HBT small-signal analysis

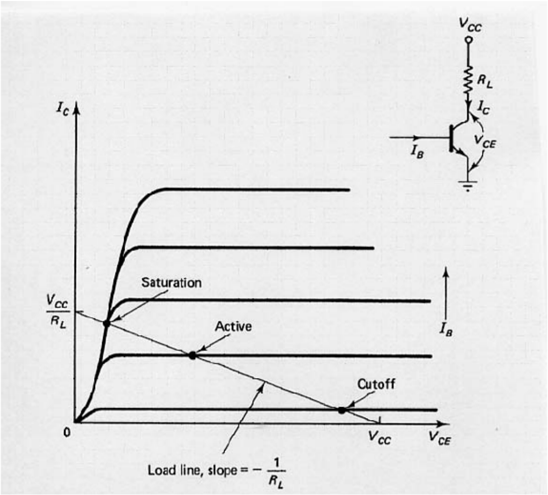
LECTURE 16

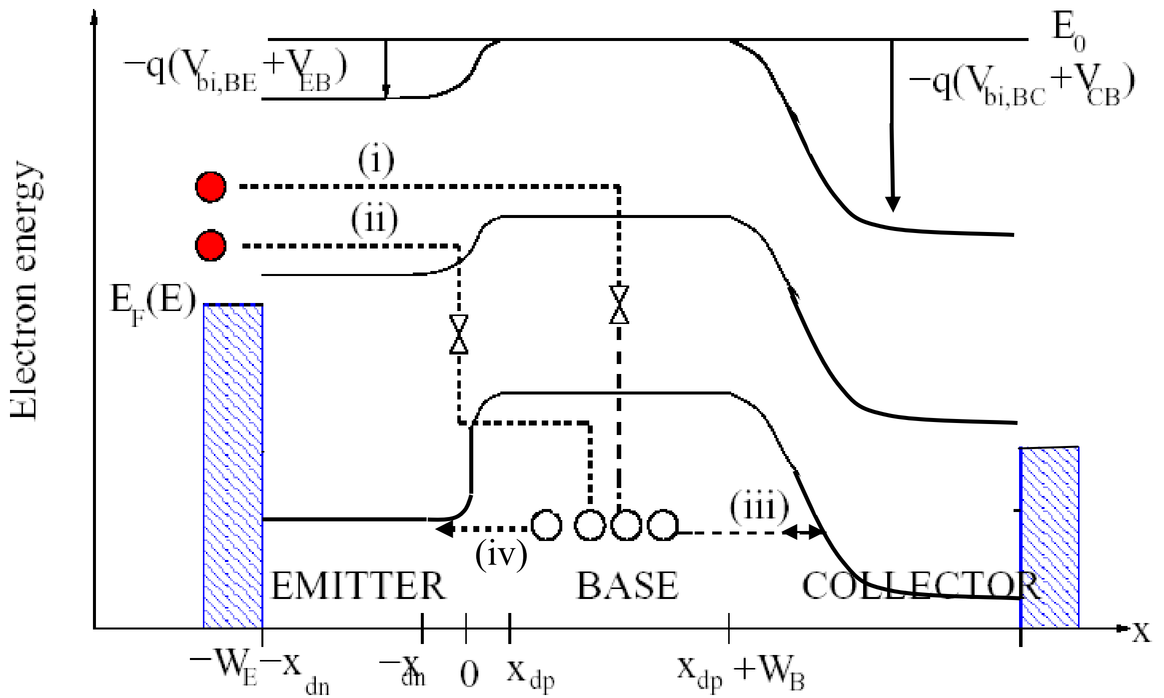
- Base current
- DC equivalent circuit
- AC small-signal analysis
- Hybrid-π equivalent circuit
- Parasitic R and C in an HBT
- Capacitance in a BT

