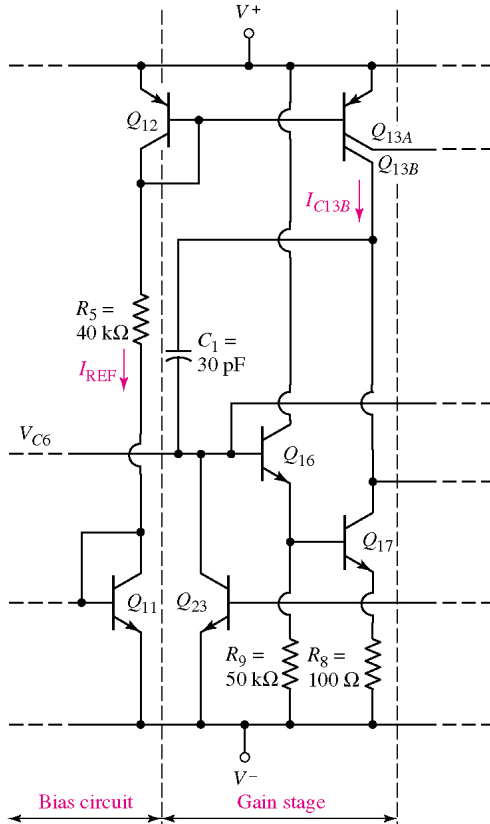


**Question:**

Gain stage for 741 op-amp is shown in **Figure 1**. Transistor  $Q_{13B}$  is scaled to **0.75** of transistor  $Q_{12}$ . Assume  $\beta = 200$  and  $V_{BE}(\text{on}) = V_{EB}(\text{on}) = 0.6 \text{ V}$ . Given that  $I_{REF} = 0.45 \text{ mA}$  and current  $I_{C16}$  can be calculated using  $I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$ . By neglecting base currents, **calculate**  $r_{\pi16}$  and  $r_{\pi17}$ . Show all your calculations clearly. [10 marks]



$$i_C = I_S e^{v_{BE}/V_T}; \text{ npn}$$

$$i_C = I_S e^{v_{EB}/V_T}; \text{ pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

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

; Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r_e = \frac{V_A}{I_{CQ}}$$

**Answer:**

$$I_{REF} = 0.45 \text{ mA}$$

$$I_{C17} = I_{C13B} = 0.75 I_{REF} \quad [2]$$

$$= (0.75)(0.45\text{m}) = 0.3375 \text{ mA} \quad [1]$$

$$I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$$

$$= I_{C17} / \beta + (I_{C17} R_8 + V_{BE17})/R_9 \quad [2]$$

$$= 0.3375\text{m}/200 + [(0.3375\text{m})(100) + 0.6]/50\text{k}$$

$$= 14.3625 \mu\text{A} \quad [1]$$

$$r_{\pi16} = (\beta V_T) / I_{C16} \quad [1]$$

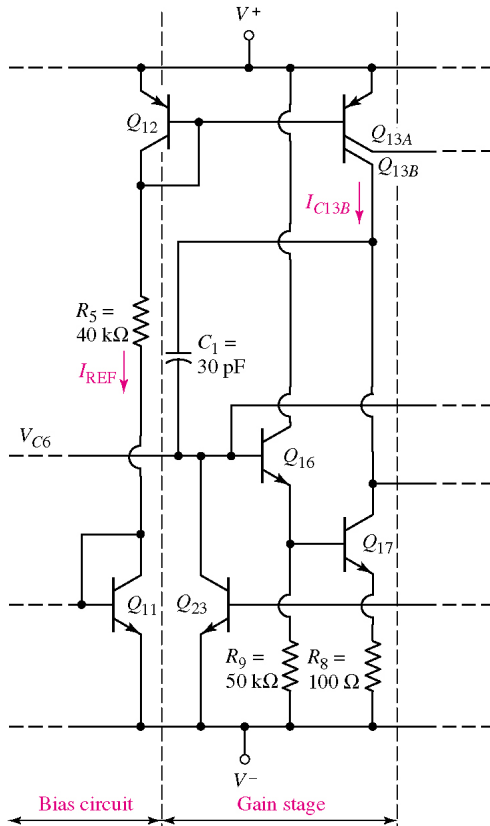
$$= (200 \times 0.026) / (14.3625 \mu\text{A}) = 362.053 \text{ k}\Omega \quad [1]$$

$$r_{\pi17} = (\beta V_T) / I_{C17} \quad [1]$$

$$= (200 \times 0.026) / (0.3375 \text{ mA}) = 15.407 \text{ k}\Omega \quad [1]$$

