ECG-Amplifier

MB Jass 2009

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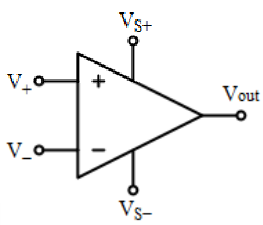
Operation amplifier (op-amp)

Properties

- DC-coupled
- High gain electronic voltage amplifier
- Inverting / non-inverting input and single output
- Output of the op-amp is usually controlled by negative feedback
- Differential amplifier (just the difference between V_+ and V_- is amplified)

Circuit diagram symbol



- V_+ : non-inverting input
- V_- : inverting input
- V_{out} : output
- V_{S+} : positive power supply
- V_{S-} : negative power supply

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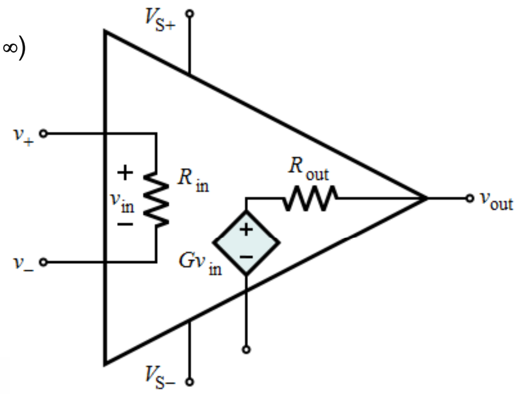
Ideal op-amp

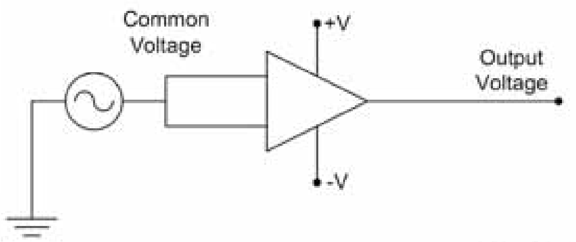
Properties for an ideal op-amp

- Zero output impedance (R_{out} = 0)
- Infinite open-loop gain
- Infinite input impedance (R_{in}= ∞)
- Zero offset voltage
- Zero noise



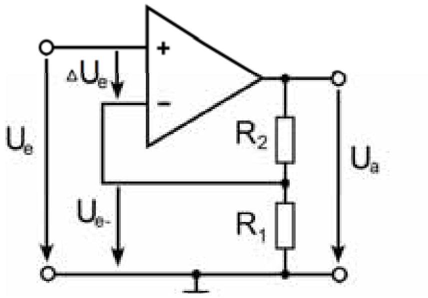
Common mode gain

- Ideal op-amps amplify only the voltage difference in its inputs
- Real op-amps amplify also voltage that is common to both inputs (common mode gain)
- Minimizing this common mode gain (i.e. maximizing the common mode rejection ratio, 'CMRR') is important for most applications



Non-inverting Amplifier

- Very high input impedance
- Small output impedance
- Gain: $U_a = (1 + \frac{R_2}{R_1}) U_e$
- Amplifies U_e regarding to the ground and not the difference between two different voltages



Instrumentation amplifier

- Type of differential amplifier (usually 3 op-amps)
- Input buffers
- Output controlled by negative feedback

<u>Characteristics</u>

- Very low DC offset
- Low drift
- Low signal noise
- Very high open-loop gain
- Very high common-mode rejection ratio
- Very high input impedance

Description of the INA 118

INA118:

- Low power, general purpose instrumentation amplifier offering excellent accuracy
- 3 op-amps (small size)
- Current-feedback input provides high gain even at high frequencies

INA118

Electrical Features

- Low offset voltage (50 μV)
- Low temperature drift (0.5 μV/K)
- High common-mode-rejection (110dB) at high gain
- Low quiescent current (350 μA at ± 1.35V supply)

- Single external resistor sets any gain from 1 to 10,000
- Internal input protection can withstand up to ±40V without damage

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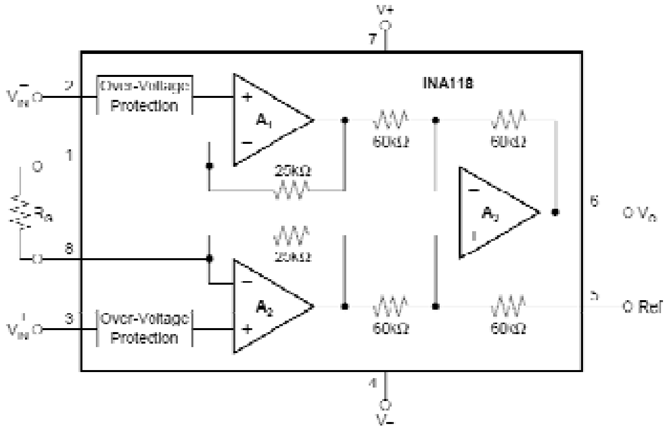
Instrumentation amplifier INA118

