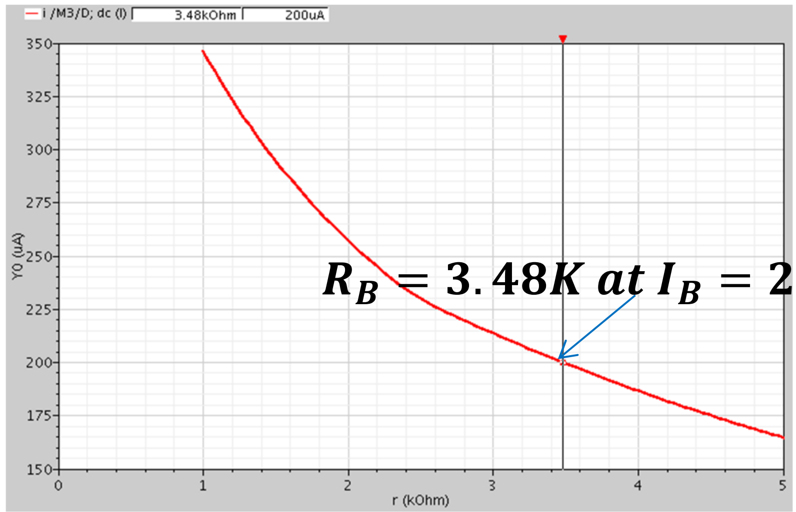
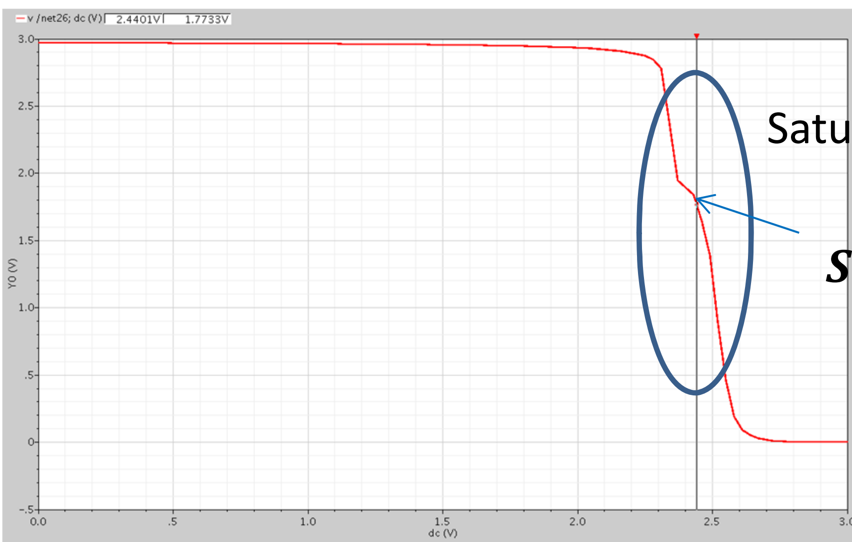
ECE 4220 Class Project #2 Solution

