University of Zagreb
Faculty of Electrical Engineering and Computing

Biomedical Instrumentation

Biopotential amplifiers

prof.dr.sc. Ratko Magjarević

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Amplifier

- The most important part of any equipment recording bioelectric potentials is the input amplifier
- Most important characteristics:
  - Differential measurement (differentia or instrumetation amplifier)
  - High gain (input signal 50uV to 1 mV)
  - High common mode rejection ratio (CMRR)
  - Frequency range typically from 0,05 Hz to >=100 Hz
  - Very high input impedance
  - Low noise

Input Signal

- Composite signal
  - useful signal – ECG: amplitude span from 50 uV to 1 mV
  - polarisation voltage (electrochemical contact potential @ electrodes) – DC component, up to 300 mV
  - interference – mains (50 Hz or 60 Hz), up to 100 mV
  - interference voltages – defibrilator shock (*n* x 1000 V) or RF surgery equipment voltages

EM Interference

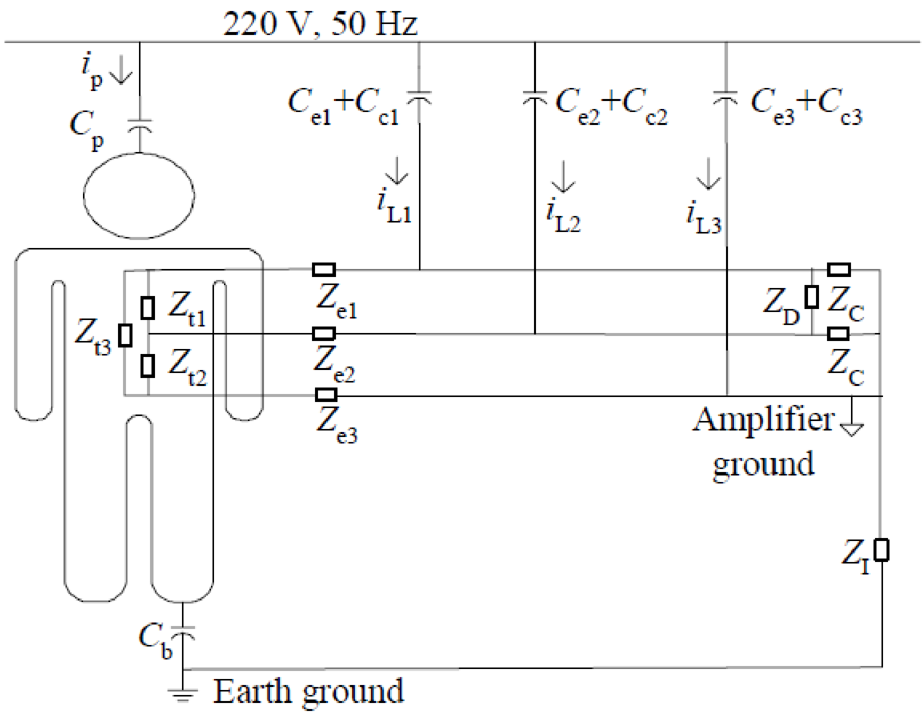


Fig. 1. Common lumped-parameter model to describe power line interference in a three-electrode system to record biopotentials.

From:

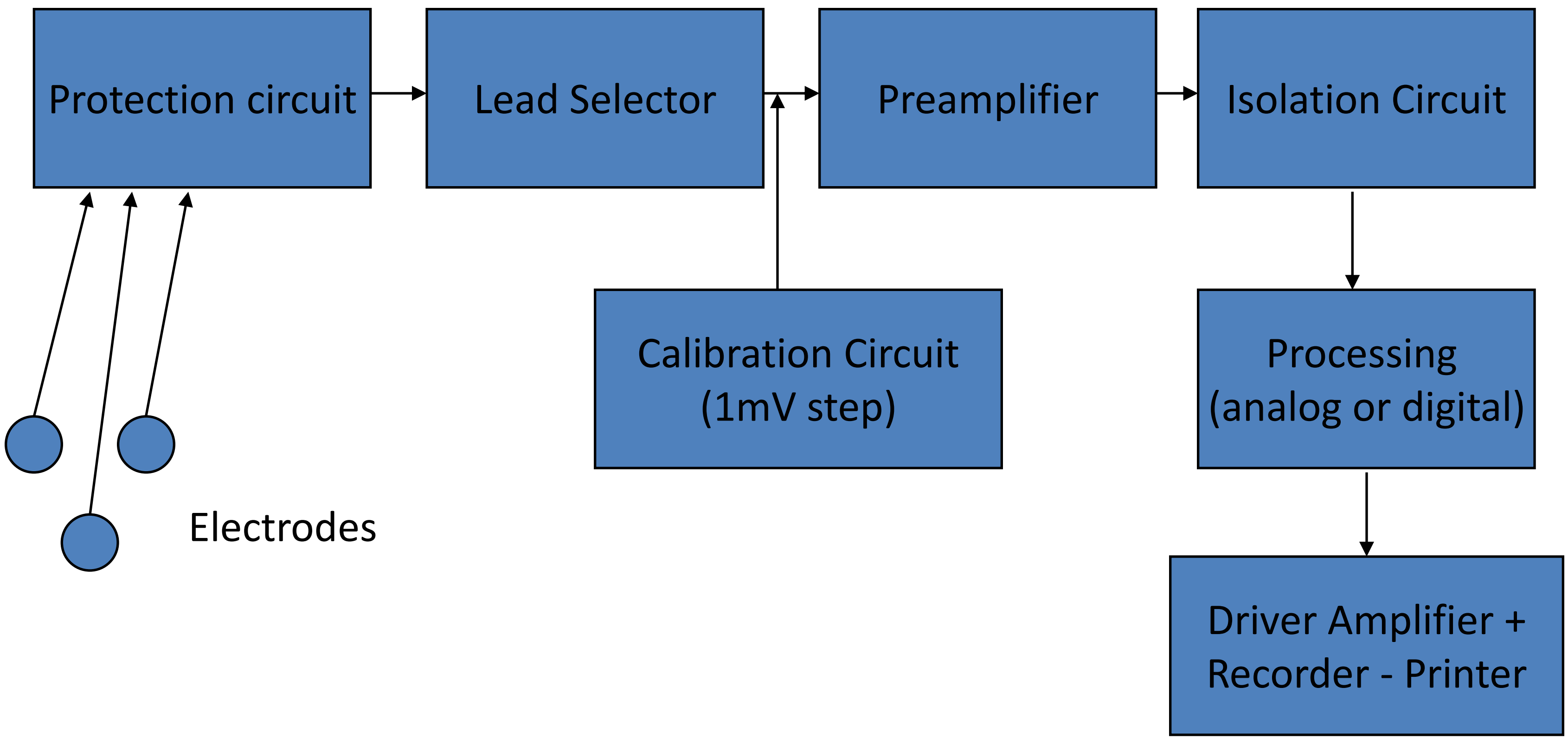
INTERFERENCE REDUCTION IN ECG RECORDINGS BY USING A DUAL GROUND ELECTRODE

Delia Díaz, Óscar Casas, Ramon Pallàs-Areny

Output

- multichannel output – 15 seconds time frame, channels synchroneous
- Print out
  - sensitivity: 2,5 mm/mV; 5 mm/mV; 10 mm/mV; 20 mm/mV
  - pape speed: 10mm/s, 25 mm/s, 50mm/s, 100 mm/s
- Data storage
  - different formats
  - MIT BIH signal database (scientific)
  - interoperability

