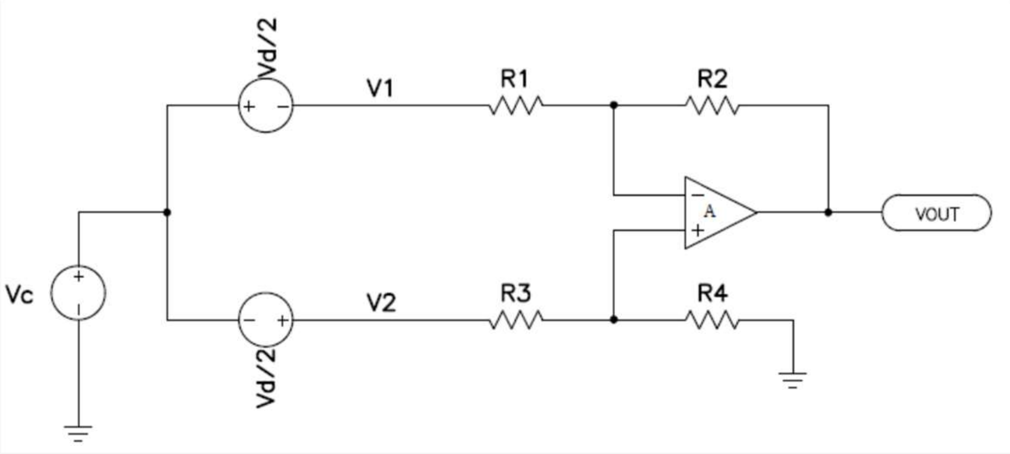
# OSNOVE BIOMEDICINSKOG INŽENJERSTVA

DIFERENCIJALNI POJAČAVAČ

# DIFERENCIJALNI POJAČAVAČ

- Polazna osnova za projektovanje elektrofizioloskog pojačavača;
- Pojačava razliku signala na svojim ulaznim priključcima;
- Veliko diferencijalno pojačanje;
- Visok CMRR;
- Mala ulazna impedansa;




$$V_1 = V_C - \frac{V_D}{2}$$

$$V_2 = V_C + \frac{V_D}{2}$$

$$V^+ = \frac{R_4}{R_3 + R_4} \cdot V_2$$

Zbog postajanja negativne povratne sprege i velikog pojačanja u otvorenoj povratnoj sprezi, naponi na invertujućem i neinvertujućem ulazu su jednaki, tj.

$$V^- = V^+ = \frac{R_4}{R_3 + R_4} \cdot V_2$$

$$V_{OUT} = \left( \frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} - \frac{R_2}{R_1} \right) \cdot V_C + \frac{1}{2} \cdot \left( \frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} + \frac{R_2}{R_1} \right) \cdot V_D$$

$$V_{OUT} = A_C \cdot V_C + A_D \cdot V_D$$

$$A_C = \frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} - \frac{R_2}{R_1}$$

$$A_D = \frac{1}{2} \cdot \left( \frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} + \frac{R_2}{R_1} \right)$$

# Diferencijalni pojačavač

Ad – Pojačanje diferencijalnog signala
Ac – Slabljenje signala zajedničkog moda

$$CMRR_{dB} = 20\log\left(\frac{A_D}{A_C}\right) = 20\log\left(\frac{R_4 \cdot (R_1 + R_2) + R_2 \cdot (R_3 + R_4)}{2 \cdot (R_4 \cdot (R_1 + R_2) - R_2 \cdot (R_3 + R_4))}\right)$$

Da bi CMRR bio što je moguće veći, neophodno je balansirati pojačavač.

$$A_C = 0$$

$$\frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} - \frac{R_2}{R_1} = 0 \Rightarrow \frac{R_4}{R_3} = \frac{R_2}{R_1}$$

$$A_D = \frac{R_2}{R_1}$$

# Diferencijalni pojačavač

Ukoliko na ulaz pojačavača postavimo elektrode istih otpornosti, pojačanje pojačavača postaje:

$$A_D = \frac{R_2}{R_1 + R_E}$$

Ukoliko na ulaz pojačavača postavimo elektrode različitih otpornosti, pojačanje pojačavača postaje:

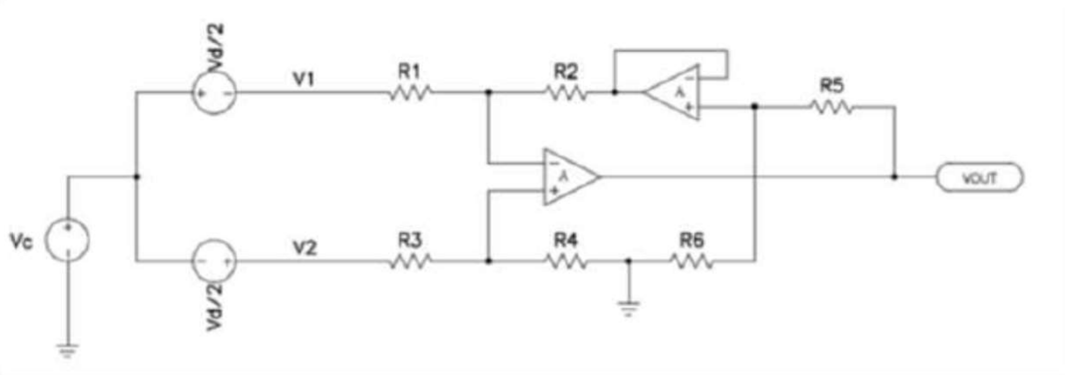
$$V_{OUT} = A_C \cdot V_C + A_D \cdot V_D$$

$$A_C = \left( \frac{R_2}{R_1 + R_2 + R_{E1}} \cdot \frac{R_1 + R_2 + R_{E1}}{R_1 + R_{E2}} - \frac{R_2}{R_1 + R_{E1}} \right)$$

$$A_D = \frac{1}{2} \cdot \left( \frac{R_2}{R_1 + R_2 + R_{E1}} \cdot \frac{R_1 + R_2 + R_{E1}}{R_1 + R_{E2}} + \frac{R_2}{R_1 + R_{E1}} \right)$$

# Modifikovani diferencijalni pojačavač

- Standardni diferencijalni pojačavač ima problem jednostavne promene diferencijalnog pojačanja;
- Problem promene pojačanja se može rešiti dodavanjem bafera i razdelnika napona u negativnu povratnu spregu;




$$V_{OUT} = \frac{R_5 + R_6}{R_6} \cdot \left(\frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} - \frac{R_2}{R_1}\right) \cdot V_C + \frac{1}{2} \cdot \frac{R_5 + R_6}{R_6} \cdot \left(\frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} + \frac{R_2}{R_1}\right) \cdot V_D$$

$$V_{OUT} = A_C \cdot V_C + A_D \cdot V_D$$

$$A_C = \frac{R_5 + R_6}{R_6} \cdot \left(\frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} - \frac{R_2}{R_1}\right)$$

$$A_D = \frac{1}{2} \cdot \frac{R_5 + R_6}{R_6} \cdot \left(\frac{R_1 + R_2}{R_1} \cdot \frac{R_4}{R_3 + R_4} + \frac{R_2}{R_1}\right)$$

