Integrated Circuit (IC) :-

is the outcome of solid-state devices & Components in the regarding of characteristics & miniaturisation of solid-state devices when solid-state devices such as transistors & diodes were invented, they replaced vaccum tubes.

→ Similarly, a new generation of solid-state electronics, i.e. IC's, is replacing the discrete components like resistors, capacitors, diodes, transistors, FETs etc. In a discrete circuit the components are separable, where as the components of IC circuits are inseparable.

→ Most of the IC's are sillicon chips with devices such as transistors, resistors & capacitors fabricated in them. A single sillicon chip can contain a few devices (or) many thousands of devices. i.e Large & Complex circuits can be reduced to a small size by IC technology

→ The advantages of IC's over discrete Components

→ Small size
→ improved performance
→ Low Cost
→ High reliability & ruggedness
→ Low power Consumption
→ Less weight & portable
→ simpler design of systems

Unit - II

Classification :- Based on the complexity levels IC's are classified as

→ Small Scale integration		(SSI)	100 transistors/chip
→ Medium	"	(MSI)	100-1000 "
→ Large	"	(LSI)	1,000 - 20,000 "
→ Very Large	"	(VLSI)	20,000 - 10,00,000
→ Ultra Large	"	(ULSI)	$10^6 - 10^7$
→ Giant Scale	"	(GSI)	more than 10^7.

→ On the basis of fabrication process used, IC's can be classified as → Monolithic → Bipolar, Unipolar
→ Hybrid

→ Based on the treatment of processing of the signal, IC's can be classified as → Linear or Analog IC's
→ Digital IC's
→ Mixed signal IC's.

→ An analog signal is

Unit - I

Introduction to Linear Integrated Circuits

A "Linear Integrated Circuit is used in a Variety of modern Electronic Equipments. The Linear integrated circuit is able to receive, process & produce a Variety of diff. Levels of Energy as the device operates.

→ To understand, what a linear integrated circuit is, first of all it is very important to understand what an "integrated circuit" (IC)" is.

→ As we are all know that, the technology grows day by day very fastly, i.e today the growth of any thing like, Communication, Control instrumentation (or) Computers is dependent upon Electronics to a great extent.

→ The "Integrated circuit" (or) "IC" is a miniature, Low cost Electronic circuit consisting of active & passive components that are joined together on a single crystal chip of silicon.

→ Each IC can have hundreds (or) millions of active & passive Elements. These IC's Can be Either "Analog" (or) "Digital"

→ So, these Analog IC's are nothing but "Linear integrated Circuits", why because, the signal o/p Level of the Circuit is a linear function of the signal i/p Level.

→ In other words, as the i/p changes, the o/p of the ckt changes proportionately (or) when we draw a graph between i/p & o/p, it would produce a straight line

→ Linear IC's are used for functions, where the signal o/p needs to vary such as for audio freq. & radio freq. amplifiers.

→ Devices like audio amplifiers, D.C amplifiers, oscillators, & multivibrators Use these Circuits.

→ The most common type of "Linear IC" is an "operational amplifier" (or) "op-amp".

→ Linear IC's are being used in a no. of Electronic applications such as in fields like audio & radio comm:, medical Electronics, instrumentation Control ---

Operational amplifiers :-

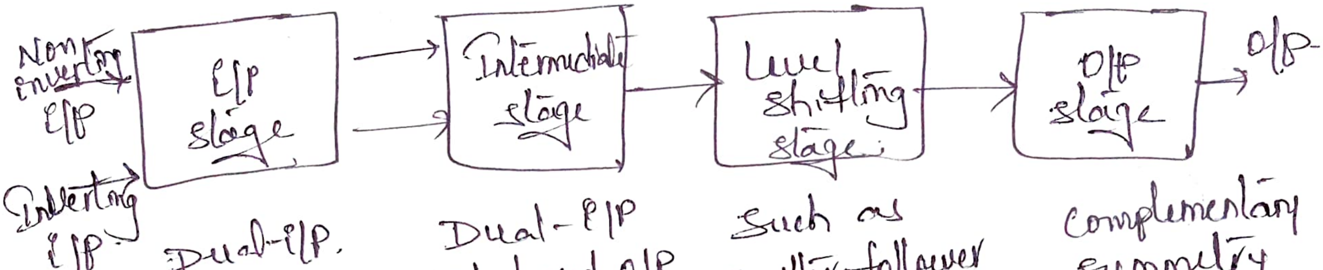
The operational amplifier is commonly is commonly referred to as "Op-amp", it is a multiterminal device, which internally is quite complex.

