L03
Operational Amplifiers Applications 2

Chapter 9
Ideal Operational Amplifiers and Op-Amp Circuits

Donald A. Neamen *(2009).* **Microelectronics**: Circuit Analysis and Design*,*

4th Edition, Mc-Graw-Hill

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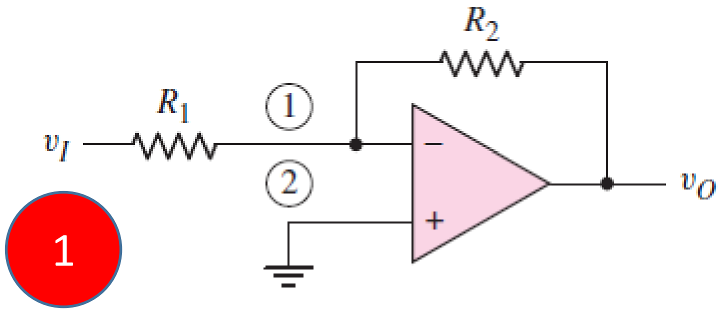
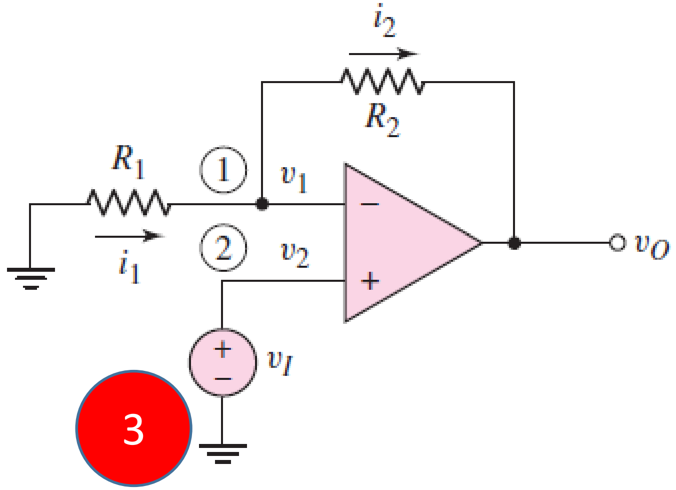
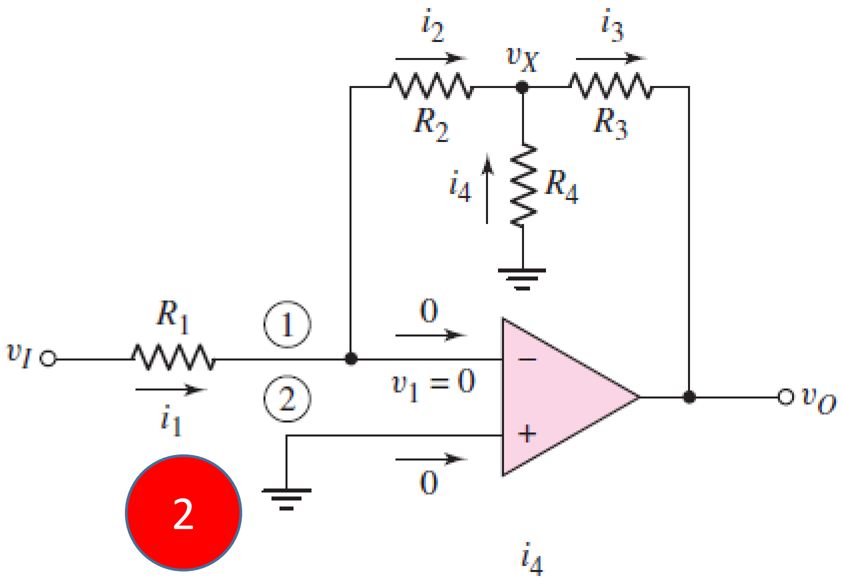
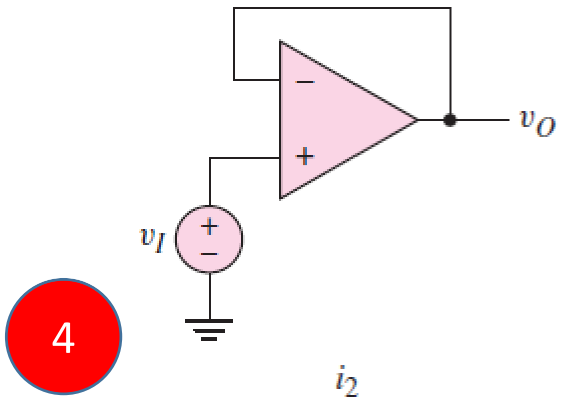
Op-Amp Applications

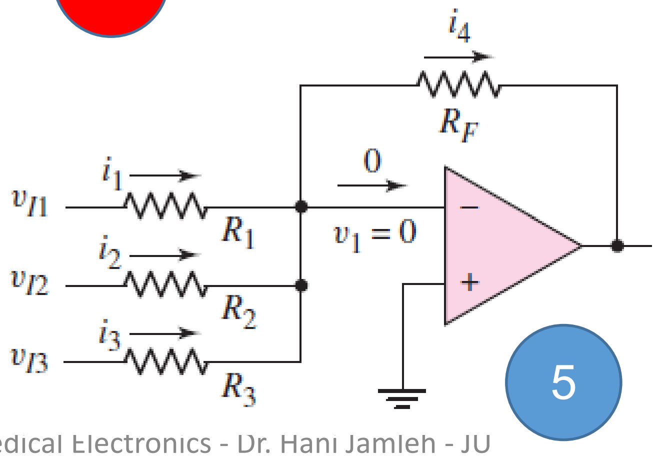
1. Inverting Amplifier
    2. Amplifier with T-Network
3. Non-Inverting Amplifier
    4. Voltage Follower (Buffer)
5. Summing Amplifier
6. Current to Voltage Converter

