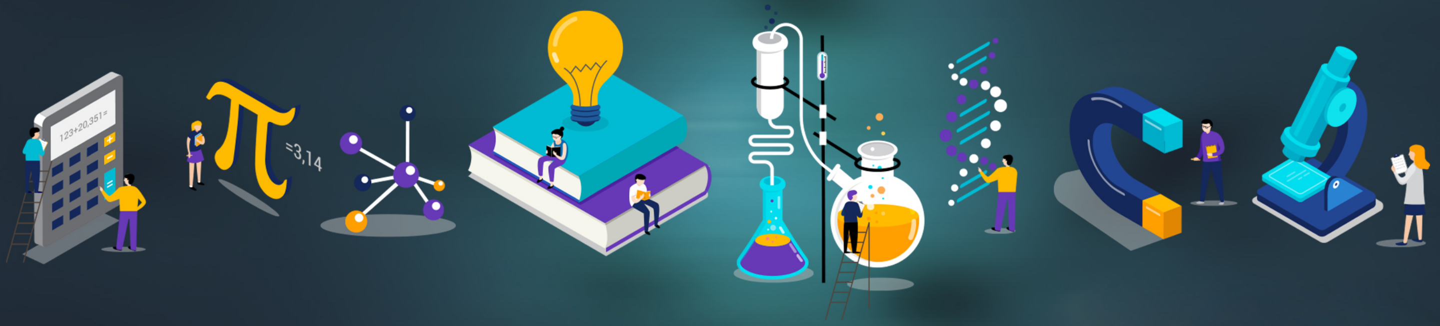


1. Operational Amplifier

1.1 Introduction

An operational amplifier is a direct-coupled high-gain amplifier usually consisting of one or more differential amplifiers.
The operational amplifier is a versatile device that can be used to amplify dc as well as ac input signals and was originally designed for performing mathematical operations such as addition, subtraction, multiplication, and integration. Thus the name operational amplifier stems from its original use for these mathematical operations and is abbreviated to $op-amp$. With the addition of suitable external feedback components, the modern day op-amp can be used for a variety of applications, such as ac and dc signal amplification, active filters, oscillators, comparators, regulators, and others.

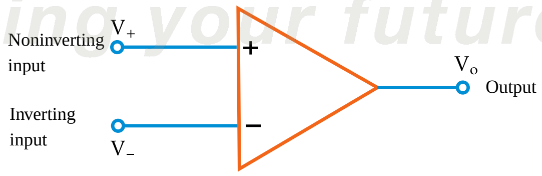


Figure 1.1: Schematic diagram of an an op-amp

A schematic diagram of an an op-amp is shown in the figure.1.1.
For simplicity, power supply and other pin connections are omitted. Since the input differential amplifier stage of the op-amp is designed to be operated in the differential mode, the differential inputs are designated by the $(+)$ and $(-)$ notations. The $(+)$ input is the noninverting input. An ac signal (or dc voltage) applied to this input produces an in-phase (or same polarity) signal at the output. On the other hand, the $(-)$ input is the inverting input because an ac signal (or dc voltage) applied to this input produces an 180° out-of-phase (or opposite polarity) signal at the output. In Figure,

$$V_+ = \text{Voltage at the noninverting input (volts)}$$
$$V_- = \text{Voltage at the inverting input (volts)}$$
$$V_o = \text{Output voltage (volts)}$$

All these voltages are measured with respect to ground.

1.2 Op-Amp characterestics

1.2.1 Input offset voltage

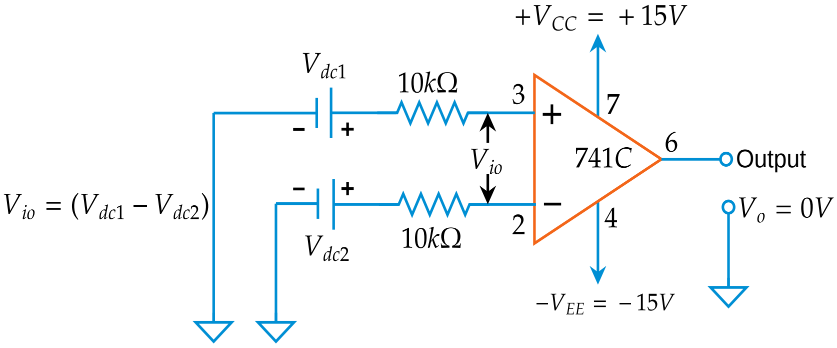


Figure 1.2: Defining input offset voltage

Input offset voltage is the voltage that must be applied between the two input terminals of an op-amp to null the output, as shown in Figure.1.2. In the figure V_{dc1} and V_{dc2} are dc voltages and R_S represents the source resistance. We denote input offset voltage by V_{io}. This voltage V_{io} could be positive or negative; therefore, its absolute value is listed on the data sheet. For a 741C the maximum value of V_{io} is 6mVdc. The smaller the value of V_{io}, the better the input terminals are matched. For instance, the 714C precision op-amp has $V_{io} = 150\mu$V maximum.

1.2.2 Input offset current

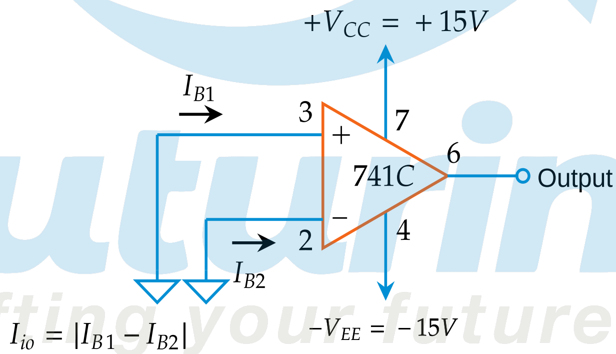


Figure 1.3: Defining input offset current

The algebraic difference between the currents into the inverting and noninverting terminals is referred to as input offset current, I_{io}. In the form of an equation,

$$I_{io} = |I_{B1} - I_{B2}|$$

where I_{B1} is the current into the noninverting input and I_{B2} is the current into the inverting input.

1.2.3 Input bias current

Input bias current, I_B, is the average of the currents that flow into the inverting and noninverting input terminals of the op-amp. In equation form,

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

$I_B = 500$nA maximum for the 741C, whereas I_B for the precision 714C is ± 7nA.
Note that the two input currents I_{B1} and I_{B2} are actually the base currents of the first differential amplifier stage.

1.2.4 Differential input resistance

Differential input resistance, R_i, (often referred to as input resistance) is the equivalent resistance that can be measured at either the inverting or noninverting input terminal with the other terminal connected to oround. For the 741C the input resistance is a relatively high 2MΩ.

1.2.5 Common Mode Rejection Ratio (CMRR)

The common-mode rejection ratio (CMRR) is defined in several essentially equivalent ways by various manufacturers. Generally, it can be defined as the ratio of the differential voltage gain A_d to the common-mode voltage gain A_{cm} that is,

$$\mathrm{CMRR} = \frac{A_d}{A_{\mathrm{cm}}} \tag{1.1}$$

The differential voltage gain A_d is the same as the large-signal voltage gain A, which is specified on the data sheets; however, the common-mode voltage gain can be determined from using the equation,

$$\mathrm{A}_{\mathrm{cm}} = \frac{V_{\mathrm{ocm}}}{V_{\mathrm{cm}}} \tag{1.2}$$

$$\text{Where },V_{\mathrm{ocm}} = \text{output common-mode voltage}$$
$$V_{\mathrm{cm}} = \text{ input common-mode voltage}$$
$$A_{\mathrm{cm}} = \text{ common-mode voltage gain}$$

Generally the A_{cm} is very small and $A_d = A$ is very large, therefore, the CMK is very large. Being a large value, CMRR is most often expressed in decibels (dB). For the 741C, CMRR is 90 dB typically.

Note **Common mode voltage:** When the same voltage is applied to both input terminals, the voltage is called a common-mode voltage, V_{cm}, and the op-amp is said to be operating in the common-mode configuration.

1.2.6 Output resistance

Output resistance, R_o, is the equivalent resistance that can be measured between the output terminal of the op-amp and the ground (or common point). It is 75Ω for the 741C op-amp.

1.2.7 Slew rate

Slew rate (SR) is defined as the maximum rate of change of output voltage per unit of time and is expressed in volts per microseconds. In equation form,

$$\mathrm{SR} = \left.\frac{dV_o}{\mathrm{dt}}\right|_{\mathrm{max}} \mathrm{V}/\mu\mathrm{s}$$

Slew rate indicates how rapidly the output of an op-amp can change in response to changes in the input frequency. The slew rate changes with change in voltage gain and is normally specified at unity $(+1)$ gain. The slew rate of an op-amp is fixed; therefore, if the slope requirements of the output signal are greater than the slew rate, then distortion occurs. Thus slew rate is one of the important factors in selecting the op-amp for ac applications, particularly at relatively high frequencies.
One of the drawbacks of the 741C is its low slew rate $(0.5\ \mathrm{V}/\mu\mathrm{s})$

1.3 The ideal Op-Amp

An ideal op-amp would exhibit the following electrical characteristics,

1. Infinite voltage gain A.
2. Infinite input resistance R_i so that almost any signal source can drive it and there is no loading of the preceding stage.
3. Zero output resistance R_o so that the output can drive an infinite number of other devices.
4. Zero output voltage when input voltage is zero.
5. Infinite bandwidth so that any frequency signal from 0 to ∞Hz can be amplified without attenuation.

6. Infinite common-mode rejection ratio so that the output common-mode noise voltage is zero.

7. Infinite slew rate so that output voltage changes occur simultaneously with input voltage changes.

There are practical op-amps that can be made to approximate some of these characteristics using a negative feedback arrangement.

1.4 Open-Loop Op-Amp Configurations(Op-Amp without feedback)

In the case of amplifiers the term open loop indicates that no connection, either direct or via another network, exists between the output and input terminals. That is, the output signal is not fed back in any form as part of the input signal, and the loop that would have been formed with feedback is open. When connected in open-loop configuration, the op-amp simply functions as a high-gain amplifier. There are three open-loop op-amp configurations,

1. Differential amplifier

2. Inverting amplifier

3. Noninverting amplifier.

1.4.1 Differential Amplifier

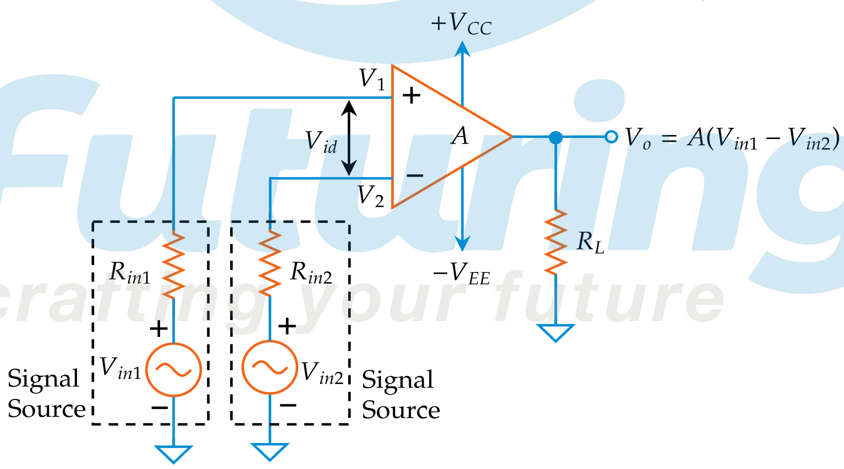


Figure 1.4: Differential Amplifier

The differential amplifier circuit amplifies the difference between signals applied to the inputs. The figure.1.4 shows the open-loop differential amplifier in which input signals $V_{\text{in }1}$ and $V_{\text{in }2}$ are applied to the positive and negative input terminals. Since the op-amp amplifies the difference between the two input signals, this configuration is called the differential amplifier.
The op-amp is a versatile device because it amplifies both ac and dc input signals. This means that $V_{\text{in }1}$ and $V_{\text{in }2}$ could be either ac or dc voltages. The source resistances $R_{\text{in }1}$ and $R_{\text{in }2}$ are normally negligible compared to the input resistance R_i. Therefore, the voltage drops across these resistors can be assumed to be zero, which then implies that $V_1 = V_{\text{in }1}$ and $V_2 = V_{\text{in }2}$. Then output voltageV_o

$$V_o = A\left(V_{\text{in }1} - V_{\text{in }2}\right) \tag{1.3}$$

Thus, as expected, the output voltage is equal to the voltage gain A times the difference between the two input voltages. Also, notice that the polarity of the output voltage is dependent on the polarity of the input difference voltage $\left(V_{\text{in }1} - V_{\text{in }2}\right)$. In open-loop configurations, gain **A** is commonly referred to as **open-loop gain**.

1.4.2 Inverting Amplifier

In an inverting amplifier only one input is applied and that is to the inverting input terminal. The noninverting input terminal is grounded . Since $V_1 = 0$ V, and $V_2 = V_{\text{in}}$

$$V_o = -AV_{\text{in}} \tag{1.4}$$

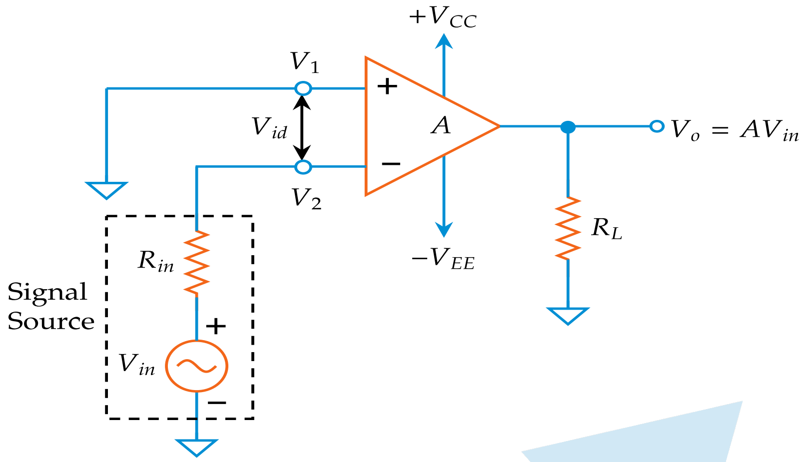


Figure 1.5: Inverting Amplifier

The negative sign indicates that the output voltage is out of phase with respect to input by 180° or is of opposite polarity. Thus in the inverting amplifier the input signal is amplified by gain A and is also inverted at the output.

