Dept. of Electronics and Electrical Communication Engineering
Indian Institute of Technology Kharagpur

VLSI DESIGN LABORATORY(EC69216)

Title:

TWO-STAGE OP AMP

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Objective:

Design and Analysis of TWO STAGE- Differential Amplifier for the given specifications.

- Vdd = 1.8V
- Av >= 1000, 60dB
- Phase Margin>=60^0
- CL = 2pF
- ICMR (+) = 1.6V
- ICMR (-) = 0.8V
- Slew Rate = 20V/usec
- Power dissipation < 0.3 mW
- GBW >= 30MHz

Introduction:

- A two-stage differential amplifier is a type of electronic amplifier that amplifies the difference between two input signals while suppressing any voltage common to both inputs.
- A two-stage amplifier can provide high gain and high output swing. The first stage is a differential amplifier, an Analog circuit with two inputs (Vin+ and Vin-) and one output (Vout), which is proportional to the difference between the two inputs. The second stage is a Common Source Amplifier.

Two-Stage Configuration:

- In a two-stage differential amplifier, two operational amplifiers (op-amps) are used in sequence. The first stage is typically a non-inverting amplifier, and the second stage is a differential amplifier. This configuration increases the gain and input resistance of the amplifier.

First Stage: Non-Inverting Amplifier:

- The first stage amplifies the input signal without inverting it. The gain of this stage is determined by the feedback resistors used in the circuit. The output of the first stage becomes the input for the second stage.

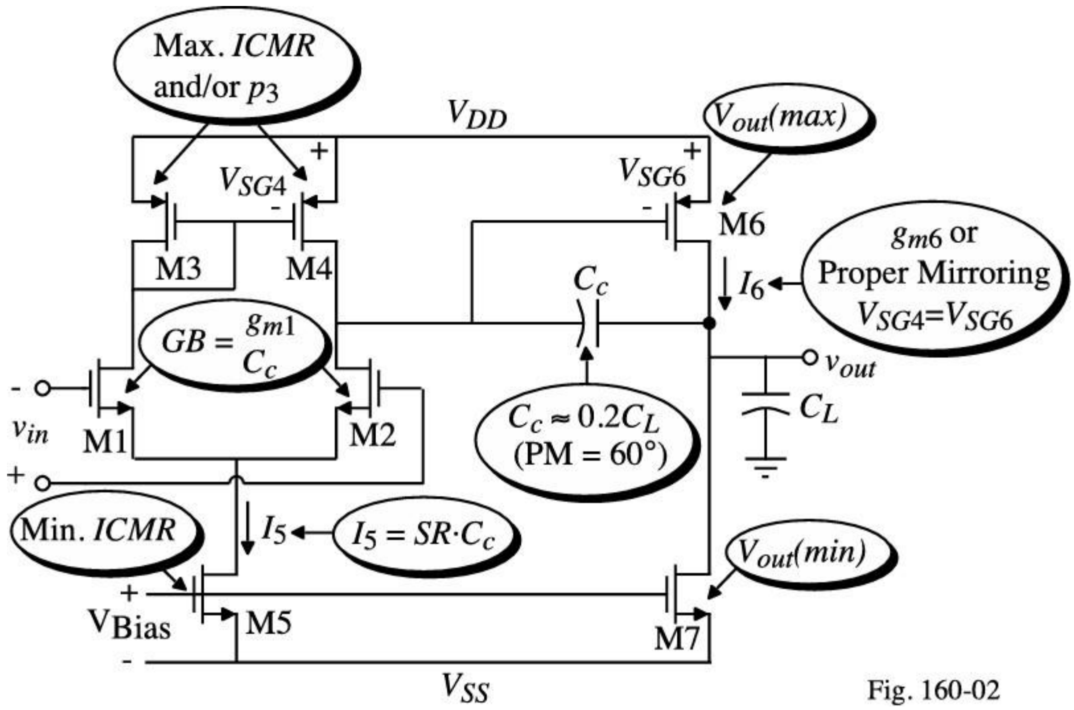


Fig. 160-02

BIAS is done by the current mirror circuit

- Gain of the differential amplifier is the product of transconductance of M1 and Rout $A_d = g_{m2} \{ r_{ds2} \| r_{ds4} \}$
- While that of CS stage is $A_v = g_{m6} \{ r_{ds6} \| r_{ds7}$

