Digital IC Design

EE5311

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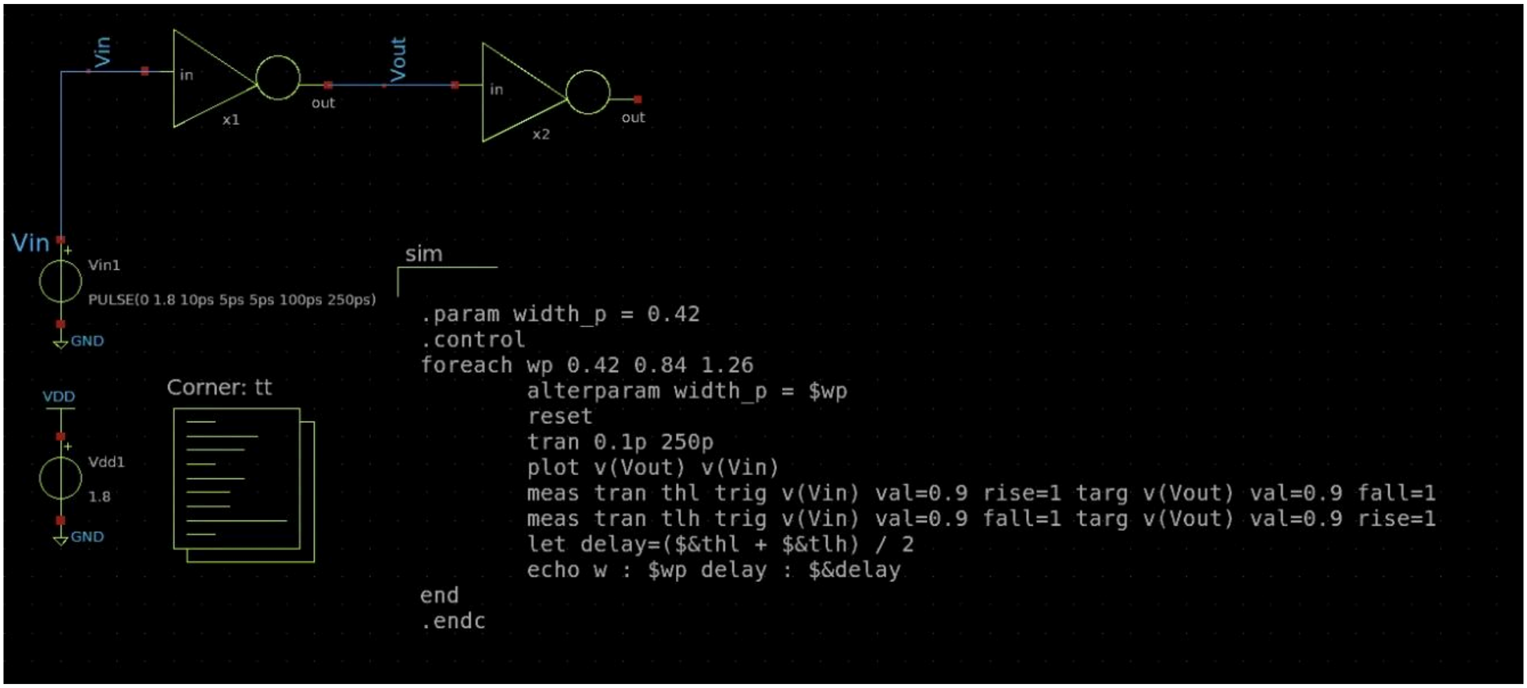
EE22B045

