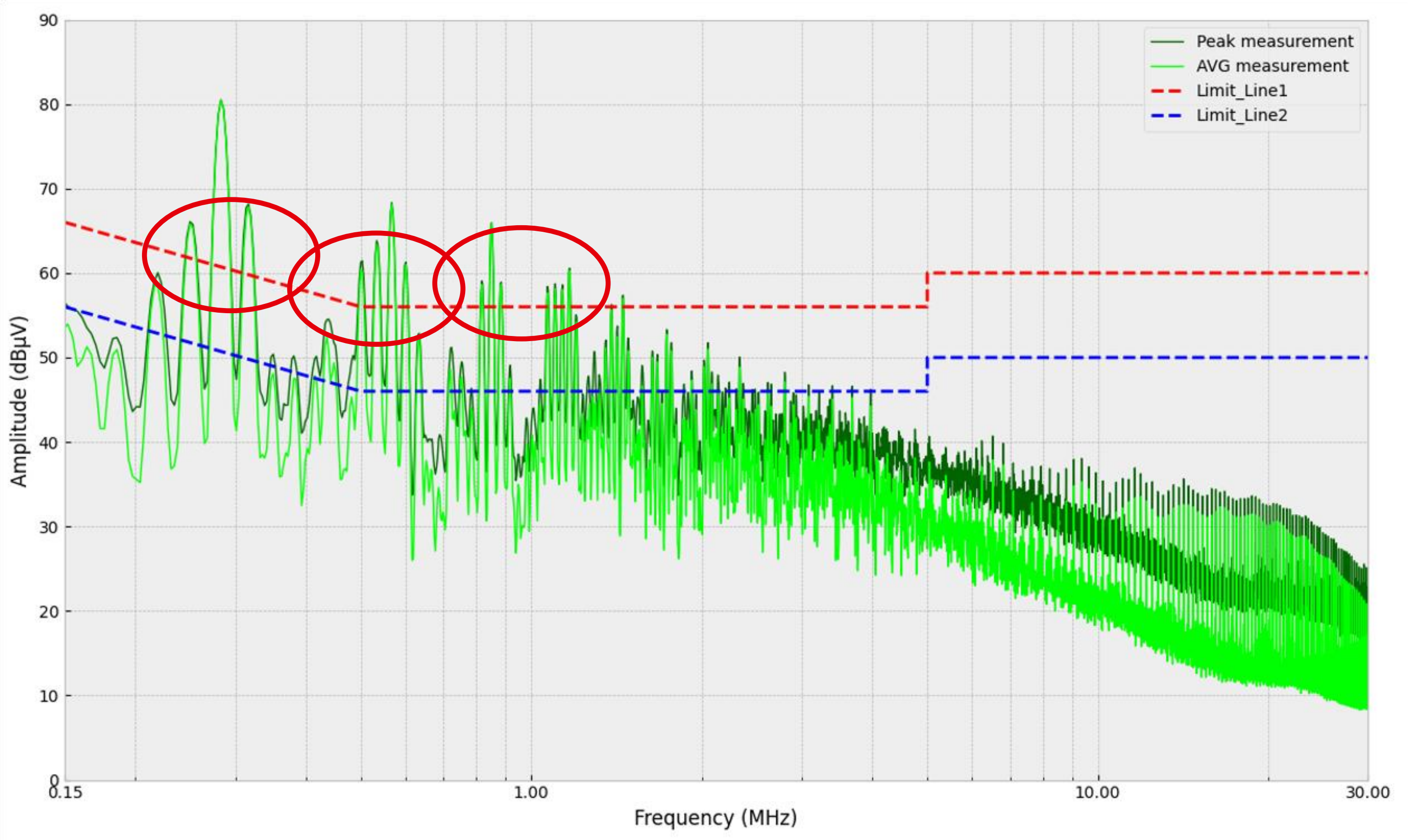
FILTERING CONSIDERATIONS FOR DC/DC CONVERTERS

SMPS FILTERING

Why do we need a filter ?

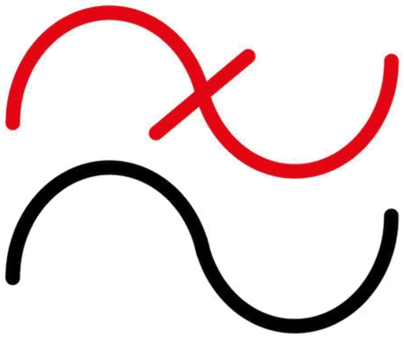
- How to meet EMC standards requirements?
  - Speak about noises
  - Circulating currents



GLOBAL POWER DESIGN SEMINAR TOUR

Filtering considerations

- SMPS filtering
  - Common mode
  - Differential mode

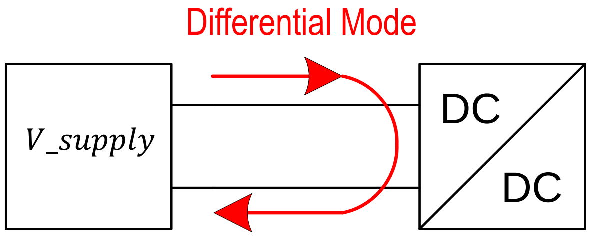


  - Input filtering
  - Output filtering

SMPS FILTERING

EMI noises sources and types : Two different coupling schemes exists

- Differential mode

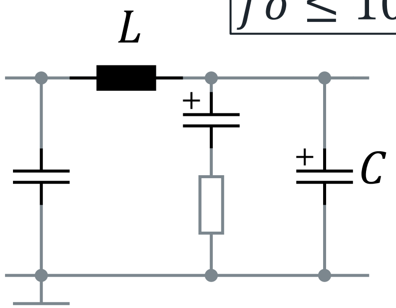


  - Source from current loop $^{di}/_{dt}$
  - Coupling by inductive way
  - More related to main switch frequency and harmonics

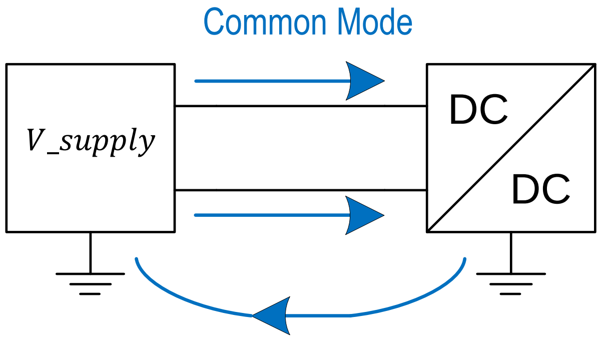
$\boxed{fo \leq 10 \cdot f_{sw}}$

➢ Filtered by LC filter

$$f_0 = \frac{1}{(2 \cdot \pi \cdot \sqrt{L \cdot C})}$$



- Common mode

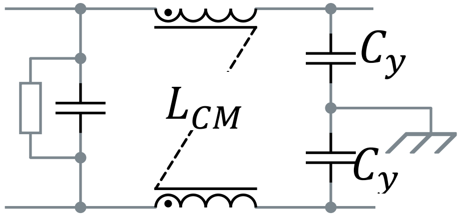


  - Source from voltage $^{dv}/_{dt}$
  - Coupling via capacitive way
  - More related to switching noises and ringing

