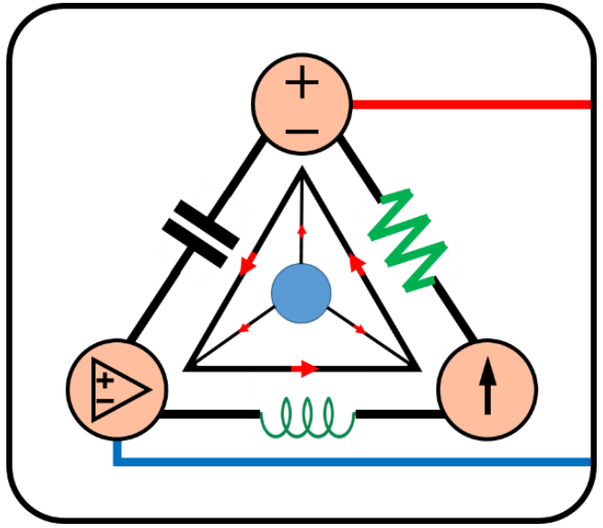
5-Mavzu: Operatsion kuchaytirgichlar.

(Lecture-5: Operational Amplifiers)

5-Mavzuning 1-qismi

(Part 1 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.

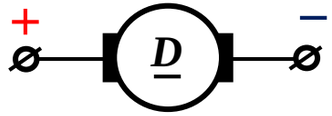
5.6. Farqlovchi kuchaytirgich.

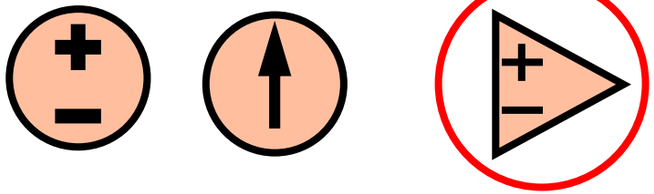
5.7. Kaskadli operatsion kuchaytirgich zanjirlari.

5.8. Qo‘llanilishi.

Elektr zanjirlarining elementlari

Faol (aktiv) elementlar





Passiv elementlar

R (Ω)

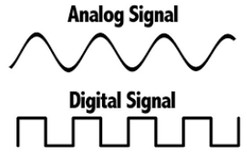
C (F)

L (H)

5.1. Operatsion kuchaytirgichlar.

Elektr zanjir tahlilining asosiy qonunlari va teoremalarini oldingi mavzularimizda o‘rganib chiqdik. Bu mavzuda muhim ahamiyatga ega bo‘lgan faol zanjir elementini o‘rganamiz.

Bu faol element **operatsion kuchaytirgich** bo‘lib, u elektr zanjirni tuzishning ko‘p imkoniyatga ega bo‘lgan asosiy qismlaridan biri hisoblanadi.



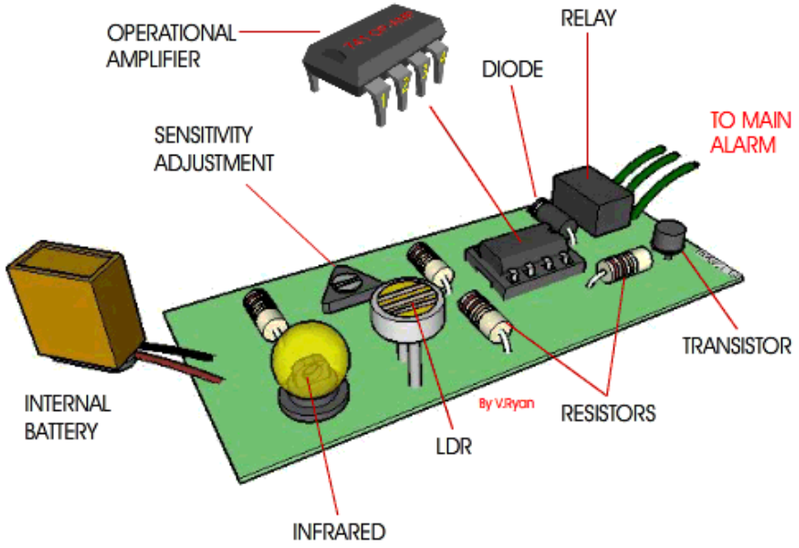


Photo source: [1] - https://semesters.in/wp-content/uploads/2016/12/alarm1a.gif

Operatsion kuchaytirgich deb, analog signallar ustidan turli amallarni bajarishga mo‘ljallangan, differensial kuchaytirish prinsipiga asoslangan, kuchlanish bo‘yicha katta kuchaytirish koeffitsientiga ega bo‘lgan ($K_u = 10^4 \dots 10^6$) integral o‘zgarmas **tok kuchaytirgichiga aytiladi**.

Bunday amallarga:

qo‘shish,

ayirish,

ko‘paytirish,

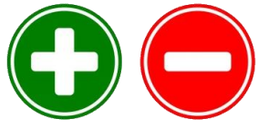
bo‘lish,

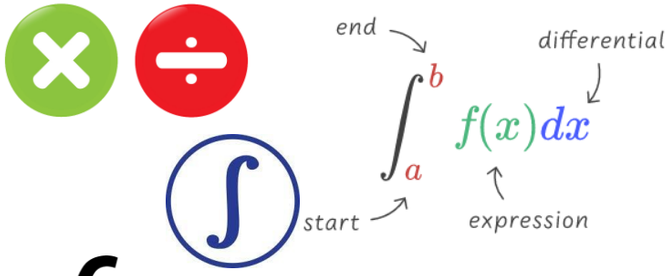
integrallash,

differensiallash,

masshtablash

kabi matematik amallar kiradi.





Hozirgi kunda operatsion kuchaytirgichlar:

analog va raqamli qurilmalarda kuchaytirish,

cheklash,

ko‘paytirish,

chastotani filtrlash,

generatsiyalash,

signallarni barqarorlashda qo‘llanilib kelmoqda.

Photo source: [2] - https://i.ytimg.com/vi/rClHWunkC6Q/maxresdefault.jpg

Operatsion kuchaytirgichlarga **musbat** va **manfiy** teskari aloqa zanjirlari kiritiladi.

Teskari aloqa zanjirlari yordamida operatsion kuchaytirgichlar yuqorida qayd etilgan amallarni (*operatsiyalarni*) bajaradilar. Qurilmalarning nomi ham shundan kelib chiqadi.

Uning tashkil etuvchi qismlari

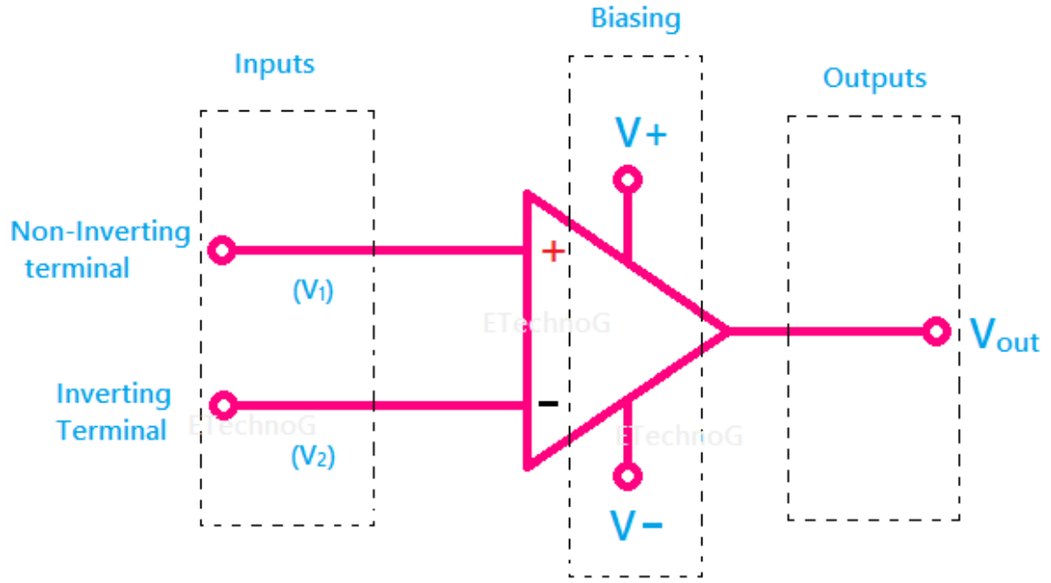


Photo source: [3] - https://2.bp.blogspot.com/-lmEED73GbOo/XEsJsh8XiOI/AAAAAAAABHY/UxOZ5sEFdLQ154Ae2OcX_KoN2niyWi5XwCLcBGAs/s1600/OpAmp%2Bsymbol.png

