EE223 Analog Integrated Circuits
Fall 2018

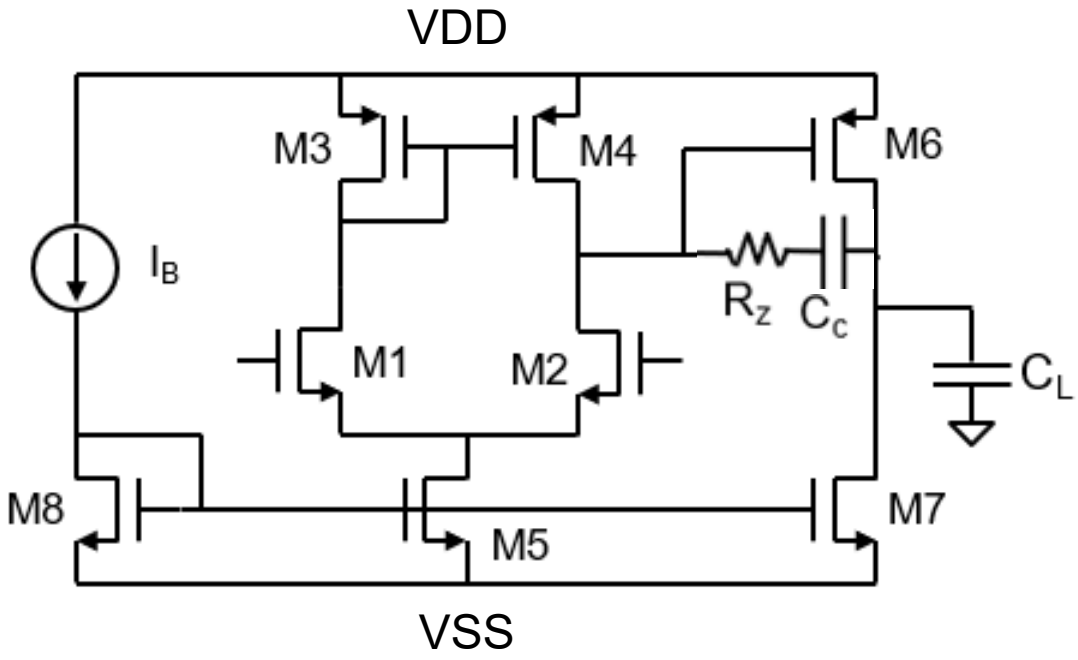
Homework #5 Hint

Sang-Soo Lee
Electrical Engineering Department
San Jose State University
sang-soo.lee@sjsu.edu

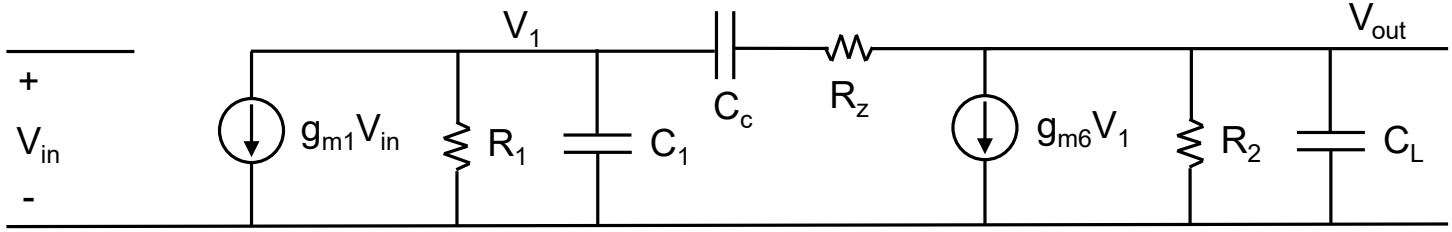
2-Stage OPAMP with RC compensation

Technology: 0.18um CMOS, VDD=1.8V, Lmin = 180nm
Target Spec:

- DC gain = 60dB
- GBW = 100MHz
- PM = 60^{o}
- Cload = 5pF



Small-Signal Model of the OPAMP



$Av = Av1\ Av2 = -g_{m1}R_1g_{m6}R_2$

$p1 \approx -1/(R_1g_{m6}R_2C_c)$

$p2 \approx -g_{m6}/C_L$ assuming C_L is very large compared to C_1 and C_c

$z = 1 / [(1/ g_{m6} - R_z)C_c]$

$GBW = Av \times p1 = g_{m1}/C_c$

$R_z = \frac{1}{g_{m6}} (1 + \frac{C_L}{C_c})$ to cancel p2 with z

Design Information

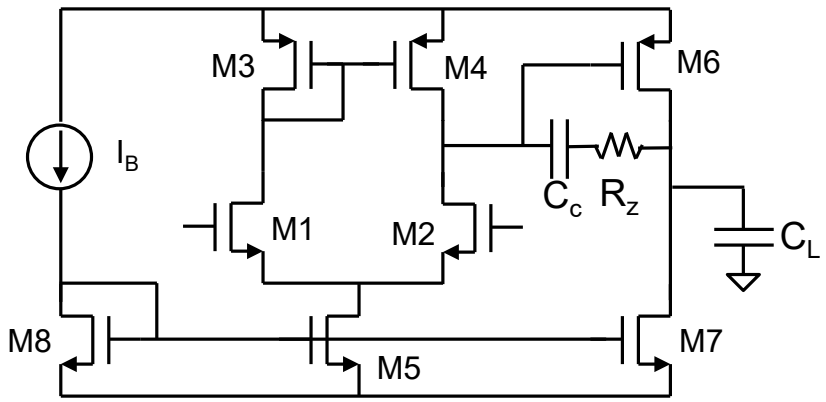
Design Spec

- Av = 60 dB
- GBW = 100 MHz
- PM = 60^{o}
- C_L = 5 pF

Assumption for Hand Calculation

- $KP_n = \mu_n C_{ox}$ = 300 uA/V^2
- $KP_p = \mu_p C_{ox}$ = 160 uA/V^2
- Vdsat = 0.2 V
- I_B = 100 uA

