



Audio processing

# Analog vs. digital

- Analog audio processing
  - Continuous signal – electrical current or voltage
  - Processing done via electrical components
- Digital signal processing
  - Sampled signal
  - Processing done on general purpose computers
  - More powerful and efficient

# Audio filter

- Analog audio filter
  - Medium that trasmits and modifies audio signal
  - Electronic components
  - Speakers – cannot cover entire spectrum
  - Mouth cavity – changing shape
- Digital audio filter
  - Algorithm that operates on digital signals
  - Approximation of analog filters
  - Better SNR



# Filter taxonomy

- Linear filters / Non-linear filters
  - Is the output result of a linear difference equation?
  - Non-linear filters create additional frequency components, not present in the original signal
- Causal / Non-causal
  - Is the output result only of past values?
- Time-invariant / Time-variant
  - Is the output the same if we send it to the filter a bit later?

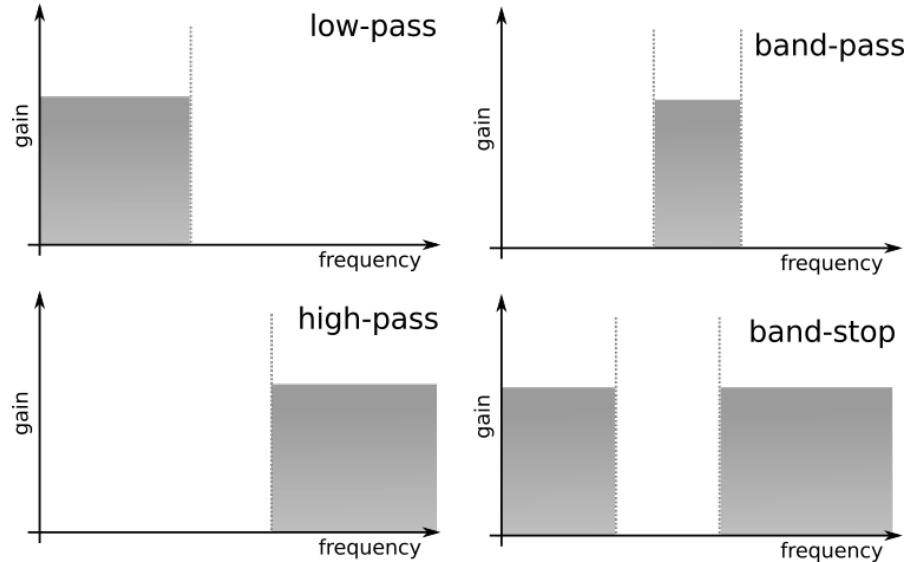
# Linear filters

$$\underbrace{y(n)}_{\text{Output}} = \underbrace{b_0x(n) + b_1x(n-1) + b_2x(n-2) + \dots}_{\text{Input}} - \underbrace{a_1y(n-1) - a_2y(n-2) - \dots}_{\text{Past output}}$$

