ASSIGNMENT-2

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1)Mosfet Resistance

Taking W/L=240/180 and simulating the Mosfet ,

a) For NMOS , considering Vdd=1.8V and initial voltage across capacitor as 1.8V.

Netlist file:

```
*Title:Q1a- NMOS Resistance

.include TSMC180.lib
.model nch_tt nmos

*Netlist

M1 ds gs 0 0 nch_tt W=0.24u L=0.18u
Vdd gs 0 DC 1.8
C1 c1 0 1pF
V2 c1 ds DC 0

.IC V(C1)=1.8
.tran 0.0005u 50u
.control

run
plot i(V2) vs V(ds)
let Req = V(ds)/i(V2)
meas tran t2 find time when v(c1)=0.9
meas tran ravg AVG Req from=0 to=t2
plot v(c1)
plot Req vs V(ds)

.endc
.end
```

Simulation result:

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
Circuit: *title:q1a- nmos resistance

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         1.8
gs                                         1.8
c1                                         1.8
v2#branch                          0.000205522
vdd#branch                                   0

 Reference value :  4.61536e-05

No. of Data Rows : 100008
t2                  =  4.504998e-09
ravg                =  6.879962e+03 from=  0.000000e+00 to=  4.640000e-09
ngspice 1 ->
```

So, We will get Req at Vdd=1.8V as 6.879kΩ.

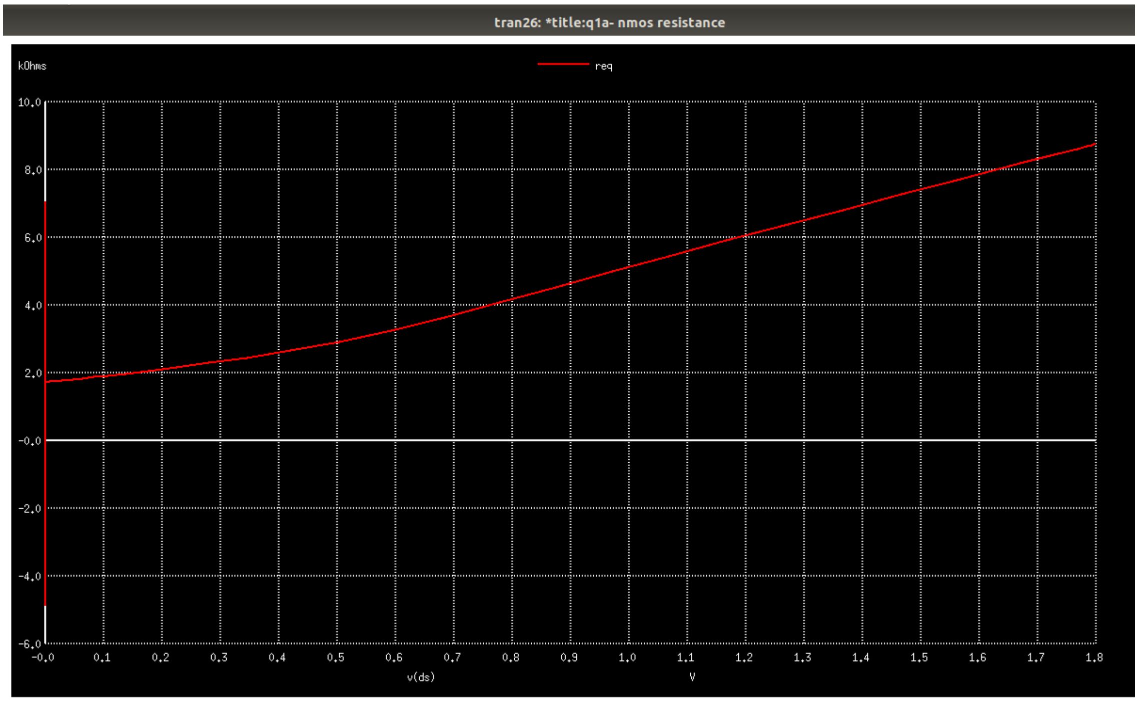


Fig-1:R Vs Vdd Graph(at Vdd=1.8V)

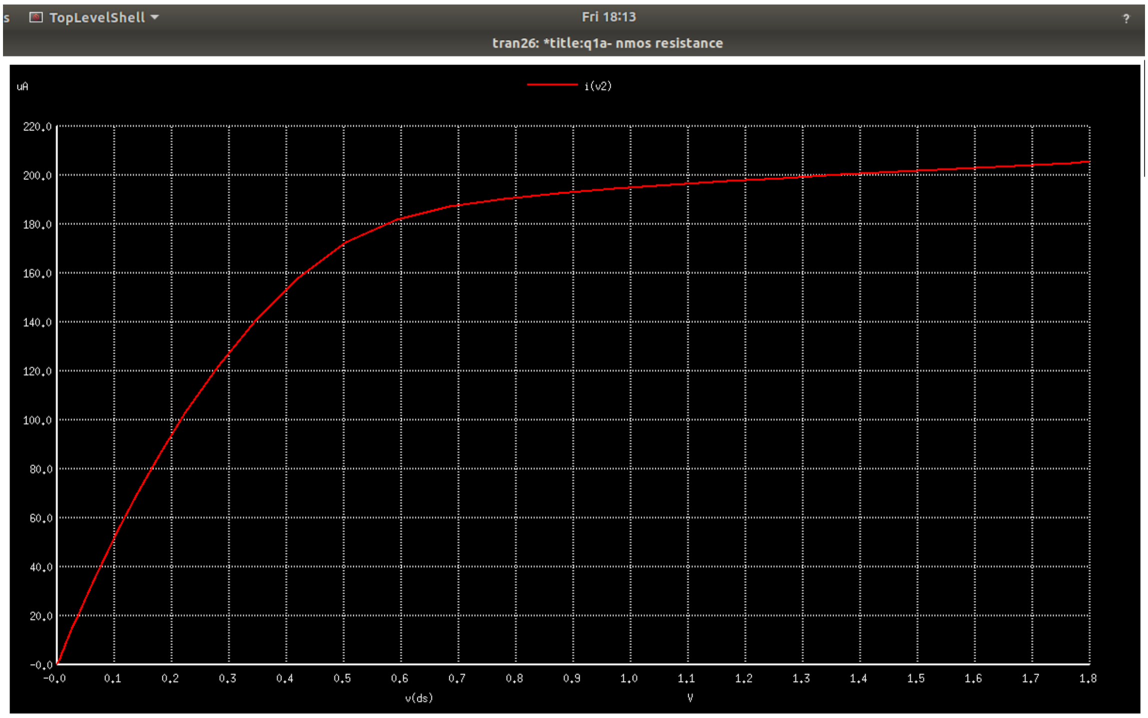


Fig -2: Id Vs Vds graph of NMOS

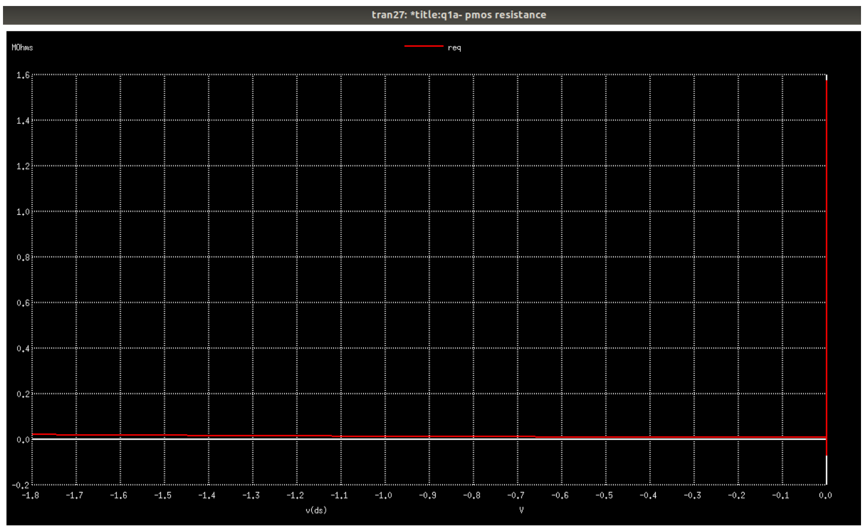
Similarly for PMOS simulation results are

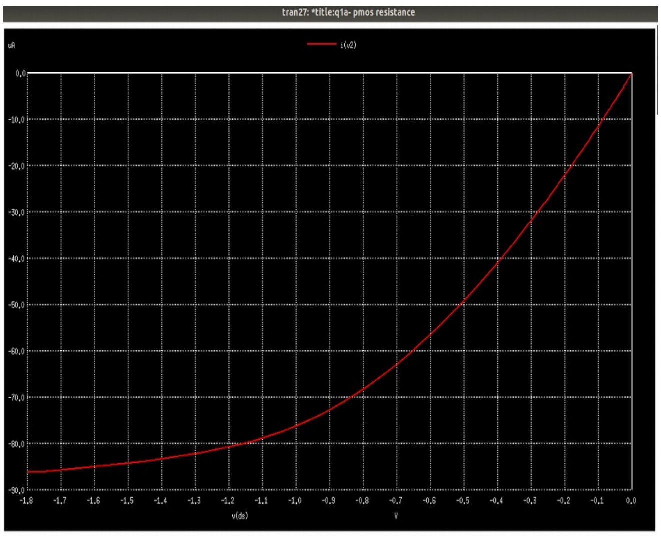
<u>Netlist file:</u>

