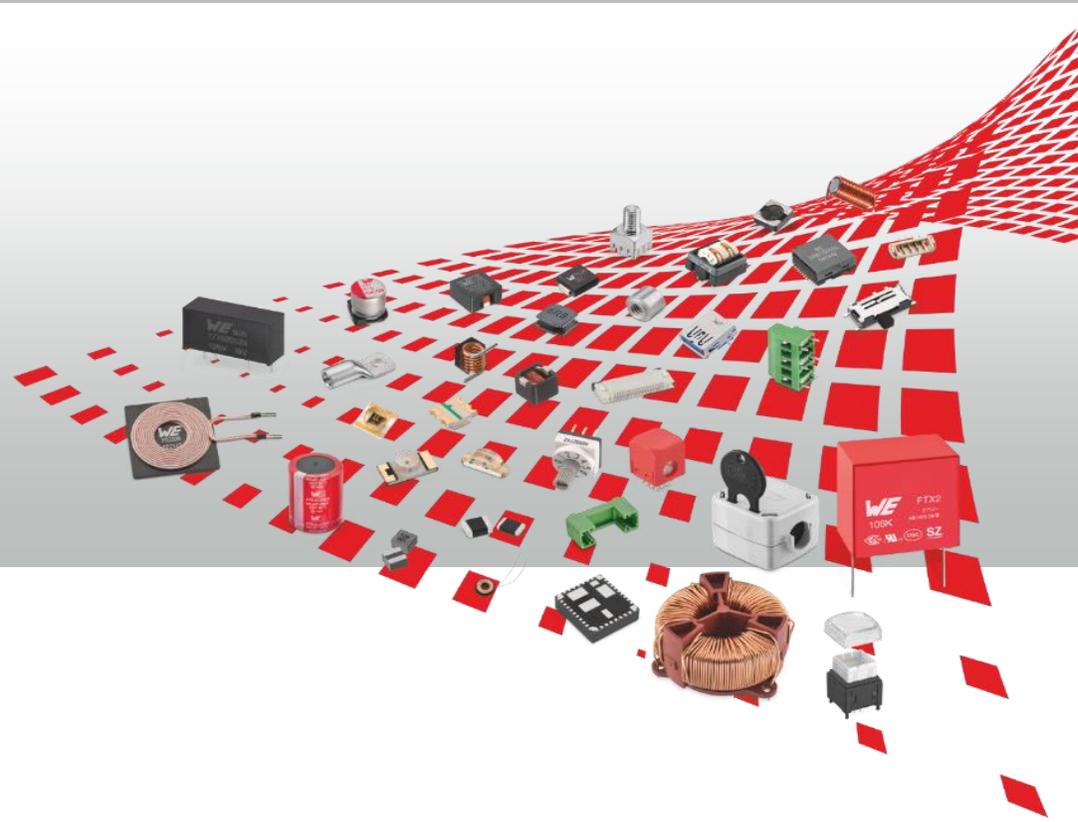


Anticipate EMC with LTSPICE

more
than you
expect



Sylvain Le Bras
Field Application Engineer

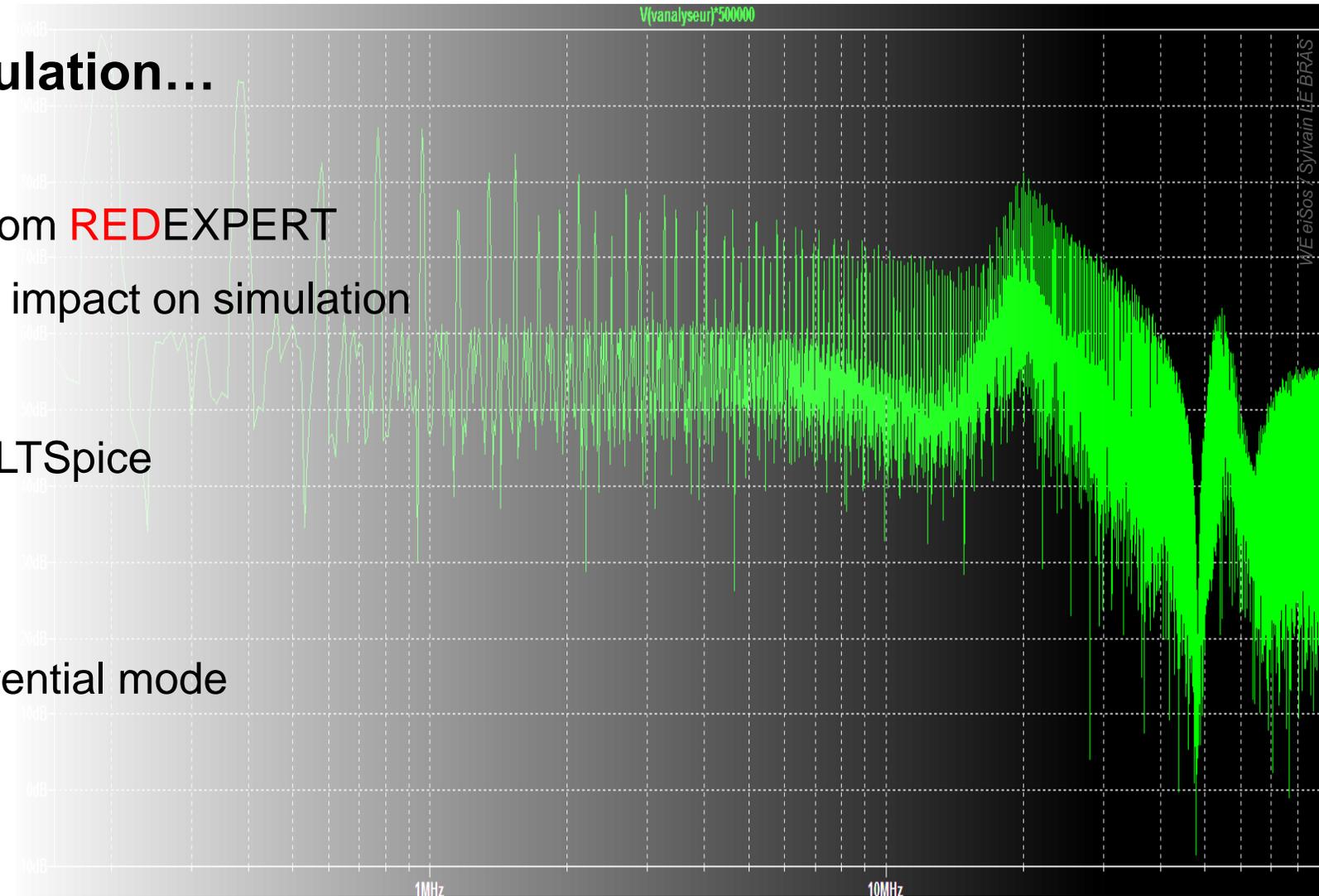
Sylvain.LeBras@we-online.com

Anticipate EMC with LTSpice

Using LTSPICE and Redexpert to check power supply designs



- **Intro : From functional simulation...**
 - Output ripple of a Buck
 - Extracting EMC accurate data from **REDEXPERT**
 - Example of (non) EMC accurate impact on simulation
- **...To EMC simulation**
 - Enabling EMC measurement in LTSpice
 - Getting Seriously Accurate ?
 - Going further with simulation
 - Splitting Common and Differential mode
 - Making simulation look real
 - Examples



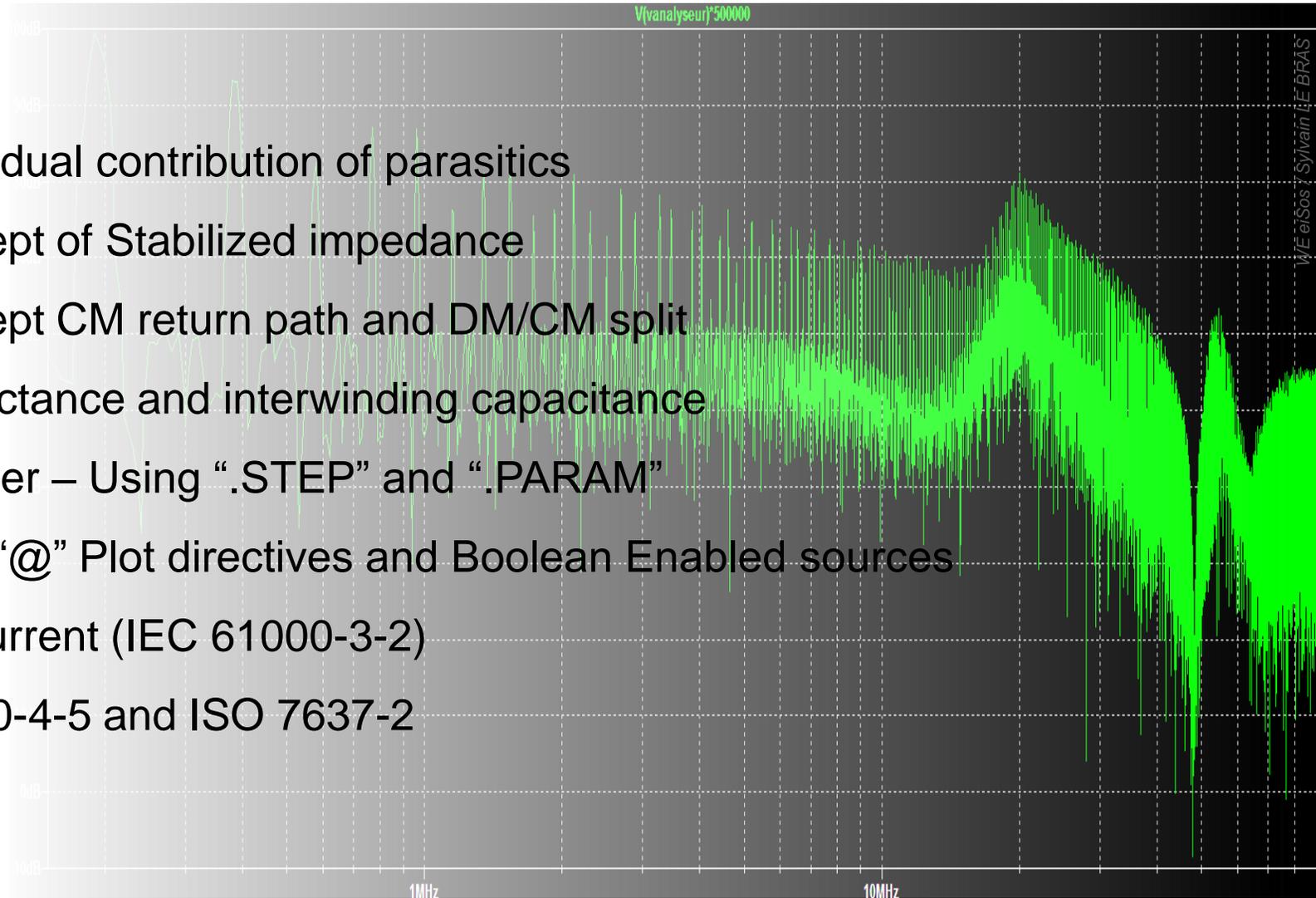
Anticipate EMC with LTSpice

Using LTSPICE and Redexpert to check power supply designs



■ Available examples

1. Output ripple of a Buck – Individual contribution of parasitics
2. Noise at Input of Buck – Concept of Stabilized impedance
3. Noise at Input of Buck – Concept CM return path and DM/CM split
4. Flyback converter – Stray inductance and interwinding capacitance
5. Brushless DC motor and inverter – Using “.STEP” and “.PARAM”
6. Evaluation of filter response – “@” Plot directives and Boolean Enabled sources
7. Power Factor and Harmonic current (IEC 61000-3-2)
8. Surges according to IEC 61000-4-5 and ISO 7637-2



WE eiSos : Stylmain IEE BRAS

Setup

Getting the tools ready



NOW PART OF



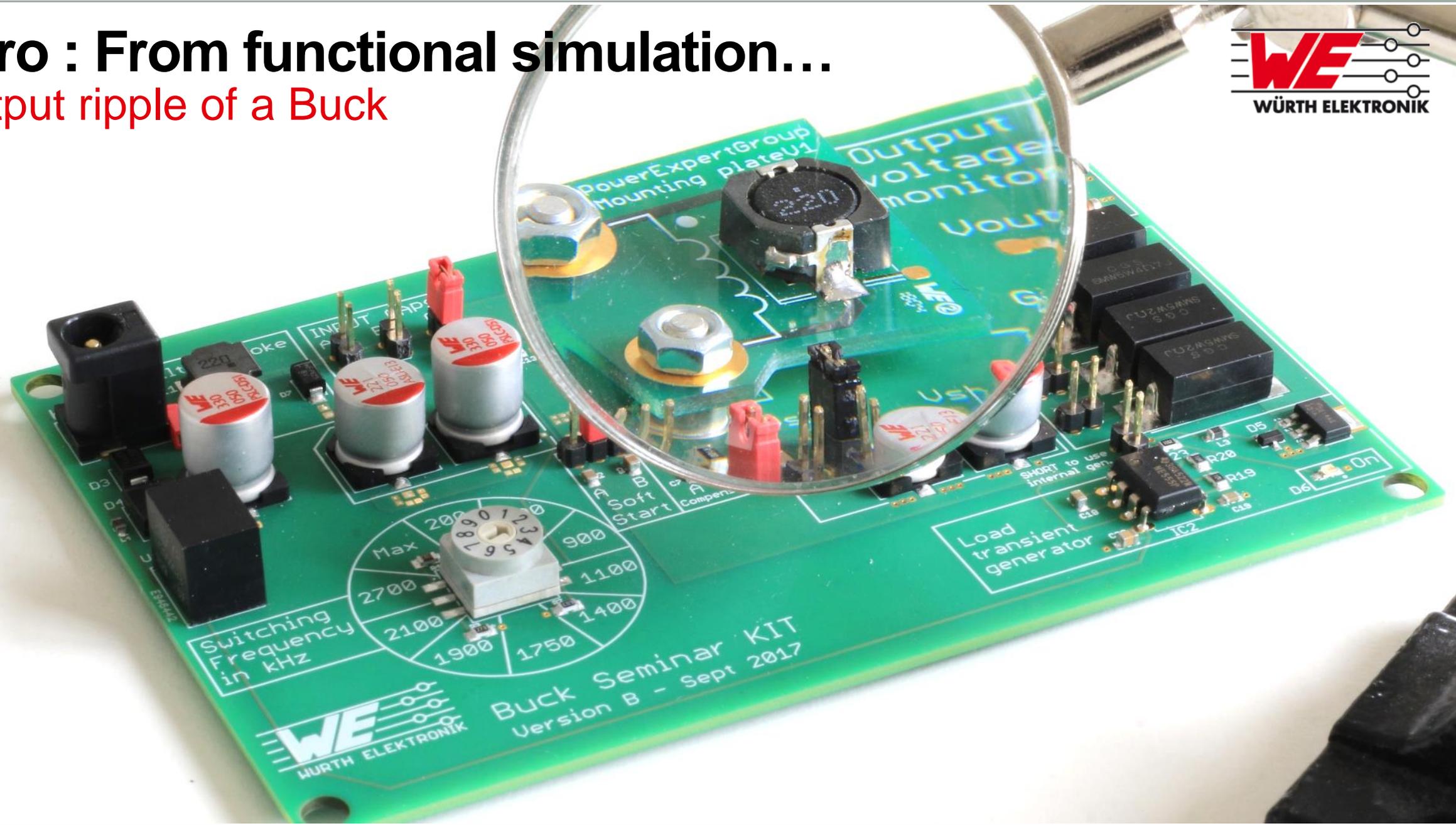
<https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html>

REDEXPERT

<https://www.we-online.com/redexpert>



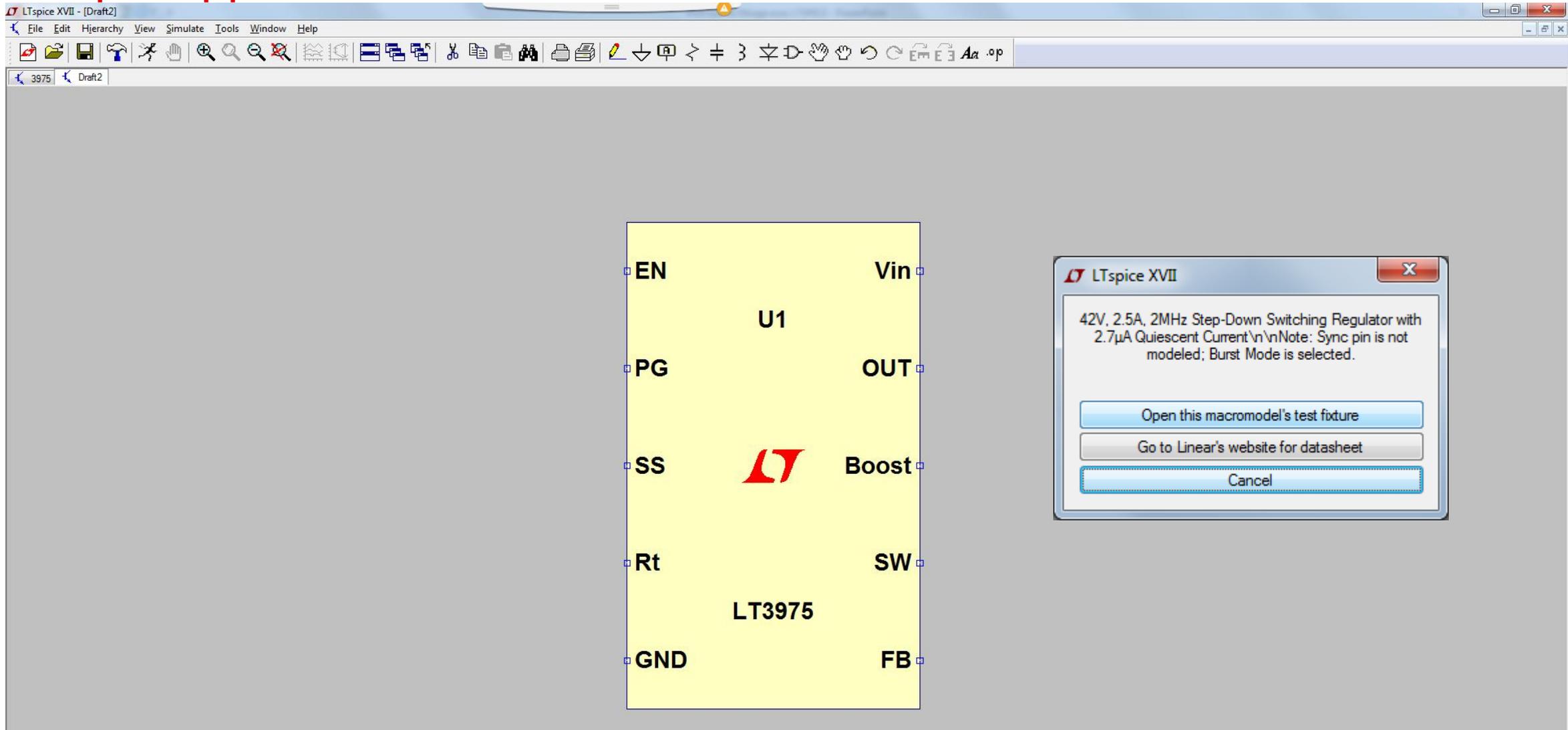
Intro : From functional simulation... Output ripple of a Buck



WE eiSos / Sylvain LE BRAS

Intro : From functional simulation...

Output ripple of a Buck



The screenshot shows the LTspice XVII interface with a schematic of an LT3975 buck converter. The schematic is a yellow rectangle containing the following pins and labels:

- EN (top left)
- Vin (top right)
- U1 (center)
- PG (middle left)
- OUT (middle right)
- SS (bottom left)
- LT (LT logo)
- Boost (bottom right)
- Rt (middle left)
- SW (middle right)
- LT3975 (bottom center)
- GND (bottom left)
- FB (bottom right)

A dialog box titled "LTspice XVII" is open on the right, displaying the following text:

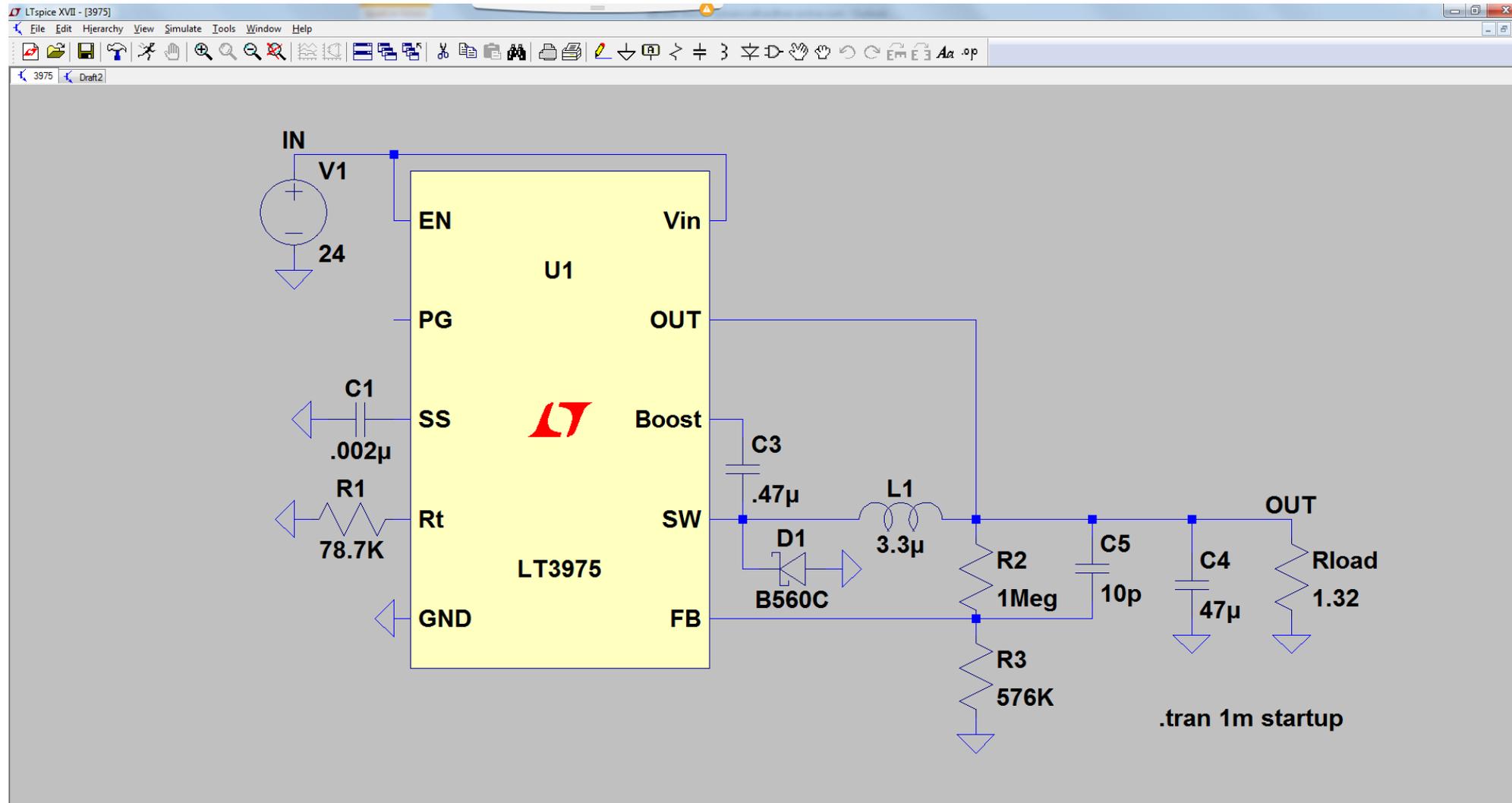
42V, 2.5A, 2MHz Step-Down Switching Regulator with 2.7µA Quiescent Current\n\nNote: Sync pin is not modeled; Burst Mode is selected.

The dialog box contains three buttons:

- Open this macromodel's test fixture
- Go to Linear's website for datasheet
- Cancel

Intro : From functional simulation...

Output ripple of a Buck (without the “hardcore mathematics”)

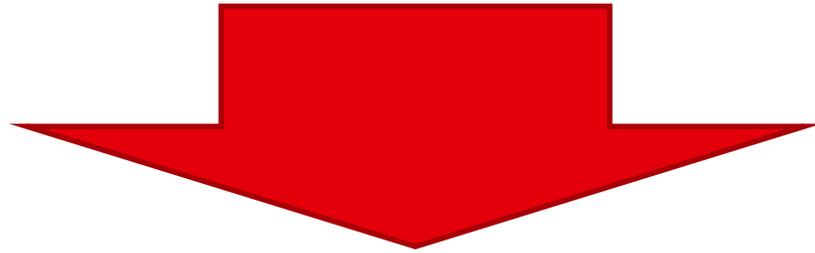


Alternate

Output ripple of a Buck

Hardcore maths ?

$$V = R \cdot I$$



$$\Delta V = Z_C \cdot \Delta I_L$$

Output ripple of a Buck

Redexpert : an ode to laziness



REDEXPERT® ALUMINIUM ELECTROLYTIC CAPACITORS APPLICATIONS

Order Code	Series	Spec	C
865230440002	WCAP-AS5H		10.0
865230343004	WCAP-AS5H		47.0
865230357007	WCAP-AS5H		330

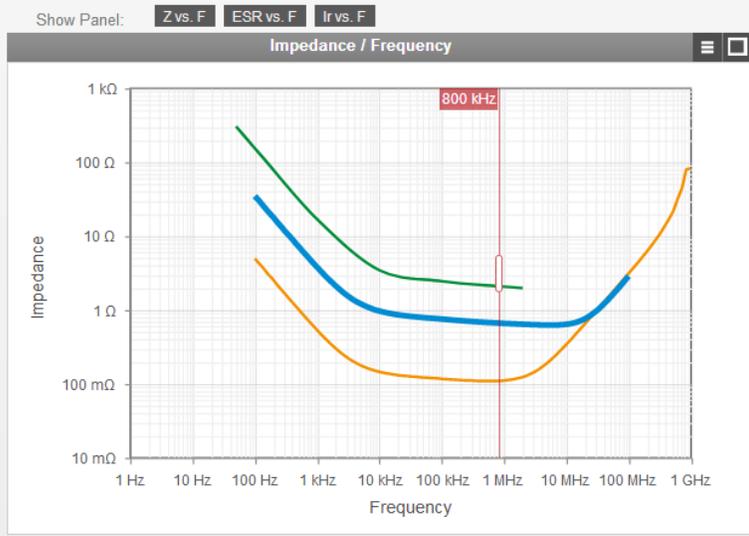
Z_C

Z@800 kHz
2.10 Ω
668 mΩ
110 mΩ

865230343004 *
WCAP-AS5H
47.0 μF - 16.0 V

865230357007 *
WCAP-AS5H
330 μF - 16.0 V

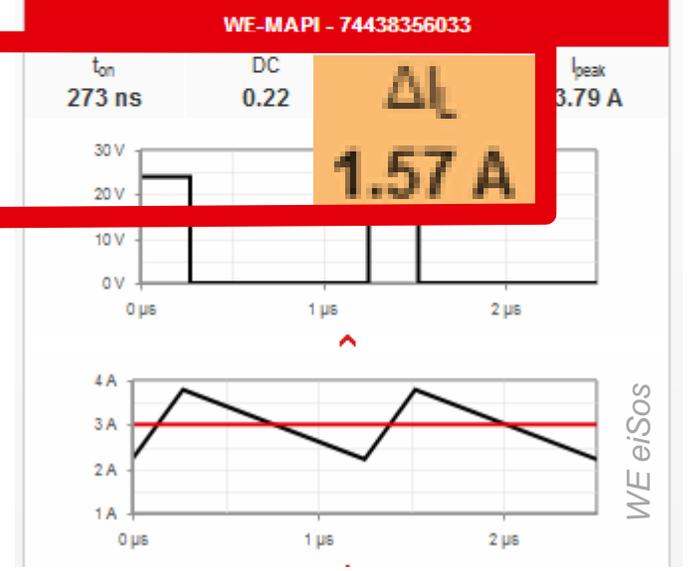
865230440002 *
WCAP-AS5H
10.0 μF - 25.0 V



REDEXPERT® POWER INDUCTORS APPLICATIONS

Buck Converter				
PARAMETERS				
Input	Output	Switch	Inductor	Diode
24.0 V 19.0-30.0 V	5.00 V 3.00 A	800 kHz	40 % Single	0.30 V
DETAILS				
I_{rms}	I_{max}	L_{opt}		
≥ 3.00 A	≥ 3.60 A	4.32 μH		

ΔI_L



Output ripple of a Buck

Redexpert : an ode to laziness



REDEXPERT® ALUMINIUM ELECTROLYTIC CAPACITORS | APPLICATIONS | HOW TO | SHARE

ITEMS LE BRAS

Filters: 1s selected 3 items

Order Code	Series	Sp...	C	V _R	Z@800 kHz	DF	Z _{max} @ 100kHz	I _{ripple} @T _{max} °C 120Hz	I _{ripple} @T _{max} 100kHz	Description	I _{leak}
865230440002	WCAP-AS5H		10.0 µF	25.0 V	2.10 Ω	< 16 %		23.0 mA		ASDB055100M025DVCTAE000	3.00
865230343004	WCAP-AS5H		47.0 µF	16.0 V	668 mΩ	< 22 %		50.0 mA		ASDD055470M016DVCTBE000	7.52
865230357007	WCAP-AS5H		330 µF	16.0 V	110 mΩ	< 22 %		300 mA		ASDF105331M016DVCTEE000	52.8

865230343004
WCAP-AS5H
47.0 µF - 16.0 V

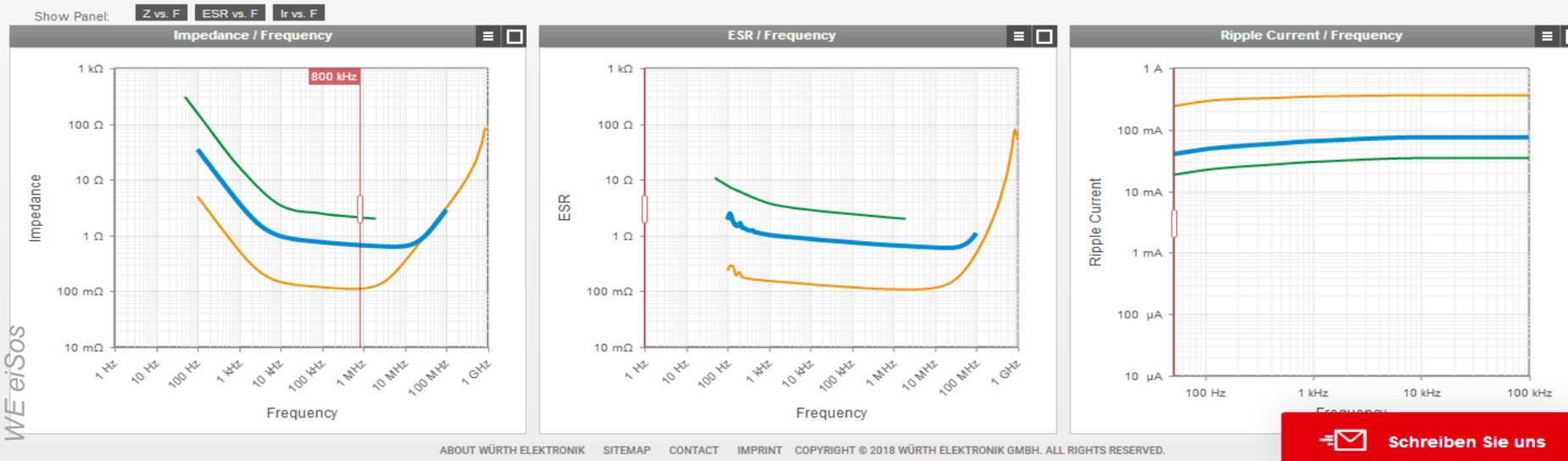
865230357007
WCAP-AS5H
330 µF - 16.0 V

865230440002
WCAP-AS5H
10.0 µF - 25.0 V

Click and type or drop
an Order Code here

Add to Cart

More...



[Link](#)

Output ripple of a Buck

Redexpert : an ode to laziness



REDEXPERT®

POWER INDUCTORS

APPLICATIONS

HOW TO

SHARE

ITEMS

LE BRAS

Buck Converter

PARAMETERS EDIT

Input	Output	Switch	Inductor	Diode
24.0 V 19.0-30.0 V	5.00 V 3.00 A	800 kHz	40 % Single	0.30 V

DETAILS

I_{rms} ≥ 3.00 A	I_{max} ≥ 3.60 A	L_{opt} 4.32 μ H
-----------------------	-----------------------	---------------------------

WE-MAPI - 74438356033

t_{on} 273 ns	DC 0.22	ΔI_L 1.57 A	I_{peak} 3.79 A
--------------------	------------	------------------------	----------------------

AC Losses 179 mW	DC Losses 359 mW	Total Losses 538 mW	ΔT_{TOT} 42.0 K
---------------------	---------------------	------------------------	----------------------------

P vs. V_{in} P vs. f_{sw} P vs. I_{out}

P vs. V_{in}

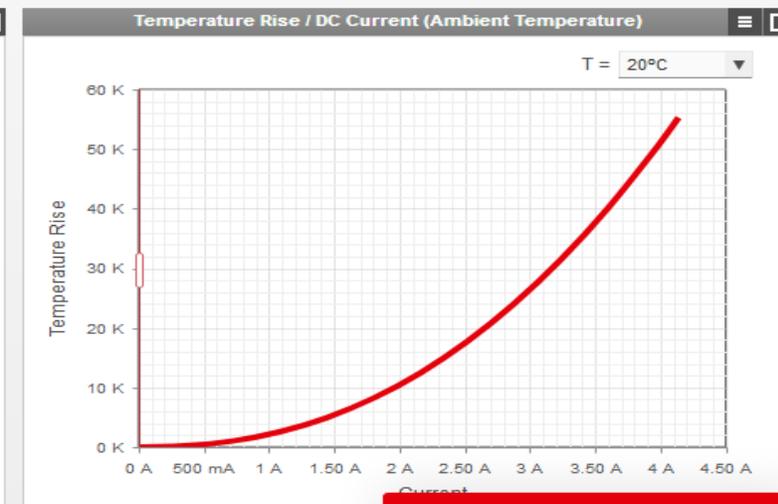
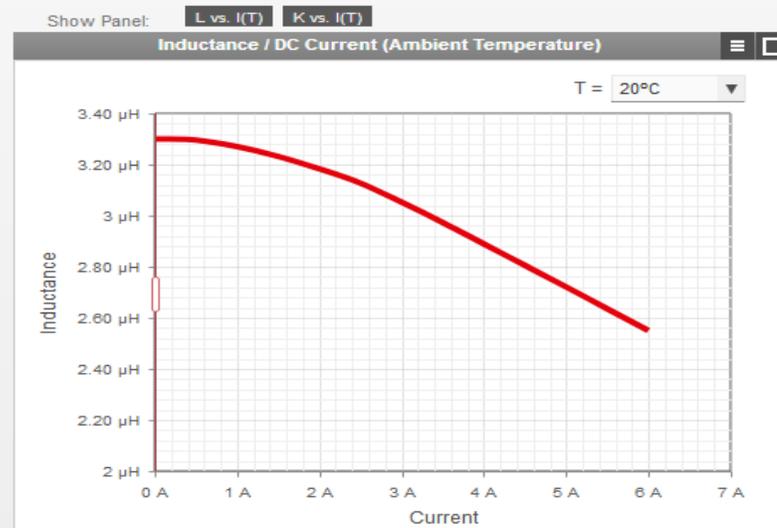
Filters: Type = Single $I_R \geq 3.00$ A $I_{sat} \geq 3.60$ A $3.02 \mu\text{H} \leq L_0 \leq 5.62 \mu\text{H}$ 100 / 180 items

Order Code	Series	Size	Sp...	Type	L_0	$R_{DC,typ}$	I_R	I_{sat}	P_{AC}	P_{DC}	P_T
74438356033	WE-MAPI	4020	PDF	Single	3.30 μ H	39.9 m Ω	3.60 A	5.50 A	179 mW	359 mW	538 mW
74438357047	WE-MAPI	4030	PDF	Single	4.70 μ H	39.9 m Ω	3.90 A	6.40 A	102 mW	359 mW	461 mW
74438357056	WE-MAPI	4030	PDF	Single	5.60 μ H	46.5 m Ω	3.60 A	6.00 A	94.9 mW	418 mW	513 mW
744071039	WE-TPC	8043	PDF	Single	3.90 μ H	13.0 m Ω	4.90 A	4.50 A	241 mW	117 mW	358 mW
744071047	WE-TPC	8043	PDF	Single	4.70 μ H	17.0 m Ω	4.80 A	4.30 A	200 mW	153 mW	353 mW
744071056	WE-TPC	8043	PDF	Single	5.60 μ H	20.0 m Ω	4.00 A	4.00 A	168 mW	180 mW	348 mW

Click and type or drop an Order Code here

Add to Cart

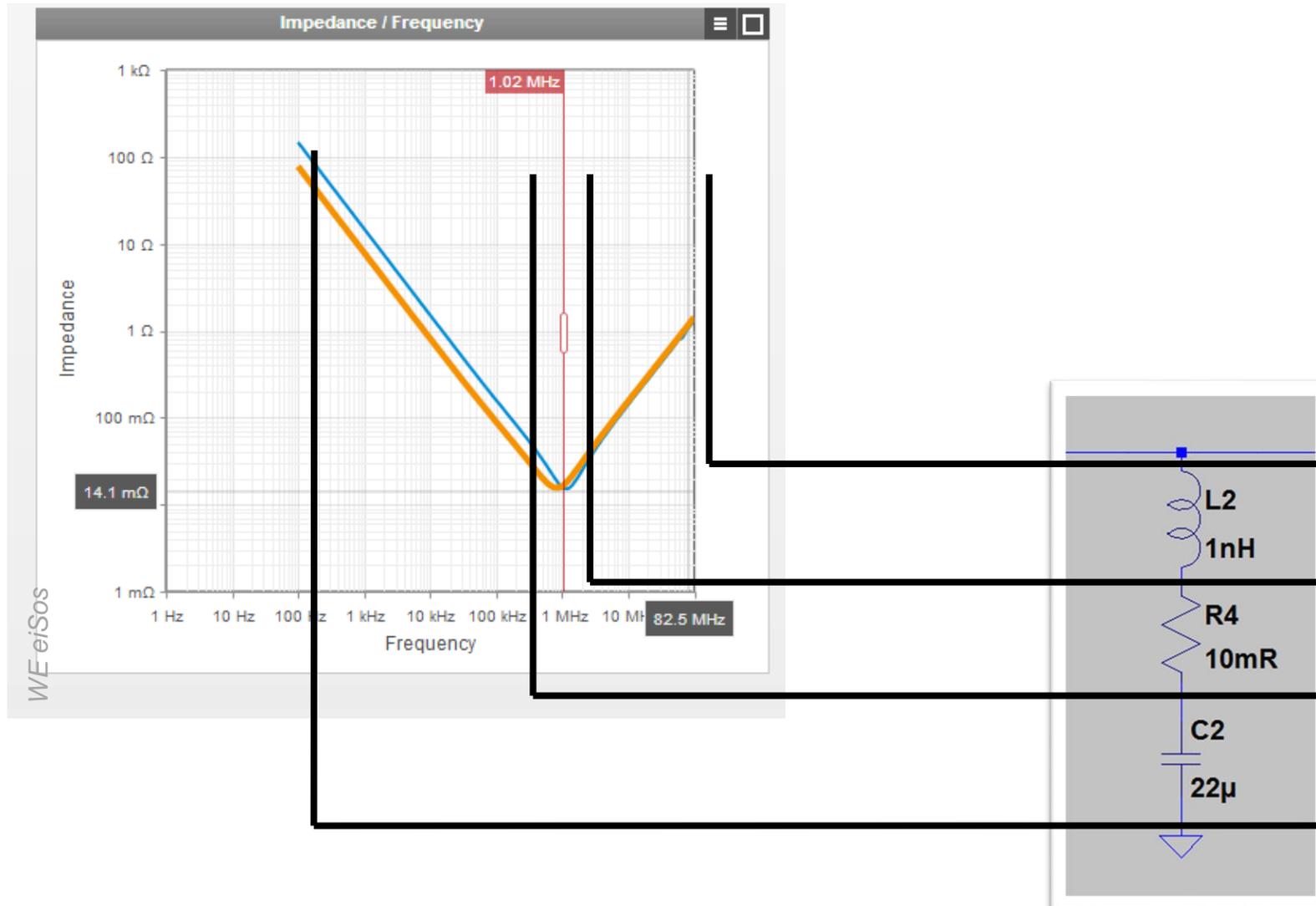
More...



