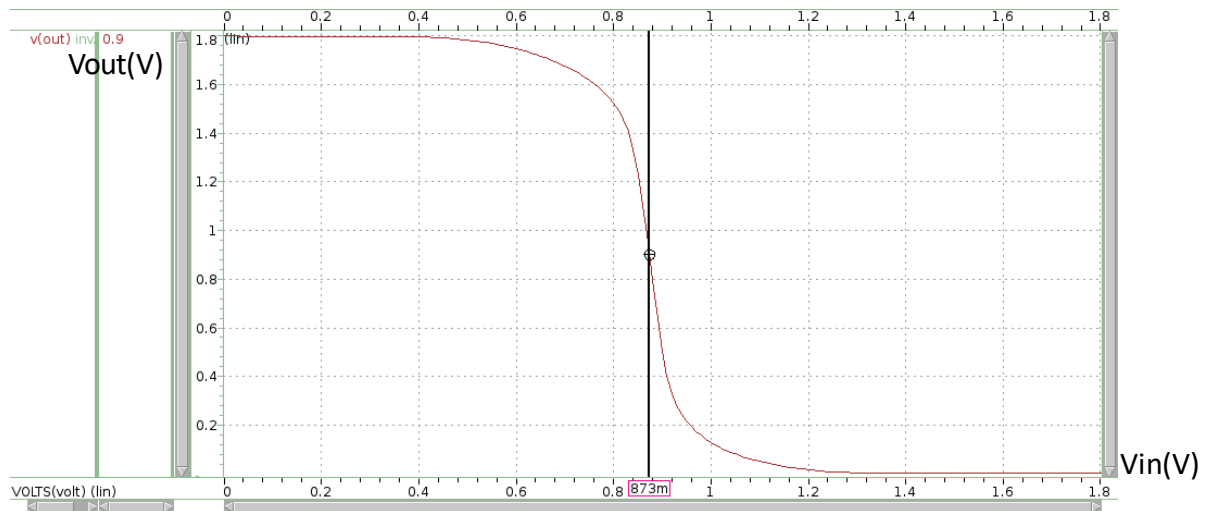


HW3  
105061112 王柏崴

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  $V_{in}=873\text{mV}$ ：



將  $V_{in}$  設為  $873\text{mV}$ ，並求此情形下的  $C_g$ ：

```

MobaTextEditor
File Edit Search View Format Special Tools
inv.sp inv.lis inv_ver2.lis inv_ver3.lis
43
44 **info** dc convergence successful at Newton-Raphson method
45 *****
46 inverter
47
48 ***** operating point information tnom= 25.000 temp= 25.000 *****
49 ***** operating point status is all simulation time is 0.
50 node =voltage node =voltage node =voltage
51
52 +0:in = 873.0000m 0:out = 905.3958m 0:vdd = 1.8000
53 +0:vss = 0.
54
55
56 maximum nodal capacitance= 1.003E-12 on node 0:vss
57
58 nodal capacitance table
59
60 node = cap node = cap node = cap
61
62 +0:in = 3.7761f 0:out = 1.0028p 0:vdd = 8.6935f
63 +0:vss = 1.0029p
64
65
66
67 **** voltage sources
68
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 167 lines Row #72 Col #

```

在一般情況下取  $\rho = 4$ ，已知：

$$F = GBH$$

$$\text{set } G = 1$$

$$B = 1(\text{no branch})$$

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

$$F = 21186$$

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

Take  $N=7$ ,

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

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

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

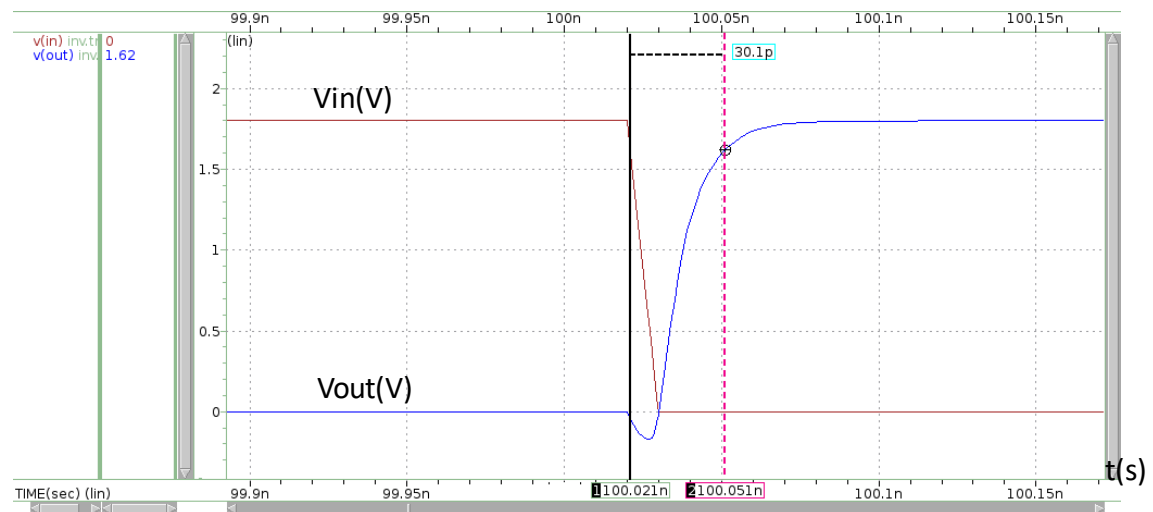
$\rho_{inv}$  與假設相近故可驗證假設正確。

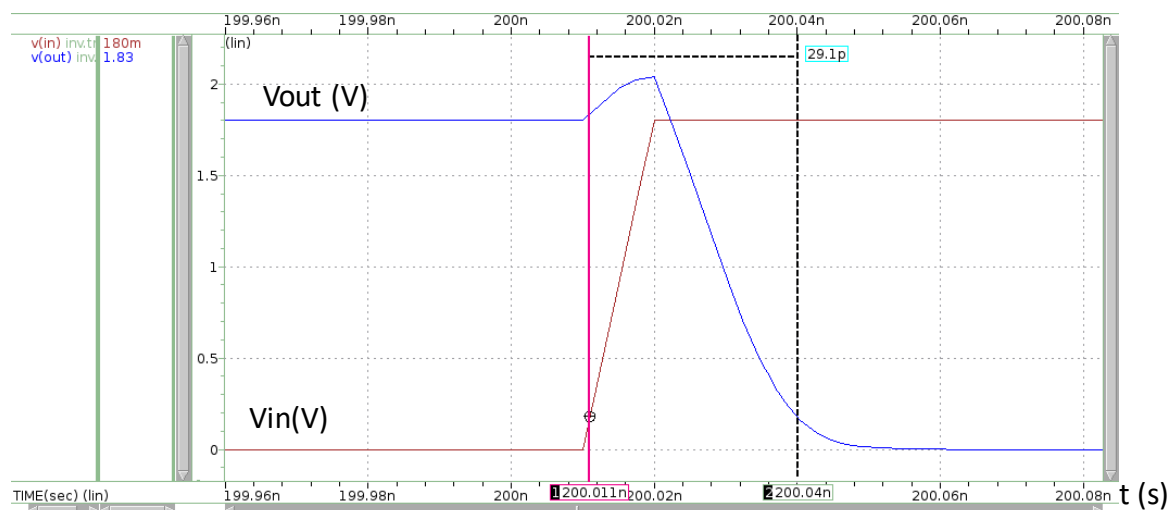
$$P = \sum_{i=1}^7 p_i = 7$$

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

(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：





```

MobaTextEditor
File Edit Search Format Syntax Special Tools
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
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 174 lines Row #1

```

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

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

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  $\tau$  後，可得：

$$\text{total delay time} = 1.066552 \text{ ns}$$

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	$\rho_{inv}$	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  $C_{in}$ ：

