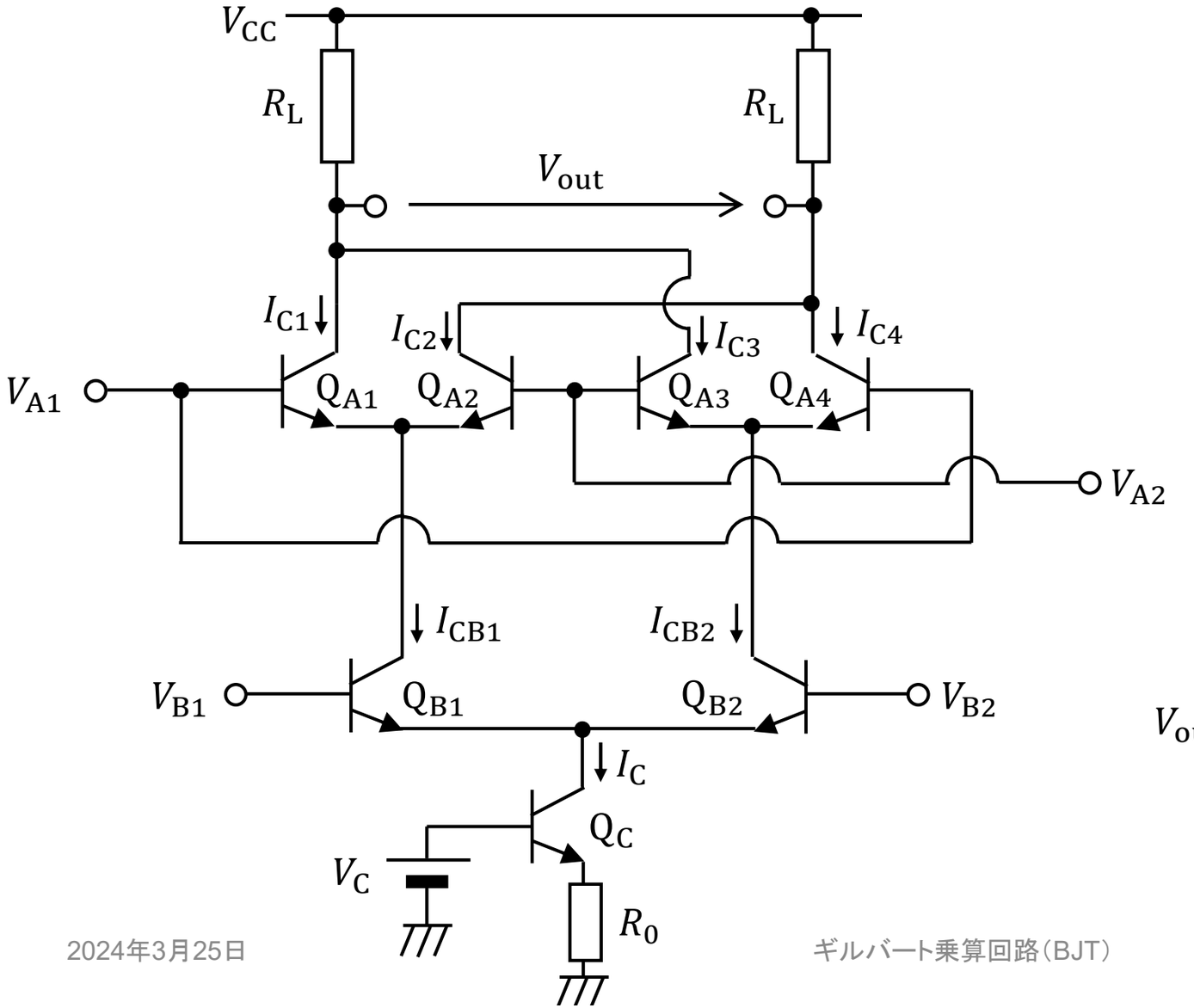
ギルバート乗算回路 (BJT)