Link

Output ripple of a Buck

Extracting EMC accurate data from RED EXPERT



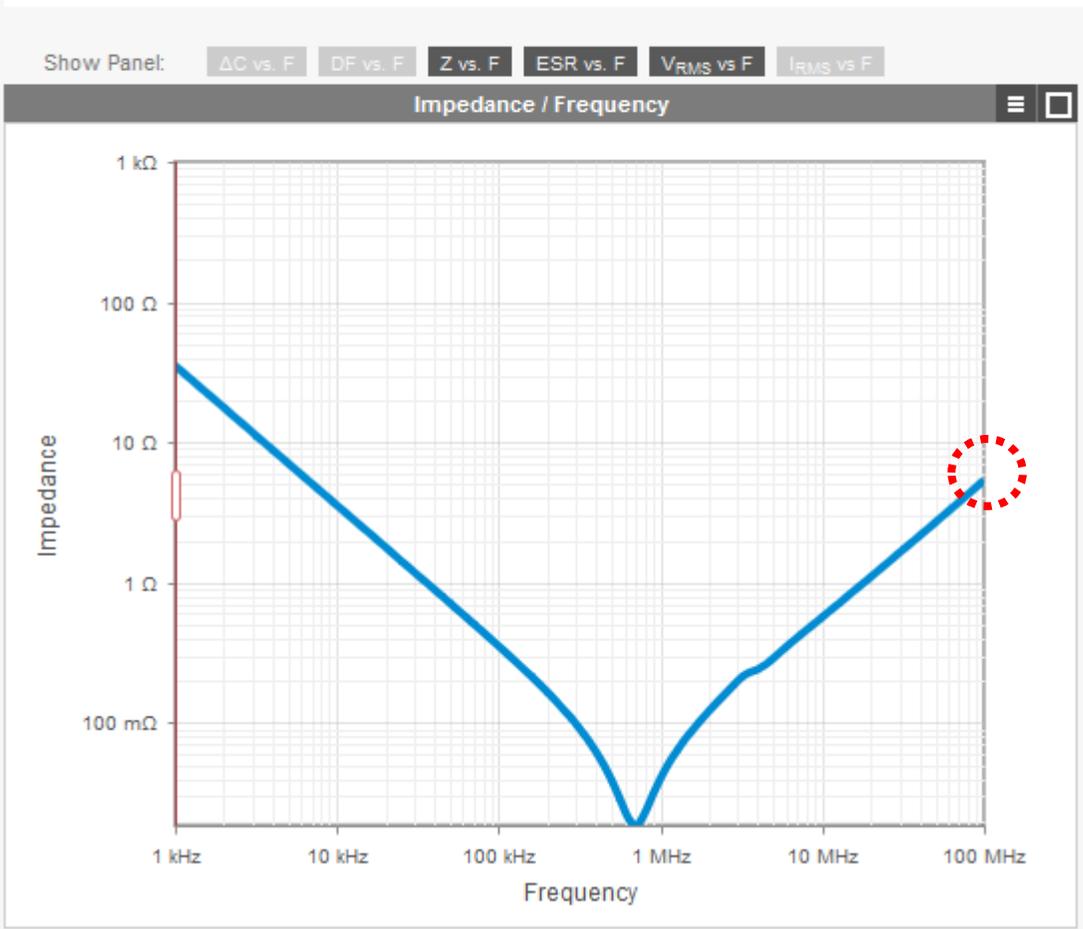


Output ripple of a Buck

Extracting EMC accurate data from RED EXPERT

890273427005C*
 WCAP-FTBE · 27.5 mm
 4.70 µF · 250 V

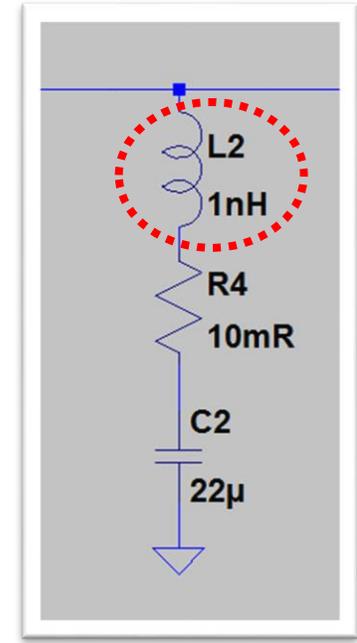
ESL identification



$$|Z_L| = L\omega$$

$$\frac{Z_L}{\omega} = L$$

$$L = \frac{|Z_L|}{2\pi F} = \frac{5}{100 \times 10^6 \times 2\pi} \cong 8 \text{ nH}$$



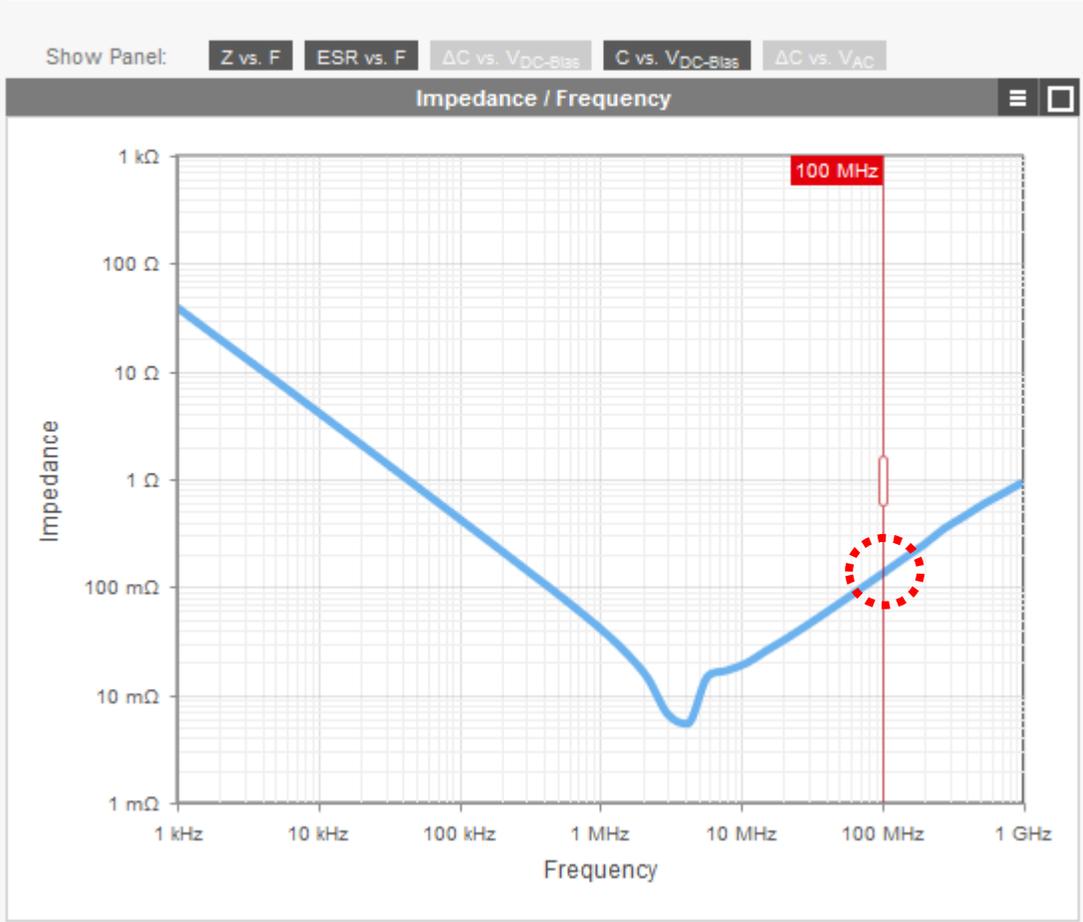


Output ripple of a Buck

Extracting EMC accurate data from RED EXPERT

885012107018 ✖
WCAP-CSGP · X5R · 0805
4.70 µF · 25.0 V

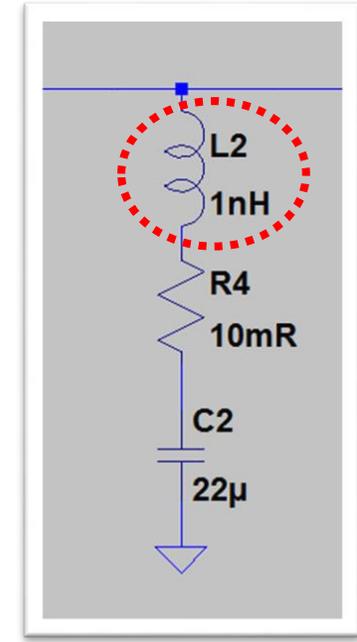
ESL identification



$$|Z_L| = L\omega$$

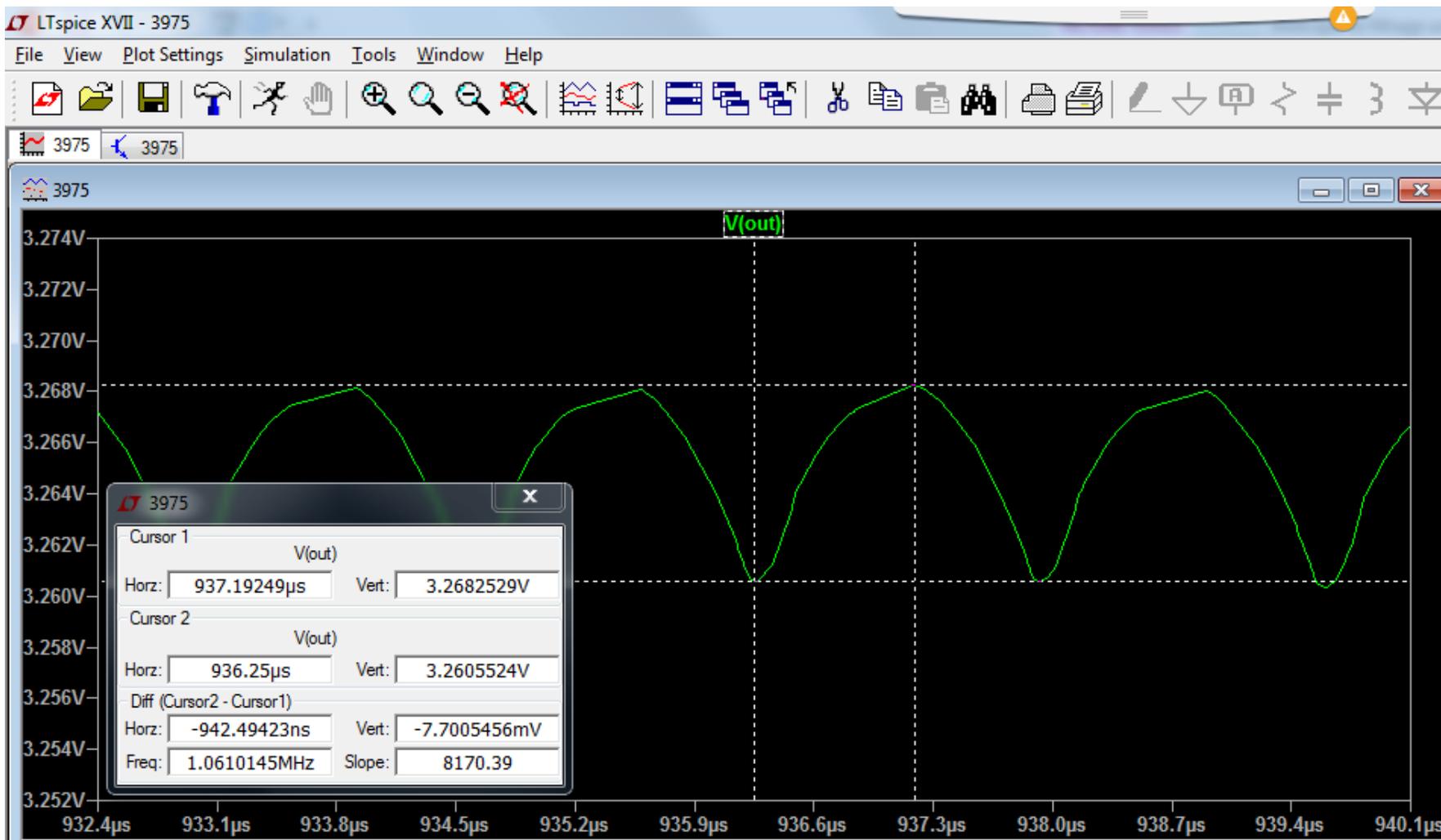
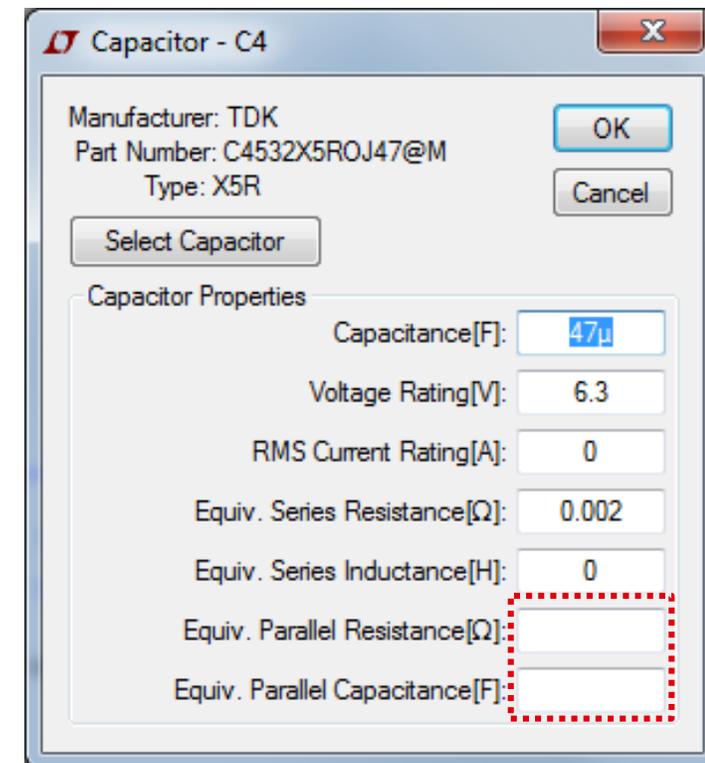
$$\frac{Z_L}{\omega} = L$$

$$L = \frac{|Z_L|}{2\pi F} = \frac{0,132}{100 \times 10^6 \times 2\pi} \cong 0.2 \text{ nH}$$



Output ripple of a Buck

Example of (non) EMC accurate impact on simulation

Capacitor - C4

Manufacturer: TDK
Part Number: C4532X5R0J47@M
Type: X5R

Select Capacitor

Capacitor Properties

Capacitance[F]: 47µ

Voltage Rating[V]: 6.3

RMS Current Rating[A]: 0

Equiv. Series Resistance[Ω]: 0.002

Equiv. Series Inductance[H]: 0

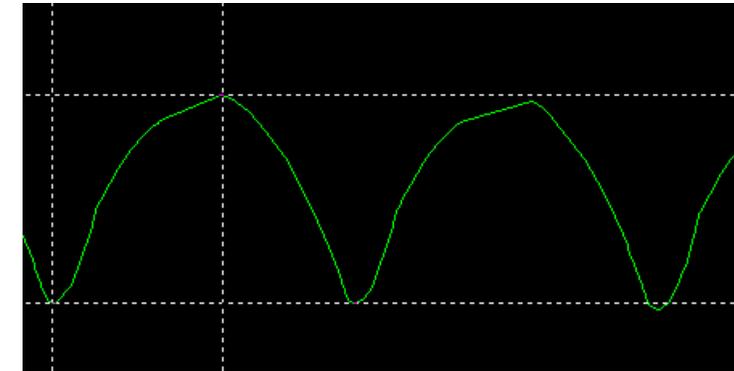
Equiv. Parallel Resistance[Ω]:

Equiv. Parallel Capacitance[F]:

- ESR = 2 mOhms
- ESL = 0 nH
- DC bias
(DC ? Like don't care ?)

Output ripple of a Buck

Example of (non) EMC accurate impact on simulation





Output ripple of a Buck

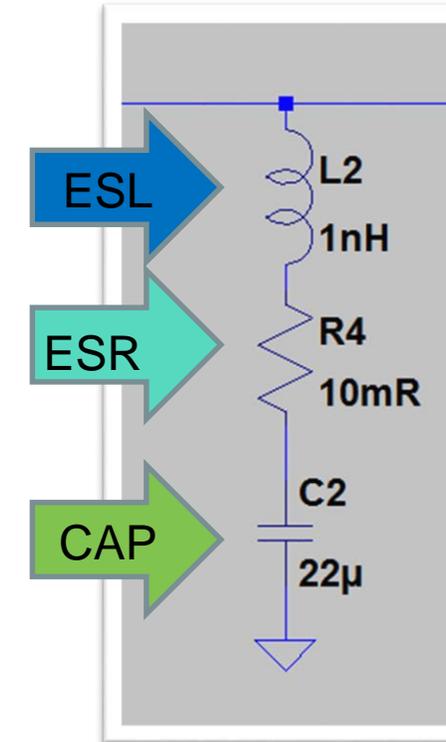
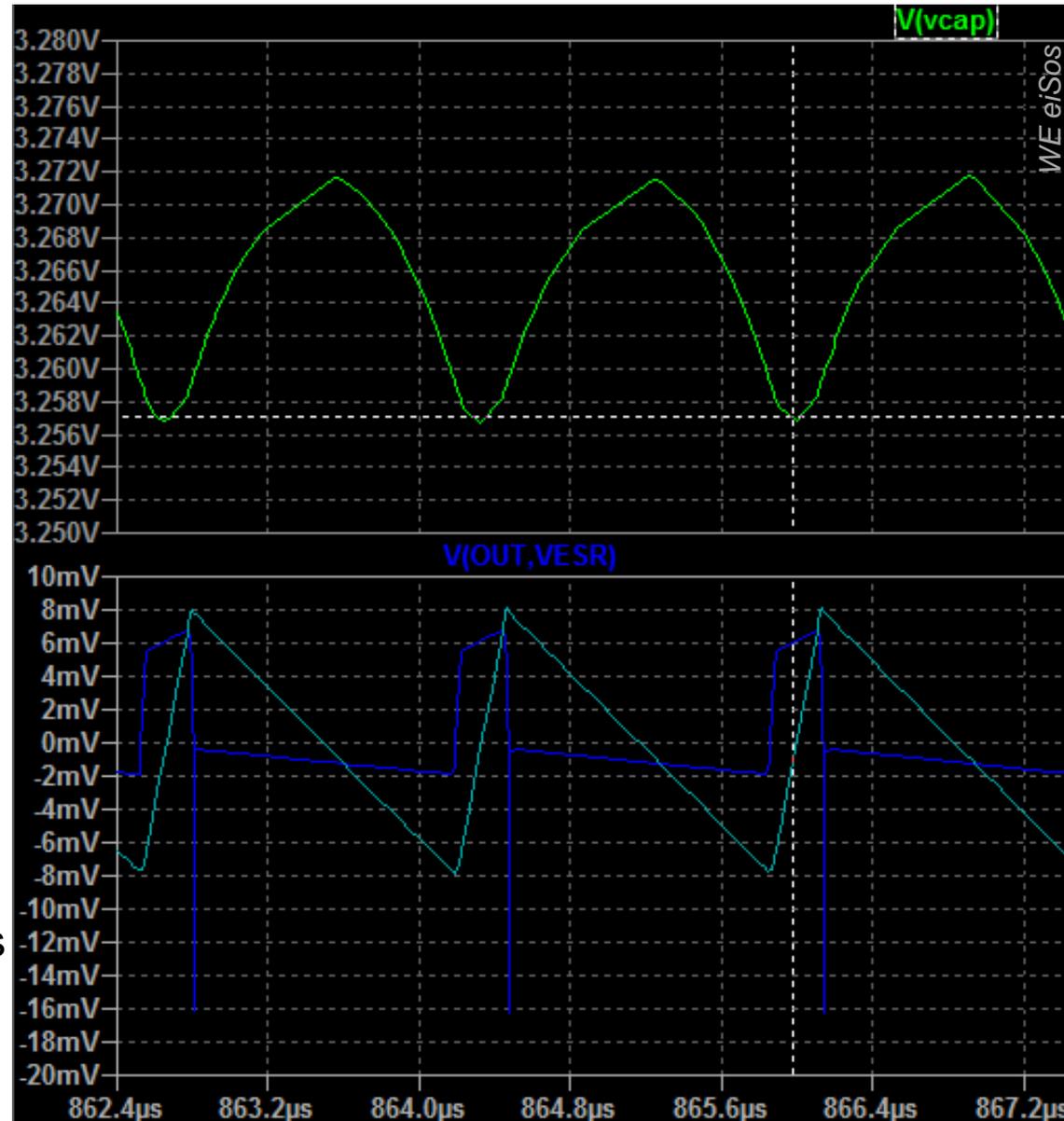
Example of EMC accurate simulation

Charge and discharge of cap

CAP → 14 mV_{p-p}

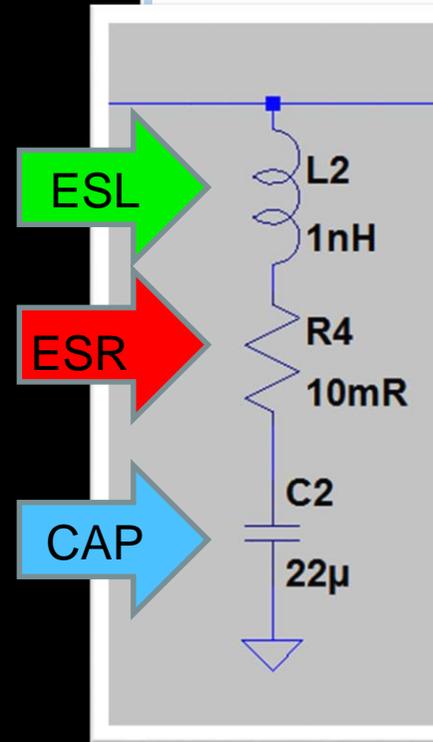
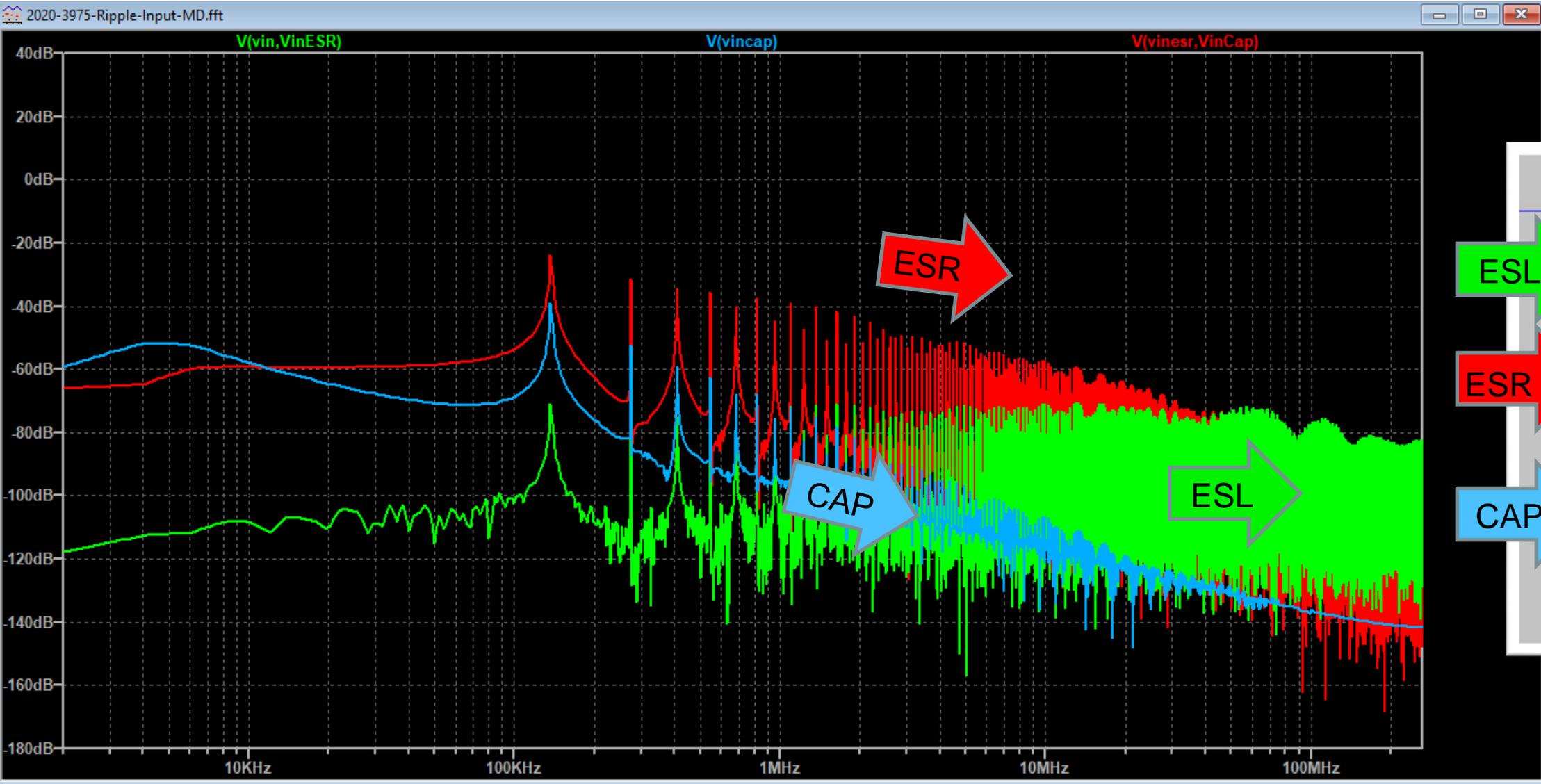
ESR → 16 mV_{p-p}

ESL → 10 mV_{p-p} at low frequencies
 25 mV_{p-p} at high frequencies



Capacitor ripple voltage example

ESR / ESL / CAP breakdown in frequency



... To EMC simulation

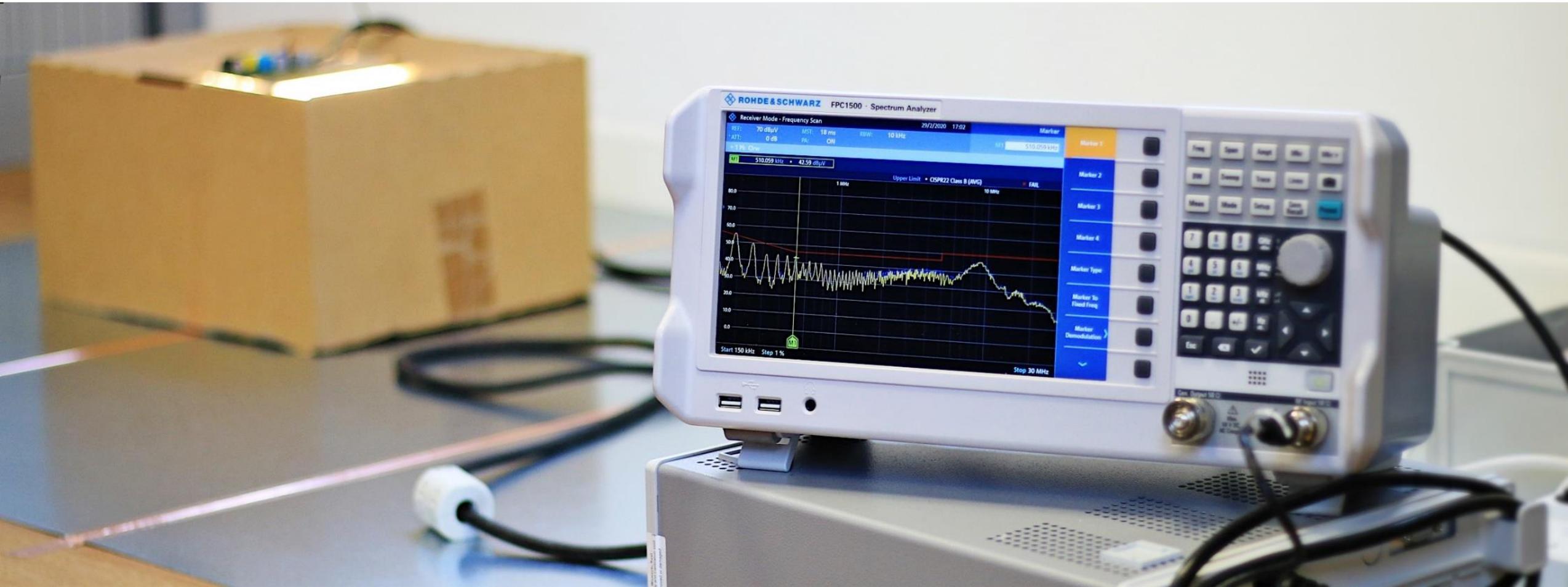
The missing link



WE eiSos / Sylvain LE BRAS

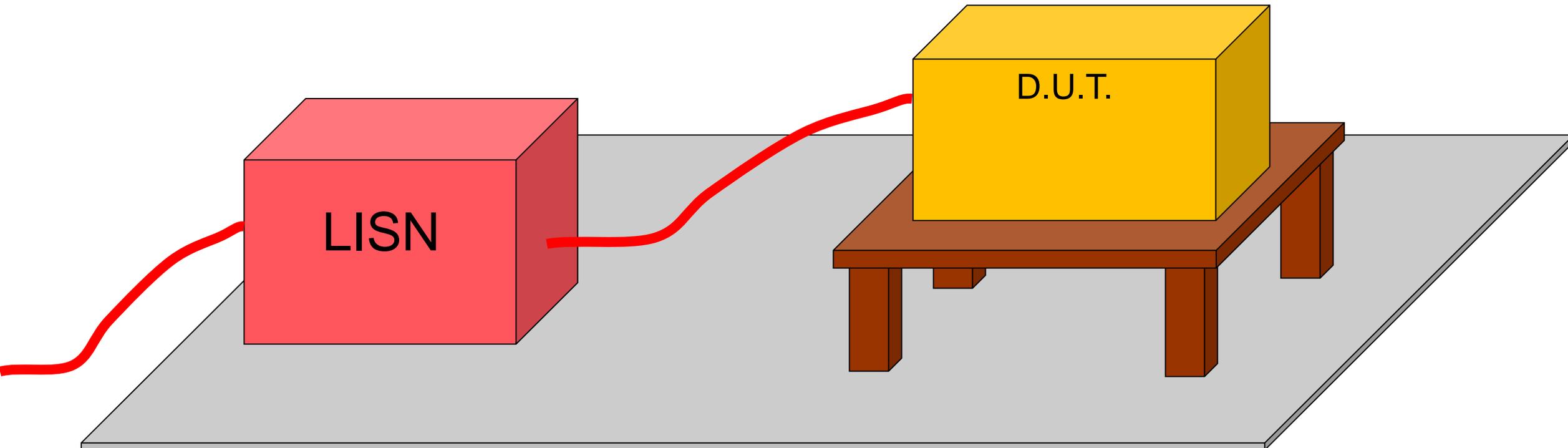
Enabling EMC accurate measurement in LTSpice

What is the keystone of conducted emissions ?



Enabling EMC accurate measurement in LTSpice

What is the keystone of conducted emissions ?

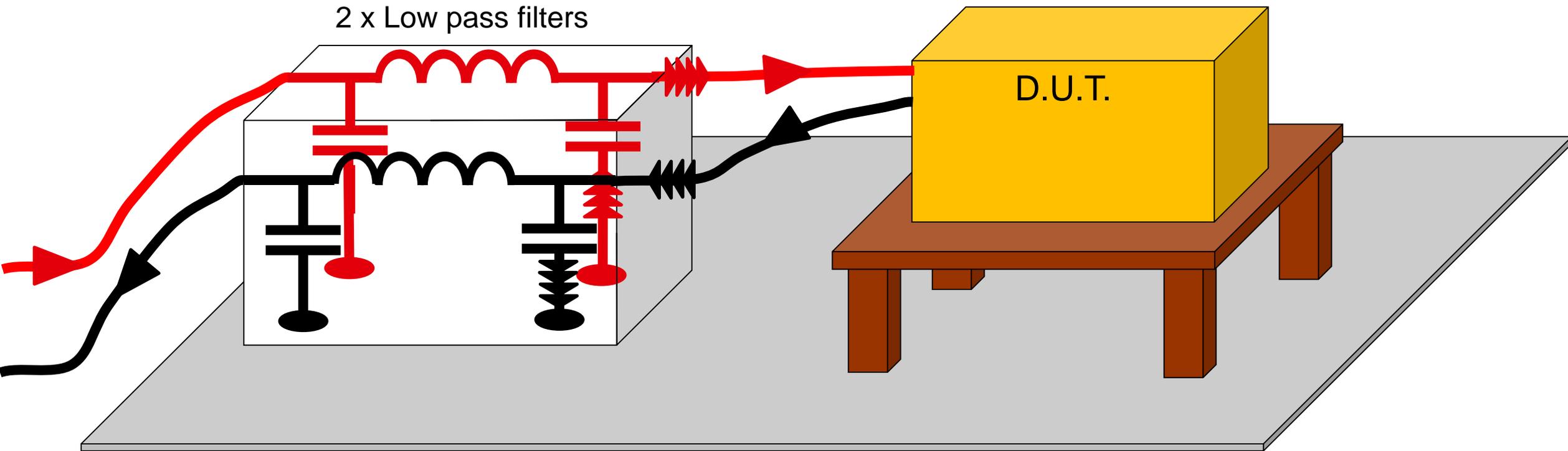


Enabling EMC accurate measurement in LTSpice

What is the keystone of conducted emissions ?



- ▶ Low Frequency
- ▄ High Frequency

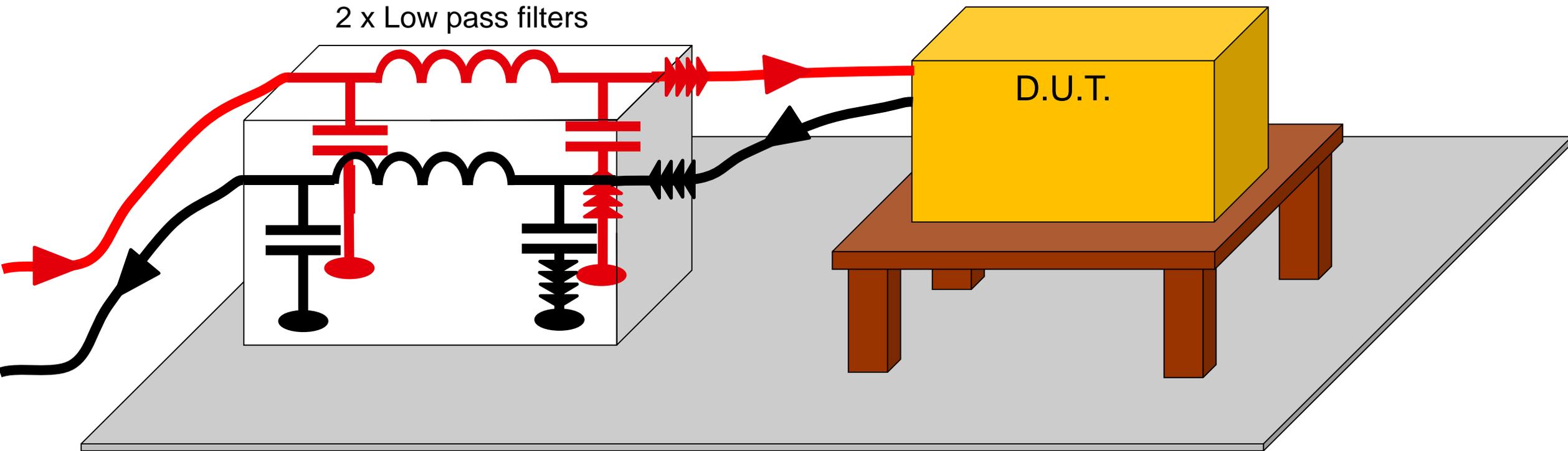


Enabling EMC accurate measurement in LTSpice

What is the keystone of conducted emissions ?

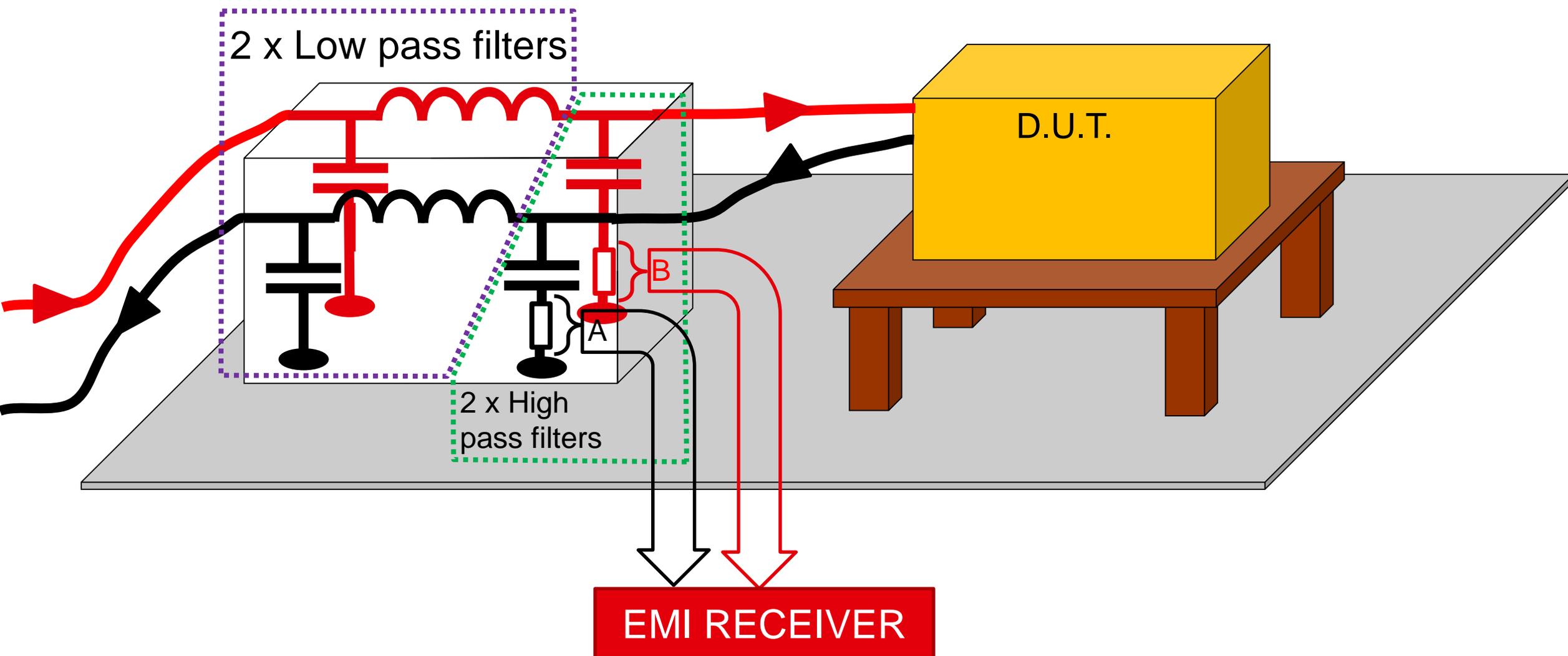


- ▶ Low Frequency
- ▄ High Frequency



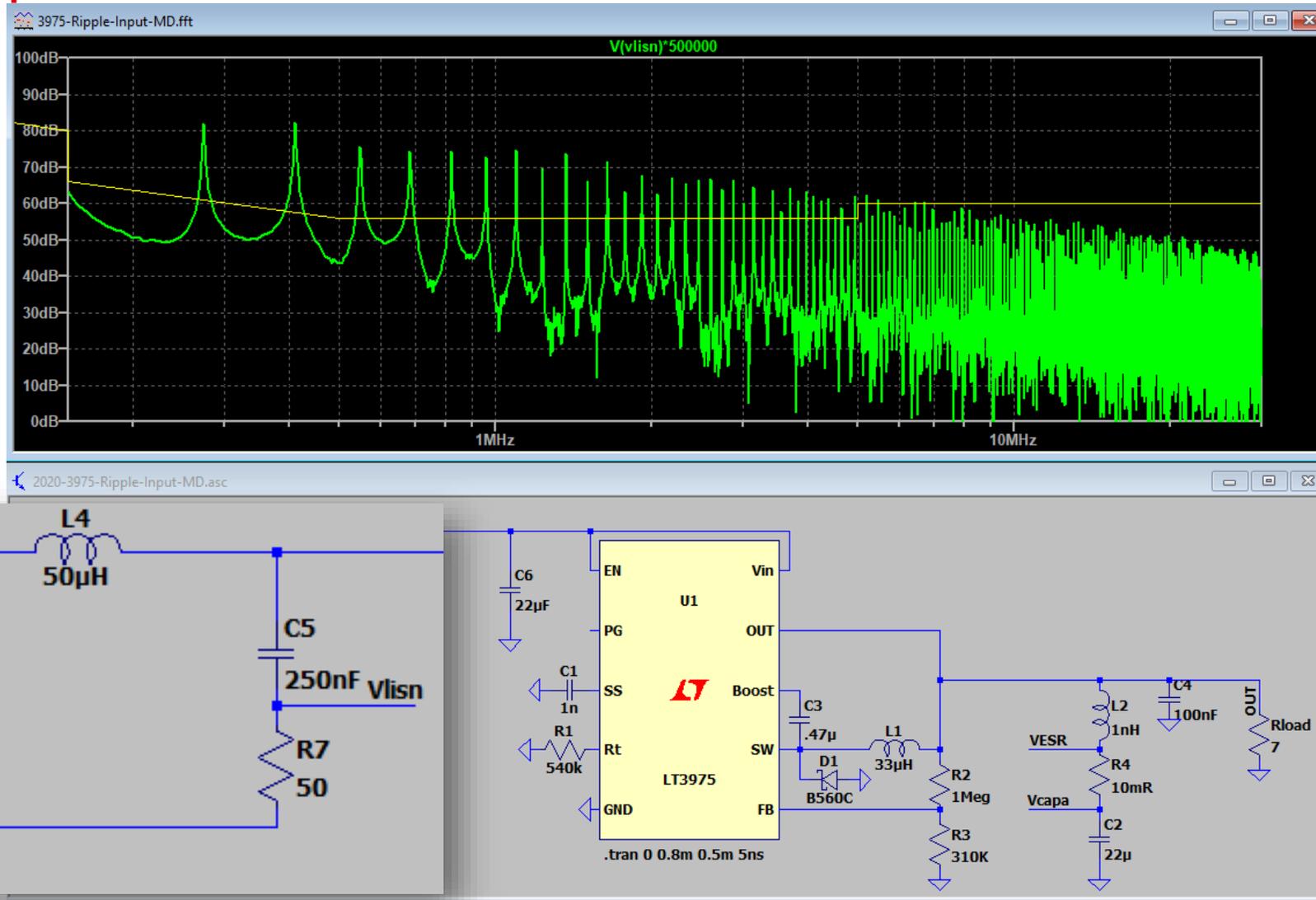
Enabling EMC accurate measurement in LTSpice

What is the keystone of conducted emissions ?



