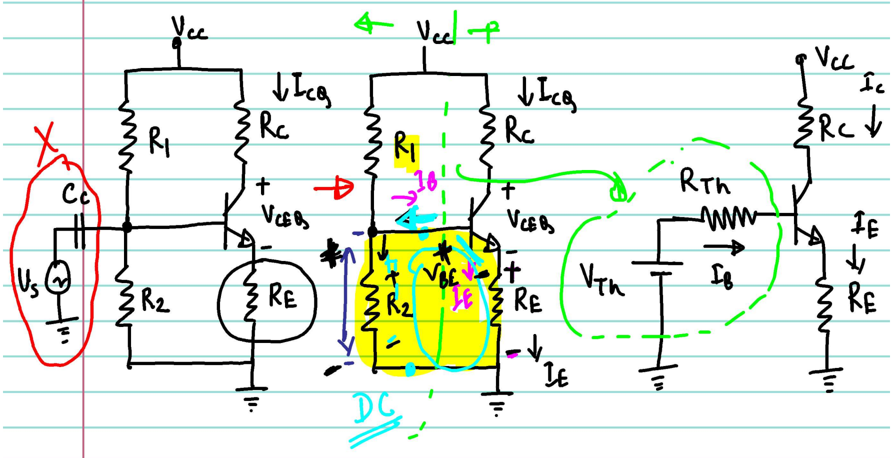
(ii) Voltage divider biasing with emitter resistance:



$$V_{Th} = V_{CC} \cdot \frac{R_2}{R_1+R_2} \quad ; \quad R_{Th} = R_1 \parallel R_2$$

$$V_{Th} = I_B \cdot R_{Th} + V_{BE\,ON} + I_E R_E \quad ; \quad I_E = (1+\beta) I_B$$

$$V_{Th} = I_B \cdot R_{Th} + V_{BE\,ON} + (1+\beta) I_B R_E.$$

$$I_B = \frac{V_{Th} - V_{BE-ON}}{R_{Th} + (1+\beta) R_E} \quad ; \quad I_C = \beta I_B$$

$$I_C = \beta \times \frac{V_{Th} - V_{BE\,ON}}{R_{Th} + (1+\beta) R_E}$$

$R_{Th} = R_1 \parallel R_2$

$$R_{Th} << (1+\beta) R_E$$

$$I_C \approx \frac{\beta (V_{Th} - V_{BE\,ON})}{\cancel{(1+\beta)} R_E} \quad ; \quad \beta >> 1 \quad 1+\beta \approx \beta$$

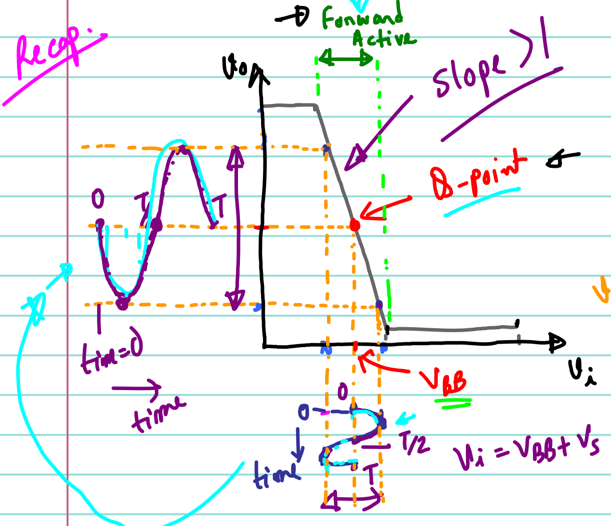
$$I_C \approx \frac{V_{Th} - V_{BE\,ON}}{R_E}$$; I_C is independent of 'β'

$$R_{Th} \approx 10\% \; R_E(1+\beta)$$

Lec-16

Basic BJT Amplifier:

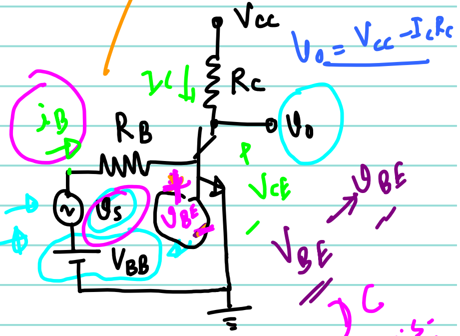
Recap:



$v_i = V_{BB} + v_s$

0.7

$v_{BB} + V_{BB} = i_B R_B + V_{BE}$

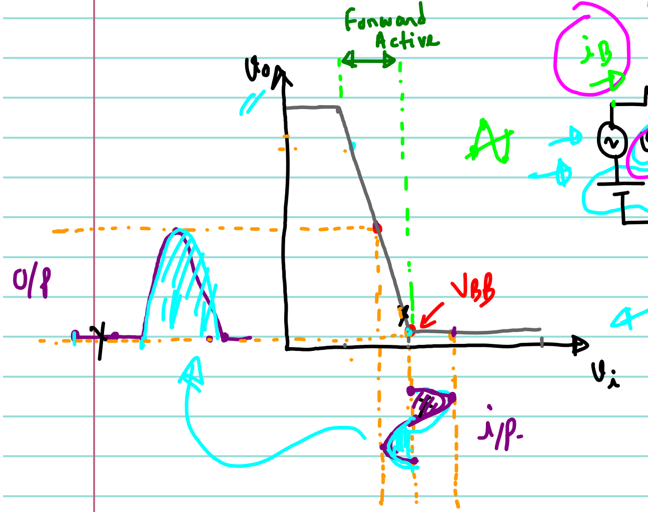


$V_o = V_{cc} - I_c R_c$

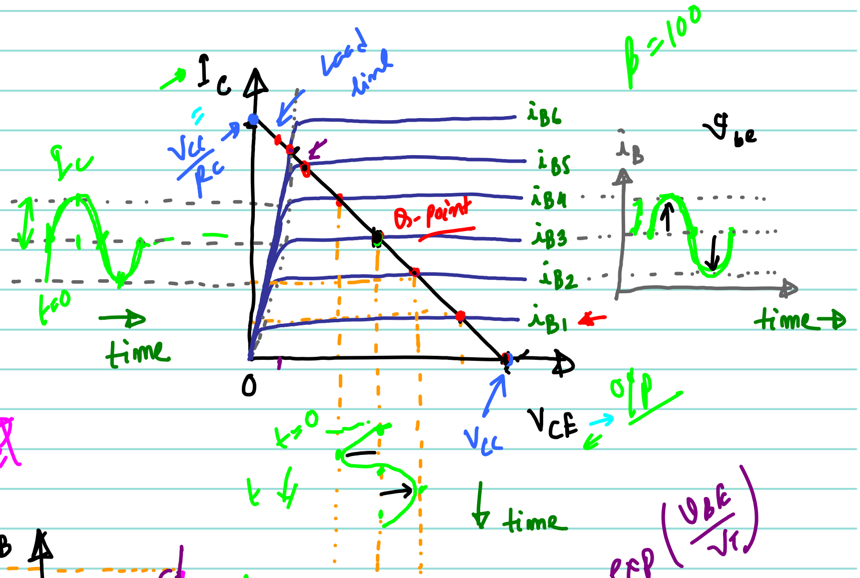
v_{BE} // V_{BE}

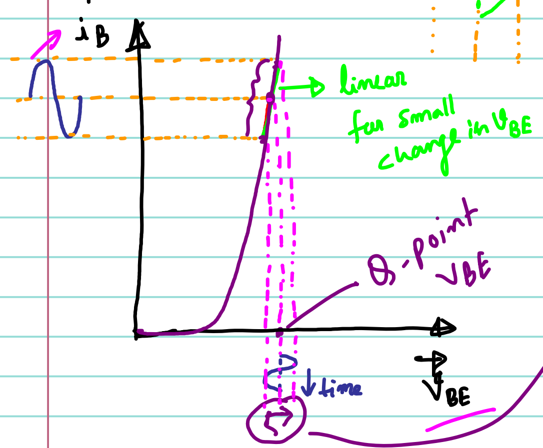
DC Analysis

AC analysis



$\beta = 100$





$i_B = \exp\left(\frac{v_{BE}}{V_T}\right)$

$i_B \propto V_{BE}$

"small signal"

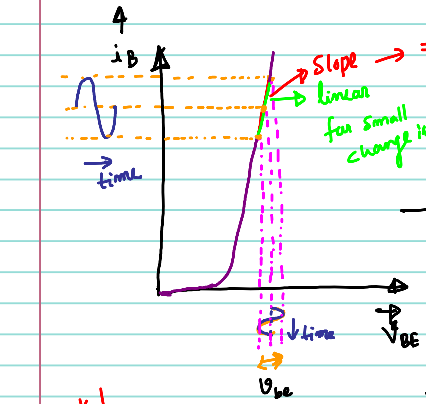
$0.7V \gg 0.026V$ (V_T)

Total value

Small signal ??

$\rightarrow i_C = I_S \exp\left(\frac{v_{BE}}{V_T}\right)$

$i_B = \frac{i_C}{\beta}$



$v_{BE} > 3V_T$

$\rightarrow i_B = \frac{I_S}{\beta} \exp\left(\frac{v_{BE}}{V_T}\right)$

$\sim 0.7V$

$\rightarrow v_{BE} = V_{BE} + v_{be}$

$i_B = \frac{I_S}{\beta} \exp\left(\frac{V_{BE}+v_{be}}{V_T}\right)$

$i_B = \frac{I_S}{\beta} \exp\left(\frac{V_{BE}}{V_T}\right) \cdot \exp\left(\frac{v_{be}}{V_T}\right)$

$x \nless 1$

$e^x = 1 + x + \underbrace{\frac{x^2}{2} + \frac{x^3}{6} + \cdots}_{\text{neglected}}$ $\leftarrow i_B = I_{BQ} \cdot \exp\left(\frac{v_{be}}{V_T}\right)$

if $x < 1$

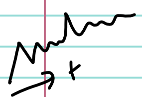
$v_{be} < 1$

$\rightarrow v_{be} < V_T$ (condition)

$i_B = I_{BQ}\left[1 + \frac{v_{be}}{V_T}\right]$; $\cancel{I_{BQ}} + i_b = \cancel{I_{BQ}} + I_{BQ} \cdot \frac{v_{be}}{V_T}$

$\frac{v_{be}}{V_T} < 1$

$i_b = I_{BQ} \cdot \frac{v_{be}}{V_T}$; $i_b \propto v_{be}$



$V_T = 26\ mV$ at $300K$ $\rightarrow$ $\boxed{v_{be} < 10\ mV}$ $\leftarrow$

$i_C = I_C + i_c$

$i_b \propto v_{be}$, $v_{be} \propto v_s$, $i_b \propto v_s$

$i_c = \beta i_b$, $v_o =$

$\rightarrow v_o = V_{CC} - i_C R_C$

$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \frac{x^4}{\ldots} \cdots \rightarrow$

$x = \frac{v_{be}}{V_T} = \frac{V_m \sin\omega t}{V_T}$

$\sin^2\omega t = \frac{1}{2}\left[1 - \cos 2\omega t\right]$

$= \frac{1}{2}\left[1 - \sin(2\omega t + 90)\right]$

$e^x = 1 + \frac{V_m \sin\omega t}{V_T} + \frac{V_m^2 \sin^2\omega t}{2V_T^2} + \left(\frac{V_m}{V_T}\right)^3 \frac{\sin^3\omega t}{6} + \cdots$

$= 1 + \frac{V_m \sin\omega t}{V_T} + \frac{V_m^2}{2V_T^2}\left[\frac{1}{2}\left\{1 - \sin(2\omega t + 90)\right]\right.$

$+ \left(\frac{V_m}{V_T}\right)^3 \times \frac{1}{6} \times \frac{1}{4}\left[3\sin\omega t - \sin 3\omega t\right]$

