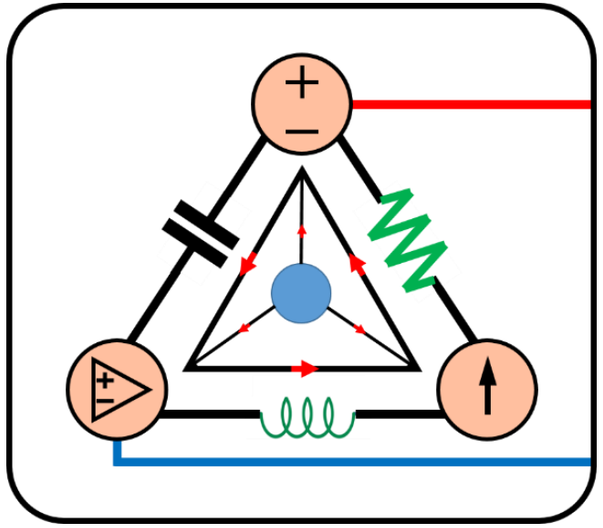
5-Mavzu: Operatsion kuchaytirgichlar.

(Lecture-5: Operational Amplifiers)

5-Mavzuning 2-qismi

(Part 2 of the Lecture-5)



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5-Mavzu: Operatsion kuchaytirgichlar.

(Lecture-5: Operational Amplifiers)

O‘quv rejasi:

5.1. Operatsion kuchaytirgichlar.

5.2. Ideal operatsion kuchaytirgichlar.

5.3. Teskari (*inverting*) kuchaytirgichlar.

5.4. Teskari bo‘lmagan (*noninverting*) kuchaytirgichlar.

5.5. Umumlashtirish kuchaytirgichi.

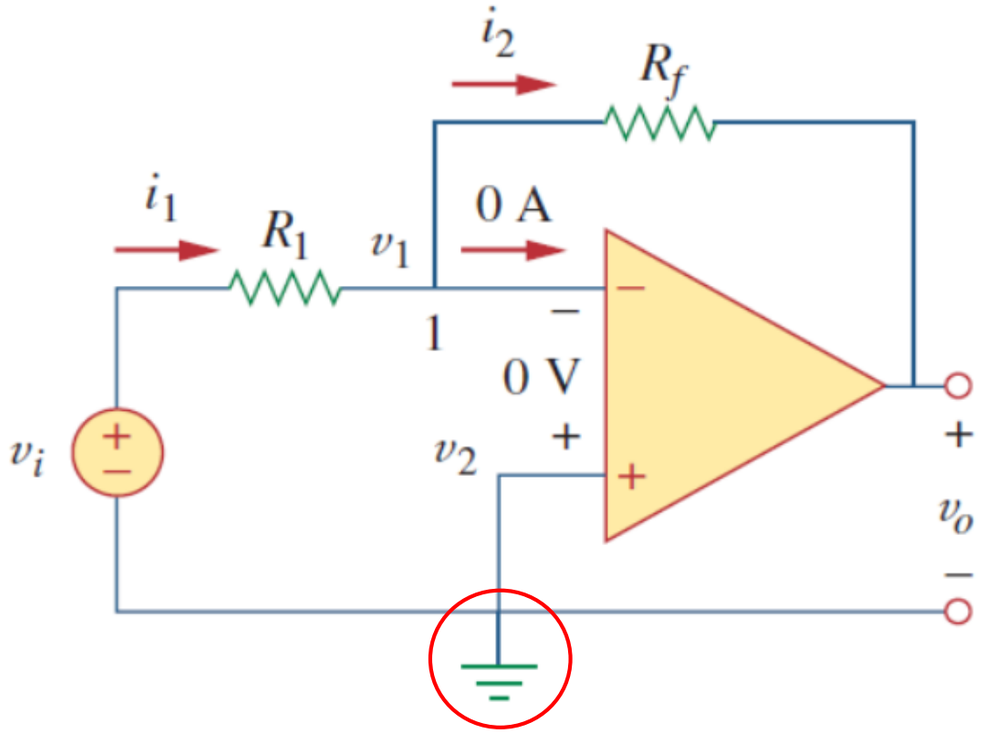
5.6. Farqlovchi kuchaytirgich.

5.7. Kaskadli operatsion kuchaytirgich zanjirlari.

5.8. Qo‘llanilishi.

5.3. Teskari (*inverting*) kuchaytirgichlar.

Biz ko‘pincha murakkab bo‘lgan zanjirlarni loyihalash uchun modul bo‘lib xizmat qiladigan ba’zi foydali operatsion kuchaytirgichli zanjirlarni bu bo‘limda ko‘rib chiqamiz.



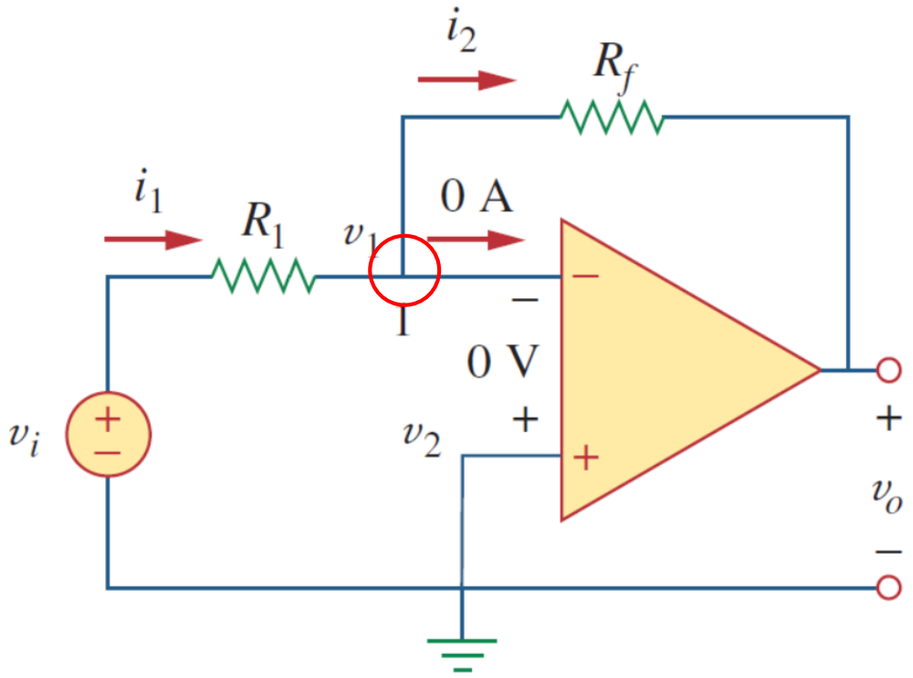
5.9-rasm. Teskari kuchartirgich

Bulardan biri teskari kuchaytirgichdir.

Bu zanjirda teskari bo‘lmagan (*non-inverting*) kirish massa (*ground*) ga ulangan.

u_1 teskari kirish qarshilik R_1 orqali ulangan va qayta aloqa o‘rnatuvchi (*feedback*) qarshilik R_f esa teskari kirish va chiqishlar orasidagi qarshilik hisoblanadi.