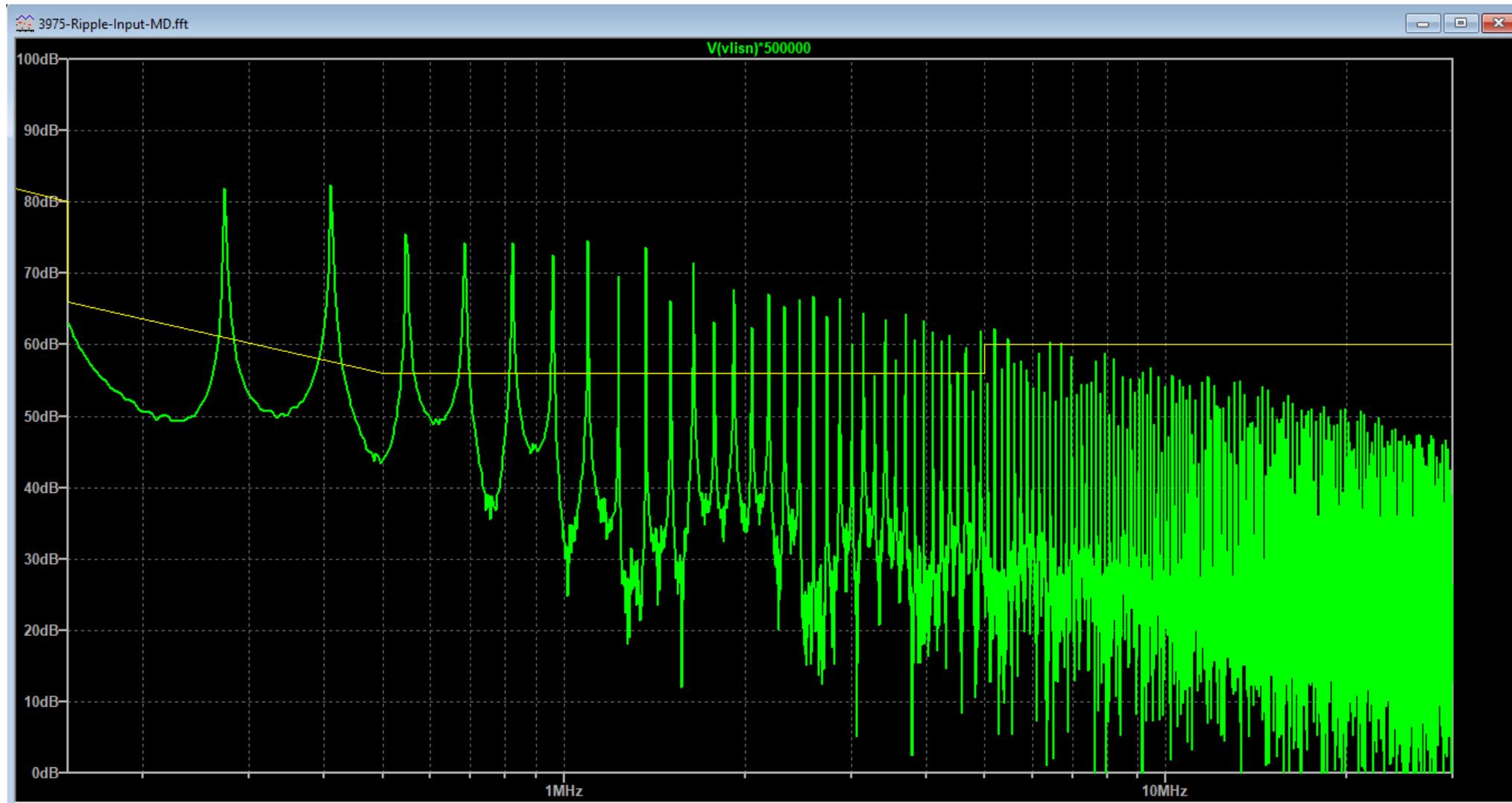
Enabling EMC accurate measurement in LTSpice

FFT with simplified LISN



Reality VS Simulation

FFT with simplified LISN



Reality VS Simulation

Conducted Emissions measurement



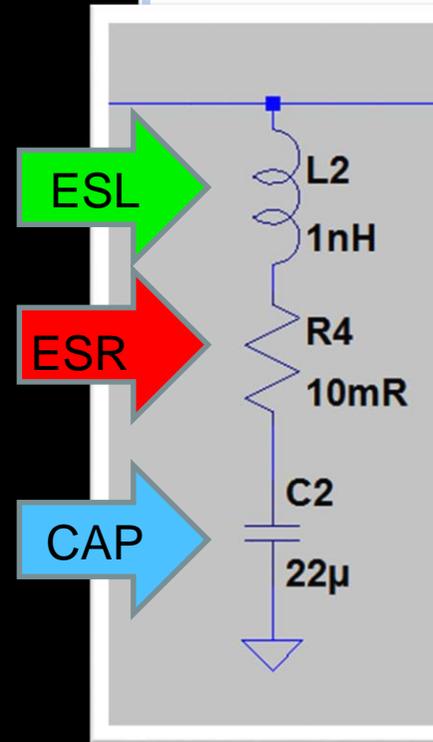
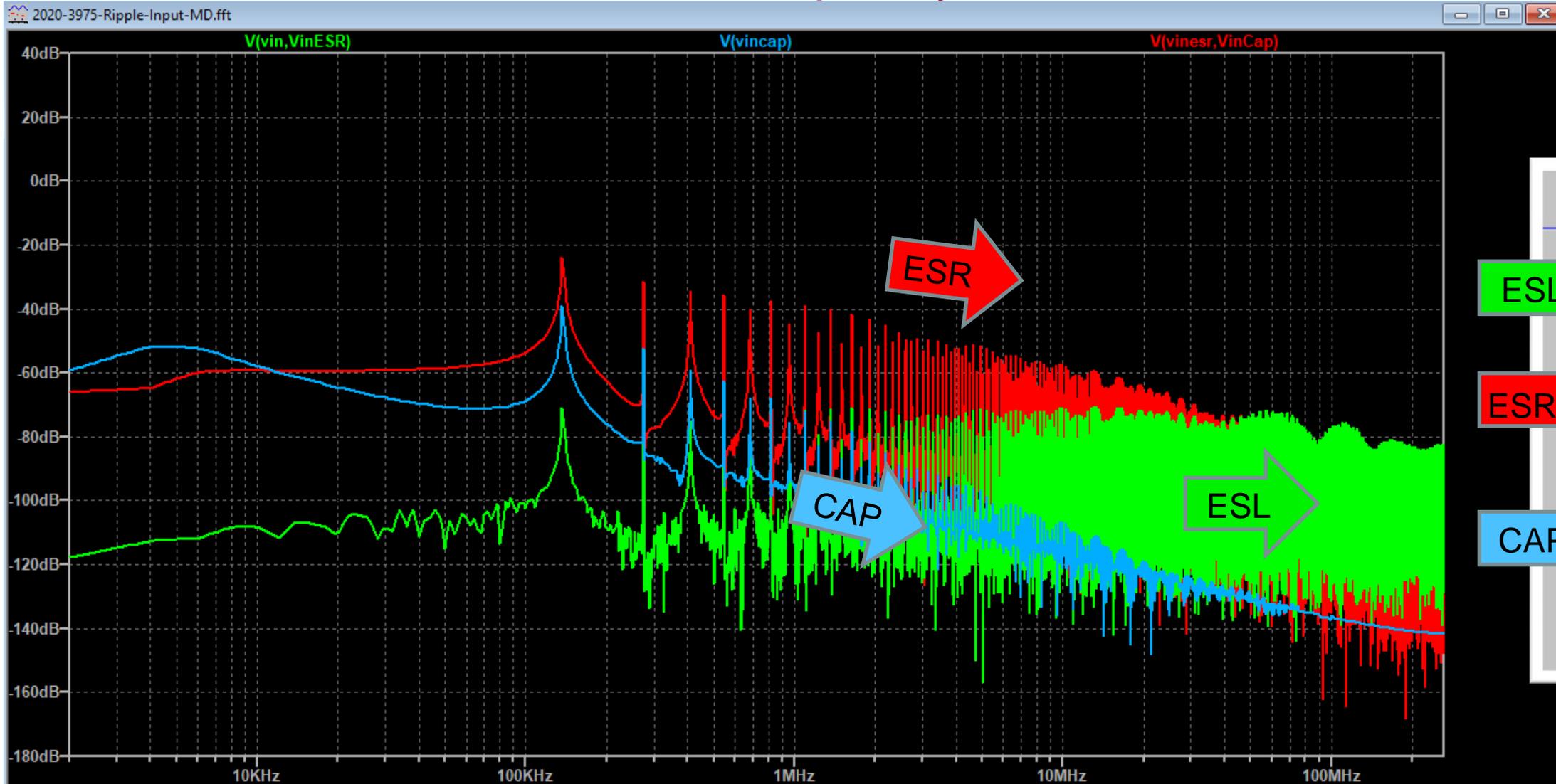
Reality VS Simulation

Conducted Emissions measurement



Reality VS Simulation

ESR / ESL / CAP breakdown in frequency



Reality VS Simulation

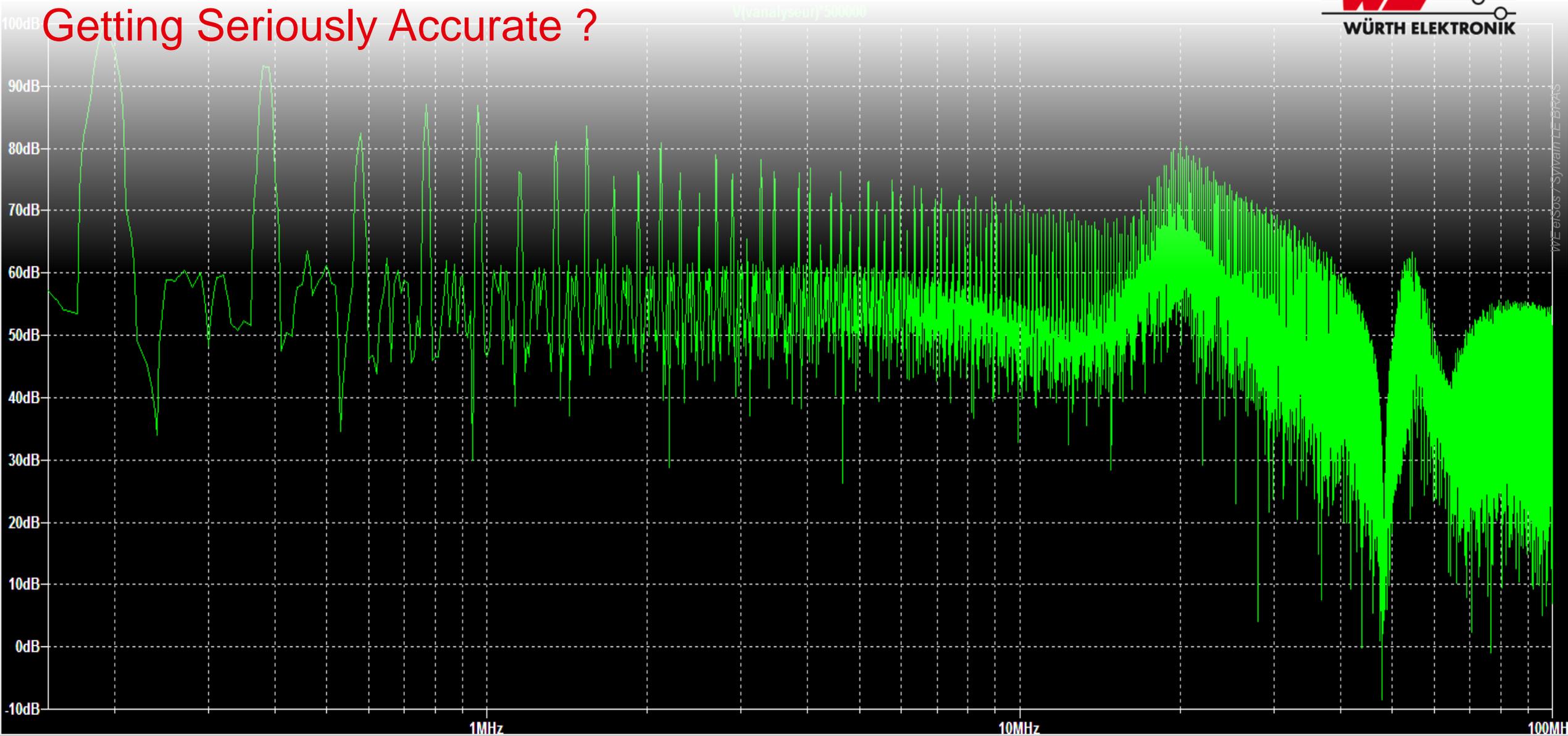


EMI measurement = \sum (Common Mode + Differential Mode)



... To EMC simulation

Getting Seriously Accurate ?

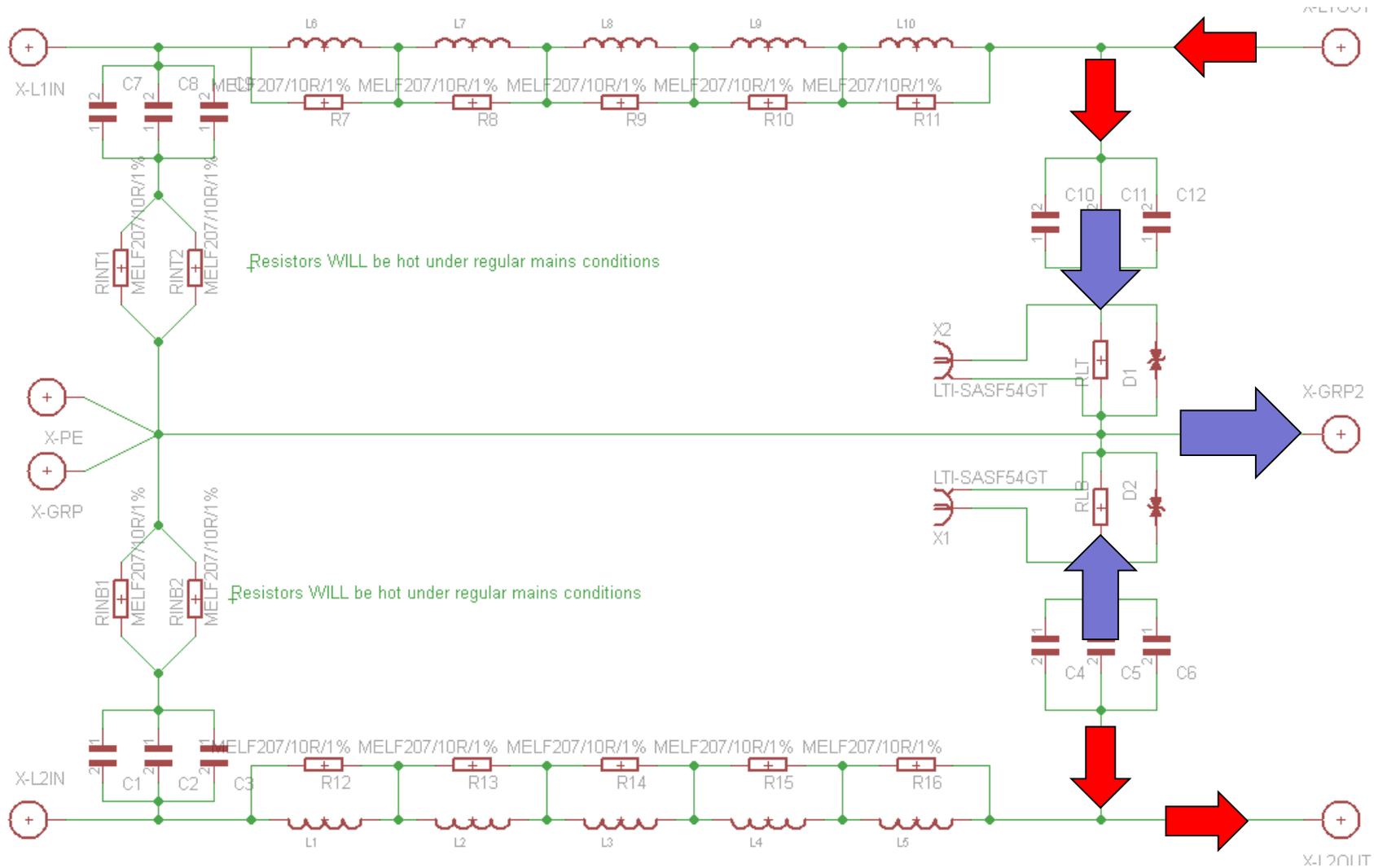


Vivanalyseur 500MHz

WE eiSos / Sylvain LE BRAS

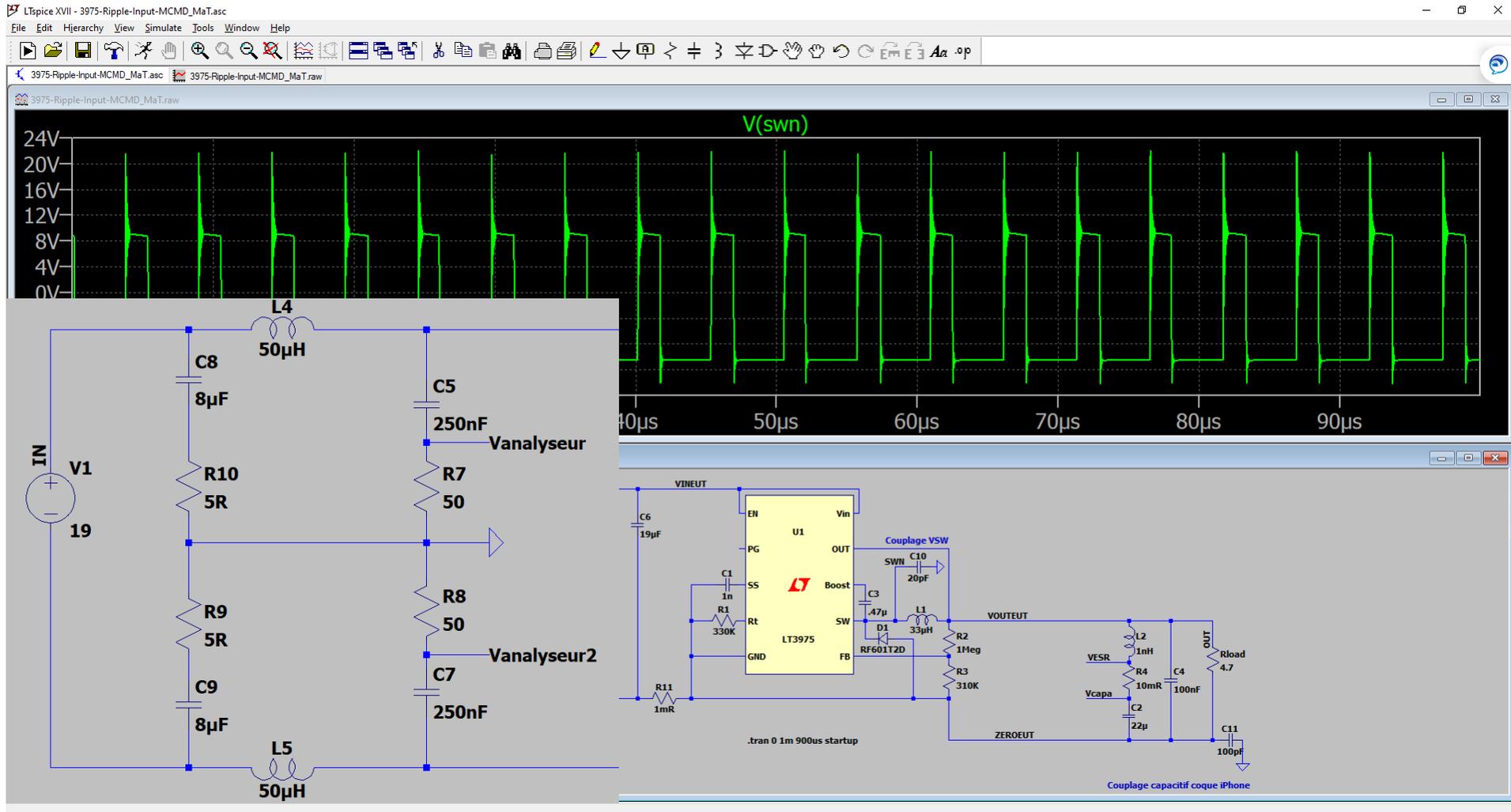
Getting Seriously Accurate ?

Actual LISN design



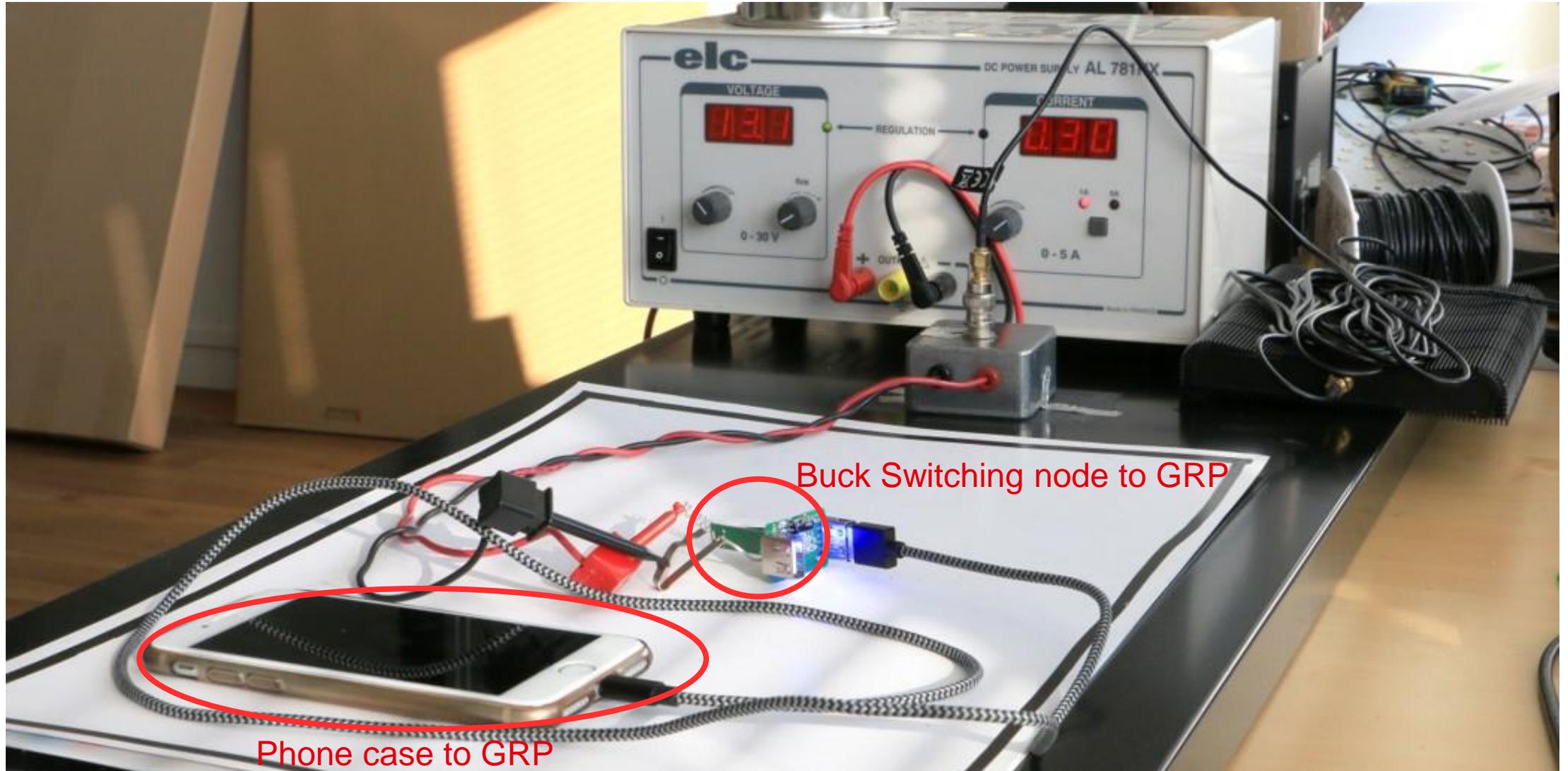
Getting Seriously Accurate ?

Simulation Ready LISN design



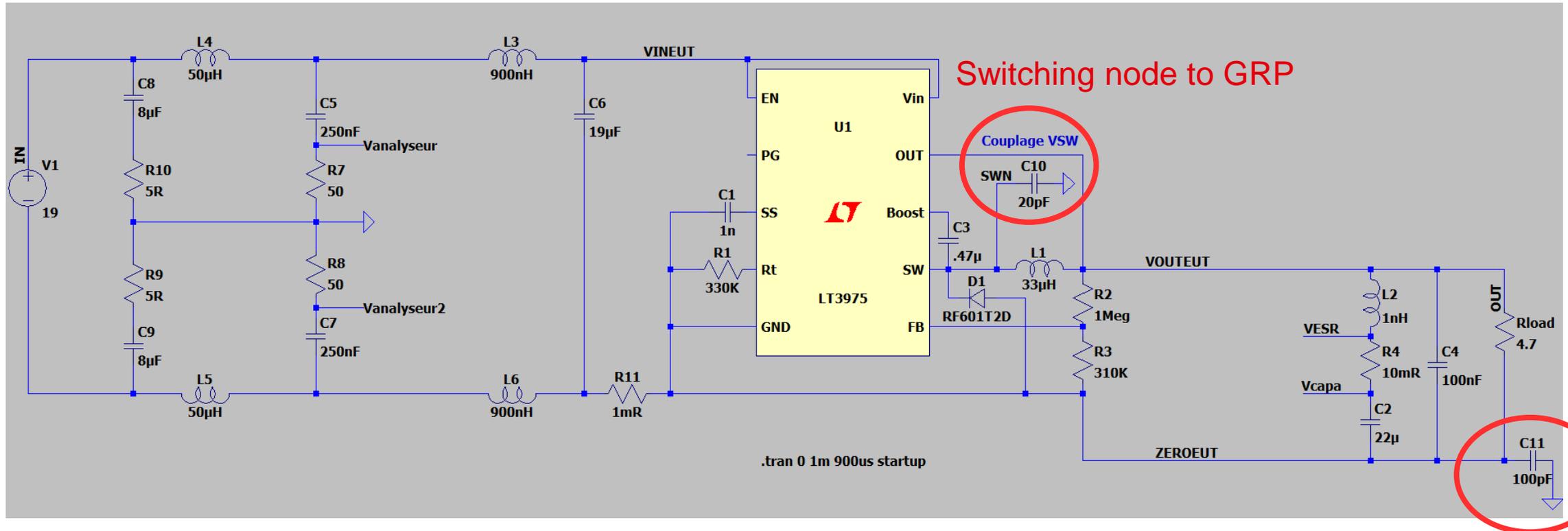
Getting Seriously Accurate ?

Adding E-Field parasitic coupling



Getting Seriously Accurate ?

Adding E-Field parasitic coupling



Phone case to GRP

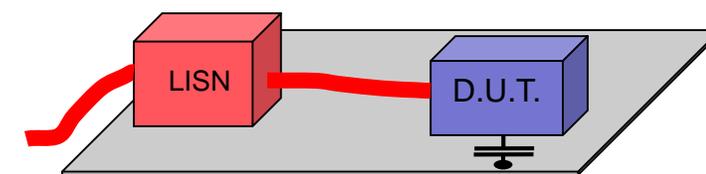
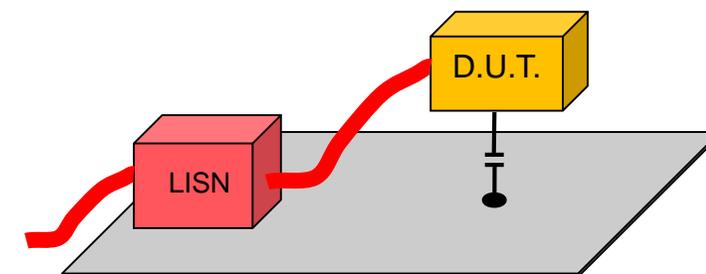
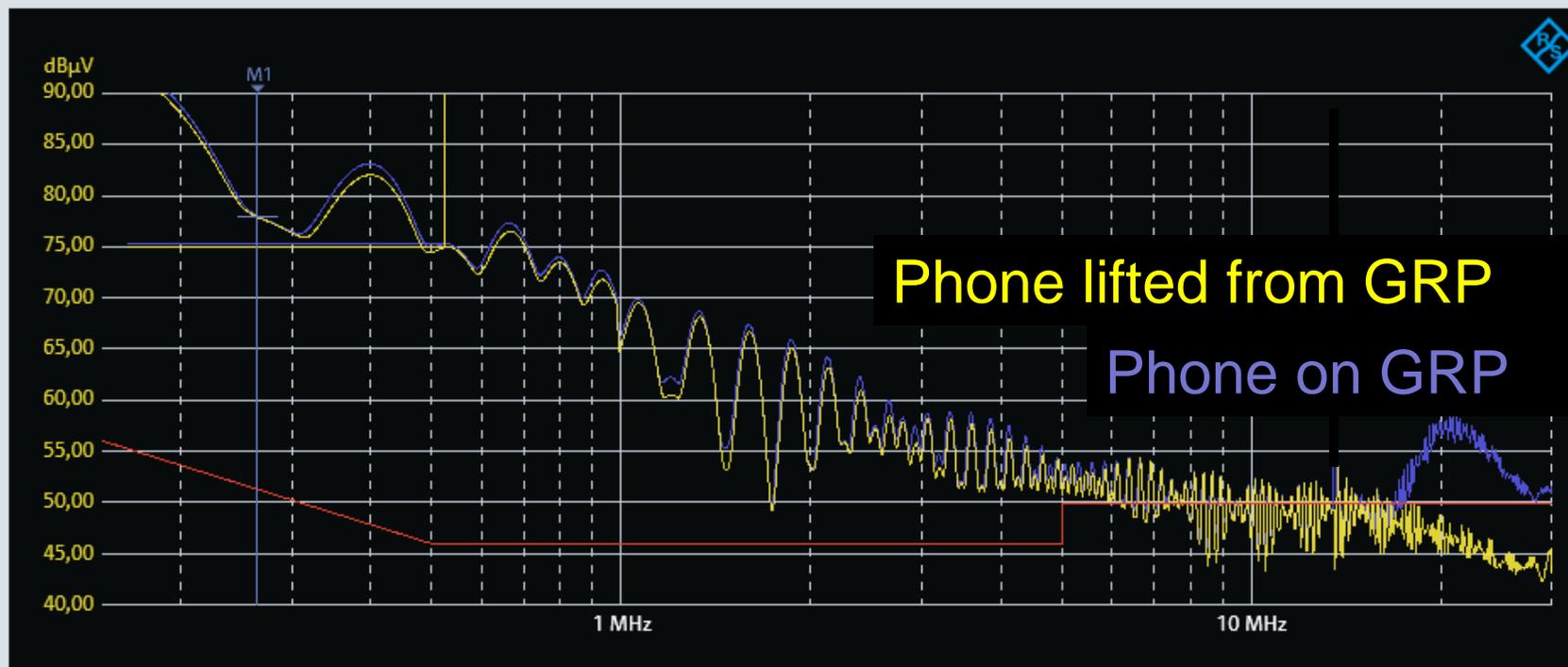
Getting Seriously Accurate ?

Reality VS Simulation

Frequency Scan

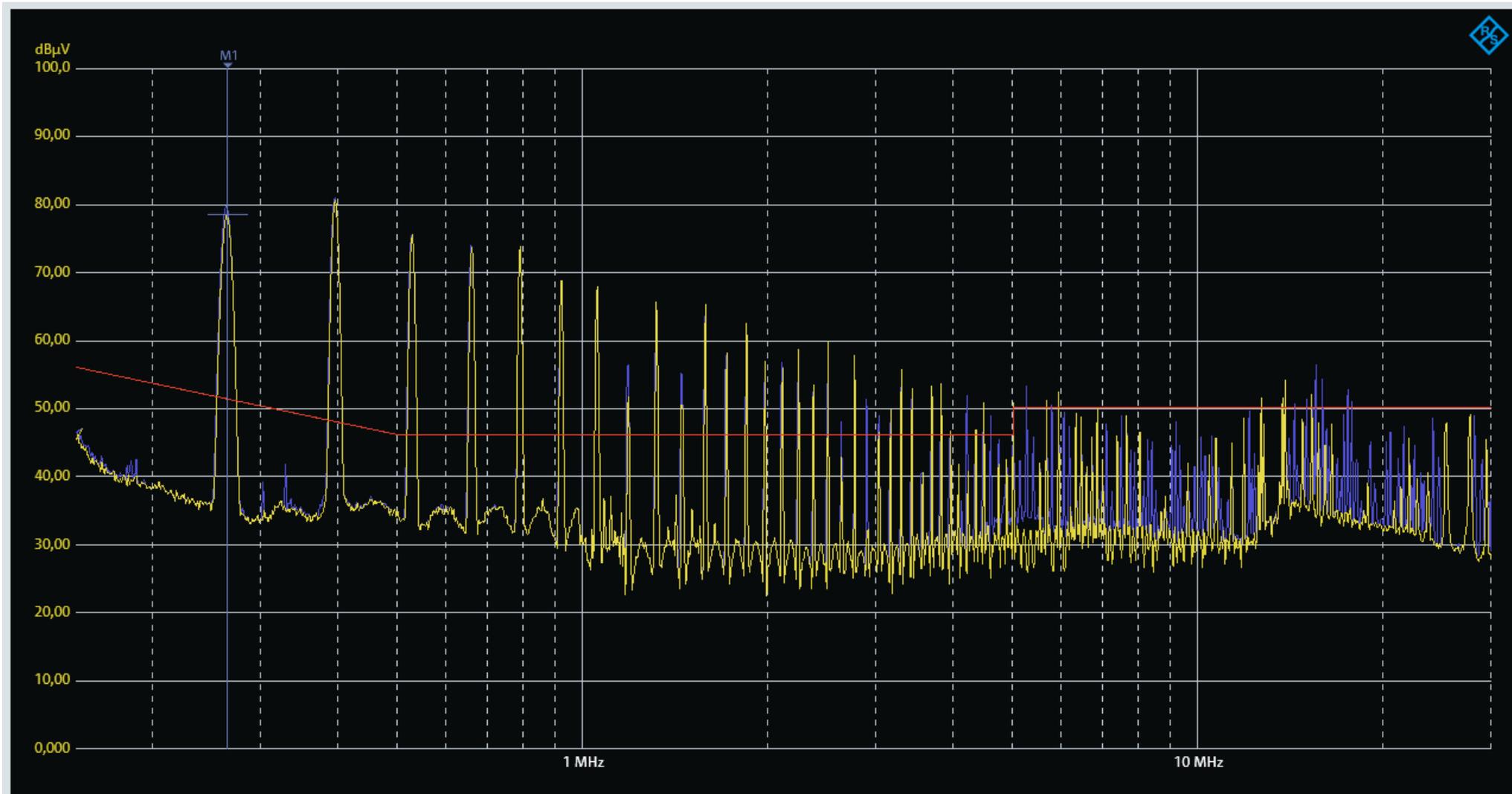
Ref Level 80 dB μ V
 RF Attenuator 10 dB
 RBW 100 kHz
 Start Frequency 150 kHz
 Stop Frequency 30 MHz

Measurement Time 10 ms
 Trace Mode Clear / Write
 Trigger Mode Free Run
 Trace Detector Average
 Scan step 0,5 %



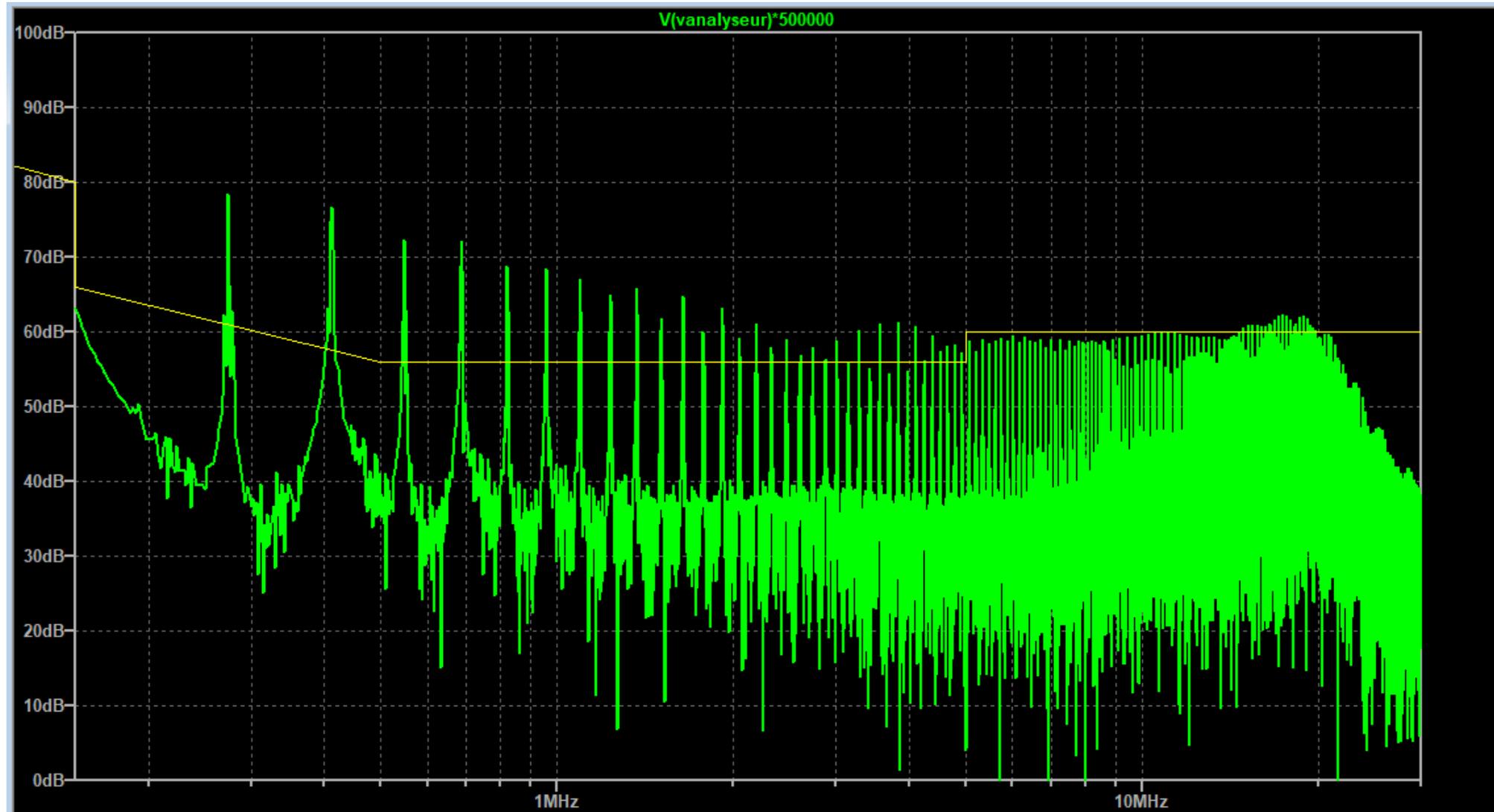
Getting Seriously Accurate ?

Reality VS Simulation



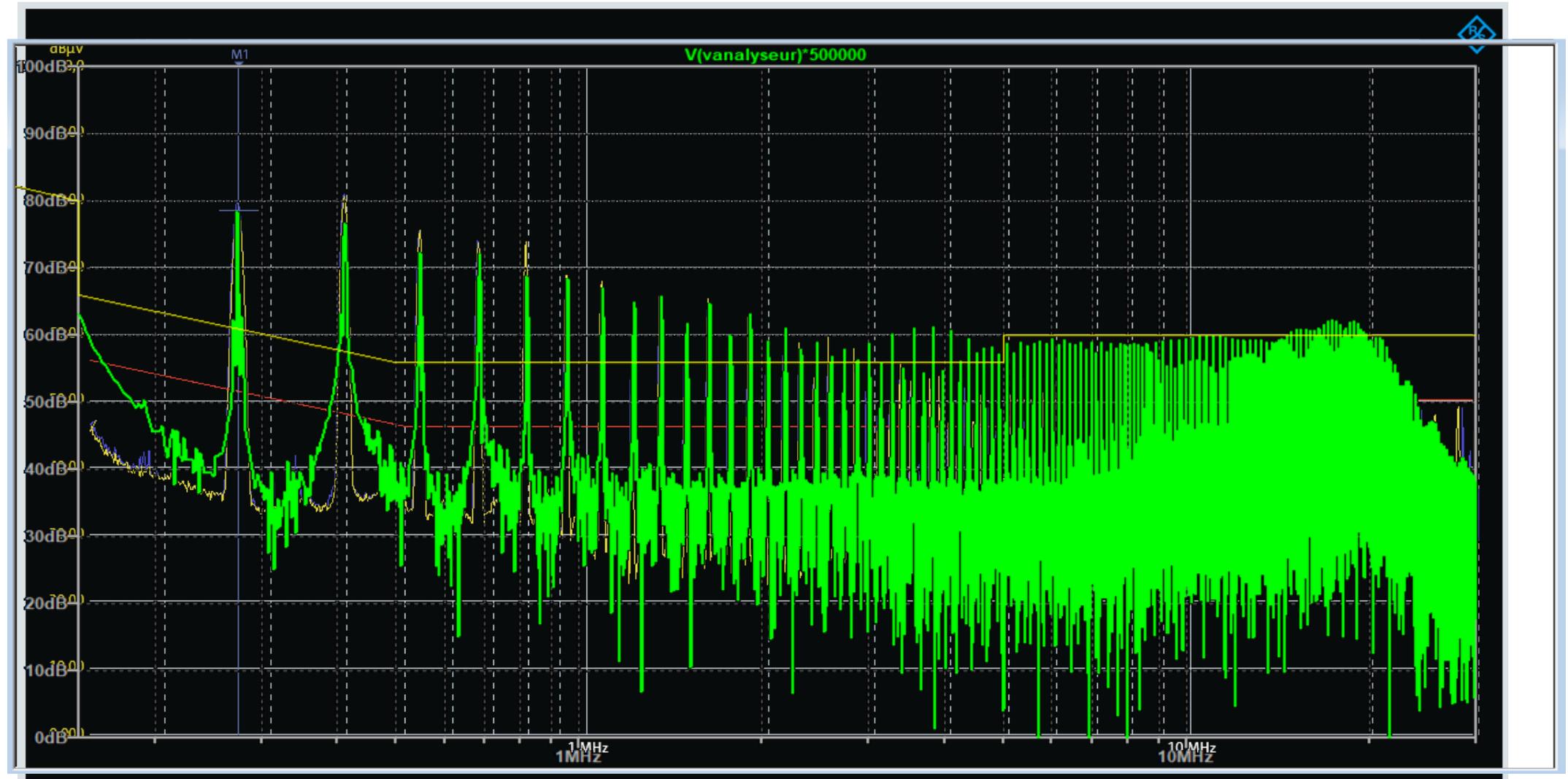
Getting Seriously Accurate ?

