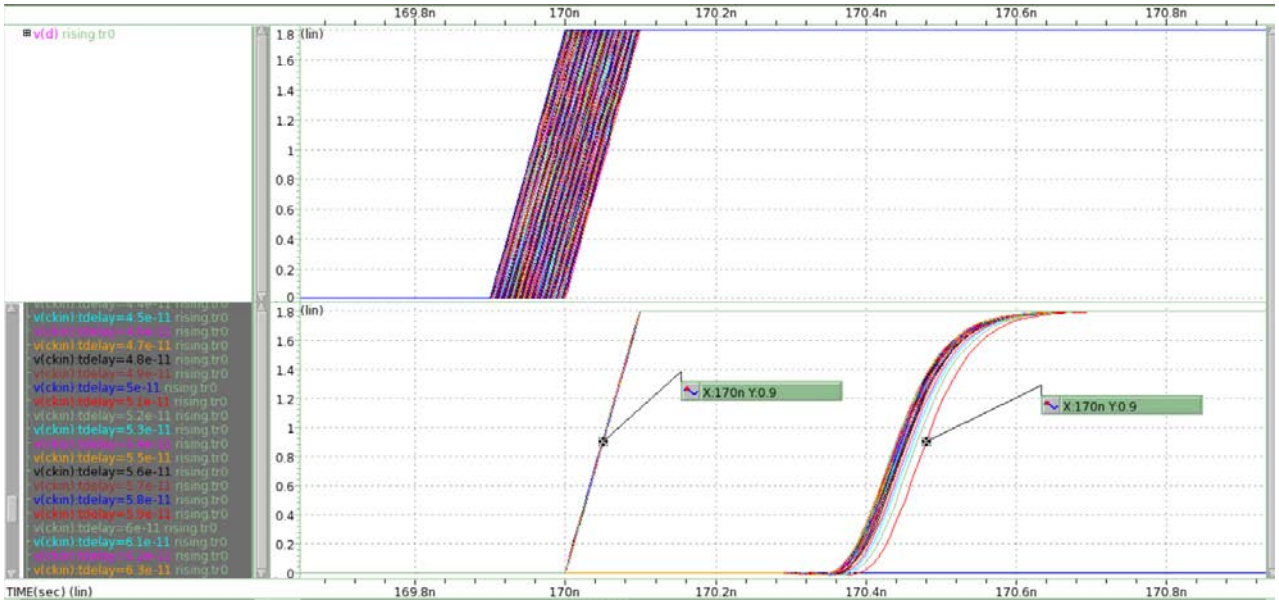
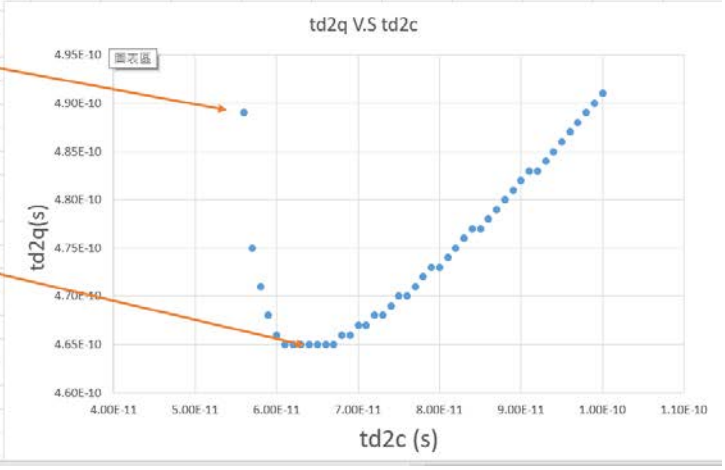
1.