1.4.3 Non-inverting Amplifier

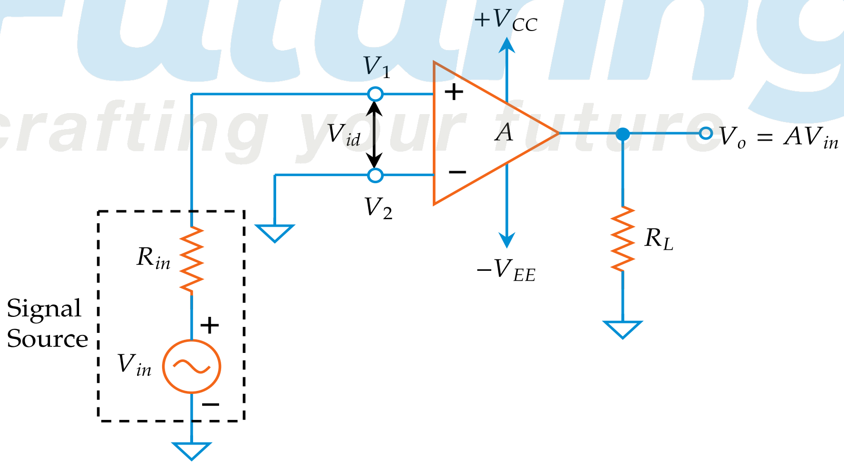


Figure 1.6: Non-inverting Amplifier

In Non-inverting configuration the input is applied to the noninverting input terminal, and the inverting terminal is connected to ground. Figure.1.6 shows the open-loop noninverting amplifier. In the circuit , $V_1 = V_{\text{in}}$ and $V_2 = 0$ V. Therefore,

$$V_o = AV_{\text{in}} \tag{1.5}$$

This means , the output voltage is larger than the input voltage by gain A and is in phase with the input signalIn all three open-loop configurations any input signal (differential or single) that is only slightly greater than zero drives the output to saturation level. This results from the very high gain (A) of the op-amp. Thus, when operated open-loop, the output of the op-amp is either negative or positive saturation or switches between positive and negative saturation levels. For this reason, open-loop op-amp configurations are not used in linear applications.

1.4.4 Drawback of Open-Loop Configuration

- Due to the high gain of the Open-loop configuration some portion is clipped out off when the output attempts to exceed the saturation level of the Op-Amp.
- The open-loop voltage gain of the op-amp is not constant.Voltage gain varies with change in temperature and power supply.Which makes opn -loop op-amp unsuitable for linier application.
- The bandwidth(Bnad frequencies for which the gain remains constant) of most open loop op-amp is negligibly small–almost zero.For this reason Open-loop op-amp is impractical in ac application

For this reasons stated open-loop op-amp is not used in linear applications.Nevertless in certain applications the open-loop op-amp is purposely used as a non linear device.

1.5 Negative Feedback Op-Amp

1.5.1 Benefits of the Negative Feedback

- High gain of the open-loop confihuration is controlled by introducing a negative feedback.
- If the signal feedback is of opposite polarity with respect to the input signal the feedback is called negative feedback
- A negative feedback is also known as degenerative feedback because when used it reduces the output voltage amplitude and in turn reduces the voltage gain.
- When used in amplifiers negative feedback stabilizes the gain,increases the bangwidth and changes the input output resistance.
- Negative feedback decreases harmonic or non linear distortion.
- Negative feedback also reduces the efffect of variation in temperature and supply voltages on the output of the op-amp.

1.5.2 Inverting Amplifier

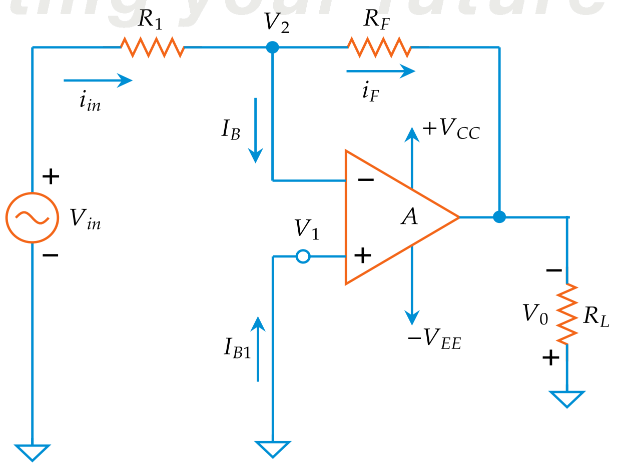


Figure 1.7: Negative feedback Inverting Amplifier

Figure shows the voltage-shunt feedback amplifier using an op-amp. The input voltage drives the inverting terminal, and the amplified as well as inverted output signal is also applied to the inverting input via the feedback resistor R_F. This arrangement forms a negative feedback because any increase in the output signal results in a feedback signal into the inverting input, causing a decrease in the output signal.
Note that the noninverting terminal is grounded, and the feedback circuit has only one resistor R_F. However, an extra resistor R_1 is connected in series with the input signal source V_{in} .

Closed Loop Voltage Gain

The closed-loop voltage gain A_F of the voltage-shunt feedback amplifier can be obtained by writing Kirchhoff's current equation at the input node V_2 as follows,

$$i_{\text{in}} = i_F + I_B$$

Since R is very large the input bias current I_B is negligibly small

$$\begin{aligned} i_{\text{in}} &\cong i_F \\ \frac{V_{\text{in}} - V_2}{R_1} &= \frac{V_2 - V_o}{R_F} \\ \text{However we know } V_1 - V_2 &= \frac{V_o}{A} \\ \text{Since } V_1 = 0 \text{ V } V_2 &= -\frac{V_o}{A} \end{aligned}$$

Substituting this value of V_2 in above Equation and rearranging, we get,

$$\begin{aligned} \frac{V_{\text{in}} + V_o/A}{R_1} &= \frac{-(V_o/A) - V_o}{R_F} \\ A_F &= \frac{V_o}{V_{\text{in}}} \\ &= -\frac{AR_F}{R_1 + R_F + AR_1} \qquad \text{(exact)} \end{aligned}$$

The negative sign in Equation indicates that the input and output signals are out of phase by 180° (or of opposite polarities). In fact, because of this phase inversion, the configuration in Figure is commonly called an inverting amplifier with feedback. Since the internal gain A of the op-amp is very large (ideally infinity), $AR_1 \gg R_1 + R_F$. This means that Equation can be rewritten as,

$$A_F = \frac{V_o}{V_{\text{in}}} = -\frac{R_F}{R_1} \qquad \text{(ideal)} \tag{1.6}$$

$$\boxed{A_F = \frac{V_o}{V_{\text{in}}} = -\frac{R_F}{R_1}}$$

Note

- Since the ratio $\frac{R_F}{R_1}$ can be set in to less than 1 it can use for more applications that cant be used by a non inverting amplifier.
- **The inverting input terminal is at virtual ground**

$$V_{id} = \frac{V_o}{A}$$

Since the value of A is very high,V_{id} is approximately zero.So the potential at each terminal should be same. Here the therminal v_1 is grounded.The voltage at V_2 should be also zero.Therfore the the terminal V_2 is said to be grounded virtually. This idea can be used to find the voltage gain easily. From the circuit ,

$$i_{in} = i_f \frac{V_{in} - V_2}{R_1} \qquad = \frac{V_2 - V_o}{R_F}$$

$$\begin{aligned} V_1 = V_2 &= 0 \\ \frac{V_{in}}{R_1} &= -\frac{V_o}{R_F} \\ A_F = \frac{V_o}{V_{in}} &= -\frac{R_F}{R_1} \end{aligned}$$

This is the same result that we got before.

Input resistance

The input resistance with feedback can be written as

$$R_{iF} = R_1 + \frac{R_F}{1+A}||R_i$$

Since R_i and A are very large.

$$\frac{R_F}{1+A}||R_i \approx 0\Omega$$

Then

$$R_{iF} = R_1$$

Output resistance

$$R_{oF} = \frac{R_0}{1+AB}$$

Where,
R_O=Output resistance of the op-amp with out feedback
A= Open-loop voltage gain of the op-amp
B= Gain of the feedback circuit

$$B = \frac{R_1}{R_1+R_F}$$

Bandwidth

We know that the gain of the amplifier with feedback is less than the gain without feedback.Therfore the bandwidth of the amplifier with feedback f_F must be larger than that without the feedback.

$$f_F = f_0(1+AB)$$

Where f_0=Break frequency of the op-amp.
which can be defined as

$$\begin{aligned} f_0 &= \frac{\text{Unit gain bandwidth}}{\text{Open-loop voltage gain}} \\ &= \frac{UGB}{A} \\ f_F &= \frac{UGB}{A}(1+AB) \\ f_F &= \frac{UGB(K)}{A} \\ \text{Where, } K &= \frac{R_F}{R_1+R_F} \\ A_F &= \frac{AK}{1+AB} \end{aligned}$$

1.5.3 Non-inverting amplifier

The noninverting amplifier with feedback (or closed-loop noninverting amplifier)called so because it uses feedback, and the input signal is applied to the noninverting input terminal of the op-amp.

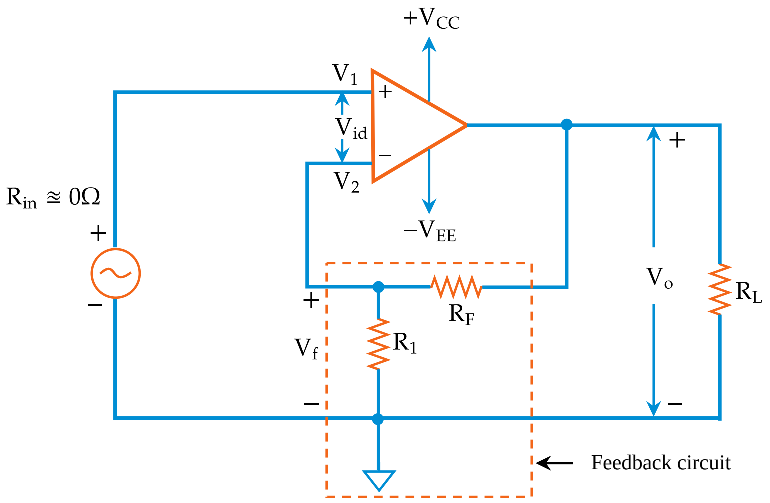


Figure 1.8: Voltage series Non Inverting Amplifier

Important terms for the voltage-series feedback amplifier:

$$V_{\text{in}} = \text{Input voltage.}$$
$$V_{\text{f}} = \text{Feedback voltage.}$$
$$V_{\text{id}} = \text{Difference input voltage.}$$
$$\text{Open-loop voltage gain (or gain without feedback) } A = \frac{V_o}{V_{id}}$$
$$\text{Here, } V_{id} = V_{\text{in}} - V_f$$
$$\text{Closed-loop voltage gain (or gain with feedback) } A_F = \frac{V_o}{V_{\text{in}}}$$
$$\text{Gain of the feedback circuit } B = \frac{V_f}{V_o}$$

Voltage gain

As defined previously, the closed-loop voltage gain is,

$$A_F = \frac{V_o}{V_{\text{in}}}$$
$$\text{But, } V_o = A\left(V_1 - V_2\right)$$
$$V_1 = V_{\text{in}}$$
$$V_2 = v_f = \frac{R_1 V_o}{R_1 + R_F} \quad \text{since } R_i \gg R_1$$
$$\text{Therefore, } V_o = A\left(V_{\text{in}} - \frac{R_1 V_o}{R_1 + R_F}\right)$$
$$\text{Rearranging we get, } V_o = \frac{A\left(R_1 + R_F\right) V_{\text{in}}}{R_1 + R_F + AR_1}$$
$$A_F = \frac{V_o}{V_{\text{in}}} = \frac{A\left(R_1 + R_F\right)}{R_1 + R_F + AR_1} \quad \text{(exact)}$$

Generally, A is very large (typically 10^5). Therefore,

$$AR_1 \gg \left(R_1 + R_F\right) \quad \text{and} \quad \left(R_1 + R_F + AR_1\right) \cong AR_1$$
$$\text{Thus, } A_F = \frac{V_o}{V_{\text{in}}}$$
$$= 1 + \frac{R_F}{R_1} \quad \text{(ideal)}$$

Note

- **A_F in terms of B**

  Feedback circuit gain B is the ratio of V_f and V_o

$$\begin{aligned} B &= \frac{V_f}{V_o} \\ &= \frac{R_1}{R_1+R_F} \\ A_F &= \frac{1}{B} \end{aligned}$$

- **A_F in terms of A and B.**

$$\begin{aligned} A_F &= \frac{V_o}{V_{\text{in}}} \\ &= \frac{A\left(R_1+R_F\right)}{R_1+R_F+AR_1} \\ A_F &= \frac{A\left(\frac{R_1+R_F}{R_1+R_F}\right)}{\frac{R_1+R_F}{R_1+R_F}+\frac{AR_1}{R_1+R_F}} \\ \text{Using Equation for B, } A_F &= \frac{A}{1+AB} \\ \text{Where, } A_F &= \text{closed-loop voltage gain} \\ A &= \text{open-loop voltage gain} \\ B &= \text{gain of the feedback circuit} \\ AB &= \text{loop gain} \end{aligned}$$

Difference Input Voltage Ideally Zero.

$$\begin{aligned} \text{We know } v_{id} &= \frac{V_o}{A} \\ \text{Since } A \text{ is very large (ideally infinite), } v_{id} &\cong 0 \\ V_1 &\cong V_2 \\ \text{Then, } V_1 &= V_{\text{in}} \\ V_2 &= v_f \\ &= \frac{R_1 V_o}{R_1+R_F} \end{aligned}$$

Substituting these values of V_1 and V_2 , we get

$$\begin{aligned} V_{\text{in}} &= \frac{R_1 V_o}{R_1+R_F} \\ \text{i.e., } A_F &= \frac{V_o}{V_{\text{in}}} \\ &= 1+\frac{R_F}{R_1} \end{aligned}$$

Input resistance with feedback.

R_i is the input resistance of the op-amp and R_{iF} is the input resistance of the amplifier with feedback.The input resistance with feedback is defined as ,

$$R_{iF} = \frac{V_{\text{in}}}{i_{\text{in}}}$$

$$= \frac{V_{\text{in}}}{v_{id}/R_i}$$

$$\text{However we know ,} V_{id} = \frac{V_o}{A} \quad \text{and} \quad V_o = \frac{A}{1+AB} V_{\text{in}}$$

$$\text{Therefore, } R_{iF} = R_i \frac{V_{\text{in}}}{v_t/A}$$

$$= AR_i \frac{V_{\text{in}}}{AV_{\text{in}}/(1+AB)}$$

$$R_{iF} = R_i(1+AB)$$

Output resistance with feedback

$$R_{oF} = \frac{R_0}{1+AB}$$

Bandwidth

$$\text{UGB} = (A)(f_o) \tag{1.7}$$

Where A = open-loop voltage gain f_o = break frequency of an op-amp or, alternatively, only for a single break frequency op-amp,

$$\text{UGB} = (A_F)(f_F) \tag{1.8}$$

Where A_F = closed-loop voltage gain f_F = bandwidth with feedback Therefore, equating Equations .1.7 and 1.8, $(A)(f_o) = (A_F)(f_F)$

$$f_F = \frac{(A)(f_o)}{A_F} \tag{1.9}$$

However, for the noninverting amplifier with feedback,

$$A_F = \frac{A}{1+AB} \tag{1.10}$$

Therefore, substituting the value of A_F in Equation 1.9, we get

$$f_F = \frac{(A)(f_o)}{A/(1+AB)} \tag{1.11}$$

$$f_F = f_o(1+AB) \tag{1.12}$$

1.5.4 Differential amplifier

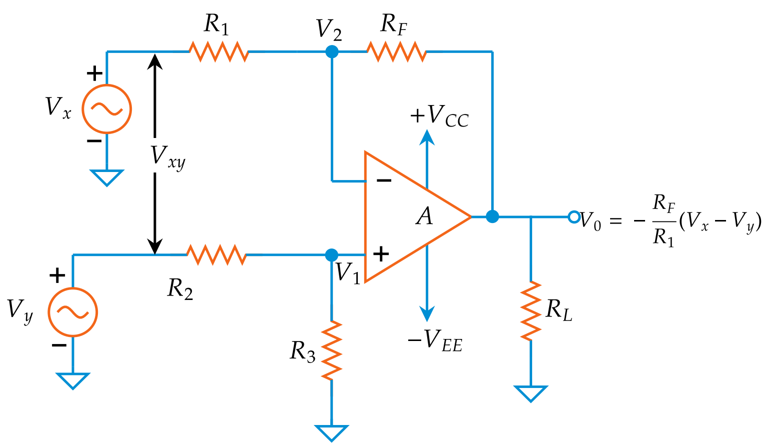


Figure 1.9

A differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. It is a combination of inverting and noninverting amplifiers. That is, when V_x is reduced to zero the circuit is a noninverting amplifier, whereas the circuit is an inverting amplifier when input V_y is reduced to zero.