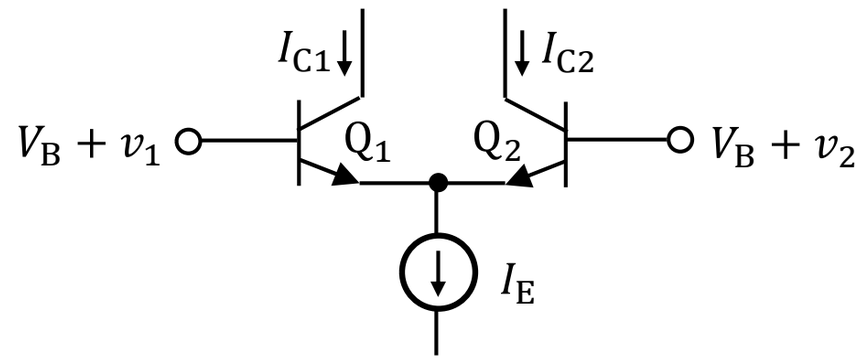
2024年3月25日（月）

和田

ギルバート乗算回路



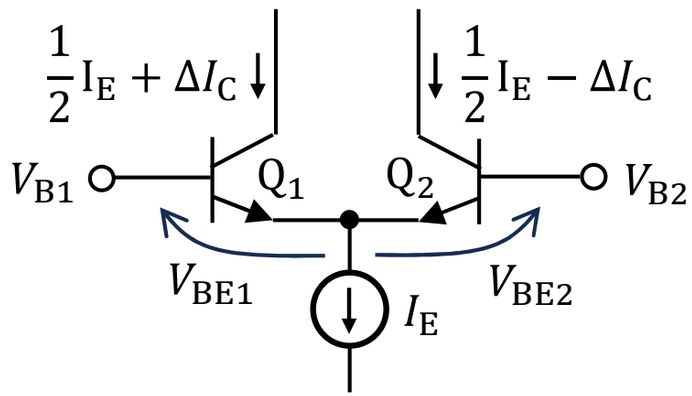
基本は差動対



次ページ参照

$$V_{out} = R_L I_C \tanh\left(\frac{V_{A1} - V_{A2}}{2V_T}\right) \tanh\left(\frac{V_{B1} - V_{B2}}{2V_T}\right)$$
$$\simeq R_L I_C \left(\frac{V_{A1} - V_{A2}}{2V_T}\right)\left(\frac{V_{B1} - V_{B2}}{2V_T}\right)$$

