EE210: Microelectronics-I

Lecture-11 : Bipolar Junction Transistor-4

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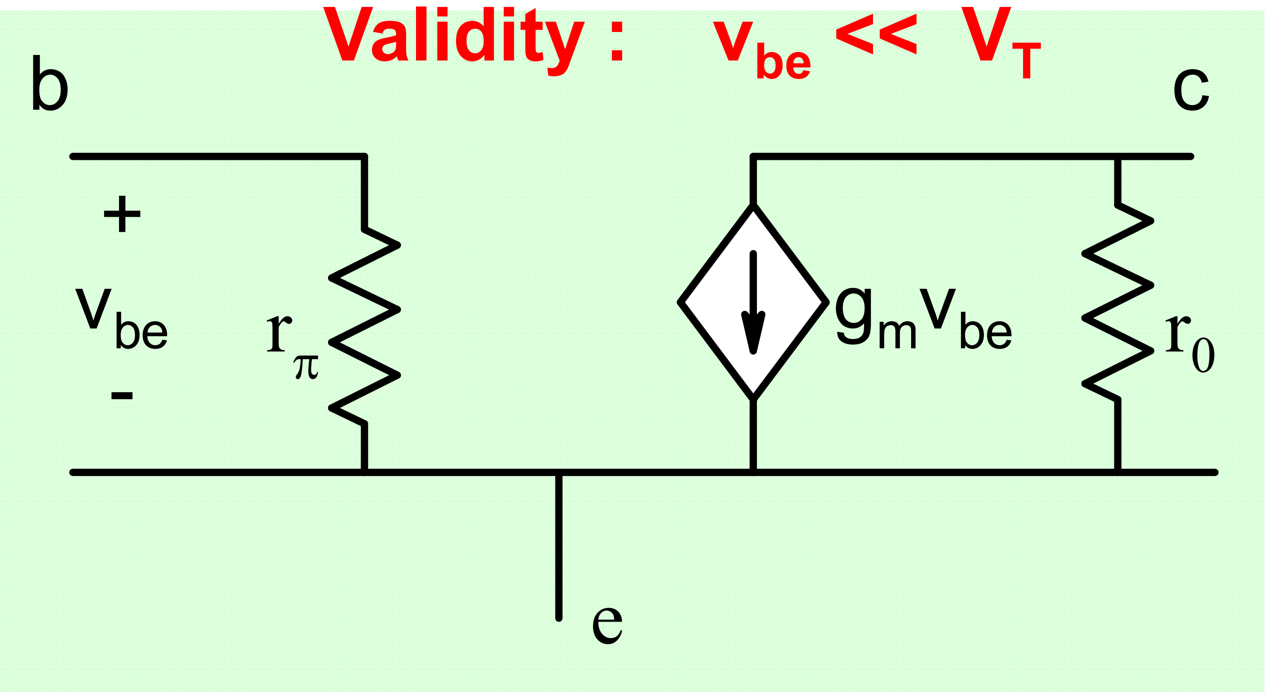
Hybrid-pi Small Signal Model : low frequency

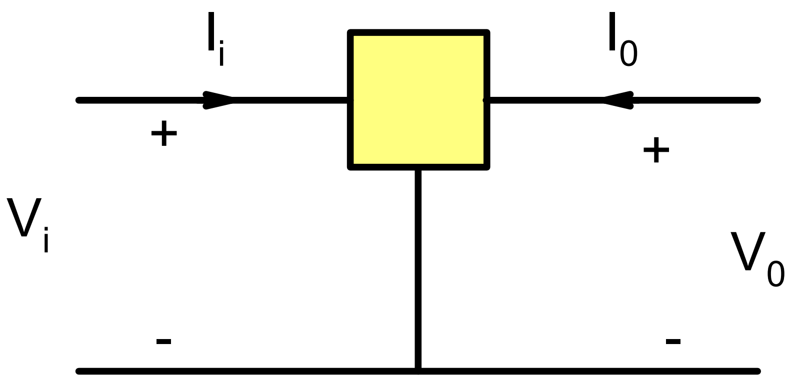


$$r_\pi = \frac{V_T}{I_B} = \frac{V_T}{I_C} \cdot \beta$$

$$g_m = \frac{I_C}{V_T} \; ; \; r_0 = \frac{V_A}{I_C}$$

$$I_b = \frac{I_S}{\beta_F}\left(\exp\left(\frac{V_{be}}{V_T}\right) - 1\right) \qquad I_c = I_S\left(\exp\left(\frac{V_{be}}{V_T}\right) - 1\right) \times \left(1 + \frac{V_{ce}}{V_A}\right)$$

Device is not strictly unilateral



$$I_i = f(V_i, V_o)$$

$$\Delta I_i = \left.\frac{\partial f}{\partial V_i}\right| \times \Delta V_i + \left.\frac{\partial f}{\partial V_o}\right| \times \Delta V_o$$

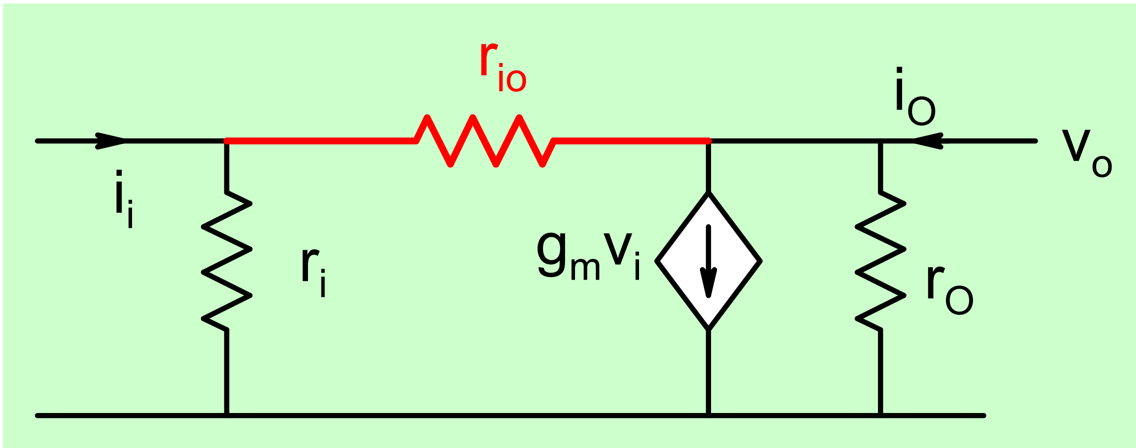
-ve

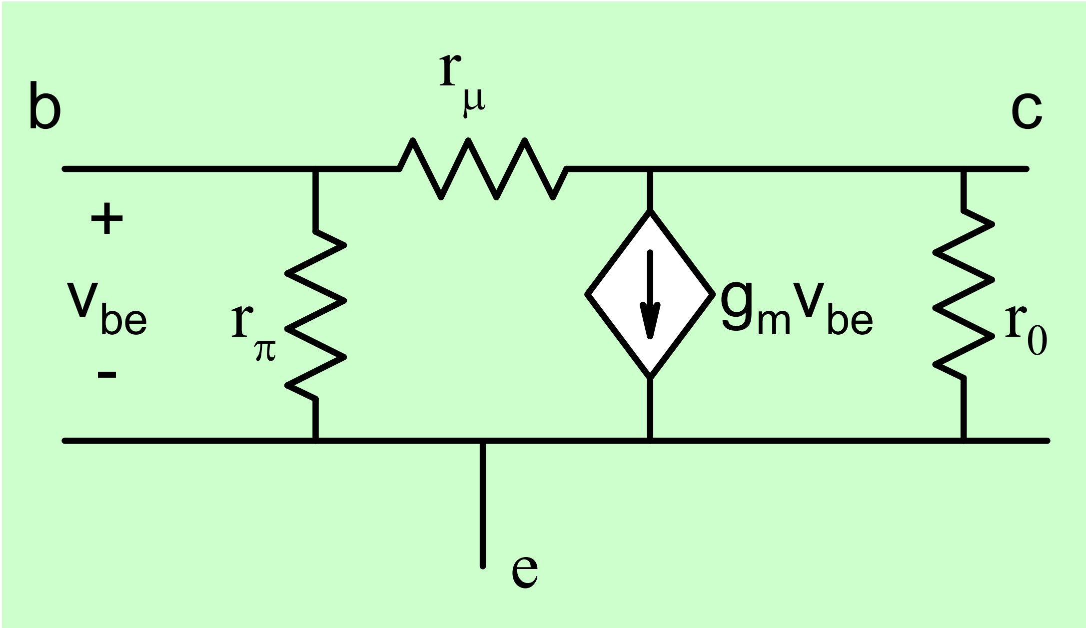
$$i_i = \frac{v_i}{r_i} - \frac{v_o}{r_{io}}$$

