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Problem 1 (FOM1)

(a)、(b)小題已寫在 HW2.xlsx 裡，圖 1 為 simulation results. FOM1 為 0.217

(C)

```
**** mosfets


subckt
element  0:m1
model    0:n_18.1
region     Saturati
 id          6.1784u
 ibs      -1.048e-21
 ibd      -298.5559a
 vgs       451.5000m
 vds       554.6994m
 vbs         0.
 vth       449.1399m
 vdsat      71.4434m
 vod         2.3601m
 beta        4.5681m
 gam eff   507.4460m
 gm        128.1826u
 gds         2.0262u
 gmb        24.8738u
 cdtot       9.0578f
 cgtot      16.6239f
 cstot      19.7697f
 cbtot      19.0138f
 cgs        11.0421f
 cgd         2.4695f
```

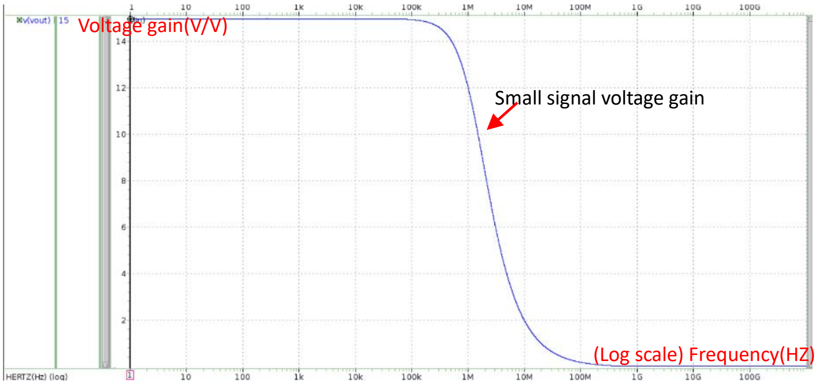

圖 1 frequency response of FMO1.

(d)In Common source, Av = -gm*(RL//ro)= $-128.183\times10^{-6}\times\frac{153000*493534.696}{153000+493534.696}$=14.971. The simulation result is 15.

Therefore, Error rate = $\frac{14.971-15}{15}=0.19\%$

(e)

