Bipolar Junction Transistors

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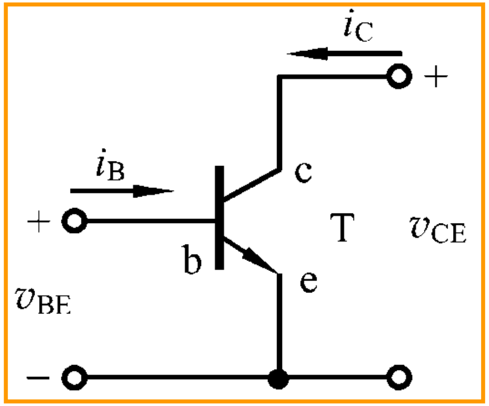
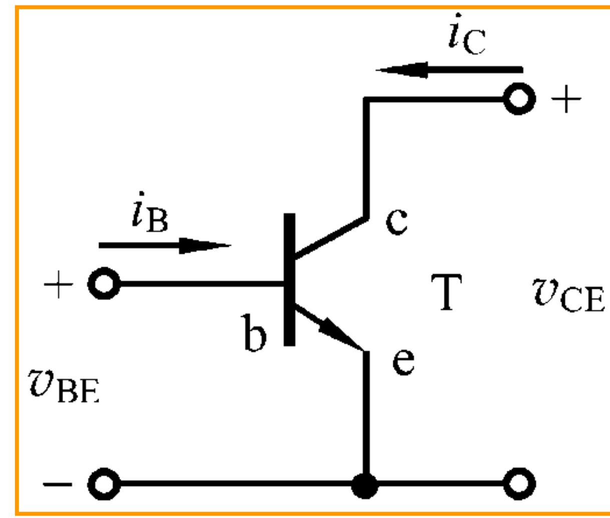
Learning objectives:

- Simple NPN transistor model
- Concept of transconductance
- Large-signal and small-signal model



$$i_C = I_S\left(e^{(\upsilon_{BE}/V_T)} - 1\right) = \frac{A_E q D_n n_i^2}{N_B W_B}\left(e^{(\upsilon_{BE}/V_T)} - 1\right)$$

$$\approx \frac{A_E q D_n n_i^2}{N_B W_B} e^{(\upsilon_{BE}/V_T)}$$



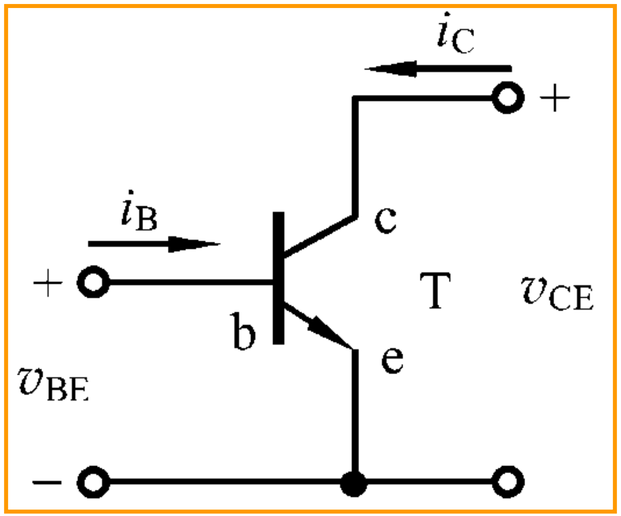
$$i_B = \left(\frac{A_E q D_p n_i^2}{N_D L_p} + \frac{A_E q W n_i^2}{2\tau_b N_A}\right)\left(e^{\left(\upsilon_{BE}/V_T\right)} - 1\right)$$

$$\approx \left(\frac{A_E q D_p n_i^2}{N_D L_p} + \frac{A_E q W n_i^2}{2\tau_b N_A}\right) e^{\left(\upsilon_{BE}/V_T\right)}$$

