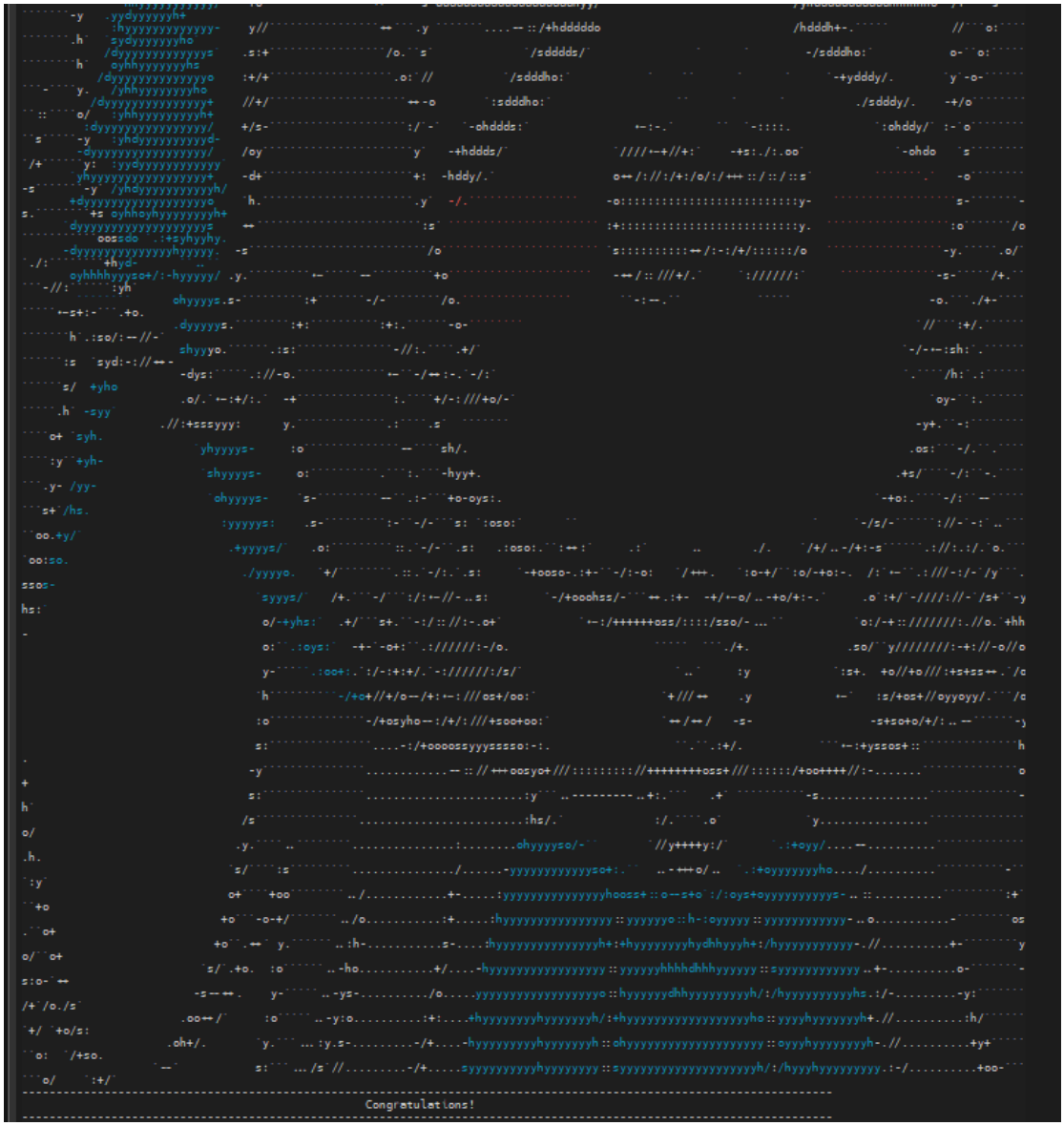
DIC 作業 4 學號:312510017　宋彥霆

4-1:

前模擬:



Netlist 合成:

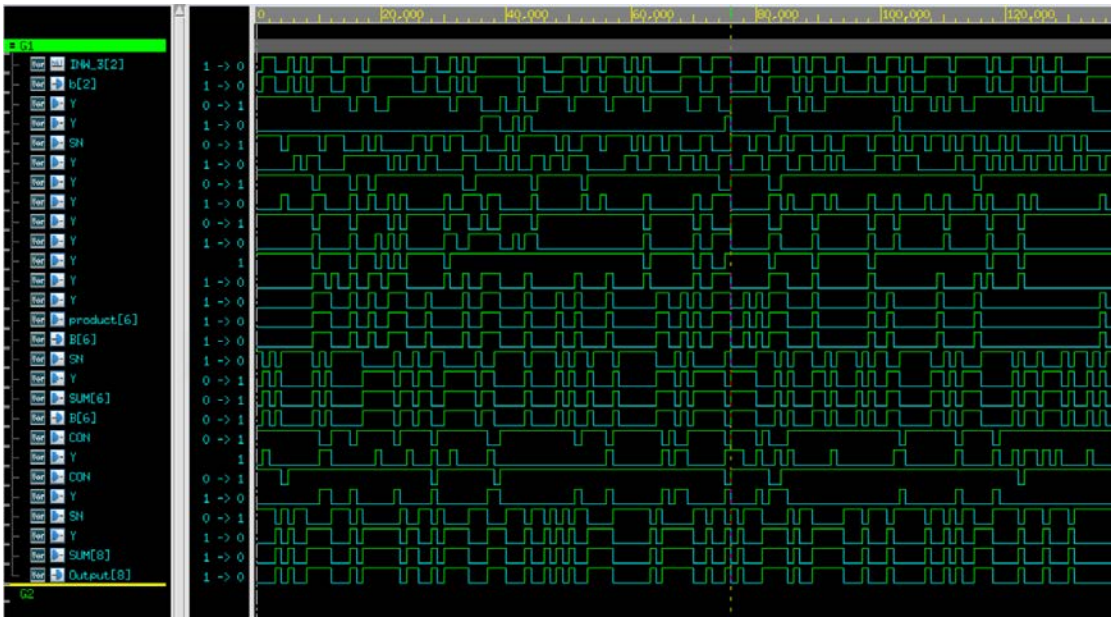
```
Startpoint: INW_3[2] (input port)
Endpoint: Output[8] (output port)
Path Group: default
Path Type: max

Point                                                   Incr       Path
-----------------------------------------------------------------------
input external delay                                    0.00       0.00 f
INW_3[2] (in)                                           0.00       0.00 f
mult_18_4/b[2] (Convolution_DW_mult_uns_0)              0.00       0.00 f
mult_18_4/U116/Y (NAND2xp33_ASAP7_75t_R)               20.81      20.81 r
mult_18_4/U114/Y (NOR2xp33_ASAP7_75t_R)                30.77      51.58 f
mult_18_4/U39/SN (FAx1_ASAP7_75t_R)                    61.57     113.15 f
mult_18_4/U95/Y (XNOR2xp5_ASAP7_75t_R)                 28.23     141.37 r
mult_18_4/U92/Y (NAND2xp33_ASAP7_75t_R)                12.63     154.01 f
mult_18_4/U91/Y (NAND2xp33_ASAP7_75t_R)                25.12     179.12 r
mult_18_4/U87/Y (NAND2xp33_ASAP7_75t_R)                14.50     193.62 f
mult_18_4/U86/Y (NAND2xp33_ASAP7_75t_R)                25.11     218.74 r
mult_18_4/U82/Y (NAND2xp33_ASAP7_75t_R)                14.50     233.23 f
mult_18_4/U81/Y (NAND2xp33_ASAP7_75t_R)                25.11     258.34 r
mult_18_4/U78/Y (XOR2xp5_ASAP7_75t_R)                  39.48     297.82 r
mult_18_4/product[6] (Convolution_DW_mult_uns_0)        0.00     297.82 r
add_1_root_add_0_root_add_18_3/B[6] (Convolution_DW01_add_2)
                                                        0.00     297.82 r
add_1_root_add_0_root_add_18_3/U1_6/SN (FAx1_ASAP7_75t_R)
                                                       40.86     338.68 r
add_1_root_add_0_root_add_18_3/U11/Y (INVx1_ASAP7_75t_R)
                                                       17.87     356.55 f
add_1_root_add_0_root_add_18_3/SUM[6] (Convolution_DW01_add_2)
                                                        0.00     356.55 f
add_0_root_add_0_root_add_18_3/B[6] (Convolution_DW01_add_0)
                                                        0.00     356.55 f
add_0_root_add_0_root_add_18_3/U1_6/CON (FAx1_ASAP7_75t_R)
                                                       22.90     379.45 r
add_0_root_add_0_root_add_18_3/U4/Y (INVx1_ASAP7_75t_R)
                                                       15.27     394.72 f
add_0_root_add_0_root_add_18_3/U1_7/CON (FAx1_ASAP7_75t_R)
                                                       20.30     415.02 r
add_0_root_add_0_root_add_18_3/U3/Y (INVx1_ASAP7_75t_R)
                                                       15.27     430.29 f
add_0_root_add_0_root_add_18_3/U1_8/SN (FAx1_ASAP7_75t_R)
                                                       37.50     467.79 f
add_0_root_add_0_root_add_18_3/U11/Y (INVx1_ASAP7_75t_R)
                                                        8.03     475.82 r
add_0_root_add_0_root_add_18_3/SUM[8] (Convolution_DW01_add_0)
                                                        0.00     475.82 r
Output[8] (out)                                         0.00     475.82 r
data arrival time                                                475.82
```

```
Output[8] (out)                                         0.00     475.82 r
data arrival time                                                475.82

max_delay                                             500.00     500.00
output external delay                                   0.00     500.00
data required time                                               500.00
-----------------------------------------------------------------------
data required time                                               500.00
data arrival time                                               -475.82
-----------------------------------------------------------------------
slack (MET)                                                      24.18
```

```
Combinational area:                426.435838
Buf/Inv area:                       44.789761
Noncombinational area:               0.000000
Macro/Black Box area:                0.000000
Net Interconnect area:      undefined  (No wire load specified)

Total cell area:                   426.435838
Total area:                 undefined
```

後模擬:

先由 nWave 叫出 timing report 中的 critical path，從波行找 critical delay，找波形變化最多的:



由上方的 marker 可以知道最大 critical delay 發生在

INW_3[2]:1->0　　output[8]:1->0

但從 timing report 看最大 critical delay 發生在

INW_3[2]:1->0　　output[8]:0->1

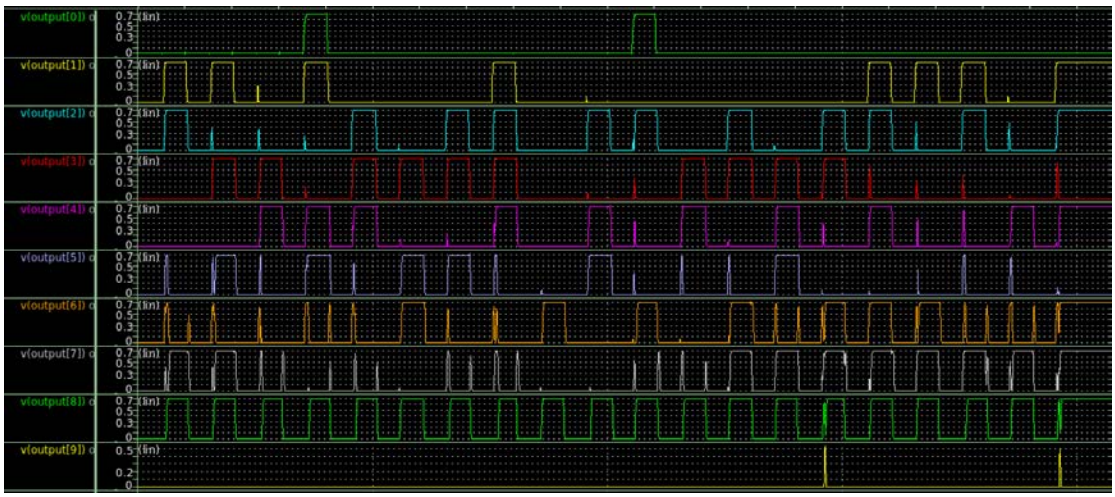
因此設計了以下 pattern:

```
Radix  1111 1111 1111 1111 1111 1111 1111 1111
Vname  IFM_0[[3:0]] IFM_1[[3:0]] IFM_2[[3:0]] IFM_3[[3:0]] INW_0[[3:0]] INW_1[[3:0]] INW_2[[3:0]] INW_3[[3:0]]
IO     iiii iiii iiii iiii iiii iiii iiii iiii
Tunit  ns
Period 1
Trise  0.00
Tfall  0.00
Tdelay 0
Vih    0.7
Vil    0.0

0000 0000 0000 0000 0000 0000 0000 0100
0000 0000 1111 1111 0000 0000 1111 1011

0000 0000 0000 0000 0000 0000 0000 0100
0000 0011 1111 1111 0000 1100 1111 1011

0000 0000 0000 0000 0000 0000 0000 0100
0000 0111 0011 1111 0000 1010 1111 1011

0000 0000 0000 0000 0000 0000 0000 0100
1001 0111 0111 0111 1010 1010 1010 1011

0000 0000 0000 0000 0000 0000 0000 0100
0111 0111 0101 1000 1010 1100 1010 1010

0000 0000 0000 0000 0000 0000 0000 0100
1001 1001 1001 1001 1010 1010 1010 1010
```

```
0000 0000 0000 0000 0000 0000 0000 0100
1010 0011 1010 0011 1100 1010 1100 1010

0000 0000 0000 0000 0000 0000 0000 0100
1111 0111 0011 0001 1011 1011 1011 1011

0000 0000 0000 0000 0000 0000 0000 0100
1000 1000 1000 1000 1010 1010 1010 1010

0000 0000 0000 0000 0000 0000 0000 0100
0111 0111 0111 0111 1011 1011 1011 1011



0000 0000 0000 0000 0000 0000 0000 0100
1101 1011 0001 0010 1010 1111 1010 1010

0000 0000 0000 0000 0000 0000 0000 0100
1010 1010 0010 0100 1010 1100 1010 1010

0000 0000 0000 0000 0000 0000 0000 0100
1111 1010 1001 1000 1010 1110 1010 1010

0000 0000 0000 0000 0000 0000 0000 0100
1010 1010 1010 1001 1111 0101 1111 1010

0000 0000 0000 0000 0000 0000 0000 0100
1111 1111 0000 1010 1100 1100 1100 1010
```

```

  0000 0000 0000 0000 0000 0000 0000 0100
  1100 1010 1010 1010 1111 1110 0100 1011

  0000 0000 0000 0000 0000 0000 0000 0100
  1111 1111 1111 1111 0000 1010 1010 1010

  0000 0000 0000 0000 0000 0000 0000 0100
  0111 1010 0111 1010 1010 1111 1010 1010

  0000 0000 0000 0000 0000 0000 0000 0100
  1010 0111 1111 1111 1010 0000 1010 1010

  0000 0000 0000 0000 0000 0000 0000 0100
  1100 1100 0000 1010 1111 1111 1111 1011

