specifications:-

DC Gain = 1000 = 60dB

GBW = 50 MHz

PM ≈ 60°

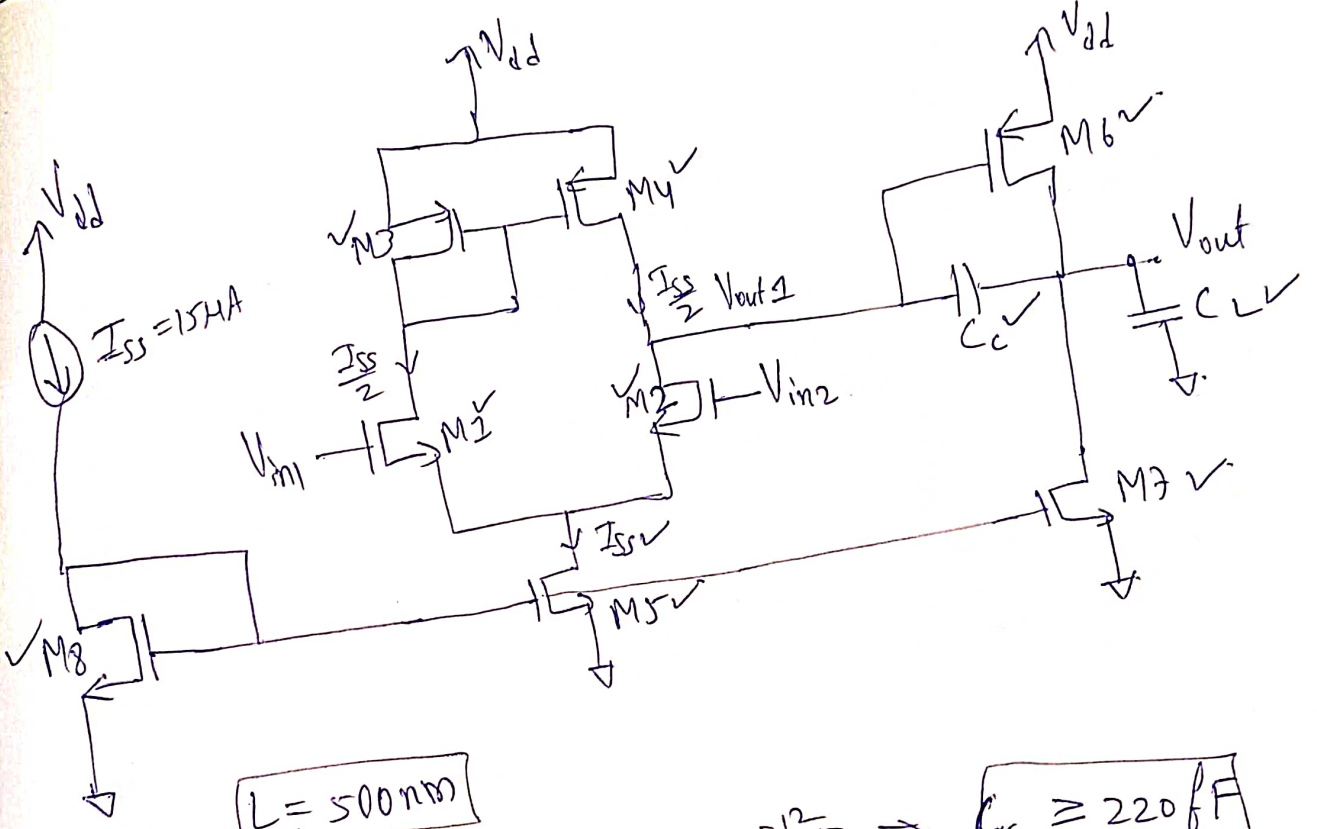
slew rate = $30 \frac{V}{\mu sec}$

$C_L = 1\,pF$

Power = 400 μW

ICMR(+) = 1.6V

ICMR(-) = 0.8V




L = 500nm

$\rightarrow C_c \geq 0.22 C_L \Rightarrow C_c \geq 0.22 \times 10^{-12} F \Rightarrow C_c \geq 220\,fF$

