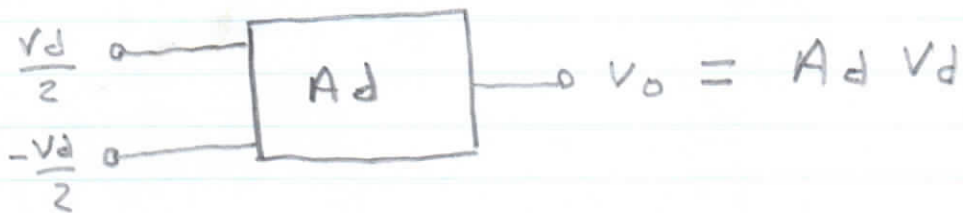


$$V_d \equiv \text{differential component} = V_{i1} - V_{i2}$$

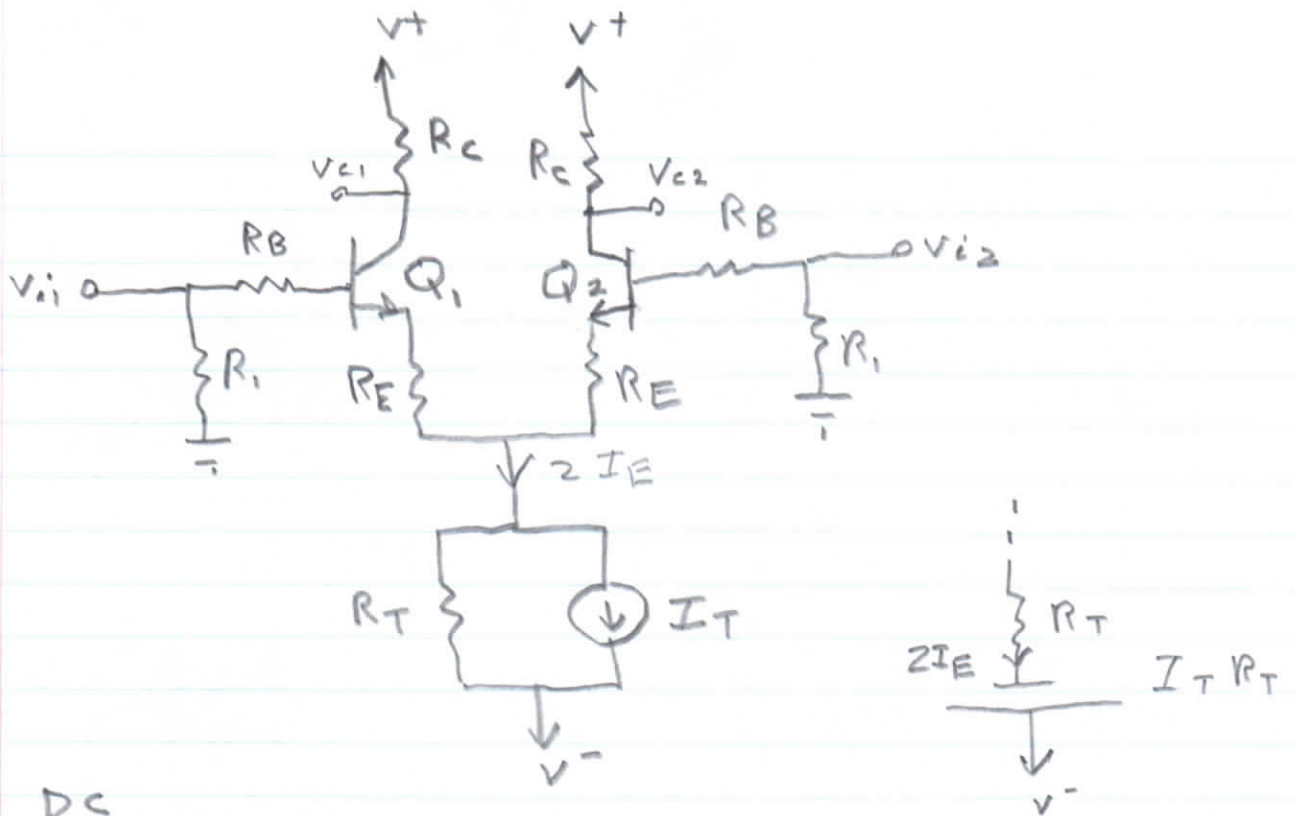
$$V_{cm} \equiv \text{common mode component} = \frac{V_{i1} + V_{i2}}{2}$$

