University of Calcutta

Semester 4

PHYSICS

Paper: PHS-A-CC-4-10-TH (OLD SYLLABUS)

OPAMP APPLICATION : LINEAR

SOLVED PROBLEMS

ASSIGNMENTS

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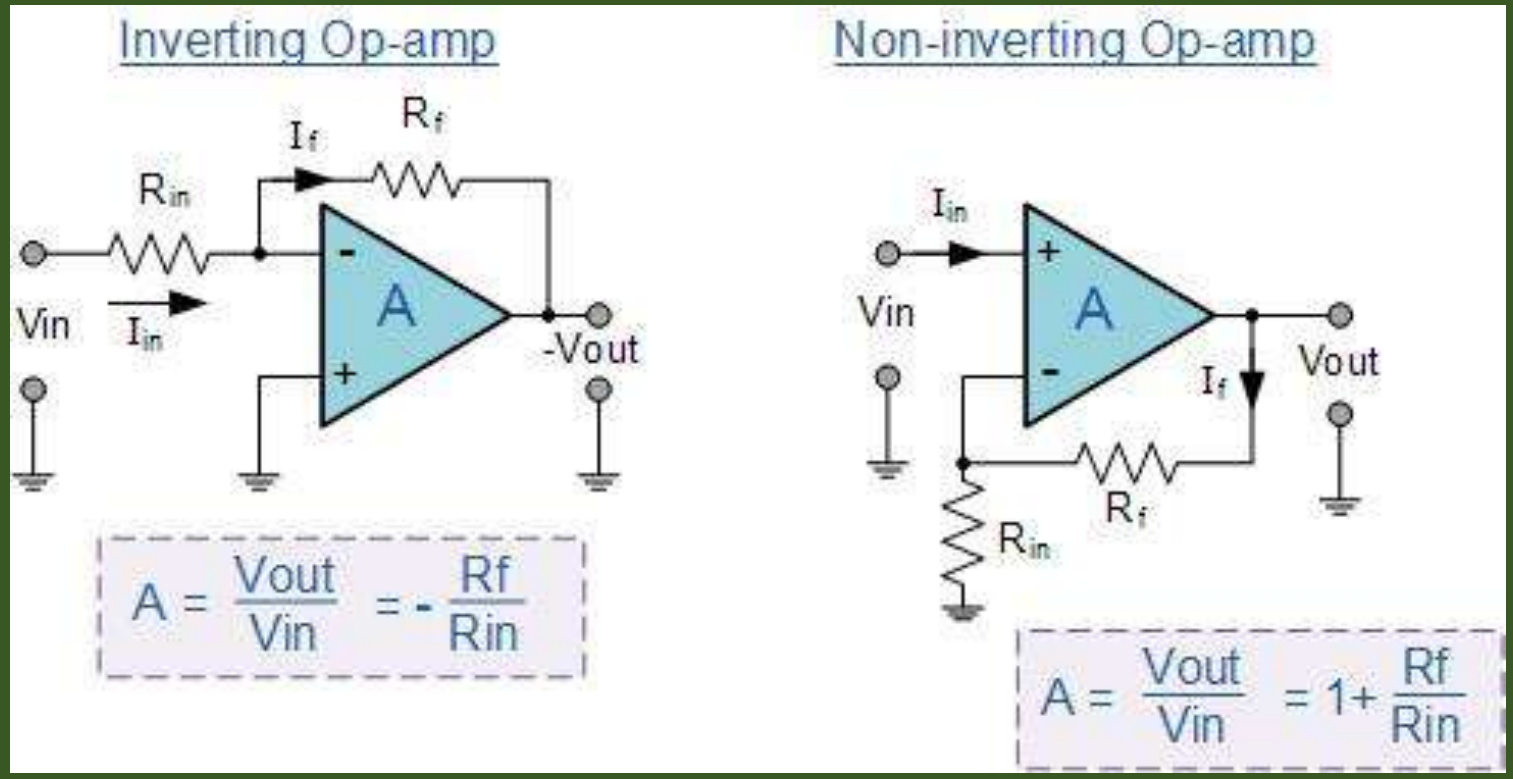
Inverting and Non-Inverting Amplifier



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Inverting Amplifier

1. Inverting amplifier: A basic inverting amplifier using an OP AMP connected with an input resistance R_1 and a feedback resistance R_f is shown in Fig. 14.6. Since R_f connects the output terminal to the inverting input terminal, it provides a *negative feedback*. The noninverting input terminal is grounded. The input and the output voltages are v_1 and v_0, respectively. Let v be the voltage at the inverting input terminal. As the open-loop gain A of the OP AMP is very high, and the output voltage v_0 is finite due to negative feedback, we have $v = v_0/A \rightarrow 0$ as $|A| \rightarrow \infty$. Therefore, the inverting input terminal is practically at the ground potential. Thus, though the point G is not actually connected to ground it is held *virtually* at ground potential, whatever be the magnitudes of v_1 and v_0.

There is an important difference between an 'actual ground' and a 'virtual ground'. When a terminal is actually grounded, any amount of current can flow to ground through the terminal. Thus an actual ground can serve as a 'sink' for infinite current. But the input impedance of an OP AMP being infinite, no current

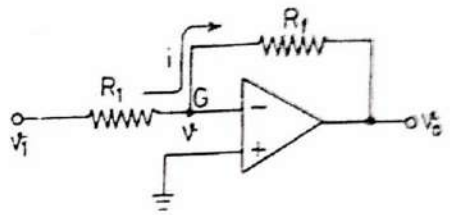


Fig 14.6 Inverting amplifier

can flow into the OP AMP through the virtual ground. So a virtual ground cannot serve as a sink for current.

The current i through the resistance R_1 is

$$i = \frac{v_1 - v}{R_1} \tag{14.8}$$

Assuming that the OP AMP is an ideal one with an infinite input impedance, the current i passes through R_f and not into the OP AMP. Kirchhoff's current law at the point G gives

$$\frac{v_1 - v}{R_1} = \frac{v - v_0}{R_f} \tag{14.9}$$

As the point G is a *virtual ground*, $v = 0$. Hence Eq. (14.9) reduces to

$$\frac{v_1}{R_1} = -\frac{v_0}{R_f} \tag{14.10}$$

The ratio of the output voltage v_0 and the input voltage v_1 is the *closed-loop gain* of the amplifier. So, the closed-loop gain of the inverting amplifier is

$$\frac{v_0}{v_1} = -\frac{R_f}{R_1} \tag{14.11}$$

Thus the closed-loop voltage gain is the ratio of the feedback resistance R_f to the input resistance R_1. The negative sign signifies that the output voltage is *inverted* with respect to the input voltage.

The input resistance of the amplifier system is

$$R_{in} = \frac{v_1}{i} = \frac{v_1}{(v_1 - v)/R_1} = R_1 \tag{14.12}$$

using Eq. (14.8) and noting that $v = 0$. It should be noted that R_{in} refers to the entire amplifier system and not to the OP AMP which has an infinite input impedance. The output resistance of the inverting amplifier is very small.

Non-Inverting Amplifier

4. Noninverting amplifier: Figure 14.7 depicts the circuit diagram of a non-inverting amplifier. The input voltage v_1 is applied to the noninverting terminal. Since the voltage gain of the OP AMP is infinite, the potential of the point G is also v_1. The current flowing into the OP AMP is negligible, its input impedance being very large. Hence, applying Kirchhoff's current law at the point G we obtain

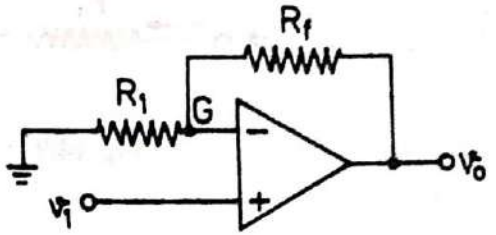


Fig 14.7 Noninverting amplifier

$$\frac{v_0 - v_1}{R_f} = \frac{v_1}{R_1} \tag{14.15}$$

or

$$\frac{v_0}{v_1} = 1 + \frac{R_f}{R_1} \tag{14.16}$$

which is the voltage gain of the amplifier system. The voltage gain is greater than unity by a factor R_f/R_1. As the gain is positive, there is no phase difference between the input voltage v_1 and the output voltage v_0. The input impedance of the circuit is high and the output impedance is low.