Symplified Biopotential Amplifier Block Diagram



Amplifier Circuits - DC coupled

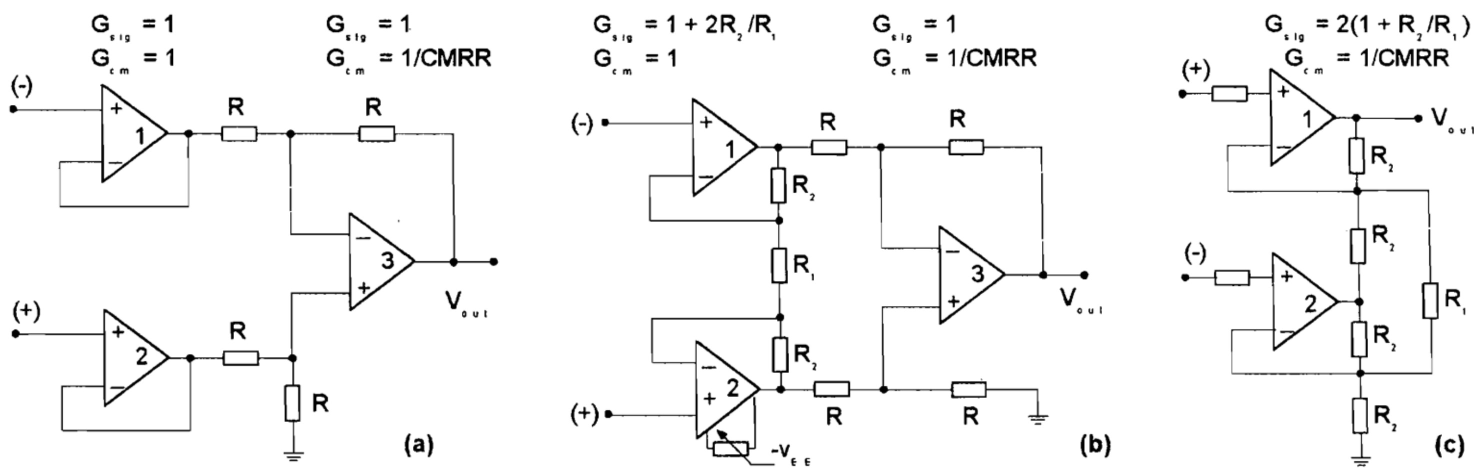


FIGURE 14.1 Typical configuration for the measurement of biopotentials. The biological signal V_{biol} appears between the two measuring electrodes at the right and left arm of the patient, and is fed to the inverting and the noninverting inputs of the differential amplifier. The right leg electrode provides the reference potential for the amplifier with a common mode voltage V_c as indicated.

$$V_{out} = G_D V_{biol} + \frac{G_D V_c}{CMRR} + G_D V_c \left(1 - \frac{Z_{in}}{Z_{in} + Z_1 - Z_2} \right).$$

7

Amplifier Circuits - AC coupled

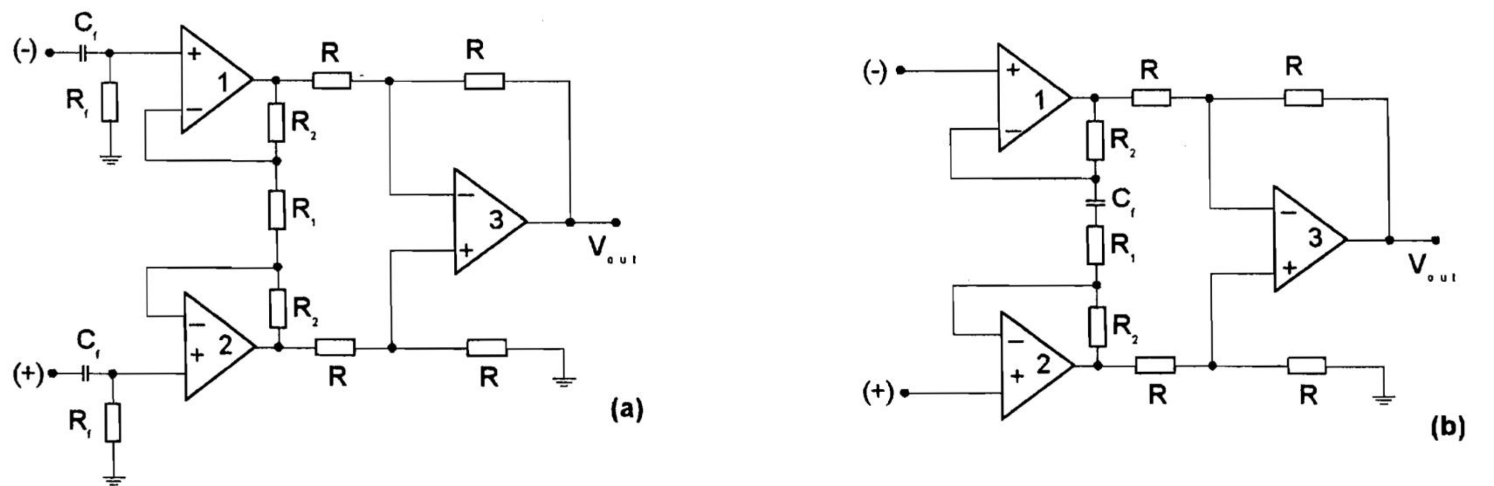


FIGURE 14.5 AC coupled instrumentation amplifier designs. The classical design using an RC high-pass filter at the inputs (a), and a high CMRR "quasi-high-pass" amplifier as proposed by Lu (b).

8

Amplifier Circuits - AC coupled

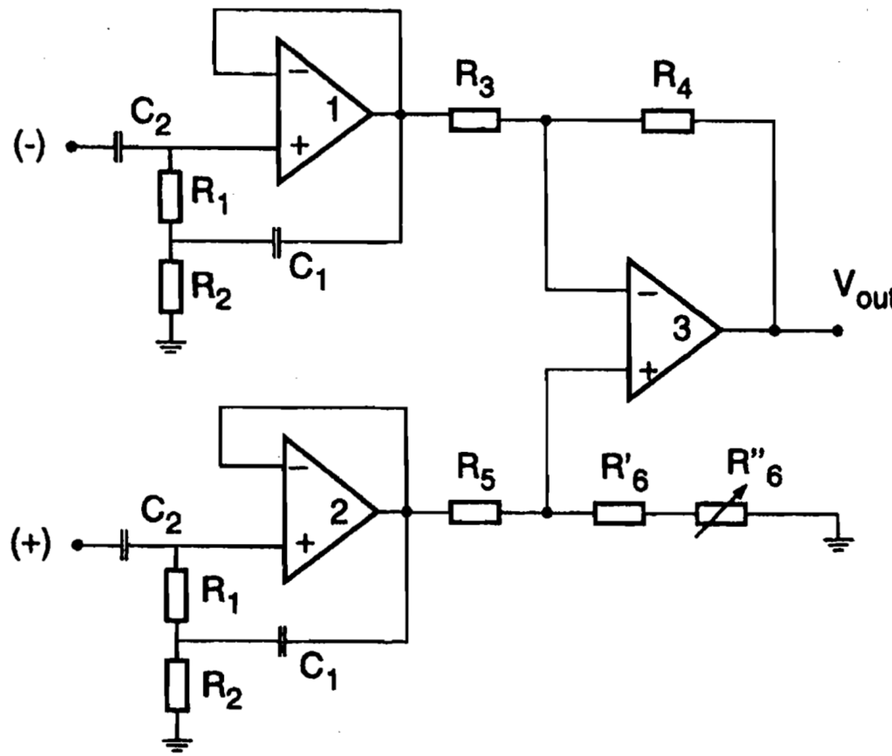
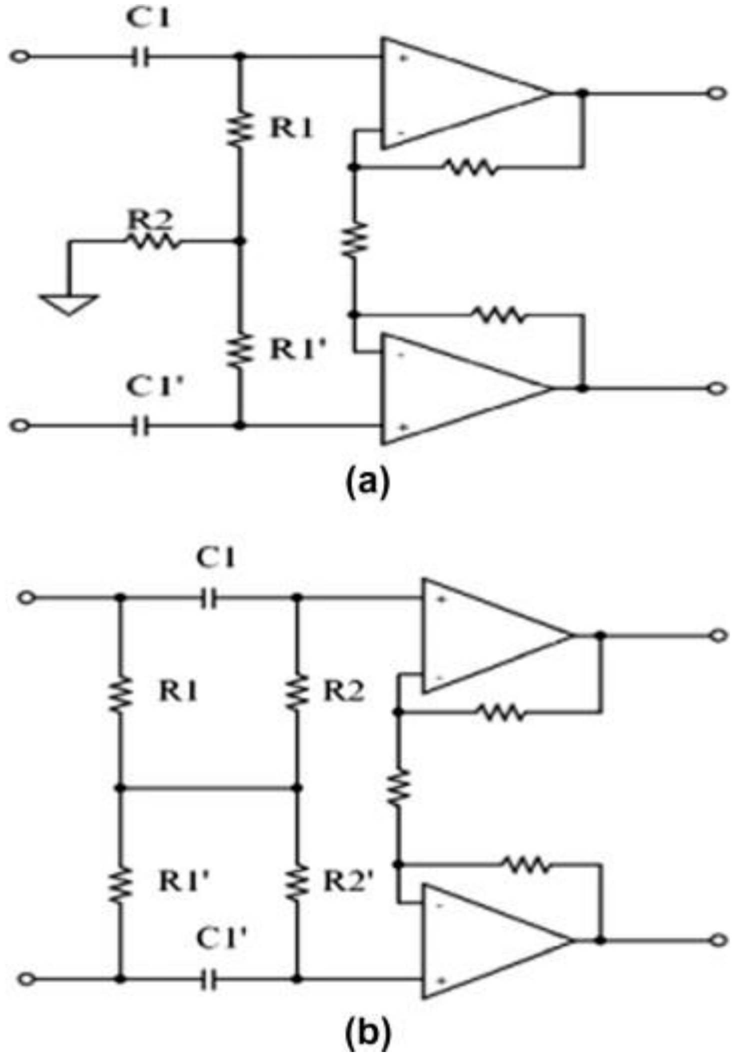


FIGURE 14.6 Composite instrumentation amplifier based on an ac-coupled first stage. The second stage is based on a one op-amp differential amplifier that can be replaced by an instrumentation amplifier.