By Mr. Smith

Differential Amplifier Design (1)- Q-1,3



$R_B = 3.48K\ at\ I_B = 2mA$

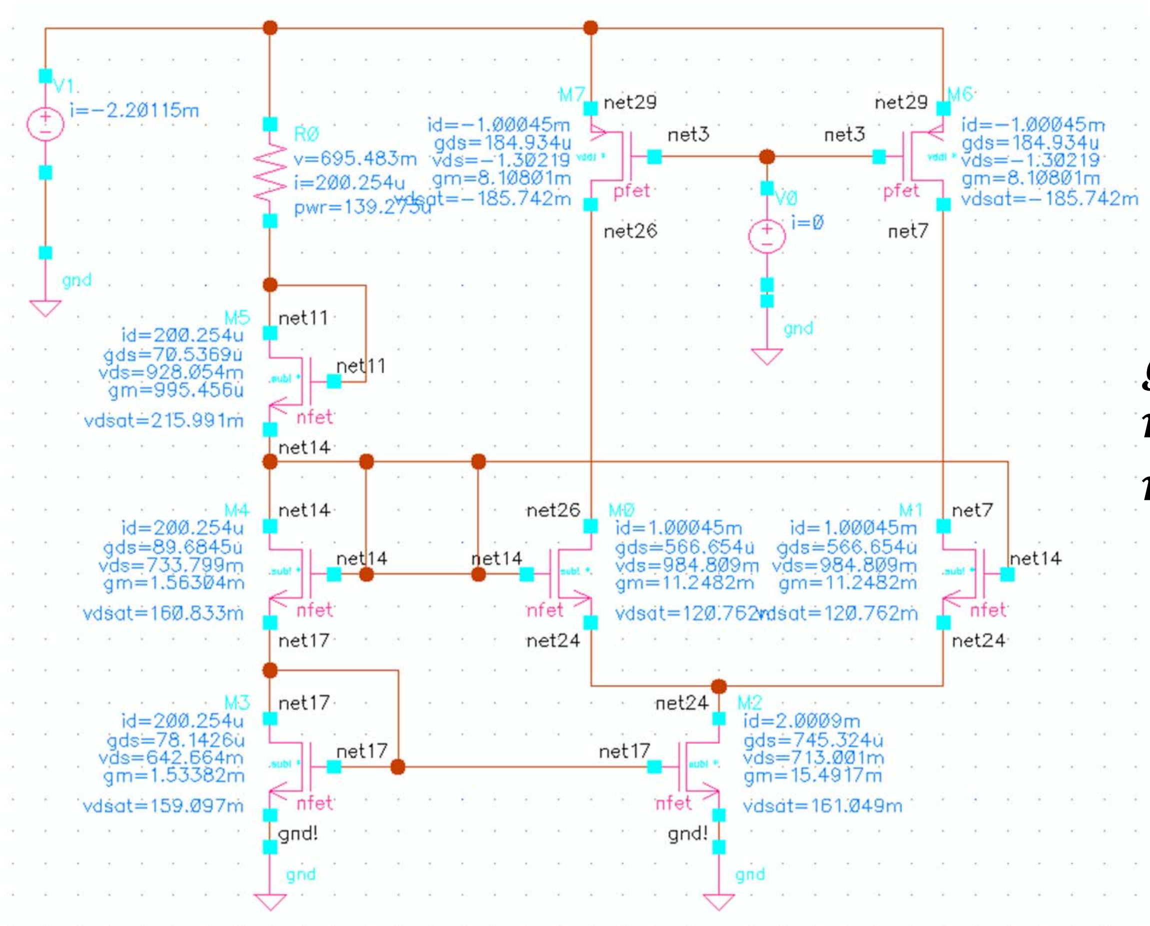


Saturation region

$Set\ V_B = 2.44$

Q-3) Answer: PMOS enters from saturation region to triode region or cut-off due to VB. For this reason, node-A, B can be sensitive to VB.

