

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING



THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

Analog IC Design Assignment-2

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M.Tech (VLSI Design)**

Assignment 2

① Calculate the gain of the following circuit

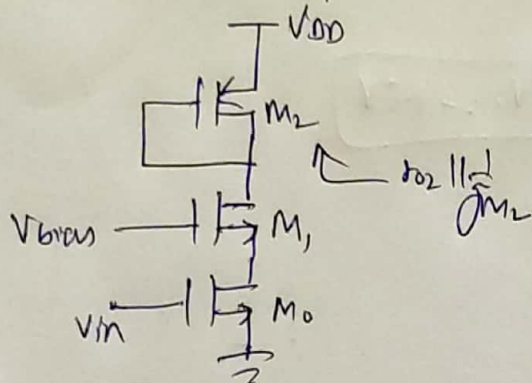
① at very low frequencies

② at very high frequencies

Assume $r_{o2} \gg r_{o1} \gg r_{o0}$, $\lambda_2 \gg \lambda_1 \gg \lambda_0$, $\lambda_2 \neq 0$

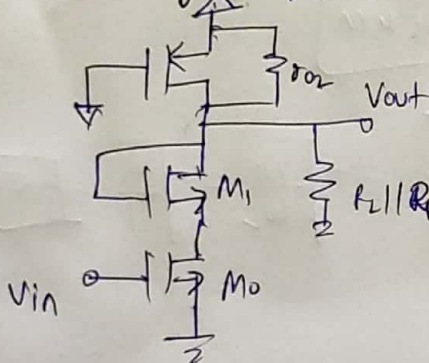
At low frequency

C_1 & C_2 are open circuits



$$A_v \approx -g_{m0} (r_{o2} \parallel \frac{1}{g_{m2}})$$

At high frequency



$$A_v \approx -g_{m0} (R_1 \parallel R_2 \parallel r_{o2})$$

② Design a common source amplifier with a diode connected load based on the schematic shown below

- Transistor M_1 is in saturation
- The min possible output voltage to keep M_1 in saturation is 0.2V
- Total power consumption of amplifier is 3mW
- Both T_{ox} have $L = 0.5 \mu m$ and for M_2 we have $W = 1 \mu m$

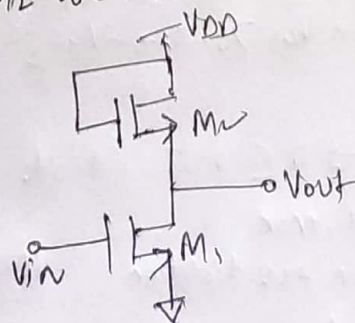
$\lambda_{NMOS} = 0$

$r_{o2} = 0$

$V_{DD} = 3V$

$V_{th}(NMOS) = 0.5V$

$\mu_n C_{ox} = 1 mA/V^2$



a) DC level of the input

M_1 must operate in sat

$$V_{GS1} \leq V_{th} \rightarrow V_{bias1} - V_{out} \leq V_{th} \rightarrow V_{bias1} \leq V_{out} + V_{th}$$

we choose $V_{bias1} = V_{out} + V_{th}$

M_1 will operate at edge of saturation at $V_{bias1} = 0.7V$

$$V_{bias1} = V_{out} + V_{th} = 0.2 + 0.5 = \boxed{0.7V}$$

b) DC level of output

$$I_D = \frac{P}{V_{DD}} = \frac{3mW}{3V} = 1mA$$

$$I_D = I_{D2} = 1mA = \frac{1}{2} \mu n C_{ox} \frac{W_2}{L} (V_{GS2} - V_{th})^2$$

$$1mA = \frac{1}{2} \times \frac{1mA}{V_L} \times \frac{1}{0.5} (V_{GS2} - 0.5)^2 \rightarrow \boxed{V_{GS2} = 1.5V}$$

