YÜKSELTGEÇ

Kazanç = $\dfrac{\text{Çıkış Gerilimi}}{\text{Giriş}}$ //

4.1 An amplifier has a gain of 15 and the input waveform shown in Fig. P4.1. Draw the output waveform.

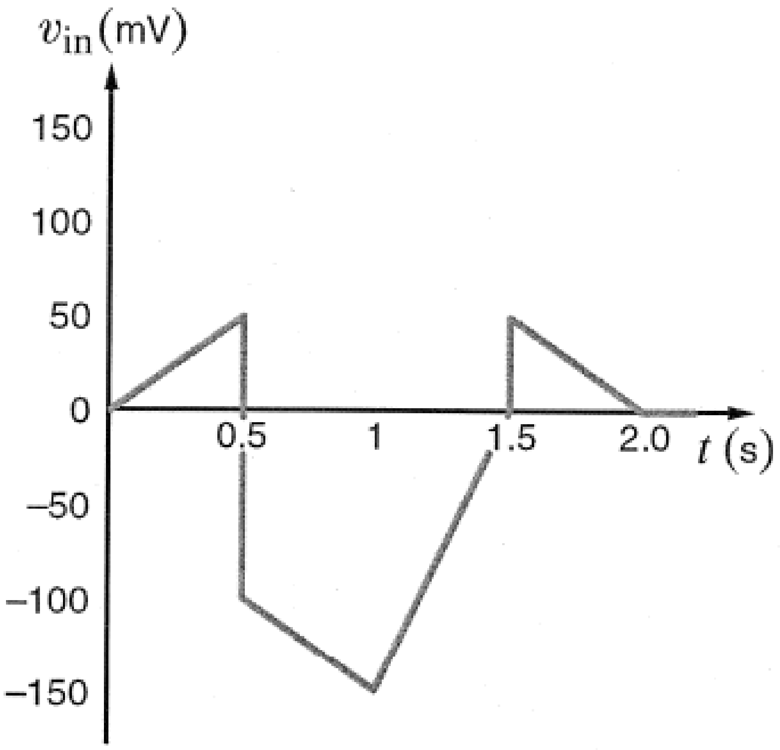
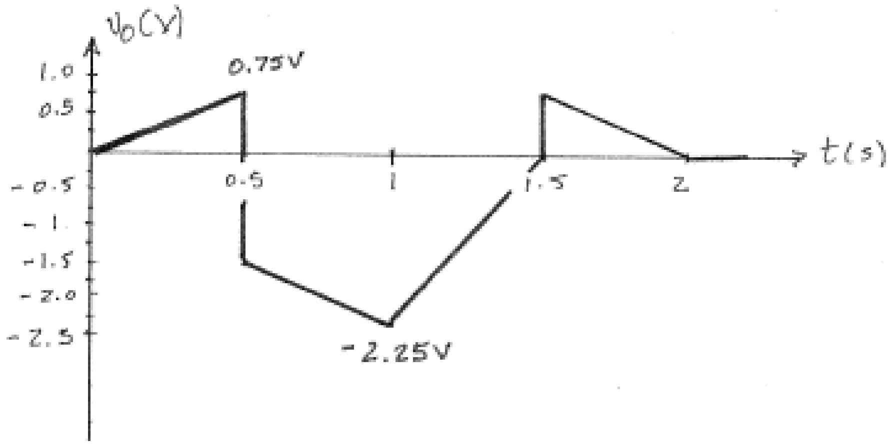


Figure P4.1

SOLUTION:

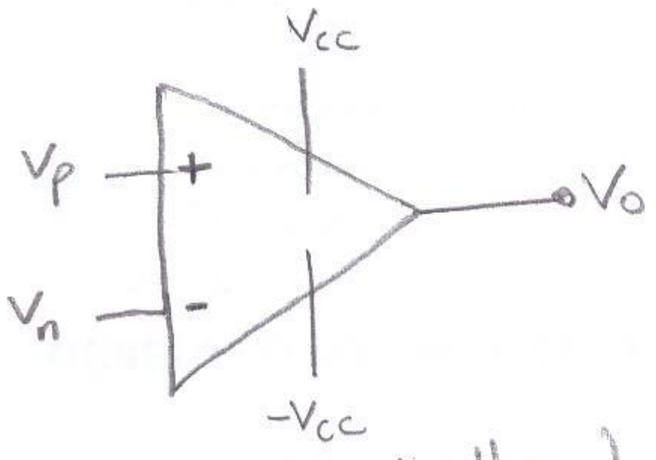


İŞLEMSEL YÜKSELTGEÇLER (opamp) (OPERATIONAL AMPLIFIER)

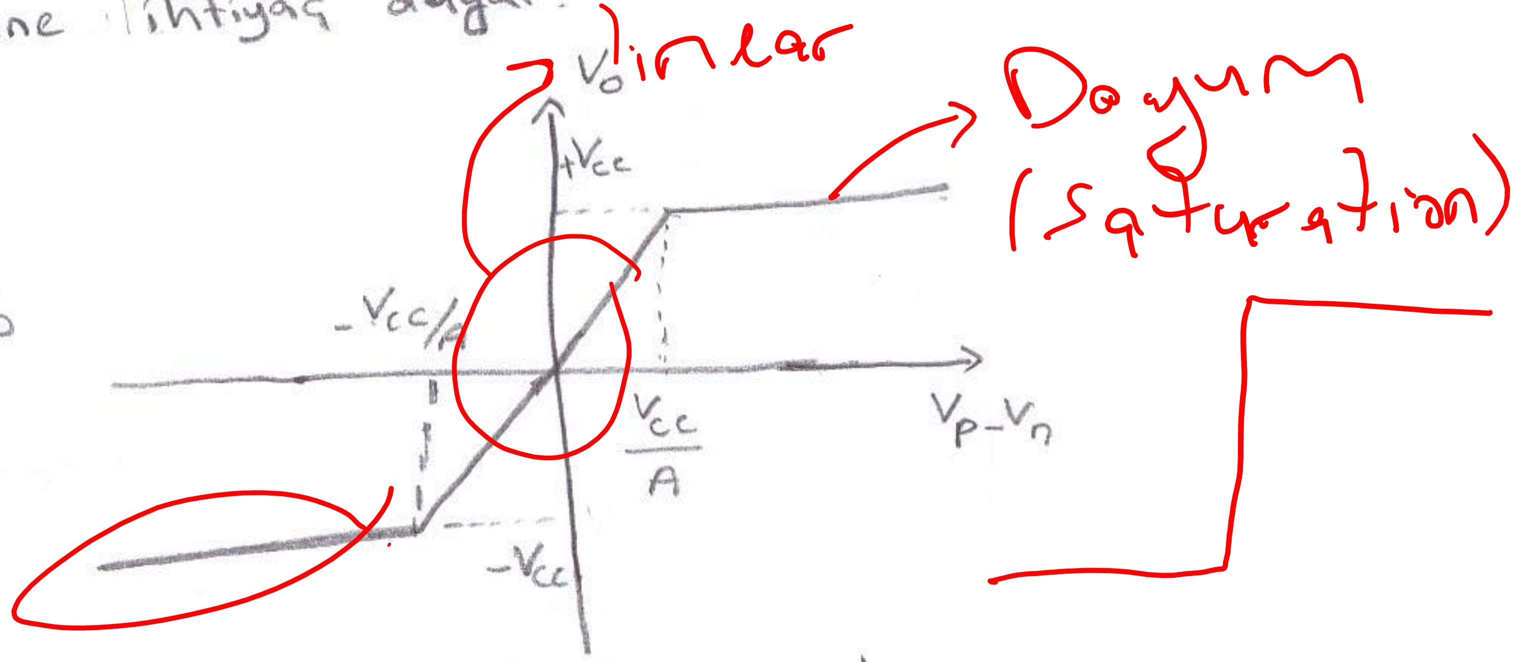
- Karşılaştırıcılar
- Aritmetik işlemciler
- Frekans filtreleri gibi uygulama alanları vardır.

İlk entegre devre bir işlemsel yükseltgeçtir.

Bir besleme gerilimine ihtiyaç duyar.



(işlemsel yükseltgeç)



işlemsel yükseltgecin çıkış gerilim grafiği.

$$V_o = \begin{cases} -V_{cc} & V_p - V_n \leq -\dfrac{V_{cc}}{A} \\ A(V_p - V_n) & -\dfrac{V_{cc}}{A} \leq V_p - V_n \leq \dfrac{V_{cc}}{A} \\ V_{cc} & V_p - V_n \geq \dfrac{V_{cc}}{A} \end{cases}$$

A: Açık devre kazancı (dizayn ile alakalı bir değerdir. $A \sim 10^5$ mertebesindedir.)

V_{cc} en fazla ∓ 25 V mertebesindedir. Dolayısıyla

$$\frac{V_{cc}}{A} \sim \frac{25}{10^5} = 0{,}25 \text{ mV}$$

(Lineer çalışma bölgesi çok dar bir bölgeye karşılık gelmektedir.)

4.3 An op-amp base amplifier has supply voltages of ±5 V and a gain of 20.

(a) Sketch the input waveform from the output waveform in Fig. P4.3.

(b) Double the amplitude of your results in (a) and sketch the new output waveform.

