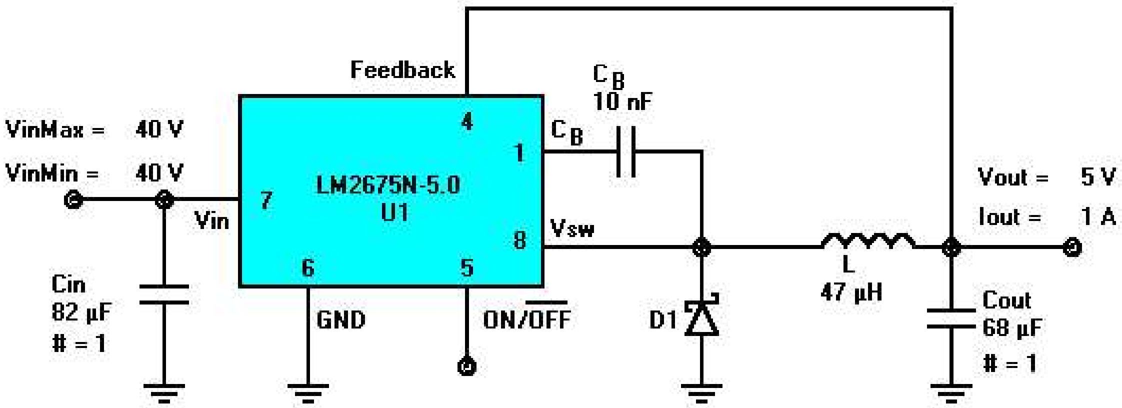
Input filter design for switching power supply:

Written by Michele Sclocchi
michele.sclocchi@nsc.com
Application Engineer
National Semiconductor

Basic step-down simple switcher power supply:



Input parameters | Results

-Maximum input voltage: $Vinput := 35V$

-Output current: $Iout := 10 \cdot A$

-Output voltage: $Vout := 5V$

-Output inductor:

inductance: $Lo := 33\mu H$

DC resistance: $R_L := 0.088\Omega$

-Output capacitor: $Co := 68\mu F$

$ESR := 0.09\Omega$

-Duty cycle: $D := 0.458$

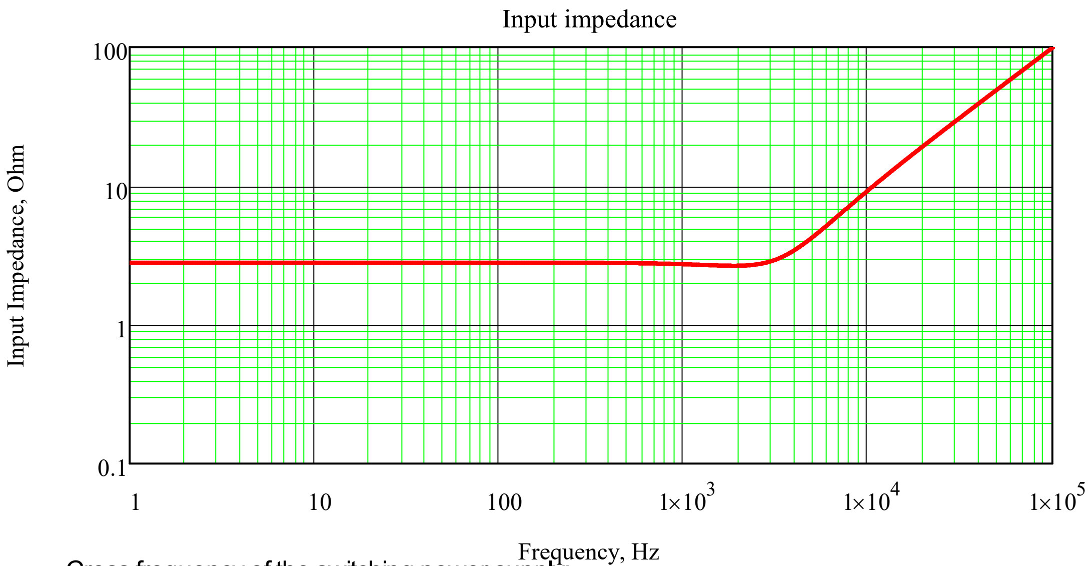
-Output impedance: $Ro := \frac{Vout}{Iout}$ $\quad Ro = 0.5 \cdot A^{-2} \cdot kg \cdot s^{-3} \cdot m^{2}$