```
*Title:Q1a- PMOS Resistance

.include TSMC180.lib
.model pch_tt pmos

*Netlist

M1 ds gs 0 0 pch_tt W=0.24u L=0.18u
Vdd gs 0 DC -1.8
C1 c1 0 1pF
V2 c1 ds DC 0

.IC V(C1)=-1.8
.tran 0.0005u 50u
.control

run
plot i(V2) vs V(ds)
let Req = V(ds)/i(V2)
meas tran t2 find time when v(c1)=-0.9
meas tran ravg AVG Req from=0 to=t2
plot v(c1)
plot Req vs V(ds)

.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
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.

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

Node                                    Voltage
----                                    -------
ds                                         -1.8
gs                                         -1.8
c1                                         -1.8
v2#branch                          -8.61958e-05
vdd#branch                                    0

 Reference value :  4.84216e-05

No. of Data Rows : 100008
t2                  =  1.104266e-08
ravg                =  1.645679e+04 from=  0.000000e+00 to=  1.114000e-08
ngspice 1 ->
```

So, We will get Req at Vdd=1.8V as 16.45kΩ.





R Vs Vdd Graph for pmos(at Vdd=1.8V)

Id Vs Vdd Graph for pmos

b) Req for different Vdds in nmos and pmos

For NMOS:

Netlist file:

```
*Title:Q1b- NMOS Resistance with varying Vdd

.include TSMC180.lib
.model nch_tt nmos

*Netlist

M1 ds gs 0 0 nch_tt W=0.24u L=0.18u
Vdd gs 0 DC 0.6
C1 c1 0 1pF
V2 c1 ds DC 0

.IC V(C1)=0.6
.tran 0.0005u 50u
.control

run
plot i(V2) vs V(ds)
let Req = V(ds)/i(V2)
meas tran t2 find time when v(c1)=0.3
meas tran ravg AVG Req from=0 to=t2
plot v(c1)
plot Req vs V(ds)

.endc
.end
```

For Vdd=1.8V:

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
Circuit: *title:q1a- nmos resistance

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         1.8
gs                                         1.8
c1                                         1.8
v2#branch                          0.000205522
vdd#branch                                   0

 Reference value :  4.61536e-05

No. of Data Rows : 100008
t2                  =  4.504998e-09
ravg                =  6.879962e+03 from=  0.000000e+00 to=  4.640000e-09
ngspice 1 ->
```

So,When Vdd=1.8V ,Req=6.879kΩ.

