Sinteza električnih filtara

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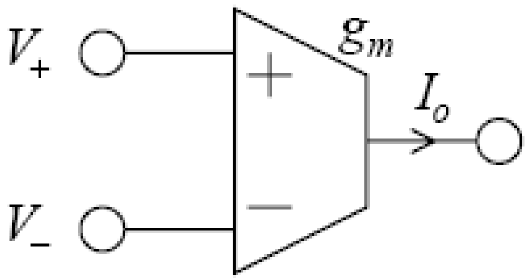
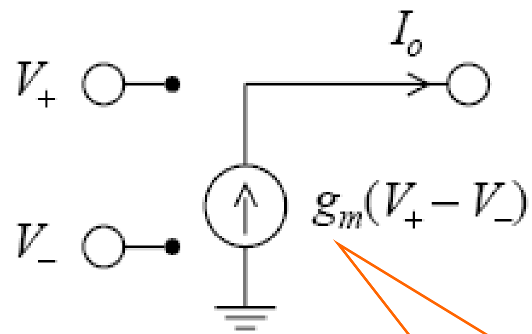
Operational transconductance amplifier (OTA) filters

- ***OTA-C filters*** (IC implemented with OTAs and poly-silicon capacitors)
- ***OTA-R-C filters*** (IC implemented with OTAs, poly-silicon capacitors, and linear full CMOS resistors)
- Analogna i digitalna kola na jednom silicijumu
- Potrebni kvalitetni filtri pre AD konverzije
- Da se koristi **mala površina na silicijumu** i da je **cena niska** – za digitalna kola kao i za analogna da se koristi **isti tehnološki postupak**
- OTA ima **širi korisni opseg učestanosti** od operacionog pojačavača

Model za OTA





Simbol kao električno kolo

Ekvivalentni model za male signale

g_m je reda 10-100 μS

$$I_o = g_m(V_+ - V_-)$$

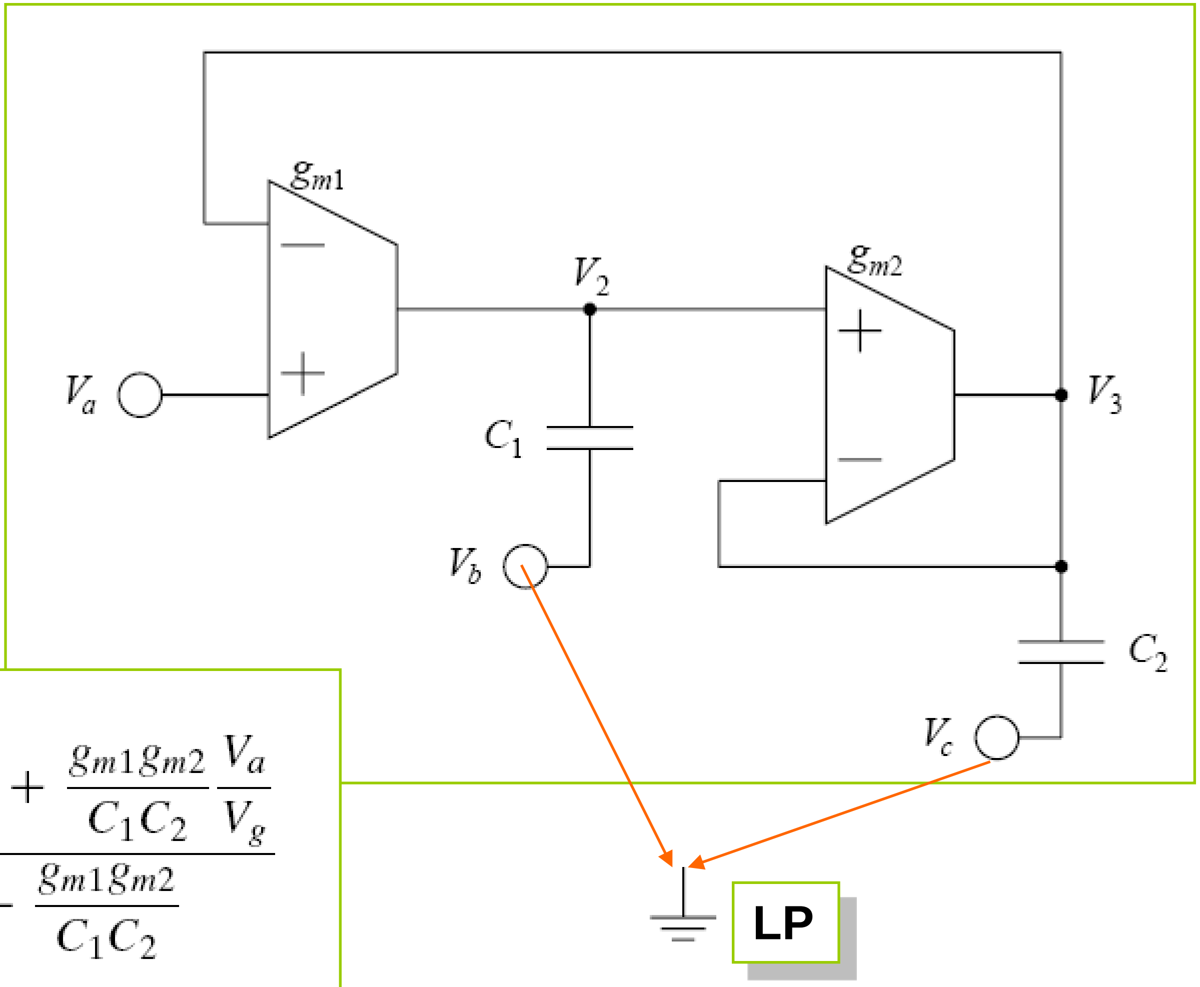
Tolerancije elemenata

- Tolerancije za $r_{cg}=C/g_m$ su 30%
- Tolerancije za $r_c=C_1/C_2$ su 0.1% za $C_1/C_2\approx 1$
- Tolerancije za $r_g=g_{m1}/g_{m2}$ su 0.5% za $g_{m1}/g_{m2}\approx 1$
- Tolerancije za $r_g=g_{m1}/g_{m2}$ su 2% za $g_{m1}/g_{m2}>>1$
- Linearan za mali opseg vrednosti ulaznog signala
- Osetljivi su na parazitne efekte
- Podešavanje na samom čipu (on-chip tuning system) koji je na istom IC

Postupci sinteze

- Prvo se projektuje
  - **LC filtri** sa dva pristupa
    - Superioran dinamički opseg
    - Manje osetljiv na tolerancije
    - Složena i neprecizna podešavanja
  - **Bikvadratne sekcije** sa op-amp
    - Za visoke učestanosti i selektivne filtre zbog preciznog podešavanja
- Konverzija u OTA realizacije

4-element OTA



$$\frac{V_3}{V_g} = \frac{s^2 \frac{V_c}{V_g} + s \frac{g_{m2}}{C_2} \frac{V_b}{V_g} + \frac{g_{m1} g_{m2}}{C_1 C_2} \frac{V_a}{V_g}}{s^2 + \frac{g_{m2}}{C_2} s + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

Moguće realizacije

$$H_{LP}(s) = \frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = V_g, \ V_b = 0, \ V_c = 0$$

$$H_{HP}(s) = \frac{s^2}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = 0, \ V_b = 0, \ V_c = V_g$$

$$H_{BP}(s) = \frac{s\frac{g_{m2}}{C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = 0, \ V_b = V_g, \ V_c = 0$$

$$H_{BR}(s) = \frac{s^2 + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m2}}{C_2}s + \frac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = V_g, \ V_b = 0, \ V_c = V_g$$

