Importance of detecting biopotentials

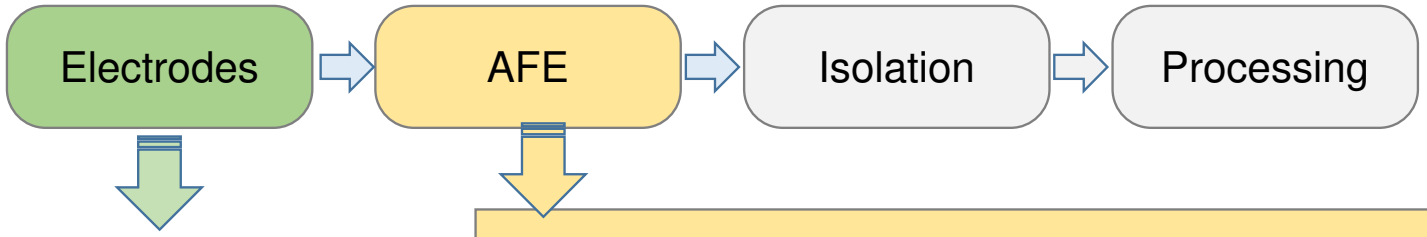
- Diagnostic purposes: Detecting a possible disease (e.g. heart and neural pathologies, etc.)
- Implantable, wearable biomedical devices:
  - Cardiac pacemakers (on demand stimulation)
  - Control of limb prostheses (smart prostheses)
  - Advanced human-machine interfaces
  - Early detection of pathological situations (e.g. , automatic defibrillator, migraine attacks) for on-demand drug delivery or electrical stimulation)
- Research: understanding the functioning of human or animal body, with particular interest in functioning of the brain

Type of biopotentials and related challenges

Main biopotentials, according to the source

- **ECG**: Electrocardiogram, produced by the electrical activity of the cardiac muscle
- **EEG**: Electroencephalogram, produced by the neurons in the brain
- **EMG**: Electromyogram, produced by the contraction and relaxation of muscles
- **ERG**: Electroretinogram, produced by the activity of the retina.

Biopotential acquisition system



- Number and position of the electrodes
- Type of electrodes

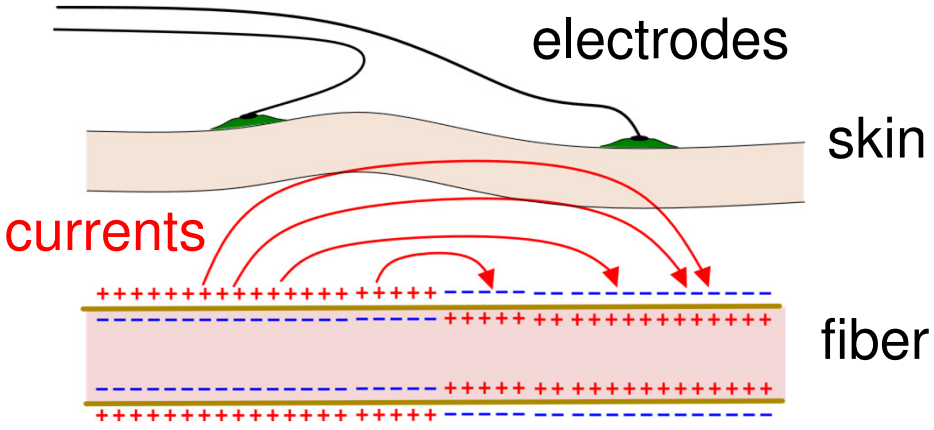
- ❑ Differential input
- ❑ High CMRR
- ❑ Specifications of:
  - Bandwidth
  - Noise
  - Input bias currents
  - Artefact correction capability
- ❑ Impedance measurement (quality of contact)

Detection of biopotential through non-invasive electrodes

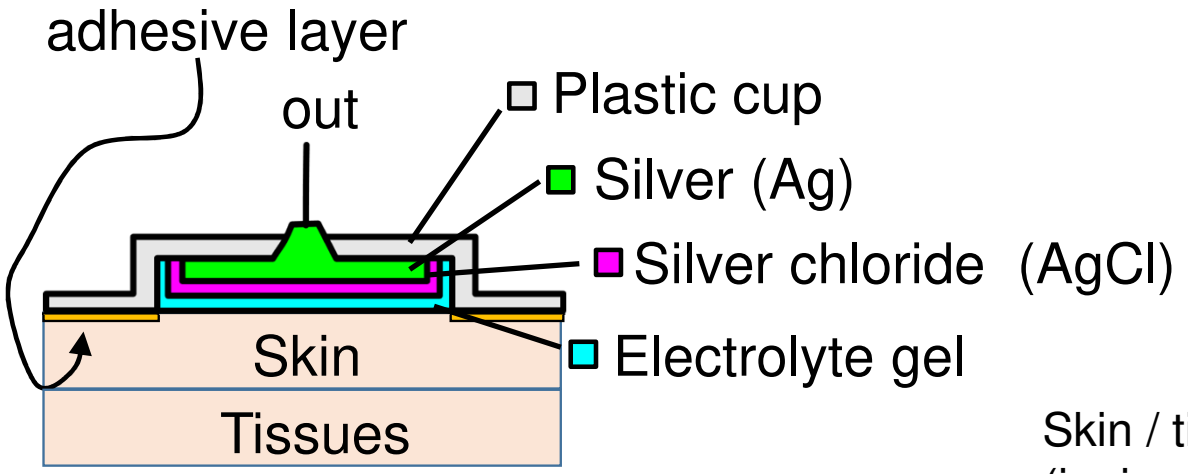
Principle: electrodes are placed on the skin

