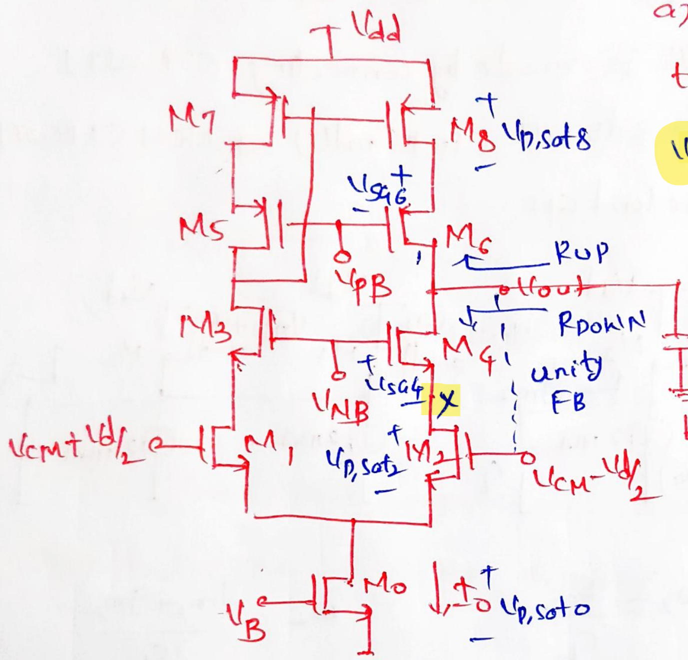
Tutorial-7

Q 1) A student has desiged an NMOS Telescope differentral amplifier with following specifications:

$I_o = 32\mu A$, $V_{ov} = 0.4V$, $\mu_n C_{ox} = 200\mu A/V^2$, $\mu_p C_{ox} = 100\mu A/V^2$, $|V_{tp}| = V_{tn} = 1V$, $\lambda = \frac{1}{100V}$, $V_{dd} = 5V$, if the channel length $L = 0.2\mu$, $C_L = 10pF$. Find

$(V_{D,sat} = V_{ov})$



a) V_{PB} required to bias transistors in saturation in (V)

$$V_{PB} = V_{DD} - V_{D,sat8} - V_{SG6}$$

$$= V_{DD} - V_{D,sat8} - V_{D,sat6} - V_{TH}$$

$$= V_{DD} - 2V_{D,sat} - V_{TH}$$

$$= 5 - 2(0.4) - 1 = 3.2V$$

b) V_{NB} Required to bias transistors in saturation in (V)

$$V_{NB} = V_{D,sato} + V_{D,sat1} + V_{GS4}$$

$$= V_{D,sato} + V_{D,sat1} + V_{Dsat4} + V_{TH}$$

$$= 3V_{D,sat} + V_{TH}$$

$$= 3(0.4) + 1 = 2.2V.$$

c) Output Common mode range in unity feedback (V).

In unity feedback,

For M_2 to be in Sat $\quad V_{out} \le V_x + V_{TH2}$

For M_4 to be in Sat $\quad V_{out} \ge V_{NB} - V_{TH4}$

$V_x = V_{NB} - V_{GS4}$

$$\underbrace{V_{NB} - V_{TH4}}_{V_{o,min}} \le V_{out} \le V_{NB} - V_{GS4} + V_{TH2}$$

$$= \underbrace{(V_{NB} - \underbrace{(V_{GS4} - V_{TH2})}_{V_{ov}})}_{V_{o,max}}$$

$OCMR = V_{o,max} - V_{min} = V_{TH4} - (V_{GS4} - V_{TH2})$

$= 1 - 0.4 = 0.6V$

d) Gain

$Gain = -G_m R_{OUT}$, $G_m = g_m$ $R_{OUT} = R_{up} \parallel R_{DOWN}$

$R_{up} = g_m r_o^2 = R_{DOWN}$. $\Rightarrow R_{OUT} = \frac{g_m r_o^2}{2}$

$Gain = \frac{g_m^2 r_o^2}{2}$

$g_m = \sqrt{2 I_D \mu_n C_{ox} \frac{W}{L}} = \frac{2 I_D}{V_{OV}} = \frac{I_{Tail}}{V_{OV}} = \frac{32}{0.4} = 80 \mu S$

$r_o = \frac{1}{\lambda I_D} = \frac{2}{\lambda I_{Tail}} = \frac{2 \times 100}{32} = 6.25 M\Omega$

$Gain = \frac{g_m^2 r_o^2}{2} = 12{,}5000$

e) Bandwidth

$Bandwidth = \frac{1}{R_{out} C_L} = \frac{1}{\frac{g_m r_o^2}{2} C_L} = 64 \ Mrad/s$

f) Charging rate of capacitor C_L (V/μs), if M_1 gate is at V_{dd} & M_2 gate is at 0V.

M_1 only turns ON & M_2 is OFF, entire current flows throw M_1, that is mirrored by current mirror & charges the output capacitor.