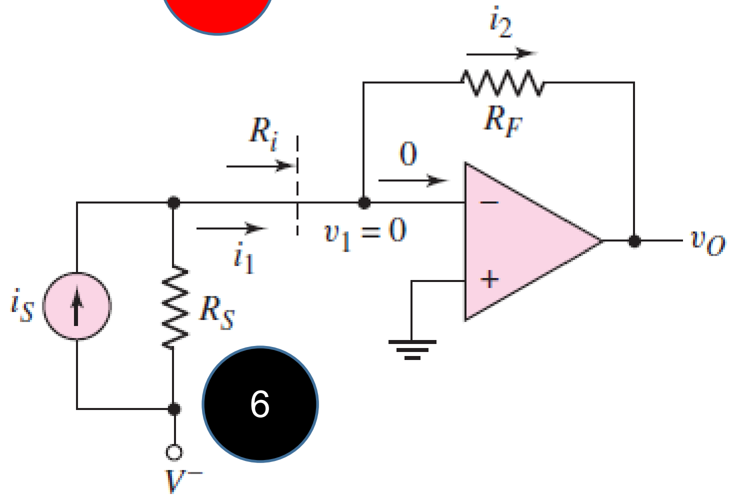






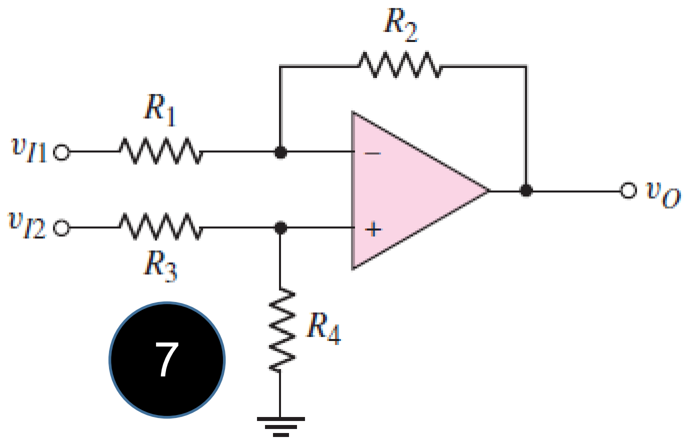


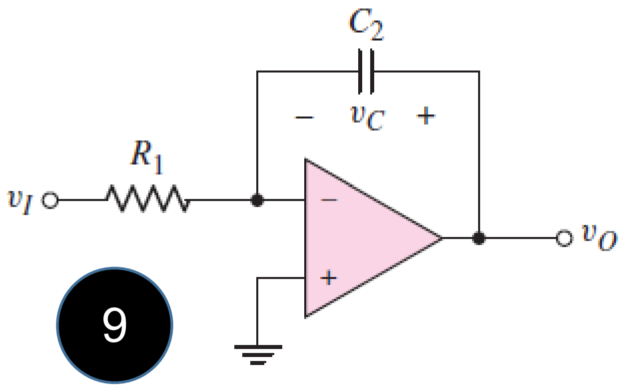


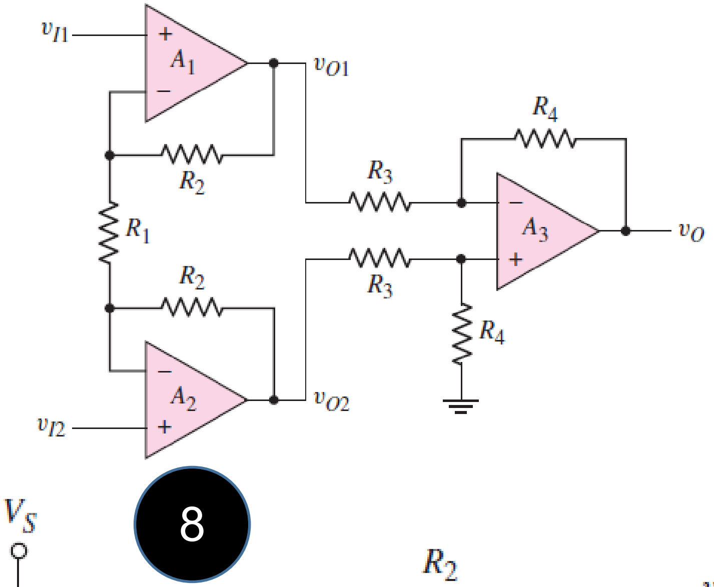


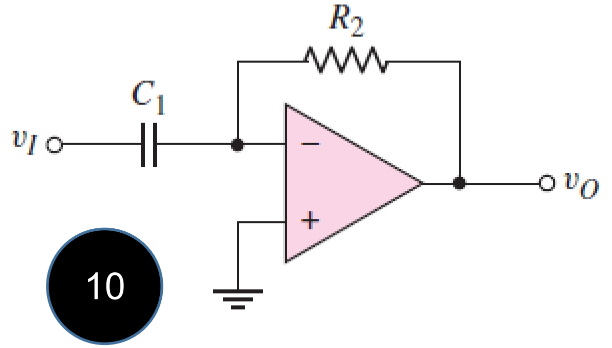
Op-Amp Applications

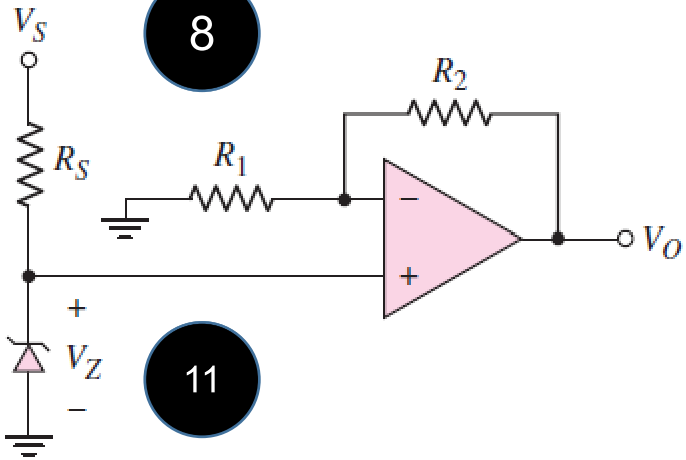
7. Difference Amplifier
8. Instrumentation Amplifier
9. Integrator
10. Differentiator
11. Reference Voltage Source Design
12. Precision Half-wave Rectifier

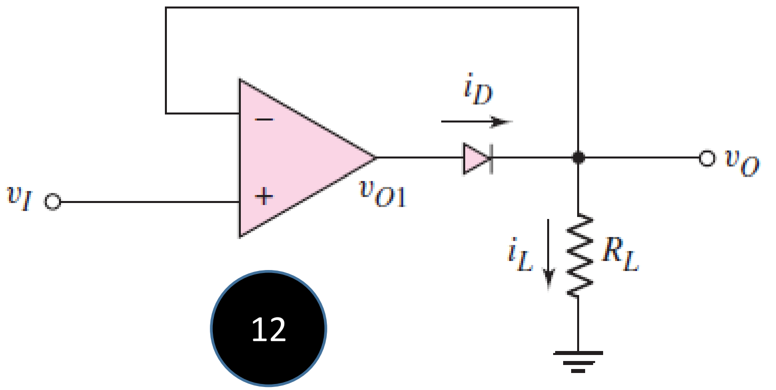












9.3 Summing Amplifier

- To analyze the op-amp circuit shown in Figure 9.14(a), we will use:
  1. The **superposition theorem** and
  2. The concept of **virtual ground**.
