ELECTRONIC PRINCIPLES AND DEVICES

Course Content

Department of Electronics and Communication.

ELECTRONIC PRINCIPLES AND DEVICES

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Unit 3 –Transistors and Operational Amplifiers

Operational Amplifier - Introduction

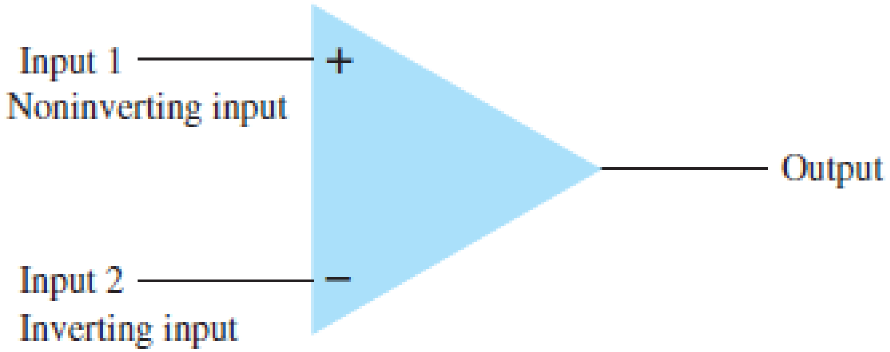


FIG. 10.1
Basic op-amp.

- Operational Amplifier or op-amp is a very high gain differential amplifier.
- It has very high input impedance. Ideally its value is infinity
- It has a low output impedance. Ideally its value is zero
- It finds applications in filters and oscillators

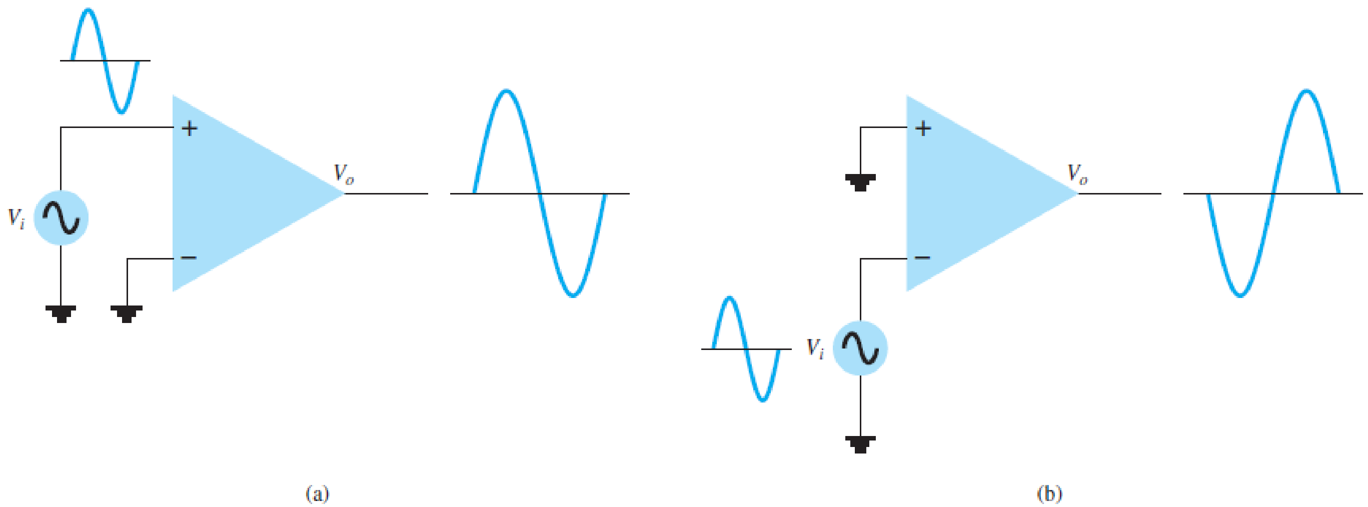


FIG. 10.2
Single-ended operation.

- **Single-ended input operation** **results when the input signal is connected to one input with the other input connected to the ground.**

- **When the input signal is applied to the inverting input, the output is phase-shifted by 180^0**

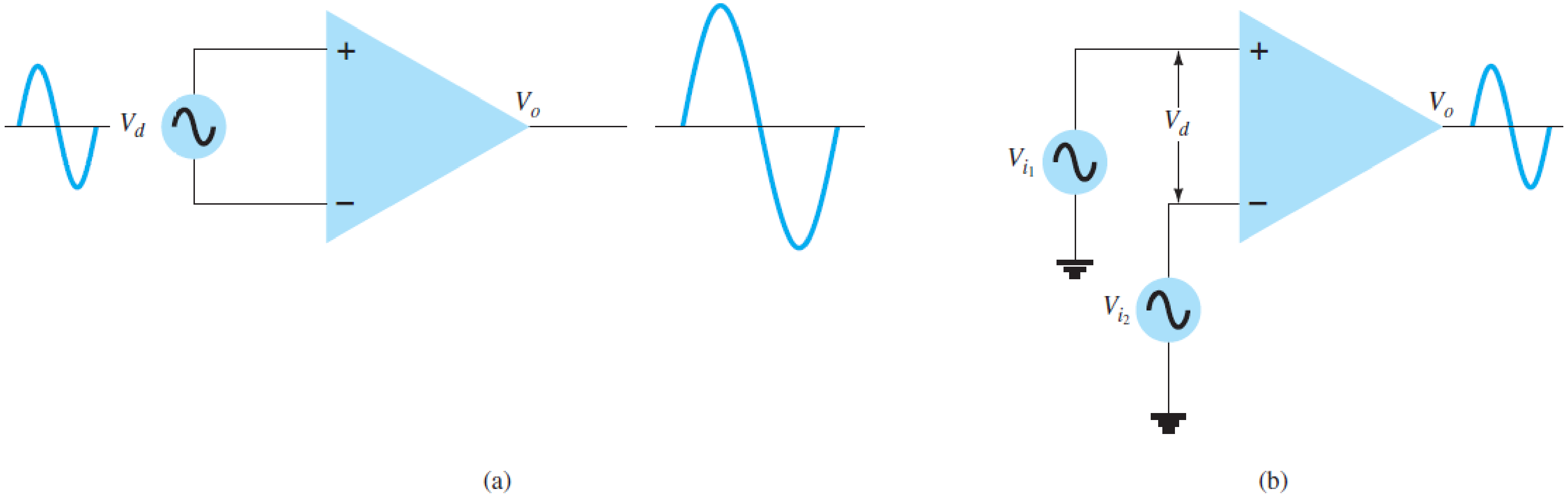


FIG. 10.3
Double-ended (differential) operation.

- Double-ended operation is one where an input, V_d is applied between the two input terminals (recall that neither input is at ground), with the resulting amplified output in phase with that applied between the inputs.
- Figure (b) shows the same action resulting when two separate signals are applied to the inputs, the difference signal being $V_{i1} - V_{i2}$

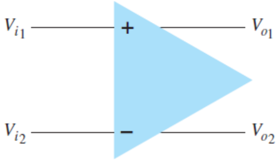


FIG. 10.4
Double-ended input with double-ended output.

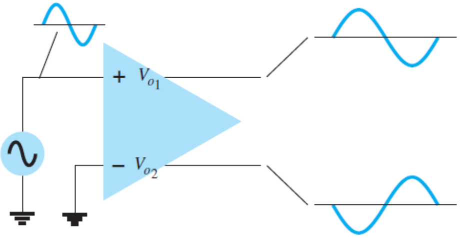


FIG. 10.5
Single-ended input with double-ended output.

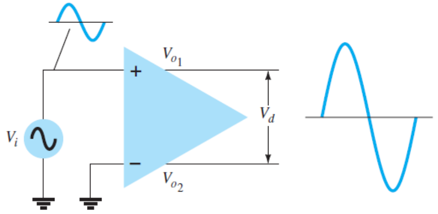


FIG. 10.6
Differential-output.

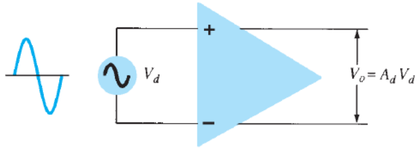


FIG. 10.7
Differential-input, differential-output operation.

- **Double Ended Output:** An input applied to either input will result in outputs from both output terminals, these outputs always being opposite in polarity.

- Figure 10.5 shows a single-ended input with a double-ended output. As shown, the signal applied to the plus input results in two amplified outputs of opposite polarity.

- Figure10.6 shows the same operation with a single output measured between output terminals This difference output signal is V_{o1}-V_{o2}. The difference output is also referred to as a *floating signal* since neither output terminal is the ground (reference) terminal.

- Figure 10.7 shows a differential input, differential output operation. The input is applied between the two input terminals, and the output is taken from between the two output terminals. This is a fully differential operation.

Common Mode Operation

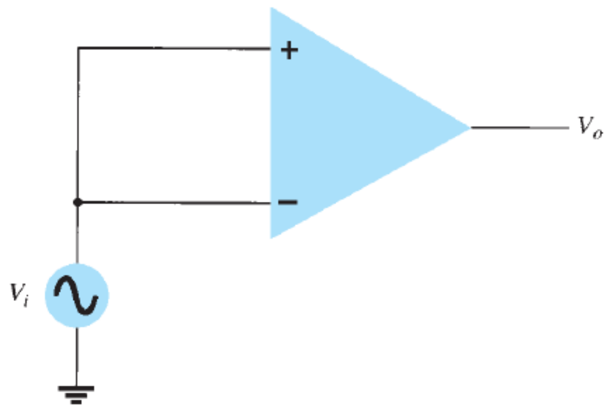


FIG. 10.8
Common-mode operation.

When the same input signal is applied to both inputs, common-mode operation results, as shown in Fig. Ideally, the two inputs are equally amplified, and since they result in opposite-polarity signals at the output, these signals cancel, resulting in 0-V output. Practically, a small output signal will result.