Podešavanja

$$\omega_p = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}$$

$$Q_p = \sqrt{\frac{g_{m1} C_2}{g_{m2} C_1}}$$

$$\omega_p = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}$$

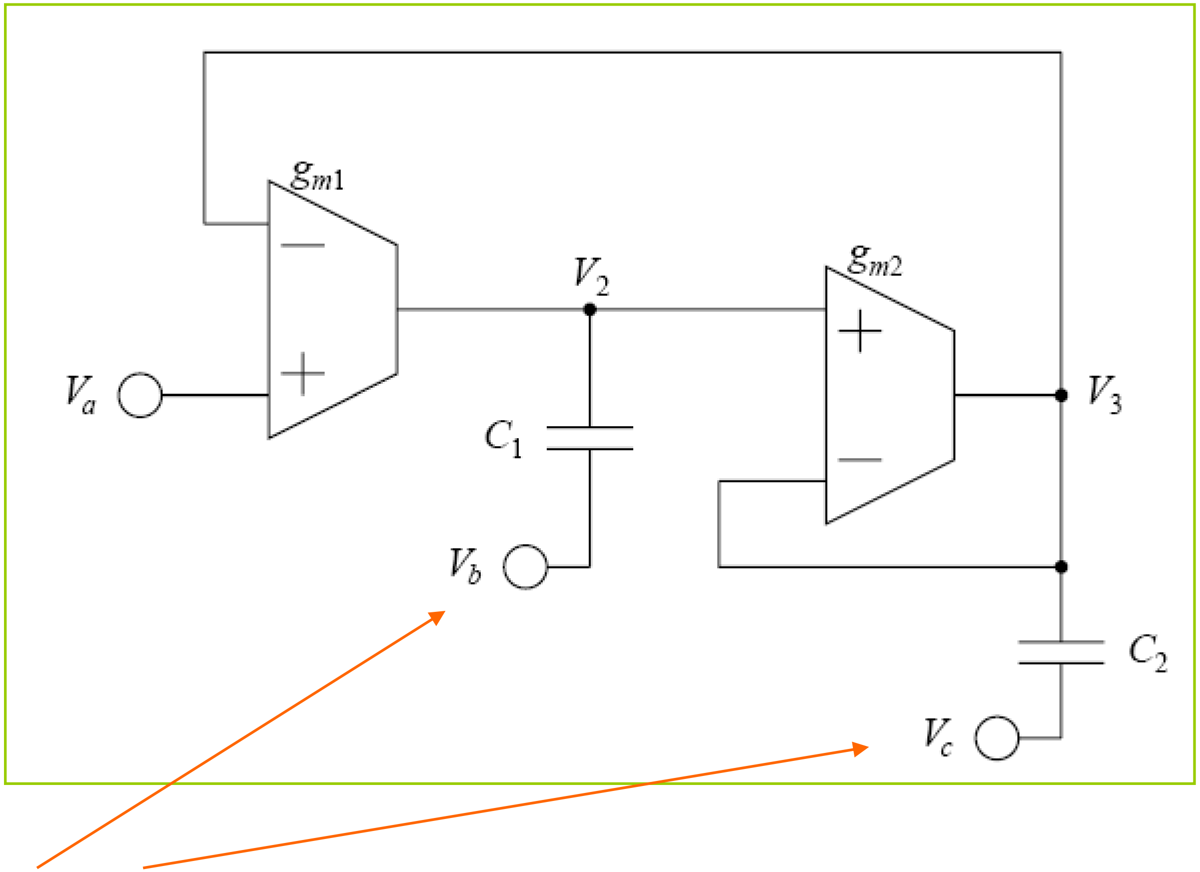
$$Q_p = \sqrt{\frac{g_{m1} C_2}{g_{m2} C_1}}$$

$$g_{m1} = g_{m2}$$

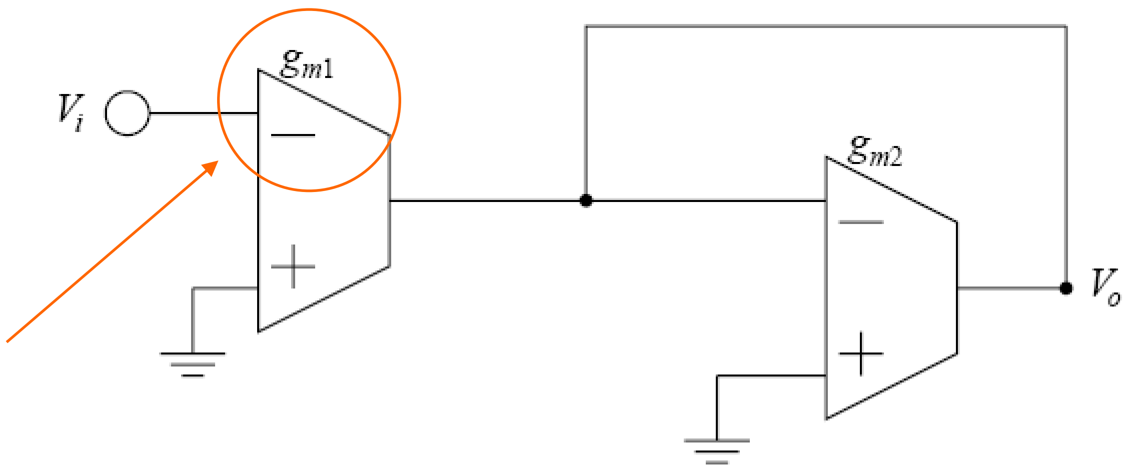
$$\omega_p = \frac{g_m}{\sqrt{C_1 C_2}}$$

