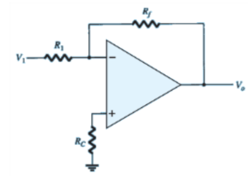
# ELECTRONIC CIRCUITS II

## CHAPTER 9.
## OP-AMP APPLICATIONS

# Constant-gain Multiplier

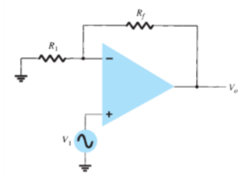
- One of the most common op-amp circuits is the inverting constant-gain multiplier, which provides a precise gain or amplification.

$$A = -\frac{R_f}{R_1}$$



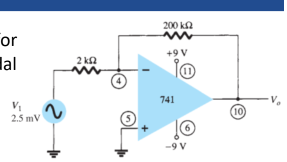

- A noninverting constant-gain multiplier is provided by the circuit

$$A = 1 + \frac{R_f}{R_1}$$




# EXERCISE

Determine the output voltage for the given circuit with a sinusoidal input of 2.5 mV.




The circuit ouses a 741 op-amp to provide a constant or fixed gain,

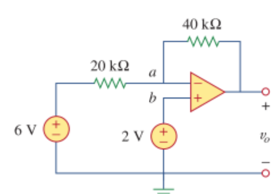
$$A = -\frac{R_f}{R_1} = -\frac{200\text{ k}\Omega}{2\text{ k}\Omega} = -100$$

The output voltage is then

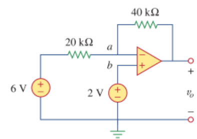
$$V_o = AV_i = -100(2.5\text{ mV}) = -250\text{ mV} = \mathbf{-0.25\text{ V}}$$

# EXERCISE

Determine $v_o$ in the op amp circuit shown in Figure.



## EXERCISE




Applying KCL at node $a$,

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

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

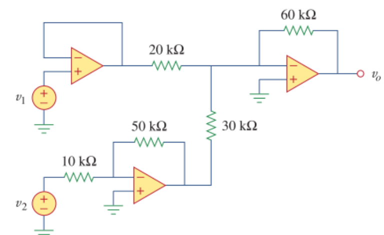
But $v_a = v_b = 2$ V for an ideal op amp, because of the zero voltage drop across the input terminals of the op amp. Hence,

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

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

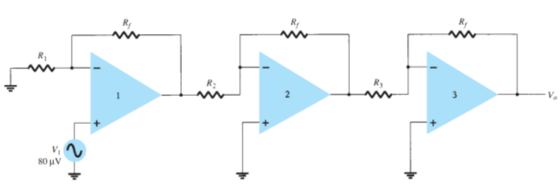
## EXERCISE

If $v_1 = 7$ V and $v_2 = 3.1$ V, find $v_o$ in the op amp circuit of Fig. 5.33.




## Multiple-Stage Gains

- When a number of stages are connected in series, the overall gain is the product of the individual stage gains.



$$A = A_1 A_2 A_3$$

where $A_1 = 1 + R_f/R_1$, $A_2 = -R_f/R_2$, and $A_3 = -R_f/R_3$.

## EXERCISE

Show the connection of an LM124 quad op-amp as a three-stage amplifier with gains of +10, -18, and -27.

Use a 270-kΩ feedback resistor for all three circuits.

What output voltage will result for an input of 150 µV?

## EXERCISE

**Solution:**

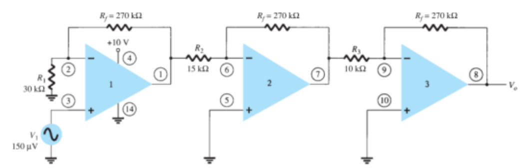
For the gain of +10, $A_1 = 1 + \frac{R_f}{R_1} = +10 \Rightarrow R_1 = \frac{R_f}{9} = \frac{270\,\text{k}\Omega}{9} = 30\,\text{k}\Omega$

For the gain of -18, $A_2 = -\frac{R_f}{R_2} = -18 \Rightarrow R_2 = \frac{R_f}{18} = \frac{270\,\text{k}\Omega}{18} = 15\,\text{k}\Omega$

For the gain of -27, $A_3 = -\frac{R_f}{R_3} = -27 \Rightarrow R_3 = \frac{R_f}{27} = \frac{270\,\text{k}\Omega}{27} = 10\,\text{k}\Omega$

## EXERCISE

$V_o = A_1 A_2 A_3 V_1$ = 150 x $10^{-6}$ x 10 x 18 x 27 = **0.729** V




## EXERCISE

Show the connection of three op-amp stages using an LM348 IC to provide outputs that are -10, -20, and -50 times larger than the input.