Circuit Diagram:

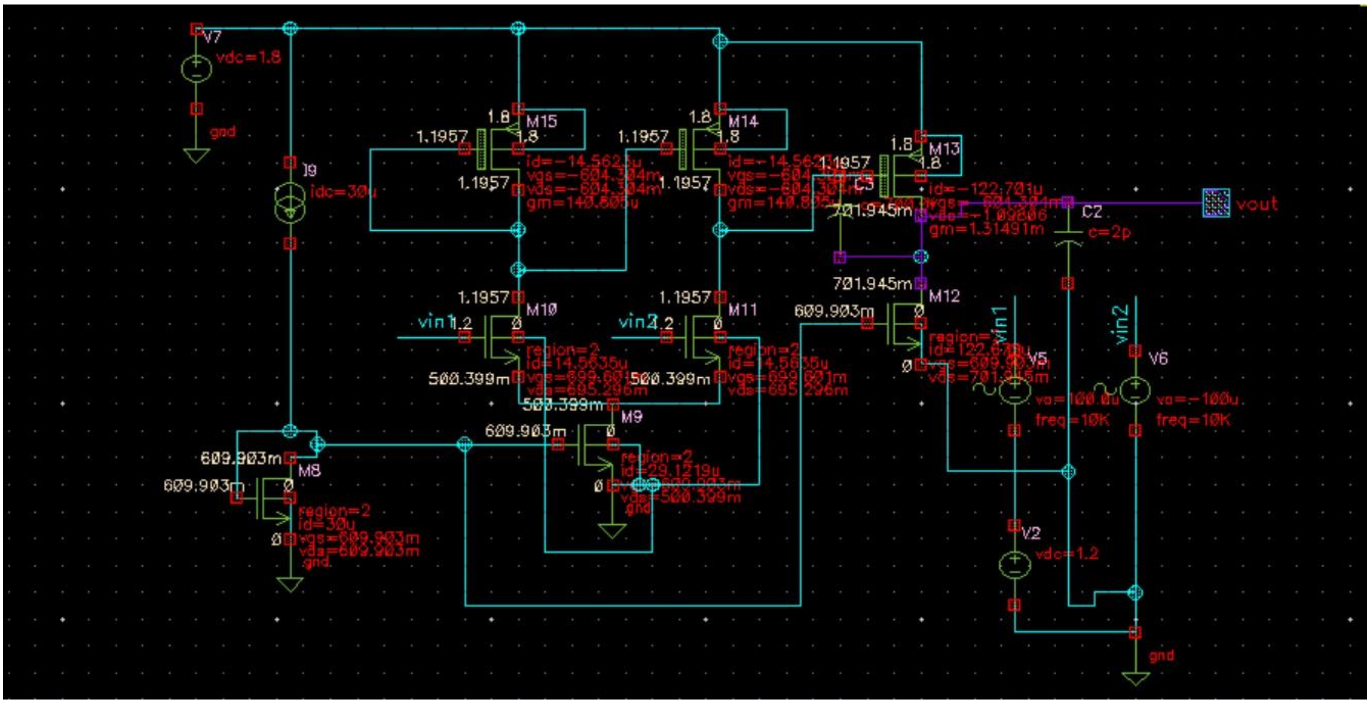


Figure: 2-stage differential amplifier

Plots:

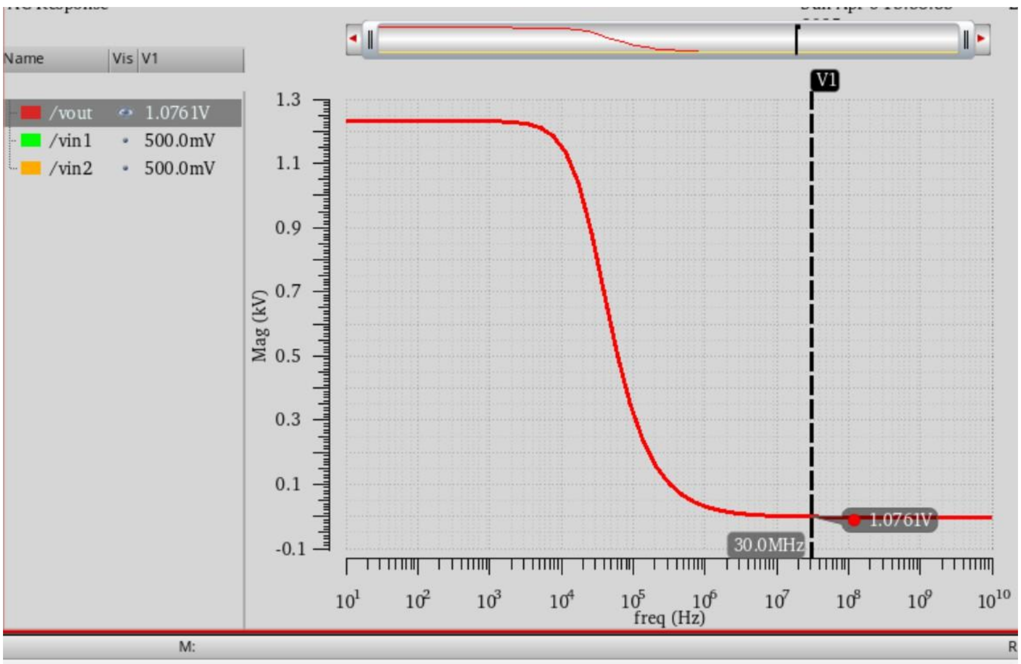


Figure: GAIN PLOT FOR DIFFERENTIAL MODE

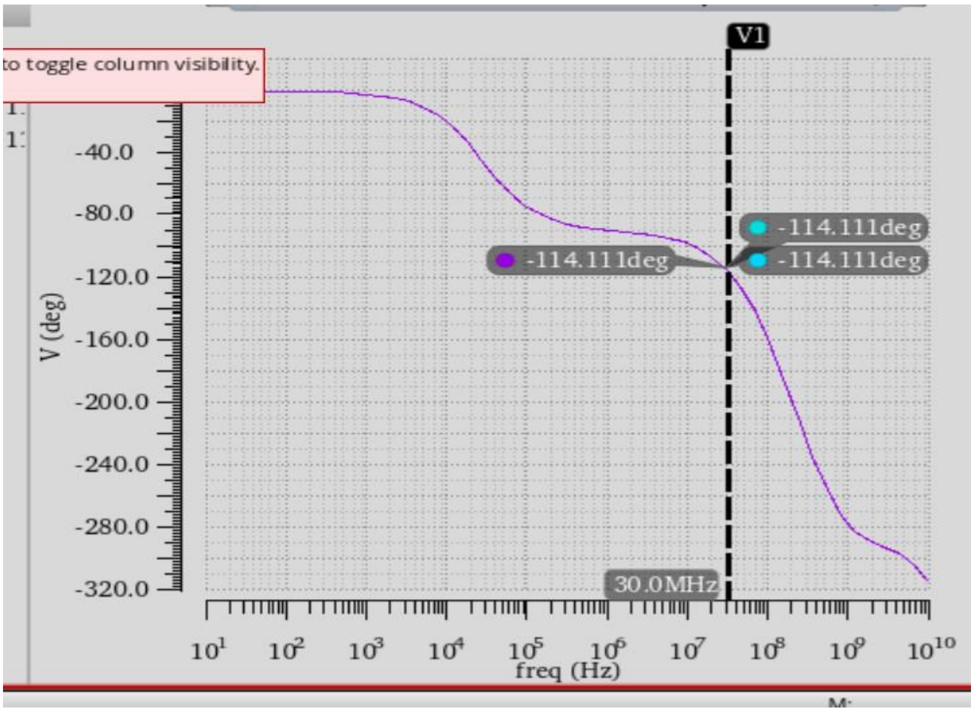


FIGURE: PHASE PLOT FOR DIFFERENTIAL MODE

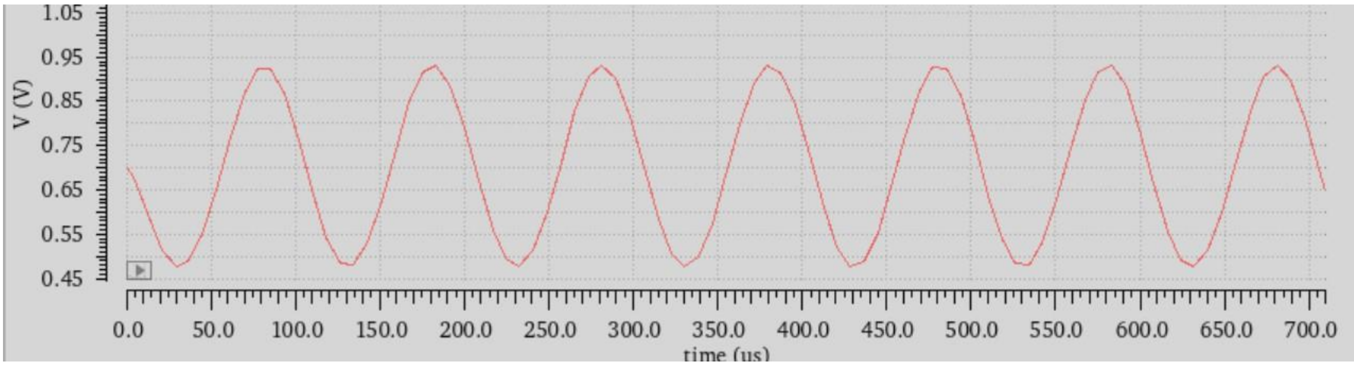


FIGURE:TRANSIENT ANALYSIS

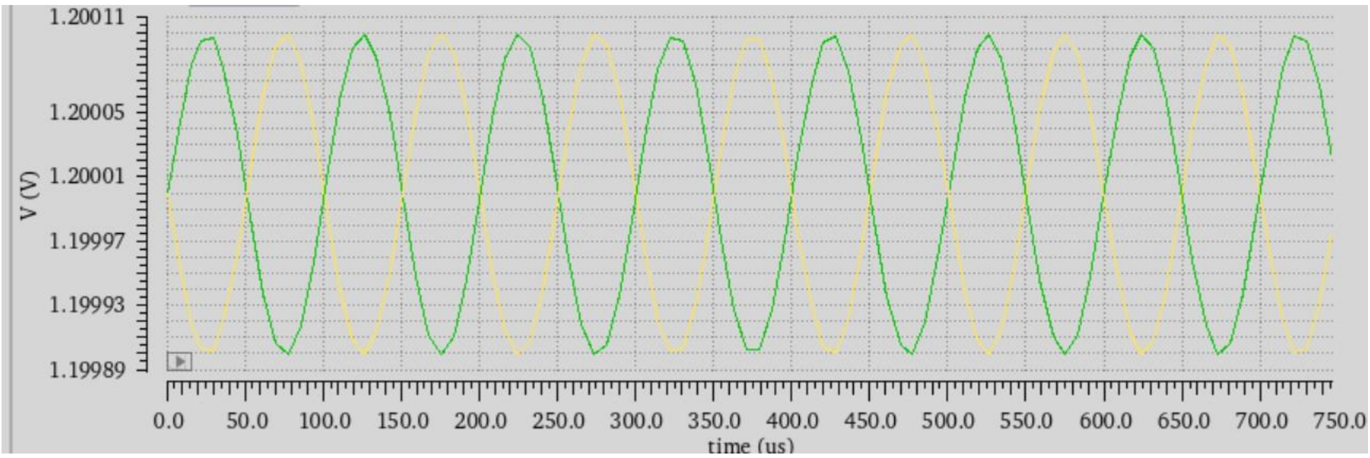


FIGURE:TRANSIENT ANALYSIS FOR VIN AS DIFFERENTIAL MODE