**Question:**

Gain stage for 741 op-amp is shown in **Figure 1**. Transistor  $Q_{13B}$  is scaled to **0.75** of transistor  $Q_{12}$ . Assume  $\beta = 180$  and  $V_{BE(\text{on})} = V_{EB(\text{on})} = 0.6 \text{ V}$ . Given that  $I_{REF} = 0.50 \text{ mA}$  and current  $I_{C16}$  can be calculated using  $I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$ . By neglecting base currents, **calculate**  $r_{\pi16}$  and  $r_{\pi17}$ . Show all your calculations clearly. [10 marks]



$$i_C = I_S e^{v_{BE}/V_T}; \text{ npn}$$

$$i_C = I_S e^{v_{EB}/V_T}; \text{ pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

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

; Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r_e = \frac{V_A}{I_{CQ}}$$

**Answer:**

$$I_{REF} = 0.50 \text{ mA}$$

$$I_{C17} = I_{C13B} = 0.75 I_{REF} \quad [2]$$

$$= (0.75)(0.50\text{m}) = 0.375 \text{ mA} \quad [1]$$

$$I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9 \quad [2]$$

$$= I_{C17}/\beta + (I_{C17} R_8 + V_{BE17})/R_9$$

$$= 0.375\text{m}/180 + [(0.375\text{m})(100) + 0.6]/50\text{k} \quad [1]$$

$$= 14.833 \mu\text{A}$$

$$r_{\pi16} = (\beta V_T) / I_{C16} \quad [1]$$

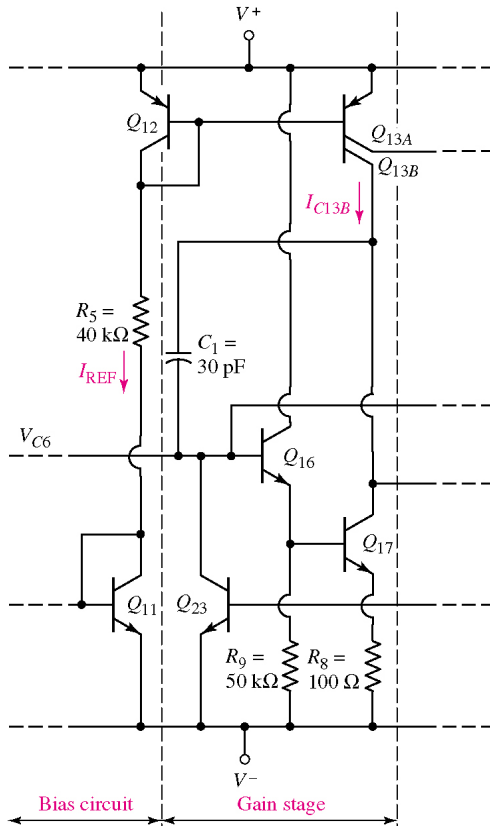
$$= (180 \times 0.026) / (14.833 \mu\text{A}) = 315.512 \text{ k}\Omega \quad [1]$$

$$r_{\pi17} = (\beta V_T) / I_{C17} \quad [1]$$

$$= (180 \times 0.026) / (0.375 \text{ mA}) = 12.48 \text{ k}\Omega \quad [1]$$

**Question:**

Gain stage for 741 op-amp is shown in **Figure 1**. Transistor  $Q_{13B}$  is scaled to **0.75** of transistor  $Q_{12}$ . Assume  $\beta = 220$  and  $V_{BE(\text{on})} = V_{EB(\text{on})} = 0.6 \text{ V}$ . Given that  $I_{REF} = 0.52 \text{ mA}$  and current  $I_{C16}$  can be calculated using  $I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$ . By neglecting base currents, **calculate**  $r_{\pi16}$  and  $r_{\pi17}$ . Show all your calculations clearly. [10 marks]



$$i_C = I_S e^{v_{BE}/V_T}; \text{npn}$$

$$i_C = I_S e^{v_{EB}/V_T}; \text{pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

