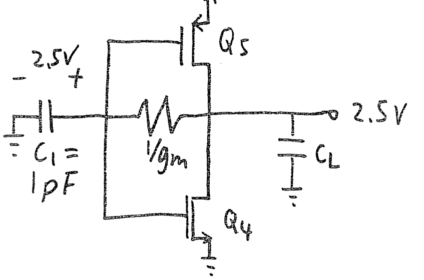
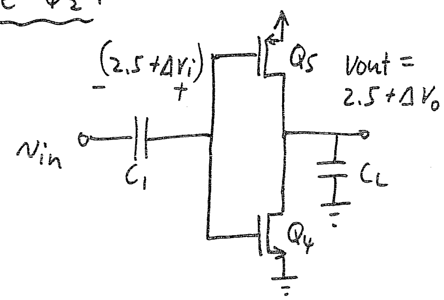
Chapter 7 - Problems

7.1) Find offset due to charge injection

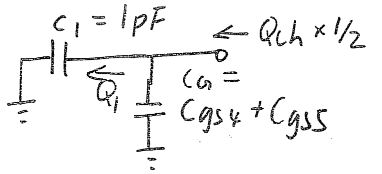
Phase ϕ_1:



Phase ϕ_2:



Channel charge stored in Q_1 is partially* injected into C_1 at the end of ϕ_{1a}.



* Assume half is injected into the node attached to the source of Q_1

$$Q_{ch} = V_{eff1} C_{ox} W_1 L_1$$

$$V_{eff1} = V_{GS1} - V_{tn}$$

$$V_{tn} = V_{tn0} + \gamma\left(\sqrt{V_{SB}+2\phi_F} - \sqrt{2\phi_F}\right)$$
$$= 0.8 + 0.5\left(\sqrt{2.5+0.7} - \sqrt{0.7}\right)$$
$$= \underline{1.28\,V}$$

$$\therefore\ V_{eff1} = (5-2.5) - 1.28 = 1.22\,V$$

$$\therefore\ Q_{ch} = 1.22V \times 1.9\times10^{-3}\,\frac{pF}{\mu m^2} \times 5\,\mu m \times 0.8\,\mu m = 9.27\times10^{-15}\,C$$

Now $C_{gs5} = 2/3\, C_{ox} W_5 L_5$ (neglect overlap capacitance)

$$= 2/3 \times 1.9\times10^{-3} \times 92 \times 0.8$$
$$= 0.093\,pF$$

$$C_{gs4} = 2/3\, C_{ox} W_4 L_4$$
$$= 0.030\,pF$$

$$\therefore\ C_G = C_{gs5} + C_{gs4} = 0.123\,pF$$

(cont.)

7.1 (cont.)

$\because \quad Q = CV$

$\therefore \quad \Delta V_i = \frac{-\Delta Q}{C} = -\frac{Q_{ch}}{2(C_1 + C_n)} = \frac{-9.27 \times 10^{-15}}{2(1pF + 0.123pF)} = -4.1mV$

Since the inverters gain is given as -24

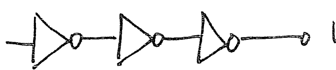
$\Delta V_o = -24 \times \Delta V_i$

$\therefore \quad \Delta V_o = -24 \times \Delta V_i = +99mV$

$\therefore$ Vout shifts up by 99mV due to charge injection.

7.2) Find the input-referred offset voltage.

From Problem 7.1, we found the output offset voltage to be +99mV.



$V_{outoff} = 99mV$

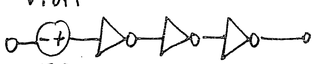
$-24 \quad -24 \quad -24$

To refer this back to the input, we divide by the total gain

ie., $\quad V_{ioff} = V_{outoff} / (-24)^3$

$V_{ioff} = -7.2\mu V$

V_{ioff}



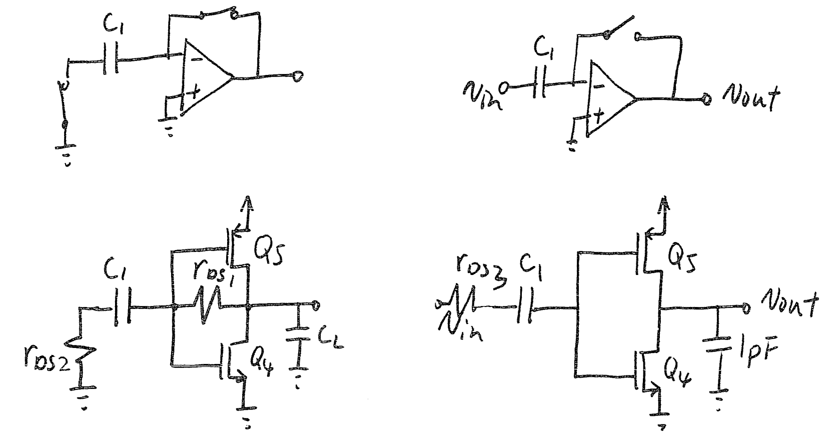
$-7.2\mu V$

7.3) Estimate time constants:

Reset Phase (ϕ_1) — Comparison Phase (ϕ_2)

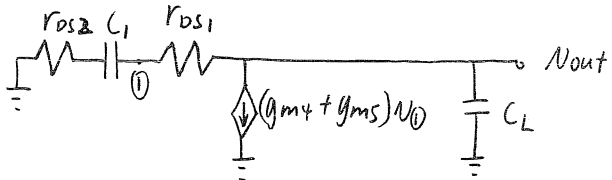
CONCEPT

CIRCUIT

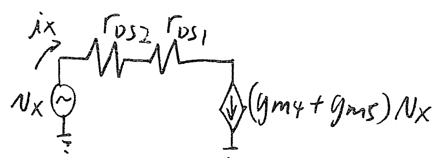


Reset Phase (ϕ_1):

To find system time constants, calculate the resistances associated with each capacitor.



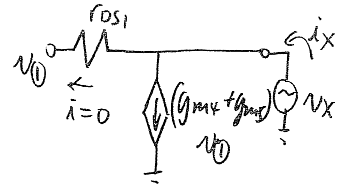
for C_1:



$i_x = (g_{m4} + g_{m5})\, v_x$

$\therefore\ R_1 = 1/(g_{m4} + g_{m5})$

for C_2:



Again,

$i_x = (g_{m4} + g_{m5})\, v_{①} = (g_{m4} + g_{m5})\, v_x$

$\therefore\ R_2 = v_x / i_x = 1/(g_{m4} + g_{m5})$

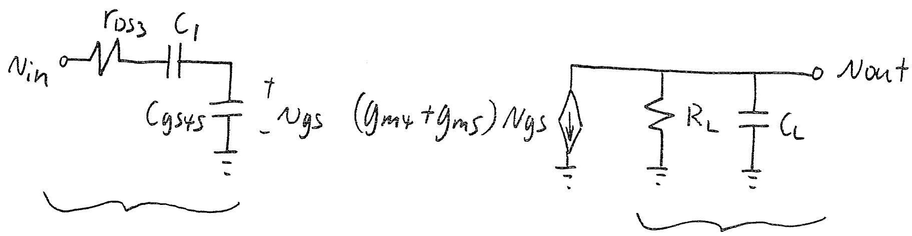
$\therefore\ \tau_{\phi_1} = \tau_1 + \tau_2 = R_1 C_1 + R_2 C_2$

$\tau_{\phi_1} = \dfrac{(C_1 + C_2)}{g_{m4} + g_{m5}}$ for the reset phase

(cont.)

7.3) (cont.)

Comparison Phase (Φ_2):



$\tau_{in} = \left(C_1 \text{ in series w/ } C_{gs45}\right) \times r_{DS3}$

$\approx C_{gs45}\, r_{DS3}$

$\tau_{out} = R_L C_L$

$= (r_{DS4} // r_{DS5}) C_L$

$$\tau_{\phi_2} = \tau_{in} + \tau_{out} = \underbrace{\cancel{r_{DS3} C_{gs45}}}^{\text{small}} + r_{DS4}//r_{DS5} \times C_L \approx r_{DS4}//r_{DS5} \times C_L$$

Calculating values:

$$g_{m4} = \mu_n C_{ox} W/L \, V_{eff4} = 92\times10^{-6} \times 30/0.8 \times (2.5-0.8)$$
$$= 5.9 \text{ mA/V}$$

$$g_{m5} = \mu_p C_{ox} W/L \, V_{eff5} = 30\times10^{-6} \times 92/0.8 \times (2.5-0.8)$$
$$= 5.9 \text{ mA/V}$$

$$r_{DS1} = \frac{1}{\mu_n C_{ox} W/L \, V_{eff1}} = \frac{1}{92\times10^{-6} \times 5/0.8 \times (2.5 - V_{tn1})} \quad \text{where}$$

$$V_{tn1} = V_{tn0} + \gamma\left(\sqrt{V_{SB1} + 2\phi_F} - \sqrt{2\phi_F}\right)$$
$$= 0.8 + 0.5\left(\sqrt{2.5+0.7} - \sqrt{0.7}\right) = 1.28\text{V}$$

$\therefore r_{DS1} = 1.4\text{k}\Omega$

$$r_{DS3} = \frac{1}{92\times10^{-6} \times 5/0.8 \times (2.5-0.8)} = 1\text{k}\Omega$$

$$\therefore \tau_{\phi_1} = \frac{C_1 + C_2}{g_{m4} + g_{m5}} = \frac{2\text{pF}}{2\times5.9\text{mA/V}} = \underline{0.17 \text{nsec}}$$

