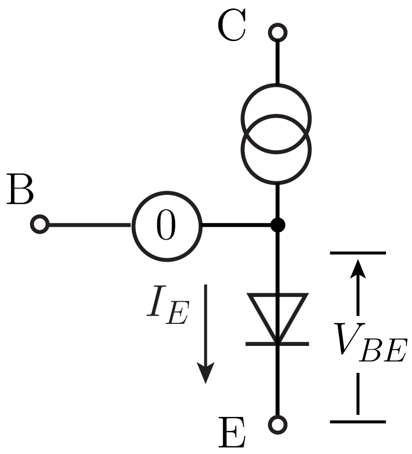
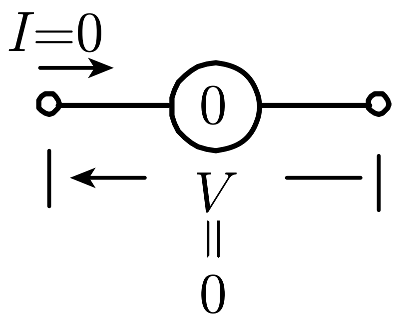
差動増幅回路の大信号特性とOTA(電圧制御電流源回路)

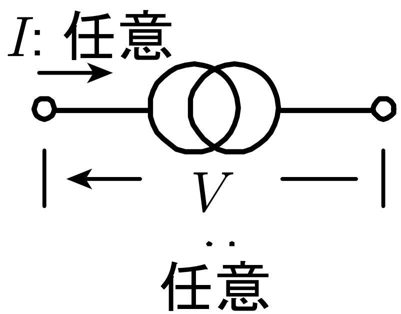
バイポーラ差動増幅回路の大信号特性

バイポーラトランジスタのモデル（大信号モデル）





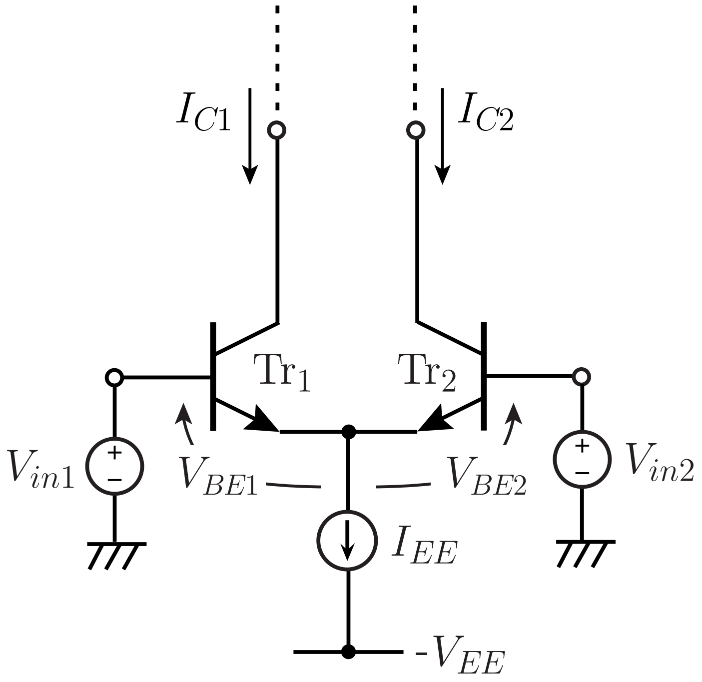
(a) ナレータ



(b) ノレータ

$$I_E = I_{ES} \exp\left(\frac{qV_{BE}}{kT}\right) \qquad I_C = I_E$$

バイポーラ差動増幅回路



$$V_{in1}-V_{BE1}+V_{BE2}-V_{in2}=0$$

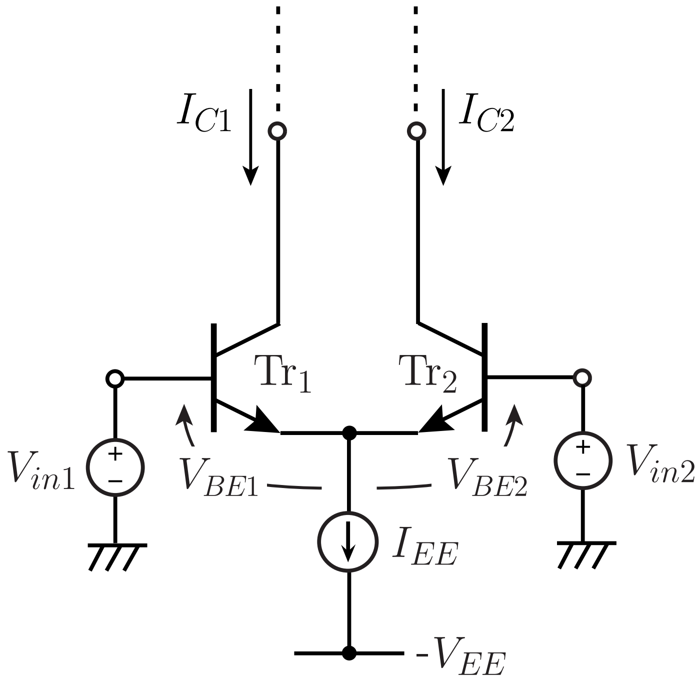
$$\Delta V_{in}=V_{in1}-V_{in2}=V_{BE1}-V_{BE2}$$

