Seminar in delavnica

Načrtovanje elektronike za EMC

Elektromagnetna združljivost (EMC)

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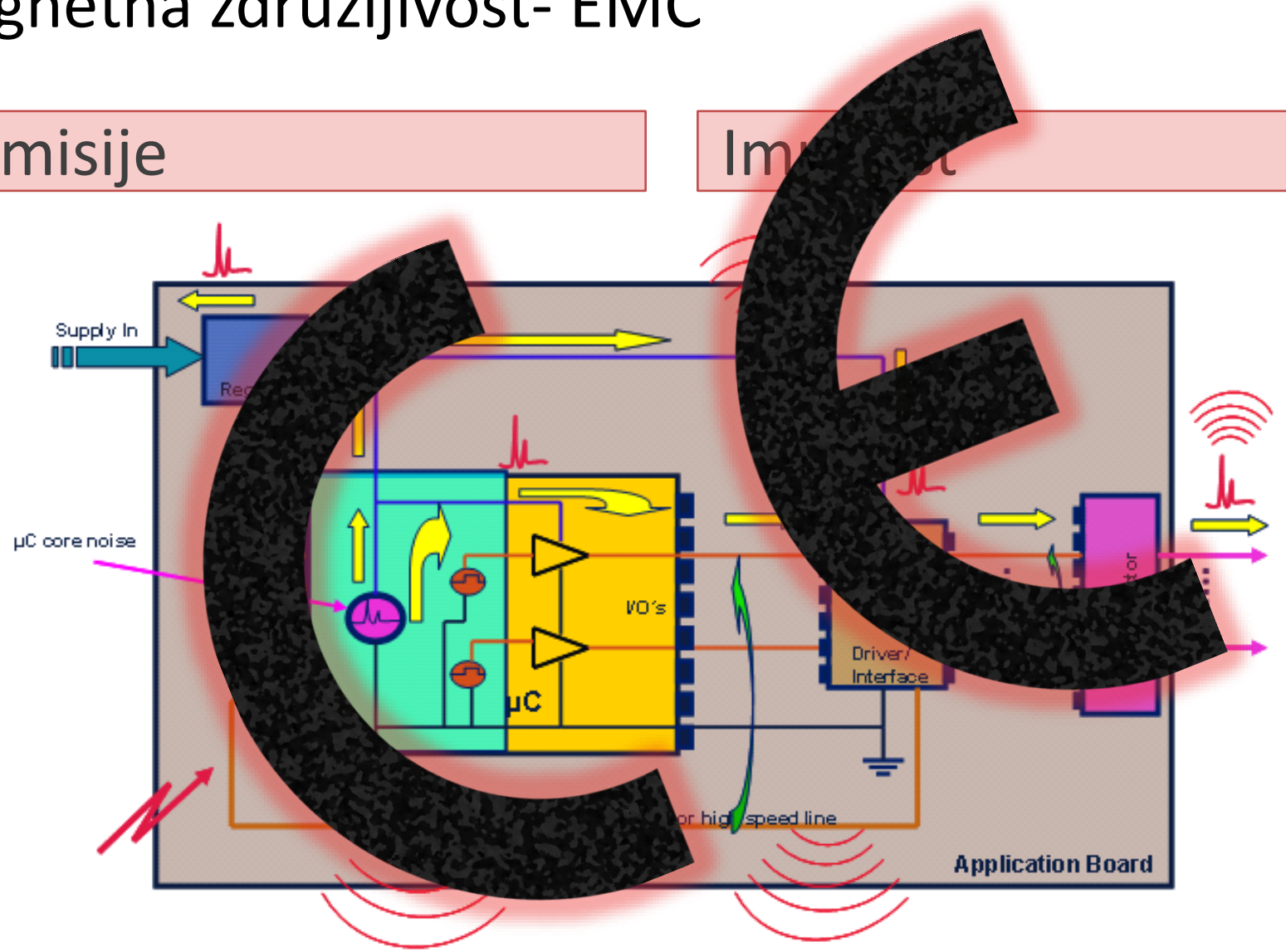
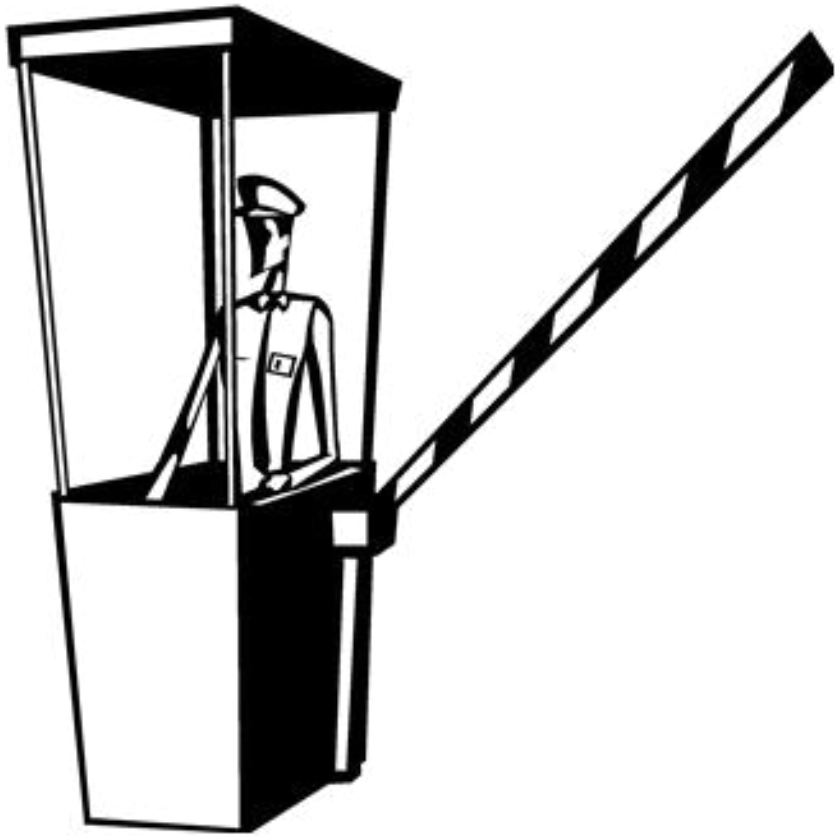
Elektromagnetna združljivost- EMC