- Using the **superposition theorem**, we will:
  1. Determine the output voltage due to each input acting alone, then
  2. Algebraically sum these terms to determine the total output.

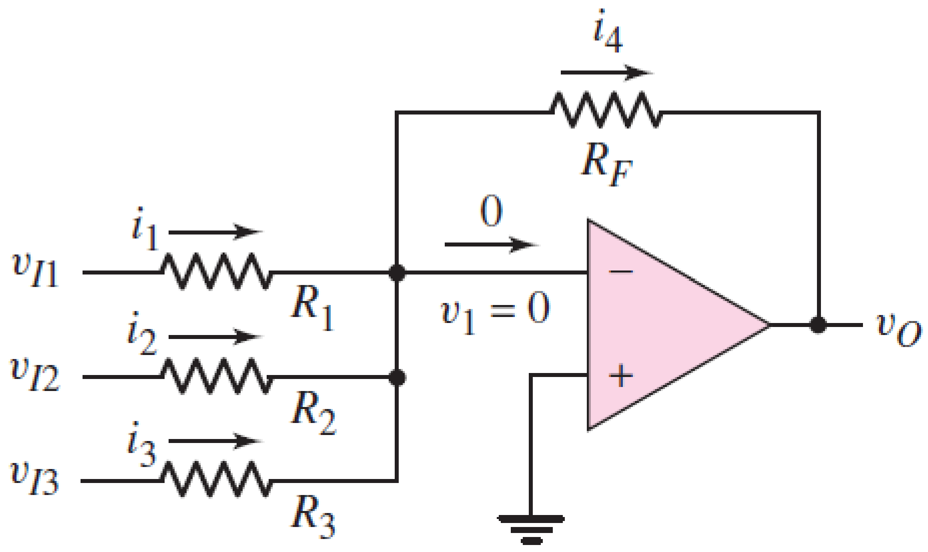


Figure 9.14(a)

9.3 Summing Amplifier

- If we set $v_{I_2} = v_{I_3} = 0$, the current i_1 is:

$$i_1 = \frac{v_{I_1}}{R_1}$$

- Since $v_{I_2} = v_{I_3} = 0$ and the inverting terminal is at virtual ground, the currents i_2 and i_3 must both be zero.
  - Current i_1 does not flow through either R_2 or R_3, but the entire current must flow through the feedback resistor R_F , as indicated in Figure 9.14(b).

