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Internal Assesment Test - I

Sub:	OPERATIONAL AMPLIFIERS & LINEAR ICS							Code:	17EE46
Date:	07/03/2019	Duration:	90 mins	Max Marks:	50	Sem:	4^{th}(A & B)	Branch:	EEE

Answer any five questions.

		Marks	OBE	
			CO	RBT
1	Explain how an Op-amp can be used as a non-inverting summer and subtractor.	10	CO1	L2
2	Demonstrate an Instrumentation amplifier with transducer bridge input. Derive the expression of output voltage for same.	10	CO1	L2
3	For a non inverting amplifier with single polarity supply R_i=50Ω=R_o, Ci=C_1=0.1uF,R_1=R_2=R_3=100k Ω, R_f=1M Ω and +Vcc=+15V.Determine bandwidth of the amplifier and maximum output voltage swing.	10	CO1	L2
4	Using a uA741 Op-amp, design a capacitor coupled non inverting amplifier. The specifications of the circuit are :-Closed loop voltage gain =3,Input voltage =2V, load resistance=2.2kΩ and lower cut off frequency =120 Hz	10	CO1	L3
5	Define slew rate, CMRR, input offset voltage, input offset current and input bias current for an Op-amp with necessary expressions.	10	CO1	L2
6	Derive the expression for closed loop gain, Ideal closed loop gain, Input resistance and output resistance of a voltage shunt feedback amplifier with circuit diagrams.	10	CO1	L2
7	With a block diagram explain the different stages of a typical Op-amp	10	CO1	L2

******All the Best*****

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7	With a block diagram explain the different stages of a typical Op-amp	10	CO1	L2

******All the Best*****

<u>Scheme Of Evaluation</u>

<u>Internal Assessment Test 1 – Mar.2019</u>

Sub:	Operation Amplifiers & Linear ICs							**Code:**	17EE46
Date:	07/03/2019	Duration:	90mins	Max Marks:	50	**Sem:**	IV	**Branch:**	EEE

Note: Answer Any Five Questions

Question #	**Description**	**Max Marks**	
1	Explain how an Op-amp can be used as a non-inverting summer and subtractor. Non-Inverting Amplifier • Circuit diagram • Explanation • Expression of output voltage Differential Amplifier as Subtractor • Circuit diagram • Explanation • Expression of output voltage	1M 2M 2M 1M 2M 2M	10M
2	Demonstrate an Instrumentation amplifier with transducer bridge input. Derive the expression of output voltage for same • Circuit of Instrumentation amplifier with transducer bridge • Explanation • Expression for output voltage	3M 3M 4M	10M
3	For a non inverting amplifier with single polarity supply $R_i=50\Omega=R_o$, $Ci=C_1=0.1uF$,$R_1=R_2=R_3=100k\ \Omega$, $R_f=1M\ \Omega$ and +Vcc=+15V.Determine bandwidth of the amplifier and maximum output voltage swing • Calculation of F_l • Calculation for F_h • Bw • Voltage swing	3M 3M 3M 1M	10M
4	Using a uA741 Op-amp, design a capacitor coupled non inverting amplifier. The specifications of the circuit are :-Closed loop voltage gain =3,Input voltage =2V, load resistance=2.2kΩ and lower cut off frequency =120 Hz • Calculate R_1,R_2’R_3 • Calculate C1,C2	6M 4M	10M

5	Define slew rate, CMRR, input offset voltage, input offset current and input bias current for an Op-amp with necessary expressions. • Slew rate • CMRR • Input offset voltage • Input offset • Bias current	2M 2M 2M 2M 2M	10M
6	Derive the expression for closed loop gain, Ideal closed loop gain, Input resistance and output resistance of a voltage shunt feedback amplifier with circuit diagrams. • Circuit for voltage shunt feedback amplifier • Expression for close loop gain • Expression for input resistance • Expression for output resistance	1M 3M 3M 3M	10M
7	With a block diagram explain the different stages of a typical Op-amp. • Block diagram • Explanation for each block I. Input stage II. Intermediate stage III. Level shifting stage IV. Output stage	2M 2M 2M 2M 2M	10M

This value is equal to the average of three inputs with a negative sign.