Tutorial - 3

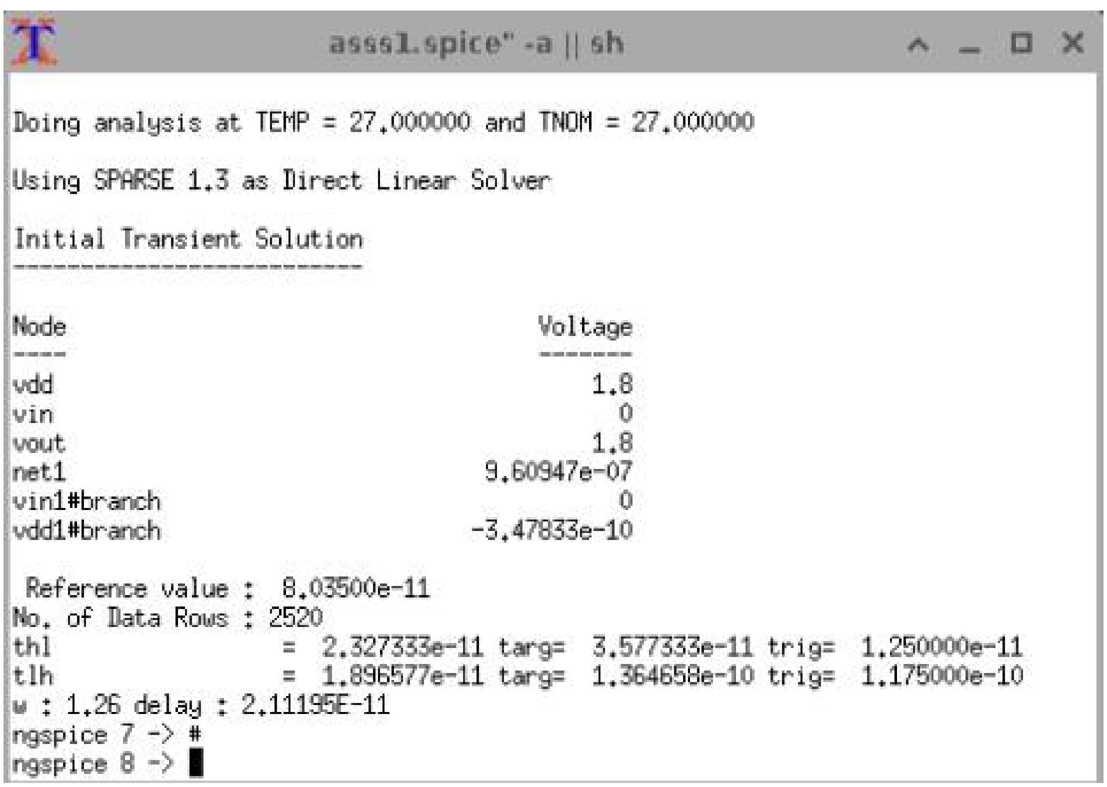
Report

Experiment - 1

Schematic for (A),(B):



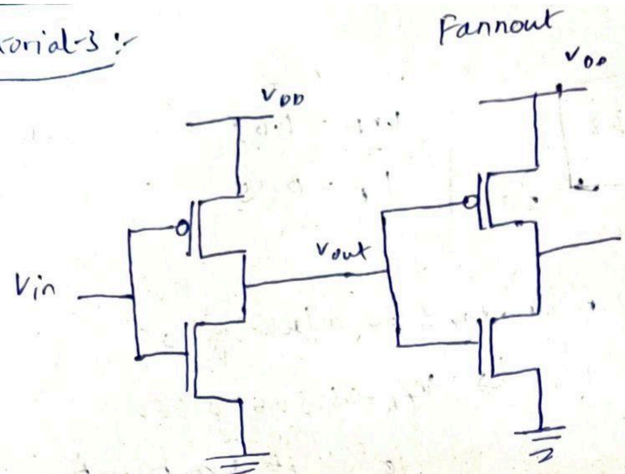
NgSpice response



Calculation:

Tutorial-3 :-

① a)



$V_{DD} = 1.8$; $L_n = L_p = 0.15\,\mu m$ $\quad W_n = 0.42\,\mu m$

$$t_{PLH} = \frac{C_{total}\, V_{DD}/2 \left(E_{CP} L_P + V_{DD} - |V_{TP}| \right)}{k_P (W/L)_P\, E_{CP} L_P \left(V_{DD} - |V_{TP}| \right)^2}$$

$$t_{PHL} = \frac{C_{total}\, V_{DD}/2 \left(E_{Cn} L_n + V_{DD} - |V_{Tn}| \right)}{k_n (W/L)_n\, E_{Cn} L_n \left(V_{DD} - V_{Tn} \right)^2}$$

$$C_{total} = C_{oxn} W_n L_n + C_{oxp} W_p L_p + C_j W_n L_{diff} + C_j W_p L_{diff}$$
$$+ C_{jsw} (W_p + 2L_{diff}) + C_{jsw} (W_n + 2L_{diff})$$
$$+ 2C_{gdop} W_p + 2C_{gdon} W_n$$

$$\approx C_{oxn} W_n L_n + C_{oxp} W_p L_p \approx (0.00834)(0.42 \times 10^{-6})(0.15 \times 10^{-6})$$
$$+ (0.00816)(W_p \times 10^{-6})(0.15 \times 10^{-6})$$

$$C_{total} \approx (W_p + 0.42)(0.08834 \times 10^{-12} \times 0.15 + 0.00816 \times 0.15 \times 10^{-12})$$

