

For the above RC network, we must insert buffers at points such that the arrival time is 1.9ns.

To achieve this, we will first number all the nodes and perform the calculations. The calculations will follow the below steps,

- a. Determine (L_i, T_i) at all the end points.
- b. Then we traverse to the point before on the same line. We can determine the load and time as shown,

$$T_i' = T_i - R_i * C_i$$

$$L_i' = L_i + C_i$$

- c. Complete this traverse back along the line for all the end points.
- d. At Fan-out points, we need to choose the optimum design option from the available design option at various points. This can be done using the below method

In case we have design options like $(L_1, T_1), (L_2, T_2), (L_3, T_3)$

$$T = \min(T_1, T_2, T_3)$$

$$L = L_1 + L_2 + L_3$$

- e. Once we do that, we must do a redundancy check. This can be done using the following method,

Suppose we have two design options (L_1, T_1) and (L_2, T_2)

If $L_1 \geq L_2$ and $T_1 \leq T_2$

Then, (L_1, T_1) is redundant.

- f. When buffer is inserted, we use different set of formulas to calculate the time.

When we insert buffer,

$$L = C_{\text{buff}}$$

$$T_{\text{buff}} = T_{\text{min}} - R_{\text{buff}} * L$$

Using these steps mentioned above, the calculations can be done to determine the various design options and buffer insertion points.

First, I will show the different points and the name of the points that I have used below

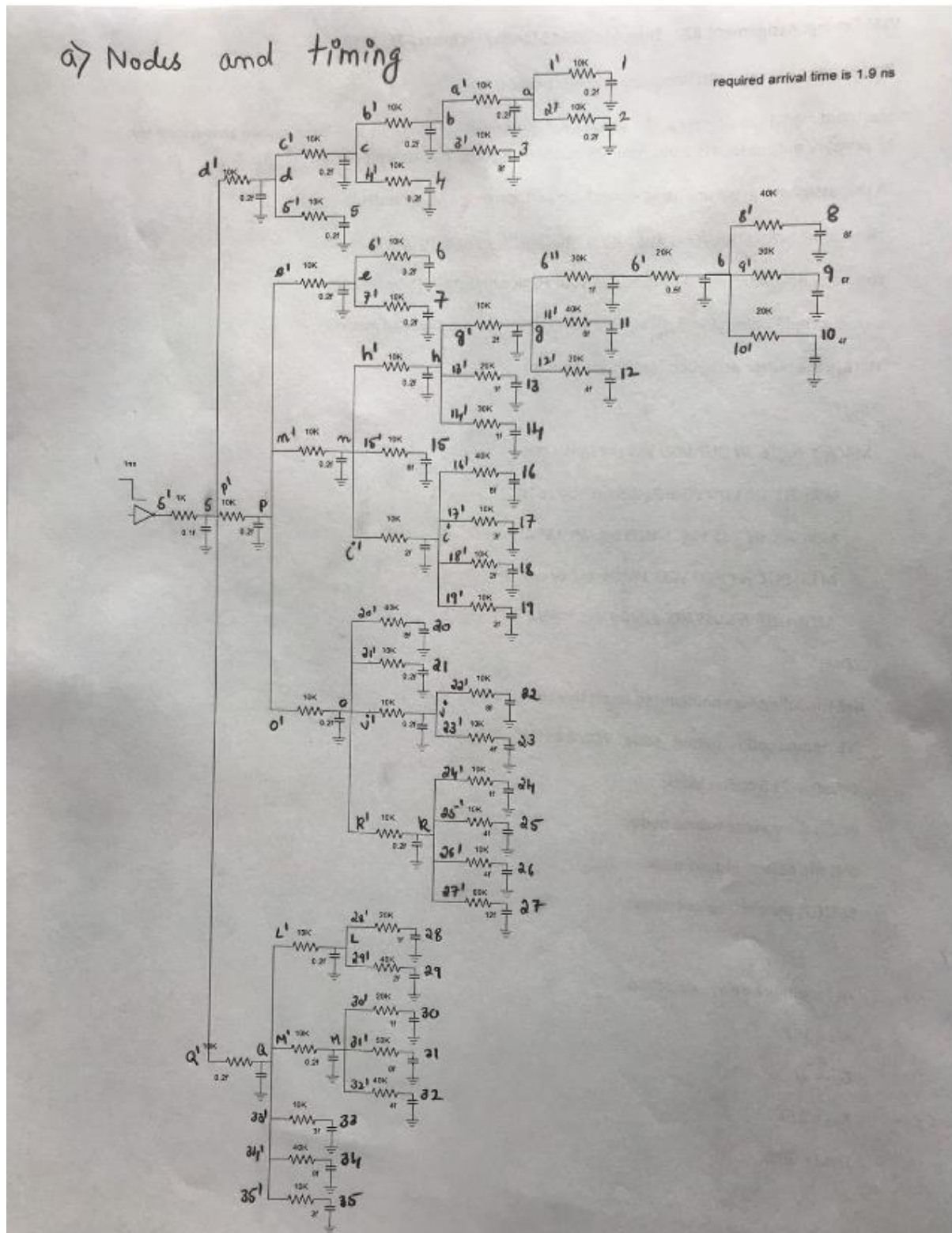


Figure 1

The Values are Tabulated as shown. The first set shown here shows the final edges and their values when traversed. These values are calculated at nodes with

| Node | Load (fF) | Time (ns) |
|------|-----------|-----------|
| 1 | 0.2 | 1.9 |
| 2 | 0.2 | 1.9 |
| 3 | 8 | 1.9 |
| 4 | 0.2 | 1.9 |
| 5 | 0.2 | 1.9 |
| 6 | 0.2 | 1.9 |
| 7 | 0.2 | 1.9 |
| 8 | 8 | 1.9 |
| 9 | 6 | 1.9 |
| 10 | 4 | 1.9 |
| 11 | 6 | 1.9 |
| 12 | 4 | 1.9 |
| 13 | 1 | 1.9 |
| 14 | 1 | 1.9 |
| 15 | 8 | 1.9 |
| 16 | 8 | 1.9 |
| 17 | 3 | 1.9 |
| 18 | 2 | 1.9 |
| 19 | 2 | 1.9 |
| 20 | 8 | 1.9 |
| 21 | 0.2 | 1.9 |
| 22 | 8 | 1.9 |
| 23 | 4 | 1.9 |
| 24 | 1 | 1.9 |
| 25 | 4 | 1.9 |
| 26 | 4 | 1.9 |
| 27 | 12 | 1.9 |
| 28 | 1 | 1.9 |
| 29 | 2 | 1.9 |
| 30 | 1 | 1.9 |
| 31 | 8 | 1.9 |
| 32 | 4 | 1.9 |
| 33 | 3 | 1.9 |
| 34 | 8 | 1.9 |
| 35 | 2 | 1.9 |

| Node | Load (fF) | Time (ns) |
|------|-----------|-----------|
| 1' | 0.2 | 1.898 |
| 2' | 0.2 | 1.898 |
| 3' | 8 | 1.82 |
| 4' | 0.2 | 1.898 |
| 5' | 0.2 | 1.898 |
| 6' | 0.2 | 1.898 |
| 7' | 0.2 | 1.898 |
| 8' | 8 | 1.58 |
| 9' | 6 | 1.72 |
| 10' | 4 | 1.82 |
| 11' | 6 | 1.66 |
| 12' | 4 | 1.78 |
| 13' | 1 | 1.88 |
| 14' | 1 | 1.87 |
| 15' | 8 | 1.82 |
| 16' | 8 | 1.58 |
| 17' | 3 | 1.87 |
| 18' | 2 | 1.88 |
| 19' | 2 | 1.88 |
| 20' | 8 | 1.58 |
| 21' | 0.2 | 1.898 |
| 22' | 8 | 1.82 |
| 23' | 4 | 1.86 |
| 24' | 1 | 1.89 |
| 25' | 4 | 1.86 |
| 26' | 4 | 1.86 |
| 27' | 12 | 1.18 |
| 28' | 1 | 1.88 |
| 29' | 2 | 1.82 |
| 30' | 1 | 1.88 |
| 31' | 8 | 1.5 |
| 32' | 4 | 1.74 |
| 33' | 3 | 1.87 |
| 34' | 8 | 1.58 |
| 35' | 2 | 1.88 |