Sec. 9.3

Base current: components

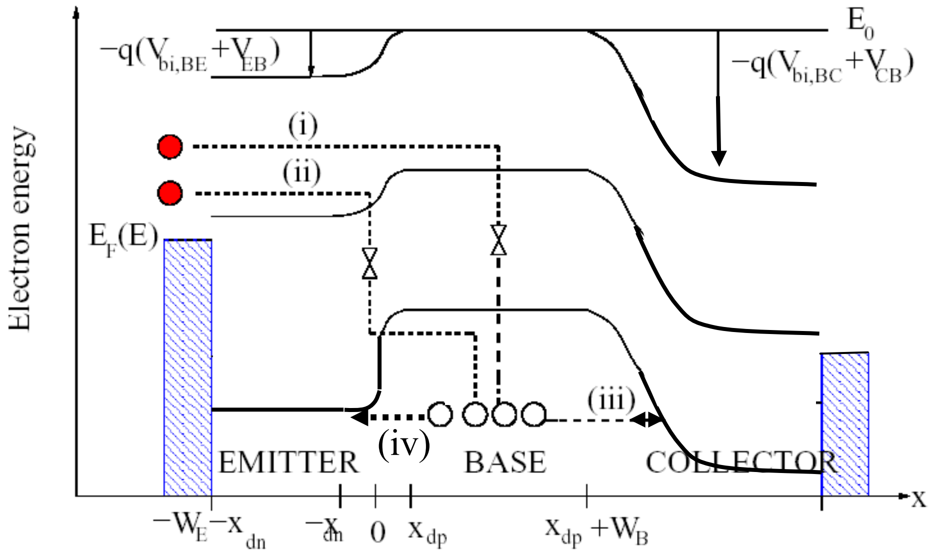
Base current components in active mode





- Which I_B components do we need to consider?

Base current: recombination in base QNR



$$
\begin{aligned}
-\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\
J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\
J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} + G_{op} \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h} + G_{op}
\end{aligned}
$$

From the toolbox

$$J_{e,\text{rec}} = \int_{J_e(x_{dp})}^{J_e(x_{dp}+W_B)} dJ_e = q\int_{x_{dp}}^{x_{dp}+W_B} \frac{n_B(x) - n_{0B}}{\tau_e}\,dx$$

Linear profile

$$
\begin{aligned}
n_B(x) &= n(x_{dp}) - \left[n(x_{dp}) - n(x_{dp}+W_B)\right](x/W_B) \\
&= \left(n_E^* + \frac{J_e(x_{dp})}{q2v_R}\right)\left(1 - \frac{x}{W_B}\right) + \left(n_C^* - \frac{J_e(x_{dp}+W_B)}{q2v_R}\right)\frac{x}{W_B}
\end{aligned}
$$

Current

$$I_{B,\text{rec}} = Aqn_{0B}\left[(e^{V_{BE}/V_{\text{th}}} - 1) + (e^{V_{BC}/V_{\text{th}}} - 1)\right]\left\{\frac{1}{\frac{2\tau_e}{W_B} + \frac{1}{2v_R}}\right\}$$