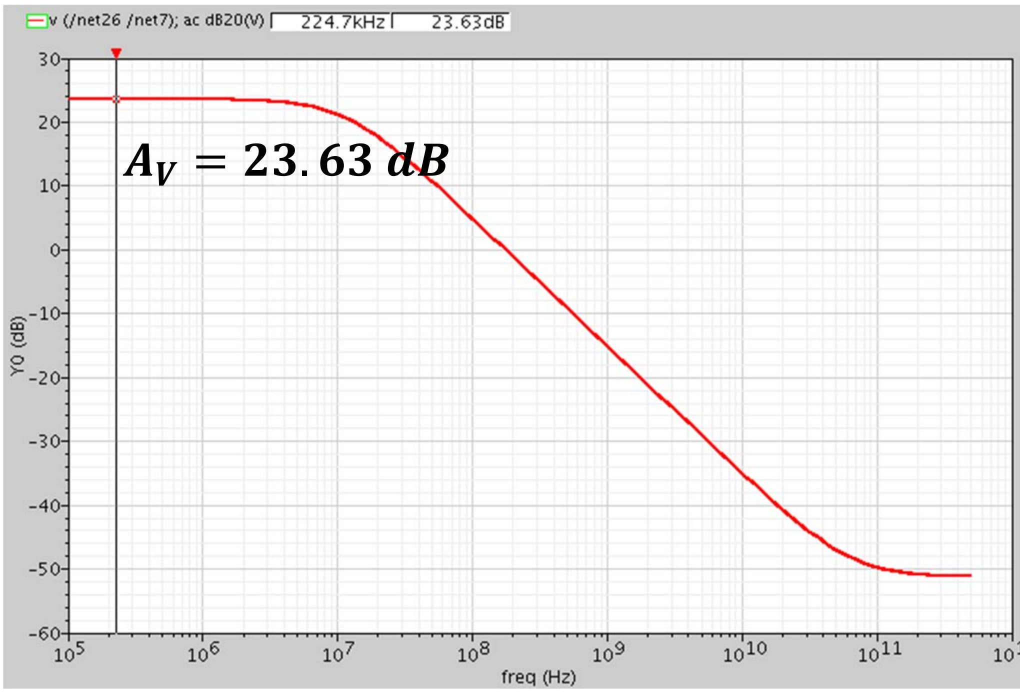
Differential Amplifier Design (1)- Q-2



$$g_m = 11.24m$$
$$r_{op} = 1/g_{p,ds} = 5.4K$$
$$r_{on} = 1/g_{n,ds} = 1.764K$$

Differential Amplifier Design (2)- Q-4,5

- ***Simulation result***



- *Small signal parameters in Step-(1)*

$g_m = 11.2m$

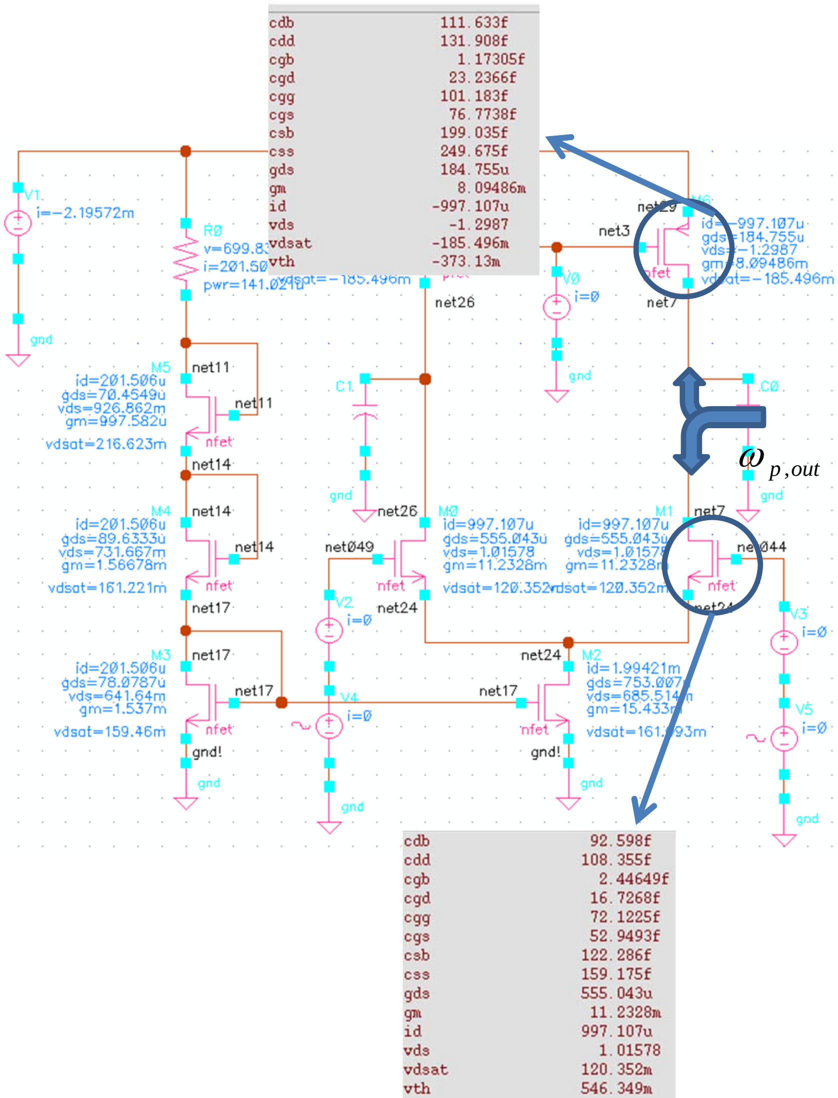
$r_{op} = 1/g_{p,ds} = 5.41K$

$r_{on} = 1/g_{n,ds} = 1.8K$

$$Av = g_m \cdot (r_{on} \parallel r_{op})$$
$$= 11.2m \cdot (1.8K \parallel 5.41K)$$
$$= 11.2m \cdot 1.35K = 15.12$$
$$= 23.59dB$$

→ Same as simulation result

Differential Amplifier Design (2)- Q-6



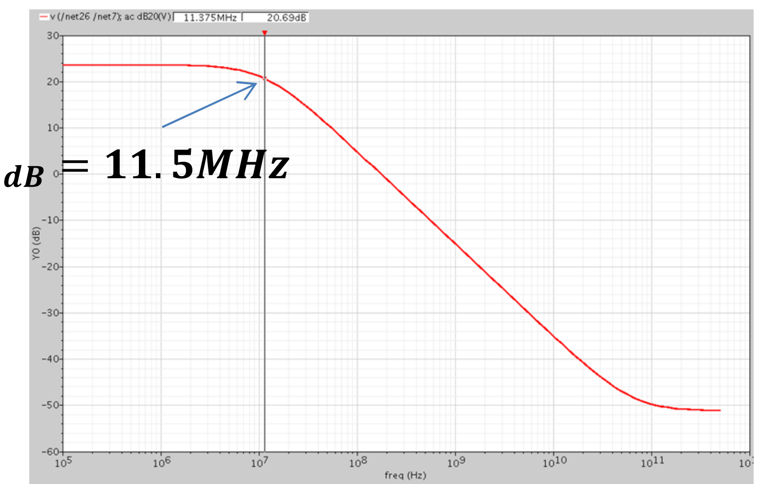
cdb	111.633f
cdd	131.908f
cgb	1.17305f
cgd	23.2366f
cgg	101.183f
cgs	76.7738f
csb	199.035f
css	249.675f
gds	184.755u
gm	8.09486m
id	-997.107u
vds	-1.2987
vdsat	-185.496m
vth	-373.13m

cdb	92.598f
cdd	108.355f
cgb	2.44649f
cgd	16.7268f
cgg	72.1225f
cgs	52.9493f
csb	122.286f
css	159.175f
gds	555.043u
gm	11.2328m
id	997.107u
vds	1.01578
vdsat	120.352m
vth	546.349m

$$\mathcal{F}_{3dB} = \omega_p/2\pi$$
$$= 1/2\cdot\pi\cdot\{1.35K\cdot(10p + 92f + 16f + 112f\}$$
$$= 11.5MHz$$ → *Same as simulation result*

$C_{DB,n} = 92f,\ \ C_{GD,n} = 16f,\ \ C_{DB,p} = 112f,\ C_L = 10p$

$$\omega_{p,out} = \frac{1}{R_L\left(C_L + C_{DB,n} + C_{GD,n} + C_{DB,p}\right)}$$