6–5–2 Noninverting Configuration

If input voltage sources and resistors are connected to the noninverting terminal as shown in Figure 6–7, the circuit can be used either as a summing or averaging amplifier through selection of appropriate values of resistors, that is, R_1 and R_F.

Q.1 Again, to verify the functions of the circuit, the expression for the output voltage must be obtained. Recall that the input resistance R_{iF} of the noninverting amplifier is very large (see Figure 6–7). Therefore, using the superposition theorem, the voltage V_1 at the noninverting terminal is

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

or

$$V_1 = \frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3} = \frac{V_a + V_b + V_c}{3} \qquad \text{(6–9)}$$

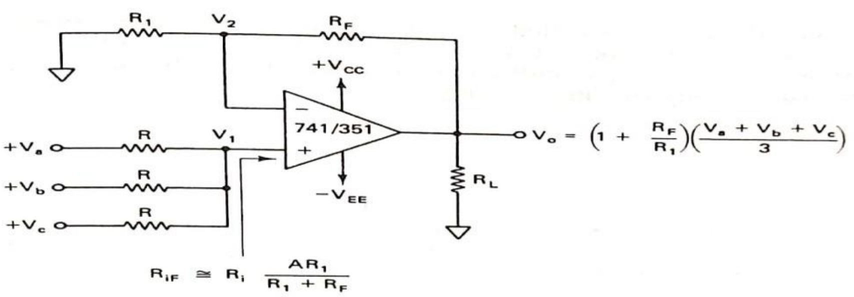

FIGURE 6–7 Noninverting configuration with three inputs can be used as an averaging amplifier or a summing amplifier.

Hence the output voltage V_o is

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

$$= \left(1 + \frac{R_F}{R_1}\right) \frac{V_a + V_b + V_c}{3} \qquad \text{(6–10a)}$$

6–5–2(a) Averaging amplifier

6–5–2(b) Summing amplifier

A close examination of Equation (6–10a) reveals that if the gain $(1 + R_F/R_1)$ is equal to the number of inputs, the output voltage becomes equal to the *sum* of all input voltages. That is, if $(1 + R_F/R_1) = 3$ [from Equation (6–10a)],

$$V_o = V_a + V_b + V_c \qquad \text{(6–10b)}$$

Hence the circuit is called a *noninverting summing amplifier.*

Again, when the circuit of Figure 6–7 is used as either an averaging or summing amplifier, offset null circuitry or an offset null compensating network must be used to improve its accuracy.

6–5–3(a) A subtractor

A basic differential amplifier can be used as a *subtractor* as shown in Figure 6–8. In this figure, input signals can be scaled to the desired values by selecting appropriate values for the external resistors; when this is done, the circuit is referred to as *scaling amplifier*. However, in Figure 6–8, all external resistors are equal in value, so the gain of the amplifier is equal to 1.

From this figure, the output voltage of the differential amplifier with a gain of 1 is

$$V_o = -\frac{R}{R}(V_a - V_b) \qquad \text{(see Section 3–5–1)}$$

That is,

$$V_o = V_b - V_a \tag{6–11}$$

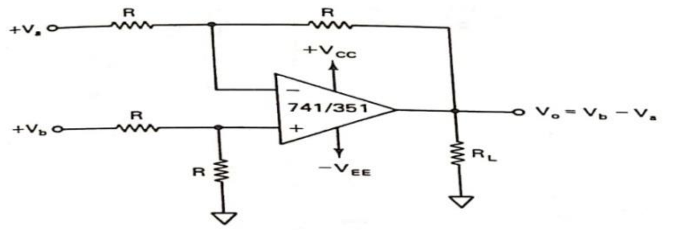

FIGURE 6–8 Basic differential amplifier used as a subtractor.

Thus the output voltage V_o is equal to the voltage V_b applied to the noninverting terminal *minus* the voltage V_a applied to the inverting terminal; hence the circuit is called a *subtráctor*.