In the circuit of Fig. 14.7, if $R_f = 0$ and $R_1 = \infty$, the circuit reduces to that of Fig. 14.8. Equation (14.16) shows that the voltage gain in this case in unity. Therefore, the circuit of Fig. 14.8 is referred to as a *unity-gain buffer* or a *voltage follower*. This circuit offers a high input impedance, and a low output impedance, and therefore can be employed as an impedance matching device between a high-impedanace source and a low impedance load.

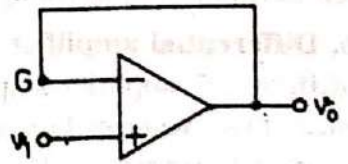
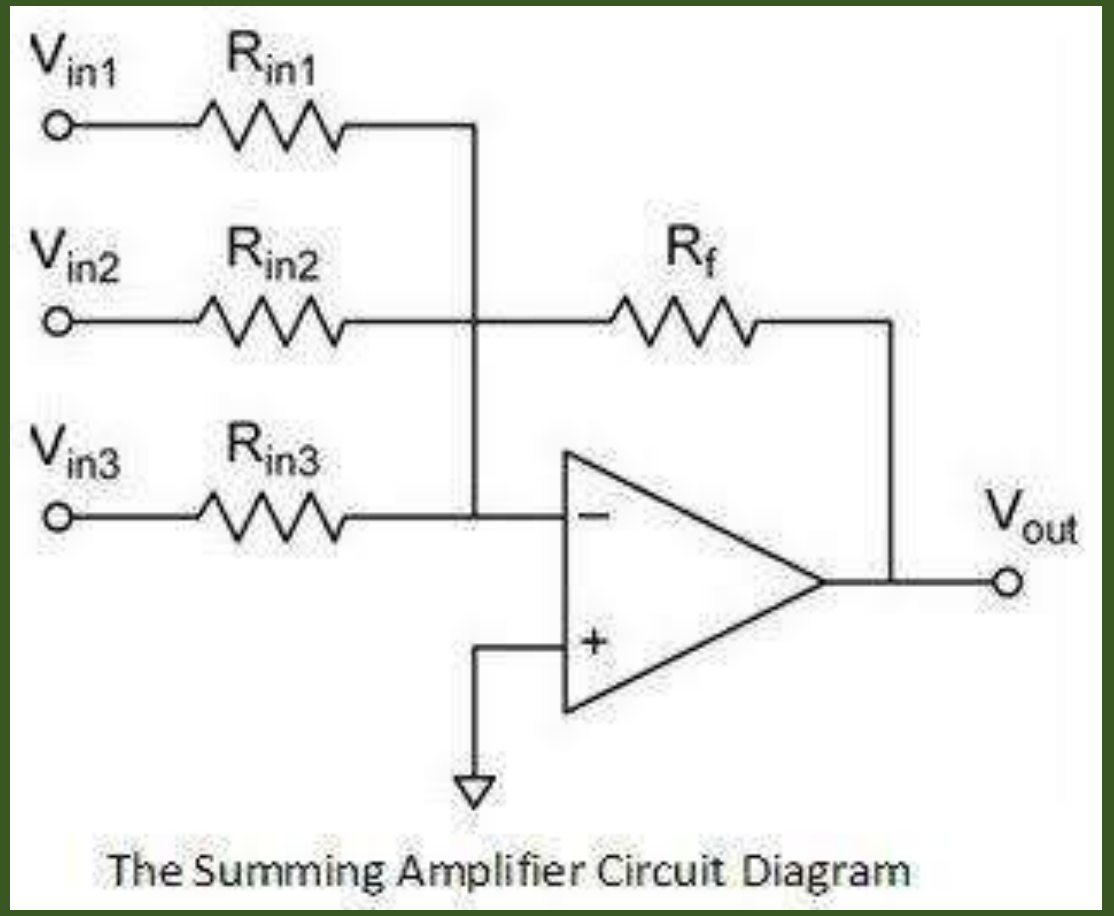


Fig 14.8 A voltage follower

Adder



The Summing Amplifier Circuit Diagram

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5. Adder or summing amplifier: Figure 14.9 gives the circuit diagram of an adder or a summing amplifier. The same reasoning as in the case of the inverting amplifier shows that the point G is a virtual ground, i.e. G is at ground potential. The input impedance of the OP AMP being infinite, the sum of the currents $i_1, i_2, \ldots, i_n$ will be equal to i_0, by Kirchhoff's current law. That is,

$$i_1 + i_2 + \ldots + i_n = i_0$$

or
$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \ldots + \frac{v_n}{R_n} = -\frac{v_0}{R_f}$$

or
$$v_0 = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \ldots + \frac{R_f}{R_n} v_n\right) \tag{14.17}$$

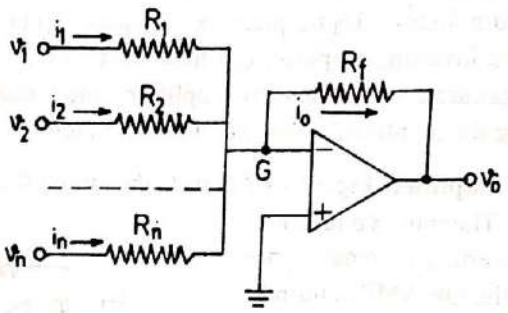


Fig 14.9 Summing amplifier

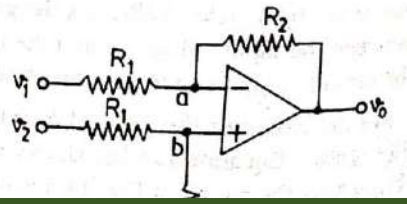
If $R_1 = R_2 = \ldots = R_n = R$, Eq. (14.17) gives

$$v_0 = -\frac{R_f}{R}(v_1 + v_2 + \ldots + v_n). \tag{14.18}$$

With $R_f = R$, Eq. (14.18) reduces to

$$v_0 = -(v_1 + v_2 + \ldots + v_n). \tag{14.19}$$

This equation shows that the output voltage v_0 is numerically equal to the algebraic sum of the input voltages $v_1, v_2, \ldots, v_n$. Hence the circuit is termed a summing amplifier or an adder. If the algebraic sum of the input voltages is very small, the output voltage v_0 is measured with $R_f > R$. From Eq. (14.18), the desired sum is obtained accurately by dividing v_0 by R_f/R_1.



Subtractive or Differential Amplifier

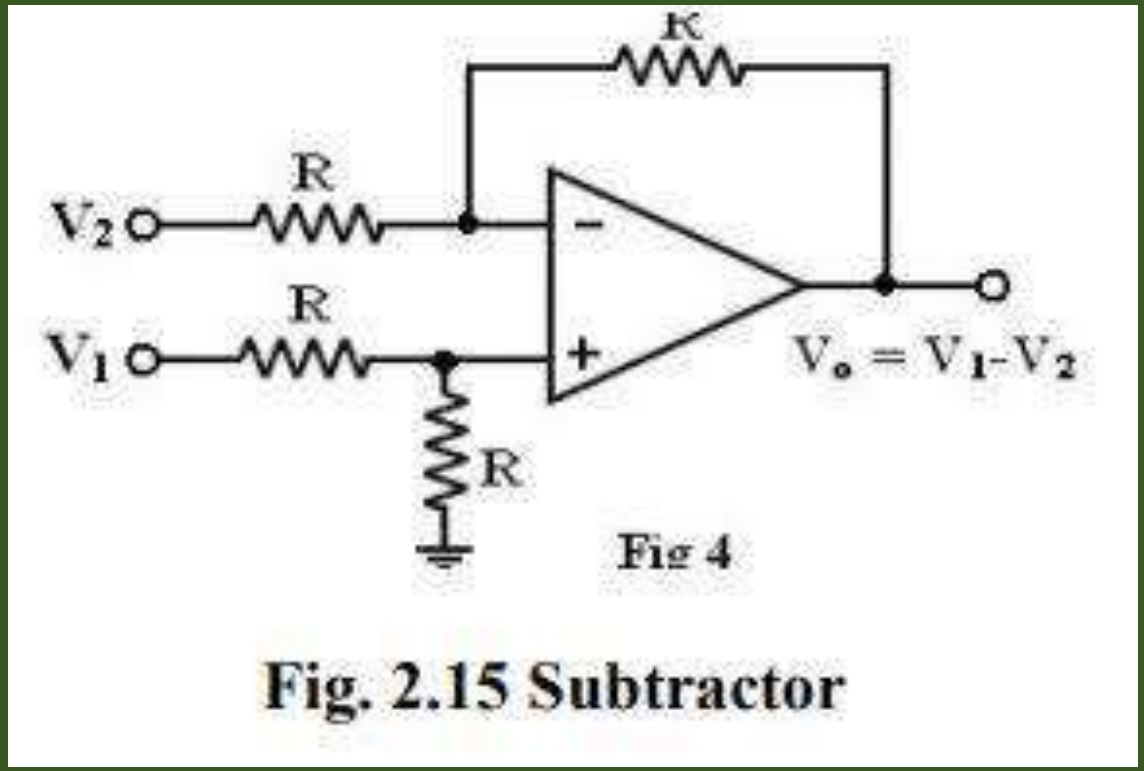


Fig. 2.15 Subtractor

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6. Differential amplifier A differential (or difference) amplifier amplifies the difference of two voltages Figure 14.10 shows the circuit diagram of a differential amplifier. Suppose that the difference between the voltages v_2 and v_1 is to be amplified. The voltage v_2 is applied to the noninverting input terminal and v_1 to the inverting input terminal of the OP AMP. The output voltage is v_0. The voltage gain of the OP AMP being infinite, the points a and b will have the same potential, say, v_x. Applying Kirchhoff's current law at a and b, we obtain respectively

