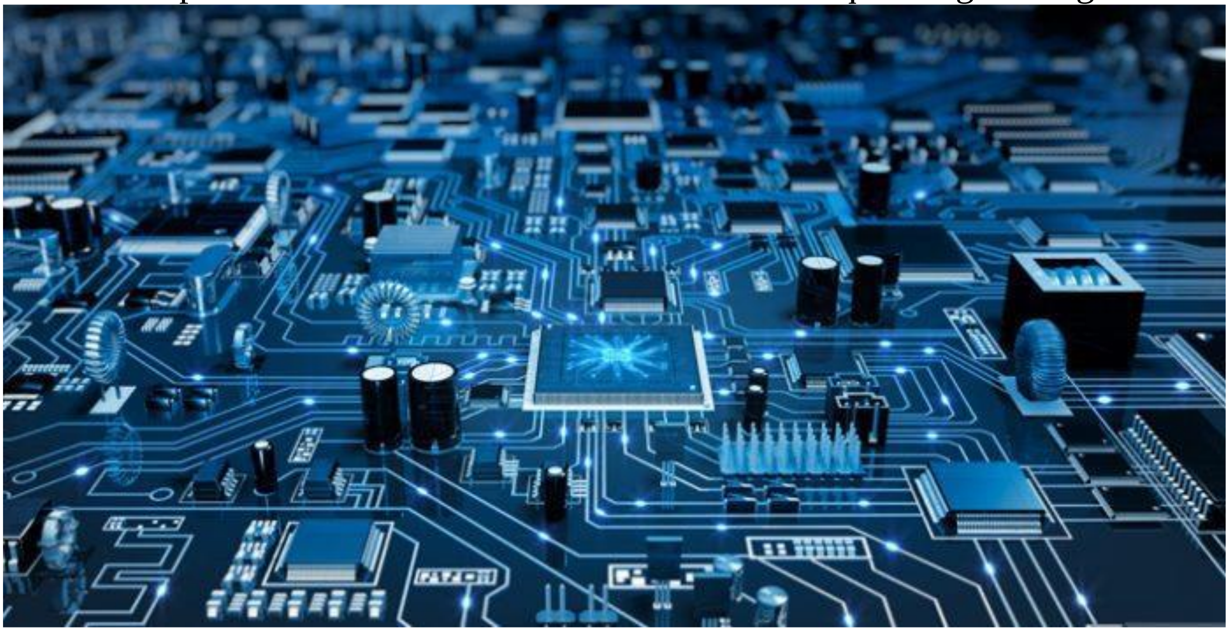
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Systems
Lecturer: Prof. Adnan Ali
Lecture:9

Mode Unit 7

Applications of Operational Amplifiers (Part 2)

For
Students of Third Stage
Department of Medical Instrumentation Techniques Engineering



By

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Engineering

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1. Overview

a. Target population:

For students of third class of Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.

b. Rationale:

An operational amplifier (often op amp or Op-Amp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op amp produces an output potential (relative to circuit ground) that is typically 100,000 times larger than the potential difference between its input terminals. Operational amplifiers had their origins in analog computers, where they were used to perform mathematical operations in linear, non-linear, and frequency-dependent circuits.

c. Objectives:

The student will be able after finishing lecture on:

- Draw the waveform of Operational Amplifier (Op-Amp).
- Identify the main types of Operational Amplifier (Op-Amp).

Applications of Operational Amplifiers

2.1 Voltage Summation:

It is po sible to scale a signal voltage, that is, to multiply it by a fixed constant, through an appropriate choice of external resistors that determine the closed-loop gain of an amplifier circuit. This operation can be accomplished in either an inverting or noninverting configuration. It is also possible to sum several signal voltages in one operational-amplifier circuit and at the same time scale each by a different factor. This called a linear combination and the circuit that produces it is often called a linear-combination circuit as shown in Fig. 2-1. For the three-input inverting amplifier of Fig. 2-1,

$$i_1 + i_2 + i_3 = i_f \quad \text{or} \quad \frac{v}{R} + \frac{v2}{R_2} + \frac{v3}{R_3} = -\frac{vo}{R_f} \Rightarrow$$