➢ Filtered by **C**ommon **M**ode **C**hoke filter and Y-Caps

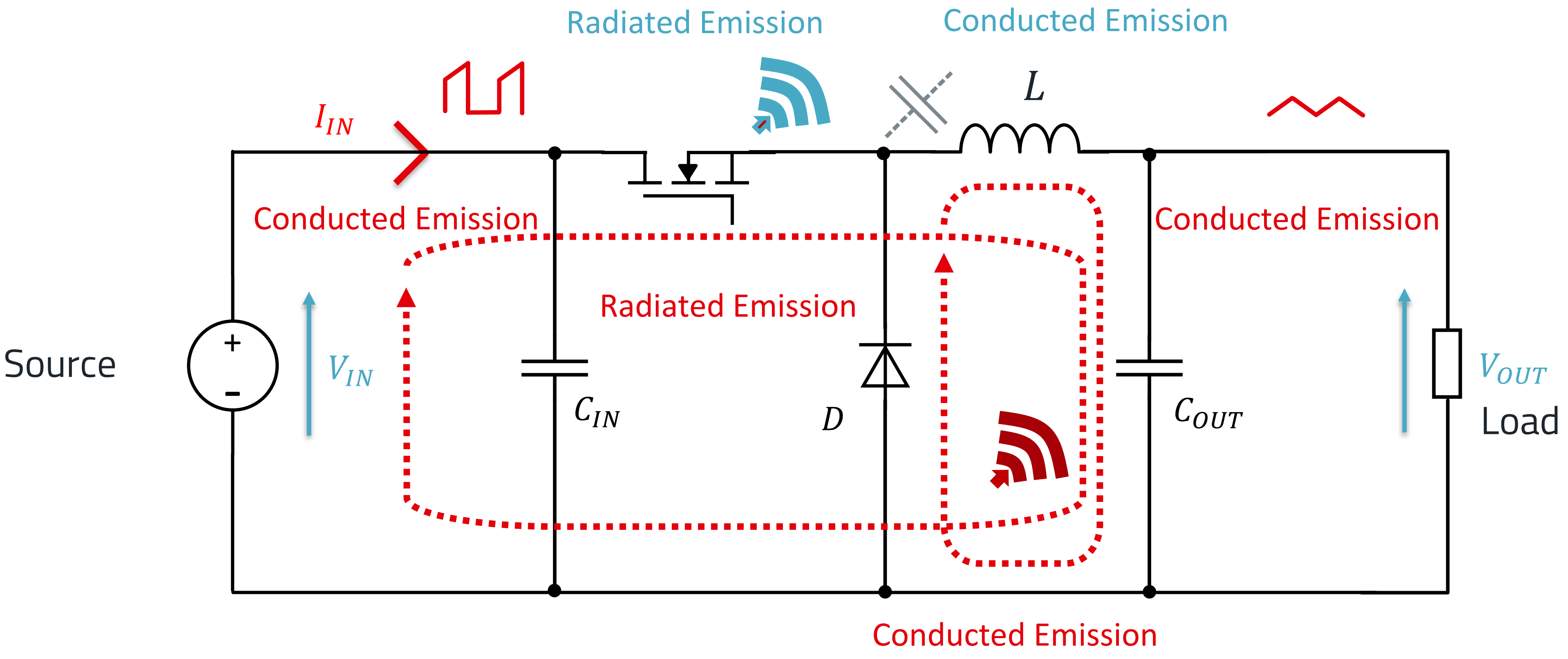
$\boxed{fo \leq 10 \cdot f_{sw}}$

$$f_0 = \frac{1}{(2 \cdot \pi \cdot \sqrt{L_{CM} \cdot 2 \cdot C_y})}$$



WHERE THE NOISE COME FROM

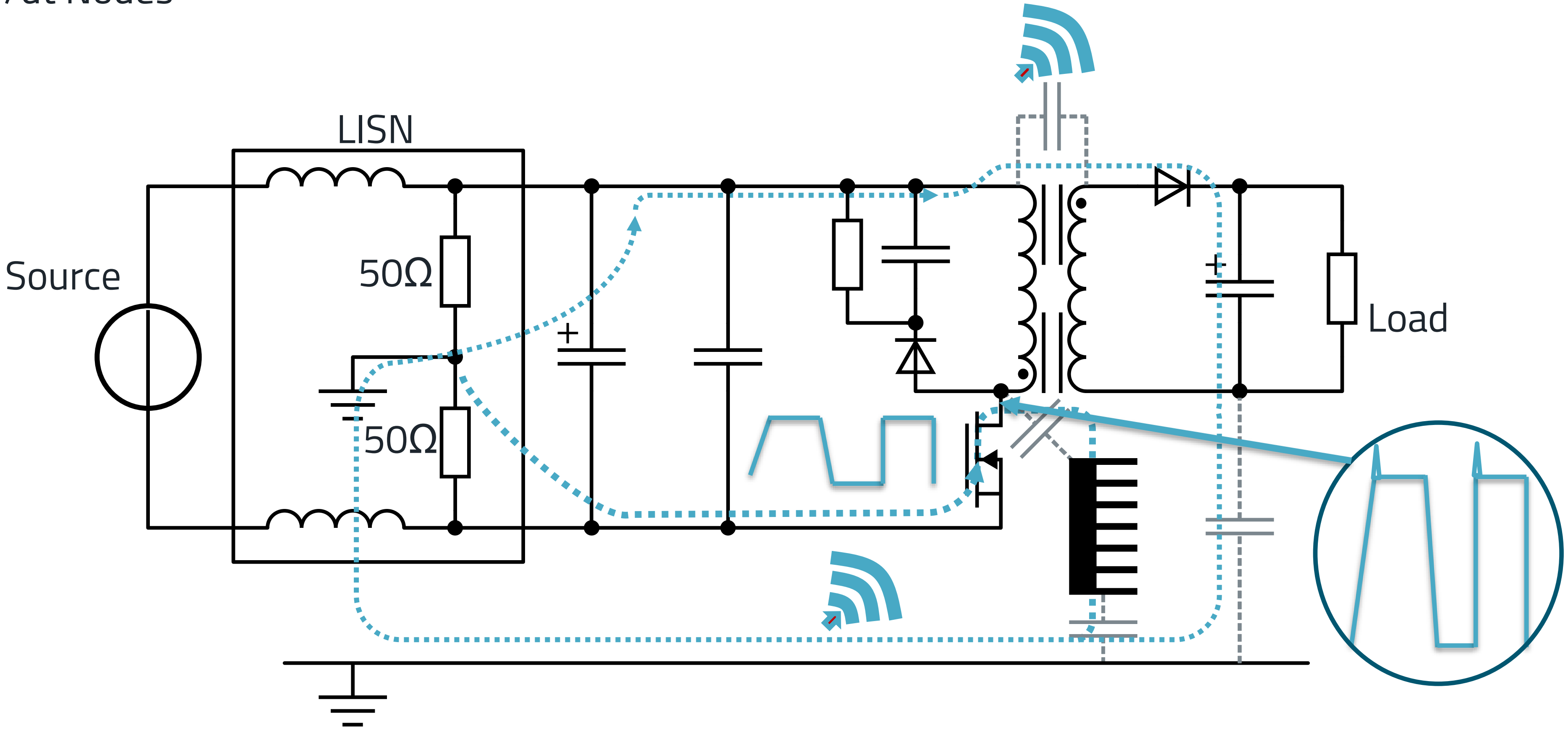
Buck topology



High di/dt cause differential mode currents by magnetic loops
High dv/dt common mode currents through parasitic capacitances

WHERE THE NOISE COME FROM

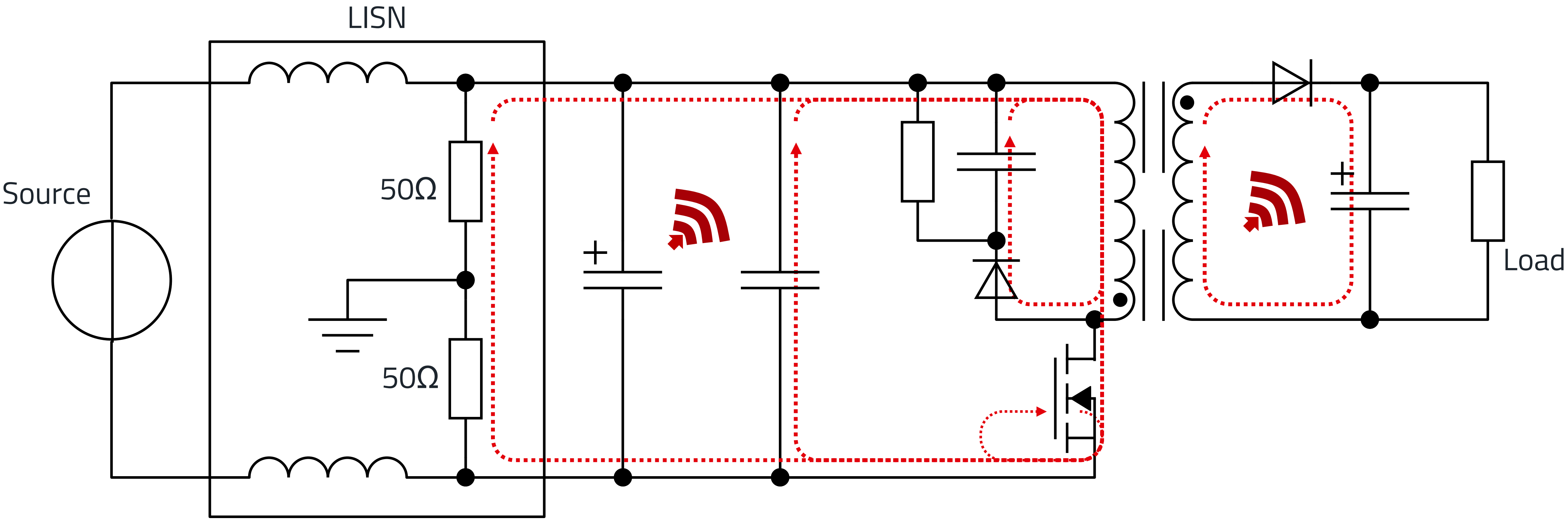
Flyback : High dV/dt Nodes



High dV/dt common mode currents through parasitic capacitances (electric dipole and monopole antennas)

WHERE THE NOISE COME FROM

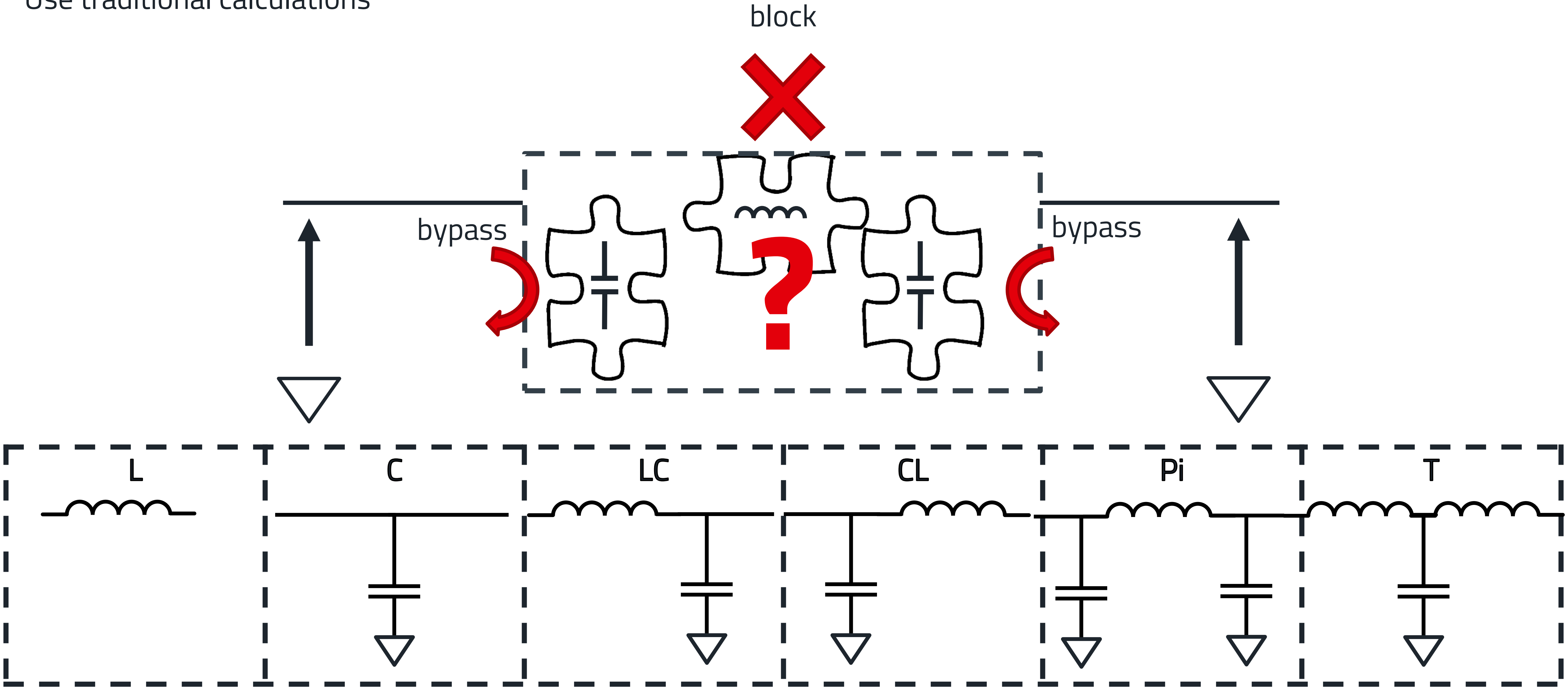
Flyback : High di/dt Loops



Inductive coupling caused by high di/dt differential mode currents (magnetic loop antennas)

FILTER TOPOLOGIES FOR IMPEDANCE SYSTEM

Use traditional calculations

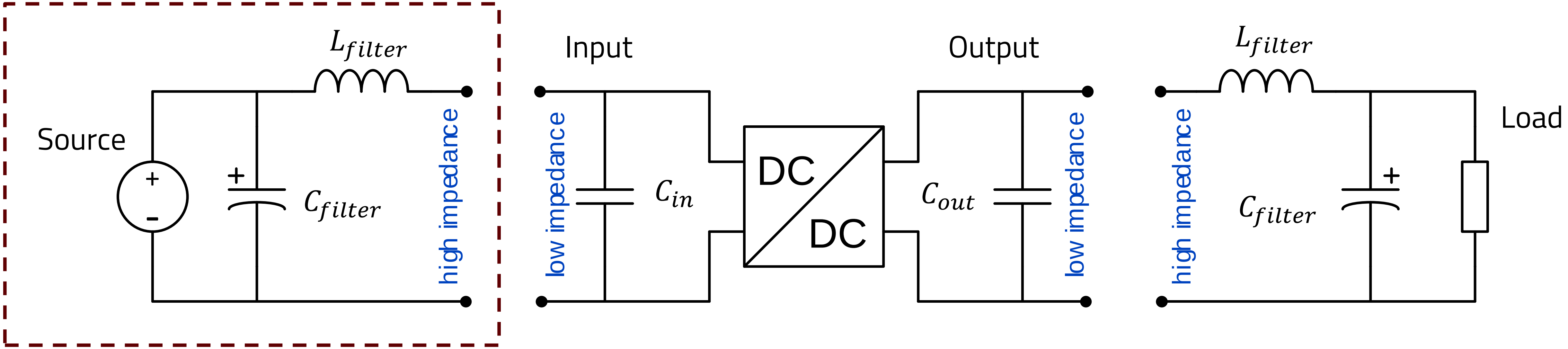


GLOBAL FILTERING

SMPS filtering : differential mode

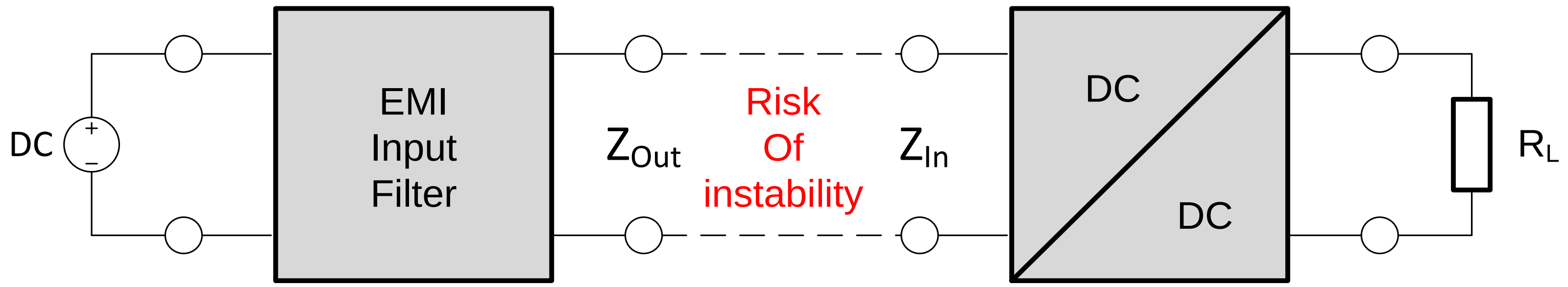
- Quick design : differential mode filtering
  - A rule of thumb is to set first -40dB attenuation noises, to set filter frequency $\frac{1}{10}$ of switching frequency.

$$L_{filter} = \frac{1}{\left(2 \cdot \pi \cdot \frac{f_{sw}}{10}\right)^2 \cdot C_{filter}}$$



OSCILLATION AT CONVERTER INPUT

CE DIFFERENTIAL MODE INPUT FILTER DESIGN



- Adding an input EMI filter to converter input can cause oscillation at converter input
- Problem could arise : the converter no longer meets response specification and may even become unstable!!!