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

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

其餘 stage 同樣：

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

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

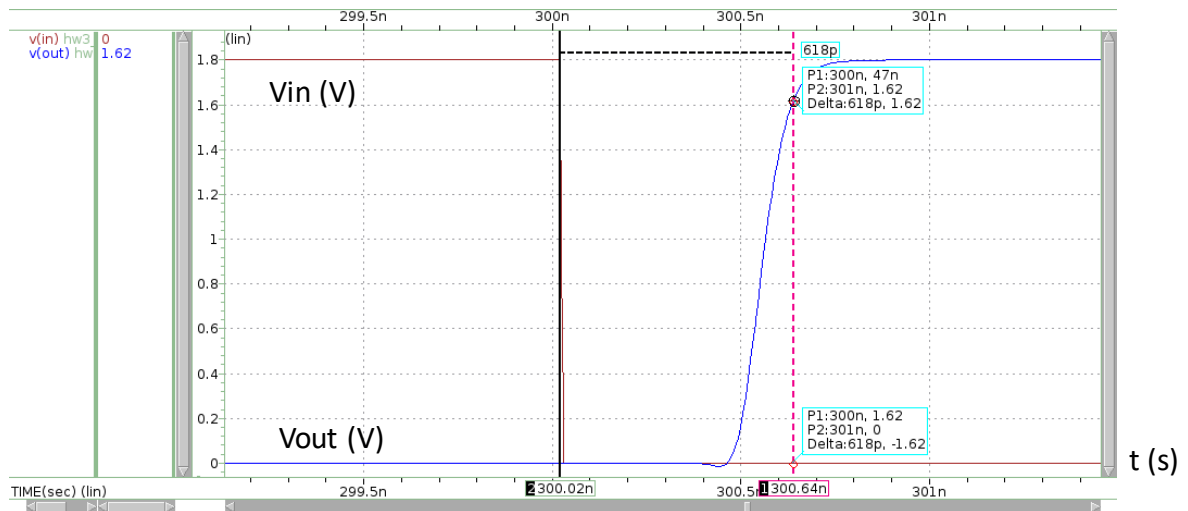
所以下一 stage 的 W 與 L 為前一 stage 的 4 倍(i.e. PMOS, NMOS size 都是 0.5u/0.18u，只是 transistor number 增加 4 倍)，因此設計出下表：

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





```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
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
C:\Users\王柏威\DOCUME~1\MobaXterm\UNIX Plain text 239 lines Row #73 Col #34

```

最後驗證設計條件是否符合模擬結論(i.e. last stage  $C_{in} = 19.28pF$ . Next stage  $C_{in} = 4$  times previous stage  $C_{in}$ ) :

```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
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.
C:\Users\王柏威\DOCUME~1\MobaXterm\UNIX Plain text 239 lines Row #73 Col #34

```

由上圖可知，結果大致符合設計條件。

(c)

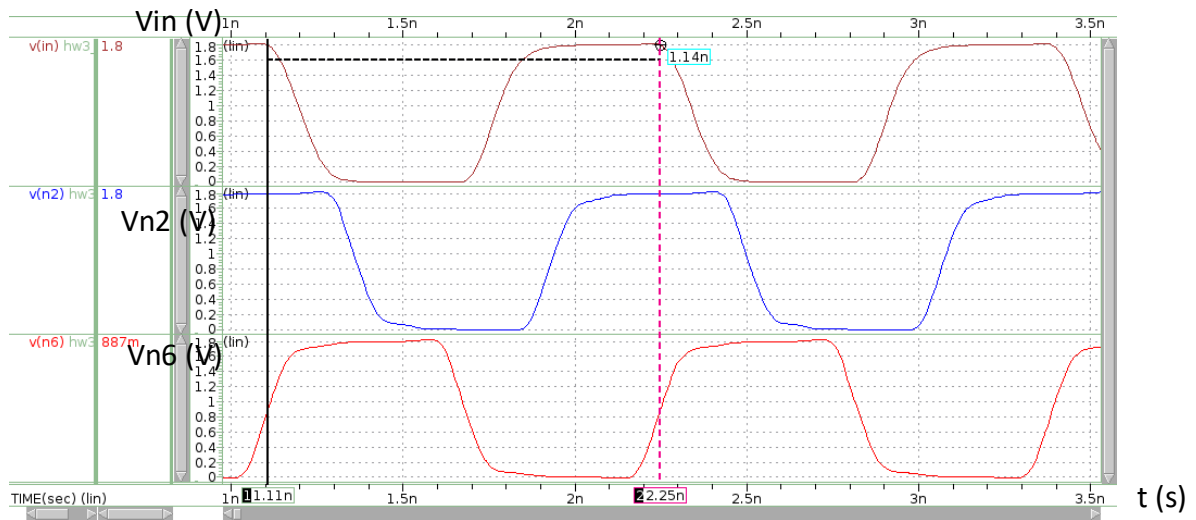
因為傳輸一訊號至 out 的 delay 為  $D = \frac{t_{pdr} + t_{pdf}}{2} = 619.5ps$ ，而傳遞訊號反轉週

期為  $T = 2D = 1239 ps$

所以震盪頻率：

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

(d)



```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_1_nochain.sp hw3_1.sp hw3_1.lis
170
171
172
173 *****
174 hw3_1
175
176 ***** transient analysis tnom= 25.000 temp= 25.000 *****
177 t_pdf= failed
178 t_pdr= failed
179 period= 1.1413n targ= 1.5811n trig= 439.8214p
180
181 ***** job concluded
182 *****
183 hw3_1
184
185 ***** job statistics summary tnom= 25.000 temp= 25.000 *****
186
187
188 ***** Machine Information *****
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 238 lines Row #1 Col #
```

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： $f = 8.071 \times 10^8 \text{ Hz}$

模擬： $f = 876040298 \text{ Hz}$

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：

$$T = \left(2 \sum d_i\right) \cdot 4RC \quad \forall d_i: \text{time delay of } i\text{th stage}$$

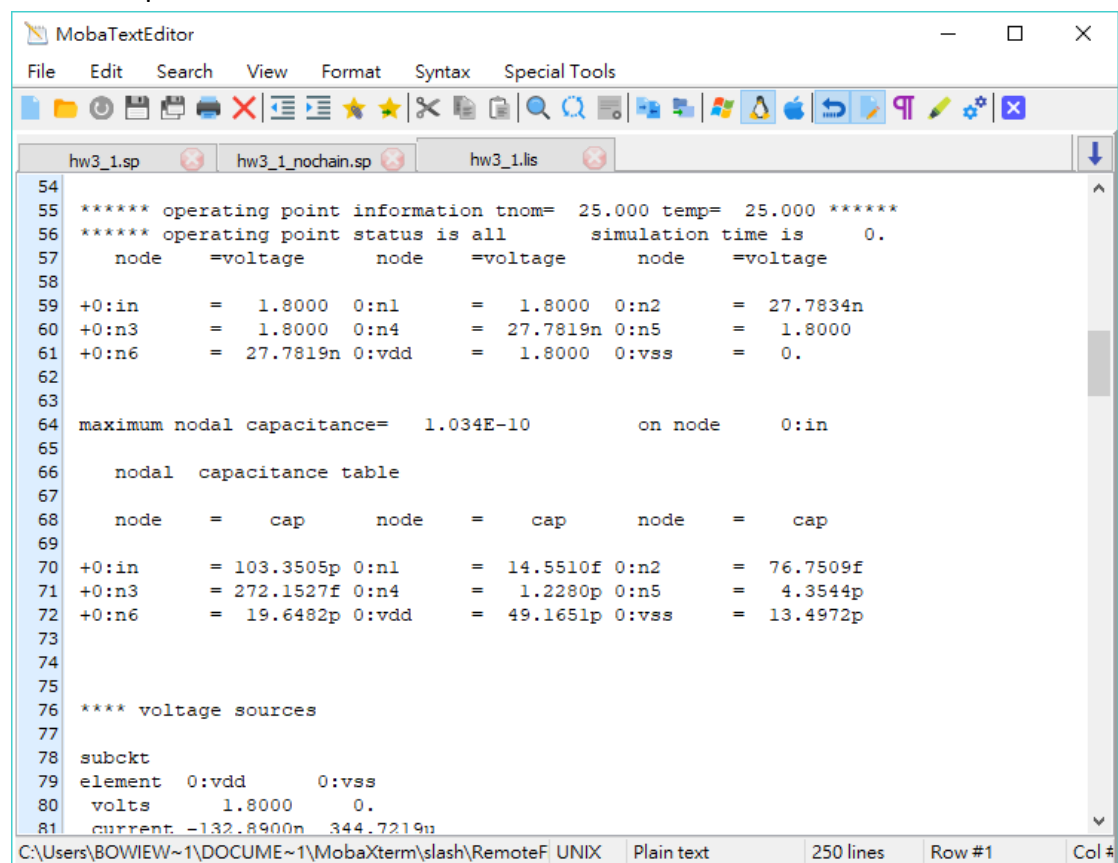
而元件的 time delay  $d_i$  與其 parasitic capacitor 和 resistance 有關：