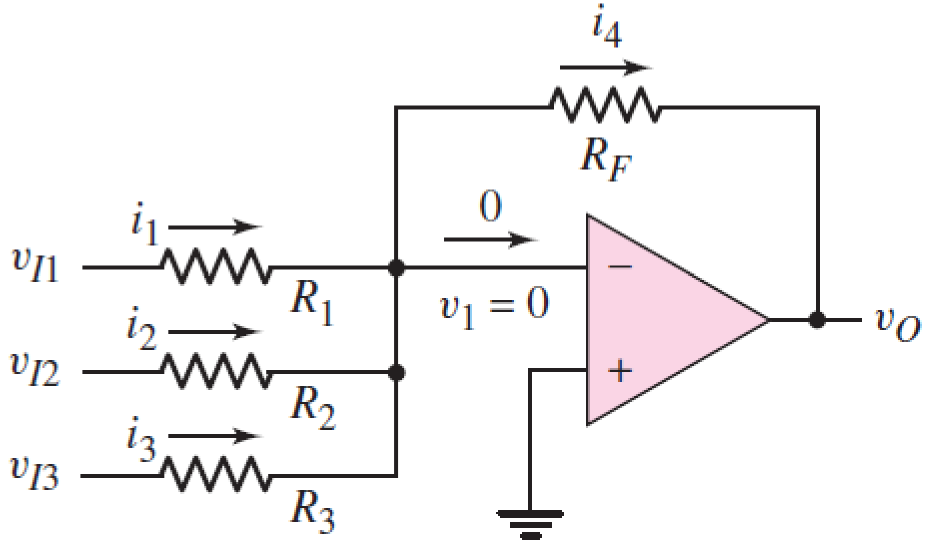


Figure 9.14(a)

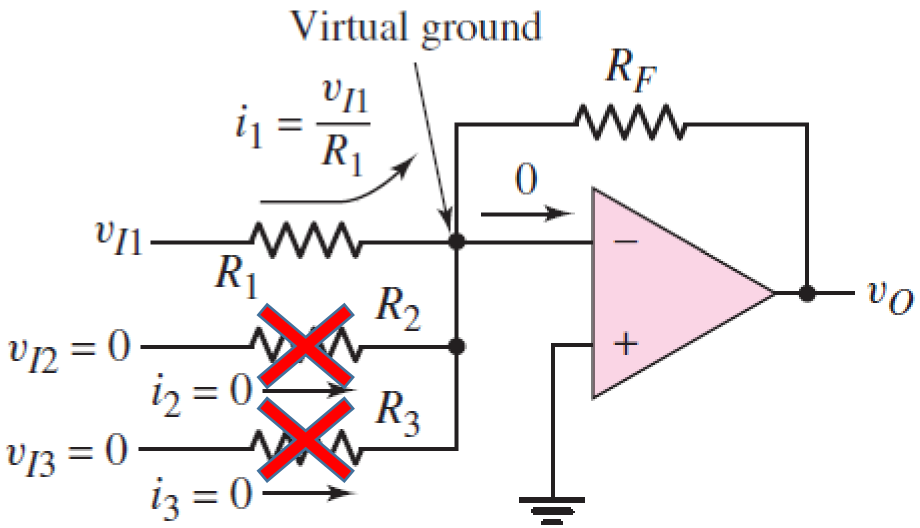


Figure 9.14(b)

9.3 Summing Amplifier

$$i_1 = \frac{v_{I_1}}{R_1}$$

- The output voltage due to v_{I_1} acting alone is:

$$v_O(v_{I_1}) = -i_1 R_F = -\left(\frac{R_F}{R_1}\right) v_{I_1}$$

- Similarly, the output voltages due to v_{I_2} and v_{I_3} acting individually are:

$$v_O(v_{I_2}) = -i_2 R_F = -\left(\frac{R_F}{R_2}\right) v_{I_2}$$

$$v_O(v_{I_3}) = -i_3 R_F = -\left(\frac{R_F}{R_3}\right) v_{I_3}$$

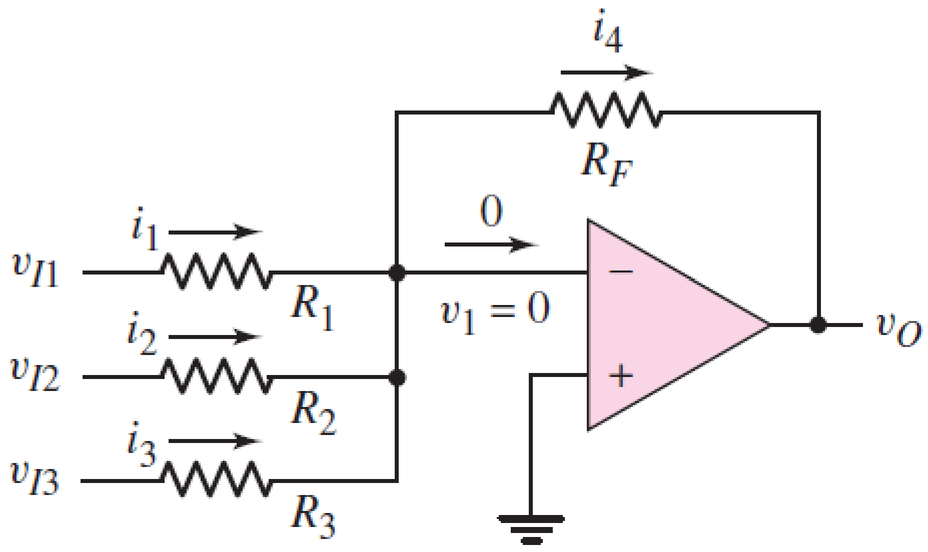


Figure 9.14(a)