$\left(\frac{V_m \sin\omega t}{V_T}\right)$

e

$= \underbrace{\left[1 + \frac{1}{4}\left(\frac{V_m}{V_T}\right)^2\right]}_{\text{Dc part}} + \overbrace{\left(\frac{V_m}{V_T}\left[1 + \frac{1}{8}\left(\frac{V_m}{V_T}\right)^2\right]\right)}^{V_1} \sin\omega t$

ω

2ω

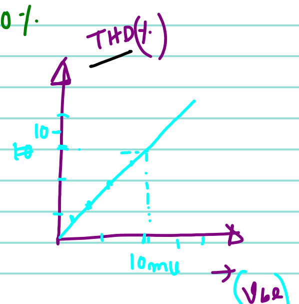
3ω

$\underbrace{-\frac{1}{4}\left(\frac{V_m}{V_T}\right)^2}_{V_2} \cdot \sin(2\omega t + 90) \underbrace{- \frac{1}{24}\left(\frac{V_m}{V_T}\right)^3}_{V_3} \sin 3\omega t + \ldots$

Harmonics $\rightarrow$ Harmonic distortion

Total Harmonic Distortion (THD) %

$= \frac{\sqrt{\sum_{2}^{m} V_m^2}}{V_1} \times 100\%$



Notations used in BJT Amplifier Section:

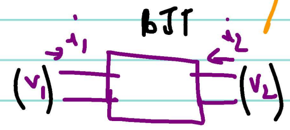
Total instantaneous value → i_B, i_C, v_{BE}, v_{CE}

DC Values → I_B, I_C, V_{BE}, V_{CE}

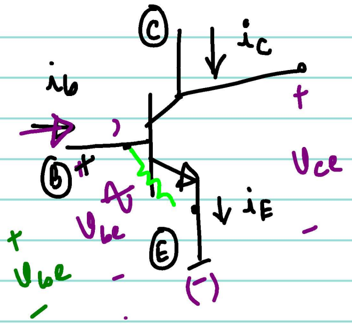
Instantaneous ac value → i_b, i_c, v_{be}, v_{ce}

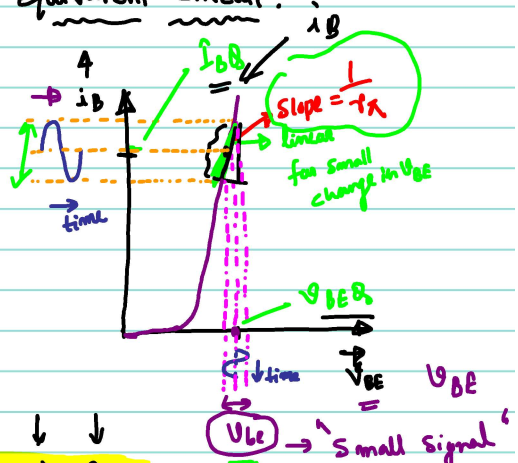
$$\left\{ \begin{array}{l} i_C = I_S \exp\left(\frac{v_{BE}}{V_T}\right) \\ i_C = \beta i_B \end{array} \right.$$

Lec-17



Small signal hybrid-π equivalent circuit:





$$\frac{i_b}{v_{be}} = \frac{1}{r_\pi} \; ; \; v_{be} = i_b r_\pi$$

r_π = diffusion resistance

→ $i_B = \frac{I_S}{\beta} \exp\left(\frac{v_{BE}}{V_T}\right)$

$$\frac{1}{r_\pi} = \frac{\partial i_B}{\partial v_{BE}}\bigg|_{Q} = \frac{I_S}{\beta V_T} \exp\left(\frac{v_{BE}}{V_T}\right)\bigg|_{\text{at Q-point}} = \frac{I_{BQ}}{V_T} = \frac{I_{CQ}}{\beta V_T}$$

$$\boxed{r_\pi = \frac{\beta V_T}{I_{CQ}}}$$

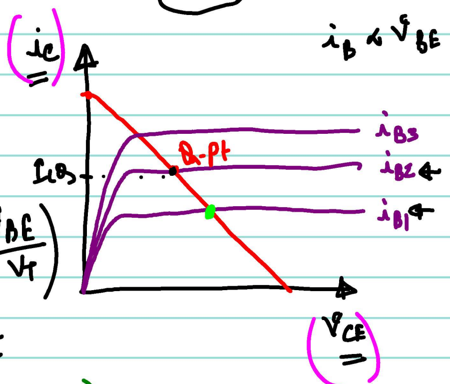
an F.W.B. base-emitter resistance

$$r_\pi^{-1} = \frac{I_{BQ}}{V_T} = \frac{I_D}{V_T}$$

$$r_\pi = \frac{V_T}{I_D}$$

→ $\Delta i_C = \frac{\partial i_C}{\partial v_{BE}}\bigg|_{Q\text{-pt}} \cdot \Delta v_{BE}$

$$i_c = \left(\frac{\partial i_C}{\partial v_{BE}}\bigg|_{Q\text{-pt}}\right)(v_{be})$$



$$\frac{\partial i_C}{\partial v_{BE}}\bigg|_{Q\text{-pt}} = \frac{\partial}{\partial v_{BE}} I_S \exp\left(\frac{v_{BE}}{V_T}\right)$$

$$\frac{\partial i_C}{\partial v_{BE}}\bigg|_{Q\text{-pt}} = \frac{I_S}{V_T} \exp\left(\frac{v_{BE}}{V_T}\right) = \frac{I_{CQ}}{V_T}$$