Emisije

Imunost



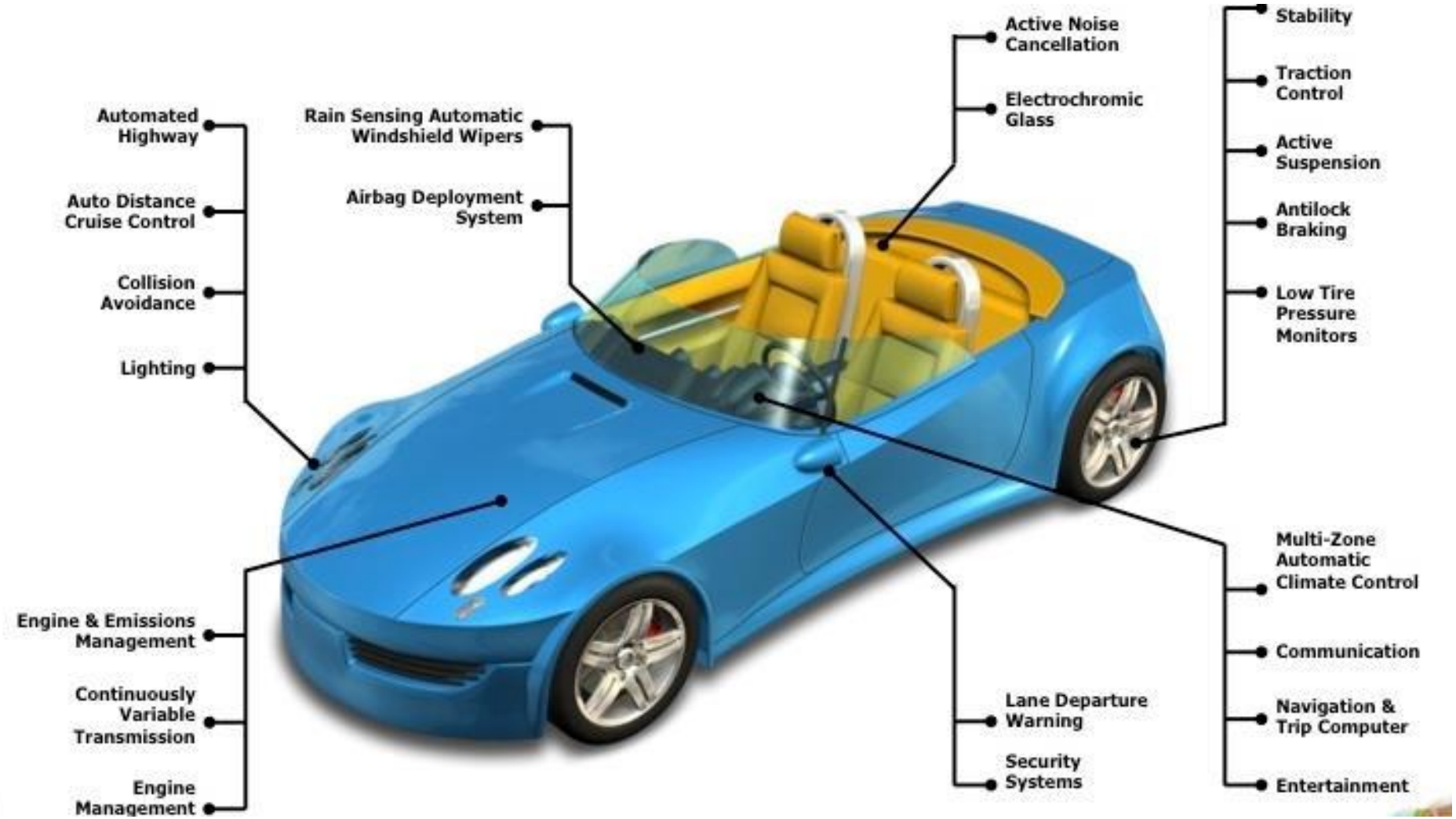
Nedolžen EMC problem



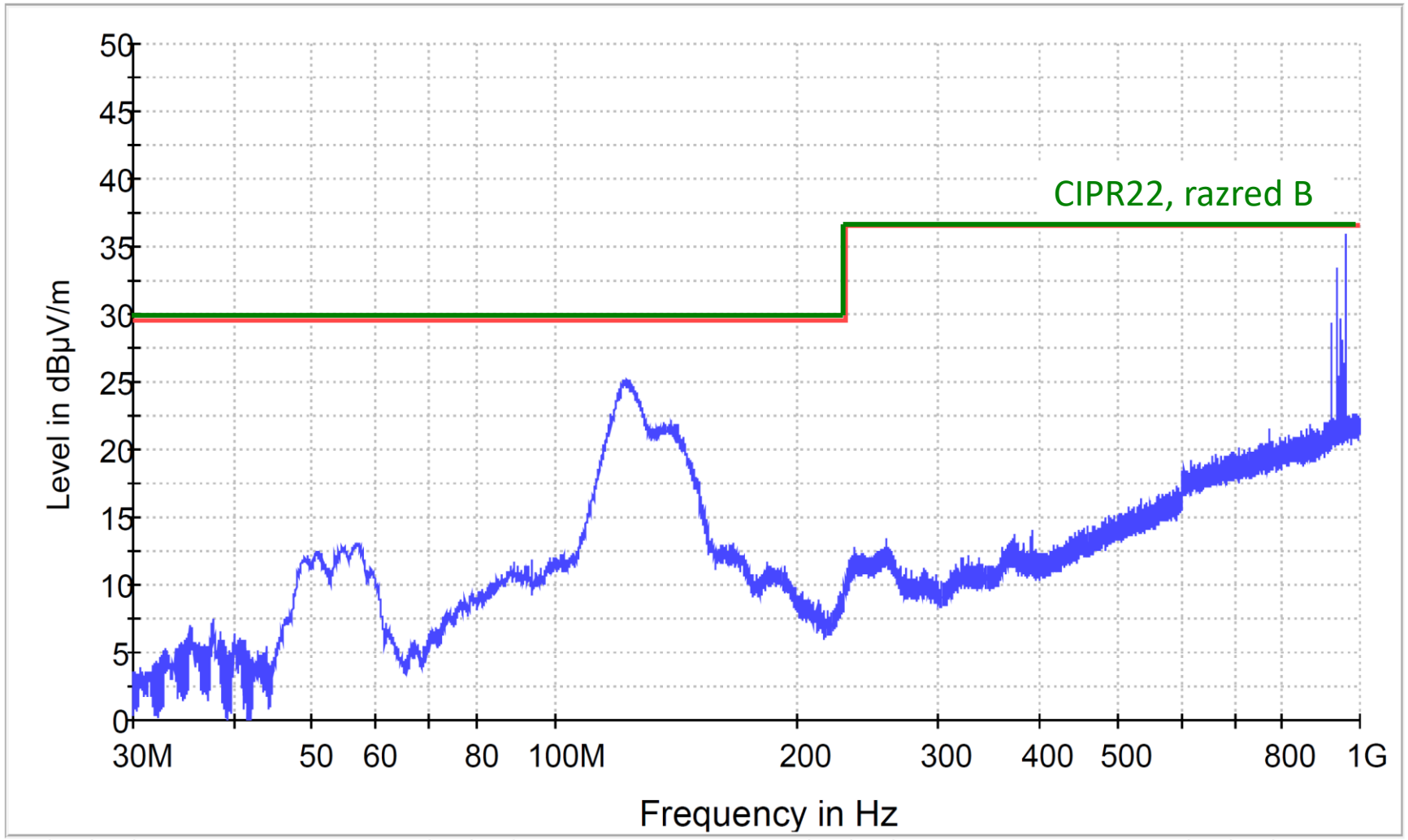
Neprijeten EMC problem

Smrtno nevaren EMC problem

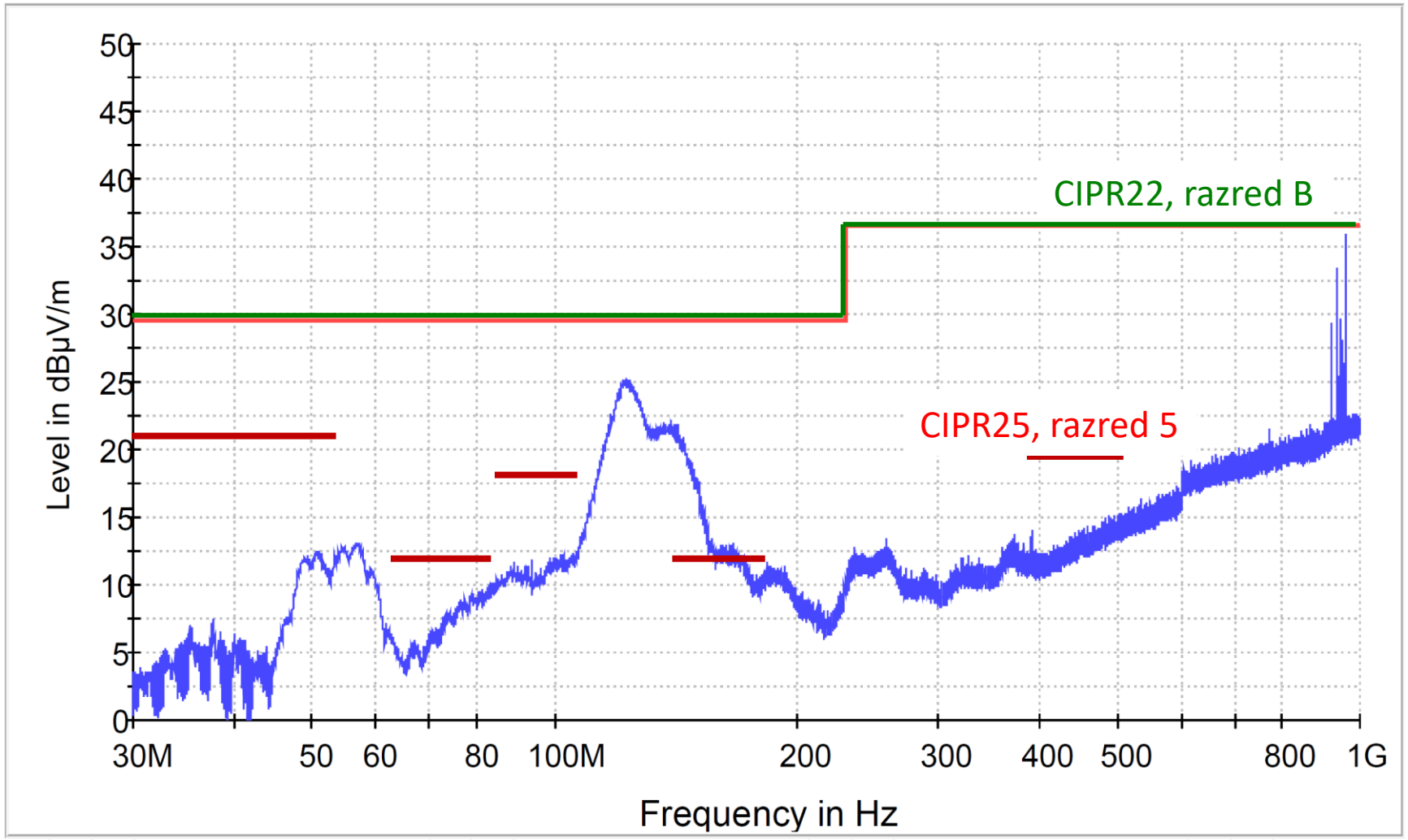
EMC v avtomobilski industriji



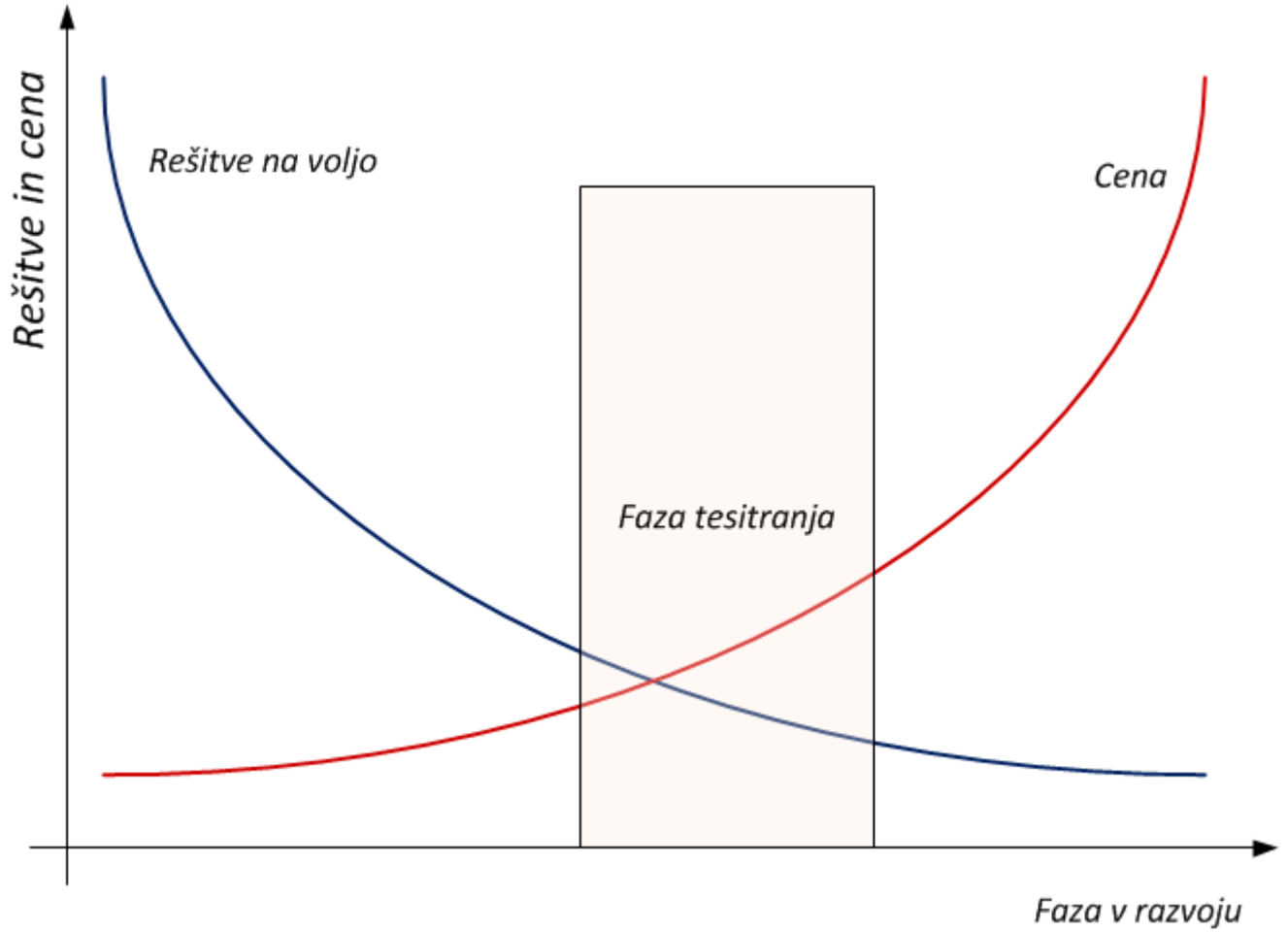
Splošne emisijske meje



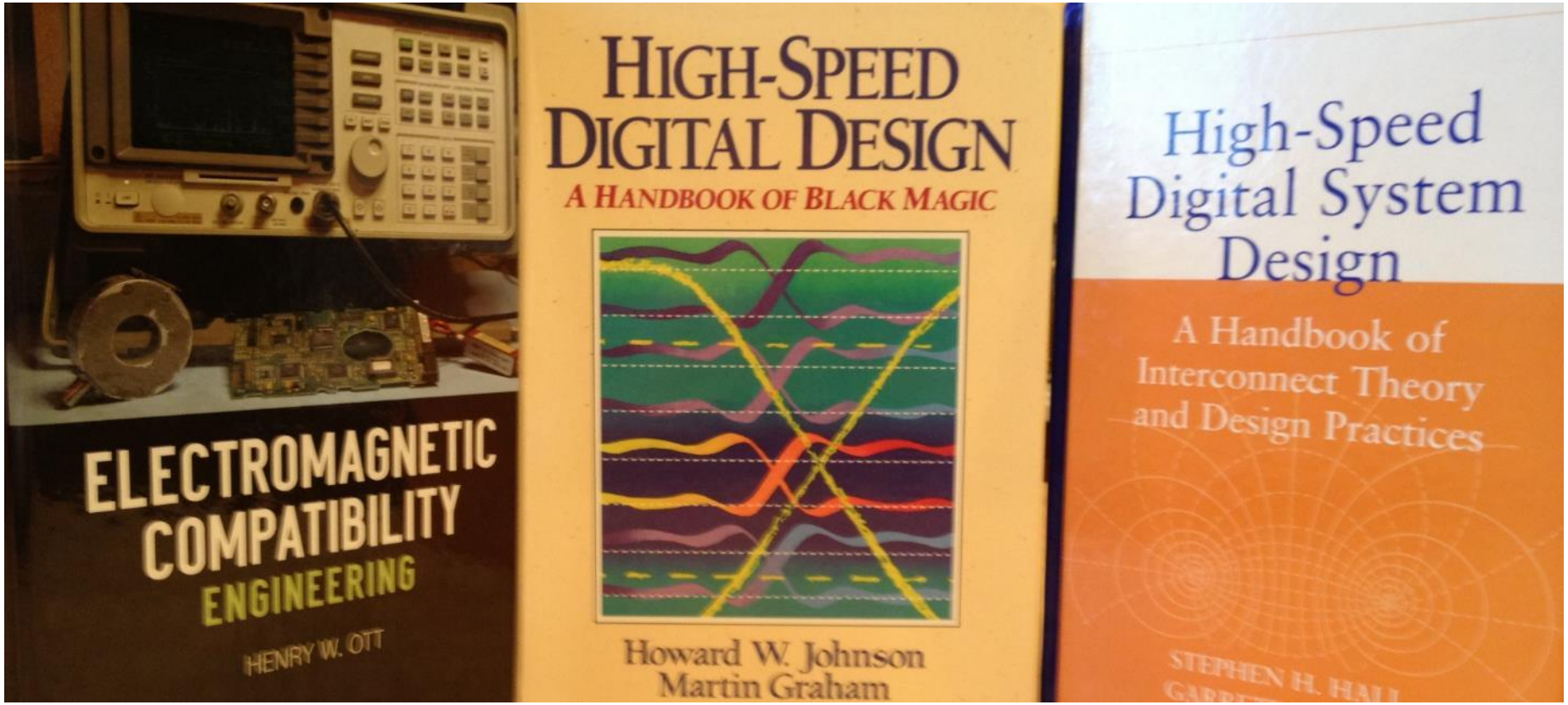
Emisijske meje v avtomobilski industriji



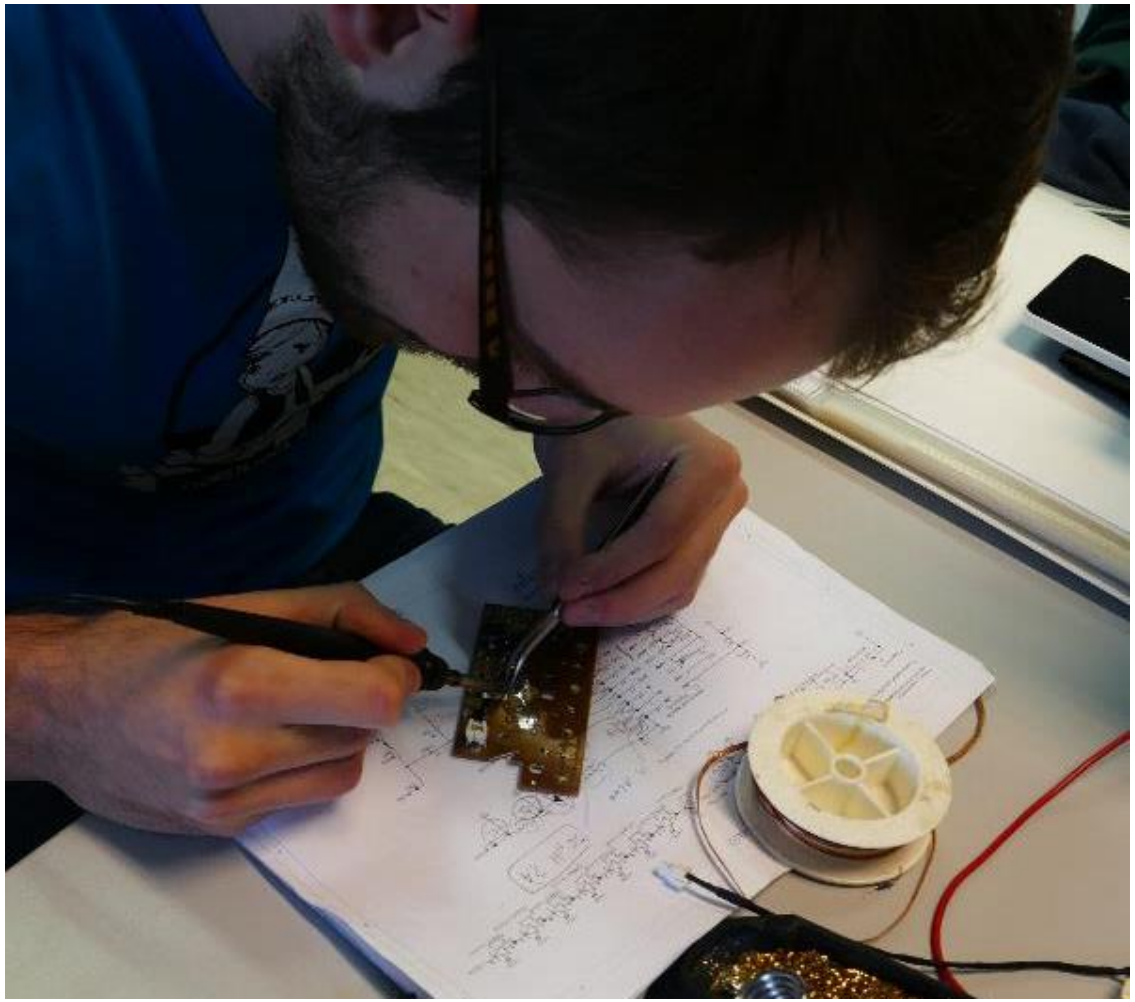
Doseganje EMC



Literatura o EMC



EMC delavnice



Osnovna delitev EMC področja

Motnja/ emisija	• Prevodna (Conducted) • Sevalna (Radiated)
Odpornost/ imunost	• Prevodna (Conducted) • Sevalna (Radiated)

Model EMC

- **izvor** sevanja (motenj),
- **Sprejemnik**
- **povezava** med izvorom in sprejemnikom.

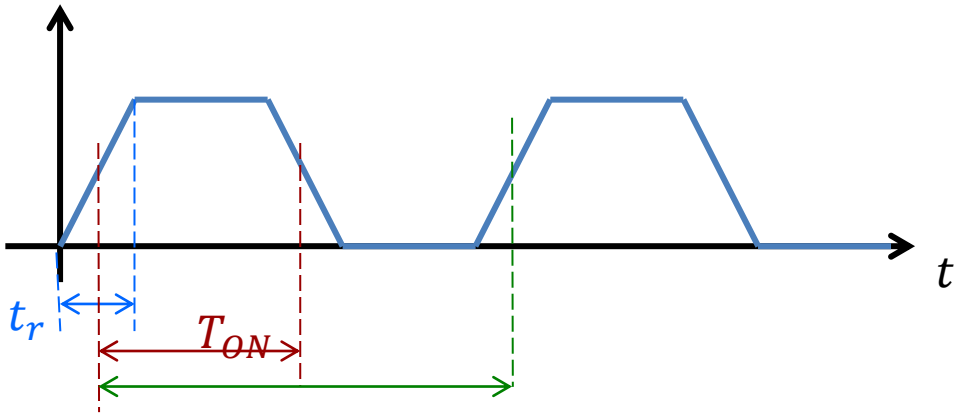
- Naravni
- Umetni
  - Namerni
  - Nenamerni

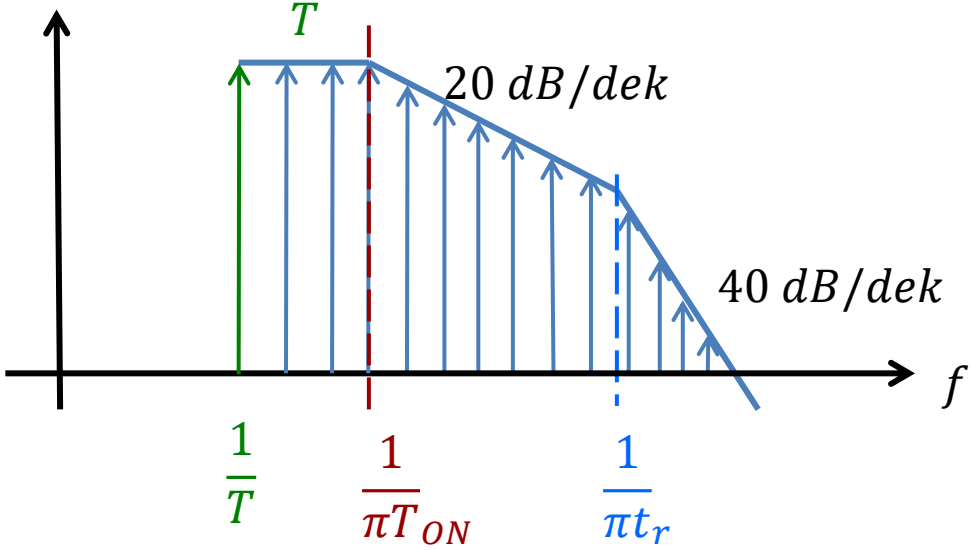
- Prevodne
- Električno polje
- Magnetno polje
- Elektromagnetno polje

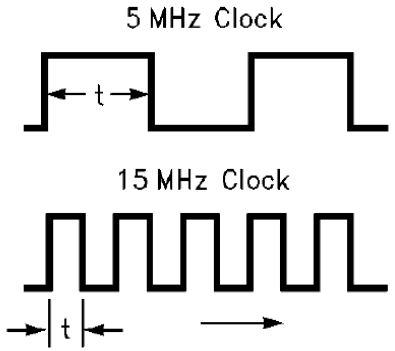
- Biološke
- Umetne

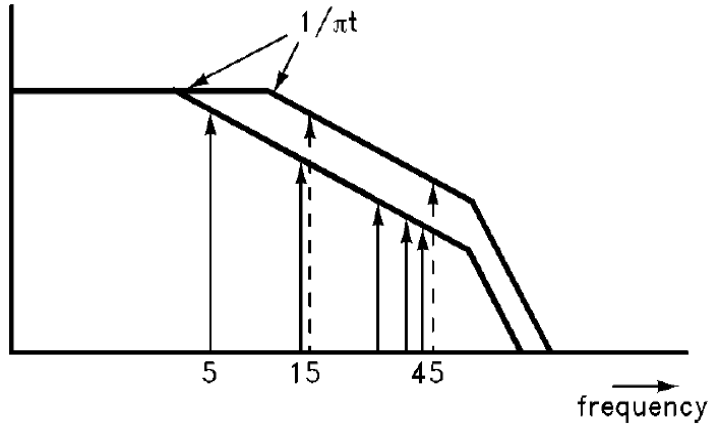
Izvori motenj

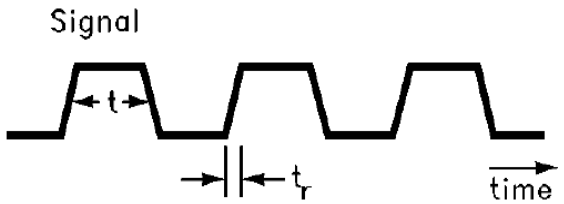
Frekvenčna vsebina signala

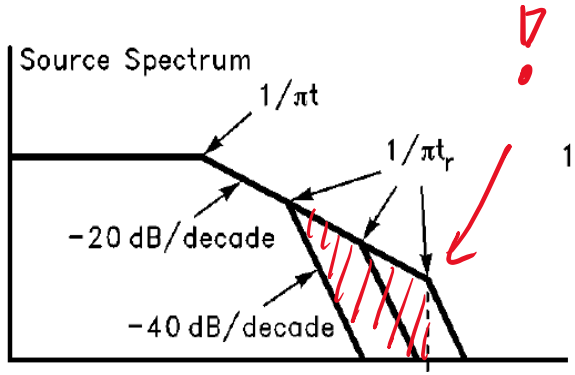








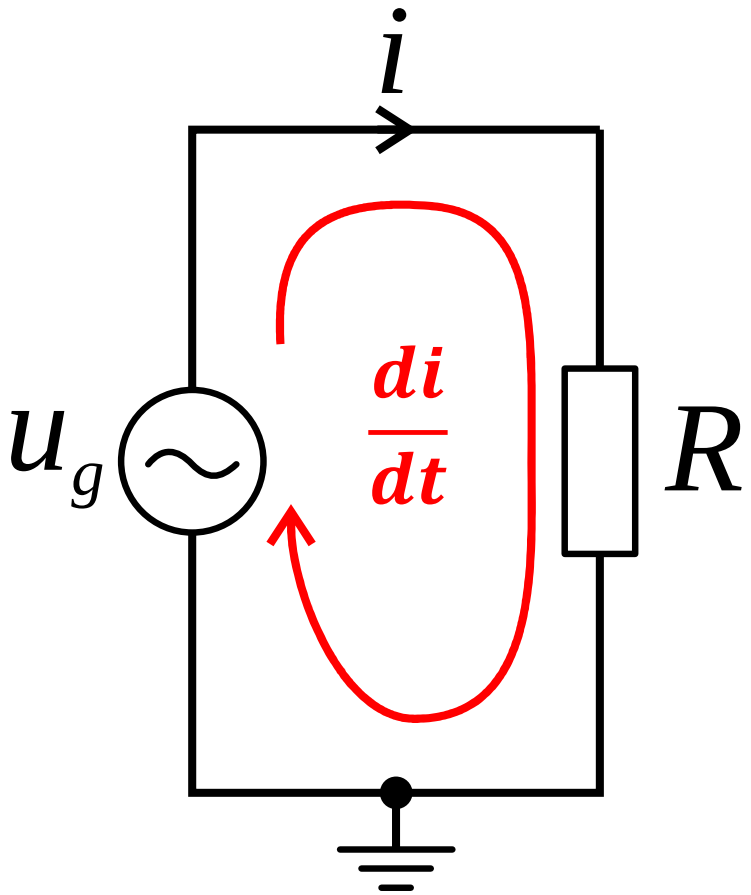




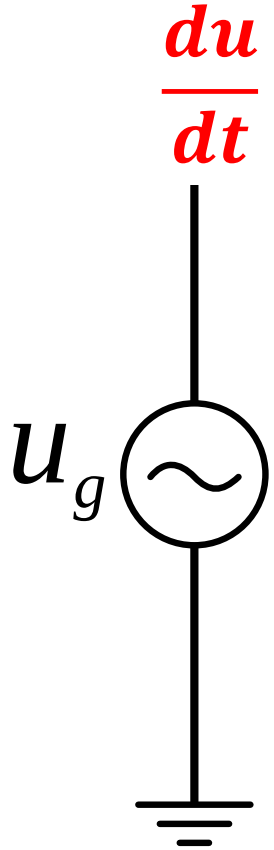
10 ns = 30 MHz
3 ns = 100 MHz
1 ns = 300 MHz

