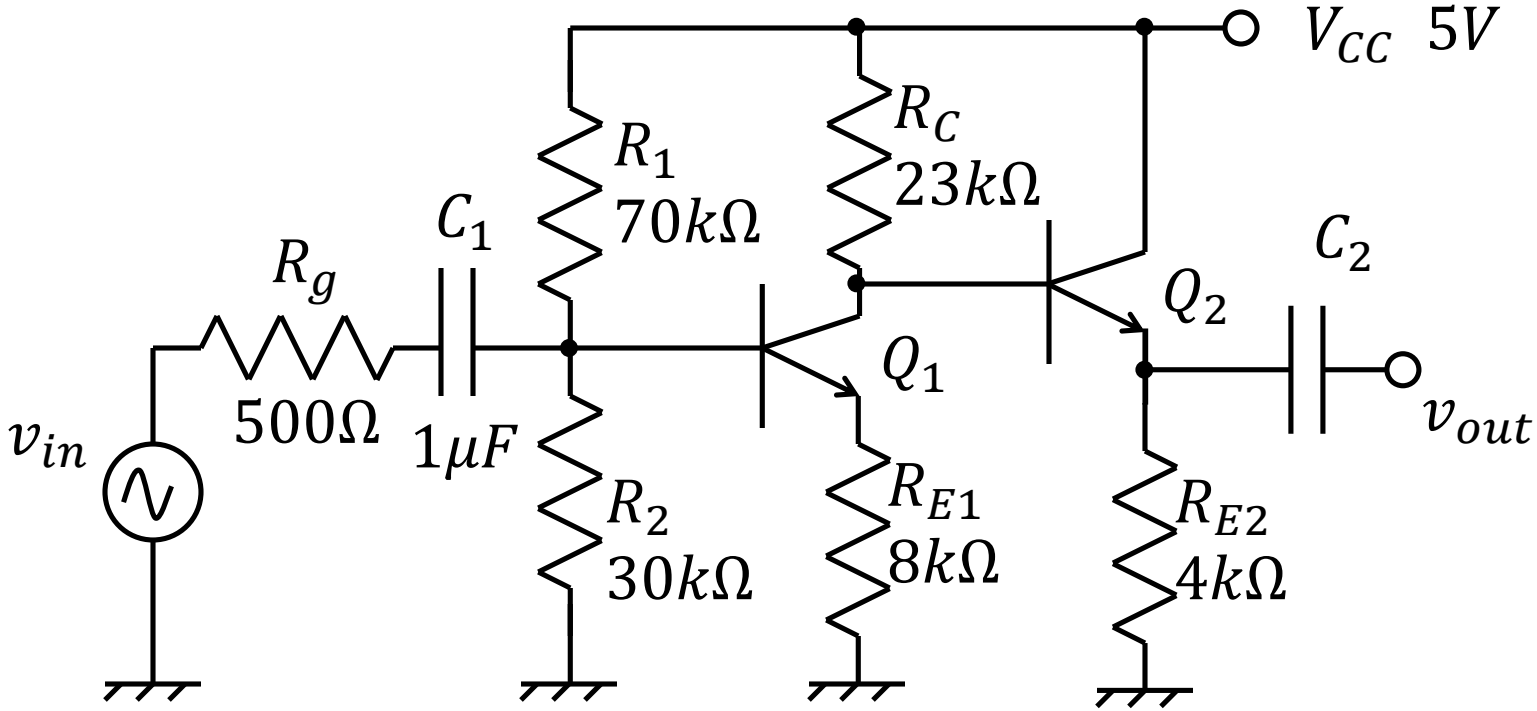
Bipolar Junction Transistor

- MOSFETと並ぶ能動デバイス
- 高周波特性に優れる

BJT増幅回路

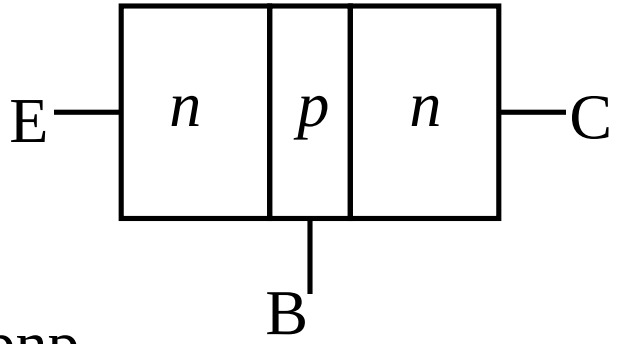


- 各部の直流電位
  - トランジスタはナレータ・ノレータモデル、$V_{BE} = 0.7$とする
- 小信号中域利得
- 出力インピーダンス
- 低域遮断周波数
  - ただし$r_b = 50\Omega, \beta_0 = 99, r_o = \infty$とする

