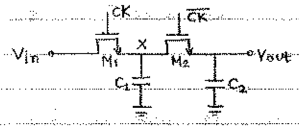
Homework #1

13/15 + 10/10 + 5/5 + 5/5 + 15/15 + 5/15

$= \frac{53}{55}$

Problem 12.10

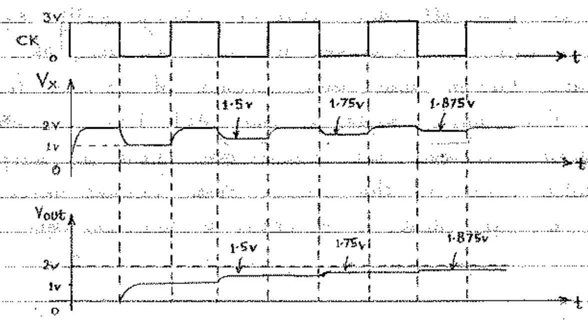


$(W/L)_1 = (W/L)_2$

$C_1 = C_2$

(a) C_1, M_1 and M_2 can be together viewed as a resistor equal to $\frac{1}{f_{CLK} C_1}$. Thus, the charging of C_2 on an average shall be given by a time constant $\tau = \frac{C_2}{f_{CLK} \cdot C_1} = \frac{1}{f_{CLK}}$

Assuming that $V_{DD} = 3v$, $V_{TN} = 0.7v$.

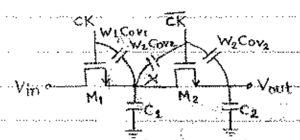


5/5

Initially when CK goes high, C_1 gets charged to $V_{in} = 2v$. When CK goes low, M_2 is ON and charge is shared between C_1 and C_2. Since, $C_1 = C_2$, $V_x = V_{out} = 1v$. Again when CK goes high, M_2 is OFF, M_1 turns ON and C_1 again charges to 2v. When CK goes low, $V_x = V_{out} = \frac{2C_1 + 1C_2}{C_1 + C_2} = 1.5v$ and so on.

3/5

(b)



If M_1, M_2 are identical, when $CK \to 1$ to 0, $\overline{CK} \to 0$ to 1, hence there will be no error in voltage at X since both the clock feedthrough errors will cancel off.

Clock feedthrough

When $\overline{CK} \to 0$ to 1, there will be some feedthrough to Vout which we undone when $\overline{CK} \to 1$ to 0 at the end of the cycle. Hence the feedthrough does not affect the output voltage in steady state. Hence, no error is introduced in the o/p because of feedthrough.

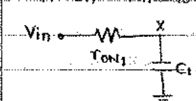
Charge injection: When CK goes low, M_1 goes off. The worst case will be when all the charges in the inversion layer go towards the right. Error in V_x due to this will be $(WL)_1 C_{ox} (V_{DD} - V_{in} - V_{TH}) \times \frac{1}{C_1}$.

Corresponding error at the output will be half of this value.

When M_2 goes off, the channel charge splits equally between C_1 and C_2. However, in order to turn ON, M_2 would have taken that same amount of charge from C_1, C_2 which it gives back when it goes OFF. Hence, channel charge from M_2 does not cause any error in output. Hence total error in the output from charge injection is only due to M_1. Thus, max. error $= \frac{(WL)_1 C_{ox} (V_{DD} - V_{in} - V_{TH})}{2 C_1}$

Max. total error in output $= \frac{(WL)_1 C_{ox} (V_{DD} - V_{in} - V_{TH})}{2 C_1}$

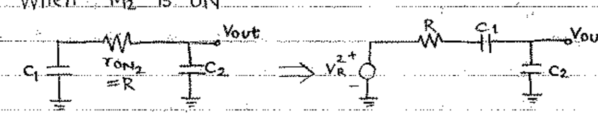
(c) When M_1 is ON, rms noise voltage at X is given as $\overline{V_{nx}}$



$\overline{V_{nx}} = \sqrt{\frac{KT}{C_1}}$

Half of this noise voltage will appear at the output when M_2 is ON.