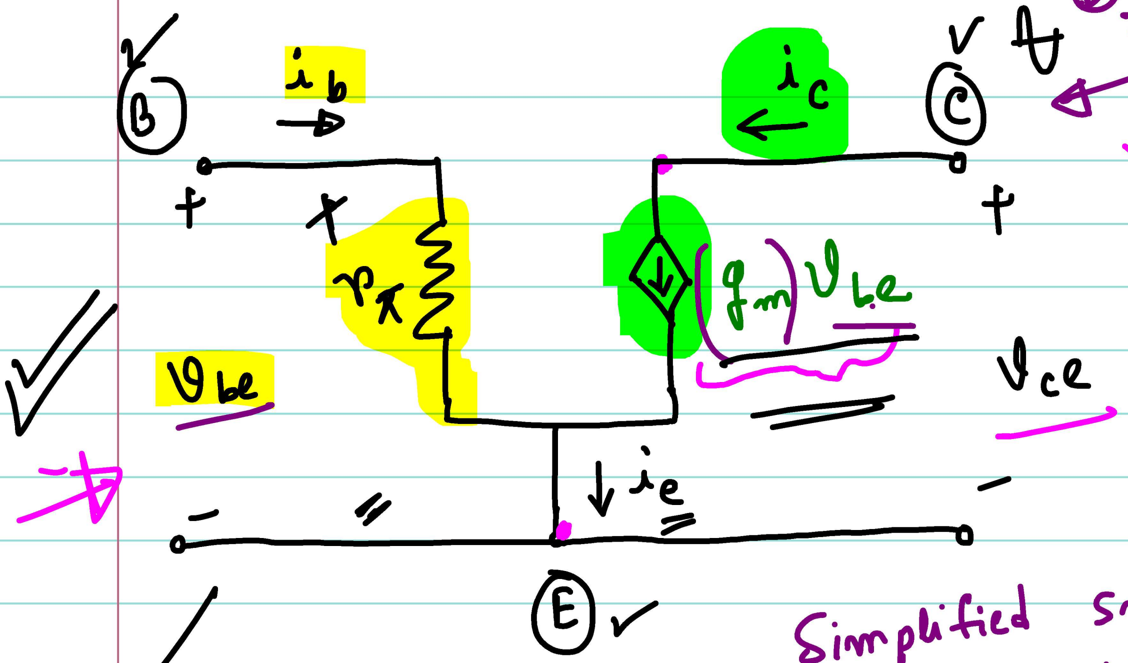
→ transconductance (g_m)

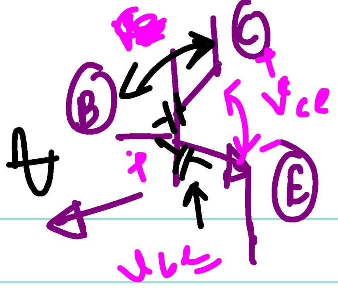
$$\boxed{g_m = \left(\frac{I_{CQ}}{V_T}\right)}$$

$\boxed{\Delta i_c} \rightarrow \boxed{i_c}$ (small)

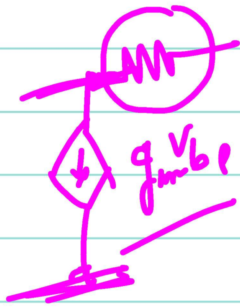
$g_m v_{be}$

Small signal parameters (g_m, r_π) are dependent on operating point (Q-pt).

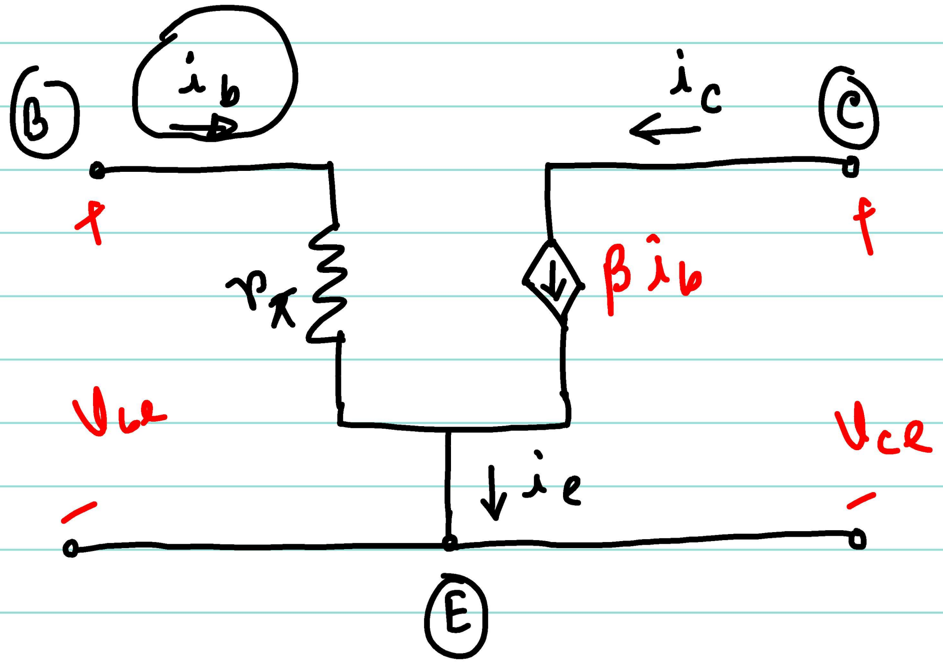




v_{be}



Simplified small-signal hybrid-π equiv. ckt.



$i_c = \beta i_b$

Ac C.E. cunt gain

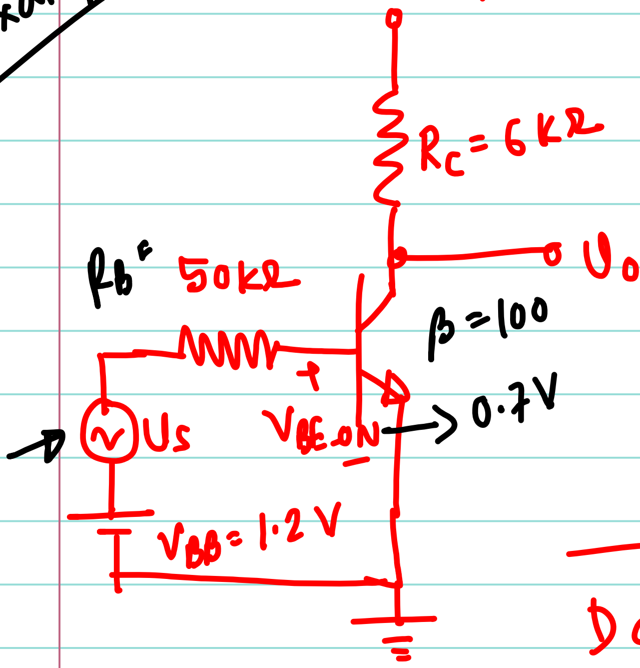
= C.E. Dc cunt gain

$$g_m \times r_\pi = \frac{I_{CQ}}{V_T} \times \frac{V_T \beta}{I_{CQ}} = \beta.$$