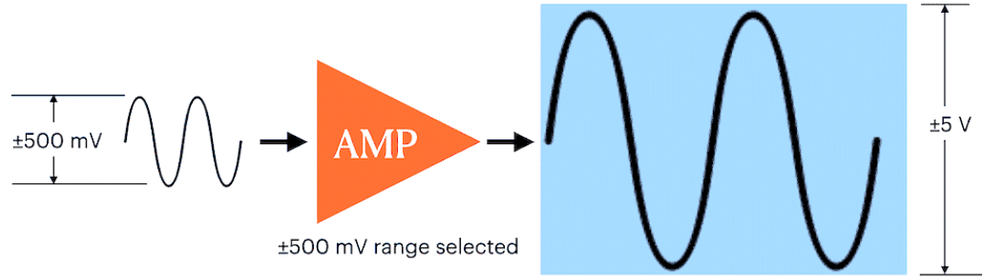
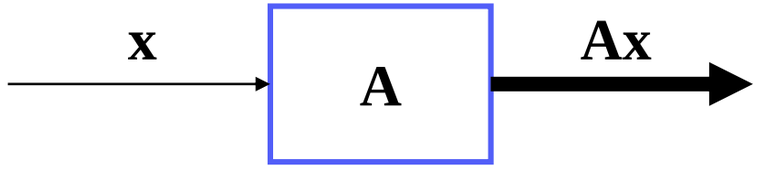


Photo source: [4] - https://www.datocms-assets.com/53444/1664351057-amplify-signal-for-the-ideal-adc-range.png?auto=format&w=1024



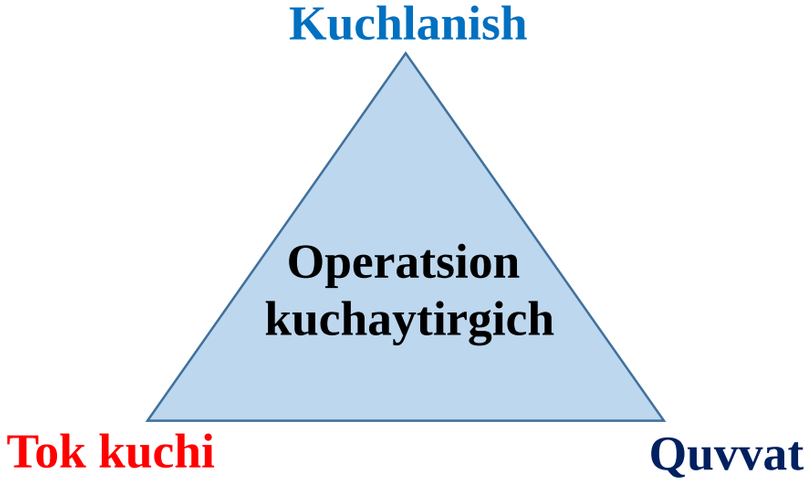
x signal A marta kuchaytiriladi.

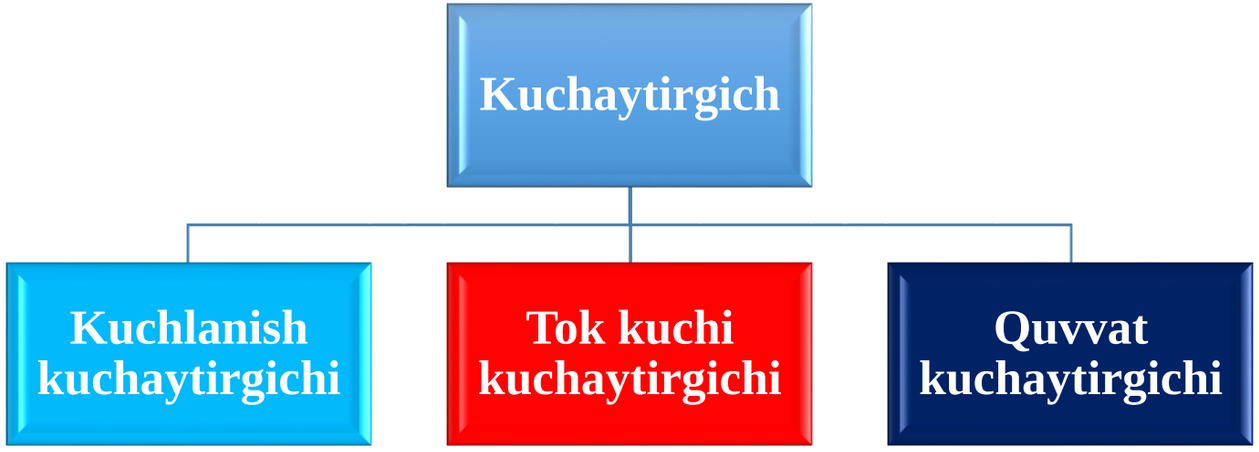
$$A = K_u = 10^4 \dots 10^6$$

Operatsion kuchaytirgich - bu kuchlanish bilan boshqariladigan kuchlanish manbai kabi ishlaydigan elektron qismidir.

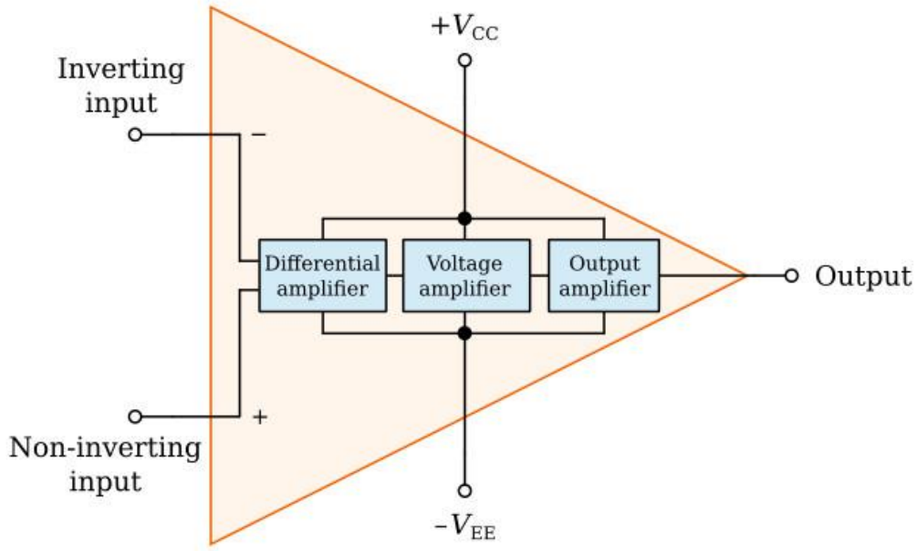
Bundan tashqari, **kuchlanish** yoki **tok** bilan boshqariladigan **tok manbasini yaratishda** ham foydalanish mumkin.

Operatsion kuchaytirgich **signallarni yig‘ishi**, **signalni kuchaytirish**, **uni birlashtirish** yoki **farqlash** kabi amallarni bajaradi.





Operatsion kuchaytirgich tashqi komponentlar masalan, rezistorlar va kondensatorlar uning terminallariga ulanganda ba’zi matematik operatsiyalarni bajarishini nazarda tutgan holda ishlab chiqilgan.



Block Diagram of Op-amp

Photo source: [5] - https://ecstudiosystems.com/discover/textbooks/basic-electronics/operational-amplifiers/images/opamp-block-diagram.jpg

Operatsion kuchaytirgich – bu 20 dan 50 tagacha **rezistorlar**, **tranzistorlar**, **kondensatorlar** va **diodlar**ning murakkab tuzilishidan iborat elektron qurilmadir.

