Introduction to Audio and Music Engineering

Lecture 16

Topics:

- Tone and frequency spectra
- Filtering and frequency content of signals
- RC Low-pass and high-pass filters
- RLC Band pass filters
- Filter banks and Graphic Equalizers

Tone?

- The quality or character of sound
- The characteristic quality or timbre of a particular instrument or voice.
- The character or quality of a musical sound or voice as distinct from its pitch and intensity.

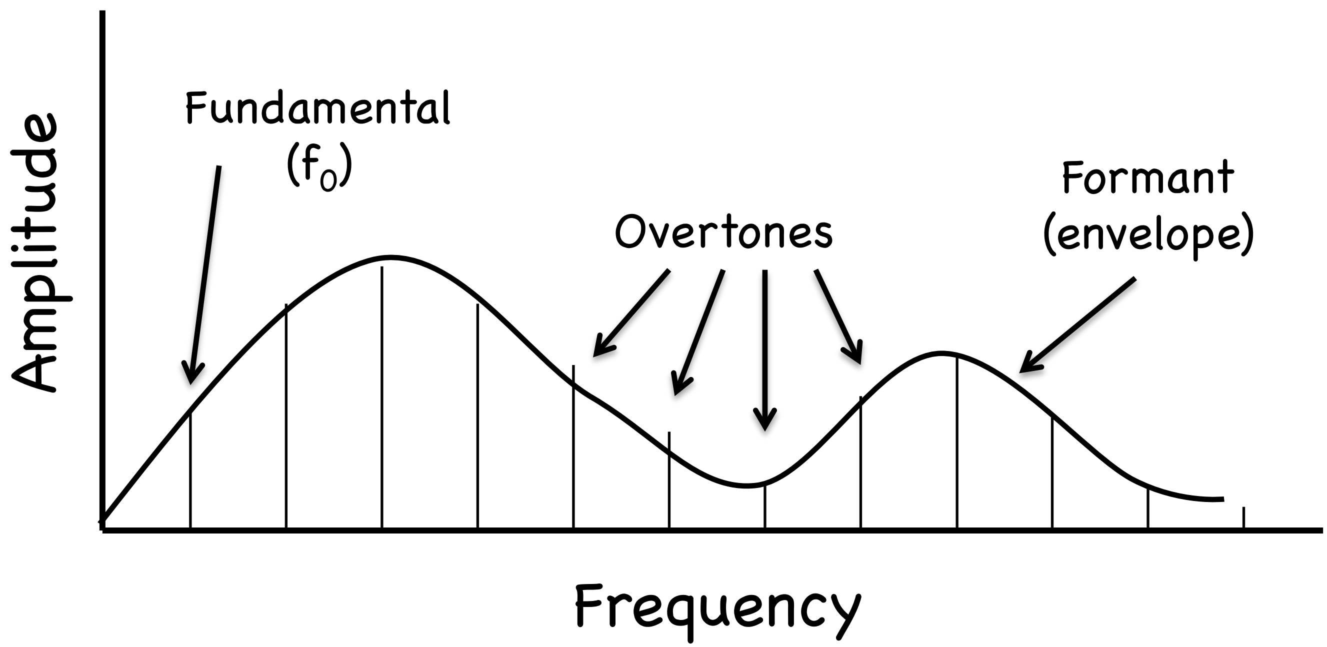
  Frequency → pitch

  Sound pressure level → intensity (loudness)

  Attack, Spectrum, Spectral evolution → tone (timbre)

Tone is related to the spectrum of a waveform.

The spectrum is a display of the frequency content of a waveform.