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

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：



```
54
55 ***** operating point information tnom= 25.000 temp= 25.000 *****
56 ***** operating point status is all simulation time is 0.
57 node =voltage node =voltage node =voltage
58
59 +0:in = 1.8000 0:n1 = 1.8000 0:n2 = 27.7834n
60 +0:n3 = 1.8000 0:n4 = 27.7819n 0:n5 = 1.8000
61 +0:n6 = 27.7819n 0:vdd = 1.8000 0:vss = 0.
62
63
64 maximum nodal capacitance= 1.034E-10 on node 0:in
65
66 nodal capacitance table
67
68 node = cap node = cap node = cap
69
70 +0:in = 103.3505p 0:n1 = 14.5510f 0:n2 = 76.7509f
71 +0:n3 = 272.1527f 0:n4 = 1.2280p 0:n5 = 4.3544p
72 +0:n6 = 19.6482p 0:vdd = 49.1651p 0:vss = 13.4972p
73
74
75
76 **** voltage sources
77
78 subckt
79 element 0:vdd 0:vss
80 volts 1.8000 0.
81 current -132.8900n 344.7219n
```

Open loop：

```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_1.sp hw3_1_nochain.sp hw3_1.lis hw3_1_nochain.lis
58
59 +0:in = 0. 0:n1 = 1.8000 0:n2 = 27.7819n
60 +0:n3 = 1.8000 0:n4 = 27.7819n 0:n5 = 1.8000
61 +0:n6 = 27.7819n 0:out = 1.8000 0:vdd = 1.8000
62 +0:vss = 0.
63
64
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.
83 current -132.9116n 0. 132.9130n
84 power 239.2409n 0. 0.
85
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 253 lines Row #81 Col #

```

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/Ci	0.00014	5.27461	3.54592	4.51217	3.54592	4.51226	5.26004
n	1	3	2	3	8	3	9
$g_i, p_i$	1	1	1	1	1	1	1
$\sum d_i$	30.21821						
Open loop							
Stage	1	2	3	4	5	6	7
Cout/Ci	4.32977	4.51223	3.54592	4.51217	3.54592	4.51226	5.25991
n	7	7	2	3	8	3	2
$g_i, p_i$	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.

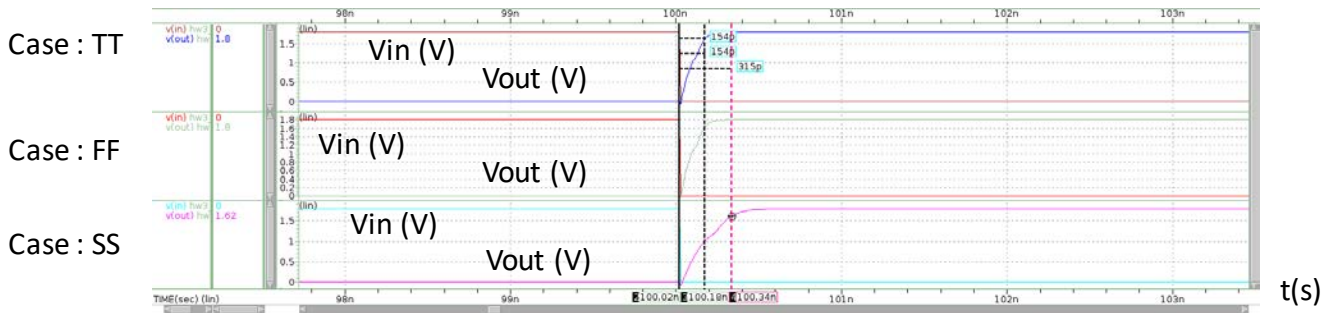
此題主要計算 power 的方式為取第一顆 inverter PMOS source 端電流在一周期內的平均值後，再乘 Vdd (1.8V) 即可得到平均功率，並利用平均功率乘時間得消耗能量，而因為題目有要求不同時間區段，以前述相同方法，只是取不同時間段的平均電流，

(a)

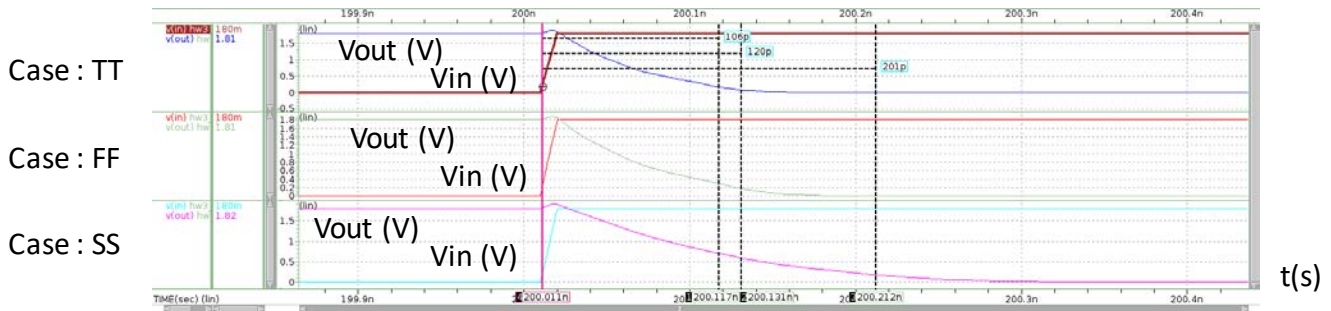
以下為利用 .MEAS 與 waveview 所找出來的 tpdf, tpd, power dissipation :

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 :

