Amirkabir University of Technology
(Tehran Polytechnic)

Electronics3

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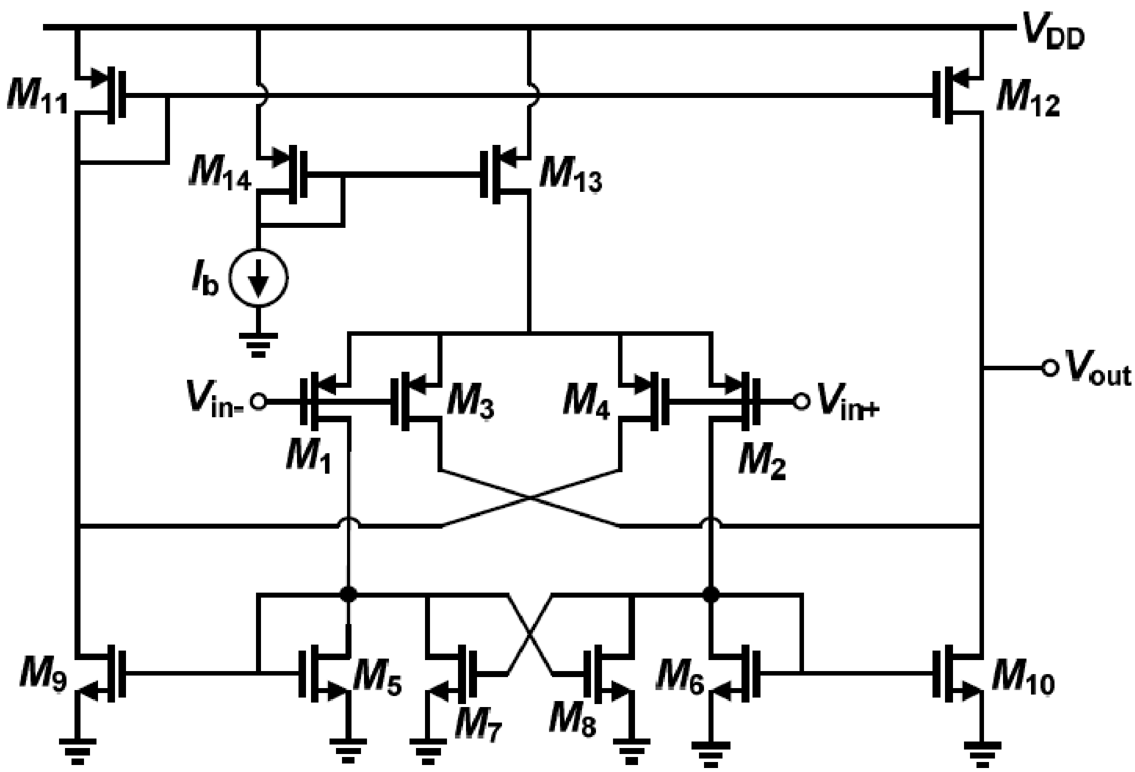
Summer99

Information:



- Open-loop DC gain ≥ 25 V/V
- Output voltage swing ≥ 0.5 V_{pp}
- CMRR ≥ 35 dB
- Settling time with 0.2% settling error in unity-gain sample & hold configuration ≤ 4 ns
- Load capacitance: $C_L = 1$ pF
- Sample & hold capacitance: $C_H = 1$ pF
- Input common-mode voltage: $V_{cmi} = 0.3$ V
- Output common-mode voltage: $V_{cmo} = 0.5$ V
- Ideal DC voltage: $V_{dc} = 0.2$ V
- Power supply voltage: $V_{DD} = 1.0$ V
- Power dissipation: as low as possible
- Technology: 90 nm CMOS

Design:

We designed the circuit using the above information and entered the numbers obtained in the software ,but the results were not obtained according to the design and a number of transistors were in the linear and cut-off area and the amount of gain and phase margin was less ,so we must We changed the design a bit to achieve the desired result ,so with experimental changes we tried the execution and made changes to get new results.