Voltage Gain

The circuit in Figure has two inputs, V_x and V_y; we will, therefore, use the superposition theorem in order to establish the relationship between inputs and output. When $V_y = 0$ V, the configuration becomes an inverting amplifier; hence the output due to V_x only is

$$V_{ox} = -\frac{R_F\,(V_x)}{R_1} \tag{1.13}$$

Similarly, when $V_x = 0$ V, the configuration is a noninverting amplifier having a voltage-divider network composed of R_2 and R_3 at the noninverting input. Therefore,

$$V_1 = \frac{R_3\,(V_y)}{R_2 + R_3} \tag{1.14}$$

and the output due to V_y then is

$$V_{oy} = \left(1 + \frac{R_F}{R_1}\right) V_1 \text{That is, } V_{oy} \qquad = \frac{R_3}{R_2 + R_3}\left(\frac{R_1 + R_F}{R_1}\right) V_y$$

Since $R_1 = R_2$ and $R_F = R_3$,

$$\begin{aligned} V_{oy} &= \frac{R_F\,(V_y)}{R_1} \\ V_o &= V_{ox} + V_{oy} \\ V_o &= -\frac{R_F}{R_1}\,(V_x - V_y) \\ &= -\frac{R_F\,(V_{xy})}{R_1} \end{aligned}$$

$$\text{Or the voltage gain } A_D = \frac{V_o}{V_{xy}} = -\frac{R_F}{R_1} \quad ; \quad A_D = -\frac{R_F}{R_1}$$

Note that the gain of the differential amplifier is the same as that of the inverting amplifier.

1.6 Comparison of Inverting and Non Inverting Amplifier

Parameter	**Noninverting Amplifier**	**Inverting Amplifier**
Voltage gain	$A_F = \frac{A\,(R_1 + R_F)}{R_1 + R_F + AR_1}$ (exact) $= \frac{A}{1 + AB}$ $= 1 + \frac{R_F}{R_1}$ (ideal)	$A_F = \frac{-AR_F.}{R_1 + R_F + AR_1}$ (exact) $= \frac{-AK}{1 + AB}$, where $K = \frac{R_F}{R_1 + R_F}$ $= -\frac{R_F}{R_1}$ (ideal)
Gain of the feedback circuit	$B = \frac{R_1}{R_1 + R_F}$	$B = \frac{R_1}{R_1 + R_F}$
Input resistance	$R_{iF} = R_i(1 + AB)$	$R_{iF} = R_1 + \left(\frac{R_F}{1+A} \Vert R_i\right)$
Output resistance	$R_{oF} = \frac{R_o}{1+AB}$	$R_{oF} = \frac{R_o}{1+AB}$
Bandwidth	$f_F = f_o(1 + AB)$ $f_F = \frac{\text{UGB}}{A_F}$	$f_F = f_o(1 + AB)$ $f_F = \frac{(\text{UGB})(K)}{A_F}$
Total output offset voltage	$V_{ooT} = \frac{\pm V_{Sat}}{1+AB}$	$V_{ooT} = \frac{\pm V_{Sat}}{1+AB}$

1.7 General Linear Application

Inverting, non inverting and differential configurations are useful in such applications as summing, scaling and averaging amplifiers.

1.7.1 Inverting Configuration

1.7.2 Summing, Scaling and Averaging Amplifiers

The figure shows the inverting configuration with three inputs $V_a, V_b and V_c$.Depending up on the feedback resistors and R_a, R_b and R_c the circuit can be used as a summing amplifier, scaling amplifier and an averaging amplifier.

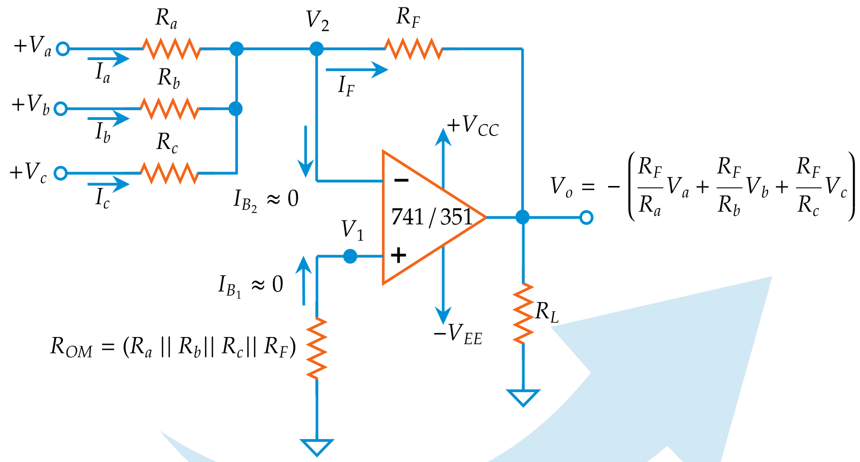


Figure 1.10: Inverting configuration with three inputs

The circuit function can be verified by examining the expression for the output voltage V_o Which is obtained by Kirchoff's current equation written at node V_2. Then ,

$$I_a + I_b + I_c = I_B + I_F b \tag{1.15}$$

$\because R_i$ and A of the op-amp are ideally infinity.

$$I_B = 0 \text{ and } V_1 = V_2 = 0V \tag{1.16}$$

$$\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = -\frac{V_o}{R_F} \tag{1.17}$$

$$V_o = -\left(\frac{R_F}{R_a}V_a + \frac{R_F}{R_a}V_b + \frac{R_F}{R_C}V_C\right) \tag{1.18}$$

Summing Amplifier

In the figure.1.10 ,if $R_a = R_b = R_c = R$, then Equation can be rewritten as

$$V_o = -\frac{R_F}{R}(V_a + V_b + V_c) \tag{1.19}$$

Then the output voltage is equal to the negative sum of all the inputs times the gain of the circuit R_F/R; hence the circuit is called a summing amplifier. Obviously, when the gain of the circuit is 1 , that is, $R_a = R_b = R_c = R_F$, the output voltage is equal to the negative sum of all input voltages. Thus,

$$V_o = -(V_a + V_b + V_c) \tag{1.20}$$

Scaling or Weighted Amplifier

If each input voltage is amplified by a different factor, in other words, weighted differently at the output, the circuit in figure.1.10 is then called a scaling or weighted amplifier. This condition can be accomplished if R_a, R_b, and R_c are different in value. Thus the output voltage of the scaling amplifier is,

$$V_o = -\left(\frac{R_F}{R_a}V_a + \frac{R_F}{R_b}V_b + \frac{R_F}{R_c}V_c\right) \tag{1.21}$$

Where, $\frac{R_F}{R_a} \neq \frac{R_F}{R_b} \neq \frac{R_F}{R_c}$

Average circuit

The circuit of figure.1.10 can be used as an averaging circuit, in which the output voltage is equal to the average of all the input voltages. This is accomplished by using all input resistors of equal value, $R_a = R_b = R_c = R$. In addition, the gain by which each input is amplified must be equal to 1 over the number of inputs; that is,

$$\frac{R_F}{R} = \frac{1}{n}$$

Where n is the number of inputs. Thus, if there are three inputs , we want $R_F/R = 1/3$. Consequently,from equation. 1.18

$$V_o = -\left(\frac{V_a + V_b + V_c}{3}\right) \tag{1.22}$$

1.7.3 Non-Inverting Configuration

1.7.4 Summing and Averaging Amplifiers

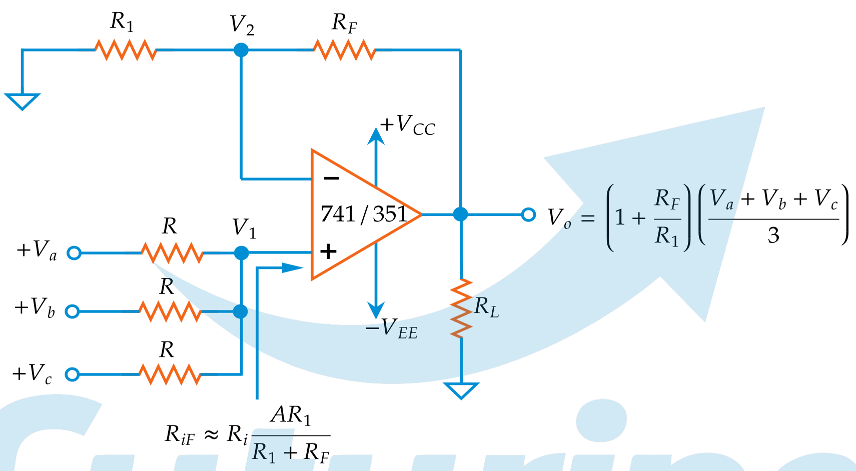


Figure 1.11: Non-Inverting configuration with three inputs

If input voltage source and resistors are connected to the non-inverting terminal , the circuit can be used as a summing or averaging amplifier through the selection of appropriate values of resistors ,i.e., R_1 and R_F

We know that the input resistance R_{if} of the non-inverting amplifier is very large, by using the superposition theorem the voltage V_1 at the non-inverting terminal is,

$$V_1 = \frac{R/2}{R+R/2}V_a + \frac{R/2}{R+R/2}V_b + \frac{R/2}{R+R/2}V_c \tag{1.23}$$

$$V_1 = \frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3} \tag{1.24}$$

$$= \frac{V_a + V_b + V_c}{3} \tag{1.25}$$

Hence the output voltage V_o is

$$V_o = \left(1 + \frac{R_F}{R_1}\right)V_1 \tag{1.26}$$

$$= \left(1 + \frac{R_F}{R_1}\right)\frac{V_a + V_b + V_c}{3} \tag{1.27}$$

Averaging amplifier

$$V_o = \left(1 + \frac{R_F}{R_1}\right)\frac{V_a + V_b + V_c}{3} \tag{1.28}$$

Equation. 1.28 shows that the output voltage is equal to the average of all input voltages times the gain of the circuit $(1 + R_F/R_1)$, hence the name averaging amplifier. Depending on the application requirement, the gain

$(1+R_F/R_1)$ can be set to a specific value. Obviously, if the gain is 1 , the output voltage will be equal to the average of all input voltages.
Note that there are two basic differences between this averaging amplifier and that using the inverting configuration
1. No sign change or phase reversal occurs between the average of the inputs and output.
2. The noninverting input voltage V_1 is the average of all inputs, whereas in the inverting averaging amplifier the output is the average of all inputs, with a negative sign.

Summing amplifier

In the equation. 1.28 if the gain $\left(1+\frac{R_F}{R_1}\right)$ is equal to the number of inputs, the output voltage becomes equal to the sum of all input voltages. That is, if $\left(1+\frac{R_F}{R_1}\right)$

$$V_o = V_a + V_b + V_c \tag{1.29}$$

Hence the circuit is called a noninverting summing amplifier.

1.7.5 Differential Configuration

1.7.6 A Substractor and Summing Amplifier

Using a basic differential op-amp configuration a substractor and a summimg amplifier may be constructed .

A Subtractor

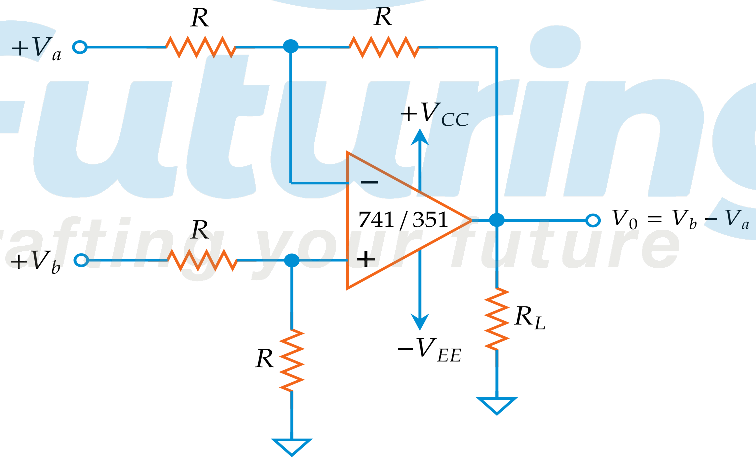


Figure 1.12: Basic differential amplifier as a subtractor

A basic amplifier can be used as a substractor as shown in the figure. In the figure the input signal can be scaled to desired value by selecting appropriate value for the external resisistors :When this is done the circuit is reffered to a scalling amplifier. However in the figure the external resistors are equal in value,so the gain of the amplifier is equal to one.
The output voltage of the differential amplifier with a gain of 1 is ,

$$V_o = -\frac{R}{R}(V_a - V_b) \tag{1.30}$$

$$\text{i.e., } V_o = V_b - V_a \tag{1.31}$$

Thus output voltage V_o is equal to the voltage V_b applied to the non-inverting terminal minus the voltage V_a applied to the inverting terminal. Hence the circuit is called a subtractor.

Summing Amplifier

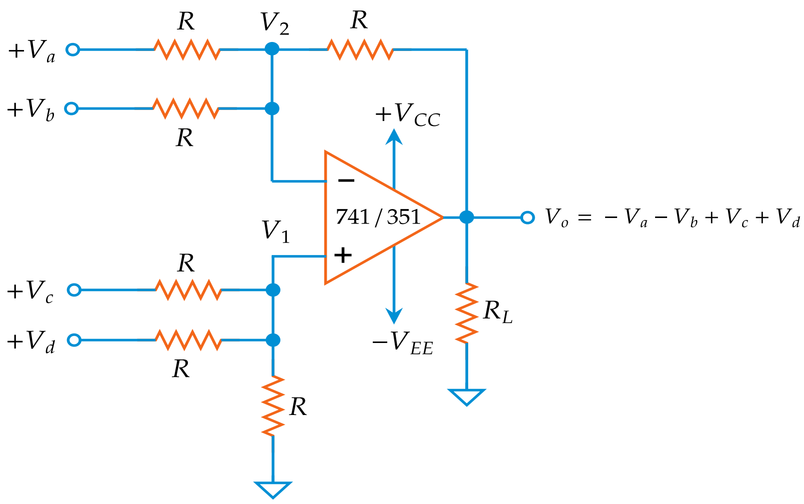


Figure 1.13: Summing amplifier Using Differential Amplifier

A four input summing amplifier may be constructed using the basic different amplifier if two additional input sources are connected, one each to the inverting and noninverting input terminals through resistor R
The output voltage equation for this circuit can be obtained by using the superposition theorem. For instance, to find the output voltage due to V_a alone, reduce all other input voltages V_b, V_c, and V_d to zero . In fact, this circuit is an inverting amplifier in which the inverting input is at virtual ground ($V_2 = 0$ V). Therefore, the output voltage is

$$V_{oa} = -\frac{R}{R}V_a = -V_a$$

Similarly, the output voltage due to V_b alone is

$$V_{ob} = -V_b$$

Now if input voltages V_a, V_b, and V_d are set to zero, the circuit in Figure becomes a noninverting amplifier in which the voltage V_1 at the noninverting input is

$$V_1 = \frac{R/2}{R+R/2}V_c = \frac{V_c}{3}$$

This means that the output voltage due to V_c alone is

$$V_{oc} = \left(1 + \frac{R}{R/2}\right)V_1 = (3)\left(\frac{V_c}{3}\right) = V_c$$

Similarly, the output voltage due to input voltage V_d alone is

$$V_{od} = V_d$$

Thus by using the superposition theorem the output voltage due to all four input voltages is given by

$$\begin{aligned} V_o &= V_{oa} + V_{ob} + V_{oc} + V_{od} \\ &= -V_a - V_b + V_c + V_d \end{aligned}$$

Notice that the output voltage is equal to the sum of the input voltages applied to the noninverting terminal plus the negative sum of the input voltages applied to the inverting terminal.