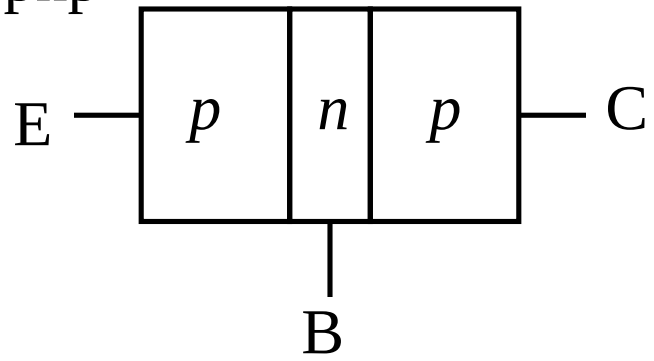
BJTの構造

教科書

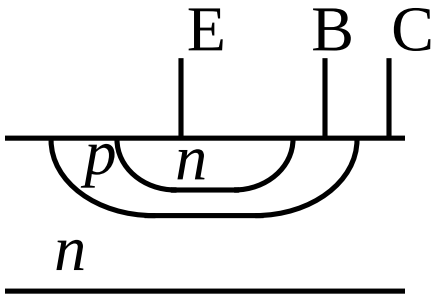
npn



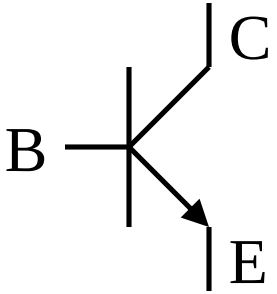
pnp

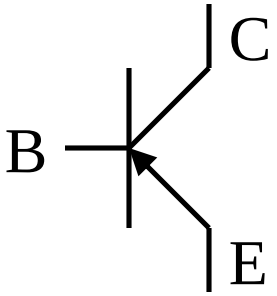


実際



シンボル

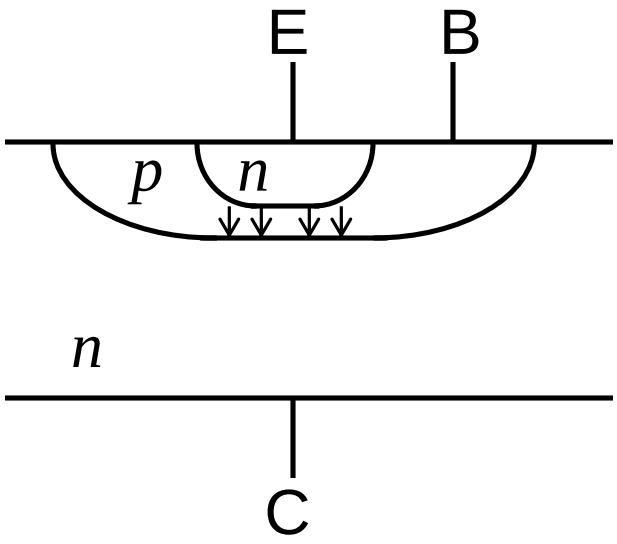




BJTの動作領域

B-E接合 / B-C接合	順	逆
順	飽和	
逆	順方向 能動領域	遮断

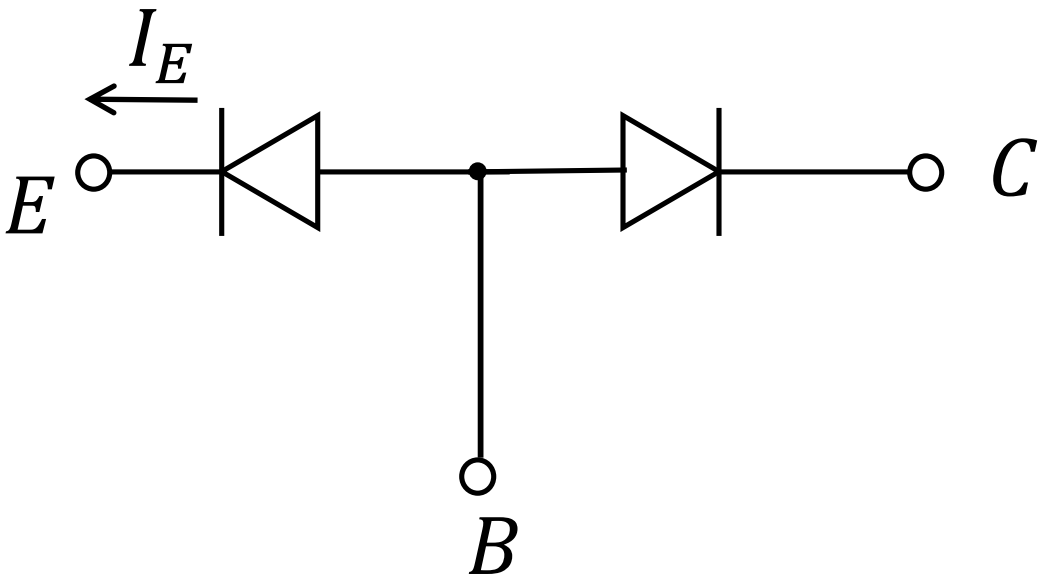
BJTの能動領域での動作



- B-E接合の電流はダイオードの式で
- B-C接合の電流はB-E接合の電流とほぼ等しい

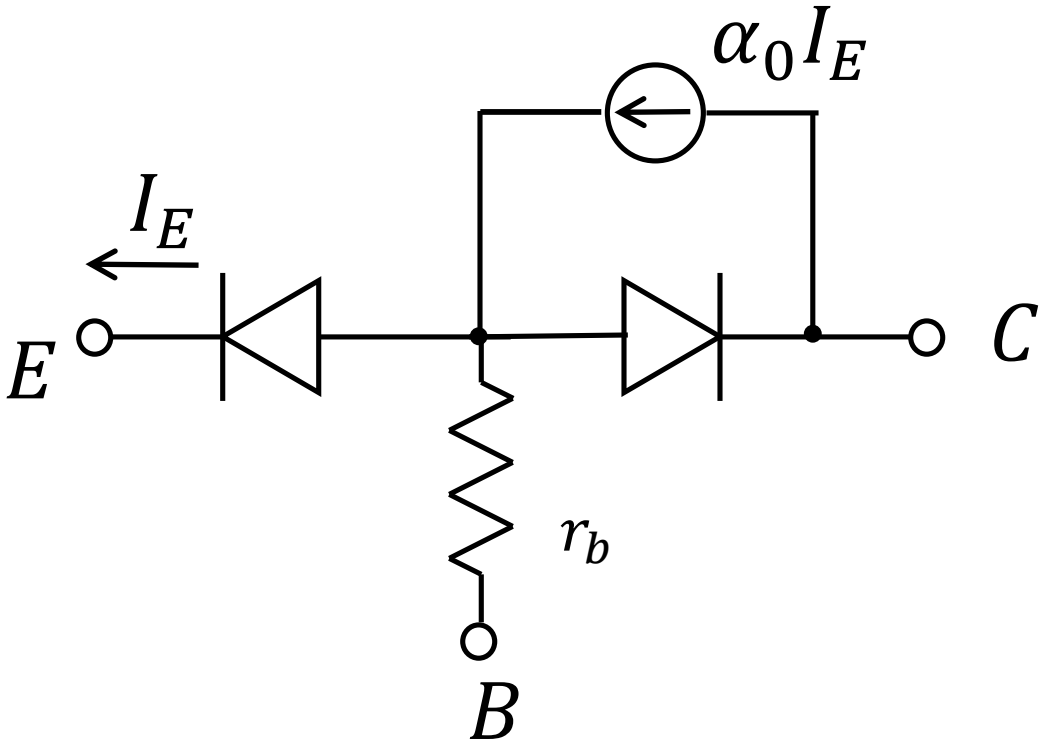
ベース領域は□が薄く、□も薄い

BJTの大域モデル(1)



ダイオードの背中合わせ接続?

BJTの大域モデル(2)



Ebers-Mollのモデル

電流增幅率

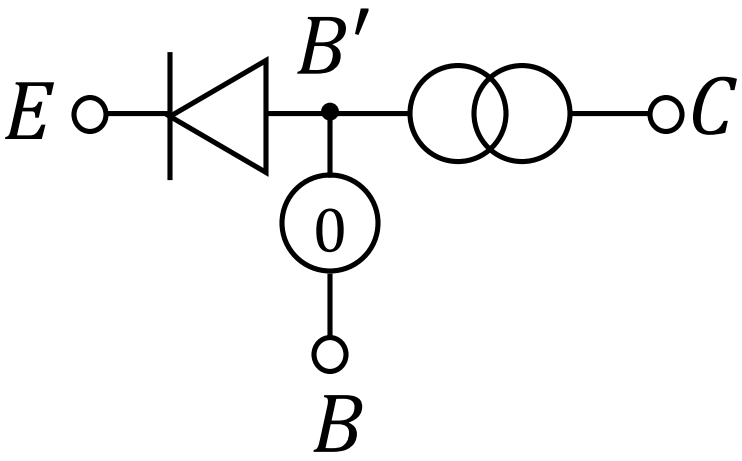
$$\alpha_0 = \frac{I_C}{I_E} \qquad \alpha = \frac{\Delta I_C}{\Delta I_E}$$

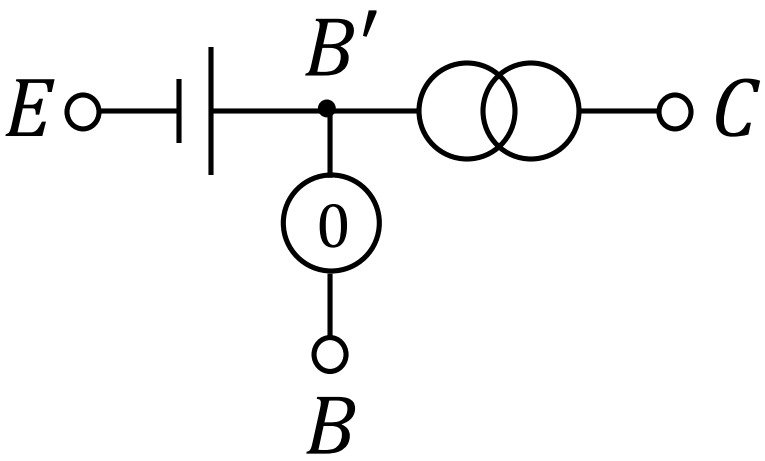
$$\beta_0 = \frac{I_C}{I_B} = \frac{I_C}{I_E - I_C} = \frac{\alpha_0}{1-\alpha_0}, \qquad \beta = \frac{\Delta I_C}{\Delta I_B} = \frac{\alpha}{1-\alpha}$$

理想トランジスタ

$\alpha_0 \to 1,$ $I_B \to 0$

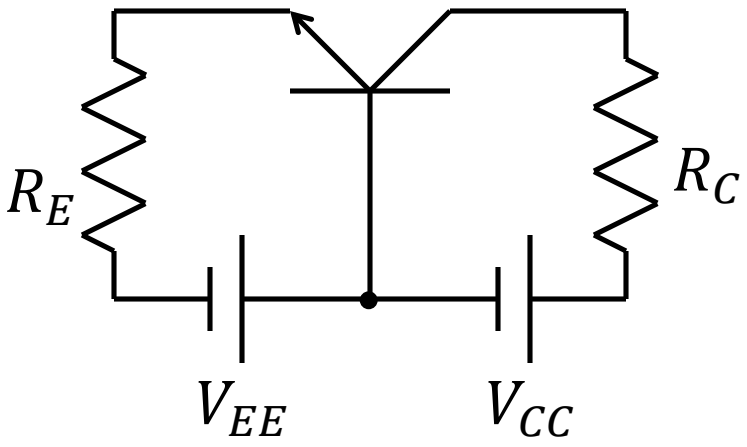
B-B'がナレータ
コレクタはノレータ



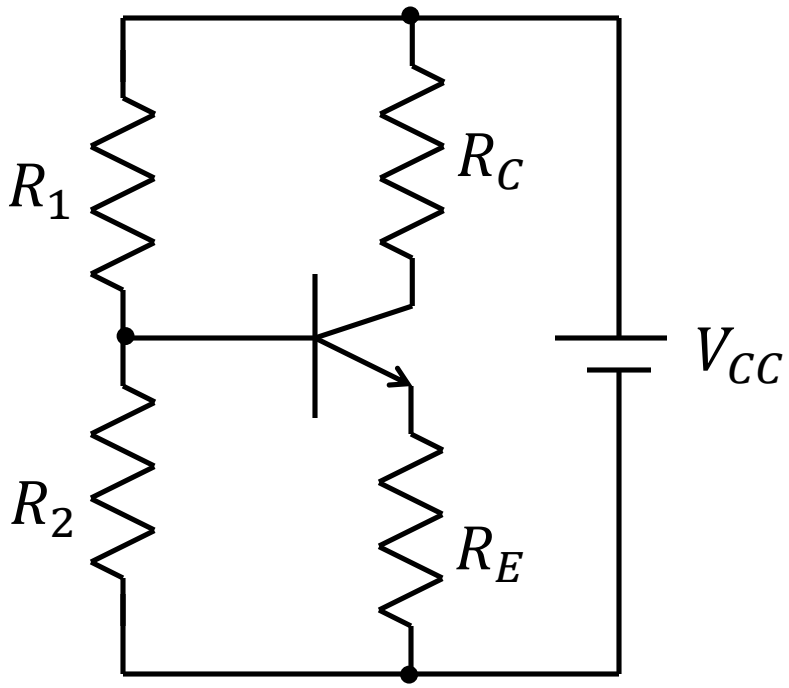


線形近似(大域)

BJTのバイアス

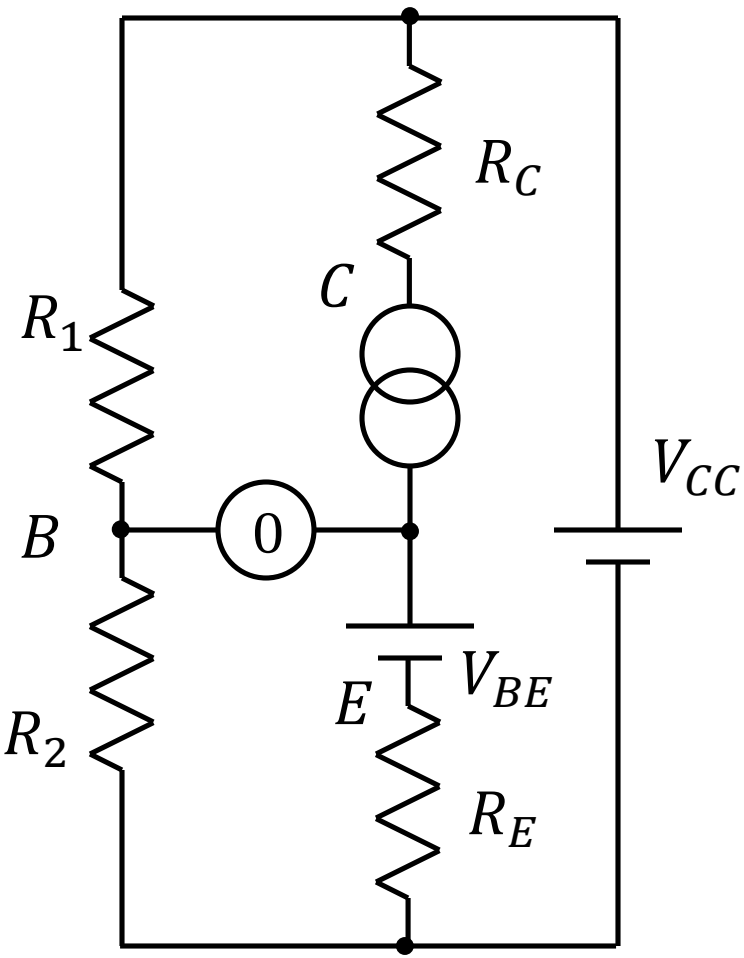


二電源バイアス



一電源バイアス

一電源バイアスの簡易計算



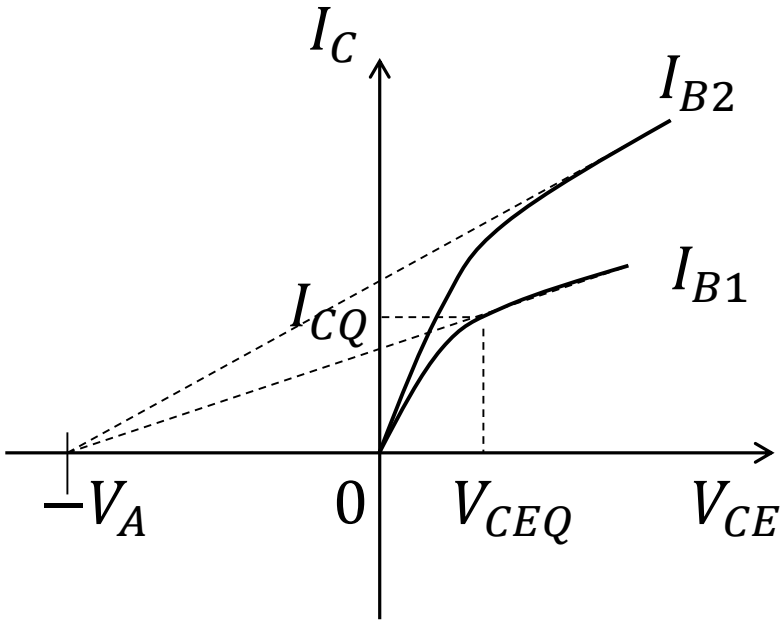
$$V_B = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$V_E = V_B - V_{BE}$$

$$I_E = \frac{V_E}{R_E} = I_C$$

$$V_C = V_{CC} - R_C I_C$$

ベース幅変調効果(Early Effect)



