Universidad
Carlos III de Madrid
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Session 16
Single-stage amplification circuits (BJT)

Electronic Components and Circuits

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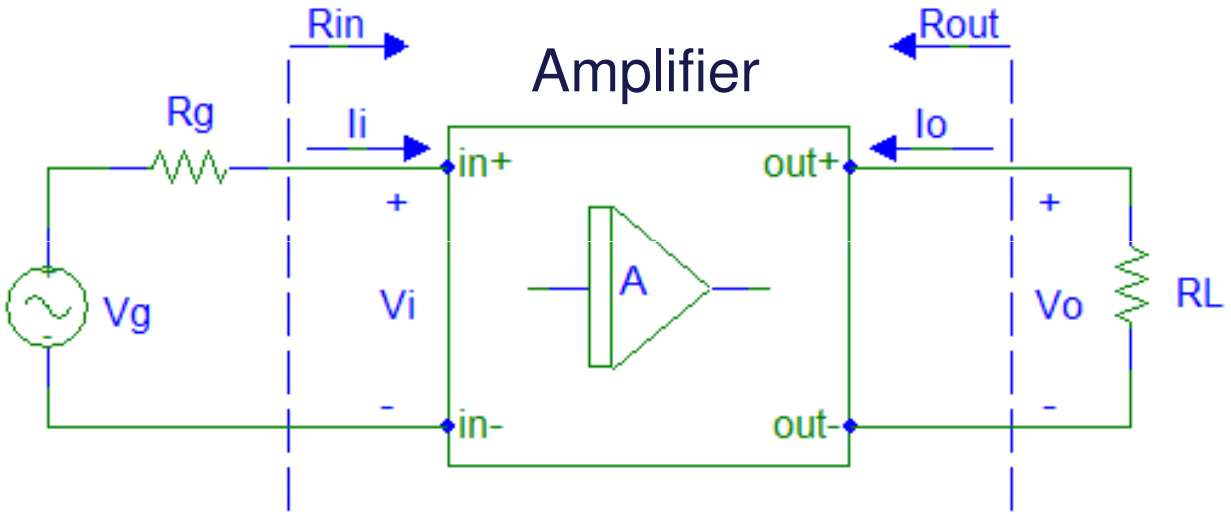
Single-stage amplification circuits Transistor configurations as an amplification device

OBJECTIVES

- To review the process of analyzing the characteristic parameters of amplifiers.
- Analyze small-signal circuits for single-stage BJT amplifiers :
  - Common emitter.
  - Common-emitter with RE (emitter degeneration).
  - Common-Colector.
  - Common-Base.
- Compare the features of these configurations.

Characteristic parameters of amplifiers



- Voltage Gain, Av y Gv

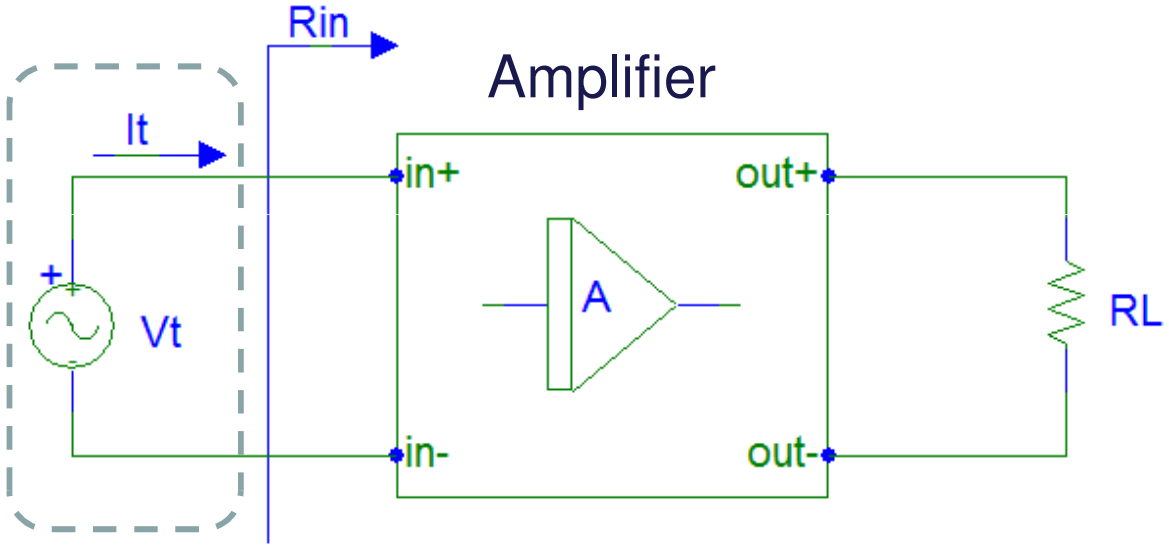
$$A_v = \frac{V_o}{V_i} \qquad G_v = \frac{V_o}{V_g} \qquad A_i = \frac{i_o}{i_i}$$

- Current Gain, Ai
- Input resistance, Rin

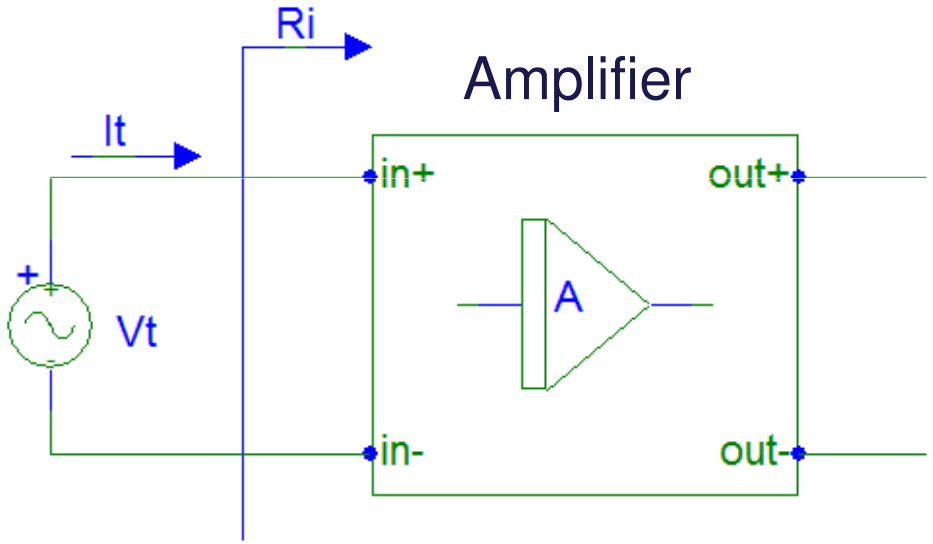
$$R_{in} = \frac{V_i}{i_i} \qquad R_{out} = \frac{V_o}{i_o}$$