1.8 The Integrator

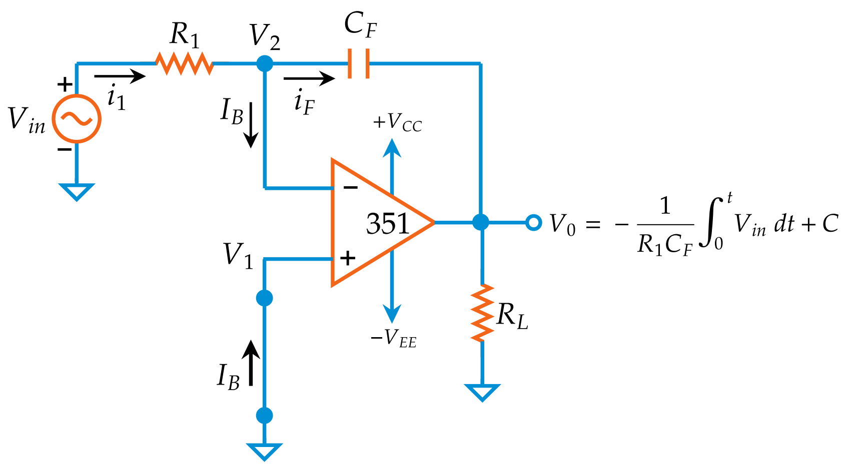


Figure 1.14

A circuit in which the output voltage waveform is the integral of the input voltage waveform is the integrator or the integration amplifier. Such a circuit is obtained by using a basic inverting amplifier configuration if the feedback resistor R_F is replaced by a capacitor C_F The expression for the output voltage V_o can be obtained by writing Kirchhoff's current equation at node V_2 ,

$$i_1 = I_B + i_F$$

Since I_B is negligibly small,

$$i_1 \cong i_F$$

Recall that the relationship between current through and voltage across the capacitor is,

$$i_c = C\frac{dv_c}{dt}$$

$$\text{Therefore, } \frac{V_{\text{in}} - V_2}{R_1} = C_F\left(\frac{d}{dt}\right)(V_2 - V_o)$$

However, $V_1 = V_2 \cong 0$ because A is very large. Therefore,

$$\frac{V_{\text{in}}}{R_1} = C_F\frac{d}{dt}(-V_o)$$

The output voltage can be obtained by integrating both sides with respect to time:

$$\int_0^t \frac{V_{\text{in}}}{R_1} dt = \int_0^t C_F\frac{d}{dt}(-V_o)\, dt$$
$$= C_F(-V_o) + V_o|_{t=0}$$
$$\text{Therefore, } V_o = -\frac{1}{R_1 C_F}\int_0^t V_{\text{in}}\, dt + C$$

Where C is the integration constant and is proportional to the value of the output voltage V_o at time $t = 0$ seconds.

Note

- The output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant R_1C_F.
- If the input is a sine wave, the output will be a cosine wave; or if the input is a square wave, the output will be a triangular wave.

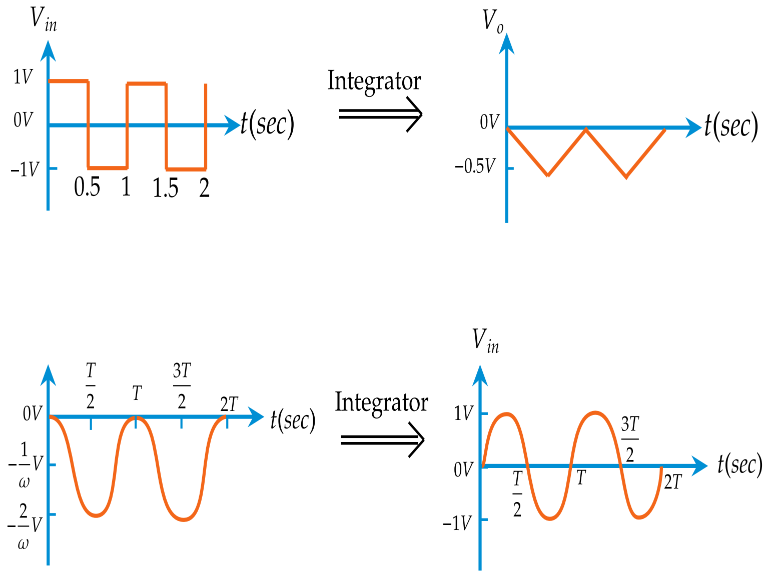


Figure 1.15

Frequency Response of an Integrator

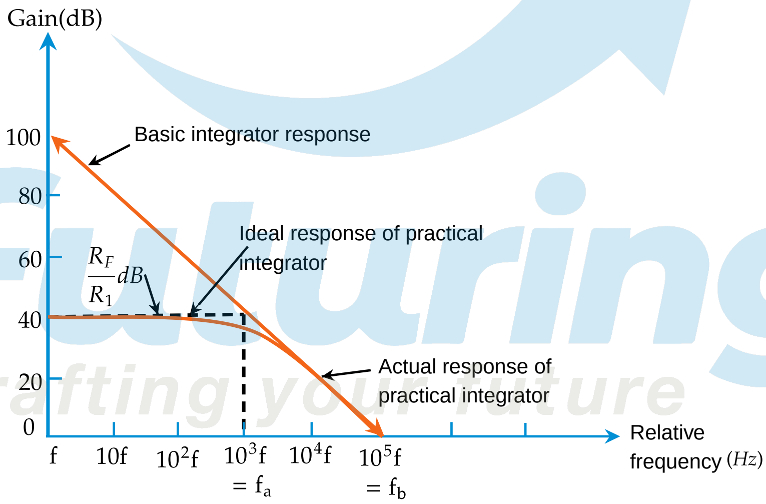


Figure 1.16: Frequency Response of an Integrator

The frequency response of an integrator is shown in the figure. 1.16 . f_b is the frequency at which the gain is $0dB$ is given by ,

$$f_b = \frac{1}{2\pi R_1 C_F} \tag{1.32}$$

But this integrator is not stable which means that the gain is not stable for acertain range of input frequencies.Aslo the gain is rolled off at low frequencies which means that rate of gain is decreasing at low frequencies.
Both the stability and low frequency roll off problem can be corrected by the addition of a R_f as shown in the practical integrator.
The frequency response of the practical integrator is also shown in the figure.In this figure f is some relative operating frequency , for frequencies f to f_a the gain $\frac{R_F}{R_1}$ is constant.However after f_a the gain decreases at a rate of 20 dB/decade.In other words between f_a and f_b the circuit act as an integrator. The gain limiting frequency f_a is given by ,

$$f_a = \frac{1}{2\pi R_F C_F}$$

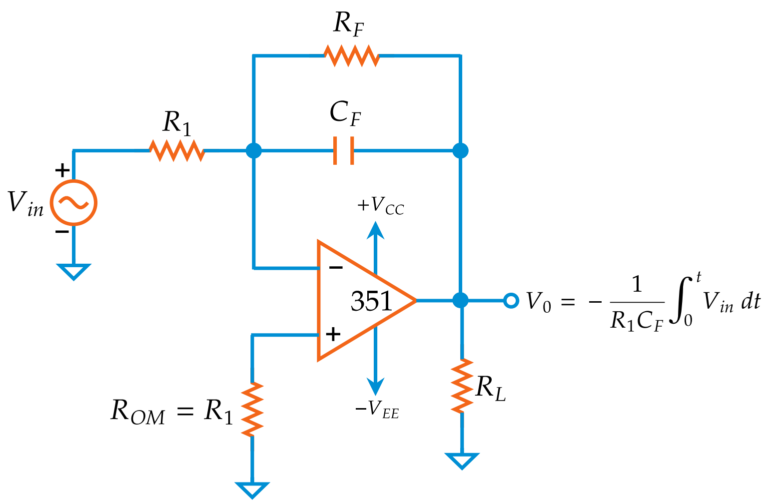


Figure 1.17: Practical integrator

1.8.1 The Differentiator

The differentiator or differentiation amplifier circuit performs the mathematical operation of differentiation. That is, the output waveform is the derivative of the input waveform. The differentiator may be constructed from a basic inverting amplifier if an input resistor R_1 is replaced by a capacitor C_1.

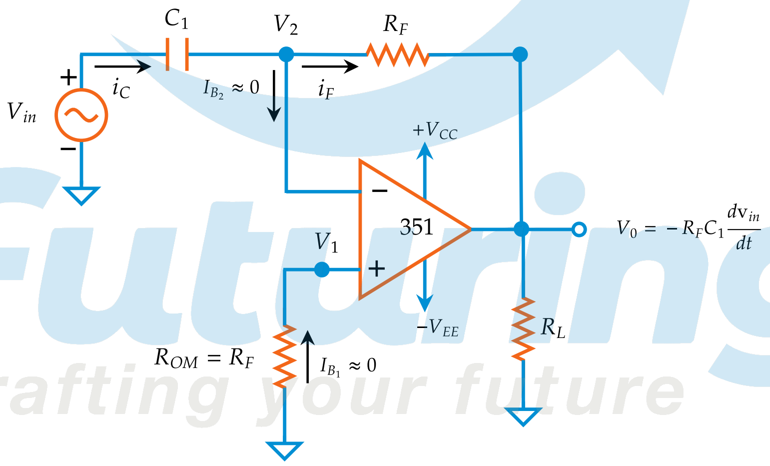


Figure 1.18

The expression for the output voltage can be obtained from Kirchhoff's current equation written at node V_2 as follows:

$$i_C = I_B + i_F \tag{1.33}$$

$$\text{Since } I_B \cong 0,\ \ i_C = i_F \tag{1.34}$$

$$C_1 \frac{d}{dt}(V_{\text{in}} - V_2) = \frac{V_2 - V_o}{R_F} \tag{1.35}$$

But $V_1 = V_2 \cong 0$ V, because A is very large. Therefore,

$$C_1 \frac{dV_{\text{in}}}{dt} = -\frac{V_o}{R_F} \tag{1.36}$$

$$\text{Or }\ V_o = -R_F C_1 \frac{dV_{\text{in}}}{dt} \tag{1.37}$$

Thus the output V_o is equal to $R_F C_1$ times the negative instantaneous rate of change of the input voltage V_{in} with time. Since the differentiator performs the reverse of the integrator's function, a cosine wave input will produce a sine wave output, ol a triangular input will produce a square wave output.

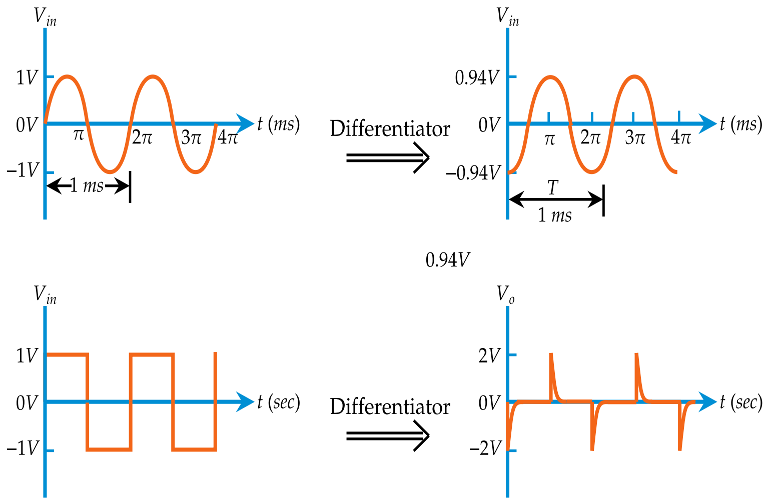


Figure 1.19

Frequency Response of a Differentiator

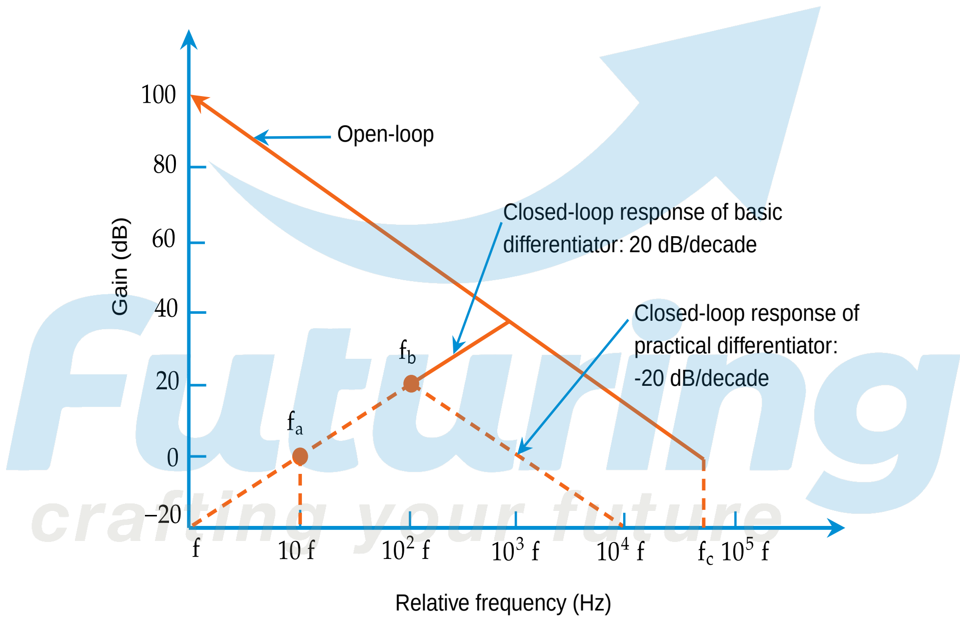


Figure 1.20: Frequency Response of a Differentiator

The frequency response of a basic differentiator is shown in the figure.1.20 In this figure.1.20 , f_a is the frequency at which the gain is the $0dB$ and is given by,

$$f_a = \frac{1}{2\pi R_F C_1} \tag{1.38}$$

And f_c is the unit gain band width of the op-amp and f is some relative opertaing frequency.

Drawback of this differentiator

Note

- The gain of the circuit $\frac{R_F}{X_{CI}}$ increase with increase in frequency at the rate of 20 dB/decade.This makes the circuit very unstable.
- The input impedance X_{C1} secreases with increase in frequency.which makes the circuit very susceptible to high frequency noise.When amplified this noise can be completely override the differentiated output signal.