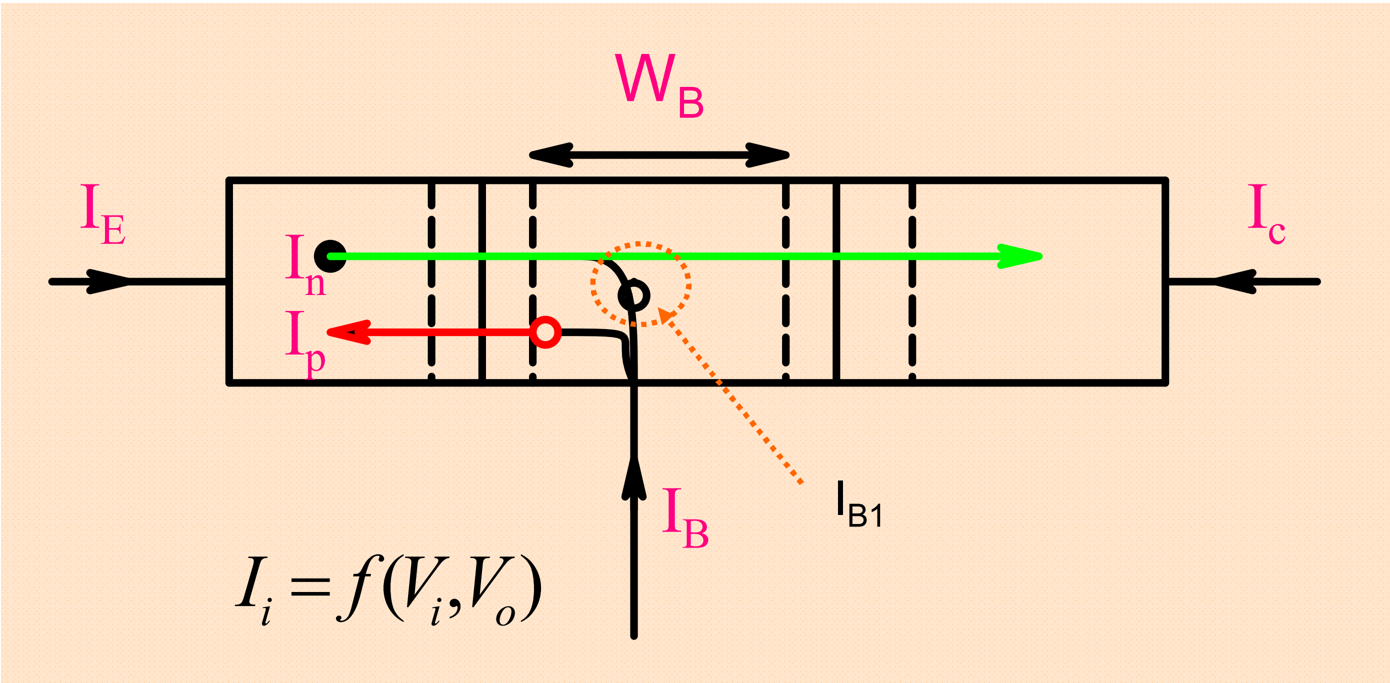
$$i_i = \left(\frac{v_i}{r_i} - \frac{v_i}{r_{io}}\right) + \frac{v_i - v_o}{r_{io}}$$

$$r_{io} >> r_i$$

100+1~100
100-99+1 =2







$I_B = I_P + I_{B1}$

$I_{B1} \alpha W_B$

$I_{B1} = f_1(V_{CB})$

Capacitances and High Frequency Model

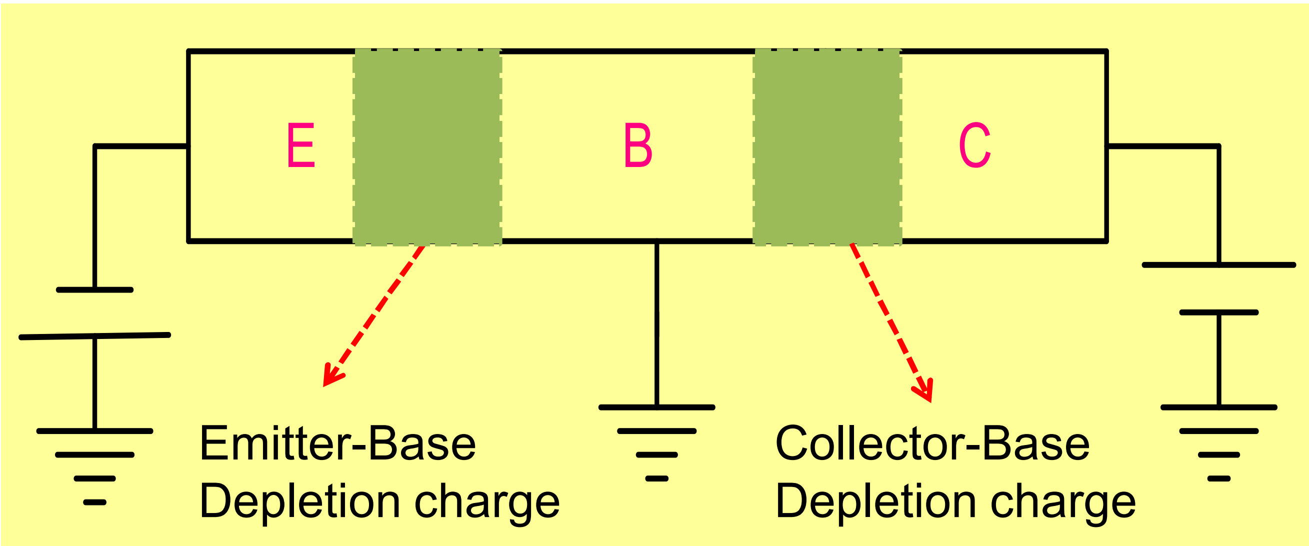
Capacitances in a BJT

Anytime we have a charge which changes with voltage, we have a capacitance

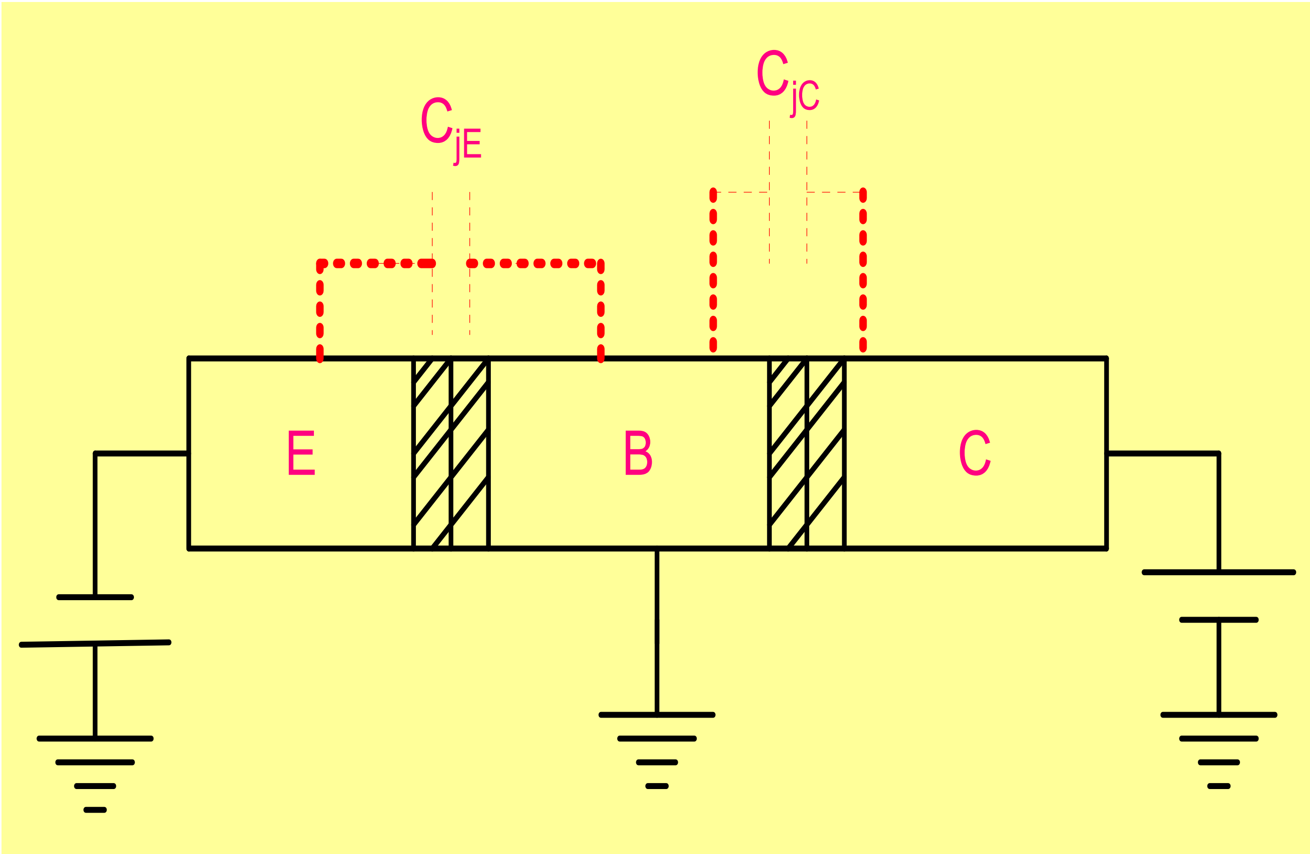
$$C = \frac{\partial Q}{\partial V}$$

There are two kinds of charges:

1. Depletion charge
2. Diffusion charge



Change in emitter-base depletion charge with base-emitter voltage gives rise to base-emitter junction capacitance. Similarly, change in collector-base depletion charge with base-collector voltage gives rise to base-collector junction capacitance

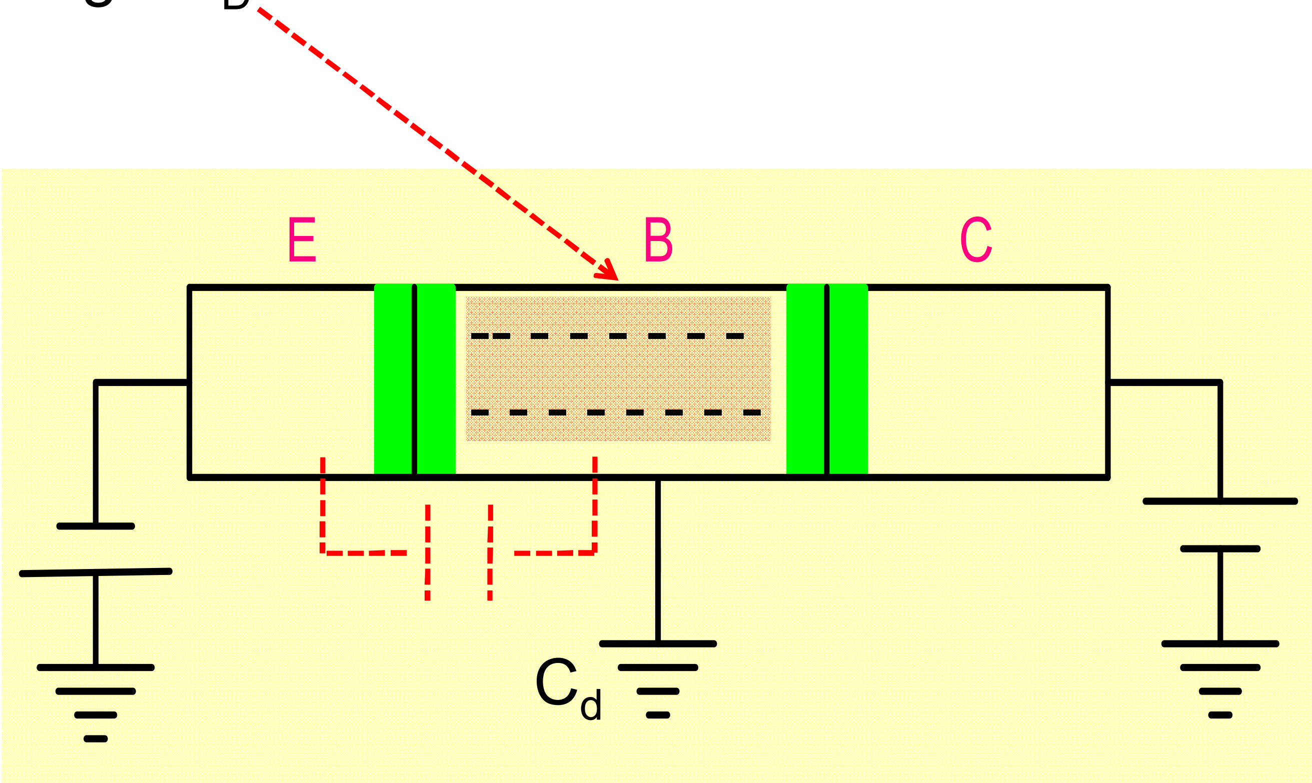


$$C_{je} = \frac{C_{jeo}}{(1 - \frac{V_{BE}}{V_{bi}})^m}$$

$$C_{jc} = \frac{C_{jco}}{(1 - \frac{V_{BC}}{V_{bi}})^m}$$

Diffusion Charge and Capacitance

When base-emitter junction is forward biased, electrons are injected into base. These excess electrons constitute diffusion charge Q_D



$$C_d = \frac{\partial Q_d}{\partial V_{be}}$$

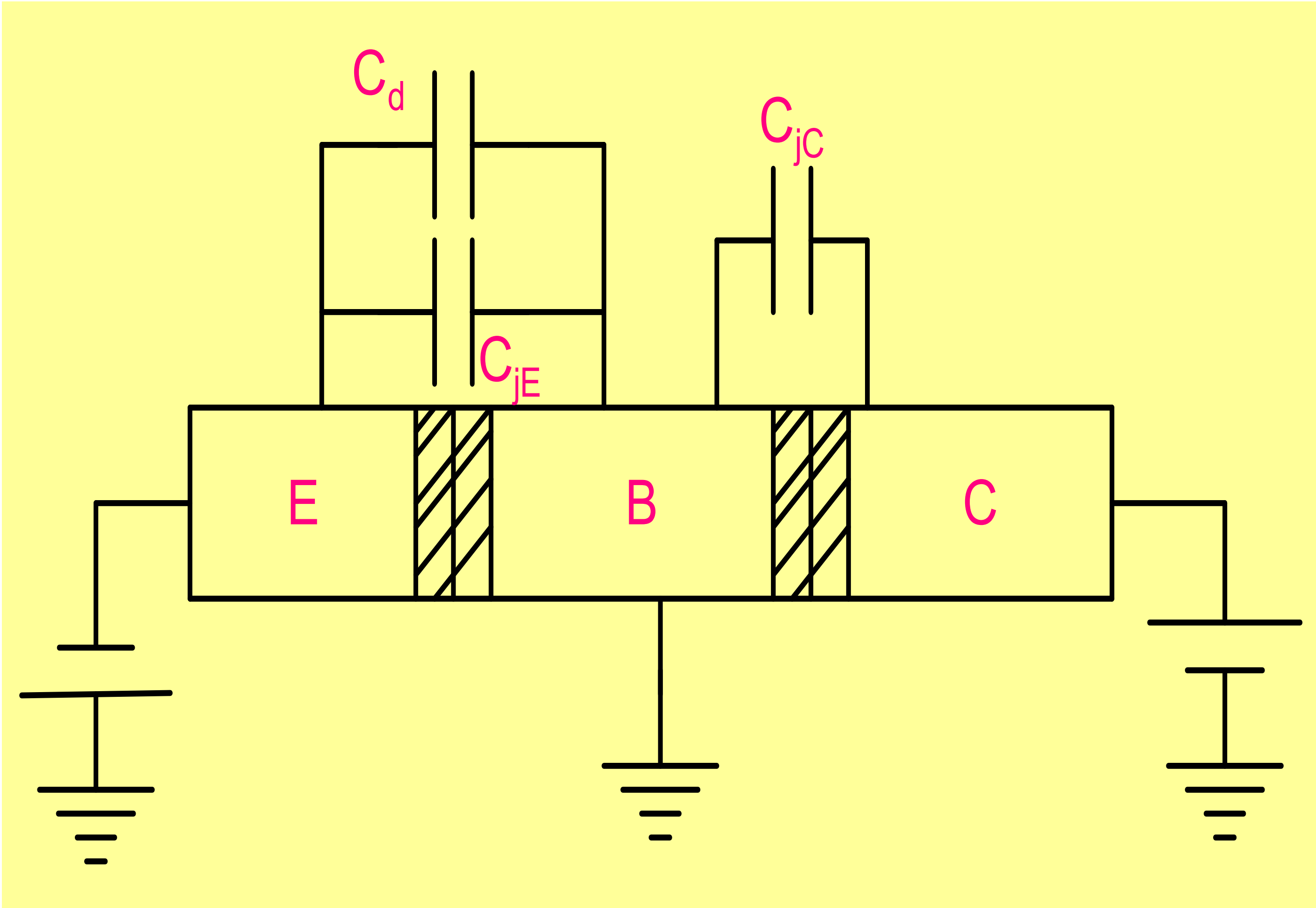
$$C_{diff} = \frac{I_C}{V_T} \times \tau_F$$