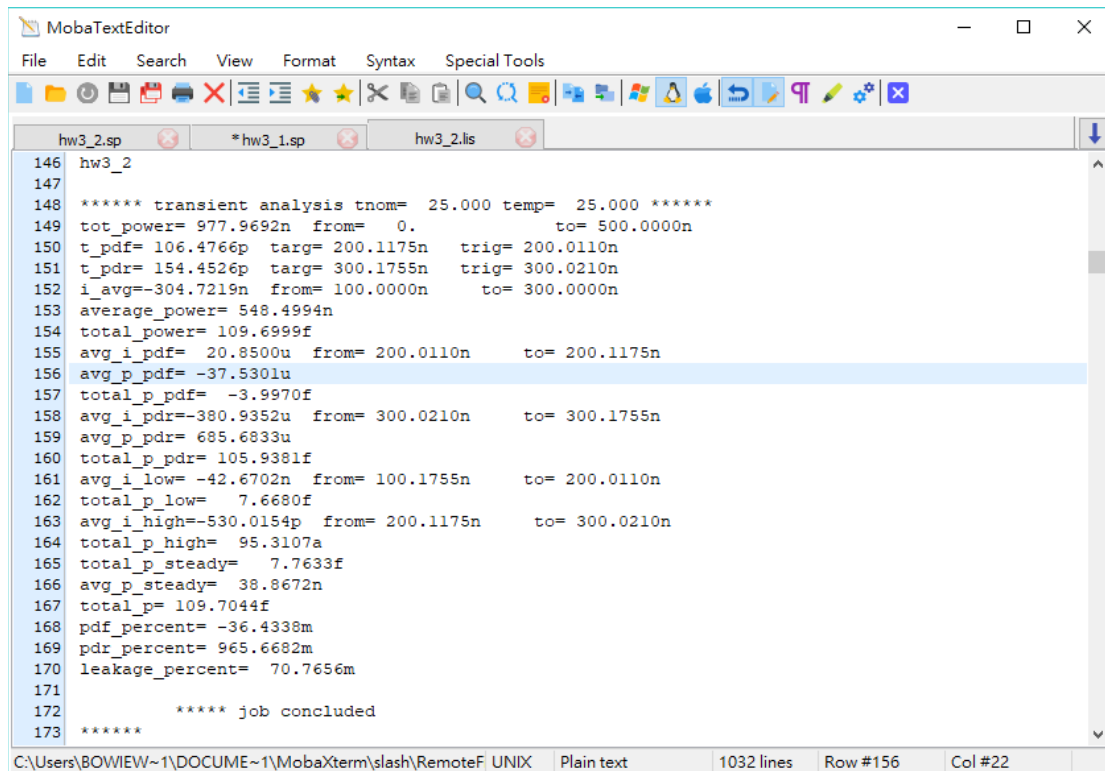


Tpdf :



Average power consumption, tpd and tpdf by meas.

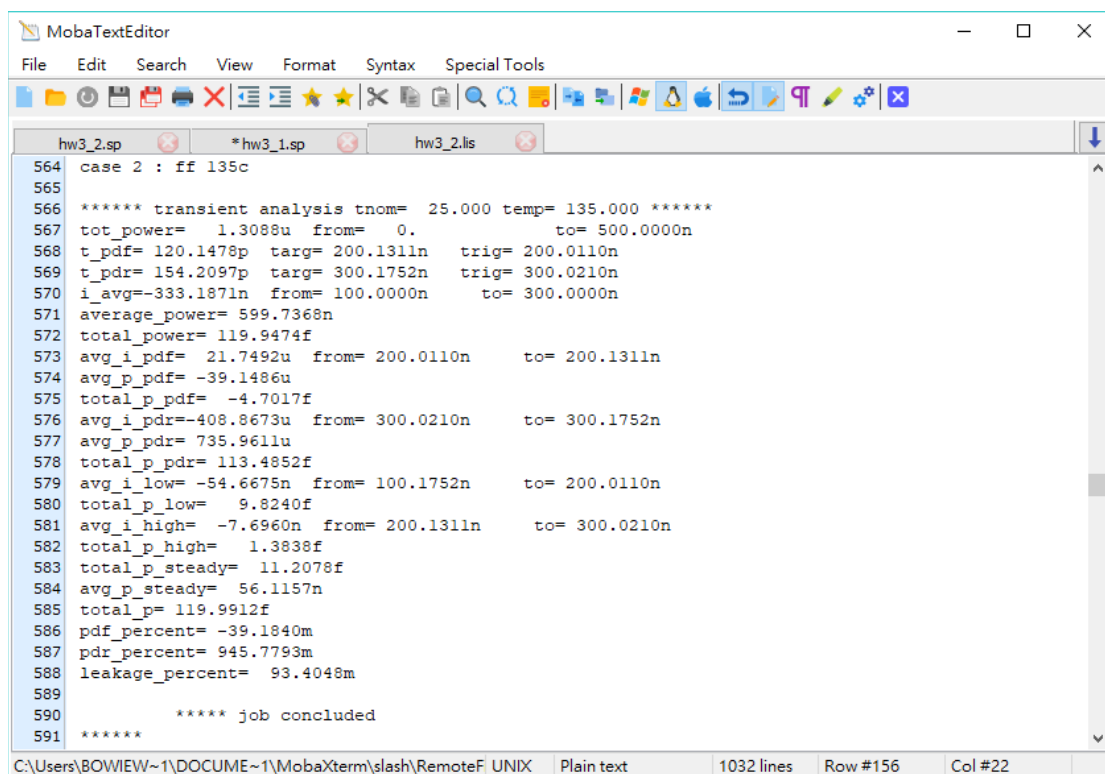
TT:



```
146 hw3_2
147
148 ***** transient analysis tnom= 25.000 temp= 25.000 *****
149 tot_power= 977.9692n from= 0. to= 500.0000n
150 t_pdf= 106.4766p targ= 200.1175n trig= 200.0110n
151 t_pdr= 154.4526p targ= 300.1755n trig= 300.0210n
152 i_avg=-304.7219n from= 100.0000n to= 300.0000n
153 average_power= 548.4994n
154 total_power= 109.6999f
155 avg_i_pdf= 20.8500u from= 200.0110n to= 200.1175n
156 avg_p_pdf= -37.5301u
157 total_p_pdf= -3.9970f
158 avg_i_pdr=-380.9352u from= 300.0210n to= 300.1755n
159 avg_p_pdr= 685.6833u
160 total_p_pdr= 105.9381f
161 avg_i_low= -42.6702n from= 100.1755n to= 200.0110n
162 total_p_low= 7.6680f
163 avg_i_high=-530.0154p from= 200.1175n to= 300.0210n
164 total_p_high= 95.3107a
165 total_p_steady= 7.7633f
166 avg_p_steady= 38.8672n
167 total_p= 109.7044f
168 pdf_percent= -36.4338m
169 pdr_percent= 965.6682m
170 leakage_percent= 70.7656m
171
172 ***** job concluded
173 *****
```

C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1032 lines Row #156 Col #22

FF :



```
564 case 2 : ff 135c
565
566 ***** transient analysis tnom= 25.000 temp= 135.000 *****
567 tot_power= 1.3088u from= 0. to= 500.0000n
568 t_pdf= 120.1478p targ= 200.1311n trig= 200.0110n
569 t_pdr= 154.2097p targ= 300.1752n trig= 300.0210n
570 i_avg=-333.1871n from= 100.0000n to= 300.0000n
571 average_power= 599.7368n
572 total_power= 119.9474f
573 avg_i_pdf= 21.7492u from= 200.0110n to= 200.1311n
574 avg_p_pdf= -39.1486u
575 total_p_pdf= -4.7017f
576 avg_i_pdr=-408.8673u from= 300.0210n to= 300.1752n
577 avg_p_pdr= 735.9611u
578 total_p_pdr= 113.4852f
579 avg_i_low= -54.6675n from= 100.1752n to= 200.0110n
580 total_p_low= 9.8240f
581 avg_i_high= -7.6960n from= 200.1311n to= 300.0210n
582 total_p_high= 1.3838f
583 total_p_steady= 11.2078f
584 avg_p_steady= 56.1157n
585 total_p= 119.9912f
586 pdf_percent= -39.1840m
587 pdr_percent= 945.7793m
588 leakage_percent= 93.4048m
589
590 ***** job concluded
591 *****
```

C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1032 lines Row #156 Col #22