Current gain $\boxed{\beta = \frac{i_C}{i_B}}$

$$i_B = \frac{i_C}{\beta} = \frac{I_S\left(e^{(\upsilon_{BE}/V_T)} - 1\right)}{\beta} = \left(\frac{I_S}{\beta}\right)\left(e^{(\upsilon_{BE}/V_T)} - 1\right)$$

According to KCL:

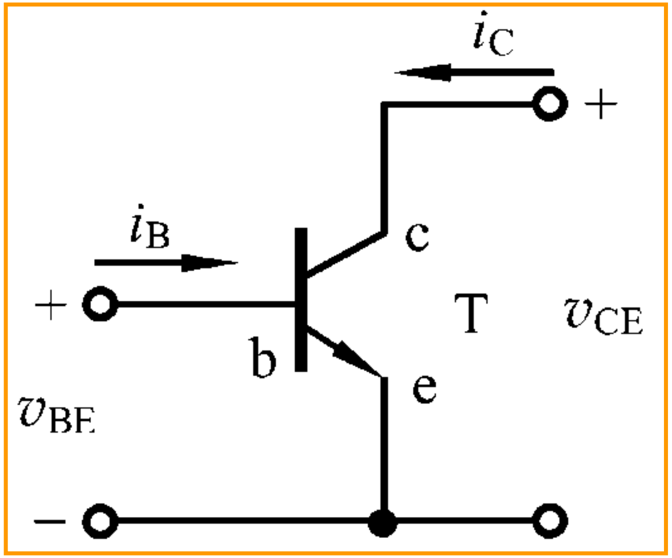


$$i_E = i_B + i_C = \frac{i_C}{\beta} + i_C$$

$$= \frac{\beta + 1}{\beta} i_C$$

$$= \frac{\beta + 1}{\beta} I_S \left(e^{(\upsilon_{BE}/V_T)} - 1 \right)$$

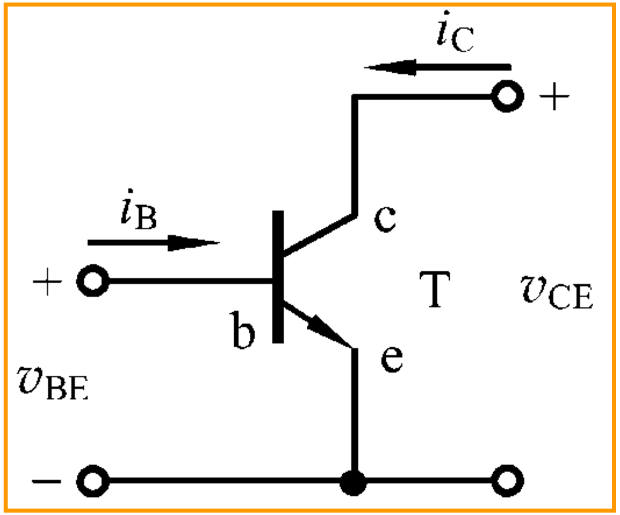
$$\alpha = \frac{i_C}{i_E} \quad \Rightarrow \quad \alpha = \frac{\beta}{\beta + 1} \quad \text{or} \quad \beta = \frac{\alpha}{1 - \alpha}$$

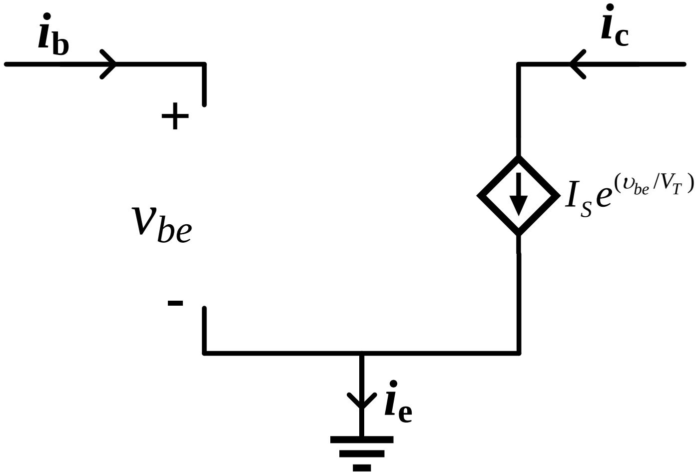


Can we simplify this circuit model?