Use a feedback resistor of $R_f$= 500 kΩ in all stages.

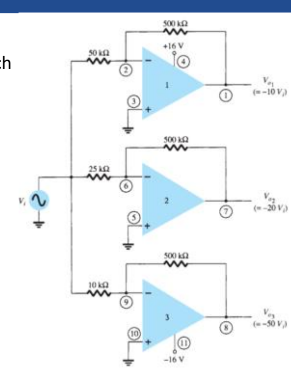
## EXERCISE

- The resistor component for each stage is calculated to be

$$R_1 = -\frac{R_f}{A_1} = -\frac{500\,\text{k}\Omega}{-10} = 50\,\text{k}\Omega$$

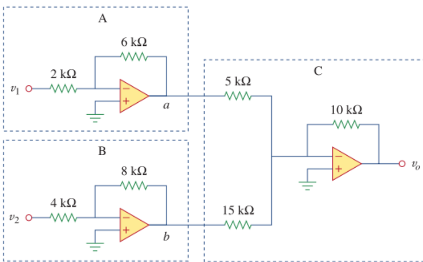
$$R_2 = -\frac{R_f}{A_2} = -\frac{500\,\text{k}\Omega}{-20} = 25\,\text{k}\Omega$$

$$R_3 = -\frac{R_f}{A_3} = -\frac{500\,\text{k}\Omega}{-50} = 10\,\text{k}\Omega$$



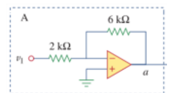
## EXERCISE

If $v_1$ = 1 V and $v_2$ = 2 V, find $v_o$ in the given op amp circuit.

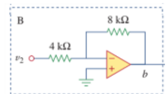



## EXERCISE

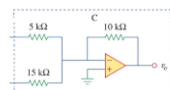
If $v_1$ = 1 V and $v_2$ = 2 V




The first amplifier of gain:
$A_1$ =-(6 kΩ/2 kΩ) = $-3v_1$ = -3




The second amplifier of gain:
$A_2$ = -(8 kΩ /4 kΩ) = $-2v_2$ = -4



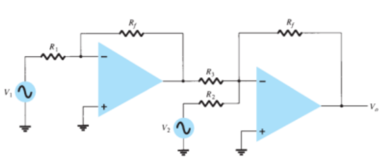

The last circuit serves as a summer of two different gains for the output of the other two circuits.

$V_o$ = -[(-3)(10 kΩ /5 kΩ +(-4)(10 kΩ /15 kΩ)]
$V_o$ = 6 + 2.667= 8.667 V

## Voltage Subtraction

**Voltage Subtraction:**

- Two signals can be subtracted from one another in a number of ways.
- Figure below shows two op-amp stages used to provide subtraction of input signals using summing circuit.

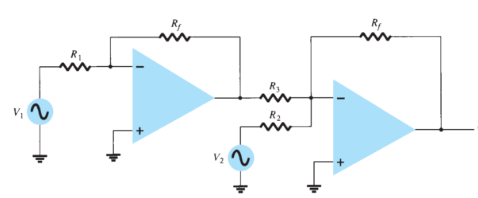



$$V_o = -\left[\frac{R_f}{R_3}\left(-\frac{R_f}{R_1}V_1\right) + \frac{R_f}{R_2}V_2\right]$$

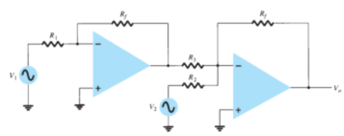
$$V_o = -\left(\frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}\frac{R_f}{R_1}V_1\right)$$

## EXERCISE

Determine the output for the given circuit with components $R_f$ = 1 MΩ, $R_1$ = 100 kΩ, $R_2$ = 50 kΩ, and $R_3$ = 500 kΩ.