Initial design:

```
M1      1       Vin-        3      dd          pch       w=1.02u     l=100n      m=29
M2      4       Vin+        3      dd          pch       w=1.02u     l=100n      m=29

M3      Vout     Vin-       3       dd         pch       w=1.02u     l=100n      m=29
M4      2        Vin+       3       dd         pch       w=1.02u     l=100n      m=29

M5      1        1          ss       ss        nch       w=1.05u     l=100n      m=5
M6      4        4          ss       ss        nch       w=1.05u     l=100n      m=5

M7      1        4          ss       ss        nch       w=1.481u    l=100n      m=10
M8      4        1          ss       ss        nch       w=1.481u    l=100n      m=10

M9      2        1          ss       ss        nch       w=1.02u     l=100n      m=29
M10     Vout     4          ss       ss        nch       w=1.02u     l=100n      m=29

M11     2        2          dd     dd          pch       w=0.888u    l=100n      m=100
M12     Vout     2          dd     dd          pch       w=0.888u    l=100n      m=100

M13     3        Vb         dd     dd          pch       w=0.52u     l=100n      m=100
M14     Vb       Vb         dd     dd          pch       w=1.18u     l=100n      m=10
```

Preliminary design results:

subckt		
element	0:m13	0:m14
model	0:pch.15	0:pch.10
region	Saturati	Saturati
id	-675.8475u	-199.9964u
ibs	0.	0.
ibd	27.4244p	4.4002p
vgs	-440.0156m	-440.0156m
vds	-274.2425m	-440.0156m

gain= 1.9605E+01

unity_gain= 5.2808E+09

phase_margin= 5.1642E+00

subckt						
element	0:m7	0:m8	0:m9	0:m10	0:m11	0:m12
model	0:nch.8	0:nch.8	0:nch.8	0:nch.8	0:pch.15	0:pch.15
region	Cutoff	Cutoff	Cutoff	Cutoff	Saturati	Saturati
id	166.3552u	166.3552u	498.2067u	498.2047u	-381.2198u	-381.2214u
ibs	0.	0.	0.	0.	0.	0.
ibd	-3.4396p	-3.4396p	-18.6769p	-18.6769p	35.5980p	35.5984p
vgs	343.9433m	343.9433m	343.9433m	343.9433m	-355.9773m	-355.9773m
vds	343.9433m	343.9433m	644.0227m	644.0196m	-355.9773m	-355.9804m

subckt						
element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:pch.10	0:pch.10	0:pch.10	0:pch.10	0:nch.8	0:nch.8
region	Saturati	Saturati	Saturati	Saturati	Cutoff	Cutoff
id	-220.9372u	-220.9372u	-116.9848u	-116.9824u	54.5809u	54.5809u
ibs	7.9531p	7.9531p	7.9531p	7.9531p	0.	0.
ibd	19.0258p	19.0258p	10.3235p	10.3234p	-1.7198p	-1.7198p
vgs	-425.7575m	-425.7575m	-425.7575m	-425.7575m	343.9433m	343.9433m
vds	-381.8143m	-381.8143m	-81.7379m	-81.7348m	343.9433m	343.9433m

Design after changes:

```
M1      1       Vin-        3       dd          pch     w=1.02u     l=100n      m=29
M2      4       Vin+        3       dd          pch     w=1.02u     l=100n      m=29

M3      Vout     Vin-       3        dd         pch     w=1.02u     l=100n      m=29
M4      2        Vin+       3        dd         pch     w=1.02u     l=100n      m=29

M5      1        1          ss        ss        nch     w=1.05u     l=100n      m=4
M6      4        4          ss        ss        nch     w=1.05u     l=100n      m=4

M7      1        4          ss        ss        nch     w=1.481u    l=100n      m=3
M8      4        1          ss        ss        nch     w=1.481u    l=100n      m=3

M9      2        1          ss        ss        nch     w=1.02u     l=100n      m=120
M10     Vout     4          ss        ss        nch     w=1.02u     l=100n      m=120

M11     2        2          dd      dd          pch     w=0.888u    l=100n      m=40
M12     Vout     2          dd      dd          pch     w=0.888u    l=100n      m=40

M13     3        Vb         dd      dd          pch     w=0.52u     l=100n      m=100
M14     Vb       Vb         dd      dd          pch     w=1.18u     l=100n      m=10

Ib      Vb       dd          dc=200u

VDD     dd        0          dc=1
VSS     ss        0          dc=0
```