Reality VS Simulation



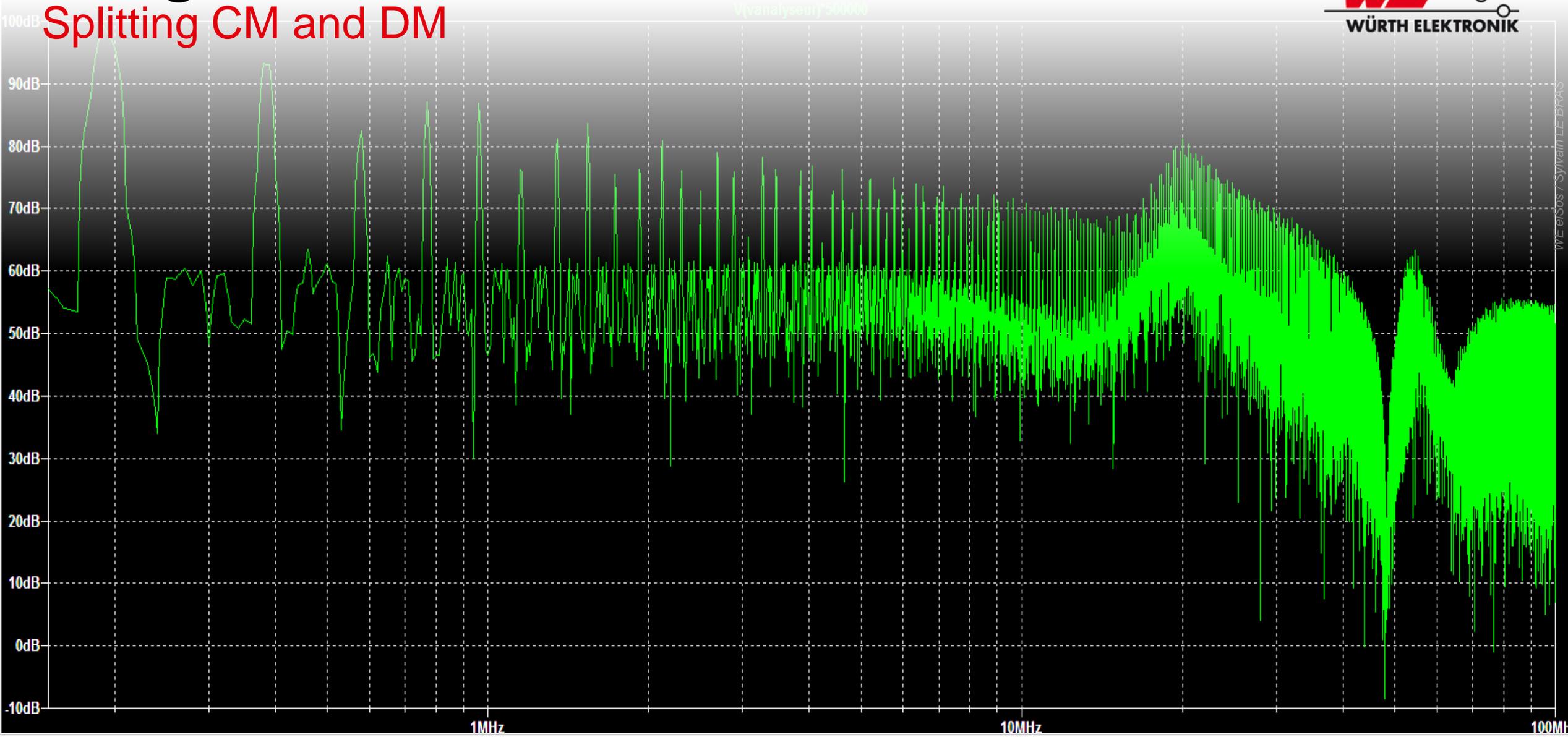
Getting Seriously Accurate ?

Reality VS Simulation



Going further with simulation

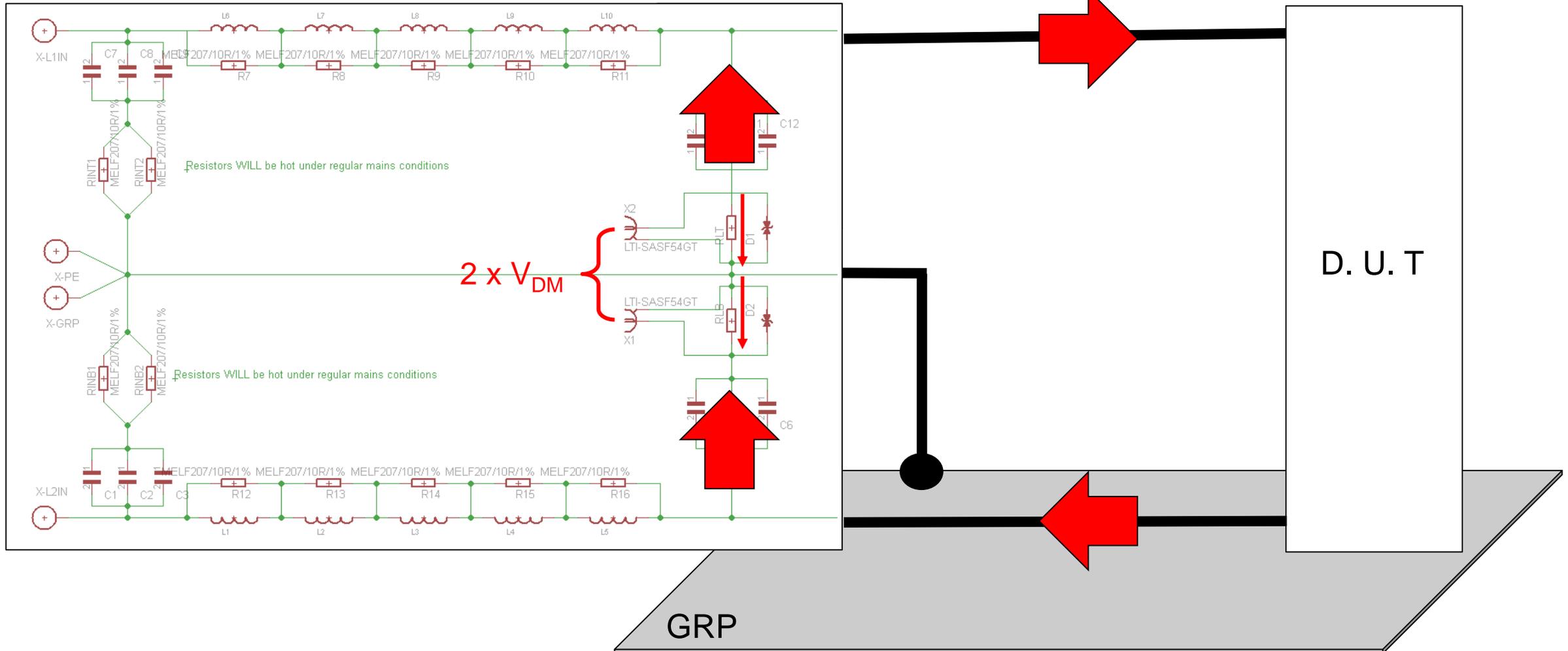
Splitting CM and DM



Going further with simulation

Splitting CM and DM

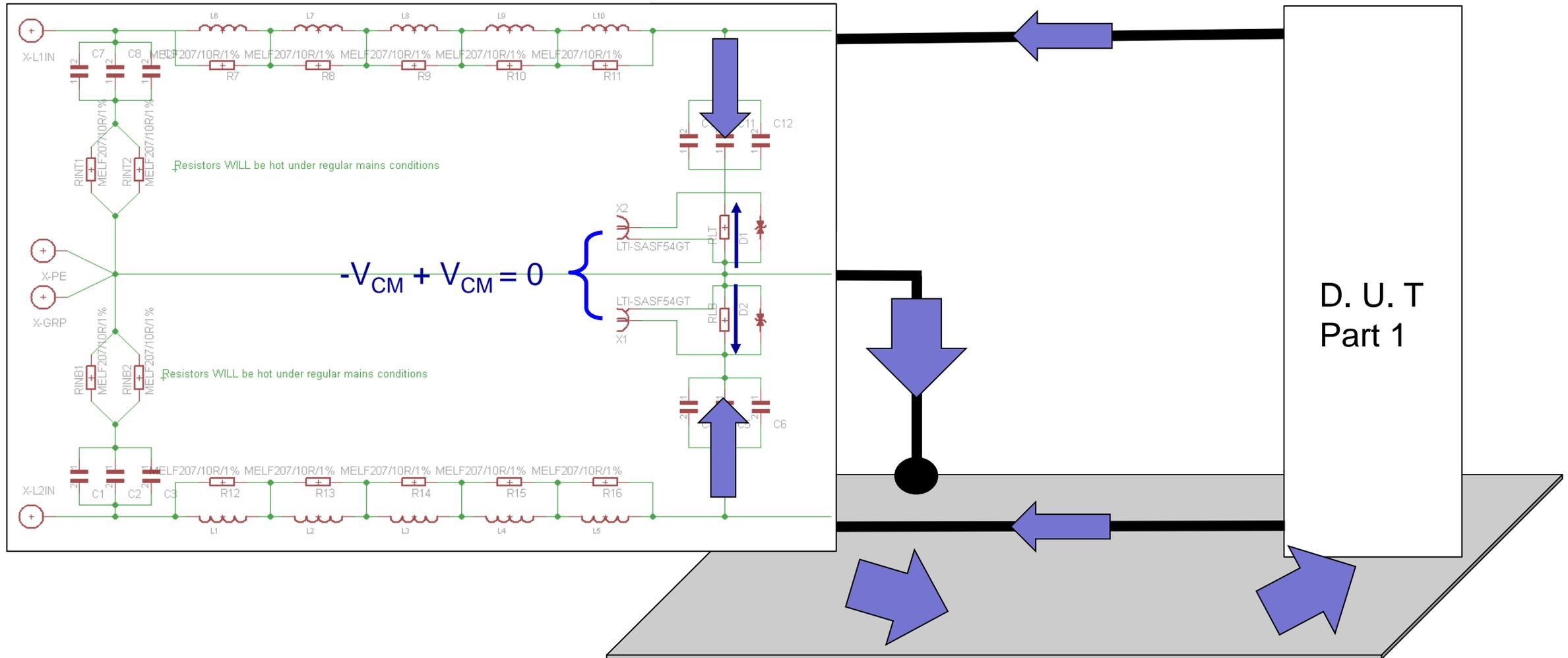
- Symmetrical interference ?



Going further with simulation

Splitting CM and DM

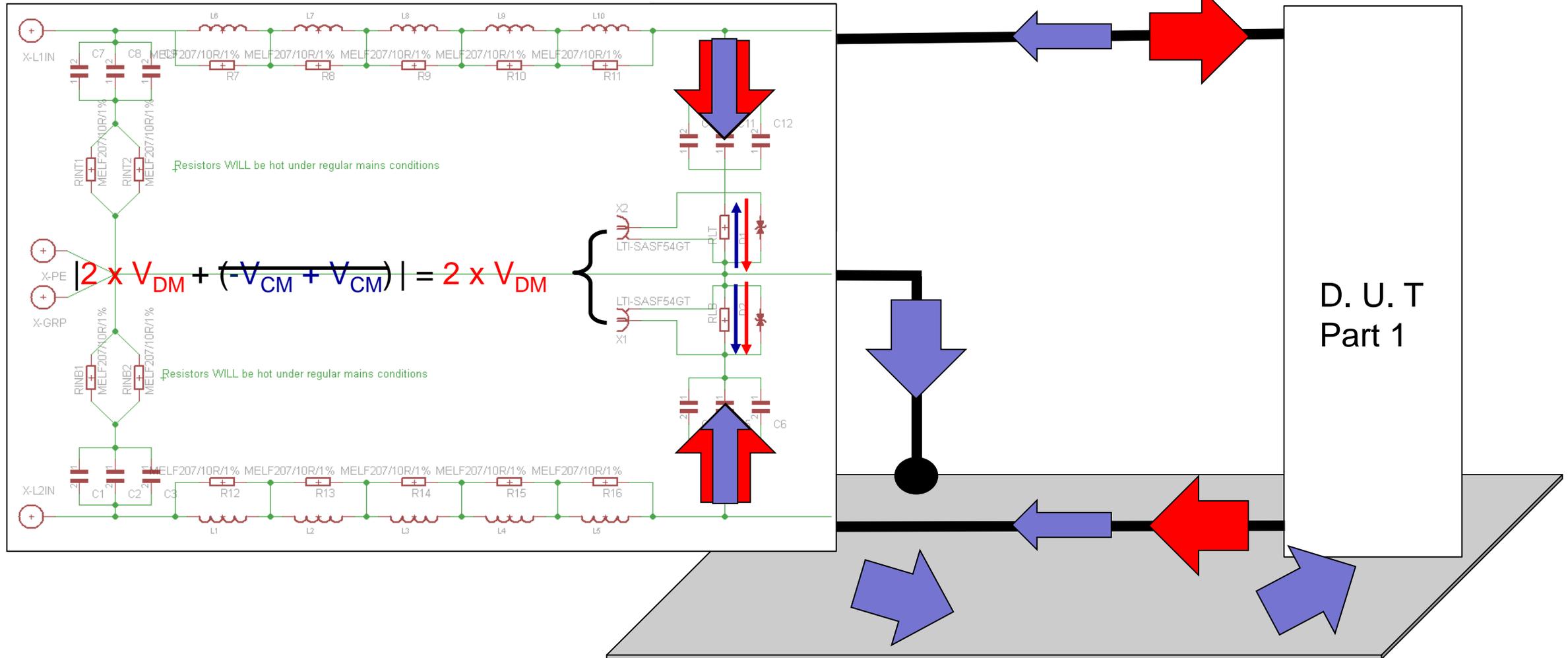
- Asymmetrical interference ?



Going further with simulation

Splitting CM and DM

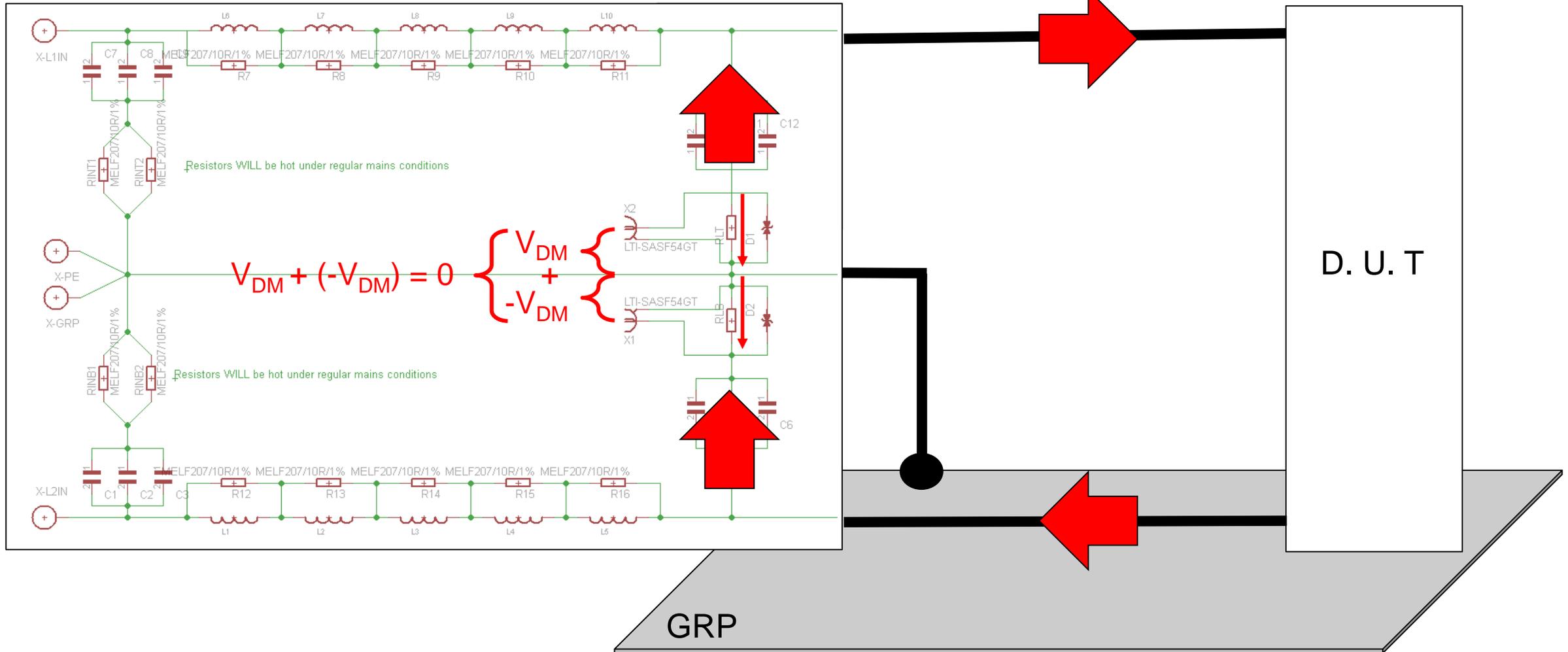
- Asymmetrical interference ?



Going further with simulation

Splitting CM and DM

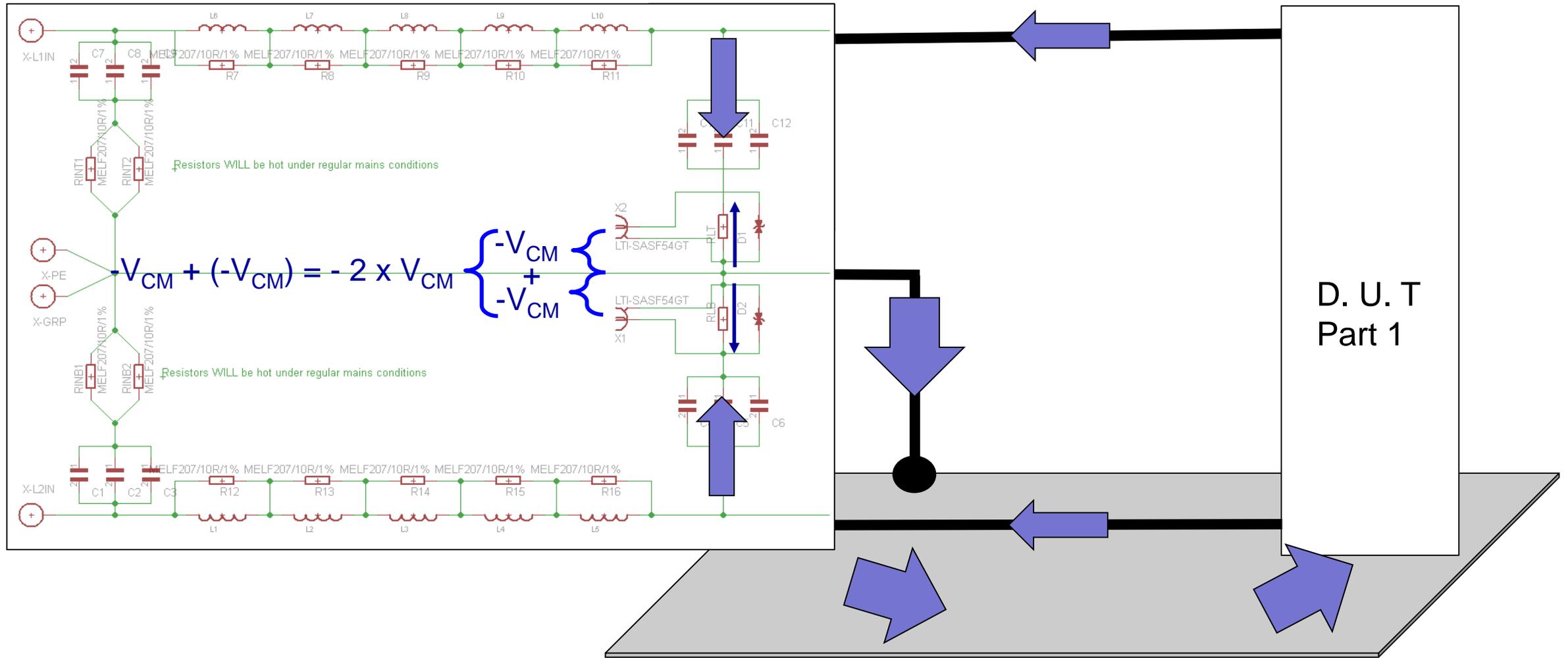
- Symmetrical interference ?



Going further with simulation

Splitting CM and DM

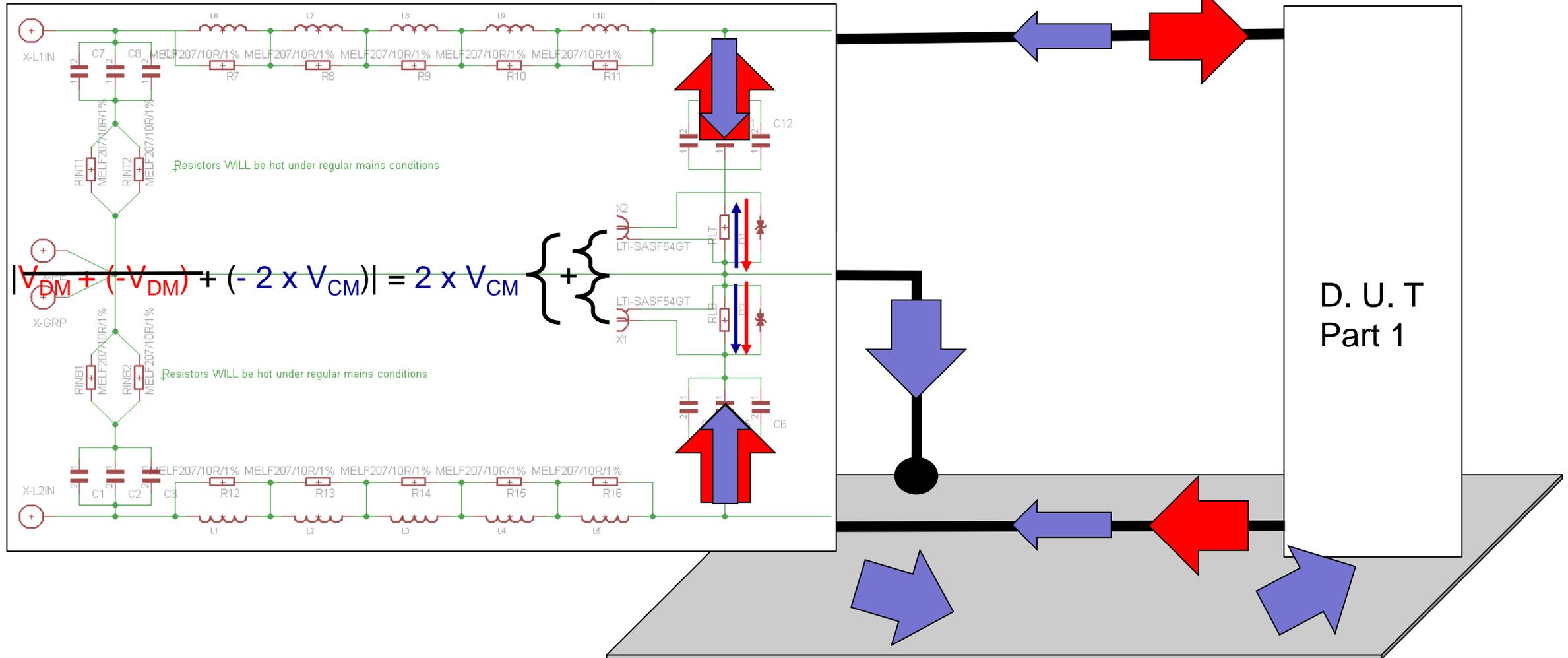
- Asymmetrical interference ?



Going further with simulation

Splitting CM and DM

- Asymmetrical interference ?



Going further with simulation

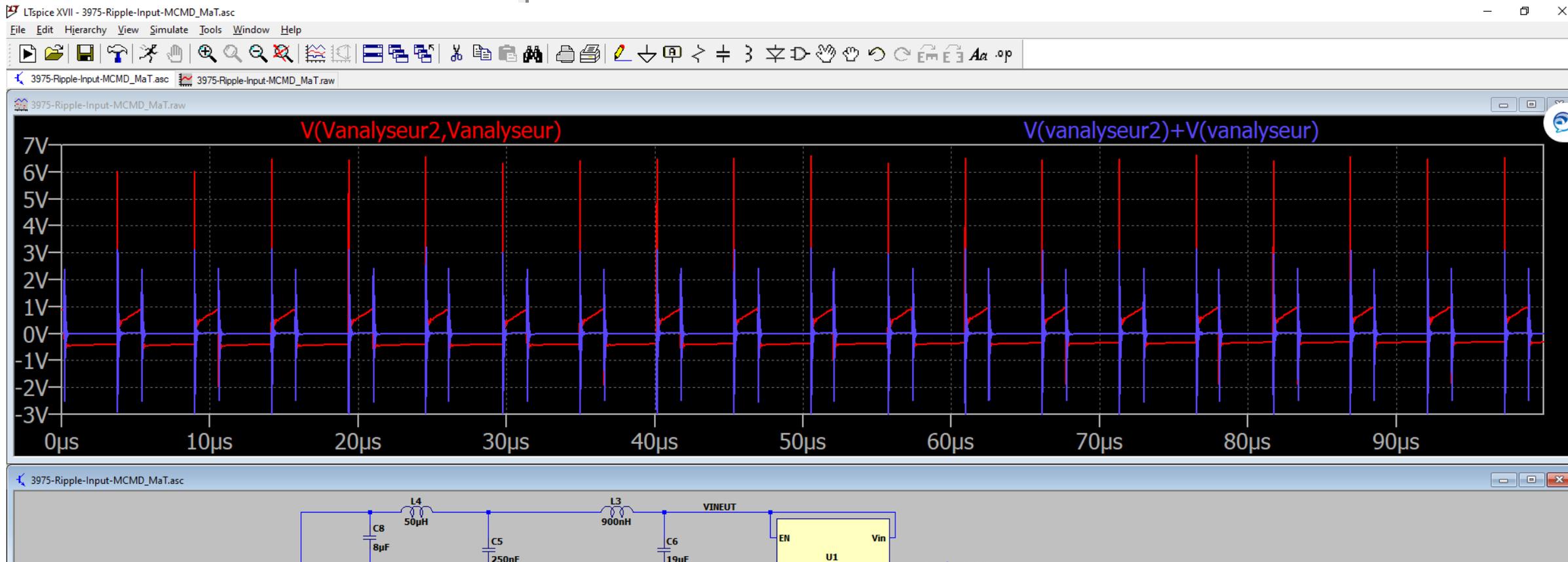
Splitting CM and DM



```
V(vanalyseur,vanalyseur2)
V(vanalyseur2)+V(vanalyseur)
```

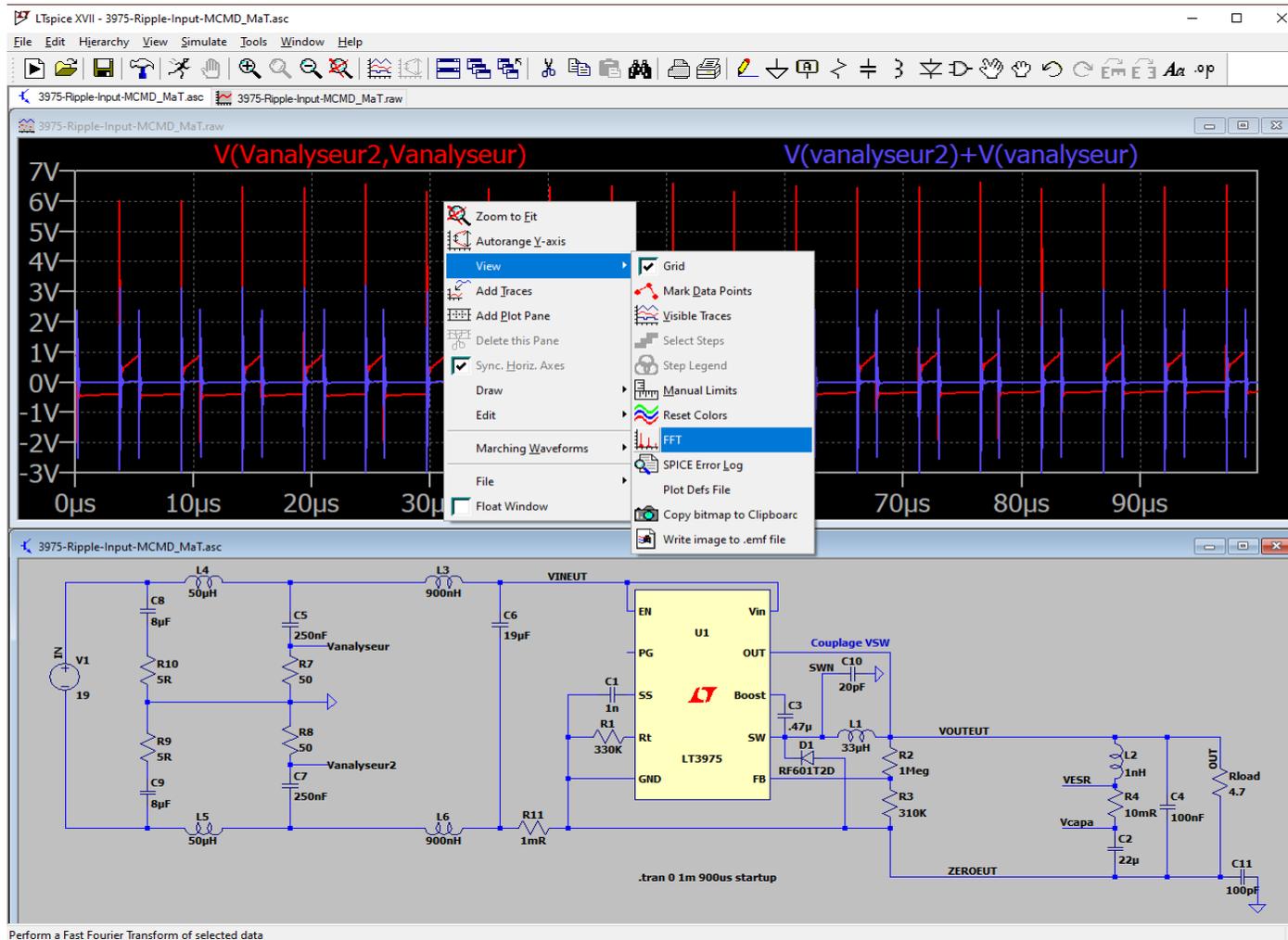
2 * DM noise

2 * CM noise



Going further with simulation

Splitting CM and DM



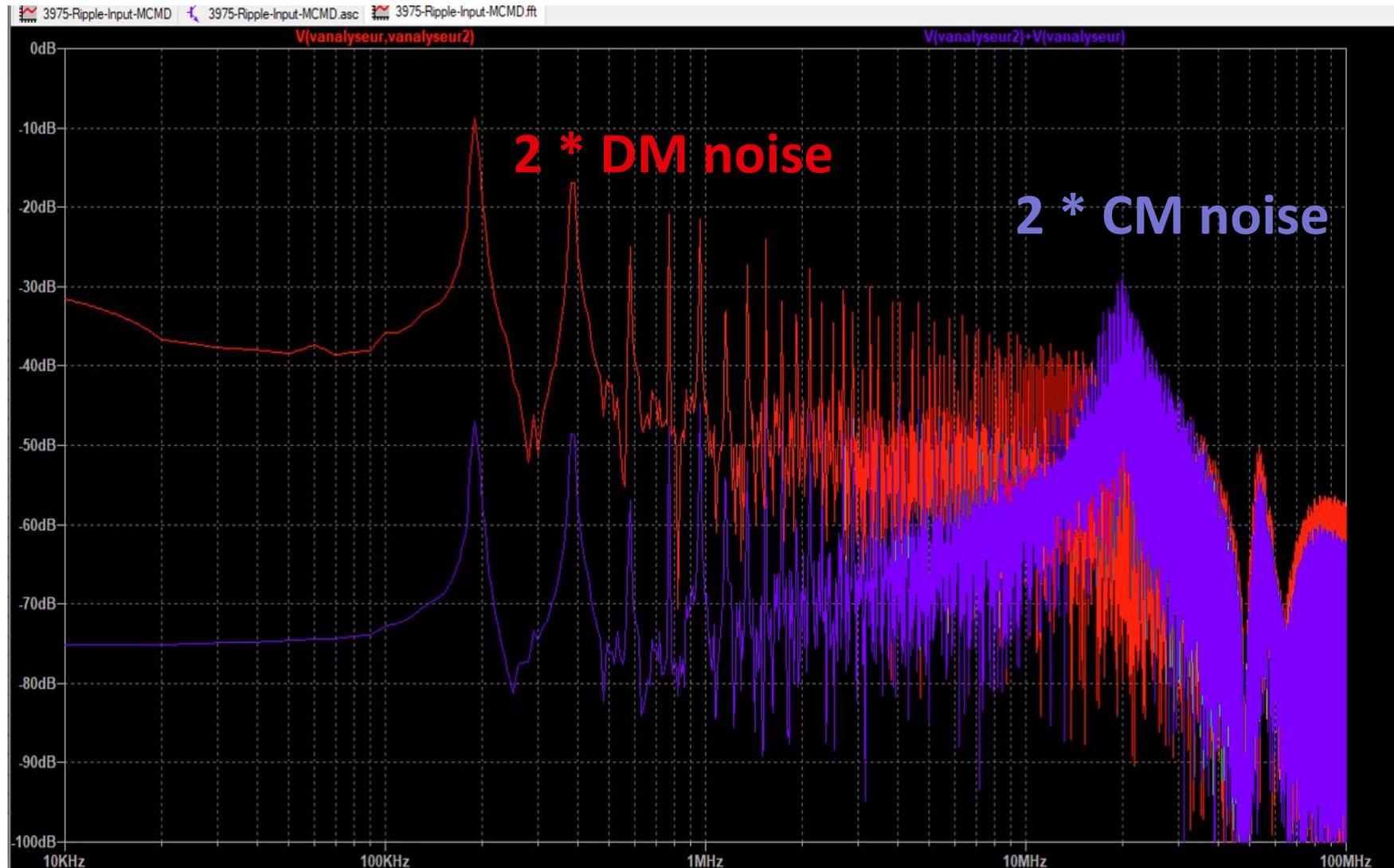
The figure shows a screenshot of the 'Select Visible Waveforms' dialog box. It contains the following elements:

- Buttons: 'OK' and 'Cancel'.
- Checkbox: 'Only list traces matching' (unchecked).
- Text input field: empty.
- Checkbox: 'Asterisks match colons' (checked).
- Section: 'Select Waveforms to Plot: Ctrl-Click to toggle, Alt-Double-Click to enter an expression'.
- Waveform list:
 - $V(vanalyseur,vanalyseur2)$ (highlighted in blue)
 - $V(vanalyseur2)+V(vanalyseur)$
- Annotations:
 - Red arrow pointing to $V(vanalyseur2)$ with text: $2 * DM\ noise$
 - Blue arrow pointing to $V(vanalyseur2)+V(vanalyseur)$ with text: $2 * CM\ noise$
- Checkbox: 'Auto Range' (checked).

Perform a Fast Fourier Transform of selected data

Going further with simulation

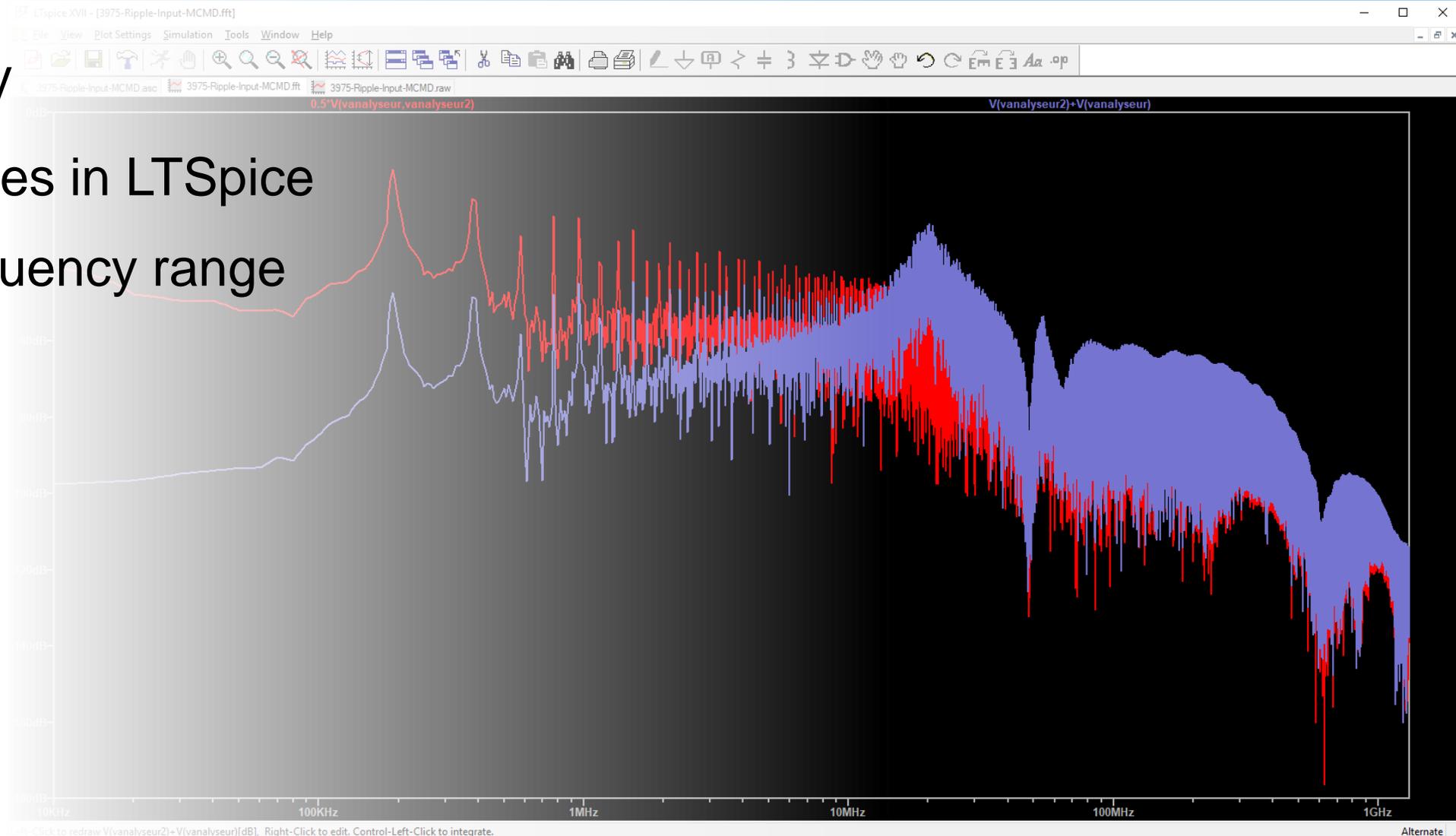
Splitting CM and DM



Going further with simulation

Making simulation look real

- Scaling to $\text{dB}\mu\text{V}$
- Loading limit lines in LTSpice
- Defining a Frequency range

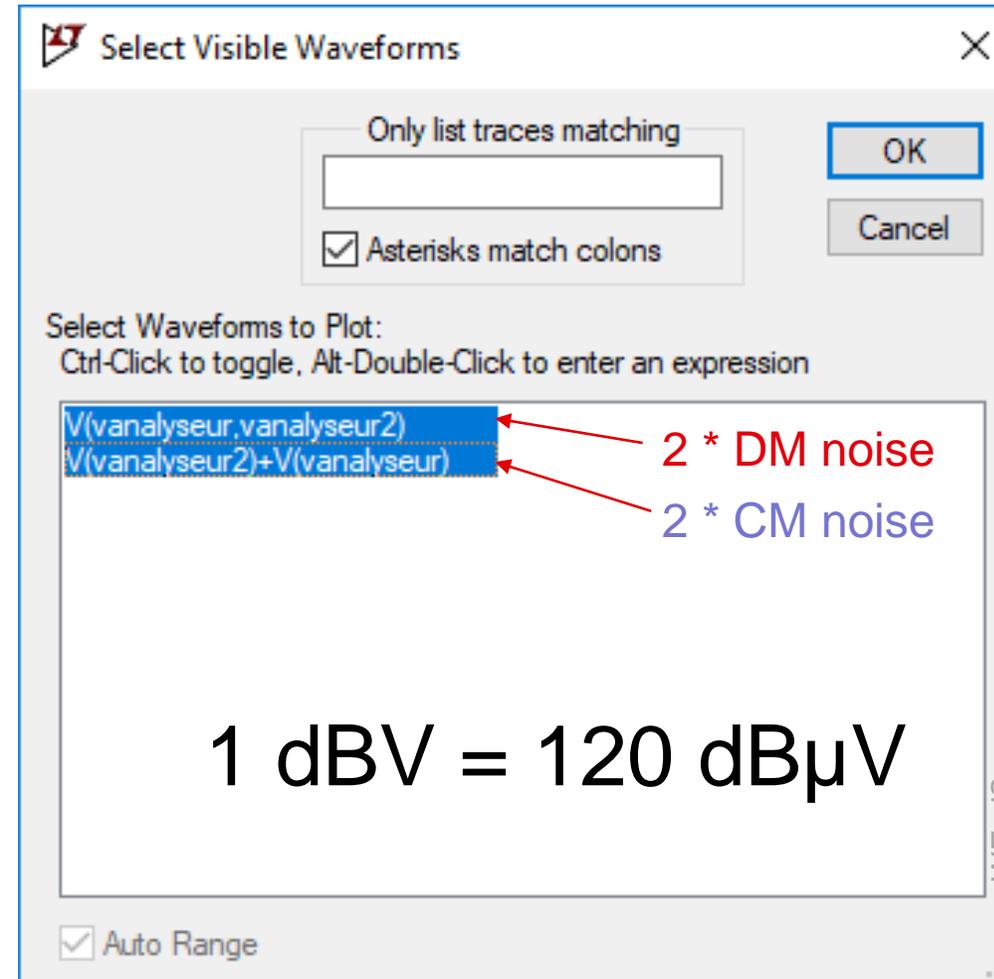


Left-Click to redraw V(vanalyseur2)+V(vanalyseur)[dB]. Right-Click to edit. Control-Left-Click to integrate.

