Problem Set - 1

Question 1

Date :

Using ID number and tutorial section, we get

$C_1 = 0.1\,(3+6)\ \mu F$

$C_1 = 0.9\ \mu F$

$R_2 = 94 + (4 \times 3)$

$= 106$

M2 is a PMOS, active region is achieved when the value of $|V_{ds}| > |V_{gs}| - |V_{th}|$ with all these values being negative. The value of V_s is set to 5 through connection to V_{DD}. Thus, the value of $V_g = V_{bias}$ has to be less than 5 while also satisfying the aforementioned equation.

For proper function, V_{ds} could be any value between -0.2 and -4.8 V.

1. At -0.2V,

$0.2 > |V_{bias} - 5| - 0.92$

$1.12 > 5 - V_{bias}$

$V_{bias} > 3.88$ V

2. At -4.8V,

$4.8 > |V_{bias} - 5| - 0.92$

$5.72 > 5 - V_{bias}$

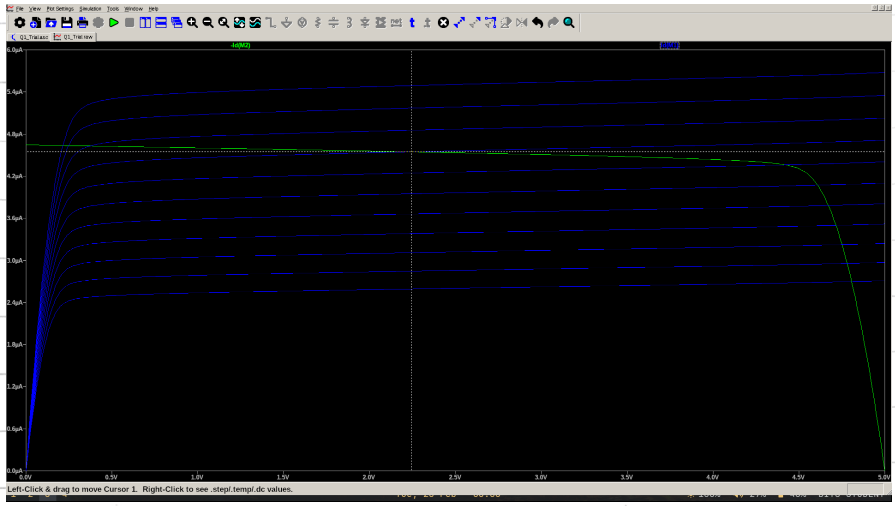
$V_{bias} > -0.72$V

Thus, the setting of the value of V_{bias} to 3.5V will ensure that M2 never goes outside the saturation region as long as V_{ds} for the PMOS does not go higher than -0.58V which is achievable as we will show in the following sections.

The Q-point is determined by plotting the V_{ds} graphs of both the loads and finding their intersection.

Date :

The below figure does that for V_{bias} set to 3.5V. Here, we can see the intersection point set is found at 1.07V. Thus, the DC operating point of the amplifier is 1.07V. (which is plotted on different lines)

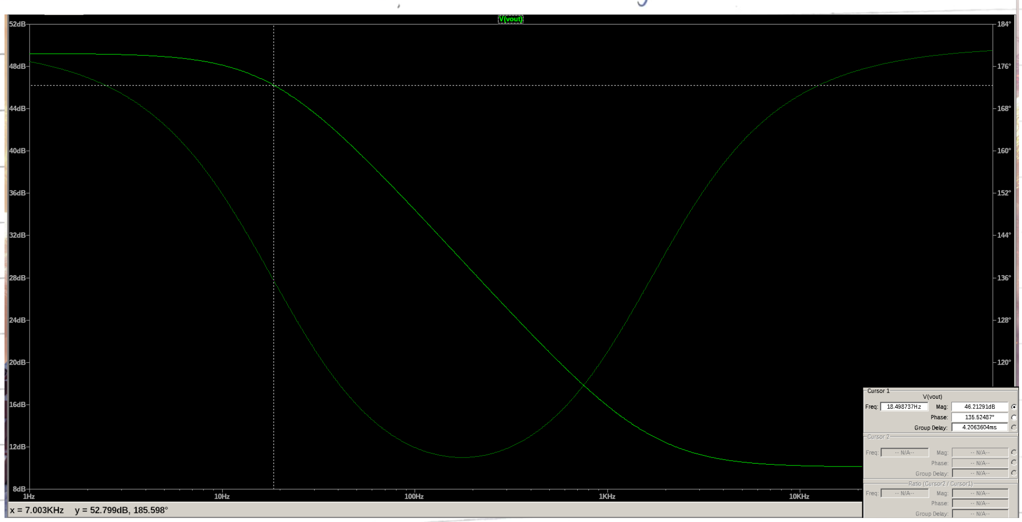


Here, we can see that the V_{ds1} is always less than 4.42V which is the condition which we used to choose 3.5V.

