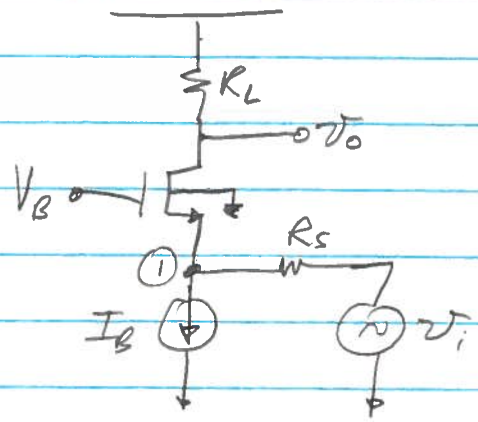
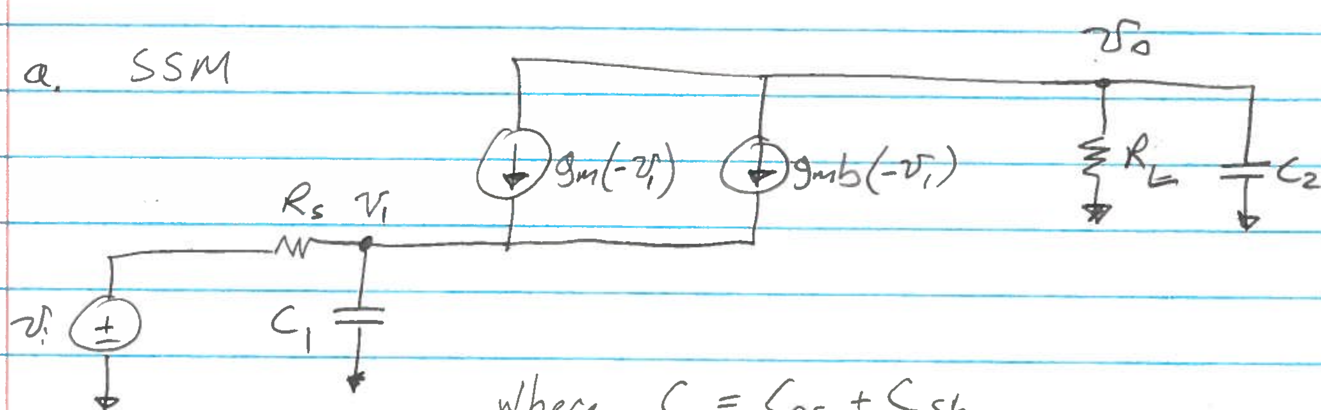
1.



a. SSM



where $C_1 = C_{gs} + C_{sb}$
$C_2 = C_{gd} + C_{db}$

b. KCL @ v_o:

$$(g_m + g_{mb})(-v_1) + \frac{v_o}{Z_{R_L} || Z_{C2}} = 0$$

$$v_1 = \frac{v_o}{(g_m + g_{mb})(Z_{R_L} || Z_{C2})} = A v_o$$

KCL @ v_1:

$$(A v_o - v_i) G_s + A v_o s C_1 + (g_m + g_{mb}) A v_o = 0$$

$$A v_o (G_s + sC_1 + g_m + g_{mb}) = v_i G_s$$

$$\frac{v_o}{v_i} = \frac{G_s}{A(G_s + sC_1 + g_m + g_{mb})}$$

$$= \frac{(g_m + g_{mb})(Z_{R_L} \| Z_{C2}) G_s}{G_s + sC_1 + g_m + g_{mb}}$$

$$= \frac{(g_m + g_{mb}) R_L}{(1 + sR_L C_2)(1 + (g_m + g_{mb}) R_s + sR_s C_1)}$$

$$\frac{v_o}{v_i} = \frac{(g_m + g_{mb}) R_L}{(1 + (g_m + g_{mb}) R_s)(1 + sR_L C_2)\left(1 + s \frac{R_s C_1}{1 + (g_m + g_{mb}) R_s}\right)}$$

