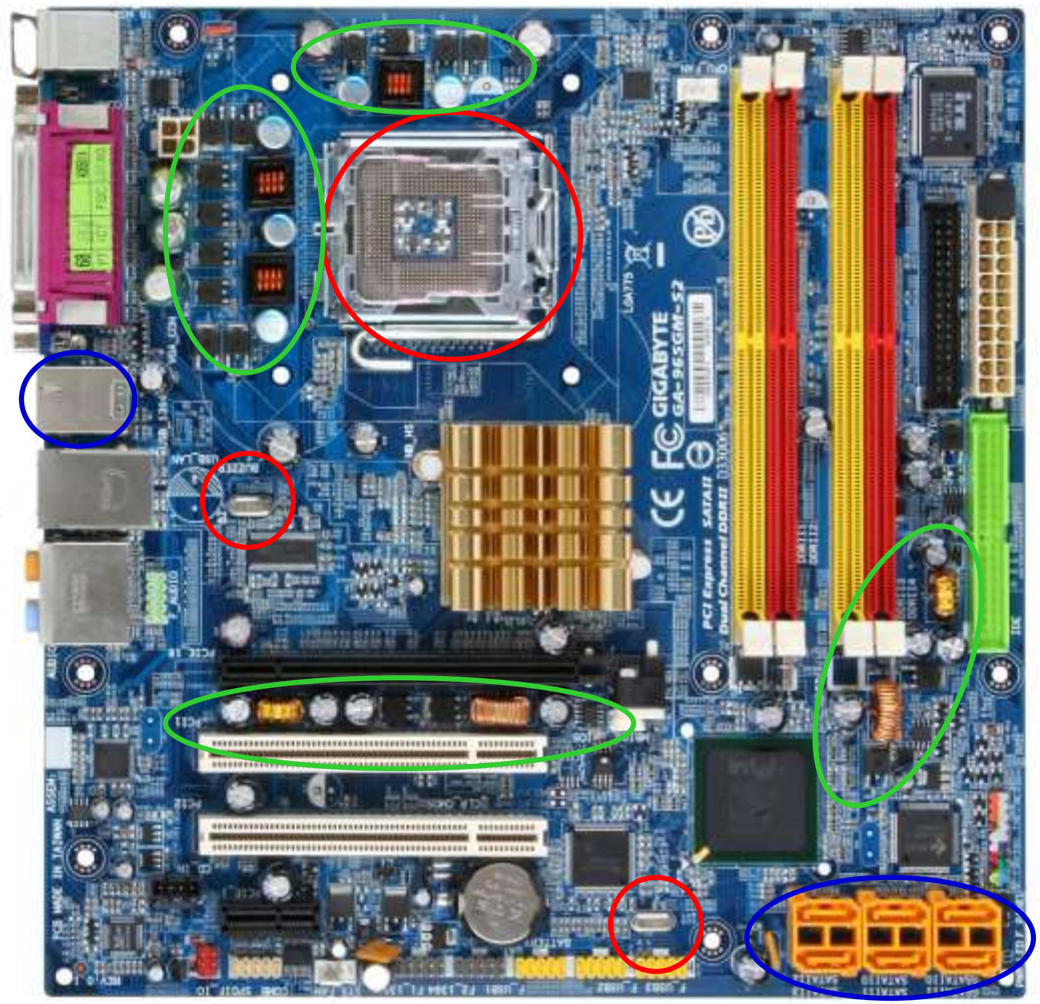


- **Data rates.** **E.g USB 2.0 480Mbps, SATA II 300Mbps**



- **DC/DC convertors and Switch mode power supplies (SMPS)** **E.g 135kHz, 2MHz**





Transmission modes

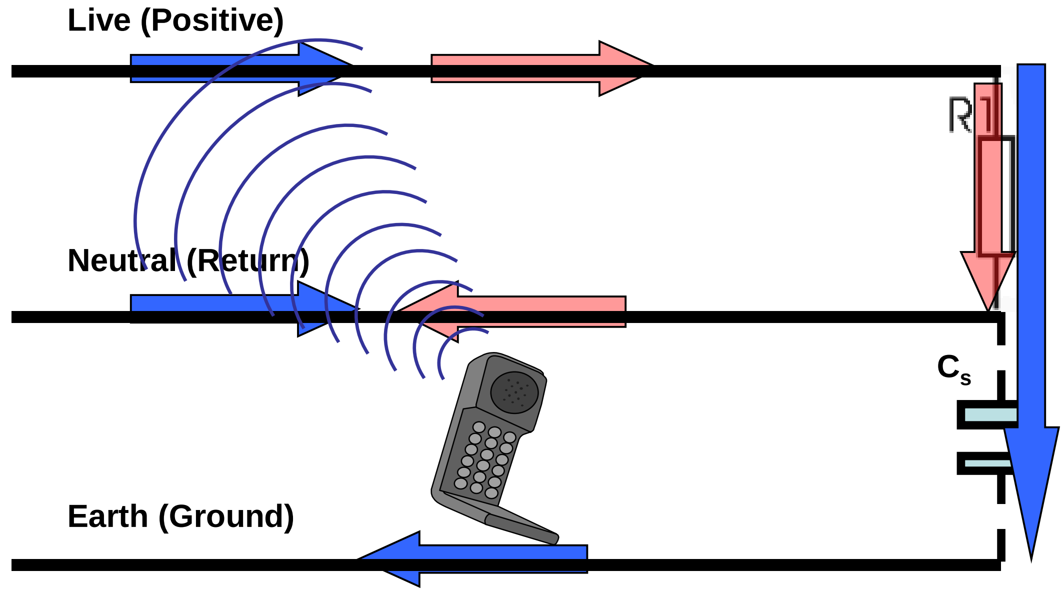
- **Recognize the transmission mode:**

Differential Mode (DM)

Signals on a line(s) with a return path

Common Mode (CM)

Noise on all lines propagating in the same direction with respect to earth



EMC – Coupling

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→ **Primary procedure**

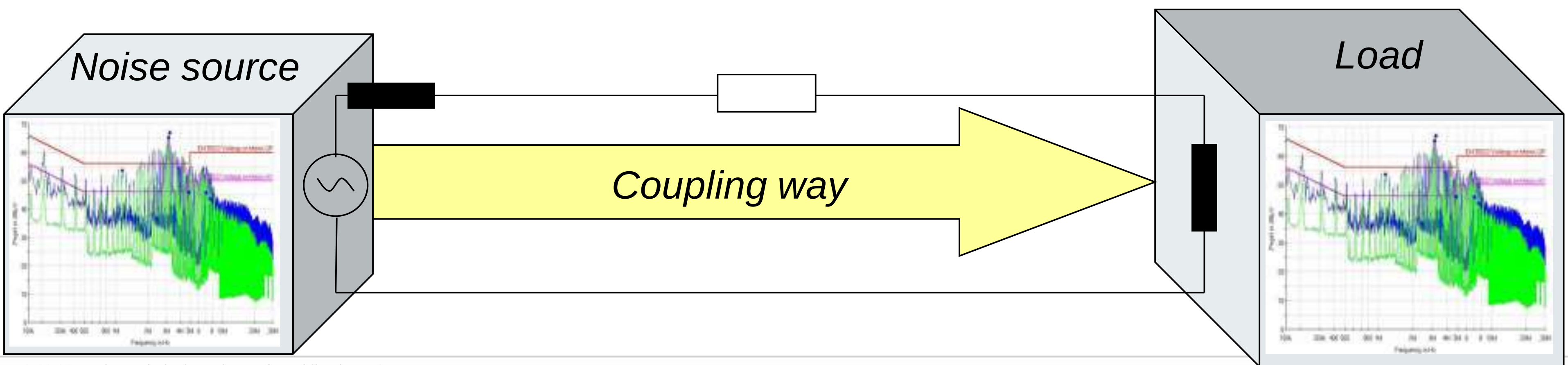
…to aim to source a low noise

→ **Secondary procedure**

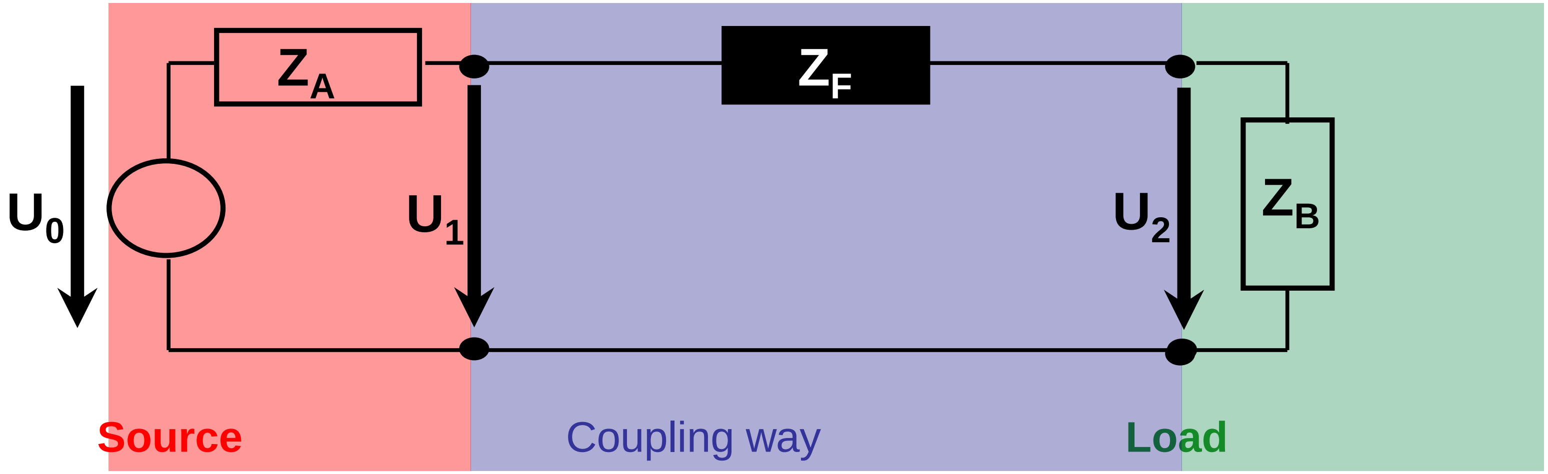
… eliminate the noise through interrupting the coupling way

→ **Tertiary procedure**

… increase the noise immunity at load



Insertion loss – Mathematical Definition



- System attenuation

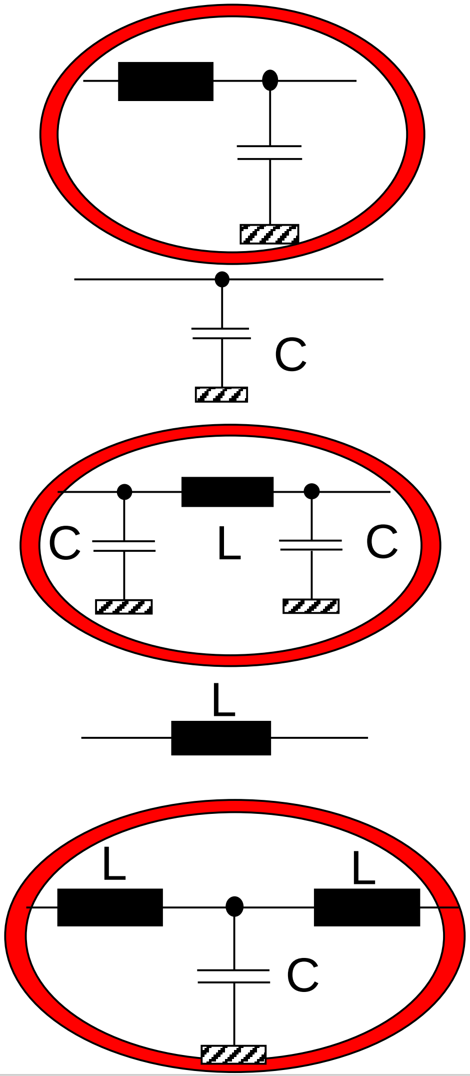
$$A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \quad in\ (dB)$$

- Impedance

$$Z_F = \left[10^{\frac{A}{20}} \cdot \left(Z_A + Z_B \right) \right] - \left(Z_A + Z_B \right) \quad in\ (\Omega)$$

Insertion loss – Differential Filter Topologies

Source Impedance	Load Impedance
low	high
high	high
high or unknown	high or unknown
low	low
low or unknown	low or unknown



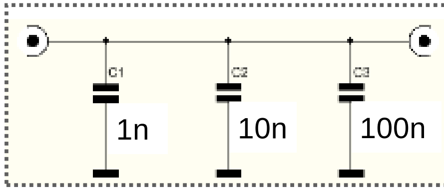
→ small C = higher SRF

Choose ferrite bead
= build no resonance with C
= broadband filter

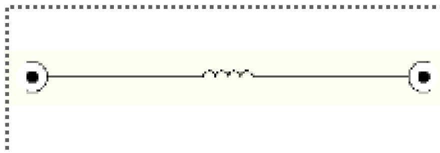
Pay attention to:
SRF of used components