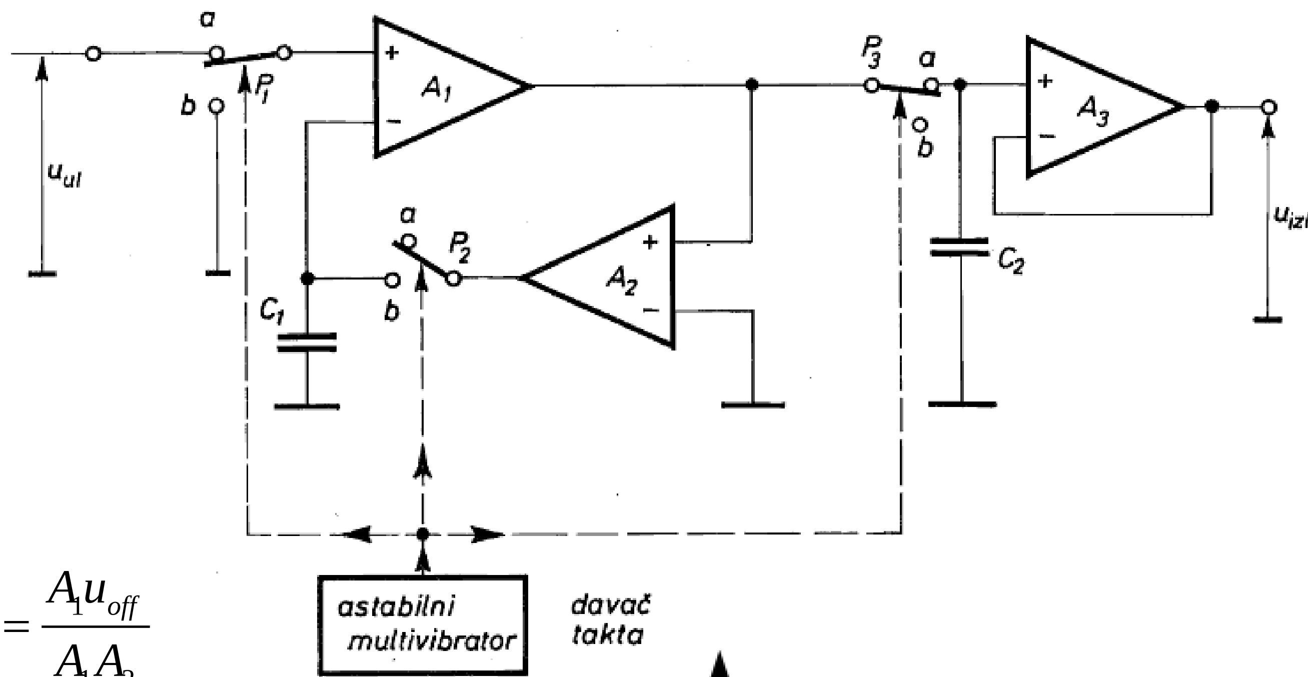
9

Amplifier Circuits - AC coupled



Auto-zero amplifiers

- Automatic nihilation of amplifier offset voltage



$$\Delta u = u_+ - u_-$$

$$u_- = A_2 \cdot u_{izl} = A_2 \cdot A_1 \cdot \Delta u$$

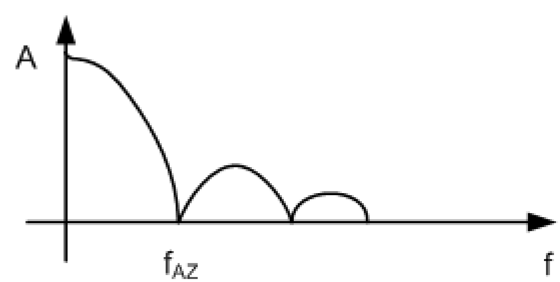
$$u_{izl} = A_1 \cdot \Delta u$$

$$\Delta u = u_+ - A_2 A_1 \cdot \Delta u$$

$$u_+ = \Delta u \left(1 + A_1 A_2\right)$$

$$\Delta u = \frac{u_+}{1 + A_1 A_2} = \frac{A_1 \cdot u_{off}}{1 + A_1 A_2} = \frac{A_1 u_{off}}{A_1 A_2}$$

$$\Delta u = \frac{u_{off}}{A_2}$$



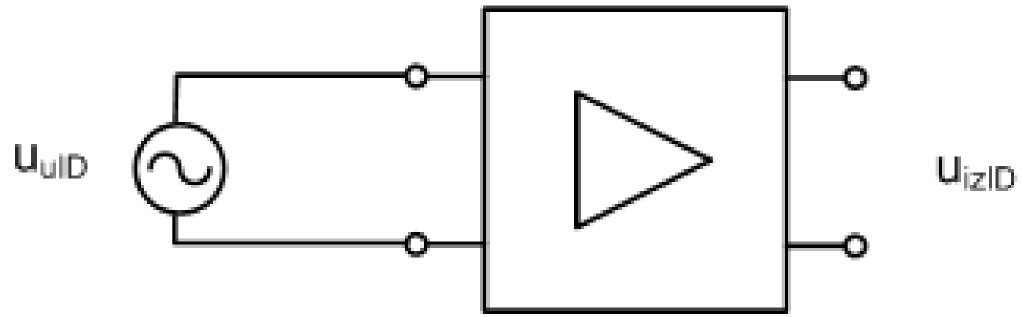
Common Mode Rejection Ratio (CMRR)

- The ratio of the differential gain over the common-mode gain
- Expressed in decibels
- Typically 100 – 120 dB for integrated instrumentation amplifiers
- Function of frequency and source-impedance unbalance.