Biz kirish kuchlanishi u_1 va chiqish kuchlanishi u_o o‘rtasidagi bog‘liqlikni topamiz.



5.9-rasm. Teskari kuchartirgich

1-tugun uchun KCL ni qo‘llaymiz:

$$i_1 = i_2 \rightarrow \frac{u_i - u_1}{R_1} = \frac{u_1 - u_o}{R_f} \qquad (5.8)$$

Ideal operatsion kuchaytirgich uchun $u_1 = u_2 = 0$ chunki, teskari bo‘lmagan terminal massaga ulangan.

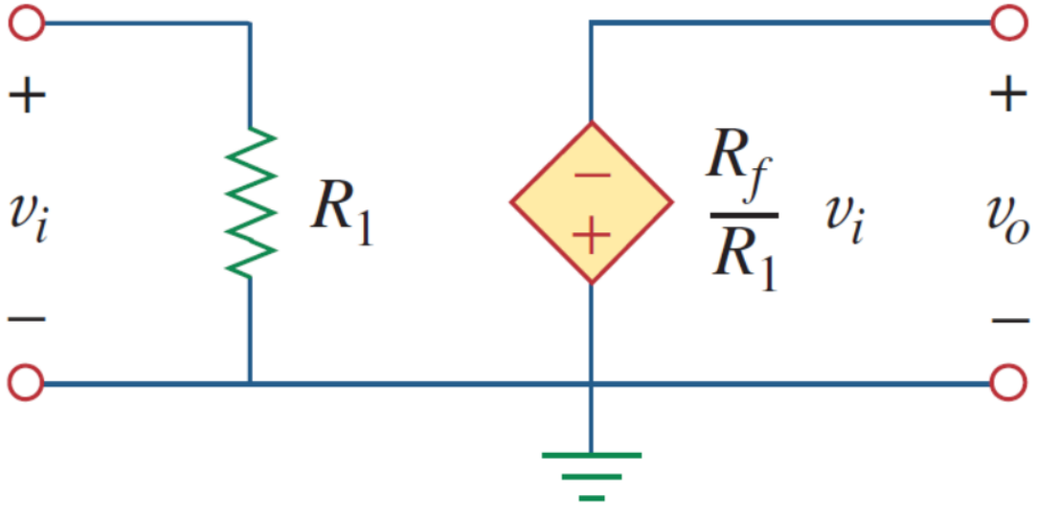
$$\frac{u_i}{R_1} = -\frac{u_o}{R_f} \quad \text{yoki} \quad u_o = -\frac{R_f}{R_1} u_i \qquad (5.9)$$

Kuchlanishni ortishi $\boldsymbol{A_u = \frac{u_o}{u_i} = -\frac{R_f}{R_1}}$ ga teng.

5.9-rasmdagi zanjirning invertor sifatida belgilanishi **manfiy** belgidan kelib chiqadi.

Shunday qilib, Inverting kuchaytirgich kirish signalini kuchaytirganda uning polaritesini (yo‘nalishini) o‘zgartiradi.

E’tibor bering, kuchayish qayta aloqa qarshiligi kirish qarshiligiga bo‘linadi, ya’ni kuchayish faqat operatsion kuchaytirgichga ulangan tashqi elementlarga bog‘liq.



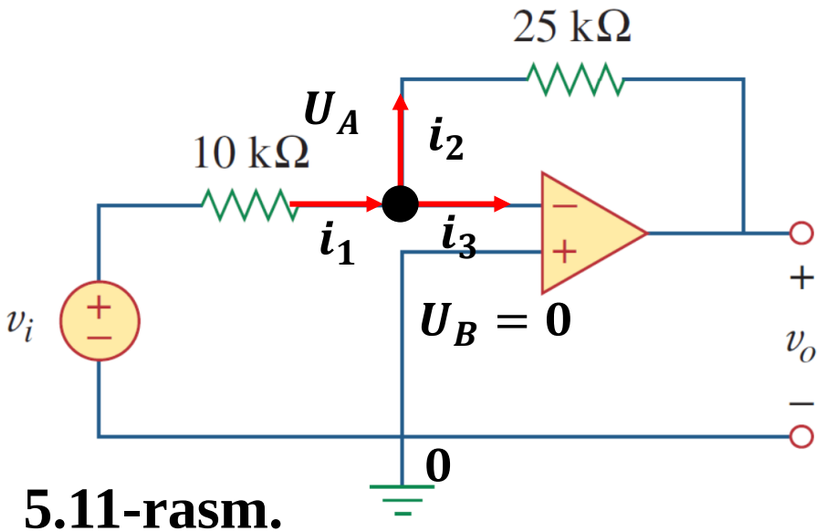
5.10-rasm. 5.9-rasmdagi inverter uchun ekvivalent sxema.

(5.9) tenglamani hisobga olgan holda, teskari kuchaytirgich uchun ekvivalent zanjir 5.10-rasmda ko‘rsatilgan.

Inverting kuchaytirgichi masalan, tok kuchidan-kuchlanish (*current-to-voltage*) ga aylantirish uchun ishlatiladi.

5.3.1-masala: 5.11-rasmdagi operatsion kuchaytirgichga qarang.

Agar $u_i = 0{,}5\ V$ ga teng bo‘lsa, tashqi kuchlanish u_o va 10 kΩ rezistordan o‘tuvchi tok kuchini aniqlang.



5.11-rasm.

Yechish:

$$\frac{u_o}{u_i} = -\frac{R_f}{R_1}$$

$$\frac{\boldsymbol{u_o}}{\boldsymbol{u_i}} = -\frac{R_f}{R_1} = -\frac{25}{10} = \boldsymbol{-2,5}$$

$$\boldsymbol{u_o} = -2{,}5u_i = -2{,}5(0{,}5) = \boldsymbol{-1{,}25\ V}$$

KCL:

$$\sum i_{in} = \sum i_{out}$$

$$i_1 = i_2 + i_3$$

$$\frac{u_i - 0}{R_1} = \frac{u_i - u_o}{R_f} + 0$$

10 kΩ rezistor orqali o‘tadigan tok:

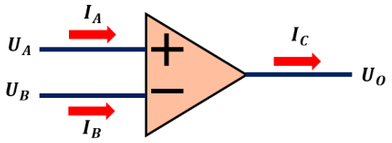
$$i = \frac{u_i - 0}{R_1} = \frac{0{,}5 - 0}{10 \cdot 10^3} = 50\ \mu A$$

25 kΩ rezistor orqali o‘tadigan tok:

$$i = \frac{u_i - u_o}{R_f} = \frac{0{,}5 - (-1{,}25)}{25 \cdot 10^3} = 70\ \mu A$$

Qoida:

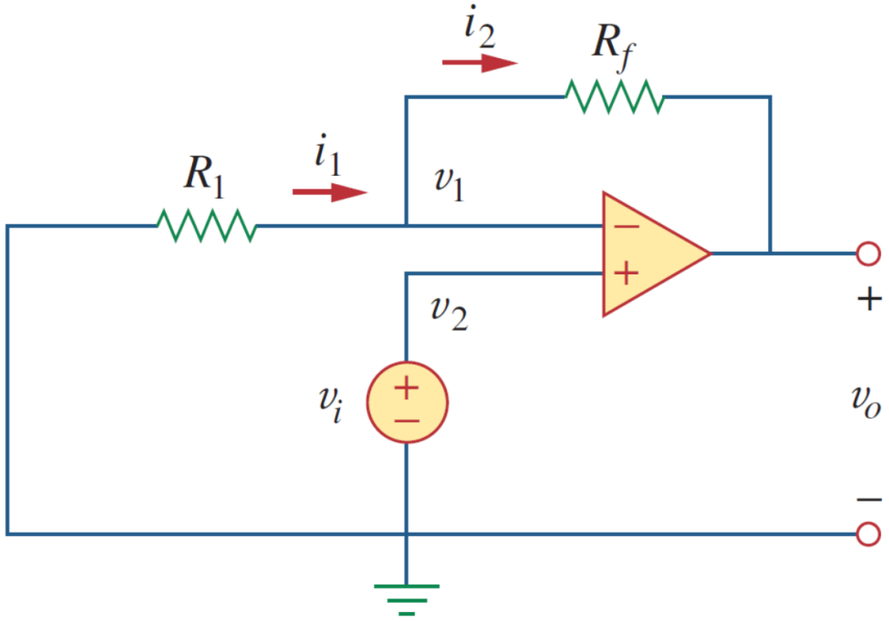
1) *Massani belgilang;*
2) $U_A = U_B\ ,V;$
3) $I_A = I_B = 0, A;$
4) $I_A + I_B \neq I_C, A;$
5) *Har doim KCL va Tugun tahlilidan foydalaniladi.*



5.4. Teskari bo‘lmagan (*noninverting*) kuchaytirgichlar.

Operatsion kuchaytirgichning yana bir muhim qo‘llanilishi teskari bo‘lmagan (*to‘g‘ri*) kuchaytirgichdir.

Bunda kirish kuchlanishi u_i to‘g‘ridan-to‘g‘ri teskari bo‘lmagan kirish terminaliga ulanadi va rezistor R_1 massa (*ground*) bilan teskari terminali o‘rtasiga ulanadi.



5.12-rasm. Teskari kuchaytirgich.

Tashqi kuchlanish ortishini ko‘rib chiqamiz.

Teskari terminal uchun KCL ni qo‘llaymiz,

$$i_1 = i_2 \rightarrow \frac{0-U_1}{R_1} = \frac{U_1-U_o}{R_f} \qquad (5.10)$$

$\boldsymbol{u_1 = u_2 = u_i}$ bo‘lgani uchun (5.10) tenglamadan quyidagini olamiz,

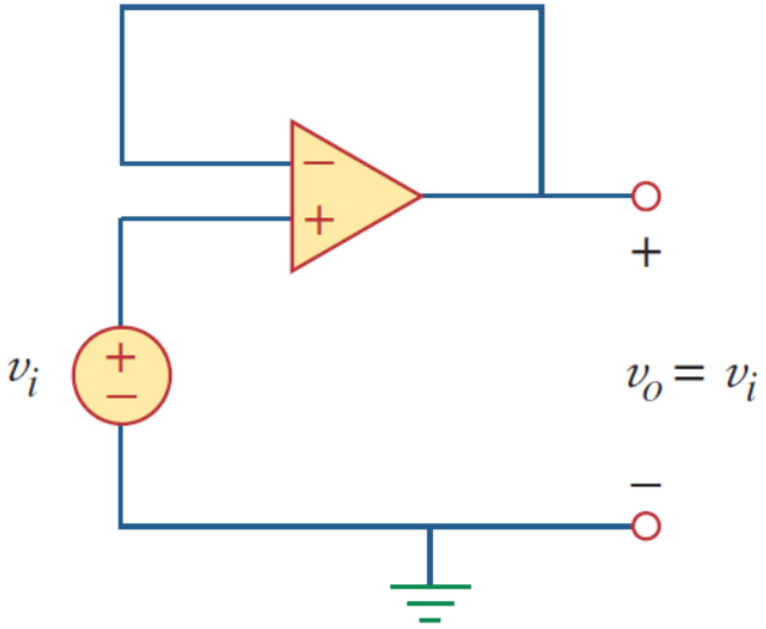
$$\frac{-u_i}{R_1} = \frac{u_i - u_o}{R_f} \qquad \text{yoki} \qquad u_o = (1 + \frac{R_f}{R_1})u_i \qquad (5.11)$$

Kuchlanish ortishi $A_U = \frac{U_0}{U_i} = 1 + \frac{R_f}{R_1}$ dir, bu salbiy belgiga ega emas. Shunday qilib, chiqish kirish bilan bir xil yo‘nalishga ega.

Teskari bo‘lmagan kuchaytirgich – bu zanjirdagi kuchlanishning ijobiy o‘sishini ta’minlash uchun mo’ljallangan operatsion kuchaytirgichdir.

O‘sish faqat tashqi rezistorlarga bog‘liq.

Agar teskari rezistor $R_f = 0$ (berk zanjir) yoki $R_1 = \infty$ (ochiq zanjir) yoki ikkalasi bo’lsa, ortish 1 ga teng bo‘ladi.



5.13-rasm. Kuchlanish takrorlagichi *(The voltage follower)*.

5.13-rasmda, bu kuchlanish takrorlagichi (*voltage follower*) deb ataladi, chunki chiqish kirishdan keyin keladi.

Kuchlanish takrorlagichi uchun

$$U_o = U_i \qquad (5.12)$$

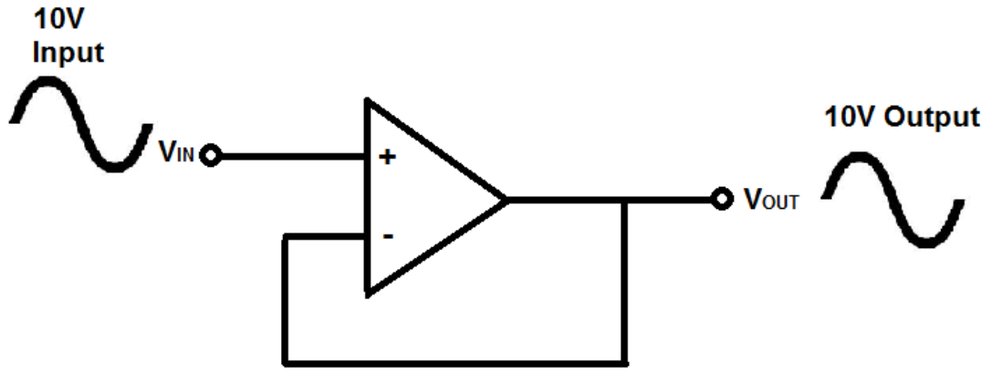
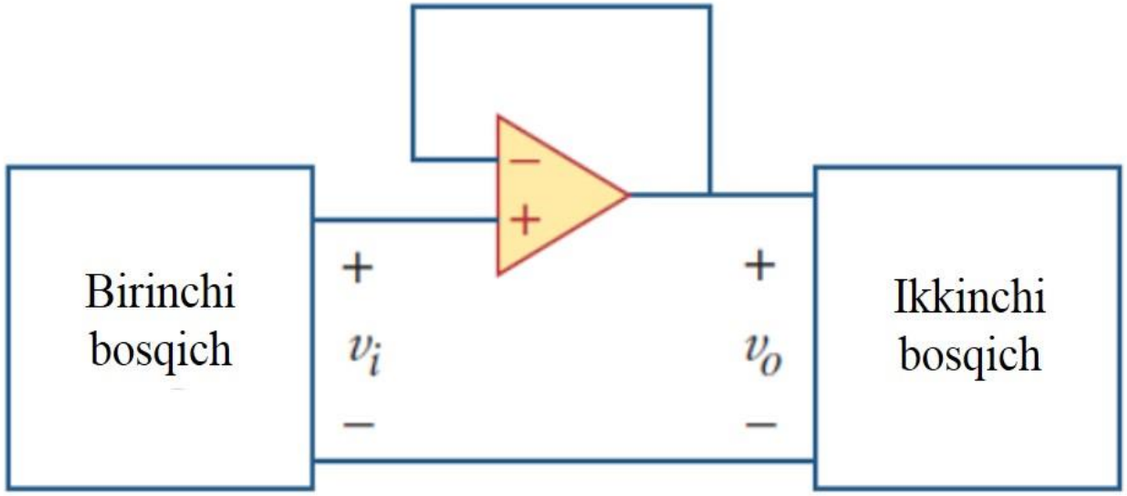


