ASSIGNMENT-3

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EE18BTECH11012

1)Impact of sizing on performance

a) For maintaining Vm=Vdd/2 in TSMC 180 library ,I considered Wp=1.17um and Wn=0.18um.This values are good to work for given condition as shown below.
Vdd=1.8V.So,Vm should be equal to 0.9V.

Fig-1:Netlist File

```
.include TSMC180.lib

Vin in 0 1.8
Vdd 1 0 1.8
*cl out 0 20e-12
M1  out in 1 1 pch_tt W = 1.17u L = 0.18u
M2  out in  0 0 nch_tt W = 0.18u L = 0.18u

.model nch_tt nmos
.model pch_tt pmos

.control
run
dc Vin 0 1.8 0.01
meas dc vm when v(out) = v(in)
plot v(out) vs v(in)

.endc
.end
```

Fig-2:Showing Vm=0.9V for considered Wp and Wn

```
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File  Edit  View  Search  Terminal  Help

Circuit: *include TSMC180.lib

Warning: Model issue on line 462 :
  .model pch_tt pmos (level=8 noimod=1 version=3.1 tnom=27 tox=4.1e-9 xj=1 ...
unrecognized parameter (xl) - ignored
unrecognized parameter (xw) - ignored
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

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.
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

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.
 Reference value :  0.00000e+00

No. of Data Rows : 181
vm                 =  9.006816e-01
ngspice 1 ->
```

(i)No external load

Netlist file and simulation results for calculating the performance of inverter(i.e.,tp) with scaling factor(s) keeping Wp/Wn as constant.

Netlist file:

For Wp=1.17u, Wn=0.18u (i.e.,s=1)

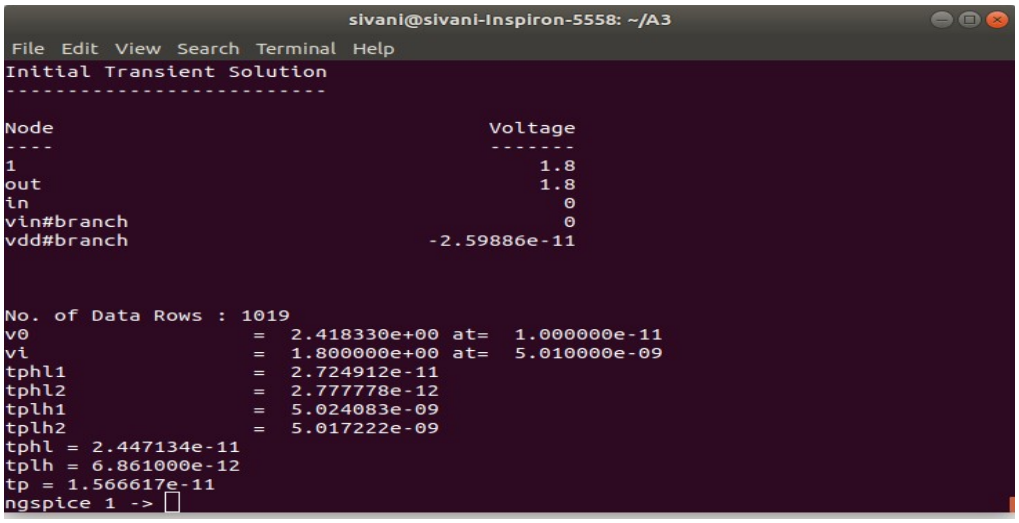
```
*Title:Q1a-Sizing of Mosfet

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 5ns 10ns)
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01ns 10ns
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```



Similarly simulating results for Wp=1.17x2=2.34u,Wn=0.36u(i.e.,s=2)and when s=3,4,5.....we get as

Scaling factor(s)	tp(in order of e^{-11}s)
1	1.566
2	1.877
3	2.0092
4	2.0639
5	2.0877
6	2.116
7	2.151
8	2.176

So,From the above results we can say that for an inverter without load tp/performance of inverter remains constant mostly when it is scaled.

(ii)With load(C_L=20pF)

Simulation results for Wp=1.17u,Wn=0.18u are

Netlist file:

```
*Title:Q1a-Sizing of Mosfet with load

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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File  Edit  View  Search  Terminal  Help
Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.59886e-11



No. of Data Rows : 522
v0                  =  1.800022e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.616434e-07
tphl2               =  2.777778e-09
tplh1               =  1.052406e-06
tplh2               =  1.017222e-06
tphl = 1.588656e-07
tplh = 3.518400e-08
tp = 9.702481e-08
ngspice 1 ->
```

For Wp=1.17x2=2.34u,Wn=0.36u(i.e., when it is scaled by 2)

Netlist file:

```
Open
Q1a_1.net  ×  Q1a_2.net  ×
*Title:Q1a-Sizing of Mosfet with load

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=2.34u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.36u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -1.90541e-11


No. of Data Rows : 524
v0                  =  1.800044e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.080709e-07
tphl2               =  2.777778e-09
tplh1               =  1.035537e-06
tplh2               =  1.017222e-06
tphl = 1.052931e-07
tplh = 1.831500e-08
tp = 6.180406e-08
ngspice 1 ->
```

Similarly similating results for s=3,4,5,..... we get

Scaling factor(s)	tp(in order of e^{-8}s)
1	9.702
2	6.180
3	4.517
4	3.583
5	2.971
6	2.565
7	2.2519
8	2.009

So,From the above results we can say that for an inverter with load tp/performance of inverter decreases when it is scaled.

b)

When Wp is increased and Wn is kept constant then t_{pLH} and t_{pHL} would be like

For Wp=1.17u,Wn=0.18u

<u>Netlist file:</u>

```
*Title:Q1a-Sizing of Mosfet with load

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.59886e-11



No. of Data Rows : 522
v0                  =  1.800022e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.616434e-07
tphl2               =  2.777778e-09
tplh1               =  1.052406e-06
tplh2               =  1.017222e-06
tphl = 1.588656e-07
tplh = 3.518400e-08
tp = 9.702481e-08
ngspice 1 -> 
```

Here,t_{pHL}=1.588e^{-7}s and t_{pLH}=3.518e^{-8}s

For Wp=1.17x2=2.34u,Wn=0.18u

<u>Netlist file:</u>

```
.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=2.34u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.59887e-11



No. of Data Rows : 524
v0                  =  1.800042e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.616771e-07
tphl2               =  2.777778e-09
tplh1               =  1.035535e-06
tplh2               =  1.017222e-06
tphl = 1.588993e-07
tplh = 1.831300e-08
tp = 8.860616e-08
ngspice 1 -> 
```

Here,t_{pHL}=1.588e^{-7}s and t_{pLH}=1.831e^{-8}s

ForWp=1.17x3=3.51u,Wn=0.18u

Netlist file:

```
.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=3.51u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.59887e-11

 Reference value :  4.62991e-06

No. of Data Rows : 525
v0                =  1.800062e+00 at=  1.600000e-09
vi                =  1.800000e+00 at=  1.010000e-06
tphl1             =  1.617100e-07
tphl2             =  2.777778e-09
tplh1             =  1.029541e-06
tplh2             =  1.017222e-06
tphl = 1.589322e-07
tplh = 1.231900e-08
tp = 8.562561e-08
ngspice 1 -> 
```

Here,t_{pHL}=1.588e^{-7}s and t_{pLH}=1.231e^{-8}s.

So,From the above observations we can understand that when Wp is increased ,keeping Wn fixed the propagation delay from high to low(t_{pHL}) remains the same(since high to low transition is done by nmos) where as low to high(t_{pLH}) eventually get reduced.

When Wn is increased and Wp is kept constant then t_{pLH} and t_{pHL} would be like

For Wp=1.17u,Wn=0.18u

Netlist file:

```
*Title:Q1a-Sizing of Mosfet with load

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.18u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.59886e-11