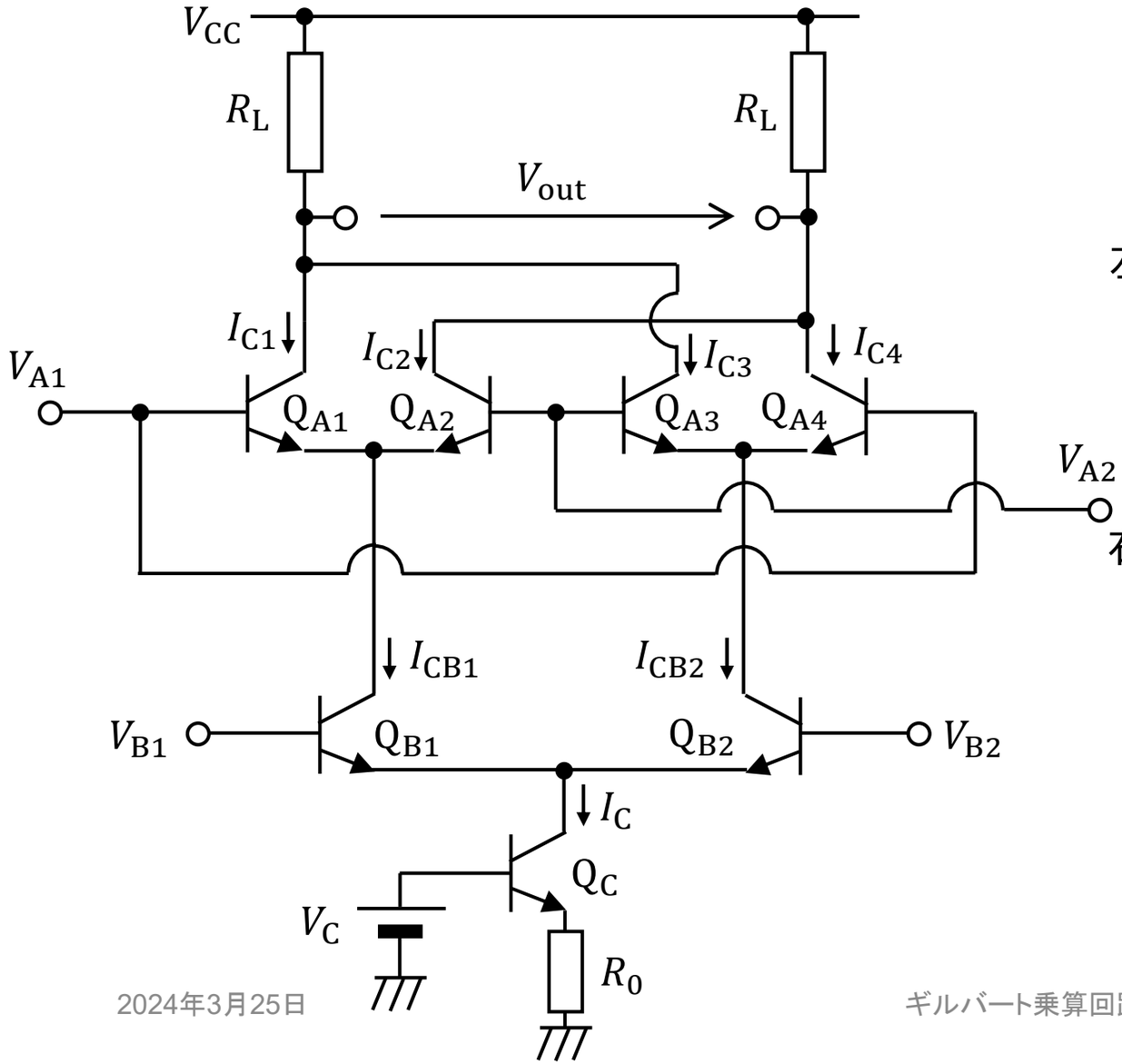
差動対



$$\frac{\frac{1}{2}\mathrm{I_E} + \Delta I_\mathrm{C}}{\frac{1}{2}\mathrm{I_E} - \Delta I_\mathrm{C}} = \frac{I_S \exp\left(\frac{V_{\mathrm{BE1}}}{V_\mathrm{T}}\right)}{I_S \exp\left(\frac{V_{\mathrm{BE2}}}{V_\mathrm{T}}\right)} = \exp\left(\frac{V_{\mathrm{BE1}} - V_{\mathrm{BE2}}}{V_\mathrm{T}}\right) = \exp\left(\frac{V_{\mathrm{B1}} - V_{\mathrm{B2}}}{V_\mathrm{T}}\right)$$

$$\Delta I_\mathrm{C} = \frac{I_\mathrm{E}}{2}\tanh\left(\frac{V_{\mathrm{B1}} - V_{\mathrm{B2}}}{2V_\mathrm{T}}\right)$$

直流特性



下

$$I_{CB1} = \frac{I_C}{2} + \Delta I_{CB}, \qquad I_{CB2} = \frac{I_C}{2} - \Delta I_{CB}$$

$$\Delta I_{CB} = \frac{I_C}{2} \tanh\left(\frac{V_{B1} - V_{B2}}{2V_T}\right)$$

左上

$$\frac{I_{C1}}{I_{C2}} = \frac{\frac{1}{2}\left(\frac{I_C}{2} + \Delta I_{CB}\right) + \Delta I_{A1}}{\frac{1}{2}\left(\frac{I_C}{2} + \Delta I_{CB}\right) - \Delta I_{A1}} = \exp\left(\frac{V_{A1} - V_{A2}}{V_T}\right)$$

$$\Delta I_{A1} = \frac{1}{2}\left(\frac{I_C}{2} + \Delta I_{CB}\right) \tanh\left(\frac{V_{A1} - V_{A2}}{2V_T}\right)$$