$$V_{BEi}=\frac{kT}{q}\ln\left(\frac{I_{Ei}}{I_{ES}}\right)$$

$$I_{Ci}=I_{Ei}$$

$$\Delta V_{in}=\frac{kT}{q}\ln\left(\frac{I_{E1}}{I_{ES}}\right)-\frac{kT}{q}\ln\left(\frac{I_{E2}}{I_{ES}}\right)$$

$$=\frac{kT}{q}\ln\left(\frac{I_{E1}}{I_{E2}}\right)$$



$$\frac{I_{E1}}{I_{E2}}=\exp\left(\frac{q\Delta V_{in}}{kT}\right)$$

$$I_{E1}+I_{E2}=I_{EE}$$

$$I_{E1}=\frac{I_{EE}}{1+\exp\left(\frac{-q\Delta V_{in}}{kT}\right)}$$

$$I_{E2}=\frac{I_{EE}}{1+\exp\left(\frac{+q\Delta V_{in}}{kT}\right)}$$

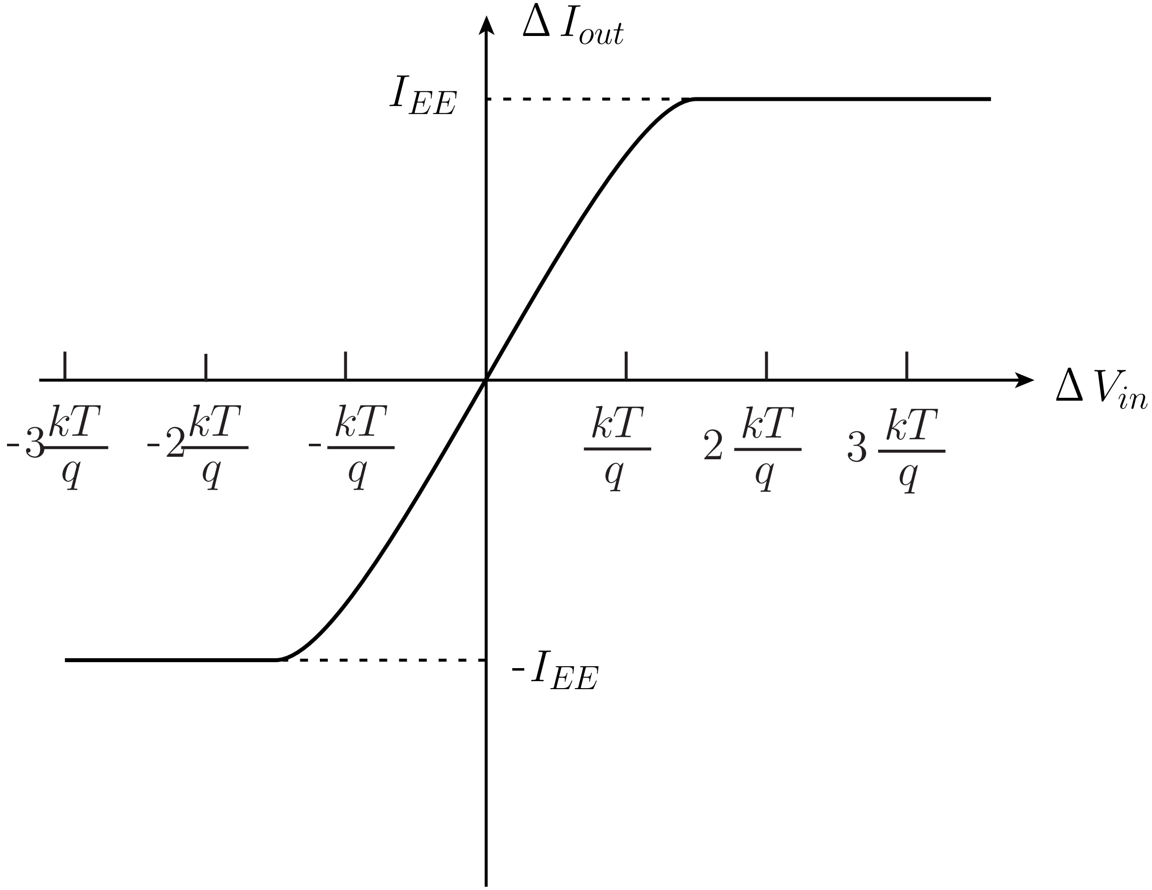
$$I_{E1}=\frac{I_{EE}}{1+\exp\left(\frac{-q\Delta V_{in}}{kT}\right)} \qquad I_{E2}=\frac{I_{EE}}{1+\exp\left(\frac{+q\Delta V_{in}}{kT}\right)}$$

$$\Delta I_{out}=I_{C1}-I_{C2}=I_{E1}-I_{E2}$$

$$=I_{EE}\left(\frac{1-\exp\left(\frac{-q\Delta V_{in}}{kT}\right)}{1+\exp\left(\frac{-q\Delta V_{in}}{kT}\right)}\right)$$