Filter topologies – Demo board

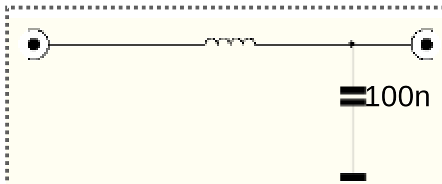
- Parallel-C-filter



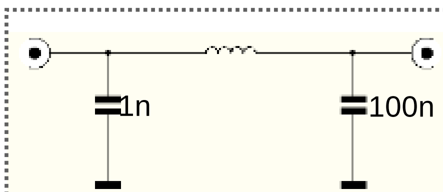
- L-filter



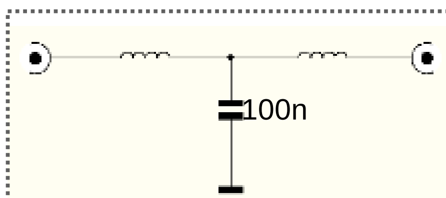
- LC-filter

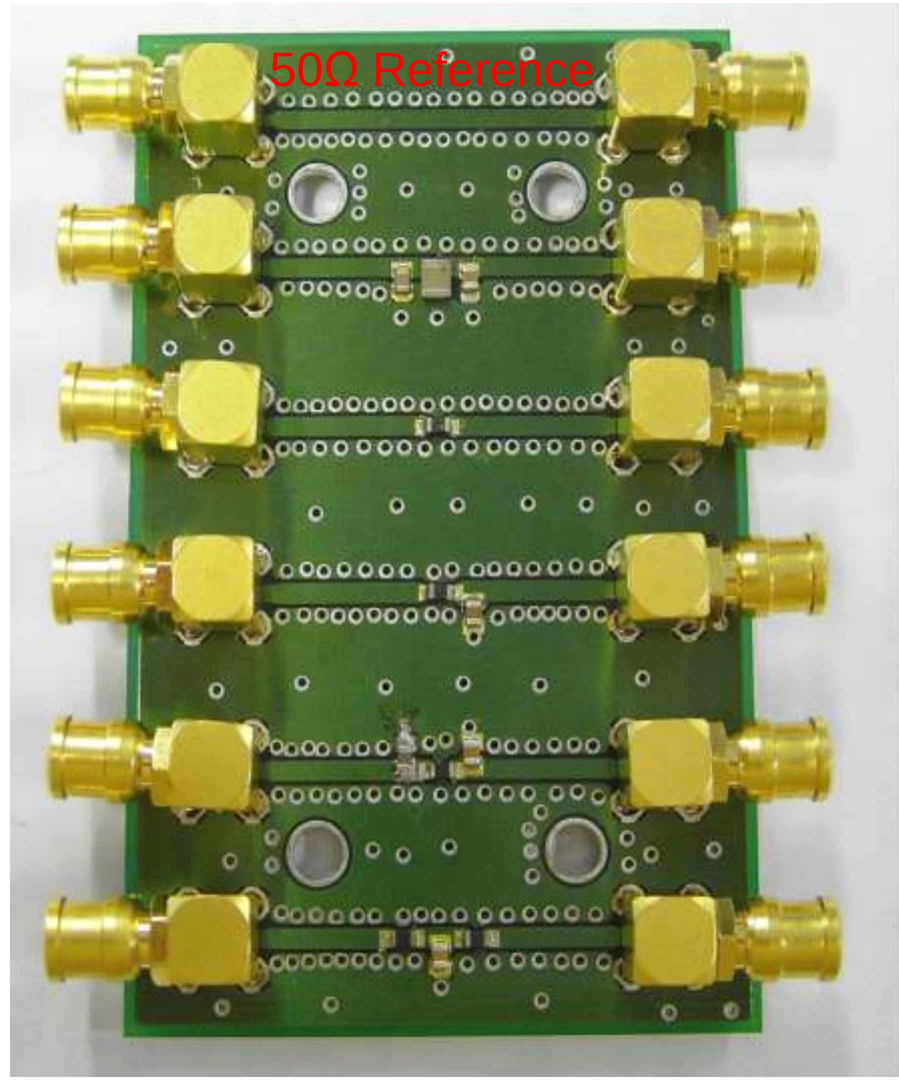


- Π-filter

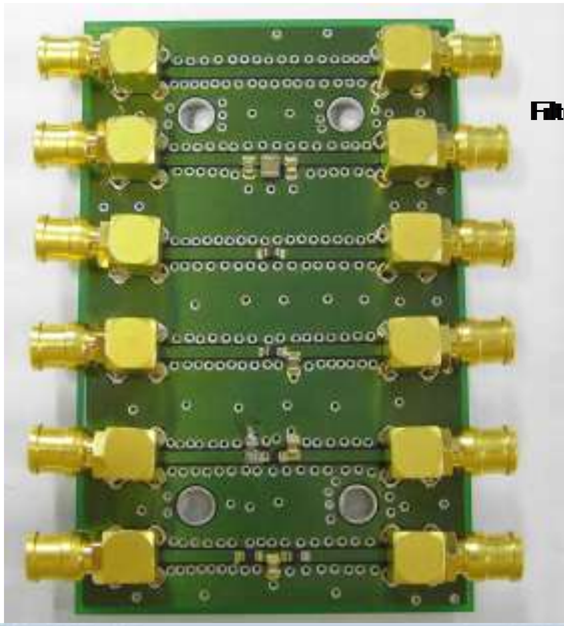


- T-filter

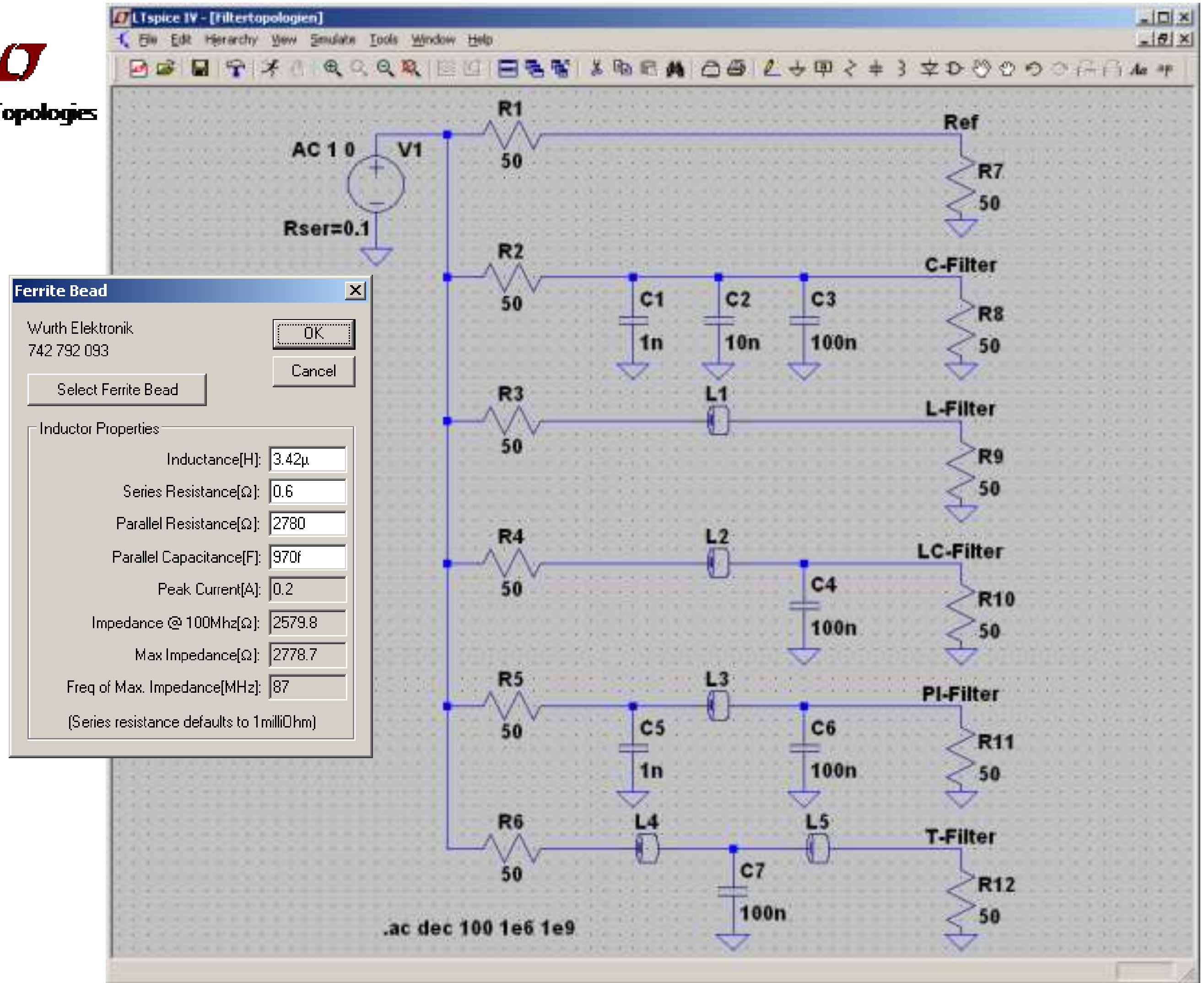


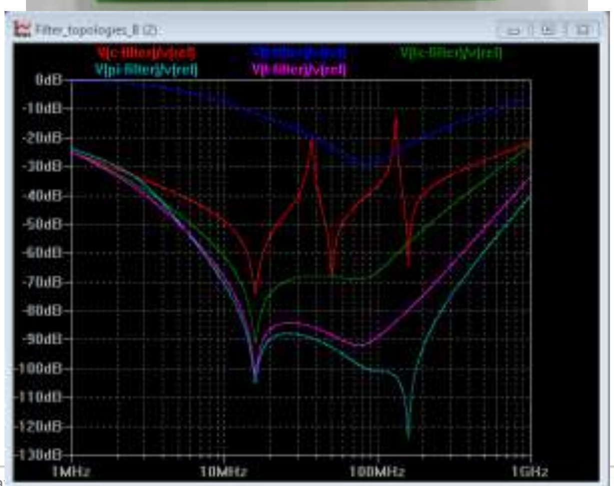


Filter Topologies – LT Spice Simulation



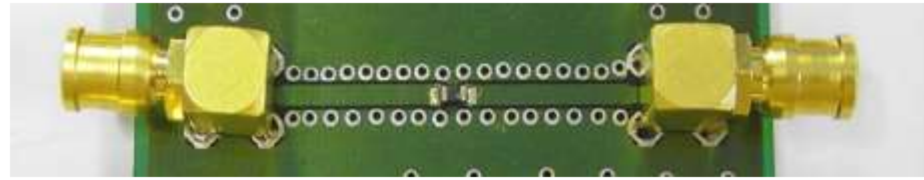
Filter Topologies





Filter topologies – L-filter

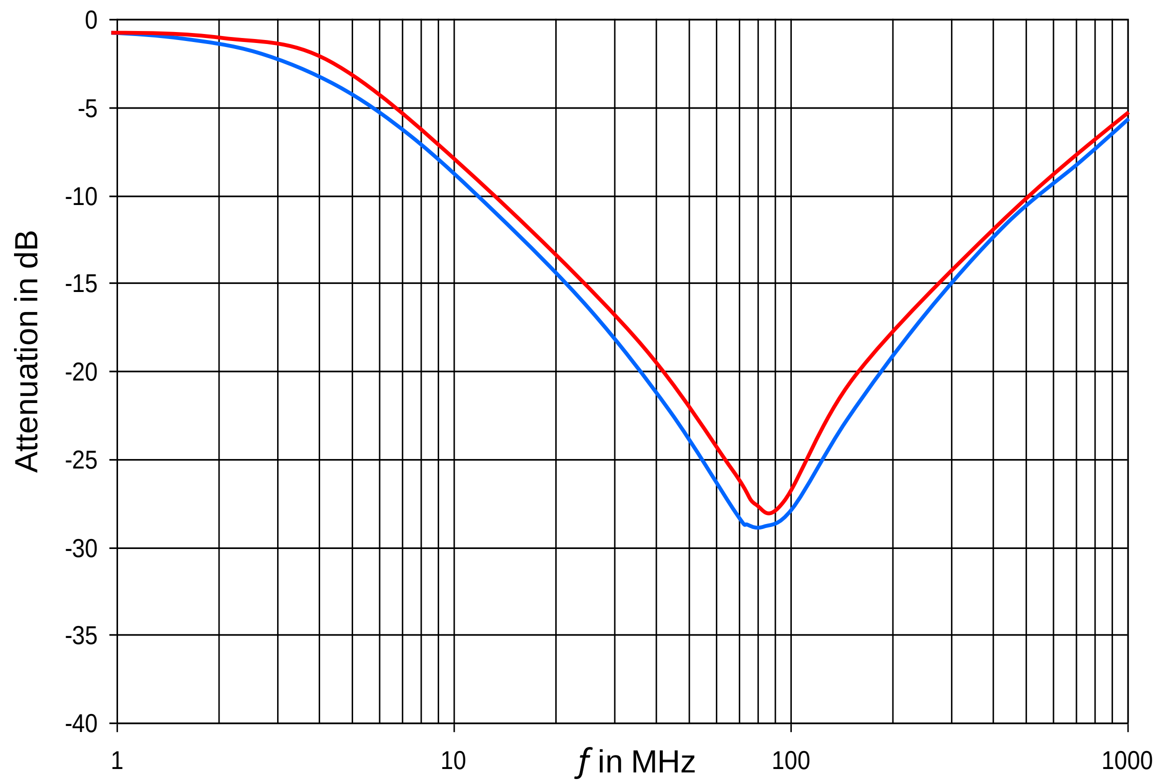
- L-filter



- A chip bead ferrite is used as an inductance.
- WE-CBF 742 792 093:

Z_{max} = 3000Ω @ 80MHz

A = -29dB @ 80MHz

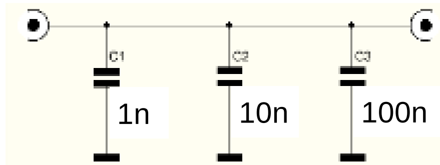


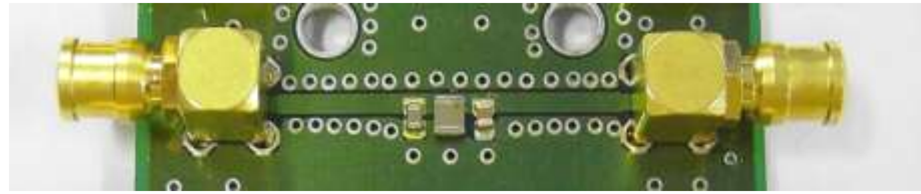
Simulated

Measured

Filter topologies – Parallel-C-filter

- Parallel-C-filter





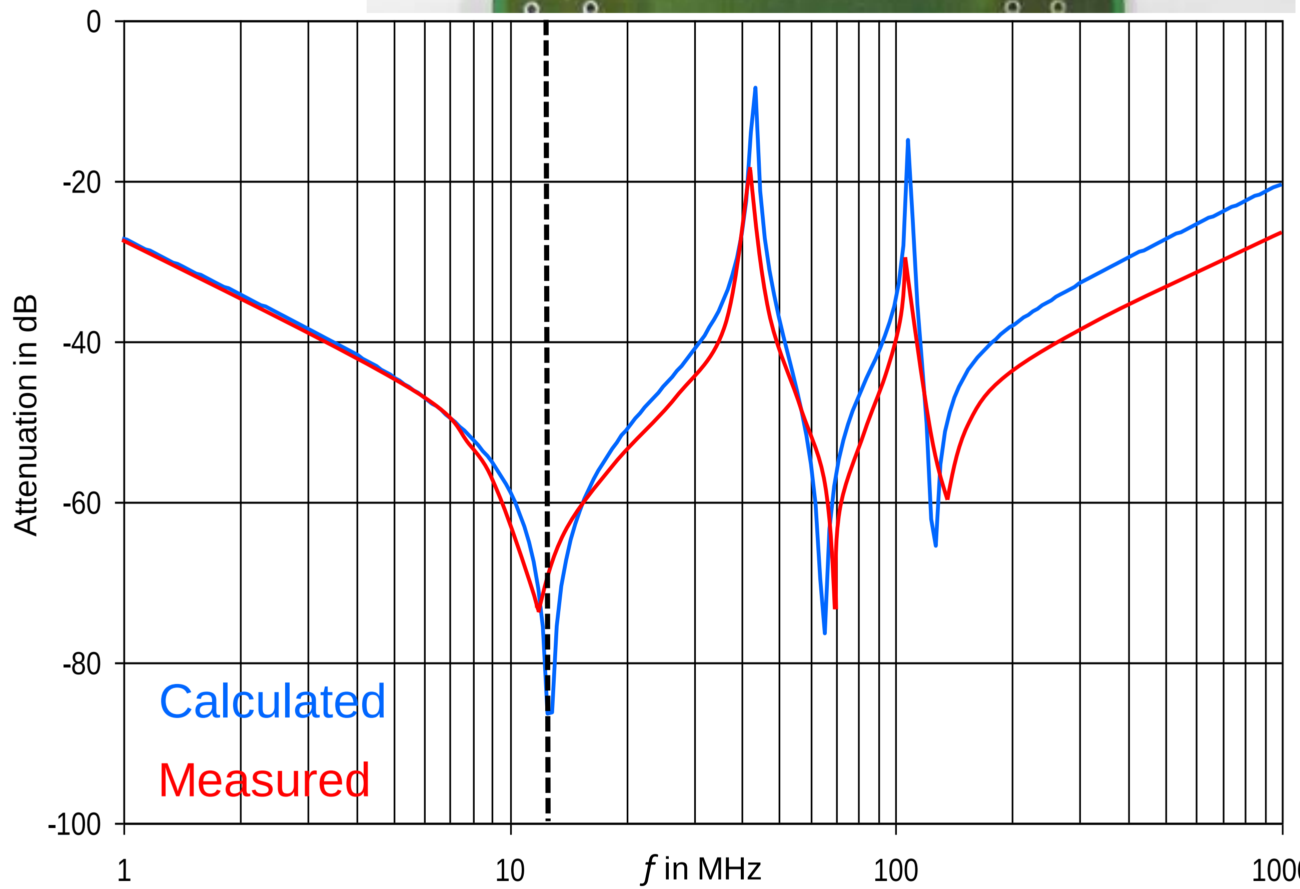
- Comparison of measurement and simulation

$$f_{res} = \frac{1}{2\pi \cdot \sqrt{L_s \cdot C}}$$

<u>Example:</u>

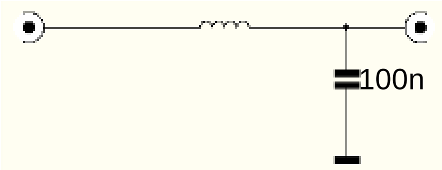
L_s = 1nH

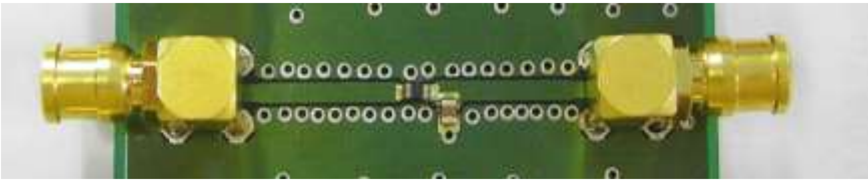
$f_{res,C3}$ = 15.915MHz



Filter topologies – LC-filter

- LC-filter





- Comparison of measurement and simulation

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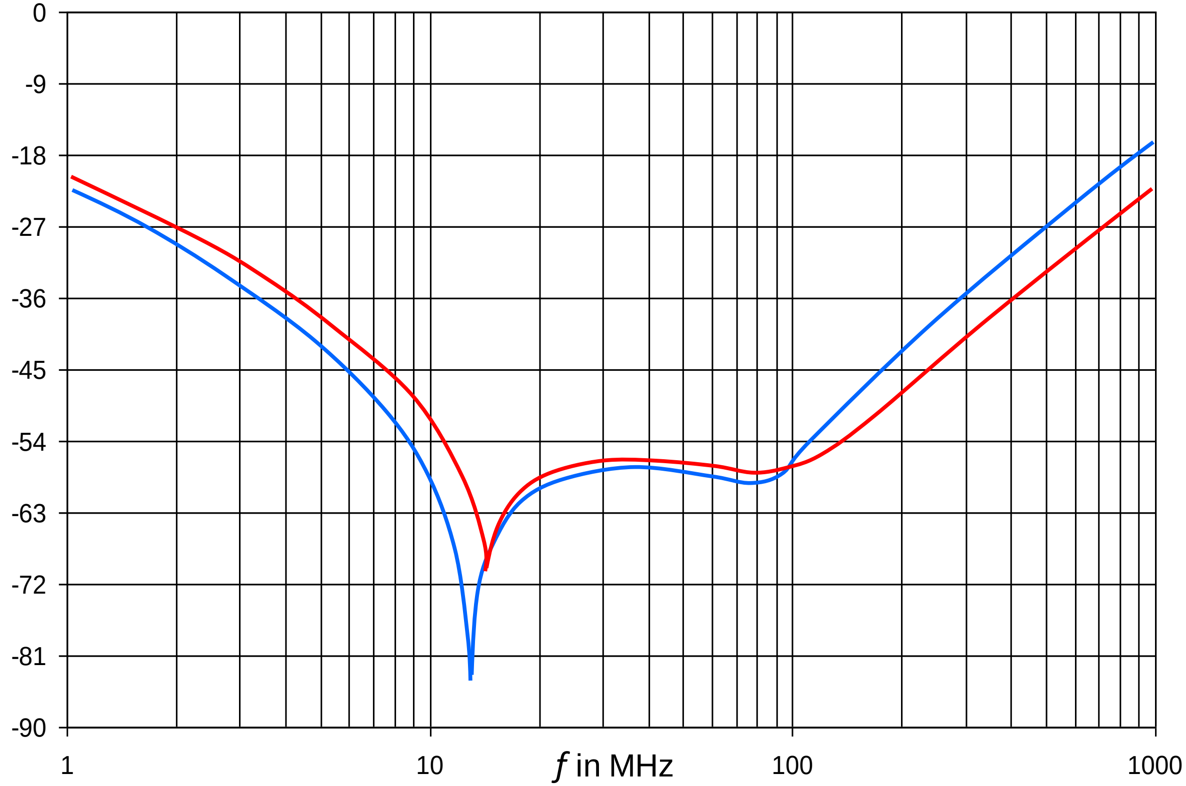
C = 100nF

