Simple Post-Filter neg. Feedback For Class-D Amplifiers Dsn Example

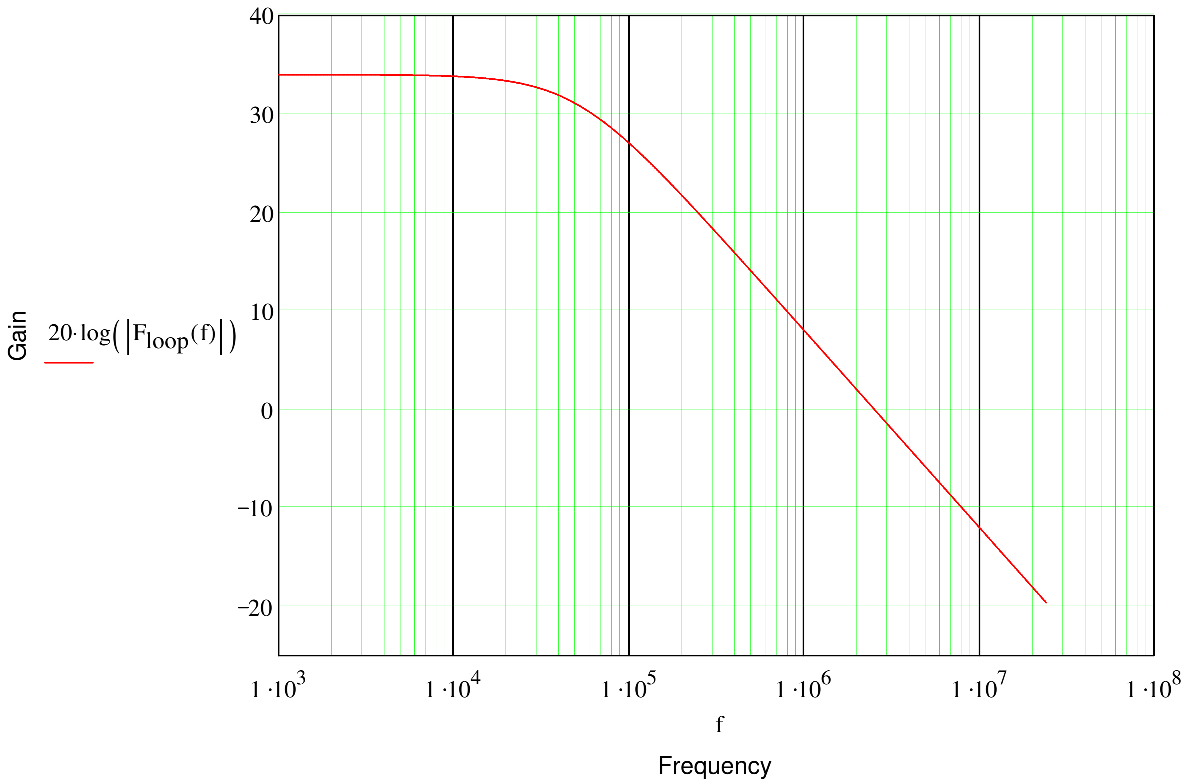
(Source : **Charles Lehmann AES Paper Presentation 2009 in Denmark charles-lehmann@bluewin.ch**)

- Amplifier Specifation Sheet **50Vrms** (**Carrier Based Amplifier** Version using a Triangle Carrier Signal)

$A := 50$ (DesiredClosed Loop)

$f_L := (1.5 \cdot 10)^4 Hz$ $T_L := \frac{1}{2 \cdot \pi f_L}$ $T_L = 3.144 \times 10^{-6}\ s$ (Desired 3dB Single Pole role off of the whole amplifier)

$F_{loop}(s) := A \cdot \frac{1}{1 + s \cdot T_L}$ $F_{loop}(f) := A \cdot \frac{1}{1 + j \cdot 2 \cdot \pi \cdot f \cdot T_L}$



Desired single pole roll off of the switching amplifier. The figures below are a design example. All the variables can be changed to accommodate for another amplifier.