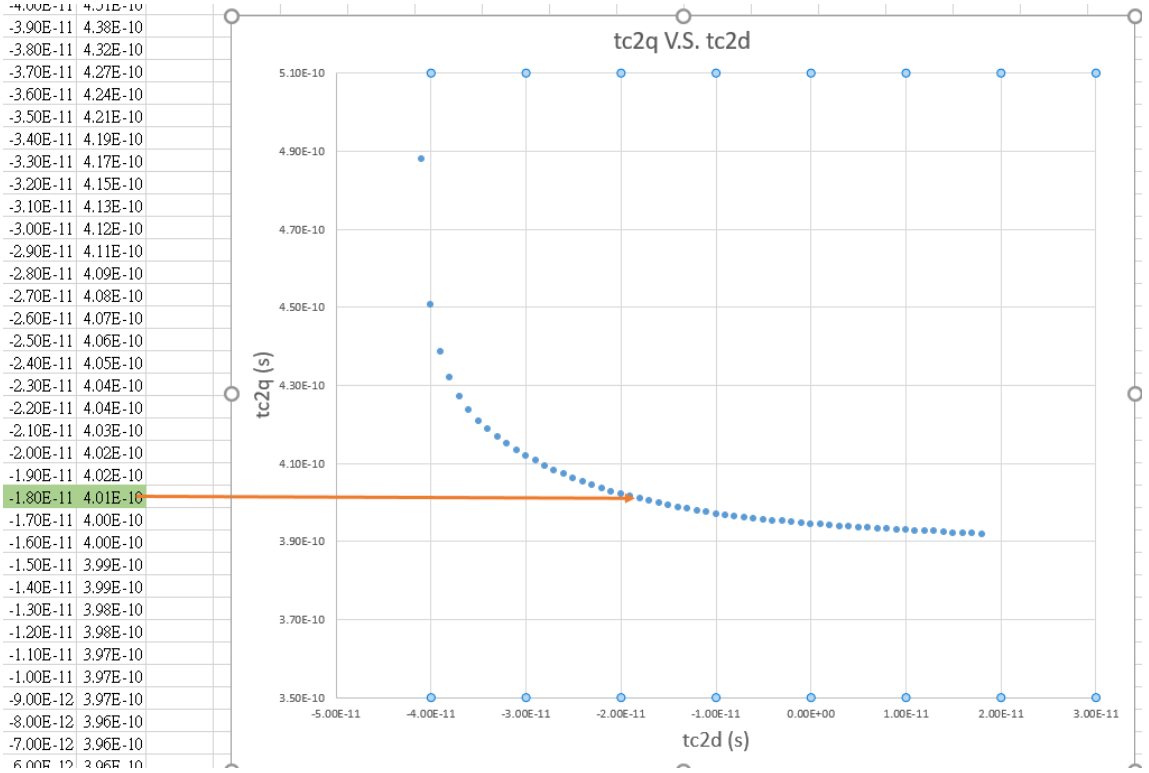
Rising characterization

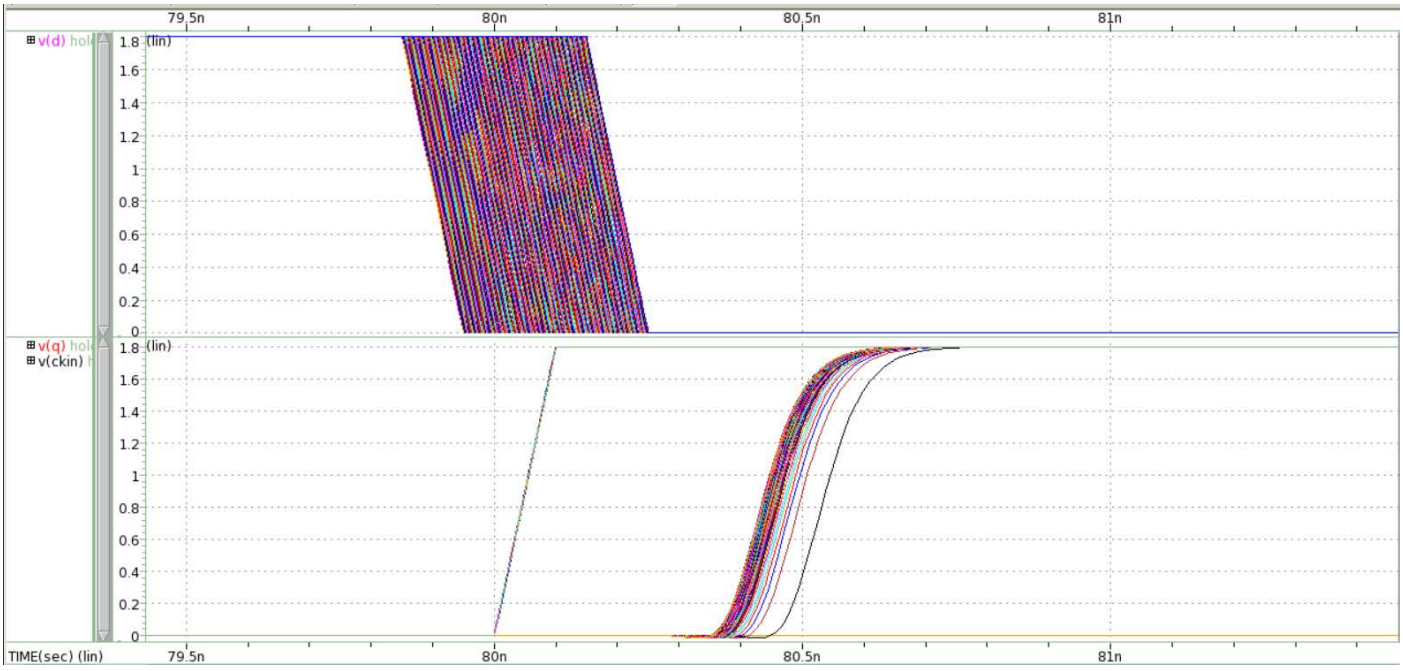


5.10E-11	5.10E-11	#######	2.04E-08	2.04E-08	25	1
5.20E-11	5.20E-11	#######	2.04E-08	2.04E-08	25	1
5.30E-11	5.30E-11	#######	2.04E-08	2.04E-08	25	1
5.40E-11	5.40E-11	#######	2.04E-08	2.04E-08	25	1
5.50E-11	5.50E-11	#######	2.04E-08	2.04E-08	25	1
5.60E-11	5.60E-11	#######	4.89E-10	4.32E-10	25	1
5.70E-11	5.70E-11	#######	4.75E-10	4.18E-10	25	1
5.80E-11	5.80E-11	#######	4.71E-10	4.13E-10	25	1
5.90E-11	5.90E-11	#######	4.68E-10	4.09E-10	25	1
6.00E-11	6.00E-11	#######	4.66E-10	4.06E-10	25	1
6.10E-11	6.10E-11	#######	4.65E-10	4.04E-10	25	1
6.20E-11	6.20E-11	#######	4.65E-10	4.03E-10	25	1
6.30E-11	6.30E-11	#######	4.65E-10	4.02E-10	25	1
6.40E-11	6.40E-11	#######	4.65E-10	4.00E-10	25	1
6.50E-11	6.50E-11	#######	4.65E-10	4.00E-10	25	1
6.60E-11	6.60E-11	#######	4.65E-10	3.99E-10	25	1
6.70E-11	6.70E-11	#######	4.65E-10	3.98E-10	25	1
6.80E-11	6.80E-11	#######	4.66E-10	3.98E-10	25	1
6.90E-11	6.90E-11	#######	4.66E-10	3.97E-10	25	1
7.00E-11	7.00E-11	#######	4.67E-10	3.97E-10	25	1
7.10E-11	7.10E-11	#######	4.67E-10	3.96E-10	25	1
7.20E-11	7.20E-11	#######	4.68E-10	3.96E-10	25	1
7.30E-11	7.30E-11	#######	4.68E-10	3.95E-10	25	1
7.40E-11	7.40E-11	#######	4.69E-10	3.95E-10	25	1

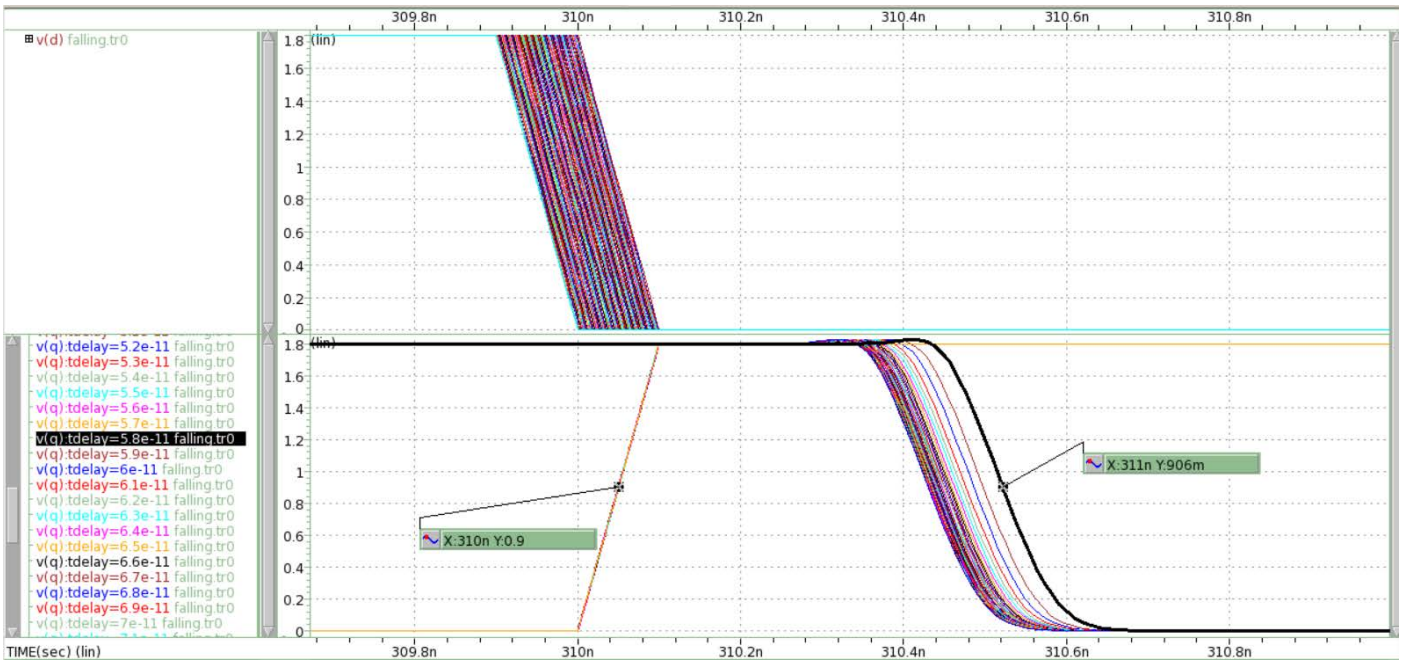


So, when td2c has minimum (465ps), tc2q = 465- 64 (setup time) = 401ps. I found tc2q=401ps on hold time excel file, and then tc2q = -18ps, which is hold time.

