Društvo za KGH Srbije

Serbian HVAC&R Society

47th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning

Some Power Quality and Electromagnetic Compatibility Issues in HVAC Equipment

Mircea Ion Buzdugan

Faculty of Building Services Engineering
Technical University of Cluj-Napoca, Romania

Belgrade, Sava Centre, 30th November – 2nd December 2016

Motto: Think EMC!

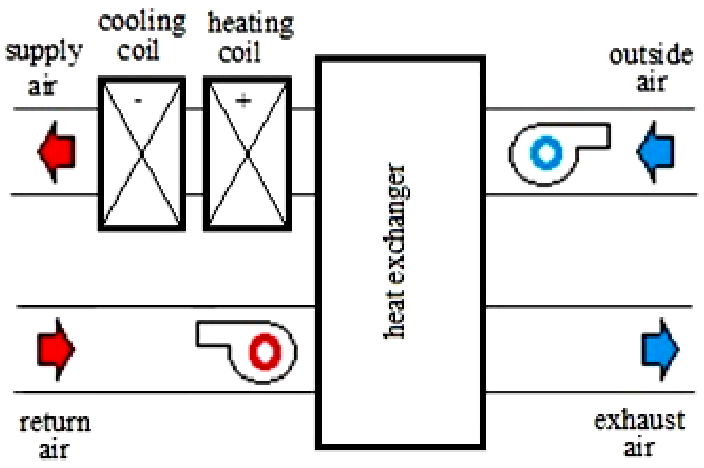
Are Electromagnetic Compatibility and Power Quality dichotomous?

A system is electromagnetically compatible with its environment if it satisfies three criteria:
1. It does not cause interference with other systems.
2. It is not susceptible to emissions from other systems.
3. It does not cause interference with itself.

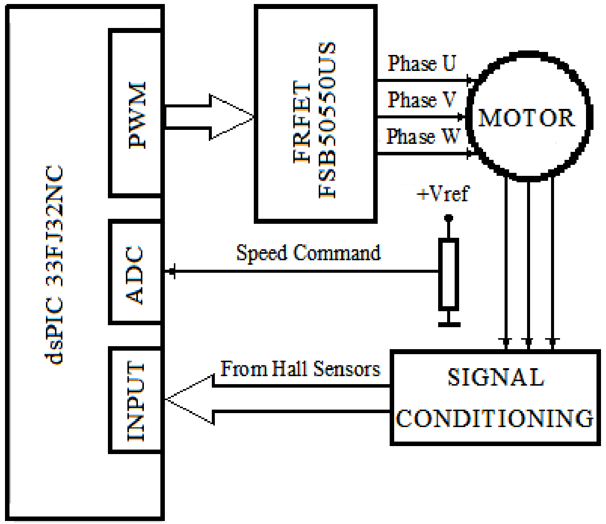
But what does Power Quality mean?

Two relevant case studies!

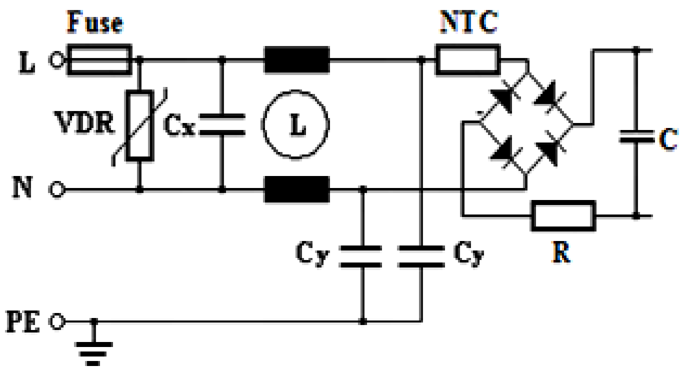
Case study no. 1: An air handling unit using two fans driven by brushless DC motors



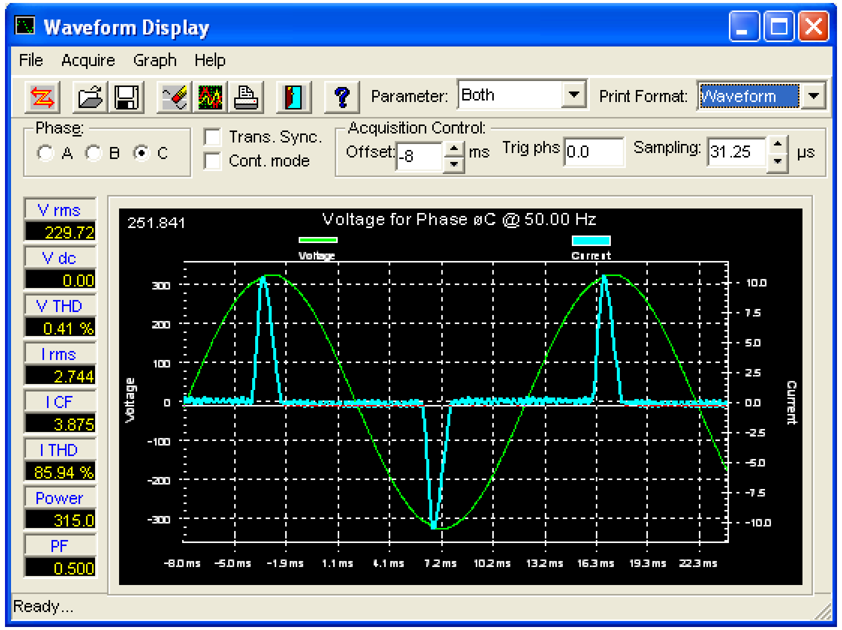
Schematic diagram of an air handling unit



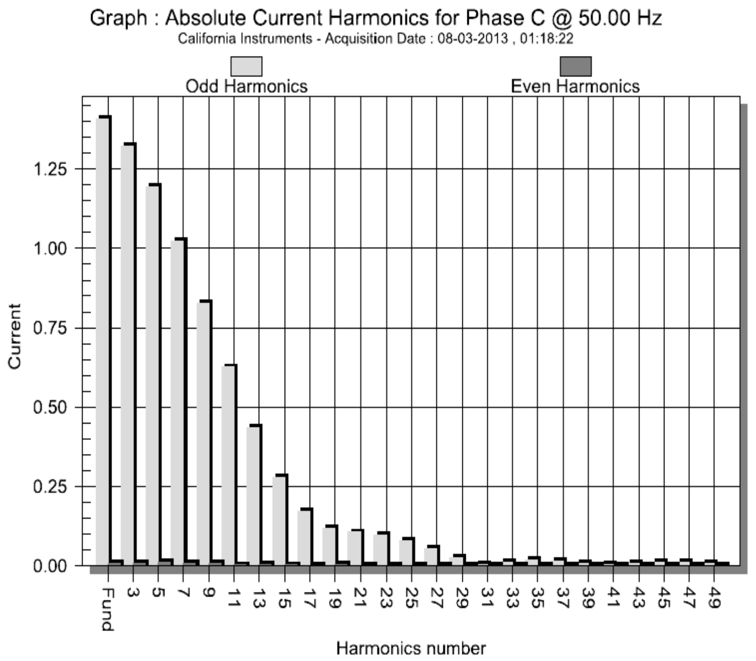
Hardware block diagram



Input stage of the drive circuit



Supply voltage and current drawn by the AHU



The FFT chart of the harmonic limits of the AHU

Harmonic limits check

California Instruments — Harmonic Limits Check

	Frequency	Actual	Limit	% of Limit	Compare
1	50.000	0.615			
2	100.000	0.006	1.080	0.556	Pass
3	150.000	0.571	2.300	24.826	Pass
4	200.000	0.008	0.430	1.860	Pass
5	250.000	0.519	1.140	45.526	Pass
6	300.000	0.003	0.300	1.000	Pass
7	350.000	0.451	0.770	58.571	Pass
8	400.000	0.003	0.230	1.304	Pass
9	450.000	0.373	0.400	93.250	Pass
10	500.000	0.003	0.184	1.630	Pass
11	550.000	0.288	0.330	87.273	Pass
12	600.000	0.008	0.153	5.229	Pass
13	650.000	0.205	0.210	97.619	Pass
14	700.000	0.006	0.131	4.580	Pass
15	750.000	0.134	0.150	89.333	Pass
16	800.000	0.003	0.115	2.609	Pass
17	850.000	0.081	0.132	61.364	Pass
18	900.000	0.005	0.102	4.902	Pass
19	950.000	0.054	0.118	45.763	Pass
20	1000.000	0.003	0.092	3.261	Pass

