Low-complexity Equalizers and Applications

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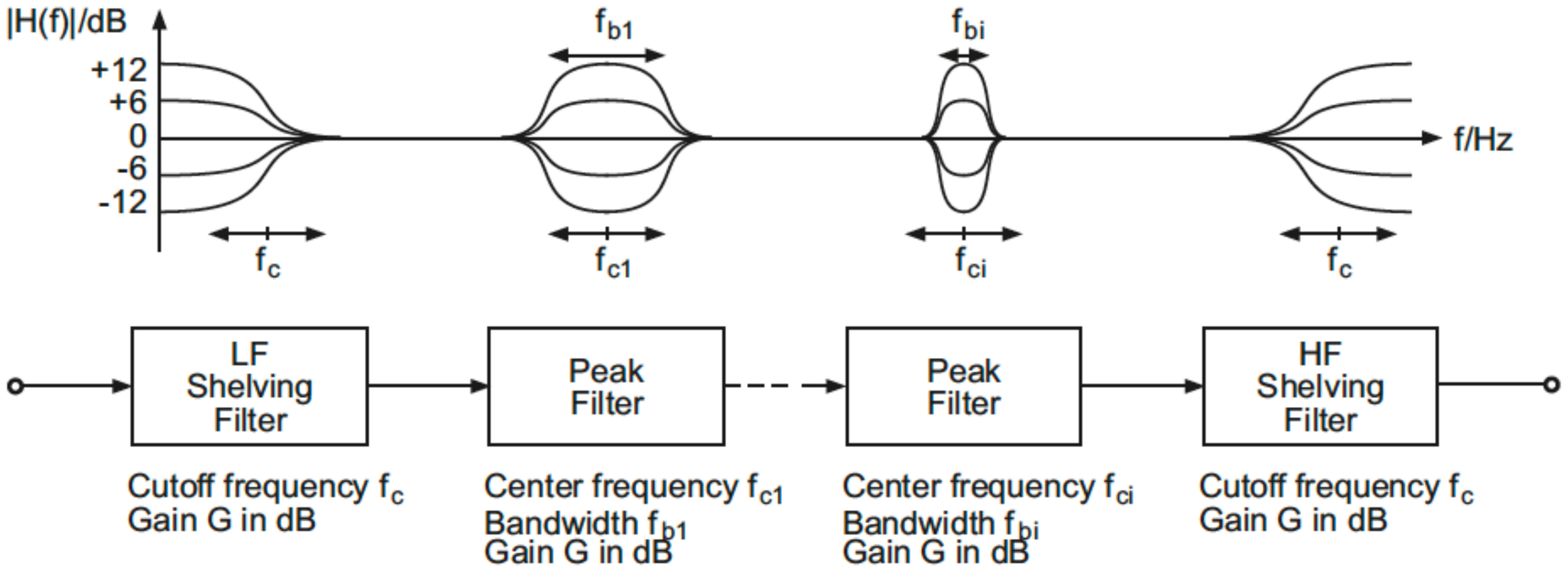
- Introduction
- LP, HP, BP, and AP filters
- Shelving and Peak equalizers
- Applications
- Conclusion

INTRODUCTION – LOW COMPLEXITY EQUALIZERS

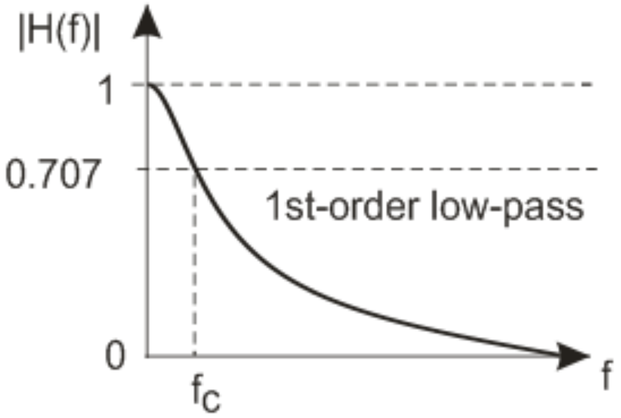


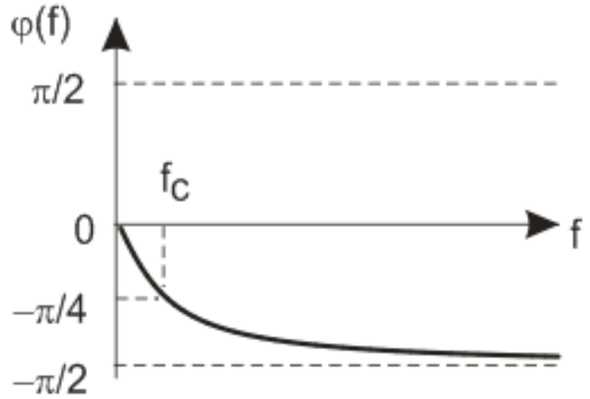
low complexity	IIR 1st order	parametric IIR 1st order	LP, HP allpass 1st order	IIR biquad 2nd order	BP allpass 2nd order	parametric Shelving	parametric Peak
coeff	3	2	1	5	2	2	3
mul	3	2	1	5	2	2	5
add	3	2	3	3	3	4	5

LP, HP, AND BP FILTERS

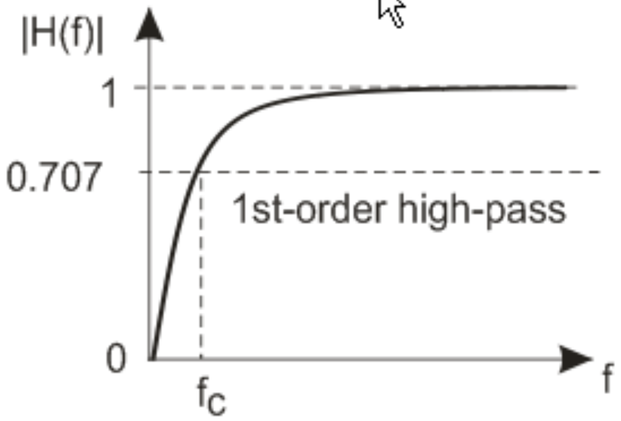
$$z^{-1} \Rightarrow -z^{-1}\frac{-b+z^{-1}}{1-bz^{-1}}$$