To the electronic interface

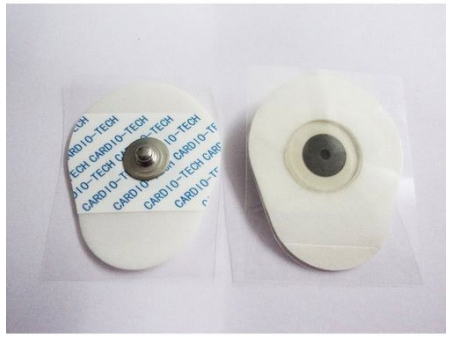
Electrically excited nerve or muscle fibers induce currents in the tissues that produce potential differences across different points of the body



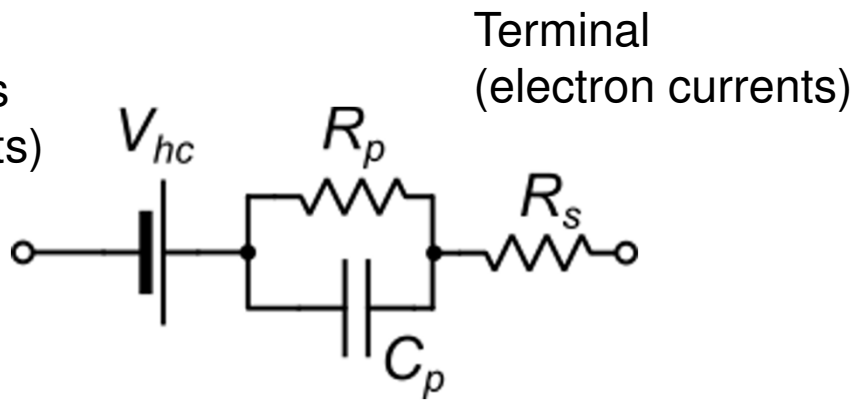
Electrodes for biopotential detection: the Ag / AgCl electrode



The Ag/AgCl electrode is one of the best option, Can be disposable or reusable.



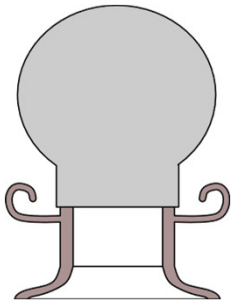
Electrode equivalent circuit



V_{hc} is the half-cell potential. It introduces a dc offset that can be critical for the AFE

Other types of electrodes

- **Metal electrodes:**
  Can be advantageous when the electrode must be reused, or the electrode position must be changed frequently. Need application of electrolyte gel.



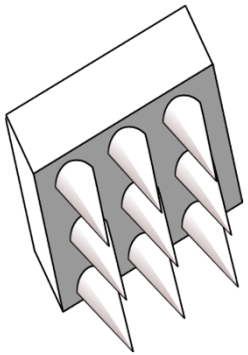
rubber cuff

metal electrode

Example: cuff electrode

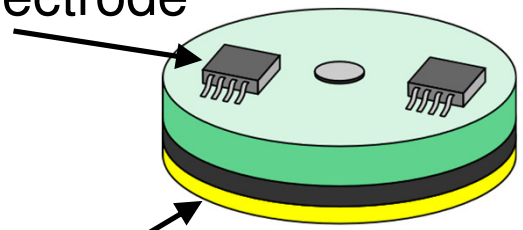
Dry electrodes
Do not need application of electrolyte gel.

- Capacitive electrodes
- Microneedle arrays
- Conductive silicone electrodes



Microneedles

Active electrode

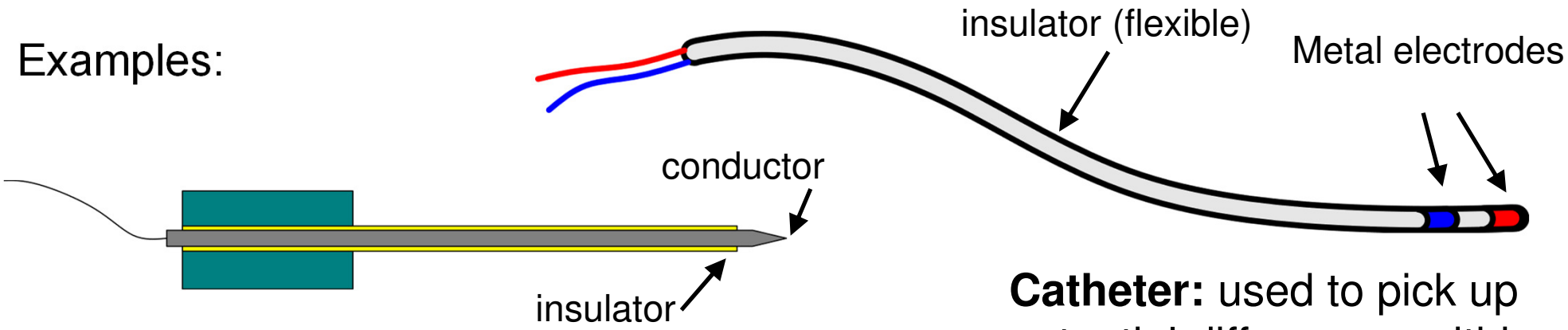


Insulator (touchless) or conductive silicone rubber

Electrodes for in-depth biopotential monitoring

Sometimes, it is necessary to detect the biopotential in a position very close to the organ that is generating it. In this case, invasive catheter or needle electrodes are required. They do not need gel, since internal tissues are wet