Alternate

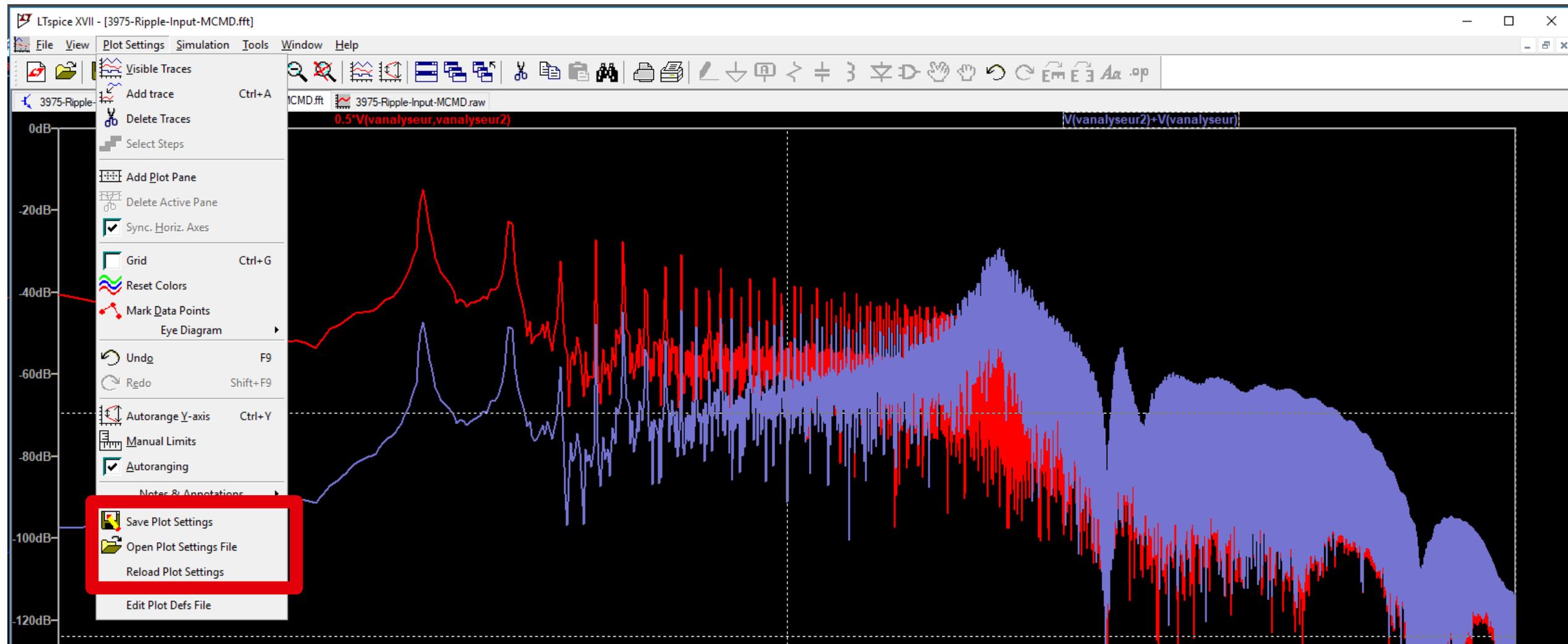
Going further with simulation

Making simulation look real



Going further with simulation

Making simulation look real





Going further with simulation

Making simulation look real – Adding limit lines



Line	Start	End	Amp dBµV start	Amp dBµV stop	Line def for LTSPICE
Line 1	9000	50000	110	110	(9000,0.316227766016838) (50000,0.316227766016838)
Line 2	50000	150000	90	80	(50000,0.0316227766016838) (150000,0.01)
Line 3	150000	500000	66	56	(150000,0.00199526231496888) (500000,0.000630957344480192)
Line 4	500000	5000000	56	56	(500000,0.000630957344480192) (5000000,0.000630957344480192)
Line 5	5000000	30000000	60	60	(5000000,0.001) (30000000,0.001)

Flyback-example-2-base - Bloc-notes

Fichier Edition Format Affichage Aide

[FFT of time domain data]

```
{
  Npanes: 1
  {
    traces: 1 {2,0,"V(vanalyseur2)+V(vanalyseur)"}
    X: ('M',0,9000,0,30000000)
    Y[0]: ('',0,1e-006,10,1)
    Y[1]: ('',0,-200,40,200)
    Log: 1 2 0
    PltMag: 1
    Line: "dB" 4 0 (9000,0.3162277660168) (50000,0.316227766)
    Line: "dB" 4 0 (50049.8435712172,0.0317065818612387) (150407.110289202,0.0100397786508485)
    Line: "dB" 4 0 (150000,0.00199526231496888) (500000,0.000630957344480192)
    Line: "dB" 4 0 (500000,0.000630957344480192) (5000000,0.000630957344480192)
    Line: "dB" 4 0 (5000000,0.001) (30000000,0.001)
  }
}
```

Fill according to EMC standards

Copy the result

Paste it here

Going further with simulation

Making simulation look real – Defining a range

10kHz to 30 MHz

0 to 120dB μ V

3975-Ripple-Input-MCMD-dbuV.plt - Bloc-notes

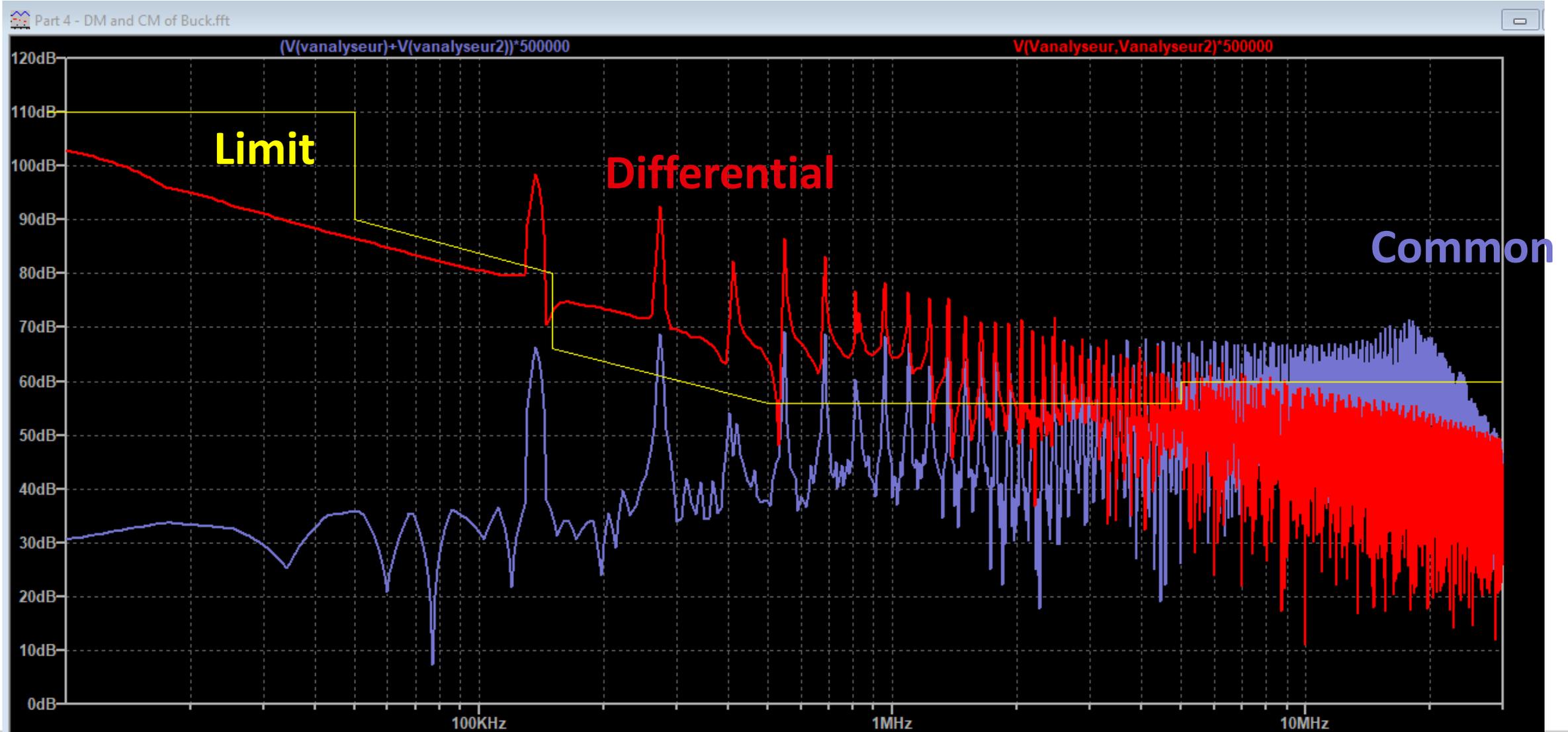
Fichier Edition Format Affichage ?

[FFT of time domain data]

```
{
  Npanes: 1
  {
    traces: 2 {65540,0,"500000*V(vanalyseur,vanalyseur2)"} {65547,0,"1000000*(V(vanalyseur2)+V(vanalyseur))"}
    X: ('M',0,10000,0,3e+007)
    Y[0]: (' ',0,1,20,1e+006)
    Log: 1 2 0
    GridStyle: 1
    PltMag: 1
    Line: "dB" 13 0 (8983.92329505352,319040.747263751) (49889.5367382049,319040.747263751)
    Line: "dB" 13 0 (50000,316227.766016838) (50000,31622.7766016838)
    Line: "dB" 13 0 (50000,31622.7766016838) (150000,10000)
    Line: "dB" 13 0 (150000,10000) (150000,1995.26231496888)
    Line: "dB" 13 0 (150000,1995.26231496888) (500000,630.957344480193)
    Line: "dB" 13 0 (500000,630.957344480193) (5000000,630.957344480193)
    Line: "dB" 13 0 (5000000,630.957344480193) (5000000,1000)
    Line: "dB" 13 0 (5000000,1000) (30000000,1000)
  }
}
```

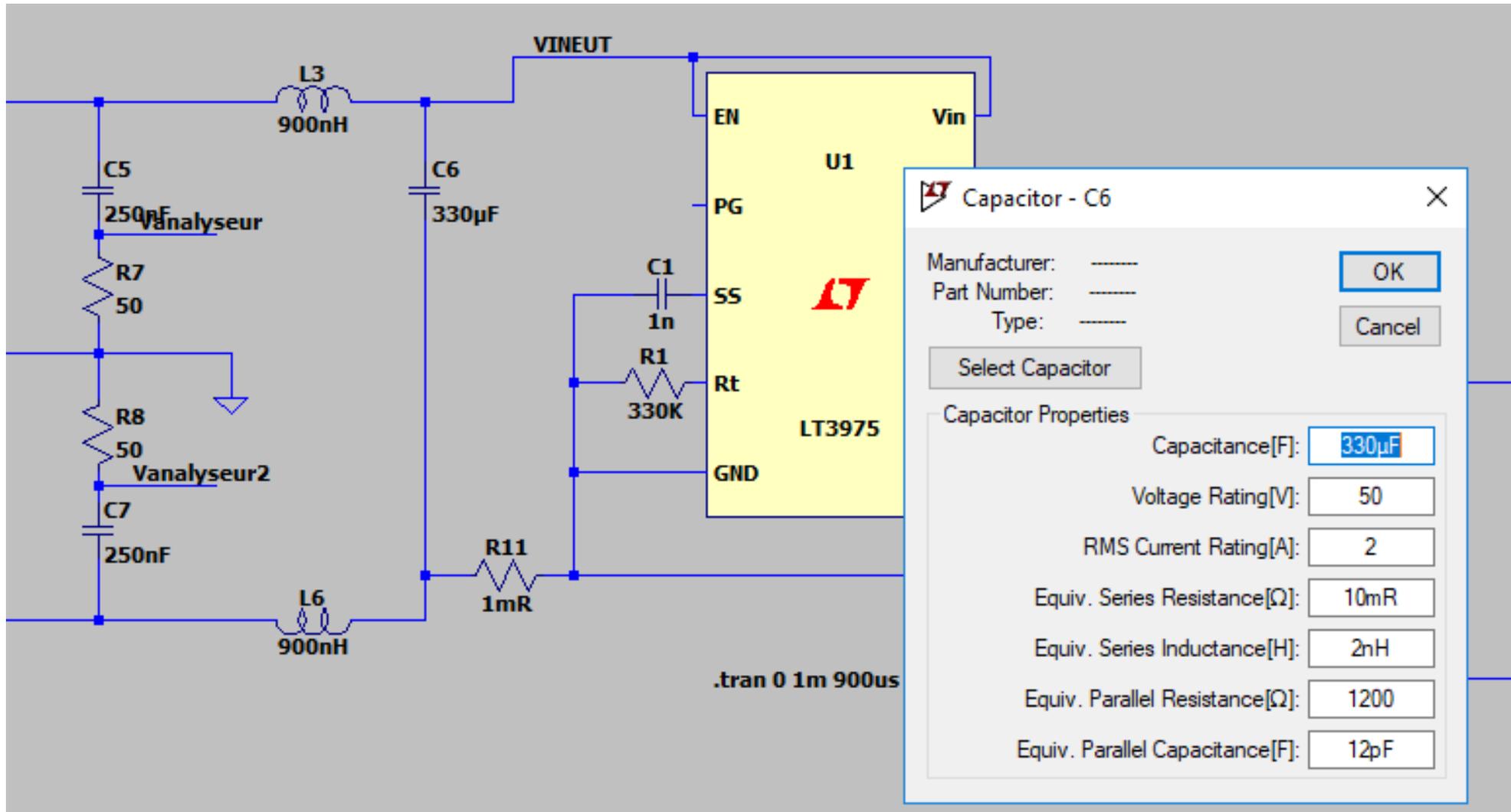
Going further with simulation

Making simulation look real – Result 😊



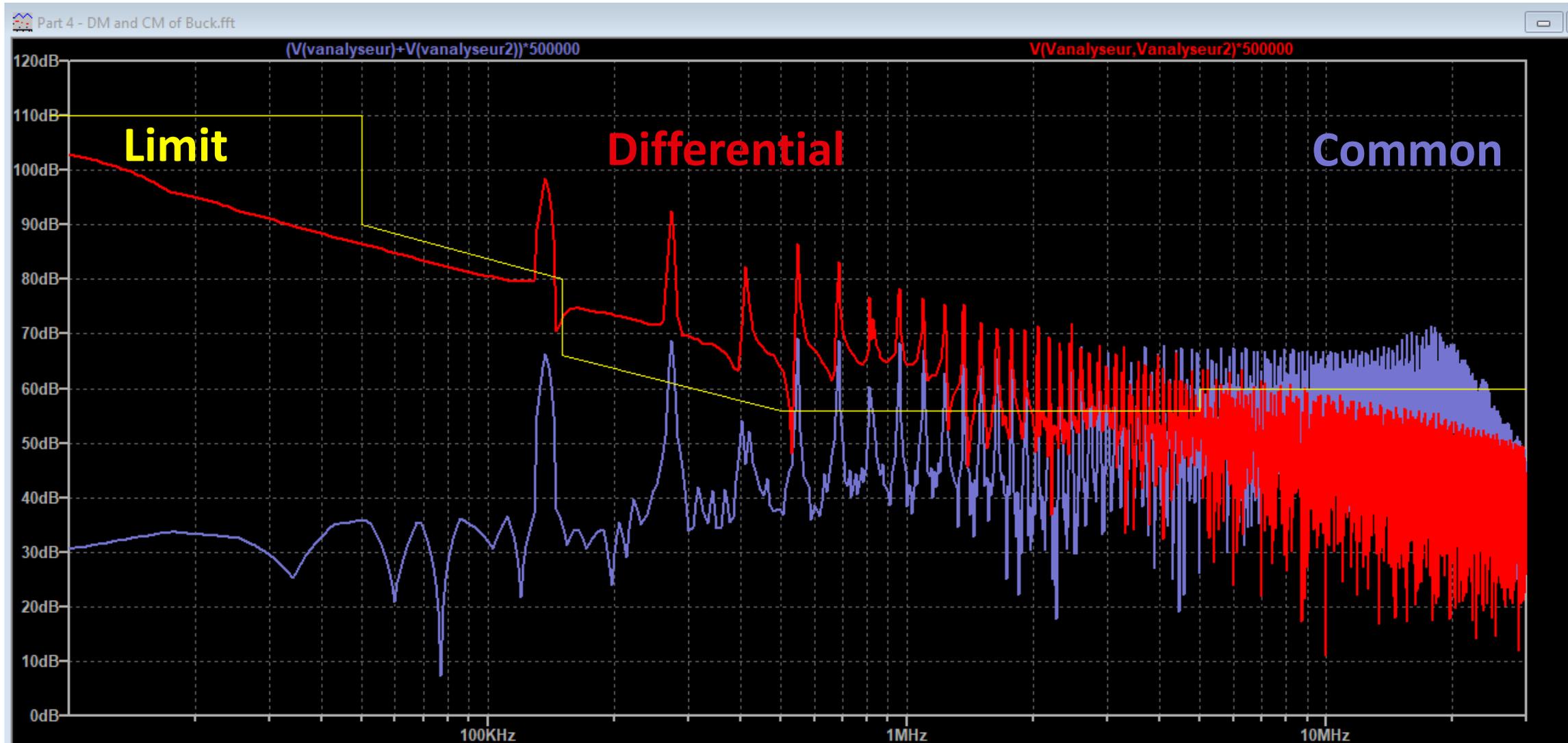
Going further with simulation

Fixing that buck in the simulation – Polymer input cap



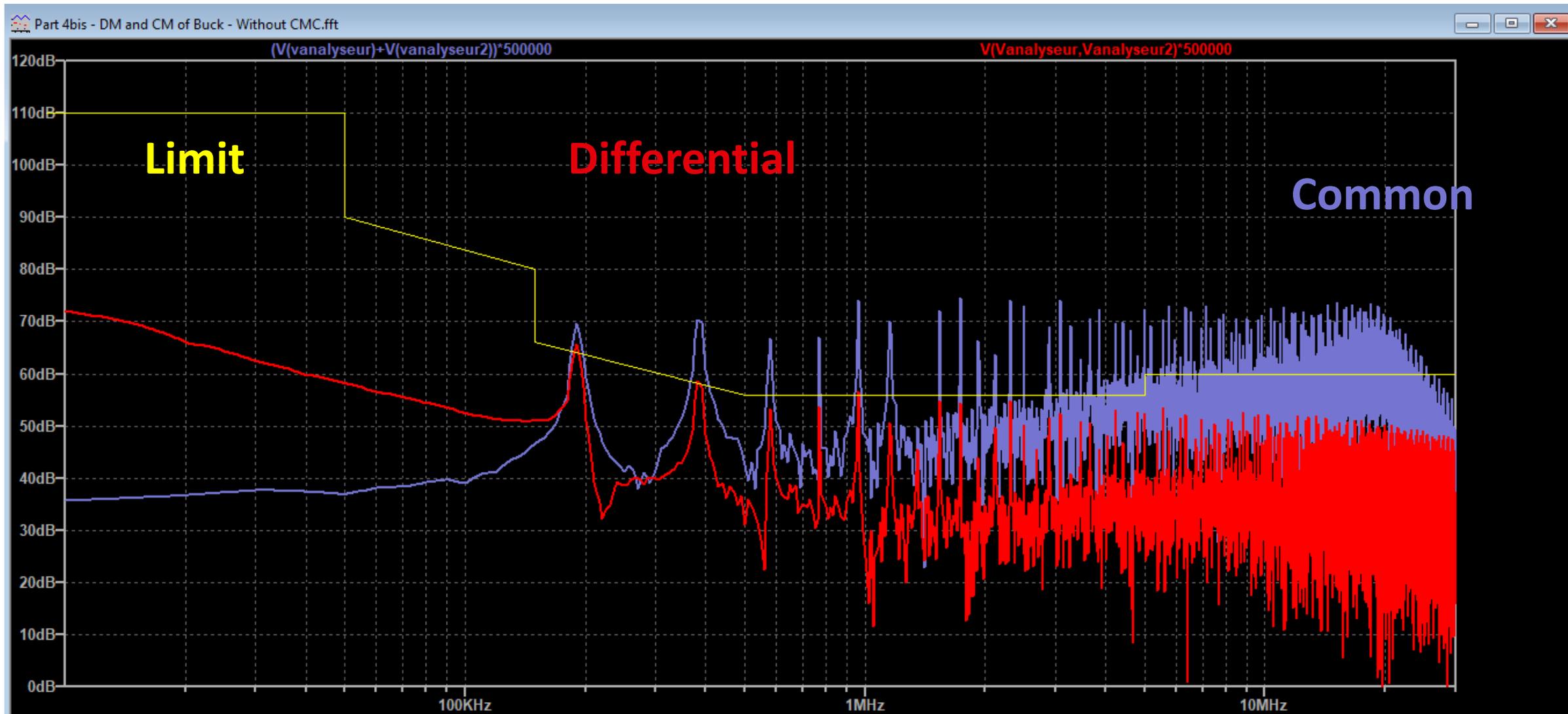
Going further with simulation

Fixing that buck in the simulation – Before Polymer Cap



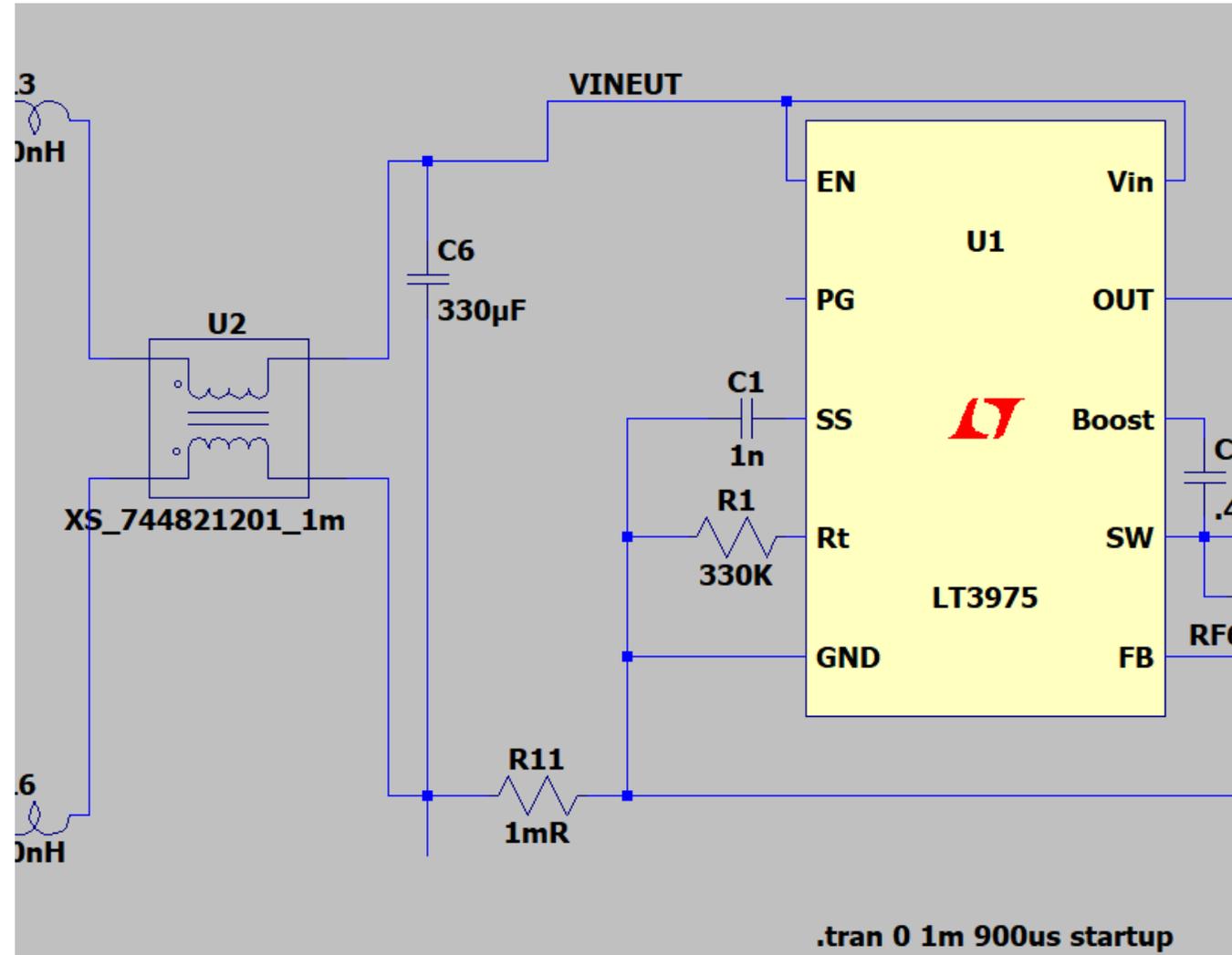
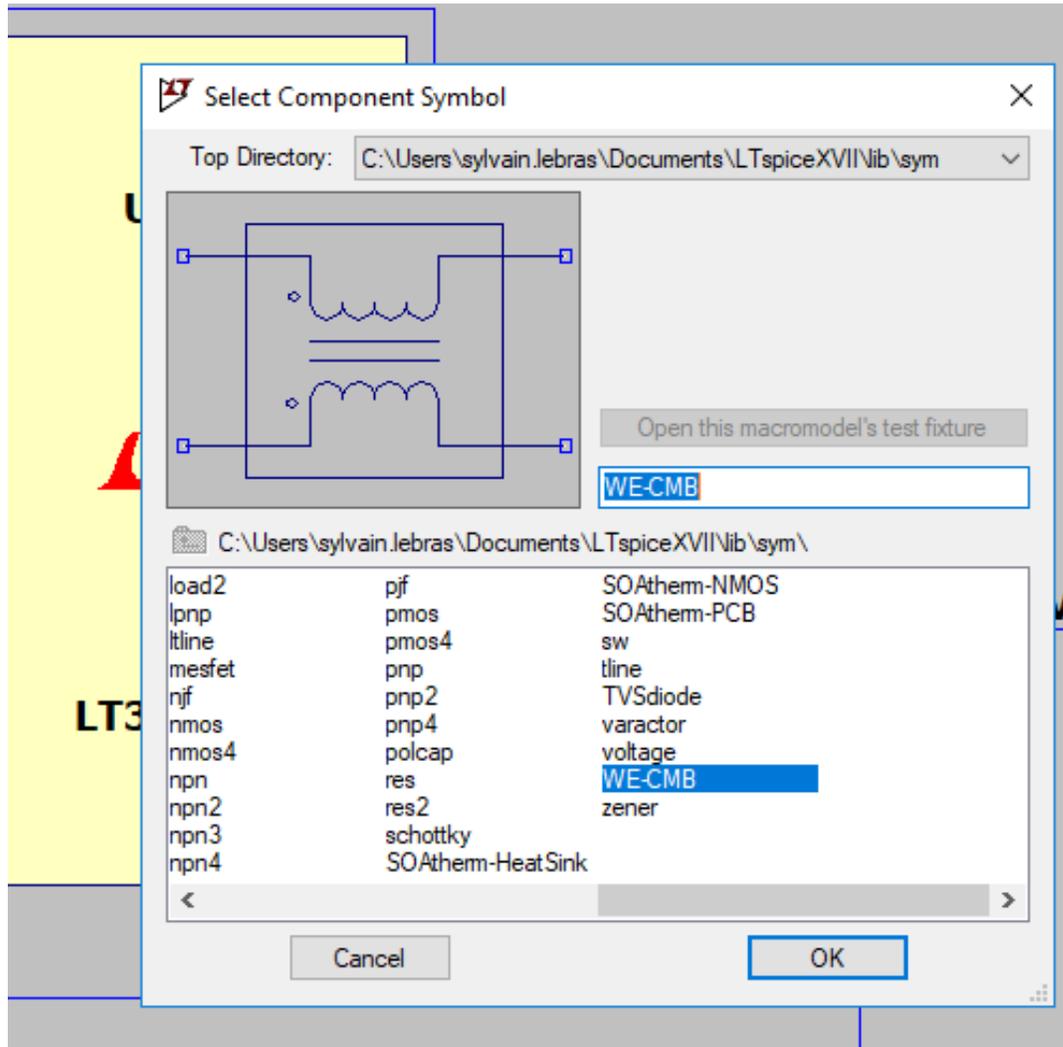
Going further with simulation

Fixing that buck in the simulation – After Polymer Cap



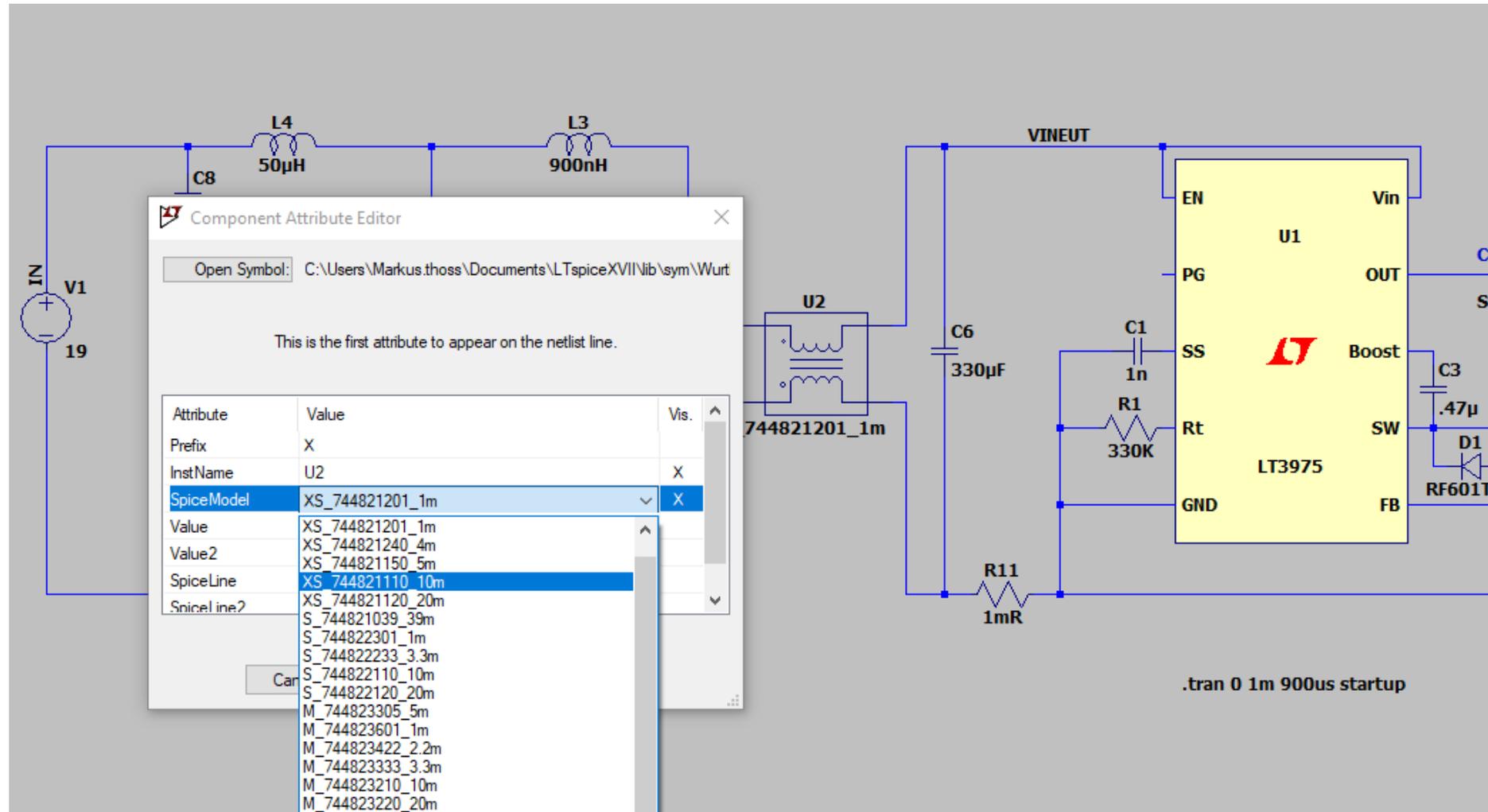
Going further with simulation

Fixing that buck in the simulation – Common mode choke



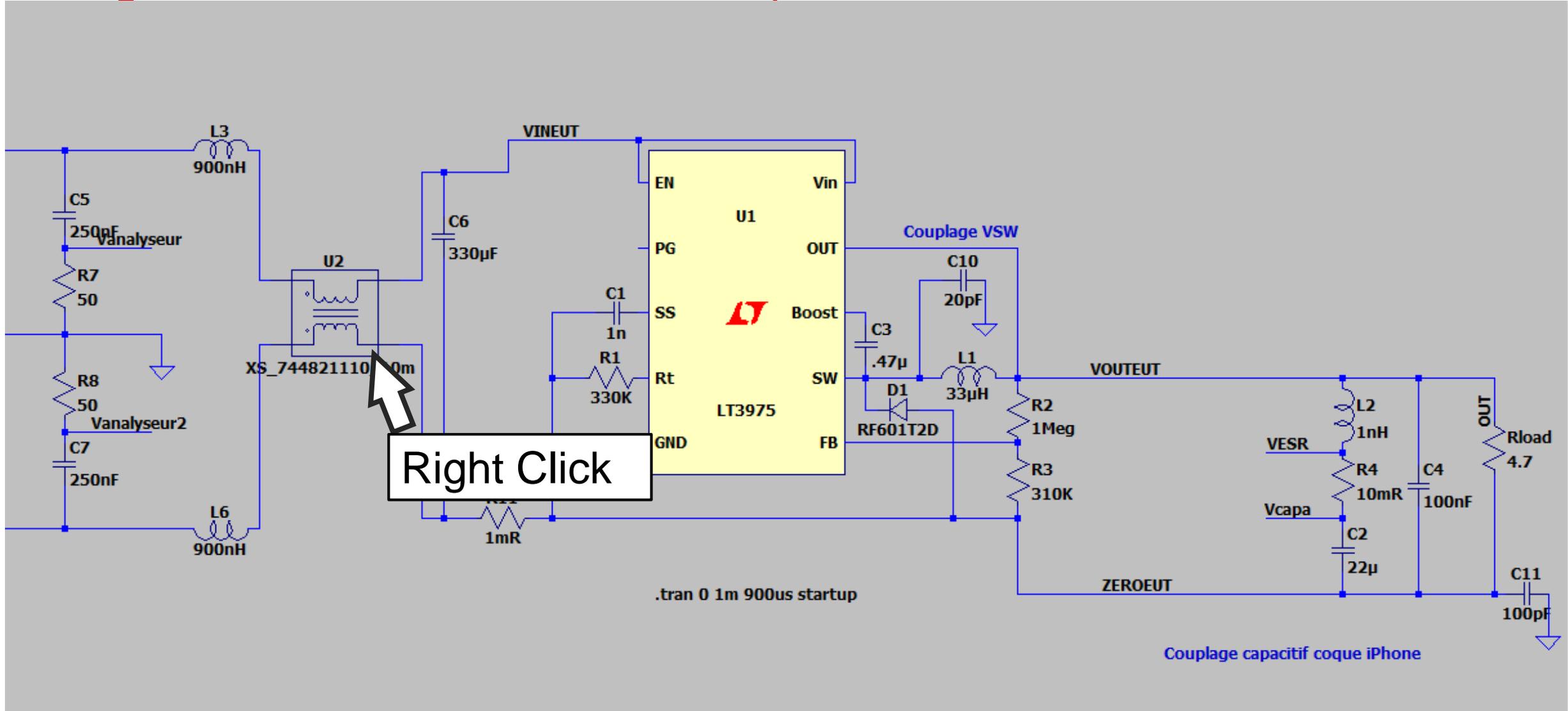
Going further with simulation

Fixing that buck in the simulation – Input Common mode choke



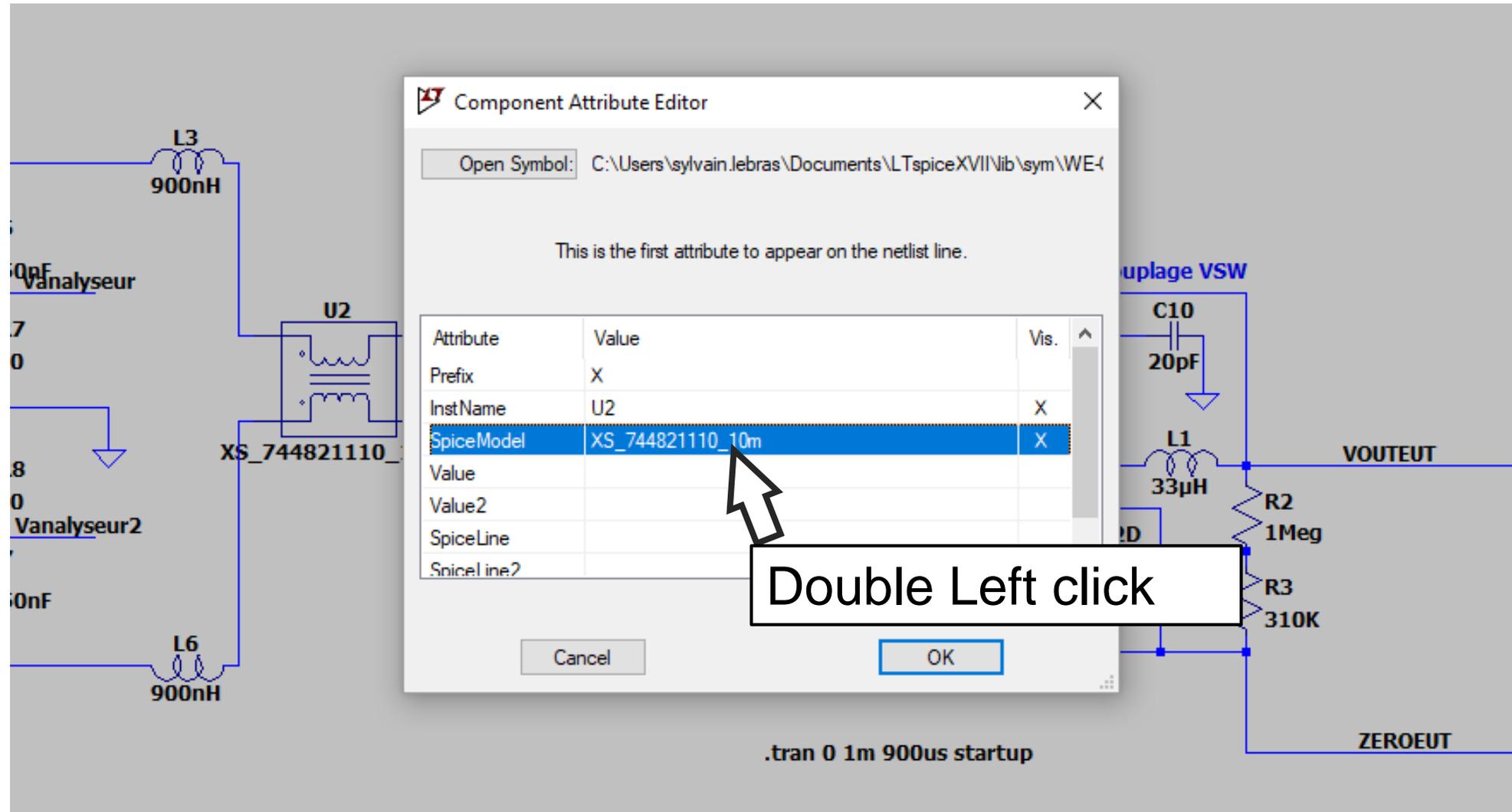
Going further with simulation

Fixing that buck in the simulation – Input Common mode choke



Going further with simulation

Fixing that buck in the simulation – Input Common mode choke



Component Attribute Editor

Open Symbol: C:\Users\sylvain.lebras\Documents\LTspiceXVII\lib\sym\WE-

This is the first attribute to appear on the netlist line.

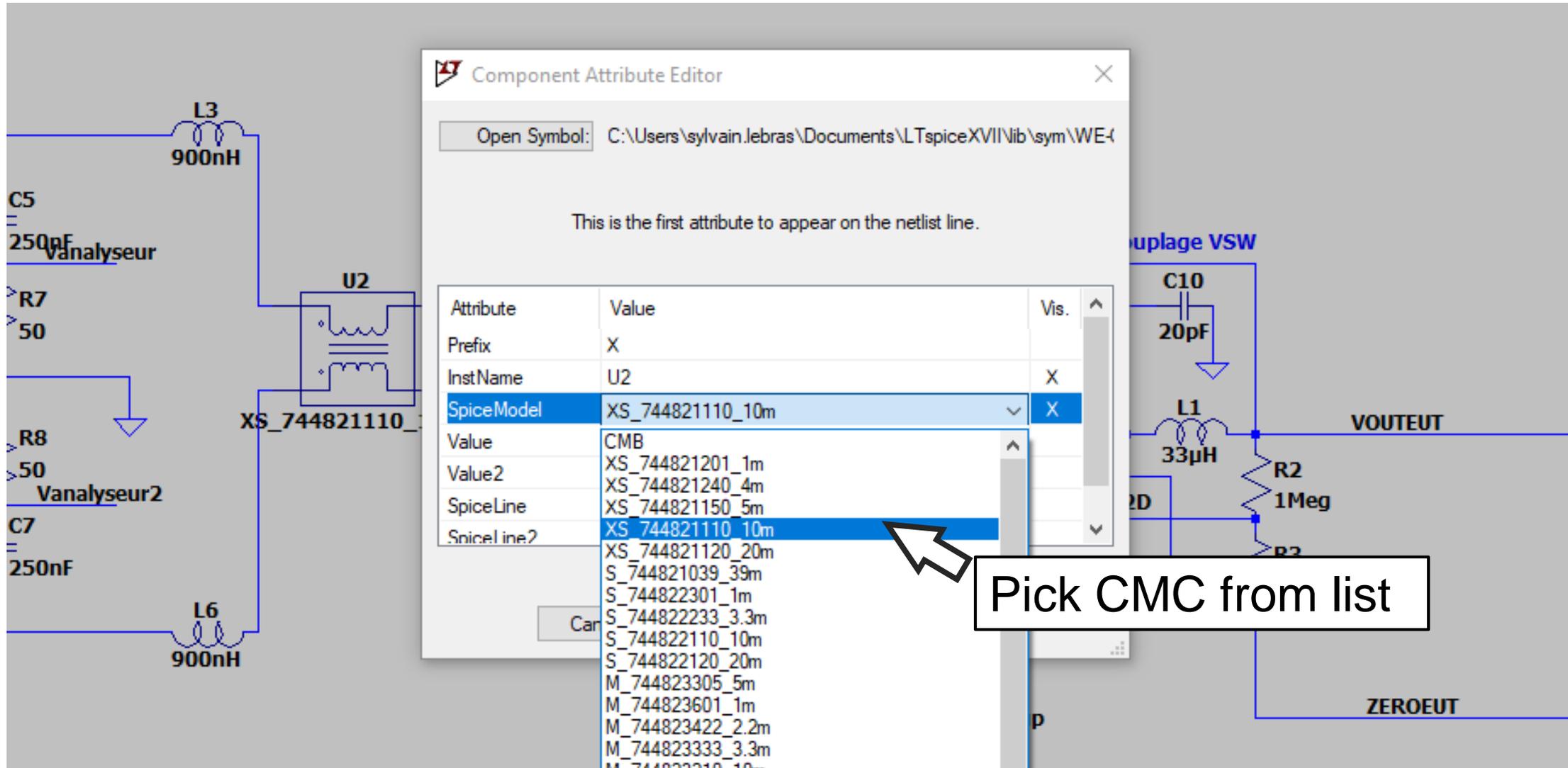
Attribute	Value	Vis.
Prefix	X	
InstName	U2	X
SpiceModel	XS_744821110_10m	X
Value		
Value2		
SpiceLine		
SpiceLine2		

Double Left click

.tran 0 1m 900us startup

Going further with simulation

Fixing that buck in the simulation – Input Common mode choke



The image shows a circuit simulation interface. On the left, a circuit diagram includes components like C5 (250nF), R7 (50), R8 (50), C7 (250nF), L3 (900nH), L6 (900nH), and a transformer U2. The transformer is labeled with the model name XS_744821110. On the right, another part of the circuit is visible, including C10 (20pF), L1 (33µH), R2 (1Meg), and output nodes VOUTUT and ZEROEUT.

