

Self Project - LTspice

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Problem Statement No 1 Technology

File: TSMC018 (180nm PDK)

LTspice files:

Que 1.a to 1.d - Project.asc

Que 1.e - EProject.asc

1. Simulation of symmetrical and skewed CMOS inverter, and pass transistor:

1.a.

(Que) Do an analysis to find out the PMOS to NMOS size ratio of the minimum-sized CMOS inverter to have equal rise and fall time.

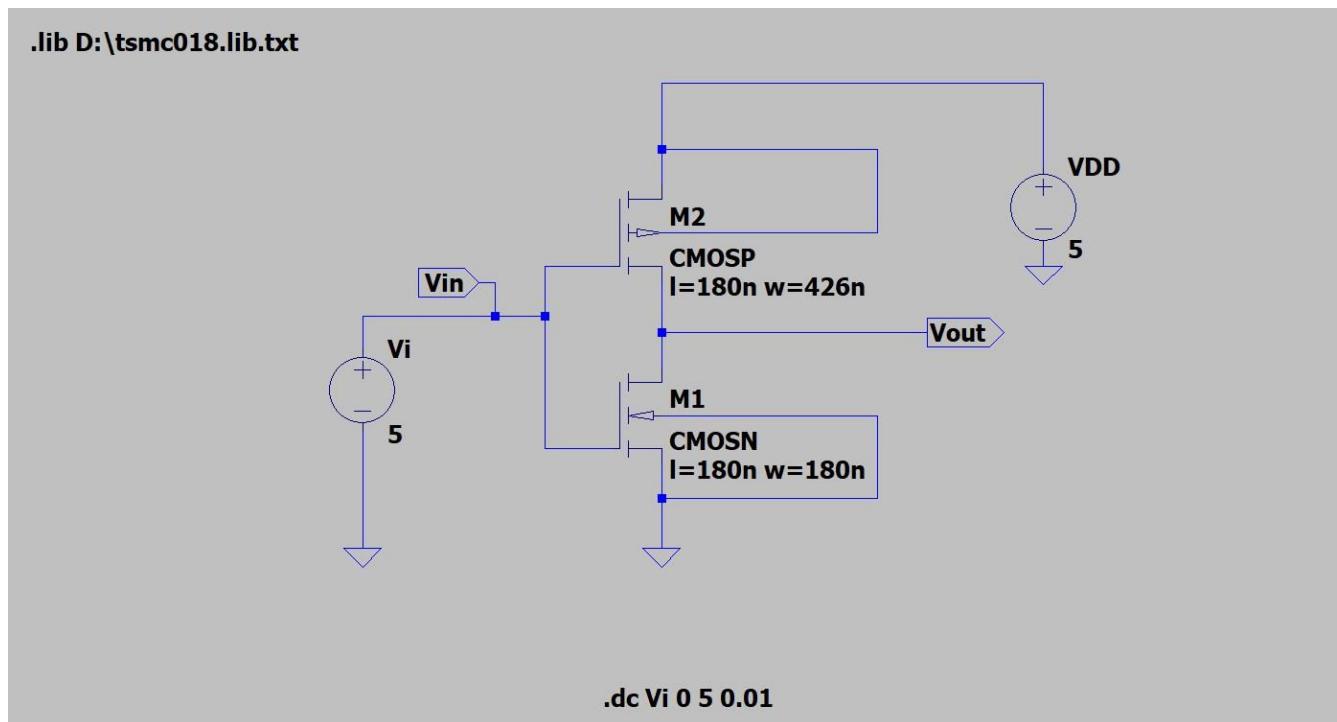
Analysis for Sizing NMOS & PMOS: $\mu_n=273.8094484$;

$\mu_p=115.6894042$

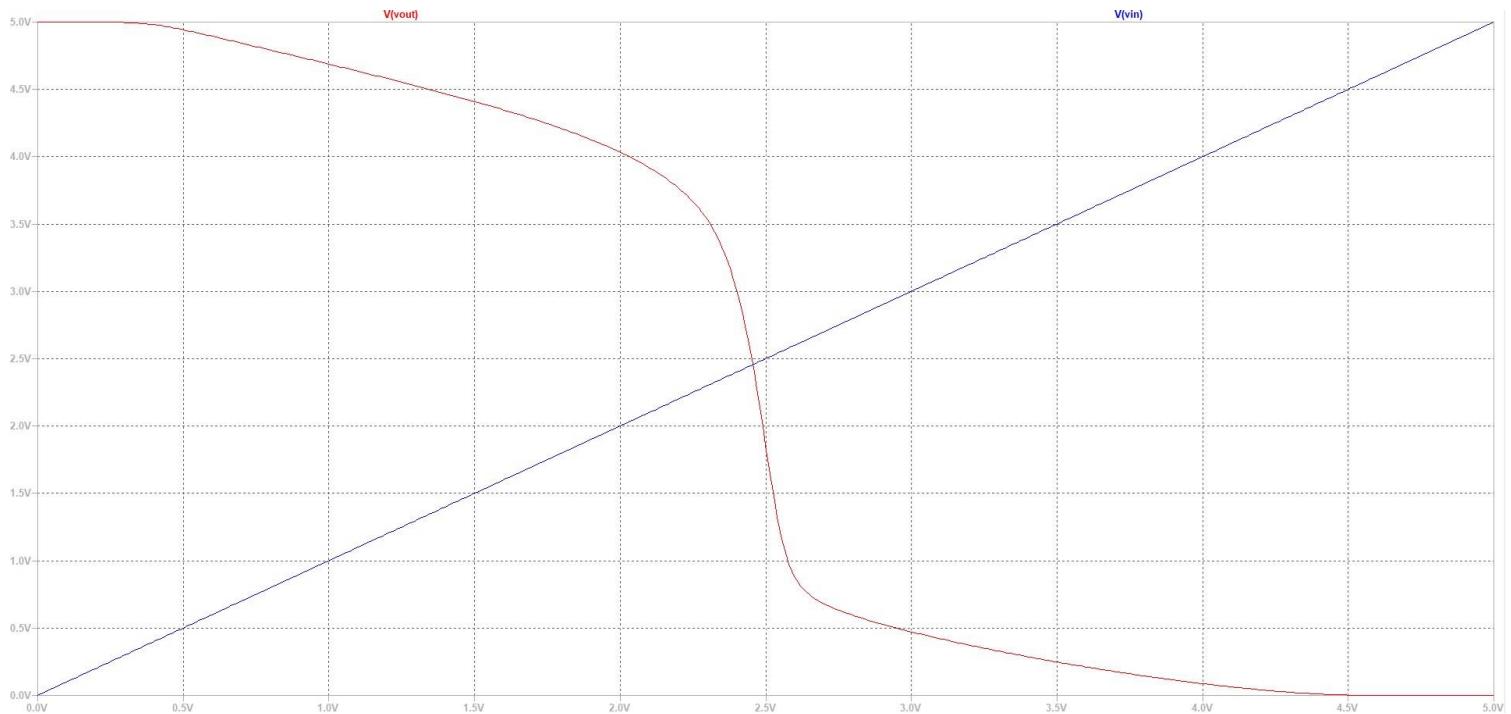
Size of PMOS = $(\mu_n/\mu_p) \times \text{Size of PMOS} = 2.36$ of NMOS

Taking minimum sized NMOS W/L=180n/180n; PMOS W/L will be equal to 426n/180n

Circuit:

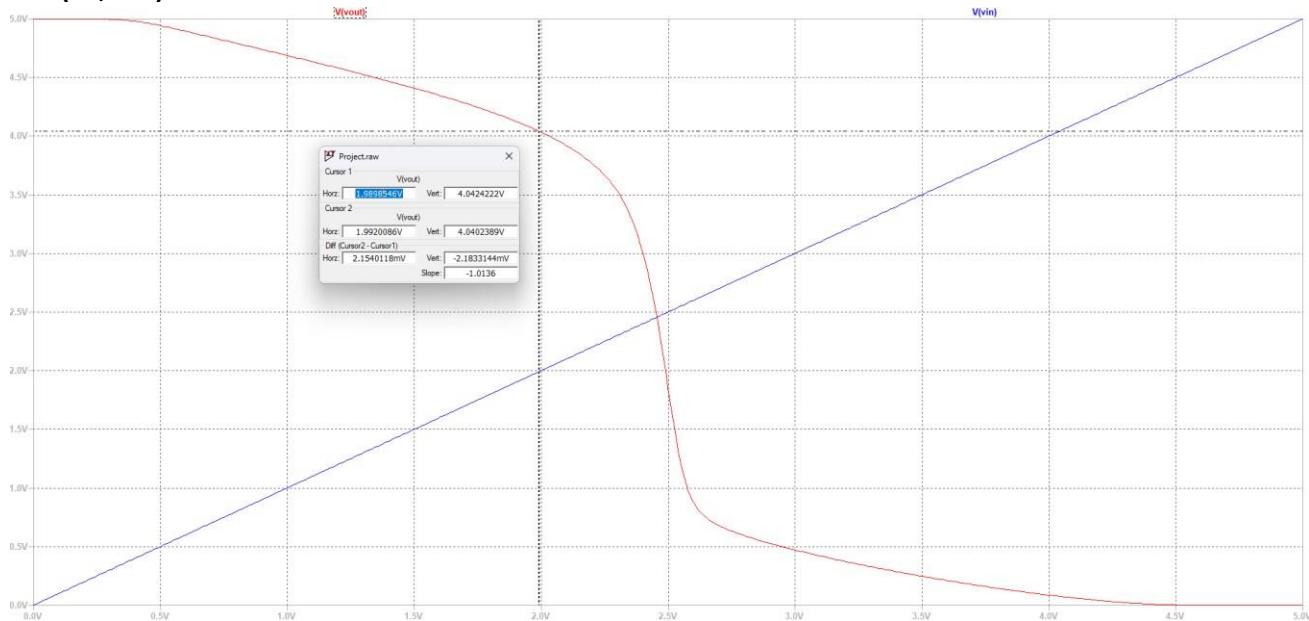


VTC:



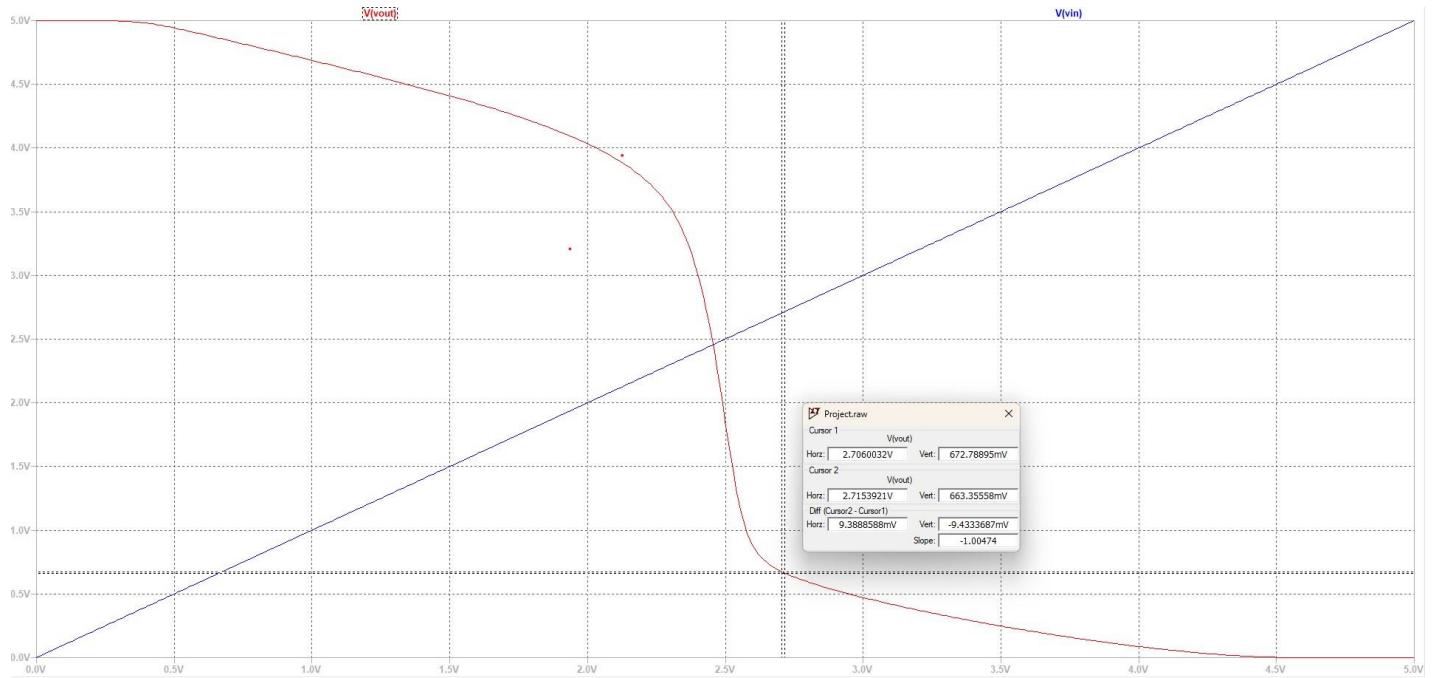
(Que) Simulate the static VTC of that inverter, and find out signaling threshold values (V_{IL} , V_{IH} , V_{OL} , V_{OH}) using the slope = -1 criterion from the VTC. Write down high and low noise margins, and the noise immunity of the inverter.

(V_{IL}, V_{OH}) :



Slope -1 point from the plot: (V_{IL}, V_{OH}) : $(1.99V, 4.04V)$

(V_{IH}, V_{OL}) :



Slope -1 point from the plot: (V_{IH}, V_{OL}) : 2.71V, 0.67V

(Que) Write down high and low noise margins, and the noise immunity of the inverter.

(V_{IL}, V_{OH}) : 1.99V, 4.04V

(V_{IH}, V_{OL}) : 2.71V, 0.67V

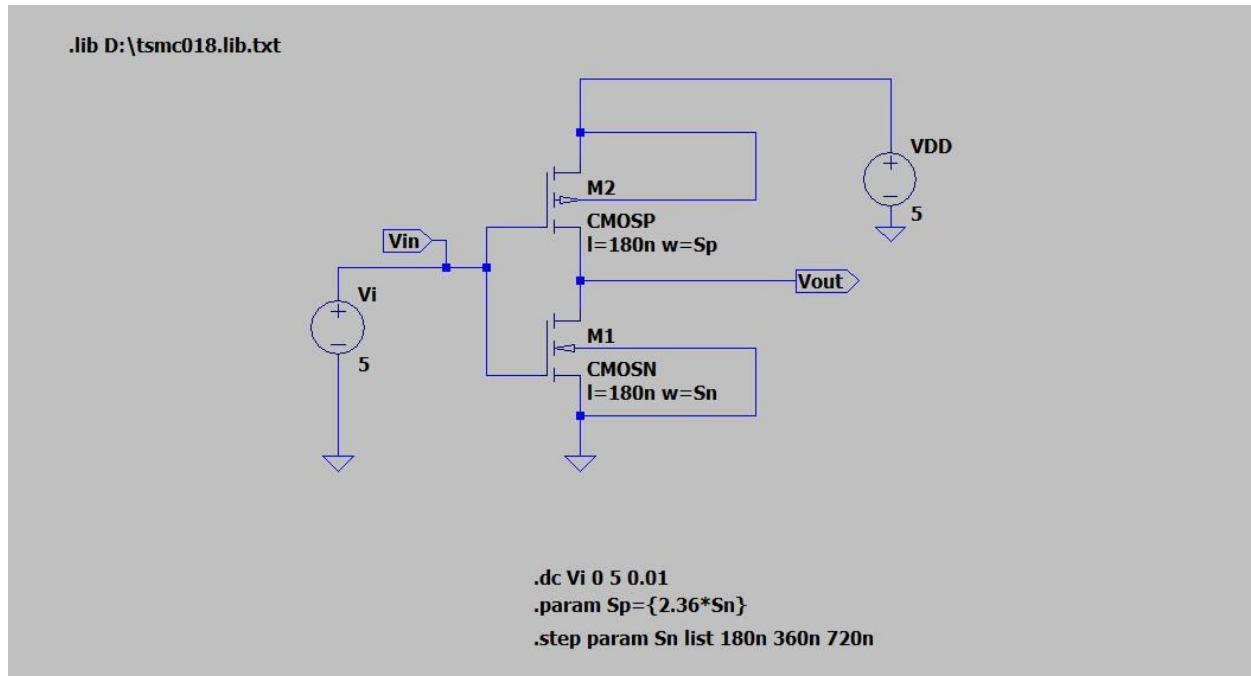
NM_L : $V_{IL} - V_{OL}$: $1.99 - 0.67 = 1.32V$

NM_H : $V_{OH} - V_{IH}$: $4.04 - 2.71 = 1.33V$

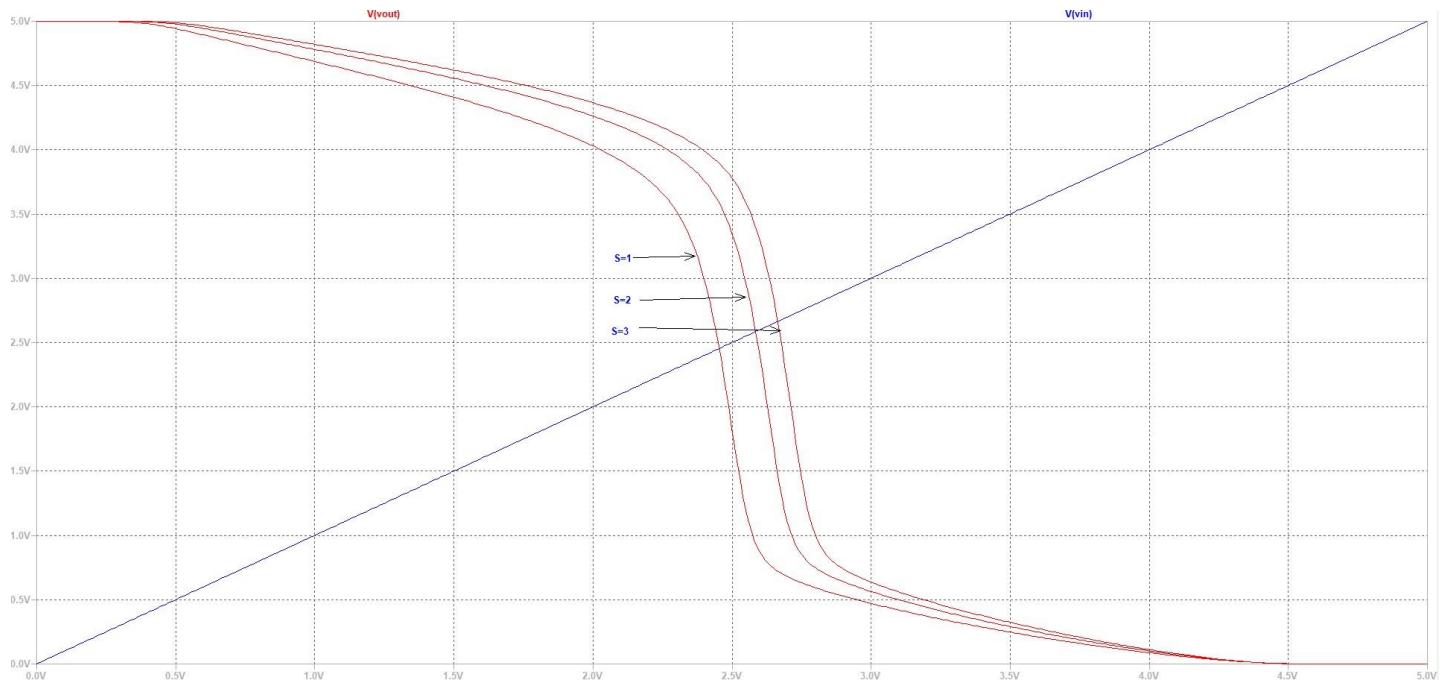
Noise immunity = $\min(NM_L, NM_H) = 1.32V$

(Que) Also, simulate the static VTC of an inverter which is sized S times the minimum-sized inverter (both NMOS and PMOS are S times the size of the corresponding NMOS and PMOS of the minimum-sized inverter) for $S = 1, 2, 4$, and plot all VTCs in a single graph with clear legends indicating how the sizing affects the VTC.