Basic Op-Amp

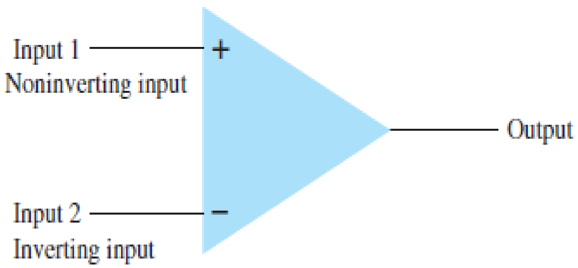
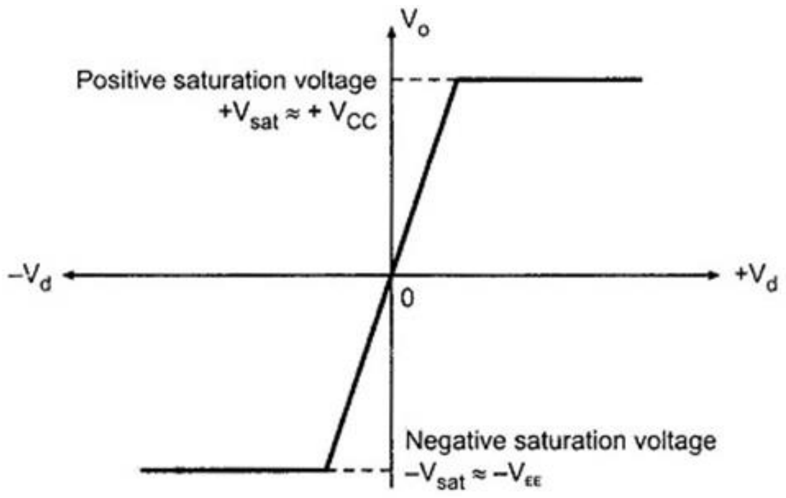


FIG. 10.1
Basic op-amp.

- **Op-Amp has two inputs as shown in the figure**
- **Input1=Noninverting input**
- **Input2= Inverting input**

Ideal Voltage Transfer Curve



Ideal voltage transfer curve

- V_d= Differential Voltage
- $+V_{sat}$ = +Ve Saturation Voltage
- $-V_{sat}$ = - Ve Saturation Voltage
- It rises linearly between $+V_{sat}$ and $-V_{sat}$

Op-Amp Parameters

Input Offset Voltage: It is the differential DC voltage that must be applied between the input terminals (inverting and non-inverting) of the op-amp to make the output voltage zero. Ideally its value is 0v. Its value is 1 mv to 6mv for IC 741.

Output offset voltage: This refers to the small DC voltage that appears at its output even when the input terminals are shorted together and no input signal is applied. This offset is caused by internal mismatches in the op-amp, such as differences in the transistor parameters or imbalances in the internal circuitry. Ideally its value is 0v.

Input Resistance: The **input resistance** of an op-amp refers to the effective resistance seen at its input terminals. It is generally measured in open-loop condition. Ideally its value is infinity. Its value is 2MΩ for IC 741 under open loop condition.

Output resistance: The **output resistance** of the op-amp is the resistance seen at the output terminal when the op-amp is configured in an open-loop condition. Ideally, its value is 0. Its value is 75Ω IC 741.

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Op-Amp Parameters

Gain Bandwidth: The frequency at which the gain drops by 3 dB is known as the cutoff frequency f_c of the Op-Amp. The unity-gain frequency f_1 and cutoff frequency are related by

$$f_1 = A_{VD} f_c$$

Unity-gain frequency may also be called the gain–bandwidth product of the op-amp. Ideally its value is infinity. Its value is 1MHz for IC741

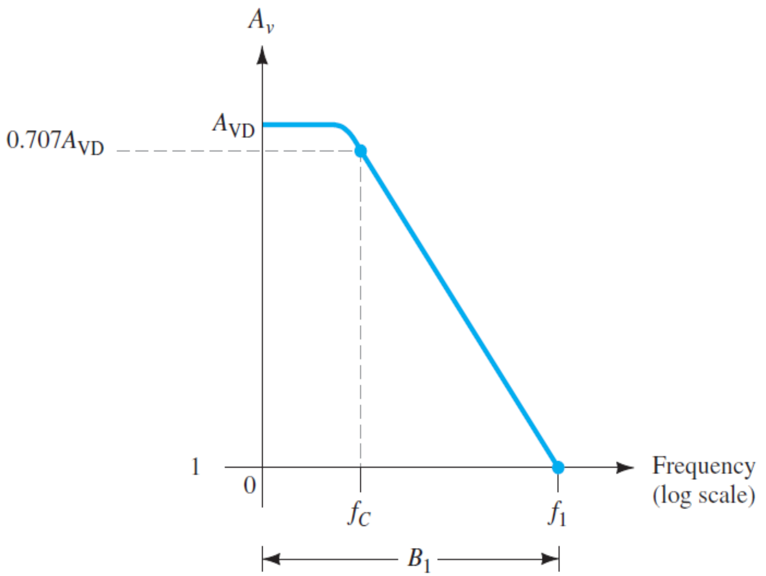

FIG. 10.47
Gain versus frequency plot.

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Op-Amp Parameters

Slew rate: The maximum rate at which amplifier output can change in volts per microsecond is known as **Slew rate**. The slew rate provides a parameter specifying the maximum rate of change of the output voltage when driven by a large step-input signal. Ideal value of slew rate is infinity. It is 0.5 V/µs for IC741

$$\boxed{SR = \frac{\Delta V_o}{\Delta t} \text{ V}/\mu\text{s}} \quad \text{with } t \text{ in } \mu\text{s}$$

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Op-Amp Parameters

Common Mode Rejection Ratio: It is the ratio of differential gain to the common mode gain of the amplifier. Ideally, CMRR is infinity. Typically, its value is 90 dB for IC741.

$$CMRR = \frac{A_d}{A_c}$$

$$A_d = Differential\ gain\ of\ the\ amplifier$$

$$A_c = Common\ mode\ gain\ of\ the\ amplifier$$

The value of CMRR can also be expressed in logarithmic terms

$$CMRR(log) = 20log_{10}\left\{\frac{A_d}{A_c}\right\}\ dB$$

. Open Loop gain

Open loop gain is the gain of the Op Amp without a positive or negative feedback. An ideal OP Amp should have an infinite open loop gain but typically it range between 20,000 and 2, 00000.

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Negative feedback in Op-amp:

Op-amps are normally used with negative feedback for the following reasons:

1. The open-loop gain of the op-amp is very high. It is typically 2 x10^5 for IC 741. Such large gain is unsuitable for linear applications. Negative feedback decreases the gain and makes it suitable for linear applications such as an amplifier.
2. The open-loop gain is not stable and varies with temperature, supply voltage and frequency whereas the gain with feedback is stable.
3. The open-loop BW is very small making it unsuitable for any practical application. With negative BW increases.

Virtual Ground Concept

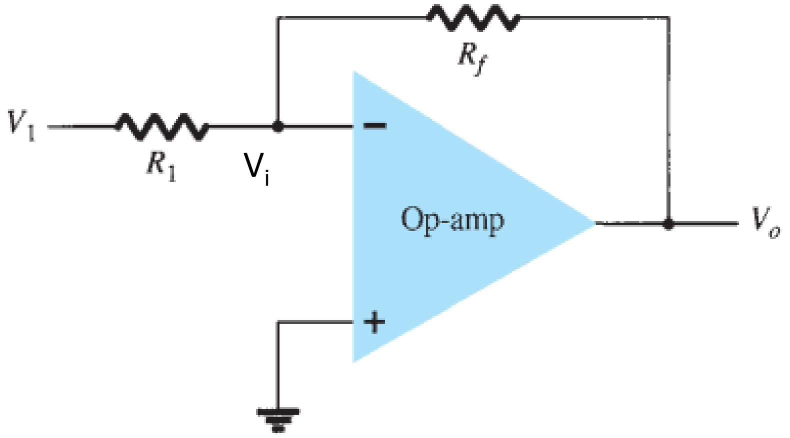


Fig. Basic Op-amp Connection

- The output voltage of an Op-amp is limited by the supply voltage V_1 as shown in the figure and the voltage gains are very high.
- For example, if V_o = -10 V and gain Av = 20,000, then the input voltage $V_i = -\frac{V0}{Av} = -\frac{10}{20{,}000}$ = 0.5 mV.
- If the circuit has an overall gain of 1, then value of V_1 is 10V.
- Compared to all other input and output voltages, the value of Vi is very small and can be considered as 0V.
- The fact that Vi ≈ 0V leads to the concept that at the amplifier input there exists a virtual short-circuit or virtual ground.