Izvori motenj

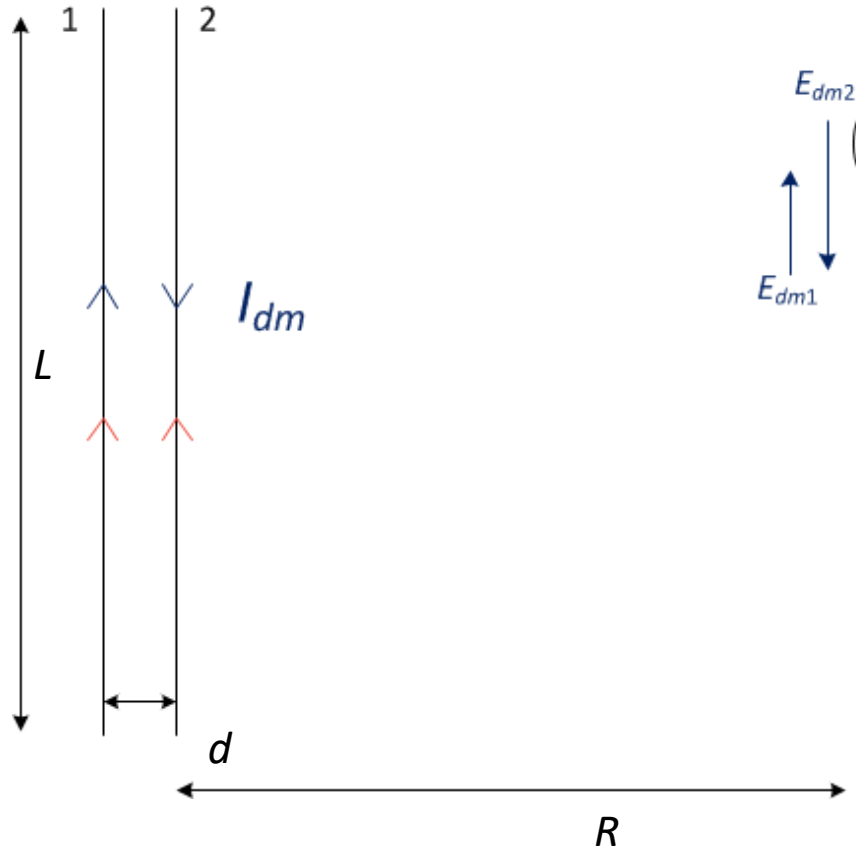
VF tokovne zanke

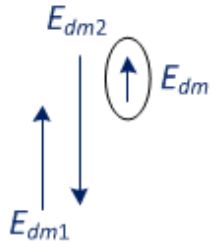


VF potenciali



Sevanje VF tokovne zanke





Linija v zraku:

$$E_{dm_{maks}}(f) = 1{,}31 \cdot 10^{-14} \frac{I_{dm}(f) f^2 Ld}{R} \; V/m$$

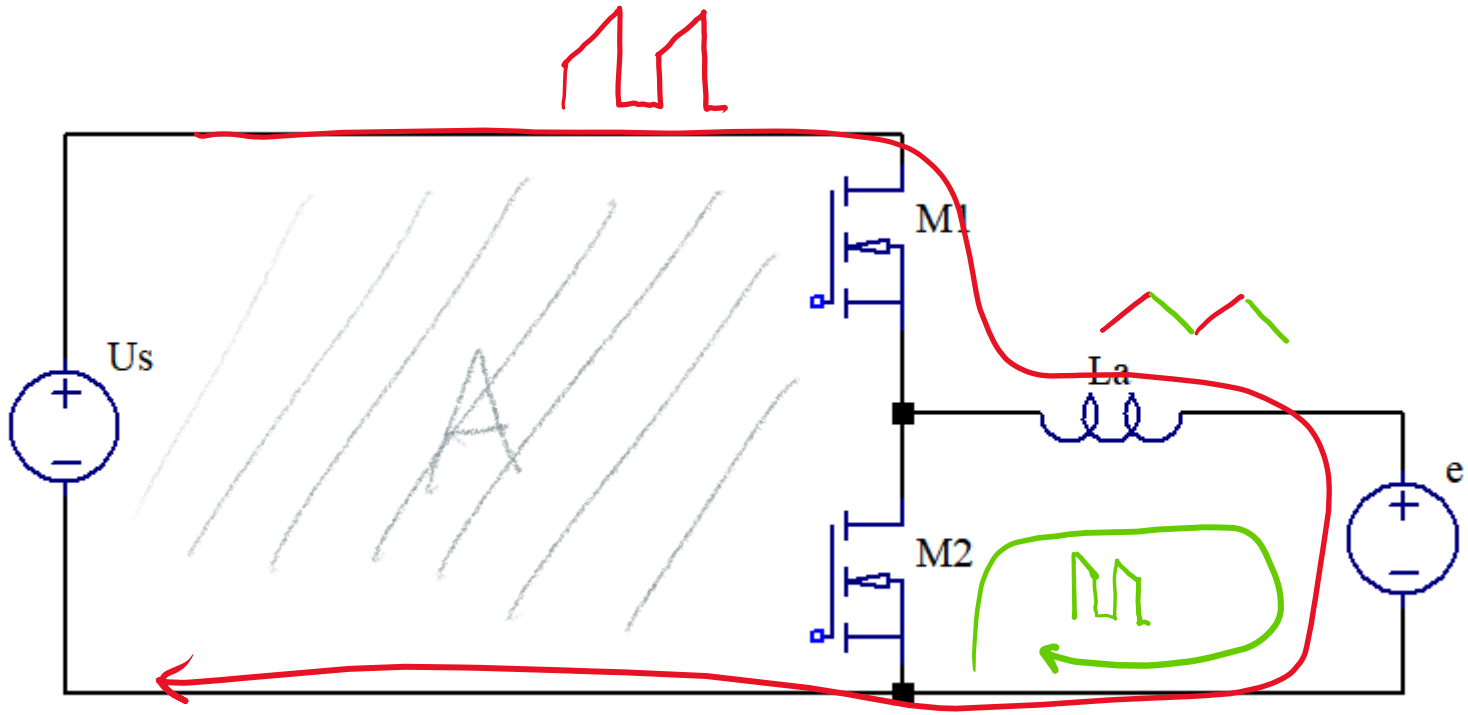
Linija na tiskanini:

$$E_{dm_{maks}}(f) = 2{,}63 \cdot 10^{-14} \frac{I_{dm}(f) f^2 Ld}{R} \; V/m$$

C. A. Balanis, Antenna theory: analysis and design. John Wiley & Sons, 2012.

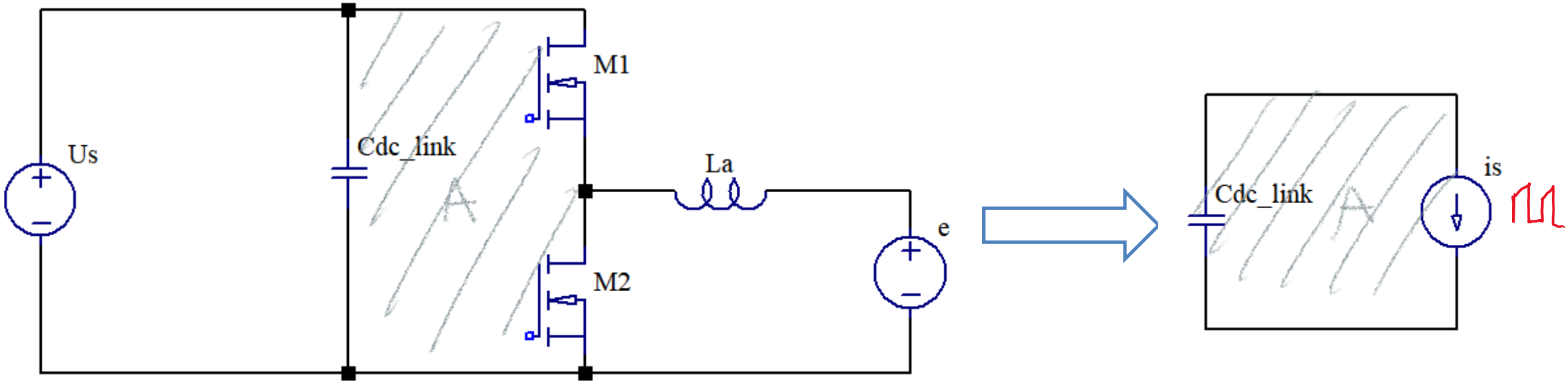
Primer 1/3 izhodne stopnje razsmernika

- Katera zanka je najbolj kritična?



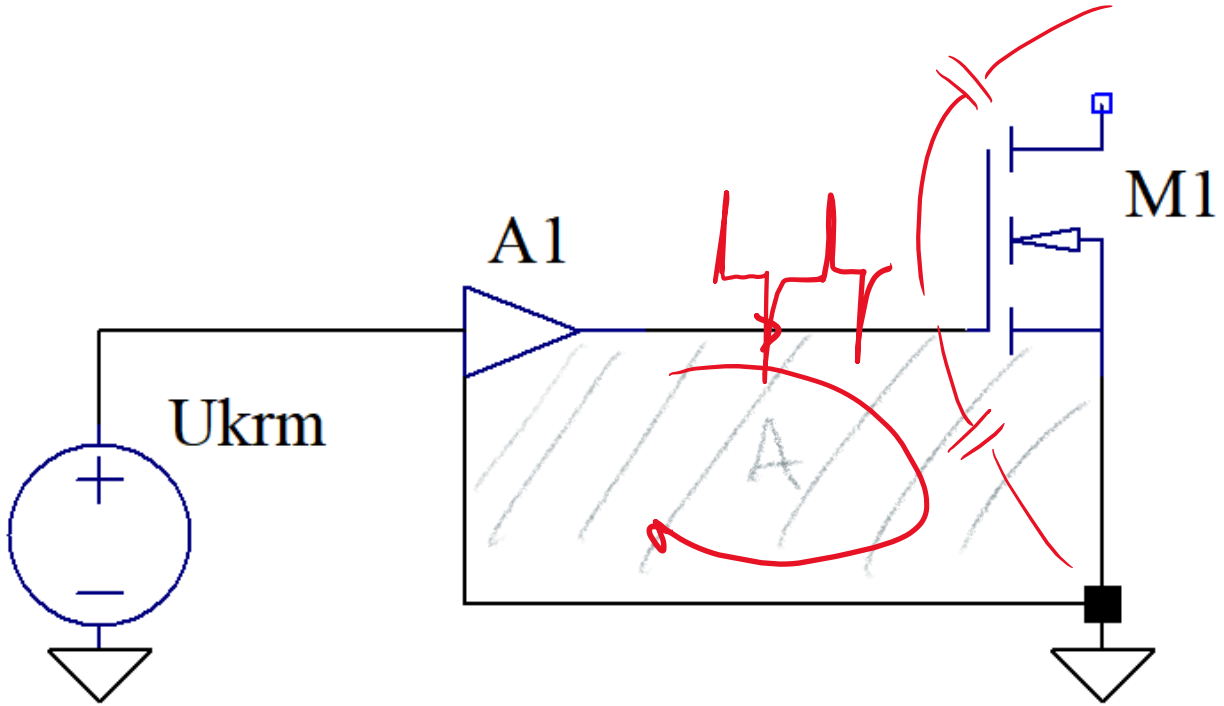
Primer 1/3 izhodne stopnje razsmernika

Kaj določa velikost kritične zanke?



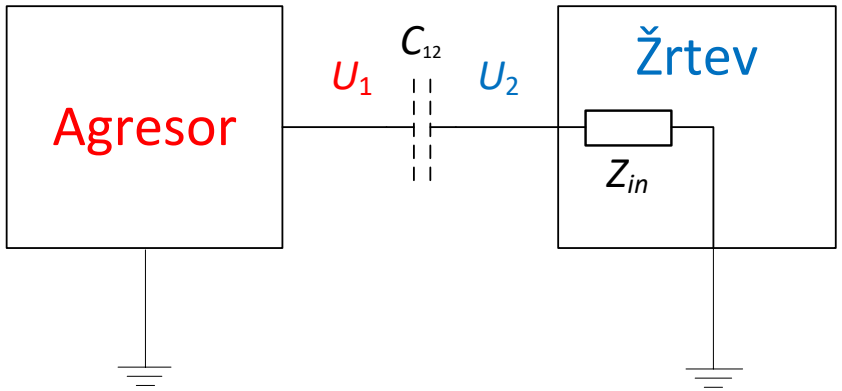
Primer 1/3 izhodne stopnje razsmernika

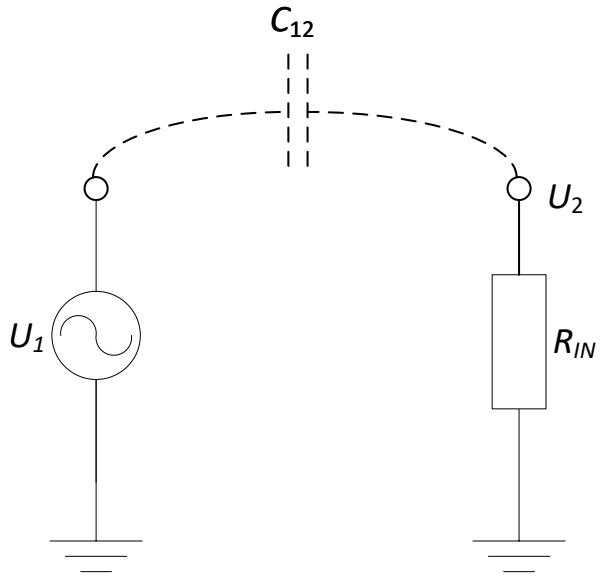
Kaj pa krmiljenje MOS?



Izvori motenj

Kritična napetostna nihanja



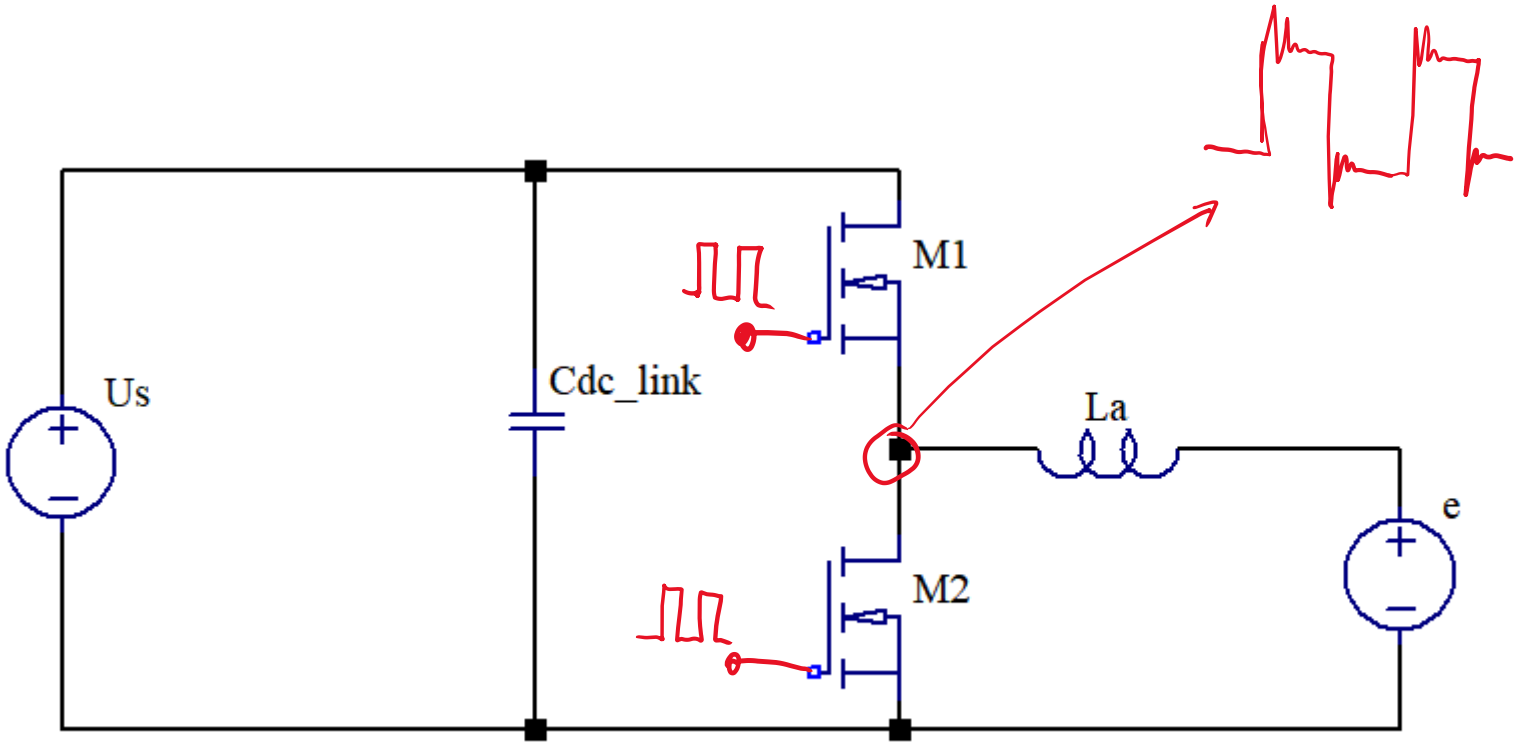


$$U_2 = C_{12}\frac{dU_1}{dt}Z_{in}$$

$$U_2 = U_1\frac{R_{IN}}{\sqrt{R_{IN}^2 + \frac{1}{\omega^2 C^2}}}$$

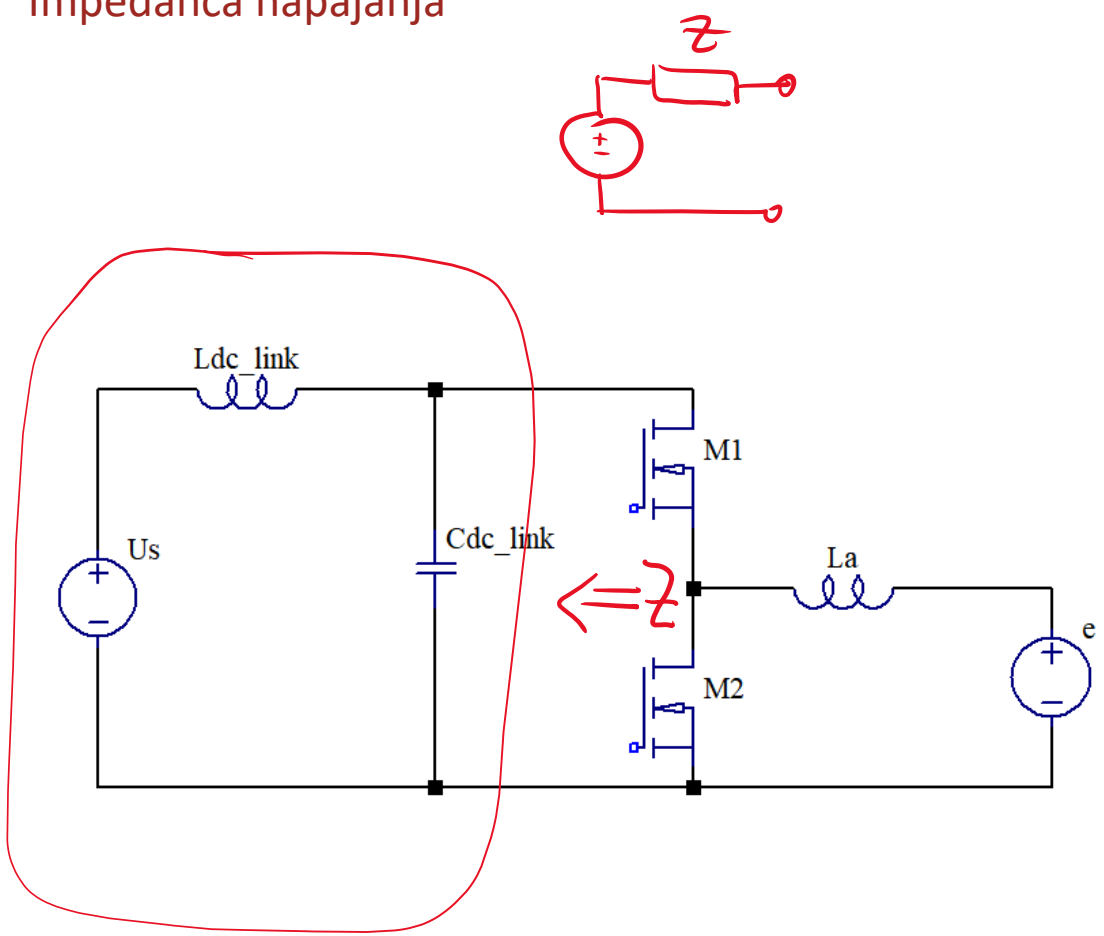
Izvori motenj

Kritična napetostna nihanja



Učinek kondenzatorjev na DC linku

Impedanca napajanja

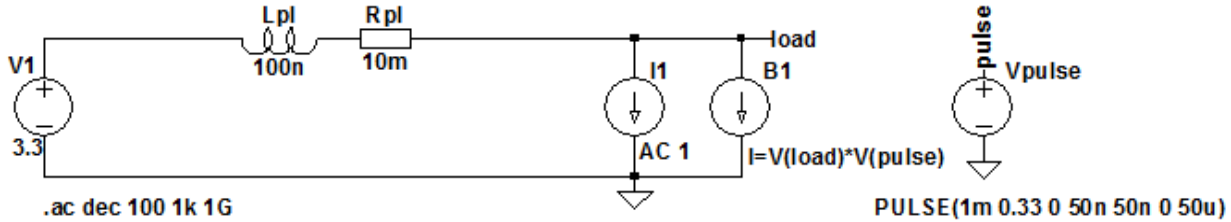


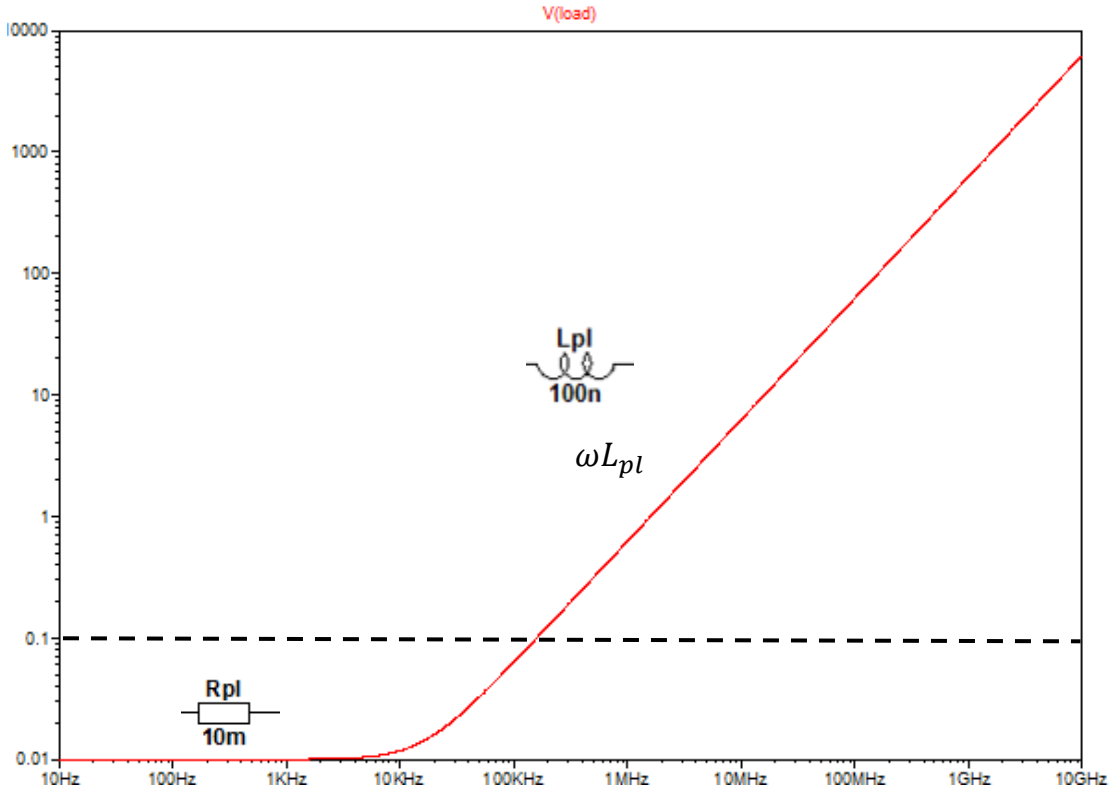
- Razmerje med
  - dopustno spremembo napetosti (ΔU_{DDmax}) in
  - spremembo toka (ΔI_{max})
- je največja dopustna impedanca napajanja.