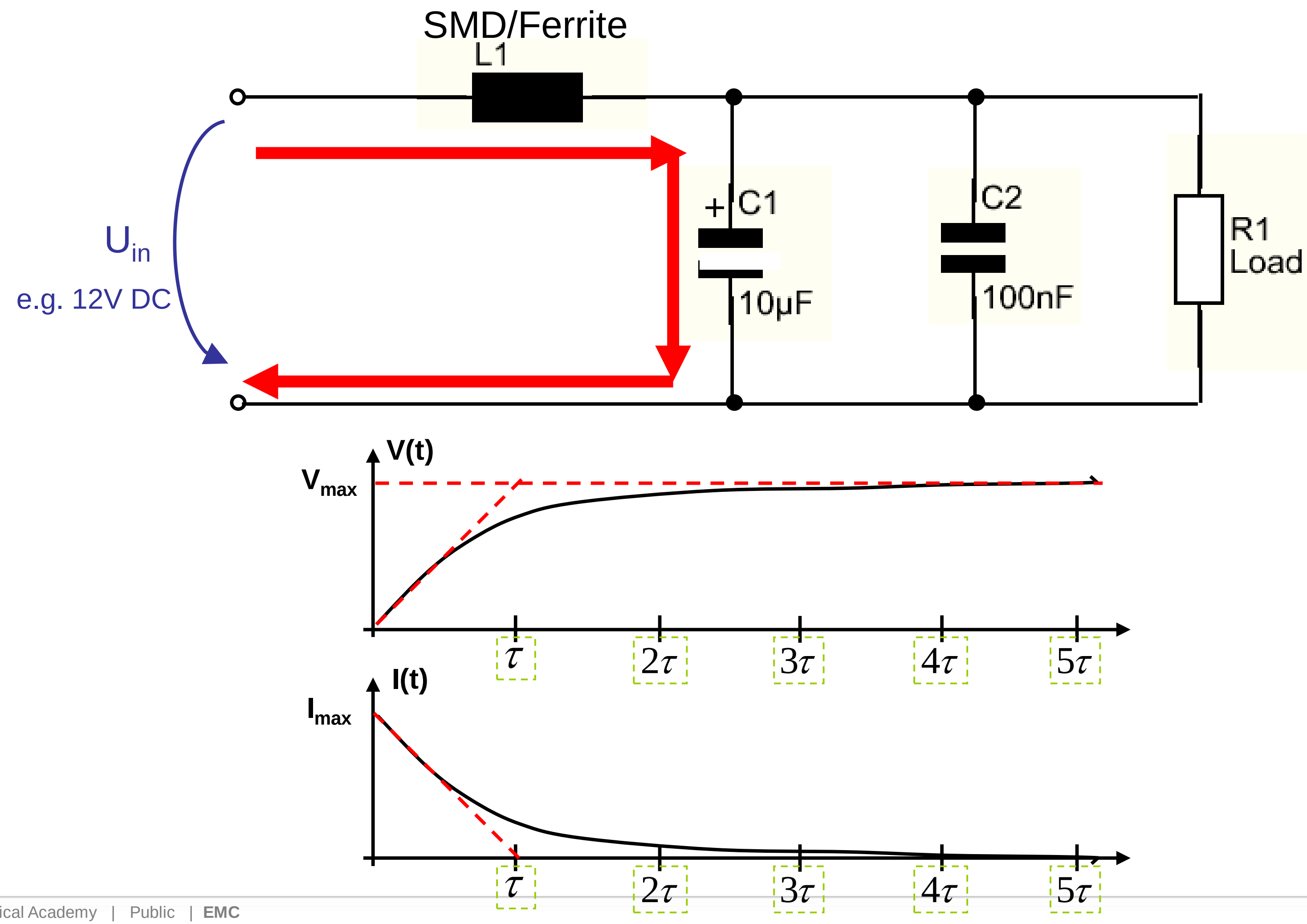
Simulated

Measured



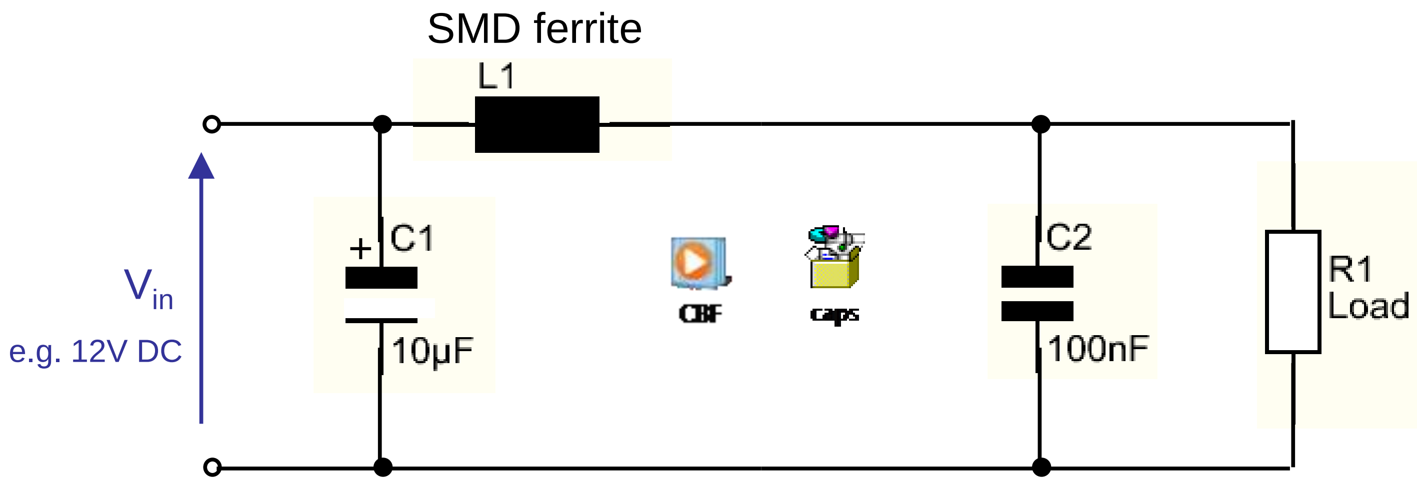
Filter topologies – LC-filter

Avoiding inrush current damage to SMD ferrite beads



Filter topologies – LC-filter

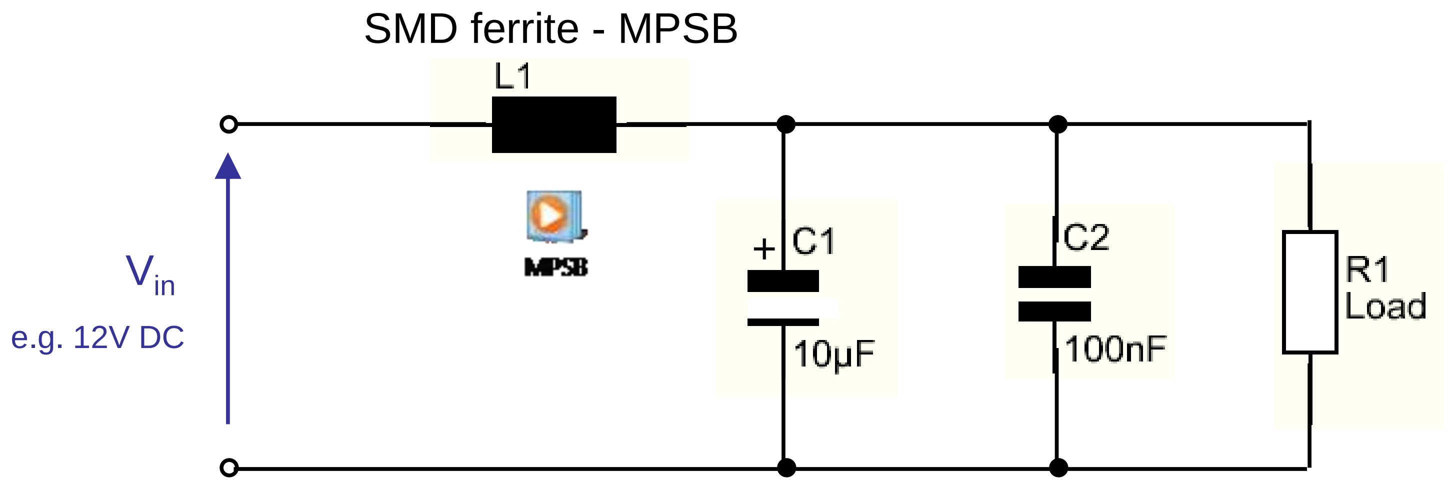
Avoiding inrush current damage to SMD ferrite beads – Option 1



- Safety for SMD ferrite against inrush/pulse current
- Not a PI-Filter

Filter topologies – LC-filter

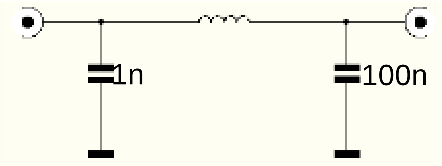
Avoiding inrush current damage to SMD ferrite beads – Option 2



- Use inrush current (pulse) rated SMD ferrite (WE-MPSB)
- Preferred solution as:
  - High impedance termination

Filter topologies – π-filter

- π-filter



- Comparison of measurement and simulation

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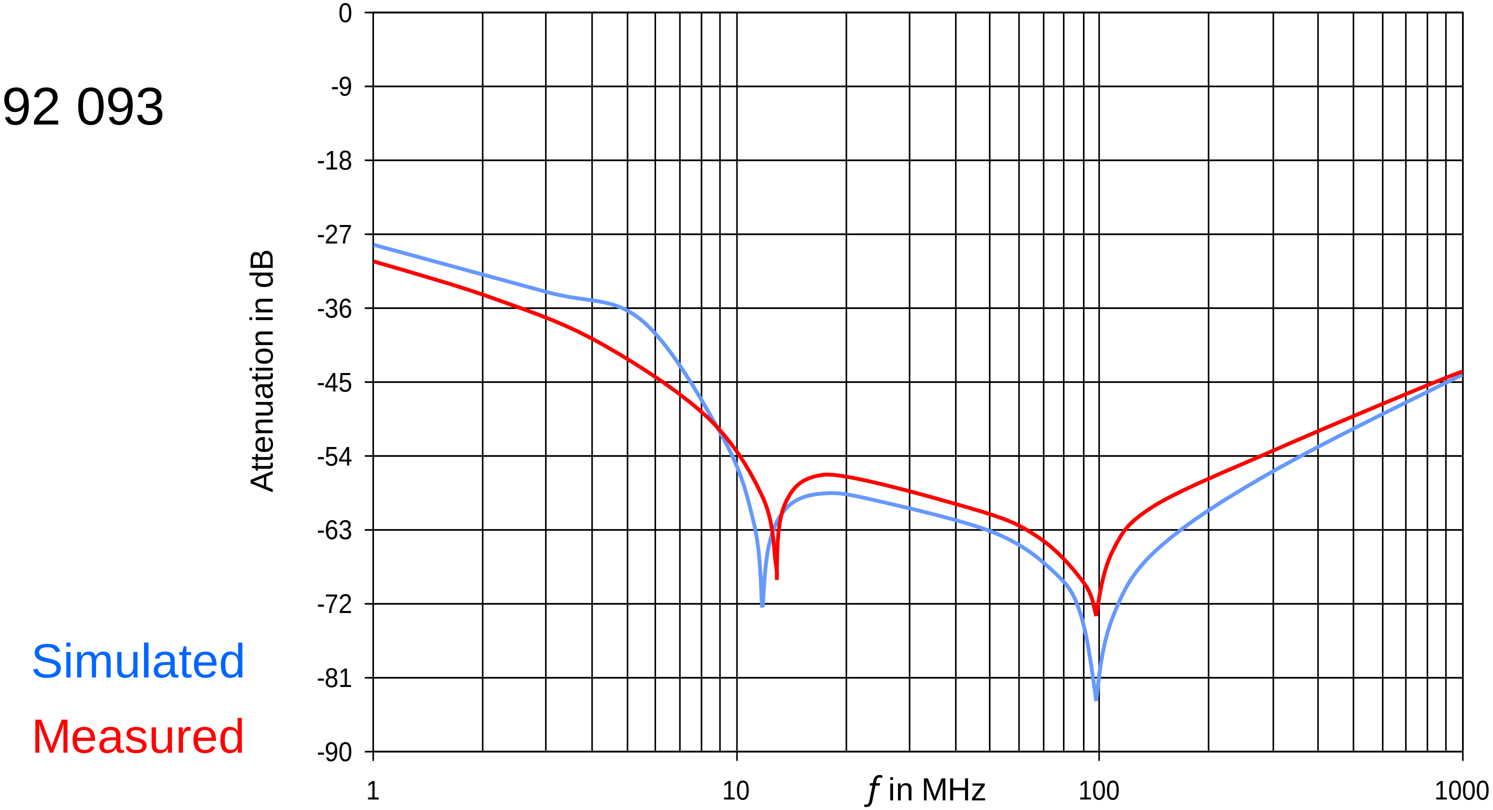
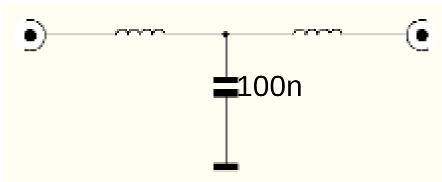
C_1 = 1nF

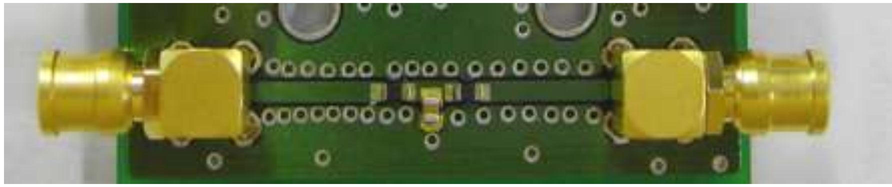
C_2 = 100nF



Filter topologies – T-filter

- T-filter





- Comparison of measurement and simulation

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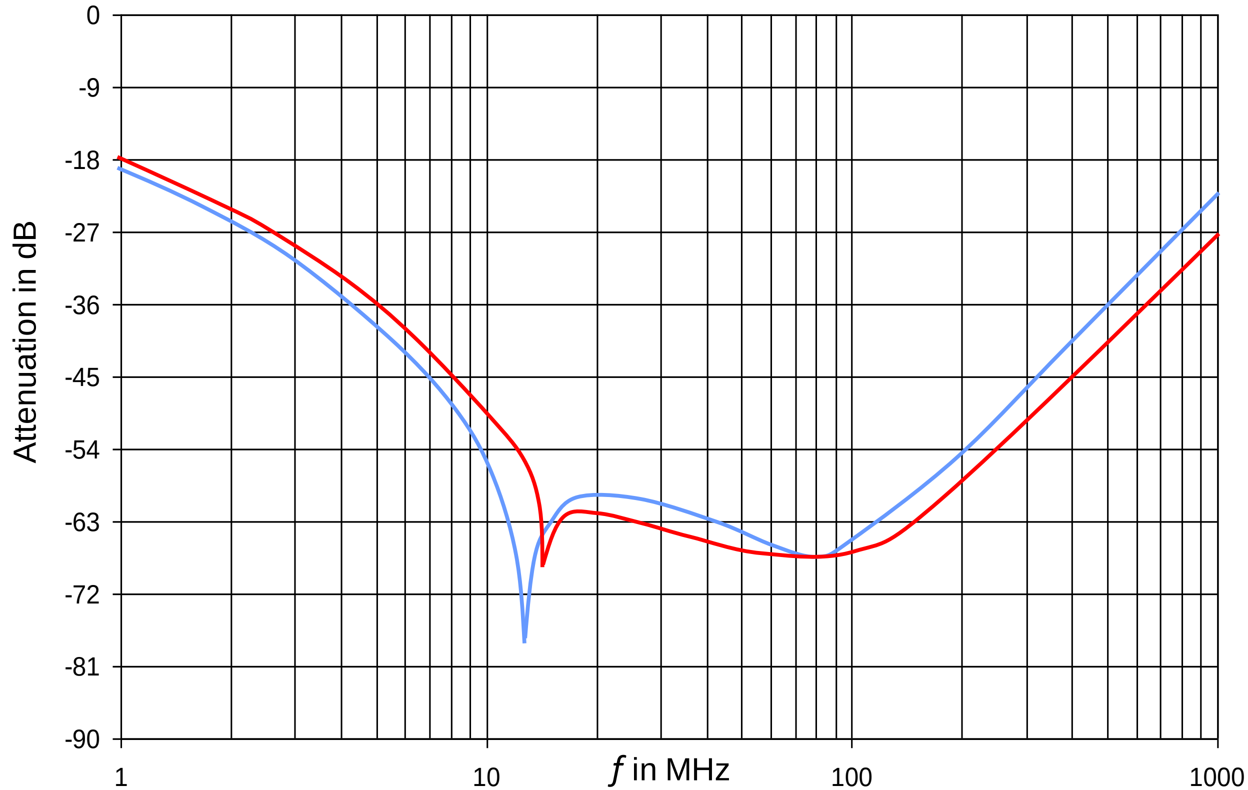
C = 100nF

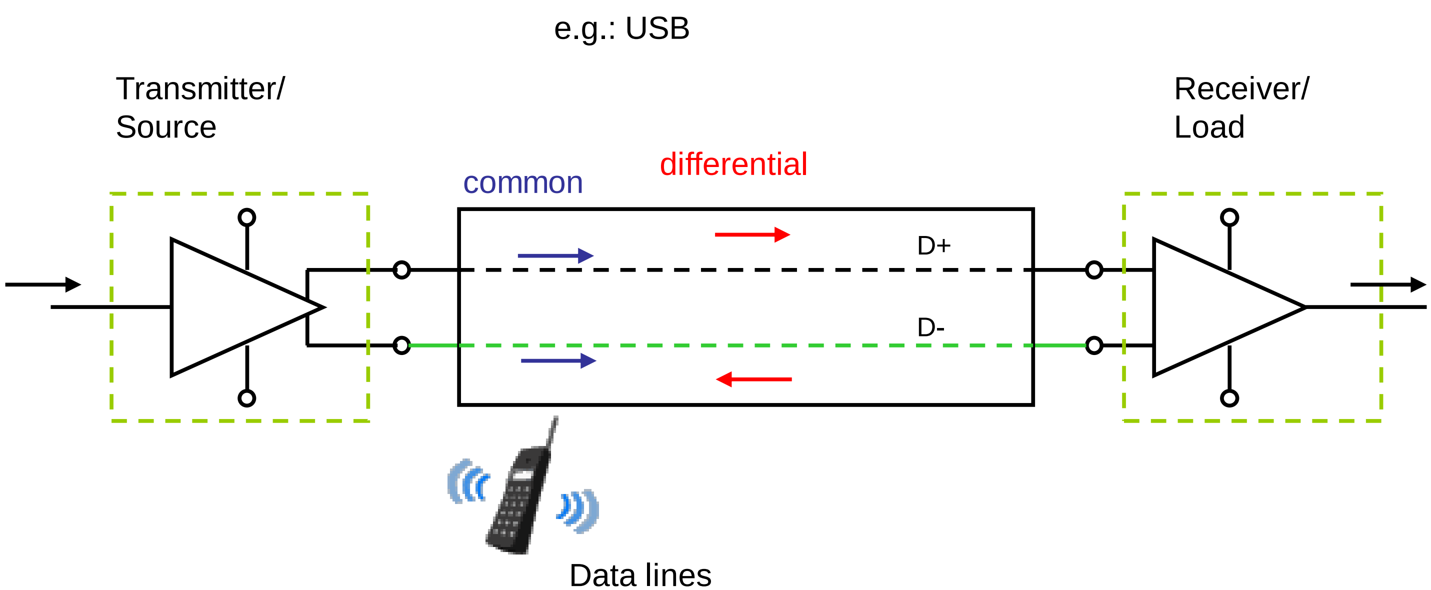
Simulated

Measured



Common Mode – Signal propagation

Noise mode:



- Common mode noise
- Differential mode noise

Common Mode Choke – Principle of Operation

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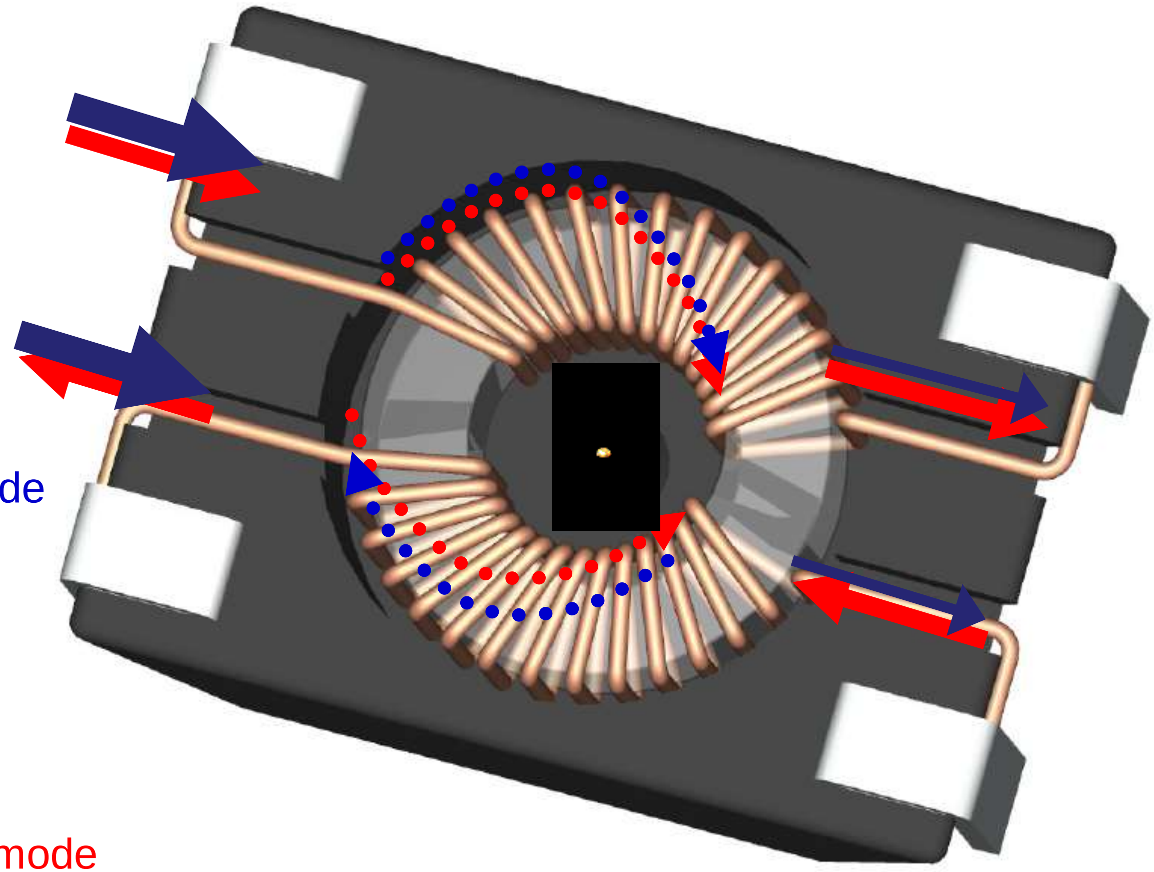
It is a Bi-directional filter

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



Intended Signal - Differential mode

Interference Signal (noise) – Common Mode

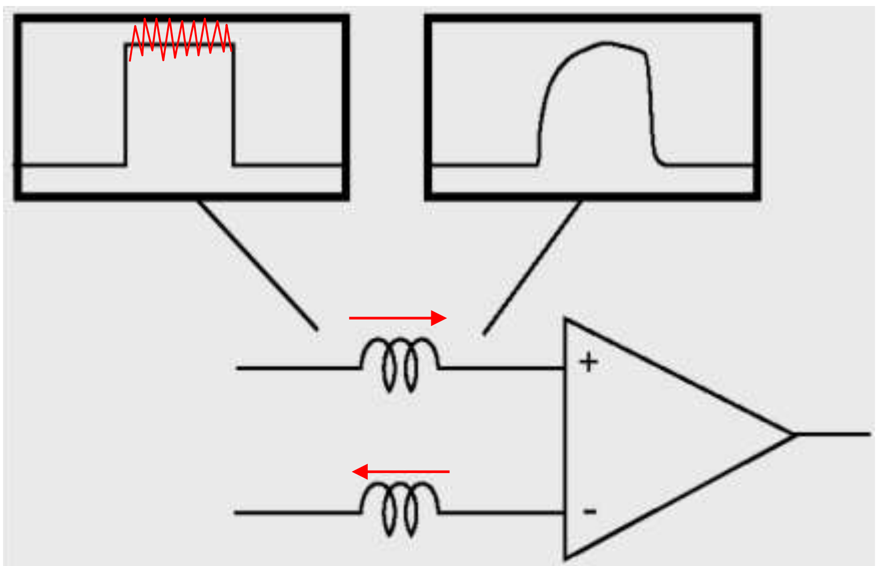
Conclusion:

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

Common Mode Choke – Advantages

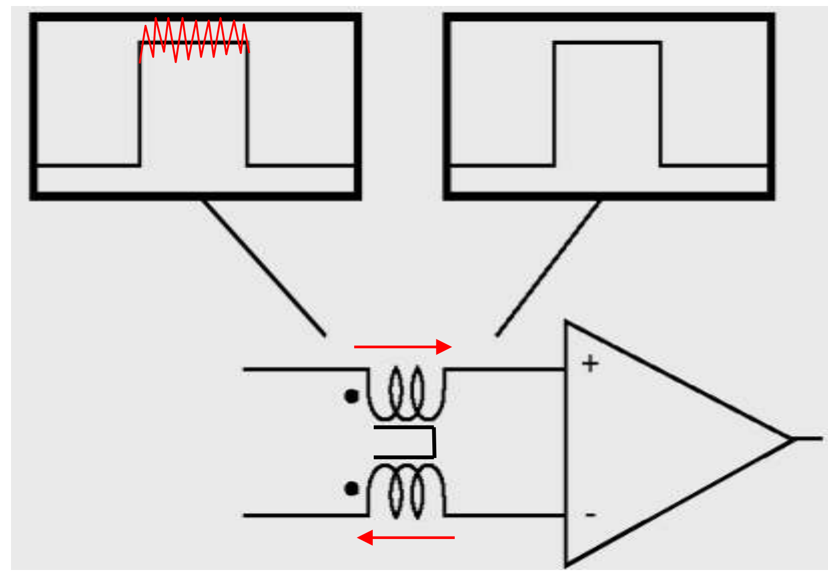
Filter with two inductors

Filter input Filter output



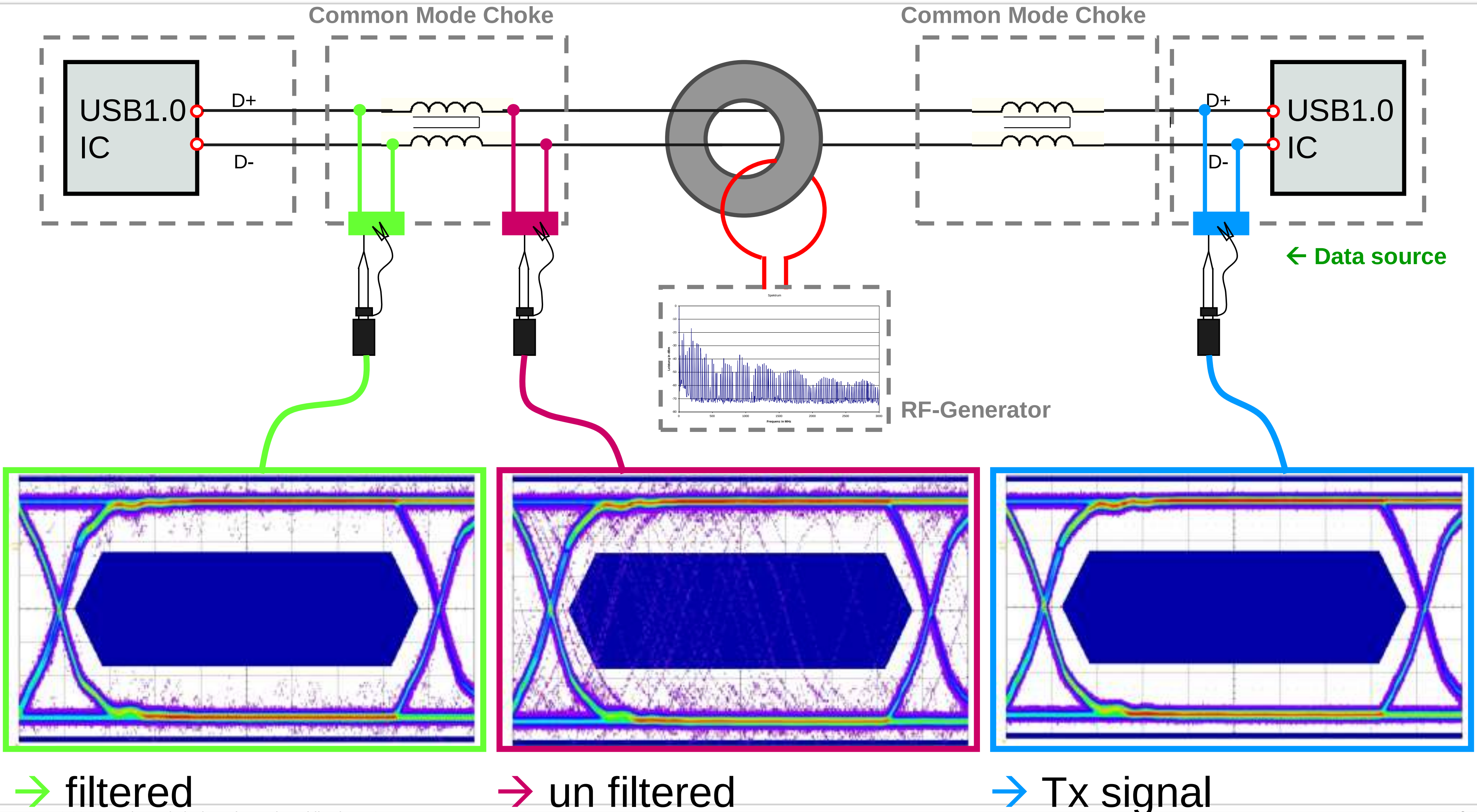
Filter with CMC

Filter input Filter output



- Signal not affected
- Noise attenuated even close to the signal frequency

Common Mode Choke – USB application



Common Mode Choke – USB application

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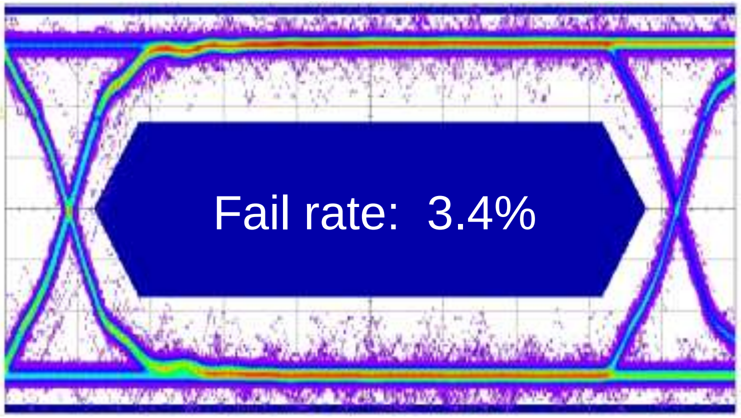
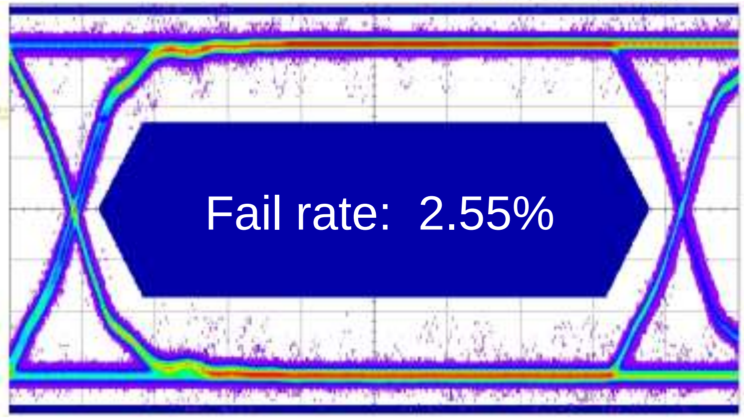
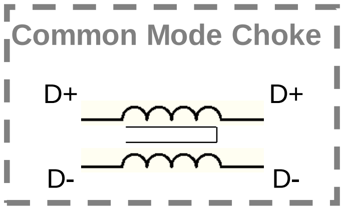