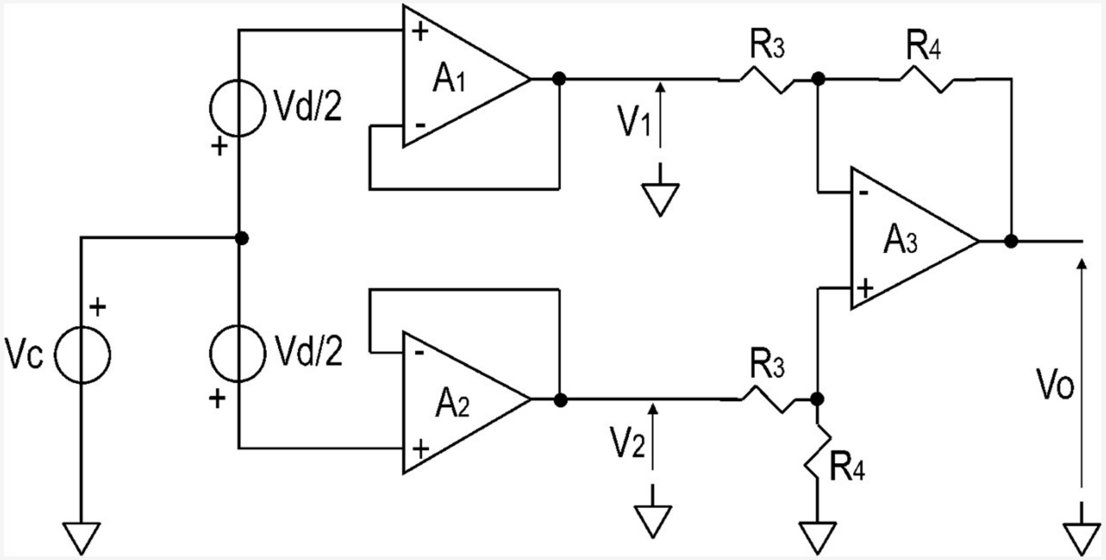
Na osnovu izraza za Ac, može se videti da modifikacija ne utiče na potiskivanje signala zajedničkog moda i da se balansiranje vrši isto kao kod standardnog diferencijalnog pojačavača.

$$A_D = \frac{R_2}{R_1} \cdot \frac{R_5 + R_6}{R_6}$$

# Modifikovani diferencijalni pojačavač

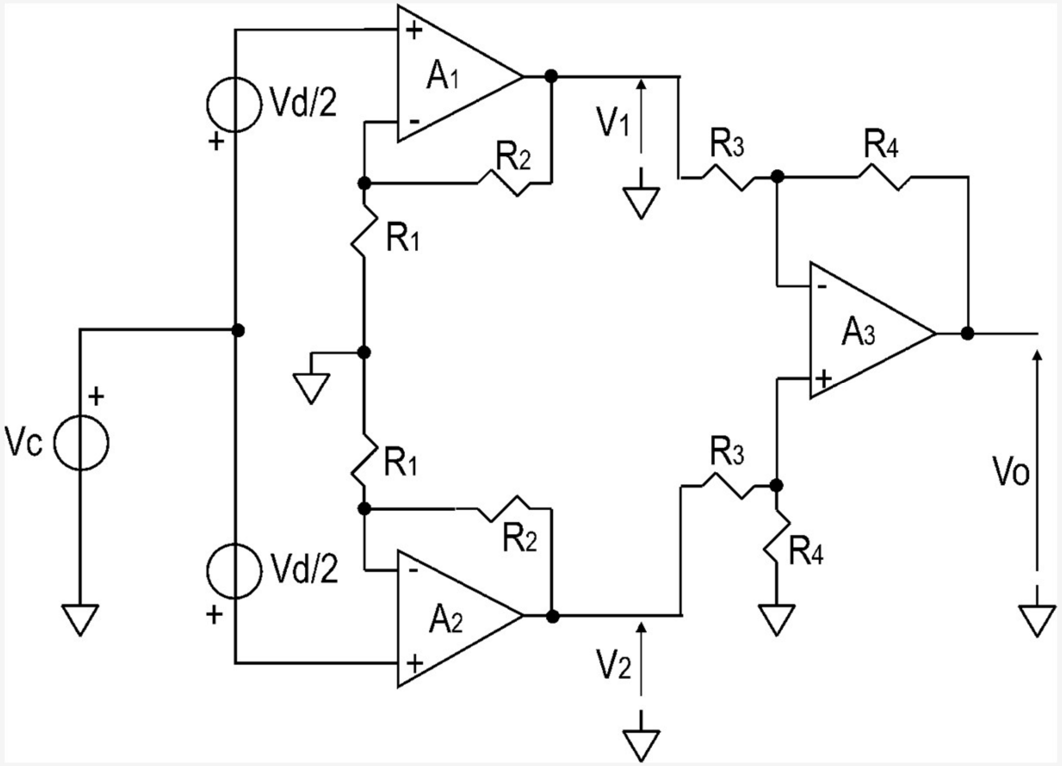
- Modifikacijom standardnog diferencijalnog pojačavača, rešen je problem jednostavne promene pojačanja;
- Pojačanje se može menjati u dva stepena. Preporuka je da se prvo postavi minimalna vrednost pojačanja pomoću otpornika R1 i R2, a u dodatnoj mreži da se postavi ostatak pojačanja;
- Jednostavna promena pojačanja se može implementirati ubacivanjem potenciometra umesto otpornika R5;
- Problem male ulazne impedanse ostaje nerešen;