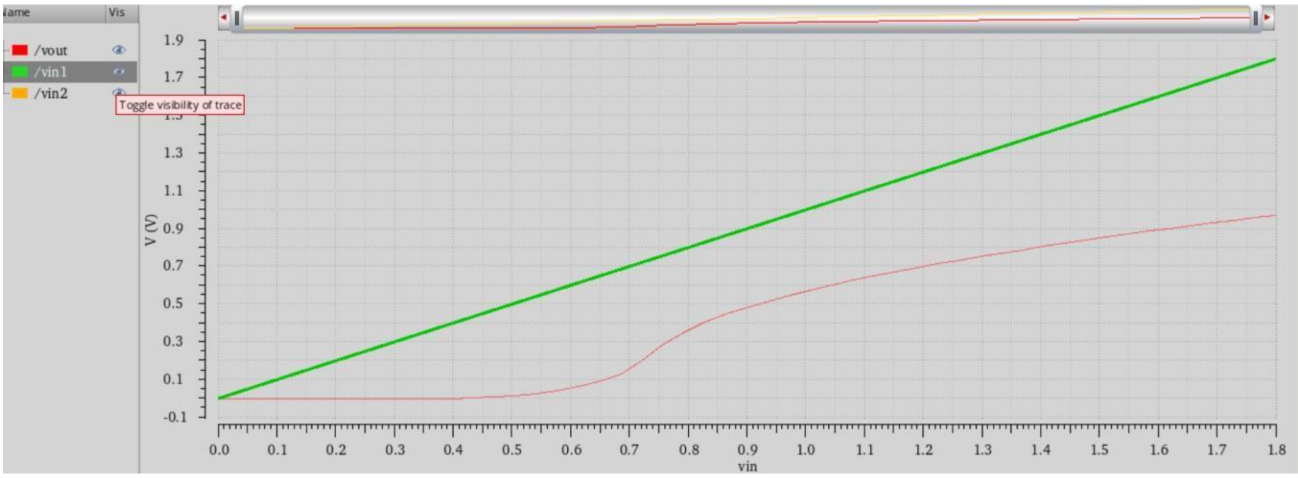


Figure: DC ANALYSIS

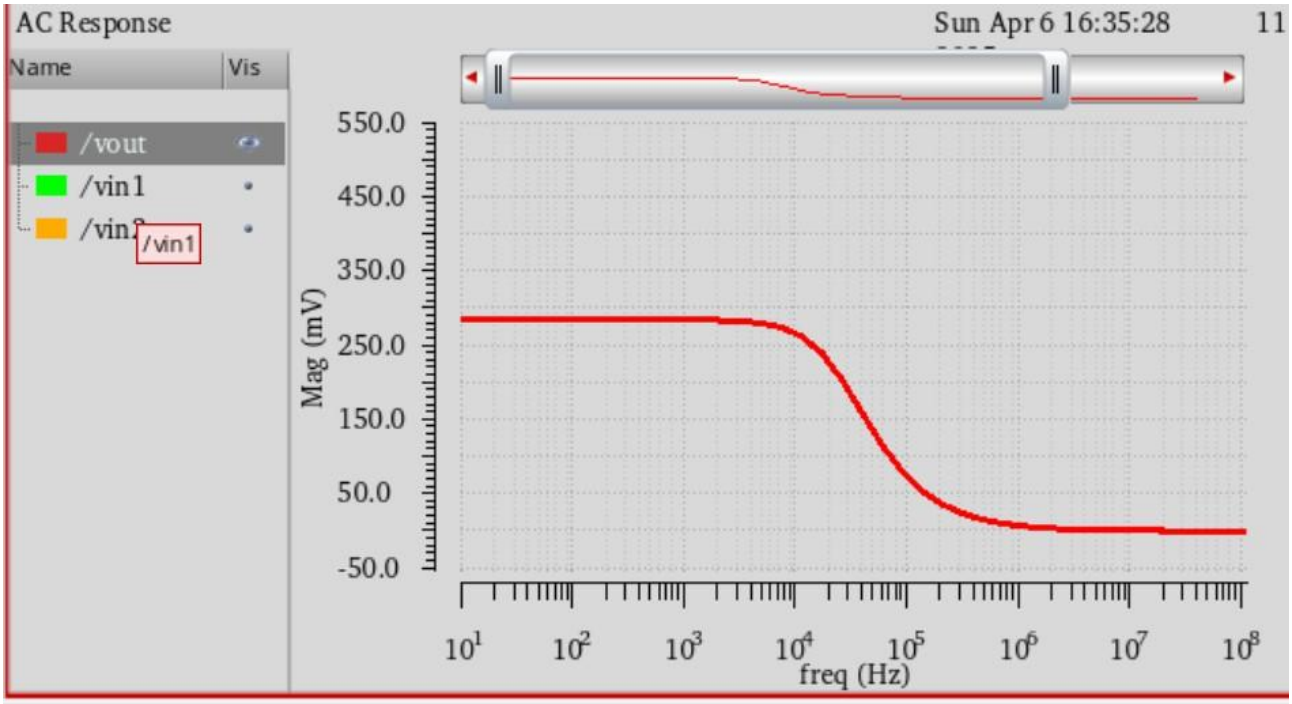


Figure: COMMON MODE GAIN

Results and Calculations:

From the circuit diagram, the theoretical and practical values are

• **Parameter**	• **Theoretical**	• **Practical**
• (W/L)9	• 2.1/0.2	• 2.1/0.2
• (W/L)8	• 2.1/0.2	• 2.1/0.2
• (W/L)10	• 1.6/0.2	• 1.8/0.4
• (W/L)11	• 1.6/0.2	• 1.8/0.4
• (W/L)15,14	• 2.6/0.2	• 6/0.4
• (W/L)13	• 2.6*8/0.2	• 3*8/0.2
• (W/L)12	• 2.1*4/0.2	• 2.1*4/0.2
• Cc	• 0.7p F	• 0.7p F
• I tail	• 30u A	• 29.129u A

Gm1	131.85u	158.138u
Gm2	1.048m	1.32902m

Calcualtions:

Date / /

$K_n = 140\mu A/V^2$, $K_p = 55\mu A/V^2$, $V_{th,n} = 0.5V$ $V_{thp} = 0.47$

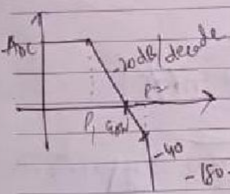
$z = \frac{g_{m2}}{C_c}$ $\quad$ $GBW = DC_{gain} \times P_1$

$P_1 = \frac{1}{g_{m2} R_1 R_2 C_c}$ $\quad$ $= \frac{g_{m1} R_1 g_{m2} R_2}{g_{m2} R_2 R_1 C_c}$

$P_2 = \frac{g_{m2}}{C_L}$ $\quad$ $GBW = \frac{g_{m1}}{C_c}$

$A_{DC} = g_{m1} R_1 g_{m2} R_2$ $\quad$ slew rate $= \frac{I_0}{C_c}$

Phase margin: $z \geq 10 \cdot GBW$



$\angle \frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{\omega}{z}\right) - \tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$

find phase at GBW:

$-180 + PM = \tan^{-1}\left(\frac{1}{10}\right) - \tan^{-1}(ADC) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$

$PM = 60° \Rightarrow \tan(24.29) = \frac{GBW}{P_2}$

$P_2 \geq 2.2\, GBW$

$\frac{g_{m2}}{C_L} \geq 2.2 \frac{g_{m1}}{C_c}$ $\quad$ (we assume zero $= 10 \cdot GBW$)

$g_{m2} = 6 g_{m1}$

$C_c \geq 0.22 C_L$

$C_L = 2pF$

$C_c > 0.44pF$

$\boxed{C_c = 500fF}$

$GBW = \frac{g_{m1}}{C_c} \geq 30 \times 10^6 \times 2\pi$

$\frac{g_{m1}}{500 \times 10^{-15}} \geq 30 \times 10^6 \times \pi$ $\quad$ $\boxed{\beta = K_n W/L}$

$g_{m1} \geq 94 \times 10^{-6} \times 2\pi \Rightarrow \sqrt{2 K_n \times \frac{W}{L} \frac{I_t}{2}} = 94 \times 10^{-6} \times 2\pi$

power $\Rightarrow$ $I_{total} \times 1.8 < 0.3mW$

$I_{total} < 166\mu A$

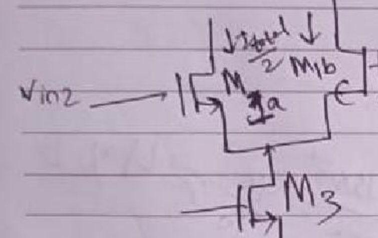
slew rate $\Rightarrow$ $\frac{I_{tot}}{C_c} \geq 20/10^{-6}$