SS :

```

964 *****
965 case 3 : ss -40c
966
967 ***** transient analysis tnom= 25.000 temp= -40.000 *****
968 tot_power= 985.4455n from= 0. to= 500.0000n
969 t_pdf= 201.0861p targ= 200.2121n trig= 200.0110n
970 t_pdr= 315.4807p targ= 300.3365n trig= 300.0210n
971 i_avg=-339.7775n from= 100.0000n to= 300.0000n
972 average_power= 611.5996n
973 total_power= 122.3199f
974 avg_i_pdf= 14.6575u from= 200.0110n to= 200.2121n
975 avg_p_pdf= -26.3836u
976 total_p_pdf= -5.3057f
977 avg_i_pdr=-210.3427u from= 300.0210n to= 300.3365n
978 avg_p_pdr= 378.6169u
979 total_p_pdr= 119.4536f
980 avg_i_low=-52.5524n from= 100.3365n to= 200.0110n
981 total_p_low= 9.4286f
982 avg_i_high=-404.1313p from= 200.2121n to= 300.0210n
983 total_p_high= 72.6046a
984 total_p_steady= 9.5012f
985 avg_p_steady= 47.6292n
986 total_p= 123.6491f
987 pdf_percent= -42.9096m
988 pdr_percent= 966.0693m
989 leakage_percent= 76.8403m
990
991 ***** job concluded
  
```

C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1032 lines Row #156 Col #22

(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:

```

MobaTextEditor
Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis
147
148 ***** transient analysis tnom= 25.000 temp= 25.000 *****
149 tot_power= 977.9692n from= 0. to= 500.0000n
150 t_pdf= 106.4766p targ= 200.1175n trig= 200.0110n
151 t_pdr= 154.4526p targ= 300.1755n trig= 300.0210n
152 i_avg=-304.7219n from= 100.0000n to= 300.0000n
153 average_power= 548.4994n
154 total_power= 109.6999f
155 avg_i_pdf= 20.8500u from= 200.0110n to= 200.1175n
156 total_p_pdf= -3.9970f
157 avg_i_pdr=-380.9352u from= 300.0210n to= 300.1755n
158 total_p_pdr= 105.9381f
159 avg_i_low=-42.6702n from= 100.1755n to= 200.0110n
160 total_p_low= 7.6680f
161 avg_i_high=-530.0154p from= 200.1175n to= 300.0210n
162 total_p_high= 95.3107a
163 total_p_steady= 7.7633f
164 total_p= 109.7044f
165 pdf_percent= -36.4338m
166 pdr_percent= 965.6682m
167 leakage_percent= 70.7656m
168 dc_t_pdr= 98.2625p targ= 300.1482n trig= 300.0500n
169 dc_t_pdf= 63.6900p targ= 200.0980n trig= 200.0343n
170
171 ***** job concluded
172 *****
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF_UNIX Plain text 1029 lines Row #164 Col #

```

```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis
64
65 nodal capacitance table
66
67 node = cap node = cap node = cap
68
69 +0:in = 5.6213f 0:n2 = 5.2928f 0:n3 = 5.2928f
70 +0:n4 = 5.2928f 0:n5 = 5.2928f 0:out = 25.3831f
71 +0:vdd = 40.4961f 0:vss = 28.0158f
72
73
74
75 **** voltage sources
76
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF_UNIX Plain text 1032 lines Row #156 Col #22

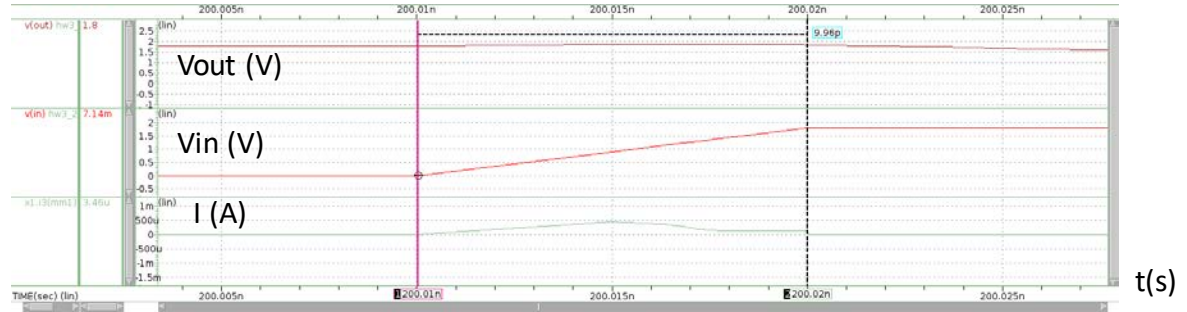
```

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

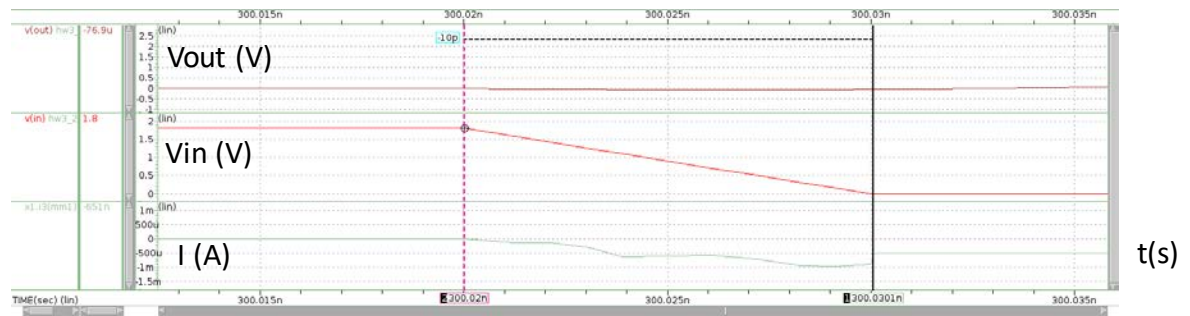
取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

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

Rising :



Falling :



FF :

```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis
564
565 ***** transient analysis tnom= 25.000 temp= 135.000 *****
566 tot_power= 1.3088u from= 0. to= 500.0000n
567 t_pdf= 120.1478p targ= 200.1311n trig= 200.0110n
568 t_pdr= 154.2097p targ= 300.1752n trig= 300.0210n
569 i_avg=-333.1871n from= 100.0000n to= 300.0000n
570 average_power= 599.7368n
571 total_power= 119.9474f
572 dc_t_pdr= 73.1340p targ= 300.1293n trig= 300.0562n
573 dc_t_pdf= 49.6873p targ= 200.0924n trig= 200.0427n
574 avg_i_pdf= 21.7492u from= 200.0110n to= 200.1311n
575 total_p_pdf= -4.7017f
576 avg_i_pdr=-408.8673u from= 300.0210n to= 300.1752n
577 total_p_pdr= 113.4852f
578 avg_i_low= -54.6675n from= 100.1752n to= 200.0110n
579 total_p_low= 9.8240f
580 avg_i_high= -7.6960n from= 200.1311n to= 300.0210n
581 total_p_high= 1.3838f
582 total_p_steady= 11.2078f
583 total_p= 119.9912f
584 pdf_percent= -39.1840m
585 pdr_percent= 945.7793m
586 leakage_percent= 93.4048m
587
588 ***** job concluded
589 *****
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1029 lines Row #164 Col #

```

```

MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis
482
483 nodal capacitance table
484
485 node = cap node = cap node = cap
486
487 +0:in = 5.8861f 0:n2 = 5.2729f 0:n3 = 5.2729f
488 +0:n4 = 5.2729f 0:n5 = 5.2729f 0:out = 26.0890f
489 +0:vdd = 40.3685f 0:vss = 28.1982f
490
491
492
493 **** voltage sources
494
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1032 lines Row #156 Col #22