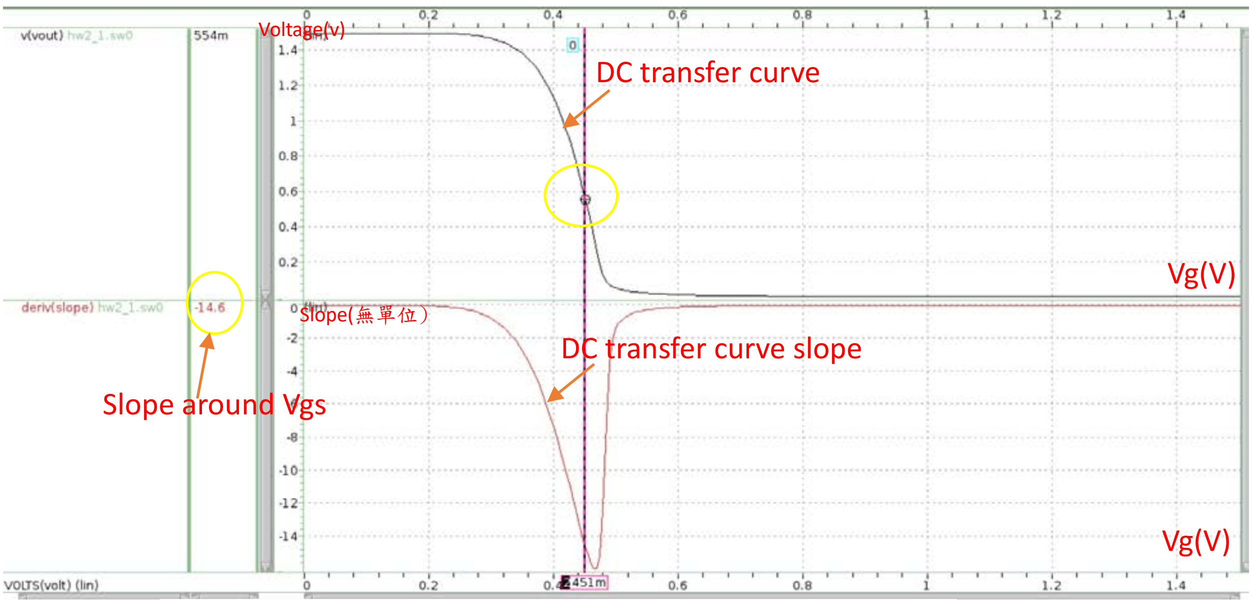

圖 2 DC transfer curve and its slope

Discussion: 可以看圖上黃色圈起來的部分，在 Vgs 附近的斜率是-14.6。在 DC transfer curve 上圖形的斜率代表 vlotage gain，所以與圖 1 模擬出來的結果 15 相差不大，Error rate $= \frac{14.6-15}{15}$ = 2.66%。誤差來源可能是在寫 hspice 的時候，DC SWEEP 掃的範圍不夠細，或是在 waveform viewer 裡頭 cursor 的精準度只到小數後 3 位，所以才有微小的差異

(f)

