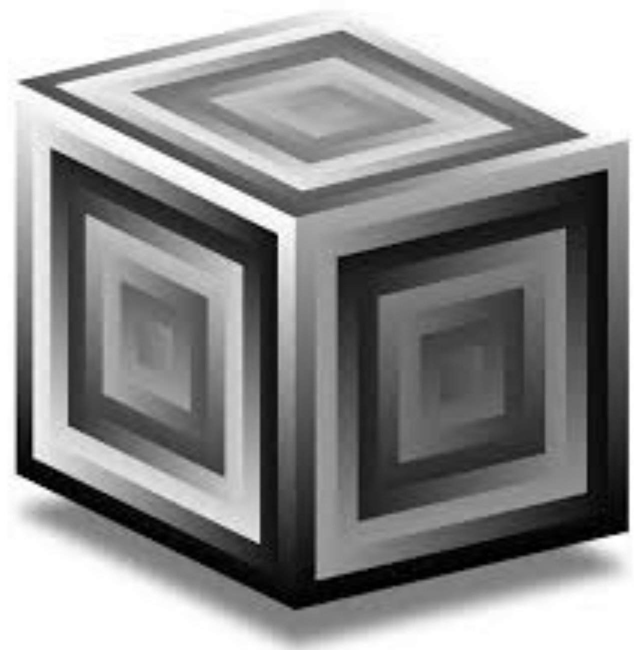
Filters

Topics Addressed

- Magnitude/Phase Response
- One Sample Delay Analysis
- Low Pass Filters
- High Pass Filters
- Band Pass Filters
- Band Stop/Reject filters



Filters

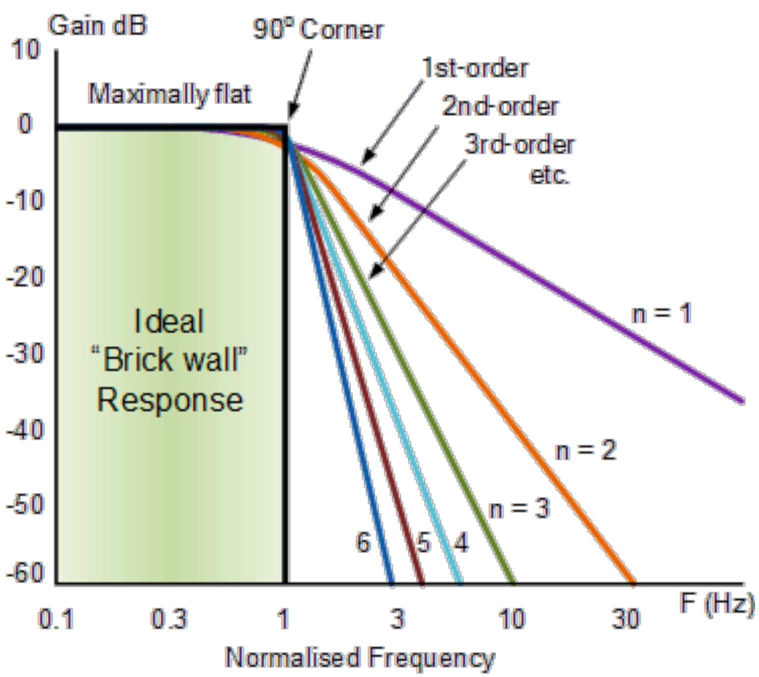
- As stated in the slides on delay, filters are any systems which boost/attenuate frequencies or changes phases in a signal. The general effect is called the frequency response and has two components:
  - Amplitude response – a mathematical expression of the **ratio** of the boost/attenuation of a signal's amplitude as a function of frequency. This is sometimes called the magnitude response.
  - Phase response – a mathematical expression of the phase delay as a function of frequency.
- Types of filters
  - High pass – attenuates low frequencies
  - Low pass – attenuates high frequencies
  - Band pass – passes frequencies between a certain range and attenuates others
  - Band reject – attenuates frequencies between a certain range and passes others
  - Allpass – passes all frequencies but affects the phase of different frequencies

