Analog Circuits FISAC

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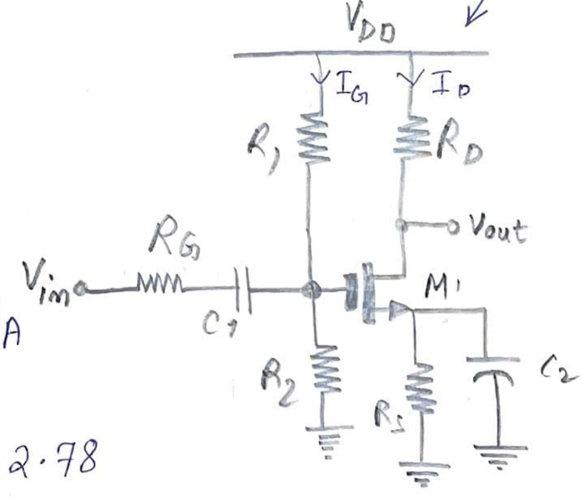
Q1] as reg. no. = 36 (last 2 digits)

required gain : -36

- input impedance = 50 kΩ = Z_{in}
- power budget = 5 mW
- $\mu_n C_{ox}$ = 100 μA / V^2
- V_{TH} = 0.5V
- λ = 0 (no channel length modulation)
- V_{DD} = 1.8V
- V_{RS} = 400 ~~mV~~ mV = 0.4V

given

given circuit



①. power budget = $V_{DD} \times I_D$

$\Rightarrow 5 \times 10^{-3} = 1.8 \times I_D$

$\Rightarrow I_D = \frac{5 \times 10^{-3}}{1.8} = 0.36 \times 10^{3}$

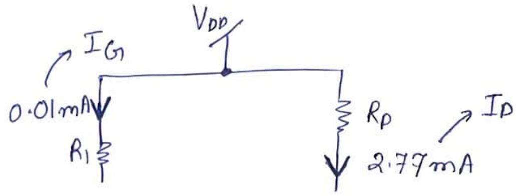
$\Rightarrow I_D = \frac{5 \times 10^{-3}}{1.8} = \underline{2.778 \times 10^{-3} A}$