Harmonic limits test report for one centrifugal fan

California Instruments — Harmonic Limits Check

	Frequency	Actual	Limit	% of Limit	Compare
1	50.000	1.391			
2	100.000	0.006	1.080	0.556	Pass
3	150.000	1.309	2.300	56.913	Pass
4	200.000	0.002	0.430	0.465	Pass
5	250.000	1.184	1.140	103.860	Fail
6	300.000	0.003	0.300	1.000	Pass
7	350.000	1.016	0.770	131.948	Fail
8	400.000	0.001	0.230	0.435	Pass
9	450.000	0.825	0.400	206.250	Fail
10	500.000	0.004	0.184	2.174	Pass
11	550.000	0.625	0.330	189.394	Fail
12	600.000	0.009	0.153	5.882	Pass
13	650.000	0.441	0.210	210.000	Fail
14	700.000	0.004	0.131	3.053	Pass
15	750.000	0.285	0.150	190.000	Fail
16	800.000	0.002	0.115	1.739	Pass
17	850.000	0.178	0.132	134.849	Fail
18	900.000	0.004	0.102	3.922	Pass
19	950.000	0.123	0.118	104.237	Fail
20	1000.000	0.001	0.092	1.087	Pass
21	1050.000	0.109	0.107	101.869	Fail
22	1100.000	0.001	0.084	1.190	Pass
23	1150.000	0.100	0.098	102.041	Fail
24	1200.000	0.002	0.077	2.597	Pass
25	1250.000	0.082	0.090	91.111	Pass

Harmonic limits test report for the air handling unit

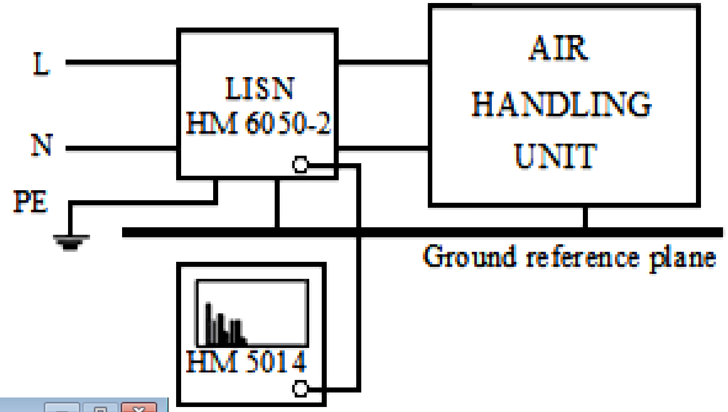
Društvo za KGH Srbije

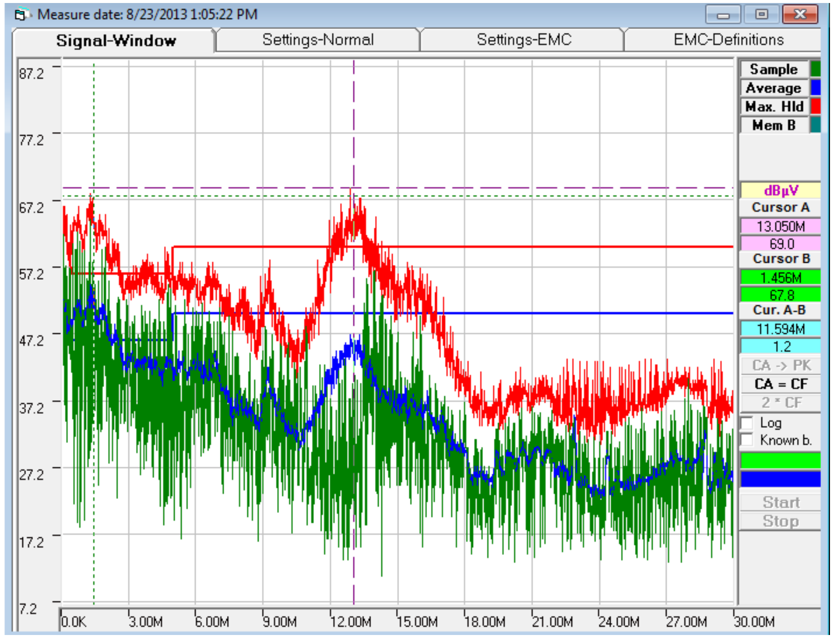
kgh

Serbian HVAC&R Society

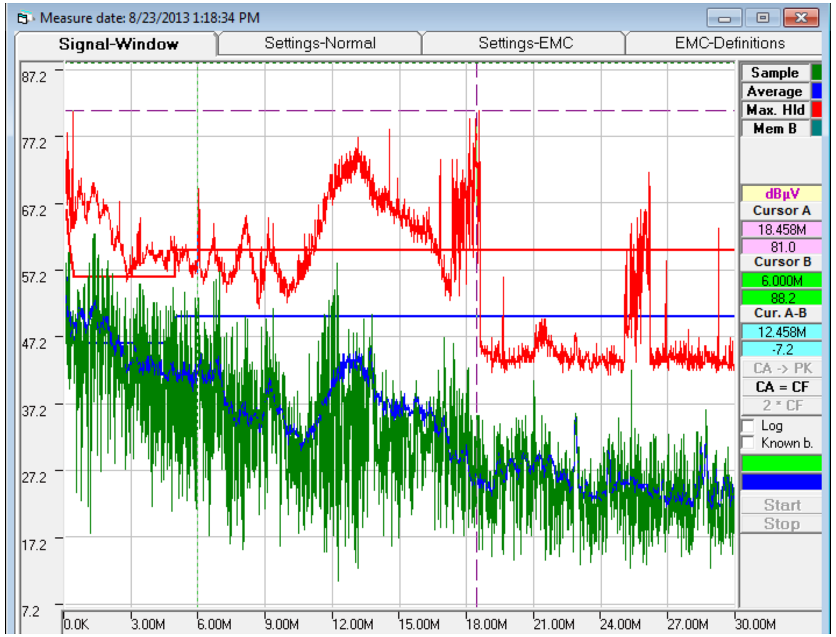
47th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning

The schematic test setup for conducted interference





Conducted interferences of a single BLDC drive in linear scale

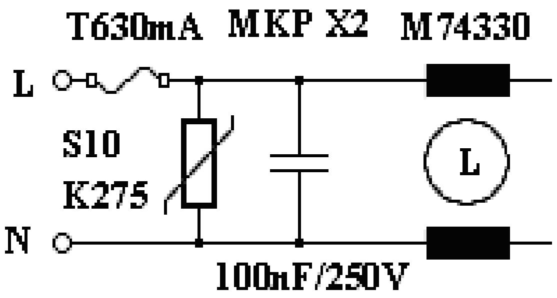


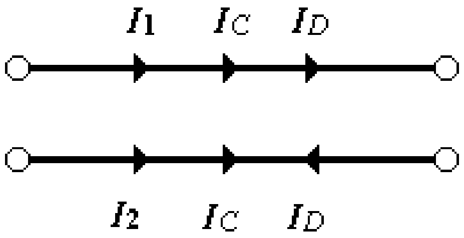
Conducted interferences of the AHU in linear scale