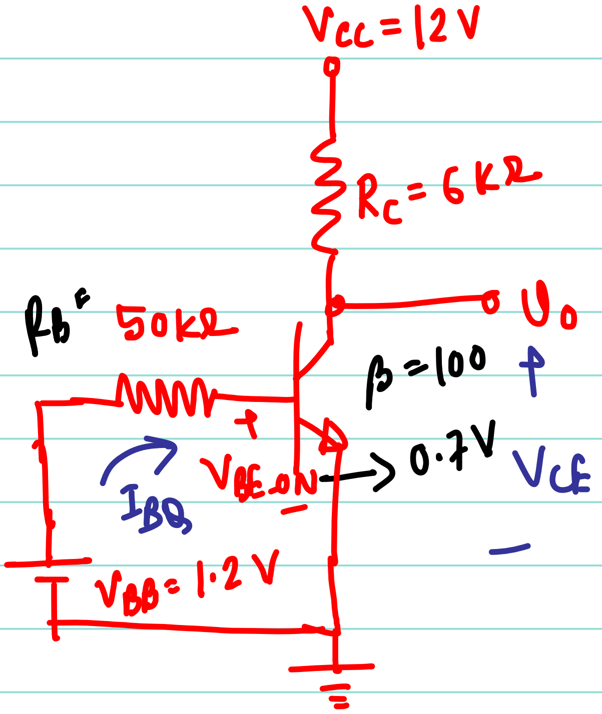
$$\boxed{g_m \times r_\pi = \beta}$$

Example

Find the Small signal gain.



→ DC equiv. ckt



Component	DC	AC
R	R	R
C	open	Short
L	Short	open.
Diode	V_γ r_f	$r_d = \frac{V_T}{I_D}$
Independent Vs	+ Vs −	short
Independent Is	Is	open.

$$I_{BQ} = \frac{1.2 - 0.7}{R_B}$$

$$I_{BQ} = 10\ \mu A$$

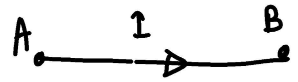
$$I_{CQ} = \beta I_{BQ} = 100 \times 10\mu A$$

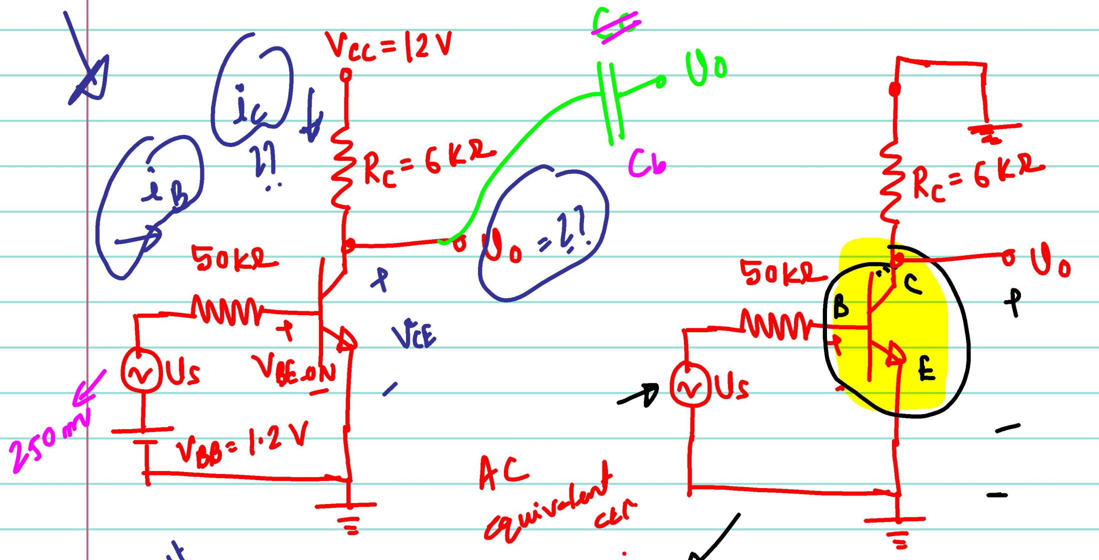
$$= 1\ mA$$

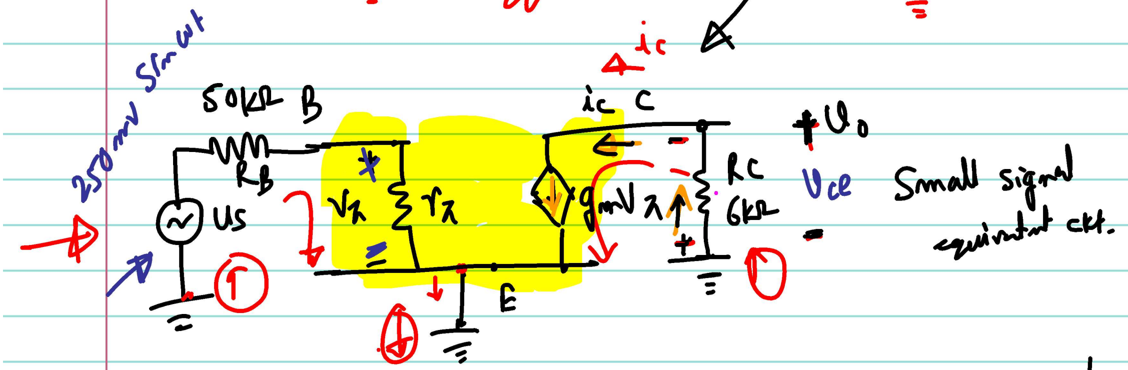
$$I_{EQ} = I_{BQ} + I_{CQ} = 1.01\ mA$$

$$V_{CEQ} = V_{cc} - I_c \cdot R_c = 6V.$$

$V_A = V_B$







$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 \times 0.026}{1 \times 10^{-3}} = 2.6\,k\Omega \qquad g_m = \frac{I_{CQ}}{V_T} = 38.5\ mA/V$$