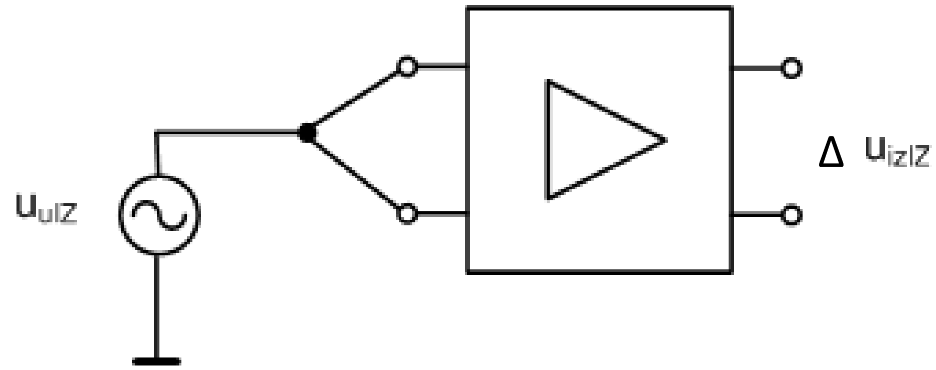
$$CMRR = \frac{G_{Diff}}{G_{Com}}$$

Measurement of CMRR

$$H = \frac{A_D}{A_Z}$$

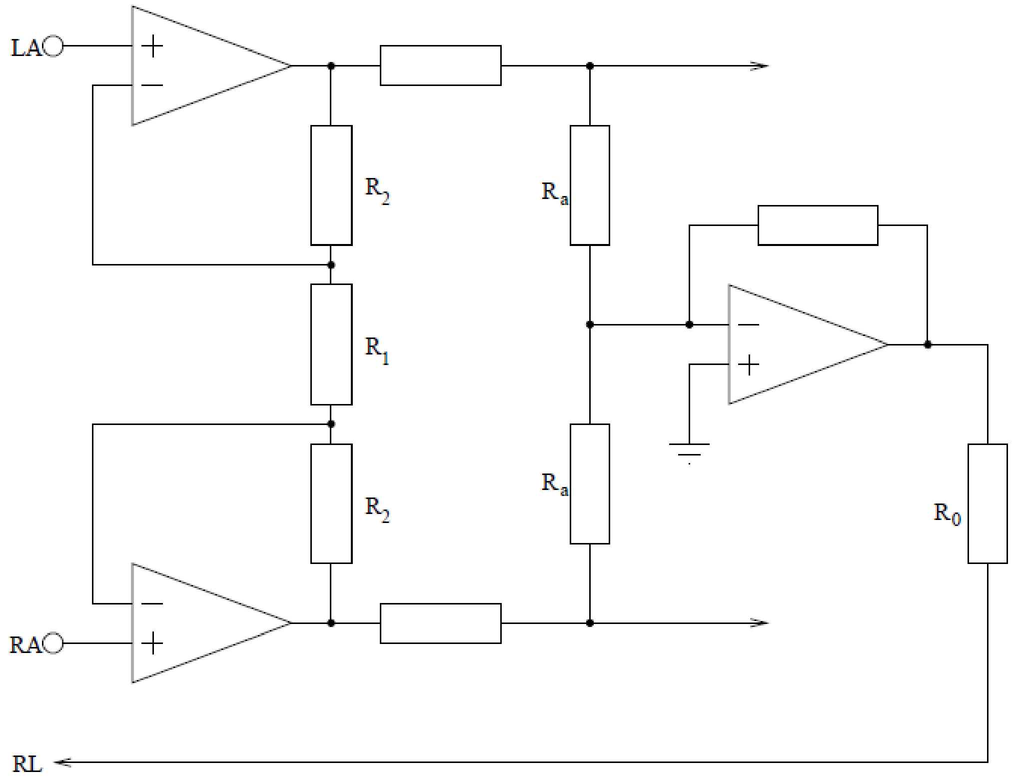


$$A_D = \frac{u_{izlD}}{u_{ulD}}$$



$$A_Z = \frac{\Delta u_{izlZ}}{u_{ulZ}}$$

Right Leg Drive Circuitry



common–mode voltage on the body is sensed by two averaging resistors R_a, inverted and fed back to the right leg through R_0. This circuit actually drives a very small amount of current (less than 1 µA) into the right leg to equal the displacement currents flowing in the body. The body therefore becomes a summing junction in a feedback loop and the negative feedback from this circuit drives the common–mode voltage to a low value.

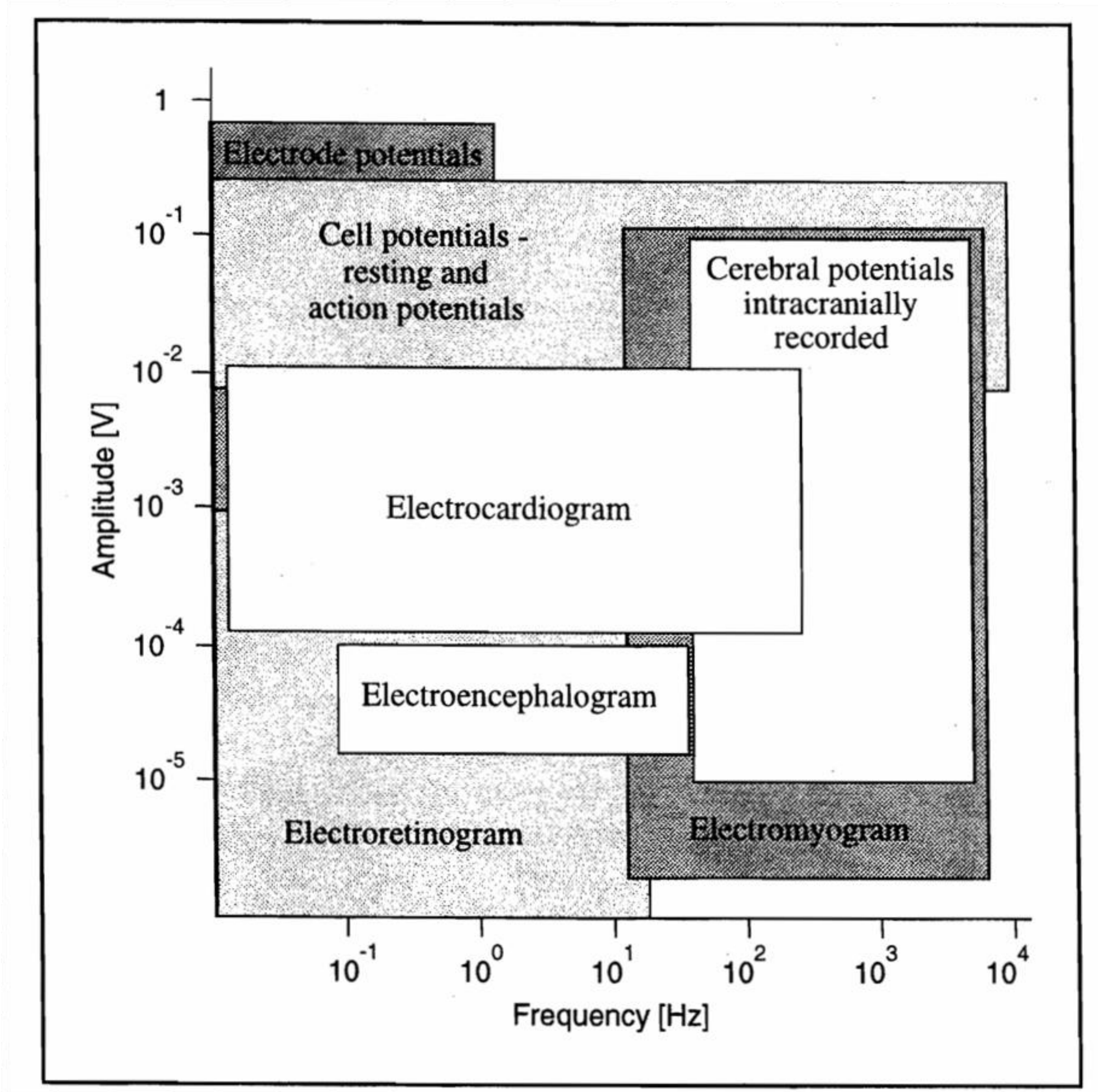


FIGURE 14.3 Amplitudes and spectral ranges of some important biosignals. The various biopotentials completely cover the area from 10^{-6} V to almost 1 V and from dc to 10 kHz.

Isolation amplifiers

- Design of isolation amps:
  - Optical coupling
    - Isolation voltage typ. 4 – 7 kV
    - fast
    - cheap
    - **Nonlinear** – digitazing of signals before the isolation gap
    - Noice high
  - Electromagnetic coupling
    - Isolation voltage up to 10 kV
    - Resolution typ. 12 bit, max. 16 bit
    - fg low, max 1 kHz
  - Capacitive coupling
    - Characteristics worse than other types, but cheapest

Isolation amplifiers

- Galvanic isolation of sensory and the measurement part of the measurement system (attached to the patient) and the processing and display part, usually powered by mains
- Floating principle of measurement of biopotentials
- The aim is also to protect the patient from the potentially dangerous voltages or currents comming from the un-isolated (mains powered part) of the system