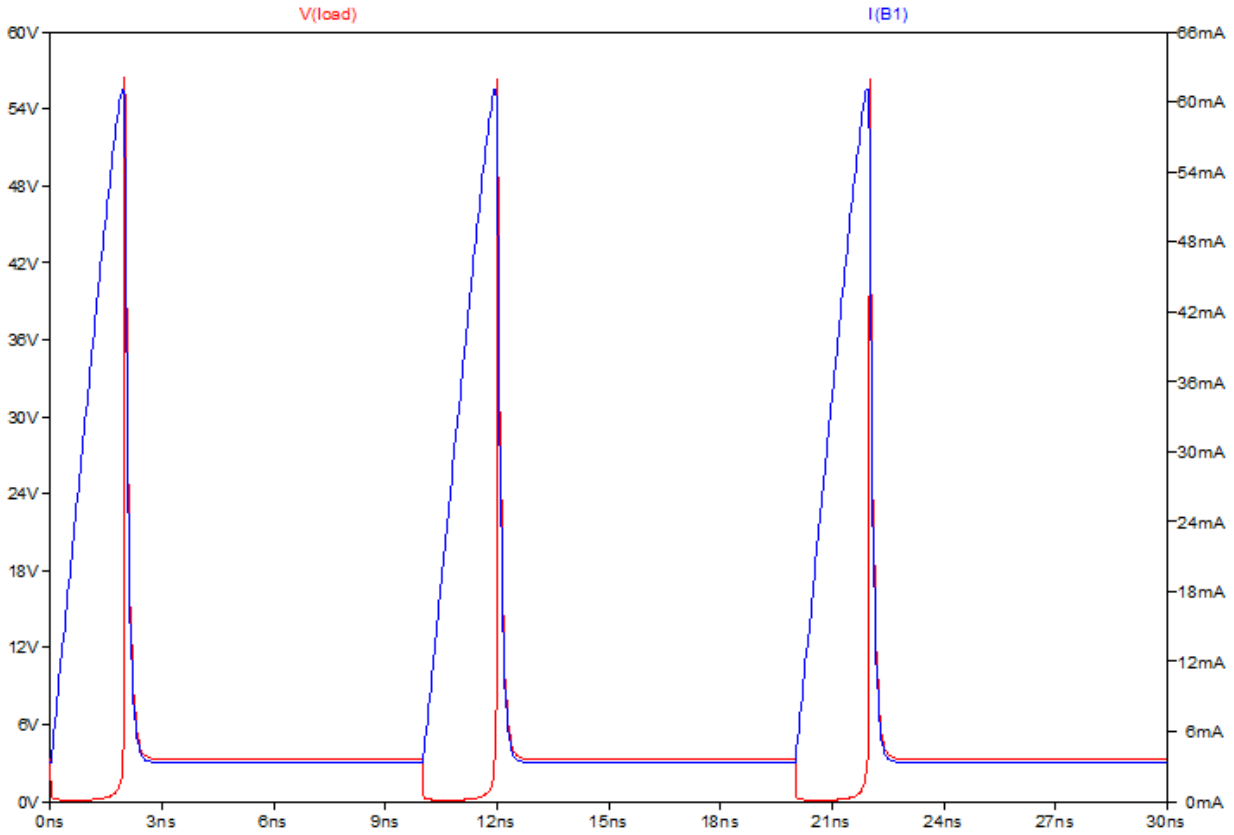
$$Z_{max} = \frac{\Delta U_{max}}{\Delta I_{max}}$$