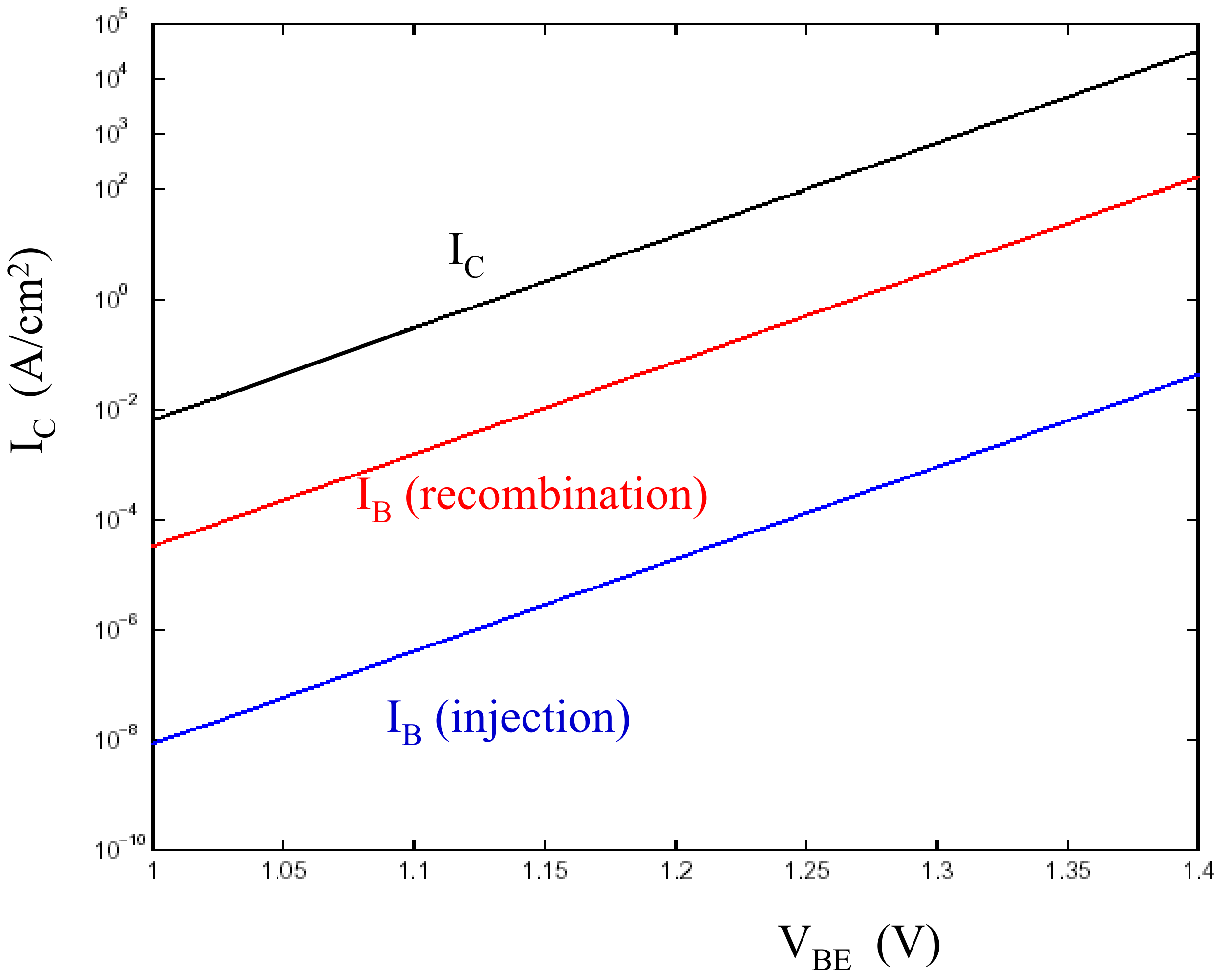
Sec. 9.3

Base current components and Gummel plot

•Why is the back-injection current so low?

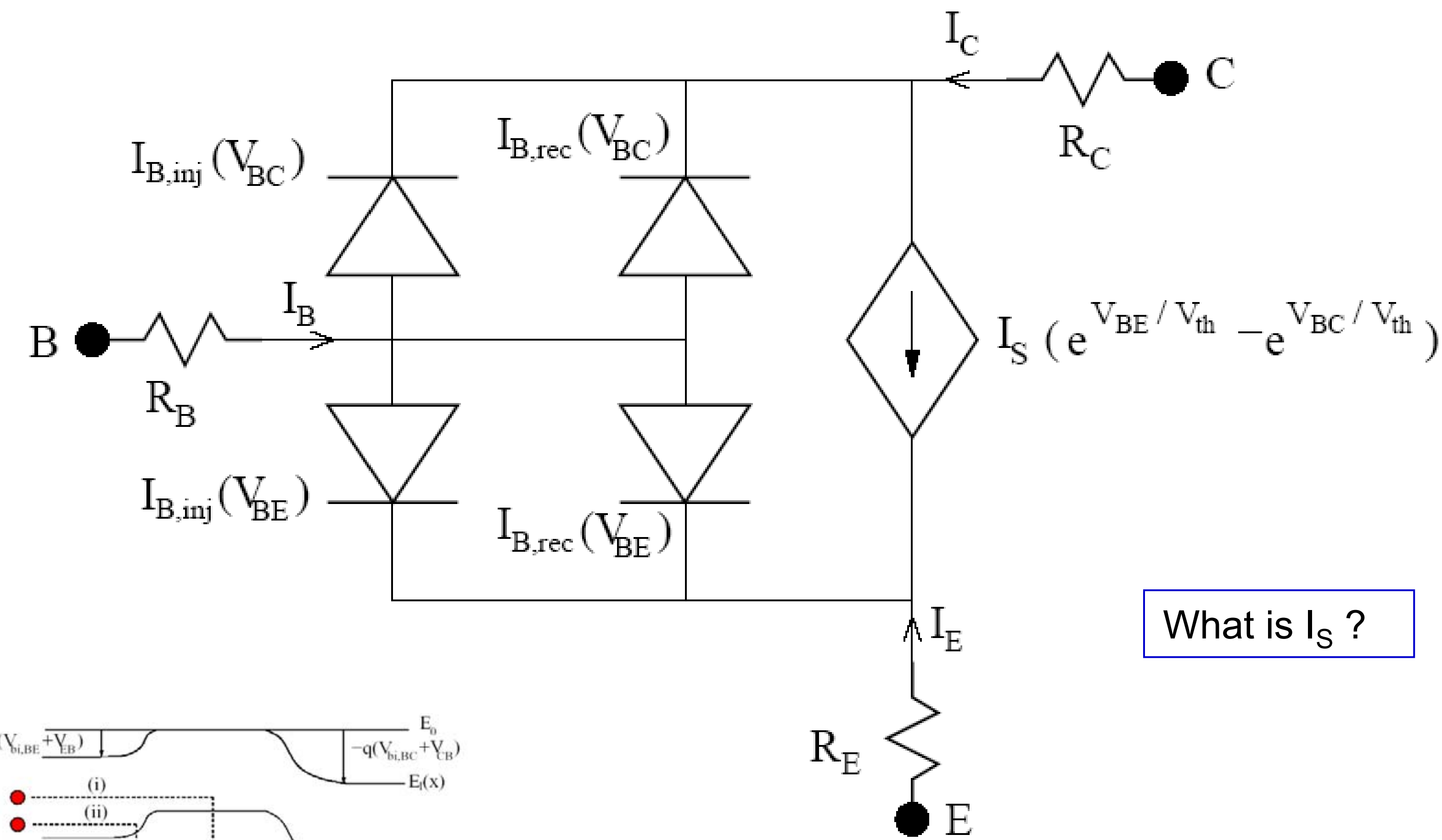
•How can there be a base recombination current if we have ignored recombination for I_C?