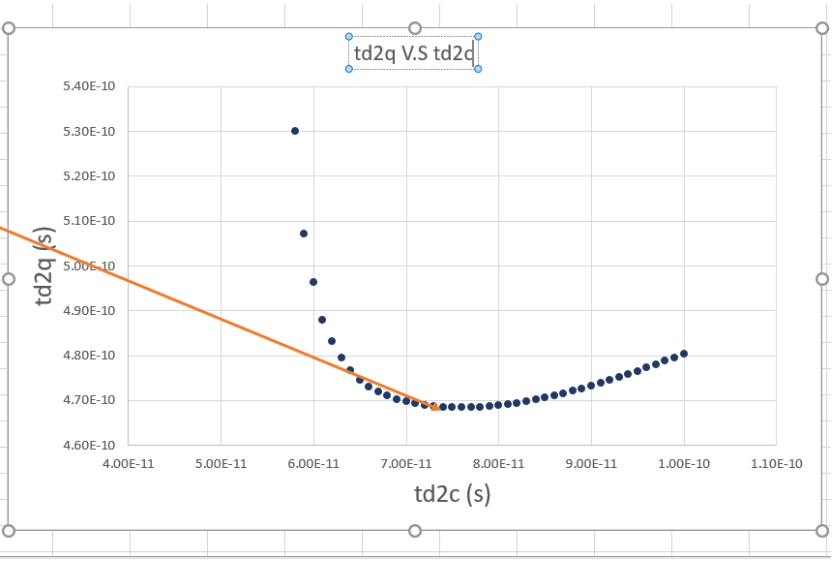




Falling characterization

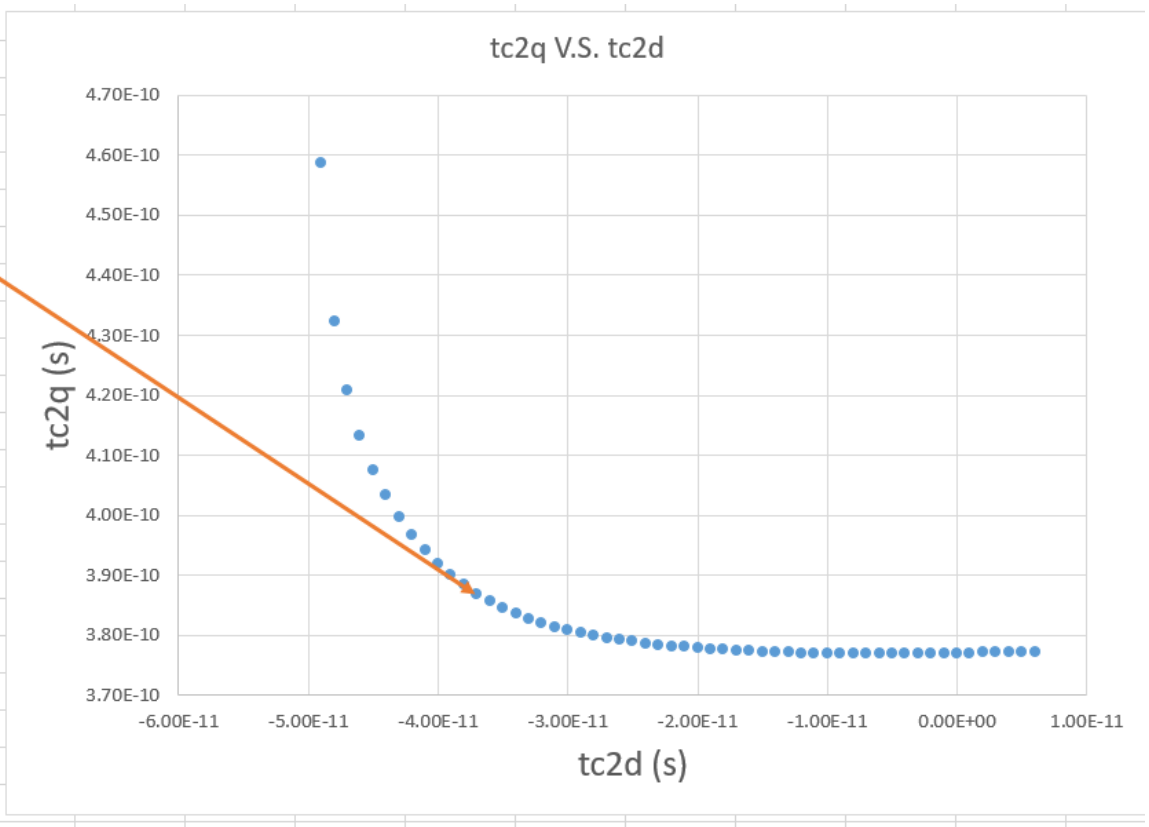


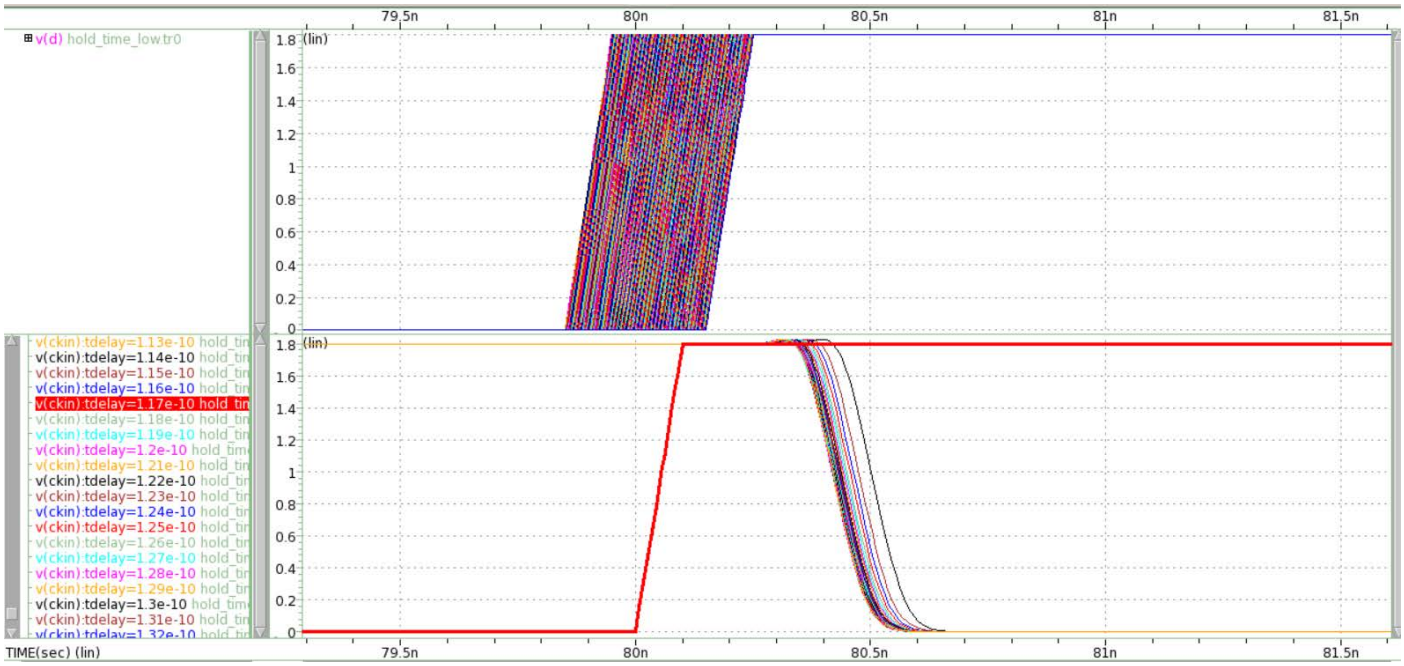
7.20E-11	7.20E-11	-7.10E-11	4.69E-10	3.97E-10	25	1
7.30E-11	7.30E-11	-7.20E-11	4.69E-10	3.96E-10	25	1
7.40E-11	7.40E-11	-7.30E-11	4.69E-10	3.95E-10	25	1
7.50E-11	7.50E-11	-7.40E-11	4.69E-10	3.94E-10	25	1
7.60E-11	7.60E-11	-7.50E-11	4.68E-10	3.92E-10	25	1
7.70E-11	7.70E-11	-7.60E-11	4.68E-10	3.91E-10	25	1
7.80E-11	7.80E-11	-7.70E-11	4.69E-10	3.91E-10	25	1
7.90E-11	7.90E-11	-7.80E-11	4.69E-10	3.90E-10	25	1
8.00E-11	8.00E-11	-7.90E-11	4.69E-10	3.89E-10	25	1
8.10E-11	8.10E-11	-8.00E-11	4.69E-10	3.88E-10	25	1
8.20E-11	8.20E-11	-8.10E-11	4.69E-10	3.87E-10	25	1
8.30E-11	8.30E-11	-8.20E-11	4.70E-10	3.87E-10	25	1
8.40E-11	8.40E-11	-8.30E-11	4.70E-10	3.86E-10	25	1
8.50E-11	8.50E-11	-8.40E-11	4.71E-10	3.86E-10	25	1
8.60E-11	8.60E-11	-8.50E-11	4.71E-10	3.85E-10	25	1
8.70E-11	8.70E-11	-8.60E-11	4.72E-10	3.85E-10	25	1
8.80E-11	8.80E-11	-8.70E-11	4.72E-10	3.84E-10	25	1
8.90E-11	8.90E-11	-8.80E-11	4.73E-10	3.84E-10	25	1
9.00E-11	9.00E-11	-8.90E-11	4.73E-10	3.83E-10	25	1
9.10E-11	9.10E-11	-9.00E-11	4.74E-10	3.83E-10	25	1
9.20E-11	9.20E-11	-9.10E-11	4.74E-10	3.82E-10	25	1