$$Q_p = \sqrt{\frac{C_2}{C_1}}$$

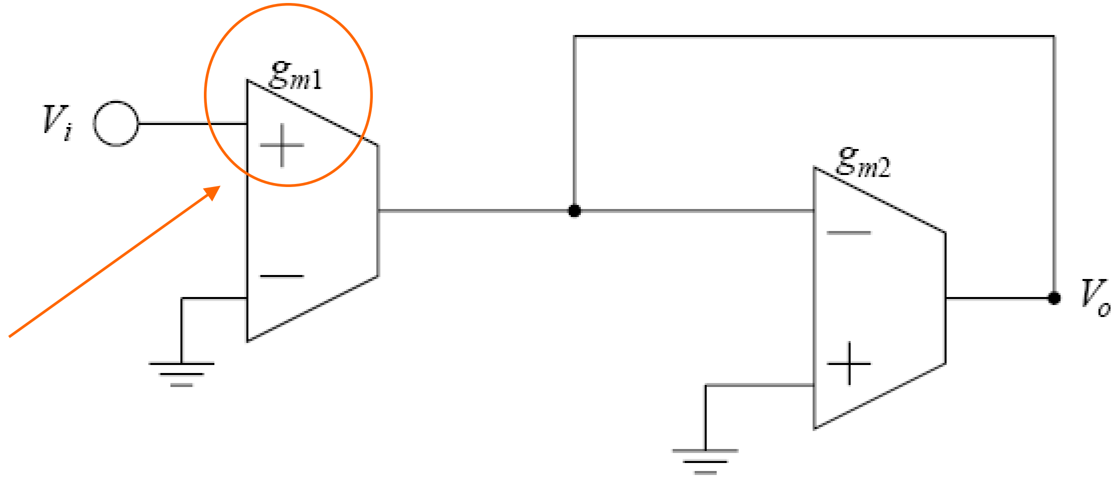
Bafer – potreban za Vb i Vc



Invertor - pojačavač

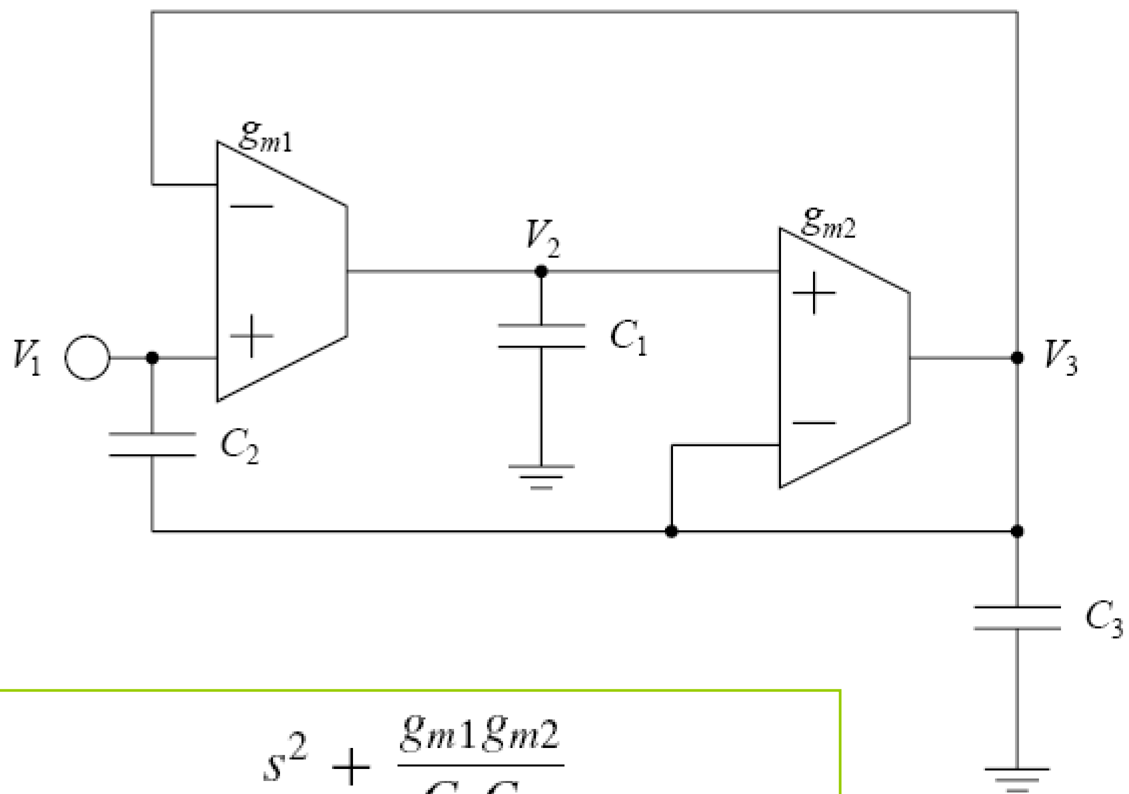


$$\frac{V_o}{V_i} = -\frac{g_{m1}}{g_{m2}}$$



$$\frac{V_o}{V_i} = \frac{g_{m1}}{g_{m2}}$$

OTA LP notch



$$H(s) = \frac{V_3}{V_1} = \frac{C_2}{C_2 + C_3} \frac{s^2 + \dfrac{g_{m1}g_{m2}}{C_1 C_2}}{s^2 + \dfrac{g_{m2}}{C_2 + C_3}s + \dfrac{g_{m1}g_{m2}}{C_1(C_2 + C_3)}}$$

Podešavanja

$$\omega_p = \sqrt{\frac{g_{m1} g_{m2}}{C_1 (C_2 + C_3)}}$$

$$Q_p = \sqrt{\frac{g_{m1} (C_2 + C_3)}{g_{m2} C_1}}$$

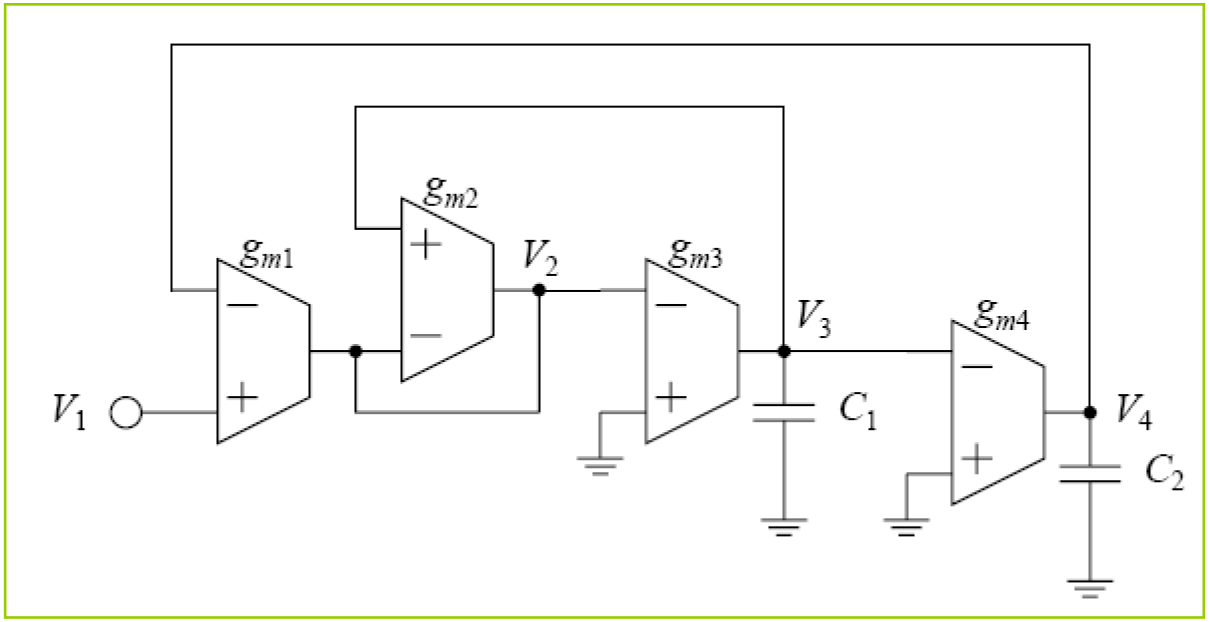
$$\omega_z = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}$$

$$\frac{\omega_p}{\omega_z} = \sqrt{\frac{C_2}{C_2 + C_3}} < 1$$

3 kondenzatora
Potrebni baferi (pojačanje)
Potrebno 4 OTA i 2 kondenzatora

$$H(s) = \frac{V_3}{V_1} = \frac{C_2}{C_2 + C_3} \frac{s^2 + \frac{g_{m1} g_{m2}}{C_1 C_2}}{s^2 + \frac{g_{m2}}{C_2 + C_3} s + \frac{g_{m1} g_{m2}}{C_1 (C_2 + C_3)}}$$

4-OTA generalni bikvad



Funkcije prenosa 4-OTA

$$H_{LP}(s) = \frac{V_4}{V_1} = \frac{\omega_p^2}{s^2 + \frac{\omega_p}{Q_p}s + \omega_p^2}$$

$$H_{BP}(s) = \frac{V_3}{V_1} = \frac{\frac{\omega_p}{Q_p}s}{s^2 + \frac{\omega_p}{Q_p}s + \omega_p^2}$$

$$H_{HP}(s) = \frac{V_2}{V_1} = \frac{s^2}{s^2 + \frac{\omega_p}{Q_p}s + \omega_p^2}$$

