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Electronics II: 3ed Year - 2015/2016
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DIFFERENTIAL AMPLIFIER CIRCUIT

The differential amplifier circuit is an extremely popular connection used in IC units. This connection can be described by considering the basic differential amplifier shown in Fig.1. Notice that the circuit has two separate inputs and two separate outputs, and that the emitters are connected together. Whereas many differential amplifier circuits use two separate voltage supplies, the circuit can also operate using a single supply.

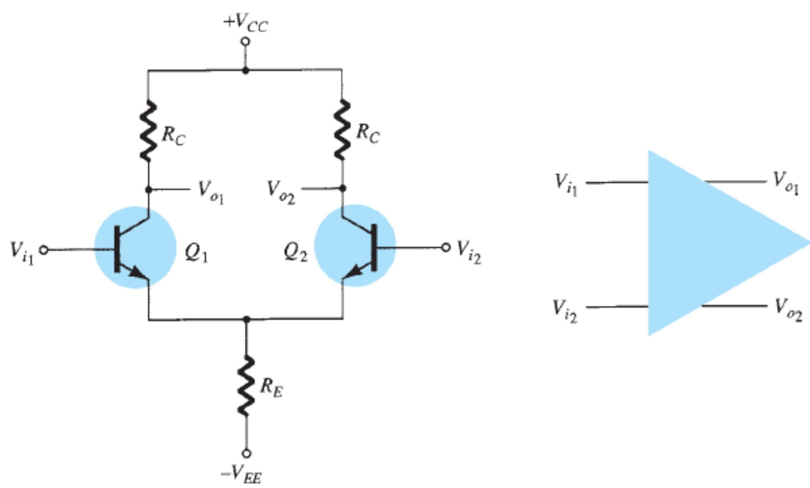

Fig.1

Basic differential amplifier circuit

If an input signal is applied to either input with the other input connected to ground, the operation is referred to as "single-ended."

If two opposite-polarity input signals are applied, the operation is referred to as "double-ended."

If the same input is applied to both inputs, the operation is called "common-mode."

The main feature of the differential amplifier is the very large gains when opposite signals are applied to the inputs as compared to the very small gain resulting from common inputs. The ratio of this difference gain to the common gain is called *common-mode rejection.*

❖ *DC Bias*

Let's first consider the dc bias operation of the circuit of Fig.1. With ac inputs obtained from voltage sources, the dc voltage at each input is essentially connected to 0 V, as shown in Fig. 2. With each base voltage at 0 V, the common-emitter dc bias voltage is

$$V_E = 0V - V_{BE} = -0.7V$$

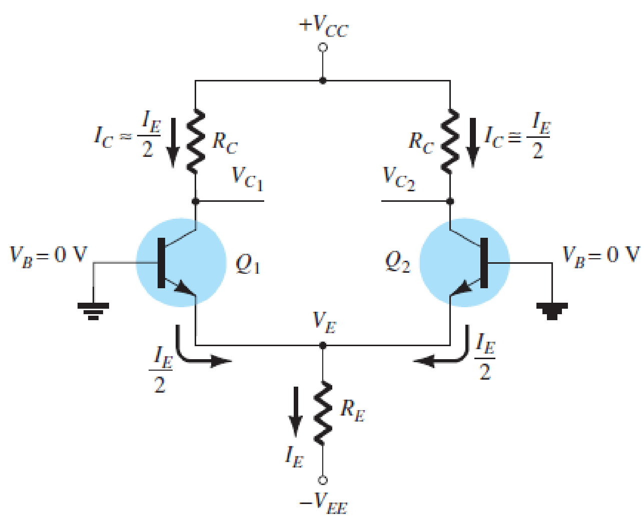

Fig. 2
DC bias of differential amplifier circuit.