$$C_{total} \approx (W_p + 0.42)(2.475) \times 10^{-15}$$

$$t_p = \frac{t_{PLH} + t_{PHL}}{2}$$

$$t_{PLH} = \frac{C_{total}\,(0.9)(3.1275 \times 10^{-6} + 1.8 - 0.7)}{\left(\frac{1}{2}(0.025)(0.00834)\right) \times \left(\frac{W_n}{L_n}\right)^2 \times (3.1275 \times 10^{-6}) \times (1.8 - 0.7)^2}$$

$$t_{PLH} = \frac{C_{total}\,(0.9)(1.1)}{9.88 \times 10^{-4}}$$

$$t_{PHL} = \frac{C_{total}\,(0.9)(1.224 \times 10^{-6} + 1.1)}{\left(\frac{1}{2}\right)(0.009)(0.00816)\left(\frac{W_p}{L_p}\right)^2 (0.009)(0.00816)\left(\frac{W_p}{L_p}\right)(1.1)^2}$$

$$= \frac{C_{total}\,(0.9)(1.1)}{14.5023 \times (W_p)^3}$$

<u>for 0.42 um:-</u>

a) $C_{total} = 2.079 \times 10^{-15}$ | $t_{PHL} = 2.3 \times 10^{-11}$

$t_{PLH} = \cancel{2}ps\ 1.8 \times 10^{-11}$ | $t_p = 2.05 \times 10^{-11}s$

b) for 0.85 µm

$t_{PHL} = 3.5 \times 10^{-11}$ $\quad t_p = 2.4 \times 10^{-11}$ sec

$t_{PLH} = 1.3 \times 10^{-11}$

c) for 1.26 µm

$t_{PHL} = 1.25 \times 10^{-11}$ $\quad t_p = 1.21 \times 10^{-11}$ sec

$t_{PLH} = 1.175 \times 10^{-11}$

(3) W_P such that t_p is minimum

$$t_p \propto \frac{V_{DD}\,(E_C L + V_{DD} - V_T)}{(V_{DD} - V_T)^2}$$

$$t_p = D \times \frac{(1.8)\,(E_C L + 1.1)}{(1.1)^2}$$

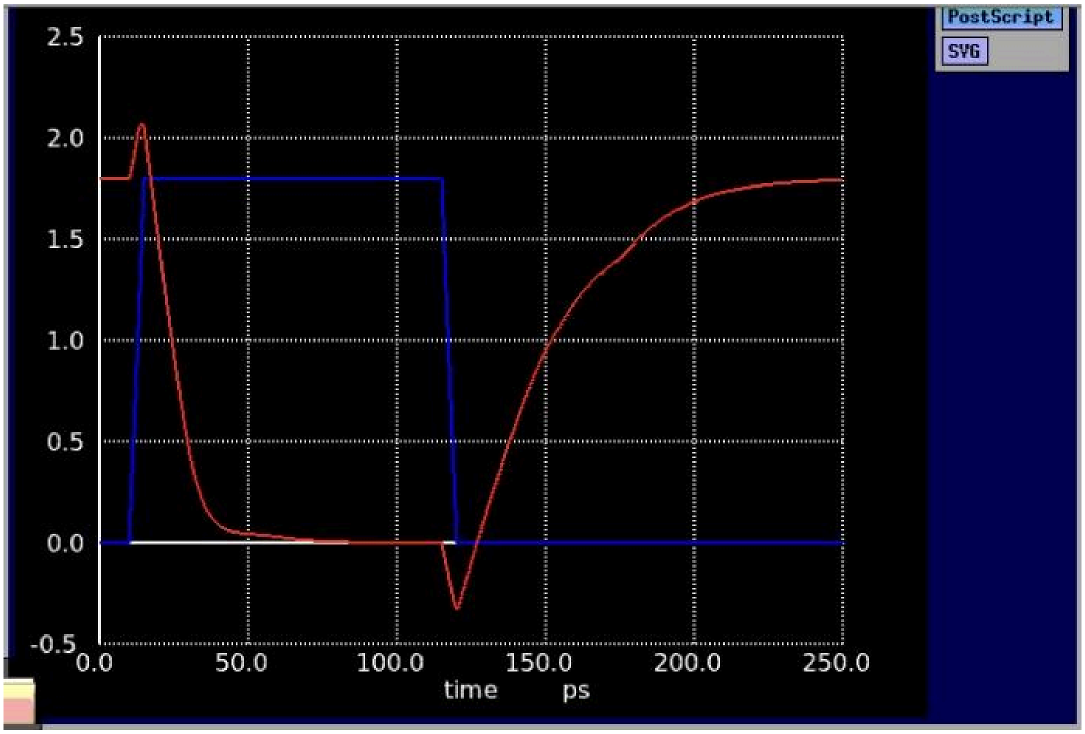
On solving this; $W_P \simeq \sqrt{\frac{K_n}{K_P}}\, W_n$

