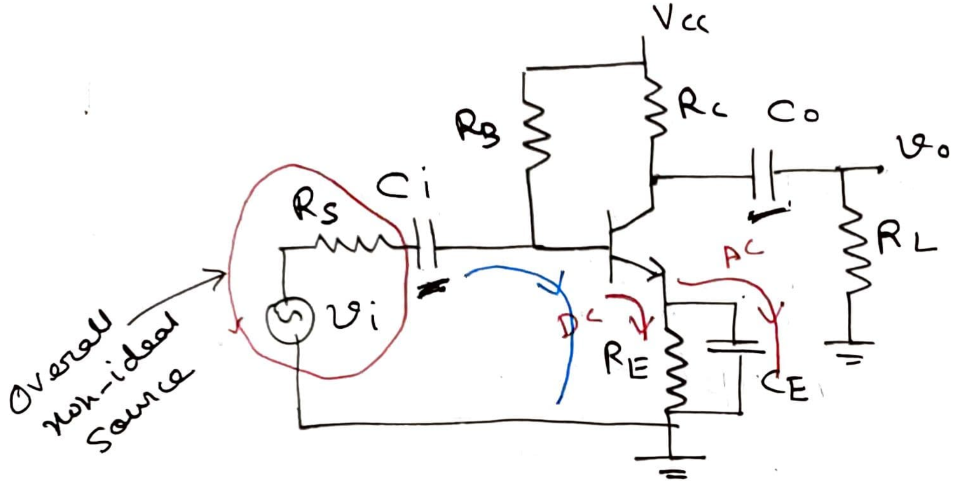
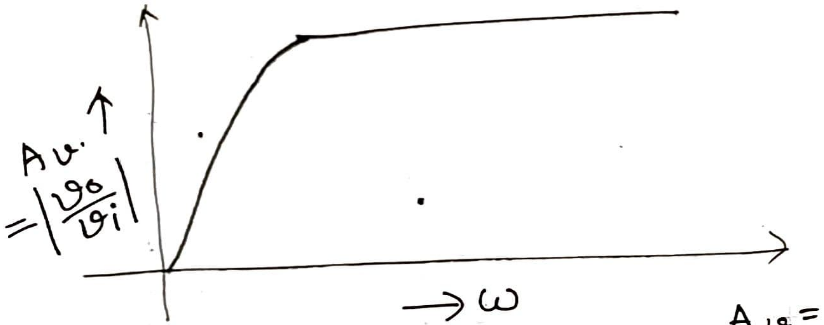


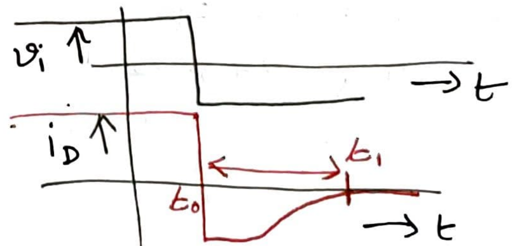


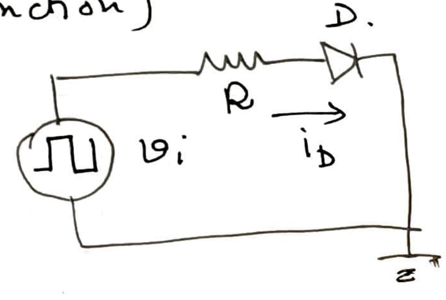
$A_v = \frac{v_o}{v_i}$

We have already noted that the capacitors C_i and C_o and C_E affect the low frequency response of the BJT amplifier. That is they decrease the gain. At low frequency C_i and C_E offers a finite impedance to the AC path. As a result the AC component of the voltage that drops across the base to emitter junction (V_π) decreases. This

decrease the AC component of base current which in turn decreases the ac component of collector current. Hence the gain decrease. The output coupling capacitor C_o on the other hand provides a finite impedance ~~at the out~~ in series with the load resistor R_L. Hence the AC component of the voltage drop across the load resistor decreases, thereby decreasing the gain magnitude. Hence, these three coupling capacitors are responsible for decreasing the gain ~~at~~ in low frequency regime.

