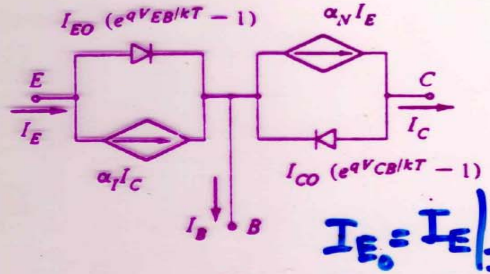
ESc201, Lecture 18: Bipolar Junction Transistor (ONLY FOR ADVANCED SUDY)

DISREGARD NOW

$\Delta p_c = 0,\ I_{EN} = a\,\Delta p_E$ & $I_{CN} = b\,\Delta p_E$ $\quad a = \frac{qAD_p}{L_p}\coth\left(\frac{W_b}{L_p}\right)$

$\Delta p_E = 0,\ I_{EI} = -b\,\Delta p_c$ & $I_{CI} = -a\,\Delta p_c$ $\quad b = \frac{qAD_p}{L_p}\,\mathrm{cosech}\left(\frac{W_b}{L_p}\right)$

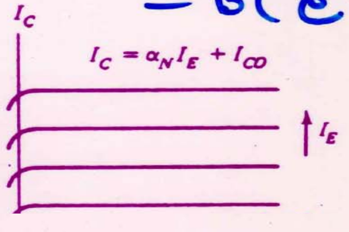


(a)

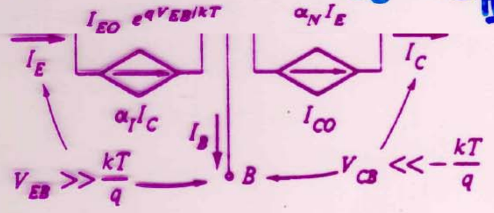
$$I_E = I_{EN} + I_{EI} = A\left(e^{qV_{EB}/kT}-1\right) - B\left(e^{qV_{CB}/kT}-1\right)$$

$$I_{E_0} = I_E\big|_{I_C=0}$$

$$I_{C_0} = I_C\big|_{I_E=0}$$



(c)



(b)

$$I_C = I_{CN} + I_{CI} = B\left(e^{qV_{EB}/kT}-1\right) - A\left(e^{qV_{CB}/kT}-1\right)$$

or
$$I_E = I_{ES}\left(e^{qV_{EB}/kT}-1\right) - \alpha_I I_{CS}\left(e^{qV_{CB}/kT}-1\right)$$

$$I_C = \alpha_N I_{ES}\left(e^{qV_{EB}/kT}-1\right) - I_{CS}\left(e^{qV_{CB}/kT}-1\right)$$

Emitter Saturation Current (normal) with $V_{CB}=0$

Collector Saturation current with $V_{EB}=0$

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Why V_{BE}= 0.7 V?

Note: I_E (and thus I_C) varies exponentially with respect to V_{BE}.

A small change in V_{BE} can cause a very large change in I_C.

As a rule of thumb, V_{BE} under the forward active mode is assumed to get pinned at 0.7 V, slightly greater than 0.6V used for cut-in voltage V_{on}.

This is only a heuristic used for quick estimate

The answer may not be accurate, however, good enough!

$I_{E_S} \cong$ pA-nA

$$I_E = I_{E_S}\left[e^{q\frac{V_{BE}}{nk_BT}} - 1\right] \cong I_{E_S} \times e^{q\frac{V_{BE}}{nk_BT}} \overset{n=1}{=} I_{E_S} \times e^{\frac{V_{BE}}{V_T}}$$

$V_T = (k_BT)/q$
= 25.9mV at 300^{o}K.
≈ 26mV at 300^{o}K.

