HW3

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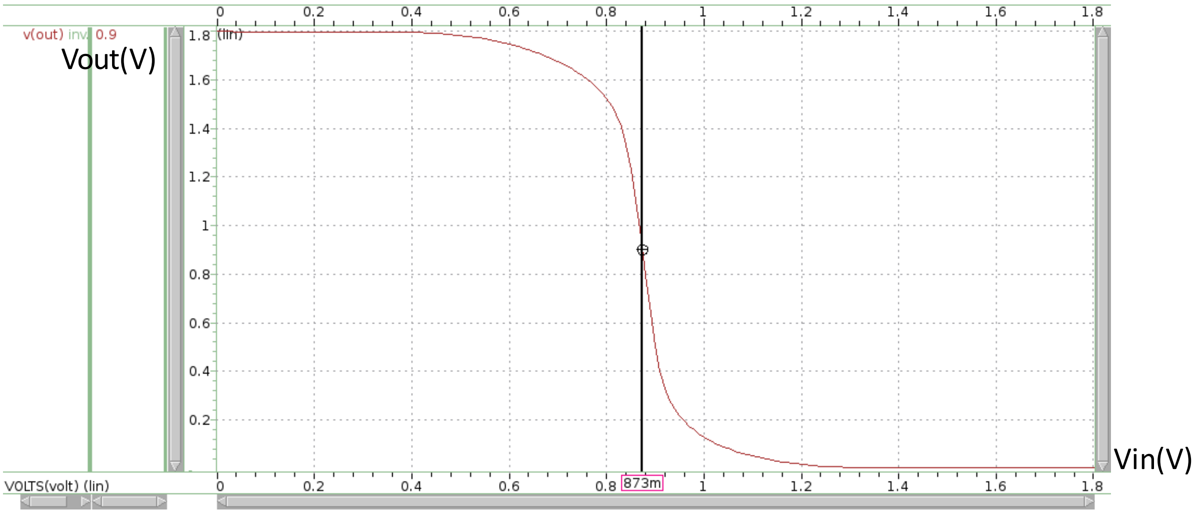
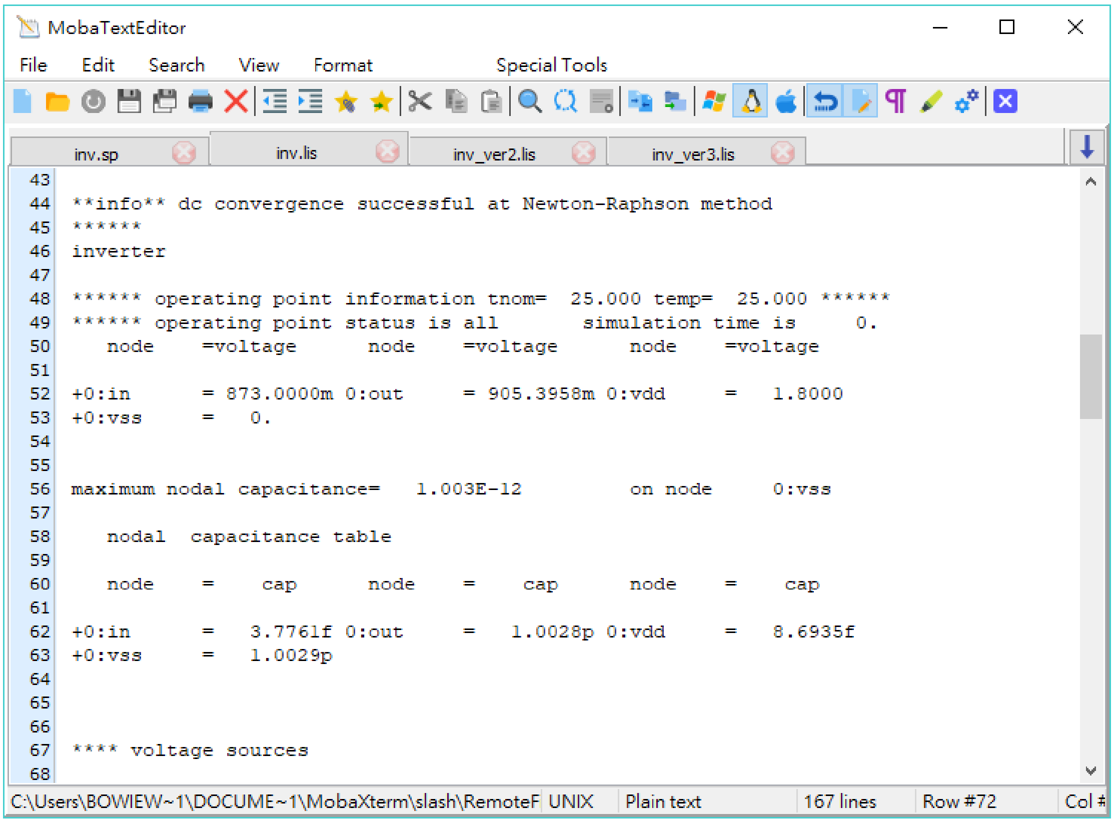
1.

(a) 已知 inverter 的$g = 1$，從 inverter $(\frac{W}{L})_p:(\frac{W}{L})_n = 3:1$的 dc curve 可知，

transition point 為 Vin=873mV：



將 Vin 設為 873mV，並求此情形下的 Cg：




```
**info** dc convergence successful at Newton-Raphson method
******
inverter

****** operating point information tnom=  25.000 temp=  25.000 ******
****** operating point status is all      simulation time is     0.
   node     =voltage      node     =voltage      node     =voltage

+0:in      = 873.0000m 0:out     = 905.3958m 0:vdd     =   1.8000
+0:vss     =   0.


maximum nodal capacitance=   1.003E-12         on node     0:vss

   nodal  capacitance table

   node     =     cap       node     =     cap       node     =     cap

+0:in      =    3.7761f 0:out     =    1.0028p 0:vdd     =    8.6935f
+0:vss     =    1.0029p



**** voltage sources
```

在一般情況下取$\rho = 4$，已知：

$$F = GBH$$

$$set\ G = 1$$

$$B = 1(nobranch)$$

$$H = \frac{C_{out}}{C_{in}} = \frac{80 \times 10^{-12}}{3.7761 \times 10^{-15}} \approx 21186$$

$$F = 21186$$

$$N = log_{\rho}(F) = log_4(F) = 7.1854$$

Take N=7,

$$G_{new} = \prod_{i=1}^{7} g_i = 1 \ \ (design\ spec.)$$

$$\therefore F_{new} = F$$

$$\therefore \rho_{inv} = F^{\frac{1}{7}} = 4.1496$$

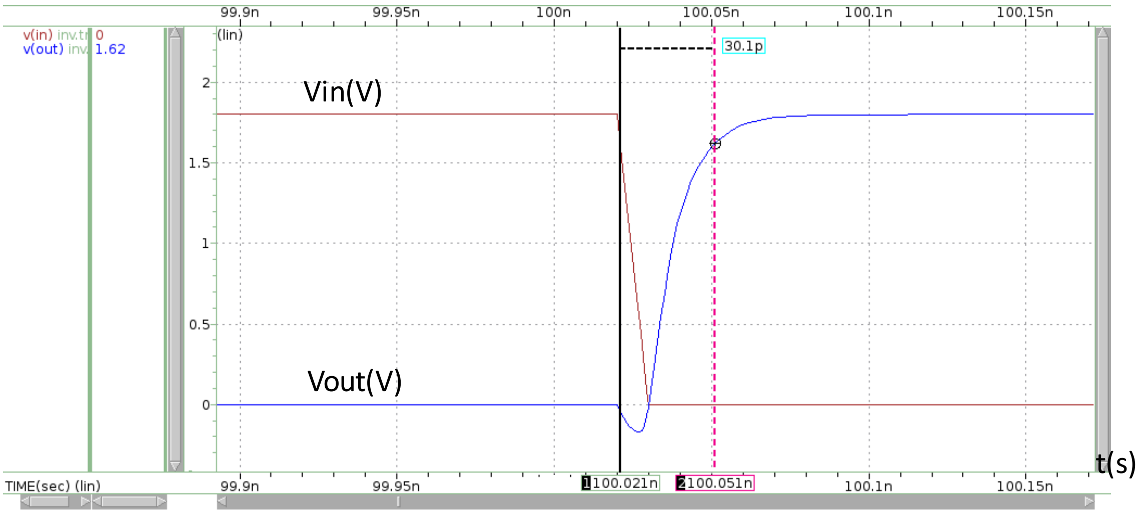
ρ_{inv}與假設相近故可驗證假設正確。

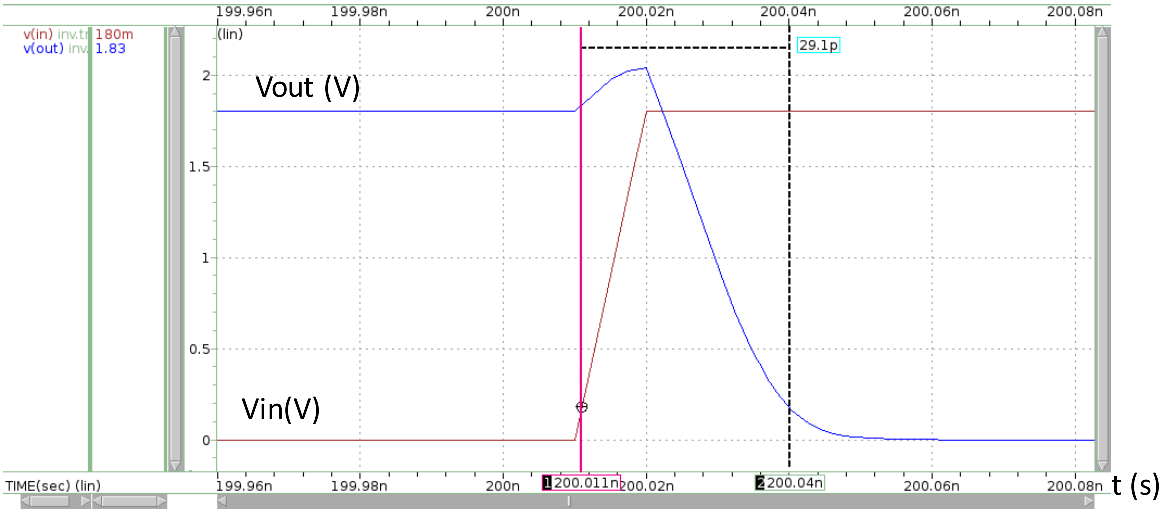
$$P = \sum_{i=1}^{7} p_i = 7$$

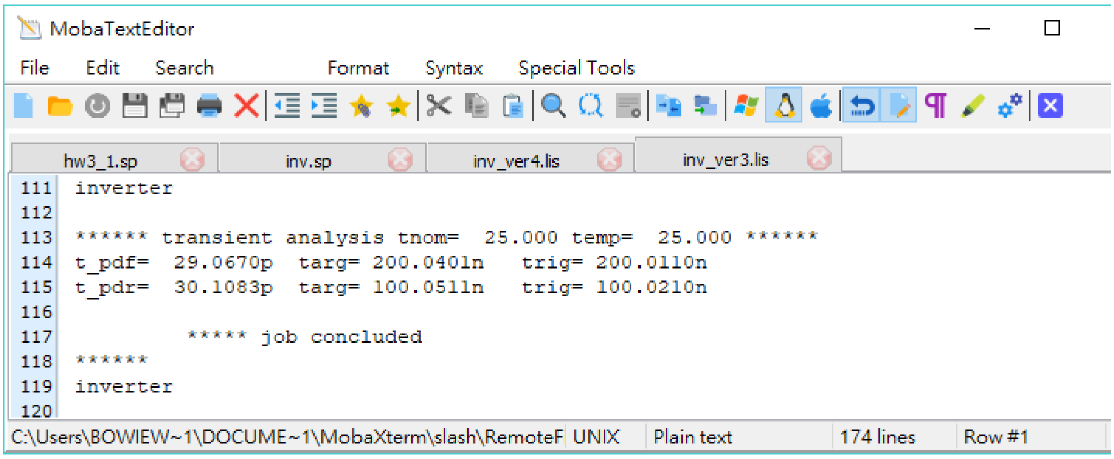
$$D = N\rho_{inv} + P = 36.0472$$

(b)