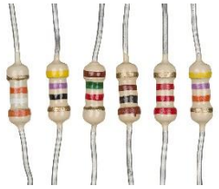


Photo source: [6] - https://upload.wikimedia.org/wikipedia/commons/thumb/7/75/Electronic-Axial-Lead-Resistors-Array.jpg/1200px-Electronic-Axial-Lead-Resistors-Array.jpg

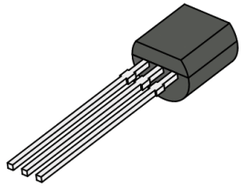


Photo source: [7] - https://www.factoryforward.com/wp-content/uploads/2018/06/Transistor.png

Photo source: [8] - https://eepower.com/uploads/education/capacitor.png

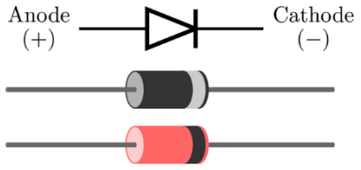


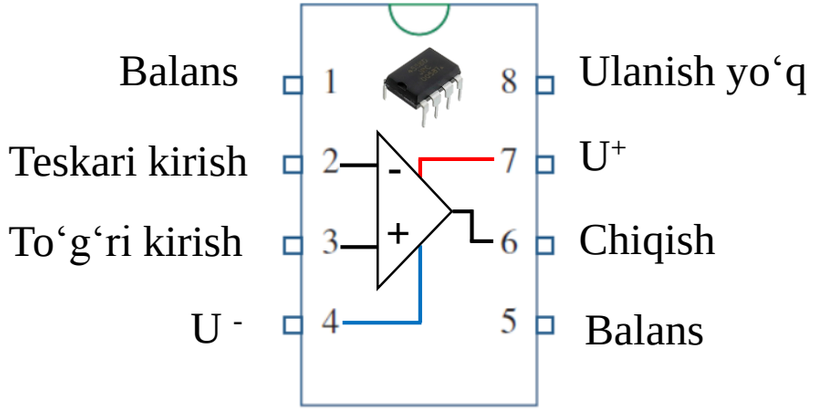
Photo source: [9] - https://4.bp.blogspot.com/-GyFxRQArb4E/WW0MVLfhCnI/AAAAAAAAAtc/jZgwkQ3E6VQ0TAJquFJM-00Y2OaIE4vCwCLcBGAs/w1200-h630-p-k-no-nu/Diode.png

Biz bu mavzu doirasida operatsion kuchaytirgichni zanjir tuzish bloki sifatida ko‘rib chiqish va uning terminallarida nima sodir bo‘lishini o‘rganamiz.

Operatsion kuchaytirgichlar sakkiz pinli terminallardan iborat (5.2-rasm, a). Uning 5 ta muhim terminallari faol hisoblanadi. 8-pin yoki terminal ishlatilmaydi, 1 va 5 terminallari bizni hozircha qiziqtirmaydi.

5.1-rasm.

Photo source: [10] - https://cdn3.volusion.com/btfzd.umflq/v/vspfiles/photos/AD282-2.jpg?v-cache=1456265112



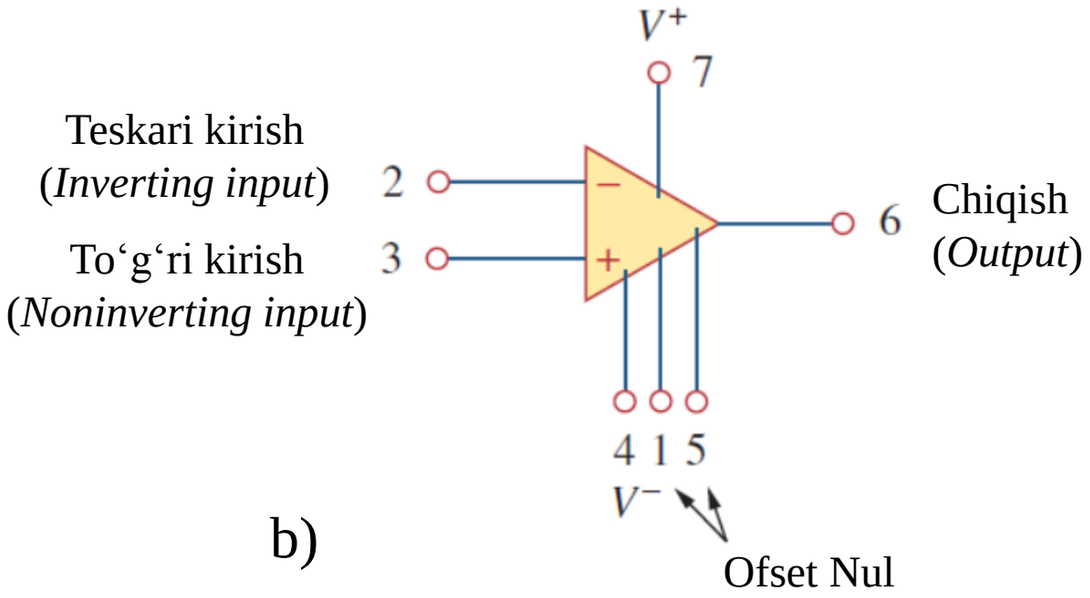
a)

5.2-rasm. Oddiy Operatsion kuchaytirgich:

a) Pin konfiguratsiyasi;

Operatsion kuchaytirgich ikkita kirish va bitta chiqishga ega.

Kirishlar mos ravishda teskari va teskari bo‘lmagan kirishlarni belgilash uchun musbat (+) va manfiy (-) bilan belgilanadi.



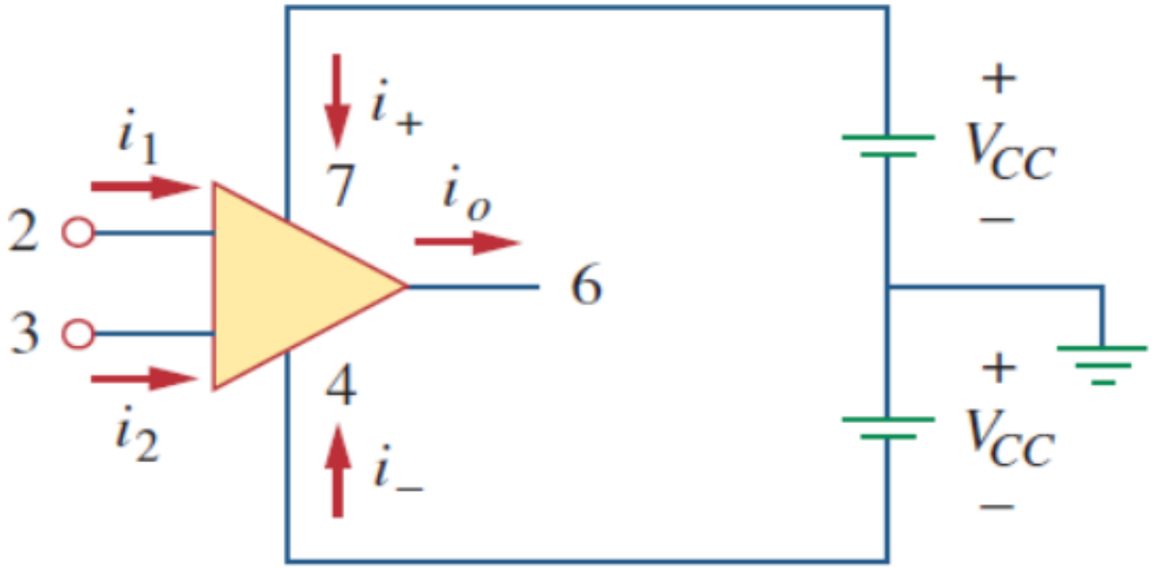
b)

1. Teskari kirish, 2-pin.
2. Teskari bo‘lmagan kirish, 3-pin.
3. Chiqish, 6-pin.
4. Musbat quvvat manbai U^+, 7-pin.
5. Manfiy quvvat manbai U^-, 4-pin.