$C_c = 500\,fF$

$\rightarrow I_{ss} = C_c SR \Rightarrow I_{ss} = 500 \times 10^{-15} \times 30 \times 10^{6} = 15 \times 10^{-6} = 15\mu A$

$\Rightarrow I_{ss} = 15\mu A$

M1, M2:-

$\rightarrow (GBW)_\omega = \frac{g_{m1}}{C_c} \Rightarrow 2\pi \times (GBW)_f \times C_c = g_{m1} = 2\pi \times (50 \times 10^6) \times 500 \times 10^{-15} \frac{F}{S}$

$g_{m1} = 157.142\,\mu\frac{F}{S} \rightarrow g_{m1} = 160\mu = g_{m2}$

$V_d - V_g + V_s$
$-V_s$
$V_{ds} - (V_g)$

$$g_{m1} = \sqrt{2\beta I_1} \Rightarrow \frac{g_m^2}{2I_1} = \mu_n C_{ox} \left(\frac{W}{L}\right)_{1,2}$$

$$\Rightarrow \left(\frac{W}{L}\right)_{1,2} = \frac{160 \times 160 \times 10^{-12}}{15 \times 10^{-6} \times 310 \times 10^{-6}} = 5.505 \Rightarrow \boxed{\left(\frac{W}{L}\right)_{1,2} = 6}$$

For M3, M4 :

$$V_{dd} - V_{in1} = V_{sd3} + V_{dg1}$$

$$V_{dg} = V_{ds} + V_{sg}$$
$$V_{dg} = V_{ds} - V_{gs}$$

$$V_{dd} - V_{in1} = V_{sd3} + V_{ds1} - V_{gs1}$$

For M1 in Saturation:

$$V_{ds1} \geq V_{gs1} - V_{t1}$$
$$V_{ds1} - V_{gs1} \geq -V_{t1}$$

$$\Rightarrow V_{dd} - V_{in1} - V_{sd3} \geq -V_{t1}$$

$$\Rightarrow V_{in1} \leq V_{dd} - V_{sd3} + V_{t1}$$

$V_{t3,max} = 510\,mV$
$V_{t1,min} = 470\,mV$

$$I_{(MR(+)} = V_{dd} + V_{t1,min} - V_{sd3,max}$$

$$I_{(MR(+)} = V_{dd} + V_{t1,min} - V_{t3,max} - \sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)}}$$

$$\sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)_{min}}} = V_{dd} + V_{t1,min} - V_{t3,max} - I_{(MR(+)} \sqrt{\frac{2I_3}{\mu_p C_{ox}\left(\frac{W}{L}\right)}}$$

$$= 1800m + 470m - 510m - 1600m$$
$$200m - 40m \quad 160m$$

$$15 \times 10^{-6} = 160 \times 160 \times 10^{-6} \times 60 \times 10^{-6} \times \left(\frac{W}{L}\right)_{3,min}$$

$$\left(\frac{W}{L}\right)_{3,min} = \frac{15 \times 10^{-6}}{160 \times 160 \times 60} = 9.765$$

$$\Rightarrow \left(\frac{W}{L}\right)_3 \geq 9.765$$

$$g_{m3} = \sqrt{2 \times \mu_p C_{ox} \times \left(\frac{W}{L}\right)_3 \times I_D} = \sqrt{15 \times 10^{-6} \times 60 \times 10^{-6} \times 12}$$

$$\boxed{\left(\frac{W}{L}\right)_{3,4} = 12}$$

$$= 10^{-6} \times \sqrt{15 \times 12 \times 60}$$

$$\boxed{g_{m3} = 103.92\,\mu}$$

$L_{min} = 0.5\mu$

For M5, M8 :