Low Pass Filters

- Low-pass filters remove high frequency components and allow low frequencies to pass.
  - We have already seen a use for low-pass filters in the analog-to-digital conversion that takes place when audio is recorded into a computer. Low pass filters remove higher frequencies that could produce aliasing.
  - Low-pass filters are standard in the use of audio production. One common use is to remove high frequencies that can result from reverb. Other examples might include emphasizing bass in a mixdown of a song.
- In an ideal world, a filter would simply remove frequencies above a certain cutoff frequency, leaving the rest to pass. This is called the “brick wall” response, and in reality, it is not possible.
  - We saw in our one-sample delay that this was not possible, and that the amplitude response was a smooth curve.

Frequency Response of A Low-Pass Filter

The following picture is the frequency response of a Butterworth low-pass filter

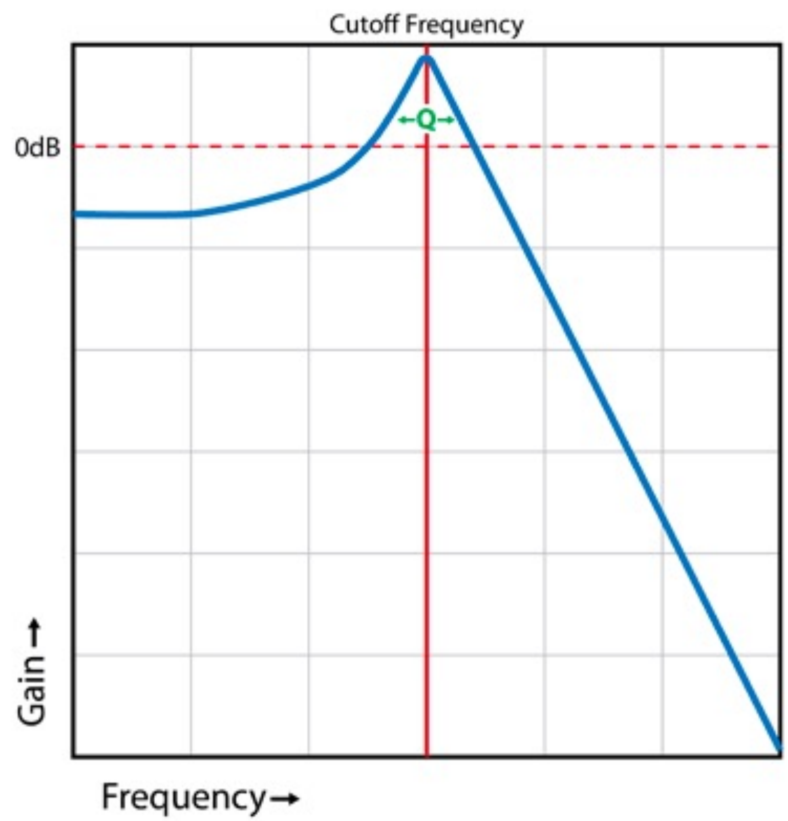


- The order of a filter determines the steepness of the slope of the cutoff.
- SuperCollider provides a second-order Butterworth low-pass filter called LPF
- A Butterworth filter is distinguished by its difference equation. There are many types of difference equations to produce low-pass filters. Butterworth LPFs are often used.
- The amplitude ratio here is measured in decibels.
  - In decibels, the ratio is computed on a logarithmic scale
- The cutoff frequency is the frequency at which the filter has an amplitude ratio of -3db.

