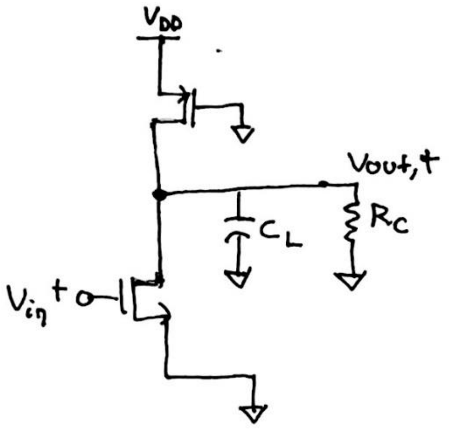
EE618 – Assignment3 – Solutions

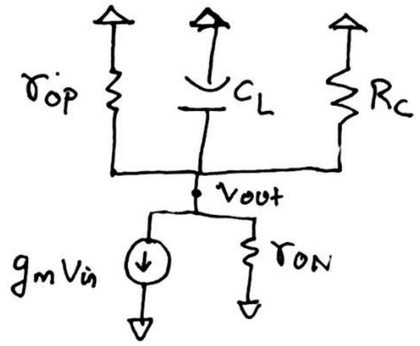
Q-1 Hand Calculations

- Node V_x will be ac ground due to differential operation.
- Drain node of M7 will also be at ac-ground.

1) Half Circuit:



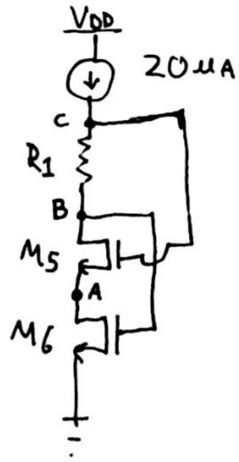
SMALL SIGNAL CKT



2) Gain = $g_{mn} \cdot [\, r_{ON} \parallel r_{OP} \parallel R_C \,]$

3) Bandwidth $\cong \dfrac{g_{out}}{C_L} = \dfrac{1/r_{ON} \parallel r_{OP} \parallel R_C}{2\pi \cdot C_L}$

4)



i) Taking Vdsat, M6 = 200mV

ii) Taking Vdsat, M5 = 150 mV

(Since Vdsat, M5 = Vdsat, M3, lower Vdsat, M5 will result in higher value of g_{m3}).

iii) Now

$V_C = V_A + V_{Tn} + V_{dsat\,M5}$

$V_B = V_{TN} + V_{dsat\,M6}$

Since $R_1 = \dfrac{V_C - V_B}{20\mu A}$, value of R_1 depends on V_A.

For M6 to remain in saturation, $V_A > V_{dsat\,M6}$

Taking $V_A = 0.45\,V$

~~iii)~~ iv) Now $R = 0.4V / 20\mu A = \underline{20 k\Omega}$

v) Now using the equation : $\left(\frac{W}{L}\right) = \frac{I_D}{V_{dsat}^2} \cdot \frac{2}{k_n}$

$W_5 = 1.2\ um$; $W_6 = 1.9\ um$

Since finger width = 0.5um → W_5 is taken $\underline{1um}$

W_6 is taken $\underline{2um}$

vi) Since $\frac{I_{d,M7}}{I_{d,M6}} = \frac{W_{M7}}{W_{M6}}$, W_{M7} will decide tail current.

Since Bandwidth $\propto I_{M7}$, we use B/W expression to find W_{M7}.

$$B/W = \frac{1}{(r_{ON} \| r_{OP} \| R_C) \cdot C_L \cdot 2\pi} \cong \frac{1}{(r_{ON} \| r_{OP}) \cdot C_L \cdot 2\pi} > 40MHz.$$

[We can ignore $R_C = 500k\Omega$ as r_{ON} & $r_{OP} \ll R_C$ (500kΩ) typically]

$$\Rightarrow \frac{I_{d,M7}}{2} \cdot \frac{(\lambda_n + \lambda_p)}{2\pi \cdot C_L} > 40 \times 10^6$$

$\Rightarrow I_{d,M7} > 420\mu A \Rightarrow$ Taking $\underline{I_{d,M7} = 400\mu A}$

[Power Dissipation $\cong (0.4) \times 1.8$ mW $= 0.7$ mW < 1.2mW]

$$\therefore \frac{W_7}{W_6} = \frac{400\mu A}{20\mu A} = \underline{20} \Rightarrow \underline{W_7 = 40\mu m}.$$