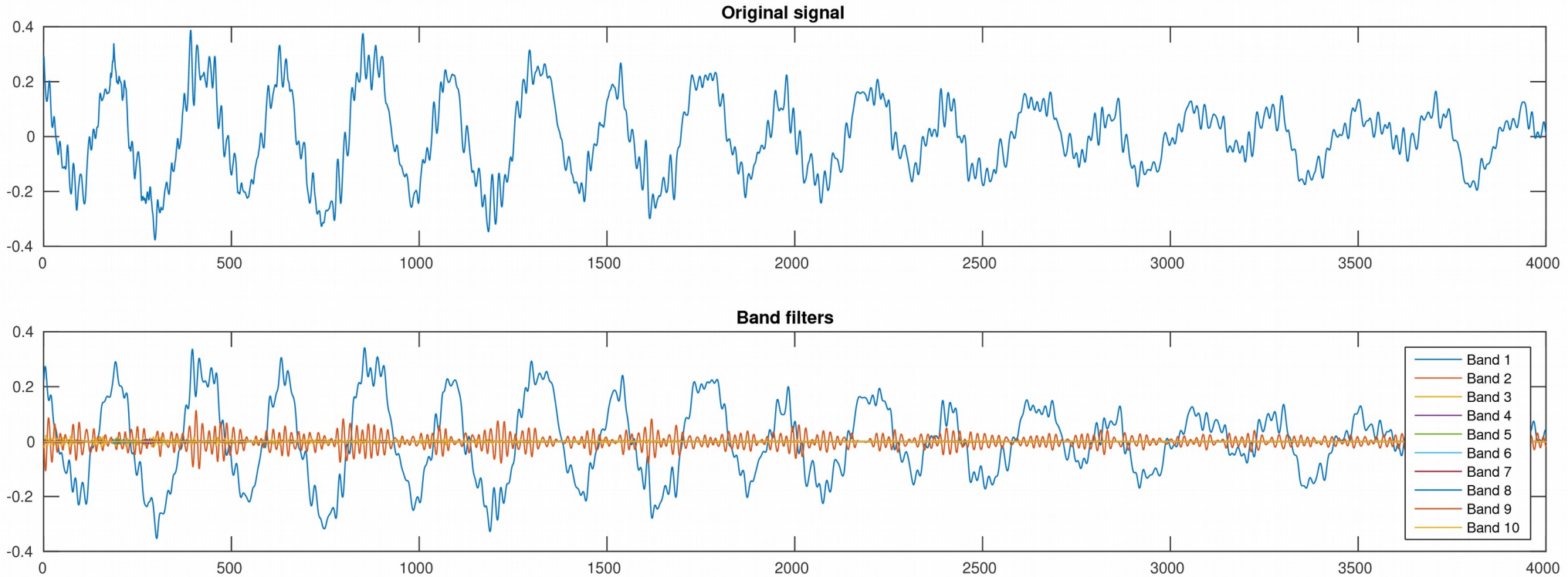
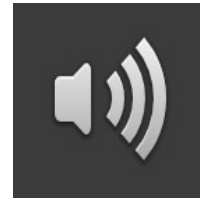
- Non-recursive filters (FIR):  $a_n = 0; \forall n > 1$ 
  - Finite response
- Recursive filters (IIR)
  - Potentially infinite response
  - Implementations more compact

# Frequency filtering

- Pass only frequencies in range
  - Low-pass
  - High-pass
  - Band-pass
  - Band-stop
- Implementations
  - Butterworth
  - Chebyshev
  - Elliptic

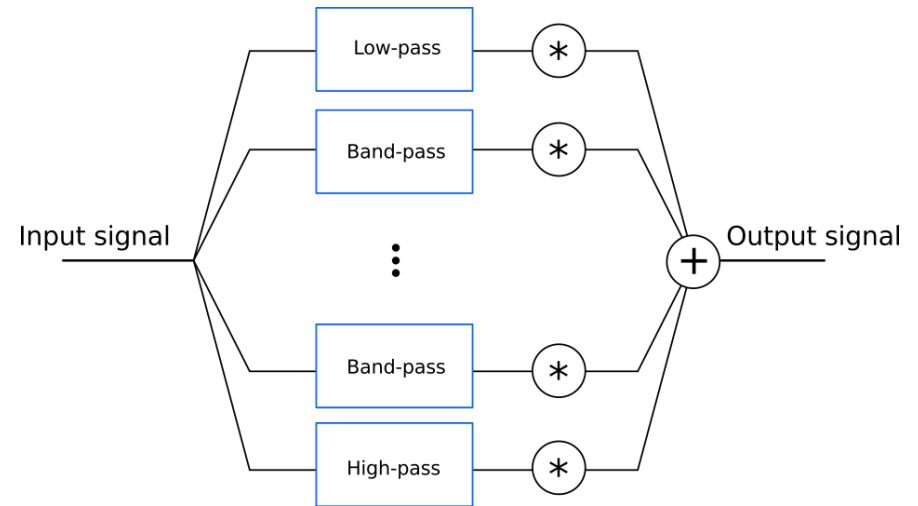
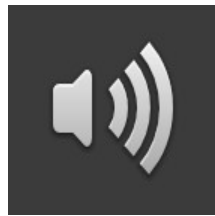


# Splitting frequency bands



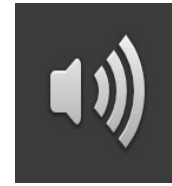
# Audio equalization

- Multi-band signal can be combined back
  - Split signal into multiple bands
  - Weight individual bands
  - Combine signal again