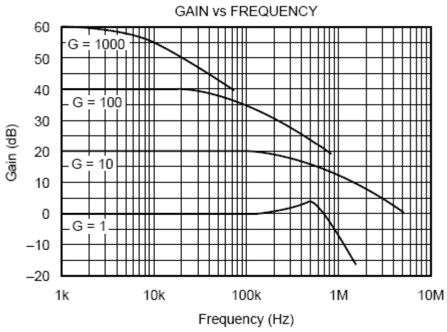
- Circuit of the Instrumentation amplifier used in our ECG-circuit

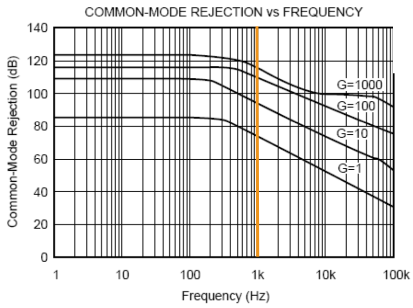


- Gain: $G = 1 + \frac{50k\Omega}{R_G}$

Performance curves (INA118)

Gain of the amplifier plotted against the frequency





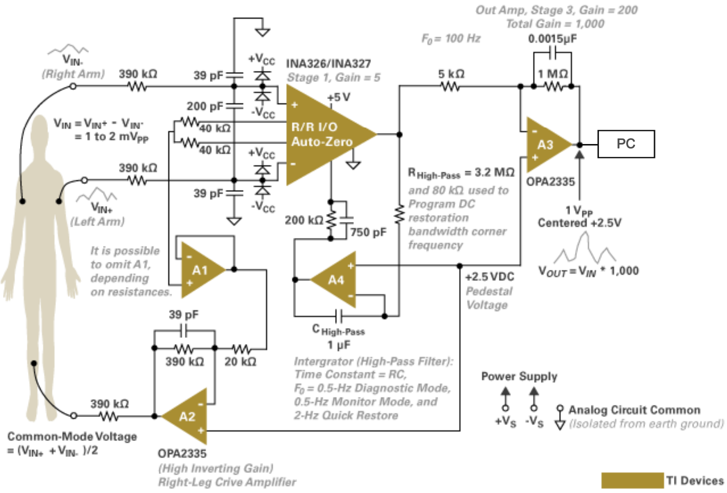
Common-mode rejection as a function of the frequency

Electrocardiogram

<u>Properties of the electric signals on the skin:</u>

- AC signal with bandwidth of 0.05 to 100 Hz, sometimes up to 1 kHz
- About 1 mV peak-to-peak amplitude
- External noise at higher frequencies
- 50/60 Hz interference
- Common-mode voltages (common to all electrodes)

Circuit schematic of an ECG



ECG

The common-mode voltage is comprised of two parts:

1) 50- or 60-Hz interferences
2) DC electrode offset potential

Other noise or higher frequencies within the biophysical bandwidth come from:

- Movement artifacts that change the skin-electrode interface
- Muscle contraction or electromyographic spikes
- Respiration
- Electromagnetic interferences
- Noise from other electronic devices that couple into the input

ECG

- Some noise can be cancelled with a high-input-impedance instrumentation amplifier (INA)