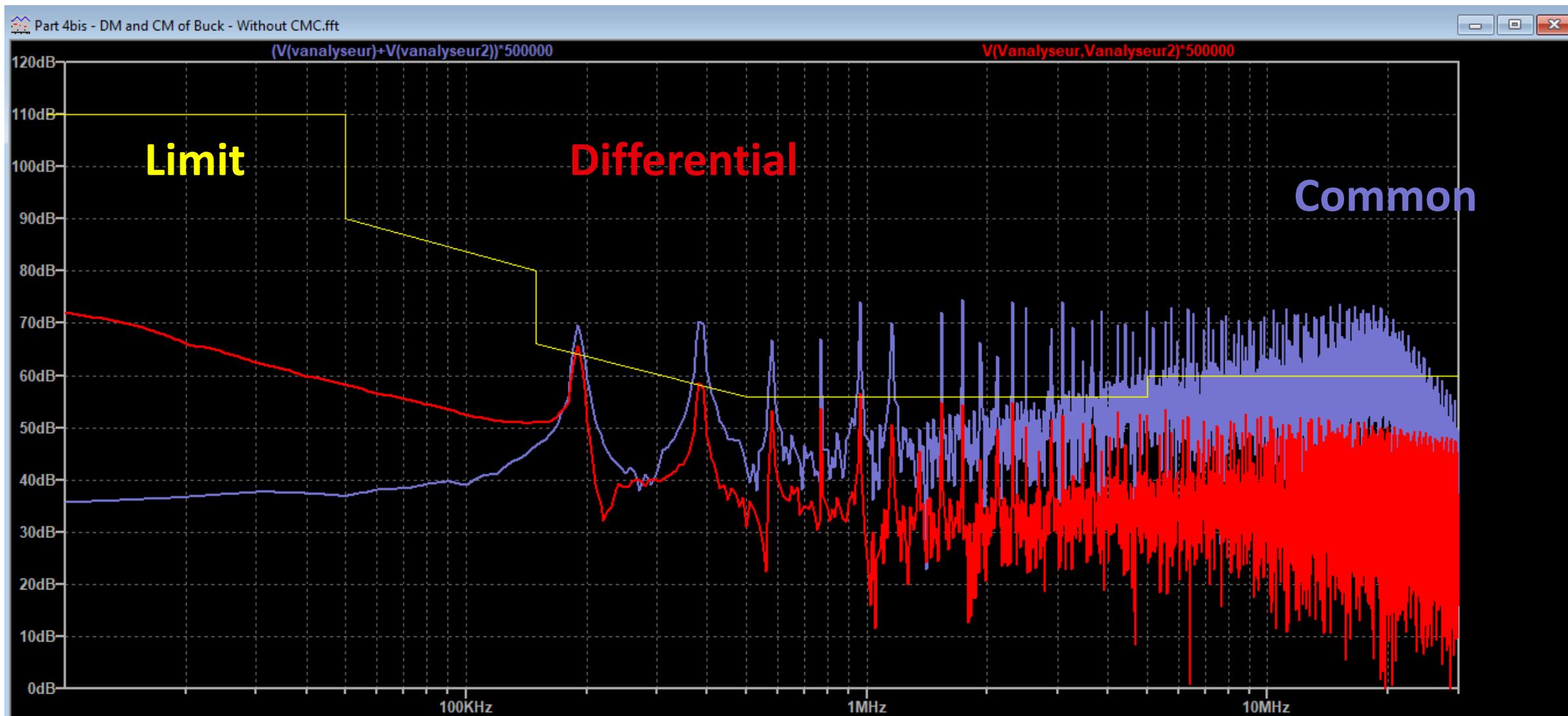
The 'Component Attribute Editor' dialog box is open, showing the following table:

Attribute	Value	Vis.
Prefix	X	
InstName	U2	X
SpiceModel	XS_744821110_10m	X
Value	CMB	
Value2	XS_744821201_1m	
SpiceLine	XS_744821240_4m	
SpiceLine2	XS_744821150_5m	
	XS_744821110_10m	
	XS_744821120_20m	
	S_744821039_39m	
	S_744822301_1m	
	S_744822233_3.3m	
	S_744822110_10m	
	S_744822120_20m	
	M_744823305_5m	
	M_744823601_1m	
	M_744823422_2.2m	
	M_744823333_3.3m	
	M_744822210_10m	

A callout box with the text "Pick CMC from list" points to the selected 'XS_744821110_10m' entry in the list.

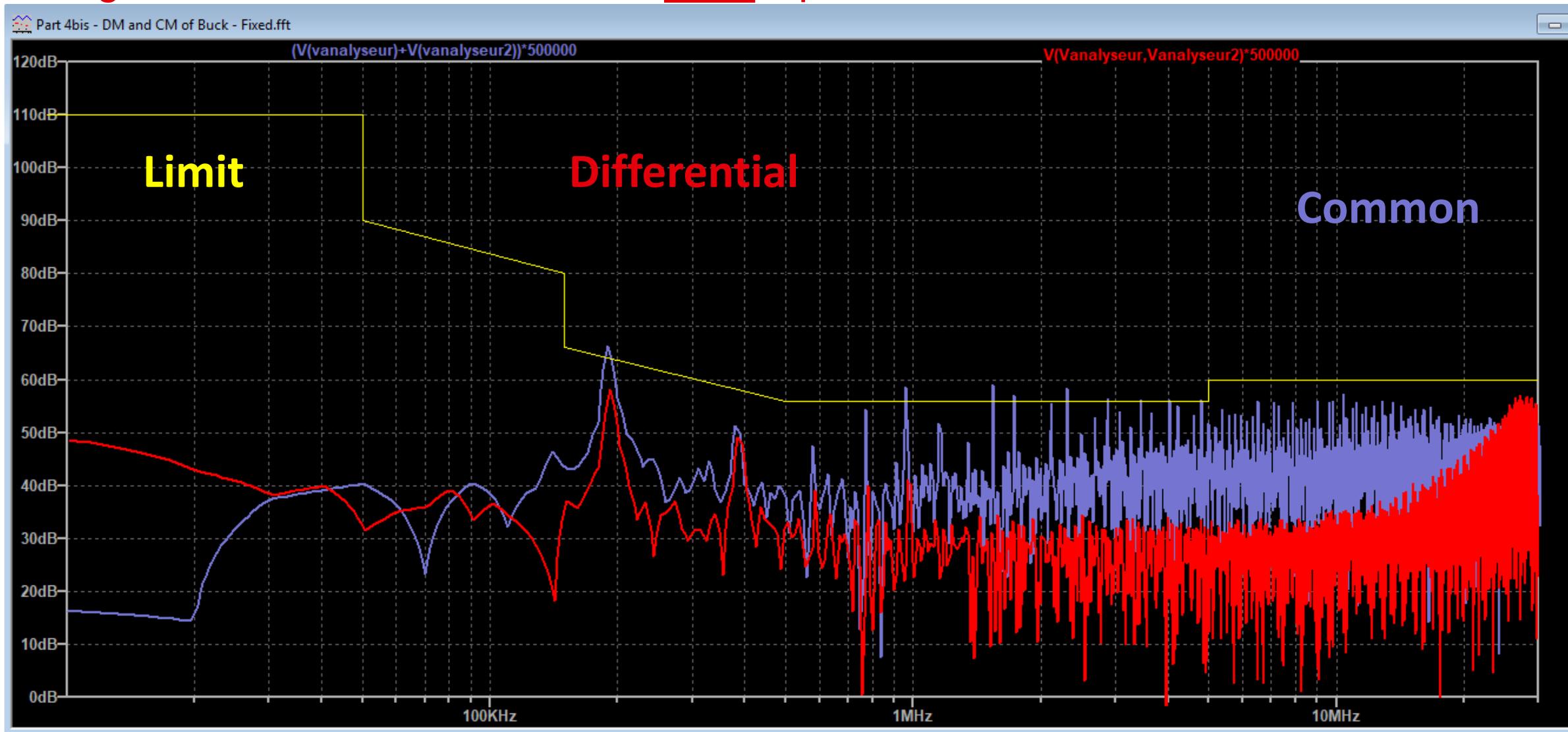
Going further with simulation

Fixing that buck in the simulation – Without Common mode choke



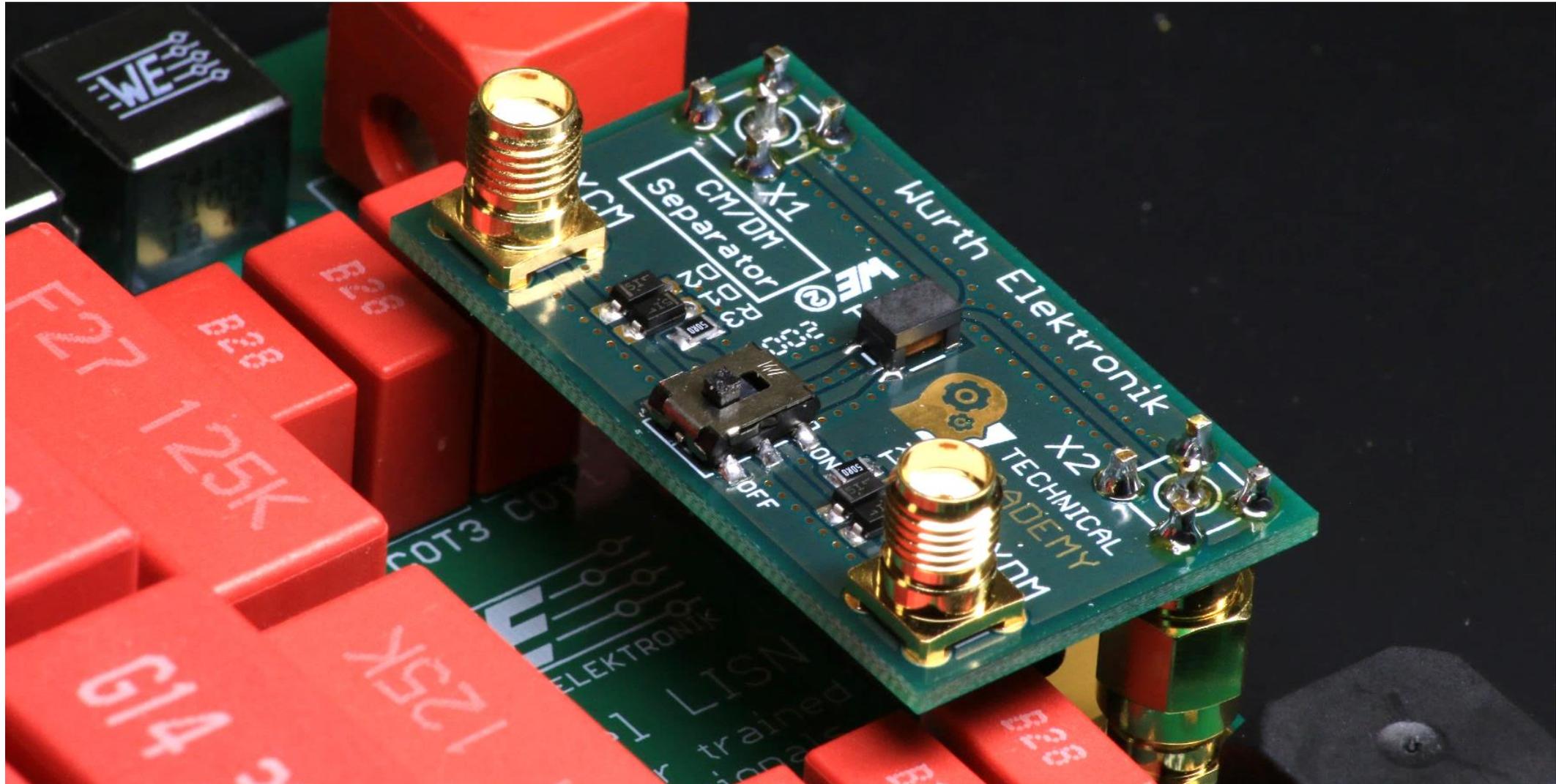
Going further with simulation

Fixing that buck in the simulation – With input Common mode choke



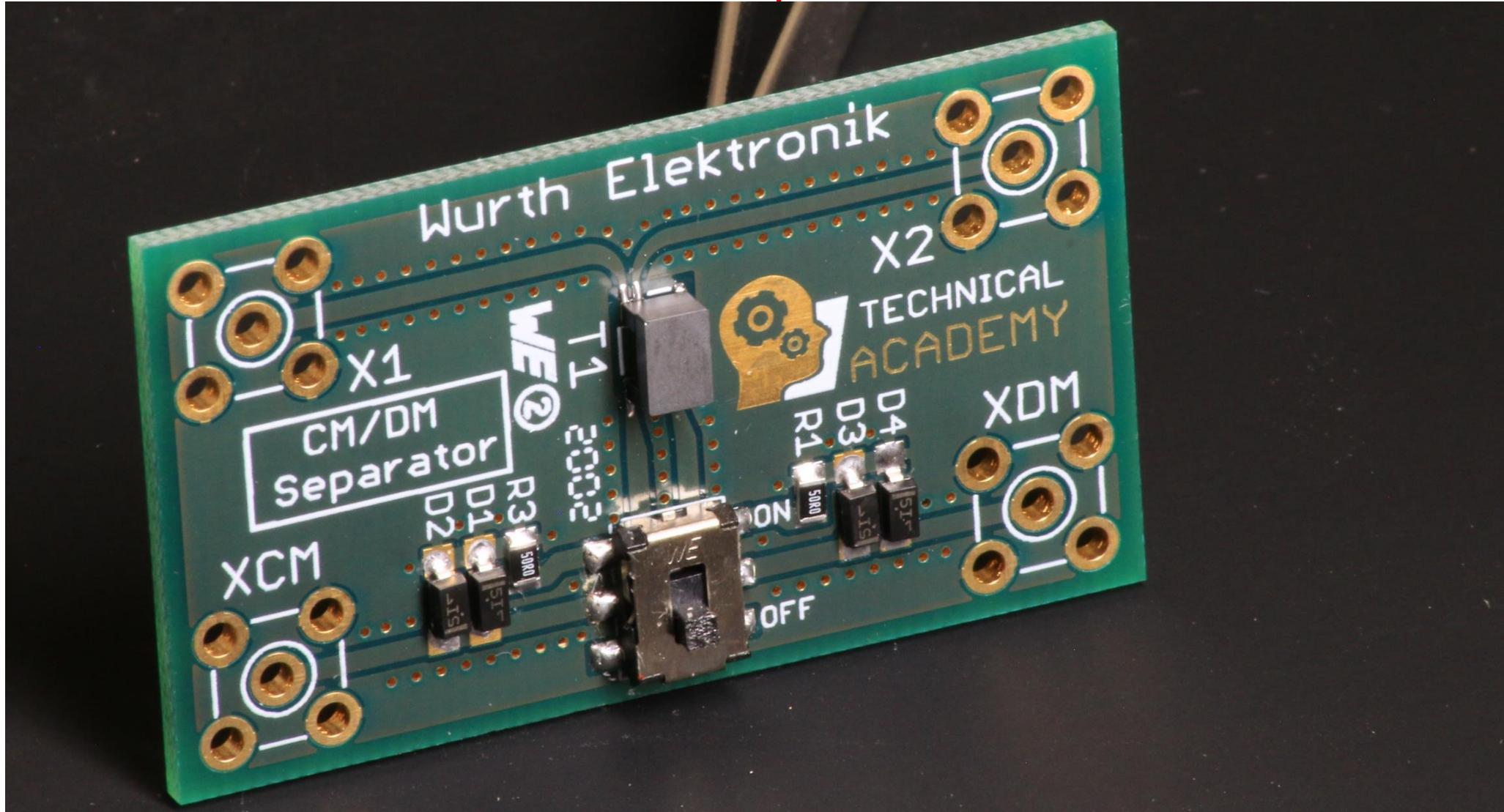
Going further ?

Common mode / Differential Mode separator in real life



Going further ?

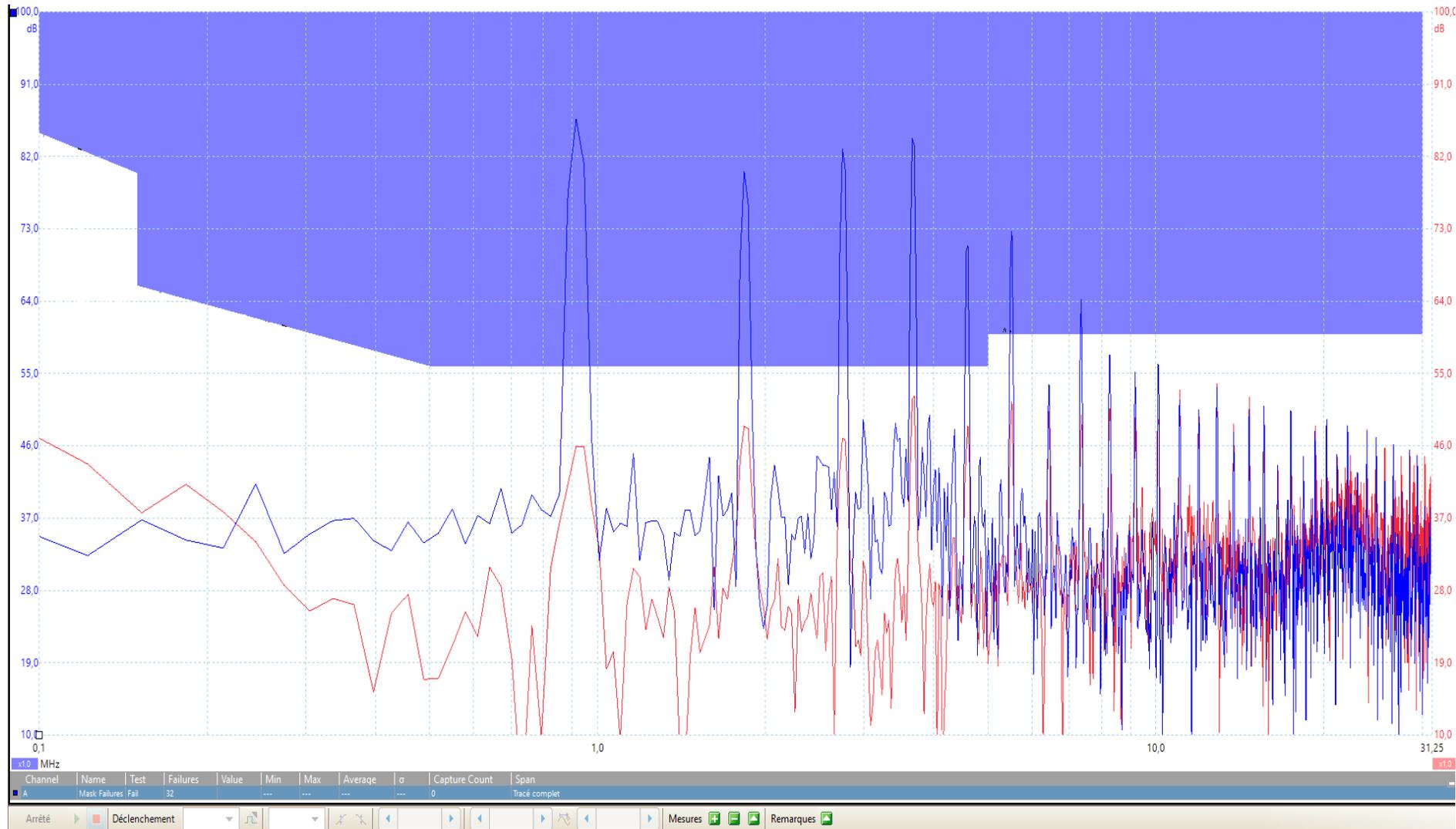
Common mode / Differential Mode separator in real life





Going further ?

Common mode / Differential Mode separator in real life



Modeling Real life examples

Flyback converter for lighting applications

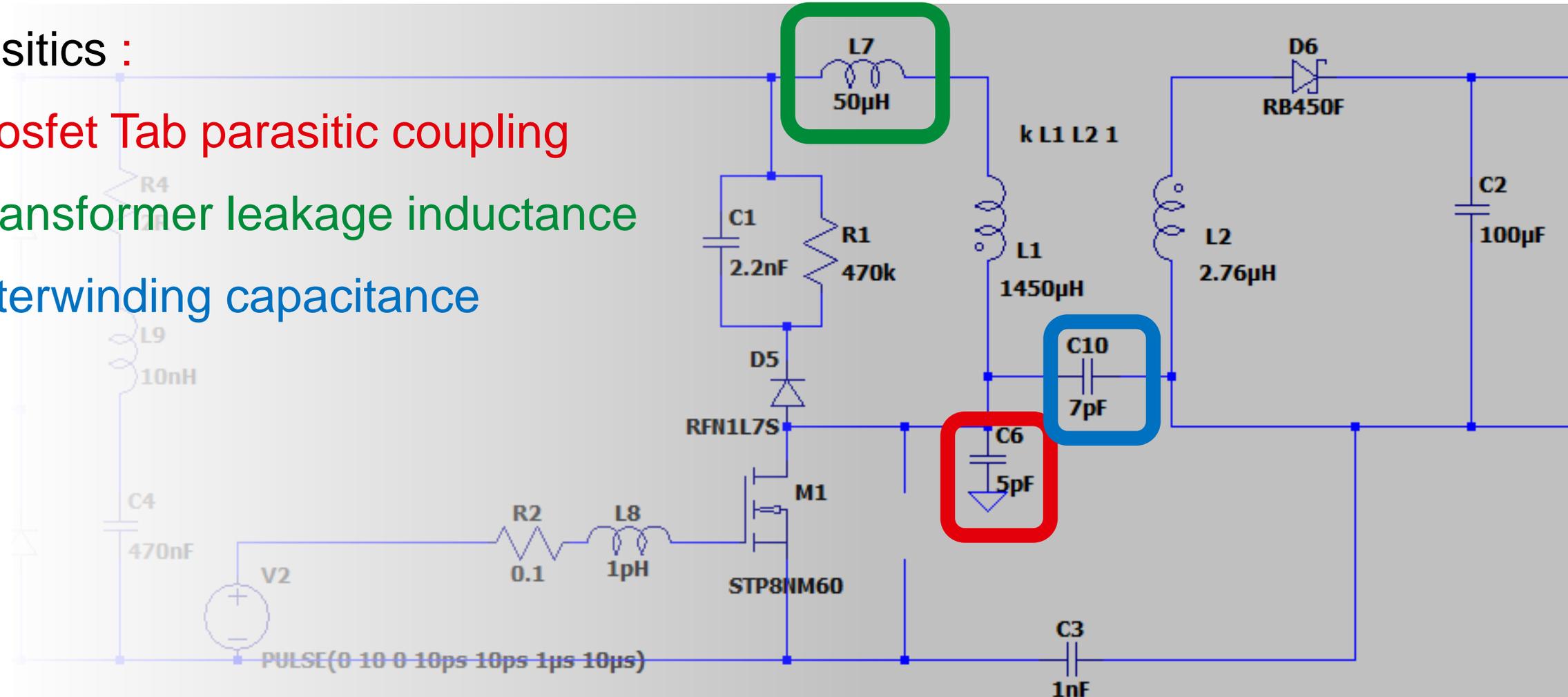


Modeling Real life examples

Flyback converter for lighting applications

Parasitics :

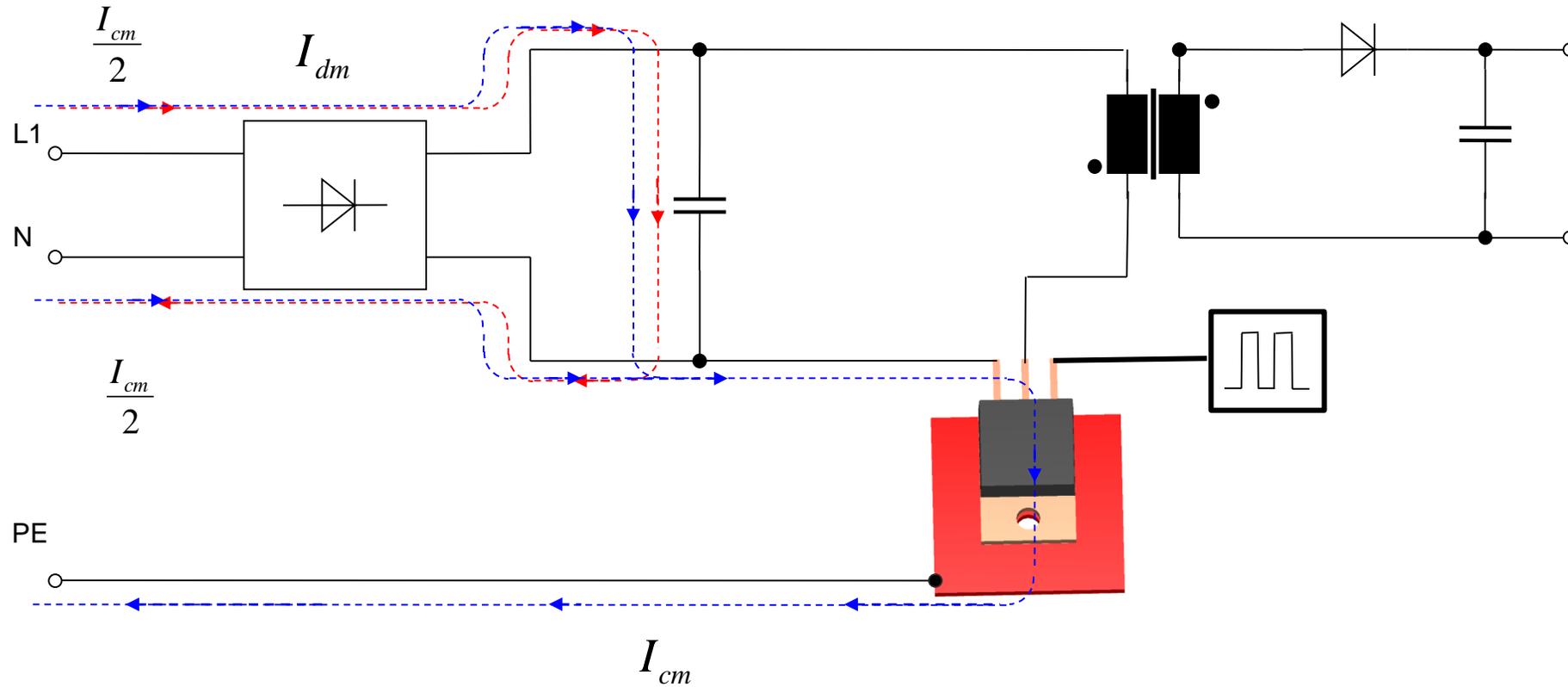
- Mosfet Tab parasitic coupling
- Transformer leakage inductance
- Interwinding capacitance



Real life examples

Flyback converter for lighting applications

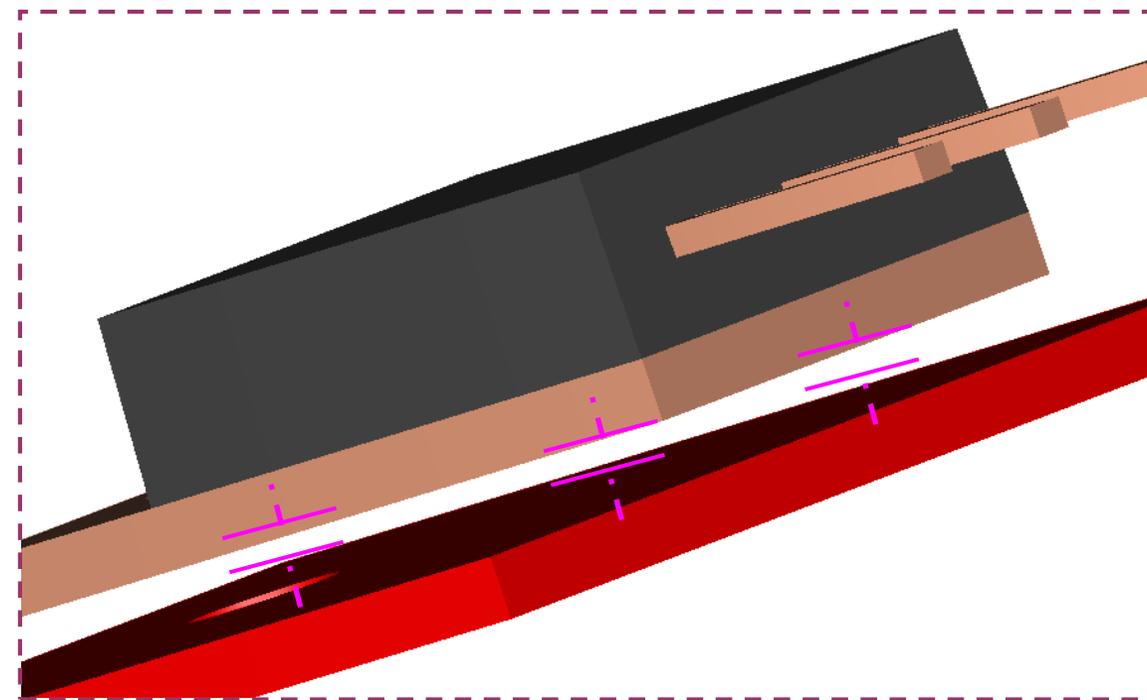
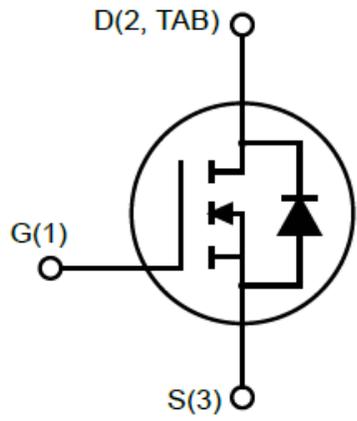
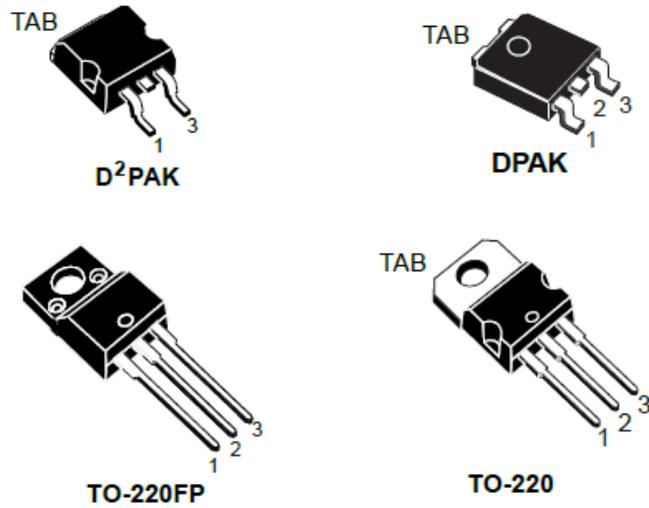
Mosfet Tab parasitic coupling



Real life examples

Flyback converter for lighting applications

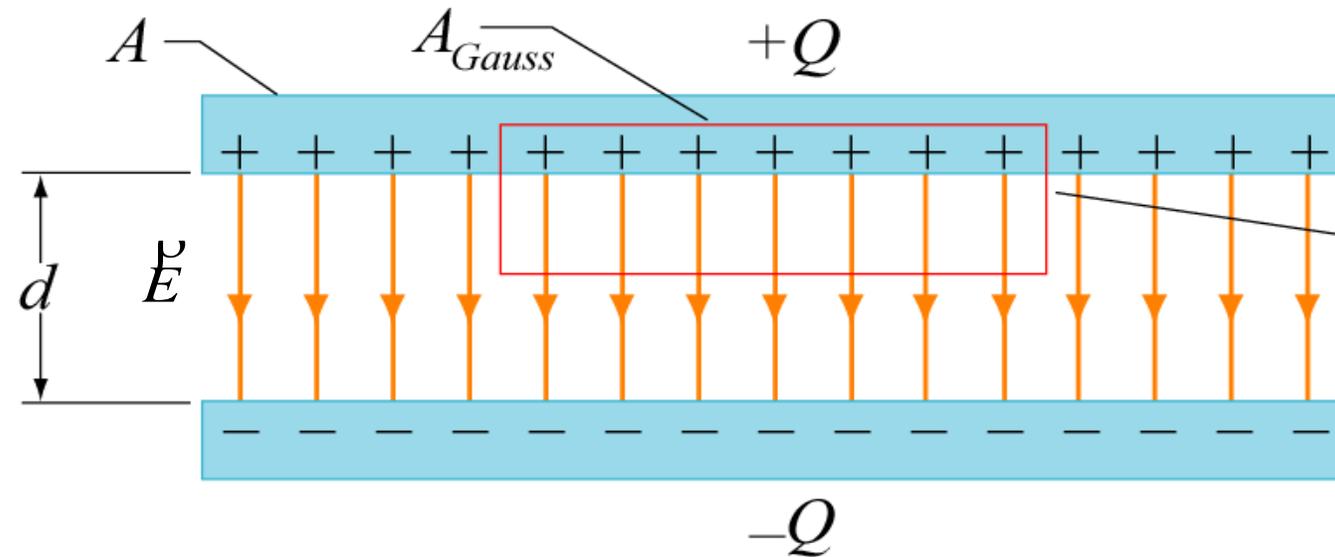
Mosfet Tab parasitic coupling



Real life examples

Flyback converter for lighting applications

Mosfet Tab parasitic coupling



$$C = \frac{\epsilon_0 A}{d}$$

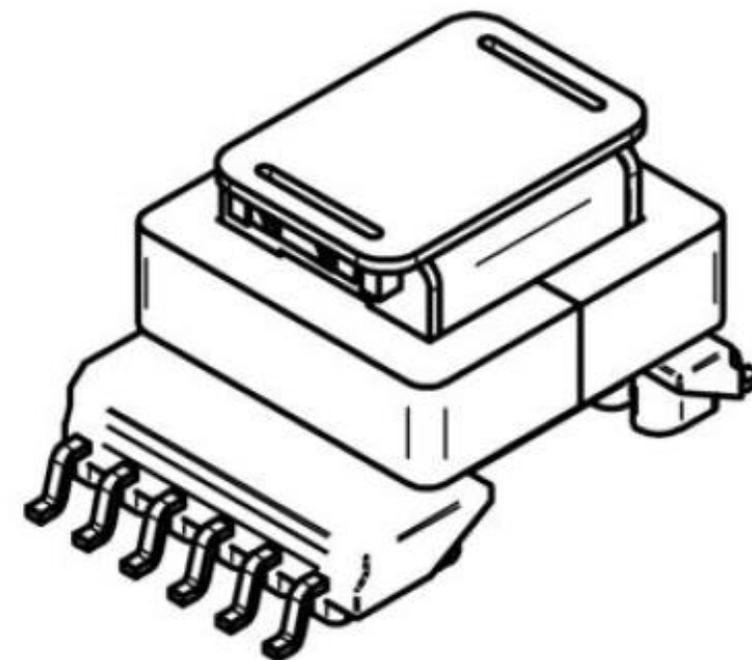
Real life examples

Flyback converter for lighting applications

Primary leakage inductance

D Electrical Properties:

Properties	Test conditions		Value	Unit	Tol.
Inductance	100 kHz/ 100 mV	L	1310	μH	$\pm 10\%$
Turns ratio		n	140 : 6 : 6 : 16		$\pm 3\%$
Saturation current	$ \Delta L/L < 20\%$	I_{sat}	0.8	A	typ.
DC Resistance 1	@ 20°C	R_{DC1}	3000.0	$\text{m}\Omega$	max.
DC Resistance 2	@ 20°C	R_{DC2}	25.0	$\text{m}\Omega$	max.
DC Resistance 3	@ 20°C	R_{DC3}	25.0	$\text{m}\Omega$	max.
DC Resistance 4	@ 20°C	R_{DC4}	450.0	$\text{m}\Omega$	max.
Leakage inductance	100 kHz/ 100 mV	L_{S}	40.0	μH	max.
Insulation test voltage	W1,4 => W2,3	U_{T}	4000	V (AC)	



WE-UOST

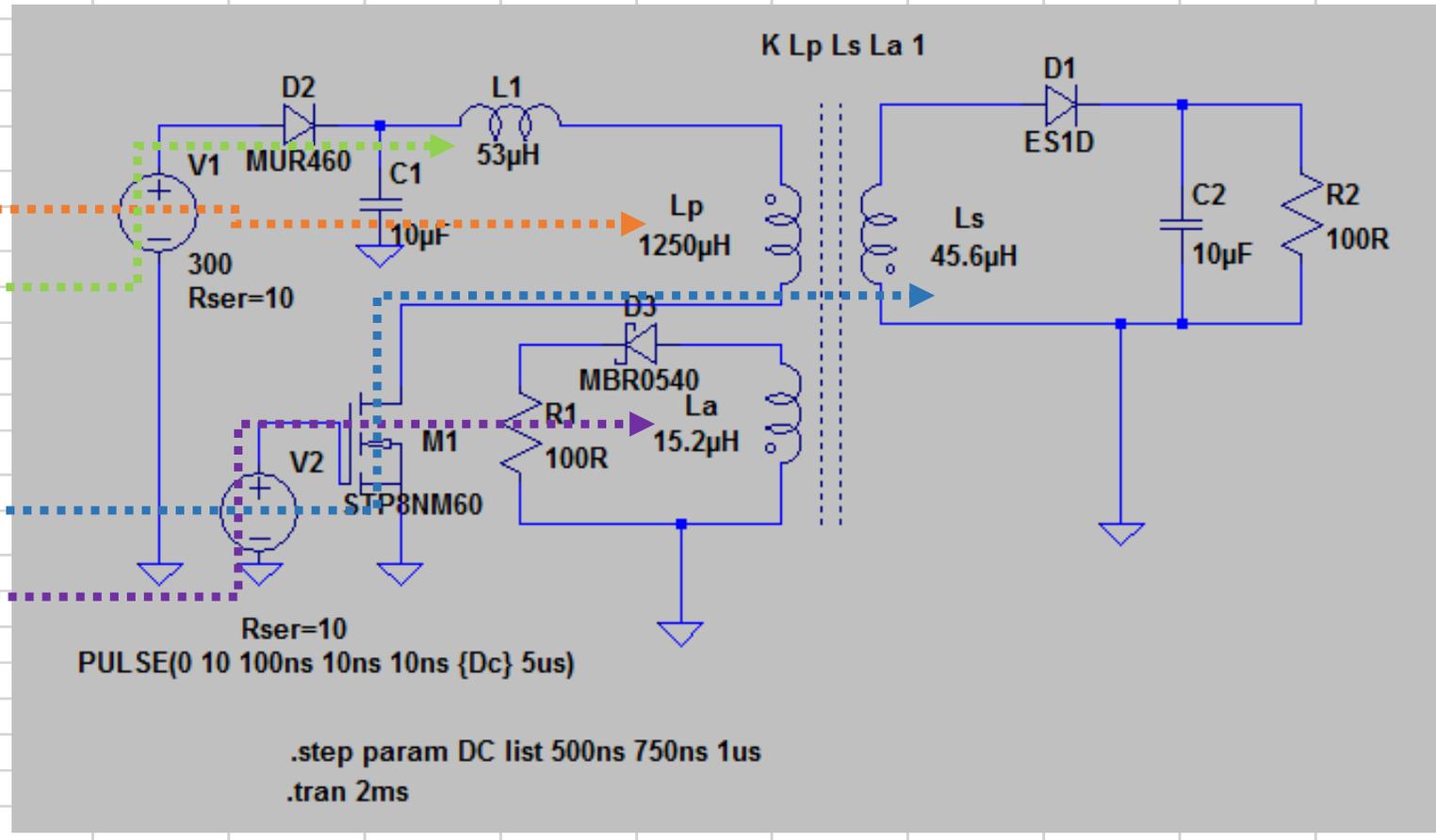
Real life examples

Turn ratio to inductance ?