Simple bipolar transistor model

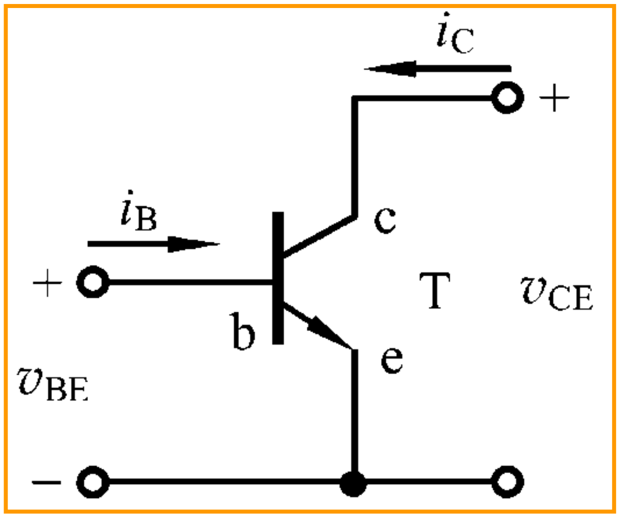
$$i_c = I_S\left(e^{(\upsilon_{be}/V_T)} - 1\right) \approx I_S e^{(\upsilon_{be}/V_T)}$$