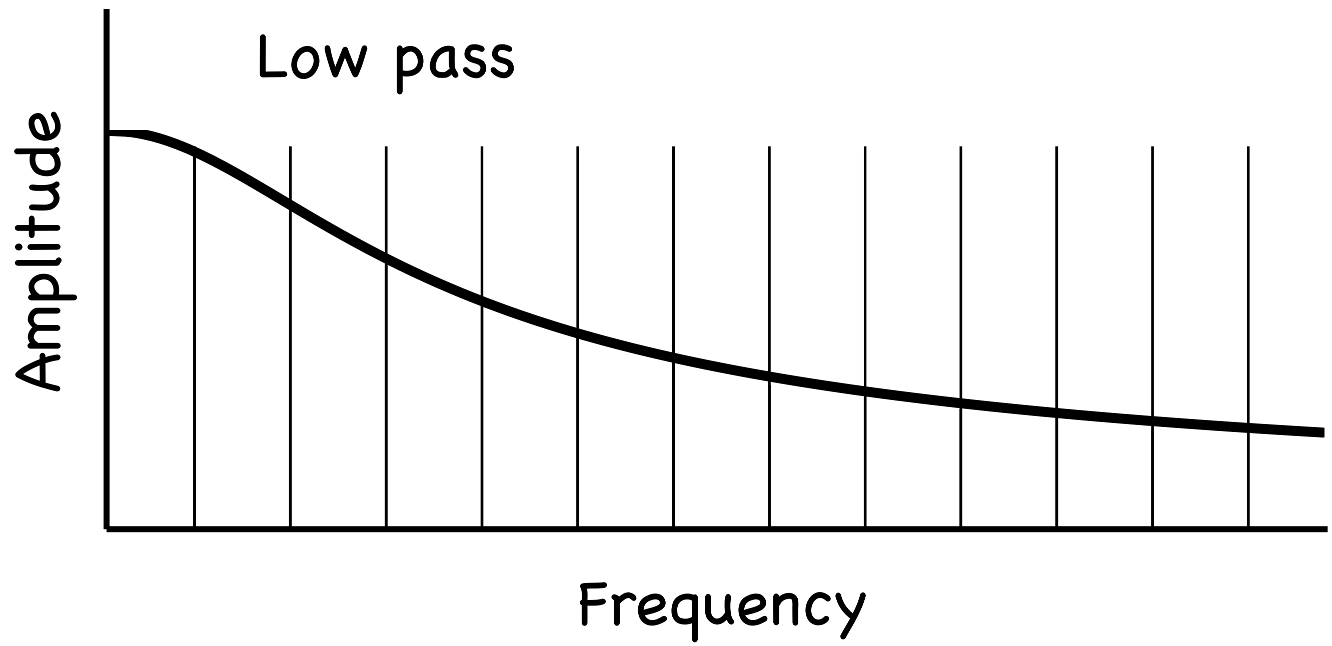


If the overtones are at integer multiples of the fundamental they are called harmonics, e.g., $2f_0 \rightarrow 2^{nd}$ harmonic, etc.

Most musical sounds have harmonic (or nearly so) overtones.