# EXERCISE



$R_f$ = 1 MΩ,
$R_1$ = 100 kΩ,
$R_2$ = 50 kΩ, and
$R_3$ = 500 kΩ.

The output voltage is calculated to be:

$$V_o = -\left[\frac{R_f}{R_3}\left(-\frac{R_f}{R_1}V_1\right) + \frac{R_f}{R_2}V_2\right] \qquad V_o = -\left(\frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}\frac{R_f}{R_1}V_1\right)$$

$$V_o = -\left(\frac{1\,\text{M}\Omega}{50\,\text{k}\Omega}V_2 - \frac{1\,\text{M}\Omega}{500\,\text{k}\Omega}\frac{1\,\text{M}\Omega}{100\,\text{k}\Omega}V_1\right) = -(20\,V_2 - 20\,V_1) = \mathbf{-20(V_2 - V_1)}$$

# EXERCISE

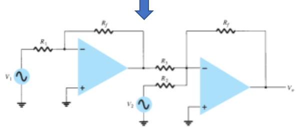
Design an op amp circuit with inputs $v_1$ and $v_2$ such that
$V_o = -5v_1 + 3v_2$.

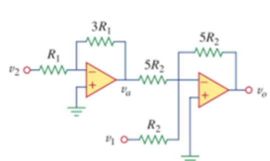
# EXERCISE

$V_o = -5v_1 + 3v_2 = -(5v_1 - 3v_2)$

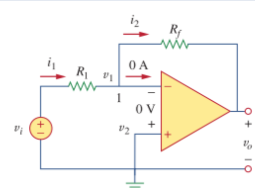
One way to design is to use more than one op amp, we may cascade an inverting amplifier and a two-input inverting summer,

$$V_o = -\left[\frac{R_f}{R_3}\left(-\frac{R_f}{R_1}V_1\right) + \frac{R_f}{R_2}V_2\right] \Rightarrow \frac{R_f}{R_2} = 5 \quad \text{and} \quad \frac{R_f}{R_3} = 1 \quad \frac{R_f}{R_1} = 3$$






# OP-AMP APPLICATIONS




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

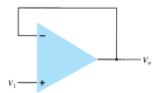
$$\frac{v_i}{R_1} = -\frac{v_o}{R_f}$$

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

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

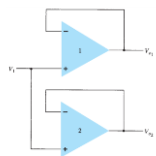
# Voltage Buffer

- A voltage buffer circuit provides a means of isolating an input signal from a load by using a stage having unity voltage gain, with no phase or polarity inversion, and acting as an ideal circuit with very high input impedance and low output impedance.



$$V_o = V_1$$

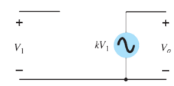
- An input signal can be provided as two separate outputs.
- The advantage of this connection is that the load connected across one output has no (or little) effect on the other output.



# Controlled Sources

- Operational amplifiers can be used to form various types of controlled sources.
- An input voltage can be used to control an output voltage or current, or an input current can be used to control an output voltage or current.
- These types of connections are suitable for use in various instrumentation

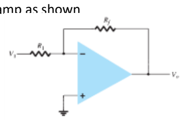
**Voltage-Controlled Voltage Source:**
An ideal form of a voltage source whose output Vo is controlled by an input voltage V1.



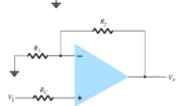
$V_o = kV_1$

# Controlled Sources

**Voltage-Controlled Voltage Source:**
This type of circuit can be built using either the inverting input or the noninverting op-amp as shown



$$V_o = -\frac{R_f}{R_1}V_1 = kV_1$$

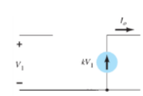


$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_1 = kV_1$$

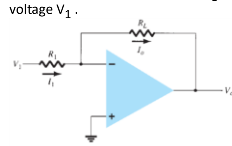
# Controlled Sources

**Voltage-Controlled Current Source:**

- An ideal form of circuit providing an output current controlled by an input voltage is shown.
- The output current is dependent on the input voltage.
- A practical circuit can be built as shown with the output current through load resistor $R_L$ controlled by the input voltage $V_1$ .