Both the stability and the high-frequency noise problems can be corrected by the addition of two components: R_1 and C_F, as shown in Figure bellow. This circuit is a practical differentiator. From frequency f to f_b, the gain increases at 20 dB/decade. However, after f_b the gain decreases at 20 dB/ decade. This 40 . dB/ decade change in gain is caused by the R_1C_1 and R_FC_F combinations. The gain. limiting frequency f_b is given by,

$$f_b = \frac{1}{2\pi R_1 C_1}$$

Where $R_1C_1 = R_FC_F$
Thus R_1C_1 and R_FC_F help to reduce significantly the effect of high-frequency input, amplifier noise, and offsets. Above all, R_1C_1 and R_FC_F make the circuit more stable by preventing the increase in gain with frequency. Generally, the value of f_b and in turn R_1C_1 and R_FC_F values should be selected such that

$$f_a < f_b < f_c$$

$$\begin{aligned} f_a &= \frac{1}{2\pi R_F C_1} \\ f_b &= \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_F C_F} \\ f_c &= \text{ unity gain-bandwidth} \end{aligned}$$

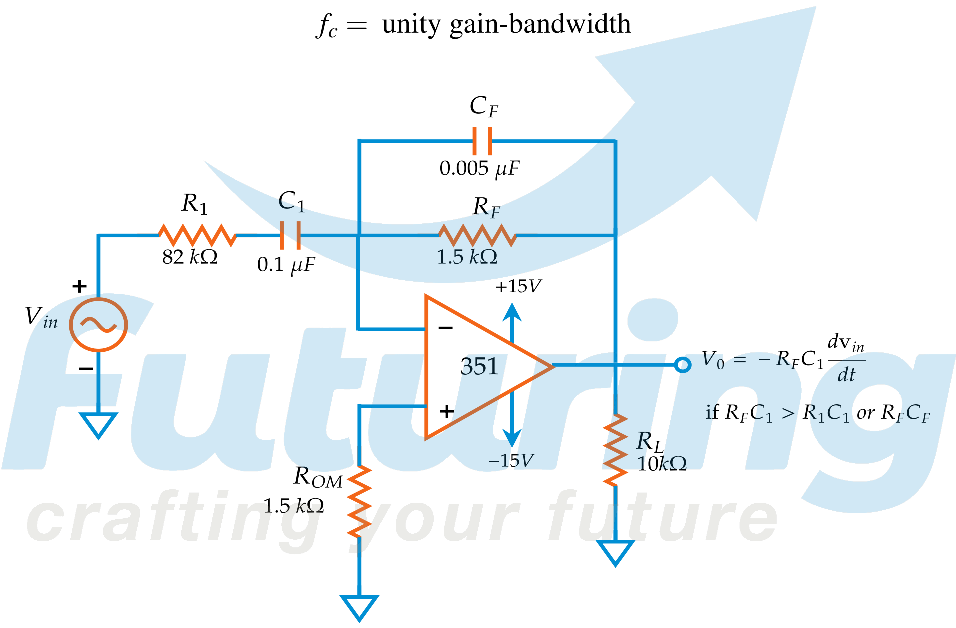
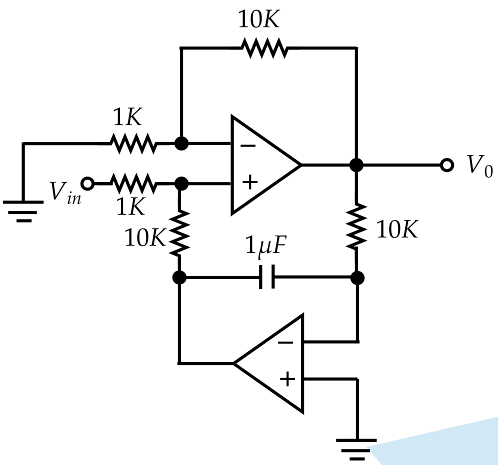


Figure 1.21

Practice Set- 1

1. A time varying signal V_{in} is fed to an op-amp circuit with output signal V_o as shown in the figure below.



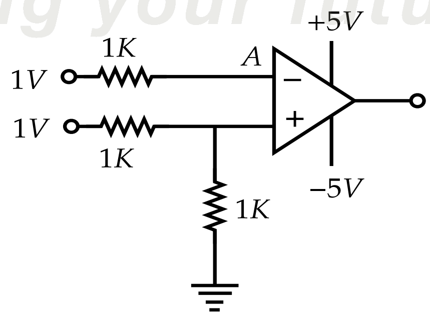
The circuit implements a

[NET/JRF(JUNE-2011)]

A. High pass filter with cutoff frequency 16 Hz
B. High pass filter with cutoff frequency 100 Hz
C. Low pass filter with cutoff frequency 16 Hz
D. Low pass filter with cutoff frequency 100 Hz

2. In the operational amplifier circuit below, the voltage at point A is

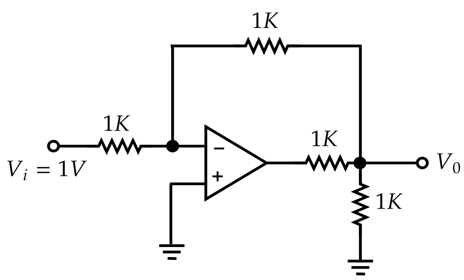
[NET/JRF(DEC-2011)]



A. 1.0 V **B.** 0.5 V **C.** 0 V **D.** $-5.0V$

3. In the op-amp circuit shown in the figure below, the input voltage is 1 V. The value of the output V_0 is

[NET/JRF(JUNE-2012)]



A. -0.33 V **B.** -0.50 V **C.** -1.00 V **D.** -0.25 V

4. In the op-amp circuit shown in the figure, V_i is a sinusoidal input signal of frequency 10 Hz and V_0 is the output signal. The magnitude of the gain and the phase shift, respectively, close to the values

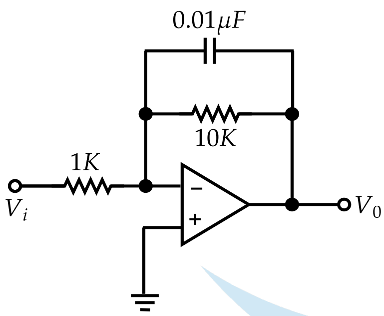
[NET/JRF(DEC-2012)]

A. $5\sqrt{2}$ and $\pi/2$

B. $5\sqrt{2}$ and $-\pi/2$

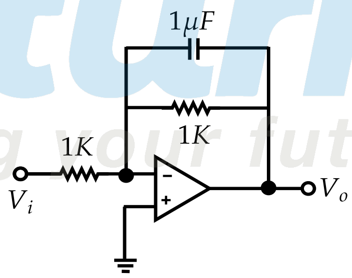
C. 10 and zero

D. 10 and π



5. Consider the op-amp circuit shown in the figure. If the input is a sinusoidal wave $V_i = 5\sin(1000t)$, then the amplitude of the output V_0 is

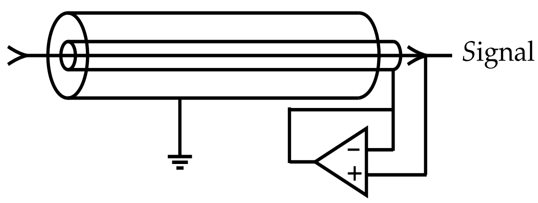
[NET/JRF(DEC-2013)]



A. $\frac{5}{2}$ **B.** 5 **C.** $\frac{5\sqrt{2}}{2}$ **D.** $5\sqrt{2}$

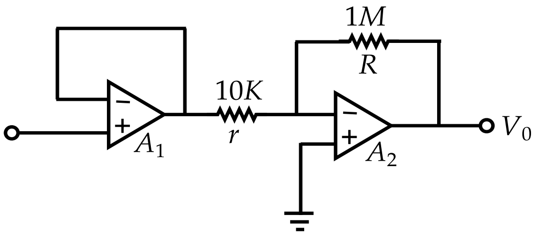
6. The inner shield of a triaxial conductor is driven by an (ideal) op-amp follower circuit as shown. The effective capacitance between the signal-carrying conductor and ground is

[NET/JRF(JUNE-2014)]



A. Unaffected **B.** Doubled **C.** Halved **D.** Made zero

7. Consider the amplifier circuit comprising of the two op-amps A_1 and A_2 as shown in the in the figure.



If the input ac signal source has an impedance of $50k\Omega$, which of the following statements is true?
[NET/JRF(DEC-2014)]

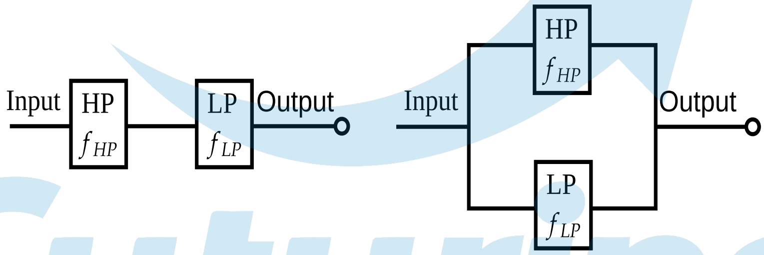
A. A_1 is required in the circuit because the source impedance is much greater than r

B. A_1 is required in the circuit because the source impedance is much less than R

C. A_1 can be eliminated from the circuit without affecting the overall gain

D. A_1 is required in the circuit if the output has to follow the phase of the input signal

8. Consider a Low Pass (LP) and a High Pass (HP) filter with cut-off frequencies f_{LP} and f_{HP}, respectively, connected in series or in parallel configurations as shown in the Figures A and B below.



(A) (B)

Which of the following statements is correct?
[NET/JRF(DEC-2014)]

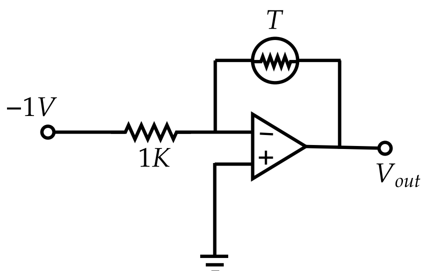
A. For $f_{HP} < f_{LP}$, A acts as a Band Pass filter and B acts as a band Reject filter

B. For $f_{HP} > f_{LP}$, A stops the signal from passing through and B passes the signal without filtering

C. For $f_{HP} < f_{LP}$, A acts as a Band Pass filter and B passes the signal without filtering

D. For $f_{HP} > f_{LP}$, A passes the signal without filtering and B acts as a Band Reject filter

9. In the circuit given below, the thermistor has a resistance $3k\Omega$ at 25^0C. Its resistance decreases by 150Ω per ${}^0C$ upon heating. The output voltage of the circuit at 30°C is
[NET/JRF(JUNE-2015)]

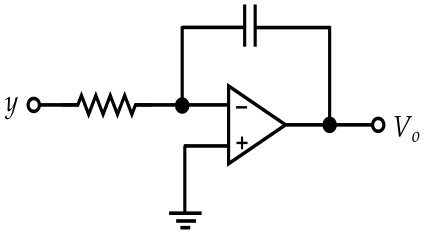


A. -3.75 V **B.** -2.25 V **C.** 2.25 V **D.** 3.75 V

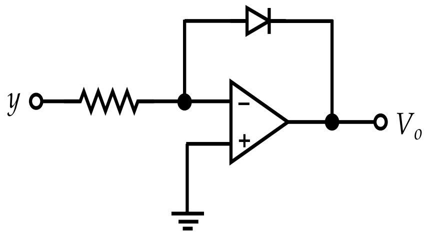
10. If the parameters y and x are related by $y = \log(x)$, then the circuit that can be used to produce an output voltage V_0 varying linearly with x is

[NET/JRF(DEC-2015)]

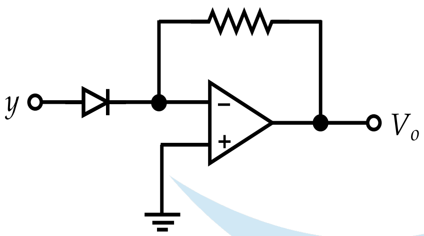
A.



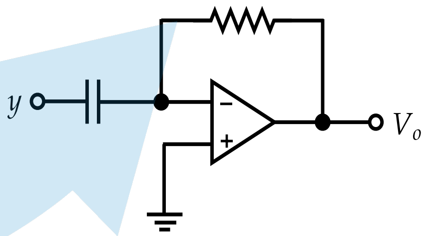
B.



C.

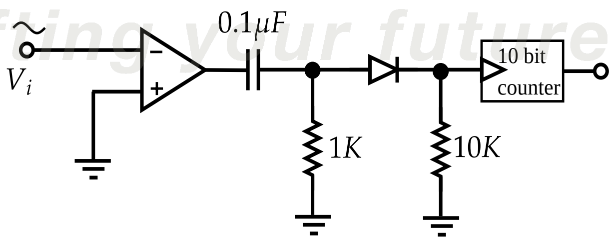


D.



11. A sinusoidal signal of peak to peak amplitude $1V$ and unknown time period is input to the following circuit for 5 second's duration. If the counter measures a value $(3E8)_H$ in hexadecimal, then the time period of the input signal is

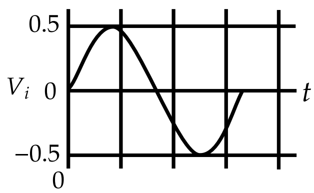
[NET/JRF(DEC-2015)]

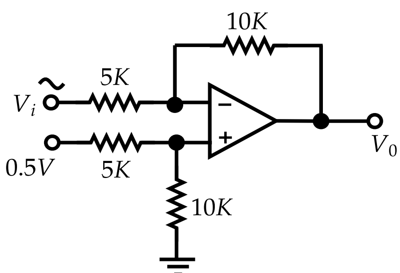


A. 2.5 ms **B.** 4 ms **C.** 10 ms **D.** 5 ms

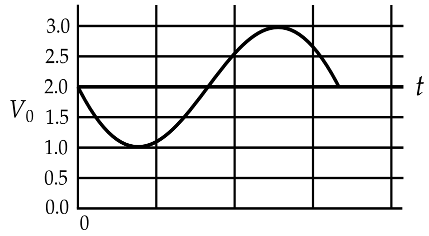
12. Given the input voltage V_i, which of the following waveforms correctly represents the output voltage V_0 in the circuit shown below?

[NET/JRF(JUNE-2016)]

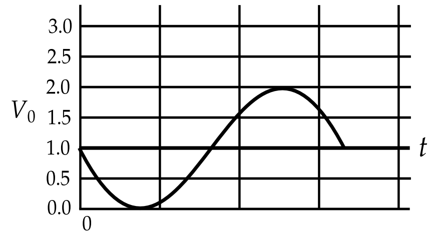




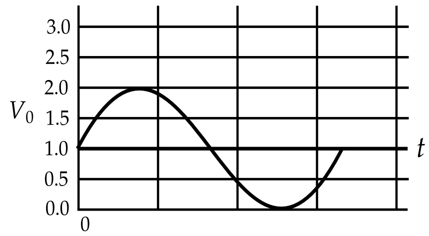
A.



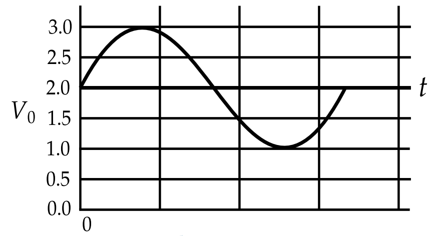
B.



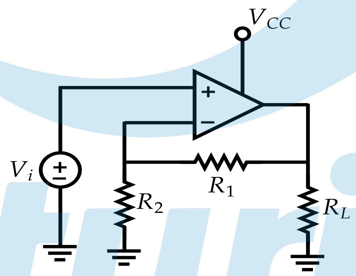
C.