右上

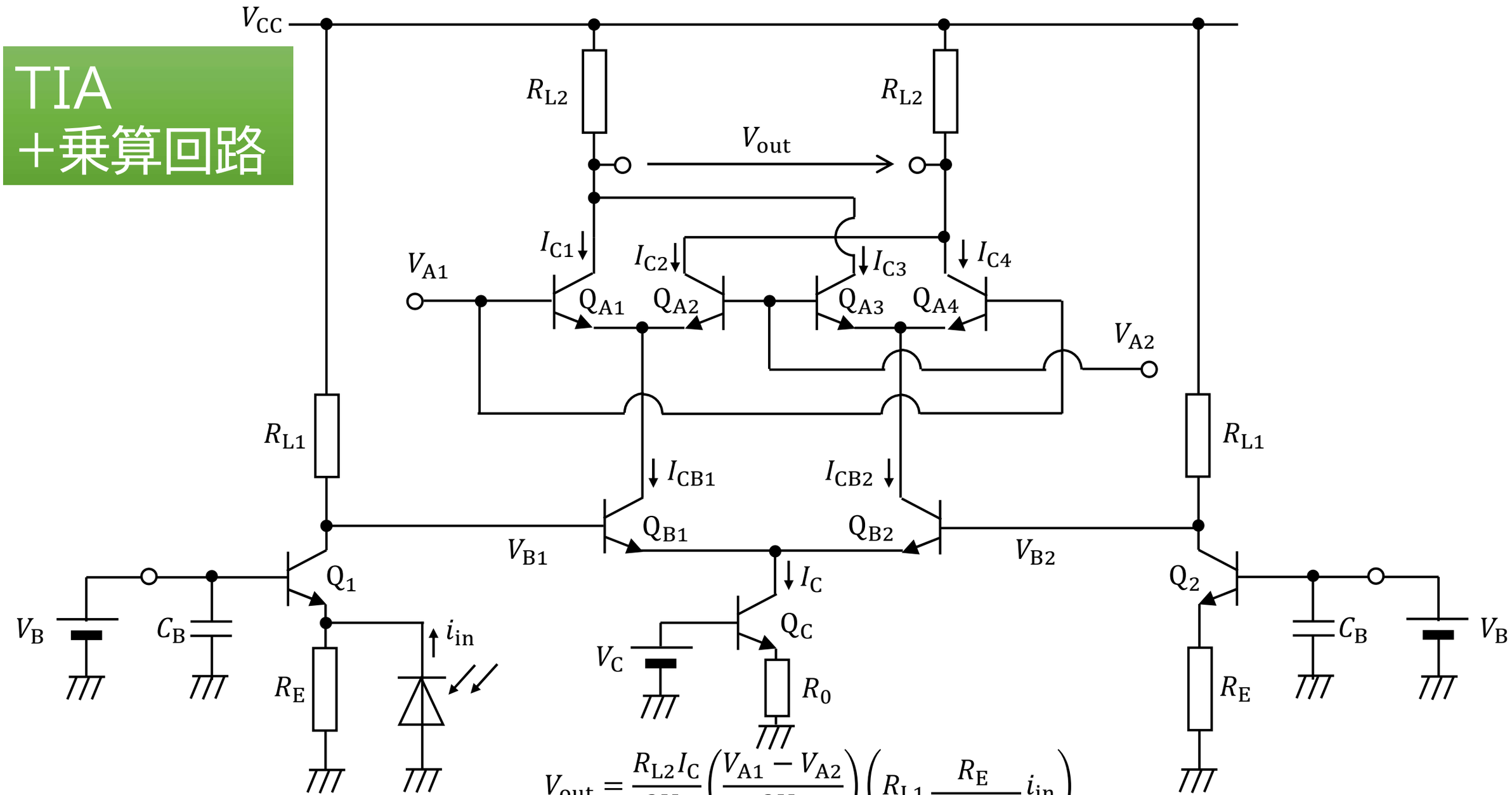
$$\frac{I_{C4}}{I_{C3}} = \frac{\frac{1}{2}\left(\frac{I_C}{2} - \Delta I_{CB}\right) + \Delta I_{A2}}{\frac{1}{2}\left(\frac{I_C}{2} - \Delta I_{CB}\right) - \Delta I_{A2}} = \exp\left(\frac{V_{A1} - V_{A2}}{V_T}\right)$$