5) Replacing the values in gain expression :

$$Gain \cong g_{m3} \cdot [r_{OP} \| r_{ON}] = \cancel{\frac{2 \cdot (I_7) / V_{sat7}}{I}}$$

$$= \frac{2 \times I_{d3} / V_{sat3}}{I_{d3} [\lambda_n + \lambda_p]} = \frac{2}{(0.15\ v)[0.36\ v^{-1}]} = 37$$

$= \underline{31\ dB} > (20\ dB$ specification$)$

The only specification to be satisfied are $V_{out,+}$ DC voltage should lie b/w 0.9 - 1.1V &

V_{out} voltage Headroom > 0.4V

→ V_{out}, headroom is the max. output swing possible while keeping all transistors in sat.

⇒ $V_{out,Headroom} = V_{out,max} - V_{out,min} > 0.4\,V$

$= (V_{DD} - V_{dsat,1}) - (V_{dsat,3} + V_{source,M3})$

$= 1.8 - V_{dsat,1} - (0.45 + 0.15) = 1.2 - V_{dsat,1} > 0.4V$

⇒ $\underline{V_{dsat,1} < 0.6\,V}$ ⇒ $\underline{V_{dsat} \text{ of } M1 < 0.6V}$.

→ Now $V_{out,CM}$ or DC value of $V_{out,p} = V_x$

$= V_{DD} - V_{SG,M1} = V_{DD} - V_{dsat1} - V_{tp}$

$= 1.3 - V_{dsat1}$ should be > 0.9 & < 1.1V

$\underline{\text{Choosing } V_{out,CM} = 1V}$ ⇒ $\underline{V_{dsat,1} = 0.3V}$.

Using Eq^n $\left(\frac{W}{L}\right) = \frac{I_d}{V_{sat}^2} \times \frac{2}{k_n}$, $W_{M1} = \underline{8um}$.

Now, $\frac{W_{M3}}{W_{M5}} = \frac{I_{M3}}{I_{M5}} = \frac{200uA}{20uA} = 10$ ⇒ $\underline{W_{M3} = 10um}$

Calculated Values

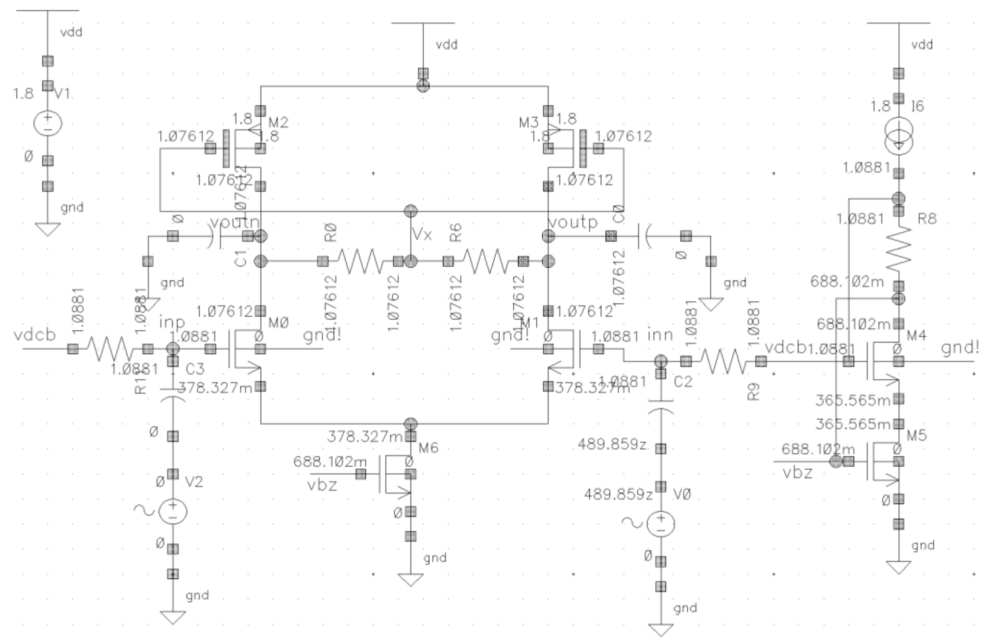
Parameter	Value
W1	8 um
W2	8 um
W3	10 um
W4	10 um
W5	1 um
W6	2 um
W7	40 um
R1	20 KΩ

Simulation Based Questions:

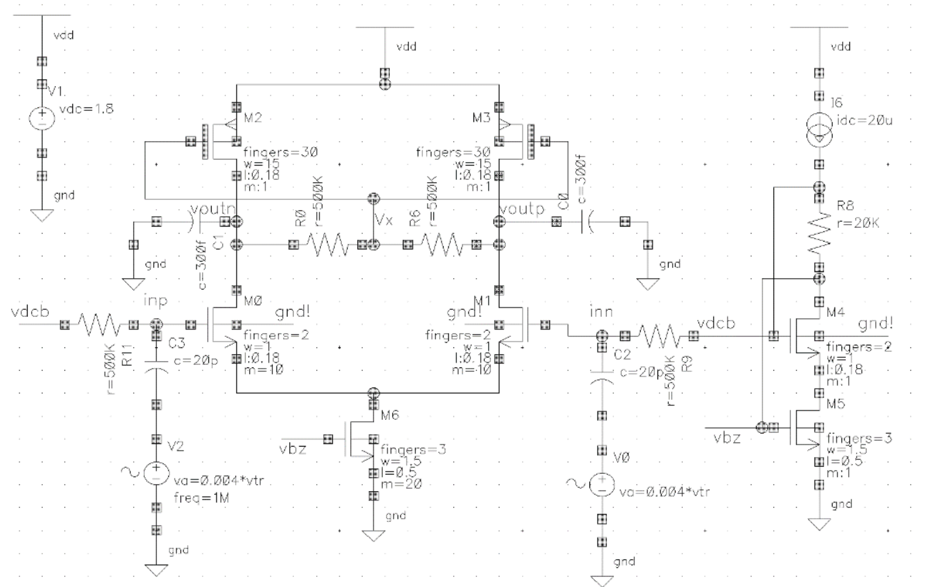
To obtain Vout,p as 1 V, W1 and W2 were increased to 15 um

To get a Vdsat,M6 = 200 mV, W6 was reduced to 1.5 um. Accordingly, W7 was reduced to 30 um