Why????

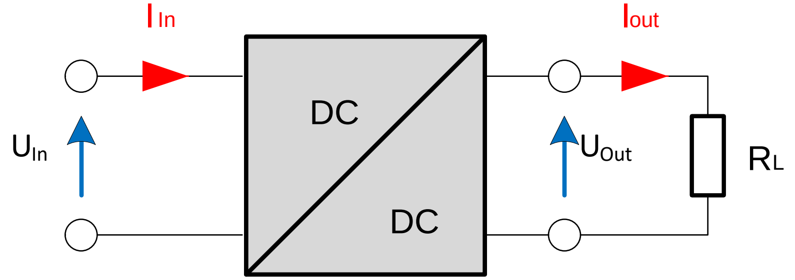
INPUT IMPEDANCE OF CONVERTER (AN EXPLANATION)

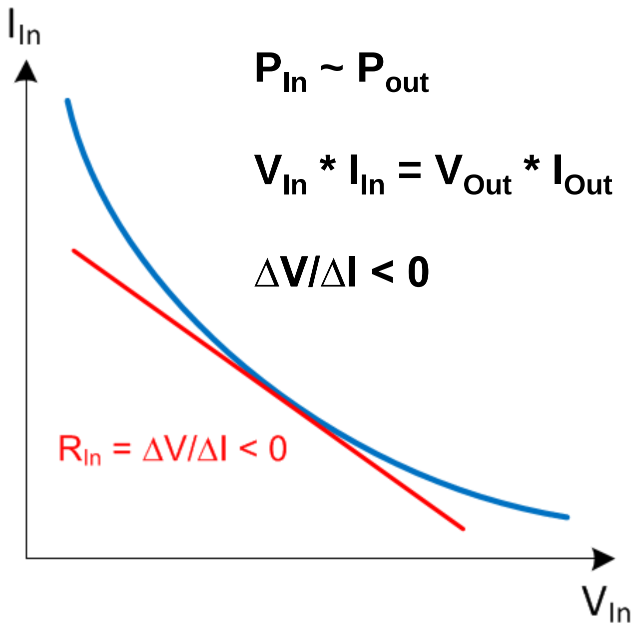
CE DIFFERENTIAL MODE INPUT FILTER DESIGN

- Input and output power of converter is near the same (efficiency drop)
- Under stable conditions output power is constant
- If the input voltage falls, the input current increases
- Voltage-current line has a negative slope

$\boxed{V_{In}\downarrow} \rightarrow \boxed{I_{In}\uparrow} \rightarrow \boxed{R_{In} < 0}$

NEGATIVE DC INPUT RESISTANCE





FILTERING DRAWBACK SOLUTION

SMPS filtering

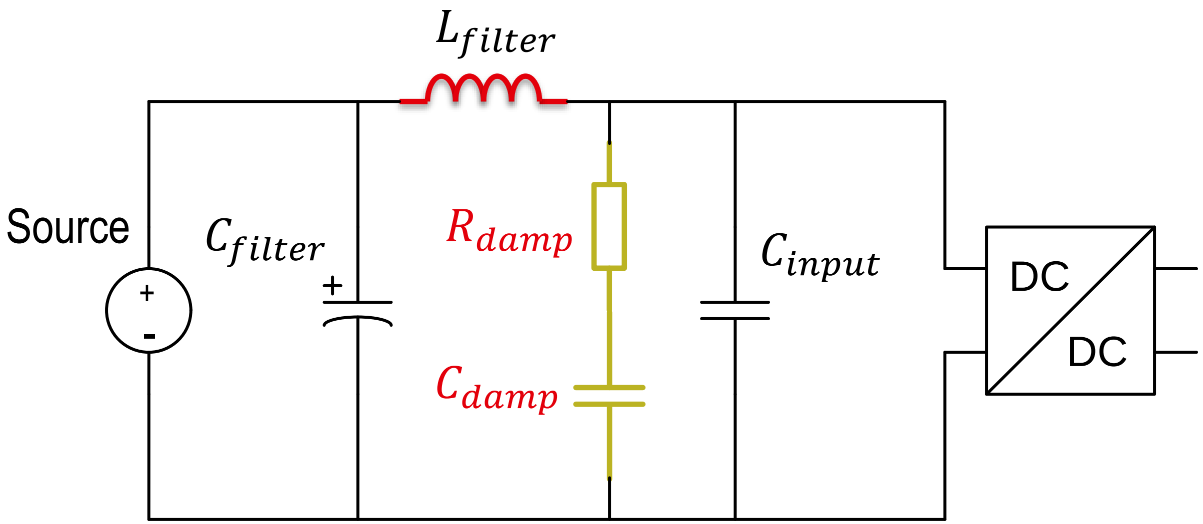
- **Filter fitting**
  - Caution must be observed with filtering, when inserting **magnetics** in power lines
  - Dampening is necessary to calm down any resonance effect
    - A dampening factor ζ of 0.707 is sufficient
  - A rule of thumb is to set few ohms max to R_damp
  - C_{damp} value near to C_{input} to avoid high ‘n’ value
  - ‘n’ should be 4

Microsoft Excel Worksheet

    - Possible with different capacitor technologies

$$n = \frac{C_{damp}}{C_{input}}$$

$$\zeta = \frac{n+1}{n} \cdot \frac{L_{filter}}{2 \cdot R_{damp} \cdot \sqrt{L_{filter} \cdot C_{input}}}$$

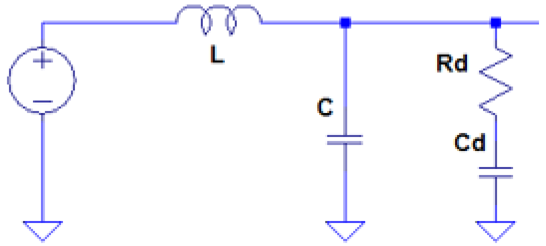


CALCULATING INPUT FILTER COMPONENTS VALUES

1) Calculate damping capacitor $C_d = \mathrm{n} \cdot Cf \qquad with\ n = 4\ or\ 6$

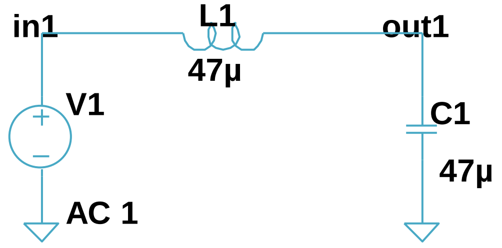
2) Calculate damping Resistor $R_d = \sqrt{\frac{L_f}{C_f}} \frac{(n+1)}{2n} \sqrt{\frac{2n^2(4+n)}{(2+n)(4+3n)}}$

Keeping the same values of undamped filter, we can add an Rd and a Cd as follows:

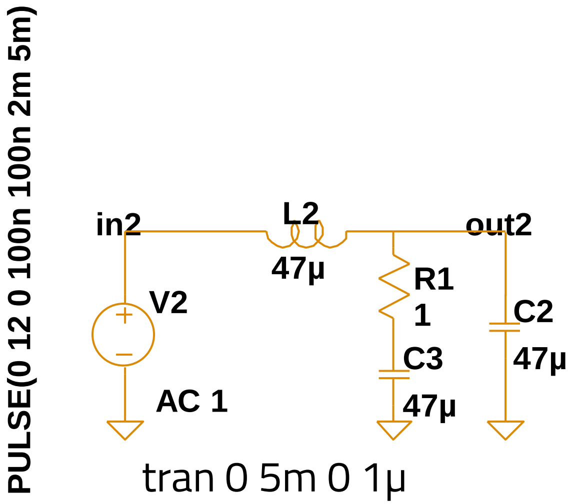


GLOBAL FILTERING

SMPS filtering : differential mode

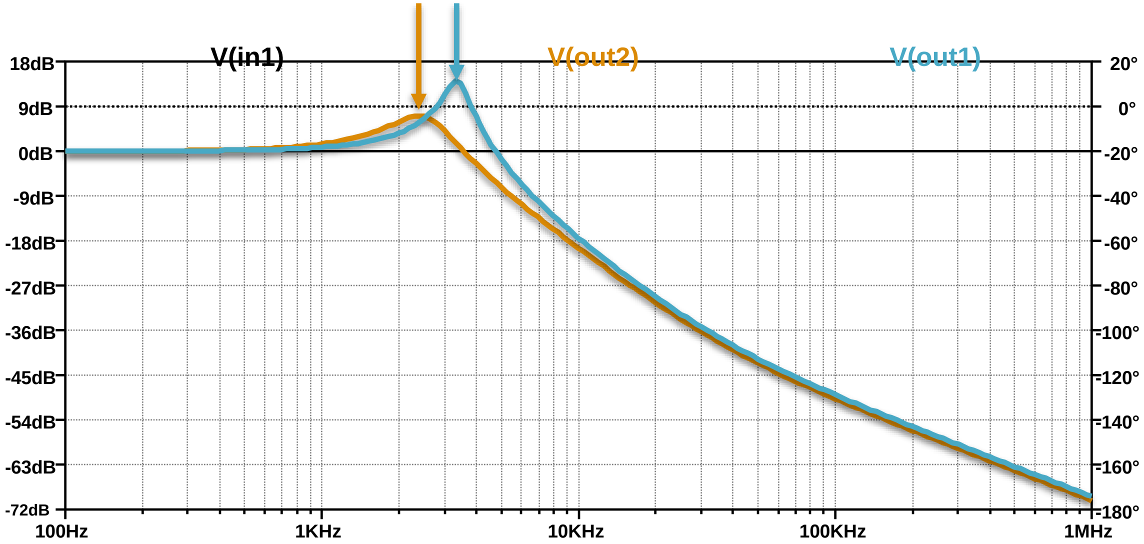


.ac dec 100 100 1Meg

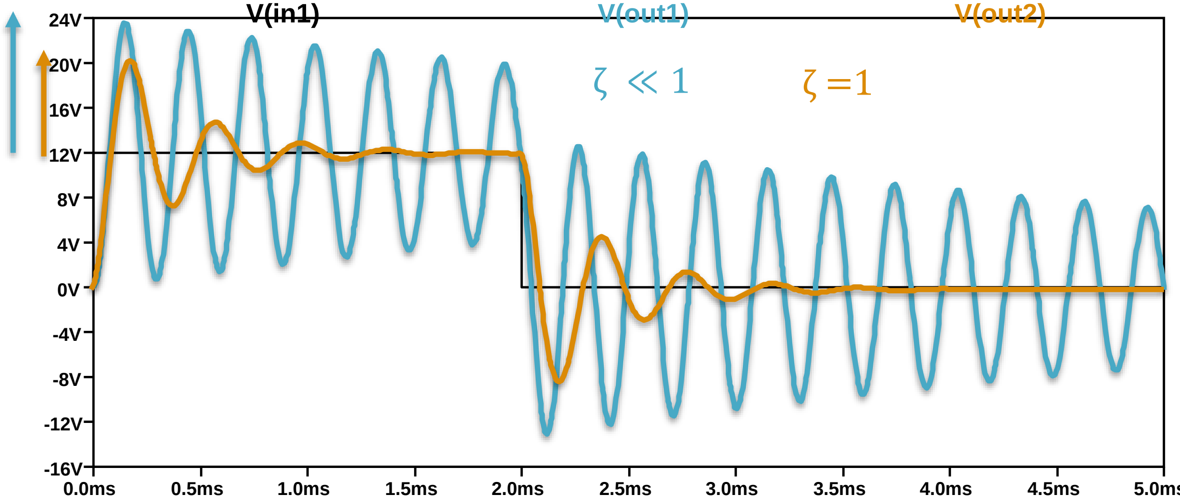


tran 0 5m 0 1µ

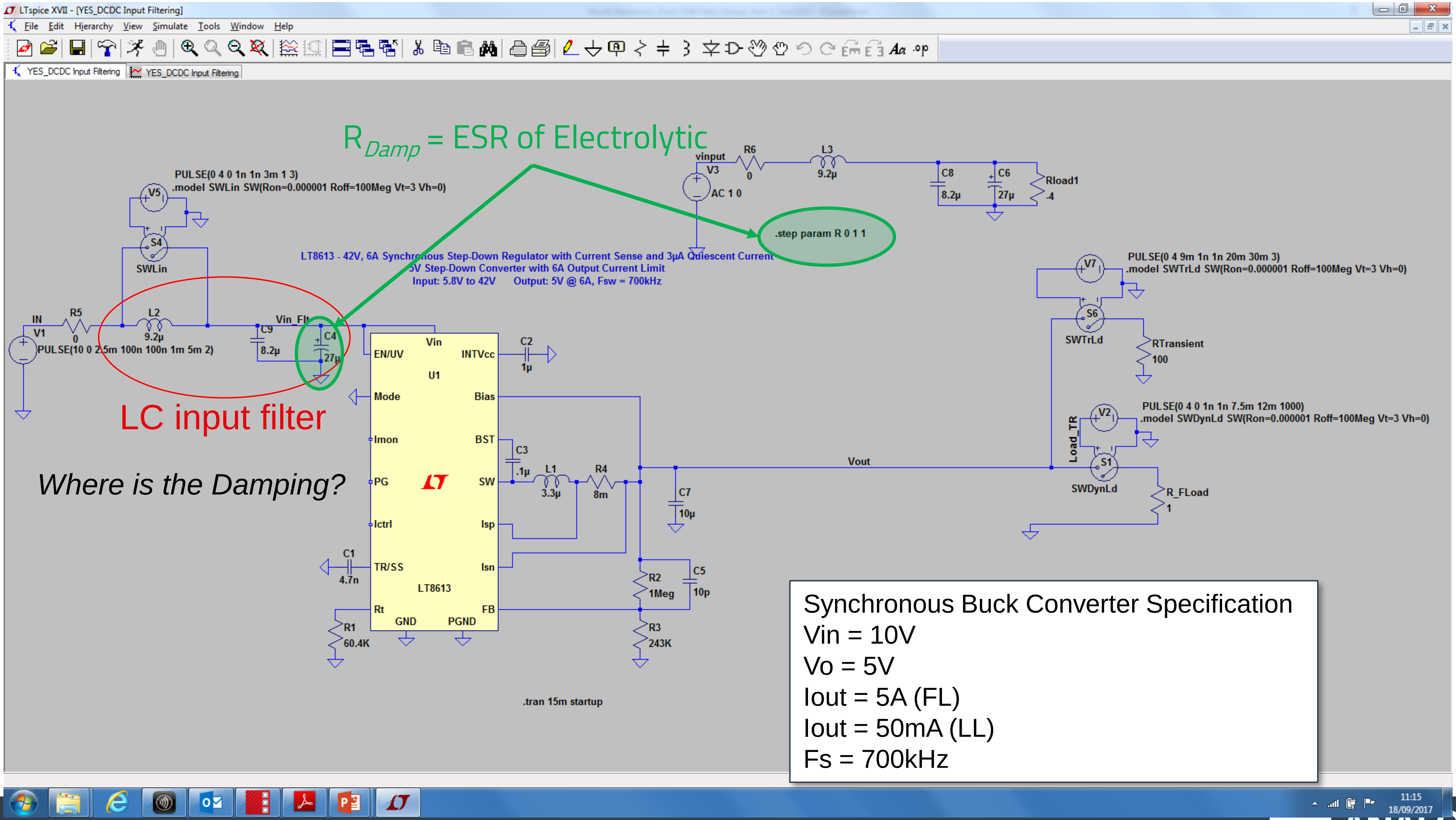
- **Frequency domain :**



- **Time domain:**

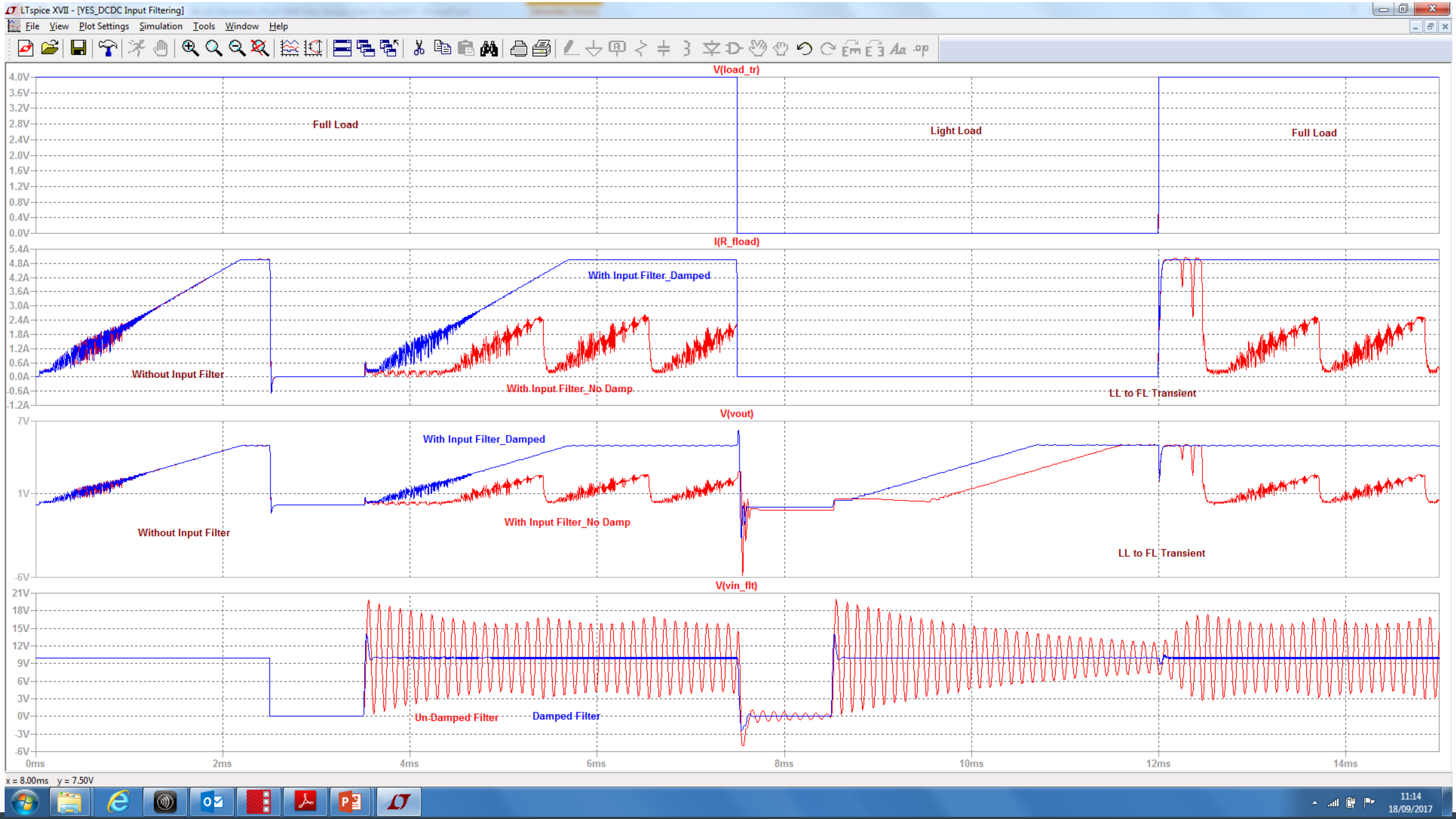


CE DIFFERENTIAL MODE FILTER DESIGN – BUCK EXAMPLE



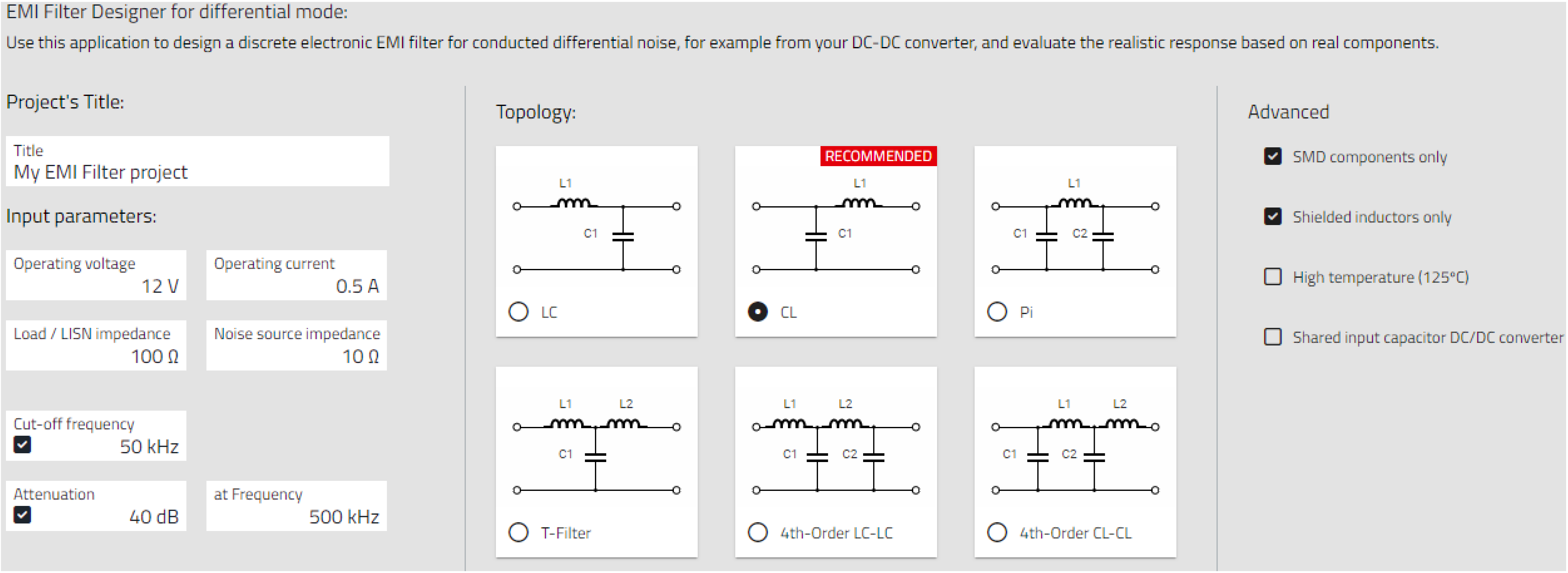
Synchronous Buck Converter Specification
Vin = 10V
Vo = 5V
Iout = 5A (FL)
Iout = 50mA (LL)
Fs = 700kHz