Results after changes:

gain= 3.1033E+01
unity_gain= 5.1556E+09
phase_margin= 6.7645E+01

subckt		
element	0:m13	0:m14
model	0:pch.15	0:pch.10
region	Saturati	Saturati
id	-683.5266u	-199.9965u
ibs	0.	0.
ibd	28.4371p	4.4002p
vgs	-440.0156m	-440.0156m
vds	-284.3695m	-440.0156m

subckt						
element	0:m7	0:m8	0:m9	0:m10	0:m11	0:m12
model	0:nch.8	0:nch.8	0:nch.8	0:nch.8	0:pch.15	0:pch.15
region	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati
id	92.0080u	92.0080u	2.4338m	2.4338m	-2.2654m	-2.2654m
ibs	0.	0.	0.	0.	0.	0.
ibd	-1.1343p	-1.1343p	-47.6996p	-47.6994p	24.1007p	24.1007p
vgs	378.0890m	378.0890m	378.0890m	378.0890m	-602.5133m	-602.5133m
vds	378.0890m	378.0890m	397.4867m	397.4852m	-602.5133m	-602.5148m

subckt

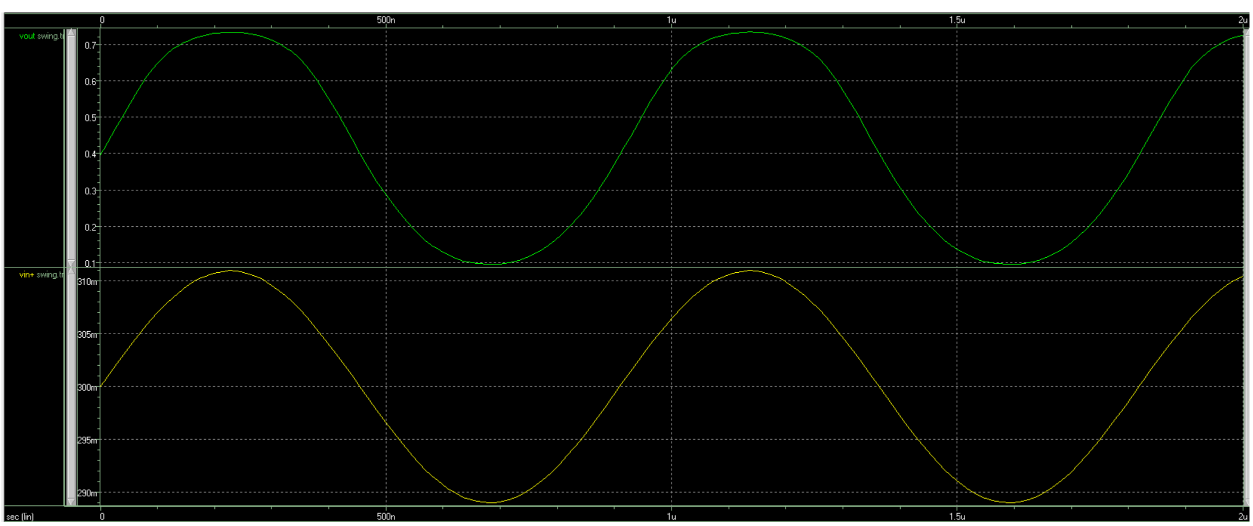
element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:pch.10	0:pch.10	0:pch.10	0:pch.10	0:nch.8	0:nch.8
region	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati
id	-173.3389u	-173.3389u	-168.4217u	-168.4214u	81.3256u	81.3256u
ibs	8.2468p	8.2468p	8.2468p	8.2468p	0.	0.
ibd	18.0355p	18.0355p	17.4730p	17.4730p	-1.5124p	-1.5124p
vgs	-415.6305m	-415.6305m	-415.6305m	-415.6305m	378.0890m	378.0890m
vds	-337.5415m	-337.5415m	-318.1453m	-318.1439m	378.0890m	378.0890m

subckt

element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:pch.10	0:pch.10	0:pch.10	0:pch.10	0:nch.8	0:nch.8
region	Saturati	Saturati	Saturati	Saturati	Saturati	Saturati
id	-173.3389u	-173.3389u	-168.4217u	-168.4214u	81.3256u	81.3256u
ibs	8.2468p	8.2468p	8.2468p	8.2468p	0.	0.
ibd	18.0355p	18.0355p	17.4730p	17.4730p	-1.5124p	-1.5124p
vgs	-415.6305m	-415.6305m	-415.6305m	-415.6305m	378.0890m	378.0890m
vds	-337.5415m	-337.5415m	-318.1453m	-318.1439m	378.0890m	378.0890m

So the circuit has obtained the desired values

For swinging ,we apply a sinusoidal input to the circuit so that the output wave does not break