$$V_0 = -\left(\frac{R_f}{R}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right) \qquad [2\text{-}1]$$

when $R = R_2 = R = R$;

$$V_0 = -\frac{R_f}{R}(V_1 + V_2 + V_3) \qquad [2\text{-}2]$$

when $R_f = R$;

$$V_0 = -(V_1 + V_2 + V_3) \qquad [2\text{-}3]$$

The feedback ratio;

$$\beta = \frac{R_p}{R_p + R_f} \qquad [2\text{-}4]$$

where $R_p = R_1 \| R_2 \| R_3$.

The optimum value of the compensation resistor is

$$R_e = R_f \| R_p = R_f \| R_1 \| R_2 \| R_3 \qquad [2\text{-}5]$$

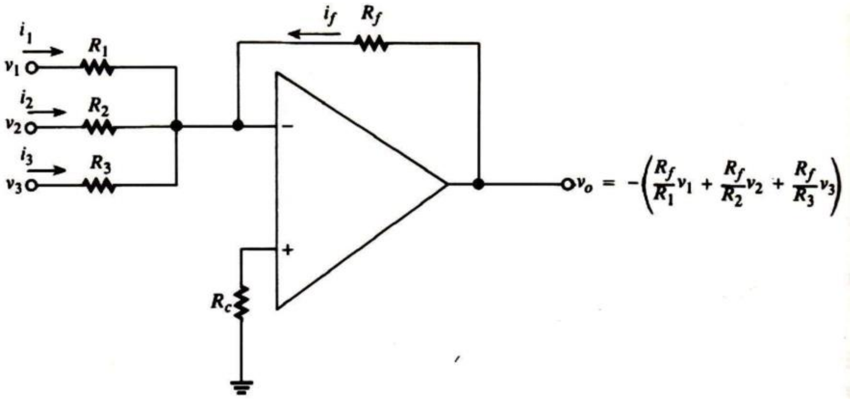


Fig. 2-1

Fig. 2-2 shows a noninverting version of the linear-combination circuit. In this example, only two inputs are connected and it can be shown that

$$V_0 = \frac{R_g + R_f}{R_g}\left(\frac{R_2}{R_1 + R_2}V_1 + \frac{R_1}{R_1 + R_2}V_2\right) \qquad [2\text{-}6]$$

Although this circuit does not invert the scaled sum, it is somewhat more cumbersome than the inverting circuit, in applications where a noninverted sum is required, it can be obtained using the inverting circuit of Fig. 2-1, followed by a unity-gain inverter.