$$V_{outDC} = V_{DD} - V_{GS2} = 3 - 1.5$$

$$\boxed{V_{outDC} = 1.5V}$$

c) width (W_1) of M_1

$$I_D = I_{D1} = 1mA = \frac{1}{2} \mu n C_{ox} \frac{W_1}{L} (V_{GS1} - V_{th})^2$$

$$1mA = \frac{1}{2} \times \frac{1mA}{V_L} \times \frac{W_1}{0.5\mu m} (0.7 - 0.5)^2 \rightarrow \boxed{W_1 = 25\mu m}$$

d) Small signal gain

$$A_v = -g_{m1} \cdot \frac{1}{g_{m2}} = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{2\mu n C_{ox} (\frac{W_1}{L})_1 I_{D1}}{2\mu n C_{ox} (\frac{W_2}{L})_2 I_{D2}}} = -\sqrt{\frac{W_1}{W_2}} = \sqrt{\frac{25}{1}} = \boxed{-5}$$

e) max o/p signal swing for a symmetric o/p signal

$$V_{outmin} = 0.2V$$

$$V_{outDC} = 1.5V$$

$$V_{outmax} = ?$$

As o/p voltage increases, the overdrive voltage of M_2 decreases up to the point where $V_{GS2} = V_{th}$. If V_{out} increases any further, M_2 will turn off. M_2 is a diode connected device & operates in saturation as long as $V_{GS2} > V_{th}$

$$M_2 \text{ in sat} \rightarrow V_{GS2} > V_{th} \rightarrow V_{GS2} > 0.5 \rightarrow -V_{GS2} < -0.5 \rightarrow V_{DD} - V_{GS2} < V_{DD} - 0.5 \rightarrow$$

$$V_{GS2} \leq V_{th} \rightarrow 0 \leq 0.5 \text{ (diode connected device)}$$

$$V_{out} < 2.5$$

$$\boxed{V_{outmax} = 2.5V}$$

$$2.5V \rightarrow V_{outmax}$$

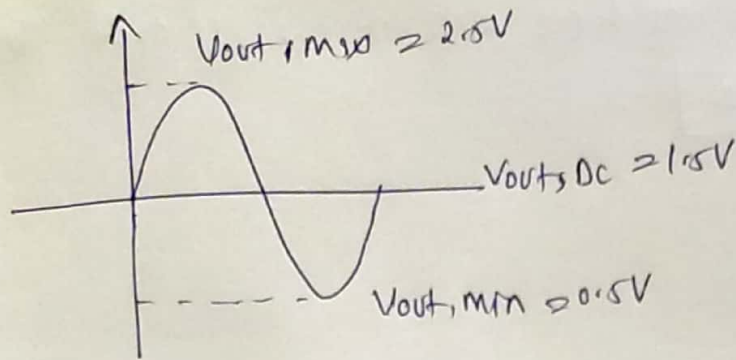
$$\uparrow 1V \text{ swing in the direction}$$

$$1.5V \rightarrow V_{outDC}$$

$$\downarrow$$

$$0.2V \rightarrow V_{outmin}$$

$$\text{max. symmetric swing} = 2 \times \min(1V, 1.3V) = 2V$$



③ In following ckt assume that all transistors are operating in saturation region. Also assume that $\lambda = r_o = \infty$, $V_{DD} = 1.0V$, $V_{bias3} = 1.15V$, $V_{th}(n) = 0.4V$ and $V_{th}(p) = -0.4V$, $\mu_n C_{ox} = 800 \mu A/V^2$, $(W/L)_1 = 40$, $\mu_p C_{ox} = 400 \mu A/V^2$, $(W/L)_2 = 40$, $(W/L)_3 = 40$ and $R_S = 100 \Omega$