The values below shown is of the fan outs and the redundant options

| Node | Load (fF) | Time (ns) | Redundancy |
|------|-----------|-----------|------------|
| a | 0.4 | 1.898 | |
| | 2 | 1.8778 | Redundant |
| a' | 0.6 | 1.892 | |
| b | 8.6 | 1.82 | |
| | 2 | 1.795 | |
| b' | 8.8 | 1.734 | Redundant |
| | 2.2 | 1.773 | |
| c | 2.4 | 1.773 | |
| | 2 | 1.752 | |
| c' | 2.6 | 1.747 | |
| | 2.2 | 1.73 | |
| d | 2.4 | 1.73 | |
| | 2.8 | 1.747 | |
| | 2 | 1.726 | |
| d' | 2.6 | 1.704 | Redundant |
| | 3 | 1.717 | |
| | 2.2 | 1.704 | |
| e | 0.4 | 1.898 | |
| | 2 | 1.877 | Redundant |
| e' | 0.6 | 1.892 | |
| f | 18 | 1.58 | |
| | 2 | 1.551 | |
| f' | 18.5 | 1.21 | Redundant |
| | 2.5 | 1.501 | |
| f'' | 3.5 | 1.396 | |
| g | 13.5 | 1.396 | |
| | 2 | 1.369 | |
| g' | 15.5 | 1.241 | Redundant |
| | 4 | 1.329 | |
| h | 6 | 1.329 | |
| | 2 | 1.306 | |
| h' | 6.2 | 1.267 | Redundant |
| | 2.2 | 1.284 | |
| i | 15 | 1.58 | |
| | 2 | 1.553 | |
| l' | 17 | 1.41 | Redundant |
| | 2.2 | 1.531 | |
| n | 12.4 | 1.284 | |
| | 2 | 1.258 | |
| n' | 12.6 | 1.158 | Redundant |
| | 2.2 | 1.236 | |

| | | | |
|----|------|-------|-----------|
| j | 12 | 1.82 | |
| | 2 | 1.794 | |
| j' | 12.2 | 1.698 | Redundant |
| | 2.2 | 1.772 | |
| k | 21 | 1.18 | |
| | 2 | 1.15 | |
| k' | 21.2 | 0.968 | |
| | 2.2 | 1.128 | |
| o | 12.6 | 1.128 | |
| | 2 | 1.102 | |
| o' | 12.8 | 1 | Redundant |
| | 2.2 | 1.08 | |
| p | 5 | 1.08 | |
| | 2 | 1.058 | |
| p' | 5.2 | 1.028 | Redundant |
| | 2.2 | 1.006 | |
| l | 3 | 1.82 | |
| | 2 | 1.799 | |
| l' | 3.2 | 1.788 | |
| | 2.2 | 1.777 | |
| m | 13 | 1.5 | |
| | 2 | 1.473 | |
| m' | 13.2 | 1.368 | Redundant |
| | 2.2 | 1.451 | |
| q | 17.4 | 1.451 | |
| | 2 | 1.422 | |
| q' | 17.6 | 1.275 | Redundant |
| | 2.2 | 1.4 | |
| s | 6.6 | 1.006 | |
| | 2 | 0.983 | |
| s' | 6.7 | 0.993 | |
| | 2.1 | 0.98 | |

Note: The design in Blue is for the buffer. Redundant options are removed at each stage.

Based on the calculation done, the buffer was inserted at points D, C, B, H, G, F, N, I, O, J, K, L, M, Q, P, S. Total of 16 Buffers was used for this problem. To compare the performance before and after buffer insertion, we need to calculate the Elmore delay with and without buffer. This will be shown below.

required arrival time is 1.9 ns

Figure 2

$$\begin{aligned}T_7 &= (2663.8 + 96 + 92 + 88 + 6 + 2) * 10^{-12} = 2.95\text{ns} \\T_8 &= (2663.8 + 96 + 92 + 88 + 6 + 2) * 10^{-12} = 2.95\text{ns} \\T_9 &= (2663.8 + 96 + 92 + 88 + 80) * 10^{-12} = 3.019\text{ns} \\T_{10} &= (2663.8 + 96 + 92 + 2) * 10^{-12} = 2.853\text{ns} \\T_{11} &= (2663.8 + 96 + 2) * 10^{-12} = 2.761\text{ns} \\T_{13} &= (2663.8 + 1009 + 6 + 2) * 10^{-12} = 3.68\text{ns} \\T_{14} &= (2663.8 + 1009 + 6 + 2) * 10^{-12} = 3.68\text{ns} \\T_{20} &= (2663.8 + 1009 + 589 + 337 + 315 + 585 + 370 + 320) * 10^{-12} = 6.18\text{ns} \\T_{23} &= (2663.8 + 1009 + 589 + 337 + 315 + 585 + 370 + 180) * 10^{-12} = 6.05\text{ns} \\T_{24} &= (2663.8 + 1009 + 589 + 337 + 315 + 585 + 370 + 80) * 10^{-12} = 5.95\text{ns} \\T_{22} &= (2663.8 + 1009 + 589 + 337 + 315 + 240) * 10^{-12} = 5.15\text{ns} \\T_{25} &= (2663.8 + 1009 + 589 + 337 + 315 + 120) * 10^{-12} = 5.03\text{ns} \\T_{21} &= (2663.8 + 1009 + 589 + 337 + 20) * 10^{-12} = 4.62\text{ns} \\T_{26} &= (2663.8 + 1009 + 589 + 337 + 30) * 10^{-12} = 4.62\text{ns} \\T_{27} &= (2663.8 + 1009 + 589 + 80) * 10^{-12} = 4.34\text{ns} \\T_{28} &= (2663.8 + 1009 + 589 + 170 + 320) * 10^{-12} = 4.75\text{ns} \\T_{29} &= (2663.8 + 1009 + 589 + 170 + 30) * 10^{-12} = 4.46\text{ns} \\T_{30} &= (2663.8 + 1009 + 589 + 170 + 20) * 10^{-12} = 4.45\text{ns} \\T_{31} &= (2663.8 + 1009 + 589 + 170 + 20) * 10^{-12} = 4.45\text{ns} \\T_{34} &= (2663.8 + 1009 + 418 + 320) * 10^{-12} = 4.41\text{ns} \\T_{35} &= (2663.8 + 1009 + 418 + 2) * 10^{-12} = 4.09\text{ns} \\T_{37} &= (2663.8 + 1009 + 418 + 122 + 80) * 10^{-12} = 4.29\text{ns} \\T_{38} &= (2663.8 + 1009 + 418 + 122 + 40) * 10^{-12} = 4.25\text{ns} \\T_{40} &= (2663.8 + 1009 + 418 + 212 + 10) * 10^{-12} = 4.31\text{ns} \\T_{41} &= (2663.8 + 1009 + 418 + 212 + 40) * 10^{-12} = 4.34\text{ns} \\T_{42} &= (2663.8 + 1009 + 418 + 212 + 40) * 10^{-12} = 4.34\text{ns} \\T_{43} &= (2663.8 + 1009 + 418 + 212 + 720) * 10^{-12} = 5.02\text{ns} \\T_{46} &= (2663.8 + 296 + 320 + 20) * 10^{-12} = 3.29\text{ns} \\T_{47} &= (2663.8 + 296 + 320 + 80) * 10^{-12} = 3.35\text{ns} \\T_{49} &= (2663.8 + 296 + 132 + 20) * 10^{-12} = 3.11\text{ns} \\T_{50} &= (2663.8 + 296 + 132 + 400) * 10^{-12} = 3.49\text{ns} \\T_{51} &= (2663.8 + 296 + 132 + 160) * 10^{-12} = 3.25\text{ns} \\T_{52} &= (2663.8 + 296 + 30) * 10^{-12} = 2.98\text{ns} \\T_{53} &= (2663.8 + 296 + 30) * 10^{-12} = 3.27\text{ns} \\T_{54} &= (2663.8 + 296 + 30) * 10^{-12} = 2.97\text{ns}\end{aligned}$$

As we can see from the above values, the Elmore delay is more than 1.9ns. This means that the arrival time will also be more than the expected arrival time. To reduce this, we insert buffers. This is shown below.

Elmore Delay Calculation without buffer: For the Elmore delay calculation, we have the following nodes as shown,