  → removes the AC line noise common to both inputs

  → amplifies the remaining unequal signals present on the inputs

→ **Let's detect an ECG with our construction**

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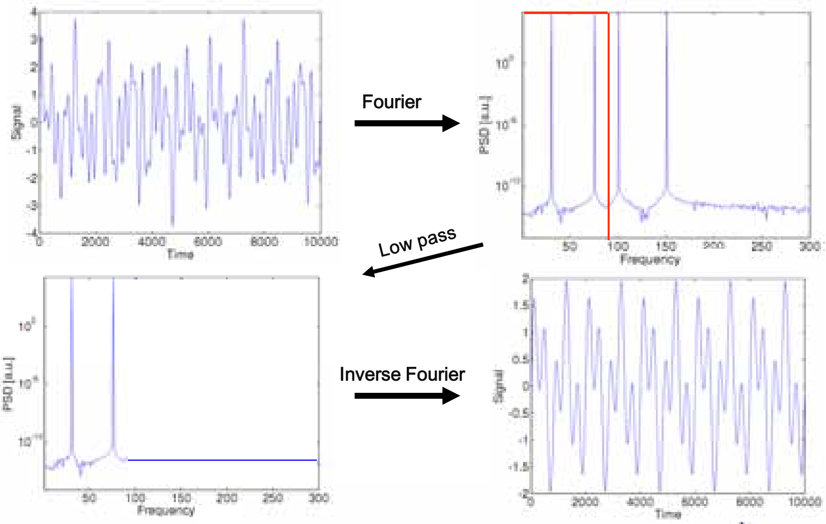
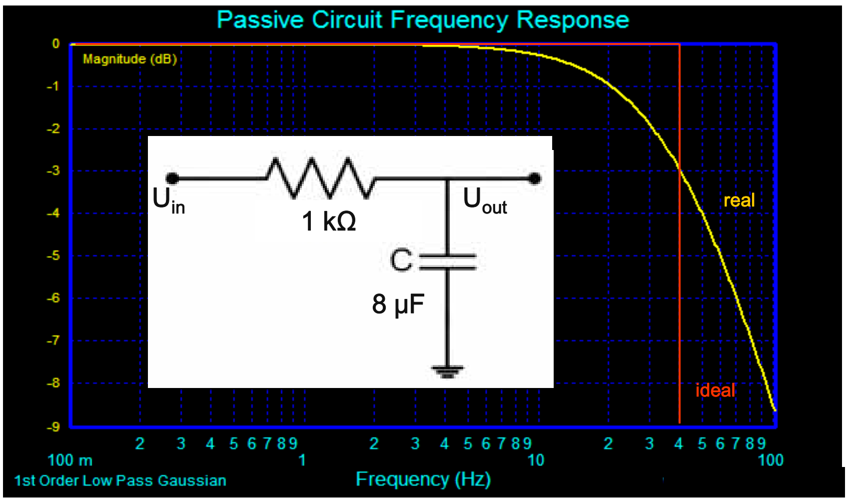
Filter

Device for manipulating the frequency content of a given signal

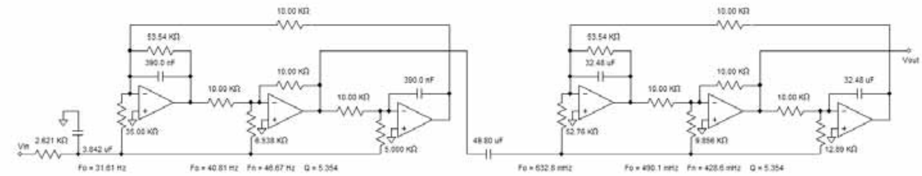


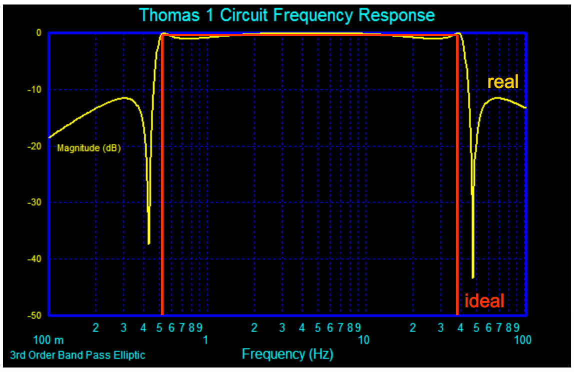
Passive analog filter: RC network



Impedance of capacitor: $Z = 1/(\omega C)$ -> $f_{co} = (RC)^{-1}$

Active analog filter

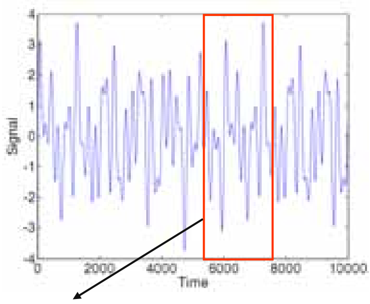




- Complex circuit
- Once it's set up, it's hard to change

Fourier Transform

- Direct manipulation of frequency content in the frequency domain is suitable for post processing only! (Whole signal has to be stored in memory)
- Possible solution for in-stream processing: windowing



Manipulation in Fourier space

Problems:

•High computational cost

•Frequency spectrum limited by window size

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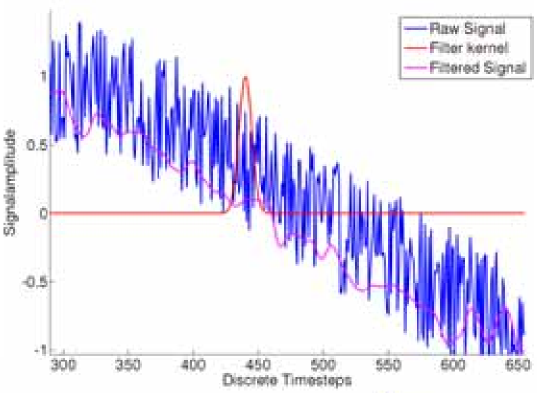
Convolution

Possibility: Operating in time domain

- Bring transfer function to time domain by inverse Fourier Transform (Impulse response)

- Cut function to realise convolution of impulse response & signal as sum

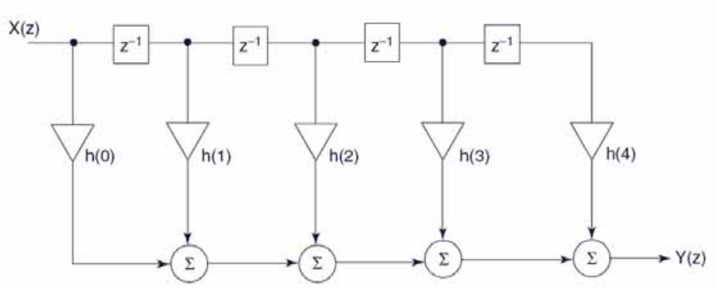
$$Y(t) = \int_{-\infty}^{\infty} T(\tau) \cdot X(t-\tau) d\tau$$



Implementation: FIR

- Simple implementation: convolution implemented as sum
- h is the filter kernel of length q

$$Y(z) = \sum_{m=0}^{q} h(m) \cdot X(z-m)$$



Major drawback:

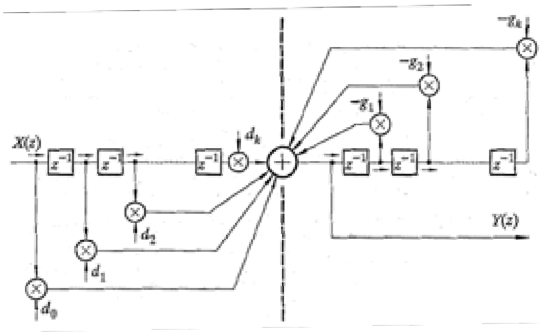
very long filters necessary to achieve good performance

Implementation: IIR

Recursive implementation:

$$Y(z) = \frac{1}{a_0}\left(\sum_{i=0}^{p} d_i X(z-i) - \sum_{j=0}^{q} g_j Y(z-j)\right)$$

both input and response are considered



Advantage:

Less coefficients required in comparison to FIR filters to get same perfomance

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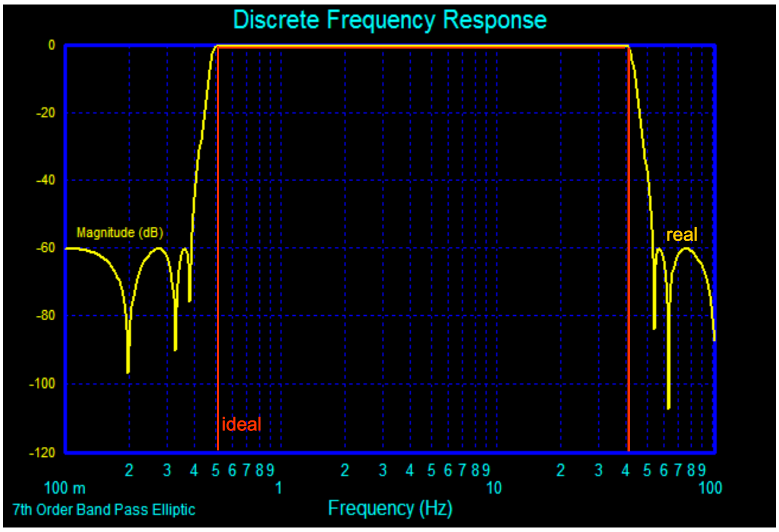
Digital Filter: Transfer function



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Advantages/Disadvantages

Advantages

- Digital filters can realise frequency responses practically not achievable with analog filters
- No tolerance of circuit components
- No complex circuitry (just a number of coefficients needed)

Disadvantages

- FIR filters need to be large to be effective (many operations)
- IIR filters may be unstable because of feed back loop
- The ADC stage creates deterministic quantisation error which is due to digital storage and computation limitations
- sample rate limitation (analog filters do not have to sample!)
- Filter design is not a simple task