When M_2 is ON



$$\frac{V_{out}}{V_R}(s) = \frac{\frac{1}{sC_2}}{R + \frac{1}{sC_1} + \frac{1}{sC_2}} = \frac{1}{1 + \frac{C_2}{C_1} + sC_2R}$$

$$S_{out}(f) = S_R(f)\left|\frac{V_{out}}{V_R}(j\omega)\right|^2$$

$$= 4kTR \frac{1}{\left(1+\frac{C_2}{C_1}\right)^2 + 4\pi^2R^2C^2f^2}$$

The total noise power at output

$$P_{n\,out} = \int_0^\infty \frac{4kTR\,df}{4\pi^2R^2C^2f^2 + \left(1+\frac{C_2}{C_1}\right)^2}$$

$$= \frac{4kTR}{2\pi RC} \times \frac{1}{1 + C_2/C_1} \tan^{-1}\left\{\frac{2\pi RCf}{1 + C_2/C_1}\right\}\Bigg|_{f=0}^{\infty}$$

$$= \frac{2kT}{\pi C_2} \times \frac{1}{2} \times \frac{\pi}{2} \qquad [\because C_1 = C_2]$$

$$= \frac{kT}{2C_2}$$

The total output noise voltage is given by 575

$$\overline{V_{n\,out}^2} = \frac{1}{4}\frac{kT}{C_1} + \frac{kT}{2C_2} = \frac{3}{4}\frac{kT}{C_1}$$

Problem 12.11

$V_{in} = V_0 \sin \omega_0 t + V_0 \qquad f_{CLK} = 50\,\text{MHz}.$

$V_0 = 0.5\,\text{V}$

$\omega_0 = 2\pi \times 10\,\text{MHz}$

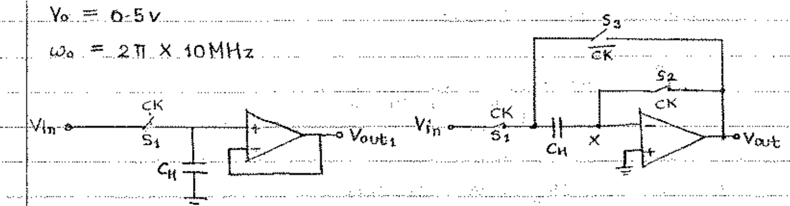
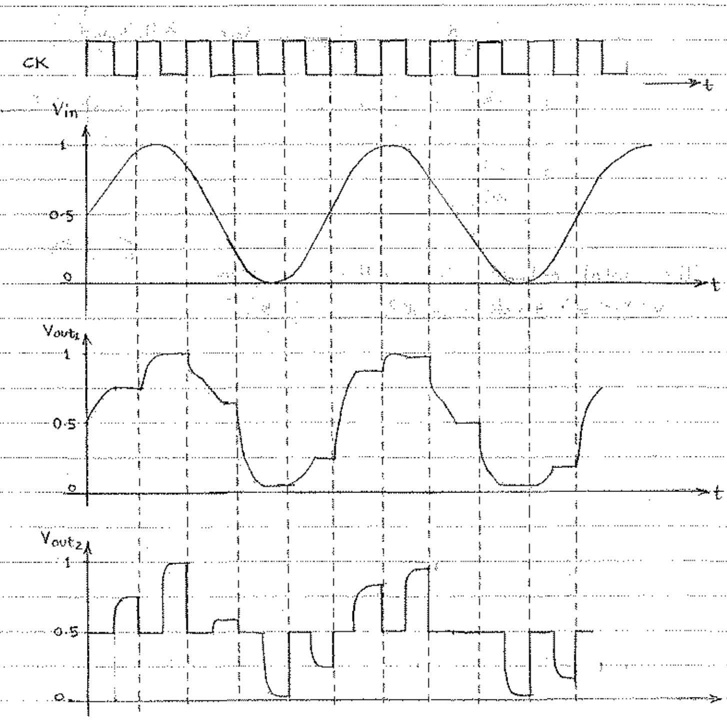
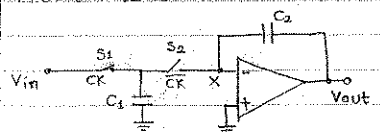


Fig 12.29(b)