$\boxed{\because I_D = 2.778 \text{ mA}}$ ≈ 2.78

②. need to assign maximum current to MOS

∵ I_D = 2.787 mA

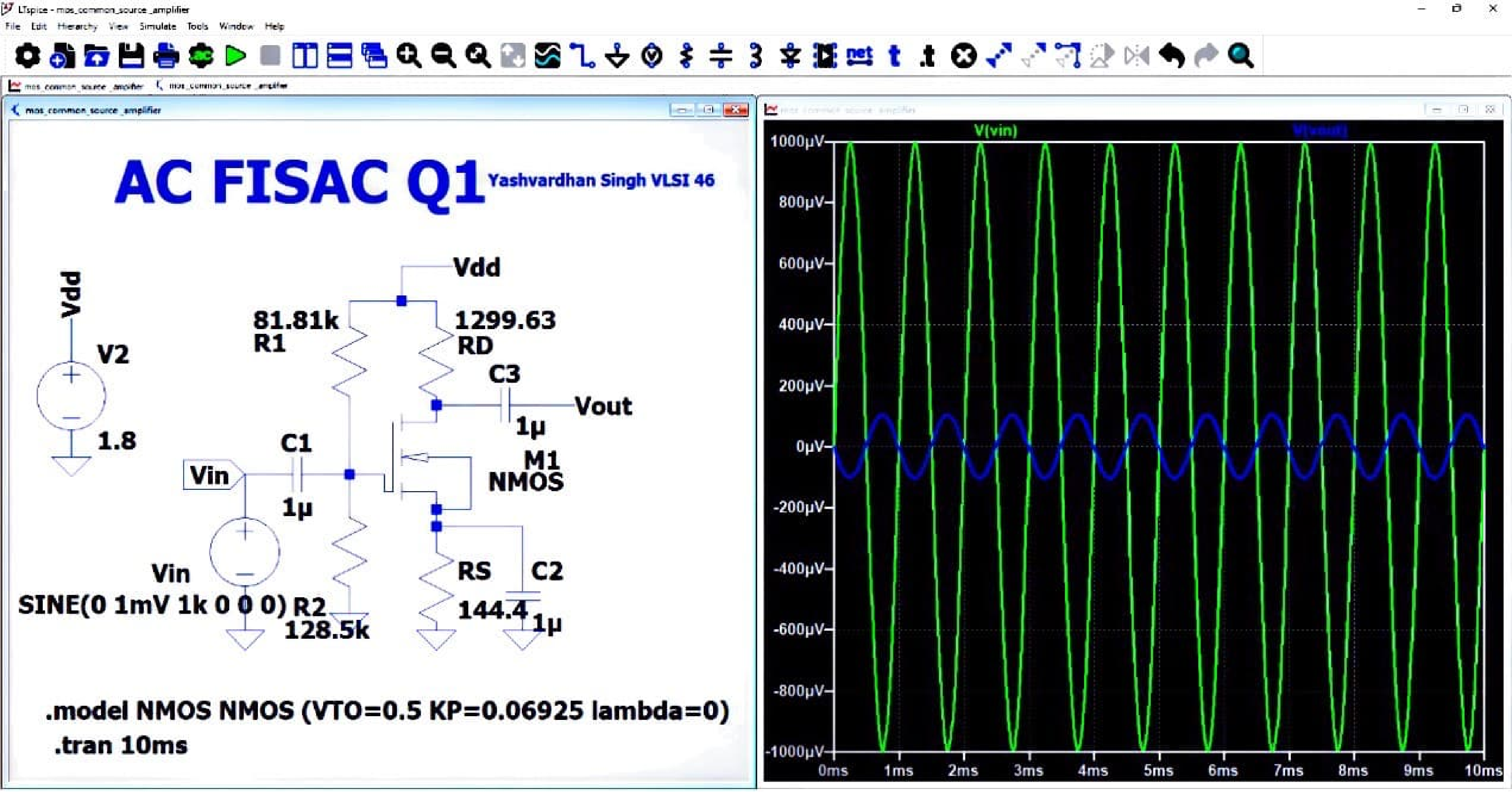
∵ I_G = 0.01 mA



let's assume V_{GS} = 0.7 V

$A_V = -g_m R_D = -36$

$g_m = \frac{2 I_{DS}}{V_{GS} - V_{TH}} = \frac{2(2.77 \times 10^{-3})}{0.2} = 27.7 \frac{mA}{V}$


LTspice - mos_common_source_amplifier
File Edit Hierarchy View Simulate Tools Window Help
mos_common_source_amplifier
AC FISAC Q1
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Vdd
V2
1.8
81.81k
R1
1299.63
RD
C3
Vout
1µ
C1
Vin
1µ
M1
NMOS
Vin
SINE(0 1mV 1k 0 0 0)
R2
128.5k
RS
144.4
C2
1µ
.model NMOS NMOS (VTO=0.5 KP=0.06925 lambda=0)
.tran 10ms
V(vin)
V(vout)
1000µV
800µV
600µV
400µV
200µV
0µV
-200µV
-400µV
-600µV
-800µV
-1000µV
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms

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$$\boxed{g_m = 27.7 \text{ mA/V}}$$

3. $g_m R_D = 36 = 27.7$ mA/V

$$R_D = \frac{36}{27.7 \times 10^{-3}} = 1299.638\,\Omega$$

$$\boxed{R_D = 1299.63\,\Omega}$$

4. V_S = voltage drop across R_S = V_{RS} = 400mV = 0.4V

$V_S = 0.4V$

$$I_{DS} = V_S / R_S \Rightarrow R_S = \frac{V_S}{I_{DS}} = \frac{0.4}{2.77 \times 10^{-3}} = 144.4\,\Omega$$

$$\boxed{R_S = 144.4\,\Omega}$$

5. $$I_{DS} = \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_{TH})^2$$

$$2.77 \times 10^{-3} = \frac{1}{2} \times 100 \times 10^{-6} \times \frac{W}{L}(0.2)^2 \Rightarrow \frac{W}{L} = 1385$$