The emitter dc bias current is then

$$I_E = \frac{V_E - (-V_{EE})}{R_E} \approx \frac{V_{EE} - 0.7V}{R_E}$$

Assuming that the transistors are well matched (as would occur in an IC unit), we obtain

$$I_{C1} = I_{C2} = \frac{I_E}{2}$$

Resulting in a collector voltage of

$$V_{C1} = V_{C2} = V_{CC} - I_C R_C = V_{CC} - \frac{I_E}{2} R_C$$

EXAMPLE (1). Calculate the dc voltages and currents in the circuit of Fig. 3.

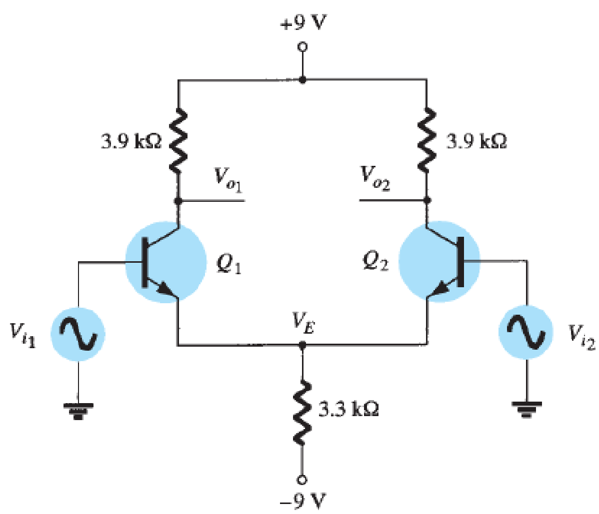

Fig. 3

Solution:

$$I_E = \frac{V_{EE} - (V_E)}{R_E} = \frac{9V - 0.7V}{33k\Omega} \approx 2.5mA$$

The collector current is then

$$I_C = \frac{I_E}{2} = \frac{2.5mA}{2} = 1.25mA$$

resulting in a collector voltage of

$$V_C = V_{CC} - I_C R_C = 9V - (1.25mA)(3.9k\Omega) \approx 4.1V$$

The common-emitter voltage is thus -0.7 V, whereas the collector bias voltage is near 4.1V for both outputs.

❖ *AC Operation of Circuit*

An ac connection of a differential amplifier is shown in Fig. 4. Separate input signals are applied as V_{i1} and V_{i2}, with separate outputs resulting as V_{o1} and V_{o2}. To carry out ac analysis, we redraw the circuit in Fig. 5. Each transistor is replaced by its ac equivalent.

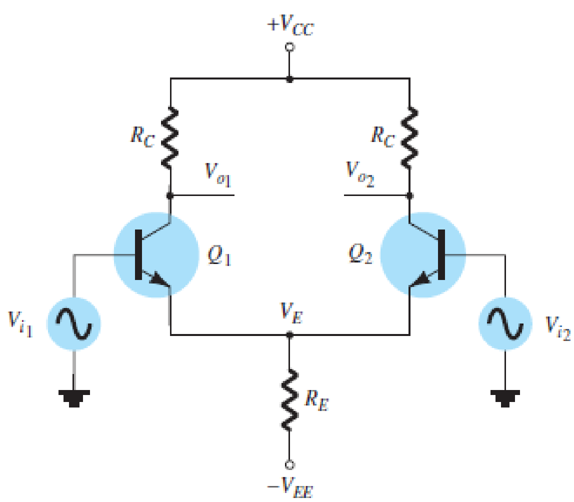

Fig. 4

AC connection of differential amplifier.