Transformers : from datasheet to LTSpice model

Primary inductance			
			1310 μH
			Lp
Leakage inductance			
			50 μH
			L1
Secondary inductance			
			2.79 μH
			Ls
Auxiliary inductance			
			19.84 μH
			La

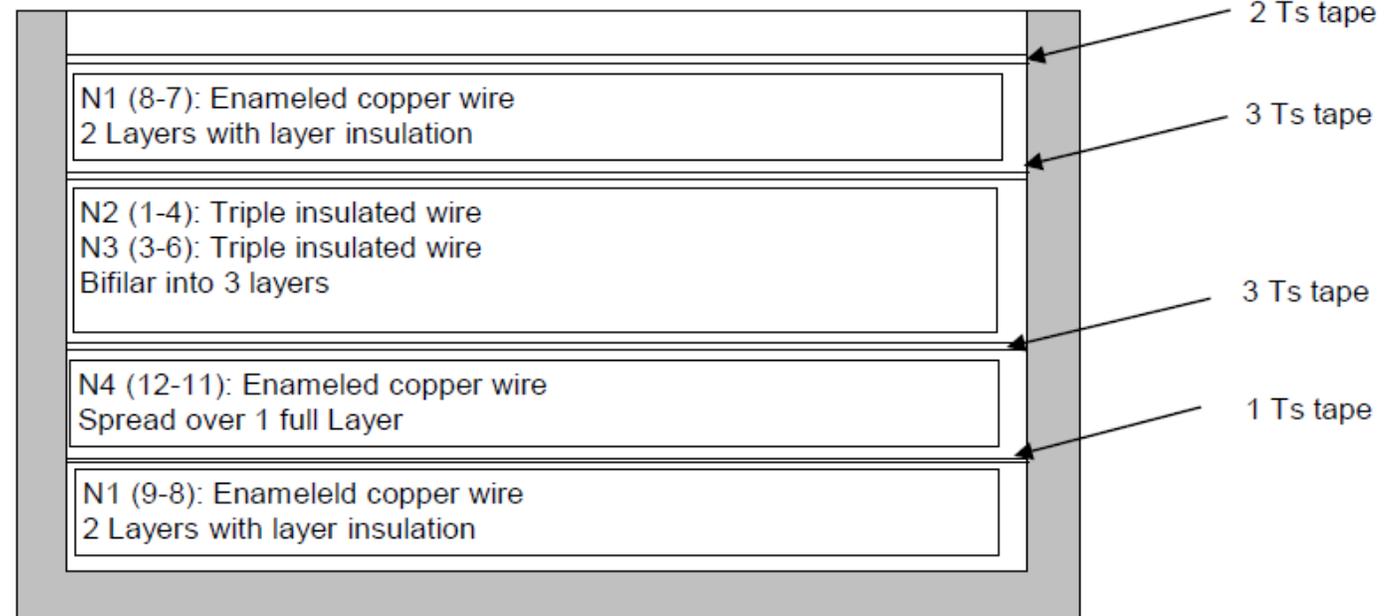
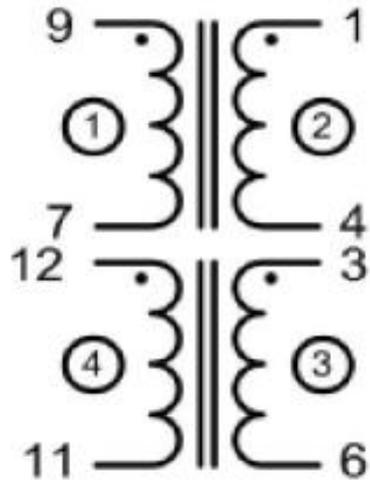
Ratio	Primary	Secondary	Aux
	130	6	16



Real life examples

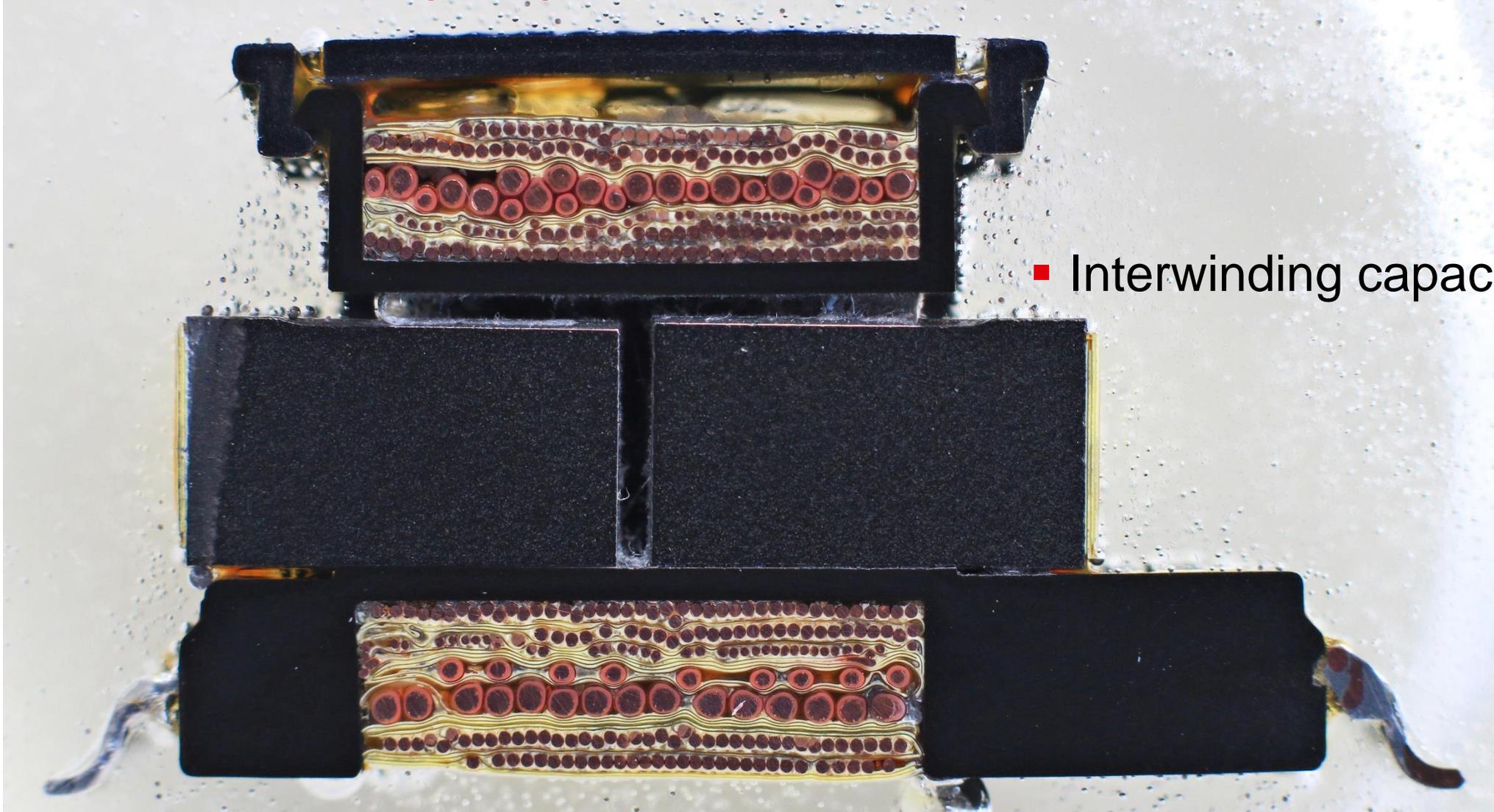
Flyback converter for lighting applications

- Interwinding capacitance ?



Real life examples

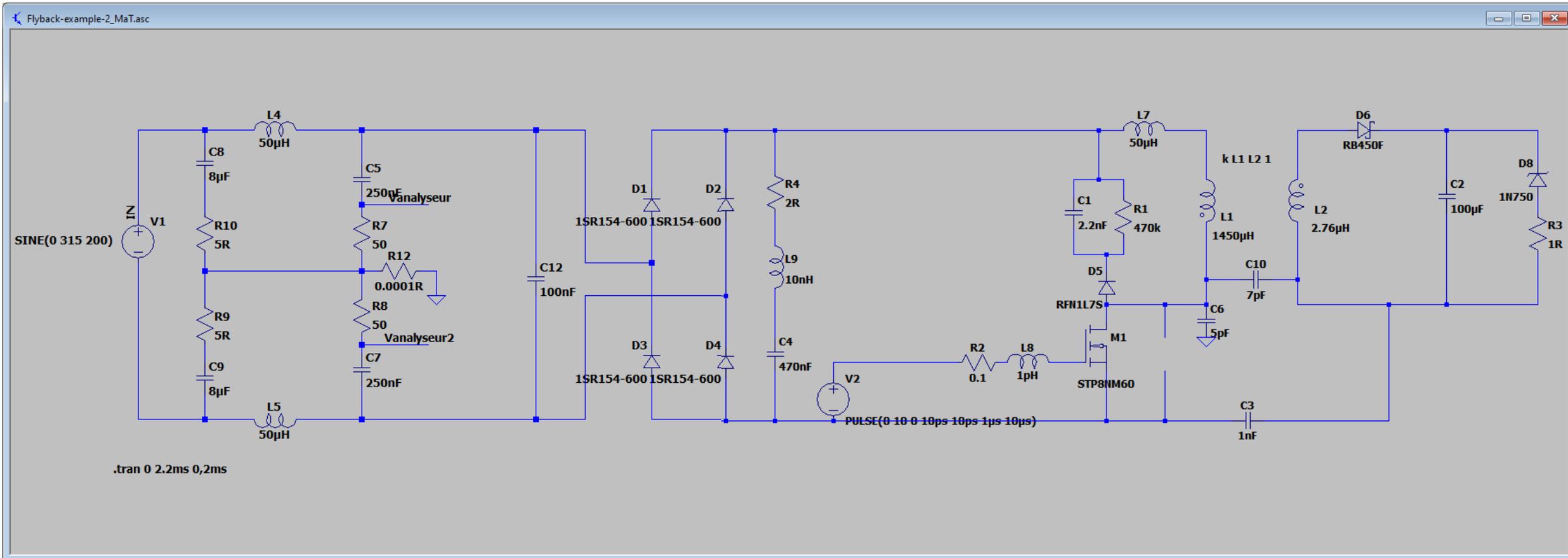
Flyback converter for lighting applications



- Interwinding capacitance ?

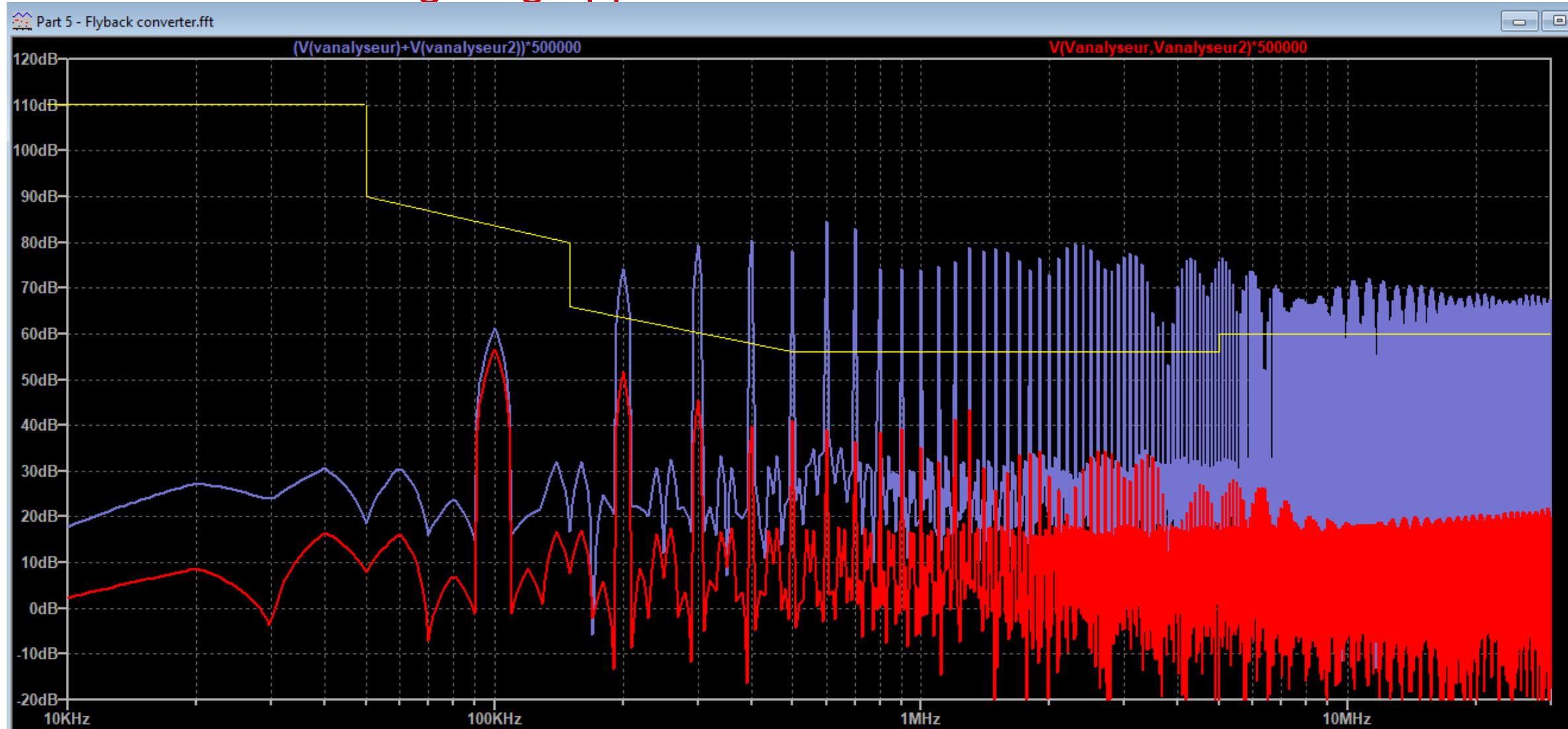
Real life examples

Flyback converter for lighting applications



Real life examples

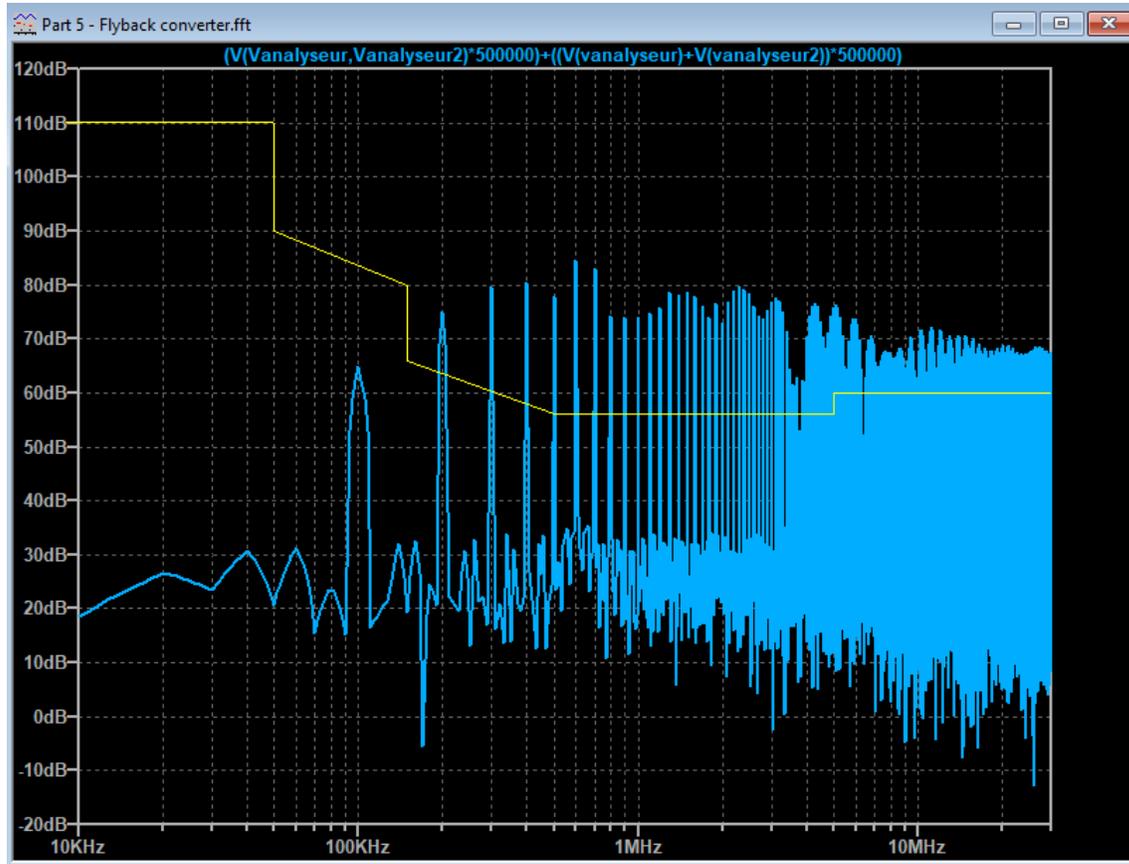
Flyback converter for lighting applications



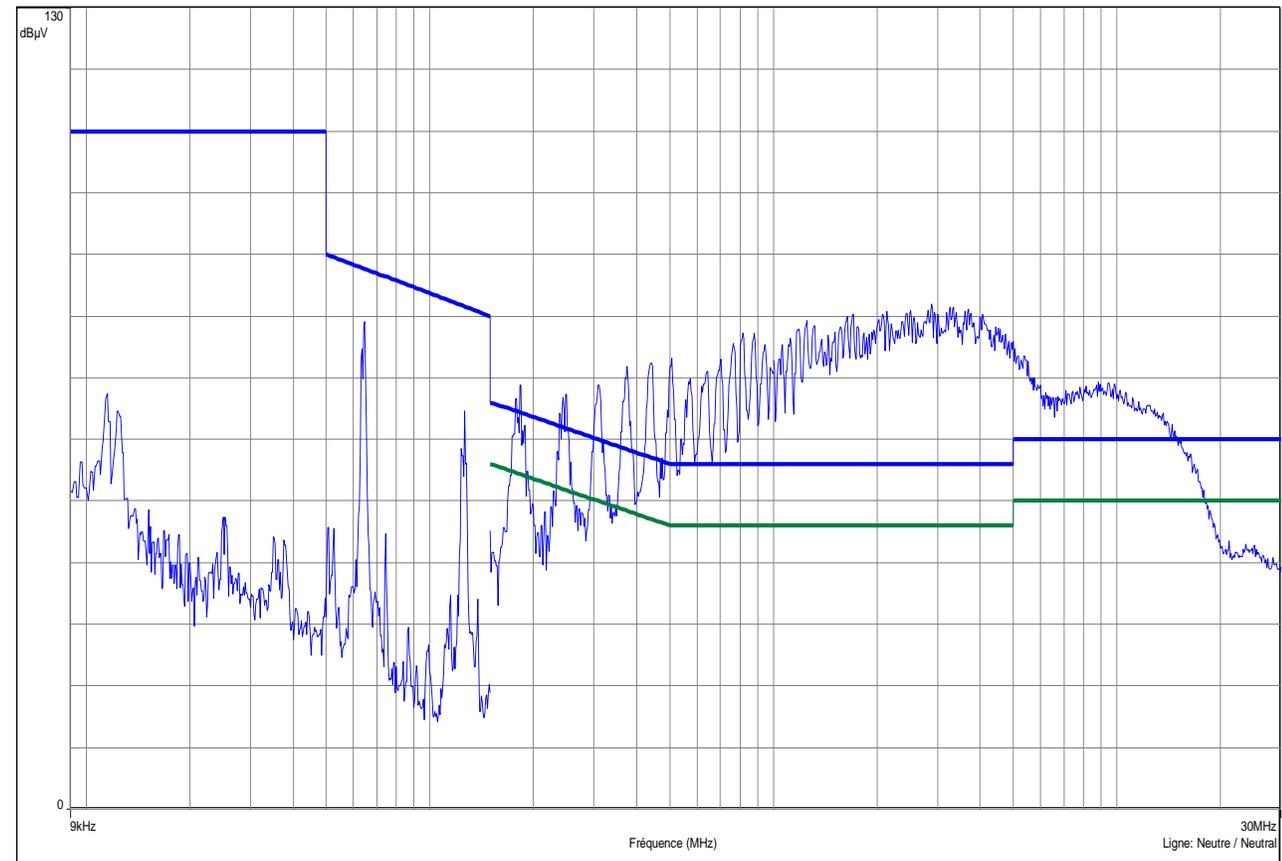
Real life examples

Flyback converter for lighting applications

Simulation



Example of actual measurement



Real life examples

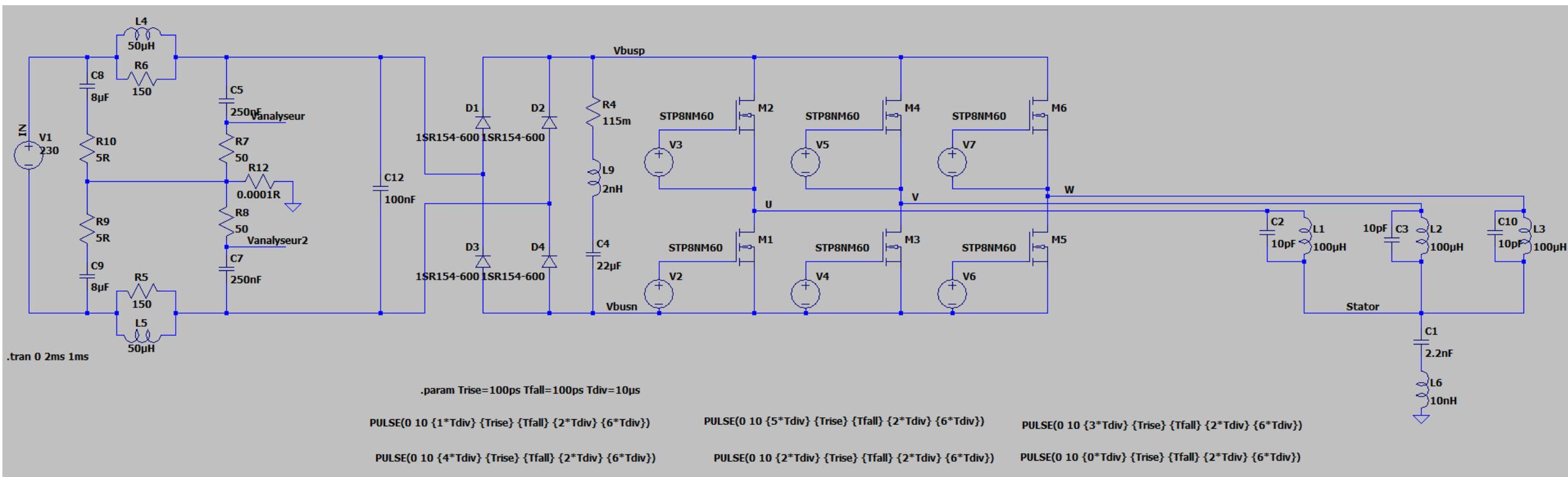
Mains voltage BLDC driver + motor



Real life examples

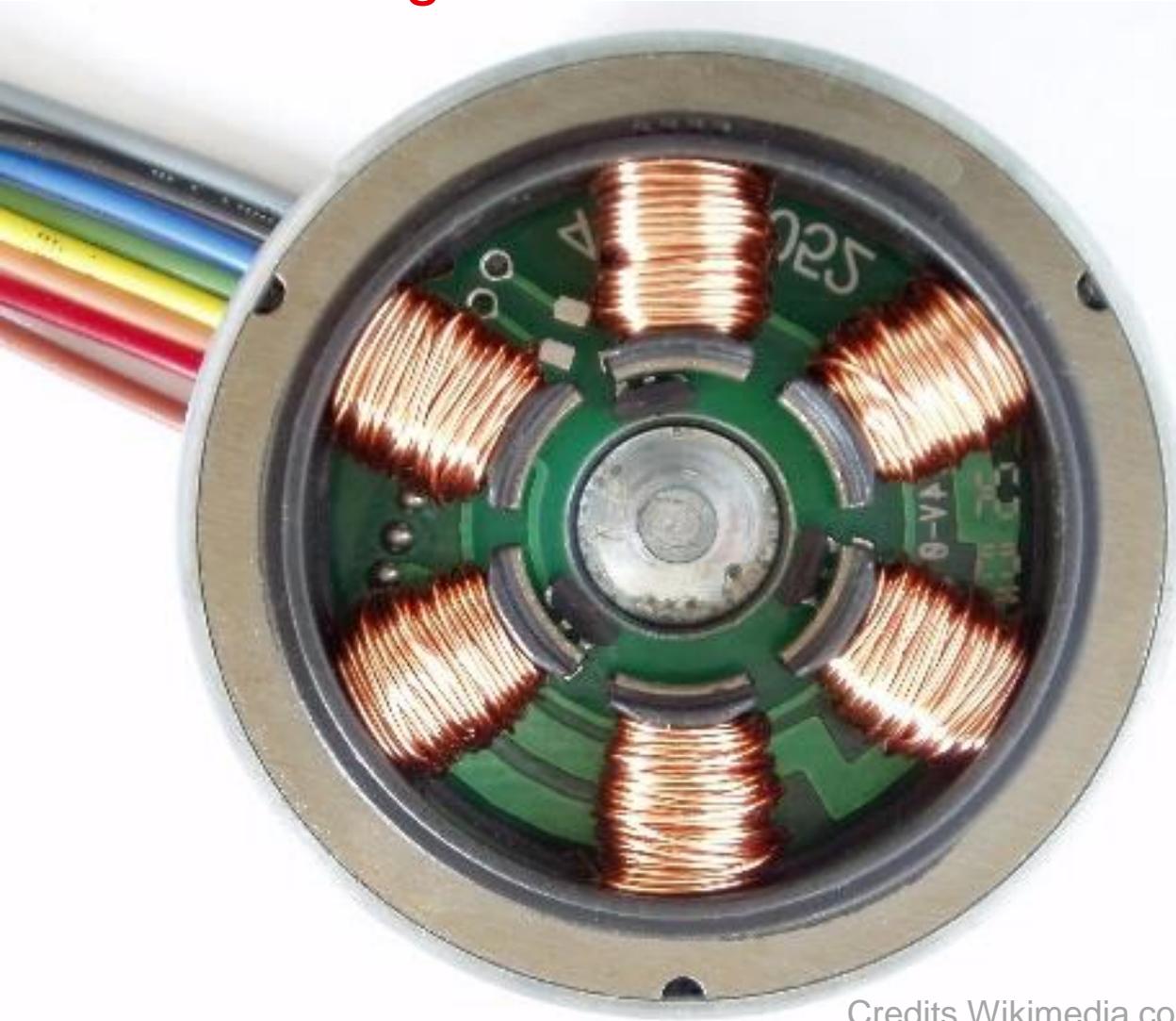
Mains voltage BLDC driver + motor

- Parasitic coupling to and through stator
- Influence of grounding
- Slew rate of driver
- Dead time impact



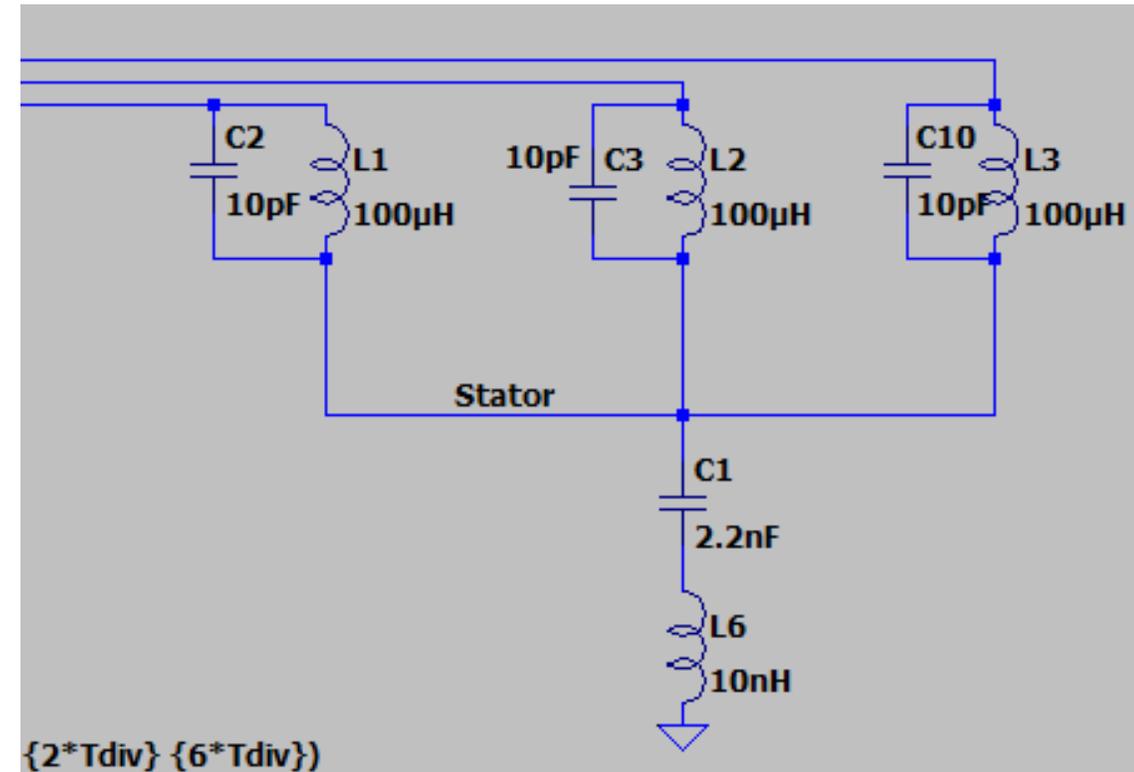
Real life examples

Mains voltage BLDC driver + motor



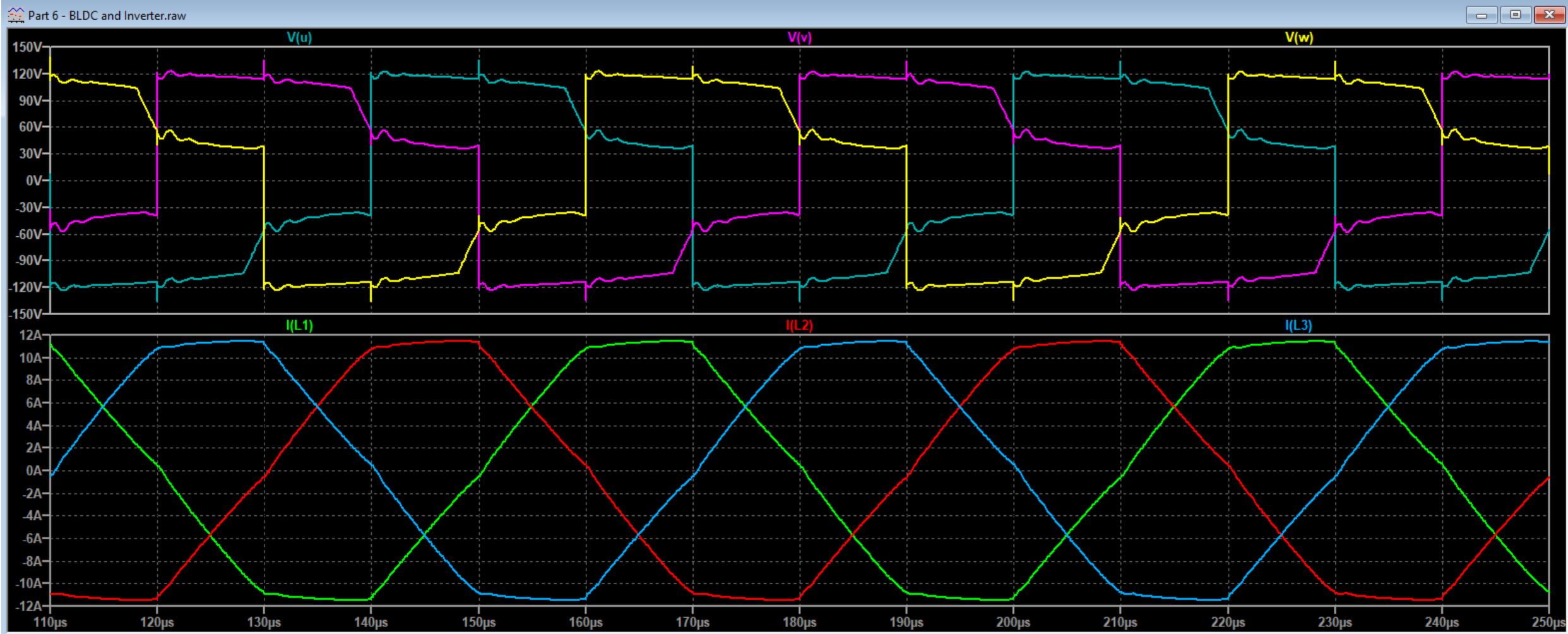
Credits Wikimedia commons {2*Tdiv} {6*Tdiv}}

- Parasitic coupling to and through stator
- Influence of grounding (of stator)



Real life examples

Mains voltage BLDC driver + motor



Real life examples

Mains voltage BLDC driver + motor

- Parametric simulation

`.param Trise=100ps Tfall=100ps Tdiv=10µs`

- `.STEP` is possible to see impact of slew rate and dead time on EMC signature

Independent Voltage Source - V3

Functions

(none)
 PULSE(V1 V2 Tdelay Trise Tfall Ton Period Ncycles)
 SINE(Voffset Vamp Freq Td Theta Phi Ncycles)
 EXP(V1 V2 Td1 Tau1 Td2 Tau2)
 SFFM(Voff Vamp Fcar MDI Fsig)
 PWL(t1 v1 t2 v2...)
 PWL FILE: Browse

DC Value

DC value:

Make this information visible on schematic:

Small signal AC analysis(.AC)

AC Amplitude:

AC Phase:

Make this information visible on schematic:

Parasitic Properties

Series Resistance[Ω]:

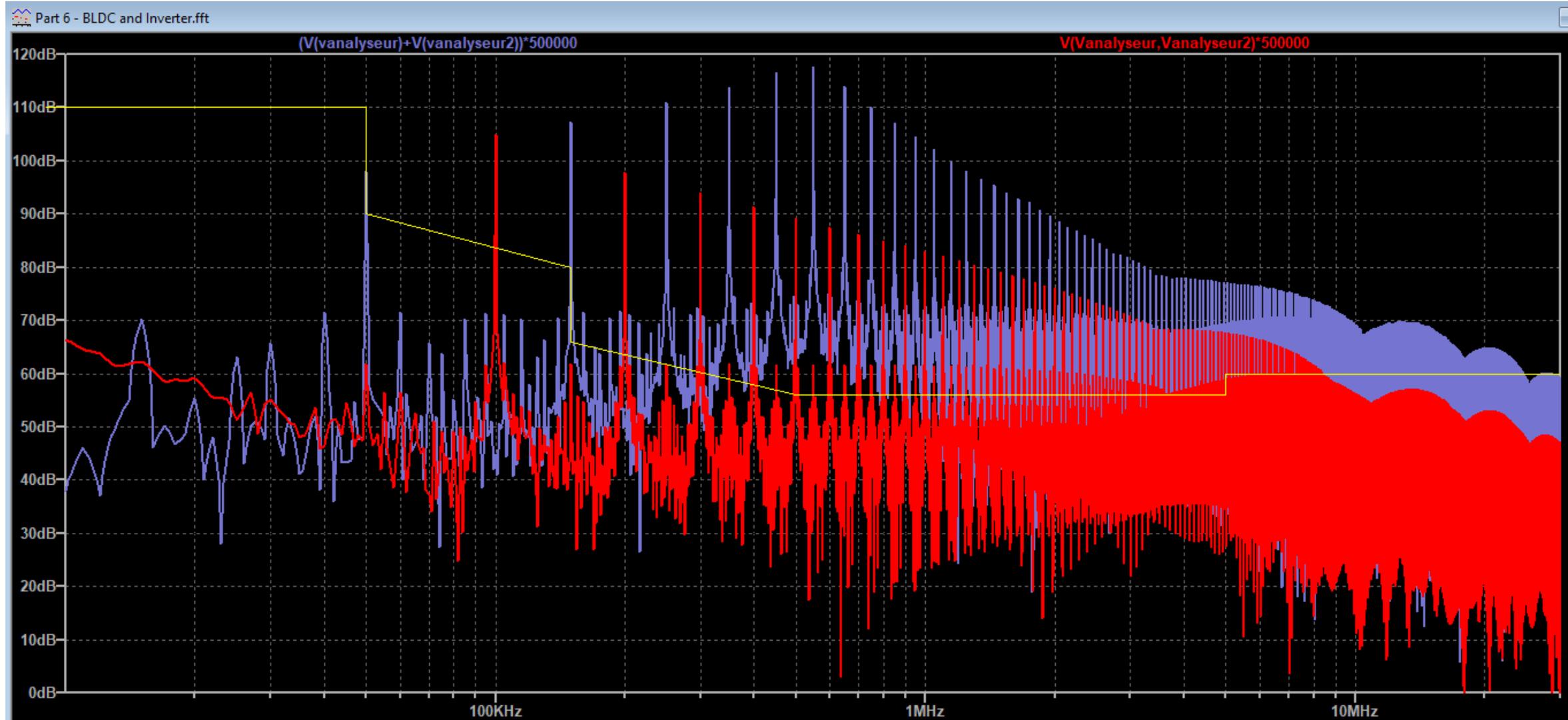
Parallel Capacitance[F]:

Make this information visible on schematic:

Vinitial[V]:	0
Von[V]:	10
Tdelay[s]:	{1*Tdiv}
Trise[s]:	{Trise}
Tfall[s]:	{Tfall}
Ton[s]:	{2*Tdiv}
Tperiod[s]:	{6*Tdiv}
Ncycles:	