Impedanca napajanja

Brez kondenzatorja

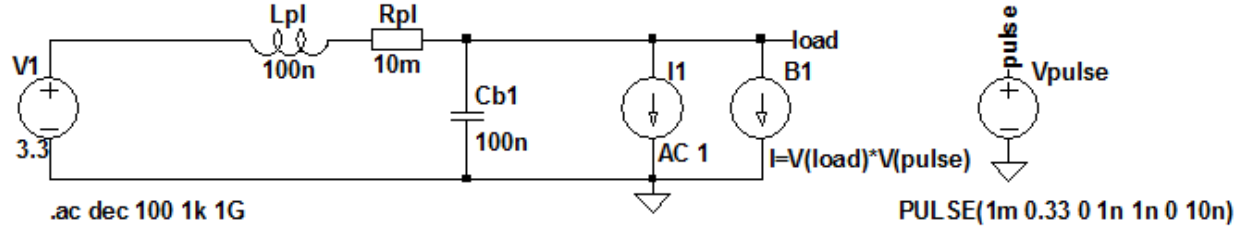


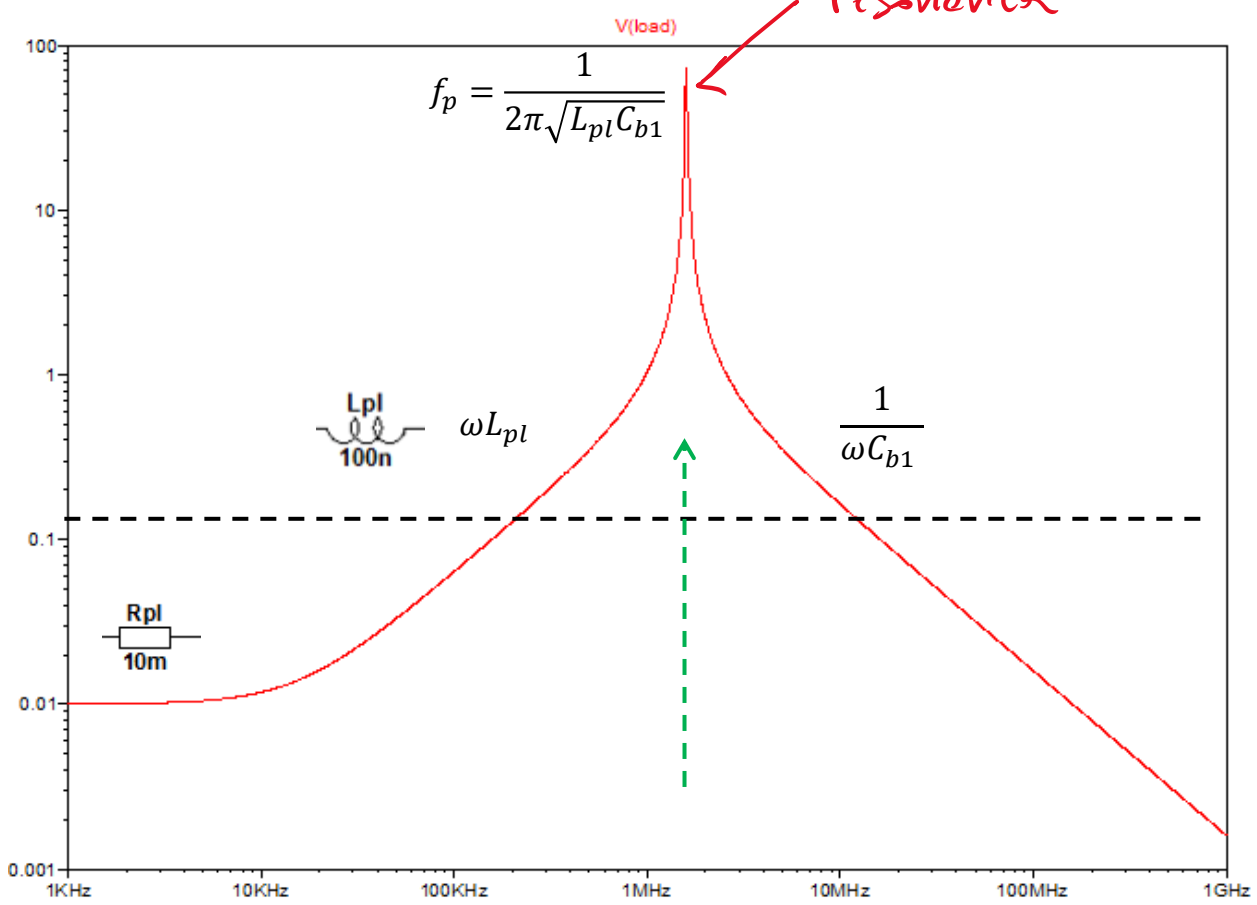


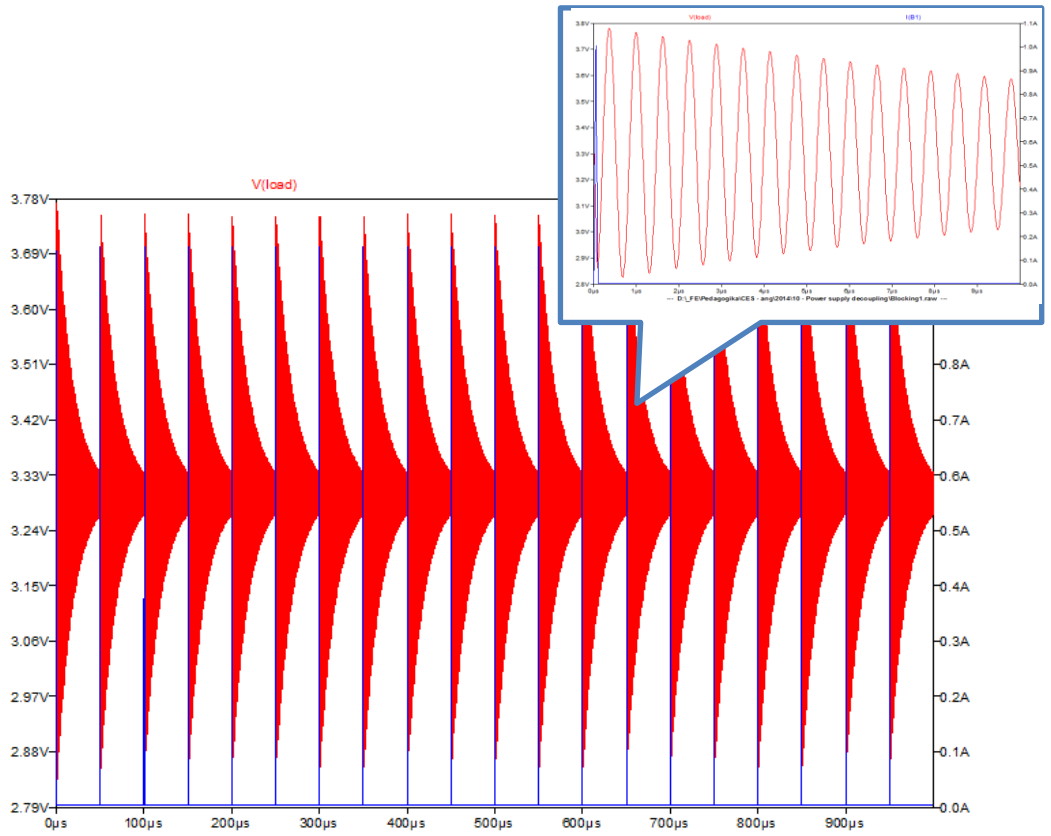


Impedanca napajanja

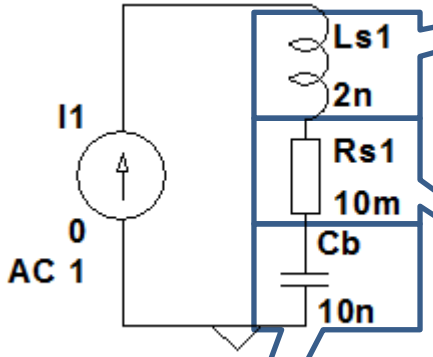
S kondenzatorjem

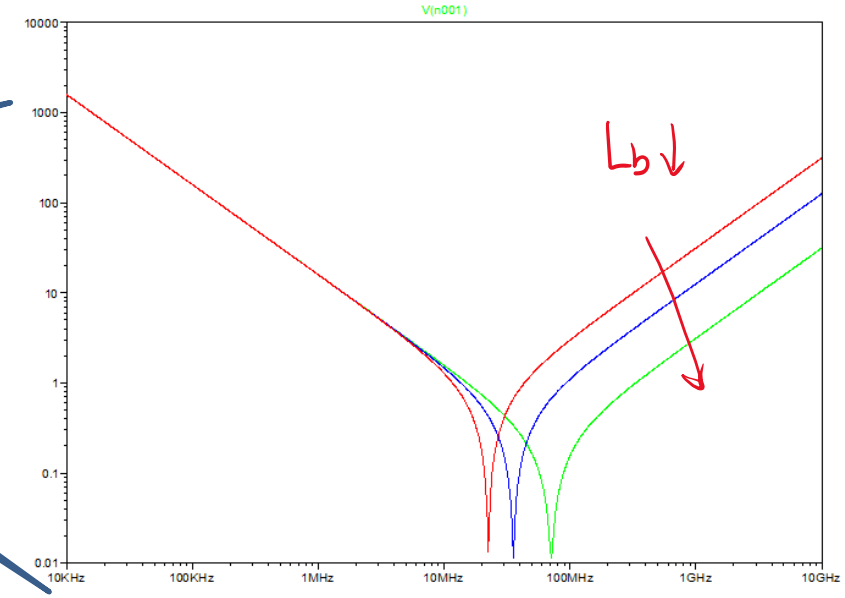


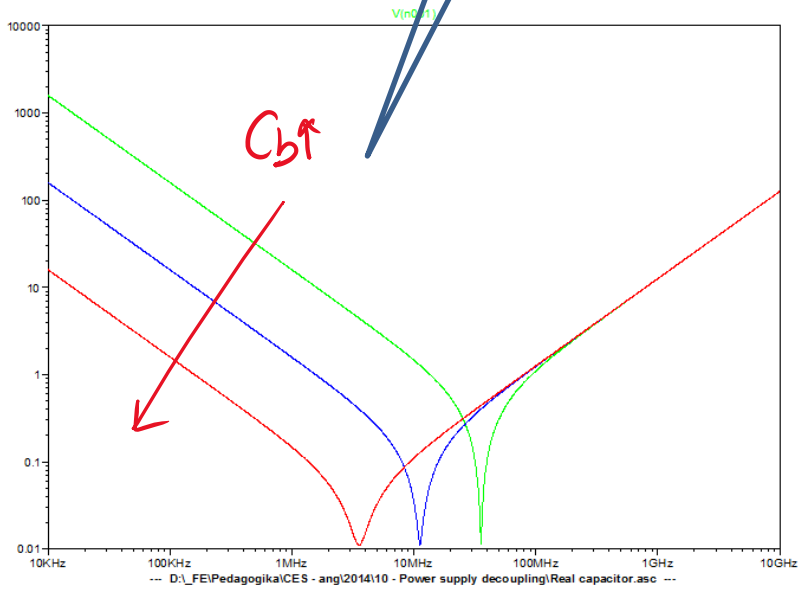


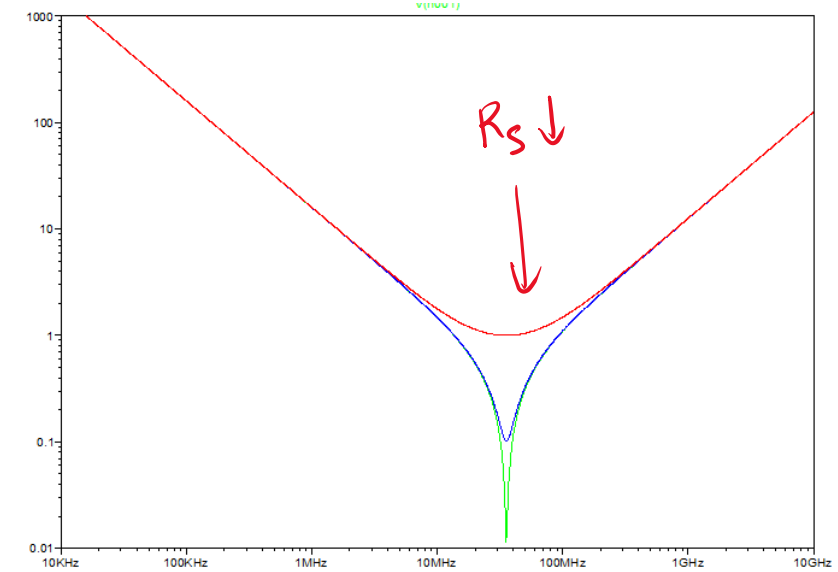


Realni kondenzator

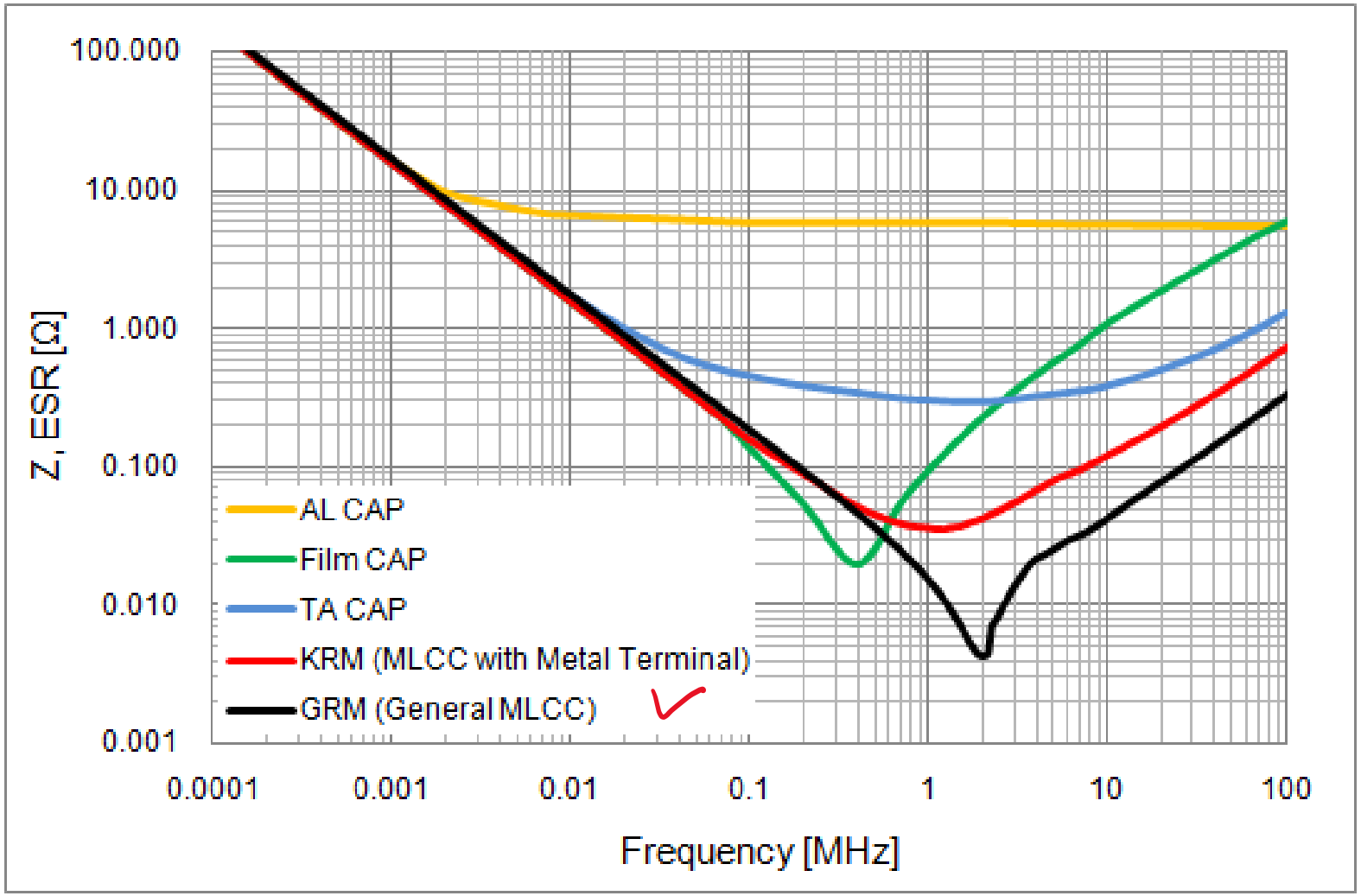






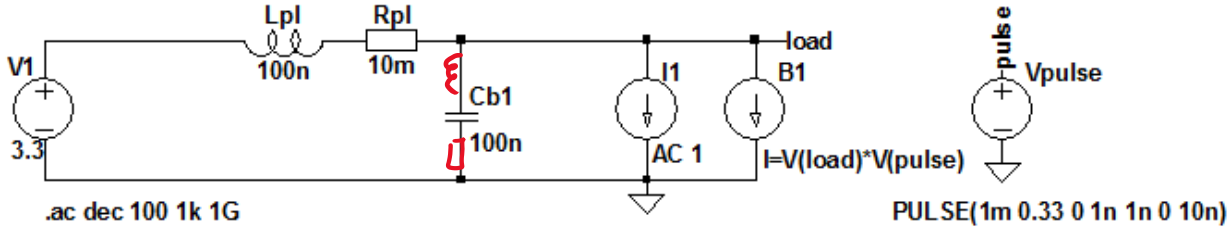


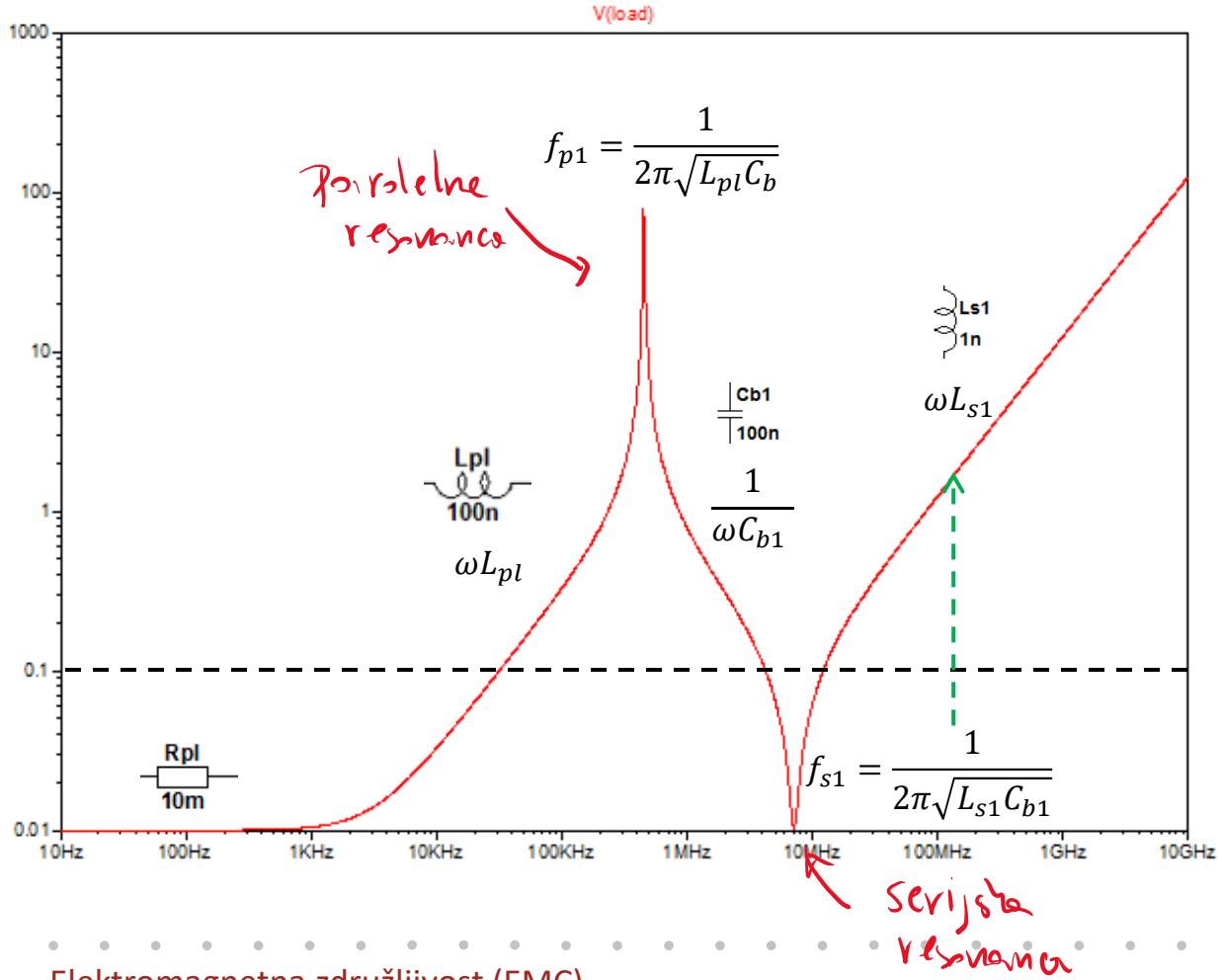
Razlika med različnimi tipi kondenzatorjev

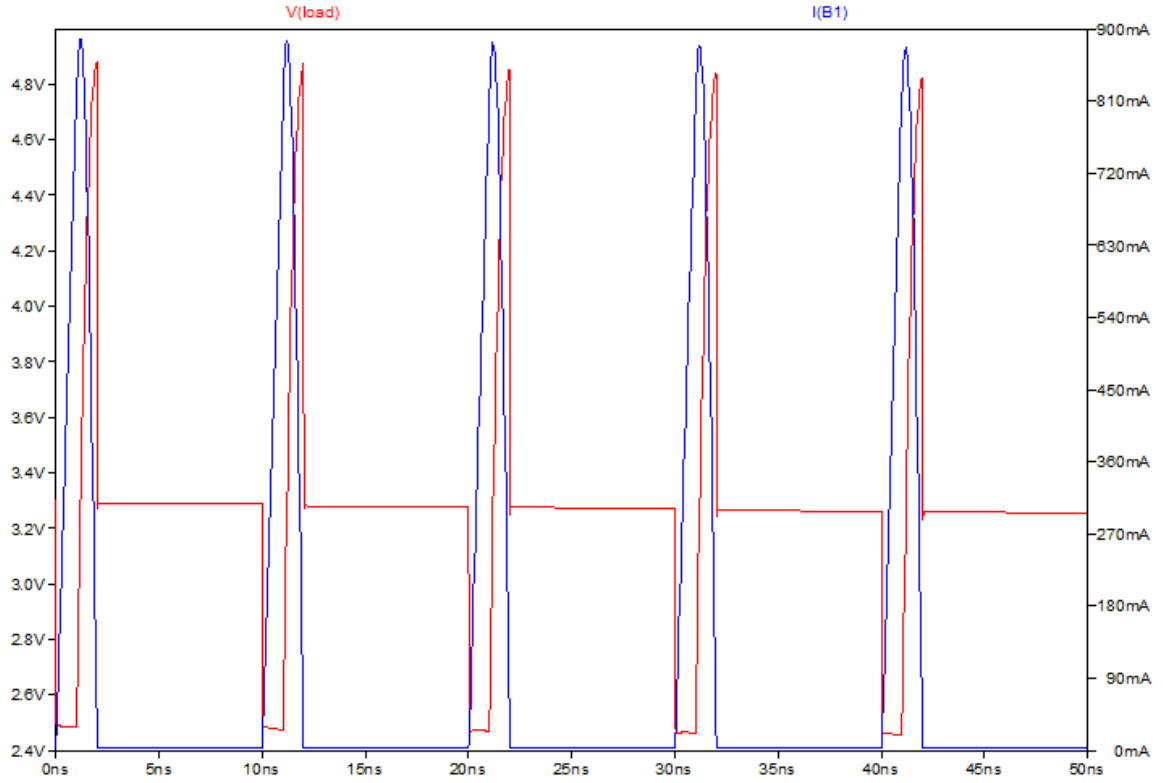


Impedanca napajanja

Z realnim kondenzatorjem

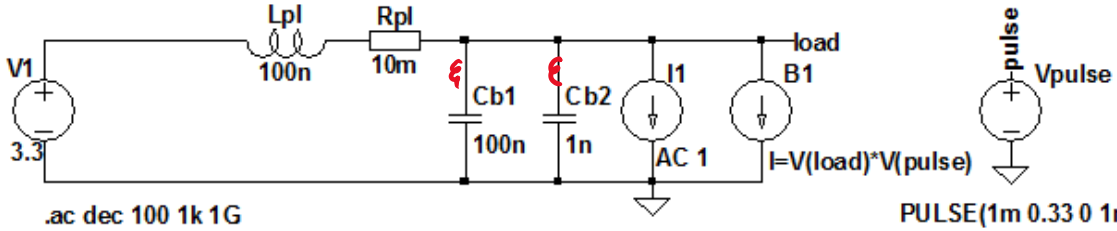


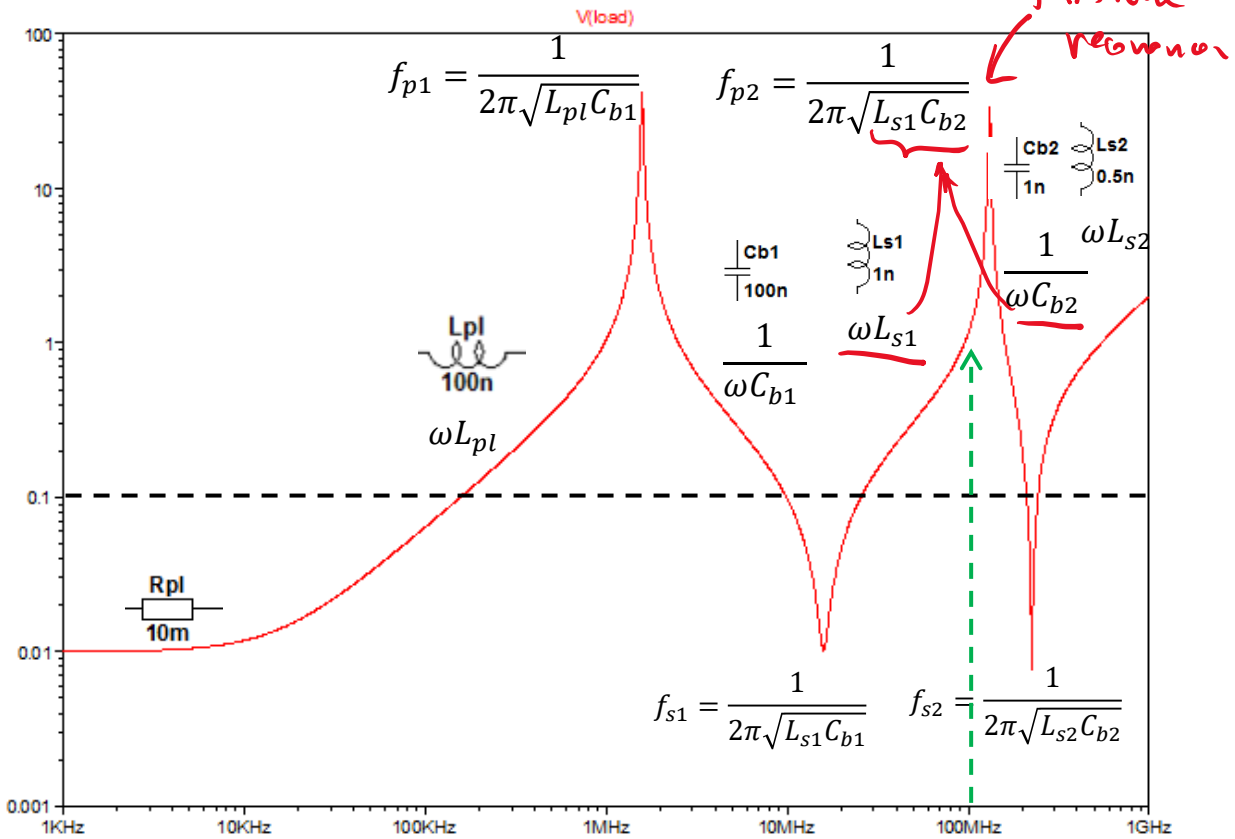


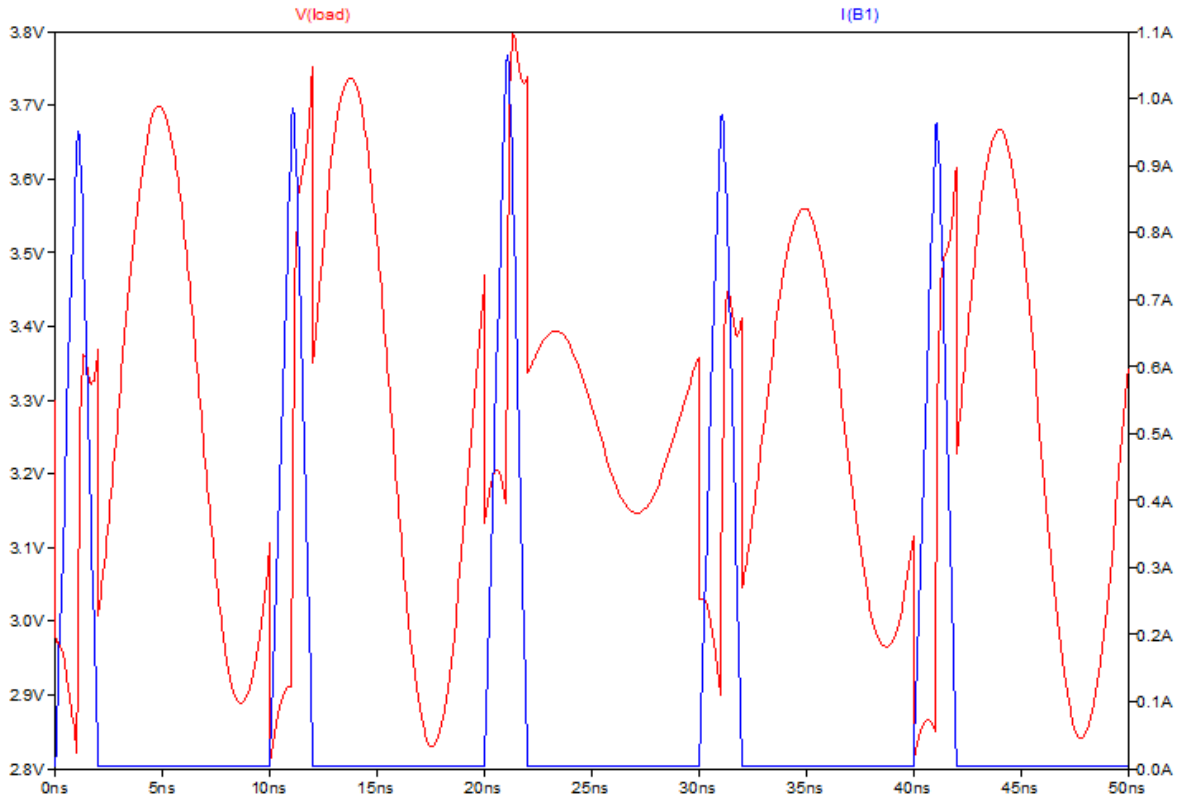


Impedanca napajanja

Z realnim kondenzatorjem + boljši kondenzator

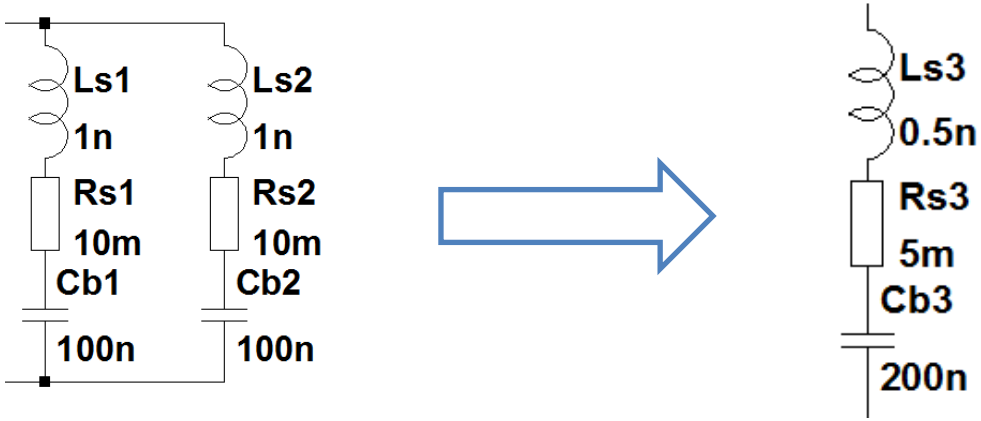


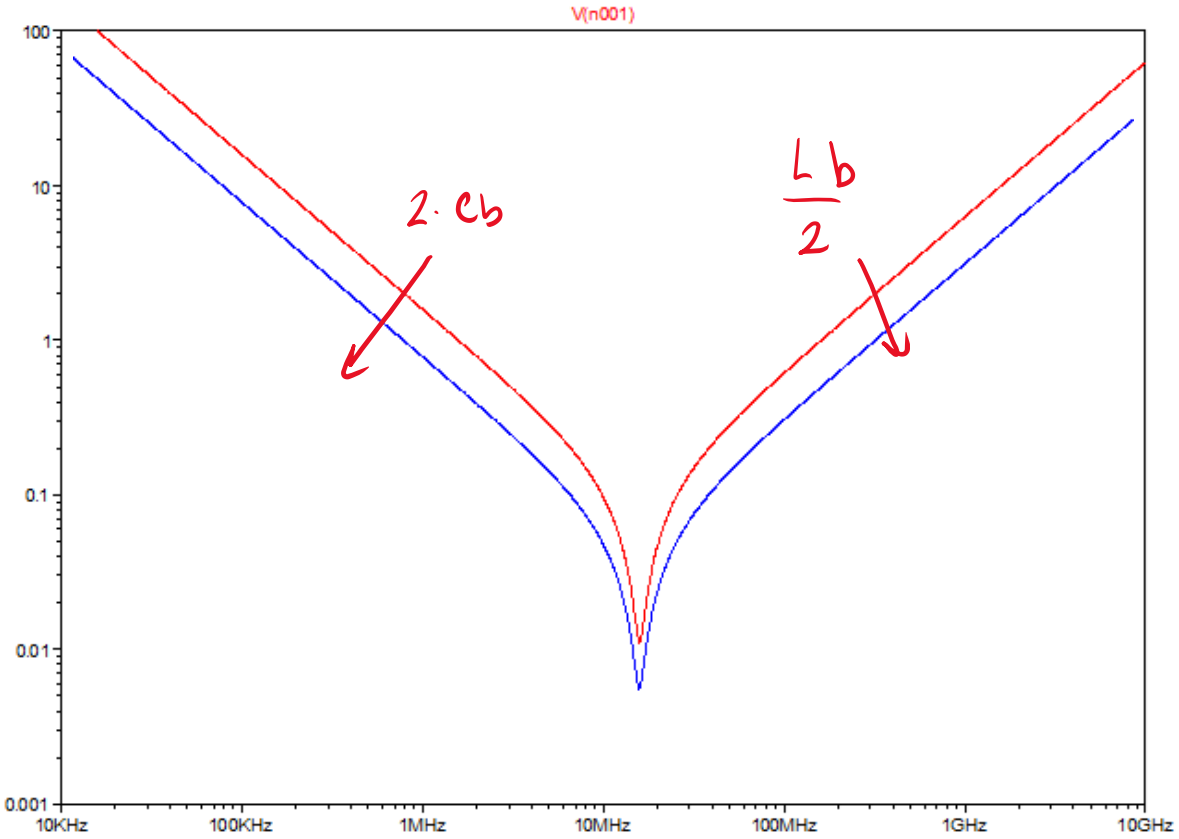




Impedanca napajanja

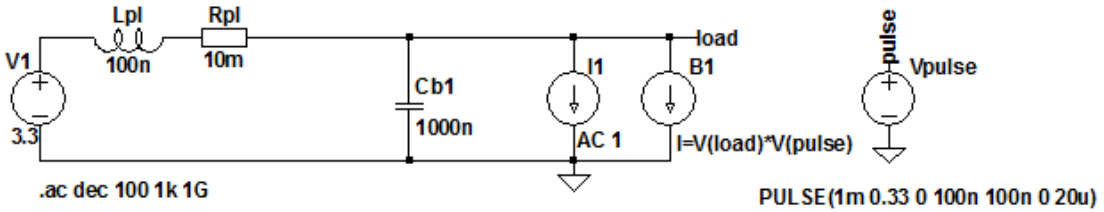
Vzporedna vezava več realnih kondenzatorjev