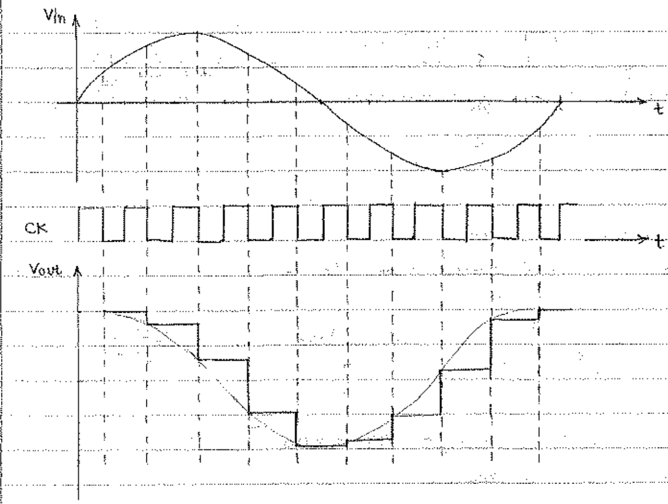
Problem 12.15



$C_1 = C_2 = 1\,pF$

$f_{CK} = 100\,MHz$

$V_{in} = 0.5\cos[2\pi(10M)t]$



S_1, S_2 and C_1 form a resistor of value $R = \frac{1}{f_{CK} C_1} = 10k\Omega$

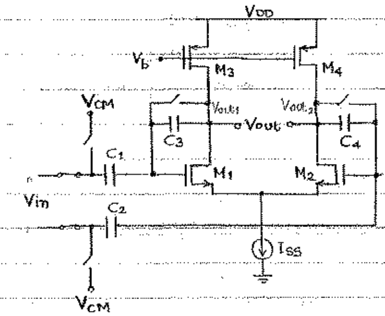
$$V_{out} = \frac{-1}{RC_2}\int_0^t V_{in}\,dt$$

$$\therefore V_{out} = -\frac{1}{RC_2}\int_0^t 0.5\cos[2\pi(10M)t]\,dt$$

$$= \frac{-0.5}{RC_2} \times \frac{\sin[2\pi(10M)t]}{2\pi \times 10M}$$

Hence, o/p amplitude $= 0.796\,v$

Problem 12.16



$(W/L)_{1-4} = 50/0.5$

$I_{SS} = 1\,mA$

$C_1 = C_2 = 2\,pF$

$C_3 = C_4 = 0.5\,pF$

$V_{out,CM} = 1.5\,v$

(a) Maximum o/p swing

$$V_{DD} - V_{ov3,4} \geq V_{out_{1,2}} \geq V_{I_{SS}} + V_{ov1,2}$$

$$\therefore V_{DD} - \sqrt{\frac{2\times 0.5m}{\mu_p C_{ox}(W/L)_3}} \geq V_{out_{1,2}} \geq V_{I_{SS}} + \sqrt{\frac{2\times 0.5m}{\mu_n C_{ox}(W/L)_1}}$$

$\therefore\ 3 - 0.508 \geq V_{out_{1,2}} \geq V_{G1} - V_{TH1}$

$\therefore\ 3 - 0.508 \geq V_{out_{1,2}} \geq 1.5 - 0.7\,v$

$\therefore\ 2.491\,v \geq V_{out_{1,2}} \geq 0.8\,v$

$\therefore$ Maximum o/p swing is $2(2.491 - 0.8) = 3.382\,v$

(b) Gain error:

Gain $A_v = -g_{m1,2}\,(r_{o1} \| r_{o3})$

$$g_{m1} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} = 3.664\,mS$$

$$r_{o1} = \frac{1}{\lambda_1 I_{D1}} = 20k\Omega$$

$$r_{o3} = \frac{1}{\lambda_2 I_{D2}} = 10k\Omega$$

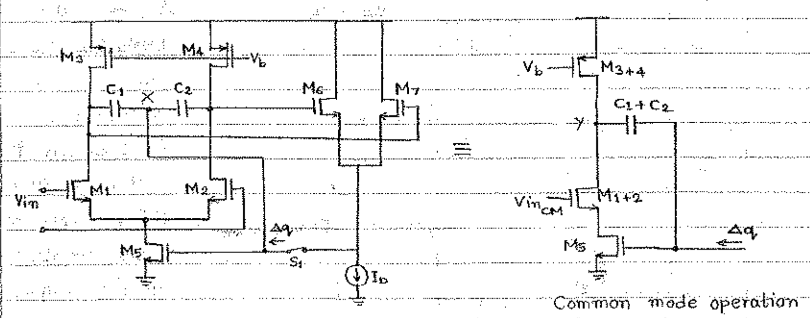
$A_v = 24.43$

$$\text{Gain error} = \frac{1}{A_v}\left(\frac{C_1}{C_3} + 1\right) = 20.46\,\%$$

(c) In amplification mode

$$T_{amp} = C_1 \times \frac{1}{G_m} = C_1 \times \frac{1}{g_{m1}} = 545.85\,ps$$