$V_{batt} := \frac{170.0}{2} V$ $V_{Triangle} := 3.0V$

$f_{sw} := 3.25 \cdot 10^5 Hz$ Carrier Switching Frequency $f_{sw} = 3.25 \times 10^5\ \frac{1}{s}$

$R_i := 1k\Omega$ Amplifier Input Impedance

Amplifiers LC-Outputfilter

$$F_{filter}(s) := \frac{1}{1 + s\cdot\frac{T_F}{Q_F} + s^2\cdot T_F^{\,2}}$$

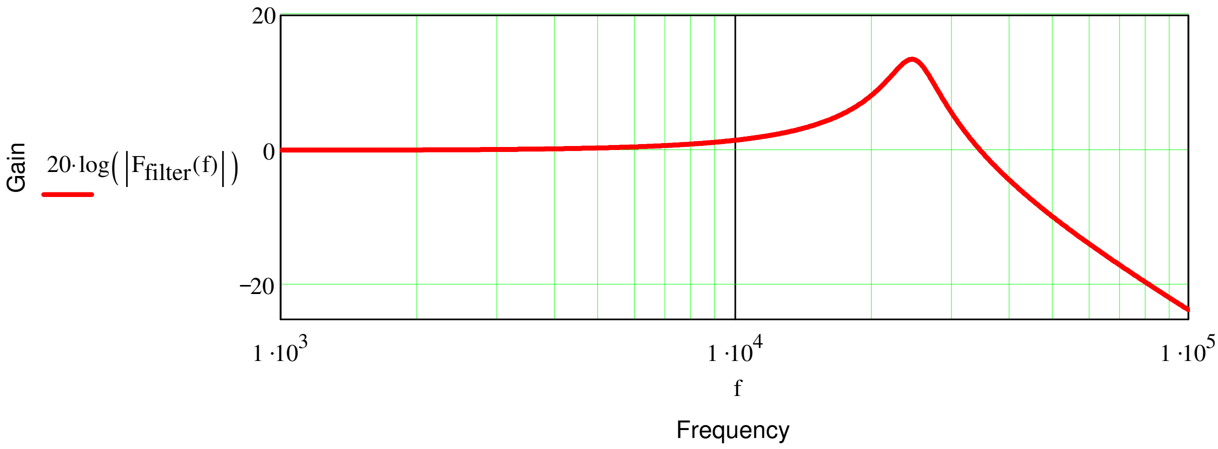
$$R_{Load} := 50\Omega$$

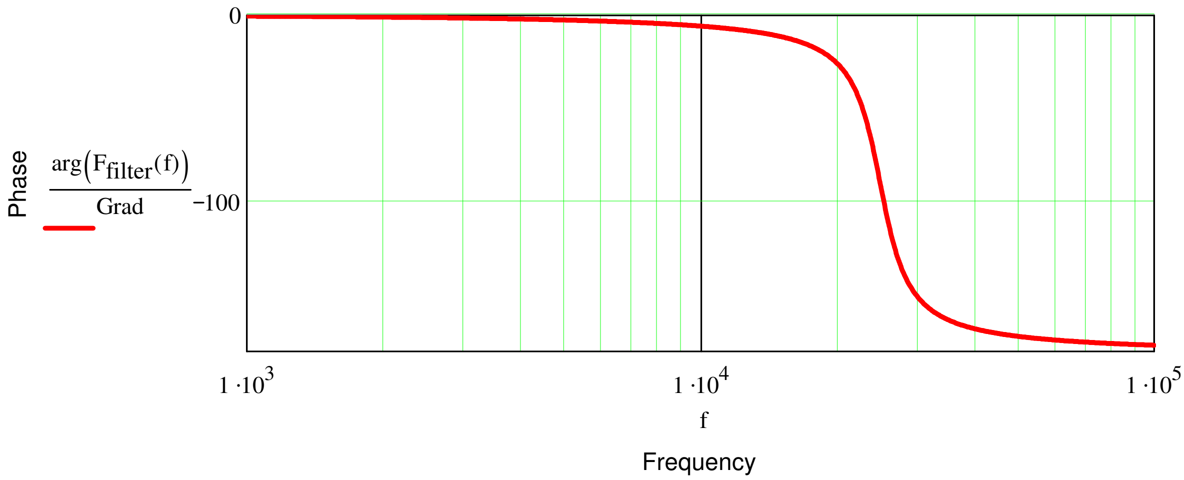
$$L_{Filt} := 68\mu H \qquad C_{Filt} := 600nF \qquad Q_F := R_{Load}\cdot\sqrt{\frac{C_{Filt}}{L_{Filt}}} \qquad Q_F = 4.697$$