Circuit:



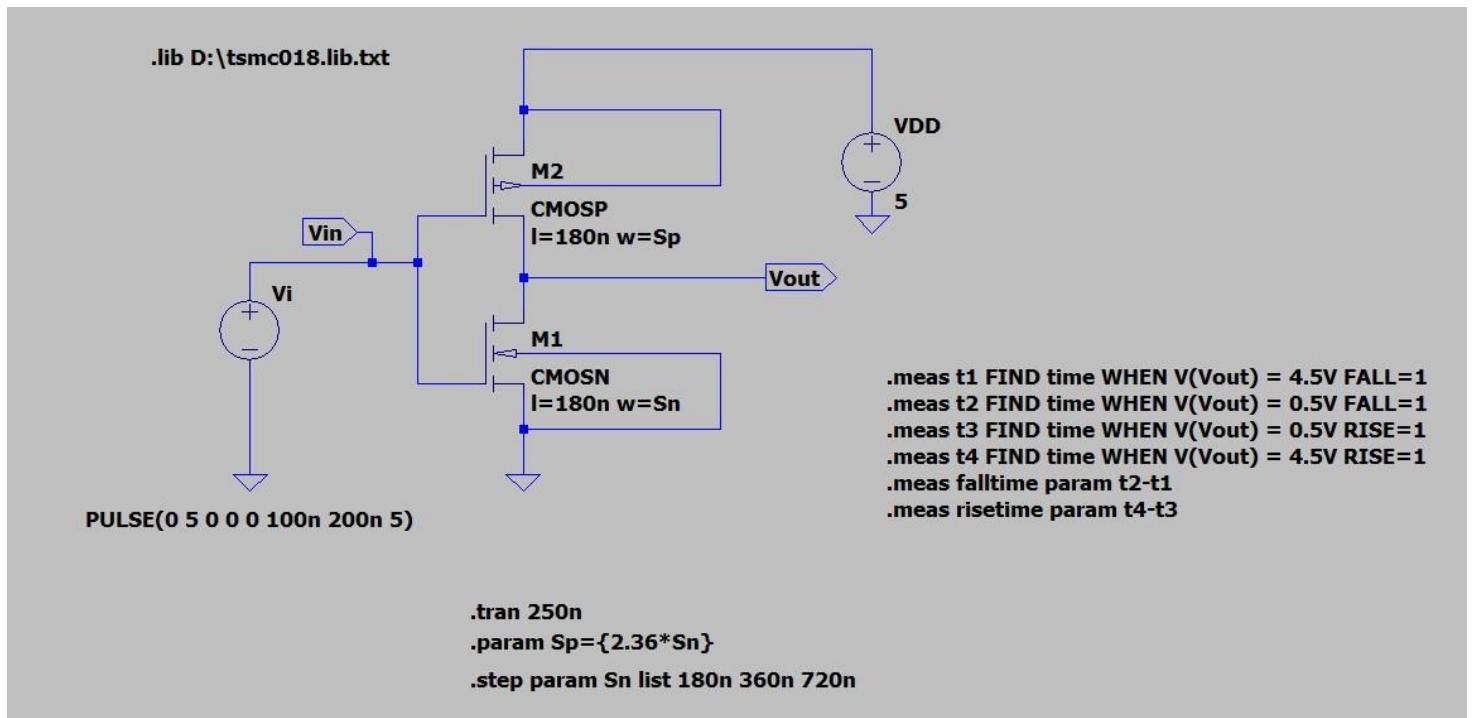
VTC:



1.b. (Without adding external capacitor)

Carry out transient analysis to find out the rise time and fall time delays of a CMOS inverter sized S =1,2,4, when (i) no external capacitor is attached

(Note: Vin is taken as pulse input with **Von=5V, Ton=100nsec, Tperiod=200nsec**)



Rise & Fall Delays:

```
SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log
Measurement: t4
step          time           at
  1          1.17327e-07    1.17327e-07
  2          1.16803e-07    1.16803e-07
  3          1.16497e-07    1.16497e-07

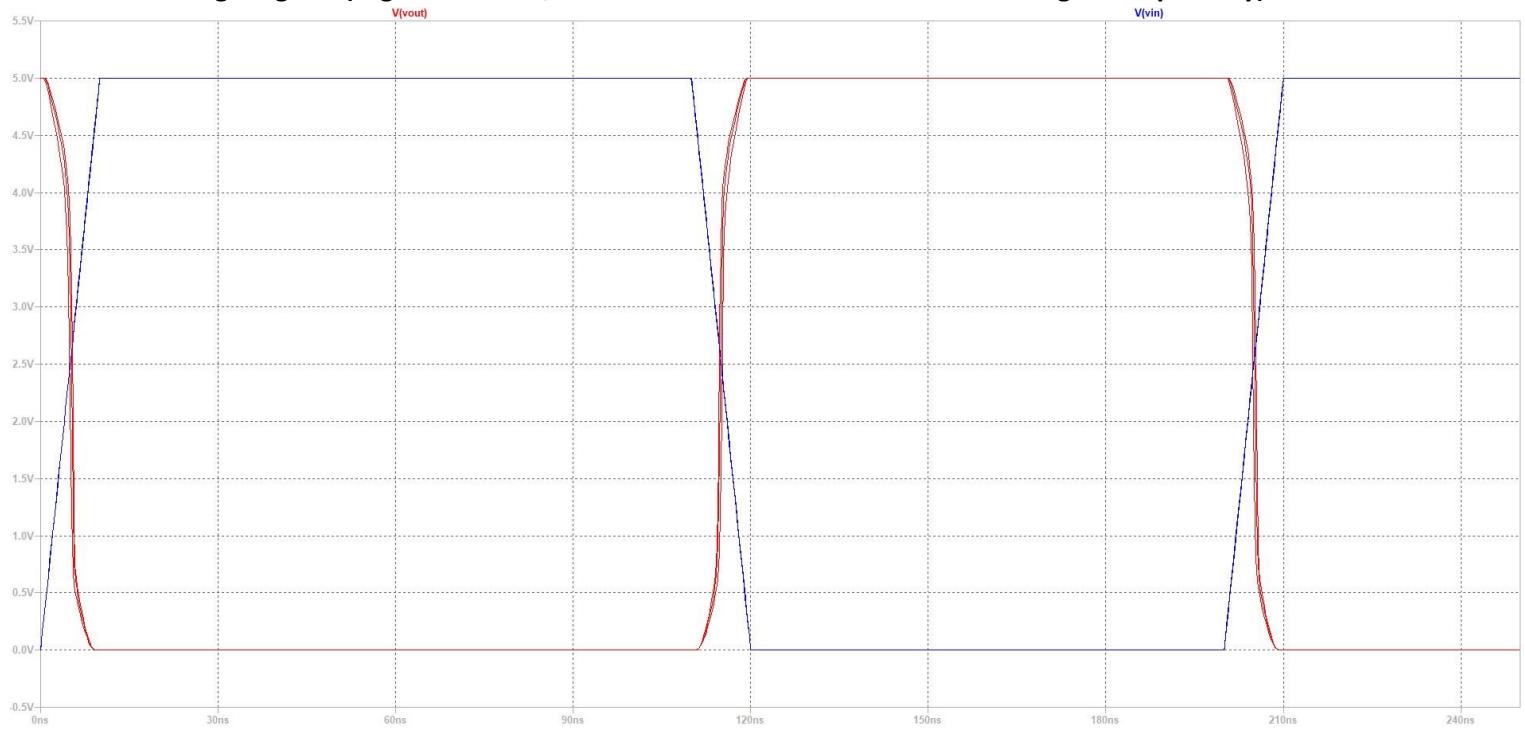
Measurement: falltime
step          t2-t1
  1          3.22116e-09
  2          2.98629e-09
  3          2.87137e-09

Measurement: risetime
step          t4-t3
  1          3.22682e-09
  2          3.0017e-09
  3          2.87529e-09
```

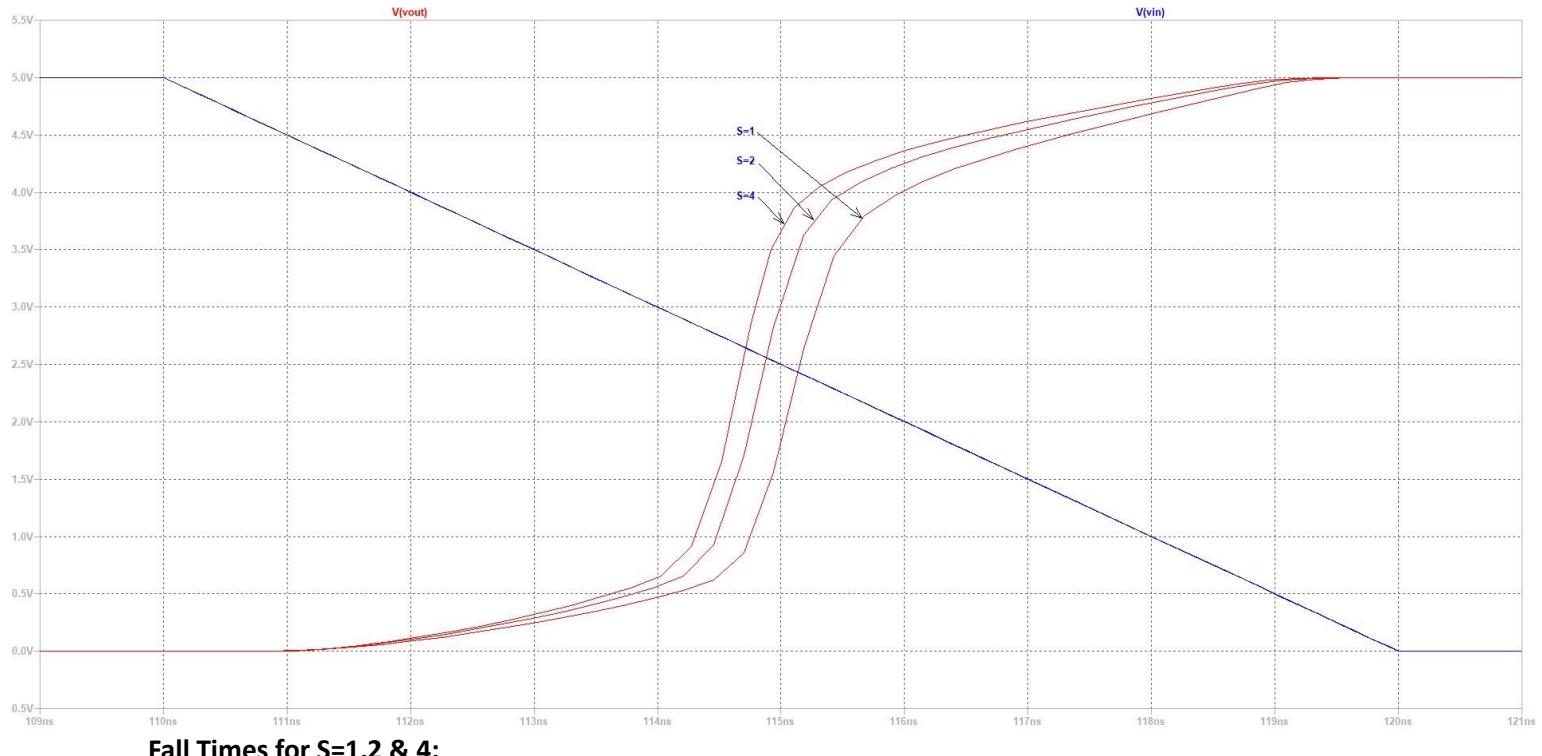
(Note: Delays are listed in order S=1, S=2 & S=4)

(Que) Plot the timing characteristics in a single graph with clearly labelled axes and legends for each value of S

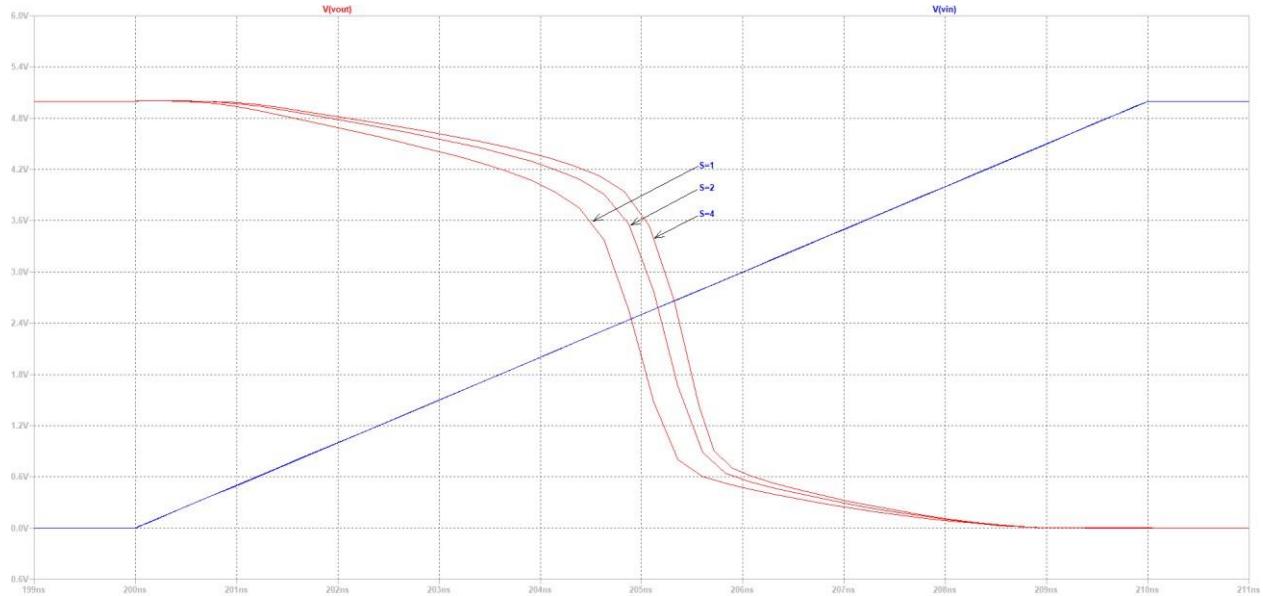
Timing Diagram (Legends for S=1,2 & 4 are shown in Rise time & Fall time figures separately):



Rise Times for S=1,2 & 4:

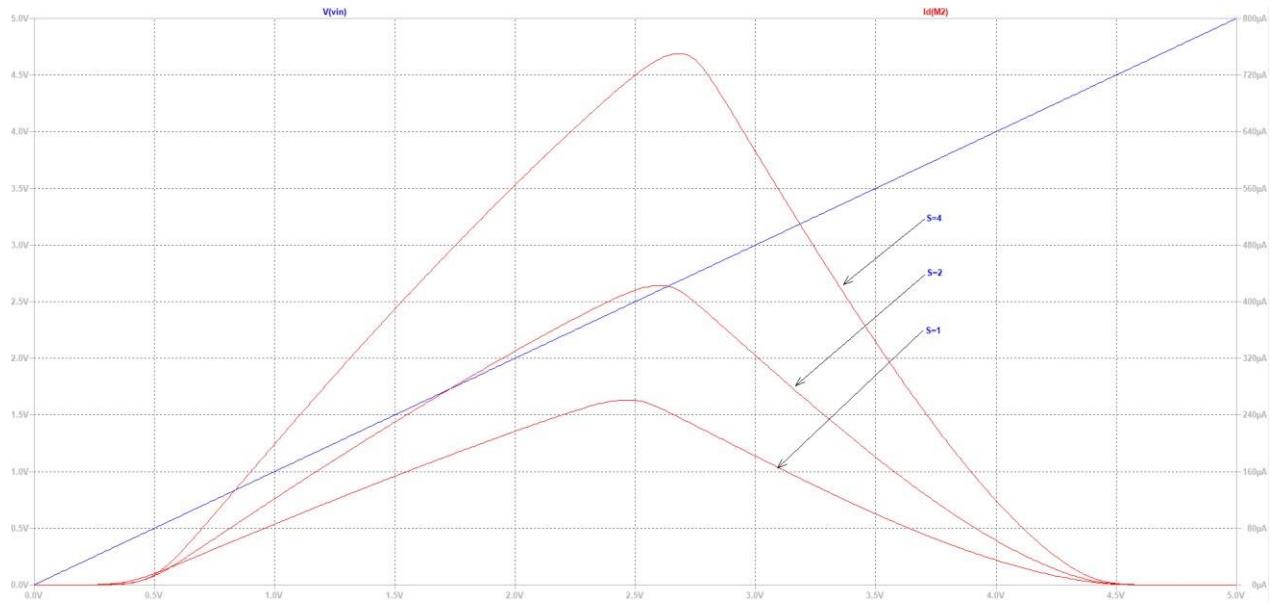


Fall Times for $S=1,2 \& 4$:

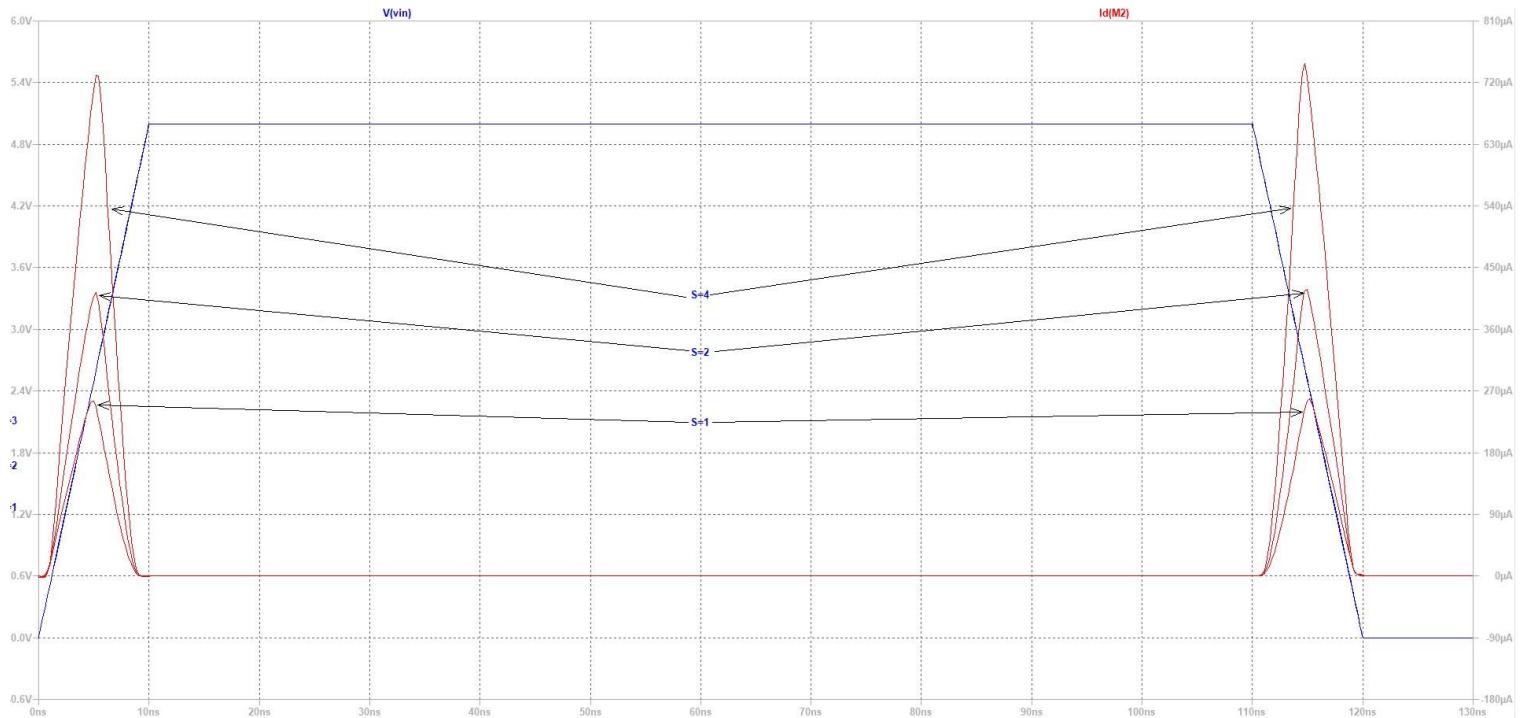


(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends for each value of S

Input voltage Vs Current (Input voltage V_{in} swept from 0V to 5V with 0.01V step):



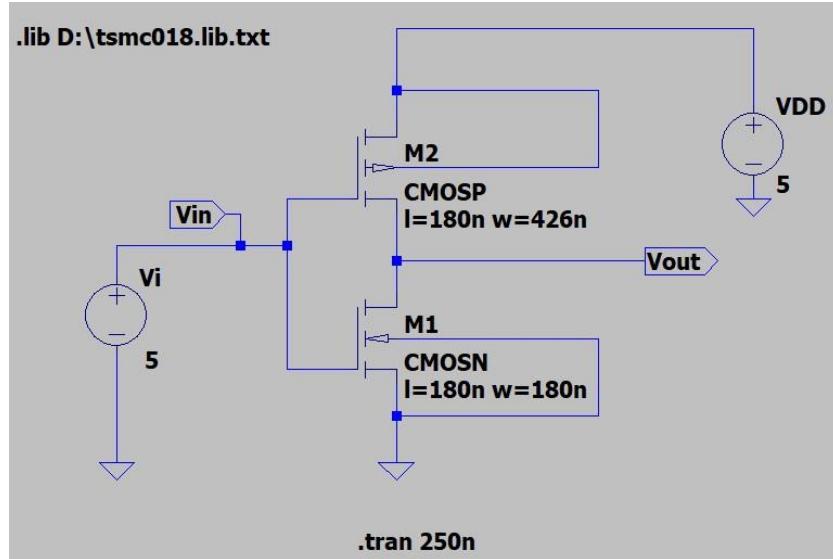
Current Vs Time:



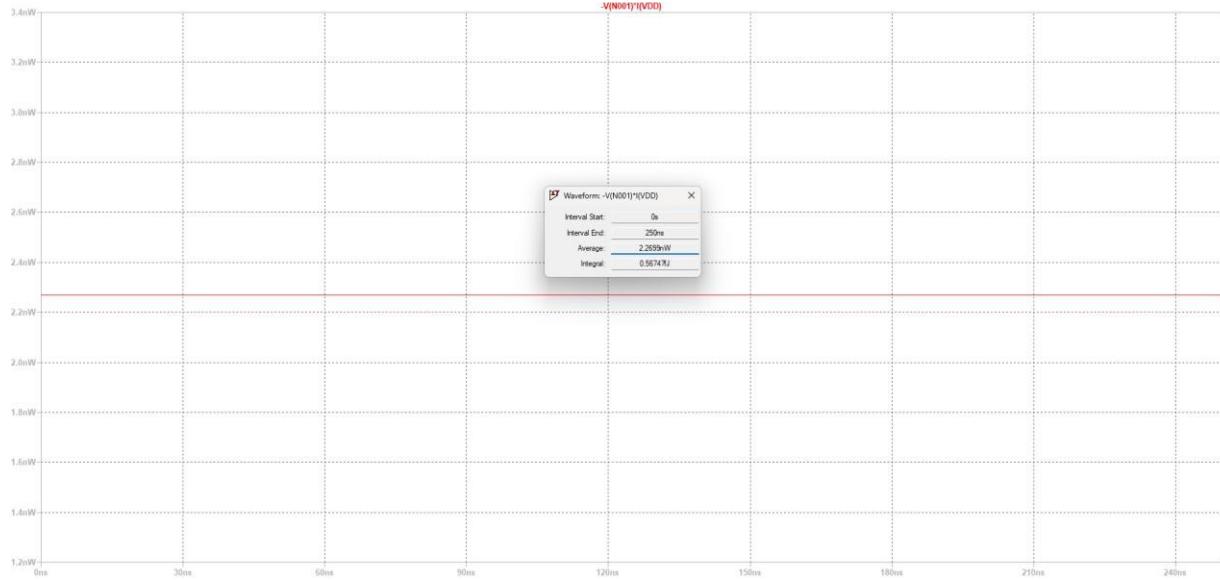
(Que) Calculate and tabulate the static and dynamic power dissipations in all cases, i.e., for each value of S and for part (i) and (ii).