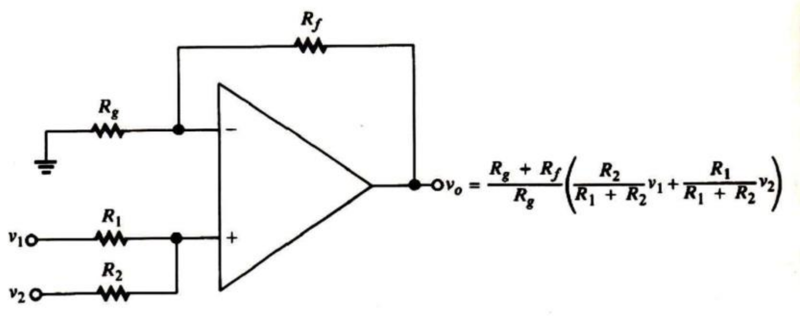


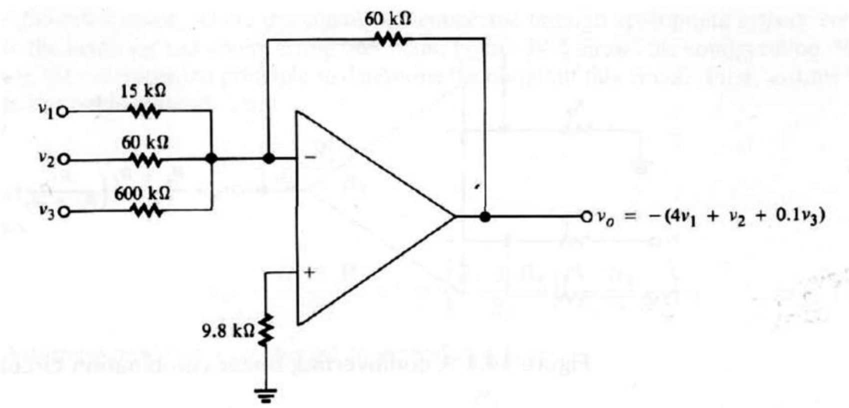
Fig. 2-2

Exercise 2-1:

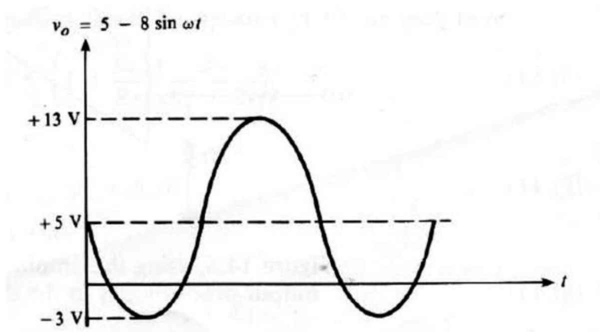
(a) Design an operational-amplifier circuit that will produce an output equal to $-(4V_1 + V_2 + 0.1V_3)$. Use $R_f = 60$ kΩ.

(b) Write an expression for the output and sketch its waveform when $V_1 = 2 \sin wt$ V, $V_2 = +5$ V dc, and $V_3 = -100$ V dc.

[Answers: (a) $R_1 = 15$ kΩ, $R_2 = 60$ kΩ, $R_3 = 600$ kΩ, $R_c = 9.8$ kΩ, Fig. 2-3(a)
(b) $V_0 = 5 - 8 \sin wt$, Fig. 2-3(b)]



(a)



(b)

Fig. 2-3

2.2 Voltage Subtraction:

Suppose we wish to produce an output voltage that equals the mathematical difference between two input signals. This operation can be performed by using a differential mode, where the signals are connected to the inverting and noninverting terminals. Fig. 2-4 shows the differential configuration. We can use the superposition principle to determine the output of this circuit;

$$V^{+} = \frac{R_2}{R + R_2} V_1 \quad \text{and} \quad V_{01} = \frac{R_3 + R}{R_3} V^{+} = \left(\frac{R_3 + R}{R_3}\right)\left(\frac{R_2}{R + R_2}\right) V_1,$$

so $V_{02} = -\frac{R}{R_3} V_2 \Rightarrow$

$$V_0 = V_{01} + V_{02} = \left(\frac{R3 + R}{R_3}\right)\left(\frac{R2}{R + R_2}\right) V_1 - \frac{R}{R_3} V_2 \qquad [2\text{-}7]$$

If $R_1 = R_3 = R$ and $R_2 = R_4 = AR \Rightarrow$

$$V_0 = V_{01} + V_{02} = \left(\frac{R + AR}{R}\right)\left(\frac{AR}{R + A}\right) V_1 - \frac{AR}{R} V_2 \Rightarrow$$

$$V_0 = A(V_1 - V_2) \qquad [2\text{-}8]$$

where A is a fixed constant, the bias compensation resistance ($R_c = R_1 || R_2$) is automatically the correct value ($R_3 || R_4$), namely $R || AR$.