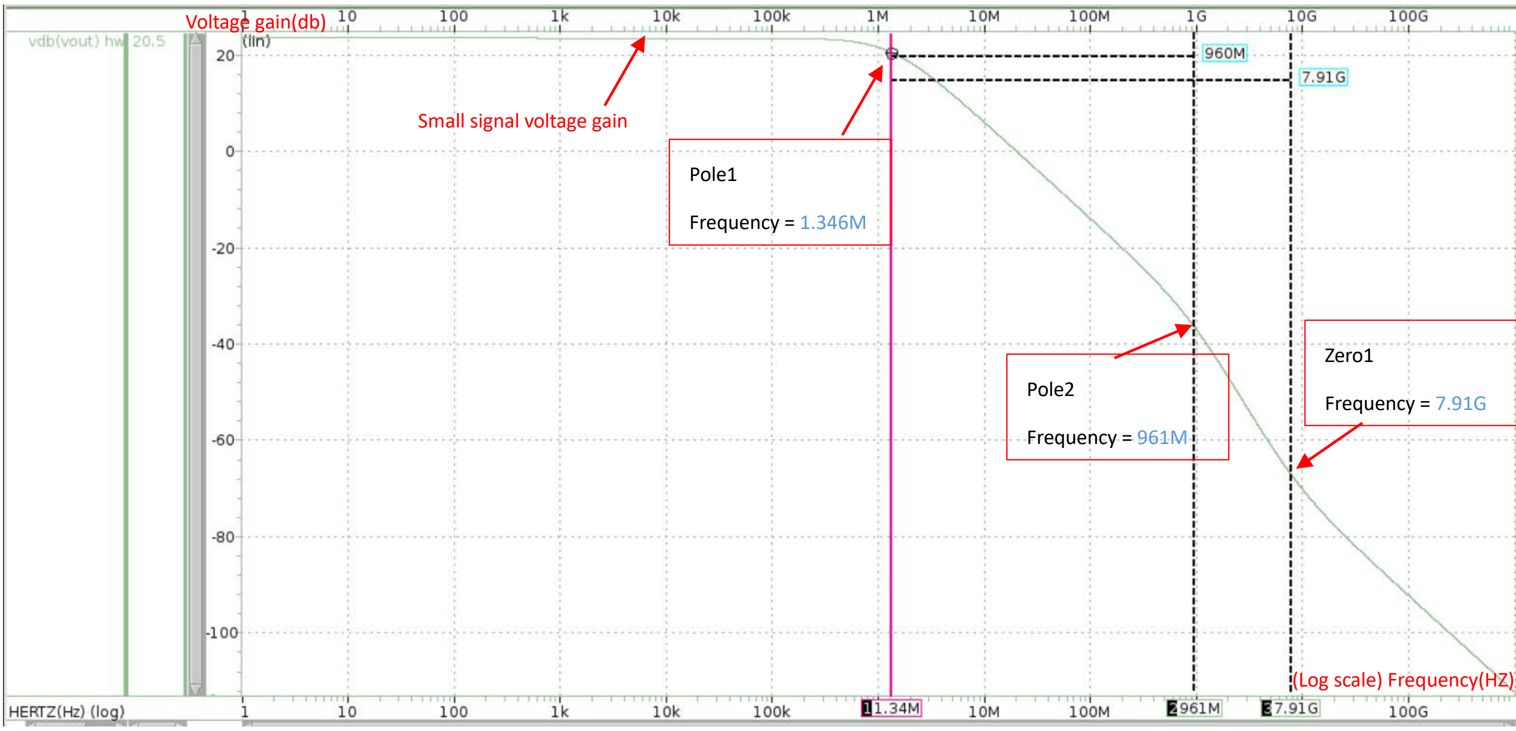

圖 3 DC pole zero analysis

```
The 1th iter
>temperature = 25

      poles (rad/sec)                 poles ( hertz)

real            imag            real

-8.45860x          0.            -1.34623x          0.
-6.03668g          0.            -960.768x          0.


      zeros (rad/sec)                 zeros ( hertz)

real            imag            real             imag

49.7205g          0.            7.91326g          0.
```

圖 4 part of *.pz0 file

hand calculation: 使用 high frequency model of Common source, (Notation: R = $R_L//r_o$)

$$\frac{V_{out}}{V_{in}}\frac{(C_{GD}-g_m)R}{as^2+bs+1}\ ,where\ \begin{Bmatrix} a=R_sR(C_{GS}C_{GD}+C_{DB}C_{GD}+C_{GS}C_{DB}+C_{GD}C_L+C_{GS}C_L) \\ b=(1+g_mR)C_{GD}R_S+R_SC_{GS}+R(C_{DB}+C_{GD}+C_L) \end{Bmatrix}$$

There is a zero

$$w_z=\frac{g_m}{C_{GD}}\ ,\ f_z=\frac{128.183\ x\ 10^{-6}}{2.470\ x\ 10^{-15}x\ 2\pi}=8.26GHz$$

There are two poles , supposed $w_{p2}\gg w_{p1}$ (dominant pole approximation)

$$w_{p1}=\frac{1}{b}=\frac{1}{(1+g_mR)C_{GD}R_S+R_SC_{GS}+R(C_{DB}+C_{GD}+C_L)}$$

$$w_{p2}=\frac{b}{a}=\frac{(1+g_mR)C_{GD}R_S+R_SC_{GS}+R(C_{DB}+C_{GD}+C_L)}{R_SR(C_{GS}C_{GD}+C_{DB}C_{GD}+C_{GS}C_{DB}+C_{GD}C_L+C_{GS}C_L)}$$

Using the value from 圖 5 , I can get two poles : (Note: $C_L=1pF$、$R_s=10kohm$)

$$f_{p1}=\frac{w_{p1}}{2\pi}=1.305MHz$$

$$f_{p2}=\frac{w_{p2}}{2\pi}=\ 1234.6\text{MHz}$$

可以發現跟 simulation results 仍然有些許的誤差，可能來自於手算過程簡略了一些數字或者是$w_{p2}\gg w_{p1}$這個假設，但w_{p2}的值相對於w_{p1}還不夠大，所以有誤差。不過整體來說 hand calculation 跟 simulation results 的數量級還算是對的。f_{p1}差不多都在 1M 這個數量級;f_{p2}差不多都在 1000M 這個數量級;f_z也差不多在 7~8G 左右的數量級。

```
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  vds        554.6994m
  vbs          0.
  vth        449.1399m
  vdsat       71.4434m
  vod          2.3601m
  beta         4.5681m
  gam eff    507.4460m
  gm         128.1826u
  gds          2.0262u
  gmb         24.8738u
  cdtot        9.0578f
  cgtot       16.6239f
  cstot       19.7697f
  cbtot       19.0138f
  cgs         11.0421f
  cgd          2.4695f
```

圖 5 small signal parameter list

(g)The followings are my observations of how to maximize FOM1.