$$\omega_p = \sqrt{\frac{g_{m1}g_{m3}}{C_1C_2}\frac{g_{m4}}{g_{m2}}}$$

$$Q_p = \sqrt{\frac{C_1g_{m1}}{C_2g_{m3}}\frac{g_{m4}}{g_{m2}}}$$

Sinteza

g_{m1}, g_{m2}, C_1, and C_2,

Biramo sami

$$g_{m3} = \frac{\omega_p}{Q_p} C_1$$

$$g_{m4} = \omega_p Q_p C_2 \frac{g_{m2}}{g_{m1}}$$

Primer

$$g_{m1} = g_{m2}$$

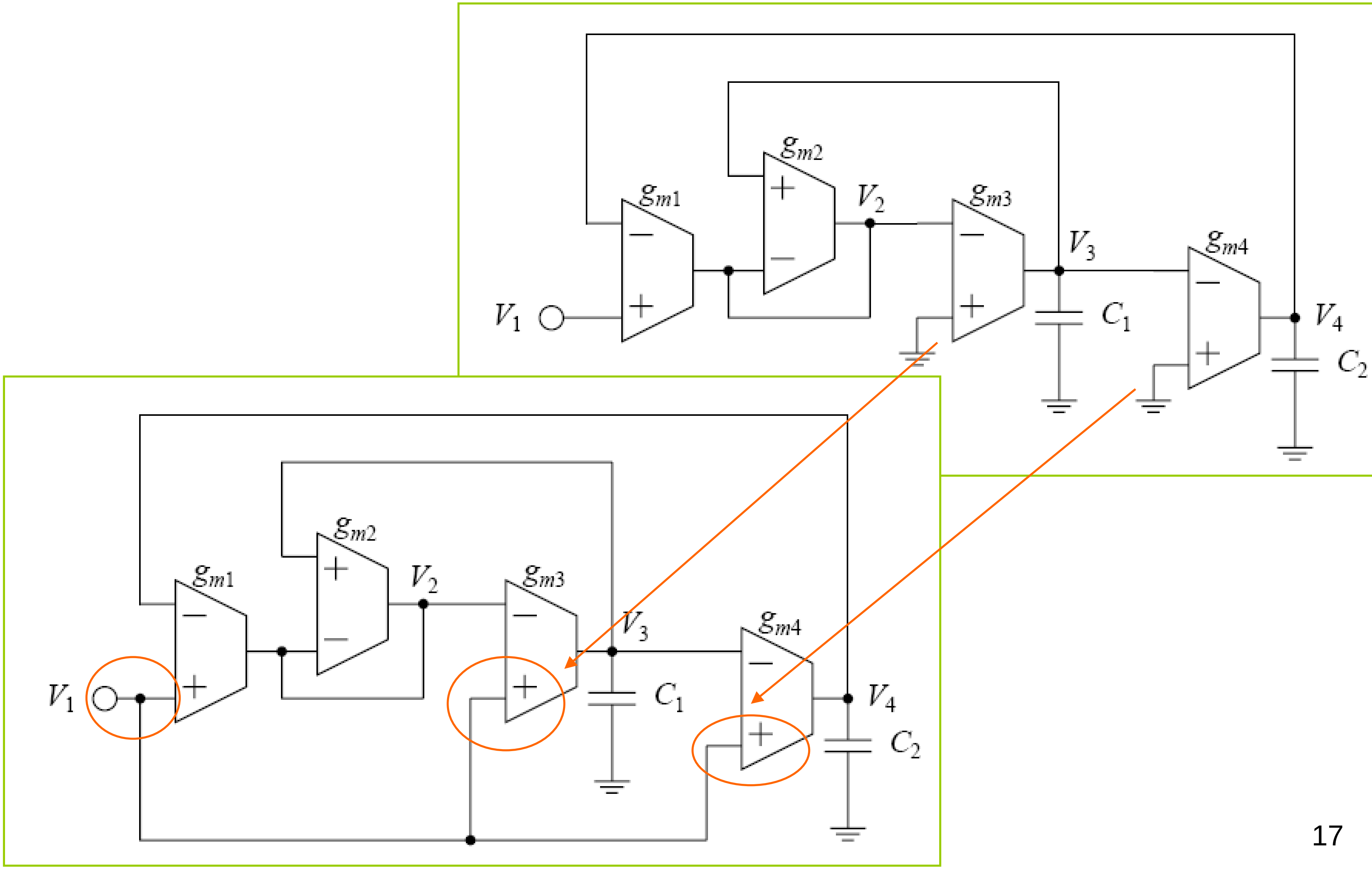
$$C_1 = C_2 = C$$

Podešavanje

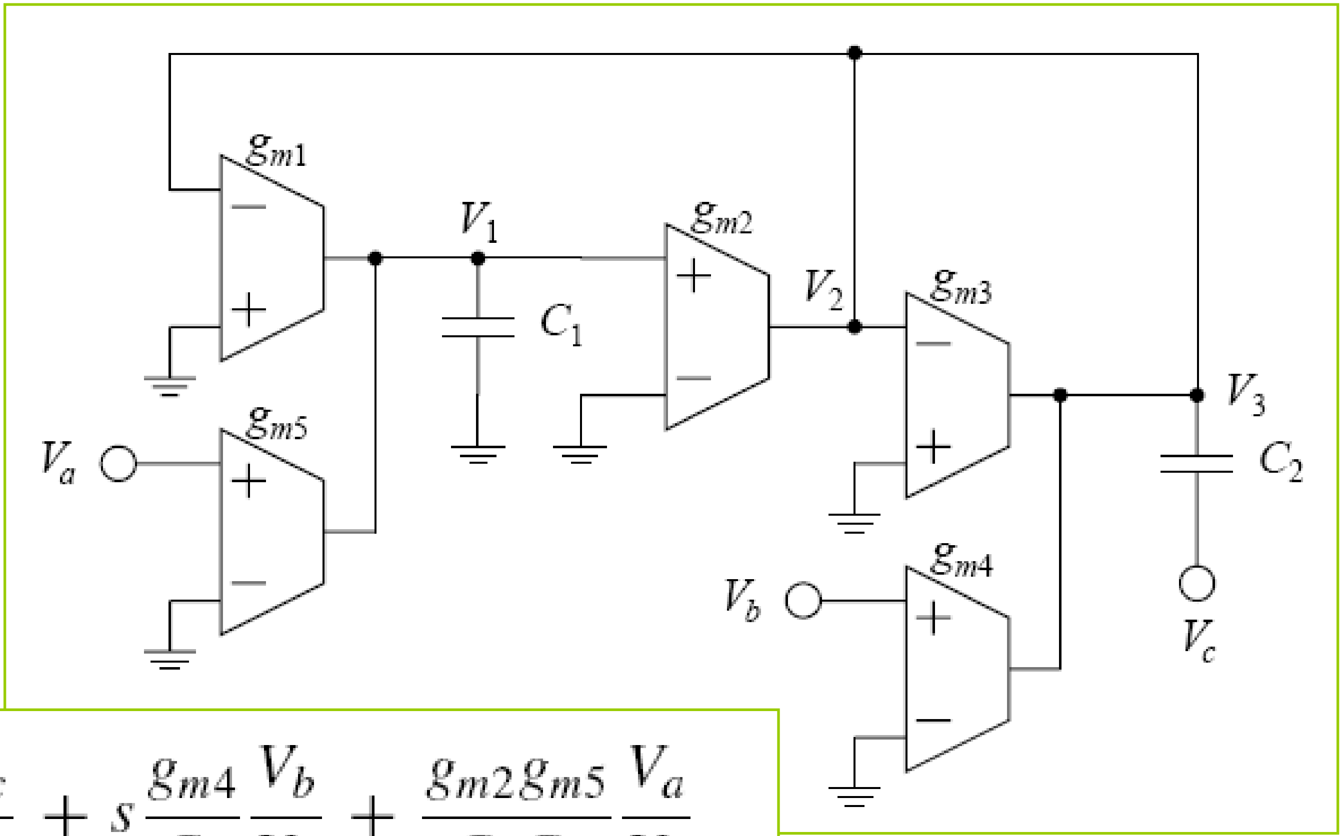
$$\omega_p = \sqrt{\frac{g_{m3} g_{m4}}{C^2}}$$

$$Q_p = \sqrt{\frac{g_{m4}}{g_{m3}}}$$

4-OTA notch



5-OTA



$$\frac{V_3}{V_g} = \frac{s^2 \frac{V_c}{V_g} + s \frac{g_{m4}}{C_2} \frac{V_b}{V_g} + \frac{g_{m2} g_{m5}}{C_1 C_2} \frac{V_a}{V_g}}{s^2 + \frac{g_{m3}}{C_2} s + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

