Problem 4 - Analog and Digital Electronics - Solutions

a) For I_{D3}:

$$I_{D3} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_3 (V_{GS_3} - V_t)^2 = 3\times10^{-4}(V_{GS}-1)^2$$

$$I_{D3} \cdot 30k + V_{GS_3} = 20$$

Solving for V_{GS_3}: $9V_{GS_3}^2 - 17V_{GS_3} - 11 = 0$

$$\Rightarrow V_{GS_3} = 2.4\,V.$$

$$\therefore I_{D3} = I_{D4} = 0.587\ mA$$

$$I_{D1} = I_{D2} = \frac{I_{D4}}{2} = 0.293\ mA.$$

$$\therefore V_o = 10 - I_{D2}\,16k = 5.31\,V.$$

b) $$A_o = \frac{1}{2} g_{m_1} R_{D1}$$

$$g_{m_1} = \sqrt{2k_n'\left(\frac{W}{L}\right)_1 I_{D_1}} = 0.34\ mA/V$$

$$\therefore A_o = 2.72$$

c) $$A_{cm} = -\frac{R_{D_1} g_{m_1}}{1 + 2g_{m_1} R_{O4}} \simeq -\frac{R_D}{2R_{O4}}$$

$$R_{O4} = \frac{1}{\lambda_4 I_{D4}} = 170\,k\Omega$$

$$\therefore A_{cm} \simeq -0.0467$$

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d) $CMRR = 20 \log \frac{|A_{ol}|}{|A_{cm}|} = 35.3\ dB$

e) $V_{in\,max}$ occurs when $Q_1 + Q_2$ are at the edge of saturation,

i.e., $V_{GD_1} = V_t$, $V_{DS_1} = V_{OV_1}$

$\therefore V_{GD_1} = 1 = V_{in\,max} - V_o = V_{in\,max} - (10 - I_{D_1}(6k))$

$\therefore V_{in\,max} = 6.31\ V$

$V_{in\,min}$ occurs when Q_4 is at edge of saturation,

i.e., $V_{GD_4} = V_t$, $V_{DS_4} = V_{OV_4}$

Now $V_{OV_4} = V_{GS_4} - V_t = 2.4 - 1 = 1.4$

& $V_{in\,min} = V_{GS_1} + V_{DS_4} - 10$

But $V_{GS_1} = \sqrt{\frac{I_{D1}}{\frac{1}{2}K_n'(\frac{W}{L})_1}} + V_t = 2.71\ V$

$\therefore V_{in\,min} = -5.89\ V$

$\therefore -5.89\ V \leq V_{in} \leq 6.31\ V$