

# Osnovi analogne elektronike

## IV semestar

### **OPERACIONI POJAČAVAČ**

# Operacioni pojačavač

Ulazni napon se dovodi na oba ulazna priključka.

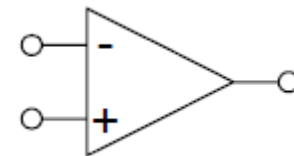
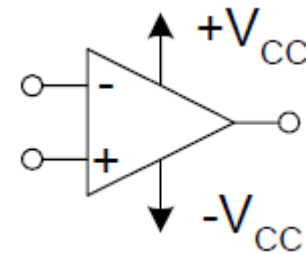
Izlazni napon je dobija sa jednog izlaznog priključka, mada postoje i operacioni pojačavači sa diferencijalnim izlazom.

Operacioni pojačavač se sastoji od:

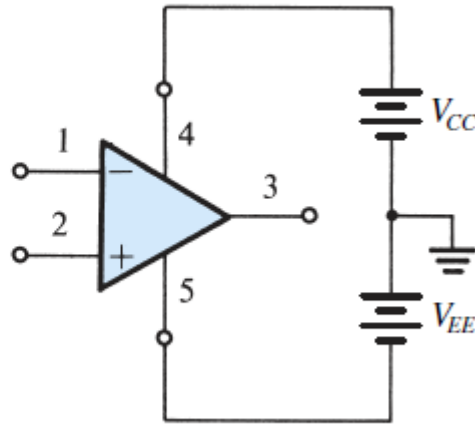
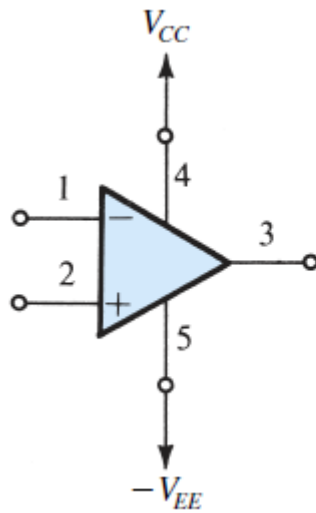
- ❖ ulaznog diferencijalnog pojačavača
- ❖ opcionog međustepena naponskog pojačanja
- ❖ izlaznog pojačavača snage.

Ulazni tranzistori su najčešće:

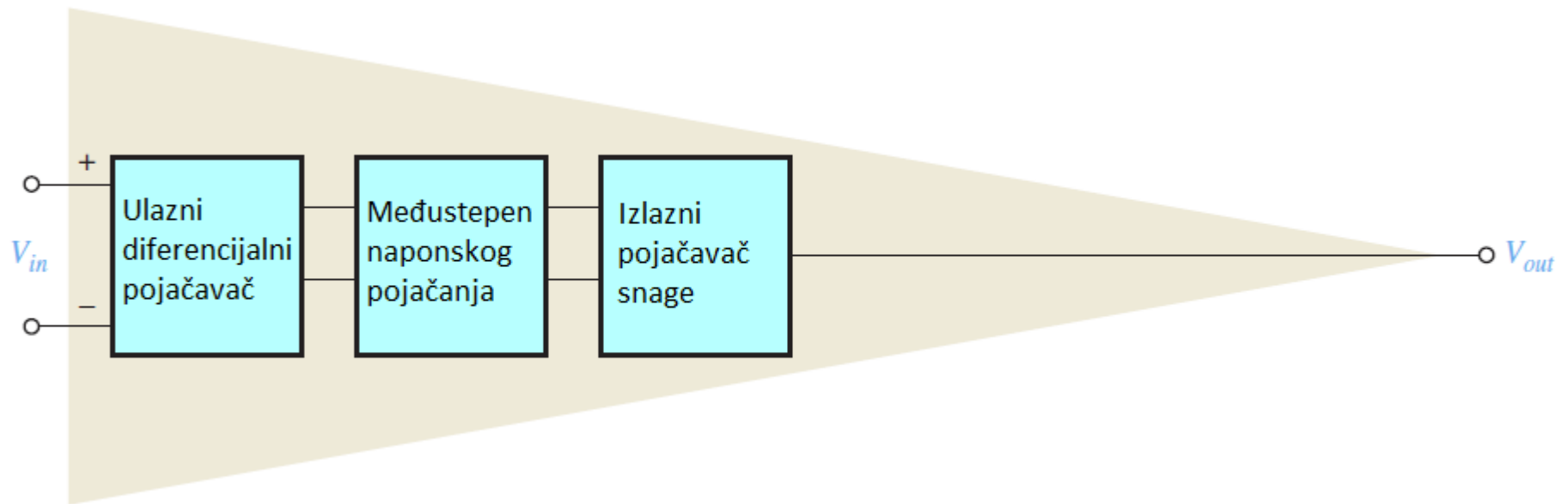
- ❖ Bipolarni NPN
- ❖ Bipolarni PNP
- ❖ N-kanalni MOSFET (NMOS)
- ❖ P-kanalni MOSFET (PMOS).



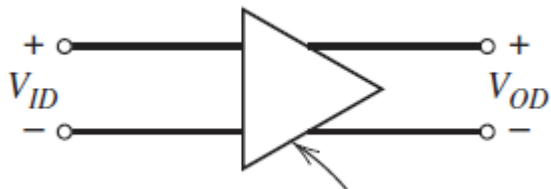
# Napajanje operacionog pojačavača



# Unutrašnja struktura operacionog pojačavača



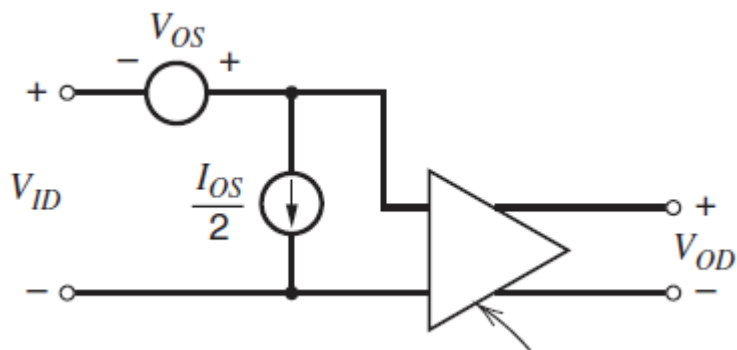
# Nesimetričan ulazni diferencijalni pojačavač



Nesimetričan diferencijalni pojačavač sa naponskim ofsetom  $V_{OS}$  i strujnim ofsetom  $I_{OS}$ .