where $C_1 = C_{gs} + C_{sb}$

$C_2 = C_{gd} + C_{db}$

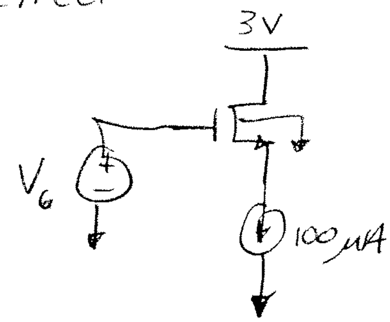
C_1

$$\text{DC gain} = \frac{(g_m + g_{mb}) R_L}{1 + (g_m + g_{mb}) R_s}$$

2 poles at $-\frac{1}{R_L C_2}$, $-\frac{1 + (g_m + g_{mb}) R_s}{R_s C_1}$

No zeros

2. Body Effect



$V_G = ?$ for $V_T = 0.8V$

$$V_T = V_{T0} + \gamma\left(\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}\right)$$

⇒ Solve for V_{SB}

$$V_{SB} = \left(\frac{V_T - V_{T0}}{\gamma} + \sqrt{|2\phi_F|}\right)^2 - |2\phi_F|$$

$$= \left(\frac{0.8V - 0.7V}{0.45V^{1/2}} + \sqrt{0.9V}\right)^2 - 0.9V$$

$$= 0.471V$$

$$V_B = 0 \Rightarrow V_S = 0.471V$$

Transistor in Saturation

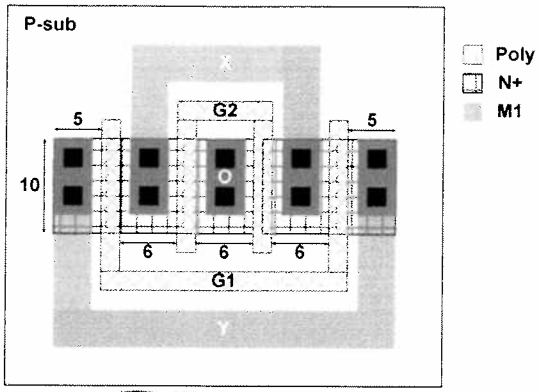
$$I_D = \tfrac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$

$$V_G = \sqrt{\frac{2I_D}{\mu C_{ox}\frac{W}{L}}} + V_T + V_S$$

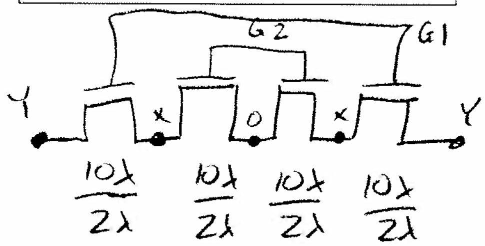
$$= \sqrt{\frac{2(100\mu A)}{(130\mu A/V^2)\left(\frac{10}{0.6}\right)}} + 0.8V + 0.471V$$

$$\boxed{V_G = 1.575V}$$

2.



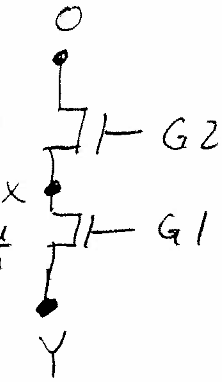
a.



$\Rightarrow$

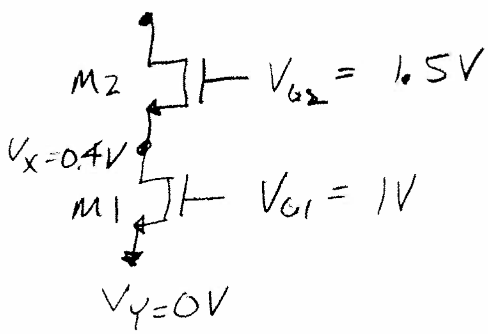
$2\left(\frac{10\lambda}{2\lambda}\right) = \frac{10\mu}{1\mu}$

$2\left(\frac{10\lambda}{2\lambda}\right) = \frac{10\mu}{1\mu}$



b.