Transient mode response:

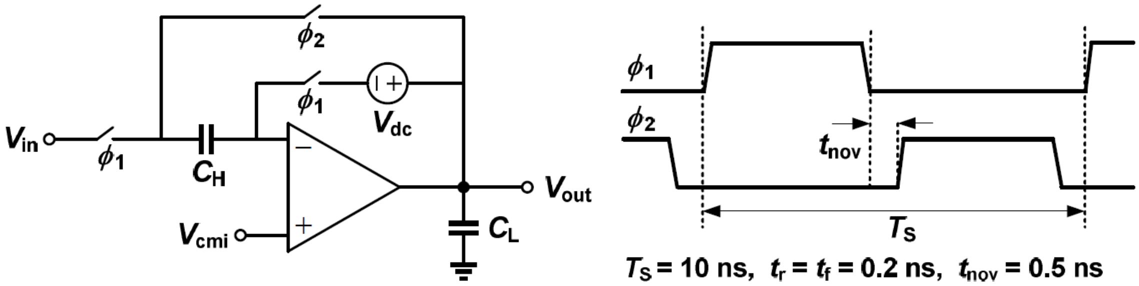
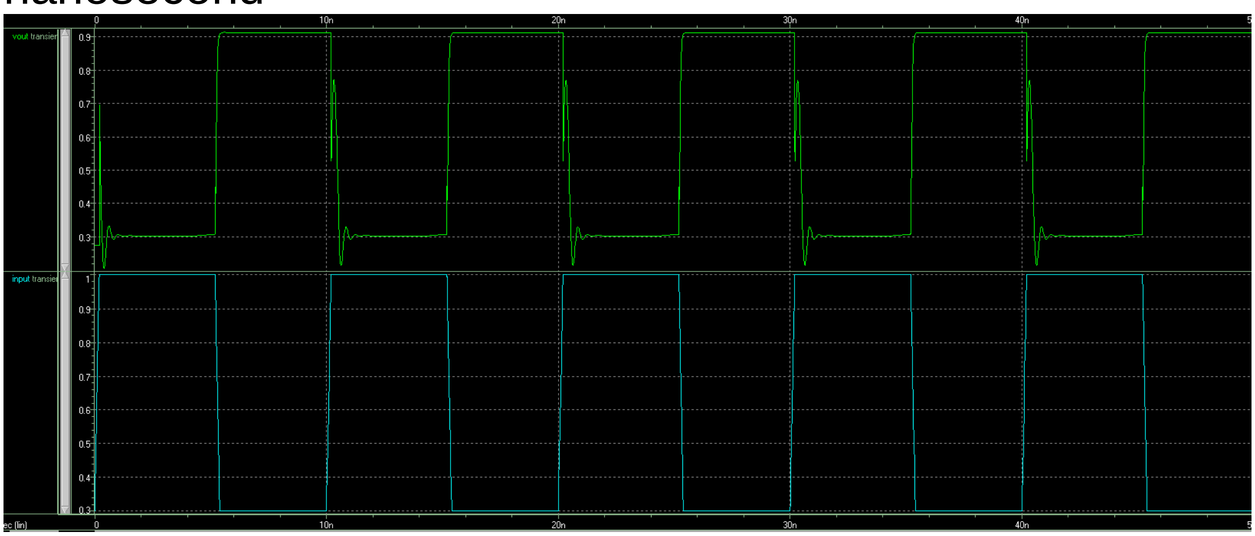