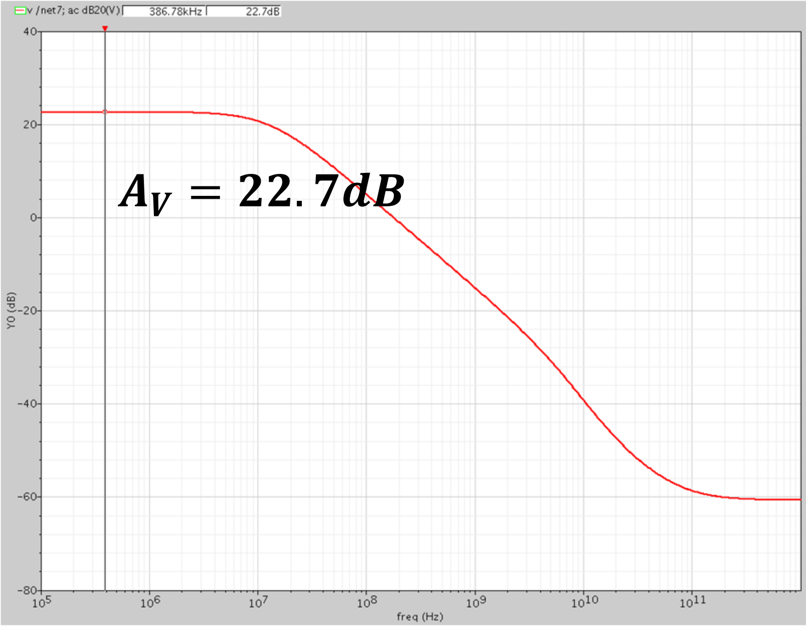


$\mathcal{F}_{3dB} = 11.5MHz$

- *Simulation result*

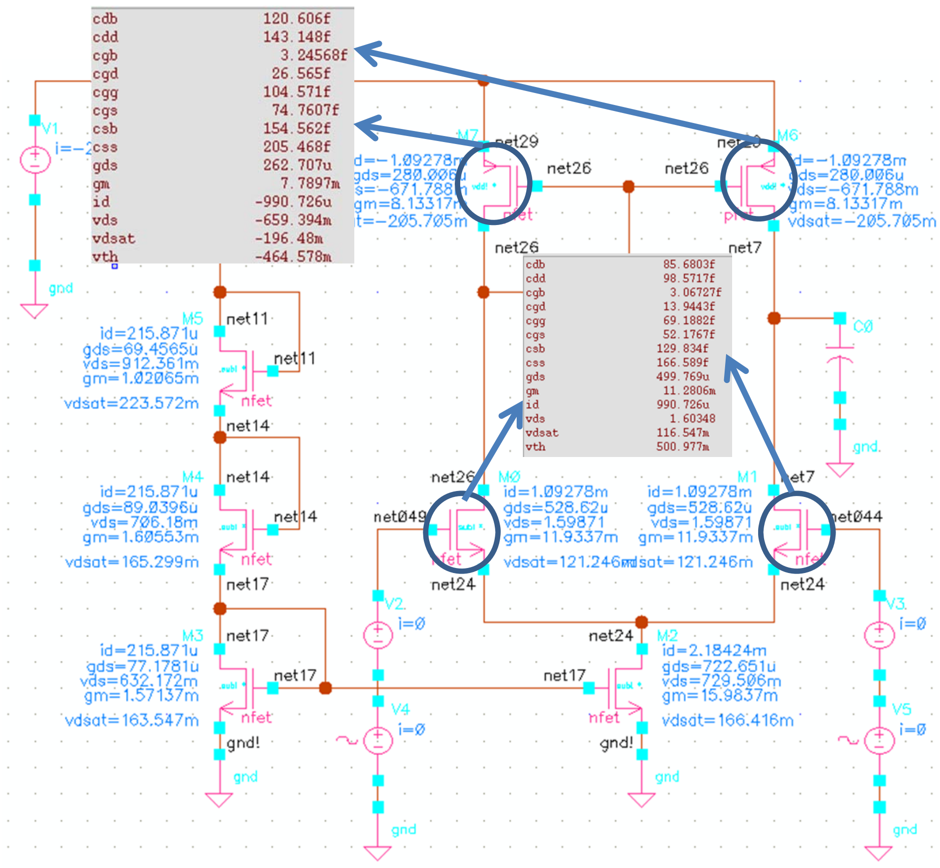
Differential Amplifier Design (3)- Q-7

➢ ***Simulation result***



Due to current mirror, the gain of single-ended output is about the same as one of Q-4.

Differential Amplifier Design (3)- Q-8



$$\omega_{p,1st} = \frac{1}{R_L\left(C_L + C_{DB,n} + C_{GD,n} + C_{DB,p}\right)}$$

$$\omega_{p,2nd} = \frac{1}{R_{L,2nd}\left(C_{DB,n} + C_{GD,n} + C_{DB,p} + 2C_{GS,p}\right)}$$

$$\omega_z = 2\omega_{p,2nd}$$

$\mathcal{F}_{p,1st} = \omega_p/2\pi$
$= 1/2 \cdot \pi \cdot \{1.236K \cdot (10p + 92f + 16f + 112f)\}$
$= 12.6MHz$