$i := 1..2000 \qquad f_i := 100^{\frac{(i-200)}{500}}$

$w_i := f_i \cdot \frac{rad}{s} \qquad s_i := 2 \cdot \pi \cdot j \cdot w_i$

-Input impedance of the power supply:

$$Zi_i := \left| \left(\frac{Ro + R_L}{D^2} \right) \cdot \left[\frac{1 + s_i \cdot \left[\frac{Lo}{Ro + R_L} + \left(ESR + \frac{Ro \cdot R_L}{Ro + R_L} \right) \cdot Co \right] + \left(s_i \right)^2 \cdot Lo \cdot Co \cdot \left(\frac{Ro + ESR}{Ro + R_L} \right)}{1 + s_i \cdot (Ro + ESR) \cdot Co} \right] \right|$$



-Cross frequency of the switching power supply:

$Fcross := 32kHz$

To meet the noise filtering requirements the input filter has to have the corner frequency around one decade below the bandwidth of the feed back loop of the power supply.

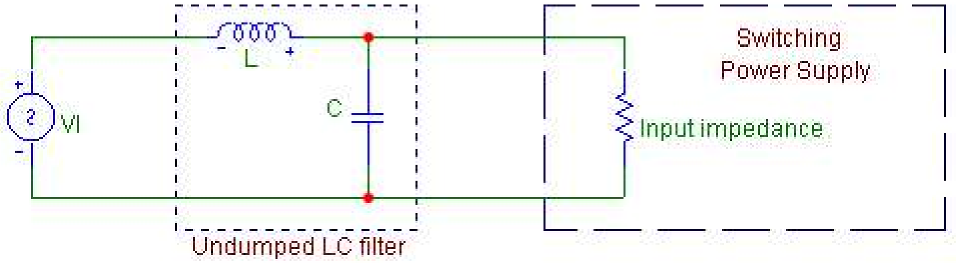
-Cut of frequency of the input filter: $fc := 5kHz$

-Cut off frequency in radiant: $\omega c := fc \cdot 2\pi \quad \omega c = 3.142 \times 10^4 \cdot s^{-1}$

-Maximum input impedance of the power supply: $Rin := 25 \cdot ohm$

-Input Capacitance of the power supply: $C := 15\mu F$

- UNDUMPED LC FILTER:



-Inductance calculated:

$$L := \frac{1}{\omega c^2 C} \qquad L = 67.547 \cdot \mu H$$

-Damping factor:

$$\zeta := \frac{L}{2 \cdot Rin \cdot \sqrt{L \cdot C}} \qquad \zeta = 0.042$$

-Inductor used:

$$Lf := 1 \mu H$$

$$Rf := 0.030 \cdot \Omega$$

-Capacitor used:

$$Cf := 33 \mu F$$

$$ESRci := 0.150 \Omega$$

-Cut off frequency of the filter:

$$fc_{filter1} := \frac{1}{2 \cdot \pi \sqrt{Lf \cdot Cf}} \qquad fc_{filter1} = 27.705 \cdot kHz$$

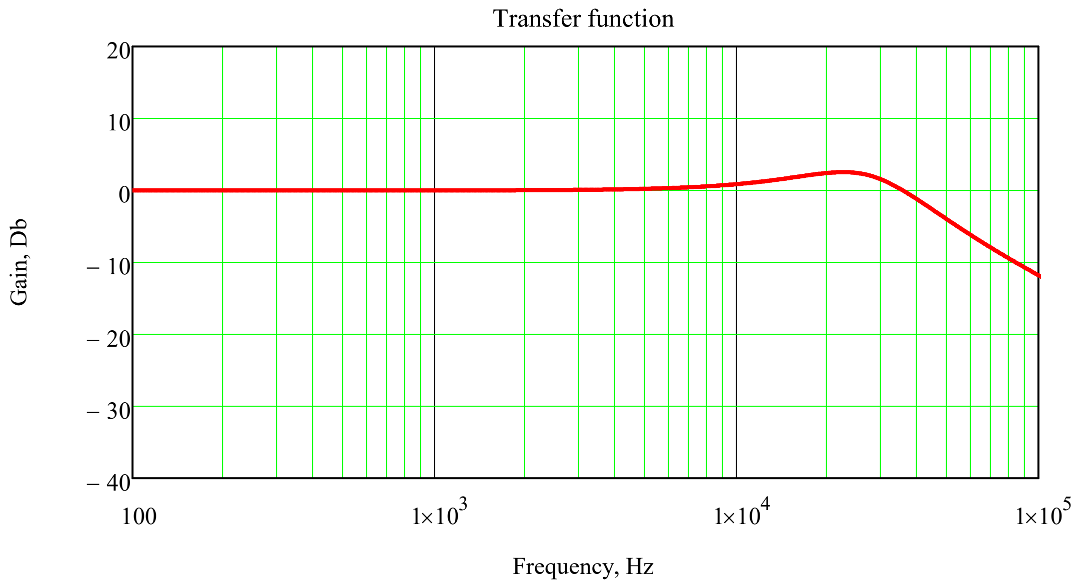
-Transfer function:

$$Z1_i := Rf + s_i \cdot Lf$$

$$Z2_i := ESRci + \frac{1}{s_i \cdot Cf}$$

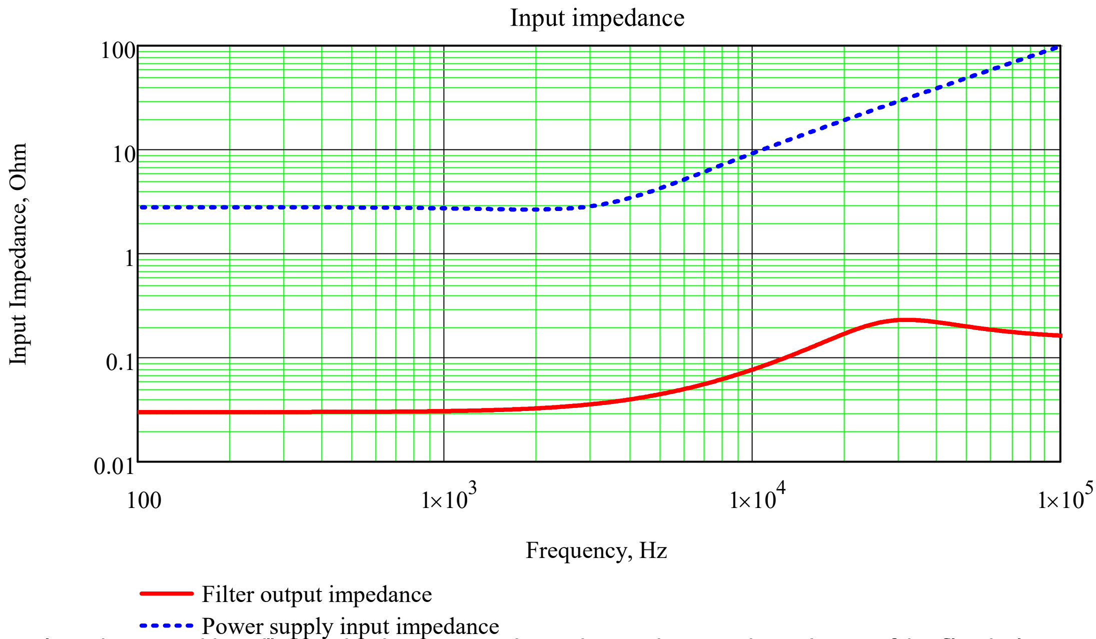
$$Z2eq_i := \frac{Z2_i \cdot Rin}{Z2_i + Rin}$$

$$Filter_i := 20 \cdot \log\left(\left|\frac{Z2eq_i}{Z2eq_i + Z1_i}\right|\right)$$



-Filter output impedance:

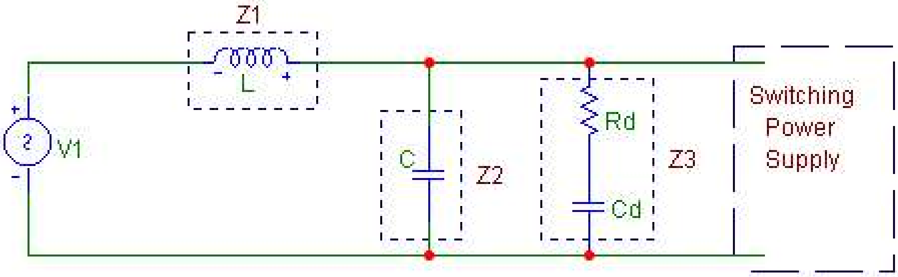
$$Zf_i := \left| \frac{Z1_i \cdot Z2_i}{Z1_i + Z2_i} \right|$$



In order to avoid oscillations it is important to keep the peak output impedance of the filter below the input impedance of the converter.
The two curves should not overlap.