1. -3db bandwidth in CS is $\frac{1}{R_L\times C_L}$. So in the only thing I can change is R_L.Therefore, I try to make R_L small.

However it cannot be too small, or the current would be large because I = $\frac{VDD-Vout}{R_L}$, assume NMOS is in saturation, Vout and R_L decreases so current increases)

2. The bias current is proportional to $\frac{W}{L}$、$(V_{GS}-V_{th})$. I try to minimize $\frac{W}{L}$ $ratio$ and avoid the NMOS to be in cutoff region at the same time. Also I want to make sure is equal to 15. So I decrease the $(V_{GS}-V_{th})$. And try to find a balance point between these influences.

(The reason why I decrease $(V_{GS}-V_{th})$: without consideration of ro, voltage is gm*RL. gm = $\frac{I_D}{V_{ov}/2}$, VDD-I_d*RL > V_{ov} to make sure NMOS is in the saturation region. So, RL < $\frac{VDD-V_{ov}}{I_D}$. Voltage gain $=\text{gm}\times R_L<\frac{2(VDD-V_{ov})}{V_{ov}}$. $So\ the\ smaller\ Vov\ is\ the\ larger\ voltage\ gain\ becomes.$)

Problem 2 (FOM2)

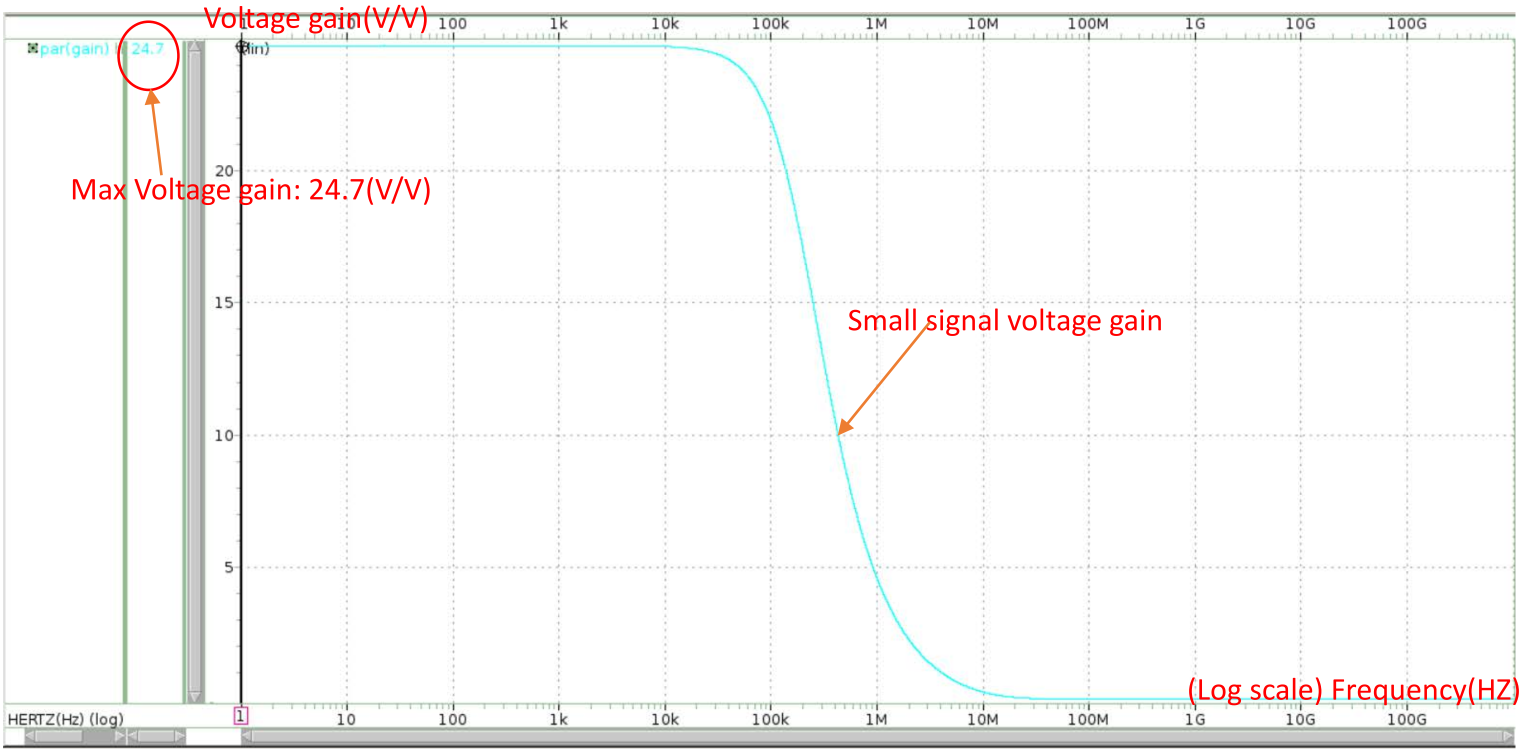

圖 6 frequency response of NMOS

The followings are my observations of how to maximize FOM2:

Av = $gm \times (R_L//r_o)$

1. I noticed the V_{GS} can dramatically influence the gain. As initially I set V_{GS} at around 0.45V. I try my best to maximize the gain, but gain was always around 16~17(V/V). And when I set V_{GS} at around 0.35, the voltage gain increased dramatically. So I try to make the V_{GS} as small as possible.