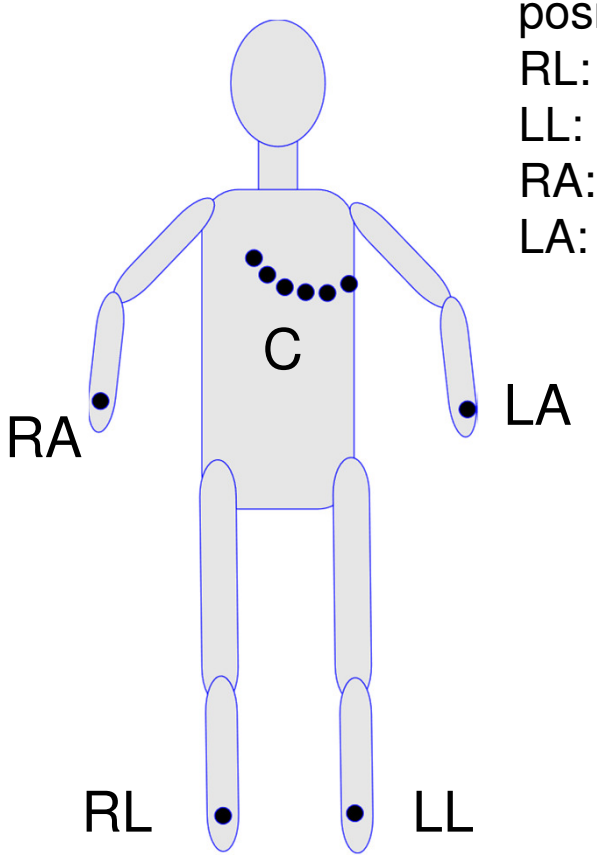
Examples:



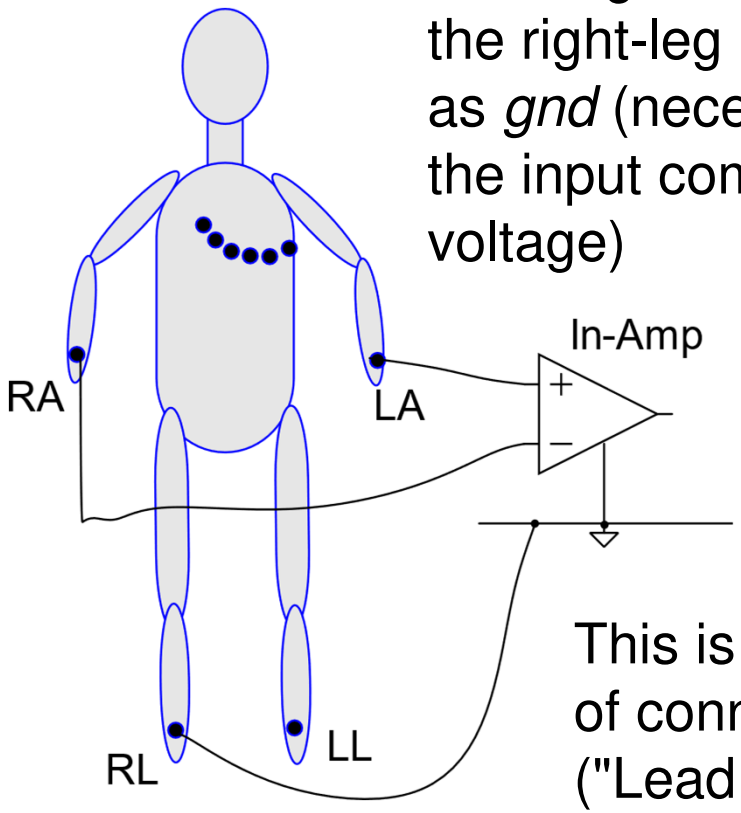
Needle electrode
(used to contact muscle fibers directly)

Catheter: used to pick up potential differences within organs (e.g. the heart). Can be brought in place through veins or arteries

Electrode position and number: **ECG**



C; chest (typically 6 positions, V1-V6)
RL: Right Leg
LL: Left Leg
RA: Right Arm
LA: Right Arm



Reading is differential with the right-leg always used as *gnd* (necessary to set the input common mode voltage)

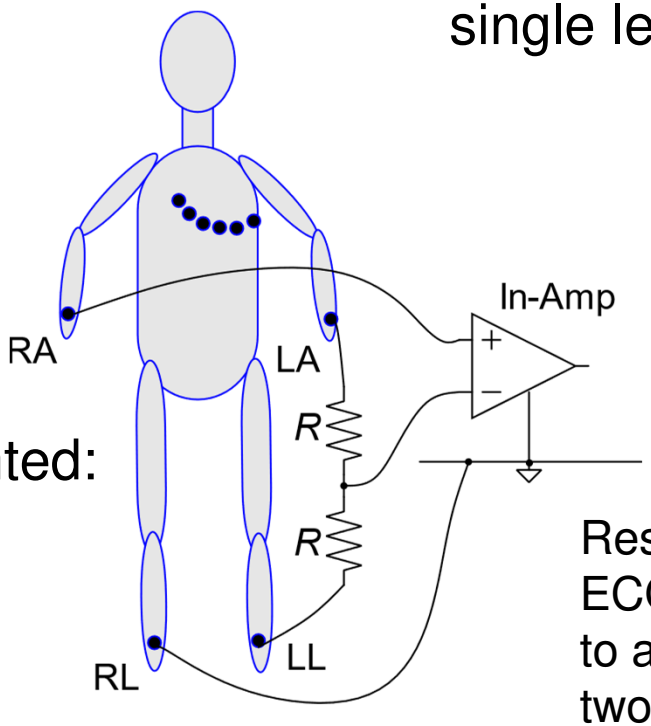
This is an example of connection ("Lead I")