An operational amp: is a direct-coupled high-gain amplifier, usually consists of one or more "differential amplifiers" & usually followed by a "Level translator" & an O/P stage. The O/P stage is generally a "push-pull" (or) "push-pull-complementary-symmetry pair".

→ The op-amp is a versatile device that can be used to amplify "D.C" as well as "a.c" i/p signals & was originally designed for computing mathematical functions such as addition, subtraction, multiplication & integration.

→ So, the name "op amp" is comes from its original operations with the use of these mathematical addition of suitable external feed back components, the modern day op-amp can be used for a variety of applications, such as a.c & d.c amplification, active filters, oscillators comparators, regulators & others.

Block diagram of op-amp :-



Dual-I/P. balanced -O/P, diff: amp:

Dual-I/P Unbalanced O/P diff: amp:

Such as Emitter-follower Using Constant current source.

complementary symmetry push-pull amplifier.

→ As, we already discussed that, an op-amp is a multistage amplifier, the Block diagram consists of ...

→ The I/P stage is the dual-I/P, balanced O/P diff. amp: This stage generally provides most of the voltage gain of the amplifier & also establishes I/P resistance of the op-amp.

→ The intermediate stage is usually another diff. amp:, which is driven by the O/P of the first stage. In most amps:'s, the intermediate stage is dual-I/P, Unbalanced O/P.

→ Because of the direct-coupling used, the d.c voltage at the O/P of the intermediate stage is well above ground potential. Therefore generally, the Level shifter is used after intermediate stage.

→ which is used to shift the d.c. level at the o/p of the intermediate stage down ward to zero volts w.r.to ground.

→ The final stage is usually a push-pull complementary amp. The o/p stage increases the o/p voltage swing & raises the current supplying capability of the op-amp. A well designed o/p stage also provides low o/p resistance.

Differential Amplifiers:-

Differential amplifier is a multi-transistor amplifier. It is the fundamental building block of analog ckt.

→ It is virtually formed the diff. amp. of the i/p part of an op-amp. It is used to provide → (or) its charac:'s are:

- → a high voltage gain
- → high common mode rejection ratio
- → very high i/p impedance
- → very low offset voltage
- → very low i/p bias current.

→ Diff: amp: Can operate in two modes.

→ Common mode

→ Differential mode

→ In Common mode, the diff: amp: gives zero o/p.

→ In diff. mode, it gives the high o/p, means that the amp: has high "Common mode Rejection Ratio".

→ As its name implies, the differential amplifier amplifies the difference b/w two i/p signals "Vin1" & "Vin2" so, the diff: amp: is also referred to as "difference amplifier".

→ The main purpose of the diff: amp: stage is to provide high gain to the difference - mode signal & cancel the common mode signal.

→ The diff: amp: can be configured in four ways by the no: of i/p signals used & the way the o/p voltage is measured. they are:

→ Dual - i/p, balanced - o/p diff: amp:

→ Dual - i/p, unbalanced o/p diff: amp:

→ Single - i/p, balanced o/p diff: amp:

→ Single - i/p, unbalanced o/p diff: amp:

→ If we use two I/P signals, that configuration is said to be "Dual I/P", Otherwise, it is a "Single I/P" Configuration.

→ If the O/P voltage is measured b/w two Collectors, it is referred to as "Balanced O/P", because both collectors are at the same d.c. potential w.r.to GND

→ However, if the O/P is measured at one of the Collectors, w.r.to GND, that Configuration is called "Unbalanced O/P"

→ Before going a deep into the diff. amp. let me tell you, the general req: (or) observations of diff: amps. are;

→ Two matched semiconductors of the same type may be BJT (or) FET's are required for the diff. amp. & they will be in Emitter-bias & all the components must be matched in all respects for proper operation of diff. amp.

→ Furthermore, the magnitude of the supply voltages +Vcc & −VEE must be Equal.

→ The diff: amp. is capable of amplifying "D.C" as well as "A.C." I/P signals. In instrumentation systems, diff. amp's are widely used to compare two I/P signals.

→ As we already discussed that, the diff. amp. requires two identical emitter biased circuits in that all the components should be matched is shown in fig:

→ Here, two transistors are identical, means they have the same characteristics.

& $RE_1 = RE_2$, $RC_1 = RC_2$

& magnitude of +Vcc is equal to magnitude of -VEE.