$V_{in1} = V_{gs1} + V_{ds5}$

$V_{ds5} \geq V_{gs5} - V_{t5}$

$V_{in1} - V_{gs1} \geq V_{gs5} - V_{t5}$

$V_{in1} \geq V_{gs1} + V_{gs5} - V_{t5}$

$V_{t1,max} = 590mV$

$$ICMR(-) = (V_{gs1} + V_{gs5} - V_{t5})_{max} = V_{t1,max} + \sqrt{\frac{I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} + V_{t5,max} + \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{5,min}}} - V_{t5,min}.$$

(or)

$$ICMR(-) = V_{gs1,max} + \underbrace{(V_{gs5} - V_{t5})_{max}}_{\Downarrow V_{ds5}} = V_{t1,max} + \sqrt{\frac{I_{SS}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}} + V_{ds5}$$

$800m - 590m - \sqrt{\frac{15\times10^{-6}}{310\times10^{-6}\times 6}} = V_{ds5}$ (210m)

$V_{ds5} = 210m - 89.8m = 120.2m$

$$I_{SS} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_5 (V_{gs} - V_t)^2 \Rightarrow \frac{2I_{SS}}{\mu_n C_{ox}} = \left(\frac{W}{L}\right)_{5,min} \times (V_{gs} - V_t)^2_{max}$$

$$\Rightarrow \left(\frac{W}{L}\right)_{5,min} = \frac{2\times15\times10^{-6}}{310\times10^{-6}} \times \frac{1}{(V_{ds5})^2} = \frac{30}{310} \times \frac{10^6}{(120.2)^2} = 6.698$$

$$\left(\frac{W}{L}\right)_5 \geq 6.698 \Rightarrow \boxed{\left(\frac{W}{L}\right)_{5,8} = 8}$$

For M6 :

$g_{m6} \geq 10 g_{m1} \Rightarrow g_{m6} = 10 g_{m1} = 1600\mu$

$V_{gs,3} = V_{gs,4} \approx V_{gs,6} \Rightarrow \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \frac{I_6}{I_4}$

$$I_p = \frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)(V_{ns}-V_t)^2 \quad , \quad g_m = \mu_p C_{ox}\left(\frac{W}{L}\right)(V_{ns}-V_t).$$

$$\Rightarrow \frac{g_{m6}}{g_{m4}} = \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} \Rightarrow \left(\frac{W}{L}\right)_{6,min} = \frac{1600\mu \times 12}{g_{m4}}$$

$$g_{m4} = \sqrt{2\beta I} = \sqrt{2 \times \mu_p C_{ox} \times \left(\frac{W}{L}\right)_4 \times 7.5\times10^{-6}} = \sqrt{15\times10^{-6}\times 60\times10^{-6}\times 12}$$

$$= 10^{-6} \times \sqrt{10800} = 103.923 \times 10^{-6}$$

$$\boxed{g_{m4} = 104\mu}$$

$$\Rightarrow \left(\frac{W}{L}\right)_{6,min} = \frac{1600\mu \times 12}{104\mu} = 184.615$$

$$\boxed{\left(\frac{W}{L}\right)_6 = 190}$$

~~For M2~~ For M7 :

$$\frac{I_6}{I_4} = \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_4} = \frac{190}{12} \Rightarrow I_6 = \frac{190}{12} \times 7.5\times10^{-6}$$

$$\boxed{I_6 = 118.75\,\mu}$$

$$\frac{I_5}{I_7} = \frac{\left(\frac{W}{L}\right)_5}{\left(\frac{W}{L}\right)_7} \Rightarrow \frac{15\,\mu A}{118.75\,\mu A} = \frac{8}{\left(\frac{W}{L}\right)_7} \Rightarrow \left(\frac{W}{L}\right)_7 = \frac{8\times(118.75)}{15}$$

$$\left(\frac{W}{L}\right)_7 = 63.33 \Rightarrow \boxed{\left(\frac{W}{L}\right)_7 = 64}$$