$$\Delta I_{A2} = \frac{1}{2}\left(\frac{I_C}{2} - \Delta I_{CB}\right) \tanh\left(\frac{V_{A1} - V_{A2}}{2V_T}\right)$$

$$\begin{aligned}(I_{C1} + I_{C3}) - (I_{C2} + I_{C4}) &= (I_{C1} - I_{C2}) + (I_{C3} - I_{C4}) \\ &= 2(\Delta I_{A1} - \Delta I_{A2}) \\ &= 2\Delta I_{CB} \tanh\left(\frac{V_{A1} - V_{A2}}{2V_T}\right)\end{aligned}$$

$$V_{out} = R_L(I_{C1} + I_{C3}) - R_L(I_{C2} + I_{C4})$$

TIA
＋乗算回路



$$V_{out} = \frac{R_{L2} I_C}{2V_T}\left(\frac{V_{A1} - V_{A2}}{2V_T}\right)\left(R_{L1}\frac{R_E}{R_E + r_e} i_{in}\right)$$

数値例

$$r_{\mathrm{e}}\left(=\frac{1}{g_{\mathrm{m}}}\right)=R_{\mathrm{E}},\qquad R_{\mathrm{L1}}=1.4\ \mathrm{k\Omega},\qquad V_{\mathrm{T}}=26\ \mathrm{mV},$$

$$V_{\mathrm{A1}}-V_{\mathrm{A2}}=2V_{\mathrm{T}},\quad R_0=100\ \Omega,\quad I_{\mathrm{C}}=1\ \mathrm{mA}\ \ (V_{\mathrm{C}}\text{を調整}),\quad R_{\mathrm{L2}}=400\ \Omega$$

$$V_{\mathrm{out}}=R_{\mathrm{L2}}I_{\mathrm{C}}\tanh\left(\frac{V_{\mathrm{A1}}-V_{\mathrm{A2}}}{2V_{\mathrm{T}}}\right)\tanh\left(\frac{R_{\mathrm{L1}}\dfrac{R_{\mathrm{E}}}{R_{\mathrm{E}}+r_{\mathrm{e}}}i_{\mathrm{in}}}{2V_{\mathrm{T}}}\right)$$

$$=0.4\times\tanh 1\times\tanh\left(\frac{0.7\ \mathrm{k\Omega}}{52\ \mathrm{mV}}i_{\mathrm{in}}\right)$$

$$V_{\mathrm{out}}\ [\mathrm{mV}]\simeq 1000\times 0.4\times\frac{2.7-0.37}{2.7+0.37}\times\frac{0.7\ i_{\mathrm{in}}\ [\mu\mathrm{A}]}{52}\fallingdotseq 4\ i_{\mathrm{in}}\ [\mu\mathrm{A}]$$

$$\frac{V_{\mathrm{out}}}{i_{\mathrm{in}}}\fallingdotseq 4\ \mathrm{k\Omega}$$

この設計では出力V_{out}をさらに 10〜40 dB程度増幅する(SF+DA 等) 必要がある。