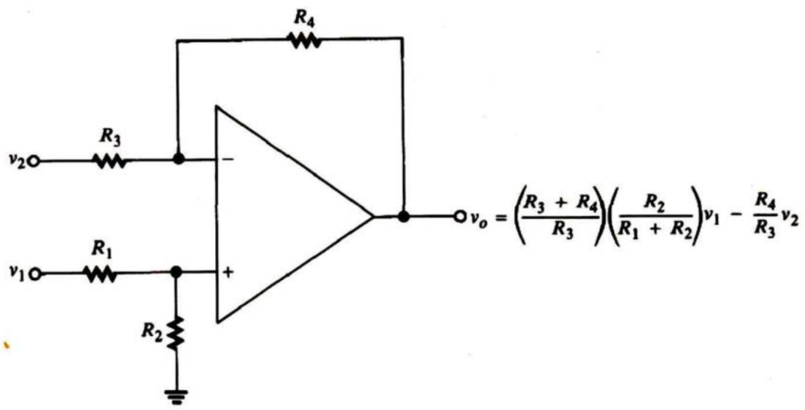


Fig. 2-4

Let the general form of the output of Fig. 2-4 be

$$V_0 = a_1 V_1 - a_2 V_2 \qquad [2\text{-}9]$$

where $a_1 = \left(\frac{R3 + R}{R_3}\right)\left(\frac{R2}{R + R_2}\right)$ and $a_2 = \frac{R}{R_3} \Rightarrow a_1 = (1 + a_2)\left(\frac{R2}{R + R_2}\right)$, but $\frac{R_2}{R + R_2} < 1$, to produce $V_0 = a_1 V_1 - a_2 V_2$, we must have $a_1 < (1 + a_2)$, this restriction limits the usefulness of the circuit.

Moreover, we note that the compensation resistance ($R_c = R_1 || R_2$) is not equal to its optimum value $R_3 || R_4$. With some algebraic complication, we can impose the additional condition $R_1 || R_2 = R_3 || R_4$ and thereby force the compensation resistance to have its optimum value. With $V_0 = a_1 V_1 - a_2 V_2$, it can be shown that the compensation resistance ($R_c = R_1 || R_2$) is optimum when the resistor values are selected in accordance with;

$$R_4 = a_1 R_1 = a_2 R_3 = R_2(1 + a_2 - a_1) \qquad [2\text{-}10]$$

Although the circuit of Fig. 2-4 is a useful and economic way to obtain a difference voltage of the form $V_0 = A(V_1 - V_2)$, our analysis has shown that it has limitations and complications when we want to produce an output of the general form $V_0 = a_1V_1 - a_2V_2$. An alternate way to obtain a scaled difference between two signal inputs is to use two inverting amplifiers, as shown in Fig. 2-5.

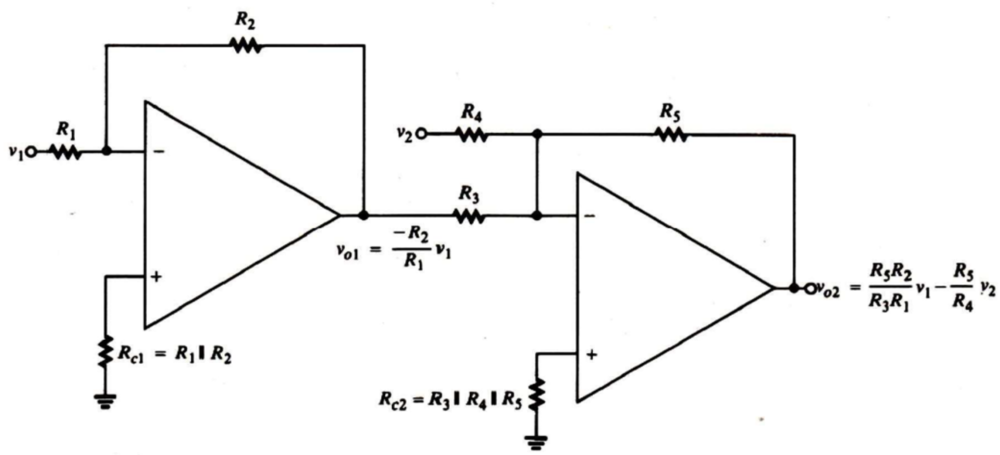


Fig. 2-5

The output of the first amplifier is

$$V_{01} = -\frac{R2}{R}V_1,$$

and the output of the second amplifier is

$$V_{02} = -\left(\frac{R}{R_3}V_{01} + \frac{R}{R}V_2\right) = V_0 = \frac{R\ R2}{R_3R}V_1 - \frac{R}{R}V_2 \qquad [2\text{-}11]$$

This equation shows that there is a great deal of flexibility in the choice of resistor values necessary to obtain $V_0 = a_1V_1 - a_2V_2$, since a large number of combinations will satisfy;

$$a_1 = \frac{R\ R_2}{R_3R} \text{ and } a_2 = \frac{R}{R}.$$

Furthermore, there are no restrictions on the choice of values for a_1 and a_2, nor any complications in setting R_c to its optimum value.

