Universität Rostock

Traditio et Innovatio

Shelving Filter Cascade with Adjustable Transition Slope and Bandwidth

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Low Order Shelving Filter Design

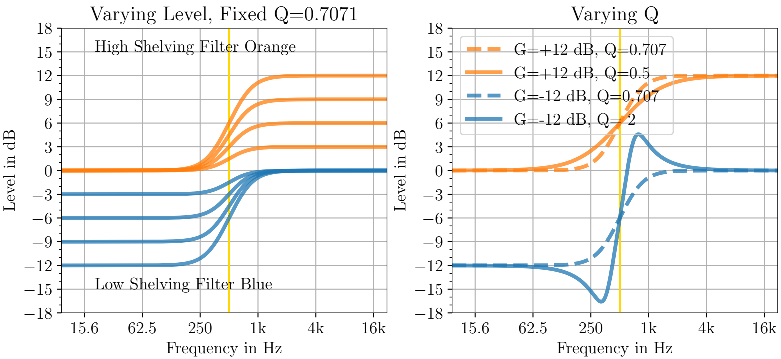

Figure: Typical 2nd order shelving filter with cutoff frequency 500 Hz defined at mid-level. Slope and transition bandwidth is linked to chosen shelving level and Q-factor.

Higher Order Shelving Filter Designs

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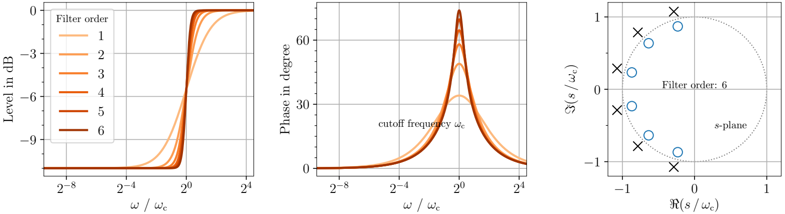
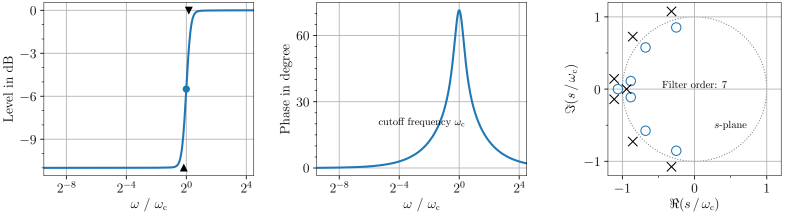
Figure: [McGrath, Baird & Jackson, 2004, 117th AES Conv.]
Approximation of a shelving filter transition band with PEQ biquads.

Higher Order Shelving Filter Designs



[Holters & Zölzer, 2006, 120th AES Conv.] Butterworth alignment of poles and zeros, cf. [US patent: #9 722 560]



[Eastty, 2008, 125th AES Conv.] Idea refinement and explicit control of transition band, cf. [US patent #9 203 366]

Proposed: Shelving Filter Cascade

Idea: **Cascade** of 1st / 2nd order low / high shelving filters to create **adjustable transition band**.
Logarithmic alignment due to filter characteristics in log-log domain, also meaningful for human hearing.

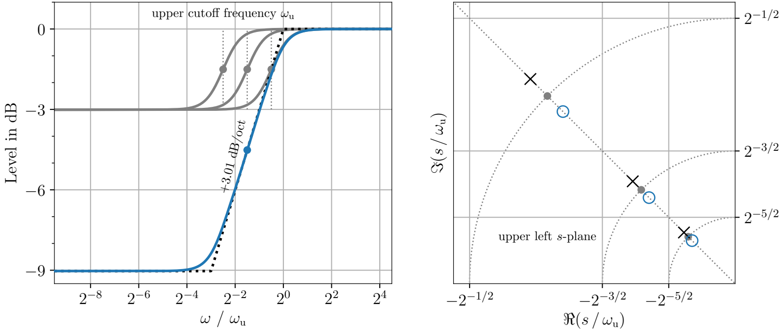
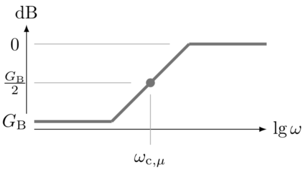


Figure: [Schultz, Hahn, Spors, 2020, 148th AES Conv.]
Example: $+3\,\mathrm{dB}/\mathrm{oct}$ slope and $-9\,\mathrm{dB}$ shelving gain achieved by one octave spacing of three biquads.