2. By decreasing Vgs, it also reduced current but increase r_o. So the difference between R_L and r_o becomes larger. Therefore I can increase R_L, *the value* of $R_L//r_o$ will be close to R_L as long as r_o is still very large. In my design r_o *is around* 6.37*Mohm*, and R_L=880kohm.
3. Also I try to make Vgs as close to Vth as much. According to my analysis in (g), the smaller Vov is, the bigger the voltage gain becomes. So in my

design Vov is only 3.55mV.

Hspice code

```
*****problem 1 (FOM1)********

.prot

.lib "cic018.l" TT

.unprot


.temp 25


.option post


M1 Vout Vg gnd gnd n_18 w = 6.6u l = 0.47u m = 1


v1 Vdd 0 1.5

v2 Vgs 0  DC 0.4515 AC 1

v3 gnd 0 0

C1 Vout 0 1p

Rs Vgs Vg 10k

RL VDD Vout 153k $gain = gm*(RL//ro), but ro > RL, RL < 19076 to be in
saturation, RL the bigger the better
```

```
.DC v2 0 1.5 0.005
.probe DC
+current = I(M1)
+vth = vth(M1)
+vov = par('V(Vg)-Vth(M1)')
+vsat = par('V(Vg)-Vth(M1)-V(Vout)')
+slope = deriv('V(Vout)')
.AC DEC 10k 1 1T
.probe AC
+gain = par("V(Vout)")
.pz V(Vout) v2   $pole zero analysis
.op
.meas AC Gainmax MAX vdb(Vout)
.meas AC bandwidth WHEN Vdb(Vout) = 'Gainmax-3'
.end
*****problem 2 (FOM2)********




.prot
.lib "cic018.l" TT
.unprot
```

```
.temp 25

.option post

M1 Vout Vg gnd gnd n_18 w = 49u l = 10u m = 1
v1 Vdd 0 1.5
v2 Vgs 0 DC 0.32 AC 1
v3 gnd 0 0
C1 Vout 0 1p
Rs Vgs Vg 10k
RL VDD Vout 880k
.DC v2 0 1.5 0.1
.probe DC
+current = I(M1)
+vth = vth(M1)
.AC DEC 10k 1 1T
.probe AC
+gain = par('V(Vout)')
+cdb = lx29(M1)
.pz V(Vout) v2   $pole zero analysis
.op
```

```
.meas Gainmax MAX Vdb(Vout)

.meas bandwidth when Vdb(Vout) = 'Gainmax-3'

.end
```