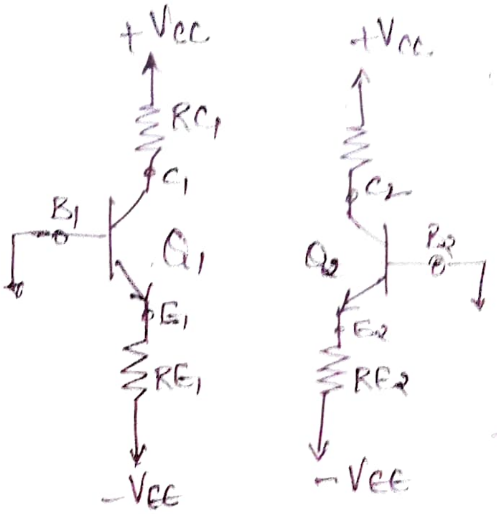


fig: two identical emitter biased ckts.

→ If we are reconnecting these two identical emitter biased ckts; we will get the diff. amplifier. First of all let we see the Dual I/P, Balanced O/P config:

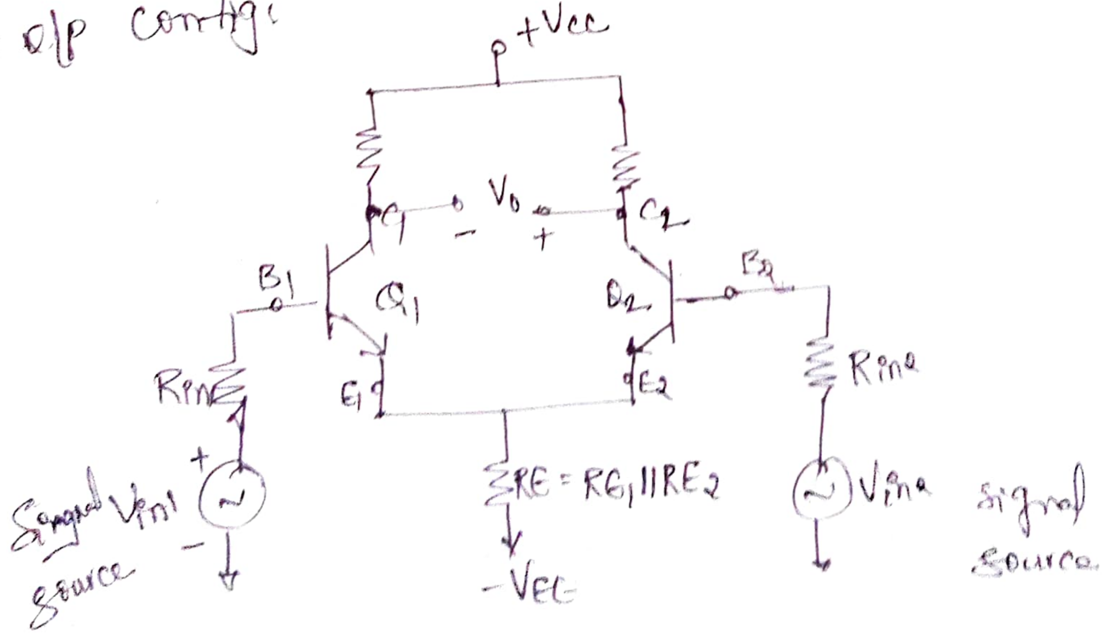


fig: Dual I/P, balanced O/P diff. amp.

Working:- (5)

To understand the working of diff: amp: Let we consider the case, when both the bases B_1 & B_2 are joined together & connected to a common mode voltage V_{cm}. so, $V_1 = V_2 = V_{CM}$.

→ As both the transistors Q_1 & Q_2 are forward biased, & matched due to symmetry of the ckt, the current I_Q divides equally through Q_1 & Q_2 i.e $i_{E1} = i_{E2} = I_Q/2$

→ The collector currents i_{C1} & i_{C2} through the resistor R_C is $\alpha \frac{I_Q}{2}$. & the voltage at each collector is $V_{CC} - \alpha \frac{I_Q}{2} R_C$ & therefore the diff: of two collector voltages $V_{01} - V_{02} = 0$.

→ Now, even if the value of V_{CM} is changed, the voltage across collectors will not change. thus the diff: amp: doesn't respond to (or) rejects the common mode i/p signals.

→ Now, Let we consider another case, when the voltage V_2 is made zero & $V_1 = 1V$ say, It can be seen that transistor 'Q_1' is conduct & Q_2 will OFF The entire current I_Q flows through Q_1

The collector voltage $V_{01} = V_{CC} - \alpha I_Q R_C$ & $V_{02} = V_{CC}$

→ However if, $V_1 = -1V$. & $V_2 = 0V$, It can be seen that 'Q_2' will be ON' & Q_1 is OFF. So, the entire current flows through 'Q_2'.