(a) Find V_{bias1} such that bias current of M_1 is $I_D = 1mA$

④ ~~Calculate~~

$$I_{D1} = 1mA = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_1 (V_{GS1} - V_{th})^2$$

$$= \frac{1}{2} \times 800 \frac{\mu A}{V^2} \times 40 (V_{GS1} - 0.4)^2$$

$$\boxed{V_{GS1} = 0.65V}$$

$$V_{bias1} = V_{GS1} + R_S I_D = 0.65 + 0.1 \times 1 = \boxed{0.75V}$$

(b) Calculate small signal voltage gain $A_{v1} = V_{out1} / V_{in}$

$$\lambda = r_o = \infty, \quad A_{v1} = \frac{-g_{m1} R_D}{1 + g_{m1} R_S}$$

$$R_D = \frac{1}{g_{m2}}, \quad R_S = 0.1k\Omega$$

$$I_{D3} = \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_3 (V_{DD} - V_{bias3} - |V_{thp}|)^2$$

$$= \frac{1}{2} \times 400 \times 40 (1.0 - 1.15 - 0.4)^2 = \boxed{500 \mu A}$$

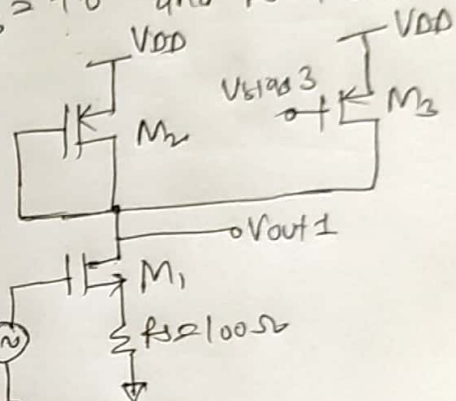
$$I_{D2} = I_{D1} - I_{D3} = 1000 \mu A - 500 \mu A = 500 \mu A$$

$$g_{m2} = \sqrt{2 \mu_p C_{ox} I_{D2}} = \sqrt{2 \times 400 \times 40 \times 500} = \boxed{4 mA/V}$$

$$g_{m1} = \sqrt{2 \mu_n C_{ox} I_{D1}} = \sqrt{2 \times 800 \times 40 \times 1000} = \boxed{8 mA/V}$$

$$R_D = \frac{1}{g_{m2}} = \frac{1}{4 mA/V} = 250 \Omega = \boxed{0.25 k\Omega}$$

$$A_{v1} = \frac{-g_{m1} R_D}{1 + g_{m1} R_S} = \frac{-8 \times 0.25}{1 + 8 \times 0.1} = \boxed{-1.11 V/V}$$