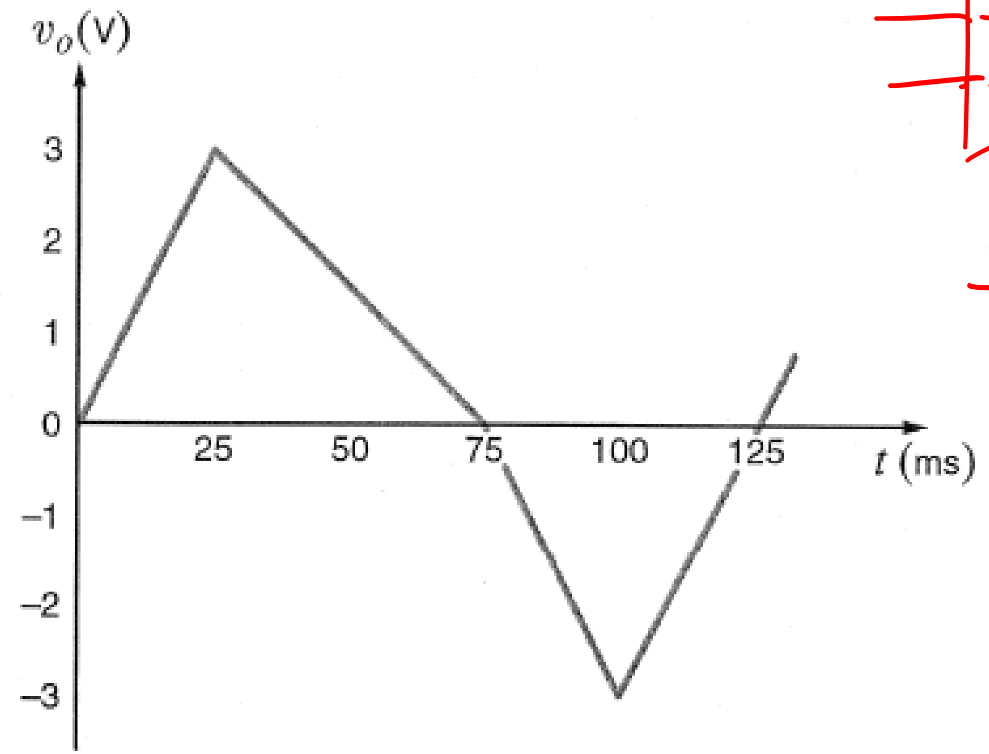
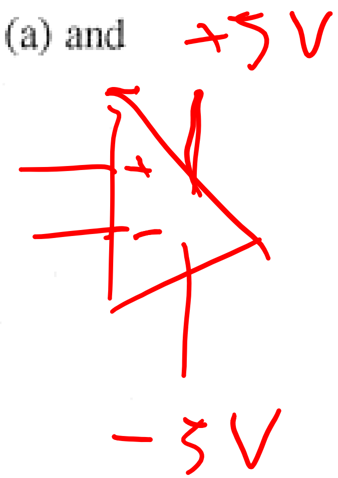
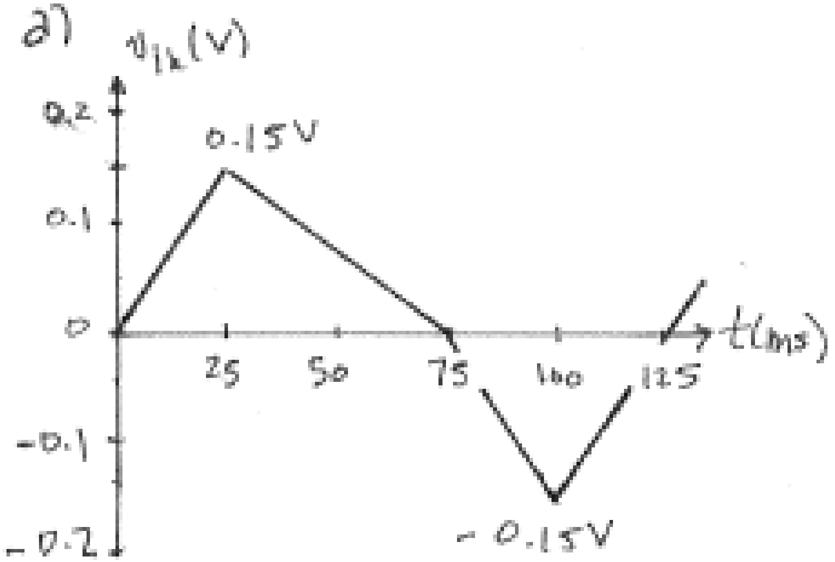
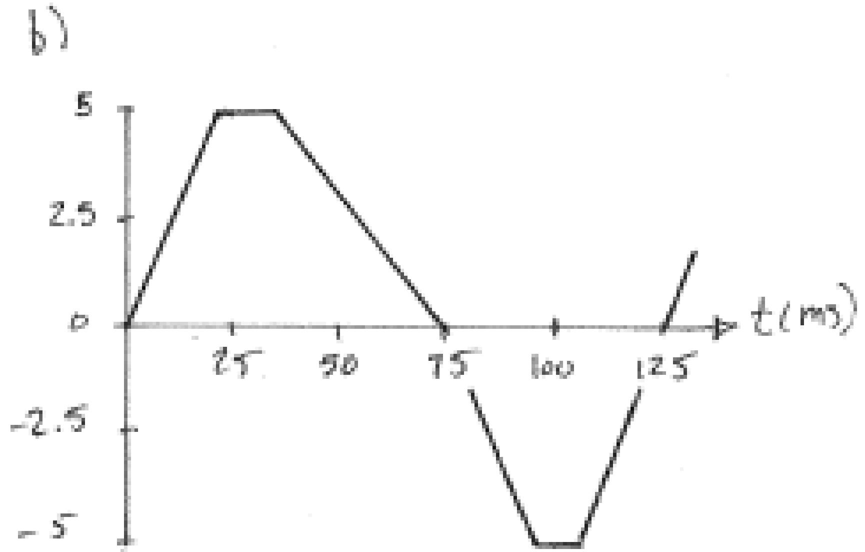


Figure P4.3







Bu yapılarıyla opamplar kullanılması zor bir
cihaz olur. Çünkü lineer çalışma bölgesi çok dar
bir bölgedir. (~ 0,2-2 mV genişliğindedir.) Giriş sinyalle-
rindeki gürültüler çok kolaylıkla cihazı doyum moduna
atabilir. Op-ampların kararlı çalışabilmesi
geri besleme devre konfigürasyonunu gerektirir.
Bu konfigürasyon, yükseltgeçlerin kullanımında
çok önemli bir kilometre taşı olmuştur.

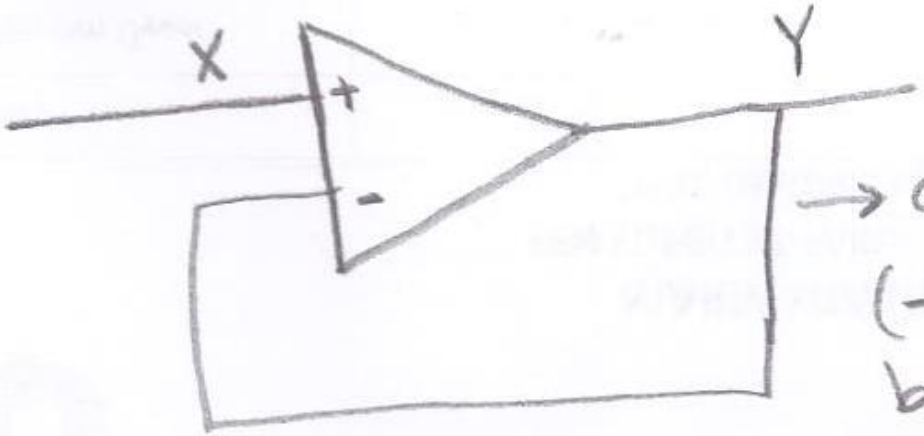
Geri Besleme

Sistemi dengede tutmak için gereklidir.

Örnek: Termostat! Eğer odanın sıcaklığı belli bir değerin altına düşürse termostat devreye girer ve ısıtıcı çalışır. Sıcaklık belli bir değerin üstüne çıkarsa termostat yine devreye girer ve ısıtıcıyı kapatır. Böylece termostat ısıtıcıya sağladığı geri besleme ile oda sıcaklığını dengede tutar.

Negatif Geri Besleme Devresi

Aynı mantık opampların kararlı çalışmasında kullanılır.



→ çıkış geriliminden (–) uca çekilen bağlantı kararlı bir çıkış gerilimi sağlar.

Eğer çıkış gerilimi düşerse, (–) uçtaki gerilimde düşer. Böylece (+) uçtaki gerilim ile (–) uçtaki gerilim farkı artar. Bu artış çıkış gerilimini arttırır. Bu döngü (+) ile (–) uçlardaki gerilimler eşitlenene kadar devam eder. (Sonuçta $V_+ = V_-$ olur.)

The **op amp** is an electronic unit that behaves like a voltage-controlled voltage source.

An **op amp** is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation, and integration.

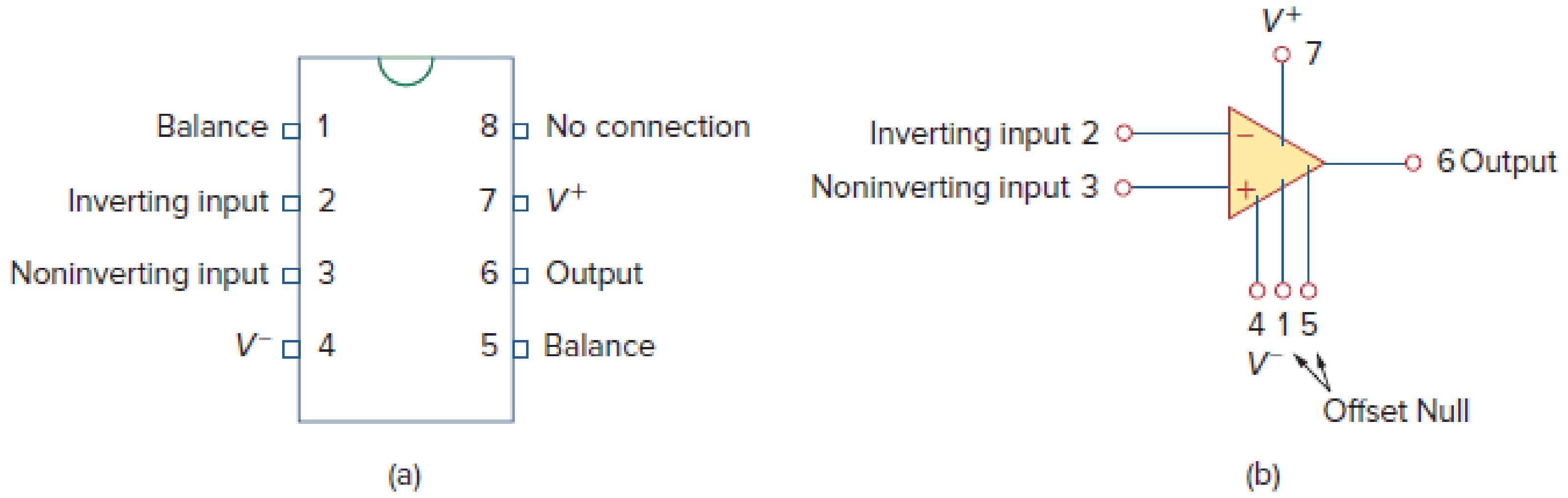


Figure 5.2
A typical op amp: (a) pin configuration, (b) circuit symbol.

The differential input voltage v_d is given by

$$v_d = v_2 - v_1 \tag{5.2}$$

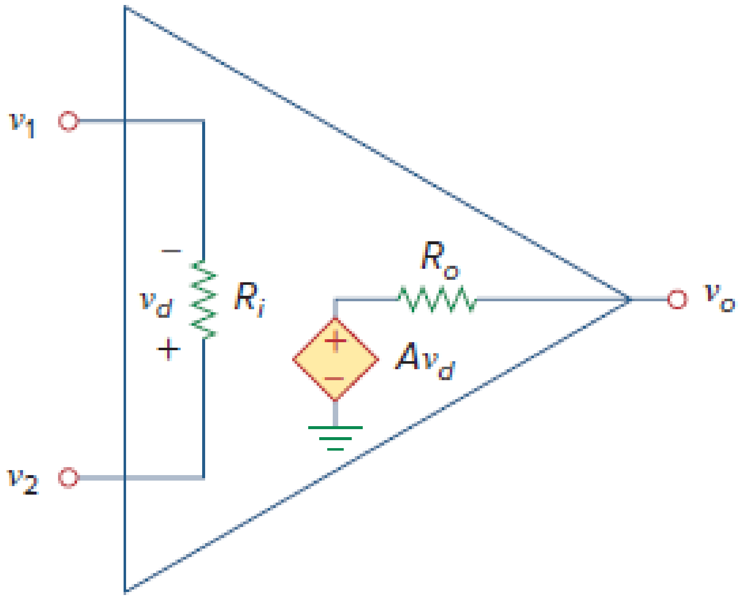
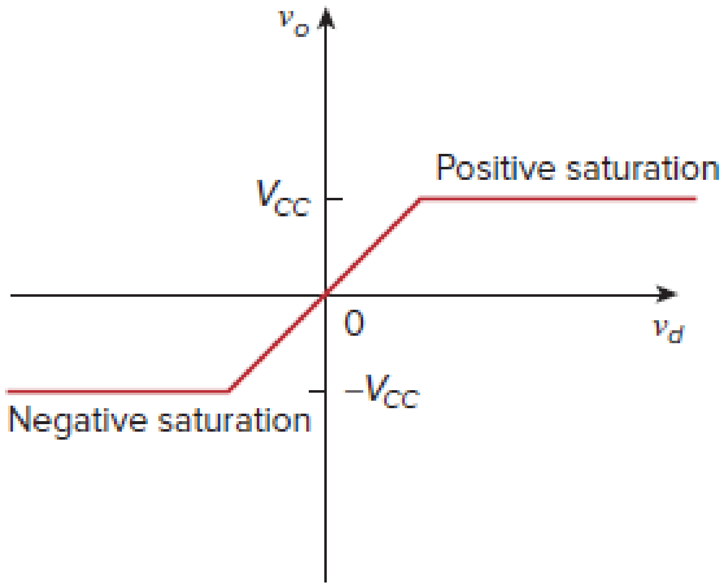


Figure 5.4
The equivalent circuit of the nonideal op amp.

where v_1 is the voltage between the inverting terminal and ground and v_2 is the voltage between the noninverting terminal and ground. The op amp senses the difference between the two inputs, multiplies it by the gain A, and causes the resulting voltage to appear at the output. Thus, the output v_o is given by

$$\boxed{v_o = Av_d = A(v_2 - v_1)} \tag{5.3}$$

A is called the *open-loop voltage gain* because it is the gain of the op amp without any external feedback from output to input. Table 5.1 shows



A practical limitation of the op amp is that the magnitude of its output voltage cannot exceed $|V_{CC}|$. In other words, the output voltage is dependent on and is limited by the power supply voltage. Figure 5.5 illustrates that the op amp can operate in three modes, depending on the differential input voltage v_d:

1. Positive saturation, $v_o = V_{CC}$.
2. Linear region, $-V_{CC} \leq v_o = Av_d \leq V_{CC}$.
3. Negative saturation, $v_o = -V_{CC}$.