The collector voltage, $V_{02} = V_{CC} - \alpha I_Q R_C$ & $V_{01} = V_{CC}$

→ Thus we can say that, the diff: amp: responds only to diff: mode signal & rejects common mode signals.

→ Already we know that, diff: amp: amplifies A.C. aswell as d.c i/p signals. To analyse the diff: amp: we, use r-parameters instead of h-parameters for a no: of reasons.

→ Because of the nature of r-parameters, ac analysis of diff: amp: with r-parameters is simpler, more straight forward, & less Com-bursome.

→ Un like with h-parameters, there is no need to manipulate the r-parameters at diff: operating levels. Except for the r_e value.

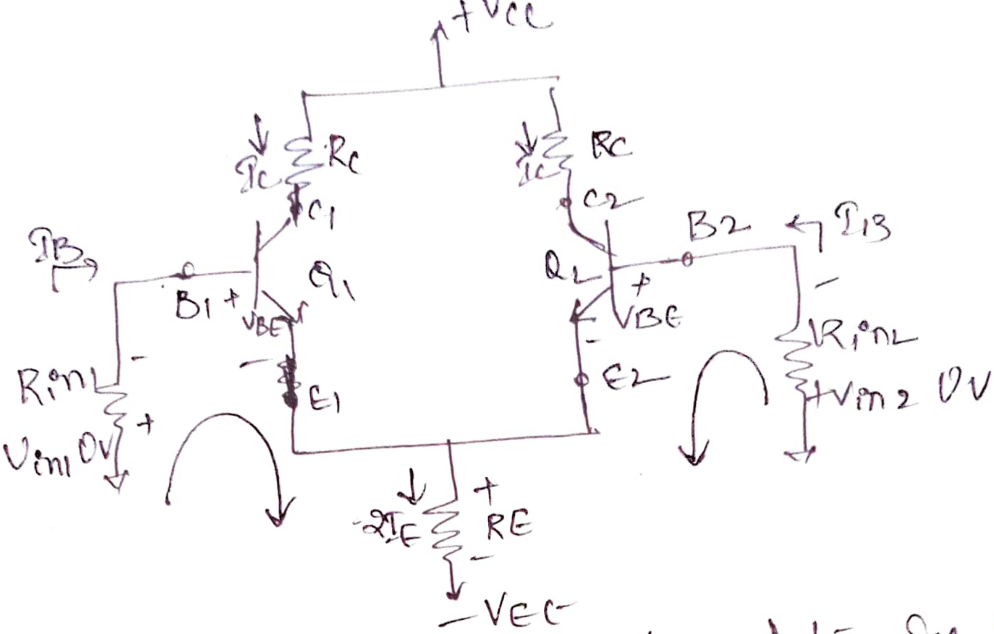
→ The performance eq.'s obtained are Easy to remember since they are not as complex as as lengthy as h-parameters eq.'s

→ the results obtained using r_e parameters are favored with actual results.

D.C. Analysis :-

To determine the operating point values (I_{CQ} & V_{CEQ}) for the diff: amp:, we need to obtain d.c eq: circuit. The d.c eq. ckt can be obtained by reducing the i/p signals V_{in1} & V_{in2} to zero.

Let we draw d.c. Eq. ckt of dual-I/P balanced O/P diff. amp.



→ Here both the Emitter biased ckts are symmetrical we need to determine the operating point for only one section. Let it will be 'Q_1'.

I_{CQ} & V_{CEQ}.

→ To find I_{CQ}, Apply Kirchoff's Voltage law at the Base-Emitter ~~jn~~ loop for Q_1

$$-R_{in} I_B - V_{BE} - R_E\, 2(I_E) + V_{EE} = 0$$

We know that, $I_B = \dfrac{I_E}{\beta_{dc}}$ & $I_C \approx I_E$

Substitute I_B value, we get

$$-R_{in} \frac{I_E}{\beta_{dc}} - V_{BE} - R_E \cdot 2 \cdot I_E + V_{EE} = 0$$

$$I_E = \frac{V_{EE} - V_{BE}}{2R_E + \dfrac{R_{in}}{\beta_{dc}}}$$

Generally $\dfrac{R_{in}}{\beta_{dc}} << 2R_E$ therefore, it will neglect.

$$\therefore I_E = \frac{V_{EE} - V_{BE}}{2R_E}.$$

From this we can say that; by selecting proper value of R_E, we can obtain a desired value of I_E for a known value of $-V_{EE}$.