The DC point for the MOSFET M1 is thus 1.07V and the DC point for M2 is 3.5V.

This maximises the gain but it clips the wave because of the large amplitude of 1V. These are just some of the drawbacks to deal with when designing.

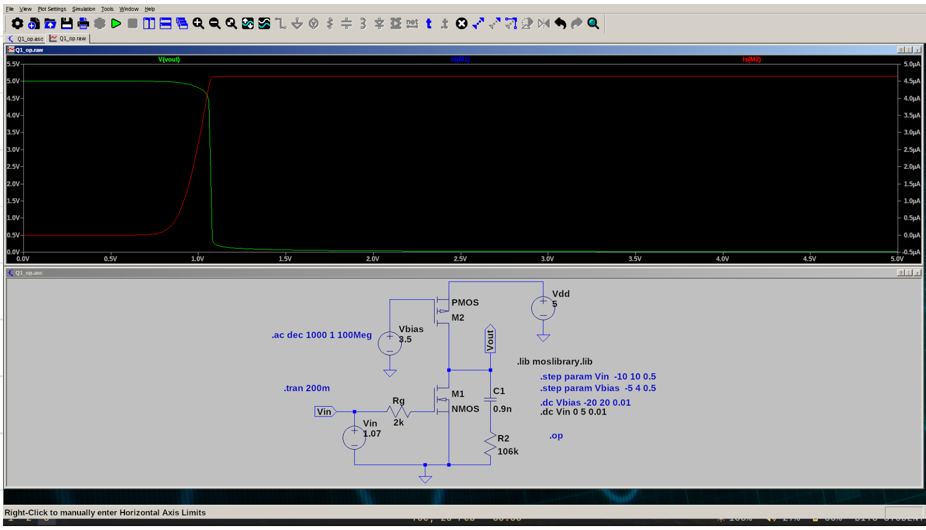
With these conditions we can plot the frequency response.



In the diagram we can see that this acts as a low pass filter with 3dB value of 18.5Hz

Date :

We will now plot the input, output characteristics to find the small signal parameters.



At $V_{in} = 1.07V$, $V_{out} = 2.08V$

$I_{ds1} = 4.55\,\mu A$, $I_{ds2} = 4.55\,\mu A$.

However, the values of r_o should be found individually.

For PMOS,

$-9.7598253\ V$

$618.51198\ \mu A$.

$-20V$

$630.35148\ \mu A$.

For NMOS,

$1.6122893V$

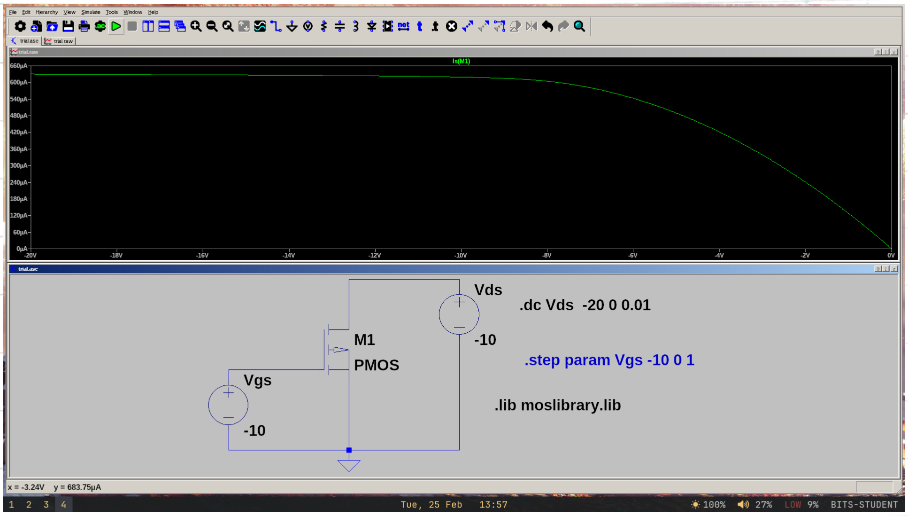
$59.813022\ \mu A$.