If we attempt to increase v_d beyond the linear range, the op amp becomes saturated and yields $v_o = V_{CC}$ or $v_o = -V_{CC}$. Throughout this book, we will assume that our op amps operate in the linear mode. This means that the output voltage is restricted by

$$-V_{CC} \leq v_o \leq V_{CC} \tag{5.4}$$

TABLE 5.1

Typical ranges for op amp parameters.

Parameter	Typical range	Ideal values
Open-loop gain, A	10^5 to 10^8	`
Input resistance, R_i	10^5 to 10^{13} Ω	`Ω
Output resistance, R_o	10 to 100 Ω	0Ω
Supply voltage, V_{CC}	5 to 24 V	

5.3 Ideal Op Amp

To facilitate the understanding of op amp circuits, we will assume ideal op amps. An op amp is ideal if it has the following characteristics:

1. Infinite open-loop gain, $A \simeq \infty$.
2. Infinite input resistance, $R_i \simeq \infty$.
3. Zero output resistance, $R_o \simeq 0$.

An **ideal op amp** is an amplifier with infinite open-loop gain, infinite input resistance, and zero output resistance.

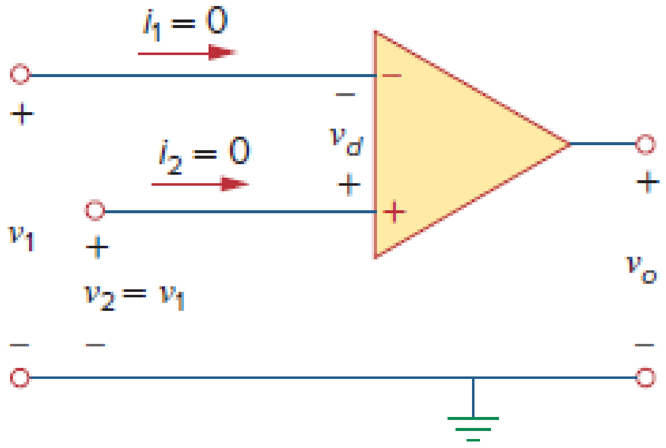


Figure 5.8
Ideal op amp model.

For circuit analysis, the ideal op amp is illustrated in Fig. 5.8, which is derived from the nonideal model in Fig. 5.4. Two important properties of the ideal op amp are:

1. The currents into both input terminals are zero:

$$\boxed{i_1 = 0, \quad i_2 = 0} \tag{5.5}$$

This is due to infinite input resistance. An infinite resistance between the input terminals implies that an open circuit exists there and current cannot enter the op amp. But the output current is not necessarily zero according to Eq. (5.1).

2. The voltage across the input terminals is equal to zero; i.e.,

$$v_d = v_2 - v_1 = 0 \tag{5.6}$$

or

$$\boxed{v_1 = v_2} \tag{5.7}$$

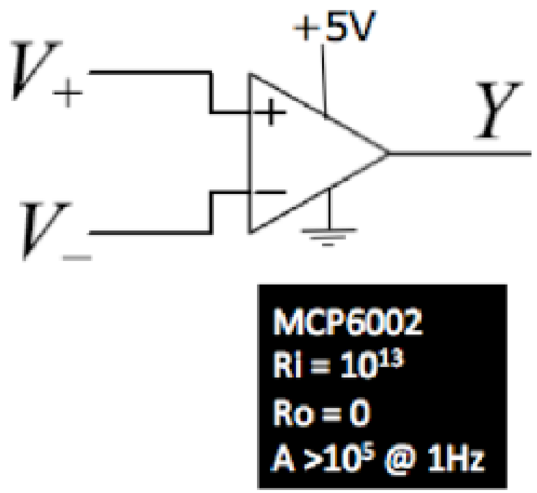
Thus, an ideal op amp has zero current into its two input terminals and the voltage between the two input terminals is equal to zero. Equations (5.5) and (5.7) are extremely important and should be regarded as the key handles to analyzing op amp circuits.

Op-amp sorularının çözüm basamakları

- Nodal analysis is simplified by making some assumptions.

Note: The op-amp often need two power supply connections. In our case, +5V and GND.

These are almost always omitted from the circuit diagram. The currents only sum to zero (KCL) if all five connections are included.



1. **Check for negative feedback:** to ensure that an increase in Y makes $(V_+ - V_-)$ decrease, Y must be connected (usually via other components) to $V-$.
2. **Assume** $V+ = V-$: Since $(V+ - V-) = YA$, this is the same as assuming that $A = \infty$. Requires negative feedback.
3. **Assume zero input current:** in most circuits, the current at the op-amp input terminals is much smaller than the other currents in the circuit, so we assume it is zero.
4. **Apply KCL at each op-amp input node separately** (input currents = 0).

5.4 Inverting Amplifier

In this and the following sections, we consider some useful op amp circuits that often serve as modules for designing more complex circuits. The first of such op amp circuits is the inverting amplifier shown in Fig. 5.10. In this circuit, the noninverting input is grounded, v_i is connected to the inverting input through R_1, and the feedback resistor R_f is connected between the inverting input and output. Our goal is to obtain

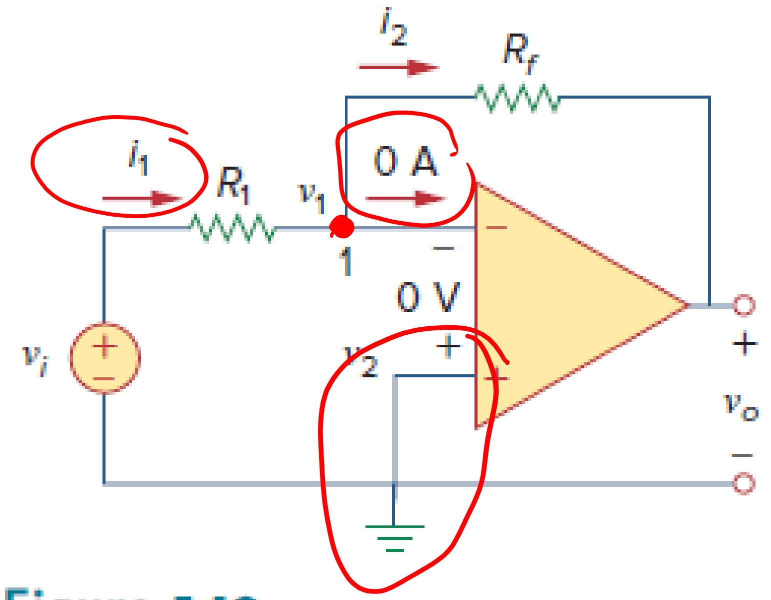


Figure 5.10 The inverting amplifier.

$V_1 = 0$

$$i_1 = \frac{v_i - 0}{R_1} = \frac{0 - V_o}{R_F}$$

$$\boxed{V_o = -\frac{R_F}{R_1} V_i}$$

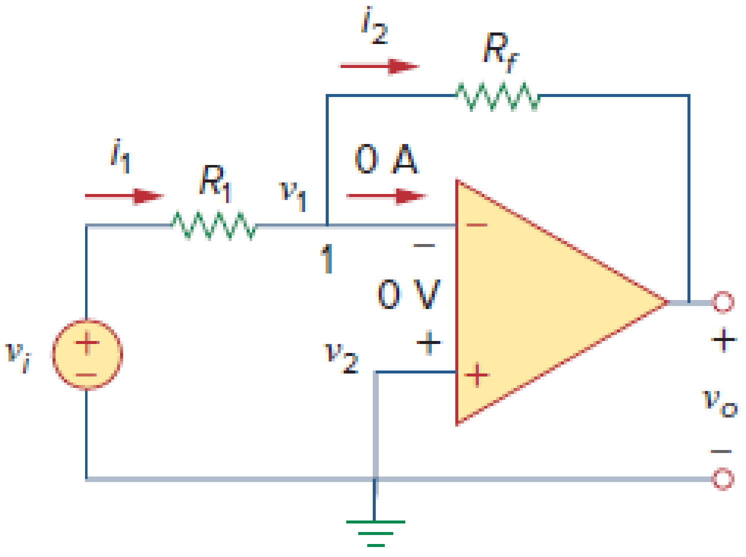


Figure 5.10
The inverting amplifier.

Note there are two types of gains: The one here is the closed-loop voltage gain A_v, while the op amp itself has an open-loop voltage gain A.

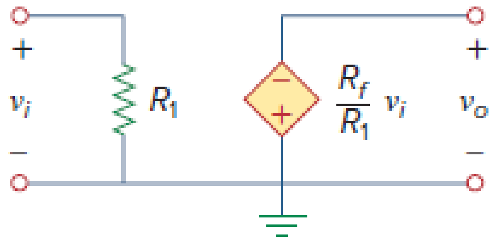


Figure 5.11
An equivalent circuit for the inverter in Fig. 5.10.

the relationship between the input voltage v_i and the output voltage v_o. Applying KCL at node 1,

$$i_1 = i_2 \quad \Rightarrow \quad \frac{v_i - v_1}{R_1} = \frac{v_1 - v_o}{R_f} \tag{5.8}$$

But $v_1 = v_2 = 0$ for an ideal op amp, since the noninverting terminal is grounded. Hence,

$$\frac{v_i}{R_1} = -\frac{v_o}{R_f}$$

or

$$\boxed{v_o = -\frac{R_f}{R_1}v_i} \tag{5.9}$$

The voltage gain is $A_v = v_o/v_i = -R_f/R_1$. The designation of the circuit in Fig. 5.10 as an *inverter* arises from the negative sign. Thus,

An inverting amplifier reverses the polarity of the input signal while amplifying it.

Example 5.3

Refer to the op amp in Fig. 5.12. If $v_i = 0.5$ V, calculate: (a) the output voltage v_o, and (b) the current in the 10 kΩ resistor.