-PARALLEL DAMPED FILTER:

In most of the cases a parallel damped filter meet easily the damping and impedance requireme



The purpose of Rd is to reduce the output peak impedance of the filter at the cutoff frequency. The capacitor Cd blocks the DC component of the input voltage.

-Damping resistance:

$$Rd := \sqrt{\frac{Lf}{Cf}} \qquad Rd = 0.174 \cdot A^{-2} \cdot kg \cdot s^{-3} \cdot m^{2}$$

$$Cd := 4 \cdot Cf \qquad Cd = 132 \cdot \mu F$$

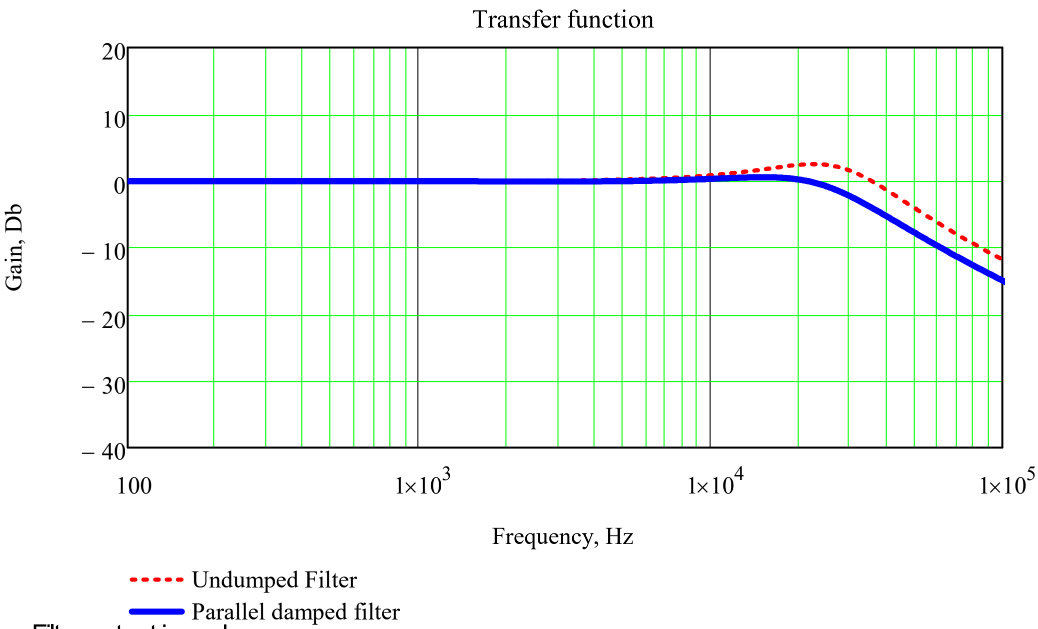
$$ESRcd := 0.200\Omega$$

$$Z3_i := \frac{1}{s_i \cdot Cd} + ESRcd + Rd$$

$$Z3eq2_i := \frac{Z2eq_i \cdot Z3_i}{Z2eq_i + Z3_i}$$