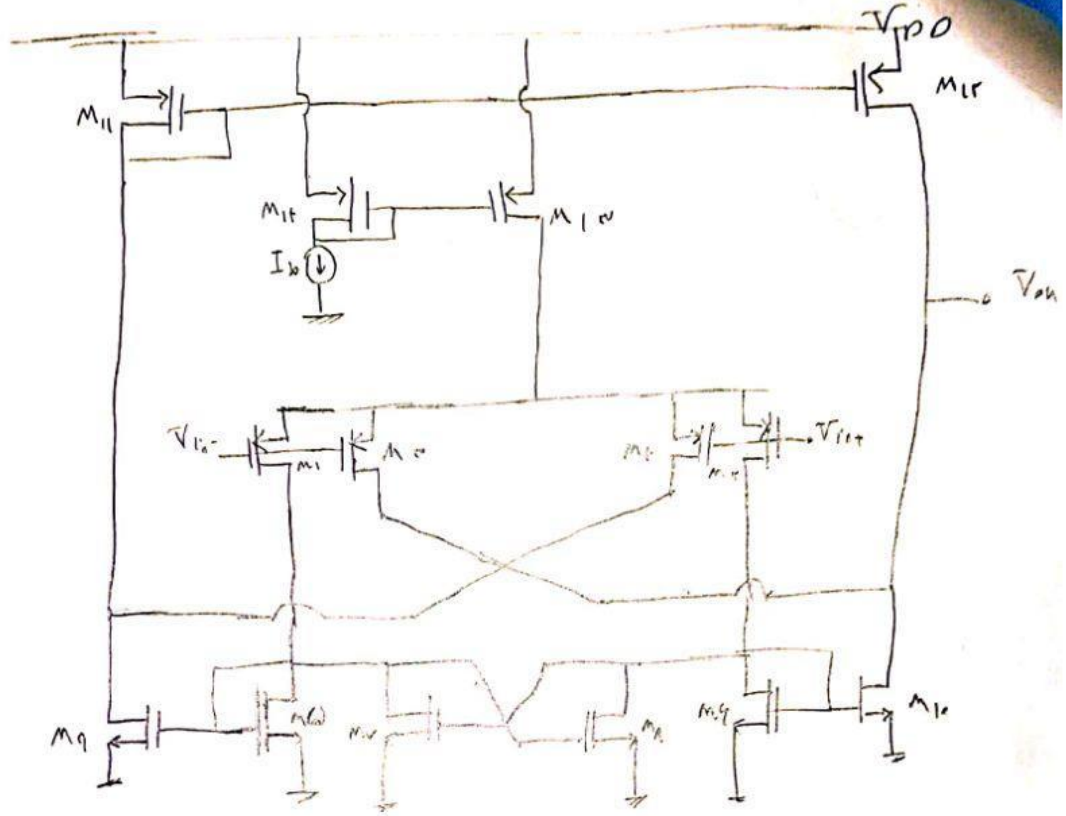
Fig. 2: Transient simulation circuit.

We need to add two capacitors and a switch that have two phase difference switches and follow the input output with phase difference.

The settling time is about one nanosecond



Theoretical calculations:



$$\left(\frac{W}{L}\right)_{۱۳} = ۱۰\left(\frac{W}{L}\right)_{۱۴} \qquad \left(\frac{W}{L}\right)_{۵,۶} = ۴\left(\frac{W}{L}\right)_{۷,۸} \qquad \left(\frac{W}{L}\right)_{۹,۱۰} = ۵\left(\frac{W}{L}\right)_{۵,۶}$$

$$\left(\frac{W}{L}\right)_{۱۱} = \left(\frac{W}{L}\right)_{۱۲} \implies I_{D۱۳} = \frac{\left(\frac{W}{L}\right)_{۱۳}}{\left(\frac{W}{L}\right)_{۱۴}} \times I_{۱۴} = ۲mA$$

$$I_{D۱} = I_{D۲} = I_{D۳} = I_{D۴} = ۰/۵mA \qquad g_{m(۱,۲,۳,۴)} = \frac{۲I_{D۱}}{V_{eff}} = ۶/۶mS$$

$$I_{D۵} = I_{D۶} = ۰/۴mA \implies I_{D۷} = I_{D۸} = ۰/۱mA \qquad g_{m(۵,۶)} = ۵/۳۳mS$$

$$I_{D۹} = I_{D۱۰} = \frac{\left(\frac{W}{L}\right)_{۹}}{\left(\frac{W}{L}\right)_{۵}} * I_{D۵} = ۲mA \qquad g_{m(۷,۸)} = ۱/۳۳mS \qquad g_{m(۹,۱۰)} = ۲۶/۶mS$$

$$I_{D۱۲} = I_{D۱۱} = -I_{D۴} + I_{D۹} = ۱/۵mA \qquad g_{m(۱۱,۱۲)} = ۲۰mS$$

$$g_{m(۱۳)} = ۲۶/۶mS \qquad g_{m(۱۴)} = ۲/۶۶mS \qquad r_{ds۱۳} = ۵K\Omega \qquad r_{ds۱۴} = ۵۰K\Omega$$

$r_{ds(1,2,3,4)} = \frac{1}{\lambda I_{D_1}} = ۲۰K\Omega \qquad r_{ds(5,6)} = ۲۵K\Omega$