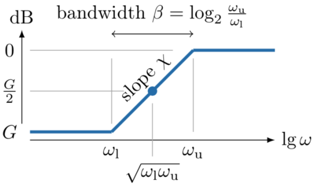
Proposed: Shelving Filter Cascade

Idea: Cascade of 1st / 2nd order low / high shelving filters to create adjustable transition band:
upper cutoff frequency $\omega_\mathrm{u} > 0$ in $\mathrm{rad/s}$,
shelving level G in dB, **slope** χ in $\mathrm{dB/octave}$, **bandwidth** $\beta > 0$ in $\mathrm{octaves}$

$$G = \mp \beta \cdot \chi$$



(a) each shelving biquad with mid-level cutoff frequency $\omega_{\mathrm{c},\mu}$.



(b) shelving filter cascade with lower / upper cutoff frequency $\omega_{\mathrm{l/u}}$.

Figure: Parameters of (a) shelving biquad and (b) shelving filter cascade.

Fixed Level with Varied Slope or Bandwidth

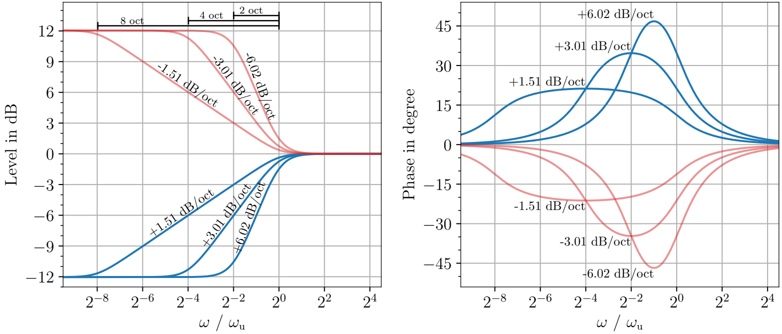


Figure: Fixed shelving level $G = \pm 12\,\mathrm{dB}$.
Varied slope χ in $\mathrm{dB/oct}$ with resulting bandwidth β in oct or vice versa.

Fixed Slope with Varied Bandwidth or Level

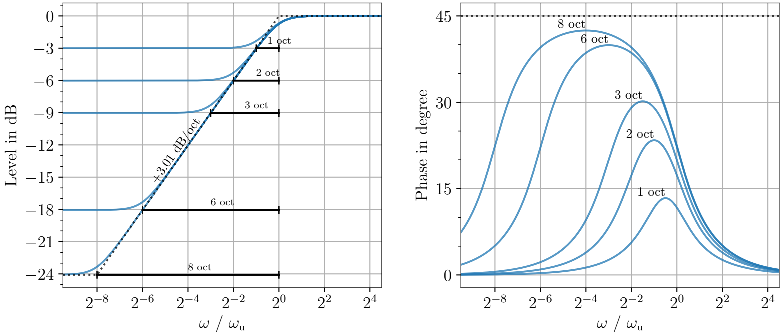


Figure: Fixed slope $\chi = 3\,\mathrm{dB}/\mathrm{oct}$.
Varied bandwidth β in oct, resulting shelving level G in dB or vice versa.

Fixed Bandwidth with Varied Level or Slope

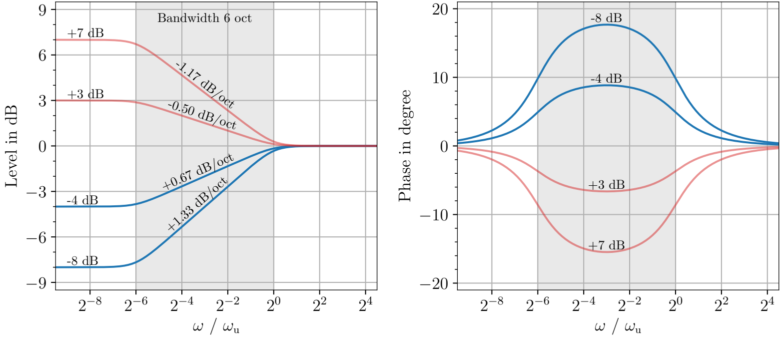


Figure: Fixed bandwidth $\beta = 6\,\mathrm{oct}$.
Varied shelving level G in dB, resulting slope χ in $\mathrm{dB/oct}$ or vice versa.

