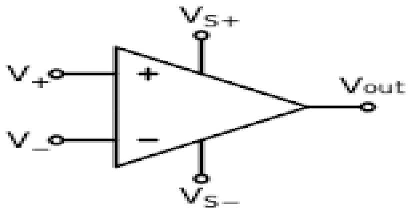
DIFFERENTIAL AMPLIFIER:

A **differential amplifier** is a type of that amplifies the difference between two input but suppresses any voltage common to the two inputs. It is an with two inputs Vin(+) and Vin(-) and one output Vo in which the output is ideally proportional to the difference between the two voltages



Vo=A[Vin(+)-Vin(-)]

Where, A is the gain of the amplifier.

There are four different types of configuration in differential amplifier which are as follows:

i)Dual input and balanced output

ii)Dual input and unbalanced output

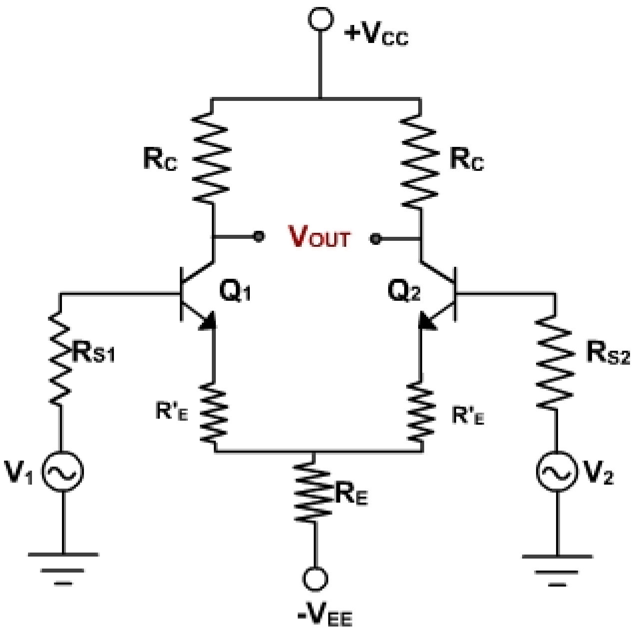
iii)Single input and balanced output

iv)Single input and unbalanced output

DUAL INPUT, BALANCED OUTPUT DIFFERENTIAL AMPLIFIER

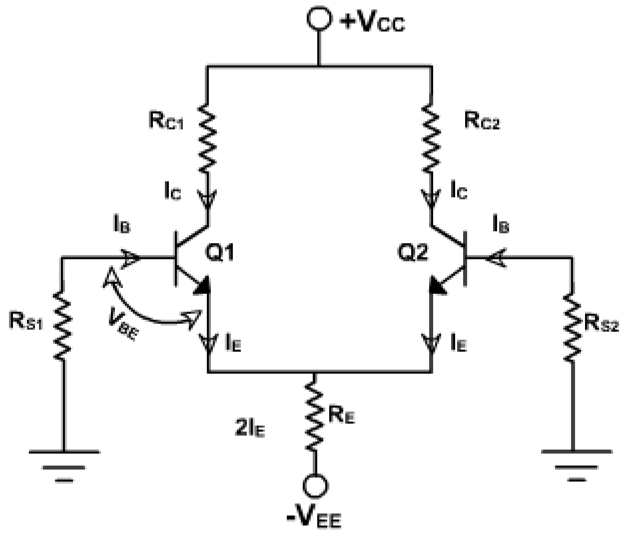
The circuit shown below is a dual-inputbalanced-output differential amplifier.Here in this circuit,the two input signals (dual input), v_{in1} and $v_{in2,}$ are applied to the bases B_1 and B_2 of transistors Q_1 and Q_2.The output v_o is measured between the two collectors C_1 and C_2 which are at the same dc potential.Because of the equal dc potential at the two collectors with respect to ground,the output is referred as a balanced output.