So, when td2c has minimum (468ps), tc2q = 465- 76 (setup time) = 389ps. I found tc2q= 388ps (~389ps) on hold time excel file, and then tc2d = -38ps, which is hold time.

-4.40E-11	4.03E-10
-4.30E-11	4.00E-10
-4.20E-11	3.97E-10
-4.10E-11	3.94E-10
-4.00E-11	3.92E-10
-3.90E-11	3.90E-10
-3.80E-11	3.88E-10
-3.70E-11	3.87E-10
-3.60E-11	3.86E-10
-3.50E-11	3.85E-10
-3.40E-11	3.84E-10
-3.30E-11	3.83E-10
-3.20E-11	3.82E-10
-3.10E-11	3.81E-10
-3.00E-11	3.81E-10
-2.90E-11	3.80E-10
-2.80E-11	3.80E-10
-2.70E-11	3.79E-10
-2.60E-11	3.79E-10
-2.50E-11	3.79E-10
-2.40E-11	3.79E-10
-2.30E-11	3.78E-10





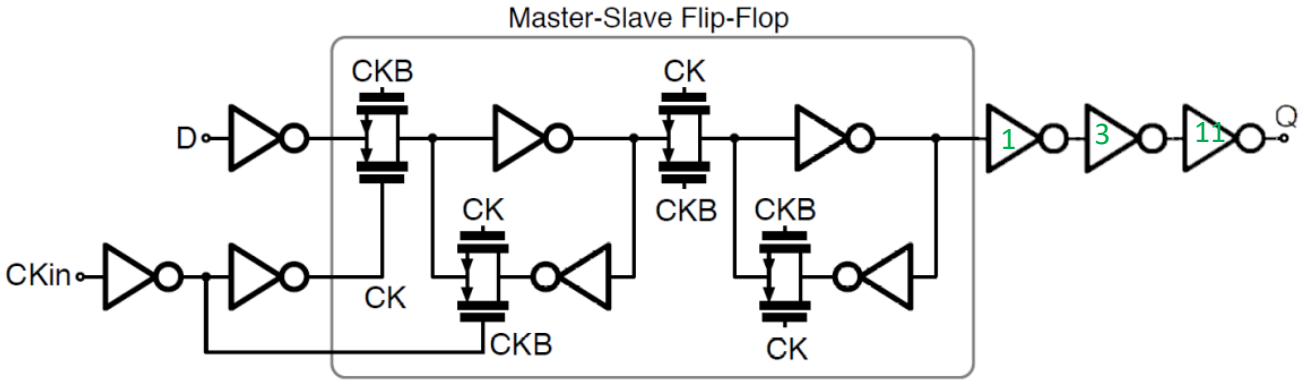
Power

```
******
* ---------------------------------------------------------------------

****** transient analysis tnom=  25.000 temp=  25.000 ******
total_avg_pwr_uw=  33.65845    from= 610.00000n     to=   1.01000u

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

2



Explain:

I added another two inverters at node Q to reduce the delay. From the last homework, I knew total capacitance of an inverter (PMOS $\frac{W}{L} = \frac{1.5u}{0.18u}$, NMOS $\frac{W}{L} = \frac{0.5u}{0.18u}$) looking from gate is 3.78fF.

Therefore, F = GBH = $1 \times 1 \times \frac{200}{3.78} = 52.91. \log_4 F = 2.862$

Since the Q is supposed to follow the polarity of D, I could only add even number of inverters.