$K_n = \frac{1}{2} u_n C_{ox,n} \frac{W_n}{L_n} = \frac{1}{2}(0.025)(0.00834) \times \frac{0.42}{0.15}$

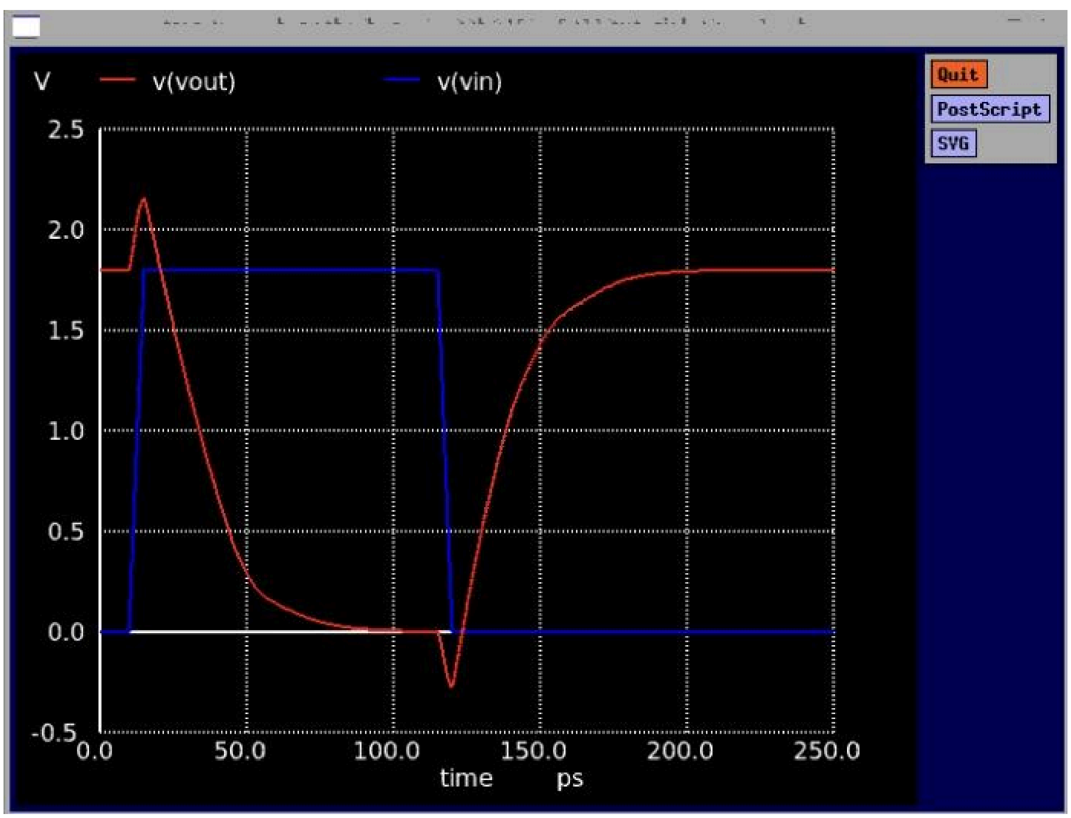
$K_n = 2.919 \times 10^{-4}$

$K_P = \frac{1}{2} u_P C_{ox,P} \frac{W_P}{L_P} = \frac{1}{2}(0.009)(0.00816) \times \frac{W_P}{0.15}$