在此為方便計算，故先求出第一顆指定 inverter 的 pull-up propagation delay 與 pull-down propagation delay：







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hw3_1.sp | inv.sp | inv_ver4.lis | inv_ver3.lis

```
111 inverter
112
113 ****** transient analysis tnom=  25.000 temp=  25.000 ******
114 t_pdf=  29.0670p  targ= 200.0401n   trig= 200.0110n
115 t_pdr=  30.1083p  targ= 100.0511n   trig= 100.0210n
116
117            ***** job concluded
118 ******
119 inverter
120
```

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因為已知，$\tau = t_{pd} = \frac{t_{pdr}+t_{pdf}}{2}$，由上面測量結果可知，

$$\tau = t_{pd} = 29.58765\ ps$$

將(a)中所計算出的 stage number N 與 stage delay：

$$D = N\rho_{inv} + P = 36.0472$$

乘上 time constant τ 後，可得：

$$total\ delay\ time\ =\ 1.066552\ ns$$

為符合題意，嘗試不同 stage number N，以求得更小 time delay，可得下表(因為為 inverter buffer 所以 N 只可為奇數)：

N	ρ_{inv}	D
3	27.67	86.0114
5	7.3318	41.659
7	4.1496	36.0472
9	3.0246	36.2214
11	2.4733	38.2

由上表可知，當 stage number N=7 時，delay 為最小，故只能取 N=7。

為求設計每一 stage 的 size，先計算最後一 stage Cin：

$$\rho_{inv} = gh = g\frac{C_{out}}{C_{in}}$$

$$\Rightarrow C_{in} = g\frac{C_{out}}{\rho_{inv}} = 1 \times \frac{80pF}{4.1496} = 19.28pF$$

其餘 stage 同樣：

$$\rho_{inv} = gh = g\frac{C_{out}}{C_{in}}$$

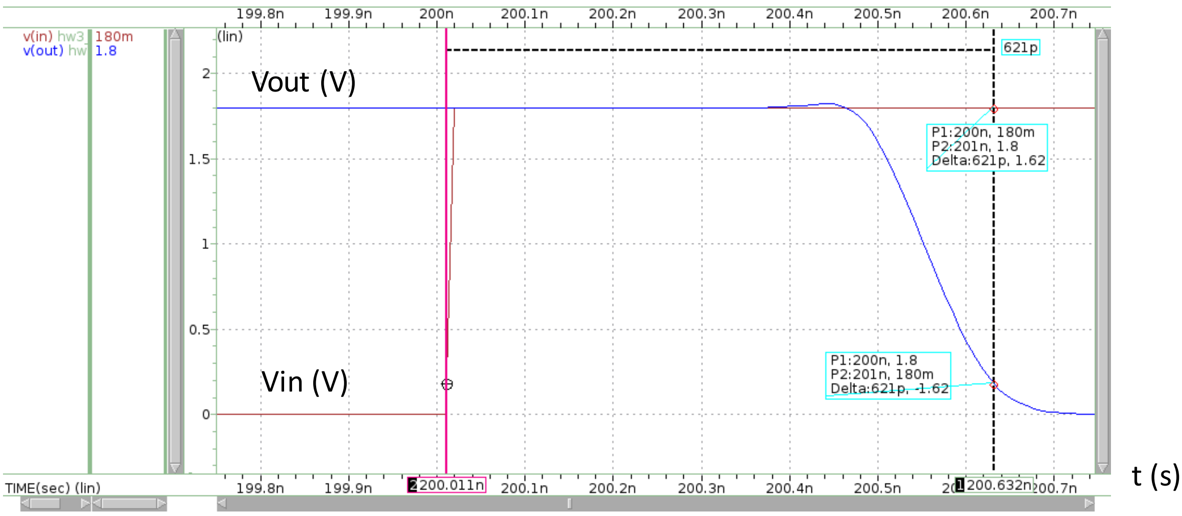
$$\Rightarrow \frac{C_{in}}{C_{out}} = \frac{g}{\rho_{inv}} = \frac{1}{4}$$

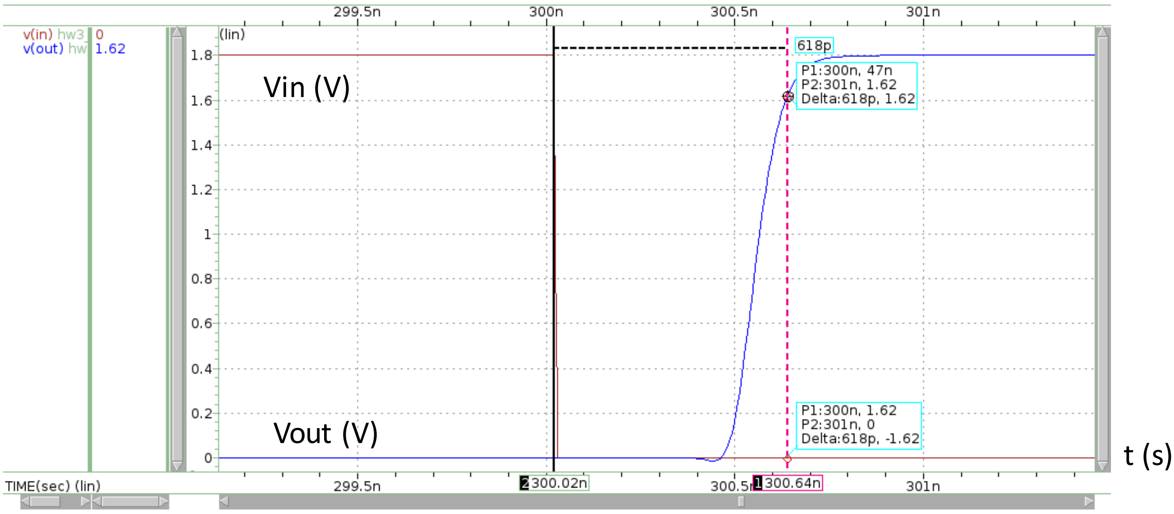
所以下一 stage 的 W 與 L 為前一 stage 的 4 倍(i.e. PMOS, NMOS size 都是 0.5u/0.18u，只是 transistor number 增加 4 倍)，因此設計出下表：

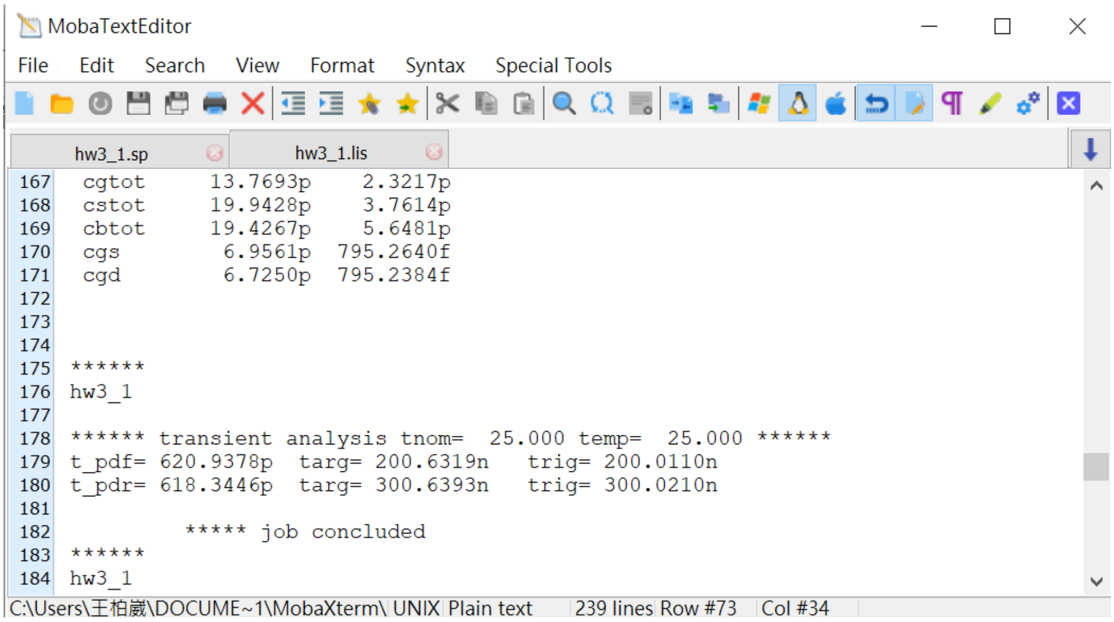
Stage	1	2	3	4	5	6	7
PMOS number	3	12	48	192	768	3072	12288
NMOS number	1	4	16	64	256	1024	4096

將設計結果模擬可得知：

tpdr	tpdf
618ps	621ps



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hw3_1.sp hw3_1.lis

```
167  cgtot      13.7693p    2.3217p
168  cstot      19.9428p    3.7614p
169  cbtot      19.4267p    5.6481p
170  cgs         6.9561p  795.2640f
171  cgd         6.7250p  795.2384f
172
173
174
175 ******
176 hw3_1
177
178 ****** transient analysis tnom=  25.000 temp=  25.000 ******
179 t_pdf= 620.9378p  targ= 200.6319n   trig= 200.0110n
180 t_pdr= 618.3446p  targ= 300.6393n   trig= 300.0210n
181
182           ***** job concluded
183 ******
184 hw3_1
```

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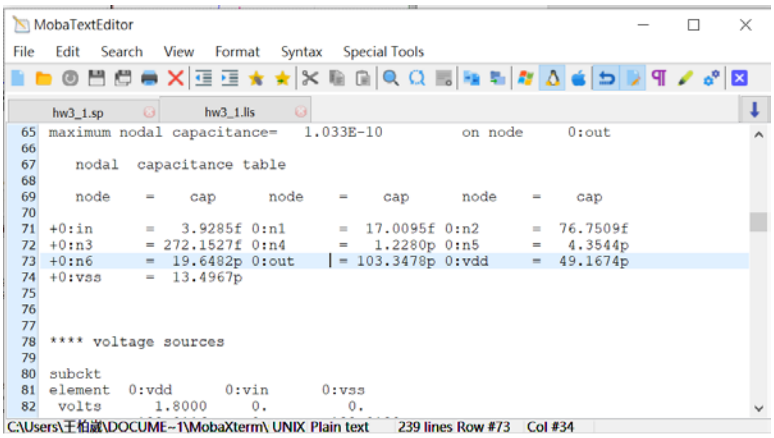
最後驗證設計條件是否符合模擬結論(i.e. last stage Cin = 19.28pF. Next stage Cin = 4 times previous stage Cin)：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hw3_1.sp hw3_1.lis

```
65 maximum nodal capacitance=   1.033E-10        on node      0:out
66
67    nodal  capacitance table
68
69    node      =     cap        node      =     cap        node      =     cap
70
71 +0:in       =    3.9285f 0:n1         =   17.0095f 0:n2         =   76.7509f
72 +0:n3       = 272.1527f 0:n4          =    1.2280p 0:n5         =    4.3544p
73 +0:n6       =   19.6482p 0:out        = 103.3478p 0:vdd         =   49.1674p
74 +0:vss      =   13.4967p
75
76
77
78 **** voltage sources
79
80 subckt
81 element   0:vdd        0:vin        0:vss
82  volts      1.8000      0.           0.
```