Add 2 more inverters,

$\hat{f} = \sqrt[3]{52.91}$ = 3.754

D = $3 \times (3.754 + 1) = 14.26$

Add 4 more inverters,

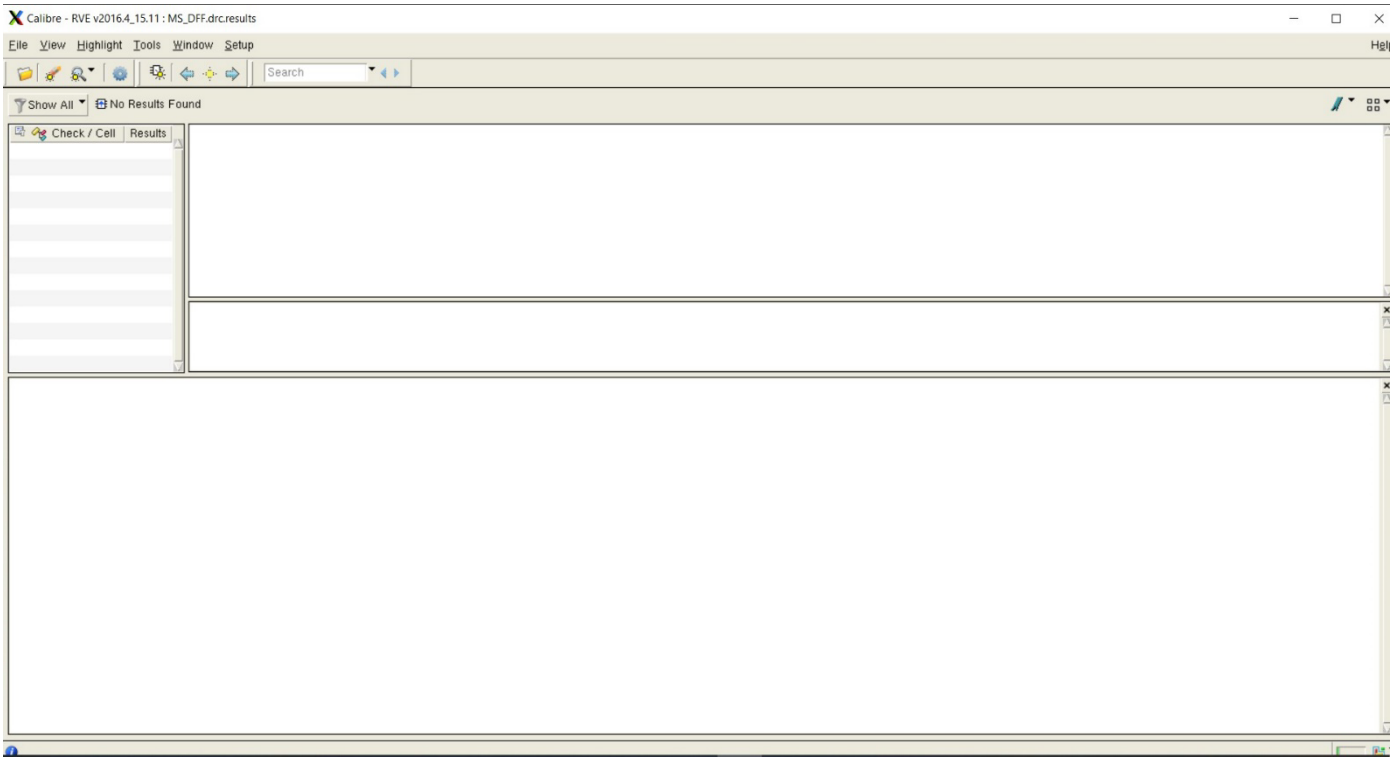
$\hat{f} = \sqrt[5]{52.91}$ = 2.21

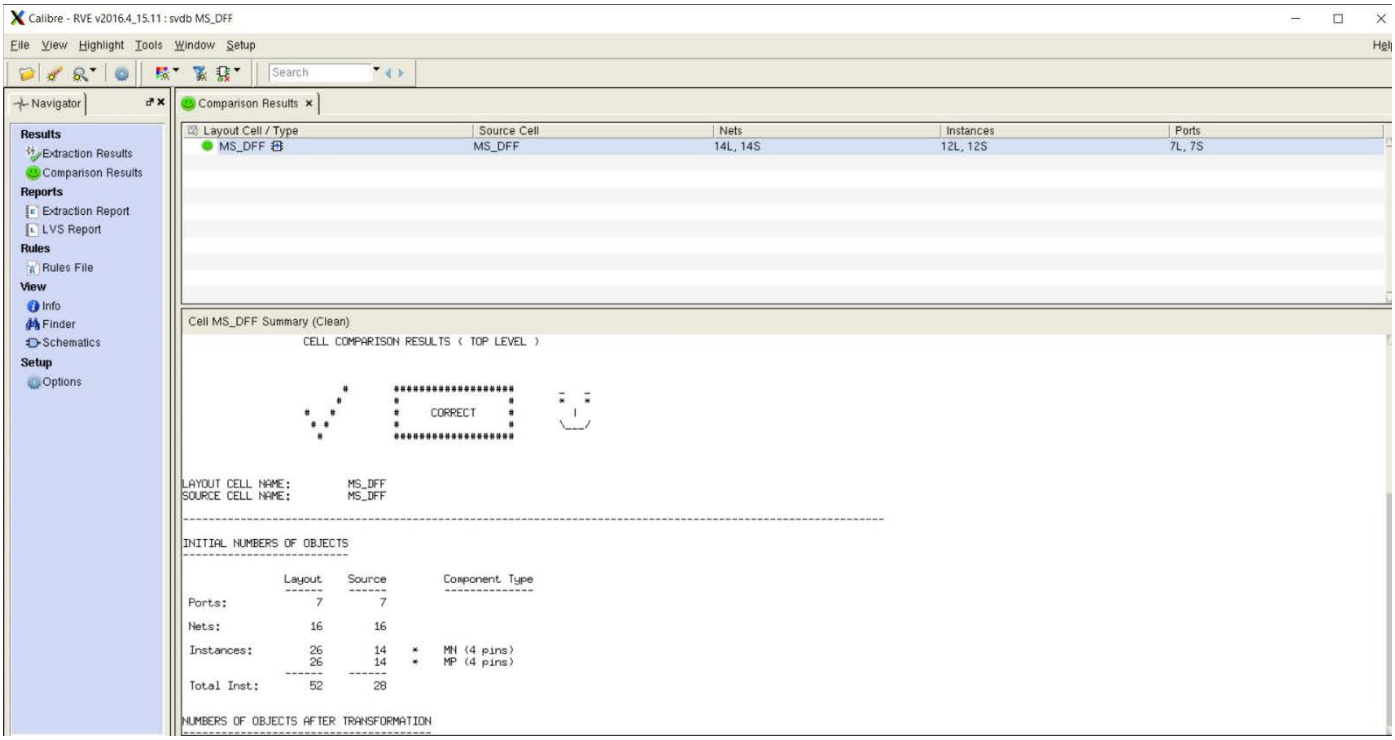
D = $3 \times (3.754 + 1) = 16.058$

So, I added 2 more inverters! 2nd inverter's size is 3X 1st inverter's size, 3rd inverter's size is 11X 1st inverter's size. (3*3.75=11.25)

Originally, without any extra inverters, minimum td2q is about 700ps~800ps. After adding them, minimum td2q goes down to 465ps.

3.



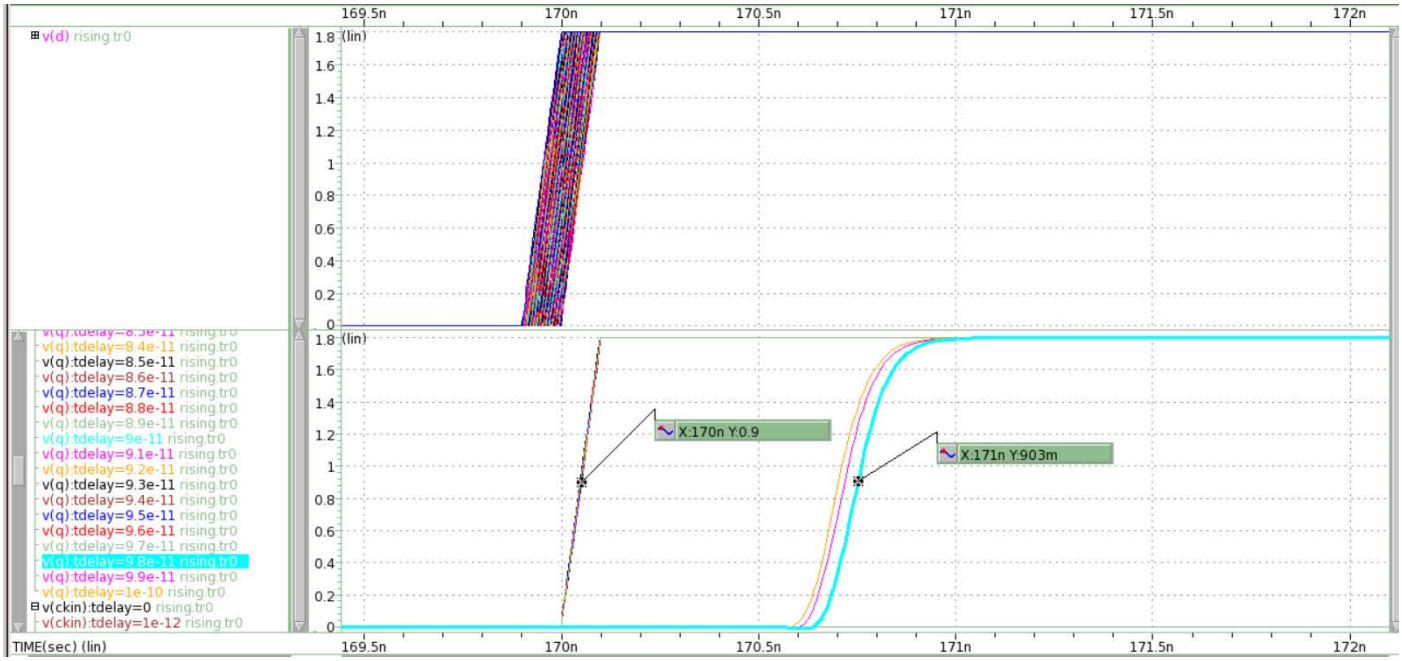


Layout consideration:

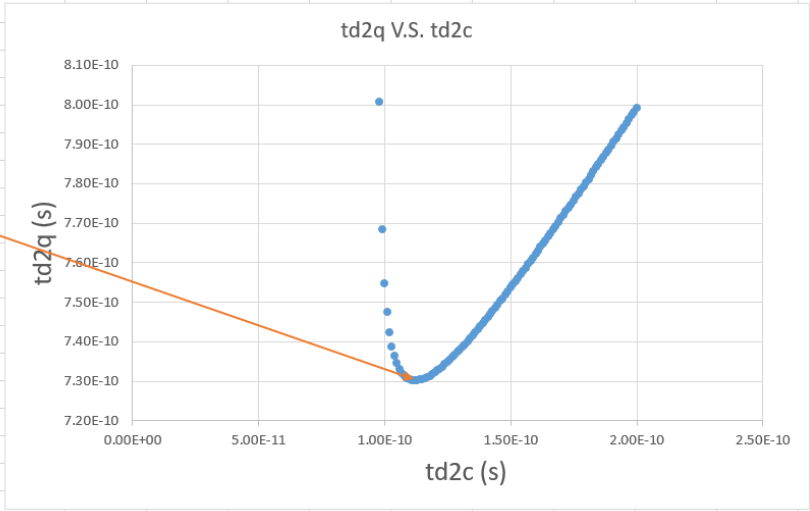
I put each transistor close to each other to reduce the length of metal, which would lead to parasitic resistors and capacitors, so that the delay wouldn't be bad. And I tried to connect nodes and nodes with metal instead of polysilicon as polysilicon has high resistance (impact the performance especially when two nodes are far away from each other).

4.

Rising characterization

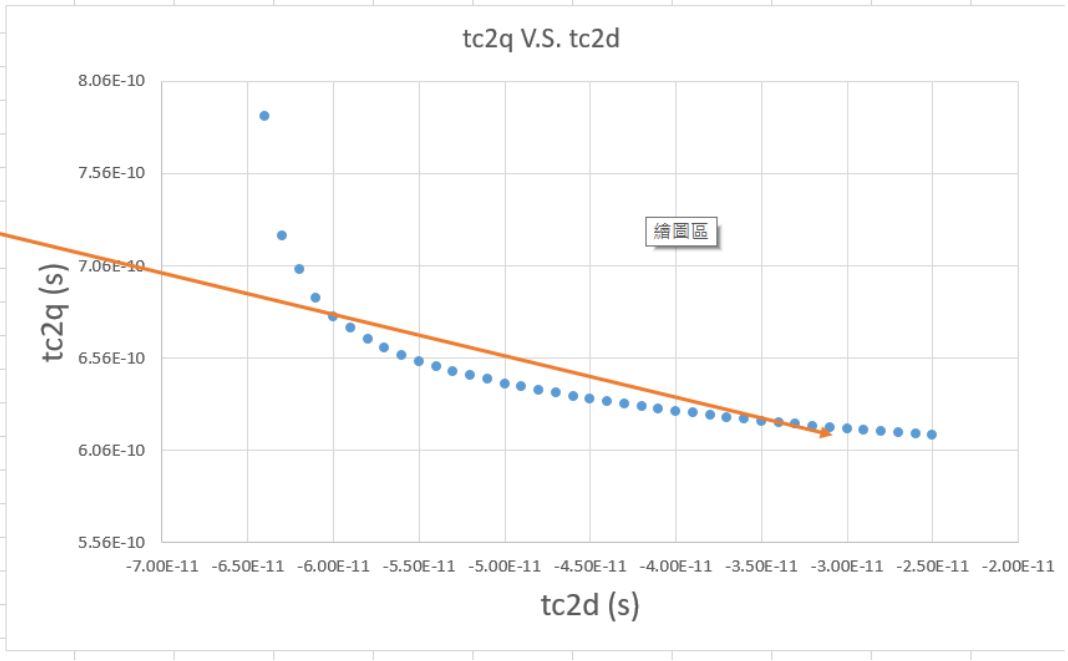


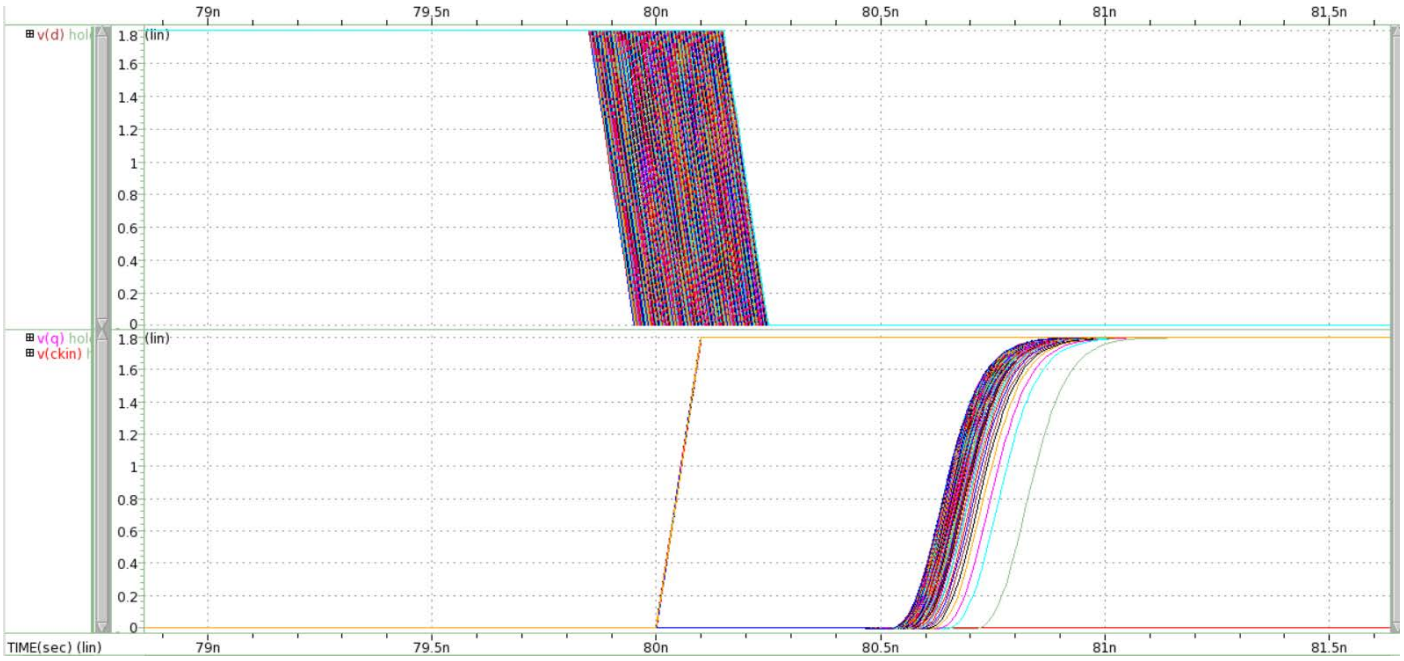
1.06E-10	1.06E-10	-1.06E-10	7.33E-10	6.27E-10	25	1
1.07E-10	1.07E-10	-1.07E-10	7.32E-10	6.25E-10	25	1
1.08E-10	1.08E-10	-1.08E-10	7.31E-10	6.23E-10	25	1