→ Next we have determine V_{CE}.

$$V_{CE} = V_C - V_E.$$

$V_C = V_{CC} - I_C R_C$

$V_E \approx -V_{BE}$

$$= (V_{CC} - I_C R_C) - (-V_{BE})$$

$$= V_{CC} + V_{BE} - I_C R_C$$

A.C Analysis :-

To perform A.C analysis to derive the expression for the "voltage gain (Ad)" & the "i/p resistance (Ri)" of the differential amplifier.

→ To perform a.c. analysis (or) derive the a.c. analysis ckt.
→ set the d.c voltages $+V_{CC}$ & $-V_{EE}$ at zero
→ substitute the small-signal T-equivalent models for the transistors.

→ Now, let we draw the small signal T-eq. model for the dual-i/p balanced o/p config:

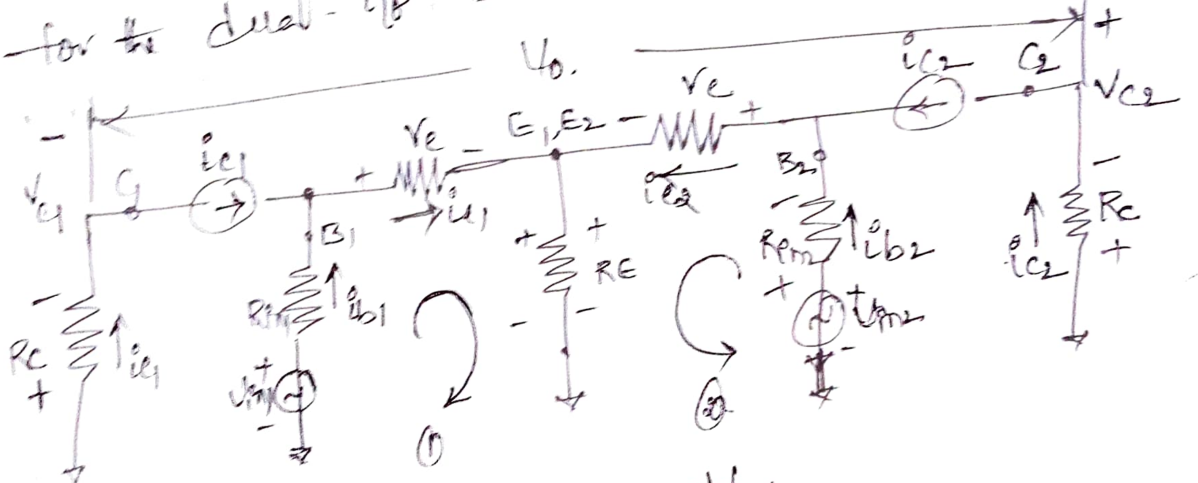


fig. a.c eq. ckt.

voltage gain :-

Before going to calculate voltage gain Ad it should be noted that, here, $R_{E_1} = R_{E_2}$ ∴ $r_{e_1} = r_{e_2}$. For this reason, the a.c emitter resistance of transistors Q_1 & Q_2 is simply denoted by "r_e"

→ The voltage across each collector resistor is shown out of phase w.r.to i/p voltages V_{in_1} & V_{in_2}

- It should be noted that, the polarity of O/P voltage 'V_o' indicates that, the voltage at collector 'C_2' is assumed to be more +ive w.r.to that 'C_1', even though both of them are -ive w.r.to GND.

- So, in order to find the voltage gain, apply Kirchoff's voltage laws for the two loops, we get,

$$V_{in1} - R_{in1} i_{b1} - r_e i_{e1} - R_E (i_{e1} + i_{e2}) = 0$$

$$V_{in2} - R_{in2} i_{b2} - r_e i_{e2} - R_E (i_{e1} + i_{e2}) = 0$$

Substituting, $i_{b1} = \frac{i_{e1}}{\beta_{ac}}$ & $i_{b2} = \frac{i_{e2}}{\beta_{ac}}$

$$\therefore V_{in1} - \frac{R_{in1}}{\beta_{ac}} i_{e1} - r_e i_{e1} - R_E (i_{e1} + i_{e2}) = 0.$$

$$V_{in2} - \frac{R_{in2}}{\beta_{ac}} i_{e2} - r_e i_{e2} - R_E (i_{e1} + i_{e2}) = 0.$$