•What is the DC gain?

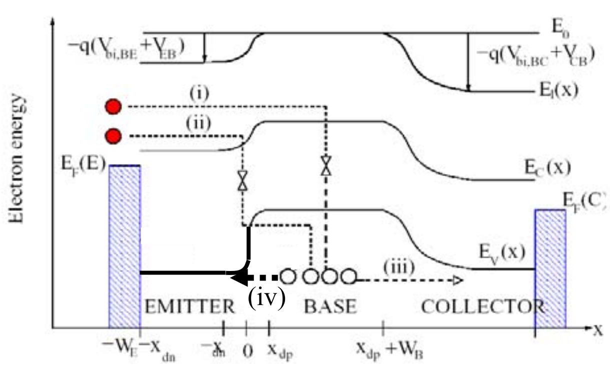


Sec. 9.4

DC Equivalent circuit

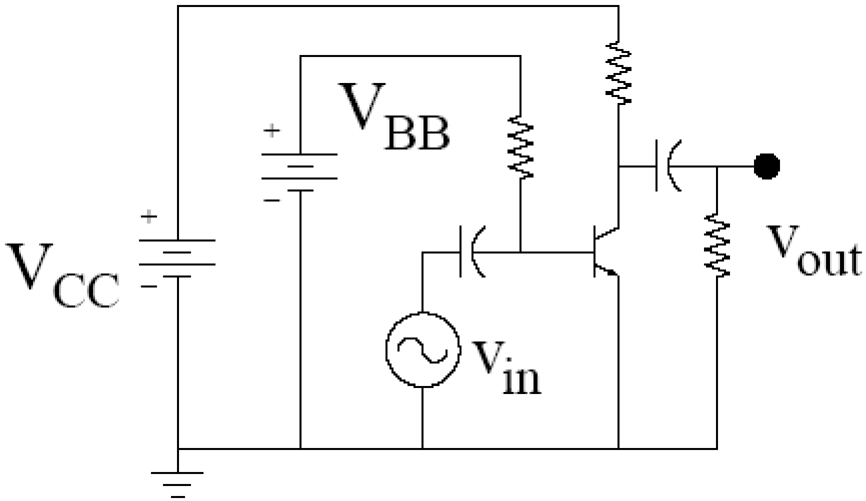


What is I_S ?



Sec. 14.2

AC small-signal operation



Notation $i_J(t) = I_J + i_j(t) \qquad J, j = 1, 2, 3\,,$

Match the numbers to the terminals

Function of 2 variables

$$i_2 = I_2(V_{21} + v_{21},\ V_{31} + v_{31})$$

Linearize

$$= I_2(V_{21}, V_{31}) + \frac{\partial I_2}{\partial V_{21}} v_{21} + \frac{\partial I_2}{\partial V_{31}} v_{31}$$

$$\equiv I_2 + g_{22} v_{21} + g_{23} v_{31}\,,$$

Does the linearization set limits for the small signal?