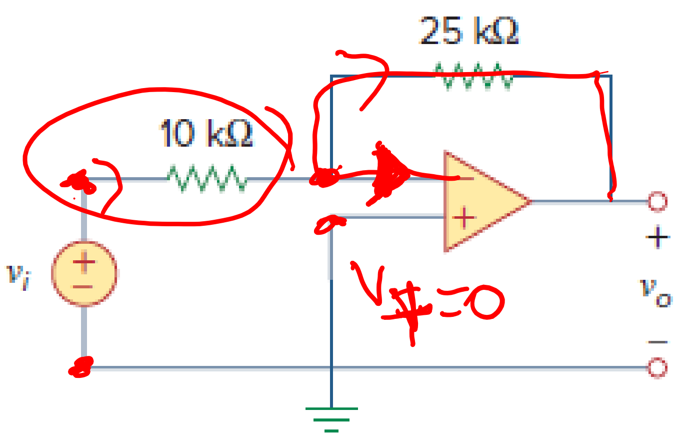


Figure 5.12
For Example 5.3.

b) $i = \dfrac{0,5-0}{10k\Omega}$

$= 50\mu A$

$$\frac{V_i - 0}{10k\Omega} = \frac{0 - V_o}{25k\Omega} \Rightarrow -\frac{25}{10} V_i = V_o$$

$$V_o = -1,25V$$

4.10 For the amplifier in Fig. P4.10, find the gain and I_o?

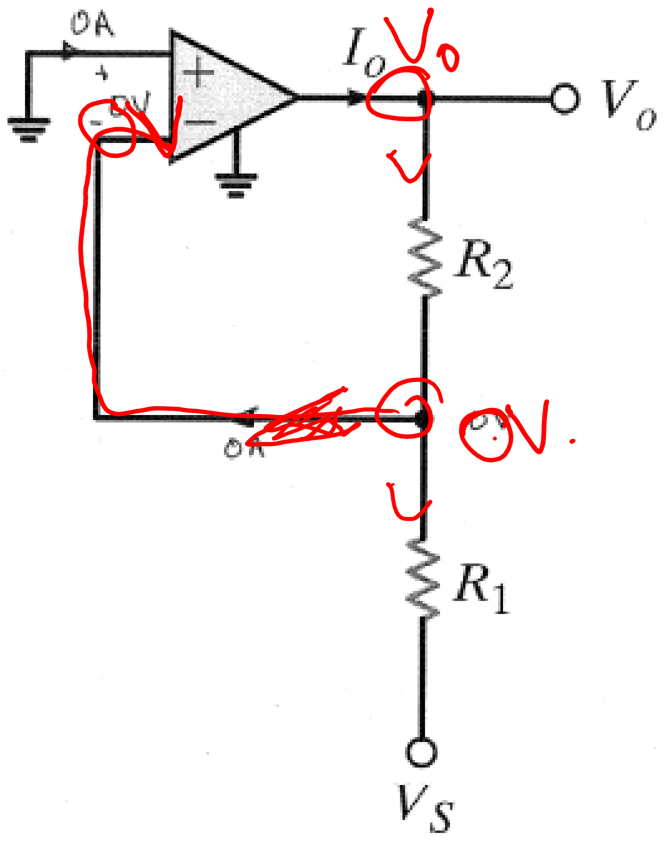


Figure P4.10

R_2 = 20 kΩ
R_1 = 3.3 kΩ
V_S = 2 V

$$\frac{V_o - 0}{R_2} = \frac{0 - V_s}{R_1}$$

$$\frac{V_o}{20} = \frac{-2}{3{,}3}$$

$$I_o = \frac{V_o - 0}{R_2}$$

TAM ÇÖZÜM:

Basic inverting configuration, $\frac{v_o}{V_S} = -\frac{R_2}{R_1} \Rightarrow \boxed{-6.06 = \frac{V_o}{V_S}}$

$I_o = V_o / R_2$ $\quad V_o = (-6.06) V_S = -12.12$

$\boxed{I_o = -606 \mu A}$

Example 5.4

Determine v_o in the op amp circuit shown in Fig. 5.14.

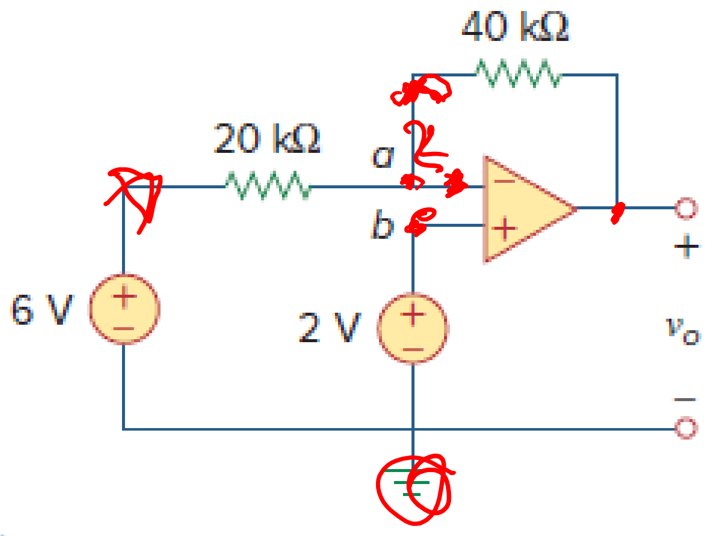


Figure 5.14
For Example 5.4.

$$\frac{6-2}{\cancel{20k\Omega}} = \frac{2-V_o}{\underset{2}{\cancel{40k\Omega}}}$$

Solution:
Applying KCL at node a,

$$\frac{v_a - v_o}{40\text{ k}\Omega} = \frac{6 - v_a}{20\text{ k}\Omega}$$

$$v_a - v_o = 12 - 2v_a \quad \Rightarrow \quad v_o = 3v_a - 12$$

But $v_a = v_b = 2$ V for an ideal op amp, because of the zero voltage drop across the input terminals of the op amp. Hence,

$$v_o = 6 - 12 = -6\text{ V}$$

Notice that if $v_b = 0 = v_a$, then $v_o = -12$, as expected from Eq. (5.9).

$$8 = 2 - V_o$$

$$\boxed{V_o = -6V}$$

5.5 Noninverting Amplifier

Another important application of the op amp is the noninverting amplifier shown in Fig. 5.16. In this case, the input voltage v_i is applied directly at the noninverting input terminal, and resistor R_1 is connected

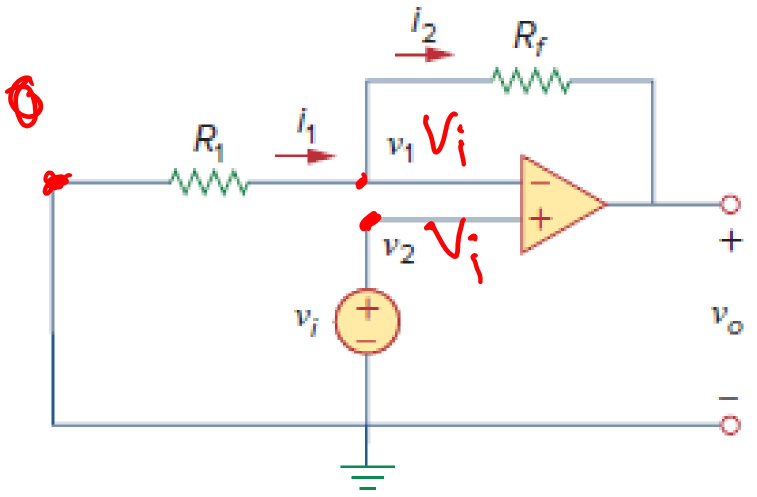


Figure 5.16
The noninverting amplifier.

$$\frac{0 - V_i}{R_1} = \frac{V_i - V_o}{R_F}$$

$$\text{Kazanç} = \frac{V_o}{V_i}$$

$$-\frac{R_F}{R_1} V_i = V_i - V_o$$

$$V_o = V_i + \frac{R_F}{R_1} V_i = V_i \left(1 + \frac{R_F}{R_1}\right)$$

Example 5.5

For the op amp circuit in Fig. 5.19, calculate the output voltage v_o.

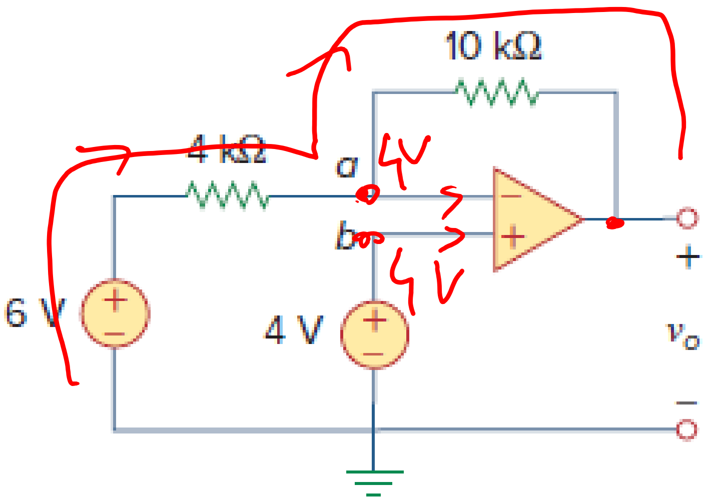


Figure 5.19
For Example 5.5.

$$\frac{6-4}{4k\Omega} = \frac{4-V_o}{10k\Omega}$$

$$5 = 4 - V_o \Rightarrow V_o = -1V$$

Solution:
We may solve this in two ways: using superposition and using nodal analysis.

■ **METHOD 1** Using superposition, we let

$$v_o = v_{o1} + v_{o2}$$

where v_{o1} is due to the 6-V voltage source, and v_{o2} is due to the 4-V input. To get v_{o1}, we set the 4-V source equal to zero. Under this condition, the circuit becomes an inverter. Hence Eq. (5.9) gives

$$v_{o1} = -\frac{10}{4}(6) = -15 \text{ V}$$

To get v_{o2}, we set the 6-V source equal to zero. The circuit becomes a noninverting amplifier so that Eq. (5.11) applies.

$$v_{o2} = \left(1 + \frac{10}{4}\right)4 = 14 \text{ V}$$

Thus,

$$v_o = v_{o1} + v_{o2} = -15 + 14 = -1 \text{ V}$$

ÇÖZÜM 2. METOT

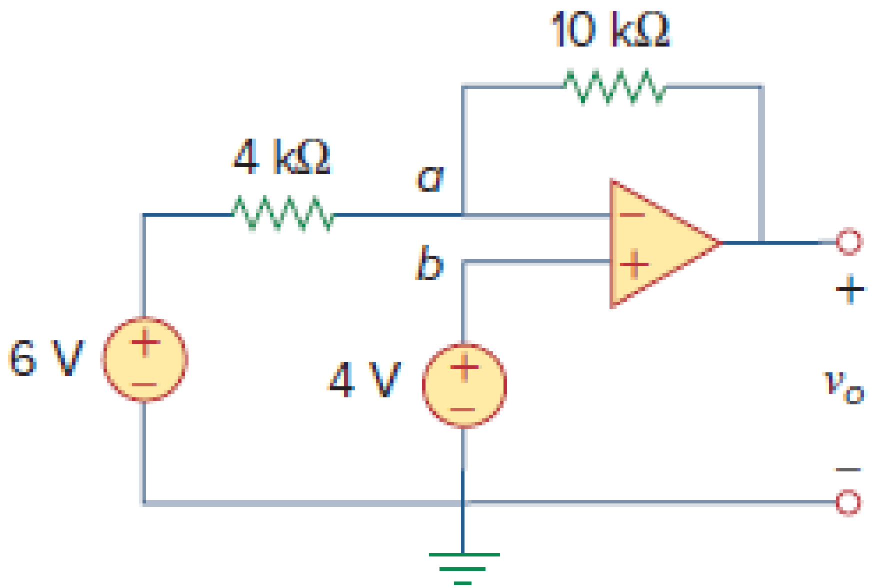


Figure 5.19
For Example 5.5.

■ **METHOD 2** Applying KCL at node a,

$$\frac{6 - v_a}{4} = \frac{v_a - v_o}{10}$$

But $v_a = v_b = 4$, and so

$$\frac{6 - 4}{4} = \frac{4 - v_o}{10} \quad \Rightarrow \quad 5 = 4 - v_o$$

or $v_o = -1$ V, as before.