Virtual Ground Concept

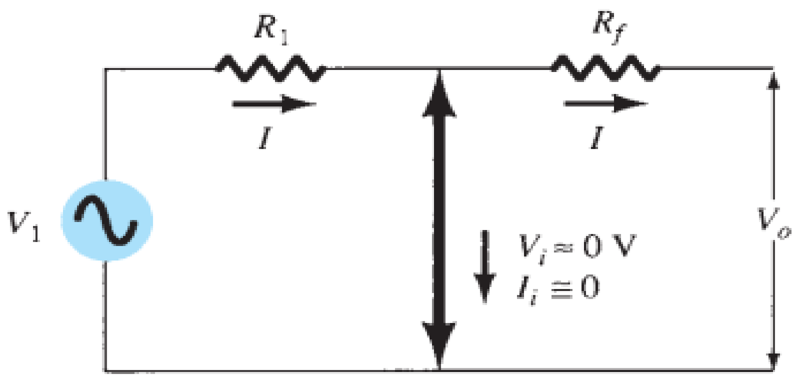


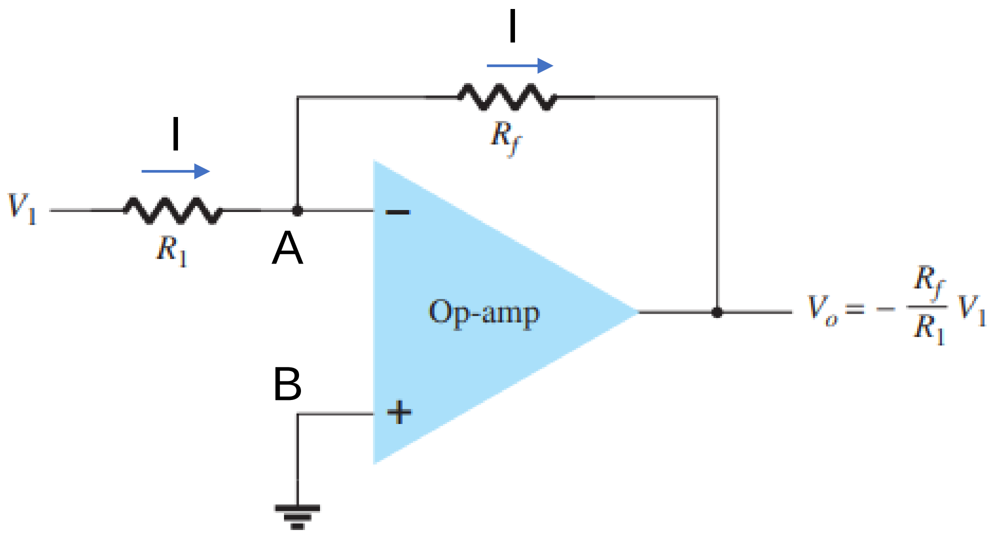
Fig. Virtual ground in Op-amp

- From above figure, Virtual short or Virtual ground implies that although the input voltage Vi is nearly 0V, there is no current through the amplifier input to ground.
- The heavy line in the figure is used to indicate that a short exists with Vi ≈ 0V.
- current will not flow through short and ground and flows only through resistors R1 and Rf as shown.
- Using the virtual ground concept, we can write equations for the current I as follows:
- $I = \frac{V1}{R1} = -\frac{V0}{Rf}$

Therefore, $\frac{\boldsymbol{V0}}{\boldsymbol{V1}} = -\frac{\boldsymbol{Rf}}{\boldsymbol{R1}}$

Practical Op-amp Circuits

1. INVERTING AMPLIFIER:



$V_A = V_B = 0$ (Virtual ground)

At Input, $I = (V_1 - V_A)/R_1 = V_1/R_1$----(1)

At Output, $I = (V_A - V_O)/R_f = -(V_O/R_f)$—(2)

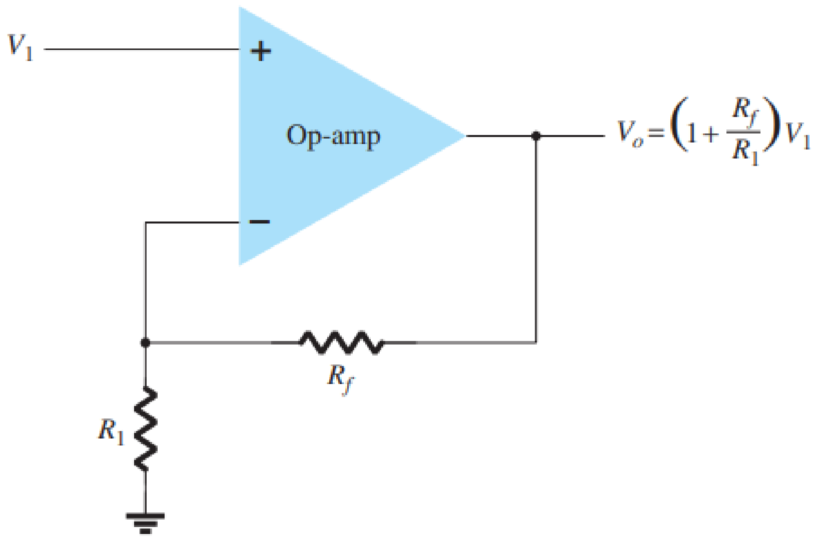
Equating 1 and 2

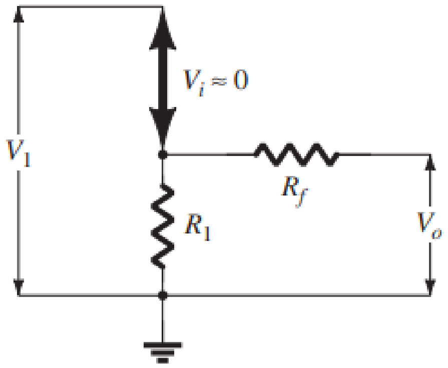
Output Voltage $\boxed{V_O = -(R_f/R_1)*V_1}$

Where Gain is $-(R_f/R_1)$

- Input is given to inverting terminal of the amplifier.
- Inverting amplifier is the most widely used constant-gain amplifier circuit.
- The output is obtained by multiplying the input by a fixed or constant gain, set by the input resistor R1and feedback resistor Rf and output is being inverted from the input.
- Output Voltage of Inverting amplifier is $V_0 = -\frac{Rf}{R1} * V_1$ (from virtual ground concept)

2. NONINVERTING AMPLIFIER:

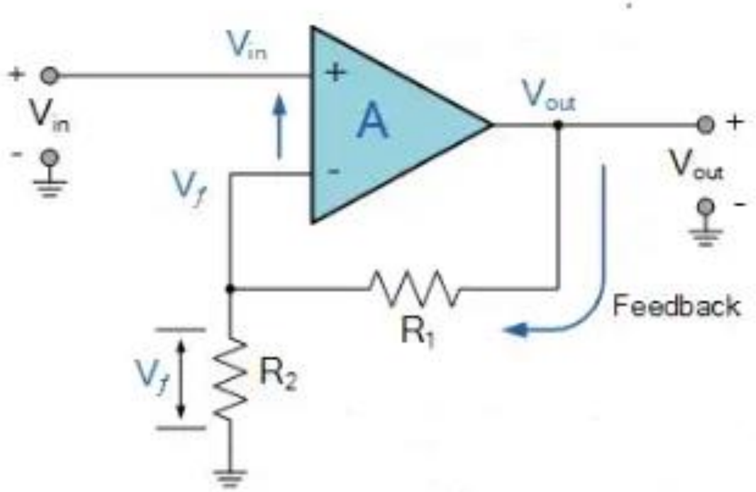




- Input is given to noninverting terminal of the op-amp.
- voltage across R_1 is V_1 (since $V_i = 0V$) and is equal to the output voltage, through a voltage divider of R1 and Rf and is given by

$$V_1 = \frac{R_1}{R_1 + R_f} V_o$$ or $$\boxed{\frac{V_o}{V_1} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1}}$$

Ideal OP-Amp Negative Feedback



$$Closed\ loop\ Gain = \frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2}$$

$$Feed\ back\ \beta = \frac{V_f}{V_{out}} = \frac{R_2}{R_1 + R_2}$$

Practical Op-amp Circuits

3. UNITY FOLLOWER OR VOLTAGE FOLLOWER:

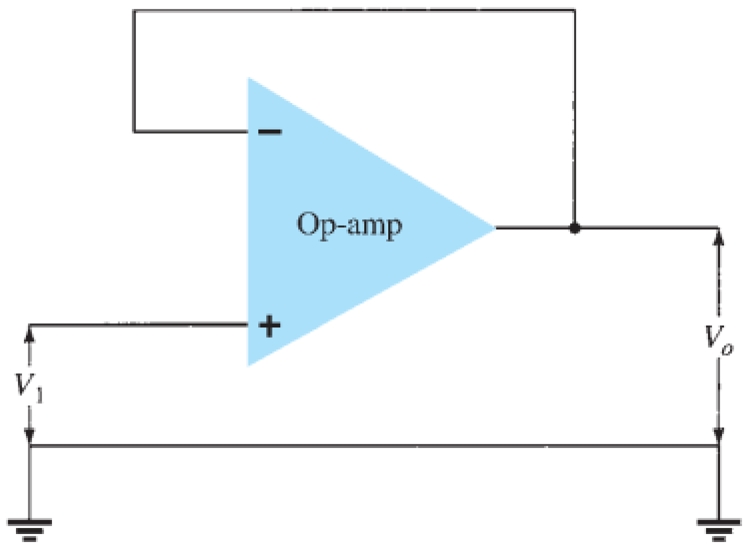


Fig a

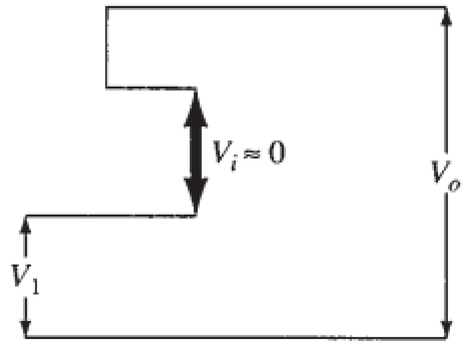


Fig b

- The unity-follower circuit provides a gain of unity with no polarity or phase reversal as shown in fig a.
- From the equivalent circuit as in fig b, $V_o = V_1$.
- It has a very high input resistance and a very low output resistance. It is used as a buffer circuit for impedance matching purposes.