CE DIFFERENTIAL MODE FILTER DESIGN – BUCK EXAMPLE



FILTER TOPOLOGIES FOR IMPEDANCE SYSTEM

Use **REDEXPERT** Tool: SMART way

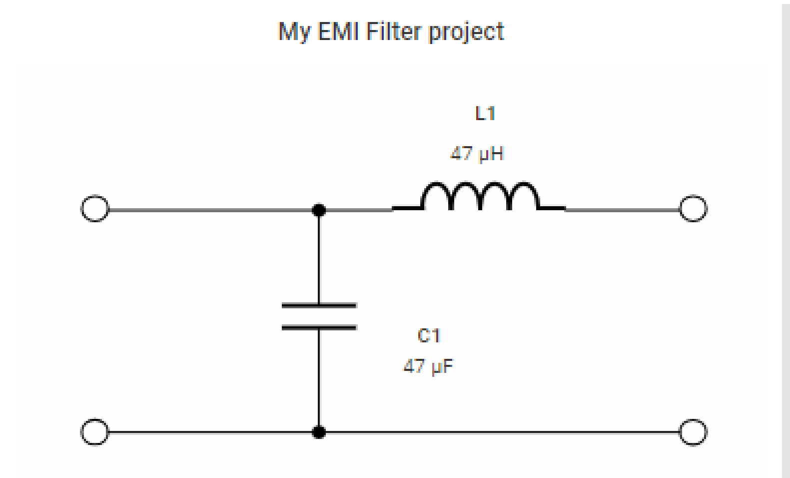


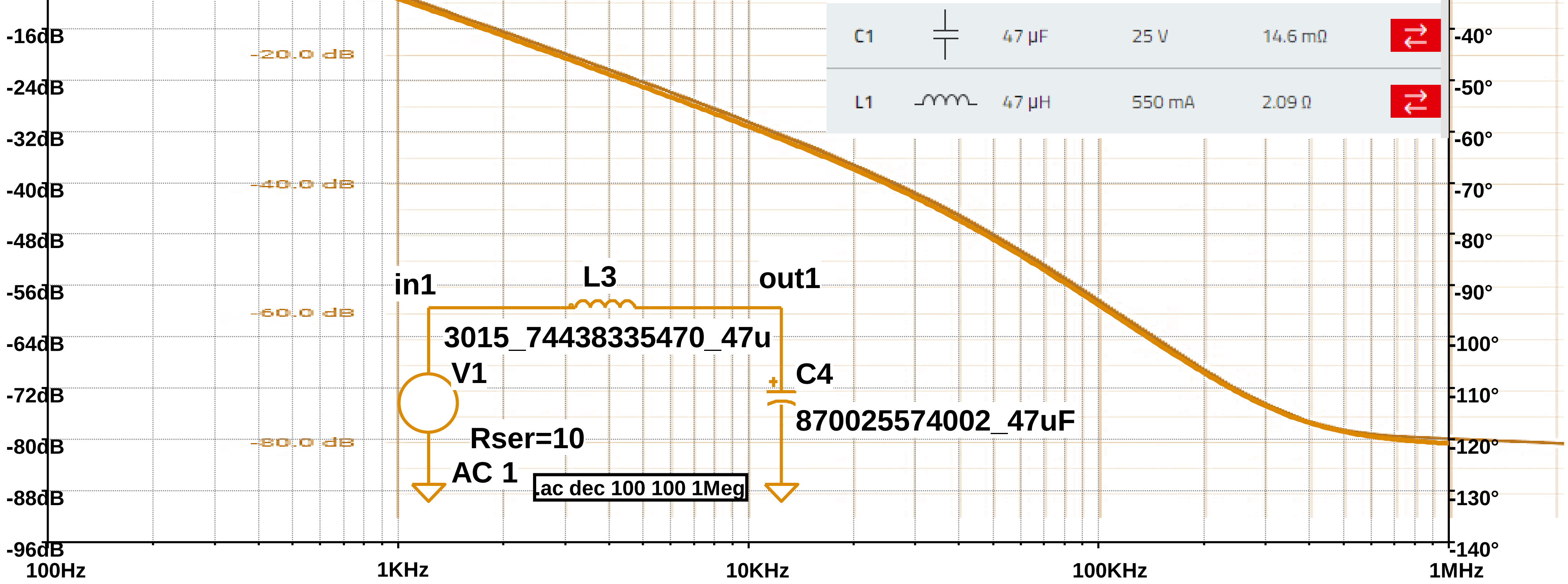
https://redexpert.we-online.com/we-redexpert/en/#/emifd-embedded

GLOBAL FILTERING

SMPS filtering : differential mode

- LtSpice and **REDEXPERT** comparison: same results!





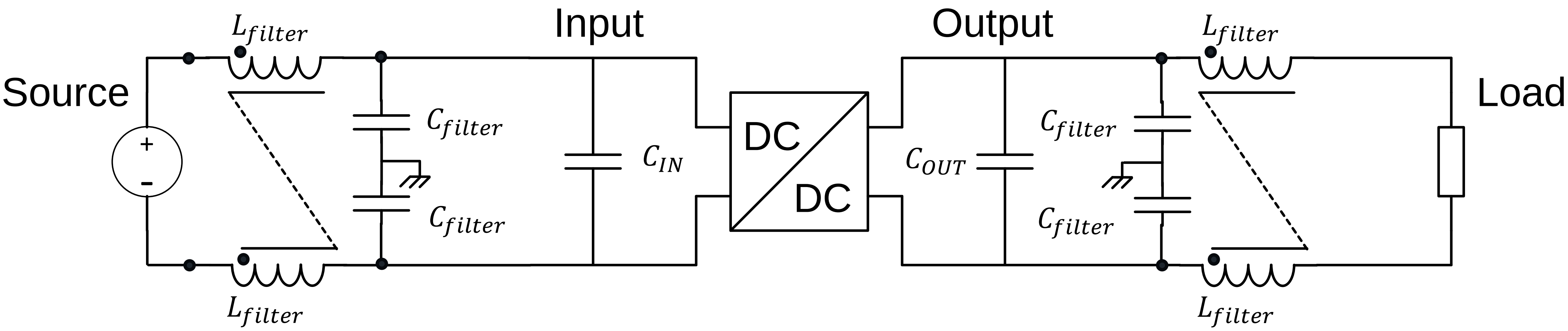
GLOBAL FILTERING

SMPS filtering : common mode

- Quick design : common mode filtering
  - To reach around 30dB~40dB attenuation :

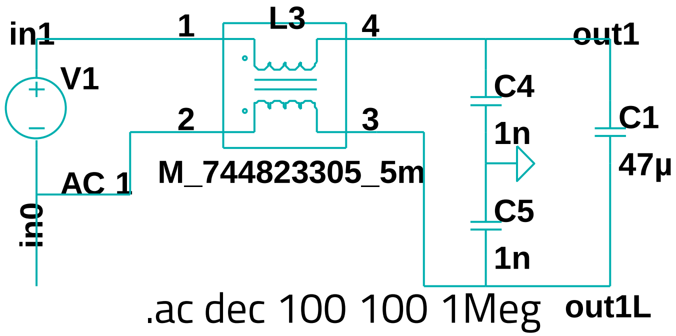
➔ Corner frequency of LC filter < 5~10 time less than converter working frequency.

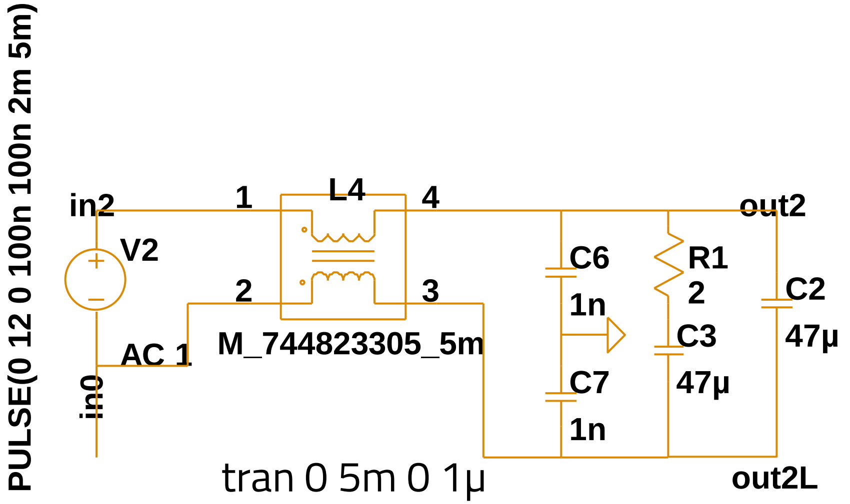
$$L_{filter} = \frac{1}{\left(2 \cdot \pi \cdot \frac{f_{SW}}{5\sim10}\right)^2 \cdot C_{filter}}$$



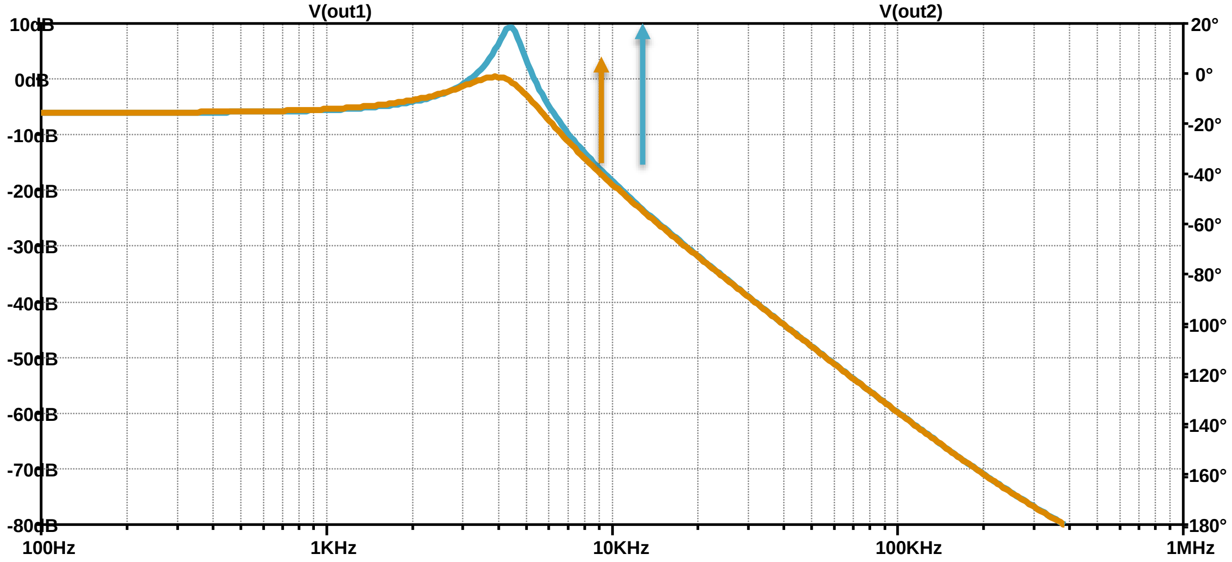
GLOBAL FILTERING

SMPS filtering : common mode

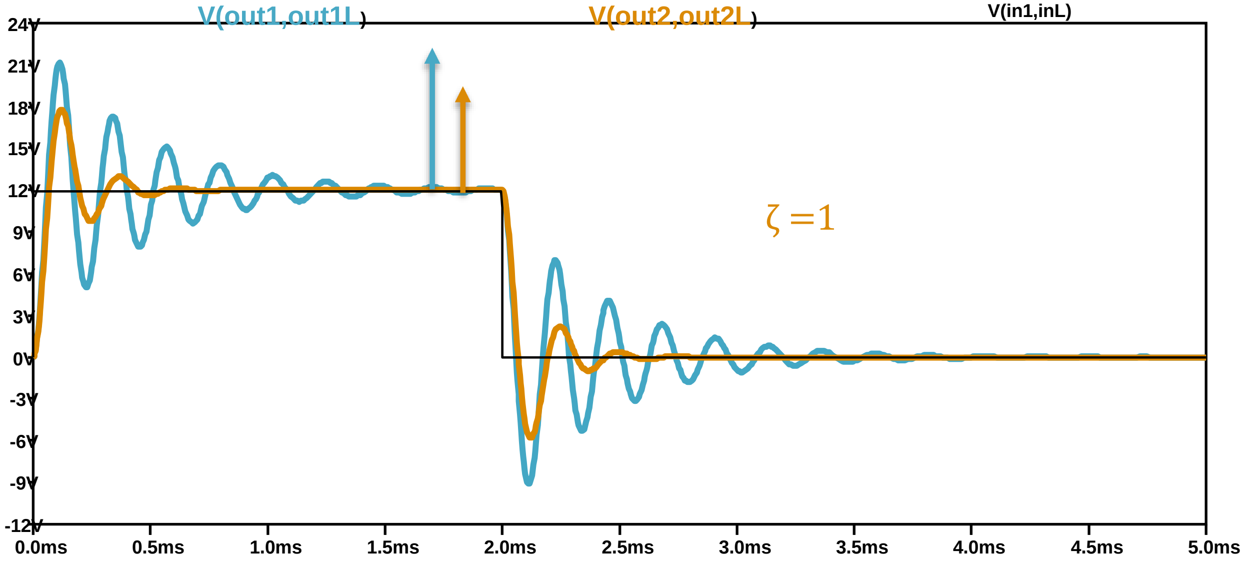




- **Frequency domain :**



- **Time domain:**



APPNOTE ANP015

DCDC & ACDC Filter Calculation / LT Spice Simulation / Measurement / Layout

ANP015

APPLICATION NOTE

ANP015 | 1-Phase Line Filter Design

Andreas Nadler and Stefan Klein

01. INTRODUCTION

The aim of this application note is to provide the reader with a comprehensive overview of the steps necessary toward a suitably dimensioned line filter whose format is as compact as possible. A discrete single-stage line filter is compared here with a discrete two-stage line filter by means of calculation, simulation and measurement. The different core materials of the common mode chokes and their properties are then explained. This application note also addresses the calculation of: varistors, leakage currents and discharge resistors. It requires a certain knowledge of passive components, filters and EMC measurement techniques.