$\frac{dv_o}{dt} = I/C_L = \frac{32}{10} = 3.2 \ V/\mu s$

9) $W_1 + W_8$ in μm

<u>W_1 (NMOS)</u>

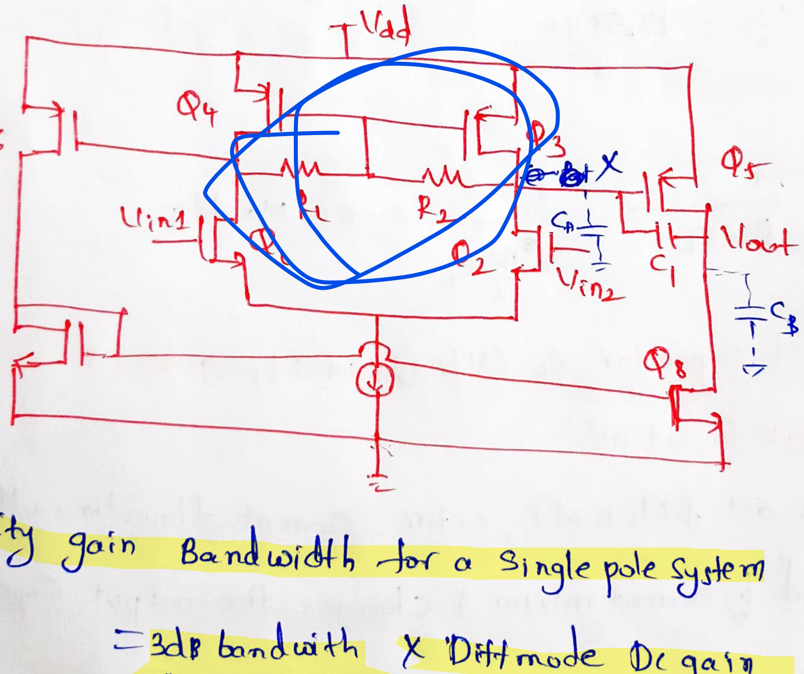
$$\frac{I_D}{2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{ov})^2 \Rightarrow W = \frac{I \times L}{\mu_n C_{ox}(V_{ov})^2} = 0.2\,u$$

<u>W_8 (PMOS)</u>

$$I/_2 = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{ov})^2 \Rightarrow W = \frac{I \times L}{\mu_p C_{ox}(V_{ov})^2} = 0.4\,u$$

$W_1 + W_8 = 0.6\,u$

Q 1) Assuming only a single (dominant) pole, find the Unity Gain Bandwidth (in Mrad/s) for the given Two stage op-amp with common-mode feedback. Assume g_m of all transistors as 8mS, $r_o = 115\,k\Omega$, $R_1 = R_2 = 60\,k\Omega$, $C_1 = 5$ pF. (~~with~~



<u>Sol:</u>

Unity gain Bandwidth for a Single pole System

= 3dB bandwith X Diff mode DC gain
(pole freq)

Dominant pole is present at node 'X'. C_1 is Miller cap

(A) ·

$C_A = C_1\left(1 + g_m \frac{r_o}{2}\right)$

$R_{out_1} = r_{o2} \| r_{o3} \| R = \frac{r_o}{2} \| R = \frac{R r_o}{2R + r_o}$

$\text{Dc gain} = \left(g_{m_1} \frac{R r_o}{2R + r_o}\right) \cdot \left(g_{m_5} \frac{r_o}{2}\right) = g_m^2 \frac{R r_o^2}{2(2R + r_o)}$

Unity Gain Bandwidth (UGB)

$= g_m^2 \frac{\cancel{R} r_o^{\cancel{2}}}{2\cancel{(2R + r_o)}} \times \frac{1}{\frac{\cancel{R r_o}}{\cancel{2R + r_o}} C_1\left(1 + \frac{g_m r_o}{2}\right)}$

$= \frac{g_m^2 r_o}{C_1(2 + g_m r_o)} = \cancel{204\,899.77\text{ Mrad/s}}$

1995.566M rad/s

Q2-) Consider the circuit shown below. Bias voltages V_{B1}, V_{B2} and bias currents in all branches keep the transistors in saturation. Calculate the ratio of magnitude of pole frequency at node X to magnitude of pole frequency at node Y.