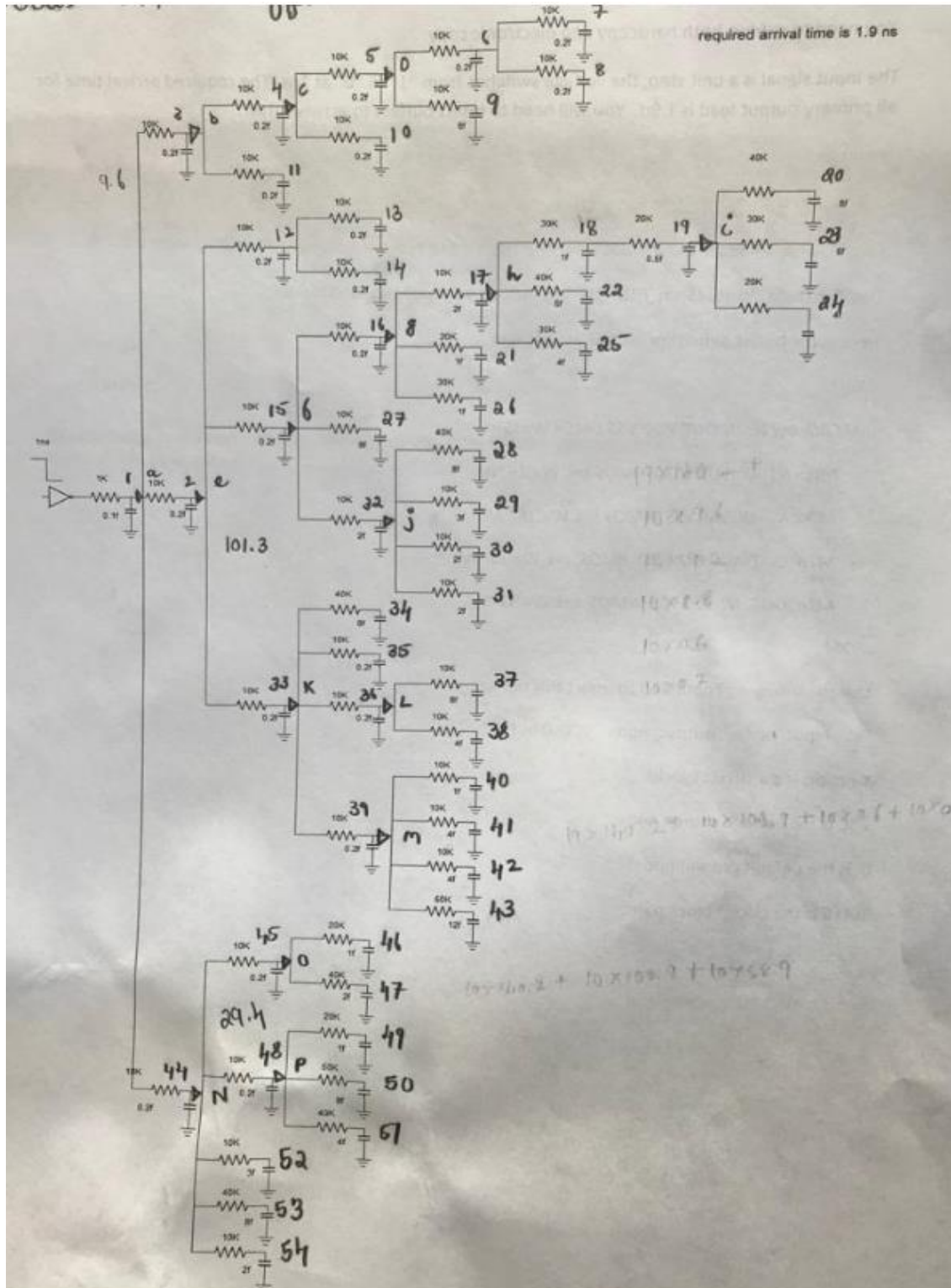
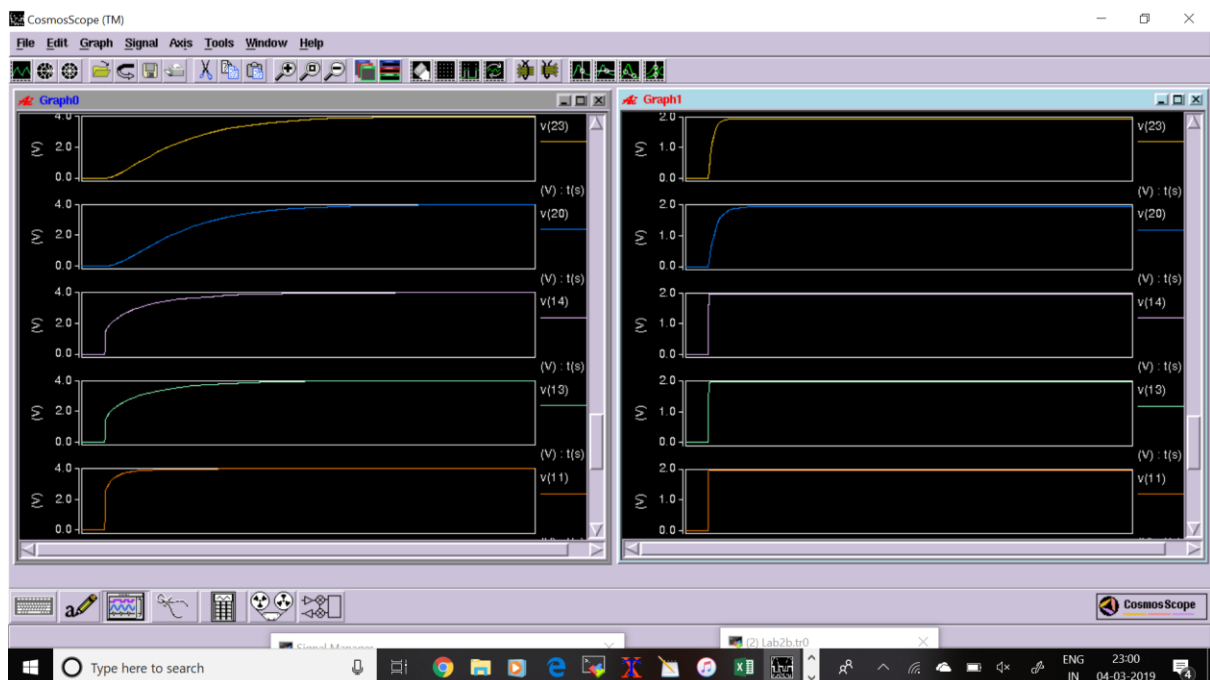
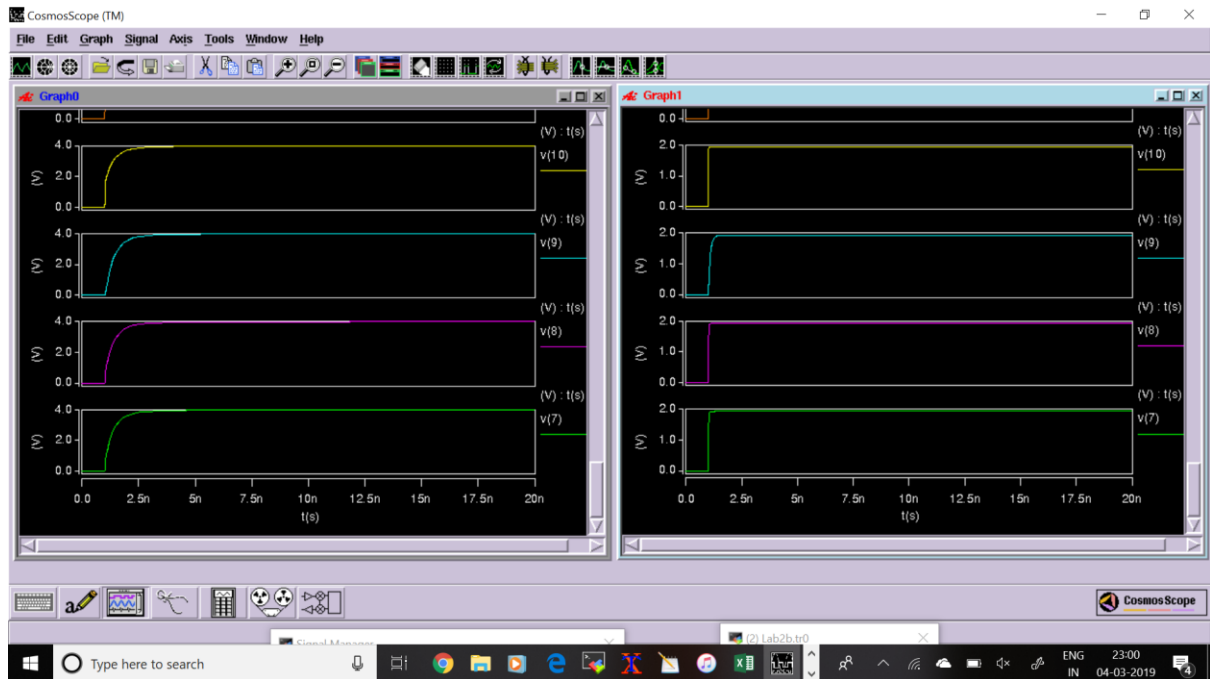