Circuit Diagram :-



DC Analysis :-

To determine the operating point values (I_{CQ} and V_{CEQ}) for the differential amplifier,we need to obtain a dc equivalent circuit.The dc equivalent circuit can be obtained simply by reducing the input signals v_{in1} and v_{in2} to zero.The dc equivalent circuit thus obtained is shown in fig below. Note that the internal resistances of the input signals are denoted by R_{in}because $R_{in1} = R_{in2}$.Since both emitter biased sections of the differential amplifier are symmetrical (matched in all respects), we need to determine the operating point collector current I_{CQ} and collector to emitter voltage V_{CEQ} for only one section.We shall determine the I_{CQ} and V_{CEQ} values for transistor Q_1 only.These I_{CQ} and V_{CEQ} values can then beused for transistor Q_2 also.



DC EQUIVALENT CIRCUIT FOR DUAL-INPUT BALANCED OUTPUT DIFFERETIAL AMPLIFIER

Applying Kirchhoff's voltage law to the base-emitter loop of the transistor Q_1,

$$R_{in}I_B - V_{BE} - R_E(2I_E) + V_{EE} = 0 \qquad (1)$$

But

$$I_B = I_E/B_{dc} \quad \text{since } I_C = I_E$$

Thus the emitter current through Q_1 is determined directly from eqn(1) as follows :

$$I_E = (V_{EE} - V_{BE})/(2R_E + R_{in}/B_{dc}) \qquad (2)$$

where V_{BE} = 0.6V for silicon transistors

V_{BE} =0.2V for germanium transistors

Generally, $R_{in}/B_{dc} << 2R_E$.Therefore, eqn(2) can be rewritten as

$$ICQ=IE = (VEE - VBE)/2RE \qquad (3)$$

From eqn(3) we see that the value of R_E sets up the emitter current in transistors Q_1 and Q_2 for a given value of V_{EE}. In other words, by selecting a proper value of R_E, we can obtain a desired value of emitter current for a known value of $-V_{EE}$. Notice that the emitter current in transistors Q_1 and Q_2 is independent of collector resistance R_C.

Next we shall determine the collector to emitter voltage V_{CE}. The voltage at the emitter of transistor Q_1 is approximately equal to V_{BE} if we assume the voltage drop across R_{in} to be negligible. Knowing the value of emitter current $I_E(=I_C)$,we can obtain the voltage at the collector V_{CC} as follows:

$$V_C = V_{CC} - R_C I_C$$

Thus the collector to emitter voltage V_{CE} is

$$V_{CE} = V_C - V_E = (V_{CC} - R_C I_C) - (-V_{EE})$$

$$VCEQ=VCE = VCC+VBE - RCIC \qquad (4)$$

Thus for both transistors we can determine the operating point values by using the eqns (2)and(4), respectively, because at the operating point $I_E=I_{CQ}$ and $V_{CEQ}=V_{CE}$

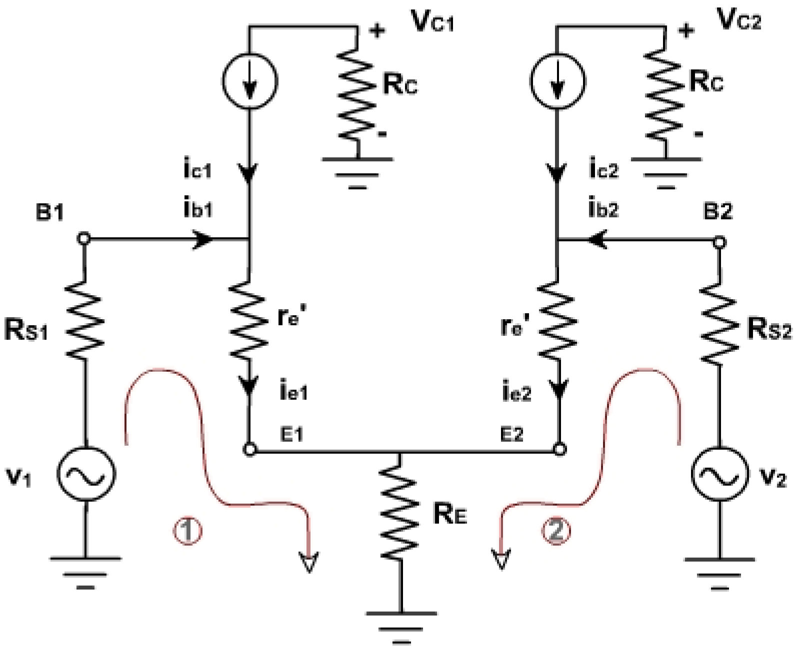
Remember that the dc analysis eqns (2) and (4) are applicable for all 4 differential amplifier configurations as long as we use the same biasing arrangement for each of them.