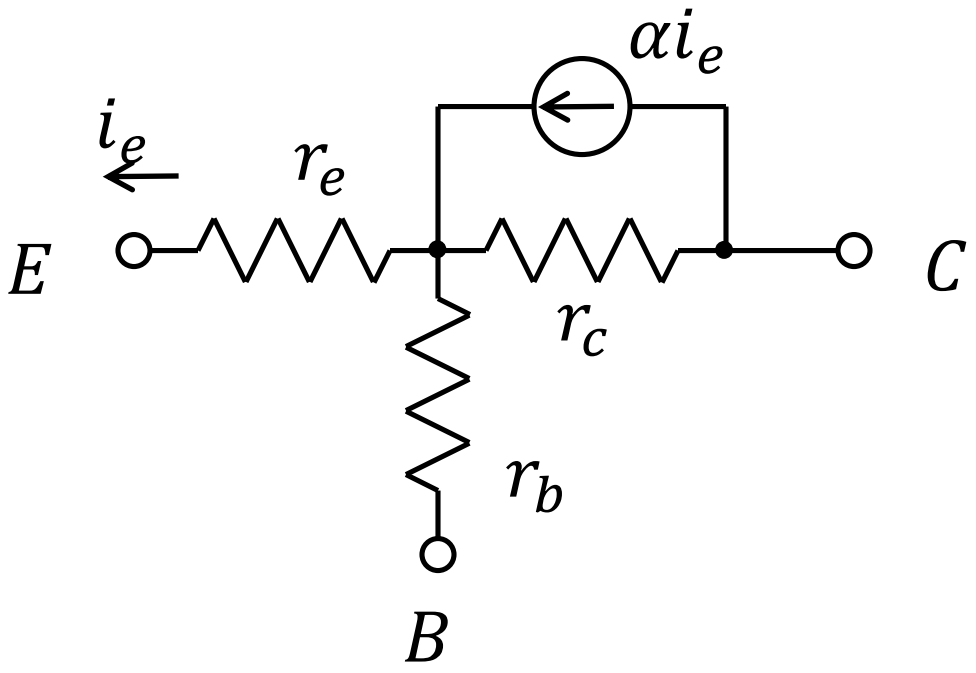
- 理想ではI_CはV_{CE}に依存しない
- 実際にはV_{CE}が大きくなるとB-C接合の空乏層が広がり実効的なベース幅が狭くなりI_Cが増加する

$$I_C = \beta_0 I_B \left(1 + \frac{V_{CE}}{V_A}\right)$$

$$r_o = \frac{V_A + V_{CEQ}}{I_{CQ}}$$

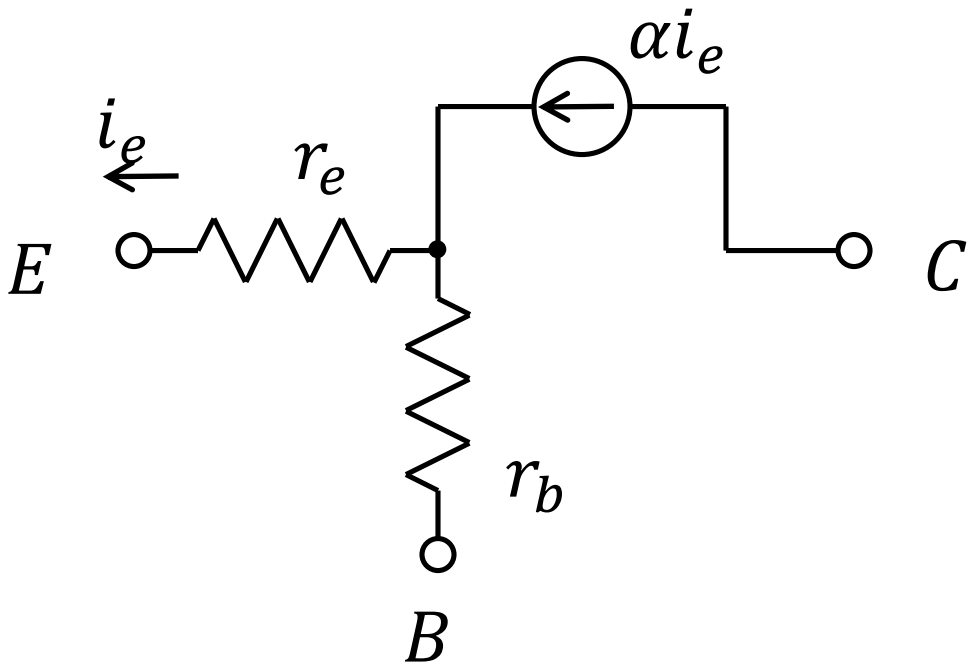
James M. Early: Effects of space-charge layer widening in junction transistors, Proc. IRE, vol.40, No.11, pp.1401-1406, Nov. 1952

小信号モデル（ベース共通）(1)



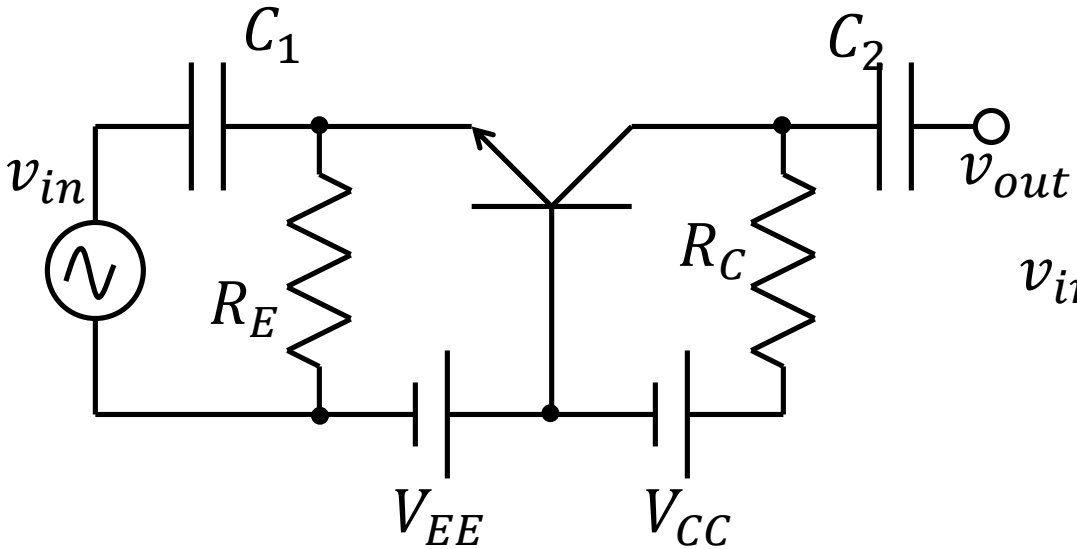
$$r_e = \frac{V_T}{I_E}$$

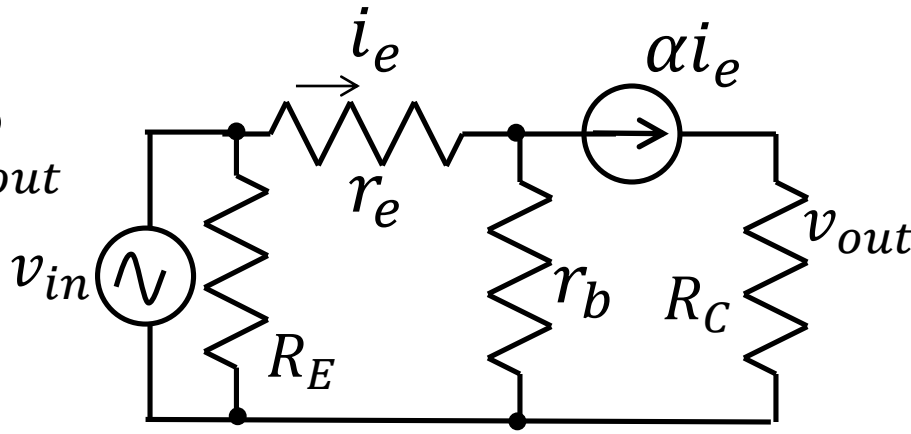
小信号モデル（ベース共通）(2)



$$r_e = \frac{V_T}{I_E}$$

ベース共通増幅回路





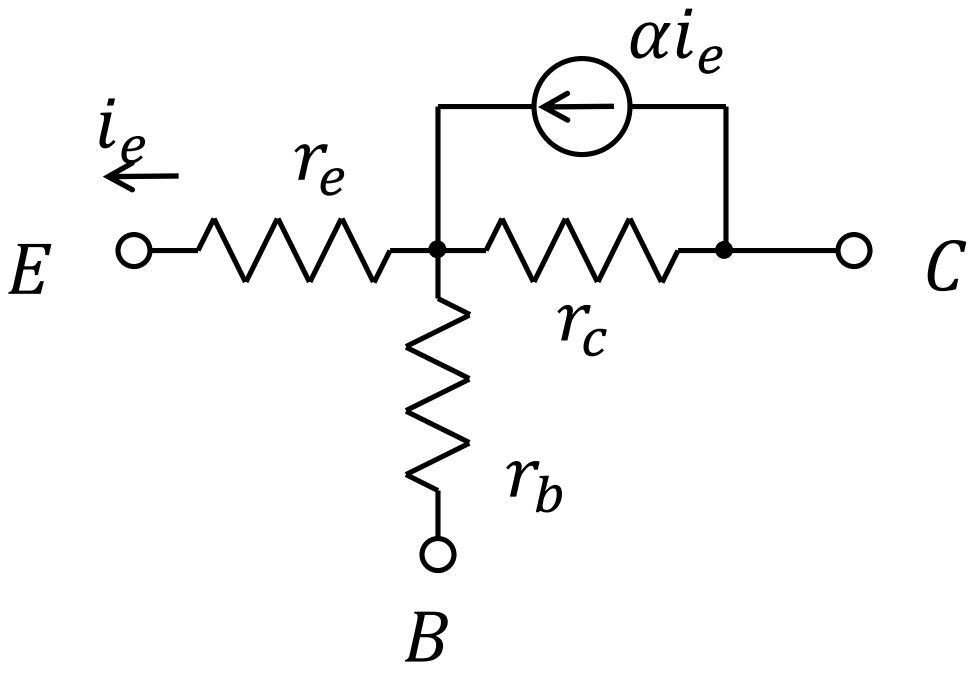
$$v_{in} = r_e i_e + (1-\alpha) r_b i_e$$

$$v_{out} = \alpha R_C i_e = \frac{\alpha R_C}{r_e + (1-\alpha) r_b} v_{in}$$

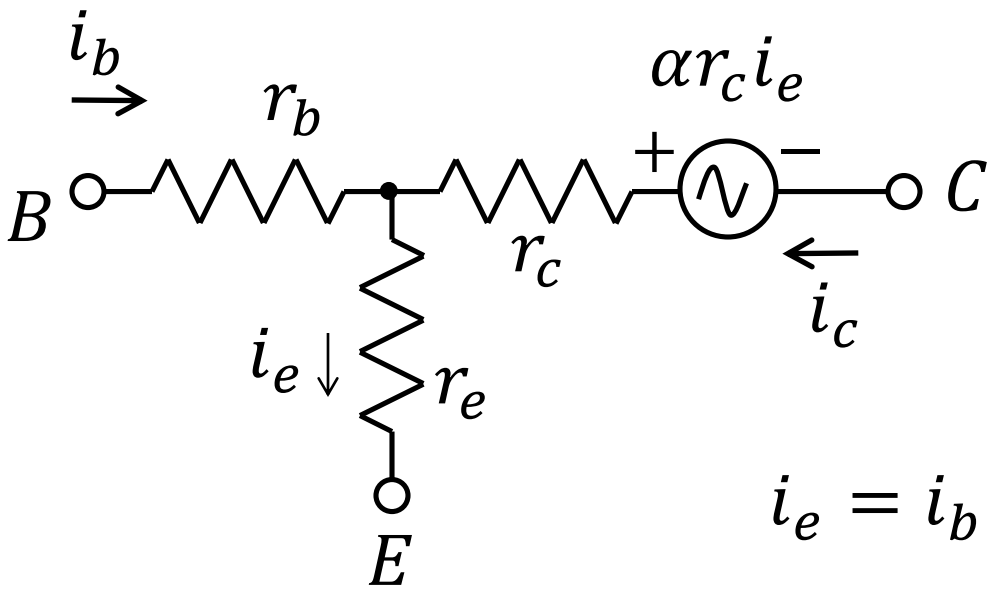
$$r_{in} = r_e + (1-\alpha) r_b$$

$$r_{out} = \infty$$

小信号モデル（エミッタ共通）(1)

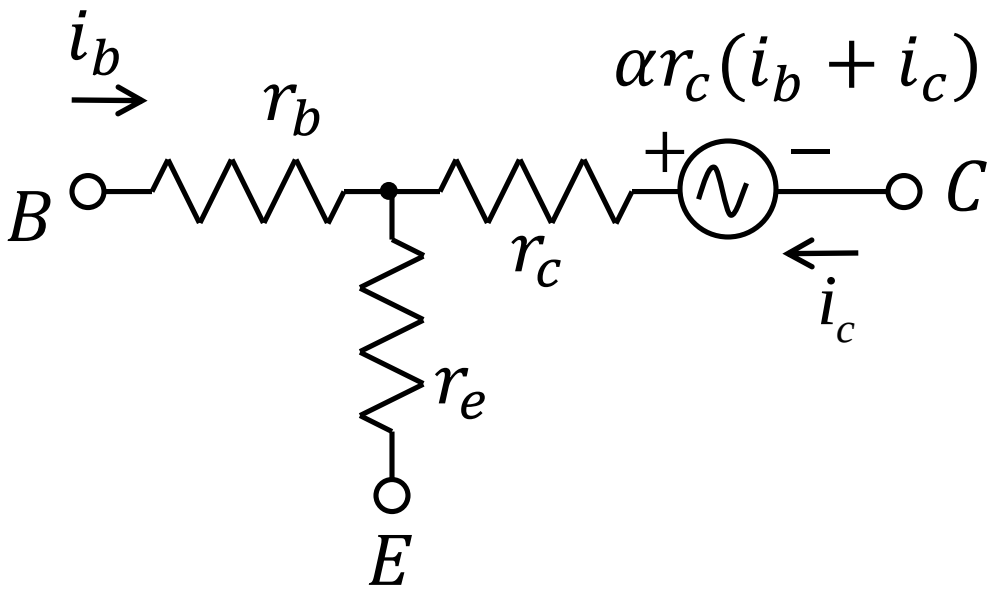


小信号モデル（エミッタ共通）(2)

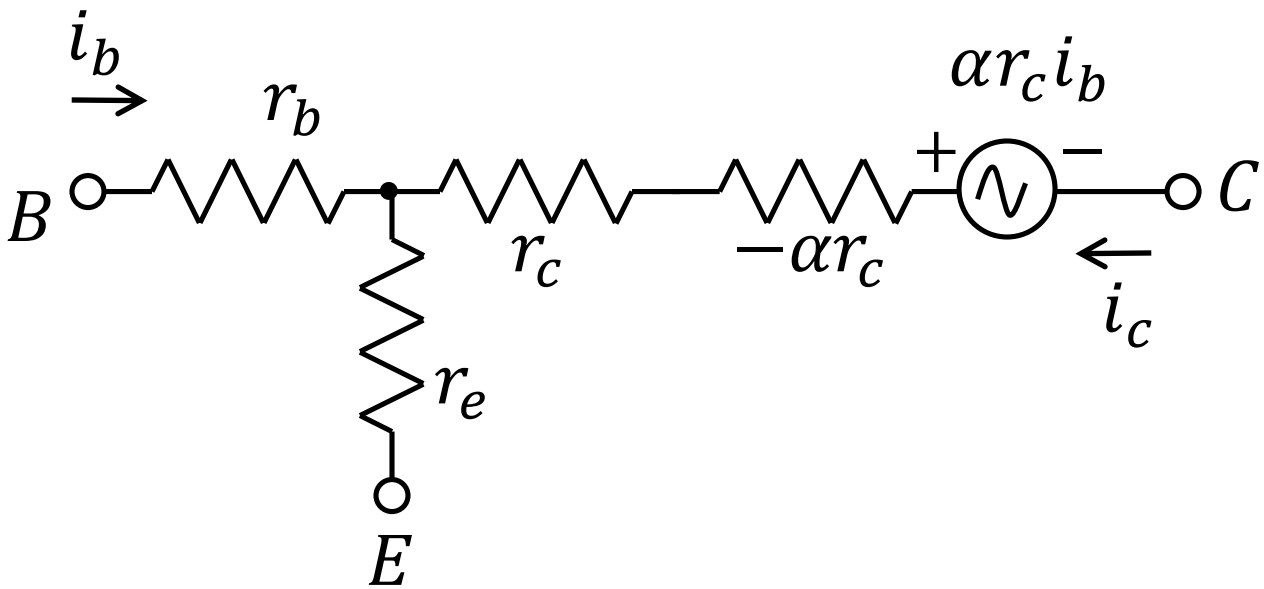


$$i_e = i_b + i_c$$

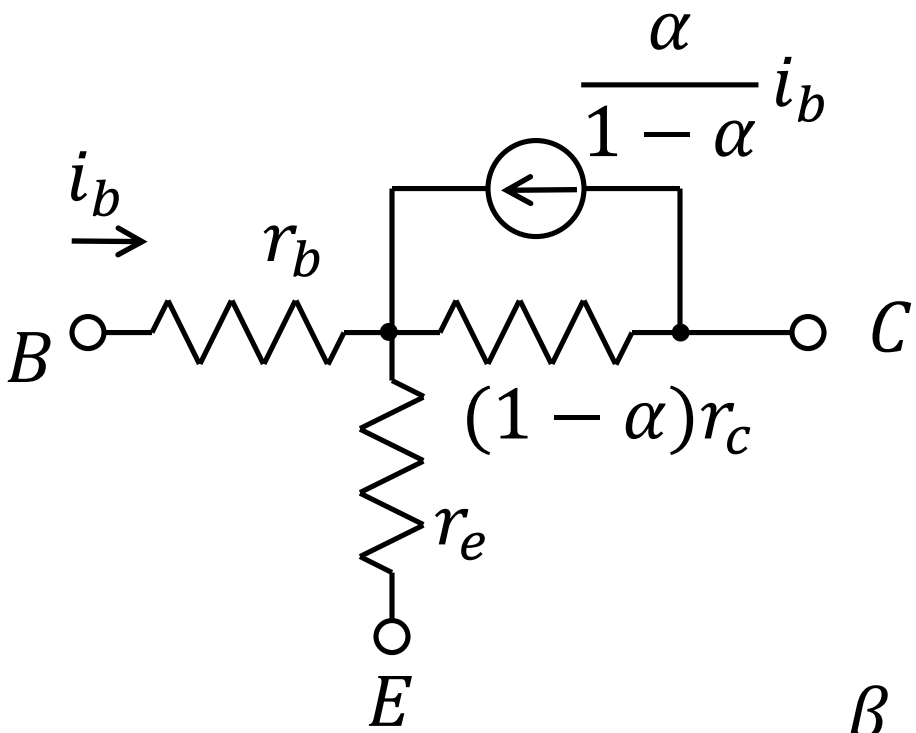
小信号モデル（エミッタ共通）(3)



小信号モデル（エミッタ共通）(4)

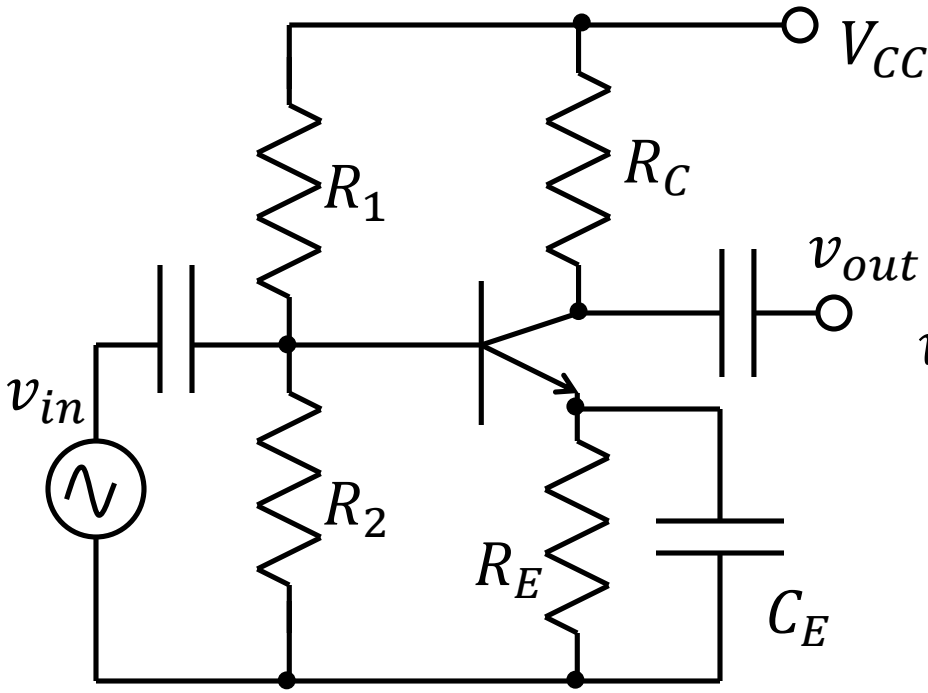


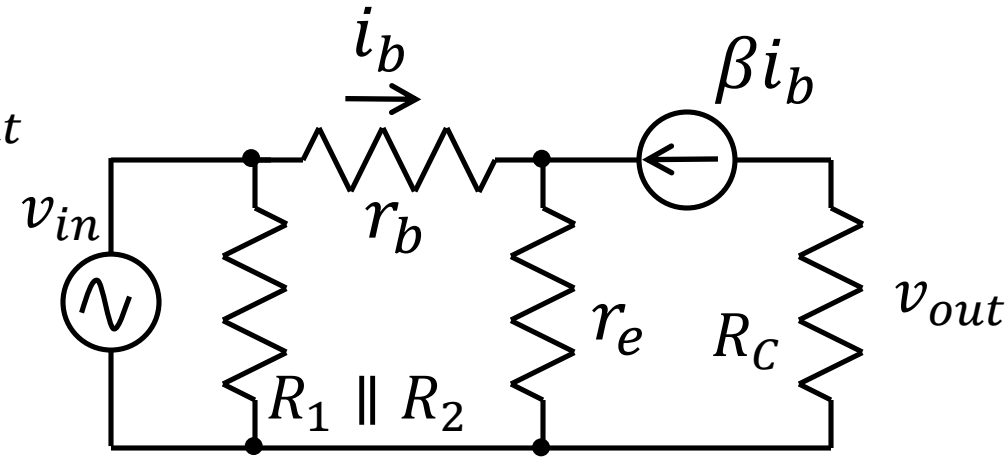
小信号モデル（エミッタ共通）(5)



$$\beta = \frac{\alpha}{1-\alpha}$$

エミッタ共通増幅回路





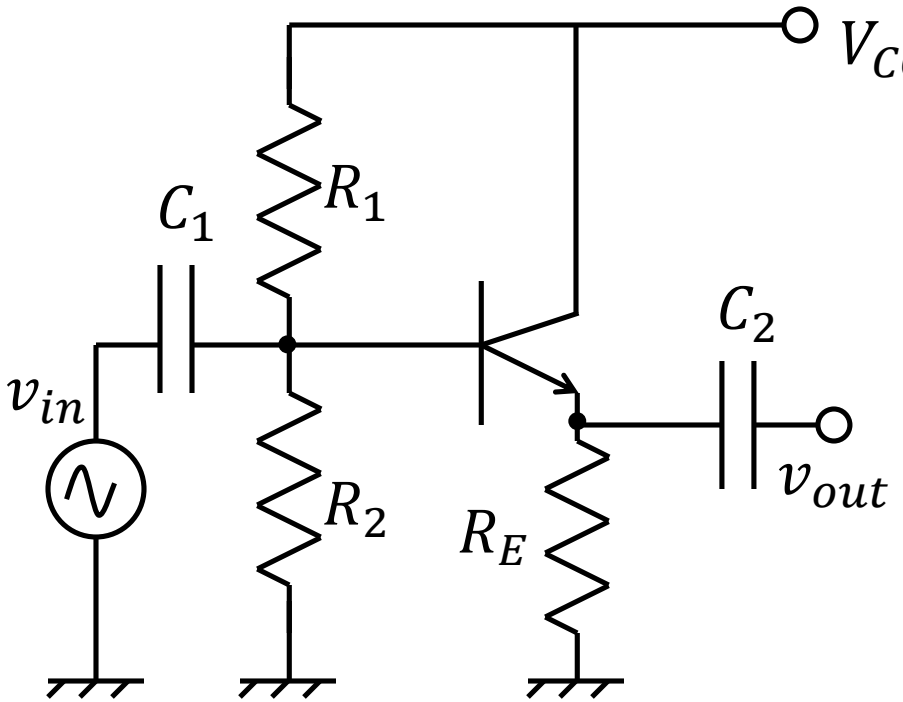
$$v_{in} = r_b i_b + (1+\beta) r_e i_b$$

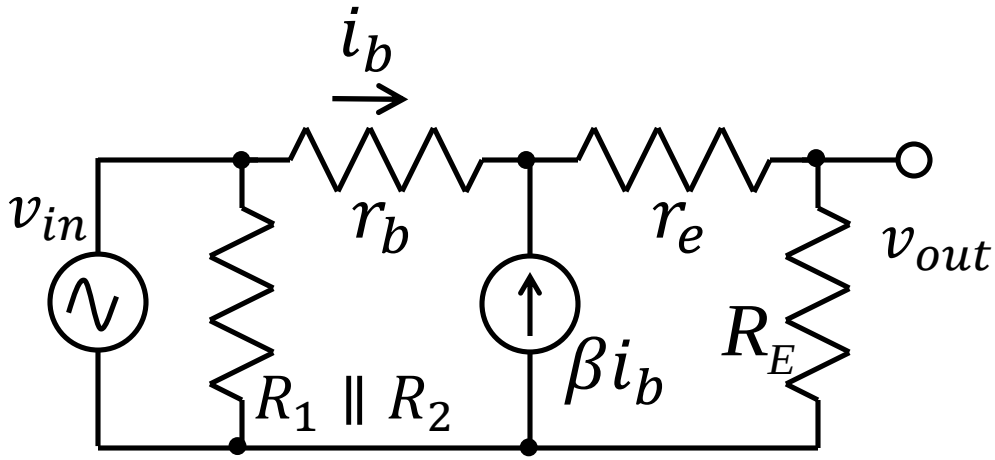
$$v_{out} = -\beta R_C i_b = \frac{-\beta R_C}{r_b + (1+\beta) r_e} v_{in}$$

$$r_{in} = r_b + (1+\beta) r_e$$

$$r_{out} = \infty$$

エミッタフォロア回路





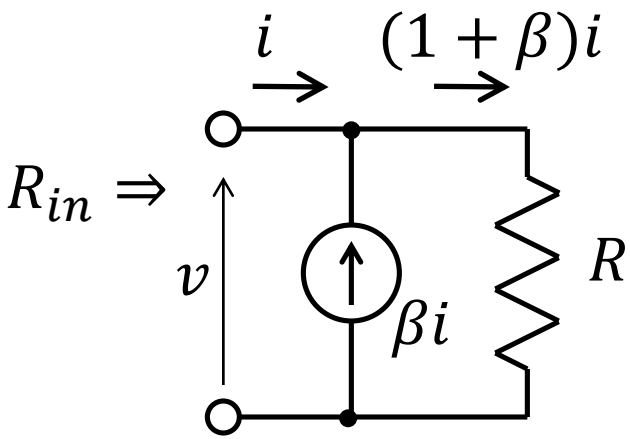
$$v_{in} = r_b i_b + (1+\beta)(r_e + R_E) i_b$$

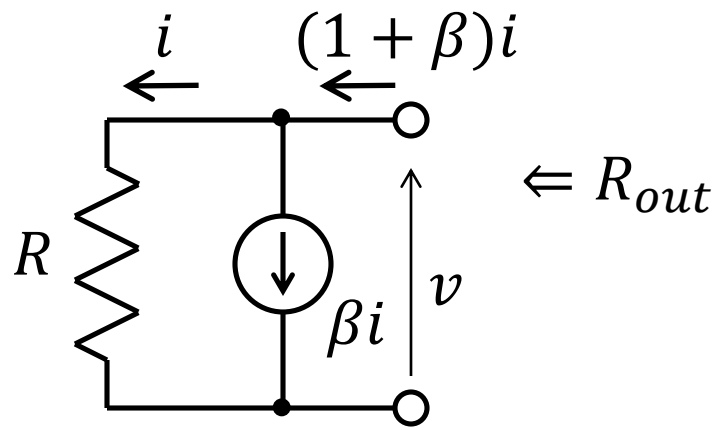
$$v_{out} = (1+\beta) R_E i_b = \frac{(1+\beta) R_E}{r_b + (1+\beta)(r_e + R_E)} v_{in}$$

