تمرین سری سوم

1)

$$2^{mA} = I_{C3} + I_{B3} + I_{B4} = I_{C3} + \frac{I_{C3}}{\beta_3} + \frac{I_{C4}}{\beta_4} \xrightarrow{\beta_{3,4} \gg 1} I_{C3} = 2^{mA}$$

$$V_{BE3} = V_{BE4} \rightarrow I_{C4} = I_{C3} = 2^{mA}$$

$$I_{E1} + I_{E2} = 2^{mA} \rightarrow I_{E1} = I_{E2} = \frac{2^{mA}}{2} = 1^{mA} = I_{C5} = I_{C6}$$

$$r_{\pi 1,2} = h_{ie1,2} = \frac{25^{mV}}{1^{mA}} \times \beta_{1,2} = 2.5^{k} \qquad \frac{1}{h_{oe1,2}} = r_{o1,2} = \frac{5^{V}}{1^{mA}} = 5^{k\Omega}$$

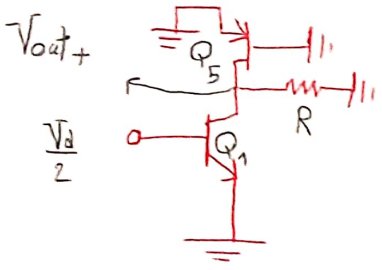
$$r_{\pi 3,4} = \frac{25^{mV}}{2^{mA}} \times 250 = 3.125^{k} \qquad r_{o3,4} = \frac{10^{V}}{2^{mA}} = 5^{k\Omega}$$

$$r_{\pi 5,6} = \frac{25^{mV}}{1^{mA}} \times 100 = 2.5^{k} \qquad r_{o5,6} = \frac{4^{V}}{1^{mA}} = 4^{k\Omega}$$

می خواهیم بهره $\frac{V_o}{V_d}$ بیاییم (در واقع چون C.E است یعنی بهره 50- باشد است)

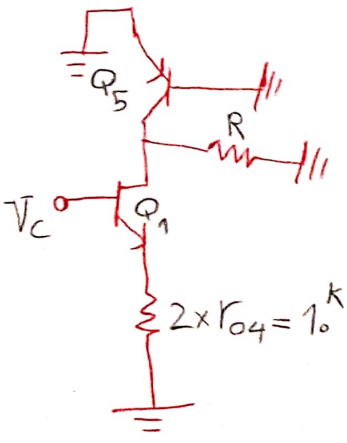
$$\rightarrow \frac{V_{o+}}{V_d} = -25 \rightarrow \frac{V_{o+}}{\frac{V_d}{2}} = -50 \qquad A_d = -25$$

چون مدار متقارن است در حالت تفاضلی نقاط وسط مدار ولتاژ صفر دارند و مدار به صورت زیر درمی آید:



$$\frac{V_{o+}}{\frac{V_d}{2}} = -50 = -\frac{(r_{o1} \| r_{o5} \| R)}{\frac{r_{\pi 1}}{\beta_1}} = -\frac{5^{k} \| 4^{k} \| R}{25^{\Omega}}$$

$$\rightarrow \boxed{R = 2.86^{k}}$$



مدار برای CMRR:

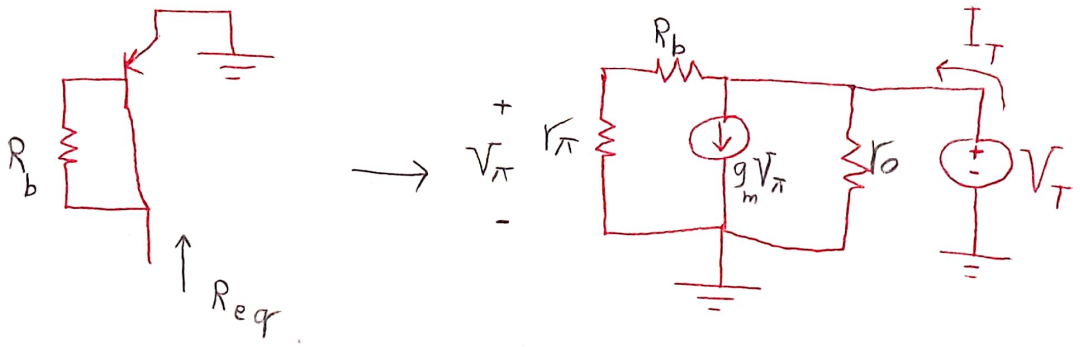
$$A_c = \frac{V_{o+}}{V_C} = \frac{-(5^{k} \| 4^{k} \| R)}{10^{k} + \frac{r_{\pi 1}}{\beta_1}}$$