$r_{ds(7,8)} = ۱۰۰K\Omega \qquad r_{ds(9,10)} = ۵K\Omega \qquad r_{ds(11,12)} = ۶/۶۶K\Omega$

$R_{out} = r_{ds12} \| r_{ds4} \| r_{ds10} = ۲۰K\Omega \| ۵K\Omega \| ۶/۶۶K = ۲/۵K\Omega$

$I_{SC} = i_{d4} + i_{d10} - i_{d12}$

$i_{ds4} = \left(0 + \frac{V_{in}}{۲}\right) g_{m4} = ۳/۳۳m\, V_{in}$

$i_{d2} = i_{d9} + i_{d8} \Rightarrow \left(0 - \frac{V_{in}}{۲}\right) g_{m2} = V_A g_{9} - V_A g_{m8}$

$-۳/۳۳\, m\, V_{in} = V_A\,(۵/۳۳m - ۱/۳۳m)$

$V_A = -\frac{۳/۳۳ V_{in}}{۴} = -۰/۸۳۲۵ V_{in}$

$i_{d10} = V_A g_{m10} = -۲۲/۱۹ (m) V_{in}$

$i_{d9} = -V_A g_{m9} = ۲۲/۱۹(m) V_{in}$

$i_{d11} = i_{d9} - i_{d4}$

$i_{d4} = i_{d2} = ۲۲/۱۹m(V_{in}) + ۳/۳۳(m) V_{in} = ۲۵/۵۲m(V_{in})$

$i_{d12} = i_{d11} = ۲۵/۵۲m\, V_{in}$

$I_{SC} = (۳/۳۳ - ۲۲/۱۹ - ۲۵/۵۲)(m) V_{in} = -۴۴/۳۸(m) = G_m$

$A_{de} = -G_m R_{out} = ۴۴/۳۸\, m \times ۲/۵K = ۱۱۰/۹۵$

$$I_{sc}' = i_{d۱۰}' + i_{d۲}' - i_{d۱۲}'$$

$$\frac{۰ - V_x}{r_{d۱۲}} = ۴(V_x - V_{cm})\, g_{m۱} \Rightarrow V_x = ۰/۹۹\, V_{cm}$$

$$i_{d۲} = i_{d۱} = (V_x - V_{cm})\, g_{m۱} = ۶/۶۶ \times ۱۰^{-۵}\, V_{in}$$

$$i_{d۱} = i_{d۵} + i_{d۷} = ۶/۶۶ \times ۱۰^{-۵}\, V_{in} = -V_B\,(۵/۳۳ + ۱/۳۳) \times ۱۰^{-۴}$$

$$V_B = ۰/۰۱\, V_{in}$$

$$i_{d۹} = V_B\, g_{m۹} = ۲۶/۶ \times ۱۰^{-۵}\, V_{in}$$

$$i_{d۱۱} = i_{d۹} - i_{d۴} = ۲ \times ۱۰^{-۴}\, V_{in} = i_{d۱۲}$$

$$i_{d۱۰} = V_B\, g_{m۱۰} = ۲۶/۶ \times ۱۰^{-۵}\, V_{in}$$

$$I_{sc} = (۲۶/۶۶ + ۶/۶۶ - ۲۰) \times ۱۰^{-۵}\, V_{in} = ۱۳/۳۲ \times ۱۰^{-۵}\, V_{in}$$

$$G_m = ۱۳/۳ \times ۱۰^{-۵}$$

$$A_{cm} = -G_m R_{out} = ۰/۳۳۳۳۵$$

$$CMMR = ۲۰ \log \frac{A_{dm}}{A_{cm}} = ۲۰ \log \frac{۱۱۰/۹۵}{۰/۳۳۳} \simeq ۵۰ > ۳۵$$

$$\omega_{p۱} = \frac{۱}{C_L R_{out}} = \frac{۱}{۱p \times ۲/۵K} = ۴ \times ۱۰^{۸}\ \frac{rad}{s}$$

$$\omega_t = \omega_{p۱} A_{de} = ۴ \times ۱۰^{۸} \times ۱۱۰/۹۵ = ۴/۴۳۸ \times ۱۰^{۱۰}\ \frac{rad}{s}$$