Decibels

- **Decibels** are a unit of measure for measuring the ratio of amplitudes but on a logarithmic scale.
- The formula for calculating decibels is $d = 20\log_{10}(\frac{a}{a_0})$ where a is the amplitude of some signal relative to some baseline amplitude a_0.
  - In audio, a_0 is usually 1 and the measurement of our output signal will be some decibel value <= 0. This can simplify our equation to $d = 20\log_{10}(a)$
  - Alternatively, given some decibel value, we can determine the amplitude of our signal with $a = 10^{d/20}$
- 3db (shorthand for decibel) is often what we perceive as one "step" of loudness. Doubling the amplitude corresponds to about 6dB change.
- See the Wikipedia article [here](#) for a nice chart of decibels versus amplitude

Resonant Low-Pass Filters

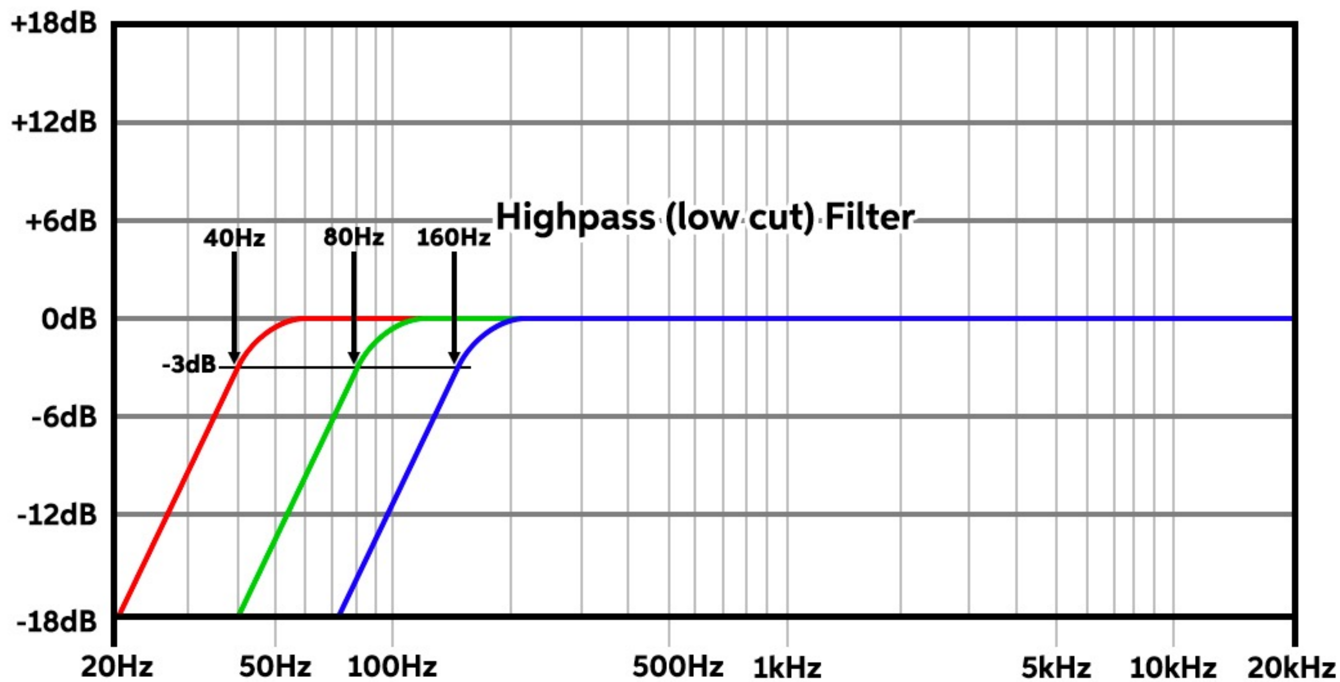


A resonant low-pass filter amplifies the frequencies around the cutoff frequency. The strength of the "hump" at the cutoff frequency is controlled by a parameter called Q. As Q gets higher, the peak becomes thinner (i.e., more pointed) and the gain becomes higher. A lower value for Q creates a broader, less pronounced peak.