~~M5~~, M5, M8 $\rightarrow \frac{4\mu}{0.5\mu}$ M6 $\rightarrow \frac{95\mu}{0.5\mu}$

M3, M4 $\rightarrow \frac{6\mu}{0.5\mu}$ M7 $\rightarrow \frac{32\mu}{0.5\mu}$

M1, M2 $\rightarrow \frac{3\mu}{0.5\mu}$

$32\mu \rightarrow 0.5$
$18.3\mu$

Result 1 : $[C_C = 250fF]$

PM ~~$\approx 52°$~~ (X), BW $\approx$ ~~53~~ MHz (X), Gain $\approx$ 64 dB (✓)

~~$\theta = -52°$~~ $\theta = -127°$.

PM = 53° (X).

~~PM = +180 + θ~~

Result 2 :

$[C_C = 230fF]$

$\theta \approx -130°$, BW = 57 MHz (X), Gain $\approx$ 64 dB (✓)

~~PM = +180 + θ~~ $\Rightarrow$ PM = $\theta + 180° = 180° - 130° = 50°$.

PM = 50° (X)

→ observed $g_{m1,2} = 117.7\mu$ → increased to $146\mu$ $\left[\text{New } \left(\frac{W}{L}\right)_{1,2} = \frac{8.5\mu}{0.5\mu}\right]$

→ observed $g_{m3,4} = 87.9\mu$ → ~~decrease~~ increased to $95\mu$ → then Gain drastically dropped to 42 dB, so got them back

→ For M5, M7, M8 → increased L to 1 μm, $\left(\frac{W}{L}\right)$ same → Gain increased by 3dB, from 65 dB to 68 dB.

⇒ BW increased

But PM ↓. (~45°)

→ So need to move P2 to right ⇒ $g_{m6}$ has to be increased.

$g_{m6} = \sqrt{2\beta I}$

limit reached.

→ can't go W beyond 100μ

→ tried with $L = L_{min} = 180nm$ → but $r_{o6}$ dropped and gain dropped to 20 dB.

→ When $C_L \rightarrow 15fF$ from 1pF

BW ↑, PM ↑ (~64°). (**).

→ ~~decrease~~ When $C_L \rightarrow 10fF$ from 200fF, BW ↑ to 190MHz, but PM (~30°)

with $C_L \rightarrow 15fF$

## After Tuning :-

→ For M5, M7, M8 → L = 1μm → $(\frac{W}{L})$ same → Because $g_{ds7}$ was high ⇒ Gain was low.

→ To increase BW → $I_{ss}$ = 20μA from 15μA.

→ For Good PM and BW → $C_c$ = 325fF

→ Obtained SR = $\frac{I_{ss}}{C_c} = \frac{20\mu A}{325fF} = 61.5 \frac{V}{\mu sec}$

→ **At Vin = ICMR(-) :-**

DC Gain = 67.5781 dB
Bandwidth = 53 – 54 MHz.
PM = 57.5568 deg

I = 19.01μA + 173.6μA
P = (192.61μA) × 1.8V
∴ P = 346.698μW

→ **At Vin = 1.2V :-**

DC Gain = 65.5928 dB
Band width = 56 – 57 MHz.
PM = 56.5794 deg

I = 20.232μA + 180.3μA
P = (200.53μA) × 1.8V
∴ P = 360.954μW

→ **At Vin = ICMR(+) :-**

DC Gain = 59.0958 dB
Band width = 55 – 56 MHz
PM = 57.434 deg.

I = 21.24μA + 185.1μA
P = (206.34μA) × 1.8V
∴ P = 371.412μW

53.3457 MHz
28.6412 mdB
54.5434 MHz
31.1331 mdB
55.5672 MHz
59.0958 dB
65.5928 dB

→ Average Power = $\frac{1079.064}{3}$ = 359.688 μW