ECG example of leads

Lead I : LA-RA
Lead II : LL-RA
Lead III : LL-LA

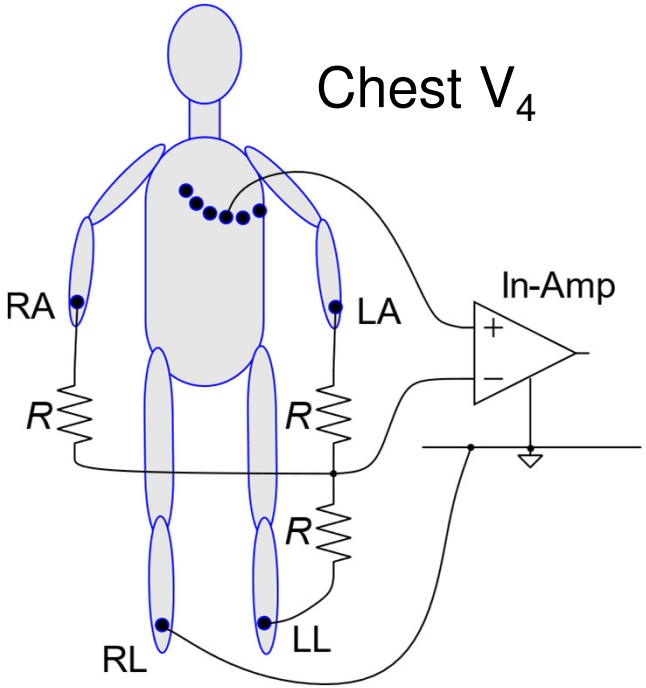
Different leads give different diagnostic information.
For monitoring purposes, a single lead is generally used

Augmented:
aVR



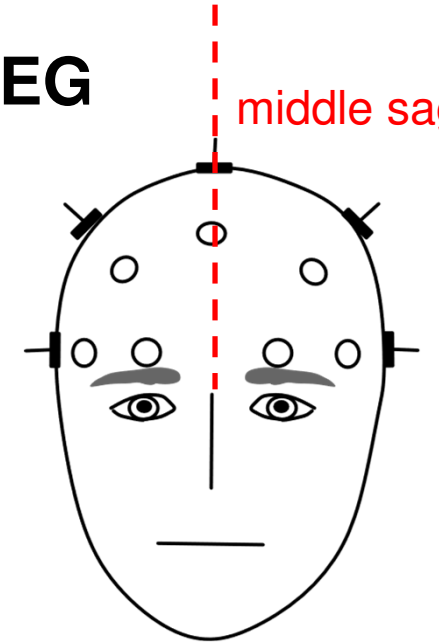
Resistors (placed inside the ECG instrument, are used to average the voltage of two or three electrodes

Chest V_4



EEG and EMG electrode placement

EEG

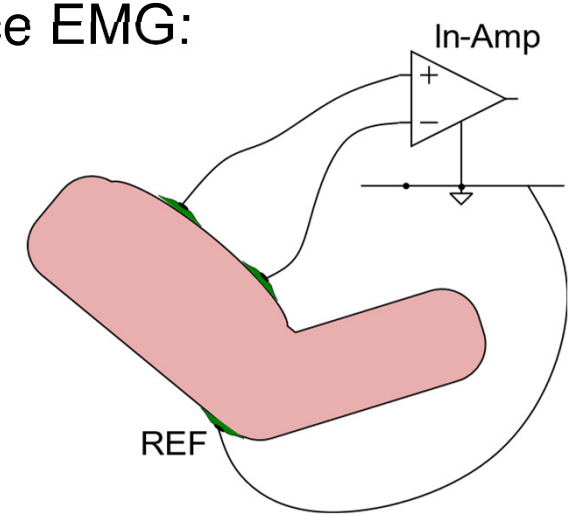


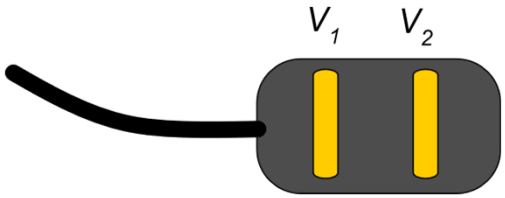
10-20 electrode system:
refers to the spacing between electrodes in terms of percentage, 10 % 20 %
(8 - 128 electrodes)

Each electrode position has a code.
Electrodes in the "middle sagittal plane" are generally used as gnd.

EMG

Surface EMG:





Compact bipolar electrode for EMG

Biopotentials characteristics

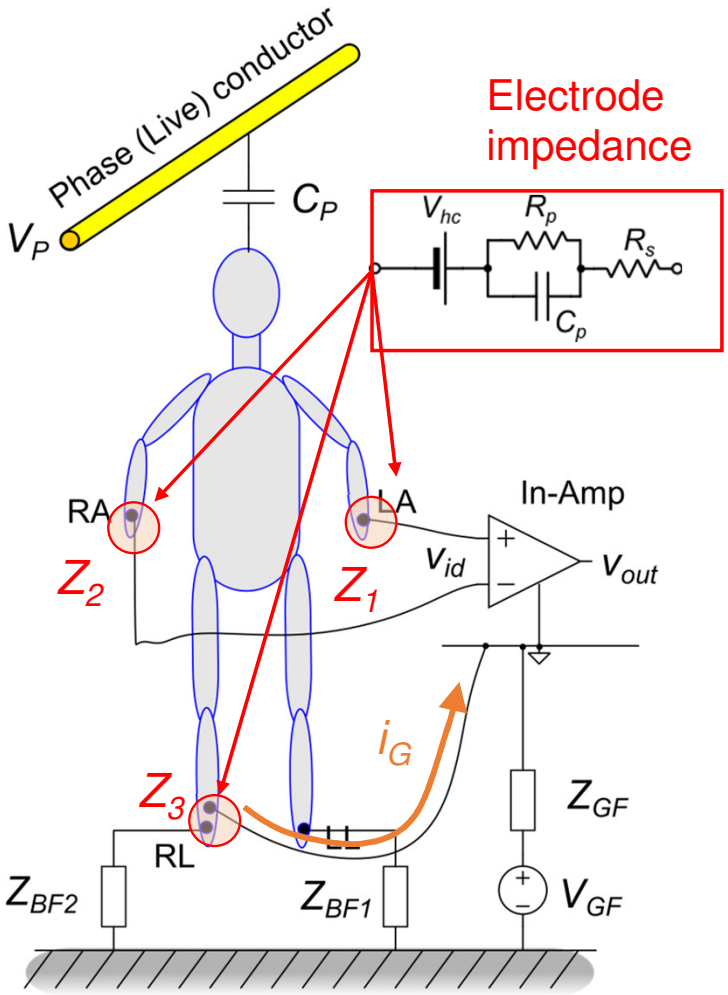
Type of biopotential	Bandwidth	Typical level
ECG	0.05 Hz - 100 Hz	1 mV -5 mV
EEG	0.5 Hz - 40 Hz	10 μV - 100 μV
EMG	20 Hz -2 kHz	1 mV - 10 mV
ERG	1 Hz - 1 kHz	10 μV - 100 μV