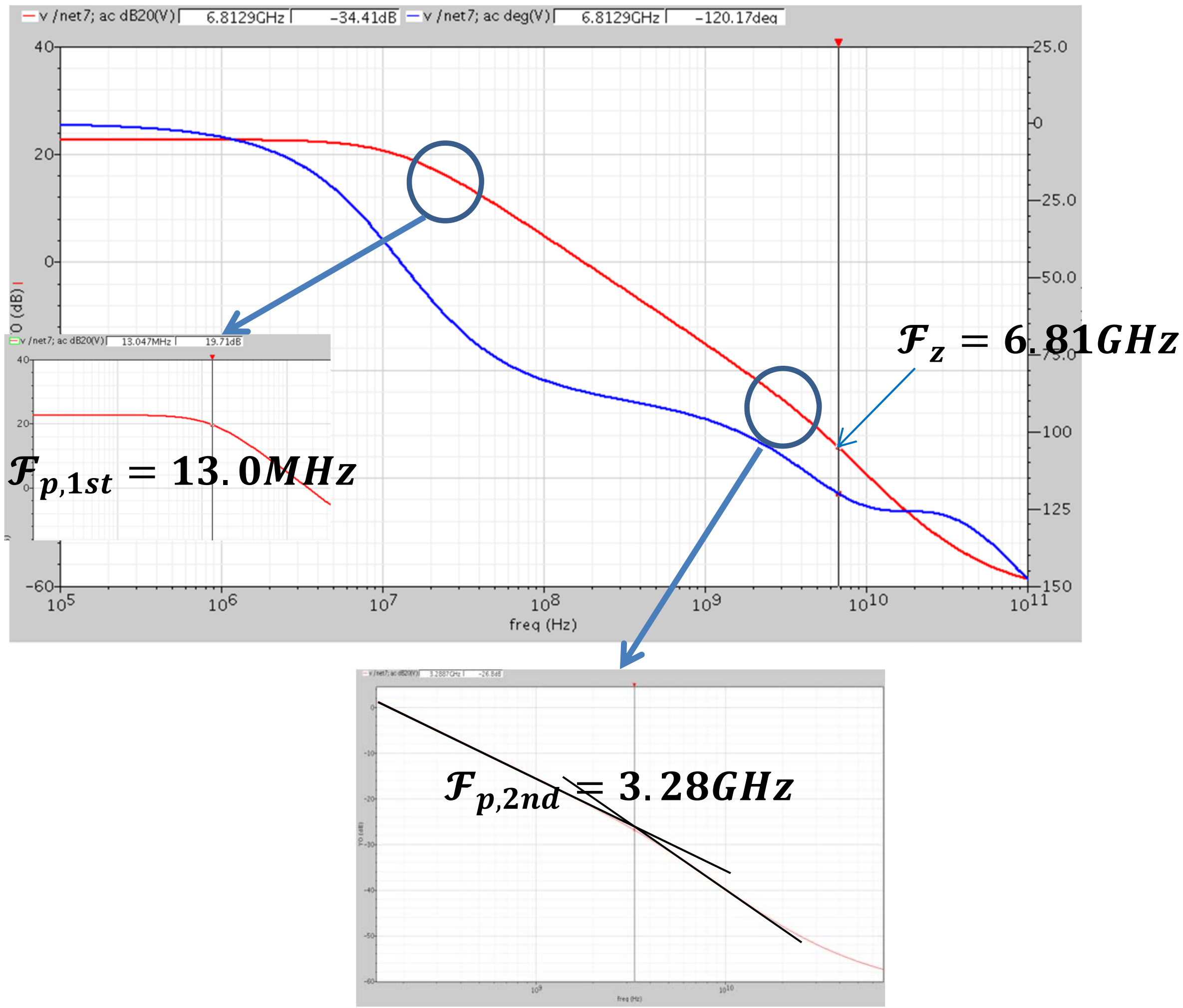
$\mathcal{F}_{p,2nd} = \omega_{p,2nd}/2\pi$
$= 1/2 \cdot \pi \cdot \{123 \cdot (92f + 16f + 120f + 150f)\}$
$= 3.42GHz$

$\mathcal{F}_z = 2 \cdot \omega_{p,2nd} = 6.84GHz$

$C_{DB,n} = 92f,\ \ C_{GD,n} = 16f,\ \ C_{DB,p} = 112f,\ C_{GS,p} = 75f,\ \ C_L = 10p,\ R_{L,2nd} = \frac{1}{g_m} = 123\ Ohm$

Differential Amplifier Design (3)- Q-8

- ***Simulation result***



- *Calculation*

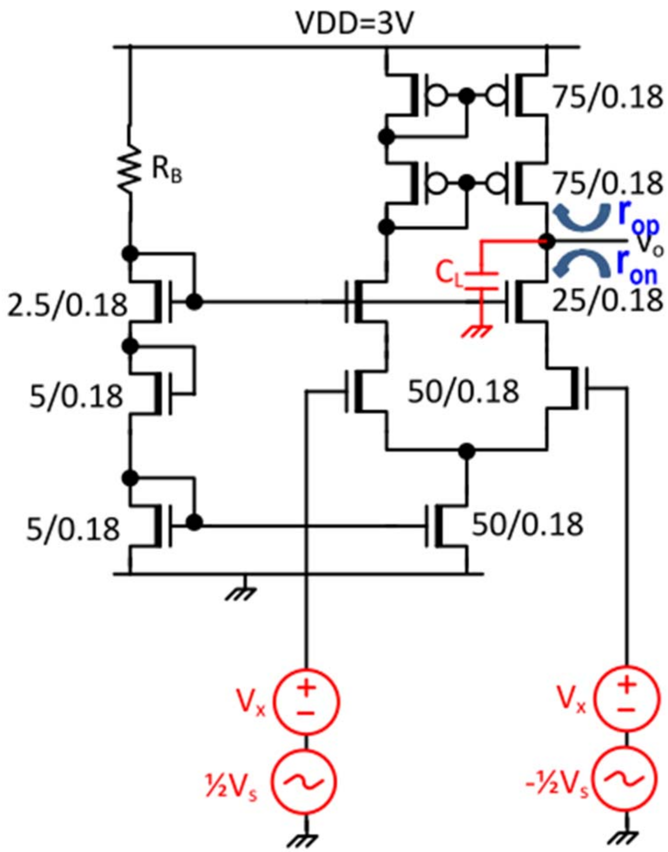
$\mathcal{F}_{p,1st} = \omega_p/2\pi = 12.6MHz$