$$= g_m \times \tau_F$$

$$\tau_F = K \times \frac{W_B^2}{\mu} + \dots$$

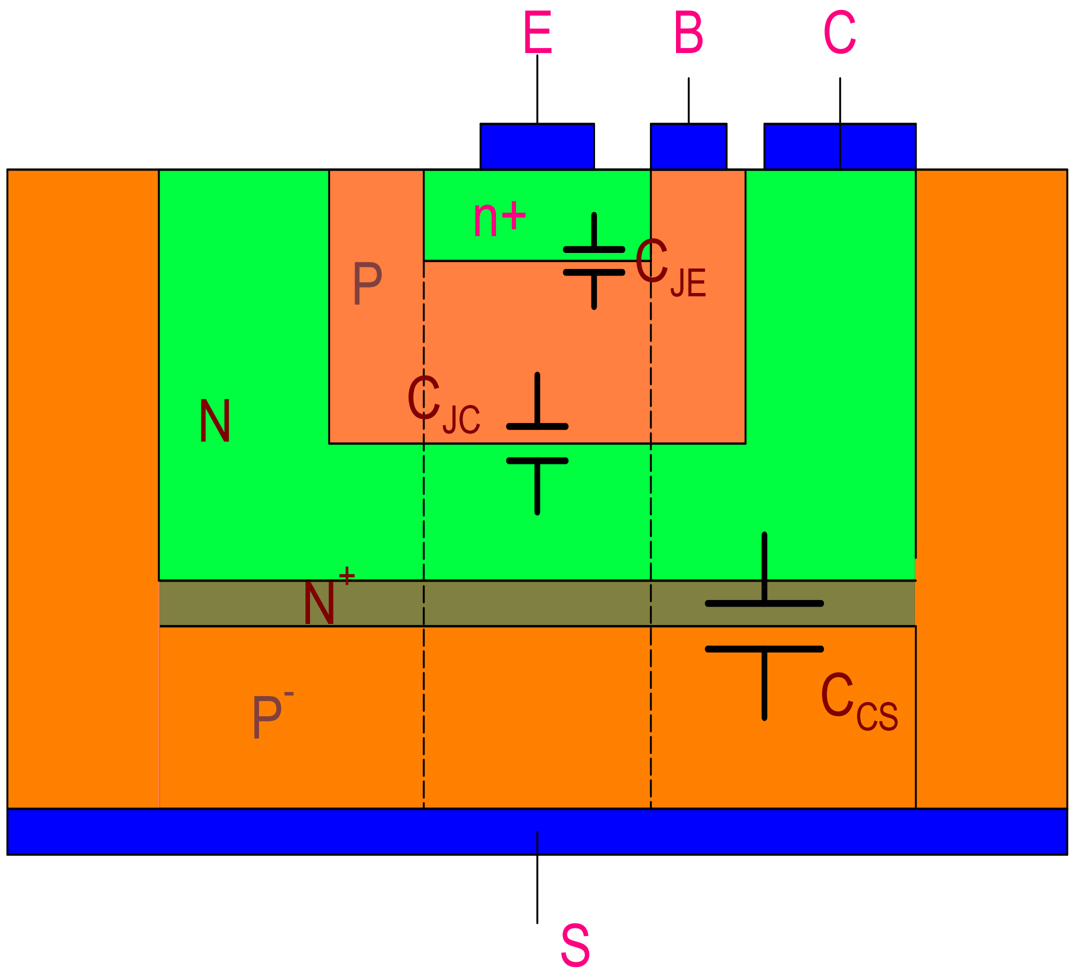
In Forward active mode, collector-base junction is reverse biased so no carriers are injected and hence there is no collector-base diffusion capacitance .

Capacitances in a BJT



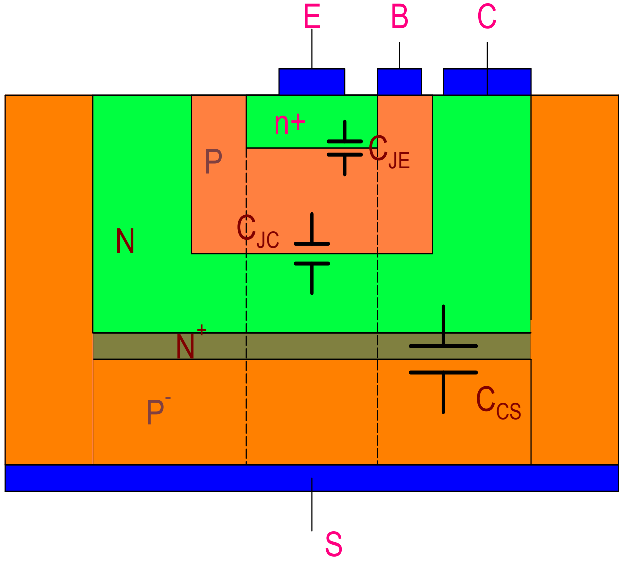
There is one more capacitance which is not observable in this one dimensional view of the transistor