- Generally, $\frac{R_{in}}{\beta_{ac}}$ & $\frac{R_{in2}}{\beta_{ac}}$ values are very small. therefore we shall neglect them, then we get,

$$V_{in1} = (r_e + R_E) i_{e1} + (R_E) i_{e2}$$

$$V_{in2} = (R_E) i_{e1} + (r_e + R_E) i_{e2}$$

We can solve the Eq:'s for i_{e1} & i_{e2} by using Cramer's Rule.

$$i_{e1} = \frac{\begin{vmatrix} V_{in1} & R_E \\ V_{in} & r_e + R_E \end{vmatrix}}{\begin{vmatrix} r_e + R_E & R_E \\ R_E & r_e + R_E \end{vmatrix}}$$

$$i_{e_1} = \frac{(r_e+R_E)\,V_{in} - (R_E)\,V_{in_2}}{(r_e+R_E)^2 - (R_E)^2}$$

Similarly, $i_{e_2} = \dfrac{\begin{vmatrix} r_e+R_E & V_{in_1} \\ R_E & V_{in_2} \end{vmatrix}}{\begin{vmatrix} r_e+R_E & R_E \\ R_E & r_e+R_E \end{vmatrix}}$

$$= \frac{(r_e+R_E)\,V_{in_2} - (R_E)\,V_{in_1}}{(r_e+R_E)^2 - (R_E)^2}$$

The O/P voltage, $V_o = V_{C_2} - V_{C_1}$

$= -i_{C_2}R_C - (-i_{C_1}R_C)$

$= i_{C_1}R_C - i_{C_2}R_C$

$= R_C\,(i_{C_1} - i_{C_2})$ $\quad (\because i_e \approx i_c)$

$= R_C\,(i_{e_1} - i_{e_2})$

then substitute i_{e_1} & i_{e_2} in V_o. then, we get.

$$V_o = R_C\left[\frac{(r_e+R_E)\,V_{in_1} - (R_E)\,V_{in_2}}{(r_e+R_E)^2 - (R_E)^2} - \frac{(r_e+R_E)\,V_{in_2} - (R_E)\,V_{in_1}}{(r_e+R_E)^2 - (R_E)^2}\right]$$

$$= R_C\left[\frac{(r_e+R_E)(V_{in_1} - V_{in_2}) + (R_E)(V_{in_1} - V_{in_2})}{(r_e+R_E)^2 - (R_E)^2}\right]$$

$$= R_C\left[\frac{(r_e+2R_E)\,(V_{in_1} - V_{in_2})}{r_e^2 + 2r_eR_E + \cancel{R_E^2} - \cancel{R_E^2}}\right]$$

$$= R_C\left[\frac{\cancel{(r_e+2R_E)}\,(V_{in_1} - V_{in_2})}{r_e\,\cancel{(r_e+2R_E)}}\right]$$

$$\therefore V_o = \frac{R_c}{r_e}(V_{in_1} - V_{in_2})$$

→ Thus, from this eq: we can say that, the diff. amp: amplifies the difference b/w two i/p signals.

→ By defining "$V_{id} = V_{in_1} - V_{in_2}$" as the diff: i/p voltage, we can write the voltage gain for the dual i/p, balanced o/p amp: is

$$\text{Voltage gain, } A_d = \frac{V_o}{V_{id}} = \frac{\frac{R_c}{r_e}(V_{in_1} - V_{in_2})}{(V_{in_1} - V_{in_2})}$$

$$\therefore A_d = \frac{R_c}{r_e}$$

→ From this eq:, we can say that, the voltage gain of diff: amp: is independent of 'Re'.

Differential i/p resistance :-

Differential i/p resistance is defined as the eq: resistance, that would be measured at either i/p terminal with other terminal grounded.

→ This means that, the i/p resistance 'R_{i1}' seen from the i/p signal source V_{in_1} is determined with the signal source V_{in_2} set at zero.