02. PRECOMPLIANCE MEASUREMENT SETUP

The two different interference current paths have to be distinguished: common mode (CM) and differential mode (DM). In an EMC acceptance test, both interference current

The two measurement outputs ($L_{,RF}$ and $N_{,RF}$) of the LISN are connected to the analog inputs 1 and 2 (50 Ω) of an oscilloscope. The mathematical function of the oscilloscope is then used to determine the interference voltage for DM and CM:

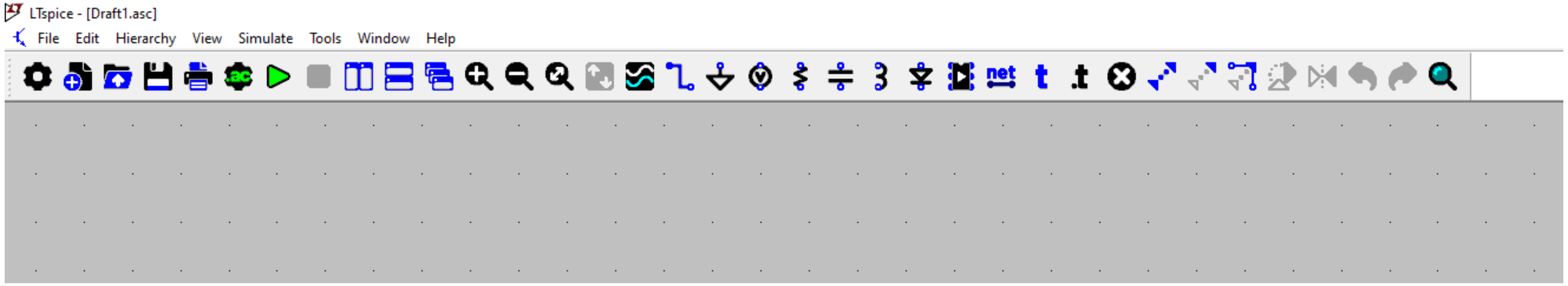
$$V_{DM} = \frac{V_{L,RF} - V_{N,RF}}{2} \qquad (1)$$

$$V_{CM} = \frac{V_{L,RF} + V_{N,RF}}{2} \qquad (2)$$

For precompliance measurement, a Rohde & Schwarz RTA4004 oscilloscope with 500 MHz analog bandwidth is used in conjunction with the desktop software R&S EMI Debug Tool and a CISPR16 LISN (own construction) (setup in Figure 2).

EMC SIMULATION

- The most portable Lab

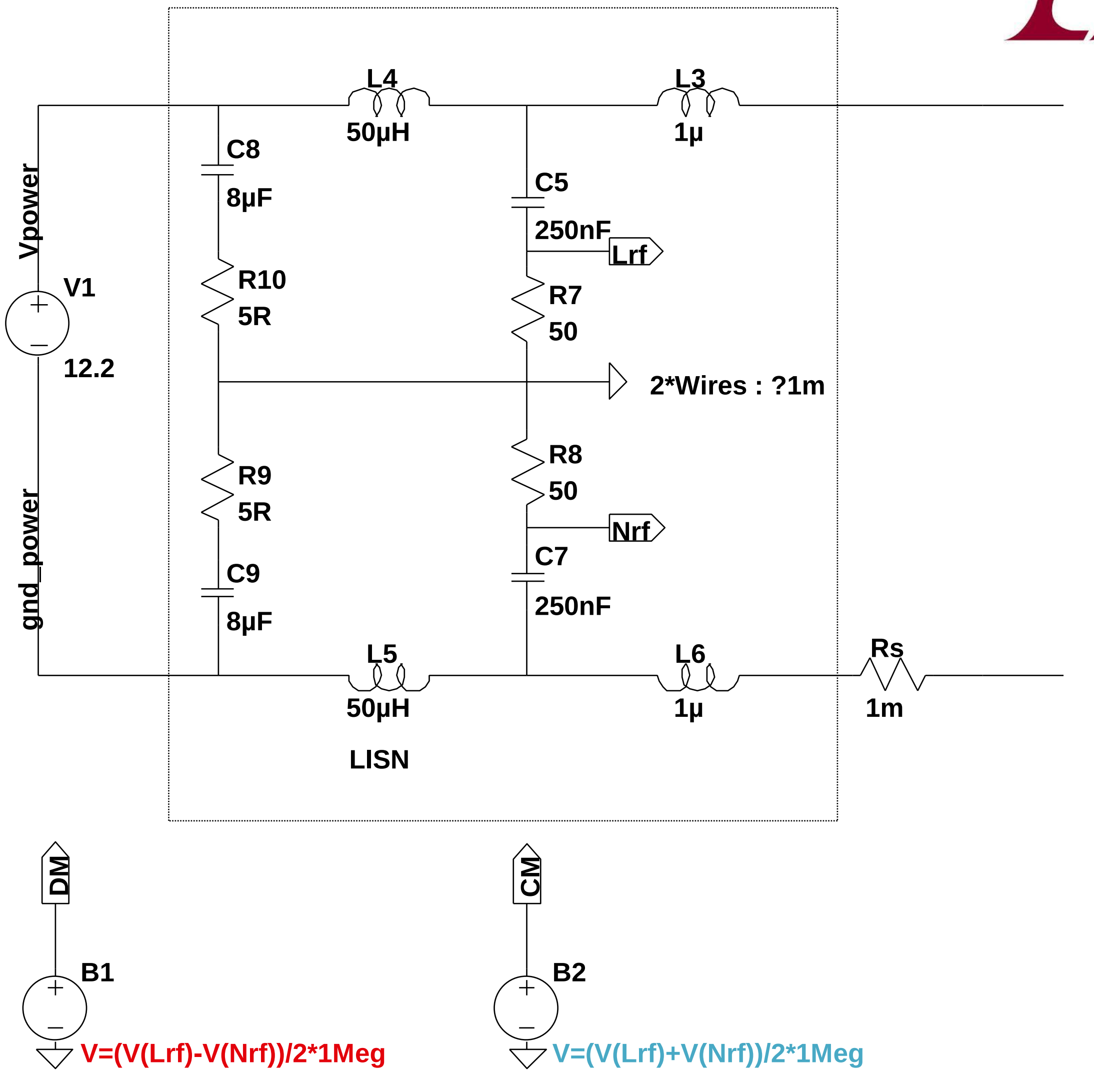


LTSPICE SIMULATION

LTSPICE SIMULATION

LISN

- Schematic
  - Typical schematic for a LISN, very common
- Common mode / differential mode
  - **CM** and **DM** are made from noise nodes Lrf and Nrf with a sum or difference

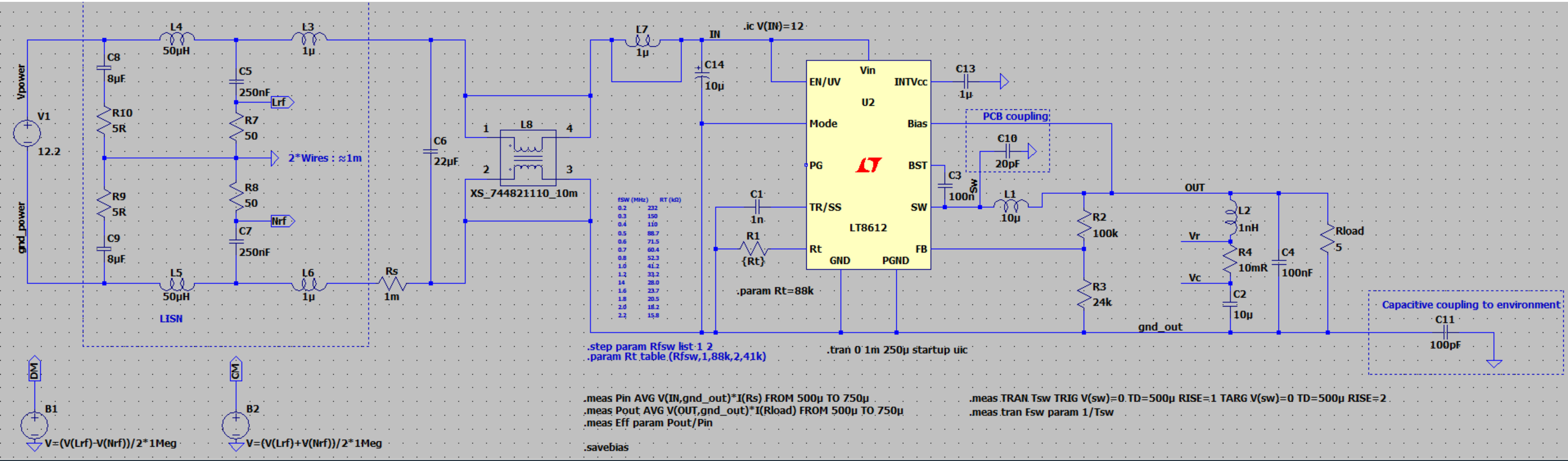


LTSPICE SIMULATION

Fsw=500kHz, Buck LT8612 12-5V 1A

- Schematic
  - $V_{DM}(\mu V) = \frac{V_{LRF} - V_{NRF}}{2} * 1\,000\,000$ $\quad$ $V_{CM}(\mu V) = \frac{V_{LRF} + V_{NRF}}{2} * 1\,000\,000$

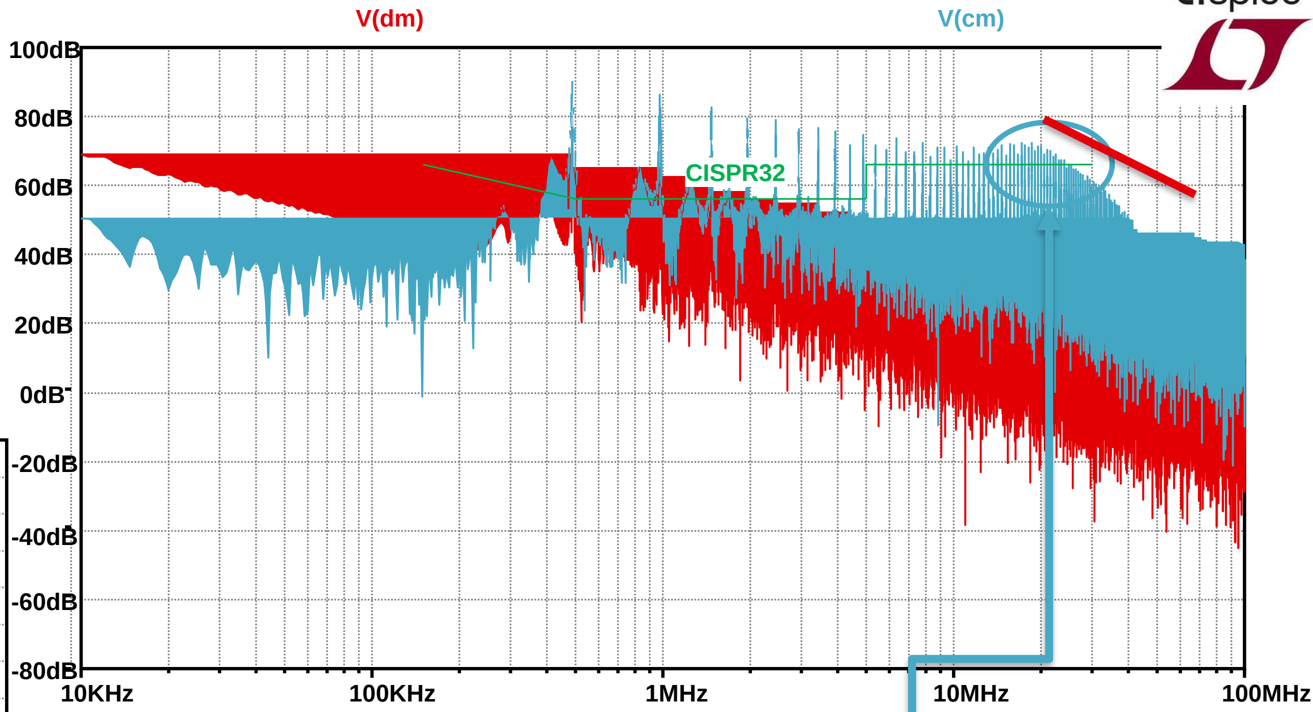
$$dB\mu V = 20 \cdot \log\left(\frac{U(V)}{1\mu V}\right) \quad \Leftrightarrow \quad 1\mu V = 0dB\mu V \qquad 1V = 1\,000\,000\mu V = 20 \cdot \log(10^6) = 120dB\mu V$$