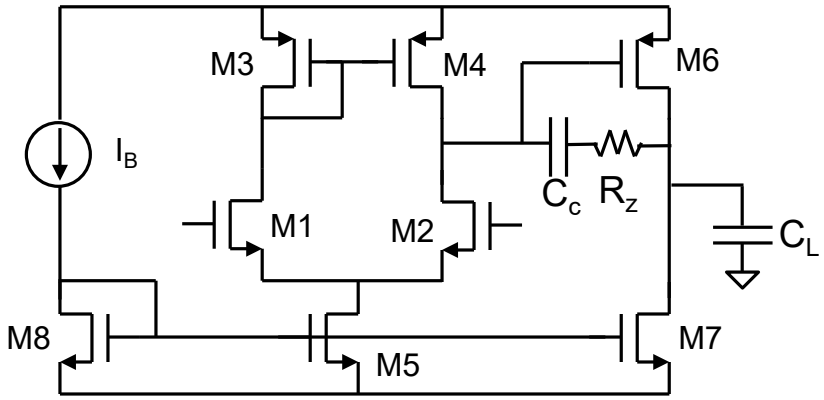
Design Procedure



1. GBW = $g_{m1} / C_c = \omega_u$
   - Pick $C_c = C_L / 3$
   - $g_{m1} = 2\pi f_u \cdot C_c$
2. If Slew-Rate Spec is given
   - $SR = 2I_1 / C_c \rightarrow I_1 = SR \cdot C_c / 2$
   - $g_{m1} = \sqrt{2KP \cdot (\frac{W}{L})_1 \cdot I_1} \rightarrow (\frac{W}{L})_1 = \frac{{g_{m1}}^2}{2KP \cdot I_1}$
3. If Slew-Rate Spec is not given
   - Pick $V_{dsat1} = 0.2V \rightarrow I_1 = \frac{g_{m1} \cdot V_{dsat1}}{2}$
   - $I_D = \frac{KP}{2}\frac{W}{L}(V_{gs} - V_t)^2 \rightarrow (\frac{W}{L})_1 = \frac{2 \cdot I_1}{KP \cdot {V_{dsat1}}^2}$
4. If ICMR (Input Common Mode Range) Spec is given
   - Choose M3 size based on $ICMR_{max}$ requirement → See next page
   - Choose M5 size based on $ICMR_{min}$ requirement → See next page
5. If ICMR (Input Common Mode Range) Spec is not given
   - Pick $V_{dsat3} = 0.2V \rightarrow (\frac{W}{L})_3 = \frac{2 \cdot I_3}{KP \cdot {V_{dsat3}}^2}$
   - Pick $V_{dsat5} = 0.2V \rightarrow (\frac{W}{L})_5 = \frac{2 \cdot I_5}{KP \cdot {V_{dsat5}}^2}$
6. Choose $g_{m6} = 10\ g_{m1}$ for 60° PM → $I_6 = 10\ I_1$ if $V_{dsat6}=V_{dsat1}=200mV$ since $g_m = \frac{2 \cdot I}{V_{dsat}}$
7. Calculate $I_6 = \frac{g_{m6} \cdot V_{dsat6}}{2} \rightarrow (\frac{W}{L})_6 = \frac{2 \cdot I_6}{KP \cdot {V_{dsat6}}^2}$

[V_{dsat6} is based on OCMR requirement]

W/L Calculation from CMR Requirement



$ICMR_{max}$

- $ICMR_{max}$ – Vgs1 + Vdsat1 = VDD – Vsg3
- $ICMR_{max}$ – Vth1 = VDD – (Vth3 + Vdsat3)
- $ICMR_{max} \approx$ VDD – Vdsat3 assuming Vth1 = Vth3
- Vdsat3 = VDD - $ICMR_{max}$
- $I_D = \frac{KP}{2}\frac{W}{L}(V_{gs} - V_t)^2 \rightarrow (\frac{W}{L})_3 = \frac{2 \cdot I_{D3}}{KP \cdot V_{dsat3}{}^2}$

$ICMR_{min}$

- $ICMR_{min}$ – Vgs1 = Vdsat5
- Vdsat5 = $ICMR_{min}$ – (Vth1 + Vdsat1)
- Use Vth1 from simulation and choose Vdsat1 = 200mV
- $(\frac{W}{L})_5 = \frac{2 \cdot I_{D5}}{KP \cdot V_{dsat5}{}^2}$

Homework#5 Design Spec

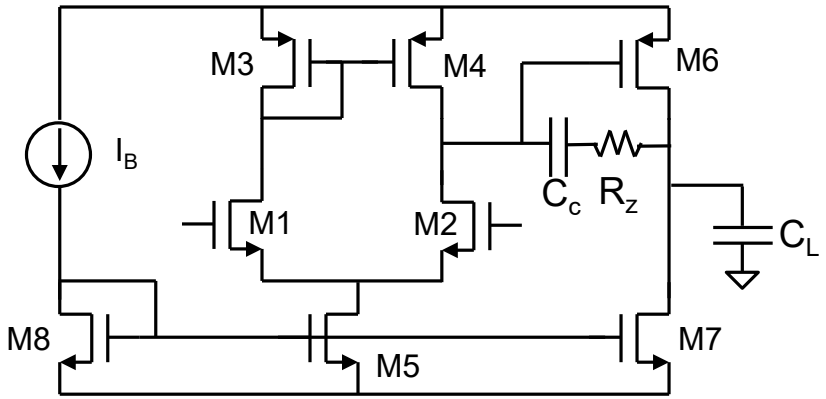
Target Design Spec

- Av = 60 dB
- GBW = 100 MHz
- PM = 60^{o}
- C_L = 5 pF

Assumption for Hand Calculation

- $KP_n = \mu_n C_{ox}$ = 300 uA/V^2
- $KP_p = \mu_p C_{ox}$ = 160 uA/V^2
- Vdsat = 0.2 V
- I_B = 100 uA
- Cancel p2 with z $\rightarrow R_z = \frac{1}{g_{m6}} \left(1 + \frac{C_L}{C_c}\right)$