$\tau_{\phi_2} = r_{DS4} // r_{DS5} \times C_L$ where

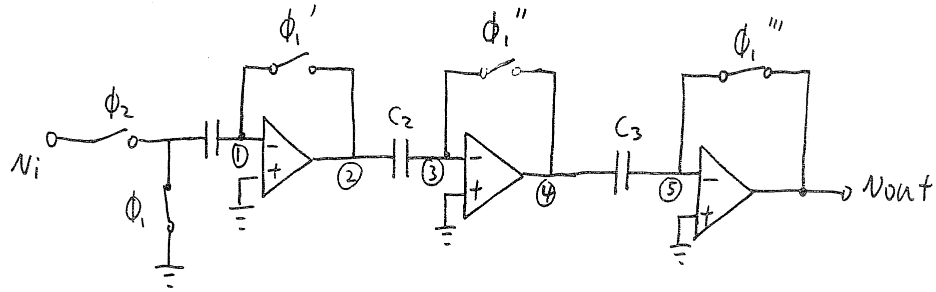
$$I_{D4} = I_{D5} = \frac{\mu_n C_{ox}}{2} \frac{W}{L} V_{eff}^2 = \frac{92\times10^{-6}}{2} \times \frac{30}{0.8}(2.5-0.8)^2$$
$$= 5\text{mA}$$

$$\therefore r_{DS4} = \frac{8000 \times 0.8}{5\text{mA}} = 1.3\text{k}\Omega, \quad r_{DS5} = \frac{12000\times0.8}{5\text{mA}} = 1.9\text{k}\Omega$$

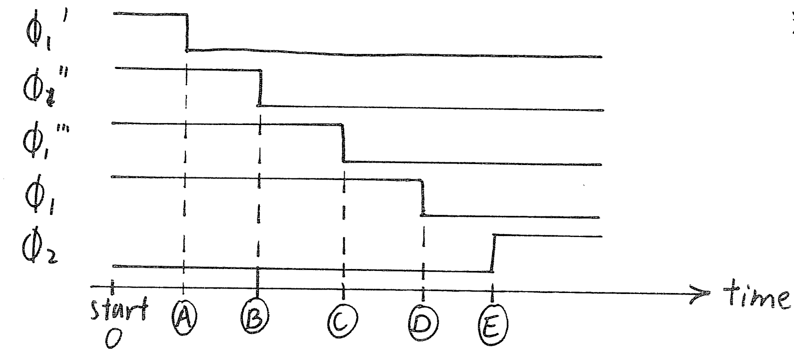
$$\therefore \underline{\tau_{\phi_2}} = 1.3\text{k}\Omega // 1.9\text{k}\Omega \times 1\text{pF} = \underline{0.77 \text{nsec}}$$

$\therefore$ The time constants during the reset and comparison phases are 0.17nsec and 0.77nsec respectively.

7.4) Show clock feedthrough is $|V_{err-3}|/(A_1 A_2)$



Clocking diagram :



* switches are closed with waveforms high *

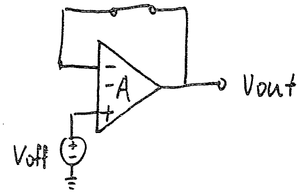
Time	V1	V2	V3	V4	V5	Vout
0	0V	0V	0V	0V	0V	0V
A	V_{err1}	$-A_1 V_{err1}$	0V	0V	0V	0V
B	V_{err1}	$-A_1 V_{err1}$	V_{err2}	$-A_2 V_{err2}$	0V	0V
C	V_{err1}	$-A_1 V_{err1}$	V_{err2}	$-A_2 V_{err2}$	V_{err3}	$-A_3 V_{err3}$
D	"	"	"	"	"	"
E	$V_i + V_{err1}$	$-A_1(V_i + V_{err1})$	$-A_1 V_i + V_{err2}$	$(A_1 A_2 V_i - A_2 V_{err2})$	↑ $(A_1 A_2 V_i + V_{err3})$	$(-A_1 A_2 A_3 V_i - A_3 V_{err3})$

∴ at the end of ϕ_2,

$$V_{out} = -(A_1 A_2 A_3 V_i + A_3 V_{err3})$$
$$= -A_1 A_2 A_3 (V_i + V_{ioff}) \quad \text{where } V_{ioff} = \frac{V_{err3}}{A_1 A_2}$$

∴ the input-referred offset is $\frac{V_{err3}}{A_1 A_2}$. Q.E.D.