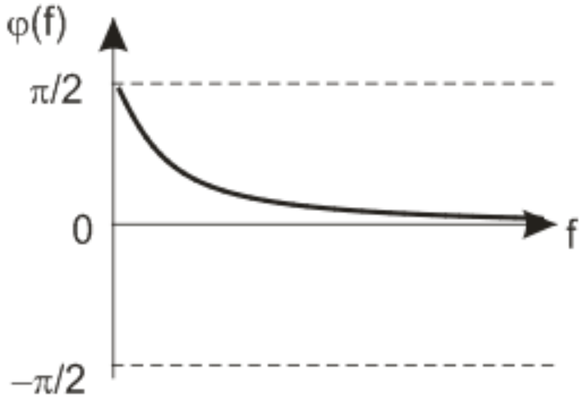
$$H_{LP}(z) = K_{LP}\frac{1+z^{-1}}{1-az^{-1}}$$



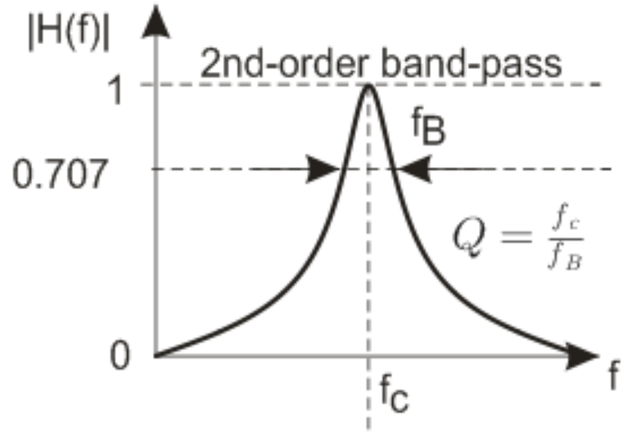


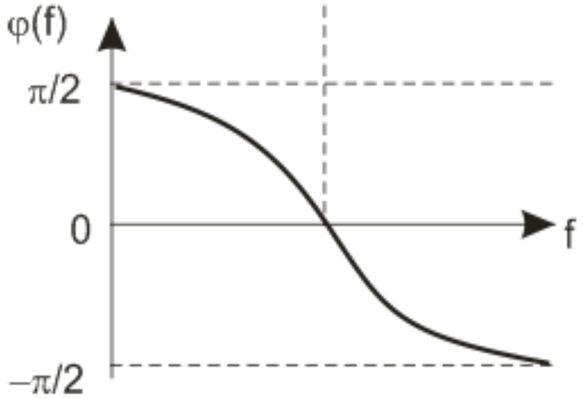
$$H_{HP}(z) = K_{HP}\frac{1-z^{-1}}{1-az^{-1}}$$





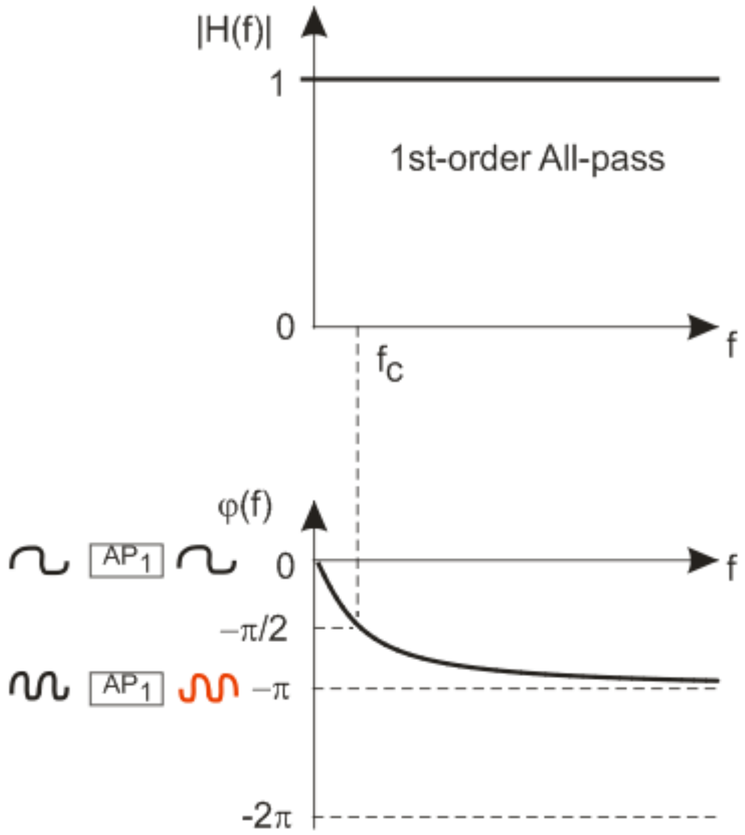
$$H_{BP}(z) = K_{BP}\frac{1-z^{-2}}{1-b(1+a)z^{-1}+az^{-2}}$$