No. of Data Rows : 522
v0                  =  1.800022e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.616434e-07
tphl2               =  2.777778e-09
tplh1               =  1.052406e-06
tplh2               =  1.017222e-06
tphl = 1.588656e-07
tplh = 3.518400e-08
tp = 9.702481e-08
ngspice 1 ->
```

Here,t_{pHL}=1.588e^{-7}s and t_{pLH}=3.518e^{-8}s

For Wp=1.17u,Wn=0.36u

Netlist file:

```
.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.36u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
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Initial Transient Solution
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Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -1.9054e-11


No. of Data Rows : 522
v0                  =  1.800024e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  1.080471e-07
tphl2               =  2.777778e-09
tplh1               =  1.052410e-06
tplh2               =  1.017222e-06
tphl = 1.052693e-07
tplh = 3.518800e-08
tp = 7.022866e-08
ngspice 1 ->
```

Here,t_{pHL}=1.052e^{-7}s and t_{pLH}=3.518e^{-8}s

For Wp=1.17u,Wn=0.54u

Netlist file:

```
.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M2  out in 1 1 pch_tt W=1.17u L=0.18u
Vin in 0 PULSE(0 1.8 0 0 0 1us 5us)
cl out 0 20e-12
M1 out in 0 0 nch_tt W=0.54u L=0.18u

.control
run
tran 0.01us 5us
meas tran v0 MAX V(out)
meas tran vi MAX V(in)
meas tran tphl1 when v(out)=0.5*v0 cross=1
meas tran tphl2 when v(in)=0.5*vi cross=1
meas tran tplh1 when v(out)=0.5*v0 cross=2
meas tran tplh2 when v(in)=0.5*vi cross=2

let tphl=tphl1-tphl2
let tplh=tplh1-tplh2
let tp=(tphl+tplh)/2
print tphl
print tplh
print tp
*plot v(out)
*plot v(in)
*plot v(out) vs v(in)
.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A3
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
out                                        1.8
in                                           0
vin#branch                                   0
vdd#branch                          -2.02022e-11



No. of Data Rows : 522
v0                  =  1.800025e+00 at=  1.600000e-09
vi                  =  1.800000e+00 at=  1.010000e-06
tphl1               =  8.075231e-08
tphl2               =  2.777778e-09
tplh1               =  1.052416e-06
tplh2               =  1.017222e-06
tphl = 7.797453e-08
tplh = 3.519400e-08
tp = 5.658427e-08
ngspice 1 ->
```

Here,t_{pHL}=7.795e^{-8}s and t_{pLH}=3.518e^{-8}s

So,From the above observations we can understand that when Wn is increased ,keeping Wp fixed the propagation delay from high to low(t_{pHL}) get reducedwhere as low to high(t_{pLH}) remains same(since low to high transition is done by pmos) .

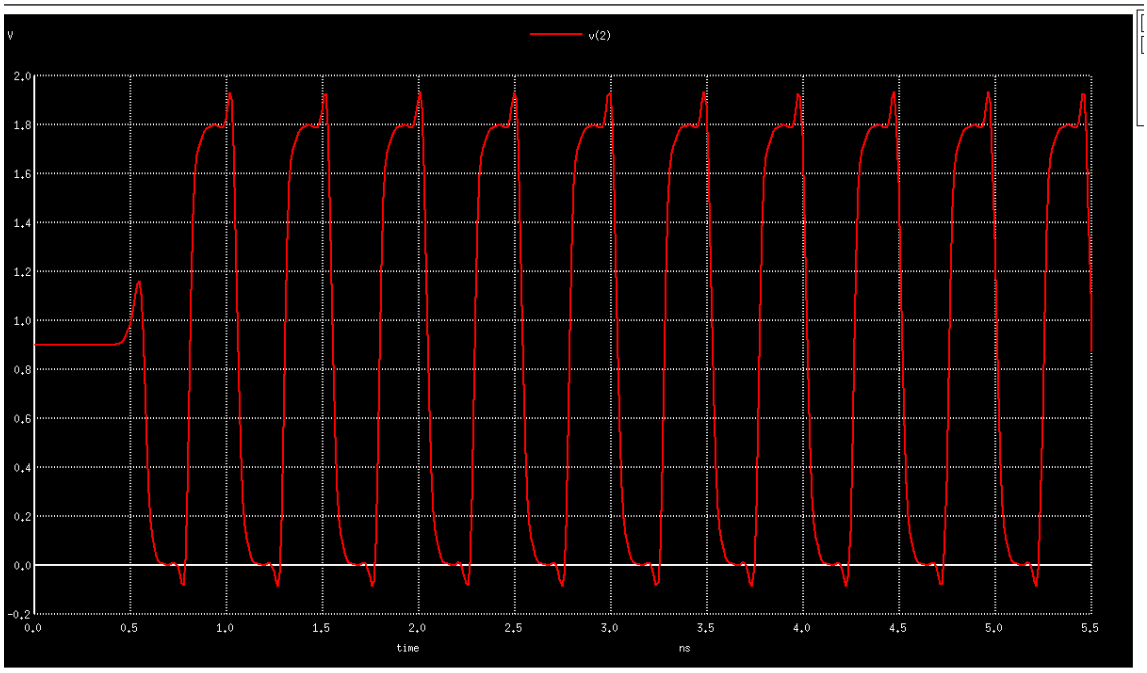
2)Ring Oscillator

a)Time response is plotted as (without external cap for ring oscillator)

Netlist file:

```
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M1p 3 2 1 1 pch_tt W=1.17u L=0.18u
M1n 3 2 0 0 nch_tt W=0.18u L=0.18u

M2p 4 3 1 1 pch_tt W=1.17u L=0.18u
M2n 4 3 0 0 nch_tt W=0.18u L=0.18u

M3p 5 4 1 1 pch_tt W=1.17u L=0.18u
M3n 5 4 0 0 nch_tt W=0.18u L=0.18u

M4p 6 5 1 1 pch_tt W=1.17u L=0.18u
M4n 6 5 0 0 nch_tt W=0.18u L=0.18u

M5p 7 6 1 1 pch_tt W=1.17u L=0.18u
M5n 7 6 0 0 nch_tt W=0.18u L=0.18u

M6p 8 7 1 1 pch_tt W=1.17u L=0.18u
M6n 8 7 0 0 nch_tt W=0.18u L=0.18u

M7p 2 8 1 1 pch_tt W=1.17u L=0.18u
M7n 2 8 0 0 nch_tt W=0.18u L=0.18u
.control
run
tran 0.01ns 5.5ns
meas tran Vomax MAX V(2)
meas tran t1 when V(2)=Vomax cross=1
```

```
sivani@sivani-Inspiron-5558: ~/A3
File  Edit  View  Search  Terminal  Help
----                                   -------
1                                          1.8
3                                     0.900689
2                                     0.900689
4                                     0.900689
5                                     0.900689
6                                     0.900689
7                                     0.900689
8                                     0.900689
vdd#branch                          -0.000298873