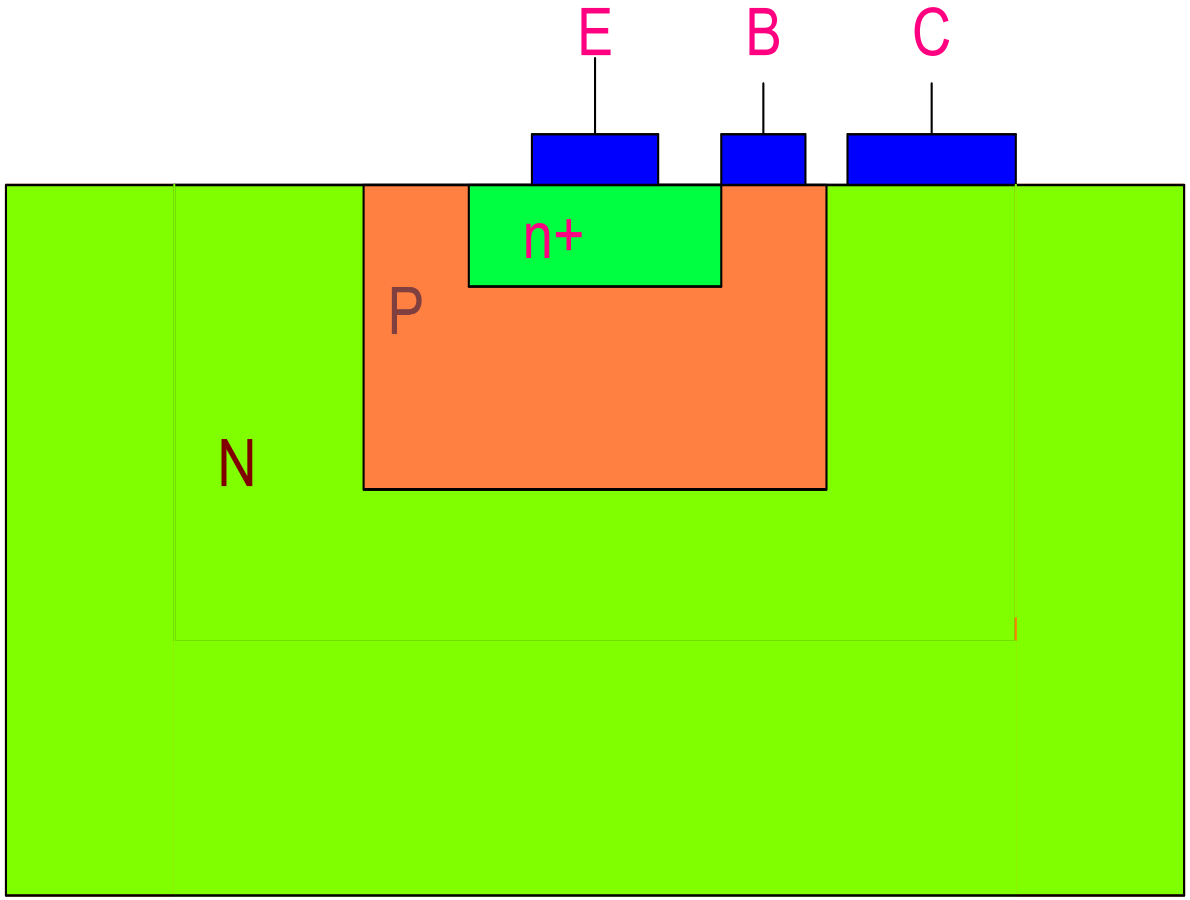
Collector Substrate Capacitance



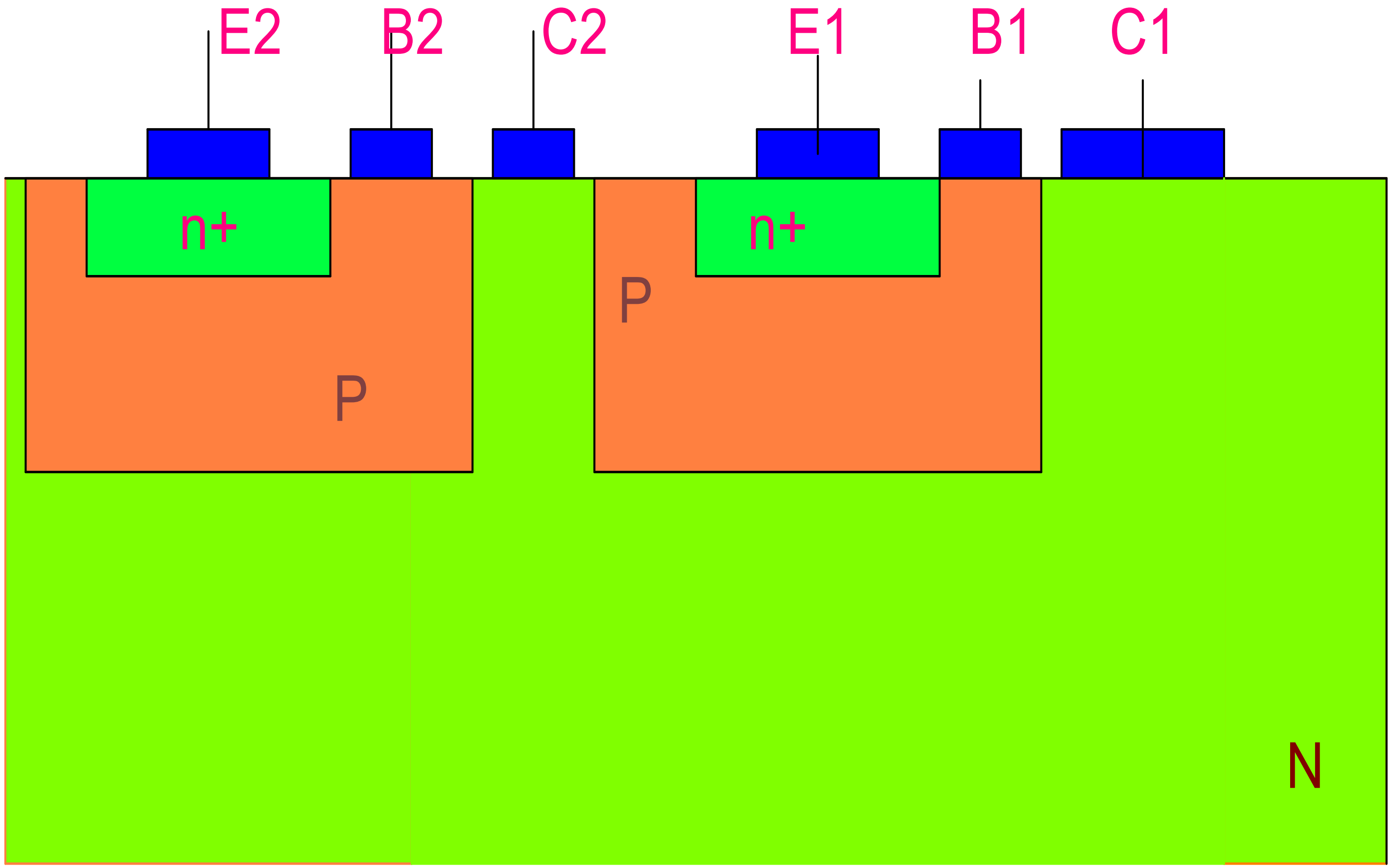
Why do we use a P substrate and not make a transistor on N-Silicon ?

Transistor on an N-substrate that serves as a Collector



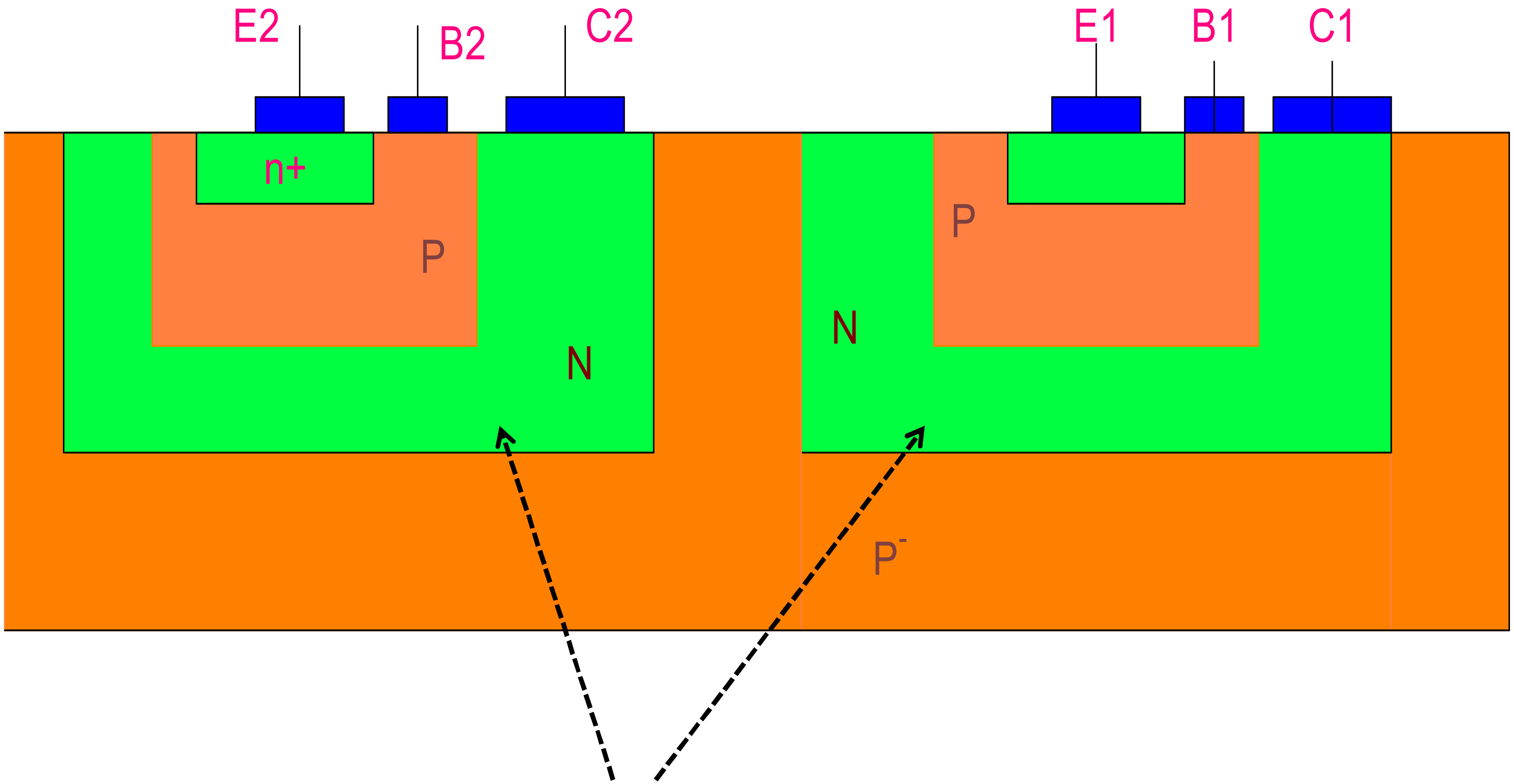


The problem is that we have to make not just one but several transistors on the same silicon substrate



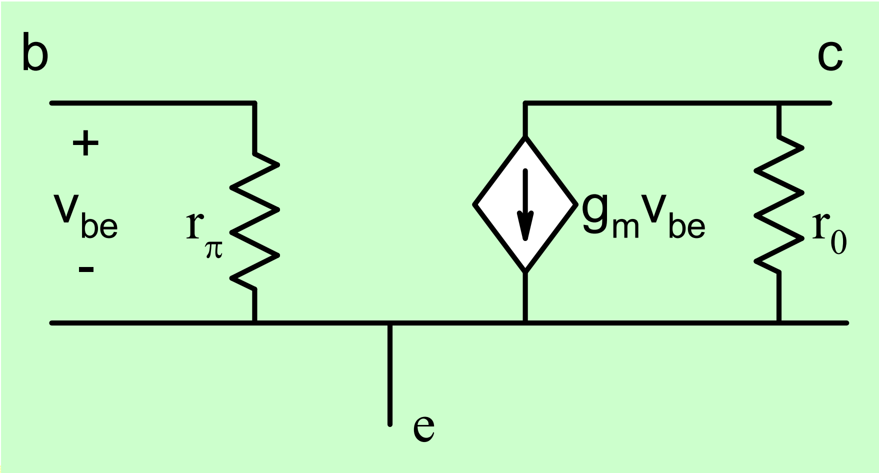
The two collectors are shorted together !