1.09E-10	1.09E-10	-1.09E-10	7.31E-10	6.22E-10	25	1
1.10E-10	1.10E-10	-1.10E-10	7.30E-10	6.20E-10	25	1
1.11E-10	1.11E-10	-1.11E-10	7.30E-10	6.19E-10	25	1
1.12E-10	1.12E-10	-1.12E-10	7.30E-10	6.18E-10	25	1
1.13E-10	1.13E-10	-1.13E-10	7.30E-10	6.17E-10	25	1
1.14E-10	1.14E-10	-1.14E-10	7.30E-10	6.16E-10	25	1
1.15E-10	1.15E-10	-1.15E-10	7.31E-10	6.15E-10	25	1
1.16E-10	1.16E-10	-1.16E-10	7.31E-10	6.15E-10	25	1
1.17E-10	1.17E-10	-1.17E-10	7.31E-10	6.14E-10	25	1
1.18E-10	1.18E-10	-1.18E-10	7.31E-10	6.13E-10	25	1
1.19E-10	1.19E-10	-1.19E-10	7.32E-10	6.13E-10	25	1
1.20E-10	1.20E-10	-1.20E-10	7.32E-10	6.12E-10	25	1
1.21E-10	1.21E-10	-1.21E-10	7.33E-10	6.12E-10	25	1
1.22E-10	1.22E-10	-1.22E-10	7.33E-10	6.11E-10	25	1
1.23E-10	1.23E-10	-1.23E-10	7.34E-10	6.11E-10	25	1
1.24E-10	1.24E-10	-1.24E-10	7.34E-10	6.10E-10	25	1
1.25E-10	1.25E-10	-1.25E-10	7.35E-10	6.10E-10	25	1



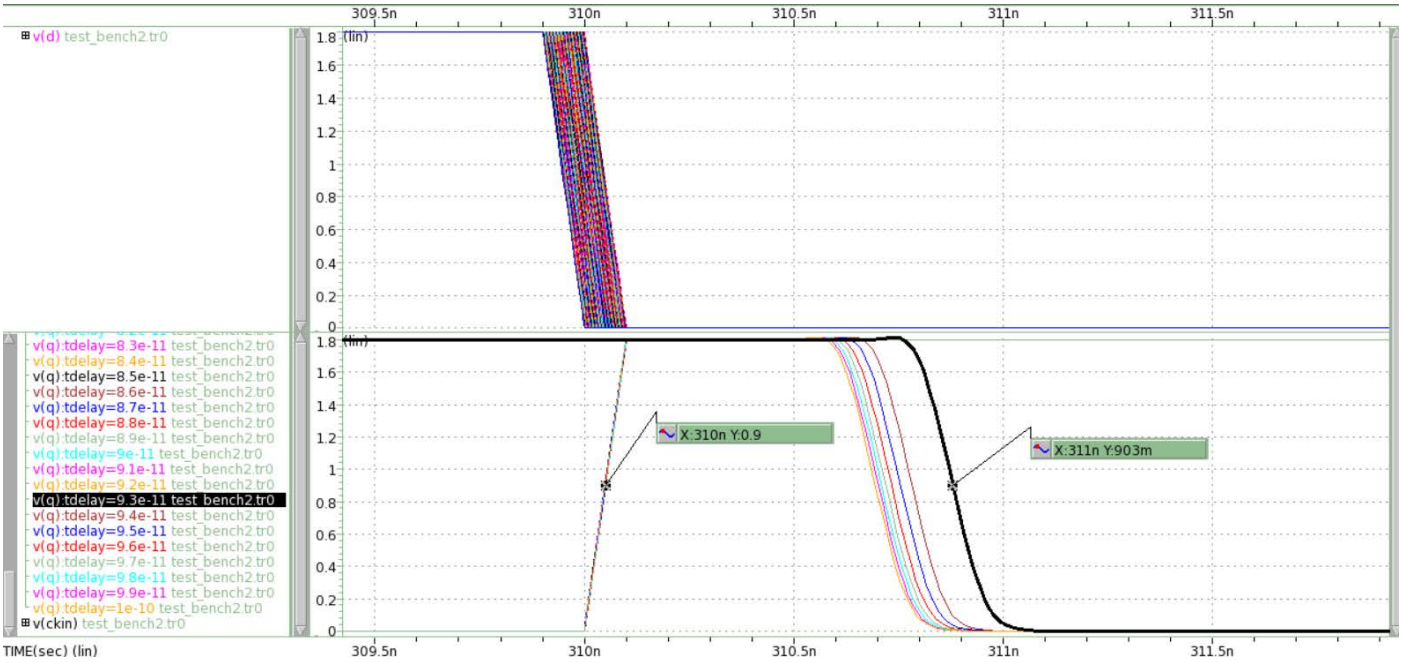
So, when td2c has minimum (730ps), tc2q = 730- 112 (setup time) = 618ps. I found tc2q= 618ps on hold time excel file, and then tc2d = -31ps, which is hold time.

-3.70E-11	6.24E-10
-3.60E-11	6.23E-10
-3.50E-11	6.22E-10
-3.40E-11	6.21E-10
-3.30E-11	6.20E-10
-3.20E-11	6.19E-10
-3.10E-11	6.18E-10
-3.00E-11	6.18E-10
-2.90E-11	6.17E-10
-2.80E-11	6.16E-10
-2.70E-11	6.15E-10
-2.60E-11	6.15E-10
-2.50E-11	6.14E-10