$$r_{in} = r_b + (1+\beta)(r_e + R_E)$$

$$r_{out} = \frac{r_b}{1+\beta} + r_e$$

インピーダンス変換作用





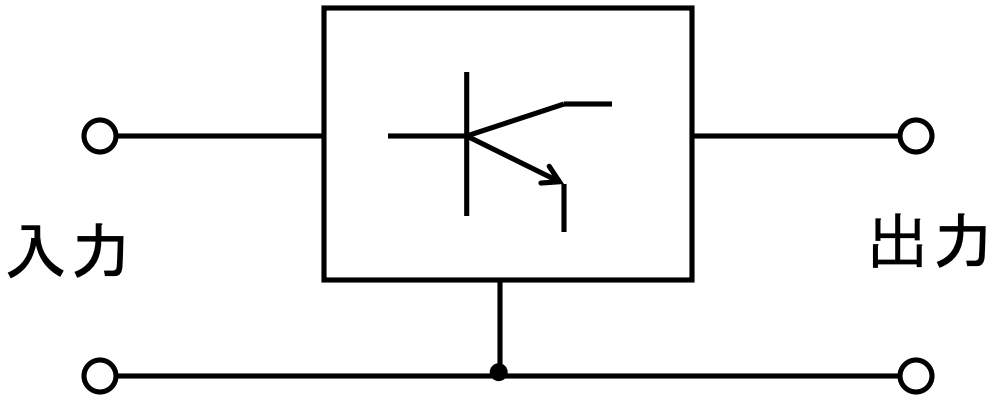
$$v = R(1+\beta)i$$

$$R_{in} = \frac{v}{i} = (1+\beta)R$$

$$v = Ri$$

$$R_{out} = \frac{v}{(1+\beta)i} = \frac{R}{1+\beta}$$

その他の増幅回路？

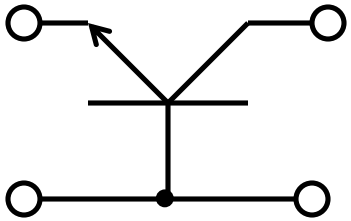


純粋に組み合わせ理論的には [ ] 通り

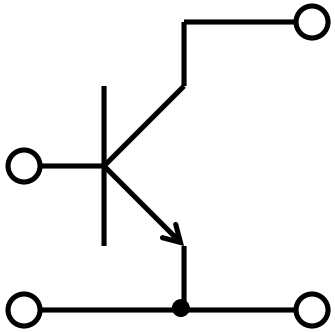
- ベースは出力端子にはならない
- コレクタは入力端子にはならない

3通り

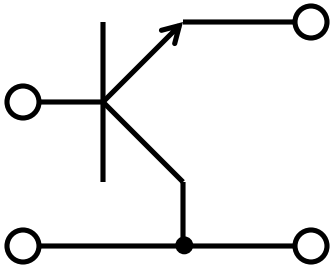
増幅回路の形式



ベース共通



エミック共通



コレクタ共通

BJTの高周波動作

高周波では

- αが周波数特性をもつ

$$\alpha = \frac{\alpha_0}{1 + \frac{j\omega}{\omega_\alpha}}$$

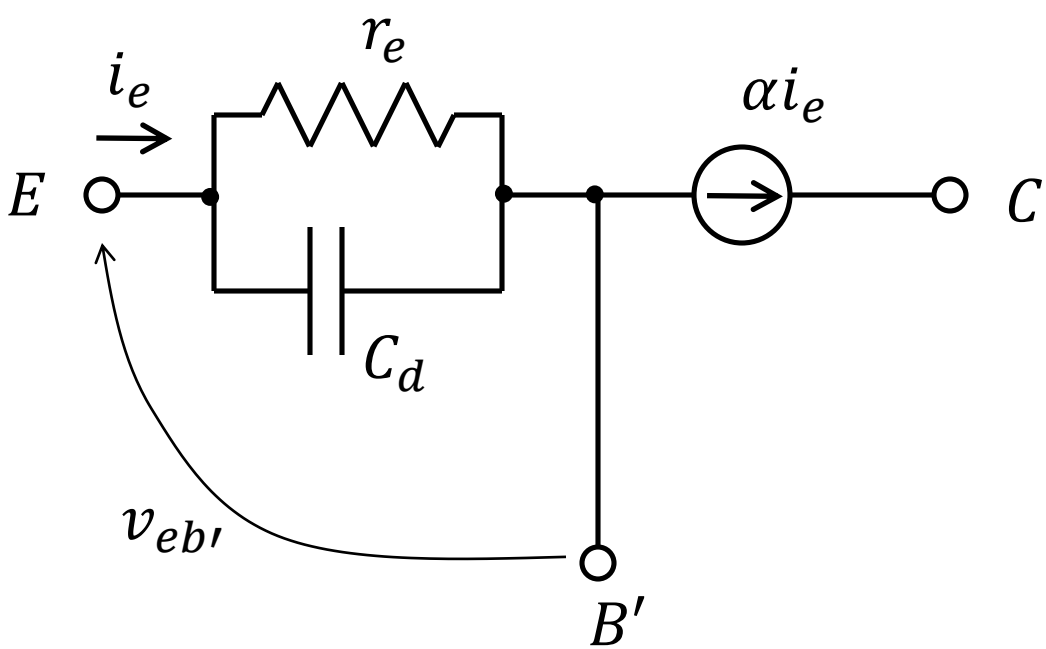
- 拡散容量が無視できない

$$r_e \Rightarrow r_e \,//\, C_d$$

$$C_d = \frac{1}{\omega_\alpha r_e}$$

BJTの高周波モデル(1)

真性トランジスタ

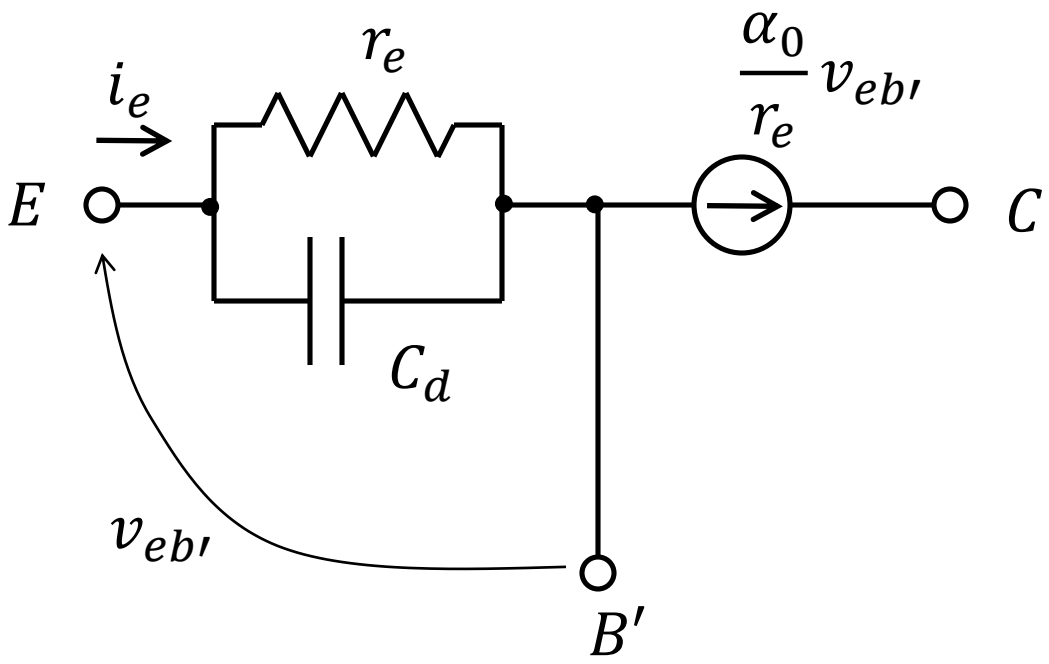


$$i_e = \frac{v_{eb'}}{r_e \,//\, \frac{1}{j\omega C_d}}$$

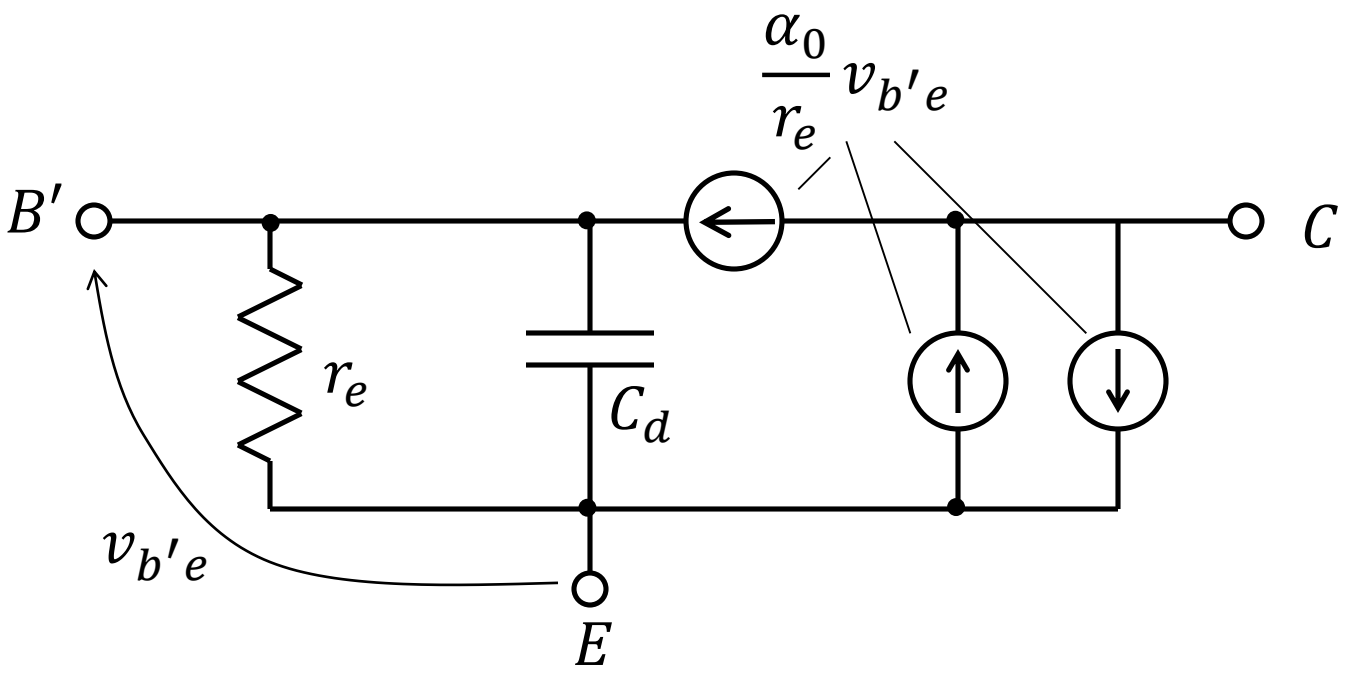
$$= \frac{v_{eb'}}{\frac{r_e}{1 + j\omega C_d}}$$

$$= \frac{v_{eb'}}{r_e}\left(1 + \frac{j\omega}{\omega_\alpha}\right)$$

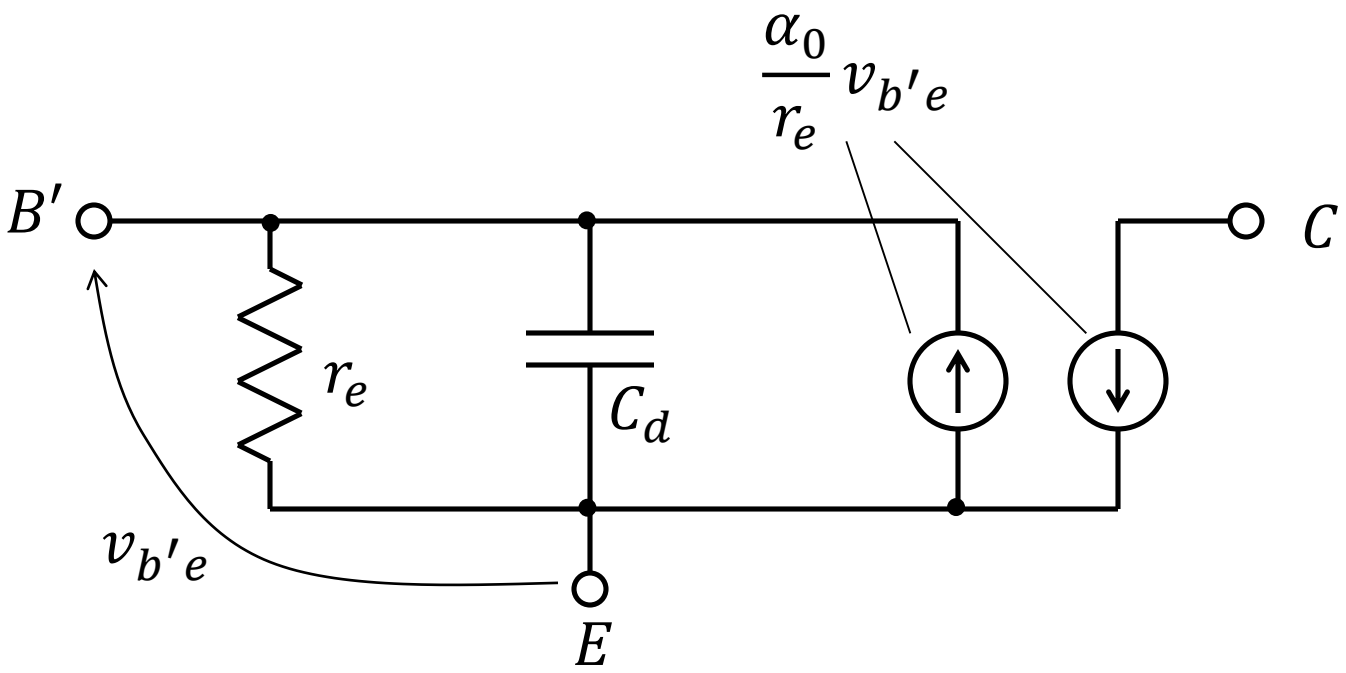
BJTの高周波モデル(2)