$V_{OS} = 0.1..2$  mV za ulazne bipolarne tranzistore

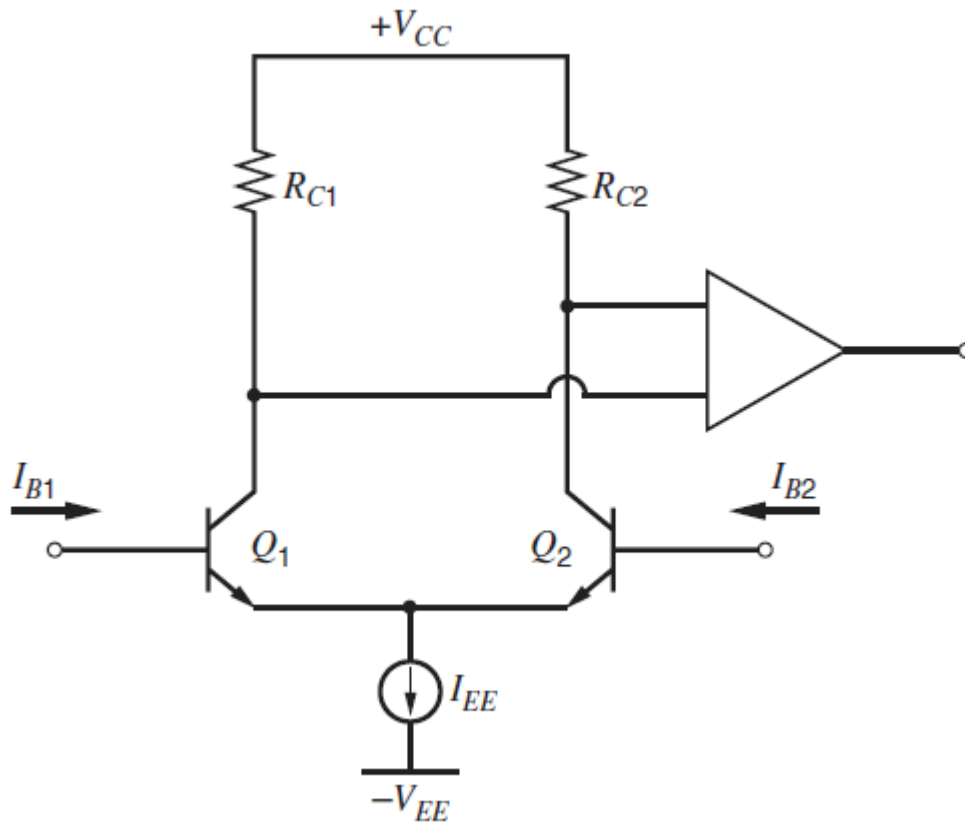
$V_{OS} = 1..20$  mV za ulazne MOS tranzistore.



$$I_{OS} = I_{B1} - I_{B2}$$

Simetričan diferencijalni pojačavač bez naponskog ofseta  $V_{OS}$  i bez strujnog ofseta  $I_{OS}$ .

# Ulazne struje polarizacije



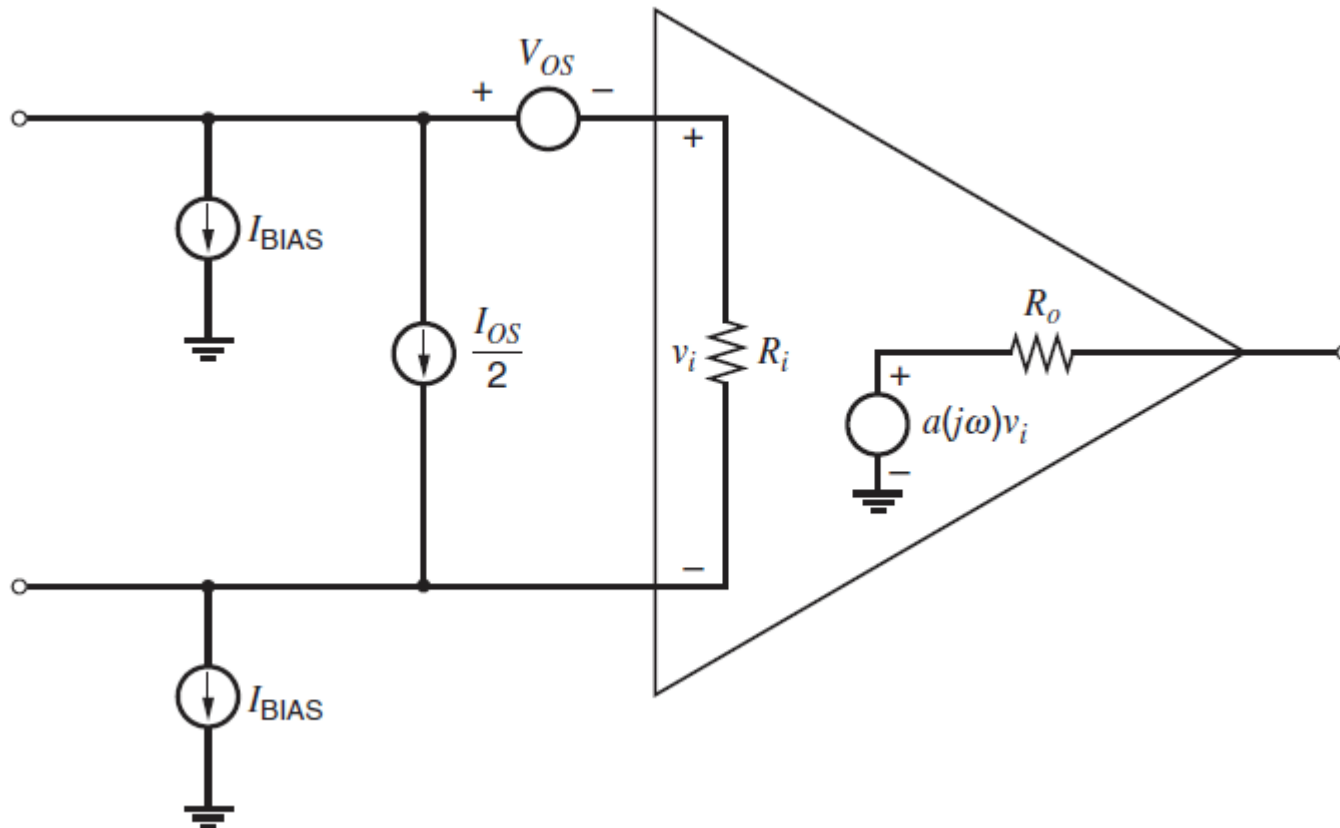
$$I_{BIAS} = \frac{I_{B1} + I_{B2}}{2}$$