Static Power: Static power is calculated as: Average powers are calculated for $V_{in} = 0V$ & $V_{in} = 5V$ by doing DC analysis. The results are then averaged.

S=1:



Power @ $V_{in}=0V$: Power: 2.2699nW



Power @ $V_{in}=5V$: Power: 64.466pW



$$\text{Static Power: } (2.2699\text{nW} + 64.466\text{pW})/2 = 1.671\text{nW}$$

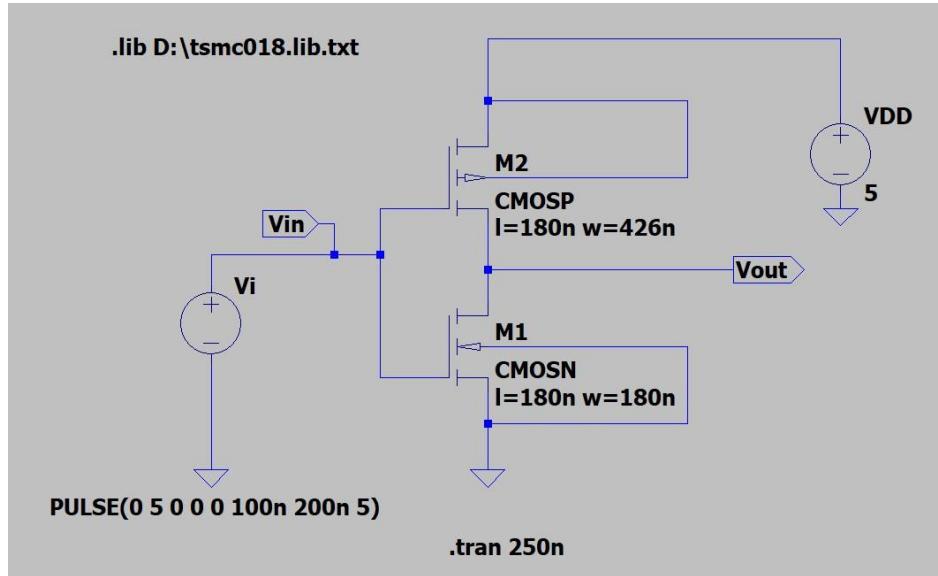
Similarly Static Power for S=1, S=2 & S=4 is calculated and tabulated as follows:

Sr. No.	S	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	561.35pW	67.019pW	0.314nW
3	4	381.32pW	86.055pW	0.233nW

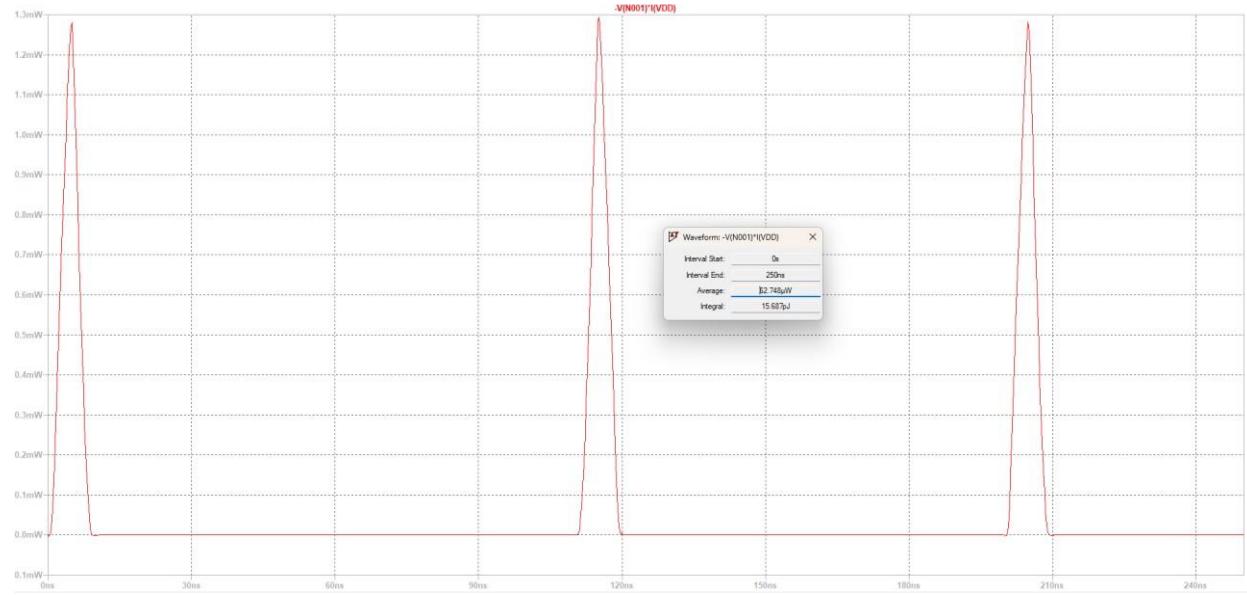
Dynamic Power: Dynamic power is calculated by pulsed input & calculating the power during output transition time.

S=1

Circuit:



Power: 62.748 μ W



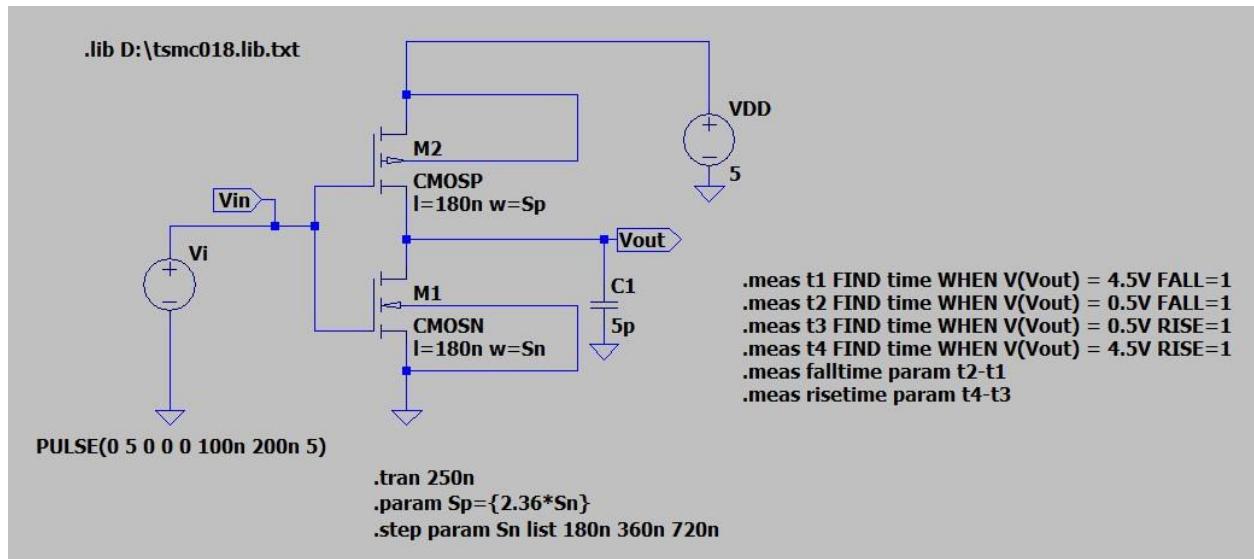
Similarly Dynamic Power for S=1, S=2 & S=4 is calculated and tabulated as follows:

Sr. No.	S	Dynamic Power
1	1	62.748 μ W
2	2	100.84 μ W
3	4	178.61 μ W

1.b. (With 5pF external capacitor)

Carry out transient analysis to find out the rise time and fall time delays of a CMOS inverter sized S =1,2,4, when (ii) an external capacitor of 5 pF is attached to the output node.

(Note: Vin is taken as pulse input with Von=5V, Ton=100nsec, Tperiod=200nsec)



Rise & Fall Delays:

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log

Measurement: t4

step	time	at
1	1.69367e-07	1.69367e-07
2	1.4363e-07	1.4363e-07
3	1.30549e-07	1.30549e-07

Measurement: falltime

step	t2-t1
1	4.60702e-08
2	3.08066e-08
3	1.85837e-08

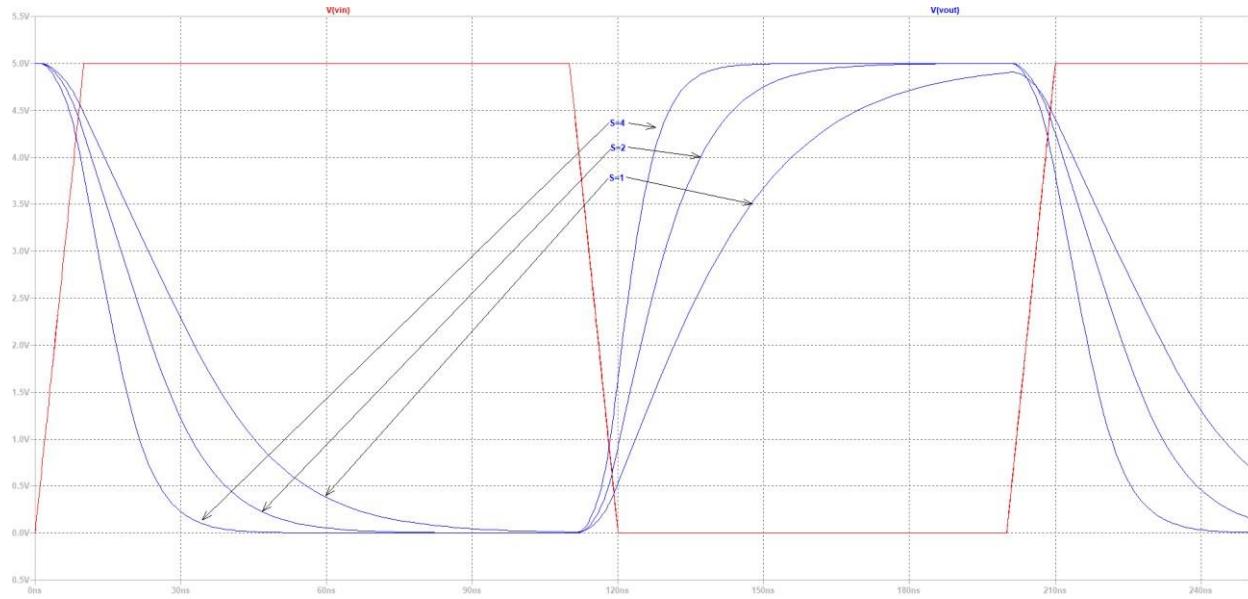
Measurement: risetime

step	t4-t3
1	4.95766e-08
2	2.55862e-08
3	1.39249e-08

(Note: Delays are listed in order S=1, S=2 & S=4)

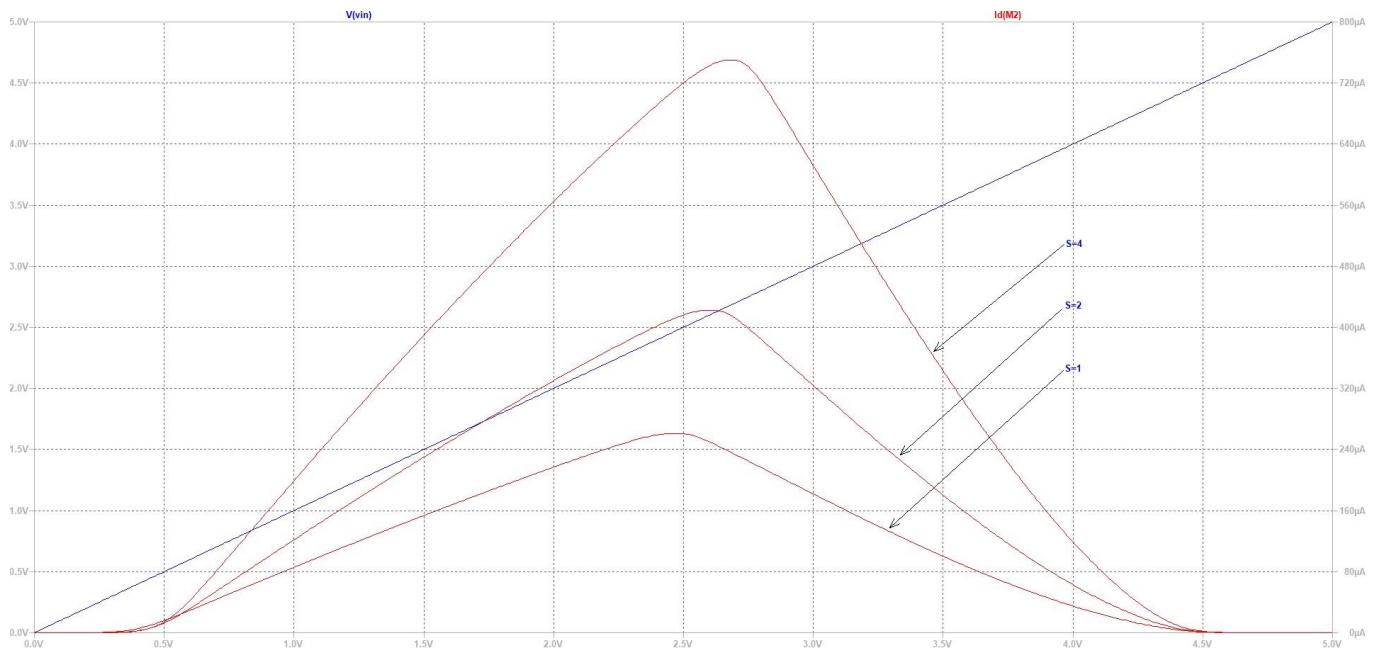
(Que) Plot the timing characteristics in a single graph with clearly labelled axes and legends for each value of S

Timing Diagram:

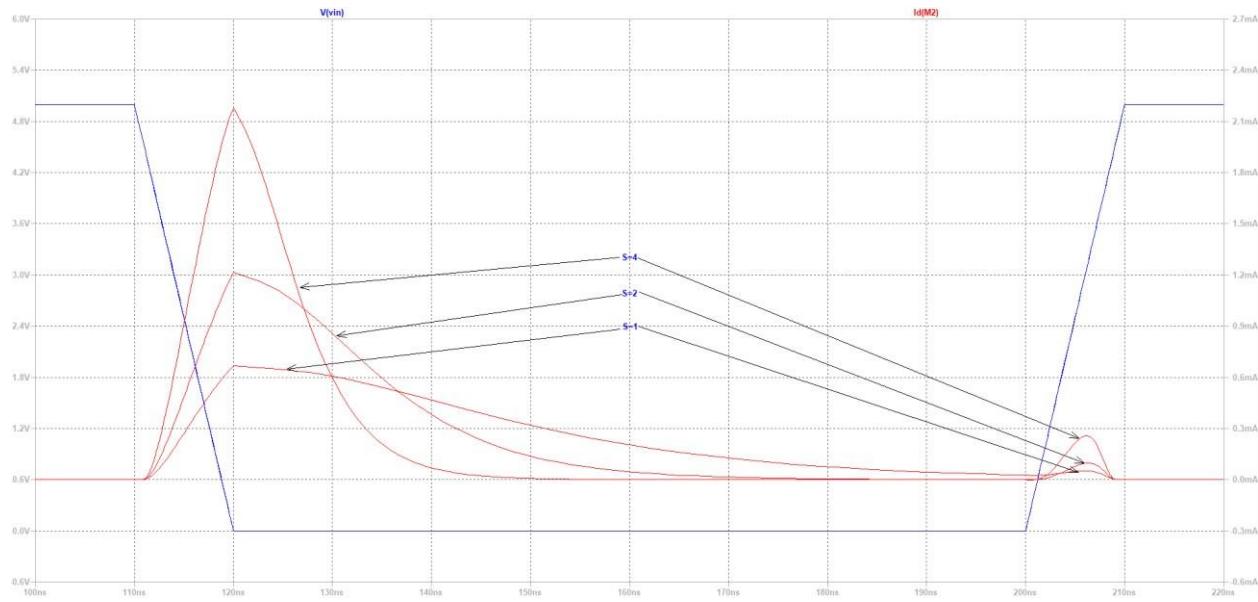


(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends for each value of S

Input voltage Vs Current (Input voltage V_{in} swept from 0V to 5V with 0.01V step):



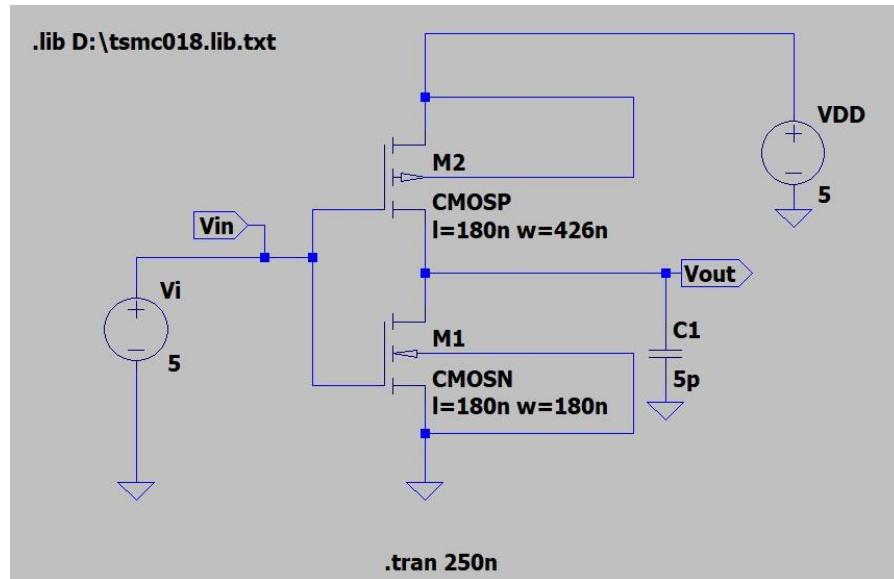
Current Vs Time:



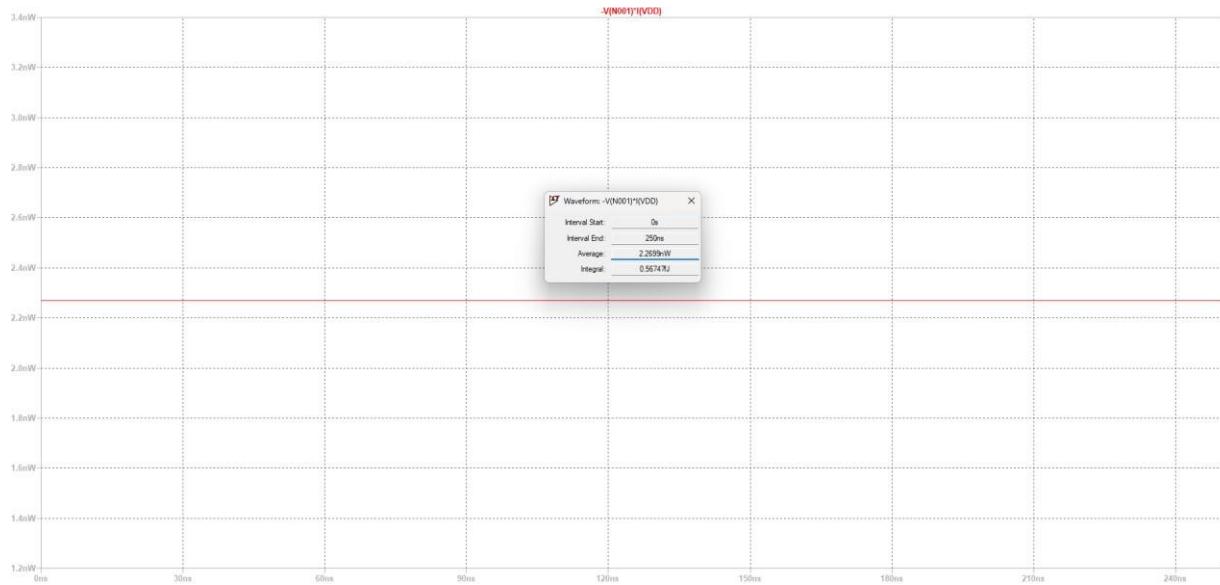
(Que) Calculate and tabulate the static and dynamic power dissipations in all cases, i.e., for each value of S and for part (i) and (ii).

Static Power: Static power is calculated as: Average powers are calculated for $Vin = 0V$ & $Vin = 5V$ by doing DC analysis. The results are then averaged.