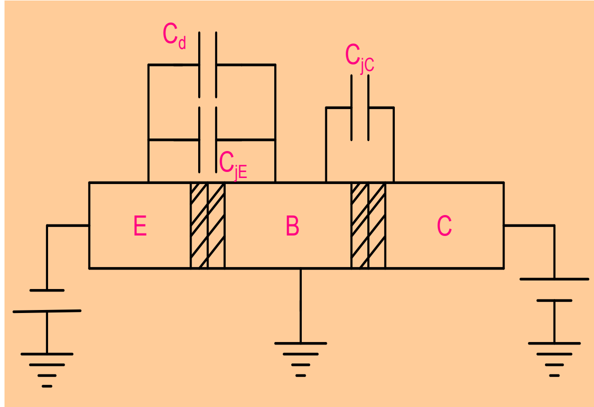
With a P-substrate, it is easy to isolate the transistors

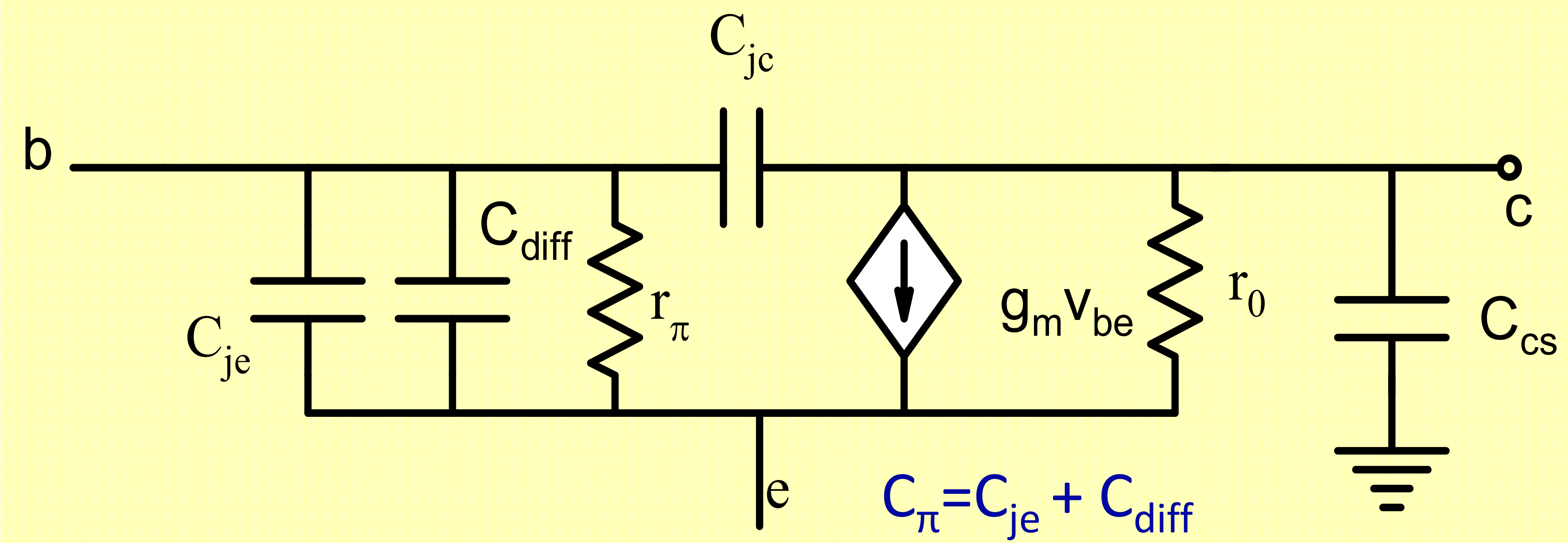


Reverse biased PN junction maintains isolation

High Frequency Hybrid-pi Model

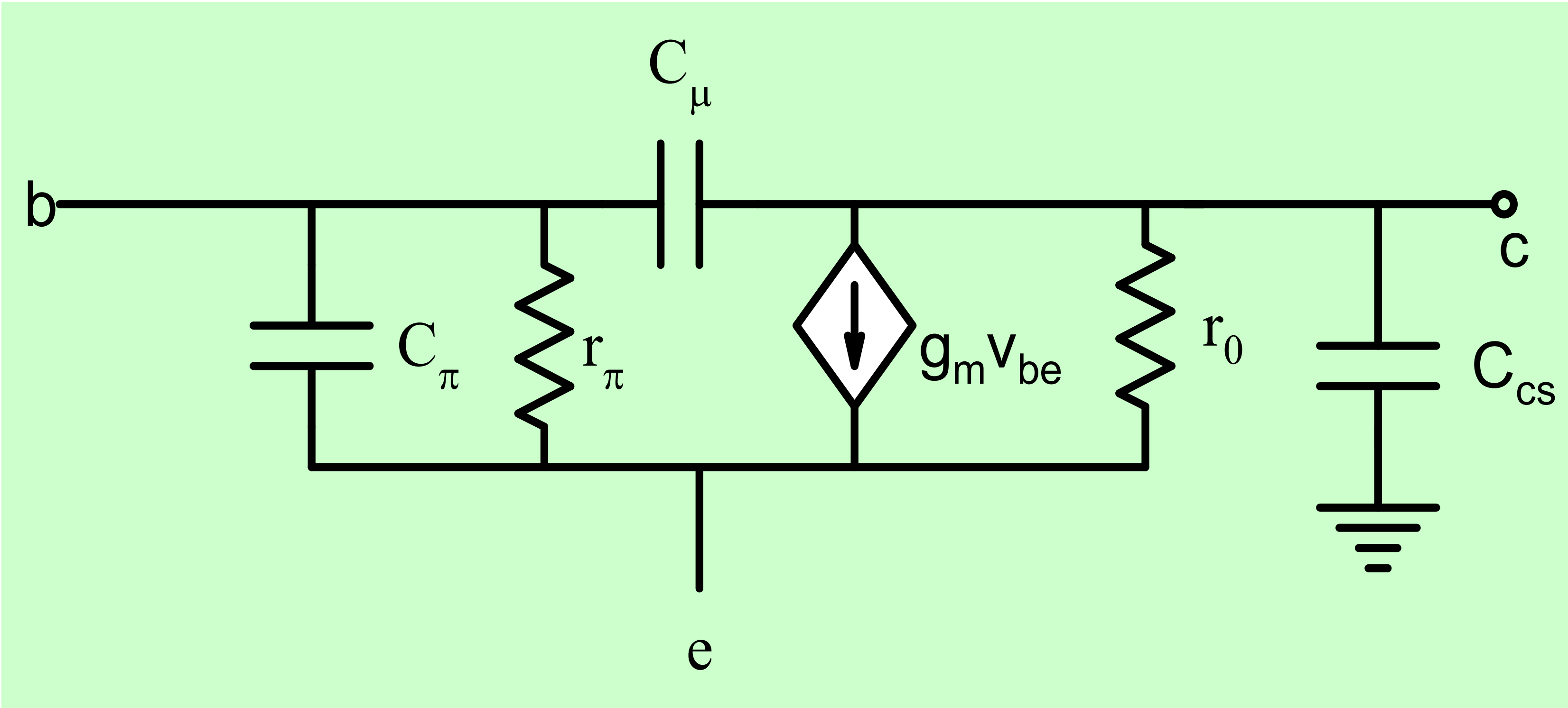






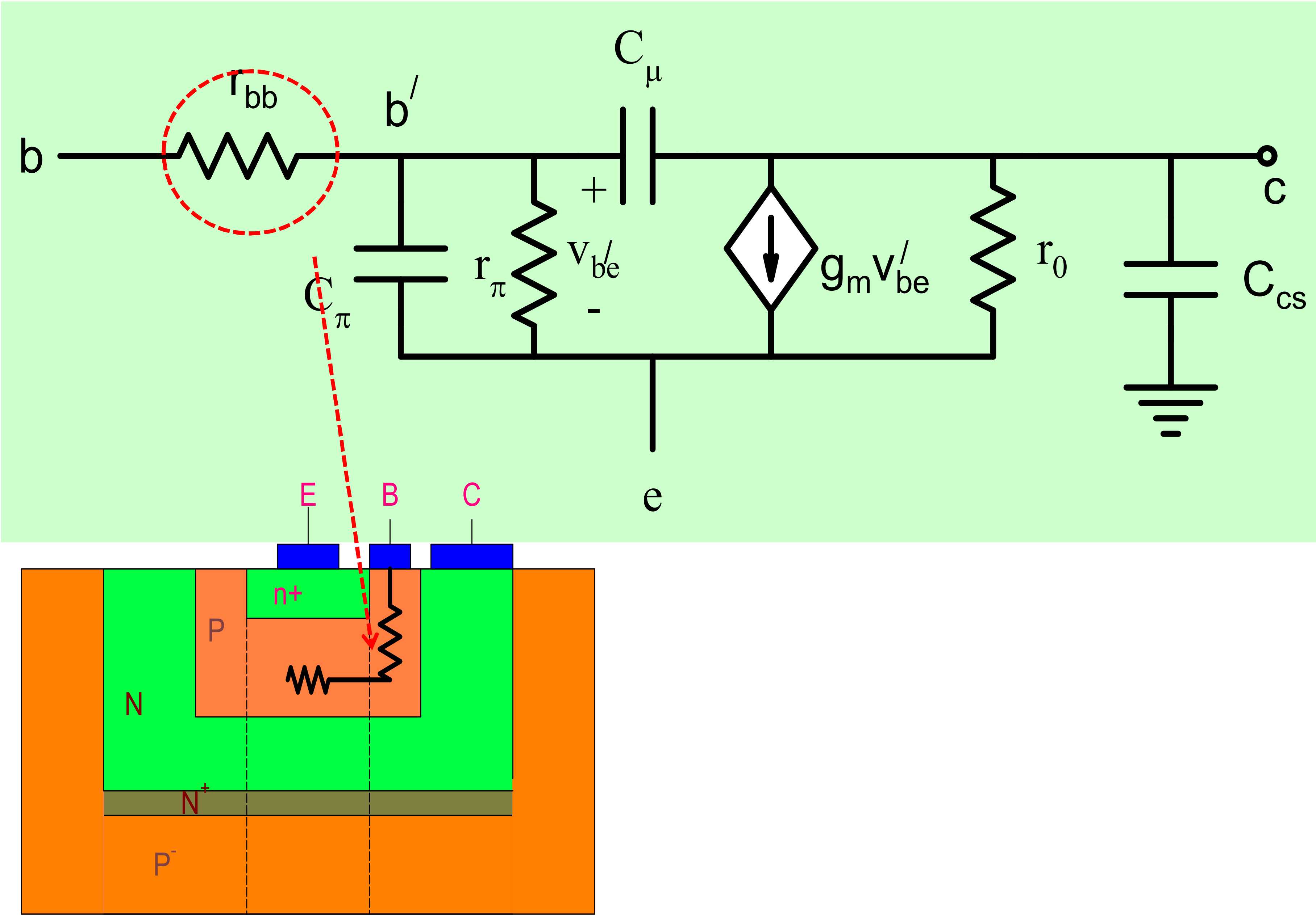
$C_\pi = C_{je} + C_{diff}$

$C_\mu = C_{jc}$



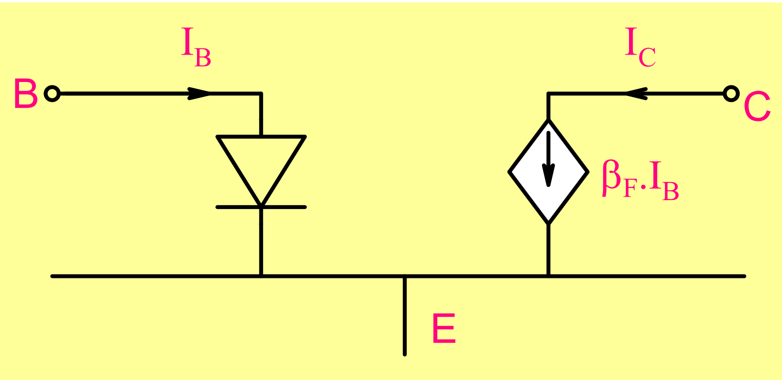
C_μ
b
c
C_π
r_π
$g_m v_{be}$
r_0
C_{cs}
e

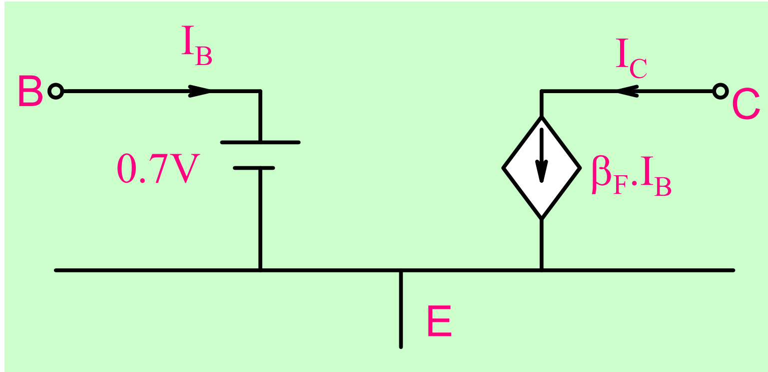
