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WÜRTH ELEKTRONIK

2009

WURTH ELECTRONICS MIDCOM INC.

EMI Compliance Solutions & Inductive Materials

Speaker: Dean Huumala

Dean.Huumala@we-online.com

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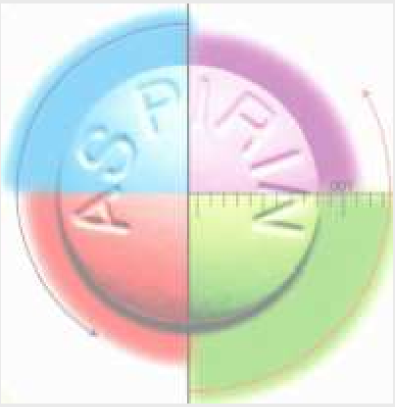
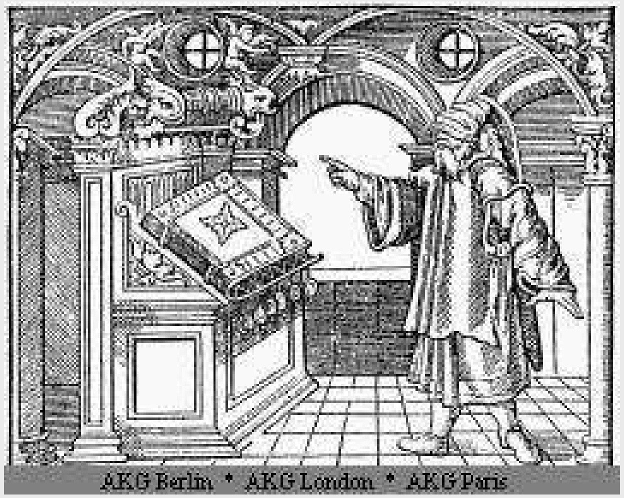
How To Control EMI?

For our customers:



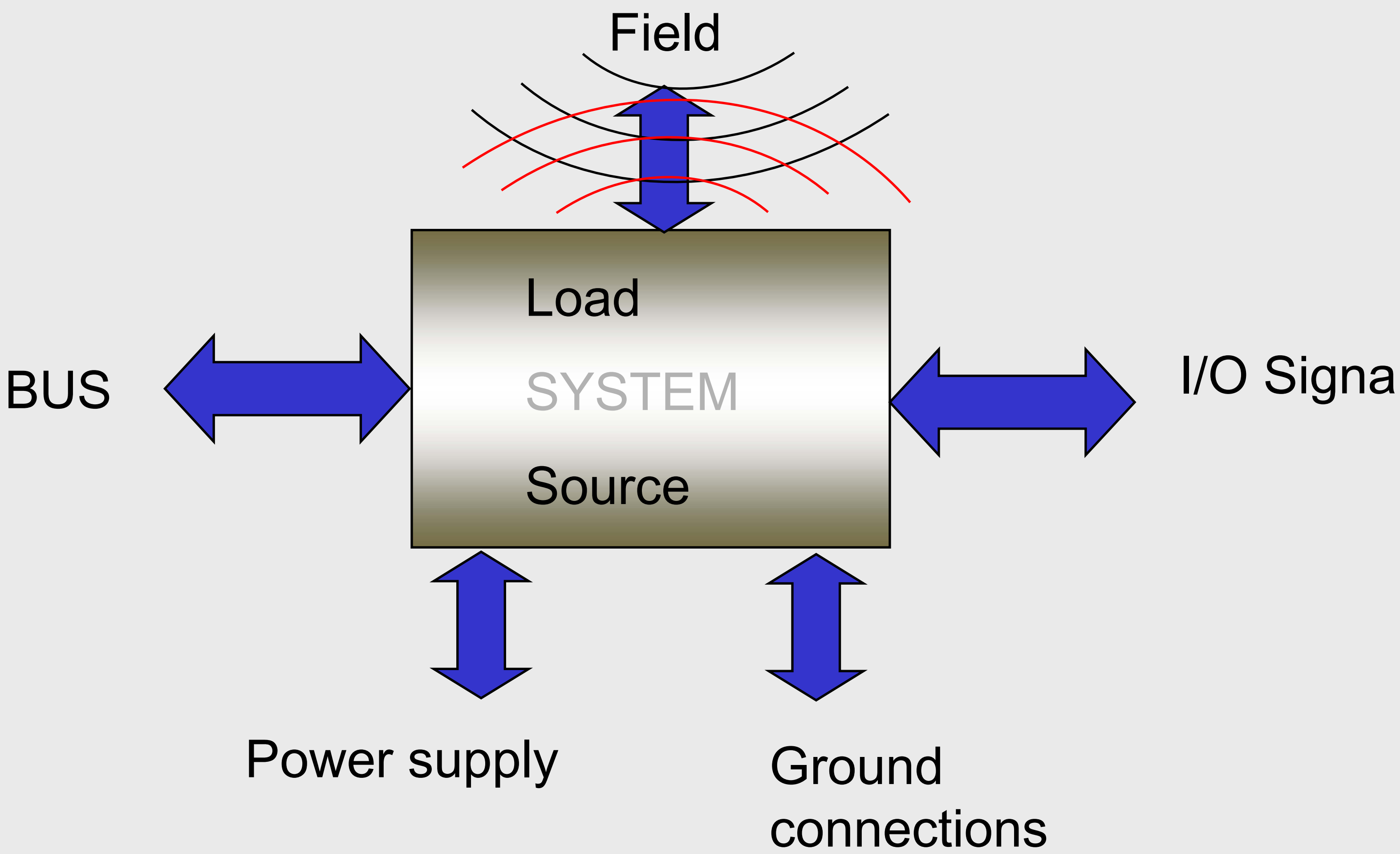
„Headache“



A mystery.........

„ like a fight: Bull (noise) and red cloth (application)“

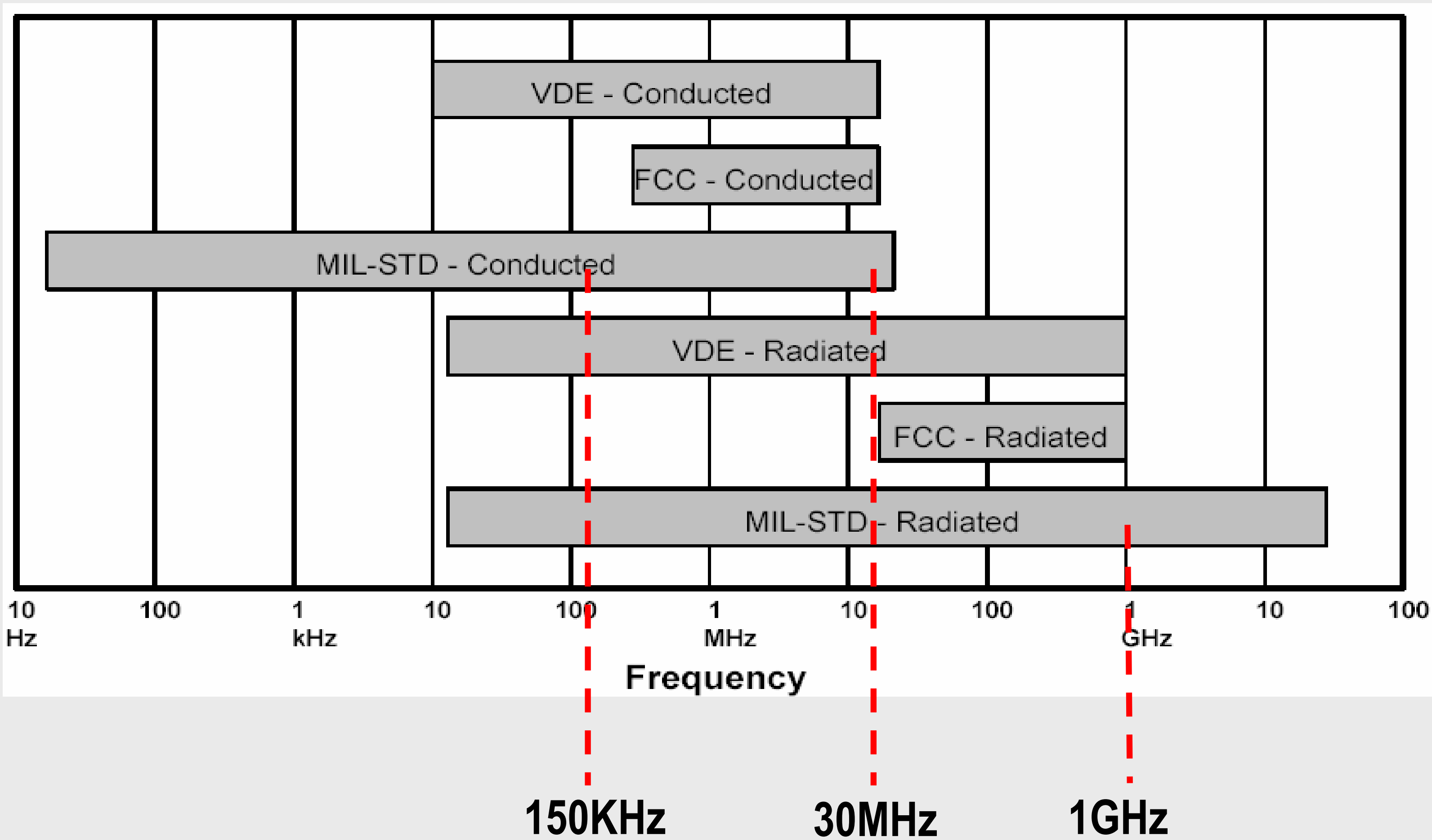
Interference - Transmitter / Receiver



Interference Characteristics

Symmetrical	Asymmetrical	Field
conducted noise	coupled noise	radiated noise
Powder–, rod core chokes	CM– chokes	EMI ferrites, shielding

Interference - Frequency Range for EMI Tests



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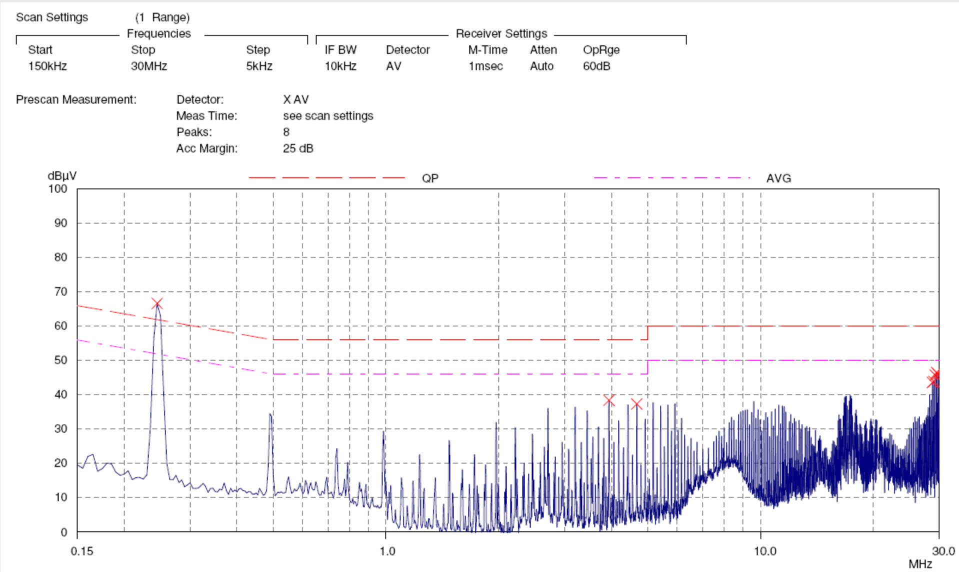
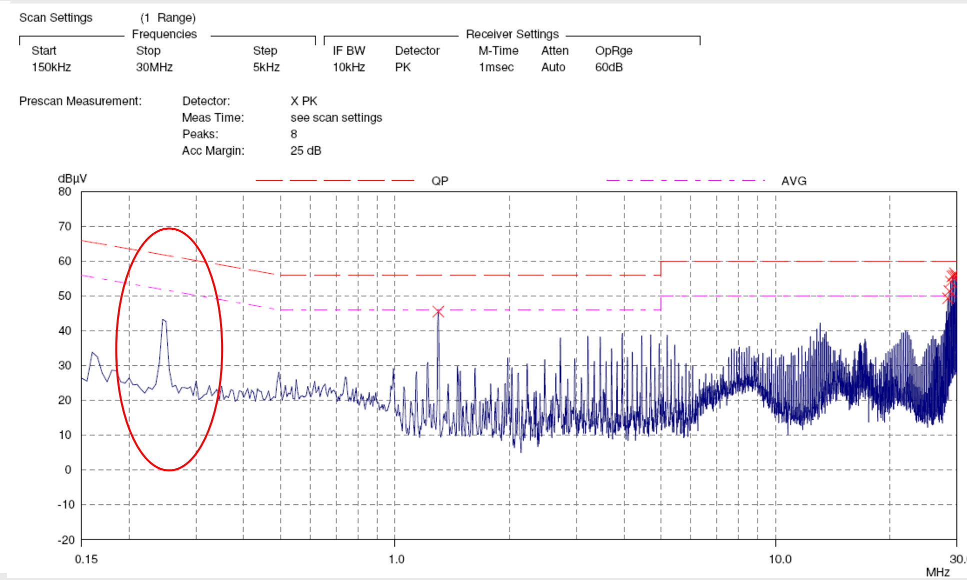
How Much Inductance is Needed?

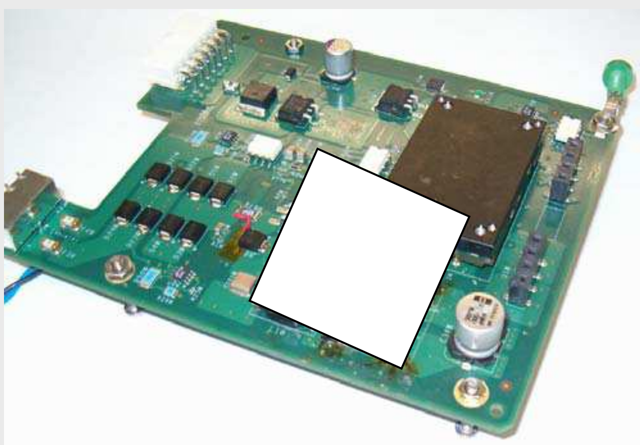




before

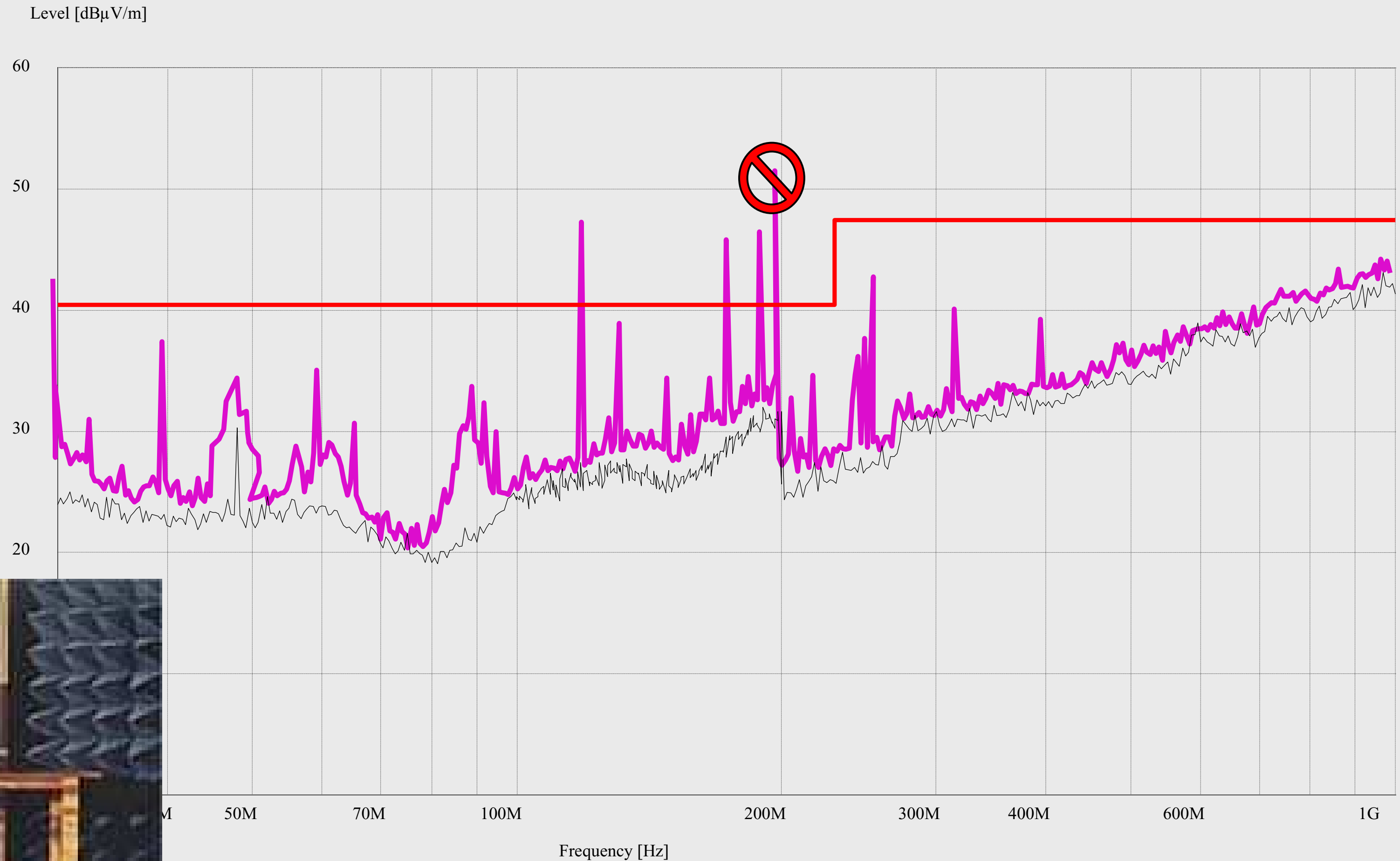
after

only changed one component

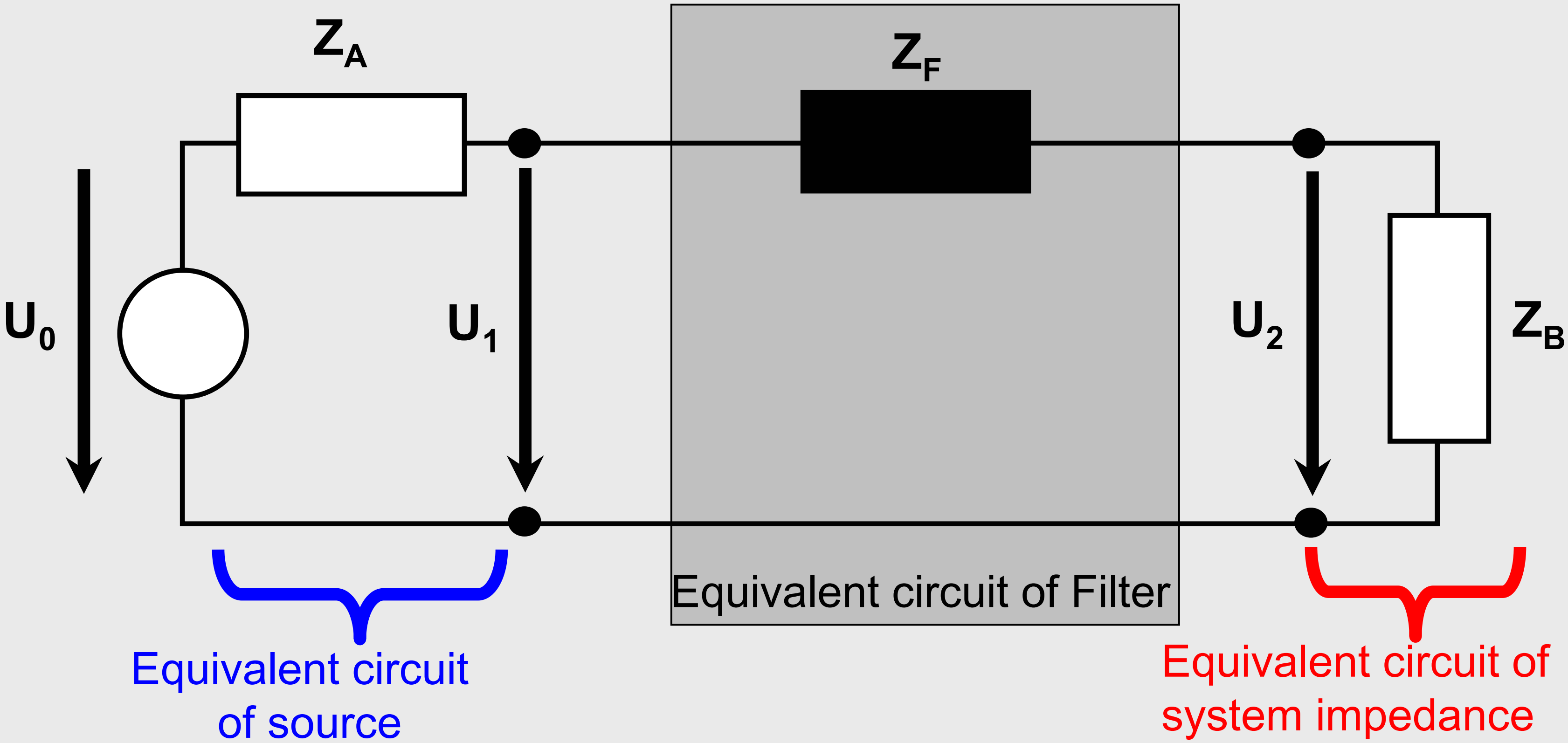


30mHy!

What Impedance is Needed?



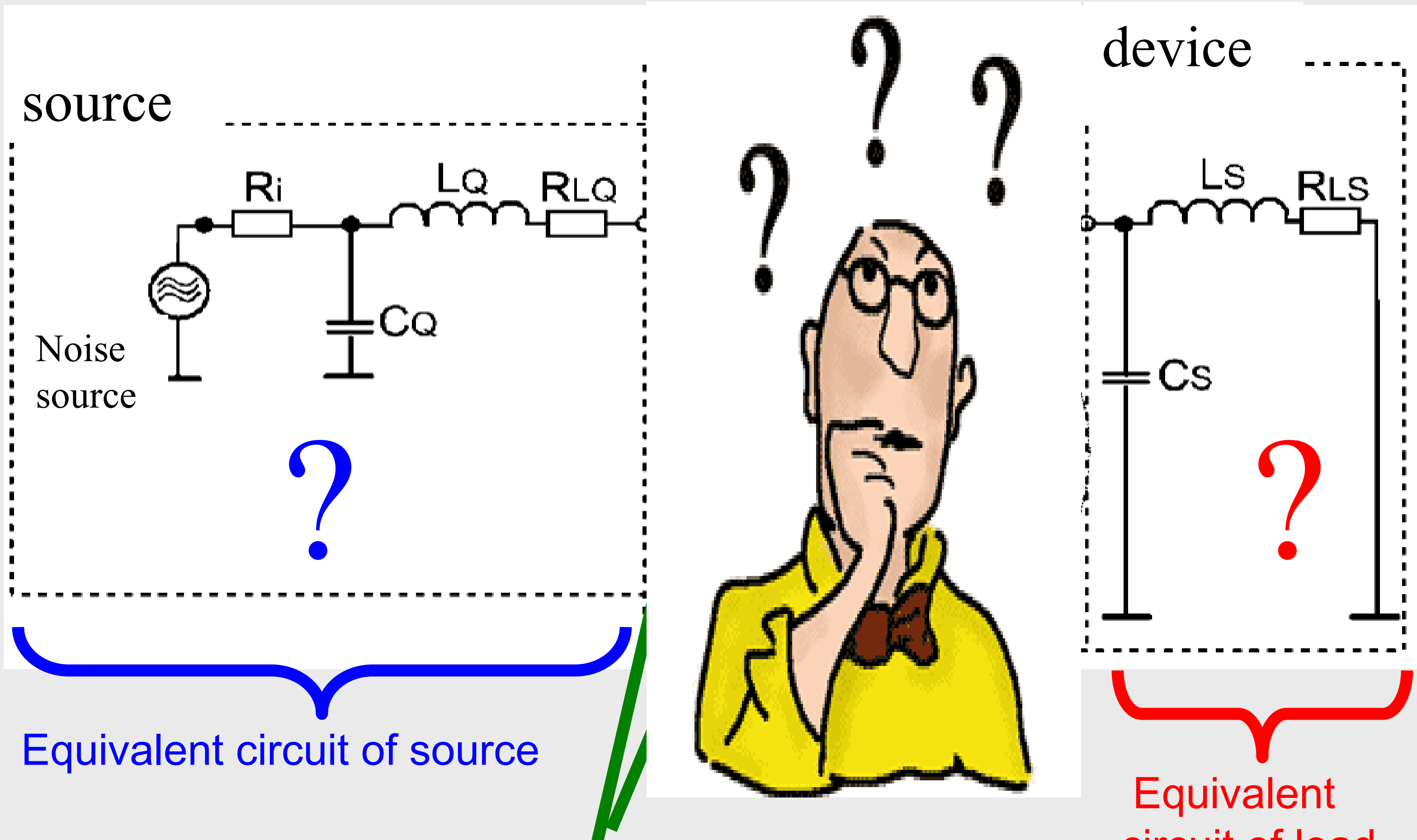
Insertion Loss Model



Insertion Loss =>

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

The Real World....... !

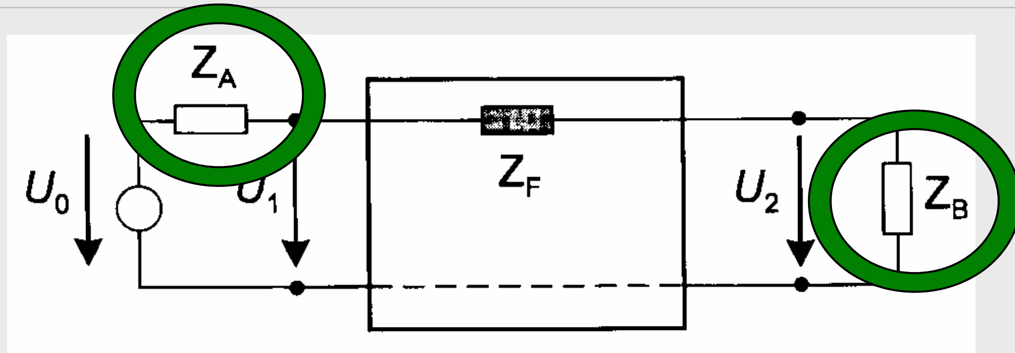


Equivalent circuit of source

for Inductor and Capacitor one can find Simulation-Models

Equivalent circuit of load

Practical Figures for *ZA / ZB*



- **Groundplanes :** **Impedance range 1 ... 2 Ω**
- **VCC-Distribution:** **Impedance range 10 ... 20 Ω**
- **Video-/ Clock-/ Dataline:** **Impedance range 50 ... 90 Ω**
- **Long Datalines:** **Impedance range 90 ... >150 Ω**

With this we can make a first decision of a Ferrite-Impedance Z_F which would suppress noise in our application :

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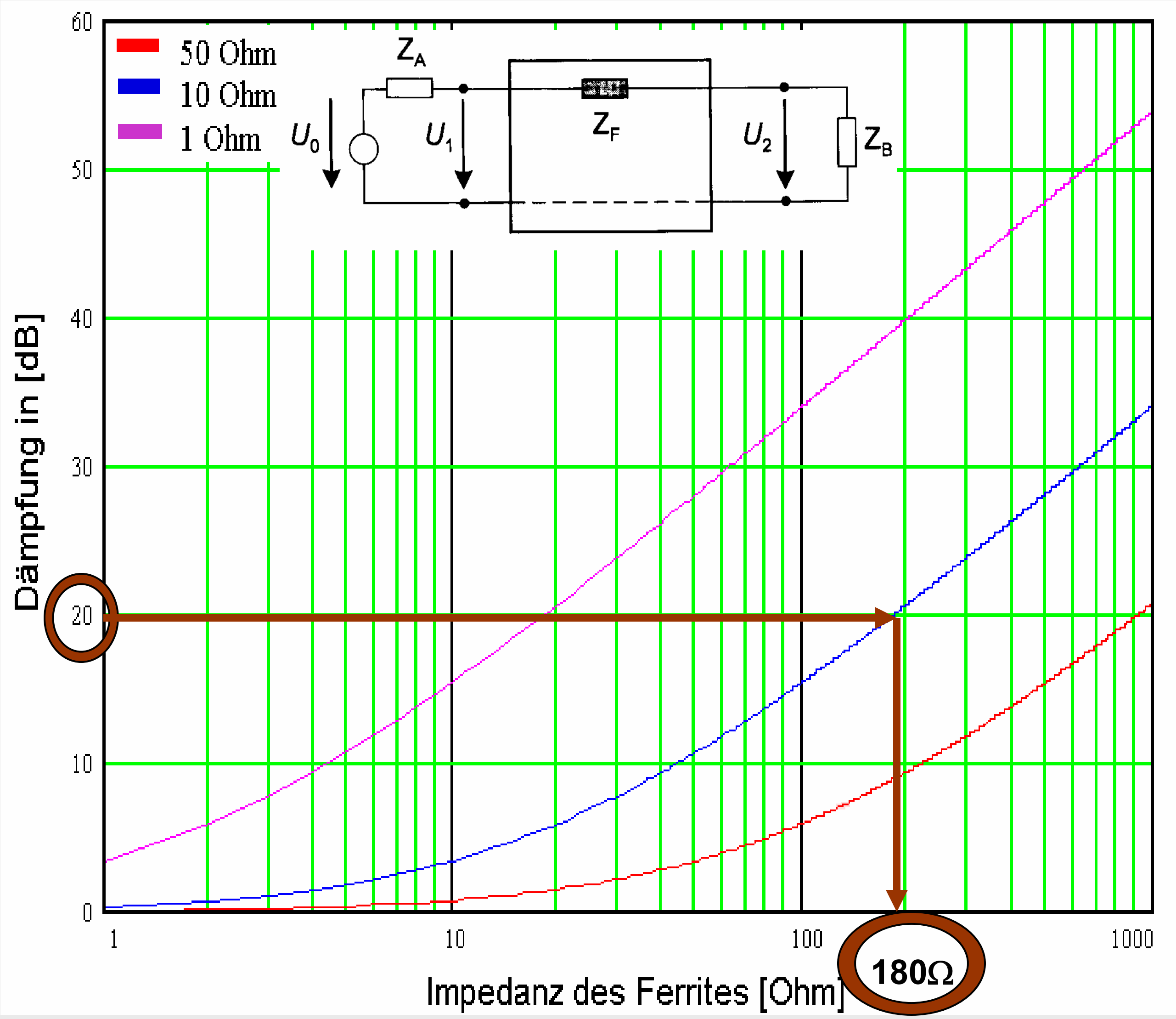
Which Impedance Z_F is Needed ?