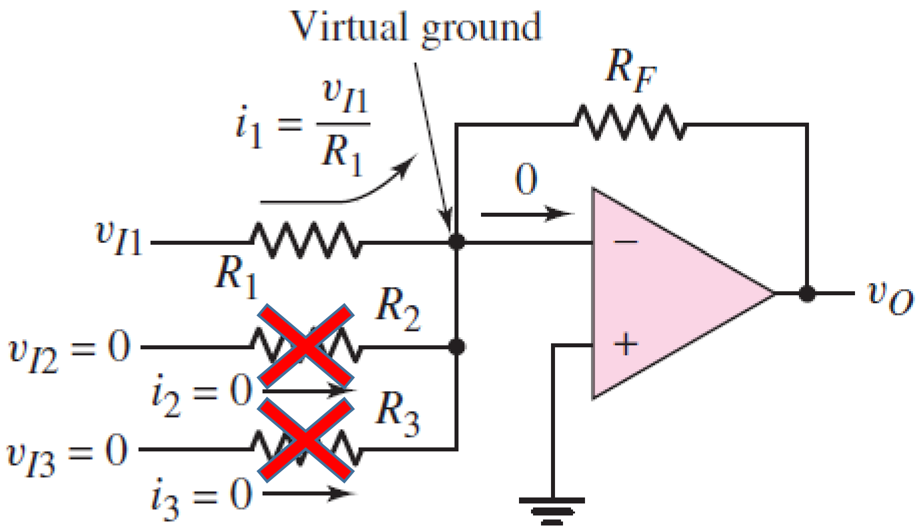


Figure 9.14(b)

9.3 Summing Amplifier

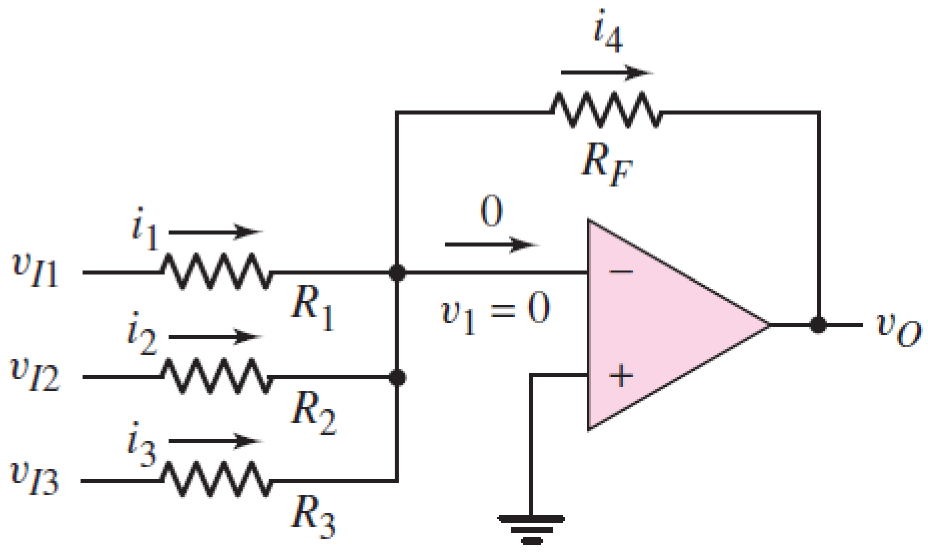


Figure 9.14(a)

- Now we have:

$$v_O(v_{I_1}) = -i_1 R_F = -\left(\frac{R_F}{R_1}\right) v_{I_1}$$

$$v_O(v_{I_2}) = -i_2 R_F = -\left(\frac{R_F}{R_2}\right) v_{I_2}$$

$$v_O(v_{I_3}) = -i_3 R_F = -\left(\frac{R_F}{R_3}\right) v_{I_3}$$

- The total output voltage is the algebraic sum of the individual output voltages:

$$v_O = v_O(v_{I_1}) + v_O(v_{I_2}) + v_O(v_{I_3})$$

$$v_O = -\left(\frac{R_F}{R_1} v_{I_1} + \frac{R_F}{R_2} v_{I_2} + \frac{R_F}{R_3} v_{I_3}\right)$$

9.3 Summing Amplifier

$$v_O = -\left(\frac{R_F}{R_1} v_{I_1} + \frac{R_F}{R_2} v_{I_2} + \frac{R_F}{R_3} v_{I_3}\right)$$

- The output voltage is the sum of the three input voltages, with different weighting factors.
- This circuit is therefore called the **inverting summing amplifier.**
- The number of input terminals and input resistors can be changed to add more or fewer voltages.
- A special case occurs when the three input resistances are equal. When $R_1 = R_2 = R_3 \equiv R$, then

$$v_O = -\frac{R_F}{R_1}(v_{I_1} + v_{I_2} + v_{I_3})$$

  - This means that the output voltage is the sum of the input voltages, with a single amplification factor.