High Frequency Hybrid-pi Model



Summary

Model of an NPN BJT in forward active mode

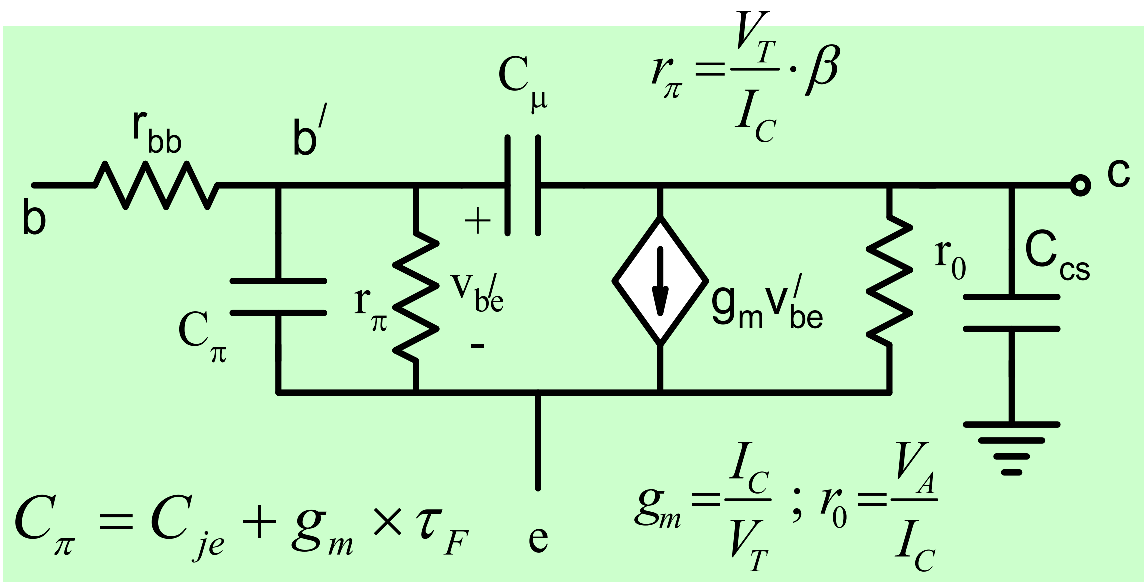




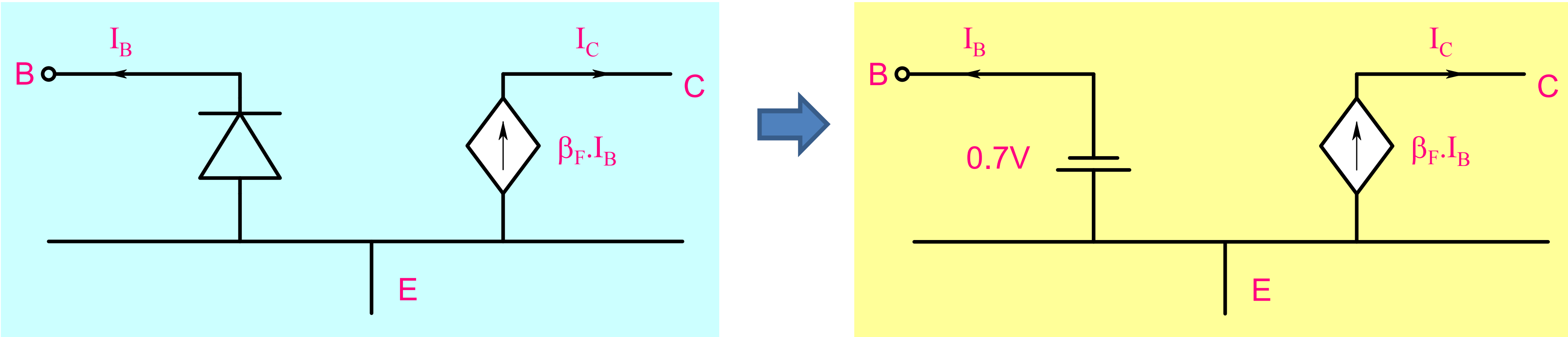
$$I_C = I_S\left(\exp(\frac{V_{BE}}{V_T}) - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$I_B = \frac{I_S\left(\exp(\frac{V_{BE}}{V_T}) - 1\right)}{\beta_F}$$

$$I_C = \beta_F\, I_B\left(1 + \frac{V_{CE}}{V_A}\right)$$



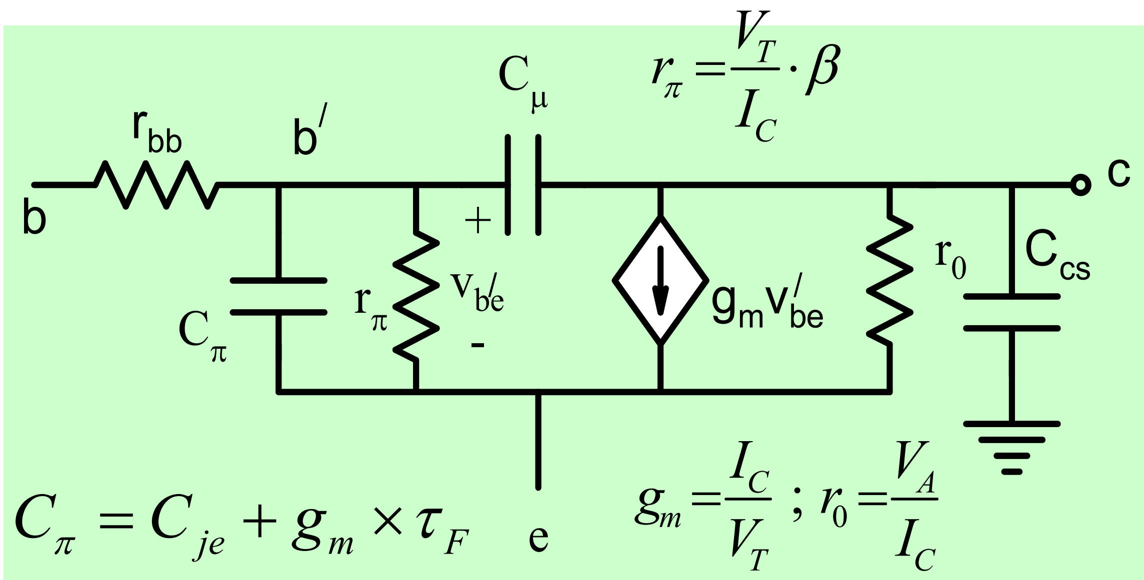
Model of an PNP BJT in forward active mode