Example Calculation



$f_u = \frac{1}{2\pi}\frac{g_{m1}}{C_c}$ = 100MHz

C_L = 5 pF

$C_c = C_L / 3$ = 1.67 pF

g_{m1} = 2π·100MHz·C_c = 2π·100MHz·1.67pF = 2π·100MHz·1.67pF = 1.05mS

$I_1 = \frac{g_{m1} \cdot V_{dsat1}}{2} = \frac{1.05m \cdot 0.2}{2} = 105\ uA$ → Choose $I_1 = 100\ uA$ in simulation

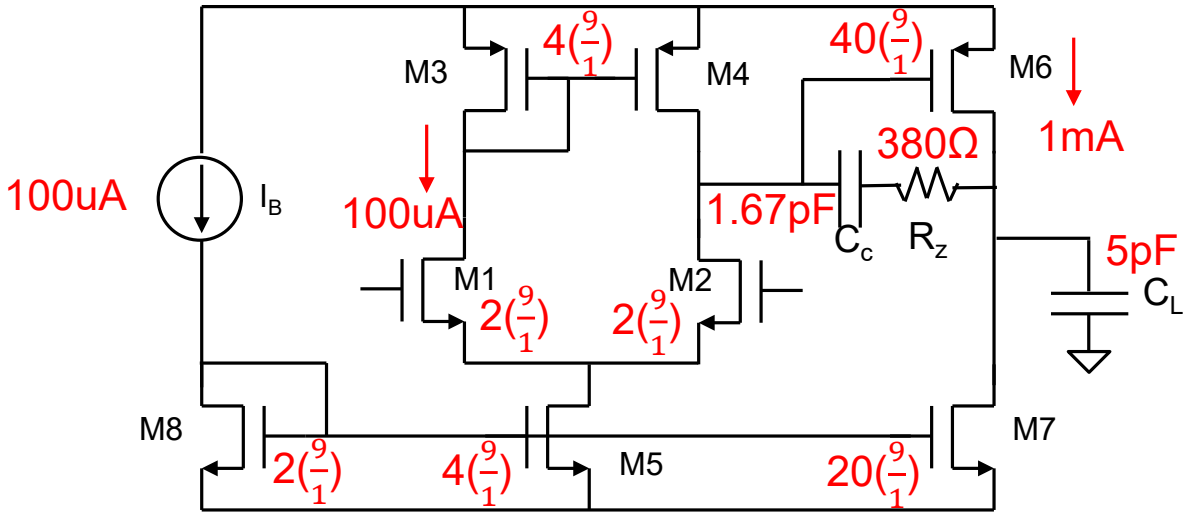
$I_1 = I_2 = I_3 = I_4 = 100\ uA$

$(\frac{W}{L})_1 = \frac{2 \cdot I_1}{KP \cdot V_{dsat1}{}^2} = \frac{2 \cdot 100u}{300u \cdot 0.2^2} = 16.67$ → Choose $(\frac{W}{L})_1 = 18 = 2(\frac{9}{1})$

$(\frac{W}{L})_3 = \frac{2 \cdot I_3}{KP \cdot V_{dsat3}{}^2} = \frac{2 \cdot 100u}{160u \cdot 0.2^2} = 31.25$ → Choose $(\frac{W}{L})_3 = 4(\frac{9}{1})$

$(\frac{W}{L})_5 = \frac{2 \cdot I_5}{KP \cdot V_{dsat5}{}^2} = \frac{2 \cdot 200u}{300u \cdot 0.2^2} = 33.35$ → Choose $(\frac{W}{L})_5 = 4(\frac{9}{1})$

Example Calculation - Continued



Choose $g_{m6} = 10\ g_{m1}$ for 60° PM

$g_{m6} = 10\ g_{m1} = 10.5$ mS

$I_6 = \frac{g_{m6} \cdot V_{dsat6}}{2} = \frac{10.5m \cdot 0.2}{2} = 1.05\ mA \rightarrow$ Choose $I_6 = 1\ mA$ in simulation