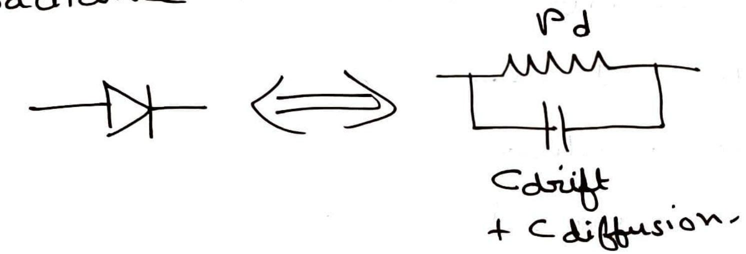
The gain in the high frequency regime on the other hand is affected by the junction capacitances of the transistor. To understand this, let us recall the switching characteristics of a diode (p-n junction)





As we already discussed earlier, in the time period between t_0 and t_1, ~~the current~~ a high magnitude of the reverse current is possible. This current is used to ~~be~~ remove the excess concentration of the minority carriers that is stored ~~a~~ near the depletion region and to induce/remove the charge to widen/thin the depletion region. ~~So, The point is that when t~~

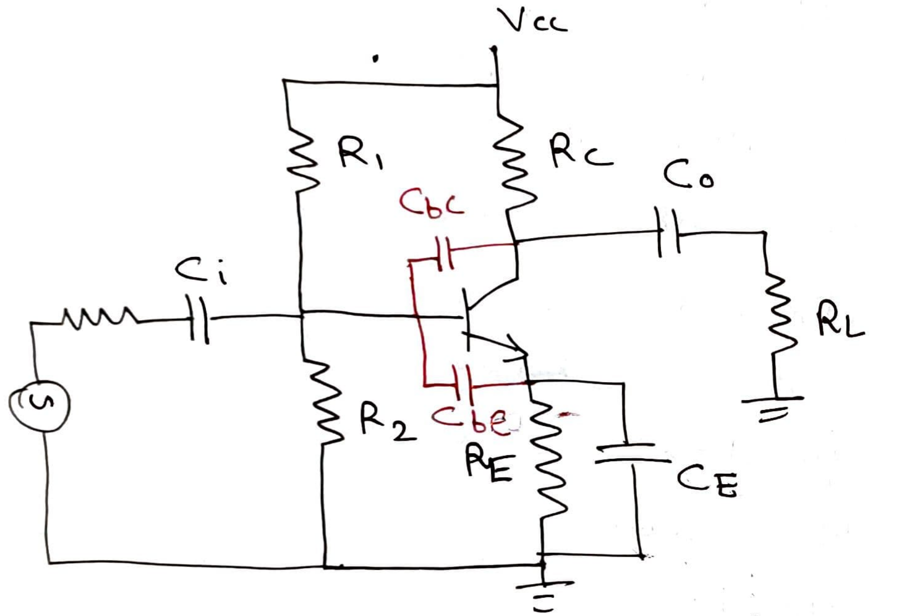
As we discussed earlier in the class, the stored depletion charge and minority carriers ~~act~~ give a capacitive effect, ~~Sto The~~ imitating the behaviour of a capacitor: the stored charge ~~or~~ and charge due to excess carriers need to be changed whenever the voltage changes. We have already noted that due to this effect, the small signal model of a diode is given by the parallel combination of the diffusion resistance and the ~~drift and d~~ depletion and diffusion capacitance.



It is clear from this model that when the AC signal changes slowly with respect to the minority carrier recombination time, the diode is ~~in~~ always in steady state with the applied voltage and so the capacitor in the equivalent model acts more or less like an open circuit. and the ~~cur~~ AC current is mainly controlled by the diffusion resistance.