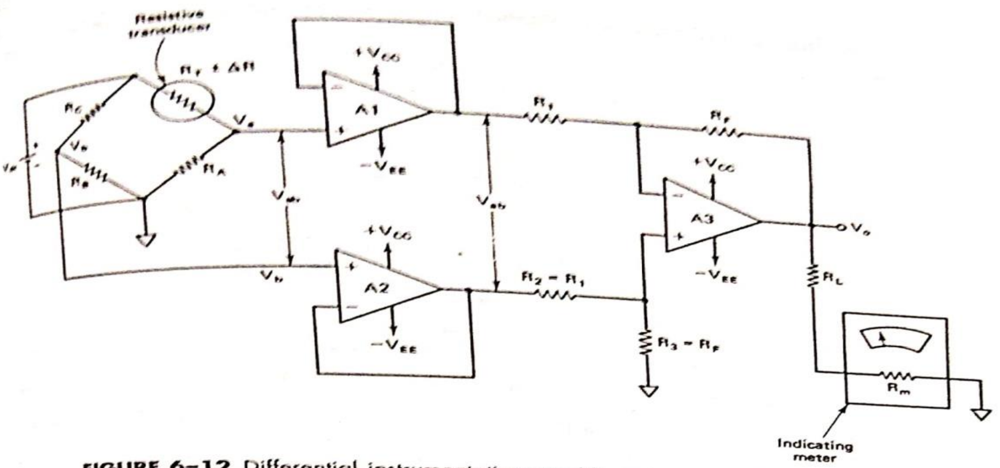

FIGURE 6–12 Differential instrumentation amplifier using a transducer bridge.

That is,

$$\frac{R_C}{R_B} = \frac{R_T}{R_A} \tag{6–13}$$

Generally, resistors R_A, R_B, and R_C are selected so that they are equal in value to the transducer resistance R_T at some *reference condition*. The reference condition is the specific value of the physical quantity under measurement at which the bridge is balanced. This value is normally established by the designer and depends on the transducer's characteristics, the type of physical quantity to be measured, and the desired application.

The bridge is balanced initially at a desired reference condition. However, as the physical quantity to be measured changes, the resistance of the transducer also changes, which causes the bridge to unbalance ($V_a \neq V_b$). The output voltage of the bridge can be expressed as a function of the change in resistance of the transducer, as described next.

Let the change in resistance of the transducer be ΔR. Since R_B and R_C are fixed resistors, the voltage V_b is constant. However, voltage V_a varies as a function

6–6–1 Instrumentation Amplifier Using Transducer Bridge

Figure 6–12 shows a simplified differential instrumentation amplifier using a transducer bridge. A *resistive transducer* whose resistance changes as a function of some physical energy is connected in one arm of the bridge with a small circle around it and is denoted by $(R_T \pm \Delta R)$, where R_T is the resistance of the transducer and ΔR the change in resistance R_T.

The bridge in the circuit of Figure 6–12 is dc excited but could be ac excited as well. For the balanced bridge at some reference condition,

$$V_b = V_a$$

or

$$\frac{R_B(V_{dc})}{R_B + R_C} = \frac{R_A(V_{dc})}{R_A + R_T}$$

of the change in transducer resistance. Therefore, according to the voltage-divider rule,

Q.2

$$V_a = \frac{R_A(V_{dc})}{R_A + (R_T + \Delta R)}$$

$$V_b = \frac{R_B(V_{dc})}{R_B + R_C}$$

Consequently, the voltage V_{ab} across the output terminals of the bridge is

$$V_{ab} = V_a - V_b = \frac{R_A V_{dc}}{R_A + R_T + \Delta R} - \frac{R_B V_{dc}}{R_B + R_C}$$

However, if $R_A = R_B = R_C = R_T = R$, then

$$V_{ab} = \frac{\Delta R(V_{dc})}{2(2R + \Delta R)} \tag{6–14}$$

The negative (−) sign in this equation indicates that $V_a < V_b$ because of the increase in the value of ΔR.