Problem 12.21



Common mode operation after S_1 turns OFF

If no charge was injected, C_1 and C_2 will hold a common mode voltage $= (V_{GS5} + V_{GS6,7}) - V_{GS5} \equiv V_{GS6,7}$

If Δq is injected towards the gate of M_5, it will produce an error voltage in the capacitors equal to $\frac{\Delta q}{(C_1+C_2)}$

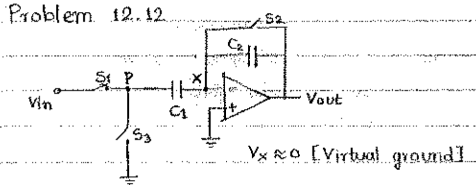
If the common-mode gain from gate of M_5 to node Y is very large, we may assume that the gate of M_5 remains fairly constant and all the error voltage appears at Y. Thus, change in the o/p CM level is approximately $\frac{\Delta q}{C_1+C_2}$.

Gain from gate of M_5 to node Y is given by

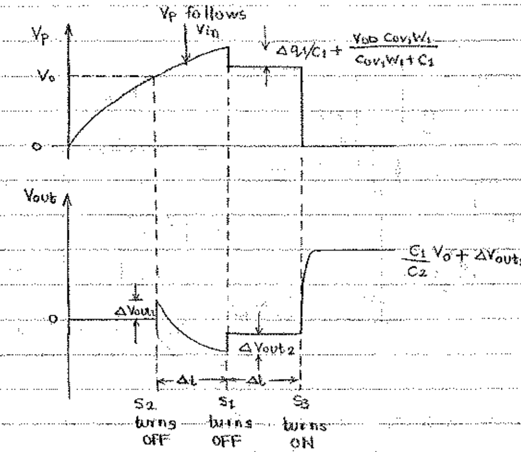
$$A = g_{m5} \times [r_{O3} \| r_{O4} \| (\{1+(g_{m1}+g_{m2})(r_{O1}\|r_{O2})\} r_{O5} + r_{O1}\|r_{O2})]$$

Thus, change in voltage at gate of $M_5 = \frac{\Delta V_Y}{A} = \frac{\Delta q}{A(C_1+C_2)}$

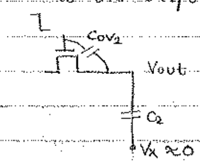
Problem 12.12



Initially when S_2 is ON,
$V_{out} = V_X \neq 0$
$\therefore V_{C_2} = 0$.



Assume that the current input value to be sampled is V_0. As soon as the switch S_2 turns OFF, there will clock feedthrough to the output.



$$\therefore \Delta V_{out}\big|_{clk\ feedthrough} = \frac{-C_{ov2} W_2 \cdot V_{DD}}{C_{ov2} + C_2}$$

Also, in worst-case there will be a charge injection on node X given by $\Delta q_2 = (WL)_2 C_{ox} (V_{DD} - V_{CM} - V_{TH})$. This charge will end up on C_2 & hence, $\Delta V_{out}\big|_{inj} = +C_2 \cdot \Delta q_2$

Thus $\Delta V_{out_1} = \Delta q_2 C_2 - \frac{C_{ov2} W_2 V_{DD}}{C_{ov2} + C_2}$

Even after S_2 turns OFF, V_P will follow V_{in} and hence this will get amplified by $(-C_1/C_2)$ and appear at output.

When S_1 turns OFF, $\Delta V_P\big|_{clk\ feedthrough} = \frac{-C_{ov1} W_1 V_{DD}}{C_{ov1} + C_1}$

Worst-case charge injection will be towards the right

$\Delta q_1 = (WL)_1 C_{ox} (V_{DD} - V_{in}|_{S_1\ turns\ OFF} - V_{TH})$. $\Delta V_{P\,inj} = -\Delta q_1 \cdot C_1$

$$\therefore \Delta V_P\big|_{S_1\ turns\ OFF} = -\Delta q_1 C_1 - \frac{C_{ov1} W_1 V_{DD}}{C_{ov1} + C_1} \Rightarrow \Delta V_{out_2} = -\frac{C_1}{C_2} \Delta V_P\big|_{S_1\ turns\ OFF}$$

When S_3 turns ON, $V_P = 0$ i.e. V_P changes overall from V_0 to 0

Hence, V_{out} will change from $(0 + \Delta V_{out_1})$ to $\left\{ \frac{C_1}{C_2} V_0 + \Delta V_{out_1} \right\}$ i.e.

where ΔV_{out} is only an offset.