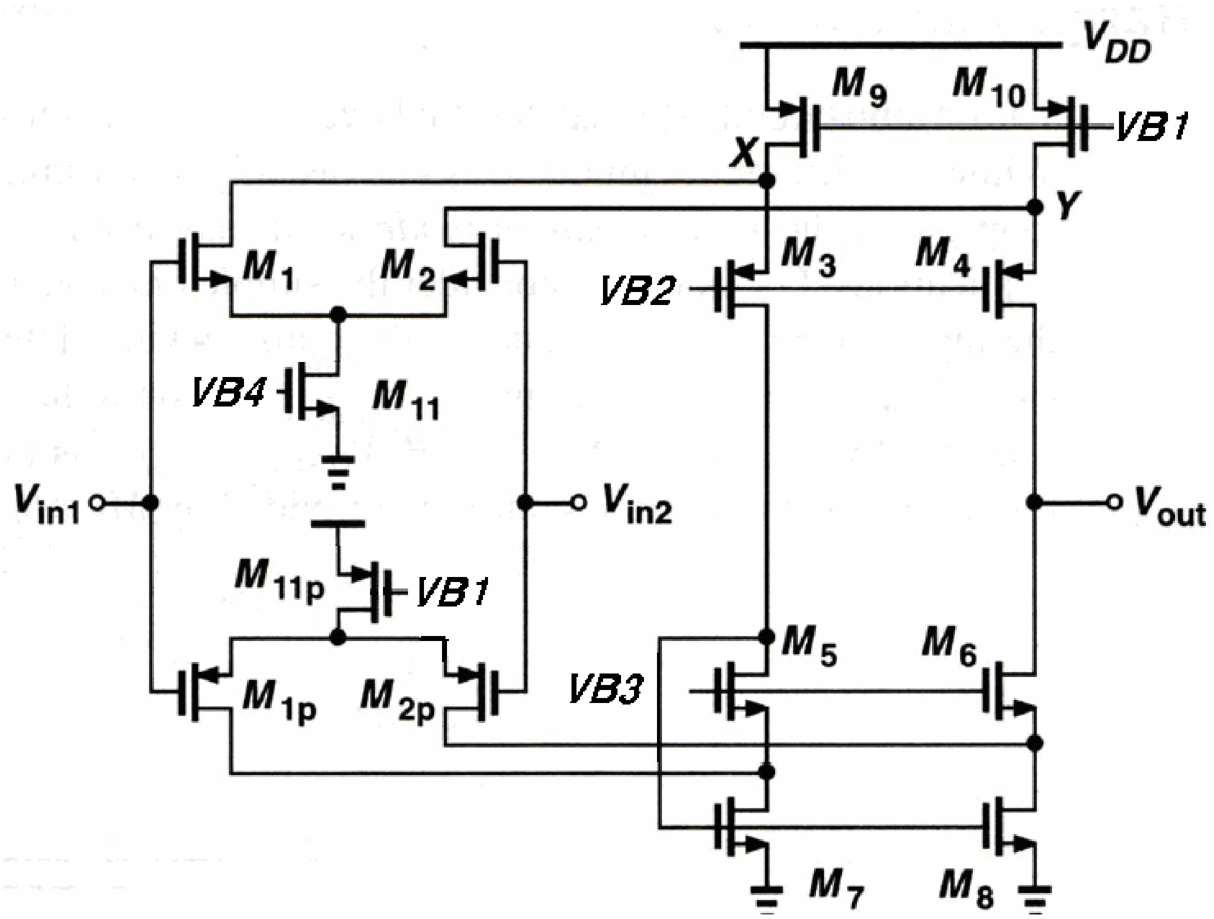
Term Project #1

20052608

김진호

Rail-to-Rail single-ended folded cascade OP amp



Ⅰ. Hand analysis

V_{DSAT}을 구하기 위해 $OVR \geq 1V$의 조건으로부터 다음을 얻을 수 있다.

$$V_{DD} - 2\times\left|V_{DSAT.P}\right| - 2\times V_{DSAT.N} \geq 1$$

$$\left|V_{DSAT.P}\right| + V_{DSAT.N} \leq 1.15$$

따라서 $V_{DSAT.N} = 0.5V$, $\left|V_{DSAT.P}\right| = 0.65V$ 으로 결정한다.

Let $V_{DSAT.N}(M_1, M_2) = 0.1V$, $V_{DSAT.P}(M_{P1}, M_{P2}) = 0.1V$

	V_{DSAT}	$I_D(mA)$	$\frac{W}{L}$	$g_m(mS)$	$r_o(K\Omega)$	W	L
M_1, M_2	0.1	0.7	1489.4	14.0	15.9	521.3	0.35
M_{P1}, M_{P2}	0.1	0.7	2916.7	14.0	11.9	1020.8	0.35
M_3, M_4	0.65	0.8	78.89	2.5	10.4	27.61	0.35
M_5, M_6	0.5	0.8	48.48	3.2	31.3	33.94	0.7
M_7, M_8	0.5	1.5	90.91	6.0	16.7	63.64	0.7
M_9, M_{10}	0.65	1.5	136.55	4.6	22.2	95.58	0.7
M_{11}	0.5	1.4	84.85	5.6	17.9	59.39	0.7
M_{P11}	0.65	1.4	127.45	4.3	23.8	89.21	0.7

<표 1. MOSFET parameters>

<표 1>의 parameter는 다음의 식을 이용하여 계산한다.

$$\frac{W}{L} = \frac{2I_D}{\mu C_{ox}(V_{DSAT})^2} \qquad gm = \frac{2I_D}{V_{DSAT}} \qquad ro = \frac{1}{\lambda I_D}$$

1. Output resistance

$$R_o = 2\left[\left\{g_{m3}r_{o3}\left(r_{o9} \parallel r_{o1}\right)\right\} \parallel \left\{g_{m5}r_{o5}\left(r_{o7} \parallel r_{op1}\right)\right\}\right]$$

$$= 353.9K\Omega$$

2. DC small signal voltage gain

$$A_{vd}(0) = G_{md}R_o$$

$$= (g_{m1} \parallel g_{mp1}) \cdot 2\left[\left\{g_{m3}r_{o3}\left(r_{o9} \parallel r_{o1}\right)\right\} \parallel \left\{g_{m5}r_{o5}\left(r_{o7} \parallel r_{op1}\right)\right\}\right]$$

$$= 2477$$

3. Slew rate

$$SR = \frac{I_D(M9) + I_D(M7)}{C_L} = \frac{1.5m + 1.5m}{10p} = 300\frac{V}{\mu s}$$

4. Gain-bandwidth product

$$GBW = \frac{1}{2\pi R_o C_L} \cdot A_{vd}(0) = 111.4MHz$$

5. Active input common mode voltage range(ICMR)

$$\max : V_{DD} + V_{THn} - \Delta_P > V_{DD}$$

$$\min : V_{SS} - \left|V_{THp}\right| + \Delta_N < V_{SS}$$

따라서 ICMR은 V_{SS}에서부터 V_{DD}까지의 범위를 가진다.

6. Power consumption

$$P = I_{SS} \times V_{DD} = 3mA \times 3.3V = 9.9mW$$

각 MOSFET의 W를 이용하여 각 MOSFET의 parameter들을 구한다.

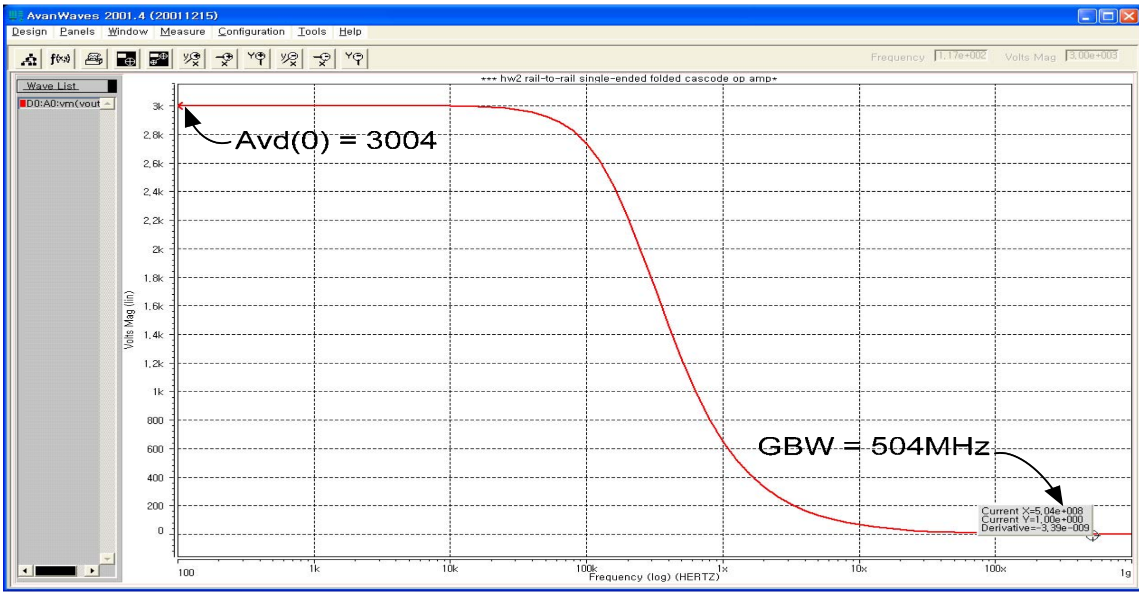
	$AS(pm)$	$AD(pm)$	$PS(\mu m)$	$PD(\mu m)$
M_1, M_2	547.3	547.3	523.4	523.4
M_{P1}, M_{P2}	1071.9	1071.9	1022.9	1022.9
M_3, M_4	28.99	28.99	29.71	29.71
M_5, M_6	35.64	35.64	36.04	36.04
M_7, M_8	66.82	66.82	65.74	65.74
M_9, M_{10}	100.36	100.36	97.68	97.68
M_{11}	62.36	62.36	61.49	61.49
M_{P11}	93.67	93.67	91.31	91.31

<표 2. MOSFET junction area parameters>

Ⅱ. *Spice simulation*

1. DC small signal voltage gain($A_{vd}(0)$) & Gain-bandwidth product

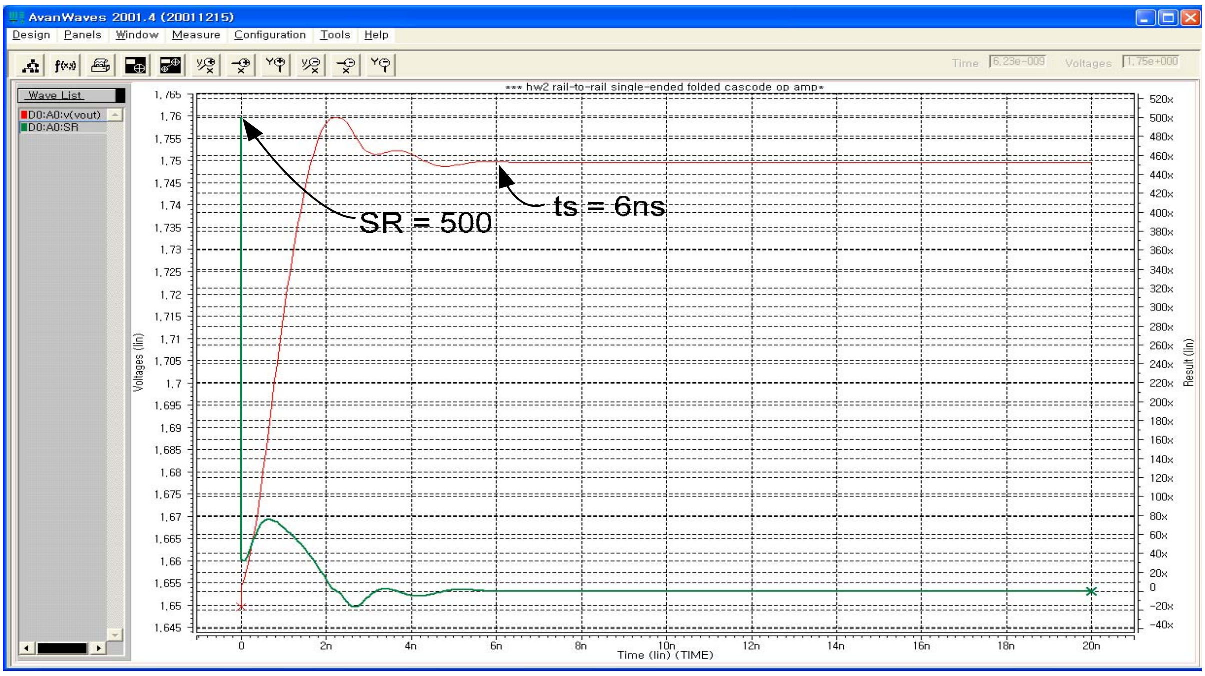
Hand analysis를 했을 때의 parameter로 simulation 했을 경우 M9, M10, M11 이 triod영역에서 동작하기 때문에 M9, M10, M11의 W값을 두 배로 하여 실행 하였다. 여기서 Vb1 = 1.45[V], Vb2 = 2.1[V], Vb3 = 1.45[V], Vb4 = 1.45[V]로 각각 simulation을 수행 하였으나 몇몇 MOSFET이 triod영역에서 동작하는 문제 때문에 Vb1 = 2.1[V], Vb2 = 1.2[V], Vb3 = 1.2[V], Vb4 = 1.5[V]로 변경하였다.



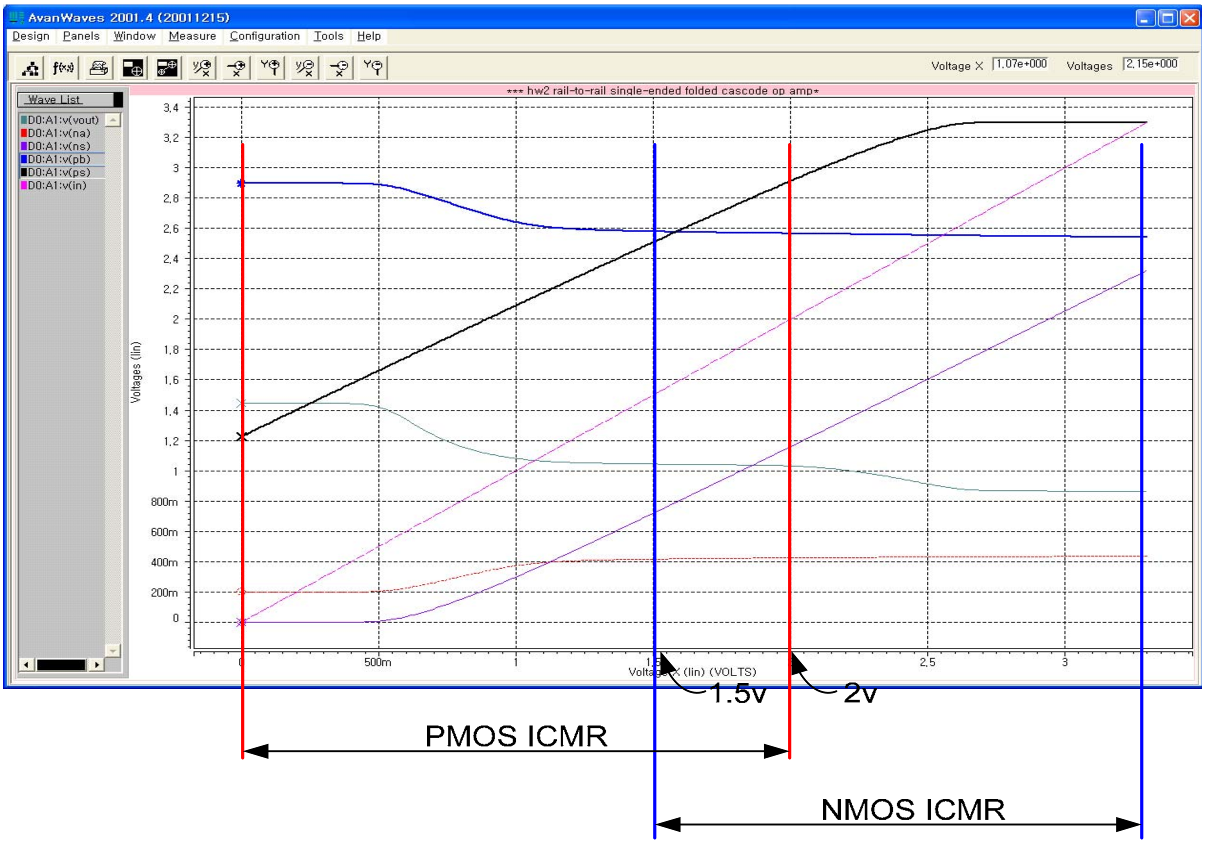
2. Power consumption

```
****   voltage sources

subckt
element   0:vvb2      0:vvb1      0:vvb3      0:vvb4      0:vdd       0:vss
volts        1.2000      2.1000      1.2000    1.5000      3.3000      0.
current      0.          0.          0.          0.          -3.6787m    20.1573a
power        0.          0.          0.          0.          12.1396m    0.

subckt
element   0:vin       0:vinb      0:vincm
volts       0.          0.          1.6500
current     0.          0.          0.
power       0.          0.          0.
```

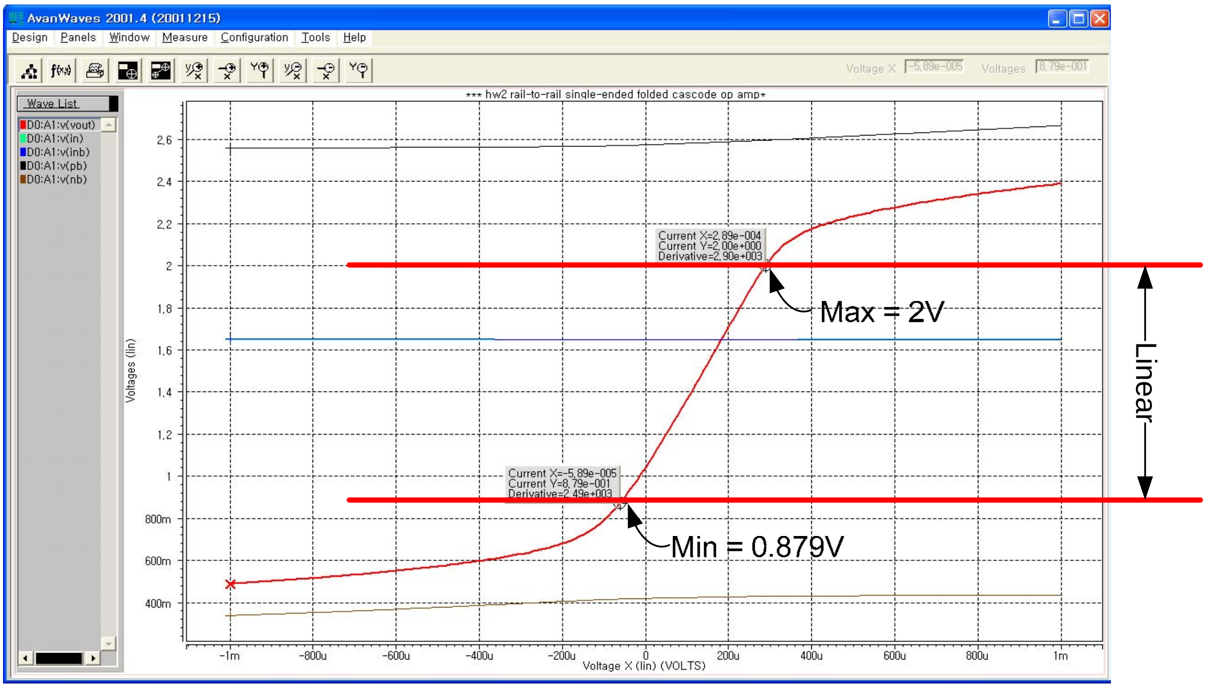
3. Slew rate SR & 0.1% settling time



4. Active input common mode voltage range(ICMR)



5. Linear output voltage range(OVR)



Voltage X -5,89e-005
Voltages 8,79e-001

Current X=2,89e-004
Current Y=2,00e+000
Derivative=2,90e+003

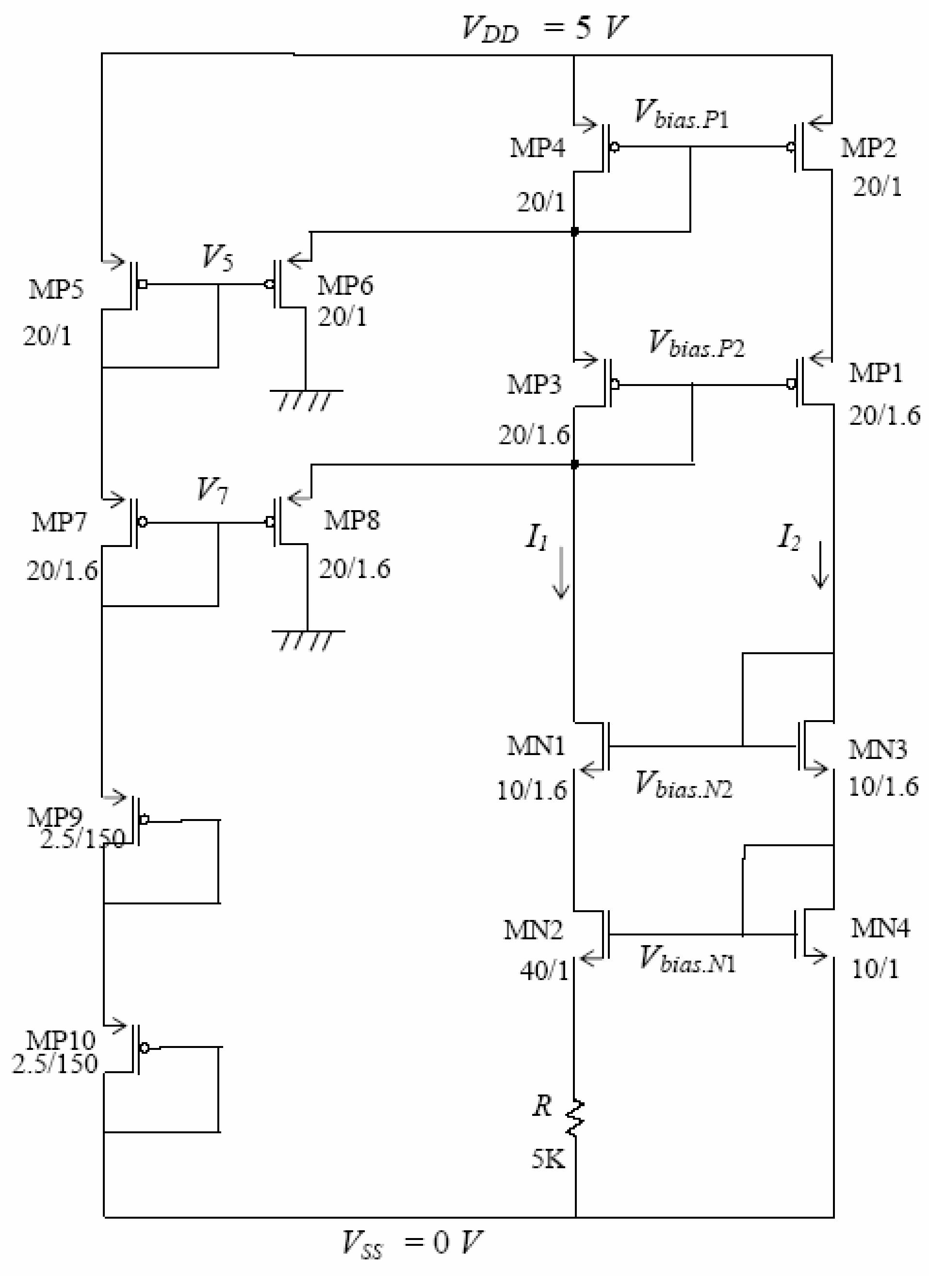
Current X=-5,89e-005
Current Y=8,79e-001
Derivative=2,49e+003

Ⅲ. *Comparison table*

Items	Hand analysis	Spice
$\sum_i W_i \times L_i$	$1473.3(\mu m)^2$	$1670.2(\mu m)^2$
DC small signal voltage gain($A_{vd}(0)$)	2477	3004
Power consumption	$OP\ \ amp : 9.9mW$	$OP\ \ amp : 12.14mW$
Slew rate(SR)	$300\frac{V}{\mu s}$	$500\frac{V}{\mu s}$
0.1% settling time(t_s) with unity gain feedback($0.1V$ step)		$6ns$
Active input common mode voltage range($ICMR$)	$V_{SS} \sim V_{DD}$	$PMOS\ : V_{SS} \sim 2V$ $NMOS\ : 1.5V \sim V_{DD}$
Gain-bandwidth product(GBW)	$111.4MHz$	$504MHz$
Linear output voltage range(OVR)		$0.879V \sim 2V$

<표 3. comparison of spec.>

Ⅳ. *Self bias & start-up circuit*



Ⅴ. *Spice source code*

```
*** HW2 rail-to-rail single-ended folded cascode OP amp*

MN7 NA X VSS VSS NMOS L=0.7U W=63.6364U as=66.8182p ad=66.8182p ps=65.7364u pd=65.7364u

MN8 NB X VSS VSS NMOS L=0.7U W=63.6364U as=66.8182p ad=66.8182p ps=65.7364u pd=65.7364u

MN5 X VB4 NA VSS NMOS L=0.7U W=33.9394U as=35.6364p ad=35.6364p ps=36.0394u pd=36.0394u

MN6 VOUT VB4 NB VSS NMOS L=0.7U W=33.9394U as=35.6364p ad=35.6364p ps=36.0394u pd=36.0394u

MP4 VOUT VB2 PB VDD PMOS L=0.35U W=27.6134U as=28.9941p ad=28.9941p ps=29.7134u pd=29.7134u

MP3 X VB2 PA VDD PMOS L=0.35U W=27.6134U as=28.9941p ad=28.9941p ps=29.7134u pd=29.7134u

MP11 PS VB1 VDD VDD PMOS   L=0.7U W=178.4U as=187.32p ad=187.32p ps=180.5u pd=180.5u

MP10 PB VB1 VDD VDD PMOS L=0.7U W=191.17U as=200.7285p ad=200.7285p ps=193.27u pd=193.27u

MP9 PA VB1 VDD VDD PMOS L=0.7U W=191.17U as=200.7285p ad=200.7285p ps=193.27u pd=193.27u

MN2 PB INB NS VSS NMOS L=0.35U W=521.27662U as=547.3405p ad=547.3405p ps=523.3766u pd=523.3766u

MN1 PA IN NS VSS NMOS L=0.35U W=521.2766U as=547.3405p ad=547.3405p ps=523.3766u pd=523.3766u

MN11 NS VB3 VSS VSS NMOS L=0.7U W=59.3939U as=62.3636p ad=62.3636p ps=61.4939u pd=61.4939u

MP2 NB INB PS VDD PMOS L=0.35U W=1020.8U as=1071.84p ad=1071.84p ps=1022.9u pd=1022.9u

MP1 NA IN PS VDD PMOS L=0.35U W=1020.8U as=1071.84p ad=1071.84p ps=1022.9u pd=1022.9u


vvb2 vb2 vss dc 1.2

vvb1 vb1 vss dc 2.1

vvb3 vb3 vss dc 1.2

vvb4 vb4 vss dc 1.5

vdd vdd vss dc 3.3

vss vss 0 dc 0

*vdd2 vdd2 vss dc 3.3


** ac with CL

CL vout 0 10pF

vin in incm ac 1

vinb inb incm ac -1

vincm incm vss dc 1.65

.ac dec 10 0.1K 100meg

*.probe vdb(vout) vp(vout)

**.op

** output range vs diff input

*einb inb incm in incm -1
```

```
*vindm in incm dc 0

*vincm incm vss dc 1.45

**.dc vindm -0.5 0.5 0.001

*.dc vindm -0.001 0.001 0.00001

*** input common mode range

*vshortin in inb dc 0

*vin in 0 dc 0

*.dc vin 0 3 0.01

**.op

* freq response

*vin in vss dc 1.45 ac 0.5

*vinb inb vss dc 1.45 ac -0.5

*.ac dec 10 1K 1000meg

*.op

** unity gain feedback with CL

*CL vout 0 20pF

**CL vout 0 0.1pF

**vin in 0 dc 1.45 pulse 1.45 1.46 0 0 0

*vin in 0 dc 1.2 pulse 1.2 2.2 0 0 0

*vshortinout inb vout dc 0

*.tran 10p 20n

***R0 VOUT VSS 0.1meg

*

.option post

*.probe v(vout) v(in) v(inb) v(ns)

*+ v(na) v(nb) v(vb1) v(vb2) v(x) v(pa) v(pb)

*+ vdb(vout)

*.probe i(MPP4) i(MNP1) i(MNP3) i(MNP10)

.inc "model0p35.txt"

.end
```