The output voltage V_{ab} of the bridge is then applied to the differential instrumentation amplifier composed of three op-amps (see Figure 6–12). The voltage followers preceding the basic differential amplifier help to eliminate loading of the bridge circuit. The gain of the basic differential amplifier is $(-R_F/R_1)$; therefore, the output V_o of the circuit is

$$V_o = V_{ab}\left(-\frac{R_F}{R_1}\right) = \frac{(\Delta R)V_{dc}}{2(2R + \Delta R)}\frac{R_F}{R_1} \tag{6–15a}$$

Generally, the change in resistance of the transducer ΔR is very small. Therefore, we can approximate $(2R + \Delta R) \cong 2R$. Thus, the output voltage

$$V_o = \frac{R_F}{R_1}\frac{\Delta R}{4R}V_{dc} \tag{6–15b}$$

The equation indicates that V_o is directly proportional to the change in resistance ΔR of the transducer. Since the change in resistance is caused by a change in physical energy, a meter connected at the output can be calibrated in terms of the units of that physical energy.

SOLUTION

a. The ac input resistance of the amplifier is

$$R_{iF} = (R_2) \| (R_3) \| [R_i(1 + AB)]$$

$$R_{iF} \cong (R_2) \| (R_3) \qquad \text{since } [R_i(1 + AB)] \gg R_2 \text{ or } R_3$$

$$R_{iF} \cong 100\ \text{k}\Omega \| 100\ \text{k}\Omega = 50\ \text{k}\Omega$$

Therefore, from Equation (6–1),

$$f_L = \frac{1}{(2\pi)(10^{-7})(50\ \text{k} + 50)} = 31.8\ \text{Hz}$$

The gain of the amplifier is $(1 + R_F/R_1) = 11$. Hence from Equation (3–10b)

$$f_H = \frac{\text{UGB}}{A_F} = \frac{1\ \text{MHz}}{11} = 90.91\ \text{kHz}$$

and

$$\text{BW} = f_H - f_L = 90.91\ \text{kHz} - 0.0318\ \text{kHz} = 90.88\ \text{kHz}$$

b. The ideal maximum output voltage swing $= +V_{CC} = +15$ V pp.

Q.3

From Eq.4-3, $C_2 = \frac{1}{2\pi f_1 R_L} = \frac{1}{2\pi \times 120\text{ Hz} \times 2.2\text{ k}\Omega}$

$\approx 0.6\ \mu F$ (use 0.68 μF standard value)

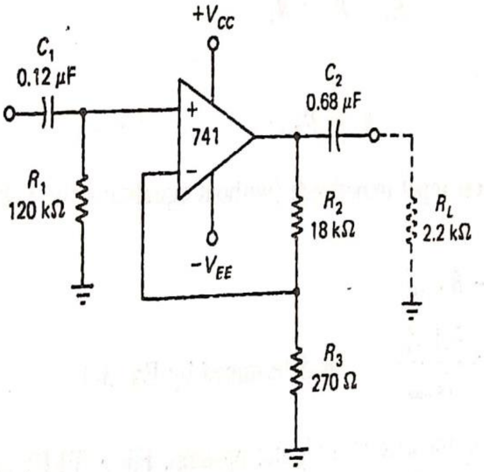

Figure 4-7 Capacitor-coupled non-inverting amplifier designed in Example 4-4.

Q.4

the required ...

Solution

The circuit is rearranged as in Fig. 4-6.
For highest Z_{in},

Eq. 3-1, $R_{1(max)} = \frac{0.1\ V_{BE}}{I_{B(max)}} = \frac{0.1 \times 0.7\text{ V}}{500\text{ nA}}$

$\approx 140\text{ k}\Omega$ (use 120 kΩ standard value)

$R_2 = 18\text{ k}\Omega$ and $R_3 = 270\ \Omega$ as in Example 3-4

From Eq. 4-2, $C_1 = \frac{1}{2\pi f_1 (R_1/10)} = \frac{1}{2\pi \times 120\text{ Hz} \times (120\text{ k}\Omega/10)}$

$= 0.11\ \mu F$ [use 0.12 μF standard value]

Q.5

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 2–2. In the figure $V_{dc\,1}$ and $V_{dc\,2}$ 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 6 mV dc. 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 μV maximum.

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,

$$SR = \left.\frac{dV_o}{dt}\right|_{maximum} \quad V/\mu s \qquad (2\text{–}8)$$

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 ...

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,

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

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

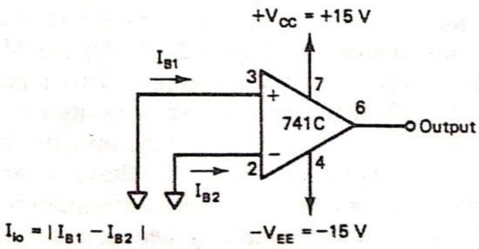

FIGURE 2–3 Defining input offset current I_{io}.