Belgrade, Sava Centre, 30th November – 2nd December 2016

Case study no. 2: A residential heating gas central 24 kW

EMI filter of the gas home heating system

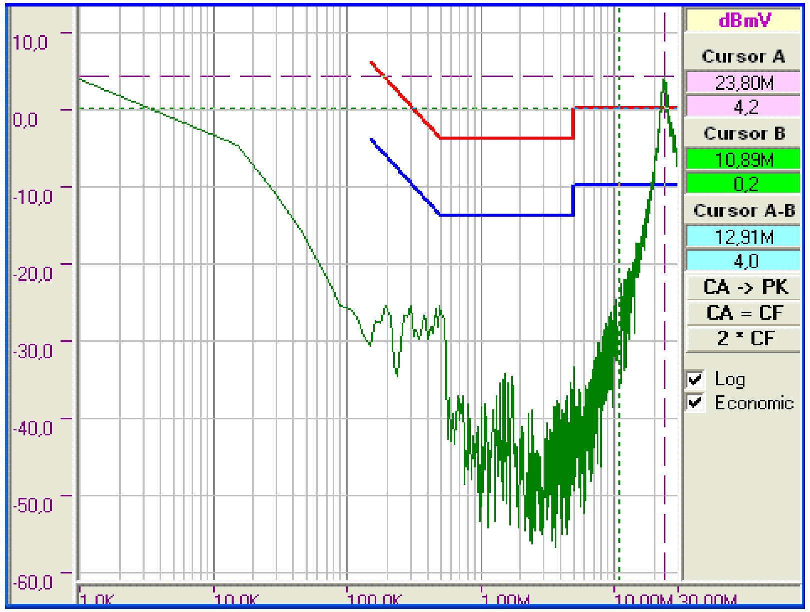


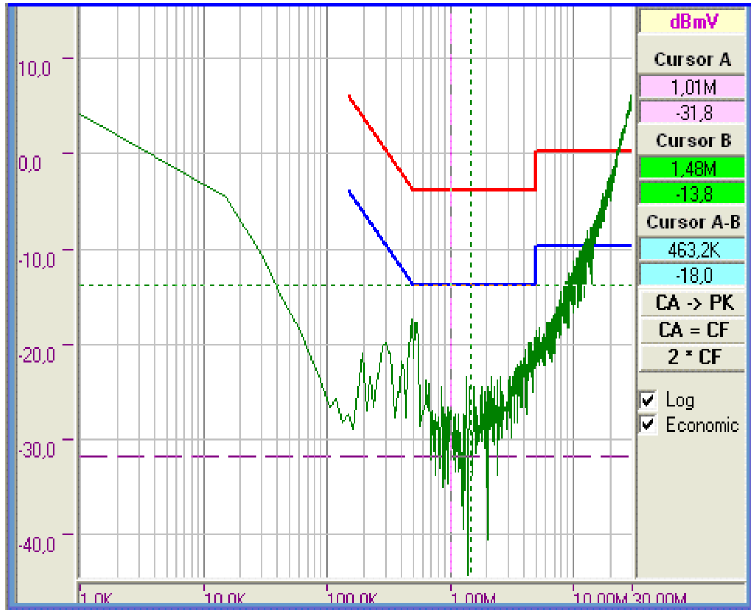


$$I_1 = I_C + I_D$$
$$I_2 = I_C - I_D$$

$$\begin{cases} I_D = \frac{1}{2}(I_1 - I_2) \\ I_C = \frac{1}{2}(I_1 + I_2) \end{cases}$$

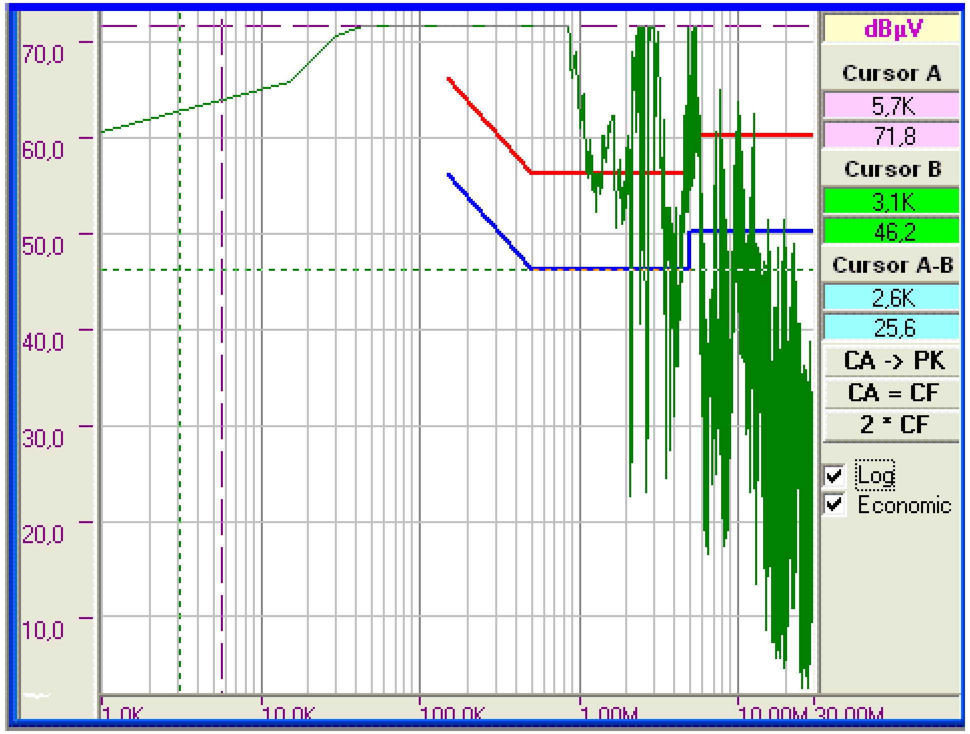
The transfer characteristics of the filter in differential mode



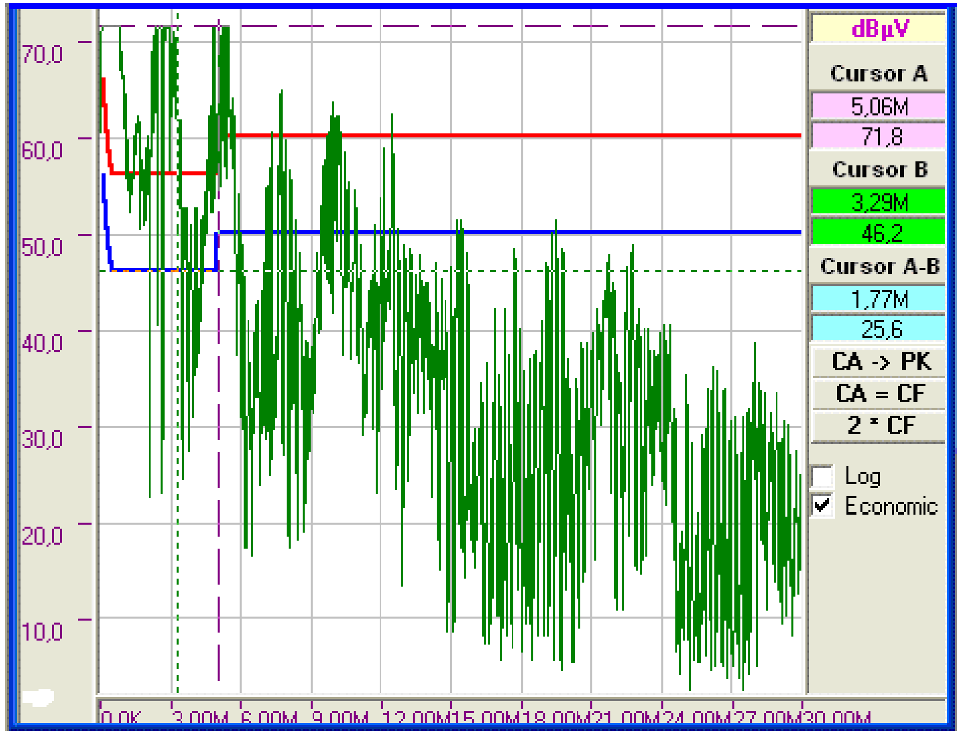


The transfer characteristics of the filter in common mode

RF conducted emissions induced in the public low voltage network by a nearby AM radio broadcasting station