D.



13. In the circuit below, the input voltage V_i is $2V, V_{cc} = 16$ V, $R_2 = 2\text{k}\Omega$ and $R_L = 10\text{k}\Omega$

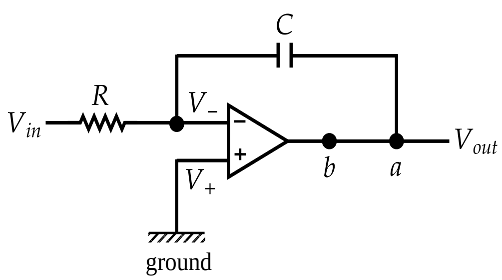


The value of R_1 required to deliver 10 mW of power across R_L is

[NET/JRF(DEC-2016)]

A. $12k\Omega$ **B.** $4k\Omega$ **C.** $8\text{k}\Omega$ **D.** $14k\Omega$

14. The gain of the circuit given below is $-\frac{1}{\omega RC}$.



The modification in the circuit required to introduce a dc feedback is to add a resistor

[NET/JRF(JUNE-2017)]

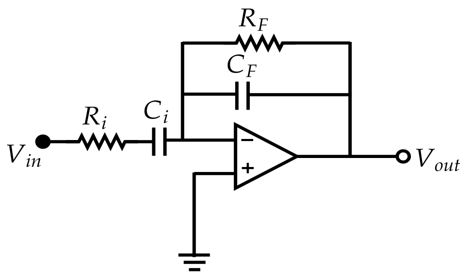
A. Between a and b

B. Between positive terminal of the op-amp and ground

C. In series with C

D. Parallel to C

15. In the following operational amplifier circuit $C_{in} = 10nF, R_{in} = 20k\Omega, R_F = 200k\Omega$ and $C_F = 100$pF



The magnitude of the gain at a input signal frequency of 16kHz is

[NET/JRF(JUNE-2017)]

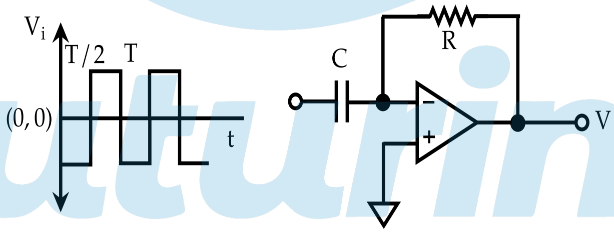
A. 67 **B.** 0.15 **C.** 0.3 **D.** 3.5

16. Two signals $A_1 \sin(\omega t)$ and $A_2 \cos(\omega t)$ are fed into the input and the reference channels, respectively, of a lock-in amplifier. The amplitude of each signal is $1V$. The time constant of the lock-in amplifier is such that any signal of frequency larger than ω is filtered out. The output of the lock-in amplifier is

[NET/JRF(JUNE-2018)]

A. $2V$ **B.** 1 V **C.** 0.5 V **D.** $0V$

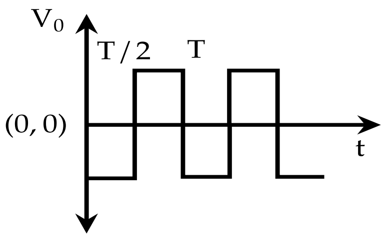
17. The input V_i to the following circuit is a square wave as shown in the following figure



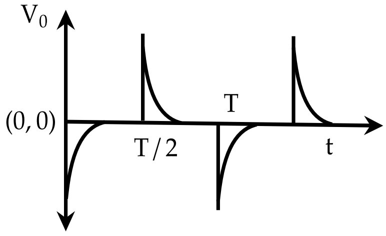
Which of the waveforms V_0 best describes the output?

[NET/JRF(JUNE-2018)]

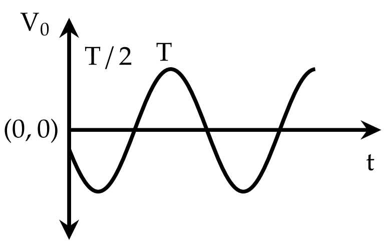
A.



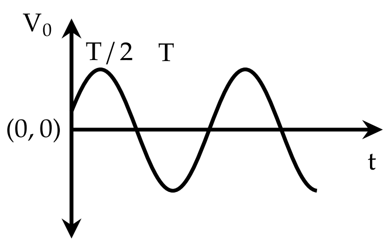
B.



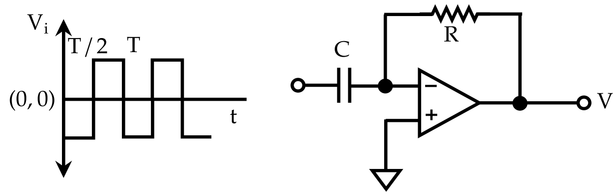
C.



D.



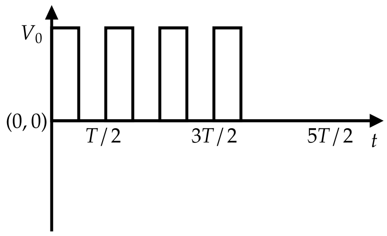
18. The input V_i to the following circuit is a square wave as shown in the following figure.



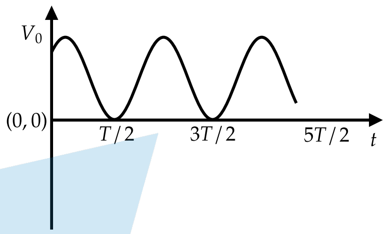
which of the waveforms best describes the output?

[NET/JRF(DEC-2018)]

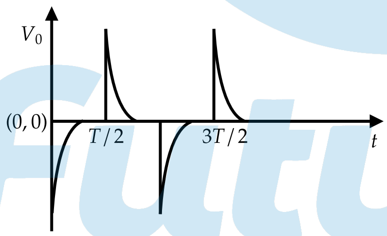
A.



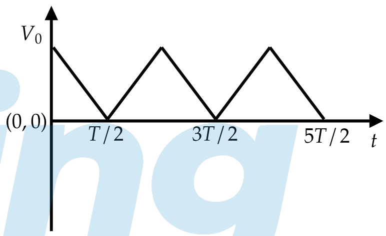
B.



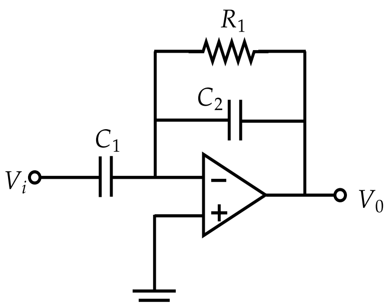
C.



D.



19. A circuit constructed using op-amp, resistor $R_1 = 1\text{k}\Omega$ and capacitors $C_1 = 1\mu\text{F}$ and $C_2 = 0.1\mu F$ is shown in the figure below.



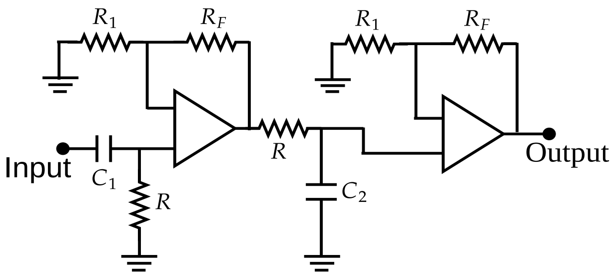
This circuit will act as a

[NET/JRF(JUNE-2019)]

A. High pass filter **B.** Low pass filter

C. Band pass filter **D.** Band reject filter

20. In the circuit diagram of a band pass filter shown below, $R = 10\text{k}\Omega$.



In order to get a lower cut-off frequency of 150 Hz and an upper cut-off frequency of 10kHz, the appropriate values of C_1 and C_2 respectively are

[NET/JRF(DEC-2019)]

A. $0.1\mu F$ and $1.5nF$ **B.** 0.3μF and 5.0nF

C. $1.5nF$ and $0.1\mu F$ **D.** 5.0nF and 0.3μF

21. The $I-V$ characteristics of the diode D in the circuit below is given by

$$I = I_s\left(e^{\frac{qV}{k_BT}} - 1\right)$$

where I_s is the reverse saturation current, V is the voltage across the diode and T is the absolute temperature.

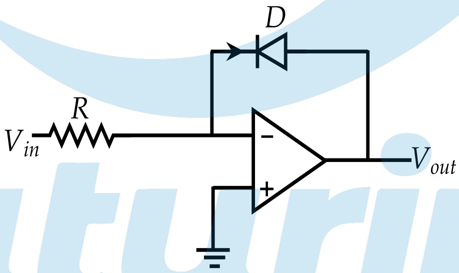


Figure 1.22

If the input voltage is V_{in} , then the output voltage V_{out} is

[NET/JRF(JUNE-2020)]

A. (a) $I_sR\ln\left(\frac{qV_{\text{in}}}{k_BT}+1\right)$ **B.** $\frac{1}{q}k_BT\ln\left(\frac{q(V_{\text{in}}+I_sR)}{k_BT}\right)$

C. $\frac{1}{q}k_BT\ln\left(\frac{V_{\text{in}}}{I_sR}+1\right)$ **D.** $-\frac{1}{q}k_BT\ln\left(\frac{V_{\text{in}}}{I_sR}+1\right)$

22. In the circuit shown below, the gain of the op-amp in the middle of its bandwidth is 10^5. A sinusoidal voltage with angular frequency $\omega = 100$rad/s is applied to the input of the op-amp.

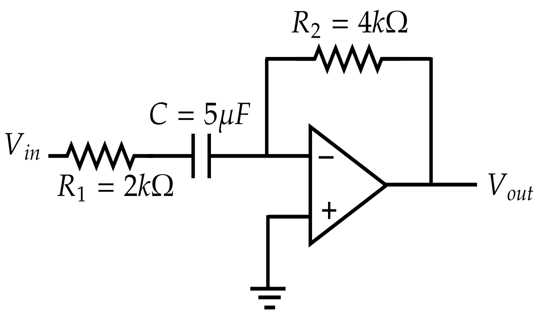


Figure 1.23

The phase difference between the input and the output voltage is

[NET/JRF(JUNE-2020)]

A. $5\pi/4$ **B.** $3\pi/4$ **C.** $\pi/2$ **D.** π

Answer key

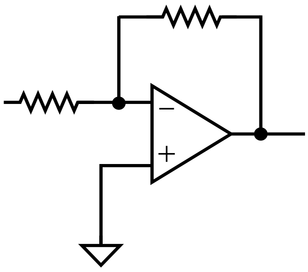
Q.No.	Answer	Q.No.	Answer
1	**C**	2	**B**
3	**B**	4	**D**
5	**C**	6	**A**
7	**A**	8	**C**
9	**C**	10	**C**
11	**D**	12	**B**
13	**C**	14	**D**
15	**D**	16	**D**
17	**B**	18	**C**
19	**A**	20	**A**
21	**C**	22	**A**

Practice Set- 2

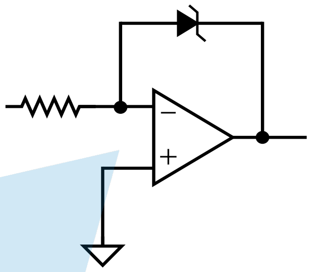
1. In one of the following circuits, negative feedback does not operate for a negative input. Which one is it? The opamps are running from ± 15 V supplies.

[GATE 2010]

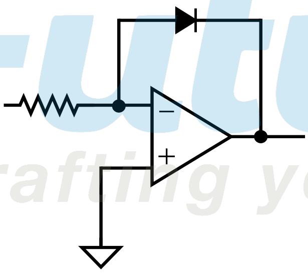
A.



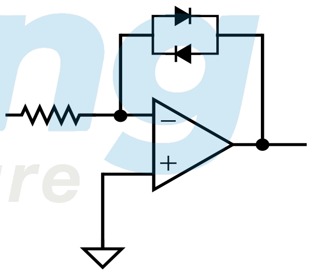
B.



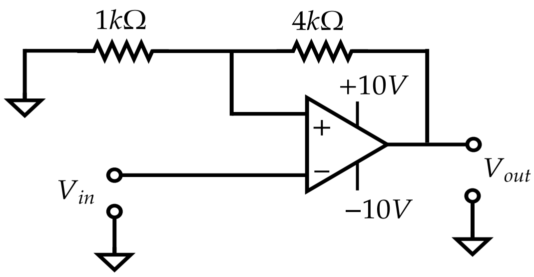
C.



D.



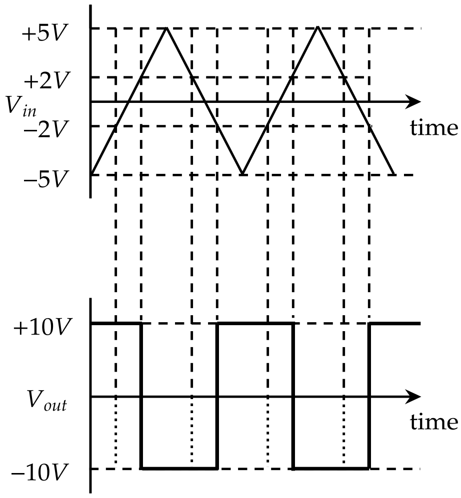
2. Consider the following circuit.



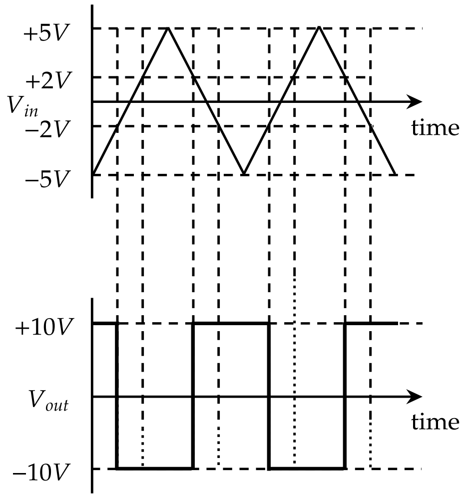
Which of the following correctly represents the output V_{out} corresponding to the input V_{in}?

[GATE 2011]

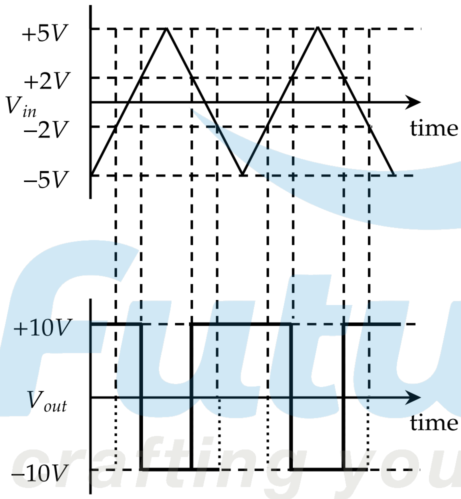
A.



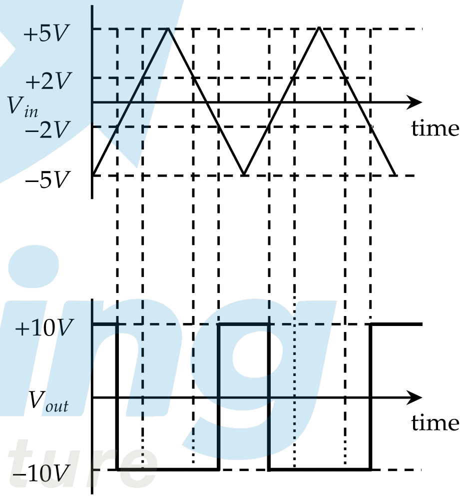
B.