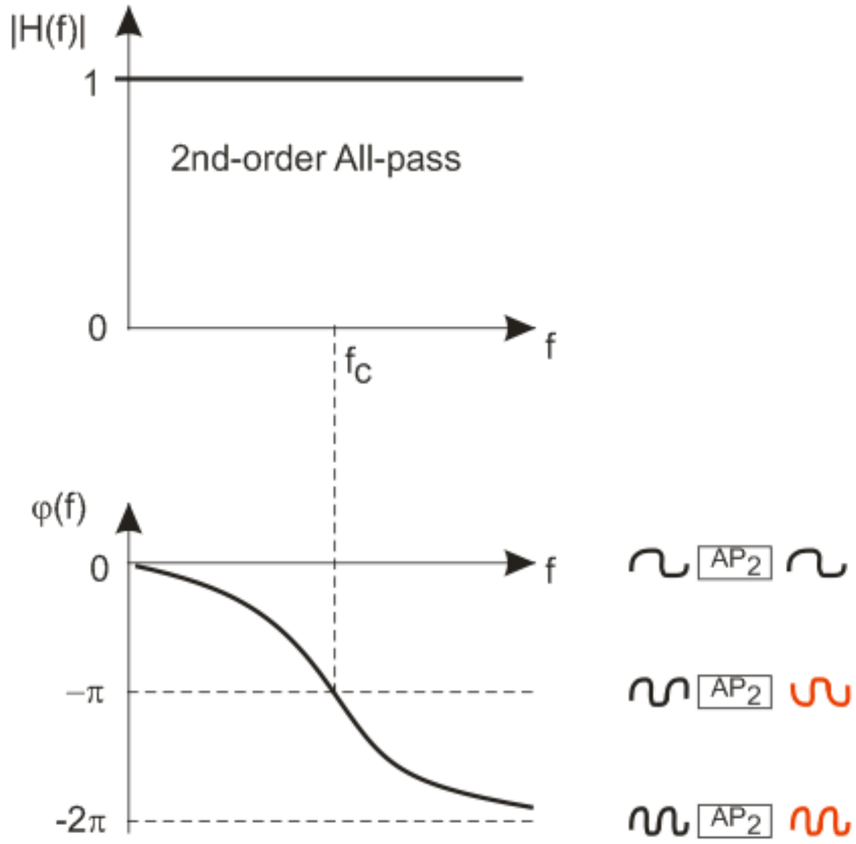


FIRST- AND SECOND-ORDER ALL-PASS FILTERS

$$H_{AP_1}(z) = \frac{-a+z^{-1}}{1-az^{-1}} \quad a = \frac{1-\sin\Omega_c}{\cos\Omega_c}$$

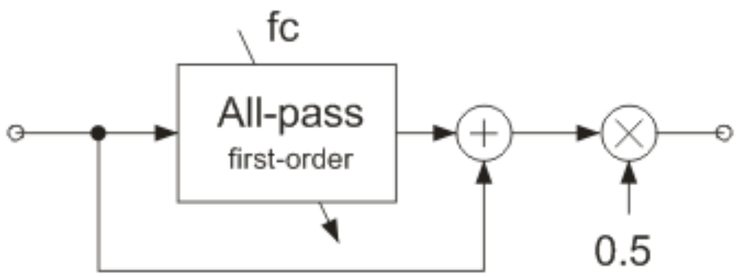


$$H_{AP_2}(z) = \frac{a-b(1+a)z^{-1}+z^{-2}}{1-b(1+a)z^{-1}+az^{-2}} \quad b = \cos\Omega_c$$