$$= -0.125$$

$$\text{CMRR}: \frac{|A_d|}{|A_c|} = 200$$

2)

ابتدا باید مقاومت معادل دیده شده از کلکتور Q_3 و Q_4 را بدست آوریم:

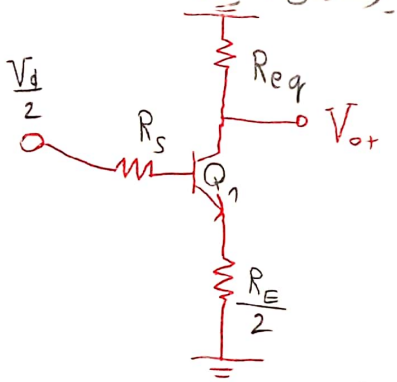


$$V_\pi = \frac{r_\pi}{r_\pi + R_b} \times V_T$$

$$KCL\ @\ V_T:\ I_T = \frac{V_T}{r_o} + g_m\left(\frac{r_\pi}{r_\pi + R_b} V_T\right) + \frac{V_T}{r_\pi + R_b}$$

$$\rightarrow I_T = V_T\left(\frac{1}{r_o} + \frac{g_m r_\pi}{r_\pi + R_b} + \frac{1}{r_\pi + R_b}\right) \rightarrow \boxed{R_{eq} = \frac{V_T}{I_T} = r_o \parallel (r_\pi + R_b) \parallel \left(\frac{r_\pi + R_b}{g_m r_\pi}\right)}$$

در حالت تفاضلی به علت تقارن وسط R_E ولتاژ صفر دارد و مدار به شکل زیر درمی آید:



$$\frac{\frac{V_{o+}}{V_d}}{2} = 2\,\frac{V_{o+}}{V_d} = 2A_d = \frac{V_o}{V_d}$$

$$= \frac{R_{eq} \parallel r_{o_1}}{\frac{R_E}{2} + \frac{r_{\pi_1}}{\beta} + \frac{R_S}{\beta}}$$

$$= \boxed{\frac{\left(r_{o_3} \parallel (r_{\pi_3} + R_b) \parallel \left(\frac{r_{\pi_3} + R_b}{g_{m3} r_{\pi_3}}\right) \parallel r_{o_1}\right)}{\frac{R_E}{2} + \frac{r_{\pi_1} + R_S}{\beta}}}$$

3)

$\beta \gg 1 \rightarrow I_{Ref} = I_R = I_C$ $\qquad V_{BE} = V_T \ln \frac{I_C}{I_S}$

$V_{BE1} = V_{BE2} + R I_{Ref} \rightarrow V_T \ln \frac{I_{Ref}}{I_S} = V_T \ln \frac{I_o}{I_S} + R I_{Ref}$ $\xrightarrow{\text{ترانزیستورها } I_S \text{ برابراست}}$

$$\rightarrow \boxed{V_T \ln \frac{I_{Ref}}{I_o} = R I_{Ref}} \rightarrow \begin{cases} I_{Ref} = 1\ mA \\ I_o = 10\ \mu A \end{cases} \rightarrow 25\ mV \ln \frac{1\ mA}{10\ \mu A} = R \times 1\ mA$$

$$\rightarrow \boxed{R = 115\ \Omega}$$

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4) $V_{BE1} = V_{BE2} \rightarrow V_T \ln \frac{I_{C1}}{I_{S1}} = V_T \ln \frac{I_{C2}}{I_{S2}} \xrightarrow{I_{S1} = \frac{3}{2} I_{S2}} \boxed{I_{C1} = \frac{3}{2} I_{C2}}$ (A)