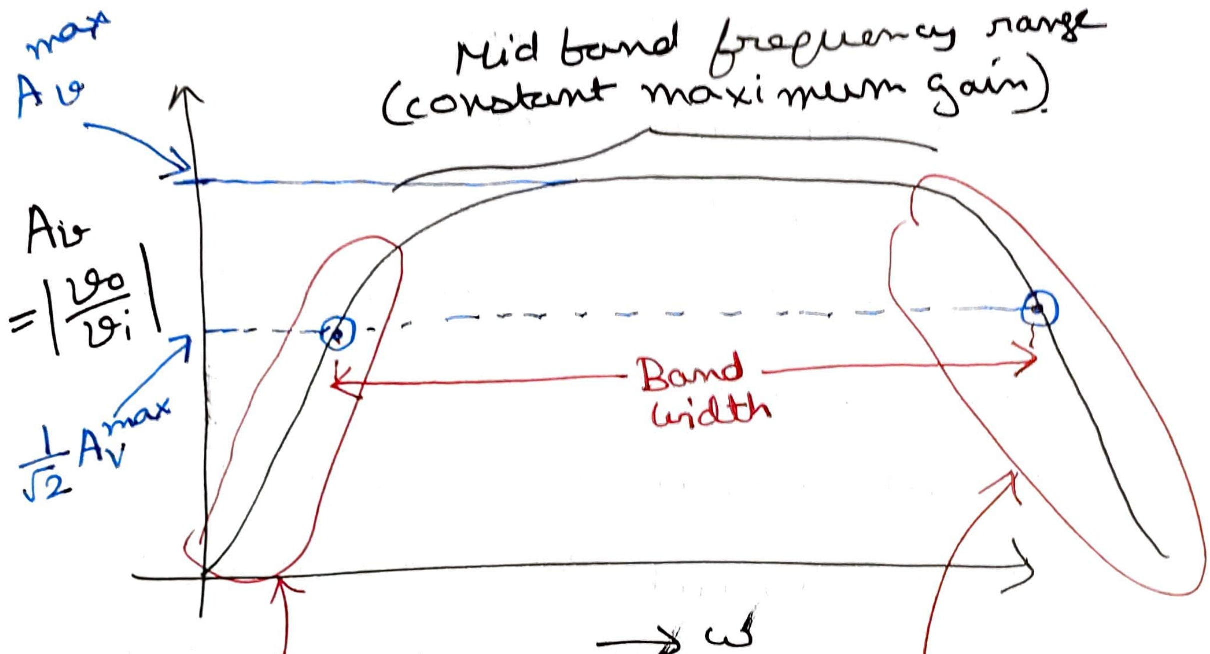
However, if the AC signal is of high frequency and change fast with respect to the minority carrier recombination time, the diode is not in steady state with the applied voltage and now the current is mainly controlled by the parallel capacitance which acts as a short-circuit.

In a transistor such ~~this~~ ~~capacitance~~ capacitive behaviour lies at the junction: The base to emitter and the ~~emitter~~ base to collector junctions. The overall effect is that due to the capacitive behaviour, the base-to-emitter junction becomes short-circuited and the magnitude of V_π decreases. which results in a decrease in the overall gain of the amplifier. The effect of the junction capacitance at the collector to emitter junction may result in a current flow at the collector, which doesnt abide the relation $i_c = \beta i_b$.



The effect may be modeled, just as in the case of the diode, by introducing ~~eo~~ effective capacitance between the base to emitter and the collector to emitter junction. Note that the capacitance C_i, C_o and C_E are externally introduced in the ~~circuit~~ circuit. The

capacitors C_{be} and C_{bc}, on the other hand are not introduced externally. These are mainly modelling parameters and takes into account the effect of excess stored minority carriers and the stored depletion layer charge that needs to change every time the voltage changes. As can be noted at high frequency C_{be} may short-circuit the base to emitter junction resulting in a decrease of V_π which is the AC component of voltage drop across the base-emitter junction. Decrease in V_π results in decrease of $i_c = g_m V_\pi$, which in turn results in decrease of gain. The modelling parameter C_{be}, and C_{bc} depend on the minority carrier recombination time and ~~has to cont~~ can be controlled to some extent (although not always) via suitable fabrication steps.



gain tapers off due to C_E, C_o and C_i

gain tapers off due to junction capacitances of the transistors

The frequency difference between the points, at which gain is $\frac{1}{\sqrt{2}}$ times the mid-band gain is known as the Bandwidth of the amplifier.