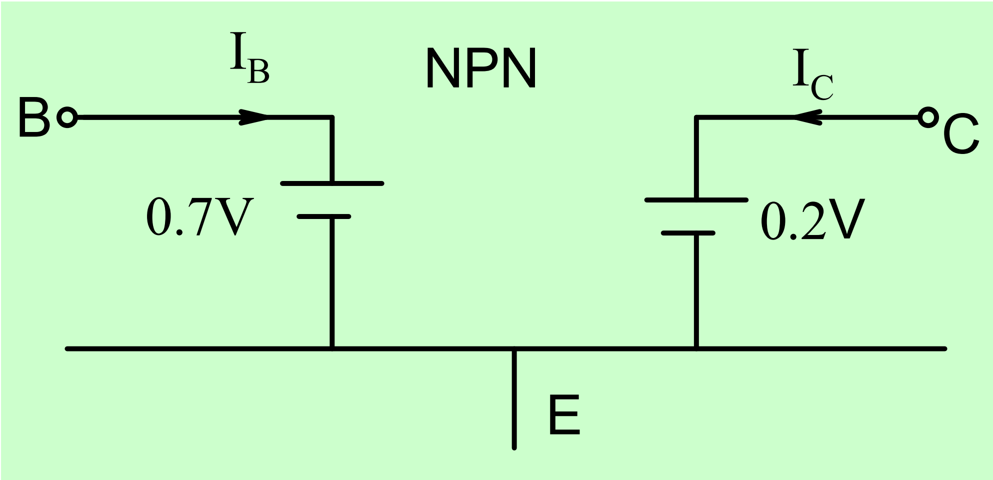
$$I_C = I_S \left(\exp\left(\frac{V_{EB}}{V_T}\right) - 1 \right) \left(1 + \frac{V_{EC}}{V_A} \right)$$

$$I_B = \frac{I_S \left(\exp\left(\frac{V_{EB}}{V_T}\right) - 1 \right)}{\beta_F}$$

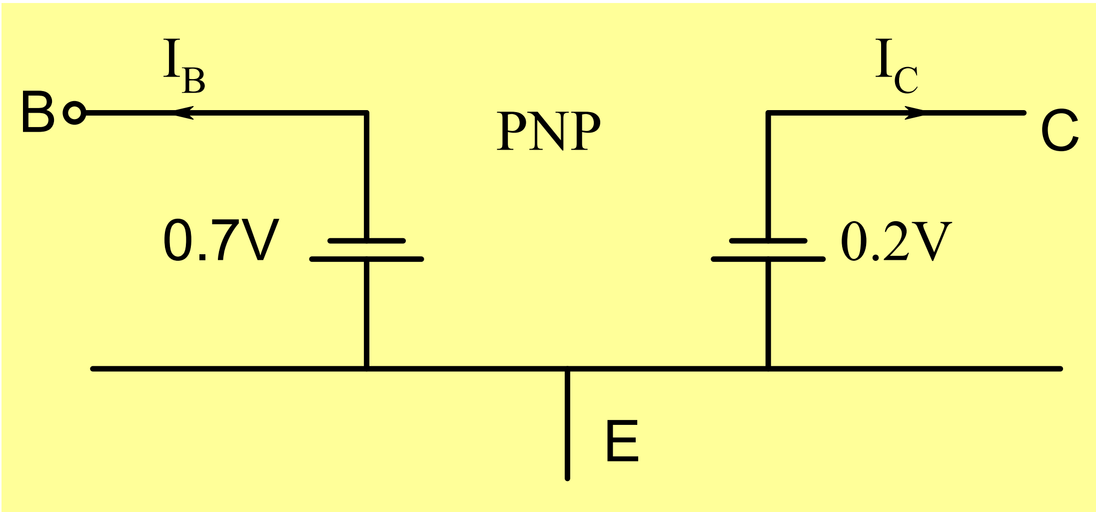
$$I_C = \beta_F \, I_B \left(1 + \frac{V_{EC}}{V_A} \right)$$



Model of a BJT in Saturation mode



$$I_C \neq \beta_F \, I_B$$



Example: BJT: NEE210A

$$I_S = 2.03\times10^{-15} A; \beta_F = 100; \beta_R = 1; V_A = 100; r_{bb} = 200\Omega; V_T = 26mV$$

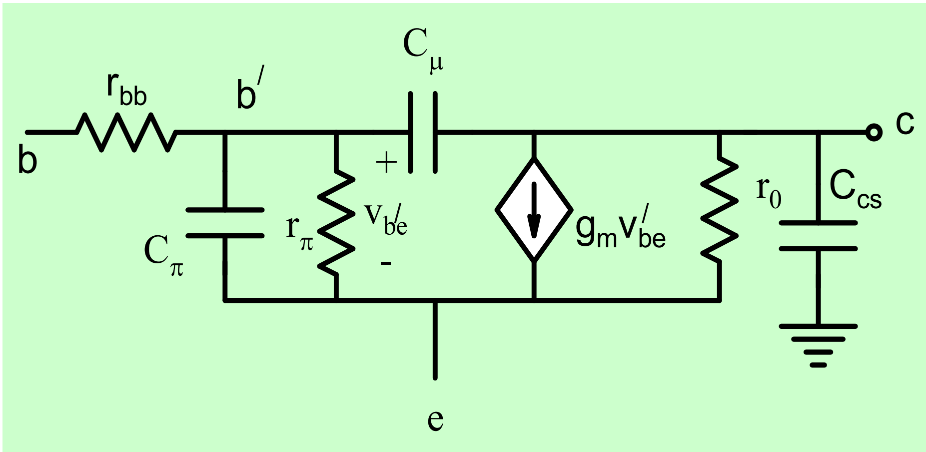
$$C_{jeo} = 1pF; C_{jco} = 0.5pF; C_{jso} = 3pF; m = 0.5; V_{bi} = 0.85; \tau_F = 1ns$$

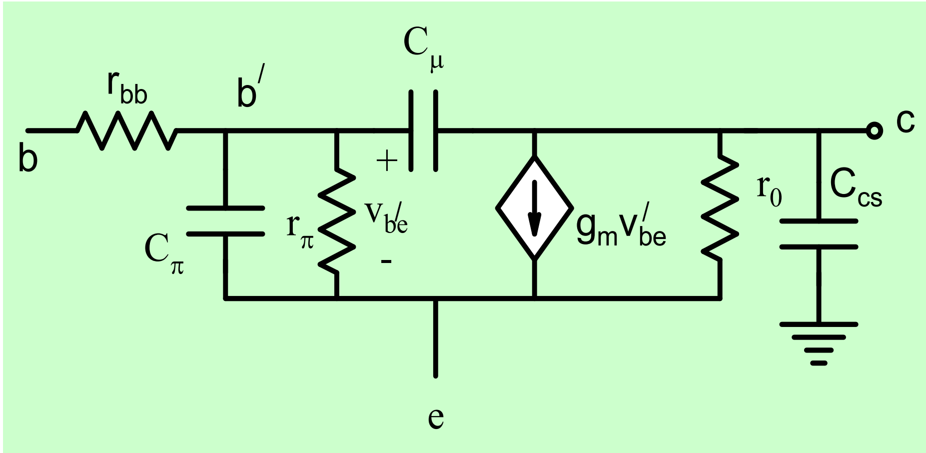
Dc bias condition:

$$V_{BE} = 0.7V;\ V_{BC} = -3V;\ V_{CS} = 2V$$

$$I_C = 1mA;\ I_B = 10\mu A$$

Small Signal Model parameters evaluated at the bias point:





$$g_m = \frac{I_C}{V_T} = 38\text{m}\Omega^{-1}\ ; \qquad r_\pi = \frac{V_T}{I_C} \times \beta = 2.6k\Omega; \qquad r_0 = \frac{V_A}{I_C} = 100\ k\Omega$$

$$C_\pi = g_m \tau_F + C_{je} = g_m \tau_F + \frac{C_{jeo}}{(1 - \frac{V_{BE}}{V_{bi}})^m} = 38.5pF$$

$$C_\mu = C_{jc} = \frac{C_{jco}}{(1 - \frac{V_{BC}}{V_{bi}})^m} = 0.23pF \qquad\qquad C_{js} = \frac{C_{jso}}{(1 + \frac{V_{CS}}{V_{bi}})^m} = 1.6pF$$