7.5) Repeat Problem 7.4, but now each opamp has input offset, V_{offi}.



$$V_{out} = -A\,(V_{off} - V_{out})$$

$$\therefore\ \underline{V_{out} = \frac{-A}{1-A} V_{off}}$$

Time	V_1	V_2	V_3	V_4	V_5	V_{out}
0	$-\frac{A_1}{1-A_1}V_{off1}$	$-\frac{A_1}{1-A_1}V_{off1}$	$-\frac{A_2}{1-A_2}V_{off2}$	$-\frac{A_2}{1-A_2}V_{off2}$	$-\frac{A_3}{1-A_3}V_{off3}$	$-\frac{A_3}{1-A_3}V_{off3}$
	$\equiv K_1$		$\equiv K_2$		$\equiv K_3$	
A	K_1+V_{err1}	$K_1 - A_1V_{err1}$	K_2	K_2	K_3	K_3
B	"	"	K_2+V_{err2}	$K_2 - A_2V_{err2}$	K_3	K_3
C	"	"	"	"	K_3+V_{err3}	$K_3 - A_3V_{err3}$
D	"	"	"	"	"	"
E	$(V_i+V_{err1}+K_1)$	$(-A_1(V_i+V_{err1})-K_1)$	$(-A_1V_1+V_{err2}+K_2)$	$(A_1A_2V_i - A_2V_{err2}+K_2)$	$(A_1A_2V_i+V_{err3}+K_3)$	

$$V_{out} = -A_1A_2A_3V_i - A_3V_{err3} + K_3$$

$$\therefore\ V_{out} = -\left(A_1A_2A_3V_i + A_3V_{err3} + \frac{A_3}{1-A_3}V_{off3}\right)$$

$$= -A_1A_2A_3\,(V_i + V_{ioff})$$

where $V_{ioff} = \dfrac{V_{err3}}{A_1A_2} + \dfrac{1}{A_1A_2(1-A_3)}V_{off3}$

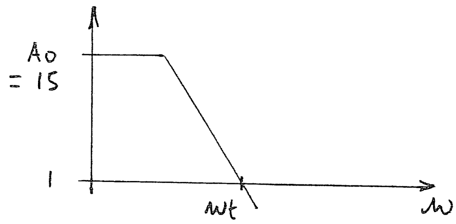
$\therefore$ the input-referred offset voltage is

$$\underline{V_{ioff} = \left(V_{err3} + \frac{1}{1-A_3}V_{off3}\right)/(A_1A_2)}$$

7.6)

$\omega_u = g_m / C_{gs}$

$\omega_t = \omega_u / 2 = g_m / 2C_{gs}$



But $\quad C_{gs} = \frac{2}{3} C_{ox} WL$

and $\quad g_m = \mu_n C_{ox} W/L \, V_{eff}$

$\therefore \omega_t = \dfrac{\mu_n \cancel{C_{ox}} W/L \, V_{eff}}{4/3 \, \cancel{C_{ox}} \cancel{W} L}$

$$\omega_t = \frac{3 \mu_n V_{eff}}{4 L^2}$$

The time constant, τ, for a single stage is

$$\tau = \frac{1}{\omega_{p1}}$$

The gain-bandwidth product $= \omega_t = A_0 \omega_{p1}$

$\therefore \omega_{p1} = \dfrac{\omega_t}{A_0}$ and $\tau = A_0 / \omega_t$

$$\tau_{comparator} = 3 \times \tau = 3A_0 / \omega_t$$

$$= \cancel{3} A_0 \times \frac{4L^2}{\cancel{3} \mu_n V_{eff}}$$

$$= \frac{4 A_0 L^2}{\mu_n V_{eff}}$$

Assuming $V_{eff} = 0.25V$, $\mu_n = 0.05 \ m^2/V \cdot s$ and a settling time of $3\tau_{comparator}$,

$$\tau_{comparator} = \frac{4(15)(0.8 \times 10^{-6})^2}{0.05 \times 0.25} = 3.07 \ nsec$$

$\therefore f_{max} = \dfrac{1}{6 \tau_{comparator}} = \dfrac{1}{6 \times 3.07 \times 10^{-9}}$