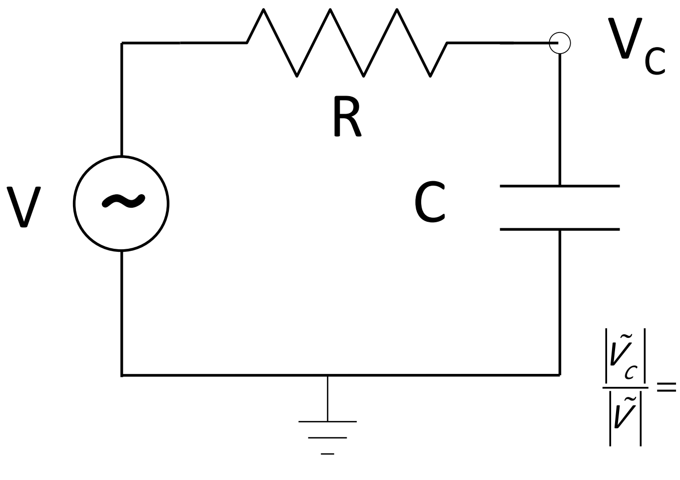
Back to circuits …

Applying a filter to alter tone …

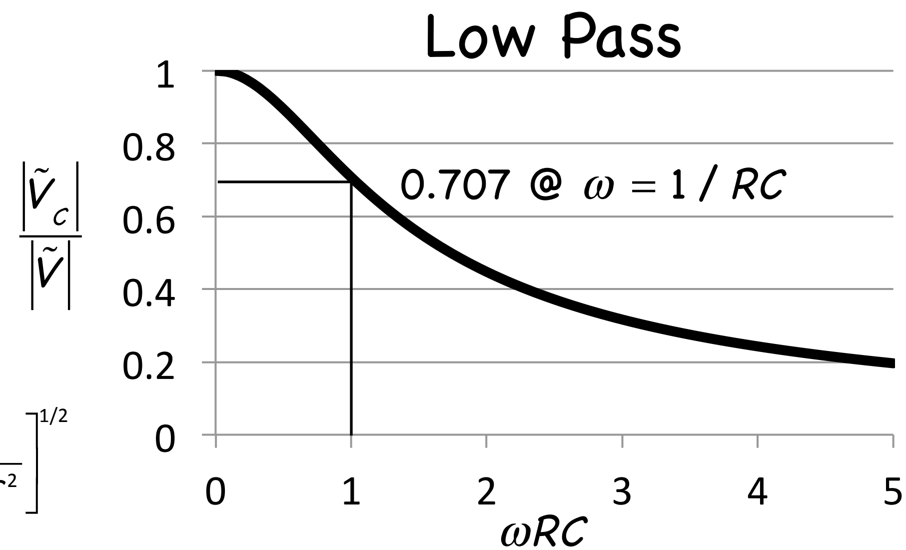


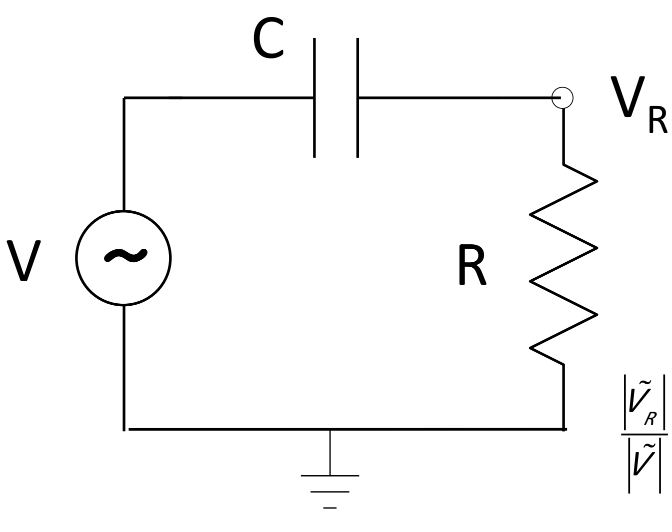
Examples …

1st order RC low-pass and high-pass filters

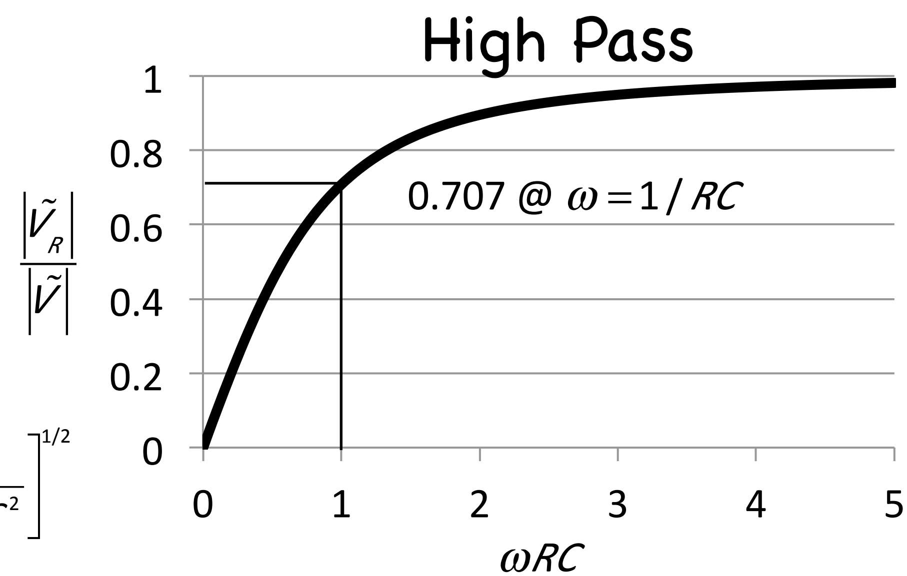


$$\frac{|\tilde{V}_C|}{|\tilde{V}|} = \left[\frac{1}{1+\omega^2 R^2 C^2}\right]^{1/2}$$





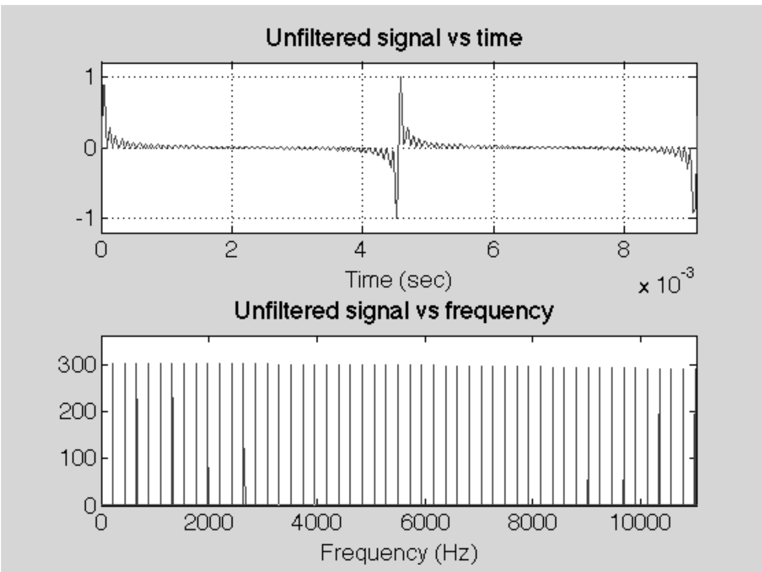
$$\frac{|\tilde{V}_R|}{|\tilde{V}|} = \left[\frac{\omega^2 R^2 C^2}{1+\omega^2 R^2 C^2}\right]^{1/2}$$