$$\frac{v_1 - v_x}{R_1} = \frac{v_x - v_0}{R_2} \tag{14.20}$$

and

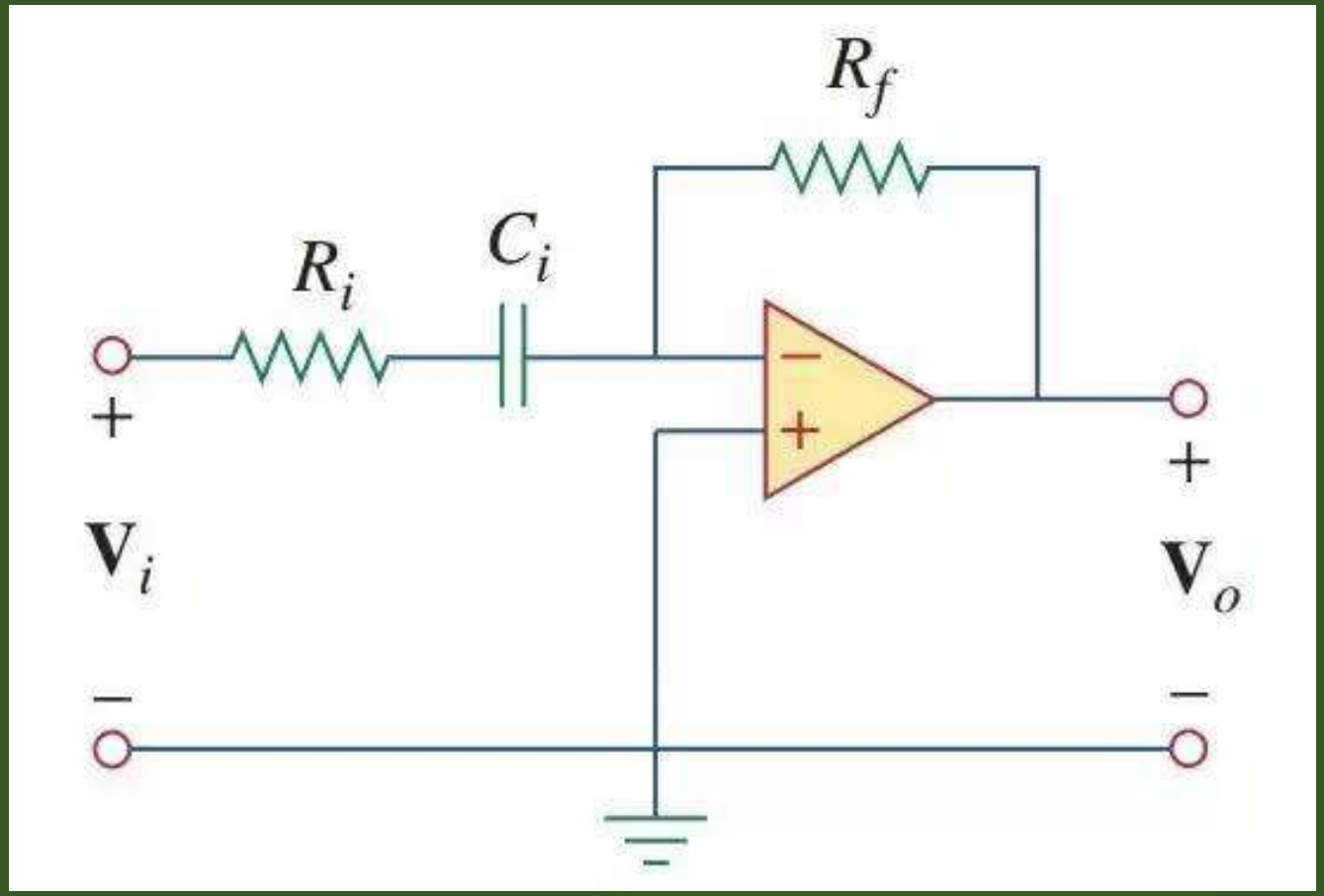
$$\frac{v_2 - v_x}{R_1} = \frac{v_x}{R_2} \tag{14.21}$$

where we have assumed that the input impedance of the OP AMP is infinite. Subtracting Eq. (14.20) from Eq. (14.21), we get

$$v_0 = \frac{R_2}{R_1}(v_2 - v_1) \tag{14.22}$$

Thus v_0 is the amplified version of the difference voltage $(v_2 - v_1)$, the voltage gain of the amplifier system being R_2/R_1.

Differentiator



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8. Differentiator: The circuit of Fig. 14.13 gives an output voltage v_0 which is proportional to the derivative of the input voltage v_1 with respect to time. Therefore, the circuit is termed a differentiator. The infinite voltage gain of the OP AMP makes G a virtual ground. The charge on the capacitor C is therefore $q = Cv_1$

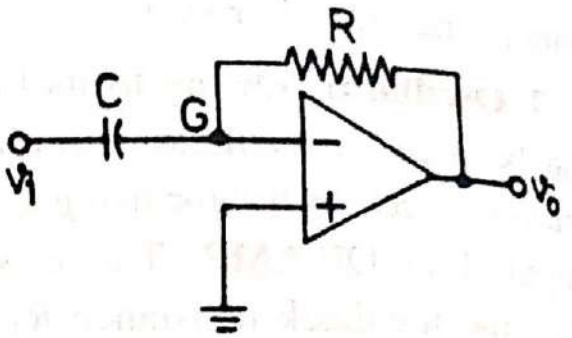


Fig 14.13 Differentiaor

or
$$v_1 = \frac{q}{C}. \qquad (14.23)$$

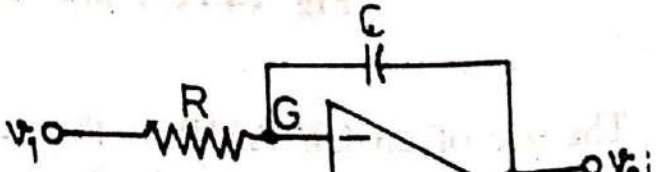
Differentiating with respect to time, we obtain