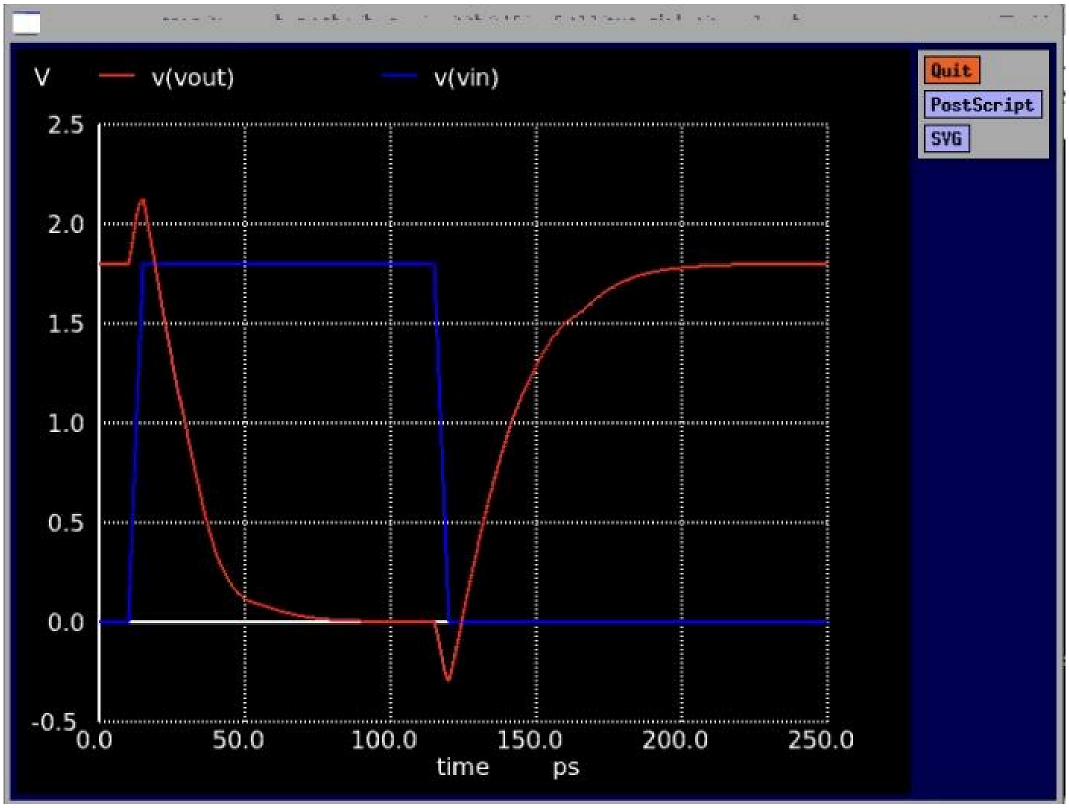
$K_P = 2.448 \times 10^{-4}$



Above figure shows the graph for (W)p = 0.42uM



Above figure shows the graph for (W)p = 0.84uM.



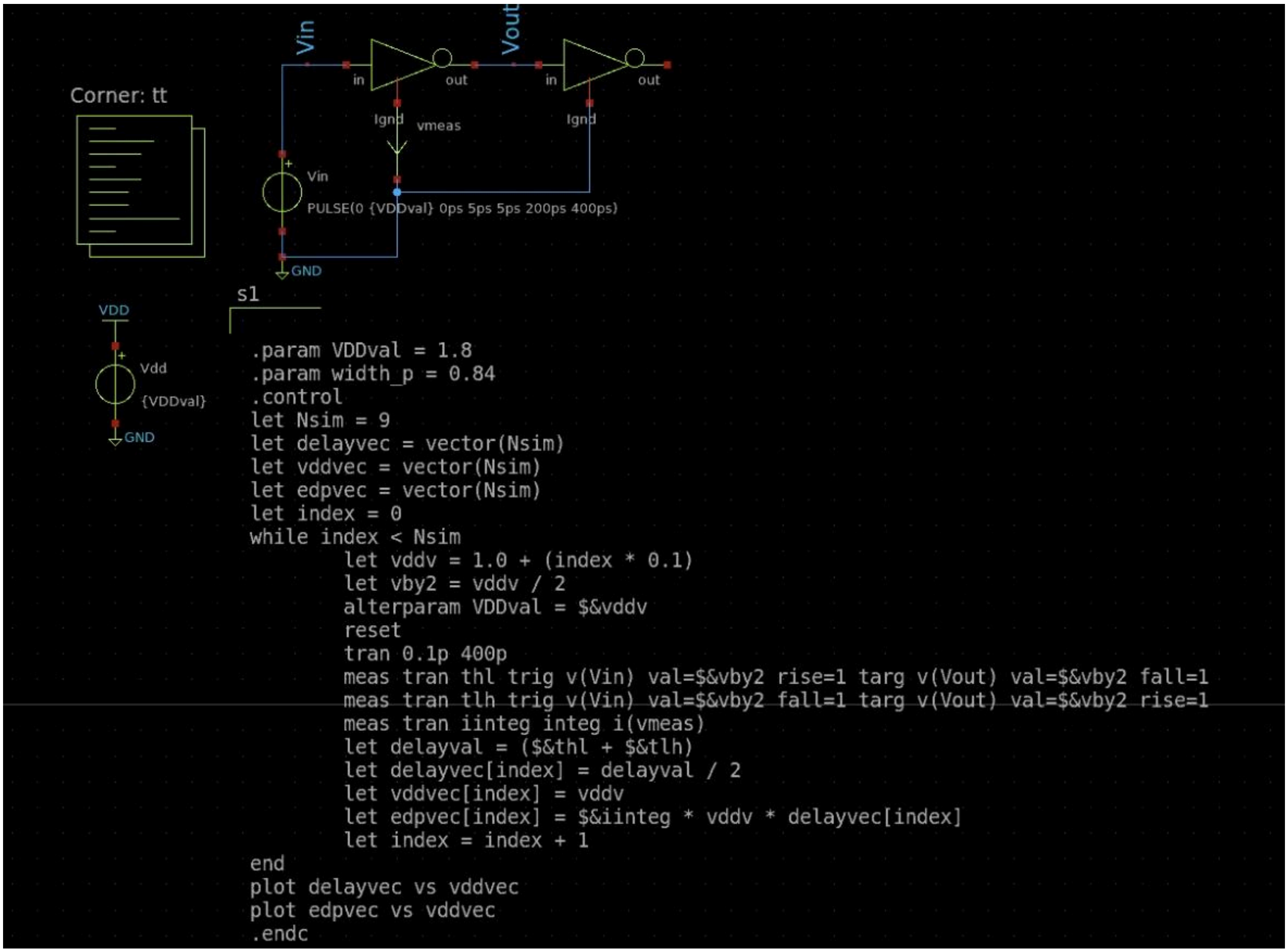
Above figure shows the graph for (W)p = 1.26uM