No. of Data Rows : 558
vomax                =   1.935241e+00 at=  2.002800e-09
t1                   =   2.002800e-09
```

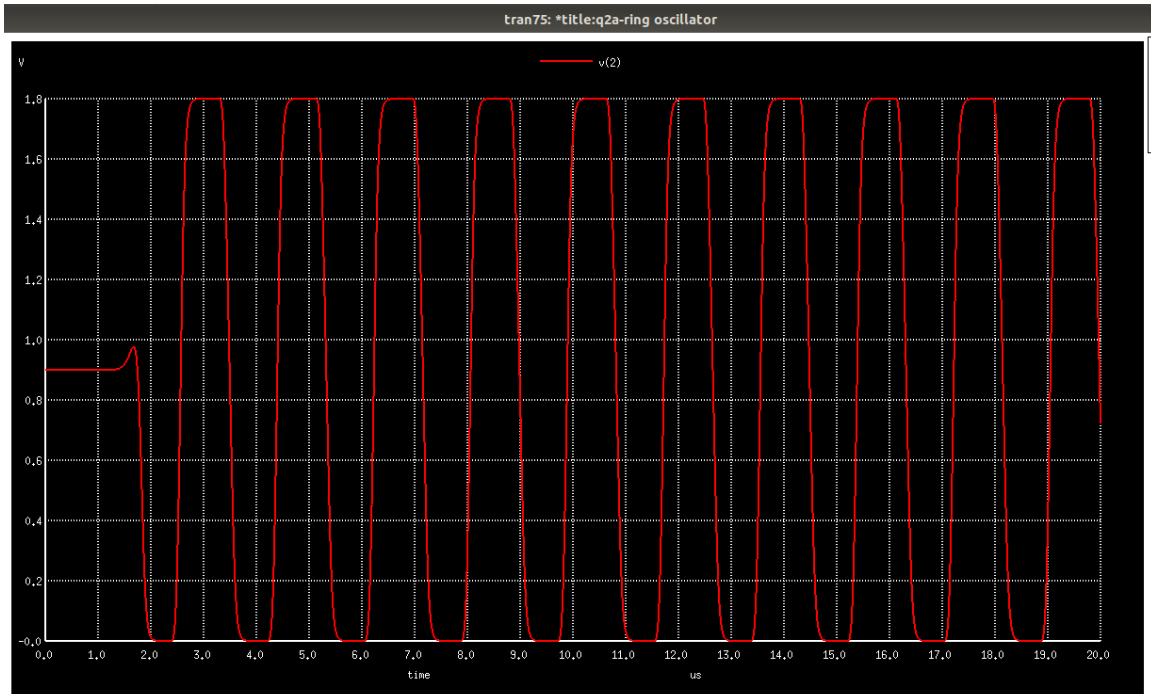


Here, frequency of oscillation =1.997GHz which is approximately 2GHz.In the time response graph,we are getting overshoots to overcome that we will connect external capacitance to ring oscillator.

When external capacitance is connected then,

Netlist file:

```
*Title:Q2a-Ring oscillator

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M1p 3 2 1 1 pch_tt W=1.17u L=0.18u
M1n 3 2 0 0 nch_tt W=0.18u L=0.18u
cl1 3 0 20p
M2p 4 3 1 1 pch_tt W=1.17u L=0.18u
M2n 4 3 0 0 nch_tt W=0.18u L=0.18u
cl2 4 0 20p
M3p 5 4 1 1 pch_tt W=1.17u L=0.18u
M3n 5 4 0 0 nch_tt W=0.18u L=0.18u
cl3 5 0 20p
M4p 6 5 1 1 pch_tt W=1.17u L=0.18u
M4n 6 5 0 0 nch_tt W=0.18u L=0.18u
cl4 6 0 20p
M5p 7 6 1 1 pch_tt W=1.17u L=0.18u
M5n 7 6 0 0 nch_tt W=0.18u L=0.18u
cl5 7 0 20p
M6p 8 7 1 1 pch_tt W=1.17u L=0.18u
M6n 8 7 0 0 nch_tt W=0.18u L=0.18u
cl6 8 0 20p
M7p 2 8 1 1 pch_tt W=1.17u L=0.18u
M7n 2 8 0 0 nch_tt W=0.18u L=0.18u
cl7 2 0 20p
.control
run
tran 20p 20u
meas tran Vomax MAX V(2)
meas tran t1 when V(2)=Vomax cross=1
meas tran t2 when V(2)=Vomax cross=3
let T=(t2-t1)
let freq=1/T
print freq
plot V(2)
.endc
.end
```