5.2-rasm. Oddiy Operatsion kuchaytirgich:

b) Sxema belgisi.

Faol element sifatida operatsion kuchaytirgich odatda 5.3-rasmda kuchlanish manbai bilan quvvatlanishi kerak.



5.3-rasm. Operatsion kuchaytirgichni quvvatlantirish.

Operatsion kuchaytirgich zanjirlarida quvvat manbalari ko‘pincha e’tiborga olinmasa ham, quvvat manbaida toklarni e’tiborsiz qoldirmaslik kerak.

KCL bo‘yicha:

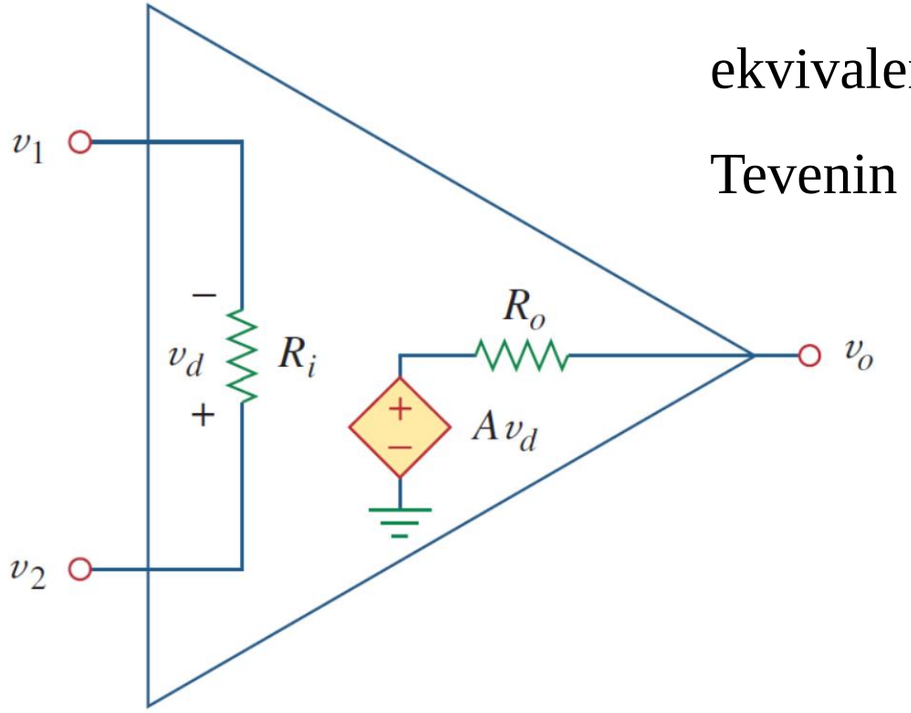
$$\boldsymbol{i_o = i_1 + i_2 + i_+ + i_-} \qquad (5.1)$$

$+U_{CC}$ – ijobiy quvvatni ta’minlanishi;

$-U_{CC}$ – salbiy quvvatni ta’minlanishi.

Chiqish qismi R_o chiqish qarshiligi bilan ketma-ket kuchlanish bilan boshqariladigan manbadan iborat.

Kirish qarshiligi $\boldsymbol{R_i}$ kirish terminallarida ko‘rinadigan Tevenin ekvivalent qarshiligi, chiqish qarshiligi $\boldsymbol{R_o}$ esa chiqishda ko‘rilgan Tevenin ekvivalent qarshiligidir.



5.4-rasm. Ideal bo‘lmagan operatsion kuchaytirgichning ekvivalent sxemasi.

Differensial kirish kuchlanish $\boldsymbol{u_d}$ tomonidan berilgan.

$$\boldsymbol{u_d = u_2 - u_1} \qquad (5.2)$$

bu yerda:

u_1 – teskasi (*inverting*) bilan massa orasidagi kuchlanish;

u_2 – teskari bo‘lmagan (*noninverting*) bilan massa orasidagi kuchlanish;

Operatsion kuchaytirgich ikkita kirish o‘rtasidagi farqni sezadi, uni kuchaytirilgan **A** ga ko‘paytiradi va natijada chiqish kuchlanishini paydo bo‘lishiga olib keladi.

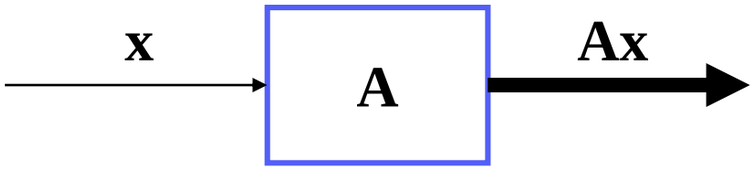
$$\boldsymbol{u_o = Au_d = A(u_2 - u_1)} \qquad (5.3)$$

5.1-jadvalda kuchlanish ortishi *A*, kirish qarshiligi R_i, chiqish qarshiligi R_o va kuchlanish manbai U_{CC} ning odatiy qiymatlari ko‘rsatilgan.

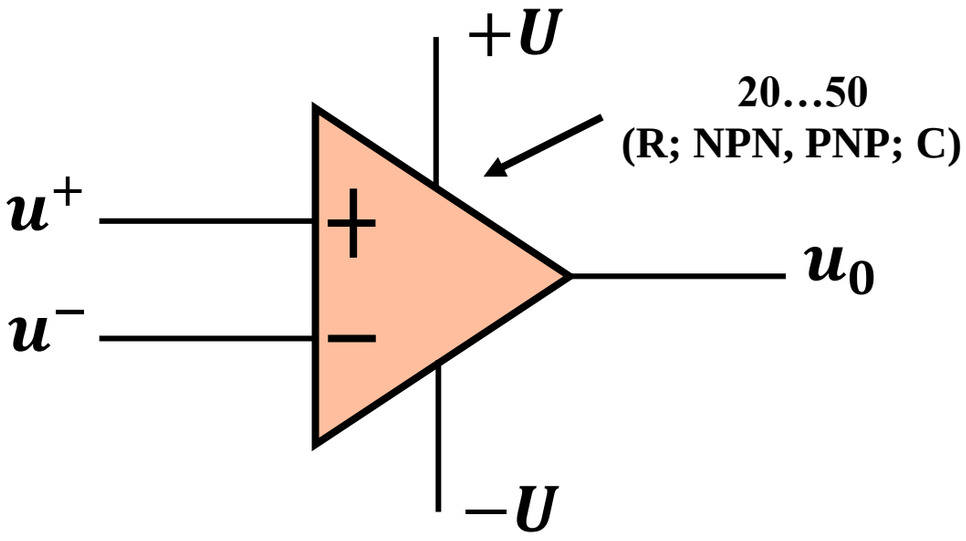
5.1-jadval

Ko‘rsatkichlar	**O‘zgarish qiymat**	**Ideal miqdori**
Kuchaytirilgan ochiq kontur, A	$10^5 – 10^8$	∞
Kirish qarshiligi, R_i	$10^5 – 10^{13}$ Ω	∞ Ω
Chiqish qarshiligi, R_o	10 – 100 Ω	0 Ω
Kuchlanish manbai, U_{CC}	5 – 24 V	

Operatsion kuchaytirgich (Op-amp):



Operatsion kuchaytirgichning amaliy cheklovi shundaki, uning chiqish kuchlanishining kattaligi $|U_{CC}|$ dan oshmasligi kerak.



Yuqori miqdori - $A = 10^4 \dots 10^6$

(high gain)

Qayta aloqa

(feedback)

Kirish farqi $u_0 = A(u^+ - u^-)$

(*Differential input*)

Qayta aloqa *(feedback)*

Qayta aloqa konsepsiyasi operation kuchaytirgich zanjirlarini tushunishimiz uchun juda muhimdir.