Input Offset Current. The algebraic difference between the currents into the inverting and noninverting terminals is referred to as *input offset current*, I_{io} (see Figure 2–3). In the form of an equation,

$$I_{io} = |I_{B1} - I_{B2}| \tag{2–1}$$

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

Common-Mode Rejection Ratio. 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,

$$\text{CMRR} = \frac{A_d}{A_{cm}} \tag{2–3}$$

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 the circuit of Figure 2–5 using the equation

$$A_{cm} = \frac{V_{ocm}}{V_{cm}} \tag{2–4}$$

where V_{ocm} = output common-mode voltage
V_{cm} = input common-mode voltage
A_{cm} = common-mode voltage gain

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

Q.6

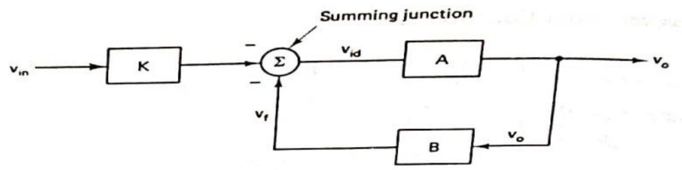

FIGURE 3–9 Block diagram of inverting amplifier with feedback using a voltage-summing junction as a model for current summing.

where $K = \dfrac{R_F}{R_1 + R_F}$, a voltage attenuation factor

$B = \dfrac{R_1}{R_1 + R_F}$, gain of the feedback circuit

A comparison of Equation (3–15) with the feedback Equation (3–6) indicates that, in addition to the phase inversion (− sign), the closed-loop gain of the inverting amplifier is K times the closed-loop gain of the noninverting amplifier, where $K < 1$.

The one-line block diagram of the inverting amplifier with feedback is shown in Figure 3–9. The reason for the block diagram is twofold: (1) to facilitate the analysis of the inverting amplifier, and (2) to express the performance equations in the same form as those for the noninverting amplifier.

The block diagram in Figure 3–3 for the noninverting amplifier and the block diagram in Figure 3–9 for the inverting amplifier are identical, except for the K block. However, the major difference is that in Figure 3–9 a voltage-summing junction is being used as a model for what is actually current summing.

To derive the ideal closed-loop gain, we can use Equation (3–15) as follows. If $AB \gg 1$, then $(1 + AB) \cong AB$ and

$$A_F = -\frac{K}{B} = -\frac{R_F}{R_1} \qquad (3\text{–}16)$$

This is the same result obtained in Equation (3–14).

3-4-3 Input Resistance with Feedback

The easiest method of finding the input resistance is to Millerize the feedback resistor R_F; that is, split R_F into its two Miller components, as shown in Figure 3–10.

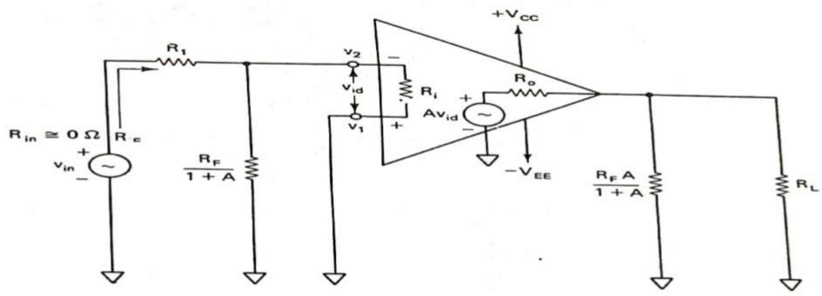

FIGURE 3–10 Inverting amplifier with Millerized feedback resistor.