```

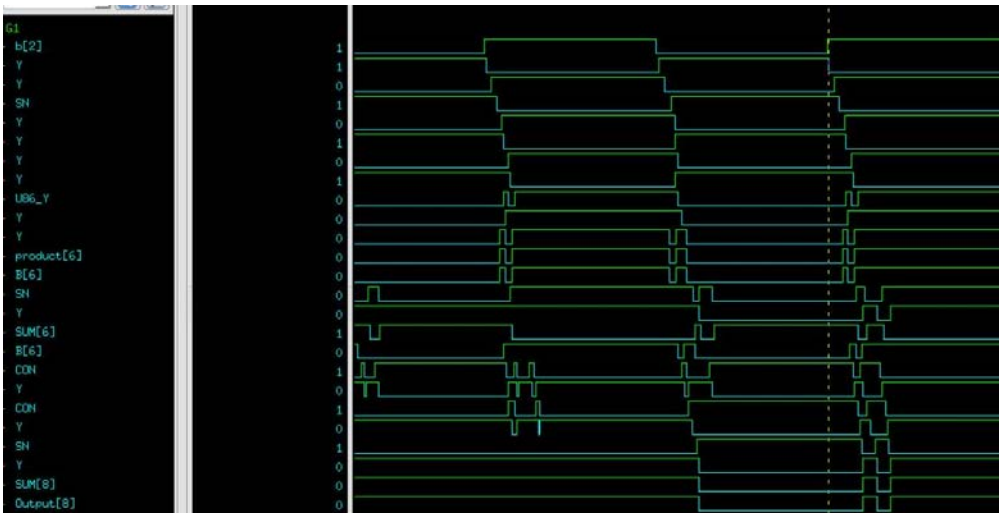
以下波形和 pattern 算出來的 output 相同，以第一個 pattern 來說，convolution 結果出來為 390，答案和 output 值一樣，同理其他的波也是，表示 convolution function 正確。



Worst case delay:　tp8(對應到 pattern 的第八行)為 worst case delay
(定電壓在 0.7V)

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 255.2336p  targ=   1.2552n   trig= 999.9807p
tp2= 252.1389p  targ=   3.2521n   trig=   3.0000n
tp3= 362.2681p  targ=   5.3623n   trig=   5.0000n
tp4= 357.1853p  targ=   7.3572n   trig=   7.0000n
tp5= 348.9332p  targ=   9.3489n   trig=   9.0000n
tp6= 226.4030p  targ=  11.2264n   trig=  11.0000n
tp7= 318.0237p  targ=  13.3180n   trig=  13.0000n
tp8= 391.1254p  targ=  15.3911n   trig=  15.0000n
tp9= 227.2580p  targ=  17.2272n   trig=  17.0000n
tp10= 358.0131p  targ=  19.3580n   trig=  19.0000n
tp11= 251.6491p  targ=  21.2516n   trig=  21.0000n
tp12= 296.0935p  targ=  23.2961n   trig=  23.0000n
tp13= 227.4442p  targ=  25.2274n   trig=  25.0000n
tp14= 212.1913p  targ=  27.2122n   trig=  27.0000n
tp15= 236.3434p  targ=  29.2363n   trig=  29.0000n
tp16= 234.4687p  targ=  31.2345n   trig=  31.0000n
tp17= 216.0257p  targ=  33.2160n   trig=  33.0000n
tp18= 352.1661p  targ=  35.3521n   trig=  35.0000n
tp19= 253.1251p  targ=  37.2531n   trig=  37.0000n
tp20= 236.8859p  targ=  39.2369n   trig=  39.0000n
average_power= 126.5324u  from=   0.            to=  42.0000n
```

根據 critical path 去設計 pattern，讓 input 的變化會使 critical path 上面的 Cell 都有產生對應的變化(根據 critical path 的 Cells 回推這些 Cell 要產生相對應的變化，他們需要哪些 input 變化)，pattern 選中一筆 critical delay 當作 EDP 中的 delay



0.3V 會 failed

0.4V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1=   1.1226n  targ=   2.1226n   trig= 999.9890p
tp2=   1.0950n  targ=   4.0911n   trig=   2.9961n
tp3=   1.6312n  targ=   6.6286n   trig=   4.9974n
tp4=   1.5820n  targ=   8.5802n   trig=   6.9982n
tp5=   1.5532n  targ=  10.5513n   trig=   8.9981n
tp6= 974.6487p  targ=  11.9716n   trig=  10.9969n
tp7=   1.4215n  targ=  14.4191n   trig=  12.9976n
tp8=   2.9805n  targ=  17.9780n   trig=  14.9975n
tp9=   3.5847n  targ=  20.5835n   trig=  16.9988n
tp10=   3.4524n  targ=  22.4509n   trig=  18.9985n
tp11=   3.3018n  targ=  24.2999n   trig=  20.9981n
tp12=   2.9839n  targ=  25.9813n   trig=  22.9975n
tp13=   2.9126n  targ=  27.9094n   trig=  24.9968n
tp14=   3.0292n  targ=  30.0250n   trig=  26.9958n
tp15=   1.5561n  targ=  30.5509n   trig=  28.9948n
tp16=   2.9618n  targ=  33.9593n   trig=  30.9975n
tp17=   3.5540n  targ=  36.5519n   trig=  32.9979n
tp18=   3.1015n  targ=  38.0968n   trig=  34.9953n
tp19=   3.0270n  targ=  40.0244n   trig=  36.9974n
tp20=   1.5391n  targ=  40.5340n   trig=  38.9949n
average_power=  37.4807u  from=   0.            to=  42.0000n
```