- Output Resistance, Rout

Input Impedance Analysis

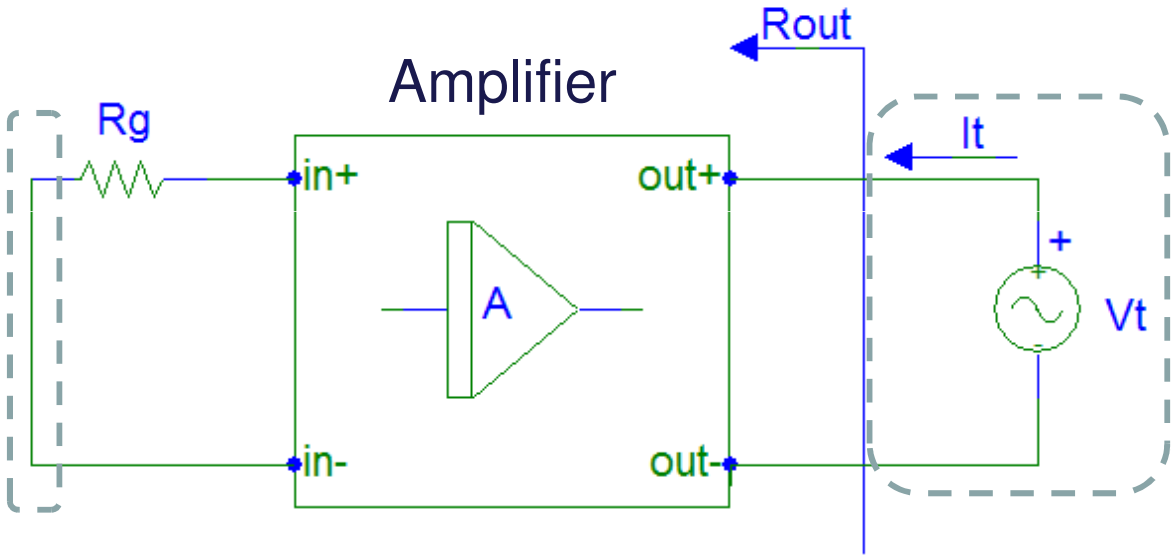


$$R_{in} = \frac{V_t}{i_t}$$

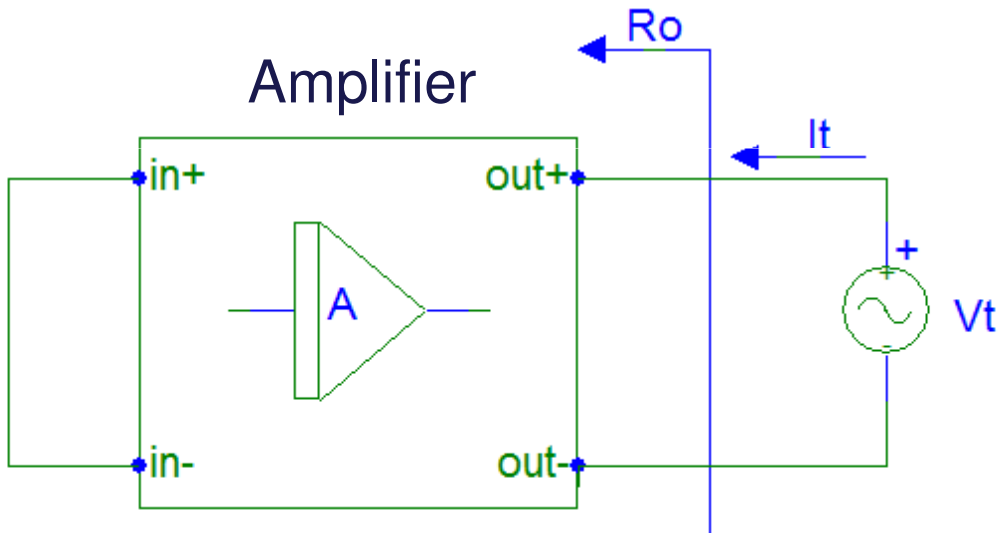


$$R_i = \left.\frac{V_t}{i_t}\right|_{R_L \to \infty}$$

Output Impedance Analysis



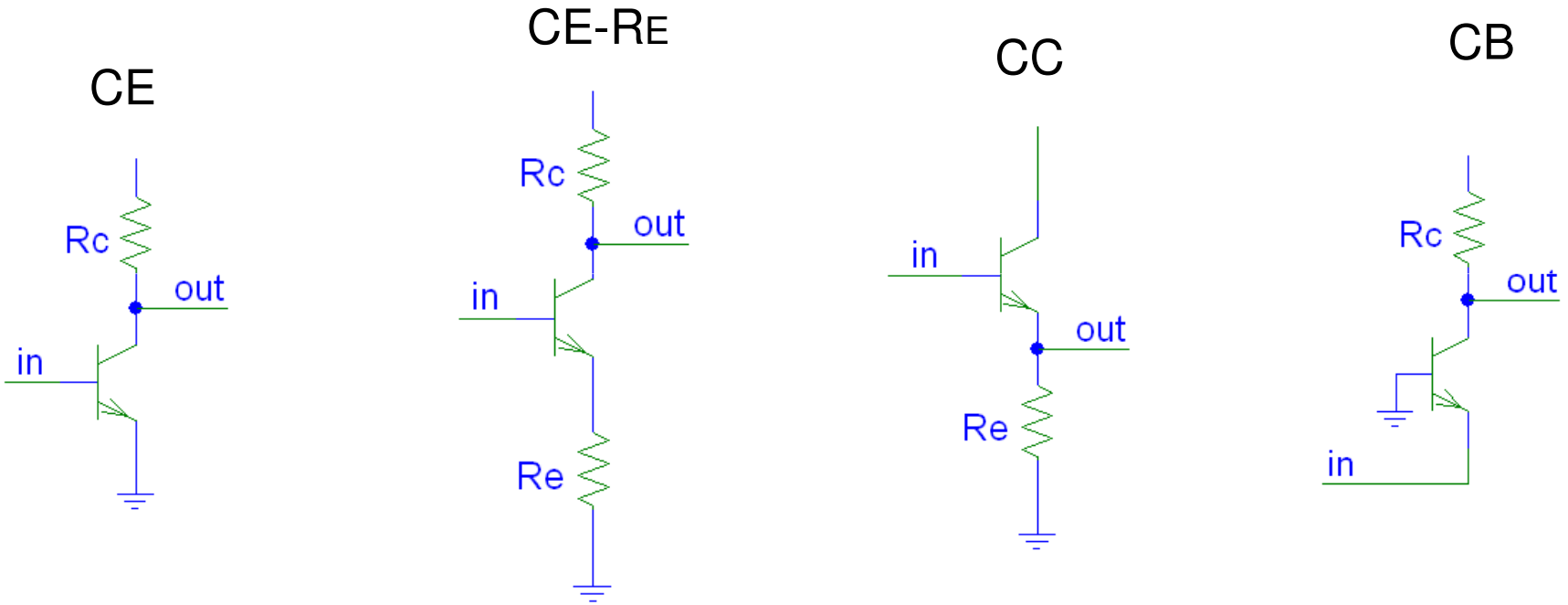
$$R_{out} = \left.\frac{V_t}{i_t}\right|_{V_g=0}$$



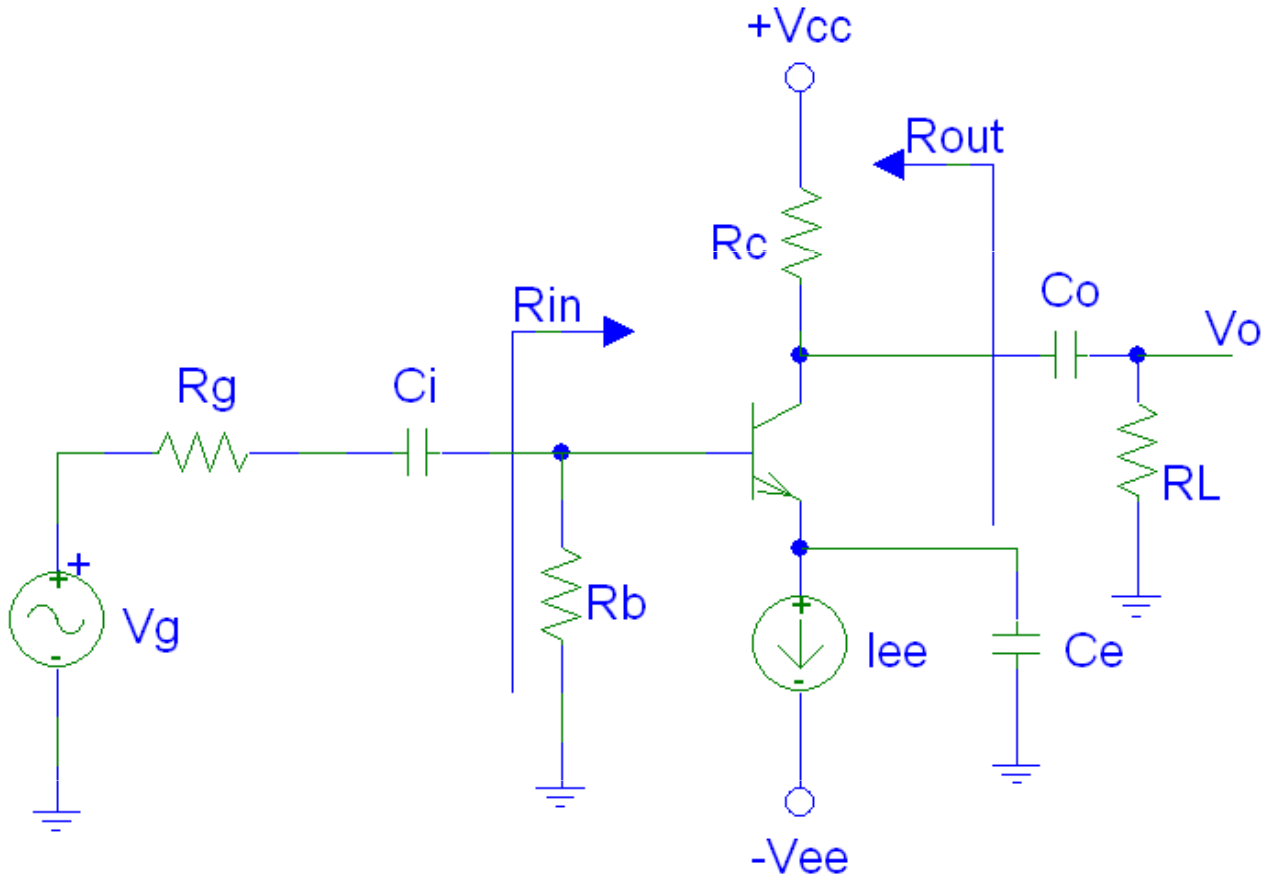
$$R_o = \left.\frac{V_t}{i_t}\right|_{V_i=0}$$

Single stage amplifiers

- Common-emitter amplifier (CE)
- Common-emitter amplifier with R_E and emitter degeneration
- Common-collector amplifier (CC) or emitter-follower
- Common-base amplifier (CB)



Common-emitter amplifier (CE)



EXAMPLE

- βo = 100
- VA = 100 V
- Rb = 100 kΩ
- Rc = 8 kΩ
- RL = 100 kΩ
- Vcc = Vee = 10V
- Iee = 1mA

$$I_{CQ} \approx 1mA$$

$$g_m = 40mA/V$$

$$r_\pi = 2{,}5k\Omega$$

$$r_0 = 100k\Omega$$

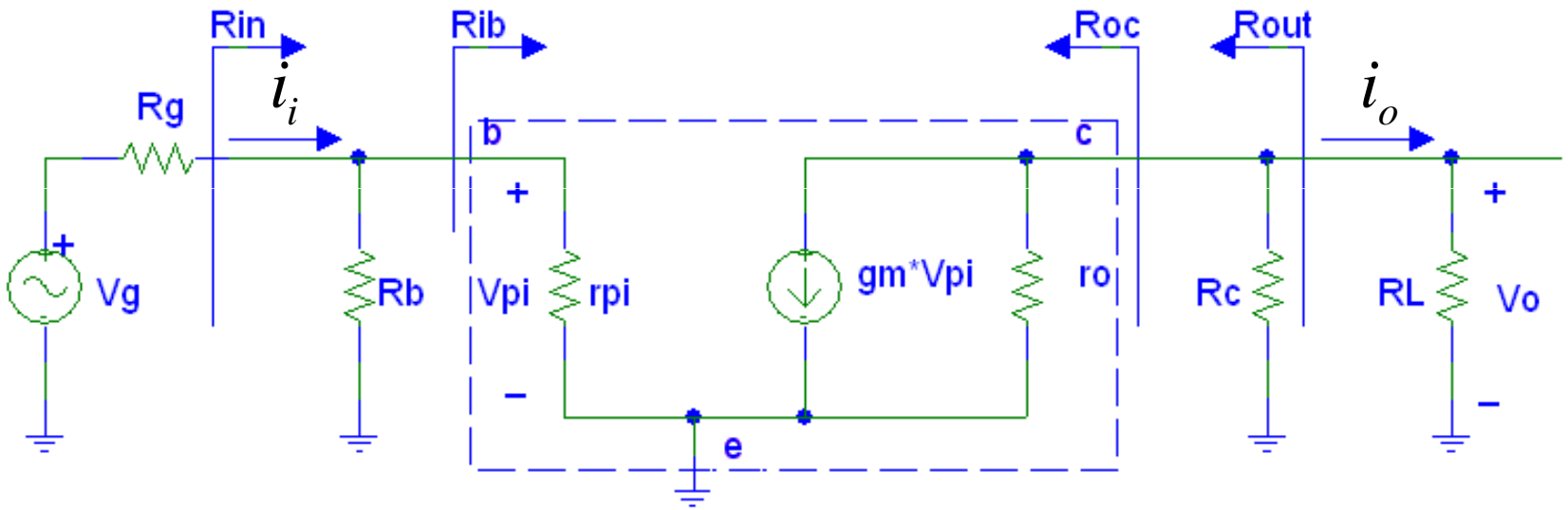
(1) BIAS ANALYSIS

$C_i, C_o, C_e \rightarrow \infty$
(Open Circuit)

$$I_E = I_{ee}$$

$$I_{CQ} \approx I_{ee}$$

Common-emitter (Impedances)