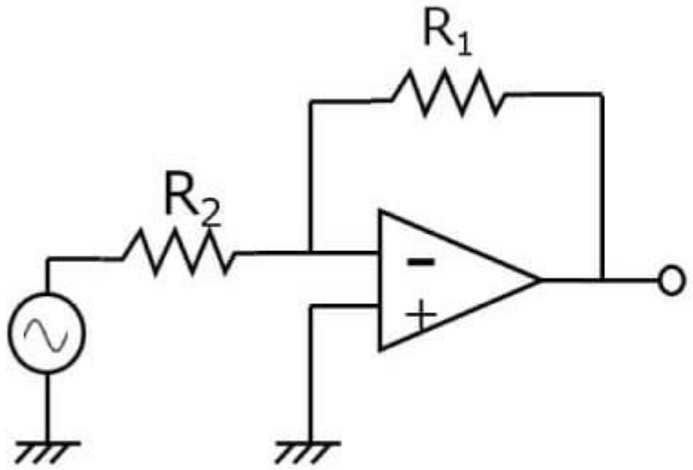


Photo source: [11] - https://toshiba.semicon-storage.com/content/dam/toshiba-ss-v3/master/en/semiconductor/knowledge/faq/linear_op-amps/Why-is-feedback-used-in-op-amps_1_en.jpg

Closed-loop gain

$$G_V = -R_2/R_1$$

Chiqish operatsion kuchaytirgichning inverting terminaliga qaytarilganda salbiy qayta aloqaga erishiladi.

Ushbu misolda chiqishdan kirishgacha bo‘lgan qayta aloqa yo‘li mavjud bo‘lganda, chiqish kuchlanishining kirish kuchlanishiga nisbati ***kuchaytirilgan yopiq kontur*** deb ataladi.

Salbiy qayta aloqa natijasida shuni ko‘rsatish mumkinki, kuchaytirilgan yopiq kontur operatsion kuchaytirgichning kuchaytirilgan ochiq konturi **A** ga deyarli qaytuvchi emas.

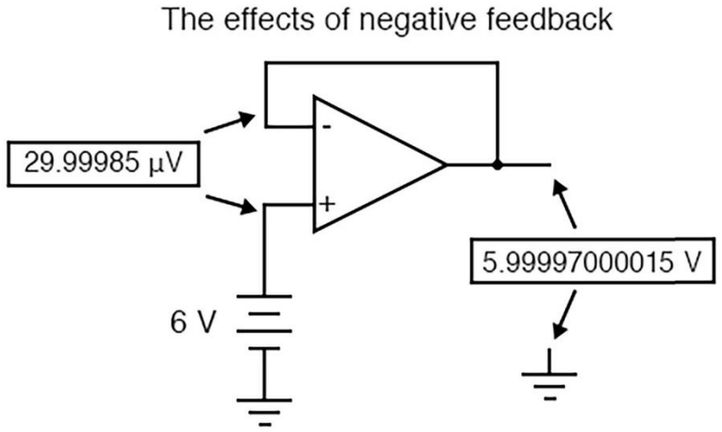
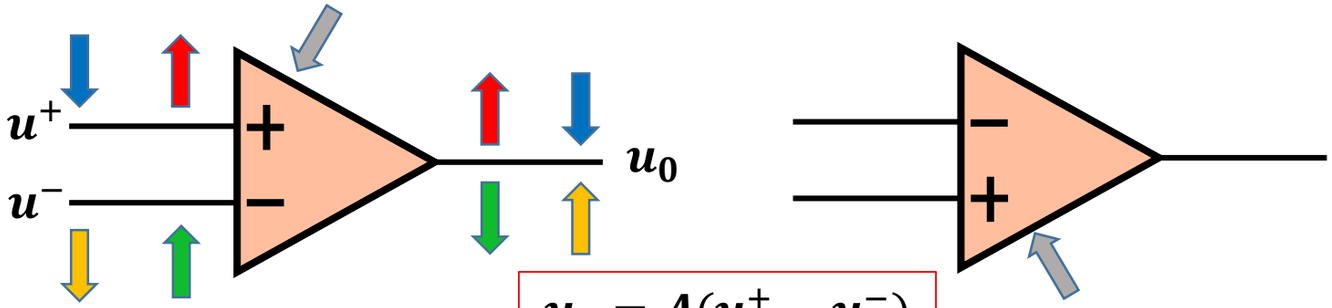
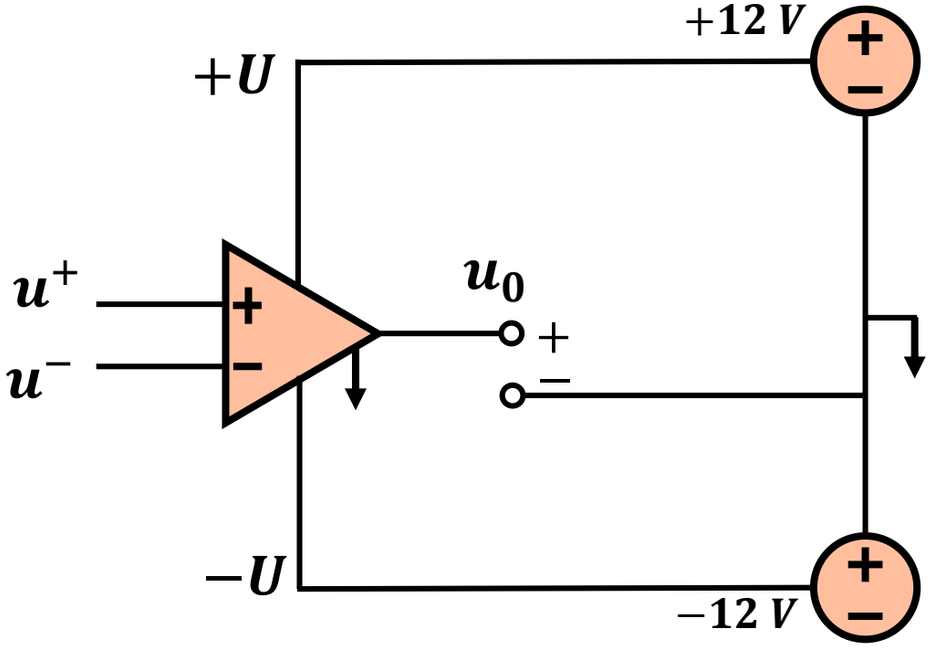


Photo source: [12] - https://www.allaboutcircuits.com/uploads/articles/the-effects-of-negative-feedback_2.jpg

Shu sababli, qaytish yo‘llari bo‘lgan elektr zanjiriga olib boradigan sxemalarda operatsion kuchaytirgichlar qo‘llaniladi.

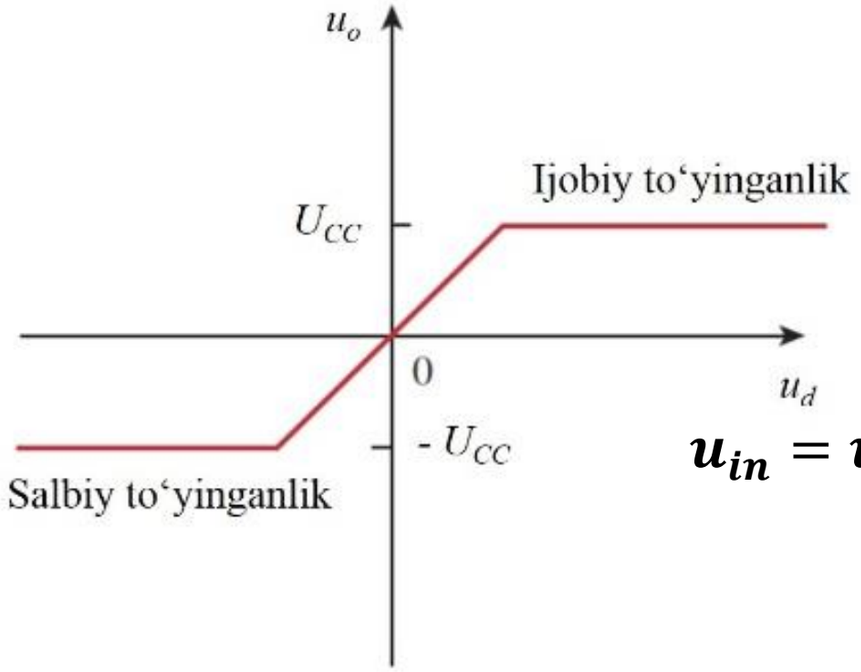


$$u_0 = A(u^+ - u^-)$$



Operatsion kuchaytirgich u_d differensial kirish kuchlanishiga qarab uchta rejimda ishlash mumkinligini ko‘rsatadi:

1. Ijobiy to‘yinganlik, $u_o = U_{CC}$.
2. Chiziqli mintaqa, $-U_{CC} \le u_o = Au_d \le U_{CC}$.
3. Salbiy to‘yinganlik, $u_o = -U_{CC}$.



$$u_{in} = u^+ - u^-$$

5.5-rasm. Differensial kirish kuchlanish u_d operatsion kuchaytirgichning chiqish kuchlanishi u_o ning funksiyasi sifatida.