$$T_F := \sqrt{L_{Filt}\cdot C_{Filt}} \qquad T_F = 6.387\times 10^{-6}\ s$$

$$F_{filter}(f) := \frac{1}{1 + j\cdot 2\cdot\pi\cdot f\cdot\frac{T_F}{Q_F} - 4\cdot\pi^2\cdot f^2\cdot T_F^{\,2}}$$

$$Fg_{LC} := \frac{1}{2\cdot\pi\cdot T_F} \qquad Fg_{LC} = 2.492\times 10^4\ \frac{1}{s}$$ (24 KHz)





IMO it is best calculate with a Q > 0.5. The filter peaks with the nominal load being used. Anyway it is just a startin point for component calculation. The amplifier must be able to tolerate any load > nominal. Even no load!

Searching for the komplex Pole(s) Compensator Transfer Function

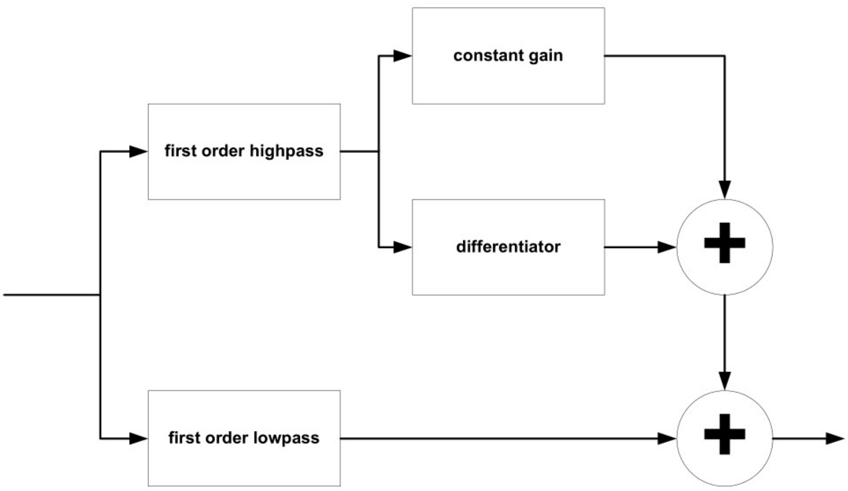
Searching for the Transfer function $f_x(s)$ that multiplied with the Transfer function of the LC-Output Filter $F_{filter}(s)$ results in the desired overall loop function $F_{loop}(s)$ (PT1 Behavior). See page 1 single pole role off.

$$F_{loop}(s) := A\cdot\frac{1}{1+s\cdot T_L} \quad = f_x(s) * \quad F_{filter}(s) := \frac{1}{1+s\cdot\frac{T_F}{Q_F}+s^2\cdot T_F^2} \qquad (ChLEq4)$$

Rearranging the equation above results in the following :

$$f_x(s) := A\cdot\left[\frac{1}{1+s\cdot T_L}+\frac{s\cdot T_L}{1+s\cdot T_L}\cdot\left(\frac{T_F}{Q_F\cdot T_L}+s\cdot T_L\cdot\frac{T_F^{\,2}}{T_L^{\,2}}\right)\right] \qquad (ChLEq7)$$

A possible solution for the linear system is the following topology for f_x



(ChLFig3)

Complex Pole (Q > 0.5) Compensator Transfer Function

$$fx(f) := A\cdot\left[\frac{1}{1+j\cdot 2\cdot\pi\cdot f\cdot T_L}+\frac{j\cdot 2\pi\cdot f\cdot T_L}{1+j\cdot 2\cdot\pi\cdot f\cdot T_L}\cdot\left(\frac{T_F}{Q_F\cdot T_L}+j\cdot 2\cdot\pi f\cdot T_L\cdot\frac{T_F^{\,2}}{T_L^{\,2}}\right)\right]$$