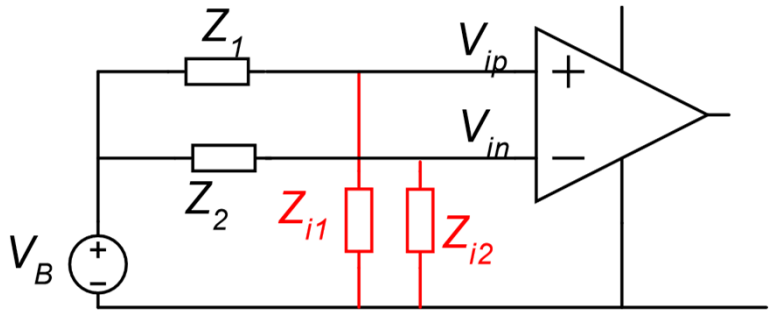
Range includes 50/60 Hz: prone to interference from power line

Very low frequency:
high pass filter is critical and exhibits long settling times (due to poles at very low frequency)

Very small magnitude.
Requires very-low noise amplifiers and careful rejection of interferences

Power line interference





$$V_B \cong i_G Z_3$$

Z3 may be large enough to produce a V_B of hundred mV

$$V_{id} = V_{ip} - V_{in} = (\alpha_1 - \alpha_2) V_B$$

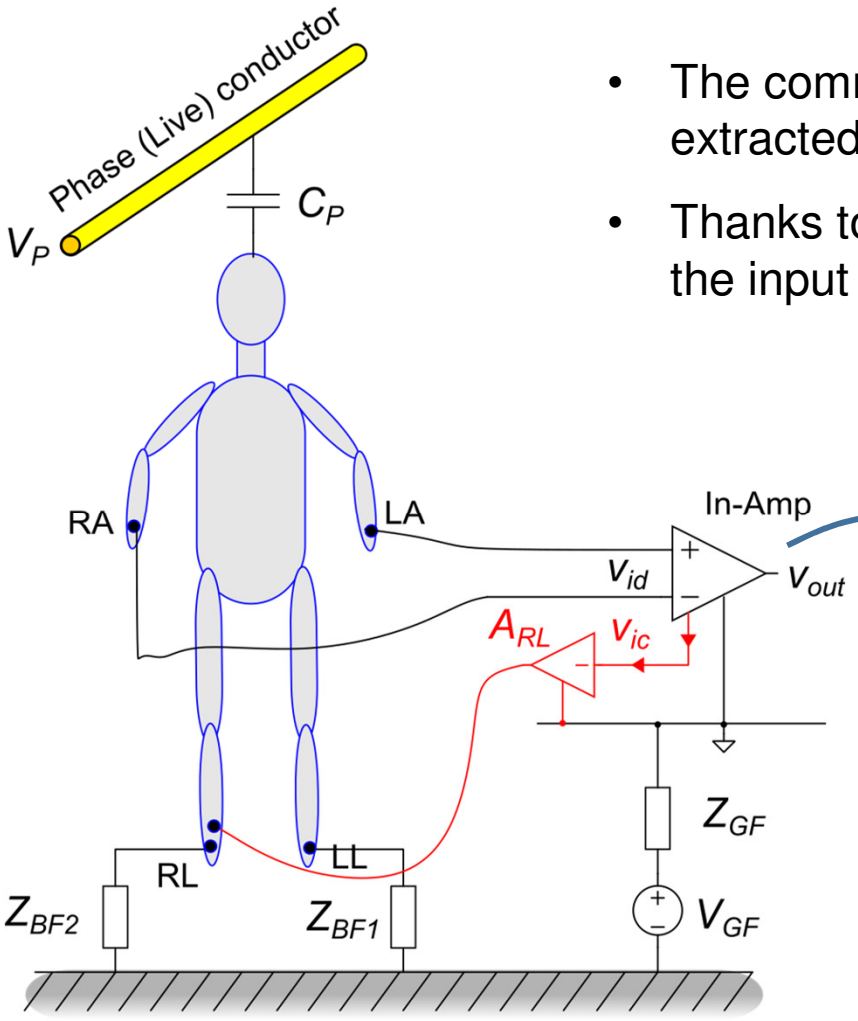
$$\alpha_1 = \frac{Z_{i1}}{Z_{i1} + Z_1}$$