$$V_{i1} = \frac{V_d}{2} + V_{cm}$$

$$V_{i2} = -\frac{V_d}{2} + V_{cm}$$



$$V_o = A_d V_d + A_{cm} V_{cm}$$



DC

$$I_B (R_i + R_B) + V_{BE} + I_E R_E + 2I_E R_T - I_T R_T + V^- = 0$$

$$I_B = \frac{-V^- + I_T R_T - V_{BE}}{(R_i + R_B) + (\beta + 1)(R_E + 2R_T)}$$

$$I_C = \beta I_B \quad I_E = (\beta + 1) I_B$$

$$V_B = -(R_i + R_B) I_B \quad V_E = V_B - V_{BE}$$

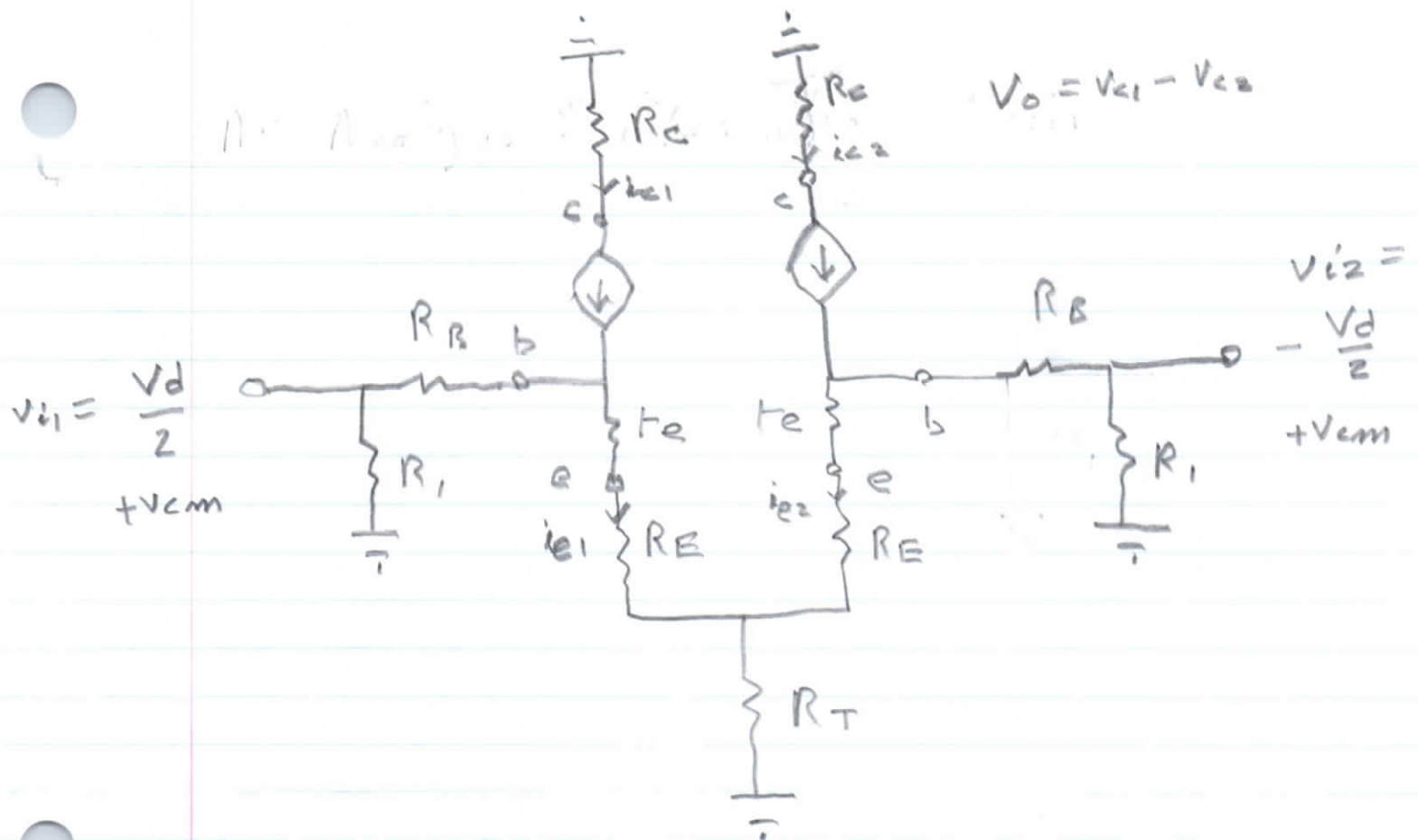
$$V_C = V^+ - I_C R_C$$

Special cases $I_T = 0$