$\boxed{I_o = \frac{9}{5} I_{C3}}$ (B) برای Q_3 و Q_4 هم به همین ترتیب داریم:

$KCL @ C_1: I_{Ref} = I_{C1} + \frac{I_{C1}}{\beta} + \frac{I_{C2}}{\beta} \xrightarrow{(A)} \boxed{I_{C2} = \frac{2\beta}{3\beta+5} I_{Ref}}$

$KCL @ C_3: I_{C2} = I_{C3} + \frac{I_{C3}}{\beta} + \frac{I_o}{\beta} \rightarrow \boxed{I_o = \frac{9\beta}{5\beta+14} I_{C2}}$

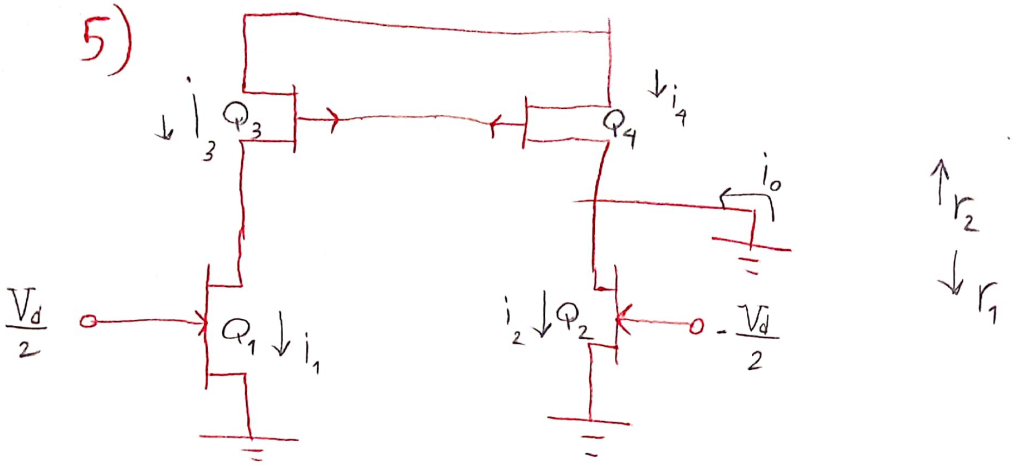
$$\boxed{I_o = \frac{9\beta}{5\beta+14} \times \frac{2\beta}{3\beta+5} \times I_{Ref}}$$

$I_o : 0.54\ mA$

$\beta = 100$ $\rightarrow \boxed{I_{Ref} \simeq 0.47\ mA}$

مدار سیگنال کوچک:

5)



$$\begin{cases} i_1 = g_m V_{GS_1} = g_m \frac{V_d}{2} = i_3 = i_4 \quad (V_{GS}\text{ برابر دارند پس جریانشان } Q_4, Q_3 \text{ برابر است}) \\ i_2 = g_m V_{GS_2} = -\frac{V_d}{2} g_m \end{cases}$$

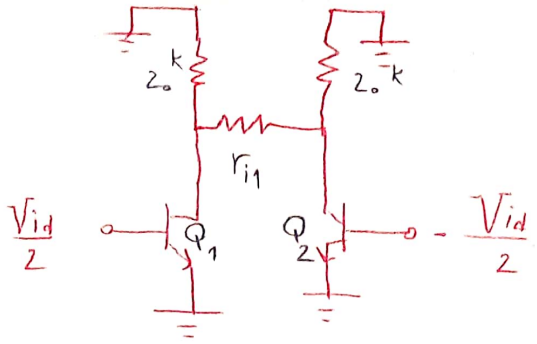
$$i_o = i_2 - i_4 = \boxed{-g_m V_d}$$

$$R_o = r_1 \| r_2 = r_{o2} \| r_{o4}$$

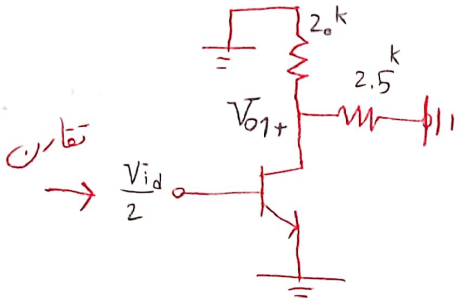
$$A_d = \frac{V_o}{V_d} = -i_o R_o = \boxed{g_m (r_{o2} \| r_{o4})}$$