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

; Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r = \frac{V_A}{I_{CQ}}$$

**Answer:**

$$I_{REF} = 0.52 \text{ mA}$$

$$I_{C17} = I_{C13B} = 0.75 I_{REF} \quad [2]$$

$$= (0.75)(0.52\text{m}) = 0.39 \text{ mA} \quad [1]$$

$$I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$$

$$= I_{C17}/\beta + (I_{C17} R_8 + V_{BE17})/R_9 \quad [2]$$

$$= 0.39\text{m}/220 + [(0.39\text{m})(100) + 0.6]/50\text{k}$$

$$= 14.552 \mu\text{A} \quad [1]$$

$$r_{\pi16} = (\beta V_T) / I_{C16} \quad [1]$$

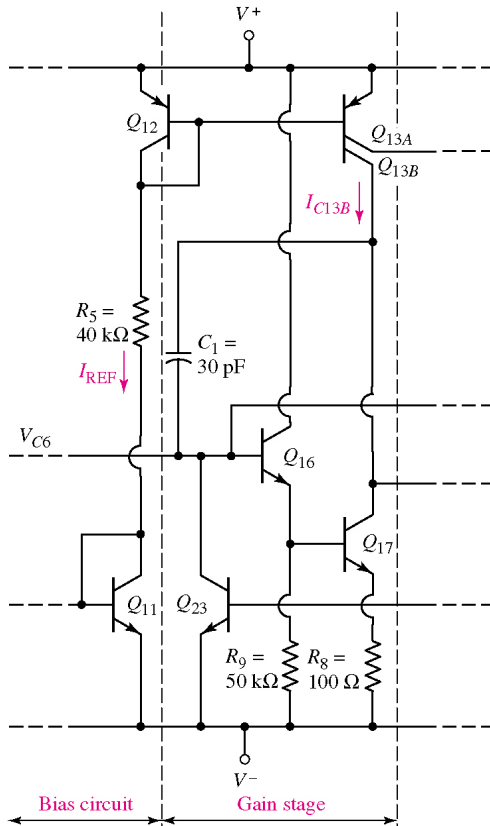
$$= (220 \times 0.026) / (14.356 \mu\text{A}) = 393.053 \text{ k}\Omega \quad [1]$$

$$r_{\pi17} = (\beta V_T) / I_{C17} \quad [1]$$

$$= (220 \times 0.026) / (0.39 \text{ mA}) = 14.667 \text{ k}\Omega \quad [1]$$

**Question:**

Gain stage for 741 op-amp is shown in **Figure 1**. Transistor  $Q_{13B}$  is scaled to **0.75** of transistor  $Q_{12}$ . Assume  $\beta = 210$  and  $V_{BE(ON)} = V_{EB(ON)} = 0.6$  V. Given that  $I_{REF} = 0.48$  mA and current  $I_{C16}$  can be calculated using  $I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$ . By neglecting base currents, **calculate**  $r_{\pi16}$  and  $r_{\pi17}$ . Show all your calculations clearly. [10 marks]



$$i_C = I_S e^{v_{BE}/V_T}; \text{npn}$$

$$i_C = I_S e^{v_{EB}/V_T}; \text{pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

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

; Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r = \frac{V_A}{I}$$

**Answer:**

$$I_{REF} = 0.48 \text{ mA}$$

$$I_{C17} = I_{C13B} = 0.75 I_{REF} \quad [2]$$

$$= (0.75)(0.48\text{m}) = 0.36 \text{ mA} \quad [1]$$

$$I_{C16} \approx I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$$

$$= I_{C17}/\beta + (I_{C17} R_8 + V_{BE17})/R_9 \quad [2]$$

$$= 0.36\text{m}/210 + [(0.36\text{m})(100) + 0.6]/50\text{k}$$

$$= 14.434 \mu\text{A} \quad [1]$$

$$r_{\pi16} = (\beta V_T) / I_{C16} \quad [1]$$

$$= (210 \times 0.026) / (14.434 \mu\text{A}) = 378.266 \text{ k}\Omega \quad [1]$$

$$r_{\pi17} = (\beta V_T) / I_{C17} \quad [1]$$

$$= (210 \times 0.026) / (0.36 \text{ mA}) = 15.167 \text{ k}\Omega \quad [1]$$