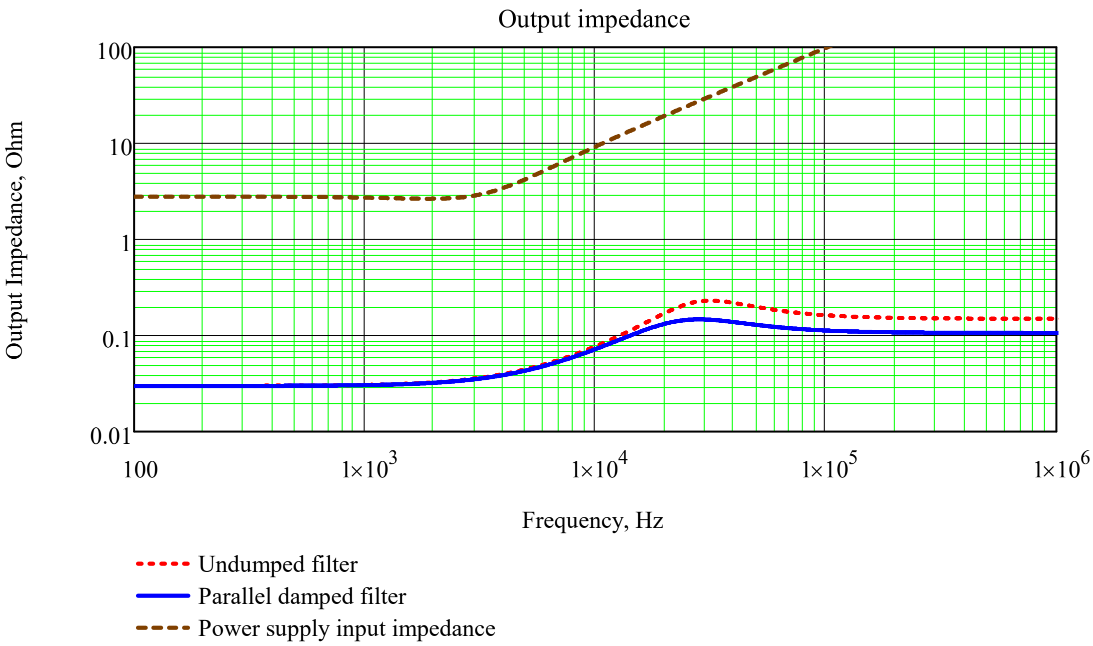
-Transfer function:

$$Filter2_i := 20 \cdot \log\left(\left|\frac{Z3eq2_i}{Z3eq2_i + Z1_i}\right|\right)$$

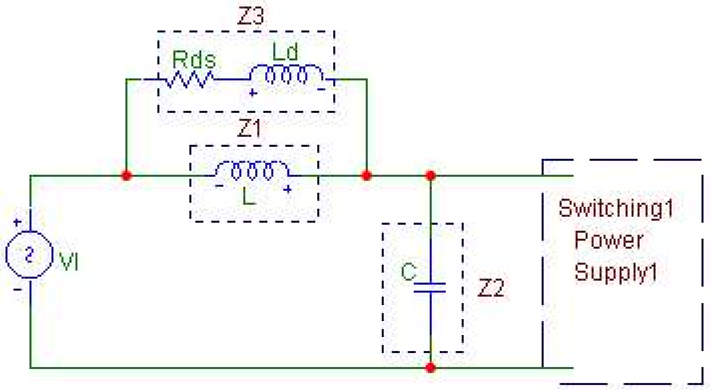


-Filter output impedance:

$$Zf2_i := \left| \frac{Z1_i \cdot Z3eq2_i}{Z1_i + Z3eq2_i} \right|$$



-SERIES DAMPED FILTER:



$$s_r := \frac{1}{2\cdot\pi\cdot\sqrt{Lf\cdot Cf}}$$

-Series inductor: $$n_3 := \frac{2}{15}$$

$$Ld := Lf\cdot n_3 \qquad Ld = 0.133\cdot\mu H$$

-Series damping resistance:

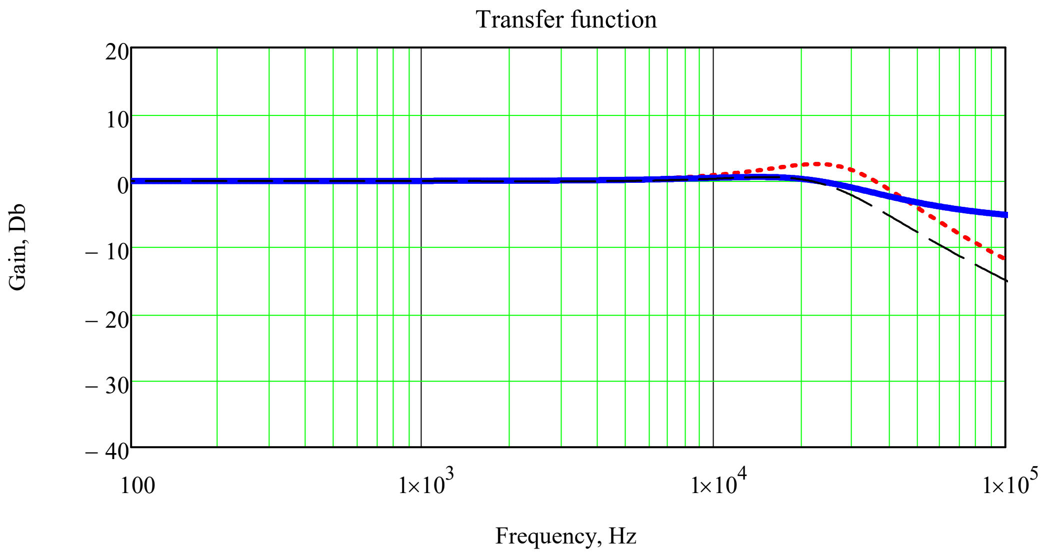
$$Rds := \frac{\sqrt{Lf}}{\sqrt{Cf}} \qquad Rds = 0.174\cdot A^{-2}\cdot kg\cdot s^{-3}\cdot m^{2}$$