$$\boxed{W/L = 1385}$$

6. $V_{GS} = 0.7V = V_G - \underset{V_S}{0.4} \Rightarrow V_G = 0.7 + 0.4 = 1.1\,V$

$$\boxed{V_G = 1.1V}$$

$$\frac{R_1 R_2}{R_1 + R_2} = R_1 \| R_2$$

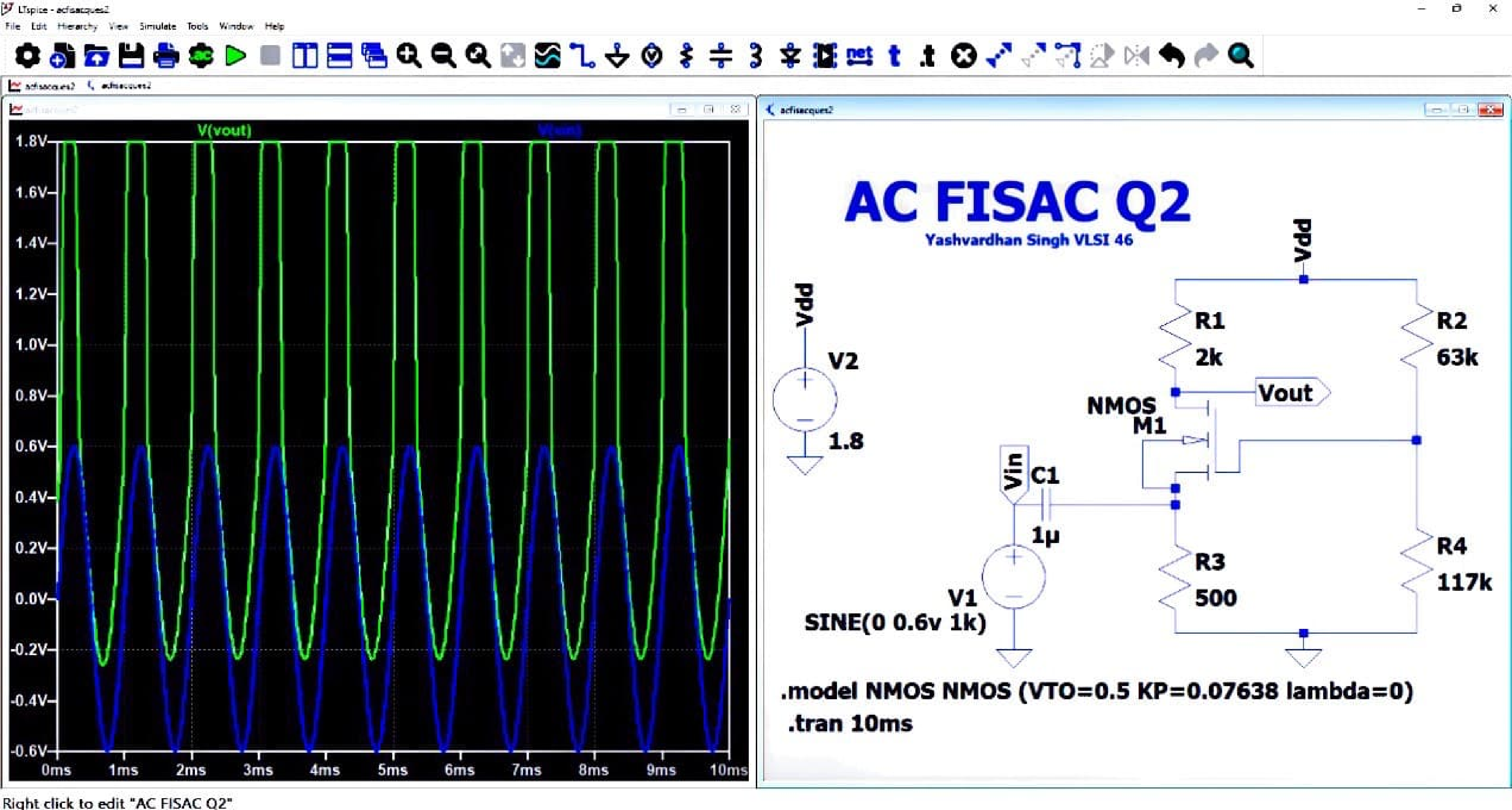
multiply R_1 on both sides

$$V_G = \frac{V_{DD} \times R_2}{R_1 + R_2} = 1.1\,V \Rightarrow \frac{1.8\, R_1 R_2}{R_1 + R_2} = 1.1(R_1)$$