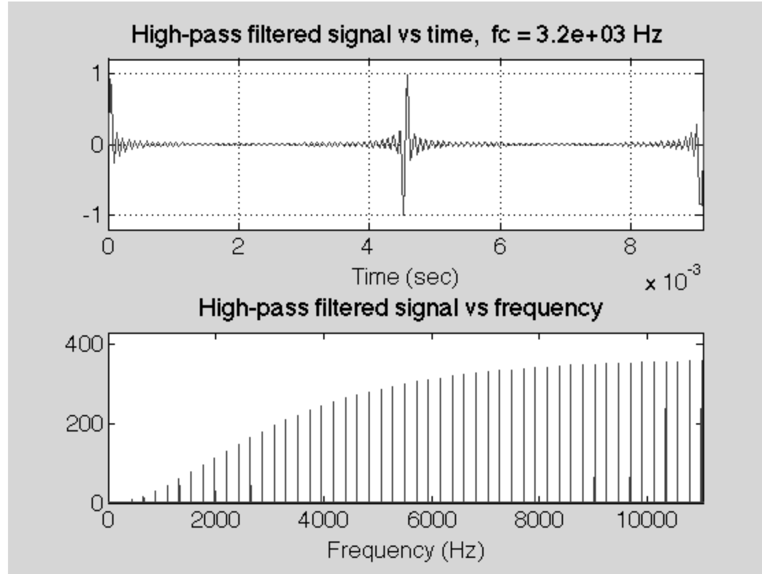
Matlab Simulation

Begin with harmonic overtone series.

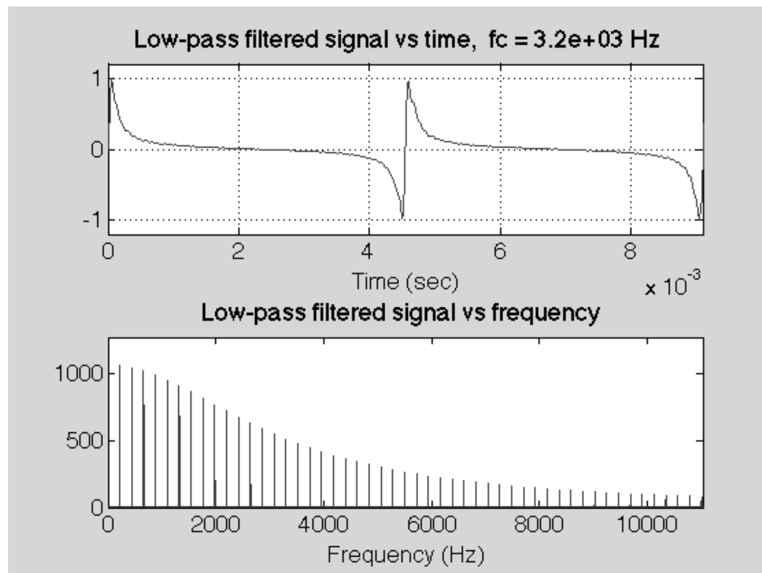
Equal amplitude sine waves
at integer multiples of f_0