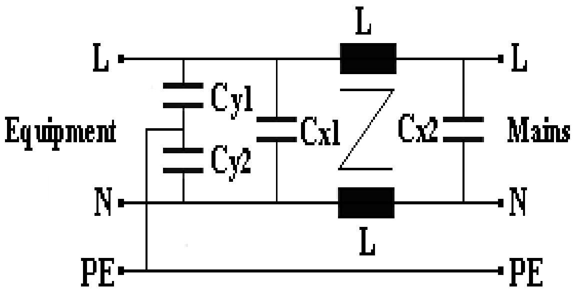


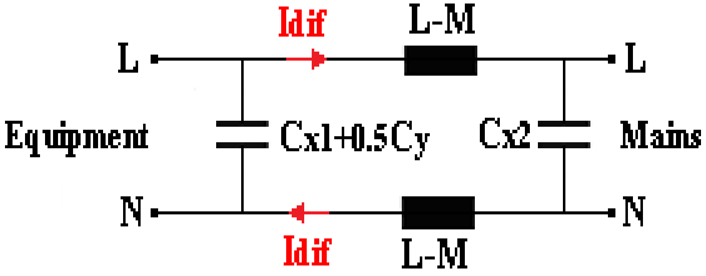
Logarithmic scale



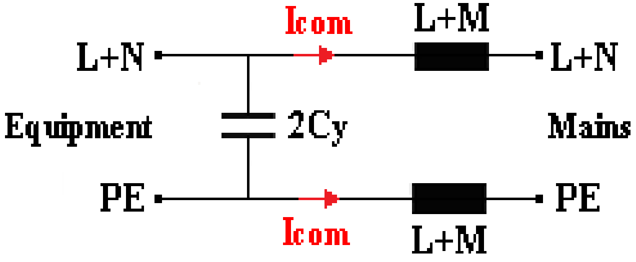
Linear scale

The topology of the power EMI filter





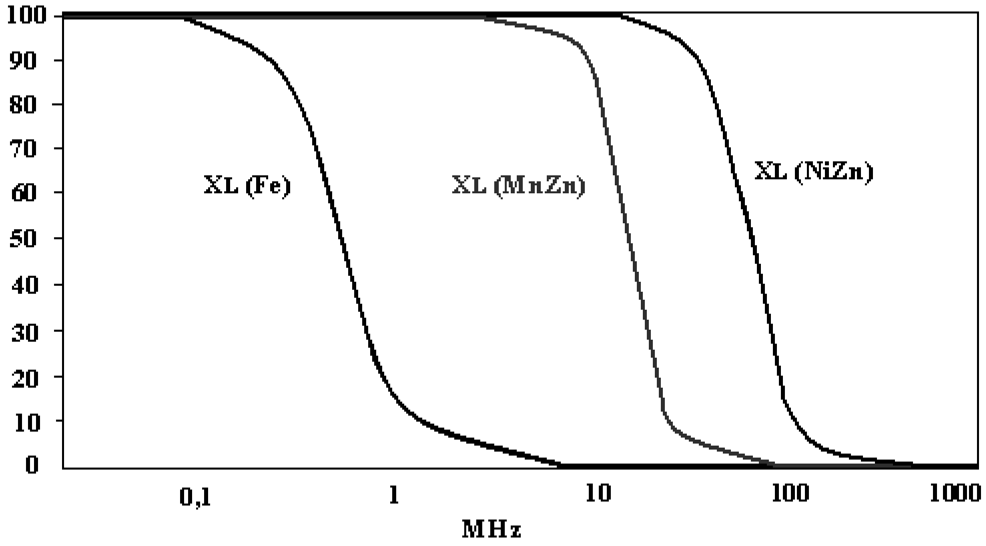
The equivalent circuit of the differential mode filter



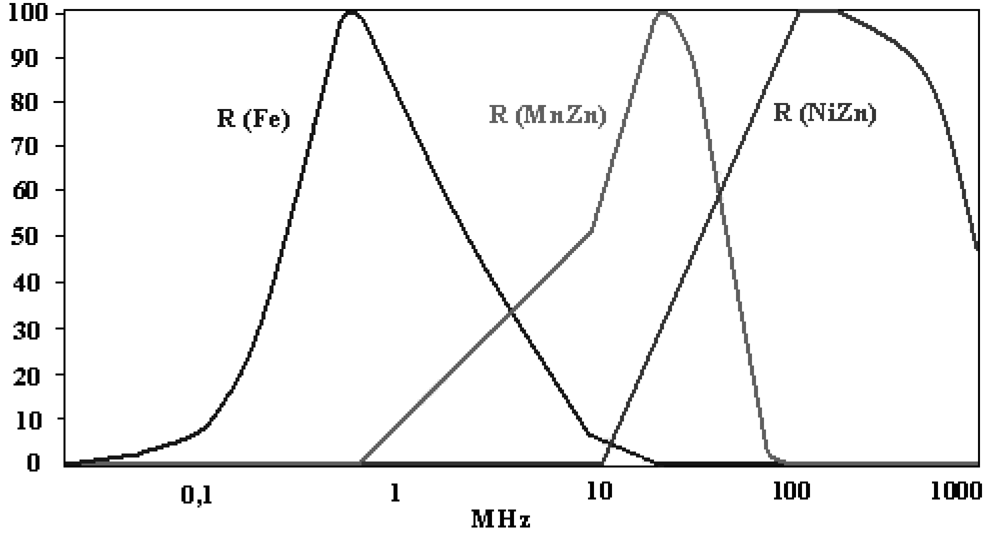
The equivalent circuit of the common mode filter

The ferrites obey to the concept of complex magnetic permeability: $\underline{\mu} = \mu' - j \cdot \mu''$

$$X = \omega \cdot L_0 \cdot \mu' \qquad R = \omega \cdot L_0 \cdot \mu'' \longrightarrow \left|\underline{Z}\right| = \sqrt{R^2 + X^2} \qquad \tan\delta = \mu'' / \mu'$$



The reactive component of different ferrite materials



The resistive component of different ferrite materials

THE NON-IDEAL BEHAVIOR OF LUMPED COMPONENTS

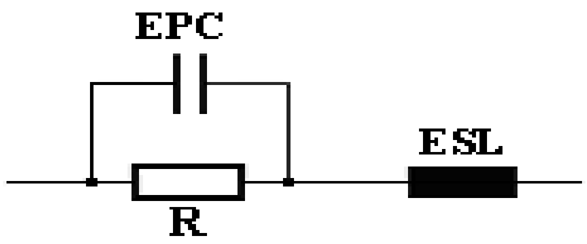
RESISTORS

Transfer function:

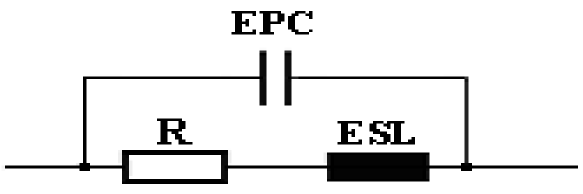
$$H(s) = ESL \frac{s^2 + \frac{s}{R \cdot EPC} + \frac{1}{ESL \cdot EPC}}{s + \frac{1}{R \cdot EPC}}$$

$$H(s) = \frac{s \cdot ESL + R}{s^2 \cdot ESL \cdot EPC + sR \cdot EPC + 1}$$

Hidden schematics:

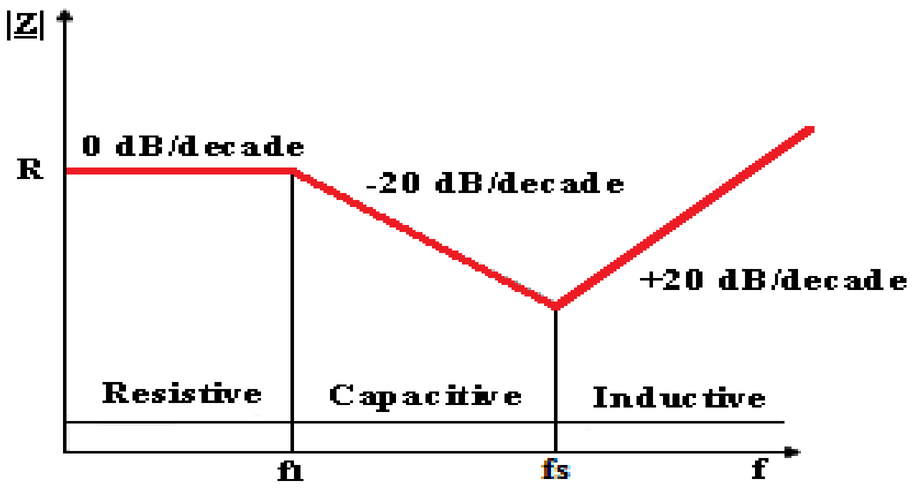


a.



b.