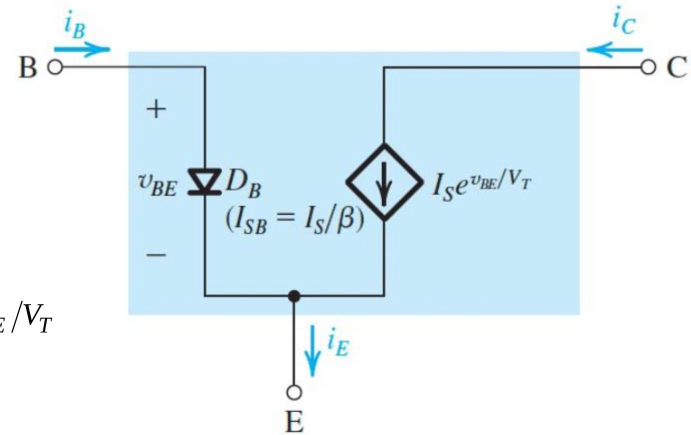


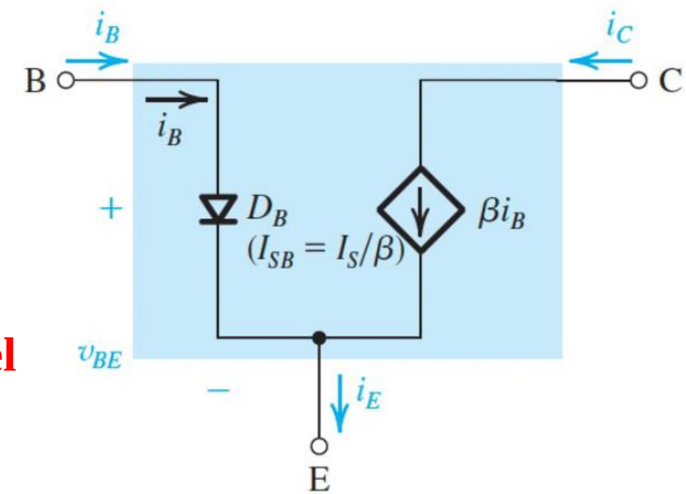
Voltage controlled current source

Simple bipolar transistor model



$$i_B = \frac{i_C}{\beta} = \frac{i_S}{\beta} e^{\upsilon_{BE}/V_T}$$





Application of a simple bipolar transistor model

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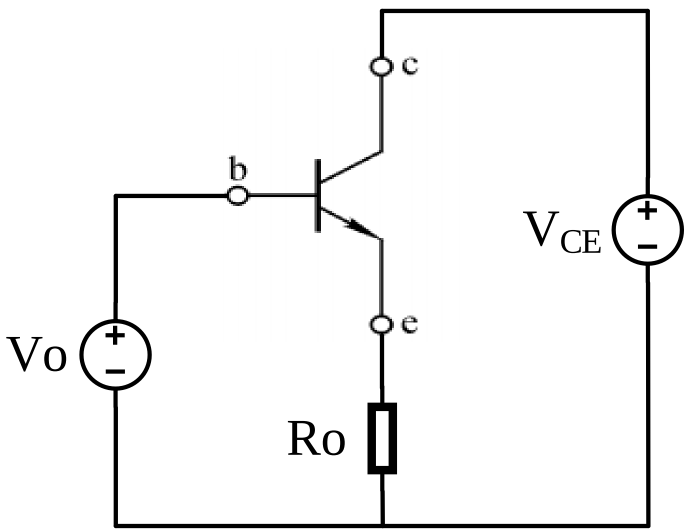
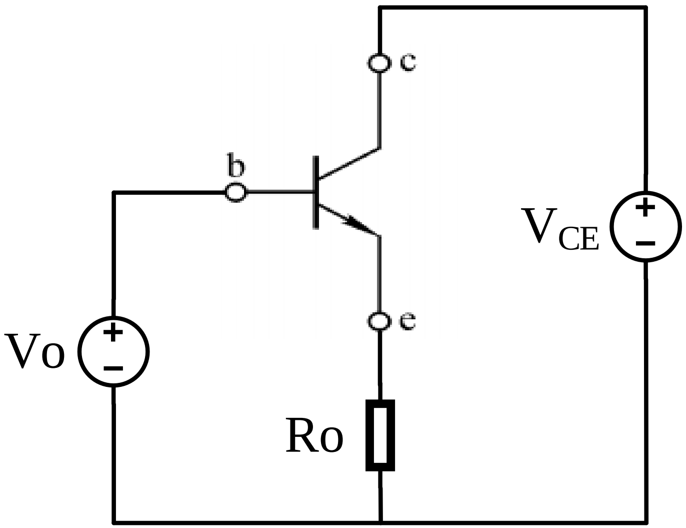


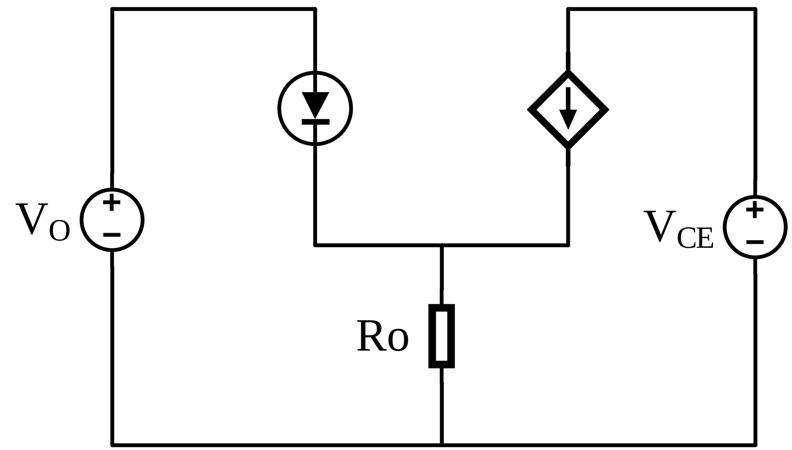
Calculate i_c ?