Biopotential Isolation Amplifier

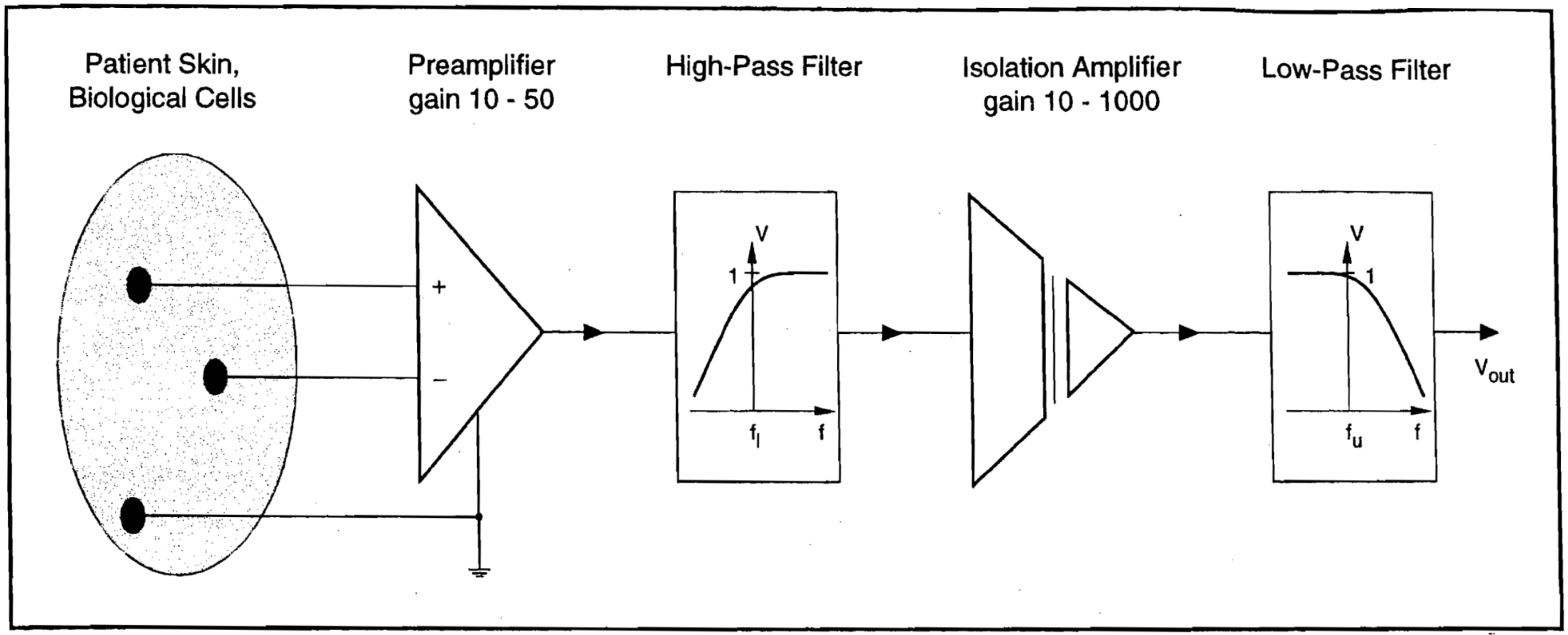
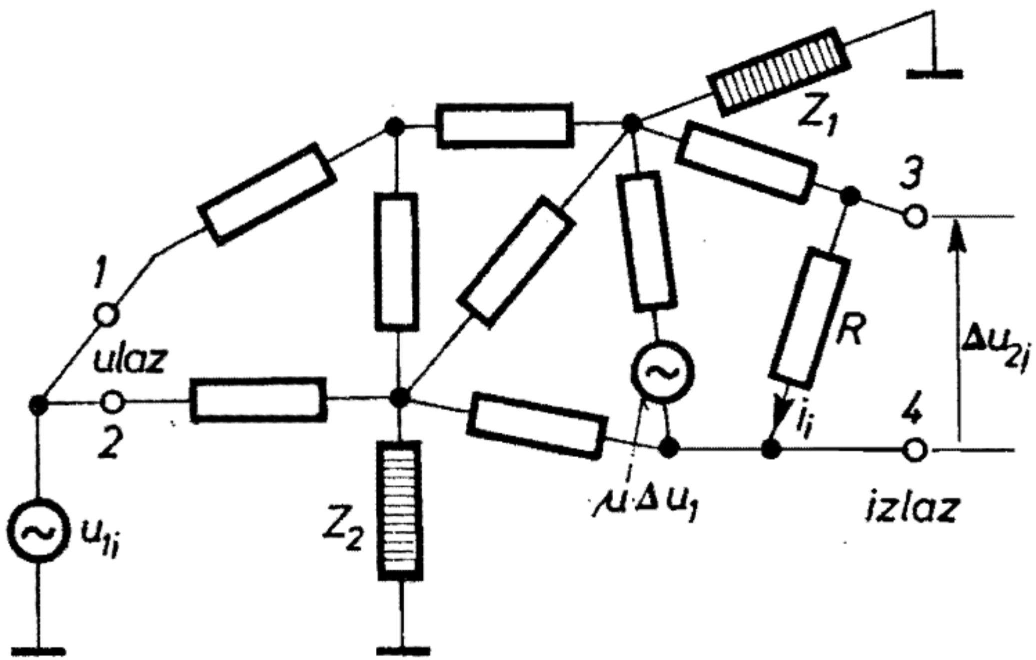


FIGURE 14.2 Schematic design of the main stages of a biopotential amplifier. Three electrodes connect the patient to a preamplifier stage. After removing dc and low-frequency interferences, the signal is connected to an output low-pass filter through an isolation stage that provides electrical safety to the patient, prevents ground loops, and reduces the influence of interference signals.

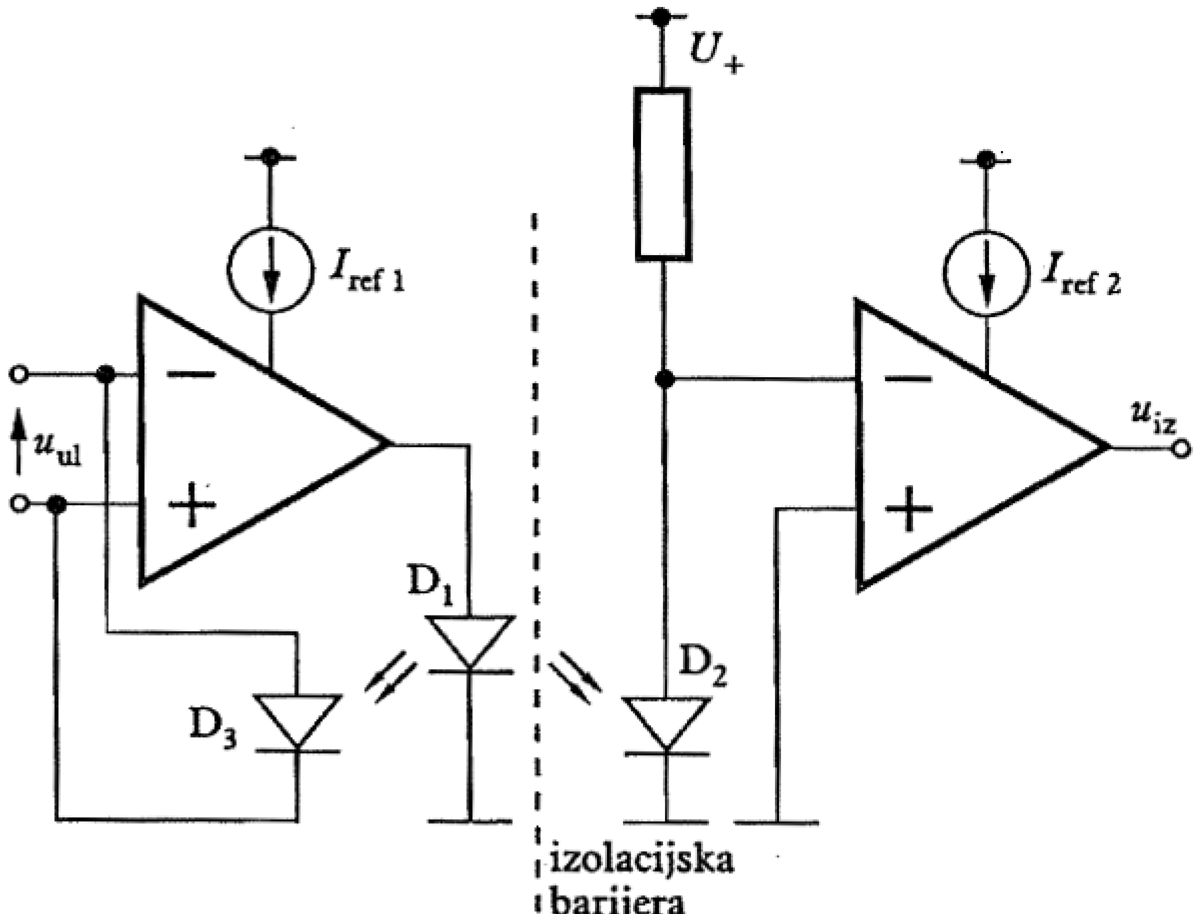
18

Principle of floating measurements



$$\lim H = \frac{A_d}{\dfrac{\Delta u_{2i}}{u_{1i}}} = \infty \qquad za\ Z_n \to \infty$$