Example 1: required attentuation = 20dB @ 200 MHz

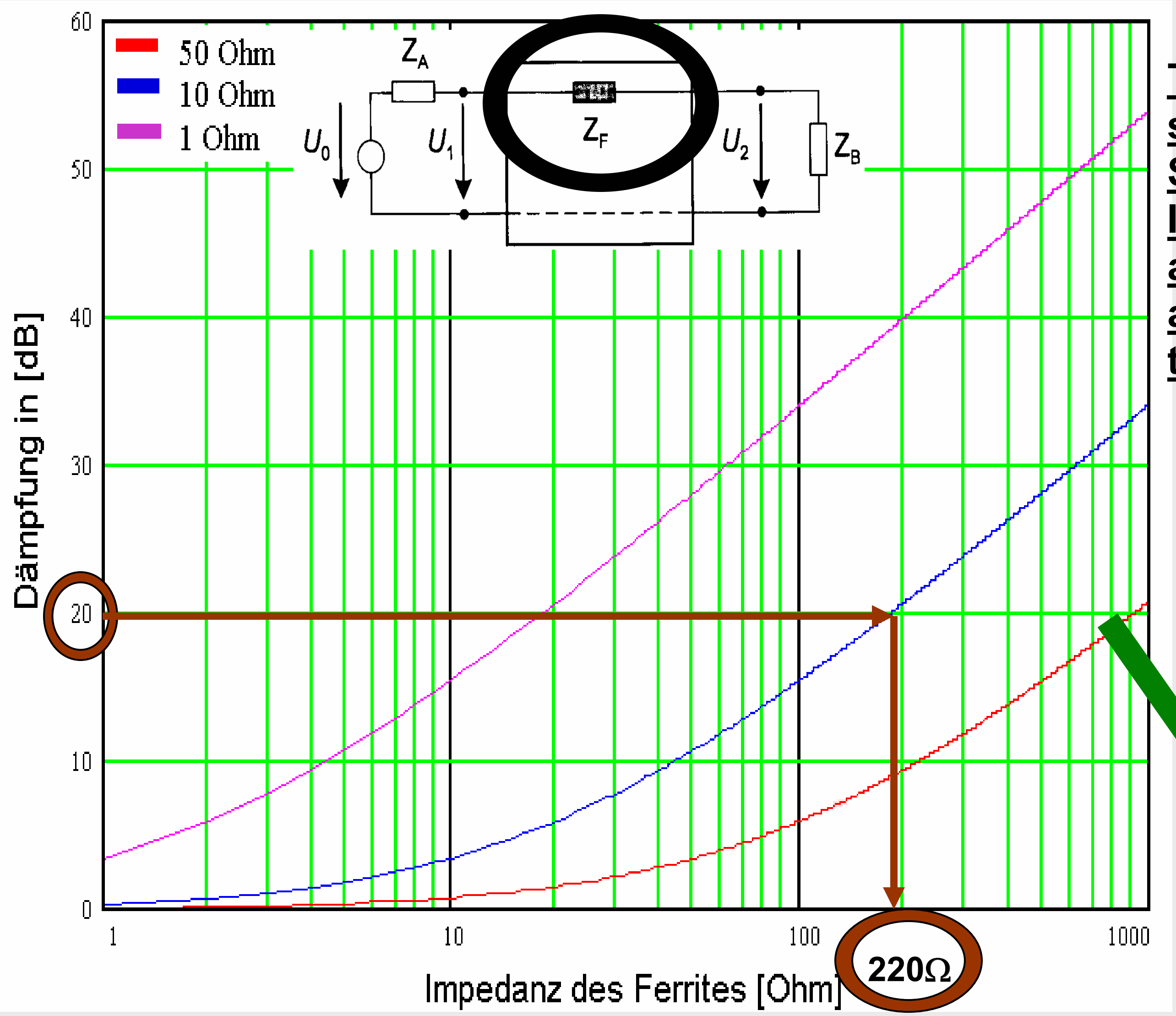
VCC-Distribution

System impedance ca. 10 Ohm

=> goto Nomogramm:

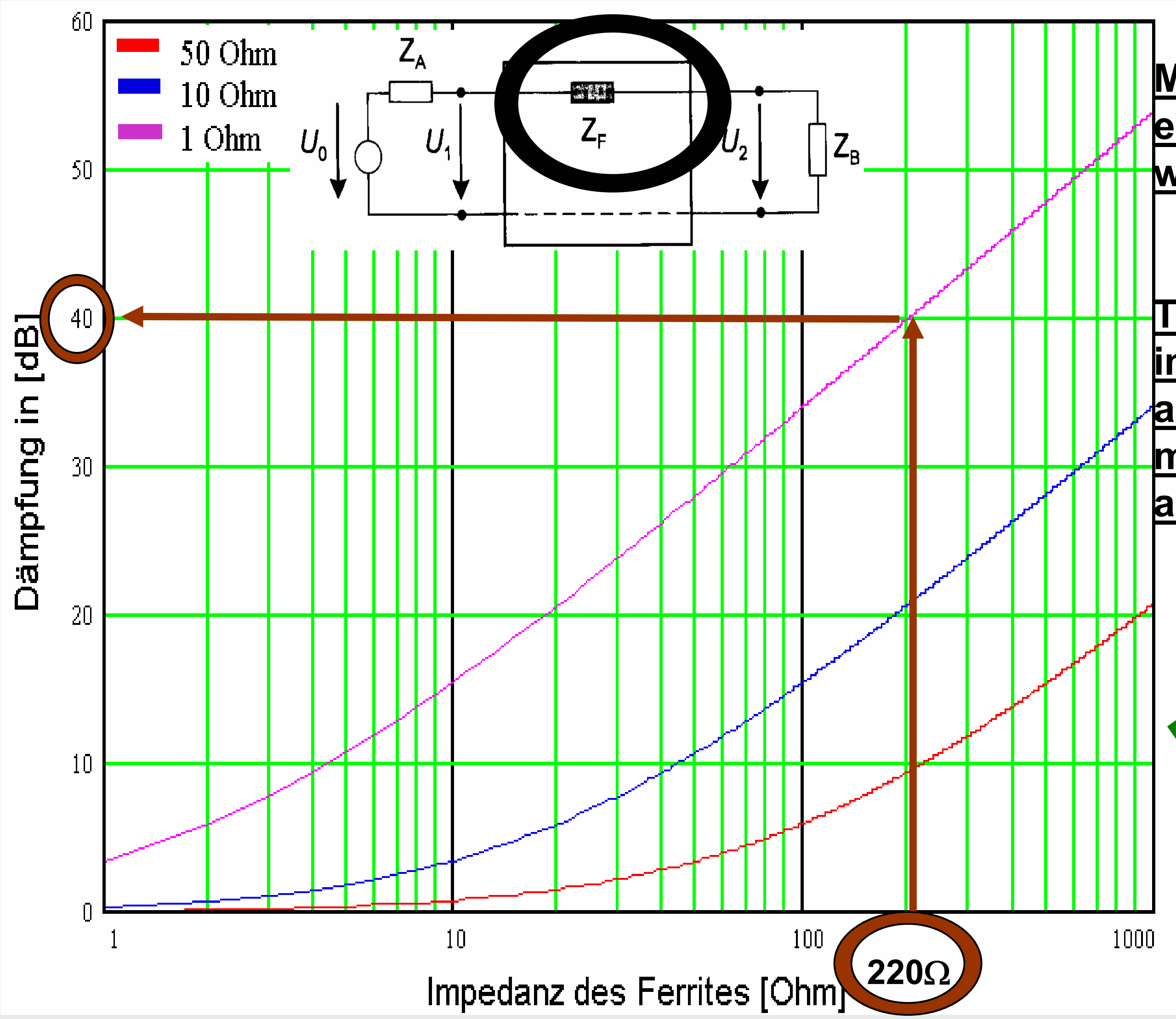
180 Ω => choose: 220 Ω

Case 1: Attentuation Reached



The initial setup that System Impedance is around 10 Ohm at 200 MHz is true !

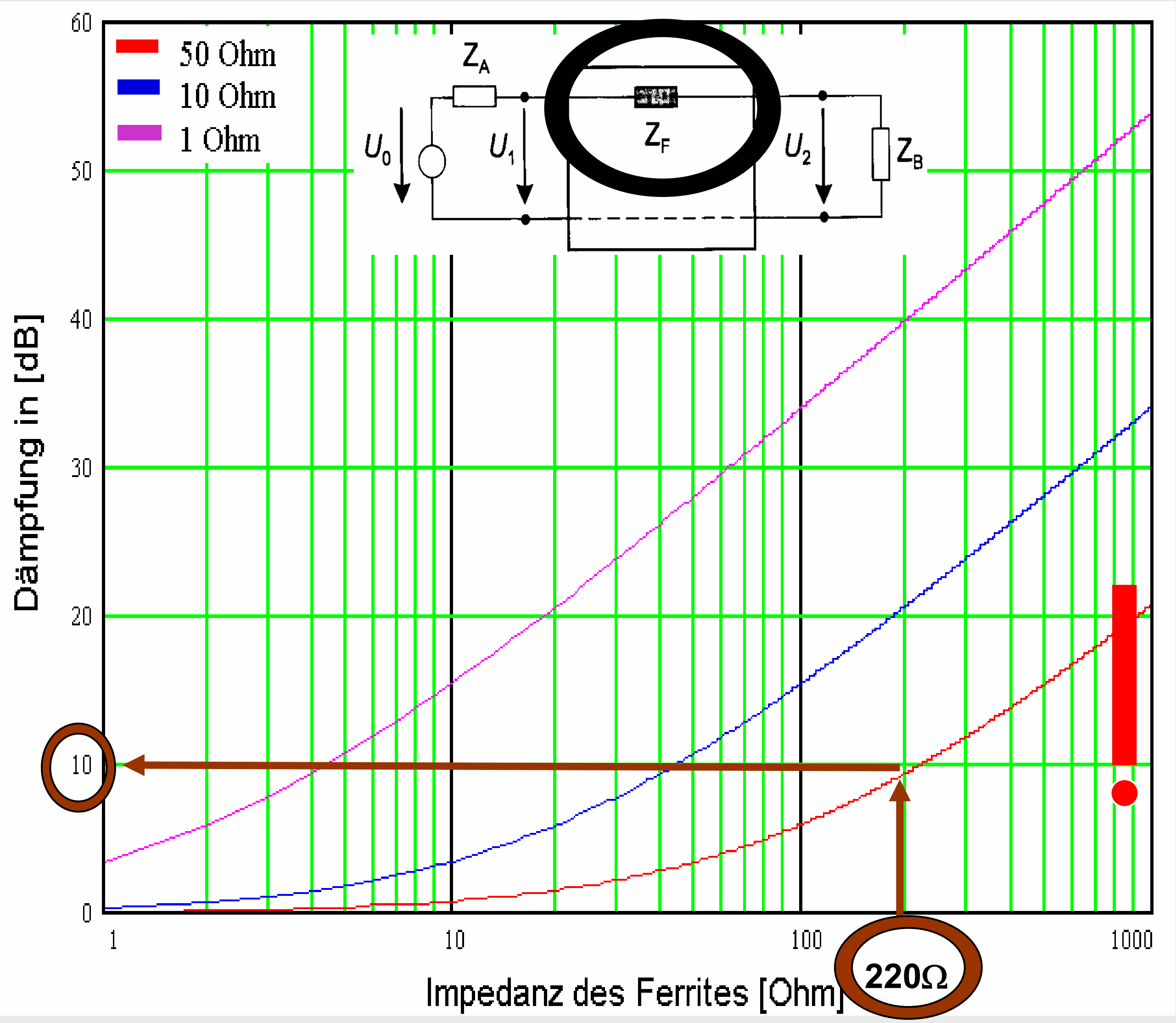
Case 2: More Attentuation



Measurement of e.g. 40dB with Ferrit.

The System-impedance ZA and ZB are much lower (at around 1 Ohm)!

Case 3: Less Attentuation



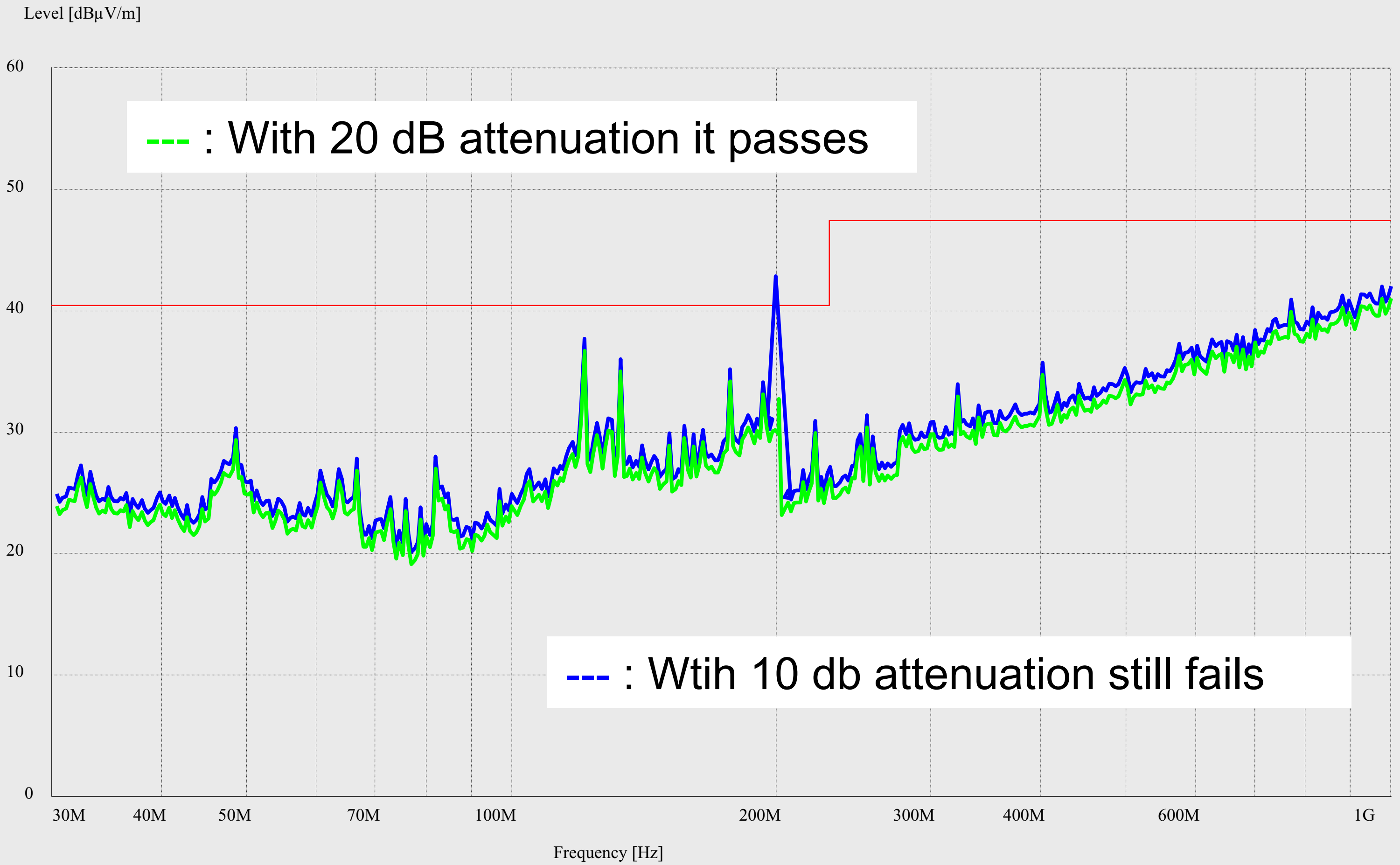
Measured only e.g. 10dB with Ferrite.

The System-impedances ZA and ZB are much higher than expected (around 50 Ohm) !

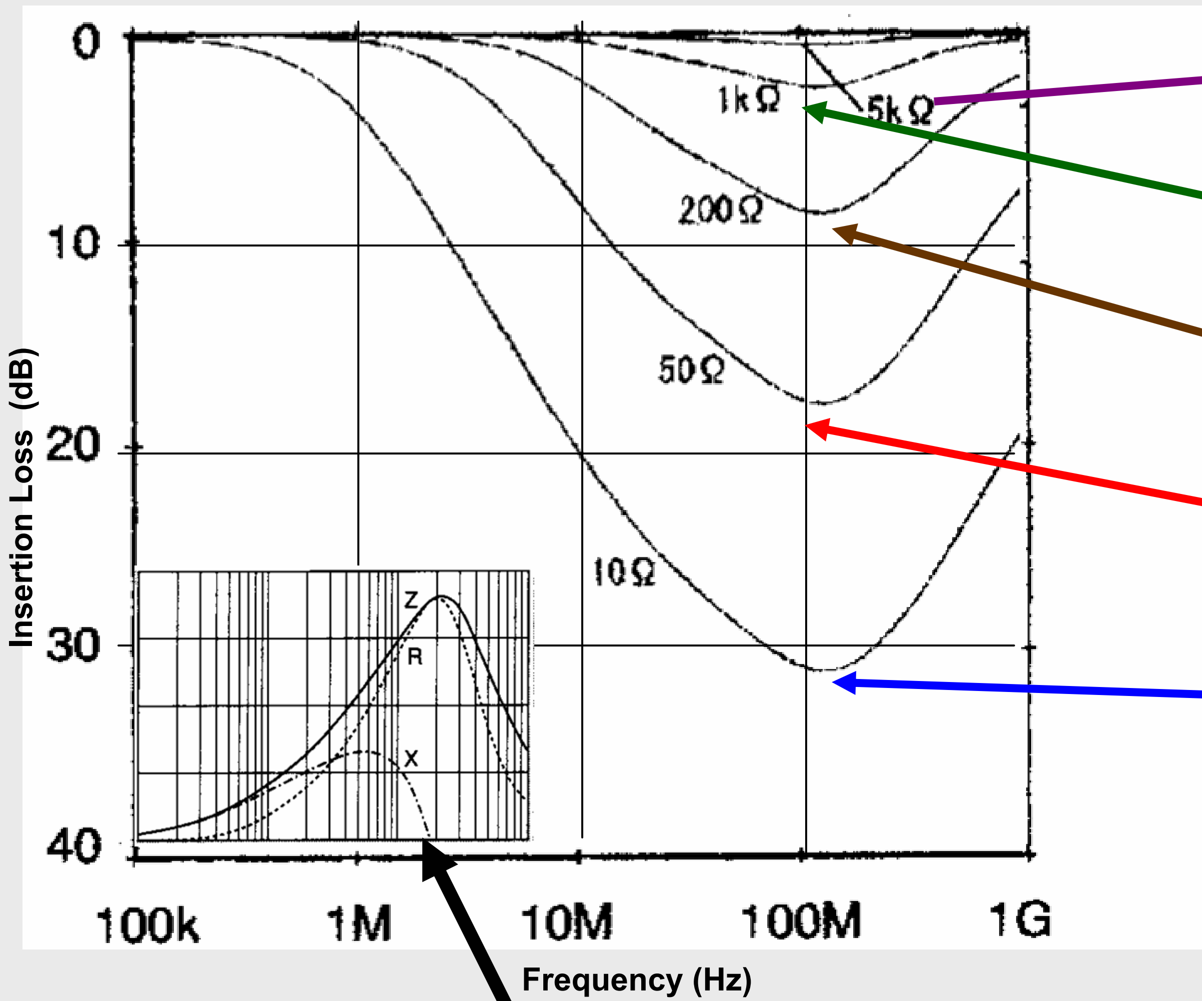
OR

Additional coupling paths not taken into account !

Analyse the Results



Insertion Loss vs. Impedance of Source/ Load (Z_A / Z_B)



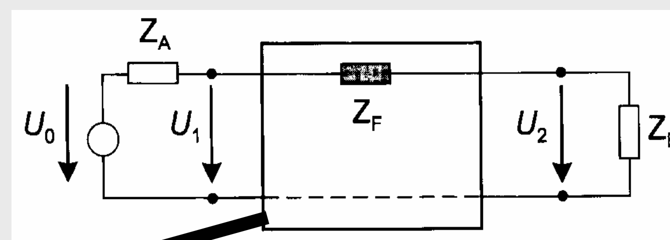
with Z_A = Z_B = 5000 Ω =constant
no effect in filtering !

A = - 3 dB max.
with Z_A = Z_B = 1000 Ω = constant

A = - 8 dB max.
with Z_A = Z_B = 200 Ω = constant

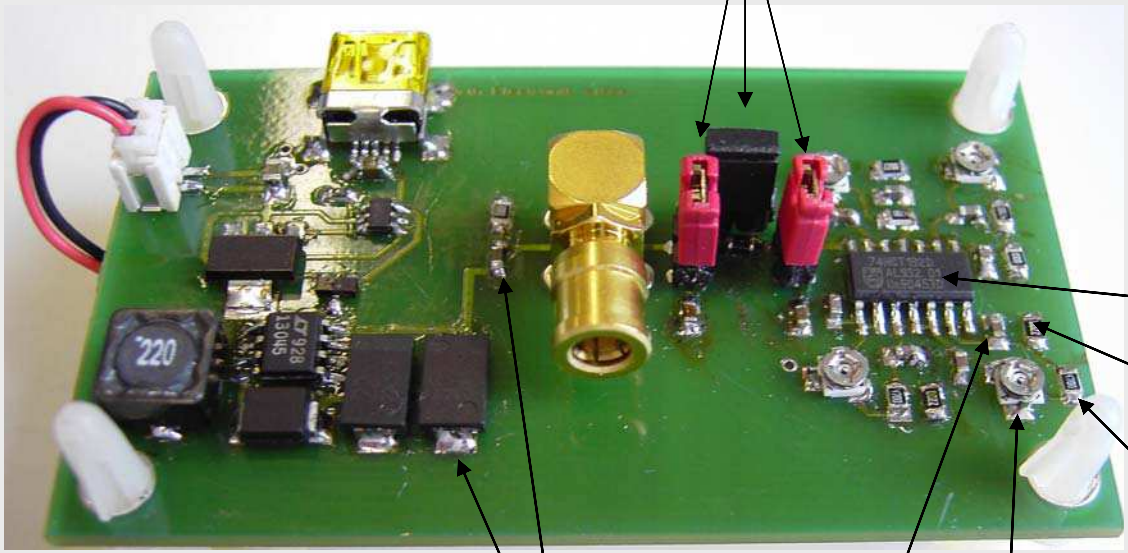
A = -18 dB max.
with Z_A = Z_B = 50 Ω = constant

A = -32 dB max.
with Z_A = Z_B = 10 Ω = constant



SMD-Ferrite Z_F = 600 Ohm @ 100 MHz

V_{cc} Decoupling Example - Test Board



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V_{cc} Decoupling Example – Discrete π-Filter

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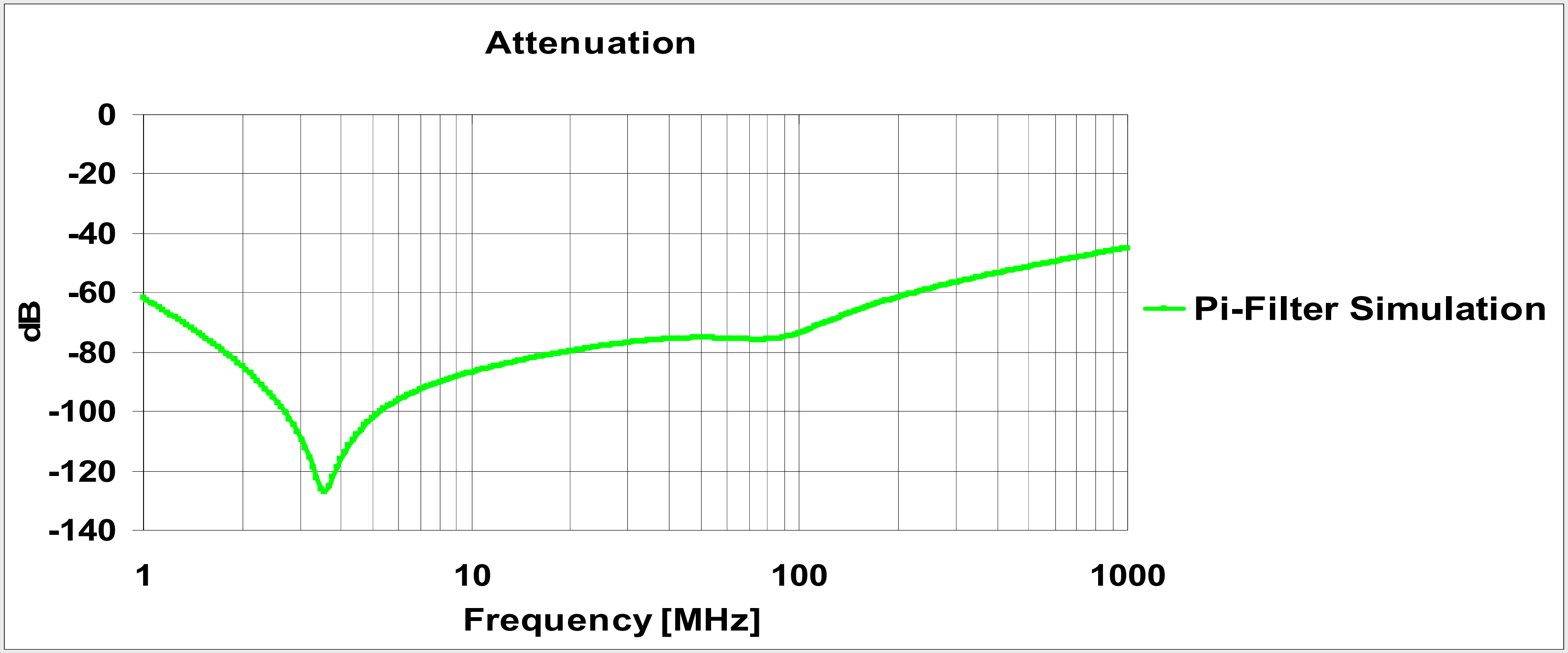
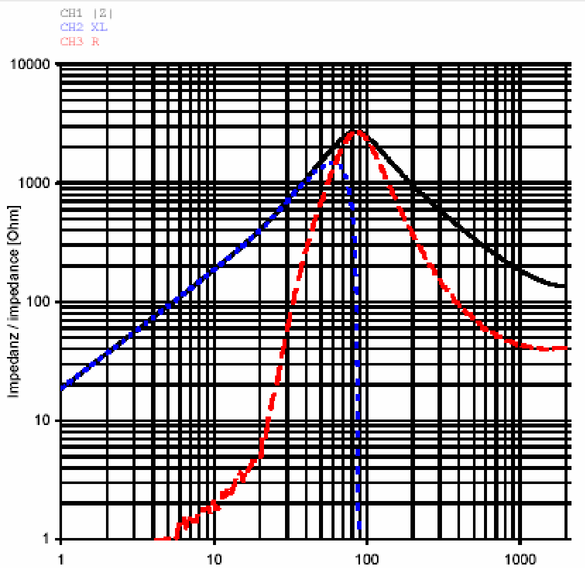
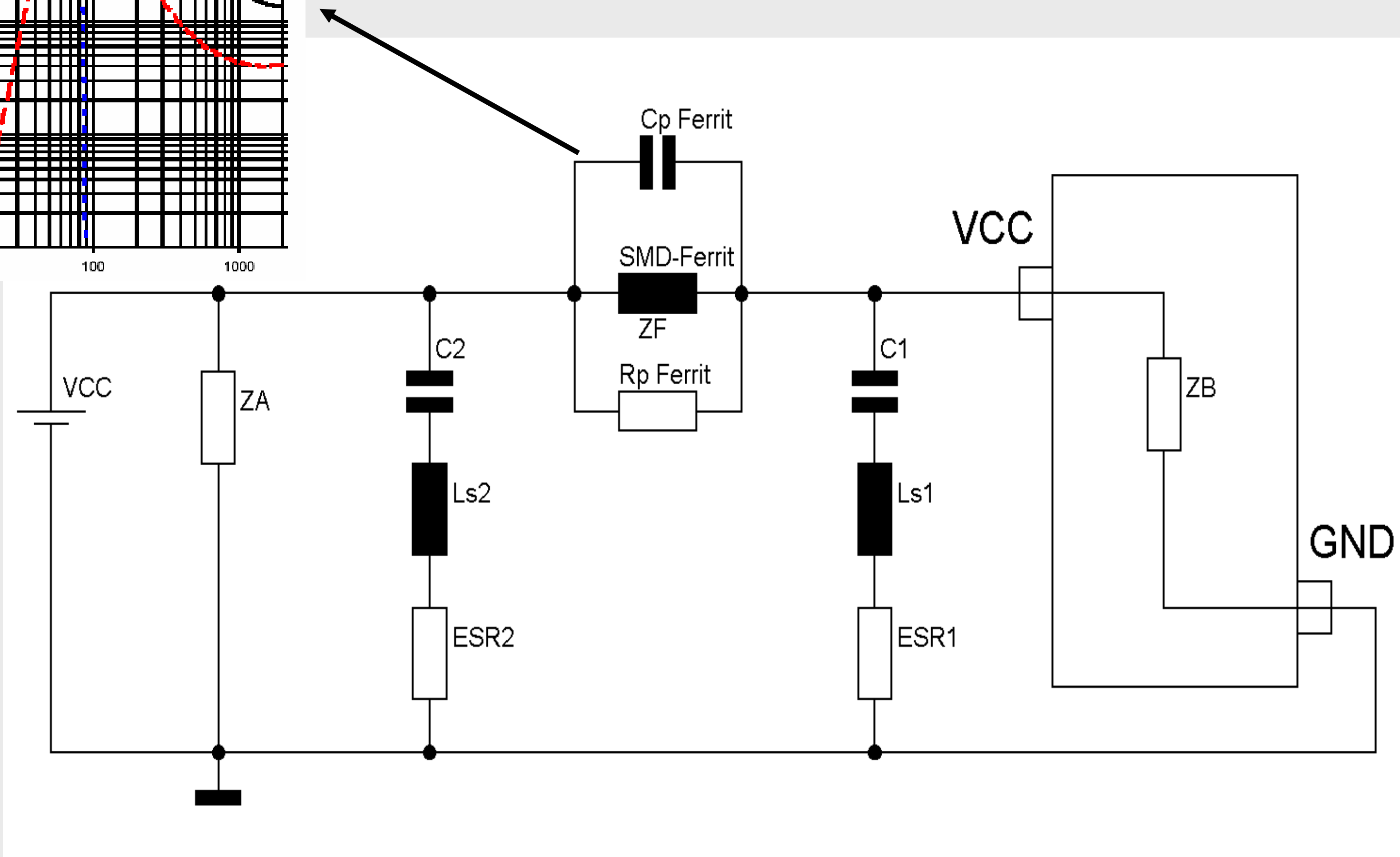
π-Filter: 1uF-742792093-1uF



V_{cc} Decoupling Example – Filter Simulation Circuit

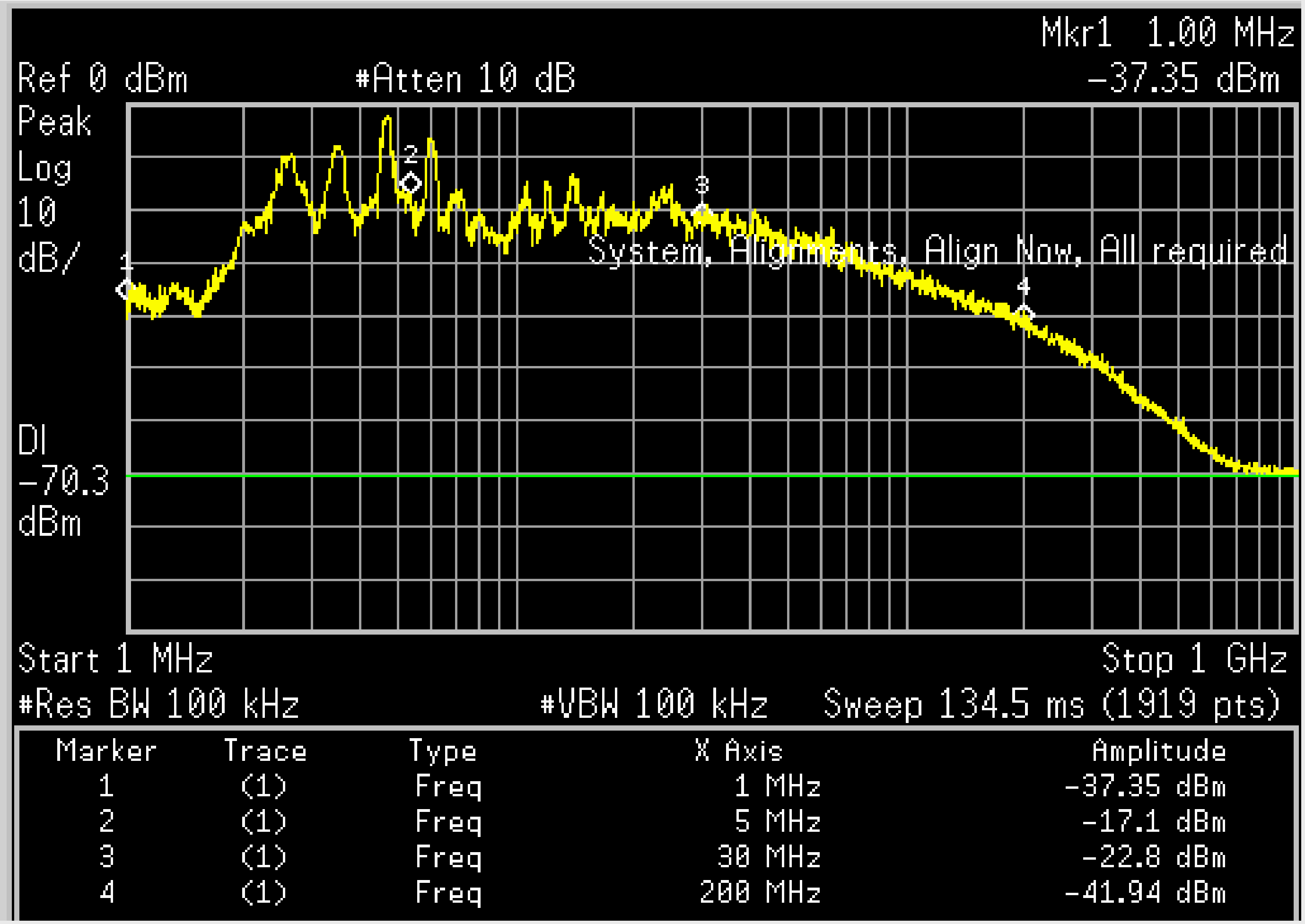


Impedance Characteristic Zmax@100MHz
742792093



V_{cc} Decoupling Example – Noise without Filter

no filtering on Vcc
(condition: max. Hold)



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V_{cc} Decoupling Example – 1uF Simulation

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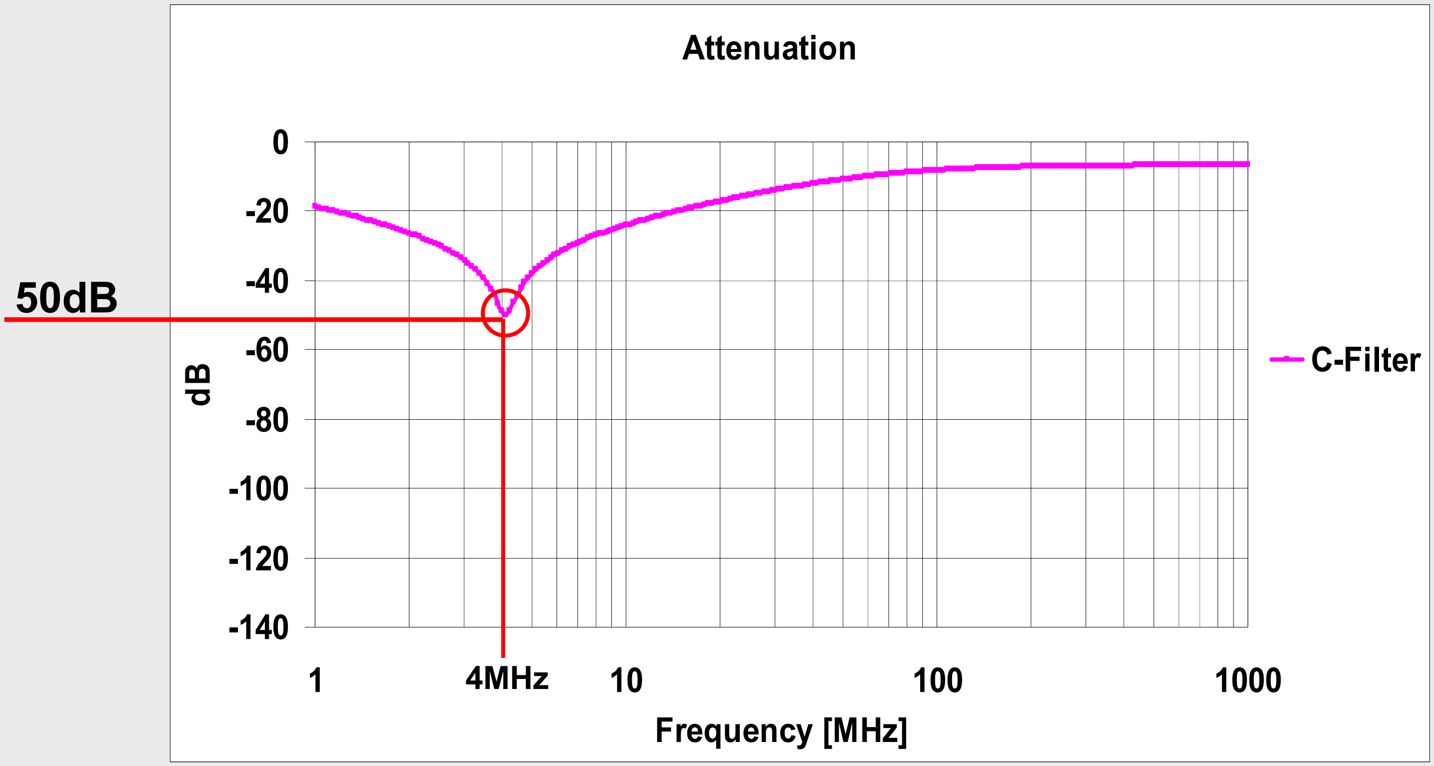
Step 1:
1uF Cap.

