HW 4 solution

1.

(a)

$$V_{offset} = V_{DD} - |V_{tp}| - V_{EB3}$$

$$= 2.5 - 0.5 - 0.5$$

$$= 1.5V$$

(b)

$$|A_v| = \frac{g_{m1}}{g_{o1} + g_{o3}}$$

$$= \frac{2I_{DQ}/V_{EB1}}{\lambda_n I_{DQ} + \lambda_p I_{DQ}}$$

$$= \frac{2}{(\lambda_n + \lambda_p) V_{EB1}}$$

$$= \frac{2}{(0.01 + 0.01) \times 0.5}$$

$$= 200$$

$$V_{offset\text{-}input} = \frac{1.5}{200} = 0.0075V$$

2

(a) $P = 2mW$

$$I_{tot} = \frac{2m}{2.5} = 800\,\mu A$$

$$I_{5,6} = \frac{800\mu}{2} = 400\,\mu A$$

$$I_{1,2,3,4,7,8,9,10} = \frac{400\mu A}{2} = 200\,\mu A$$

$$\left(\frac{W}{L}\right)_{5,6} = \frac{2 \times 400\mu}{\mu_p C_{ox} V_{EB}^2} = 384$$

$$\left(\frac{W}{L}\right)_{3,4} = \frac{2 \times 200\mu}{\mu_p C_{ox} V_{EB}^2} = 192$$

$$\left(\frac{W}{L}\right)_{1,2,7,8,9,10} = \frac{2 \times 200\mu}{\mu_n C_{ox} V_{EB}^2} = 64$$

(b)

$$SR = \frac{I_T}{2C_L} = \frac{2 \times 200\mu}{2 \times 2p} = 100\,V/\mu s$$

(c)

$$V_{out+} = V_{DD} - 2V_{EB}$$

$$= 2.5 - 2 \times 0.25$$

$$= 2$$

$$V_{out-} = V_{SS} + 2V_{EB}$$

$$= -2.5 + 2 \times 0.25$$

$$= -2$$

(d)

$$|A_v| = g_{m1} R_{out}$$

$$R_{out} \approx \left[g_{m4} r_{ds4} (r_{ds6} \parallel r_{ds2})\right] \parallel (g_{m10} r_{ds10} r_{ds8})$$

$$= \frac{1}{\dfrac{\lambda_p I_4 (\lambda_p I_6 + \lambda_n I_2)}{g_{m4}} + \dfrac{\lambda_n^2 I_{10} I_8}{g_{m10}}}$$

$$= \frac{1}{\dfrac{\frac{1}{2} I_T^2 \lambda_p (\lambda_p + \frac{1}{2}\lambda_n)}{\frac{2 \times \frac{1}{2} I_T}{V_{EB}}} + \dfrac{\frac{1}{4} \lambda_n^2 I_T^2}{\frac{2 \times \frac{1}{2} I_T}{V_{EB}}}}$$

$$= \frac{1}{\frac{1}{2} I_T \lambda_p (\lambda_p + \frac{1}{2}\lambda_n) V_{EB} + \frac{1}{4} \lambda_n^2 I_T V_{EB}}$$

$$|A_v| = \frac{\frac{2 \times \frac{1}{2} I_T}{V_{EB}}}{\frac{1}{2} I_T \lambda_p (\lambda_p + \frac{1}{2}\lambda_n) V_{EB} + \frac{1}{4} \lambda_n^2 I_T V_{EB}}$$

$$= \frac{1}{\frac{1}{2} \lambda_p (\lambda_p + \frac{1}{2}\lambda_n) V_{EB}^2 + \frac{1}{4} \lambda_n^2 V_{EB}^2}$$

$$= \frac{1}{\frac{1}{2} \times 0.01 \times (0.01 + \frac{1}{2} \times 0.01) \times 0.25^2 + \frac{1}{4} \times 0.01^2 \times 0.25^2}$$

$$= 160000 \text{ V/V}$$

3.

From the last problem,

$$A_{V\text{-}FC} = 160000$$

With the reference opamp, we have

$$A_V = \frac{2}{V_{EB,1}(\lambda_1+\lambda_3)}$$

Assume we have same V_{EB},

then $$A_{V\text{-}o} = \frac{2}{0.25 \times 0.02} = 400$$

Therefore, the folded cascode amplifier achieves much higher gain than the reference opamp. with the same power.