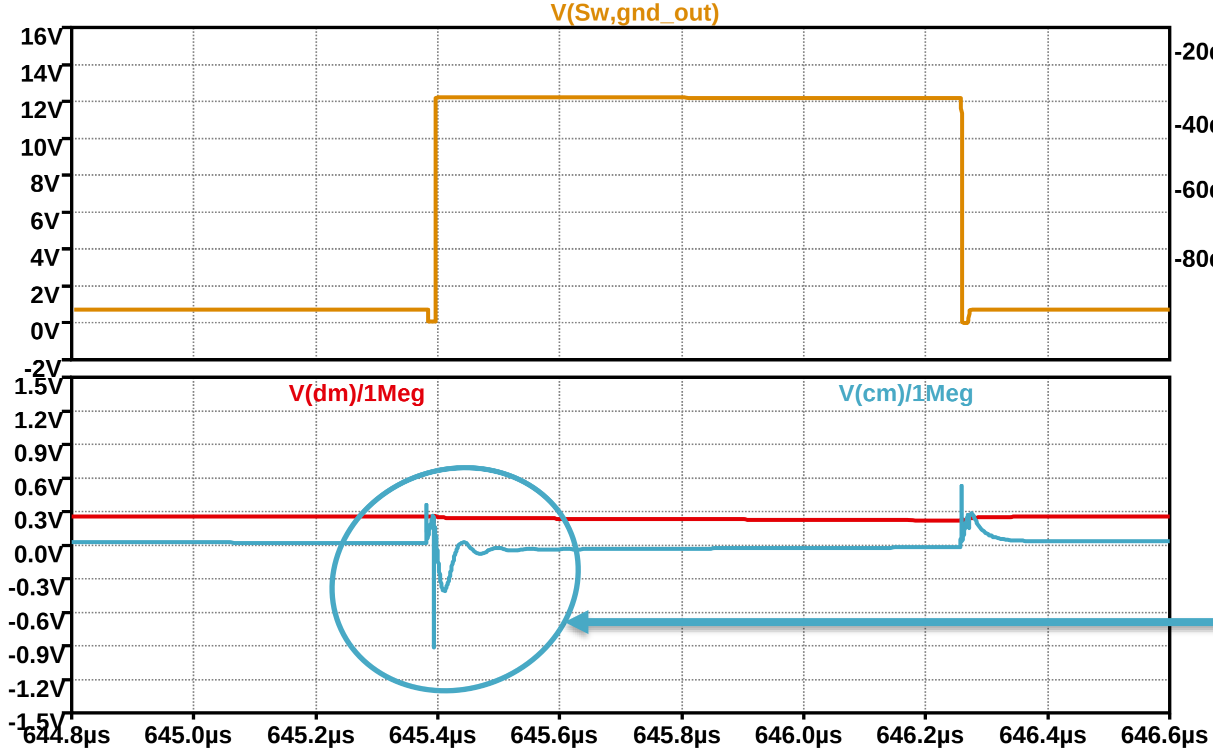


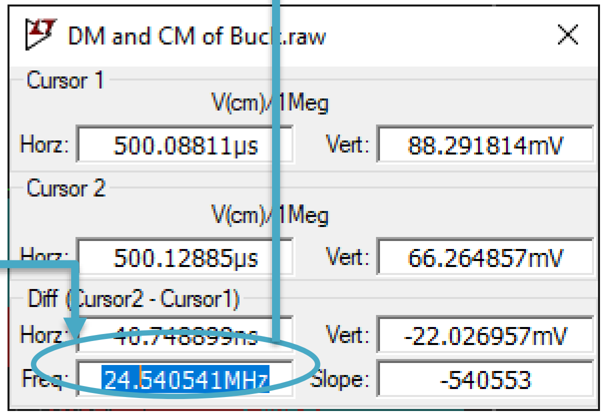
LTSPICE SIMULATION

Fsw=500kHz, Buck LT8612 12-5V 1A

- Time and frequency link
  - Perturbation frequency



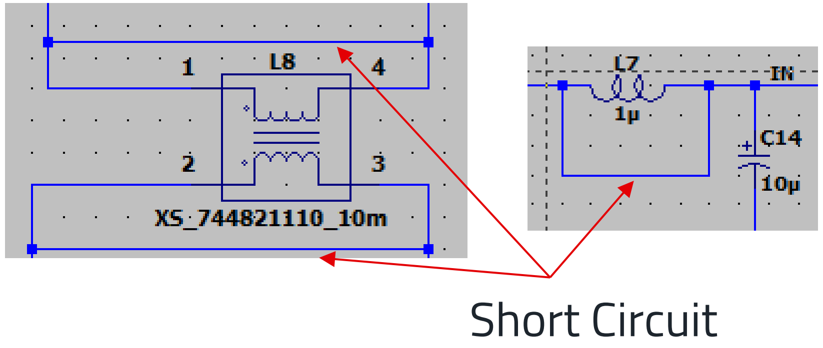


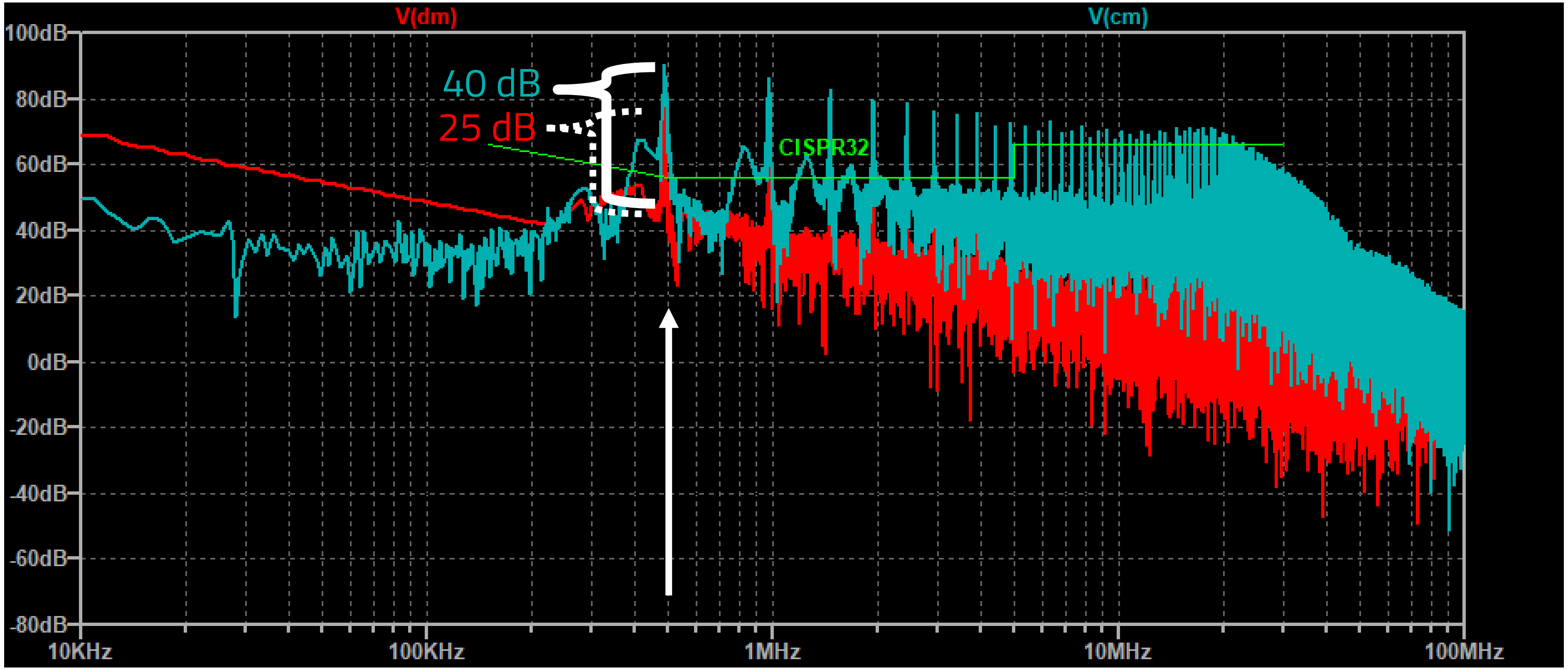


LTSPICE SIMULATION

Fsw=500kHz, Buck LT8612 12-5V 1A

- **No filter** :extra wideband noises, Fsw main disturbance





LTSPICE SIMULATION

REDEXPERT Selection of the differential Mode Inductor

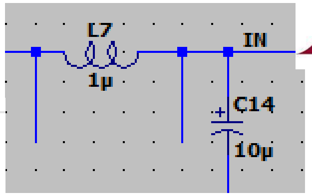
- Quick calculation example

$$L_{filter} = \frac{1}{\left(2 \cdot \pi \cdot \frac{f_{sw}}{10}\right)^2 \cdot C_{filter}} = \frac{1}{\left(2 \cdot \pi \cdot \frac{500k}{10}\right)^2 \cdot 10\mu F}$$

$$L_{filter} = \frac{1}{(2 \cdot \pi \cdot 50k)^2 \cdot 10\mu F}$$

$$L_{filter} = 1\mu H$$

Iterative calculation could be used to reach a common value, **frequency to no need to be ultra precise.**



WE-MI SMT Multilayer Inductor
L 0.047 to 33 µH | I_R 3 to 300 mA | $R_{DC\ max.}$ 0.15 to 1.85 Ω

WE-SD Rod Core Choke
L 2 to 10 µH | L_1 10 µH | I_R 3 to 15 A | I_R 15 A | $R_{DC\ 1}$ 5.7 mΩ

WE-FI Leaded Toroidal Line Choke EXTENDED
L 8.2 to 860 µH | L_1 140 to 150 µH | I_R 1.1 to 5.4 A | $R_{DC\ max.}$ 0.042 to 0.26 Ω

WE-TI Radial Leaded Wire Wound Inductor
L 1 to 68000 µH | L_1 1500 µH | I_R 0.68 A | $R_{DC\ max.}$ 0.01 Ω to 112000 mΩ

WE-SI Leaded Toroidal Storage Choke EXTENDED
Shielded | L 12 to 1619 µH | I_R 1.1 to 14.5 A

WE-RCIT Rod Core Inductor THT
L 2 to 10 µH | I_R 3 to 15 A | R_{DC} 1.7 to 33 mΩ

WE-RCIS Rod Core Inductor SMT
L 1 to 10.4 µH | $R_{DC\ max.}$ 1.1 to 33 mΩ

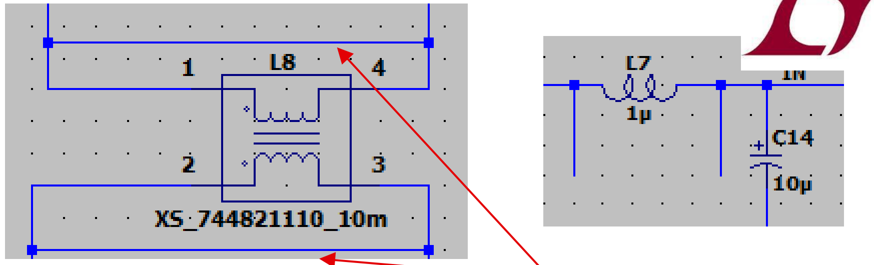
WE-PD2 SMT Power Inductor
L 1 to 2200 µH | $R_{DC\ max.}$ 0.009 to 5.3 Ω