C.



D.



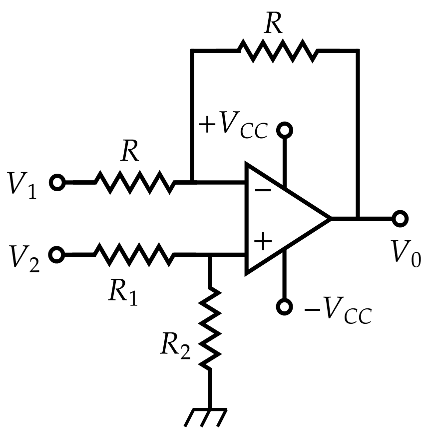
3. If the peak output voltage of a full wave rectifier is 10 V, its d.c. voltage is

[GATE 2012]

A. 10.0 V **B.** 7.07 V **C.** 6.36 V **D.** 3.18 V

4. In the following circuit, for the output voltage to be $V_0 = (-V_1 + V_2/2)$ the ratio R_1/R_2 is

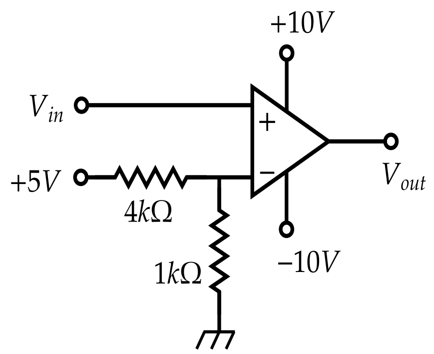
[GATE 2012]



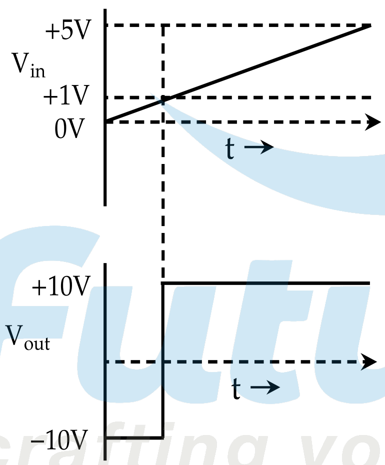
A. 1/2 **B.** 1 **C.** 2 **D.** 3

5. Consider the following OP-AMP circuit. Which one of the following correctly represents the output V_{out} corresponding to the input V_{in} ?

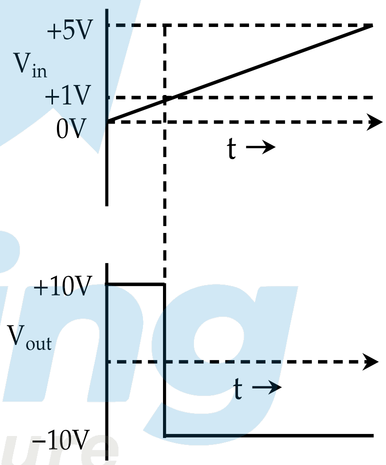
[GATE 2012]



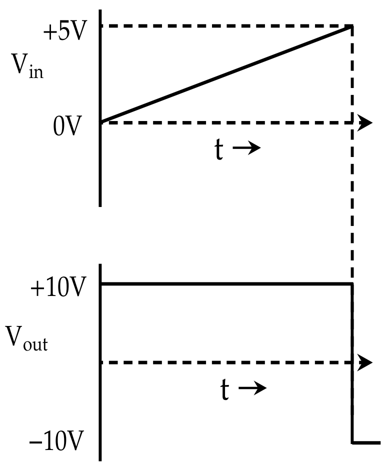
A.



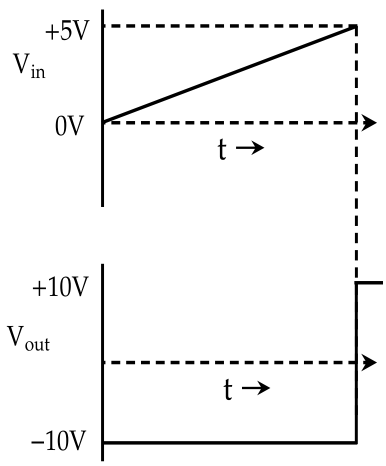
B.



C.

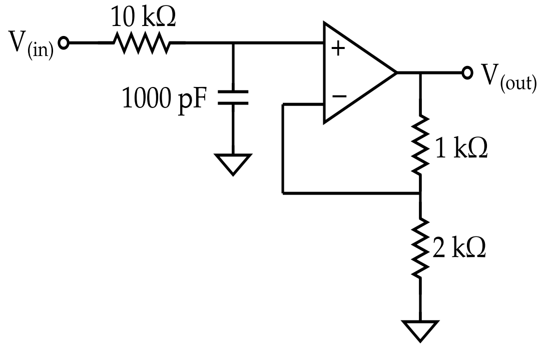


D.



6. For this circuit the frequency above which the gain will decrease by 20*dB* per decade is

[GATE 2013]



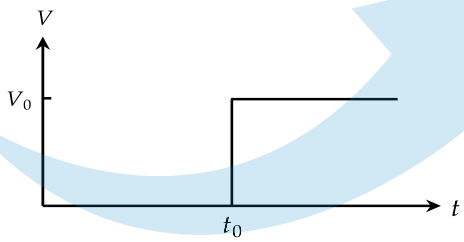
A. 15.9kHz **B.** 1.2kHz **C.** 5.6kHz **D.** 22.5kHz

7. At 1.2kHz the closed loop gain is

[GATE 2013]

A. 1 **B.** 1.5 **C.** 3 **D.** 0.5

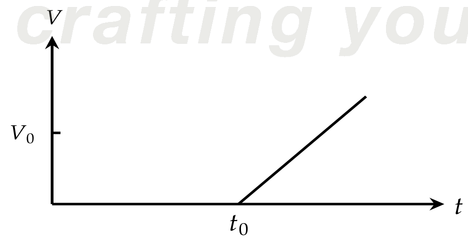
8. The input given to an ideal OP-AMP integrator circuit is



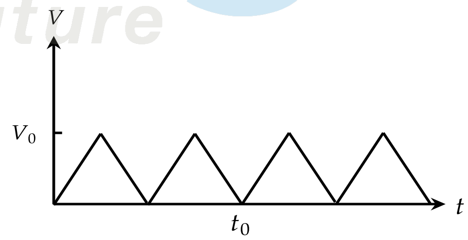
The correct output of the integrator circuit is

[GATE 2014]

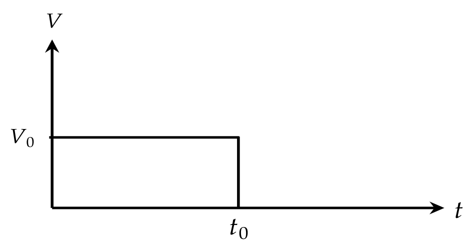
A.



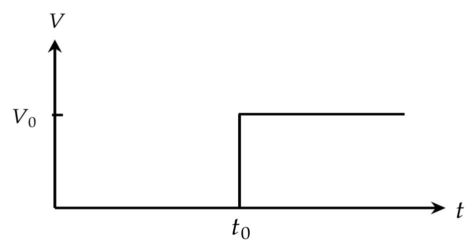
B.



C.



D.



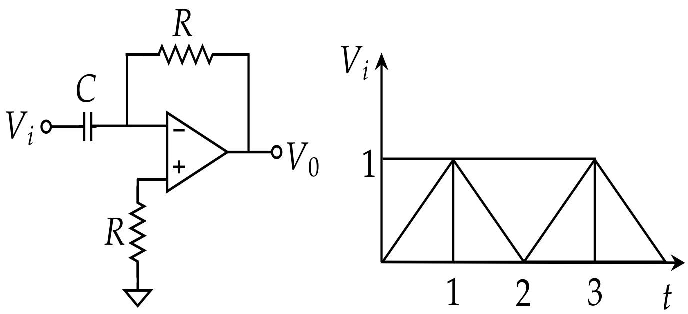
9. A low pass filter is formed by a resistance R and a capacitance C. At the cut-off angular frequency $\omega_C = \frac{1}{RC}$ the voltage gain and the phase of the output voltage relative to the input voltage respectively are

[GATE 2014]

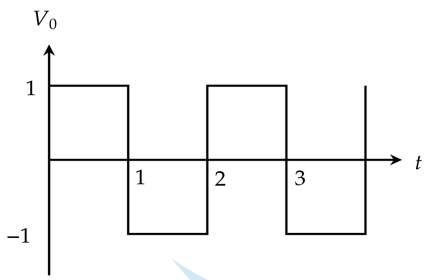
A. 0.71 and 45° **B.** 0.71 and −45° **C.** 0.5 and −90° **D.** 0.5 and 90°

10. Consider the circuit shown in the figure, where $RC = 1$. For an input signal V_i shown below, choose the correct V_0 from the options:

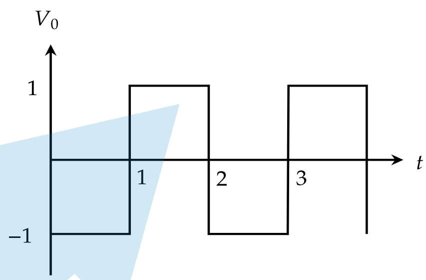
[GATE 2015]



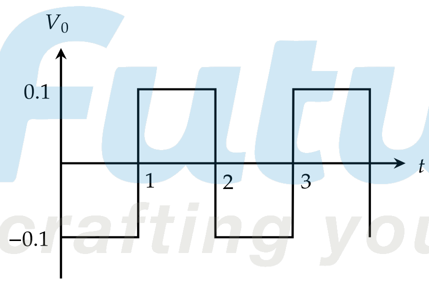
A.



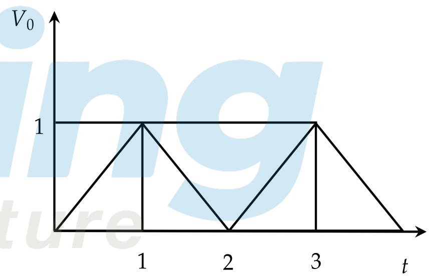
B.



C.

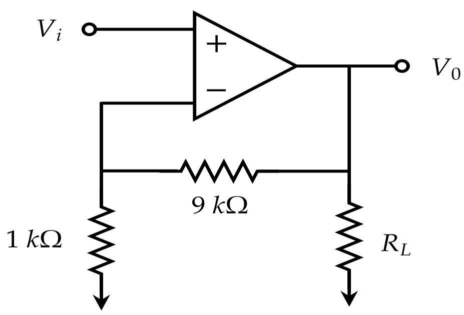


D.



11. In the given circuit, if the open loop gain $A = 10^5$ the feedback configurations and the closed loop gain A_f are

[GATE 2015]



A. series-shunt, $A_f = 9$

B. series-series, $A_f = 10$

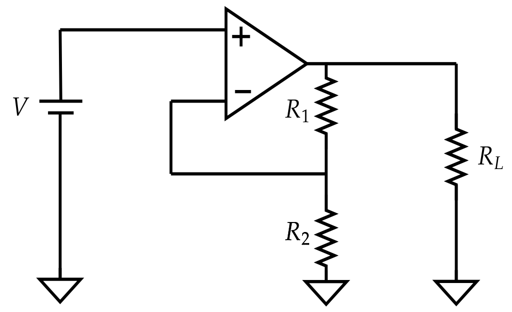
C. series-shunt, $A_f = 10$

D. shunt-shunt, $A_f = 10$

12. Consider an ideal operational amplifier as shown in the figure below with $R_1 = 5k\Omega, R_2 = 1k\Omega, R_L = 100k\Omega$. For an applied input voltage $V = 10$mV, the current passing through R_2 is............... μA. (up to

two decimal places)

[GATE 2017]



13. For an operational amplifier (ideal) circuit shown below,

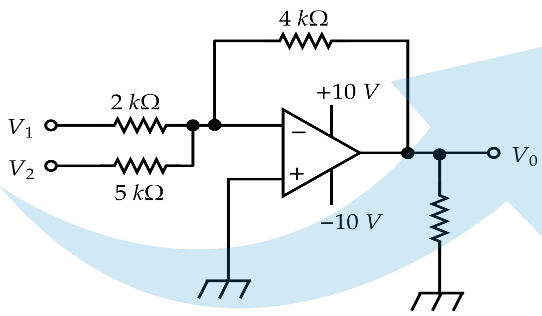


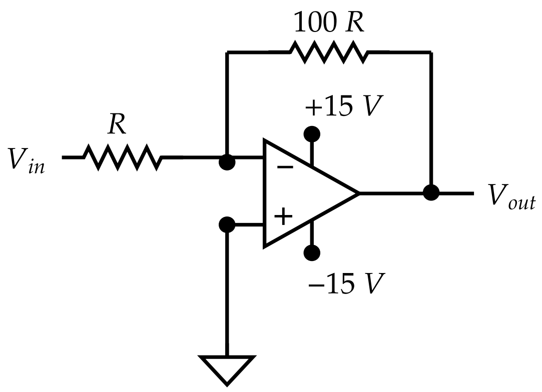
Figure 1.24

If $V_1 = 1V$ and $V_2 = 2V$, the value of V_0 is ———V (up to one decimal place).

[GATE 2018]

14. For the following circuit, what is the magnitude of V_{out} if $V_{\text{in}} = 1.5V$?

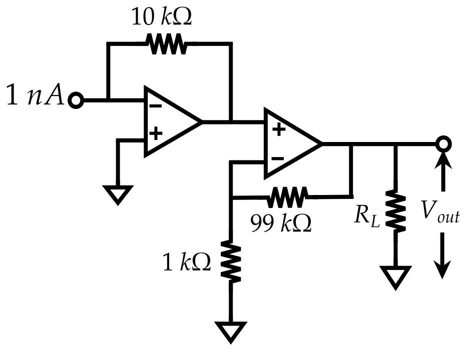
[GATE 2018]



A. 0.015 V **B.** 0.15 V **C.** 15 V **D.** 150 V

15. What is the voltage at the output of the following operational amplifier circuit. [See in the figure]?

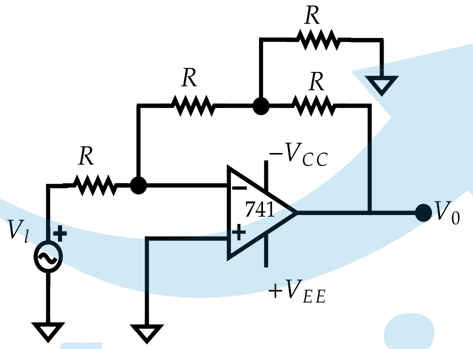
[JEST 2015]



A. 1 V **B.** 1mV **C.** $1\mu V$ **D.** $1nV$

16. Consider a 741 operational amplifier circuit as shown below, where $V_{CC} = V_{EE} = +15V$ and $R = 2.2\text{k}\Omega$. If $v_I = 2mV$, what is the value of v_0 with respect to the ground?