# Baferovani diferencijalni pojačavač



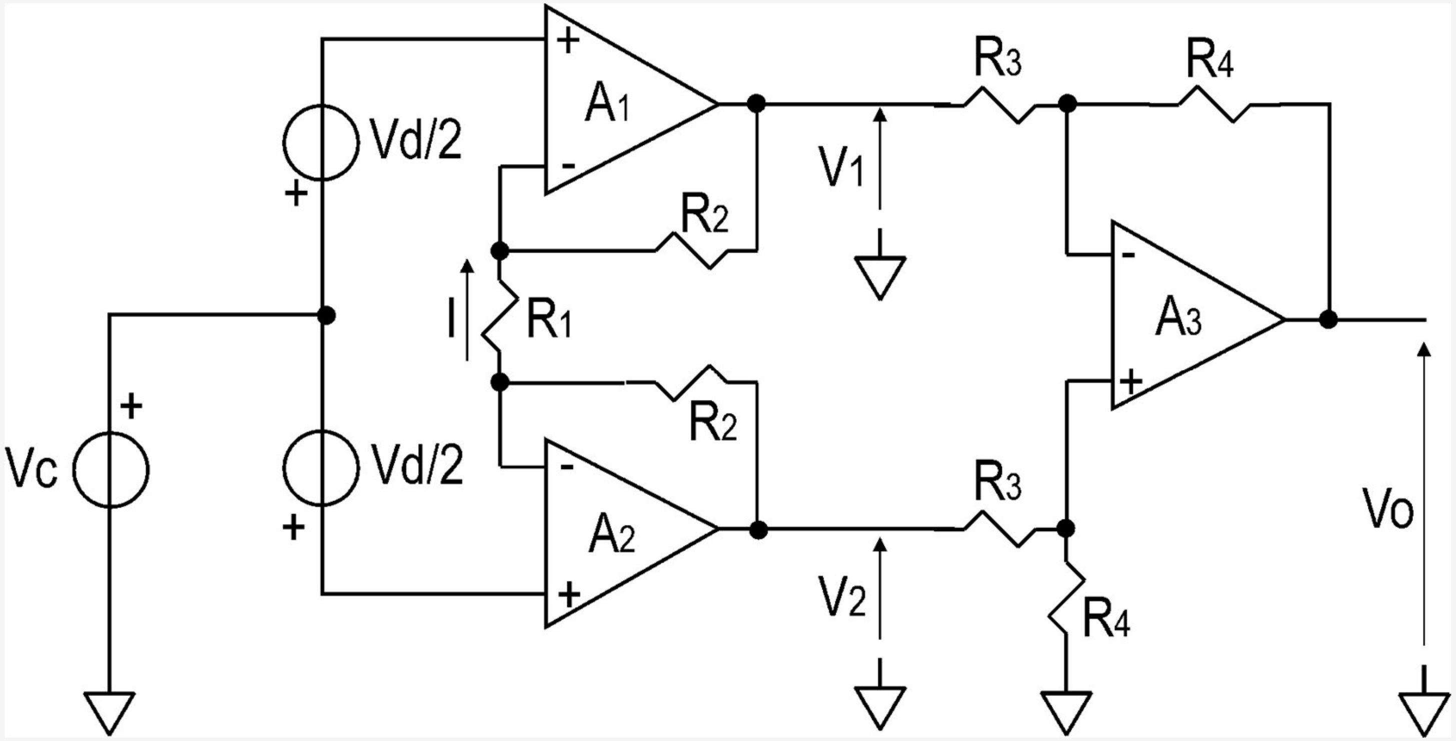

$$V_1 = V_c - \frac{V_d}{2} \quad V_2 = V_c + \frac{V_d}{2} \quad V_o = \frac{R_4}{R_3}\left(V_2 - V_1\right)$$

# Ulazni stepen sa neinvertujućim pojačavačima



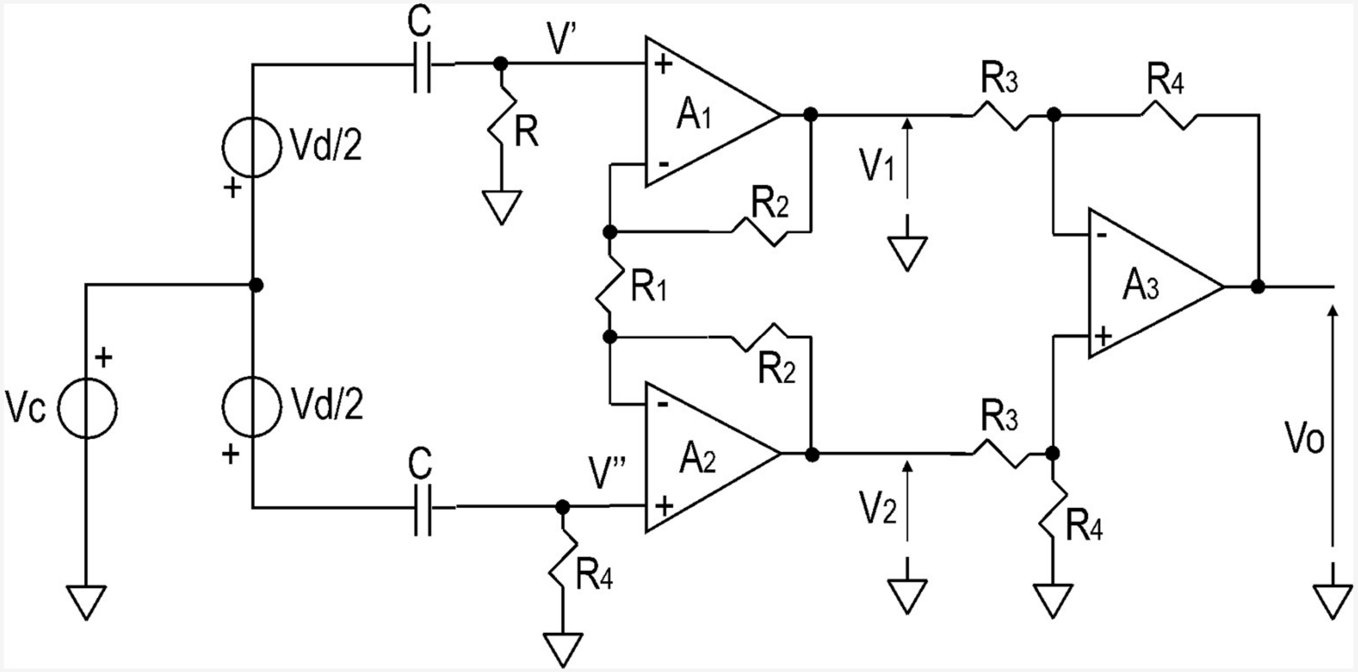

$$V_1 = \left(1 + \frac{R_2}{R_1}\right)\left(V_c - \frac{V_d}{2}\right) \quad V_2 = \left(1 + \frac{R_2}{R_1}\right)\left(V_c + \frac{V_d}{2}\right) \quad V_o = \frac{R_4}{R_3}\left(V_2 - V_1\right)$$