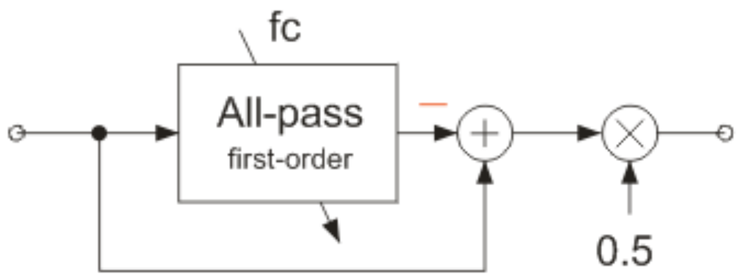


ALL-PASS REALIZATIONS OF LP, HP, AND BP

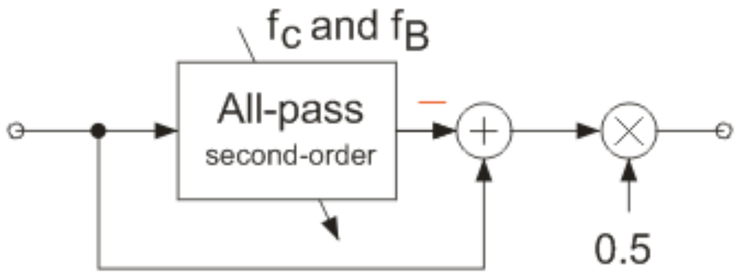
1st-order low-pass



1st-order high-pass

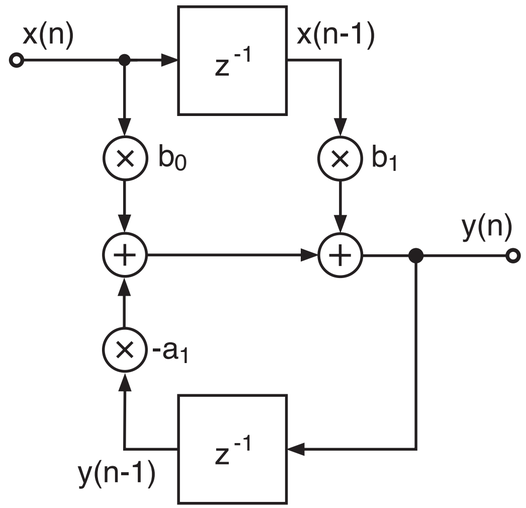


2nd-order band-pass

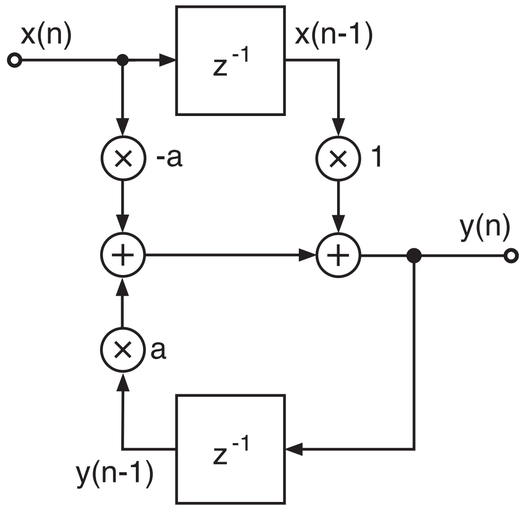


FIRST-ORDER FILTERS

1st order filter

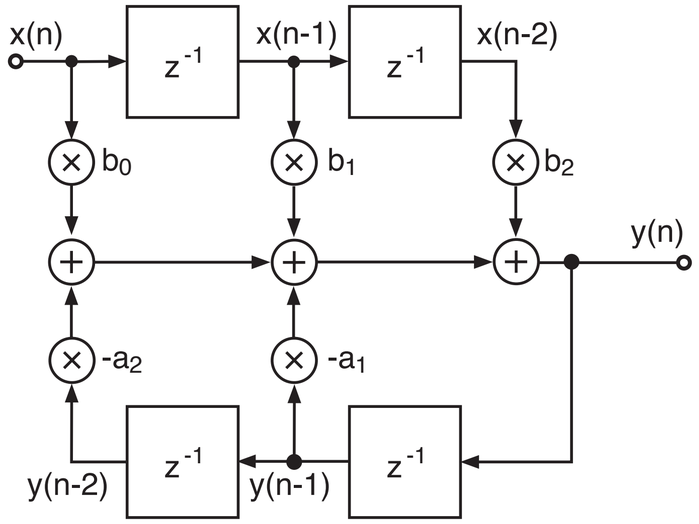


1st order all-pass

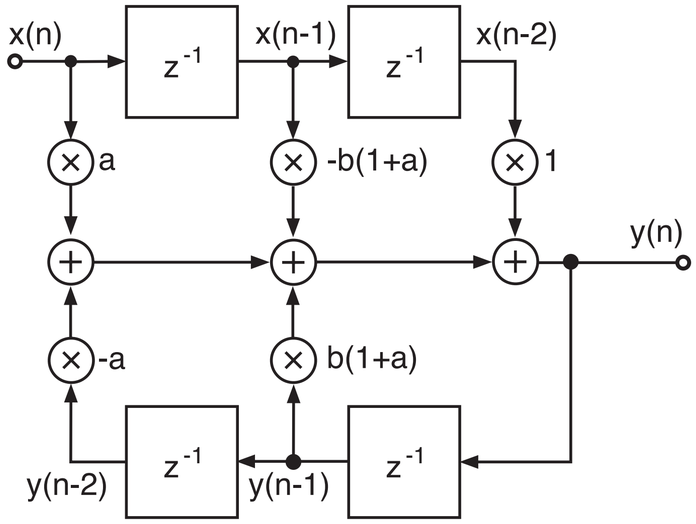


SECOND-ORDER FILTERS

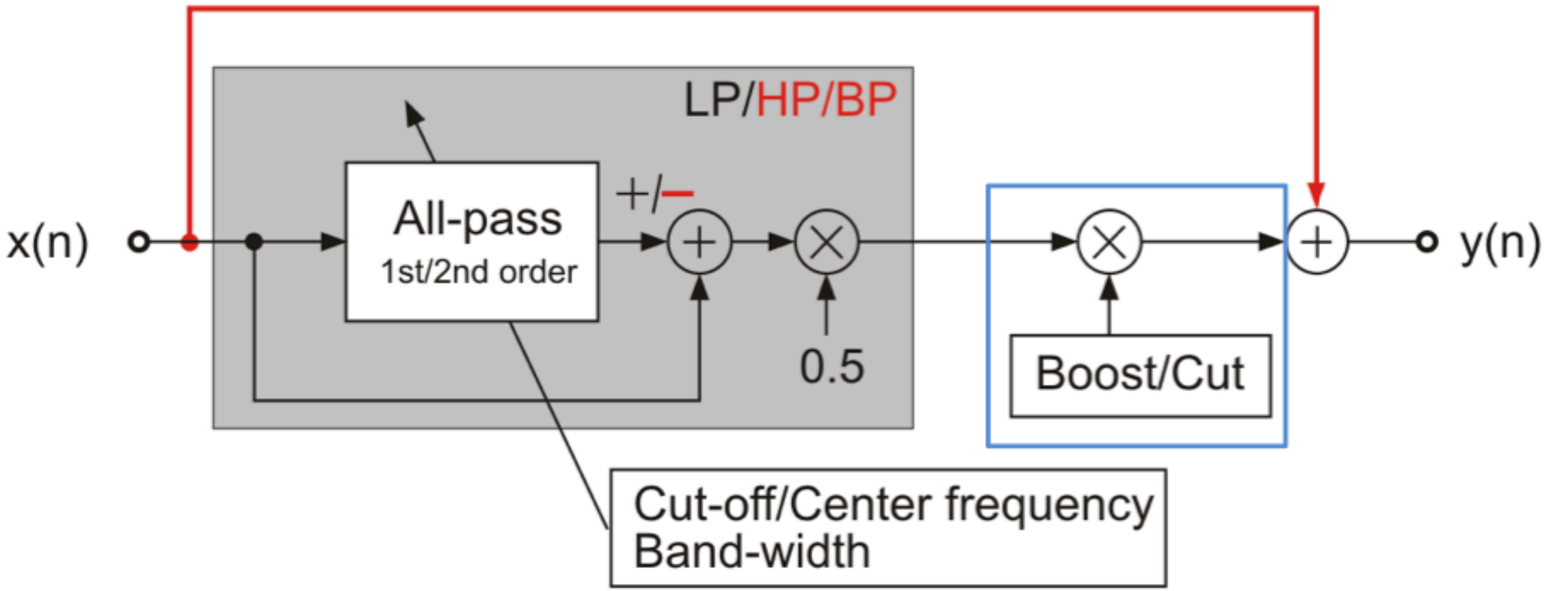
2nd order filter



2nd order all-pass



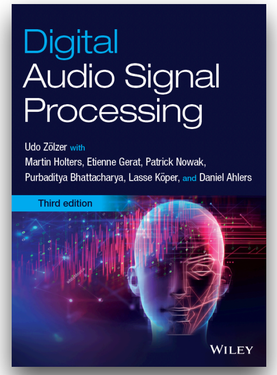
PARAMETRIC EQUALIZER



$$H_{LFS}(z) = 1 + B/C \cdot H_{LP}(z)$$

$$H_{HFS}(z) = 1 + B/C \cdot H_{HP}(z)$$

$$H_{PEAK}(z) = 1 + B/C \cdot H_{BP}(z)$$

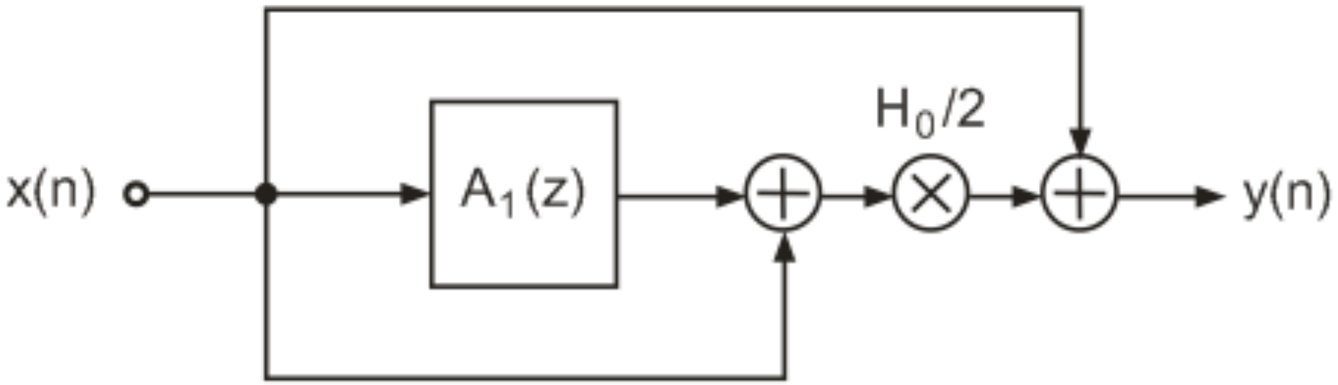


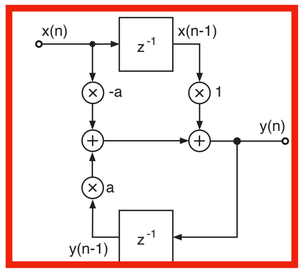
LOW-FREQUENCY SHELVING FILTER