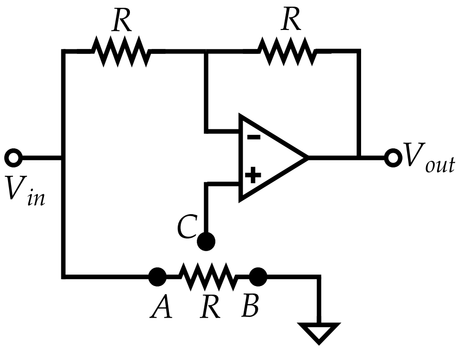
[JEST 2017]



A. -1mV **B.** $-2mV$ **C.** $-3mV$ **D.** $-4mV$

17. Analyse the ideal op-amp circuit in the figure. Which one of the following statements is true about the output voltage V_{out}, when terminal ' C ' is connected to point ' A ' and then to point ' B '?

[JEST 2019]



A. $V_{\text{out}} = V_{\text{in}}$ and $V_{\text{out}} = -V_{\text{in}}$ when ' C ' is connected to ' A ' and ' B ', respectively

B. $V_{\text{out}} = -V_{\text{in}}$ and $V_{\text{out}} = V_{\text{in}}$ when ' C ' is connected to ' A ' and ' B ', respectively

C. $V_{\text{out}} = -V_{\text{in}}$ when ' C ' is connected to either ' A ' or ' B '

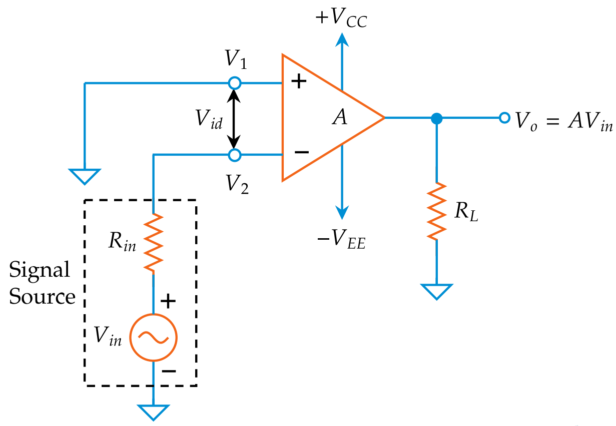
D. $V_{\text{out}} = V_{\text{in}}$ when ' C ' is connected to either ' A ' or ' B '

Answer key

Q.No.	Answer	Q.No.	Answer
1	**C**	2	**A**
3	**C**	4	**D**
5	**A**	6	**A**
7	**B**	8	**A**
9	**B**	10	**B**
11	**C**	12	**10**μA
13	**-3.6V**	14	**C**
15	**B**	16	**C**
17	**A**		

Practice set -3

1. Determine the output voltage for the inverting amplifier for the following figure?



(a) $V_{in} = 20mVdc$
(b) $V_{in} = -50\mu V$ peak sin wave
Assume the value of A to be 2×10^5

Solution:
(a)

$$V_o = -AV_{in} = -2 \times 10^5 \times 20 \times 10^{-3} = -400V$$

This is theoretical value.The actual value will be ne negative saturation voltage -14.
(b)

$$V_o = -AV_{in} = -2 \times 10^5 \times -50 \times 10^{-6} = 10V$$

This means that output is a sinwave ,since it is less than the output voltage swing of ± 14

2. IC 741 op-amp having the following parameters connected in a non inverting amplifier with $R_i = 1k\Omega$ and $R_f = 10k\Omega$
$A = 200000$
$R_i = 2M\Omega$
$R_0 = 75\Omega$
$f_0 = 5Hz$
supply voltage $= \pm 15$
Compute the value of A_f, R_{if}, R_{of}, F_f

Solution: let us calculate the value B first.

$$B = \frac{R_1}{R_1 + R_F} = \frac{1k\Omega}{1k\Omega + 10K\Omega} = \frac{1}{11}$$

$$1 + AB = 1 + \frac{200000}{11} = 18182.8$$

$$A_f = \frac{A}{1+AB} = \frac{200000}{18128.8} = 10.99$$

$$R_{if} = R_i(1+AB) = 2M\Omega \times 18182.8 = 36.4G\Omega$$

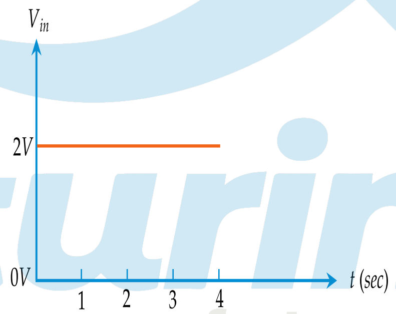
$$R_{of} = \frac{R_o}{1+AB} = \frac{75}{18182.8} = 4.12M\Omega$$
$$F_f = f_o(1+AB) = 5 \times 18182.8 = 90.9kHz$$

3. If the sin wave of 1V peak at 1000Hz is applied to the differentiator Find the output voltage?

Solution: Since V_p =1V and f=1000Hz the input voltage is

$$\begin{aligned} V_{in} &= V_p \sin \omega t \\ &= \sin(2\pi)(10^3)t \\ V_o &= -R_F C_1 \frac{dV_{in}}{dt} \\ &= -(1.5k\Omega)(0.1\mu F)\frac{d}{dt}\left[\sin(2\pi)(10^3)t\right] \\ &= -(1.5k\Omega)(0.1\mu F)(2\pi)(10^3)\cos\left[2\pi 10^3 t\right] \end{aligned}$$

4. An input of step dc voltage as shown in the figure is fed to a integrator of $R_1 C_F = 1sec$ .Find the output voltage and sketch it?



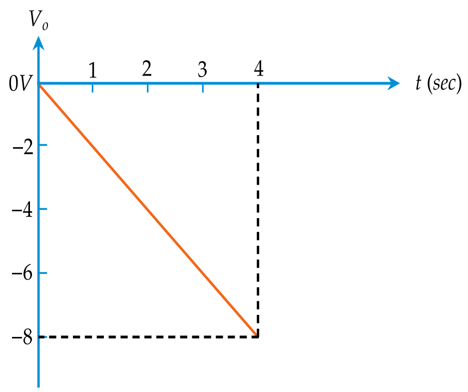
Solution: The input function is constant begining at T=0 seconds.That is $V_{in} = 2V$ for $0 \leqq T \leqq 4$.Therfore by using the equation ,

$$V_o = -\frac{1}{R_1 C_F}\int_0^t V_{\text{in}}\, dt + C$$

$$V_o = \int_0^4 2dt$$

$$= -[2 \times 4] = -8V$$

The output waveform is shown in the figure.The waveform is called ramp wavefunction

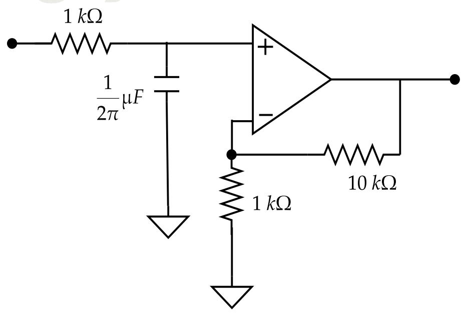


5. For inverting amplifier $R_1 = 470\Omega$ and $R_F = 4.7k\Omega$.Assume that the op-amp is a 741 with specification given below
$A = 200000$
$R_i = 2M\Omega$
$R_0 = 75\Omega$
$f_0 = 5Hz$
Supply voltage $= \pm 15$
Compute the value of A_f, R_{if}, R_{of}, F_f

Solution: Using the given values of R_1 and R_F

$$
\begin{aligned}
K &= \frac{R_F}{R_1 + R_F} = \frac{4700}{470 + 4700} = \frac{1}{1.1} \\
B &= \frac{R_1}{R_1 + R_F} = \frac{470}{470 + 4700} = \frac{1}{11} \\
1 + AB &= \left[1 + (2 \times 10^5)(1/11)\right] = 18182.8 \\
A_F &= \frac{-AK}{1 + AB} = \frac{-200000(1/1.1)}{18182.8} = -10 \\
R_{iF} &= R_1 + \left(\frac{R_F}{1 + A} \parallel R_i\right) \\
R_{iF} &= 470\Omega + \left[\frac{4700}{200000} \parallel 2 \times 10^6\right] \\
R_{oF} &= \frac{R_0}{1 + AB} \\
&= \frac{75}{18182.8} = 4.12M\Omega \\
F_f &= f_0(1 + AB) \\
&= \frac{5 \times 18182.8}{1/1.1} = 100kHz
\end{aligned}
$$

6. For an ideal op-amp circuit given below, the dc gain and the cut off frequency respectively are?



A. 1 and 1kHz **B.** 1 and 100 Hz
C. 11 and 1kHz **D.** 11 and 100 Hz

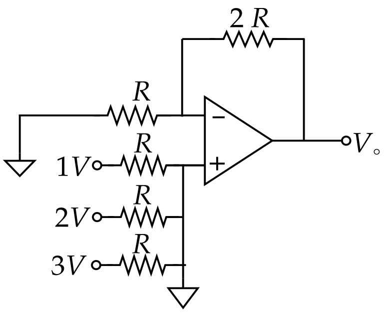
Solution:

$$
\begin{aligned}
\text{DC Gain} &= 1 + \frac{R_F}{R_1} \\
&= 1 + \frac{10}{1} = 11
\end{aligned}
$$

$$\text{And } f_H = \frac{1}{2\pi RC}$$
$$= \frac{1}{2\pi \times 1 \times \frac{1}{2\pi}}$$
$$= 1\text{kHz}$$

The correct option is **(c)**

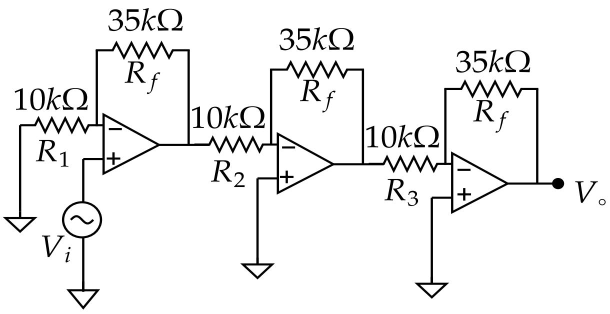
7. The output voltage V_0 of the OPAMP circuit given below is........ V



Solution:

$$V_0 = \left(1+\frac{R_F}{R_1}\right)V_1$$
$$V_0 = \left(1+\frac{2R}{R}\right)V_1$$
$$= 3V_1$$
$$\text{Where, } V_1 = \frac{R/2}{R+R/2}\times 1 + \frac{R/2}{R+R/2}\times 2 + \frac{R/2}{R+R/2}\times 3$$
$$V_1 = \frac{1}{3}\times 1 + \frac{1}{3}\times 2 + \frac{1}{3}\times 3$$
$$= 2V$$
$$V_0 = 6V$$

8. For the input voltage $V_1(200mV)\sin(400t)$, the amplitude of the output voltage (V_0) of the given OPAMP circuit is V. (Round off to 2 decimal places)

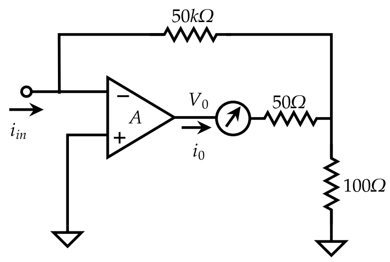


Solution:

$$V_{01} = \left(1+\frac{35}{10}\right)v_i$$
$$= (4\cdot 5\times 200\text{mV})\sin(400t)$$

$$V_{02} = -\frac{35}{10} \times (4 \cdot 5 \times 200\text{mV})\sin(400t)$$
$$V_0 = -\frac{35}{10} \times \left(\frac{-35}{10}\right)(4 \cdot 5 \times 200\text{mV})\sin(400t)$$
$$V_m = (3.5 \times 3.5 \times 4.5 \times 200)\text{mV}$$
$$= 11.03 \text{ Volts}$$

9. A current feedback to an amplifier is applied in the following circuit



The voltage gain of the amplifier is $A = 200$ and the input impedance is $10^6\Omega$. The output current i_0 and the output voltage V_0 corresponding to an input current $i_{\text{in}} = 10\mu A$ are

a. $i_0 = -5$ mA and $V_0 = -0.10$ V

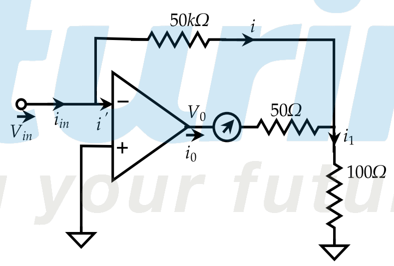
b. $i_0 = -2mA$ and $V_0 = -0.55$ V

c. $i_0 = -5mA$ and $V_0 = -0.75$ V

d. $i_0 = -2mA$ and $V_0 = -0.75$ V

e. $i_0 = -5$ mA and $V_0 = -0.5$ V

Solution:



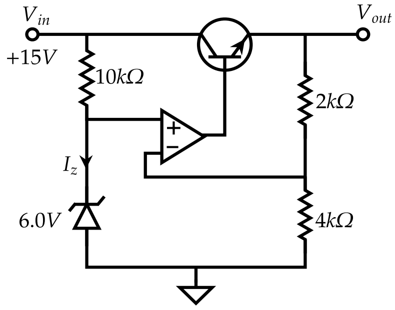
Take all currents in mA and resistance in $k\Omega$

$$V_P = V_0 - 0.05i_0$$
$$i_1 = \frac{V_p}{0.1} = \frac{V_0 - 0.05i_0}{0.1}$$
$$i = i_1 - i_0 = \frac{V_0 - 0.05i_0}{0.1} - i_0$$
$$= \frac{V_0 - 0.15i_0}{0.1}$$
$$i' = i_{\text{in}} - i$$
$$V_{\text{in}} = R_{\text{in}}\, i' = 10^1\left(i_{\text{in}} - i\right)$$
$$= 10^3\left(10^{-2} - i\right) = 10^3\left(10^{-2} - \frac{V_0 - 0.15i_0}{0.1}\right)$$

$$-\frac{V_0}{200} = (10 - (V_0 - 0.15i_0))\,10^4$$
$$10^4 V_0 - 1500i_0 - \frac{V_0}{200} = 10$$

v_e and i_0 given is (c) satisfies above equation.
So the correct answer is **option(c)**

10. Consider the voltage regulator circuit shown in the figure below :



The current in the Zener diode I_z and the output voltage V_{out} are, respectively

a. 1.5 mA and 6.0 V

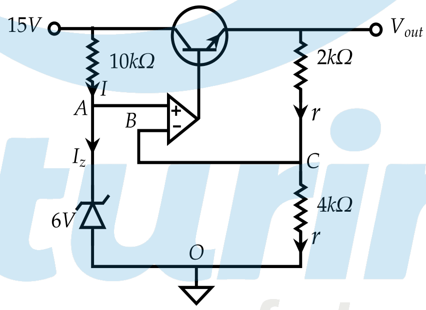
b. 1.5 mA and 9.7 V

c. 0.9 mA and 9.0 V

d. 0.9 mA and 8.3 V

e. 0.9 mA and 6.0 V

Solution:



$$V_A = 6 \text{ V}$$

$$I = \frac{15-6}{10} = 0.9 \text{ mA} = I_z \text{ Using virtual ground.}$$

$$V_B = V_d = 6 \text{ V} = V_C$$

$$I' = \frac{6-0}{4} = 1.5 \text{ mA}$$

$$V_{\text{out}} = V_C + I'R$$

$$= 6 + 1.5 \times 2$$

$$= 9 \text{ V}$$