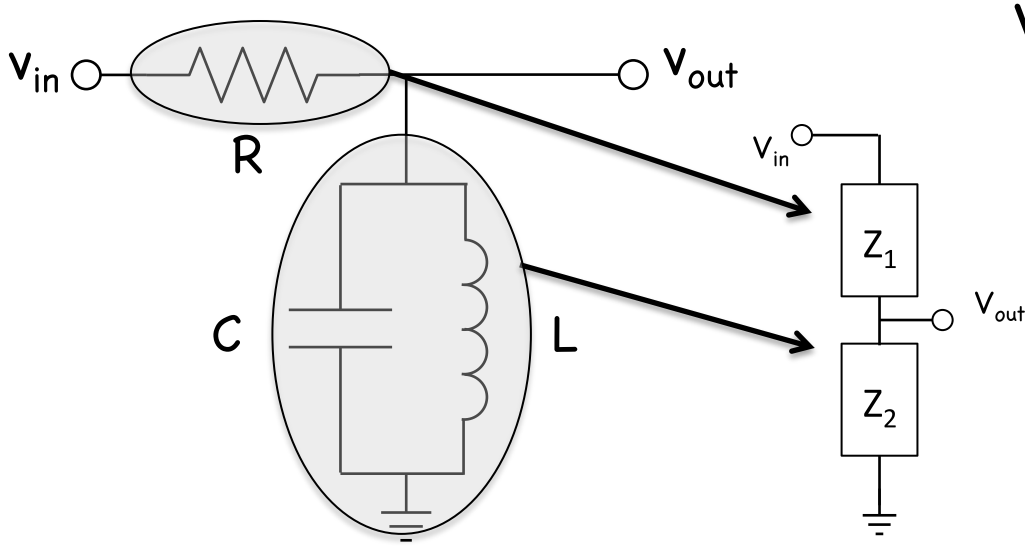
High Pass



Low Pass



Band Pass Filters

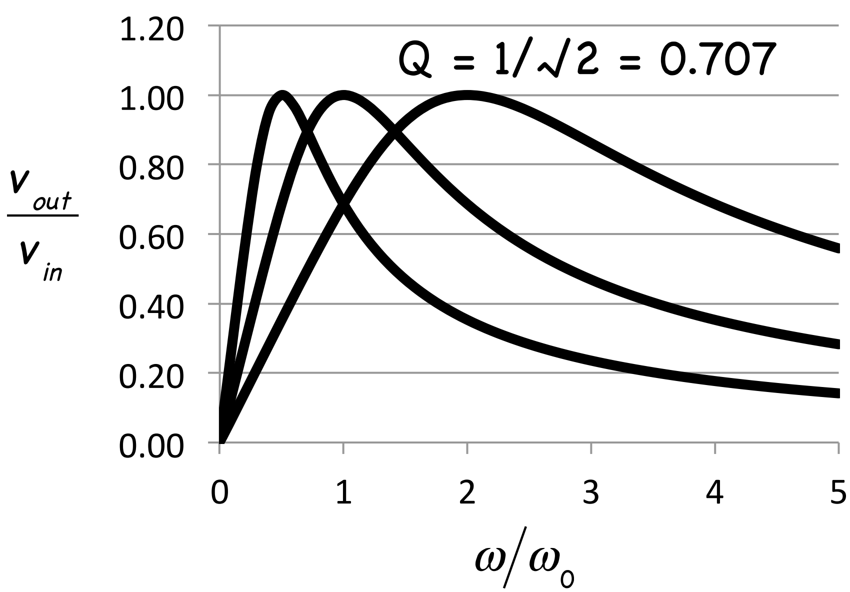


Voltage divider: R & L//C

$$v_{out} = v_{in}\frac{Z_2}{Z_1 + Z_2}$$

$$L//C = \frac{j\omega L \cdot \frac{1}{j\omega C}}{j\omega L + \frac{1}{j\omega C}} = \frac{j\omega L}{1-\omega^2 LC}$$

$$v_{out} = v_{in}\frac{\frac{j\omega L}{1-\omega^2 LC}}{R + \frac{j\omega L}{1-\omega^2 LC}}$$



$$v_{out} = v_{in}\frac{\frac{\omega}{\omega_0}Q}{\left[\left(1-\frac{\omega^2}{\omega_0^2}\right)^2 + \frac{\omega^2}{\omega_0^2}Q^2\right]^{1/2}}$$