$$\frac{dv_1}{dt} = \frac{1}{C}\frac{dq}{dt} = \frac{i}{C} \qquad (14.24)$$

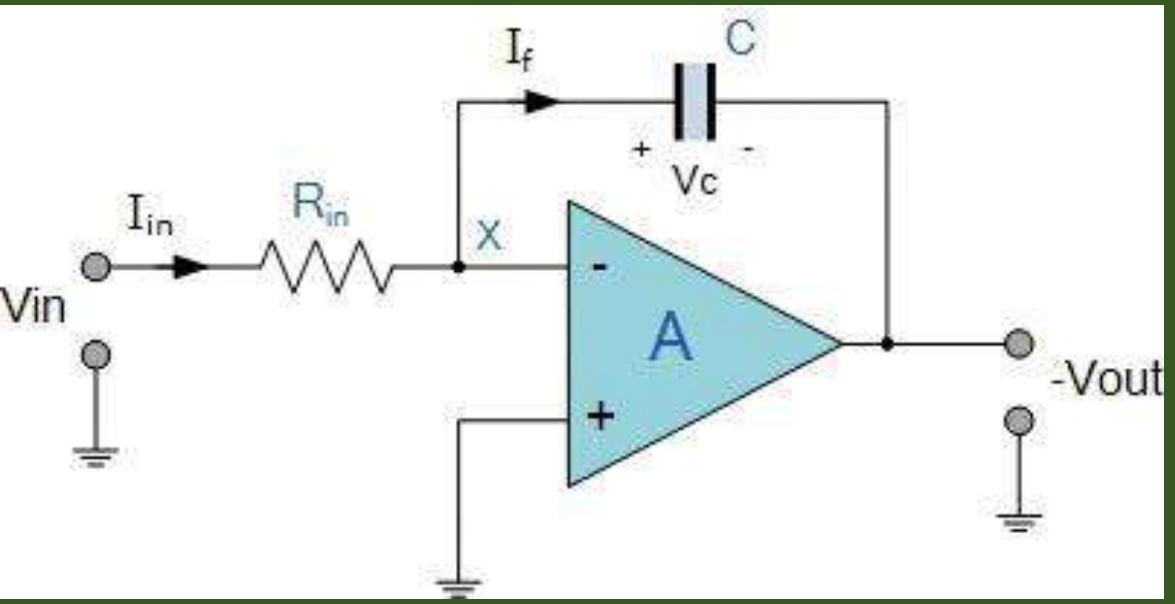
where i is the current flowing through the capacitor. Since the input impedance of the OP AMP is infinite, the current i flows through the resistance R also. Therefore, $i = -v_0/R$, so that Eq. (14.24) gives

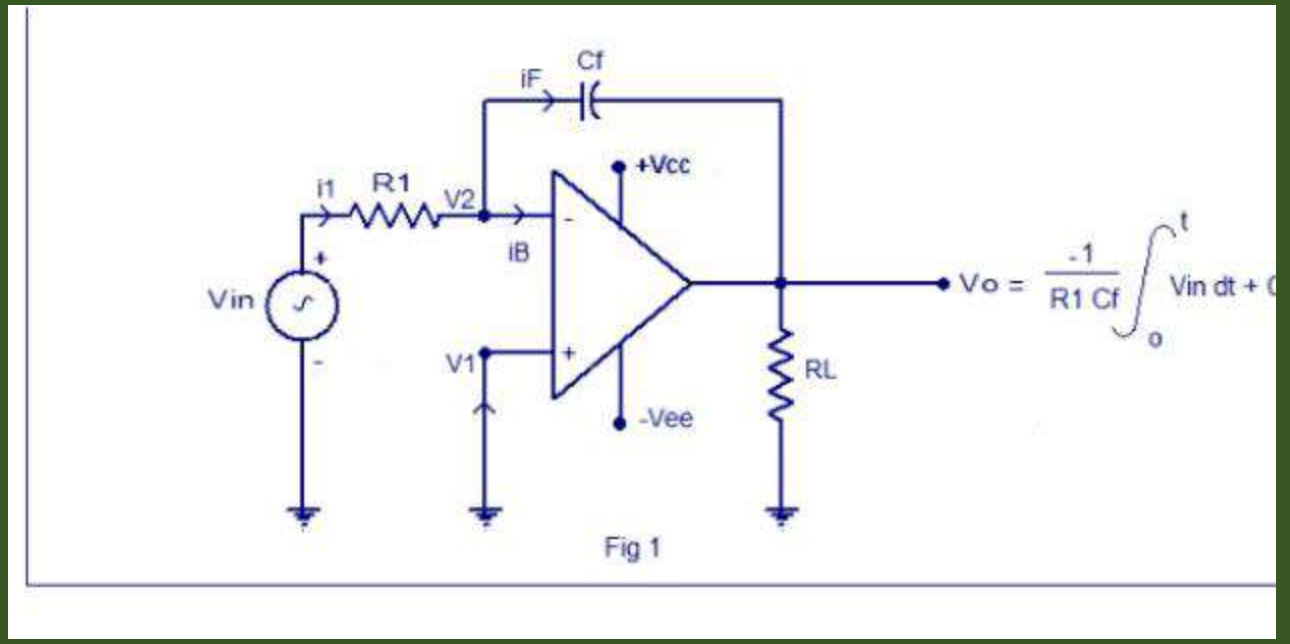
$$v_0 = -CR\frac{dv_1}{dt} \qquad (14.25)$$

Obviously, the output voltage v_0 is proportional to the time derivative of the input voltage v_I, the proportionality constant being $-CR$.



Integrator Amplifier





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...constant

9. Integrator: If the positions of R and C in the circuit of Fig. 14.13 are interchanged, the resulting circuit, depicted in Fig. 14.14, is an integrator. As the gain of the OP AMP is infinite, the point G is a virtual ground. The current i flowing through the resistance R is $i = v_1/R$. The input impedance of the OP AMP being infinite, the current i flows through the feedback capacitor C to produce the output voltage v_0. Therefore,

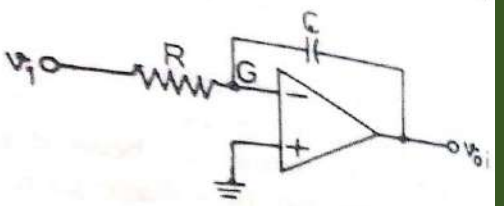
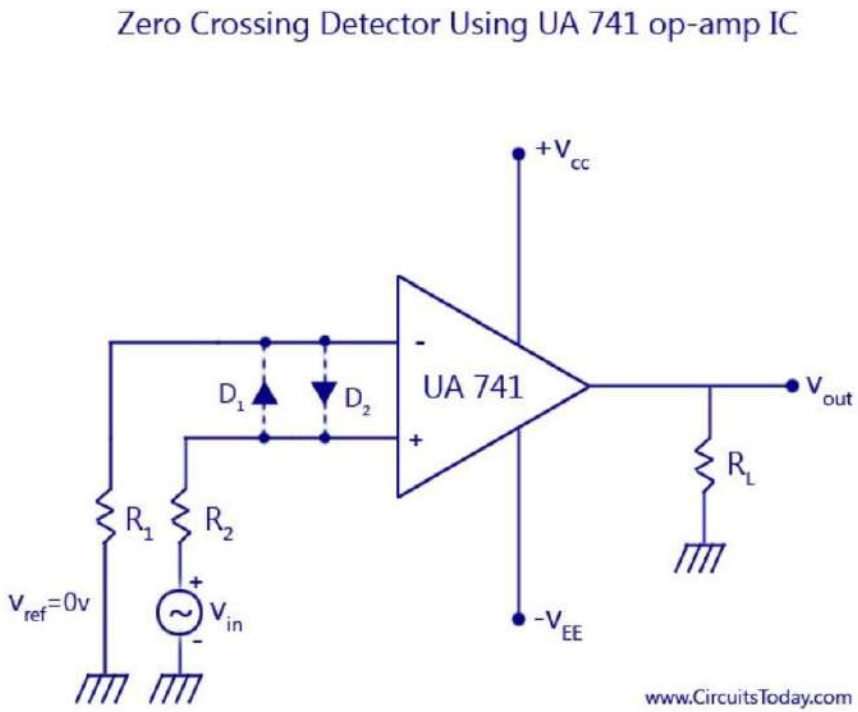


Fig. 14.14 Integrator

$$v_0 = -\frac{1}{C}\int_0^t i\,dt = -\frac{1}{CR}\int_0^t v_1\,dt\,. \tag{14.26}$$

The output voltage v_0 is thus proportional to the time integral of the input voltage v_I, the proportionality constant being $-1/(CR)$. Hence the circuit is referred to as an integrator. Integrators find applications in sweep or ramp generators, in filters, and in simulation studies in analog computers.

Zero Crossing Detector

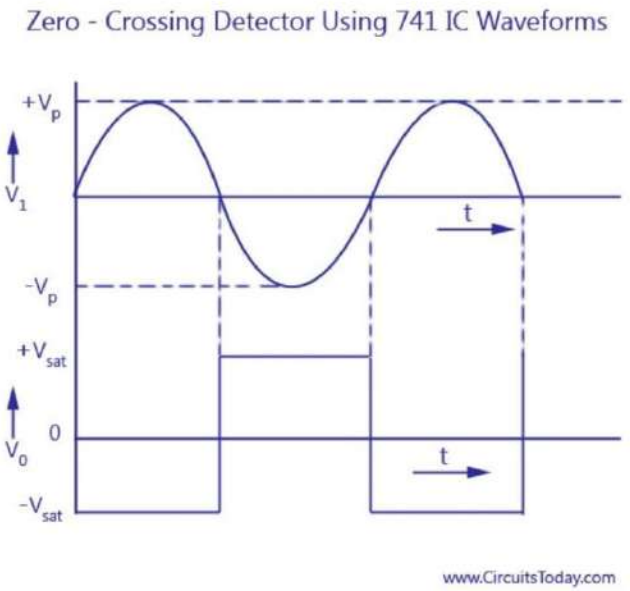


Zero-Crossing Detector Using UA741 op-amp IC

Zero Crossing Detector using 741 IC

The zero crossing detector circuit is an important application of the **op-amp comparator circuit**. It can also be called as the sine to square wave converter. Anyone of the inverting or non-inverting comparators can be used as a zero-crossing detector. The only change to be brought in is the reference voltage with which the input voltage is to be compared, must be made zero (Vref = 0V). An input sine wave is given as Vin. These are shown in the circuit diagram and input and output waveforms of an inverting comparator with a 0V reference voltage.