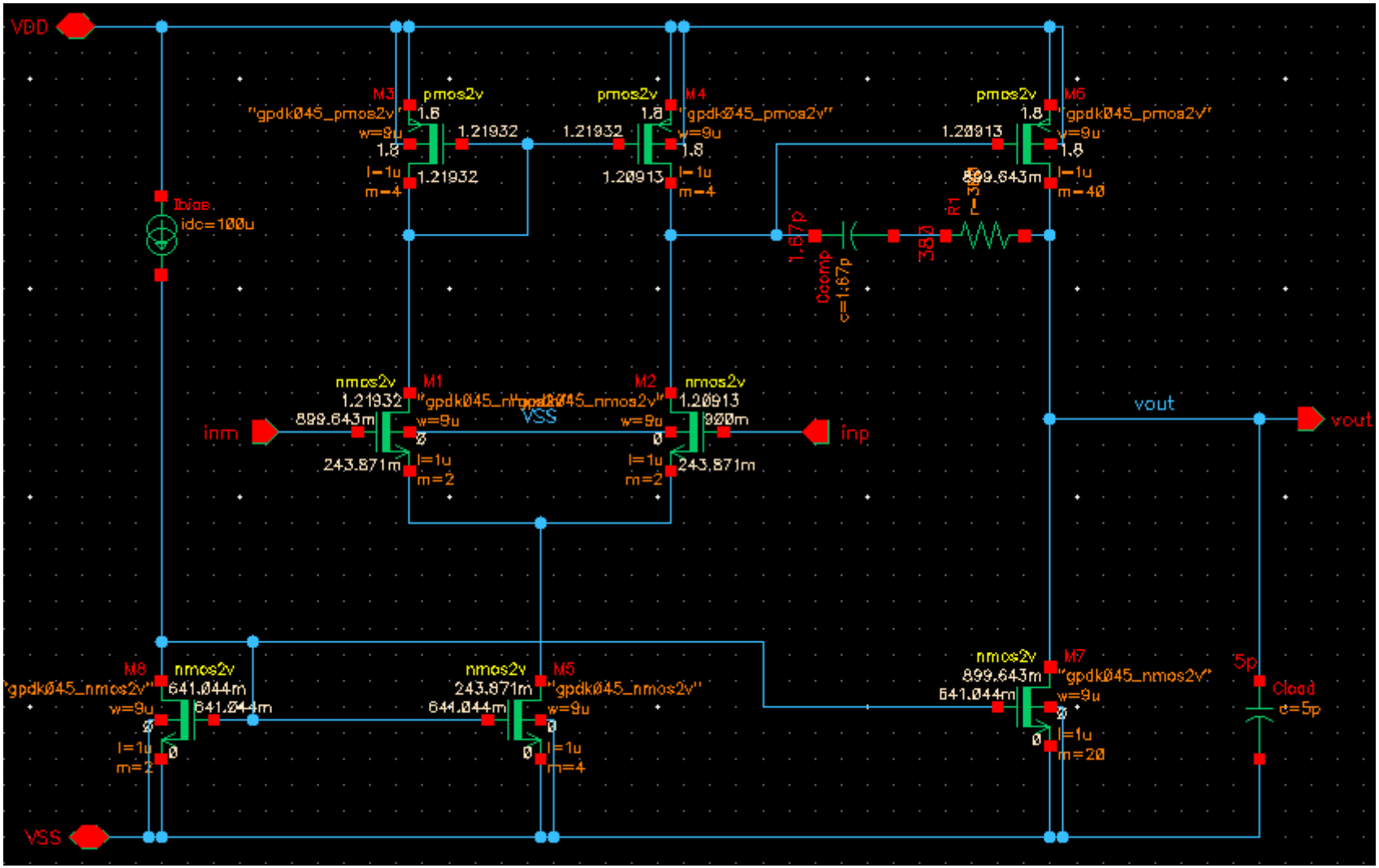
$I_6 = I_7 = 1\ mA$

$(\frac{W}{L})_6 = 10 \cdot (\frac{W}{L})_4 = 10 \cdot 4(\frac{9}{1}) \rightarrow$ Choose $(\frac{W}{L})_6 = 40\ (\frac{9}{1})$