Take: $V_{dd} = 3.3V$, $R_D = 2k\Omega$, $R_S = 0.1k\Omega$

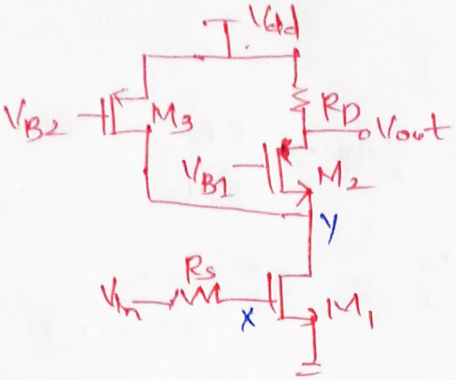
$g_{m1} = 5mS$, $g_{m2} = 2mS$, $g_{m3} = 1mS$

$C_{gs1} = 14fF$ $C_{gd1} = 6fF$ $C_{db1} = 3fF$ $C_{sb1} = 2fF$

$C_{gs2} = 14fF$ $C_{gd2} = 7fF$ $C_{db2} = 5fF$ $C_{sb2} = 7fF$

$C_{gs3} = 10fF$ $C_{gd3} = 4fF$ $C_{db3} = 4fF$ $C_{sb3} = 3fF$

Assume drain-source small signal resistance of the transistors to be large.



Sol:

Pole freq at X (P_x) $= \frac{1}{2\pi R_x C_x}$

$C_x = C_{gs} + (1+|A_1|)C_{gd_1}$

$A_1 = -g_{m_1}\left(\frac{1}{g_{m_2}}\right)$

$(r_{o1}, r_{o2} = r_{o3} \to \infty)$

$R_x = R_s$

$$P_x = \frac{1}{2\pi R_s\left[C_{gs1} + \left(1+\frac{g_{m1}}{g_{m2}}\right)C_{gd1}\right]} = 45.495 \text{ GHz}$$

Pole frequency at y (P_y) $= \frac{1}{2\pi R_y C_y}$ $R_y = \frac{1}{g_{m2}}$

$C_y = C_{db1} + C_{gs2} + C_{sb2} + C_{gd3} + C_{db3} + \left(1+\frac{1}{|A_1|}\right)C_{gd1}$, $|A_1| = \frac{g_{m2}}{g_{m1}}$

$$P_y = \frac{1}{2\pi\left(\frac{1}{g_{m2}}\right)[C_y]} = \frac{1}{2\pi \times \frac{1}{2} \times \frac{202}{5}} = 7.878 \text{ GHz}$$

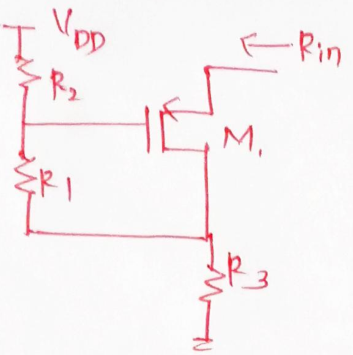
$$\text{Ratio} = \frac{P_x}{P_y} = \frac{45.495}{7.878} = 5.775$$

Q3) Determine the small signal input resistance Rin (in kΩ) for the circuit shown below.

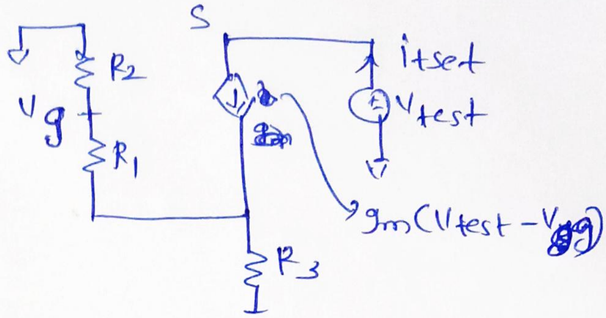
Done

Take: $V_{dd} = 10V$, $R_1 = 7k\Omega$, $R_2 = 18k\Omega$, $R_3 = 2k\Omega$, $g_{m1} = 2.8mS$

Assume source-drain small signal resistance of the transistor to be large.



Sol :



$$i_{test} = g_m (V_{test} - V_g) \quad -①$$

$$V_g = \underbrace{\frac{g_m (V_{test} - V_g) R_3}{R_3 + R_1 + R_2}}_{\text{Current division}} \times R_2$$

$$V_g \left[1 + \frac{g_m R_3 R_2}{R_1 + R_2 + R_3} \right] = \frac{g_m V_{test} R_2 R_3}{R_1 + R_2 + R_3}$$

$$V_g = \frac{V_{test} \cdot g_m R_2 R_3}{R_1 + R_2 + R_3 + g_m R_3 R_2} \quad -②$$

from ① & ②

$$\frac{i_{test}}{V_{test}} = \frac{g_m (R_1 + R_2 + R_3) + \cancel{g_m^2 R_2 R_3} - \cancel{g_m^2 R_2 R_3}}{R_1 + R_2 + R_3 + g_m R_2 R_3}$$

$$R_{in} = \frac{V_{test}}{i_{test}} = \frac{1}{g_m} \left[\frac{R_1 + R_2 + R_3 + g_m R_2 R_3}{R_1 + R_2 + R_3} \right]$$

$$= \frac{1}{g_m} \left[1 + \frac{g_m R_2 R_3}{R_1 + R_2 + R_3} \right]$$

$$R_{in} = 1.6904 \ k\Omega$$