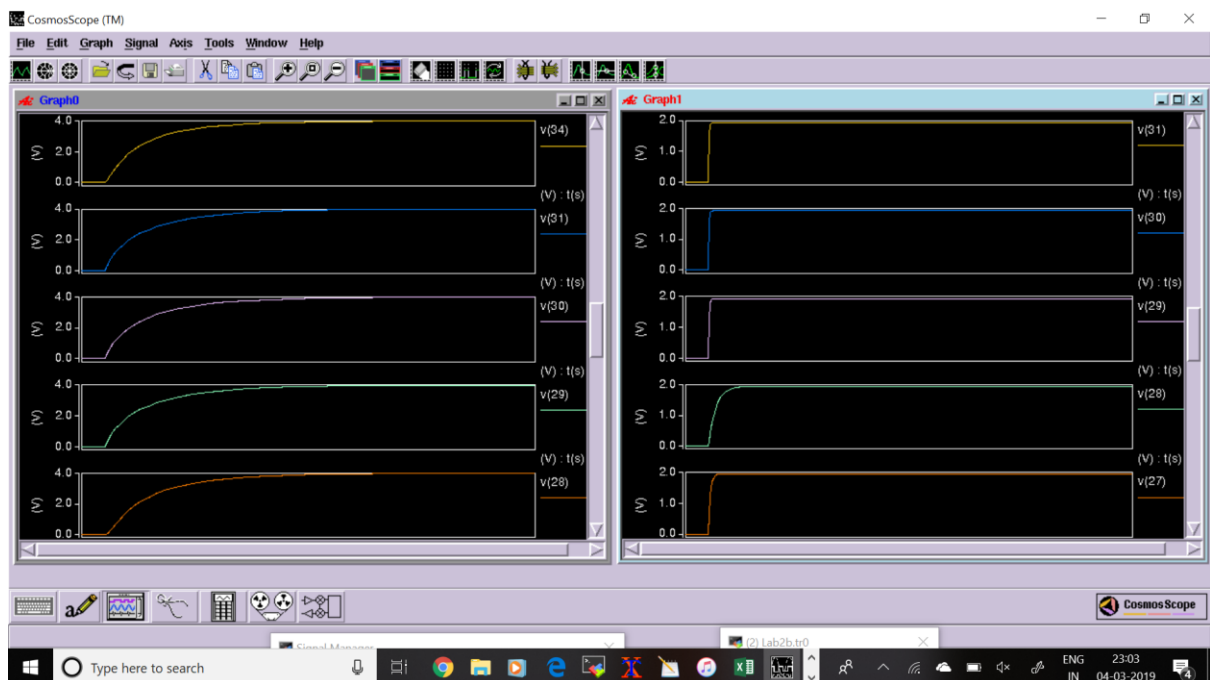
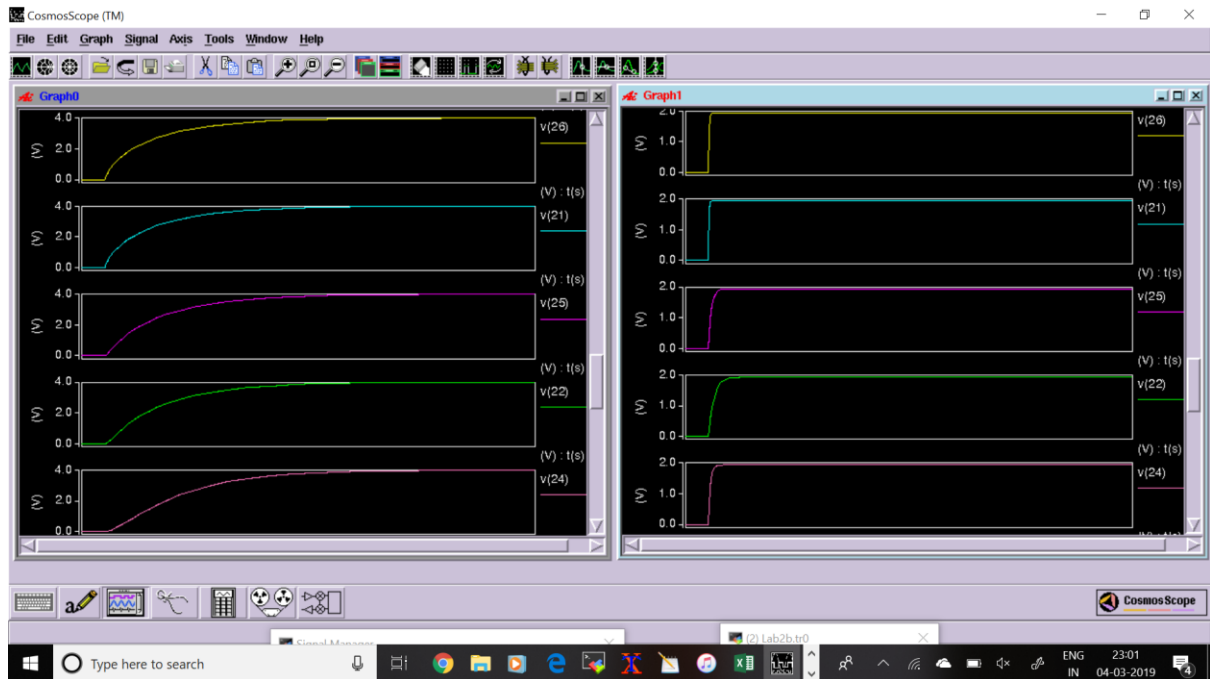
Figure 3

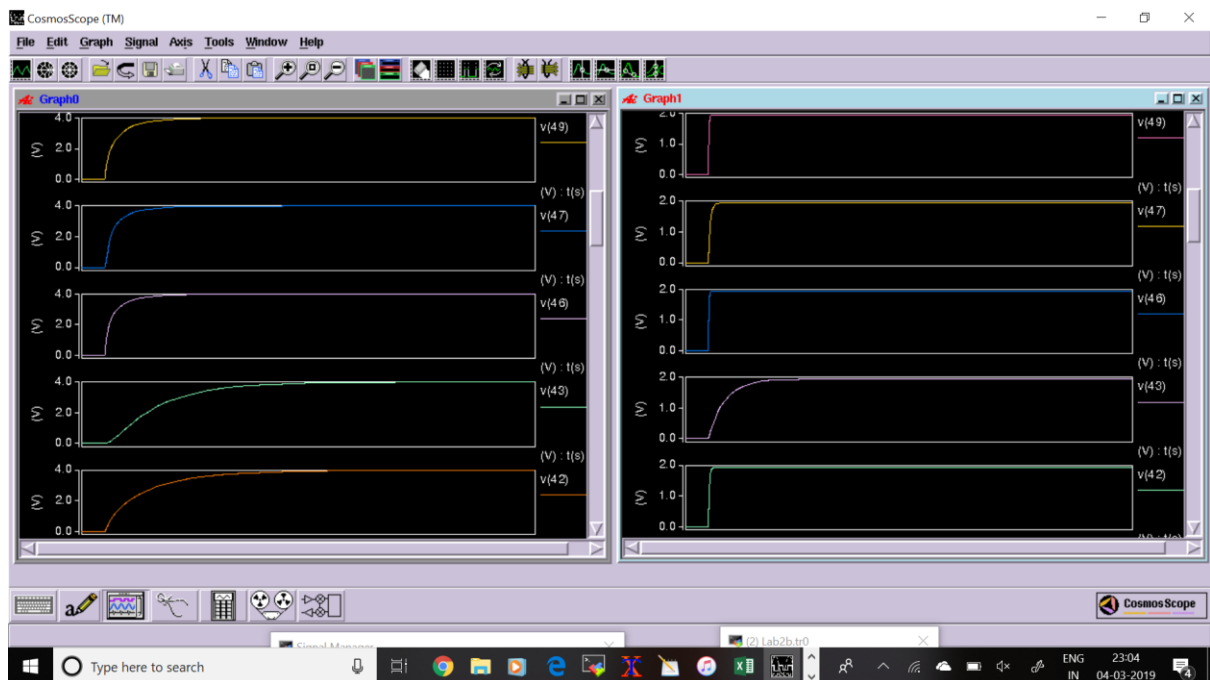
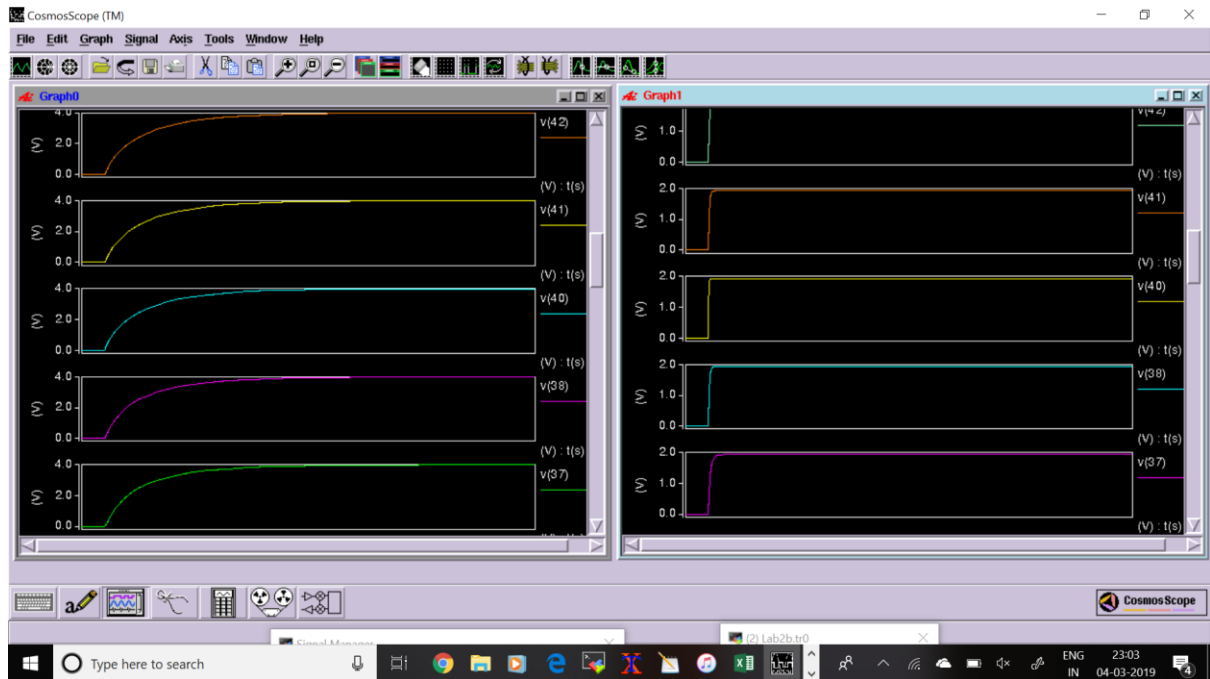
$$\begin{aligned}T_7 &= (39.9 + 22 + 22 + 22 + 6 + 2 + 80 + 3.3 + 1.2 + 1.2 + 4.2) * 10^{-12} = 0.203\text{ns} \\T_8 &= (39.9 + 22 + 22 + 22 + 6 + 2 + 80 + 3.3 + 1.2 + 1.2 + 4.2) * 10^{-12} = 0.203\text{ns} \\T_9 &= (39.9 + 22 + 22 + 22 + 8 + 80 + 3.3 + 1.2 + 1.2 + 4.2) * 10^{-12} = 0.203\text{ns} \\T_{10} &= (39.9 + 22 + 22 + 2 + 60 + 3.3 + 1.2 + 1.2) * 10^{-12} = 0.151\text{ns} \\T_{11} &= (39.9 + 22 + 2 + 40 + 3.3 + 1.2) * 10^{-12} = 0.108\text{ns} \\T_{13} &= (39.9 + 22 + 6 + 2 + 40 + 3.3 + 2.5) * 10^{-12} = 0.115\text{ns} \\T_{14} &= (39.9 + 22 + 6 + 2 + 40 + 3.3 + 2.5) * 10^{-12} = 0.115\text{ns} \\T_{20} &= (39.9 + 22 + 22 + 22 + 40 + 105 + 50 + 320 + 3.3 + 2.5 + 7.1 + 2 + 6.75 + 9) * 10^{-12} = 0.771\text{ns} \\T_{23} &= (39.9 + 22 + 22 + 22 + 40 + 105 + 50 + 180 + 3.3 + 2.5 + 7.1 + 2 + 6.75 + 9) * 10^{-12} = 0.631\text{ns} \\T_{24} &= (39.9 + 22 + 22 + 22 + 40 + 105 + 50 + 80 + 3.3 + 2.5 + 7.1 + 2 + 6.75 + 9) * 10^{-12} = 0.531\text{ns} \\T_{22} &= (39.9 + 22 + 22 + 22 + 40 + 240 + 3.3 + 2.5 + 7.1 + 2 + 6.75) * 10^{-12} = 0.507\text{ns} \\T_{25} &= (39.9 + 22 + 22 + 22 + 40 + 120 + 3.3 + 2.5 + 7.1 + 2 + 6.75) * 10^{-12} = 0.387\text{ns} \\T_{21} &= (39.9 + 22 + 22 + 22 + 20 + 3.3 + 2.5 + 7.1 + 2 + 120) * 10^{-12} = 0.220\text{ns} \\T_{26} &= (39.9 + 22 + 22 + 22 + 30 + 3.3 + 2.5 + 7.1 + 2 + 100) * 10^{-12} = 0.230\text{ns} \\T_{27} &= (39.9 + 22 + 22 + 80 + 3.3 + 2.5 + 7.1 + 100) * 10^{-12} = 0.236\text{ns} \\T_{28} &= (39.9 + 22 + 22 + 40 + 320 + 3.3 + 2.5 + 7.1 + 80) * 10^{-12} = 0.536\text{ns} \\T_{29} &= (39.9 + 22 + 22 + 40 + 30 + 3.3 + 2.5 + 7.1 + 80) * 10^{-12} = 0.246\text{ns} \\T_{30} &= (39.9 + 22 + 22 + 40 + 20 + 3.3 + 2.5 + 7.1 + 80) * 10^{-12} = 0.236\text{ns} \\T_{31} &= (39.9 + 22 + 22 + 40 + 20 + 3.3 + 2.5 + 7.1 + 80) * 10^{-12} = 0.236\text{ns} \\T_{34} &= (39.9 + 22 + 22 + 320 + 3.3 + 2.5 + 6.3 + 60) * 10^{-12} = 0.476\text{ns} \\T_{35} &= (39.9 + 22 + 22 + 2 + 3.3 + 2.5 + 6.3 + 80) * 10^{-12} = 0.158\text{ns} \\T_{37} &= (39.9 + 22 + 22 + 22 + 80 + 3.3 + 2.5 + 6.3 + 6 + 80) * 10^{-12} = 0.284\text{ns} \\T_{38} &= (39.9 + 22 + 22 + 22 + 40 + 3.3 + 2.5 + 6.3 + 6 + 80) * 10^{-12} = 0.244\text{ns} \\T_{40} &= (39.9 + 22 + 22 + 22 + 10 + 3.3 + 2.5 + 6.3 + 10.5 + 80) * 10^{-12} = 0.218\text{ns} \\T_{41} &= (39.9 + 22 + 22 + 22 + 40 + 3.3 + 2.5 + 6.3 + 10.5 + 80) * 10^{-12} = 0.248\text{ns} \\T_{42} &= (39.9 + 22 + 22 + 22 + 40 + 3.3 + 2.5 + 6.3 + 10.5 + 80) * 10^{-12} = 0.248\text{ns} \\T_{43} &= (39.9 + 22 + 22 + 22 + 720 + 3.3 + 2.5 + 6.3 + 10.5 + 80) * 10^{-12} = 0.928\text{ns} \\T_{46} &= (39.9 + 22 + 22 + 80 + 3.3 + 8.7 + 1.5 + 60) * 10^{-12} = 0.177\text{ns} \\T_{47} &= (39.9 + 22 + 22 + 20 + 3.3 + 8.7 + 6.5 + 60) * 10^{-12} = 0.237\text{ns} \\T_{49} &= (39.9 + 22 + 22 + 80 + 3.3 + 8.7 + 6.5 + 60) * 10^{-12} = 0.182\text{ns} \\T_{50} &= (39.9 + 22 + 22 + 400 + 3.3 + 8.7 + 6.5 + 60) * 10^{-12} = 0.562\text{ns} \\T_{51} &= (39.9 + 22 + 22 + 160 + 3.3 + 8.7 + 60) * 10^{-12} = 0.322\text{ns} \\T_{52} &= (39.9 + 22 + 30 + 3.3 + 8.7 + 40) * 10^{-12} = 0.143\text{ns} \\T_{53} &= (39.9 + 22 + 320 + 3.3 + 8.7 + 40) * 10^{-12} = 0.433\text{ns} \\T_{54} &= (39.9 + 22 + 20 + 3.3 + 8.7 + 40) * 10^{-12} = 0.133\text{ns}\end{aligned}$$