$$H(z) = 1 + \frac{H_0}{2}[1 + A_1(z)] \quad A_1(z) = \frac{-a + z^{-1}}{1 - az^{-1}}$$

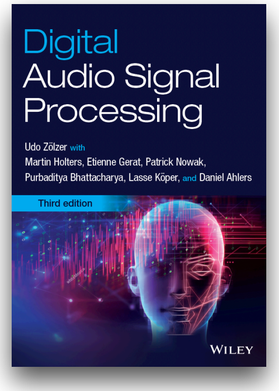
$$H(z = 1) = V_0 = 1 + H_0, V_0 = 10^{G/20} \rightarrow H_0 = 10^{G/20} - 1$$

First-order LF Shelving Filter





$$a_B = \frac{1 - \tan\frac{\Omega_c}{2}}{1 + \tan\frac{\Omega_c}{2}}, a_C = \frac{V_0 - \tan\frac{\Omega_c}{2}}{V_0 + \tan\frac{\Omega_c}{2}}$$

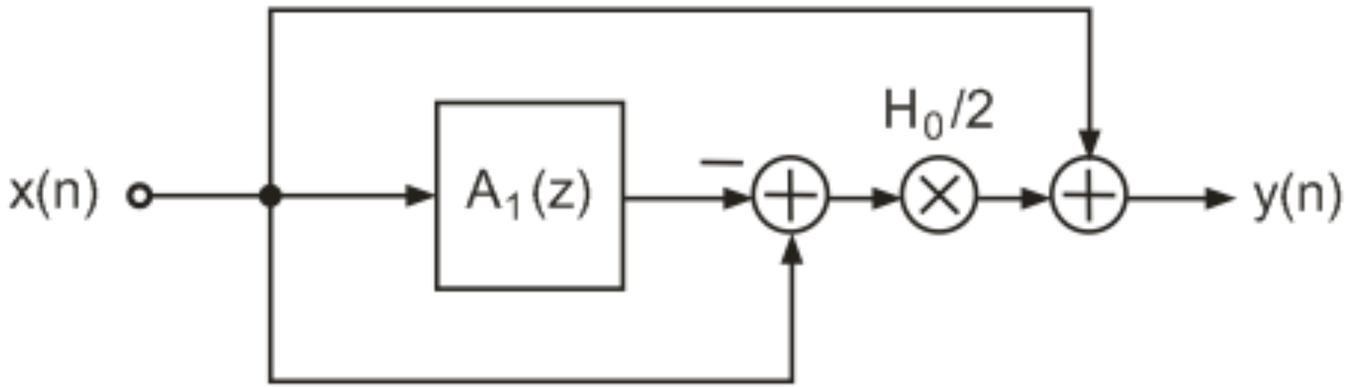


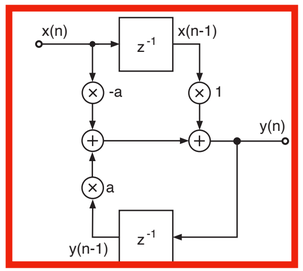
HIGH-FREQUENCY SHELVING FILTER

$$H(z) = 1 + \frac{H_0}{2}[1 - A_1(z)] \quad A_1(z) = \frac{-a + z^{-1}}{1 - az^{-1}}$$

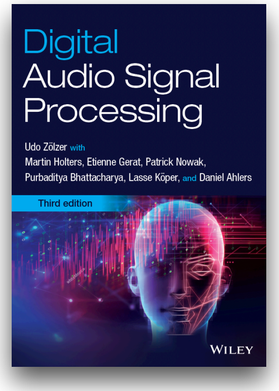
$$H(z = -1) = V_0 = 1 + H_0, V_0 = 10^{G/20} \rightarrow H_0 = 10^{G/20} - 1$$

First-order HF Shelving Filter





$$a_B = \frac{1 - \tan\frac{\Omega_c}{2}}{1 + \tan\frac{\Omega_c}{2}}, \; a_C = \frac{1 - V_0 \tan\frac{\Omega_c}{2}}{1 + V_0 \tan\frac{\Omega_c}{2}}$$