Funkcije prenosa 5-OTA

$$H_{LP}(s) = \frac{\dfrac{g_{m2}g_{m5}}{C_1C_2}}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = V_g, \quad V_b = 0, \quad V_c = 0$$

$$H_{HP}(s) = \frac{s^2}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = 0, \quad V_b = 0, \quad V_c = V_g$$

$$H_{BP}(s) = \frac{s\dfrac{g_{m4}}{C_2}}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad V_a = 0, \quad V_b = V_g, \quad V_c = 0$$

Funkcije prenosa 5-OTA

$$H_{BR}(s) = \frac{s^2 + \dfrac{g_{m2}g_{m5}}{C_1C_2}}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad g_{m1} = g_{m5}$$

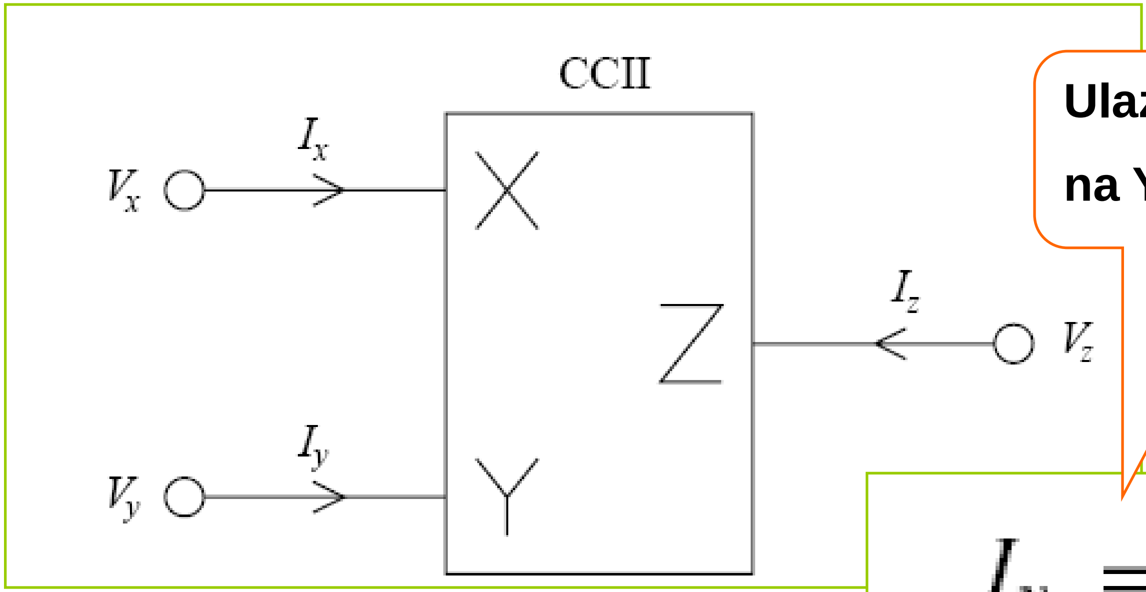
$$H_{LPN}(s) = \frac{s^2 + \dfrac{g_{m2}g_{m5}}{C_1C_2}}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad g_{m1} < g_{m5}$$

$$H_{HPN}(s) = \frac{s^2 + \dfrac{g_{m2}g_{m5}}{C_1C_2}}{s^2 + \dfrac{g_{m3}}{C_2}s + \dfrac{g_{m1}g_{m2}}{C_1C_2}}, \quad g_{m1} > g_{m5}$$

Current-conveyor (CC) Filters

- Tehnologija je optimizovana za digitalna kola a analogna kao podrška za AD konverziju
- Osnovni element je tranzistor
- Druga generacija CC – CCII

Model



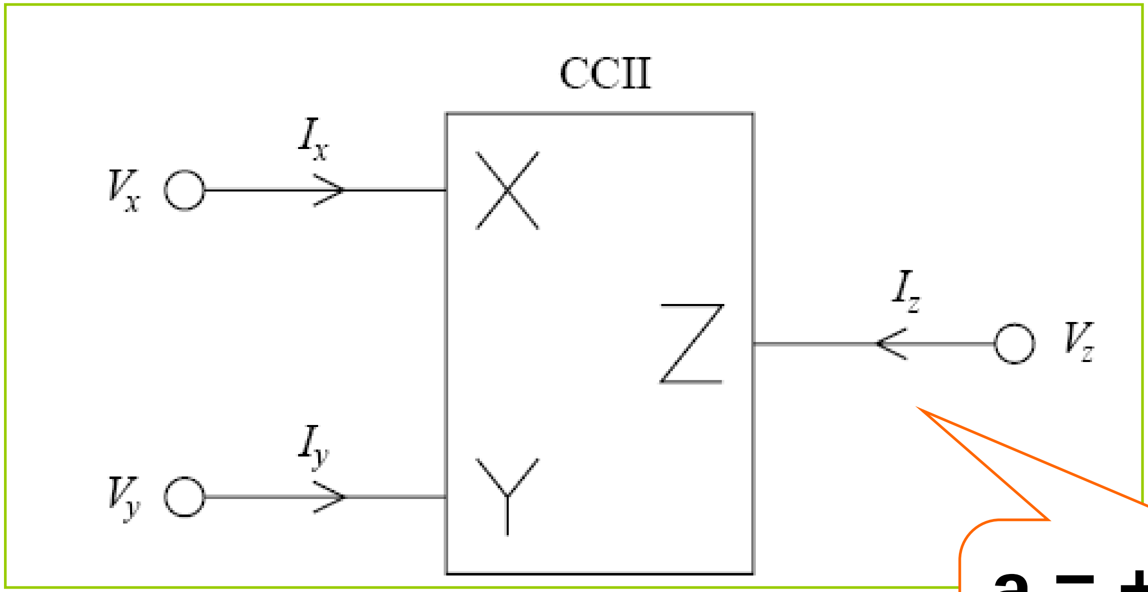
Ulazna impedansa na Y ulazu je ∞

$$I_y = 0$$

$$V_x = V_y$$

$$I_z = a I_x$$

Model



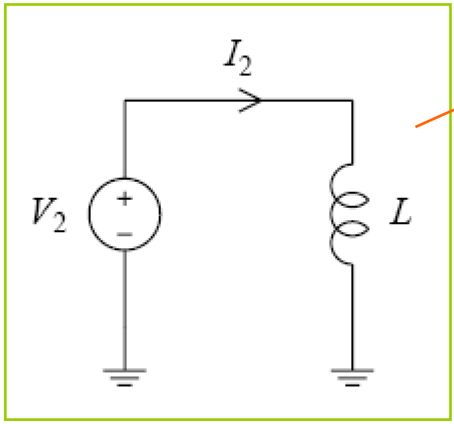
a = +1 CCII+

a = -1 CCII-

Postupci sinteze

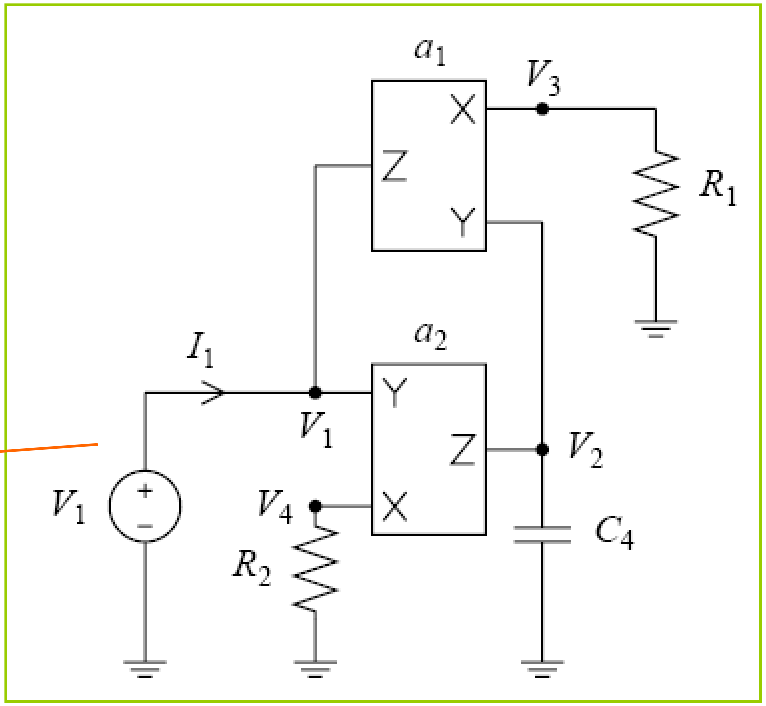
- Prvo se projektuje
  - **LC filtri** sa dva pristupa
    - Manje osetljiv na tolerancije
  - **Bikvadratne sekcije** sa op-amp
    - Iste karakteristike kao aktivni RC
- Konverzija u CC realizacije