Vo = 5V, V_{CE} = 12V, Ro = 100 Ω

$$I_S = 5 \times 10^{-16} A$$

Application of a simple bipolar transistor model



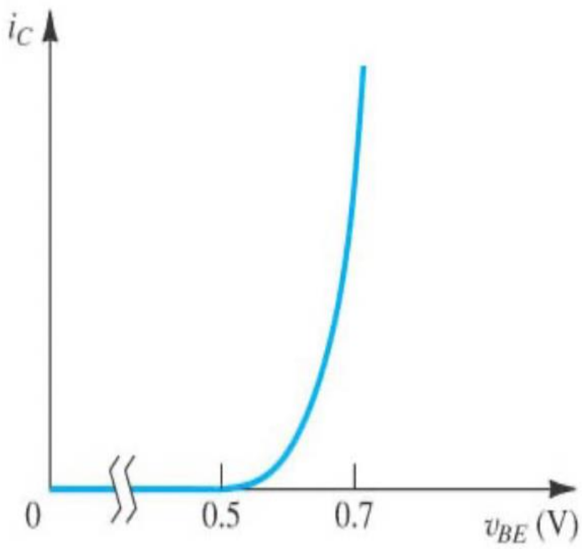


Vo = 5V, V_{CE} = 12V, Ro = 100 Ω

$$I_S = 5 \times 10^{-16} A$$

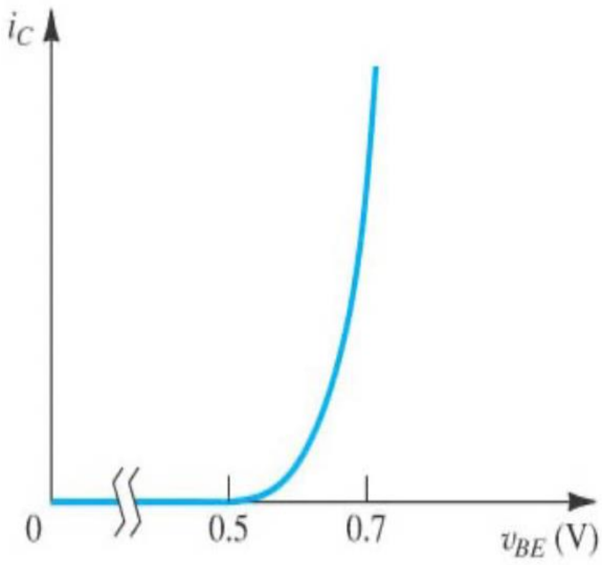
$$V_o = V_{BE} + R_o \cdot I_E \approx V_T \ln \frac{I_C}{I_S} + R_o \cdot I_C$$

Concept of transconductance:



When v_{BE} has a fluctuation, how will it affect i_C?

Concept of transconductance:



$$g_m = \frac{\Delta i_c}{\Delta \upsilon_{BE}} = \frac{di_c}{d\upsilon_{BE}}$$

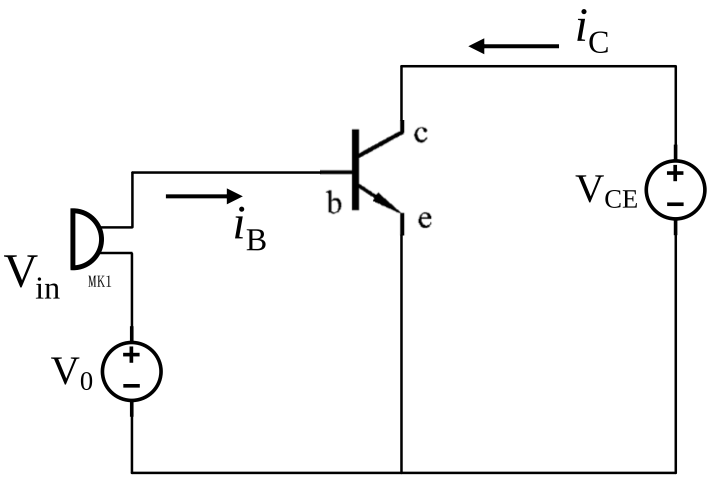
$$i_c = I_S e^{\upsilon_{BE}/V_T}$$

$$g_m = \frac{d}{d\upsilon_{BE}}\left(I_S e^{\upsilon_{BE}/V_T}\right) = \frac{I_S}{V_T} e^{\upsilon_{BE}/V_T} = \frac{i_c}{V_T}$$