$$I_{OS} = I_{B1} - I_{B2}$$

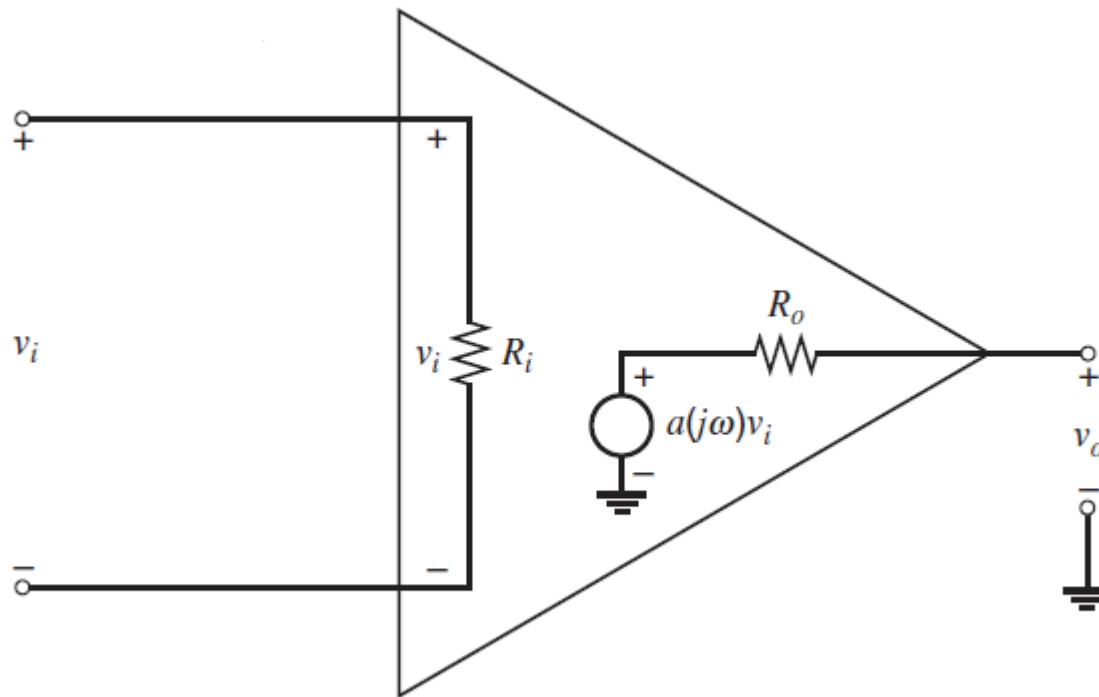
$I_{BIAS} = 10..100$  nA i  $I_{OS} < 2..20$  nA za ulazne bipolarne tranzistore

$I_{BIAS}$  i  $I_{OS} < 1$  fA = 0.001 pA za ulazne MOS tranzistore.