```

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

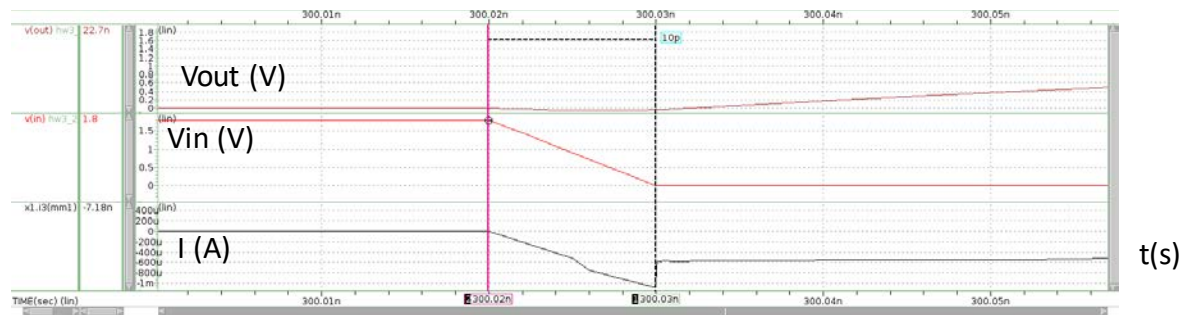
取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

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

Rising :



Falling :



SS :

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis
962 *****
963 case 3 : ss -40c
964
965 ***** transient analysis tnom= 25.000 temp= -40.000 *****
966 tot_power= 985.4455n from= 0. to= 500.0000n
967 t_pdf= 201.0861p targ= 200.2121n trig= 200.0110n
968 t_pdr= 315.4807p targ= 300.3365n trig= 300.0210n
969 i_avg=-339.7775n from= 100.0000n to= 300.0000n
970 average_power= 611.5996n
971 total_power= 122.3199f
972 dc_t_pdr= 231.1262p targ= 300.3005n trig= 300.0694n
973 dc_t_pdf= 139.6286p targ= 200.1866n trig= 200.0470n
974 avg_i_pdf= 14.6575u from= 200.0110n to= 200.2121n
975 total_p_pdf= -5.3057f
976 avg_i_pdr=-210.3427u from= 300.0210n to= 300.3365n
977 total_p_pdr= 119.4536f
978 avg_i_low= -52.5524n from= 100.3365n to= 200.0110n
979 total_p_low= 9.4286f
980 avg_i_high=-404.1313p from= 200.2121n to= 300.0210n
981 total_p_high= 72.6046a
982 total_p_steady= 9.5012f
983 total_p= 123.6491f
984 pdf_percent= -42.9096m
985 pdr_percent= 966.0693m
986 leakage_percent= 76.8403m
987
988 ***** job concluded
989 *****
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1029 lines Row #164 Col #
```