C-Filter with 1uF



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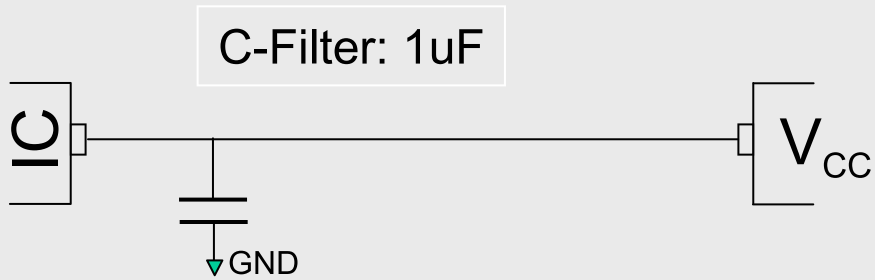
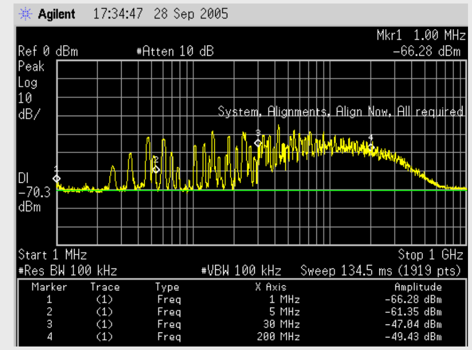
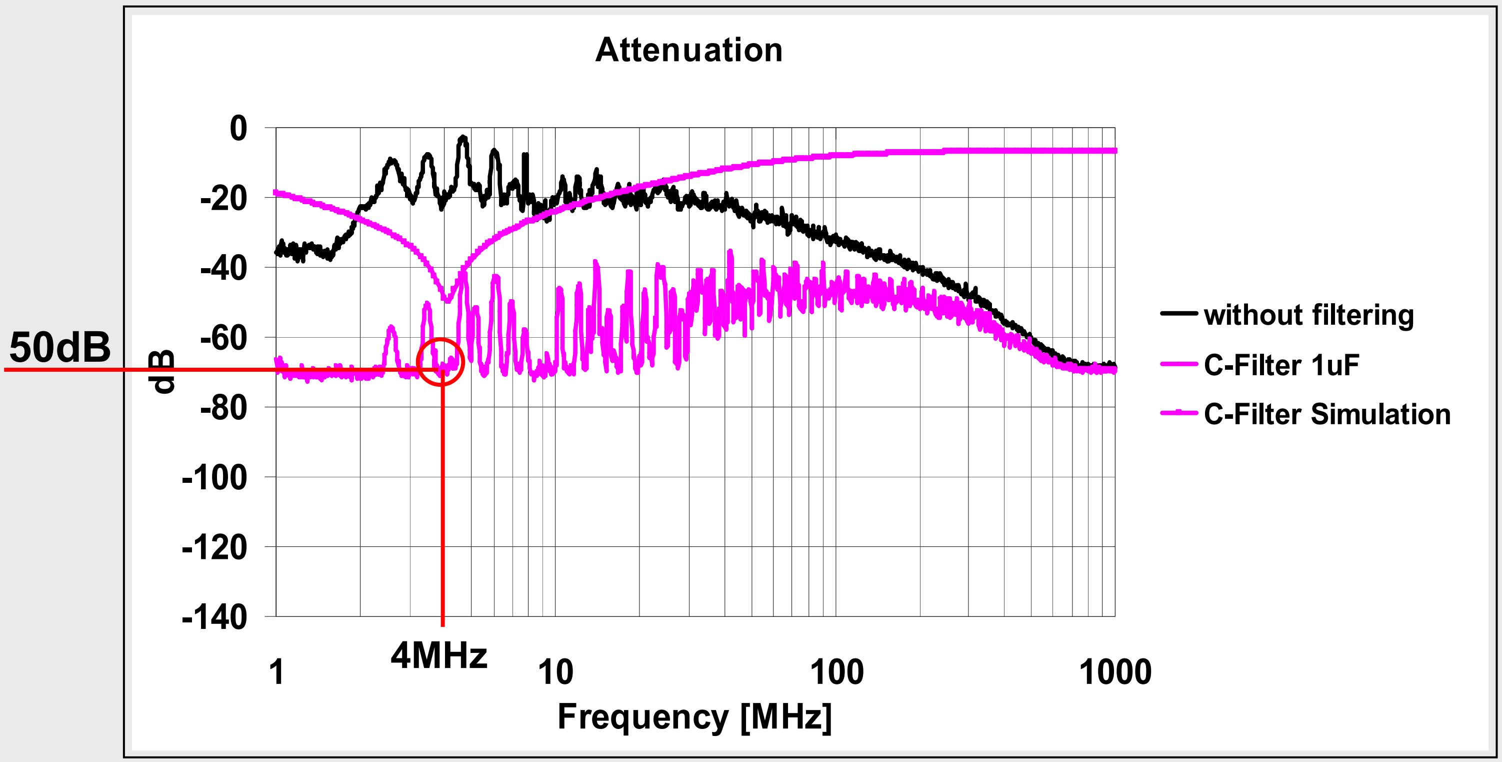
V_{cc} Decoupling Example – 1uF Results

Step 1:
1uF Cap.



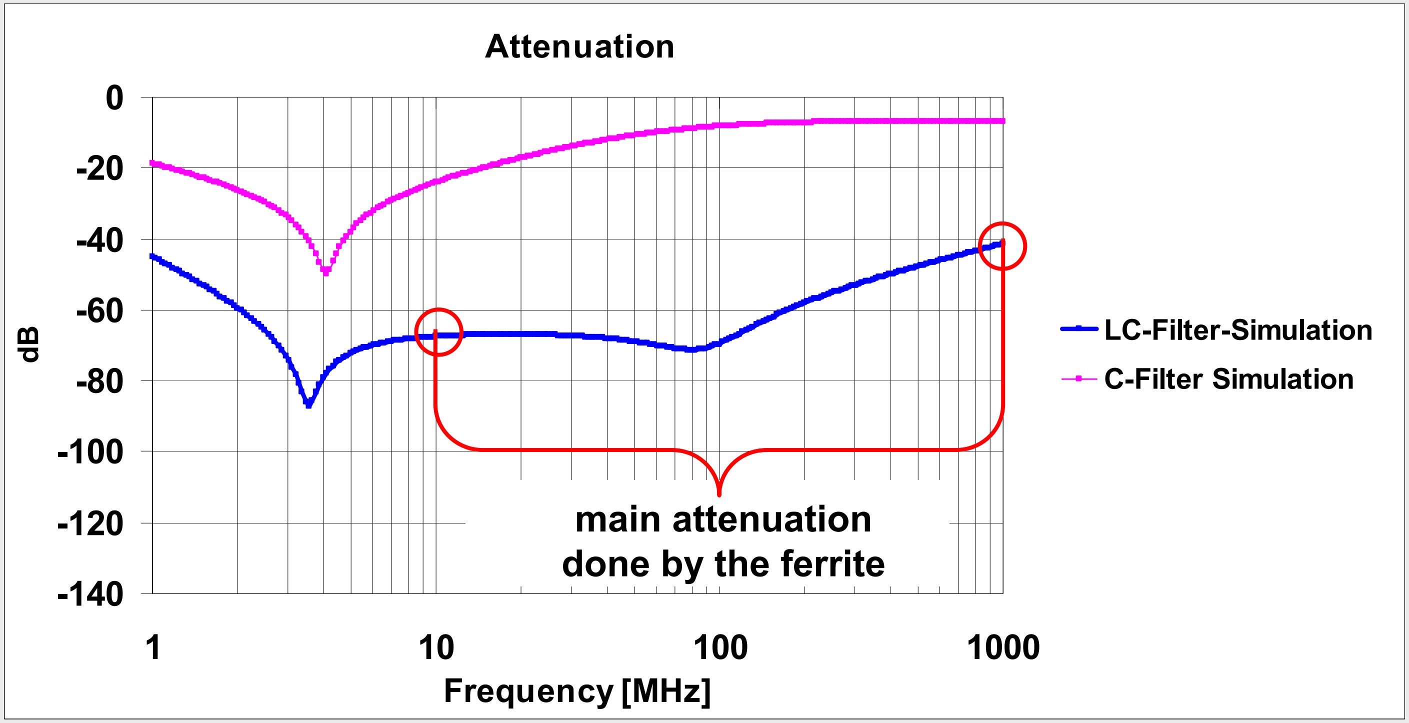




V_{cc} Decoupling Example – 1uF and Ferrite Simulation

Step 2:
1uF Cap.
& Ferrite

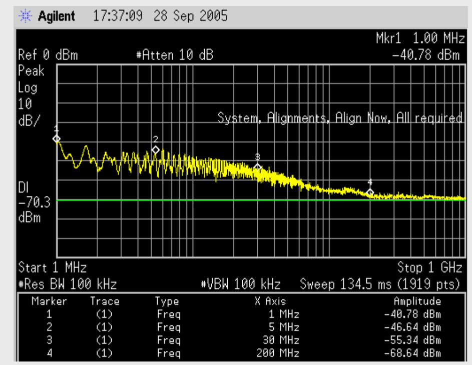
LC-Filter: 1uF-742792093

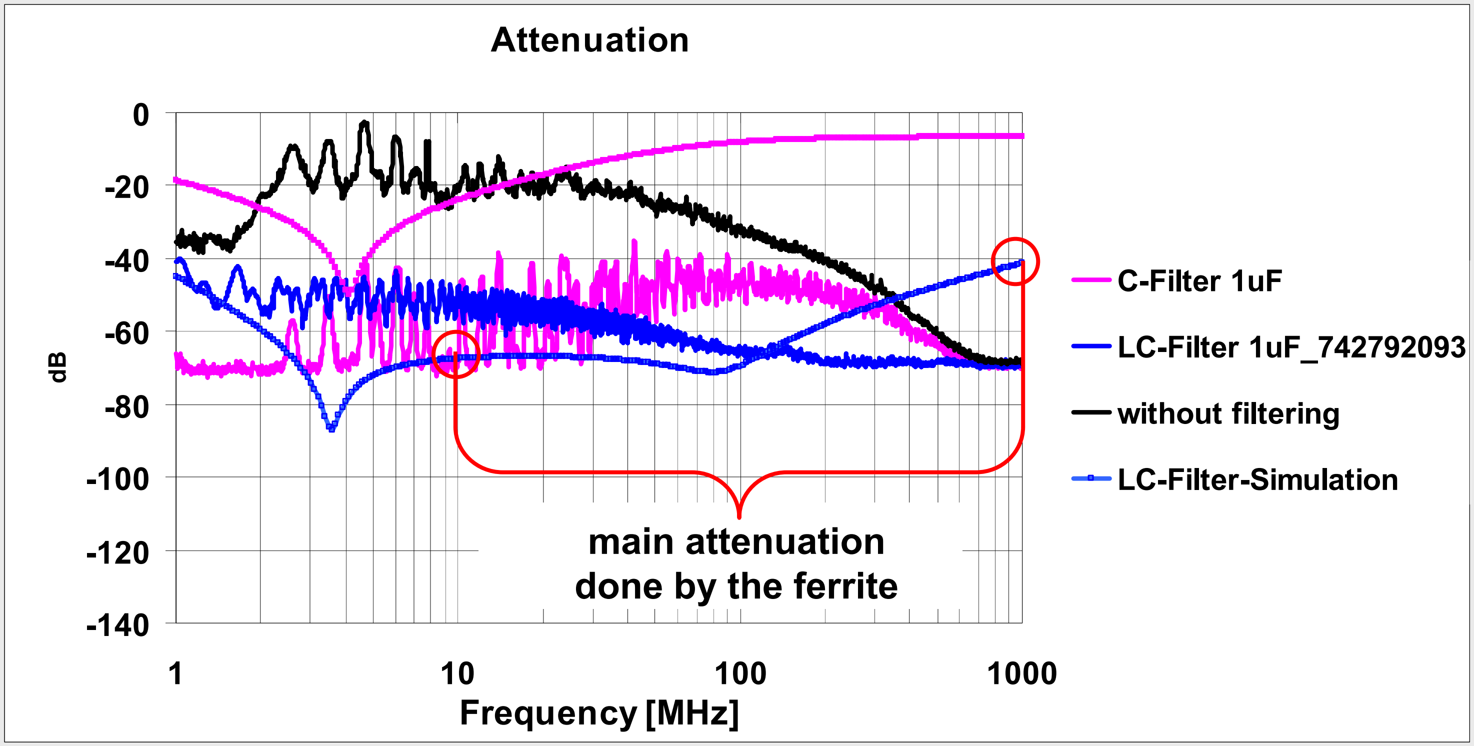


V_{cc} Decoupling Example – 1uF and Ferrite Results

Step 2:
1uF Cap.
& Ferrite

LC-Filter: 1uF-742792093

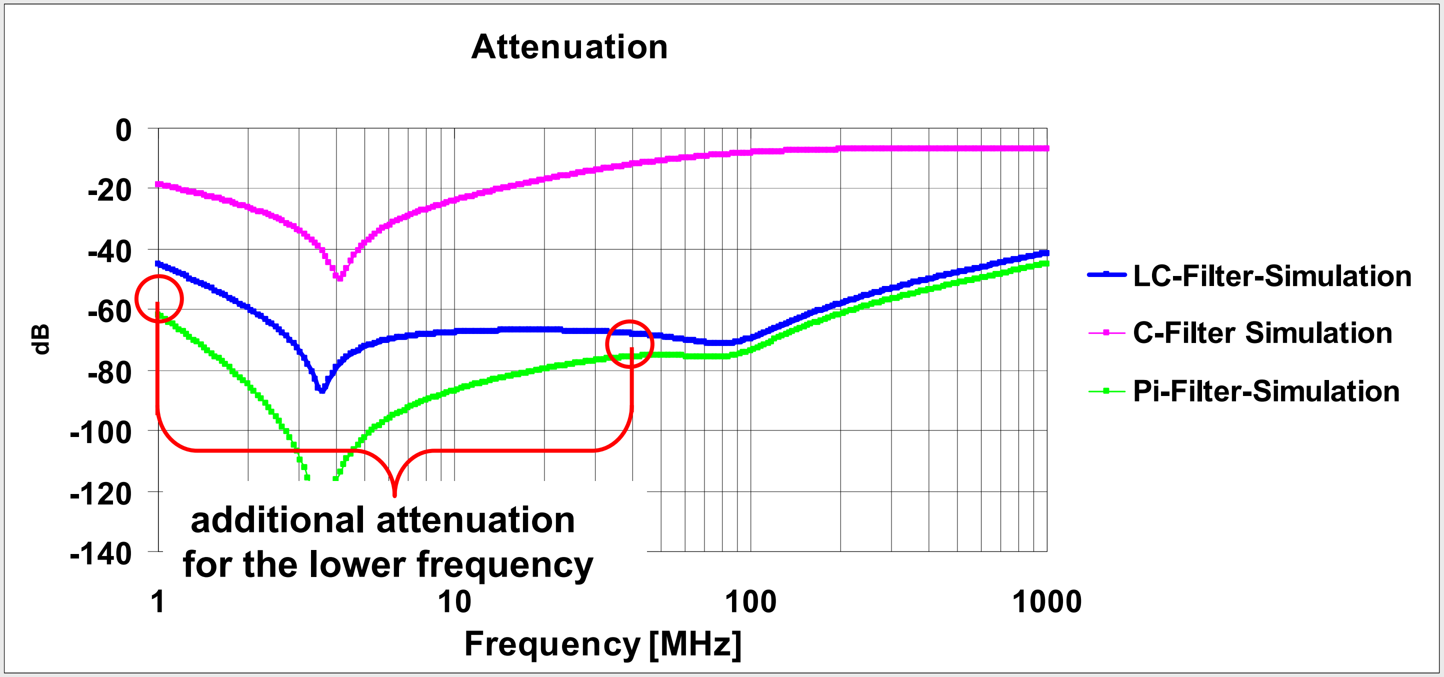




V_{cc} Decoupling Example – Pi Filter Simulation

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

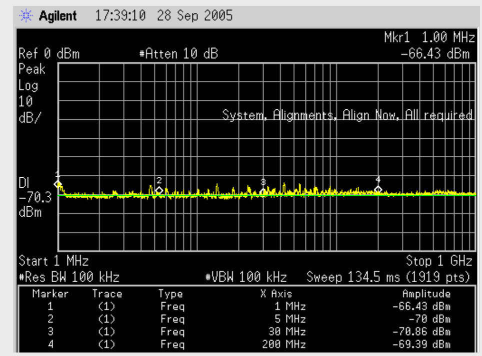
π-Filter: 1uF-742792093-1uF

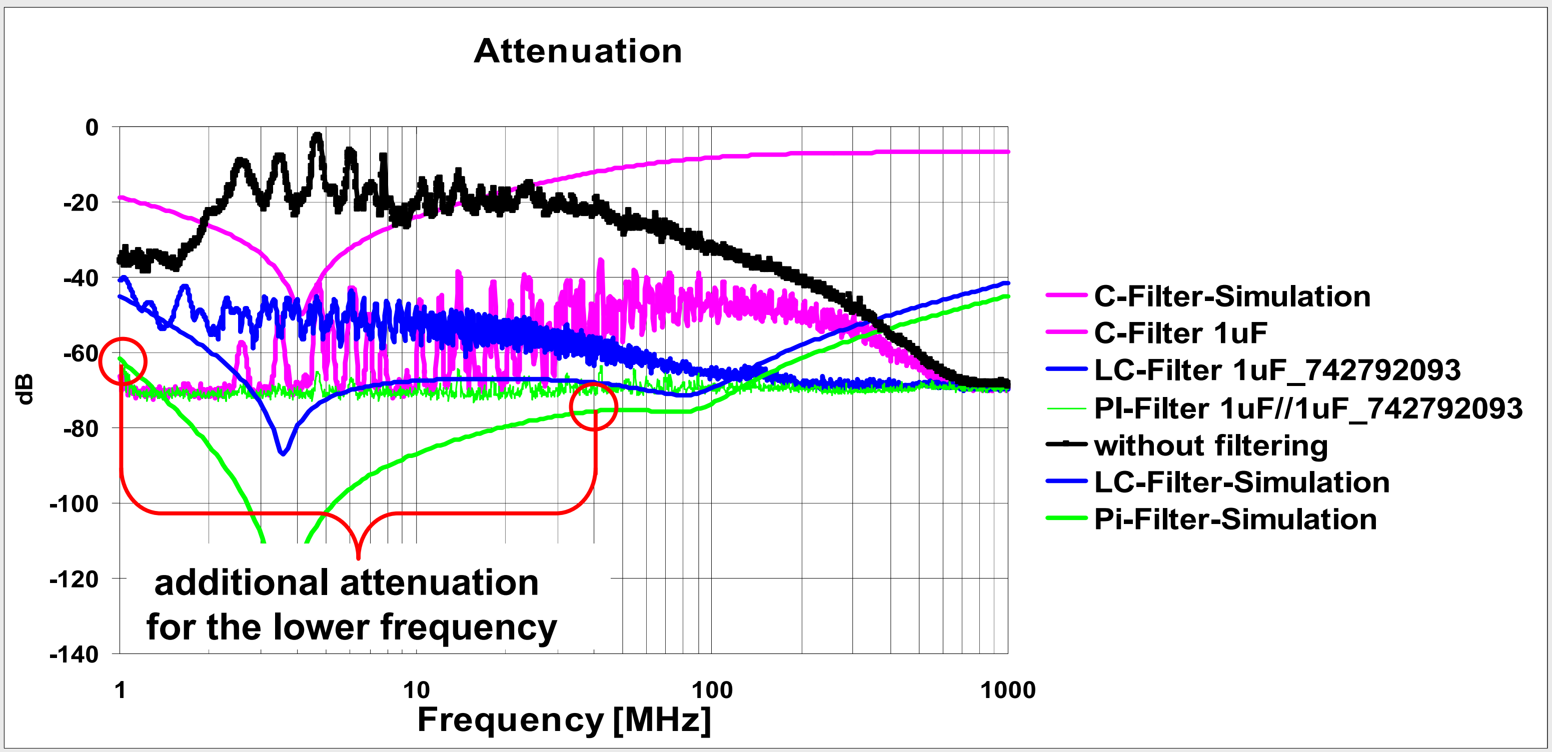


V_{cc} Decoupling Example – Pi Filter Results

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

π-Filter: 1uF-742792093-1uF

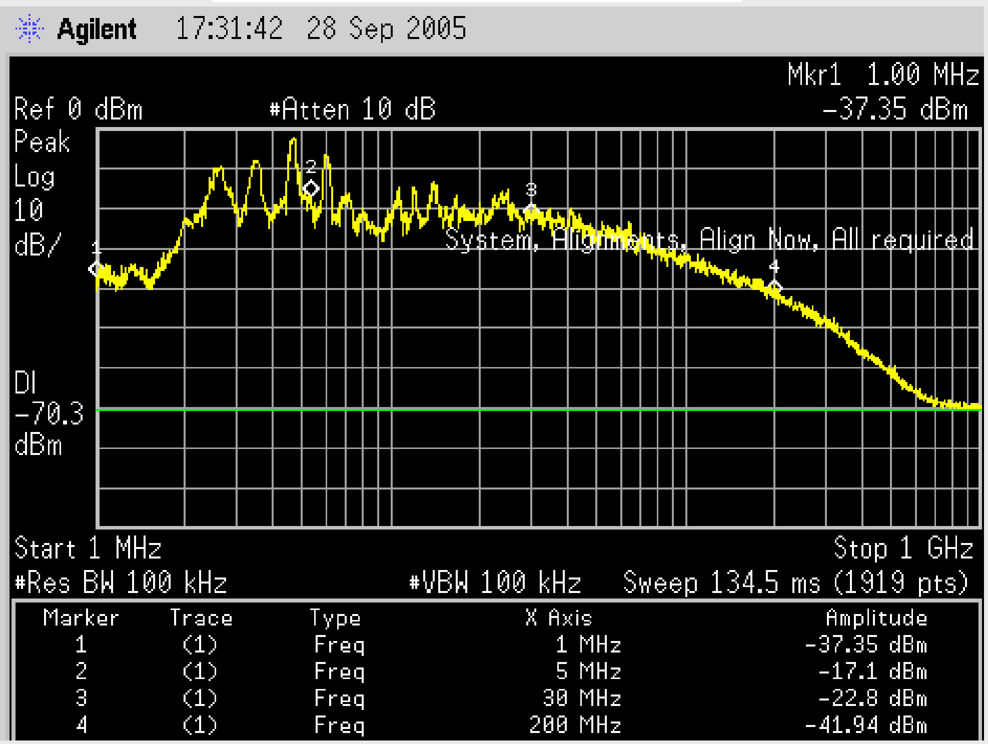




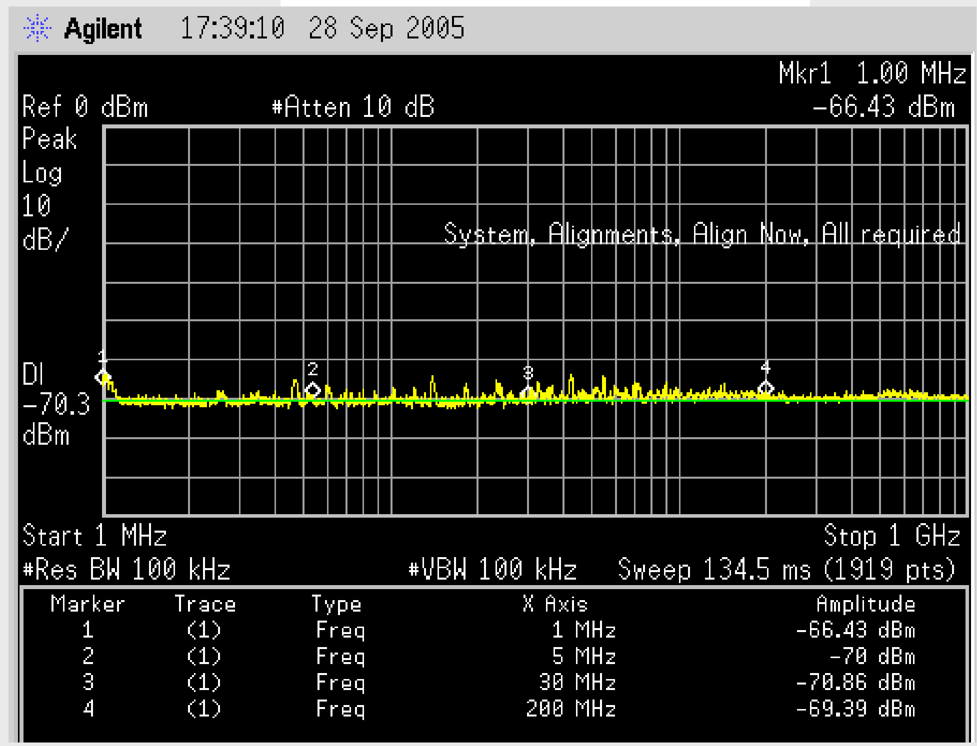
V_{cc} Decoupling Example – Final Result

π-Filter: 1uF-742792093-1uF

no filtering on Vcc



filtering on Vcc



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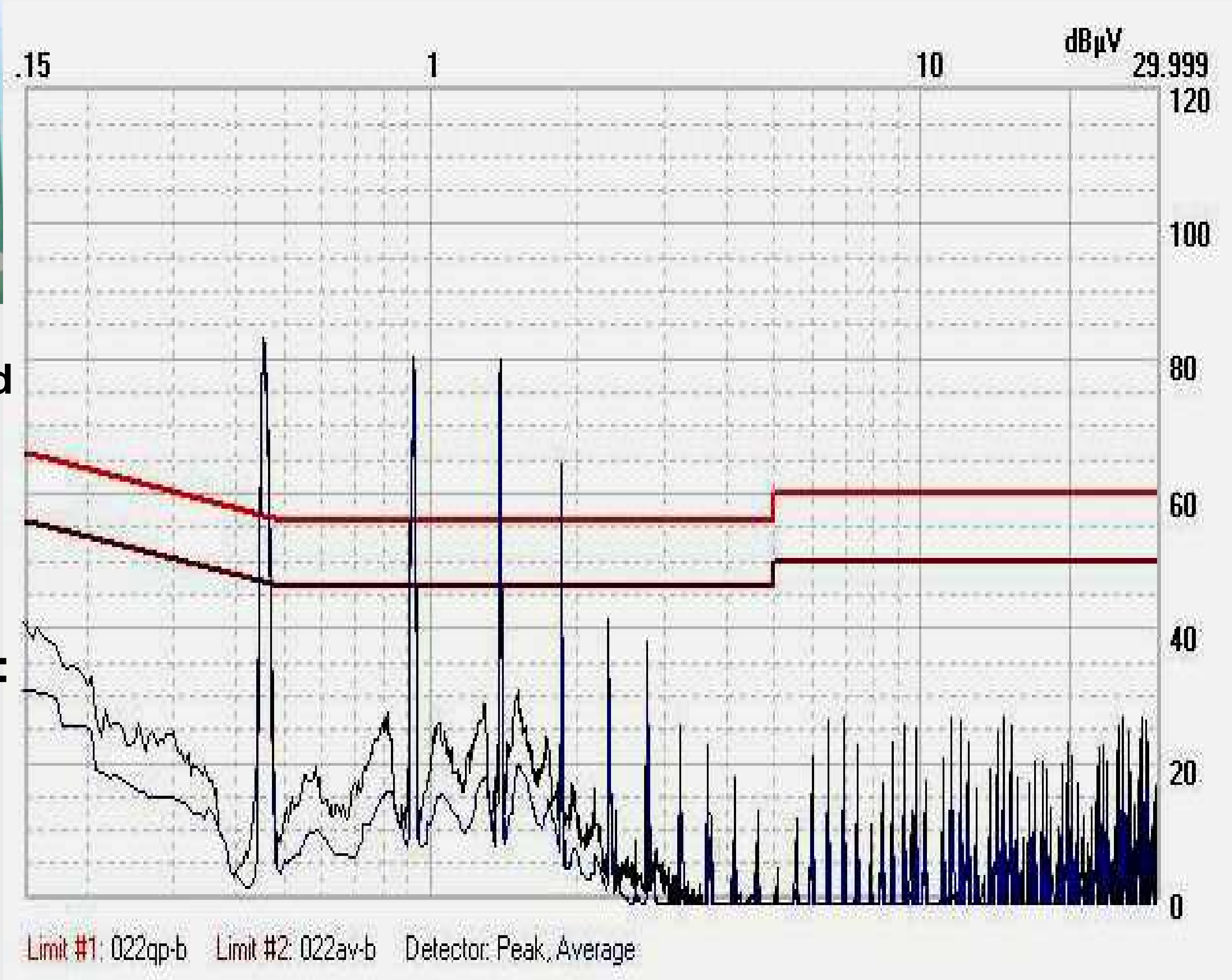
EMI: Conducted Emission w/o Filter

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

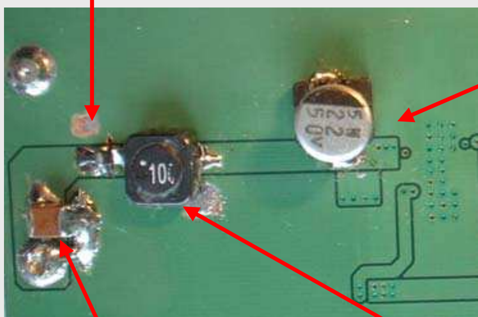
Test without EMC filter:
Peak 82dBµV
→ 26dB above limit