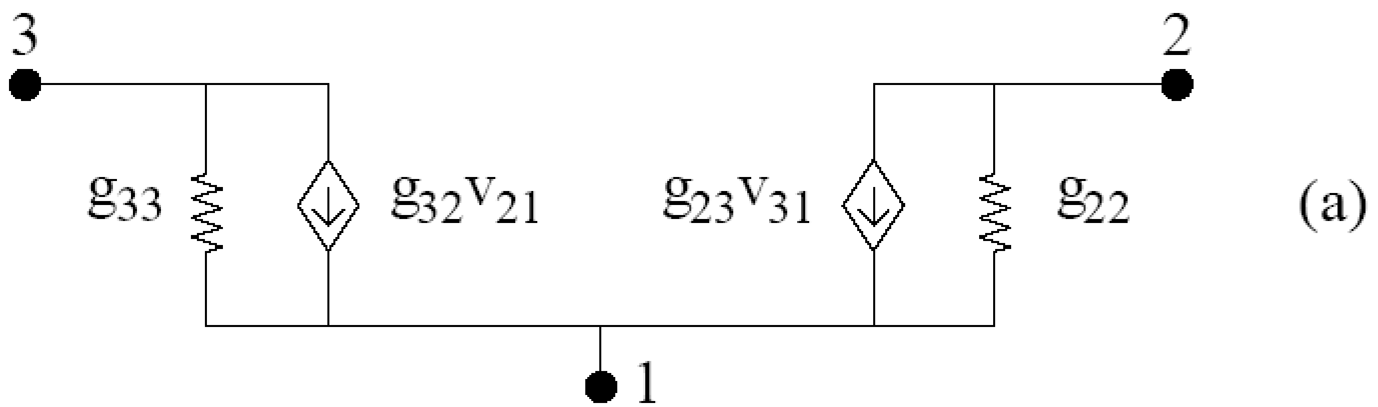
Sec. 14.2

AC small-signal equivalent circuit

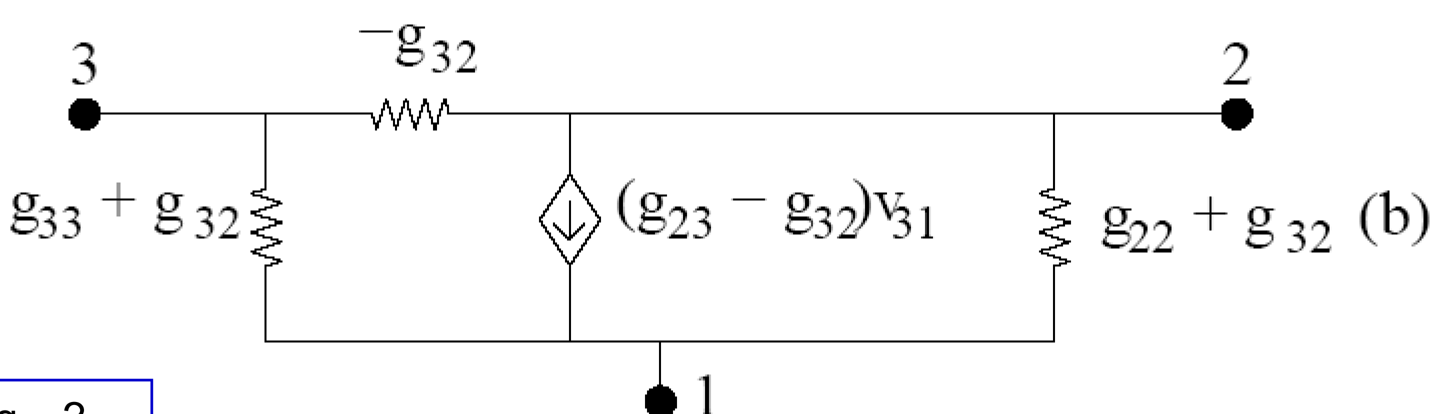
small-signal base current

$$i_3 = \frac{\partial I_3}{\partial V_{31}} v_{31} + \frac{\partial I_3}{\partial V_{21}} v_{21} = g_{33} v_{31} + g_{32} v_{21} \,,$$

2-generator circuit



1-generator circuit

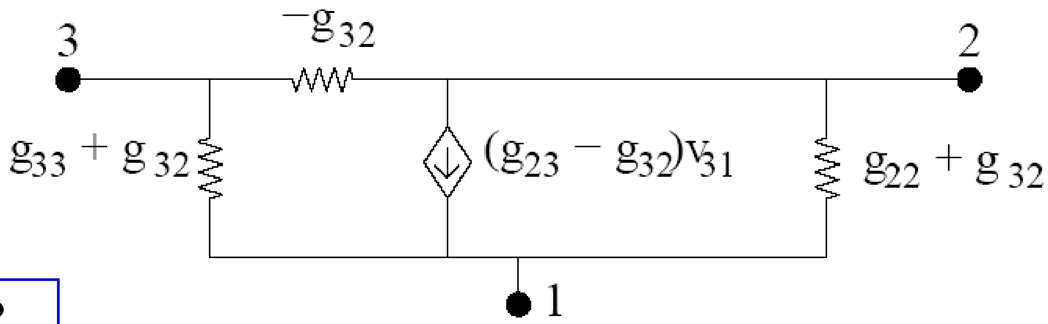


What is $-g_{32}$?