$$I_B = \frac{-V^- - V_{BE}}{R_i + R_B + (\beta + 1)(R_E + 2R_T)}$$

$$R_T = \infty$$

$$I_B = \frac{I_T}{2(\beta + 1)} \quad I_E = \frac{I_T}{2}$$



Differential

$$i_{e1} = \frac{V_d}{\frac{R_B}{\beta+1} + 2R_E + 2r_e} = -i_{e2}$$

$$v_{c1} = -\alpha i_{e1} R_C = -v_{c2}$$

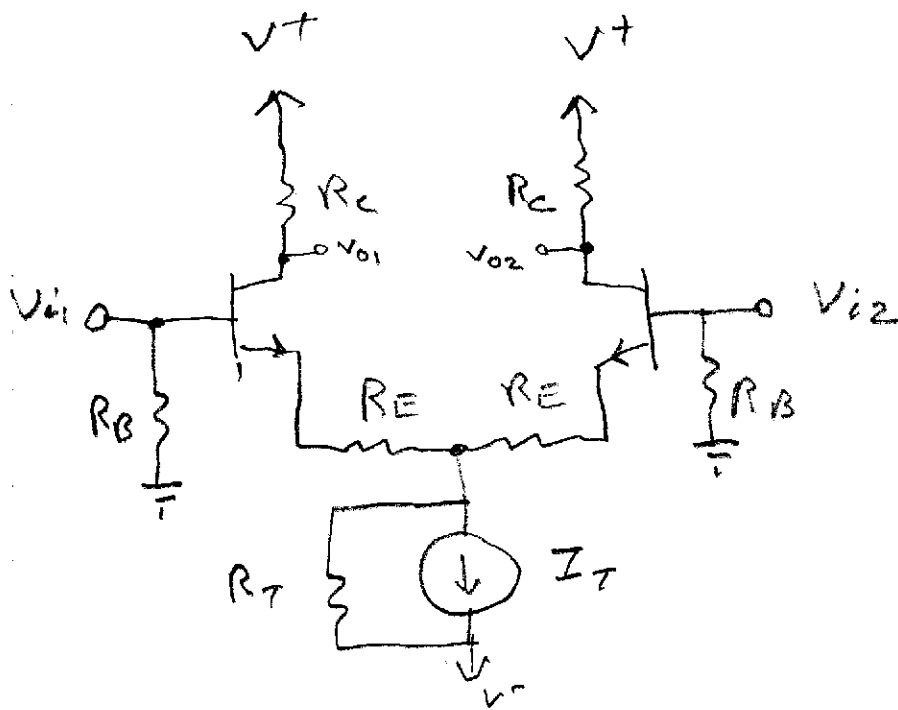
$$v_o = v_{c1} - v_{c2} = A_d V_d$$

$$A_d = -\frac{2R_C \alpha}{\frac{R_B}{\beta+1} + 2(R_E + r_e)} \approx -\alpha \frac{R_C}{R_E + r_e}$$