Uzemljen kalem



$$Z_{in2} = \frac{V_2}{I_2} = Ls$$

$$Z_{in1} = Z_{in2}$$

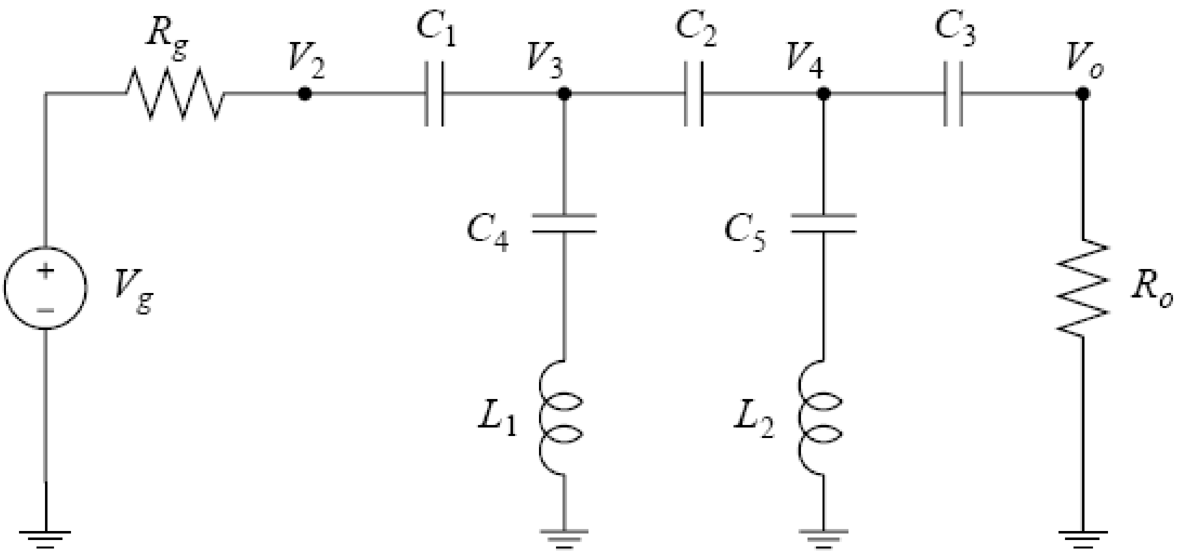


$$Z_{in1} = \frac{V_1}{I_1} = \frac{CR_1R_2}{-\,a_1a_2}s$$

$$L = \frac{CR_1R_2}{-\,a_1a_2} > 0$$

$a_1 = 1 \qquad a_2 = -1 \qquad L = CR_1R_2$

Primer



$$H(s) = H_1(s)H_2(s)$$

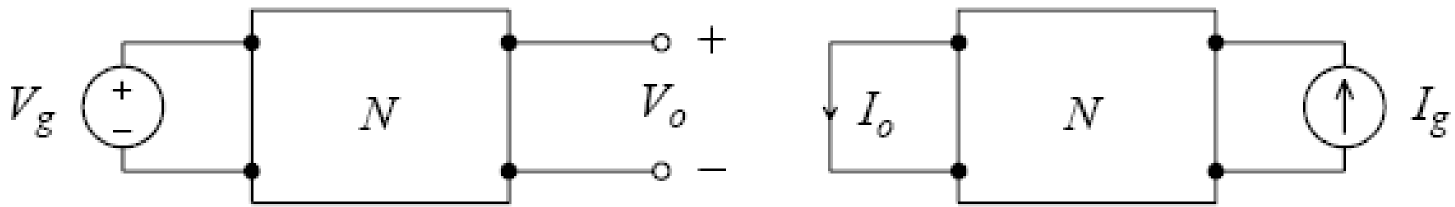
$$H_1(s) = \frac{1+C_4Ls^2}{C_1+C_4+C_1C_4Rs+C_1C_4Ls^2}$$

$$H_2(s) = \frac{C_1^2C_2R(1+C_4Ls^2)s}{C_1+2C_2+C_4+2C_1C_2Rs+C_1C_4Rs+C_1C_4Ls^2+2C_2C_4Ls^2+2C_1C_2C_4LRs^3}$$

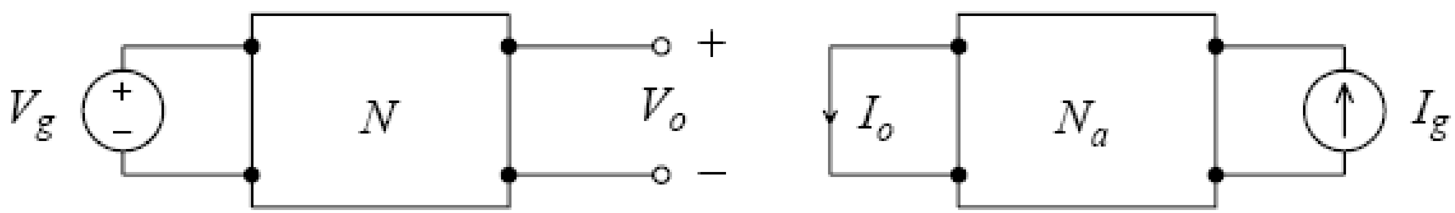
$$R_g = R_o = R, \quad C_3 = C_1, \quad C_5 = C_4, \quad L_2 = L_1 = L$$

Op-amp RC - CC

reciprocal network



(a)



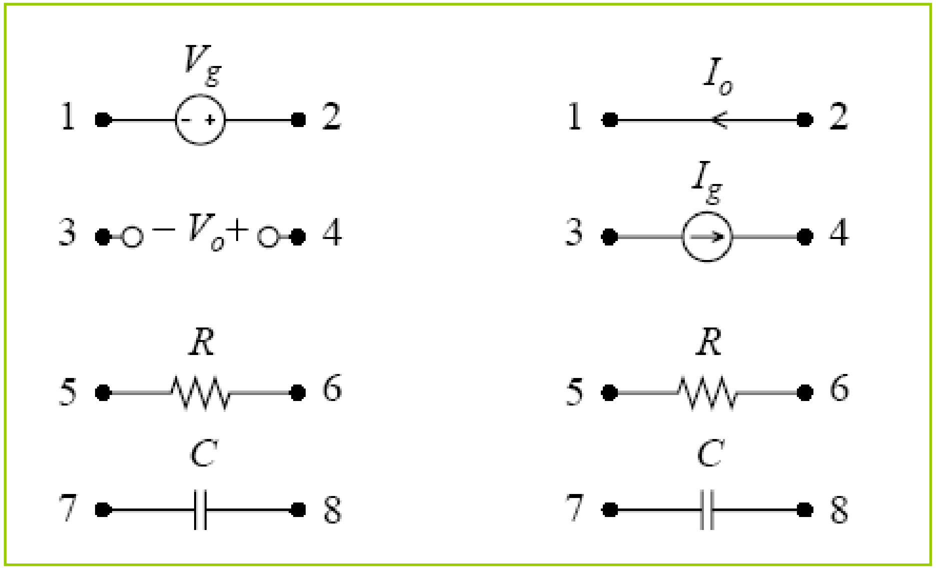
interreciprocal networks, $\frac{V_o}{V_g} = \frac{I_o}{I_g}$