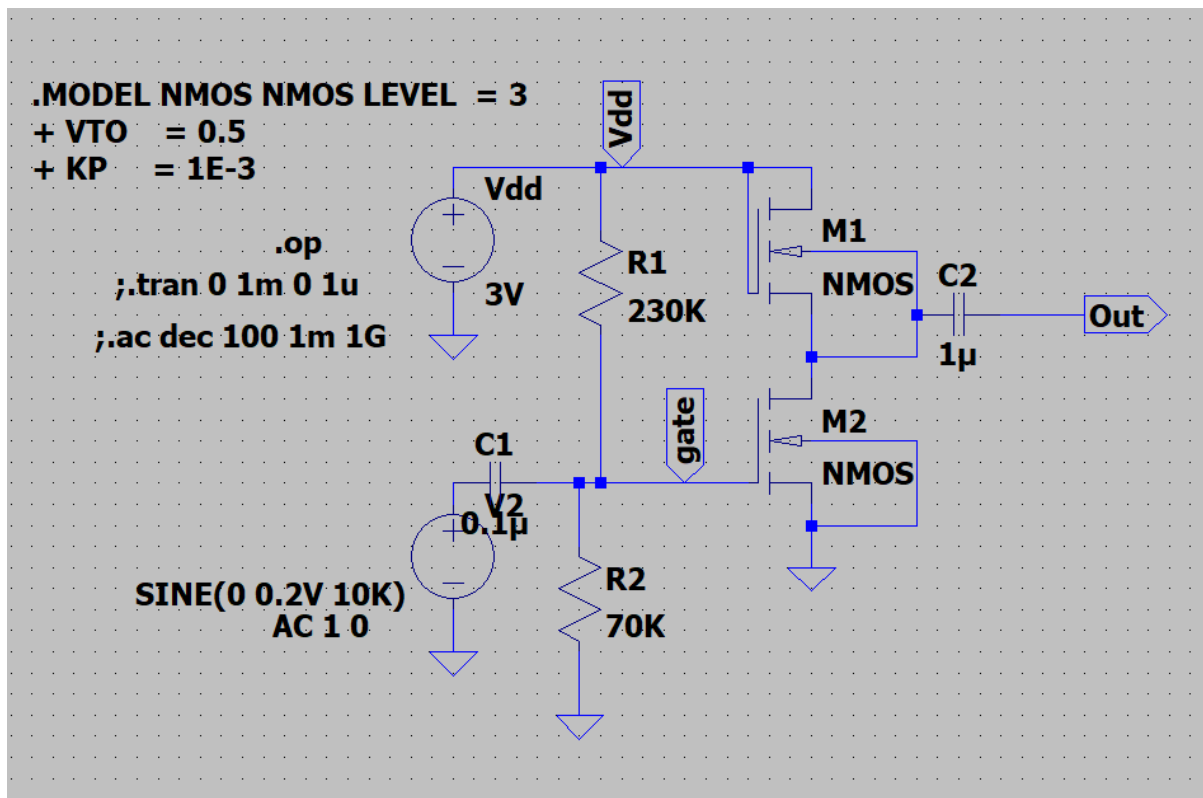


① Calculate the small-signal o/p impedance seen at the o/p node V_{out}

$$R_{out} = \frac{1}{g_{m2}} = R_D = \boxed{250 \Omega}$$

Assignment-2(LTSPICE)

Question-3 Diagram:



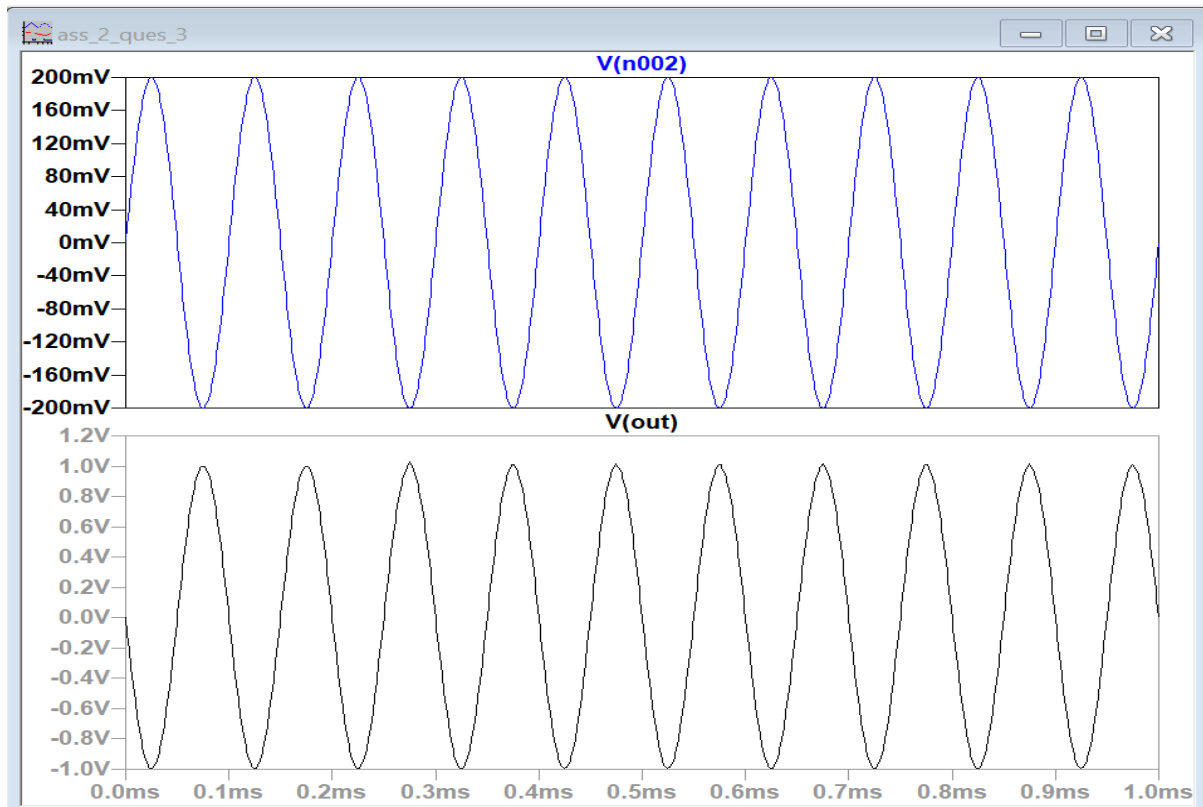
DC Operating Point Values:

* C:\Users\singh\Downloads\ass_2_ques_3.asc

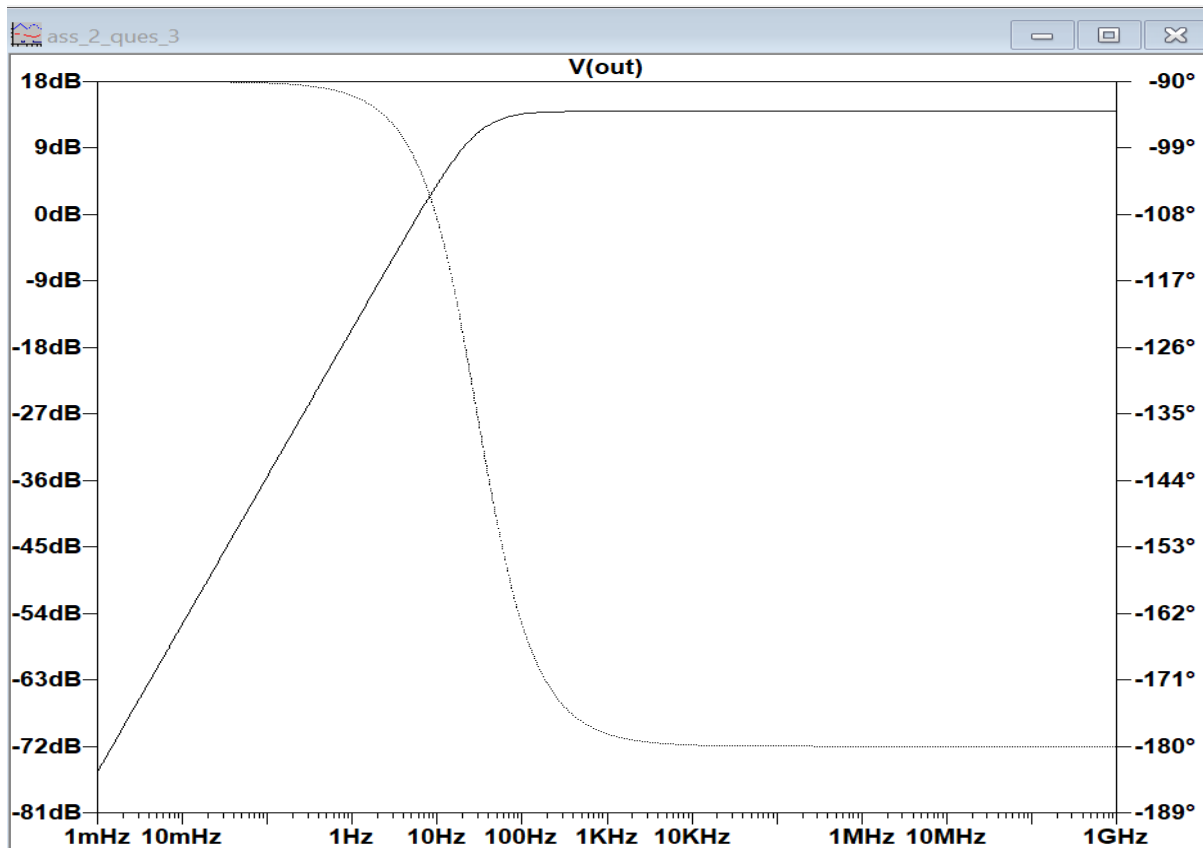
--- Operating Point ---

V(vdd):	3	voltage
V(n001):	1.5	voltage
V(gate):	0.7	voltage
V(n002):	0	voltage
V(out):	1.5e-006	voltage
Id(M2):	0.001	device_current
Ig(M2):	0	device_current
Ib(M2):	-1.51e-012	device_current
Is(M2):	-0.001	device_current
Id(M1):	0.001	device_current
Ig(M1):	0	device_current
Ib(M1):	-1.51e-012	device_current
Is(M1):	-0.001	device_current
I(C2):	-1.5e-018	device_current
I(C1):	7e-020	device_current
I(R2):	1e-005	device_current
I(R1):	1e-005	device_current
I(V2):	7e-020	device_current
I(Vdd):	-0.00101	device_current

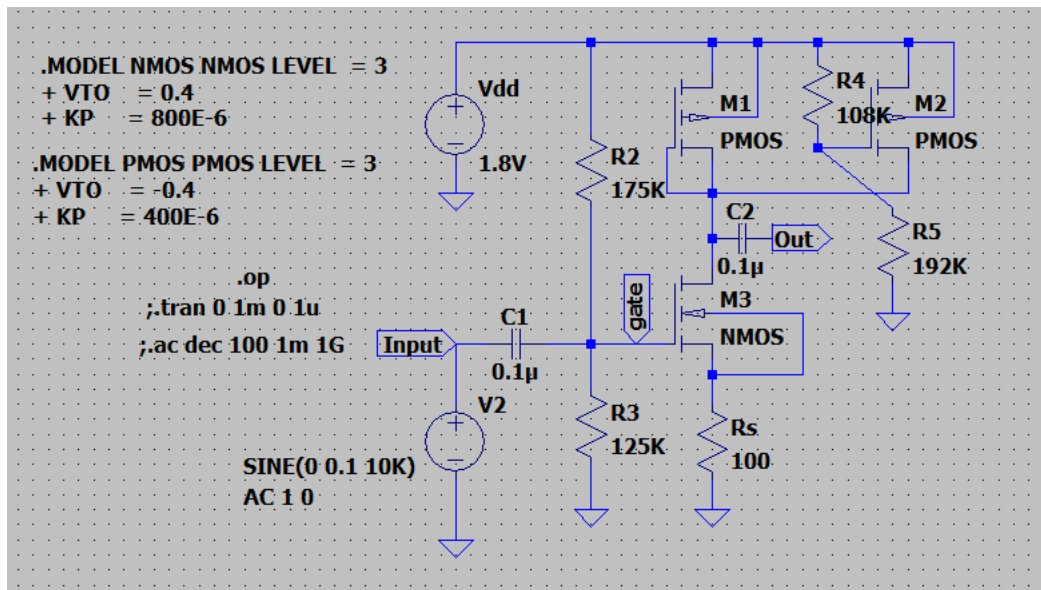
Transient Analysis:



Ac Analysis:



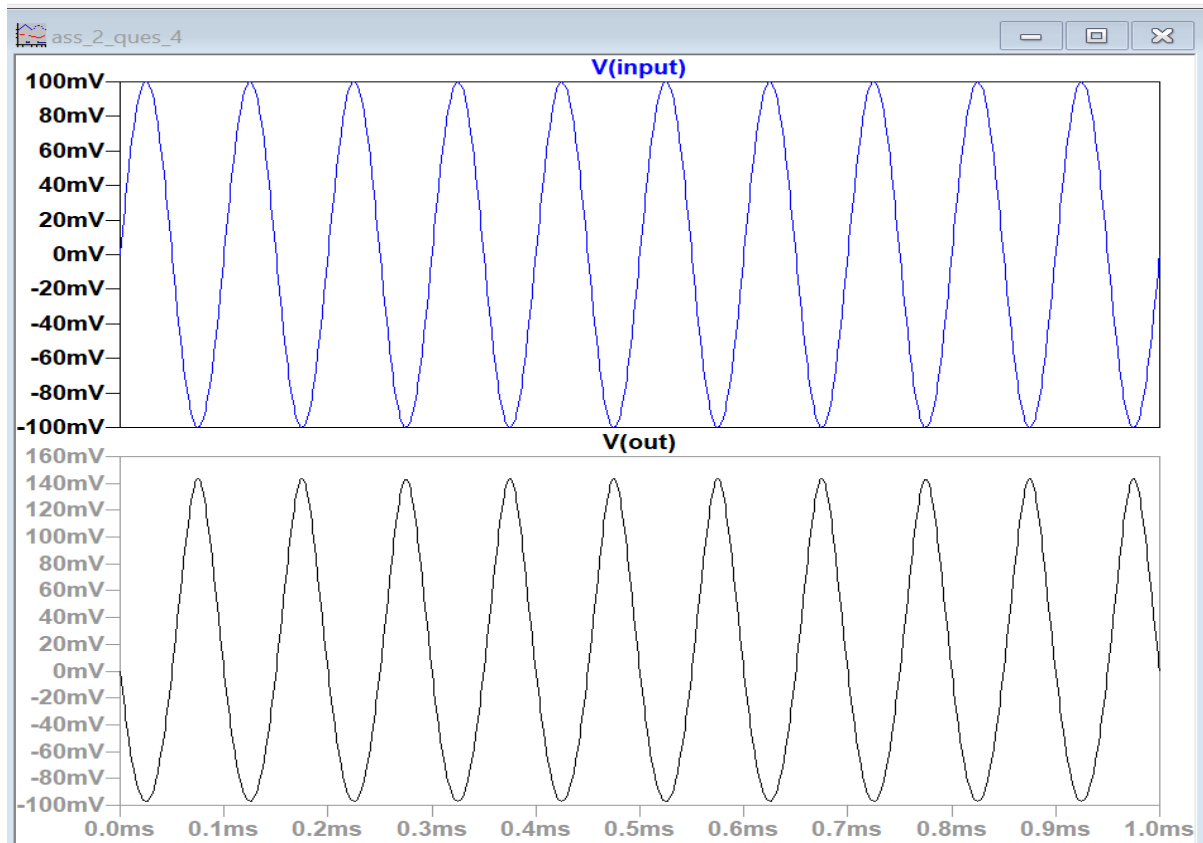
Question-4 Diagram:



DC Operating Point Values:

* C:\Users\singh\Downloads\ass_2_ques_4.asc		
--- Operating Point ---		
V(n001):	1.8	voltage
V(n003):	1.14802	voltage
V(n002):	1.152	voltage
V(gate):	0.75	voltage
V(n004):	0.1	voltage
V(input):	0	voltage
V(out):	1.14802e-007	voltage
Id(M3):	0.001	device_current
Ig(M3):	0	device_current
Ib(M3):	-1.05802e-012	device_current
Is(M3):	-0.001	device_current
Id(M2):	0.000492032	device_current
Ig(M2):	-0	device_current
Ib(M2):	6.61985e-013	device_current
Is(M2):	-0.000492032	device_current
Id(M1):	0.000507971	device_current
Ig(M1):	-0	device_current
Ib(M1):	6.61985e-013	device_current
Is(M1):	-0.000507971	device_current
I(C2):	-1.14802e-019	device_current
I(C1):	7.5e-020	device_current
I(R5):	6e-006	device_current
I(R4):	6e-006	device_current
I(R3):	6e-006	device_current
I(R2):	6e-006	device_current
I(Rs):	0.001	device_current
I(V2):	7.5e-020	device_current
I(Vdd):	-0.001012	device_current

Transient Analysis:



AC Analysis:

