Analog Processing

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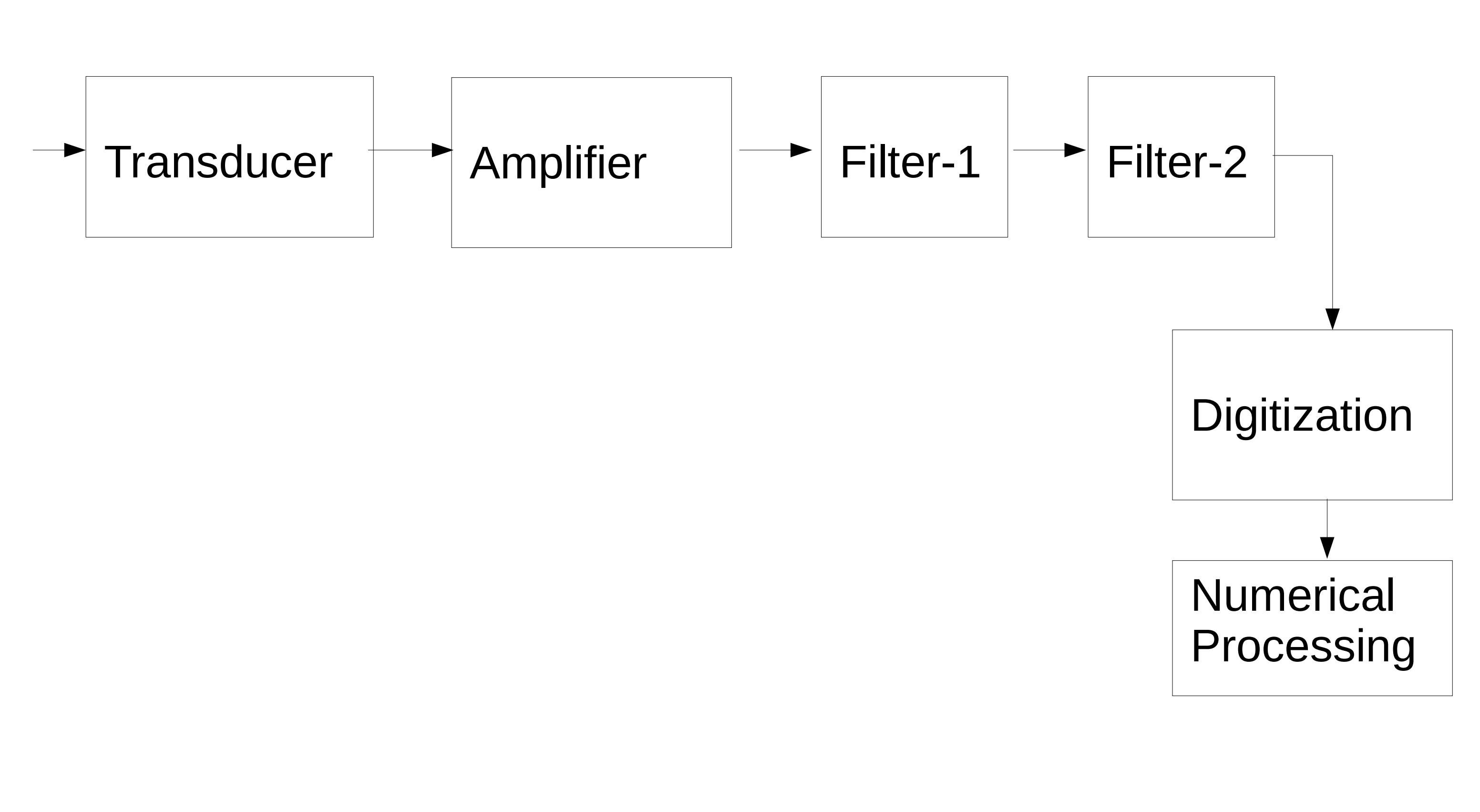
Lecture - Outline

- Amplifiers
- Frequency filtering
- Filter Characteristics – Gain and Phase
- Phase Distortion in Biological Signals
- Offline Filtering

Measurement schematic



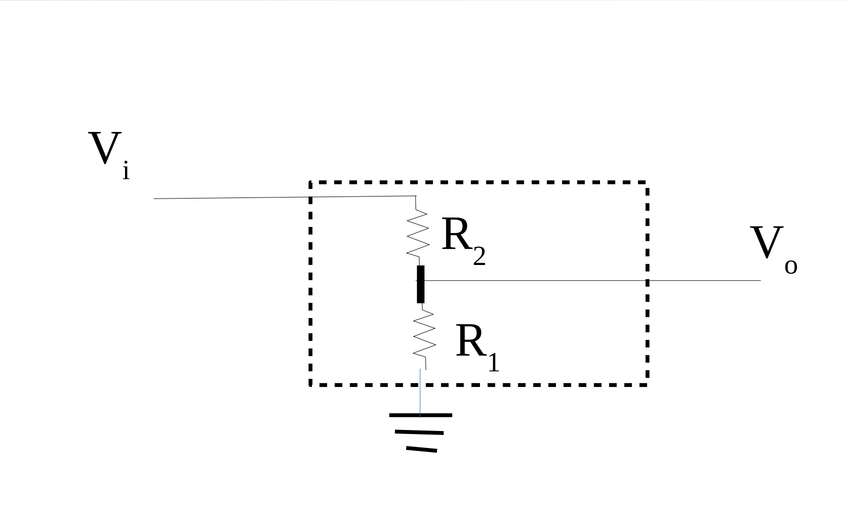
Considerations in Designing Sub-systems (i.e.,Transducers, Amplifiers, Filters)

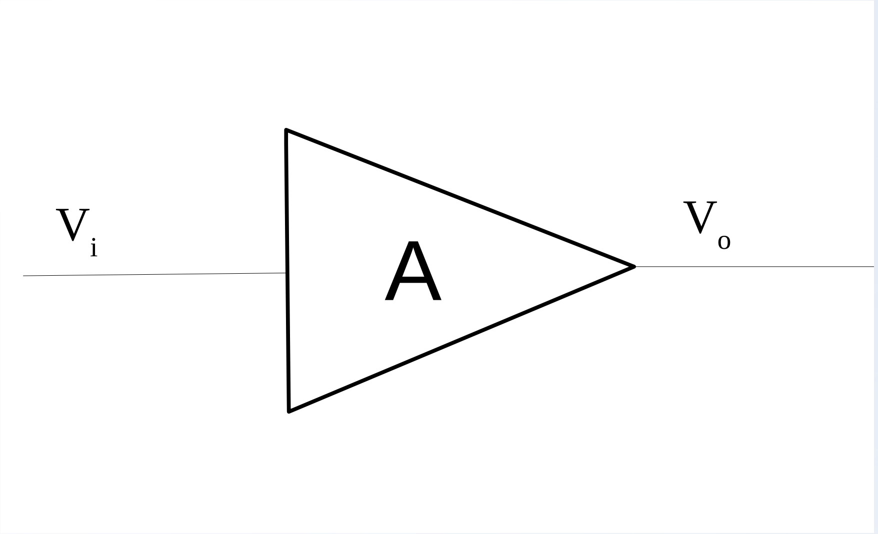
- The subsystem must draw very little power from the preceding subsystem
  - In the case of voltage signals, the subsystem must draw as little current as possible
  - This means the input impedance must be very high
- The subsystem must be capable of delivering as much power as the following or next subsystem requires
  - In the case of voltage signals, the subsystem must be able to deliver as much current as required
  - This means the output impedance must be very small

Thevenin and Norton equivalent for any voltage or current source

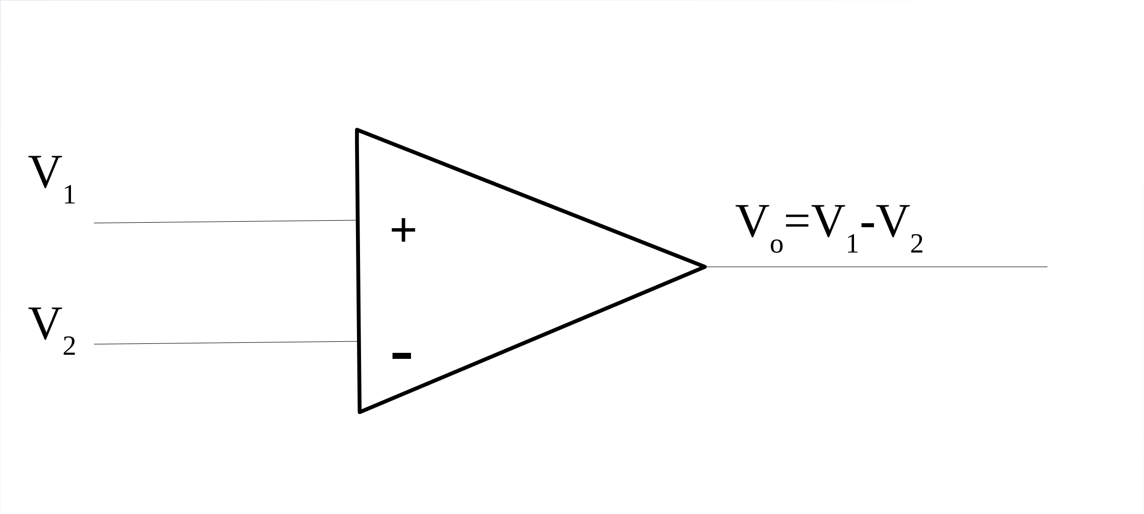
- Any voltage or current source can be represented by:
  - A perfect voltage source with a series impedance
    - (Thevenin equivalent)
  - A perfect current source with a shunt impedance
    - (Norton equivalent)

Attenuators and Amplifiers





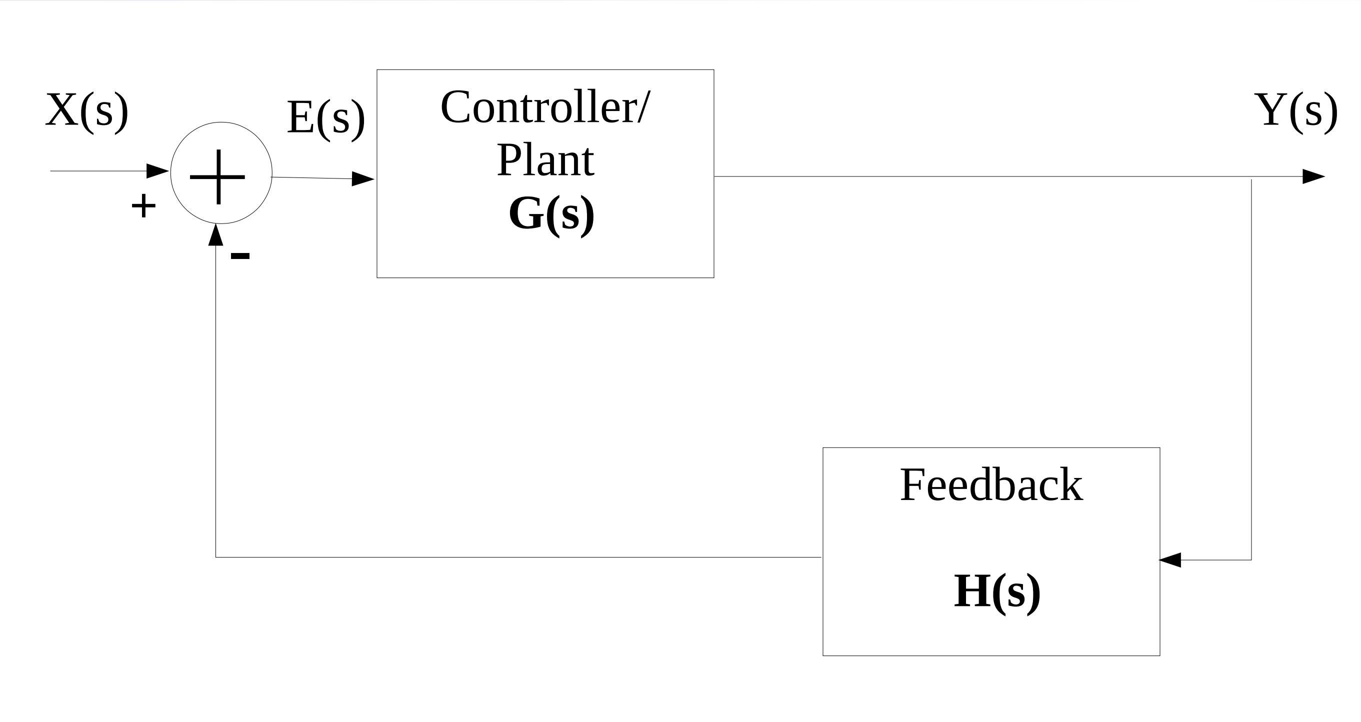
Difference or Differential Amplifier



Operational Amplifiers

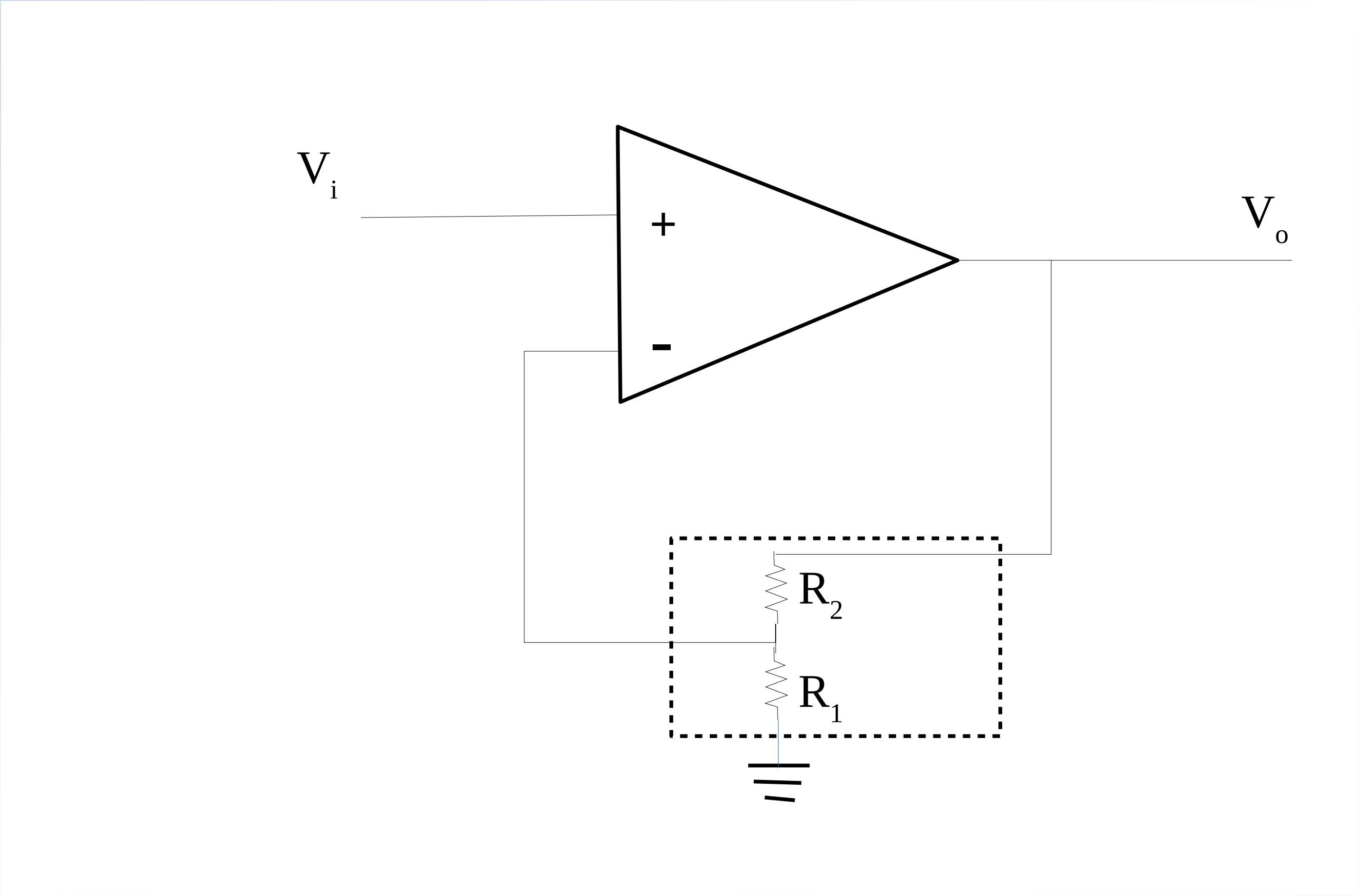
- Amplifier with differential inputs suitable for feedback circuits
- Very high gain
- Very high input impedance
- Low output impedance

Feedback Control System



$$\frac{Y(s)}{X(s)} = \frac{G(s)}{1+G(s)H(s)}$$

Basic Amplifier with Adjustable Gain



$$\frac{V_o}{V_i} = \frac{A}{1 + A\,.\,R_1/(R_1+R_2)}$$

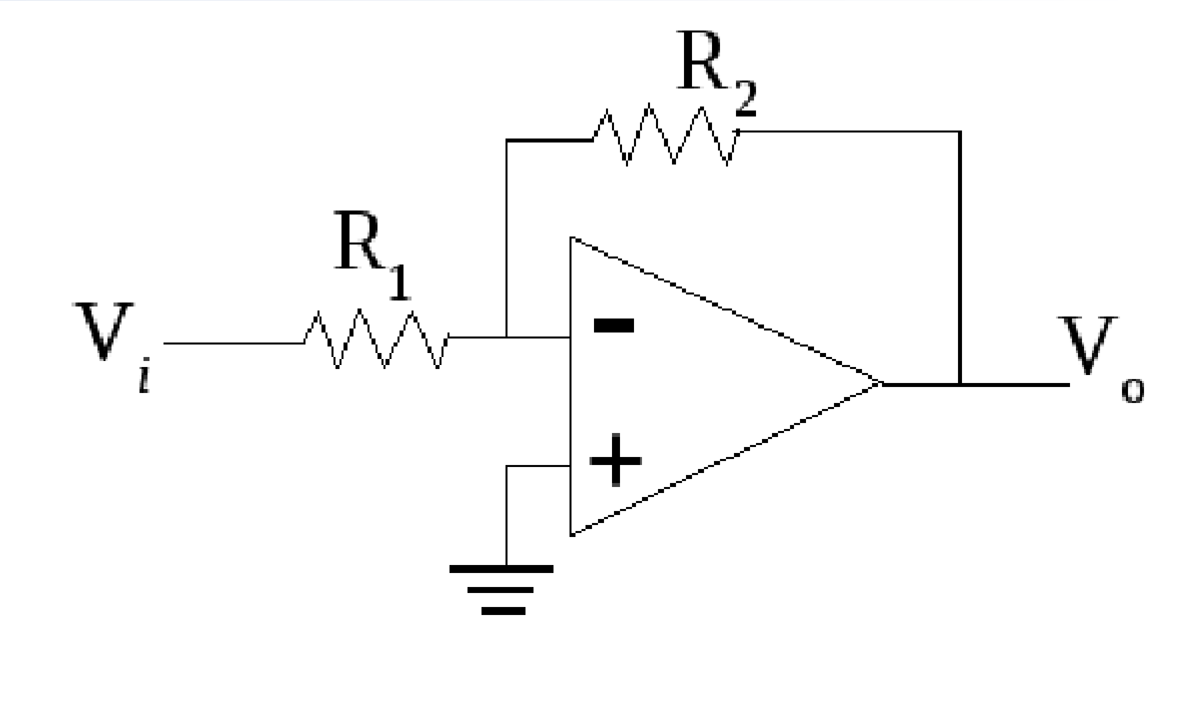
$$= \frac{1}{1/A + R_1/(R_1+R_2)}$$

$$\approx 1 + \frac{R_2}{R_1} \qquad as\ A \rightarrow \infty$$

Simple Analysis of Op-Amp Circuits

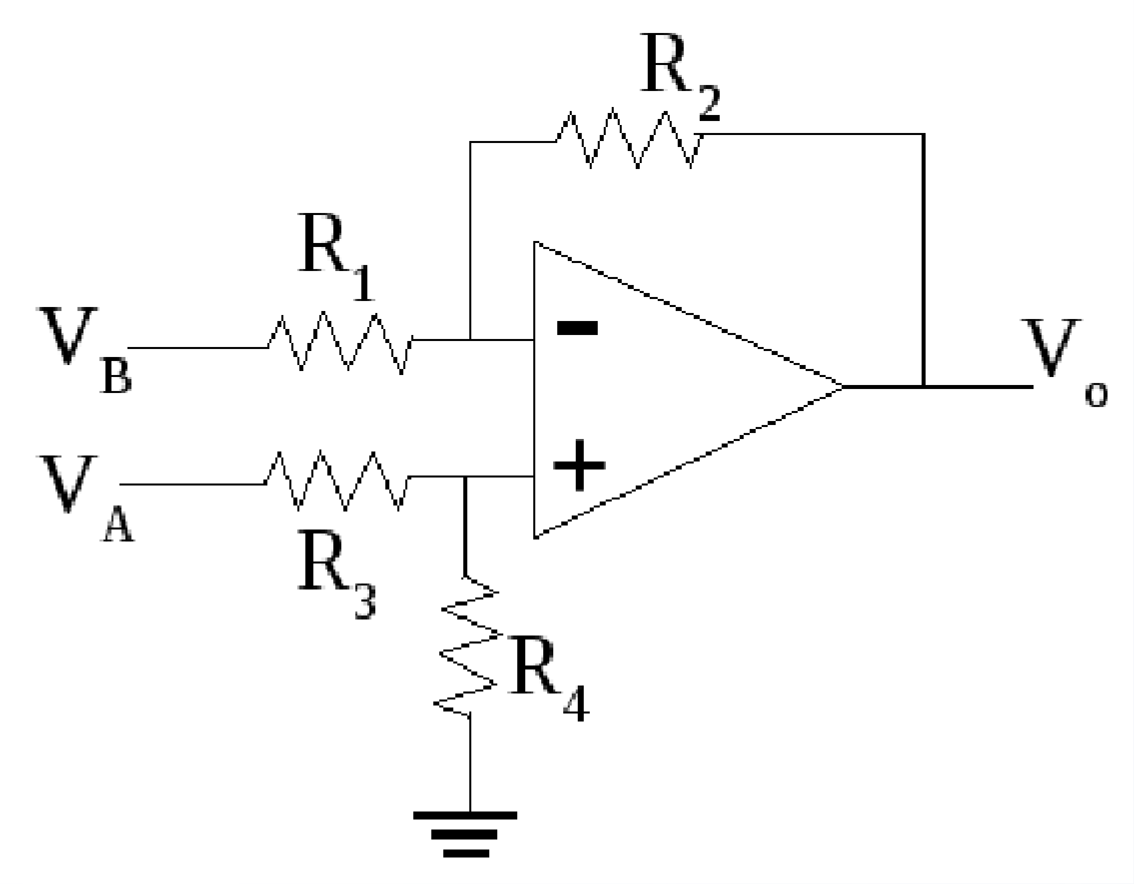
- Due to high input impedance the current into amplifier at the two inputs is zero
- From the above point, the effective potential difference between the two inputs is zero ("virtually connected" or concept of "virtual ground")
- The output is: $V_o=(V_a-V_b)G$, with $G\rightarrow$ very large

Inverting Amplifier

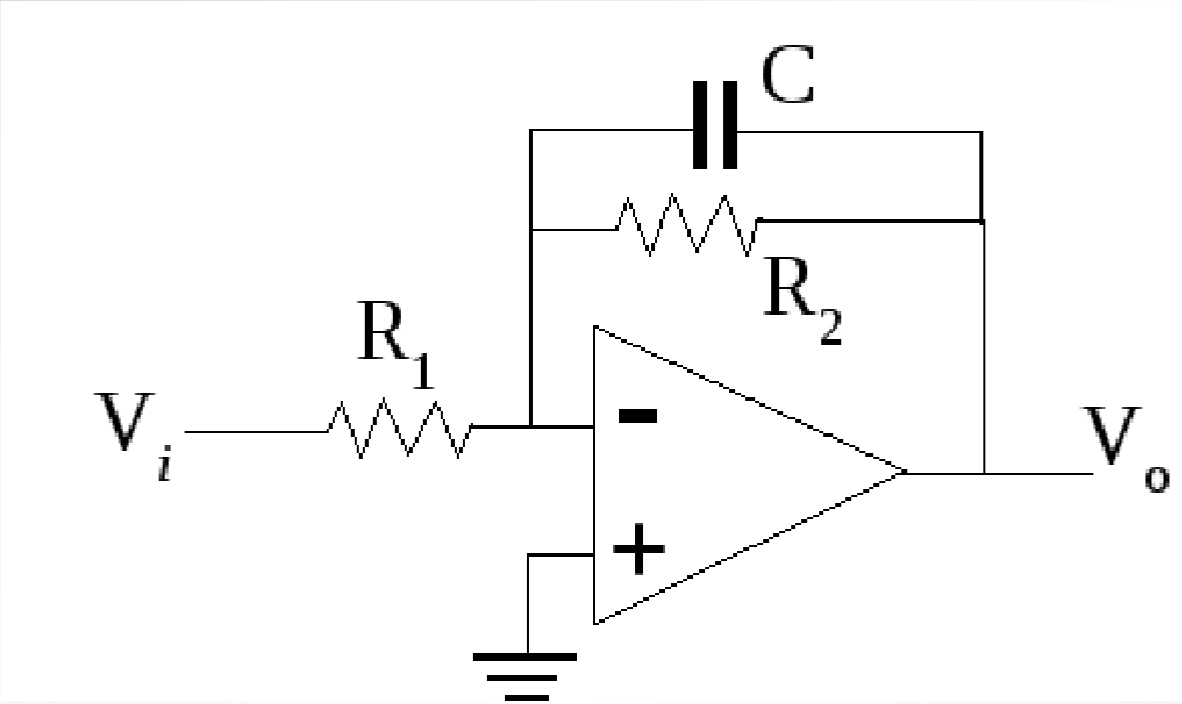


$$\frac{V_o}{V_i} = \frac{-R_2}{R_1}$$

Differential Amplifier

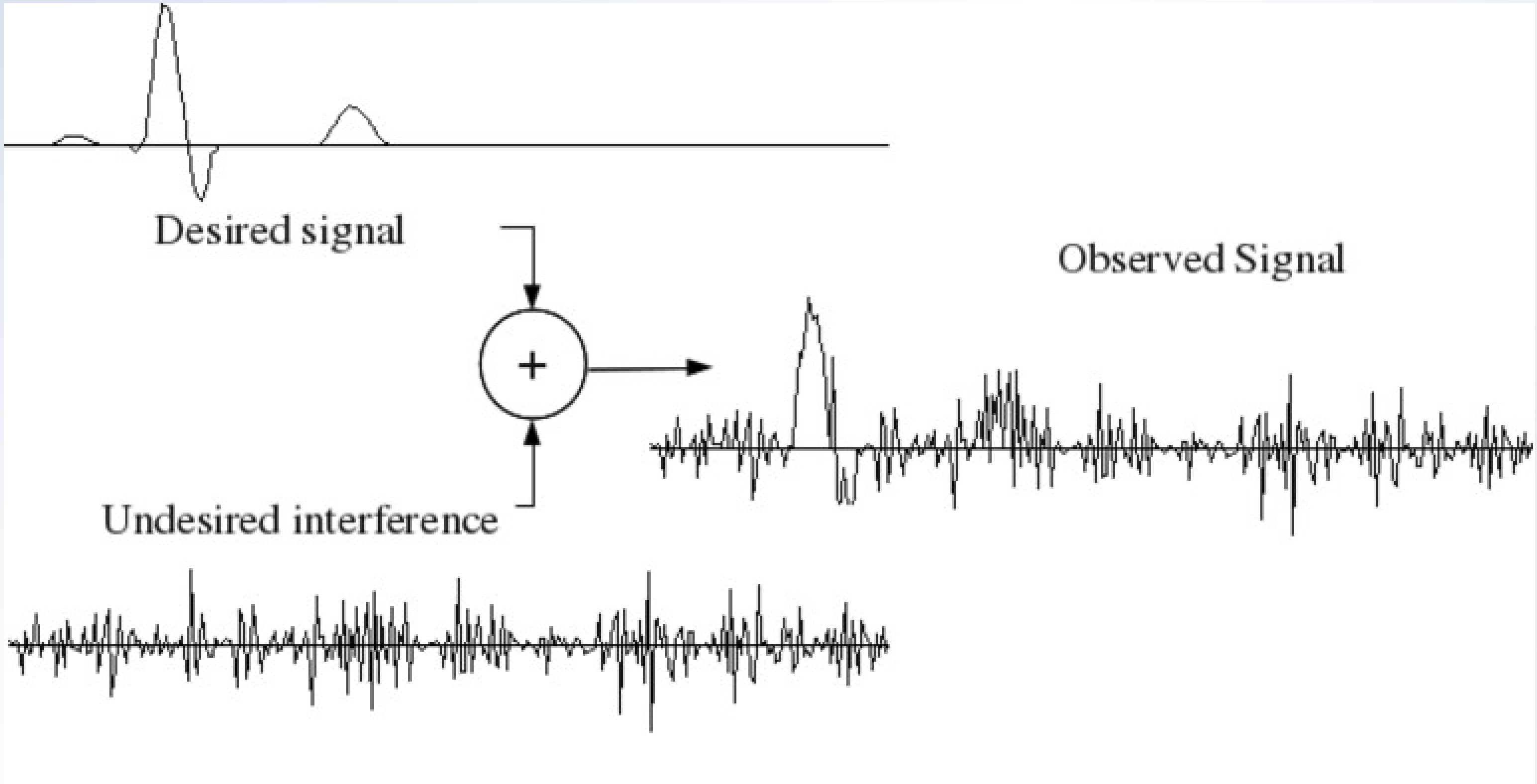


Low-Pass Filter

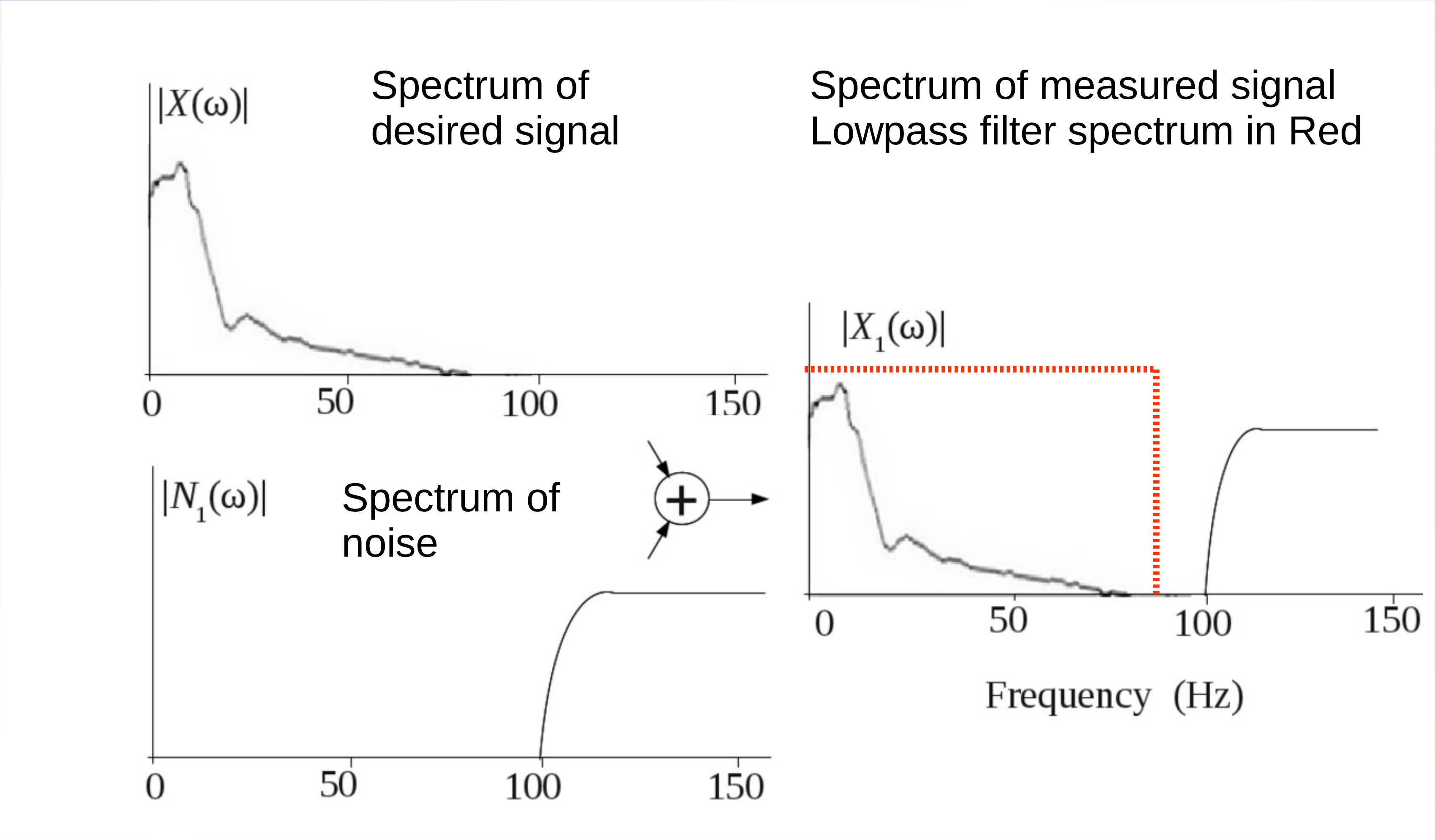


$$\frac{V_o(s)}{V_i(s)} = \frac{-R_2 \;||\; C}{R_1} = \frac{-R_2/R_1}{1+R_2Cs}$$

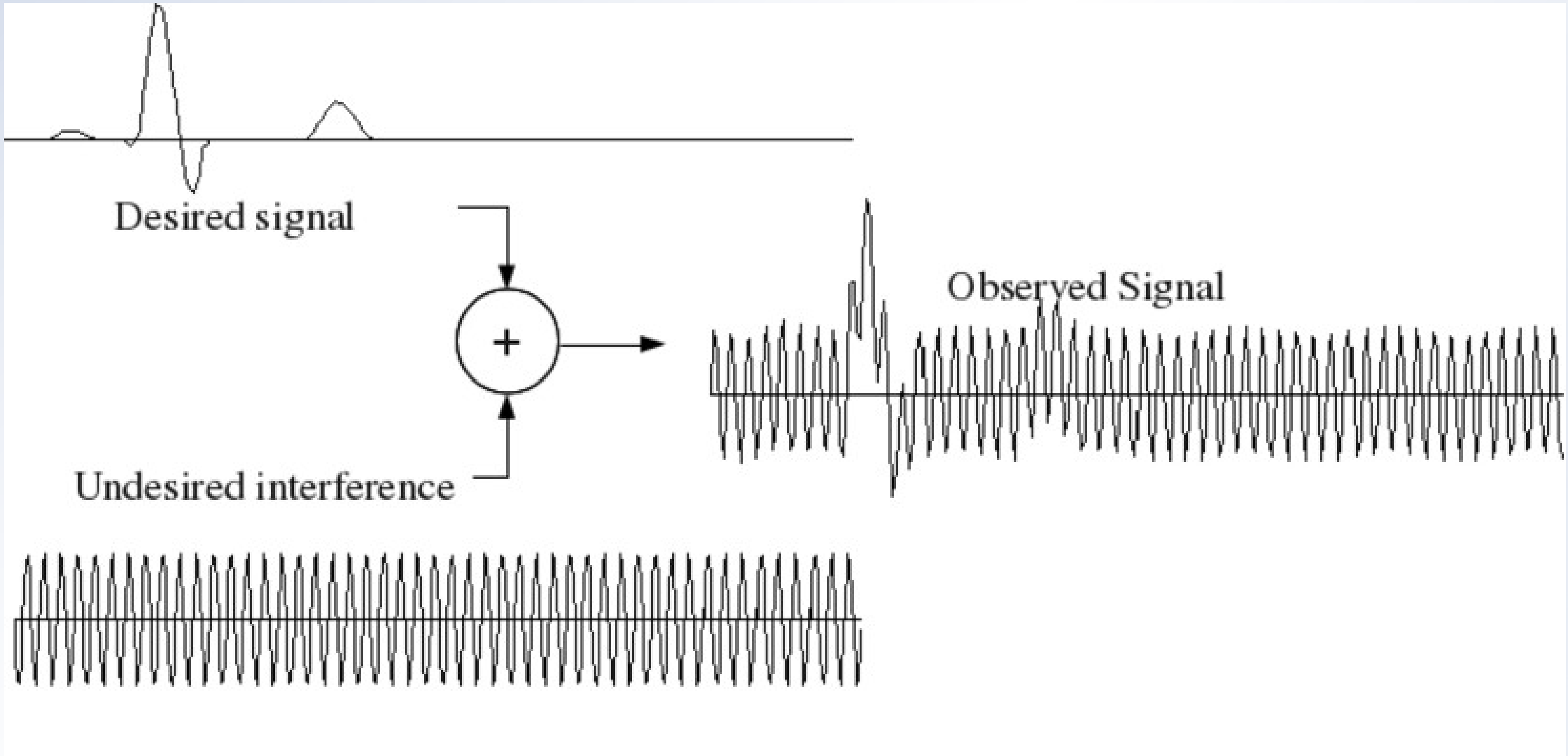
Signal contaminated by noise distinctly separated in frequency



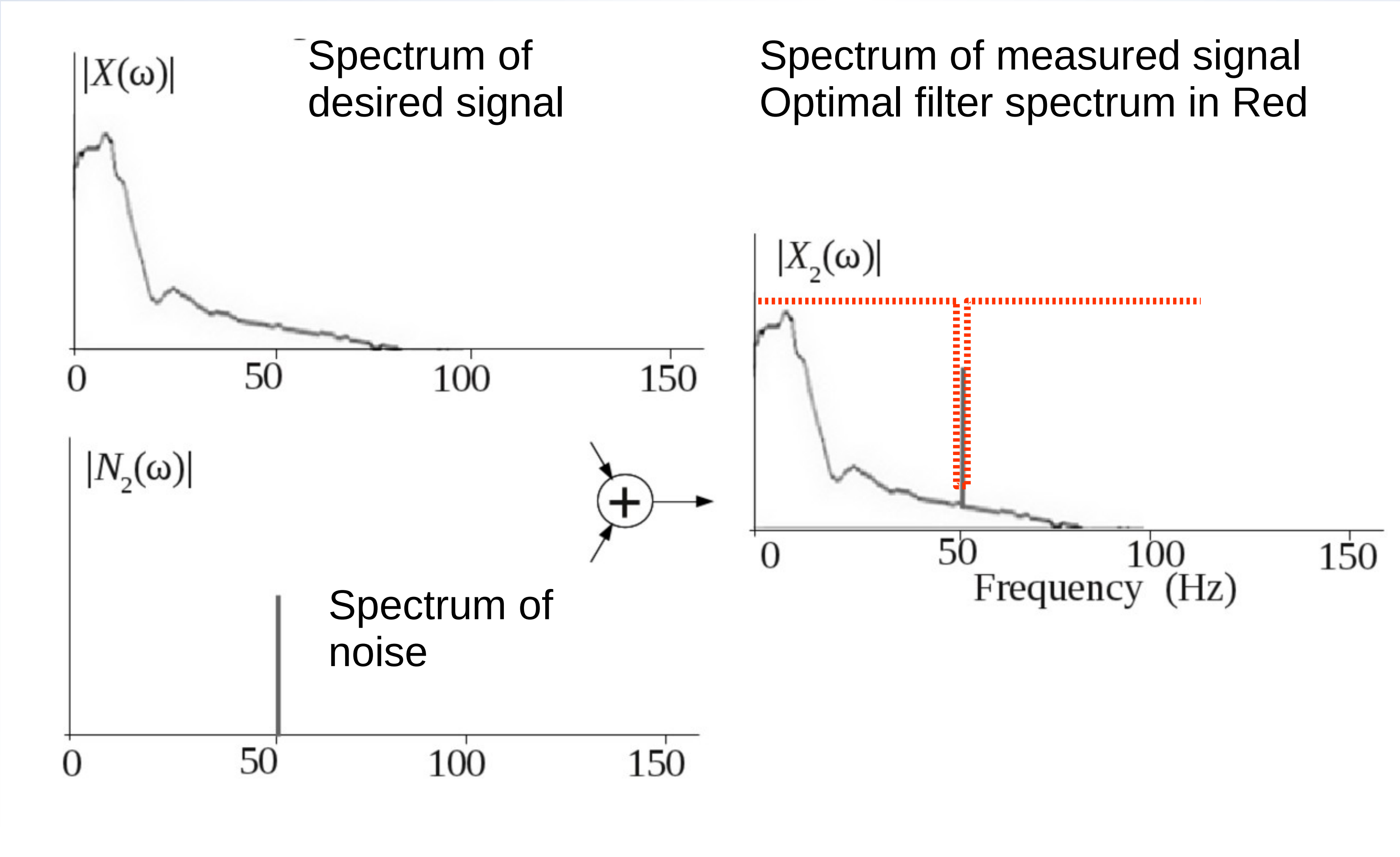
Lowpass filtering of distinct high frequency noise