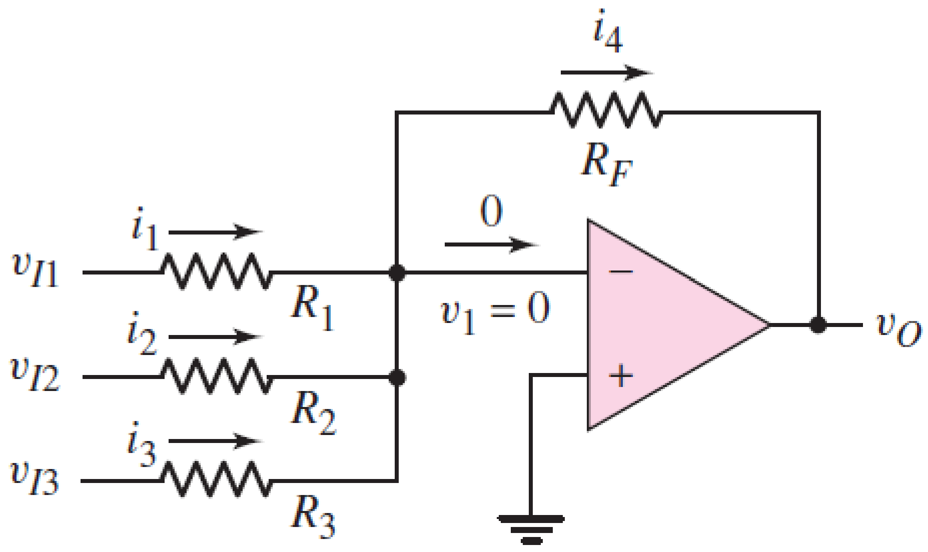


Figure 9.14(a)

Discussion

- Up to this point, we have seen that op-amps can be used to:
  - Multiply a signal by a constant (e.g.$\frac{R_F}{R_1}$)
  - Sum a number of signals with prescribed weights.
    - ➢ These are mathematical operations.
- Later in the chapter, we will see that op-amps can also be used to integrate and differentiate.
  - These circuits are the building blocks needed to perform analog computations—hence the original name of operational amplifier.

Discussion

- Opamps, however, are versatile and can do much more than just perform mathematical operations, as we will continue to observe through the remainder of this course.

DESIGN EXAMPLE 9.4

- **Objective**: Design a summing amplifier to produce a specified output signal.
- **Specifications**: The output signal generated from an ideal amplifier circuit is:

$$v_{O1} = 1.2 - 0.5\,\sin\omega t\ (V)$$

- Design a summing amplifier to be connected to the amplifier circuit such that the output signal is:

$$v_O = 2 \cdot \sin\omega t\ (V)$$

DESIGN EXAMPLE 9.4

$$v_{O1} = 1.2 - 0.5\ \sin\omega t\ (V) \rightarrow v_O = 2 \cdot \sin\omega t\ (V)$$

- **Choices**:
  1. Standard precision resistors with tolerances of $\pm 1\ percent$ are to be used in the final design.
  2. Assume an ideal op-amp is available.

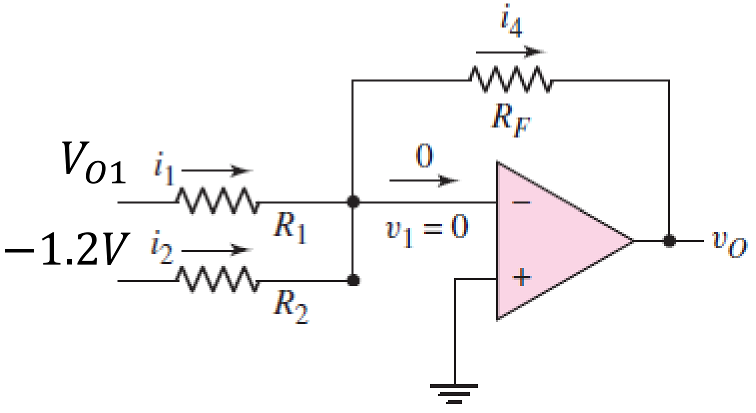


Figure 9.14

- **Solution**: In this case, we need only two inputs to the summing amplifier, as shown in Figure 9.14.
  - One input to the summing amplifier is the output of the ideal amplifier circuit and
  - The second input should be a DC voltage to cancel the $+1.2V$ signal from the amplifier circuit.

DESIGN EXAMPLE 9.4

$$v_{O1} = 1.2 - 0.5\,\sin\omega t\ (V) \rightarrow v_O = 2 \cdot \sin\omega t\ (V)$$

- If the voltage gains of each input to the summing amplifier are equal, then an input of $-1.2V$ at the second input will cancel the $+1.2V$ from the amplifier circuit.
- For a $-0.5V$ sinusoidal input signal and a desired $2V$ sinusoidal output signal, the summing amplifier gain must be:

$$A_v = -\frac{R_F}{R_1} = \frac{2}{-0.5} = -4$$

- If we choose the input resistances to be:

$$R_1 = R_2 = 30k\Omega$$

- Then the feedback resistance must be:

$$R_F = 4 \times 30k\Omega = 120k\Omega$$

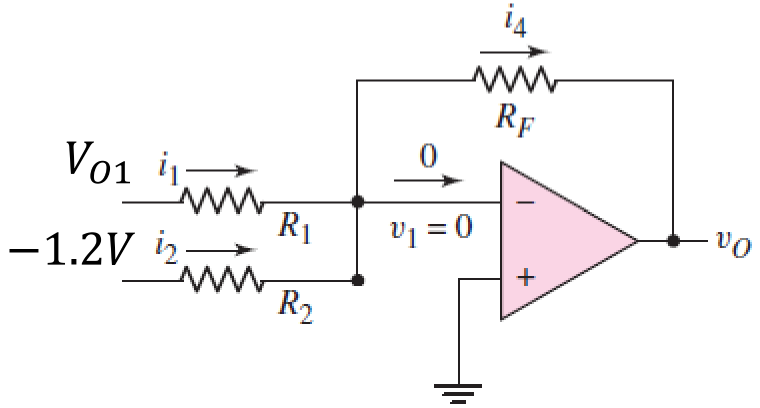
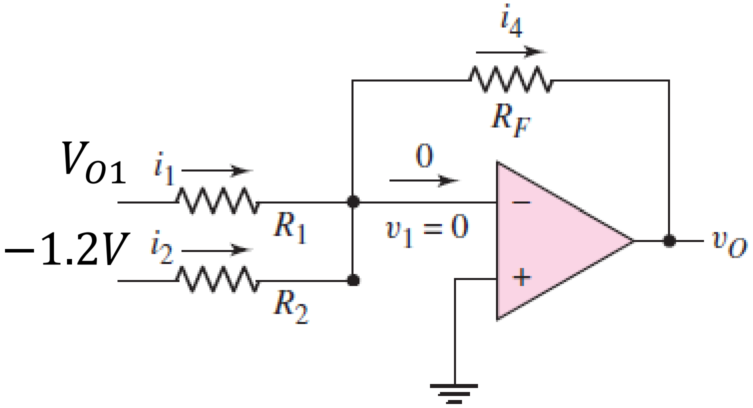


Figure 9.14

DESIGN EXAMPLE 9.4

$$v_{O1} = 1.2 - 0.5\,\sin\omega t\ (V) \rightarrow v_O = 2\cdot\sin\omega t\ (V)$$
$$R_1 = R_2 = 30k\Omega$$
$$R_F = 4\times 30k\Omega = 120k\Omega$$



- **Trade-offs**: From Appendix C, we can choose precision resistor values of $R_F = 124k\Omega$ and $R_1 = R_2 = 30\ k\Omega$. The ratio of the ideal resistors is 4.13.
- Considering the $\pm 1\ percent$ tolerance values, the output of the summing amplifier is:

$$v_O = -\frac{R_F(1\pm 0.01)}{R_1(1\pm 0.01)}\cdot(1.2 - 0.5\sin\omega t) - \frac{R_F(1\pm 0.01)}{R_2(1\pm 0.01)}\cdot(-1.2)$$

  - The DC output voltage is in the range:
$$-0.1926\ \le\ v_O(DC)\ \le\ 0.1926\,V$$
  - The peak ac output voltage is in the range:
$$1.967 \le v_O(ac) \le\ 2.047\ V$$

Table C.1 Standard resistance values ($\times 10^n$)

10	16	**27**	43	**68**
11	**18**	30	**47**	75
12	20	**33**	51	**82**
13	**22**	36	**56**	91
15	24	**39**	62	**100**

EXERCISE PROBLEM Ex. 9.4

- Design an inverting summing amplifier that will produce an output voltage of:

$$v_O = -3(v_{I_1} + 2v_{I_2} + 0.3v_{I_3} + 4v_{I_4})$$

- The maximum resistance is to be limited to:

$$R_{max} = 400\ k\Omega$$

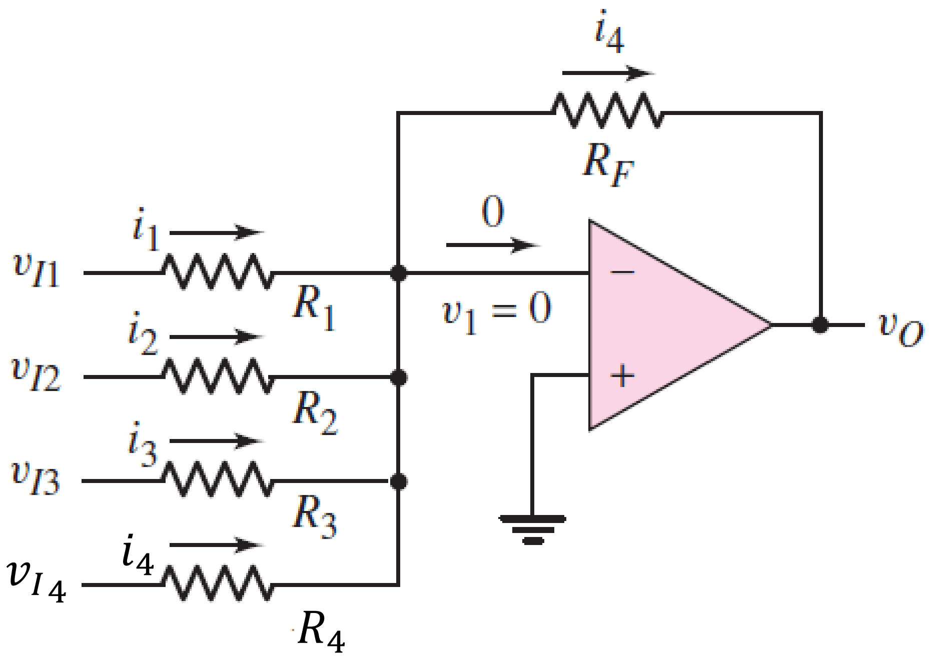
- **Answer**: Recall the summing amplifier output for three inputs:

$$v_O = -\left(\frac{R_F}{R_1}v_{I_1} + \frac{R_F}{R_2}v_{I_2} + \frac{R_F}{R_3}v_{I_3}\right)$$

- We expand it for Four inputs as:

$$v_O = -\left(\frac{R_F}{R_1}v_{I_1} + \frac{R_F}{R_2}v_{I_2} + \frac{R_F}{R_3}v_{I_3} + \frac{R_F}{R_4}v_{I_4}\right)$$

- Let $R_3 = R_{max} = 400k\Omega$. Why R_3?