$$Z3s_i := Rds + s_i\cdot Ld$$

$$Z13_i := \frac{Z1_i\cdot Z3s_i}{Z1_i + Z3s_i}$$

-Transfer function:

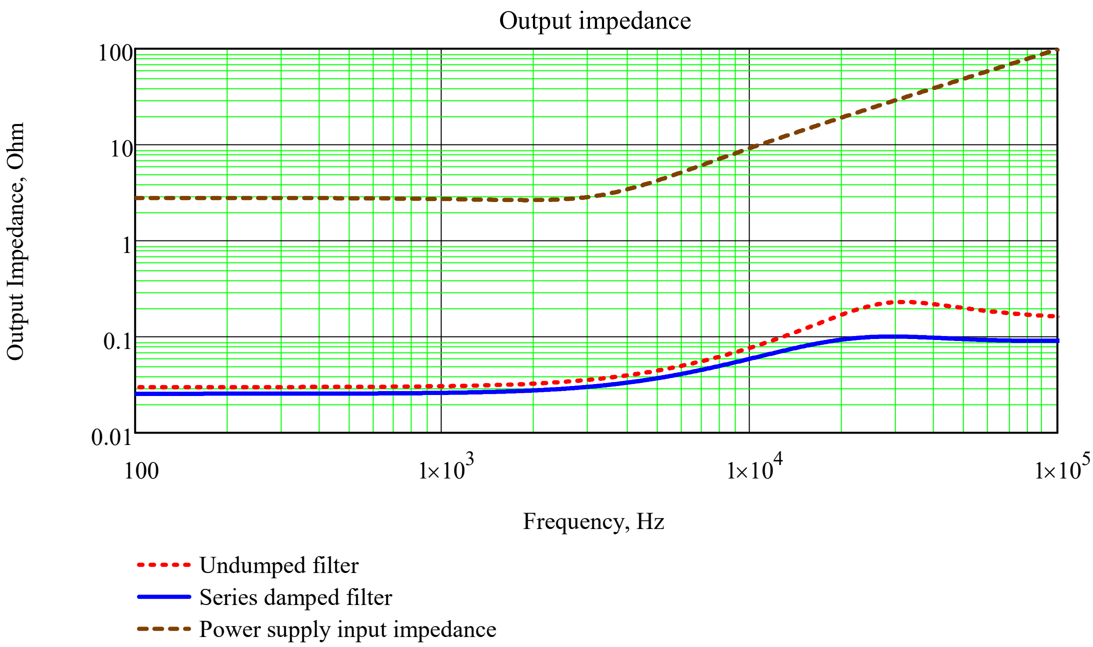
$$Filter3_i := 20\cdot\log\left(\left|\frac{Z2_i}{Z2_i + Z13_i}\right|\right)$$