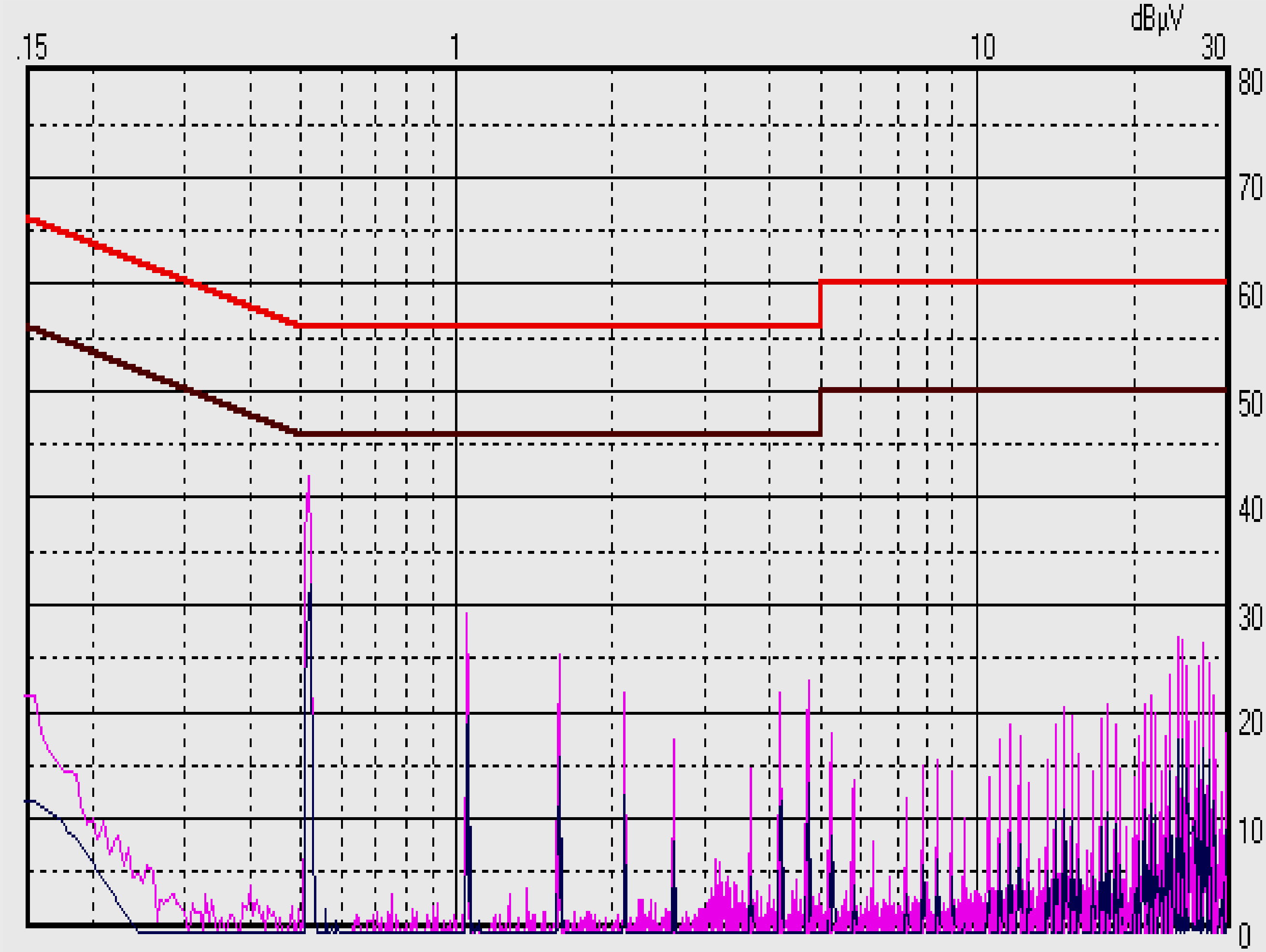


EMI: Conducted Emission with Filter

Ferrite bead

High ESR Elco to damp cable





Test with additional L=10uH, C=3.3uF 50V 1210 input filter

Peak=42dBµV/m
∅=32dBµV/m

Peak & ∅ 14dB below limit

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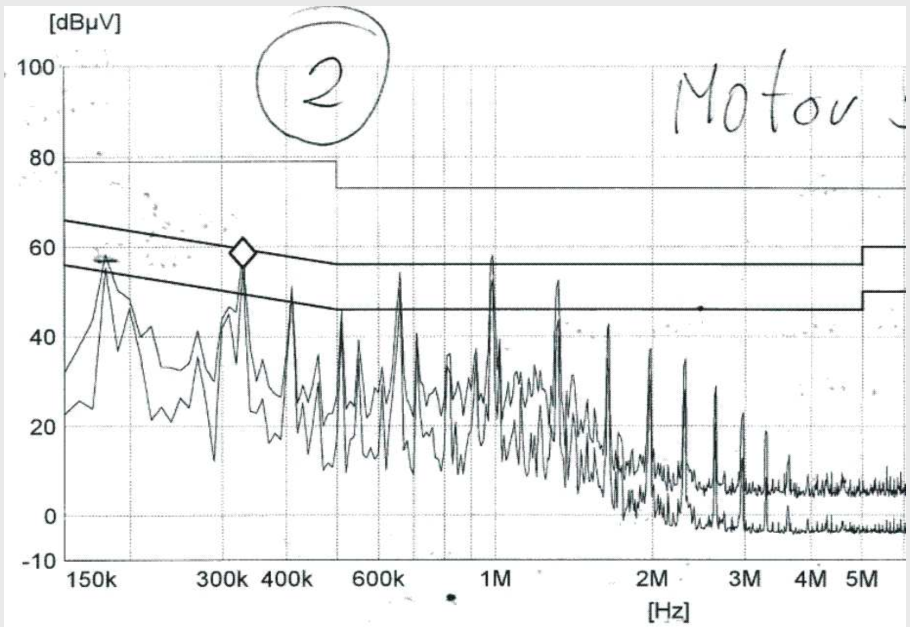
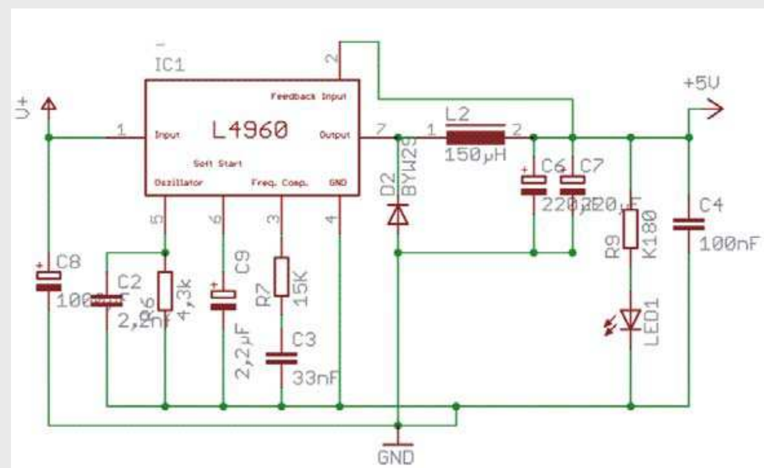
EMI: Conducted Emission Measurement

- Power supply V 1.0



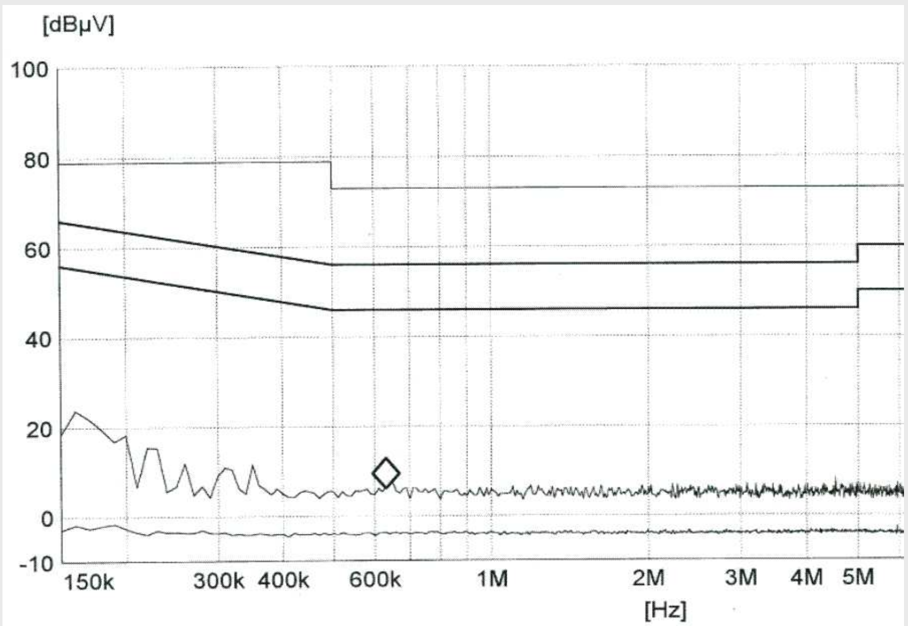
PCB

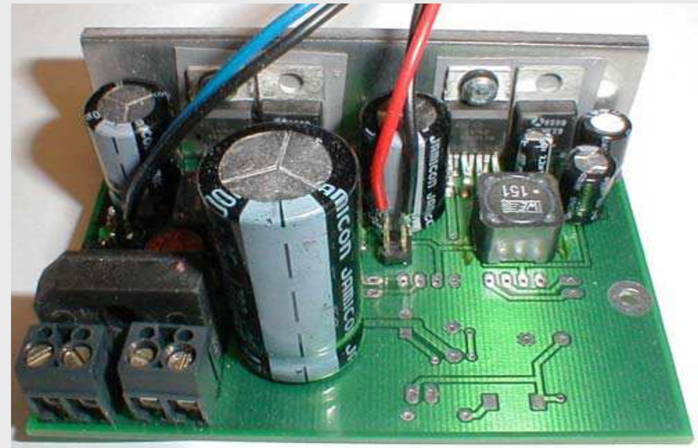


Buck Converter ST L4960/2.5A/fs 85-115KHz

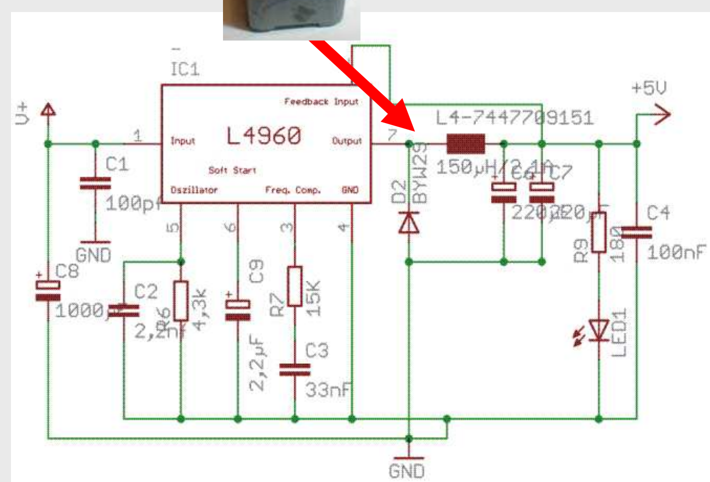
EMI: Conducted Emission Measurement

- Power supply V 1.1





PCB



Schematic

EMI: Be Aware:

- **Select the right parts for your application**

- **Do not always look on cost**

Very easy solution with a dramatic result!!!

Choke before

or

Choke after

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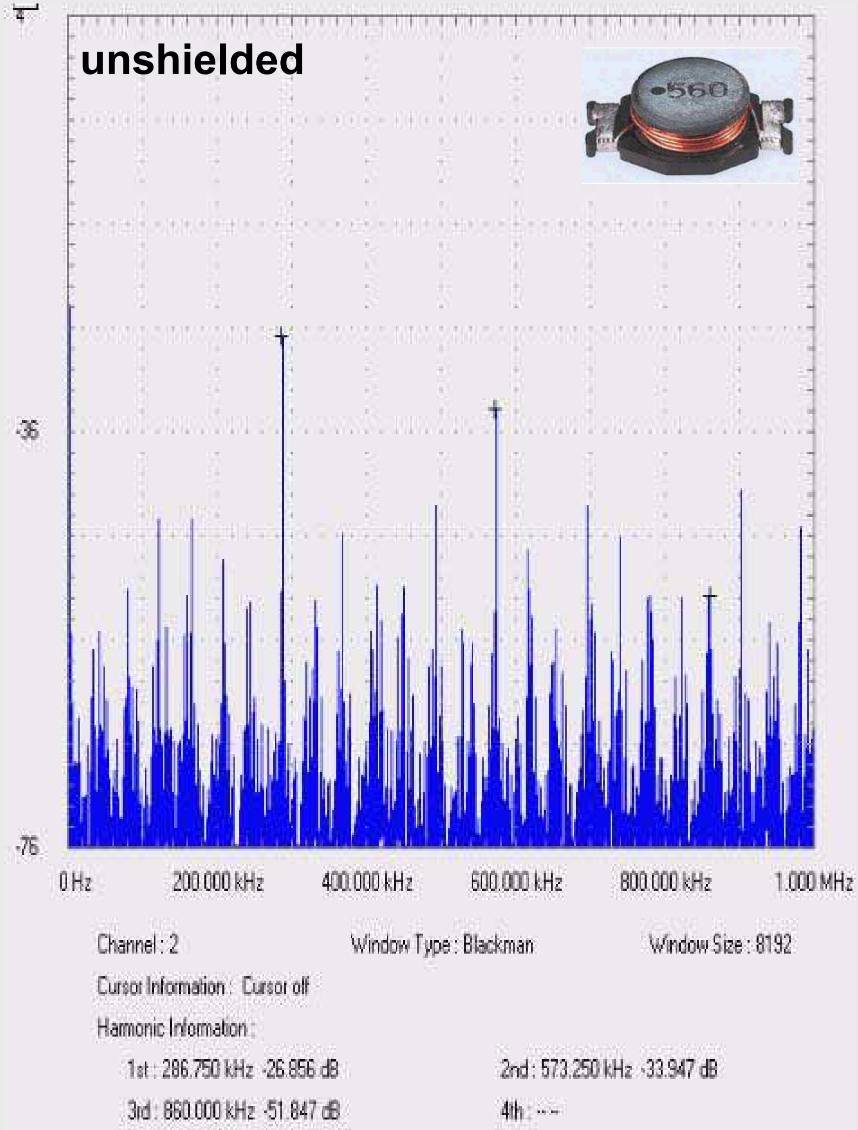
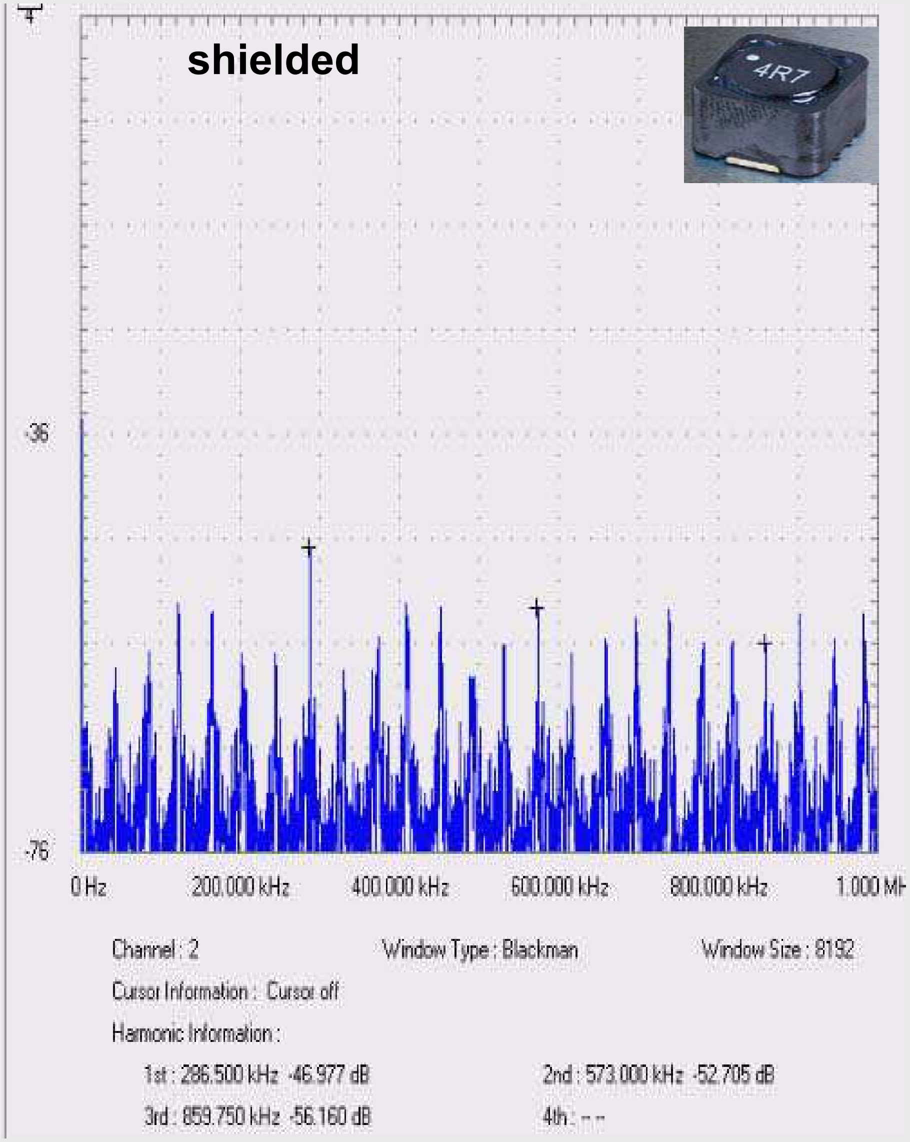
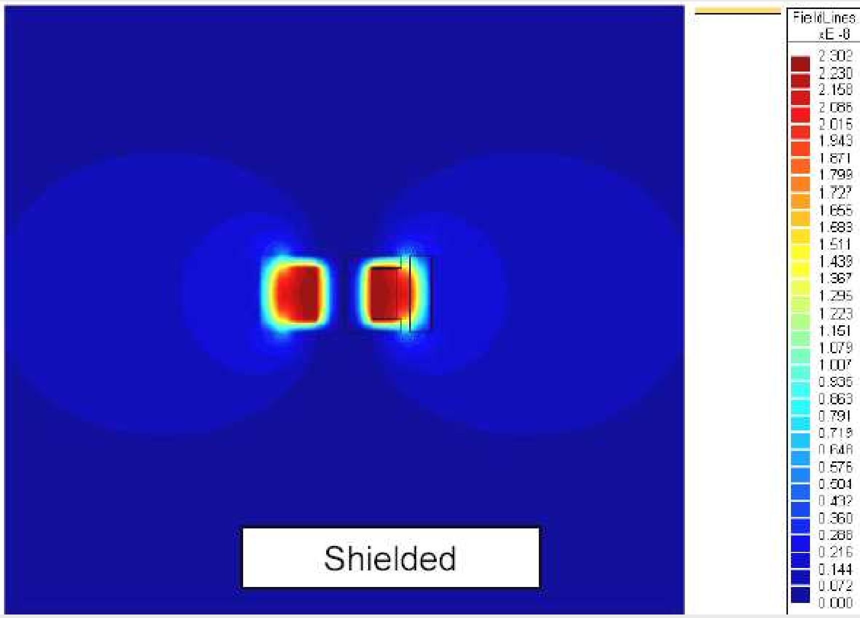
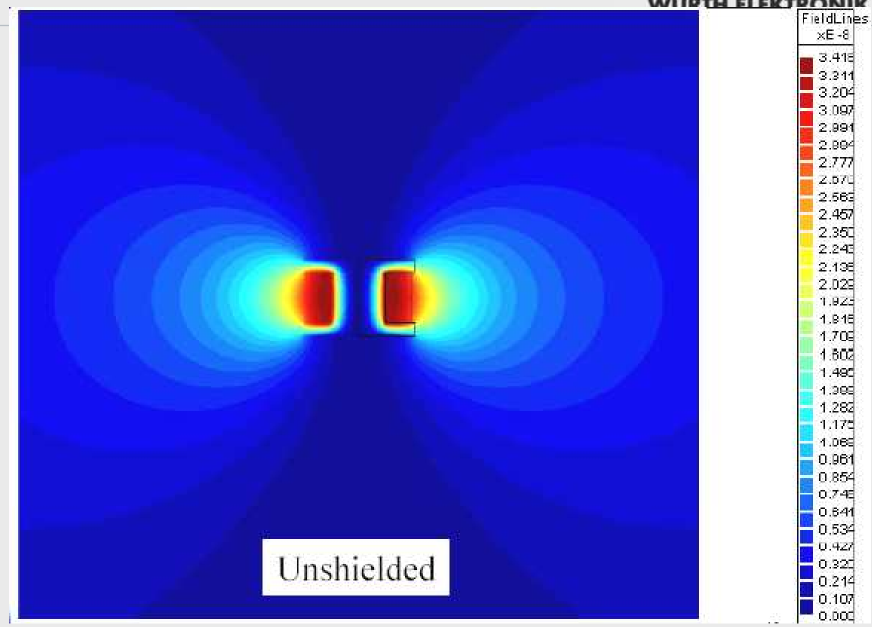
EMI: Shielded vs. Unshielded Power Inductor





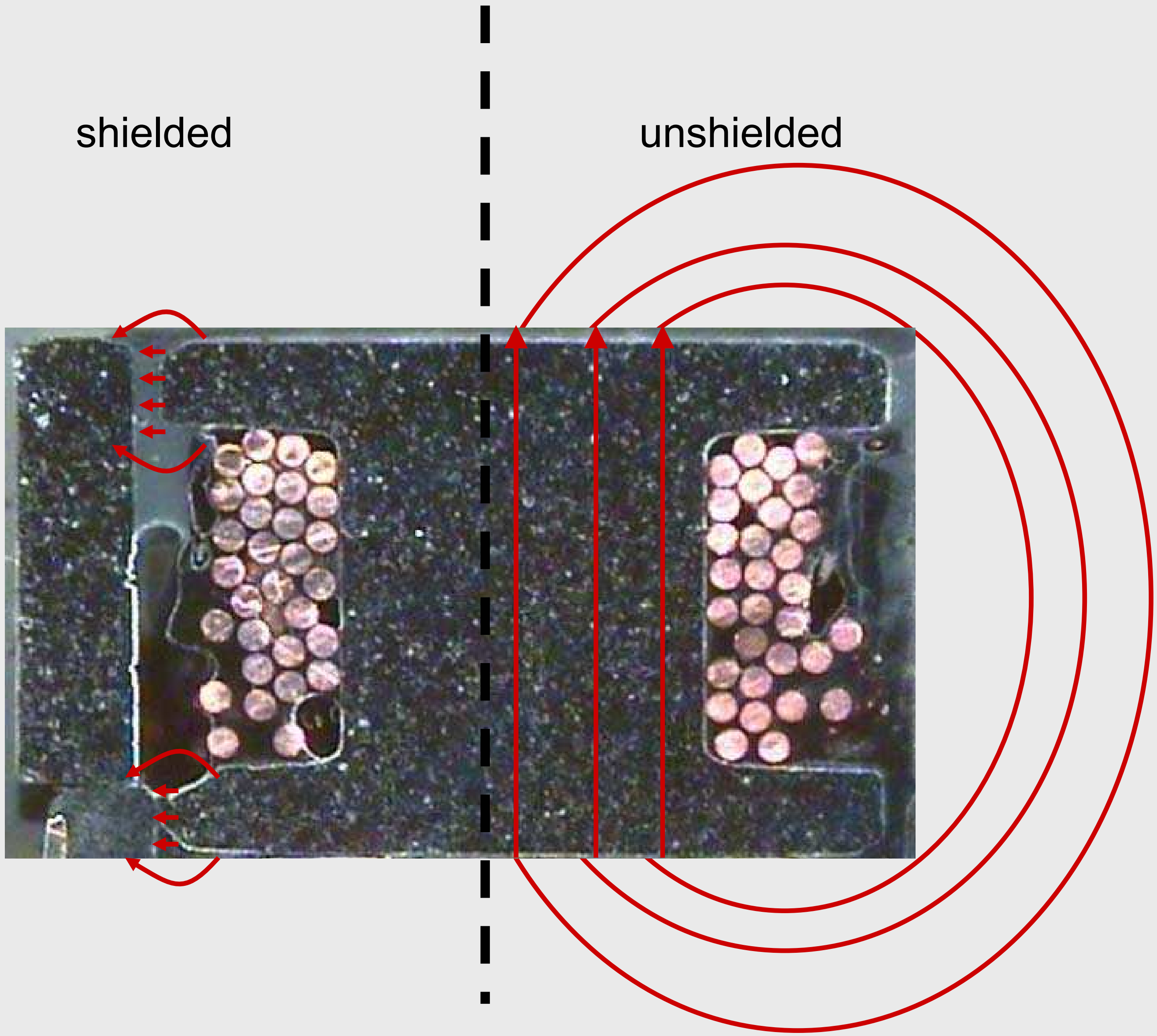
EMI: Shielded vs. Unshielded Power Inductor





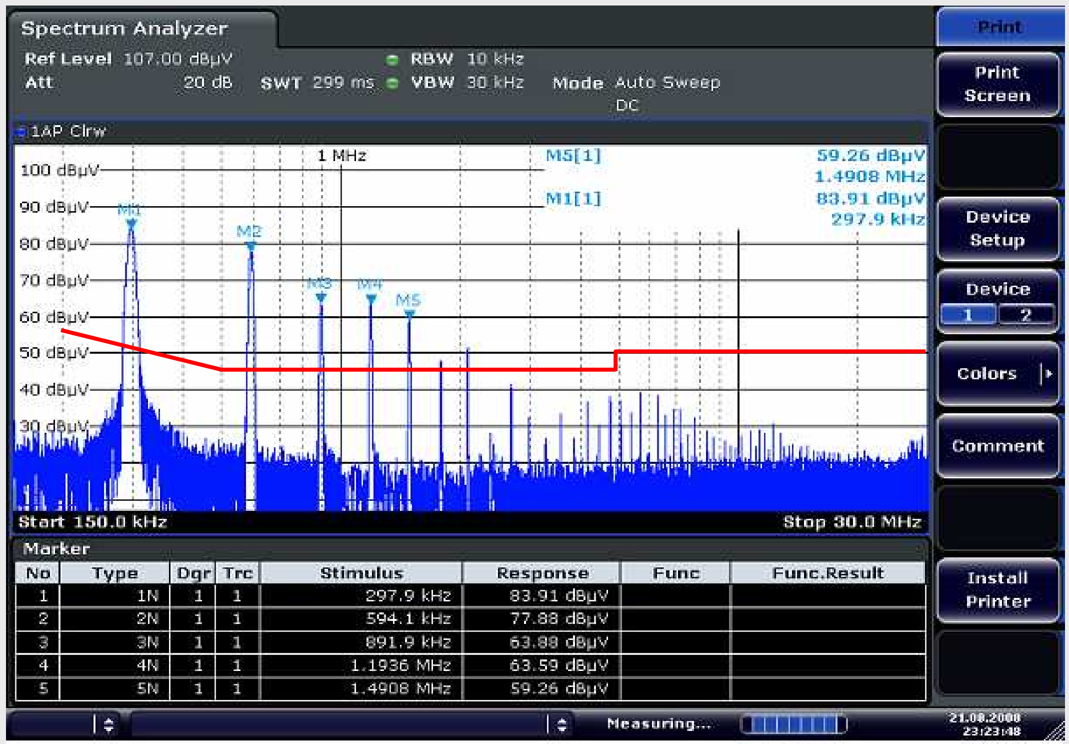
EMI: Shielded vs. Unshielded Power Inductor

- Magnetic field



Conducted Emissions Example – Test and Compare

- Differential Choke
- Bifilar Wound Common Mode Choke
- Sector Wound Common Mode Choke
- Chip Bead



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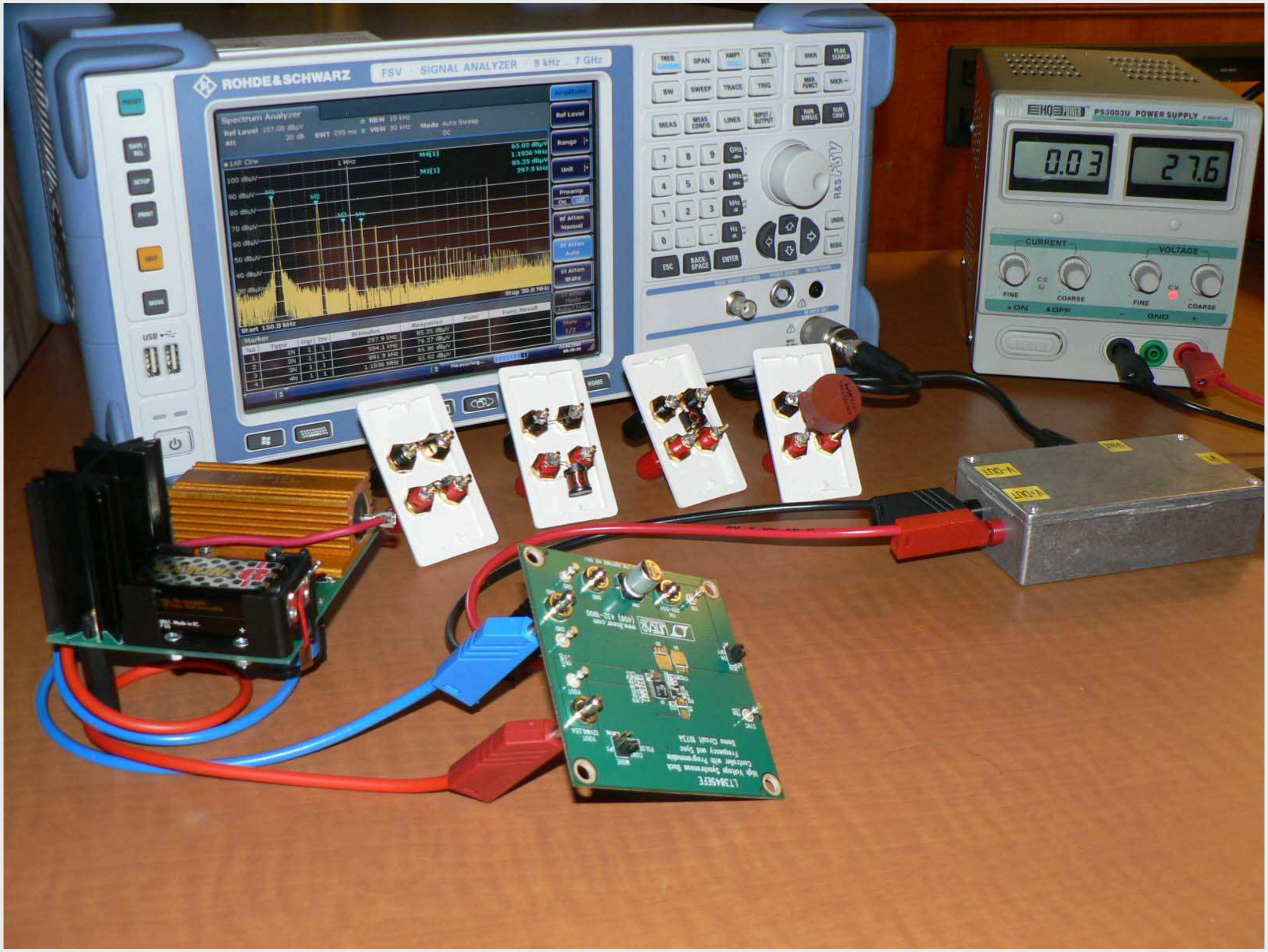
Conducted Emissions Example - Test Setup



a) no load
b) 1.5A load
150KHz fsw.