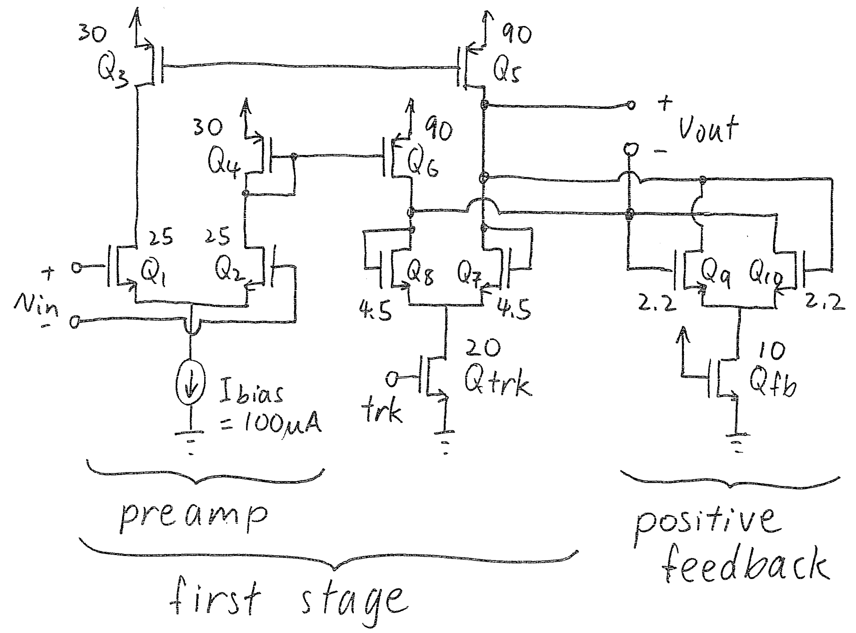
$\therefore f_{max} = 54 \ MHz$ is the maximum frequency of operation

resolution $= A_0^3 = 15^3 = 3375$

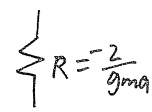
$= 71 \ dB$

7.7) Determine the transistor sizes.

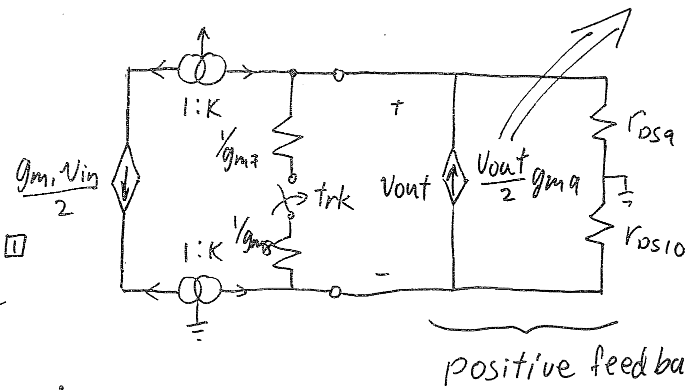
* Devices are all of length $L = 0.8\mu m$ *



ASIDE: by source absorption



Simplified small signal model



$$K = \frac{W_{5,6}}{W_{3,4}} = \frac{2 I_{D5,6}}{I_{bias}} \quad \boxed{1}$$

KCL at $V_{out}+$:

negligible

$$K g_{m1} \frac{v_{in}}{2} + \frac{v_{out}}{2} g_{m9} - v_{out}/\left(1/g_{m7} + 1/g_{m8}\right) - \cancel{v_{out}/(r_{os9} + r_{os10})} = 0$$

$$\therefore\; v_{in} K \frac{g_{m1}}{2} + v_{out}\left(\frac{g_{m9}}{2} - \frac{g_{m7} g_{m8}}{g_{m7} + g_{m8}}\right) \approx 0$$

$$\therefore\; \frac{v_{out}}{v_{in}} \approx \frac{-K g_{m1}/2 \times (2(g_{m7} + g_{m8}))}{g_{m9}(g_{m7} + g_{m8}) - 2 g_{m7} g_{m8}} = \frac{-K g_{m1}(g_{m7} + g_{m8})}{g_{m9}(g_{m7} + g_{m8}) - 2 g_{m7} g_{m8}}$$

Assuming Q_7 and Q_8 are matched so that $g_{m7} = g_{m8}$

$$\therefore\; \frac{v_{out}}{v_{in}} = \frac{K g_{m1}}{g_{m7} - g_{m9}} \quad \boxed{A}$$

Tracking gain

(cont.)

7.7 (cont.)

The gain of the first stage is determined by ignoring the positive feedback circuit.

$\therefore$ Let $g_{m9} \equiv 0$

and $\frac{v_{out}}{v_{in}} = \frac{K\, g_{m1}}{g_{m7}} \equiv 5$

$\therefore$ $g_{m7} = K/5 \times g_{m1}$ $\boxed{B}$

Setting the tracking gain to 10 gives

$$\frac{K\, g_{m1}}{g_{m7} - g_{m9}} \equiv 10 \quad \boxed{C}$$

sub $\boxed{B} \rightarrow \boxed{C}$

$$\frac{K g_{m1}}{K/5 \times g_{m1} - g_{m9}} = 10$$

$g_{m9} = \frac{K g_{m1}}{10}$ $\boxed{D}$ or $g_{m9} = 1/2\, g_{m7}$ $\boxed{E}$

Under ideal bias conditions, $V_{out+} = V_{out-}$. Thus, even though Q_9 and Q_{10} are cross-coupled unlike Q_7 and Q_8, their terminals are biassed at the same voltages as Q_9 and Q_{10}.