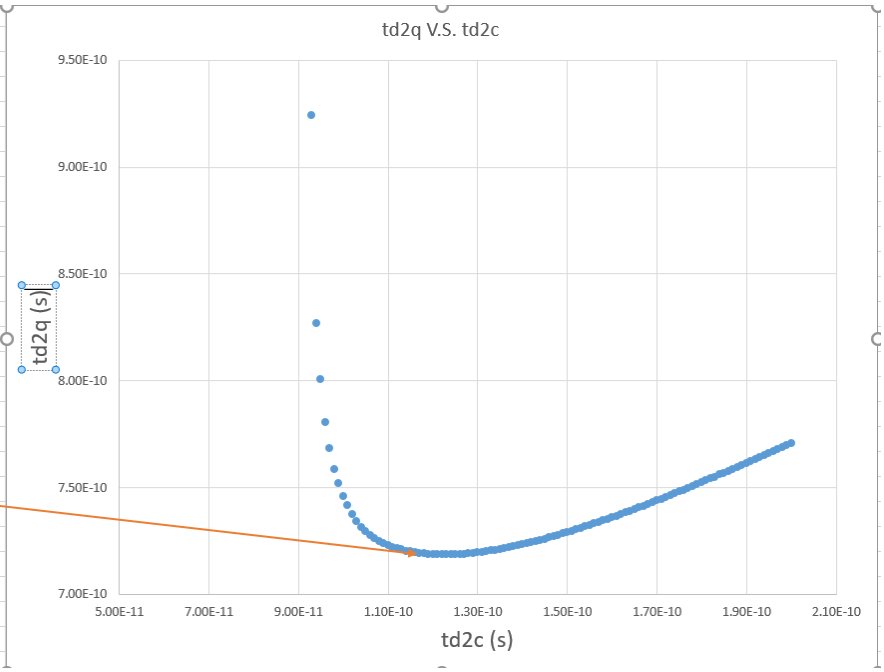




Falling characterization

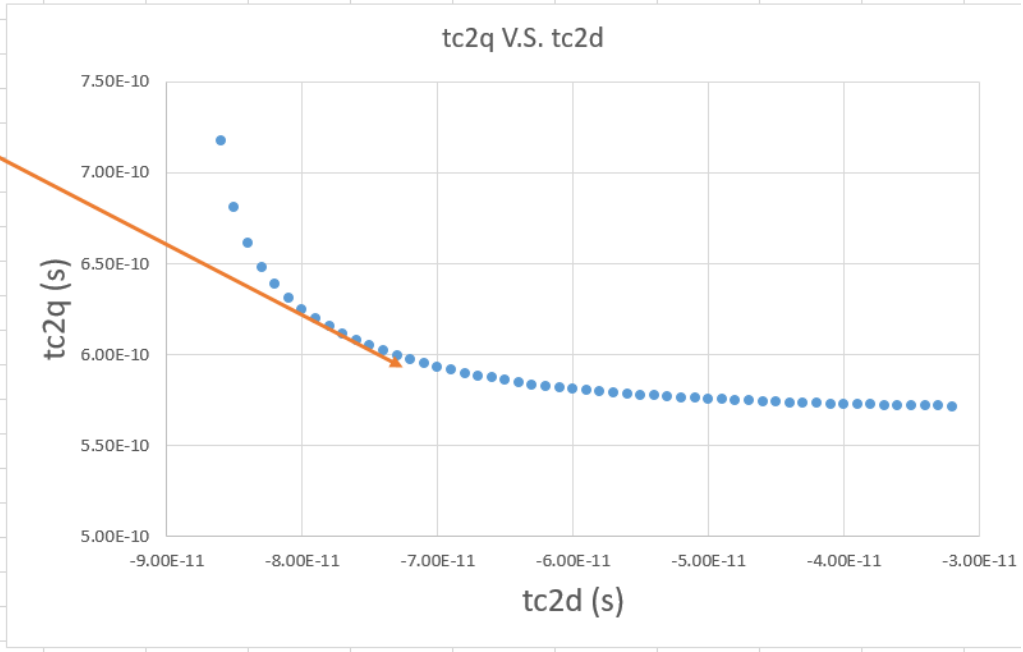


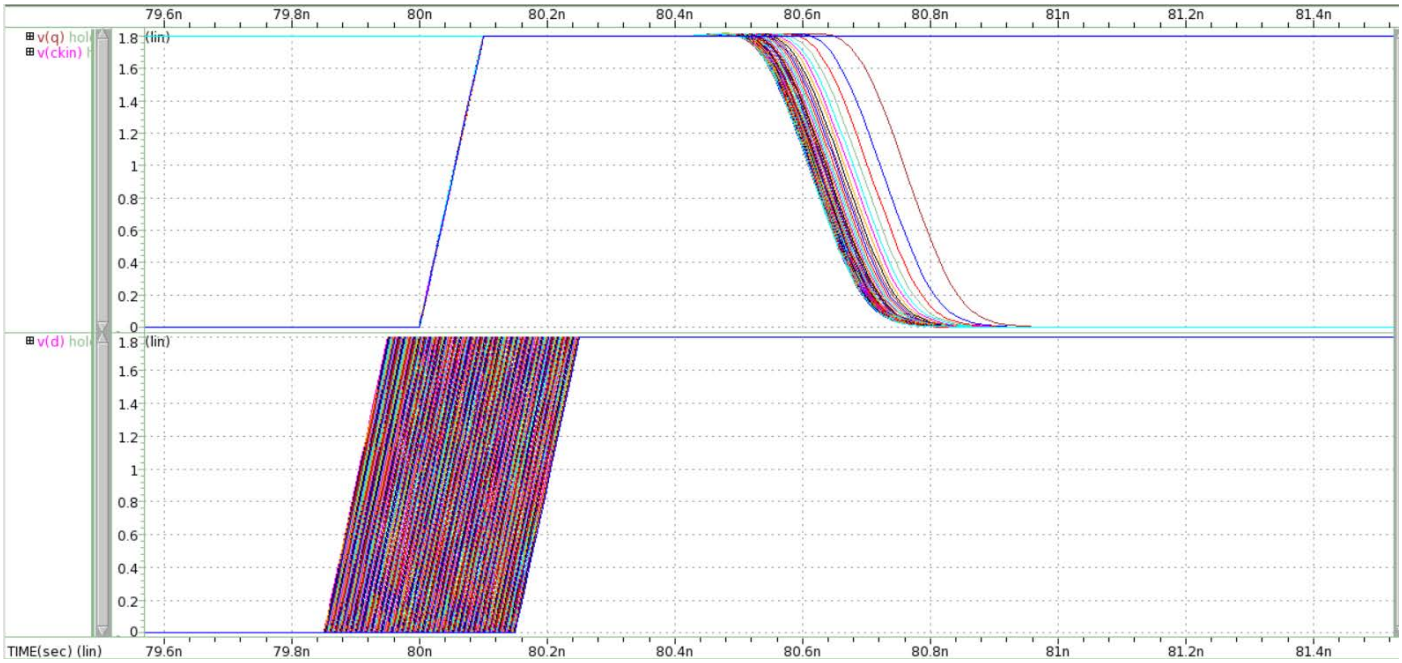
1.04E-10	1.04E-10	-1.04E-10	7.31E-10	6.27E-10	25	1
1.05E-10	1.05E-10	-1.05E-10	7.29E-10	6.24E-10	25	1
1.06E-10	1.06E-10	-1.06E-10	7.27E-10	6.21E-10	25	1
1.07E-10	1.07E-10	-1.07E-10	7.26E-10	6.19E-10	25	1
1.08E-10	1.08E-10	-1.08E-10	7.25E-10	6.17E-10	25	1
1.09E-10	1.09E-10	-1.09E-10	7.24E-10	6.15E-10	25	1
1.10E-10	1.10E-10	-1.10E-10	7.23E-10	6.13E-10	25	1
1.11E-10	1.11E-10	-1.11E-10	7.22E-10	6.11E-10	25	1
1.12E-10	1.12E-10	-1.12E-10	7.21E-10	6.09E-10	25	1
1.13E-10	1.13E-10	-1.13E-10	7.21E-10	6.08E-10	25	1
1.14E-10	1.14E-10	-1.14E-10	7.20E-10	6.06E-10	25	1
1.15E-10	1.15E-10	-1.15E-10	7.20E-10	6.05E-10	25	1
1.16E-10	1.16E-10	-1.16E-10	7.20E-10	6.04E-10	25	1
1.17E-10	1.17E-10	-1.17E-10	7.19E-10	6.02E-10	25	1
1.18E-10	1.18E-10	-1.18E-10	7.19E-10	6.01E-10	25	1
1.19E-10	1.19E-10	-1.19E-10	7.19E-10	6.00E-10	25	1
1.20E-10	1.20E-10	-1.20E-10	7.19E-10	5.99E-10	25	1
1.21E-10	1.21E-10	-1.21E-10	7.19E-10	5.98E-10	25	1
1.22E-10	1.22E-10	-1.22E-10	7.19E-10	5.97E-10	25	1
1.23E-10	1.23E-10	-1.23E-10	7.19E-10	5.96E-10	25	1
1.24E-10	1.24E-10	-1.24E-10	7.19E-10	5.95E-10	25	1
1.25E-10	1.25E-10	-1.25E-10	7.19E-10	5.94E-10	25	1
1.26E-10	1.26E-10	-1.26E-10	7.19E-10	5.93E-10	25	1