Current Gain

The sum of the collection component and the recombination component must always equal the injection component (charge conservation)

$I_E = I_B + I_C$

Common Emitter Current Gain (β) = I_C / I_B

Common Base Current Gain (α) = I_C / I_E

Thus, β = α / (1−α) and α = β / (β +1)

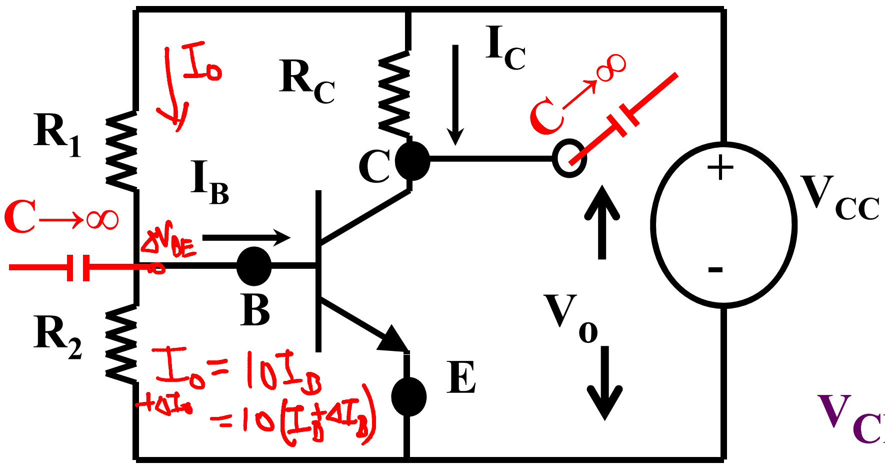
For a good transistor I_B should be as small as possible or α →1 and hence β is quite large (100 – 500)

Closer is the value of α to 1, better is the BJT !

Modes of Operation : BE and BC junction can either be forward biased or reverse biased, which gives 4 possible modes of operation.

1. Forward Active Mode: BE junction forward biased AND BC junction reverse biased.
2. Reverse Active Mode: BE junction reverse biased AND BC junction forward biased.
3. Saturation Mode: Both junctions forward biased.
4. Cutoff Mode: Both junctions Reverse biased.

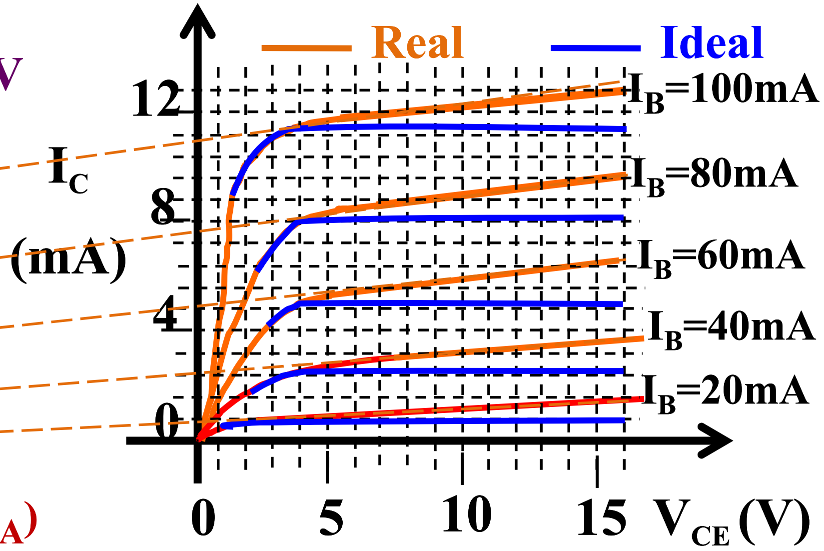
Common Emitter (CE) Configuration



Once V_{CE} drops below 0.7 V, the BJT enters the saturation mode of operation. With further reduction in V_{CE}, the BJT moves deeper into saturation. This is the digital mode of operation of BJTs. However, BJTs used in analog circuits should never ever enter this mode of operation. Always check for analog circuits if V_{CE} is >0.7V.