# Instrumentacioni pojačavač sa tri operaciona pojačavača



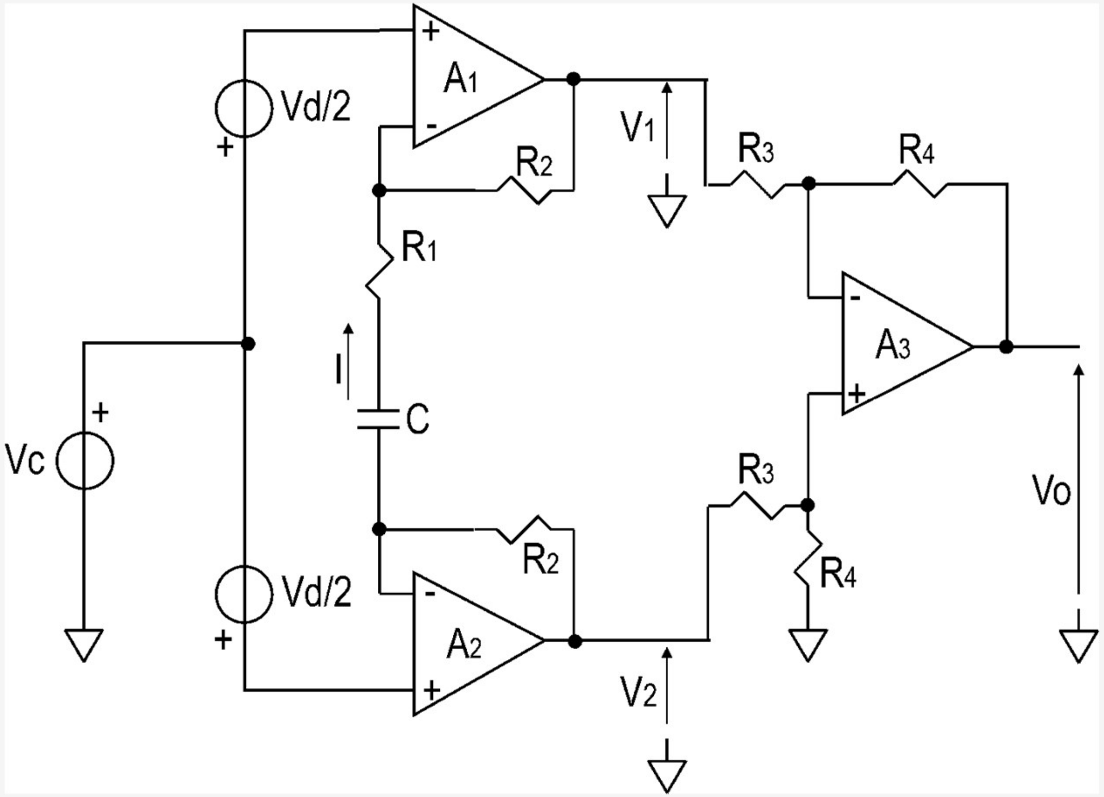

$$I = \frac{V_d}{R_1} \quad V_1 = V_c - (1 + \frac{2R_2}{R_1})\frac{V_d}{2} \quad V_2 = V_c + (1 + \frac{2R_2}{R_1})\frac{V_d}{2} \quad V_o = \frac{R_4}{R_3}\left(V_2 - V_1\right)$$

# Potiskivanje jednosmerne komponente diferencijalnog signala na ulazu pojačavača



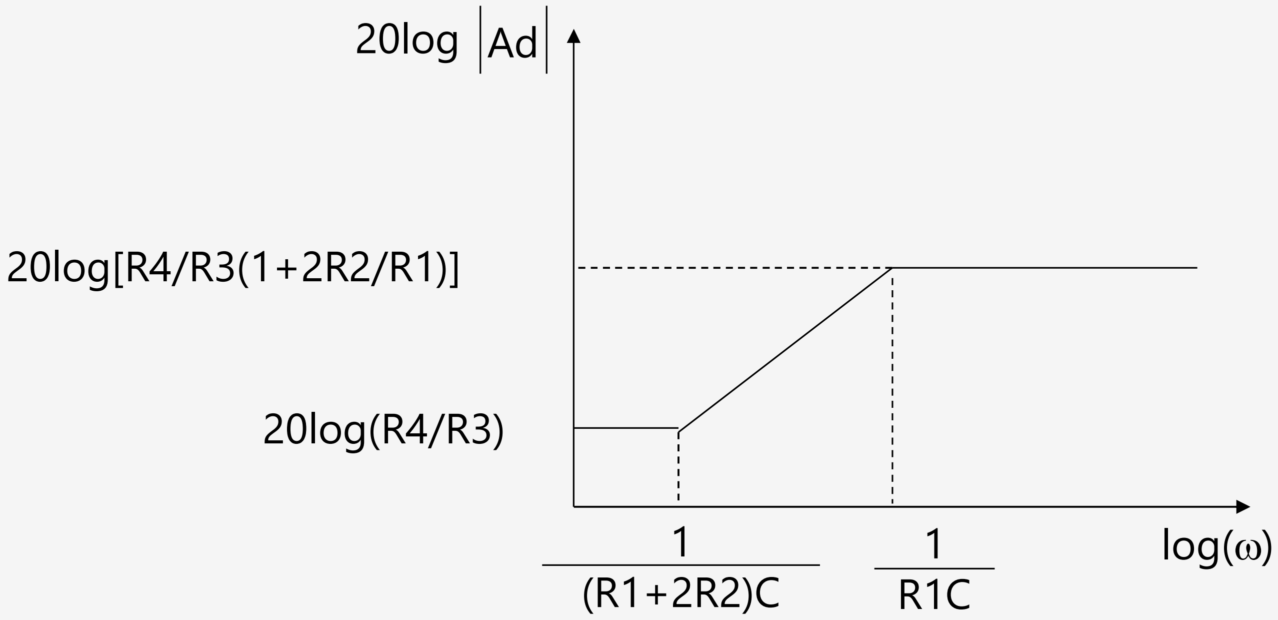

$$V' = \left(V_c - \frac{V_d}{2}\right)\frac{sCR}{1+sCR} \quad V'' = \left(V_c + \frac{V_d}{2}\right)\frac{sCR}{1+sCR} \quad V_o = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1}\right)\frac{sCR}{1+sCR}V_d$$