Otically coupled isolation amp

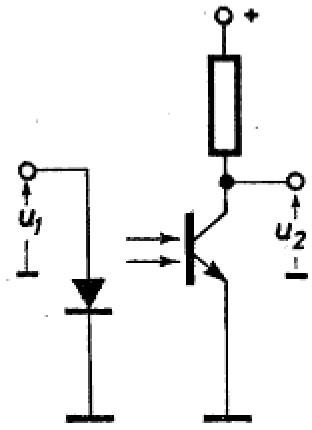


Linearisation

$$u_2 = f^{-1}\left(\frac{u_1}{R_1}\right)$$

$$i_2 = f\left(u_1\right)$$

$$i_2{}' = f'\left(u_3\right)$$



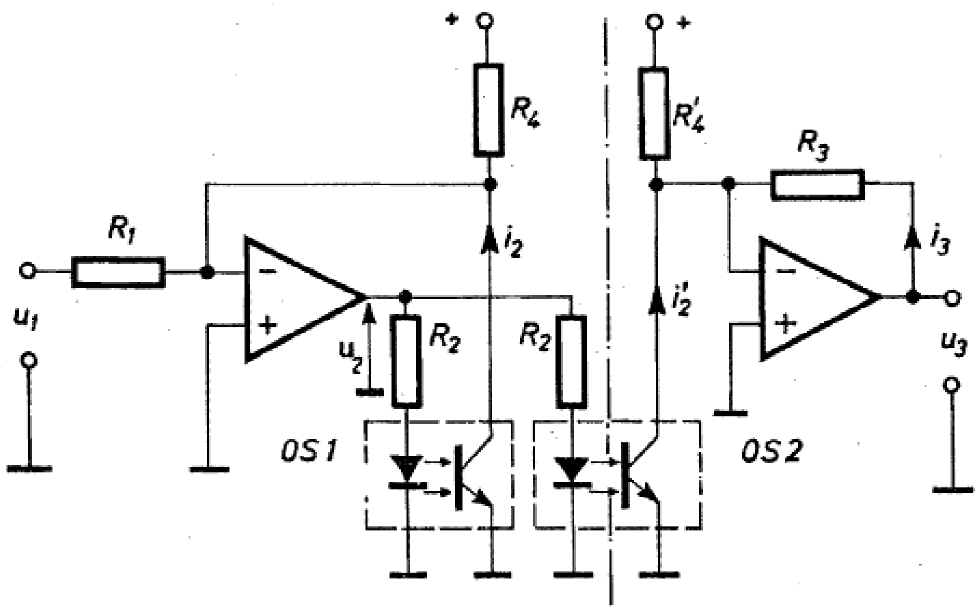
$$\frac{u_3}{R_3} = f'\left(u_2\right)$$

$$\frac{u_3}{R_3} = f'\left[f^{-1}\left(\frac{u_1}{R_1}\right)\right]$$

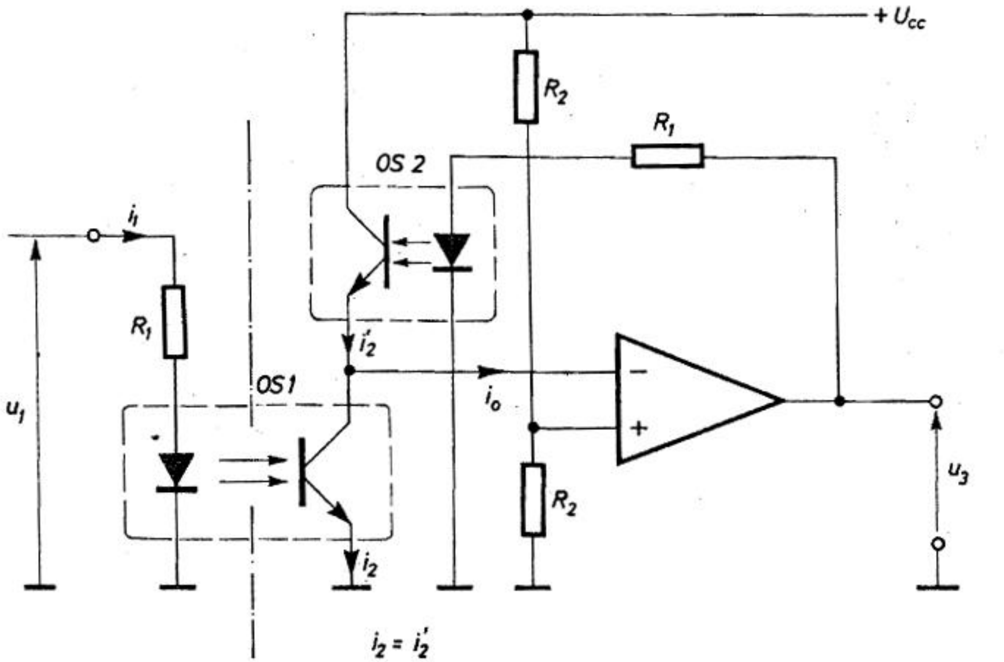
$$\frac{u_3}{R_3} = f'\left[f^{-1}\left(\frac{u_1}{R_1}\right)\right] = \frac{u_1}{R_1}$$

$$f\left(u_1\right) = f'\left(u_3\right) \qquad \frac{u_3}{u_1} = \frac{R_3}{R_1}$$