# Neidealni operacioni pojačavač kombinovana šema

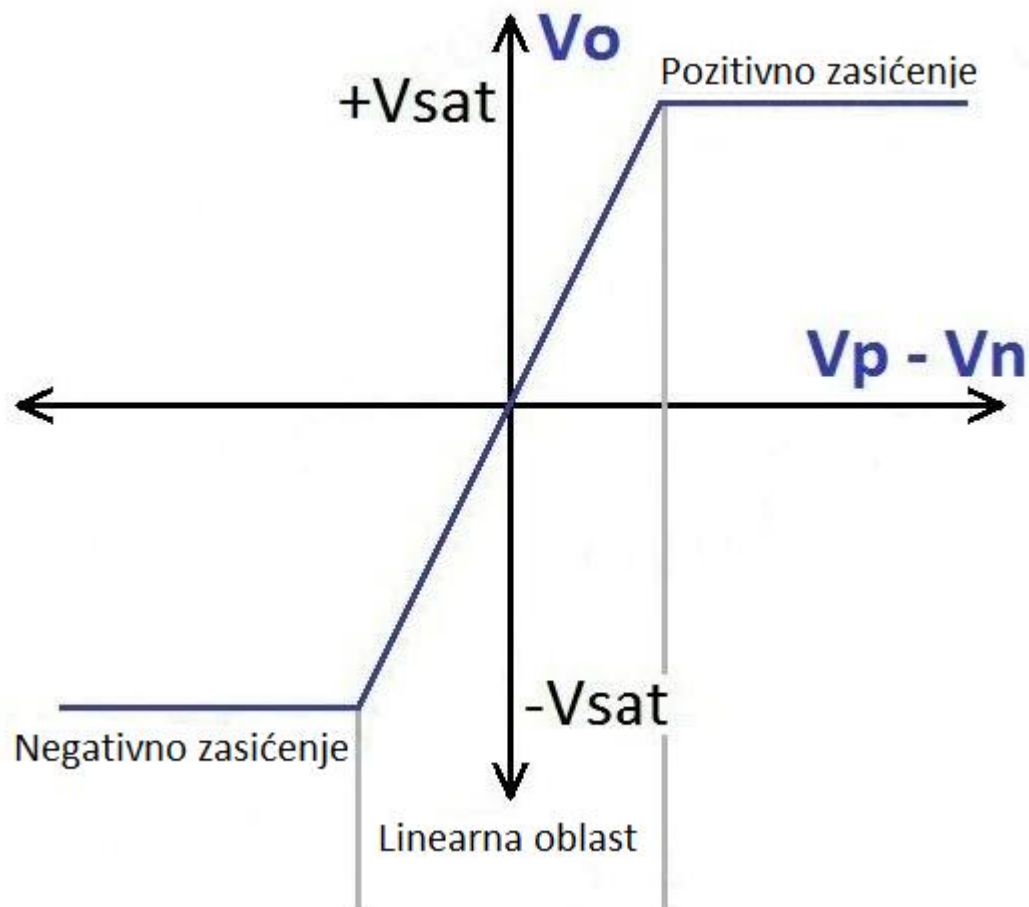


# Neidealni operacioni pojačavač šema za male signale





# Aproksimativna prenosna karakteristika neidealnog operacionog pojačavača



# Ulazne i izlazne otpornosti

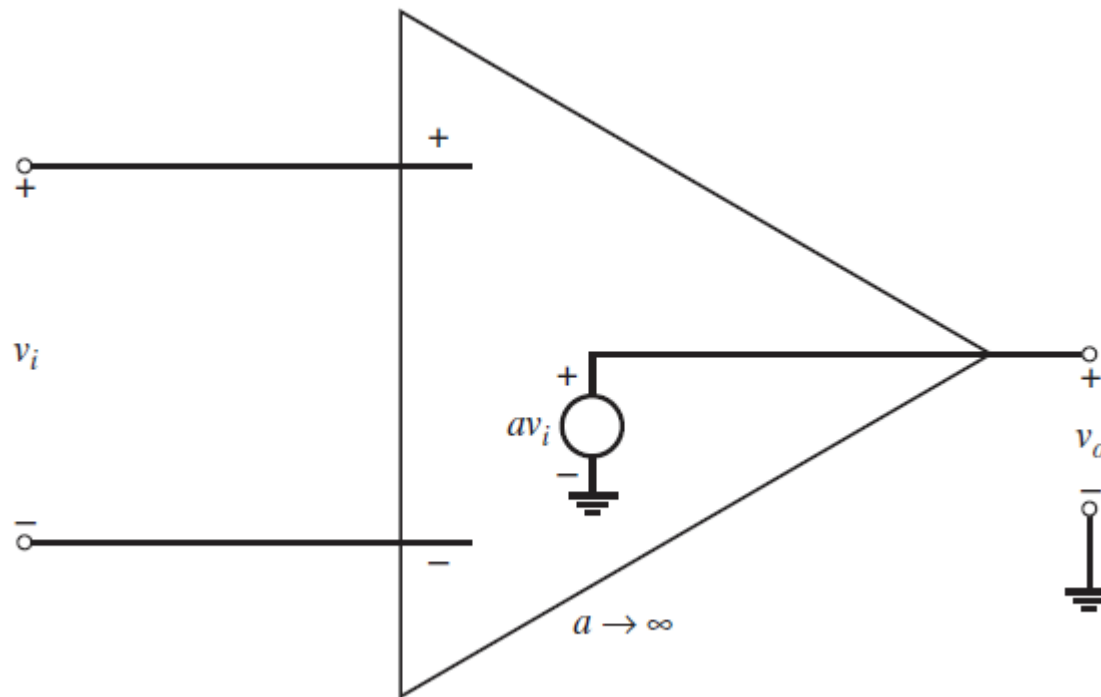
$R_i = 100 \text{ k}\Omega \dots 1 \text{ M}\Omega$  za ulazne bipolarne tranzistore (input)

$R_i \rightarrow \infty$  za ulazne MOS tranzistore

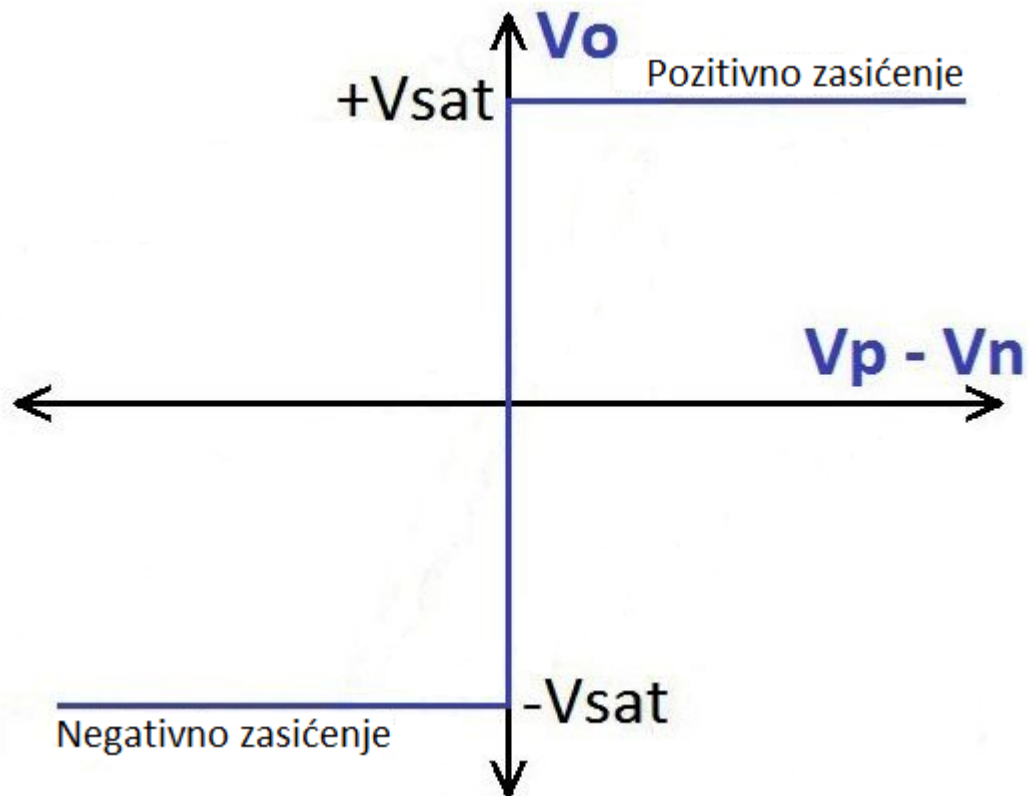
$R_o = 40 \text{ }\Omega \dots 100 \text{ }\Omega$  za izlazne bipolarne tranzistore (output)

$R_o = 400 \text{ }\Omega \dots 1 \text{ k}\Omega$  za izlazne MOS tranzistore.

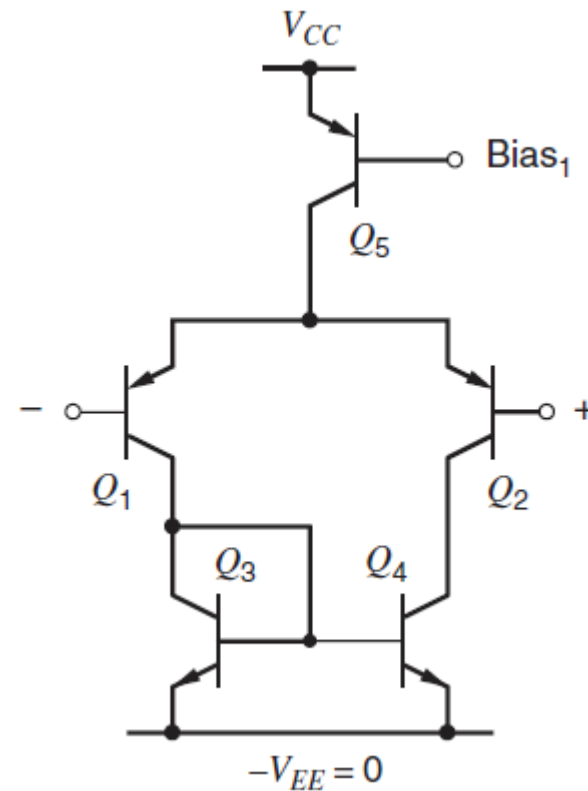
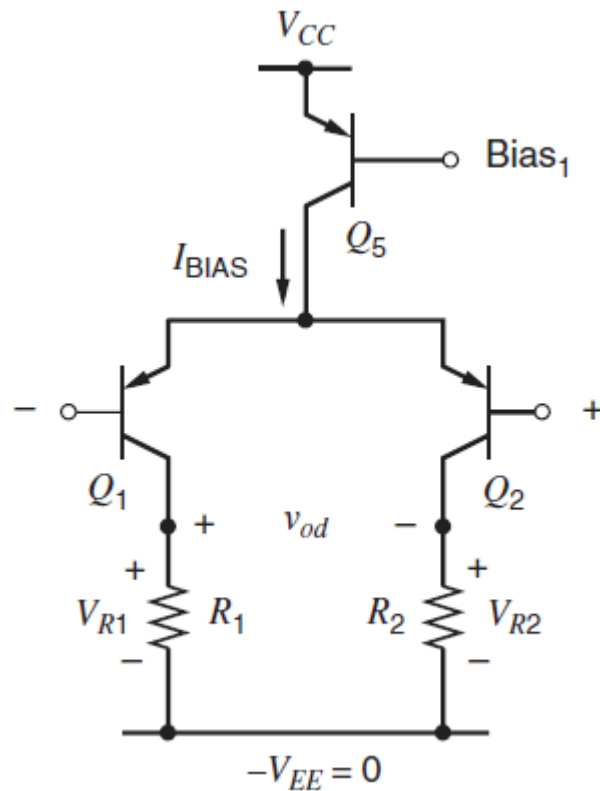
# Idealni operacioni pojačavač šema za male signale