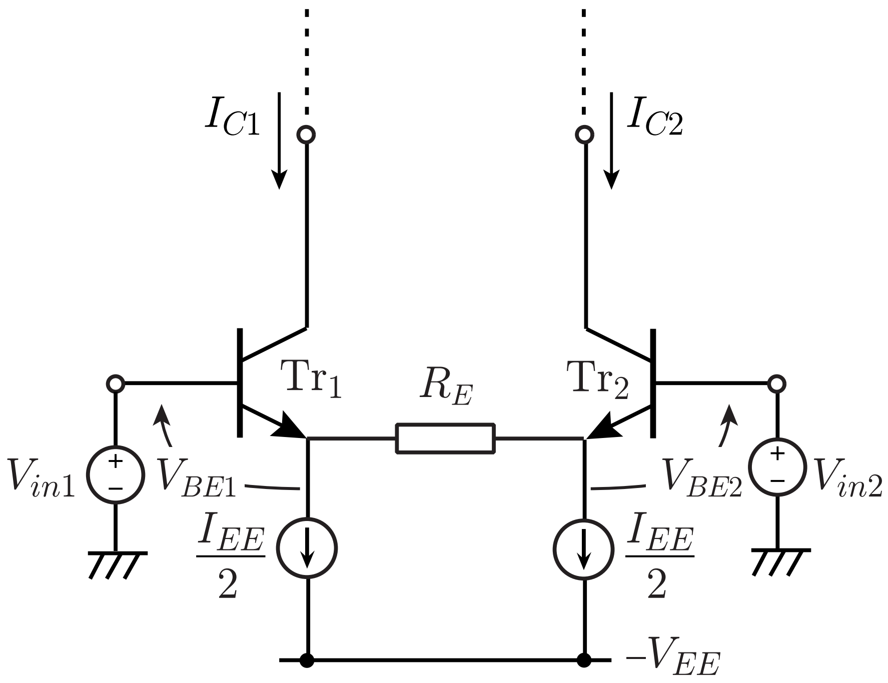
$$=I_{EE}\left(\frac{\exp\left(\frac{q\Delta V_{in}}{2kT}\right)-\exp\left(\frac{-q\Delta V_{in}}{2kT}\right)}{\exp\left(\frac{q\Delta V_{in}}{2kT}\right)+\exp\left(\frac{-q\Delta V_{in}}{2kT}\right)}\right)=I_{EE}\tanh\left(\frac{q\Delta V_{in}}{2kT}\right)$$