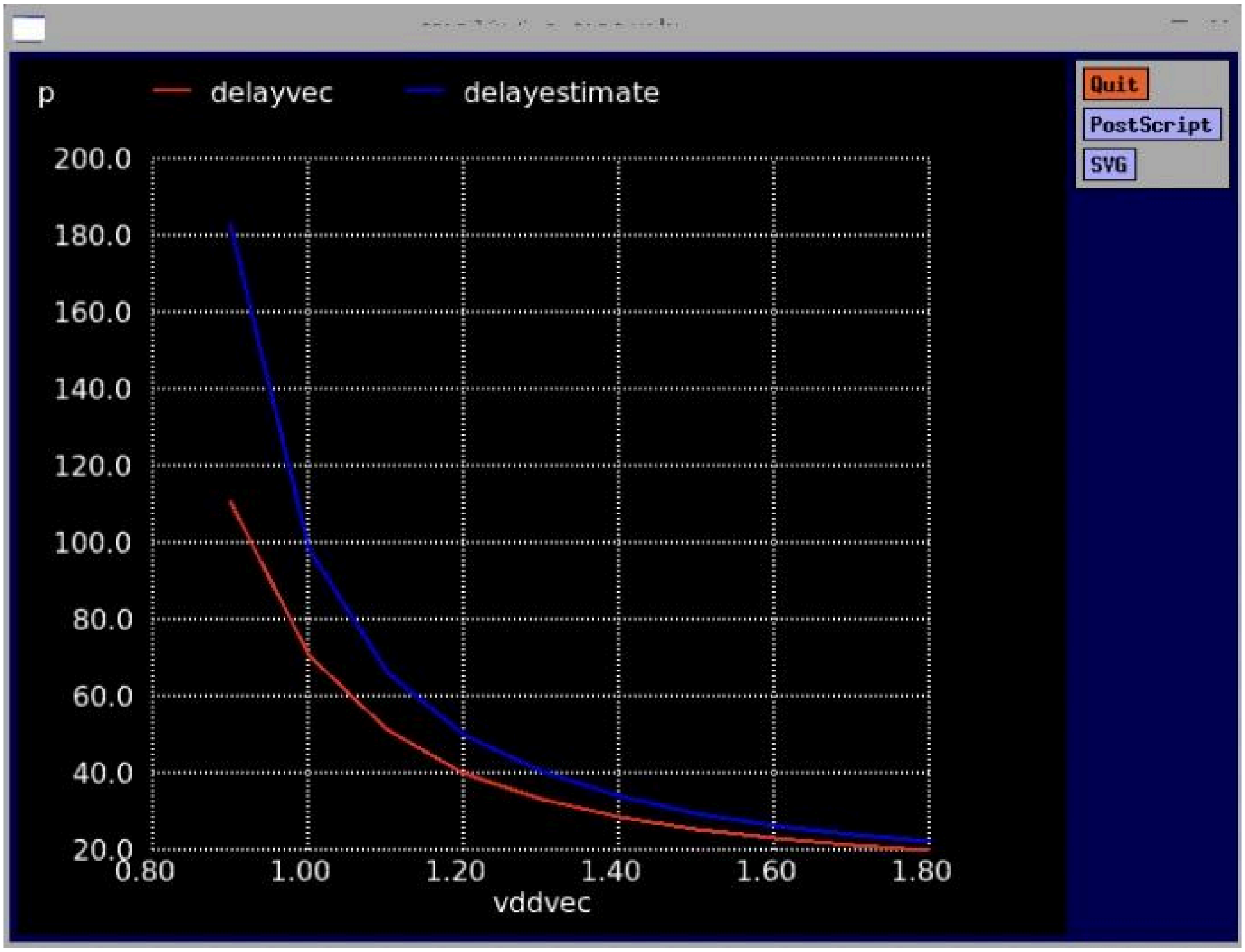
Tp for Wp = 0.42uM = 2.18 x 10^-11 sec
Tp for Wp = 0.84uM = 1.99 x 10^-11 sec
Tp for Wp = 1.26uM = 2.11 x 10^-11 sec