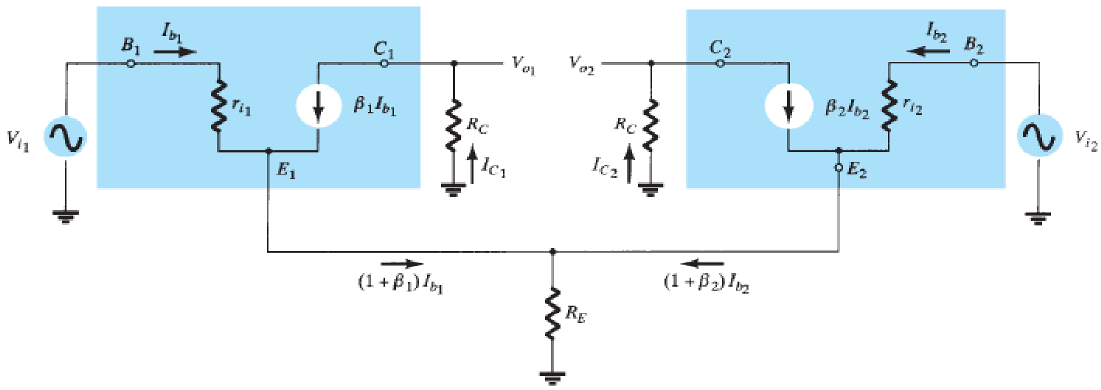

Fig. 5

AC equivalent of differential amplifier circuit

- ***Single-Ended AC Voltage Gain***:- To calculate the single-ended ac voltage gain, Vo/V_i, apply signal to one input with the other connected to ground, as shown in Fig. 6.

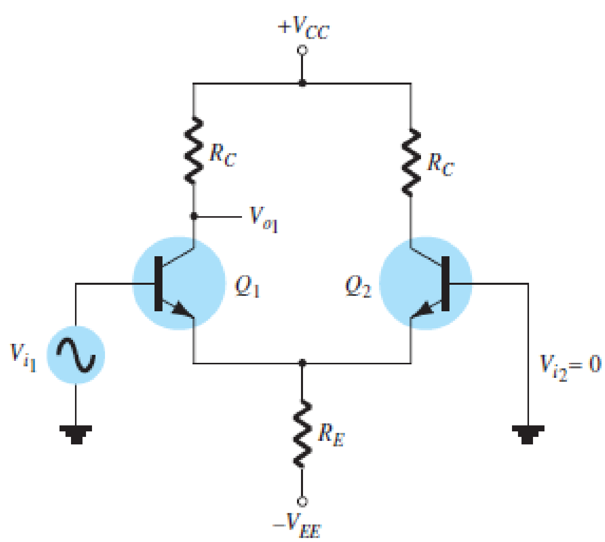

Fig. 6

Connection to calculate $A_{V_1} = V_{o_1}/V_{i_1}$.

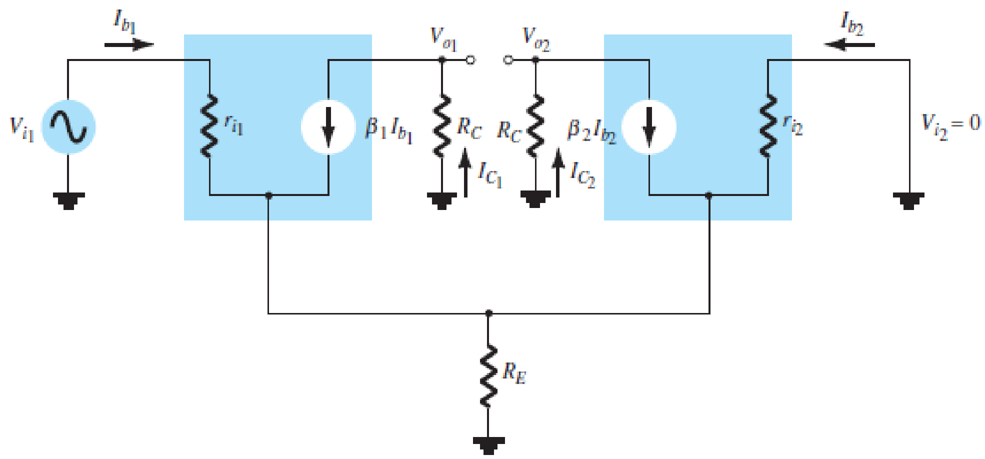

Fig. 7
AC equivalent of circuit in Fig. 6.