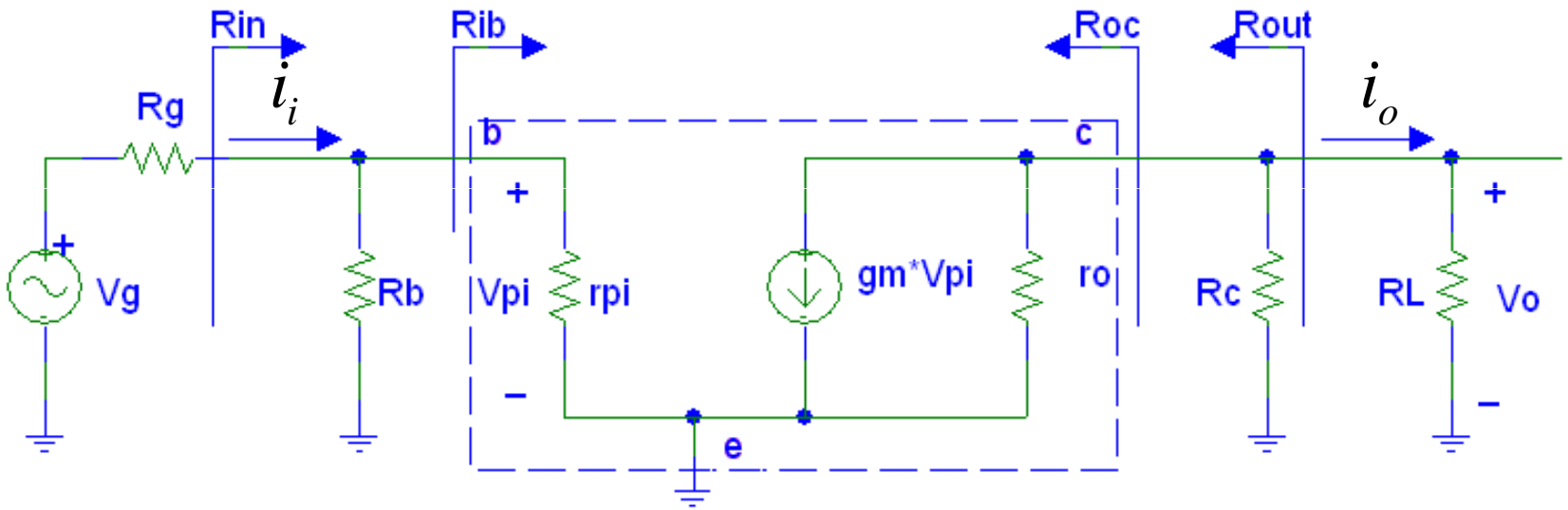


(2) SMALL SIGNAL ANALYSIS

$$R_{ib} = r_\pi \qquad R_{in} = R_b \,//\, r_\pi \qquad R_{in}\big|_{R_b >> r_\pi} \approx r_\pi$$

$$R_{oc} = r_o \qquad R_{out} = R_c \,//\, r_o \qquad R_{out}\big|_{r_o >> R_c} \approx R_c$$

Common-emitter (Small Signal)

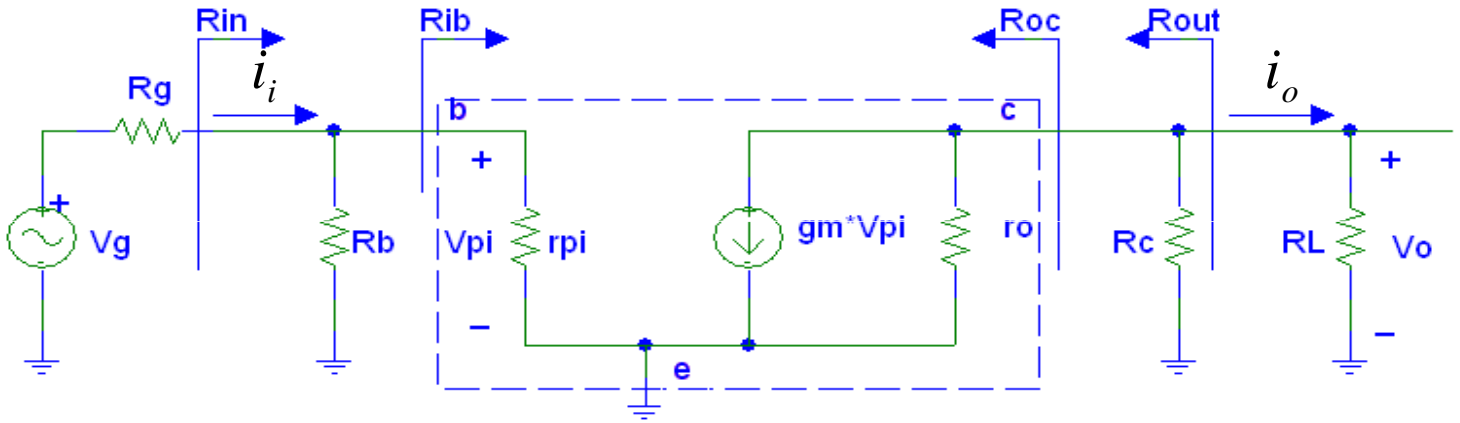


(2) SMALL SIGNAL ANALYSIS

$$i_i = \frac{V_g}{R_g + R_{in}} \qquad V_\pi = V_g \frac{R_{in}}{R_g + R_{in}}$$

$$i_o = -g_m V_\pi \frac{R_{out}}{R_L + R_{out}} \qquad V_o = -g_m V_\pi (r_o \,//\, R_c \,//\, R_L)$$

Common-emitter (Gain)



$$A_v = \frac{V_o}{V_\pi} = -g_m (r_o \,//\, R_c \,//\, R_L)$$

$$G_v = \frac{V_o}{V_g} = -g_m (r_o \,//\, R_c \,//\, R_L) \frac{R_{in}}{R_g + R_{in}}$$

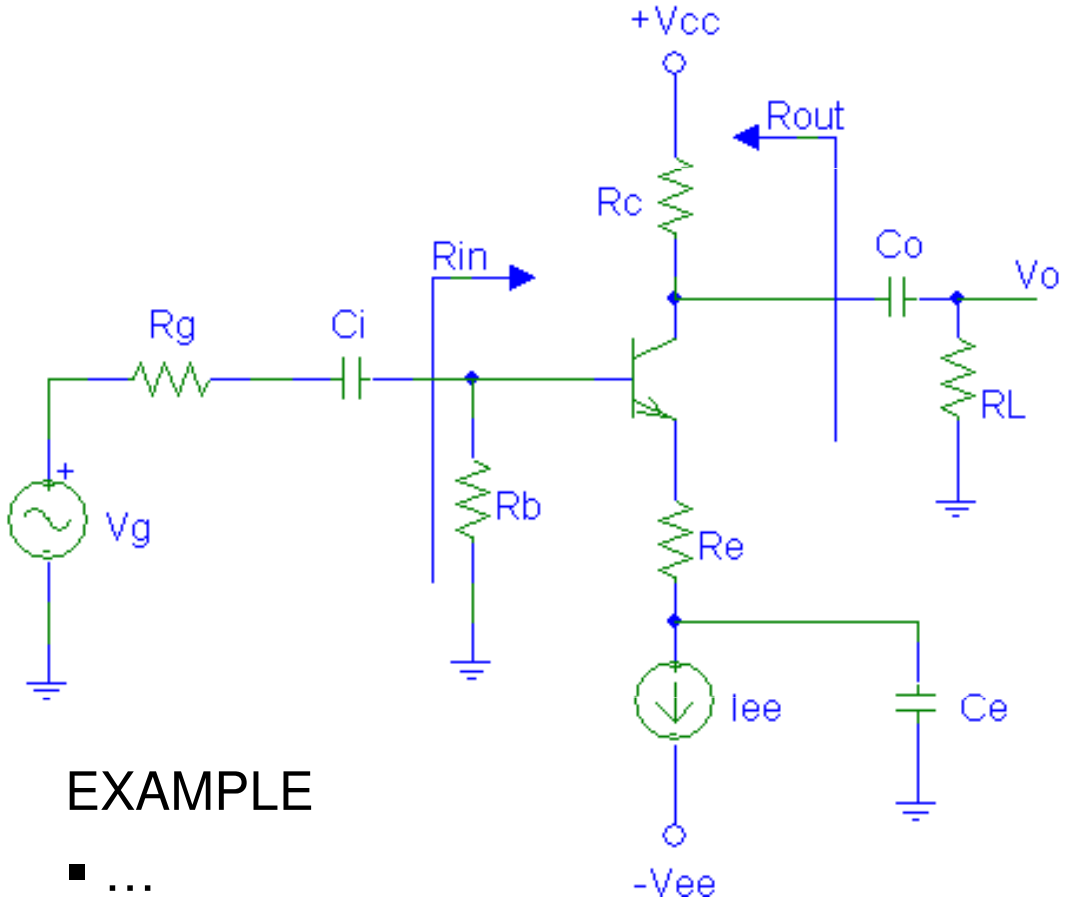
$$A_i = \frac{i_o}{i_i} = -g_m \frac{R_{out}}{R_L + R_{out}} R_{in}$$

$$A_{vo}\Big|_{r_o >> R_c} \approx -g_m R_c$$

$$G_v\Big|_{R_b >> r_\pi} \approx -\frac{\beta_o}{R_g + r_\pi} (r_o \,//\, R_c \,//\, R_L)$$