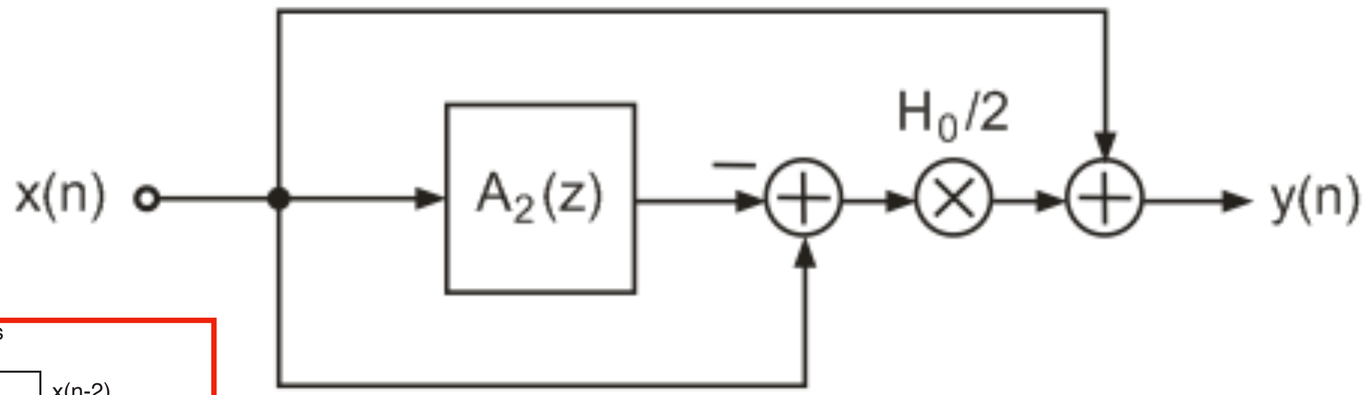


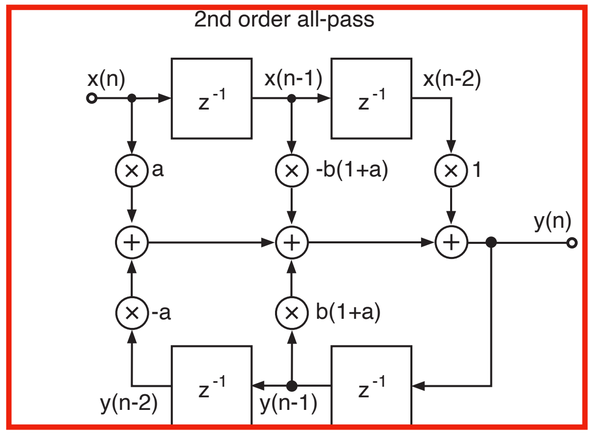
PEAK FILTER

$$H(z) = 1 + \frac{H_0}{2}[1 - A_2(z)] \quad A_2(z) = \frac{a - b(1+a)z^{-1} + z^{-2}}{1 - b(1+a)z^{-1} + az^{-2}}$$

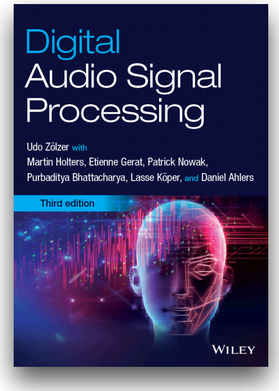
$$H(e^{j\Omega_c}) = V_0 = 1 + H_0, V_0 = 10^{G/20} \rightarrow H_0 = 10^{G/20} - 1$$

Second-order Peak Filter

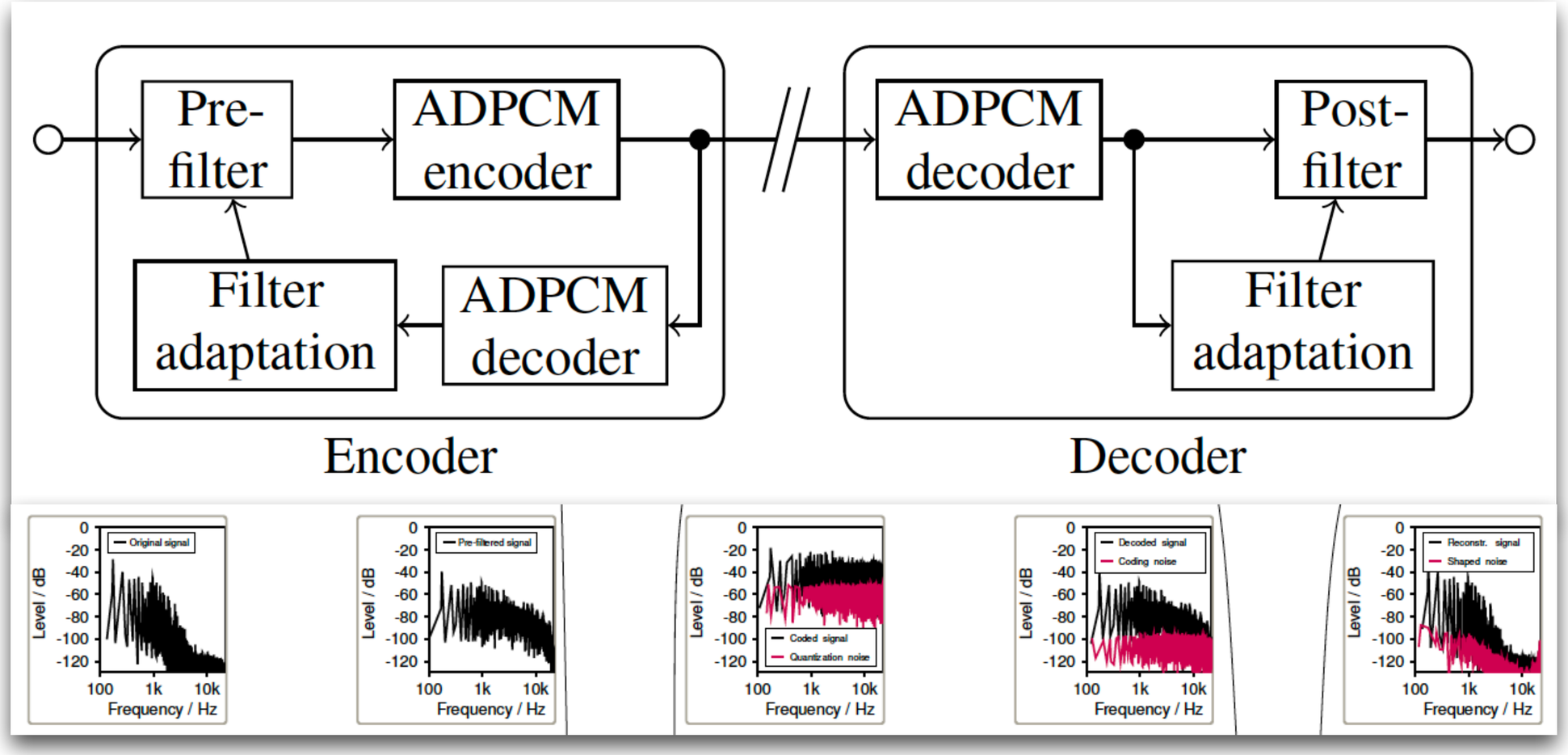




$$b = \cos\Omega_c, a_B = \frac{1 - \tan\frac{\Omega_b}{2}}{1 + \tan\frac{\Omega_b}{2}}, a_C = \frac{V_0 - \tan\frac{\Omega_b}{2}}{V_0 + \tan\frac{\Omega_b}{2}}$$