The ac equivalent of this connection is drawn in Fig. 7. The ac base current can be calculated using the base 1 input Kirchhoff voltage loop (KVL) equation. If one assumes that the two transistors are well matched, then

$$I_{b1} = I_{b2} = I_b$$

$$r_{i1} = r_{i2} = r_i = \beta r_e$$

With R_E very large (ideally infinite), the circuit for obtaining the KVL equation simplifies to that of Fig. 8, from which we can write.

$$V_{i1} - I_b r_i - I_b r_i = 0$$

So that

$$I_b = \frac{V_{i1}}{2r_i} = \frac{V_i}{2\beta r_e}$$

If we also assume that

$$\beta_1 = \beta_2 = \beta$$

Then

$$I_c = \beta I_b = \beta \frac{V_i}{2\beta r_e} = \frac{V_i}{2r_e}$$

and the output voltage magnitude at either collector is

$$V_o = I_c R_c = \frac{V_i}{2r_e} R_c$$

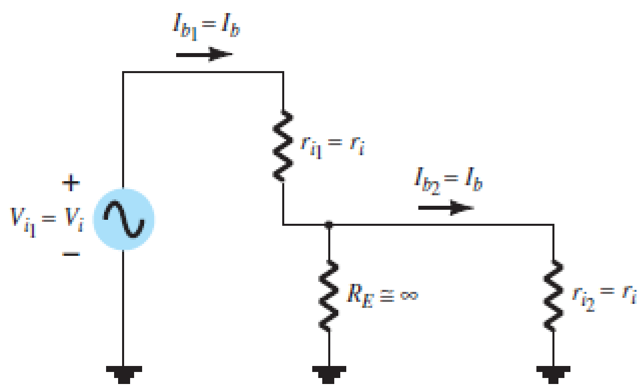

Fig. 8
Partial circuit for calculating I_b.

for which the single-ended voltage gain magnitude at either collector is

$$A_v = \frac{V_o}{V_i} = \frac{R_c}{2r_e}$$

EXAMPLE (2):- Calculate the single-ended output voltage V_{o1} for the circuit of Fig. 9.

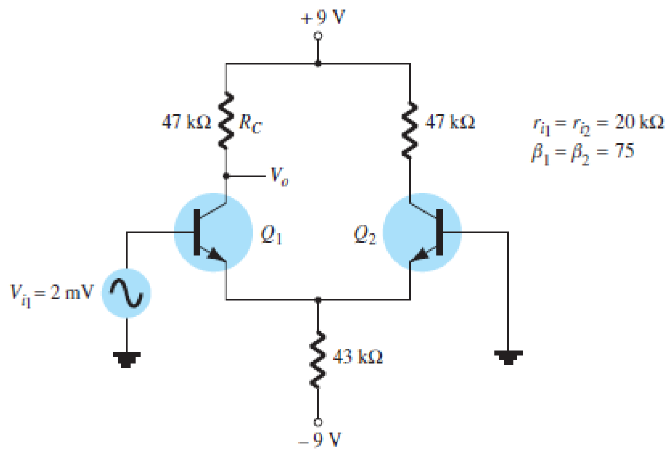

Fig. 9

Solution: The dc bias calculations provide

$$I_E = \frac{V_{EE} - (V_E)}{R_E} = \frac{9V - 0.7V}{43k\Omega} = 193\mu A$$

The collector current is then

$$I_C = \frac{I_E}{2} = \frac{193\mu A}{2} = 96.5\mu A$$

So that

$$V_C = V_{CC} - I_C R_C = 9V - (96.5\mu A)(47k\Omega) = 4.5V$$

The value of r_e is then

$$r_e = \frac{26mv}{I_E} = \frac{26mv}{193\mu A} = 134\Omega$$

The ac voltage gain magnitude can be calculated

$$A_v = \frac{V_o}{V_i} = \frac{R_c}{2r_e} = \frac{47k\Omega}{2(134\Omega)} = 175.3$$