$V_{CEsat} \approx 0.2V$

This course would only deal with Ideal characteristics

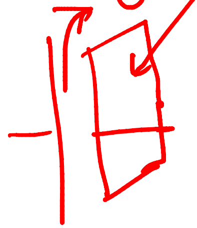


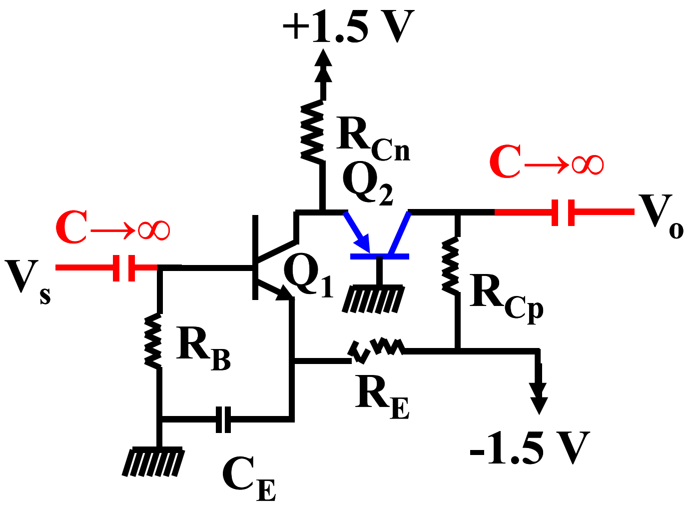
All meet the x-axis at a point, called the EARLY voltage (V_A)

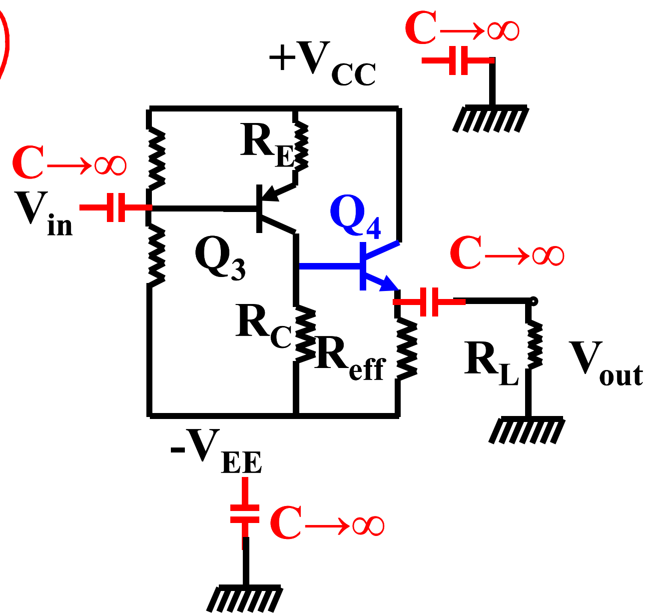
Common Collector (CC) Configuration

Common Base (CB) Configuration

$C = \frac{\epsilon A}{t}$

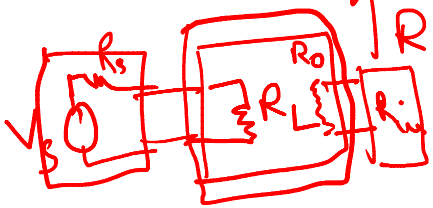






Non-inverting voltage gain and output resistance very similar to CE configuration But input impedance much lower than CE

High Input Impedance
But Low output Impedance
with Gain $\approx < 1$.