$$A_{i(sc)}\Big|_{R_b >> r_\pi} = -\beta_o$$

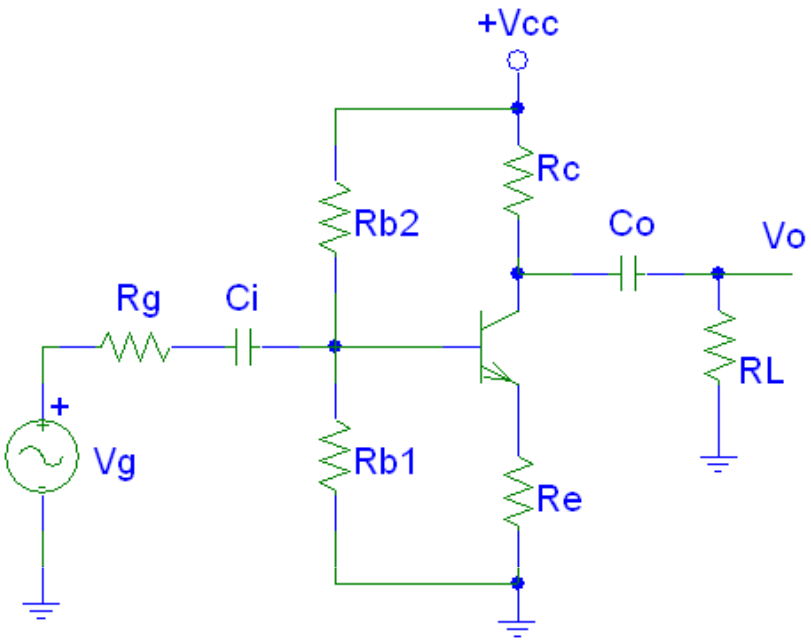
Common-emitter amplifier with RE



EXAMPLE

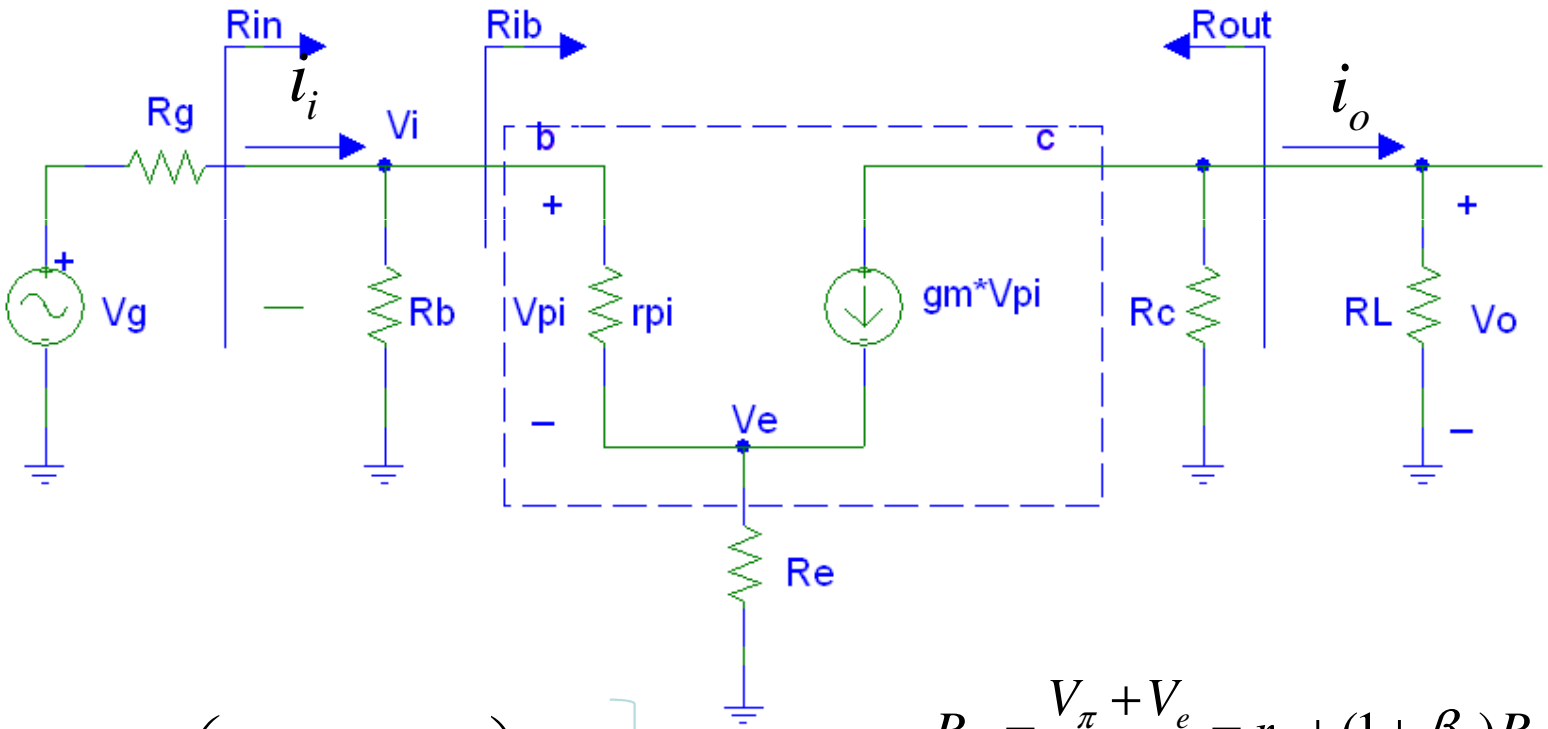
- …
- Re = 1 kΩ

$$I_{CQ} \approx 1mA$$



$$R_b = R_{b1} // R_{b2}$$

Common-emitter with RE (Impedace)



$$V_e = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi \right) \cdot R_e$$

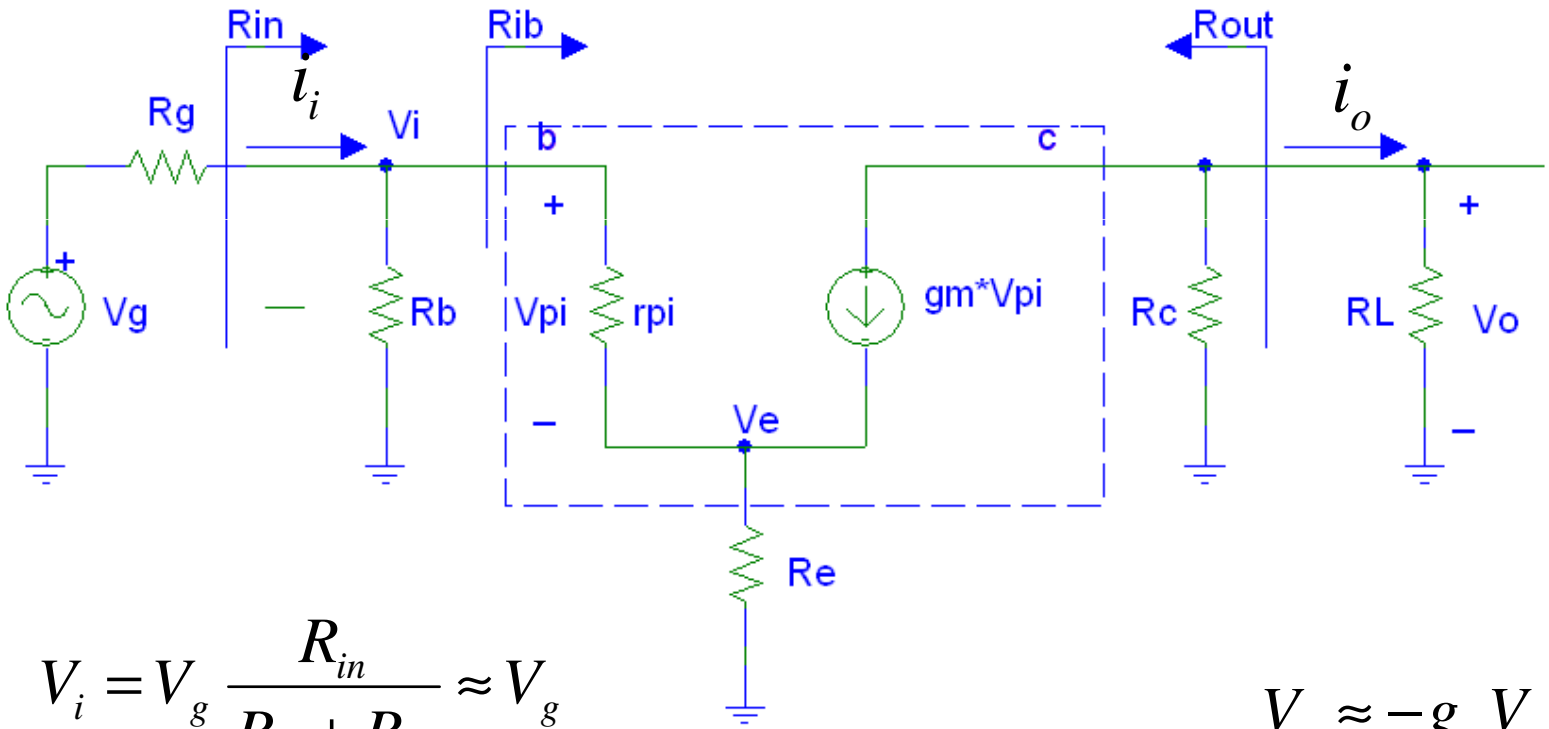
$$V_i = V_\pi + V_e$$

$$R_{ib} = \frac{V_\pi + V_e}{V_\pi / r_\pi} = r_\pi + (1+\beta_o) R_e$$

$$R_{in} = R_b \,//\left[r_\pi + (1+\beta_o) R_e \right]$$

$$R_{out}\Big|_{r_o >> R_c} \approx R_c$$

Common-emitter with R_E (Small Signal)



$$V_i = V_g \frac{R_{in}}{R_g + R_{in}} \approx V_g$$

$$V_e = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi \right) \cdot R_e$$

$$V_i = V_\pi + V_e$$

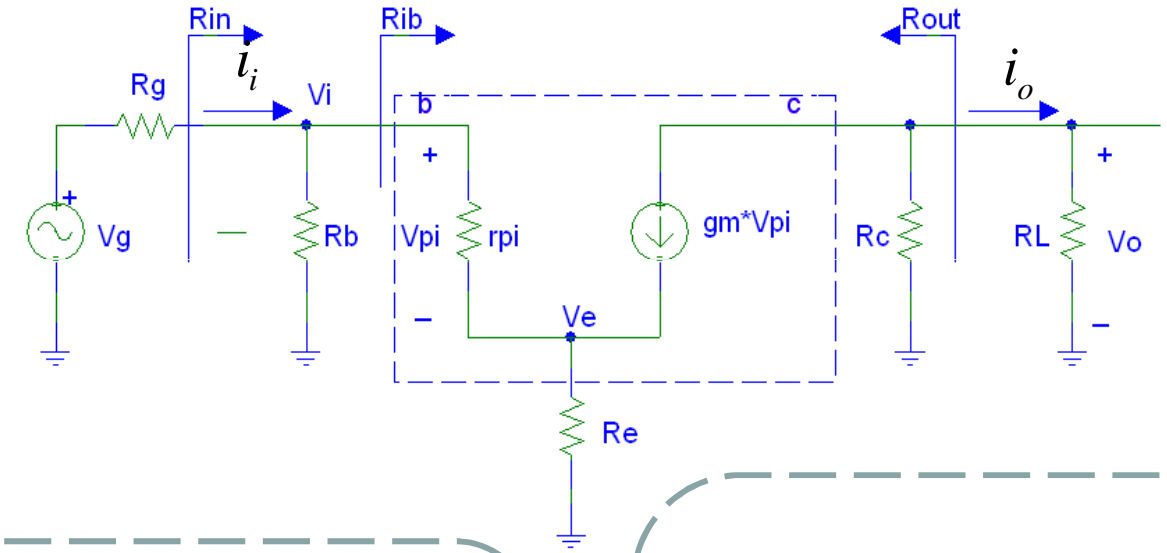
$$\frac{V_\pi}{V_i} \approx \frac{1}{1 + g_m R_e}$$

$$V_o \approx -g_m V_\pi (R_c \,//\, R_L)$$

$$i_i = \frac{V_g}{R_g + R_{in}}$$

$$i_o = -g_m V_\pi \frac{R_{out}}{R_L + R_{out}}$$

Common-emitter with RE (Gain)



$$A_v = \frac{V_o}{V_i} = -\frac{\beta_o (R_c \,//\, R_L)}{r_\pi + (1+\beta_o)\cdot R_e}$$