# Potiskivanje jednosmerne komponente diferencijalnog signala na ulazu pojačavača

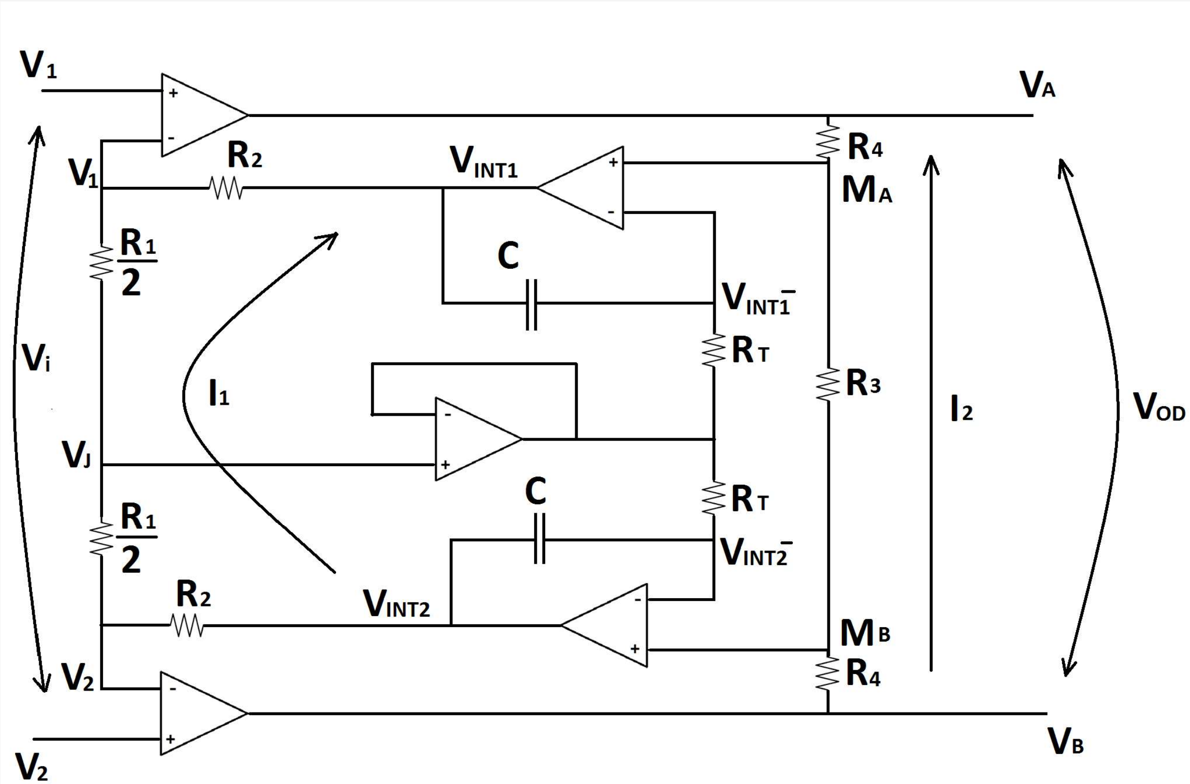



$$I = \frac{V_d}{R_1 + \frac{1}{sC}} \quad V_1 = V_c - \left(1 + \frac{2R_2}{R_1 + \frac{1}{sC}}\right)\frac{V_d}{2} \quad V_2 = V_c + \left(1 + \frac{2R_2}{R_1 + \frac{1}{sC}}\right)\frac{V_d}{2} \quad V_o = \frac{R_4}{R_3}\frac{1 + sC(R_1 + 2R_2)}{1 + sCR_1}V_d$$