4.9 Determine the gain of the amplifier in Fig. P4.9. What is the value of I_o? **CS**

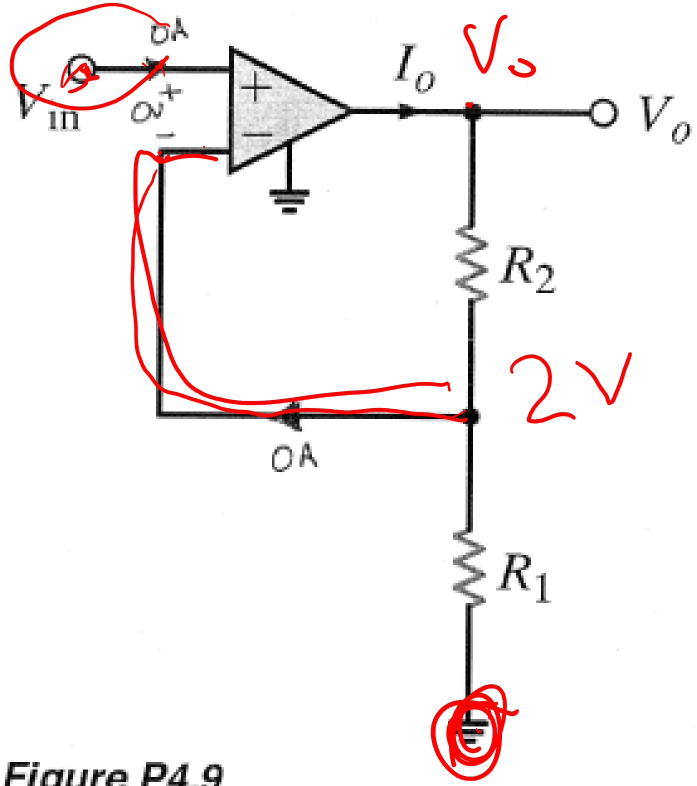


Figure P4.9

$R_2 = 20\ \text{k}\Omega$

$R_1 = 3.3\ \text{k}\Omega$

$V_{in} = 2\ \text{V}$

$$\frac{V_o - 2}{20} = \frac{2 - 0}{3,3}$$

$$V_o - 2 = \frac{40}{3,3}$$

$$V_o = \frac{40}{3,3} + 2$$

$$I_o = \frac{V_o - 0}{R_1 + R_2} = \frac{14,12}{23,3} =$$

ÇÖZÜM:

Basic noninverting configuration

$$\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1} \Rightarrow \boxed{\frac{V_o}{V_{in}} = 7.06}$$

If $V_{in} = 2V$, $v_o = 14.12V$

$$I_o = \frac{v_o}{R_1 + R_2} = 606\mu A \qquad \boxed{I_o = 606\mu A}$$

4.11 Using the ideal op-amp assumptions, determine the values of V_o and I_1 in Fig. P4.11.

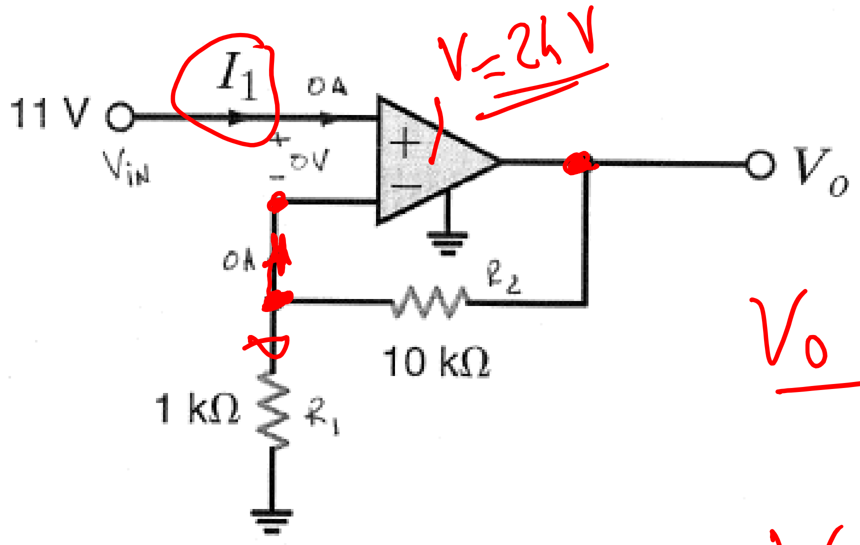


Figure P4.11

$$I_1 = 0$$

$$\frac{V_o - 11}{R_2} = \frac{11 - 0}{R_1}$$

$$\frac{V_o - 11}{10 \cancel{k\Omega}} = \frac{11}{1 \cancel{k\Omega}}$$

$$V_o = 121 \text{ V}$$

?

121 V besleme gerilimi olan 24 V'den büyük olduğu için cihaz doyum moduna geçer.

Cevap: V_o=24 V

4.12 Using the ideal op-amp assumptions, determine I_1, I_2, and I_3 in Fig. P4.12. **PSV**

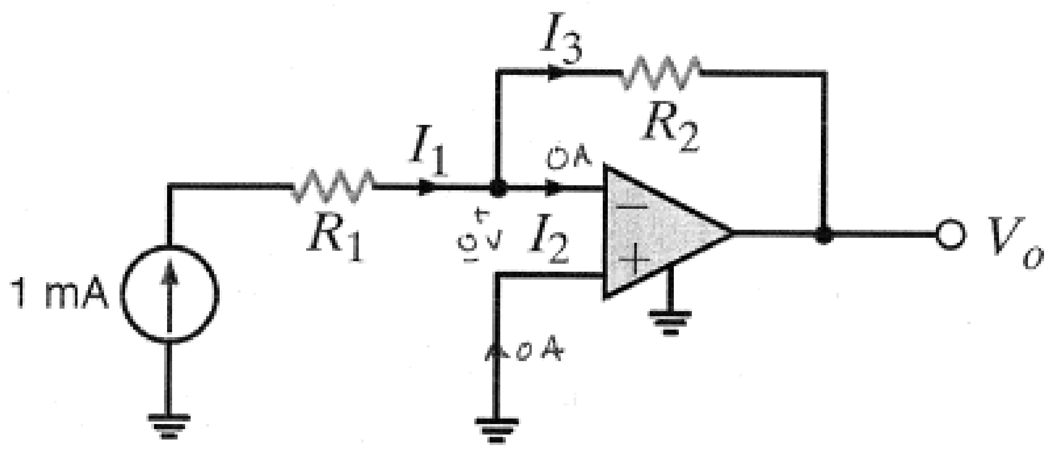


Figure P4.12

$\boxed{I_1 = 1mA}$ $\boxed{I_2 = 0A}$ (ideal op-amp)

By KCL,

$I_3 = I_1 - I_2$ $\boxed{I_3 = 1mA}$

4.18 Find V_o in the circuit in Fig. P4.18 assuming the op-amp is ideal.

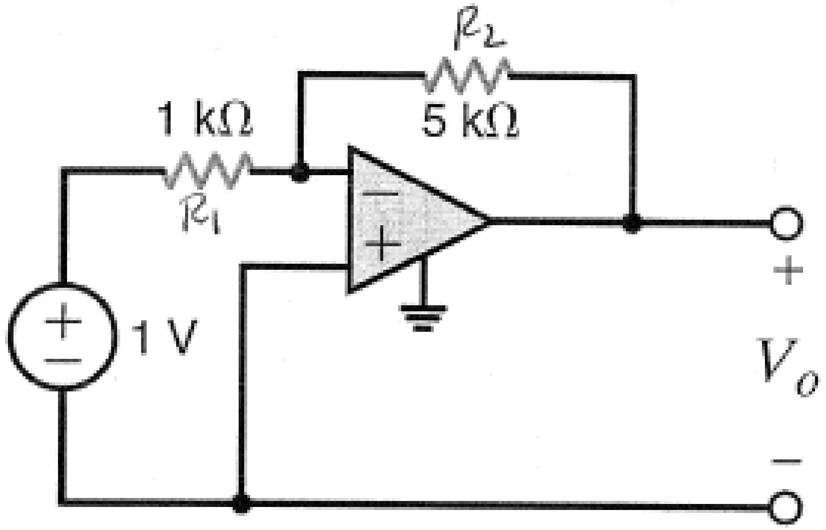


Figure P4.18

Basic inverting configuration.

$$V_o = V_s \left[- R_2/R_1 \right] \qquad V_o = 1\left(-\frac{5000}{1000}\right) \qquad \boxed{V_o = -5V}$$

4.21 Determine the relationship between v_1 and i_o in the circuit shown in Fig. P4.21. CS

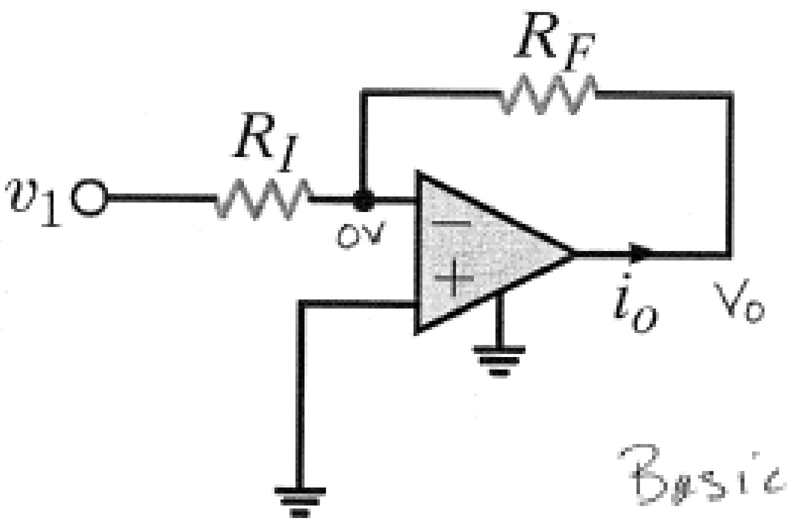


Figure P4.21

Basic inverting configuration:

$$\frac{V_o}{V_1} = -\frac{R_F}{R_I} \qquad i_o = \frac{V_o}{R_F} = -V_1/R_I$$

$$\boxed{\frac{i_o}{V_1} = -\frac{1}{R_I}}$$

4.22 Find V_o in the network in Fig. P4.22 and explain what effect R_1 has on the output.

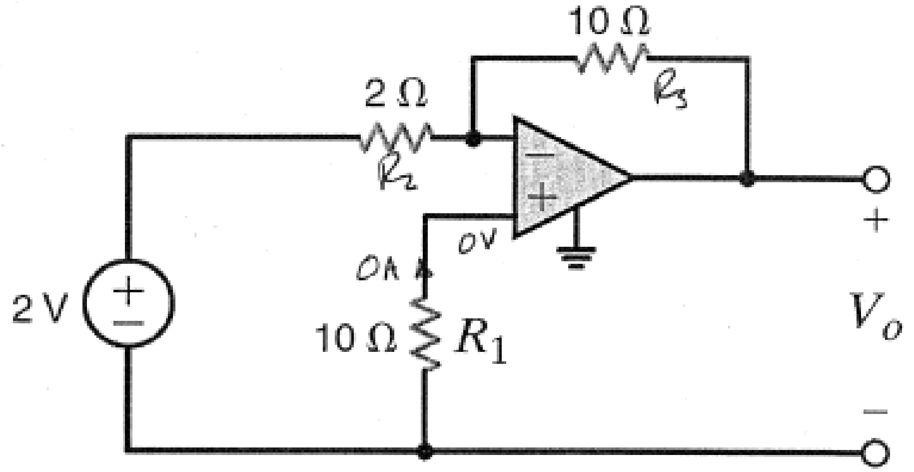


Figure P4.22

Since $i_{in} = 0$ for ideal op amp, voltage across $R_1 = 0$ and v_+ input is at 0V as well. Result is a basic inverting configuration.

$$V_o = -2\left(R_3/R_2\right) \Rightarrow \boxed{V_o = -10V}$$

R_1 has no impact on the circuit at all!