$\mathcal{F}_{p,2nd} = \omega_{p,2nd}/2\pi = 3.42GHz$

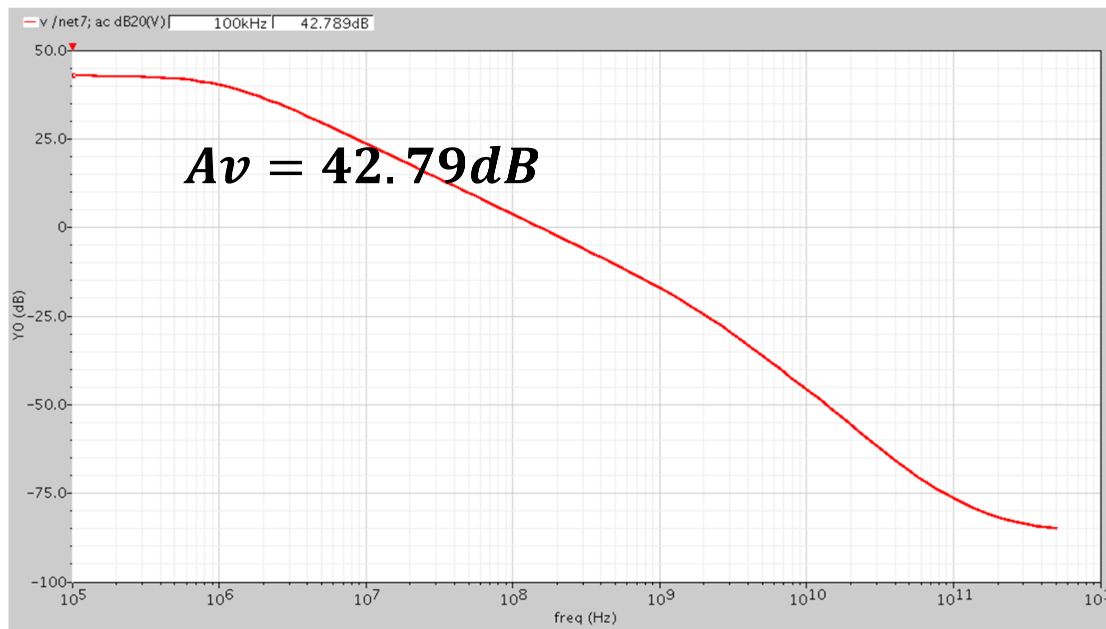
$\mathcal{F}_{z} = 2 \cdot \omega_{p,2nd} = 6.84GHz$