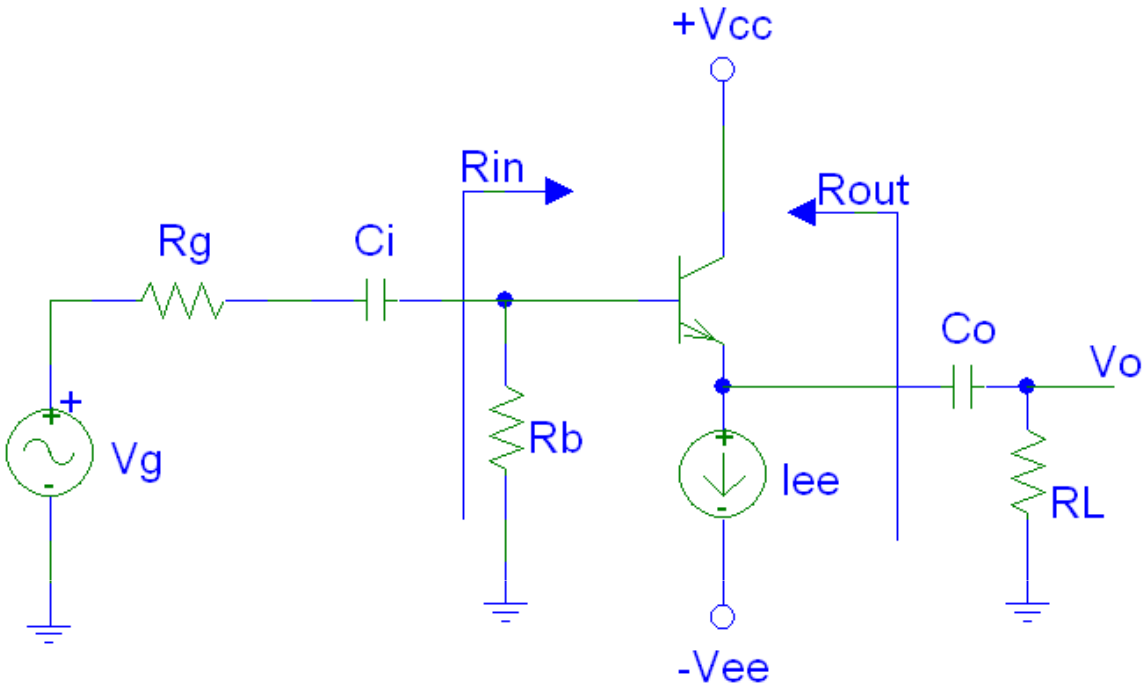
$$A_i = \frac{i_o}{i_i} = -\beta_o \frac{R_c}{R_L + R_c} \frac{R_b + R_{ib}}{R_b}$$

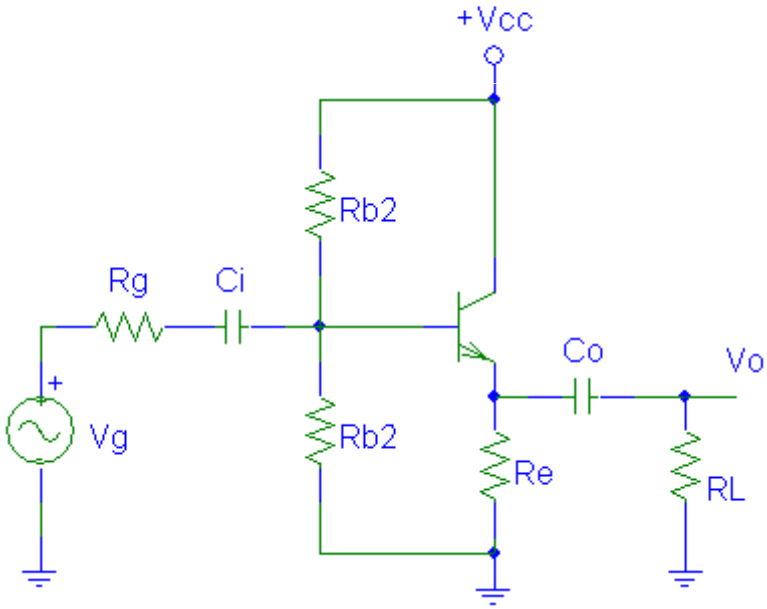
$$G_v\Big|_{r_\pi << \beta_o R_e}^{R_g << R_{in}} \approx -\frac{(R_c \,//\, R_L)}{R_e} \approx -\frac{R_c}{R_e} \cdot \frac{R_L}{R_c + R_L}$$

$$A_{vo} = -\frac{\beta_o R_c}{r_\pi + (1+\beta_o) R_e} \approx -\frac{g_m R_c}{1 + g_m R_e}$$

$$A_{i(sc)}\Big|_{R_b >> R_{ib}}^{Rg << R_{in}} \approx -\beta_o$$

Common-collector amplifier (CC)





EXAMPLE

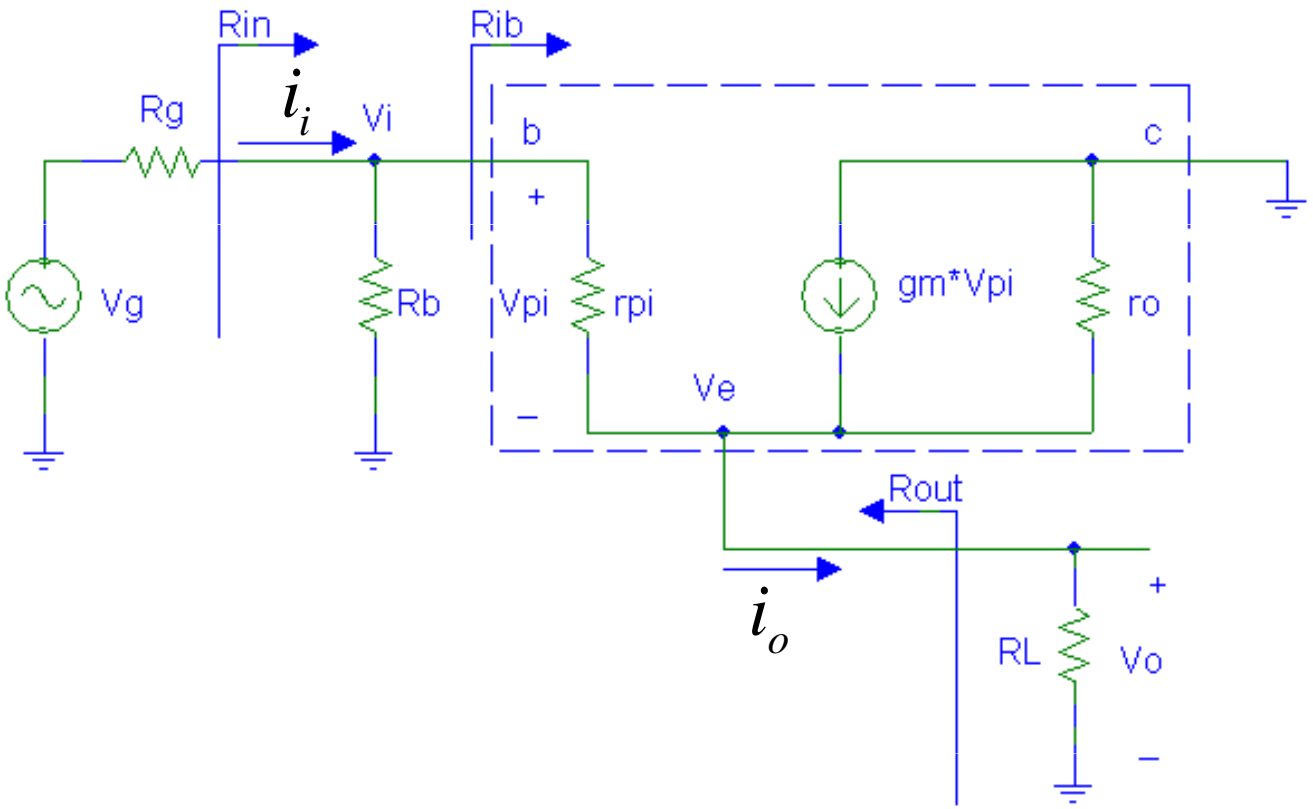
- …

$$I_{CQ} \approx 1mA$$

$$R_b = R_{b1} \,//\, R_{b2}$$

$$R_{EMITTER} = R_e \,//\, R_L$$

Common-collector (Impedances)