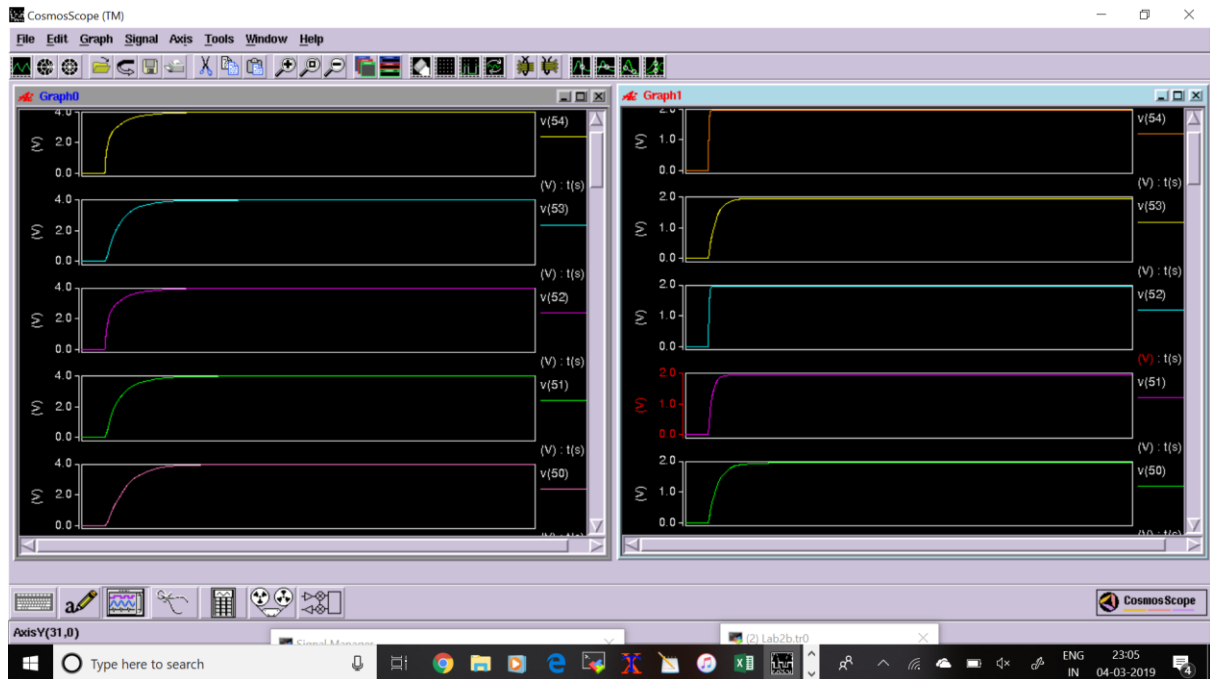
As we can see from the above values, when buffer gets inserted at the determined points, the Elmore delay drops down by a large value. The expected arrival can be achieved using the buffers at these positions determined.

Waveform: On the left is the one without buffer. On the right is the one with buffer.









The comparison clearly shows the reduction of delay. The buffer adds a small value to the delay, but in an overall view, brings down the delay by a large value. Hence adding buffers at the determined points in the design will help make the design more efficient.