Sec. 14.3

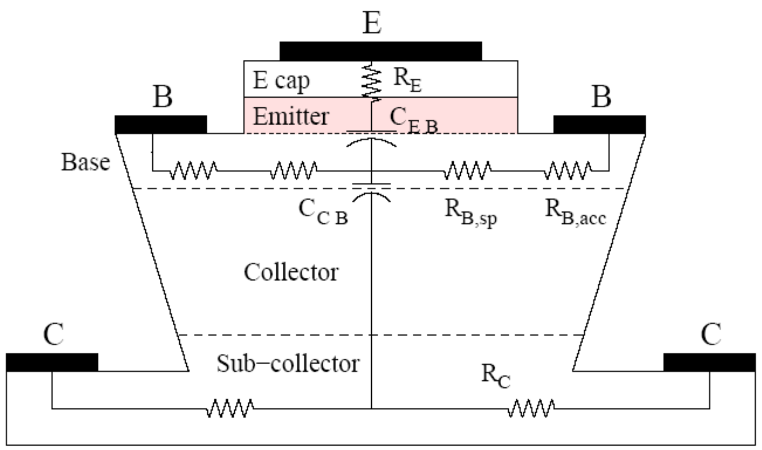
Hybrid-π equivalent circuit

1-generator
conductance circuit

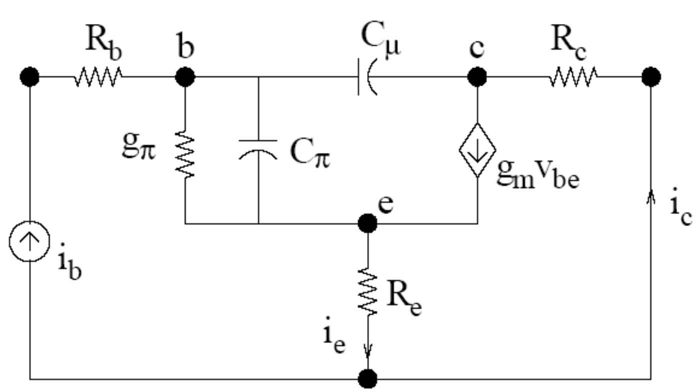


What are the conductances called?

HBT with parasitic R's
and C's identified



Hybrid-π equivalent circuit under AC
short-circuit at the output.



What components have been left out?

Sec. 12.1

Capacitance

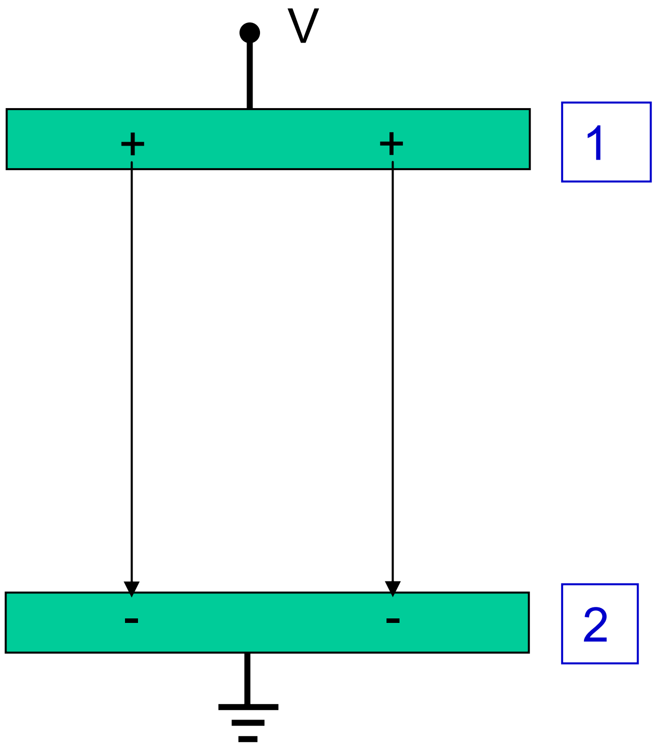
Generally:

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

Specifically:

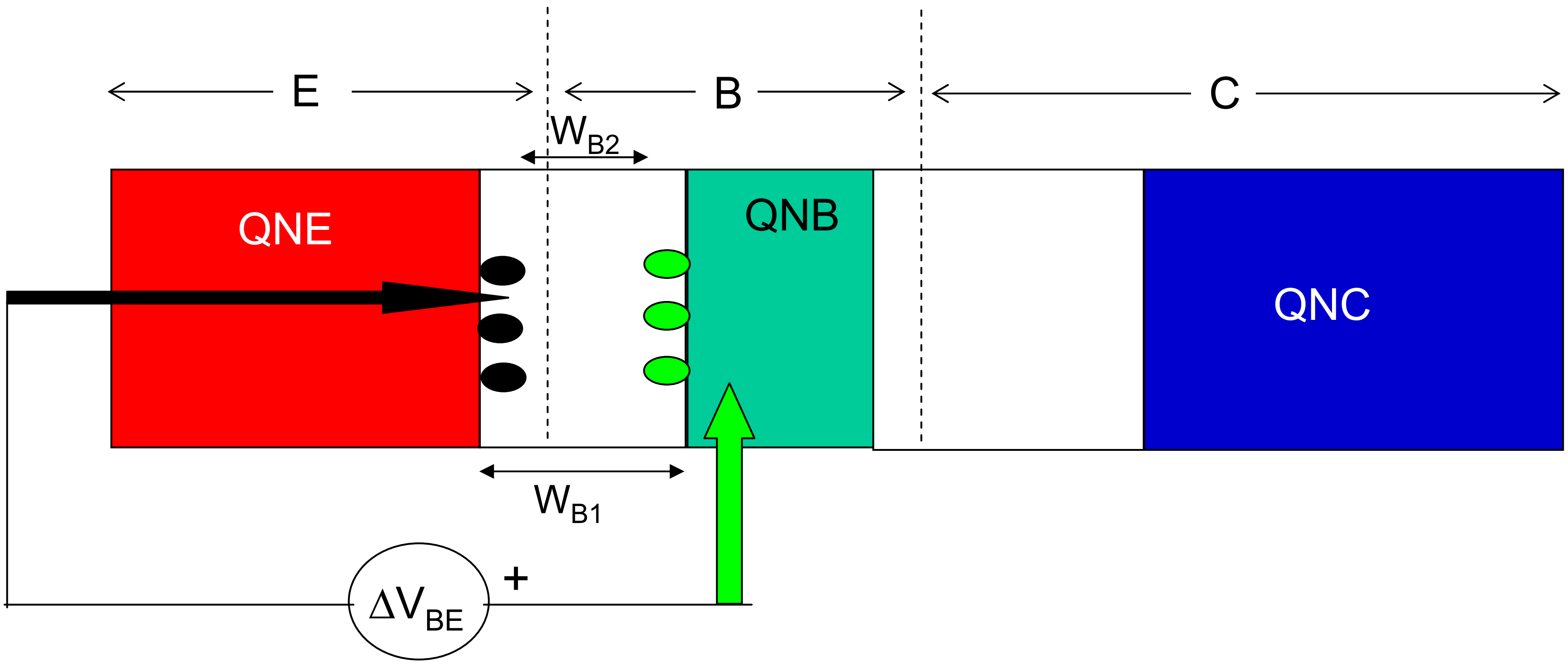
$$C_{jk} = -\frac{\partial Q_j}{\partial V_k} \qquad \text{if } j \neq k$$