Low Pass Filters in SC

- There are numerous filters available to you in SuperCollider. We will focus on two but you should experiment with the others.
- You can use a low-pass filter UGen called LPF which takes a frequency parameter called freq which is the cutoff frequency.
  - The UGen LPF is a second-order butterworth filter.
  - See the lecture code for a way to use a low-pass filter to make a digital representation of waves with a low-pass filter
- For a resonant filter, you can use RLPF which takes a frequency parameter for the cutoff frequency.
  - The Q parameter is actually called rq which is the inverse of Q.
  - See the lecture code to see how a high Q can actually filter out noise to produce pitch.
  - Remember that a higher Q produces resonance at the cutoff frequency.

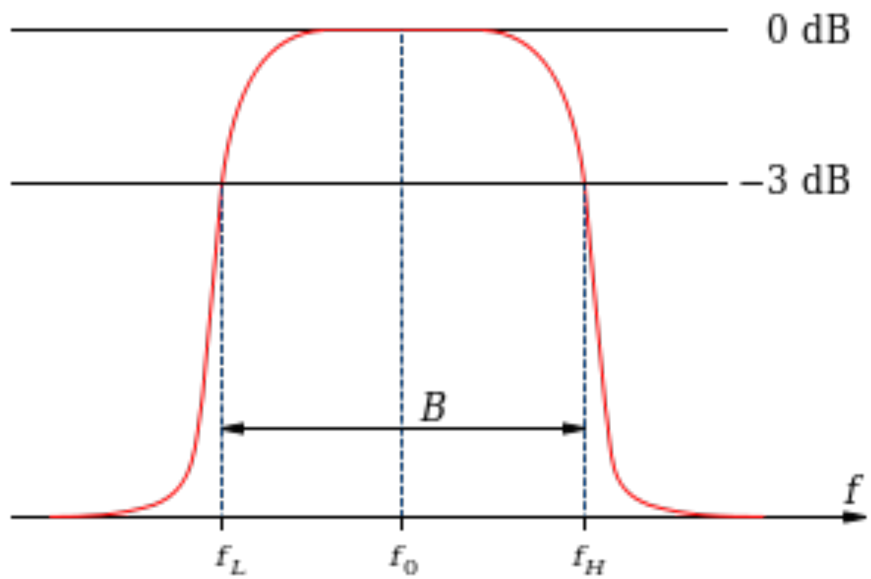
High-pass Filters



High-pass Filters in SC

- A high-pass Butterworth filter is a standard high-pass filter in digital audio.
  - The UGen HPF is a second-order high-pass Butterworth filter
- A high-pass resonant filter is the high-pass equivalent of a resonant low-pass filter
  - The UGen RHPF is a high-pass resonant filter
  - Like RLPF, RHPF uses the reciprocal of Q as its argument to control resonance.
- Other high-pass filters in SuperCollider
  - BHiPass
  - BHiPass4