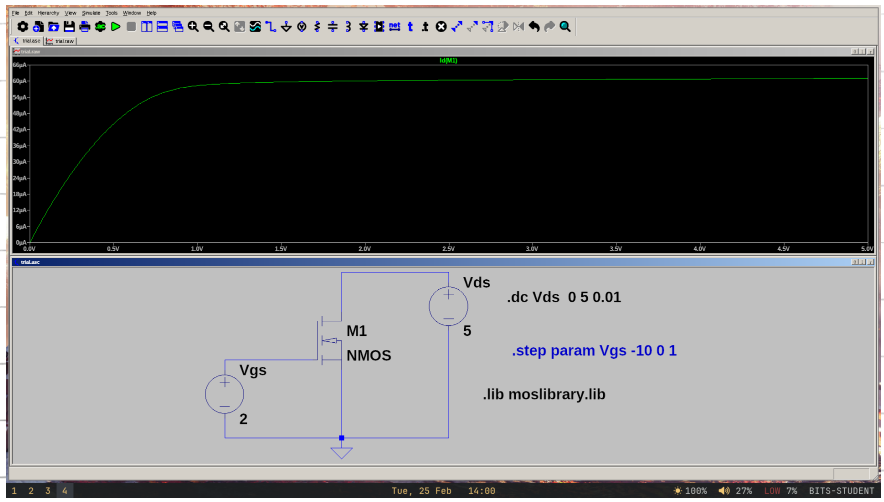
$5V$

$61.104969\ \mu A$.

And generally $\gamma = 0.287\sqrt{V}$

Date :





$$g_{m_1} = \frac{2I_D}{V_{ov}} = \frac{2\times 4.55}{1.07-0.67} = 22.75\ \mu\mho$$

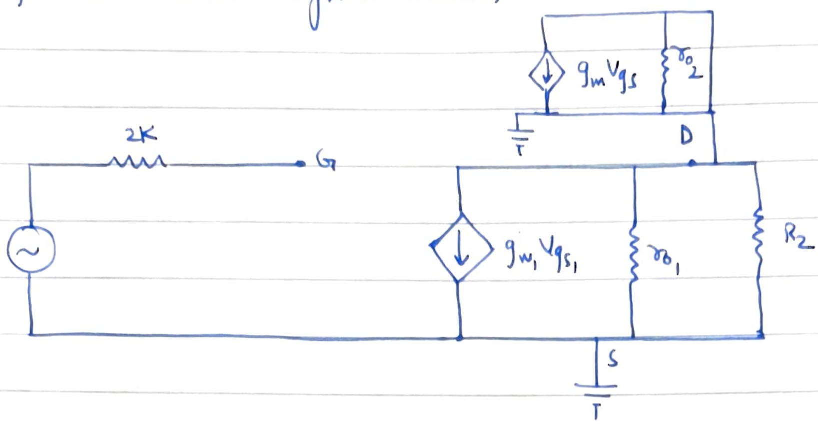
$$r_{o_1} = \frac{5-1.612}{61.105-59.813} = 2.622\ M\Omega$$

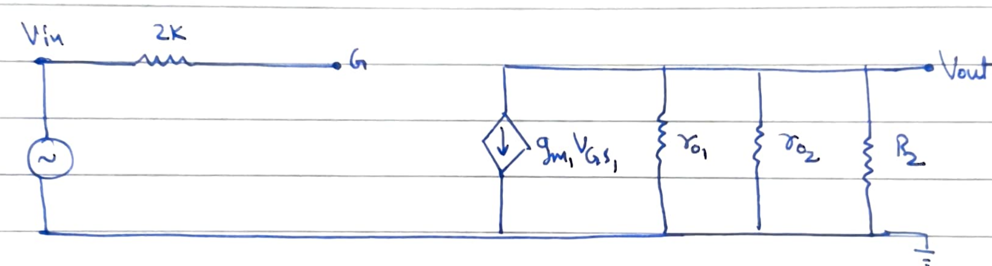
$$G_{m_2} = \frac{2I_D}{V_{ov}} = \frac{2\times 4.55}{5-3.5-0.921} = 15.71\ \mu\mho$$

$$R_{o_2} = \left|\left(-9.760-(-20)\right)/\left(618.512-630.351\right)\right| = 0.865\ M\Omega$$