Large-signal and small-signal model:

Large-signal: the signal is arbitrarily large

Small-signal: the signal perturbs the bias point by only a small amount (small compared to V_T)



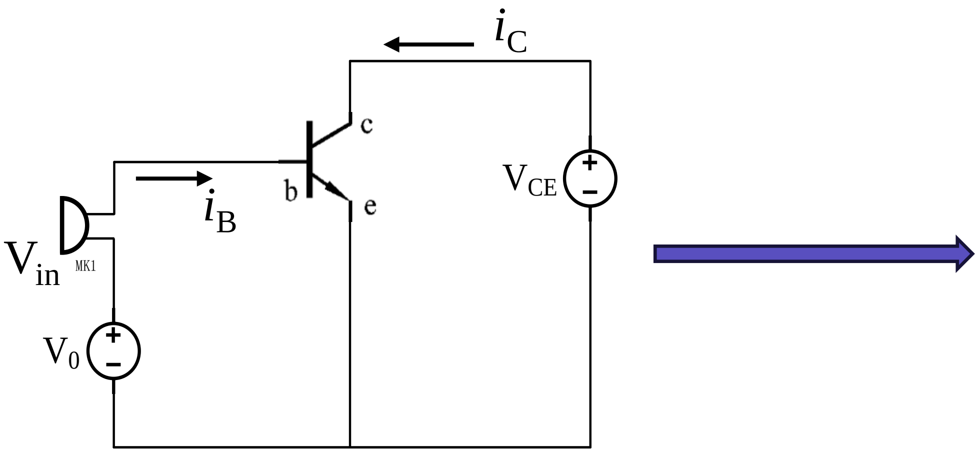
$$V_{in} = V_m \sin \omega t$$

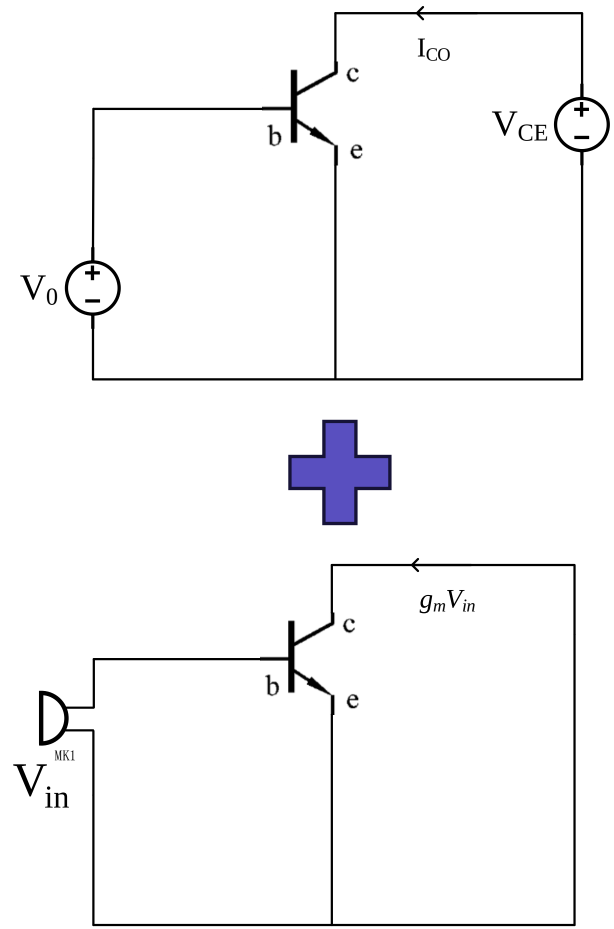
$$i_C = I_S e^{(\frac{V_0 + V_{in}}{V_T})} = I_S e^{(\frac{V_0}{V_T})} \cdot e^{(\frac{V_m \sin \omega t}{V_T})}$$