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由上圖可知，結果大致符合設計條件。

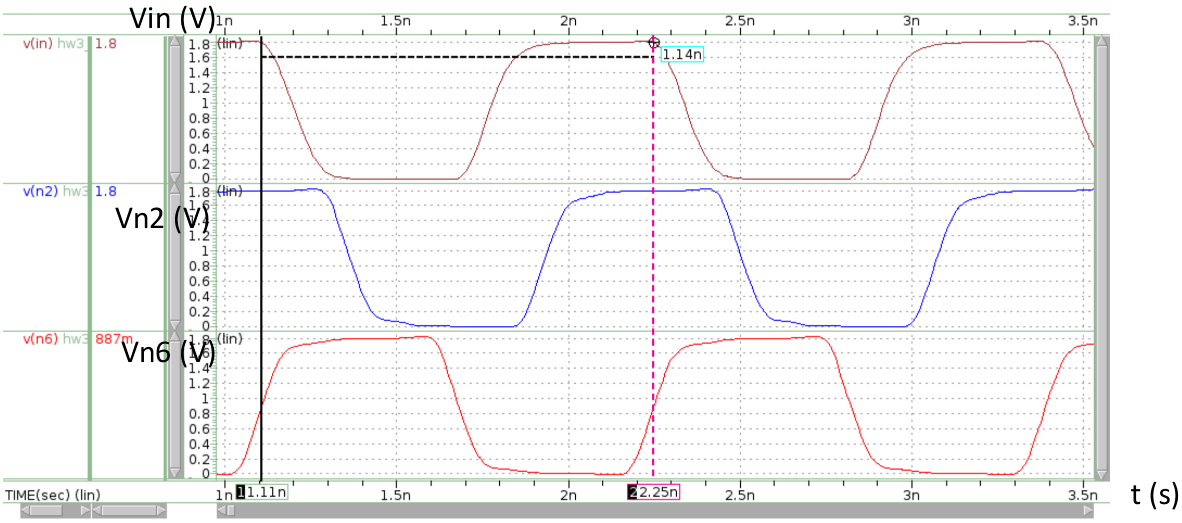
(c)

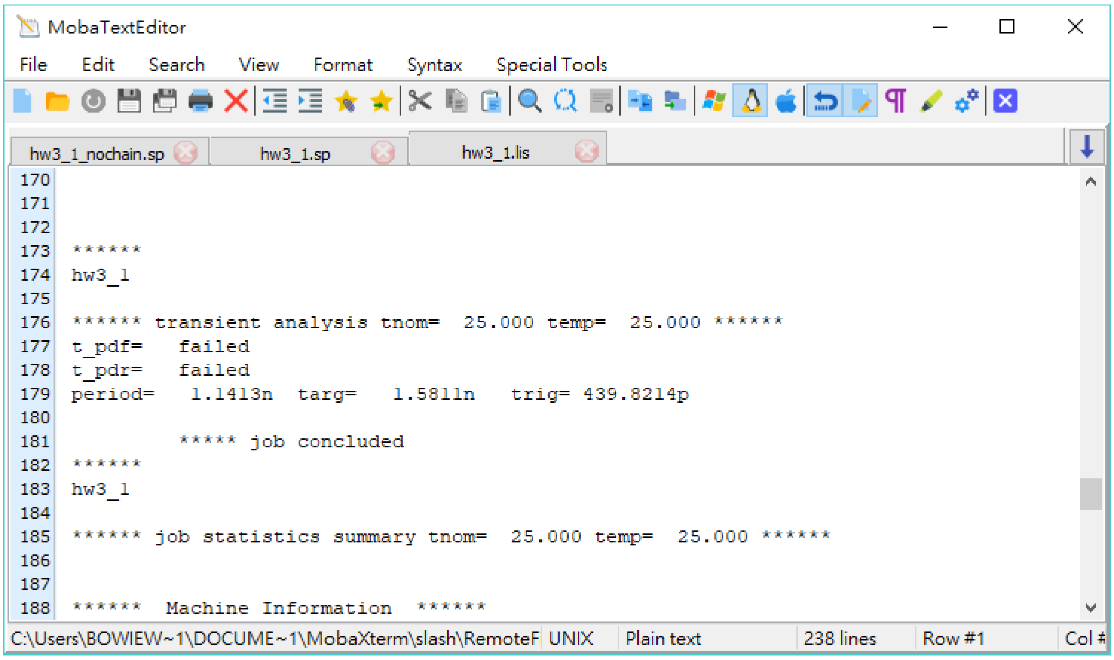
因為傳輸一訊號至 out 的 delay 為$D = \frac{t_{pdr} + t_{pdf}}{2} = 619.5ps$，而傳遞訊號反轉週期為$T = 2D = 1239\ ps$

所以震盪頻率：

$$f = \frac{1}{T} = 8.071 \times 10^{8} Hz$$

(d)





將 in 設 initial condition = 1.8V 後，可得上面兩張結果。

$$f = \frac{1}{T} = \frac{1}{1.1413ns} = 876193814.1\ Hz$$

(e)

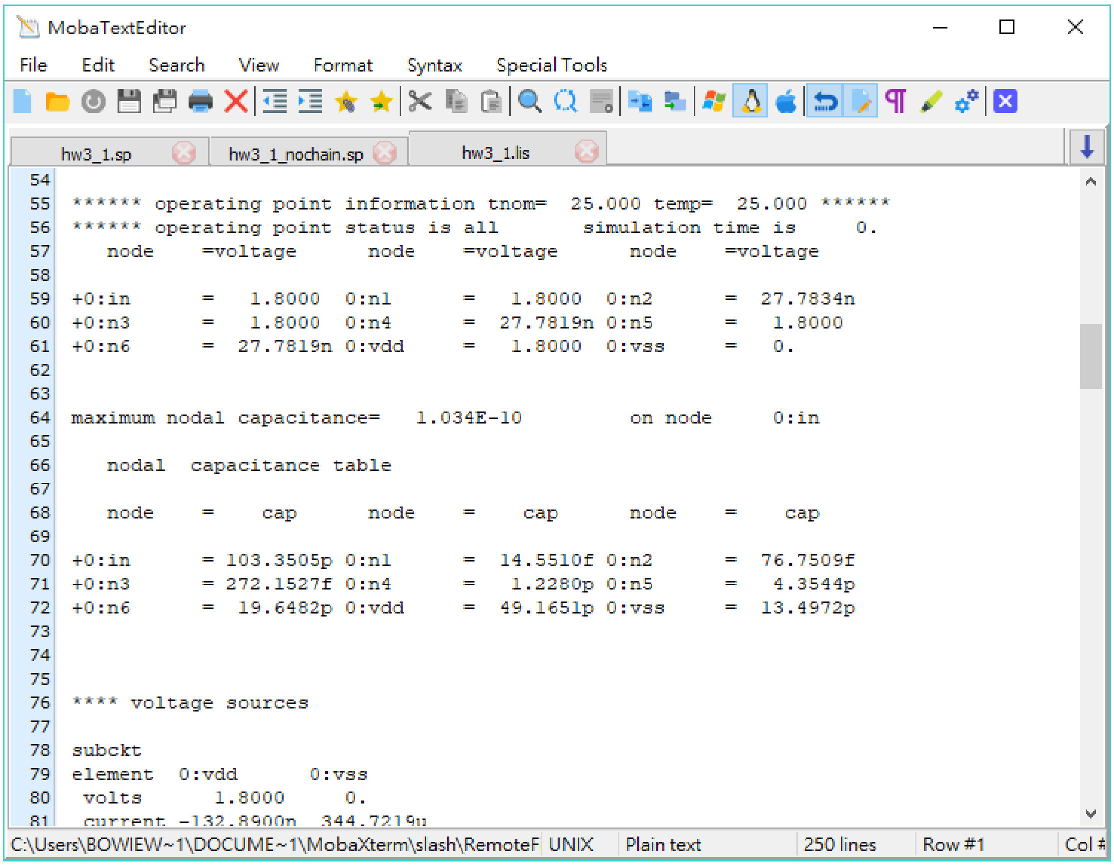
由(c)與(d)可發現，手算預估頻率與實際模擬頻率有些差異，但數量級一樣：
手算：$f = 8.071 \times 10^{8} Hz$
模擬：$f = 876040298\, Hz$
誤差百分比：8.54%
因為 Ring oscillator 是透過每 stage delay time 實現 input 與 output 的時間差，並利用時間差產生 oscillation period，因此：

$$T = \left(2 \sum d_i\right) \cdot 4RC\ \forall d_i : time\ delay\ of\ ith\ stage$$

而元件的 time delay d_i與其 parasitic capacitor 和 resistance 有關：

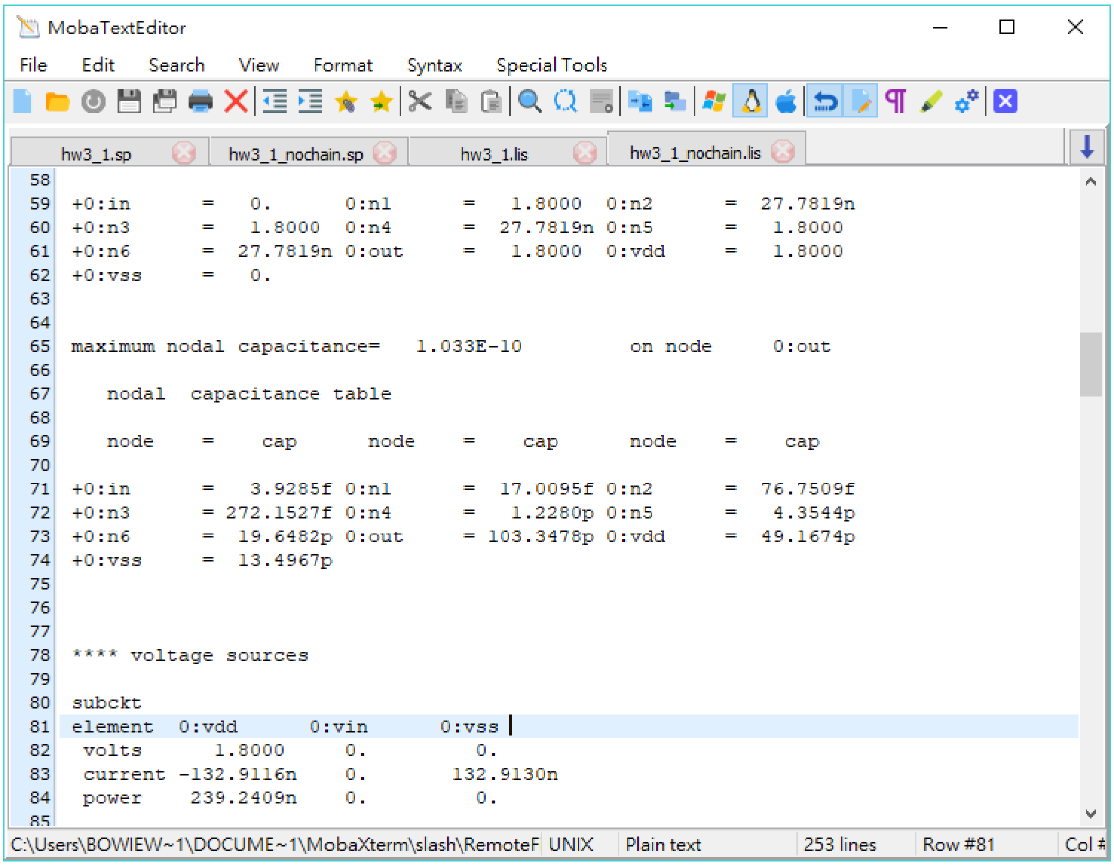
$$d_i = g_i h_i + p_i = g_i \frac{C_{out,i}}{C_{in,i}} + p_i$$

因為前面手算時是用 open loop 情況下的各值進行計算，而實際卻是 closed loop，因此以下為討論為何兩者會有誤差。
下面兩張為模擬 closed loop 與 open loop 情形時，每 node 的 capacitance：
Closed loop：




```
****** operating point information tnom=  25.000 temp=  25.000 ******
****** operating point status is all       simulation time is     0.
   node     =voltage       node     =voltage       node     =voltage

+0:in       =   1.8000   0:n1       =   1.8000   0:n2       =  27.7834n
+0:n3       =   1.8000   0:n4       =  27.7819n  0:n5       =   1.8000
+0:n6       =  27.7819n  0:vdd      =   1.8000   0:vss      =   0.


maximum nodal capacitance=    1.034E-10          on node      0:in

   nodal   capacitance table

   node     =    cap        node     =    cap        node     =    cap

+0:in       = 103.3505p  0:n1       =   14.5510f  0:n2      =  76.7509f
+0:n3       = 272.1527f  0:n4       =    1.2280p  0:n5      =   4.3544p
+0:n6       =  19.6482p  0:vdd      =   49.1651p  0:vss     =  13.4972p



**** voltage sources

subckt
element  0:vdd        0:vss
 volts        1.8000      0.
 current  -132.8900n   344.7219u
```

Open loop：




```
+0:in      =   0.       0:n1      =   1.8000  0:n2      =  27.7819n
+0:n3      =   1.8000  0:n4      =  27.7819n 0:n5      =   1.8000
+0:n6      =  27.7819n 0:out     =   1.8000  0:vdd     =   1.8000
+0:vss     =   0.


maximum nodal capacitance=   1.033E-10         on node      0:out

   nodal  capacitance table

   node    =    cap       node    =    cap       node    =    cap

+0:in      =   3.9285f 0:n1      =  17.0095f 0:n2      =  76.7509f
+0:n3      = 272.1527f 0:n4      =   1.2280p 0:n5      =   4.3544p
+0:n6      =  19.6482p 0:out     = 103.3478p 0:vdd     =  49.1674p
+0:vss     =  13.4967p



**** voltage sources

subckt
element  0:vdd        0:vin        0:vss
 volts      1.8000      0.          0.
 current -132.9116n     0.        132.9130n
 power    239.2409n     0.          0.
```

從上圖可發現 open loop 每 node 的電容都不相同，並可整理出下表：

Closed Loop							
Stage	1	2	3	4	5	6	7
Cout/Cin	0.000141	5.274613	3.545922	4.512173	3.545928	4.512263	5.260049
g_i, p_i	1	1	1	1	1	1	1
$\sum d_i$	30.21821						
Open loop							
Stage	1	2	3	4	5	6	7
Cout/Cin	4.32977	4.512237	3.545922	4.512173	3.545928	4.512263	5.259912
g_i, p_i	1	1	1	1	1	1	1

$\sum d_i$	26.65109

從上表最終計算出的 delay 可發現，因為 closed loop 在 stage two h_i雖然較 open loop 的大，但 stage one 極小，而使整體 delay closed loop 較 open loop 小，也因此模擬 oscillation frequency 較手算大一些。

2.