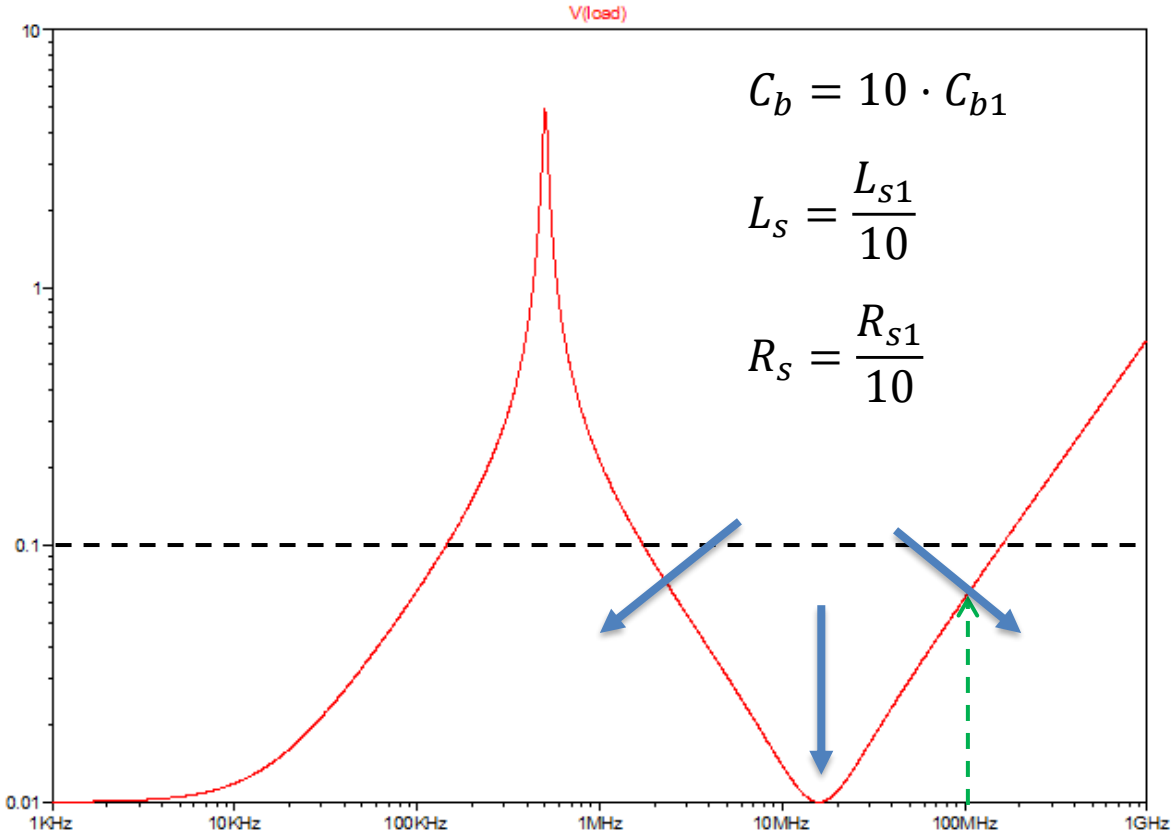




Impedanca napajanja

Vzporedna vezava več realnih kondenzatorjev

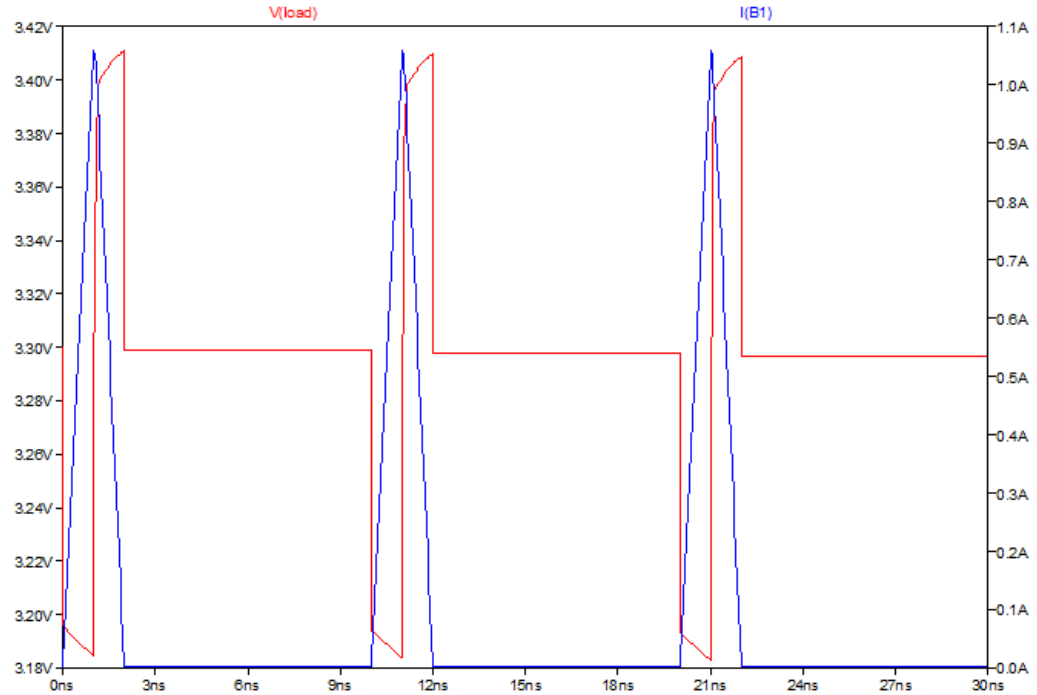




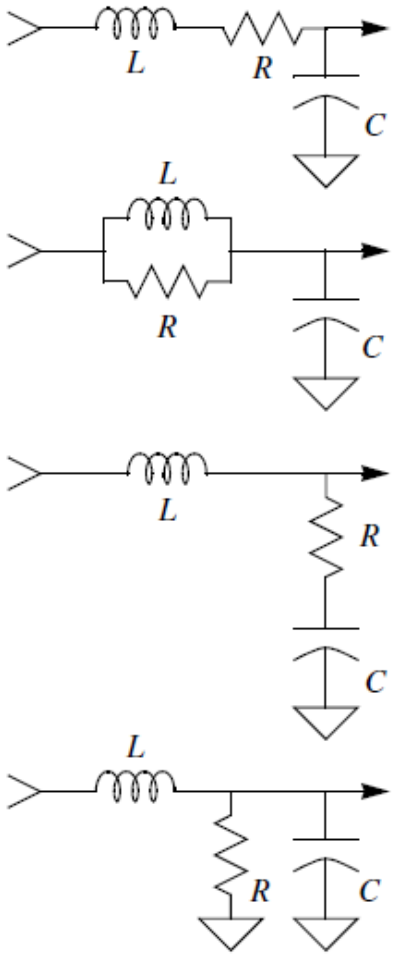
$$C_b = 10 \cdot C_{b1}$$

$$L_s = \frac{L_{s1}}{10}$$

$$R_s = \frac{R_{s1}}{10}$$



Dušenje nihajnih krogov



A. Reduced output voltage
Decreased supply regulation

$$R_{crit} = 2\sqrt{\frac{L}{C}}$$

B. Poor decoupling

$$R_{crit} = \frac{1}{2}\sqrt{\frac{L}{C}}$$

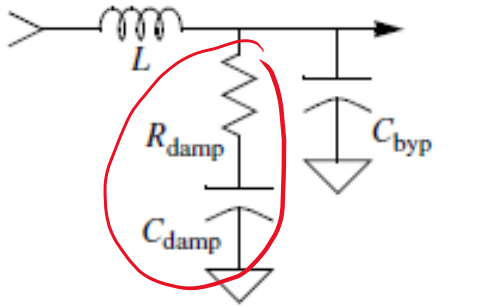
C. Decreased bypass effectiveness

$$R_{crit} = 2\sqrt{\frac{L}{C}}$$

D. High power dissipation

$$R_{crit} = \frac{1}{2}\sqrt{\frac{L}{C}}$$

- Dušilni RC člen



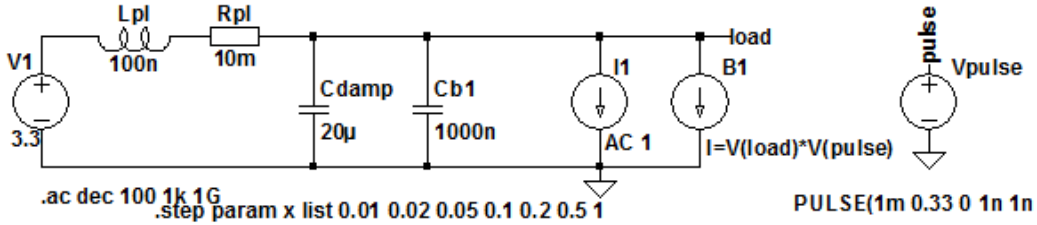
$$C_{damp} > 16 C_{byp}$$

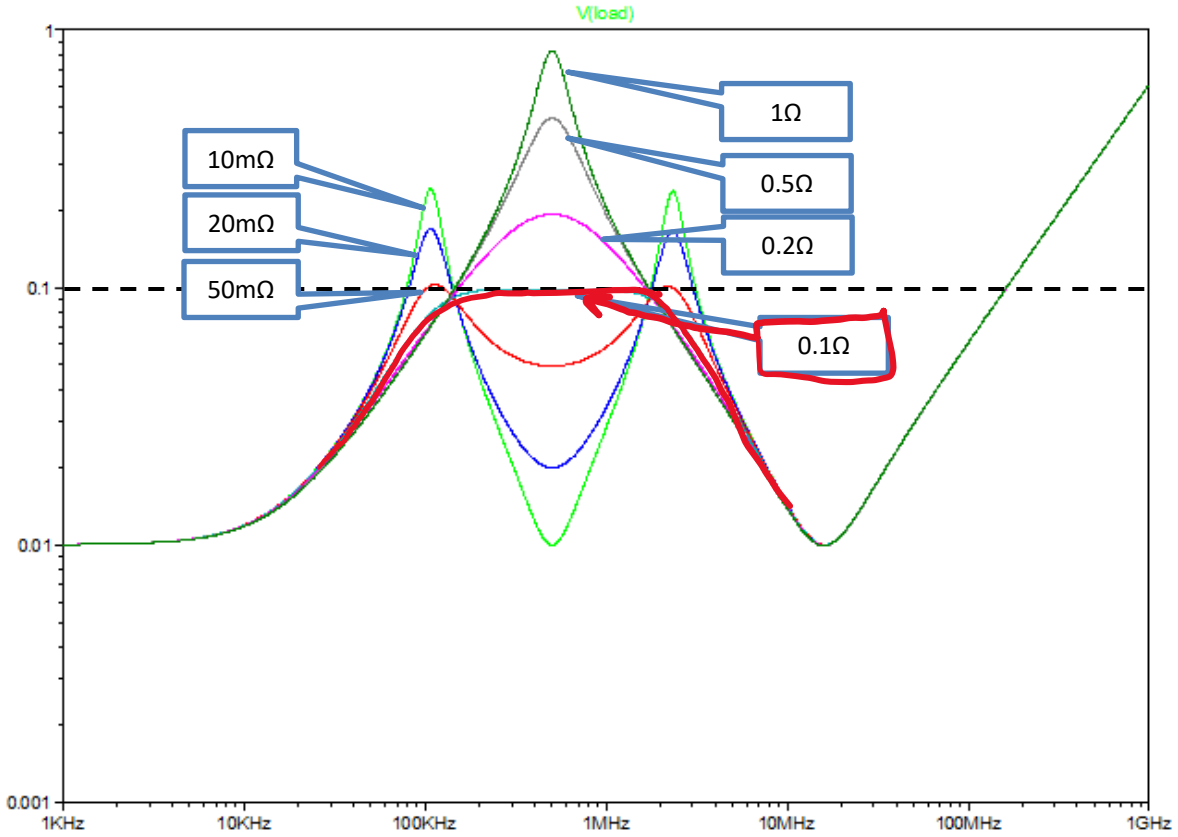
$$R_{damp} > 2\sqrt{\frac{L}{C_{damp}}}$$

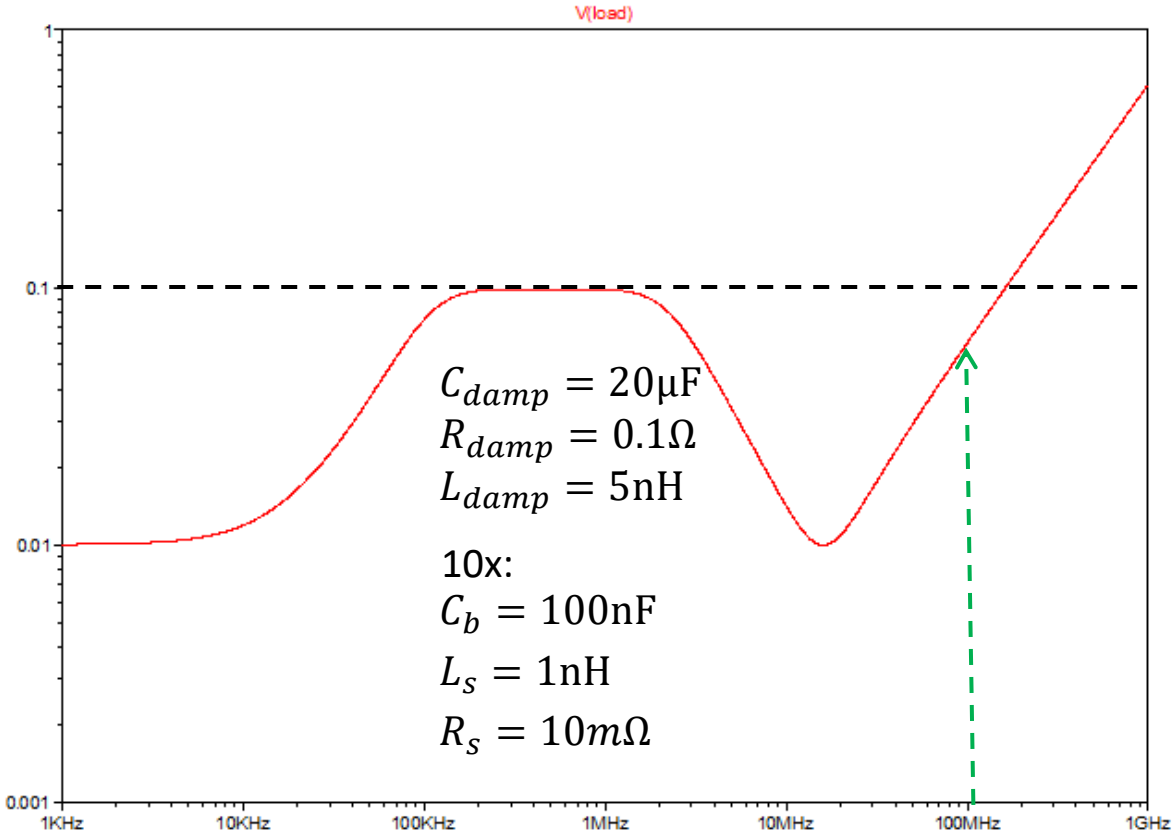
$$R_{damp} < \frac{1}{2}\sqrt{\frac{L}{C_{byp}}}$$

Impedanca napajanja

Vzporedna vezava več realnih kondenzatorjev z dušenjem

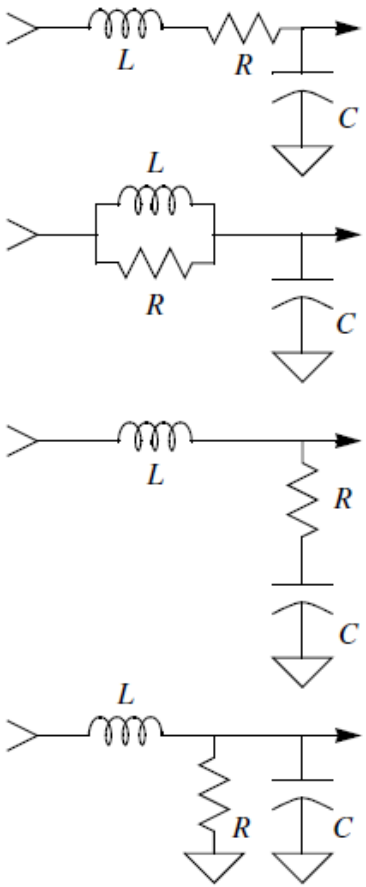






Kaj pa visokofrekvenčna nihanja?