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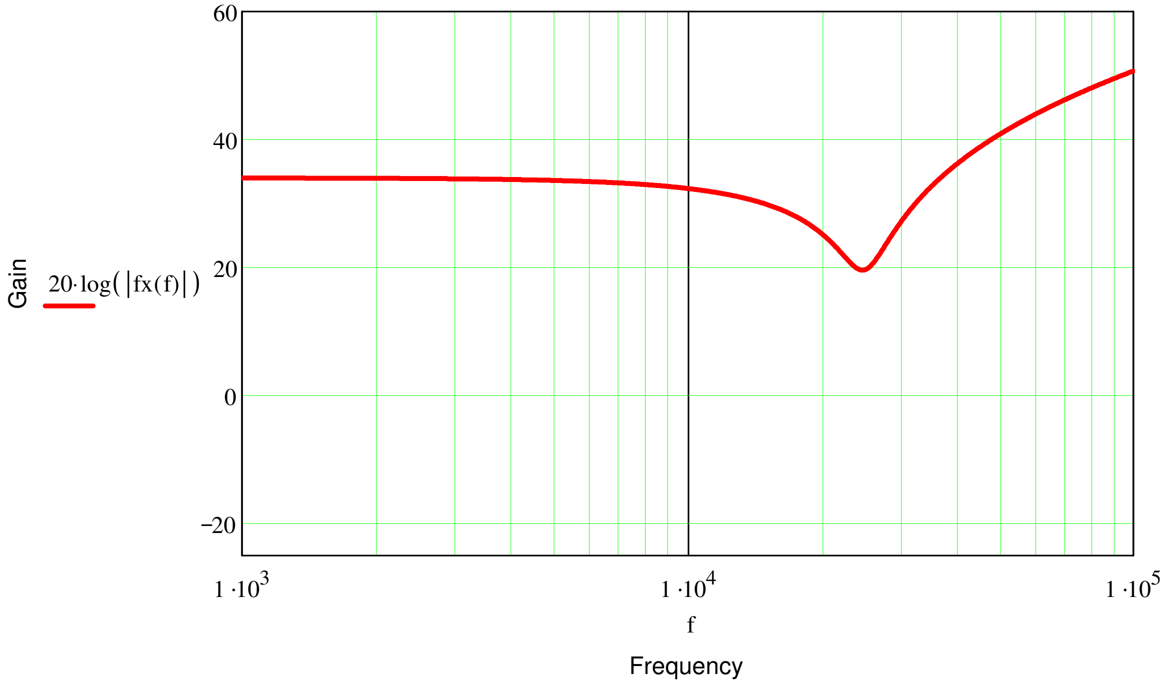
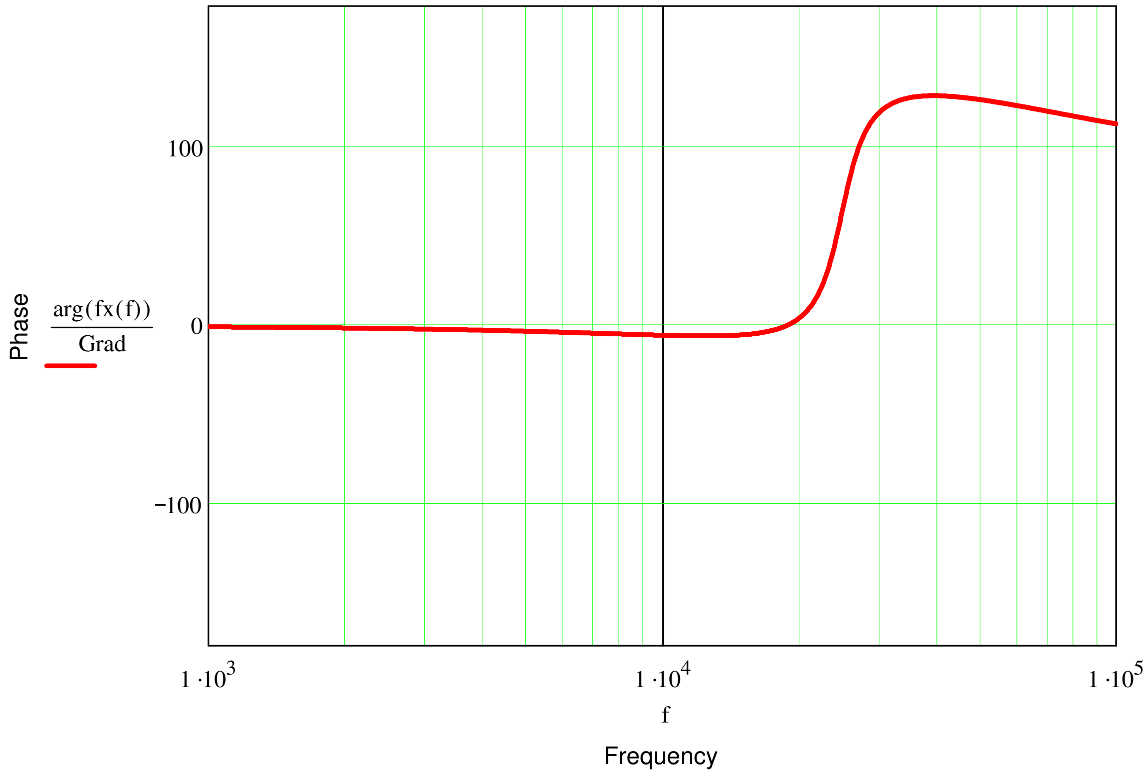