# Frekvencijska karakteristika pojačavača

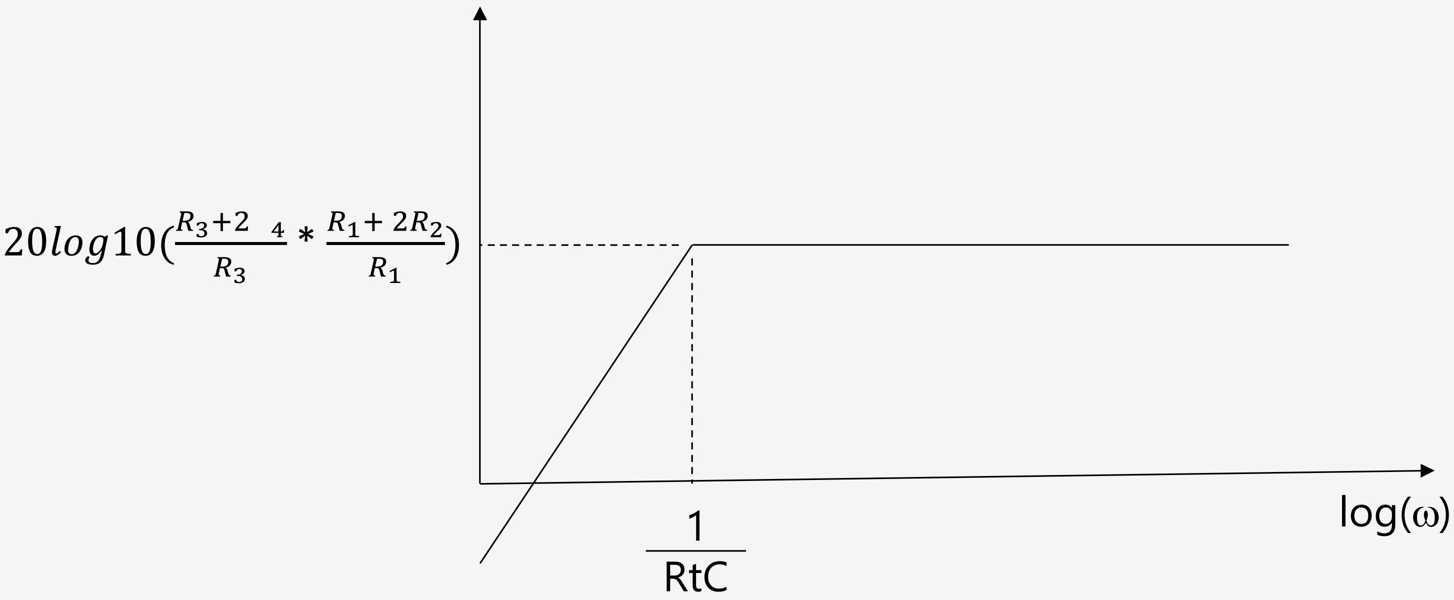


# Potiskivanje jednosmerne komponente diferencijalnog signala na ulazu pojačavača

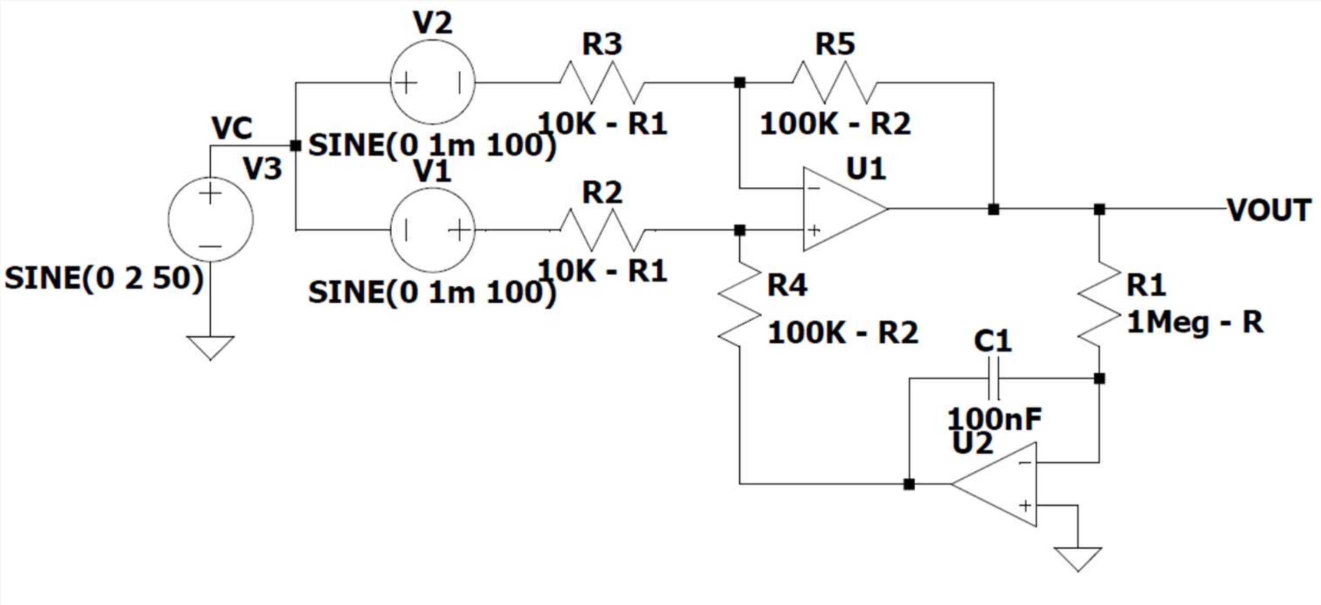



$$\frac{V_{OD}}{V_i}(s) = \frac{R_3+2R_4}{R_3} * \frac{R_1+2R_2}{R_1} * \frac{sRC_T}{1+sCR_T}$$