$= 1.8(R_1 \| R_2) = 1.1 R_1$ ← here $R_1 \| R_2$ is $Z_{in} = 50\,k\Omega$

$= 1.8 \times 50 \times 10^3 = 1.1 R_1$

$\Rightarrow \boxed{R_1 = 81.81\,k\Omega}$ and $\boxed{R_2 = 128.5\,k\Omega}$



LTspice - acfisacques2
File Edit Hierarchy View Simulate Tools Window Help
V(vout)
V(vin)
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
0ms 1ms 2ms 3ms 4ms 5ms 6ms 7ms 8ms 9ms 10ms
acfisacques2
AC FISAC Q2
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Vdd
V2
1.8
R1
2k
R2
63k
Vout
NMOS
M1
Vin
C1
1µ
R3
500
R4
117k
V1
SINE(0 0.6v 1k)
.model NMOS NMOS (VTO=0.5 KP=0.07638 lambda=0)
.tran 10ms
Right click to edit "AC FISAC Q2"

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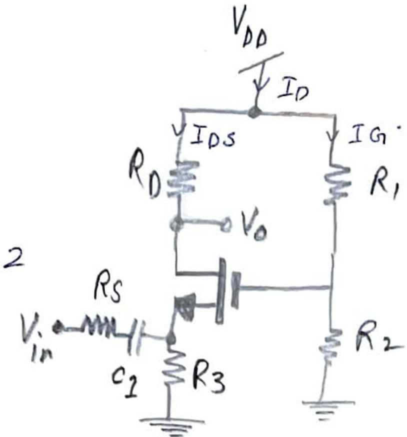
Q2] Given:

- voltage gain $\Rightarrow A_V = 36$
- $R_S = 0$
- $R_3 = 500\,\Omega$
- $R_{IN} = 50\,\Omega$
- $PB = 2\,mW$
- $V_{DD} = 1.8\,V$
- $\mu_n C_{ox} = 100\,\mu A/V^2$
- $V_{TH} = 0.5\,V$
- $\lambda = 0$ (no CLM)



$\Rightarrow PB = 2\times10^{-3} = V_{DD}\times I_D = 1.8\times I_D$

$I_D = 1.111\times10^{-3}\,A = 1.11\,mA$

$I_{DS} = 1.10\,mA \quad I_G = 0.01\,mA$

$\boxed{I_D = 1.11\,mA}$

$\Rightarrow R_{in} = \dfrac{1}{g_m \| R_3} \rightarrow g_m = R_{in}^{-1} - R_3^{-1}$

$\boxed{g_m = 0.018\,\Omega}$

$\boxed{V_{GS} = 0.62\,V}$

$\Rightarrow g_m = 0.018\,\Omega^{-1}$

$\Rightarrow g_m = \dfrac{2 I_{DS}}{V_{GS}-V_{TH}} \Rightarrow V_{GS} = \dfrac{2\times1.10\times10^{-3}}{0.018} + 0.5 = 0.62\,V$

$\Rightarrow I_{DS} = \dfrac{\mu_n C_{ox}}{2}\cdot\dfrac{W}{L}(V_{GS}-V_{TH})^2 = \dfrac{100\times10^{-6}}{2}(0.62-0.5)^2\dfrac{W}{L}$