```
sivani@sivani-Inspiron-5558: ~/A3
File  Edit  View  Search  Terminal  Help

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
3                                     0.900689
2                                     0.900689
4                                     0.900689
5                                     0.900689
6                                     0.900689
7                                     0.900689
8                                     0.900689
vdd#branch                          -0.000298873

 Reference value :  1.99691e-05

No. of Data Rows : 1000008
vomax                =  1.800008e+00 at=  1.060415e-05
t1                   =  3.273812e-06
t2                   =  5.105278e-06
freq = 5.460107e+05
ngspice 1 ->
```

Here,Frequency of oscillation is approximately 0.546Mhz.

b)Propagation delay

Netlist file:

File: /home/sivani/A3/Q2b.net Page 1 of 1

```
*Title:Q2b-Tp of Ring oscillator
.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos
*Netlist
Vdd 1 0 1.8
M1p 3 2 1 1 pch_tt W=1.17u L=0.18u
M1n 3 2 0 0 nch_tt W=0.18u L=0.18u
cl1 3 0 20p
M2p 4 3 1 1 pch_tt W=1.17u L=0.18u
M2n 4 3 0 0 nch_tt W=0.18u L=0.18u
cl2 4 0 20p
M3p 5 4 1 1 pch_tt W=1.17u L=0.18u
M3n 5 4 0 0 nch_tt W=0.18u L=0.18u
cl3 5 0 20p
M4p 6 5 1 1 pch_tt W=1.17u L=0.18u
M4n 6 5 0 0 nch_tt W=0.18u L=0.18u
cl4 6 0 20p
M5p 7 6 1 1 pch_tt W=1.17u L=0.18u
M5n 7 6 0 0 nch_tt W=0.18u L=0.18u
cl5 7 0 20p
M6p 8 7 1 1 pch_tt W=1.17u L=0.18u
M6n 8 7 0 0 nch_tt W=0.18u L=0.18u
cl6 8 0 20p
M7p 2 8 1 1 pch_tt W=1.17u L=0.18u
M7n 2 8 0 0 nch_tt W=0.18u L=0.18u
cl7 2 0 20p
.control
run
tran 20p 20u
meas tran Vomax MAX V(2)
meas tran t1 when V(2)=Vomax cross=1
meas tran t2 when V(2)=Vomax cross=3
let T=(t2-t1)
let freq=1/T
let tpo=T/14
print tpo
pri
.endc
.end
```

sivani@sivani-Inspiron-5558: ~/A3

File Edit View Search Terminal Help

```
Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                        1.8
3                                     0.900689
2                                     0.900689
4                                     0.900689
5                                     0.900689
6                                     0.900689
7                                     0.900689
8                                     0.900689
vdd#branch                         -0.000298873

 Reference value :  1.99921e-05

No. of Data Rows : 1000008
vomax                =  1.800008e+00 at=  1.060415e-05
t1                   =  3.273812e-06
t2                   =  5.105278e-06
tpo = 1.308190e-07
pri: no such command available in ngspice
ngspice 1 ->
```

So,From above we get Propagation delay is 130.819ns.This delay in ring oscillator is more compared to 1(a) due to more no. of stages.

c)When the inverter is sized,

For Wp=1.17x2=2.34u,wp=0.18u

Netlist file:

```
*Title:Q2c-Ring oscillator

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M1p 3 2 1 1 pch_tt W=2.34u L=0.18u
M1n 3 2 0 0 nch_tt W=0.18u L=0.18u
cl1 3 0 20p
M2p 4 3 1 1 pch_tt W=2.34u L=0.18u
M2n 4 3 0 0 nch_tt W=0.18u L=0.18u
cl2 4 0 20p
M3p 5 4 1 1 pch_tt W=2.34u L=0.18u
M3n 5 4 0 0 nch_tt W=0.18u L=0.18u
cl3 5 0 20p
M4p 6 5 1 1 pch_tt W=2.34u L=0.18u
M4n 6 5 0 0 nch_tt W=0.18u L=0.18u
cl4 6 0 20p
M5p 7 6 1 1 pch_tt W=2.34u L=0.18u
M5n 7 6 0 0 nch_tt W=0.18u L=0.18u
cl5 7 0 20p
M6p 8 7 1 1 pch_tt W=2.34u L=0.18u
M6n 8 7 0 0 nch_tt W=0.18u L=0.18u
cl6 8 0 20p
M7p 2 8 1 1 pch_tt W=2.34u L=0.18u
M7n 2 8 0 0 nch_tt W=0.18u L=0.18u
cl7 2 0 20p
.control
run
tran 10n 20u
meas tran Vomax MAX V(2)
meas tran t1 when V(2)=Vomax cross=1
meas tran t2 when V(2)=Vomax cross=3
let T=(t2-t1)
let freq=1/T
print freq
.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A3
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Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
3                                     0.985172
2                                     0.985172
4                                     0.985172
5                                     0.985172
6                                     0.985172
7                                     0.985172
8                                     0.985172
vdd#branch                          -0.000382299

 Reference value :  1.81228e-05

No. of Data Rows : 2008
vomax                =  1.800015e+00 at=  1.135280e-05
t1                   =  9.912155e-06
t2                   =  1.135222e-05
freq = 6.944131e+05
ngspice 1 ->
```

Here frequency is 0.69Mhz.

For Wp=1.17x3=3.51u,wp=0.18u
Netlist file:

```
1  of 1   Close Preview
File: /home/sivani/A3/Q2c.net                                  Page 1 of 1

*Title:Q2c-Ring oscillator

.include TSMC180.lib
.model nch_tt nmos
.model pch_tt pmos

*Netlist
Vdd 1 0 1.8
M1p 3 2 1 1 pch_tt W=3.51u L=0.18u
M1n 3 2 0 0 nch_tt W=0.18u L=0.18u
cl1 3 0 20p
M2p 4 3 1 1 pch_tt W=3.51u L=0.18u
M2n 4 3 0 0 nch_tt W=0.18u L=0.18u
cl2 4 0 20p
M3p 5 4 1 1 pch_tt W=3.51u L=0.18u
M3n 5 4 0 0 nch_tt W=0.18u L=0.18u
cl3 5 0 20p
M4p 6 5 1 1 pch_tt W=3.51u L=0.18u
M4n 6 5 0 0 nch_tt W=0.18u L=0.18u
cl4 6 0 20p
M5p 7 6 1 1 pch_tt W=3.51u L=0.18u
M5n 7 6 0 0 nch_tt W=0.18u L=0.18u
cl5 7 0 20p
M6p 8 7 1 1 pch_tt W=3.51u L=0.18u
M6n 8 7 0 0 nch_tt W=0.18u L=0.18u
cl6 8 0 20p
M7p 2 8 1 1 pch_tt W=3.51u L=0.18u
M7n 2 8 0 0 nch_tt W=0.18u L=0.18u
cl7 2 0 20p
.control
run
tran 10n 20u
meas tran Vomax MAX V(2)
meas tran t1 when V(2)=Vomax cross=1
meas tran t2 when V(2)=Vomax cross=3
let T=(t2-t1)
let freq=1/T
print freq
.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A3
File  Edit  View  Search  Terminal  Help

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
1                                          1.8
3                                     1.03095
2                                     1.03095
4                                     1.03095
5                                     1.03095
6                                     1.03095
7                                     1.03095
8                                     1.03095
vdd#branch                          -0.000428748

 Reference value :  1.85728e-05

No. of Data Rows : 2008
vomax                =  1.800021e+00 at=  6.852800e-06
t1                   =  6.852545e-06
t2                   =  1.324257e-05
freq = 1.564939e+05
ngspice 1 ->
```

So,sizing increases frequency of oscillation.
As sizing increases frequency the power consumption also increases with sizing(since Frequency and power consumption are directly proportional to each other).

d)Using a switch/flip flop between input and output (i.e., in backward connection) at the required time instant can make the ring oscillator to be in ON/OFF condition.