→ *Same as simulation result*

Differential Amplifier Design (4)- Q-9

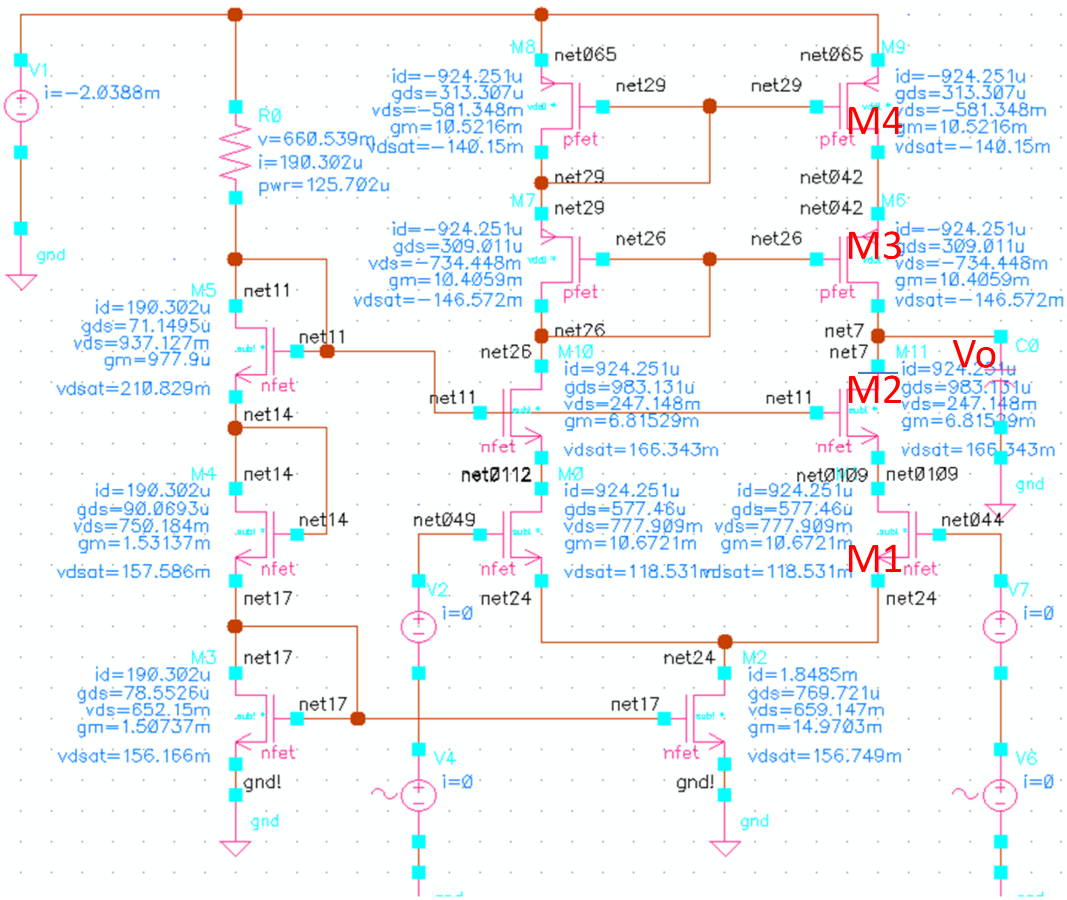


➤ ***Simulation result***



$$Av = 42.79dB$$

Differential Amplifier Design (4)- Q-10



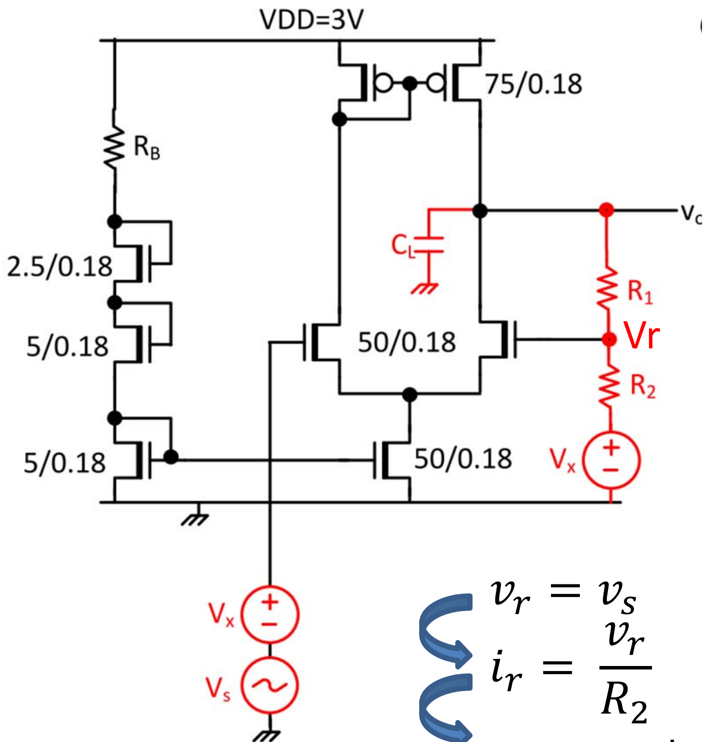
$$Av = g_{m1} \cdot (r_{on} \parallel r_{op})$$
$$= 10.4m \cdot (14.5K \parallel 113.6K)$$
$$= 10.4m \cdot 12.858\text{K} = 133.7 = 42.52\text{dB}$$

➢ *It is the same as the simulation result.*

$$r_{on} = r_{o1} + r_{o2} + g_{m2} \cdot r_{o1} \cdot r_{o2} = 14.5K$$
$$r_{op} = r_{o3} + r_{o4} + g_{m3} \cdot r_{o3} \cdot r_{o4} = 113.6K$$

$$g_{m1} = 10.6m$$
$$g_{m2} = 6.8m$$
$$r_{o1} = 1/g_{ds1} = 1.73K$$
$$r_{o2} = 1/g_{ds2} = 1.0K$$
$$g_{m3} = 10.4m$$
$$r_{o3} = 1/g_{ds3} = 3.23K$$
$$r_{o4} = 1/g_{ds4} = 3.19K$$