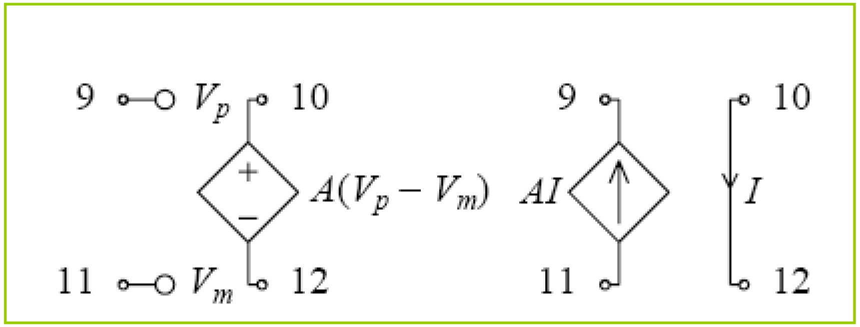
Na mreža dobijena iz *N* mreže

- Passive R and C elements in N_a are the same as those in N.
- The ideal input voltage source of N is converted to a short circuit, and the current through it becomes the output of N_a.
- The port of N at which the output voltage is taken becomes a current source in N_a.

- A voltage-controlled voltage source is converted to a current-controlled current source: The controlled voltage source, AV, is converted to a short circuit through which flows the controlling current I, while the controlling voltage V is converted to a controlled current source, AI.

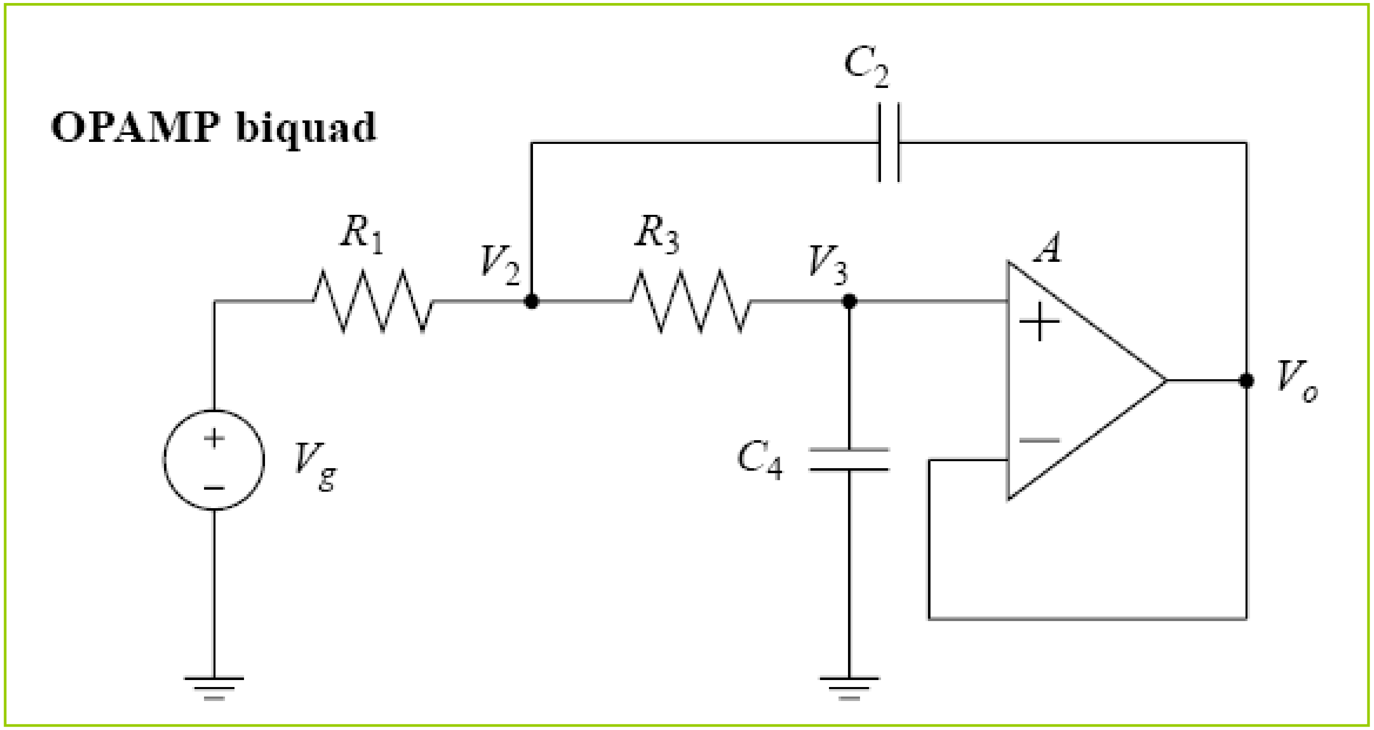
Na mreža dobijena iz *N* mreže





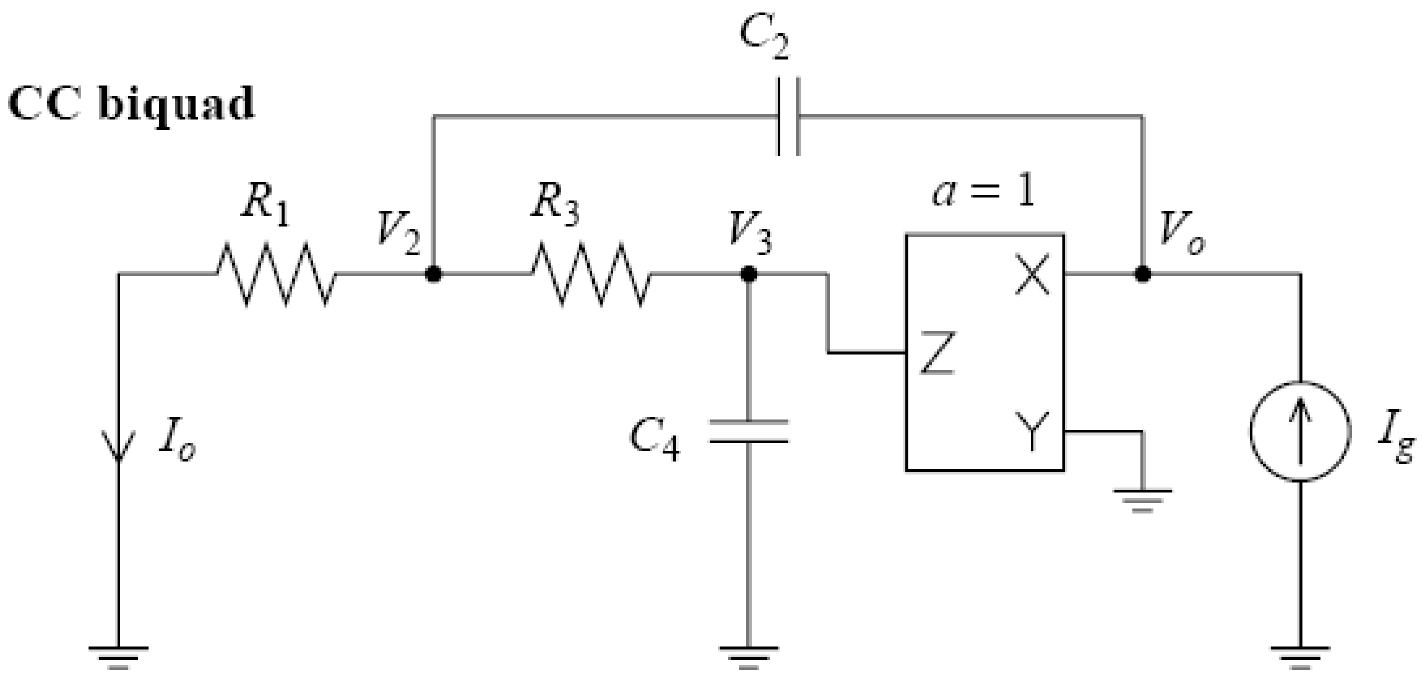
Primer

Sallen–Key lowpass op amp biquad.