# Frekvencijska karakteristika pojačavača

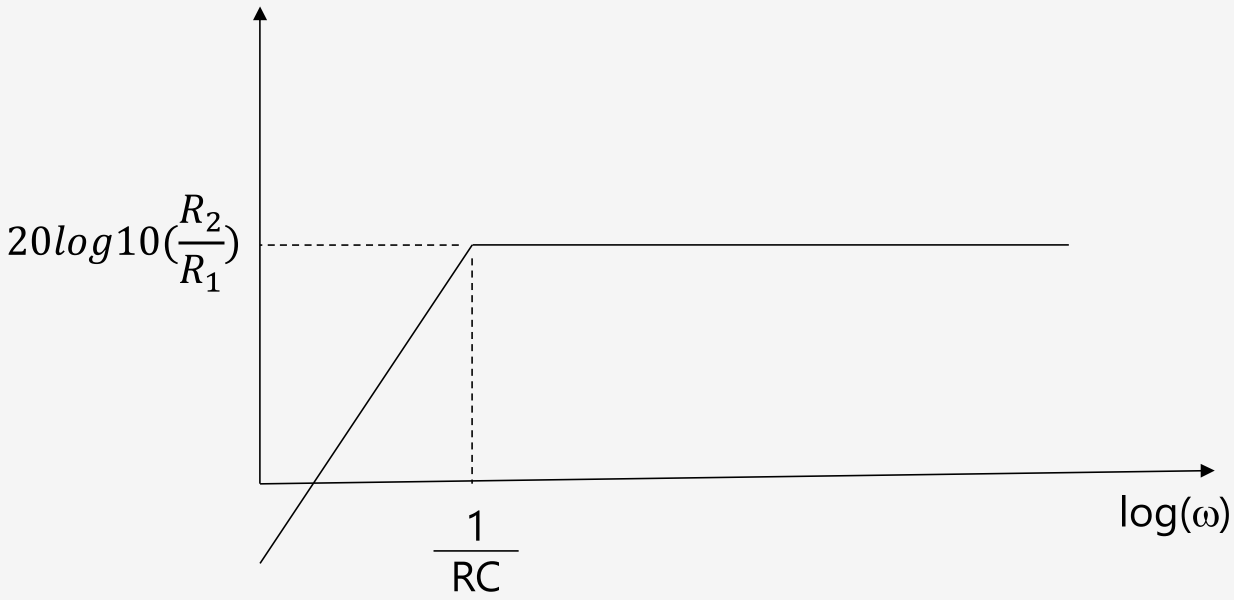


# Potiskivanje jednosmerne komponente diferencijalnog signala u diferencijalnom pojačavaču

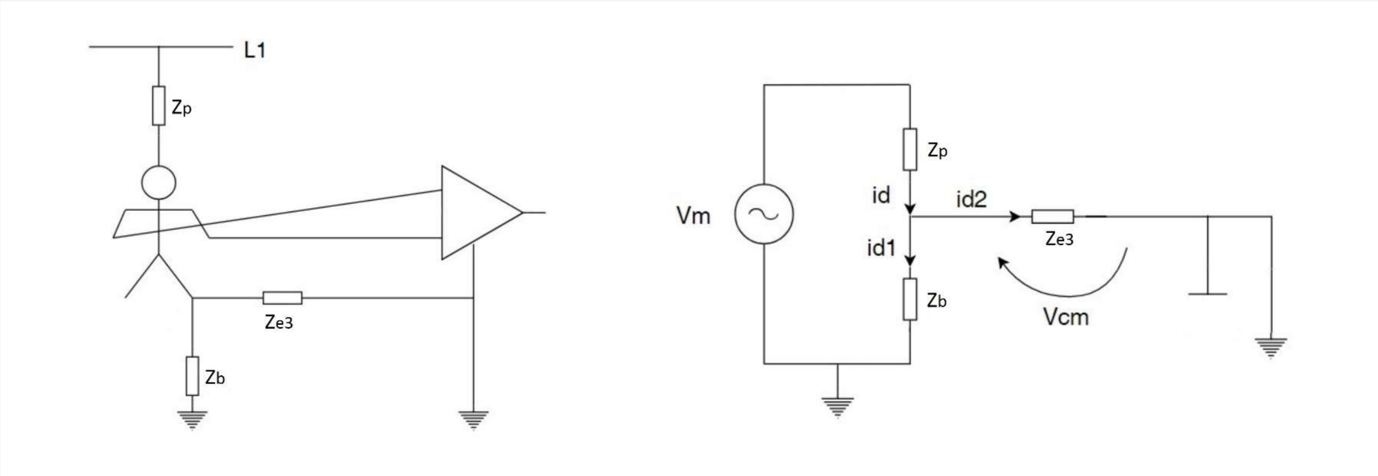



$$\frac{V_o(s)}{V_i(s)} = \frac{R_2}{R_1}\frac{sRC}{1+sRC}$$

# Frekvencijska karakteristika pojačavača



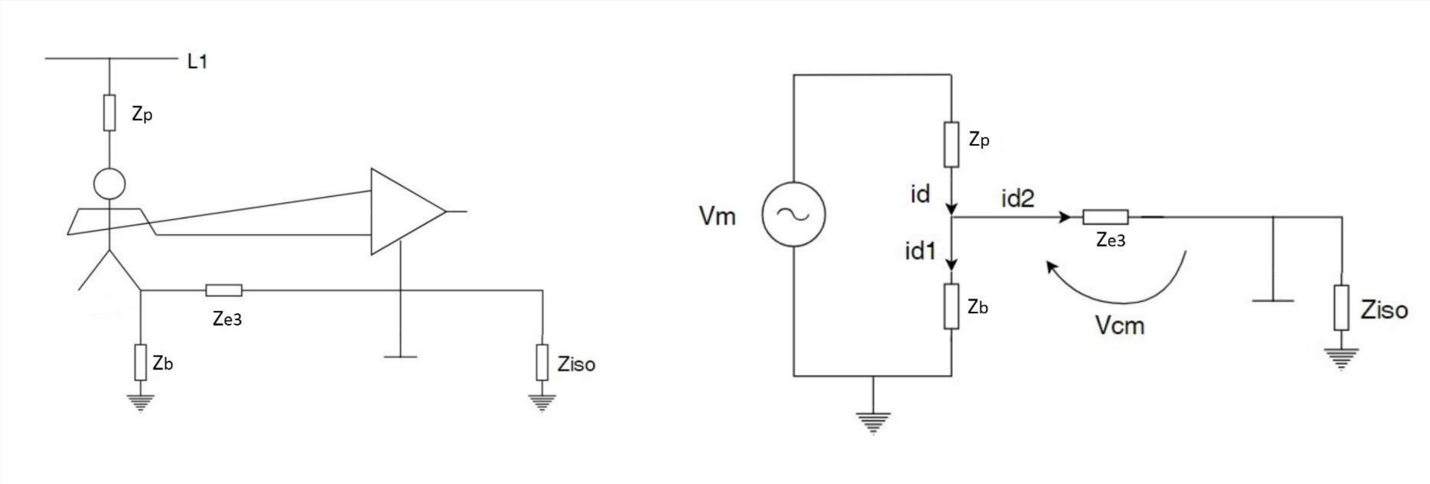
# Treća elektroda - uzemljena




$$Z_{e3} \ll Z_b \rightarrow i_{d2} \approx i_d$$

$$V_{cm} = Z_{e3} i_d$$

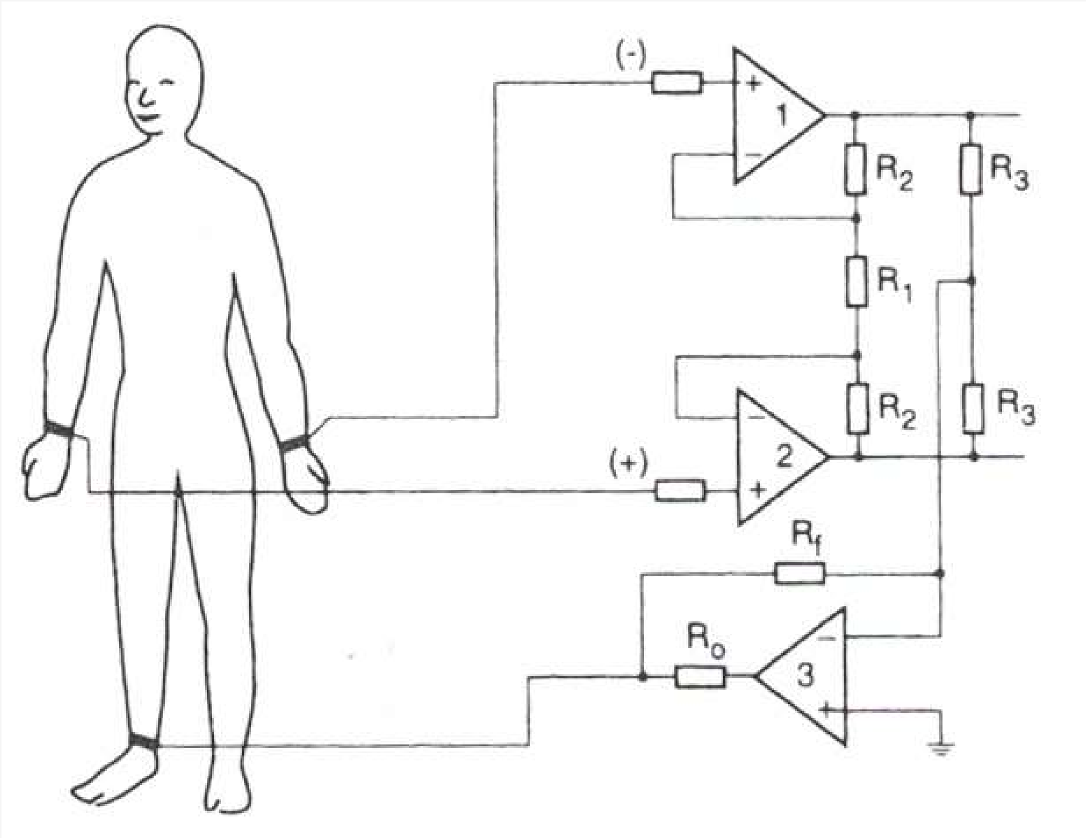
# Treća elektroda – spojena na masu izolovanog pojačavača



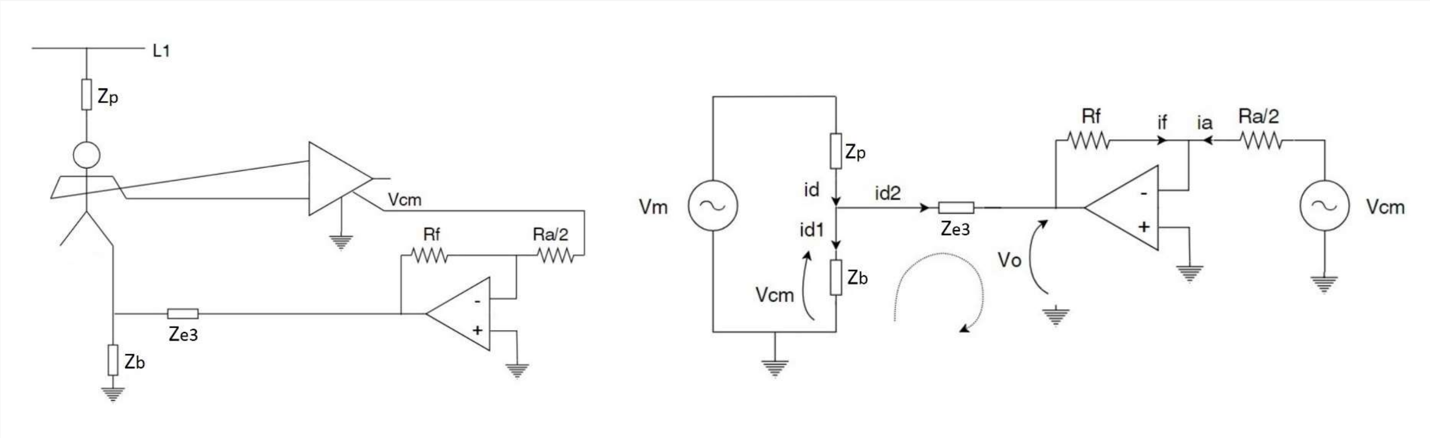

$$i_{d2} = i_d \frac{Z_b}{Z_b + Z_{e3} + Z_{iso}} \qquad V_{cm} = i_{d2} Z_{e3}$$