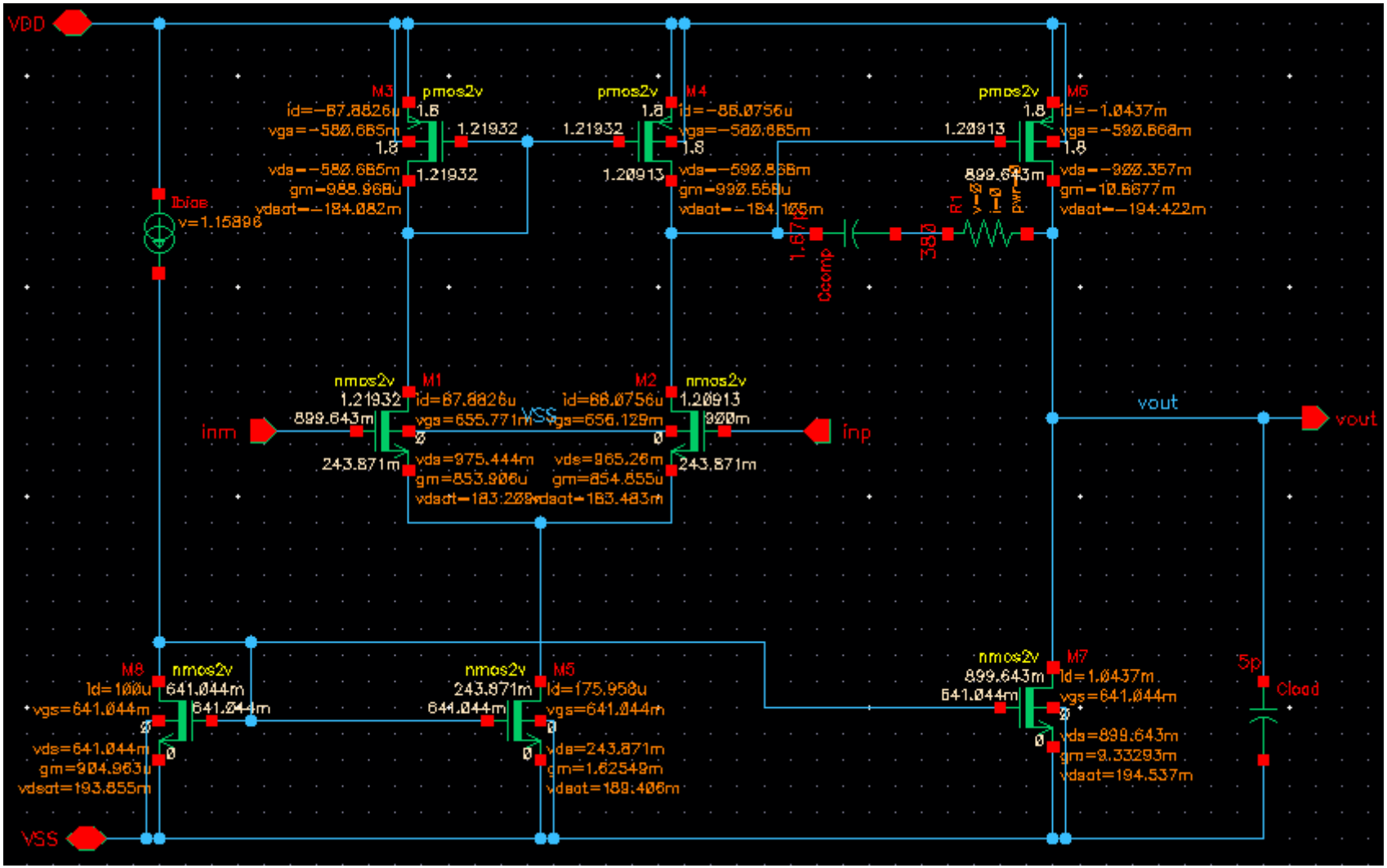
$(\frac{W}{L})_7 = 5 \cdot (\frac{W}{L})_5 = 5 \cdot 4(\frac{9}{1}) \rightarrow$ Choose $(\frac{W}{L})_3 = 20(\frac{9}{1})$