AC Analysis:-

To perform ac analysis to derive the expression for the voltage gain A_d and input resistance R_i of a differential amplifier:

1) Set the dc voltages $+V_{CC}$ and $-V_{EE}$ at 0
2) Substitute the small signal T equivalent models for the transistors

Figure below shows resulting ac equivalent circuit of the dual input balanced output differential amplifier



AC EQUIVALENTCIRCUIT FOR DUAL-INPUT BALANCED OUTPUT DIFFERETIAL AMPLIFIER

Voltage Gain :-

Before we proceed to derive the expression for the voltage gain A_d the following should be noted about the circuit in the figure above

1) $I_{e1}=I_{e2}$; therefore $r_{e1}=r_{e2}$. For this reason the ac emitter resistance of transistors Q_1 and Q_2 is simply denoted by r_e.
2) The voltage across each collector resistor is shown out of phase by 180^0 w.r.t the input voltages v_{in1} and v_{in2}.

Writing Kirchhoff's voltage eqautions for loops 1 and 2 gives us

$$v_{in1} – R_{in1}i_{b1} – r_e i_{e1} – R_E(i_{e1}+i_{e2}) = 0 \qquad (5)$$

$$v_{in2} – R_{in2}i_{e2} – r_e i_{e2} – R_E(i_{e1}+i_{e2}) = 0 \qquad (6)$$

Substituting current relations $i_{b1} = i_{e1}/B_{ac}$ and $i_{b2} = i_{e2}/B_{ac}$ yields

$$v_{in1} – R_{in1}i_{e1}/B_{ac} – r_e i_{e1} – R_E(i_{e1}+i_{e2}) = 0$$

$$v_{in2} – R_{in2}i_{e2}/B_{ac} – r_e i_{e2} – R_E(i_{e1}+i_{e2}) = 0$$

Generally, R_{in1}/B_{ac} and R_{in2}/B_{ac} values are very small therefore we shall neglect them here for simplicity and rearrange these equations as follows:

$$(r_e+R_E)i_{e1} + R_{E2}i_{e2} = v_{in1} \qquad (7)$$

$$R_{E2}i_{e1} + (r_e+R_E)i_{e2} = v_{in2} \qquad (8)$$

Eqns (7) and (8) can be solved simultaneously for i_{e1} and i_{e2} by using Cramer's rule:

$$I_{e1} = |(v_{in1}/v_{in2})(R_E/r_e+R_E)|/|\{(r_e+R_E)/R_E\}\{R_E/(r_e+R_E)\}| \quad (9a)$$

$=\{(r_e+R_E)v_{in1} - R_E v_{in2}\}/\{(r_e+R_E)^2 - (R_E)^2\}$

Similarly

$$I_{e2} = |(v_{in1}/v_{in2})\{(r_e+R_E)/R_E\}|/|\{(r_e+R_E)/R_E\}\{R_E/(r_e+R_E)\}| \quad (9b)$$

$=\{(r_e+R_E)v_{in2} - R_E v_{in2}\}/\{(r_e+R_E)^2 - (R_E)^2\}$

The output voltage is

$$v_o = v_{c2} - v_{c1}$$

$$= -R_C i_{c2} - (-R_C i_{c1}) \quad (10)$$

$$= R_C i_{c1} - R_C i_{c2}$$

$$=R_C(i_{e1} - i_{e2}) \qquad \text{since } i_c = i_e$$

Substituting current relations i_{e1} and i_{e2} in eqn(10), we get

$$v_o = R_C[\{(r_e+R_E)v_{in1} - R_E v_{in2}\}/\{(r_e+R_E)^2 - (R_E)^2\} - \{(r_e+R_E)v_{in2} - R_E v_{in1}\}/\{(r_e+R_E)^2 - (R_E)^2\}]$$

$$= R_C[\{(r_e+R_E)(v_{in1} - v_{in2})+(R_E)(v_{in1} - v_{in2})\}/\{(r_e+R_E)^2 - (R_E)^2\}]$$

$$=R_C[(r_e+2R_E)(v_{in1} - v_{in2})/r_e(r_e+2R_E)]$$

$$=(R_C/r_e)(v_{in1} - v_{in2}) \quad (11)$$

Thus a differential amplifier amplifies the difference between two input signals as expected,the figure below shows the input and output waveforms of the dual-input balanced-output differential amplifier. By defining $v_{id} = v_{in1}$ as the difference in input voltages, we can write the voltage-gain equation of the dual-input balanced-output differential amplifier as follows:

$$Ad = vo/vid = RC/re$$

(12)