$$\omega_0 = \frac{1}{(LC)^{1/2}}$$

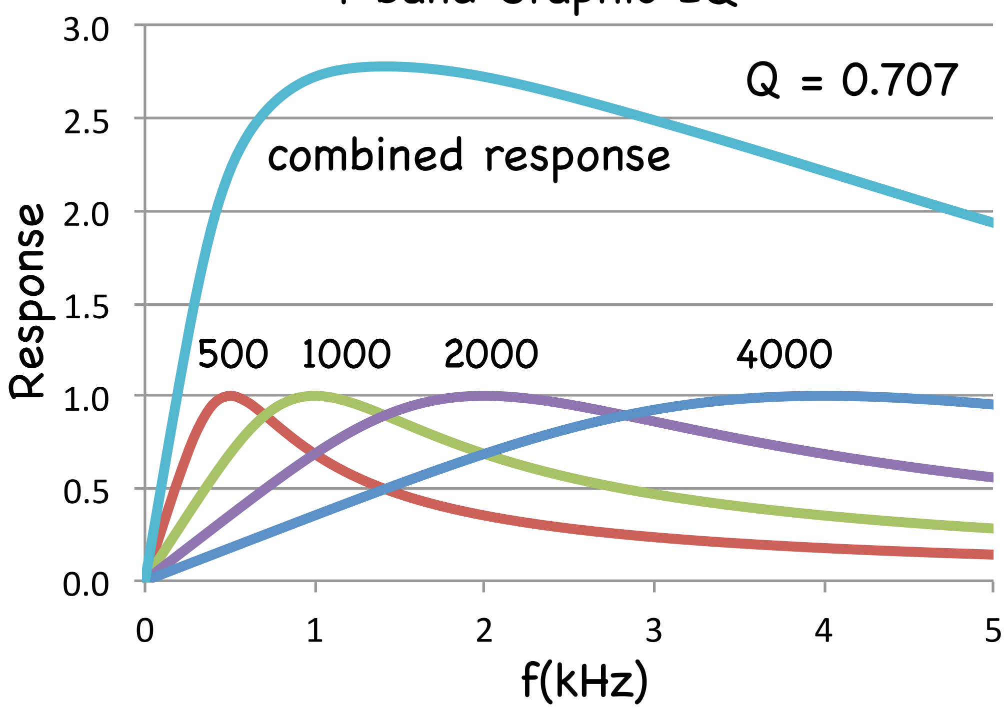
$$Q = \frac{\omega_0 L}{R}$$

Graphic Equalizer

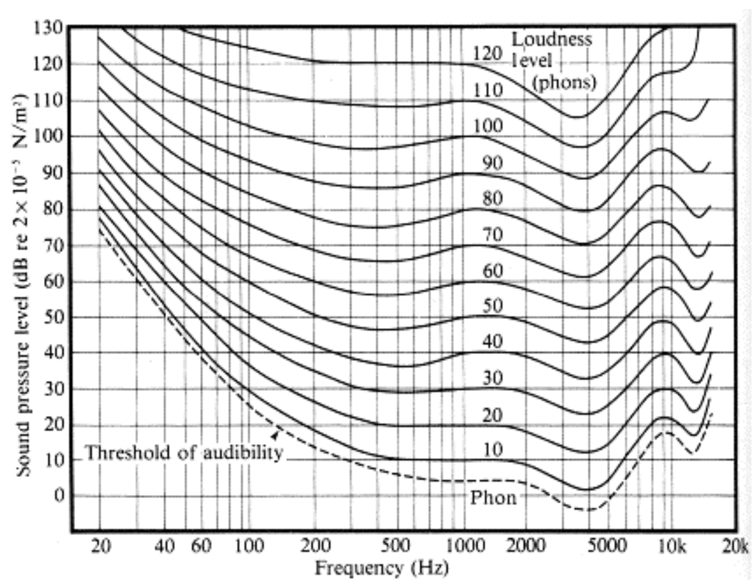
Bank of bandpass filters …

$Q = 1/\sqrt{2} = 0.707$ → Butterworth Bandpass (2nd order)

4-band Graphic EQ



Fletcher Munson – hearing response



It's OK if the filter response decreases a bit (≈ -3 dB) at high frequencies because human hearing sensitivity increases (≈ +20 dB).

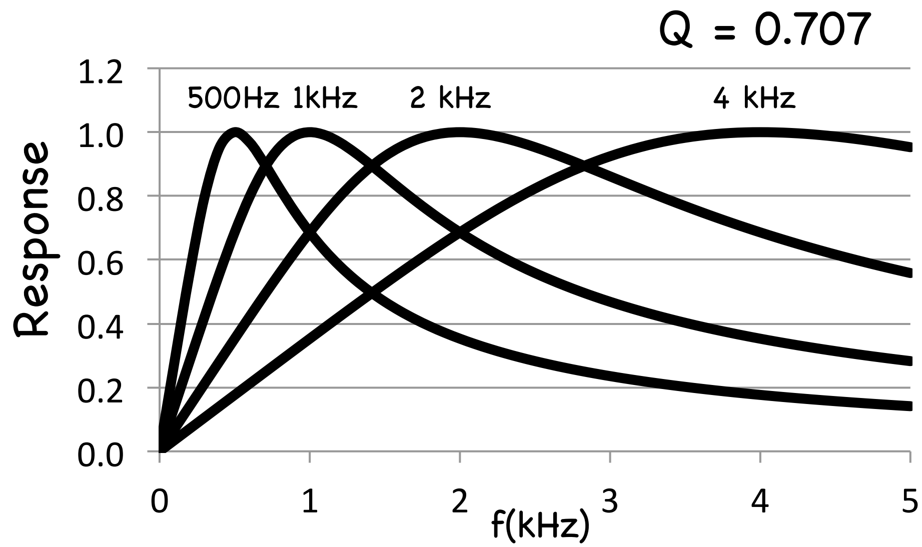
Octave filters (Constant "Q")