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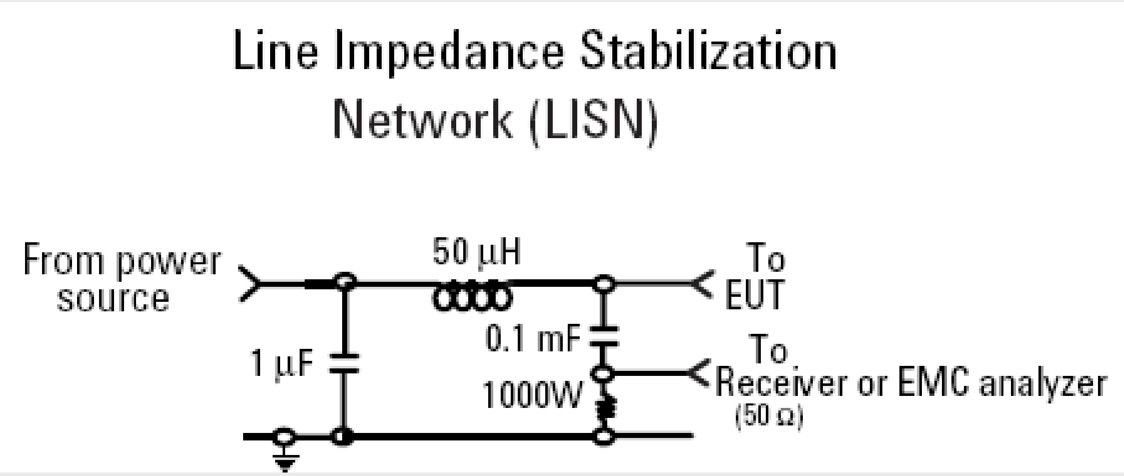
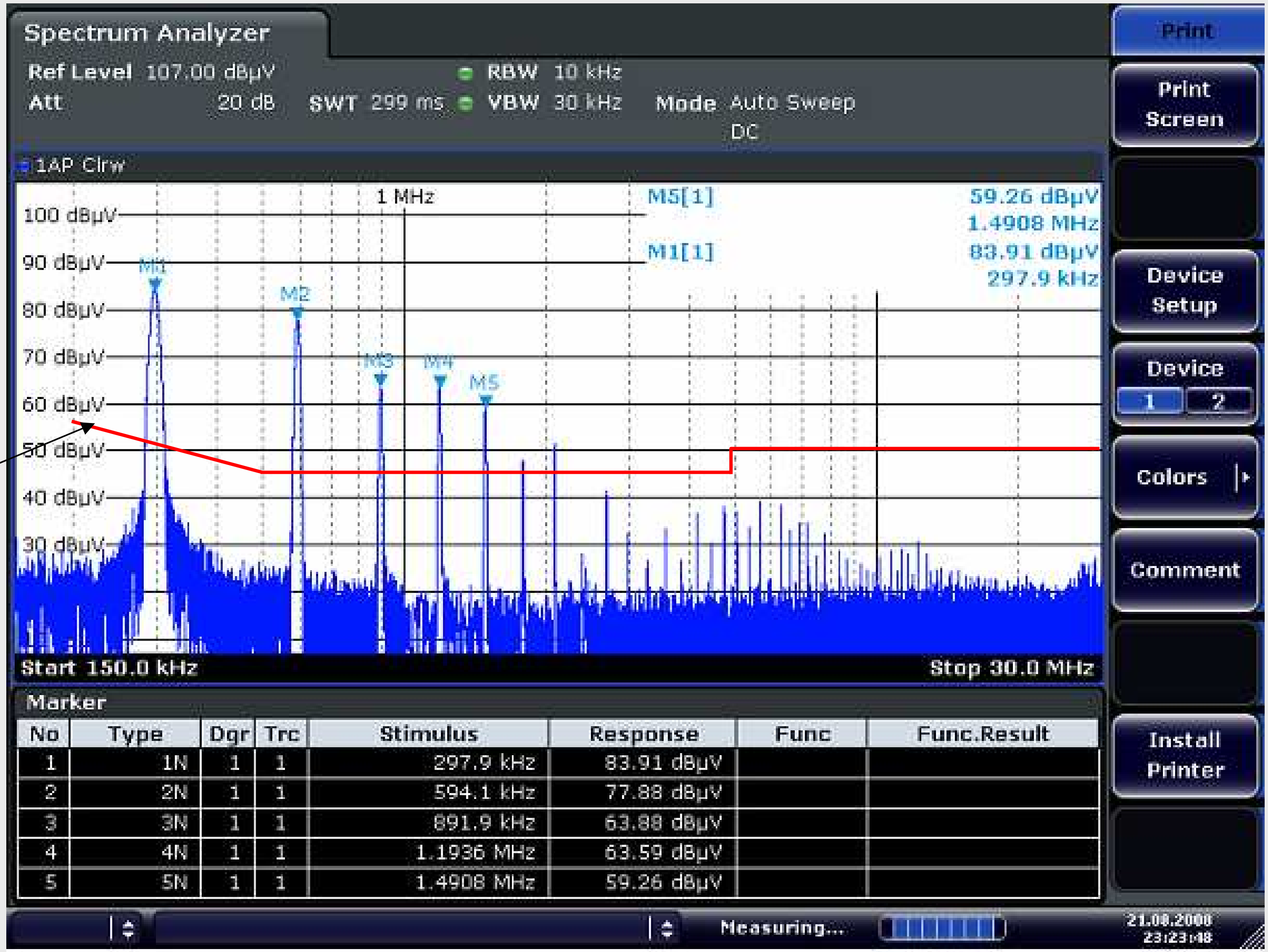
Conducted Emissions Example - LISN



- Isolates DUT from Power Source (typically mains) Noise
- Provide characteristic Impedance to DUT (50ohms in this case)
- Path for Conducted noise from DUT to Spectrum Analyser

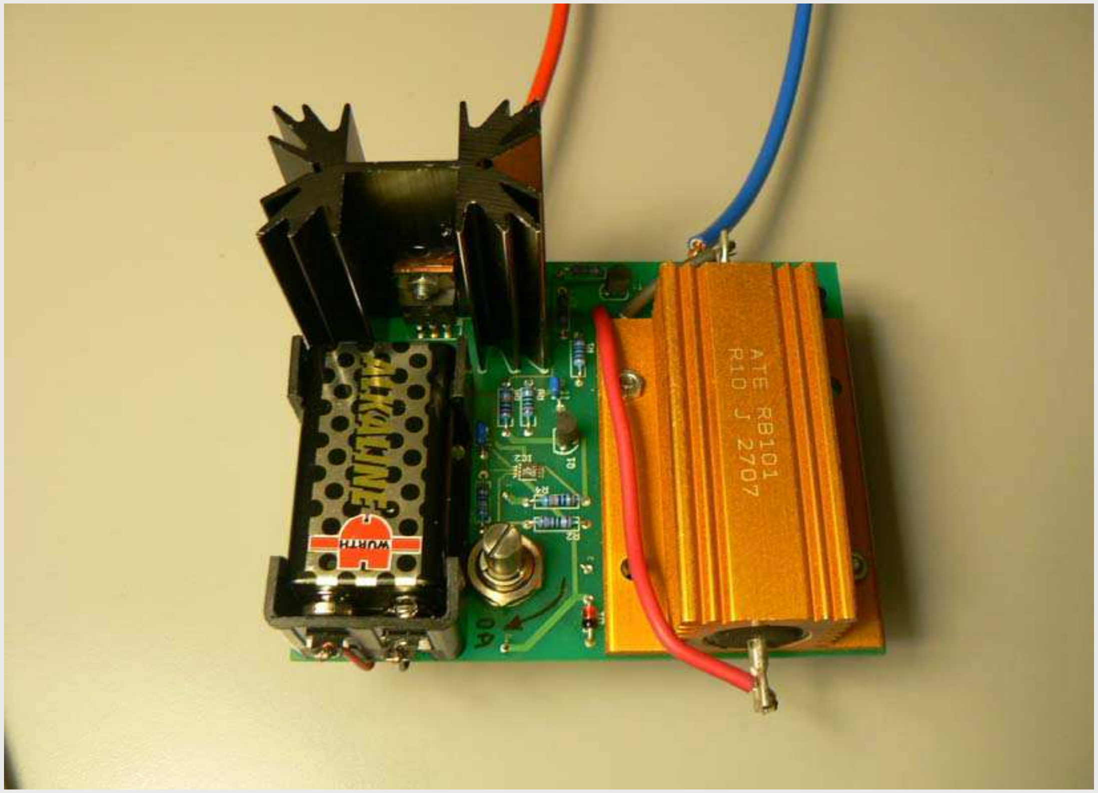
The 1 µF in combination with the 50 µH inductor is the filter that isolates the mains from the EUT. The 50 µH inductor isolates the noise generated by the EUT from the mains. The 0.1 µF couples the noise generated by the EUT to the EMC analyzer or receiver. At frequencies above 150 kHz, the EUT signals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

Conducted Emissions Example – Demo Board



FCC Class B limit

Conducted Emissions Example – Electrical Load



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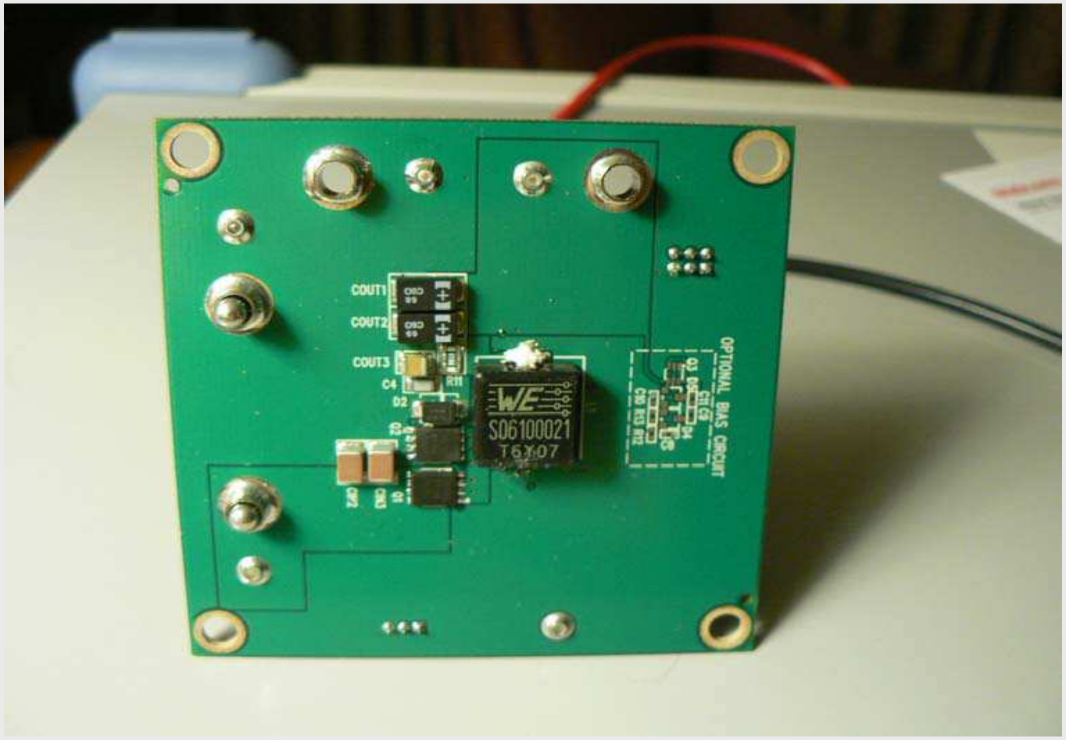
Conducted Emissions Example – Test Board

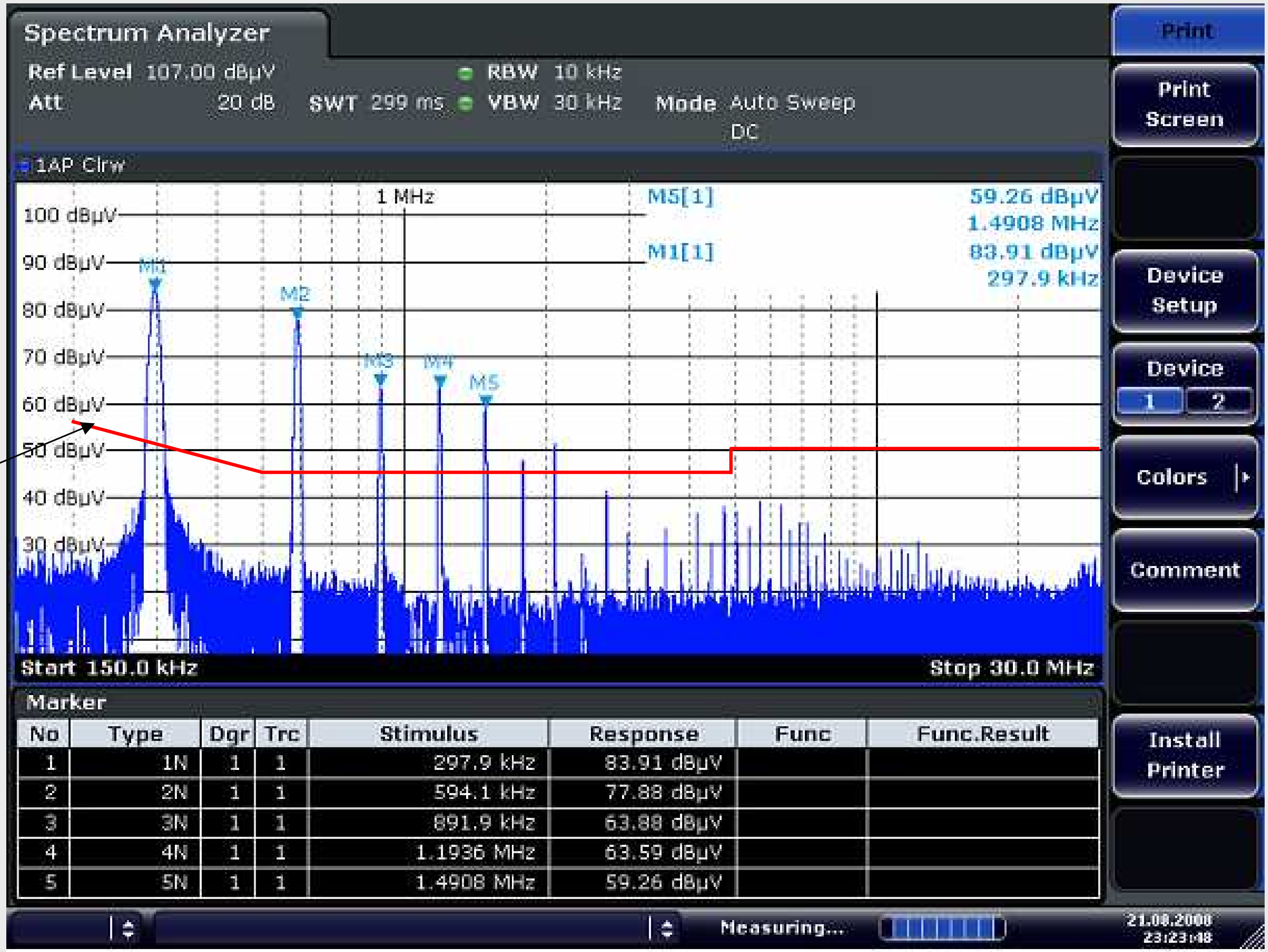
- DC/DC Converter
- Input Voltage20V-25V
- Output Voltage12V/6.25A
- Fsw: 150KHz

Testcondition:
- no load
- max. load 1.5A



Conducted Emissions Example – No Filter

FCC Class B limit



Conducted Emissions Example – Differential Choke

Differential Line Choke 220uH

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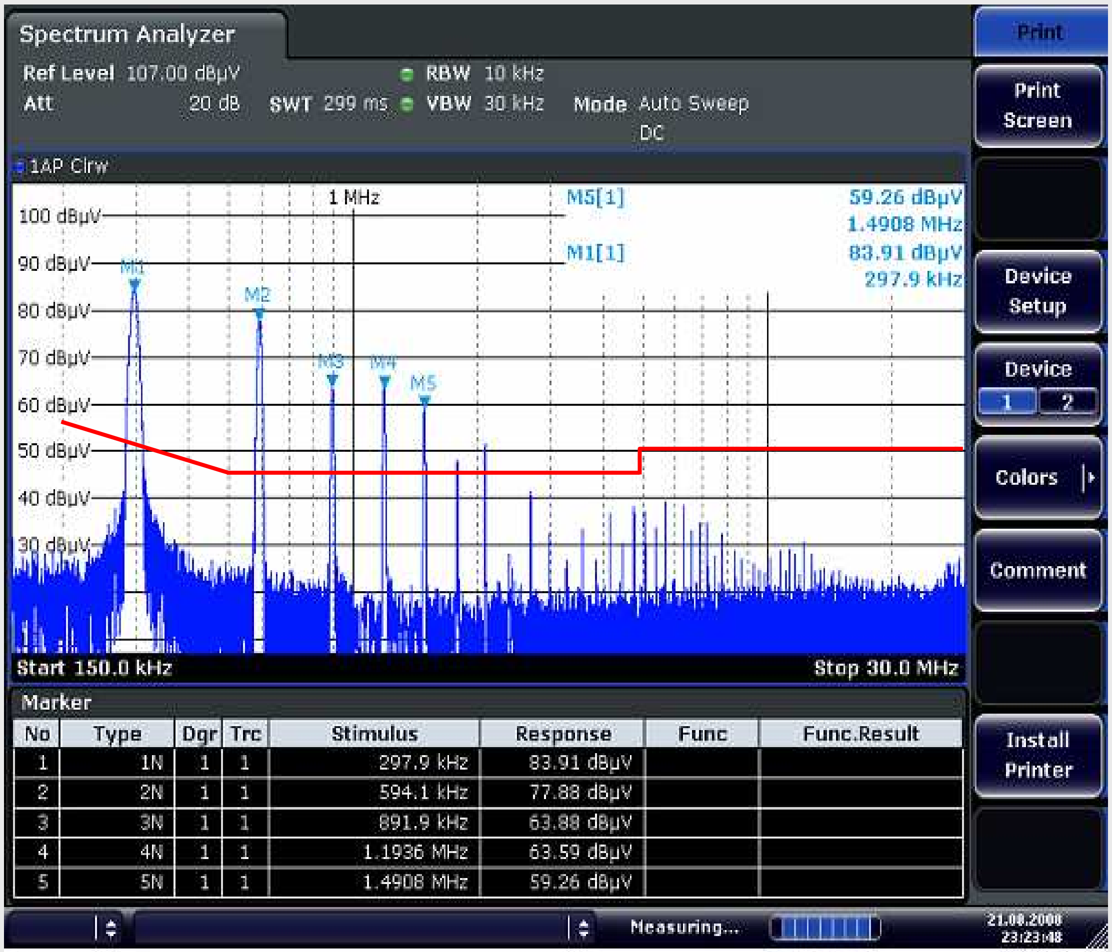
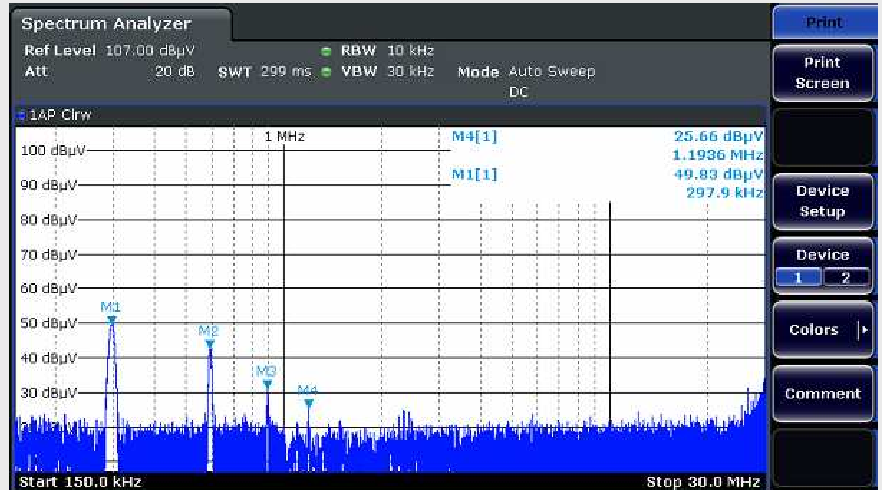
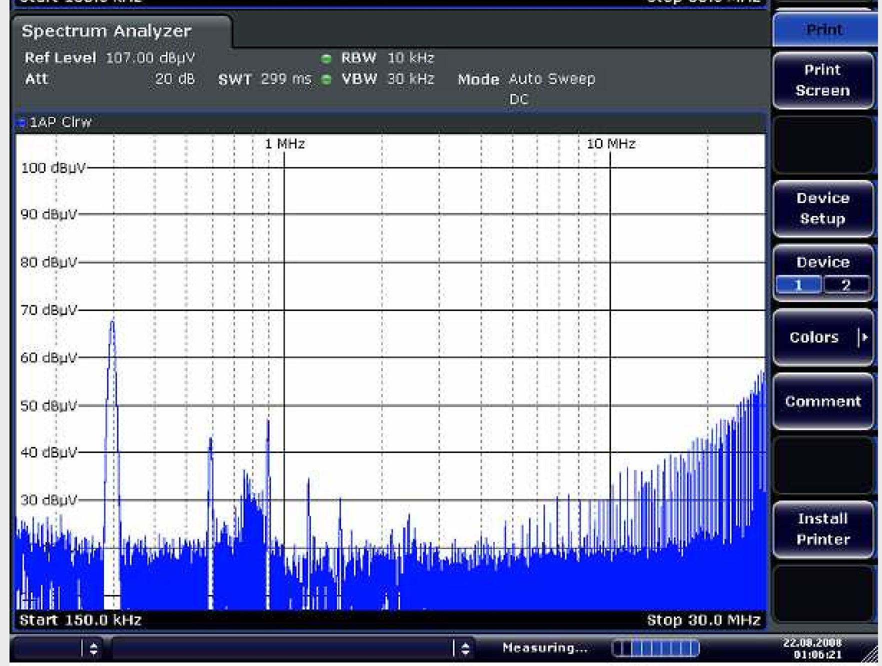
Conducted Emissions Example – Differential Choke Results

no load >

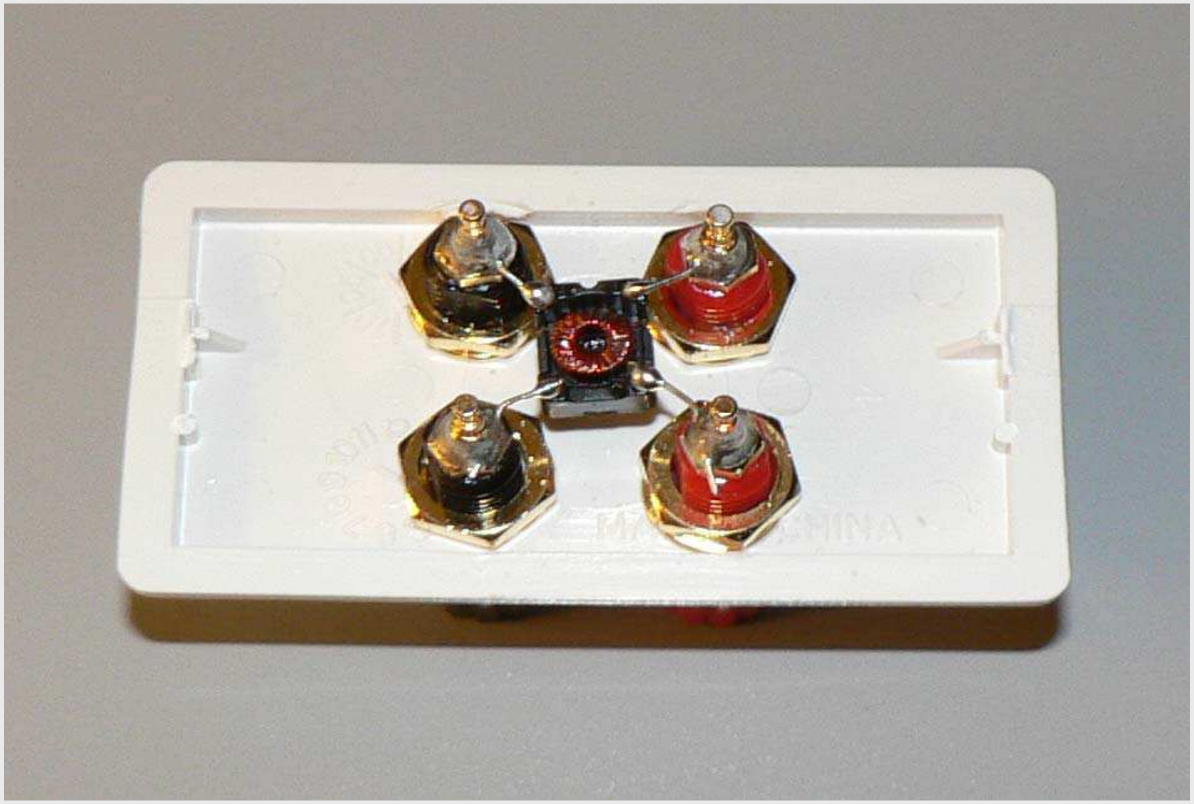






load 1.5A>

Conducted Emissions Example – Bifilar CMC

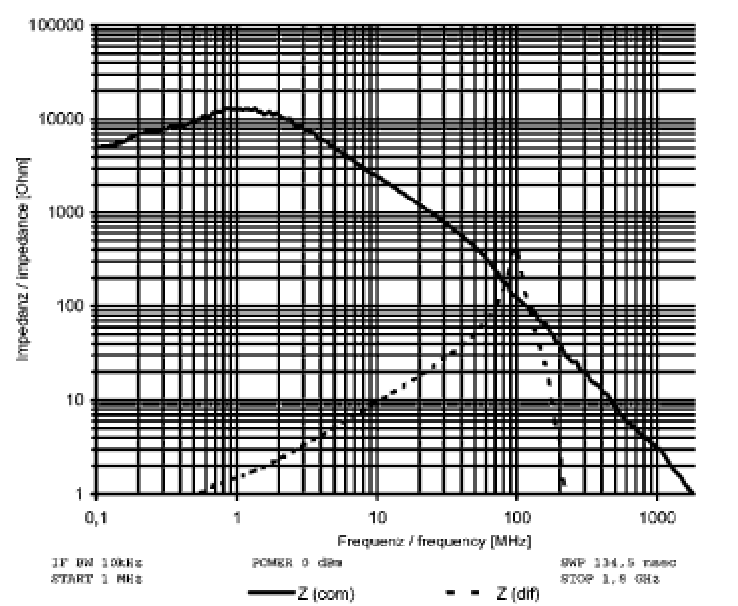


CMC 4.7mH Bifilar Winding

Conducted Emissions Example – Bifilar CMC

Artikel-Nr.	Induktivität (µH)	R_{DC} (Ω)	I_N (mA)	Impedanz max. (Ω)
744272121	2 x 120	0,025	2500	460
744272221	2 x 220	0,032	2200	780
744272251	2 x 250	0,035	2000	970
744272471	2 x 470	0,065	1600	1750
744272102	2 x 1000	0,180	950	3600
744272222	2 x 2200	0,300	750	7500
744272332	2 x 3300	0,360	650	8900
744272392	2 x 3900	0,540	520	9600
744272472	2 x 4700	0,720	350	13000

744 272 472



Warning: Don't try this at home!

For Demonstration Purposes Only!