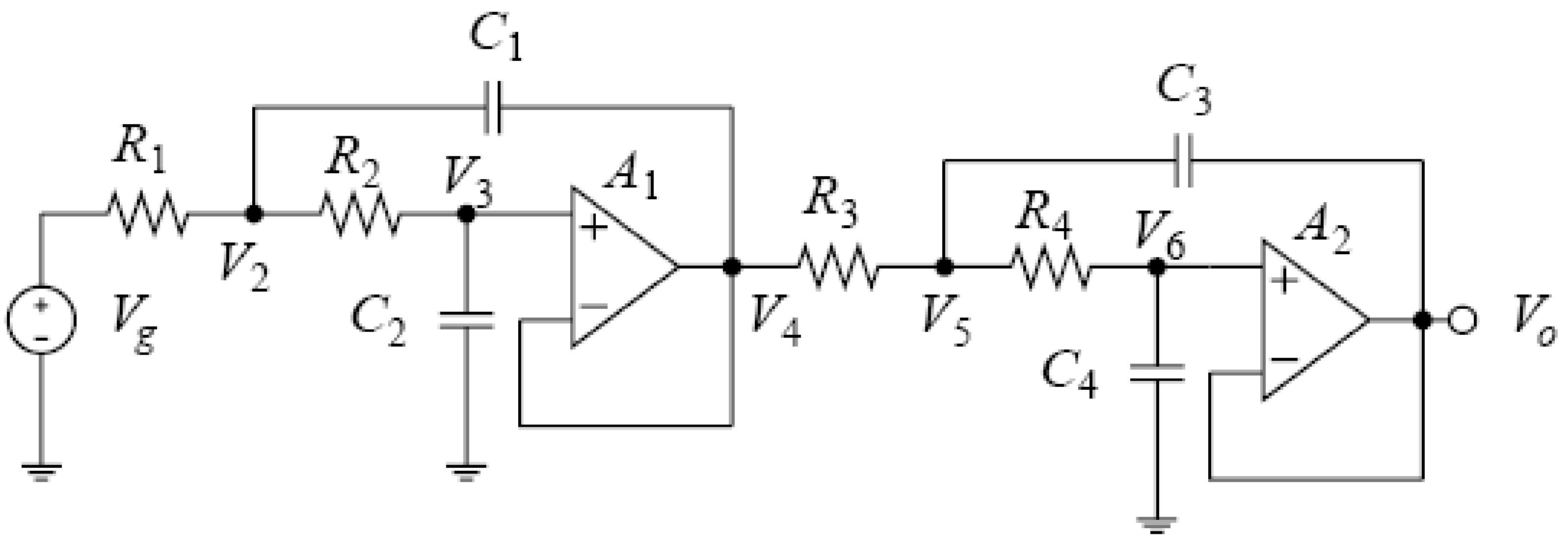


$$H(s) = \frac{\frac{1}{C_2 C_4 R_1 R_3}}{s^2 + \frac{R_1 + R_3}{C_2 R_1 R_3} s + \frac{1}{C_2 C_4 R_1 R_3}}$$

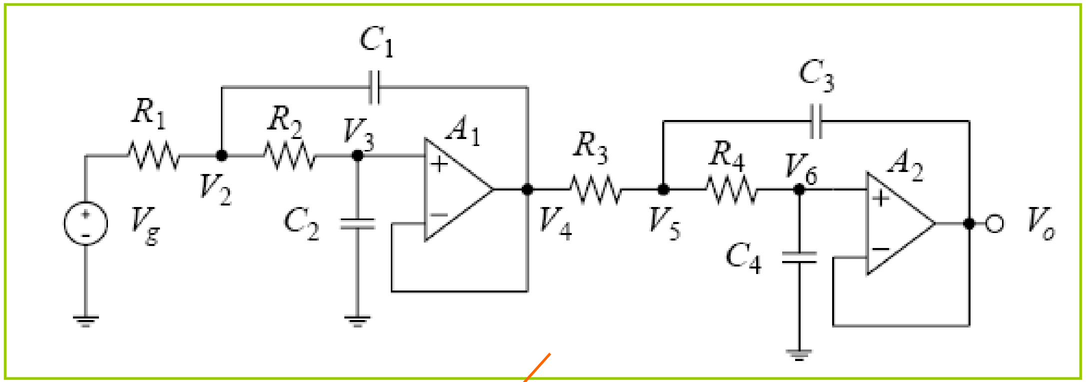
CC Sallen-Key

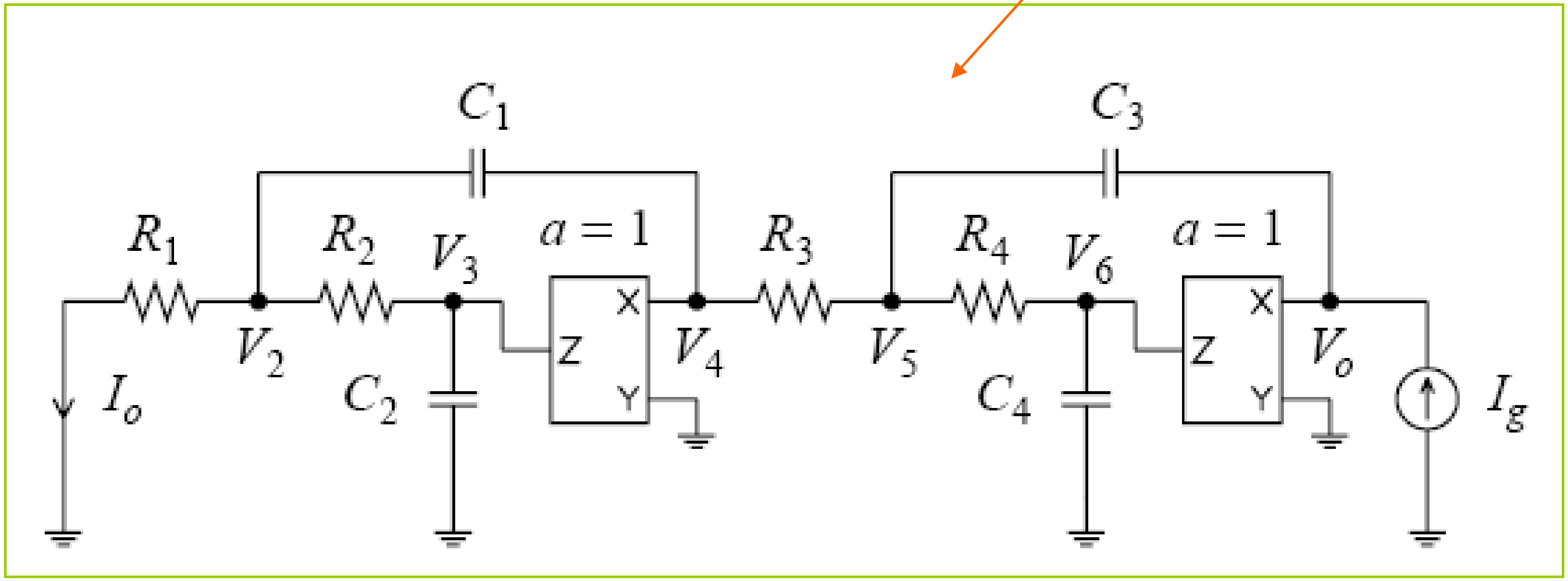


Kaskadna veza Op-amp RC



CC kaskadna veza





Sinteza OTA i CC

- Zadati specifikacije
- Odabrati funkciju prenosa
- Uraditi sintezu sa LC ili aktivni RC
- Konverzija u OTA ili CC
- Verifikacija
- Analiza tolerancija