Practical Op-amp Circuits

4. SUMMING AMPLIFIER:

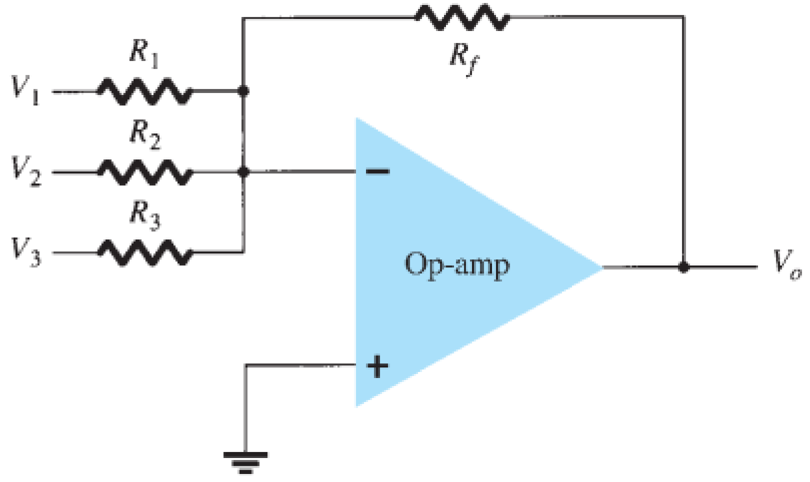


Fig a

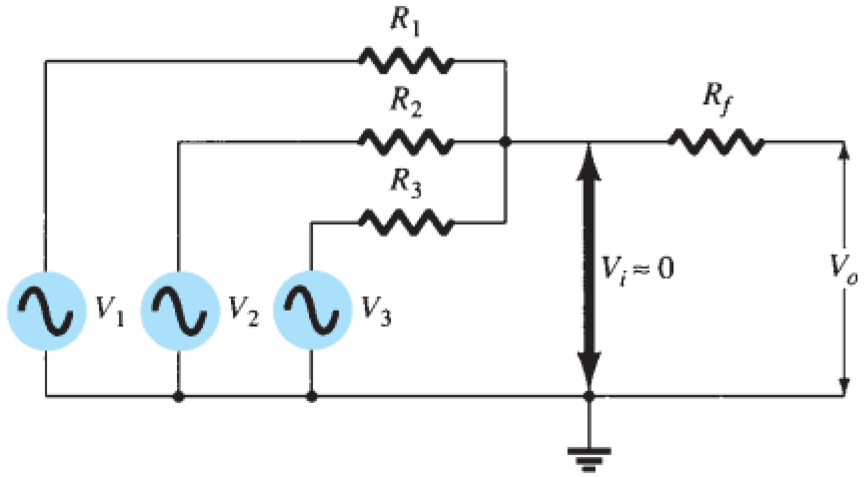
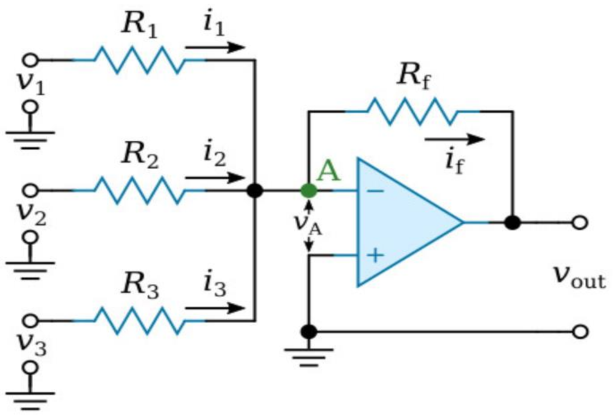


Fig b

- Above figure shows a three-input inverting summing amplifier circuit, which algebraically sums(adds) three voltages, each multiplied by a constant-gain(through resistors).
- If more inputs are used, they each add an additional component to the output.

Practical Op-amp Circuits

OUTPUT OF A SUMMING AMPLIFIER:



Applying KCL at node A,

$$i_1 + i_2 + i_3 = i_f \qquad \text{---(1)}$$

Where,

$$i_1 = \frac{v_1 - v_A}{R_1} \qquad i_3 = \frac{v_3 - v_A}{R_3}$$

$$i_2 = \frac{v_2 - v_A}{R_2} \qquad i_f = \frac{v_A - v_{out}}{R_f} \qquad \text{----(2)}$$

Substituting eq (2) in (1) and considering V_A =0(Virtual ground),

$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = \frac{-v_{out}}{R_f}$$

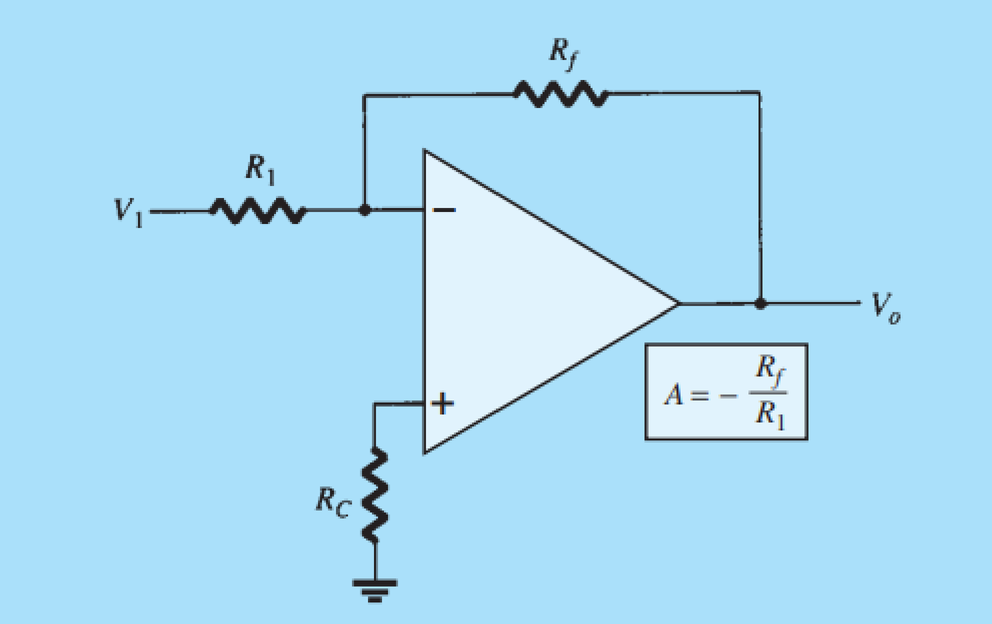
or

$$v_{out} = -R_f\left(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3}\right)$$

Practical Op-amp Circuits

5. CONSTANT GAIN/FIXED GAIN AMPLIFIER:

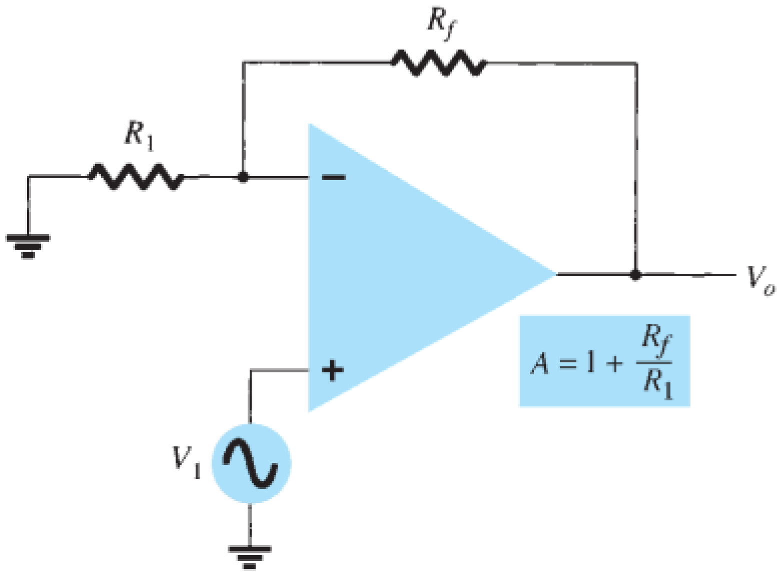
a. Inverting Constant gain Multiplier: Provides a precise gain of $$A = -\frac{R_f}{R_1}$$



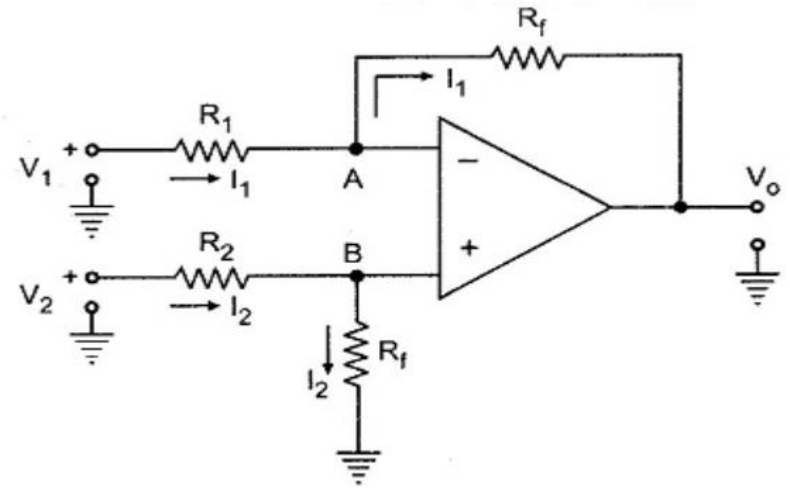
Practical Op-amp Circuits

5. CONSTANT GAIN/FIXED AMPLIFIER:

b. Non-Inverting Constant gain Multiplier: Provides a precise gain of $A = 1 + \frac{R_f}{R_1}$



6. VOLTAGE SUBTRACTION:

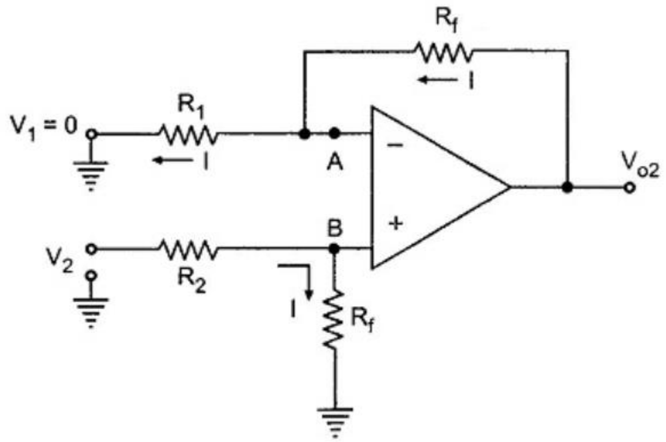


- Superposition principle is used to find the relation between output and input.
- Let V_{o1} be the output, with input V_1, assuming V_2 to be zero. And V_{o2} be the output, with input V_2 , assuming V_1 to be zero.
- With V_2 zero, the circuit acts as an inverting amplifier and the output equation is

$$V_{o1} = -\frac{R_f}{R_1} V_1 \quad \text{------(1)}$$

Practical Op-amp Circuits

While with V_1 as zero, the circuit reduces to as shown.