$\dfrac{W}{L} = \dfrac{1.1\times10^{-3}\times2\times10^4}{(0.12)^2} = 1527.778$

$\boxed{\dfrac{W}{L} = 1527.78}$

$\Rightarrow V_{GS} + V_S = 0.62 + I_{DS}R_3 = 0.62 + 1.1\times10^{-3}(500)$

$V_G = 1.17\,V$

$\boxed{V_G = 1.17\,V}$

$\Rightarrow A_V = g_m R_D = 0.018\times R_D = 36 \Rightarrow$

$R_D = 36/0.018 = 2000$

$\boxed{R_D = 2000 = 2k\,\Omega}$

$\Rightarrow R_2 = \dfrac{V_G}{I_G} = \dfrac{1.17}{0.01}\times1000 = 117\,k\Omega$

$\boxed{R_2 = 117\,k\Omega}$

$\Rightarrow R_1 = \dfrac{V_{DD}-V_G}{I_G} = \dfrac{1.8-1.17}{0.01}\times1000 = 63\times10^3$

$\boxed{R_1 = 63k\,\Omega}$

$\Rightarrow$ all parameters found! $K_p = \dfrac{100\times10^{-6}\times1527.78}{2} = 0.07638$

03] $R_1 + R_2$ is very large → } given
$\therefore \lambda = 0$ ⟶ }

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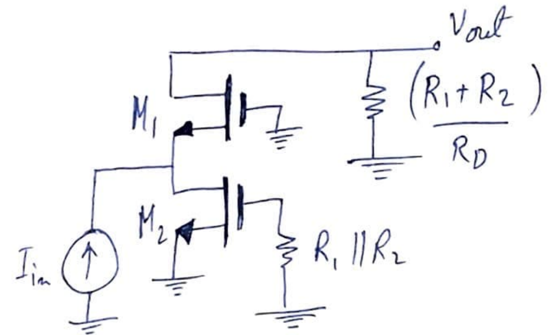
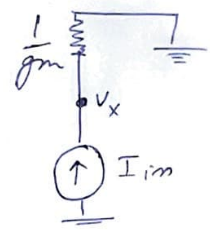


$$R_{o,open} = \frac{V_{out}}{I_{in}}$$



$$V_{out}/V_x = g_m R_D$$

$$V_x = I_{in}/g_m$$

$$\frac{V_{out}}{I_{in}/g_m} = g_m R_D$$

$$\therefore R_{o,open} = \frac{V_{out}}{I_{in}} = R_D$$

$$R_{IN,open} = V_x/I_{in} \Rightarrow \boxed{R_{IN,open} = 1/g_m}$$ → input impedance

$$R_{out,open} = R_D \parallel R_1 + R_2$$

Since $R_1 + R_2 >> R_D$

$R_D \parallel R_1 + R_2 \simeq R_D$ (anything parallel to ∞ is that thing itself).

$\boxed{R_{out,open} = R_D}$ → output impedance

Closed loop parameters

$$K = V_F/V_{out} = \frac{R_2}{R_1 + R_2}$$

$$R_{out\,closed} = \frac{R_D}{1 + K R_D} = R_D \Big/ 1 + \frac{R_2 R_o g_{m2}}{R_1 + R_2}$$

$$= \frac{R_{out\,open}}{1 + K R_o} = \boxed{R_D \Big/ 1 + \frac{R_D R_2 g_{m2}}{R_1 + R_2}}$$ → R_{out} closed

$$R_{in\,closed} = \frac{R_{IN\,open}}{1 + k R_o} \Rightarrow k = \frac{g_{m2} R_2}{R_1 + R_2}$$

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Q4.] 4^{th} order Butterworth LPF

$f_c = 1kHz$

passband gain = 5

$C = 0.1\mu F$

order = 4 $\Rightarrow$ $\therefore N = 4$ $\quad H_o = 5$ (given)

$f_c = 1\times10^3\ Hz \longrightarrow \omega_c = 2\pi f_c = 6283.1853$ rad/s

Transfer function: for 4th order

$$H(s) = \frac{H_o}{(s^2+\alpha_1\omega_c s+\omega_c^2)(s^2+\alpha_2\omega_c s+\omega_c^2)}$$

α_1, α_2 damping factors, for 4th order are:

$\alpha_1 = 0.765$

$\alpha_2 = 1.848$

$$H(s) = \frac{5}{(s^2+4806.24s+39478417.38)(s^2+11605.83s+39478417.38)}$$

$f_{c\,stage\,1} = \frac{f_c}{0.924}$ $\quad$ lets assume $R_1 = R_2 = R_3 = R_4 = R_7 = 1k\Omega$