Theoretical Bode plots of the impedance variation with frequency



first cut-off frequency

$$f_1 = \frac{1}{2\pi R \cdot ECP}$$

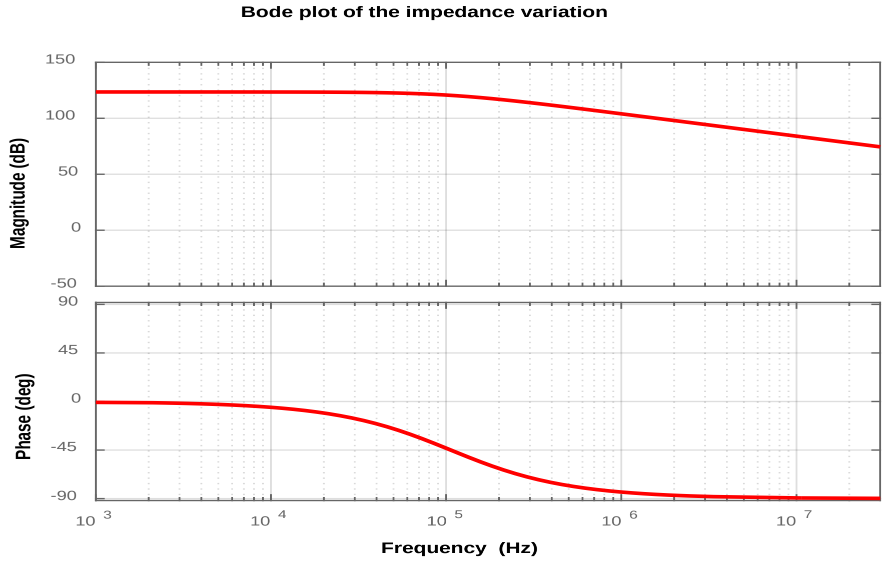
self resonant frequency

$$f_S = \frac{1}{2\pi \sqrt{ESL \cdot EPC}}$$

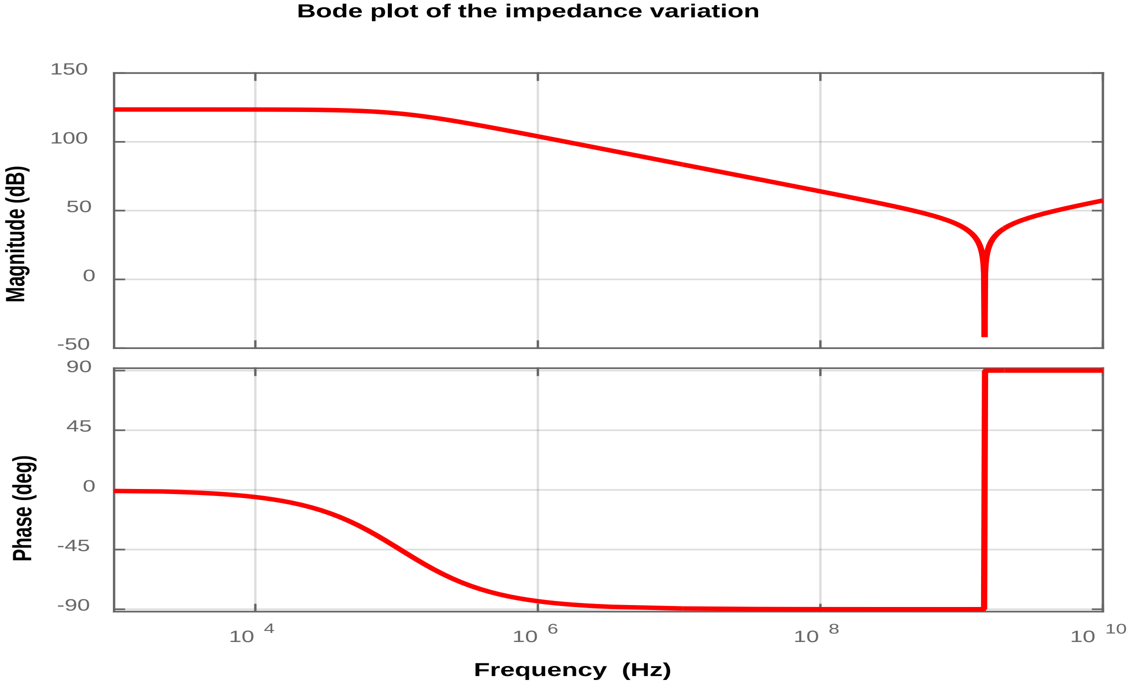
Društvo za KGH Srbije kgh Serbian HVAC&R Society

47th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning

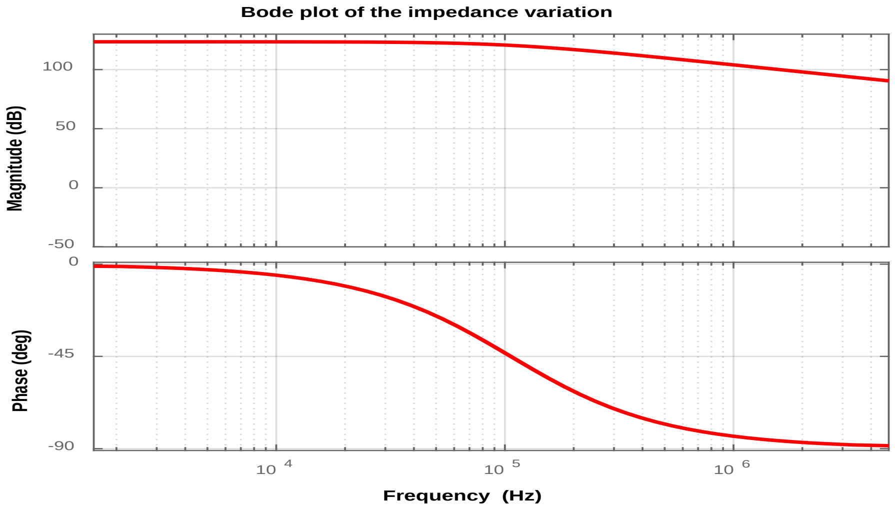
Bode plots of the model from Fig. a. in the relevant range for conducted emissions



Bode plots of the transfer function for a resistor.



Bode plots of the model from Fig. b in the relevant range for conducted emissions



Belgrade, Sava Centre, 30th November – 2nd December 2016

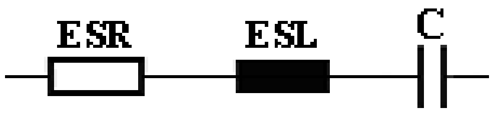
CAPACITORS

Transfer function:

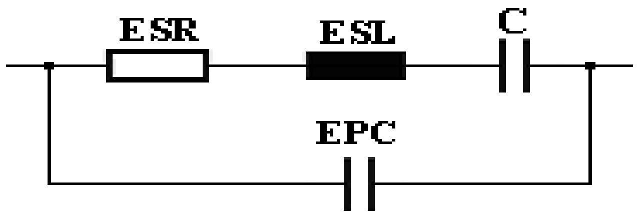
$$H(s) = ESL\frac{s^2 + \frac{s \cdot ESR}{ESL} + \frac{1}{ESL \cdot C}}{s}$$

$$H(s) = \frac{1}{s \cdot EPC + \left(ESR + s \cdot ESL + \frac{1}{sC}\right)^{-1}}$$

Hidden schematics:

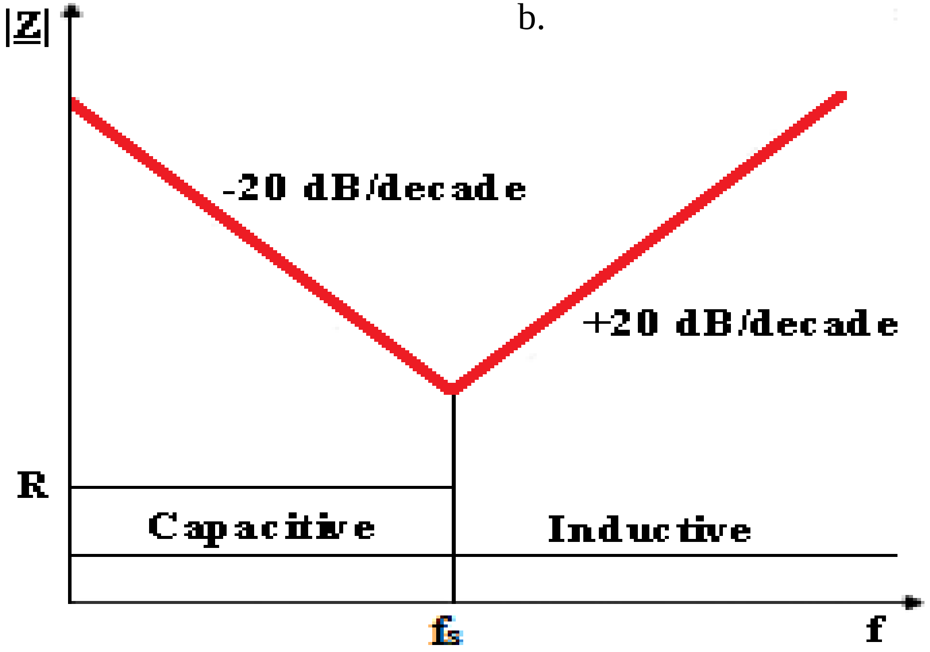


a.



b.

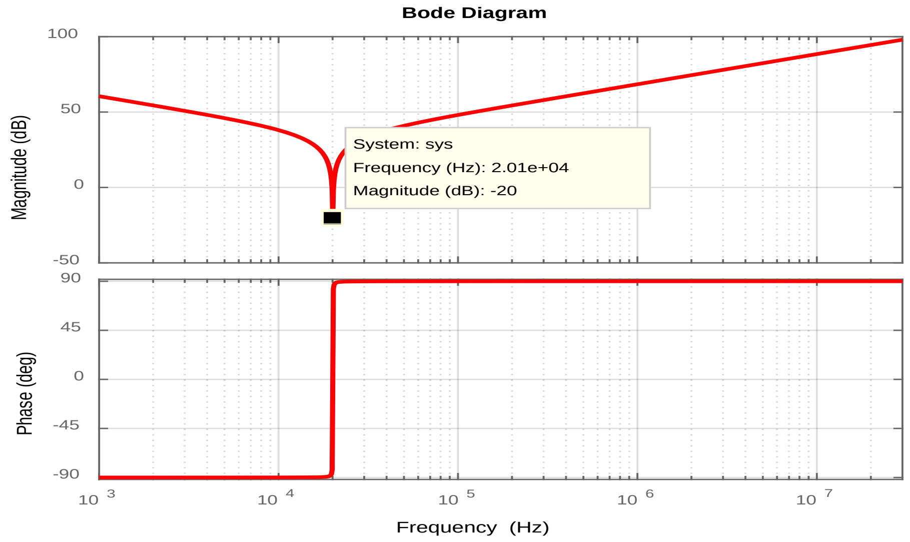
Theoretical Bode plots of the impedance variation with frequency



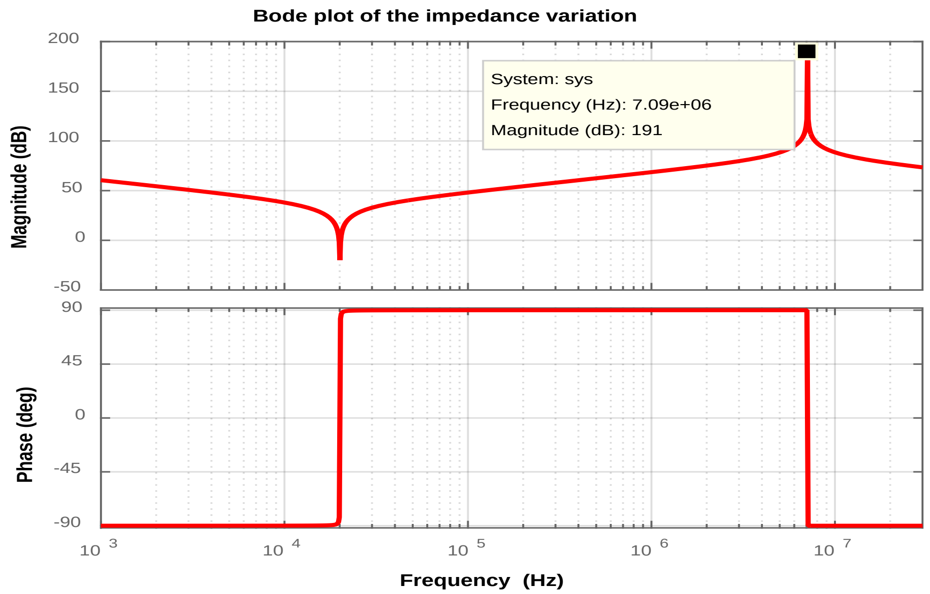
self resonant frequency

$$f_s = \frac{1}{2\pi\sqrt{ESL \cdot C}}$$

47th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning



Bode plots of the impedance variation with frequency of the capacitor from Fig. a



Bode plots of the impedance variation with frequency of the capacitor from Fig. b

series resonance frequency

$$\omega_s \cdot ESL = \frac{1}{\omega_s C}$$

parallel resonance frequency

$$\omega_p \cdot ESL = \frac{1}{\omega_p \cdot EPC}$$

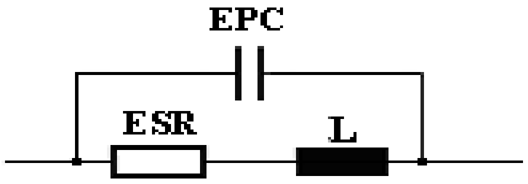
INDUCTORS

Transfer function:

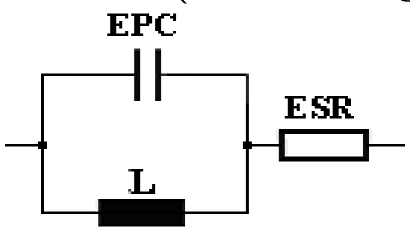
$$H_L(s) = ESR\frac{\frac{sL}{ESR}+1}{s^2L\cdot EPC + s\cdot ESR\cdot EPC + 1}$$

$$H_L(s) = \left(s\cdot EPC + \frac{1}{sL}\right)^{-1} + ESR$$

Hidden schematics:



a.



b.