Let potential of node B be V_B. The potential of node A is same as B i.e. $V_A = V_B$ (Virtual short). Applying voltage divider rule to the input V_2 loop,

$$V_B = \frac{R_f}{R_2 + R_f} V_2 \quad \text{-----(2)}$$

$$I = \frac{V_A}{R_1} = \frac{V_B}{R_1} \quad \text{------(3)}$$

$$I = \frac{V_{o2} - V_A}{R_f} = \frac{V_{o2} - V_B}{R_f} \quad \text{------(4)}$$

Equating the equations (3) and (4),

Practical Op-amp Circuits

$$\frac{V_B}{R_1} = \frac{V_{o2} - V_B}{R_f}$$

$$V_{o2} = \frac{R_1 + R_f}{R_1} V_B$$

$$V_{o2} = \left[1 + \frac{R_f}{R_1}\right] V_B \qquad \text{-----(5)}$$

Substituting V_B from (2) in (5) we get,

$$V_{o2} = \left[1 + \frac{R_f}{R_1}\right]\left[\frac{R_f}{R_2 + R_f}\right] V_2$$

Hence using Superposition principle,

$$V_o = V_{o1} + V_{o2}$$

$$= -\frac{R_f}{R_1} V_1 + \left[1 + \frac{R_f}{R_1}\right]\left[\frac{R_f}{R_2 + R_f}\right] V_2$$

Practical Op-amp Circuits

If $R_1 = R_2$,

$$V_o = -\frac{R_f}{R_1} V_1 + \left[1 + \frac{R_f}{R_1}\right]\left[\frac{R_f}{R_1 + R_f}\right] V_2$$

$$= -\frac{R_f}{R_1} V_1 + \frac{R_f}{R_1} V_2$$

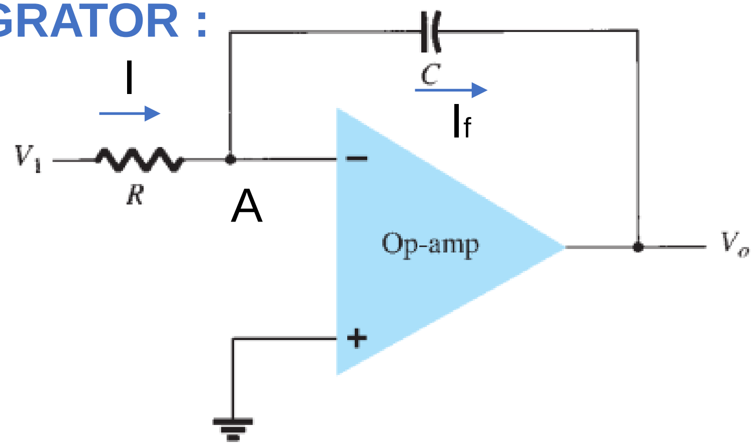
$$V_o = +\frac{R_f}{R_1}(V_2 - V_1)$$

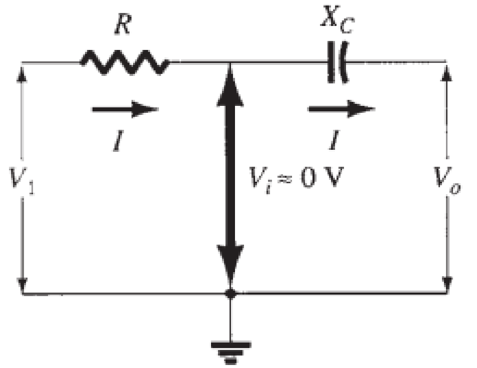
- The output voltage is proportional to the difference between the two input voltages. Thus it acts as a Subtractor using Op Amp circuit or difference amplifier.

If $R_1 = R_2 = R_f$ is selected, then $V_o = V_2 - V_1$

Practical Op-amp Circuits

7. INTEGRATOR :





- Integrator has capacitor as a feedback element.
- Integration is summing the area under a waveform or a curve over a period of time.
- If a fixed voltage is applied in the form of a square wave as an input to an integrator circuit, the output voltage grows over a period of time, resulting in a ramp voltage.

Applying KCL at node A, $I=I_f$ ----(1)

Where $I= (V_1-V_A)/R$ and $I_f = C*d(V_A-V_0)/dt$ ----(2)

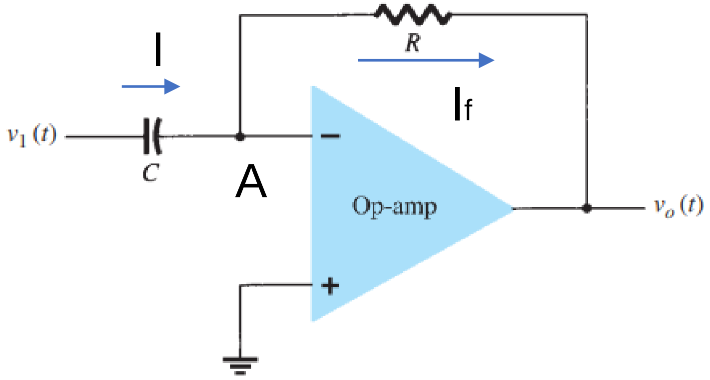
($V_A=0$ due to virtual ground property)

Substituting 2 in 1,

$$\frac{V_I - 0}{R} = C\frac{d(0 - V_o)}{dt}$$ or $$\frac{dV_o}{dt} = -\frac{1}{RC}V_I$$

$$V_{out}(t) = -\frac{1}{RC}\int_0^t V_{in}(t)\,dt$$ Where Scale factor is $1/RC$

8. DIFFERENTIATOR :



- A differentiator op amp circuit produces an output signal proportional to the input signal's rate of change.
- Involves an inverting amplifier with a capacitor at the input terminal.

Applying KCL at node A, $I=I_f$ ----(1)

Where $I= C*d(V_i-V_A)/dt$ and $I_f = (V_A—V_0)/R$----(2)

($V_A=0$ due to virtual ground property)

Substituting 2 in 1,

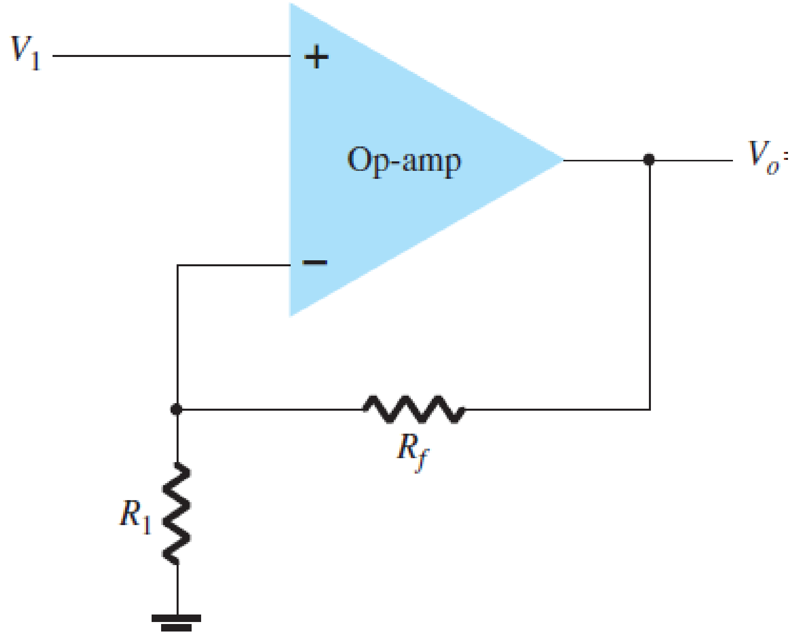
$$C\frac{\mathrm{d}v_i}{\mathrm{d}t} = -\frac{v_0}{R}$$

$$v_0 = -RC\frac{\mathrm{d}v_i}{\mathrm{d}t}$$

Where the scale factor is -RC

Numerical-1

Calculate the output voltage of a noninverting amplifier shown in figure



$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_1 = \left(1 + \frac{500\,\mathrm{k\Omega}}{100\,\mathrm{k\Omega}}\right)(2\,\mathrm{V}) = 6(2\,\mathrm{V}) = \mathbf{+12\,V}$$

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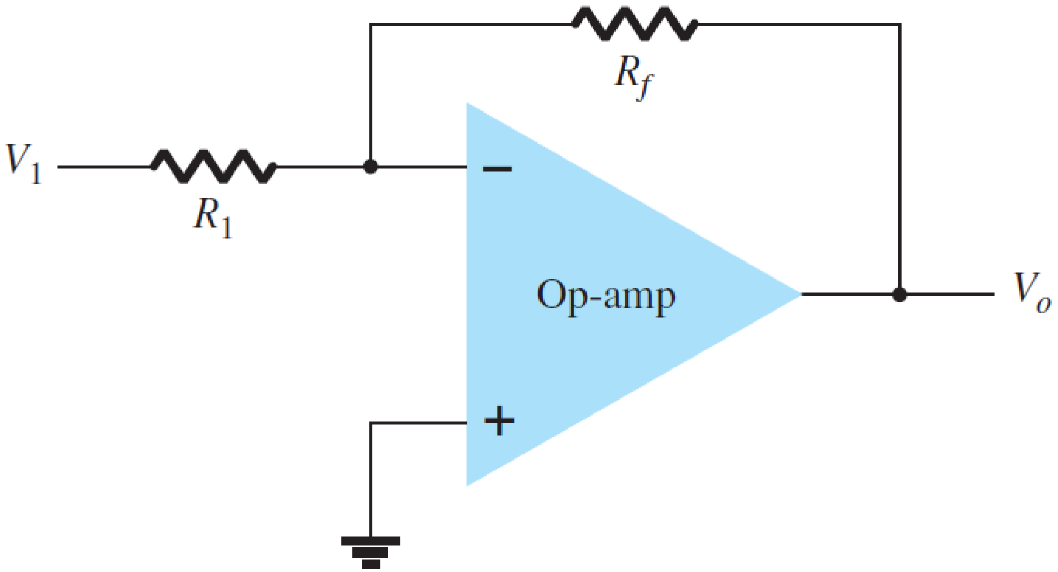
Numerical-2

If the circuit of the figure has R_1=100K Ohms and R_f=500K Ohms, What is the output voltage if V_1= 2V?