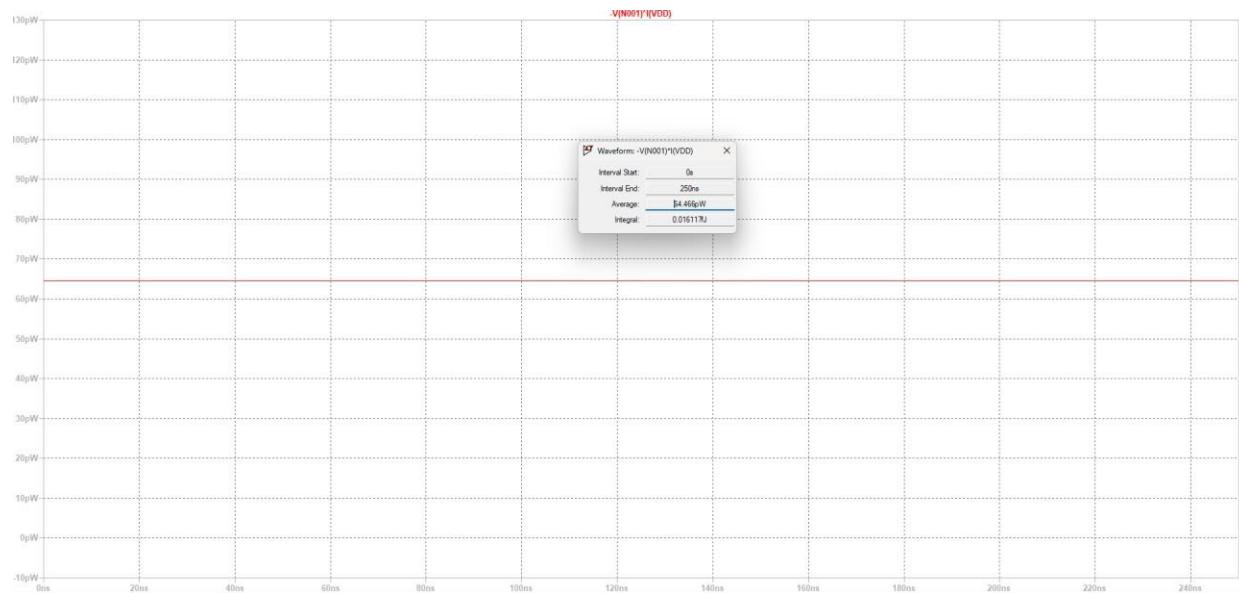
$S=1$:



Power @ Vin=0V: Power: 2.2699nW



Power @ Vin=5V: Power: 64.466pW



Static Power: $(2.2699\text{nW} + 64.466\text{pW})/2 = 1.671\text{nW}$

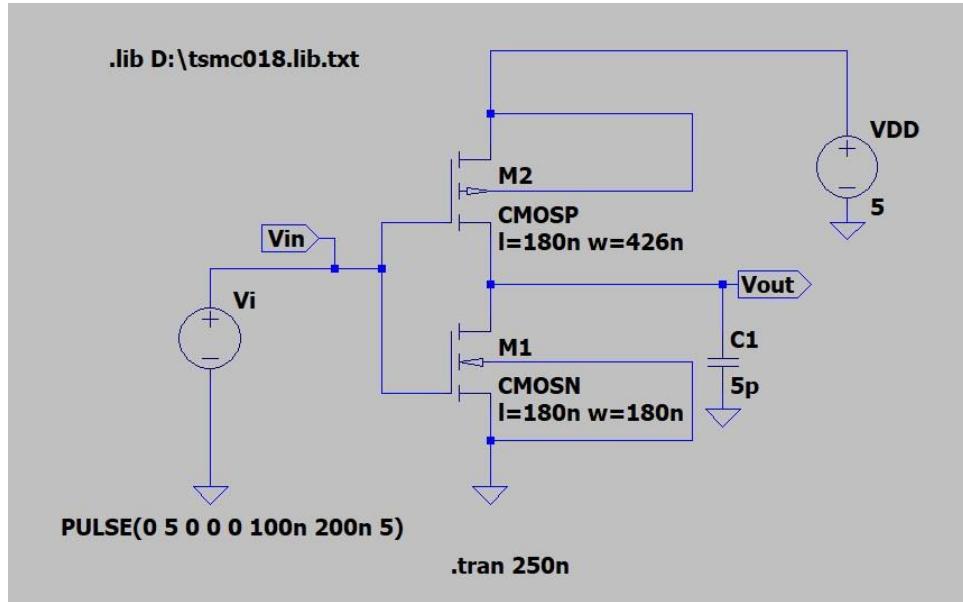
Similarly Static Power for S=1, S=2 & S=4 is calculated and tabulated as follows:

Sr. No.	S	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	561.35pW	67.019pW	1.168nW
3	4	381.32pW	86.055pW	1.177nW

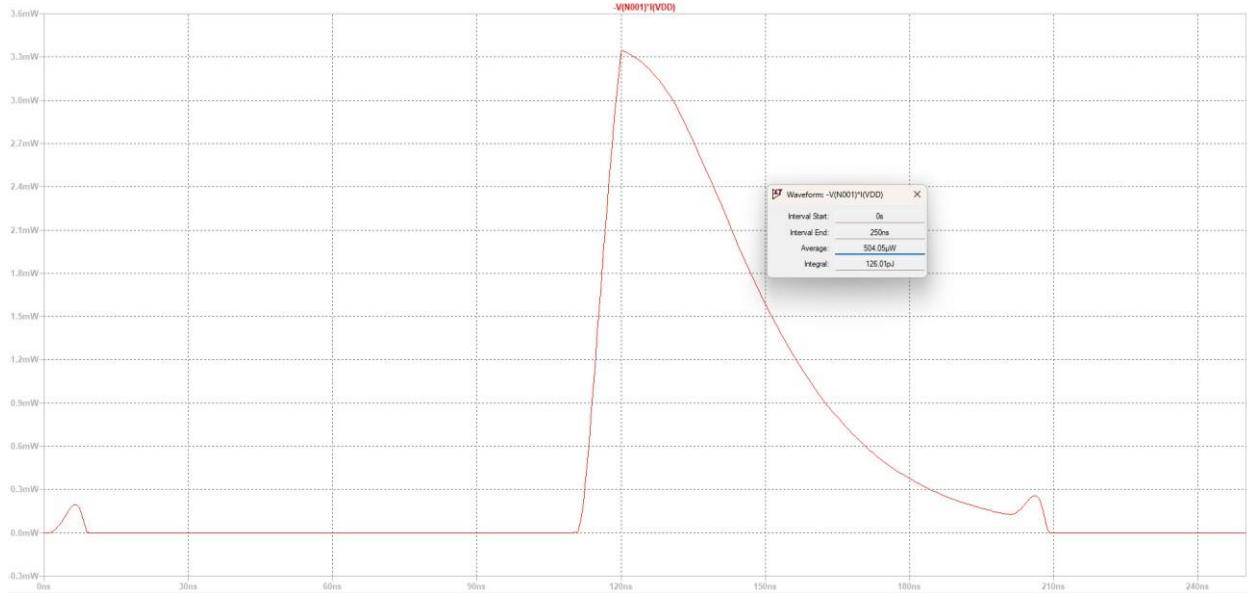
Dynamic Power: Dynamic power is calculated by pulsed input & calculating the power during output transition time.

S=1

Circuit:



Power: $504.05\mu W$



Similarly Dynamic Power for S=1, S=2 & S=4 is calculated and tabulated as follows:

Sr. No.	S	Dynamic Power
1	1	$504.05\mu W$
2	2	$526.77\mu W$

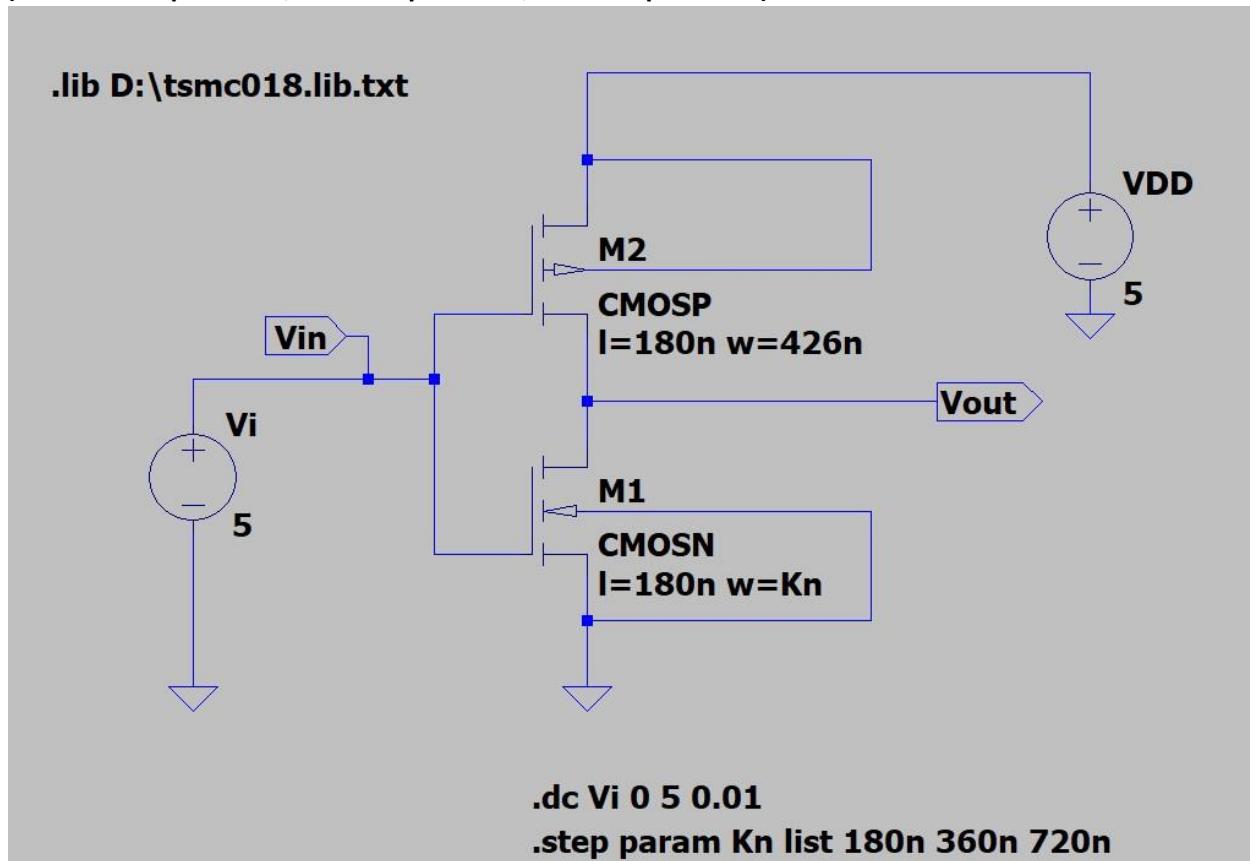
3	4	568.11μW
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1.c.

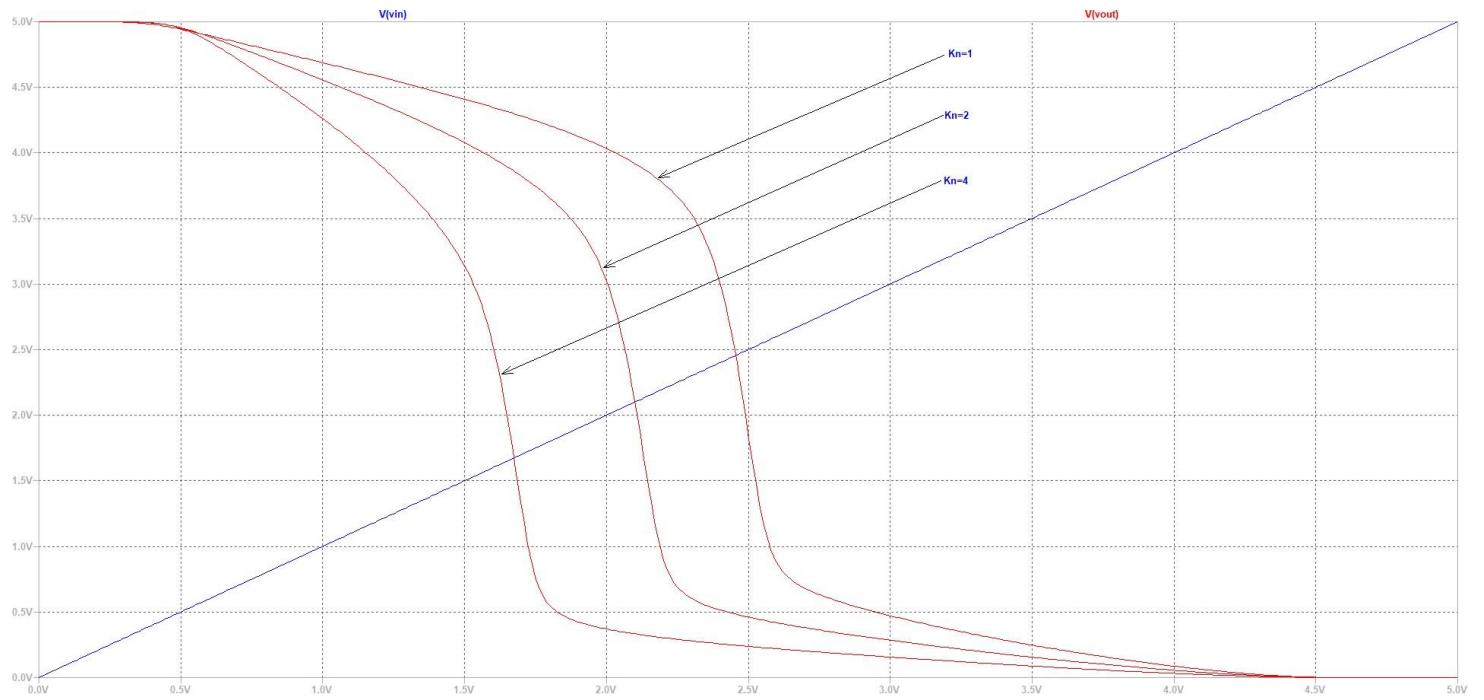
(Que) Simulate the static VTC of an inverter in which the NMOS is sized K_n times the size of the corresponding NMOS of the minimum-sized inverter for $K_n = 1, 2, 4$, keeping the size of the PMOS the same as that of the corresponding PMOS of the minimum-sized inverter.

Circuit:

(For Kn=1 - Wp=180nm, Kn=2 - Wp=360nm, Kn=4 - Wp=720nm)



VTC:

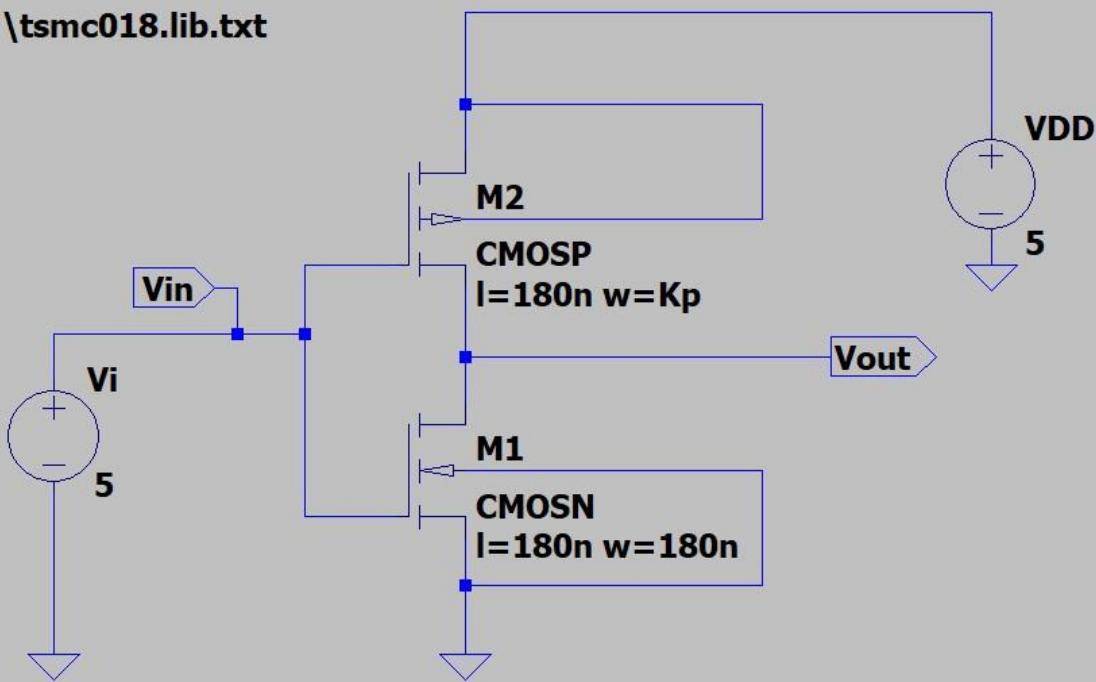


(Que) Similarly, simulate the static VTC of an inverter in which the PMOS is sized K_p times the size of the corresponding PMOS of the minimum-sized inverter for $K_p = 1, 2, 4$, keeping the size of the NMOS the same as that of the corresponding NMOS of the minimum-sized inverter.

Circuit:

(For $K_p=1$ - $W_p=426\text{nm}$, $K_p=2$ - $W_p=852\text{nm}$, $K_p=4$ - $W_p=1704\text{nm}$)

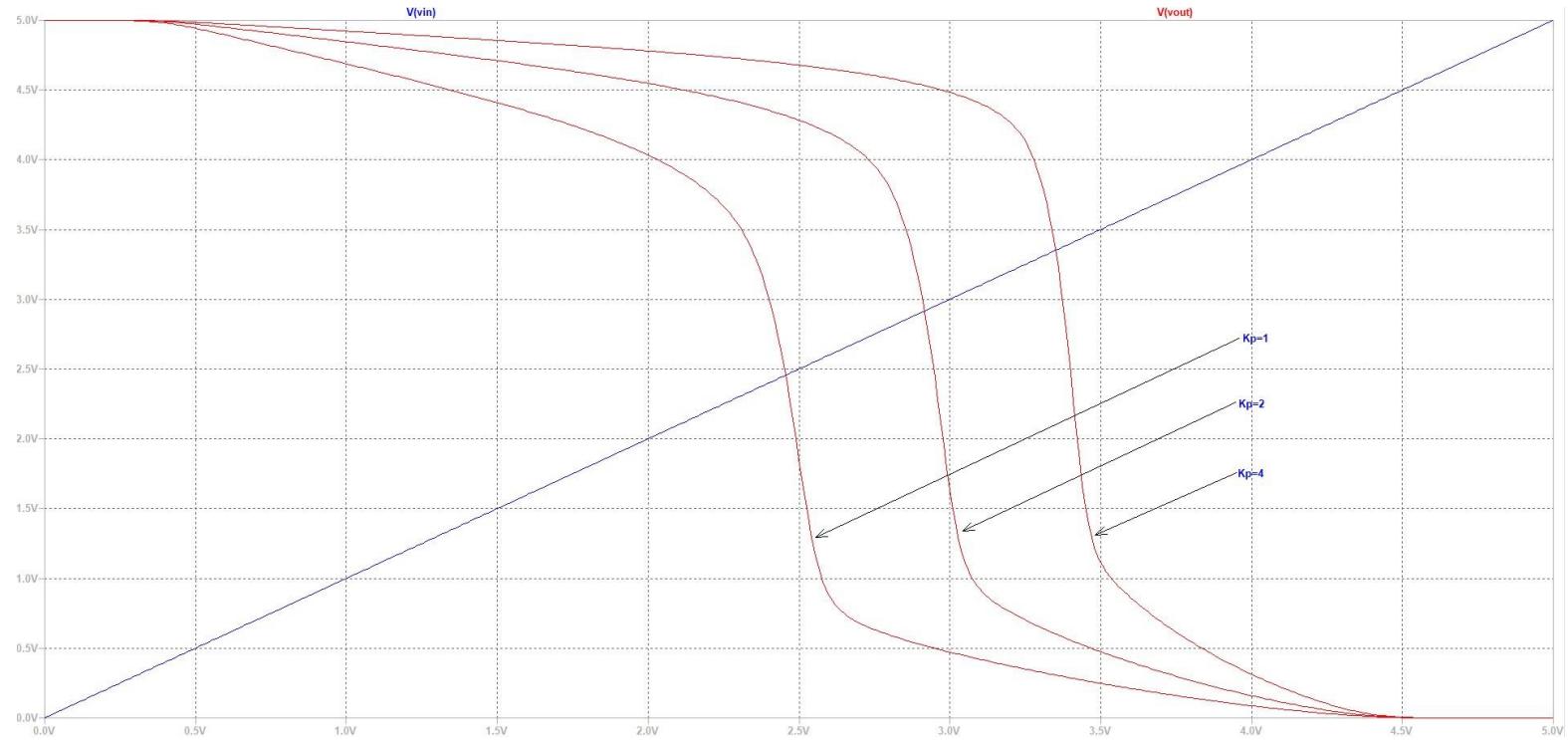
.lib D:\tsmc018.lib.txt



.dc Vi 0 5 0.01

.step param Kp list 426n 852n 1704n

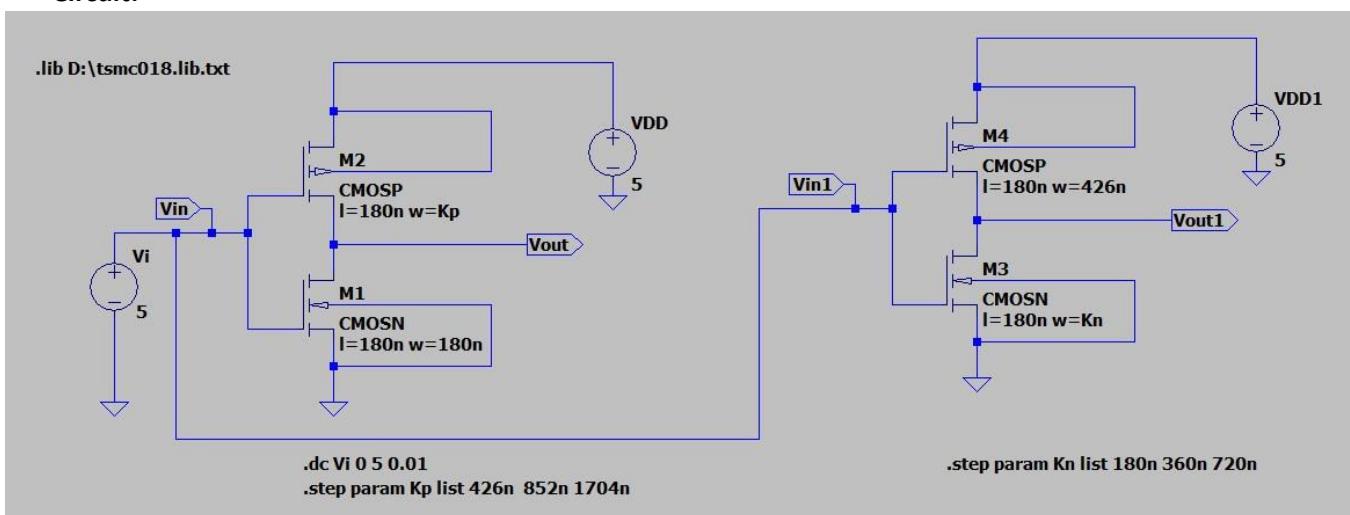
VTC:



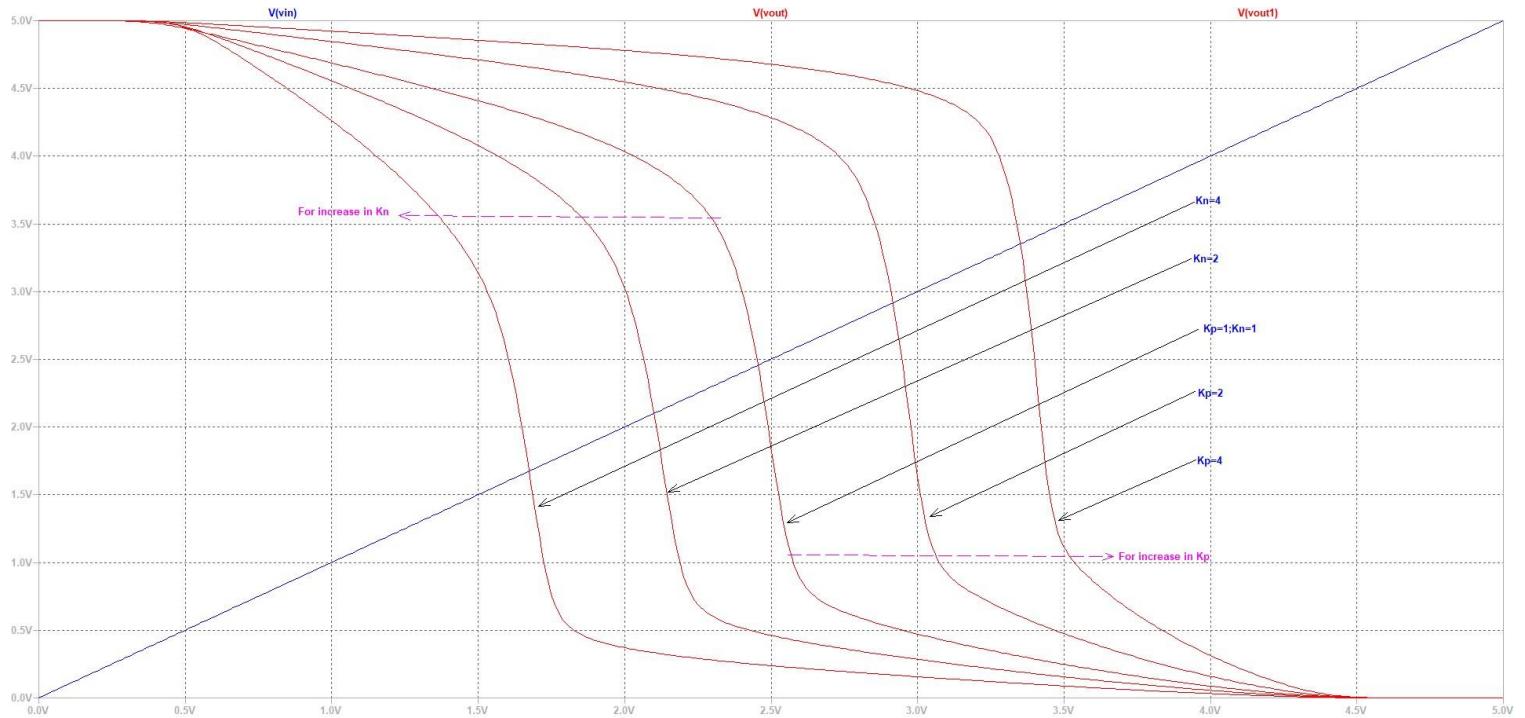
(Que) Plot all these VTCs in a single graph with clear legends indicating how sizing of skewed CMOS inverter affects the VTC.

To plot all VTCs together, CMOS inverter circuit is duplicated. In 1st circuit, Wn is kept constant that of minimum sized inverter (180nm) & Kp is varied. In 2nd circuit, Wp is kept constant that of minimum sized inverter (426nm) & Kn is varied.

Circuit:



VTC:

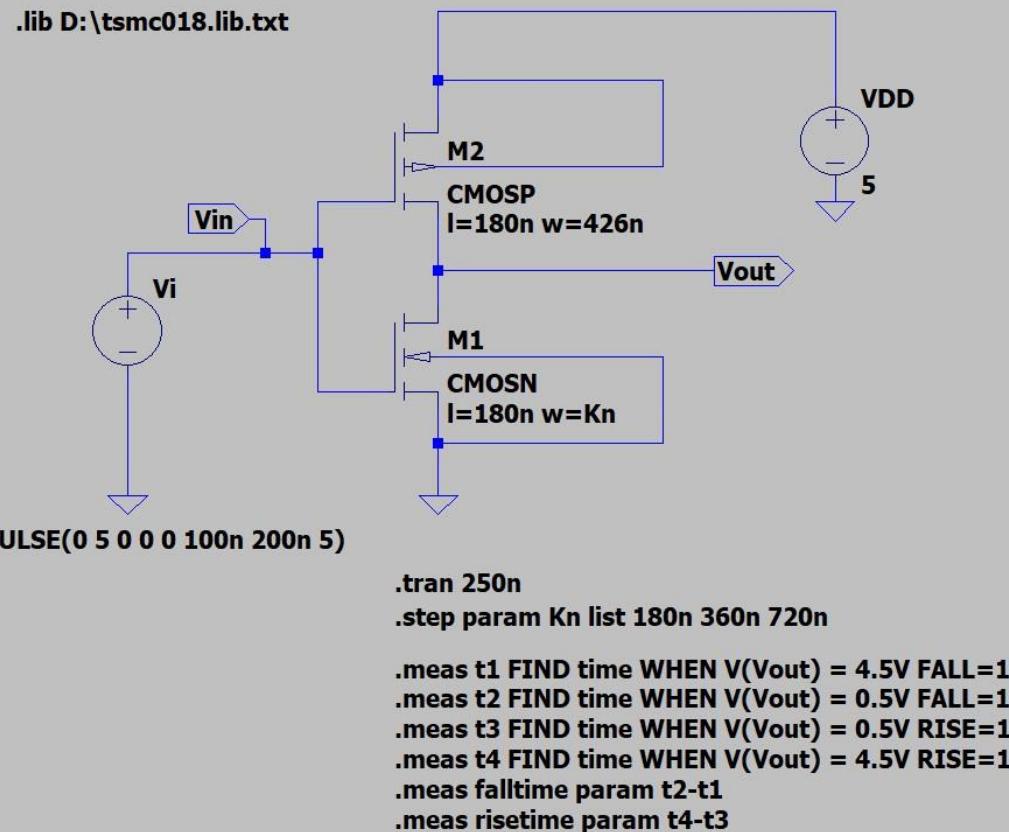


Observation: VTC shifts to left for increasing K_n values & shifts to right for increasing K_p values.

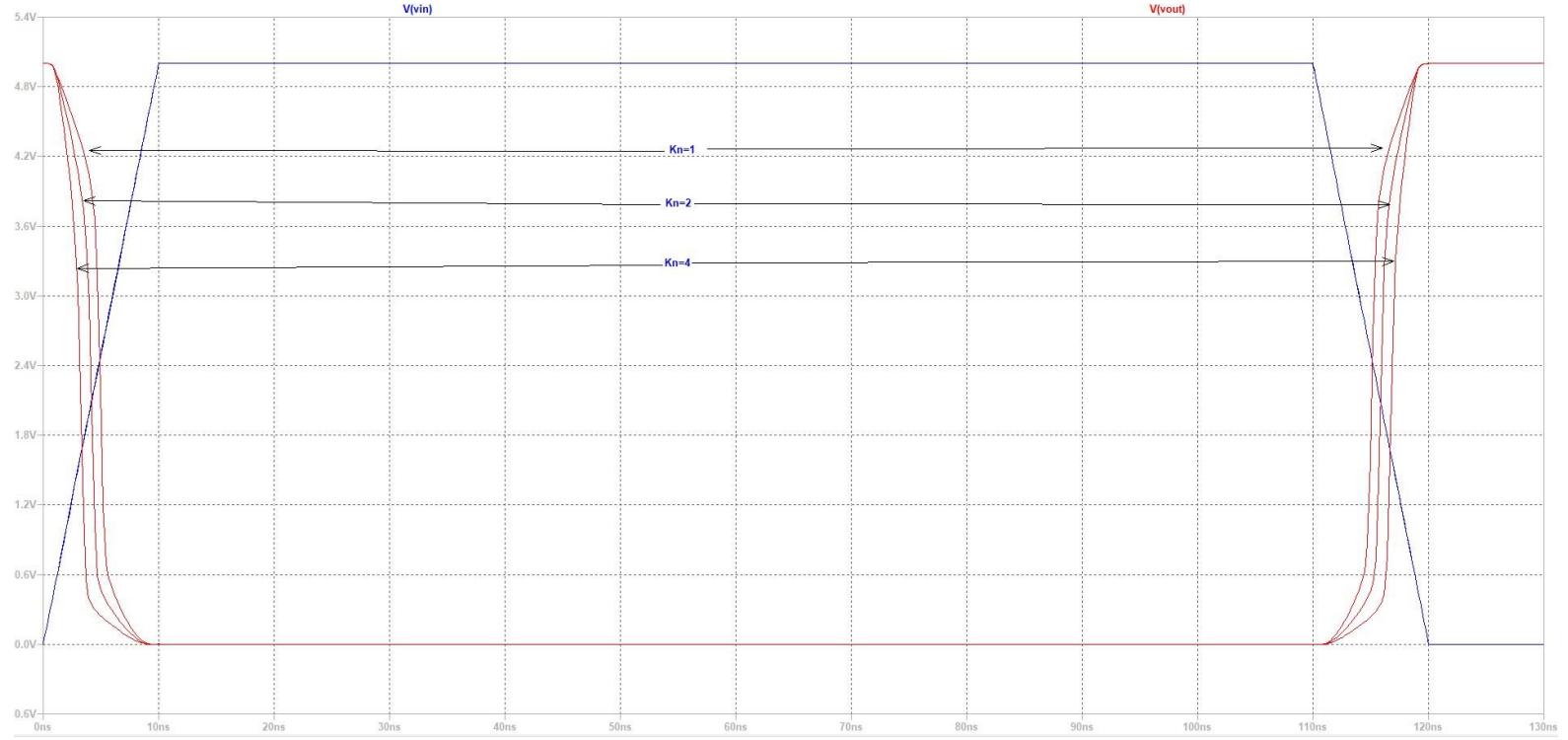
1.d.

(Que) Carry out transient analysis to find out the rise time and fall time delays in each case when **Case (i) no external capacitor is attached**

Part(i) Kn is varied Circuit:



Timing Diagram:



(Que) Tabulate the rise time and fall time delays obtained.

Rise & Fall Times: (For Kn=1, Kn=2, Kn=4)

```

LT SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log

Measurement: t4
step          time           at
  1           1.17322e-07   1.17322e-07
  2           1.17885e-07   1.17885e-07
  3           1.18318e-07   1.18318e-07

Measurement: falltime
step          t2-t1
  1           3.22017e-09
  2           2.77454e-09
  3           2.0887e-09

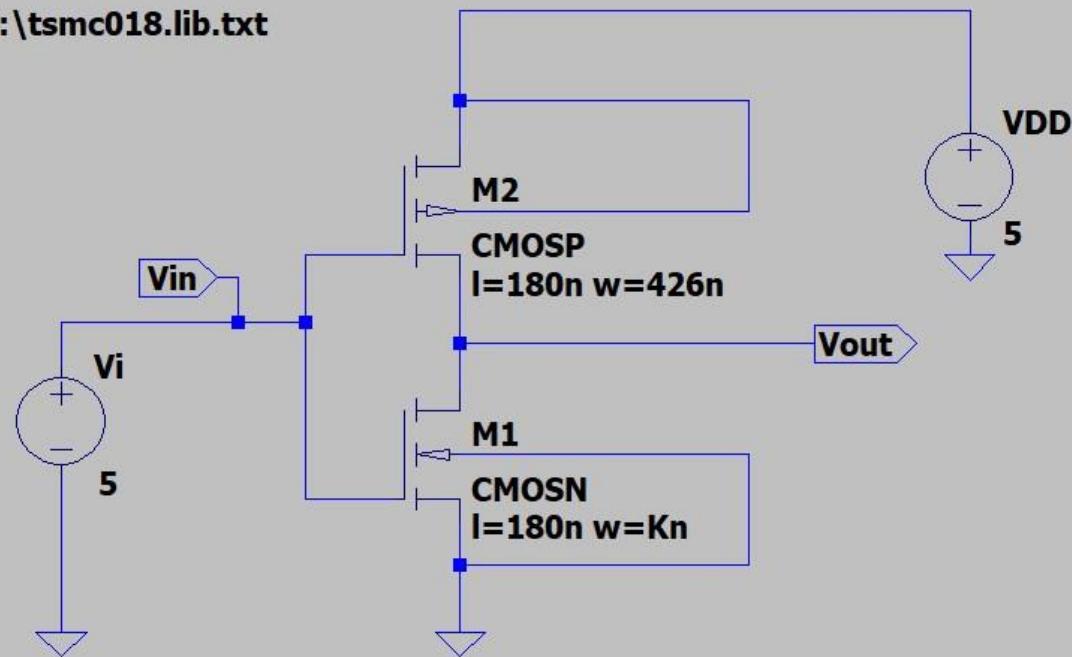
Measurement: risetime
step          t4-t3
  1           3.22665e-09
  2           2.77031e-09
  3           2.10259e-09

```

(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends.

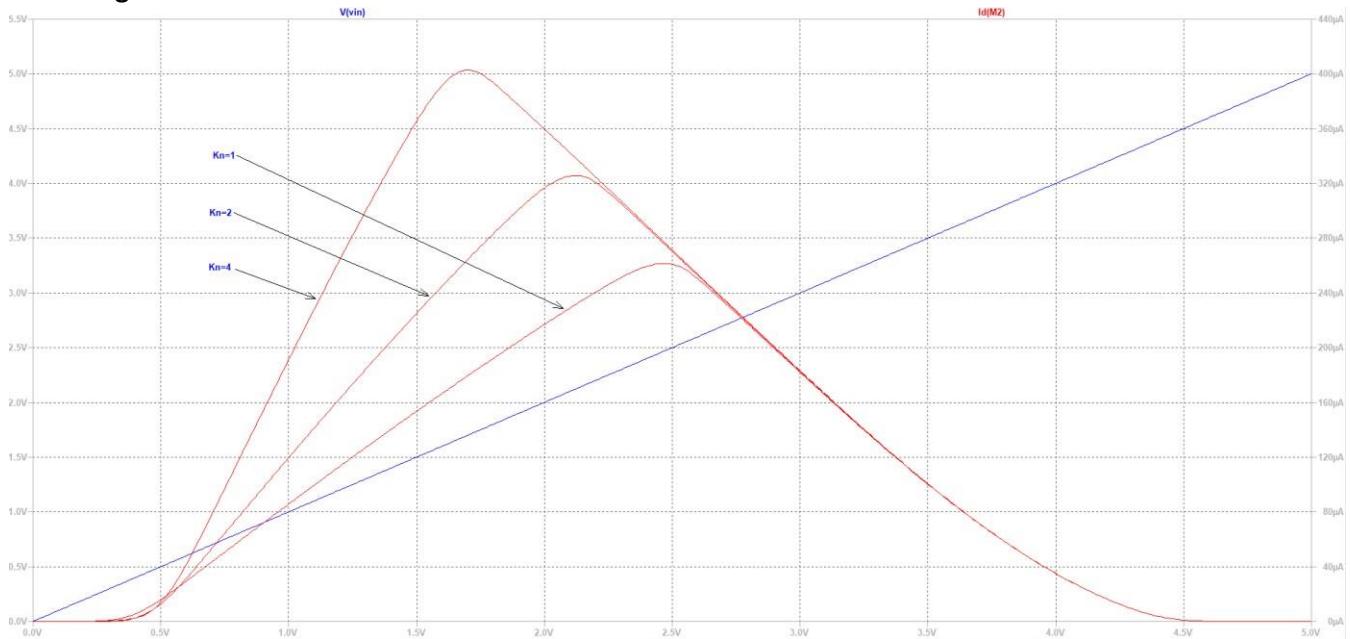
Circuit: (Kn is varied)

.lib D:\tsmc018.lib.txt



.dc V_i 0 5 0.01
.step param Kn list 180n 360n 720n

Voltage Vs Current:



Static & Dynamic Power Tables:

(Note: Static & Dynamic powers are calculated using same process as that of question 1.b part)

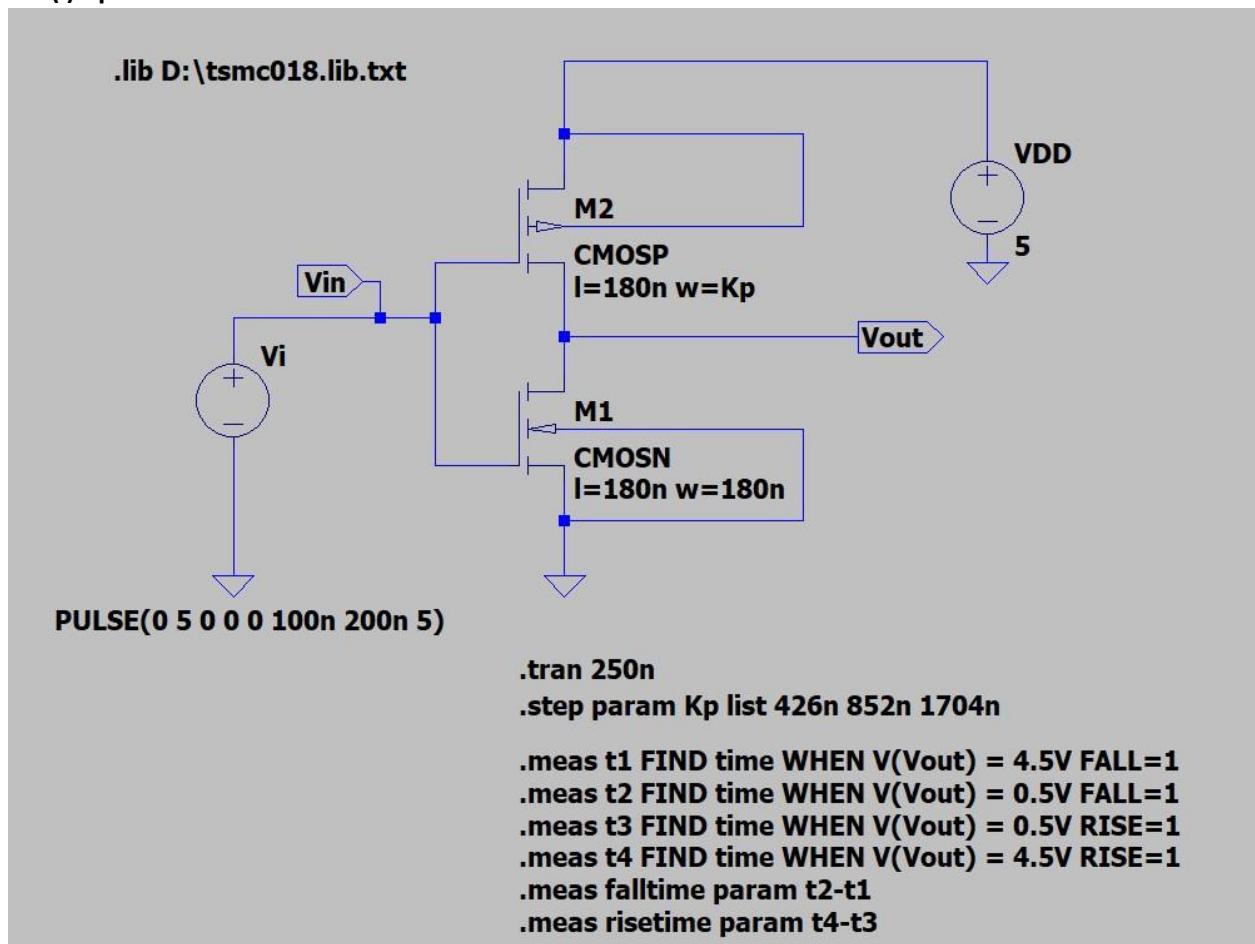
Static Power:**Static Power for Kn=1, Kn=2 & Kn=4 is calculated and tabulated as follows:**

Sr. No.	Kn	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	561.35pW	64.466pW	0.313nW
3	4	381.32pW	64.466pW	0.223nW

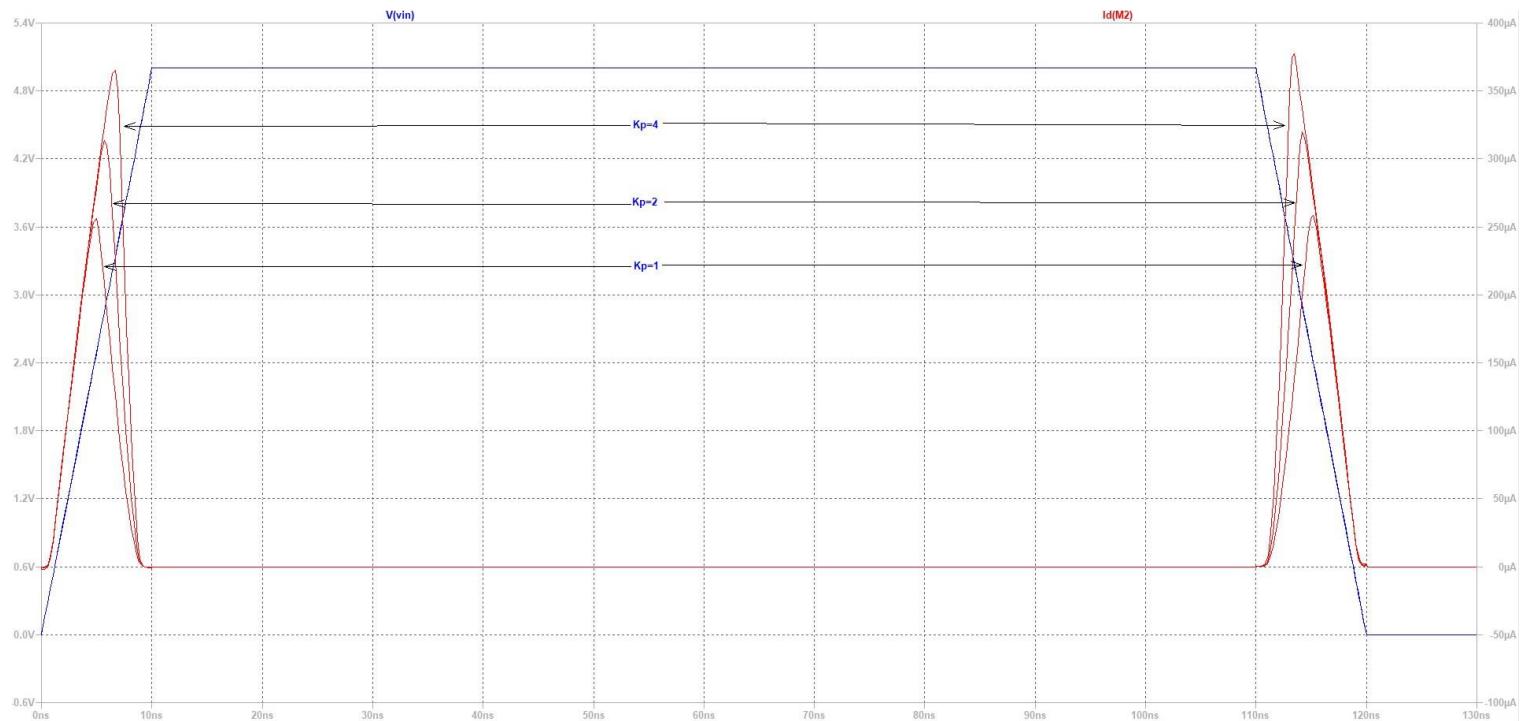
Dynamic Power:**Dynamic Power for Kn=1, Kn=2 & Kn=4 is calculated and tabulated as follows:**

Sr. No.	Kn	Dynamic Power
1	1	62.748μW
2	2	75.891μW
3	4	91.733μW

Part(i) K_p is varied Circuit:



Timing Diagram:



(Que) Tabulate the rise time and fall time delays obtained.