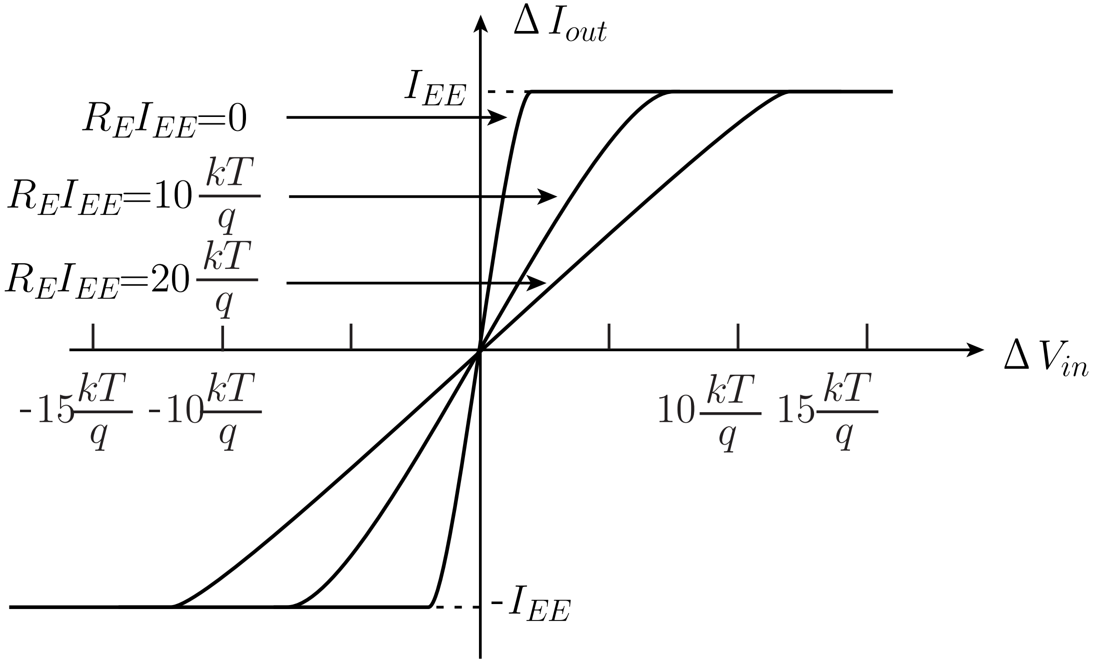
バイポーラ差動増幅回路の大信号特性



線形範囲：数十mV程度

線形入力範囲の拡大

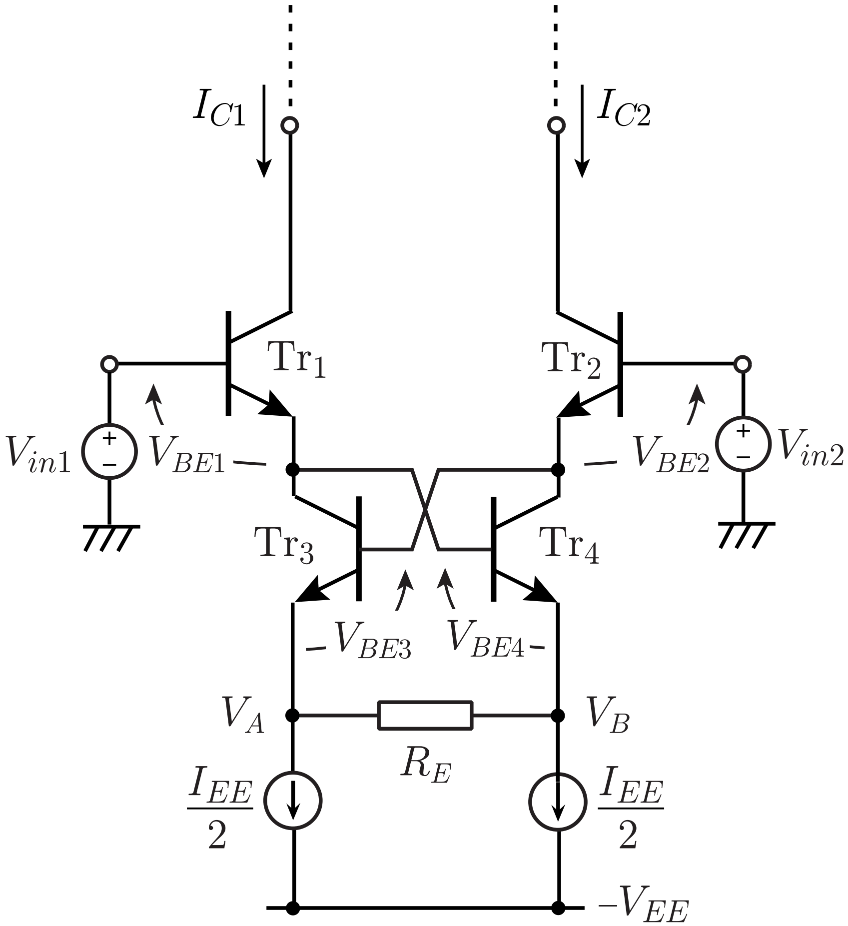




伝達コンダクタンスの低減

Caprio's Quad

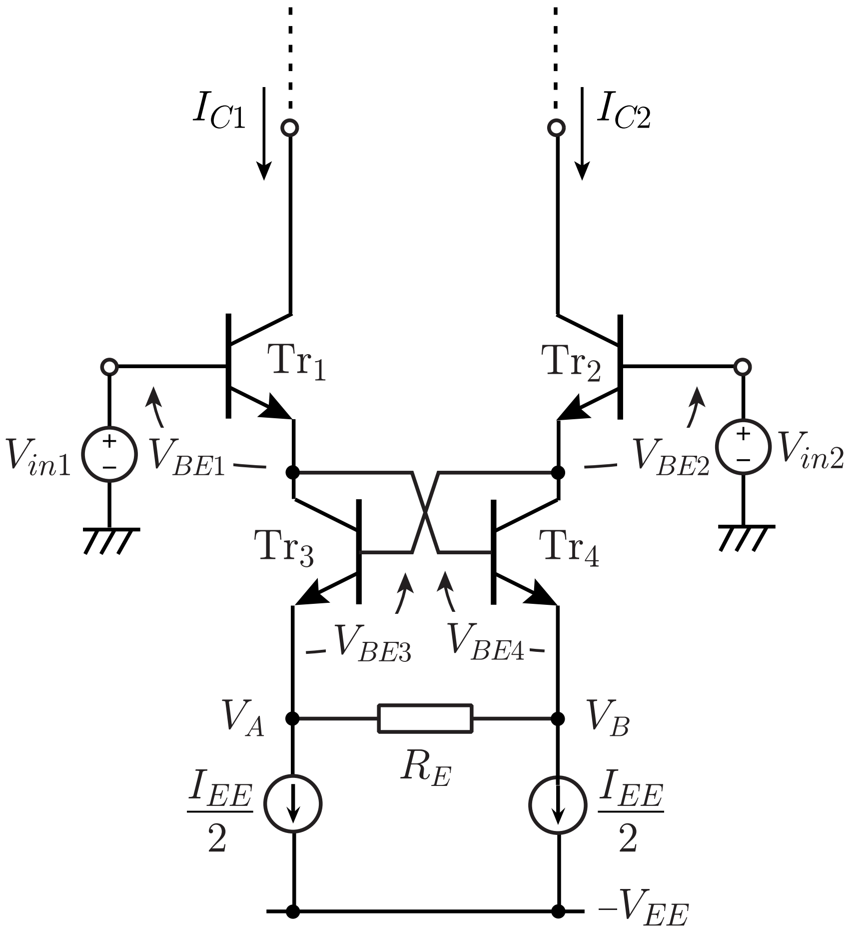
$$V_{BE}=\frac{kT}{q}\ln\left(\frac{I_E}{I_{ES}}\right)$$