0.45V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 710.9234p  targ=   1.7109n   trig= 999.9876p
tp2= 696.6875p  targ=   3.6967n   trig=   3.0000n
tp3=   1.0373n  targ=   6.0373n   trig=   5.0000n
tp4=   1.0044n  targ=   8.0044n   trig=   7.0000n
tp5= 983.3541p  targ=   9.9760n   trig=   8.9926n
tp6= 622.5328p  targ=  11.6225n   trig=  11.0000n
tp7= 902.8179p  targ=  13.9028n   trig=  13.0000n
tp8=   1.0971n  targ=  16.0971n   trig=  15.0000n
tp9= 622.4107p  targ=  17.6167n   trig=  16.9943n
tp10=   1.0066n  targ=  20.0066n   trig=  19.0000n
tp11= 698.6848p  targ=  21.6987n   trig=  21.0000n
tp12= 829.5092p  targ=  23.8295n   trig=  23.0000n
tp13= 626.9795p  targ=  25.6270n   trig=  25.0000n
tp14= 583.9674p  targ=  27.5840n   trig=  27.0000n
tp15= 657.2037p  targ=  29.6572n   trig=  29.0000n
tp16= 650.3558p  targ=  31.6503n   trig=  31.0000n
tp17= 609.8753p  targ=  33.6086n   trig=  32.9987n
tp18= 987.8820p  targ=  35.9879n   trig=  35.0000n
tp19= 699.9009p  targ=  37.6999n   trig=  37.0000n
tp20= 656.8250p  targ=  39.6568n   trig=  39.0000n
average_power=  48.1839u  from=   0.            to=  42.0000n
```

0.5V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 512.5823p  targ=   1.5126n   trig= 999.9862p
tp2= 503.1114p  targ=   3.5031n   trig=   3.0000n
tp3= 746.1804p  targ=   5.7462n   trig=   5.0000n
tp4= 723.3724p  targ=   7.7234n   trig=   7.0000n
tp5= 708.9922p  targ=   9.7090n   trig=   9.0000n
tp6= 449.9070p  targ=  11.4499n   trig=  11.0000n
tp7= 649.9051p  targ=  13.6499n   trig=  13.0000n
tp8= 790.0876p  targ=  15.7901n   trig=  15.0000n
tp9= 451.8715p  targ=  17.4519n   trig=  17.0000n
tp10= 721.5062p  targ=  19.7118n   trig=  18.9903n
tp11= 503.4428p  targ=  21.5034n   trig=  21.0000n
tp12= 597.5339p  targ=  23.5975n   trig=  23.0000n
tp13= 452.4500p  targ=  25.4524n   trig=  25.0000n
tp14= 421.8838p  targ=  27.4219n   trig=  27.0000n
tp15= 473.6462p  targ=  29.4736n   trig=  29.0000n
tp16= 469.1979p  targ=  31.4692n   trig=  31.0000n
tp17= 439.9460p  targ=  33.4399n   trig=  33.0000n
tp18= 708.2413p  targ=  35.6980n   trig=  34.9898n
tp19= 505.6576p  targ=  37.5056n   trig=  37.0000n
tp20= 474.0937p  targ=  39.4741n   trig=  39.0000n
average_power=  60.5742u  from=   0.            to=  42.0000n
```

0.55V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 400.9226p  targ=   1.4009n   trig= 999.9849p
tp2= 394.4316p  targ=   3.3944n   trig=   3.0000n
tp3= 582.0118p  targ=   5.5820n   trig=   5.0000n
tp4= 564.9336p  targ=   7.5649n   trig=   7.0000n
tp5= 553.3611p  targ=   9.5533n   trig=   9.0000n
tp6= 353.3055p  targ=  11.3533n   trig=  11.0000n
tp7= 507.7209p  targ=  13.5077n   trig=  13.0000n
tp8= 617.3678p  targ=  15.6174n   trig=  15.0000n
tp9= 354.3593p  targ=  17.3543n   trig=  17.0000n
tp10= 565.8922p  targ=  19.5659n   trig=  19.0000n
tp11= 394.5311p  targ=  21.3945n   trig=  21.0000n
tp12= 467.1164p  targ=  23.4671n   trig=  23.0000n
tp13= 355.0572p  targ=  25.3550n   trig=  25.0000n
tp14= 330.9133p  targ=  27.3309n   trig=  27.0000n
tp15= 370.9052p  targ=  29.3709n   trig=  29.0000n
tp16= 367.6262p  targ=  31.3676n   trig=  31.0000n
tp17= 342.7376p  targ=  33.3427n   trig=  33.0000n
tp18= 556.0429p  targ=  35.5560n   trig=  35.0000n
tp19= 396.3731p  targ=  37.3964n   trig=  37.0000n
tp20= 371.2020p  targ=  39.3712n   trig=  39.0000n
average_power=  73.6958u  from=   0.            to=  42.0000n
```

0.6V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 332.2436p  targ=   1.3322n   trig= 999.9835p
tp2= 327.1680p  targ=   3.3272n   trig=   3.0000n
tp3= 478.9615p  targ=   5.4789n   trig=   5.0000n
tp4= 467.0530p  targ=   7.4670n   trig=   7.0000n
tp5= 456.8258p  targ=   9.4568n   trig=   9.0000n
tp6= 293.4135p  targ=  11.2934n   trig=  11.0000n
tp7= 419.4227p  targ=  13.4194n   trig=  13.0000n
tp8= 510.2032p  targ=  15.5102n   trig=  15.0000n
tp9= 294.2924p  targ=  17.2943n   trig=  17.0000n
tp10= 468.0001p  targ=  19.4680n   trig=  19.0000n
tp11= 327.1117p  targ=  21.3271n   trig=  21.0000n
tp12= 386.6193p  targ=  23.3866n   trig=  23.0000n
tp13= 294.9826p  targ=  25.2950n   trig=  25.0000n
tp14= 275.1174p  targ=  27.2751n   trig=  27.0000n
tp15= 307.5616p  targ=  29.3075n   trig=  29.0000n
tp16= 304.8482p  targ=  31.3048n   trig=  31.0000n
tp17= 283.3015p  targ=  33.2833n   trig=  33.0000n
tp18= 460.3951p  targ=  35.4604n   trig=  35.0000n
tp19= 328.8173p  targ=  37.3288n   trig=  37.0000n
tp20= 307.7090p  targ=  39.3077n   trig=  39.0000n
average_power=  89.2259u  from=   0.            to=  42.0000n
```