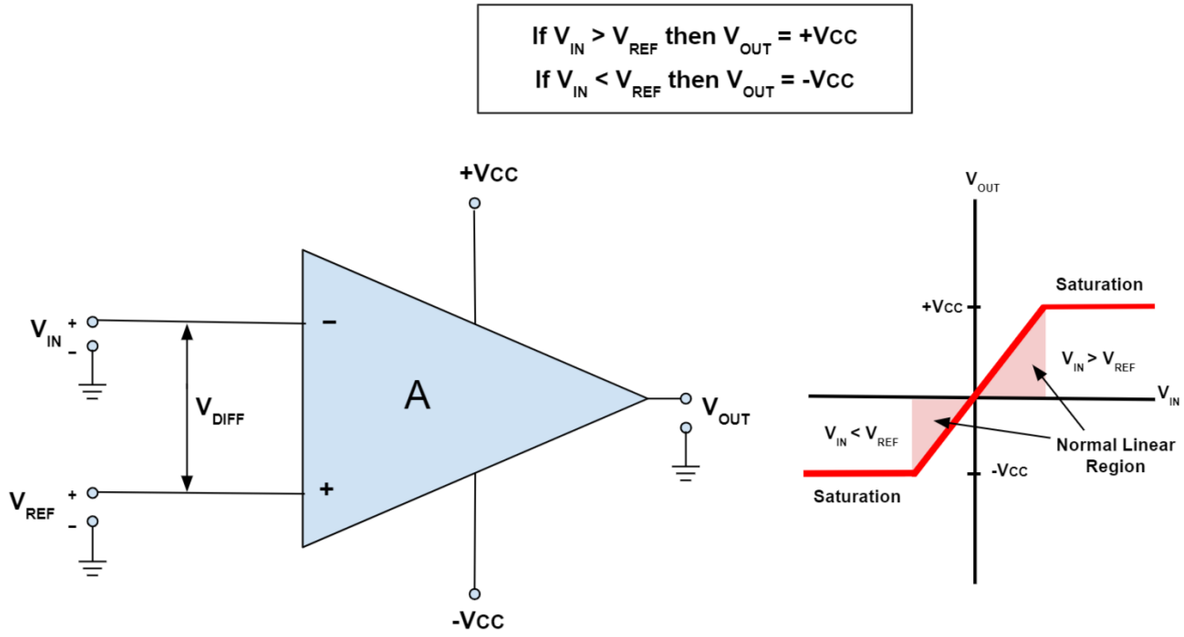
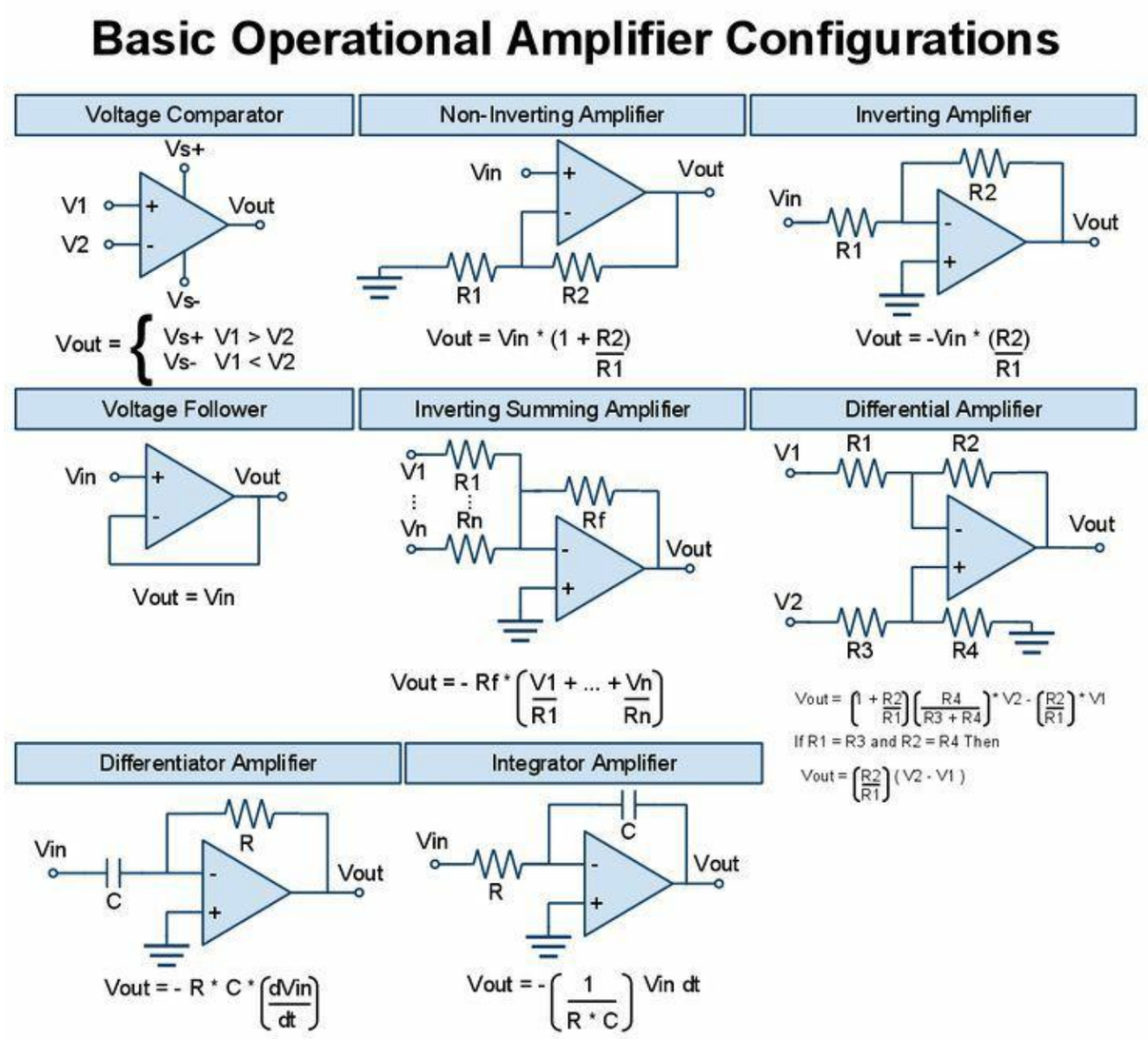