Differential Amplifier Design (5)- Q-11,12



$$v_r = v_s$$

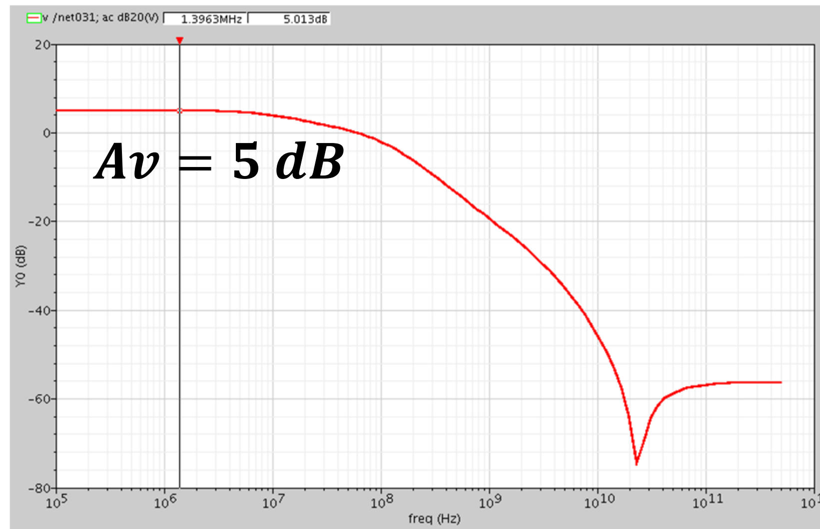
$$i_r = \frac{v_r}{R_2}$$

$$v_o = v_r + i_r R_1$$

$$A_v = \frac{v_o}{v_s} = 1 + \frac{R_1}{R_2}$$

- *If R1 = R2, the Av is 6dB.*
- *Set R1=R2=1M ohm.*

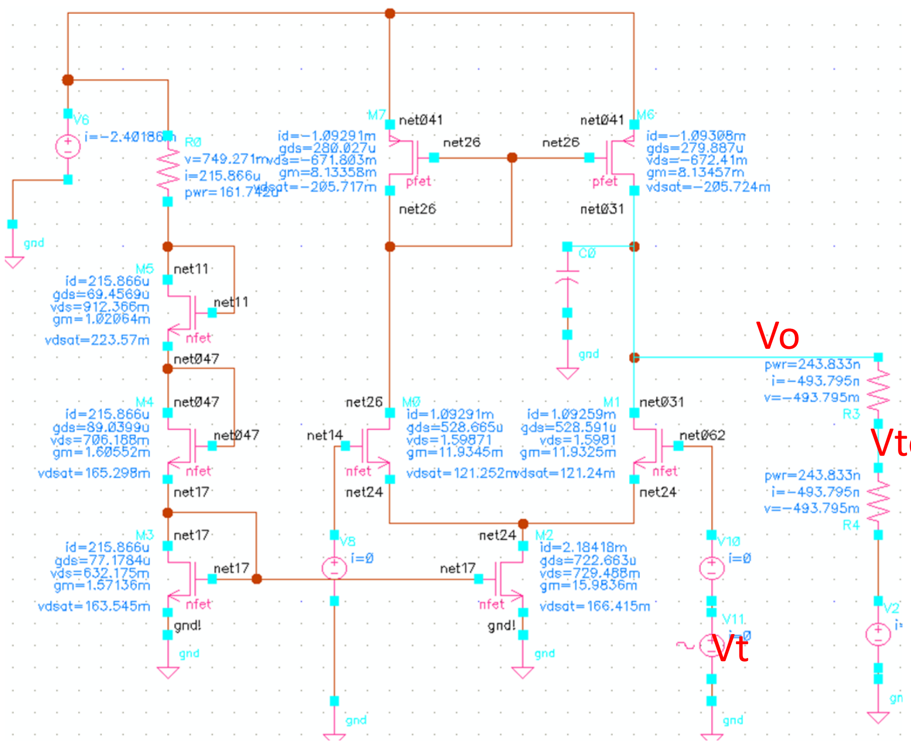
- ***Simulation result***



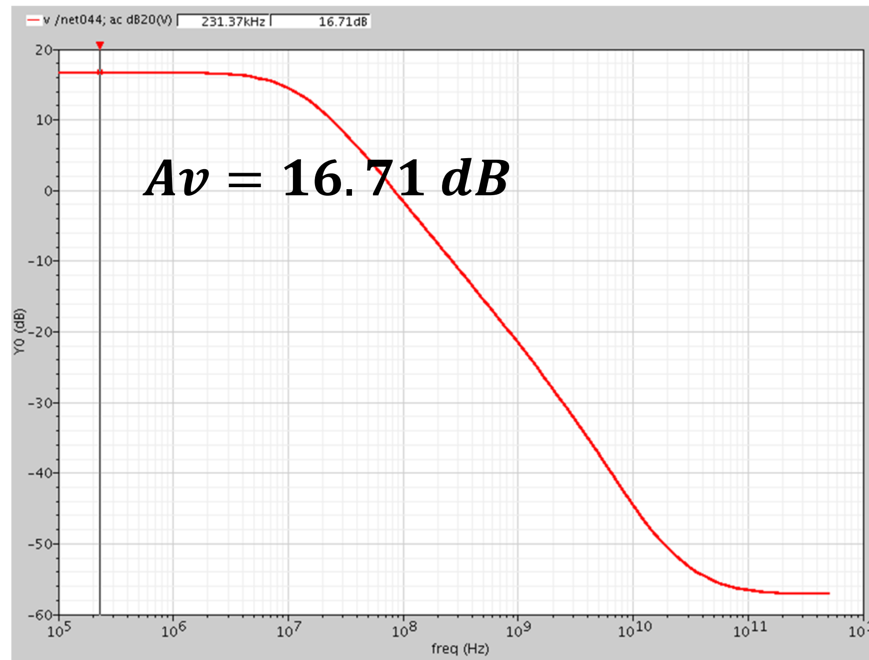
- *Due to small loop gain, the simulation gain is less than the expected 6dB.*

❖ Using the calculated gain in Q-13, $A_v = \left(1 + \frac{R_1}{R_2}\right) \cdot \left(\frac{T}{T+1}\right) = 2 \cdot 0.88 =$ $1.76 = 4.91dB$ → Same as the simulation result

Differential Amplifier Design (6)- Q-13



- ***Simulation result***



$$T = \frac{v_{to}}{v_t} = \frac{v_o}{v_t} \cdot \left(\frac{R_2}{R_1 + R_2}\right) = 0.5 \cdot g_m \cdot \{r_{on} \parallel r_{op} \parallel (R_1 + R_2)\}$$

$$= 0.5 \cdot 11.9m \cdot (3.57K \parallel 1.89K \parallel 2M)$$

$$= 0.5 \cdot 11.9m \cdot 1.234K = 7.34$$

$$= 17.31dB$$

→ *Same as simulation result*