APPENDIX

1. HSPICE Code for design without Buffer (The Nodes are taken with reference to figure 2 in the above report)

**This file will describe the HSPICE of Lab 2*

**HSPICE code for without buffer*

**Define the voltage source that is unit step function*

vs Vin gnd PWL(0 0V 1n 0V 1.01n 4V 10.01n 4V 20n 4v 50n 4v)

**Define the design*

.option post

**Defining R in the design*

R1 Vin 1 1K

R2 1 2 10k

R3 1 3 10k

R4 3 4 10k

R5 4 5 10k

R6 5 6 10k

R7 6 7 10k

R8 6 8 10k

R9 5 9 10k

R10 4 10 10k

R11 3 11 10k

R12 2 12 10k

R13 12 13 10k

R14 12 14 10k

R15 2 15 10k

R16 15 16 10k

R17 16 17 10k

R18 17 18 30k

R19 18 19 20k

R20 19 20 40k

R21 16 21 20k

R22 17 22 40k

R23 19 23 30k

R24 19 24 20k

R25 17 25 30k

R26 16 26 30k

R27 15 27 10k

R28 32 28 40k

R29 32 29 10k

R30 32 30 10k

R31 32 31 10k

R32 15 32 10k

R33 2 33 10k
R34 33 34 40k
R35 33 35 10k
R36 33 36 10k
R37 36 37 10k
R38 36 38 10k
R39 33 39 10k
R40 39 40 10k
R41 39 41 10k
R42 39 42 10k
R43 39 43 60k
R44 1 44 10k
R45 44 45 10k
R46 45 46 20k
R47 45 47 40k
R48 44 48 10k
R49 48 49 20k
R50 48 50 50k
R51 48 51 40k
R52 44 52 10k
R53 44 53 40k
R54 44 54 10k

**Defining C in the design*

C1 1 gnd 0.1fF
C2 2 gnd 0.2fF
C3 3 gnd 0.2fF
C4 4 gnd 0.2fF
C5 5 gnd 0.2fF
C6 6 gnd 0.2fF
C7 7 gnd 0.2fF
C8 8 gnd 0.2fF
C9 9 gnd 8fF
C10 10 gnd 0.2fF
C11 11 gnd 0.2fF
C12 12 gnd 0.2fF
C13 13 gnd 0.2fF
C14 14 gnd 0.2fF
C15 15 gnd 0.2fF
C16 16 gnd 0.2fF
C17 17 gnd 2fF
C18 18 gnd 1fF
C19 19 gnd 0.5fF
C20 20 gnd 8fF
C21 21 gnd 1fF
C22 22 gnd 6fF
C23 23 gnd 6fF

C24 24 gnd 4fF
C25 25 gnd 4fF
C26 26 gnd 1fF
C27 27 gnd 8fF
C28 28 gnd 8fF
C29 29 gnd 3fF
C30 30 gnd 2fF
C31 31 gnd 2fF
C32 32 gnd 2fF
C33 33 gnd 0.2fF
C34 34 gnd 8fF
C35 35 gnd 0.2fF
C36 36 gnd 0.2fF
C37 37 gnd 8fF
C38 38 gnd 4fF
C39 39 gnd 0.2fF
C40 40 gnd 1fF
C41 41 gnd 4fF
C42 42 gnd 4fF
C43 43 gnd 12fF
C44 44 gnd 0.2fF
C45 45 gnd 0.2fF
C46 46 gnd 1fF
C47 47 gnd 2fF
C48 48 gnd 0.2fF
C49 49 gnd 1fF
C50 50 gnd 8fF
C51 51 gnd 4fF
C52 52 gnd 3fF
C53 53 gnd 8fF
C54 54 gnd 2fF

.tran 0.01n 20n
.print tran V(vs) V(7)
.print tran V(vs) V(8)
.print tran V(vs) V(9)
.print tran V(vs) V(10)
.print tran V(vs) V(11)
.print tran V(vs) V(13)
.print tran V(vs) V(14)
.print tran V(vs) V(20)
.print tran V(vs) V(23)
.print tran V(vs) V(24)
.print tran V(vs) V(22)
.print tran V(vs) V(25)
.print tran V(vs) V(21)
.print tran V(vs) V(26)

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.print tran V(vs) V(27)
.print tran V(vs) V(28)
.print tran V(vs) V(29)
.print tran V(vs) V(30)
.print tran V(vs) V(31)
.print tran V(vs) V(34)
.print tran V(vs) V(35)
.print tran V(vs) V(37)
.print tran V(vs) V(38)
.print tran V(vs) V(40)
.print tran V(vs) V(41)
.print tran V(vs) V(42)
.print tran V(vs) V(43)
.print tran V(vs) V(46)
.print tran V(vs) V(47)
.print tran V(vs) V(49)
.print tran V(vs) V(50)
.print tran V(vs) V(51)
.print tran V(vs) V(52)
.print tran V(vs) V(53)
.print tran V(vs) V(54)
.option post
```

```
.end
```

2. HSPICE Code for design with Buffer (The Nodes are taken with reference to figure 2 in the above report)

```
*This file will describe the HSPICE of Lab 2
*HSPICE code for without buffer
.include ./cmos45nm_PTM_HP
*Define the voltage source that is unit step function
vs Vin gnd PWL(0 0V 1n 0V 1.01n 4V 10.01n 4V 20n 4v 50n 4v)

*BUFFER Macro
.MACRO buf16 IN OUT VDD VSS L=45n W=45n
M0p N1 IN VDD VDD PMOS L=L W='16*W'
M0n N1 IN VSS VSS NMOS L=L W='16*W'
M1p OUT N1 VDD VDD PMOS L=L W='32*W'
M1n OUT N1 VSS VSS NMOS L=L W='32*W'