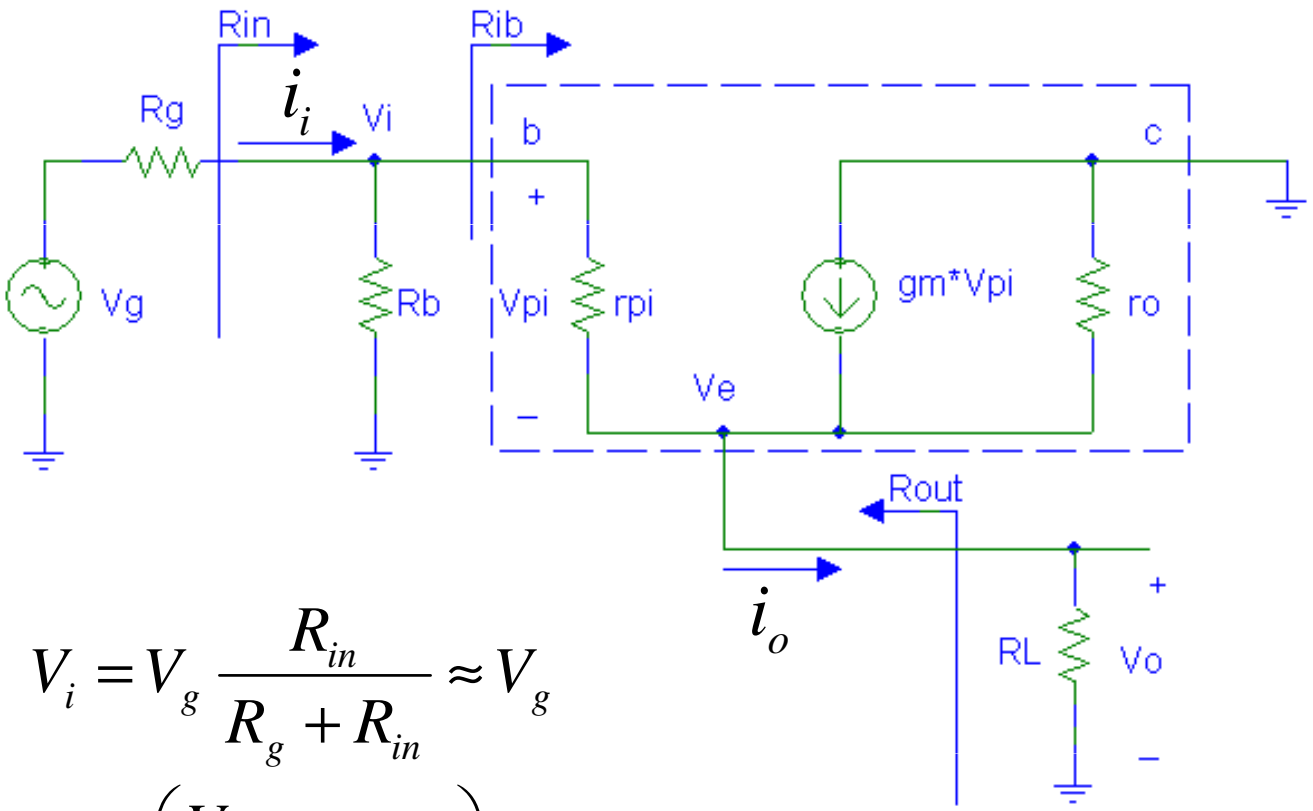


$$R_{EM} = r_o \,//\, R_L$$

$$R_{out} = r_o \,//\, \frac{r_\pi + (R_b \,//\, R_g)}{1+\beta_o} \approx \frac{r_\pi + (R_b \,//\, R_g)}{1+\beta_o}$$

$$R_{ib} = \frac{V_\pi + V_e}{V_\pi / r_\pi} = r_\pi + (1+\beta_o)\cdot R_{EM}$$

Common-collector (Small Signal)



$$R_{EM} = r_o \,//\, R_L$$

$$V_i = V_g \frac{R_{in}}{R_g + R_{in}} \approx V_g$$

$$V_e = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi \right) \cdot R_{EM}$$

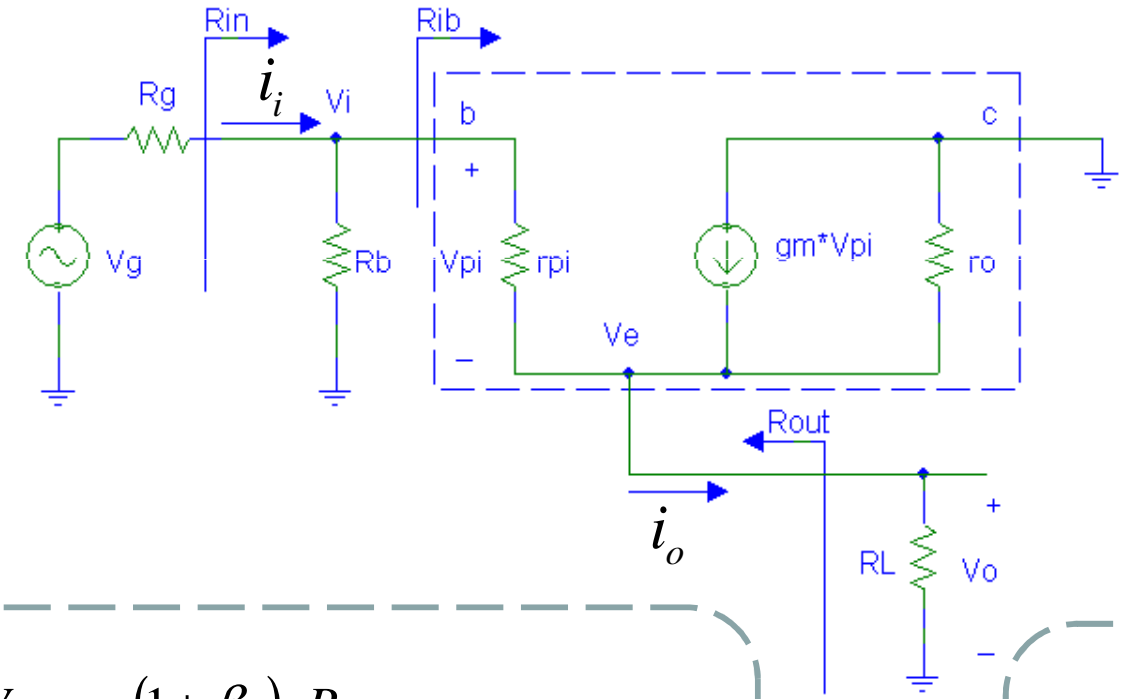
$$V_i = V_\pi + V_e$$

$$V_o = V_e$$

$$i_i = \frac{V_g}{R_g + R_{in}}$$

$$i_o = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi \right) \left(\frac{r_o}{r_o + R_L} \right)$$

Common-collector (Gain)



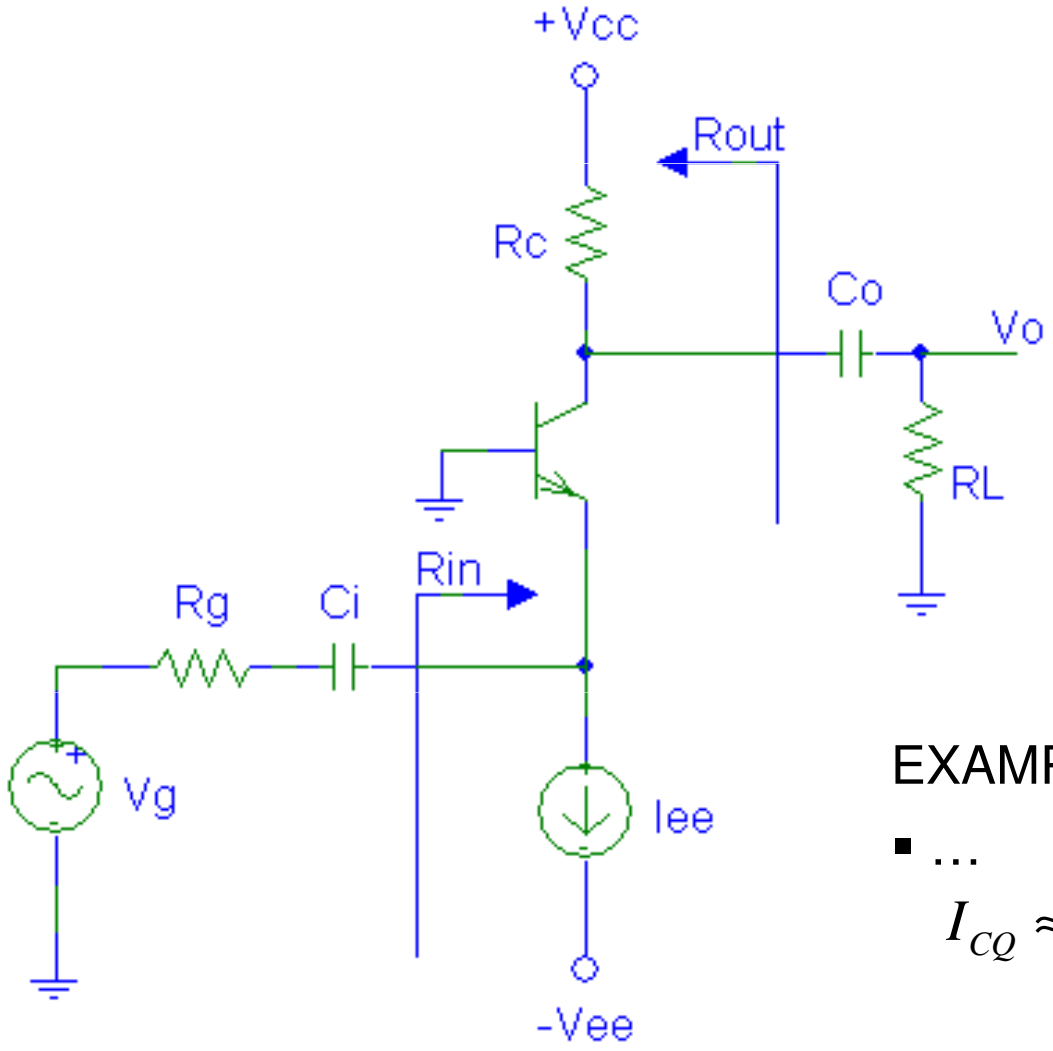
$$A_v = \frac{V_o}{V_i} = \frac{(1+\beta_o)\cdot R_{EM}}{r_\pi + (1+\beta_o)\cdot R_{EM}}$$

$$A_i = \frac{i_o}{i_i} = (1+\beta_o)\frac{r_o}{r_o + R_L}\frac{R_b + R_{ib}}{R_b}$$

$$G_v = \frac{V_o}{V_g} \approx 1$$

$$A_{i(sc)}\Big|_{R_b >> R_{ib}}^{Rg << R_{in}} \approx 1 + \beta_o$$

Common-base amplifier (CB)