$V_o = 0.5V$



Top Transistor M2

$V_{GS} = 1.5V - 0.4V = 1.1V$

$V_{DS} = 0.5V - 0.4V = 0.1V$

$V_{DS} = 0.1V < V_{GS} - V_T = 1.1V - 0.7V = 0.4V$

M2 $\Rightarrow$ Triode

Bottom Transistor M1

$V_{GS} = 1V \qquad V_{DS} = 0.4V$

$V_{DS} = 0.4V > V_{GS} - V_T = 1V - 0.7V = 0.3V$

M1 $\Rightarrow$ Saturation

- $C_{\circ}$ Top Transistor M2 Gate cap

M2 = Triode

$$C_{gs2} = C_{gd2} = \frac{W L_{eff} C_{ox}}{2} + W C_{ov}$$

$$= \frac{10\mu(1\mu - 2L_D) C_{ox}}{2} + 10\mu C_{ov}$$

$$M_2 \text{ Total } C_{g2} = C_{gs2} + C_{gd2} = 2\left[\frac{10\mu(1\mu - 2L_D) C_{ox}}{2} + 10\mu C_{ov}\right]$$

$$= \boxed{9\mu^2 C_{ox} + 20\mu C_{ov}}$$

Bottom Transistor M1 Gate cap

M1 = Saturation

$$C_{gs1} = \tfrac{2}{3} W L_{eff} C_{ox} + W C_{ov}$$

$$= \tfrac{2}{3}(10\mu)(1\mu - 2L_D) C_{ox} + 10\mu C_{ov}$$

$$C_{gd1} = W C_{ov} = 10\mu C_{ov}$$

$$M1 \text{ Total } C_{g1} = C_{gs1} + C_{gd1} = \tfrac{2}{3}(10\mu)(1\mu - 2L_D) C_{ox} + 2(10\mu) C_{ov}$$

$$= 6\mu^2 C_{ox} + 20\mu C_{ov}$$

2b

d. * Node O Junction Cap

Node O = Drain M2 (Triode)

Note: $C_{jc} = \sqrt{\frac{q \epsilon_{si} N_{sub}}{4\phi_F}}$

$$C_{JO} = C_j A_O + C_{jsw} P_O + C_{jc} \frac{W_2 L_{eff}}{2}$$

$$= C_j (10\lambda)(6\lambda) + C_{jsw} (2)(6\lambda + 10\lambda) + C_{jc} \frac{2(10\lambda)(L - 2L_D)}{2}$$

$$= C_j (5\mu)(3\mu) + C_{jsw}(2)(8\mu) + C_{jc} \frac{2(5\mu)(1\mu - 2L_D)}{2}$$

$$\boxed{C_{JO} = C_j 15\mu^2 + 4.5\mu^2 C_{jc} + C_{jsw}(16\mu)}$$

* Node X Junction Cap

Node X = Source M2 (Triode) & Drain M1 (Sat)

$$C_{JX} = C_j A_X + C_{jsw} P_X + C_{jc} \frac{W_2 L_{eff}}{2}$$

$$= C_j (10\lambda)(6\lambda)(2) + C_{jsw}(2)(16\lambda)(2) + C_{jc} \frac{2(10\lambda)(L - 2L_D)}{2}$$

$$= C_j (5\mu)(3\mu)(2) + C_{jsw}(2)(8\mu)(2) + C_{jc} \frac{2(5\mu)(1\mu - 2L_D)}{2}$$

$$\boxed{C_{JX} = C_j 30\mu^2 + 4.5\mu^2 C_{jc} + C_{jsw}(32\mu)}$$

* Node Y Junction Cap ⇒ Source M1 (Sat)

$$C_{JY} = C_j A_Y + C_{jsw} P_Y + C_{jc} \tfrac{2}{3} W_1 L_{eff}$$

$$= C_j (10\lambda)(5\lambda)(2) + C_{jsw}[30\lambda](2) + C_{jc} \tfrac{2}{3}(2)(10\lambda)(L - 2L_D)$$

$$\boxed{C_{JY} = C_j 25\mu^2 + 6\mu^2 C_{jc} + C_{jsw}(30\mu)}$$

3. Capacitor Matching

a. Match two caps of unit size 8 and 3.75

$$\frac{C_1}{C_u} = 8 \Rightarrow 8\,(4\mu \times 4\mu) \text{ unit caps}$$

$$\frac{C_2}{C_u} = 3.75 \Rightarrow 2 \text{ unit caps} + 1 \text{ non-unit cap}$$
$$\text{w/ } A_{nu} = 1.75 A_u$$

$$\Rightarrow K = 1.75$$

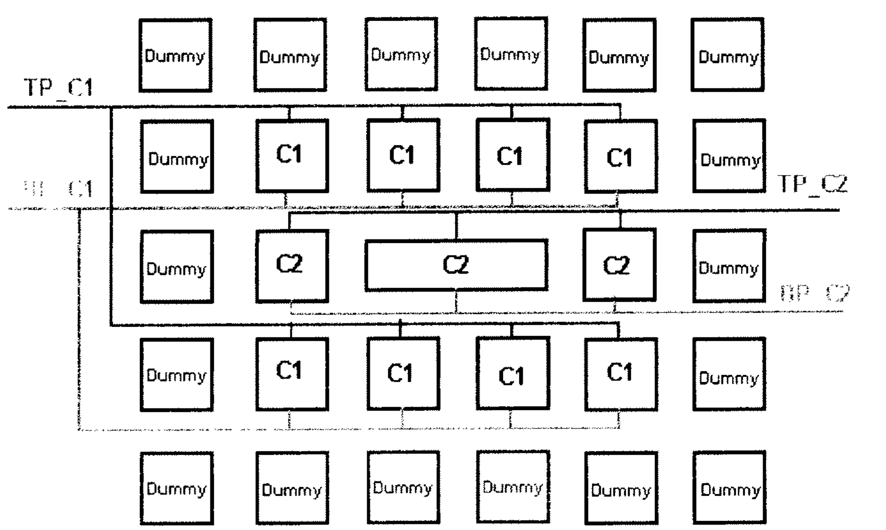
$$y_{nu} = X_u\left(K \pm \sqrt{K^2 - K}\right) = 4\mu\left(1.75 \pm \sqrt{1.75^2 - 1.75}\right)$$
$$= 11.583\mu \text{ or } 2.417\mu$$

$$X_{nu} = \frac{K X_u^2}{y_{nu}} = \frac{1.75\,(4\mu)^2}{11.583\mu \text{ or } 2.417\mu} = 2.417\mu \text{ or } 11.583\mu$$

$C_1 = 8\,(4\mu * 4\mu)$ unit caps

$C_2 = 2\,(4\mu \times 4\mu)$ unit caps $+\ 1\,(11.583\mu \times 2.417\mu)$ cap

Potential Layout: (From Harish Krishnamoorthy)



b. Rounding to 0.1μ

$$\text{Non-Unit Cap} = 11.583\mu \times 2.417\mu$$

$$\Longrightarrow 11.6\mu \times 2.4\mu$$

$$\text{Ideal Ratio} = \frac{8}{3.75} = 2.133$$

$$\text{Actual Ratio} = \frac{8(4_\mu \times 4_\mu)}{2(4_\mu \times 4_\mu) + (11.6\mu)(2.4\mu)}$$

$$= 2.139$$

$$\%\ \text{Error} = \frac{2.139 - 2.133}{2.133} \times 100\%$$

$$\boxed{\%\ \text{Error} = 0.28\%}$$