$I_{total} \geq 14 \times 10^{-6}$

$\therefore I_{total} = 30 \mu A$

$ICMR^{(+)} = 0.8 \Rightarrow V_{gs_{M_1}} - V_{th,n} = \sqrt{\dfrac{2 I_{tot}}{2 \times \beta_{M_1}}}$

$\beta_{M_1} = k_n \left(\dfrac{W}{L}\right)_{M_1} = 140 \times 10^{-6} \times \dfrac{W}{L}$



for $ICMR^{(-)}$

$V_g = 0.8, \; V_s = (V_{dsat})_{M_3}$

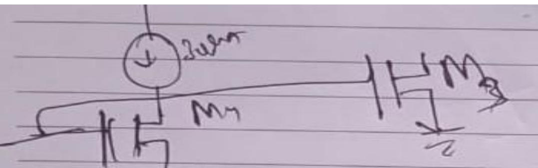
$0.3 - \sqrt{\dfrac{I_{total}}{\beta_{M_1}}} = (V_{dsat})_{M_3}$

from $g_{m_1} \Rightarrow \sqrt{\beta I_t} = 2\pi \times 10^{-6} \times 4\pi$

$(V_{dsat})_{M_3} = 0.3 - \dfrac{2\pi \times 10^{-6} \times 4\pi}{\beta_{M_1}} = 0.3 - \dfrac{15 \times 10^{-6}}{3.75 \times 10^{-6} \times 4\pi^2} \approx 0.2 \approx \boxed{V_{gs_{M_3}} - V_{th}}$

$\beta_{M_1} = \dfrac{225 \times 10^{-12} \times 4\pi^2}{30 \times 10^{-6}} = 3.75 \times 10^{-6} \times 4\pi^2 \times 2$

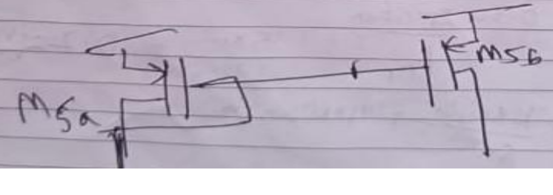
$10^{-6} \times \left(\dfrac{W}{L}\right)_{M_1} \times 70 \times 0.2^2 = 30 \mu A$



$\boxed{\left(\dfrac{W}{L}\right)_{M_4} = \dfrac{30}{70 \times 0.04} = 10.714}$

$\boxed{\left(\dfrac{W}{L}\right)_{M_3} = 10.7}$

$\left(\dfrac{W}{L}\right)_{M_1} = \dfrac{\beta}{k_n} = \dfrac{4\pi^2 \times 15 \times 10^{-6}}{150 \times 10^{-6}} = \dfrac{4\pi^2}{10} \approx 4 \times 2$



Considering ICMR$^+$ $\Rightarrow$ $V_{dM_1} > V_{gM_1} - V_{th}$

$$V_{dsat} + V_{th} = V_{gM_1}$$

$$(V_{in})_{max} = V_{d_1} + V_{th}$$

$$(V_{in})_{max} = V_{dd} - V_{sg_5} + V_{th} \Rightarrow \boxed{V_{sg_5} = 0.67}$$

$$I_5 = \frac{\beta_{M5}}{2}(V_{sg} - 0.47)^2$$

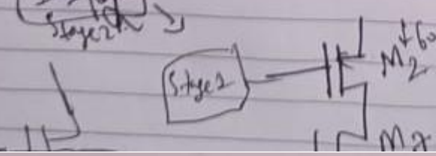
$$15 \times 10^{-6} = \frac{55 \times 10^{-6}}{2}\frac{W}{L}(V_{sg} - 0.47)^2$$

$$\left(\frac{W}{L}\right)_{M5} = \frac{(30/2)}{55 \times (0.2)^2} = 13.27$$

Now for Stage '2' $\Rightarrow$ Power $10^{-6} \times 30 \times 1.8 + 1.8 \times I \leq 0.3\text{mW}$

$$\boxed{I \leq 190}$$

$\boxed{I = 90}$ Stage 2



for a $\frac{W_{M_2}}{L} = \left(\frac{W}{L}\right)_{M_5} \times 90$

$$\boxed{\left(\frac{W}{L}\right)_{M_7} = \left(\frac{W}{L}\right)_{M_3} \times 4}$$

bcoz $I_{M_7} = 90$