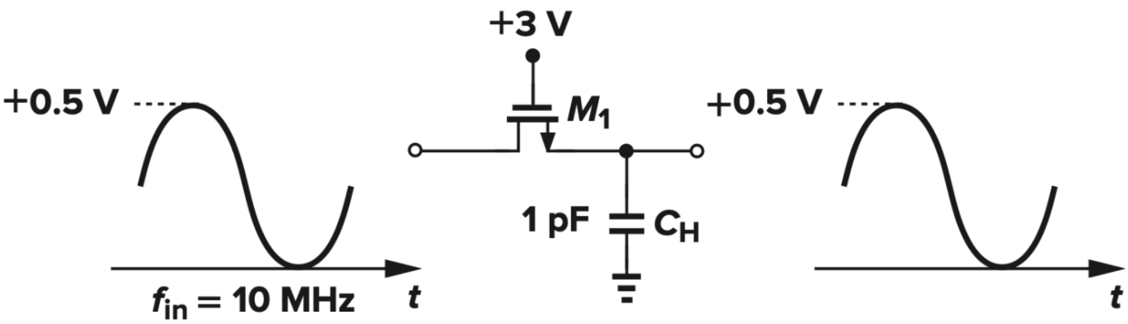
EE-523 – Exercise 3 Solutions

1. Let's calculate the minimum and maximum on resistance of M_1 by assuming $\mu_n C_{ox} = 50\frac{\mu A}{V^2}$, W/L=10/1, V_{TH}=0.7V, VDD=3V, and $\gamma = 0$.



$$V_{GD} = (3 - V_{in}) > V_{TH}$$
$$V_{GD} = (3 - V_{out}) > V_{TH} \quad \text{if } V_{out} = \text{Drain}$$

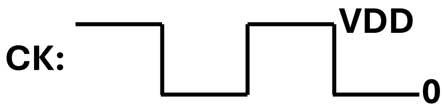
In any case, M_1 is in <u>triode region</u>.

f_{in}=10MHz: assuming little phase shift and that V_{out} tracks V_{in}: $V_{out} \approx V_{in}$.

$$R_{on} = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{DD} - V_{in} - V_{TH})}$$

- For $V_{in} = 0V$: $R_{on,min} = 870\Omega$
- For $V_{in} = 0.5V$: $R_{on,max} = 1111\Omega$
- If $V_{in,max}$=1.5V: $R_{on,max} = 2500\Omega$.

2. Let's assume:



$$R_{on,eq} = R_{on,N} \parallel R_{on,P}$$

$$R_{on,eq} = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_N (V_{DD} - V_{in} - V_{TH,N})} \parallel \frac{1}{\mu_p C_{ox}\left(\frac{W}{L}\right)_P \left(V_{in} - |V_{TH,P}|\right)}$$

$$R_{on,eq} = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_N (V_{DD} - V_{TH,N}) - \left[\mu_n C_{ox}\left(\frac{W}{L}\right)_N - \mu_p C_{ox}\left(\frac{W}{L}\right)_P\right] V_{in} - \mu_p C_{ox}\left(\frac{W}{L}\right)_P |V_{THP}|}$$

- If $\mu_p C_{ox}\left(\frac{W}{L}\right)_P = \mu_n C_{ox}\left(\frac{W}{L}\right)_N$

R_{on} is independent of input level.

3. We must have $\Delta q_1 = \Delta q_2$
   - $\Delta q_1 = W_1 L_1 C_{ox}(V_{CK} - V_{in} - V_{TH,N}) = W_2 L_2 C_{OX}(V_{in} - |V_{TH,P}|) = \Delta q_2$

   For only one V_{in}, we have $\boldsymbol{\Delta q_1 = \Delta q_2}$.

4. **In the amplification mode: $\boldsymbol{V_X \neq 0 = -V_{out}/A_{v_1}}$**

Charge on C_H is raised to $C_H V_0 + C_{in} V_X$ due to conservation of charge at X.

- Voltage across $C_H = \frac{C_H V_0 + C_{in} V_X}{C_H}$
- $V_X = V_{out} - \frac{C_H V_0 + C_{in} V_X}{C_H} = -\frac{V_{out}}{A_{v_1}}$
- $V_{out} = \frac{V_o}{1 + \frac{1}{A_{v_1}}\left(\frac{C_{in}}{C_H} + 1\right)} \approx V_o\left[1 - \left(\frac{1}{A_{v_1}}\right)\left(\frac{C_{in}}{C_H} + 1\right)\right]$

Gain error of 0.1%:

$$\left(\frac{C_{in}}{C_H} + 1\right)\left(\frac{1}{A_{v_1}}\right) = 0.1\%$$

$$\left(\frac{0.5}{2} + 1\right)\left(\frac{1}{A_{v_1}}\right) = 0.1\%$$

$$A_{v_1} = 1250$$