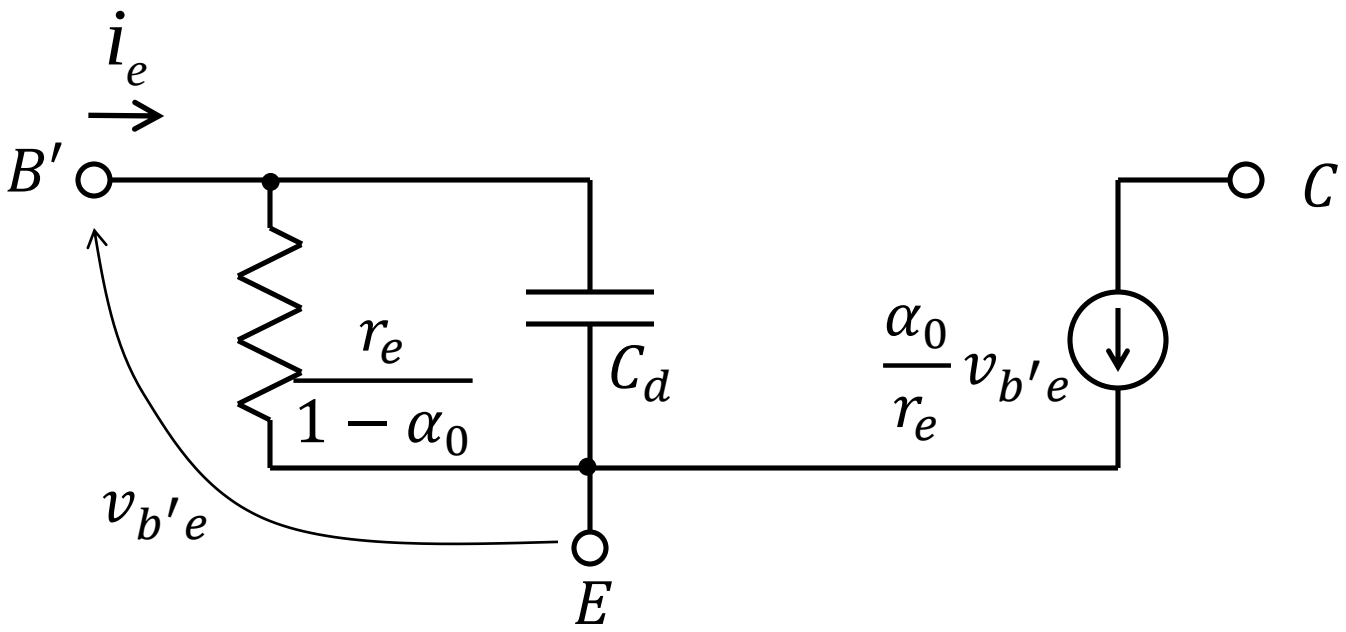
BJTの高周波モデル(3)



BJTの高周波モデル(4)

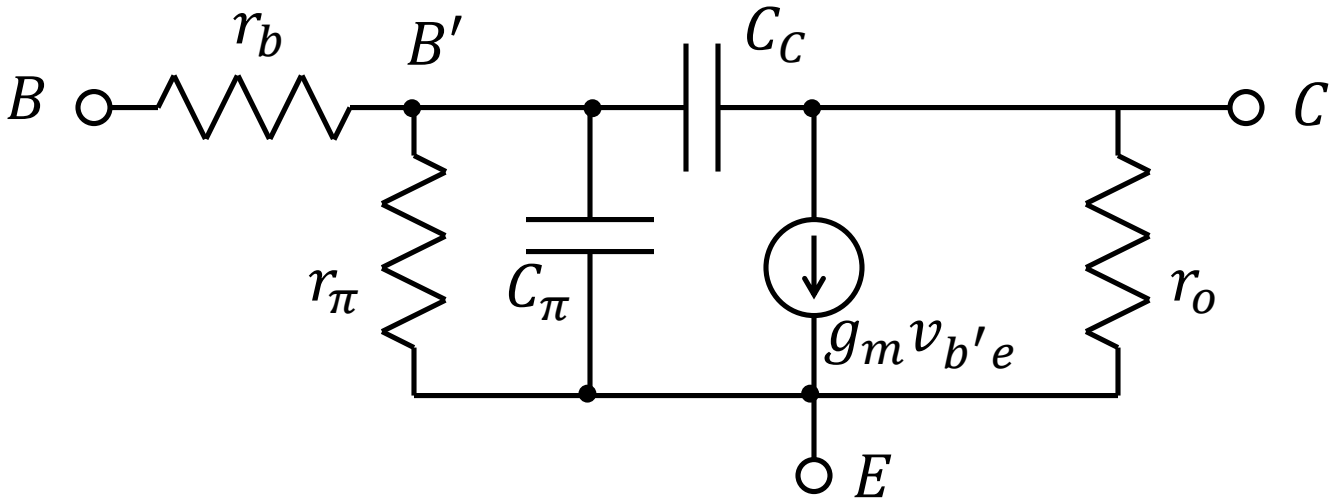


BJTの高周波モデル(5)



BJTの高周波モデル(6)