$A = 1 + \frac{R_6}{R_1} \Rightarrow R_6 = (A-1)R_7 = \underline{\underline{4k\Omega}}$
$\qquad\qquad\qquad\qquad\qquad\quad \underset{5}{\downarrow} \quad \underset{1000}{\downarrow}$

$f_{c\,stage\,2} = \frac{f_c}{0.383}$ $\quad R_{1,2,3,4,5,7} = 1k\Omega$

$R_6 = 4k\Omega$

$$PS_1 = \frac{1}{Q_1 K_1 \omega} + \frac{1}{Q_2 K_2 \omega} \Rightarrow$$

$K_1 = K_2 = 1$

$\left.\begin{matrix} Q_1 = 0.5412 \\ Q_2 = 1.3066 \end{matrix}\right\}$ quality factors

for simplicity, assume $C_1 = C_2$ & $C_3 = C_4$

$C_1 = C_2 = \frac{1}{R\omega Q_1} = 296.23\,nF$ (R considered as $1k\Omega$)

$C_3 = C_4 = \frac{1}{R\omega Q_2} = 139.37\,nF$ ($R = 1k\Omega$)

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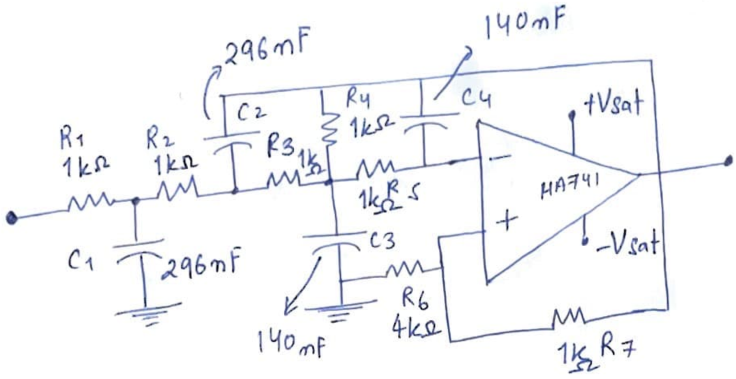
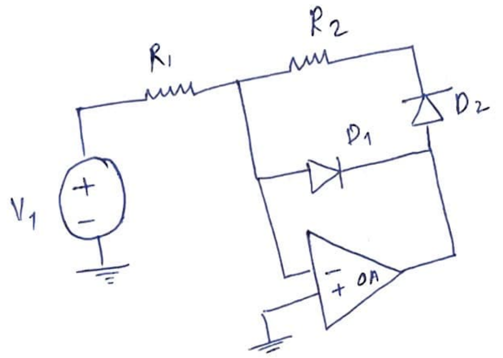
4th Order Butterworth LPF ckt. :



Q5]

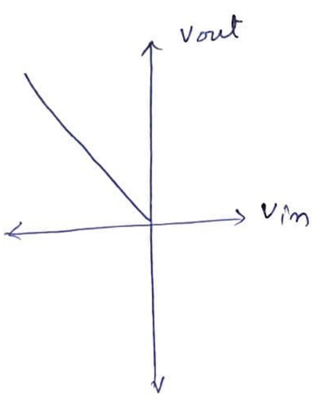


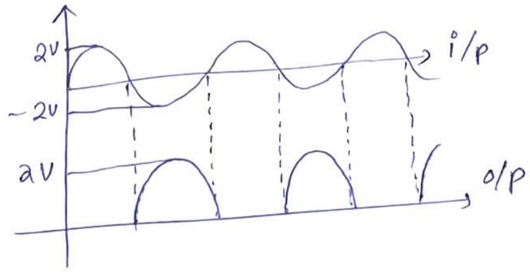
$R_1 = R_2$

$\pm V_{sat} = \pm 12\,V$

- The given circuit is a precision half-wave rectifier.
- When i/p voltage is greater than 0, D_1 is conductive & D_2 is non-conductive, so the voltage is 0.
- when input voltage is less than 0, D_1 doesn't conduct whereas D_2 conducts, and the op-amp works in inverting configuration.