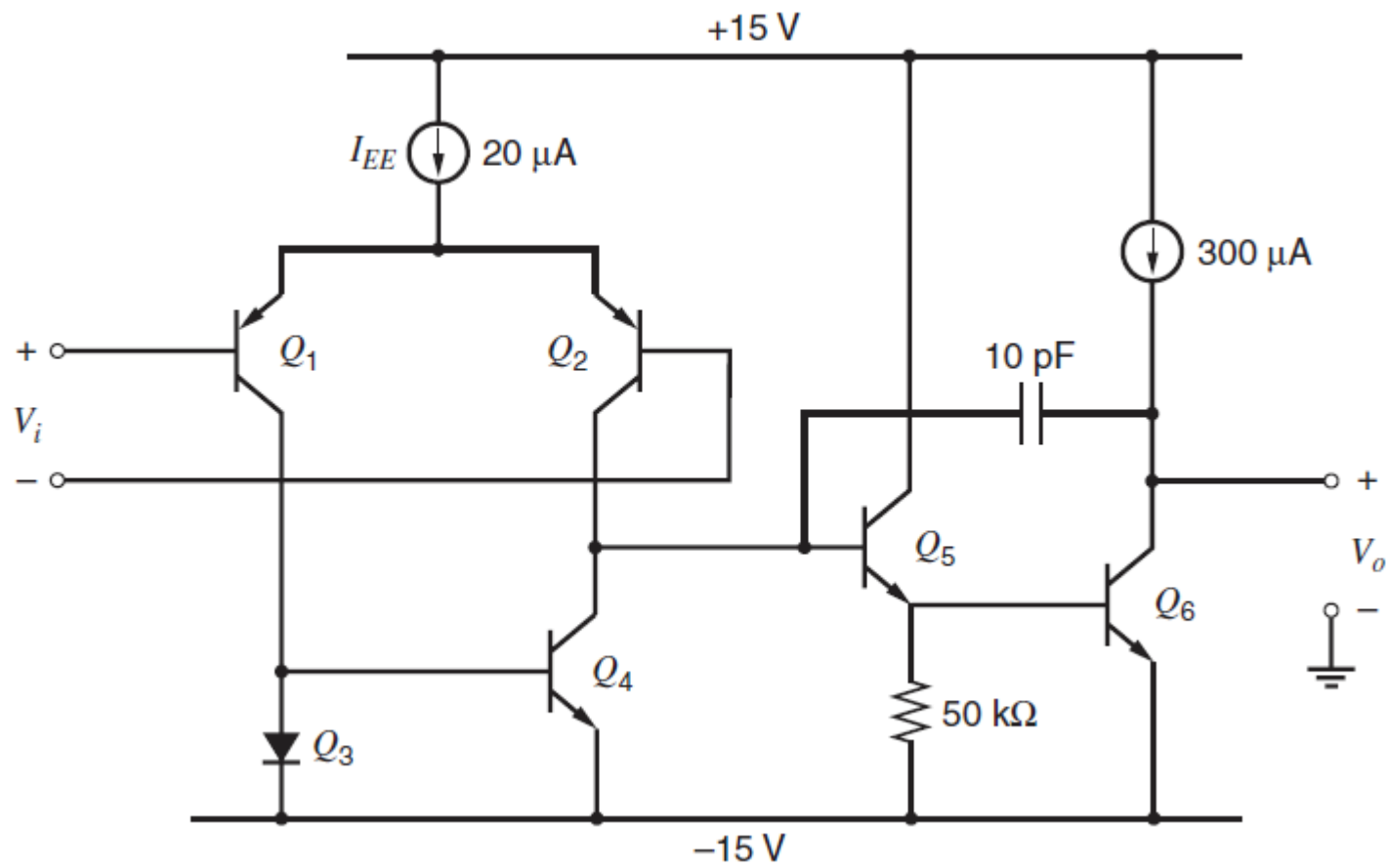
# Aproksimativna prenosna karakteristika idealnog operacionog pojačavača



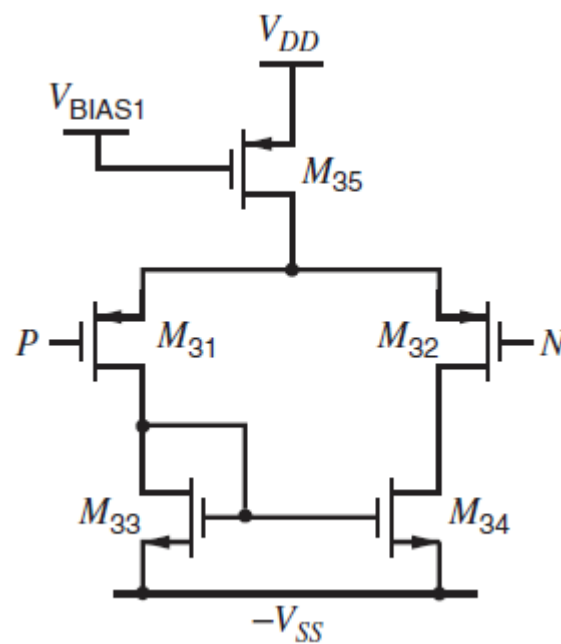
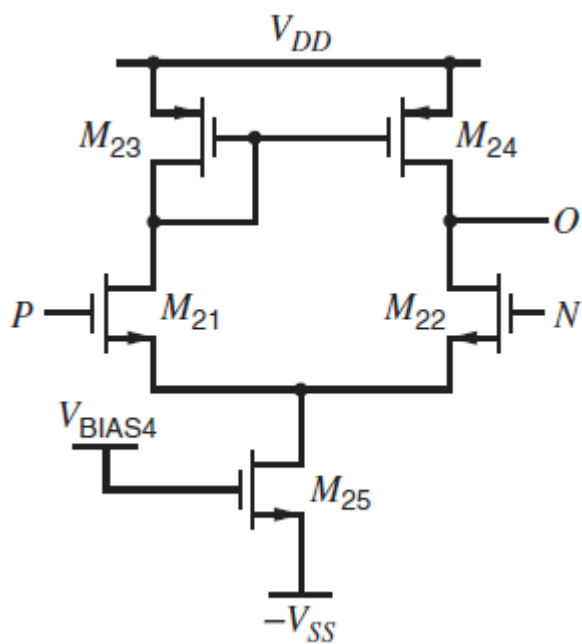
# Ulazni diferencijalni pojačavač principijelna šema sa bipolarnim tranzistorima