4.23 Determine the expression for v_o in the network in Fig. P4.23.

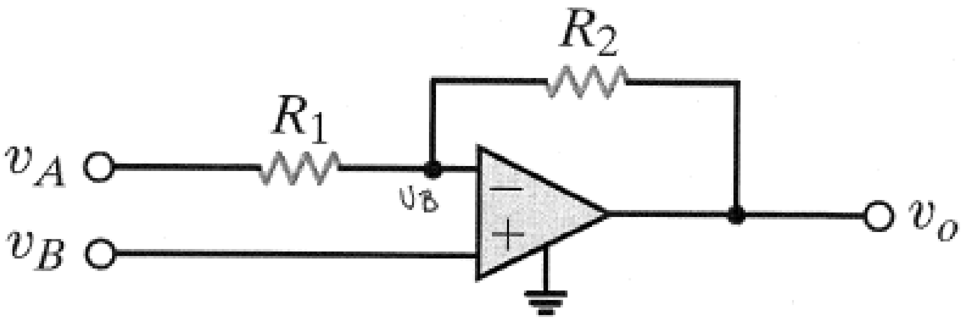


Figure P4.23

KCL at v_- node:

$$\frac{v_A - v_B}{R_1} + \frac{v_o - v_B}{R_2} = 0$$

$$\boxed{v_o = v_B\left(1 + \frac{R_2}{R_1}\right) - v_A\left(R_2/R_1\right)}$$

5.6 Summing Amplifier

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

But

$$i_1 = \frac{v_1 - v_a}{R_1}, \quad i_2 = \frac{v_2 - v_a}{R_2}$$
$$i_3 = \frac{v_3 - v_a}{R_3}, \quad i = \frac{v_a - v_o}{R_f} \tag{5.14}$$

We note that $v_a = 0$ and substitute Eq. (5.14) into Eq. (5.13). We get

$$\boxed{v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right)} \tag{5.15}$$

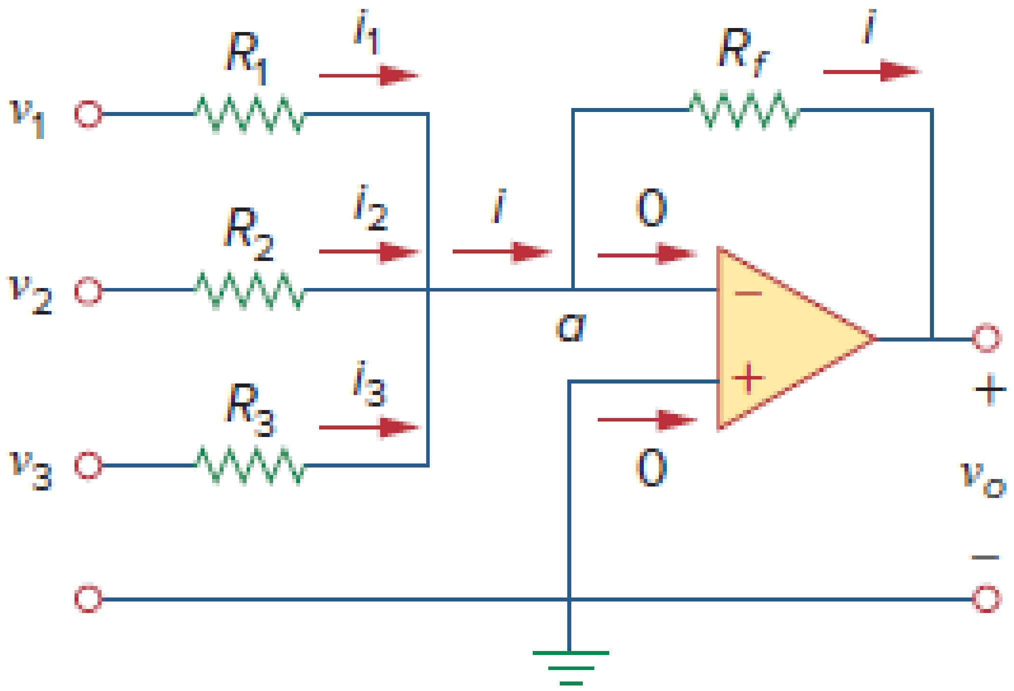


Figure 5.21
The summing amplifier.

Example 5.6

Calculate v_o and i_o in the op amp circuit in Fig. 5.22.

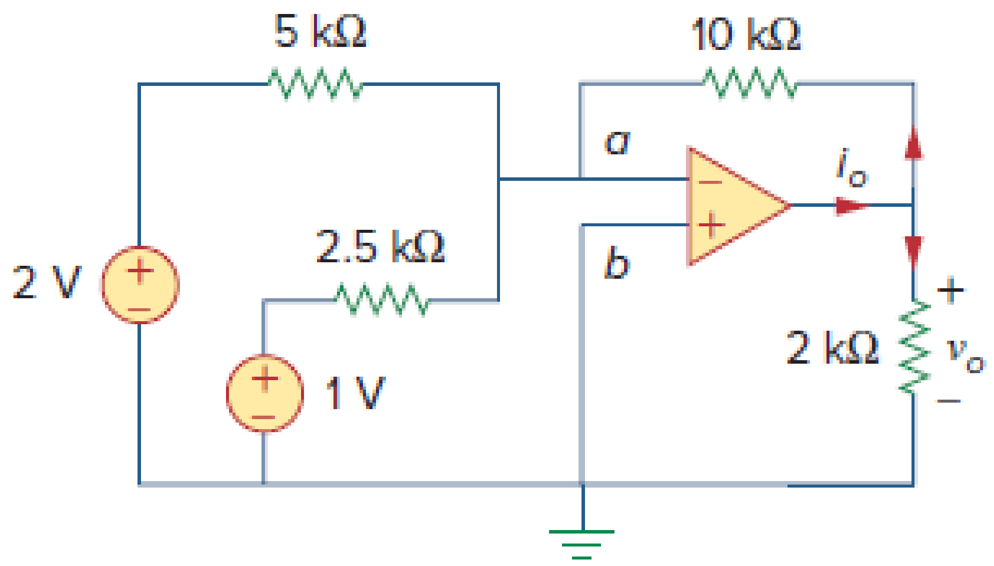


Figure 5.22
For Example 5.6.

Solution:

This is a summer with two inputs. Using Eq. (5.15) gives

$$v_o = -\left[\frac{10}{5}(2) + \frac{10}{2.5}(1)\right] = -(4+4) = -8\text{ V}$$

The current i_o is the sum of the currents through the 10- and 2-kΩ resistors. Both of these resistors have voltage $v_o = -8$ V across them, since $v_a = v_b = 0$. Hence,

$$i_o = \frac{v_o - 0}{10} + \frac{v_o - 0}{2}\text{ mA} = -0.8 - 4 = -4.8\text{ mA}$$

5.7 Difference Amplifier

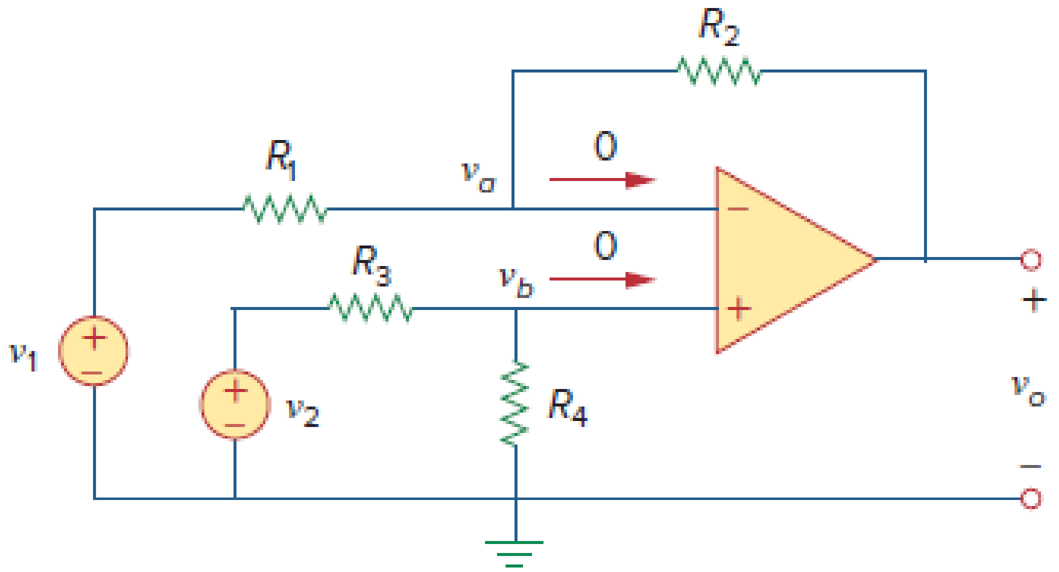


Figure 5.24
Difference amplifier.

Derste tahtada çıkarımını yaptık.

$$v_o = \frac{R_2(1 + R_1/R_2)}{R_1(1 + R_3/R_4)} v_2 - \frac{R_2}{R_1} v_1$$

SORU

4.29 In the network in Fig. P4.29 derive the expression for v_o in terms of the inputs v_1 and v_2. CS

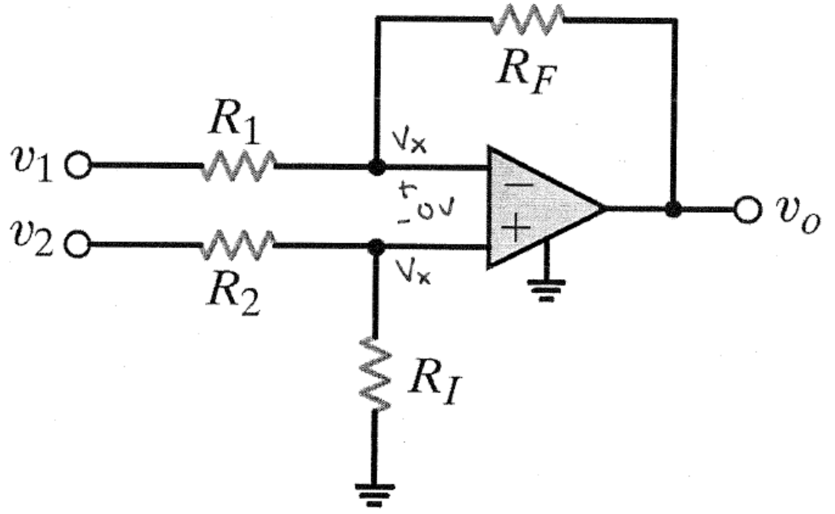


Figure P4.29

KCL at v_+ input: $\dfrac{v_2 - v_x}{R_2} = \dfrac{v_x}{R_I} \Rightarrow v_x = v_2\left(\dfrac{R_I}{R_I + R_2}\right)$

KCL at v_- input: $\dfrac{v_1 - v_x}{R_1} = \dfrac{v_x - v_0}{R_F} \Rightarrow v_0 = v_x\left(1 + \dfrac{R_F}{R_1}\right) - \dfrac{R_F}{R_1} v_1$

$$\boxed{v_0 = v_2\left(\frac{R_I}{R_I + R_2}\right)\left(\frac{R_1 + R_F}{R_1}\right) - \frac{R_F}{R_1} v_1}$$