$$V_o = -\frac{R_f}{R_1}V_1 = -\frac{500\text{ k}\Omega}{100\text{ k}\Omega}(2\text{ V}) = \mathbf{-10\ V}$$

Numerical-3

3. What is the Output voltage in the Circuit shown in Figure

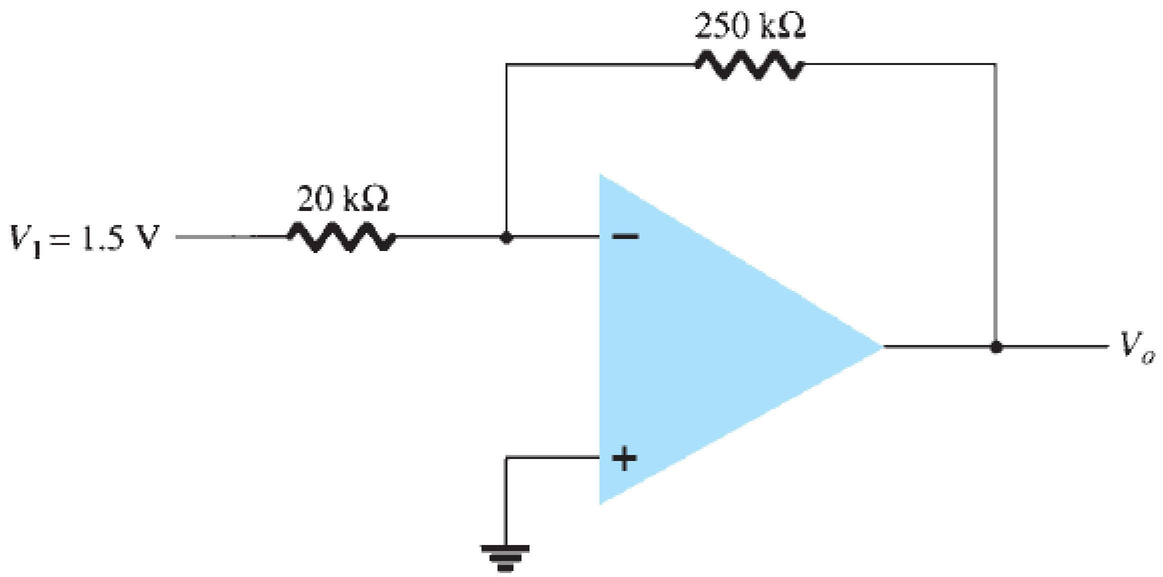


FIG. 10.62

$$V_o = -\frac{R_F}{R_1}V_1 = -\frac{250\ \text{k}\Omega}{20\ \text{k}\Omega}(1.5\ \text{V}) = \mathbf{-18.75\ V}$$

Numerical-4

What is the range of voltage gain adjustment in the circuit of the figure shown

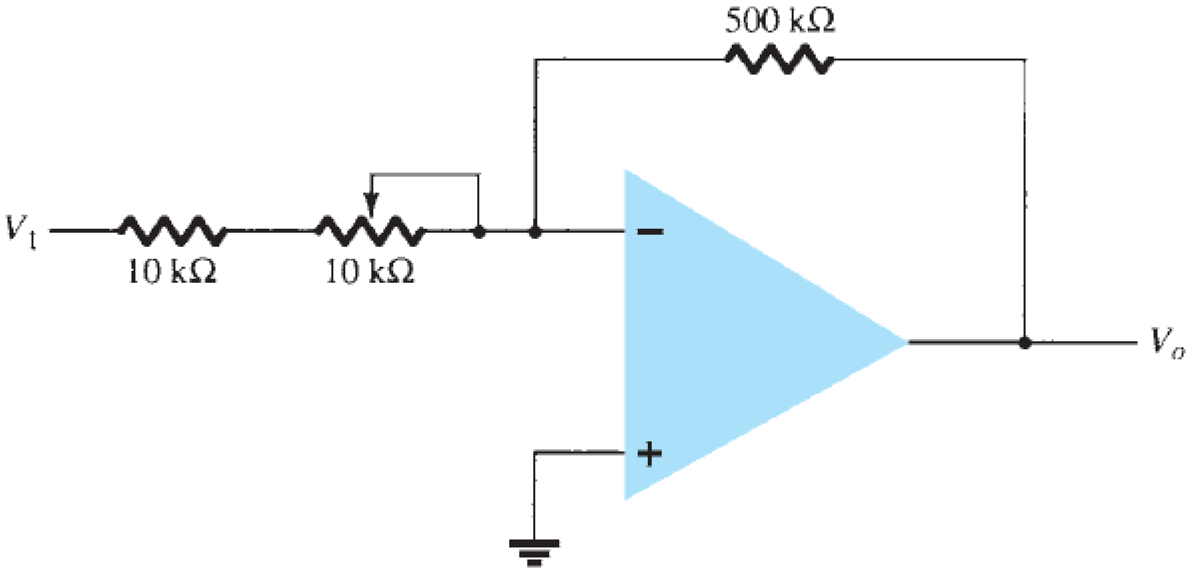


FIG. 10.63

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

For $R_1 = 10\ \text{k}\Omega$:

$$A_v = -\frac{500\ \text{k}\Omega}{10\ \text{k}\Omega} = \mathbf{-50}$$

For $R_1 = 20\ \text{k}\Omega$:

$$A_v = -\frac{500\ \text{k}\Omega}{20\ \text{k}\Omega} = \mathbf{-25}$$

Numerical-5

What is the input voltage that results in an output of 2V in circuit shown in Figure

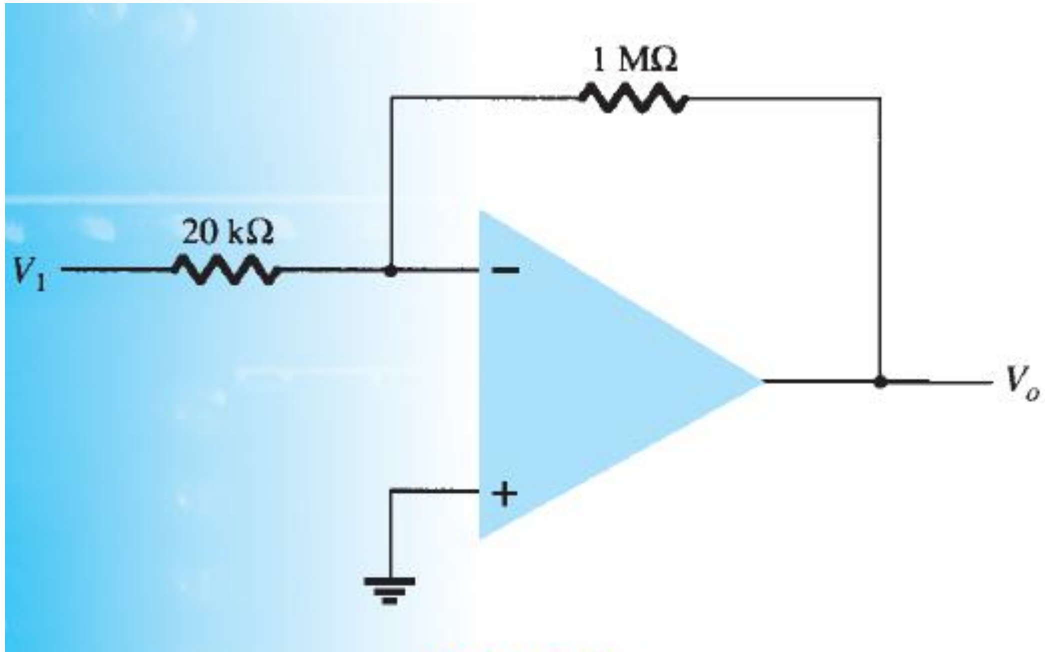


FIG. 10.64

$$V_o = -\frac{R_f}{R_1}V_1 = -\left(\frac{1\ \text{M}\Omega}{20\ \text{k}\Omega}\right)V_1 = 2\ \text{V}$$

$$V_1 = \frac{2\ \text{V}}{-50} = \mathbf{-40\ mV}$$

Numerical-6

What is the range of output voltage in the circuit shown in the figure if the input can vary from 0.1 to 0.5 V?

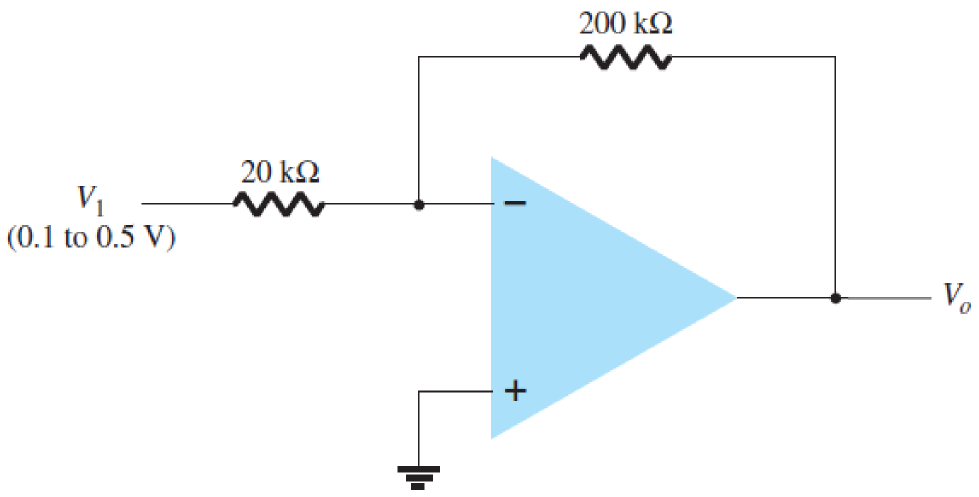


FIG. 10.65

$$V_o = -\frac{R_F}{R_1}V_1 = -\frac{200\ \text{k}\Omega}{20\ \text{k}\Omega}V_1 = -10\ V_1$$