0.65V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 286.8772p  targ=   1.2869n   trig= 999.9821p
tp2= 283.1348p  targ=   3.2831n   trig=   3.0000n
tp3= 410.0772p  targ=   5.4101n   trig=   5.0000n
tp4= 402.5447p  targ=   7.4025n   trig=   7.0000n
tp5= 393.4414p  targ=   9.3934n   trig=   9.0000n
tp6= 254.2777p  targ=  11.2543n   trig=  11.0000n
tp7= 360.5766p  targ=  13.3606n   trig=  13.0000n
tp8= 440.4315p  targ=  15.4404n   trig=  15.0000n
tp9= 255.0089p  targ=  17.2550n   trig=  17.0000n
tp10= 403.3084p  targ=  19.4033n   trig=  19.0000n
tp11= 282.8282p  targ=  21.2828n   trig=  21.0000n
tp12= 333.9164p  targ=  23.3339n   trig=  23.0000n
tp13= 255.3937p  targ=  25.2554n   trig=  25.0000n
tp14= 238.1479p  targ=  27.2381n   trig=  27.0000n
tp15= 265.7369p  targ=  29.2657n   trig=  29.0000n
tp16= 263.4401p  targ=  31.2634n   trig=  31.0000n
tp17= 243.4997p  targ=  33.2435n   trig=  33.0000n
tp18= 397.0626p  targ=  35.3970n   trig=  35.0000n
tp19= 284.4118p  targ=  37.2844n   trig=  37.0000n
tp20= 266.2883p  targ=  39.2663n   trig=  39.0000n
average_power= 105.7332u  from=   0.            to=  42.0000n
```

0.7V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 255.2336p  targ=   1.2552n   trig= 999.9807p
tp2= 252.1389p  targ=   3.2521n   trig=   3.0000n
tp3= 362.2681p  targ=   5.3623n   trig=   5.0000n
tp4= 357.1853p  targ=   7.3572n   trig=   7.0000n
tp5= 348.9332p  targ=   9.3489n   trig=   9.0000n
tp6= 226.4030p  targ=  11.2264n   trig=  11.0000n
tp7= 318.0237p  targ=  13.3180n   trig=  13.0000n
tp8= 391.1254p  targ=  15.3911n   trig=  15.0000n
tp9= 227.2580p  targ=  17.2272n   trig=  17.0000n
tp10= 358.0131p  targ=  19.3580n   trig=  19.0000n
tp11= 251.6491p  targ=  21.2516n   trig=  21.0000n
tp12= 296.0935p  targ=  23.2961n   trig=  23.0000n
tp13= 227.4442p  targ=  25.2274n   trig=  25.0000n
tp14= 212.1913p  targ=  27.2122n   trig=  27.0000n
tp15= 236.3434p  targ=  29.2363n   trig=  29.0000n
tp16= 234.4687p  targ=  31.2345n   trig=  31.0000n
tp17= 216.0257p  targ=  33.2160n   trig=  33.0000n
tp18= 352.1661p  targ=  35.3521n   trig=  35.0000n
tp19= 253.1251p  targ=  37.2531n   trig=  37.0000n
tp20= 236.8859p  targ=  39.2369n   trig=  39.0000n
average_power= 126.5324u  from=   0.            to=  42.0000n
```

0.75V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 232.3255p  targ=   1.2323n   trig= 999.9794p
tp2= 229.8054p  targ=   3.2298n   trig=   3.0000n
tp3= 327.5987p  targ=   5.3276n   trig=   5.0000n
tp4= 324.4154p  targ=   7.3244n   trig=   7.0000n
tp5= 316.2838p  targ=   9.3163n   trig=   9.0000n
tp6= 206.4666p  targ=  11.2065n   trig=  11.0000n
tp7= 287.5484p  targ=  13.2875n   trig=  13.0000n
tp8= 355.0094p  targ=  15.3550n   trig=  15.0000n
tp9= 207.1000p  targ=  17.2071n   trig=  17.0000n
tp10= 325.2681p  targ=  19.3253n   trig=  19.0000n
tp11= 229.2239p  targ=  21.2292n   trig=  21.0000n
tp12= 268.8462p  targ=  23.2688n   trig=  23.0000n
tp13= 207.2429p  targ=  25.2072n   trig=  25.0000n
tp14= 193.5874p  targ=  27.1936n   trig=  27.0000n
tp15= 215.3439p  targ=  29.2153n   trig=  29.0000n
tp16= 213.5125p  targ=  31.2135n   trig=  31.0000n
tp17= 196.2016p  targ=  33.1962n   trig=  33.0000n
tp18= 318.1500p  targ=  35.3181n   trig=  35.0000n
tp19= 230.7810p  targ=  37.2308n   trig=  37.0000n
tp20= 215.8492p  targ=  39.2158n   trig=  39.0000n
average_power= 147.4321u  from=   0.            to=  42.0000n
```

0.8V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 215.5908p  targ=   1.2156n   trig= 999.9780p
tp2= 213.3056p  targ=   3.2133n   trig=   3.0000n
tp3= 301.4233p  targ=   5.3014n   trig=   5.0000n
tp4= 300.3043p  targ=   7.3003n   trig=   7.0000n
tp5= 291.0441p  targ=   9.2910n   trig=   9.0000n
tp6= 191.6160p  targ=  11.1916n   trig=  11.0000n
tp7= 265.4115p  targ=  13.2654n   trig=  13.0000n
tp8= 328.6481p  targ=  15.3286n   trig=  15.0000n
tp9= 192.3907p  targ=  17.1924n   trig=  17.0000n
tp10= 301.0849p  targ=  19.3011n   trig=  19.0000n
tp11= 212.7238p  targ=  21.2127n   trig=  21.0000n
tp12= 248.4693p  targ=  23.2484n   trig=  23.0000n
tp13= 192.3664p  targ=  25.1923n   trig=  25.0000n
tp14= 179.8166p  targ=  27.1798n   trig=  27.0000n
tp15= 199.9680p  targ=  29.1999n   trig=  29.0000n
tp16= 198.2074p  targ=  31.1982n   trig=  31.0000n
tp17= 182.1737p  targ=  33.1822n   trig=  33.0000n
tp18= 292.7300p  targ=  35.2927n   trig=  35.0000n
tp19= 214.3558p  targ=  37.2143n   trig=  37.0000n
tp20= 200.4118p  targ=  39.2004n   trig=  39.0000n
average_power= 174.5224u  from=   0.            to=  42.0000n
```