Date :

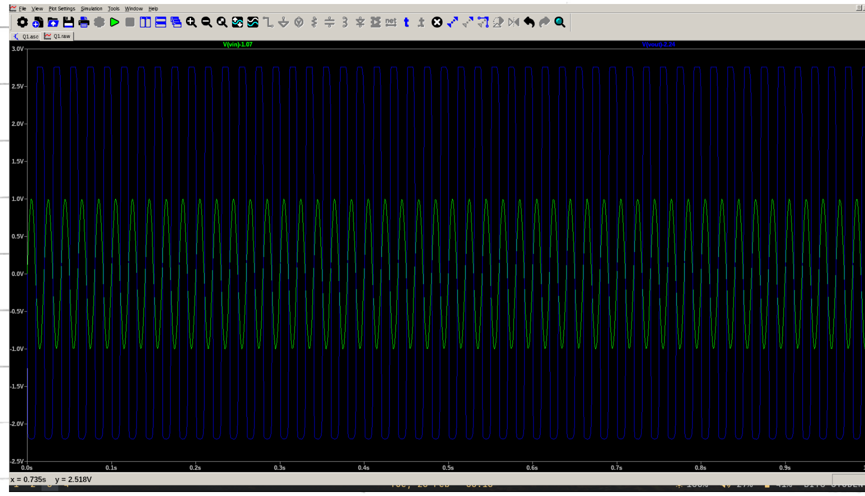
Now for the small signal model,





Gain $= -g_{m_1}(r_{o1} \| r_{o2} \| R_2) = -22.75\,\mu\mho \times 0.0911\,M\Omega = -2.07$

This can be seen in the input and output waves of an example wave.



Problem Set - 1

Question 2

→ Hand calculations for z, y, h parameters for low and high frequencies :-

For Low Frequencies (1K Hz) :-

Z - Parameters (Open circuit Impedance parameters) :-

We know :- $V_1 = Z_{11} I_1 + Z_{12} I_2$

$V_2 = Z_{21} I_1 + Z_{22} I_2$.

$\Rightarrow Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0}$. $\quad Z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1=0}$.

$Z_{21} = \left.\frac{V_2}{I_1}\right|_{I_2=0}$ $\quad Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$.

At low frequencies, capacitors act as open circuits

$\Rightarrow C_1 = C_2 \to \infty$

$\Rightarrow R_{total} = R_1 + R_2 + R_3 + R_4$.

Using resistances, we find Z-parameters of the circuit.

$Z_{11} = R_1 + R_2 = 36k\Omega + 44k\Omega = \underline{\underline{80k\Omega}}$

$Z_{12} = R_2 = \underline{\underline{44 k\Omega}}$

$Z_{21} = R_3 = \underline{\underline{22 k\Omega}}$

$Z_{22} = R_3 + R_4 = 22k + 50k = \underline{\underline{72k\Omega}}$

$\Rightarrow$ Z Parameters = $\begin{bmatrix} 80k & 44k \\ 22k & 72k \end{bmatrix} \Omega$.

Y Parameters (Short circuit Admittance Parameters) :-

We know :- $I_1 = y_{11} V_1 + y_{12} V_2$

$I_2 = y_{21} V_1 + y_{22} V_2$

Also, $[Y] = [Z]^{-1}$

$$\Rightarrow \quad y_{11} = \frac{Z_{22}}{\Delta}, \quad y_{12} = \frac{-Z_{12}}{\Delta}$$

$$y_{21} = \frac{-Z_{21}}{\Delta}, \quad y_{22} = \frac{Z_{11}}{\Delta}.$$

where $\Delta = Z_{11} Z_{22} - Z_{12} Z_{21}$.