# Trostepeni operacioni pojačavač principijelna šema



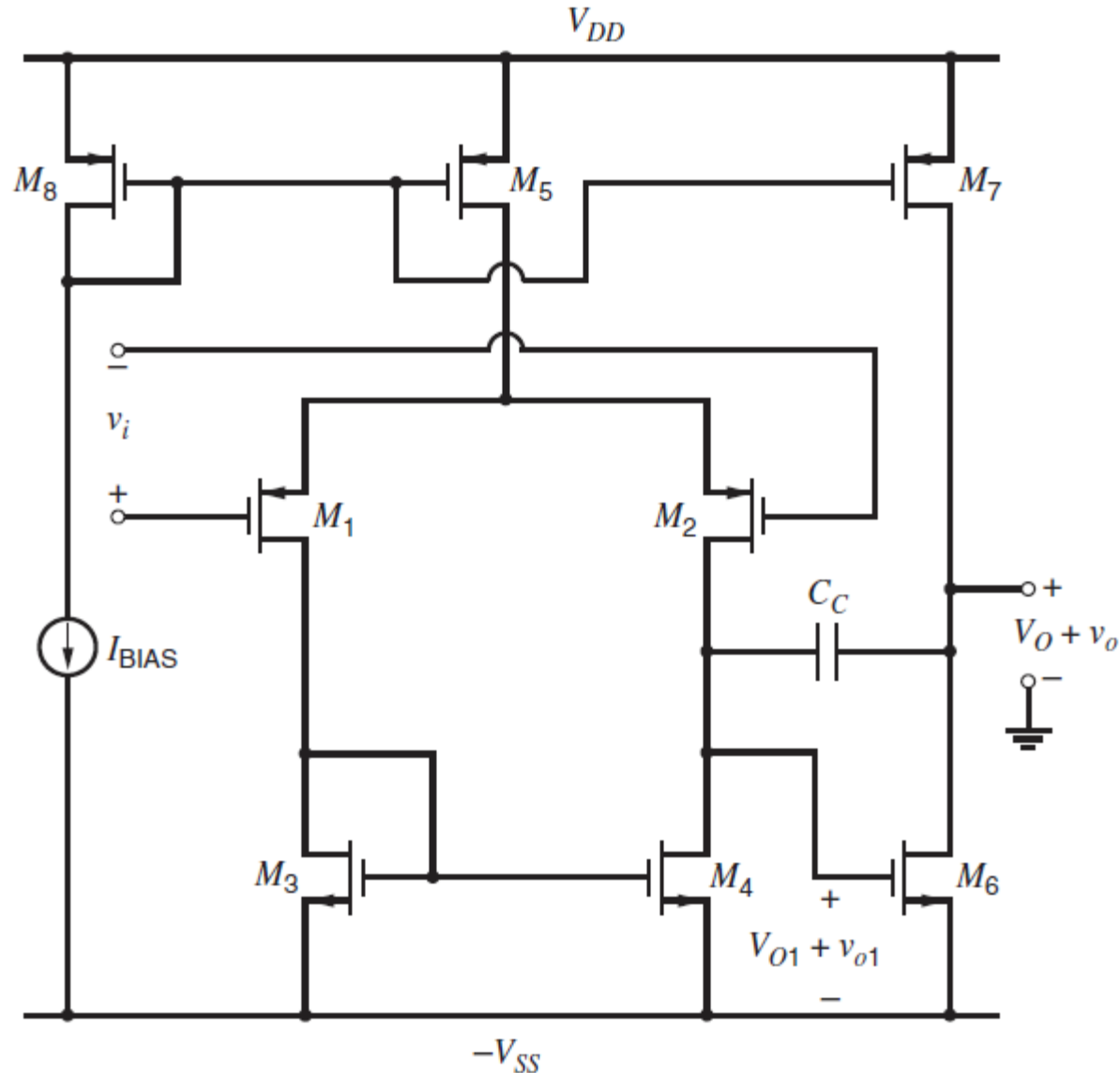
# Ulazni diferencijalni pojačavač principijelna šema sa MOSFET-ima