Dušenje kvalitete nihajnega kroga s feritno dušilko



A. Reduced output voltage
Decreased supply regulation

$$R_{crit} = 2\sqrt{\frac{L}{C}}$$

B. Poor decoupling

$$R_{crit} = \frac{1}{2}\sqrt{\frac{L}{C}}$$

C. Decreased bypass effectiveness

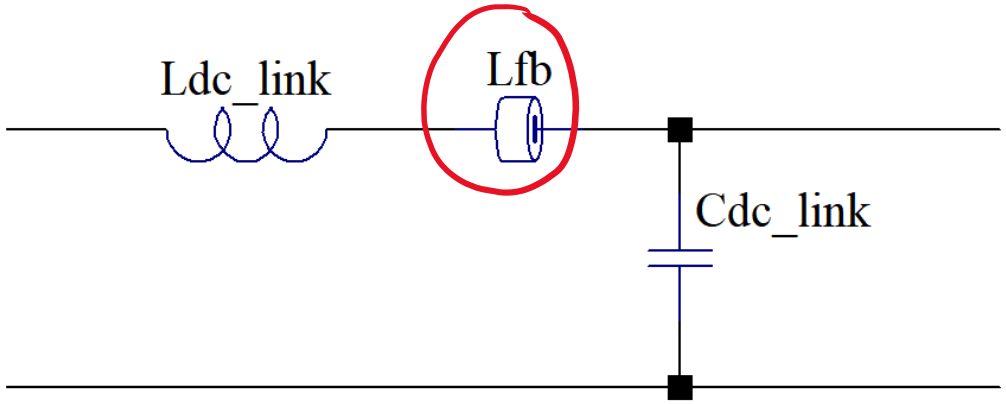
$$R_{crit} = 2\sqrt{\frac{L}{C}}$$

D. High power dissipation

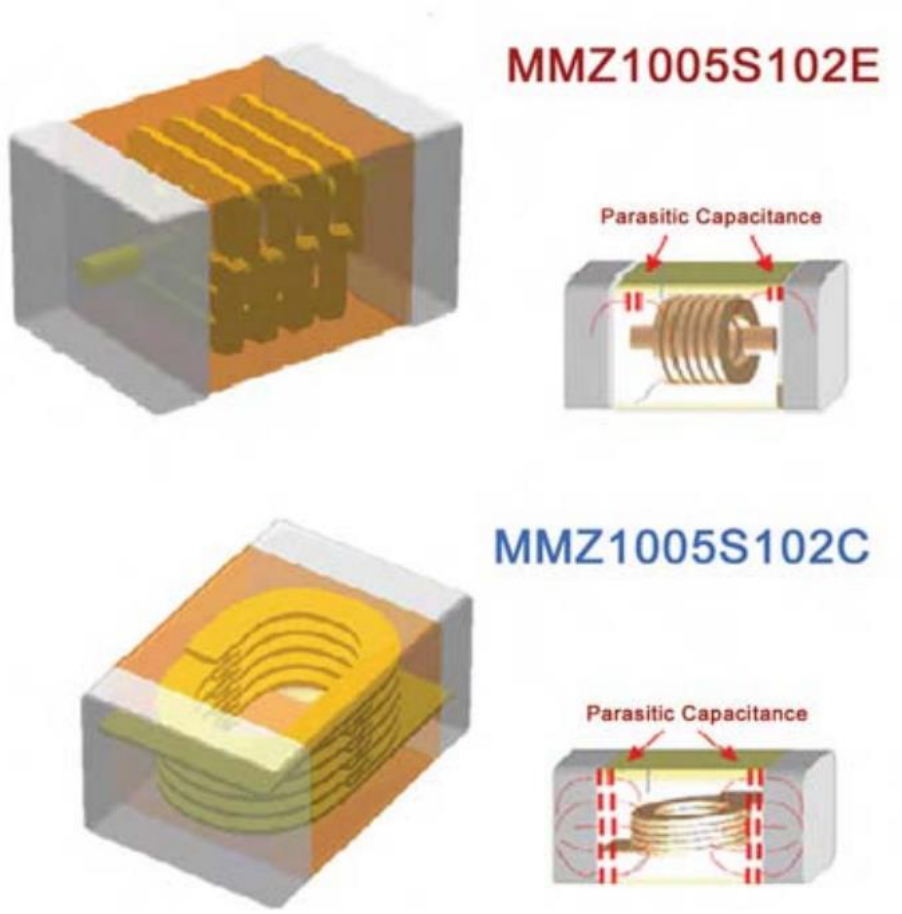
$$R_{crit} = \frac{1}{2}\sqrt{\frac{L}{C}}$$

$R_{DC} \to 0$

R @ 50 MHz ↑



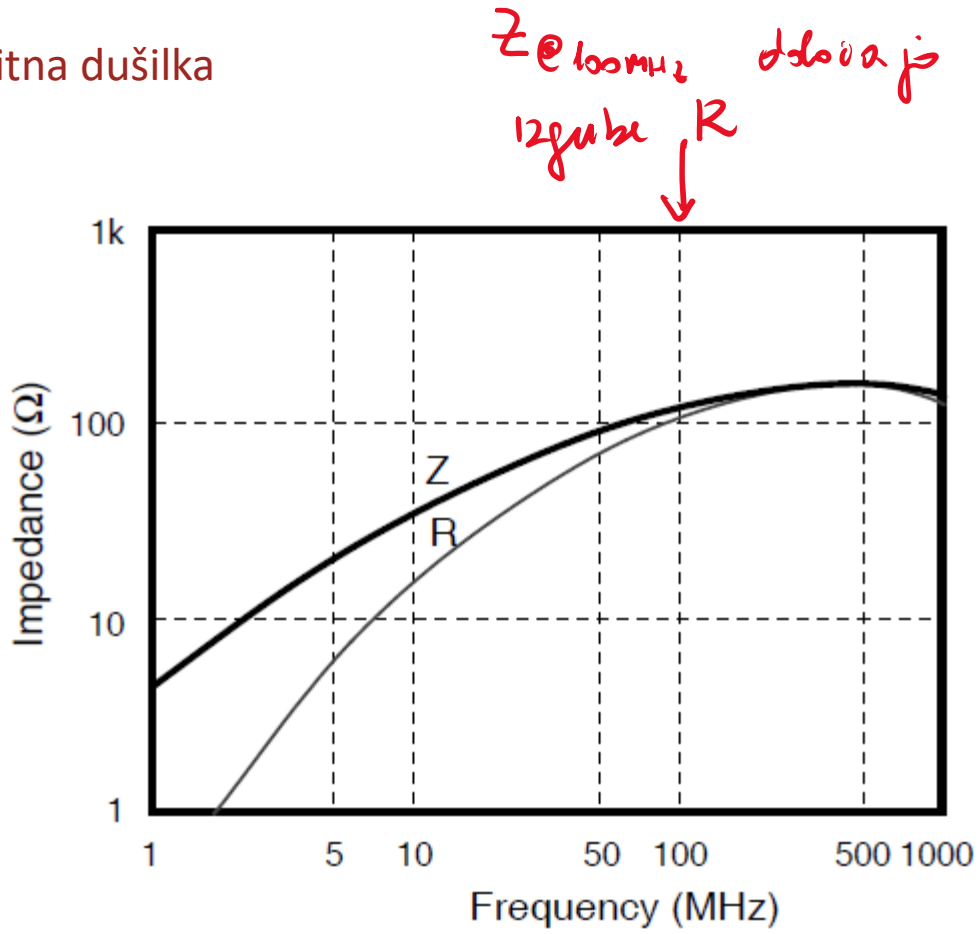
Feritne dušilke



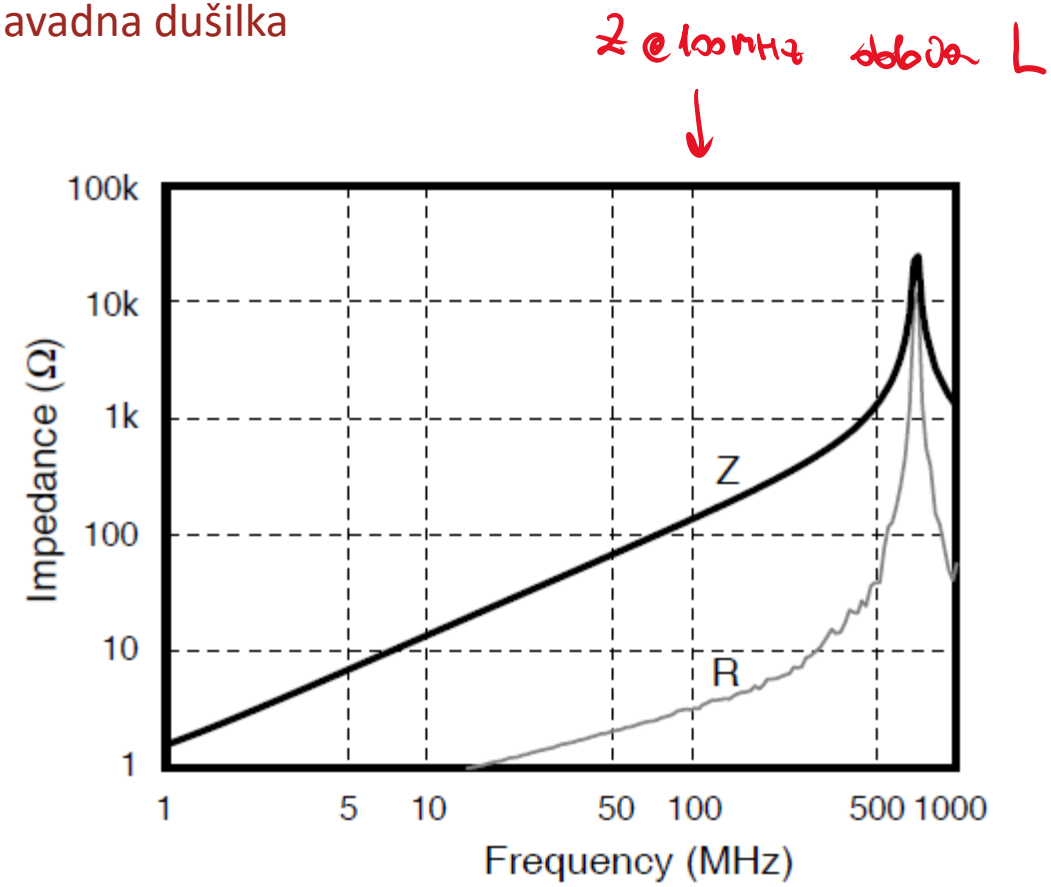
Part No.	Impedance (Ω)[100MHz]*1	DC resistance (Ω)max.	Rated current*2 (A)max.	Thickness T(mm)
MPZ1608S300A	30±10Ω	0.01	5	0.6
MPZ1608S600A	60±25%	0.02	3.5	0.6
MPZ1608S101A	100±25%	0.03	3	0.6
MPZ1608S221A	220±25%	0.05	2.2	0.8
MPZ1608R391A	390±25%	0.12	1.2	0.8
MPZ1608S471A	470±25%	0.15	1	0.8
MPZ1608S601A	600±25%	0.15	1	0.8
MPZ1608Y600B	60±25%	0.03	2.3	0.8
MPZ1608Y101B	100±25%	0.04	2	0.8
MPZ1608Y151B	150±25%	0.05	1.8	0.8
MPZ1608D300B	30±10Ω	0.06	1.8	0.8
MPZ1608D600B	60±25%	0.1	1.2	0.8
MPZ1608D101B	100±25%	0.15	1	0.8

Razlika med feritno in navadno dušilko

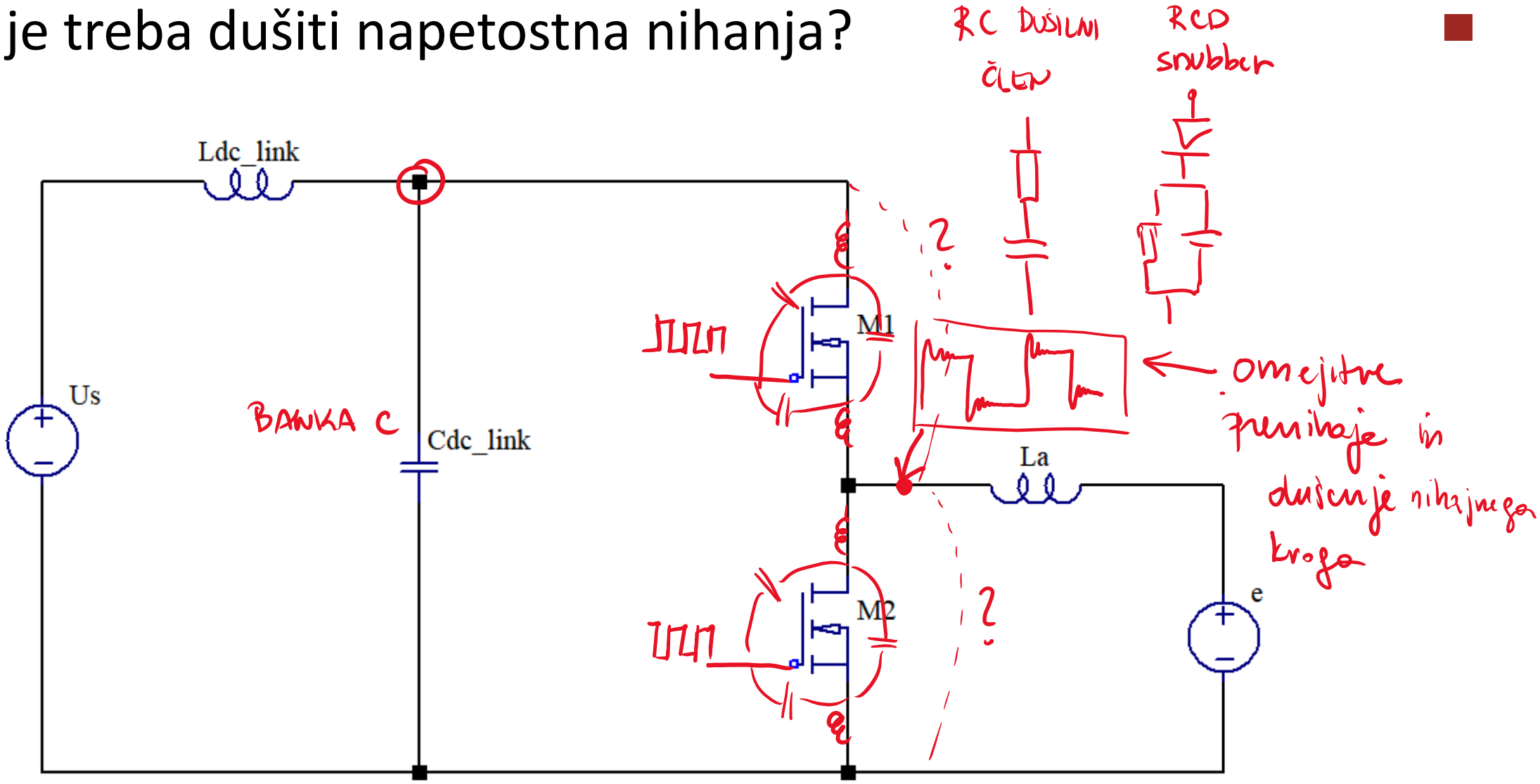
Feritna dušilka



Navadna dušilka

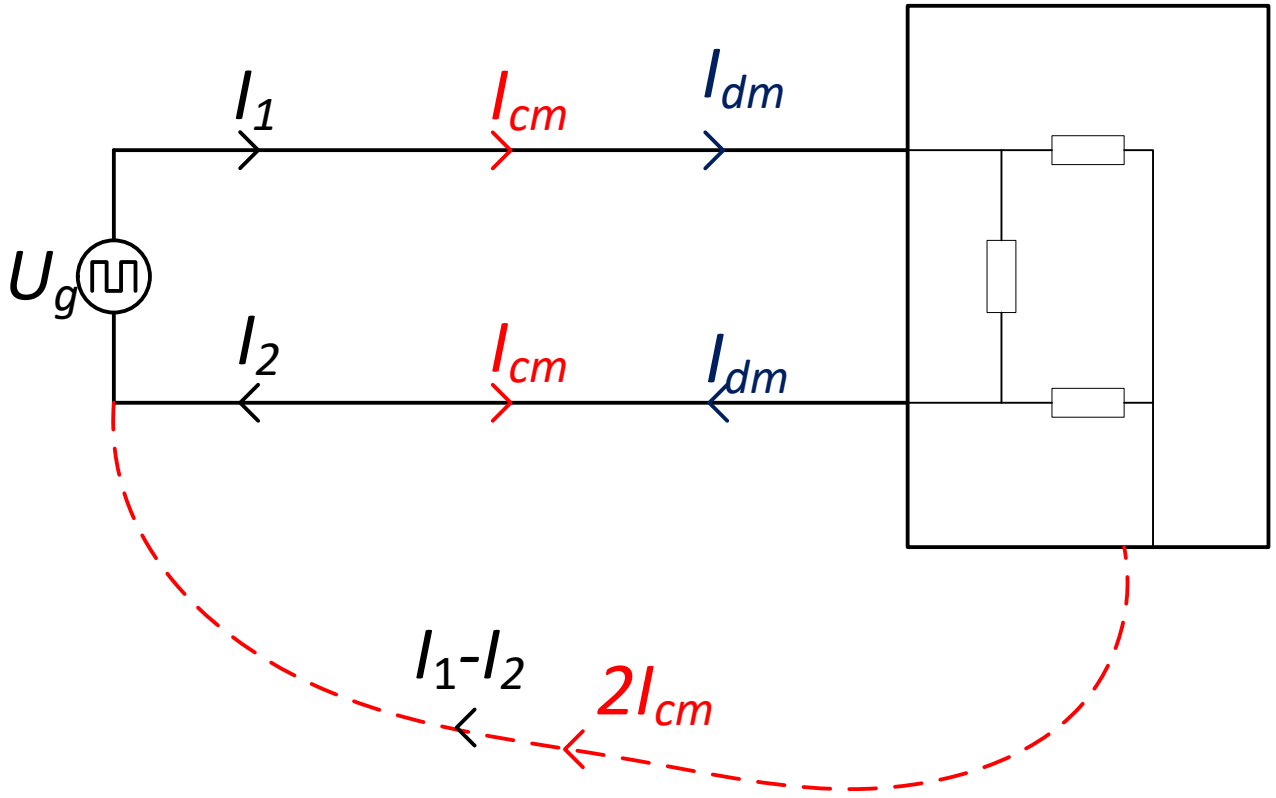


Kje vse je treba dušiti napetostna nihanja?



Izvori motenj

Diferencialni in sofazni signali



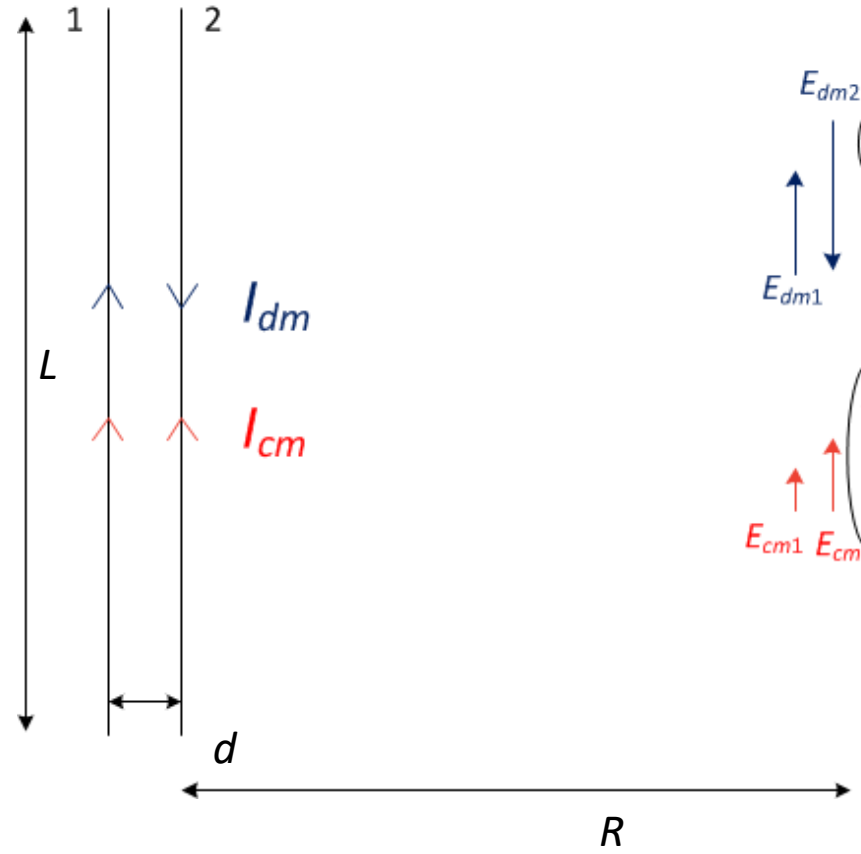
$$I_1 = I_{dm} + I_{cm}$$

$$I_2 = I_{dm} - I_{cm}$$

$$I_{dm} = \frac{I_1 + I_2}{2}$$

$$I_{cm} = \frac{I_1 - I_2}{2}$$

Primerjava diferencialne in sofazne motnje



Linija v zraku:

$$E_{dm_{maks}}(f) = 1{,}31 \cdot 10^{-14} \frac{I_{dm}(f) \boldsymbol{f^2} Ld}{R} \; V/m$$

Linija na tiskanini:

$$E_{dm_{maks}}(f) = 2{,}63 \cdot 10^{-14} \frac{I_{dm}(f) \boldsymbol{f^2} Ld}{R} \; V/m$$

Linija v zraku:

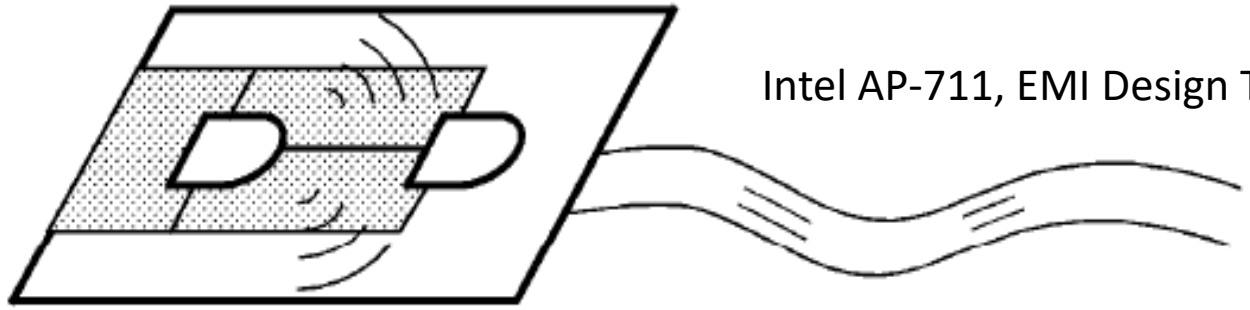
$$E_{cm_{maks}}(f) = \pi \cdot 10^{-7} \frac{I_{cm}(f) \boldsymbol{f} L}{R} \; V/m$$

$f \cdot L$

C. A. Balanis, Antenna theory: analysis and design. John Wiley & Sons, 2012.

Primerjava diferencialne in sofazne motnje

- Signali na PCB
  - Majhne tokovne zank
  - Protifazni zančni toko
  - $Edm = 2{,}63 \cdot 10^{-14}$:
- $I = 1\,mA, f = 100\,MHz, A = 1\,cm^2$
- $E = 26\frac{\mu V}{m}$@ 1 m

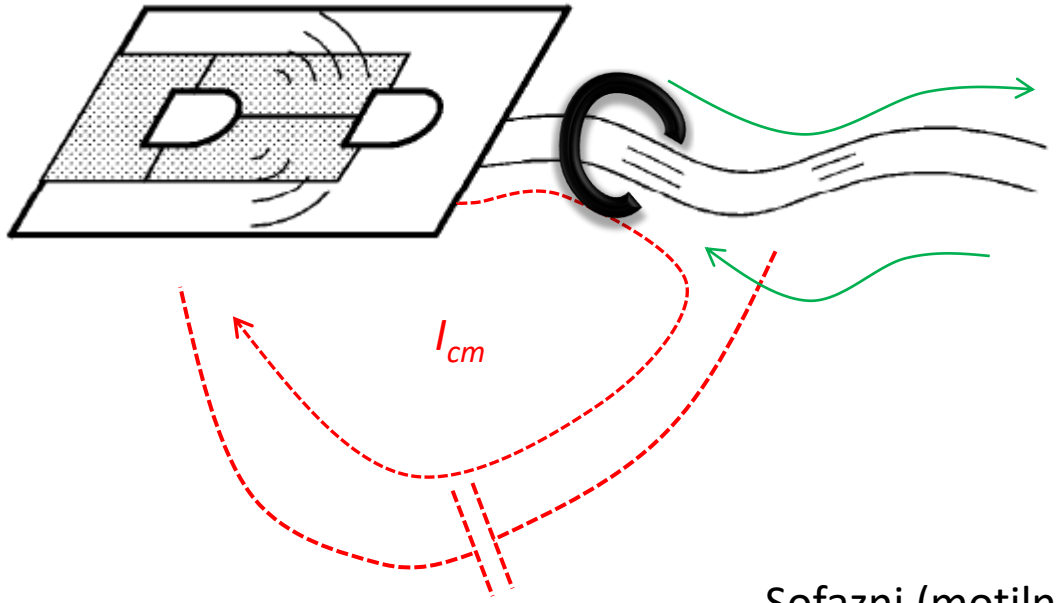


Intel AP-711, EMI Design Techniques

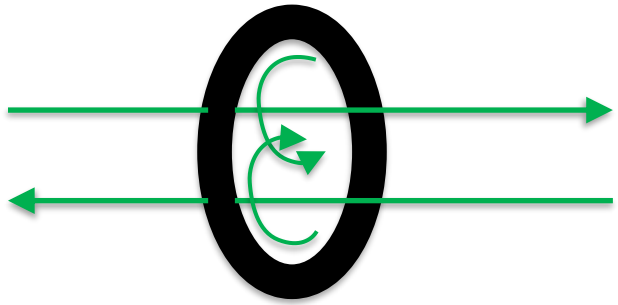
- Signali na povezovalnem kablu
  - Velike dipolne antene (dolžine L)
  - Sofazni tokovi (I)
  - $Ecm = \pi \cdot 10^{-7}\frac{I_{cm} f L}{R}$
- $I = 0.8\,\mu A, f = 100MHz, L = 1m$
- $E = 26\frac{\mu V}{m}$@ 1 m !

$$26\frac{\mu V}{m} = 20 \cdot \log\left(\frac{26}{1}\right) = 28\ dB\mu V/m$$

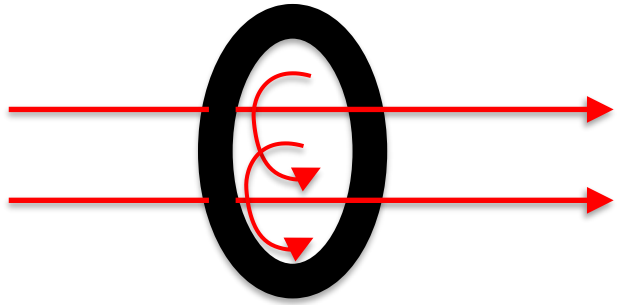
Feritni obroček



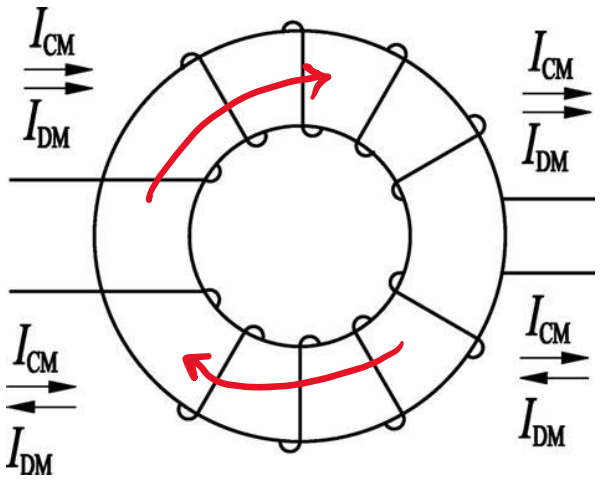
Diferencialni (koristni) signali

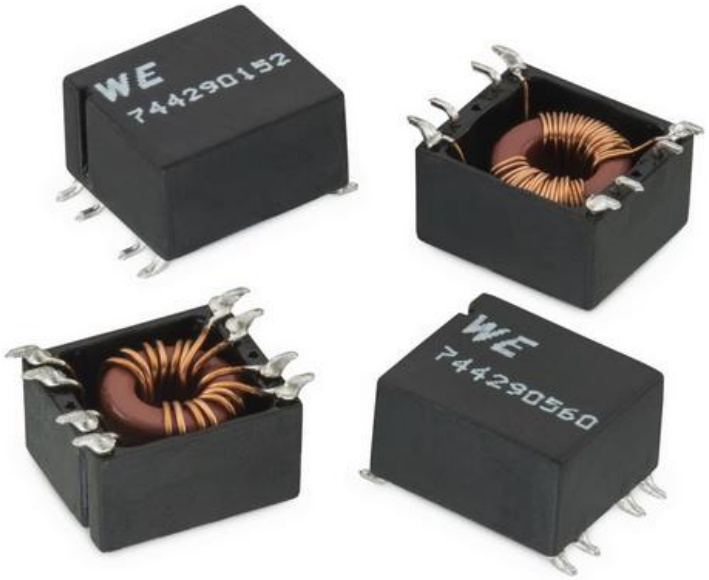


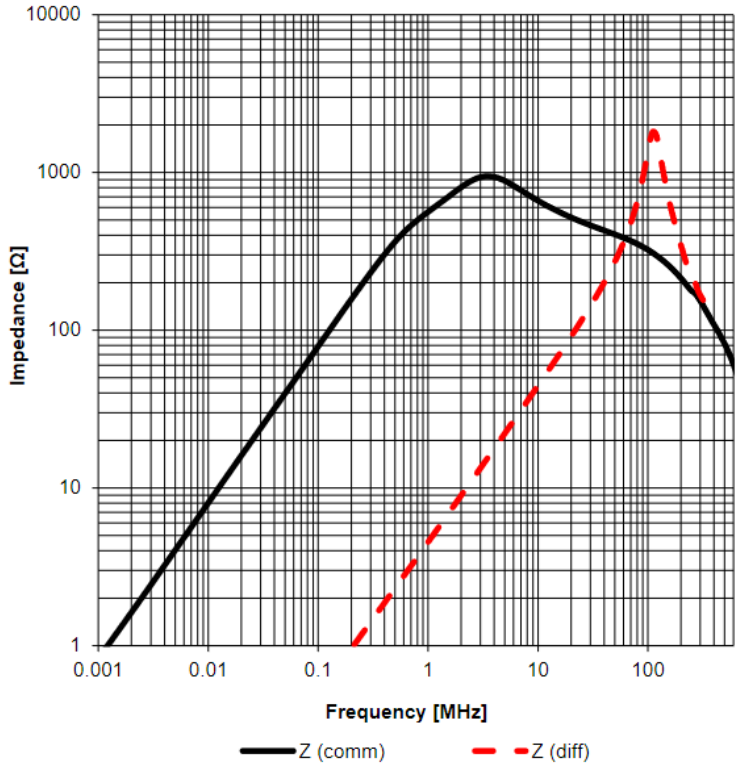
Sofazni (motilni) signali



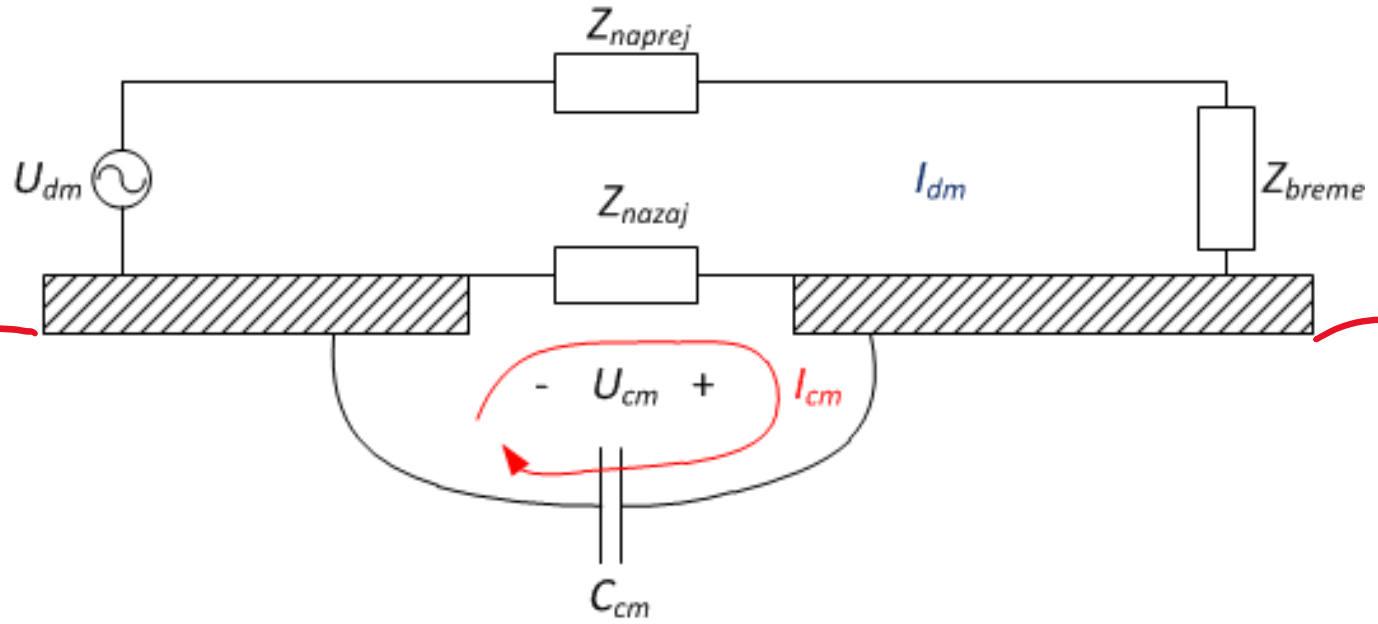
CM dušilke


I_{CM}
I_{DM}
I_{CM}
I_{DM}
I_{CM}
I_{DM}
I_{CM}
I_{DM}


WE
744290152
WE
744290560


10000
1000
100
10
1
Impedance [Ω]
0.001
0.01
0.1
1
10
100
Frequency [MHz]
Z (comm)
Z (diff)

Tokovni mehanizem generiranja sofaznih motenj

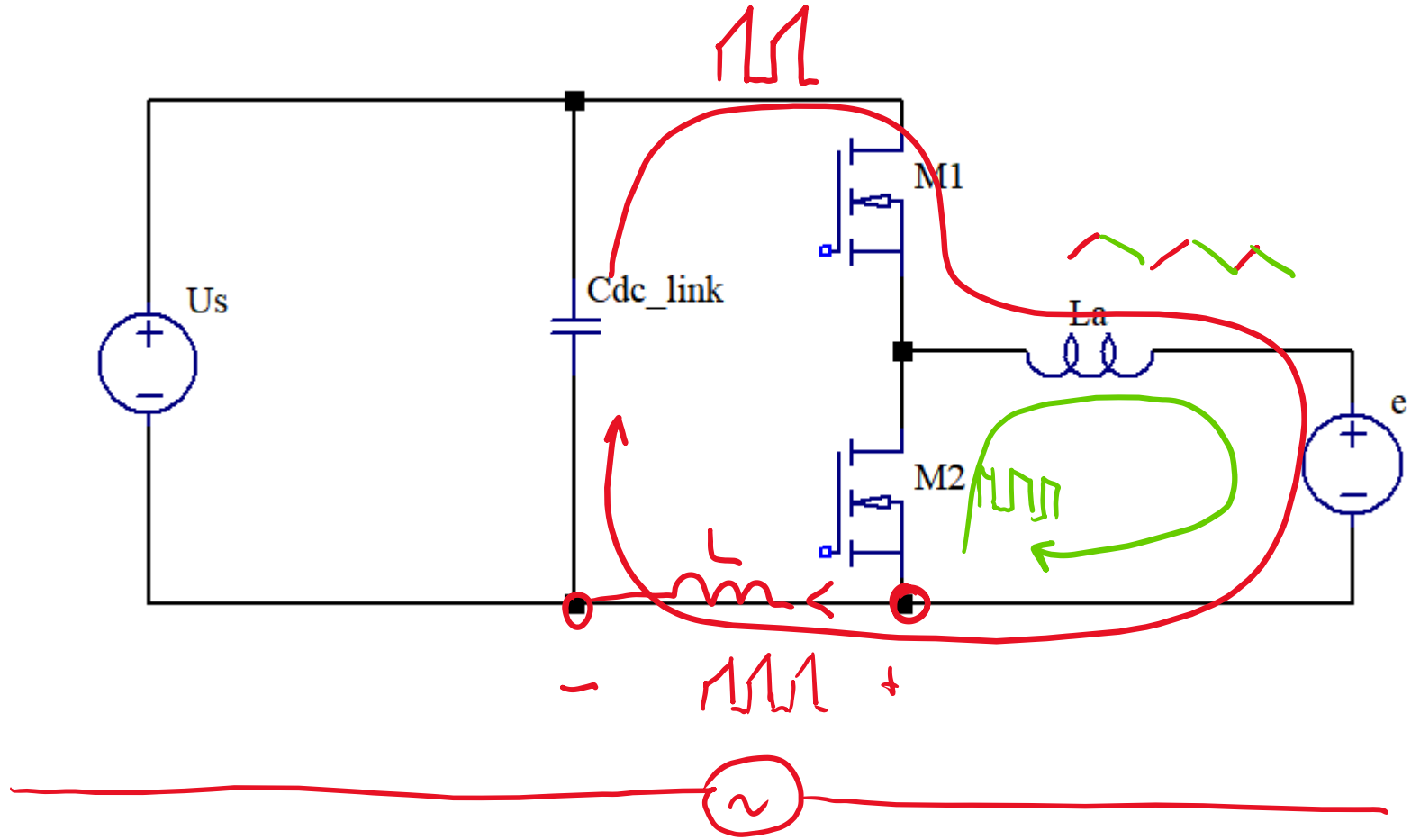


$$I_{dm} = \frac{U_{dm}}{Z_{breme} + Z_{naprej} + Z_{nazaj}} \qquad U_{cm} = I_{dm} \cdot Z_{nazaj} \qquad I_{cm} = j\omega C_{cm} U_{cm}$$

$$Z_{nazaj} = j\omega L_{nazaj}, Z_{breme} = R_{breme}, Z_{naprej} = 0 \rightarrow I_{cm} = -\omega^2 L_{nazaj} C_{cm} \frac{U_{dm}}{R_{breme}}$$

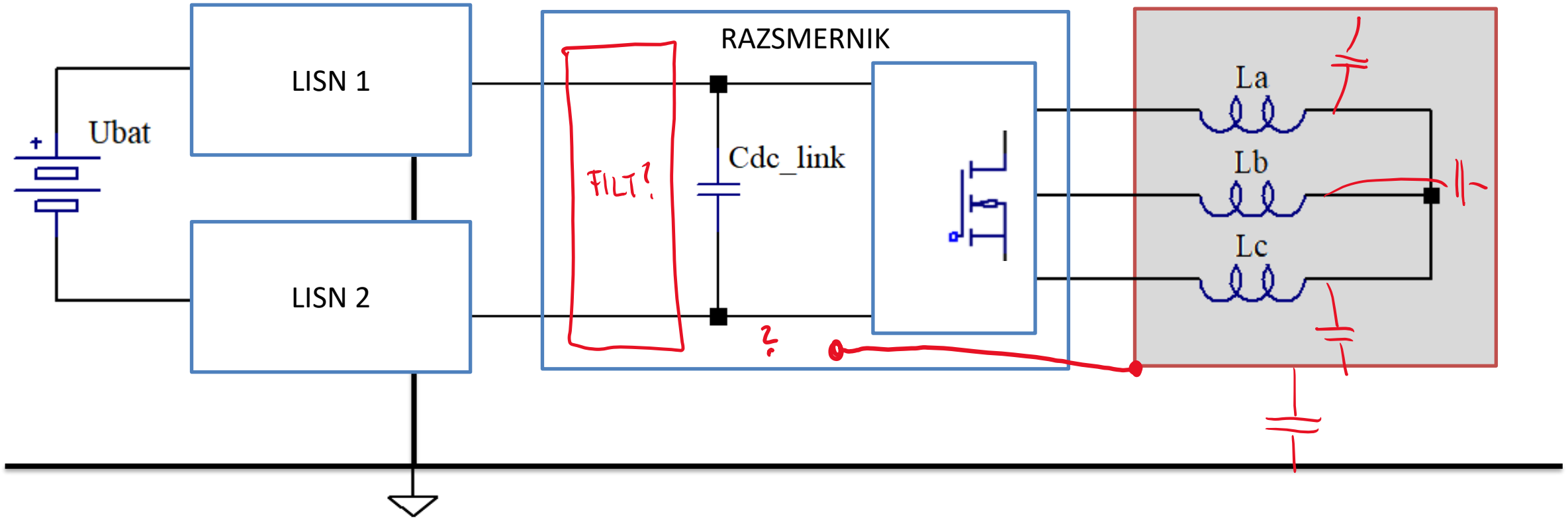
Primer 1/3 izhodne stopnje razsmernika

Kje se ustvari tokovno generirana sofazna motnja?



Primer celotnega sklopa

Kje se generirajo motnje?



Zakaj EMC?

http://www.compliance-club.com/archive/old_archive/Bananaskins.htm

Resnica

"Some of the worst printed circuit boards we've seen were designed by engineers who were trying to comply with a list of EMC design rules.„

Todd Hubing

Resnica v praksi