→ Similarily, the i/p signal source, V_{in1} is set at zero to determine the i/p Resistance 'R_{i2}' seen from the i/p signal source V_{in2}. (9)

→ Usually, the source Resistances R_{in1} & R_{in2} are very small & hence they will be ignored.

$$R_{i1} = \left| \frac{V_{in1}}{i_{b1}} \right|_{V_{in2}=0} = \left| \frac{V_{in1}}{i_{e1}/\beta_{ac}} \right|_{V_{in2}=0}$$

Substitute 'i_{e1}' value in this Eq:, we get,

$$R_{i1} = \frac{\beta_{ac} V_{in1}}{\frac{(r_e + R_E)V_{in1} - (R_E)(0)}{(r_e+R_E)^2 - (R_E)^2}} \quad ; \quad [\because V_{in2}=0]$$

$$\Rightarrow r_e^2 + 2r_eR_E + \cancel{R_E^2} - \cancel{R_E^2}$$

$$= \frac{\beta_{ac}(r_e^2 + 2r_eR_E)}{(r_e+R_E)}$$

$$R_{i1} = \frac{\beta_{ac} r_e (r_e + 2R_E)}{(r_e+R_E)}$$

Generally, $R_E >> r_e$, which implies that, $(r_e + 2R_E) \approx 2R_E$

$(r_e + R_E) \approx R_E$

$$\therefore R_{i1} = \frac{\beta_{ac} r_e (2\cancel{R_E})}{\cancel{R_E}}$$

$$\boxed{\therefore R_{i1} = 2 \cdot \beta_{ac} r_e}$$

Similarly, $R_{i2} = \left| \frac{V_{in2}}{i_{b2}} \right|_{V_{in1}=0} = \left| \frac{V_{in2}}{i_{e2}/\beta_{ac}} \right|_{V_{in1}=0}$

By substituting i_{e2}' value in R_{i2}, we get,

$$R_{i2} = \frac{\beta_{ac} V_{in}}{\frac{(r_e + R_E) V_{in} - R_E (0)}{(r_e + R_E)^2 - (R_E)^2}} = \frac{\beta_{ac}}{\frac{(r_e + R_E) - 0}{r_e^2 + 2R_E + \cancel{R_E^2} - \cancel{R_E^2}}}$$

$$= \frac{\beta_{ac}\, r_e (r_e + 2R_E)}{(r_e + R_E)}.$$

However, $(r_e + 2R_E) \cong 2R_E$ & $(r_e + R_E) \approx R_E$.

$$\therefore R_{i2} = \frac{\beta_{ac}\, r_e (2\cancel{R_E})}{\cancel{R_E}}$$

$$\boxed{\therefore R_{i2} = 2\beta_{ac} r_e.}$$

Output resistance :- Output resistance is defined as the Eq. resistance that would be measured at either O/P terminal w.r.to GND.

→ Therefore, the O/P resistance "R_{O1}" is measured b/w collector 'C_1' & GND is equal to that of collector resistance 'R_C'.

→ Similarly, the O/P resistance 'R_{O2}' is measured at collector 'C_2' w.r.to GND is equal to that of collector resistance 'R_C'.

$$\boxed{\therefore R_{O1} = R_{O2} = R_C}$$

→ The current gain of the diff: amp: is undefined. why because, the diff: amp: uses the common-emitter amplifier, so like the CE-amp:, the diff: amp: is also a "small signal-amp:"

→ There-fore, generally it is used as a voltage amplifier. & not as a current (or) power amp.

→ So, in the a.c analysis we are calculating the voltage gain of diff: amp:

→ We are per-forming D.C analysis, inorder to know the operating points $i_E \approx i_C$ & V_{CE} means here we have to bias the amp.

→ Biasing means the process of applying proper supply voltages & currents.

→ Here, we are using Emitter biasing, so, for that reason, in the d.c analysis, we are calculating 'I_E' & 'V_{CE}'

→ And the a.c analysis is performed to know the gain of the amp: (or) to know how the amp: is better works

→ And in the a.c analysis the voltage gain is independent of 'R_E' it depends only on a.c emitter resistance 'r_e'.