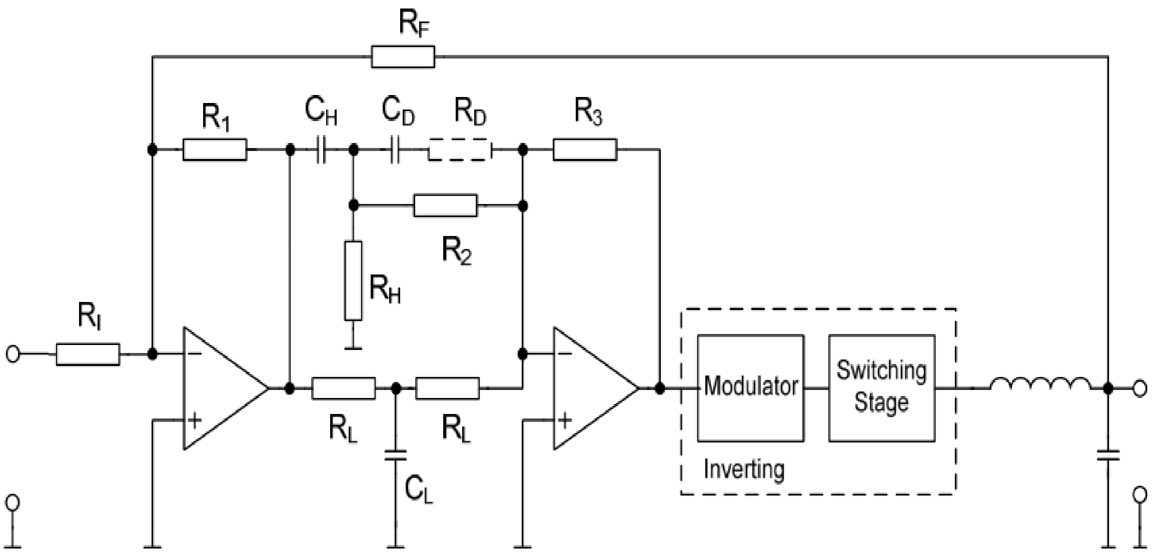
Amplitude & Phase Plot for the Complex Pole Compensator (Q > 0.5) fx(f)