0.9V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 193.6672p  targ=   1.1936n   trig= 999.9752p
tp2= 192.0238p  targ=   3.1920n   trig=   3.0000n
tp3= 266.4913p  targ=   5.2665n   trig=   5.0000n
tp4= 268.8393p  targ=   7.2688n   trig=   7.0000n
tp5= 255.9153p  targ=   9.2559n   trig=   9.0000n
tp6= 172.2287p  targ=  11.1722n   trig=  11.0000n
tp7= 236.2506p  targ=  13.2362n   trig=  13.0000n
tp8= 293.7364p  targ=  15.2937n   trig=  15.0000n
tp9= 172.7745p  targ=  17.1728n   trig=  17.0000n
tp10= 269.5874p  targ=  19.2696n   trig=  19.0000n
tp11= 191.2559p  targ=  21.1912n   trig=  21.0000n
tp12= 221.0908p  targ=  23.2211n   trig=  23.0000n
tp13= 172.9053p  targ=  25.1729n   trig=  25.0000n
tp14= 162.0902p  targ=  27.1621n   trig=  27.0000n
tp15= 179.8790p  targ=  29.1799n   trig=  29.0000n
tp16= 178.4398p  targ=  31.1784n   trig=  31.0000n
tp17= 164.5435p  targ=  33.1645n   trig=  33.0000n
tp18= 255.5167p  targ=  35.2555n   trig=  35.0000n
tp19= 192.8741p  targ=  37.1928n   trig=  37.0000n
tp20= 180.3718p  targ=  39.1804n   trig=  39.0000n
average_power= 240.9650u  from=   0.            to=  42.0000n
```

1.0V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 181.9558p  targ=   1.1819n   trig= 999.9725p
tp2= 180.7424p  targ=   3.1807n   trig=   3.0000n
tp3= 246.8605p  targ=   5.2468n   trig=   5.0000n
tp4= 251.8806p  targ=   7.2519n   trig=   7.0000n
tp5= 242.0305p  targ=   9.2420n   trig=   9.0000n
tp6= 161.6892p  targ=  11.1617n   trig=  11.0000n
tp7= 219.8395p  targ=  13.2198n   trig=  13.0000n
tp8= 274.0489p  targ=  15.2740n   trig=  15.0000n
tp9= 162.3494p  targ=  17.1623n   trig=  17.0000n
tp10= 252.3910p  targ=  19.2524n   trig=  19.0000n
tp11= 179.8041p  targ=  21.1798n   trig=  21.0000n
tp12= 205.3163p  targ=  23.2053n   trig=  23.0000n
tp13= 162.3705p  targ=  25.1623n   trig=  25.0000n
tp14= 152.7774p  targ=  27.1528n   trig=  27.0000n
tp15= 169.3166p  targ=  29.1693n   trig=  29.0000n
tp16= 167.9544p  targ=  31.1679n   trig=  31.0000n
tp17= 157.2250p  targ=  33.1572n   trig=  33.0000n
tp18= 236.4814p  targ=  35.2365n   trig=  35.0000n
tp19= 181.5418p  targ=  37.1815n   trig=  37.0000n
tp20= 169.8363p  targ=  39.1698n   trig=  39.0000n
average_power= 387.0724u  from=   0.            to=  42.0000n
```

1.1V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 177.8817p  targ=   1.1779n   trig= 999.9697p
tp2= 177.0843p  targ=   3.1771n   trig=   3.0000n
tp3= 238.1095p  targ=   5.2381n   trig=   5.0000n
tp4= 244.3694p  targ=   7.2443n   trig=   7.0000n
tp5= 235.7692p  targ=   9.2357n   trig=   9.0000n
tp6= 158.0867p  targ=  11.1581n   trig=  11.0000n
tp7= 212.5017p  targ=  13.2125n   trig=  13.0000n
tp8= 264.9732p  targ=  15.2649n   trig=  15.0000n
tp9= 158.6908p  targ=  17.1587n   trig=  17.0000n
tp10= 245.8155p  targ=  19.2458n   trig=  19.0000n
tp11= 175.8071p  targ=  21.1758n   trig=  21.0000n
tp12= 197.9138p  targ=  23.1979n   trig=  23.0000n
tp13= 158.6137p  targ=  25.1586n   trig=  25.0000n
tp14= 149.8994p  targ=  27.1499n   trig=  27.0000n
tp15= 165.8771p  targ=  29.1659n   trig=  29.0000n
tp16= 164.5490p  targ=  31.1645n   trig=  31.0000n
tp17= 159.2629p  targ=  33.1592n   trig=  33.0000n
tp18= 219.4806p  targ=  35.2195n   trig=  35.0000n
tp19= 177.7636p  targ=  37.1777n   trig=  37.0000n
tp20= 166.3197p  targ=  39.1663n   trig=  39.0000n
average_power= 811.0404u  from=   0.            to=  42.0000n
```

1.2V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 181.7679p  targ=   1.1817n   trig= 999.9670p
tp2= 181.0564p  targ=   3.1810n   trig=   3.0000n
tp3= 241.4091p  targ=   5.2414n   trig=   5.0000n
tp4= 243.8734p  targ=   7.2438n   trig=   7.0000n
tp5= 238.2422p  targ=   9.2382n   trig=   9.0000n
tp6= 161.6352p  targ=  11.1616n   trig=  11.0000n
tp7= 213.7272p  targ=  13.2137n   trig=  13.0000n
tp8= 266.0634p  targ=  15.2660n   trig=  15.0000n
tp9= 162.2091p  targ=  17.1622n   trig=  17.0000n
tp10= 247.7359p  targ=  19.2477n   trig=  19.0000n
tp11= 179.3997p  targ=  21.1794n   trig=  21.0000n
tp12= 198.8019p  targ=  23.1988n   trig=  23.0000n
tp13= 162.1862p  targ=  25.1622n   trig=  25.0000n
tp14= 153.8489p  targ=  27.1538n   trig=  27.0000n
tp15= 167.3005p  targ=  29.1673n   trig=  29.0000n
tp16= 168.0097p  targ=  31.1680n   trig=  31.0000n
tp17= 168.0074p  targ=  33.1680n   trig=  33.0000n
tp18= 201.3853p  targ=  35.2014n   trig=  35.0000n
tp19= 181.6266p  targ=  37.1816n   trig=  37.0000n
tp20= 169.6751p  targ=  39.1696n   trig=  39.0000n
average_power=   1.6554m  from=   0.            to=  42.0000n
```