$R_z = \frac{1}{10.5m}\left(1 + \frac{5}{1.67}\right) = 380\ \Omega$

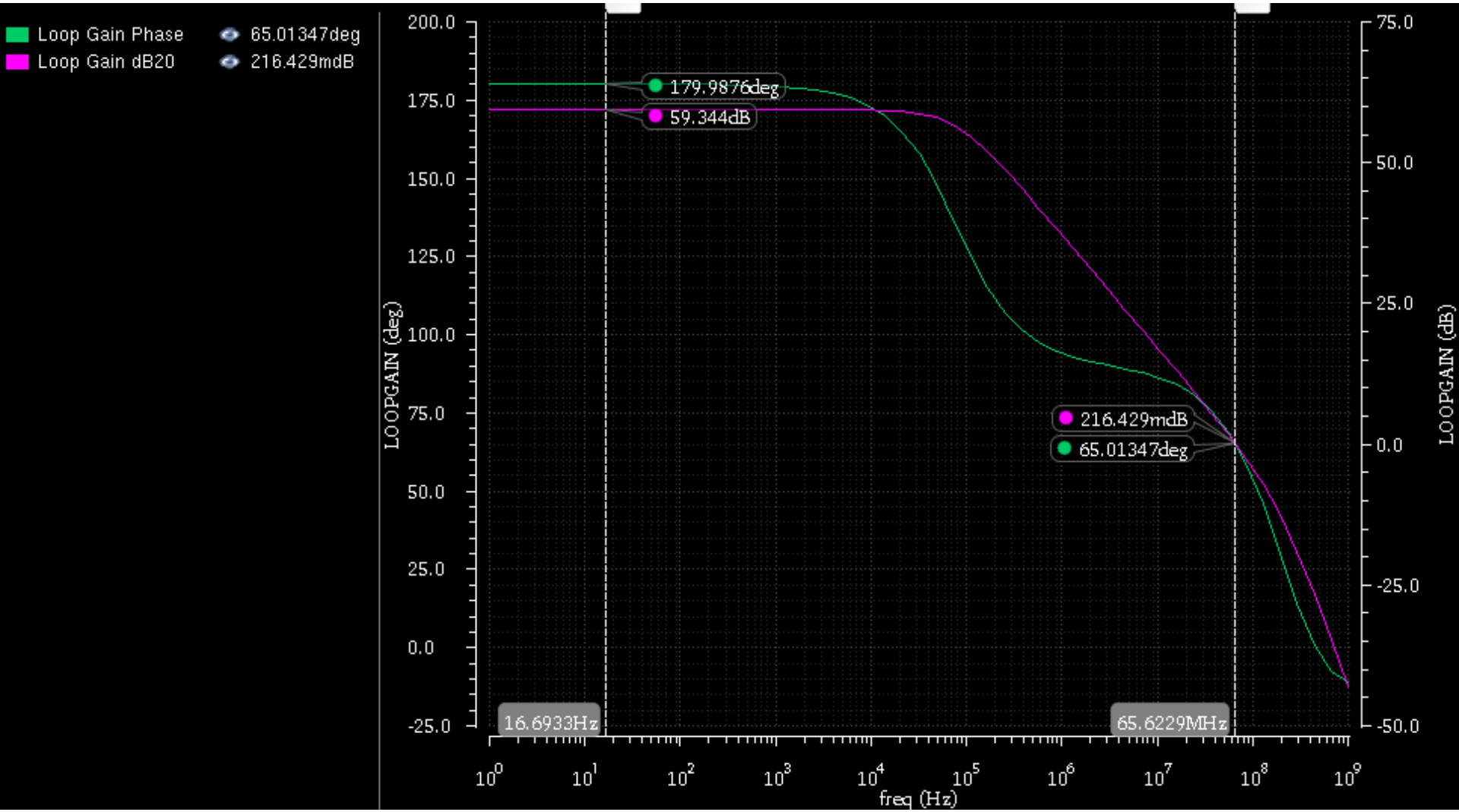
2-Stage OPAMP Schematic



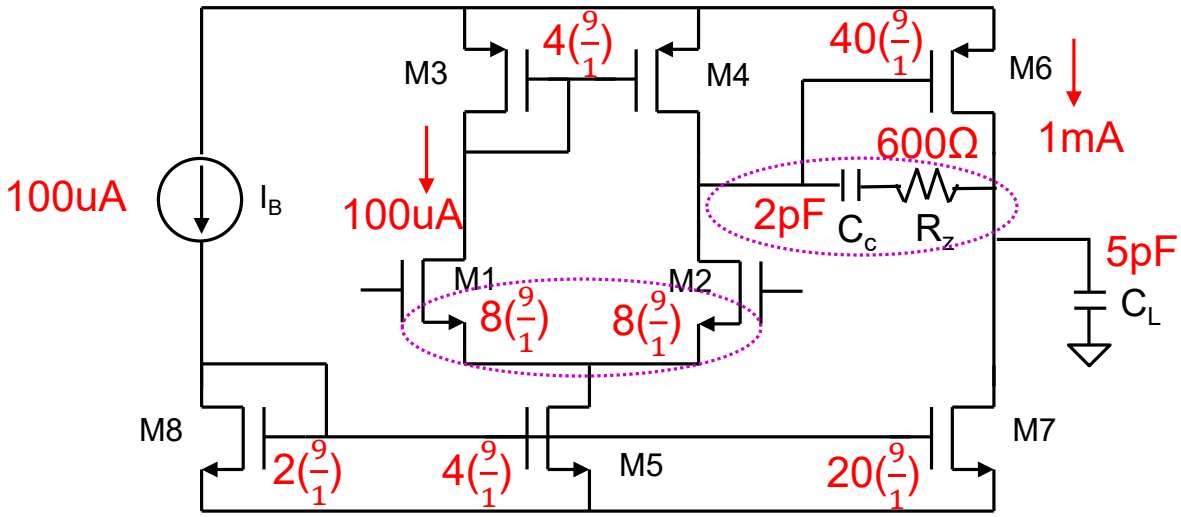
DC Operating Points



AC simulation



New Size



To achieve f_u = 100MHz from 65MHz in simulation, increase gm1

1. Simulate with a new size and check f_u and PM

$$(\frac{W}{L})_1 = 2(\frac{9}{1}) \rightarrow (\frac{W}{L})_1 = 8(\frac{9}{1})$$