As shown in the waveform, for a referenc voltage 0V, when the input sine wave passe through zero and goes in positive directior the output voltage Vout is driven int negative saturation. Similarly, when th input voltage passes through zero and goe in the negative direction, the output voltag is driven to positive saturation. The diode D1 and D2 are also called clamp diodes They are used to protect the op-amp fron damage due to increase in input voltage They clamp the differential input voltages t either +0.7V or -0.7V.



Zero-Crossing Detector Using 741IC -Waveforms

For an input sine wave, the output of the zero-crossing detector being a square wave,

In certain applications, the input voltage may be a low frequency waveform. This means that the waveform only changes slowly. This causes a delay in time for the input voltage to cross the zero-level. This causes further delay for the output voltage to switch between the upper and lower saturation levels. At the same time, the input noises in the op-amp may cause the output voltage to switch between the saturation levels. Thus zero crossing are detected for noise voltages in addition to the input voltage. These difficulties can be removed by using a **regenerative feedback circuit with a positive feedback** that causes the output voltage to change faster thereby eliminating the possibility of any false zero crossing due to noise voltages at the op-amp input.

Clear your idea – Zero Crossing Detector

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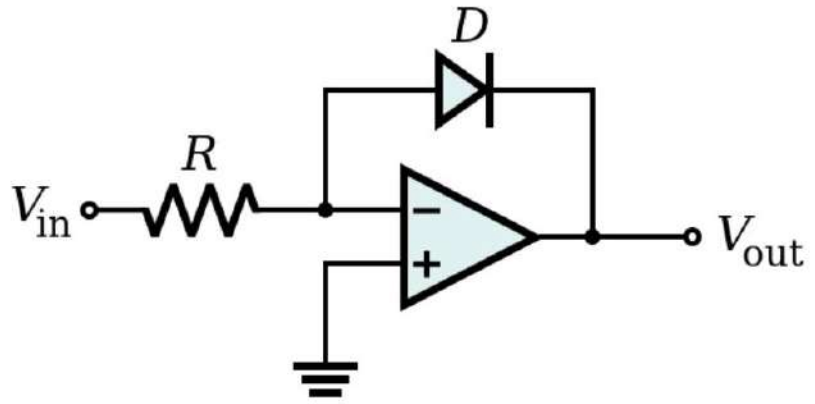
A **log amplifier** is an amplifier for which the output voltage V_{out} is K times the natural log of the input voltage V_{in}. This can be expressed as,

$$V_{\text{out}} = K \ln\left(\frac{V_{\text{in}}}{V_{\text{ref}}}\right)$$

where V_{ref} is the normalization constant in volts and K is the scale factor.

The logarithm amplifier gives an output voltage which is proportional to the logarithm of applied input voltage.

Basic op-amp diode circuit



Basic op-amp diode log converter

The relationship between the input voltage V_{in} and the output voltage V_{out} is given by:

$$V_{\text{out}} = -V_{\text{T}} \ln\left(\frac{V_{\text{in}}}{I_{\text{S}}\, R}\right)$$

where I_{S} and V_{T} are the saturation current and the thermal voltage of the diode respectively.

12. Logarithmic amplifier: If the feedback resistor R_f in the circuit of Fig. 14.6 is replaced by a diode, we obtain a *logarithmic amplifier* giving an output voltage v_0 that changes as the logarithm of the input voltage v_1. The circuit of logarithmic amplifier is shown in Fig. 14.17.

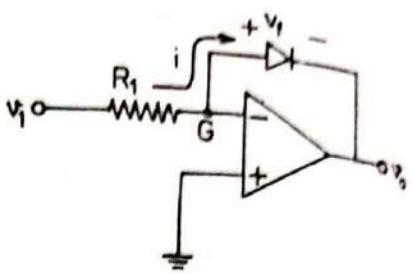


Fig. 14.17 A logarithmic amplifier for positive input voltage v_1

The volt-ampere characteristic of the diode is given by Eq. (5.5), viz.

$$i = I_s\left[\exp\left(\frac{e\,v_f}{\eta\,k_B\,T}\right) - 1\right]$$

Here i is the diode current for the forward voltage v_f. If $e\,v_f/(\eta\,k_B\,T) >> 1$ or, $i >> I_s$, we have

$$i \approx I_s \exp\left(\frac{e\,v_f}{\eta\,k_B\,T}\right)$$

or,
$$\ln\left(\frac{i}{I_s}\right) = \frac{e\,v_f}{\eta\,k_B\,T}$$

or,
$$v_f = \frac{\eta\,k_B\,T}{e}\ln\left(\frac{i}{I_s}\right)$$

Since G is a virtual ground in Fig. 14.17, we have $i = v_1/R_1$ and the output voltage is

$$v_0 = -\,v_f = -\,\frac{\eta\,k_B\,T}{e}\ln\left(\frac{v_1}{I_s R_1}\right).$$

Hence v_0 responds to the logarithm of v_1.

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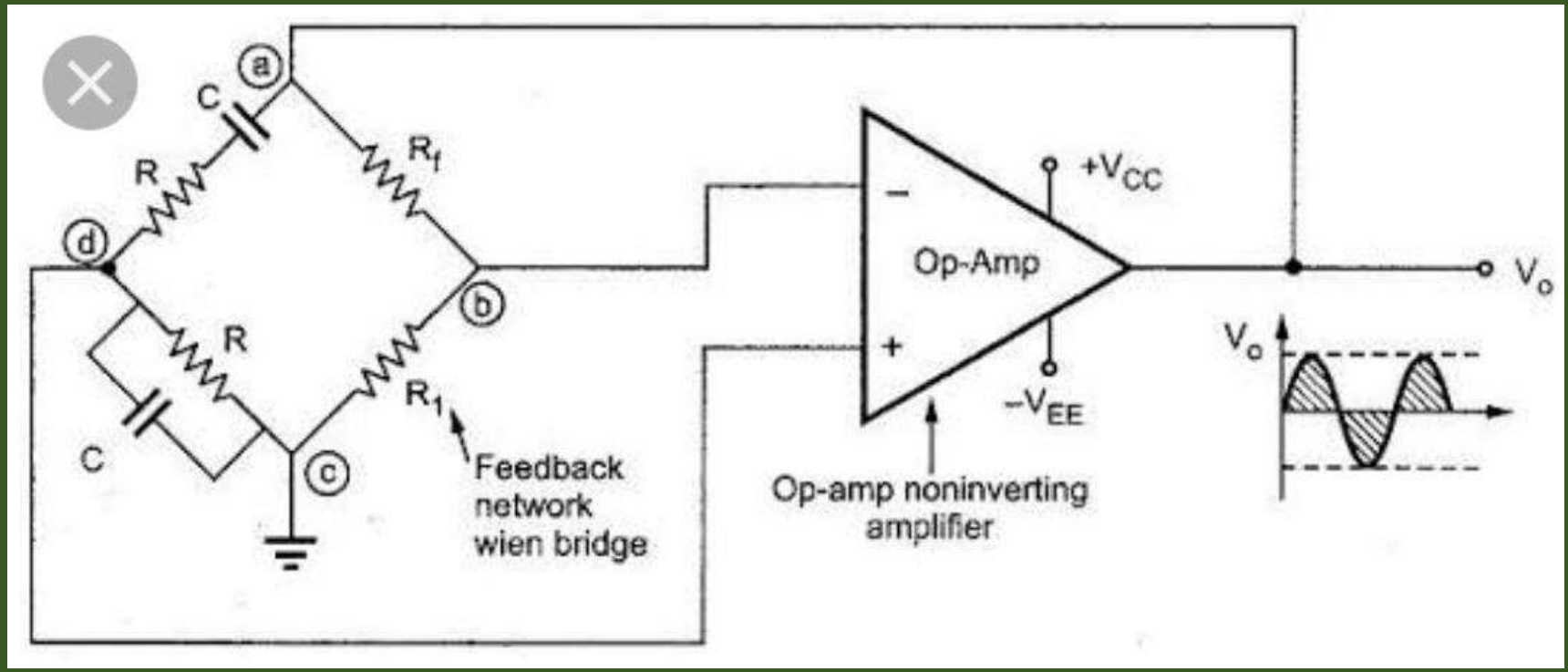
Weinig Bridge Oscillator



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14-19 THE WIEN BRIDGE OSCILLATOR

An oscillator circuit in which a balanced bridge is used as the feedback network is the Wien bridge[10] oscillator shown in Fig. 14-34. The active element is an operational amplifier (Chap. 15) which has a very large positive voltage gain

($V_o = A_V V_i$), negligible output resistance, and very high (infinite) input resistance. We assume further that A_V is constant over the range of frequencies of operation of this circuit.