WE-LQ SMT Inductor
Unshielded | L 1 to 2200 µH | I_R 0.04 to 1.8 A | $R_{DC\ max.}$ 0.08 to 47 Ω

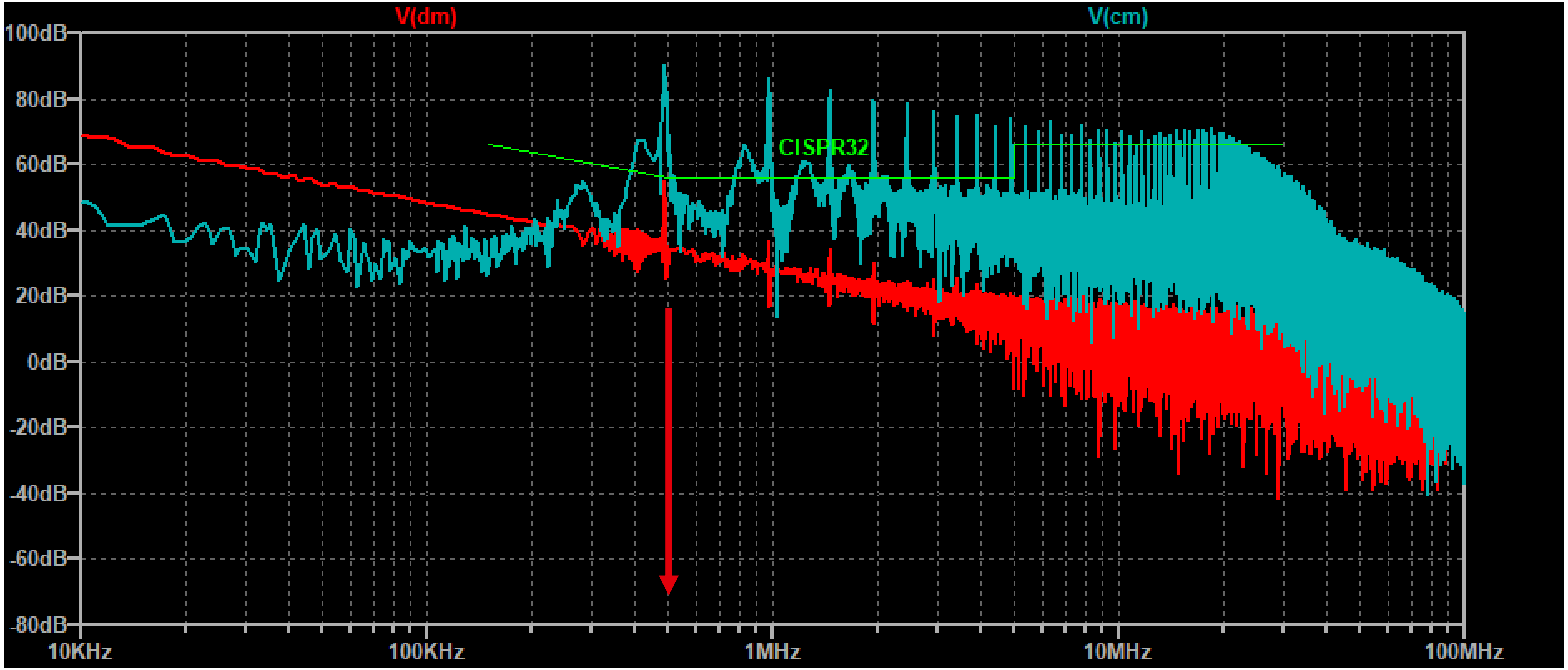
LTSPICE SIMULATION

LtSpice simulation

- **With DM only** : DM filtering action !



Short Circuit



$L_{filter}=1\mu H$

LTSPICE SIMULATION

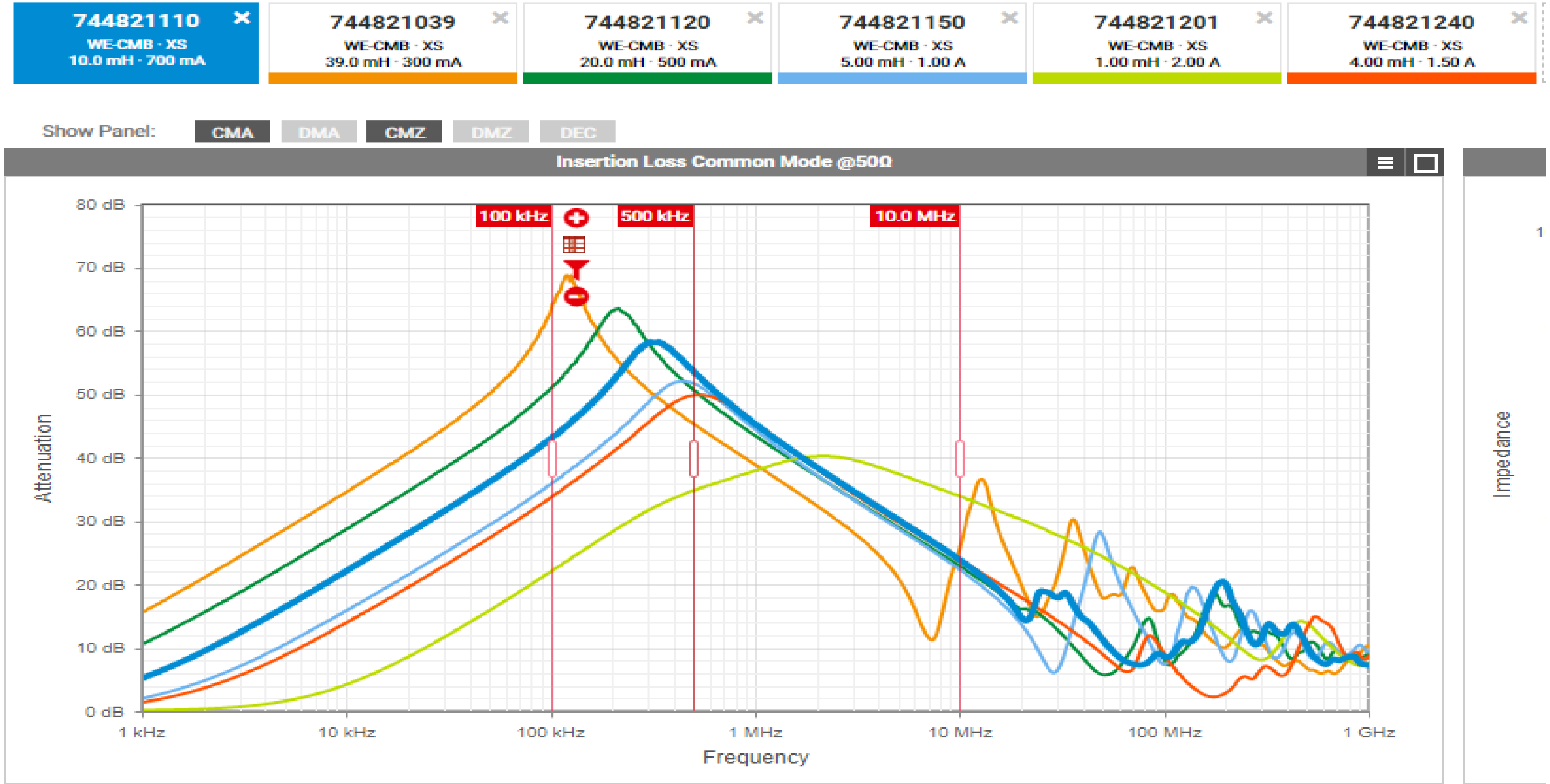
Selection of the Common Mode chokes (Fsw=500kHz, Buck LT8612 12-5V 1A ($I\_in > 400mA$)

- Need 40bB for 500kHz and try to find wide BW : 100kHz to 10MHz

Use **REDEXPERT**

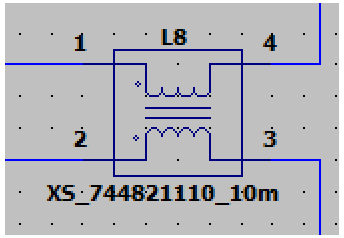
WE-CMB – XS comparison

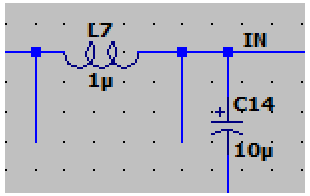
10mH [744821110]() seems to be well centered and enough attenuation

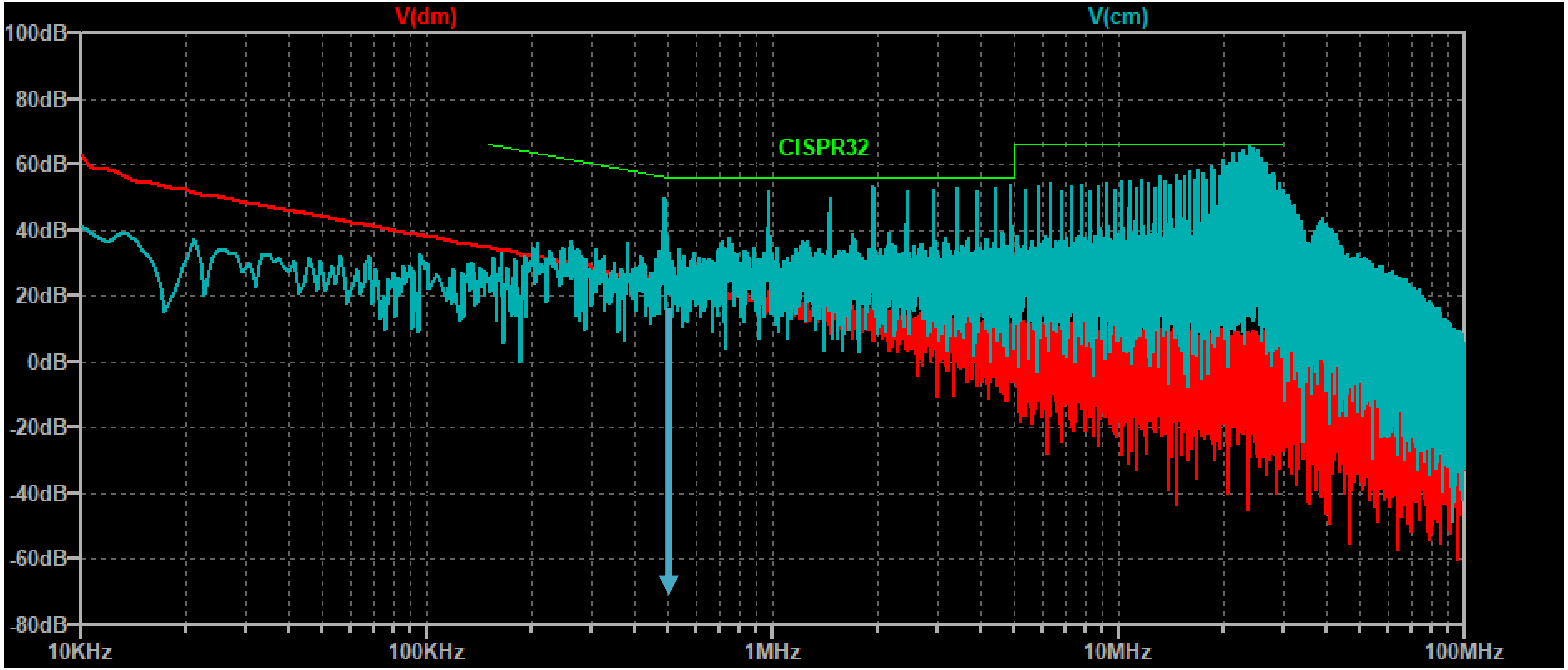


LtSpice simulation

- With DM+CM : Noise killer... Ready to go to EMC Lab!







$L_{CMC}=10mH$