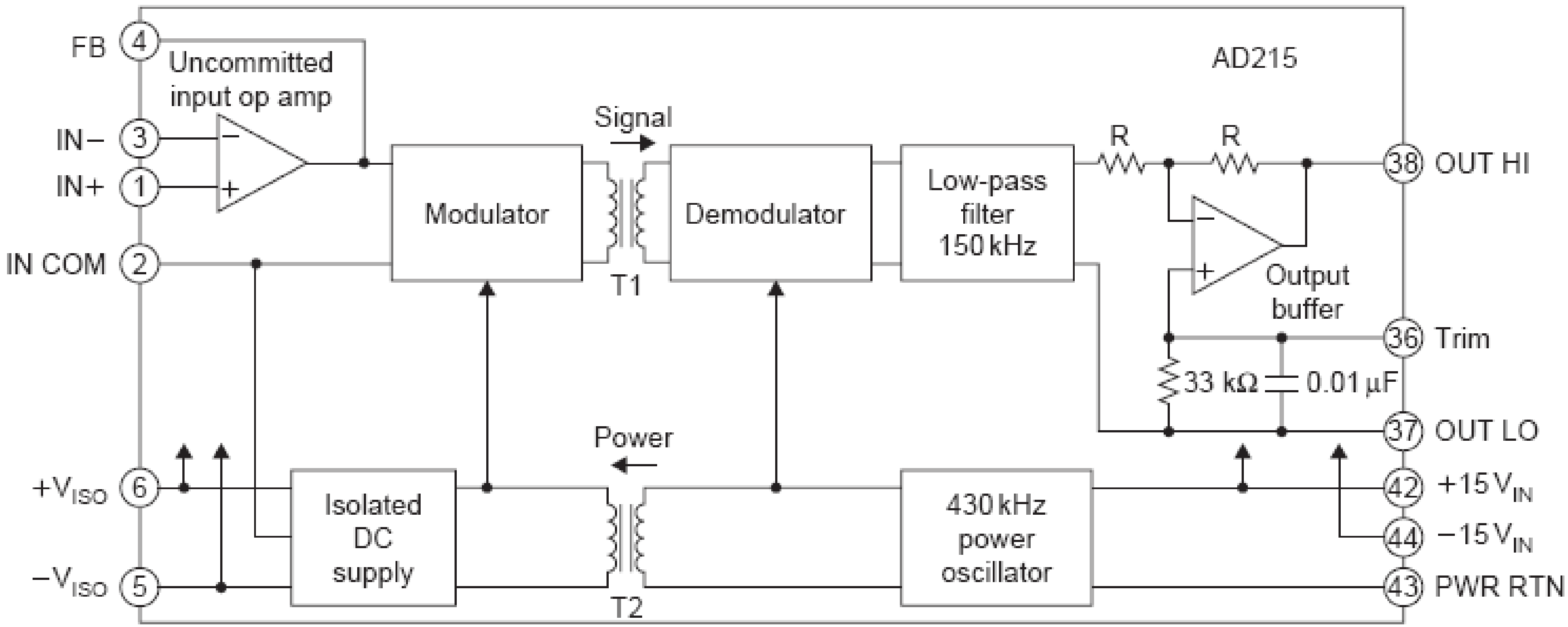
$$u_1 = u_3$$



Linearisation

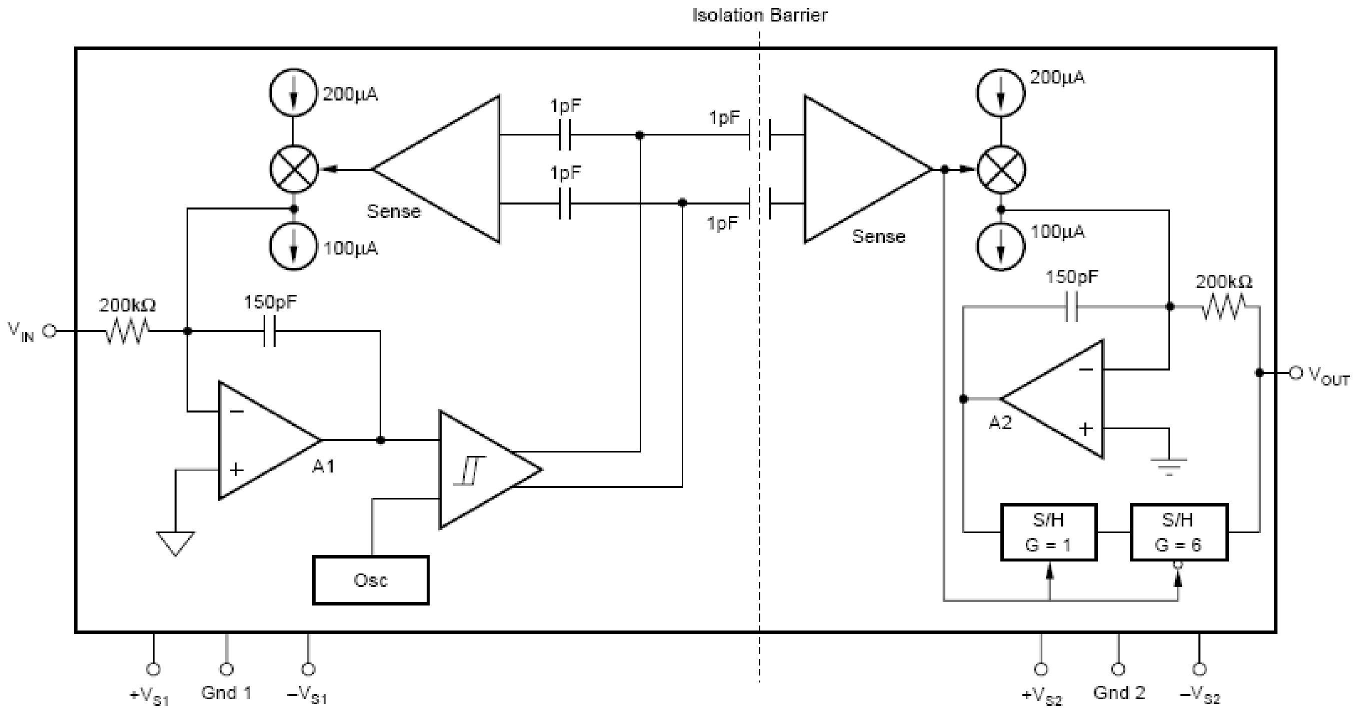


EM coupled amps - AD 215

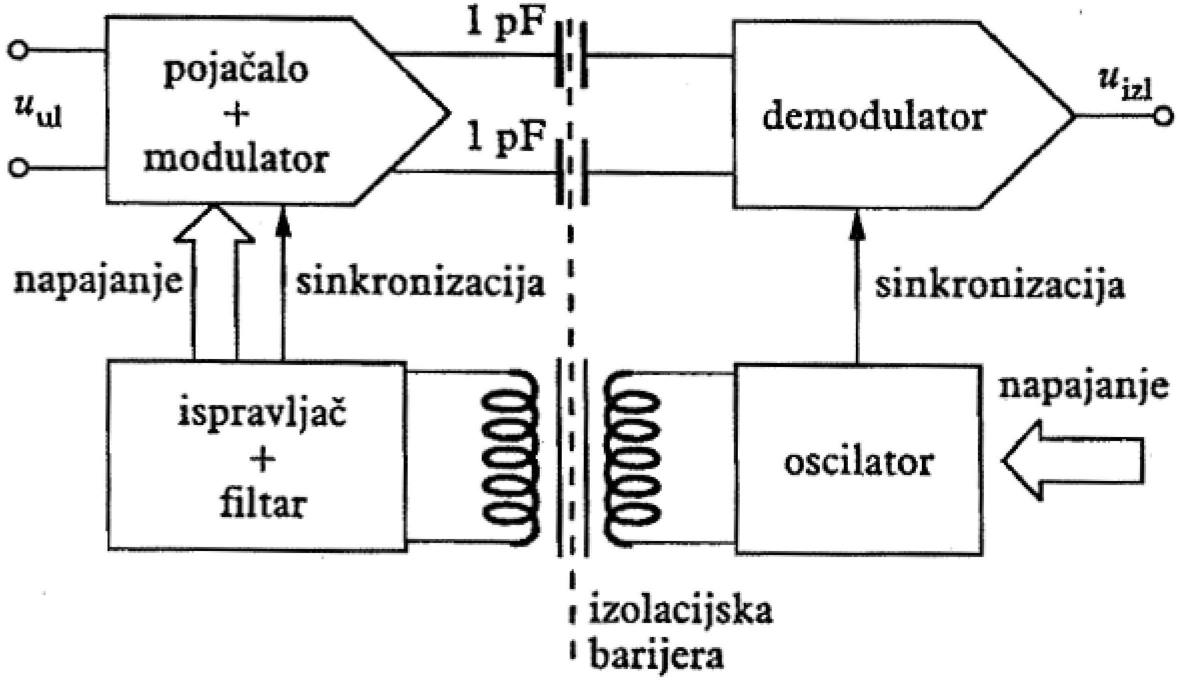


Capacitavly coupled isolation amps

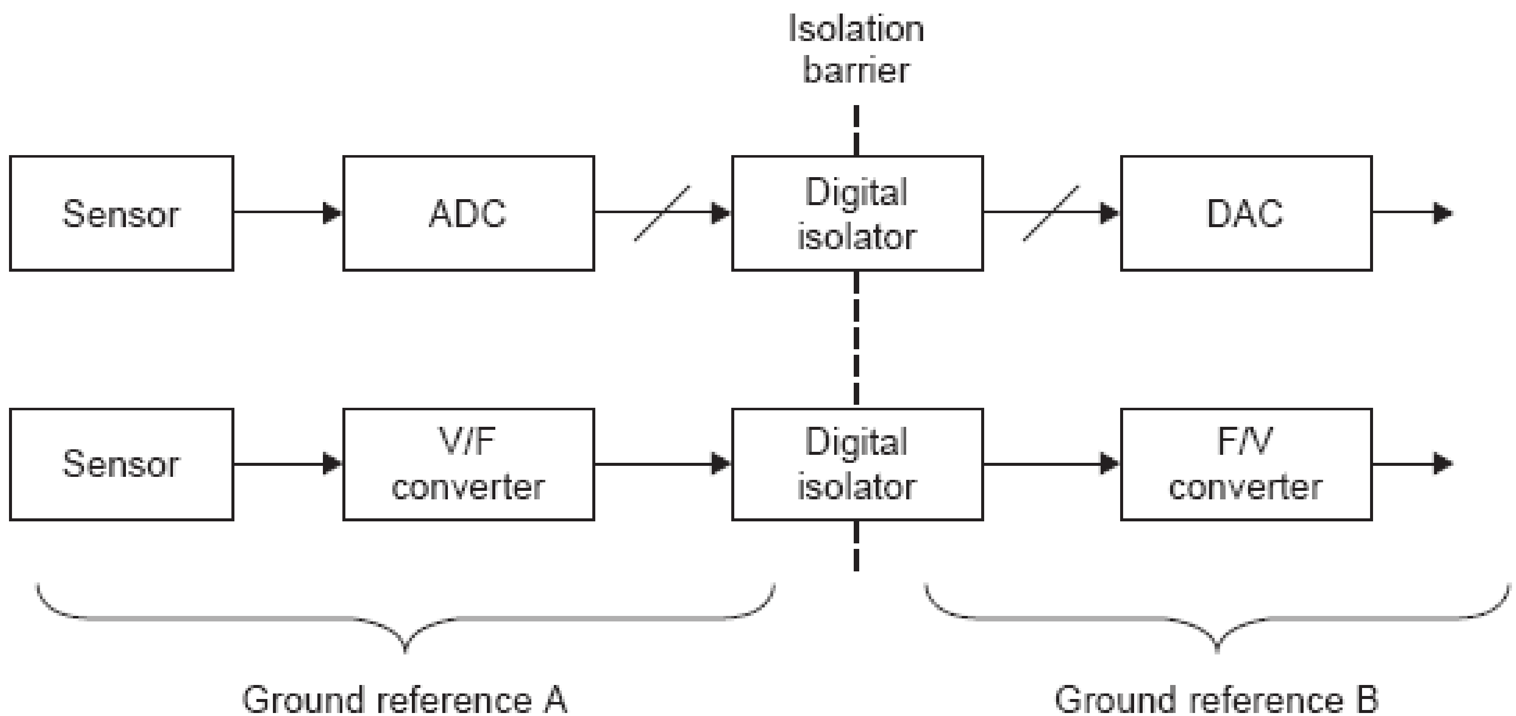
- ISO 124
- The input signal is frequency modulated
- f_{osc} 500 kHz; $V_{izo} = 2{,}4\ kV_{ef}$