For $V_1 = 0.1$ V:

$$V_o = -10(0.1\ \text{V}) = \mathbf{-1\ V}$$

For $V_1 = 0.5$ V:

$$V_o = -10(0.5\ \text{V}) = \mathbf{-5\ V}$$

V_o ranges from **–1 V to –5 V**

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Numerical-7

What is the range of output voltage developed in the circuit shown in the figure

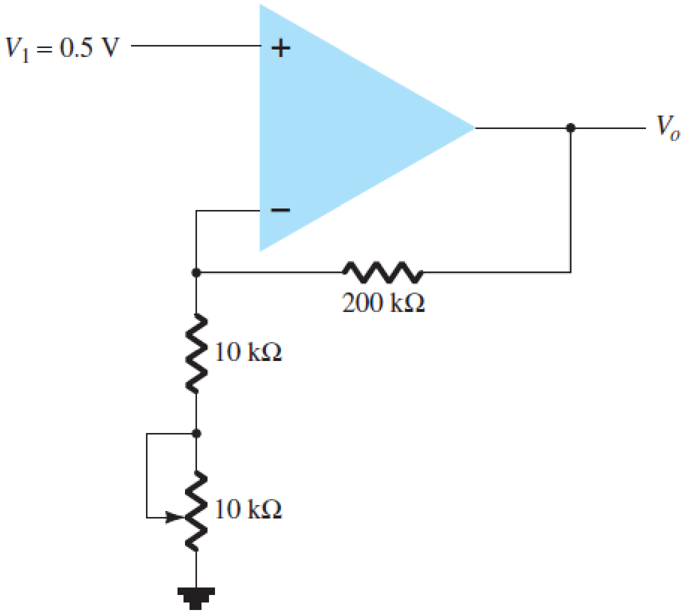

FIG. 10.67
Problem 7.

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

For $R_1 = 10\ \text{k}\Omega$:

$$V_o = \left(1 + \frac{200\ \text{k}\Omega}{10\ \text{k}\Omega}\right)(0.5\ \text{V}) = 21(0.5\ \text{V}) = \mathbf{10.5\ V}$$

For $R_1 = 20\ \text{k}\Omega$:

$$V_o = \left(1 + \frac{200\ \text{k}\Omega}{20\ \text{k}\Omega}\right)(0.5\ \text{V}) = 11(0.5\ \text{V}) = \mathbf{5.5\ V}$$

V_o ranges from 5.5 V to 10.5 V.

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Numerical-8

What is the results in the circuit shown if the input for an input of V_1= - 0.3 V?

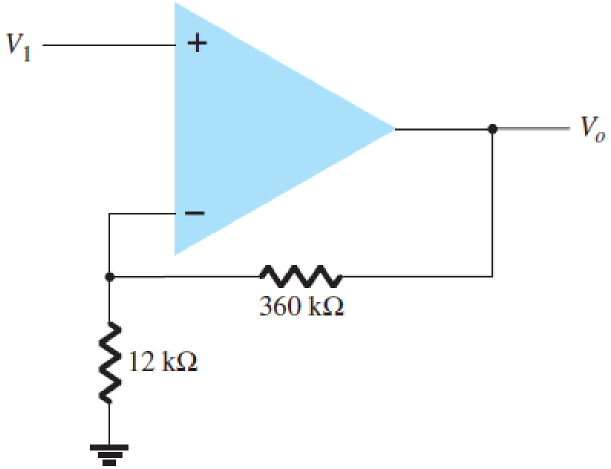


FIG. 10.66

$$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\ \text{k}\Omega}{12\ \text{k}\Omega}\right)(-0.3\ \text{V})$$

$$= 31(-0.3\ \text{V}) = \mathbf{-9.3\ V}$$

Numerical-9

What input must be applied to the input of the circuit shown in the figure to result in an output of 2.4 V?

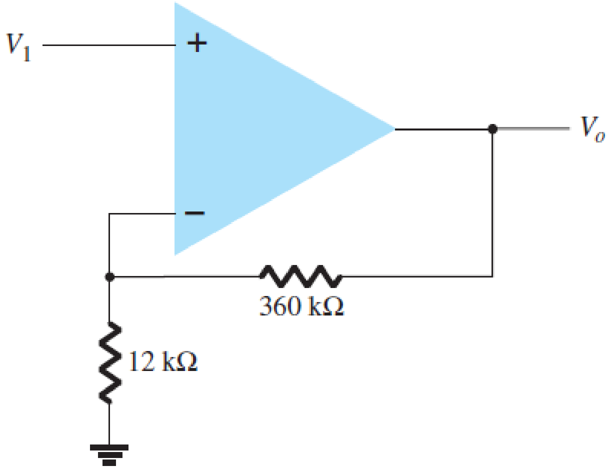


FIG. 10.66

$$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 = \left(1 + \frac{360\ \text{k}\Omega}{12\ \text{k}\Omega}\right)V_1 = 2.4\ \text{V}$$

$$V_1 = \frac{2.4\ \text{V}}{31} = \mathbf{77.42\ mV}$$

Numerical-10

What output voltage results in the circuit shown in the figure for $V_1 = +0.5V$?

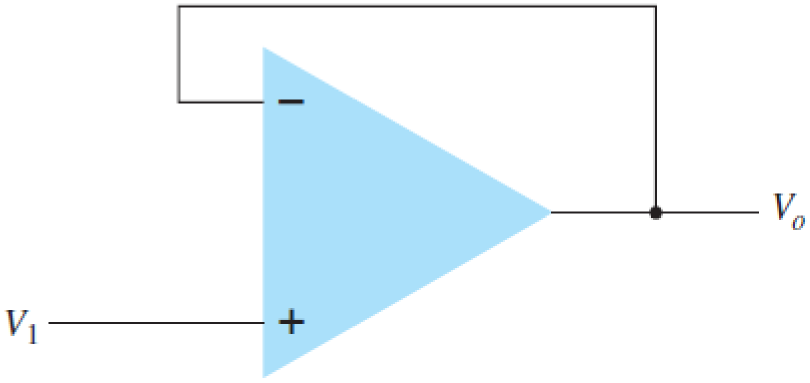


FIG. 10.70

$$V_o = V_1 = +0.5\text{ V}$$

Practical Op-amp Circuits

Numerical-11

Calculate the output voltage of a noninverting amplifier for values of V1 = 2V, Rf = 500 k, and R1 = 100k.

Soln: $$V_o = \left(1 + \frac{R_f}{R_1}\right)V_1 = \left(1 + \frac{500\,\text{k}\Omega}{100\,\text{k}\Omega}\right)(2\text{ V}) = 6(2\text{ V}) = \mathbf{+12\ V}$$

Practical Op-amp Circuits

Numerical-12

Calculate the output voltage of an op-amp summing amplifier for the following sets of voltages and resistors. Use Rf = 1 M in all cases.

a. V1 = +1 V, V2 = +2 V, V3 = +3 V, R1 = 500 k, R2 = 1 M, R3 = 1 M.

b. V1 = -2 V, V2 = +3 V, V3 = +1 V, R1 = 200 k, R2 = 500 k, R3 = 1 M.

Soln: Using Summing Amplifier Equation,

$$\text{a. } V_o = -\left[\frac{1000\,\text{k}\Omega}{500\,\text{k}\Omega}(+1\text{ V}) + \frac{1000\,\text{k}\Omega}{1000\,\text{k}\Omega}(+2\text{ V}) + \frac{1000\,\text{k}\Omega}{1000\,\text{k}\Omega}(+3\text{ V})\right]$$

$$= -[2(1\text{ V}) + 1(2\text{ V}) + 1(3\text{ V})] = \mathbf{-7\,V}$$

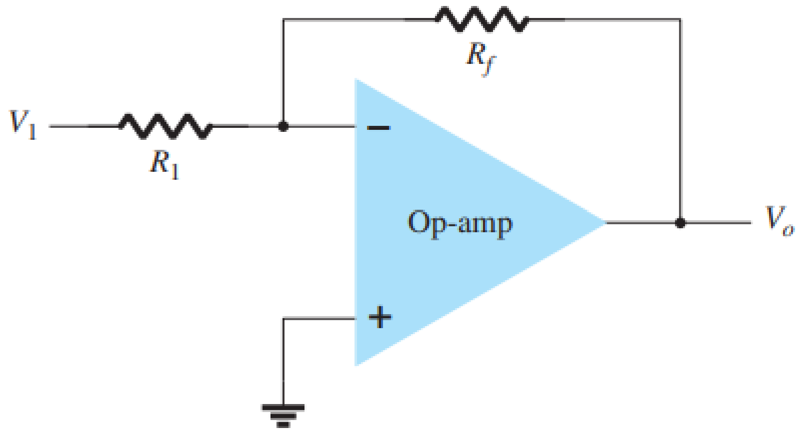
$$\text{b. } V_o = -\left[\frac{1000\,\text{k}\Omega}{200\,\text{k}\Omega}(-2\text{ V}) + \frac{1000\,\text{k}\Omega}{500\,\text{k}\Omega}(+3\text{ V}) + \frac{1000\,\text{k}\Omega}{1000\,\text{k}\Omega}(+1\text{ V})\right]$$

$$= -[5(-2\text{ V}) + 2(3\text{ V}) + 1(1\text{ V})] = \mathbf{+3\,V}$$

Practical Op-amp Circuits

Numerical-13

For the circuit shown, R1 = 100 k and R f 500 k, what output voltage results for an input of V1 = 2 V?