$\therefore$ To satisfy equation $\boxed{E}$, we simply scale device widths such that

$$W_{9,10} = 1/2\, W_{7,8} \quad \boxed{F}$$

Note that the drain currents are also scaled

i.e., $I_{D9,10} = \frac{1}{2} I_{D7,8}$ $\boxed{G}$

Now find $W_{7,8}$ in terms of $W_{1,2} = 25\,\mu m$:

From $\boxed{B}$, $\boxed{I}$

$$g_{m7} = K/5\, g_{m1} = \frac{2}{5} \times \frac{I_{D5,6}}{I_{bias}} \times g_{m1}$$

where $I_{D5,6} = I_{D7,8} + I_{D9,10}$ $\boxed{H}$

$\boxed{G} \rightarrow \boxed{H}$ $= 3/2\, I_{D7,8}$

(cont.)

7.7) (cont.)

$$\therefore \quad g_{m7}^2 = \left(\frac{\cancel{2}}{5}\times\frac{3}{\cancel{2}}\,\frac{I_{D7,8}}{I_{bias}}\times g_{m1}\right)^2$$

$$\therefore \quad \frac{2\cancel{\mu_n C_{ox}}}{\cancel{4}} W_{7,8}\, \cancel{I_{D7,8}} = \frac{9}{25}\times\frac{I_{D7,8}^{\cancel{2}}}{I_{bias}^{\cancel{2}}}\times\frac{2\cancel{\mu_n C_{ox}}}{\cancel{4}} W_{1,2}\,\frac{\cancel{I_{bias}}}{2}$$

$$\frac{W_{7,8}}{W_{1,2}} = \frac{9}{50}\,\frac{I_{D7,8}}{I_{bias}} \qquad \text{for } W_{1,2} = 25\,\mu m$$

$$\therefore \quad W_{7,8} = 9/2\,\frac{I_{D7,8}}{I_{bias}}\,\mu m$$

If we let $I_{D7,8} = I_{bias}$,

$$\therefore \quad W_{7,8} = 9/2\,\mu m = 4.5\,\mu m$$

$$\therefore \quad W_{9,10} = 1/2\,W_{7,8} = 2.2\,\mu m$$

$$\therefore \quad K = \frac{2 I_{D5,6}}{I_{bias}} = \frac{\cancel{2}\,(3/\cancel{2}\, I_{D7,8})}{I_{bias}} = 3 = \frac{W_{5,6}}{W_{3,4}}$$

If we let $W_{3,4} = 30\,\mu m$

then $W_{5,6} = 90\,\mu m$

Since Q_{trk} and Q_{fb} operate as switches in the triode region, their size is not critical.
If we set

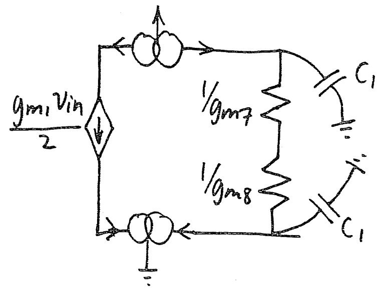
$$W_{trk} = 20\,\mu m,$$

then to match voltage levels as closely as possible choose

$$W_{fb} = 1/2\,W_{trk} = 10\,\mu m$$

Final device widths are marked on the original schematic diagram.

7.8) Estimate time constant in track mode, $\tau_{trk} \triangleq \tau_{gain} + \tau_{pre}$



Gain stage

$$\tau_{gain} = \frac{C_1}{g_{m7}}$$

where $C_1 = C_{db5} + C_{db7} + C_{gs10} + C_{db9}$

$\approx C_{db5}$ (device Q_5 is much larger than devices Q_7, Q_9, Q_{10})

$= A_{d5} C_{d5} + P_{dsw5} \times C_{ov}$

$= 30 \times 4 \times 0.8 \times 4.5 \times 10^{-4}\ pF/\mu m^2$

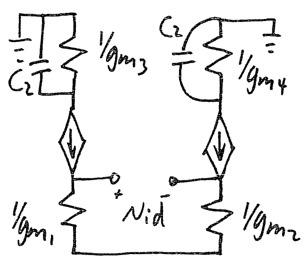
$+ 2 \times 4 \times 0.8 \times 2.5 \times 10^{-4}\ pF/\mu m$

$C_1 \triangleq 52 fF$

and $g_{m7} = 0.107\ mA/V$ from Problem 7.7.

$$\therefore \tau_{gain} = \frac{52 \times 10^{-15} F}{0.107 \times 10^{-3} A/V} = 0.47\ nsec$$

Now look at time constant associated with the preamp, τ_{pre}.