$SR^+ \Rightarrow M_۳, M_۴: off \Rightarrow M_۶, M_۸: off \Rightarrow M_{۱۰}: off,\ M_۱, M_۲: on$

$$\overset{۲mA}{I_{D۱۲}} = I_{D۱} + I_{D۲} = ۲ I_{D۱} \Rightarrow I_{D۱} = ۱mA \Rightarrow I_{D۱} = I_{D۲}$$

$$I_{D1} = I_{D5} + I_{D7} = 1mA \Rightarrow I_{D7} = 0.2\,mA \Rightarrow I_{D5} = 0.8\,mA$$

$4I_{D7}$

$$I_{D9} = \frac{\left(\frac{W}{L}\right)_9}{\left(\frac{W}{L}\right)_5} \times I_{D5} = 4mA$$

$$I_{D11} = I_{D9} - \cancel{I_{D4}} = 4mA \Rightarrow I_{D11} = I_{D12} = 4mA$$

$$I_{CL} = I_{12} - I_{D2} = 4 - 1 = 3mA$$

$$(SR)^+ = \frac{I_{CL}}{C_L} = \frac{5m}{1p} = 5 \times 10^9 \frac{V}{s}$$

$$(SR)^- \Rightarrow M_{(1,3,5,7,9)}: off \qquad M_2, M_4: on$$

$$I_{D2} = I_{D4} = 1mA \qquad I_{D2} = I_{D6} + I_{D8} \Rightarrow I_{D8} = 0.2\,mA$$

$$I_{D6} = 0.8\,mA \qquad I_{D10} = 5 \times 0.8 = 4mA$$

$$I_{D11} = -I_{D4} = -1mA \qquad I_{D11} = I_{12} = -1mA$$

$$I_{CL^-} = 4m + 1m = 5mA$$

$$(SR)^- = \frac{5m}{1p} = 5 \times 10^9 \frac{V}{s}$$

$$t_s = \frac{\Delta V - \sqrt{2}\, V_{eff}}{SR} - \frac{1}{\beta \omega_t} Ln\left(\frac{\delta\%}{100}\right)$$

$$= \frac{1 - \sqrt{2} \times 0.15}{5 \times 10^9} - \frac{1}{0.643 \times 10^{10}} Ln\left(2 \times 10^{-3}\right) \Rightarrow$$

$$0.15\,ns + 1.4\,ns = 1.55\,ns$$

$\mu_n C_{ox} = ۶۰ \frac{\mu A}{V^2} \qquad \mu_p C_{ox} = ۱۵۰ \qquad L_{min} = ۰/۱ \mu m$

$\left(\frac{W}{L}\right) = \frac{۲ I_D}{\mu C_{ox} V_{eff}^2} \qquad \left(\frac{W}{L}\right)_{۱۴} = \frac{۴۰۰}{۱۵۰ \times (۰/۱۵)^2} = ۱۱۸/۵۱$

$W_{۱۴} = ۱۱/۸۵۱ \mu m \qquad \left(\frac{W}{L}\right)_{۱۳} = \frac{۲۰۰۰}{۱۵۰ \times ۰/۰۲۲۵} = ۵۲۹/۵۹ \Rightarrow W_{۱۳} = ۵۲/۹۵۹ \mu m$

$\left(\frac{W}{L}\right)_{۱,۲,۳,۴} = \frac{۱۰۰۰}{۱۵۰ \times ۰/۰۲۲۵} = ۲۹۶/۲۹ \Rightarrow W_{۱,۲,۳,۴} = ۲۹/۶۲۹ \mu m$

$\left(\frac{W}{L}\right)_{۵,۶} = \frac{۸۰۰}{۶۰۰ \times ۰/۰۲۲۵} = ۵۹/۲۶ \Rightarrow W_{۵,۶} = ۵/۹۲۶ \mu m$

$\left(\frac{W}{L}\right)_{۷,۸} = \frac{۲۰۰}{۶۰۰ \times ۰/۰۲۲۵} = ۱۴/۸۱ \qquad W_{۷,۸} = ۱/۴۸۱ \mu m$

$\left(\frac{W}{L}\right)_{۹,۱۰} = \frac{۴۰۰۰}{۶۰۰ \times ۰/۰۲۲۵} = ۲۹۶/۲۹ \Rightarrow W_{۹,۱۰} = ۲۹/۶۲۹ \mu m$

$\left(\frac{W}{L}\right)_{۱۱,۱۲} = \frac{۳۰۰۰}{۱۵۰ \times ۰/۰۲۲۵} = ۸۸۸/۸ \Rightarrow W_{۱۱,۱۲} = ۸۸/۸۸۸ \mu m$