A_v^{max}

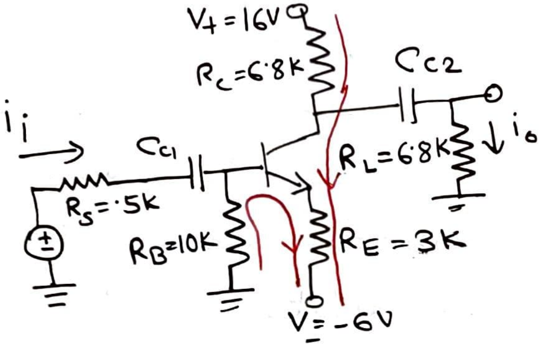
6.25

$\beta = 100$, $V_A = \infty$

$g_m, r_\pi, r_o = ?$

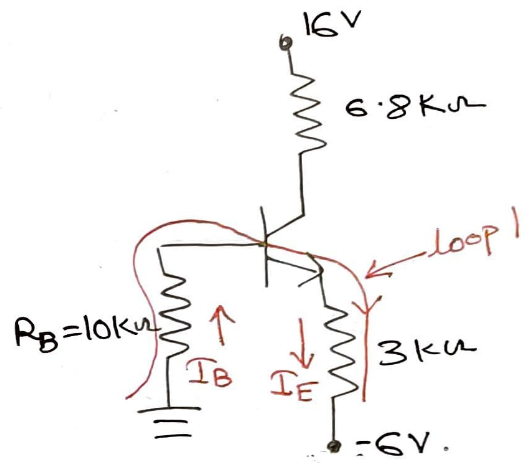
$A_v = \frac{v_o}{v_i}$

$A_i = \frac{i_o}{i_i}$



To find the gain, we need to find the small signal parameters of the amplifier, such as g_m, r_π and r_o. To find these parameters, we first need to do a DC analysis of the circuit. This is because the ac or small ~~parameters~~ signal parameters such as g_m, r_π etc depend on the DC biasing point or the Q-point of the transistor amplifier.

For DC analysis, we can open circuit the paths containing capacitors because capacitors act as open circuits for DC voltage/currents. The redlines in the figure show the paths of DC currents. Hence for DC analysis, the circuit we need to analyze is the following.



We first analyze loop 1 which contains the base-emitter junction. Applying KVL, we get.

$$6V = I_{BQ} \times 10 + V_{BE(ON)} + I_{EQ} \times 3$$

$$= 10 I_{BQ} + 0.7 + 101 I_{BQ} \times 3$$

$$\Rightarrow I_{BQ} = \frac{6-0.7}{313} \text{ mA} \simeq .0169 \text{ mA}.$$

$$I_{EQ} = 101 I_B = 101 \times .0169 \text{ mA}.$$

$$= 1.71 \text{ mA}$$

$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{0.026 \text{ V}}{0.0169 \text{ mA}} = 1.53 \text{ K}\Omega$$

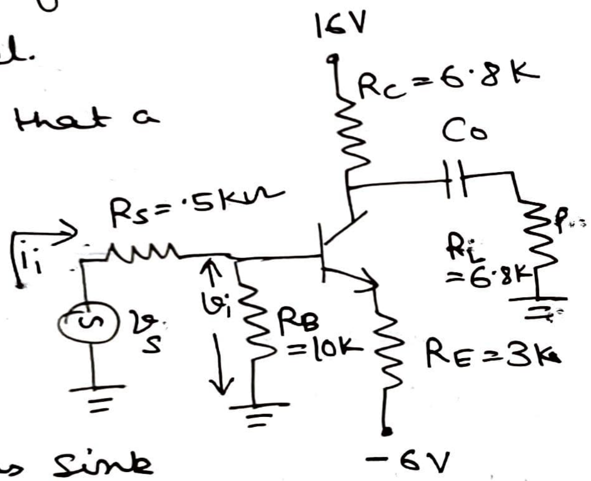
$$g_m = \frac{\beta}{r_\pi} = \frac{100}{1.53 \text{ K}\Omega} = 65.35 \text{ millimho}$$