  ↳ $V_{out} = \dfrac{-R_2}{R_1} V_{in}$ or V_1





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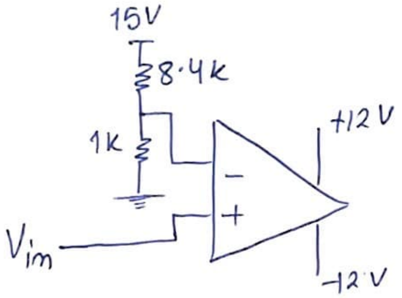
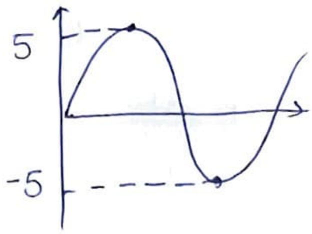
Q6)

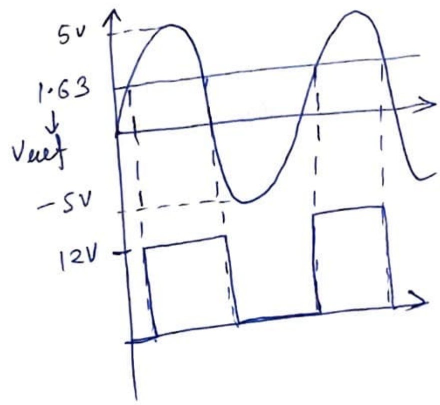




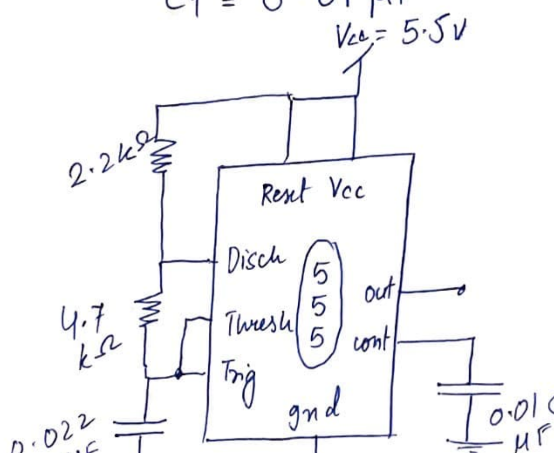
This is a non-inverting comparator.

i/p : non-inverting terminal
~~o/p~~ reference i/p : inverting terminal

$$V_{ref} = \frac{15 \times R_2}{R_1 + R_2} = \frac{16}{9.2} = 1.63V$$



Q7) (i) $R_1 = 2.2k\Omega$
$R_2 = 4.7k\Omega$
$C_2 = 0.022\mu F$
$C_1 = 0.01\mu F$
$V_{cc} = 5.5V$



$$F = \frac{1}{RC} = \frac{1}{6.9 \times 10^3 \times 0.022 \times 10^{-6}}$$

$R = R_1 + R_2 = 2.2 + 4.7 = 6.9k\Omega$

$f = 6.587 kHz$

$$T = \frac{1}{f} = 0.176ms$$

$T_{on} = 0.69(R_A + R_B)C = 0.1047 ms$

Duty-cycle : $\frac{T_{on}}{T} = \frac{0.1047}{0.176} = 59.48\%$

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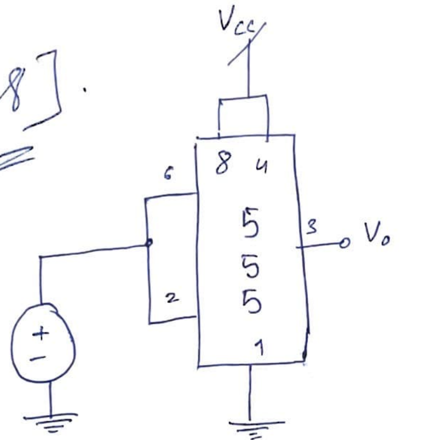
Q7] (ii) when a diode is connected b/w the discharge & threshold pins of a 555 timer configured as an astable multivibrator the output frequency will remain the same but the duty cycle reduces to less than 50%.