$$I_{E1}=I_{E3} \qquad V_{BE1}=V_{BE3}$$
$$I_{E2}=I_{E4} \longrightarrow V_{BE2}=V_{BE4}$$

$$V_A=V_{in2}-V_{BE2}-V_{BE3}$$
$$V_B=V_{in1}-V_{BE1}-V_{BE4}$$

$$\boxed{V_A-V_B=V_{in2}-V_{in1}}$$



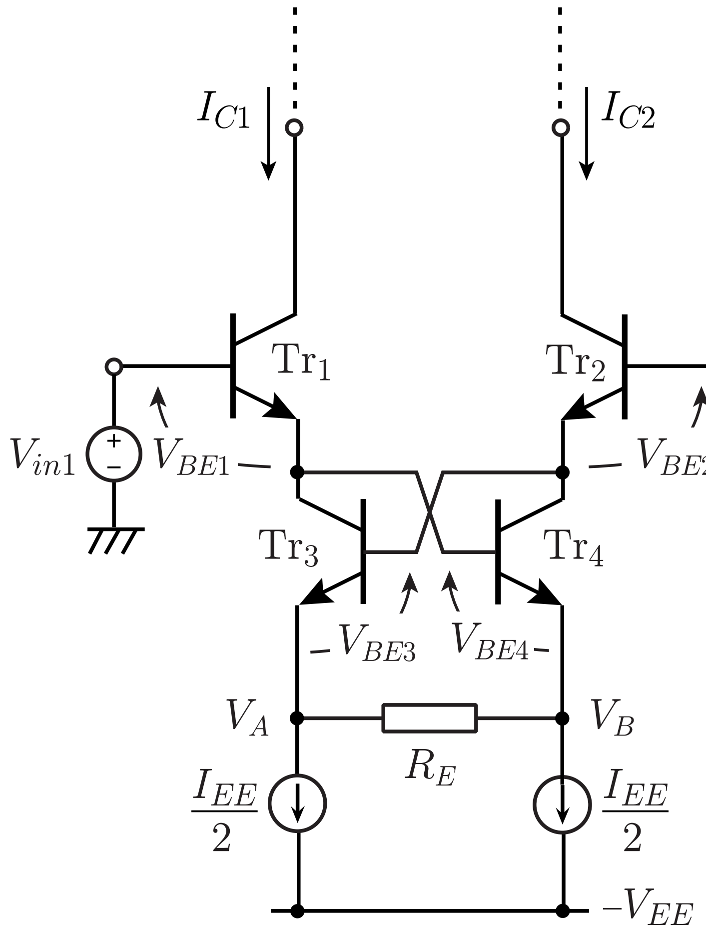
$$V_A - V_B = V_{in2} - V_{in1}$$

$$\boxed{I_{RE} = \frac{V_{in2} - V_{in1}}{R_E} = \frac{-\Delta V_{in}}{R_E}}$$

$$I_{C1} = \frac{I_{EE}}{2} + I_{RE}$$

$$I_{C2} = \frac{I_{EE}}{2} - I_{RE}$$

$$\Delta I_{out} = I_{C1} - I_{C2} = 2 I_{RE} \boxed{= \frac{-2}{R_E} \Delta V_{in}}$$