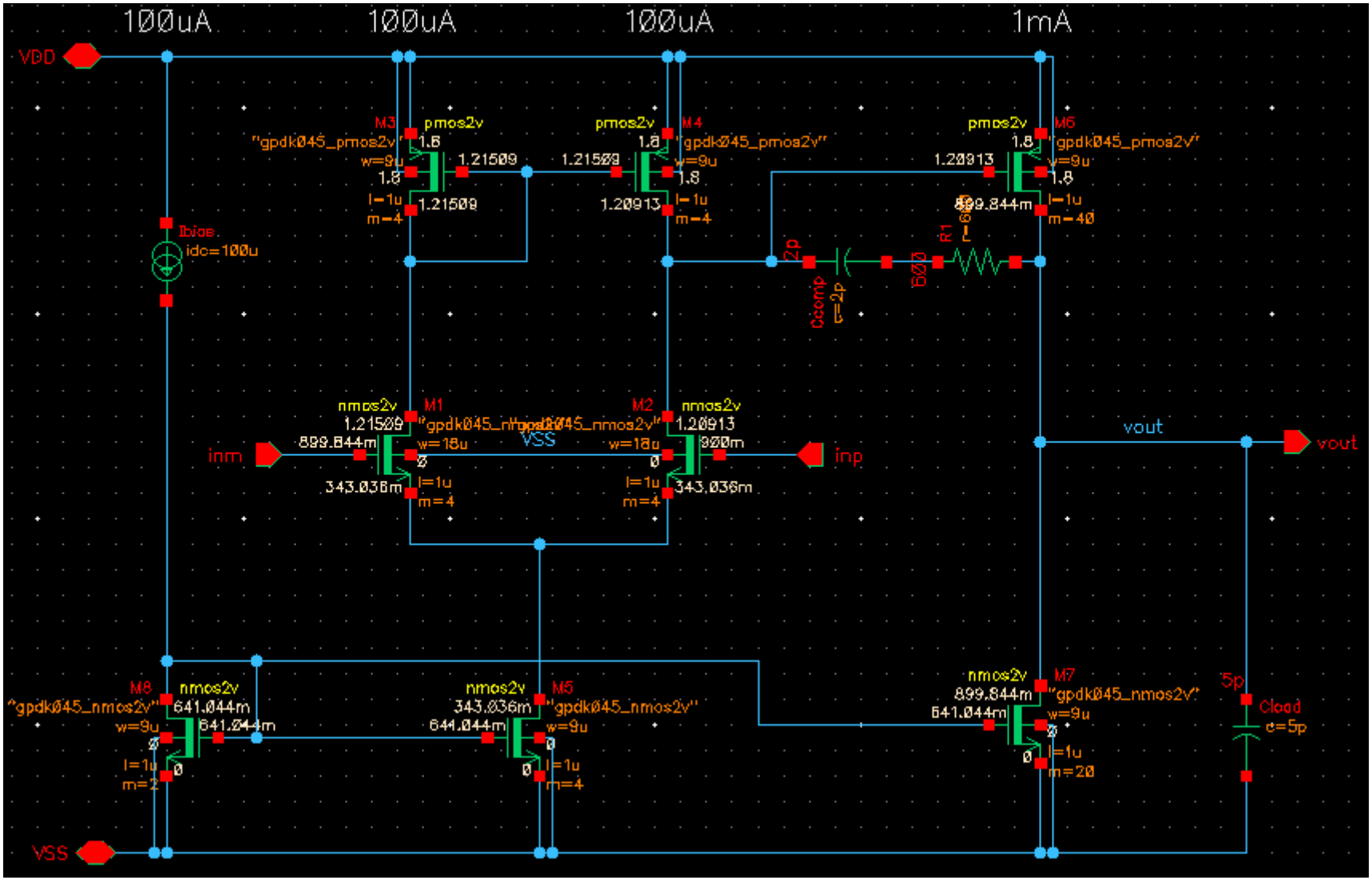
2. If the PM is low, increase Cc

$$C_c = 1.6 \text{ pF} \rightarrow C_c = 2 \text{ pF}$$

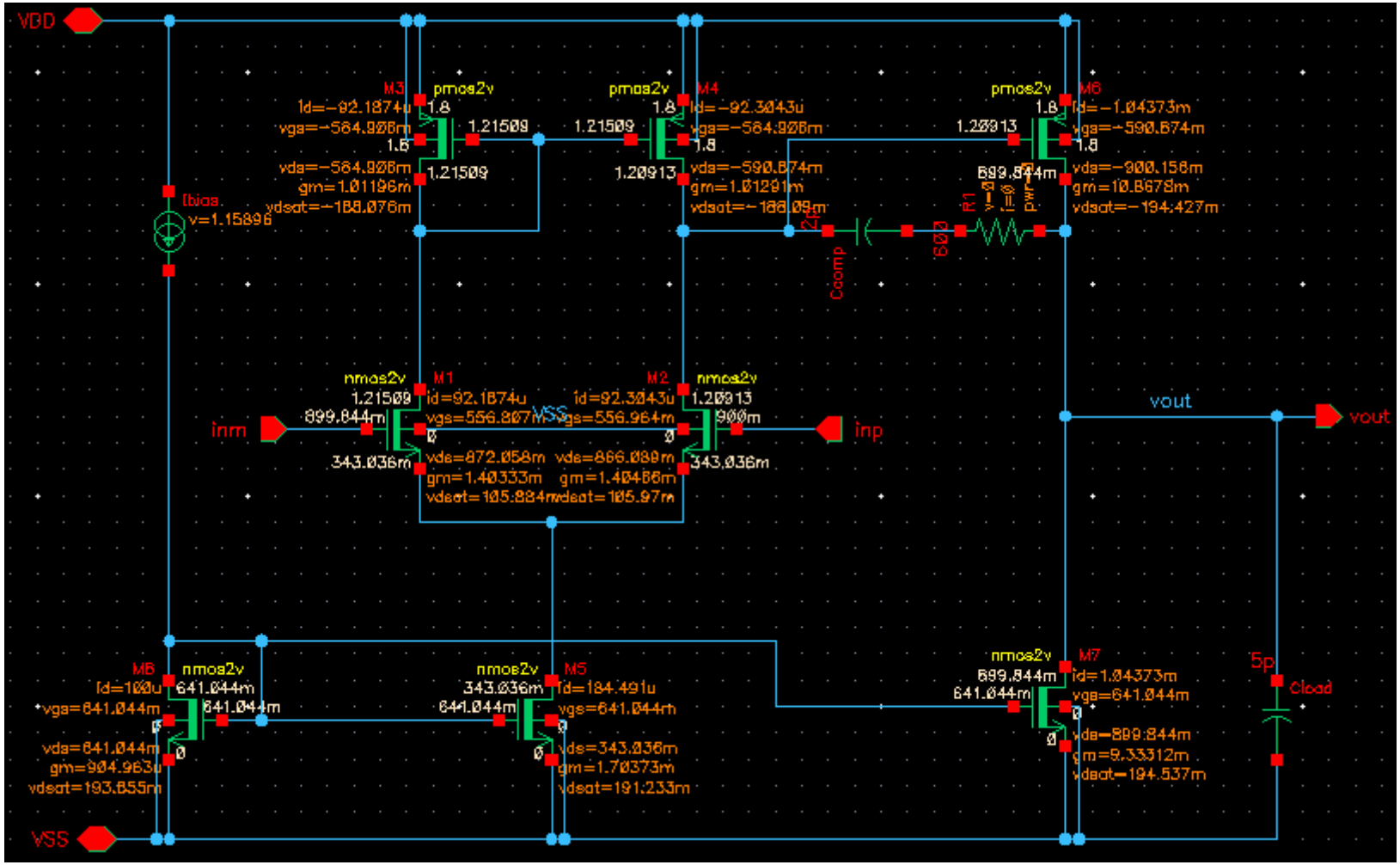
3. Adjust R_z up or down to see if you can get an optimum response