Increase Z →



CM → 32 Ohm
DM → 0.7 Ohm
@ 12 MHz

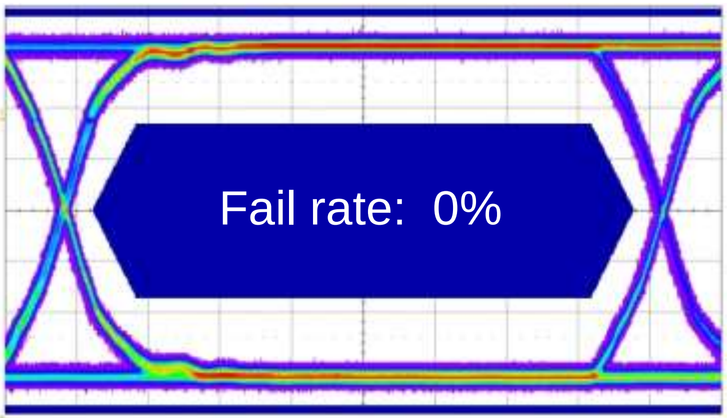


CM → 41 Ohm
DM → 0.7 Ohm
@ 12 MHz

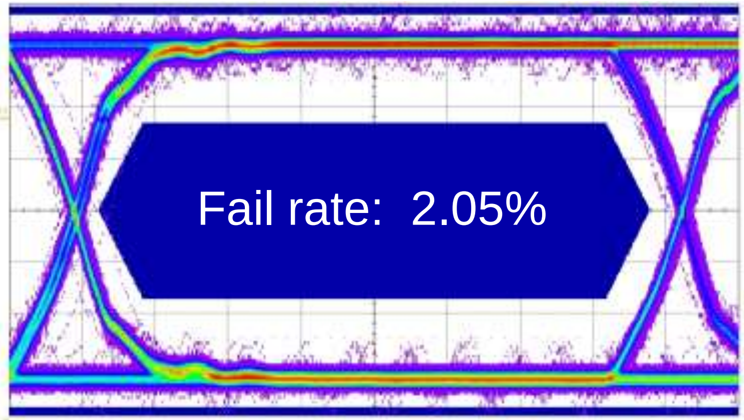
↓

CM → 363 Ohm
DM → 1 Ohm
@ 12 MHz

CM → 77 Ohm
DM → 1 Ohm
@ 12 MHz



← Increase Z

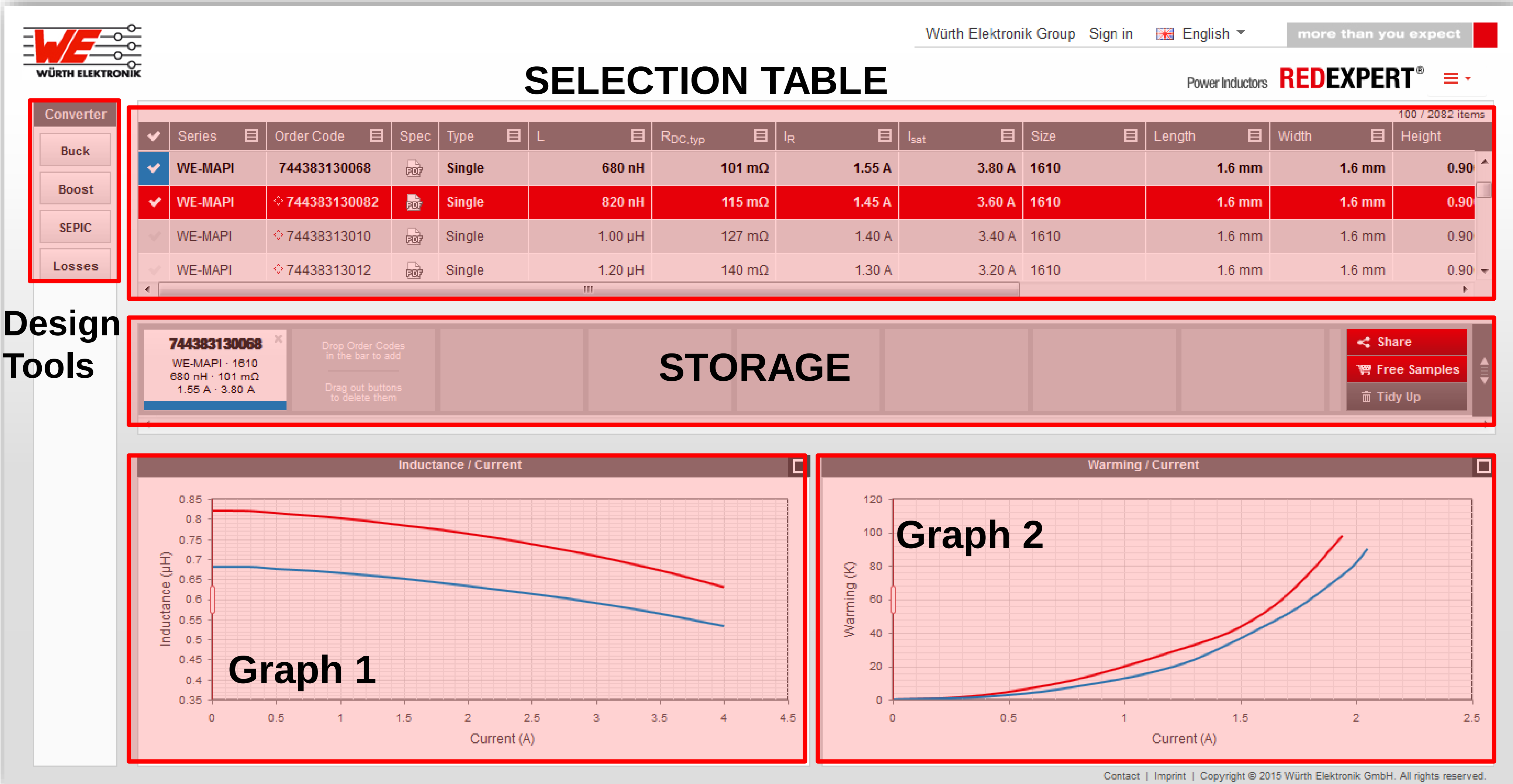


REDEXPERT

REDEXPERT


World's most accurate AC loss model
The losses determined with REDEXPERT are based on real time DCDC measurements with its typical current and voltage waveforms. Besides all core and winding losses they do also consider losses in the air gap.
Calculate the AC losses
Power Inductors
REDEXPERT

User Interface



REDEXPERT

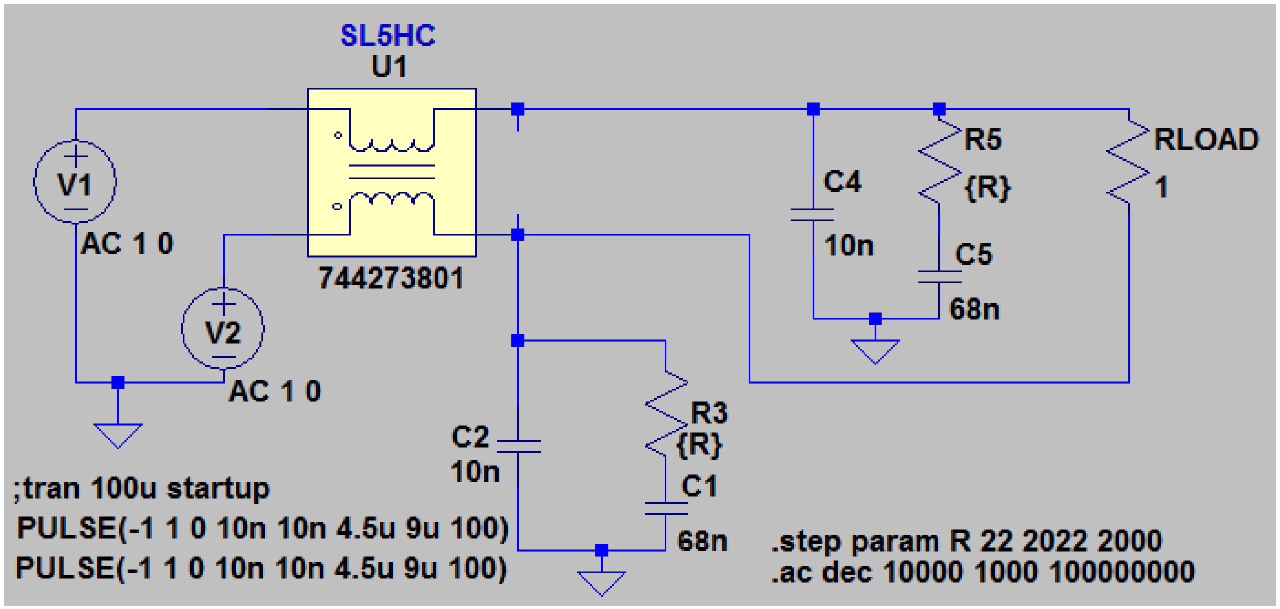
https://www.we-online.com/redexpert/#/module/1

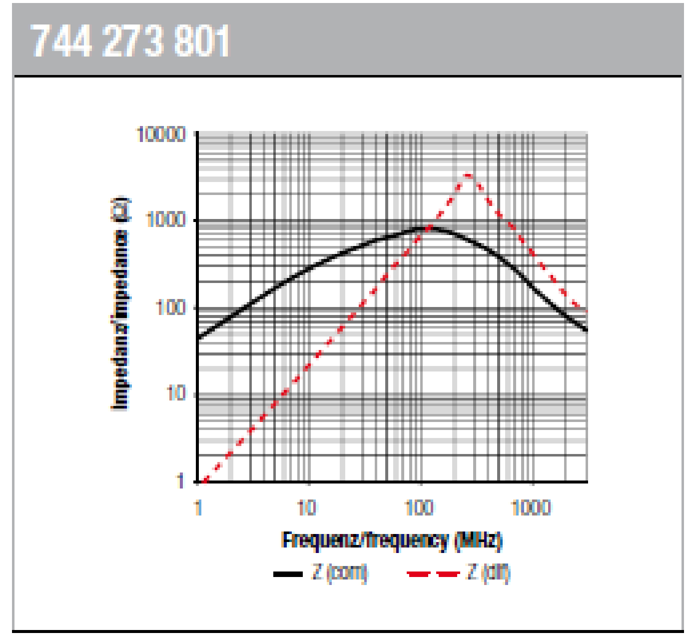
www.we-online.com/redexpert

PRACTICAL EMI FILTER DESIGN CONSIDERATIONS

Common Mode Filter Design

With Chassis / EMC Ground





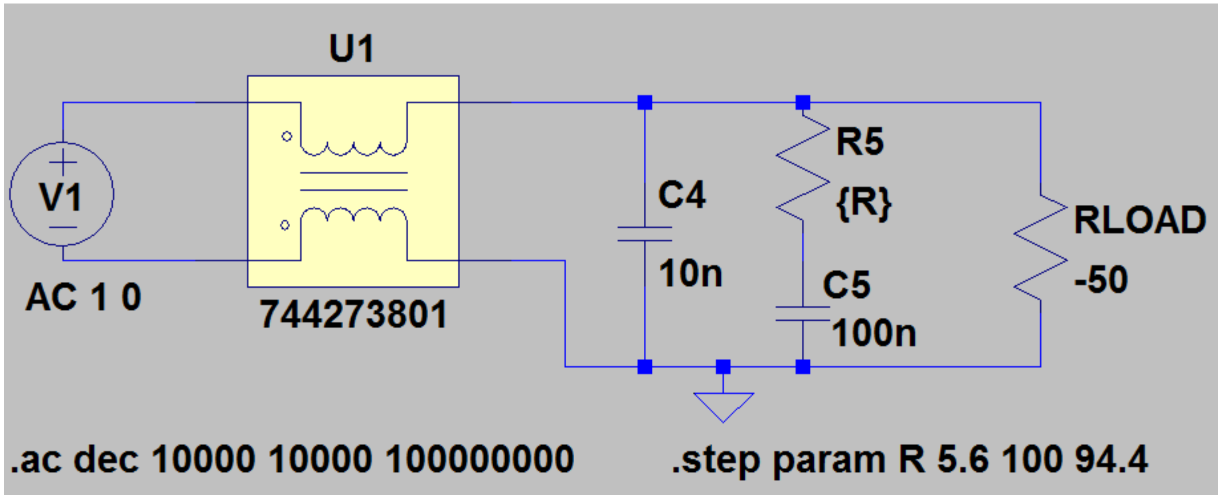
- Power Supply Switching Frequency Considerations (L)
- EMI Higher Frequency Considerations (Z)
- Layout and Tracking
- Capacitor with and without Damping