Signal contaminated by noise overlapping in frequency



Filtering Overlapping Noise

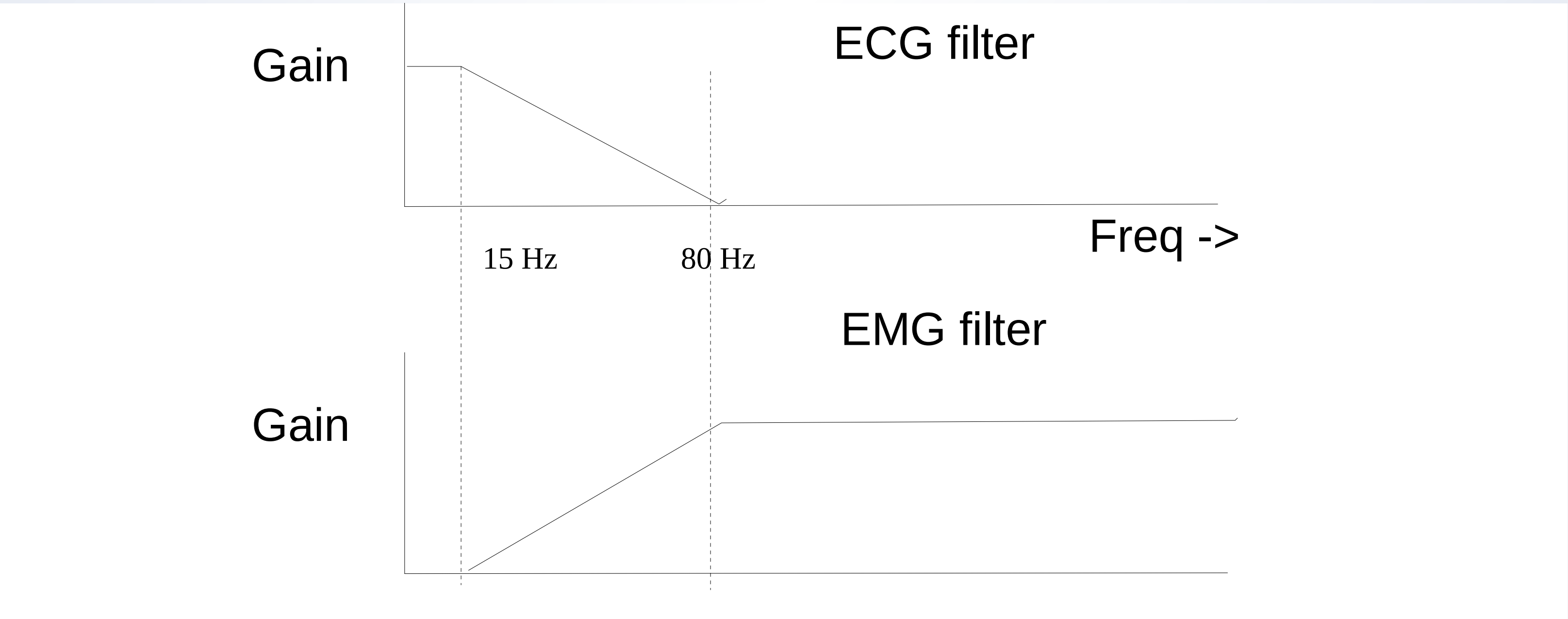


Optimal Filter - I

- Keep as much of the signal as possible
- Remove as much of the noise as possible
- This means:
  - In the frequencies where the signal and noise overlap, the filter attenuation is proportional to the ratio of signal to noise
  - In the frequencies where they don't overlap, keep all the signal and remove all the noise

Optimal Filter - II

- Consider the EMG and ECG both of which can be picked up simultaneously by electrodes on the chest
  - ECG spectrum: 0.05Hz-80Hz
  - EMG spectrum: 15Hz-300Hz



Cascading Filters

- The Laplace Transform converts the input-output relation in simple algebraic terms – i.e., only multiplications and divisions
- Multiple filters can be cascaded, and the cumulative effect is a multiplication of the individual input-output relations

Real Filters

- Real-time and offline filtering
- Implementation
  - Physical filters/Electrical – online/realtime
- Physical filters and online filters
  - Causal , cannot use future data
  - Have finite phase shift or time lag
- Offline filters (Digital Filters)
  - Can use “virtual future” data that has been stored

Phase shift in filters

- Phase shift can disrupt time relations in waveforms
- Phase shift can introduce lag between synchronous signals
- Linear phase filters introduce constant time lag to all frequencies
- Time lag: $\tau = \frac{\phi}{\omega}$ where ϕ is the phase shift and ω is the frequency

Characterizing Filters

- Frequency response
- Step response