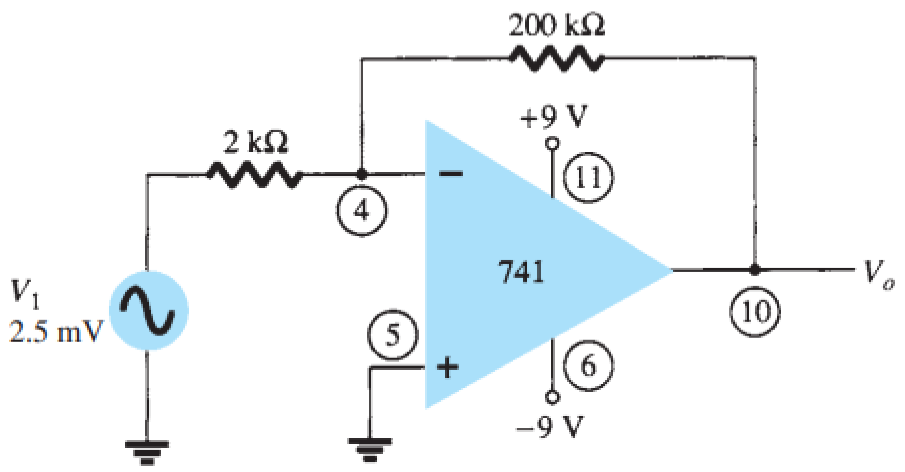


Soln: $$V_o = -\frac{R_f}{R_1}V_1 = -\frac{500\ \text{k}\Omega}{100\ \text{k}\Omega}(2\ \text{V}) = \mathbf{-10\ V}$$

Practical Op-amp Circuits

Numerical-14

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



Soln:

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

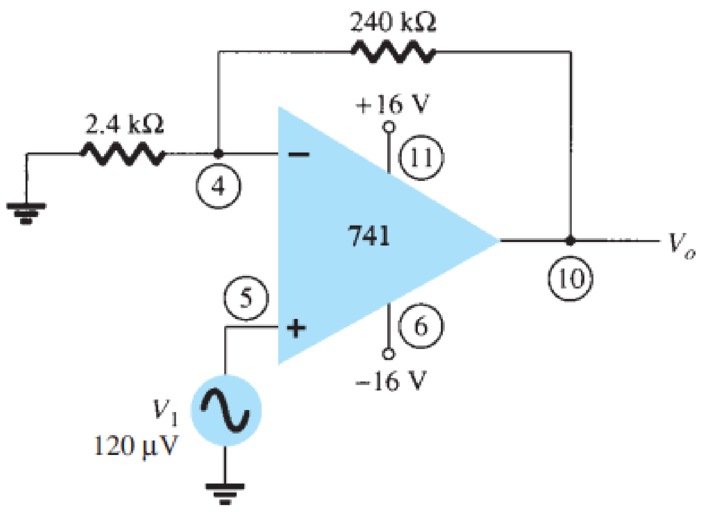
The output voltage is then

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

Practical Op-amp Circuits

Numerical-15

Calculate the output voltage from the circuit of Fig for an input of 120 mV.



Soln: Gain $A = 1 + \frac{R_f}{R_1} = 1 + \frac{240\ \text{k}\Omega}{2.4\ \text{k}\Omega} = 1 + 100 = 101$

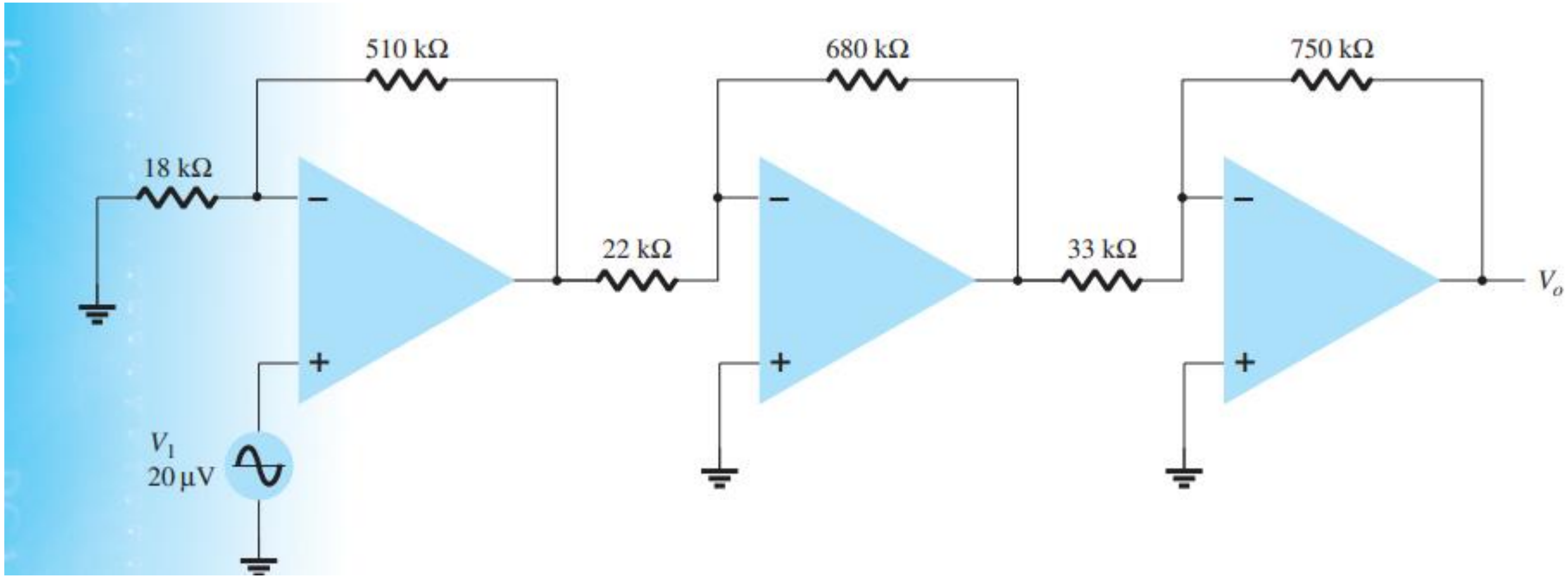
The output voltage is then

$$V_o = AV_i = 101(120\ \mu\text{V}) = \mathbf{12.12\ mV}$$

Practical Op-amp Circuits

Numerical-16

Calculate the output voltage in the circuit.



Soln:

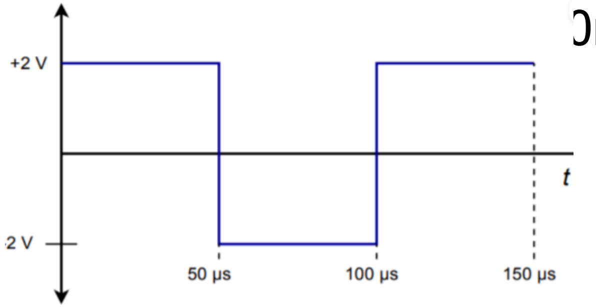
$$V_o = \left(1 + \frac{510\text{ k}\Omega}{18\text{ k}\Omega}\right)(20\ \mu\text{V})\left[-\frac{680\text{ k}\Omega}{22\text{ k}\Omega}\right]\left[-\frac{750\text{ k}\Omega}{33\text{ k}\Omega}\right]$$

$$= (29.33)(-30.91)(-22.73)(20\ \mu\text{V})$$

$$= \mathbf{412\ mV}$$

Numerical-17

Sketch the output of the integrator circuit if the input signal is a 10 kHz, 2 V peak square wave. 0nF.



Soln:

$$V_{in}(t) = 2 \text{ from } t = 0, \text{ to } t = 50\mu s$$

$$V_{in}(t) = -2 \text{ from } t = 50\mu s, \text{ to } t = 100\mu s$$

$$V_{out}(t) = -\frac{1}{R_i C}\int V_{in}(t)dt$$

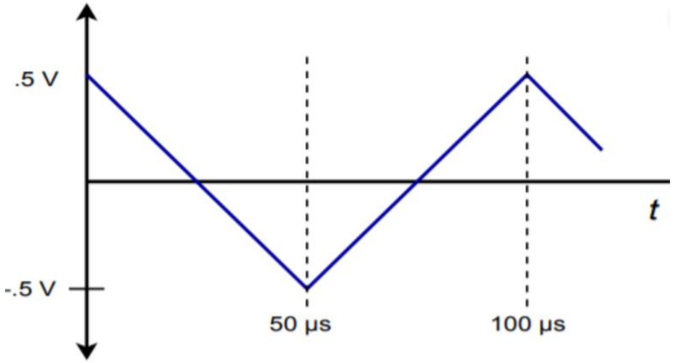
$$V_{out}(t) = -\frac{1}{10\text{ k} \times 10\text{ nF}}\int_0^{50\mu s} 2dt$$

$$V_{out}(t) = -10^4 \times 2 \times t\Big|_{t=0}^{t=50\mu s}$$

$$V_{out} = -20000 \times 50\mu s$$

$$V_{out} = -1V$$

Vout represents total change over the 50 µs half-cycle interval with peak to peak output voltage of -1V. Where minus represents 180 degree phase shift output The resulting waveform is a ramp signal.



Numerical-18

Sketch the output waveform for the differentiator circuit if the input is 3 volt peak triangle wave at 4 kHz. Assume Rf=5KΩ and C=10nF

Soln:

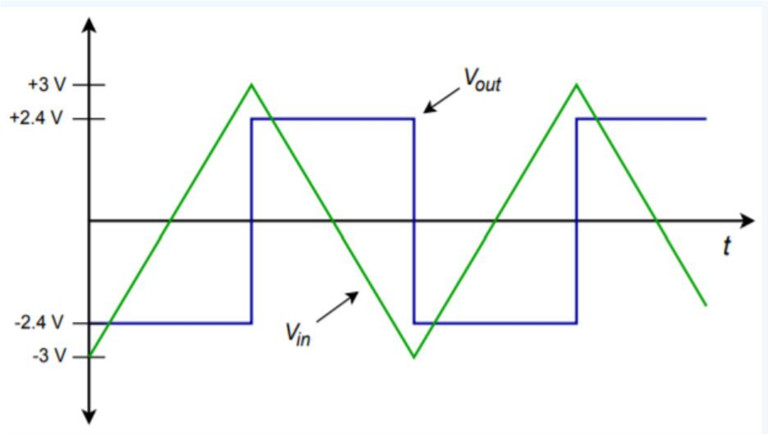
$$T = \frac{1}{4kHz}$$
$$T = 250\mu s$$

The slope (considering p-p) is

$$Slope = \frac{6V}{125\mu s}$$
$$Slope = 48000V/s$$

$$V_{in}(t) = 48000t$$

$$V_{out}(t) = -R_f C \frac{dV_{in}(t)}{dt}$$
$$V_{out}(t) = -5k \times 10nF \frac{d48000t}{dt}$$
$$V_{out}(t) = -2.4V \text{ Peak}$$



THANK YOU

Department of Electronics and Communication