$$V_{cm} = \frac{Z_b}{Z_b + Z_{e3} + Z_{iso}} Z_{e3} i_d$$

# DRL kolo - Driven Right Leg



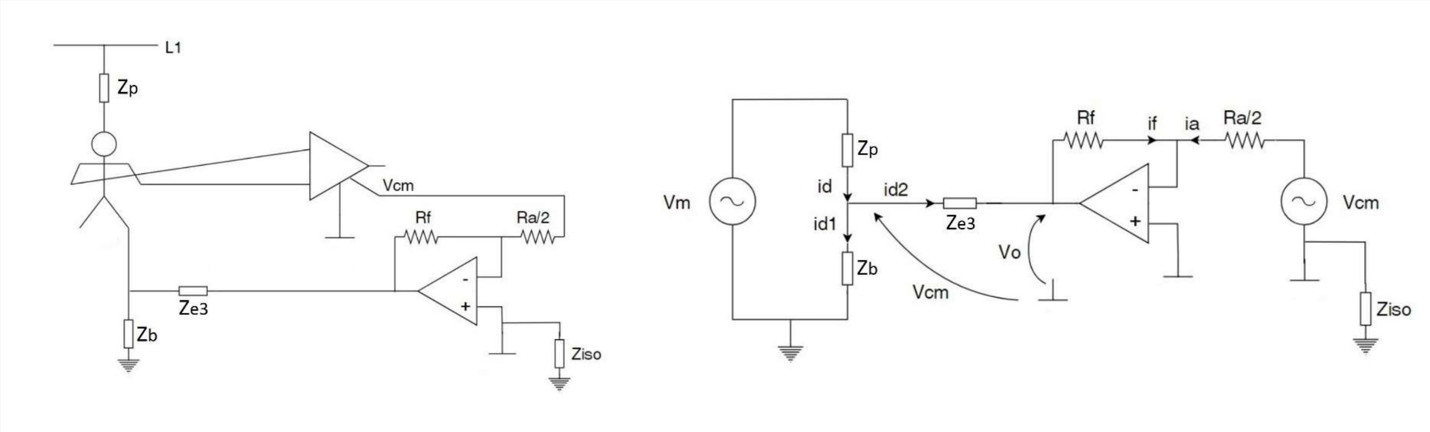
# DRL kolo kod uzemljenog pojačavača
# Driven Right Leg




$$\frac{2V_{cm}}{R_a} + \frac{V_o}{R_f} = 0 \qquad V_o = -\frac{2R_f}{R_a} V_{cm} \qquad V_{cm} = V_o + Z_{e3} i_{d2} \qquad Z_b \gg Z_{e3} \rightarrow \; i_{d2} \approx i_d$$

$$V_{cm} = V_o + Z_{e3} i_d \qquad V_{cm} = -\frac{2R_f}{R_a} V_{cm} + Z_{e3} i_d \qquad V_{cm}\left(1 + \frac{2R_f}{R_a}\right) = Z_{e3} i_d \qquad V_{cm} = \frac{1}{\left(1 + \frac{2R_f}{R_a}\right)} Z_{e3} i_d$$

# DRL kolo kod izolovanog pojačavača
Driven Right Leg




$$i_{d2} \approx i_d \frac{Z_b}{Z_b + Z_{e3} + Z_{iso}} \qquad \frac{2V_{cm}}{R_a} + \frac{V_o}{R_f} = 0 \qquad V_o = -\frac{2R_f}{R_a} V_{cm} \qquad V_{cm} = V_o + Z_{e3} i_{d2}$$

$$V_{cm} = -\frac{2R_f}{R_a} V_{cm} + Z_{e3} i_{d2} \qquad V_{cm} = \frac{Z_{e3}}{\left(1 + \frac{2R_f}{R_a}\right)} i_{d2} \qquad V_{cm} = \frac{1}{\left(1 + \frac{2R_f}{R_a}\right)} \frac{Z_b}{Z_b + Z_{e3} + Z_{iso}} Ze3 i_d$$

# Komercijalni pojačavači – AD8232 Analog Devices

## FEATURES

Fully integrated single-lead ECG front end
Low supply current: 170 µA (typical)
Common-mode rejection ratio: 80 dB (dc to 60 Hz)
Two or three electrode configurations
High signal gain (G = 100) with dc blocking capabilities
2-pole adjustable high-pass filter
Accepts up to ±300 mV of half cell potential
Fast restore feature improves filter settling
Uncommitted op amp
3-pole adjustable low-pass filter with adjustable gain
Leads off detection: ac or dc options
Integrated right leg drive (RLD) amplifier
Single-supply operation: 2.0 V to 3.5 V
Integrated reference buffer generates virtual ground
Rail-to-rail output
Internal RFI filter
8 kV HBM ESD rating
Shutdown pin
20-lead, 4 mm × 4 mm LFCSP and LFCSP_SS package
Qualified for automotive applications

## APPLICATIONS

Fitness and activity heart rate monitors
Portable ECG
Remote health monitors
Gaming peripherals
Biopotential signal acquisition

## FUNCTIONAL BLOCK DIAGRAM

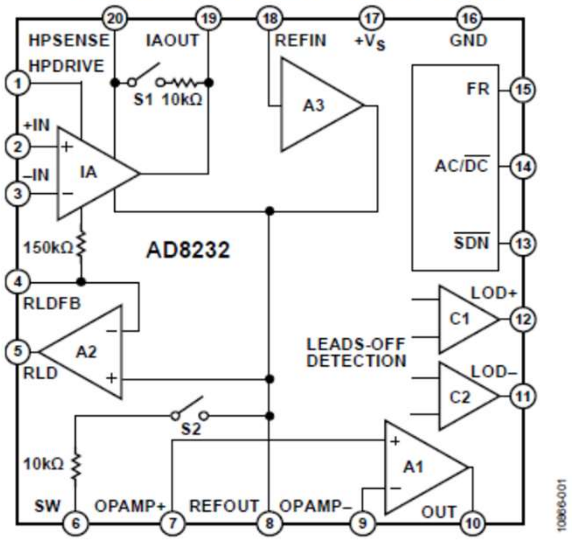



*Figure 1.*

# Komercijalni pojačavači – AD8232 Analog Devices