Notice that the voltage-gain equation of the differential amplifier is independent of R_E since R_E did not appear in the gain eqn(12). Another point of interest is that this equation is identical to the voltage-gain equation of the common emitter amplifier.

Differential Input Resistance:-

Differential input resistance is defined as the equivalent resistance that would be measured at either input terminal with the other terminal grounded.

$$R_{i1} = |v_{in1}/i_{b1}|_{Vin2=0}$$

$$=|v_{in}/(i_e/B_{ac})|_{Vin2=0}$$

Substituting the value of i_{e1} from eqn(9a), we get

$$R_{i1} = B_{ac}v_{in1}/[\{(r_e+R_E)v_{in1} - R_E(0)\}/\{(r_e+R_E)^2 - (R_E)^2\}] \quad (13)$$

$$=[B_{ac}(r_e^2+2r_eR_E)]/(r_e+R_E)$$

$$=[B_{ac}\, r_e(r_e+2R_E)]/(r_e+R_E)$$

Generally, $R_E >> r_e$, which implies that $(r_e+2R_E) = 2R_E$ and $(r_e+R_E) = R_E$.

Therefore eqn(13) can be rewritten as

$$R_{i1} = B_{ac}r_e(2R_E)/R_E = 2B_{ac}r_e \quad (14)$$

Similarly, the input resistance R_{i2} seen from the input signal source v_{in2} is defined as

$$R_{i2} = |v_{in2}/i_{b2}|_{Vin1=0}$$

$$=|v_{in2}/(i_{e2}/B_{ac})|_{Vin1=0}$$

Substituting the value of i_{e2} from eqn(9b), we get

$$R_{i2} = B_{ac}v_{in2}/[\{(r_e+R_E)v_{in2} - R_E(0)\}/\{(r_e+R_E)^2 - (R_E)^2\}] \quad (15)$$

$=[B_{ac}(r_e^2+2r_eR_E)]/(r_e+R_E)$

$=[B_{ac}\, r_e(r_e+2R_E)]/(r_e+R_E)$

However, (r_e+2R_E) and $(r_e+R_E) = R_E$ if $R_E>>r_e$. Therefore eqn(15) can be rewritten as

$$Ri2 = Bacre(2RE)/RE = 2Bacre \quad (16)$$

Output Resistance:-

Output resistance is defined as the equivalent resistance that would be measured at either output terminal w.r.t ground.

$$Ro1 = Ro2 = RC \quad (17)$$

The current gain of the differential amplifier is undefined; therefore, the current-gain equation will not be derived for any of the four differential amplifier configurations.

Common mode Gain:-

A common mode signal is one that drives both inputs of a differential amplifier equally. The common mode signal is interference, static and other kinds of undesirable pickup etc.

The connecting wires on the input bases act like small antennas. If a differential amplifier is operating in an environment with lot of electromagnetic interference, each base picks up an unwanted interference voltage. If both the transistors were matched in all respects then the balanced output would be theoretically zero. This is the important characteristic of a differential amplifier. It discriminates against common mode input signals. In other words, it refuses to amplify the common mode signals.

The practical effectiveness of rejecting the common signal depends on the degree of matching between the two CE stages forming the differential amplifier. In other words, more closely are the currents in the input transistors, the better is the common mode signal rejection e.g. If v_1 and v_2 are the two input signals, then the output of a practical op-amp cannot be described by simply

$$v_0 = A_d\,(v_1-v_2)$$

In practical differential amplifier, the output depends not only on difference signal but also upon the common mode signal (average).

$$v_d = (v_1-v_2)$$

and v_C = ½ (v_1 + v_2)

The output voltage, therefore can be expressed as

$v_O = A_1 v_1 + A_2 v_2$

Where A_1& A_2 are the voltage amplification from input 1(2) to output under the condition that input 2 (1) is grounded.