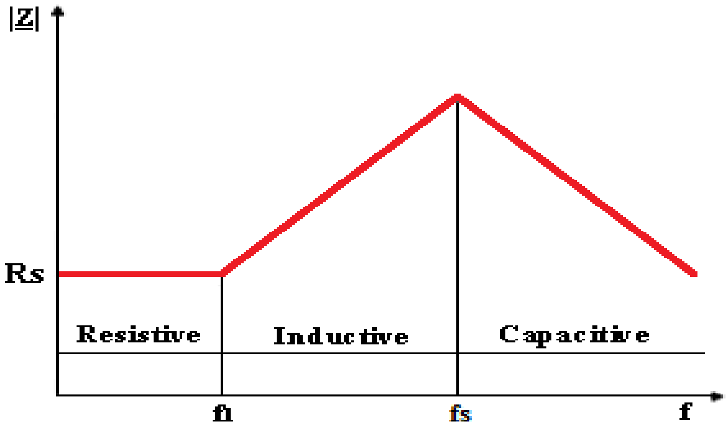
Theoretical Bode plots of the impedance variation with frequency

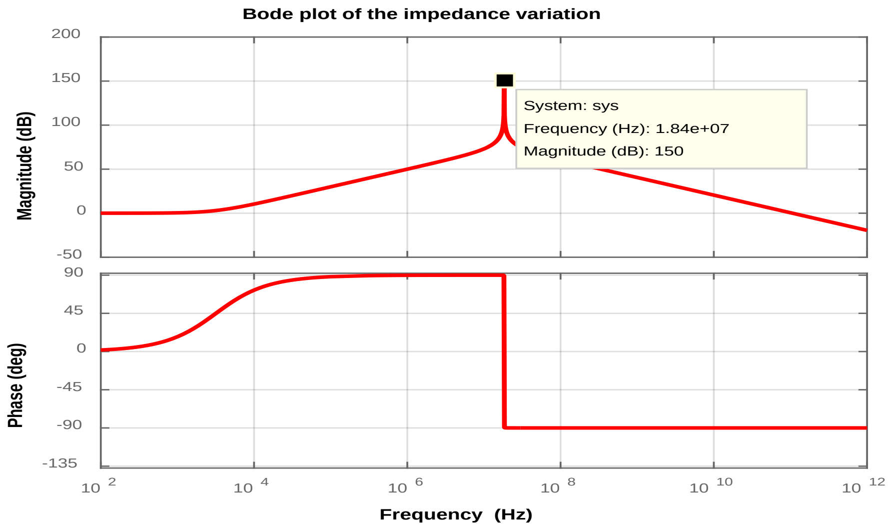
cut-off frequency

$$f_1 = \frac{ESR}{2\pi L}$$

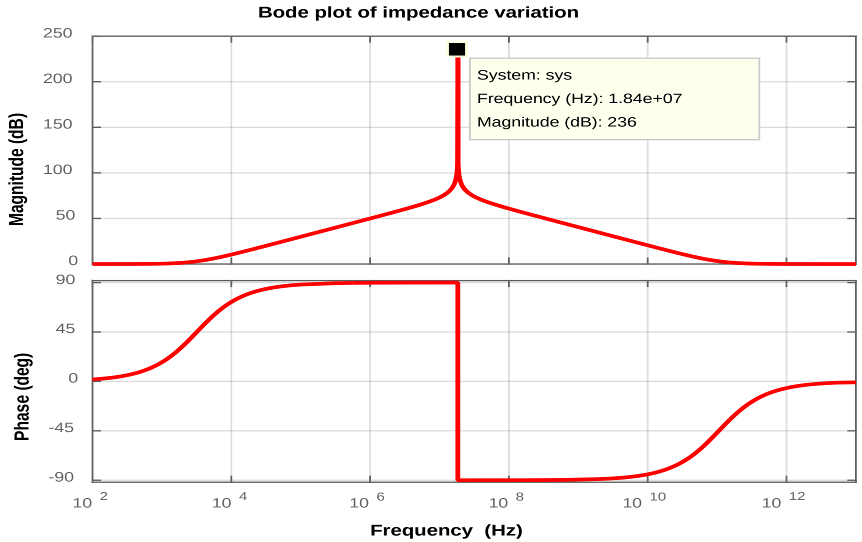
self resonant frequency

$$\omega_p \cdot L = \frac{1}{\omega_p \cdot EPC}$$

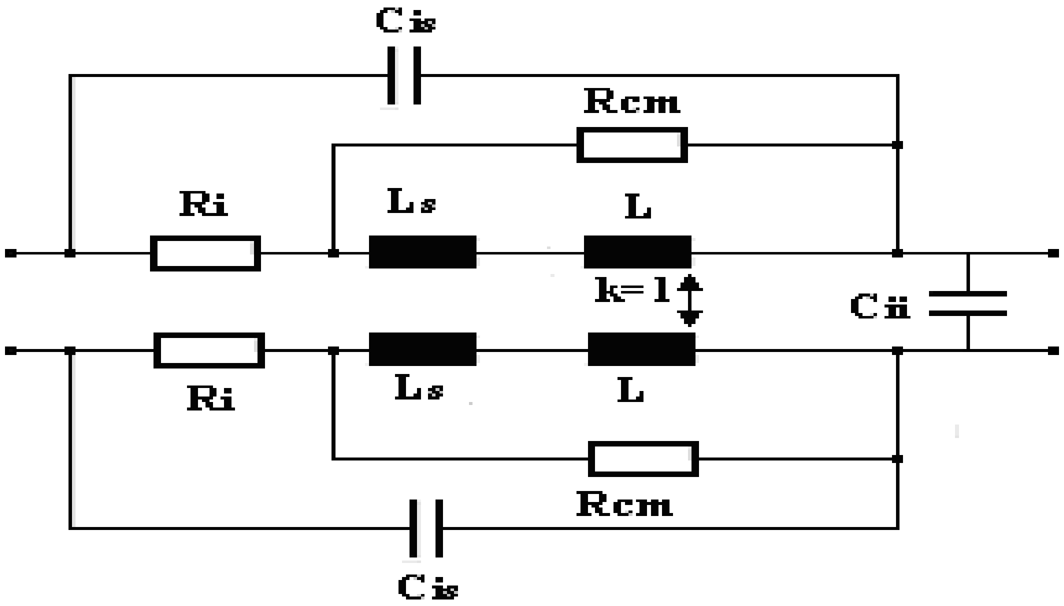




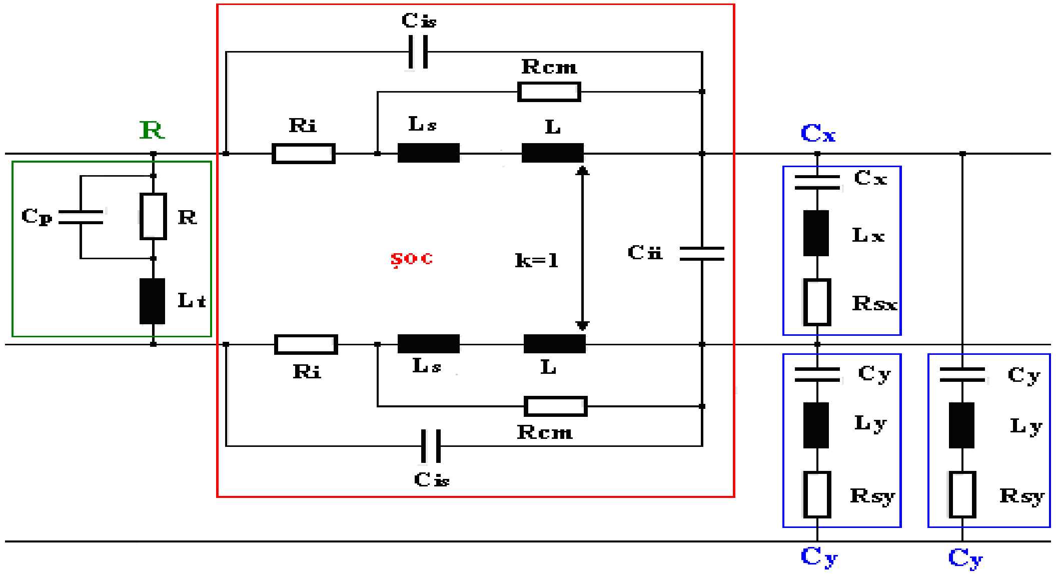
Bode plots of the impedance variation with frequency of the inductor from Fig. a