$$\alpha_2 = \frac{Z_{i2}}{Z_{i2} + Z_2}$$

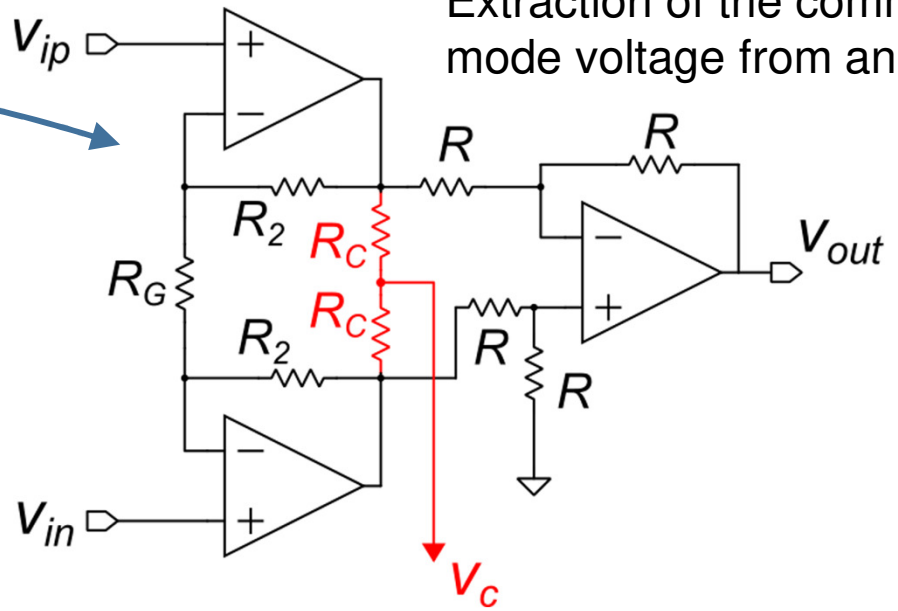
Due to mismatch of electrode impedance (Z_1,Z_2), $\alpha_1 \neq \alpha_2$ and V_B produces a differential input

Right Leg Drive (RLD) Method

- The common mode voltage of the in-amp input terminals is extracted and amplified with a high-gain inverting amplifier (A_{RL})
- Thanks to the high loop gain, virtual ground is established at the input of A_{RL}, meaning that V_{ic} is strongly attenuated.



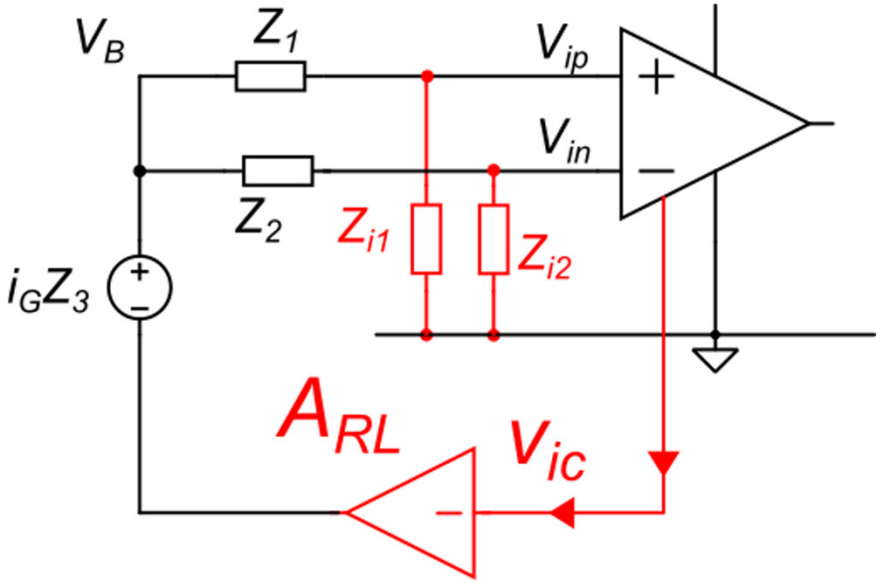
Extraction of the common mode voltage from an in-amp



Right Leg Drive (RLD) Method

$$V_{ip} = \alpha_1 V_B$$

$$V_{in} = \alpha_2 V_B$$



$$V_{id} = V_{ip} - V_{in} = (\alpha_1 - \alpha_2) V_B$$

$$V_{ic} = \frac{V_{ip} + V_{in}}{2} = \frac{(\alpha_1 + \alpha_2)}{2} V_B \Rightarrow V_{ic} = \alpha_m V_B$$

α_m

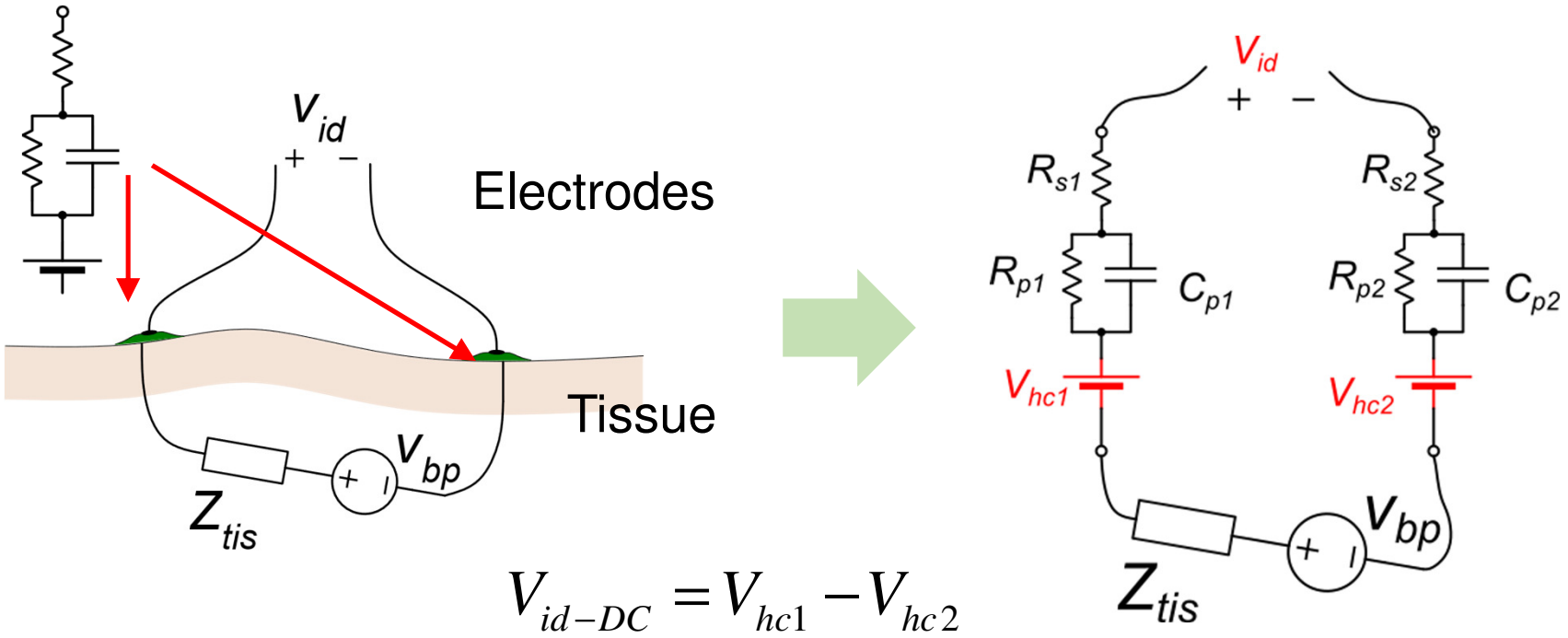
$$V_B = i_G Z_3 - V_{ic} A_{RL} \Rightarrow V_{ic} = \alpha_m (i_G Z_3 - V_{ic} A_{RL})$$