Photo source: [13] - https://media.monolithicpower.com/wysiwyg/7_15.png



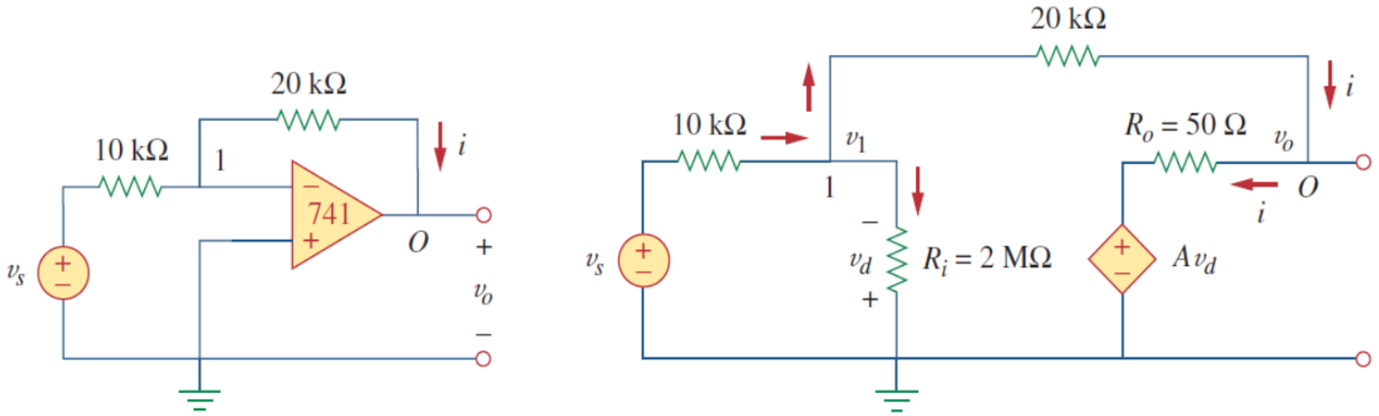
Agar biz u_d ni chiziqli o‘zgarish qiymatidan tashqariga oshirishga harakat qilsak, operatsion kuchaytirgich to‘yingan bo‘ladi va $u_o = U_{CC}$ yoki $u_o = -U_{CC}$ tenglikni beradi.

Quyidagi tenglik operatsion kuchaytirgich uchun o‘rinli bo‘ladi.

$$-U_{CC} \le u_o \le U_{CC} \qquad (5.4)$$

Photo source: [14] - https://i.pinimg.com/originals/c7/3d/3f/c73d3fc9a3ae30cd236935bab85098c0.jpg

$2 \cdot 10^5$, kirish qarshiligi 2 MΩ va chiqish qarshiligi 50 Ω ga teng. Yopiq konturdagi kuchaytirgich u_0/u_s ni toping. $u_s = 2\ V$ ga teng bo‘lganda tok kuchi *i* ni aniqlang.



a) b)

5.5-rasm. a) Asl zanjir; b) Ekvivalent zanjir.

Yechish: 1-tugun uchun KCL ni qo‘llaymiz:

$$\frac{u_s - u_1}{10 \cdot 10^3} = \frac{u_1}{2000 \cdot 10^3} + \frac{u_1 - u_o}{20 \cdot 10^3}$$

$$200u_s = 301u_1 - 100u_o$$

$$2u_s \cong 3u_1 - u_o \quad \rightarrow \quad u_1 = \frac{2u_s + u_o}{3} \qquad (5.1.1)$$

Agar, $u_s = 2\ V$, $u_o = 3{,}9999398$ V bo‘lsa,

$$u_1 = 20{,}066667\ \mu V$$

$$\boldsymbol{i = \frac{u_1 - u_o}{20 \cdot 10^3} = 0{,}19999\ mA}$$

O tugunida,

$$\frac{u_1 - u_o}{20 \cdot 10^3} = \frac{u_0 - Au_d}{50}$$

Lekin $u_d = -u_1$ va A = 200 000.

$$u_1 - u_o = 400(u_o + 200\ 000u_1) \qquad (5.1.2)$$

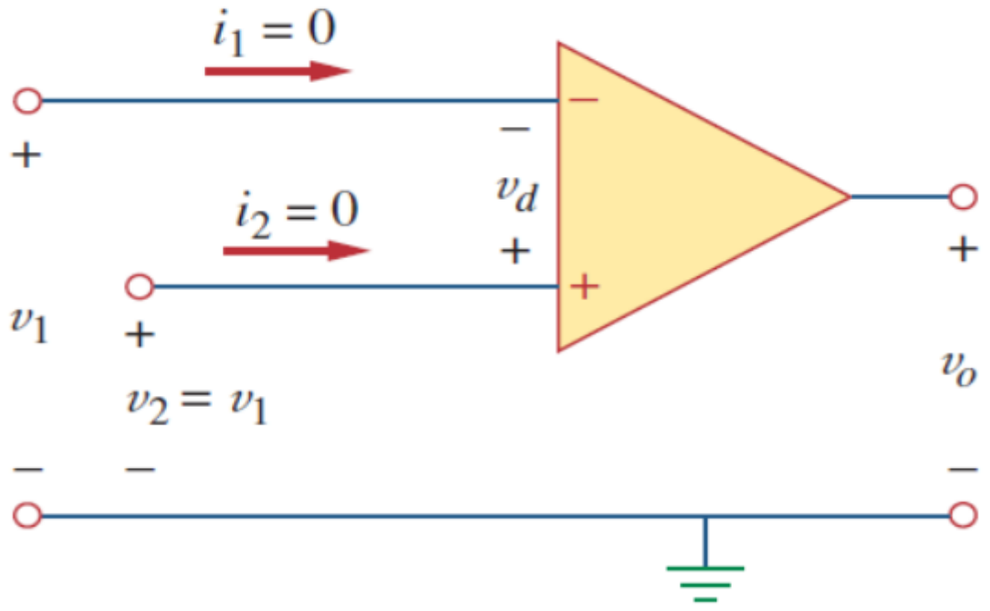
$$0 \cong 26{,}667{,}067u_a + 53{,}333{,}333u_s$$

$$\boldsymbol{\frac{u_o}{u_s} = -1{,}9999699}$$

5.2. Ideal operatsion kuchaytirgichlar.

Operatsion kuchaytirgich zanjirlarini tushunishni osonlashtirish uchun biz ideal operatsion kuchaytirgichlarni qabul qilamiz.

Operatsion kuchaytirgich quyidagi xususiyatlarga ega bo‘lsa ideal bo‘ladi:



1. Ochiq kontur kuchaytirgichi cheksiz, $A \cong \infty$.
2. Kirish qarshiligi cheksiz, $R_i \cong \infty$.
3. Chiqish qarshiligi 0, $R_o \cong 0$.

5.7-rasm. Ideal operatsion kuchaytirgich modeli.

Ideal operatsion kuchaytirgichning ikkita muhim xususiyati mavjud:

1. Ikkala kirish terminalidagi toklar nolga teng: $\boldsymbol{i_1 = 0}$, $\boldsymbol{i_2 = 0}$ (5.5)

Bu cheksiz kirish qarshiligi bilan bog‘liq. Kirish terminallari orasidagi cheksiz qarshilik u yerda ochiq zanjir mavjudligini va tok kuchi operatsion kuchaytirgichga kira olmasligini bildiradi.

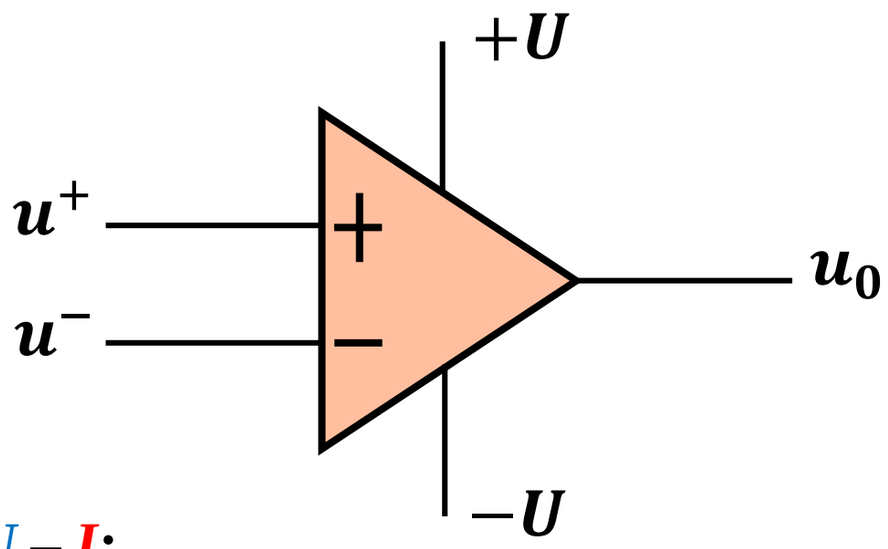
2. Kirish terminallaridagi kuchlanish nolga teng: ya’ni,

$$\boldsymbol{u_d = u_2 - u_1 = 0} \quad (5.6)$$

yoki

$$\boldsymbol{u_1 = u_2} \quad (5.7)$$

Ideal operatsion kuchaytirgich o‘zining ikkita kirish terminaliga va 0 tok kuchiga ega hamda ikkita kirish terminali orasidagi kuchlanish ham 0 ga teng.