Constraint: Discrete Steps for Shelving Level

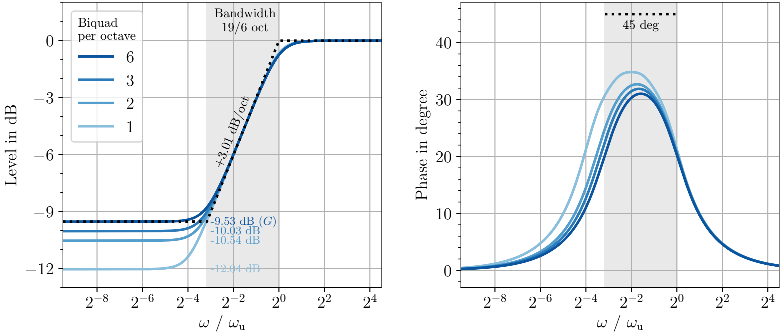


Figure: The resulting shelving level deviates from G for less than $N_O = 6$ biquads per octave. Slope $\chi = 3\,\mathrm{dB/oct}$ and shelving level $G = -\frac{19}{6}\chi \approx -9.5\,\mathrm{dB}$ yields bandwidth $\beta = 19/6\,\mathrm{oct}$.

Constraint: Ripple Along Transition Slope

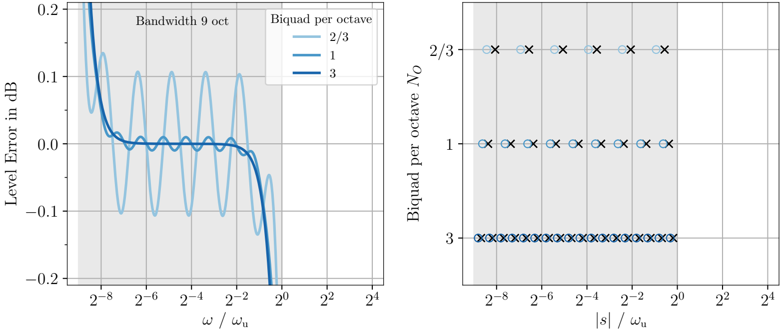


Figure: Left: Deviation $20\,\lg|H(\omega)| - 20\,\lg|H_{\text{ideal slope}}(\omega)|$.
Right: distribution of poles (x) and zeros (o).
$\beta = 9\,\text{oct}$, $G = -10\,\lg(2) \approx -3\,\text{dB}$ yields
$\chi = \frac{10}{9}\,\lg(2) \approx +0.3345\,\text{dB/oct}$.

Discrete-Time Filter Design

Straightforward design with bilinear or matched-z transform of biquads as long as upper cutoff frequency f_u much smaller than sampling frequency f_s.

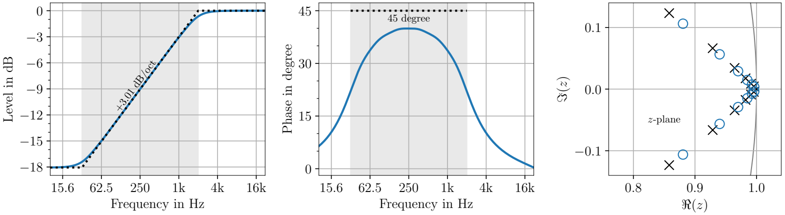
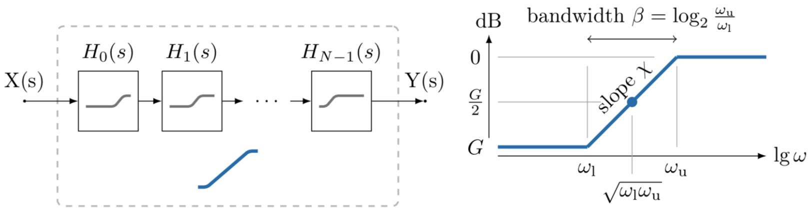


Figure: Digital filter design with bilinear transform, cascade of 6 biquads.
$3\,\mathrm{dB/oct}$ slope over a $6\,\mathrm{oct}$ bandwidth,
$f_\mathrm{u} = 2\mathrm{kHz}$, $f_\mathrm{s} = 48\,\mathrm{kHz}$, $N_O = 1$ biquad per octave.

Summary

- Proposing a shelving filter with adjustable parameters : shelving level G, bandwidth β, slope χ



- Cascade of 2nd order shelving filters, logarithmically spaced along frequency
- Limitations are not severe but design must be carefully adapted to specific target application, i.e. choosing appropriate number of biquads per octave and the total amount of biquads
- Potential applications: line array equalizers, audio mixing and production, sound field synthesis pre-filters, equal loudness contour equalizers