Tr3について

$$V_{C3}=V_{in1}-V_{BE1}$$

$$V_{B3}=V_{in2}-V_{BE2}$$

$$V_{C3}>V_{B3}\rightarrow$$

$$\boxed{V_{in1}-V_{BE1}>V_{in2}-V_{BE2}}$$

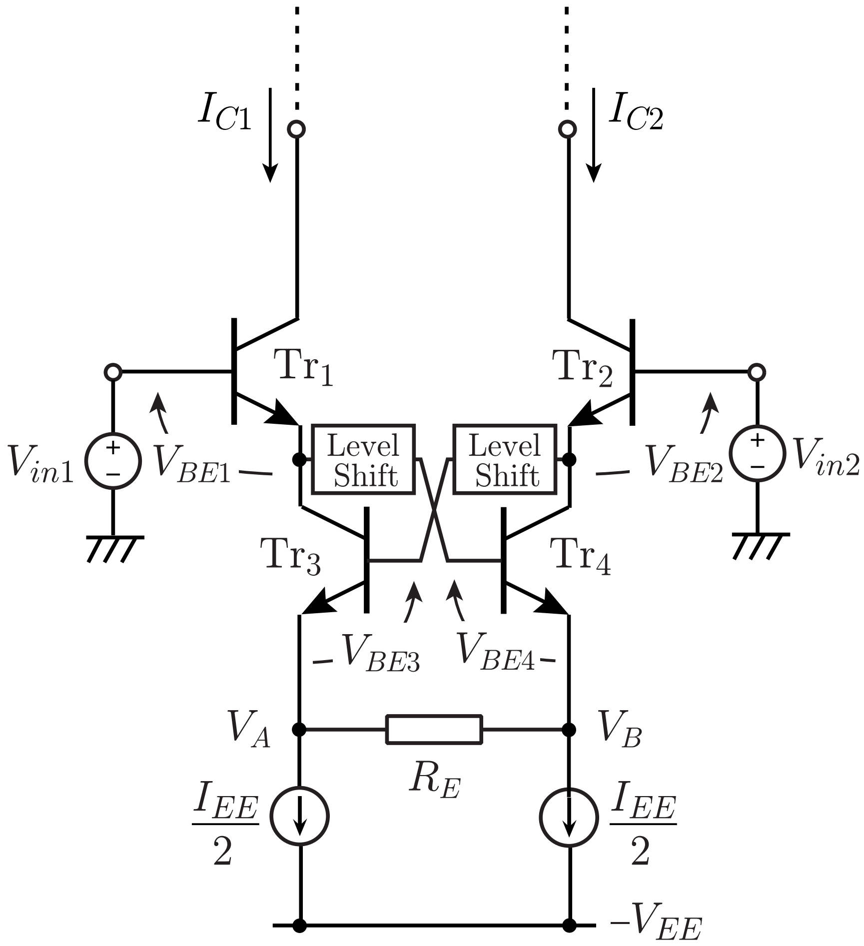
Tr4について

$$V_{C4}=V_{in2}-V_{BE2}$$

$$V_{B4}=V_{in1}-V_{BE1}$$

$$V_{C4}>V_{B4}\rightarrow$$

$$\boxed{V_{in1}-V_{BE1}<V_{in2}-V_{BE2}}$$



$$V_{C3}=V_{in1}-V_{BE1}$$

$$V_{B3}=V_{in2}-V_{BE2}-V_{shift}$$

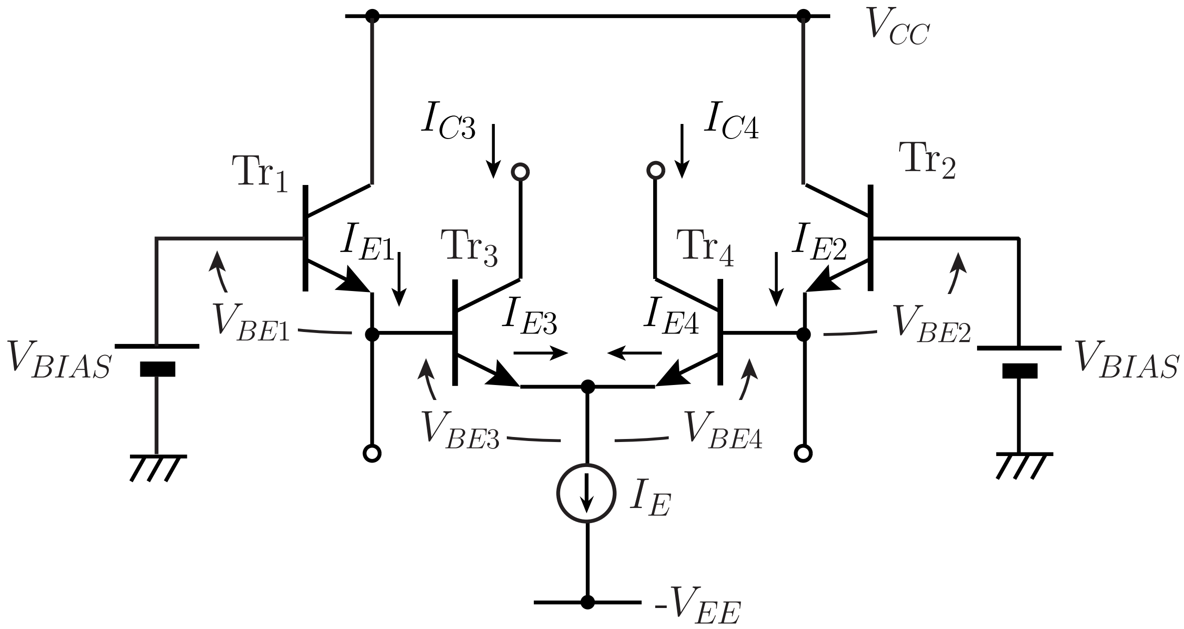
$$\boxed{V_{in1}-V_{BE1}>V_{in2}-V_{BE2}-V_{shift}}$$