3-3-5 Output Resistance with Feedback

Output resistance is the resistance determined looking back into the feedback amplifier from the output terminal as shown in Figure 3–5. This resistance can be

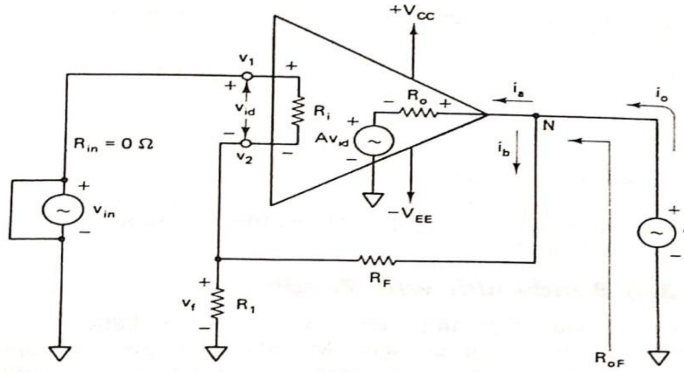

FIGURE 3–5 Derivation of output resistance with feedback.

In the circuit of Figure 3–10, the input resistance with feedback R_{iF} is

$$R_{iF} = R_1 + \frac{R_F}{1 + A} \| (R_i) \qquad \text{(exact)}$$

Since R_i and A are very large.

$$\frac{R_F}{1 + A} \| R_1 \cong 0\ \Omega$$

Hence

$$R_{iF} + R_1 \qquad \text{(ideal)}$$

obtained by using Thévenin's theorem for *dependent* sources. Specifically, to find output resistance with feedback R_{oF}, reduce independent source v_{in} to zero, apply an external voltage v_o, and then calculate the resulting current i_o. In short, the R_{oF} is defined as follows:

$$R_{oF} = \frac{v_o}{i_o} \qquad \text{(3–9a)}$$

Writing Kirchhoff's current equation at output node N, we get

$$i_o = i_a + i_b$$

since $[(R_F + R_1) \| R_i] \gg R_o$ and $i_a \gg i_b$. Therefore,

$$i_o \cong i_a$$

The current i_o can be found by writing Kirchhoff's voltage equation for the output loop:

$$v_o - R_o i_o - A v_{id} = 0$$

$$i_o = \frac{v_o - A v_{id}}{R_o}$$

However,

$$v_{id} = v_1 - v_2$$

$$= 0 - v_f$$

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

Therefore,

$$i_o = \frac{v_o + AB v_o}{R_o}$$

Substituting the value of i_o in Equation (3–9a), we get

$$R_{oF} = \frac{v_o}{(v_o + AB v_o)/R_o}$$

$$= \frac{R_o}{1 + AB} \qquad \text{(3–9b)}$$

This result shows that the output resistance of the voltage-series feedback amplifier is $1/(1 + AB)$ times the output resistance R_o of the op-amp. That is, the output resistance of the op-amp with feedback is much smaller than the output resistance without feedback.

3–3–6 Bandwidth with Feedback

Q.7

1–3 BLOCK DIAGRAM REPRESENTATION OF A TYPICAL OP-AMP

Since an op-amp is a multistage amplifier, it can be represented by a block diagram as shown in Figure 1–1.

The input stage is the dual-input, balanced-output differential amplifier. This stage generally provides most of the voltage gain of the amplifier and also establishes the input resistance of the op-amp. The intermediate stage is usually another differential amplifier, which is driven by the output of the first stage. In most am-

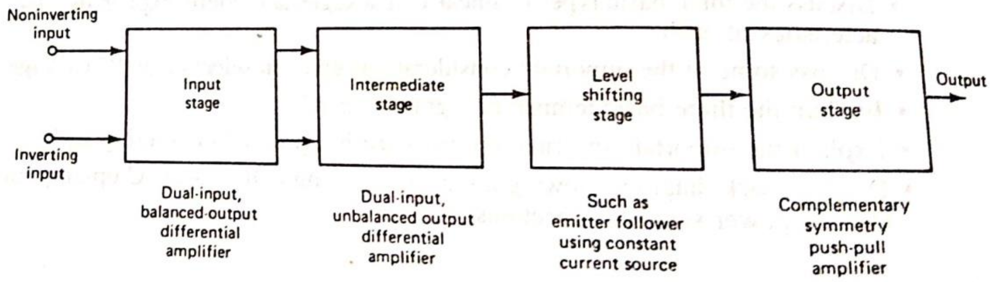

FIGURE 1–1 Block diagram of a typical op-amp.