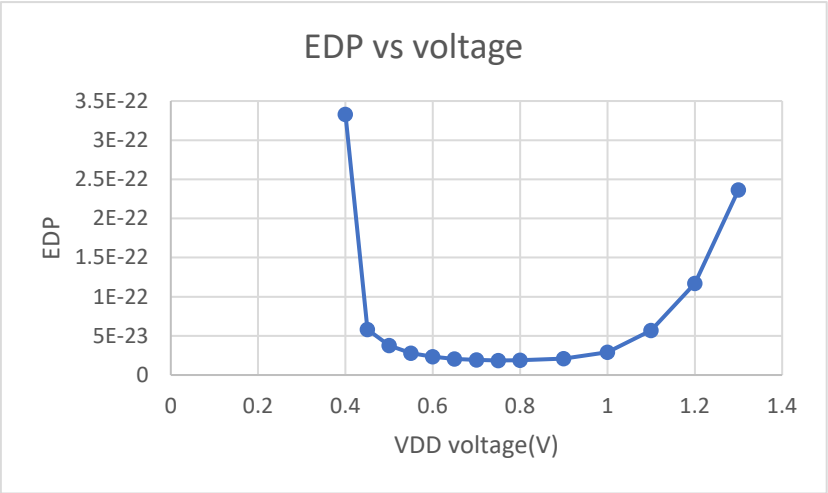
1.3V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tp1= 197.4456p  targ=   1.1974n   trig= 999.9642p
tp2= 196.7636p  targ=   3.1967n   trig=   3.0000n
tp3= 262.8966p  targ=   5.2629n   trig=   5.0000n
tp4= 257.8074p  targ=   7.2578n   trig=   7.0000n
tp5= 252.8451p  targ=   9.2528n   trig=   9.0000n
tp6= 176.5891p  targ=  11.1766n   trig=  11.0000n
tp7= 227.0998p  targ=  13.2271n   trig=  13.0000n
tp8= 280.5875p  targ=  15.2806n   trig=  15.0000n
tp9= 177.2554p  targ=  17.1772n   trig=  17.0000n
tp10= 261.2009p  targ=  19.2612n   trig=  19.0000n
tp11= 222.2407p  targ=  21.1773n   trig=  20.9551n
tp12= 210.9762p  targ=  23.2109n   trig=  23.0000n
tp13= 177.1100p  targ=  25.1771n   trig=  25.0000n
tp14= 169.1078p  targ=  27.1691n   trig=  27.0000n
tp15= 176.3835p  targ=  29.1764n   trig=  29.0000n
tp16= 182.5724p  targ=  31.1825n   trig=  31.0000n
tp17= 186.3012p  targ=  33.1863n   trig=  33.0000n
tp18= 215.6087p  targ=  35.2156n   trig=  35.0000n
tp19= 197.6341p  targ=  37.1976n   trig=  37.0000n
tp20= 176.0187p  targ=  39.1760n   trig=  39.0000n
average_power=   3.0032m  from=   0.            to=  42.0000n
```

Analyze and plot EDP-voltage figure:

將 critical path delay × power × delay time，即為在該電壓下的 energy-delay product

voltage(V)	delay(s)	power(W)	EDP
0.4	2.98E-09	3.75E-05	3.32955E-22
0.45	1.10E-09	4.82E-05	5.79955E-23
0.5	7.90E-10	6.06E-05	3.78127E-23
0.55	6.17E-10	7.37E-05	2.80886E-23
0.6	5.10E-10	8.92E-05	2.32262E-23
0.65	4.40E-10	1.06E-04	2.05101E-23
0.7	3.91E-10	1.27E-04	1.93568E-23
0.75	3.55E-10	1.47E-04	1.85811E-23
0.8	3.29E-10	1.75E-04	1.88501E-23
0.9	2.94E-10	2.41E-04	2.07907E-23
1	2.74E-10	3.87E-04	2.90702E-23
1.1	2.65E-10	8.11E-04	5.69438E-23
1.2	2.66E-10	1.66E-03	1.17185E-22
1.3	2.81E-10	3.00E-03	2.3644E-22



Find out the minimal energy-delay product by voltage scaling:

改變電壓求曲線，透過改變 VDD 電壓，我們可以得知當 VDD 下降時，功率可以下降，但相對的 Delay 會上升，為此我們需要探討 E×D 的數值以追求在 Delay 和功率損耗的最佳化，故我們得到 E×D−VDD 的曲線，而在 E×D−VDD 曲線最小值的地方大約落在 0.8V 左右。

所以，**minimal energy-delay product 發生在 0.8V 左右**

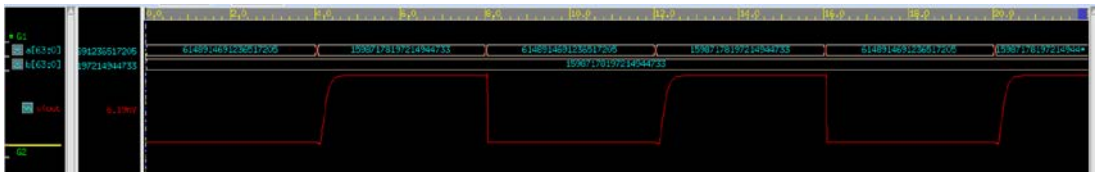
4-2:

一開始 syn_parallel.tcl file 電路的合成結果:

```
Startpoint: B[47] (input port)
Endpoint: Out (output port)
Path Group: default
Path Type: max

Point                                    Incr       Path
-----------------------------------------------------------
input external delay                     0.00       0.00 r
B[47] (in)                               0.00       0.00 r
U79/Y (XNOR2xp5_ASAP7_75t_R)            14.28      14.28 r
U87/Y (NAND4xp25_ASAP7_75t_R)           18.47      32.74 f
U74/Y (NOR5xp2_ASAP7_75t_R)             26.10      58.84 r
U83/Y (NAND4xp25_ASAP7_75t_R)           21.97      80.81 f
U10/Y (NOR5xp2_ASAP7_75t_R)             17.38      98.19 r
Out (out)                                0.00      98.19 r
data arrival time                                  98.19

max_delay                              280.00     280.00
output external delay                    0.00     280.00
data required time                                280.00
-----------------------------------------------------------
data required time                                280.00
data arrival time                                 -98.19
-----------------------------------------------------------
slack (MET)                                       181.81
```