```

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
895
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 1029 lines Row #164 Col #

```

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

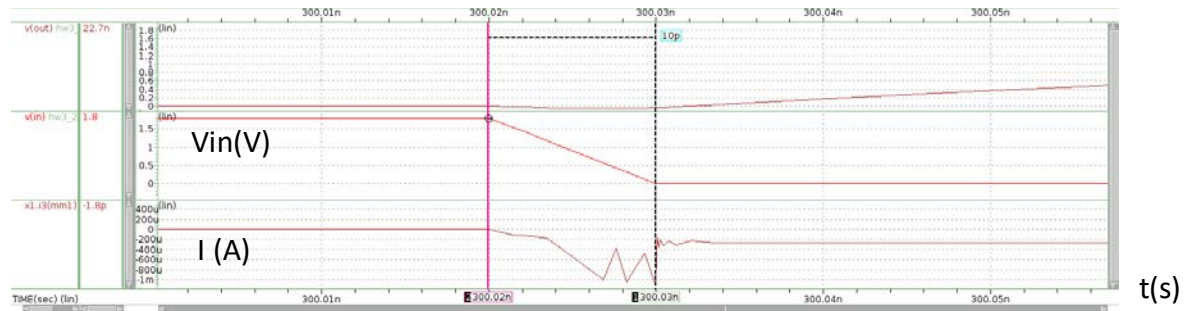
取 Vin 從 0V->1.8V 與 1.8V->0V 時，流經第一顆 inverter source 端的電流平均值，再乘 1.8V 即可得到 short 時的 power，利用.meas 計算可得

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

Rising :



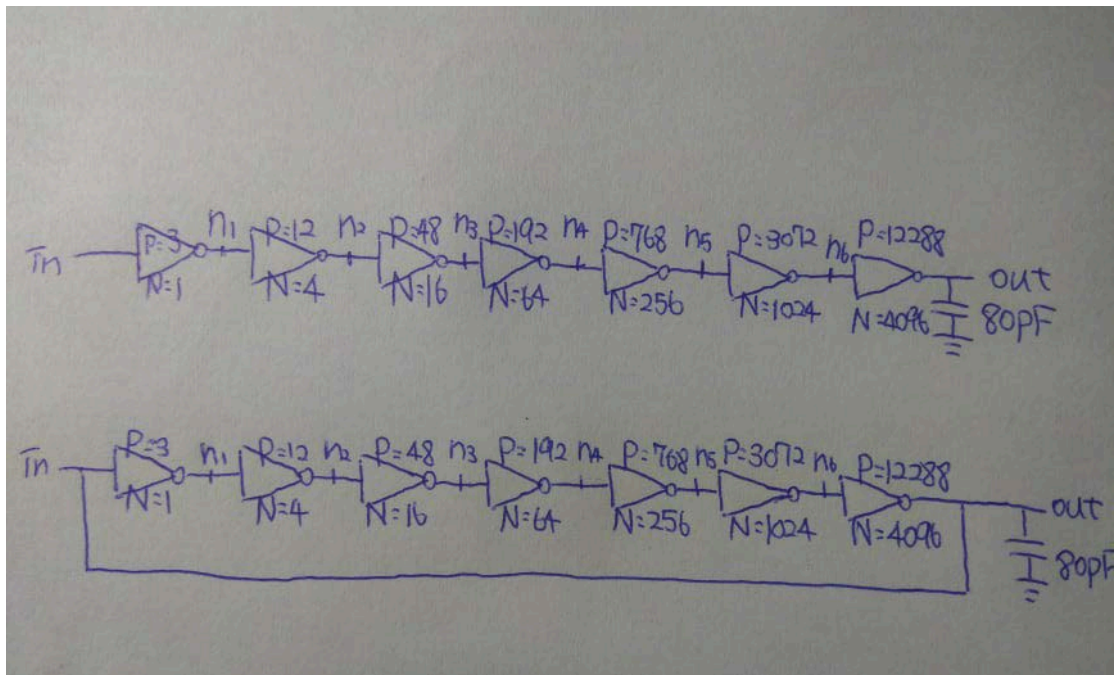
Falling :



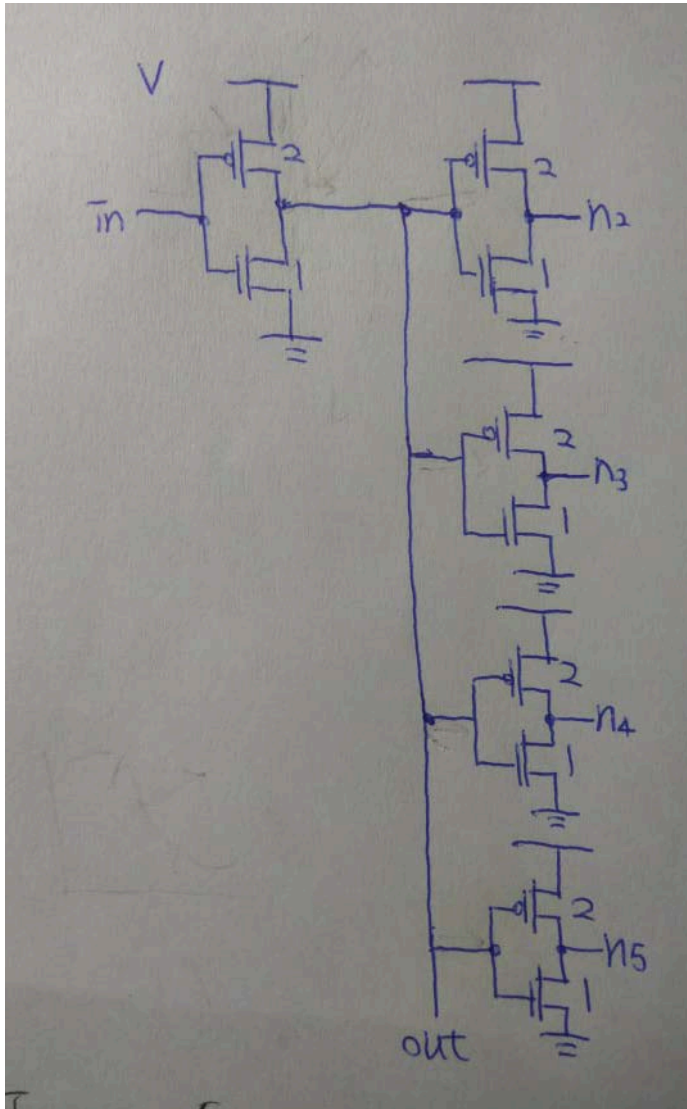
schematic circuit:



1.



2.



.Sp file

Hw3\_1.sp :

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp hw3_2.lis hw3_2.lis hw3_1.sp
1 hw3_1
2 .protect
3 .lib 'cic018.1' TT
4 .unprotect
5 .temp 25
6 .option
7 + post $output waveform to user
8 + acout=0 runlv1=6 $increase simulation accuracy
9 + captable $list every node capacitance
10
11
12 .param vd=1.8
13
14 *****circuit*****
15 .SUBCKT inv1 in out vdd vss
16 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=3
17 MM0 out in vss vss N_18 W=0.5u L=0.18u m=1
18 .ENDS
19 *****
20 .SUBCKT inv2 in out vdd vss
21 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=12
22 MM0 out in vss vss N_18 W=0.5u L=0.18u m=4
23 .ENDS
24 *****
25 .SUBCKT inv3 in out vdd vss
26 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=48
27 MM0 out in vss vss N_18 W=0.5u L=0.18u m=16
28 .ENDS
29 *****
30 .SUBCKT inv4 in out vdd vss
31 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=192
32 MM0 out in vss vss N_18 W=0.5u L=0.18u m=64
33 .ENDS
34 *****
35 .SUBCKT inv5 in out vdd vss
36 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=768
37 MM0 out in vss vss N_18 W=0.5u L=0.18u m=256
38 .ENDS
39 *****
40 .SUBCKT inv6 in out vdd vss
41 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=3072
42 MM0 out in vss vss N_18 W=0.5u L=0.18u m=1024
43 .ENDS
44 *****
45 .SUBCKT inv7 in out vdd vss
46 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=12288
47 MM0 out in vss vss N_18 W=0.5u L=0.18u m=4096
48 .ENDS
49 *****
50
51
52
53
54
55
56 *****call the circuit***
57 v1 in n1 vdd vss inv1
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 91 lines Row #1 Col #1
```

```
MobaTextEditor
Edit Search View Format Syntax Special Tools
hw3_2.sp hw3_2.lis hw3_2.lis hw3_1.sp
36 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=768
37 MM0 out in vss vss N_18 W=0.5u L=0.18u m=256
38 .ENDS
39 *****
40 .SUBCKT inv6 in out vdd vss
41 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=3072
42 MM0 out in vss vss N_18 W=0.5u L=0.18u m=1024
43 .ENDS
44 *****
45 .SUBCKT inv7 in out vdd vss
46 MM1 out in vdd vdd P_18 W=0.5u L=0.18u m=12288
47 MM0 out in vss vss N_18 W=0.5u L=0.18u m=4096
48 .ENDS
49 *****
50
51
52
53
54
55
56 *****call the circuit***
57 x1 in n1 vdd vss inv1
58 x2 n1 n2 vdd vss inv2
59 x3 n2 n3 vdd vss inv3
60 x4 n3 n4 vdd vss inv4
61 x5 n4 n5 vdd vss inv5
62 x6 n5 n6 vdd vss inv6
63 x7 n6 in vdd vss inv7
64
65 CL in GND 80p
66
67 *****
68
69 *****define source*****
70 vdd vdd 0 vd
71 vss vss 0 0
72 ***Vin in GND PULSE 0 vd 0.01n 0.01n 0.01n 100n 200n
73 *****
74
75 *****analysis*****
76 .op
77 .Meas tran t_pdf TRIG v(in) VAL='0.1*vd' rise=2
78 + TARG v(out) VAL='0.1*vd' FALL=2
79 .Meas tran t_pdr TRIG v(in) VAL='0.9*vd' FALL=2
80 + TARG v(out) VAL='0.9*vd' rise=2
81 .Meas tran period TRIG v(in) VAL='vd' fall=2
82 + TARG v(in) VAL='vd' FALL=3
83
84 ***.dc Vin 0 vd 0.01
85 .ic V(n1) = 1.8
86 .tran 0.01n 500n
87
88 *****
89
90 .end
91
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 91 lines Row #1 Col #1
```

Hw3\_2.sp

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis hw3_2.lis
1 hw3_2
2 .protect
3 .lib 'cic018.1' TT
4 .unprotect
5 .temp 25
6 .option
7 + post $output waveform to user
8 + acout=0 runlvl=6 $increase simulation accuracy
9 + captable $list every node capacitance
10
11
12 .param vd=1.8
13
14 *****circuit*****
15 .SUBCKT invl in out vdd vss
16 MM1 out in vdd vdd P_18 W=2u L=0.18u m=1
17 MM0 out in vss vss N_18 W=1u L=0.18u m=1
18
19 .ENDS
20 *****
21
22 *****call the circuit***
23 x1 in out vdd vss invl
24 x2 out n2 vdd vss invl
25 x3 out n3 vdd vss invl
26 x4 out n4 vdd vss invl
27 x5 out n5 vdd vss invl
28
29
30
31
32 *****
33
34 *****define source*****
35 vdd vdd 0 vd
36 vss vss 0 0
37 Vin in GND PULSE 0 vd 0.01n 0.01n 0.01n 100n 200n
38 *****
39
40 *****analysis*****
41 .op
42
43 .MEASURE TRAN tot_power avg power
44
45 .Meas tran t_pdf TRIG v(in) VAL='0.1*vd' rise=2
46 + TARG v(out) VAL='0.1*vd' FALL=2
47 .Meas tran t_pdr TRIG v(in) VAL='0.9*vd' fall=2
48 + TARG v(out) VAL='0.9*vd' rise=2
49 ***** power per period
50 .measure TRAN i_avg AVG I3(x1.MM1) from=100n to=300n
51 .Meas tran average_power param = 'i_avg * -1.8'
52 .Meas tran total_power param = 'i_avg * -1.8 * (300n-100n)'
53
54 ***** pdf / pdr power dissipation
55
56 .Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1175n
57 .meas tran avg_P_pdf param = 'avg_I_pdf * -1.8'
```

C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 193 lines Row #81 Col #59

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis hw3_2.lis
49 ***** power per period
50 .measure TRAN i_avg AVG I3(x1.MM1) from=100n to=300n
51 .Meas tran average_power param = 'i_avg * -1.8'
52 .Meas tran total_power param = 'i_avg * -1.8 * (300n-100n)'
53
54 ***** pdf / pdr power dissipation
55
56 .Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1175n
57 .meas tran avg_P_pdf param = 'avg_I_pdf *-1.8'
58 .meas tran total_P_pdf param = 'avg_I_pdf *-1.8 * (200.1175n-200.0110n)'
59 .Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1755n
60 .meas tran avg_P_pdr param = 'avg_I_pdr *-1.8'
61 .meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.1755n-300.0210n)'
62
63 ***** leakage power dissipation
64 .Meas tran avg_I_low AVG I3(x1.MM1) from=100.1755n to=200.0110n
65 .meas tran total_P_low param = 'avg_I_low *-1.8 * (200.0110n-100.1755n)'
66 .Meas tran avg_I_high AVG I3(x1.MM1) from=200.1175n to=300.0210n
67 .meas tran total_P_high param = 'avg_I_high *-1.8 * (300.0210n-200.1175n)'
68 .meas tran total_P_steady param = 'total_P_high + total_P_low'
69 .meas tran avg_P_steady param = 'total_P_steady / ((200.0110n-100.1755n)+(300.0210n-200.1175n))'
70
71 ***** total power dissipation and percentage
72 .meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
73 .meas tran pdf_percent param = ' total_P_pdf / total_P'
74 .meas tran pdr_percent param = ' total_P_pdr / total_P'
75 .meas tran leakage_percent param = ' total_P_steady / total_P'
76
77 ***** dc short
78 .meas tran avg_dcr_i AVG I3(x1.MM1) from=200.01n to=200.02n
79 .meas tran avg_dcr_p param = 'avg_dcr_i*-1.8*0.01n'
80
81 .meas tran avg_dcf_i AVG I3(x1.MM1) from=300.02n to=300.03n
82 .meas tran avg_dcf_p param = 'avg_dcf_i*-1.8*0.01n'
83
84 .meas tran avg_dc_p param = '(avg_dcf_p+avg_dcr_p)/0.02n'
85
86
87
88 .dc vin 0 1.8 0.01
89 .tran 0.01n 500n
90
91
92
93 **Gate-to-drain current
94 .plot tran LX4(x1.MM1)
95 .plot tran LX4(x2.MM1)
96 .plot tran LX4(x3.MM1)
97 .plot tran LX4(x4.MM1)
98 .plot tran LX4(x5.MM1)
99
100
101 **Drain current
102 .plot tran LX3(x1.MM1)
103 .plot tran LX3(x2.MM1)
104 .plot tran LX3(x3.MM1)
105 .plot tran LX3(x4.MM1)
C:\Users\BOWIEWE~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 193 lines Row #81 Col #59
```