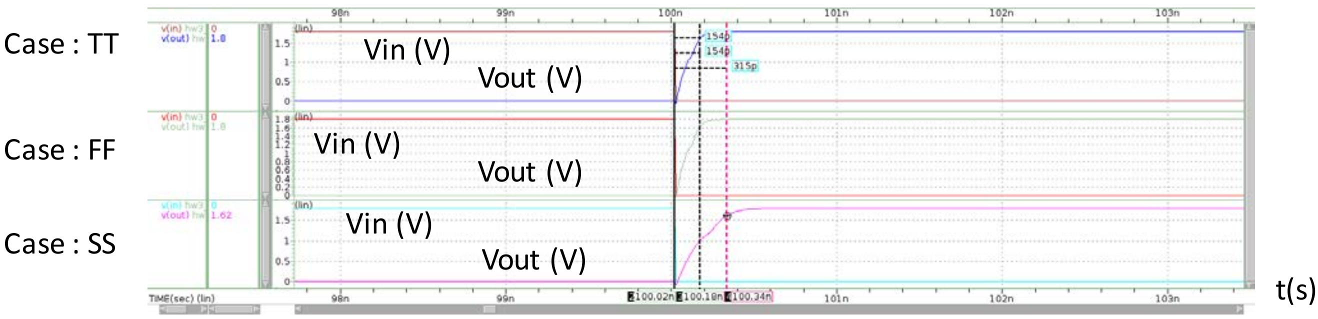
此題主要計算 power 的方式為取第一顆 inverter PMOS source 端電流在一周期內的平均值後，再乘 Vdd (1.8V)即可得到平均功率，並利用平均功率乘時間得消耗能量，而因為題目有要求不同時間區段，以前述相同方法，只是取不同時間段的平均電流，

(a)

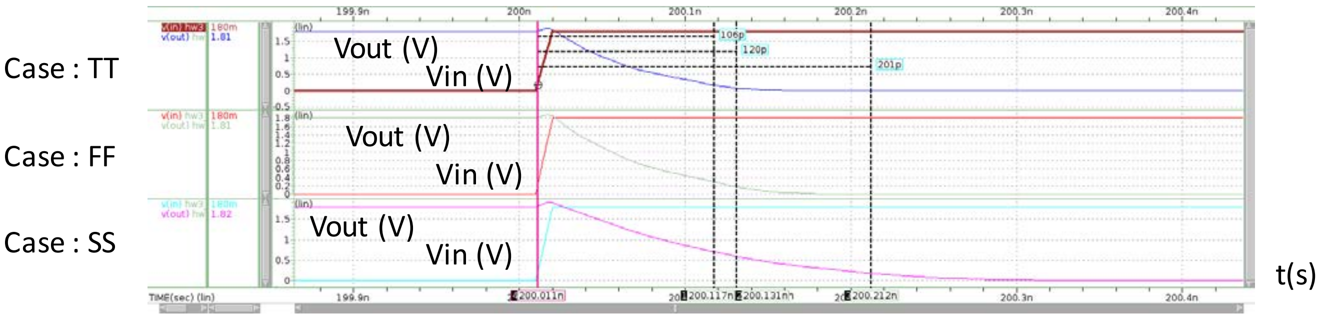
以下為利用.MEAS 與 waveview 所找出來的 tpdf, tpdr, power dissipation：

Corner	t_{pdf} (s)	t_{pdr} (s)	Energy (J)	average power (W)
TT	106.4766p	154.4526p	109.6999f	548.4994n
FF	120.1478p	154.2097p	119.9474f	599.7368n
SS	201.0861p	315.4807p	122.3199f	611.5996n

Tpdr：

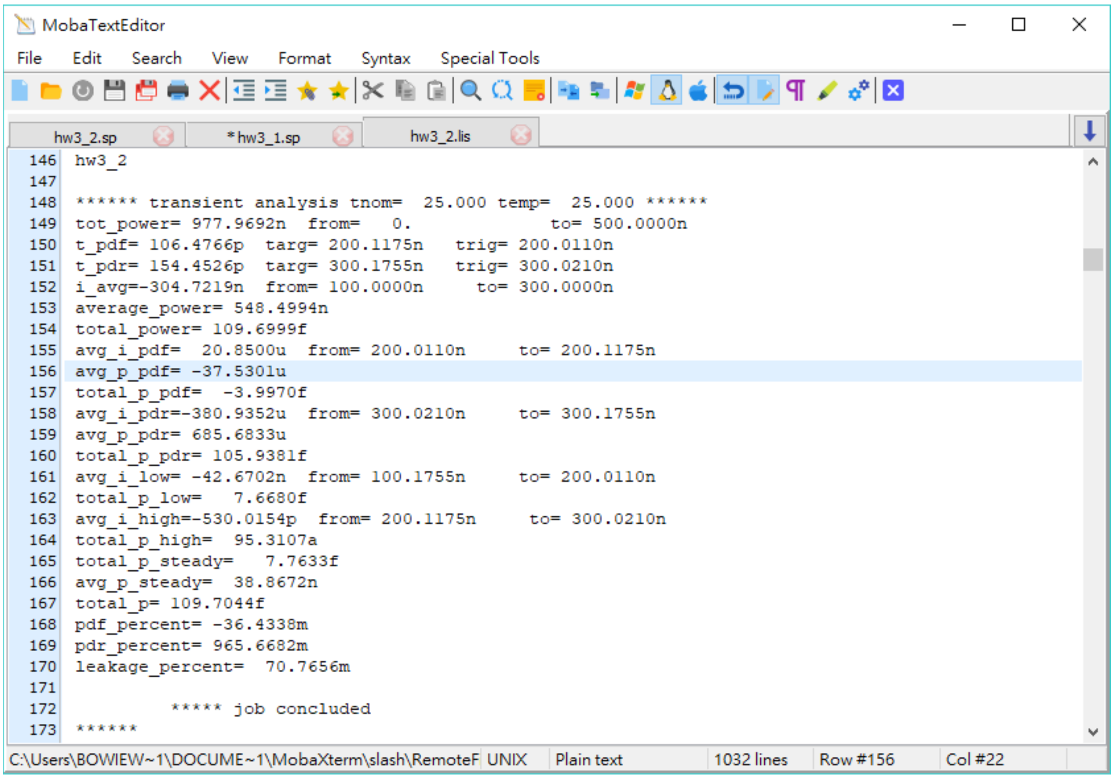


Tpdf：



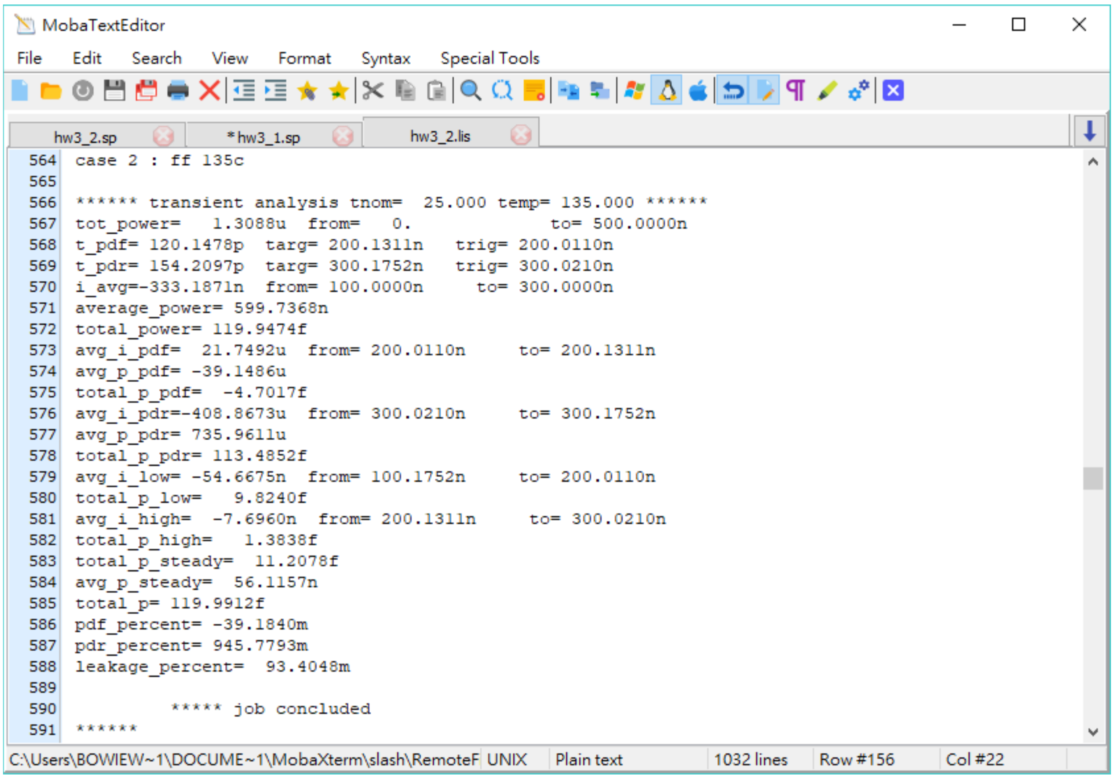
Average power consumption, tpdr and tpdf by meas.