Preamp stage

$\tau_{pre} = C_2/g_{m3}$ where

$C_2 = C_{db3} + C_{gs3} + C_{gs5} + \cancel{C_{db1}}$ negligible $\because Q_1$ small

$C_{db3} = A_{d3} C_{d3} + P_{dsw3} \times C_{ov}$

$= 100 \times 0.8 \times 4 \times 4.5 \times 10^{-4} +$

$(2 \times 4 \times 0.8 + 100) \times 2.5 \times 10^{-4}$

$= 170 fF$

$C_{gs5} = 2/3\, WLC_{ox} + WC_{ov}$

$= 2/3 \times 30 \times 0.8 \times 1.9 \times 10^{-3}$

$+ 30 \times 2 \times 10^{-4}$

$= 40 fF$

$C_{gs3} = 2/3\, WLC_{ox} + WC_{ov}$

$= 2/3 \times 100 \times 0.8 \times 1.9 \times 10^{-3} + 100 \times 2 \times 10^{-4}$

$= 120 fF$

$\therefore C_2 = 170 + 120 + 40 fF = 330 fF$

and $g_{m3} = \sqrt{2 \mu_n C_{ox} W/L\, I_{D3}} = \sqrt{2 \times 30 \times 10^{-6} \times 100/0.8 \times 50 \times 10^{-6}}$

$= 0.612\ mA/V$

$$\therefore \tau_{pre} = \frac{330 \times 10^{-15}}{0.612 \times 10^{-3}} = 0.54\ nsec$$

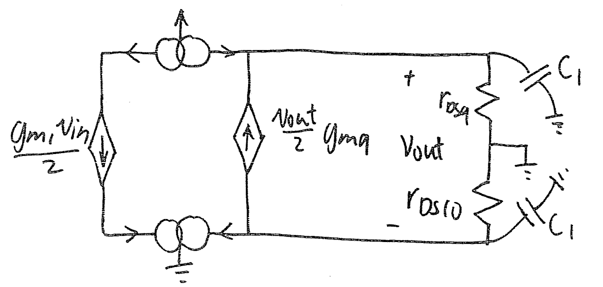
$\therefore \tau_{trk} \approx \tau_{gain} + \tau_{pre} = 1.01\ nsec$

(cont.)

7.8 (cont.)

Assuming it takes three time constants to settle from a step change of 50 mV, it would take 3 nsec.

7.9) Determine time constant in latch mode.



From Problem 7.8,

$C_1 = 52fF$

$g_{m9} = \sqrt{2\mu_n C_{ox} W/L \, I_{D9}}$

$= \sqrt{2\times 92\times 10^{-6} \times 2.4/0.8 \times 5\times 10^{-6}}$

$= 53\ \mu A/V$

KCL at V_{out+}:

$$\frac{g_{m1}}{2}V_{in} + \frac{V_{out}}{2}g_{m9} - \frac{V_{out}}{r_{os9}+r_{os10}} - V_{out}\, s\frac{C_1}{2} = 0$$

$$\therefore \frac{V_{out}}{V_{in}} \cong \frac{-g_{m1}/\cancel{2}}{g_{m9}/\cancel{2} - 1/(\cancel{2}r_{os9}) - sC_1/\cancel{2}}$$

$$= \frac{g_{m1}}{C_1(s - g_{m9}/C_1 + 1/C_1 r_{os9})} \approx \underline{\frac{g_{m1}}{C_1} \times \frac{1}{s - g_{m9}/C_1}}$$

$\therefore$ there is an unstable pole at

$\omega = g_{m9}/C_1$

and the associated time constant is

$\tau = C_1/g_{m9} = 52fF/0.53\,mA/V$

$\underline{\tau = 0.99\ nsec}$

For a differential output of 2 V,

$V_{out}(t) = V_{out0}\, e^{t/\tau}$

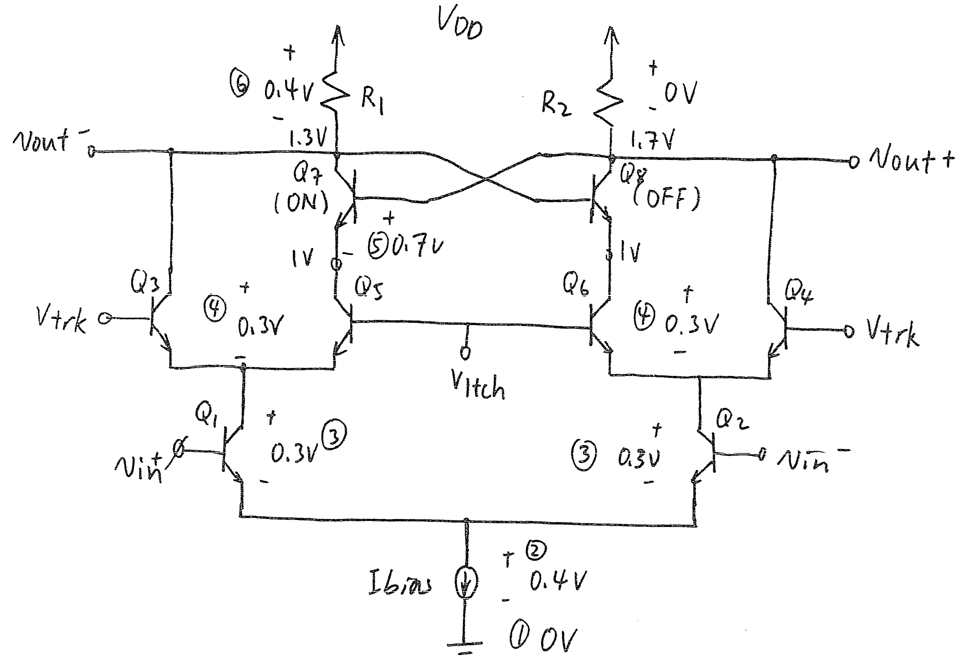
$\therefore \quad 2V = 0.05\, e^{t/0.99\times 10^{-9}}$