EXERCISE PROBLEM Ex. 9.4

$$v_O = -3(v_{I_1} + 2v_{I_2} + 0.3v_{I_3} + 4v_{I_4})$$

$$v_O = -\left(\frac{R_F}{R_1}v_{I_1} + \frac{R_F}{R_2}v_{I_2} + \frac{R_F}{R_3}v_{I_3} + \frac{R_F}{R_4}v_{I_4}\right)$$

- Let $R_3 = R_{max} = 400k\Omega. \rightarrow 390k\Omega + 10\text{k}\Omega$
- $R_F = 3 \times 0.3 \cdot 400k\Omega = 360k\Omega$
- $R_1 = \frac{360\text{k}}{3} = 120\text{k}\Omega$
- $R_2 = \frac{360\text{k}}{3\times 2} = 60\text{k}\Omega \rightarrow 47k\Omega + 13k\Omega$
- $R_4 = \frac{360\text{k}}{3\times 4} = 30\text{k}\Omega$

Table C.1 Standard resistance values ($\times 10^n$)

10	16	**27**	43	**68**
11	**18**	30	**47**	75
12	20	**33**	51	**82**
13	**22**	36	**56**	91
15	24	**39**	62	**100**

EXERCISE PROBLEM Ex. 9.4

- Using the results of previous part for $R's$ values. Determine v_O for:

$a)\ v_{I_1} = 0.1V, v_{I_2} = -0.2V, v_{I_3} = -1V, v_{I_4} = 0.05V;$

  - **Answer**: $v_O = +1.2V$

$b)\ v_{I_1} = -0.2V, v_{I_2} = 0.3V, v_{I_3} = 1.5V, v_{I_4} = -0.1V;$

  - **Answer**: $v_O = -1.35V$

9.4 Noninverting Amplifier

- In our previous discussions, the feedback element R_2 or R_F was connected between the output and the inverting terminal creating a negative feedback loop.
- However, a signal can be applied to the noninverting terminal while still maintaining negative feedback.

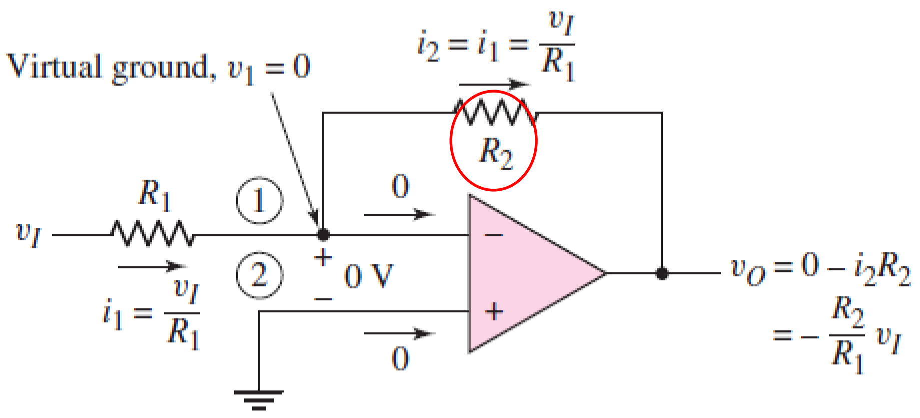


Figure 9.10

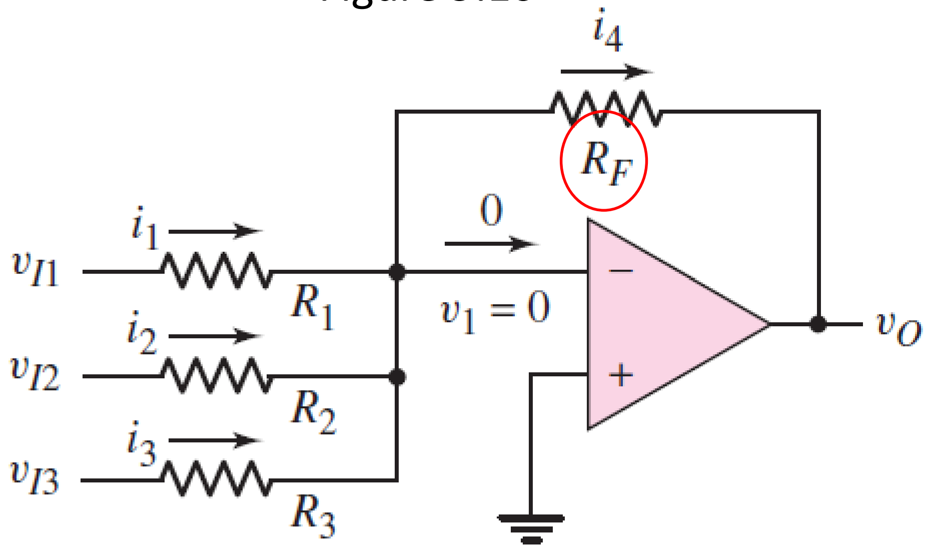


Figure 9.14(a)