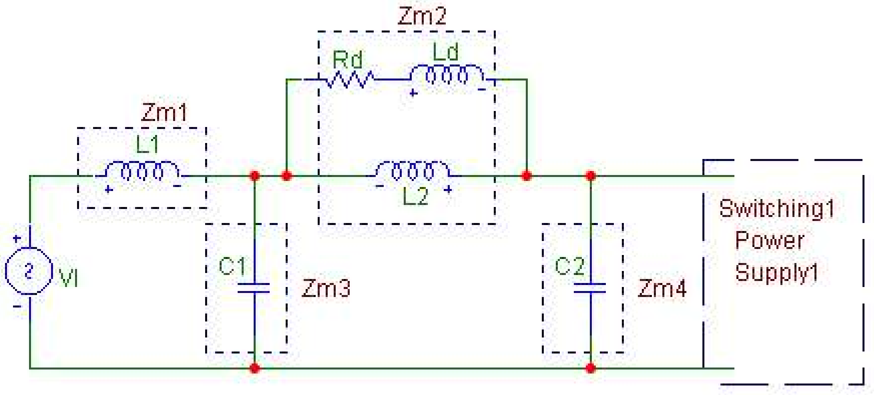
With the series damped filter the attenuation at high frequency is attenuated.

-Filter output impedance:

$$Zf3_i := \left| \frac{Z2_i \cdot Z13_i}{Z2_i + Z13_i} \right|$$



-MULTIPLE FILTER SECTIONS:



-First LC filter:

$L1 := \frac{Lf}{4}$ $\quad L1 = 0.25\cdot\mu H$ $\quad RL1 := 0.1\Omega$

$C1 := \frac{Cf}{4}$ $\quad C1 = 8.25\cdot\mu F$ $\quad ESRc1 := 0.120\Omega$

$$fm1 := \frac{1}{2\cdot\pi\cdot\sqrt{L1\cdot C1}} \qquad fm1 = 110.821\cdot kHz$$

-Second LC filter:

$L2 := 7\cdot L1$ $\quad L2 = 1.75\cdot\mu H$ $\quad RL2 := 0.1\Omega$

$C2 := 4\cdot C1$ $\quad C2 = 33\cdot\mu F$ $\quad ESRc2 := 0.120\Omega$

$$fm2 := \frac{1}{2\cdot\pi\cdot\sqrt{L2\cdot C2}} \qquad fm2 = 20.943\cdot kHz$$

$$Rd4 := \sqrt{\frac{L1}{C2}} \qquad Rd4 = 0.087\cdot A^{-2}\cdot kg\cdot s^{-3}\cdot m^{2}$$

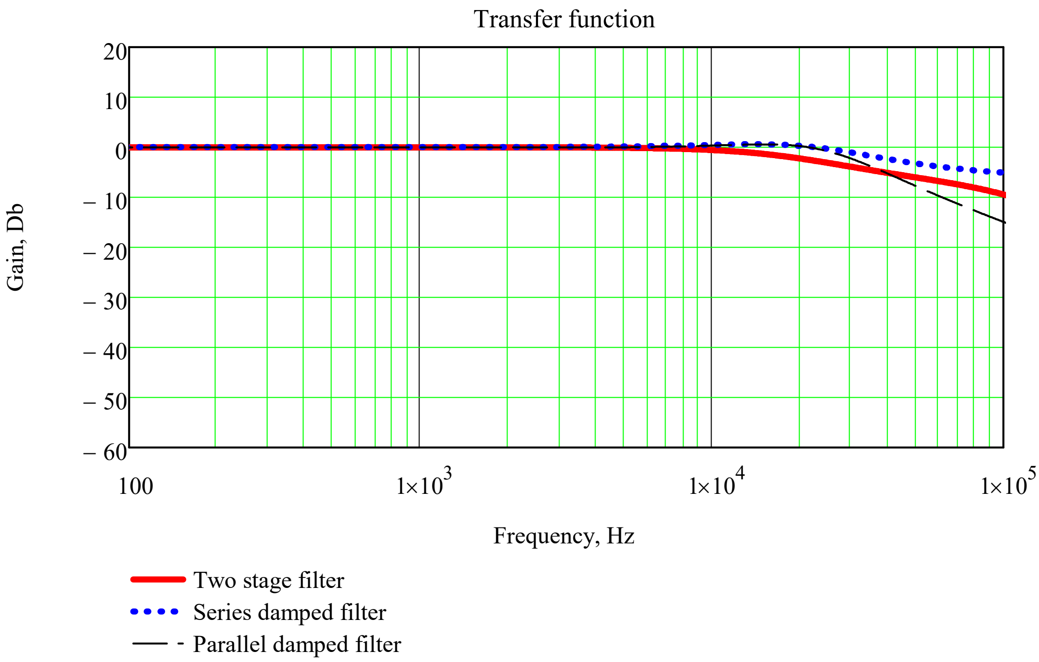
$$Ld4 := \frac{L1}{8}$$

$$Zm1_i := s_i\cdot L1 + RL1 \qquad Zm2_i := \frac{1}{s_i\cdot C1} + ESRc1$$

$$Zm3_i := \frac{(Rd4 + s_i\cdot Ld4)\cdot(s_i\cdot L2 + RL2)}{(Rd4 + s_i\cdot Ld4) + s_i\cdot L2 + RL2} \qquad Zm4_i := \frac{1}{s_i\cdot C2} + ESRc2$$