$$C_{jk} = +\frac{\partial Q_j}{\partial V_k} \qquad \text{if } j = k$$



Sec. 12.3.1

Emitter-base junction-storage capacitance



$$C_{EB,j} = \boxed{}$$

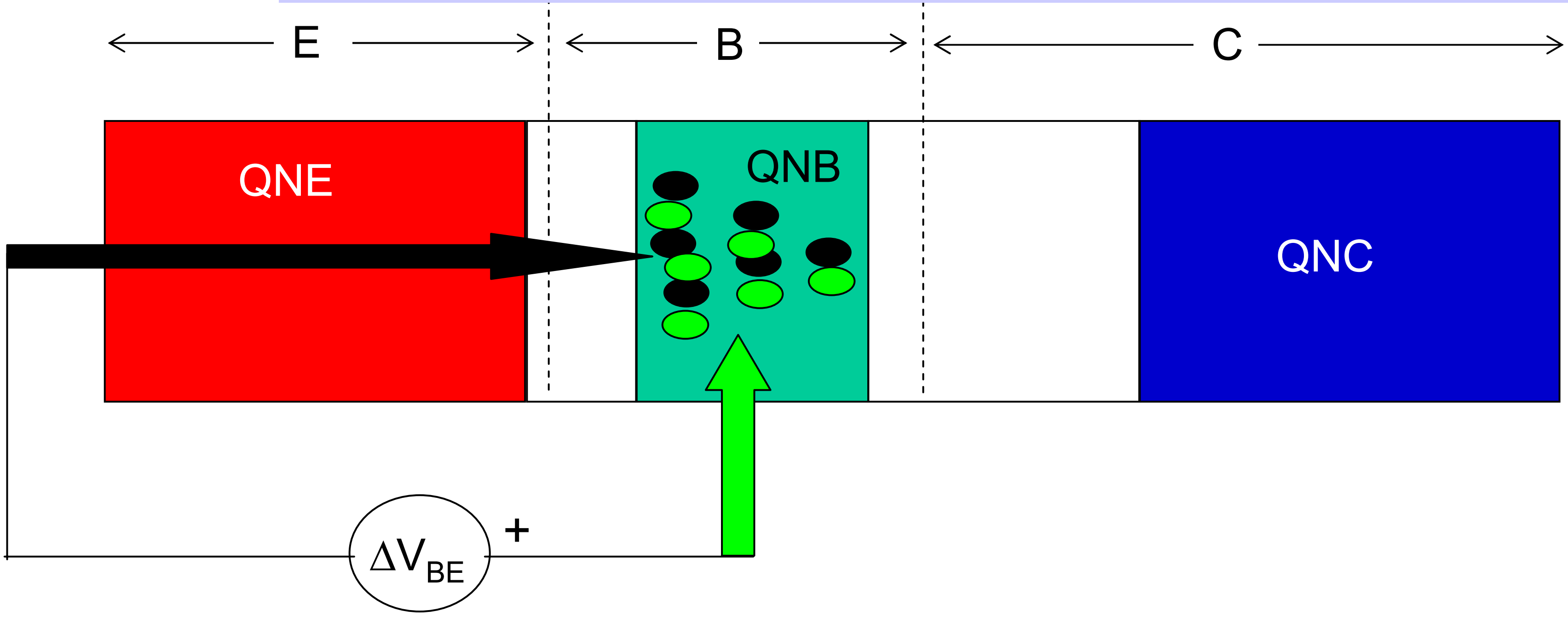
$$C_{EB,j} \equiv \boxed{}$$

- $\Delta Q_{E,j}$ is the change in charge entering the device through the emitter and creating the new width of the depletion layer (narrowing it in this example),
- in response to a change in V_{BE} (with E & C at AC ground).
- It can be regarded as a parallel-plate cap.

What is the voltage dependence of this cap?

Sec. 12.3.2

Emitter-base base-storage capacitance: concept

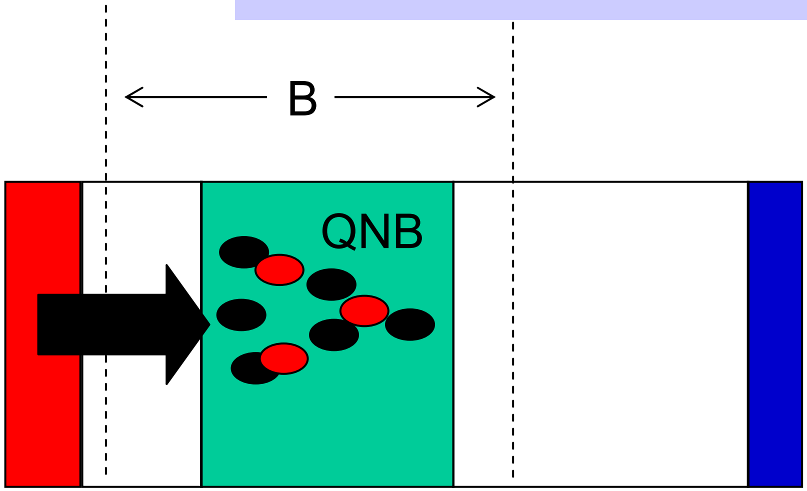


$$C_{EB,b} = -\frac{\quad}{\quad}$$

- $\Delta Q_{E,b}$ is the change in charge entering the device through the emitter and resting in the base (the black electrons),
- in response to a change in V_{BE} (with E & C at AC ground).
- It's not a parallel-plate cap, and we only count one carrier.

Sec. 12.3.2

Emitter-base base-storage capacitance: evaluation



$$Q_{E,b}(V_{BE}) = -q\frac{1}{2}W_B A\left[n_{0p}\exp(\frac{V_{BE}}{V_{th}}) - n(W_B)\right] - qW_B An(W_B)$$

Take $\frac{\Delta Q_{E,b}}{\Delta V_{BE}} \rightarrow \frac{dQ_{E,b}}{dV_{BE}}$

Hence $C_{EB,b}$

$$n(0,V_{BE1}) = n_{0p}\exp(V_{BE1}/V_{th})$$

$$n(0,V_{BE,2}) = n_{0p}\exp(V_{BE2}/V_{th})$$

What is the voltage dependence of $C_{EB,b}$?