$I_o = kV_1$

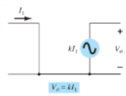


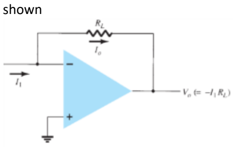
$$I_o = \frac{V_1}{R_1} = kV_1$$

# Controlled Sources

**Current-Controlled Voltage Source:**

- An ideal form of a voltage source controlled by an input current is shown.
- The output voltage is dependent on the input current. A practical form of the circuit is built using an op-amp as shown

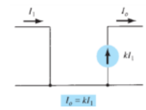


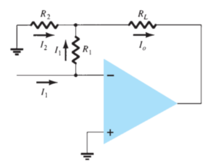




$$V_o = -I_1R_L = kI_1$$

# Controlled Sources

- **Current-Controlled Current Source:**
- An ideal form of a circuit providing an output current dependent on an input current is shown.
- In this type of circuit, an output current is provided dependent on the input current.
- A practical form of the op-amp circuit is shown .



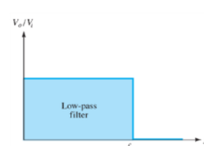

$$I_o = I_1 + I_2 = I_1 + \frac{I_1R_1}{R_2} = \left(1 + \frac{R_1}{R_2}\right)I_1 = kI_1$$

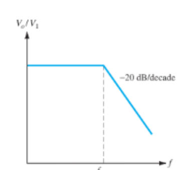
# ACTIVE FILTERS

- A popular application uses op-amps to build active filter circuits.
- A filter circuit can be constructed using passive components: resistors and capacitors.
- An active filter additionally uses an amplifier to provide voltage amplification and signal isolation or buffering.
- A filter that provides a constant output from dc up to a cutoff frequency $f_{OH}$ and then passes no signal above that frequency is called an ideal ***low-pass filter***.
- A filter that provides or passes signals above a cutoff frequency $f_{OL}$ is a ***high-pass filter***,
- When the filter circuit passes signals that are above one ideal cutoff frequency and below a second cutoff frequency, it is called a ***bandpass filter.***

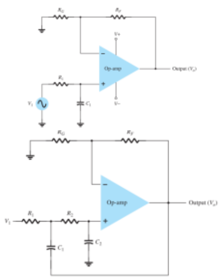
# Low-Pass Filter

- A first-order, low-pass filter using a single resistor and capacitor is shown in first figure.
- An active filter using op-amp has a practical slope of - 20 dB per decade, as shown in second figure.



## Low-Pass Filter



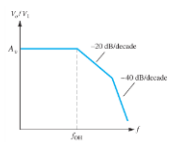

The voltage gain below the cutoff frequency is constant at

$$A_v = 1 + \frac{R_F}{R_G}$$

At a cutoff frequency of

$$f_{OH} = \frac{1}{2\pi R_1 C_1}$$

Connecting two sections of filter as results in a second-order low-pass filter with cutoff at - 40 dB per decade
The circuit voltage gain and the cutoff frequency are the same for the second-order circuit as for the first-order filter circuit,

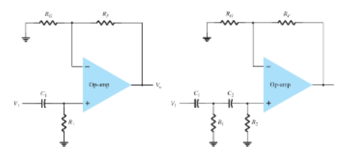


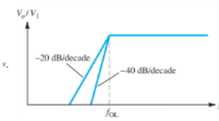

## High-Pass Active Filter

First- and second-order high-pass active filters can be built as shown. The amplifier gain and  he amplifier cutoff frequency is

$$A_v = 1 + \frac{R_F}{R_G}$$

$$f_{OH} = \frac{1}{2\pi R_1 C_1}$$




## Bandpass Filter

Figure shows a bandpass filter using two stages, the first a high-pass filter and the second a low-pass filter, the combined operation being the desired bandpass response.