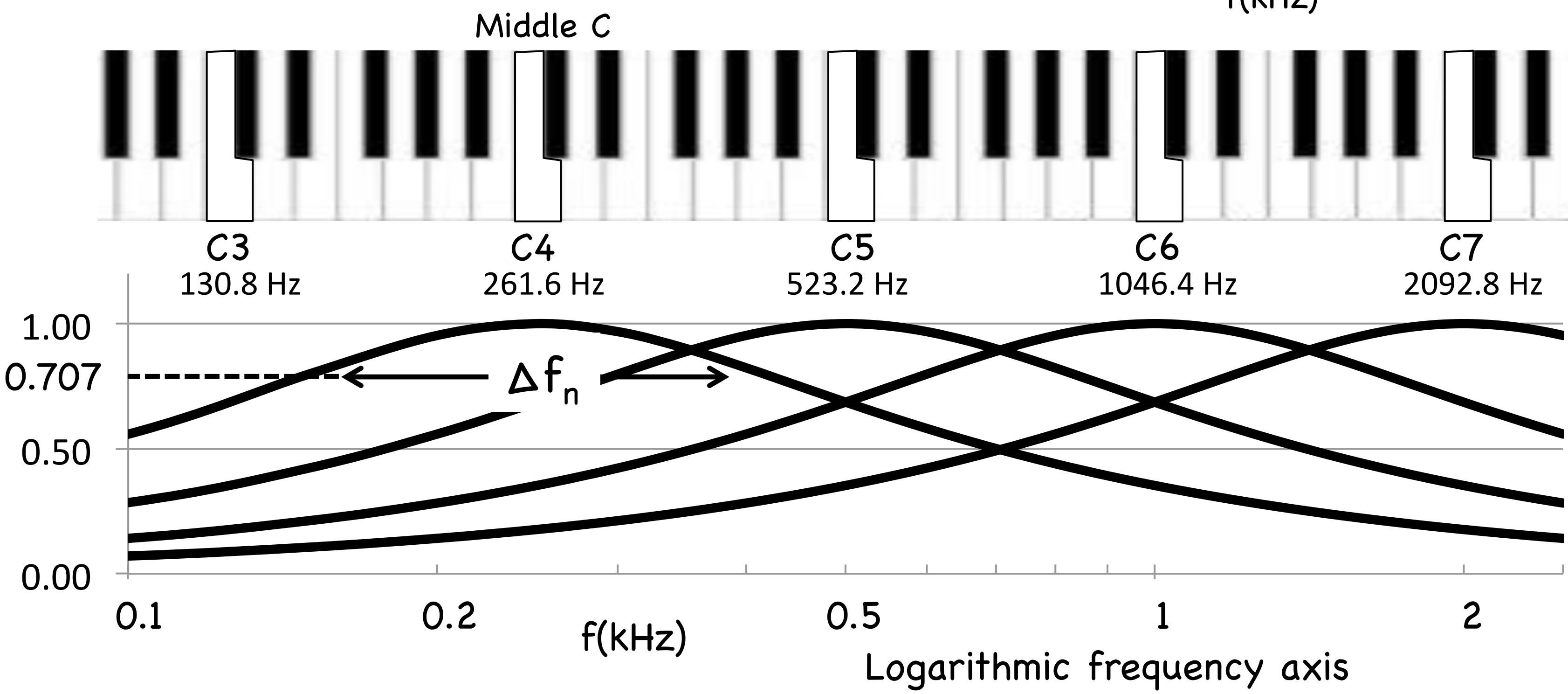
Center frequencies increase by octaves (x2):

$$f_{n+1} = 2f_n$$

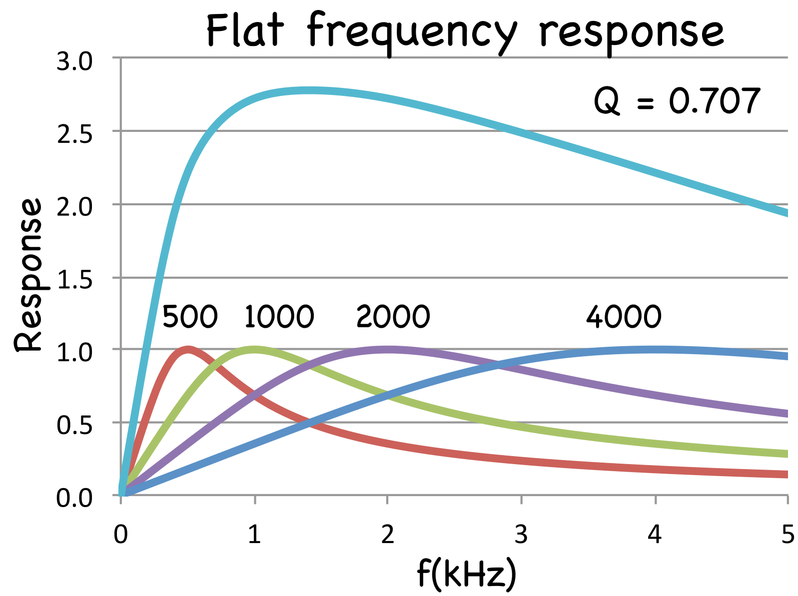
Fractional bandwidth is fixed:

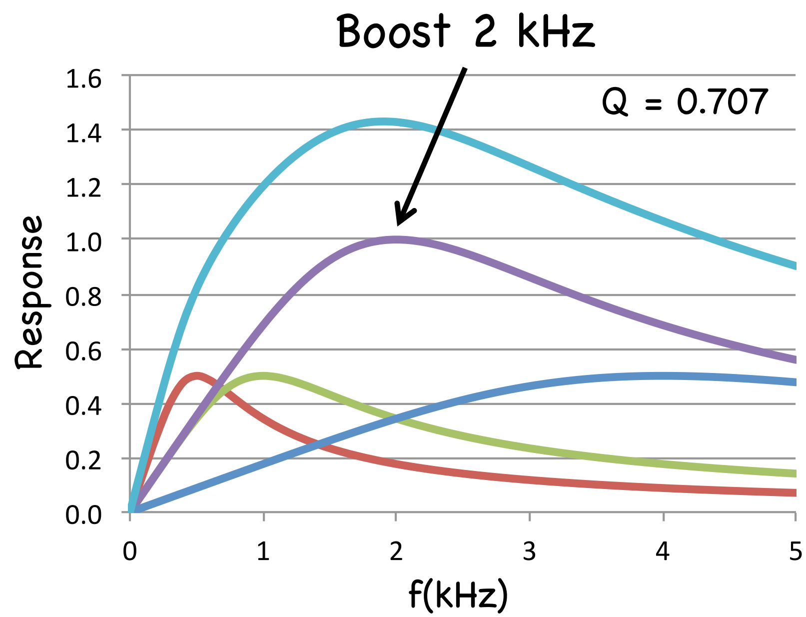
$$\Delta f_n / f_n = Q^{-1}$$



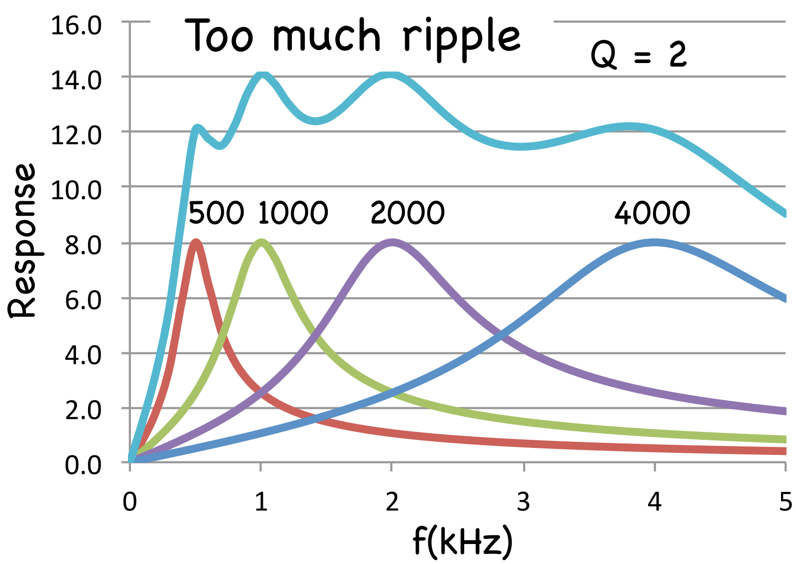


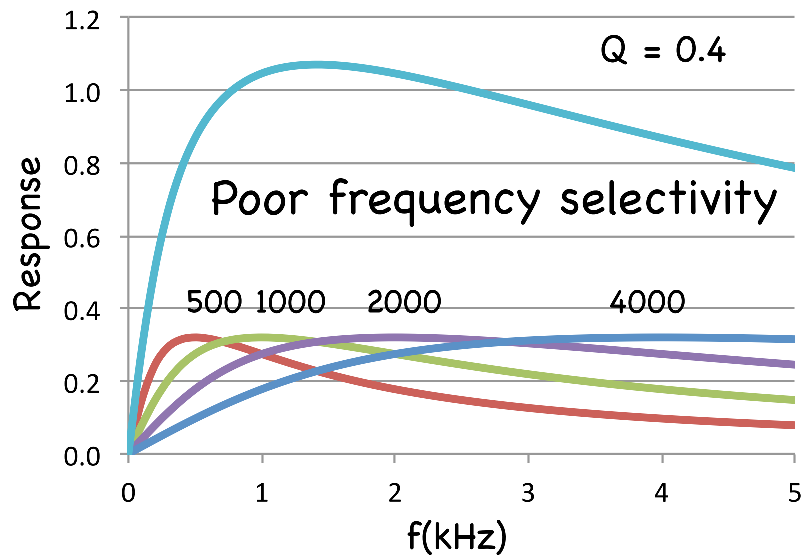
Filter Performance ...





Tradeoff between ripple and frequency selectivity ...





10-Band Graphic EQ Demonstration
using Matlab/Simulink

fc = [31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 16000] Hz