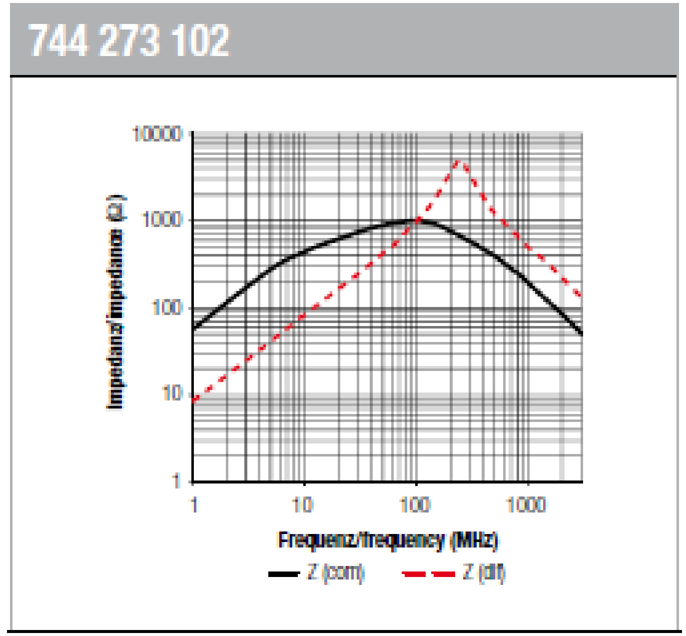
744 273 801

CMC w Chassis

Common Mode Filter Design

DM (Leakage) Effect





- Load Impact
- Capacitor Damping

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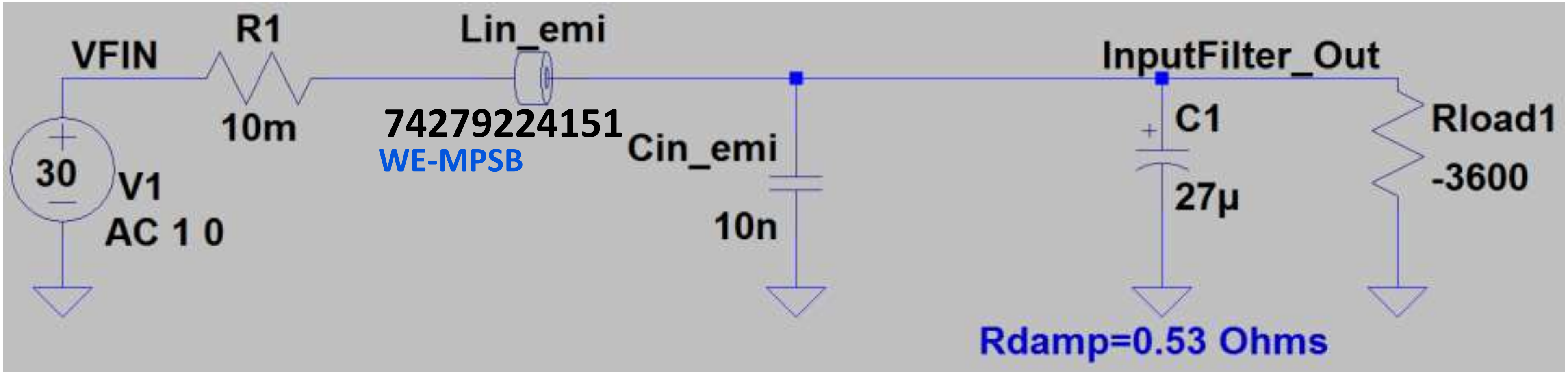
CMC DM Effect

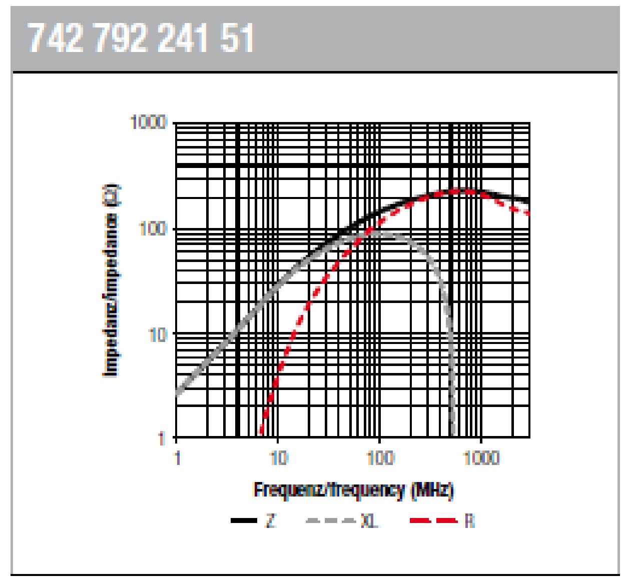
Differential Mode Filter Design – Input



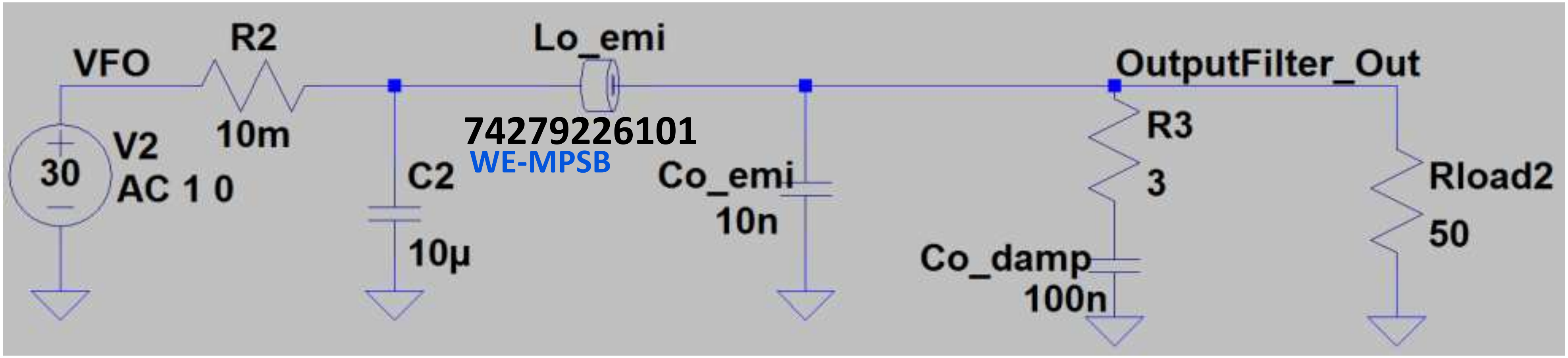
- Load Impact
- EMI Higher Frequency Considerations
- Pulse Rating (WE-MPSB)
- Layout and Tracking
- Capacitor Damping and Stability

Buck Filter AC Analysis

742 792 241 51



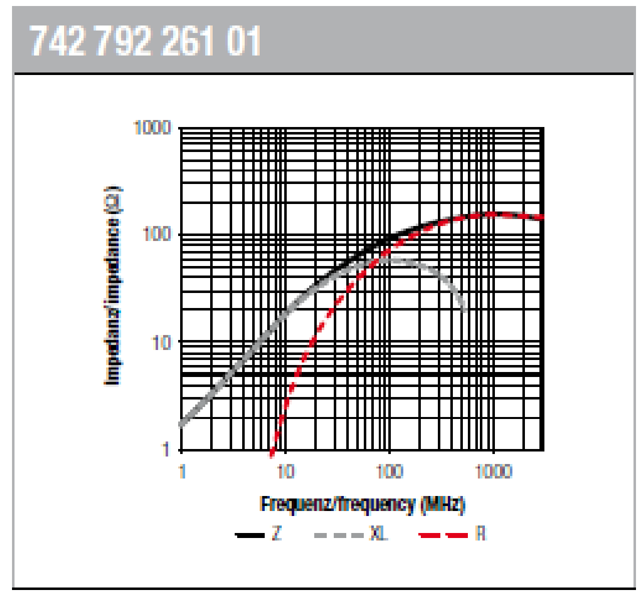
Differential Mode Filter Design – Output



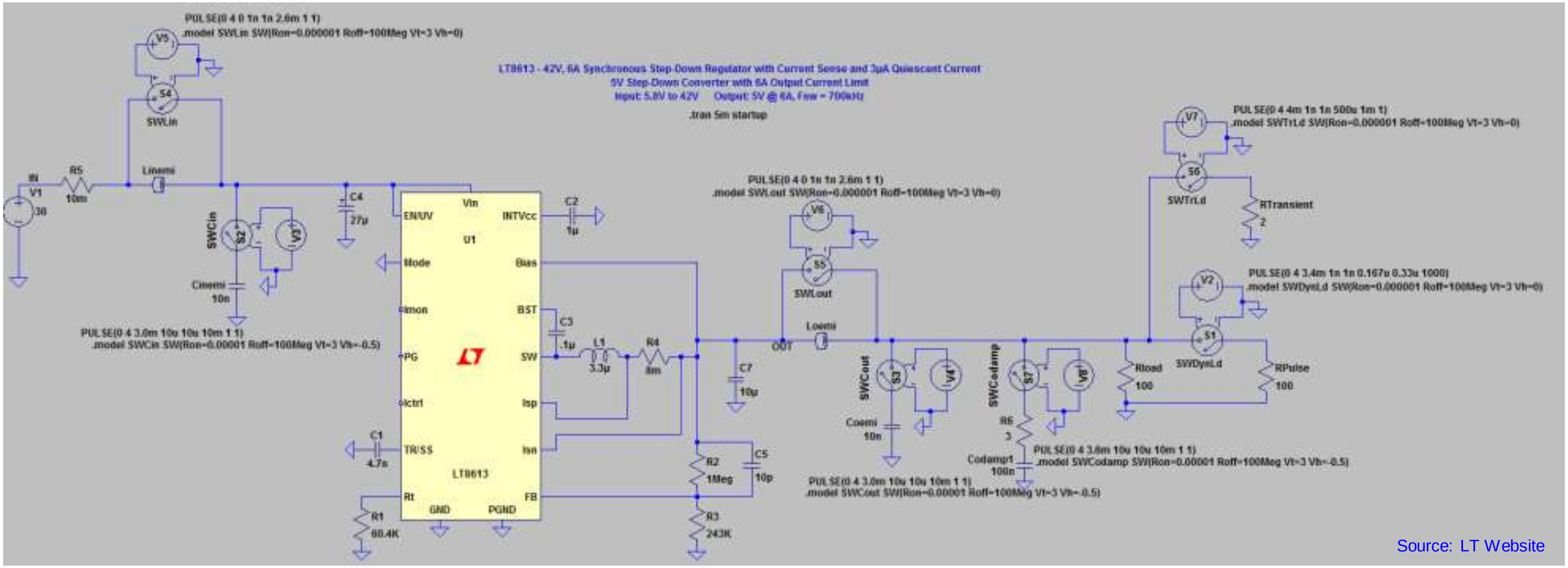
- Load Impact
- EMI Higher Frequency Considerations
- Pulse Rating (WE-MPSB)
- Layout and Tracking
- Capacitor Damping

Buck Filter AC Analysis

742 792 261 01



Differential Mode Filter Design – Buck Example



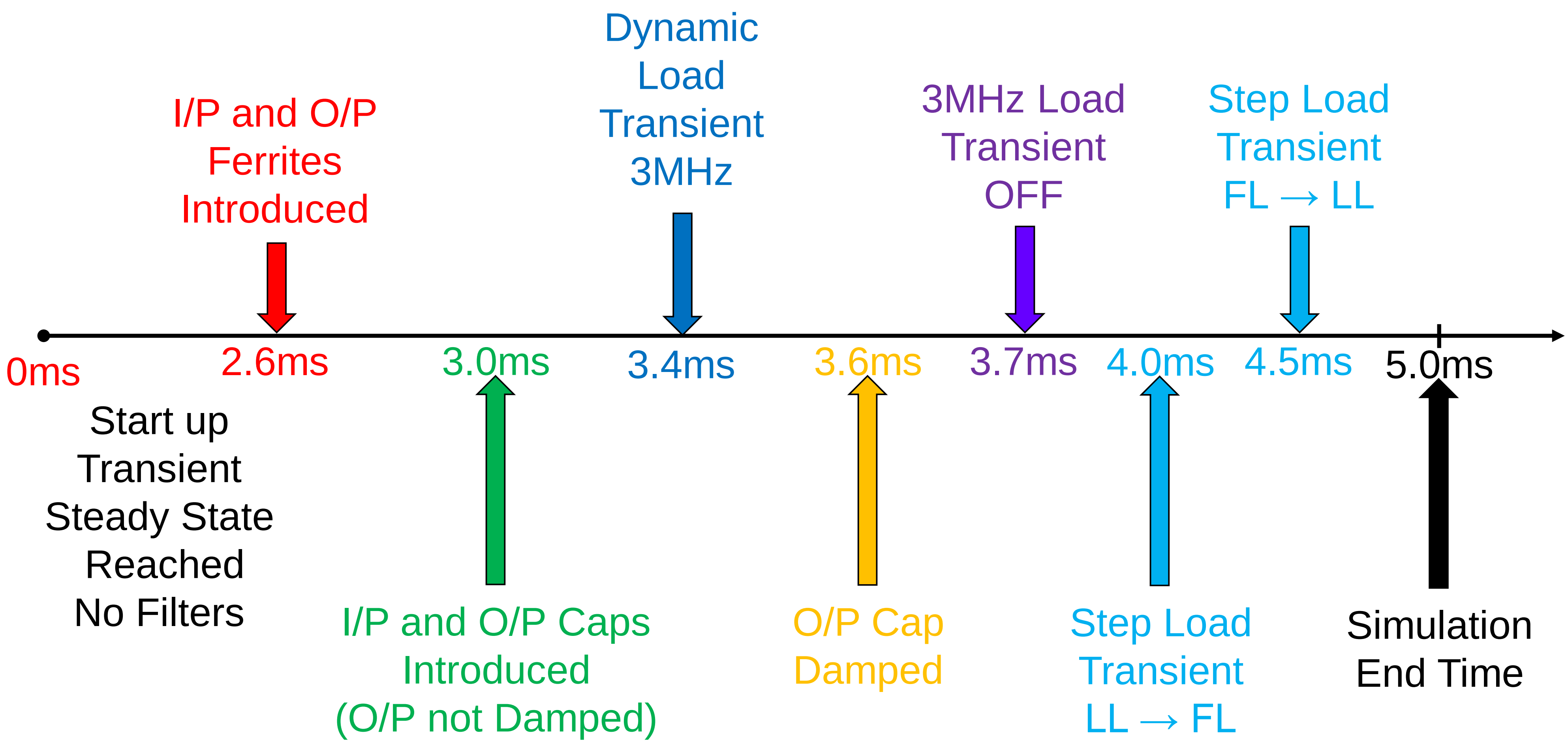
Start Up Conditions:

- No EMI Filters on I/P or O/P
- Max Vin = 30V
- Vout = 5V, Min Load 50mA (DCM)
- Actual filter component models used (no ideals)

Buck Filtering

Differential Mode Filter Design – Buck Example

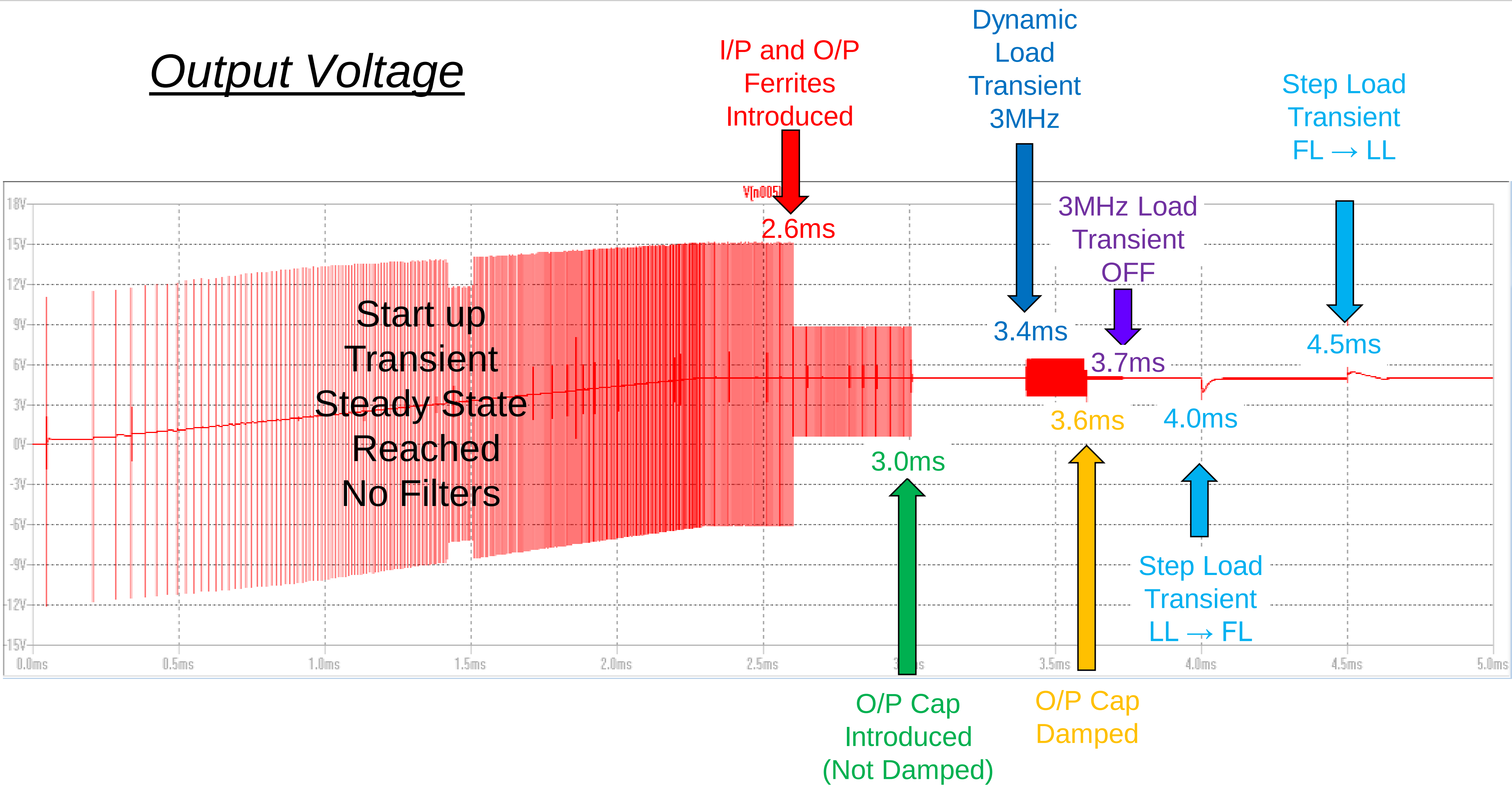
Simulation Timeline



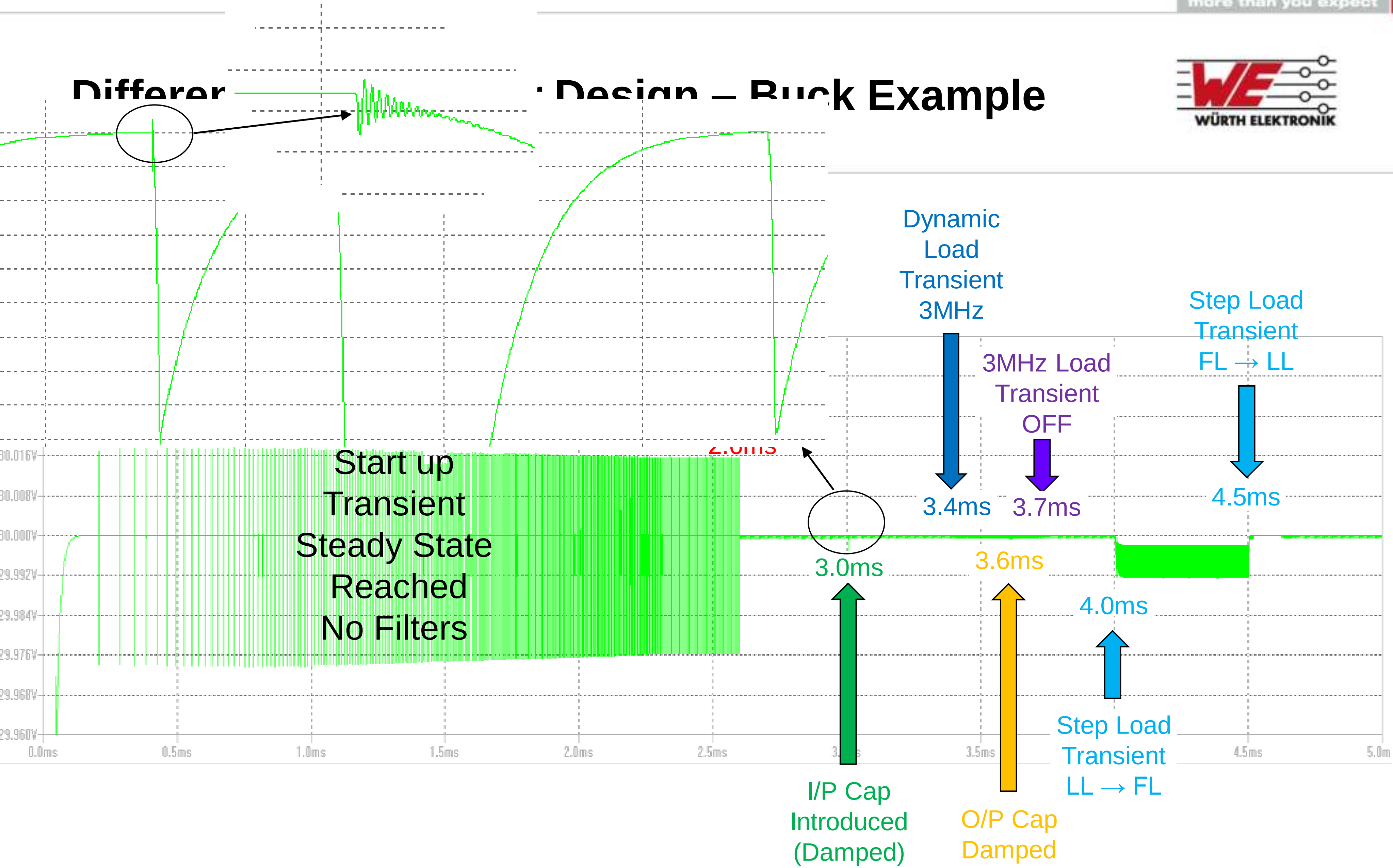
Differential Mode Filter Design – Buck Example

WÜRTH ELEKTRONIK

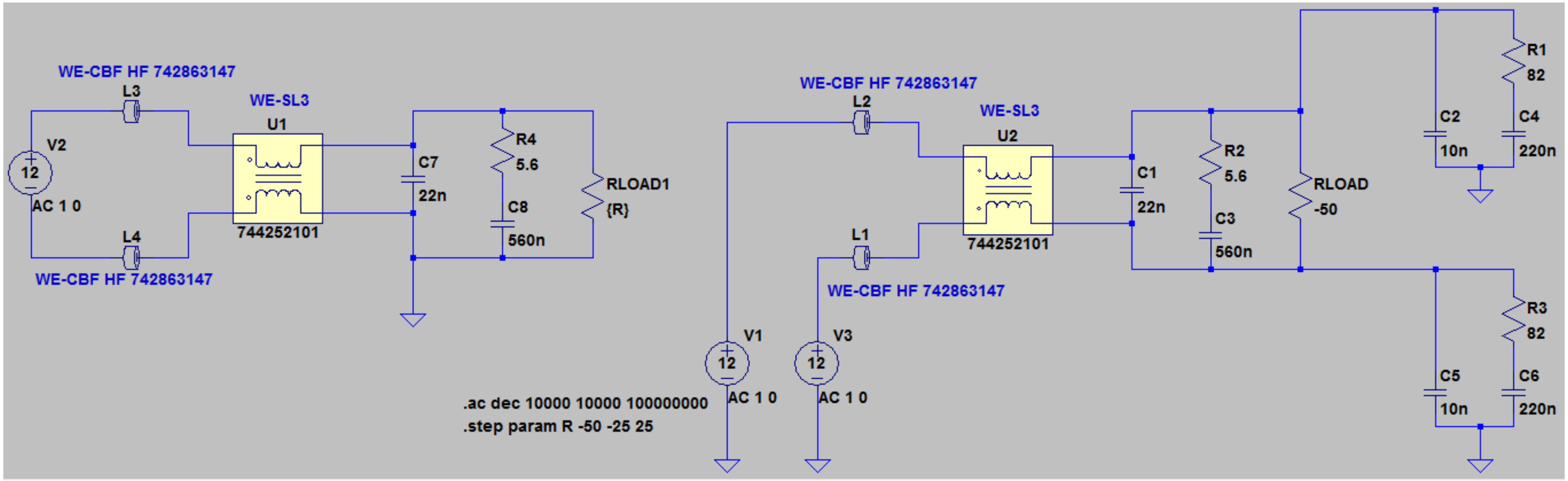
Output Voltage

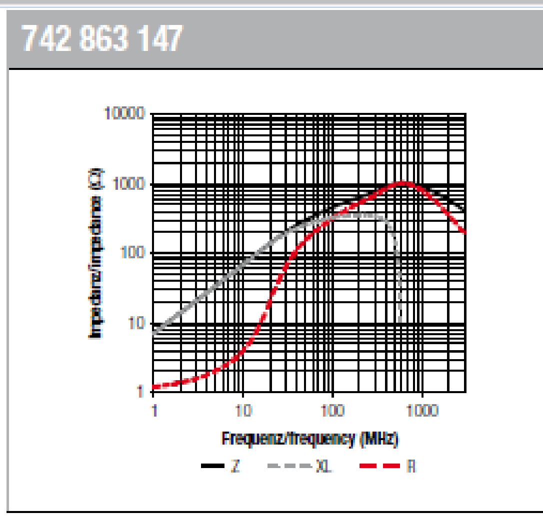


Differer … Design – Buck Example



EMI Filter Design – Recommended Architecture

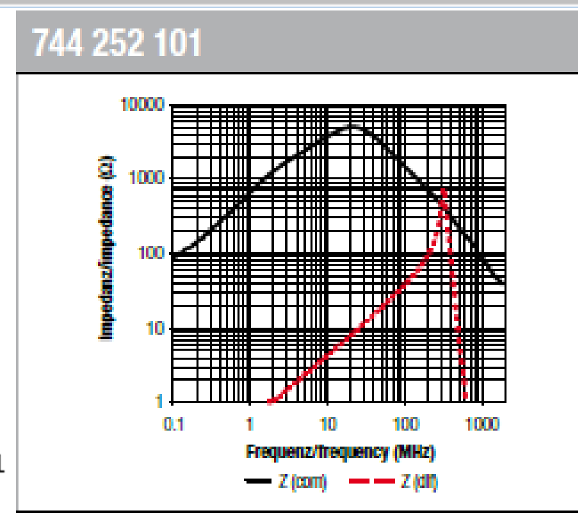




EMI DM_CM Input Filter

742863147

744252101



Thank you

Any Questions