Optimal width for less delay here is 0.84uM

Experiment - 1

Schematic for (B) & (C):



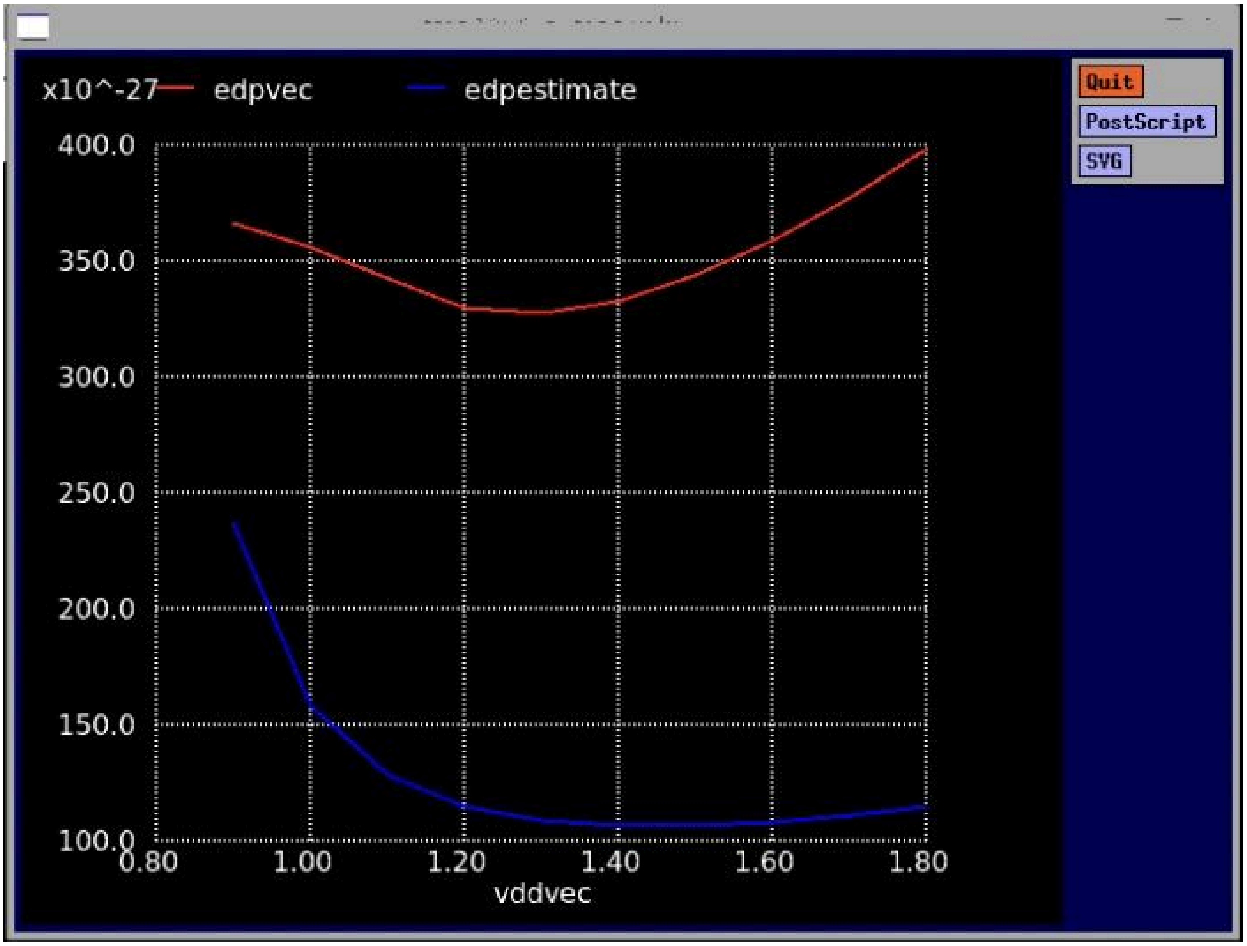


Above figure shows Delay as a function of VDD increased from 1 to 1.8V as steps of 0.1
The Blue Plot is the Estimated Delay and the Red Plot is the Calculated Delay.