If this transfer function exists and can be mapped to real world circuits, then the initial phase margin of the whole amplifier will be close to 90 degrees.

For a Half Bridge like topology (ChL AES paper) the following mapping can be used to get this transfer function fx(f



- The closed loop gain A_{cl} in the topology above is : $A_{cl} := -\frac{R_f}{R_i}$ see Picture of Topology

- Modulator Gain is (inverting Power Comparator): $A_{HS} := \frac{V_{batt}}{V_{Triangle}}$ $A_{HS} = 28.333$

$$A_{loop} := \frac{-R_1 \cdot R_3}{R_F} \cdot \left[\frac{1}{2R_L} \cdot \frac{1}{1 + s \cdot .5R_L \cdot C_L} + \frac{s \cdot C_H \cdot \left(\frac{R_H \cdot R_2}{R_2 + R_H}\right)}{1 + s \cdot C_H \cdot \left(\frac{R_H \cdot R_2}{R_2 + R_H}\right)} \cdot \left(\frac{1}{R_2} + s \cdot C_D\right) \right] \cdot A_{HS} \cdot F_{filter}(s) \qquad \text{(ChLEq8)}$$

Approximation : $A_{lloop} := \frac{-R_1 \cdot R_3}{2 \cdot R_F \cdot R_L} \cdot \frac{1}{1 + s \cdot 0.5 \cdot R_L \cdot C_L} \cdot A_{HS}$

The forward transfer function is :

$$A_F := \frac{-R_1 \cdot R_3}{Ri} \cdot \left[\frac{1}{2R_L} \cdot \frac{1}{1 + s \cdot 0.5R_L \cdot C_L} + \frac{s \cdot C_H \cdot \left(\frac{R_H \cdot R_2}{R_2 + R_H}\right)}{1 + s \cdot C_H \cdot \left(\frac{R_H \cdot R_2}{R_2 + R_H}\right)} \cdot \left(\frac{1}{R_2} + s \cdot C_D\right) \right] \cdot A_{HS} \cdot F_{filter}(s) \qquad \text{(ChLEq9)}$$

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Approximation forward transfer function is : $A_{lF} := \frac{-R_1 \cdot R3}{2 \cdot R_i \cdot R_L} \cdot \frac{1}{1 + s \cdot 0.5 \cdot R_L \cdot C_L} \cdot A_{HS}$

The closed loop gain : $A_{cl} := A$ (from Amplifier Spec Pg 1) $R_f := A_{cl} \cdot R_i$ $R_f = 5 \times 10^4\ \Omega$

- Calculation of the Unity Gain Point. The amplifier is a "natural" sampling Amplifier. Sampling Theorem applies.

Specify nyquist distance : $D_{Nyquist} := 3.25$

Unitiy gain point : $f_T := \frac{f_{sw}}{D_{Nyquist}}$ $f_T = 1 \times 10^5\ \frac{1}{s}$

(feedback factor)

The Feedback Factor is : $A_{lloop} := \frac{f_T}{f_L}$ $A_{lloop} = 1.975$

$A_{fbf} := \text{rund}(A_{lloop})$

DC-Gain forward path is : $A_{cl} \cdot A_{fbf} = 100$

According to equation 9 (ChL eq. 9) the DC gain of the forward Function is :is : $A_{lF} := \frac{-R_1 \cdot R_3}{2 \cdot R_i \cdot R_L} \cdot A_{HS}$

Select $R_L := 1k\Omega$ $\frac{A_{cl} \cdot A_{fbf}}{A_{HS}} = 3.529$

Minimum Compensator internal DC Gain : $IntGain_{Min} := \frac{A_{cl} \cdot A_{fbf} \cdot 2}{A_{HS}} \cdot R_i \cdot R_L$ $IntGain_{Min} = 7.059 \times 10^6\ \Omega^2$

R1 and R3 : $\sqrt{IntGain_{Min}} = 2.657 \times 10^3\ \Omega$

$R_1 := 2.7k\Omega$ $R_3 := 2.7k\Omega$ Other gain settings are possible as long as the product is about the same.

$C_L := \frac{1}{2 \cdot \pi \cdot f_L \cdot 0.5 \cdot R_L}$ (ChL Eq11) $C_L = 6.288 \times 10^{-9}\ F$ (select 6.2 nF !)

$R_2 := 2 \cdot R_L \cdot \frac{Q_F \cdot Fg_{LC}}{f_L}$ (ChL Eq12) $R_2 = 4.623 \times 10^3\ \Omega$ (select 4.7 kOhm!)

$R_H := 1.5k\Omega$ (R_H shall be reasonable smaller than R_2)

$C_H := \frac{R_H + R_2}{2 \cdot \pi \cdot f_L \cdot R_H \cdot R_2}$ (ChLEq13) $C_H = 2.776 \times 10^{-9}\ F$ (select 2.7 nF !)

$C_D := \frac{1}{4 \cdot \pi \cdot f_L \cdot R_L} \cdot \left(\frac{f_L}{Fg_{LC}}\right)^2$ (ChLEq14) $C_D = 6.489 \times 10^{-9}\ F$ (select 6.8nF !)