Rise & Fall Times: (For Kp=1, Kp=2, Kp=4)

```
tspice018.lib.txt
SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log

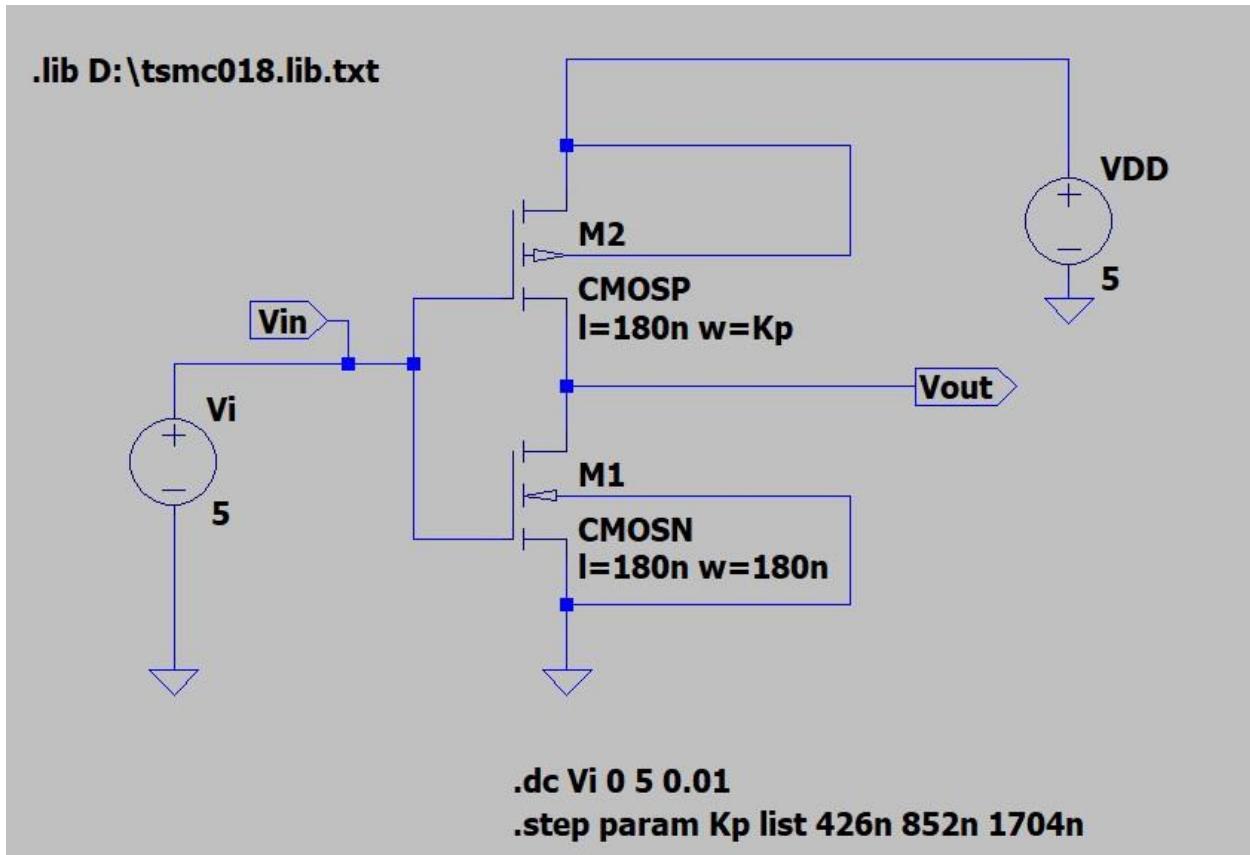
Measurement: t4
step          time          at
 1           1.17322e-07   1.17322e-07
 2           1.15786e-07   1.15786e-07
 3           1.14095e-07   1.14095e-07

Measurement: falltime
step          t2-t1
 1           3.22017e-09
 2           2.71576e-09
 3           1.75681e-09

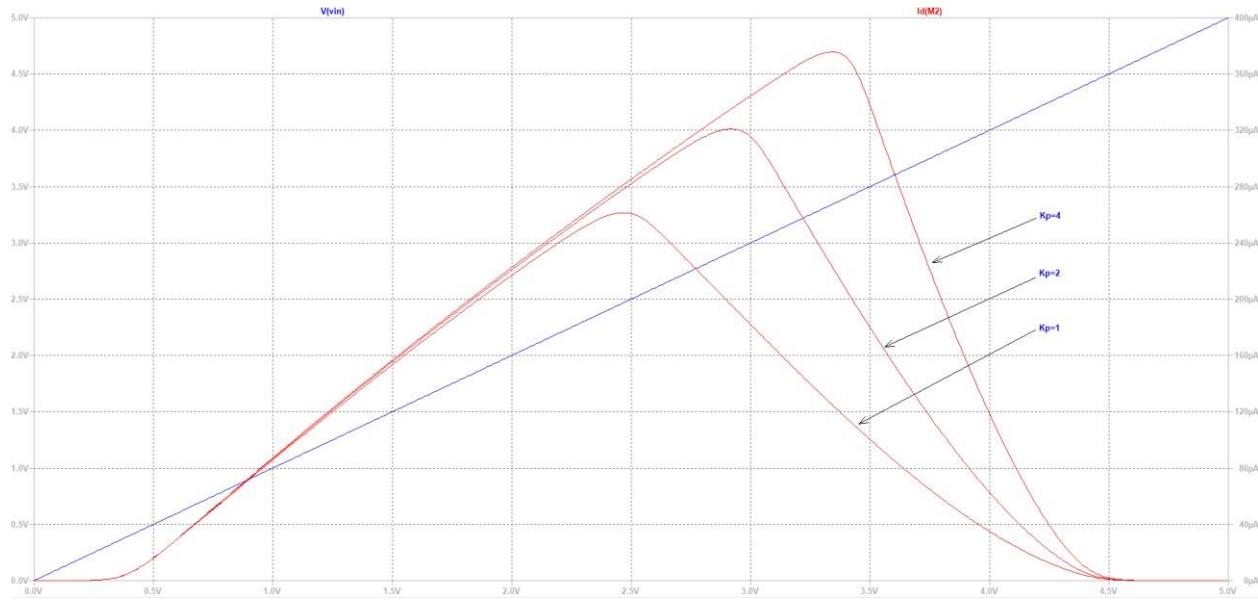
Measurement: risetime
step          t4-t3
 1           3.22665e-09
 2           2.72522e-09
 3           1.7653e-09
```

(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends.

Circuit: (Kp is varied)



Voltage Vs Current:



Static & Dynamic Power Tables:

(Note: Static & Dynamic powers are calculated using same process as that of question 1.b part)

Static Power:

Static Power for Kp=1, Kp=2 & Kp=4 is calculated and tabulated as follows:

Sr. No.	Kp	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	2.2699nW	67.019pW	1.168nW
3	4	2.2699nW	86.055pW	1.178nW

Dynamic Power:

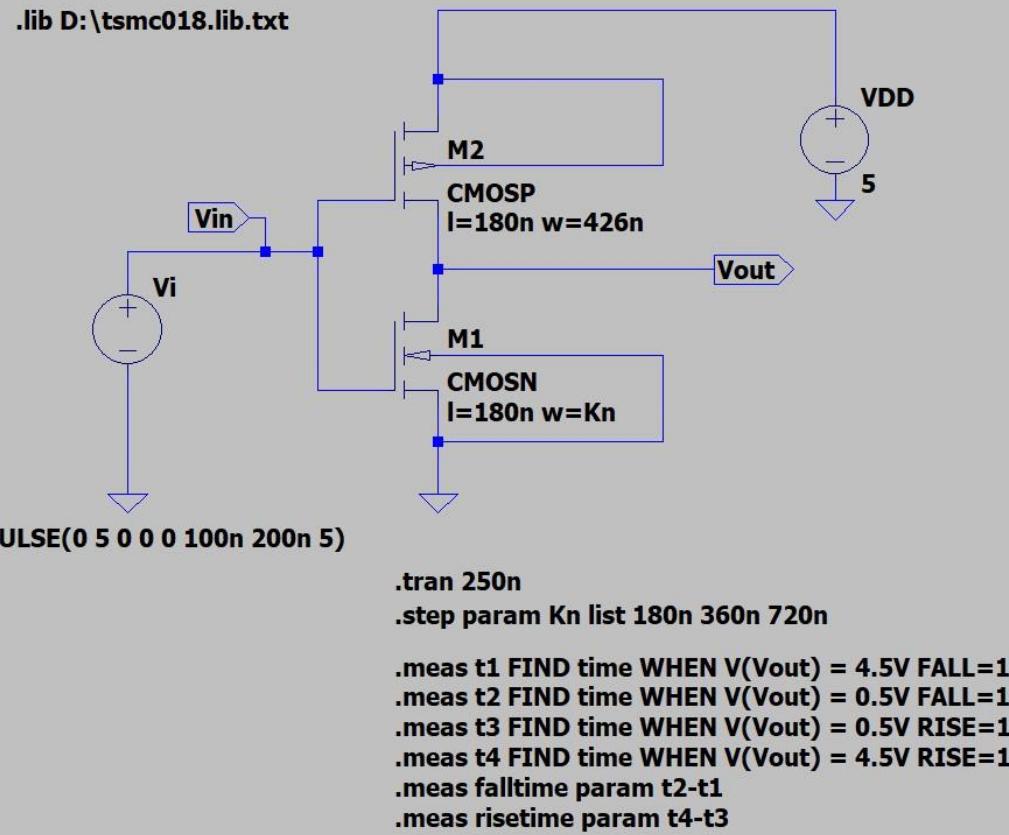
Dynamic Power for Kp=1, Kp=2 & Kp=4 is calculated and tabulated as follows:

Sr. No.	Kp	Dynamic Power
1	1	62.748μW
2	2	78.705μW
3	4	93.802μW

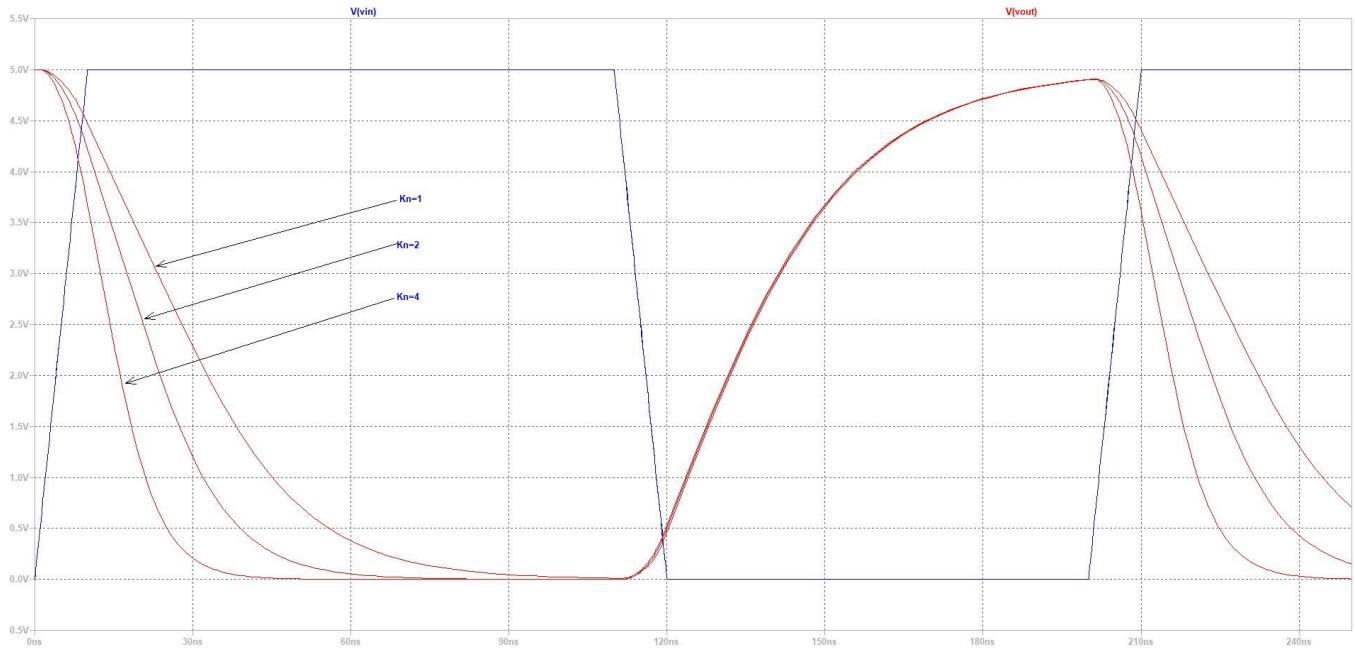
1.d.

Case (ii) 5pF external capacitor is attached

Part(i) Kn is varied Circuit:



Timing Diagram:



(Que) Tabulate the rise time and fall time delays obtained.

Rise & Fall Times: (For Kn=1, Kn=2, Kn=4)

```

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log

step          time          at
 1           1.69217e-07   1.69217e-07
 2           1.69421e-07   1.69421e-07
 3           1.69711e-07   1.69711e-07

Measurement: falltime
step          t2-t1
 1           4.60702e-08
 2           3.08452e-08
 3           1.87046e-08

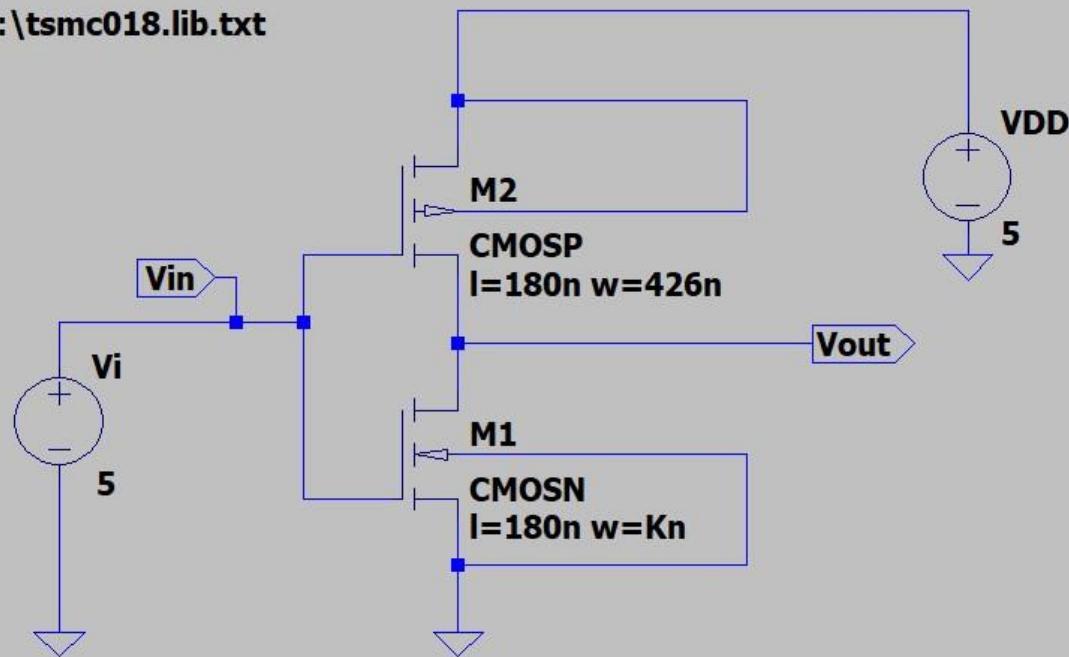
Measurement: risetime
step          t4-t3
 1           4.94349e-08
 2           4.94319e-08
 3           4.94336e-08

```

(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends.

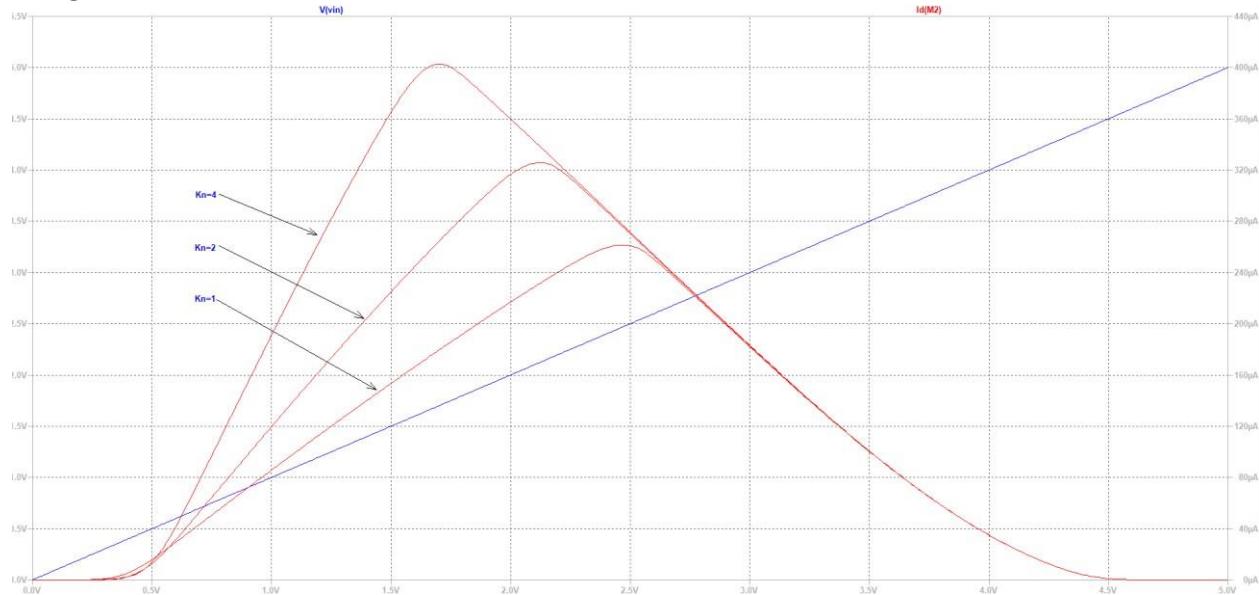
Circuit: (Kn is varied)

.lib D:\tsmc018.lib.txt



.dc V_i 0 5 0.01
.step param Kn list 180n 360n 720n

Voltage Vs Current:



Static & Dynamic Power Tables:

(Note: Static & Dynamic powers are calculated using same process as that of question 1.b part)

Static Power:

Static Power for Kn=1, Kn=2 & Kn=4 is calculated and tabulated as follows:

Sr. No.	Kn	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	561.35pW	64.466pW	0.312nW
3	4	381.32pW	64.466pW	0.223nW

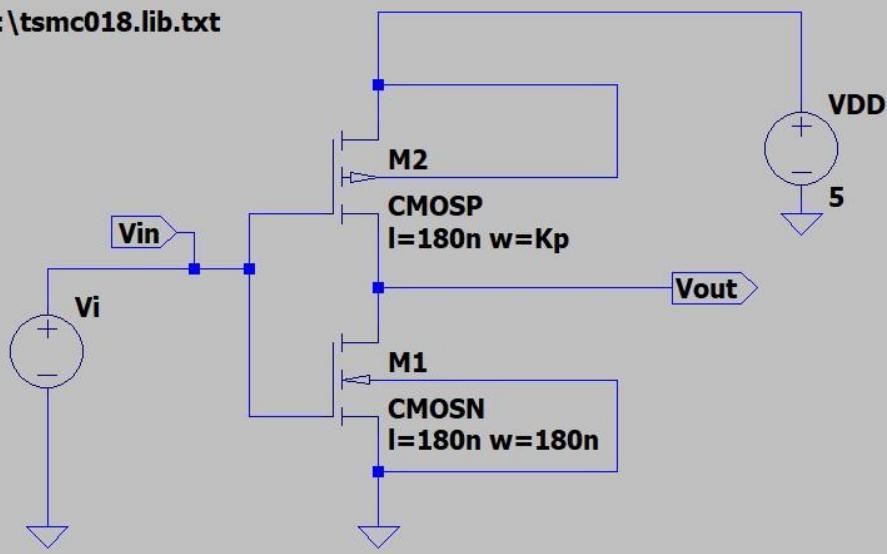
Dynamic Power:

Dynamic Power for Kn=1, Kn=2 & Kn=4 is calculated and tabulated as follows:

Sr. No.	Kn	Dynamic Power
1	1	504.05μW
2	2	509.07μW
3	4	516.98μW

Part(i) Kp is varied Circuit:

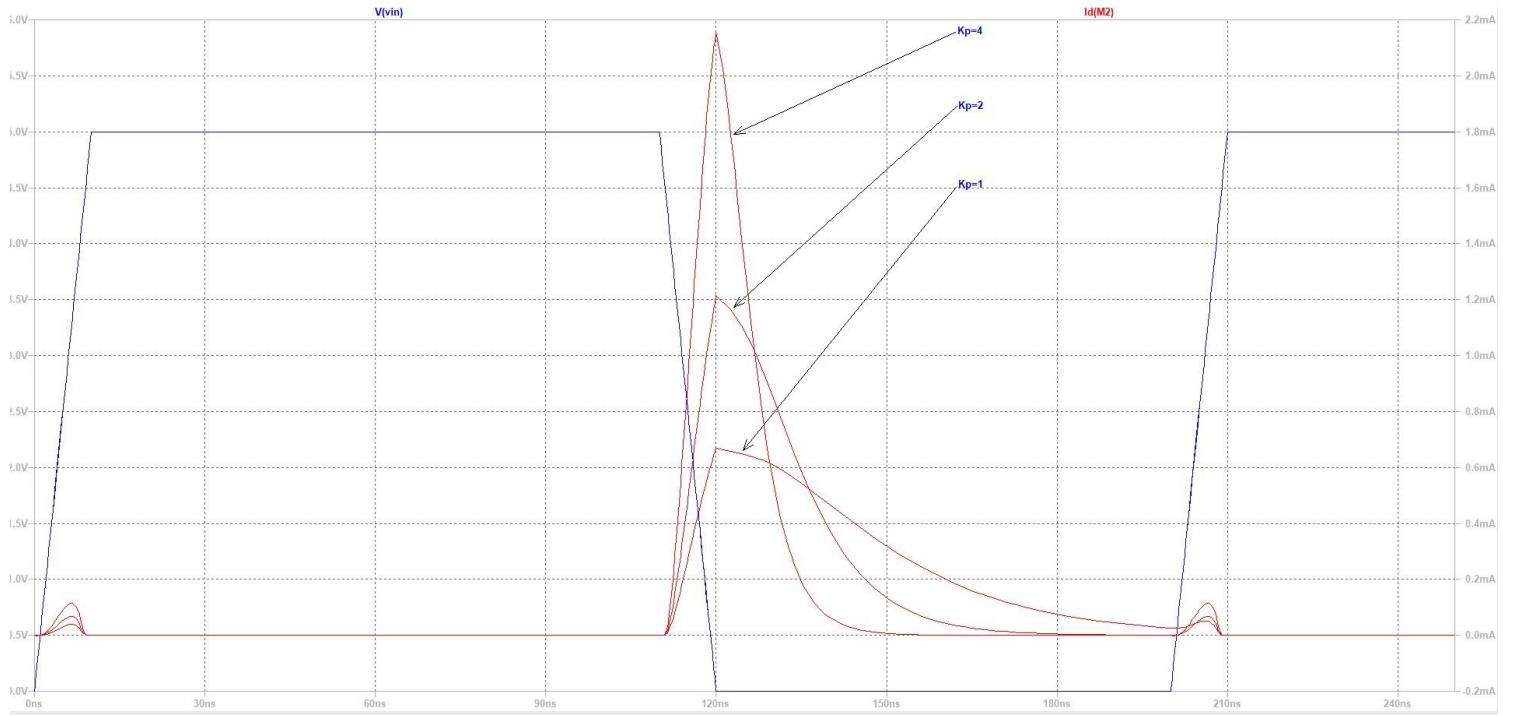
.lib D:\tsmc018.lib.txt



PULSE(0 5 0 0 0 100n 200n 5)

```
.tran 250n
.step param Kp list 426n 852n 1704n
.meas t1 FIND time WHEN V(Vout) = 4.5V FALL=1
.meas t2 FIND time WHEN V(Vout) = 0.5V FALL=1
.meas t3 FIND time WHEN V(Vout) = 0.5V RISE=1
.meas t4 FIND time WHEN V(Vout) = 4.5V RISE=1
.meas falltime param t2-t1
.meas risetime param t4-t3
```

Timing Diagram:



(Que) Tabulate the rise time and fall time delays obtained.

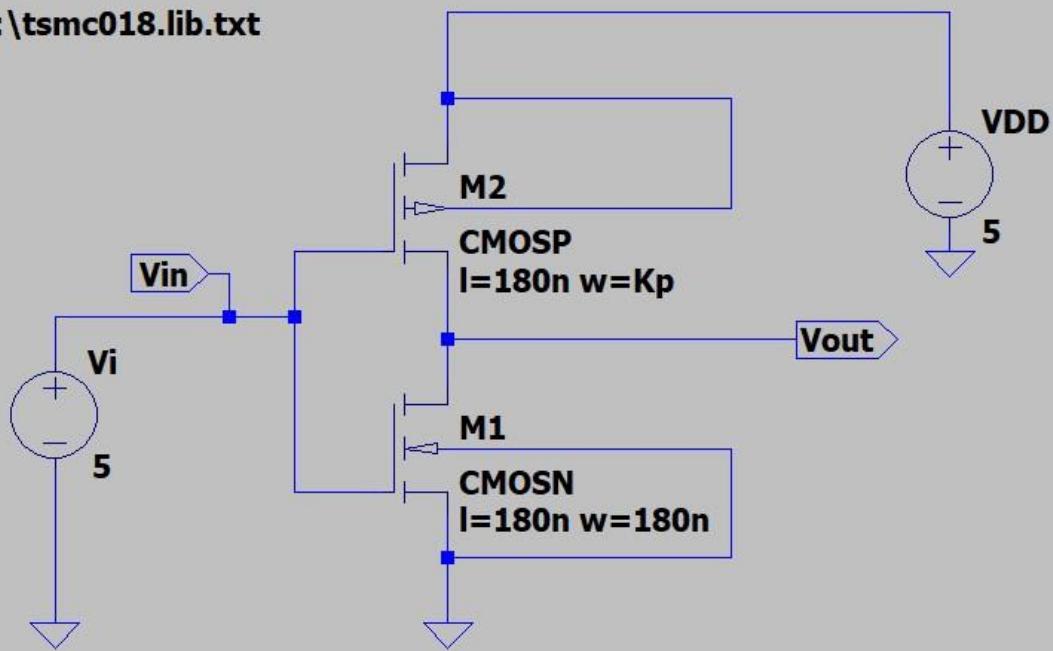
Rise & Fall Times: (For Kp=1, Kp=2, Kp=4)

SPICE Error Log: C:\Users\winay\AppData\Local\LTspice\Project.log		
Measurement: t4		
step	time	at
1	1.69217e-07	1.69217e-07
2	1.43392e-07	1.43392e-07
3	1.30162e-07	1.30162e-07
Measurement: falltime		
step	t2-t1	
1	4.60702e-08	
2	4.60692e-08	
3	4.60708e-08	
Measurement: risetime		
step	t4-t3	
1	4.94349e-08	
2	2.55754e-08	
3	1.4014e-08	

(Que) Find out the current drawn from the power supply in all cases as the input voltage is swept slowly w.r.t the output, and plot the current vs input voltage in a single graph with clear legends.

Circuit: (Kp is varied)

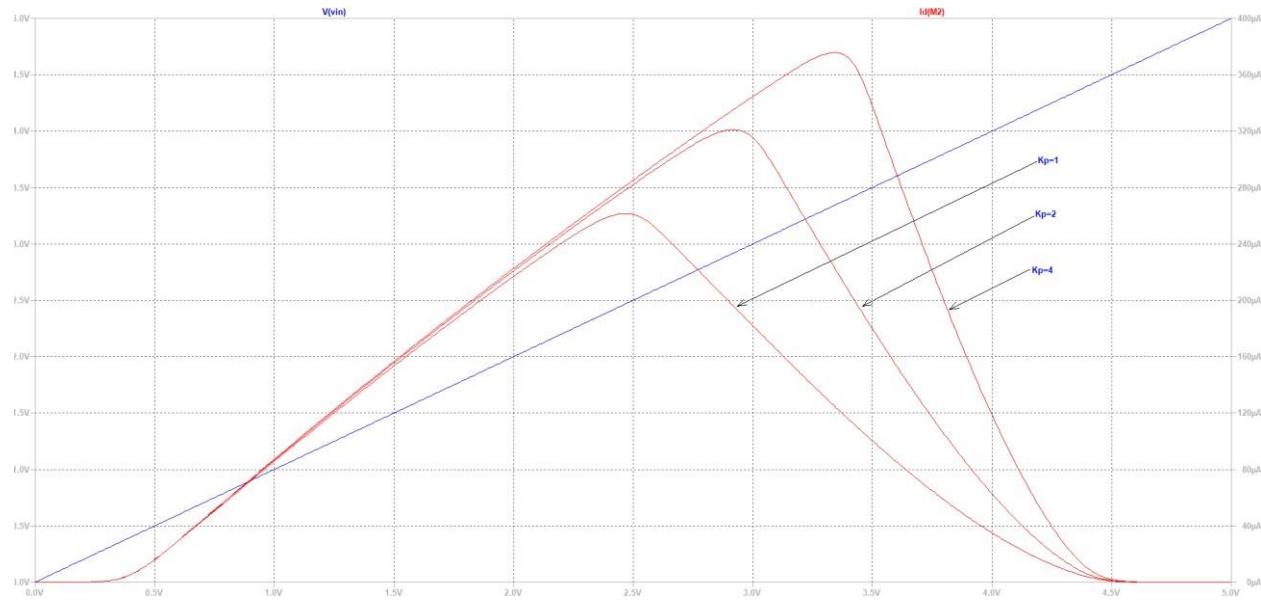
.lib D:\tsmc018.lib.txt



.dc Vi 0 5 0.01

.step param Kp list 426n 852n 1704n

Voltage Vs Current:



Static & Dynamic Power Tables:

(Note: Static & Dynamic powers are calculated using same process as that of question 1.b part)

Static Power:

Static Power for Kp=1, Kp=2 & Kp=4 is calculated and tabulated as follows:

Sr. No.	Kp	Power @ Vin = 0V	Power @ Vin = 5V	Static Power
1	1	2.2699nW	64.466pW	1.167nW
2	2	2.2699nW	67.019pW	1.168nW
3	4	2.2699nW	86.055pW	1.178nW

Dynamic Power:

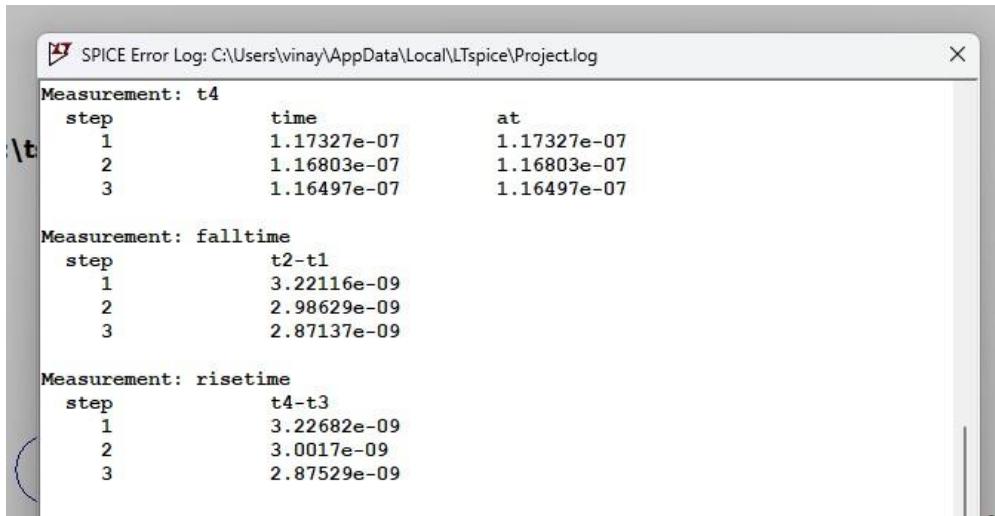
Dynamic Power for Kp=1, Kp=2 & Kp=4 is calculated and tabulated as follows:

Sr. No.	Kp	Dynamic Power
1	1	504.05μW
2	2	518.34μW
3	4	530.16μW

1.e.

Create a circuit consisting of a NMOS pass transistor having size Kn=1,2,4, driving an NMOS inverter of minimum size connected to the source/drain of the NMOS pass transistor (choose the resistor value in the NMOS inverter to have equal rise and fall times which also should be equal to that of a minimumsized symmetrical CMOS inverter).

From result 1.b. - Rise & Fall Delays for minimum sized CMOS inverter: (3.22nsec for S=1)



```
SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Project.log

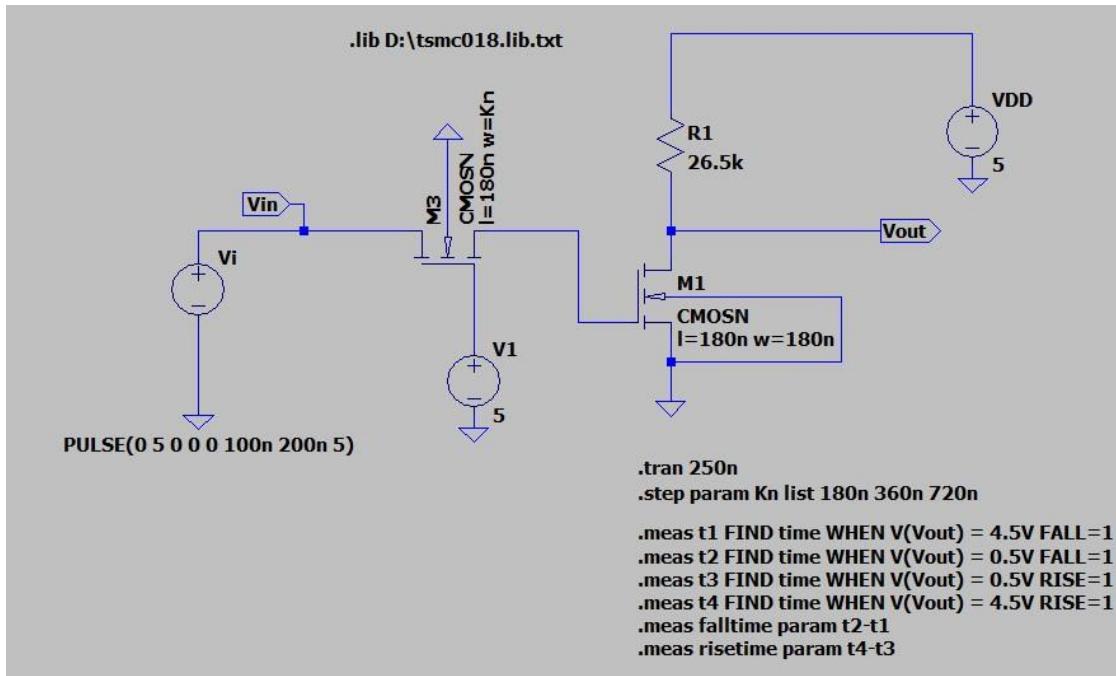
Measurement: t4
step      time      at
 1        1.17327e-07  1.17327e-07
 2        1.16803e-07  1.16803e-07
 3        1.16497e-07  1.16497e-07

Measurement: falltime
step      t2-t1
 1        3.22116e-09
 2        2.98629e-09
 3        2.87137e-09

Measurement: risetime
step      t4-t3
 1        3.22682e-09
 2        3.0017e-09
 3        2.87529e-09
```

(Note: Delays are listed in order S=1, S=2 & S=4)

Now creating NMOS inverter with pass transistor for which rise & fall delays are matched with CMOS inverter:



Circuit:

Rise & Fall Delays-

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Eproject.log

```

Measurement: t4
step          time           at
  1           1.18955e-07   1.18955e-07
  2           1.18954e-07   1.18954e-07
  3           1.18954e-07   1.18954e-07

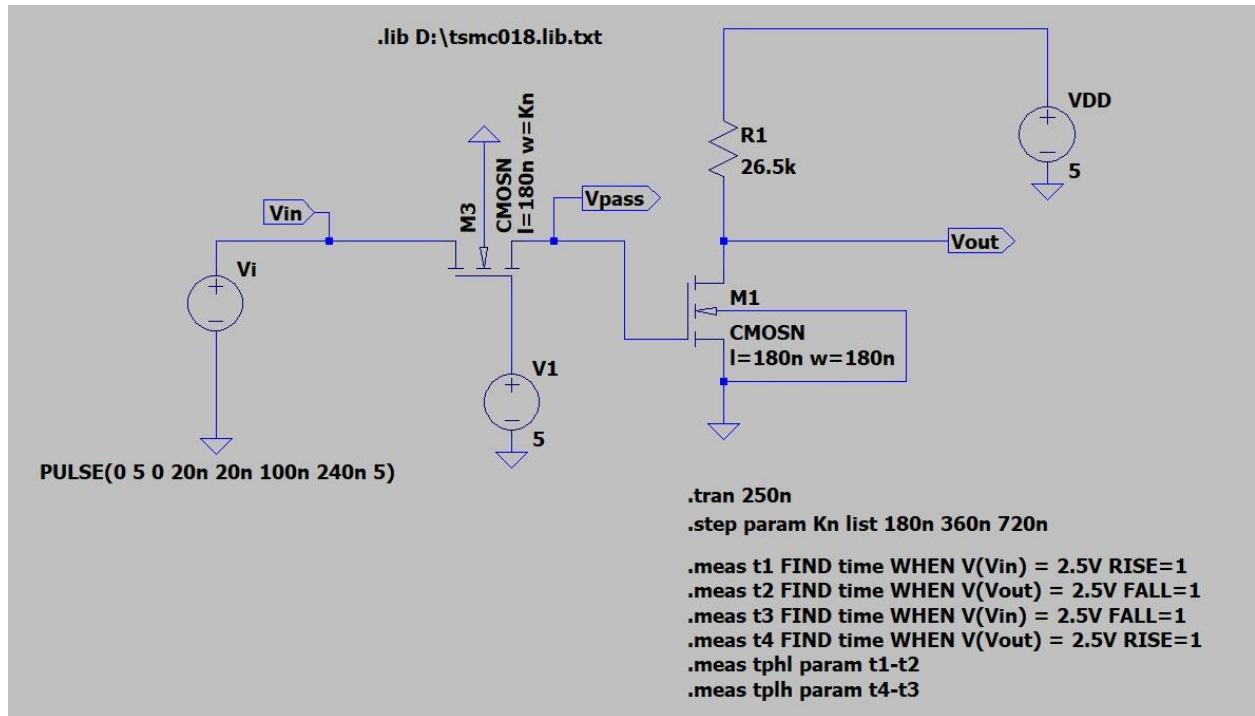
Measurement: falltime
step          t2-t1
  1           3.18833e-09
  2           3.18848e-09
  3           3.18862e-09

Measurement: risetime
step          t4-t3
  1           3.2106e-09
  2           3.21001e-09
  3           3.20956e-09

```

(Que) Apply an input signal to the source/drain of the NMOS pass transistor of which the gate is connected to VDD, and plot the voltage waveform at the input and output of the inverter and tabulate the delay at both the input and output of the inverter for all values of Kn, when the input signal varies slowly from (i) low to high, (ii) high to low.