SORU

4.30 Find V_o in the circuit in Fig. P4.30.

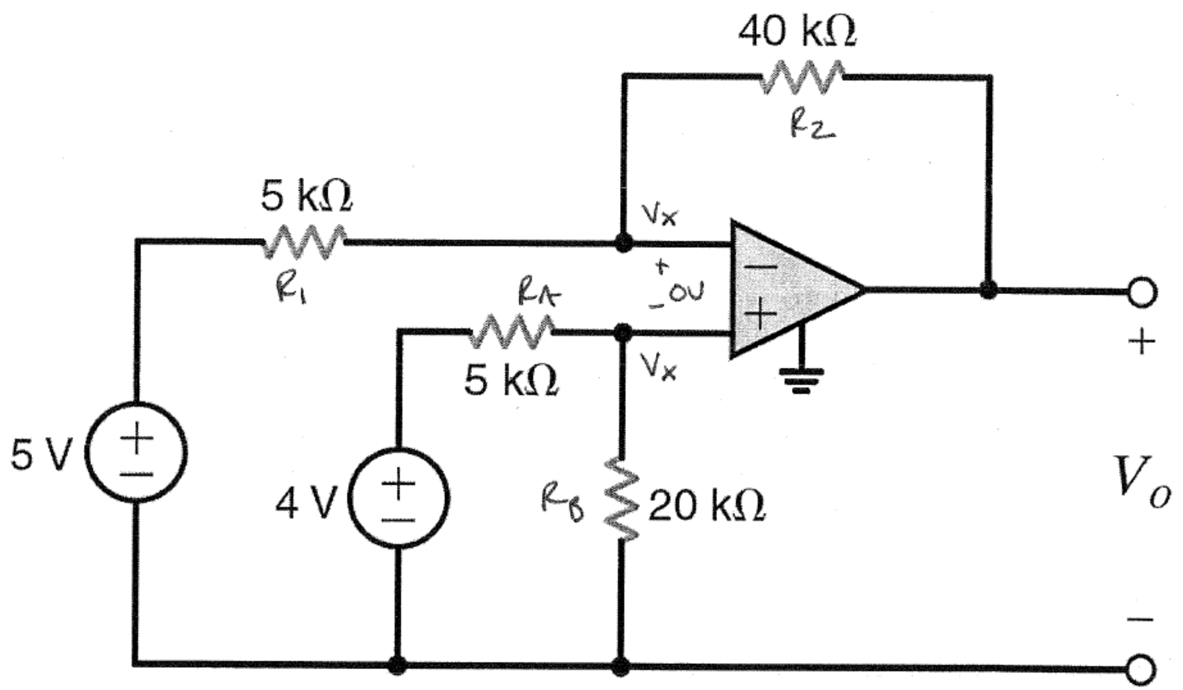


Figure P4.30

KCL at V_- input: $\frac{5 - V_x}{R_1} = \frac{V_x - V_o}{R_2} \Rightarrow V_x = 5\left(\frac{R_2}{R_1+R_2}\right) + V_o\left(\frac{R_1}{R_1+R_2}\right)$

KCL @ V_+ input: $\frac{4 - V_x}{R_A} = \frac{V_x}{R_B} \Rightarrow V_x = \frac{4R_B}{R_A+R_B}$

$$5\left(\frac{R_2}{R_1+R_2}\right) + V_o\left(\frac{R_1}{R_1+R_2}\right) = \frac{4R_B}{R_A+R_B}$$

$$V_o = \left(\frac{4R_B}{R_A+R_B} - \frac{5R_2}{R_1+R_2}\right)\frac{R_1+R_2}{R_1}$$

$$\boxed{V_o = -11.2V}$$

SORU

4.31 Find V_o in the circuit in Fig. P4.31.

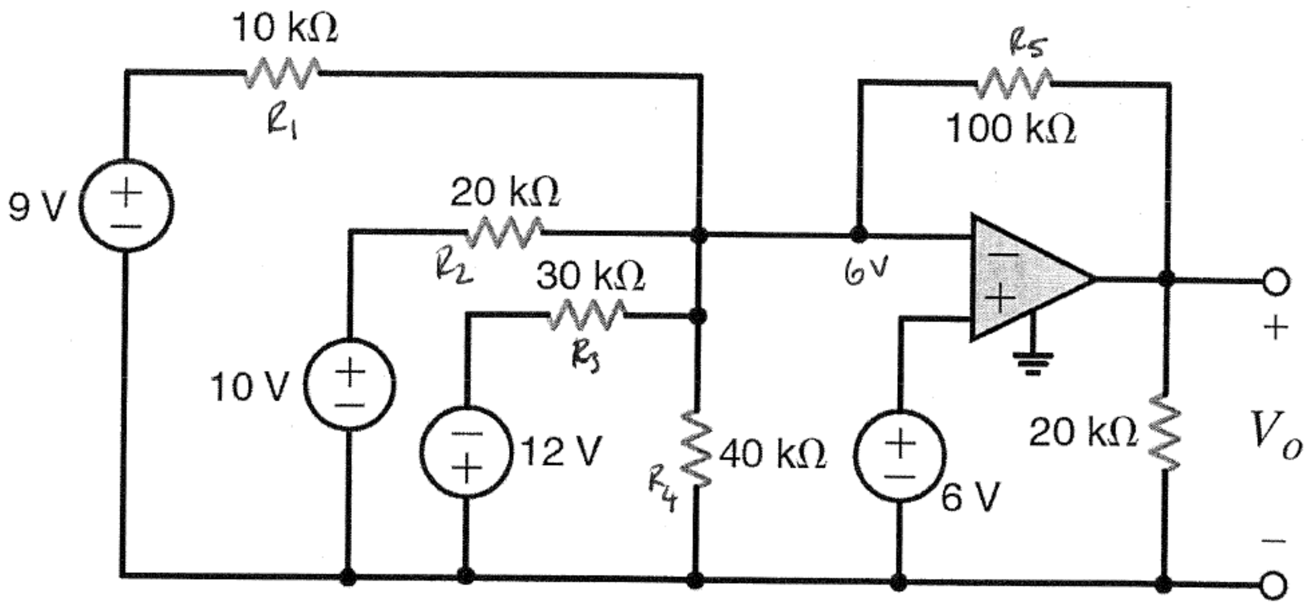


Figure P4.31

Besleme gerilimi =24 V

ÇÖZÜM

KCL at V_- input:

$$\frac{9-6}{R_1} + \frac{10-6}{R_2} + \frac{-12-6}{R_3} = \frac{6}{R_4} + \frac{6-V_o}{R_5}$$

$$\frac{3}{10^4} + \frac{4}{2\times10^4} - \frac{18}{3\times10^4} = \frac{6}{4\times10^4} + \frac{6}{10^5} - \frac{V_o}{10^5}$$

$$\boxed{V_o = 31V}$$

Bulduğumuz çıkış gerilimi, besleme geriliminden yüksek olduğu için Cihaz doyuma gider. Çıkış gerilimi = 24 V.

SORU

4.32 Determine the expression for the output voltage, v_o, of the inverting summer circuit shown in Fig. P4.32.

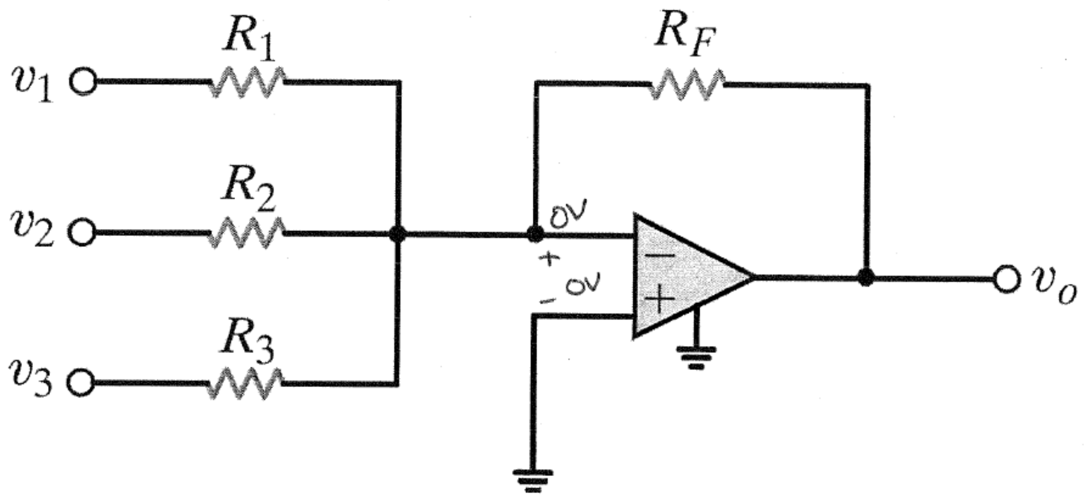


Figure P4.32

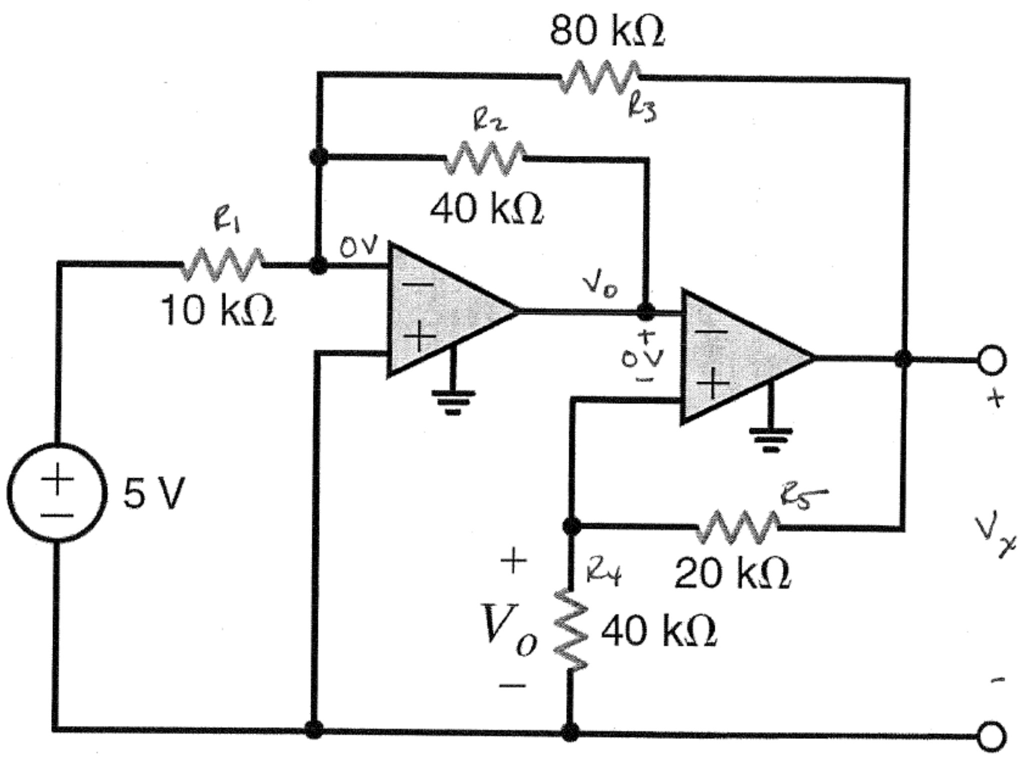
ÇÖZÜM

KCL at V_- input: $$\frac{v_1 - 0}{R_1} + \frac{v_2 - 0}{R_2} + \frac{v_3 - 0}{R_3} = \frac{0 - v_0}{R_F}$$

$$\boxed{v_0 = -\frac{R_F}{R_1}v_1 - \frac{R_F}{R_2}v_2 - \frac{R_F}{R_3}v_3}$$

SORU

4.35 Find V_o in the circuit in Fig. P4.35. **PSV**



ÇÖZÜM

KCL at v_- of 1st op amp: $$\frac{5}{R_1} + \frac{v_o}{R_2} + \frac{v_x}{R_3} = 0 \Rightarrow v_x = -\frac{R_3}{R_1}(5) - \frac{R_3}{R_2} v_o$$

KCL at v_+ of 2nd op amp: $$\frac{v_o}{R_4} + \frac{v_o - v_x}{R_5} = 0 \Rightarrow v_x = v_o\left(1 + R_5/R_4\right)$$