# Dvostepeni operacioni pojačavač detaljna šema



# Dvostepeni operacioni pojačavač pojačanje za male signale

$$A_{v1} = \frac{v_{o1}}{v_i}$$

$$A_{v1} = g_{m1}(r_{o2} || r_{o4})$$

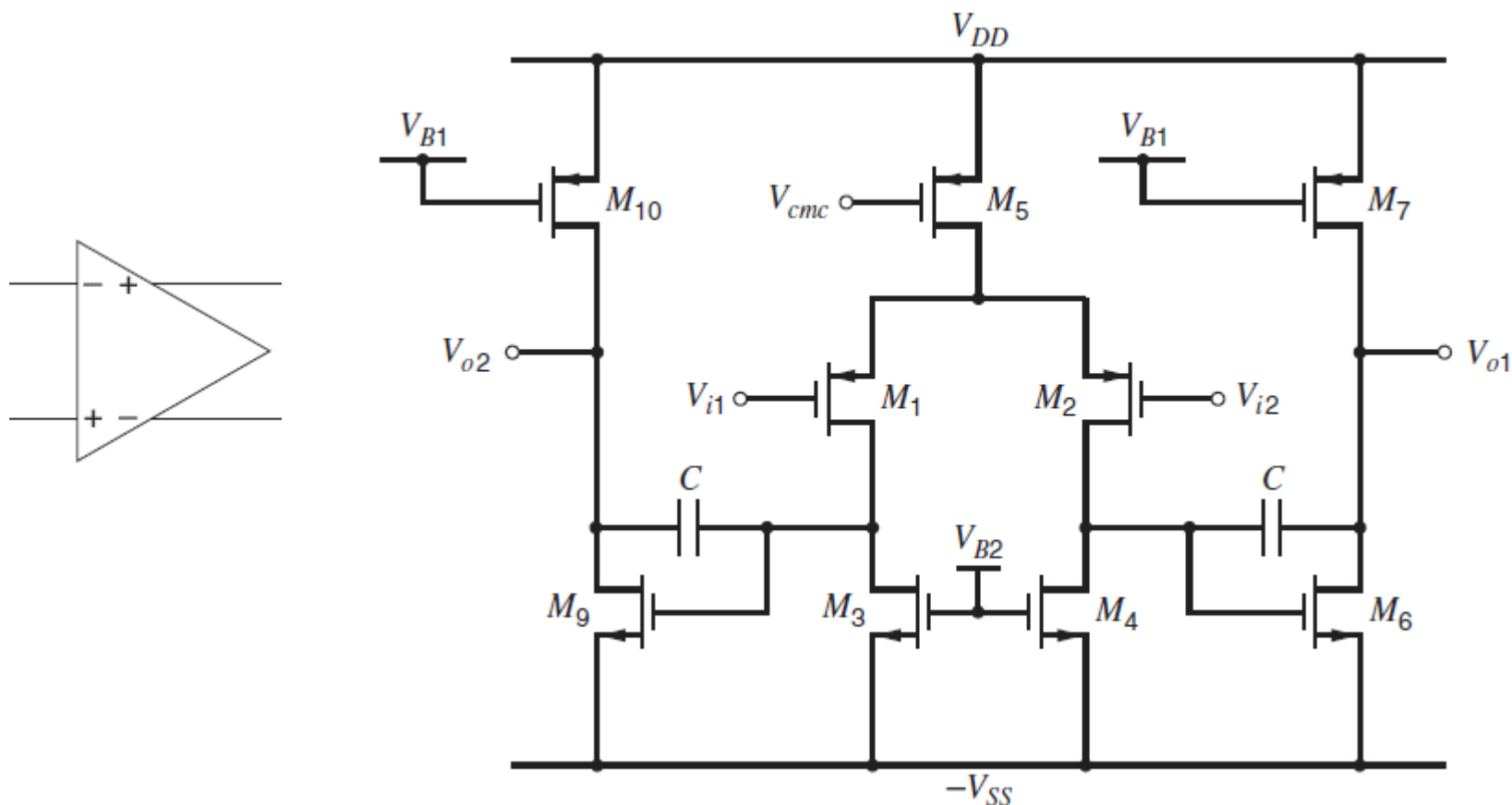
$$A_{v2} = -g_{m6}R_o$$

$$R_o = r_{o6} || r_{o7}$$

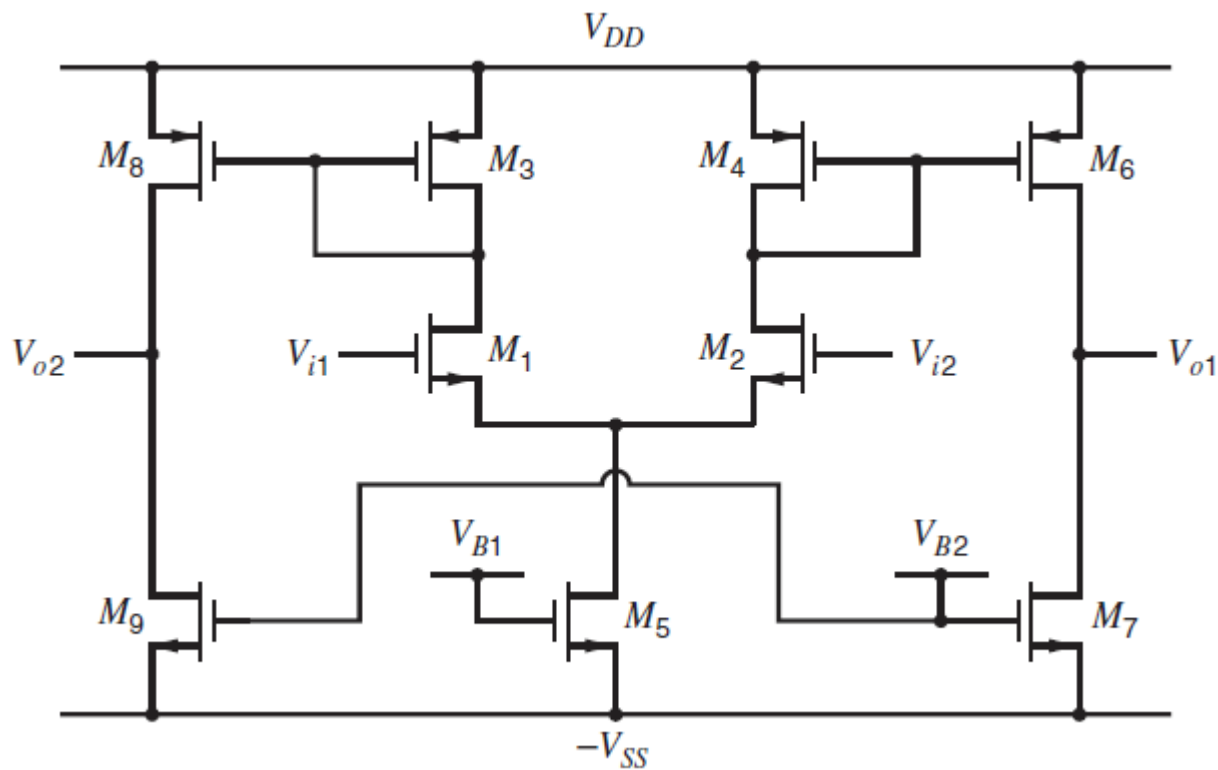
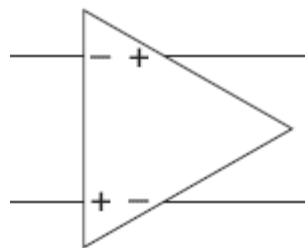
$$A_v = A_{v1}A_{v2} = -g_{m1}(r_{o2} || r_{o4})g_{m6}(r_{o6} || r_{o7})$$

$$\begin{aligned} A_v &= -g_{m1} \left( \frac{\frac{|V_{A2}|}{|I_{D2}|} \frac{V_{A4}}{|I_{D2}|}}{\frac{|V_{A2}|}{|I_{D2}|} + \frac{V_{A4}}{|I_{D2}|}} \right) g_{m6} \left( \frac{\frac{V_{A6}}{I_{D6}} \frac{|V_{A7}|}{I_{D6}}}{\frac{V_{A6}}{I_{D6}} + \frac{|V_{A7}|}{I_{D6}}} \right) \\ &= -\frac{g_{m1}}{|I_{D2}|} \frac{g_{m6}}{I_{D6}} \left( \frac{|V_{A2}|V_{A4}}{|V_{A2}| + V_{A4}} \right) \left( \frac{V_{A6}|V_{A7}|}{V_{A6} + |V_{A7}|} \right) \end{aligned}$$