TT :



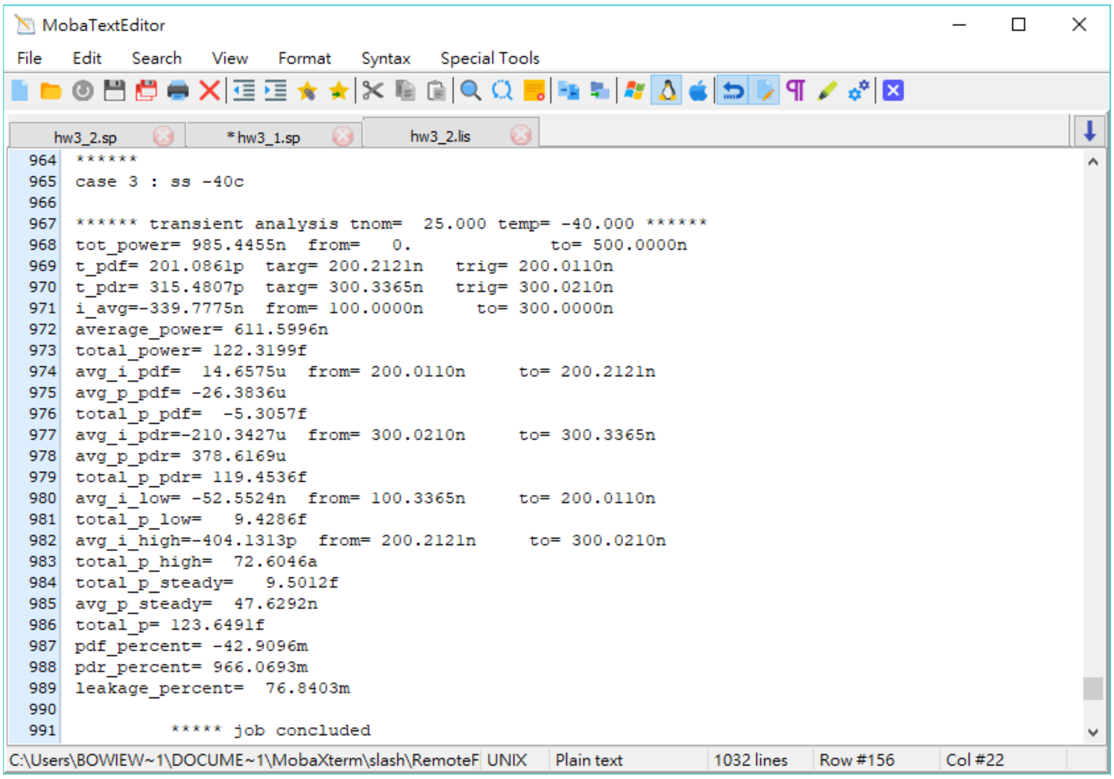
```
hw3_2

****** transient analysis tnom=  25.000 temp=  25.000 ******
tot_power= 977.9692n  from=    0.           to= 500.0000n
t_pdf= 106.4766p  targ= 200.1175n   trig= 200.0110n
t_pdr= 154.4526p  targ= 300.1755n   trig= 300.0210n
i_avg=-304.7219n  from= 100.0000n     to= 300.0000n
average_power= 548.4994n
total_power= 109.6999f
avg_i_pdf=  20.8500u  from= 200.0110n     to= 200.1175n
avg_p_pdf= -37.5301u
total_p_pdf=  -3.9970f
avg_i_pdr=-380.9352u  from= 300.0210n     to= 300.1755n
avg_p_pdr= 685.6833u
total_p_pdr= 105.9381f
avg_i_low= -42.6702n  from= 100.1755n     to= 200.0110n
total_p_low=   7.6680f
avg_i_high=-530.0154p  from= 200.1175n     to= 300.0210n
total_p_high=  95.3107a
total_p_steady=   7.7633f
avg_p_steady=  38.8672n
total_p= 109.7044f
pdf_percent= -36.4338m
pdr_percent= 965.6682m
leakage_percent=  70.7656m

         ***** job concluded
******
```

FF :



```
case 2 : ff 135c

****** transient analysis tnom=  25.000 temp= 135.000 ******
tot_power=    1.3088u  from=    0.           to= 500.0000n
t_pdf= 120.1478p  targ= 200.1311n   trig= 200.0110n
t_pdr= 154.2097p  targ= 300.1752n   trig= 300.0210n
i_avg=-333.1871n  from= 100.0000n     to= 300.0000n
average_power= 599.7368n
total_power= 119.9474f
avg_i_pdf=  21.7492u  from= 200.0110n     to= 200.1311n
avg_p_pdf= -39.1486u
total_p_pdf=  -4.7017f
avg_i_pdr=-408.8673u  from= 300.0210n     to= 300.1752n
avg_p_pdr= 735.9611u
total_p_pdr= 113.4852f
avg_i_low= -54.6675n  from= 100.1752n     to= 200.0110n
total_p_low=   9.8240f
avg_i_high=  -7.6960n  from= 200.1311n     to= 300.0210n
total_p_high=    1.3838f
total_p_steady=  11.2078f
avg_p_steady=  56.1157n
total_p= 119.9912f
pdf_percent= -39.1840m
pdr_percent= 945.7793m
leakage_percent=  93.4048m

         ***** job concluded
******
```

SS :




```
******
case 3 : ss -40c

****** transient analysis tnom=  25.000 temp= -40.000 ******
tot_power= 985.4455n  from=   0.          to= 500.0000n
t_pdf= 201.0861p  targ= 200.2121n   trig= 200.0110n
t_pdr= 315.4807p  targ= 300.3365n   trig= 300.0210n
i_avg=-339.7775n  from= 100.0000n     to= 300.0000n
average_power= 611.5996n
total_power= 122.3199f
avg_i_pdf=  14.6575u  from= 200.0110n     to= 200.2121n
avg_p_pdf= -26.3836u
total_p_pdf=  -5.3057f
avg_i_pdr=-210.3427u  from= 300.0210n     to= 300.3365n
avg_p_pdr= 378.6169u
total_p_pdr= 119.4536f
avg_i_low= -52.5524n  from= 100.3365n     to= 200.0110n
total_p_low=   9.4286f
avg_i_high=-404.1313p  from= 200.2121n     to= 300.0210n
total_p_high=  72.6046a
total_p_steady=   9.5012f
avg_p_steady=  47.6292n
total_p= 123.6491f
pdf_percent= -42.9096m
pdr_percent= 966.0693m
leakage_percent=  76.8403m

         ***** job concluded
```

(b)

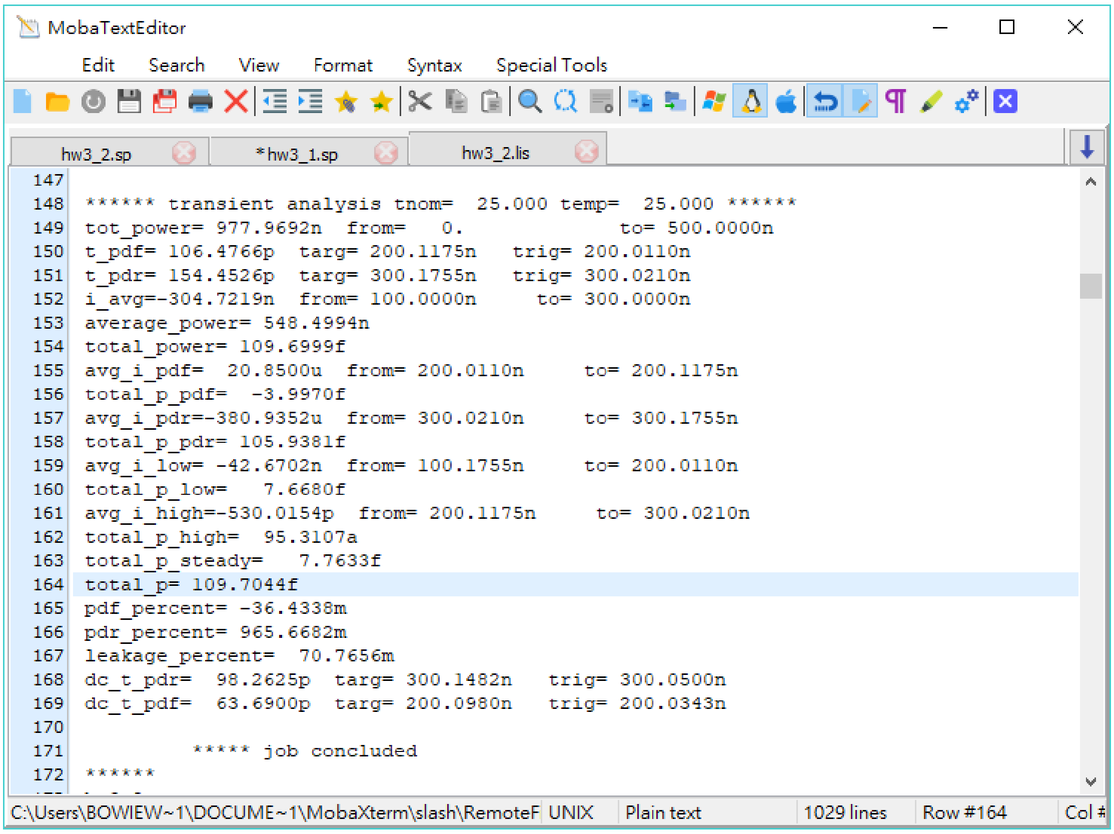
以下為各區段時間內的 average power, power dissipation (energy) 及百分比:

Corner/interval	Pdf	Pdr	Leakage	Total
TT				
Average power(W)	-37.5301u	685.6833u	38.8672n	548.4994n
Total Energy(J)	-3.9970f	105.9381f	7.7633f	109.7044f
Percent.	-36.4338m	965.6682m	70.7656m	100%
FF				
Average power(W)	-39.1486u	735.9611u	56.1157n	599.7368n
Total energy(J)	-4.7017f	113.4852f	11.2078f	119.9912f
Percent.	-39.1840m	945.7793m	93.4048m	100%
SS				
Average power(W)	-26.3836u	378.6169u	47.6292n	611.5996n
Total energy(J)	-5.3057f	119.4536f	9.5012f	123.6491f

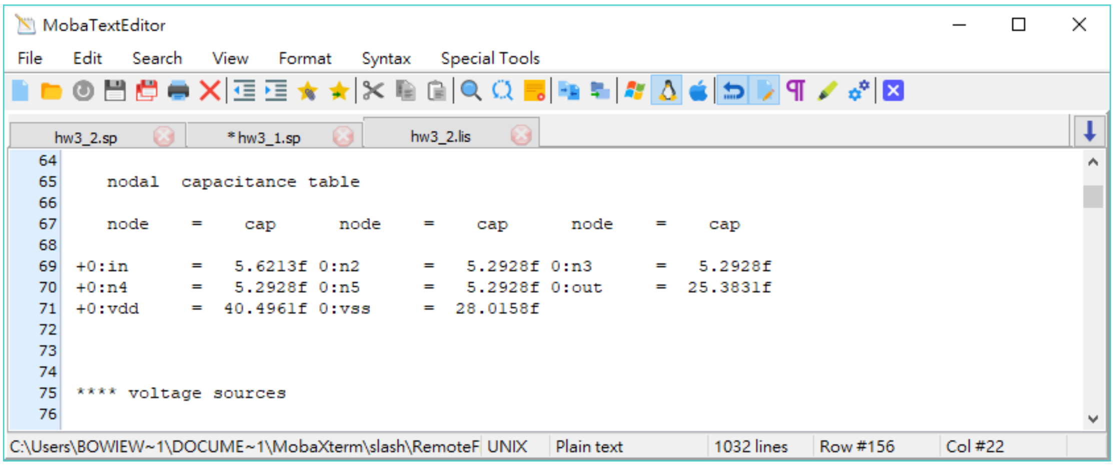
Percent.	-42.9096m	966.0693m	76.8403m	100%

以下為各 corner 下的各項 measure 及 node capacitance，和計算 dc short 及 parasitic capacitance power dissipation:

TT :




```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tot_power= 977.9692n  from=    0.          to= 500.0000n
t_pdf= 106.4766p  targ= 200.1175n   trig= 200.0110n
t_pdr= 154.4526p  targ= 300.1755n   trig= 300.0210n
i_avg=-304.7219n  from= 100.0000n     to= 300.0000n
average_power= 548.4994n
total_power= 109.6999f
avg_i_pdf=  20.8500u  from= 200.0110n     to= 200.1175n
total_p_pdf=  -3.9970f
avg_i_pdr=-380.9352u  from= 300.0210n     to= 300.1755n
total_p_pdr= 105.9381f
avg_i_low= -42.6702n  from= 100.1755n     to= 200.0110n
total_p_low=   7.6680f
avg_i_high=-530.0154p  from= 200.1175n     to= 300.0210n
total_p_high=  95.3107a
total_p_steady=   7.7633f
total_p= 109.7044f
pdf_percent= -36.4338m
pdr_percent= 965.6682m
leakage_percent=  70.7656m
dc_t_pdr=  98.2625p  targ= 300.1482n   trig= 300.0500n
dc_t_pdf=  63.6900p  targ= 200.0980n   trig= 200.0343n

         ***** job concluded
******
```