To find the loop gain $-\beta A$, we break the loop at the point marked P and apply an external voltage V_o' across terminals 3 and 4.

Since $V_o = A_V V_i$, the loop gain is given by

$$\text{Loop gain} = \frac{V_o}{V_o'} = \frac{V_i}{V_o'} A_V = -\beta A \tag{14-70}$$

Two auxiliary voltages V_1 and V_2 are indicated in Fig. 14-34 such that $V_i = V_2 - V_1$. From Eq. (14-70) $A = A_V$ and

$$-\beta = \frac{V_i}{V_o'} = \frac{V_2 - V_1}{V_o'} = \frac{Z_2}{Z_1 + Z_2} - \frac{R_2}{R_1 + R_2} \tag{14-71}$$

It is not difficult to show that Z_1 and Z_2 have the same phase angle at the frequency

$$f_o = \frac{1}{2\pi RC} \tag{14-72}$$

and that at this frequency $Z_1 = (1 - j)R$ and $Z_2 = (1 - j)R/2$. Hence $V_2 = \frac{1}{3}V_o'$, at $\omega = \omega_o$. If a null is desired, then R_1 and R_2 must be chosen so that $V_i = 0$. From Eq. (14-71) $R_2/(R_1 + R_2) = \frac{1}{3}$, or $R_1 = 2R_2$.

In the present case, where the bridge is used as the feedback network for an oscillator, the loop gain of Eq. (14-70) must equal unity and must have zero phase. Thus, since A_V is a positive number, the phase of $-\beta$ from Eq. (14-71) must be zero, but the magnitude must not be zero. This is accomplished by taking the ratio $R_2/(R_1 + R_2)$ smaller than $\frac{1}{3}$.

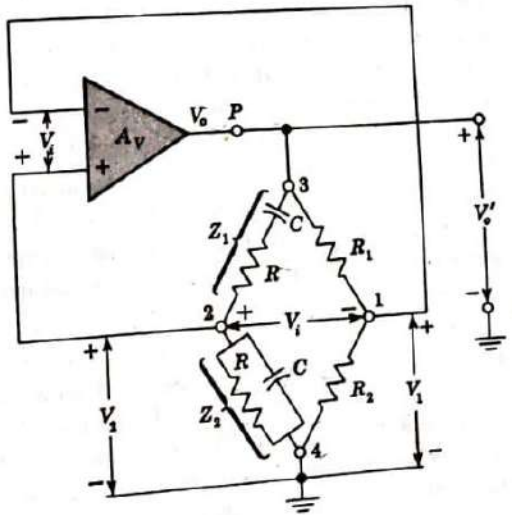

Fig. 14-34 Wien bridge oscillator using an operational amplifier as the active element.

If we let

$$\frac{V_1}{V_o'} = \frac{R_2}{R_1 + R_2} = \frac{1}{3} - \frac{1}{\delta}$$

where δ is a number greater than 3, then

$$-\beta = \frac{V_2 - V_1}{V_o'} = \frac{V_2}{V_o'} - \frac{1}{3} + \frac{1}{\delta} \tag{14-73}$$

At $\omega = \omega_o$, $V_2/V_o' = \frac{1}{3}$ and $\beta = -1/\delta$. The condition $-\beta A = 1$ is now satisfied by making

$$\delta = A_V \tag{14-74}$$

Note that the frequency of oscillation is precisely the null frequency of the balanced bridge, given by Eq. (14-72). At any other frequency V_2 is not in phase with V_o', and therefore $V_i = V_2 - V_1$ is not in phase with V_o', so that the condition $-\beta A = 1$ is satisfied only at the one frequency f_o.

Continuous variation of frequency is accomplished by varying simultaneously the two capacitors (ganged variable air capacitors). Changes in frequency range are accomplished by switching in different values for the two identical resistors R.

Solved Problems

▶ **Example 1.** *An inverting amplifier has* $R_1 = 20\,\text{k}\Omega$ *and* $R_f = 100\,\text{k}\Omega$. *Find the output voltage and the input current for an input voltage of* 1 V. **(Punjab Univ.)**

Solution: Here, the input resistance, $R_1 = 20\,\text{k}\Omega$

Feedback resistance, $R_f = 100\,\text{k}\Omega$

and the input voltage, $v_i = 1\,\text{V}$.

The closed-loop voltage gain of an inverting amplifier gives,

$$\frac{v_0}{v_i} = -\frac{R_f}{R_1}$$

$$\therefore \text{ Output voltage, } v_0 = -v_i \frac{R_f}{R_1} = -\left(1 \times \frac{100 \times 10^3}{20 \times 10^3}\right) = -5\text{V}$$

$$\text{The } \textit{input current} = \frac{v_i}{R_1} = \frac{1}{20 \times 10^3}\,\text{A} = \mathbf{0.05\ mA}$$

▶ **Example 2.** *Calculate the actual output voltage of an integrator after* 2 sec *for the input voltage of* 1 V d.c. *Given that the input resistance* $= 100\,\text{k}\Omega$ *and the feedback capacitance* $= 1\,\mu\text{F}$. **(Calcutta Hons.)**

Solution: Given, the input resistance, $R = 100\,\text{k}\Omega = 100 \times 10^3\,\Omega$

Feedback capacitance, $C = 1\,\mu\text{F} = 1 \times 10^{-6}\,\text{F}$

Input voltage $v_i = 1\,\text{V}$ and time $t = 2\,\text{s}$

$$\therefore \text{ The output voltage, } v_0 = -\frac{1}{CR}\int_0^t v_i\,dt$$

$$= -\frac{1}{10^{-6} \times 100 \times 10^3}\int_0^2 1\,dt$$

$$= -\frac{1}{10^{-1}} \times 2\text{ volt} = \mathbf{-20\ volt}$$

► **Example 3.** *A ramp voltage of* 1.5 V (*as shown in* Fig. 12.12) per millisecond *is applied to an OP AMP differentiator for having* $R = 2\,\text{k}\Omega$ *and* $C = 0.01\,\mu\text{F}$. *Find the output voltage and its waveform.* **(Calcutta Hons.)**

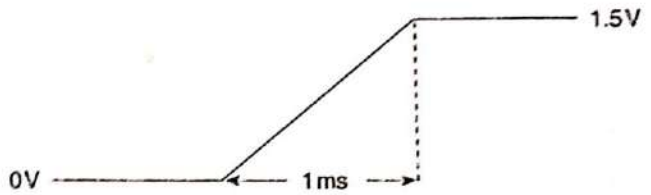

Fig. 12.12

Solution: From Fig. 12.12, $\dfrac{dv_i}{dt} = \dfrac{1.5\,\text{V}}{1\,\text{ms}} = 1.5\,\text{V/ms}$, for $0 < t < 1\,\text{ms}$

and $\dfrac{dv_i}{dt} = 0$, for outside this interval.

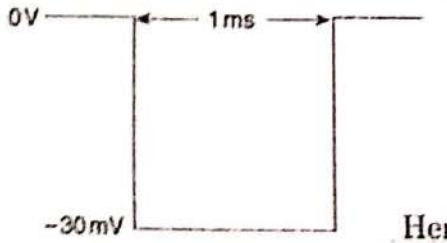

Fig. 12.13

Given, $R = 2\,\text{k}\Omega = 2 \times 10^3\,\Omega$

and $C = 0.01\,\mu\text{F} = 0.01 \times 10^{-6}\,\text{F}$.