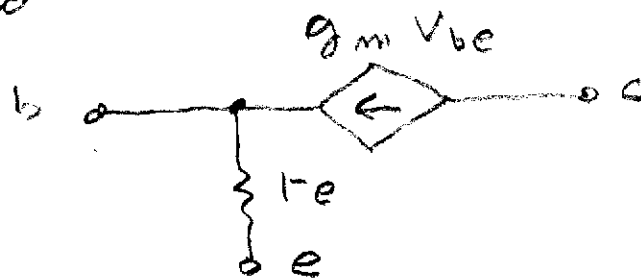
Common Mode

$$i_{e1} = i_{e2} = \frac{V_{cm}}{\frac{R_B}{\beta+1} + r_e + R_E + 2R_T}$$

$$A_{cm} = -\alpha \frac{R_C}{\frac{R_B}{\beta+1} + r_e + R_E + 2R_T}$$



Simplified Small signal T Model



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

$$g_m = \frac{I_c}{V_T}$$

$$V_{id} = V_{i1} - V_{i2}$$

$$V_{icm} = \frac{V_{i1} + V_{i2}}{2}$$

$$V_{i1} = \frac{V_{id}}{2} + V_{icm}$$

$$V_{i2} = -\frac{V_{id}}{2} + V_{icm}$$

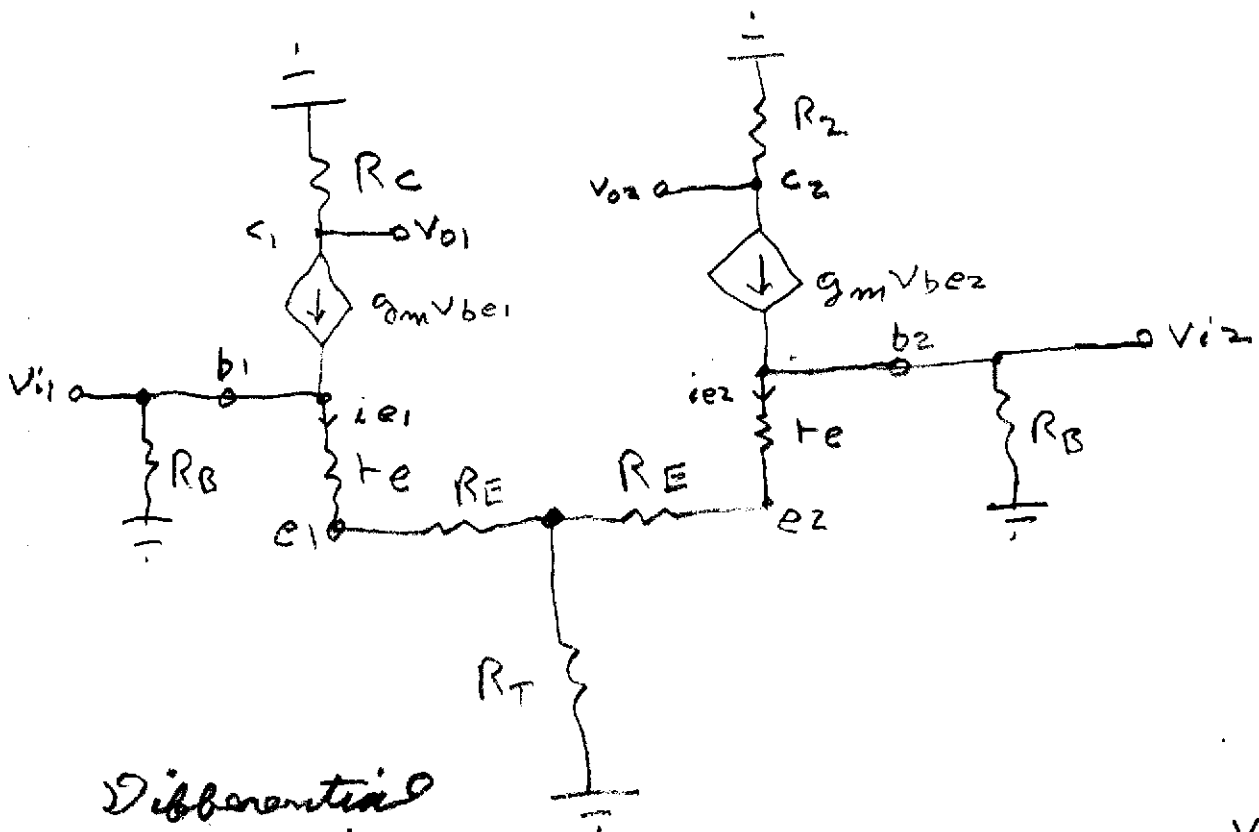
$$V_{od} = V_{o1} - V_{o2}$$

$$V_{ocm} = \frac{V_{o1} + V_{o2}}{2}$$

$$A_d = \frac{V_{od}}{V_{id}}$$

$$A_{cm} = \frac{V_{ocm}}{V_{icm}}$$

Small Signal



Differential

$$V_{i1} = \frac{V_d}{2} \quad V_{i2} = -\frac{V_d}{2} \quad i_{e1} = -i_{e2} = \frac{V_d}{2(r_e + R_E)}$$

$$i_{c1} = -i_{c2} = g_m \cdot t_e \cdot i_{e1} = \frac{I_c}{V_T} \cdot \frac{V_T}{I_E} \cdot \frac{V_d}{2(t_e + R_E)}$$