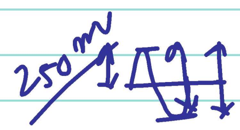
$$\text{gain} = \frac{V_o}{V_s} = \frac{-i_c R_c}{V_s} = \frac{-g_m V_\pi R_C}{V_s}$$

$$\left[V_\pi = V_s \times \frac{r_\pi}{R_B + r_\pi} \right]$$

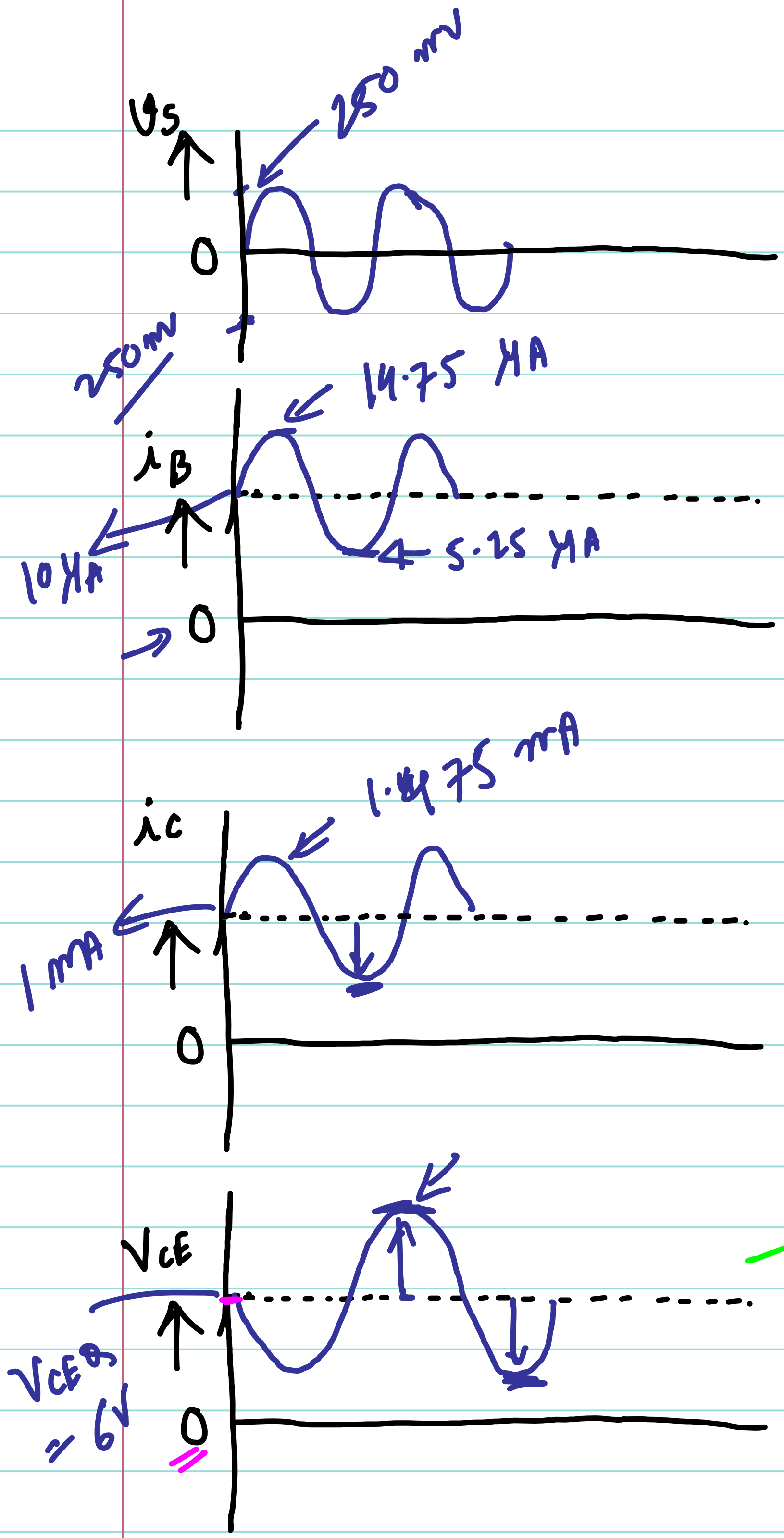
$$= -\frac{g_m R_C \cdot \cancel{V_s}}{\cancel{V_s}} \times \frac{r_\pi}{R_B + r_\pi}$$

$$\rightarrow \text{gain} = -\frac{g_m R_C r_\pi}{R_B + r_\pi} \leftarrow$$

$V_s = 0.25 \sin \omega t$ V.



gain = −11.4



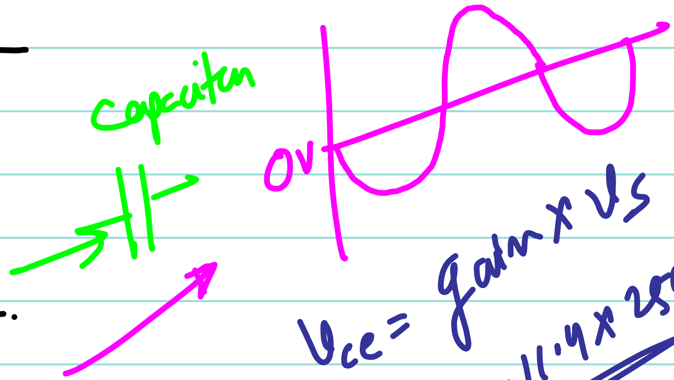
$i_b = v_s \times \frac{1}{r_\pi + R_B}$ sinωt

$= 250\,mV \times \frac{1}{2.6 + 50}$

$= 4.75$ sinωt

$i_c = \beta \cdot i_b$

$= 0.475$ mA.