$\therefore\ RC = 2 \times 10^3 \times 0.01 \times 10^{-6}\,\text{s} = 0.02\,\text{ms}$

Hence the *output voltage* for $0 < t < 1$ ms is given by

$$v_0 = -RC\frac{dv_i}{dt} = -(0.02 \times 1.5)\,\text{V} = -0.03\,\text{V} = \mathbf{-30\,mV}$$

Otherwise, however, $\boldsymbol{v_0 = 0}$.

The waveform of the output voltage is illustrated in Fig. 12.13 above.

► **Example 5.** *Show that the output voltage of the circuit in Fig.* 12.15 *is given by*

$$v_0 = v_2 \cdot \frac{R_1 + R_2}{R_3 + R_4} \cdot \frac{R_4}{R_1} - v_1 \cdot \frac{R_2}{R_1}$$

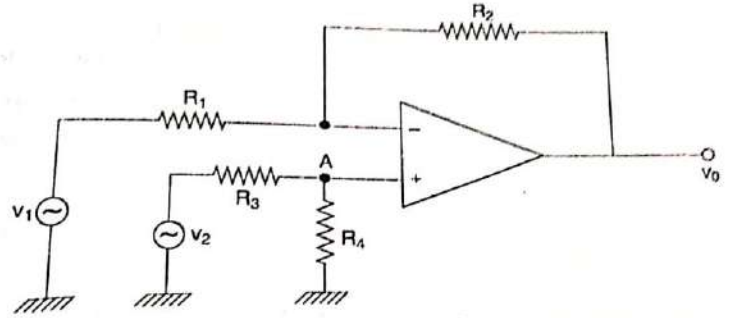

Fig. 12.15

Solution: The resultant output voltage is obtained by the superposition principle.

The input voltage v_1 alone produces an output given by

$$v' = -\frac{R_2}{R_1}v_1.$$

The voltage at the non-inverting terminal is given by

$$v_A = \frac{v_2}{R_3 + R_4}R_4.$$

But v_A alone produces an output given by

$$v'' = \left(1 + \frac{R_2}{R_1}\right)v_A = \frac{v_2 R_4}{R_3 + R_4} \cdot \frac{R_1 + R_2}{R_1}$$

$$= v_2 \cdot \frac{R_1 + R_2}{R_3 + R_4} \cdot \frac{R_4}{R_1}$$

The resultant output v_0 is given by $v_0 = v'' + v'$.

$$\therefore\ \boldsymbol{v_0 = v_2 \frac{R_1 + R_2}{R_3 + R_4} \cdot \frac{R_4}{R_1} - v_1 \frac{R_2}{R_1}}$$

1. The inverting amplifier circuit of Fig. 14.6 has $R_1 = 1\ \text{k}\Omega$ and $R_f = 3\ \text{k}\Omega$. Determine the output voltage, the input resistance, and the input current for an input voltage of 2 V.

Ans. The output voltage is

$$v_0 = -(R_f/R_1)\, v_1 = -(3/1) \times 2 = -6\ \text{V}$$

The input resistance is

$$R_{in} \approx R_1 = 1\ \text{k}\Omega.$$

The input current is

$$i = \frac{v_1}{R_1} = \frac{2}{1}\ \text{mA} = 2\ \text{mA}.$$

2. The noninverting amplifier circuit of Fig. 14.7 has $R_f = 5\ \text{k}\Omega$ and $R_1 = 2\ \text{k}\Omega$. What is the voltage gain?

Ans. The voltage gain is

$$A_v = 1 + \frac{R_f}{R_1} = 1 + \frac{5}{2} = 3.5$$

3. When a voltage $v_1 = +40\ \mu\text{V}$ is applied to the noninverting input terminal and a voltage $v_2 = -40\ \mu\text{V}$ is applied to the inverting input terminal of an OP AMP, an output voltage $v_0 = 100\ \text{mV}$ is obtained. But, when $v_1 = v_2 = +40\ \mu\text{V}$, one obtains $v_0 = 0.4\ \text{mV}$. Calculate the voltage gains for the difference and the common-mode signals, and the common-mode rejection ratio.

Ans. In the first case, the difference signal is $v_d = v_1 - v_2 = 40 - (-40) = 80\ \mu\text{V}$ and the common-mode signal is $v_c = (v_1 + v_2)/2 = (40\text{-}40)/2 = 0$. The output voltage is

$$v_0 = A_d v_d + A_c v_c, \qquad \text{(i)}$$

Where A_d and A_c are the voltage gains for the difference signal and the common-mode signal, respectively, Substituting the values of v_0, v_d and v_c for the first case in (i), we obtain

$$100 \times 10^3 = A_d \times 80 + A_c \times 0.$$

or,
$$A_d = \frac{10^5}{80} = 1250$$

In the second case, $v_d = v_1 - v_2 = 40\text{-}40 = 0$ and $v_c = (v_1 + v_2)/2 = (40 + 40)/2 = 40\ \mu\text{V}$. Putting the values in (i) gives

$$0.4 \times 10^3 = A_d \times 0 + A_C \times 40$$

or,
$$A_c = \frac{0.4 \times 10^3}{40} = 10$$

The common-mode rejection ratio is

$$\text{CMRR} = \left|\frac{A_d}{A_c}\right| = \frac{1250}{10} = 125.$$

4. Find the output voltage v_0 of the three-input summing amplifier circuit of Fig. 14.18.

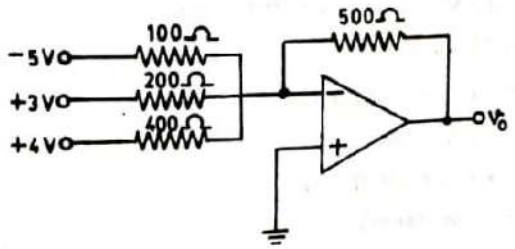

Fig 14.18

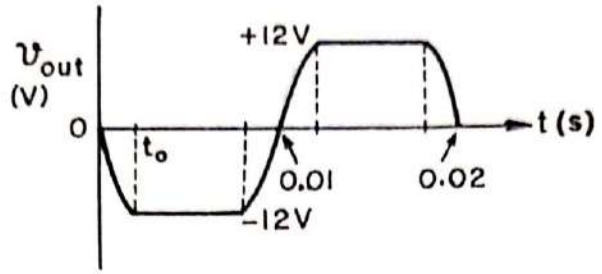

Fig. 14.20

The variation of v_{out} with t over a full cycle ($0 \le t \le 0.02$s) in shown in Fig. 14.20.

6. A ramp voltage of 1.5 V (as shown in Fig. 14.21) per millisecond is applied to an OP AMP differentiator having $R = 2\ \text{k}\Omega$ and $C = 0.01\ \mu\text{F}$. Find the output voltage and its waveform. (C.U. 1999)

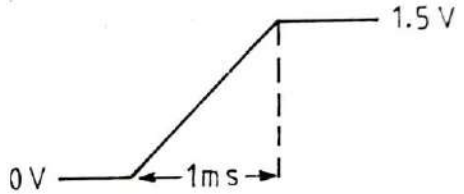

Fig. 14.21

Ans. The output voltage is $v_0 = -RC\frac{dv_i}{dt}$.

Here v_i is as shown in Fig. 14.21. For $0 < t < 1$ ms, $\frac{dv_i}{dt} = \frac{1.5\text{V}}{1\text{ms}}$; otherwise $\frac{dv_i}{dt} = 0$.

Also, $RC = 2 \times 0.01$ ms.

Hence $v_0 = -0.02 \times 1.5 = -0.03$ V $= -30$ mV for $0 < t < 1$ ms, Otherwise, $v_0 = 0$.

The waveform of v_0 is shown in Fig. 14.22.

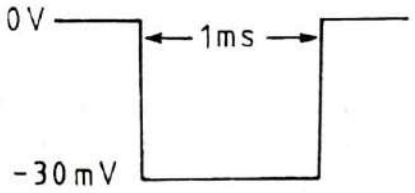

Fig. 14.22

Ans. Equation (14.17) gives for the output voltage

$$v_0 = -\left(\frac{500}{100}\times -5 + \frac{500}{200}\times 3 + \frac{500}{400}\times 4\right)$$

$$= -(-25 + 7.5 + 5) = 12.5 \text{ V}$$

5. Compute the voltage gain for the amplifier shown in Fig 14.19. Find the output voltage v_{out} if the input voltage is $v_{in} = 0.5 \sin 100\,\pi t$ volt. (C.U. 1996).