$$V_{ic} = \frac{\alpha_m}{1 + \alpha_m A_{RL}} i_G Z_3 \qquad A_{RL} >> 1 \qquad V_{ic} \cong 0$$

$$V_B = \frac{1}{\alpha_m} V_{ic} \cong 0$$

Then, the strong reduction of the input common mode voltage results in a corresponding reduction of the differential mode disturbance voltage caused by the common mode.

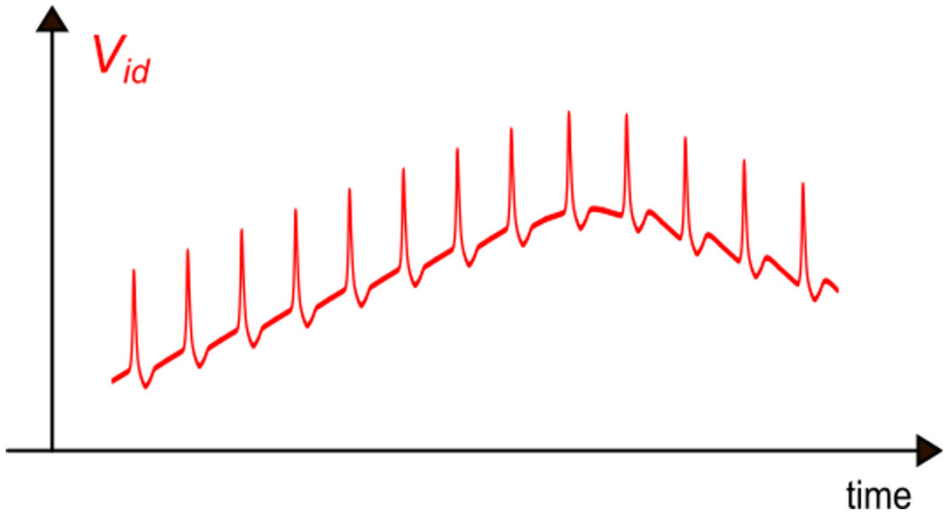
Electrode offset



$$V_{id-DC} = V_{hc1} - V_{hc2}$$

Due to mismatch in the electrodes, their degradation with time, or to local differences in the electrolyte composition, the half-cell potentials can be different. DC voltage up to **several tens mV** may appear

Electrode offset



The DC offset slowly varies with time, producing the so-called "baseline-drift"

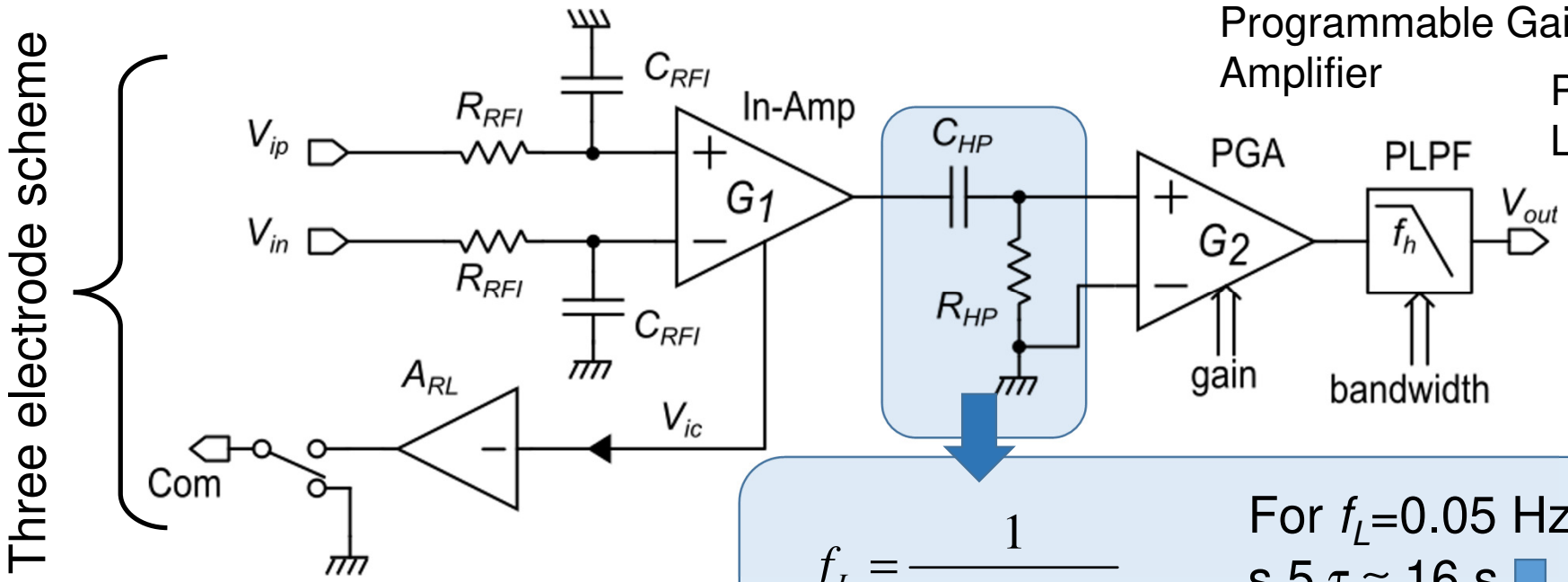
This phenomenon can be very important, distorting the useful signal and causing saturation of the amplifier.