$$V_{C4}=V_{in2}-V_{BE2}$$

$$V_{B4}=V_{in1}-V_{BE1}-V_{shift}$$

$$\boxed{V_{in1}-V_{BE1}-V_{shift}<V_{in2}-V_{BE2}}$$

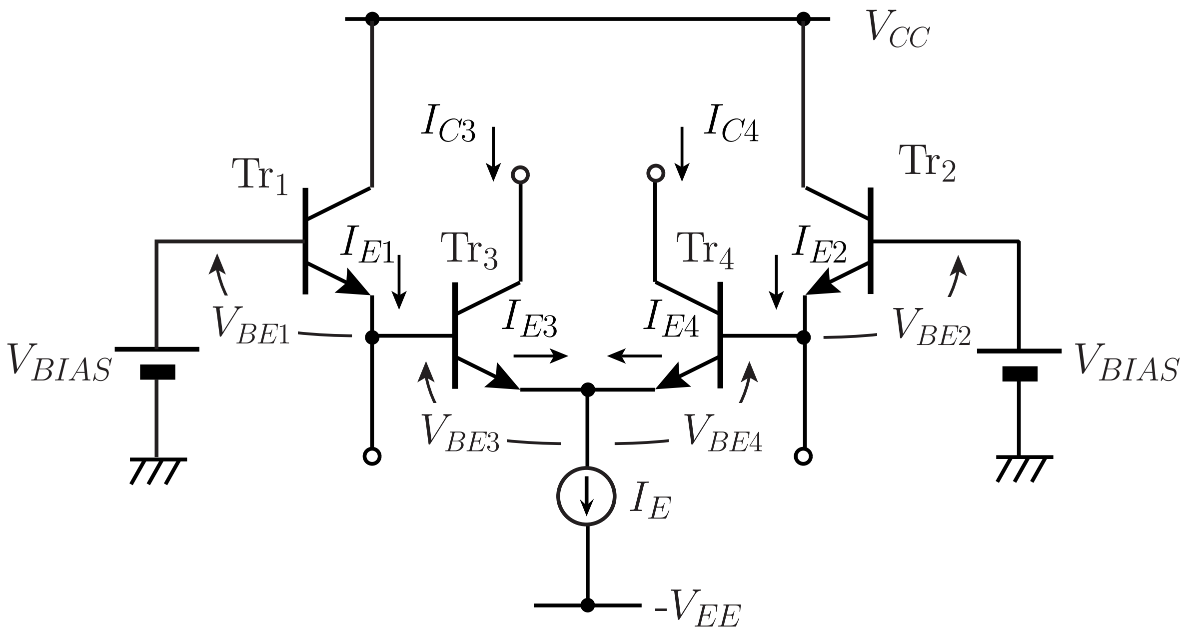
伝達コンダクタンスの電子的制御



$$V_{BE1}+V_{BE3}=V_{BE2}+V_{BE4}$$

$$\frac{kT}{q}\ln\left(\frac{I_{E1}}{I_{ES}}\right)+\frac{kT}{q}\ln\left(\frac{I_{E3}}{I_{ES}}\right)=\frac{kT}{q}\ln\left(\frac{I_{E2}}{I_{ES}}\right)+\frac{kT}{q}\ln\left(\frac{I_{E4}}{I_{ES}}\right)$$