Load is 1.5A

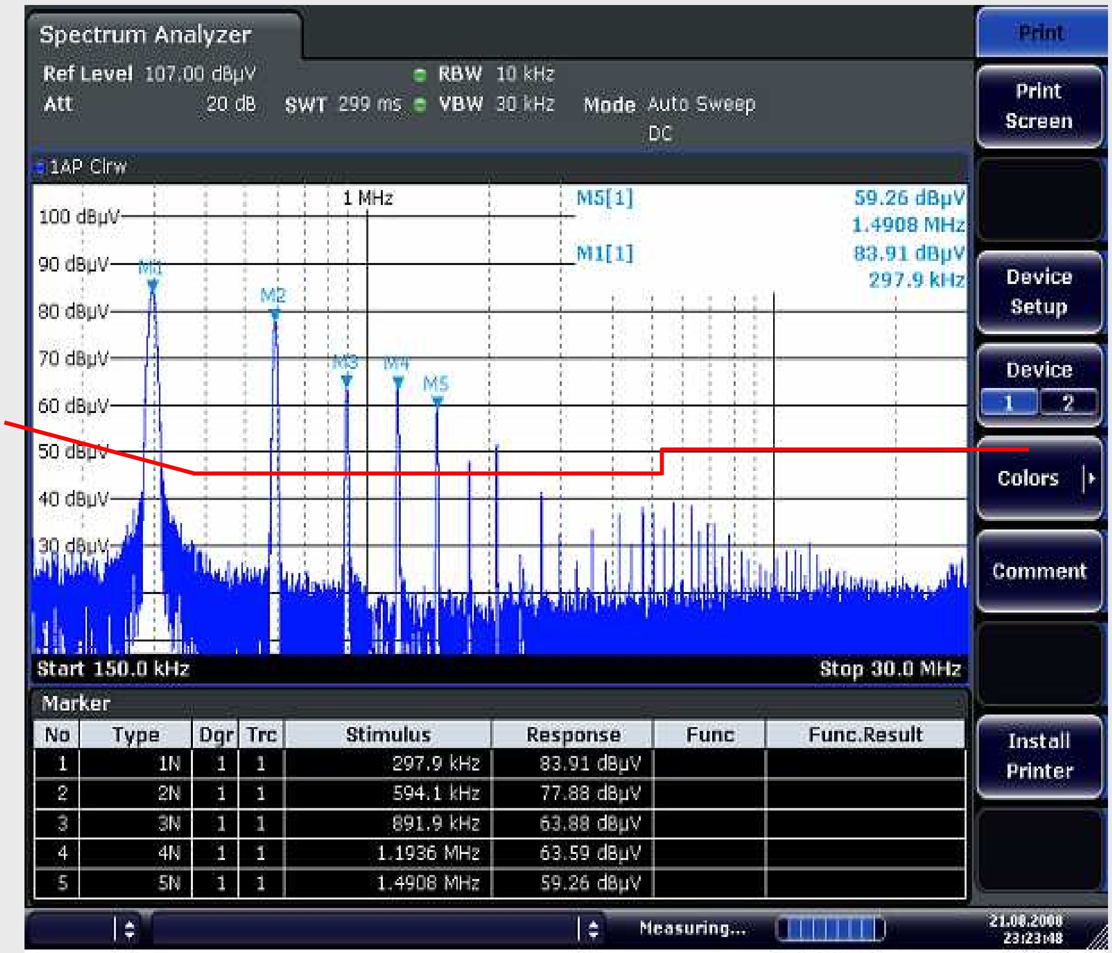
And….. CMC

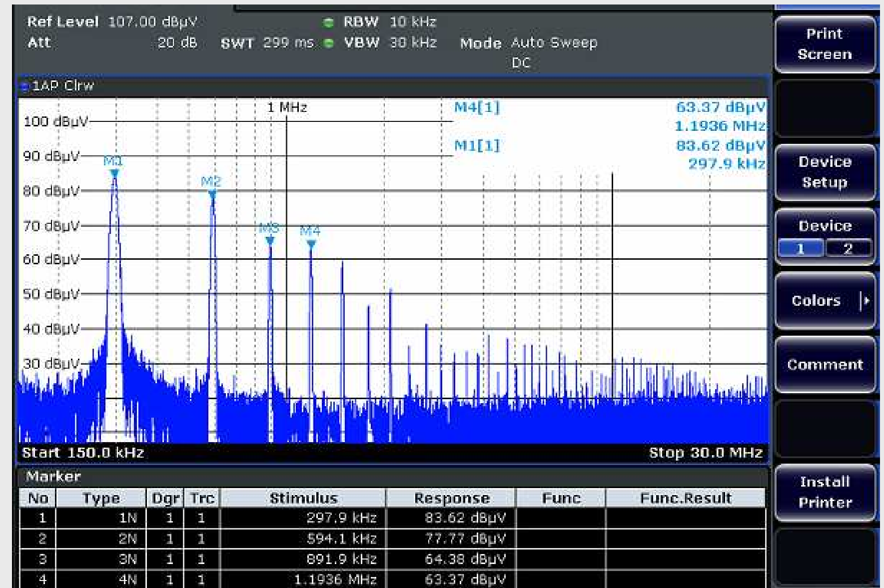
CMC 4.7mH Bifilar Winding

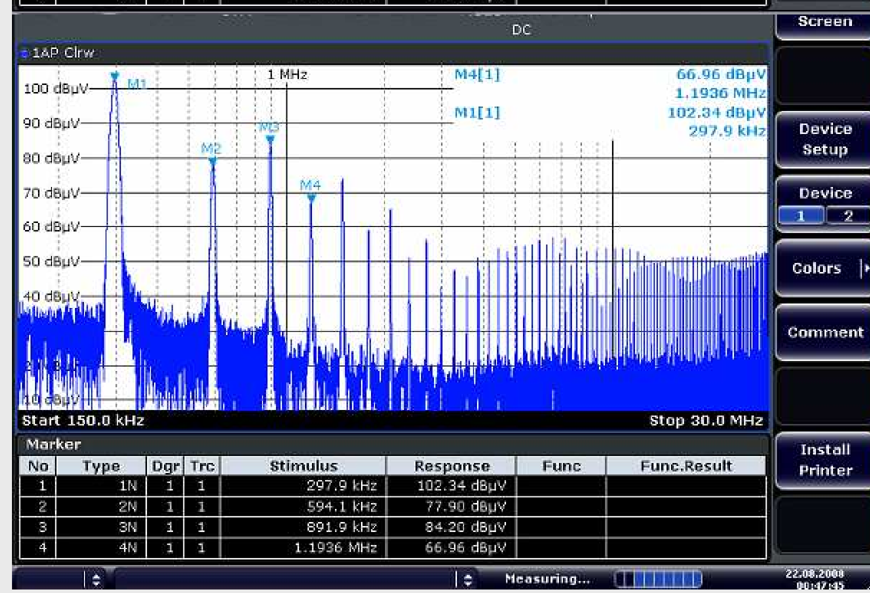
more than you expect

Conducted Emissions Example – Bifilar CMC Results

no load >







CMC 4.7mH Bifilar Winding

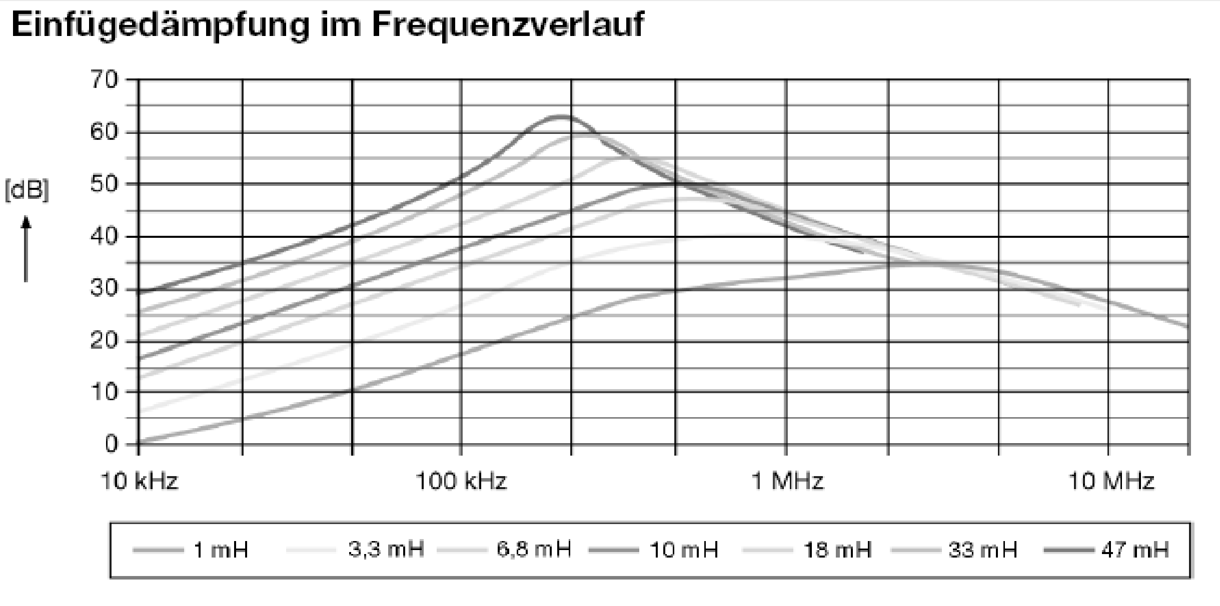
load 1.5A>

Conducted Emissions Example – Sector CMC

CMC 47mH sectional winding

more than you expect

Conducted Emissions Example – Sector CMC

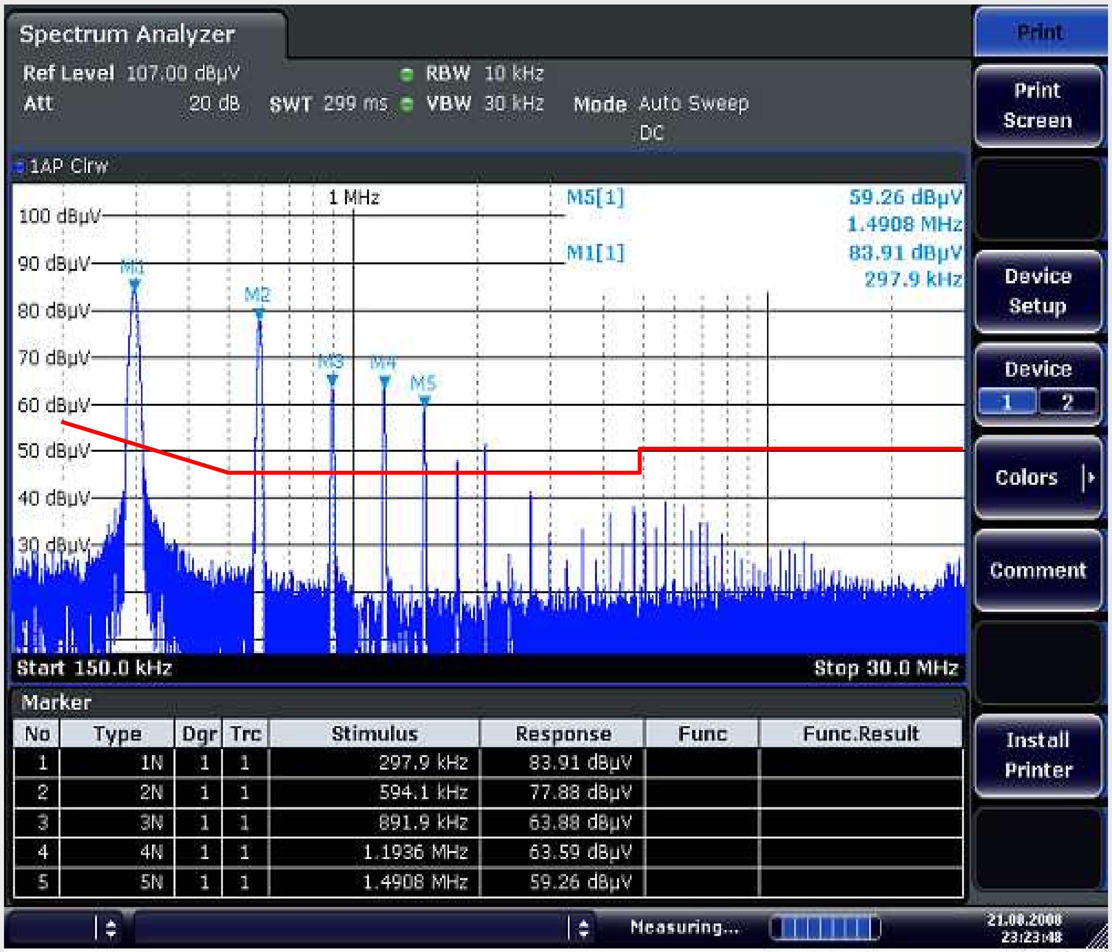


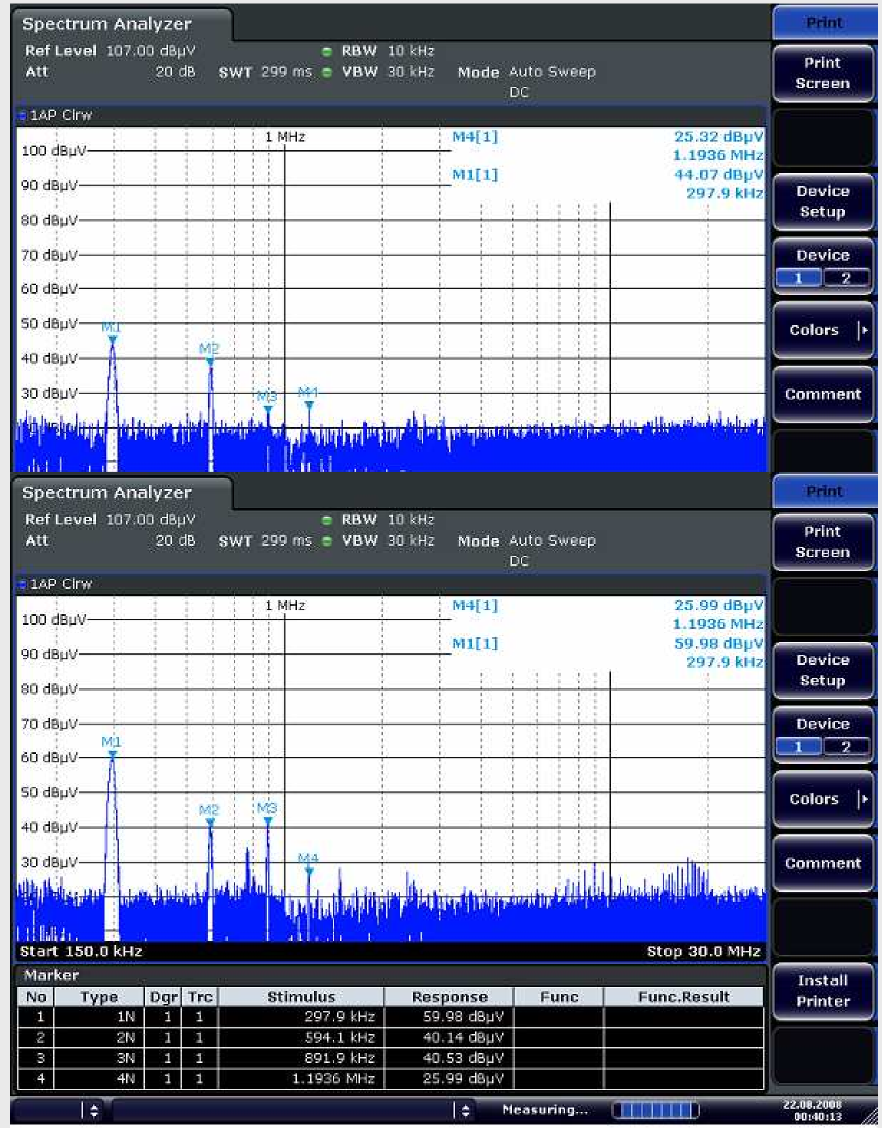
CMC 47mH Sectional Winding
Leakage Inductance Ls~ 250uH (5% of L)

more than you expect

Conducted Emissions Example – Sector CMC Results

no load >





CMC 47mH sectional winding

load 1.5A>

more than you expect

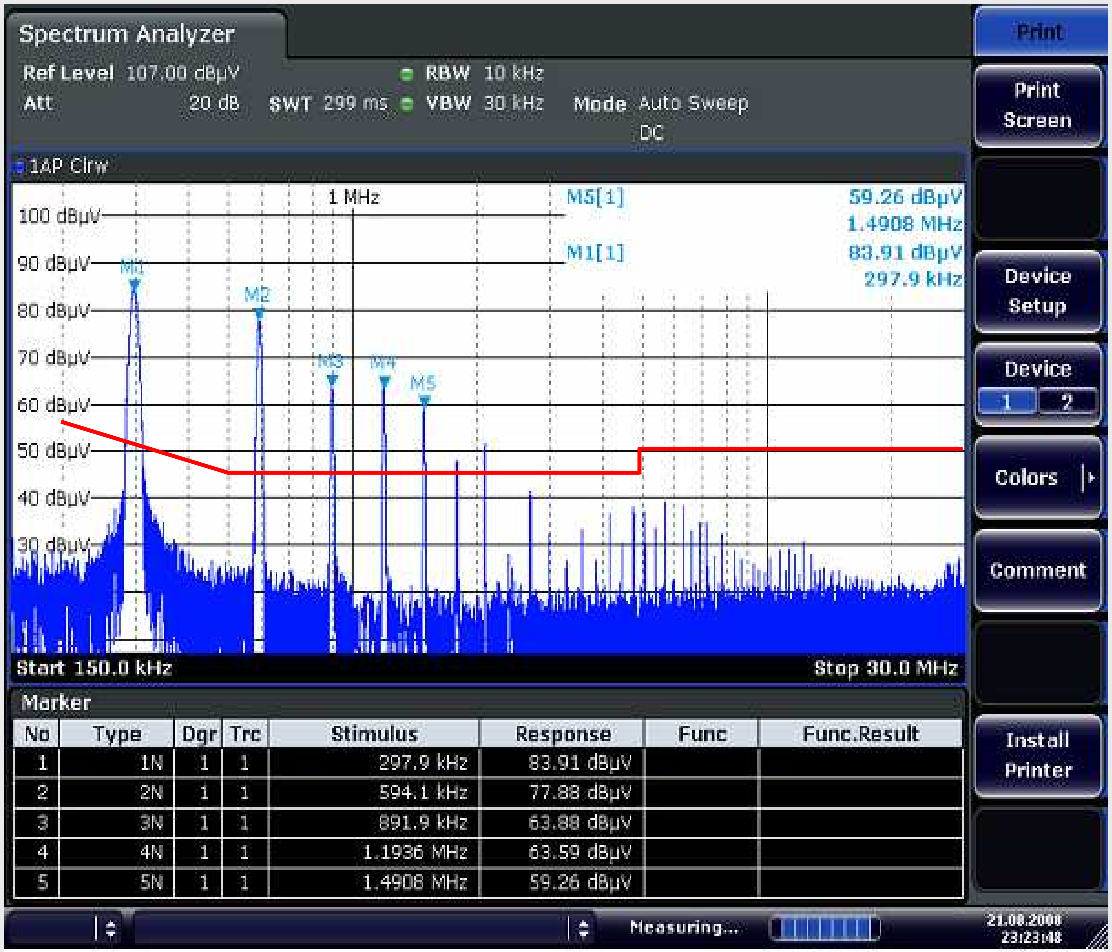
Conducted Emissions Example – Chip Bead

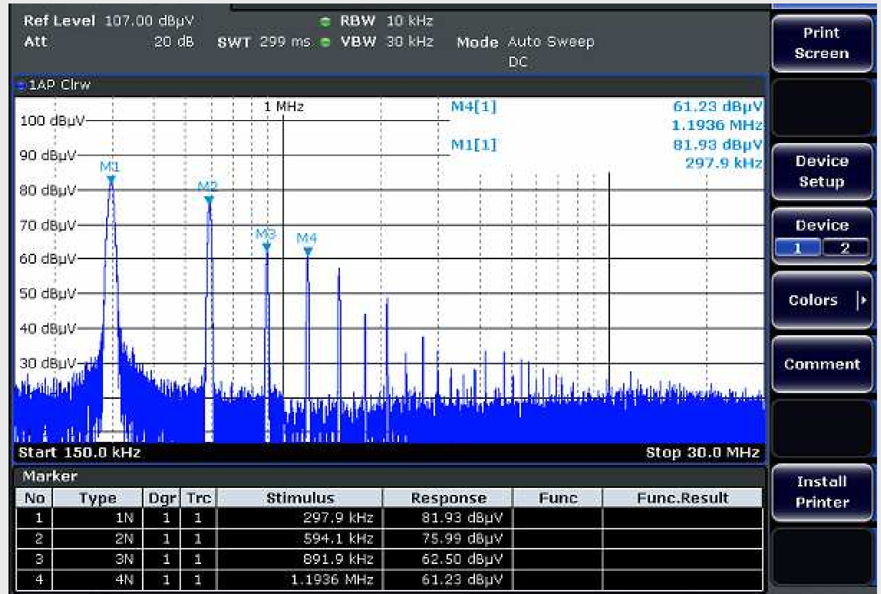
Chip Bead 530Ω / 3A

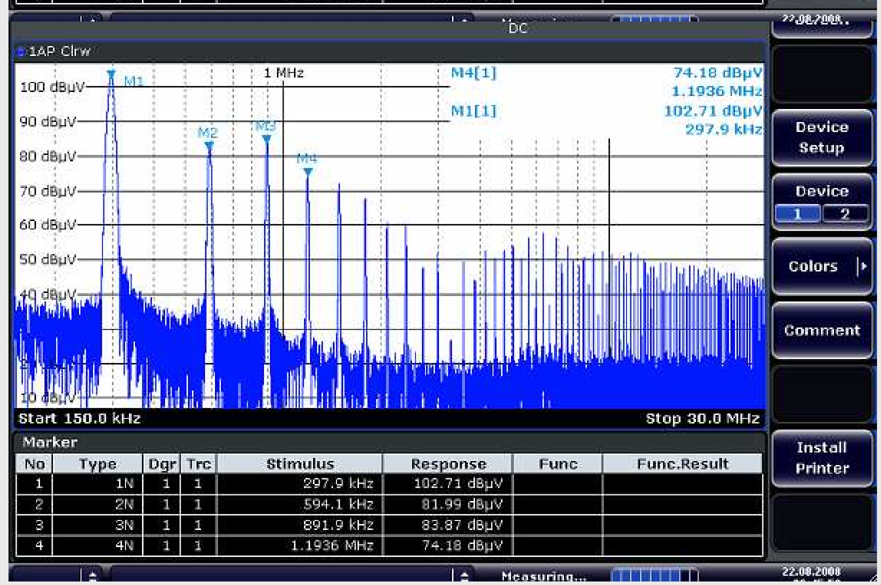
more than you expect

Conducted Emissions Example – Chip Bead Results

no load >



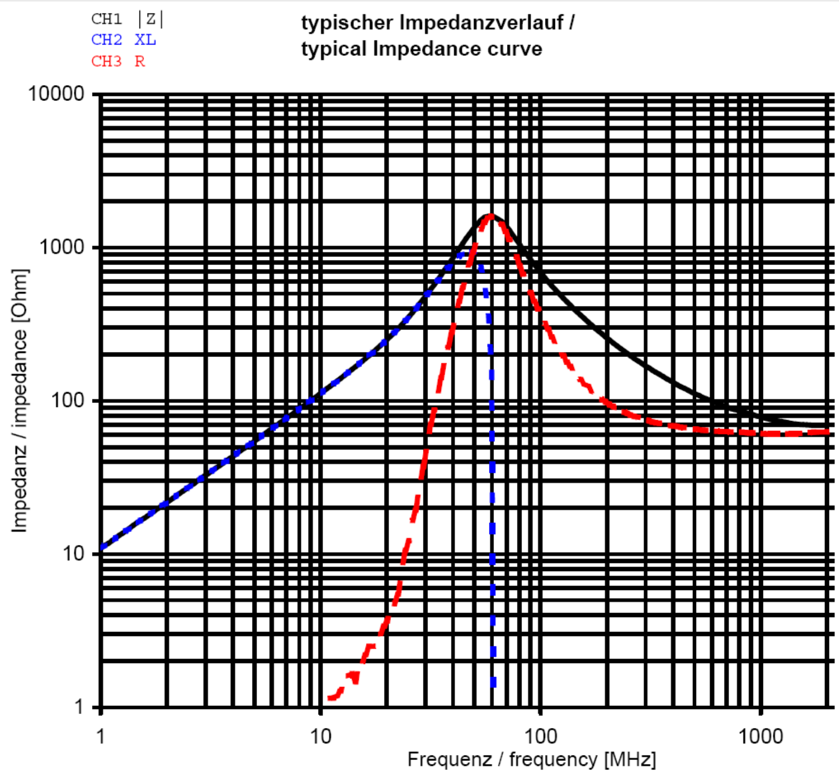


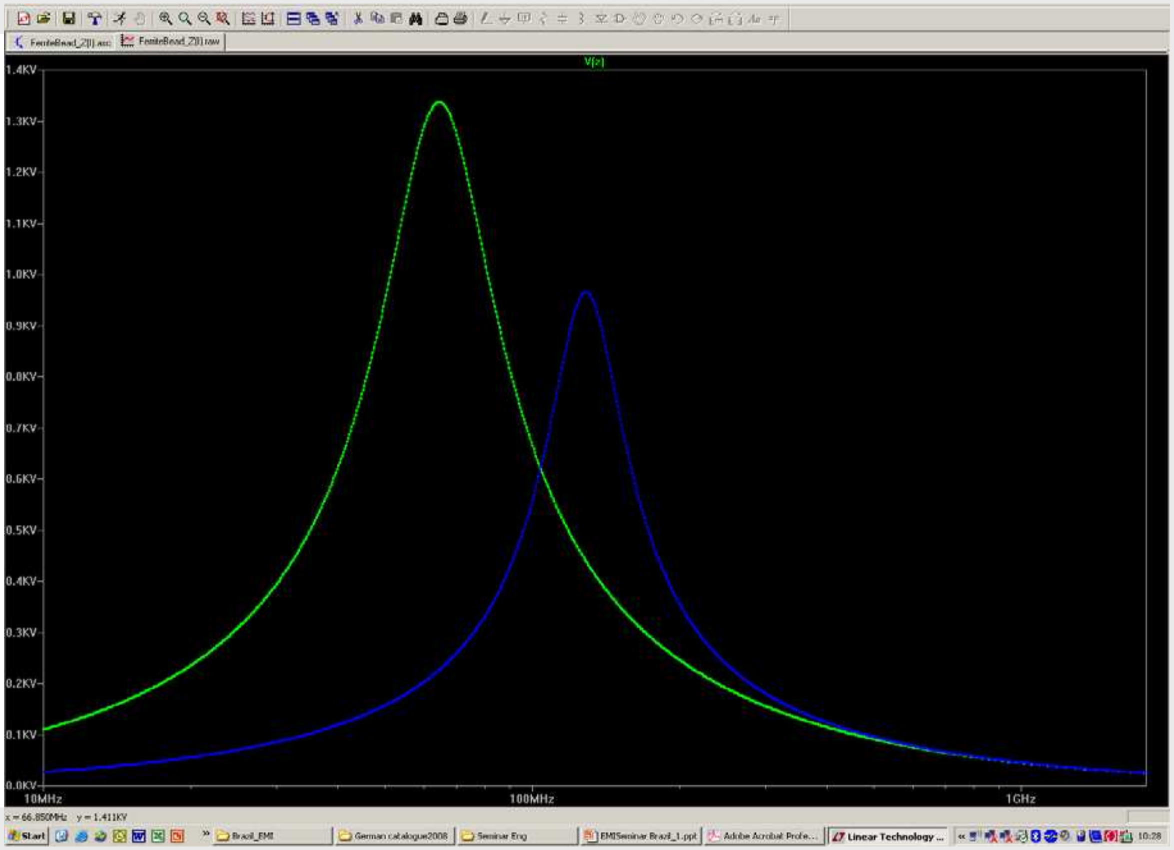


Chip Bead 530Ω / 3A

load 1.5A>

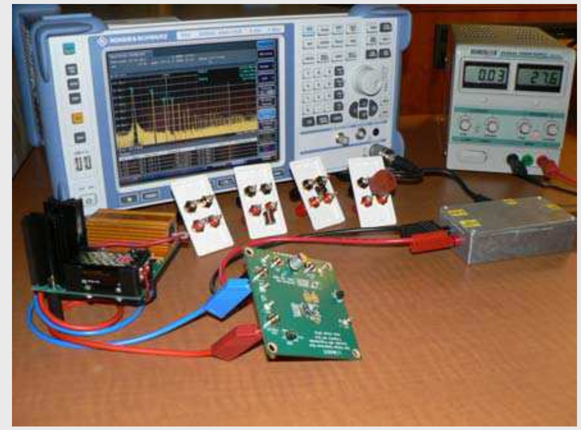
Conducted Emissions Example – Chip Bead





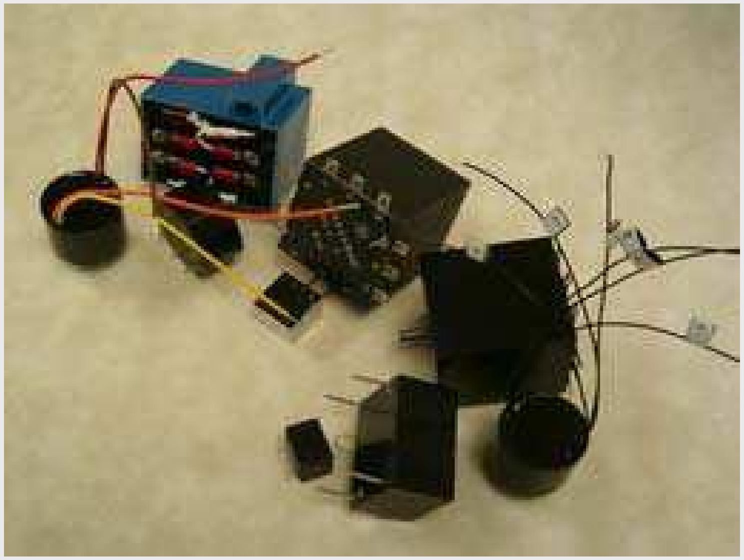
Chip Bead 530Ω / 3A

Conducted Emissions Example - Conclusions



- High Frequency Noise Appears Under Load
- Noise is Differential Mode
- Differential Choke
  - Attenuates low frequency noise because of SRF
- Bifilar CMC
  - Does not attenuate because of very low leakage inductance.
- Sector CMC
  - Attenuates both high and low because of leakage inductance with high SRF.
- Chip Bead
  - Without a load there is some affect at high frequencies, but with a load the bead pre-magnetizes and there is no affect at all.

Transformers for EMC – What to Choose

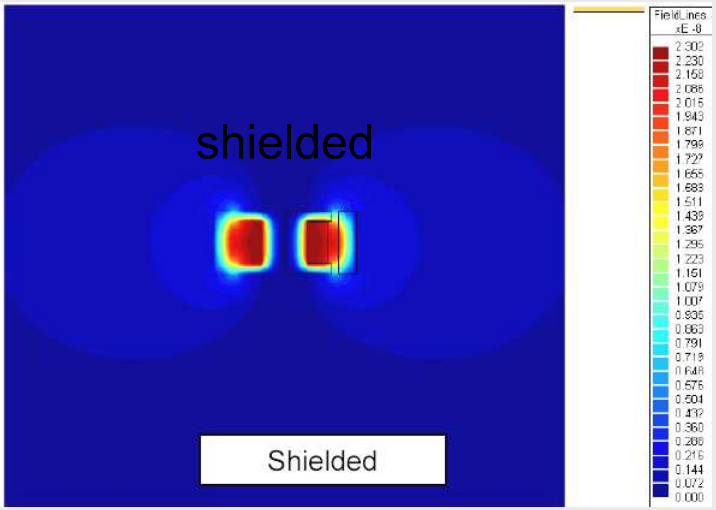


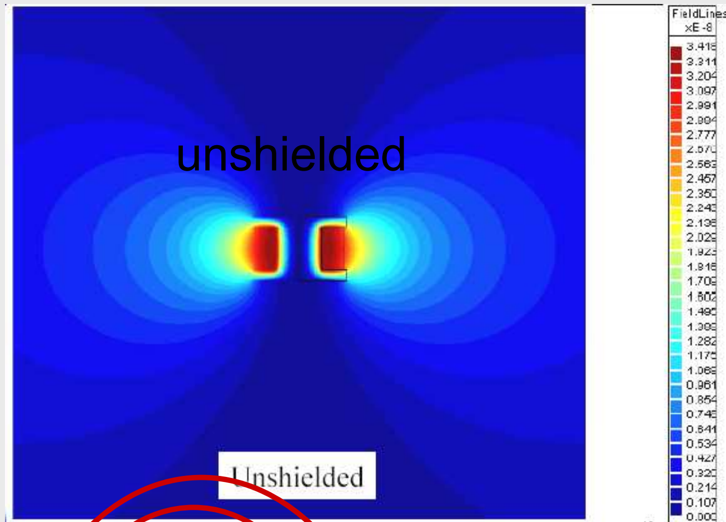
Transformers for EMC – No Antennas Please!

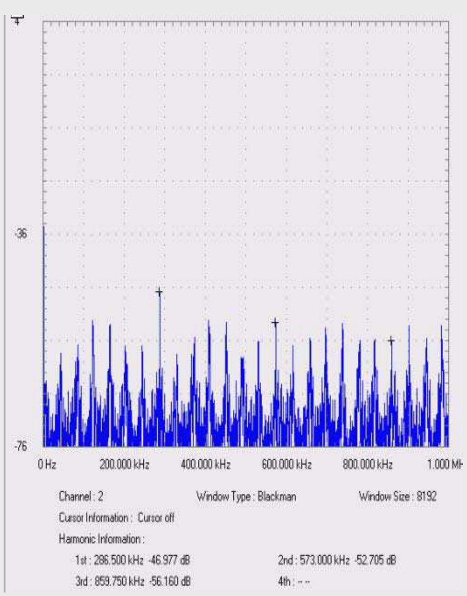
Enough Said!

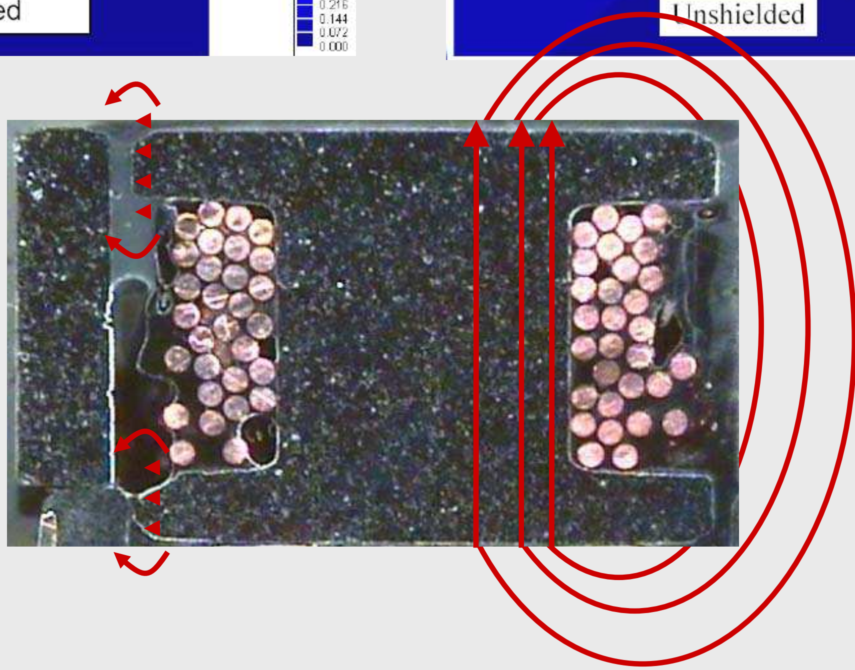
Flying Leads Make Great Antennas.

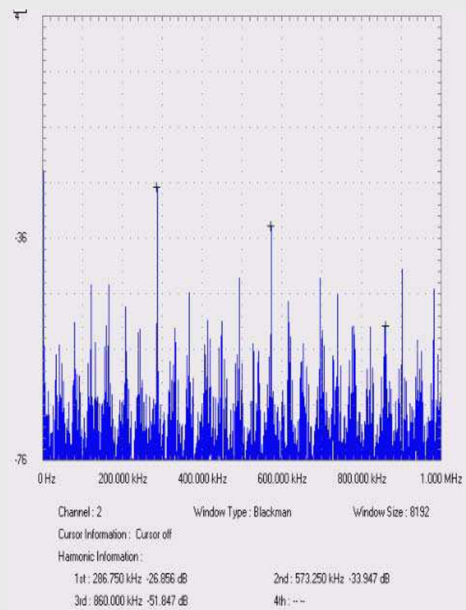
Transformers for EMC – No External Gaps









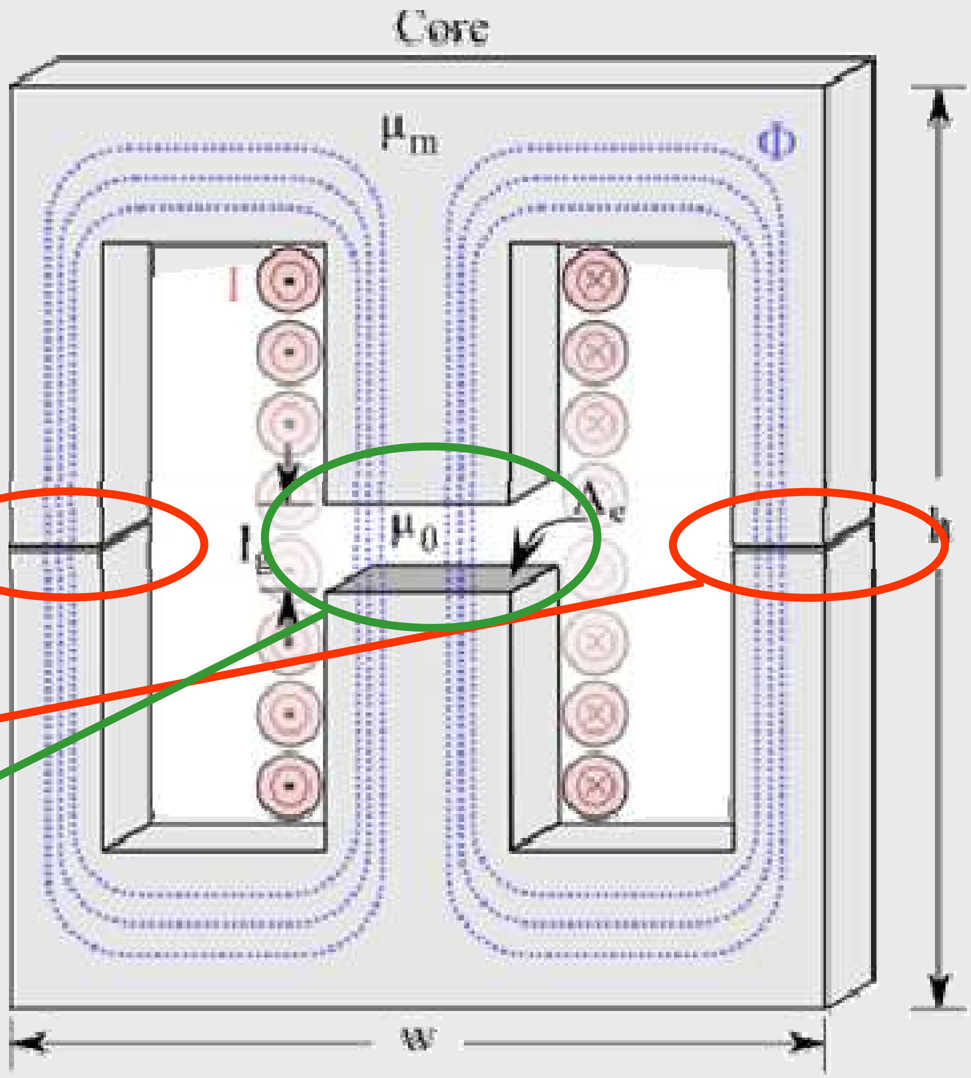


Transformers for EMC – No External Gaps

- Center Leg Gap Only
  - Windings Shield
- No Gaps in Outer Legs
  - Nothing to Shield

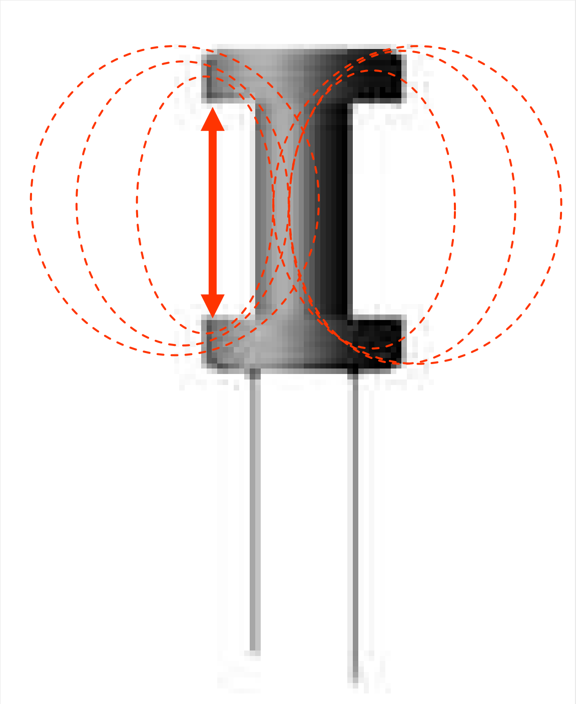
No Gaps Here

Gap Here



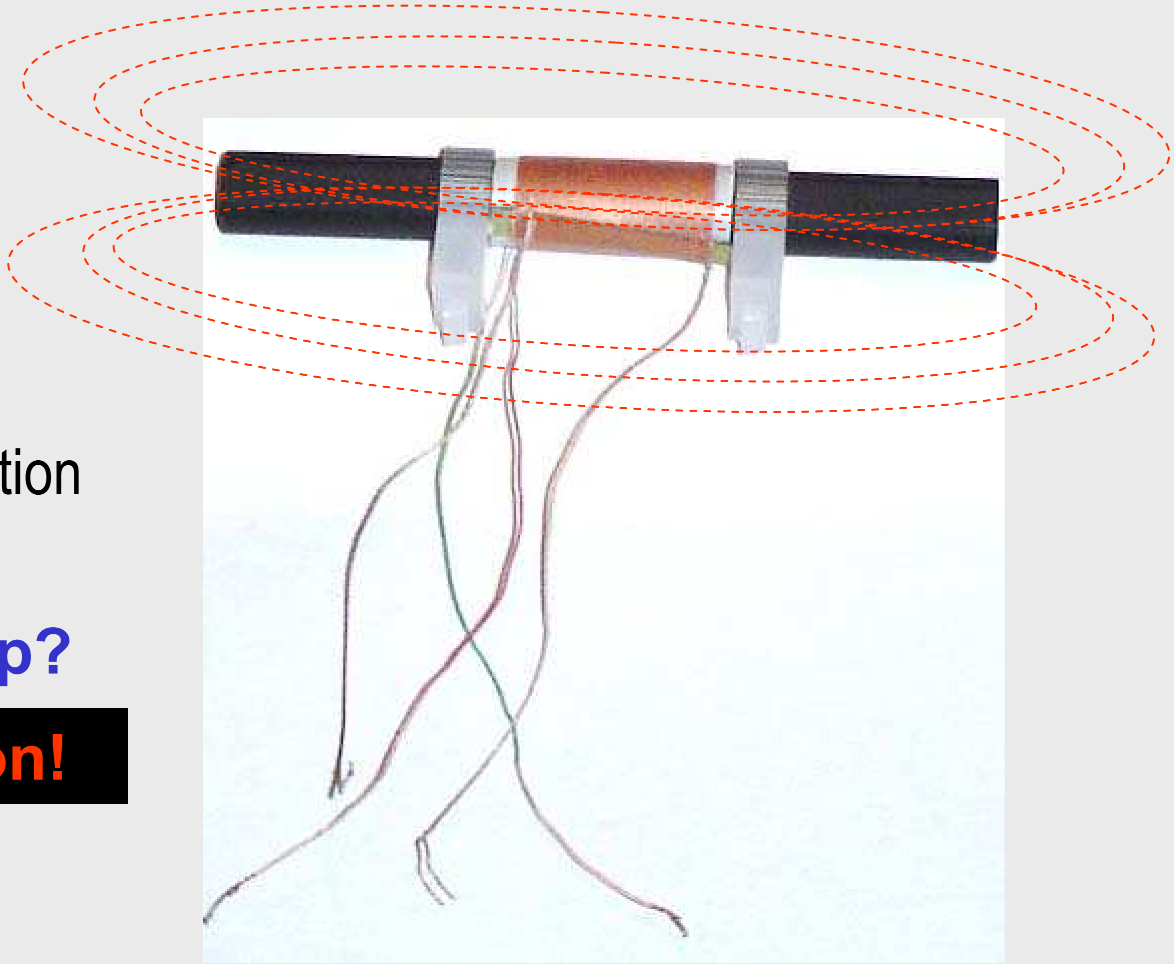
Transformers for EMC – No Drum Cores

- Drum Core Style
- Very Large Gap
- Much Radiation



Not a good solution!