The DC component must be removed with a high pass filter.

ECG	**0.05 Hz - 100 Hz**

For example, ECG recording would require a filter with a lower cut-off frequency og 0.05 Hz

Versatile AFE schematic



Programmable Gain Amplifier

Programmable Low Pass Filter

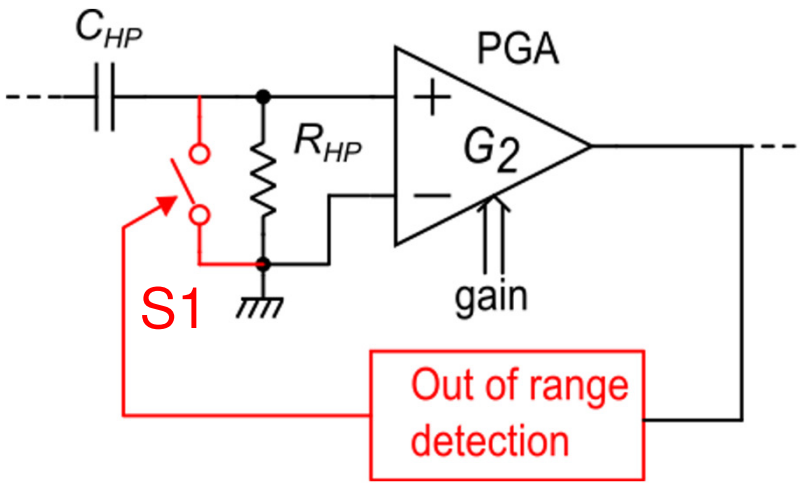
$$f_L = \frac{1}{2\pi R_{HP} C_{HP}}$$

$$\tau = R_{HP} C_{HP} = \frac{1}{2\pi f_L}$$

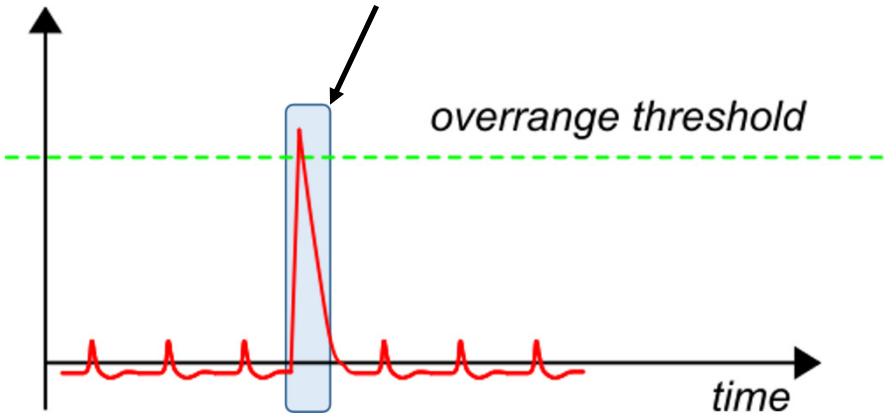
For f_L=0.05 Hz, τ=3.18 s 5 $\tau \cong$ 16 s

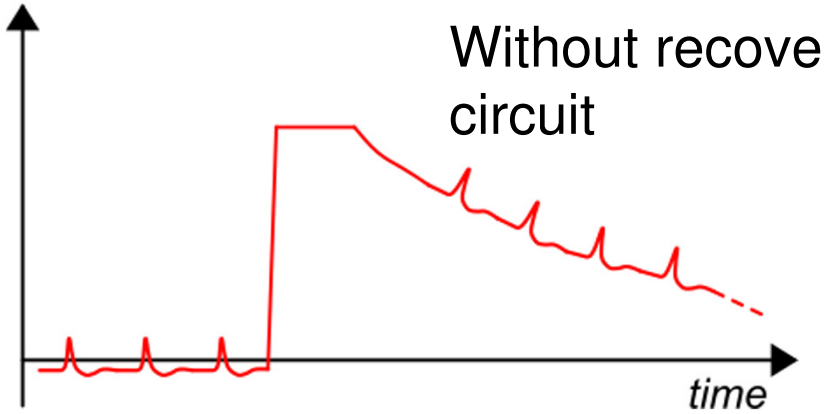
Such a long settling time can lead to long period of unavailability

Baseline fast recovery circuit



Switch S1 is activated for a fixed time





Without recovery circuit

Amplifier saturation caused by a disturbance

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[3] Analog Devices, " Biopotential Electrode Sensors in ECG/EEG/EMG Systems" https://www.analog.com/en/technical-articles/biopotential-electrode-sensors-ecg-eeg-emg.html#:~:text=A%20biopotential%20electrode%20is%20a,ion%20current%20to%20electron%20current.