Bode plots of the impedance variation with frequency of the inductor from Fig. b



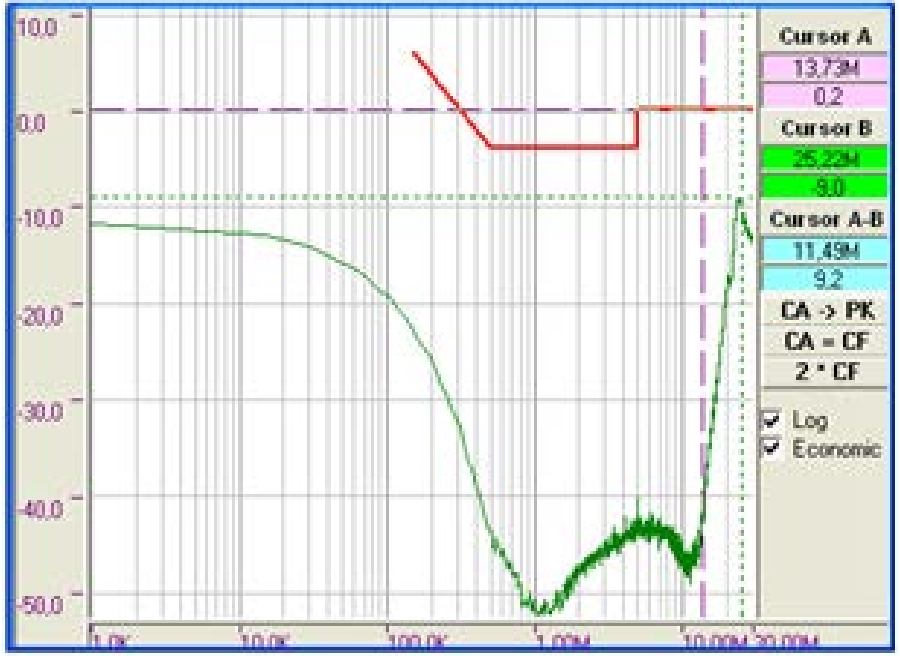
Equivalent schematics of the common mode choke



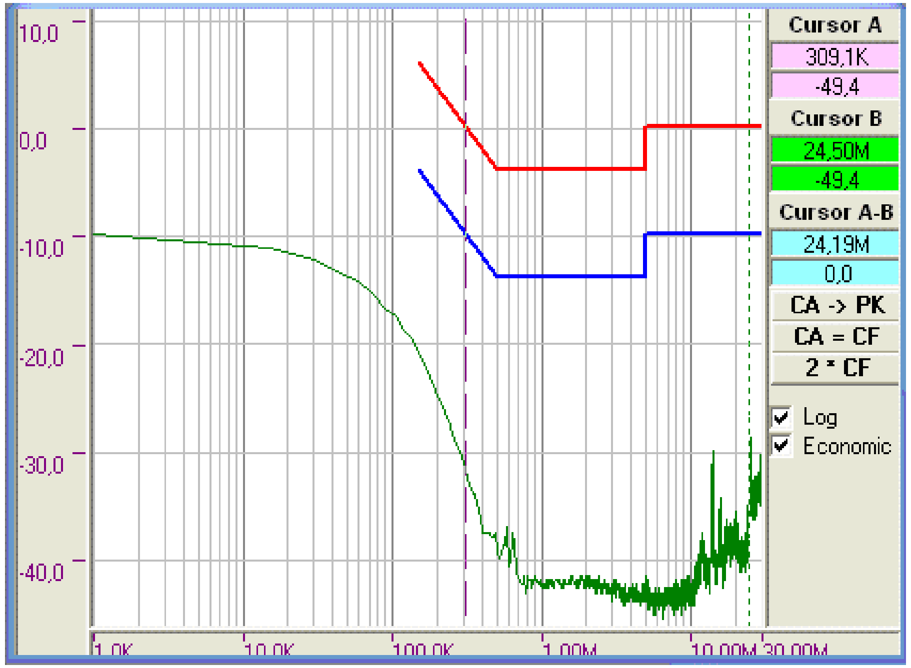
Equivalent schematics of an EMI filtering cell

The interest in the components' behavior was focused on the high frequencies where they are to be used to reduce conducted and/or radiated emissions.

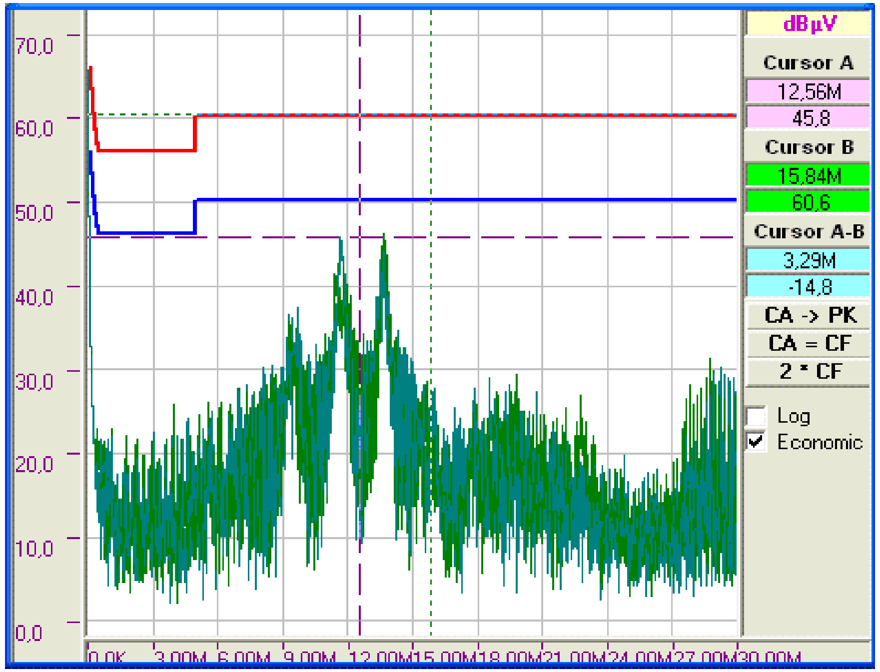
In order to obtain consistent results, apart from the conventional parameters and stress de-rating factors (power dissipation, limiting voltage and current, operating temperature range, etc.), one should think also in terms of nonideal behaviour of the circuit elements in the equivalent model.



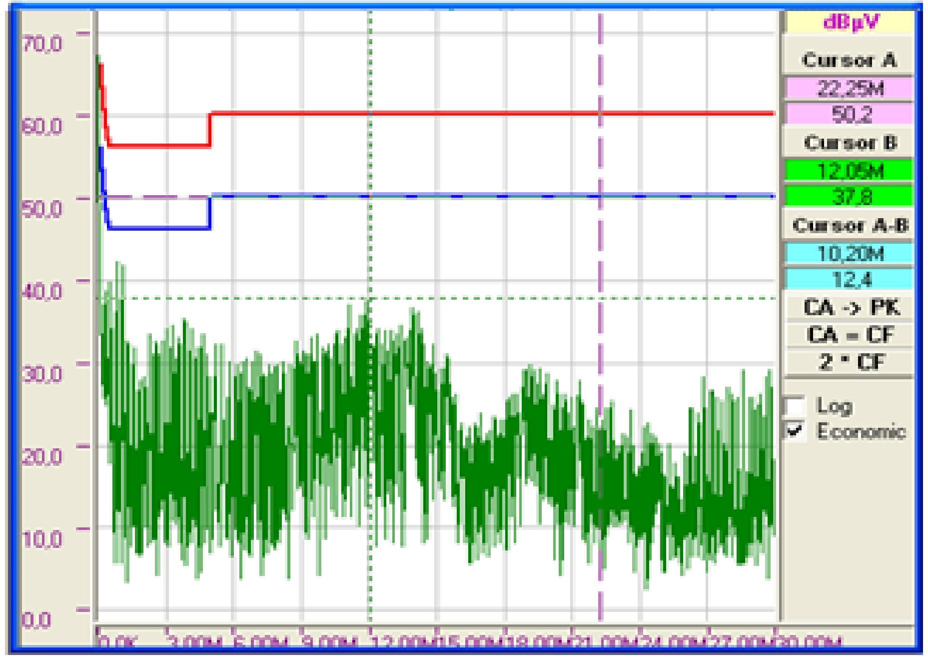
EMI filter transfer characteristics
in differential mode



EMI filter transfer characteristics
in common mode



Final spectrum of RF emissions of the AHU



Final spectrum of RF emissions of the gas heating central

Conclusions!

Thank you for your attention!

Društvo za KGH Srbije
kgh
Serbian HVAC&R Society

47th International Congress and Exhibition on Heating, Refrigeration and Air-Conditioning

Belgrade, Sava Centre, 30th November – 2nd December 2016