Exercise 2-2:

If the resistor values in Fig. 2-4 are chosen in according with
$R_4 = a_1R_1 = a_2R_3 = R_2(1 + a_2 - a_1)$, then,
assuming that $a_1 < (1 + a_2)$, show that

(a) $V_0 = a_1V_1 - a_2V_2$, and
(b) the compensation resistance ($R_c = R_1||R_2$) has its optimum value ($R_3||R_4$).

Exercise 2-3:

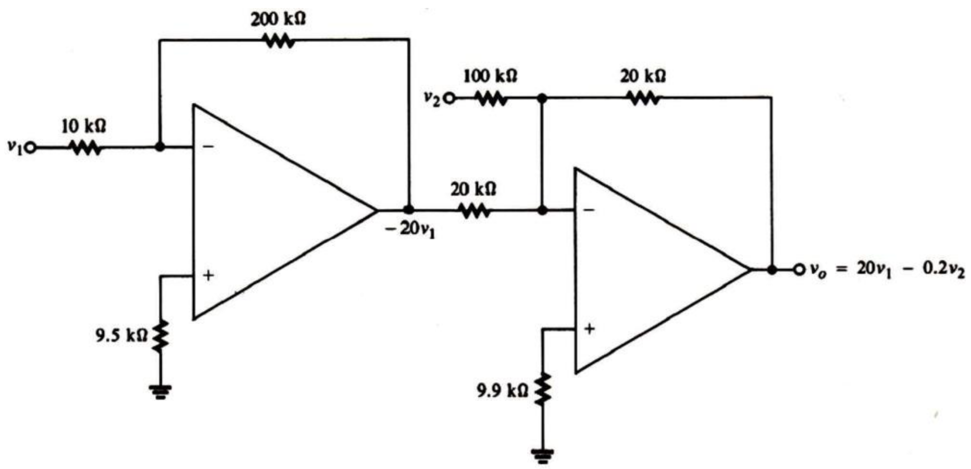
Design an operational-amplifier circuit using the differential configuration to produce the output $V_0 = 0.5V_1 - 2.0V_2$. Assume $R_4 = 100$ kΩ. Check if the compensation resistance has its optimum value.

[Answer: $R_1 = 200$ kΩ, $R_2 = 40$ kΩ, $R_3 = 50$ kΩ, $R_c = 9.8$ kΩ,
$R_c = R_1||R_2 = 33.3$ kΩ $= R_3||R_4$ (as required)]

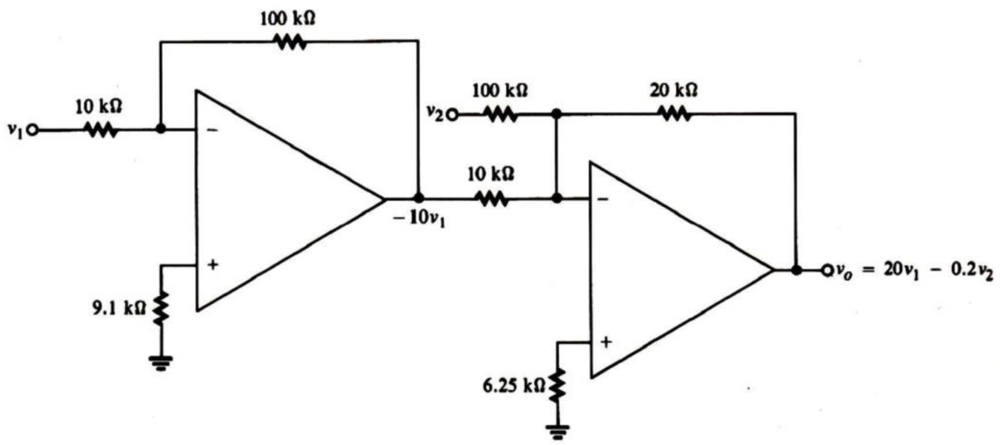
Exercise 2-4:

Design an op-amp circuit to produce the output $V_0 = 20V_1 - 0.2V_2$. First, check if you can use the differential circuit.