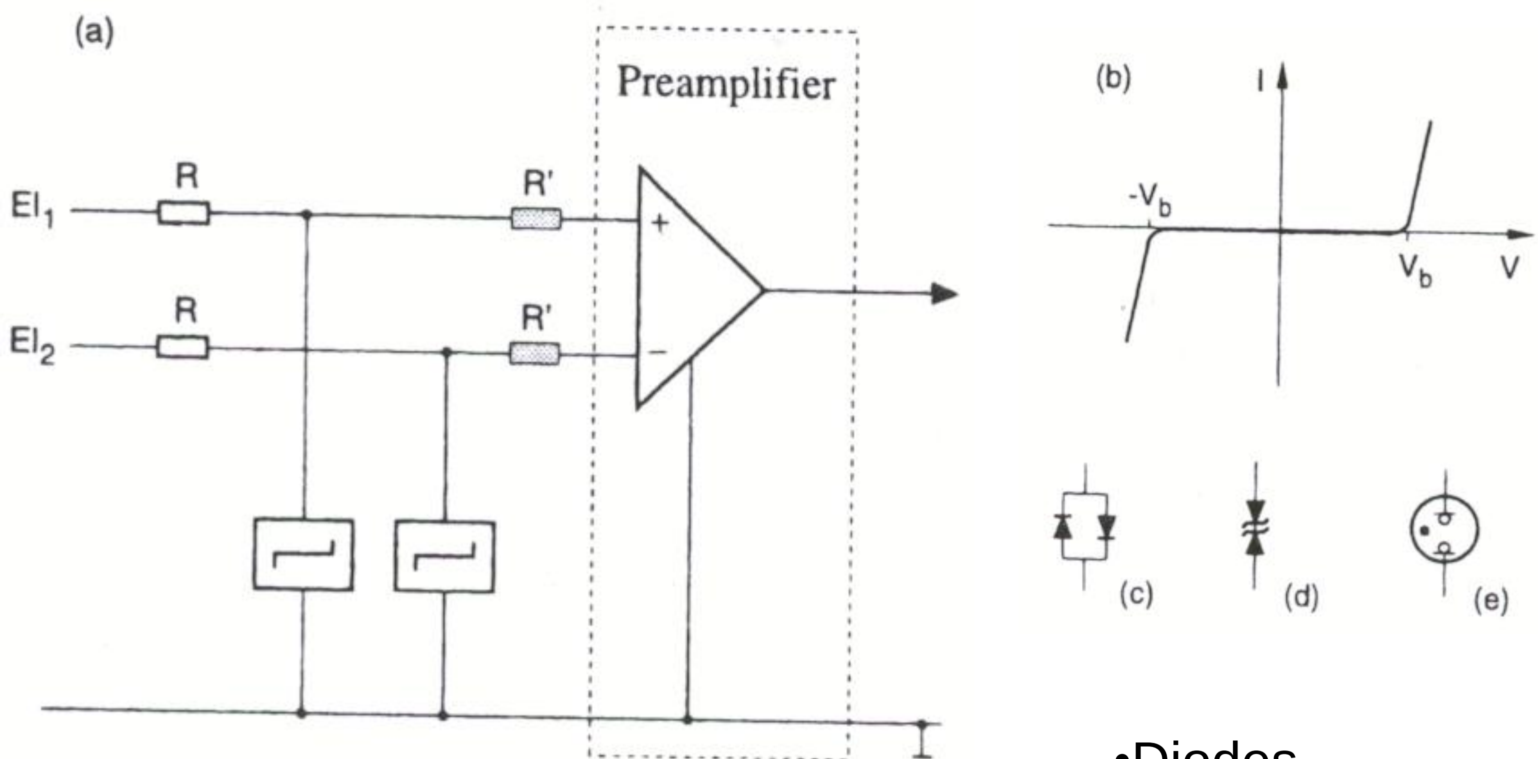
Capacitively coupled isolation amps



Digital isolation amp principles



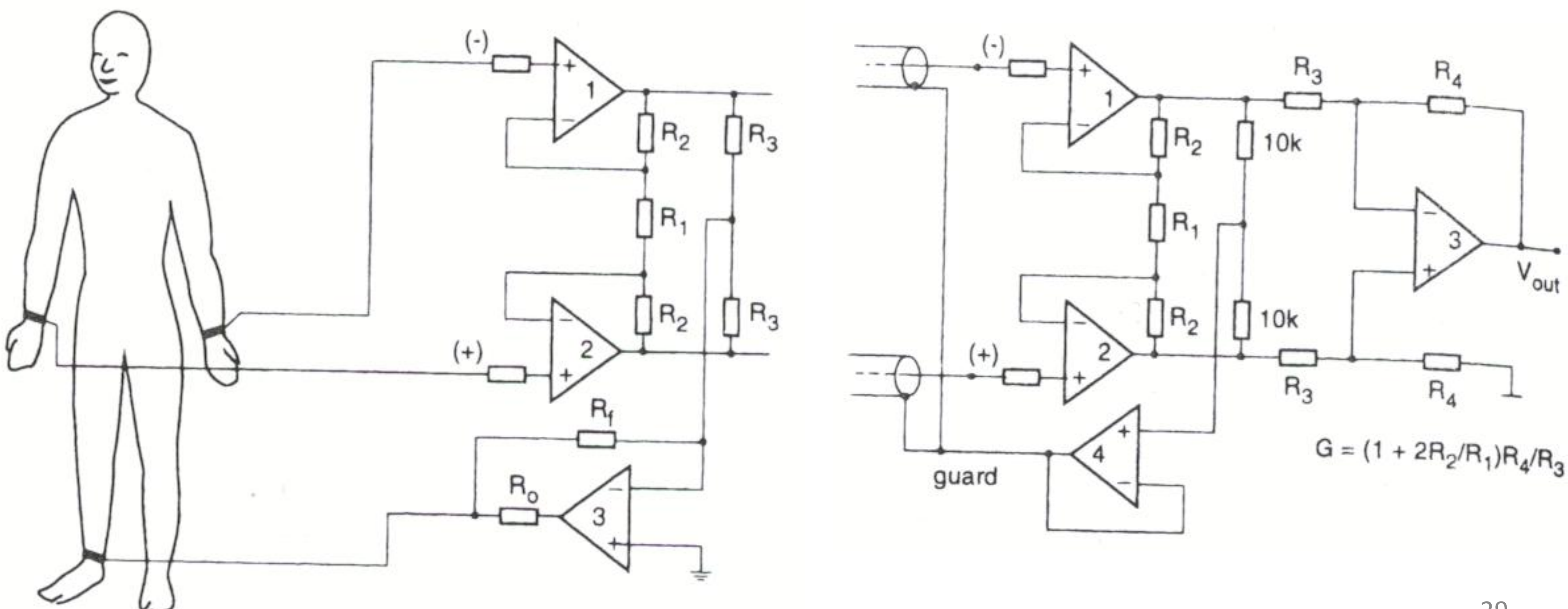
Protection of the input of the amplifier



- Diodes
- Zener diodes
- Gas-discharge tubes

Input guarding

- Increases:
  - input impedance of the amplifier
  - CMRR



Literature

- John G. Webster: Medical Instrumentation, Chapter 6, Biopotential Amplifiers

- Homework: Problems 5.17 and 5.18