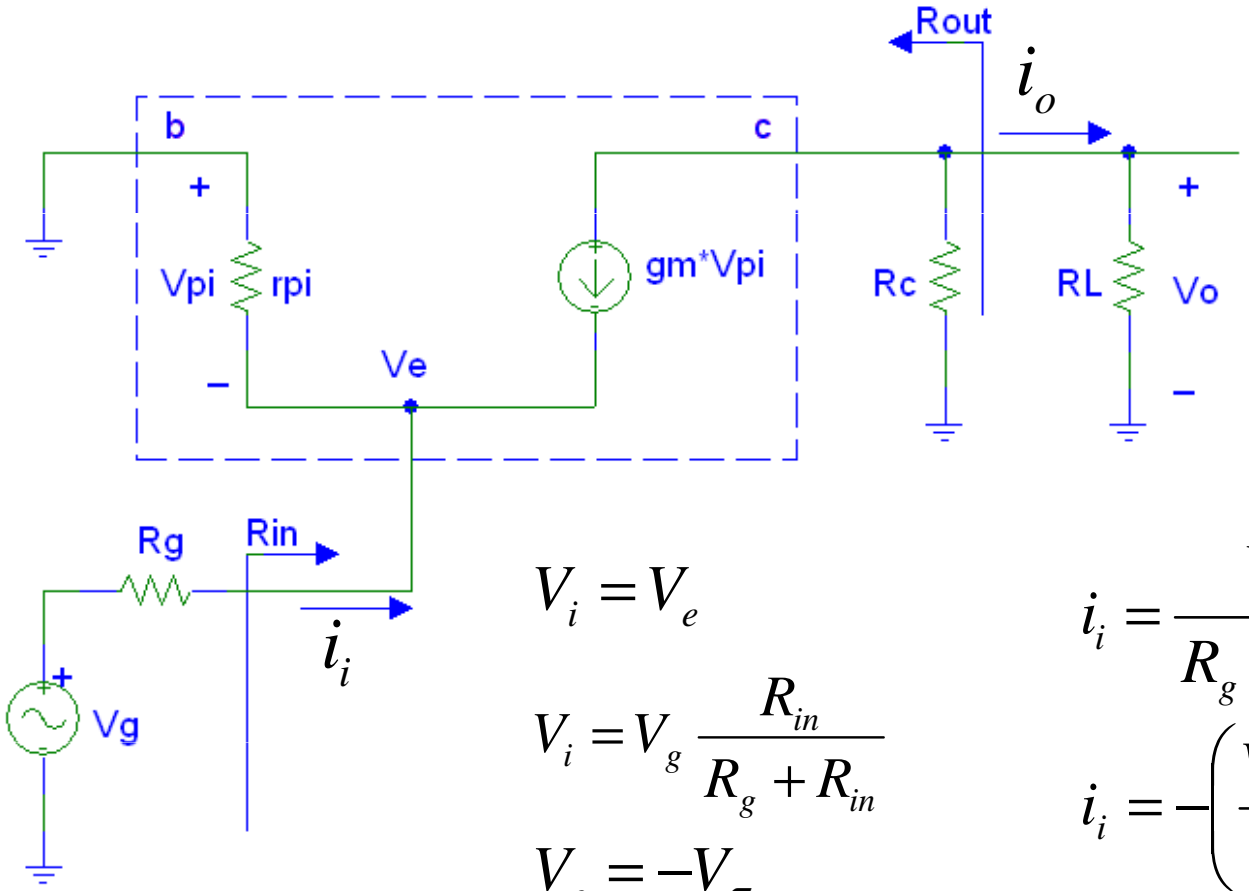


EXAMPLE

- …

$$I_{CQ} \approx 1mA$$

Common-base (Small Signal)



$$V_i = V_e$$

$$V_i = V_g \frac{R_{in}}{R_g + R_{in}}$$

$$V_e = -V_\pi$$

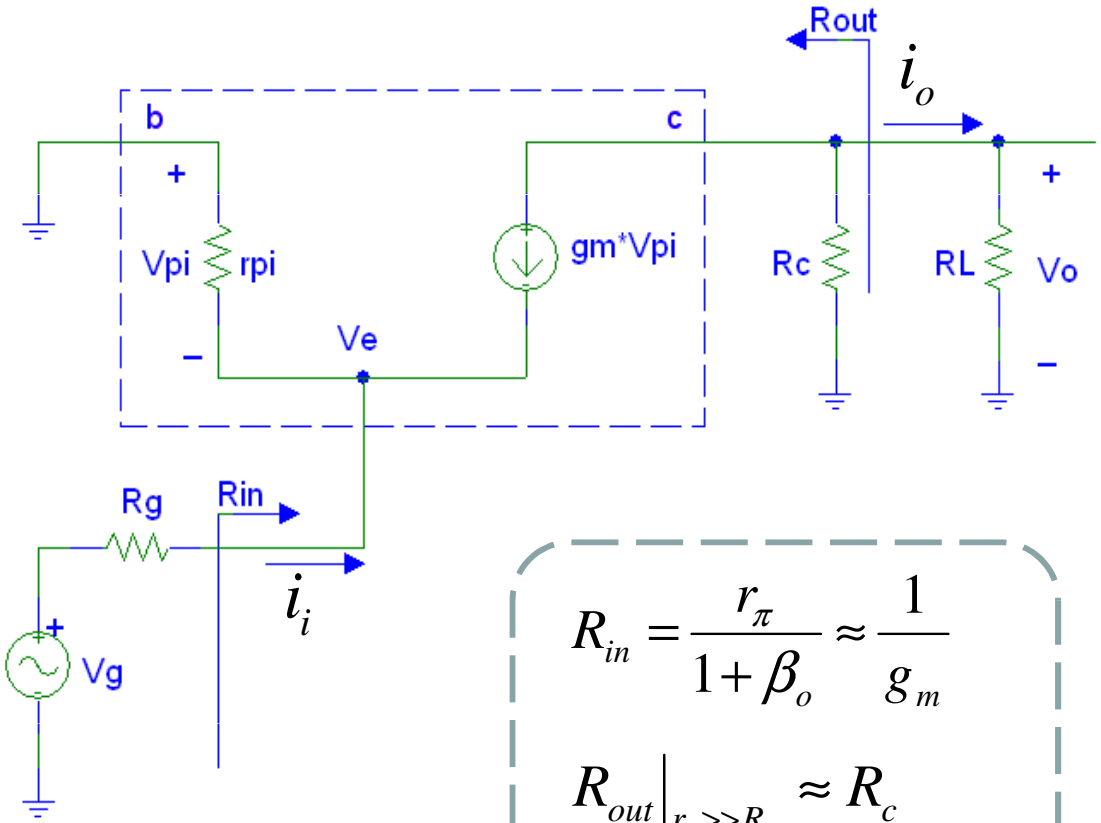
$$V_o \approx -g_m V_\pi (R_c // R_L)$$

$$i_i = \frac{V_g}{R_g + R_{in}}$$

$$i_i = -\left(\frac{V_\pi}{r_\pi} + g_m V_\pi \right)$$

$$i_o = -g_m V_\pi \frac{R_{out}}{R_L + R_{out}}$$

Common-base (Characteristics)



$$A_v = \frac{V_o}{V_i} = +g_m (R_c \,//\, R_L)$$

$$R_{in} = \frac{r_\pi}{1+\beta_o} \approx \frac{1}{g_m}$$

$$R_{out}\Big|_{r_o >> R_c} \approx R_c$$

$$A_{vo} = +g_m R_c$$

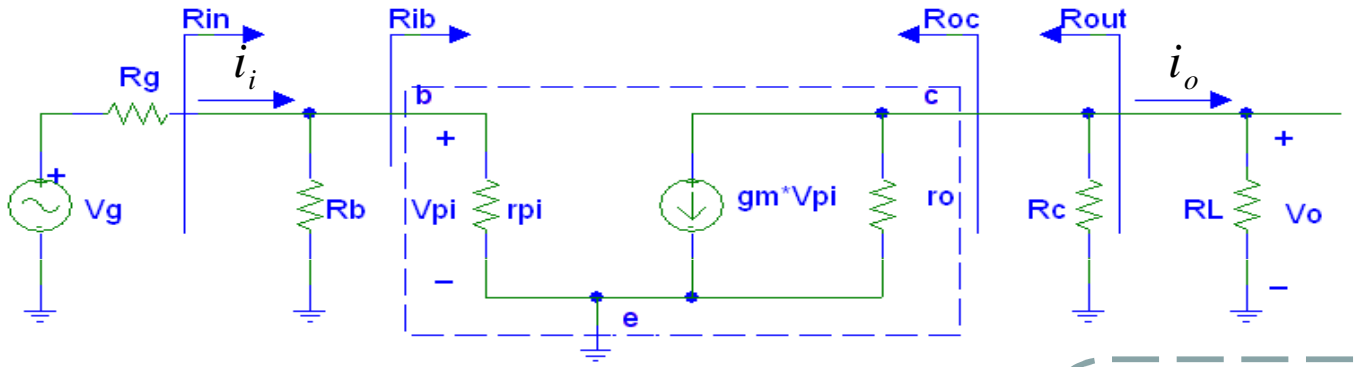
$$A_{i(sc)} = \alpha$$

Comparison

Stage	Rin	Rout	Av	Ai(sc)
CE	$R_b // r_\pi \approx r_\pi$	$R_c // r_o$	✸ $-g_m(r_o // R_c // R_L)$	$-g_m R_{in} \approx -\beta_o$
CE-RE	✸ $R_b // [r_\pi + (1+\beta_o)R_e]$	R_c	✸ $-\dfrac{\beta_o(R_c // R_L)}{r_\pi + (1+\beta_o)\cdot R_e}$	$-\beta_o \dfrac{R_b + R_{ib}}{R_b} \approx -\beta_o$
CC	✸ $R_b // [r_\pi + (1+\beta_o)\cdot R_{EM}]$	✸ $\dfrac{r_\pi + (R_b // R_g)}{1+\beta_o}$	$\dfrac{(1+\beta_o)\cdot R_{EM}}{r_\pi + (1+\beta_o)\cdot R_{EM}} \approx 1$	$(1+\beta_o)\dfrac{R_b + R_{ib}}{R_b}$
CB	$\dfrac{r_\pi}{1+\beta_o} \approx \dfrac{1}{g_m}$ ✸	R_c	$+g_m(R_c // R_L)$	$\dfrac{\beta_o}{(1+\beta_o)} = \alpha$

$$G_v = A_v \frac{R_{in}}{R_g + R_{in}} \qquad G_v\Big|_{CE}^{máx} \approx -g_m r_o = -\frac{V_A}{V_T} \qquad G_v\Big|_{CC}^{máx} \approx 1$$

ANNEX 1: Characteristics CE



$$R_{ib} = r_\pi$$

$$R_{oc} = r_o$$

$$R_{in} = R_b \,//\, r_\pi \qquad R_{in}\big|_{R_b >> r_\pi} \approx r_\pi$$

$$R_{out} = R_c \,//\, r_o \qquad R_{out}\big|_{r_o >> R_c} \approx R_c$$

$$A_v = \frac{V_o}{V_\pi} = -g_m (r_o \,//\, R_c \,//\, R_L)$$

$$A_{vo} = -g_m (r_o \,//\, R_c)$$

$$A_{vo}\big|_{r_o >> R_c} \approx -g_m R_c$$

$$G_v = \frac{V_o}{V_g} = -g_m (r_o \,//\, R_c \,//\, R_L)\frac{R_{in}}{R_g + R_{in}}$$

$$G_v\big|_{R_b >> r_\pi} \approx -\frac{\beta_o}{R_g + r_\pi}(r_o \,//\, R_c \,//\, R_L)$$