6)

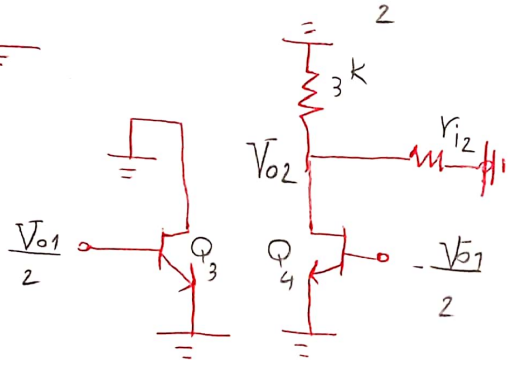
طبقه اول



r_{i1} مقاومت دیده شده از بین های Q_4 و Q_5 است که برابر با $2.5^k \parallel 2.5^k = 5^k$ است.



$$\frac{\frac{V_{o1+}}{\frac{V_{id}}{2}}}{} = \frac{V_{o1}}{V_{id}} = \frac{-(2.5^k \parallel 2.0^k)}{\frac{r_{\pi 1}}{\beta}} = \boxed{-22.2}$$

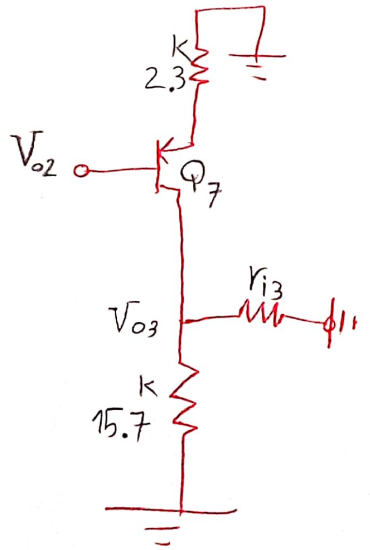


$$r_{i2} = r_{\pi 7} + \beta R_4 = 232.5^k$$

$$\frac{V_{o2}}{\left(-\frac{V_{o1}}{2}\right)} = -\frac{r_{i2} \parallel 3^k}{\frac{r_{\pi 4}}{\beta}} \approx -118.47$$

$$\rightarrow \frac{V_{o2}}{V_{o1}} = \boxed{+59.2}$$

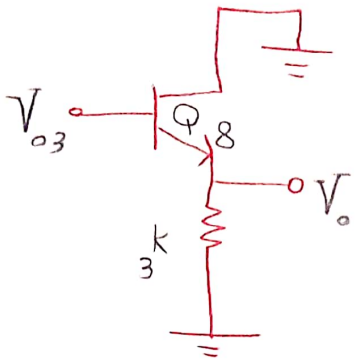
طبقه سوم:



$$r_{i3} = r_{\pi 8} + \beta \times R_6 = 300.5^k$$

$$\frac{V_{o3}}{V_{o2}} = -\frac{r_{i3} \parallel 15.7^k}{\frac{r_{\pi 7}}{\beta} + 2.3^k} \approx \boxed{-6.42}$$

4 طبقه:



$$\frac{V_o}{V_{o3}} = \frac{3^k}{3^k + \frac{r_{\pi 8}}{\beta}} = 0.998 \simeq \boxed{1}$$

بنابراین: $\frac{V_o}{V_{id}} = \frac{V_{o1}}{V_{id}} \times \frac{V_{o2}}{V_{o1}} \times \frac{V_{o3}}{V_{o2}} \times \frac{V_o}{V_{o3}}$

$$= (-22.2) \times (59.2) \times (-6.42) \times 1 \simeq \boxed{+8437.4}$$

با توجه به تحلیل DC (مدار آن در صفحه آخر تمرین ها است)، $V_{b7} = 12^V$ و $V_{C7} = 0.7^V$ است.

پس Q_7 علاوه بر تأمین بهره، نقش DC shifter را دارد.