.EOM

*Define the design
.option post
```

**Defining R in the design*

R1 Vin 1 1K

R2 a 2 10k

R3 a 3 10k

R4 b 4 10k

R5 c 5 10k

R6 d 6 10k

R7 6 7 10k

R8 6 8 10k

R9 d 9 10k

R10 c 10 10k

R11 b 11 10k

R12 e 12 10k

R13 12 13 10k

R14 12 14 10k

R15 e 15 10k

R16 f 16 10k

R17 g 17 10k

R18 h 18 30k

R19 18 19 20k

R20 i 20 40k

R21 g 21 20k

R22 h 22 40k

R23 i 23 30k

R24 i 24 20k

R25 h 25 30k

R26 g 26 30k

R27 f 27 10k

R28 j 28 40k

R29 j 29 10k

R30 j 30 10k

R31 j 31 10k

R32 f 32 10k

R33 e 33 10k

R34 k 34 40k

R35 k 35 10k

R36 k 36 10k

R37 l 37 10k

R38 l 38 10k

R39 k 39 10k

R40 m 40 10k

R41 m 41 10k
R42 m 42 10k
R43 m 43 60k
R44 a 44 10k
R45 n 45 10k
R46 o 46 20k
R47 o 47 40k
R48 n 48 10k
R49 p 49 20k
R50 p 50 50k
R51 p 51 40k
R52 n 52 10k
R53 n 53 40k
R54 n 54 10k

**Defining C in the design*

C1 1 gnd 0.1fF
C2 2 gnd 0.2fF
C3 3 gnd 0.2fF
C4 4 gnd 0.2fF
C5 5 gnd 0.2fF
C6 6 gnd 0.2fF
C7 7 gnd 0.2fF
C8 8 gnd 0.2fF
C9 9 gnd 8fF
C10 10 gnd 0.2fF
C11 11 gnd 0.2fF
C12 12 gnd 0.2fF
C13 13 gnd 0.2fF
C14 14 gnd 0.2fF
C15 15 gnd 0.2fF
C16 16 gnd 0.2fF
C17 17 gnd 2fF
C18 18 gnd 1fF
C19 19 gnd 0.5fF
C20 20 gnd 8fF
C21 21 gnd 1fF
C22 22 gnd 6fF
C23 23 gnd 6fF
C24 24 gnd 4fF
C25 25 gnd 4fF
C26 26 gnd 1fF
C27 27 gnd 8fF

C28 28 gnd 8fF
C29 29 gnd 3fF
C30 30 gnd 2fF
C31 31 gnd 2fF
C32 32 gnd 2fF
C33 33 gnd 0.2fF
C34 34 gnd 8fF
C35 35 gnd 0.2fF
C36 36 gnd 0.2fF
C37 37 gnd 8fF
C38 38 gnd 4fF
C39 39 gnd 0.2fF
C40 40 gnd 1fF
C41 41 gnd 4fF
C42 42 gnd 4fF
C43 43 gnd 12fF
C44 44 gnd 0.2fF
C45 45 gnd 0.2fF
C46 46 gnd 1fF
C47 47 gnd 2fF
C48 48 gnd 0.2fF
C49 49 gnd 1fF
C50 50 gnd 8fF
C51 51 gnd 4fF
C52 52 gnd 3fF
C53 53 gnd 8fF
C54 54 gnd 2fF

**Buffer insertion*

X1 1 a Vin gnd buf16
X2 3 b Vin gnd buf16
X3 4 c Vin gnd buf16
X4 5 d Vin gnd buf16
X5 2 e Vin gnd buf16
X6 15 f Vin gnd buf16
X7 16 g Vin gnd buf16
X8 17 h Vin gnd buf16
X9 19 i Vin gnd buf16
X10 32 j Vin gnd buf16
X11 33 k Vin gnd buf16
X12 36 l Vin gnd buf16
X13 39 m Vin gnd buf16
X14 44 n Vin gnd buf16

X15 45 o Vin gnd buf16

X16 48 p Vin gnd buf16

**Perform the analysis*

.tran 0.01n 20n

.print tran V(vs) V(7)

.print tran V(vs) V(8)

.print tran V(vs) V(9)

.print tran V(vs) V(10)

.print tran V(vs) V(11)

.print tran V(vs) V(13)

.print tran V(vs) V(14)

.print tran V(vs) V(20)

.print tran V(vs) V(23)

.print tran V(vs) V(24)

.print tran V(vs) V(22)

.print tran V(vs) V(25)

.print tran V(vs) V(21)

.print tran V(vs) V(26)

.print tran V(vs) V(27)

.print tran V(vs) V(28)

.print tran V(vs) V(29)

.print tran V(vs) V(30)

.print tran V(vs) V(31)

.print tran V(vs) V(34)

.print tran V(vs) V(35)

.print tran V(vs) V(37)

.print tran V(vs) V(38)

.print tran V(vs) V(40)

.print tran V(vs) V(41)

.print tran V(vs) V(42)

.print tran V(vs) V(43)

.print tran V(vs) V(46)

.print tran V(vs) V(47)

.print tran V(vs) V(49)

.print tran V(vs) V(50)

.print tran V(vs) V(51)

.print tran V(vs) V(52)

.print tran V(vs) V(53)

.print tran V(vs) V(54)

.option post

.end

[illegible]

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T151

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| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AE |
|----|----|---|-----|-----|---|---|------|---|----|---|------|-------|-----------|---|---|---|---|---|---|---|---|---|---|---|---|---|----|----|
| 32 | 30 | 1 | 1.9 | 30' | | 1 | 1.88 | | i | | 6 | 1.329 | | | | | | | | | | | | | | | | |
| 33 | 31 | 8 | 1.9 | 31' | | 8 | 1.5 | | | | 2 | 1.306 | | | | | | | | | | | | | | | | |
| 34 | 32 | 4 | 1.9 | 32' | | 4 | 1.74 | | n' | | 6.2 | 1.587 | Redundant | | | | | | | | | | | | | | | |
| 35 | 33 | 3 | 1.9 | 33' | | 3 | 1.87 | | | | 2.2 | 1.284 | | | | | | | | | | | | | | | | |
| 36 | 34 | 8 | 1.9 | 34' | | 8 | 1.58 | | i | | 15 | 1.58 | | | | | | | | | | | | | | | | |
| 37 | 35 | 2 | 1.9 | 35' | | 2 | 1.88 | | | | 2 | 1.553 | | | | | | | | | | | | | | | | |
| 38 | | | | | | | | | f' | | 17 | 1.41 | Redundant | | | | | | | | | | | | | | | |
| 39 | | | | | | | | | | | 2.2 | 1.311 | | | | | | | | | | | | | | | | |
| 40 | | | | | | | | | n | | 12.4 | 1.284 | | | | | | | | | | | | | | | | |
| 41 | | | | | | | | | | | 2 | 1.258 | | | | | | | | | | | | | | | | |
| 42 | | | | | | | | | n' | | 12.8 | 1.158 | Redundant | | | | | | | | | | | | | | | |
| 43 | | | | | | | | | | | 2.2 | 1.236 | | | | | | | | | | | | | | | | |
| 44 | | | | | | | | | j | | 12 | 1.82 | | | | | | | | | | | | | | | | |
| 45 | | | | | | | | | | | 2 | 1.794 | | | | | | | | | | | | | | | | |
| 46 | | | | | | | | | f' | | 12.2 | 1.698 | Redundant | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | k | | 2.2 | 1.772 | | | | | | | | | | | | | | | | |
| 48 | | | | | | | | | | | 21 | 1.18 | | | | | | | | | | | | | | | | |
| 49 | | | | | | | | | | | 2 | 1.15 | | | | | | | | | | | | | | | | |
| 50 | | | | | | | | | k' | | 21.2 | 0.988 | | | | | | | | | | | | | | | | |
| 51 | | | | | | | | | | | 2.2 | 1.128 | | | | | | | | | | | | | | | | |
| 52 | | | | | | | | | o | | 12.6 | 1.128 | | | | | | | | | | | | | | | | |
| 53 | n' | | | | | | | | | | 2 | 1.102 | | | | | | | | | | | | | | | | |
| 54 | | | | | | | | | o' | | 12.8 | 1 | Redundant | | | | | | | | | | | | | | | |
| 55 | | | | | | | | | | | 2.2 | 1.08 | | | | | | | | | | | | | | | | |
| 56 | | | | | | | | | p | | 5 | 1.08 | | | | | | | | | | | | | | | | |
| 57 | | | | | | | | | | | 2 | 1.058 | | | | | | | | | | | | | | | | |
| 58 | | | | | | | | | p' | | 5.2 | 1.028 | Redundant | | | | | | | | | | | | | | | |
| 59 | | | | | | | | | | | 2.2 | 1.006 | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | i | | 3 | 1.82 | | | | | | | | | | | | | | | | |
| 61 | | | | | | | | | | | 2 | 1.799 | | | | | | | | | | | | | | | | |
| 62 | | | | | | | | | f' | | 3.2 | 1.788 | | | | | | | | | | | | | | | | |
| 63 | | | | | | | | | | | 3.3 | 1.772 | | | | | | | | | | | | | | | | |

Sheet1Sheet2

70%

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| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB |
|----|--------|--------|-------------|---------|--------|-----|-----|-----|-----|----|------|-------|-----------|---|---|---|---|---|---|---|---|---|---|---|---|---|----|----|
| 62 | | | | | | | | | | f | 3.2 | 1.788 | | | | | | | | | | | | | | | | |
| 63 | | | | | | | | | | m | 2.2 | 1.777 | | | | | | | | | | | | | | | | |
| 64 | | | | | | | | | | m' | 2 | 1.473 | Redundant | | | | | | | | | | | | | | | |
| 65 | | | | | | | | | | q | 17.4 | 1.451 | | | | | | | | | | | | | | | | |
| 66 | | | | | | | | | | q' | 2 | 1.422 | Redundant | | | | | | | | | | | | | | | |
| 67 | | | | | | | | | | s | 6.6 | 1.006 | | | | | | | | | | | | | | | | |
| 68 | | | | | | | | | | s' | 2 | 0.983 | | | | | | | | | | | | | | | | |
| 69 | | | | | | | | | | | 6.7 | 0.993 | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | 2.1 | 0.98 | | | | | | | | | | | | | | | | |
| 71 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 74 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 76 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 77 | Elmore | Delay | Calculation | without | buffer | | | | | | | | Time(ps) | | | | | | | | | | | | | | | |
| 78 | Node | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 79 | 1 | 2663.8 | 96 | 92 | 88 | 6 | 2 | | | | | | 2947.8 | | | | | | | | | | | | | | | |
| 80 | 2 | 2663.8 | 96 | 92 | 88 | 6 | 2 | | | | | | 2947.8 | | | | | | | | | | | | | | | |
| 81 | 3 | 2663.8 | 96 | 92 | 88 | 80 | | | | | | | 3019.8 | | | | | | | | | | | | | | | |
| 82 | 4 | 2663.8 | 96 | 92 | 2 | | | | | | | | 2853.8 | | | | | | | | | | | | | | | |
| 83 | 5 | 2663.8 | 96 | 2 | | | | | | | | | 2761.8 | | | | | | | | | | | | | | | |
| 84 | 6 | 2663.8 | 1009 | 6 | 2 | | | | | | | | 3680.8 | | | | | | | | | | | | | | | |