Dual-i/p Balanced o/p :-

D.C analysis :- $V_o = V_{c2} - V_{c1}$

$$I_E = \frac{V_{EE} - V_{BE}}{2R_E}$$

$$V_{CE} = V_{cc} + V_{BE} - I_E R_C$$

A.C analysis :-

$$A_d = \frac{R_C}{r_e}$$

$$R_{i1} = R_{i2} = 2\beta_{ac} r_e$$

$$R_{o1} = R_{o2} = R_C$$

Dual-i/p Unbalanced o/p

D.C. analysis :- $V_o = V_{c2}$

$$I_E = I_{CQ} = \frac{V_{EE} - V_{BE}}{2R_E + R_{in}/\beta_{dc}}$$

$$V_{CE} = V_{CEQ} = V_{CC} + V_{BE} - R_C I_{CQ}$$

A.C. analysis :-

$$A_d = \frac{V_o}{V_{id}} = \frac{R_C}{2r_e}$$

$$R_{i1} = R_{i2} = 2\beta_{ac} r_e$$

$$R_o = R_C$$

Single-i/p Balanced o/p :-

D.C analysis :-

$$I_E = I_{CQ} = \frac{V_{EE} - V_{BE}}{2R_E + R_{in}/\beta_{dc}}$$

$$V_{CE} = V_{CEQ} = V_{CC} + V_{BE} - I_{CQ} R_C$$

A.C analysis :- $V_o = V_{c2} - V_{c1}$

$$A_d = \frac{R_C}{r_e}$$

$$R_i = 2\beta_{ac} r_e$$

$$R_{o1} = R_{o2} = R_C$$

Single-i/p Un-Balanced o/p :-

D.C. analysis :-

$$I_E = I_{CQ} = \frac{V_{EE} - V_{BE}}{2R_E + R_{in}/\beta_{dc}}$$

$$V_{CE} = V_{CEQ} = V_{CC} + V_{BE} - I_{C}$$

A.C analysis :-

$$V_o = V_{c2} = i_{c2} R$$

$$A_d = \frac{R_C}{2r_e}$$

$$R_i = 2\beta_{ac} r_e$$

$$R_o = R_C$$

Voltage follower :-

In the non-inverting amp: if, $R_f = 0$, & $R_1 = \infty$, we get $V_o = V_i\left(\frac{R_1+R_f}{R_1}\right)\left(\frac{\infty+0}{\infty}\right) = \frac{\infty}{\infty}$

∴ we get $V_o = V_i$

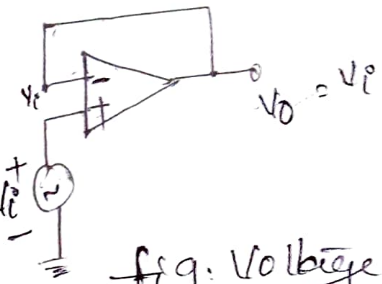


fig: Voltage follower

→ That is the O/P voltage is equal to the i/p voltage, both in magnitude & phase. In other words, we can also say that, the O/P voltage follows the i/p voltage exactly.

→ Hence, such a circuit is called a Voltage-follower i.e its gain is Unity. So, that it's also called as "Unity gain ckt"

→ The use of unity gain ckt, lies in the fact that, its i/p impedance is very high (i.e MΩ) & O/P impedance is zero. Therefore, it draws negligible current from the source.

→ Thus a voltage follower may be used as "buffer" for impedance matching, i.e to connect to a high impedance source to a low impedance load.

Differential Amplifier:-

A circuit that amplifies the difference b/w two signals is called a "difference" (or) "differential amplifier" is shown in below fig:

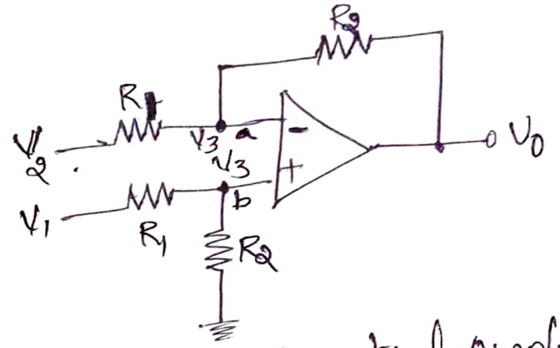


fig. Differential Amplifier

Analysis:-

Since, the diff: voltage (V_d) at the i/p. terminals of op-amp is zero, the nodes 'a' & 'b' are at the same potential i.e 'V_3'.

→ The nodal Eq: at node 'a' is

$$\frac{V_3 - V_2}{R_1} + \frac{V_3 - V_0}{R_2} = 0 \quad = V_3\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_2}{R_1} = \frac{V_0}{R_2} \quad \text{—(1)}$$

At node 'b' is

$$\frac{V_3 - V_1}{R_1} + \frac{V_3}{R_2} = 0. \quad = V_3\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_1}{R_1} = 0. \quad \text{—(2)}$$

Subtract eq. (2) from (1) we get,

$$\frac{1}{R_1}(V_1 - V_2) = \frac{V_0}{R_2}$$

$$\boxed{\therefore \quad V_0 = \frac{R_2}{R_1}(V_1 - V_2).}$$

→ Such a ckt is very useful in detecting very small differences in signals, since the gain R_2/R_1 can be choosen to be very large.

→ For Ex: if $R_2 = 100 R_1$, then a small diff: $(V_1 - V_2)$ is "amplified 100 times"