Transformers for EMC – No Rod Cores



- Rod Core Style
- Huge Gap – Much Radiation
- This is an AM Antenna

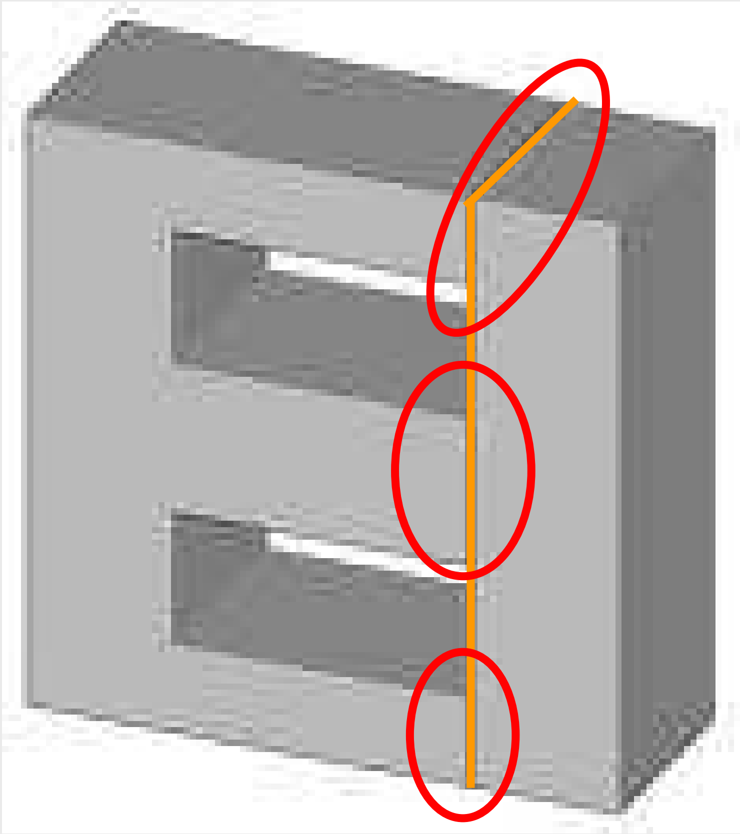
So Where is the Gap?

Not a good solution!

What is this?

Transformers for EMC – No EI Core

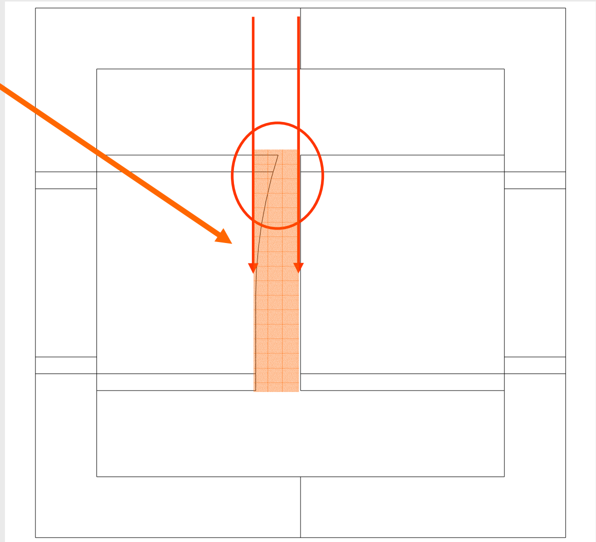
- EI Core Style
- Mylar or Tape Used for Gap
- Three Unshielded Gaps



Not a good solution!

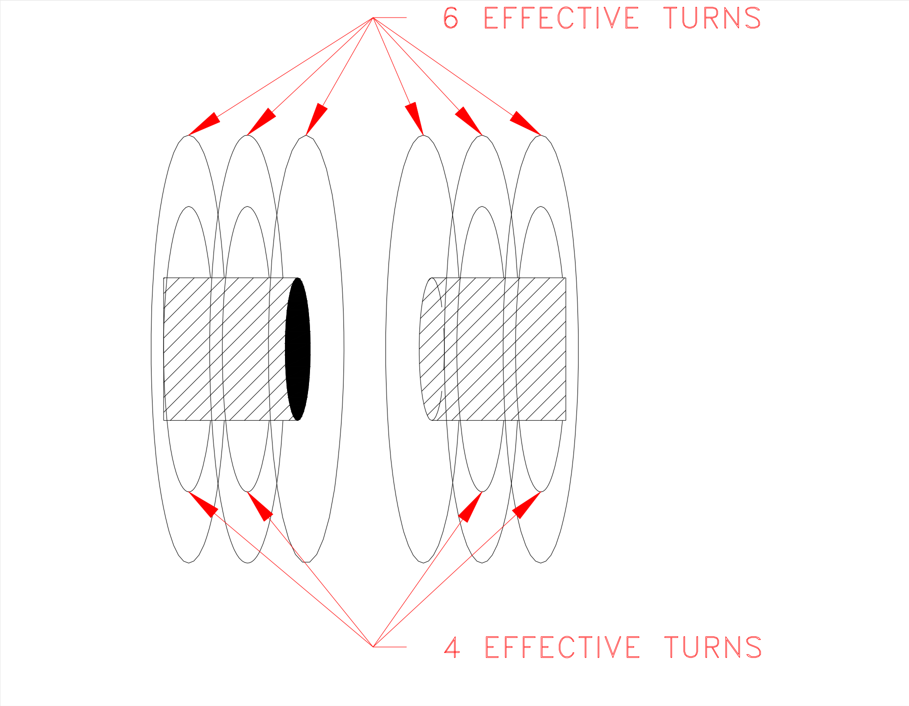
Transformers for EMC – Gap

- Gap Must be Perpendicular to Flux Lines
  - Here Only One Side is Gapped
- Uneven Gaps Are Inefficient, Why?
  - Core Saturates at Minimum Gap.
  - Requires a Larger Gap
- Also Larger Gap – More Potential EMI



Transformers for EMC - Fringing Affect

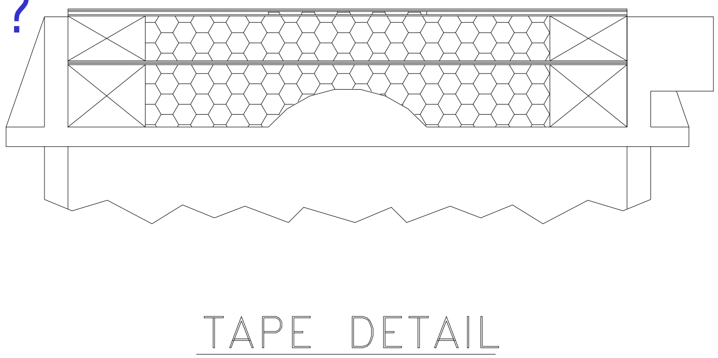
Turns Over Gap May Not "Count"

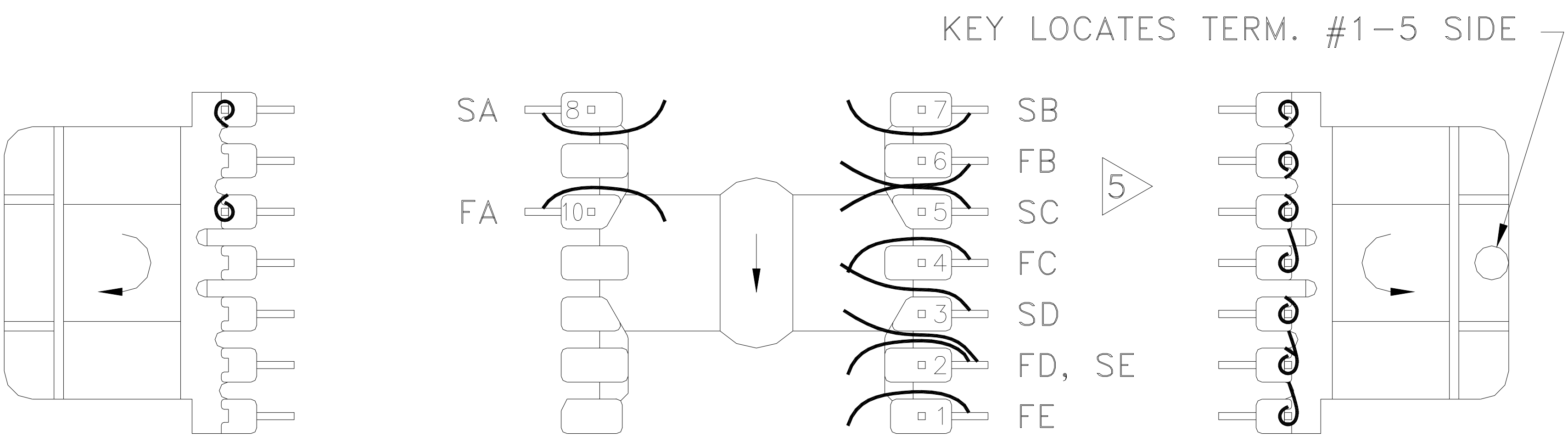


Large Gaps over Two Section Coil – May Need Symmetrical Gap

Transformers for EMC - Fringing Effect

- How Can We Compensate for Fringing?
  - Adjust Turns Ratio
  - Symmetrical Gap
  - New Design with Smaller Gap
  - Avoid Gap with Winding

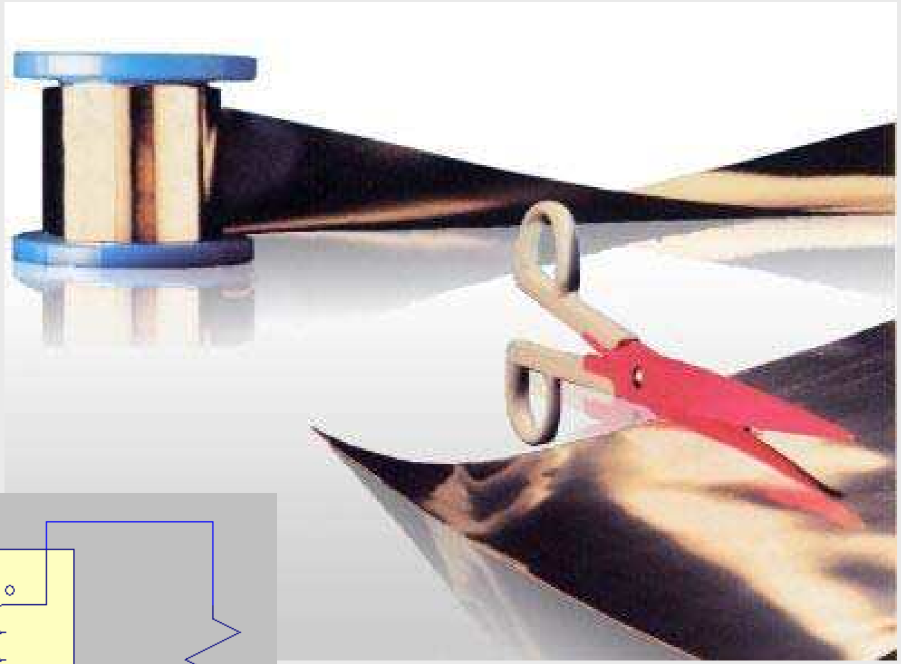


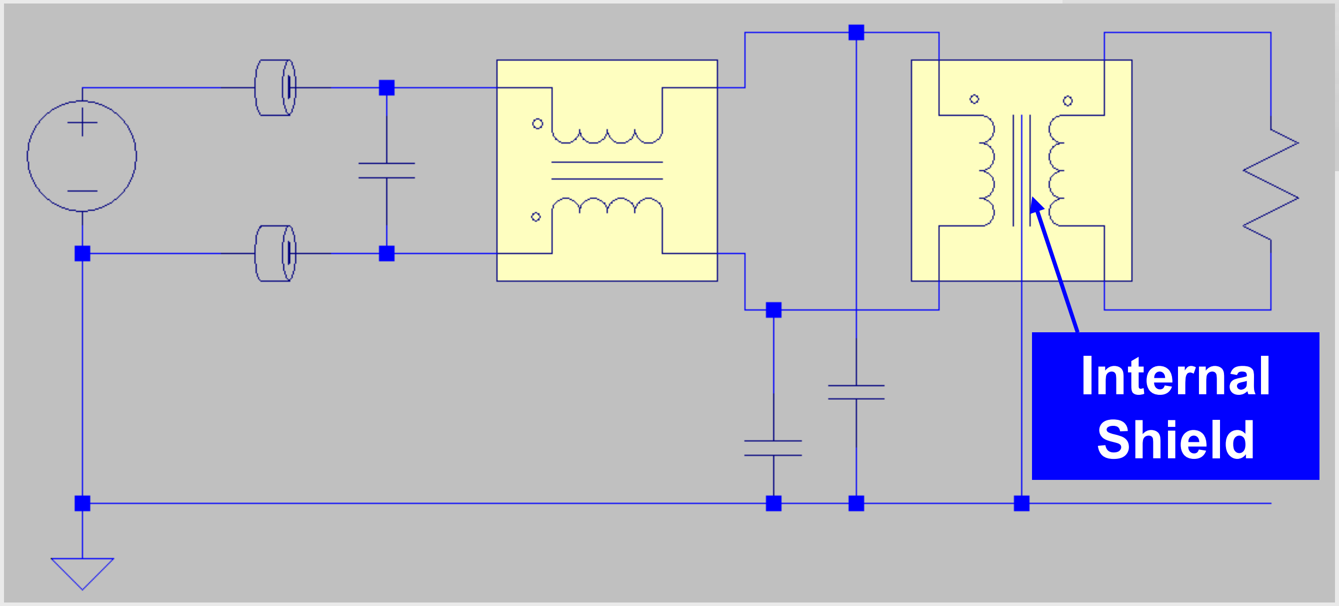


more than you expect

Transformers for EMC – Internal Shields

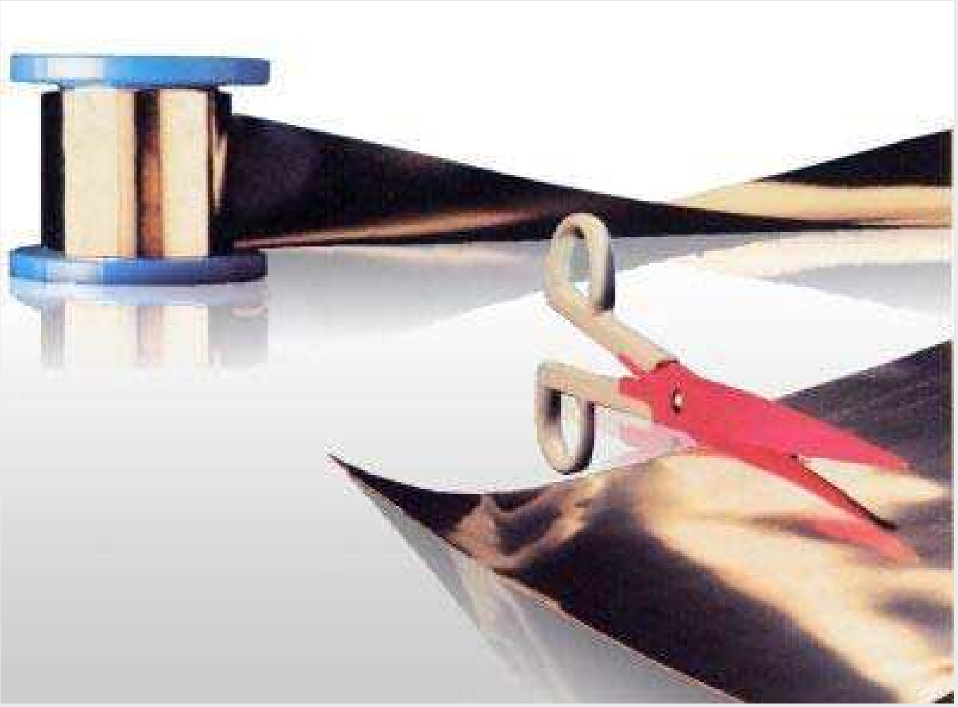
- Shield both Conducted and Radiated Noise
- Copper Foil or Wound Magnet Wire?
- Copper Foil Shields – Expensive, Why?
  - Must Build Shield
  - Must be Cuffed with Tape
  - Winding Machine Stopped to Apply
- All Shields Take Away from Winding Area

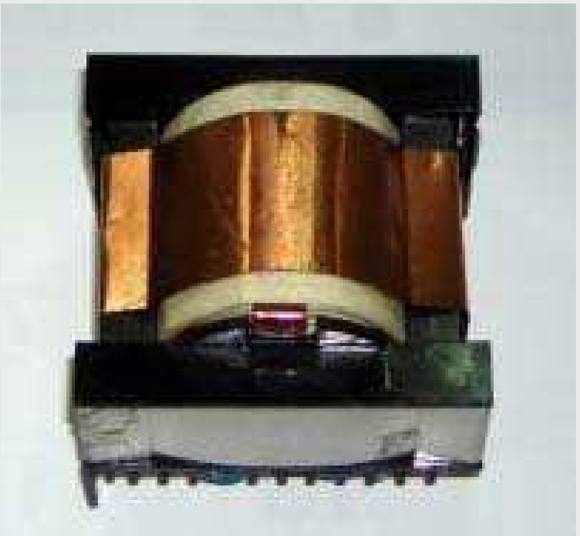




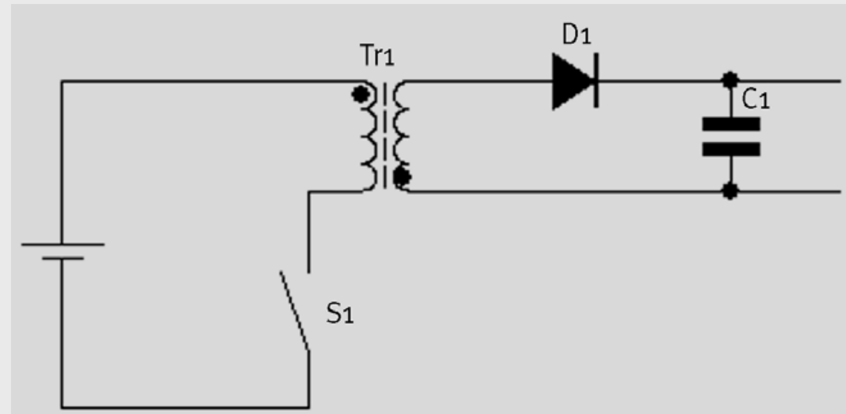
Transformers for EMC – External Shields

- How Do External Shields Differ from Internal Shields?
- **Shield Radiated Noise ONLY!**
- **As Expensive as Internal Shields**



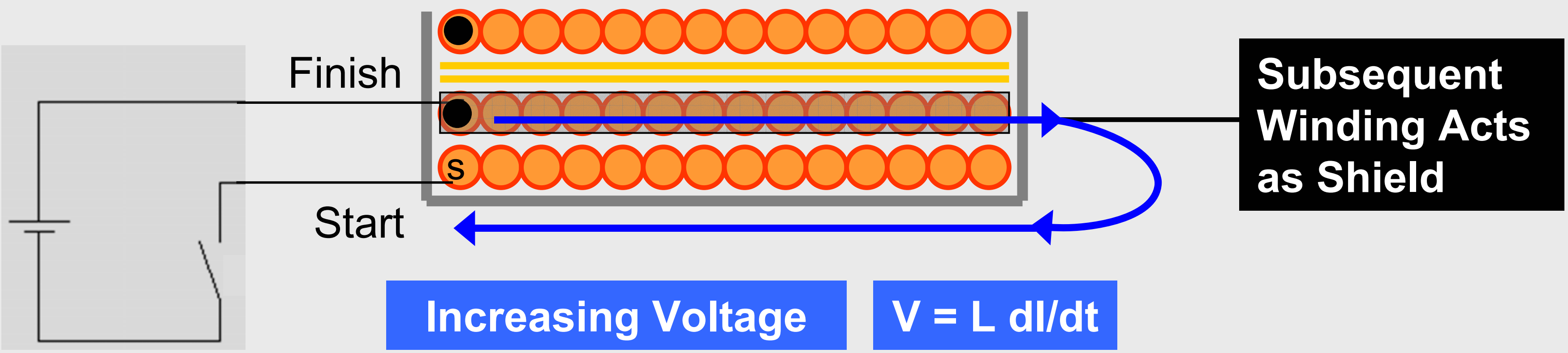


Transformers for EMC – Multi-layer Primary Termination

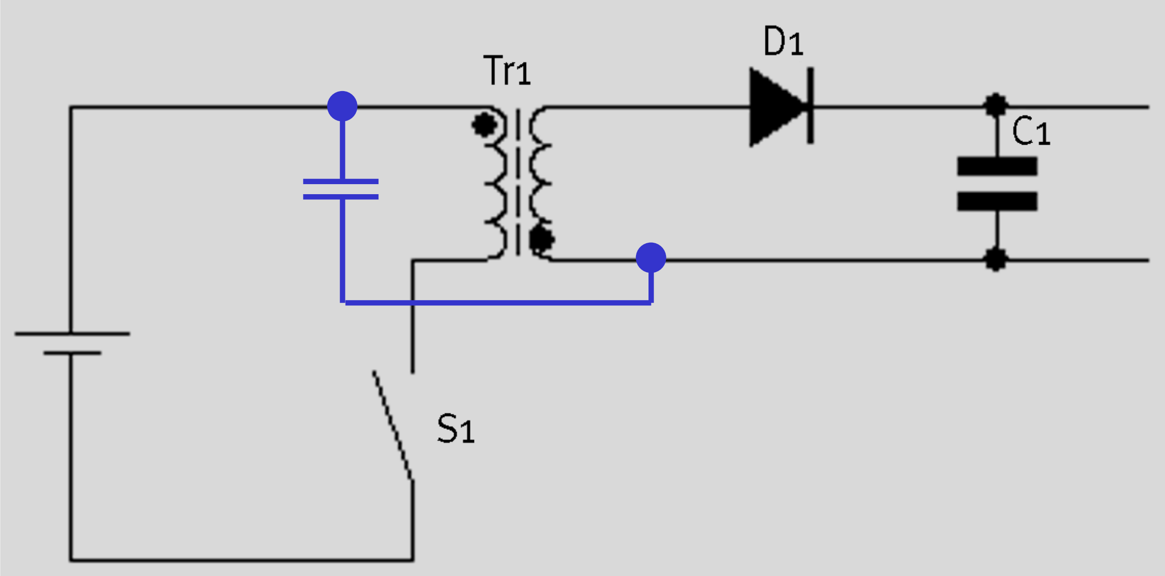


- How does One Terminate a Multi-layer Primary?
- **Terminate Start to Switch so Subsequent Layer/s Shield High dv/dt Windings from outside world.**

Nc Perfectly Fine on
Fi if Consistent. ?



Transformers for EMC – Y-Cap Termination



- Noise Couples Through the Transformer via C_{WW}
  - Noise Seeks Path to Primary Circuit
  - Without Path, Noise May Become Conducted Emissions
- Y-Cap Across Transformer Reduces Noise
  - Tune the Capacitor for Optimum Loss vs. Noise Reduction
  - Capacitor Usually in the 2.2nF to 4.7nF range
  - Y-Caps to Transformer Terminals not on Switch nor on Diode
  - Close to Transformer as Possible

What Can We Do?

Decrease Cww?

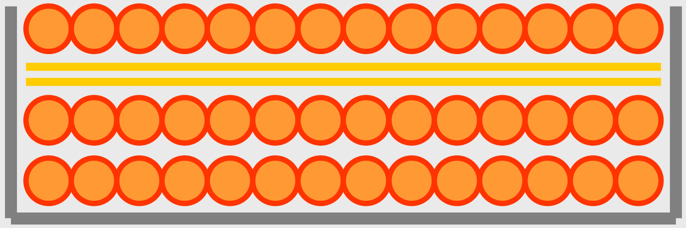
What Else Can We Do?

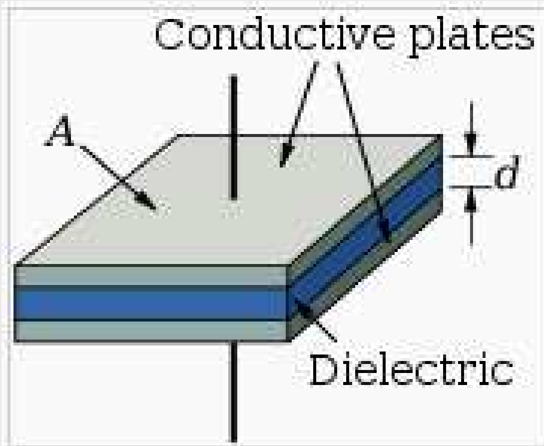
Transformers for EMC – Reducing C_{ww}

- High Cww Causes Conducted Emissions
- May Reduce Cww, but What Happens?
- Leakage Inductance Increases
- L_{LKG} can be Controlled by Snubber but Efficiency and Cost Suffer
- Balance Between Cww and Lkg

more than you expect

Transformers for EMC – Reducing Cww





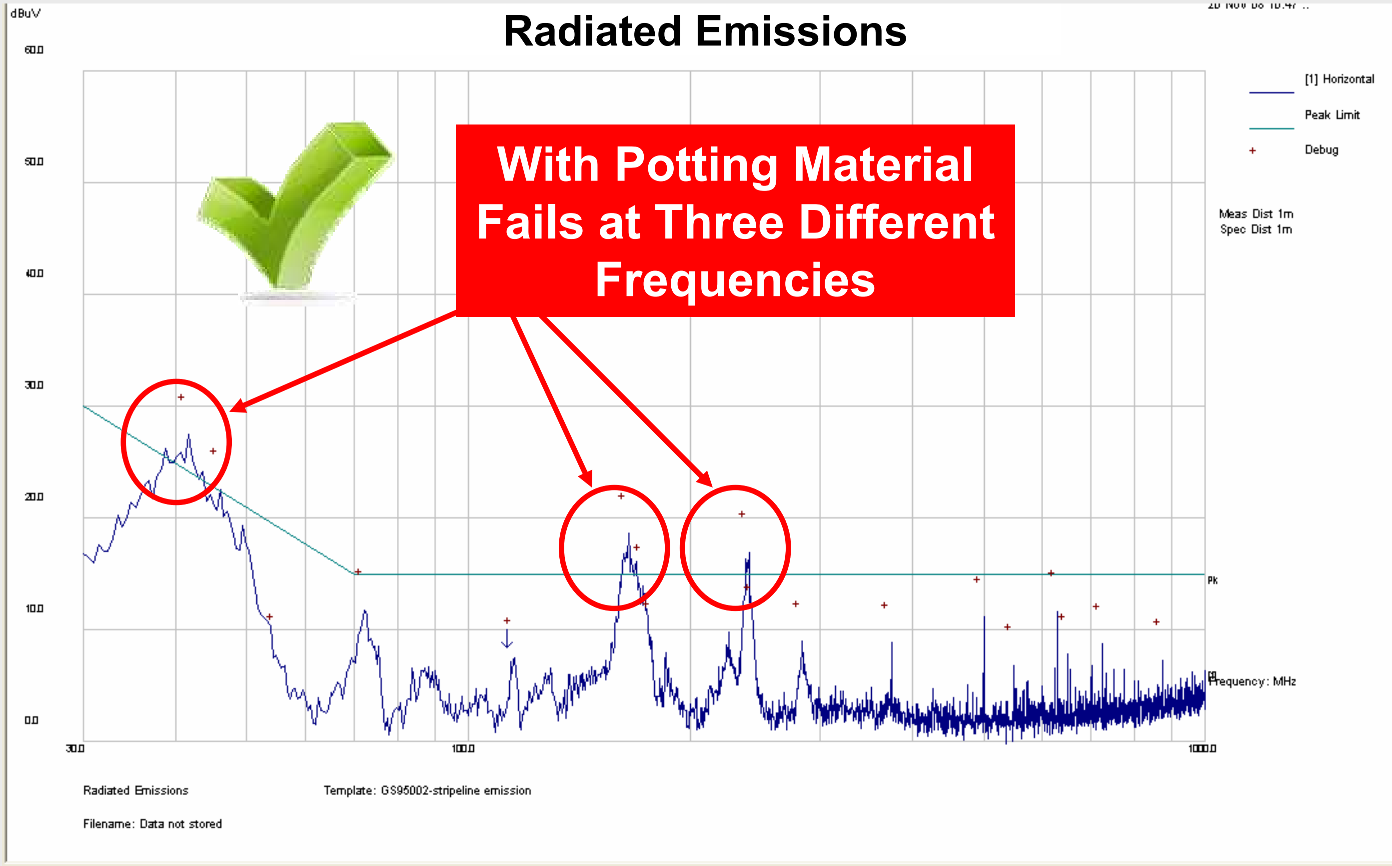
How Do We Reduce Capacitance?