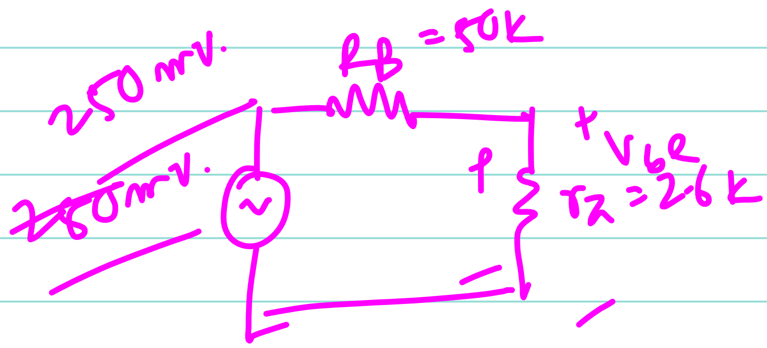


$V_{ce} = gain \times v_s$

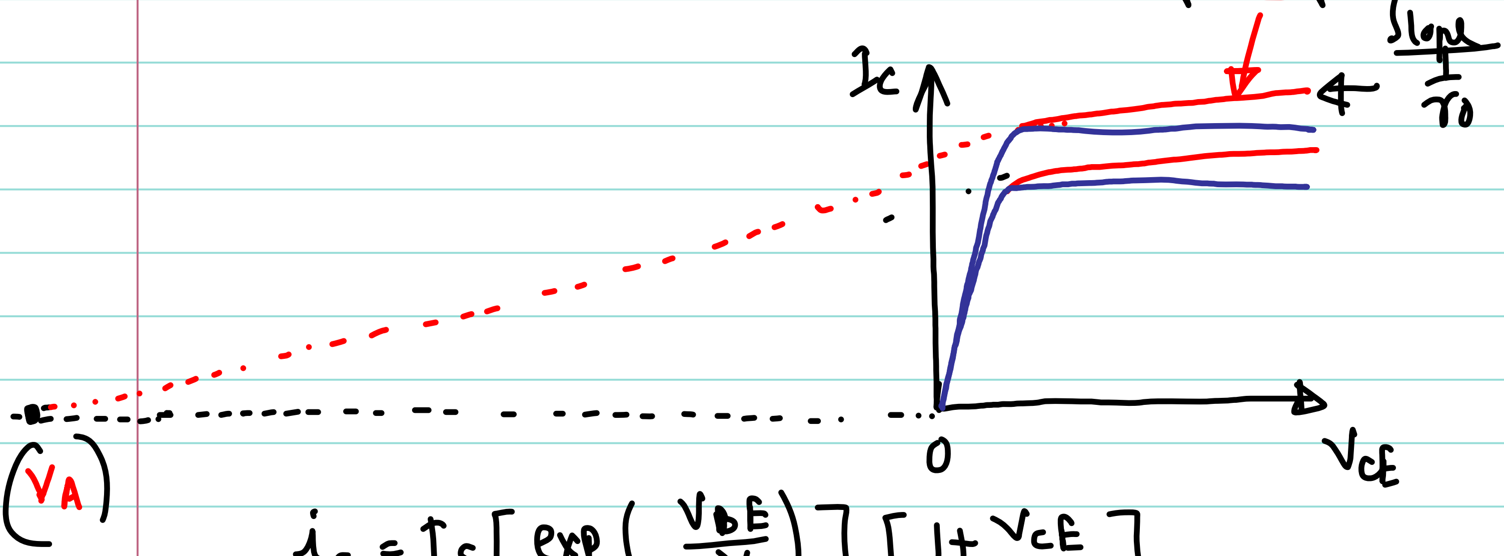
$= -11.4 \times 250\,mV$

$v_{be} \rightarrow 10\,mV$

$v_{be} = 12.36$ mV.



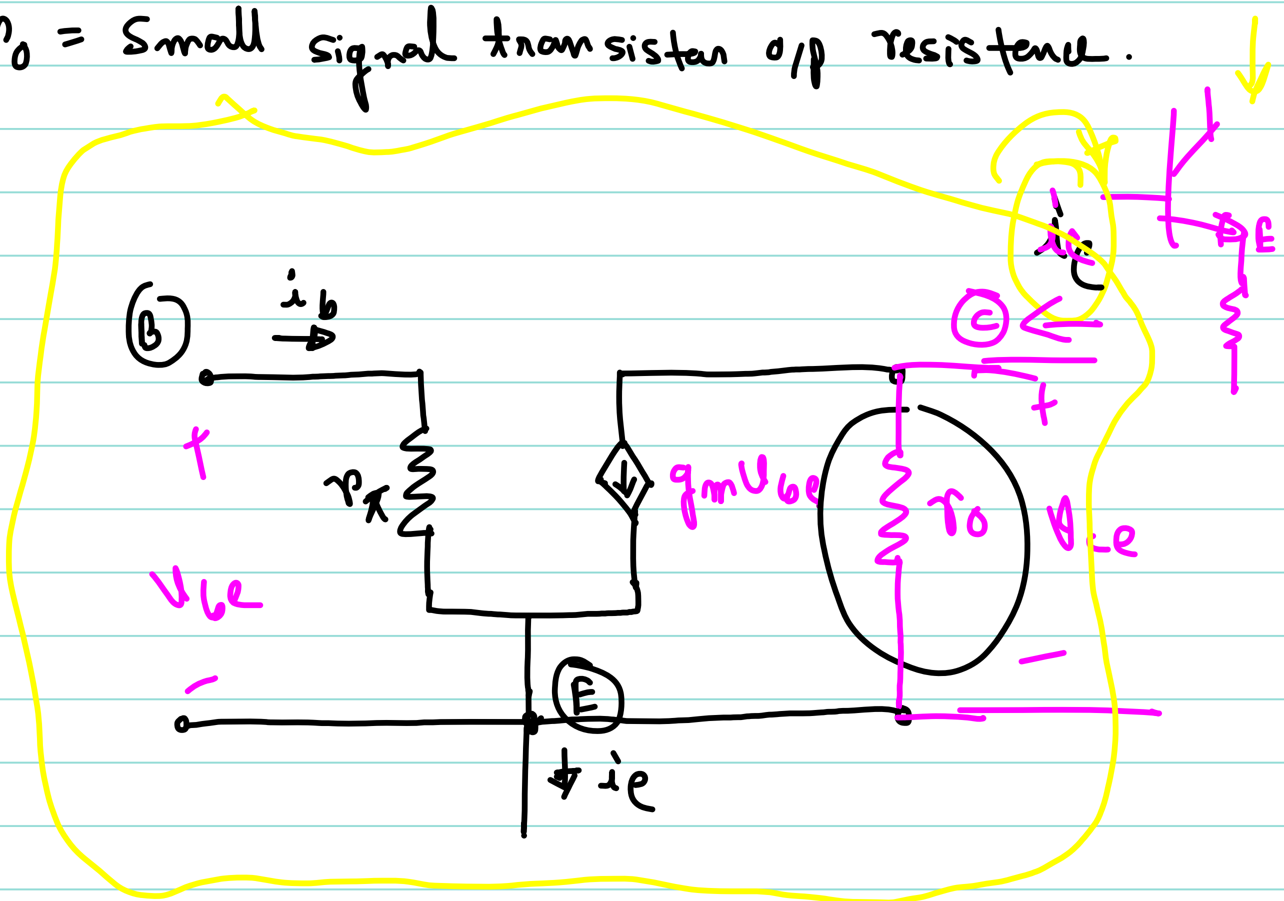
Hybrid - π equivalent circuit considering early effect