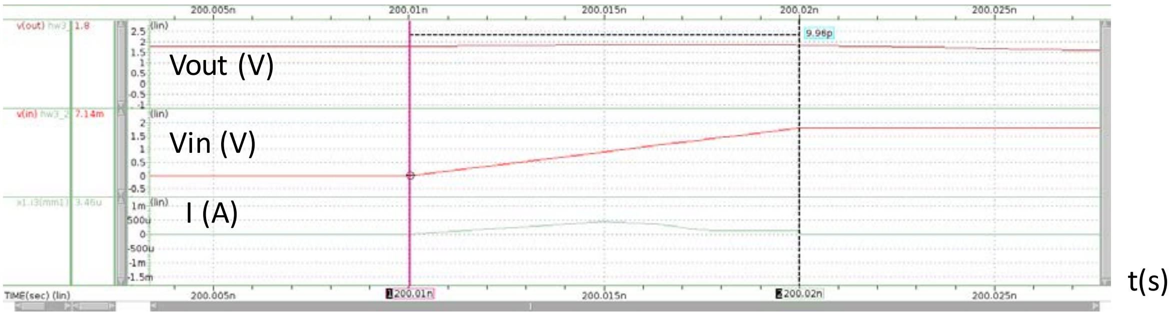

```
    nodal   capacitance table

    node      =     cap       node      =     cap       node      =     cap

+0:in         =    5.6213f 0:n2         =    5.2928f 0:n3         =    5.2928f
+0:n4         =    5.2928f 0:n5         =    5.2928f 0:out        =   25.3831f
+0:vdd        =   40.4961f 0:vss        =   28.0158f


**** voltage sources
```

$$P_{\text{dynamic}} = C_{\text{out}} {V_{DD}}^2 f$$
$$= 25.3831fF \times 1.8^2 \times 5M\ Hz$$
$$= 4.11206 \times 10^{-7}\ \text{W}$$

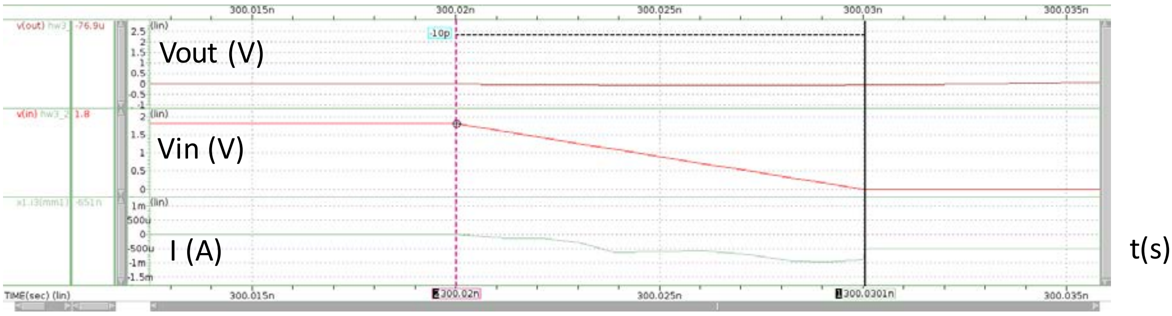
取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

$$\mathrm{P_{dc}} = 265.6942 \times 10^{-6}\ W$$

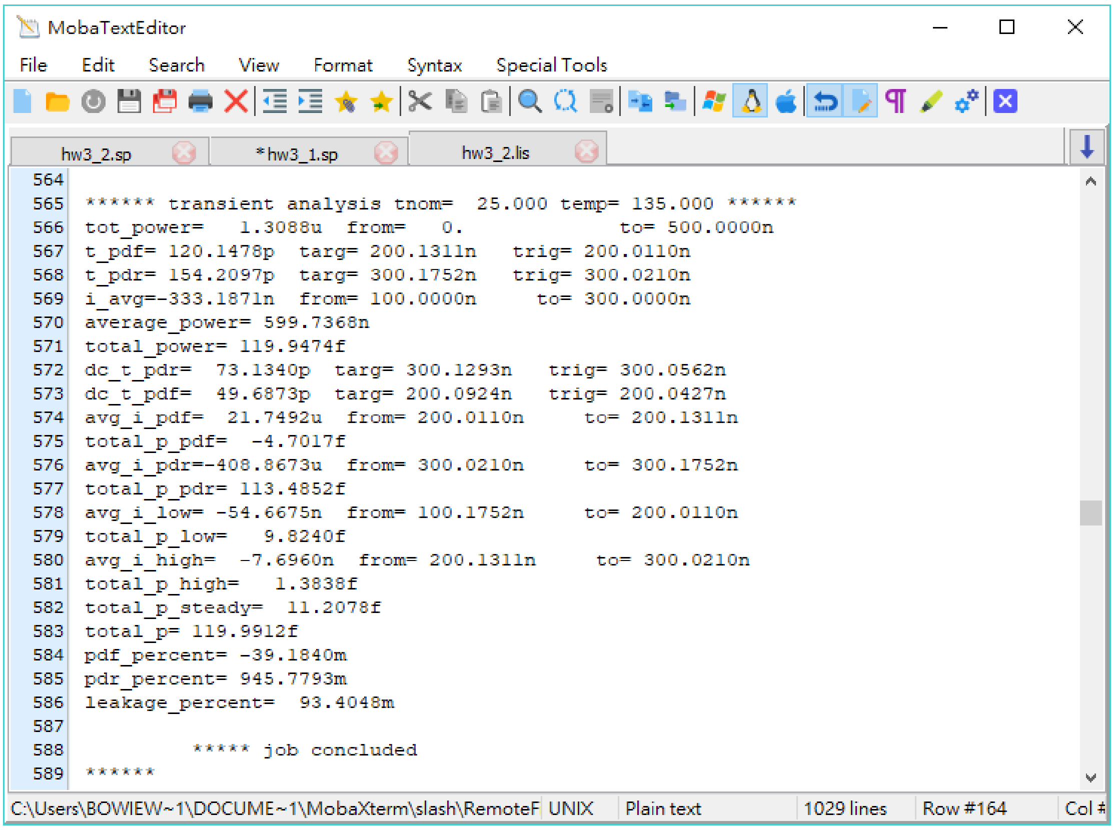
Rising :



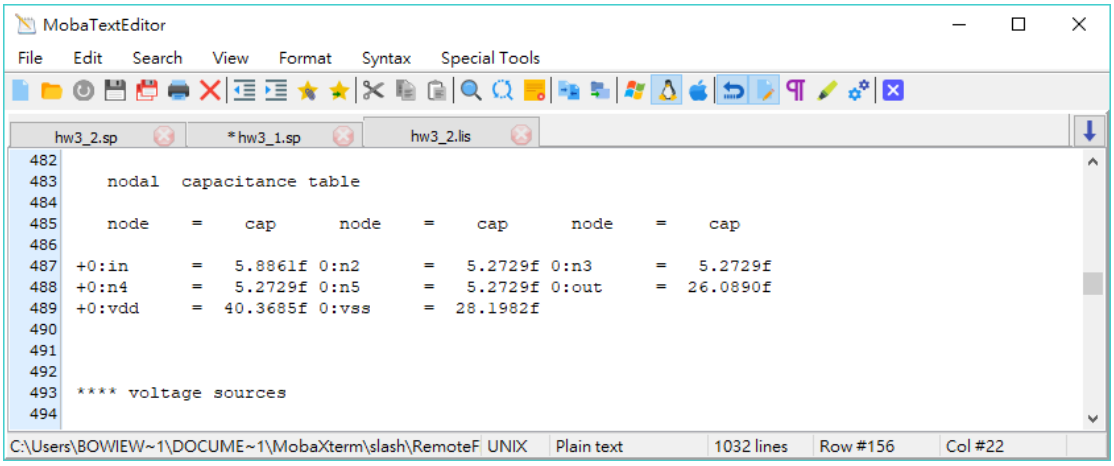
Falling :



FF :



```
****** transient analysis tnom=  25.000 temp= 135.000 ******
tot_power=   1.3088u  from=    0.            to= 500.0000n
t_pdf= 120.1478p  targ= 200.1311n   trig= 200.0110n
t_pdr= 154.2097p  targ= 300.1752n   trig= 300.0210n
i_avg=-333.1871n  from= 100.0000n      to= 300.0000n
average_power= 599.7368n
total_power= 119.9474f
dc_t_pdr=  73.1340p  targ= 300.1293n   trig= 300.0562n
dc_t_pdf=  49.6873p  targ= 200.0924n   trig= 200.0427n
avg_i_pdf=  21.7492u  from= 200.0110n      to= 200.1311n
total_p_pdf=  -4.7017f
avg_i_pdr=-408.8673u  from= 300.0210n      to= 300.1752n
total_p_pdr= 113.4852f
avg_i_low= -54.6675n  from= 100.1752n      to= 200.0110n
total_p_low=   9.8240f
avg_i_high=  -7.6960n  from= 200.1311n      to= 300.0210n
total_p_high=   1.3838f
total_p_steady=  11.2078f
total_p= 119.9912f
pdf_percent= -39.1840m
pdr_percent= 945.7793m
leakage_percent=  93.4048m

         ***** job concluded
******
```



```
   nodal   capacitance  table

   node      =    cap       node      =    cap       node      =    cap

+0:in        =    5.8861f 0:n2        =    5.2729f 0:n3        =    5.2729f
+0:n4        =    5.2729f 0:n5        =    5.2729f 0:out       =   26.0890f
+0:vdd       =   40.3685f 0:vss       =   28.1982f



**** voltage sources
```

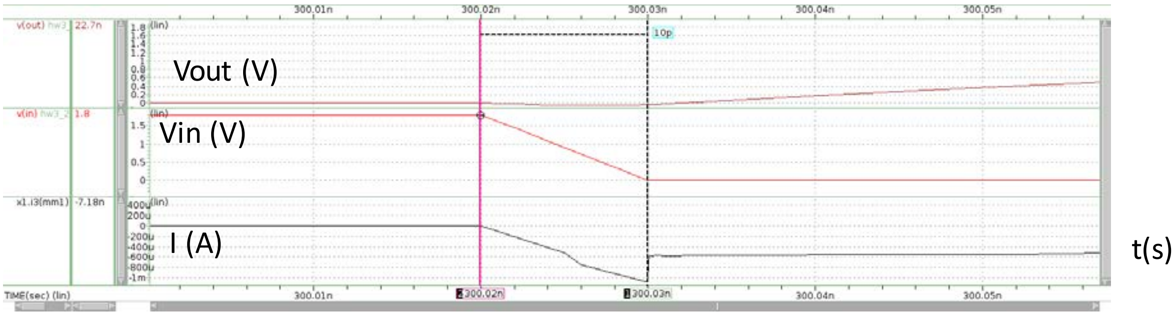
$$P_{dynamic} = C_{out}V_{DD}{}^{2}f$$
$$= 26.089fF \times 1.8^{2} \times 5M\ Hz$$
$$= 4.2264 \times 10^{-7}\ W$$