1. **Schematic with annotated Node Voltages:**



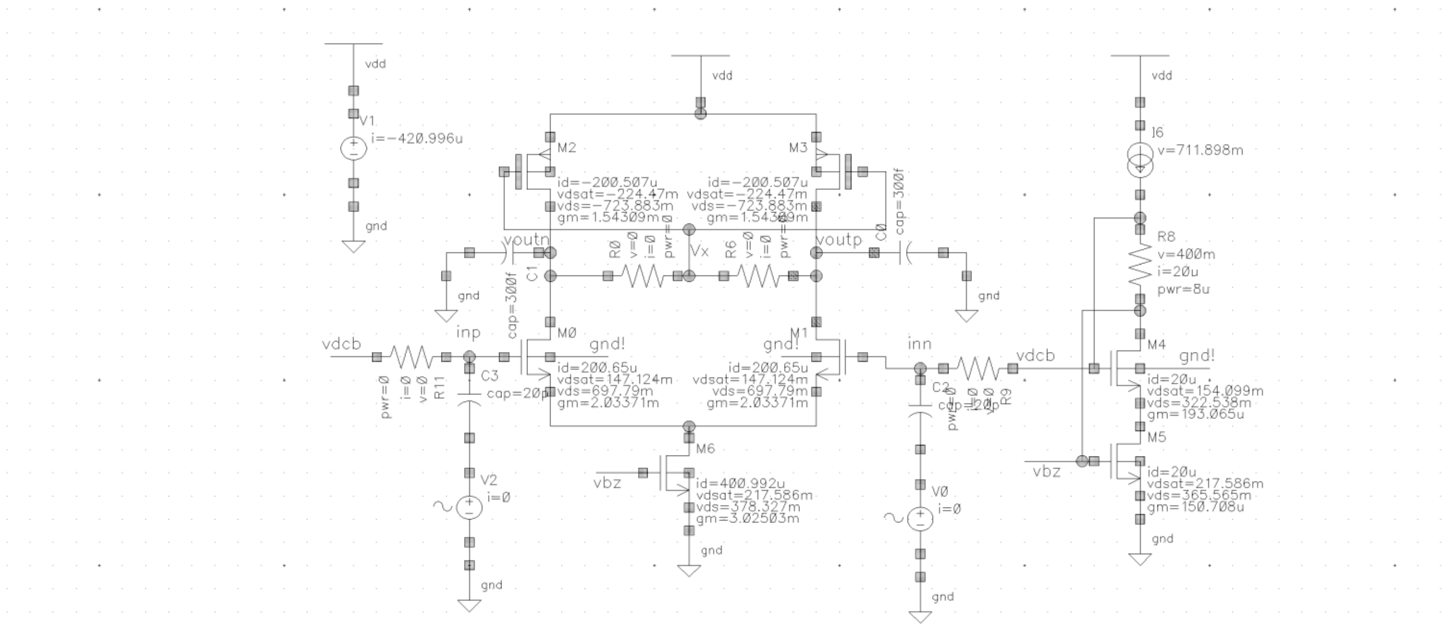
2. **Transistor Sizing:**



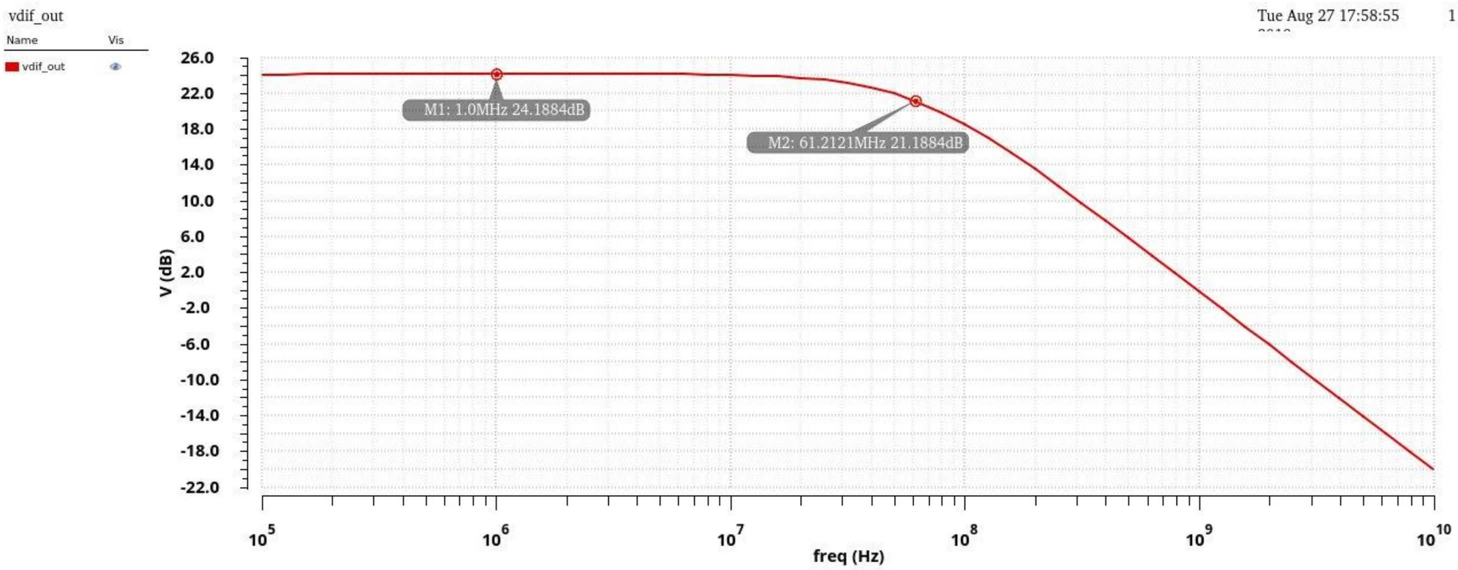
Transistor Sizing:

	Vdsat (V)	W (um)	Multipliers	No of fingers
M1	**0.224**	**15 um**	**1**	**30**
M2	**0.224**	**15 um**	**1**	**30**
M3	**0.142**	**1 um**	**10**	**2**
M4	**0.142**	**1 um**	**10**	**2**
M5	**0.154**	**1 um**	**1**	**2**
M6	**0.217**	**1.5 um**	**1**	**3**
M7	**0.217**	**1.5 um**	**20**	**3**
R1 value:	**20 KΩ**			