From previous calculations, we have

$Z_{11} = 80k\Omega$; $Z_{12} = 44k\Omega$; $Z_{21} = 22k\Omega$; $Z_{22} = 72k\Omega$

$$\Rightarrow \Delta = (80k)(72k) - (44k)(22k)$$

$$= 5760 M\Omega^2 - 968 M\Omega^2$$

$$= 4792 M\Omega^2$$

$$Y_{11} = \frac{72k}{4792M} \simeq 15.03 \mu S.$$

$$Y_{12} = \frac{-44k}{4792M} = -9.18 \mu S.$$

$$Y_{21} = \frac{-22k}{4792M} = -4.59 \mu S.$$

$$Y_{22} = \frac{80k}{4792M} \simeq 16.7 \mu S.$$

$$\Rightarrow \quad [Y] = \begin{bmatrix} 15.03\mu & -9.18\mu \\ -4.59\mu & 16.7\mu \end{bmatrix} S.$$

H-parameters (Hybrid Parameters):-

We know :- $V_1 = h_{11} I_1 + h_{12} V_2$

$I_2 = h_{21} I_1 + h_{22} V_2$.

We can express h parameters in terms of Z parameters by:-

$$h_{11} = Z_{11} \quad , \quad h_{12} = \frac{Z_{12}}{Z_{22}}$$

$$h_{21} = \frac{Z_{21}}{Z_{11}} \quad , \quad h_{22} = \frac{1}{Z_{22}}$$

From previous calculations, we have.

$Z_{11} = 80k\Omega$; $Z_{12} = 44k\Omega$; $Z_{21} = 22k\Omega$; $Z_{22} = 72k\Omega$

$$h_{11} = Z_{11} = 80k\Omega.$$

$$h_{12} = \frac{44k}{72k} = 0.611$$

$$h_{21} = \frac{22k}{80k} = 0.275.$$

$$h_{22} = \frac{1}{72k} = 13.89\mu S$$

$$[H] = \begin{bmatrix} 80k\Omega & 0.611 \\ 0.275 & 13.89\mu S \end{bmatrix}.$$

For high frequency (10 MHz).

At high frequencies, capacitors act as short circuits i.e. $C_1 = C_2 = 0$.

Z Parameters :- (Open circuit impedance parameters)

$Z_{11} = R_1 = 36\,k\Omega$ [as C_2 is shorted, R_2 is redundant].

$Z_{12} = R_2 = 0$

$Z_{21} = 0$ (no coupling).

$Z_{22} = R_2 \,||\, (R_3 + R_4)$

$= 36k \,||\, 72k$

$= \dfrac{36k \times 72k}{36k + 72k} = 24\,k\Omega$.

$$\Rightarrow [Z] = \begin{bmatrix} 36k & 0 \\ 0 & 24k \end{bmatrix} \Omega.$$

Y Parameters (Short circuit impedance parameters).

We know $[Y] = [Z]^{-1}$.

For a diagonal Matrix $[Z] = \begin{bmatrix} Z_{11} & 0 \\ 0 & Z_{22} \end{bmatrix}$,

inverse is $[Y] = \begin{bmatrix} 1/Z_{11} & 0 \\ 0 & 1/Z_{22} \end{bmatrix}$.

$$\Rightarrow [Y] = \begin{bmatrix} 1/36k & 0 \\ 0 & 1/24k \end{bmatrix}$$

$$\Rightarrow [Y] = \begin{bmatrix} 27.78\mu & 0 \\ 0 & 41.67\mu \end{bmatrix} S$$

Date
Page

H-parameters :- (Hybrid parameters).

We know,

$$h_{11} = Z_{11} \qquad h_{12} = \frac{Z_{12}}{Z_{22}}$$

$$h_{21} = \frac{Z_{21}}{Z_{11}} \qquad h_{22} = \frac{1}{Z_{22}}.$$

$\Rightarrow h_{11} = 36k\Omega.$

$$h_{12} = \frac{0}{24k} = 0$$

$$h_{21} = \frac{0}{36k} = 0.$$

$$h_{22} = \frac{1}{24k} = 41.67\mu S$$

$$\Rightarrow [h] = \begin{bmatrix} 36k\Omega & 0 \\ 0 & 41.67\mu S \end{bmatrix}.$$

Value of I_1 in high frequency:-

We know:-

$\rightarrow I_1 = \frac{V_1}{R_1}$

$\rightarrow V_1 = 15V$

$\rightarrow R_1 = 36k\Omega = 36\times10^3\Omega.$

$$\Rightarrow I_1 = \frac{15}{36\times10^3}$$

$$I_1 = 416.67\mu A.$$

→ For maximum power transfer, the value of load connected to the output should be equal to the value of internal resistance.

$\Rightarrow R_s = R_L$.

$\Rightarrow R_L = 36 k\Omega$.

→ The value of V_2 remains constant with the change in capacitance C_1.