$$i_{c1} = -i_{c2} = \alpha \frac{V_d}{2(I_E + R_E)}$$

$$V_{O1} = -V_{O2} = -\alpha \frac{V_d R_C}{2(r_e + R_E)}$$

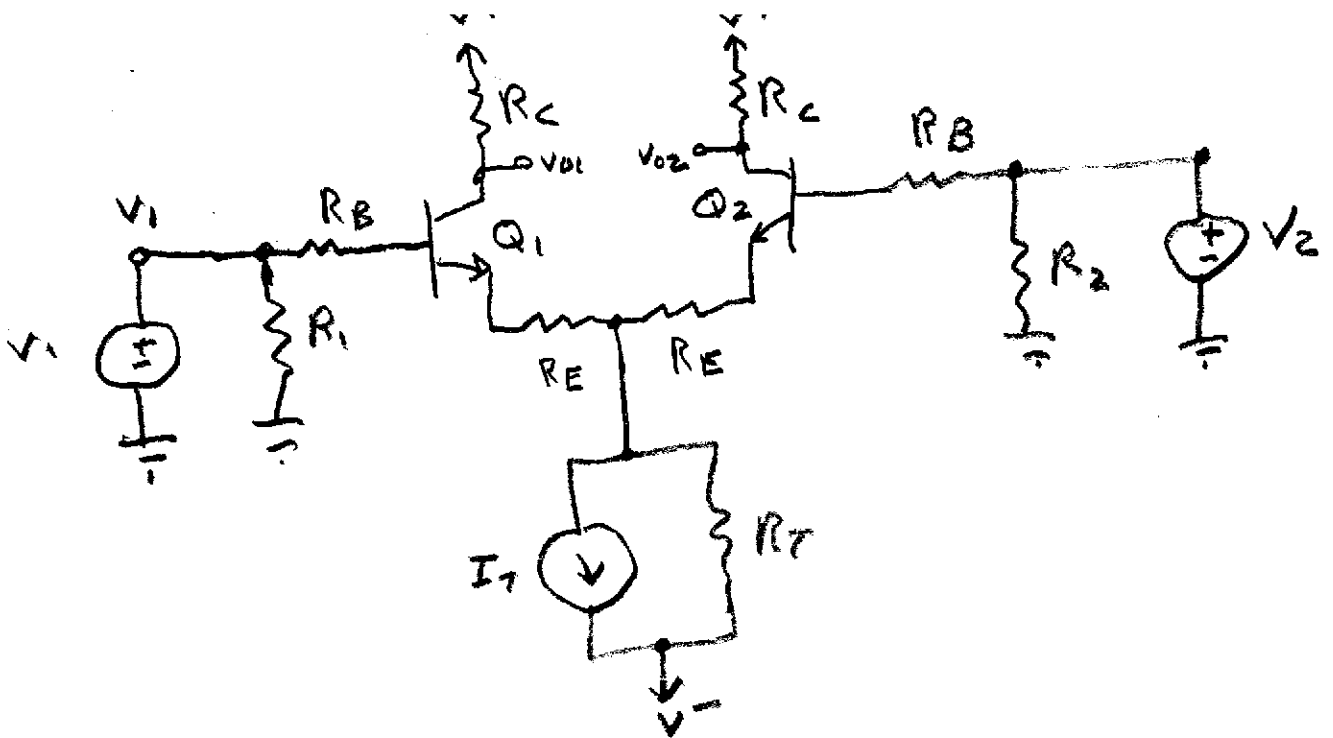
$$A_d = \frac{V_{od}}{V_{id}} = \frac{V_{o1} - V_{o2}}{V_{i1} - V_{i2}} = -\alpha \frac{R_c}{r_e + R_E}$$

Common Mode $V_{e1} = V_{e2} = V_{icm}$

$$I_{e1} = I_{e2} = \frac{V_{icm}}{1 + R_E + 2R_T}$$

$$V_{o1} = V_{o2} = \frac{r_e g_m R_c}{r_e + R_E + 2R_T}$$

$$A_{em} = \frac{\alpha R_c}{r_e + R_E + 2R_T}$$



$$I_B R_B + V_{BE} + I_E R_E + 2 I_E R_T - I_T R_T + V^- = 0$$

$$I_B = \frac{-V^- + I_T R_T - V_{BE}}{R_B + (\beta + 1)(R_E + 2 R_T)}$$

$$I_C = \beta I_B \quad I_E = (\beta + 1) I_B$$