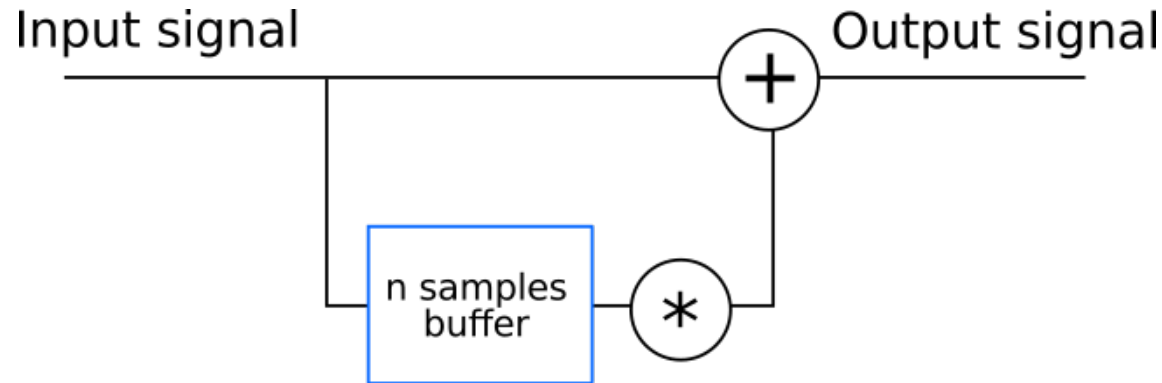




# Delay

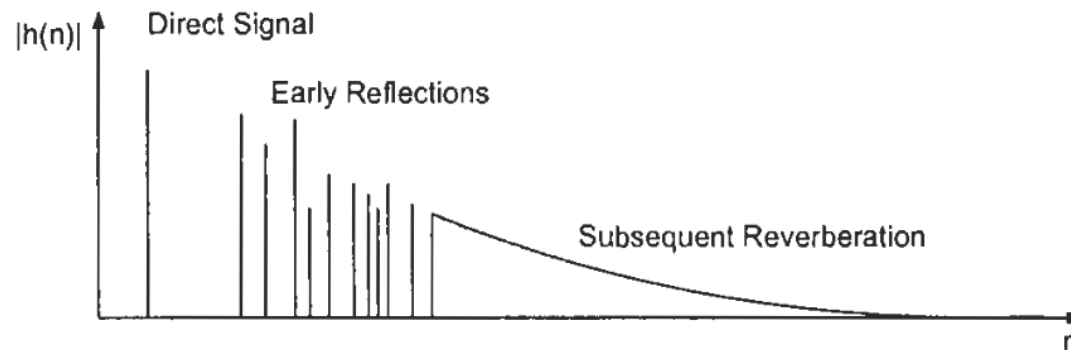


- A time-shifted signal is added to the original
- Delay below 100ms is not perceived as delay

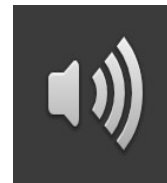


# Echo

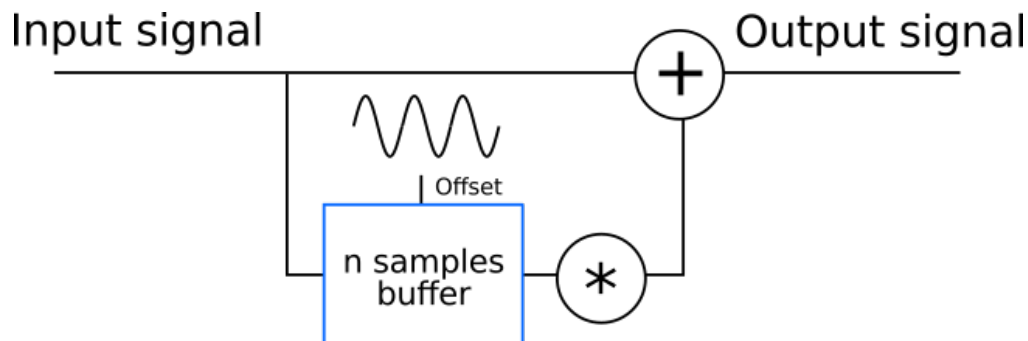
- Echo filter – simulate acoustics of a room
  - Multiple decaying delays – early reflections
  - Subsequent reverberation – random signal



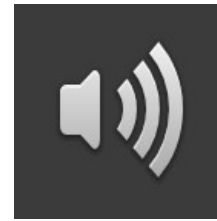
# Flanger



- Delay varies with low frequency
- Non-linear filter



# Distortion



- Overdriven guitar effect
- Clipping of high energy frequencies
  - Soft clipping
  - Hard clipping
- Non-linear filter
  - New frequencies in the signal

$$y(n) = \frac{(1 + k)x(n)}{1 + k|x(n)|}$$