| 85 | 7 | 2663.8 | 1009 | 6 | 2 | | | | | | | | 3680.8 | | | | | | | | | | | | | | | |
| 86 | 8 | 2663.8 | 1009 | 589 | 337 | 315 | 585 | 370 | 320 | | | | 6188.8 | | | | | | | | | | | | | | | |
| 87 | 9 | 2663.8 | 1009 | 589 | 337 | 315 | 585 | 370 | 180 | | | | 6048.8 | | | | | | | | | | | | | | | |
| 88 | 10 | 2663.8 | 1009 | 589 | 337 | 315 | 585 | 370 | 80 | | | | 5948.8 | | | | | | | | | | | | | | | |
| 89 | 11 | 2663.8 | 1009 | 589 | 337 | 315 | 585 | | | | | | 5159.8 | | | | | | | | | | | | | | | |
| 90 | 12 | 2663.8 | 1009 | 589 | 337 | 315 | 120 | | | | | | 4933.8 | | | | | | | | | | | | | | | |
| 91 | 13 | 2663.8 | 1009 | 589 | 337 | 20 | | | | | | | 4618.8 | | | | | | | | | | | | | | | |
| 92 | 14 | 2663.8 | 1009 | 589 | 337 | 30 | | | | | | | 4628.8 | | | | | | | | | | | | | | | |
| 93 | 15 | 2663.8 | 1009 | 589 | 337 | 30 | | | | | | | 4241.8 | | | | | | | | | | | | | | | |

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| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB |
|-----|--------|--------|-------------|------|--------|-----|----|-----|----|-----|---|---|--------------|-------------------|-----|-----|-----|------|---|---|---|---|---|---|---|---|----|----|
| 93 | 15 | 2663.8 | 1009 | 589 | 80 | | | | | | | | 4341.8 | | | | | | | | | | | | | | | |
| 94 | 16 | 2663.8 | 1009 | 589 | 170 | 320 | | | | | | | 4751.8 | | | | | | | | | | | | | | | |
| 95 | 17 | 2663.8 | 1009 | 589 | 170 | 30 | | | | | | | 4461.8 | | | | | | | | | | | | | | | |
| 96 | 18 | 2663.8 | 1009 | 589 | 170 | 20 | | | | | | | 4451.8 | | | | | | | | | | | | | | | |
| 97 | 19 | 2663.8 | 1009 | 589 | 170 | 20 | | | | | | | 4451.8 | | | | | | | | | | | | | | | |
| 98 | 20 | 2663.8 | 1009 | 418 | 320 | | | | | | | | 4410.8 | | | | | | | | | | | | | | | |
| 99 | 21 | 2663.8 | 1009 | 418 | 2 | | | | | | | | 4092.8 | | | | | | | | | | | | | | | |
| 100 | 22 | 2663.8 | 1009 | 418 | 122 | 80 | | | | | | | 4292.8 | | | | | | | | | | | | | | | |
| 101 | 23 | 2663.8 | 1009 | 418 | 122 | 40 | | | | | | | 4252.8 | | | | | | | | | | | | | | | |
| 102 | 24 | 2663.8 | 1009 | 418 | 212 | 10 | | | | | | | 4312.8 | | | | | | | | | | | | | | | |
| 103 | 25 | 2663.8 | 1009 | 418 | 212 | 40 | | | | | | | 4342.8 | | | | | | | | | | | | | | | |
| 104 | 26 | 2663.8 | 1009 | 418 | 212 | 40 | | | | | | | 4342.8 | | | | | | | | | | | | | | | |
| 105 | 27 | 2663.8 | 1009 | 418 | 212 | 720 | | | | | | | 5022.8 | | | | | | | | | | | | | | | |
| 106 | 28 | 2663.8 | 296 | 320 | 20 | | | | | | | | 3299.8 | | | | | | | | | | | | | | | |
| 107 | 29 | 2663.8 | 296 | 320 | 80 | | | | | | | | 3359.8 | | | | | | | | | | | | | | | |
| 108 | 30 | 2663.8 | 296 | 132 | 20 | | | | | | | | 3111.8 | | | | | | | | | | | | | | | |
| 109 | 31 | 2663.8 | 296 | 132 | 400 | | | | | | | | 3491.8 | | | | | | | | | | | | | | | |
| 110 | 32 | 2663.8 | 296 | 132 | 160 | | | | | | | | 3251.8 | | | | | | | | | | | | | | | |
| 111 | 33 | 2663.8 | 296 | 30 | | | | | | | | | 2989.8 | | | | | | | | | | | | | | | |
| 112 | 34 | 2663.8 | 296 | 320 | | | | | | | | | 3279.8 | | | | | | | | | | | | | | | |
| 113 | 35 | 2663.8 | 296 | 20 | | | | | | | | | 2979.8 | | | | | | | | | | | | | | | |
| 114 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 115 | Elmore | Delay | Calculation | with | buffer | | | | | | | | Buffer Delay | Buffer path delay | | | | | | | | | | | | | | |
| 116 | Node | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 117 | 1 | 39.9 | 22 | 22 | 22 | 6 | 2 | | | | | | 80 | 3.3 | 1.2 | 1.2 | 4.2 | | | | | | | | | | | |
| 118 | 2 | 39.9 | 22 | 22 | 22 | 6 | 2 | | | | | | 80 | 3.3 | 1.2 | 1.2 | 4.2 | | | | | | | | | | | |
| 119 | 3 | 39.9 | 22 | 22 | 22 | 8 | | | | | | | 80 | 3.3 | 1.2 | 1.2 | 4.2 | | | | | | | | | | | |
| 120 | 4 | 39.9 | 22 | 22 | 2 | | | | | | | | 60 | 3.3 | 1.2 | 1.2 | | | | | | | | | | | | |
| 121 | 5 | 39.9 | 22 | 2 | | | | | | | | | 40 | 3.3 | 1.2 | | | | | | | | | | | | | |
| 122 | 6 | 39.9 | 22 | 6 | 2 | | | | | | | | 40 | 3.3 | 2.5 | | | | | | | | | | | | | |
| 123 | 7 | 39.9 | 22 | 6 | 2 | | | | | | | | 40 | 3.3 | 2.5 | | | | | | | | | | | | | |
| 124 | 8 | 39.9 | 22 | 72 | 72 | 72 | 60 | 108 | 50 | 320 | | | 120 | 3.3 | 2.5 | 3.1 | 3 | 6.75 | 8 | | | | | | | | | |

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| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB |
|-----|----|------|----|-----|-----|-----|-----|----|-----|---|-----|---|-----|-----|-----|------|------|---|---|--------|---|---|---|---|---|---|----|----|
| 123 | 7 | 39.9 | 22 | 6 | 2 | | | | | | 40 | | 3.3 | 2.5 | | | | | | 115.7 | | | | | | | | |
| 124 | 8 | 39.9 | 22 | 22 | 22 | 40 | 105 | 50 | 320 | | 120 | | 3.3 | 2.5 | 7.1 | 2 | 6.75 | 9 | | 771.55 | | | | | | | | |
| 125 | 9 | 39.9 | 22 | 22 | 22 | 40 | 105 | 50 | 180 | | 120 | | 3.3 | 2.5 | 7.1 | 2 | 6.75 | 9 | | 631.55 | | | | | | | | |
| 126 | 10 | 39.9 | 22 | 22 | 22 | 40 | 105 | 50 | 80 | | 120 | | 3.3 | 2.5 | 7.1 | 2 | 6.75 | 9 | | 531.55 | | | | | | | | |
| 127 | 11 | 39.9 | 22 | 22 | 22 | 40 | 240 | | | | 100 | | 3.3 | 2.5 | 7.1 | 2 | 6.75 | | | 507.55 | | | | | | | | |
| 128 | 12 | 39.9 | 22 | 22 | 22 | 40 | 120 | | | | 100 | | 3.3 | 2.5 | 7.1 | 2 | 6.75 | | | 507.55 | | | | | | | | |
| 129 | 13 | 39.9 | 22 | 22 | 22 | 20 | | | | | 80 | | 3.3 | 2.5 | 7.1 | 2 | | | | 220.8 | | | | | | | | |
| 130 | 14 | 39.9 | 22 | 22 | 22 | 30 | | | | | 80 | | 3.3 | 2.5 | 7.1 | 2 | | | | 230.8 | | | | | | | | |
| 131 | 15 | 39.9 | 22 | 22 | 22 | 80 | | | | | 60 | | 3.3 | 2.5 | 7.1 | | | | | 236.8 | | | | | | | | |
| 132 | 16 | 39.9 | 22 | 22 | 40 | 320 | | | | | 80 | | 3.3 | 2.5 | 7.1 | | | | | 536.8 | | | | | | | | |
| 133 | 17 | 39.9 | 22 | 22 | 40 | 30 | | | | | 80 | | 3.3 | 2.5 | 7.1 | | | | | 246.8 | | | | | | | | |
| 134 | 18 | 39.9 | 22 | 22 | 40 | 20 | | | | | 80 | | 3.3 | 2.5 | 7.1 | | | | | 236.8 | | | | | | | | |
| 135 | 19 | 39.9 | 22 | 22 | 40 | 20 | | | | | 80 | | 3.3 | 2.5 | 7.1 | | | | | 236.8 | | | | | | | | |
| 136 | 20 | 39.9 | 22 | 22 | 320 | | | | | | 60 | | 3.3 | 2.5 | 6.3 | | | | | 476 | | | | | | | | |
| 137 | 21 | 39.9 | 22 | 22 | 2 | | | | | | 60 | | 3.3 | 2.5 | 6.3 | | | | | 156 | | | | | | | | |
| 138 | 22 | 39.9 | 22 | 22 | 22 | 80 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 6 | | | | 284 | | | | | | | | |
| 139 | 23 | 39.9 | 22 | 22 | 22 | 40 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 6 | | | | 244 | | | | | | | | |
| 140 | 24 | 39.9 | 22 | 22 | 22 | 10 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 10.5 | | | | 218.5 | | | | | | | | |
| 141 | 25 | 39.9 | 22 | 22 | 22 | 40 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 10.5 | | | | 248.5 | | | | | | | | |
| 142 | 26 | 39.9 | 22 | 22 | 22 | 40 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 10.5 | | | | 248.5 | | | | | | | | |
| 143 | 27 | 39.9 | 22 | 22 | 22 | 720 | | | | | 80 | | 3.3 | 2.5 | 6.3 | 10.5 | | | | 928.5 | | | | | | | | |
| 144 | 28 | 39.9 | 22 | 22 | 20 | | | | | | 60 | | 3.3 | 8.7 | 1.5 | | | | | 177.4 | | | | | | | | |
| 145 | 29 | 39.9 | 22 | 22 | 80 | | | | | | 60 | | 3.3 | 8.7 | 1.5 | | | | | 237.4 | | | | | | | | |
| 146 | 30 | 39.9 | 22 | 22 | 20 | | | | | | 60 | | 3.3 | 8.7 | 6.5 | | | | | 192.4 | | | | | | | | |
| 147 | 31 | 39.9 | 22 | 22 | 400 | | | | | | 60 | | 3.3 | 8.7 | 6.5 | | | | | 562.4 | | | | | | | | |
| 148 | 32 | 39.9 | 22 | 22 | 160 | | | | | | 60 | | 3.3 | 8.7 | 6.5 | | | | | 322.4 | | | | | | | | |
| 149 | 33 | 39.9 | 22 | 22 | 30 | | | | | | 40 | | 3.3 | 8.7 | | | | | | 143.9 | | | | | | | | |
| 150 | 34 | 39.9 | 22 | 320 | | | | | | | 40 | | 3.3 | 8.7 | | | | | | 433.9 | | | | | | | | |
| 151 | 35 | 39.9 | 22 | 20 | | | | | | | 40 | | 3.3 | 8.7 | | | | | | 335.9 | | | | | | | | |

Sheet1Sheet2

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