Put in numbers,

$$v_x = -40 - 2v_o \quad \& \quad v_x = 1.5 v_o$$

Eliminate v_x,

$$\boxed{v_o = -11.43\,V}$$

SORU

4.36 Find v_o in the circuit in Fig. P4.36.

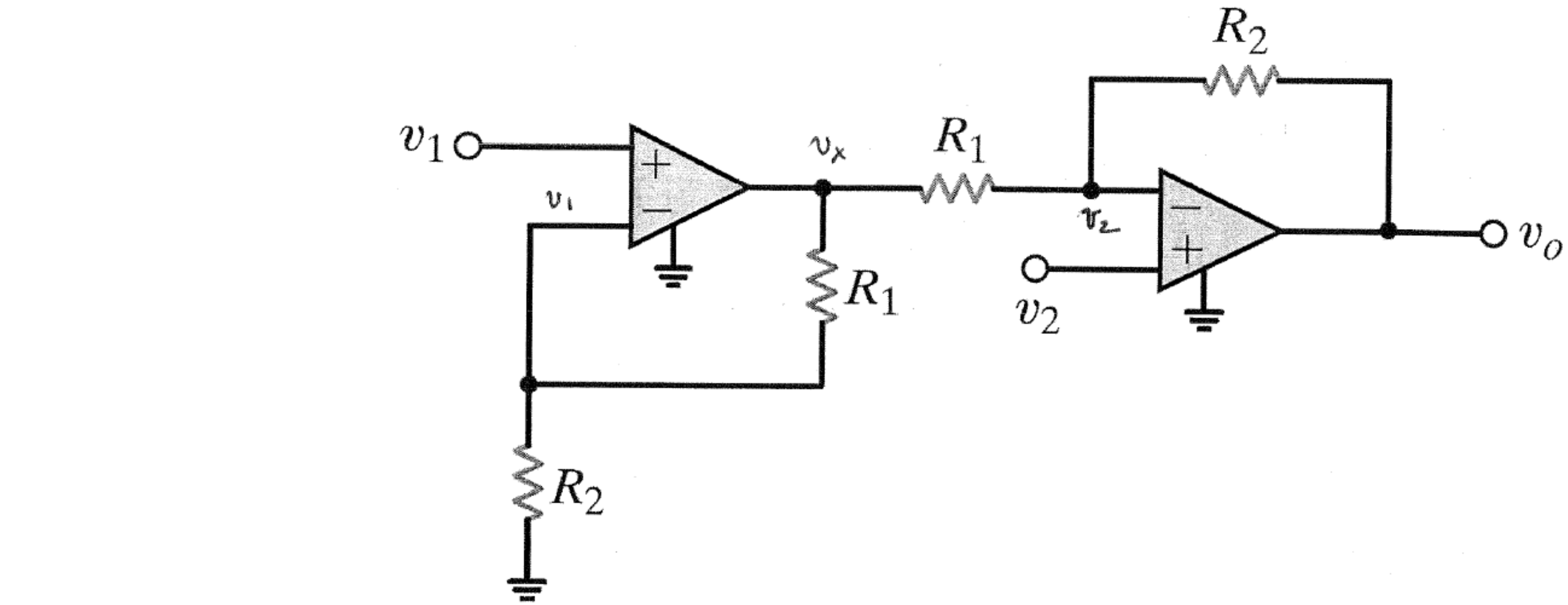


Figure P4.36

ÇÖZÜM

1^{st} Op amp in basic non-inverting configuration:

$$\frac{v_x}{v_1} = 1 + \frac{R_1}{R_2} \Rightarrow v_x = v_1\left(\frac{R_2 + R_1}{R_2}\right)$$

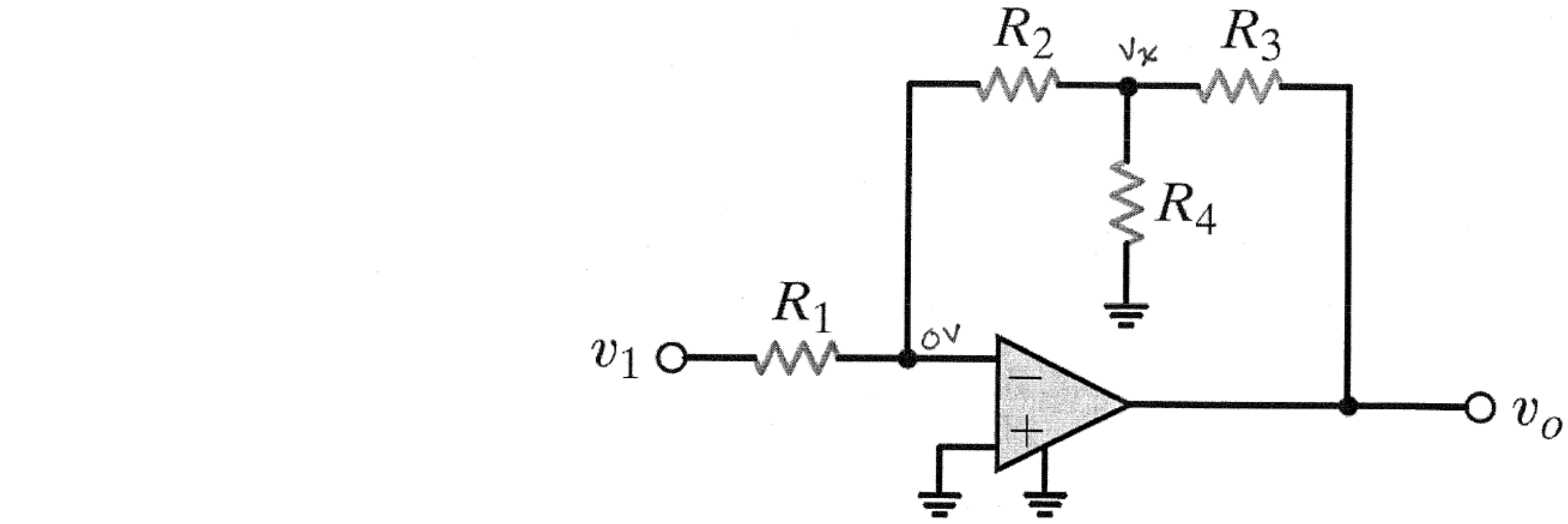
KCL at v_- of 2^{nd} op amp: $\frac{v_x - v_2}{R_1} + \frac{v_o - v_2}{R_2} = 0$

$$v_o = v_2\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} v_x$$

$$\boxed{v_o = \left(1 + \frac{R_2}{R_1}\right)(v_2 - v_1)}$$

SORU

4.38 Find v_o in the circuit in Fig. P4.38. **PSV**



ÇÖZÜM

KCL at v_- input: $\dfrac{v_1}{R_1} + \dfrac{v_x}{R_2} = 0$ $\qquad v_x = -\dfrac{R_2}{R_1} v_1$

KCL at v_x node: $\dfrac{v_x}{R_2} + \dfrac{v_x}{R_4} + \dfrac{v_x - v_o}{R_3} = 0$ $\qquad v_o = v_x\left(\dfrac{R_3}{R_2} + \dfrac{R_3}{R_4} + 1\right)$

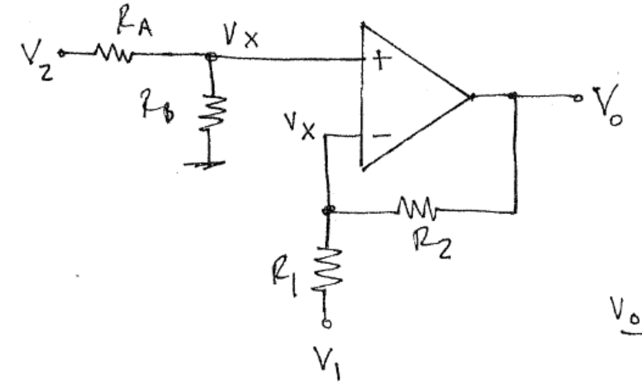
$$\boxed{v_o = v_1\left[1 + \frac{R_3}{R_2} + \frac{R_3}{R_4}\right]\left(-\frac{R_2}{R_1}\right)}$$

SORU

4.44 Design an op-amp circuit that has the following input/output relationship:

$$V_o = -5\,V_1 + 0.5\,V_2$$

A single op-amp will do if we use both + & − inputs.



KCL at V_+,

$$\frac{V_2 - V_x}{R_A} = \frac{V_x}{R_B} \Rightarrow \frac{V_x}{V_2} = \frac{R_B}{R_A + R_B}$$

KCL at V_-,

$$\frac{V_o - V_x}{R_2} = \frac{V_x - V_1}{R_1}$$

$$V_o = V_x\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1}V_1$$

$$V_o = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_B}{R_A + R_B}\right)V_2 - \frac{R_2}{R_1}V_1$$

So, $R_2/R_1 = 5$

Now, $\dfrac{6R_B}{R_A + R_B} = \dfrac{1}{2}$

Choose $R_1 = 1k\Omega$ $\Rightarrow$	$R_2 = 5k\Omega$
Choose $R_B = 1k\Omega$ $\Rightarrow$	$R_A = 11k\Omega$

SORU

4FE-2 Determine the output voltage V_o of the summing op-amp circuit shown in Fig. 4PFE-2.

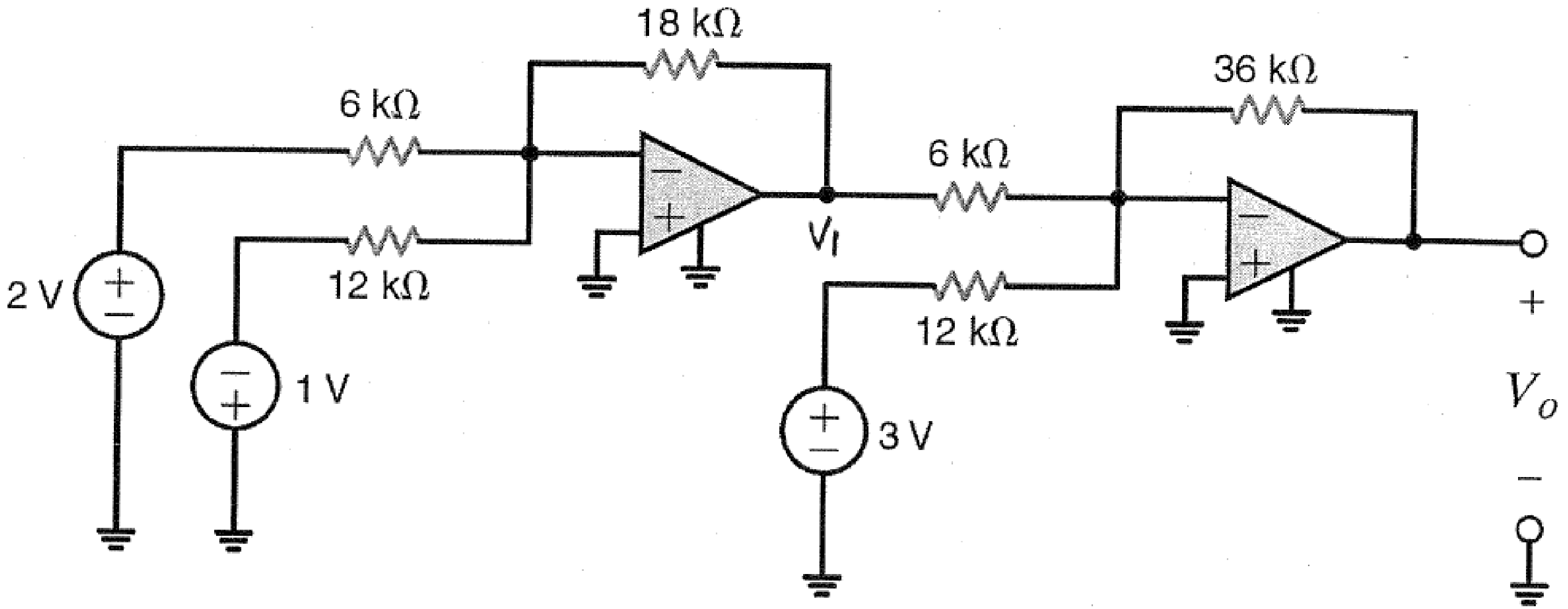


Figure 4PFE-2

ÇÖZÜM

$$V_1 = -2\left(\frac{18\times10^3}{6\times10^3}\right) + 1\left(\frac{18\times10^3}{12\times10^3}\right) = -4.5V$$

$$V_0 = -V_1\left(\frac{36\times10^3}{6\times10^3}\right) - 3\left(\frac{36\times10^3}{12\times10^3}\right) \Rightarrow \boxed{V_0 = 18V}$$