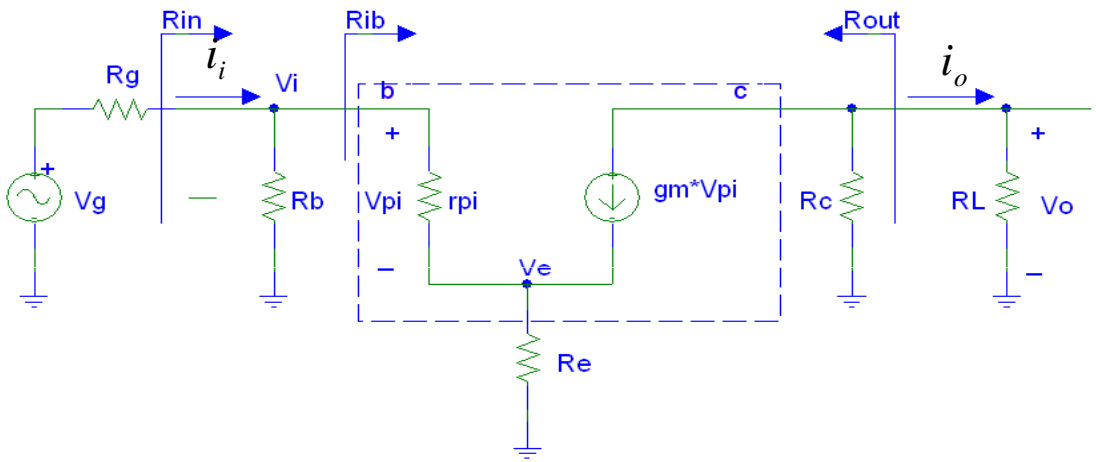
$$G_v\Big|_{R_b >> r_\pi}^{R_g << r_\pi} \approx -g_m (r_o \,//\, R_c \,//\, R_L)$$

$$A_i = \frac{i_o}{i_i} = -g_m \frac{R_{out}}{R_L + R_{out}} R_{in}$$

$$A_{i(sc)} = -g_m R_{in}$$

$$A_{i(sc)}\big|_{R_b >> r_\pi} = -\beta_o$$

ANNEX 2: Characteristics CE with RE



$$R_{ib} = \frac{V_\pi + V_e}{V_\pi / r_\pi} = r_\pi + (1+\beta_o)R_e$$

$$R_{in} = R_b \,//\left[r_\pi + (1+\beta_o)R_e\right]$$

$$R_{out}\Big|_{r_o >> R_c} \approx R_c$$

$$A_v = \frac{V_o}{V_i} = -\frac{\beta_o (R_c \,//\, R_L)}{r_\pi + (1+\beta_o)\cdot R_e}$$

$$G_v = \frac{V_o}{V_g} = -\frac{\beta_o (R_c \,//\, R_L)}{r_\pi + (1+\beta_o)R_e} \cdot \frac{R_{in}}{R_g + R_{in}}$$

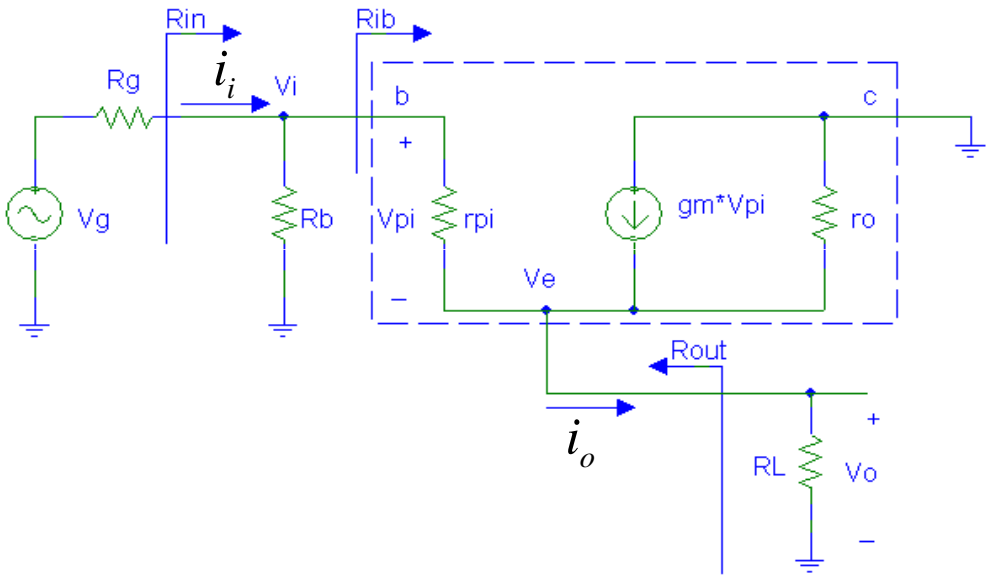
$$A_i = \frac{i_o}{i_i} = -\beta_o \frac{R_c}{R_L + R_c} \frac{R_b + R_{ib}}{R_b}$$

$$A_{vo} = -\frac{\beta_o R_c}{r_\pi + (1+\beta_o)R_e} \approx -\frac{g_m R_c}{1 + g_m R_e}$$

$$G_v\Big|_{r_\pi << \beta_o R_e}^{R_g << R_{in}} \approx -\frac{(R_c \,//\, R_L)}{R_e} \approx -\frac{R_c}{R_e} \cdot \frac{R_L}{R_c + R_L}$$

$$A_{i(sc)} = -\beta_o \frac{R_b + R_{ib}}{R_b} \qquad A_{i(sc)}\Big|_{R_b >> R_{ib}}^{Rg << R_{in}} \approx -\beta_o$$

ANNEX 3: Characteristics CC



$$R_{ib} = \frac{V_\pi + V_e}{V_\pi / r_\pi} = r_\pi + (1+\beta_o)\cdot R_{EM}$$

$$R_{in} = R_b \,//\left[r_\pi + (1+\beta_o)\cdot R_{EM}\right]$$

$$R_{out} = r_o \,// \frac{r_\pi + \left(R_b \,// R_g\right)}{1+\beta_o} \approx \frac{r_\pi + \left(R_b \,// R_g\right)}{1+\beta_o}$$

$$G_v = \frac{V_o}{V_g} = \frac{(1+\beta_o)\cdot R_{EM}}{r_\pi + (1+\beta_o)\cdot R_{EM}} \cdot \frac{R_{in}}{R_g + R_{in}} \approx 1$$

$$A_v = \frac{V_o}{V_i} = \frac{(1+\beta_o)\cdot R_{EM}}{r_\pi + (1+\beta_o)\cdot R_{EM}}$$

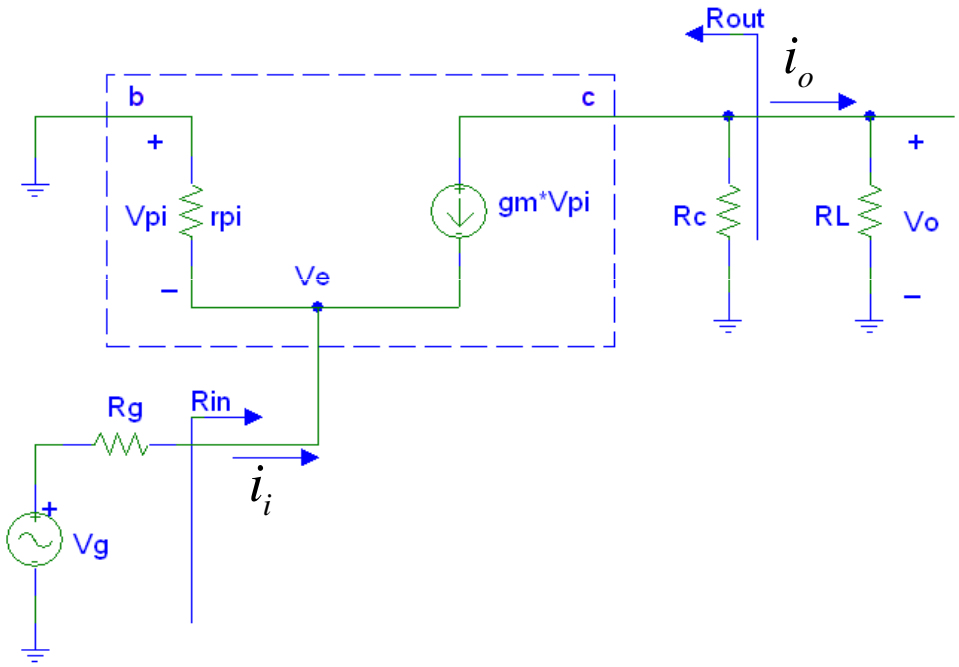
$$A_{vo} = \frac{(1+\beta_o)\cdot r_o}{r_\pi + (1+\beta_o)\cdot r_o} \approx 1$$

$$A_i = \frac{i_o}{i_i} = (1+\beta_o)\frac{r_o}{r_o + R_L}\frac{R_b + R_{ib}}{R_b}$$

$$A_{i(sc)} = (1+\beta_o)\frac{R_b + R_{ib}}{R_b}$$

$$A_{i(sc)}\Big|_{\substack{Rg<<R_{in} \\ R_b>>R_{ib}}} \approx 1+\beta_o$$

ANNEX 4: Characteristics CB



$$R_{in} = \frac{r_\pi}{1+\beta_o} \approx \frac{1}{g_m}$$

$$R_{out}\Big|_{r_o >> R_c} \approx R_c$$

$$A_v = \frac{V_o}{V_i} = +g_m (R_c \,//\, R_L)$$

$$A_{vo} = +g_m R_c$$

$$G_v = \frac{V_o}{V_g} = +g_m (R_c \,//\, R_L)\frac{R_{in}}{R_g + R_{in}}$$

$$G_v = \frac{V_o}{V_g} = g_m (R_c \,//\, R_L)\frac{1}{1+g_m R_g}$$

$$A_i = \frac{i_o}{i_i} = \frac{\beta_o}{(1+\beta_o)}\frac{R_c}{R_c + R_L} = \alpha\frac{R_c}{R_c + R_L}$$

$$A_{i(sc)} = \alpha$$