Q8].



$V_{cc} = 6V$

$V_i = 3 + 3\sin \pi t$

555 timer.

threshold voltage

$= \frac{1}{3} V_{cc}$ & $\frac{2}{3} V_{cc}$

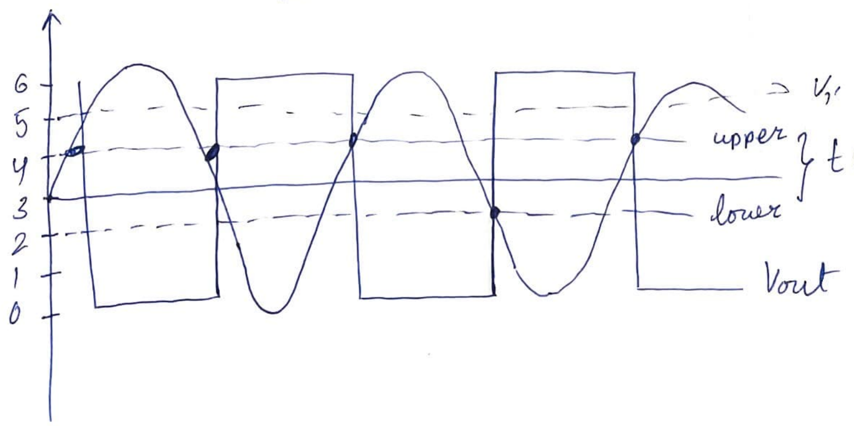
$\frac{1}{3} \times 6 = 2V$ [lower th]

$\frac{2}{3} \times 6 = 4V$ [upper th]

$V_i = 3 + 3\sin(\pi t)$

range $= -1$ to 1

$V_i = 0V$ $V_i = 3+3 = 6V$



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Q9.

Monostable multivibrator circuit

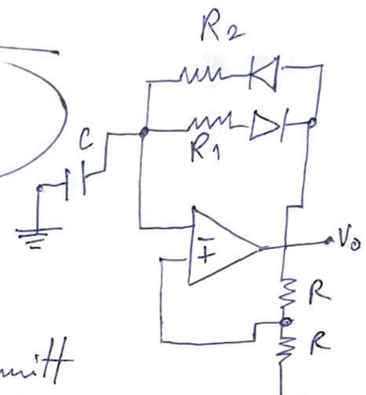
$V_{in}(1-e^{-t/R_1C_1}) \rightarrow$ charging

$$V_{th} = V_{in}(1-e^{-T/R_1C_1})$$

$$e^{-T/R_1C_1} = 1 - \frac{V_{Th}}{V_{in}}$$

$$T = \frac{-T}{R_1C_1} \ln\left(1 - \frac{V_{TH}}{V_{in}}\right)$$

$$T = R_1 C_1 \ln\left(\frac{V_{in}}{V_{in} - V_{Th}}\right)$$



Q10.) ① $C = 0.1 \mu F$
$R = 1k\Omega$
$R_1 = 2k\Omega$
$R_2 = 1k\Omega$

given ckt. is similar to Schmitt trigger relaxation oscillator.

Since the diodes face opposite directions only one of them will conduct behaving as a rectified waveform and oscillator

$$T = 2R_F C \ln\left(1 + \frac{2R}{R}\right) \rightarrow \text{Time period}$$

Half of waveform $\Rightarrow R_F = 2k\Omega$

$$T = 2 \times 2000 \times 0.1 \times 10^{-6} \times \ln(1+2000)$$

$$T = 3.04 ms$$

other half $= R_F = 1k\Omega$

$$T = 2 \times 1000 \times 0.1 \times 10^{-6} \ln(1+2000)$$

$$T = 1.52 ms$$

Q10) ii) $R_1 = R_2 = 2k\Omega$

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repeating above,

when

$R = 2k\Omega$

$T = 3.04ms$

and,

since both $R = 2k\Omega$,

$T_{total} = (3.04)2 = \underline{6.08ms}$