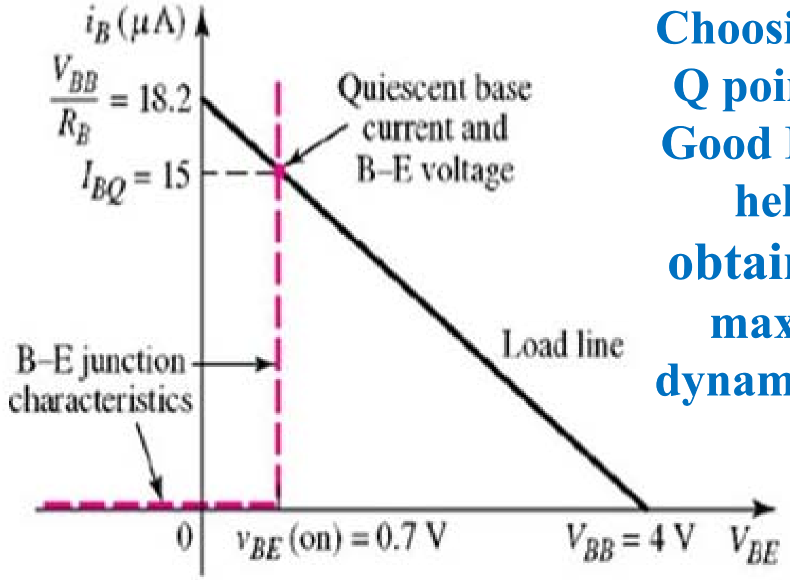
$\uparrow R_L \not> R_s$ $\downarrow$

$R_o << R_{in}$

Henceforth : Only Common Emitter (CE) Configuration in this course

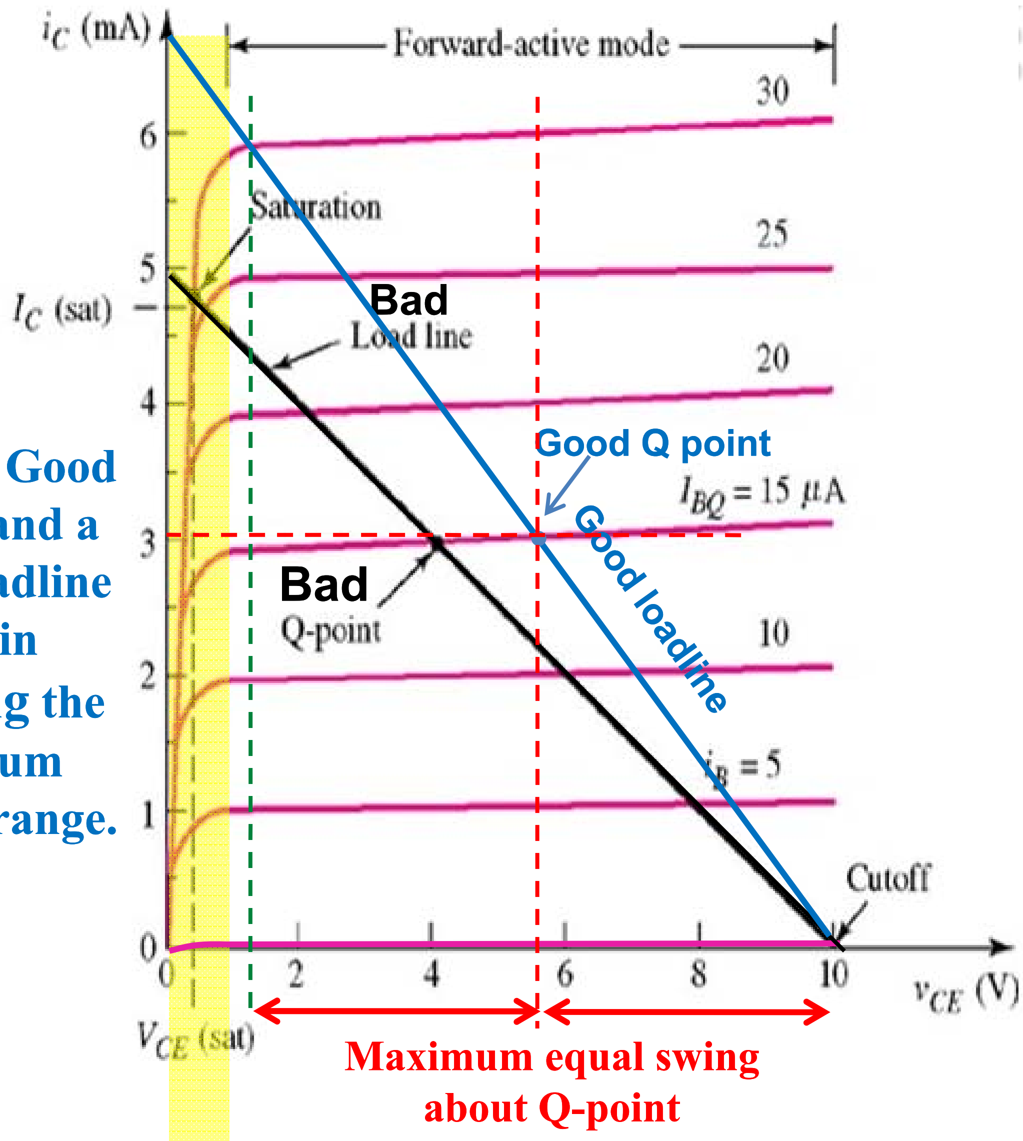
If I_B varies from 0→15→30μA linearly, the collector current swing is distorted as I_C which should have reached 6mA does not do so because of saturation.

Saturation Region



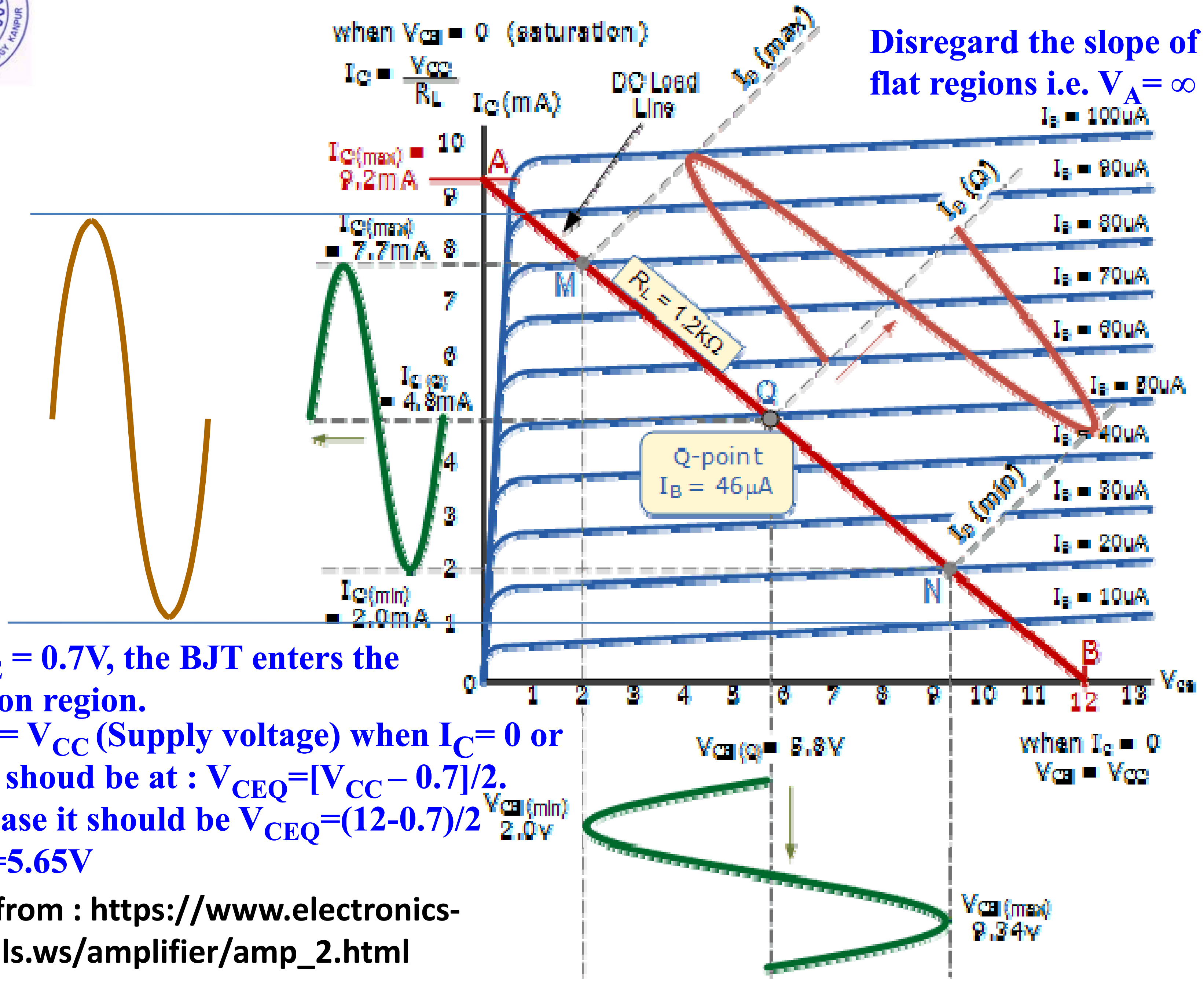
Base – Emitter junction characteristics
(a)

Choosing Good Q point and a Good Loadline helps in obtaining the maximum dynamic range.



Taken form **https://slideplayer.com/**

Disregard the slope of the flat regions i.e. $V_A = \infty$



For V_{CE} = 0.7V, the BJT enters the saturation region.

$V_{CE_{max}} = V_{CC}$ (Supply voltage) when I_C= 0 or

Q-point shoud be at : $V_{CEQ}=[V_{CC} - 0.7]/2$.

In this case it should be V_{CEQ}=(12-0.7)/2 =11.3/2=5.65V

Taken from : https://www.electronics-tutorials.ws/amplifier/amp_2.html

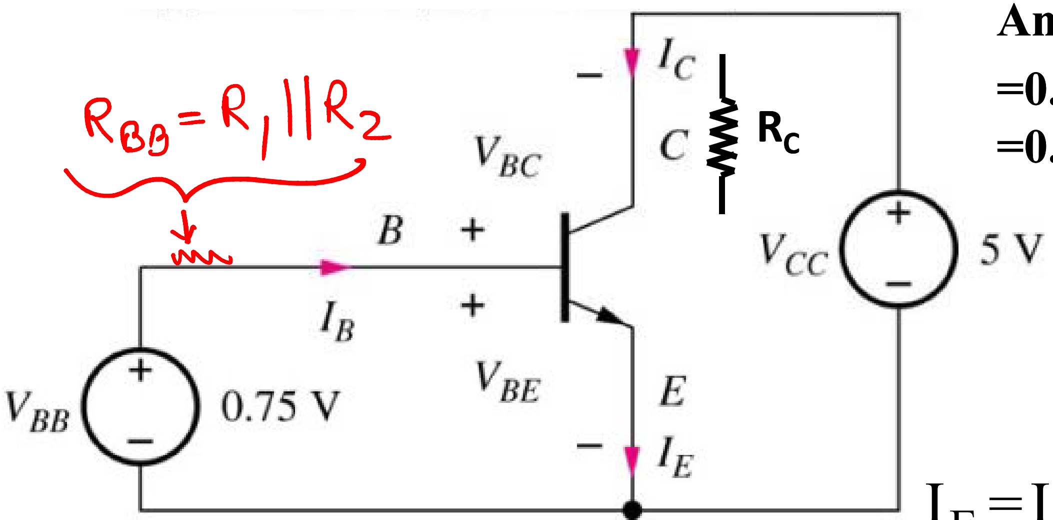
Then, the transistor is replaced by its – *small signal ac model*
Subsequently, usual network analysis is done to obtain:

1) **Voltage Gain (A_v)**
2) **Current Gain (A_i)**
3) **Power Gain ($A_p = |A_i . A_v|$)**
4) **Input Resistance (R_{in})**
5) **Output Resistance (R_{out})**

Problem of Biasing: Terminal voltages and currents.

Given data: $V_{BB} = 0.75V$, $V_{CC} = 5.0V$, $I_S = 10^{-16}$ A, $\beta_F = 50$, $\beta_R = 1$, $V_T = 25.0$ mV.

What is the maximum value of a resistance added to the collector (R_C)?



Analysis: $V_{BE} = 0.75$ V, $V_{BC} = V_{BB} - V_{CC} = 0.75V - 5.0V = -4.3V$ or $V_{CE} = 5V > V_{BE} = 0.75V$. **The BJT is forward active mode.**

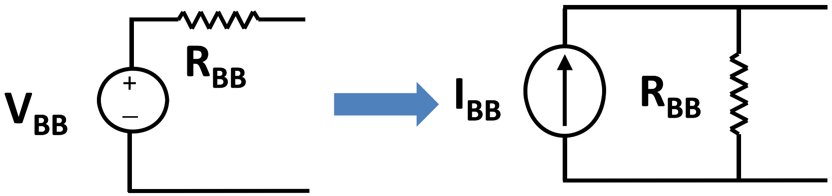
$$I_E \cong I_{E_S} \times e^{\frac{V_{BE}}{V_T}}$$

$$= 10^{-16} \times e^{0.75/0.025} = 1.07mA$$

$$I_E = I_B + I_C = 1.05 + 0.0214 = 1.0714 mA$$

$$\alpha_F = \frac{I_C}{I_E} = \frac{I_C}{1.07mA} = \frac{\beta}{\beta+1} = \frac{50}{51} = 0.9804, \; I_C = 1.05mA$$

$$I_B = \frac{I_C}{\beta_F} = \frac{1.05 mA}{50} = 21.0 \mu A$$



$$V_{R_C} = 1.05mA \times R_C = 5 - 0.75V \text{ or } R_{C_{max}} = 4.05k\Omega$$

$$\text{or } R_{C_{req}} = 2.025k\Omega \text{ for best biasing}$$

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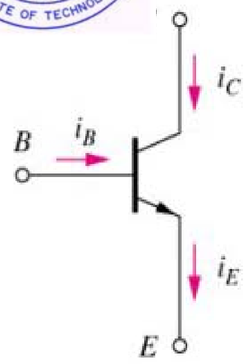

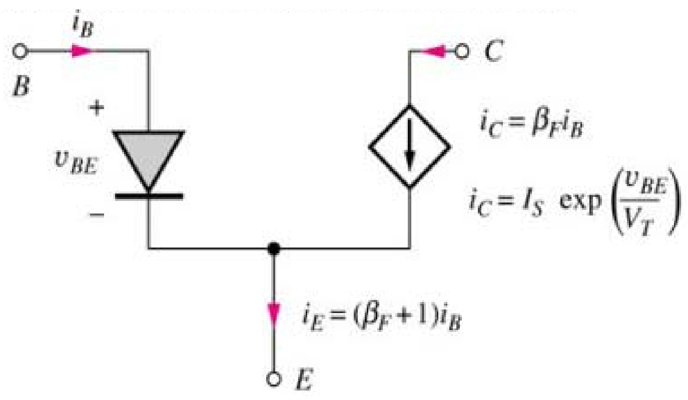

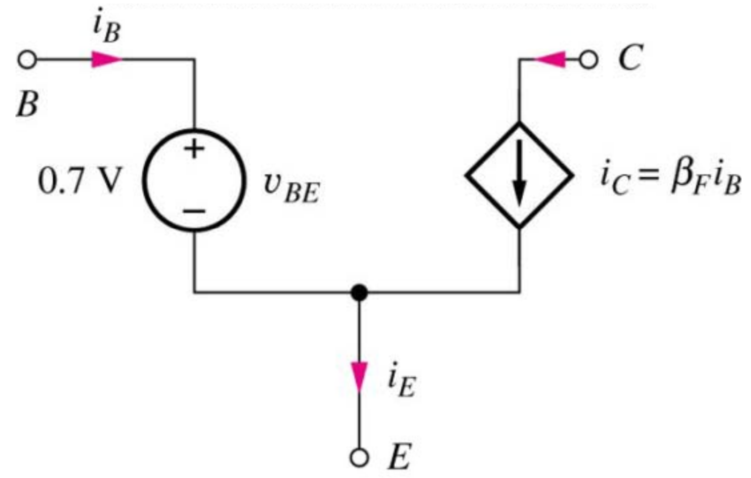

Current in base-emitter diode is amplified by common-emitter current gain β_F and appears at collector-base and collector currents are exponentially related to base-emitter voltage.

Base-emitter diode is replaced by constant voltage drop model(V_{BE} = 0.7 V) since it is forward-biased in forward-active region.

DC base and emitter voltages differ by 0.7 V diode voltage drop in forward-active region.