$$= I_{CO} \cdot e^{(\frac{V_m \sin \omega t}{V_T})} \boxed{\approx} I_{CO} \cdot (1 + \frac{V_m \sin \omega t}{V_T})$$

$$= I_{CO} + \frac{I_{CO}}{V_T} V_m \sin \omega t$$

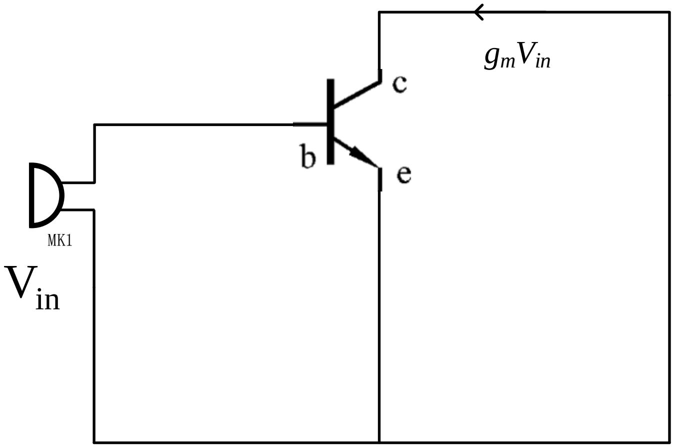
$$= I_{CO} + g_m V_m \sin \omega t$$

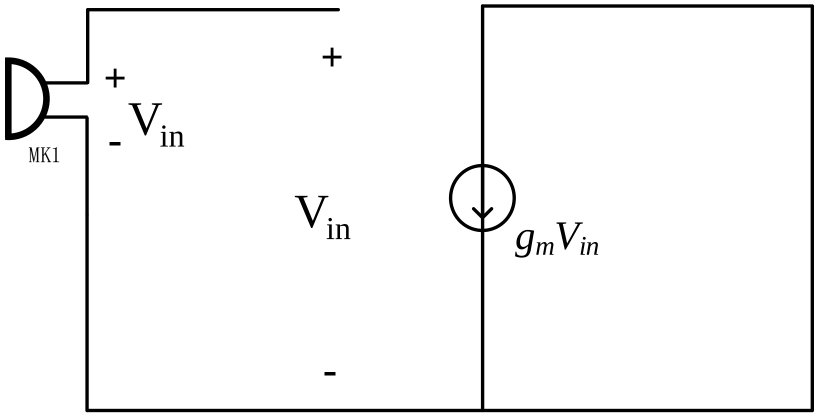


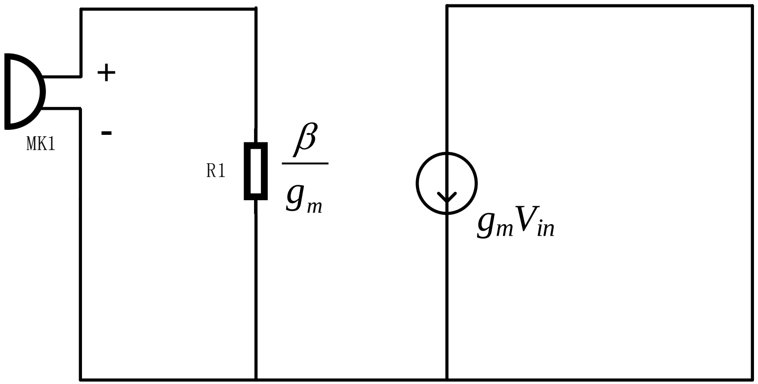


In small-signal model:

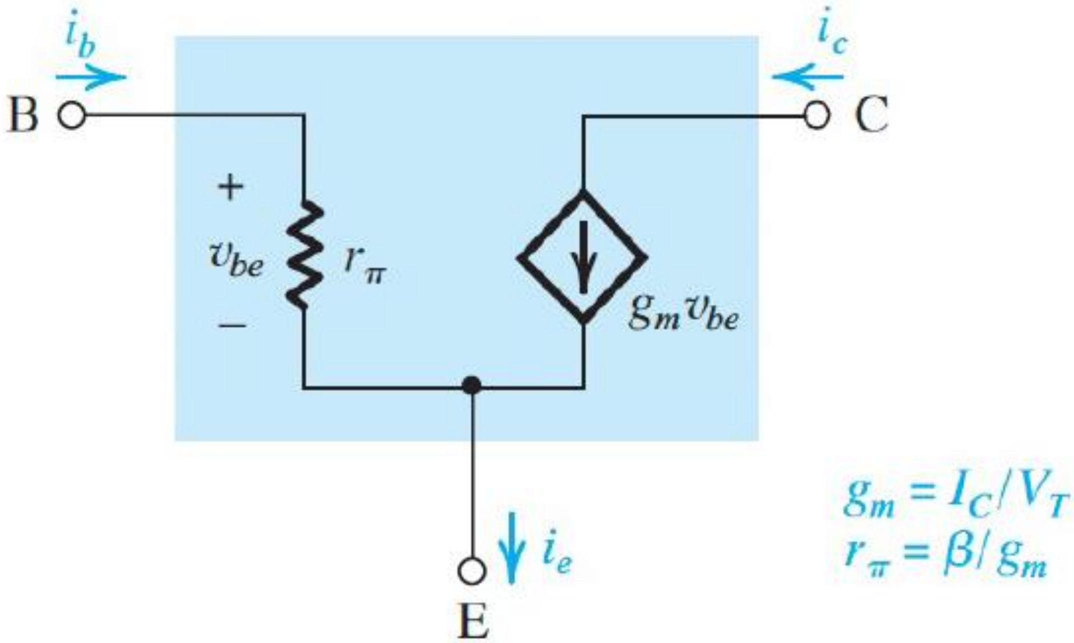
DC sources are short.

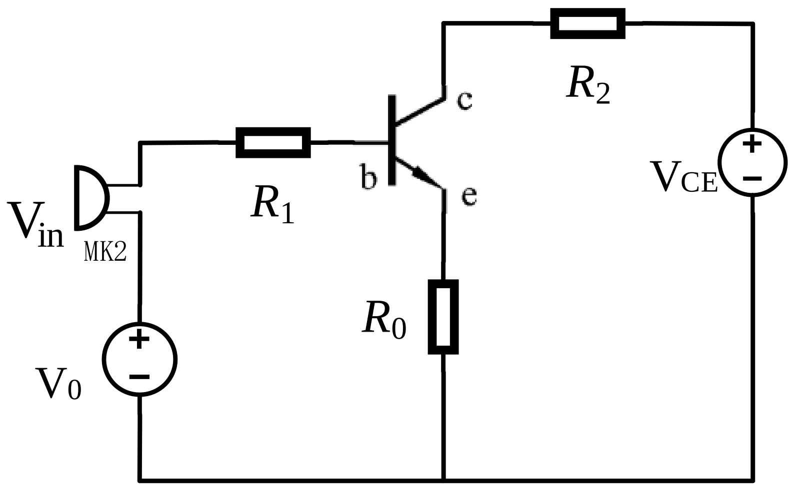






$$i_B = \frac{i_C}{\beta} = \frac{i_{CO}}{\beta} + \frac{g_m V_{in}}{\beta}$$


i_b
B
i_c
C
+
v_{be}
r_π
−
$g_m v_{be}$
i_e
E
$g_m = I_C / V_T$
$r_\pi = \beta / g_m$



Draw the large-signal and small-signal models?

Thanks