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis hw3_2.lis
97 .plot tran LX4(x4.MM1)
98 .plot tran LX4(x5.MM1)
99
100
101 **Drain current
102 .plot tran LX3(x1.MM1)
103 .plot tran LX3(x2.MM1)
104 .plot tran LX3(x3.MM1)
105 .plot tran LX3(x4.MM1)
106 .plot tran LX3(x5.MM1)
107 *****Current entering the drain
108 .plot tran I1(x1.MM1)
109 .plot tran I1(x1.MMO)
110 *****Current entering the gate
111 .plot tran I2(x1.MM1)
112 .plot tran I2(x1.MMO)
113 .plot tran I2(x2.MM1)
114 .plot tran I2(x2.MMO)
115 .plot tran I2(x3.MM1)
116 .plot tran I2(x3.MMO)
117 .plot tran I2(x4.MM1)
118 .plot tran I2(x4.MMO)
119 .plot tran I2(x5.MM1)
120 .plot tran I2(x5.MMO)
121
122
123 *****Current leaving the source
124 .plot tran I3(x1.MM1)
125 .plot tran I3(x1.MMO)
126 *****Current entering the substrate
127 .plot tran I4(x1.MM1)
128 .plot tran I4(x1.MMO)
129
130 .alter case 2 : FF 135C
131 .temp 135
132 .lib 'cic018.1' FF
133
134
135 ***** pdf / pdr power dissipation
136
137 .Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.1311n
138 .meas tran avg_P_pdf param = 'avg_I_pdf *-1.8 '
139 .meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.1311n-200.0110n)'
140 .Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1752n
141 .meas tran avg_P_pdr param = 'avg_I_pdr *-1.8 '
142 .meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.1752n-300.0210n)'
143
144 ***** leakage power dissipation
145 .Meas tran avg_I_low AVG I3(x1.MM1) from=100.1752n to=200.0110n
146 .meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.1752n)'
147 .Meas tran avg_I_high AVG I3(x1.MM1) from=200.1311n to=300.0210n
148 .meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.1311n)'
149 .meas tran total_P_steady param = 'total_P_high + total_P_low'
150 .meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.1752n)+(300.0210n-200.1311n))'
151
152
153 *****total power dissipation and percentage
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 193 lines Row #81 Col #59
```

```
MobaTextEditor
File Edit Search View Format Syntax Special Tools
hw3_2.sp *hw3_1.sp hw3_2.lis hw3_2.lis
138 .meas tran avg_P_pdf param = 'avg_I_pdf *-1.8 '
139 .meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.1311n -200.0110n)'
140 .Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.1752n
141 .meas tran avg_P_pdr param = 'avg_I_pdr *-1.8 '
142 .meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.1752n-300.0210n)'
143
144 ***** leakage power dissipation
145 .Meas tran avg_I_low AVG I3(x1.MM1) from=100.1752n to=200.0110n
146 .meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.1752n)'
147 .Meas tran avg_I_high AVG I3(x1.MM1) from=200.1311n to=300.0210n
148 .meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.1311n)'
149 .meas tran total_P_steady param = 'total_P_high + total_P_low'
150 .meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.1752n)+(300.0210n-200.1311n))'
151
152
153 *****total power dissipation and percentage
154 .meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
155 .meas tran pdf_percent param = ' total_P_pdf / total_P'
156 .meas tran pdr_percent param = ' total_P_pdr / total_P'
157 .meas tran leakage_percent param = ' total_P_steady / total_P'
158
159 *****
160
161 .alter case 3 : SS -40C
162 .temp -40
163 .lib 'cic018.1' SS
164
165
166 ***** pdf / pdr power dissipation
167
168 .Meas tran avg_I_pdf AVG I3(x1.MM1) from=200.0110n to=200.2121n
169 .meas tran avg_P_pdf param = 'avg_I_pdf *-1.8'
170 .meas tran total_P_pdf param = 'avg_I_pdf *-1.8 *(200.2121n -200.0110n)'
171 .Meas tran avg_I_pdr AVG I3(x1.MM1) from=300.0210n to=300.3365n
172 .meas tran avg_P_pdr param = 'avg_I_pdr *-1.8'
173 .meas tran total_P_pdr param = 'avg_I_pdr *-1.8 * (300.3365n-300.0210n)'
174 ***** leakage power dissipation
175
176 .Meas tran avg_I_low AVG I3(x1.MM1) from=100.3365n to=200.0110n
177 .meas tran total_P_low param = 'avg_I_low *-1.8 *(200.0110n-100.3365n)'
178 .Meas tran avg_I_high AVG I3(x1.MM1) from=200.2121n to=300.0210n
179 .meas tran total_P_high param = 'avg_I_high *-1.8 *(300.0210n-200.2121n)'
180 .meas tran total_P_steady param = 'total_P_high + total_P_low'
181 .meas tran avg_P_steady param = 'total_P_steady/((200.0110n-100.3365n)+(300.0210n-200.2121n))'
182
183 *****total power dissipation and percentage
184 .meas tran total_P param = 'total_P_steady + total_P_pdr + total_P_pdf'
185 .meas tran pdf_percent param = ' total_P_pdf / total_P'
186 .meas tran pdr_percent param = ' total_P_pdr / total_P'
187 .meas tran leakage_percent param = ' total_P_steady / total_P'
188
189 *****
190
191 .end
192
193
C:\Users\BOWIEW~1\DOCUME~1\MobaXterm\slash\RemoteF UNIX Plain text 193 lines Row #81 Col #59
```