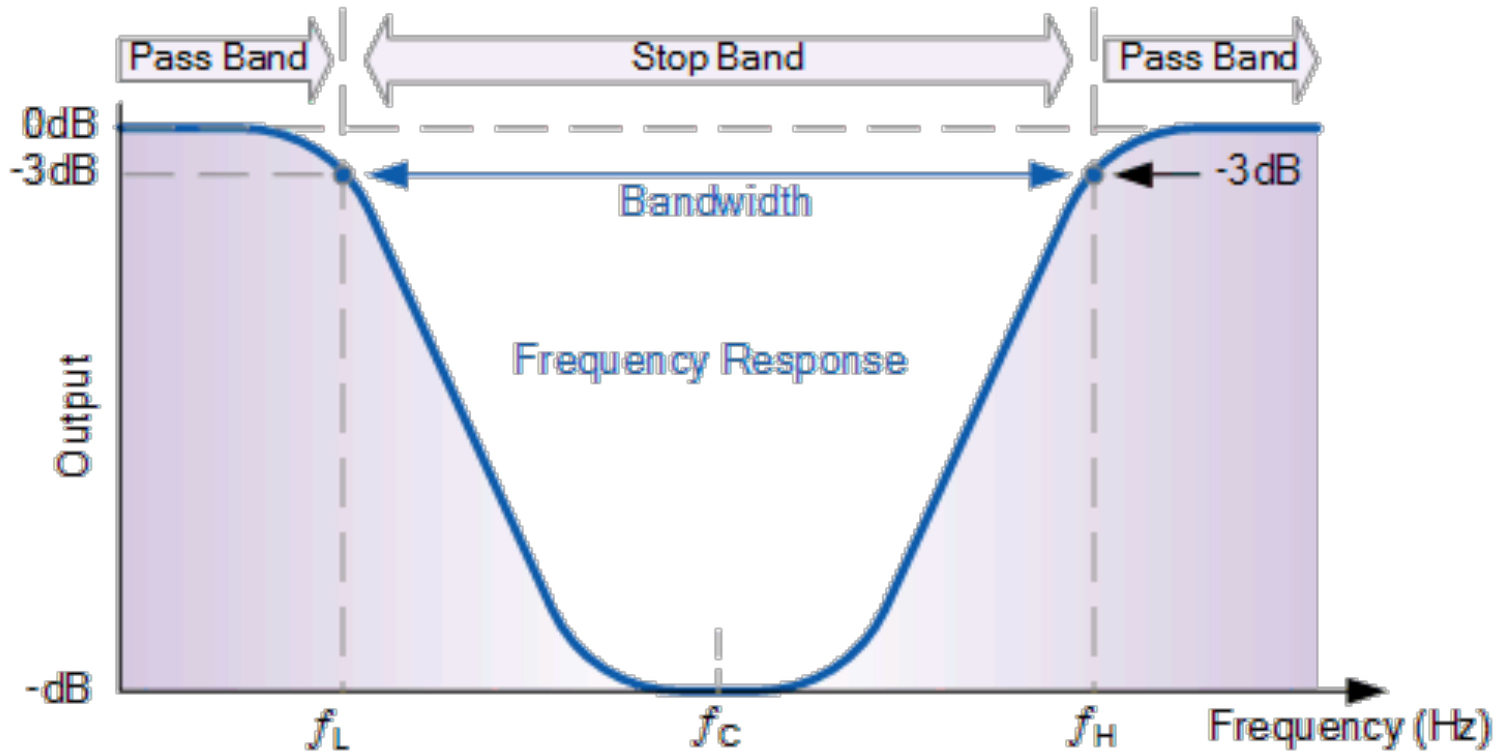
Bandpass Filters



Bandpass Filters

- Bandpass filters are defined by some center frequency (notated as f_0 on the previous slide) and a lower and higher frequency each positioned at -3db.
  - The lower and higher frequencies are symmetric about a **logarithmic** scale of frequency.
  - The span from f_h to f_L is called the passband (not to be confused with bandpass) and passes all the frequencies within the range while rejecting those outside the range. The passband is notated as *B* on the previous slide.
- The parameter Q controls the width of the passband about the center frequency.
  - We can define Q as such: $Q = \frac{center\ frequency}{bandwidth} = \frac{f_0}{f_h - f_l}$
- The UGen BPF is a bandpass filter with a reciprocal Q as a control for the width of the bandpass filter.

Bandstop Filters



Note that frequency is on a logarithmic scale and hence symmetric.

Bandstop Filters

- Also sometimes called band-reject filters
- Band-stop filters are defined by some center frequency (notated as f_c on the previous slide) and a lower and higher frequency each positioned at -3db.
  - The lower and higher frequencies are symmetric about a **logarithmic** scale of frequency.
  - The span from f_h to f_L is called the stopband and rejects all the frequencies within the range while passing those outside the range.
- The parameter Q controls the width of the stopband about the center frequency.
  - We can define Q as such: $Q = \frac{center\ frequency}{bandwidth} = \frac{f_0}{f_h - f_l}$
- The UGen BRF is a band-reject filter with a reciprocal Q as a control for the width of the bandstop filter.