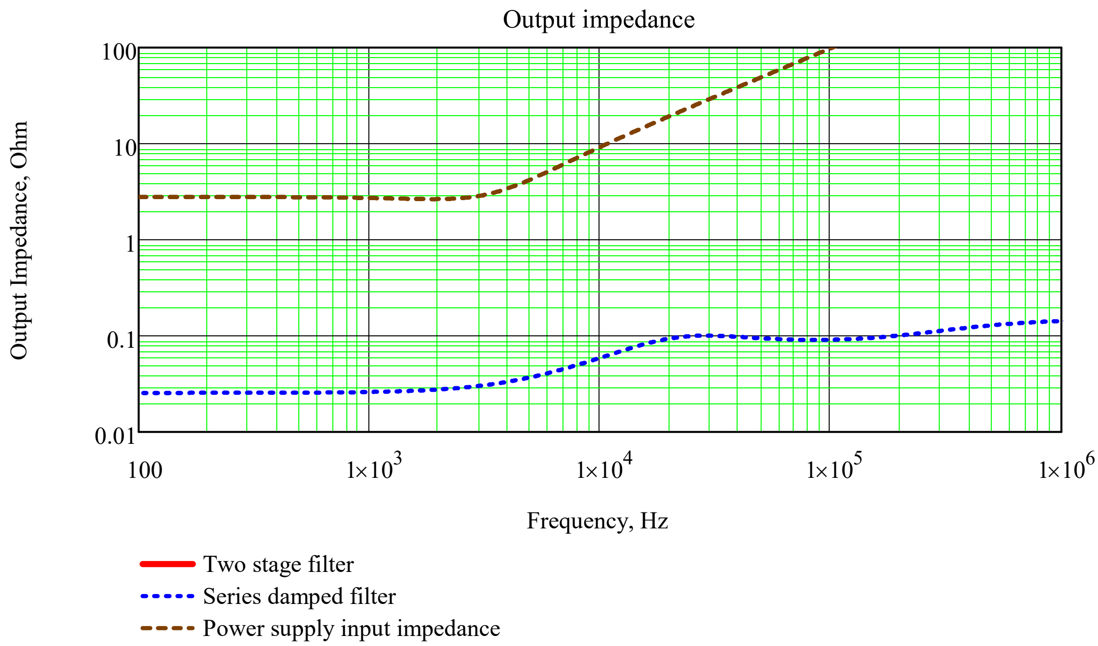
-Transfer function:

$$\mathrm{Filter4}_i := 20\cdot\log\left(\left|\frac{\mathrm{Zm4}_i}{\dfrac{\mathrm{Zm1}_i\cdot \mathrm{Zm2}_i}{\mathrm{Zm1}_i + \mathrm{Zm2}_i} + \mathrm{Zm3}_i + \mathrm{Zm4}_i}\cdot\frac{\mathrm{Zm2}_i}{\mathrm{Zm1}_i + \mathrm{Zm2}_i}\right|\right)$$



-Filter output impedance:

$$\mathrm{Zf4}_i := \left|\frac{\mathrm{Zm4}_i\cdot\dfrac{\mathrm{Zm1}_i\cdot \mathrm{Zm2}_i}{\mathrm{Zm1}_i + \mathrm{Zm2}_i}\cdot \mathrm{Zm3}_i}{\dfrac{\mathrm{Zm1}_i\cdot \mathrm{Zm2}_i}{\mathrm{Zm1}_i + \mathrm{Zm2}_i} + \mathrm{Zm3}_i + \mathrm{Zm4}_i}\right|$$



Output impedance
Output Impedance, Ohm
100
10
1
0.1
0.01
100
1×10^3
1×10^4
1×10^5
1×10^6
Frequency, Hz
Two stage filter
Series damped filter
Power supply input impedance