$$i_c = I_s \left[\exp\left(\frac{V_{BE}}{V_T} \right) \right] \left[1 + \frac{V_{CE}}{V_A} \right]$$

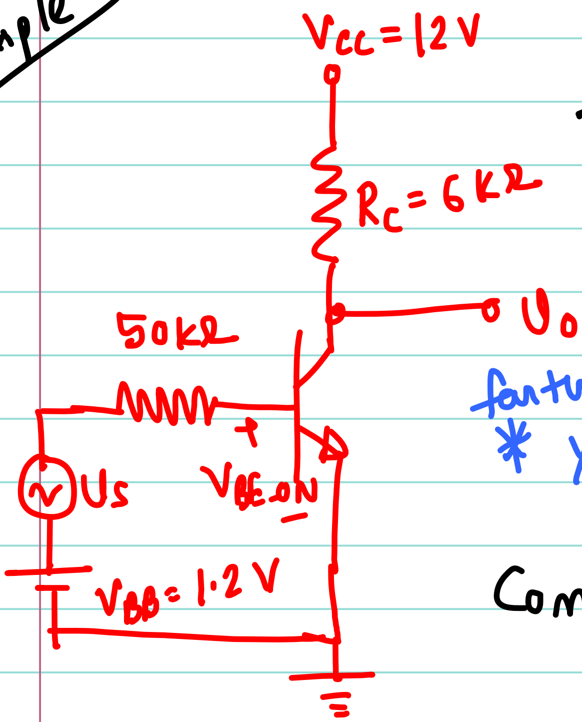
$$\frac{1}{r_0} = \frac{\partial i_c}{\partial V_{CE}} = \frac{I_{CQ}}{V_A} \; ; \; r_0 = \frac{V_A}{I_{CQ}}.$$

r_0 = Small signal transistor o/p resistence.



earlier gain = -11.4 ; without Early effect

Example



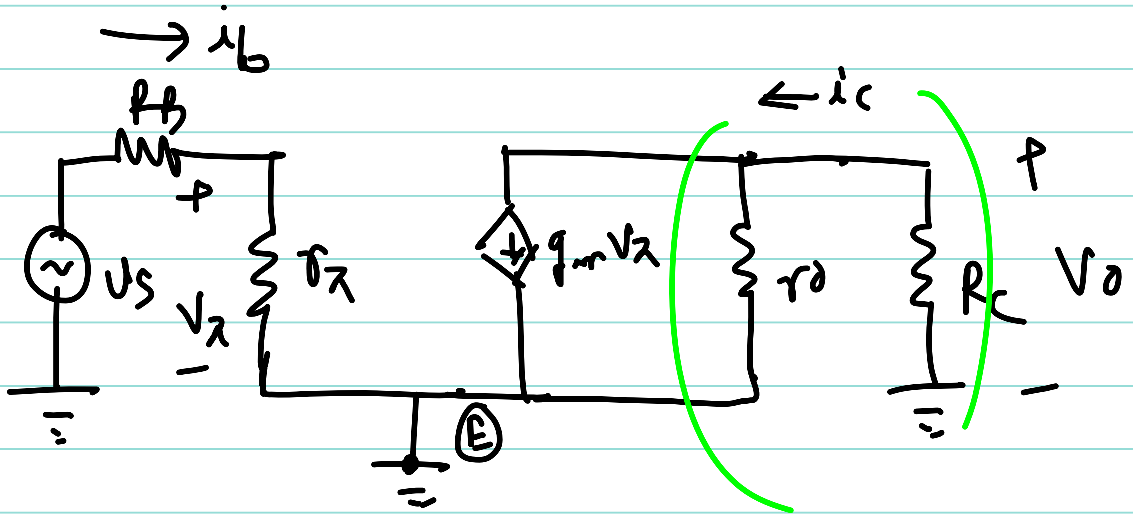
Find the Small signal gain.

Repeat this Considering Early Effect *

for this problem

* You can neglect Early effect during DC Analysis

Consider $V_A = 50\,V$.



$$V_o = -g_m V_\pi (R_C \| r_o) \; ; \quad V_\pi = V_s \times \frac{r_\pi}{r_\pi + R_B}$$

$$\text{gain} = \frac{V_o}{V_s} = -g_m \left(\frac{r_\pi}{r_\pi + R_B}\right)(R_C \| r_o)$$

gain. $= -10.18$

Equivalent circuit for p-n-p BJT