$$\boxed{I_{E1}I_{E3}=I_{E2}I_{E4}}$$



$$I_{E3}+I_{E4}=I_E$$

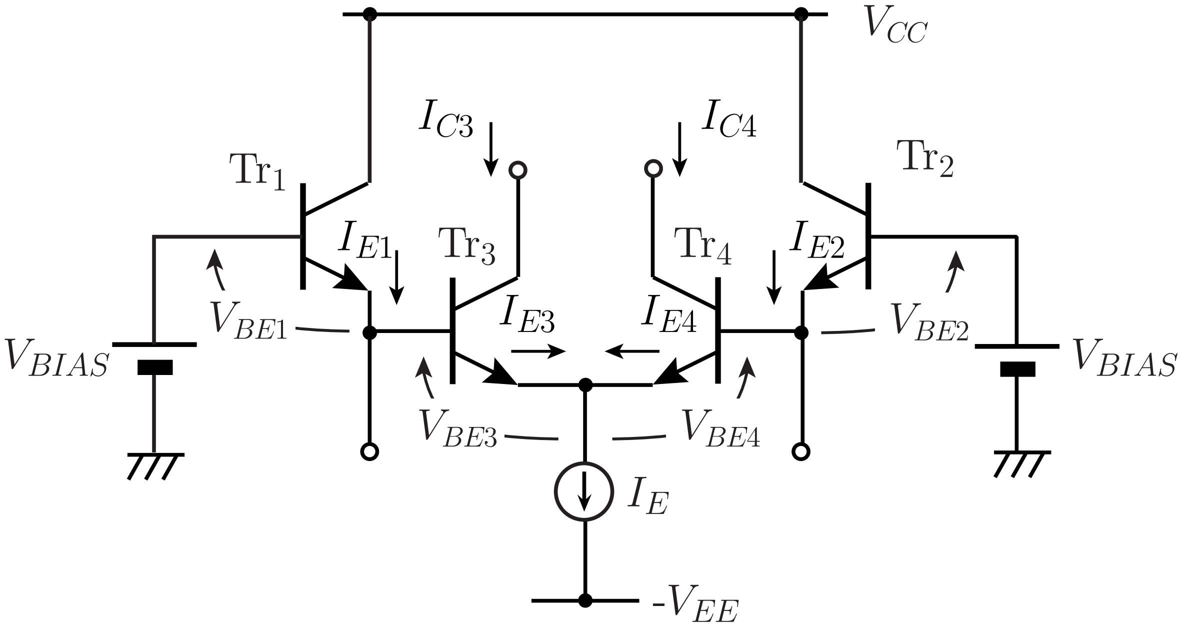
$$I_{E1}+I_{E2}=I_D$$

$$\longrightarrow \quad I_{E1}I_{E3}=I_{E2}I_{E4}$$

$$I_{E1}I_{E3}=(I_D-I_{E1})(I_E-I_{E3})$$

$$I_{E1}I_E+I_{E3}I_D=I_EI_D$$

$$\boxed{\frac{I_{E1}}{I_D}+\frac{I_{E3}}{I_E}=1}$$



$$I_{E3}+I_{E4}=I_E$$

$$I_{E1}+I_{E2}=I_D$$

$$\frac{I_{E1}}{I_D}+\frac{I_{E3}}{I_E}=1$$

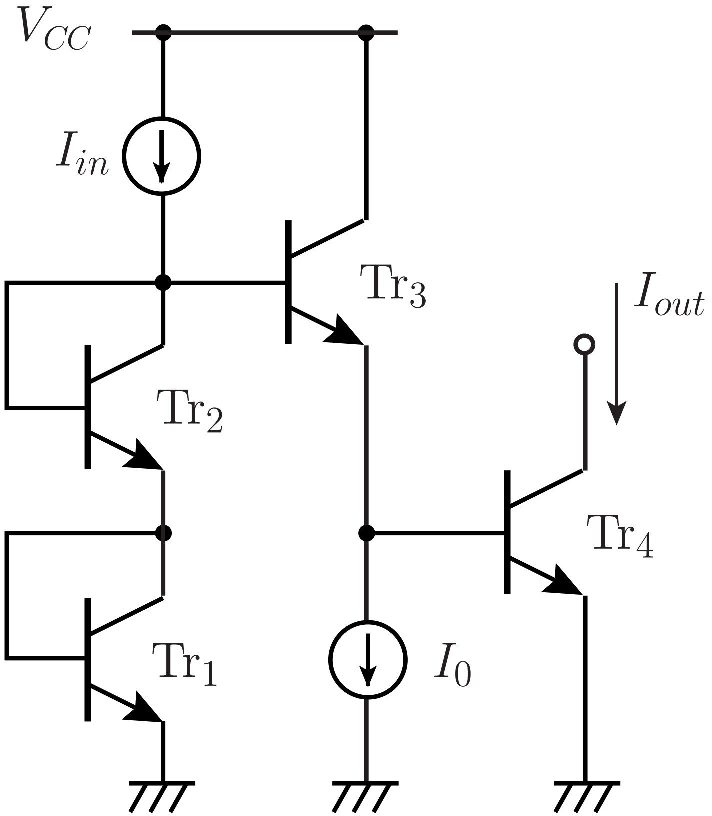
$$\boxed{A_I=\frac{I_{C3}-I_{C4}}{I_{E1}-I_{E2}}}=\frac{I_{E3}-I_{E4}}{I_{E1}-I_{E2}}=\frac{2I_{E3}-I_E}{2I_{E1}-I_D}=\frac{I_E}{I_D}\frac{2\frac{I_{E3}}{I_E}-1}{2\frac{I_{E1}}{I_D}-1}$$

$$\boxed{A_I=\frac{I_E}{I_D}\frac{2\frac{I_{E3}}{I_E}-1}{2(1-\frac{I_{E3}}{I_E})-1}=-\frac{I_E}{I_D}}$$

問：バイポーラトランジスタのエミッタ電流が

$$I_E = I_S \exp \frac{qV_{BE}}{kT}$$

であり，コレクタ電流がエミッタ電流に等しいとき，
下図の回路の出力電流I_{out}と入力電流I_{in}の関係式を導出せよ.



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