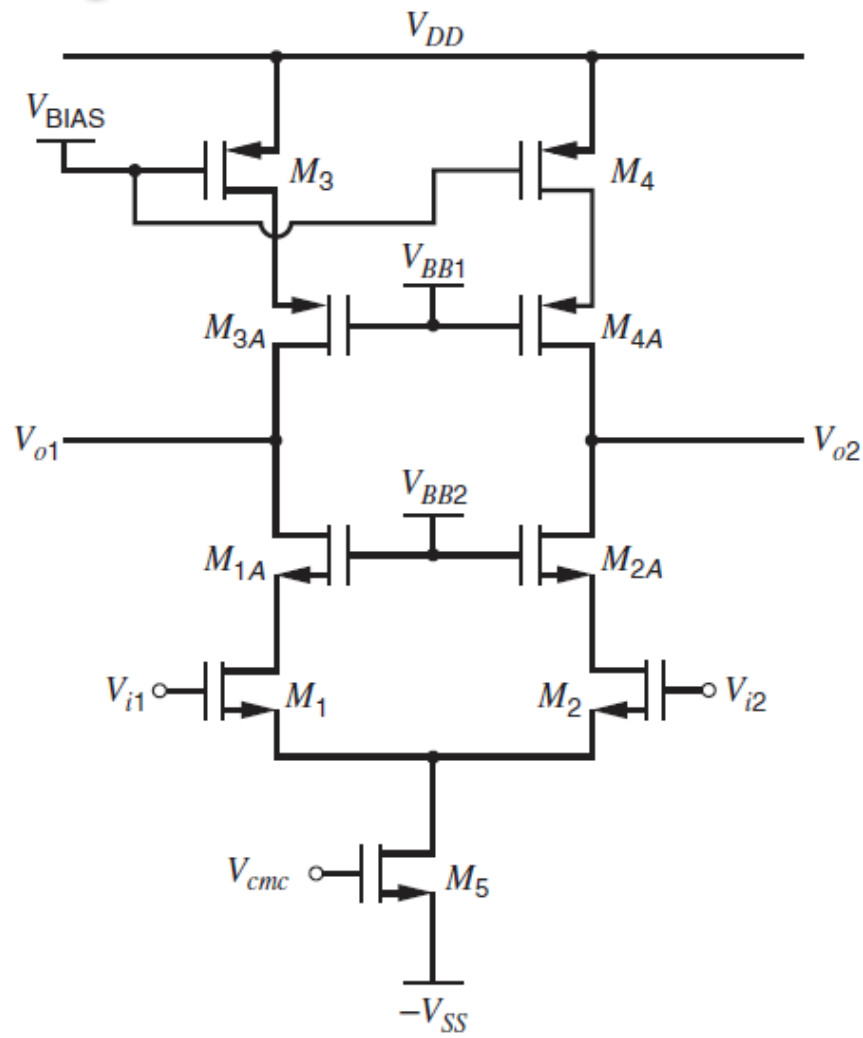
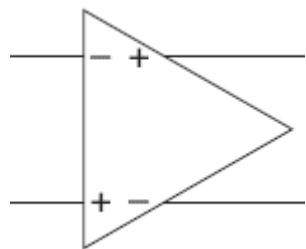
# Dvostepeni operacioni pojačavač sa strujnim izvorima i diferencijalnim izlazom



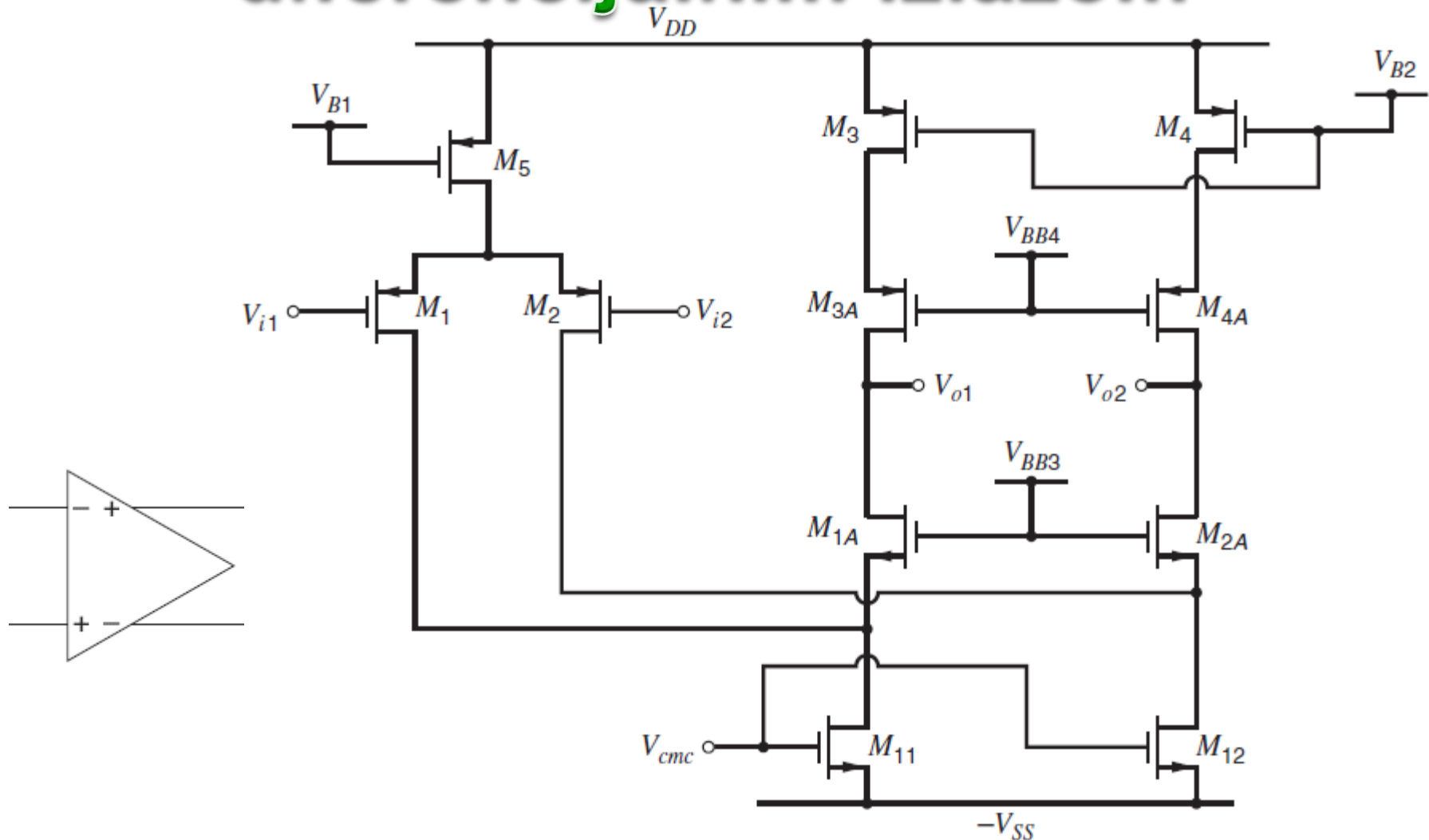
# Dvostepeni operacioni pojačavač sa strujnim ogledalima i diferencijalnim izlazom



# Operacioni pojačavač sa teleskopskom kaskodom i diferencijalnim izlazom



# Operacioni pojačavač sa presavijenom kaskodom i diferencijalnim izlazom



# Osnovi analogne elektronike

## IV semestar

### **OPERACIONI POJAČAVAČ**