3. DC Operating Points:



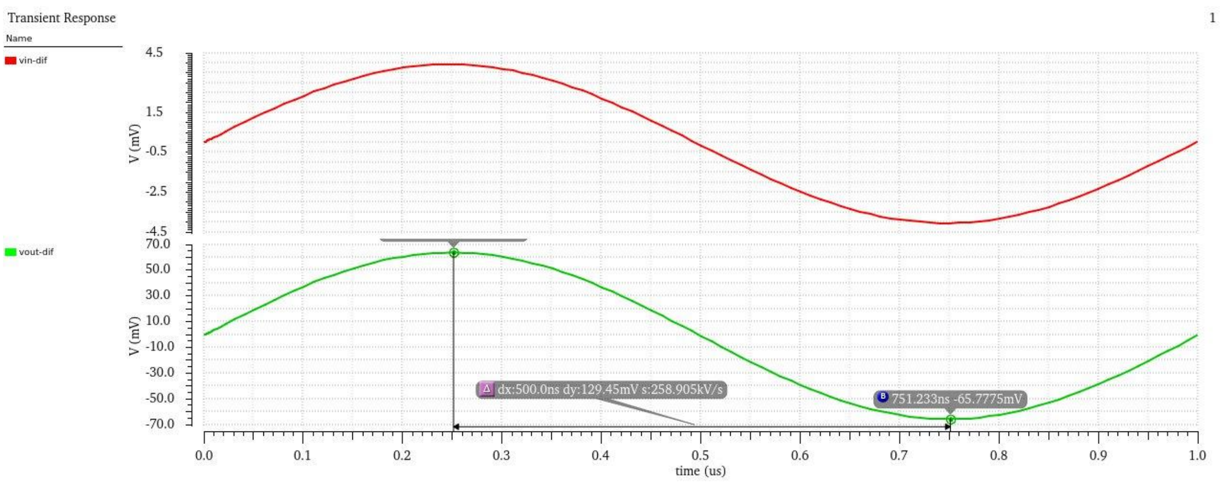
4. AC Plot:



DC Gain: 24.2 dB

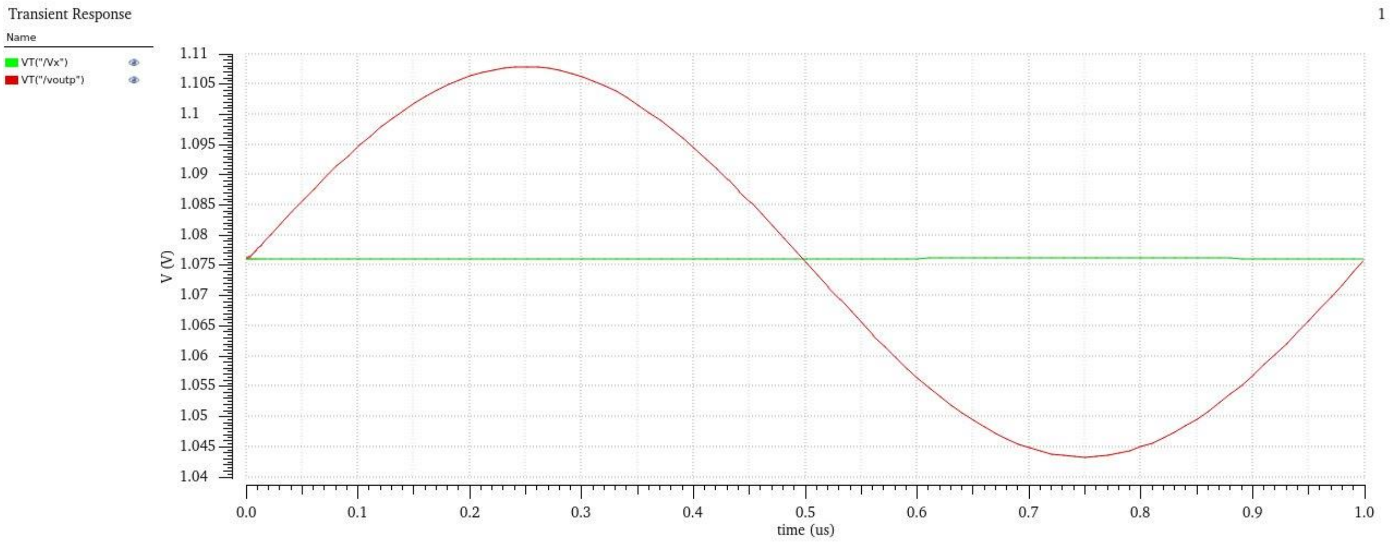
3dB Bandwidth: 61.2 MHz

5. Transient Pot:



Vout pk-pk = 127.45 mV

Voutp and Vx:



This shows Vx is at ac ground.

Parameter	Value Obtained	Specification
DC Power Consumption	0.76 mW	< 1.2 mW
Vout+ DC voltage	1 V	0.9 – 1.1 V
Differential Gain	24.2 dB	>20 dB
Vout Bandwidth	61 MHz	>40 MHz