(5.5) va (5.7) tenglamalar juda muhim va ularni operatsion kuchaytirgichli zanjirlarni tahlil qilish uchun asosiy omil hisoblanadi.

Ikki xususiyatdan foydalanib, kuchlanishni hisoblash uchun kirish qismi qisqa tutashuv sifatida ishlaydi, tok kuchini hisoblash uchun esa kirish porti ochiq tutashuv sifatida ishlaydi.

$U - I$:

- $u_0 = A(u^+ - u^-)$

$u_0 = Au_{in}$

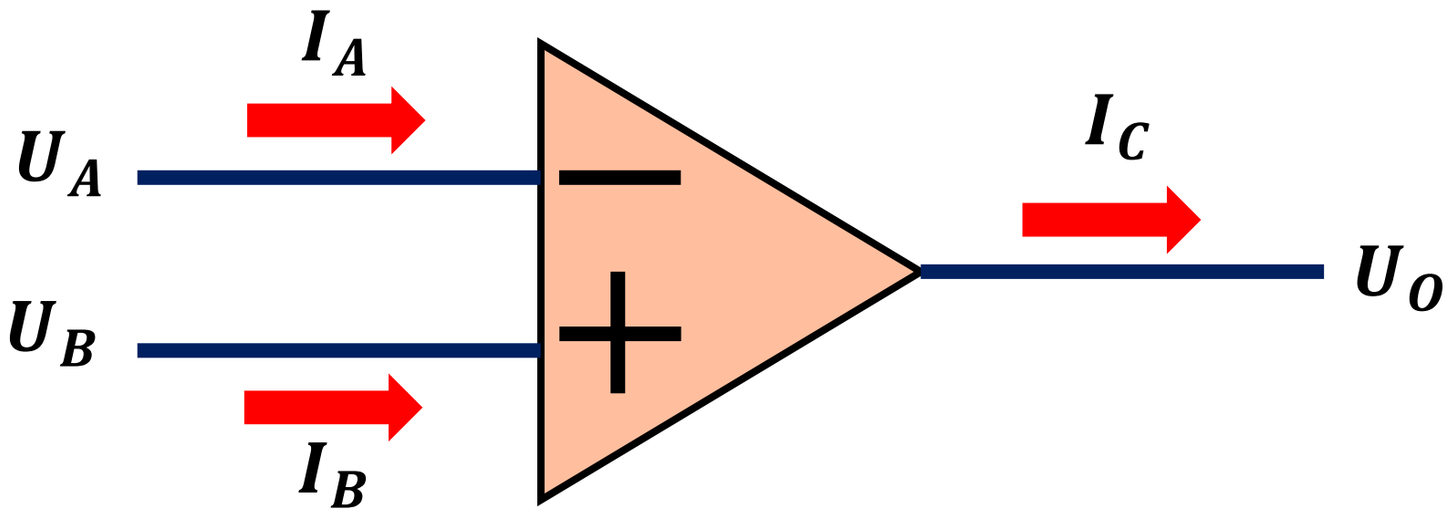
$u_{in} = u^+ - u^-$

Op-amp faqat kuchlanishni sezadi. Shuning uchun,

- $i_0 = 0$

Ushbu ikkala munosabat Op-amp ni hisoblashda qulaylikni ta’minlaydi.

Operatsion kuchaytirgichli zanjirlarni hisoblash va tahlil qilishda quyidagi qoidaga amal qilinadi:



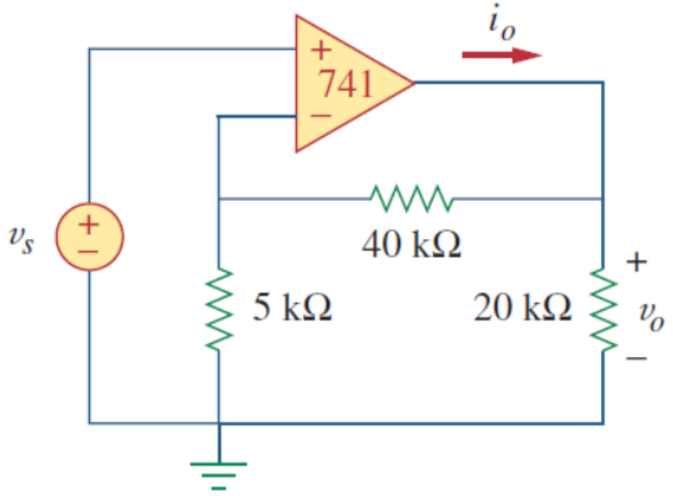
1) $U_A = U_B\ ,V$

2) $I_A = I_B = 0, A$

3) $I_A + I_B \neq I_C, A$

4) *Har doim KCL va Tugun tahlilidan foydalaniladi.*

5.2.1-masala: 741 operatsion kuchaytirgich yopiq konturining kuchayishi u_o/u_s ni ideal operatsion kuchaytirgich modelidan foydalanib hisoblang. $u_s = 1\ V$ ga teng bo‘lganda tok kuchi i_o ni aniqlang.



5.8-rasm.

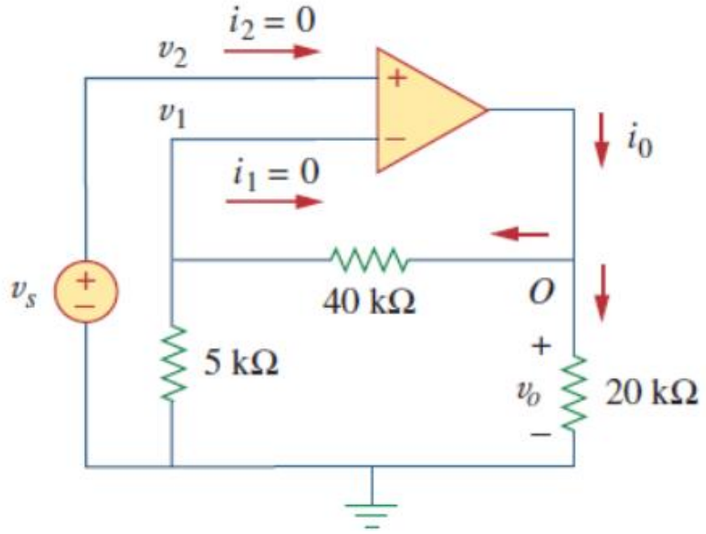
Yechish:

$$u_2 = u_s \qquad (5.2.1)$$

KBQ (VDR):

$$u_1 = \frac{5}{5+40} \cdot u_o = \frac{u_o}{9} \qquad (5.2.2)$$

$$u_2 = u_1 \qquad (5.2.3)$$



(5.2.1) va (5.2.2) tenglamalarni (5.2.3) ga almashtirsak,

$$u_s = \frac{u_o}{9} \quad \rightarrow \quad \frac{u_o}{u_s} = 9 \qquad (5.2.4)$$

O tugun uchun,

$$i_o = \frac{u_o}{40+5} + \frac{u_0}{20}\ mA \qquad (5.2.5)$$

$u_s = 1\ V$, bo‘lganda $u_o = 9\ V$.

$$i_o = \frac{9}{40+5} + \frac{9}{20} = 0{,}2 + 0{,}45 = 0{,}65\ mA$$

FOYDALANILGAN MANBALAR:

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2. https://i.ytimg.com/vi/rClHWunkC6Q/maxresdefault.jpg
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E'TIBORINGIZ UCHUN RAHMAT!!!