- Multi-section or Narrow Bobbin
  - Reduces Area and Increases Distance
- Lots of Tape
  - Increases Distance
- Reduce Dielectric Constants, **How?**
  - No Potting Compounds or Varnishes
  - Does Not Affect Leakage Inductance

$$C = \epsilon_r \epsilon_0 \frac{A}{d} \text{ (in SI units)}$$

How is L_{lgk} Affected?

Transformers for EMC – No Varnish or Potting



List of Debug Frequencies

No	Frequency MHz	Raw dBuV	Cable Loss	AF dB	Level dBuV	Measurement Type	Pol	Hgt cm	Azt Deg	Limit dBuV	Margin dB	Pass /Fail	Comments
1	41.640	47.0	10.4	-30.0	27.4	Peak [Scan]	H	100	0	24.2	3.2	Fail	
2	46.005	42.1	10.4	-30.0	22.6	Peak [Scan]	H	100	0	22.4	.1	Fail	
3	54.735	27.2	10.4	-30.0	7.7	Peak [Scan]	H	100	0	19.3	-11.6	Pass	
4	72.195	31.1	10.5	-29.9	11.7	Peak [Scan]	H	100	0	15.0	-3.2	Pass	
5	115.360	26.6	10.6	-29.8	7.4	Peak [Scan]	H	100	0	15.0	-7.5	Pass	
6	164.830	37.4	10.7	-29.5	18.6	Peak [Scan]	H	100	0	15.0	3.6	Fail	

Counter: Test: of Step: of Range: >>>

Assessment: Debug Scan / Formal Peak Test / Both

Storage: Trace 1 / Trace 2 / Both

Begin Assessment

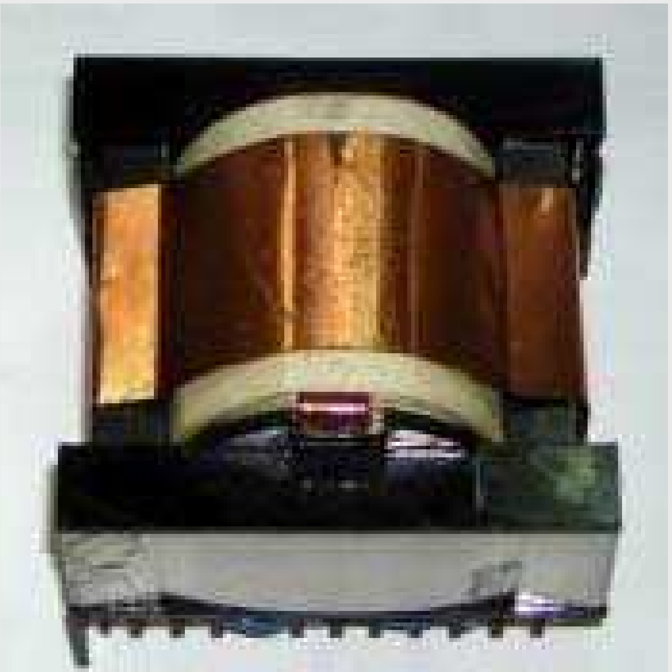
Debug Peak

Library of Known Ambients

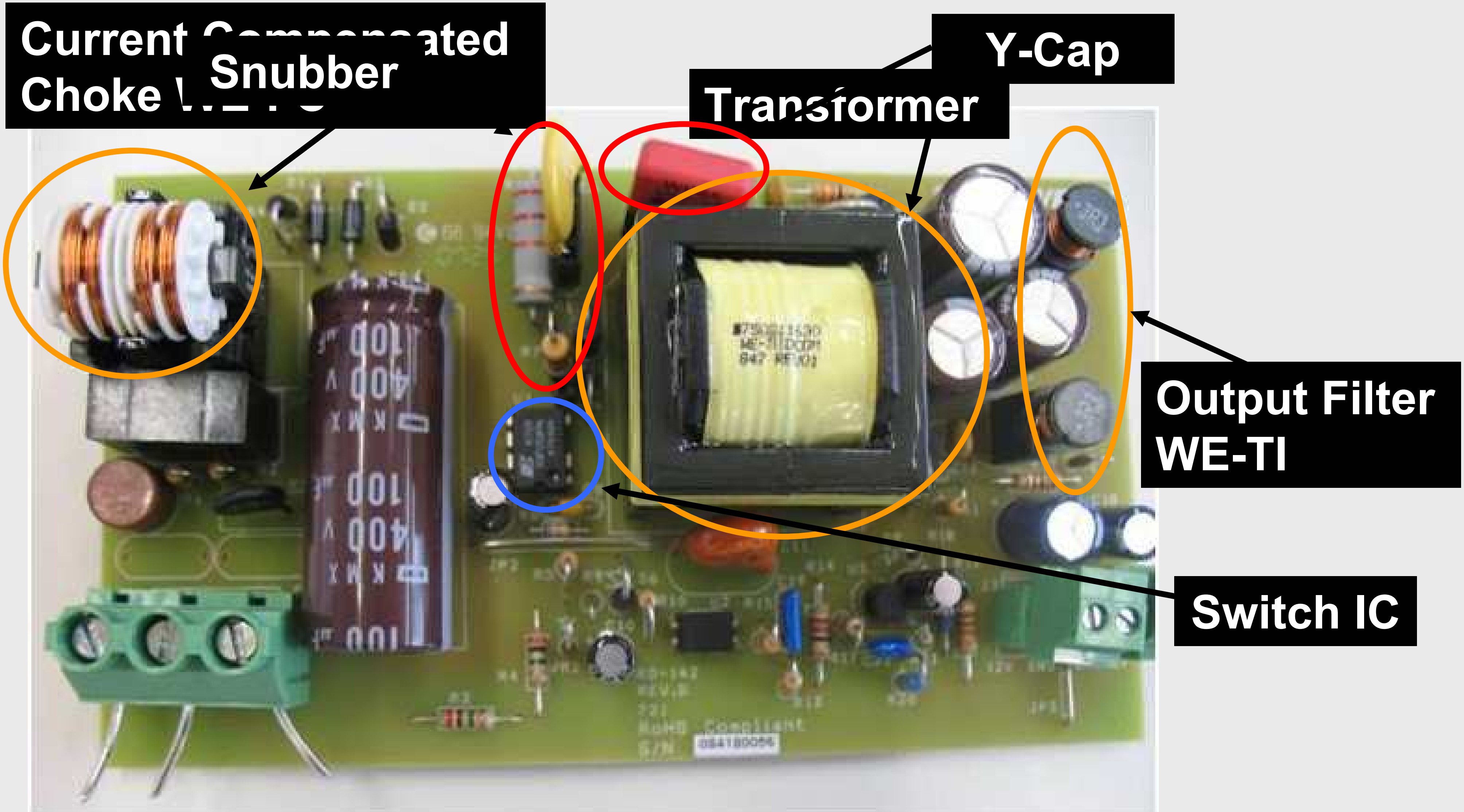
Transformers for EMC - Small Designs

Why Build Smaller Designs?

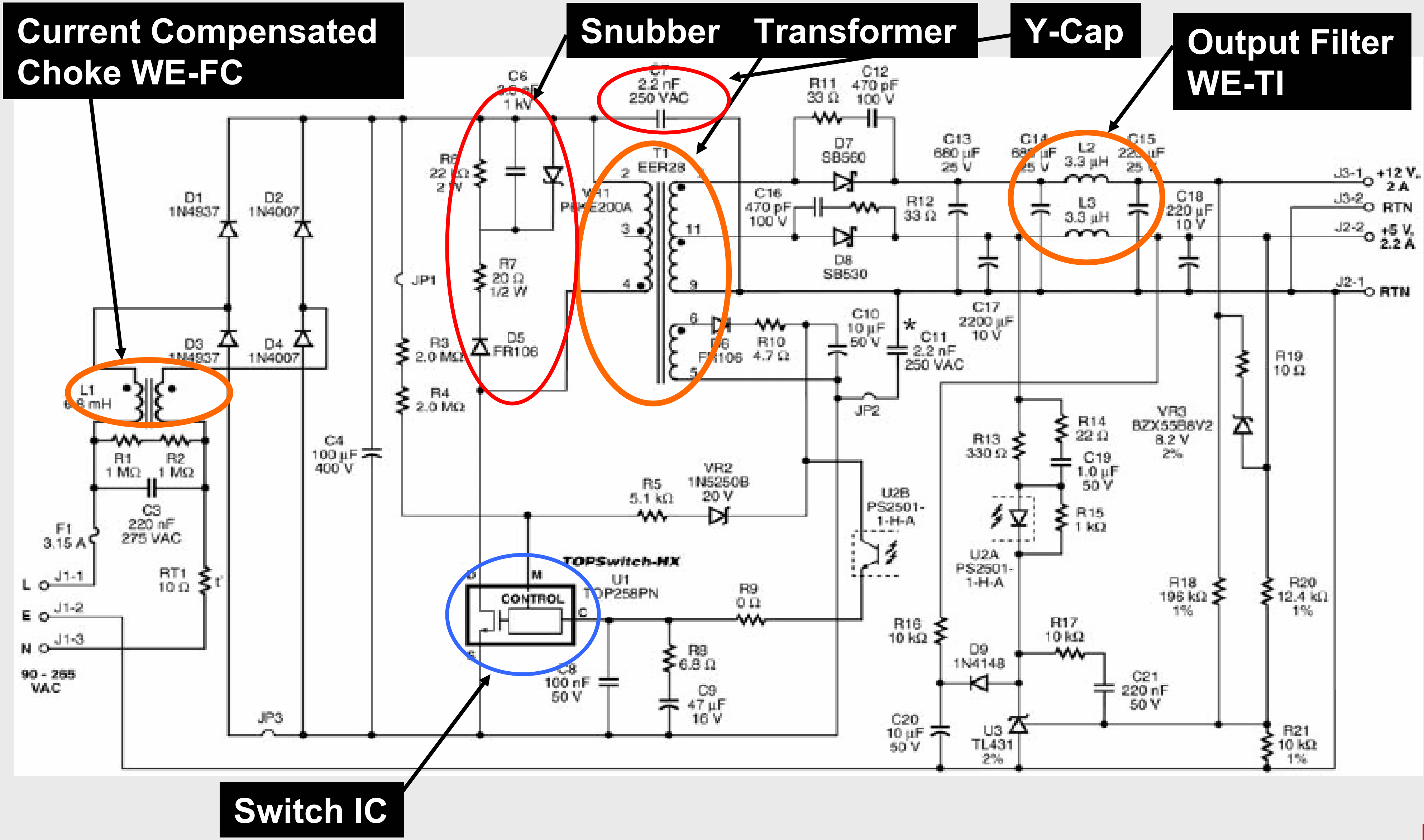
- Build Smaller More Compact Transformers
- Smaller Transformers have less Parasitics
  - Less Capacitance
  - Smaller Leads (ie. Smaller Antennas)
  - Smaller Gaps
  - Less Leakage Inductance
- Less Conducted and Less Radiated Noise



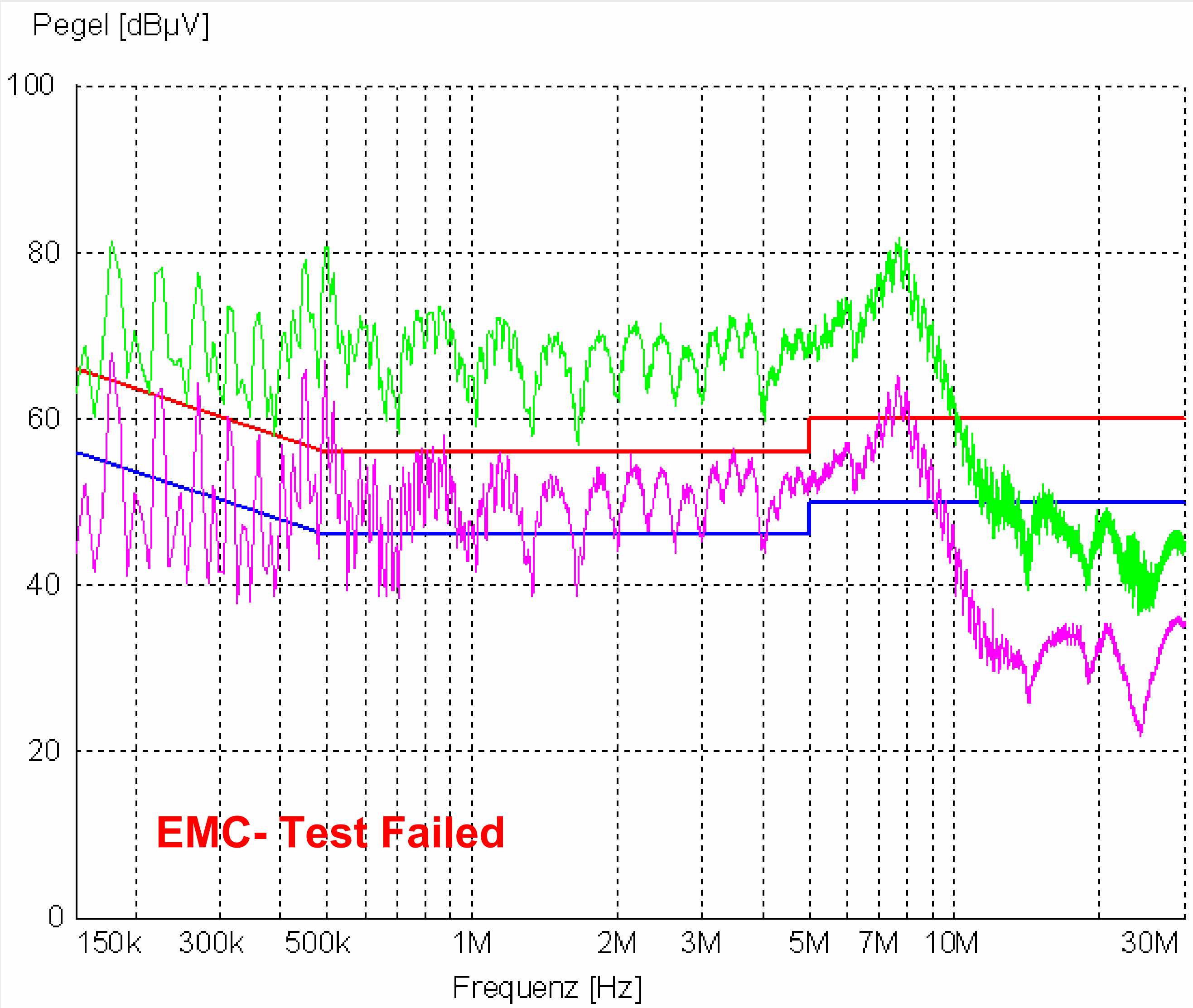
Transformers for EMC – Power Supply



Transformers for EMC – Schematic



Transformers for EMC – Example 1



- **Without Current Compensated Choke**
- **With Adjusted Snubber**
- **Without Adjusted Y-Cap**

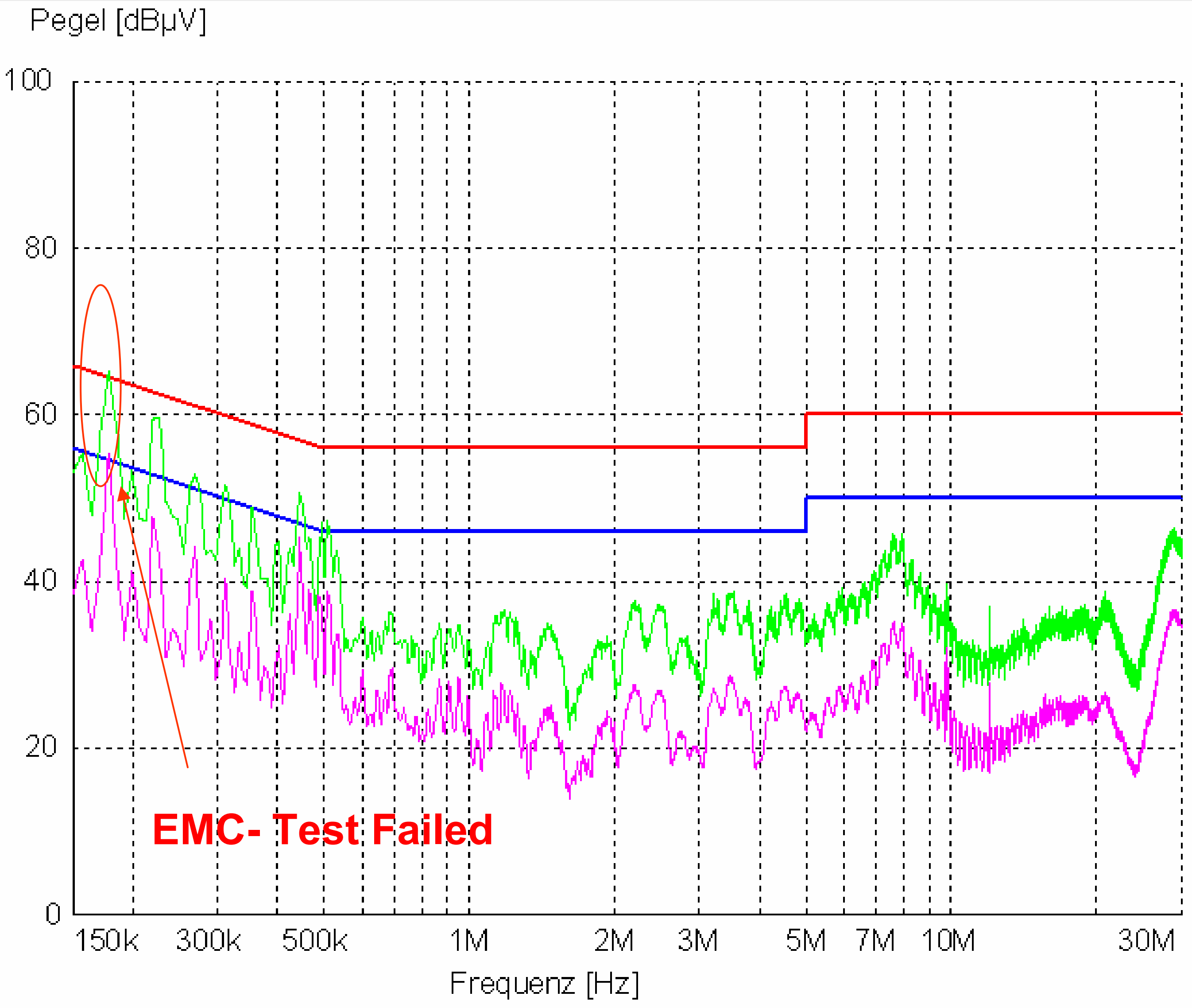
Peak

Avg.

Peak

Avg.

Transformers for EMC – Example 2



- With Current Compensated Choke
- With Adjusted Snubber
- Without Adjusted Y-Cap

Peak

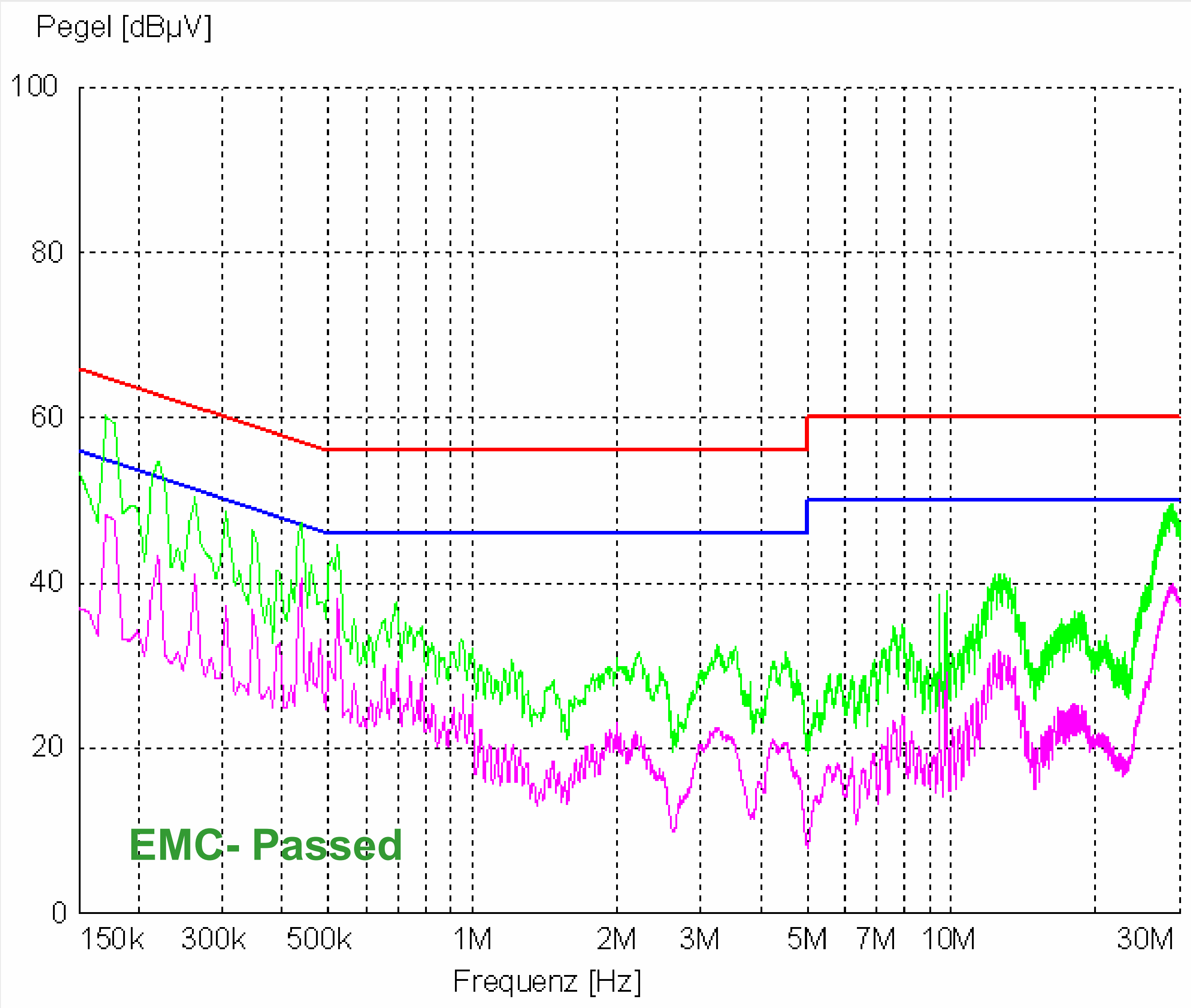
Avg.

Peak

Avg.

more than you expect

Transformers for EMC – Example 3



- •With Current Compensated Choke
- •With Adjusted Snubber
- •With Adjusted Y-Cap

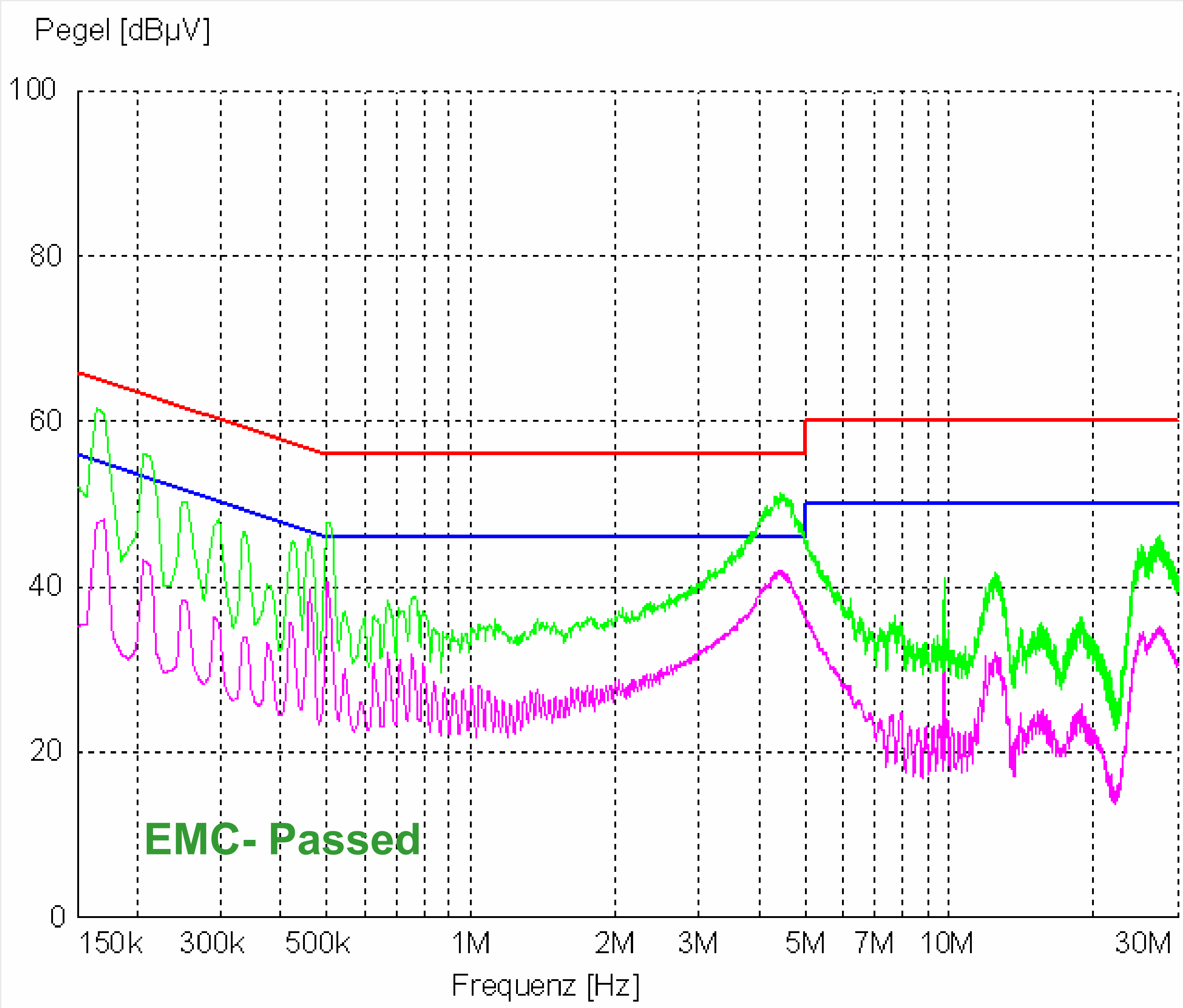
Peak

Avg.

Peak

Avg.

Transformers for EMC – Example 4



- **With Current Compensated Choke**
- **Without Adjusted Snubber**
- **With Adjusted Y-Cap**

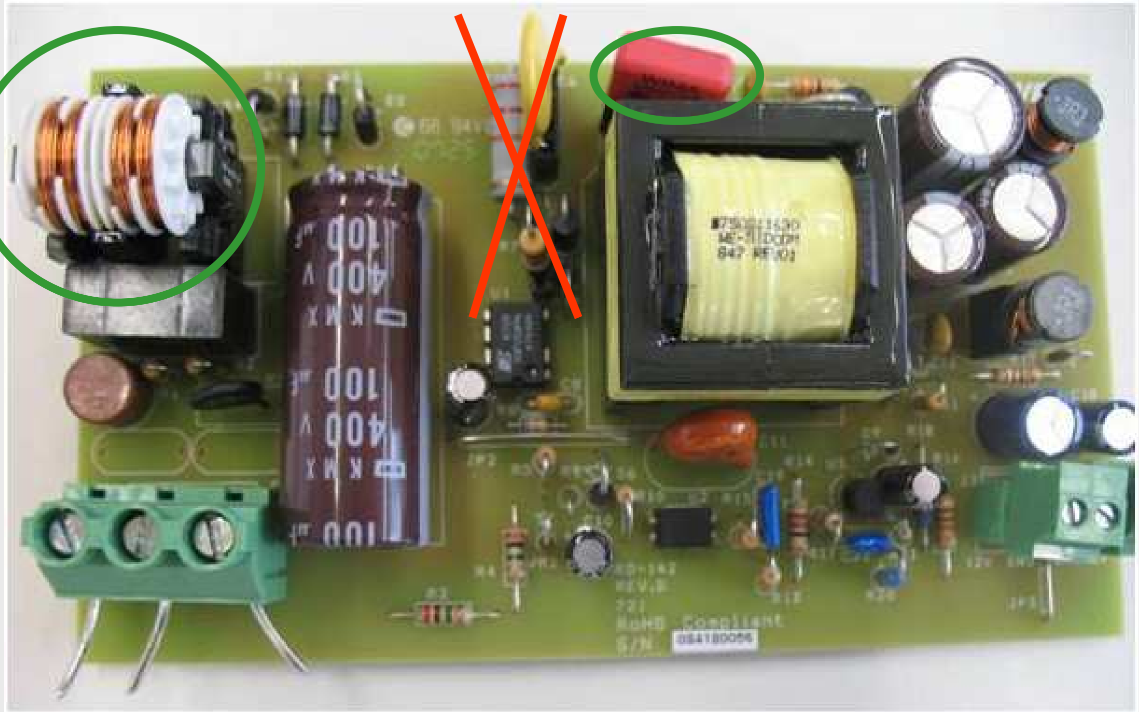
Peak

Avg.

Peak

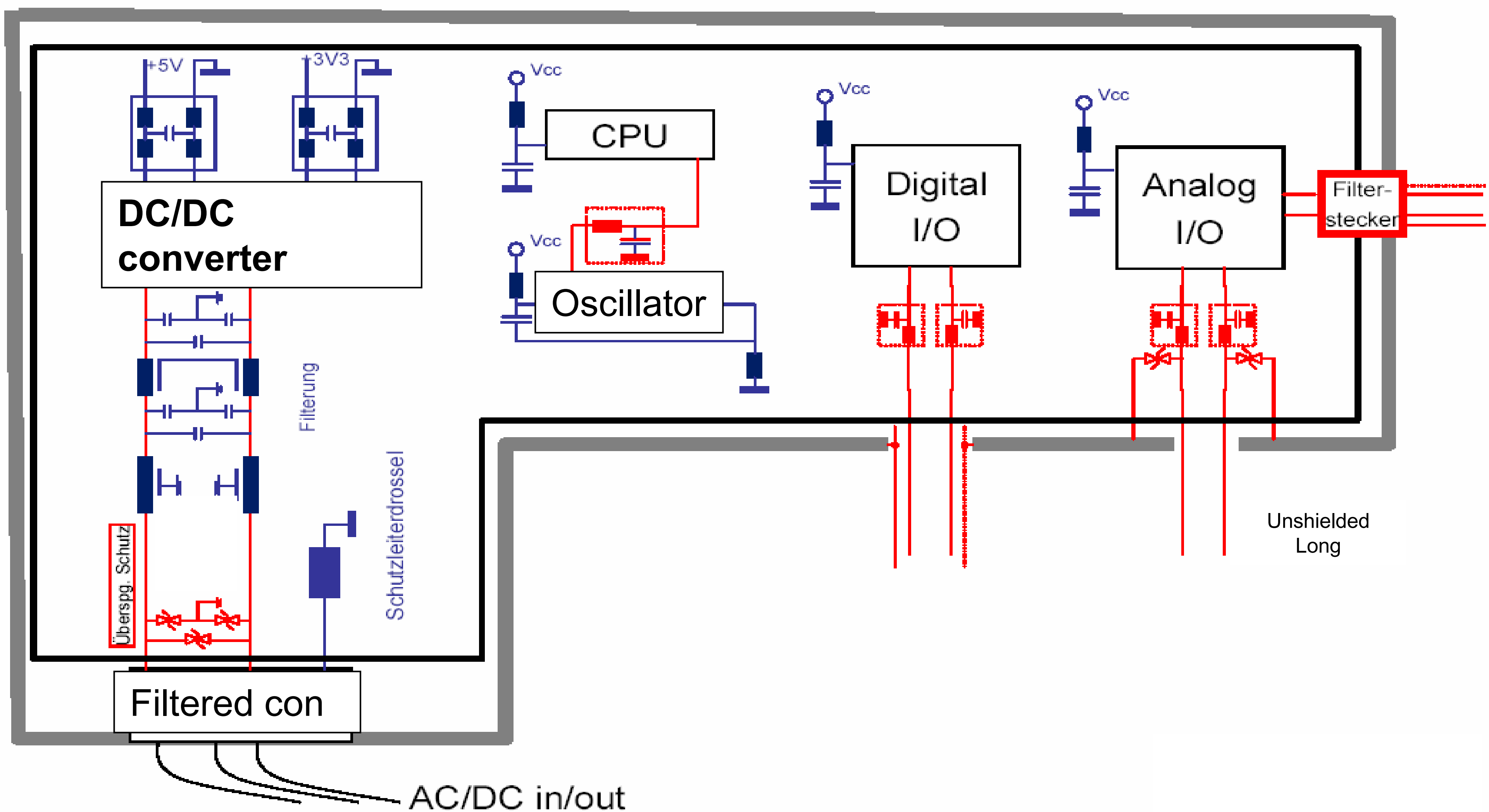
Avg.

Transformer for EMC – Conclusion for this Supply



- Necessary to Pass
  - Current Compensated Choke
  - Y-Caps
- Not Necessary to Pass
  - Optimized Snubber

Applications



more than you expect

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