$$R_z = 380\ \Omega \rightarrow R_z = 600\ \Omega$$

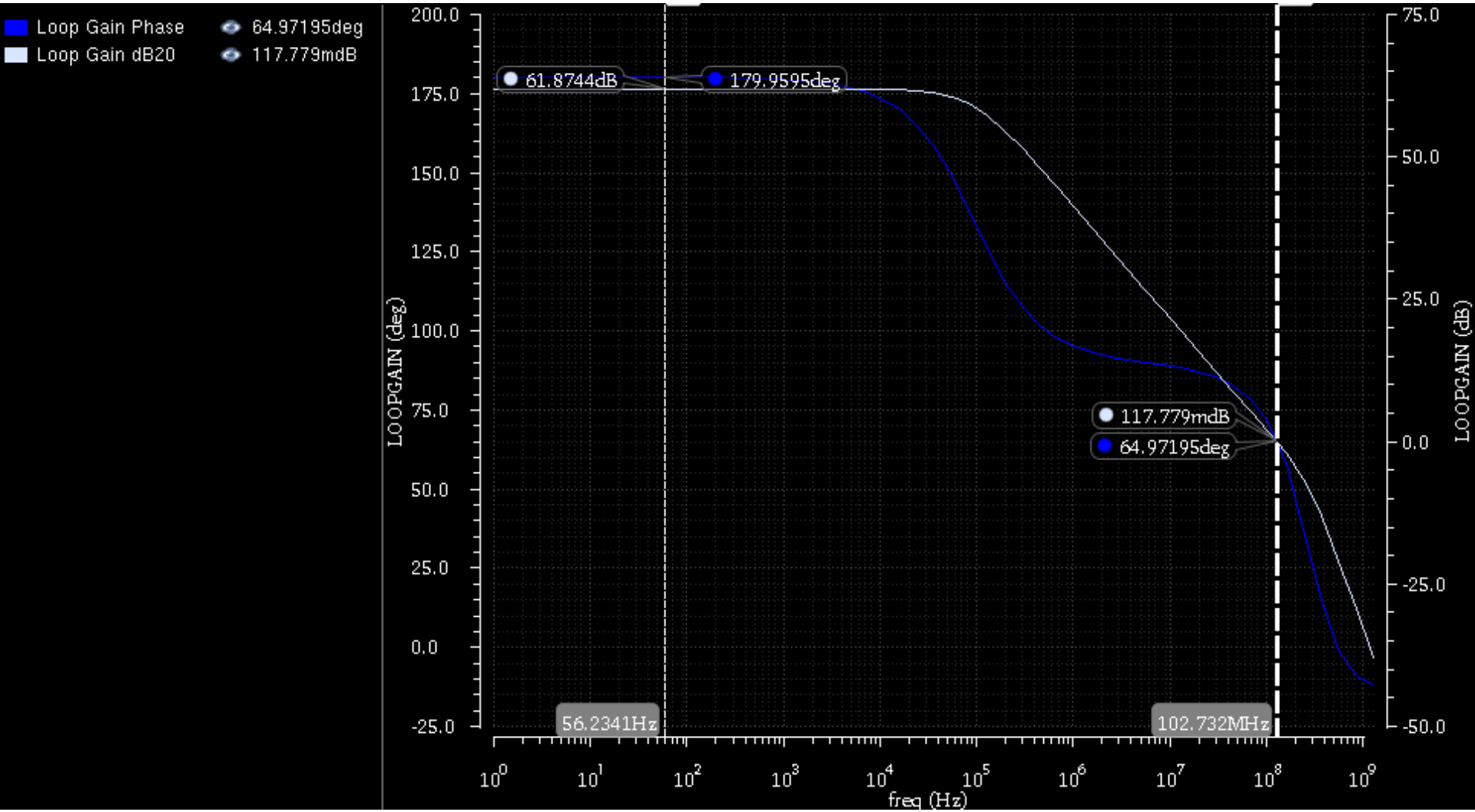
Schematic with New Size



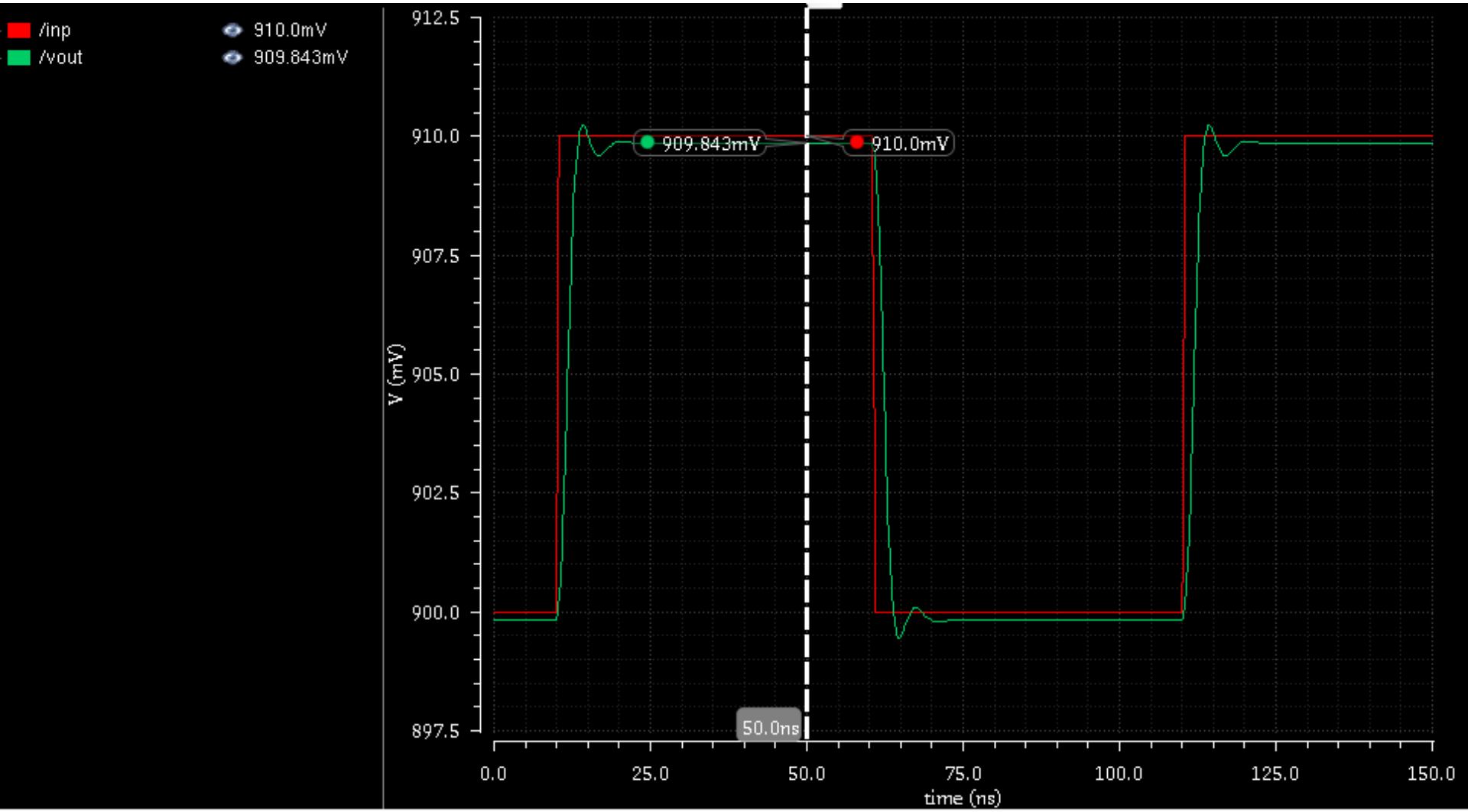
DC Operating Points



AC simulation



Transient Simulation for 10mV Pulse



Transient Simulation for 500mV Pulse