providing an output ac voltage of magnitude

$$V_o = A_v V_i = (175.3)(2mv) = 350.6mv = 0.35v$$

- ***Double-Ended AC Voltage Gain***:- A similar analysis can be used to show that for the condition of signals applied to both inputs, the differential voltage gain magnitude is

$$A_v = \frac{V_o}{V_d} = \frac{R_c}{r_e}$$

Where $V_d = V_{i1} - V_{i2}$.

- ***Common-Mode Operation of Circuit***:- Whereas a differential amplifier provides large amplification of the difference signal applied to both inputs, it should also provide as small an amplification of the signal common to both inputs. An ac connection showing common input to both transistors is shown in Fig. 10. The ac equivalent circuit is drawn in Fig. 11, from which we can write.

$$I_b = \frac{V_i - 2(\beta + 1)I_b R_E}{r_i}$$

which can be rewritten as

$$I_b = \frac{V_i}{r_i + 2(\beta + 1)R_E}$$

The output voltage magnitude is then

$$V_o = I_c R_c = \beta I_b R_c = \frac{\beta V_i R_c}{r_i + 2(\beta + 1)R_E}$$

providing a voltage gain magnitude of

$$A_v = \frac{V_o}{V_i} = \frac{\beta R_c}{r_i + 2(\beta + 1)R_E}$$

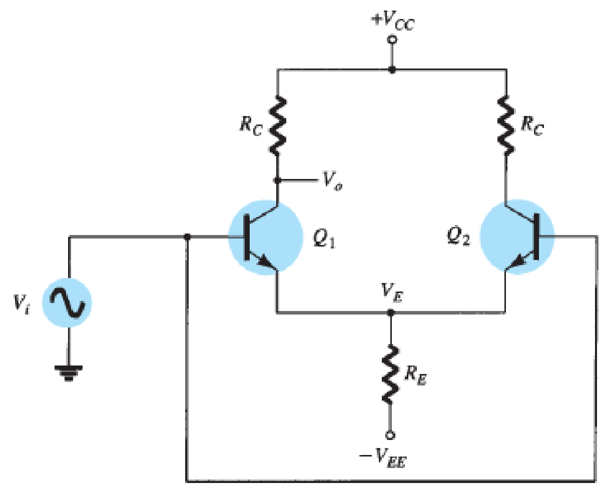

Fig. 10
Common-mode connection.

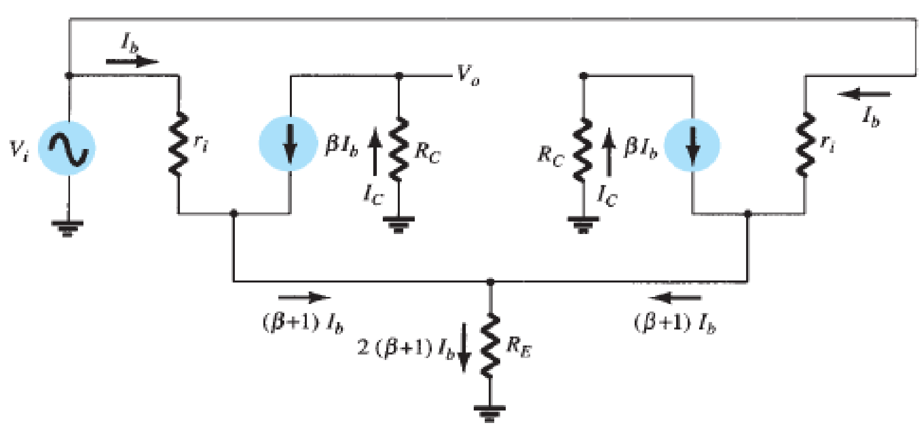

Fig. 11
AC circuit in common-mode connection.