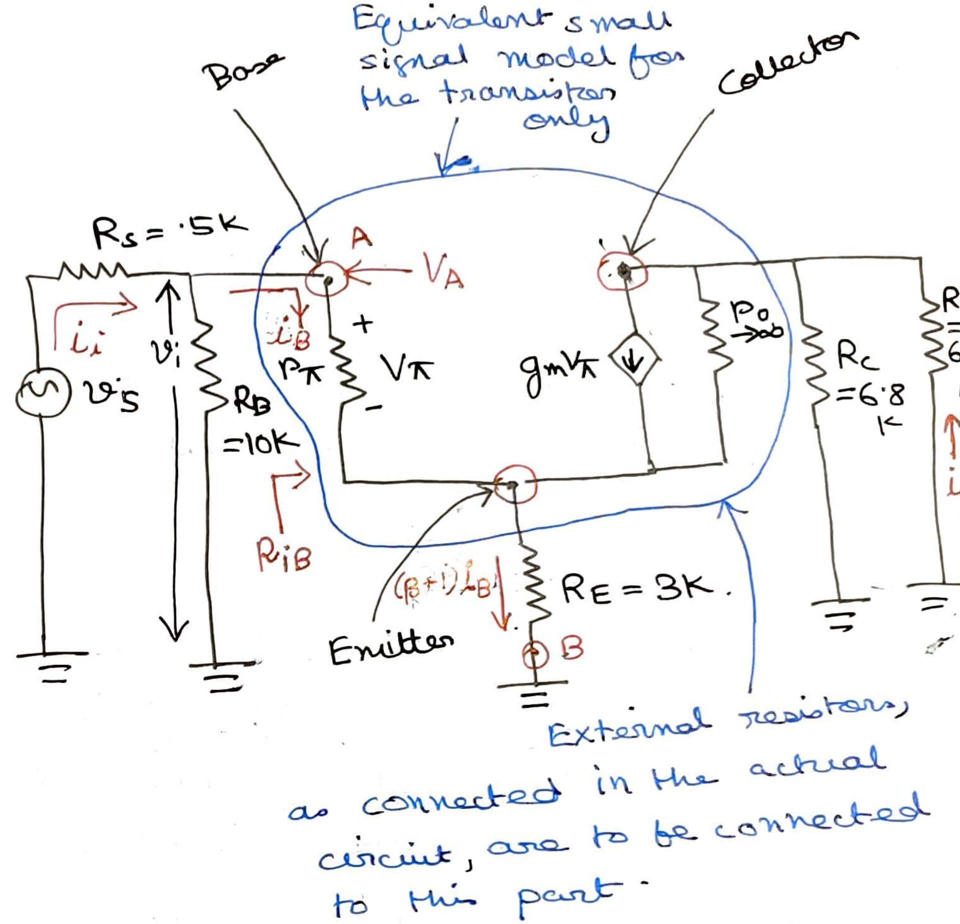
$$= 0.065 \text{ mho}$$

$$r_o \cong \frac{V_A}{I_{CQ}} \cong \frac{V_A}{I_{EQ}} \to \infty$$

We have now found out the small signal parameters. Hence, we are now ready for AC analysis. For AC analysis we first derive the small signal model.

Let us recall that a DC source cannot create AC current. Hence, the DC source point, can only act as sink for ac currents and thats why we are good to go for AC analysis if we repace the DC source points with AC ground. So, in the small signal model we replace all the DC source points with AC grounds.





In this problem, the analysis is a little bit complicated since the emitter resistor R_E is not bypassed with a capacitor C_E. The problem lies in the fact that a current of magnitude i_B is flowing through r_π. But through R_E, which is in series with r_π, a current of magnitude $(\beta+1) i_B$ is flowing.

Here one asks the question: what is the equivalent resistance seen when one looks into the base terminal. In other words, ~~that~~ what is the ratio of the voltage at the base terminal and the current flowing into the base terminal. That is, what is $R_{iB} = \frac{V_A}{i_B}$.

V_A and i_B are shown in the figure. The parameter $R_{iB} = \frac{V_A}{i_B}$ is known as the input resistance at the Base of the ~~amp~~ transistor.

We again write KVL for the ~~base~~ between the points A and B shown in the figure.

$$V_A = i_B r_\pi + (\beta+1)\, i_B R_E$$

$$\Rightarrow \frac{V_A}{i_B} = r_\pi + (\beta+1) R_E$$

$$\Rightarrow R_{iB} = r_\pi + (\beta+1) R_E.$$

It is ~~to~~ noteworthy that the resistance R_E gets reflected as $(\beta+1)R_E$ in the input resistance at the Base due to different magnitudes of current flowing through r_π and R_E. This is known as the resistance reflection rule. ~~He~~

The total resistance, thus seen by the voltage source v_s is $R_i = R_B \| R_{iB}$

$$= R_B \| [r_\pi + (\beta+1)R_E]$$

$$R_s = 0.5\,k\Omega$$

$$R_B = 10\,k\Omega$$

$$R_{iB} = r_\pi + (\beta+1)R_E$$

$$= 1.535\,k\Omega + 101 \times 3\,k\Omega$$

$$= 304.535\,k\Omega.$$

Also called the total input resistance of the amplifier

$$R_i = \cancel{0.5\,k\Omega} + (10\,k\Omega \| 304.535\,k\Omega)$$

$$= \cancel{0.5\,k\Omega} + 9.682\,k\Omega$$

$$\cancel{= 10.182\,k\Omega}.$$

$$= \frac{v_i}{i_i}$$

The voltage between the points A and B

$$v_{AB} = \frac{v_s}{R_s + R_i} \times (R_B \| R_{iB})$$

$$= \frac{v_s}{10.182} \times 9.682$$

$$V_\pi = V_{AB} \times \frac{r_\pi}{R_{iB}}$$

$$= V_{AB} \frac{1.535}{304.535}$$

$$= v_s \times \frac{9.682}{10.182} \times \frac{1.535}{304.535}$$

$$= 0.00479 v_s.$$

$$i_c = g_m V_\pi$$

$$= 0.0651 \times .00479 v_s.$$

$$= 0.000311 v_s.$$

Since $r_o \to \infty$, the output voltage v_o is given by.

$$v_o = -i_c (R_C \| R_L)$$

$$= - 0.000311 v_s \times (6.8 \| 6.8) k\Omega$$

$$= -1.0602 v_s.$$

$$\Rightarrow \frac{v_o}{v_s} = -1.0602$$

The negative sign of the gain indicates phase inversion.

It should be noted that we use capital letters to denote DC signals while small letters (in italics) to denote AC signals. For example, I_B would generally denote the DC component or biasing component of the base current while i_B is used to denote the AC component of the Base current.

Now, let us calculate $|i_o/i_i|$.

$$|i_o| = \left|\frac{v_o}{R_L}\right| = \left\{\frac{\cancel{g_m v_\pi \times (R_C \| R_L)}}{\cancel{R_L}}\right\}$$

$$\cancel{= g_m V_\pi \times \frac{R_C}{R_C + R_L}}$$

$$\cancel{= \frac{g_m V_\pi}{2}}$$

$$= \frac{1.0602 v_s}{R_L}$$

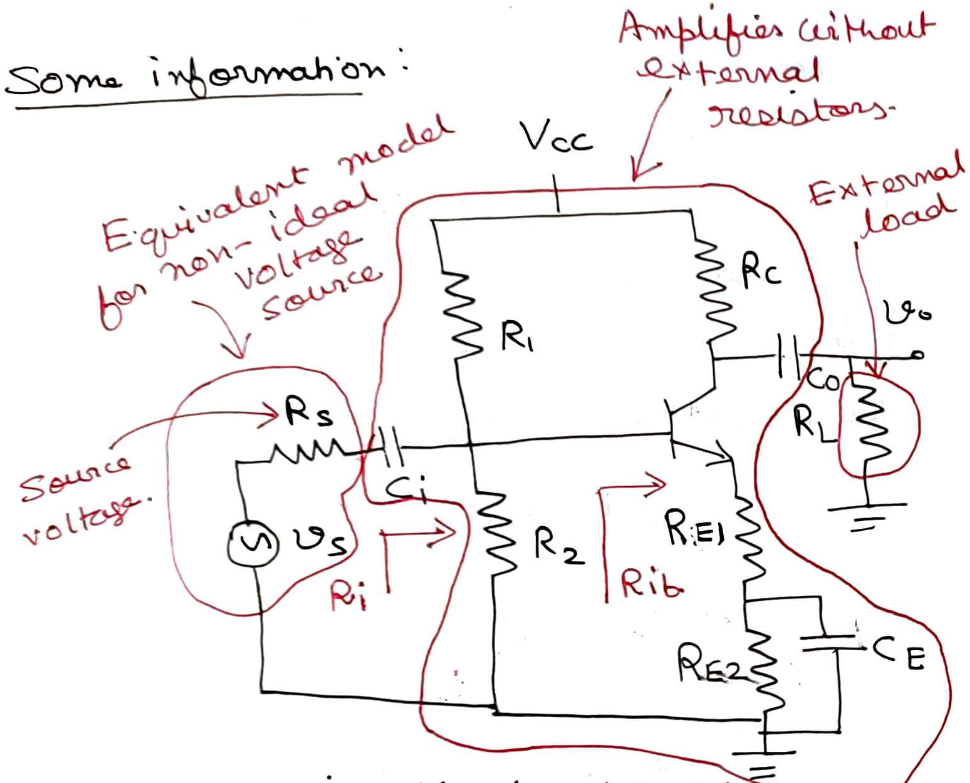
$$|i_i| = \frac{v_s}{R_i + R_s}$$

So, $\left|\frac{i_o}{i_i}\right| = \frac{1.062(R_i + R_s)}{R_L}$

$$= \frac{1.062 \times 10.182\,k\Omega}{6.8\,k\Omega}$$

$$= 1.5901$$

Some information:



The above circuit denotes the ~~voltage-d~~ circuit of a practical (but simplest) BJT amplifier in voltage Divider configuration.

i) R_S denotes the source resistance and generally can't be controlled.

ii) V_{CC} is the biasing voltage and is used to bring the transistor in forward active mode.

iii) R_1 and R_2 are the base to emitter biasing resistors. These two resistors are used to choose or control the ~~ques~~ quiscent base current. I_{BQ} to some extent.

iv) R_C ~~and R_E~~, on the other hand (and also R_E to some extent) can be used to choose the value of quiescent collector to emitter voltage V_{CEQ}.

v) The capacitor C_i is used to prevent the DC current from flowing through v_s. This results in prevention of unnecessary power wastage. Moreover, a high value of DC current, if allowed through v_s, may damage the v_s source (which may be a delicate electronic component).

vi) C_o is used to block any DC voltage across R_L because we only want the AC signal across the load.

vi) C_E is used to bypass the resistance R_{E2}. This reduces the effective resistance seen by the AC path.

~~vii) C_i, C_o and C_E~~

vii) The DC current through the emitter sees a resistance $R_{E1}+R_{E2}$ at the emitter terminal. The emitter resistance is mainly used to stabilize I_{CQ} and V_{CEQ} against variation in β. This can be understood by the following Eqs.

Equation of KVL for DC current and DC voltage

$$V_{Th} = I_B R_{Th} + V_{BE(ON)} + I_{EQ}(R_{E1}+R_{E2})$$

$$\Rightarrow V_{Th} - V_{BE(ON)} = I_{BQ}R_{Th} + (\beta+1)I_{BQ}(R_{E1}+R_{E2})$$

$$\Rightarrow I_{BQ} = \frac{V_{Th} - V_{BE(ON)}}{R_{Th} + (\beta+1)(R_{E1}+R_{E2})}$$

$$\therefore I_{CQ} = \beta I_{BQ}$$

$$= (V_{Th} - V_{BE(ON)}) \times \frac{\beta}{R_{Th} + (\beta+1)(R_{E1}+R_{E2})}$$

If $\beta >> 1$,

$$I_{CQ} \cong \frac{V_{Th} - V_{BE(ON)}}{R_{E1}+R_{E2}}.$$

So, I_{CQ}, and hence V_{CEQ} doesnot depend on β and thus the Q-point is stabilized against any variation in β.

viii) It can be seen that C_E bypasses (for AC signals) a part of the emitter resistor R_{E2}. The resistance R_{E1} is intentionally left in the AC path. This resistor stabilizes the AC gain of the transistor against any variation in β. It can be shown that if $\beta >> 1$, the AC gain $A_v \cong -\frac{R_C}{R_E}$ (See section 6.4.2)

ix) The input base resistance R_{ib} is defined as the resistance seen looking into the base of the transistor. Ask the question:- If the voltage at the base of the transistor increases by an amount ΔV_B, what is the increase in base current ΔI_B.

The input base resistance ~~related~~ relates ΔV_B to ΔI_B as:-

$$\Delta V_B = R_{ib} \, \Delta I_B .$$

We already discussed that

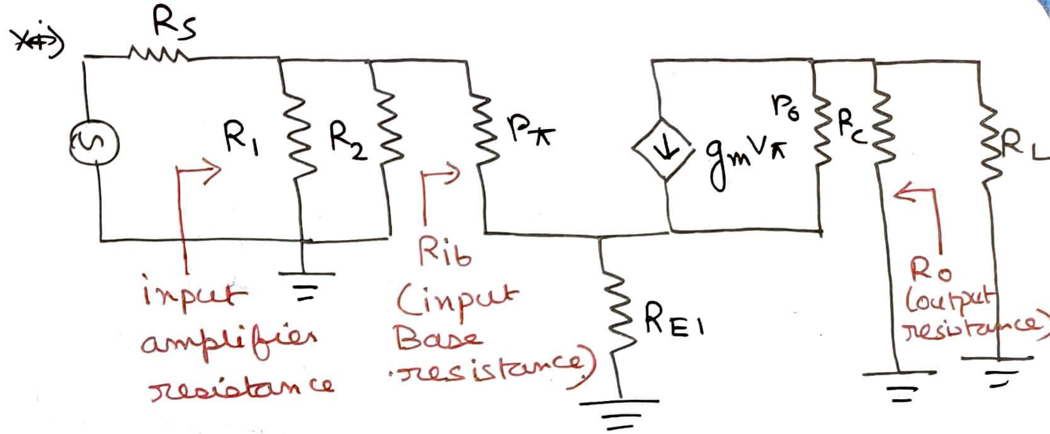
$$R_{ib} = r_\pi + (\beta + 1) R_{E1}$$

Note that the input base resistor is defined only for AC signals. So, the resistance R_{E2} is not considered (because it is bypassed).