Circuit:



Propagation Delays (From Vin to Vout):

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Eproject.log

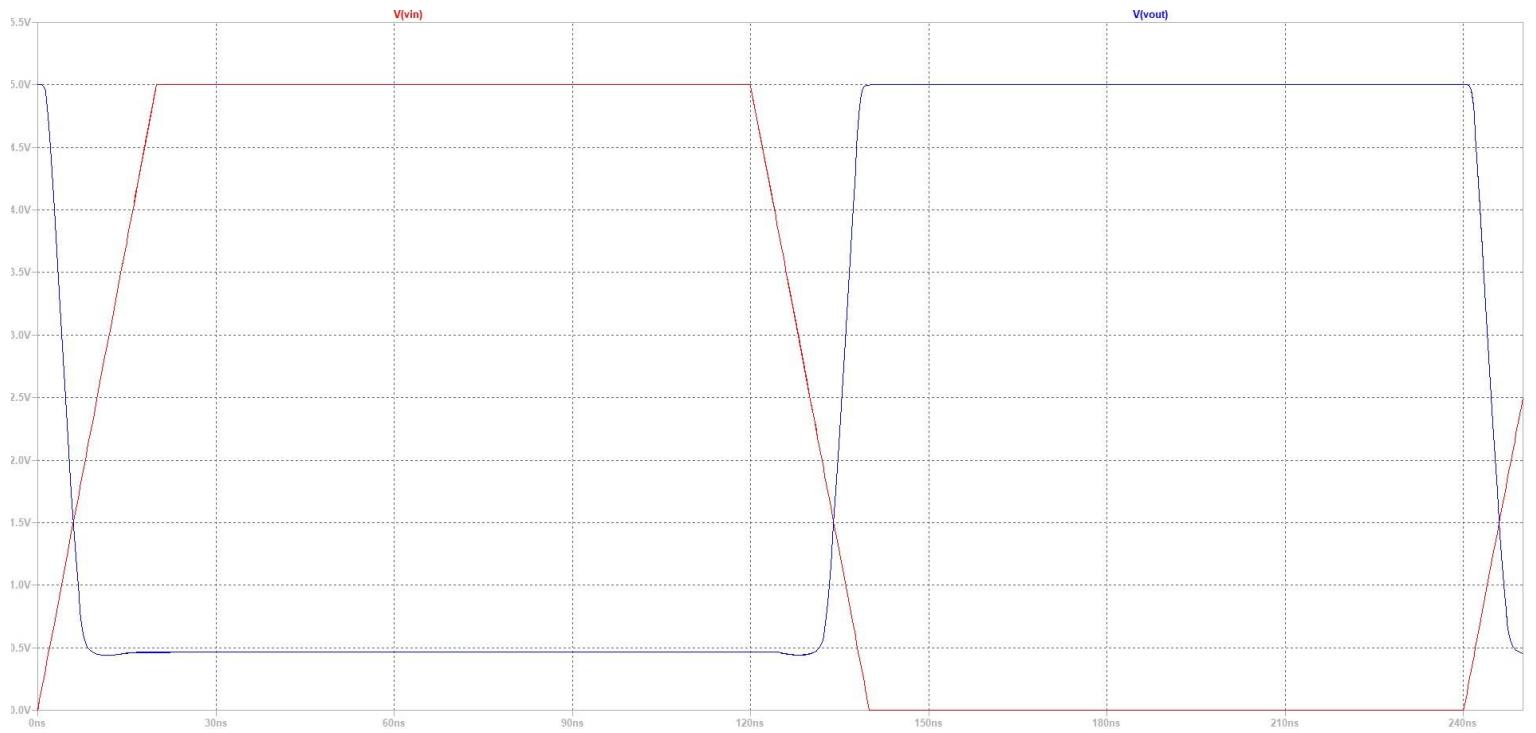
```

Measurement: tphl
step          t1-t2
 1            5.32241e-09
 2            5.32304e-09
 3            5.32353e-09

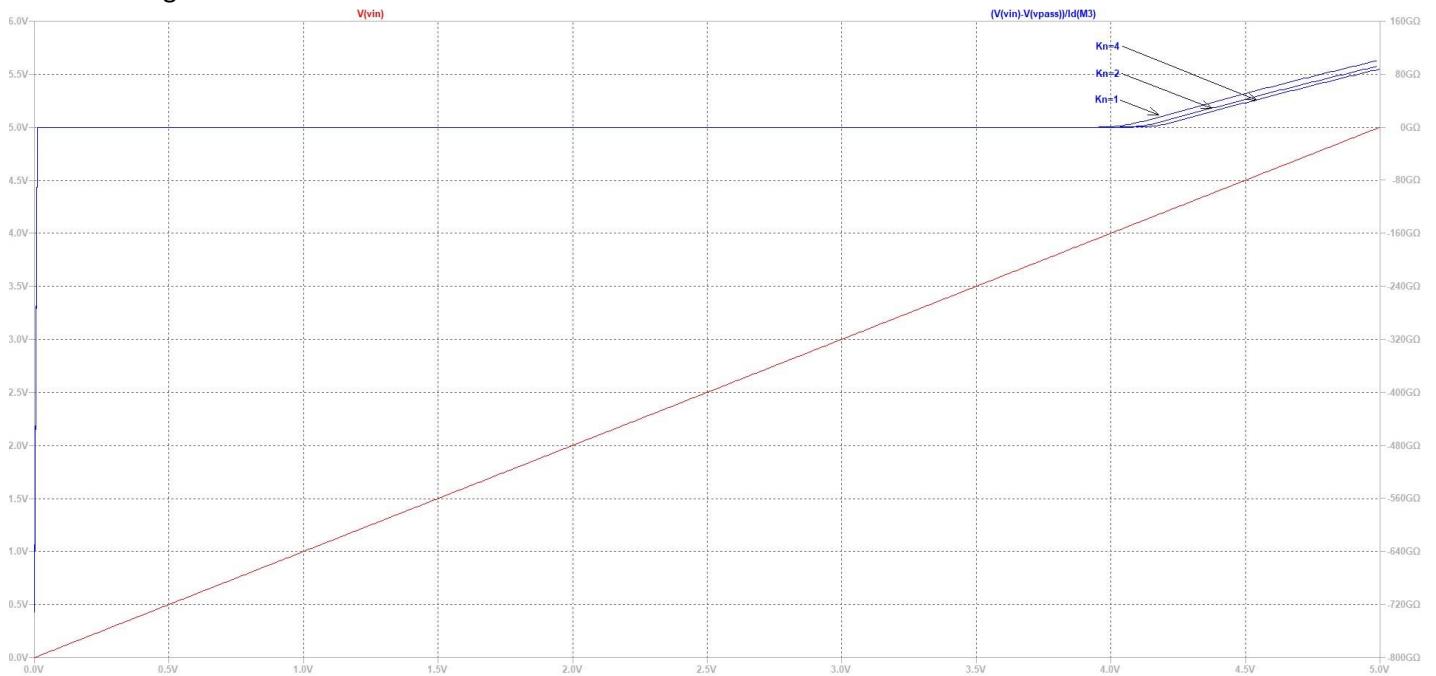
Measurement: tplh
step          t4-t3
 1            5.33575e-09
 2            5.33512e-09
 3            5.33462e-09

```

Timing Diagram:



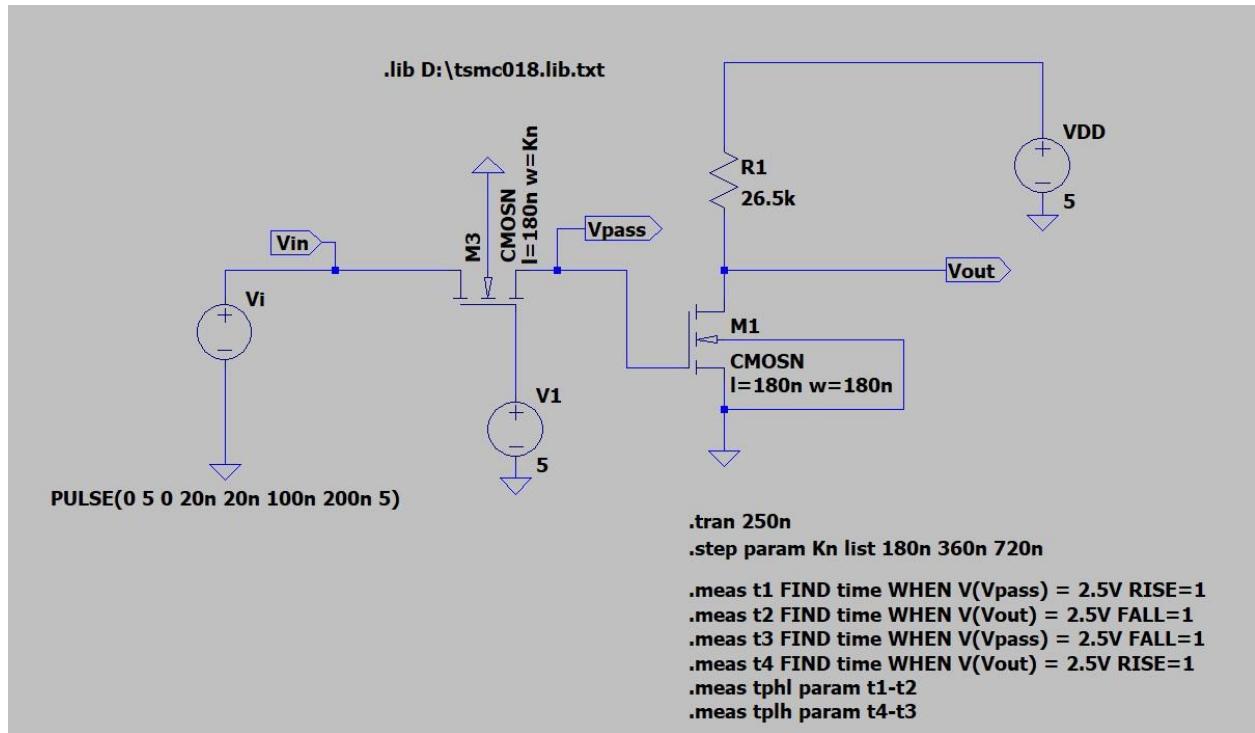
(Que) Plot the resistance of the pass transistor vs input voltage in a single graph with clearly labelled axes and legends for all values of K_n .



Observation: For increasing value of Kn, the resistance is decreasing.

(Que) Do another simulation to plot the voltage waveform at the input and output of the inverter and tabulate the delay at both the input and output of the inverter for all values of Kn, when the source/drain of the NMOS pass transistor is connected to VDD and the input signal which is applied to the gate of the NMOS pass transistor varies slowly from (i) low to high, (ii) high to low.

Circuit:



Propagation Delays (From Vpass to Vout):

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Eproject.log

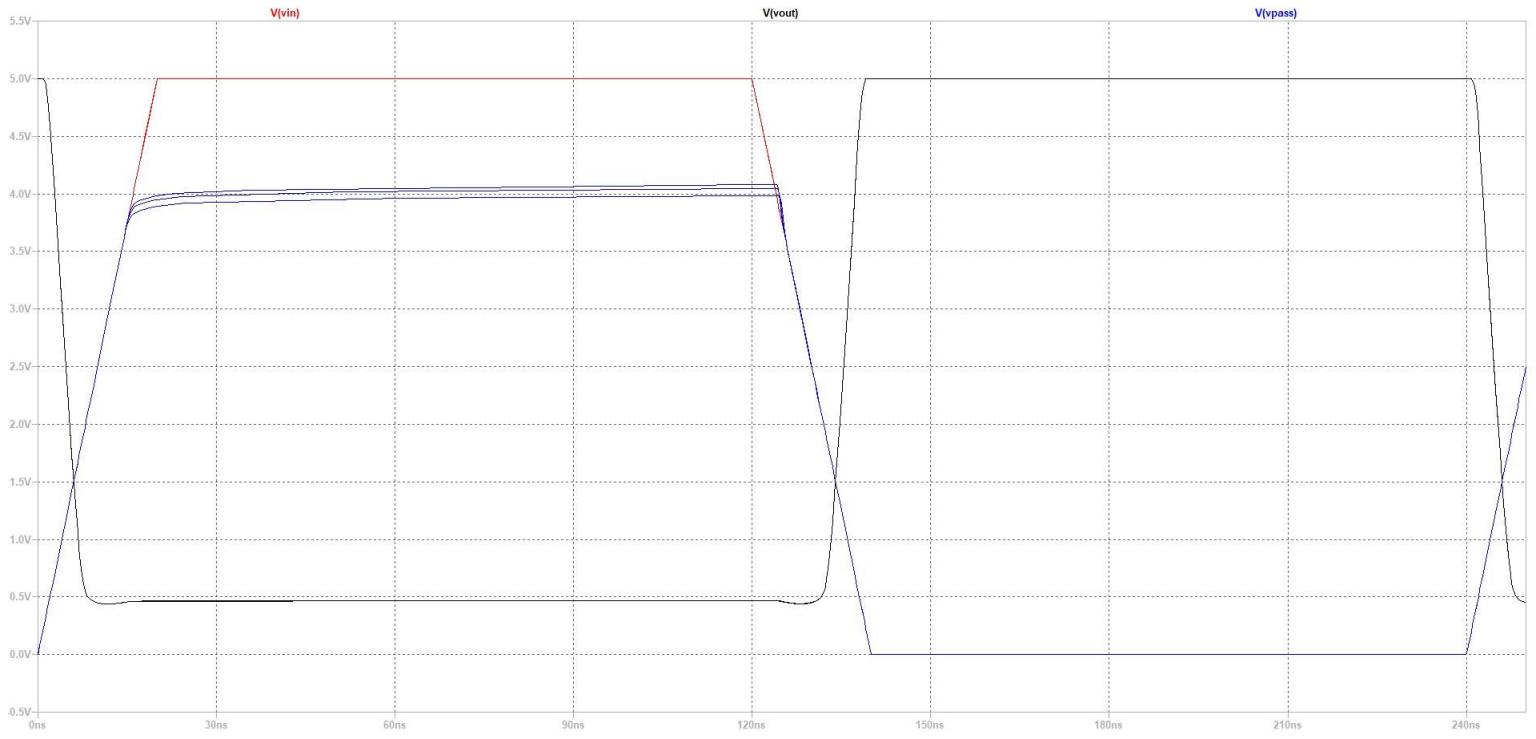
```

Measurement: tphl
step      t1-t2
 1        5.32455e-09
 2        5.32483e-09
 3        5.32508e-09

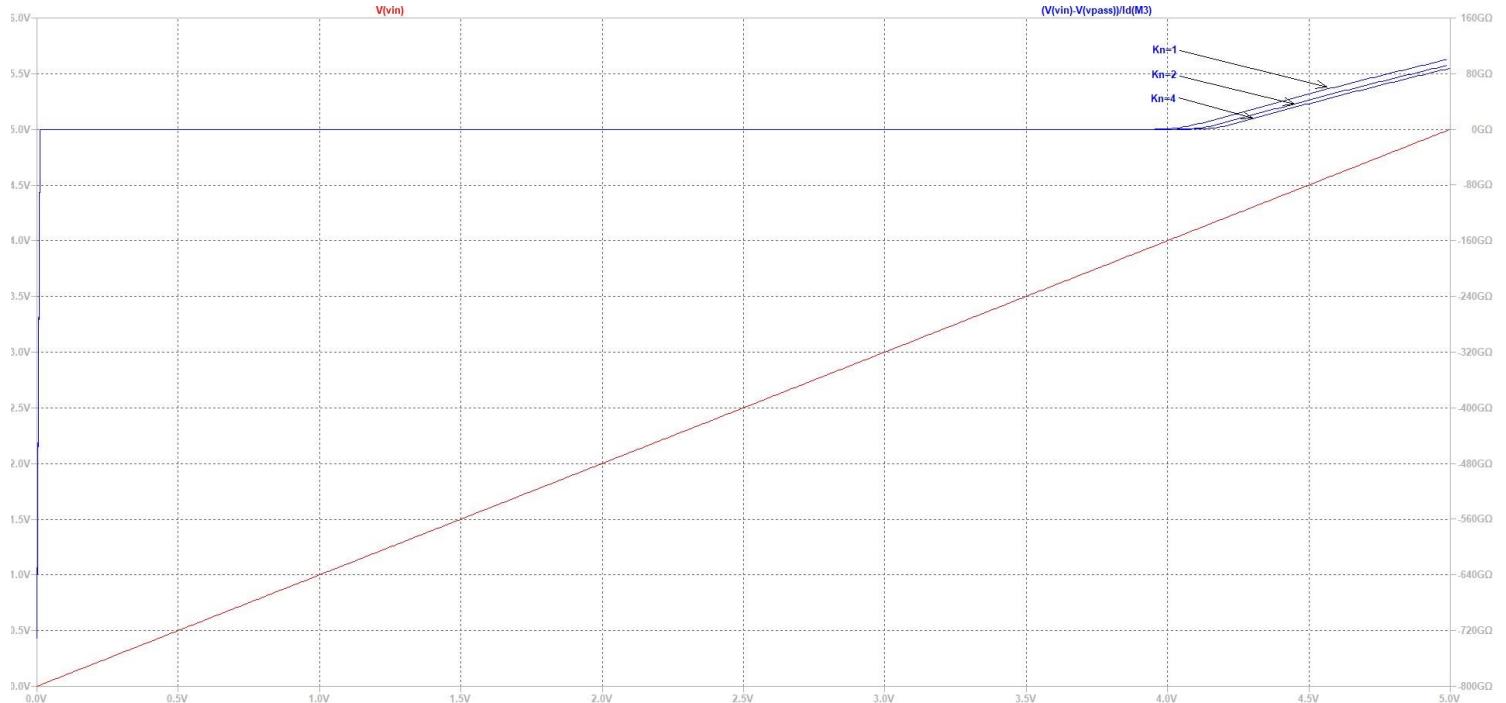
Measurement: tplh
step      t4-t3
 1        5.33361e-09
 2        5.33332e-09
 3        5.33307e-09

```

Timing Diagram:



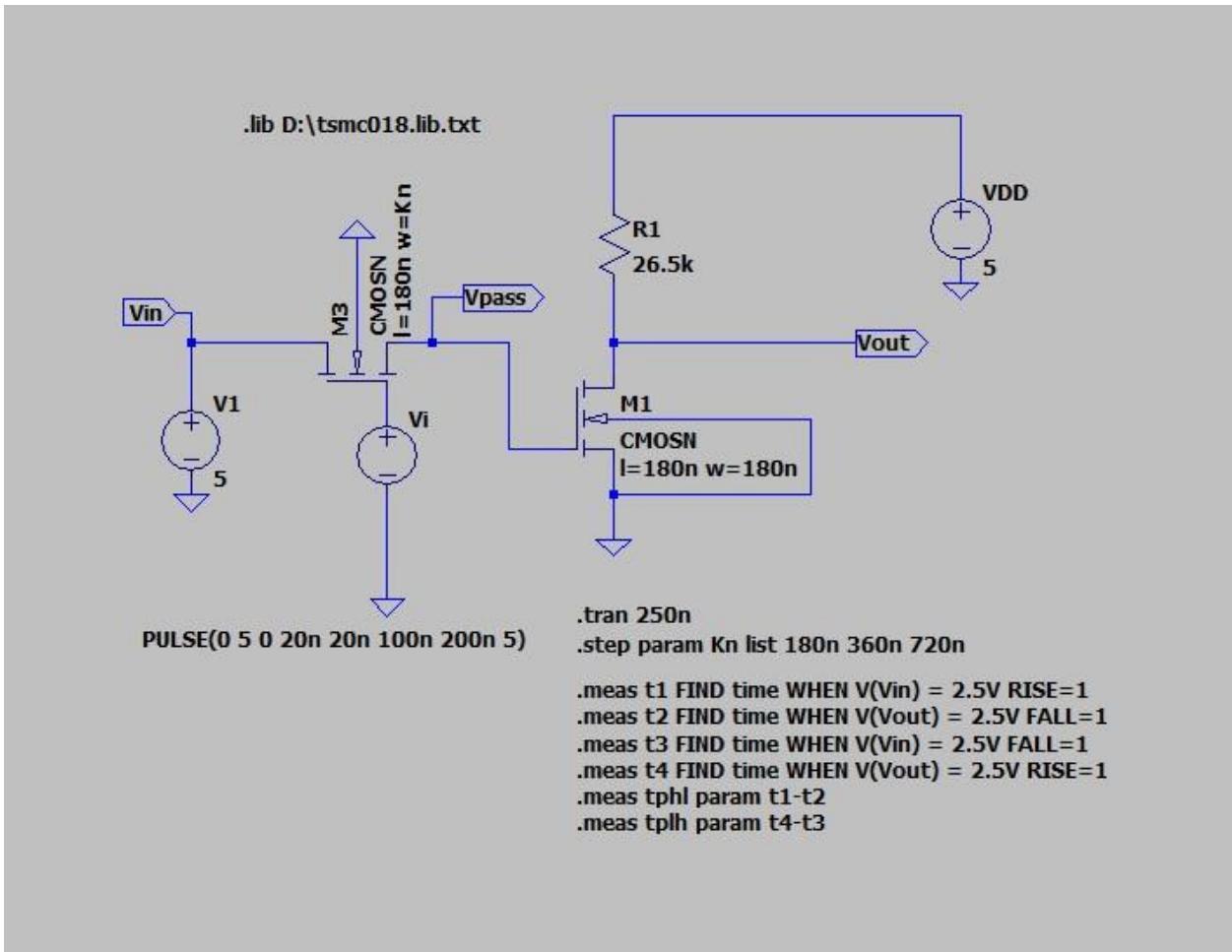
(Que) Plot the resistance of the pass transistor vs input voltage in a single graph with clearly labelled axes and legends for all values of Kn.



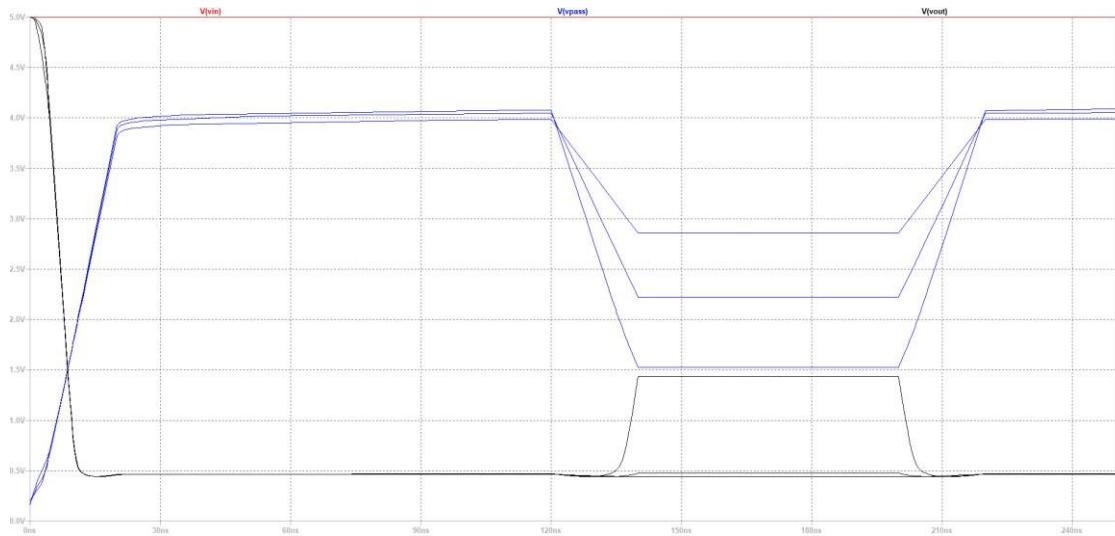
Observation: For increasing value of Kn, the resistance is decreasing.

If drain/source is connected to Vdd & input is connected to gate:

Circuit:



Timing Diagram:



Delays:

(Note: The pass transistor Source voltage does not reach to Vdd so delay calculation gives error)

```

SPICE Error Log: C:\Users\vinay\AppData\Local\LTspice\Eproject.log
X

Circuit: * C:\Users\vinay\AppData\Local\LTspice\Eproject.asc

Ignoring BSIM parameter XL
Ignoring BSIM parameter XW
Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.
Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.
Direct Newton iteration for .op point succeeded.
.step kn=1.8e-07
.step kn=3.6e-07
.step kn=7.2e-07

Measurement "t1" FAIL'ed

Measurement: t2
  step      time          at
    1       6.96049e-09   6.96049e-09
    2       7.01528e-09   7.01528e-09
    3       7.00107e-09   7.00107e-09

Measurement "t3" FAIL'ed

Measurement "t4" FAIL'ed

Measurement "tphl" FAIL'ed

Measurement "tplh" FAIL'ed

```

Resistance plots:

(Note: As Kn value increases, the resistance value drops.)