1.27E-10	1.27E-10	-1.27E-10	7.19E-10	5.92E-10	25	1
1.28E-10	1.28E-10	-1.28E-10	7.19E-10	5.91E-10	25	1
1.29E-10	1.29E-10	-1.29E-10	7.19E-10	5.90E-10	25	1
1.30E-10	1.30E-10	-1.30E-10	7.19E-10	5.89E-10	25	1



So, when td2c has minimum (719ps), tc2q = 719- 123 (setup time) = 596ps. I found tc2q= 595ps (~596ps) on hold time excel file, and then tc2d = -71ps, which is hold time.

-7.40E-11	6.02E-10
-7.30E-11	6.00E-10
-7.20E-11	5.97E-10
-7.10E-11	5.95E-10
-7.00E-11	5.93E-10
-6.90E-11	5.92E-10
-6.80E-11	5.90E-10
-6.70E-11	5.88E-10
-6.60E-11	5.87E-10
-6.50E-11	5.86E-10
-6.40E-11	5.85E-10
-6.30E-11	5.84E-10
-6.20E-11	5.83E-10
-6.10E-11	5.82E-10
-6.00E-11	5.81E-10
-5.90E-11	5.80E-10
-5.80E-11	5.79E-10
-5.70E-11	5.79E-10
-5.60E-11	5.78E-10
-5.50E-11	5.78E-10





Power

```
* ------------------------------------------------------------------

****** transient analysis tnom=  25.000 temp=  25.000 ******
total_avg_pwr_uw=  44.80439   from= 610.00000n     to=   1.01000u

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

5.

	Pre-layout simulation		Post-layout simulation	
	Rising	Falling	Rising	Falling
t_{SU}	64ps	76ps	112ps	123ps
t_H	-18ps	-38ps	-31ps	-71ps
minimum t_{D2Q}	465ps	468ps	730ps	719ps
minimum t_{CK2Q}	390ps	380ps	599ps	569ps
Power consumption (mW)	0.033658		0.04480439	
Layout area (μm^2)	1460			