x) The input resistance to the amplifier is the resistance seen by the AC source, So, R_s is left out (because R_s is a part of the AC source). The resistance seen by the AC source (discussed earlier) is

$$R_i = (R_1 \| R_2 \| R_{ib})$$

x)



Small signal model for the circuit shown in the last page.

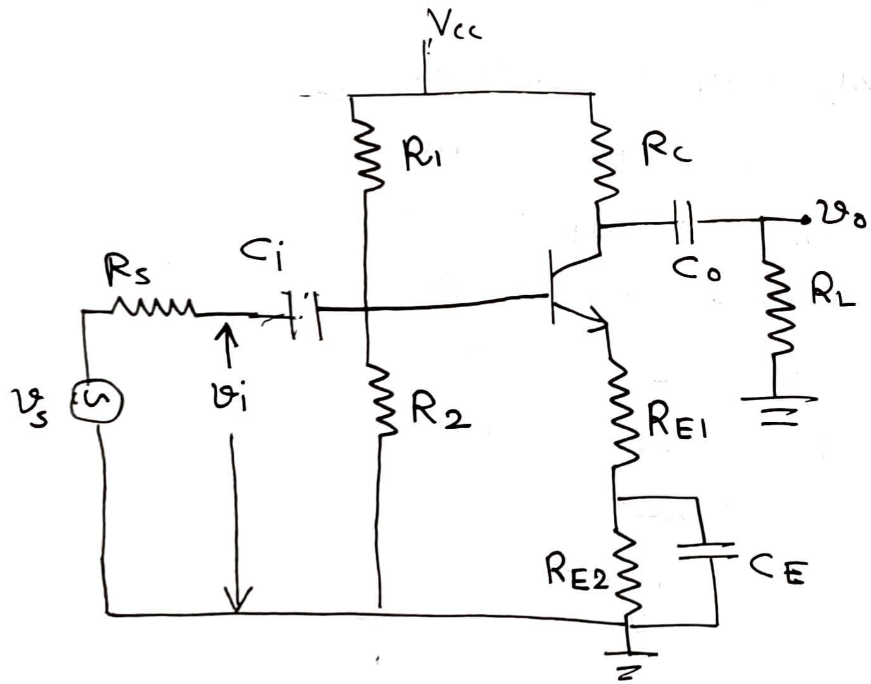
xi) <u>Output resistance</u>: The output resistance relates the small increase ~~the collecto~~ in the output voltage to the small ~~increase in~~ change in collector current.

Since R_L, is not a part of the amplifier, R_L is not included in the output resistance. So, the output resistance, given $r_o = \infty$, is given by

$$R_o = R_c .$$

Loading effect:

A change in overall gain of the amplifier due to external resistors is called loading effect. The resistance R_S and R_L denote the source resistance and load resistor and are ~~ext~~ external resistors to the amplifier



When a transistor amplifier is bought from the market, the parameter $A_v^{no\text{-}load} = \frac{v_o^{R_L\to\infty}}{v_i}$ is specified.

~~However~~, Due to R_S and R_L, the overall gain is reduced. Let us first consider the source loading effect will $R_L \to \infty$.

$$A_v = \frac{v_o^{R_L\to\infty}}{v_s}$$

$$= \frac{v_o^{R_L\to\infty}}{v_i} \times \frac{v_i}{v_s}$$

$$= \frac{v_o^{R_L\to\infty}}{v_i} \times \frac{R_i}{R_i+R_s}$$

$$= A_v^{no\text{-}load} \times \frac{R_i}{R_i+R_s}.$$

R_i = input resistance $= (R_1 \| R_2 \| R_{ib})$

$R_{ib} = r_\pi + (\beta+1) R_{E1}$

Similarly, we can calculate the loading effect of the load resistor R_L. We will discuss the load resistor loading effect via a numerical problem. Note that the ~~loading~~ while calculating the loading effect, we are only intersted in the AC loading effect.