```
Combinational area:                161.663038
Buf/Inv area:                        0.000000
Noncombinational area:               0.000000
Macro/Black Box area:                0.000000
Net Interconnect area:      undefined  (No wire load specified)

Total cell area:                   161.663038
```

將.tr0 檔用 nWave 開啟，由以下波型可以知道 Function is correct:

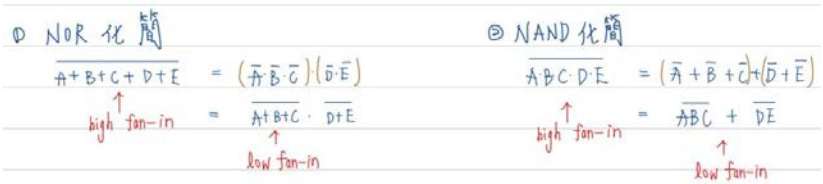


Settting:

1. Supply voltage = 0.4V
2. Output loading = 5f capacitance
3. 在每個邏輯閘的輸出加 wire loading 3f capacitance
4. 在每個 input 後皆加 buffer

化簡方法:

將多個 fan-in 的 cell，藉由布林運算換成 low fan-in 的 cell，並從 library 裡去找，同一個 gate 盡量找 Area 最大的 cell 去換。



我們量 minimized-delay(from a0 first rising(0.2V) to output first rising(0.2V))

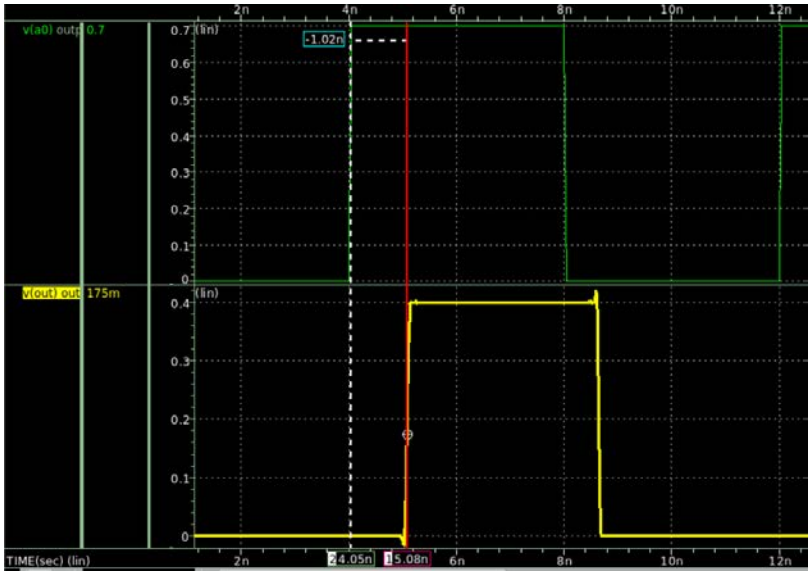
Min_Delay = 1.066 ns (less than 1.5ns)

Trising = 73.27ps； Tfalling = 46.47ps (all less than 100ps) 皆符合規格

0.4V:

```
.TITLE '4-2 minimized_comparator'
tmin_delay       trising_out      tfalling_out     average_power
temper           alter#
 1.066e-09        7.327e-11        4.647e-11        2.808e-05
  25.0000         1
```

波形如下:



從 asap7sc7p5t_SIMPLE_RVT_TT_08302018.lib file 裡面可以看到以下面積資訊:
Area information:

NOR2x2_ASAP7_75t_R:	2.3328	um2
NOR3x2_ASAP7_75t_R:	4.6656	um2
AND2x6_ASAP7_75t_R:	2.79936	um2
NAND2x2_ASAP7_75t_R:	2.3328	um2
NAND3x2_ASAP7_75t_R:	4.6656	um2
OR2x6_ASAP7_75t_R:	2.79936	um2
XOR2x1_ASAP7_75t_R:	2.56608	um2
XNOR2x1_ASAP7_75t_R:	2.56608	um2
BUFx24_ASAP7_75t_R:	6.99840	um2

Minimized:
0.4V:

```
.TITLE '4-2 minimized_comparator'
tmin_delay       trising_out      tfalling_out     average_power
temper           alter#
 1.066e-09        7.327e-11        4.647e-11        2.808e-05
  25.0000         1
```

0.7V:

```
.TITLE '4-2 minimized_comparator'
tmin_delay       trising_out      tfalling_out     average_power
temper           alter#
 2.419e-10        1.944e-11        1.337e-11        9.466e-05
  25.0000         1
```

Synthesized (未 minimized 過的)

0.4V:

```
.TITLE '.title ex4_2'
tmin_delay       trising_out      tfalling_out     average_power
temper           alter#
 2.511e-09        1.500e-09        1.011e-10        2.076e-05
  25.0000         1
```

0.7V:

```
.TITLE '.title ex4_2'
tmin_delay       trising_out      tfalling_out     average_power
temper           alter#
 5.136e-10        3.649e-10        2.988e-11        7.093e-05
  25.0000         1
```

	Synthesized(未 minimized 過的)		
	Power(W)	Performance(ns)	Area(um^2)
0.4V	2.076*10^-5	2.511	1102.248
0.7V	7.903*10^-5	0.5136	1102.248

	Minimized		
	Power(W)	Performance(ns)	Area(um^2)
0.4V	2.808*10^-5	1.066	1216.9
0.7V	9.466*10^-5	0.2419	1216.9

Analyze:

可以發現 0.4V 會相較於 normal voltage(0.7V)的 power 更低，但相對的 delay 就會比較長，面積部分因為皆是相同的 cell 組成，所以會相同；另外 Synthesized 的，相對 minimize 的 comparator 來說，delay 當然更大，但因為 cell 沒有被刻

意換成大一點的，所以 power 會比較低，Area 也會比較小。

PPA 總結:

Power consumption： 無論在 0.4V 還是 0.7 V 的情況下，Minimized Comparator 的功耗比 Synthesized Comparator 高，這是由於電晶體數增加，導致功耗的增加。

Performance (Delay): 在 0.4V 和 0.7V 的情況下，Minimized Comparator 的性能（延遲）都優於 Synthesized Comparator 。這代表使用多級邏輯閘的設計來代替 high fan-in 的優化方式確實有效果。

Area: Minimized Comparator 的面積都比 Synthesized Comparator 大。這是由於為了實現性能好處而引入了一些額外的電路，這導致了比一開始的比較器有更大的面積。