$t = 0.99\times 10^{-9} \ln 40$

$= \underline{3.65\ nsec}$

$\therefore$ it takes 3.65 nsec.

7.10) Find the minimum power supply voltage.

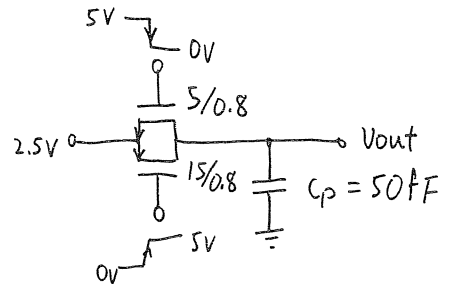


From the above diagram we see that the minimum voltage drops from R_2 through devices Q_7, Q_5, Q_1 & I_{bias} to ground add up to 1.7V. Assuming $V_{DD} = 1.7V$, we see that V_{out}^- is at $1.7V - 0.4V = 1.3V$.

∴ we have correctly assumed that Q_8 is off.

∴ this circuit requires a minimum supply voltage of 1.7V.

7.11)



Determine the voltage change due to each device.

N-MOS:

$$\Delta V_N = -\frac{\overset{?}{V_{effn}}\, C_{ox} W_n L_n}{2C_p} \quad \text{where}$$

$$V_{effn} = 5V - 2.5V - \overset{?}{V_{tn}}$$

$$V_{tn} = V_{tno} + \gamma\left(\sqrt{V_{SB} + 2\phi_F} - \sqrt{2\phi_F}\right)$$

$$= 0.8 + 0.5\left(\sqrt{2.5 + 0.7} - \sqrt{0.7}\right)$$

$$V_{tn} = 1.28V$$

$$\therefore V_{effn} = 1.22V$$

$$\therefore \Delta V_N = -\frac{1.22V \times 1.9\times10^{-3}\, pF/\mu m^2 \times 5 \times 0.8}{2 \times 50 \times 10^{-15}} = \underline{-93\,mV}$$

PMOS:

$$\Delta V_p = \frac{\overset{?}{V_{effp}}\, C_{ox} W_p L_p}{2C_p} \quad \text{where}$$

$$V_{effp} = 2.5V - 0 - \overset{?}{V_{tp}}$$

$$V_{tp} = V_{tpo} + \gamma\left(\sqrt{V_{BS} - 2\overset{?}{\phi_F}} - \sqrt{2\phi_F}\right)$$

To determine ϕ_F, use

$$\gamma = \frac{\sqrt{2qK_{si}\varepsilon_0 N_A}}{C_{ox}}$$

$$\therefore 0.8 = \frac{\sqrt{2\times1.602\times10^{-19}\times 8.85\times10^{-12}\times 11.8\times N_A}}{1.9\times10^{-15}}$$

$$\therefore \underline{N_A = 6.9\times10^{22}}\ m^{-3}$$

$$\Rightarrow \phi_F = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) = \frac{1.38\times10^{-23}\times 300}{1.602\times10^{-19}}\ln\left(\frac{6.9\times10^{22}}{1.1\times10^{16}}\right)$$

$$= 0.40\,V$$

(cont.)

7.11 (cont.)

$\therefore V_{tp} = -0.9 - 0.8(\sqrt{2.5+0.8} - \sqrt{0.8})$
$= 1.64V$

$\therefore V_{eff_p} = 2.5 - 1.64\,V = 0.86\,V$

$\therefore \Delta V_p = \dfrac{0.86V \times 1.9\times10^{-3}\,pF \times 15 \times 0.8}{2\times50\times10^{-3}\,pF} = {}^{+}196\,mV$

$\therefore \Delta V_{out} = \Delta V_n + \Delta V_p = -93mV + 196mV$
$= +103\,mV$

$\therefore$ the final output voltage is $2.5V + 103mV \approx 2.6V$