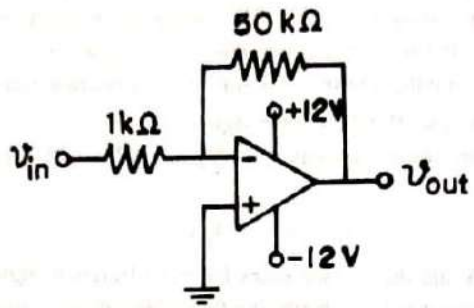

Fig. 14.19

Ans. The voltage gain of the given inverting amplifier is

$$A = -\frac{50\ k\Omega}{1\ k\Omega} = -50.$$

If the operation were entirely linear, the output voltage would have been

$$v_{out} = A\ v_{in} = -50 \times 0.5 \sin 100\,\pi\, t = -25 \sin 100\,\pi t \text{ V}.$$

But since the supply voltage is ± 12V, the OP AMP is saturated when $|v_{out}|$ attains 12 V. Let at time $t = t_0$, $v_{out} = -12$V. Then

$$-12 = -25 \sin 100\,\pi t_0$$

or,
$$t_0 = \frac{1}{100\,\pi} \sin^{-1}\left(\frac{12}{25}\right) = 1.59 \times 10^{-3}\ s.$$

Thus over the entire cycle, we have $v_{out} = -25 \sin 100\,\pi t$ V when $0 \le t \le t_0$

$= -12$ V when $t_0 \le t \le (0.01 - t_0)$.

$= -25 \sin 100\,\pi t$ V

when $0.01 - t_0 \le t \le 0.01 + t_0$

$= +12$ V when

$0.01 + t_0 \le t \le 0.02 - t_0$

$= -25 \sin 100\,\pi t$V

When $0.02 - t_0 \le t \le 0.02$ s.

Assignments

PROBLEMS

1. In an OP AMP, when the voltage applied to the noninverting input terminal is $v_1 = 50\ \mu$ V and that applied to the inverting input terminal is $v_2 = -50\ \mu$ V, what is the output voltage, if the voltage gain for the difference signal is A_d? If the common-mode rejection ratio is 1000, calculate the percentage difference of the output voltage obtained with $v_1 = 500\ \mu$V and $v_2 = 400\ \mu$ V. (**Ans.** $100A_d\ \mu$ V; 0.45%)

2. An OP AMP inverting amplifier has an input resistor of 10 kΩ and a feedback resistor of 50 kΩ. If the input voltage is 0.5 V, find the output voltage and the input current. (C.U. 1991) (**Ans** - 2.5 V, 50 μ A)

3. In the difference amplifier circuit of Fig 14.10, $R_2 = 2$ kΩ and $R_1 = 500\ \Omega$. Calculate the voltage gain of the amplifier. If $v_1 = -0.3$ V and $v_2 = 0.5$ V, what is the output voltage? (**Ans.** 4; 3.2V)

4. If v_1 and v_2 are two voltages (with respect to ground), how would you construct an OP AMP circuit to get the voltage $v_0 = 2v_1 - v_2$?

An OP AMP inverting amplifier has an input resistor of 10 kΩ and a feedback resistor of 50 kΩ. If the input voltage is 0.5 V, find the output voltage and the input current.
(Calcutta Hons.) [−2.5 V, 50μA]

2. Compute the voltage gain for the amplifier shown in Fig. 12.18. Find the output voltage v_{out} if the input voltage is $v_{in} = 0.5 \sin 100\pi t$ volt.

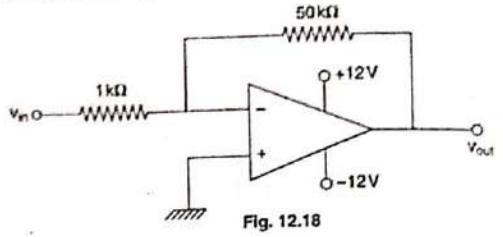

Fig. 12.18

(Calcutta Hons.) [$-25 \sin 100\pi t$ for linear operation]

3. Calculate the voltage v_0 in the following circuit of Fig. 12.19.

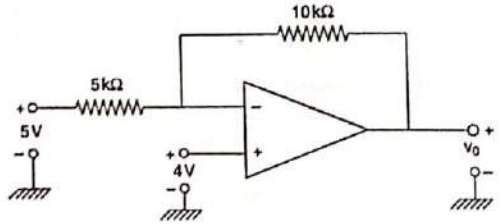

Fig. 12.19 (Calcutta Hons.) [2 V]

4. In the circuit of Fig. 12.9, $R = 100\,\text{k}\Omega$ and $C = 1\,\mu\text{F}$. If the input voltage v_i is a ± 10 V, 250 Hz square wave, determine the output voltage v_0. (Calcutta Hons.)

[A triangular wave of amplitude 0.2 V and frequency 250 Hz]

5. Design an OP AMP circuit which will give an output voltage $v_0 = 0.5v_1 - 2v_2$ for two input voltages v_1 and v_2. (Calcutta Hons.)

6. In the following circuit of Fig. 12.20, determine the value of V_0 in volt.

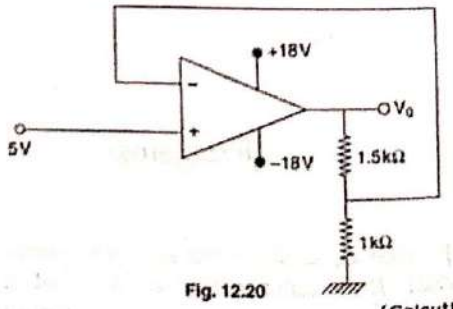

Fig. 12.20

(Calcutta Hons.) [12.5 V]

7. If, in the circuit of Fig. 12.21, the resistance R changes from 1 kΩ to 2 kΩ, explain whether the current through the 500Ω resistance will change. Find the voltage V_0 in each case.

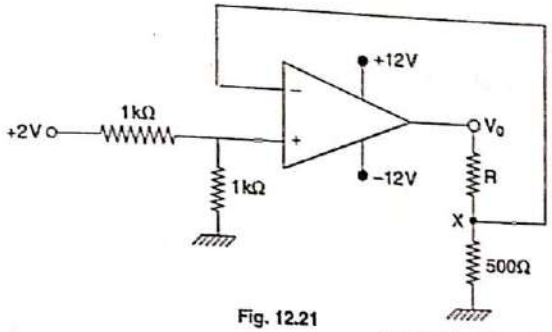

Fig. 12.21

(Calcutta Hons.) [No; 3V, 5V]

8. A voltage $5 \sin 2000\pi t$ mV is applied to the input of an OP AMP integrator (Fig. 12.9) for which $R = 100\,\text{k}\Omega$ and $C = 1\,\mu\text{F}$. Calculate the output voltage.

(Agra Univ.) $\left[\frac{1}{40\pi}(\cos 2000\pi t - 1)\,\text{mV}\right]$

9. What is the output voltage in the circuit of Fig. 12.22? Explain the operation of the circuit.

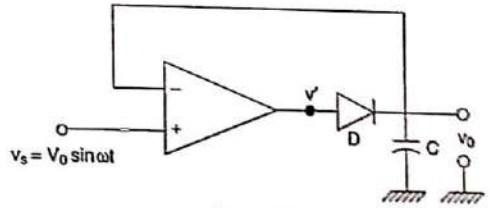

Fig. 12.22 (Calcutta Hons.)

10. An inverting OP AMP has an input resistor of 10 kΩ and a feedback resistor of 100 kΩ. If the input voltage is 0.5 V, find the output voltage and the input current. (Calcutta Hons.) [-5V, 50μA]

11. Design a circuit using one or more OP AMPs whose output is given as $v_0 = 2v_1 + 5v_2$ where v_1 and v_2 are the two inputs. (Burdwan Hons.)

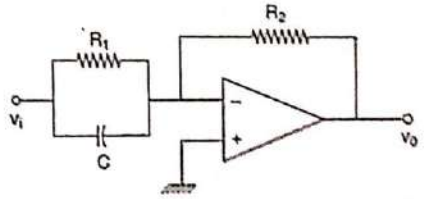

Fig. 12.23

12. For the circuit of Fig. 12.23, show that the output voltage is

$$v_0 = -\frac{R_2}{R_1} v_i - CR_2 \frac{dv_i}{dt}.$$

If the input is a ramp of the form $v_i = \alpha t$ where α is a positive constant, find the output voltage v_0. (GATE)