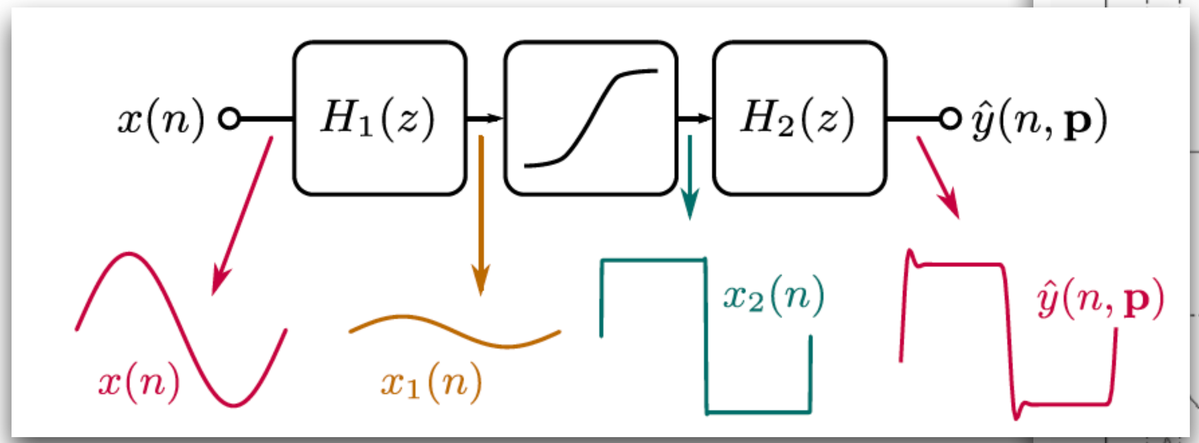


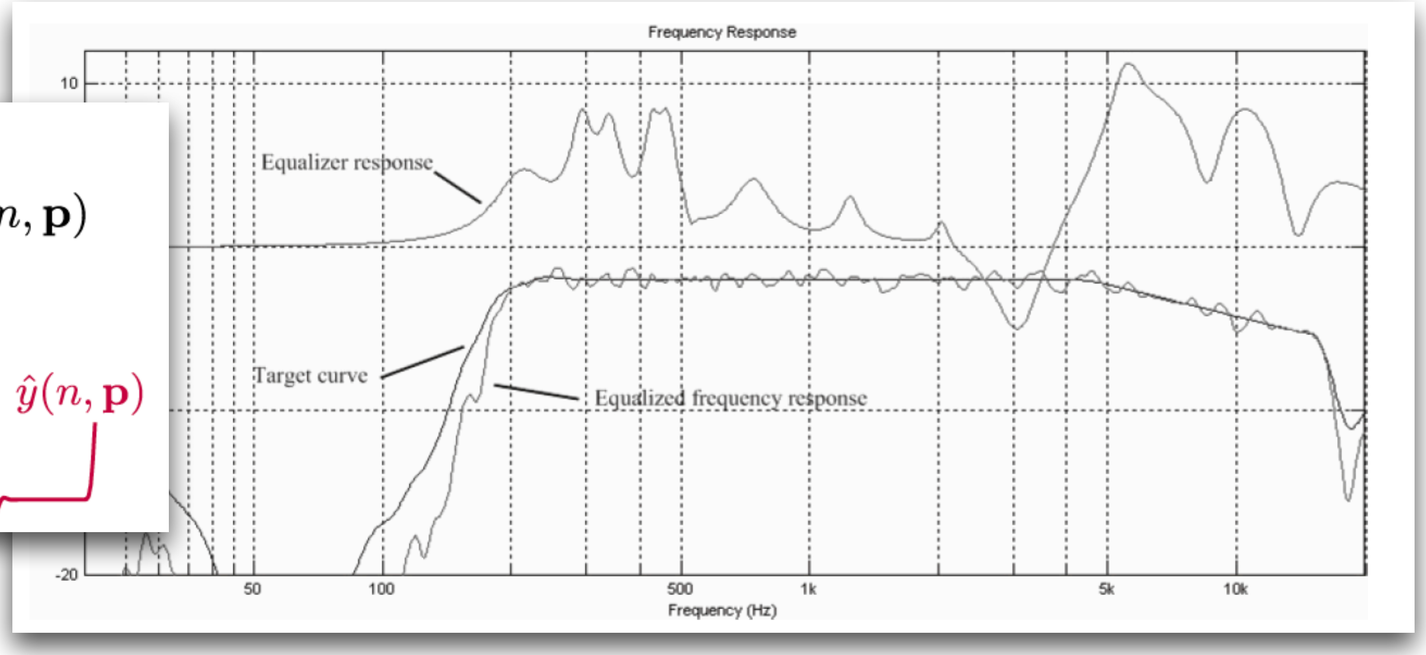
Delay-free Audio Coding



M. Holters, U. Zölzer, „Delay-free Lossy Audio Coding Using Shelving Pre- and Post-filters," ICASSP, 2008, Las Vegas

Amp/Loudpspeaker Modeling

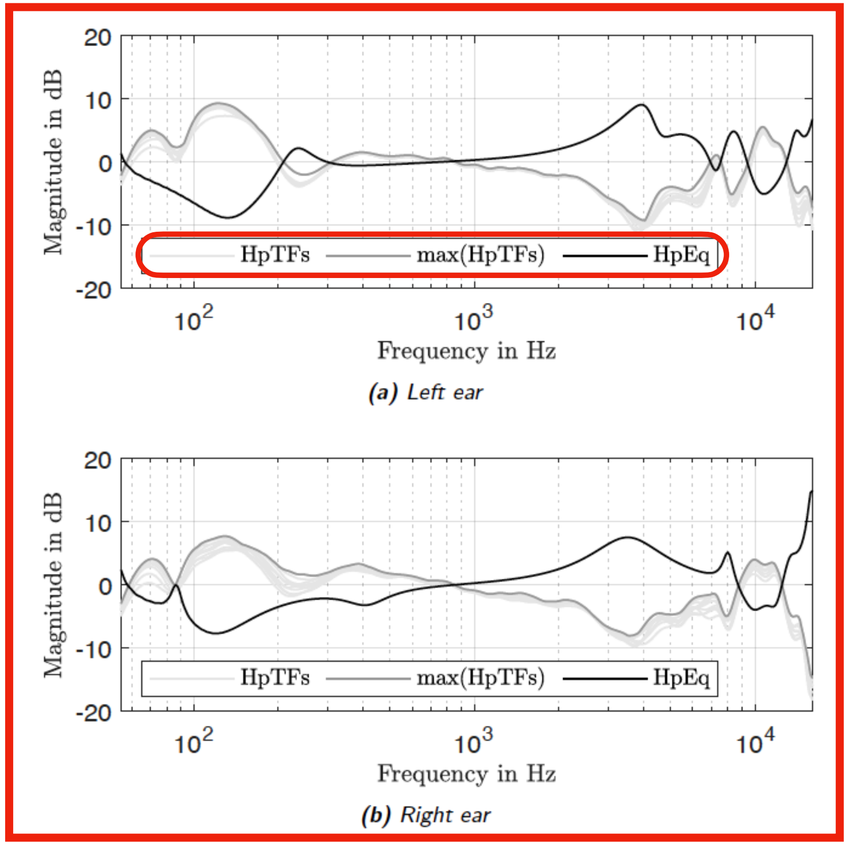


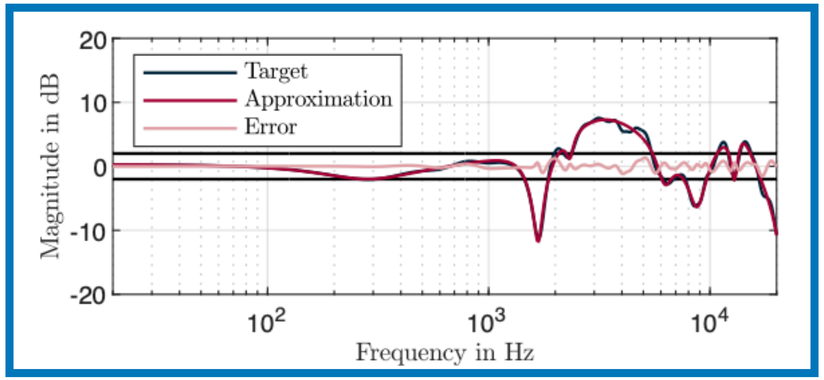


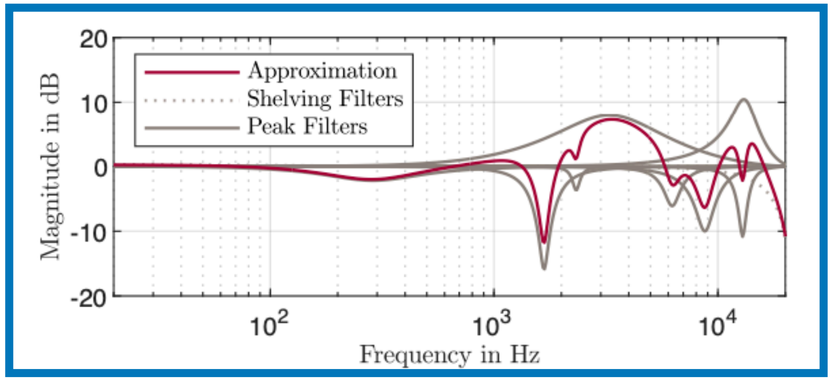
F. Eichas, and U. Zölzer, „Gray-Box Modeling of Guitar Amplifiers," JAES Vol 66, No 12 pp. 1006-1015; December 2018

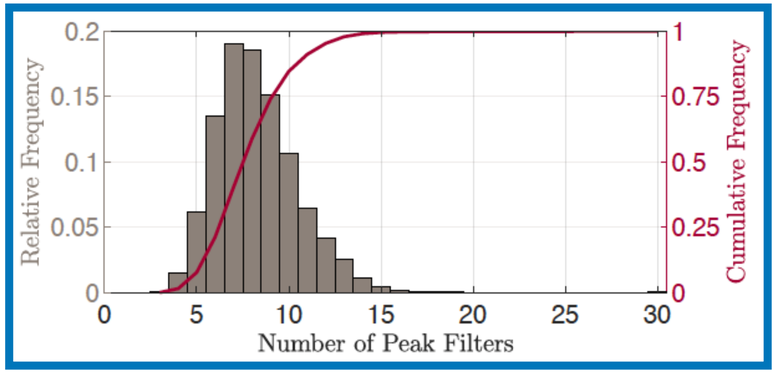
H. Behrends et.al., „Automatic Equalization Using Parametric IIR Filters," JAES Vol 59, No 3, pp. 102-109; March 2011

Headphone and HRTF









P. Nowak, Spatial Audio Through Headphones Based on HRTFs Approximated by Parametric IIR Filters, Diss 2022

P. Nowak et.al., Automatic Approximation of Head-Related Transfer Functions Using Parametric IIR Filters, DAGA 2020

References

U. Zölzer, Digital Audio Signal Processing, 3rd ed, J. Wiley & Sons, 2022.

U. Zölzer (Ed), DAFX- Digital Audio Effects, 2nd ed, J. Wiley & Sons, 2011.

F. Keiler, U. Zölzer, “Parametric Second- and Fourth-Order Shelving Filters for Audio Applications“, Proc. of IEEE 6th Workshop on Multimedia Signal Processing, Siena, Italy, September 29 - October 1, 2004.

S. J. Orfanidis, “High-order digital parametric equalizer design”, J. Audio Eng. Soc., vol. 53, no. 11, pp. 1026–1046, 2005.

M. Holters, U. Zölzer: “Parametric Recursive Higher-Order Shelving Filters“. Preprint 6722, 120 AES Convention, May 2006, Paris.

M. Holters, U. Zölzer: “Graphic Equalizer Design Using Higher-Order Recursive Filters“ Proc DAFx-06, September 2006, Montreal.