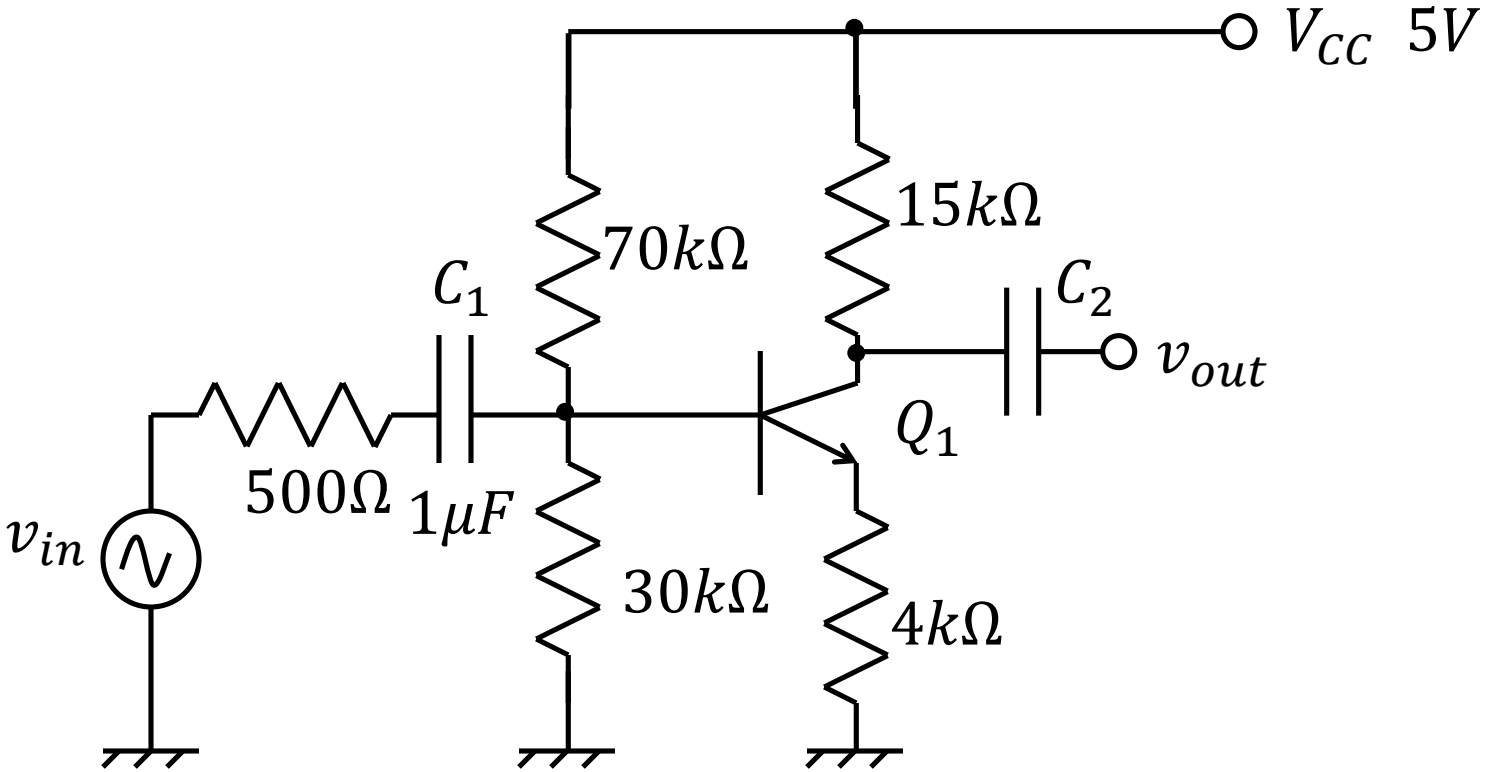
寄生素子の付加



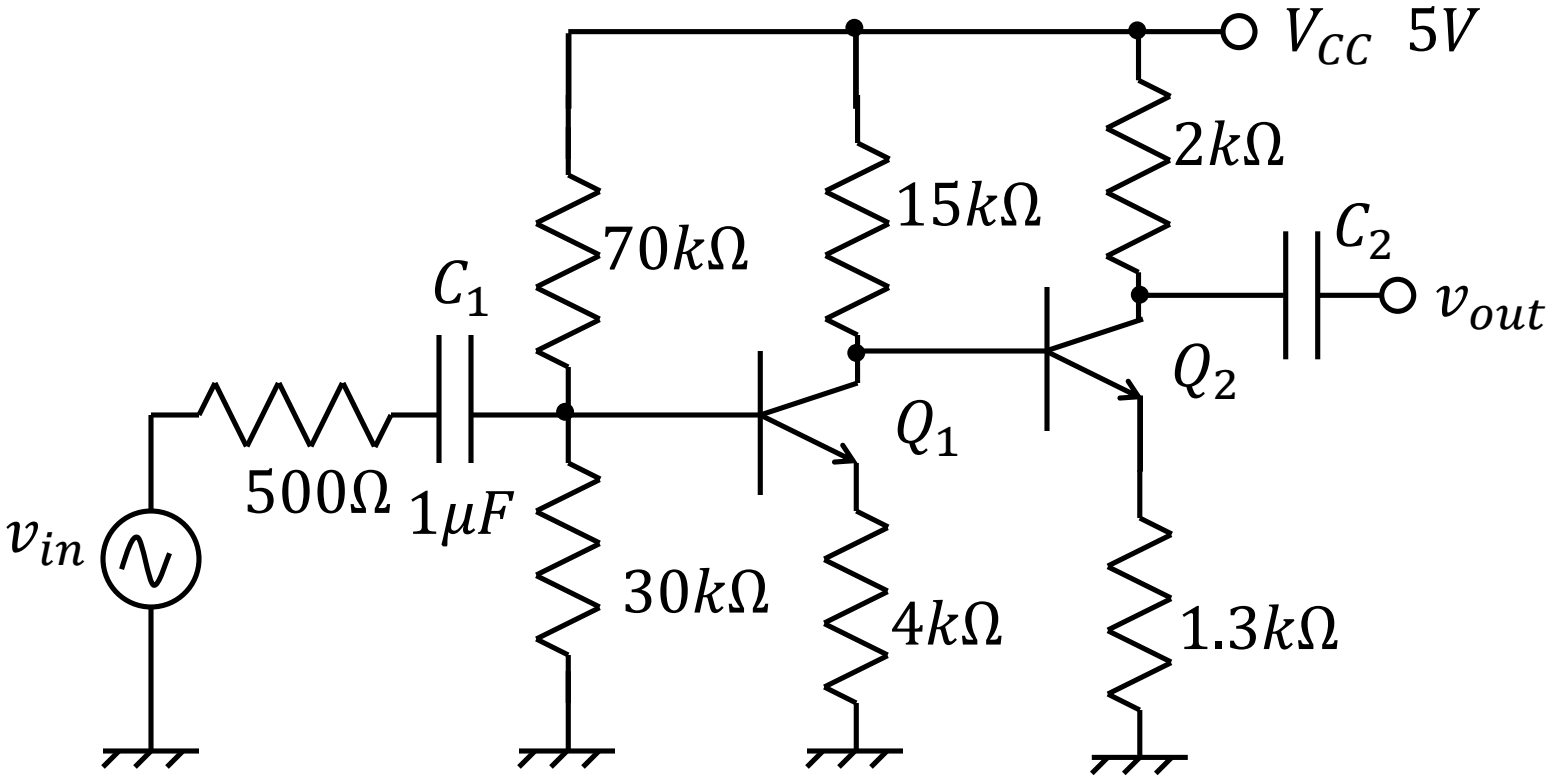
$$r_\pi = \frac{r_e}{1-\alpha_0}, \qquad C_\pi = C_d + C_{je} \cong C_d$$

$$C_C = C_{jc}, \qquad g_m = \frac{\alpha_0}{r_e}$$

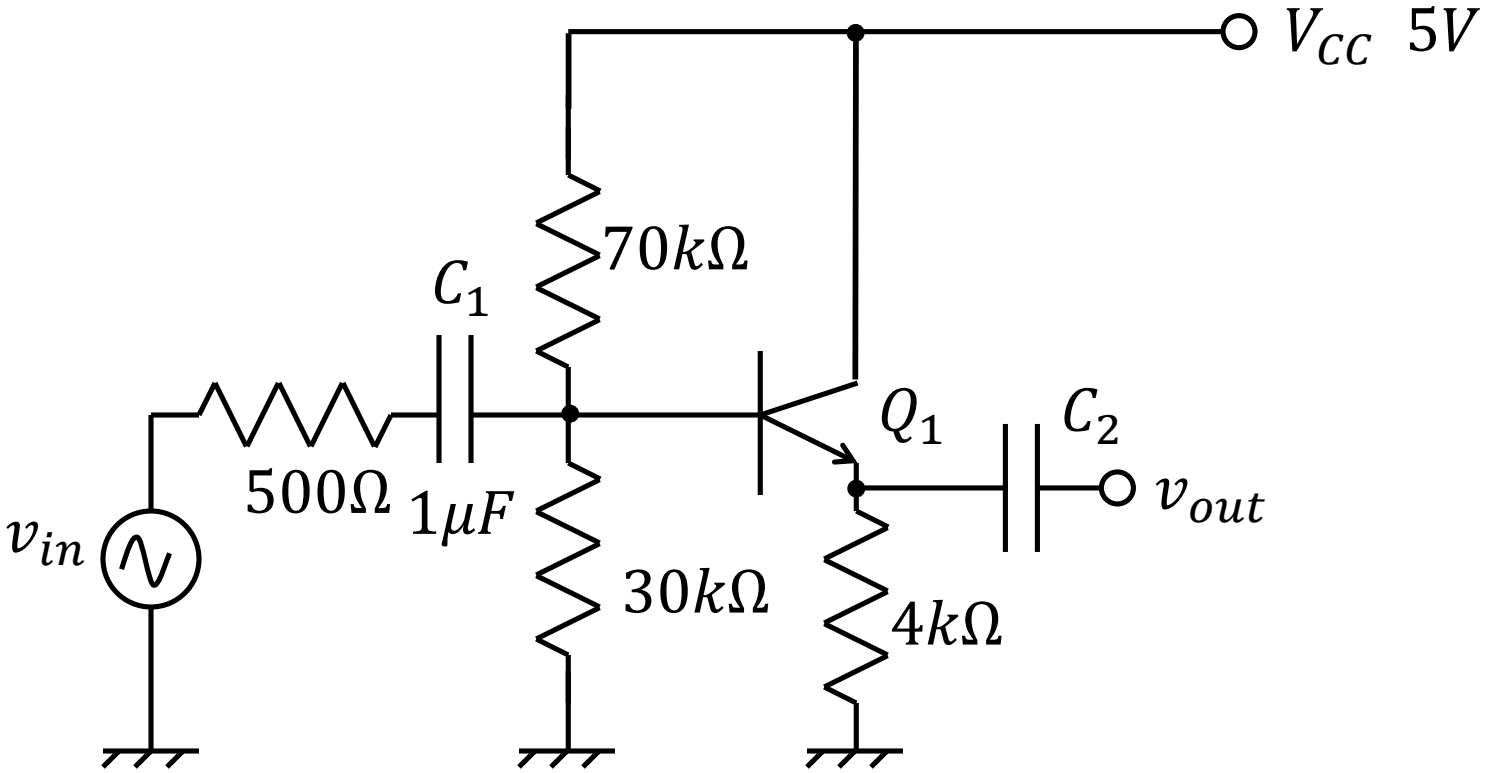
練習問題1



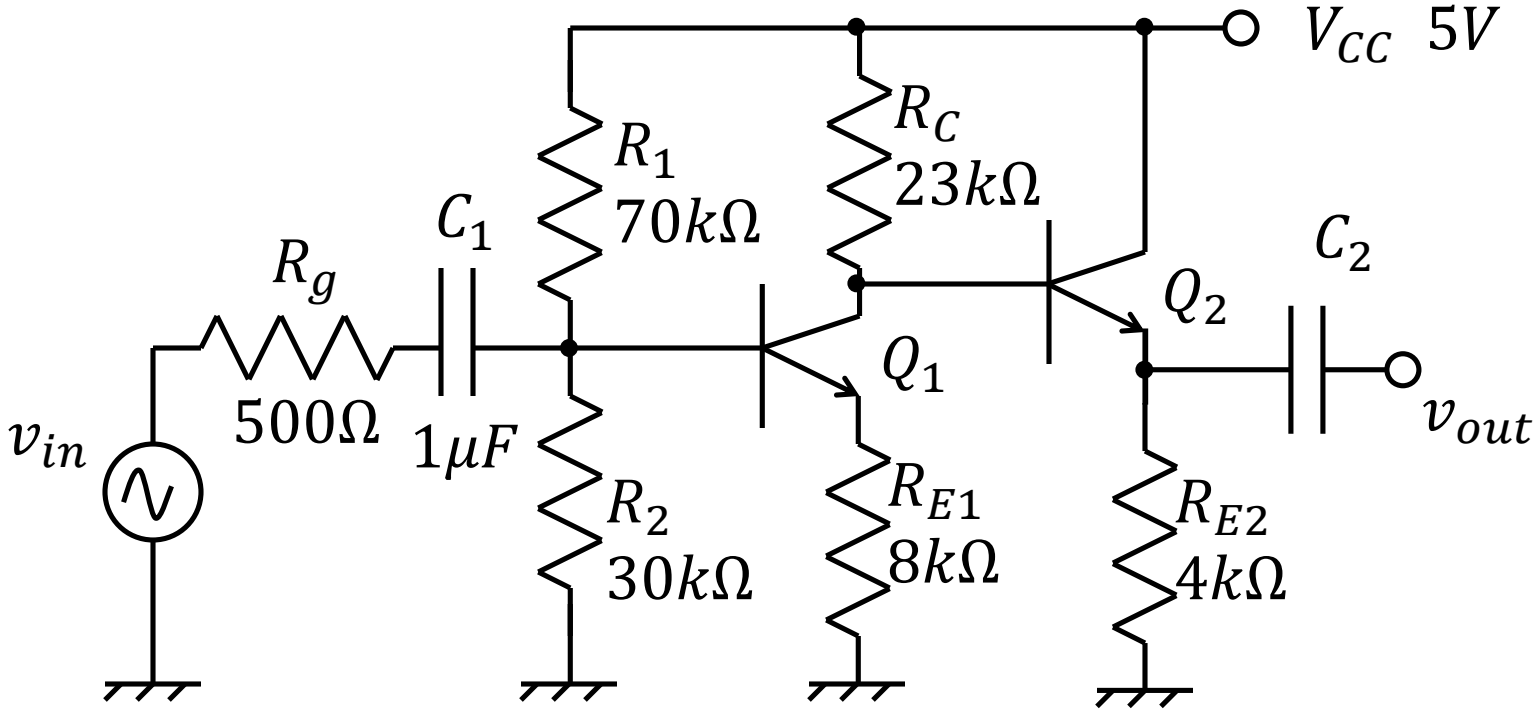
練習問題2



練習問題3



宿題6



- 各部の直流電位
  - トランジスタはナレータ・ノレータモデル、$V_{BE} = 0.7$とする
- 小信号中域利得
- 出力インピーダンス
- 低域遮断周波数
  - ただし$r_b = 50\Omega, \beta_0 = 99, r_o = \infty$とする