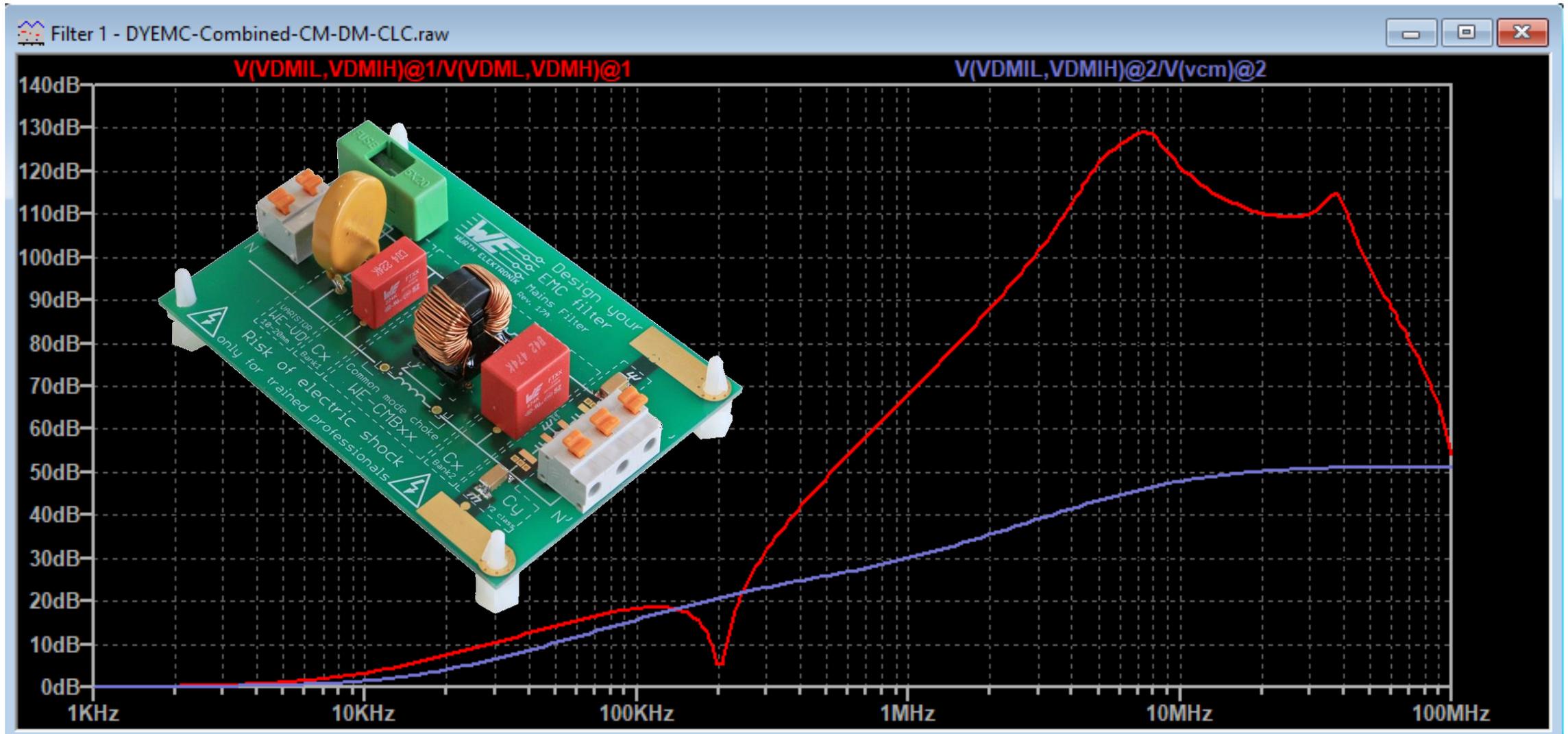
Real life examples

Mains voltage BLDC driver + motor



Evaluation of Filter Insertion losses

Design your EMC filter in LTspice



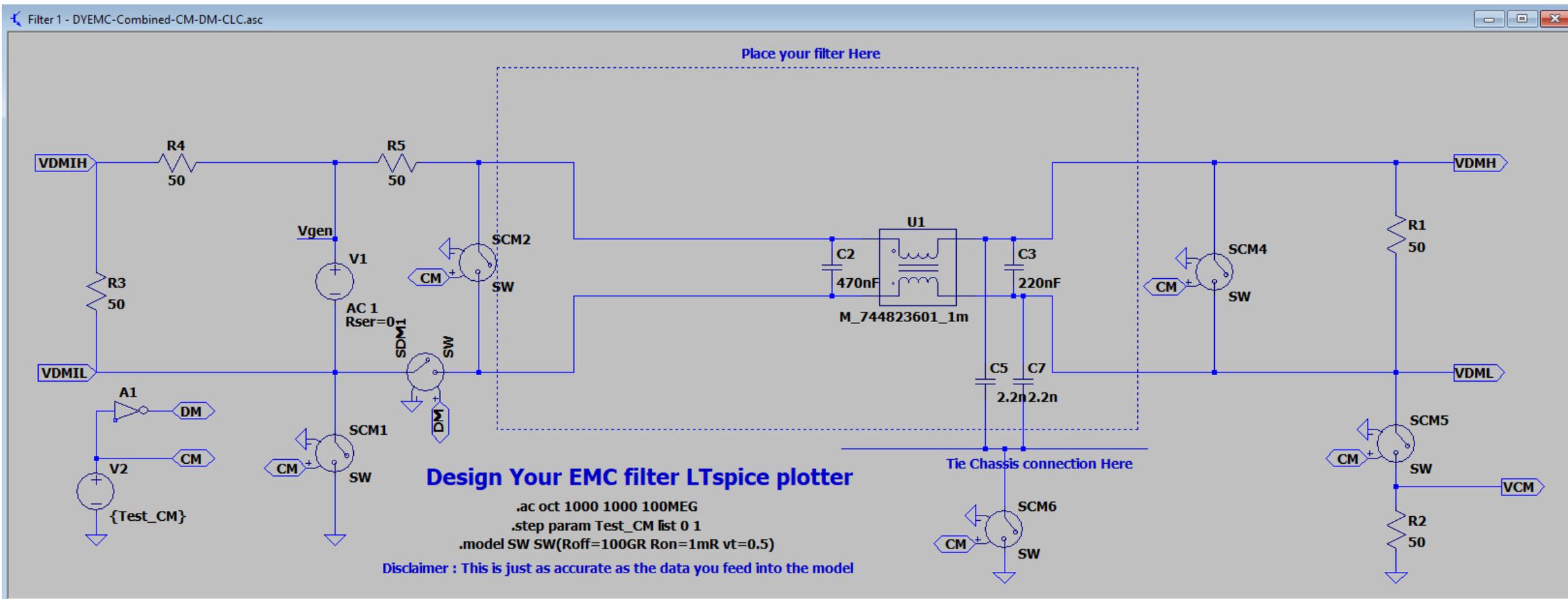
Evaluation of Filter Insertion losses

Design your EMC filter in LTspice



V(VDMIL,VDMIH)@1/V(VDML,VDMH)@1

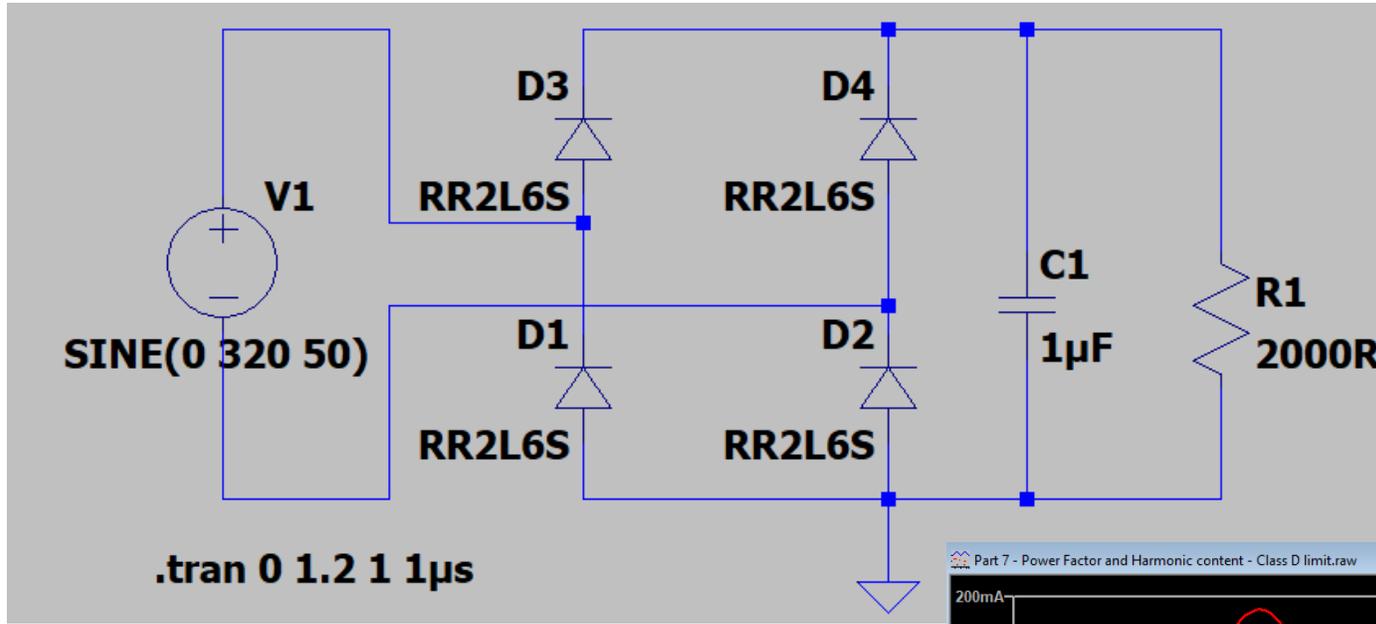
V(VDMIL,VDMIH)@2/V(vcm)@2



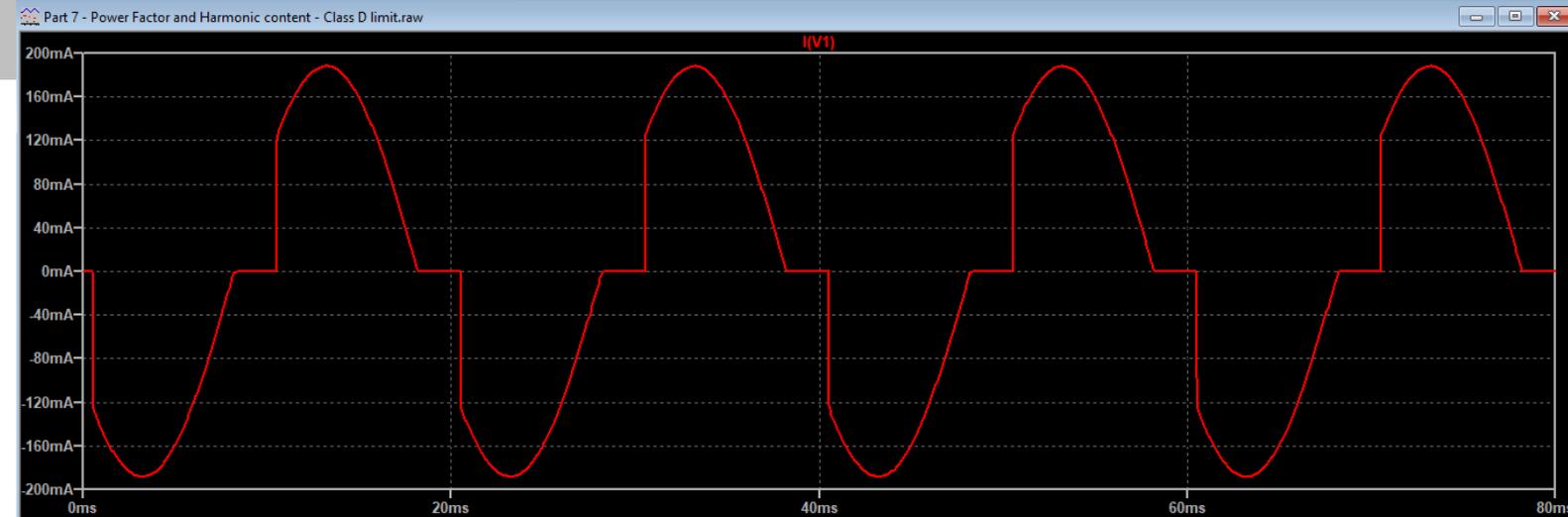


Power Factor and Harmonic current

Anticipate IEC 61000-3-2

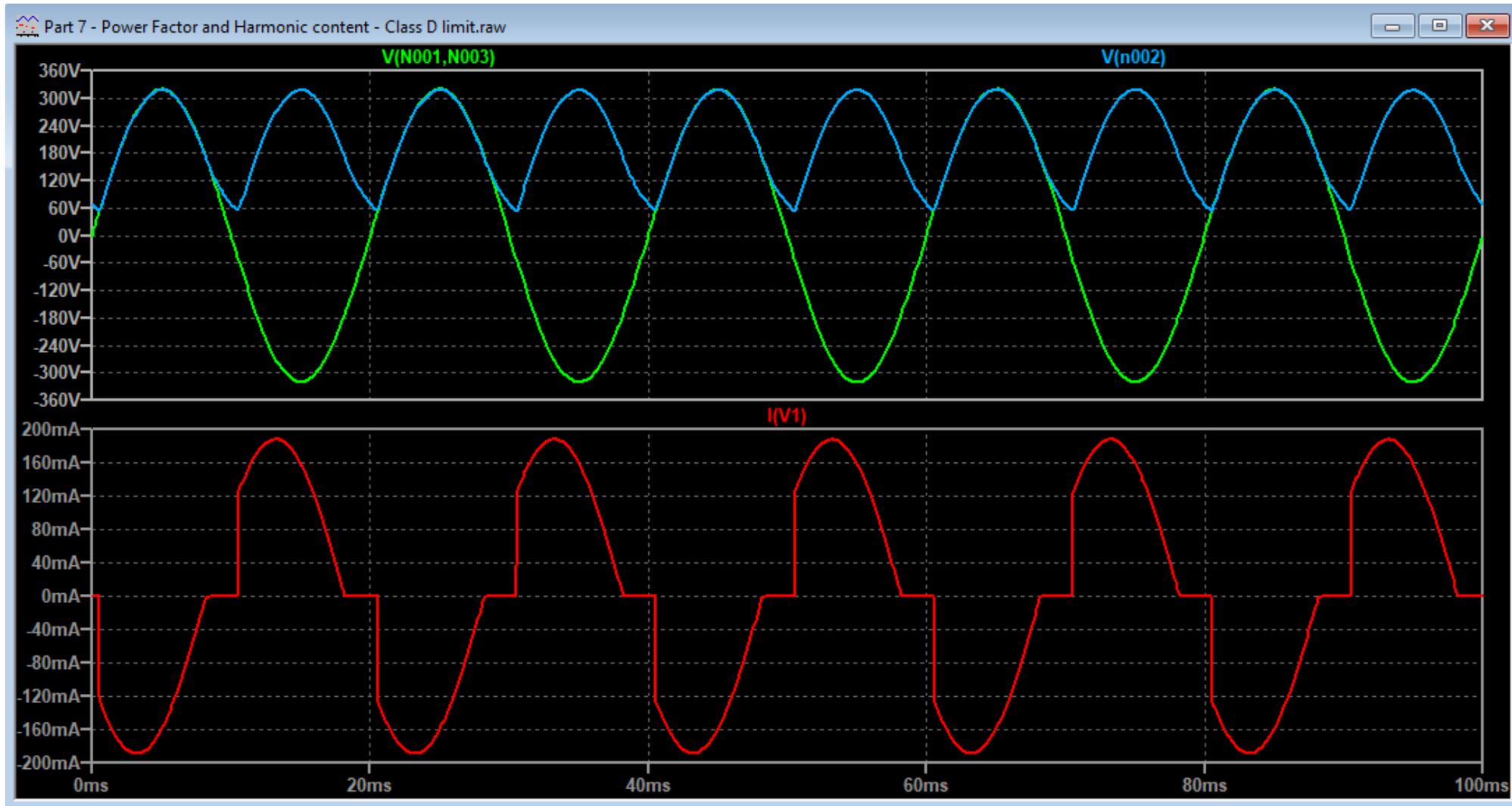


Harmonic order (n)	Maximum permissible harmonic current per watt (mA/W)
3	3.4
5	1.9
7	1.0
9	0.5
11	0.35
13	0.3
$15 \leq n \leq 39$ (odd harmonics only)	$3.85/n$



Power Factor and Harmonic current

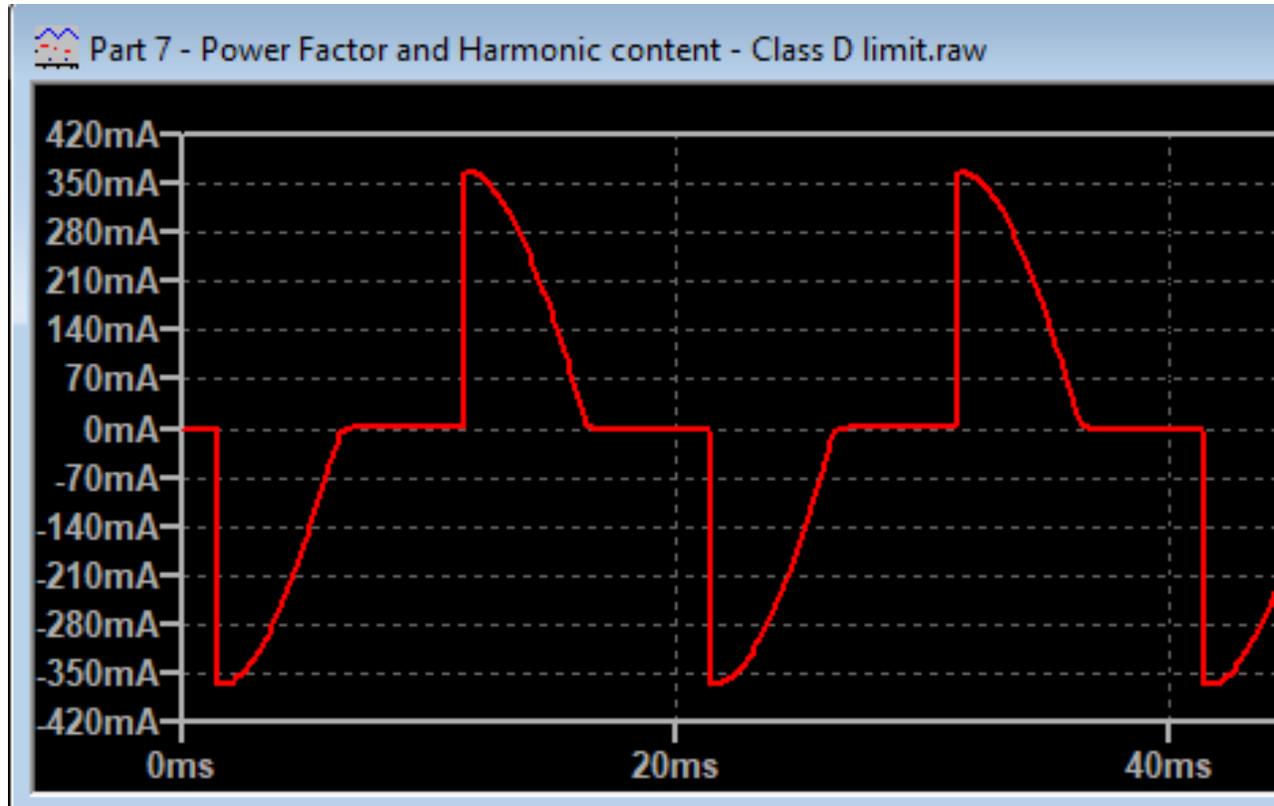
Anticipate IEC 61000-3-2



Power Factor and Harmonic current

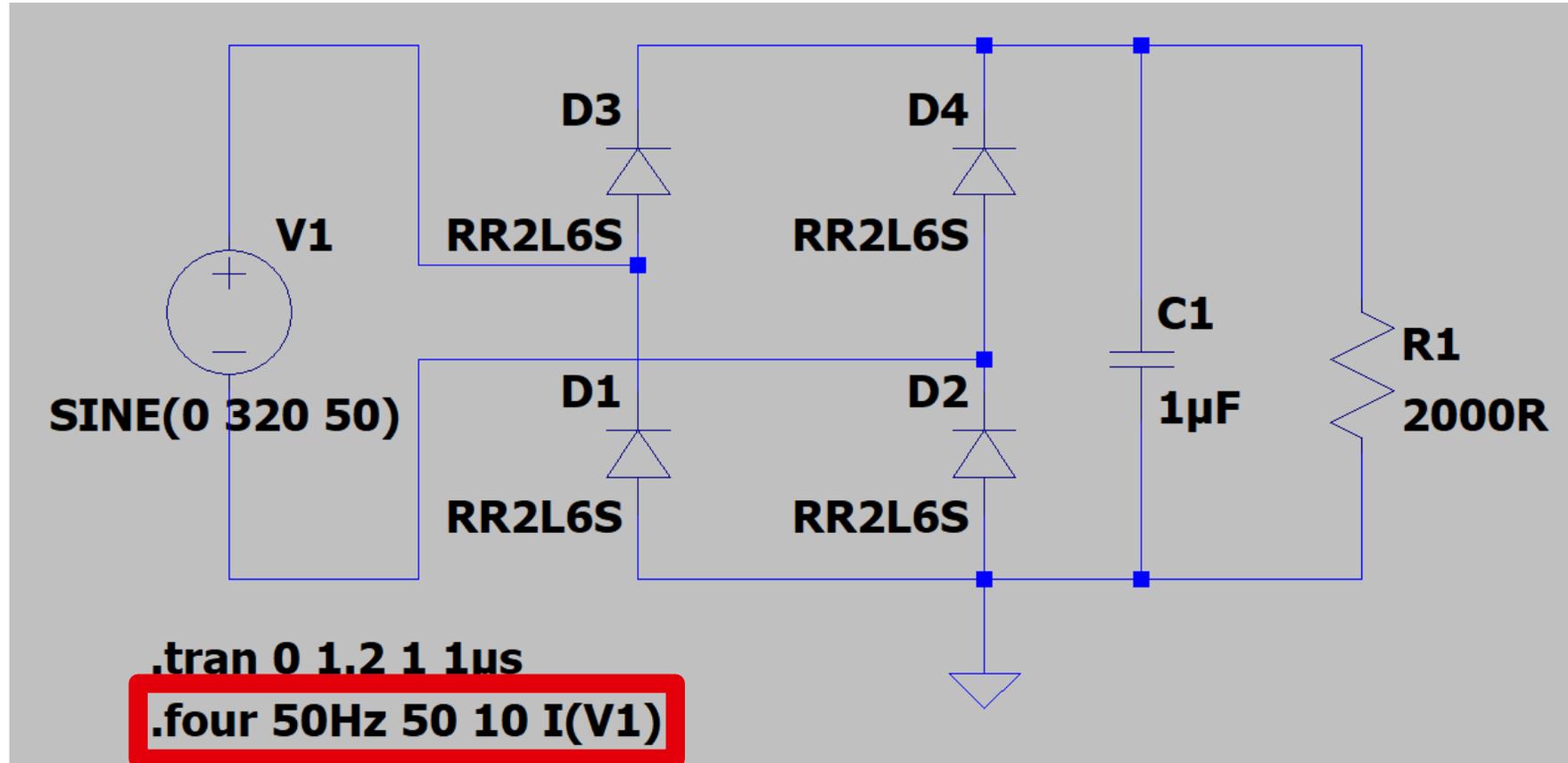
Anticipate IEC 61000-3-2

Harmonic order (n)	Maximum permissible harmonic current per watt (mA/W)
3	3.4
5	1.9
7	1.0
9	0.5
11	0.35
13	0.3
$15 \leq n \leq 39$ (odd harmonics only)	$3.85/n$



Power Factor and Harmonic current

.FOUR directive to Anticipate IEC 61000-3-2





Power Factor and Harmonic current

.FOUR directive to Anticipate IEC 61000-3-2

LTspice XVII - Part 7 - Power Factor and Harmonic conten

File Edit Hierarchy View Simulate Tools Window

Zoom Area Ctrl+Z
Zoom Back Ctrl+B
Zoom to Fit
Pan

Show Grid Ctrl+G
Mark Unconn. Pins 'U'
Mark Anchors 'A'

Bill of Materials
Efficiency Report

SPICE Netlist
SPICE Error Log

Visible Traces
Autorange Y-axis
Marching Waves
Set Probe Reference

SPICE Error Log: C:\Users\sylvain.lebras\Docur

Fourier components of I(v1)
DC component: 5.23172e-007

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	5.000e+01	1.760e-01	1.000e+00	-156.56°	0.00°
2	1.000e+02	3.265e-07	1.855e-06	57.75°	214.31°
3	1.500e+02	2.687e-02	1.526e-01	102.46°	259.01°
4	2.000e+02	1.123e-06	6.379e-06	2.94°	159.50°
5	2.500e+02	2.074e-02	1.178e-01	108.42°	264.98°
6	3.000e+02	2.040e-07	1.159e-06	-164.89°	-8.33°
7	3.500e+02	1.391e-02	7.904e-02	108.04°	264.59°
8	4.000e+02	9.960e-07	5.658e-06	-63.52°	93.04°
9	4.500e+02	8.532e-03	4.847e-02	93.80°	250.36°
10	5.000e+02	9.480e-07	5.386e-06	125.74°	282.30°
11	5.500e+02	6.452e-03	3.665e-02	64.05°	220.61°
12	6.000e+02	7.110e-07	4.039e-06	-101.44°	55.12°
13	6.500e+02	6.362e-03	3.614e-02	41.96°	198.52°
14	7.000e+02	1.526e-06	8.671e-06	51.93°	208.48°
15	7.500e+02	5.865e-03	3.332e-02	29.38°	185.94°
16	8.000e+02	4.225e-07	2.401e-06	-89.14°	67.42°
17	8.500e+02	4.761e-03	2.705e-02	14.64°	171.20°
18	9.000e+02	1.168e-06	6.634e-06	-50.15°	106.41°
19	9.500e+02	3.923e-03	2.229e-02	-8.40°	148.16°
20	1.000e+03	8.830e-07	5.016e-06	-105.51°	51.05°
21	1.050e+03	3.752e-03	2.131e-02	-31.96°	124.60°
22	1.100e+03	1.000e-06	5.785e-06	100.00°	25.00°
45	2.250e+03	1.732e-03	9.838e-03	98.91°	255.46°
46	2.300e+03	7.944e-07	4.513e-06	-44.86°	111.70°
47	2.350e+03	1.685e-03	9.573e-03	77.95°	234.51°
48	2.400e+03	1.657e-07	9.416e-07	-81.86°	74.69°
49	2.450e+03	1.657e-03	9.412e-03	59.24°	215.79°
50	2.500e+03	7.697e-07	4.373e-06	-107.70°	48.86°

Total Harmonic Distortion: 23.211629% (23.614123%) PF=0.893698 (0.8929)

Ampera Fraction of fundamental

Fourier Component	Normalized Component
1.760e-01	1.000e+00
3.265e-07	1.855e-06
2.687e-02	1.526e-01
1.123e-06	6.379e-06
2.074e-02	1.178e-01
2.040e-07	1.159e-06
1.391e-02	7.904e-02
9.960e-07	5.658e-06
8.532e-03	4.847e-02
9.480e-07	5.386e-06
6.452e-03	3.665e-02
7.110e-07	4.039e-06
6.362e-03	3.614e-02
1.526e-06	8.671e-06
5.865e-03	3.332e-02
4.225e-07	2.401e-06
4.761e-03	2.705e-02
1.168e-06	6.634e-06
3.923e-03	2.229e-02
8.830e-07	5.016e-06
3.752e-03	2.131e-02
1.000e-06	5.785e-06
1.732e-03	9.838e-03
7.944e-07	4.513e-06
1.685e-03	9.573e-03
1.657e-07	9.416e-07
1.657e-03	9.412e-03
7.697e-07	4.373e-06

monic content - Class D limit.log

Phase [degree]	Normalized Phase [deg]
-156.56°	0.00°
57.75°	214.31°
102.46°	259.01°
2.94°	159.50°
108.42°	264.98°
-164.89°	-8.33°
108.04°	264.59°
-63.52°	93.04°
93.80°	250.36°
125.74°	282.30°
64.05°	220.61°
-101.44°	55.12°
41.96°	198.52°
51.93°	208.48°
29.38°	185.94°
-89.14°	67.42°
14.64°	171.20°
-50.15°	106.41°
-8.40°	148.16°
-105.51°	51.05°
-31.96°	124.60°
100.00°	25.00°
98.91°	255.46°
-44.86°	111.70°
77.95°	234.51°
-81.86°	74.69°
59.24°	215.79°
-107.70°	48.86°

Power Factor and Harmonic current

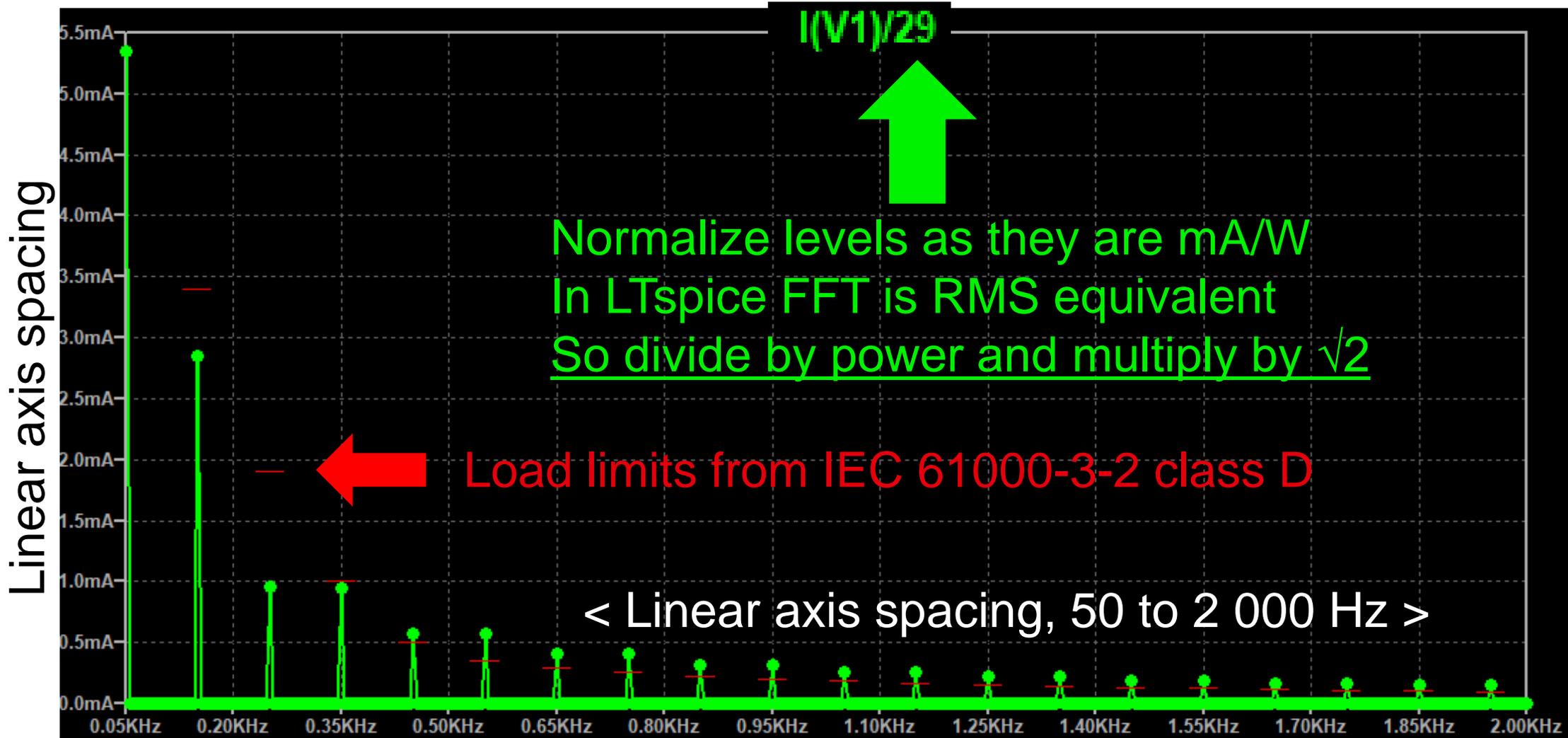
Graphical method to anticipate IEC 61000-3-2



IEC 61000-3-2 Class D - LTSpice limit line calculator						
in 50Hz base		Start Freq	End Freq	mA/W start	Line def for LTSPICE plot settings file	
Line	3	130	170	3.4	Line: "A" 4 0	(130,0.0034) (170,0.0034)
Line	5	230	270	1.9	Line: "A" 4 0	(230,0.0019) (270,0.0019)
Line	7	330	370	1	Line: "A" 4 0	(330,0.001) (370,0.001)
Line	9	430	470	0.5	Line: "A" 4 0	(430,0.0005) (470,0.0005)
Line	11	530	570	0.35	Line: "A" 4 0	(530,0.00035) (570,0.00035)
Line	13	630	670	0.296153846	Line: "A" 4 0	(630,0.000296153846153846) (670,0.000296153846153846)
Line	15	730	770	0.256666667	Line: "A" 4 0	(730,0.000256666666666667) (770,0.000256666666666667)
Line	17	830	870	0.226470588	Line: "A" 4 0	(830,0.000226470588235294) (870,0.000226470588235294)
Line	19	930	970	0.202631579	Line: "A" 4 0	(930,0.000202631578947368) (970,0.000202631578947368)
Line	21	1030	1070	0.183333333	Line: "A" 4 0	(1030,0.000183333333333333) (1070,0.000183333333333333)
Line	23	1130	1170	0.167391304	Line: "A" 4 0	(1130,0.000167391304347826) (1170,0.000167391304347826)
Line	25	1230	1270	0.154	Line: "A" 4 0	(1230,0.000154) (1270,0.000154)
Line	27	1330	1370	0.142592593	Line: "A" 4 0	(1330,0.000142592592592593) (1370,0.000142592592592593)
Line	29	1430	1470	0.132758621	Line: "A" 4 0	(1430,0.000132758620689655) (1470,0.000132758620689655)
Line	31	1530	1570	0.124193548	Line: "A" 4 0	(1530,0.000124193548387097) (1570,0.000124193548387097)
Line	33	1630	1670	0.116666667	Line: "A" 4 0	(1630,0.000116666666666667) (1670,0.000116666666666667)
Line	35	1730	1770	0.11	Line: "A" 4 0	(1730,0.00011) (1770,0.00011)
Line	37	1830	1870	0.104054054	Line: "A" 4 0	(1830,0.000104054054054054) (1870,0.000104054054054054)
Line	39	1930	1970	0.098717949	Line: "A" 4 0	(1930,9.87179487179487E-05) (1970,9.87179487179487E-05)

Power Factor and Harmonic current

Graphical method to anticipate IEC 61000-3-2



Power Factor and Harmonic current

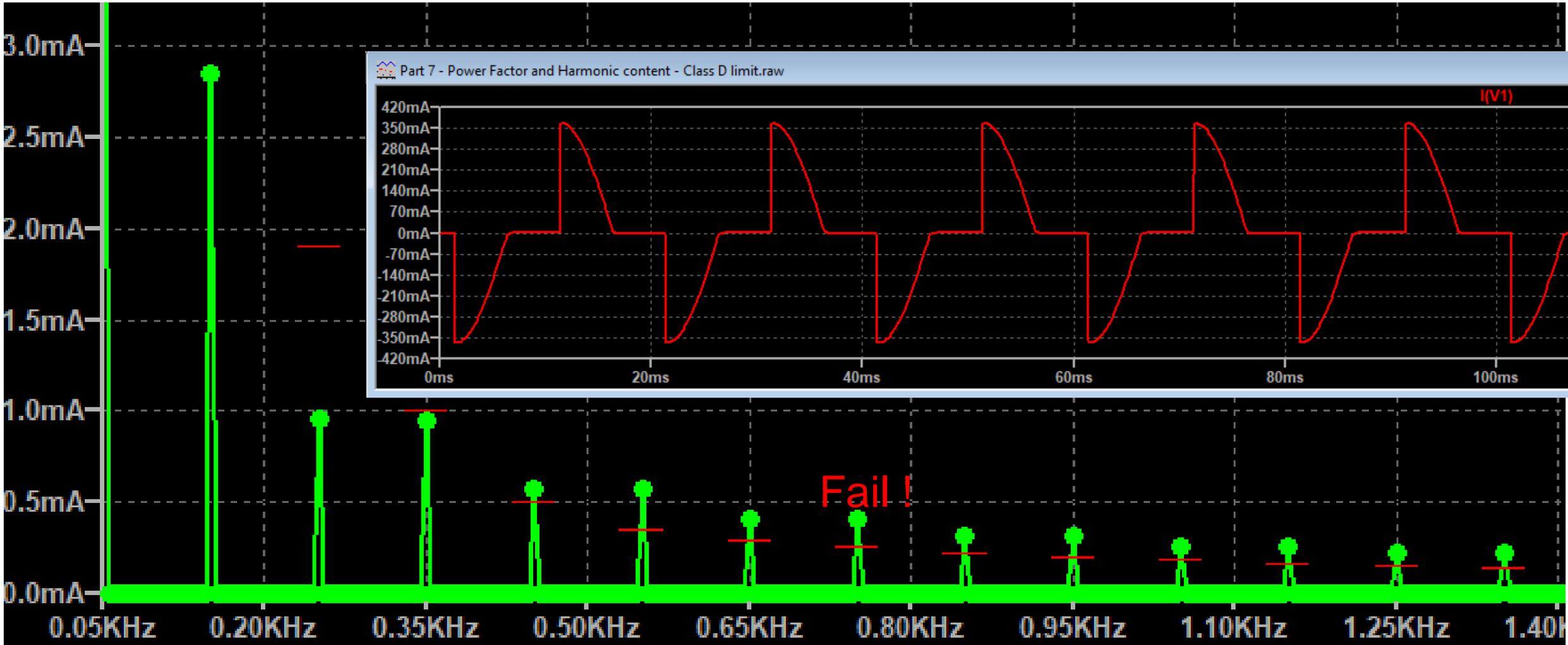
Graphical method to anticipate IEC 61000-3-2





Power Factor and Harmonic current

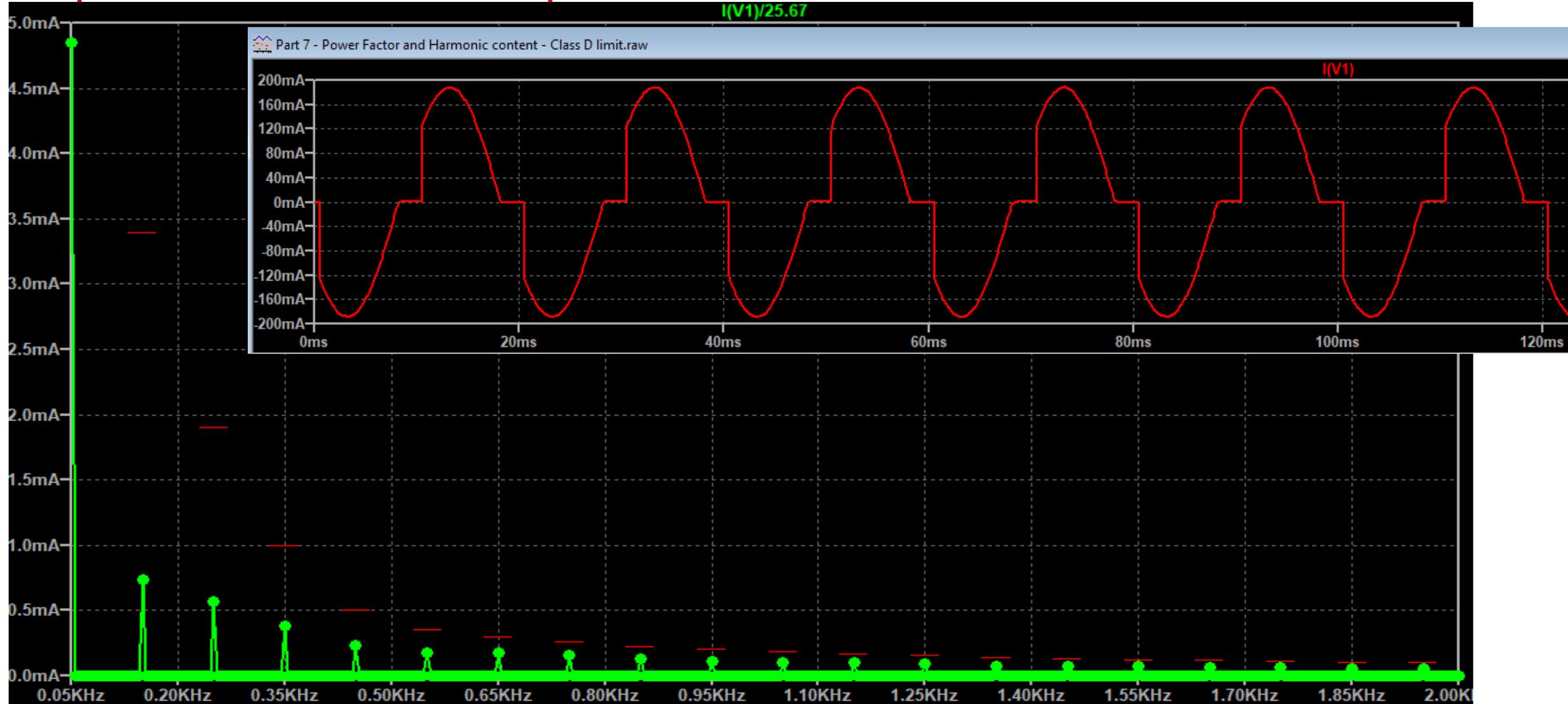
Graphical method to anticipate IEC 61000-3-2





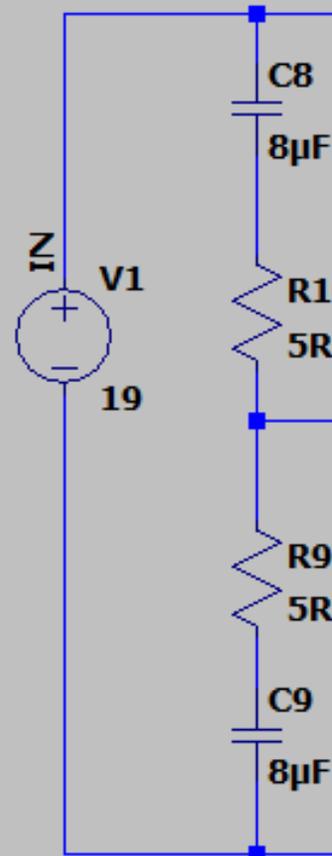
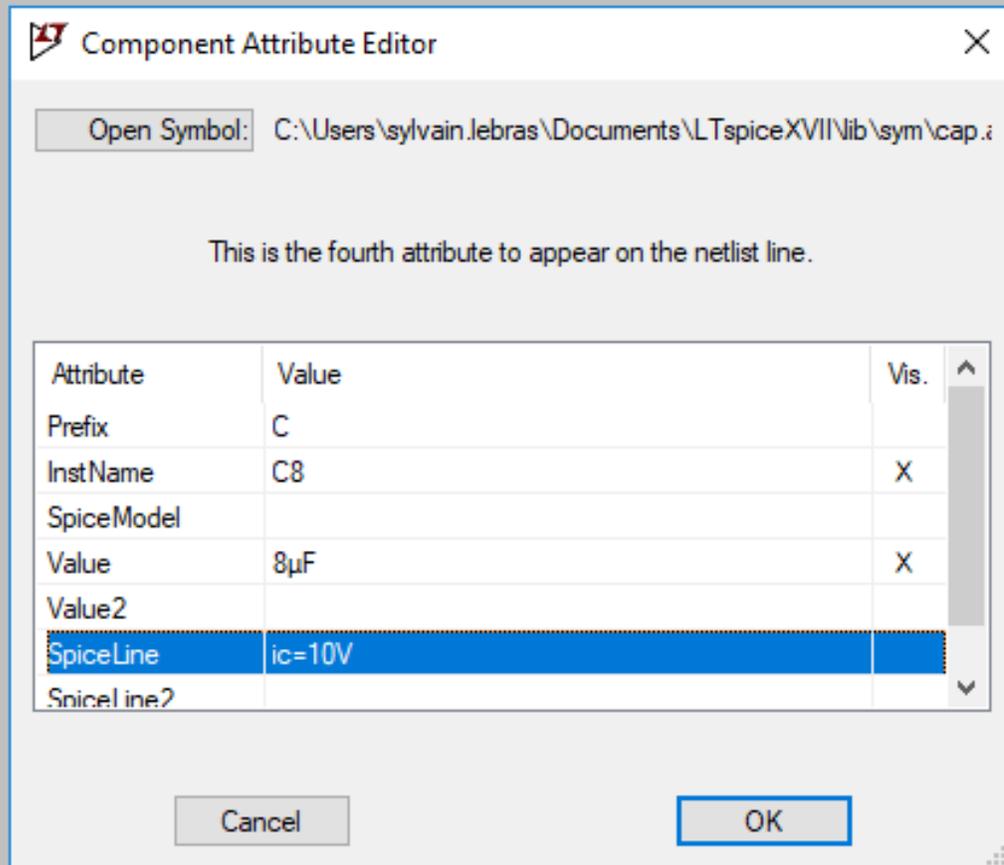
Power Factor and Harmonic current

Graphical method to anticipate IEC 61000-3-2



Good to know

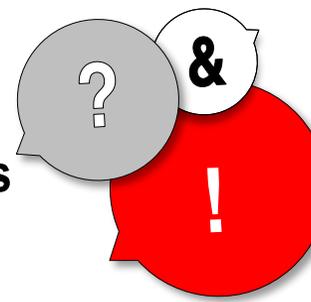
Speed up simulations



Setting initial condition

- Ctrl + Right Click
- SpiceLine
 - ic=10V

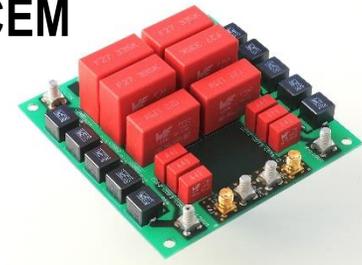
Questions & Réponses



Si vous souhaitez approfondir un des sujets ou avoir la modélisation d'un cas non traité aujourd'hui faites nous un retour nous organiserons un session de formation

Avec plus de 200 inscrits il y aura beaucoup de questions, les réponses peuvent prendre un peu de temps

Les schémas, BOM, Gerbers du matériel CEM seront rendus disponibles sur GitHub



Sylvain.LeBras@we-online.com



Vous recevrez un lien avec les fichiers utilisés pendant cette présentation

- Part 1 - Testfixture.asc
- Part 1 - Testfixture.plt
- Part 2 - Modified Testfixture - 1 output voltage.plt
- Part 2 - Modified Testfixture - 2 Breakdown.plt
- Part 2 - Modified Testfixture.asc
- Part 2 - Modified Testfixture.plt
- Part 3 - Ripple-Input-MD.asc
- Part 3 - Ripple-Input-MD-1 Time based display.plt
- Part 3 - Ripple-Input-MD-2 Frequency based display.plt
- Part 3 - Ripple-Input-MD-4 Frequency based display Breakdown.plt
- Part 4 - DM and CM of Buck - 1 FFT analysis.plt
- Part 4 - DM and CM of Buck - 2 Time based CMDM split.plt
- Part 4 - DM and CM of Buck - 3 FFT display of CMDM split.plt
- Part 4 - DM and CM of Buck.asc
- Part 4bis - DM and CM of Buck - Fixed.asc
- Part 5 - Flyback converter - 1 FFT split analysis.plt
- Part 5 - Flyback converter.asc
- Part 6 - BLDC and Inverter.asc
- Part 6 - BLDC and Inverter.log
- Part 6 - BLDC and Inverter.op.raw
- Part 7 - Power Factor and Harmonic content - Class D limit.asc
- Part 7 - Power Factor and Harmonic content - Class D limit.log
- Part 7 - Power factor and Harmonic content.plt
- Part 8 - DYEMC-Combined-CM-DM-CLC.asc
- Part 8 - DYEMC-Combined-CM-DM-CLC.plt