Analytical Expression:

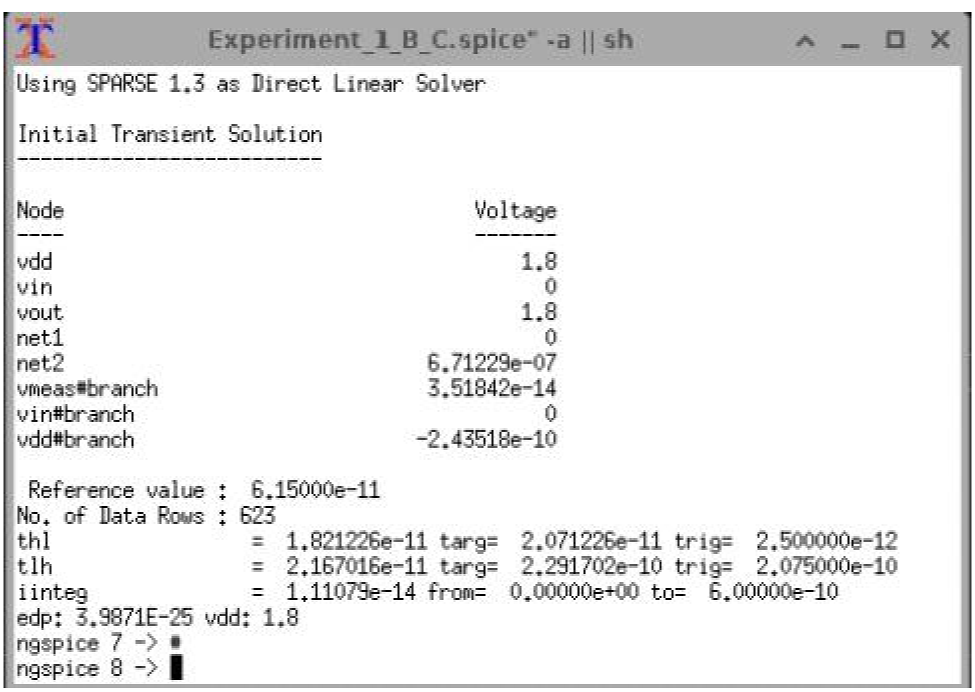
The delay decreases as VDD increases, following an Inverse relationship.

Tp = K * Vdd / (Vdd - Vt)^2



Above Figure shows the Energy Density Product vs VDD.
The Blue Plot is the estimated EDP. and The Red Plot is the Calculated EDP.

<u>NgSPice Response:</u>



Experiment_1_B_C.spice" -a || sh

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Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
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Node                                   Voltage
----                                   -------
vdd                                        1.8
vin                                          0
vout                                       1.8
net1                                         0
net2                               6.71229e-07
vmeas#branch                       3.51842e-14
vin#branch                                   0
vdd#branch                        -2.43518e-10

 Reference value :  6.15000e-11
No. of Data Rows : 623
thl                 =  1.821226e-11 targ=  2.071226e-11 trig=  2.500000e-12
tlh                 =  2.167016e-11 targ=  2.291702e-10 trig=  2.075000e-10
iinteg              =  1.11079e-14 from=  0.00000e+00 to=  6.00000e-10
edp: 3.9871E-25 vdd: 1.8
ngspice 7 -> 
ngspice 8 -> 
```

Calculations:

$$\omega_p \approx \sqrt{\frac{k_n}{k_p}}\, \omega_n$$

$$\omega_p \approx \frac{1}{\sqrt{\omega_p}} \times 1.09 \times 0.42 \implies \omega_p = (0.458)^{2/3}$$

$$\boxed{\omega_p \approx 0.59} \rightarrow \text{after approximation}$$

(c) Optimum V_{DD} :-

$$\frac{\partial EDP}{\partial V_{DD}} = 0 \implies V_{DD_{min}} = \frac{5V_T - E_cL}{4} + \frac{\sqrt{(5V_T - E_cL)^2 + 24V_T(E_cL - 4)}}{4}$$

$$V_{DD_{min}} = \frac{4.5 - \cancel{0}}{4} + \frac{\sqrt{20.25 + 24 \times (0.7)(-0.7)}}{4}$$

$$= \frac{4.5}{4} + 0.72 \simeq 1.845V$$

$V_{DD_{optimal}} \approx 1.845V$.

- The End -