取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

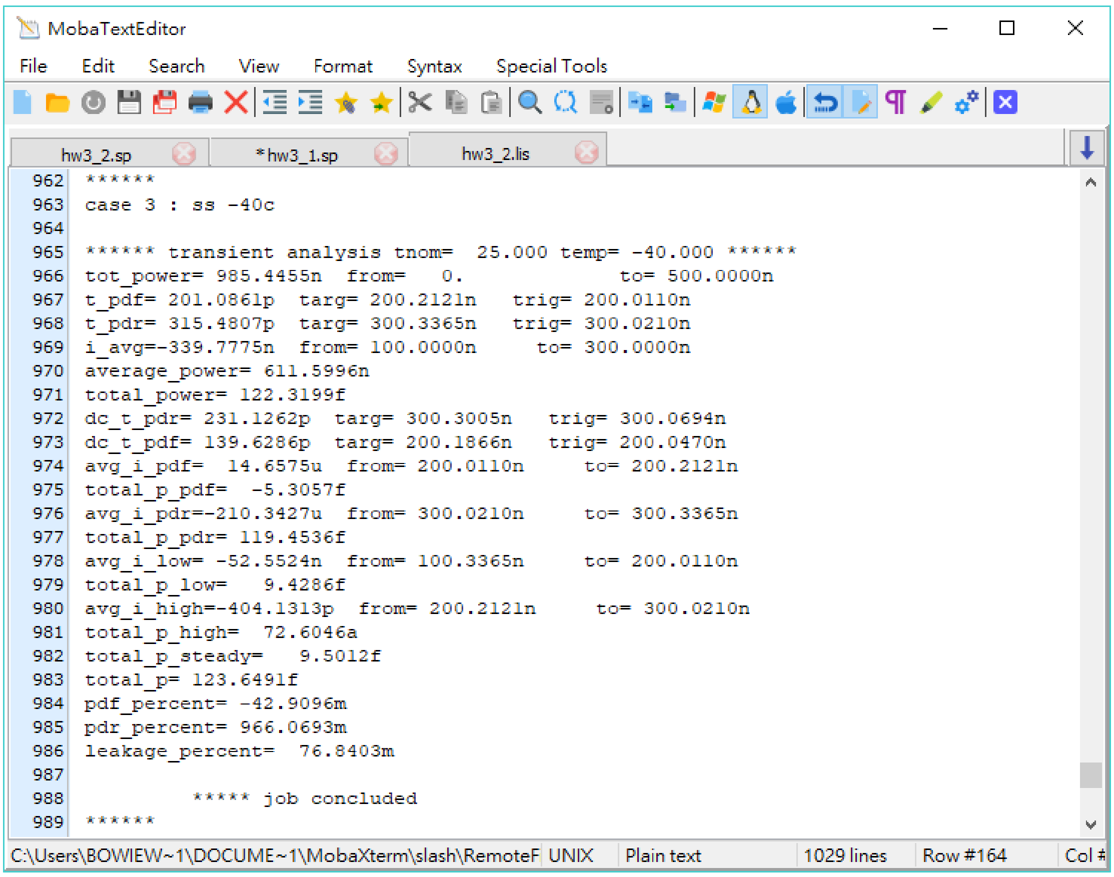
$$P_{dc} = 140.1073 \times 10^{-6}\ W$$

Rising :

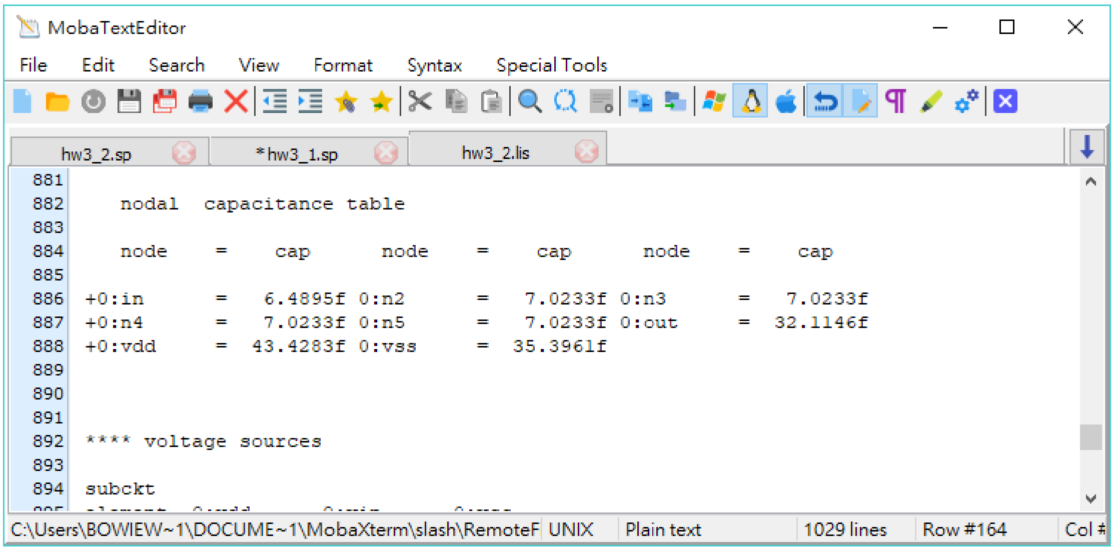
Falling :



SS :




```
******
case 3 : ss -40c

****** transient analysis tnom=  25.000 temp= -40.000 ******
tot_power= 985.4455n  from=    0.          to= 500.0000n
t_pdf= 201.0861p  targ= 200.2121n   trig= 200.0110n
t_pdr= 315.4807p  targ= 300.3365n   trig= 300.0210n
i_avg=-339.7775n  from= 100.0000n     to= 300.0000n
average_power= 611.5996n
total_power= 122.3199f
dc_t_pdr= 231.1262p  targ= 300.3005n   trig= 300.0694n
dc_t_pdf= 139.6286p  targ= 200.1866n   trig= 200.0470n
avg_i_pdf=  14.6575u  from= 200.0110n     to= 200.2121n
total_p_pdf=  -5.3057f
avg_i_pdr=-210.3427u  from= 300.0210n     to= 300.3365n
total_p_pdr= 119.4536f
avg_i_low= -52.5524n  from= 100.3365n     to= 200.0110n
total_p_low=   9.4286f
avg_i_high=-404.1313p  from= 200.2121n     to= 300.0210n
total_p_high=  72.6046a
total_p_steady=   9.5012f
total_p= 123.6491f
pdf_percent= -42.9096m
pdr_percent= 966.0693m
leakage_percent=  76.8403m

         ***** job concluded
******
```



```
MobaTextEditor
File  Edit  Search  View  Format  Syntax  Special Tools
hw3_2.sp   *hw3_1.sp   hw3_2.lis
881
882     nodal  capacitance table
883
884     node     =    cap       node     =    cap       node     =    cap
885
886  +0:in       =    6.4895f 0:n2       =    7.0233f 0:n3       =    7.0233f
887  +0:n4       =    7.0233f 0:n5       =    7.0233f 0:out      =   32.1146f
888  +0:vdd      =   43.4283f 0:vss      =   35.3961f
889
890
891
892  **** voltage sources
893
894  subckt
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```
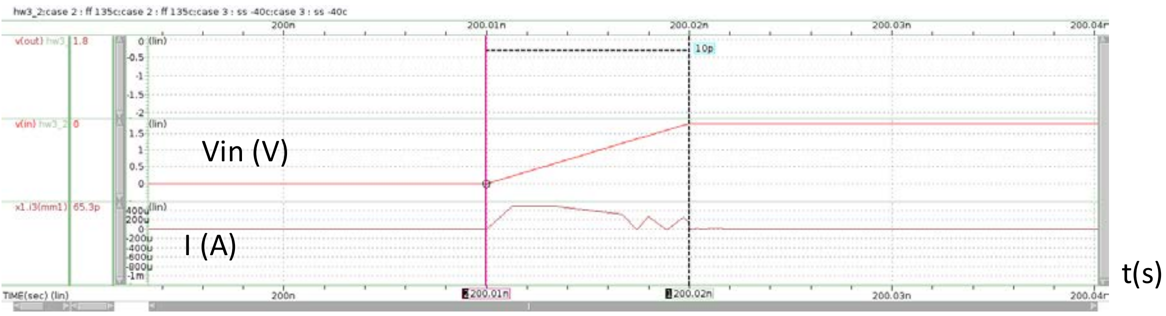

$$P_{dynamic} = C_{out}{V_{DD}}^2 f$$
$$= 32.1146fF \times 1.8^2 \times 5M\ Hz$$
$$= 5.2026 \times 10^{-7}\ W$$

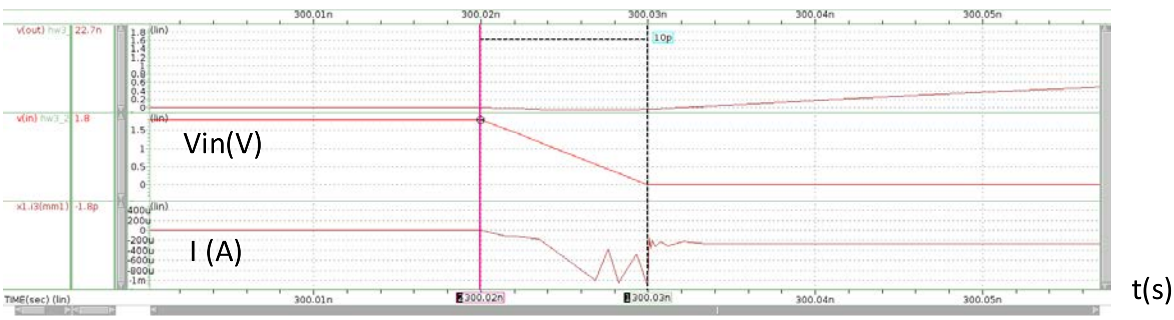
取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

$$P_{dc} = 140.1073 \times 10^{-6} W$$

Rising :

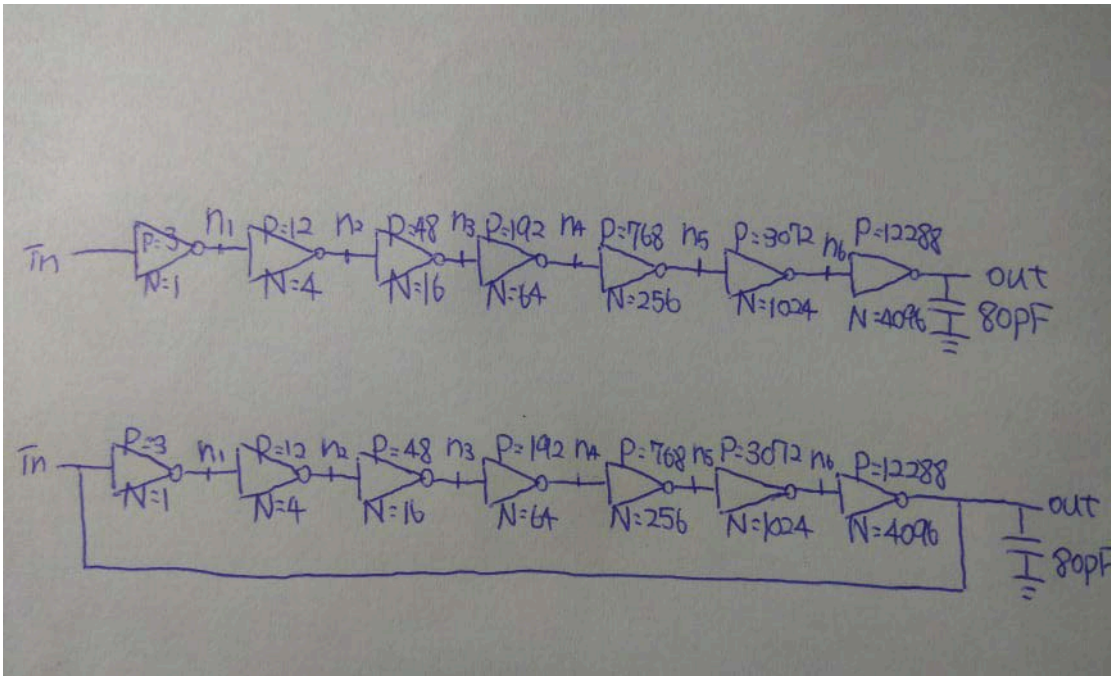


Falling :

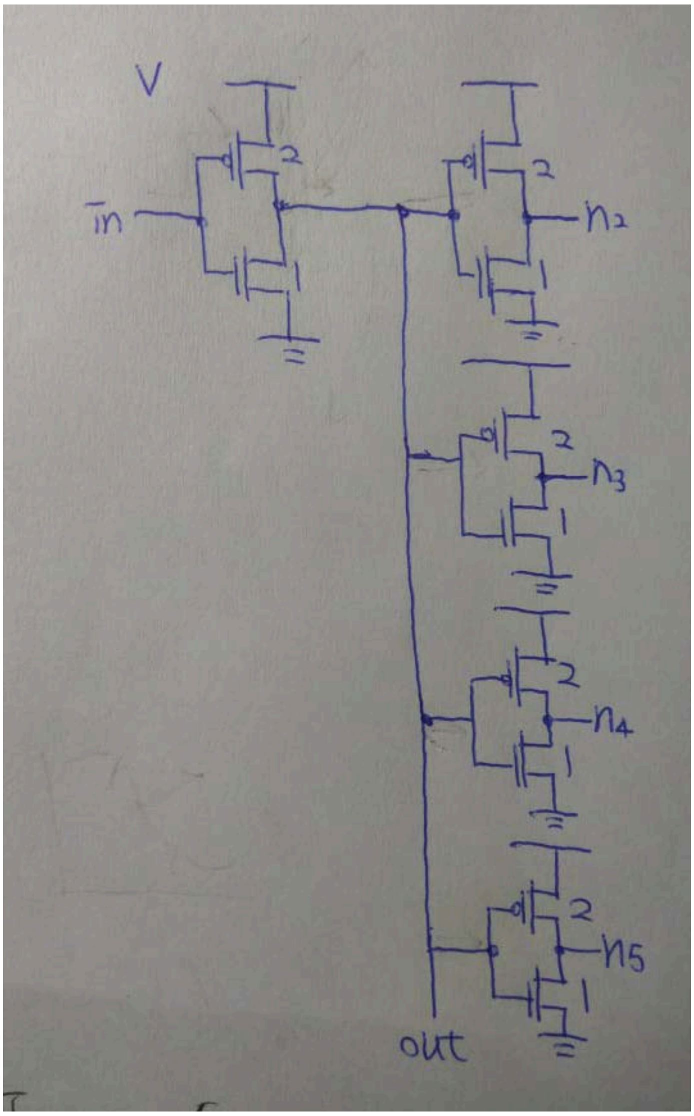


schematic circuit:

1.


In
P=3
N=1
n1
P=12
N=4
n2
P=48
N=16
n3
P=192
N=64
n4
P=768
N=256
n5
P=3072
N=1024
n6
P=12288
N=4096
out
80pF
In
P=3
N=1
n1
P=12
N=4
n2
P=48
N=16
n3
P=192
N=64
n4
P=768
N=256
n5
P=3072
N=1024
n6
P=12288
N=4096
out
80pF

2.



.Sp file

Hw3_1.sp：

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File Edit Search View Format Syntax Special Tools

hw3_2.sp hw3_2.lis hw3_2.lis hw3_1.sp