[Answer: $a_1 = 20 > (1 + a_2) = 1.2$ (we cannot use the differential circuit), Two of many design models are shown in Fig. 2-6(a) and (b)]



(a)



(b)

Fig. 2-6

Exercise 2-5:

(a) Design an operational-amplifier circuit using two inverting configurations to produce the output $V_0 = -10V_1 + 5V_2 + 0.5V_3 - 20V_4$. Choose feedback resistor $R_f = 100\ k\Omega$ for each amplifier.

(b) Assuming that the unity-gain frequency of each amplifier is 1 MHz, find the approximate, overall, closed-loop bandwidth of your solution.

[Answers: (a) One of many possible solutions is shown in Fig. 2-7, (b) $BW_{CL(Overall)}$ = Min. (BW_{CL1}= 153.8 kHz, BW_{CL2}= 31.2 kHz) = 31.2 kHz]

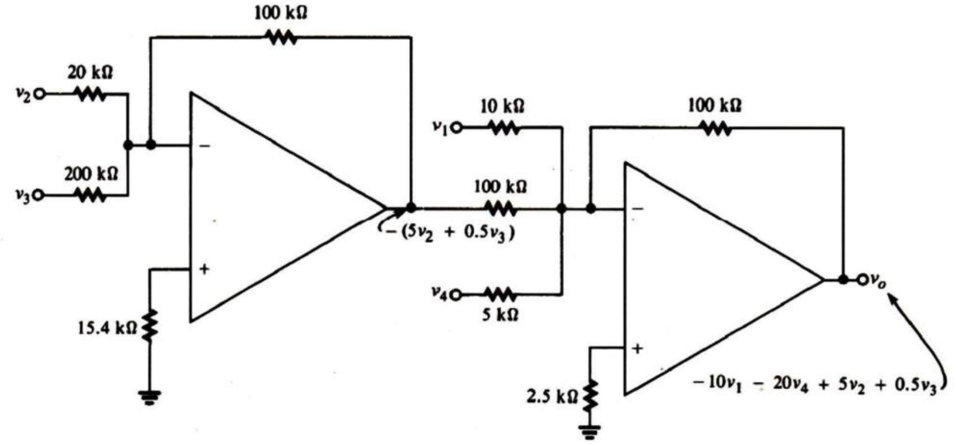

100 kΩ
20 kΩ
v_2
200 kΩ
v_3
15.4 kΩ
10 kΩ
v_1
100 kΩ
$-(5v_2 + 0.5v_3)$
v_4
5 kΩ
100 kΩ
v_o
2.5 kΩ
$-10v_1 - 20v_4 + 5v_2 + 0.5v_3$

Fig. 2-7

Exercise 2-6: Design Op-Amp circuit to give the following outputs.

1- $V_o = -2\,V_1 - 5V_2$

2- $V_o = 10\,V_1 - 5V_2$

3- $V_o = -5\,V_1 + 3V_2$

4- $V_o = 8\,V_1 - 7V_2$

5- $V_o = V_1 + 2V_2 + 3V_3$

6- $V_o = -3V_1 - 3V_2 - 4V_3 - 5V_4$

7- $V_o = 2V_1 - 3V_2 + 12V_3 - 6V_4$

8- $V_o = 2V_1 + 4V_2 + 8V_3 - 16V_4$

9- $V_o = V_1 + 2V_2 + 3V_3 - 12V_4$

10- $V_o = -V_1 - 4V_2 - 8V_3 + 8V_4$