Photo source: [15] - https://www.learningaboutelectronics.com/images/Voltage-follower-example.png

Chiqish kuchlanishi kirish kuchlanishidan keyin bo‘lgan elektron zanjir ***kuchlanish takrorlagichi*** deb nomlanadi.

Boshqacha qilib aytaganda, kuchlanish takrorlagichi - bu chiqish kuchlanishi kirish kuchlanishi bilan bir xil bo‘lib qoladigan elektron zanjirdir.



Operatsion kuchaytirgich yordamida kuchlanish takrorlagichini loyihalashimiz mumkin.

5.14-rasm. Elektr zanjirining ikkita kaskadli bosqichini ajratish uchun ishlatiladigan kuchlanish takrorlagichi.

Bunday zanjir juda yuqori kirish qarshiligiga (*impedens*) ega va shuning uchun 5.14-rasmda tasvirlanganidek, bir zanjirni boshqasidan ajratish uchun oraliq bosqichli (*yoki bufer*) kuchaytirgich sifatida foydalidir.

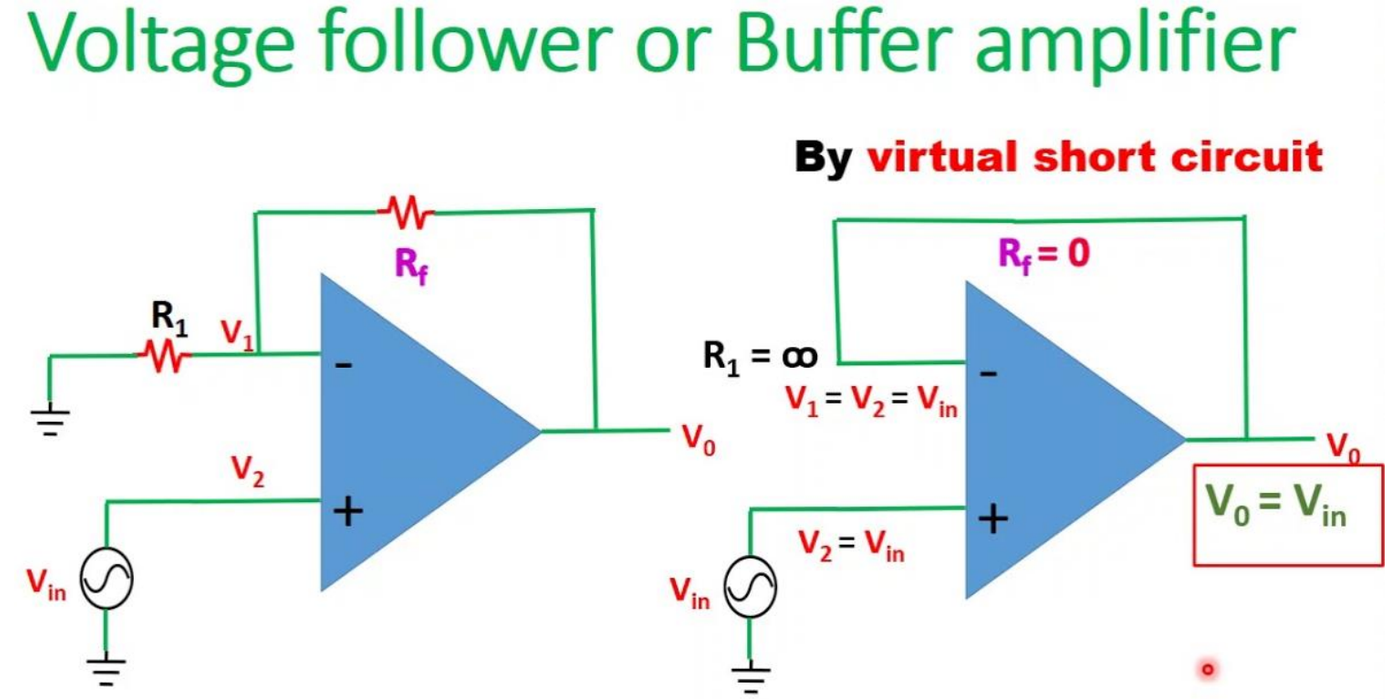
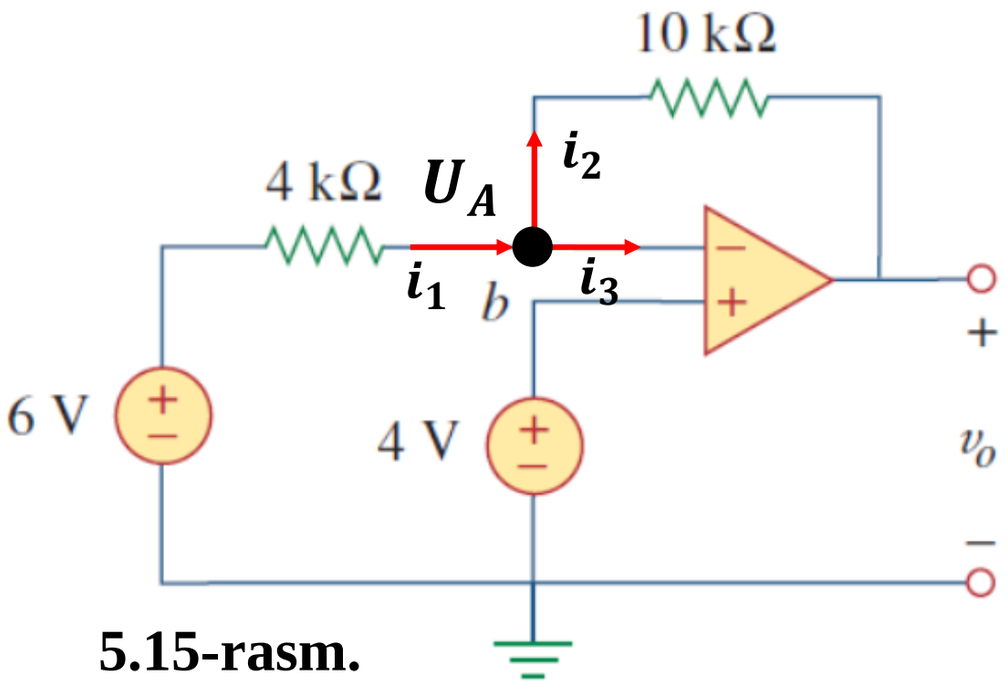


Photo source: [16] - https://i.ytimg.com/vi/gtJPeh3HvHU/maxresdefault.jpg

Kuchlanish taqrorlagichi ikki bosqich o‘rtasidagi o‘zaro ta’sirni minimallashtiradi va bosqichlararo yuklanishni bartaraf qiladi.

u_o ni aniqlang.



5.15-rasm.

Yechish:

Superpozitsiya usuli bo‘yicha:

$$u_o = u_{o1} + u_{o2}$$

$u_{o1} = 6\ V$ $\quad u_o = -\frac{R_f}{R_1}u_i \quad$ $u_{o1} = -\frac{10}{4}6 = -15\ V$

$u_{o2} = 4\ V$ $\quad u_o = (1+\frac{R_f}{R_1})u_i \quad$ $u_{o2} = \left(1+\frac{10}{4}\right)4 = 14\ V$

$$u_o = u_{o1} + u_{o2} = -15 + 14 = -1\ V$$

A tugun uchun KCL dan foydalanamiz:

$$\sum i_{in} = \sum i_{out}$$

$$i_1 = i_2 + i_3$$

$$\frac{u_i - 0}{R_1} = \frac{u_i - u_o}{R_f} + 0$$

$$\frac{6 - u_a}{4} = \frac{u_a - u_o}{10}$$

$$u_a = u_b = 4\ V$$

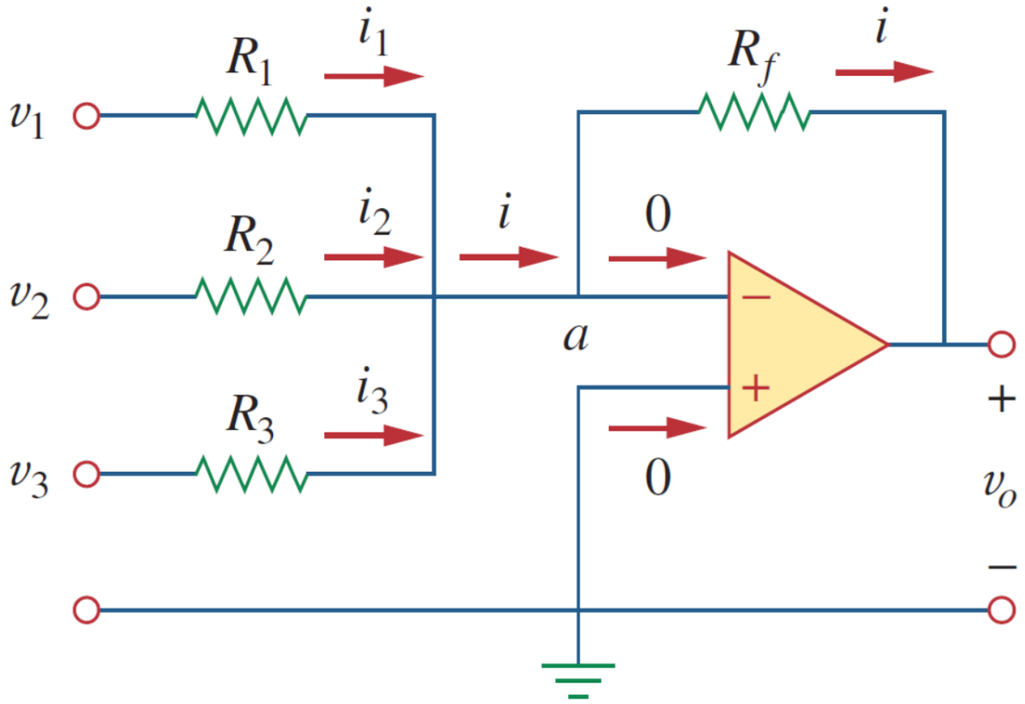
$$\frac{6-4}{4} = \frac{4-u_o}{10} \rightarrow 5 = 4 - u_o$$

5=5

$$u_o = -1\ V$$

5.5. Umumlashtirish kuchaytirgichi.

Kuchaytirishdan tashqari, operatsion kuchaytirgich qo‘shish va ayirishni ham amalga oshirishi mumkin.



5.16-rasm. Kuchaytirgichni umumlashtirish.

Umumlashtirish ushbu bo‘limda tasvirlangan yig‘ish kuchaytirgichi tomonidan amalga oshiriladi.

Umumlashtiruvchi kuchaytirgich bir nechta kirishlarni birlashtirgan va kirishlarning vaznli yig‘indisi bo‘lgan chiqishni ishlab chiqaradigan operatsion kuchaytirgichli zanjiridir.

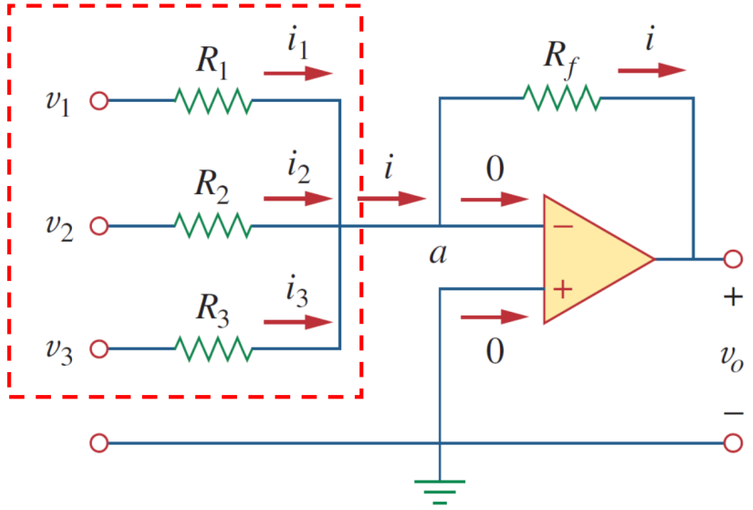
Bu teskari konfiguratsiyasi bir vaqtning o‘zida ko‘plab kirishlarni boshqarishi mumkinligidan foydalanadi.

Har bir operatsion kuchaytirgichning kiruvchisiga kiradigan tok kuchi nolga teng ekanligini yodda tutishimiz kerak. a tugun uchun KCL ni qo‘llaymiz:

$$i = i_1 + i_2 + i_3 \tag{5.13}$$

$$i_1 = \frac{u_1 - u_a}{R_1},\ i_2 = \frac{u_2 - u_a}{R_2},\ i_3 = \frac{u_3 - u_a}{R_3},\ i = \frac{u_a - u_o}{R_f} \tag{5.14}$$

$u_a = 0$ va (5.14) tenglamani (5.13) ga almashtirsak, quyidagiga ega bo‘lamiz:

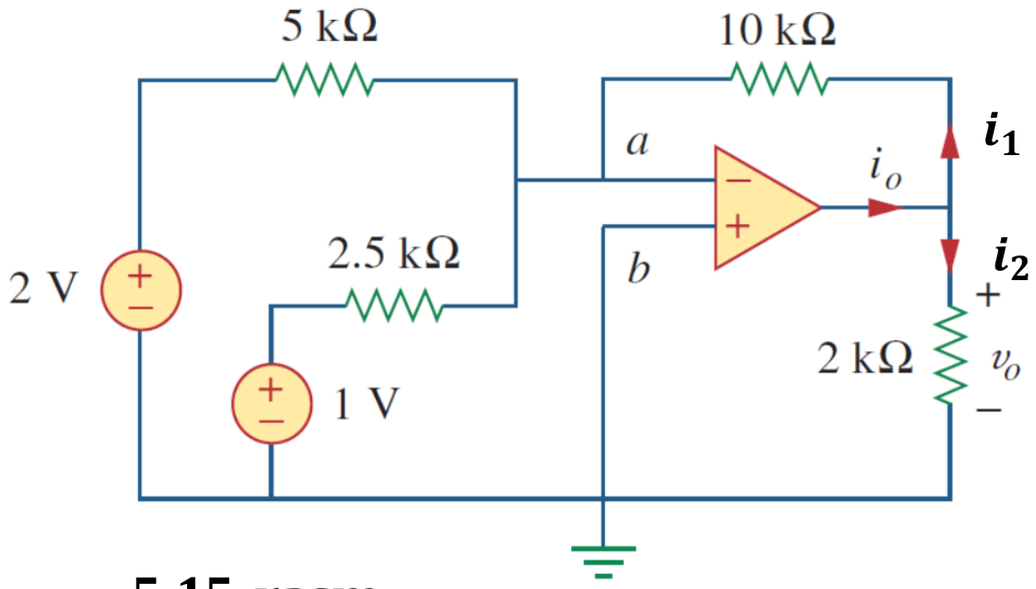


$$u_o = -\left(\frac{R_f}{R_1}u_1 + \frac{R_f}{R_2}u_2 + \frac{R_f}{R_3}u_3\right) \tag{5.15}$$

Chiqish kuchlanishi kirishlarning vaznli yig‘indisi ekanligini ko‘rsatamiz. Shuning uchun yig‘indi deb ataladi.

Yig‘indida uchtadan ortiq kirish bo‘lishi mumkin.

5.5.1-masala: 5.17-rasmdagi operatsion kuchaytirgichli zanjir uchun tashqi kuchlanish u_0 ni va tok kuchi i_0 ni aniqlang.



5.15-rasm.

Yechish:

$$u_o = -\left(\frac{R_f}{R_1}u_1 + \frac{R_f}{R_2}u_2 + \frac{R_f}{R_3}u_3\right)$$

$$\boldsymbol{u_o = -\left(\frac{10}{5}2 + \frac{10}{2{,}5}1\right) = -(4+4) = -8\ V}$$

KCL bo‘yicha $\sum i_{in} = \sum i_{out}$ $\quad i_o = i_1 + i_2$

$u_o = -8\ V$

$u_a = u_b = 0.$

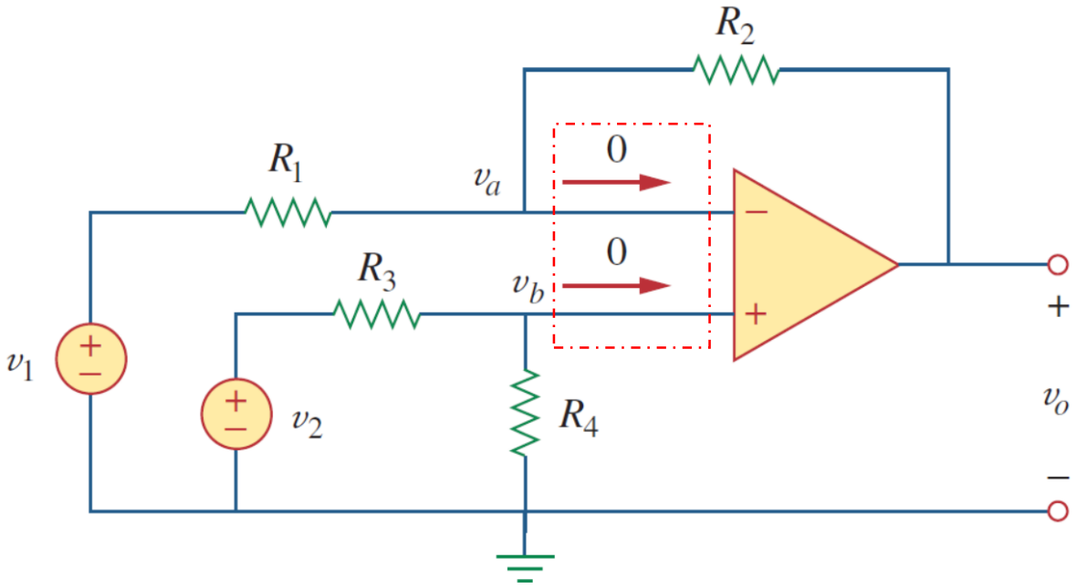
$$i_o = \frac{u_o - u_a}{R_f} + \frac{u_o - 0}{R_3}$$

$$\boldsymbol{i_o = \frac{u_o - 0}{10} + \frac{u_o - 0}{2} = -0{,}8 - 4 = -4{,}8\ mA}$$

5.6. Farqlovchi kuchaytirgich.

Qo‘shish umumlashtirish kuchaytirgichi orqali amalga oshirilgan bo‘lsa, ayirish farqlovchi kuchaytirgich orqali yoritiladi.

Farqlovchi (*yoki differensial*) kuchaytirgichlar ikkita kirish signallari orasidagi farqni kuchaytirish uchun turli hollarda qo‘llaniladi. Ular kuchaytirgichli asboblarning birinchi avlodlari hisoblanadi.

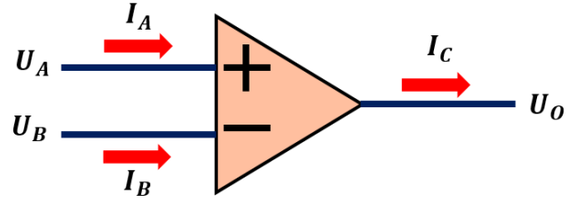


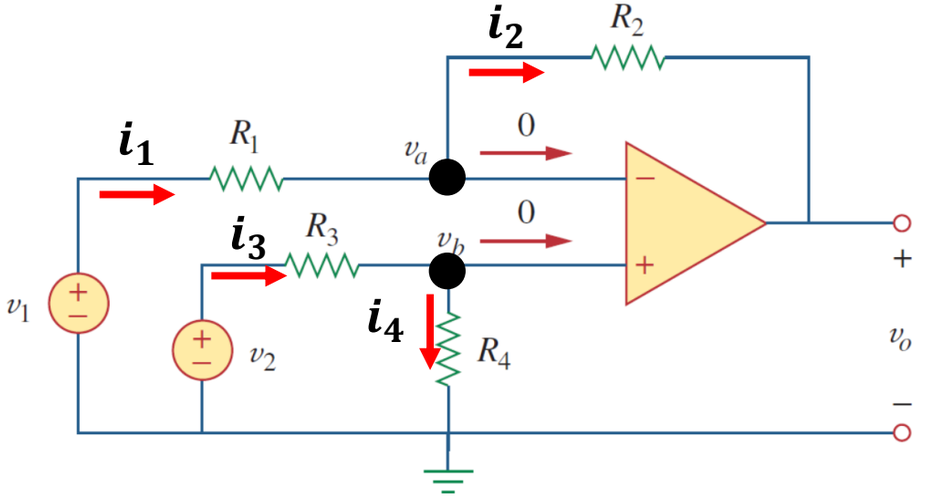
5.16-rasm. Farqlovchi kuchaytirgich.

Farqlovchi kuchaytirgich - bu ikkita kirish signallari o‘rtasidagi farqni kuchaytiradi.

Lekin ikkita kirish uchun umumiy bo‘lgan signallarni rad etadigan qurilmadir.

$$I_A = I_B = 0, A.$$





a tugun uchun KCL ni qo‘llaymiz: $\boldsymbol{i_1 = i_2}$

$$\frac{0-u_a+u_1}{R_1} = \frac{u_a-u_o}{R_2} \rightarrow \frac{u_1}{R_1} - \frac{u_a}{R_1} = \frac{u_a}{R_2} - \frac{u_o}{R_2} \rightarrow \frac{u_o}{R_2} = \frac{u_a}{R_2} + \frac{u_a}{R_1} - \frac{u_1}{R_1}$$

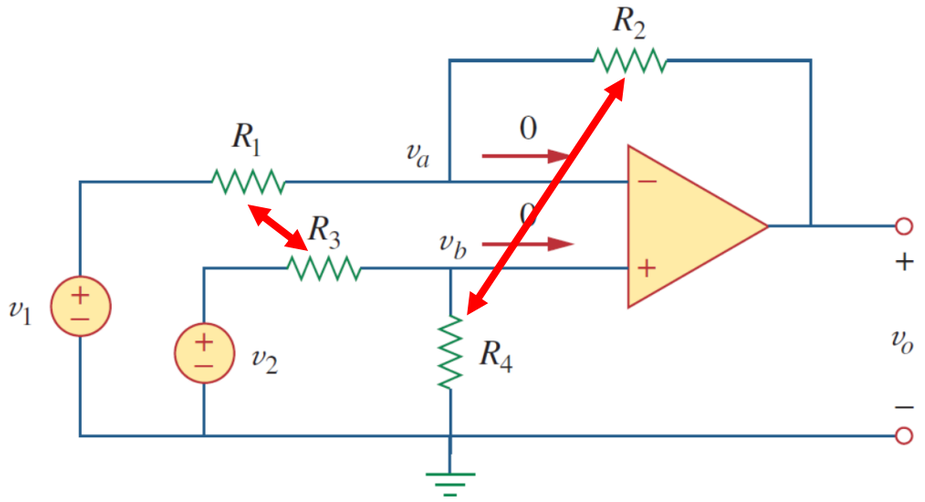
$$\boldsymbol{u_o = \left(\frac{R_2}{R_1} + 1\right) u_a - \frac{R_2}{R_1} u_1} \qquad (5.16)$$

b tugun uchun KCL ni qo‘llaymiz: $\boldsymbol{i_3 = i_4}$

$$\frac{0-u_b+u_2}{R_3} = \frac{u_b-0}{R_4} \qquad \text{yoki,} \qquad \boldsymbol{u_b = \frac{R_4}{R_3+R_4} u_2} \qquad (5.17)$$

$u_a = u_b$ bo‘lganligi uchun, (5.17) tenglamani (5.16) tenglamaga almashtiramiz:

$$u_o = \left(\frac{R_2}{R_1} + 1\right) \frac{R_4}{R_3+R_4} u_2 - \frac{R_2}{R_1} u_1 \qquad \text{yoki,} \qquad \boldsymbol{u_o = \frac{R_2\left(1+\frac{R_1}{R_2}\right)}{R_1\left(1+\frac{R_3}{R_4}\right)} u_2 - \frac{R_2}{R_1} u_1} \qquad (5.18)$$



Farqlovchi kuchaytirgich ikkita kirish uchun umumiy signalni rad etishi kerakligi sababli, kuchaytirgich $u_1 = u_2$ bo‘lganda $u_o = 0$ bo‘lgan xususiyatga ega bo‘lishi kerak.

Bu xususiyat mavjud bo‘ladi qachonki,

$$R_1 = R_3$$
$$R_2 = R_4$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad (5.19)$$

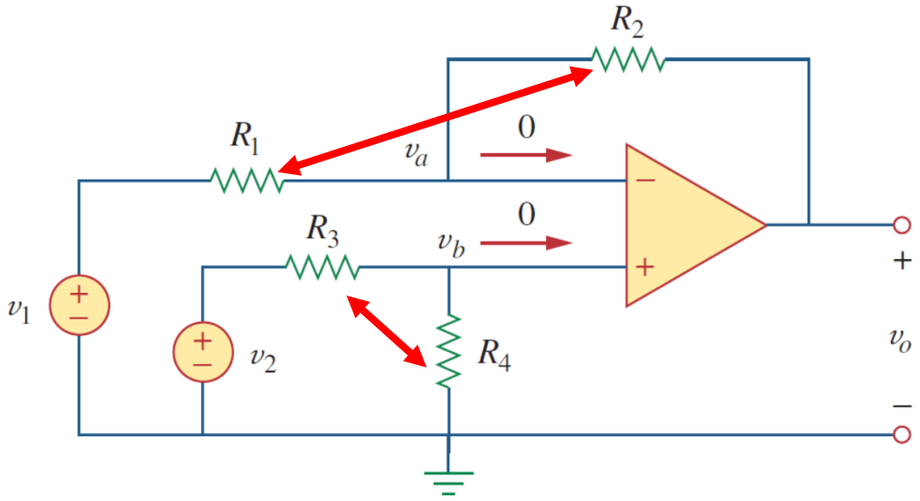
Shunday qilib, operatsion kuchaytirgich zanjiri farqlovchi kuchaytirgichi bo‘lsa, (5.18) tenglama quyidagi ko‘rinishga keladi:

$$u_o = \frac{R_2\left(1+\frac{R_1}{R_2}\right)}{R_1\left(1+\frac{R_3}{R_4}\right)}u_2 - \frac{R_2}{R_1}u_1 \quad \rightarrow \quad \boldsymbol{\frac{R_2}{R_1}}$$

- bu miqdor **A** ni bildiradi.

$$\boldsymbol{u_o = \frac{R_2}{R_1}(u_2 - u_1)} \qquad (5.20)$$

$$\boldsymbol{u_o = A(u_2 - u_1)}$$



$$R_1 = R_2$$
$$R_3 = R_4$$

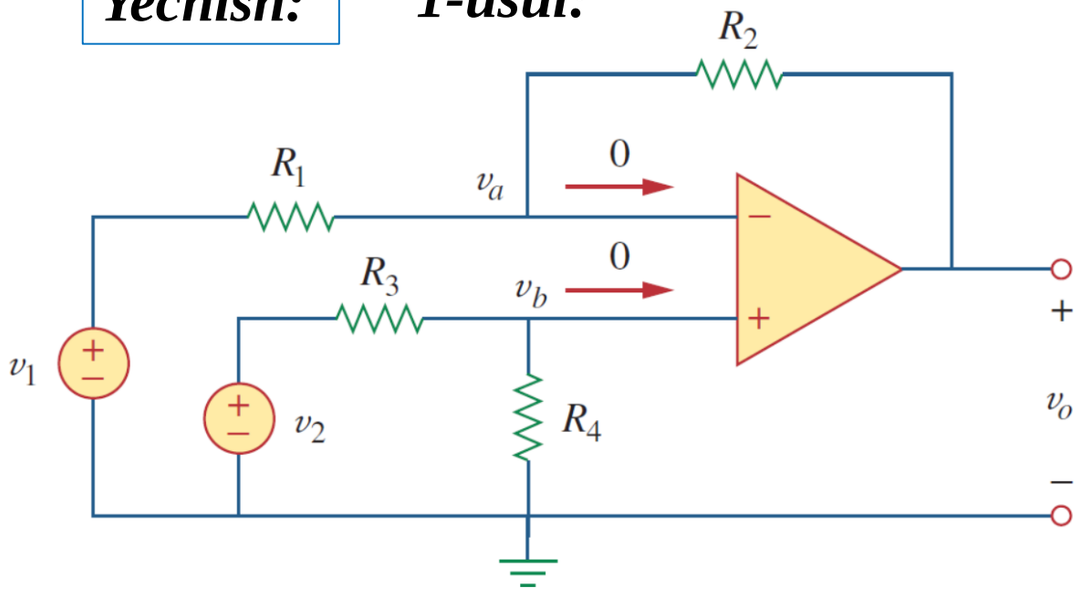
Farqlovchi kuchaytirgich chiqish bilan ayiruvchiga aylanadi:

$$u_o = \frac{R_2(1+\frac{R_1}{R_2})}{R_1(1+\frac{R_3}{R_4})}u_2 - \frac{R_2}{R_1}u_1 \quad \rightarrow \quad \boldsymbol{u_o = u_2 - u_1} \qquad (5.21)$$

5.6.1-masala: u_1 va u_2 kirishlari bilan operatsion kuchaytirgich zanjirini shunday loyihalashtiringki, $u_o = -5u_1 + 3u_2$ bo‘lsin.

Zanjir quyidagini talab etadi:

Yechish: ***1-usul:***



5.16-rasm. Farqlovchi kuchaytirgich.

$$u_o = 3u_2 - 5u_1 \qquad (5.6.1)$$

$$u_o = \frac{R_2(1+\frac{R_1}{R_2})}{R_1(1+\frac{R_3}{R_4})}u_2 - \frac{R_2}{R_1}u_1$$

$$\frac{R_2}{R_1} = 5$$

yoki,

$$R_2 = 5R_1 \qquad (5.6.2)$$

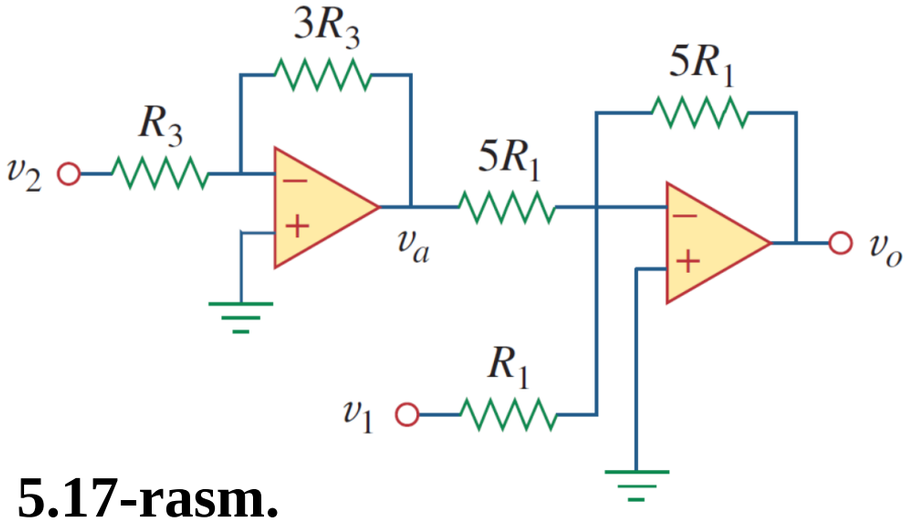
$$5\frac{(1+\frac{R_1}{R_2})}{(1+\frac{R_3}{R_4})} = 3 \quad \rightarrow \quad \frac{\frac{6}{5}}{1+\frac{R_3}{R_4}} = \frac{3}{5}$$

yoki, $\quad 2 = 1 + \frac{R_3}{R_4} \quad \rightarrow \quad R_3 = R_4 \qquad (5.6.3)$

Agar biz $R_1 = 10\ k\Omega$ va $R_3 = 20\ k\Omega$ ni tanlasak, u holda $R_2 = 50\ k\Omega$ va $R_4 = 20\ k\Omega$

5.6.1-masala: u_1 va u_2 kirishlari bilan operatsion kuchaytirgich zanjirini shunday loyihalashtiringki, $u_o = -5u_1 + 3u_2$ bo‘lsin.

Yechish: ***2-usul:***



5.17-rasm.

Umumlashtirish uchun:

$$u_o = -u_a - 5u_1 \qquad (5.6.4)$$

Inverting uchun: $u_a = -3u_2 \qquad (5.6.5)$

$$\boldsymbol{u_o = 3u_2 - 5u_1}$$

Agar biz bir nechta operatsion kuchaytirgichdan foydalanmoqchi bo‘lsak, 5.17-rasmda ko‘rsatilganidek, teskari (*inverting*) kuchaytirgichni va ikki kirishli teskari umumlashtiruvchini kaskadlashimiz mumkin.

$R_1 = R_2 \quad R_3 = R_4$

$$\boldsymbol{u_o = u_2 - u_1}$$

$\frac{R_2}{R_1} = 4$

yoki,

$R_2 = 4R_1$

$R_1 = R_3 \quad R_2 = R_4$

$$\boldsymbol{u_o = \frac{R_2}{R_1}(u_2 - u_1)}$$

Agar, $R_1 = 10\ k\Omega$, $R_3 = 10\ k\Omega$,

$R_2 = 40\ k\Omega$, $R_4 = 40\ k\Omega$

$R_1 = 10\ k\Omega$ va $R_3 = 20\ k\Omega$

yoki,

$R_1 = R_3 = 10\ k\Omega$ ni tanlashimiz mumkin.

FOYDALANILGAN MANBALAR:

15.https://www.learningaboutelectronics.com/images/Voltage-follower-example.png

16.https://i.ytimg.com/vi/gtJPeh3HvHU/maxresdefault.jpg

E'TIBORINGIZ UCHUN RAHMAT!!!