```
hw3_1
.protect
.lib 'cic018.l' TT
.unprotect
.temp 25
.option
+ post      $output waveform to user
+ acout=0 runlvl=6  $increase simulation accuracy
+ captable    $list every node capacitance


.param vd=1.8

***********circuit***********
.SUBCKT inv1 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=3
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=1
.ENDS
*****************************
.SUBCKT inv2 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=12
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=4
.ENDS
******************************
.SUBCKT inv3 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=48
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=16
.ENDS
***************
.SUBCKT inv4 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=192
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=64
.ENDS
***************
.SUBCKT inv5 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=768
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=256
.ENDS
***************
.SUBCKT inv6 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=3072
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=1024
.ENDS
***************
.SUBCKT inv7 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=12288
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=4096
.ENDS
***************






**********call the circuit***
x1 in n1 vdd vss inv1
```

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```
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=768
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=256
.ENDS
***************
.SUBCKT inv6 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=3072
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=1024
.ENDS
***************
.SUBCKT inv7 in out vdd vss
MM1 out in vdd vdd P_18 W=0.5u   L=0.18u m=12288
MM0 out in vss vss N_18 W=0.5u  L=0.18u m=4096
.ENDS
***************






**********call the circuit***
x1 in n1 vdd vss inv1
x2 n1 n2 vdd vss inv2
x3 n2 n3 vdd vss inv3
x4 n3 n4 vdd vss inv4
x5 n4 n5 vdd vss inv5
x6 n5 n6 vdd vss inv6
x7 n6 in vdd vss inv7

CL in GND 80p

*****************************

********define source********
vdd    vdd    0 vd
vss    vss    0 0
***Vin in GND PULSE 0 vd 0.01n 0.01n 0.01n 100n 200n
*****************************

*********analysis***********
.op
.Meas tran t_pdf TRIG v(in) VAL='0.1*vd' rise=2
+                  TARG v(out) VAL='0.1*vd' FALL=2
.Meas tran t_pdr TRIG v(in) VAL='0.9*vd' FALL=2
+                  TARG v(out) VAL='0.9*vd' rise=2
.Meas tran period TRIG v(in) VAL='vd' fall=2
+                  TARG v(in) VAL='vd' FALL=3

***.dc Vin 0 vd 0.01
.ic V(n1) = 1.8
.tran 0.01n 500n

****************************

.end

```

Hw3_2.sp

MobaTextEditor

File Edit Search View Format Syntax Special Tools

hw3_2.sp | *hw3_1.sp | hw3_2.lis | hw3_2.lis

```
hw3_2
.protect
.lib 'cic018.l' TT
.unprotect
.temp 25
.option
+ post       $output waveform to user
+ acout=0 runlvl=6  $increase simulation accuracy
+ captable     $list every node capacitance


.param vd=1.8

***********circuit***********
.SUBCKT inv1 in out vdd vss
MM1 out in vdd vdd P_18 W=2u   L=0.18u m=1
MM0 out in vss vss N_18 W=1u  L=0.18u m=1

.ENDS
*****************************

**********call the circuit***
x1 in out vdd vss inv1
x2 out n2 vdd vss inv1
x3 out n3 vdd vss inv1
x4 out n4 vdd vss inv1
x5 out n5 vdd vss inv1




*****************************

********define source********
vdd    vdd    0 vd
vss    vss    0 0
Vin in GND PULSE 0 vd 0.01n 0.01n 0.01n 100n 200n
*****************************

*********analysis***********
.op

.MEASURE TRAN tot_power avg power

.Meas tran t_pdf TRIG v(in) VAL='0.1*vd' rise=2
+                  TARG v(out) VAL='0.1*vd' FALL=2
.Meas tran t_pdr TRIG v(in) VAL='0.9*vd' fall=2
+                  TARG v(out) VAL='0.9*vd' rise=2
********** power per period
.measure TRAN i_avg AVG I3(x1.MM1) from=100n to=300n
.Meas tran average_power param = 'i_avg * -1.8'
.Meas tran total_power param = 'i_avg * -1.8 * (300n-100n)'

********** pdf / pdr power dissipation

.Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1175n
.meas tran avg_P_pdf param = 'avg_I_pdf *-1.8'
```

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MobaTextEditor

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hw3_2.sp | *hw3_1.sp | hw3_2.lis | hw3_2.lis

```
********** power per period
.measure TRAN i_avg AVG I3(x1.MM1) from=100n to=300n
.Meas tran average_power param = 'i_avg * -1.8'
.Meas tran total_power param = 'i_avg * -1.8 * (300n-100n)'

********** pdf / pdr power dissipation

.Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1175n
.meas tran avg_P_pdf param = 'avg_I_pdf *-1.8'
.meas tran total_P_pdf param = 'avg_I_pdf *-1.8 * (200.1175n-200.0110n)'
.Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1755n
.meas tran avg_P_pdr param = 'avg_I_pdr *-1.8'
.meas tran total_P_pdr param = 'avg_I_pdr *-1.8 *(300.1755n-300.0210n)'

********** leakage power dissipation
.Meas tran avg_I_low AVG I3(x1.MM1) from=100.1755n to=200.0110n
.meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.1755n)'
.Meas tran avg_I_high AVG I3(x1.MM1) from=200.1175n to=300.0210n
.meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.1175n)'
.meas tran total_P_steady param = 'total_P_high + total_P_low'
.meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.1755n)+(300.0210n-200.1175n))'

********** total power dissipation and percentage
.meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
.meas tran pdf_percent param = ' total_P_pdf / total_P'
.meas tran pdr_percent param = ' total_P_pdr / total_P'
.meas tran leakage_percent param = ' total_P_steady / total_P'

********** dc short
.meas tran avg_dcr_i AVG I3(x1.MM1) from=200.01n to=200.02n
.meas tran avg_dcr_p param = 'avg_dcr_i*-1.8*0.01n'

.meas tran avg_dcf_i AVG I3(x1.MM1) from=300.02n to=300.03n
.meas tran avg_dcf_p param = 'avg_dcf_i*-1.8*0.01n'

.meas tran avg_dc_p param ='(avg_dcf_p+avg_dcr_p)/0.02n'



.dc vin 0 1.8 0.01
.tran 0.01n 500n



**Gate-to-drain current
.plot tran LX4(x1.MM1)
.plot tran LX4(x2.MM1)
.plot tran LX4(x3.MM1)
.plot tran LX4(x4.MM1)
.plot tran LX4(x5.MM1)


**Drain current
.plot tran LX3(x1.MM1)
.plot tran LX3(x2.MM1)
.plot tran LX3(x3.MM1)
.plot tran LX3(x4.MM1)
```

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```
.plot tran LX4(x4.MM1)
.plot tran LX4(x5.MM1)


**Drain current
.plot tran LX3(x1.MM1)
.plot tran LX3(x2.MM1)
.plot tran LX3(x3.MM1)
.plot tran LX3(x4.MM1)
.plot tran LX3(x5.MM1)
*****Current entering the drain
.plot tran I1(x1.MM1)
.plot tran I1(x1.MM0)
*****Current entering the gate
.plot tran I2(x1.MM1)
.plot tran I2(x1.MM0)
.plot tran I2(x2.MM1)
.plot tran I2(x2.MM0)
.plot tran I2(x3.MM1)
.plot tran I2(x3.MM0)
.plot tran I2(x4.MM1)
.plot tran I2(x4.MM0)
.plot tran I2(x5.MM1)
.plot tran I2(x5.MM0)


*****Current leaving the source
.plot tran I3(x1.MM1)
.plot tran I3(x1.MM0)
******Current entering the substrate
.plot tran I4(x1.MM1)
.plot tran I4(x1.MM0)

.alter case 2 : FF 135C
.temp 135
.lib 'cic018.l' FF


********* pdf / pdr power dissipation

.Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1311n
.meas tran avg_P_pdf param = 'avg_I_pdf *-1.8 '
.meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.1311n -200.0110n)'
.Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1752n
.meas tran avg_P_pdr param = 'avg_I_pdr *-1.8 '
.meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.1752n-300.0210n)'

********* leakage power dissipation
.Meas tran avg_I_low AVG I3(x1.MM1) from=100.1752n to=200.0110n
.meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.1752n)'
.Meas tran avg_I_high AVG I3(x1.MM1) from=200.1311n to=300.0210n
.meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.1311n)'
.meas tran total_P_steady param = 'total_P_high + total_P_low'
.meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.1752n)+(300.0210n-200.1311n))'


**********total power dissipation and percentage
```

```
.meas tran avg_P_pdf param = 'avg_I_pdf *-1.8 '
.meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.1311n -200.0110n)'
.Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1752n
.meas tran avg_P_pdr param = 'avg_I_pdr *-1.8 '
.meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.1752n-300.0210n)'

********* leakage power dissipation
.Meas tran avg_I_low AVG I3(x1.MM1) from=100.1752n to=200.0110n
.meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.1752n)'
.Meas tran avg_I_high AVG I3(x1.MM1) from=200.1311n to=300.0210n
.meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.1311n)'
.meas tran total_P_steady param = 'total_P_high + total_P_low'
.meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.1752n)+(300.0210n-200.1311n))'


**********total power dissipation and percentage
.meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
.meas tran pdf_percent param = ' total_P_pdf / total_P'
.meas tran pdr_percent param = ' total_P_pdr / total_P'
.meas tran leakage_percent param = ' total_P_steady / total_P'

*************************************************

.alter case 3 : SS -40C
.temp -40
.lib 'cic018.l' SS


********* pdf / pdr power dissipation

.Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.2121n
.meas tran avg_P_pdf param = 'avg_I_pdf *-1.8'
.meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.2121n  -200.0110n)'
.Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.3365n
.meas tran avg_P_pdr param = 'avg_I_pdr *-1.8'
.meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.3365n-300.0210n)'
********* leakage power dissipation

.Meas tran avg_I_low AVG I3(x1.MM1) from=100.3365n to=200.0110n
.meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.3365n)'
.Meas tran avg_I_high AVG I3(x1.MM1) from=200.2121n to=300.0210n
.meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.2121n)'
.meas tran total_P_steady param = 'total_P_high + total_P_low'
.meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.3365n)+(300.0210n-200.2121n))'

**********total power dissipation and percentage
.meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
.meas tran pdf_percent param = ' total_P_pdf / total_P'
.meas tran pdr_percent param = ' total_P_pdr / total_P'
.meas tran leakage_percent param = ' total_P_steady / total_P'

*****************************

.end
```