Fold-cascode : $$GB = \frac{P\Theta}{V_{DD}V_{EB}C_L}$$

reference opamp: $$GB = \frac{P}{V_{DD}V_{EB}C_L}$$

Therefore, the folded cascode amplifier consumes more power than the reference opamp with the same GB achievement.

4.

From problem 2,

$$A_{V\text{-}FC} = 160000$$

For the telescopic cascode opamp, (assume all $V_{EB} = 0.25$)

$$A_{V-TC} = \frac{4}{0.25^2 (0.01^2 + 0.01^2)}$$

$$= 320000$$

Folded cascode:

$$GB_{-FC} = \frac{P\theta}{V_{DD} V_{EB_1} C_L}$$

Telescopic cascode:

$$GB_{-TC} = \frac{P}{V_{DD} V_{EB_1} C_L}$$

To obtain the similar GB, folded cascode dissipates more power.

5.

(a)

$$I_{DQ} = \frac{P}{V_{DD}} = \frac{100\mu}{2.5} = 40\mu A$$

$$GB = \frac{g_{m_1}}{C_L} = \frac{\frac{2 I_{DQ}}{V_{EB_1}}}{C_L} = \frac{\frac{2 \times 40\mu}{0.2}}{C_L} = \frac{400\mu}{C_L} = \frac{4 \times 10^{-4}}{C_L}$$

(b)

$$I_{DQ} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} V_{EB_1}^2$$

$$40\mu = \frac{1}{2} \times 100\mu \times \frac{W}{L} \times 0.2^2$$

$$\frac{W}{L} = 20$$

(c)

$W = 40u$

Assume, the source and drain junctions extend 2 um beyond the gate.

$$C_{db} = 429a \times 2 \times 40 + 311a \times (40\times2 + 2\times2)$$

$$= 60.444 \text{ fF}$$

(d)

DC gain will not change

without C_{db}

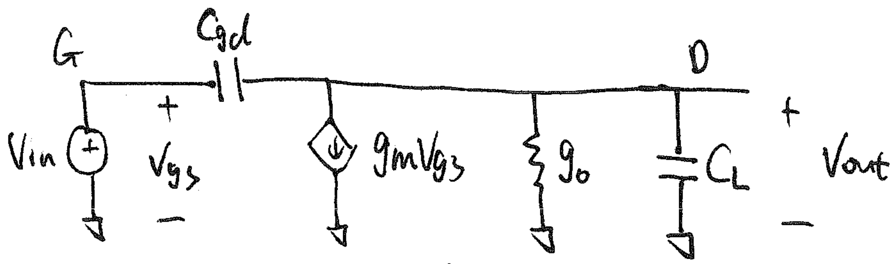
$$GB = \frac{4\times10^{-4}}{500\times10^{-15}} = 8\times10^{8}$$

with C_{db}

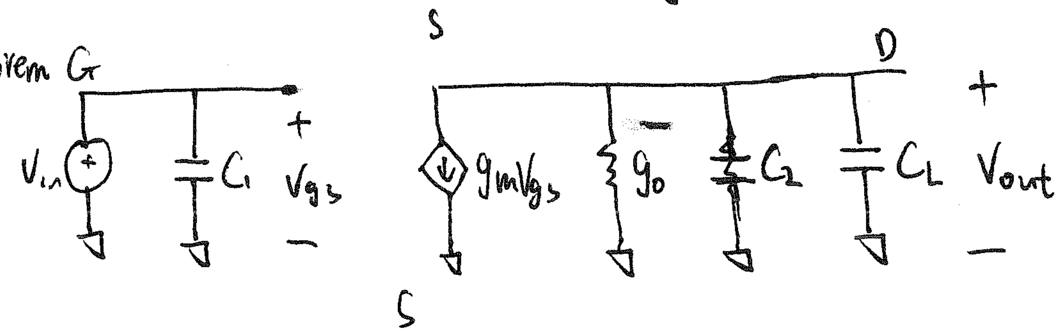
$$GB = \frac{4\times10^{-4}}{560.444\times10^{-15}} = 7.137\times10^{8}$$

As we can see, GB degrades when C_{db} presents.

(e)



Miller's theorem
⇒



$$C_1 = \frac{C_{gd}}{1 - A_v} \qquad C_2 = \frac{C_{gd}}{1 - \frac{1}{A_v}}$$

then: $GB = \frac{g_{m1}}{C_L + C_2}$

therefore, C_{gd} also degrades GB performance.

(f)

$C_{gd} = C_{gd\text{-}ov} \times W = 206a \times 20$

$= 4.12fF$