For Vdd=1.5V:

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
Circuit: *title:q1b- nmos resistance with varying vdd

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         1.5
gs                                         1.5
c1                                         1.5
v2#branch                           0.00015317
vdd#branch                                   0

 Reference value :  4.97041e-05

No. of Data Rows : 100008
t2                  =  5.050958e-09
ravg                =  7.708582e+03 from=  0.000000e+00 to=  5.140000e-09
ngspice 1 ->
```

So,When Vdd=1.5V ,Req=7.7kΩ.

<u>For Vdd=1.2V:</u>

```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
Circuit: *title:q1b- nmos resistance with varying vdd

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         1.2
gs                                         1.2
c1                                         1.2
v2#branch                          9.96922e-05
vdd#branch                                   0

 Reference value :  4.89281e-05

No. of Data Rows : 100008
t2                  =  6.238649e-09
ravg                =  9.325816e+03 from=  0.000000e+00 to=  6.640000e-09
ngspice 1 ->
```

So,When Vdd=1.2V ,Req=9.325kΩ.

<u>For Vdd=0.9V:</u>

```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
Circuit: *title:q1b- nmos resistance with varying vdd

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         0.9
gs                                         0.9
c1                                         0.9
v2#branch                          4.83046e-05
vdd#branch                                   0

 Reference value :  4.78156e-05

No. of Data Rows : 100008
t2                  =  9.751521e-09
ravg                =  1.452800e+04 from=  0.000000e+00 to=  1.014000e-08
ngspice 1 ->
```

So,When Vdd=0.9V ,Req=14.528kΩ.

<u>For Vdd=0.6V:</u>

```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
Circuit: *title:q1b- nmos resistance with varying vdd

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.

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

Node                                   Voltage
----                                   -------
ds                                         0.6
gs                                         0.6
c1                                         0.6
v2#branch                          7.50728e-06
vdd#branch                                   0

 Reference value :  4.69621e-05

No. of Data Rows : 100008
t2                  =  4.328849e-08
ravg                =  6.395063e+04 from=  0.000000e+00 to=  4.364000e-08
ngspice 1 ->
```

So,When Vdd=0.6V ,Req=63.95kΩ.

Similarly,

<u>For PMOS</u>

<u>Netlist file:</u>

```
*Title:Q1b- PMOS Resistance with varying Vdd

.include TSMC180.lib
.model pch_tt pmos

*Netlist

M1 ds gs 0 0 pch_tt W=0.24u L=0.18u
Vdd gs 0 DC -0.6
C1 c1 0 1pF
V2 c1 ds DC 0

.IC V(C1)=-0.6
.tran 0.0005u 50u
.control

run
plot i(V2) vs V(ds)
let Req = V(ds)/i(V2)
meas tran t2 find time when v(c1)=-0.3
meas tran ravg AVG Req from=0 to=t2
plot v(c1)
plot Req vs V(ds)

.endc
.end
```

<u>For Vdd=1.8V:</u>

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
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.

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

Node                                       Voltage
----                                       -------
ds                                            -1.8
gs                                            -1.8
c1                                            -1.8
v2#branch                             -8.61958e-05
vdd#branch                                       0

 Reference value :  4.84216e-05

No. of Data Rows : 100008
t2                  =  1.104266e-08
ravg                =  1.645679e+04 from=  0.000000e+00 to=  1.114000e-08
ngspice 1 ->
```

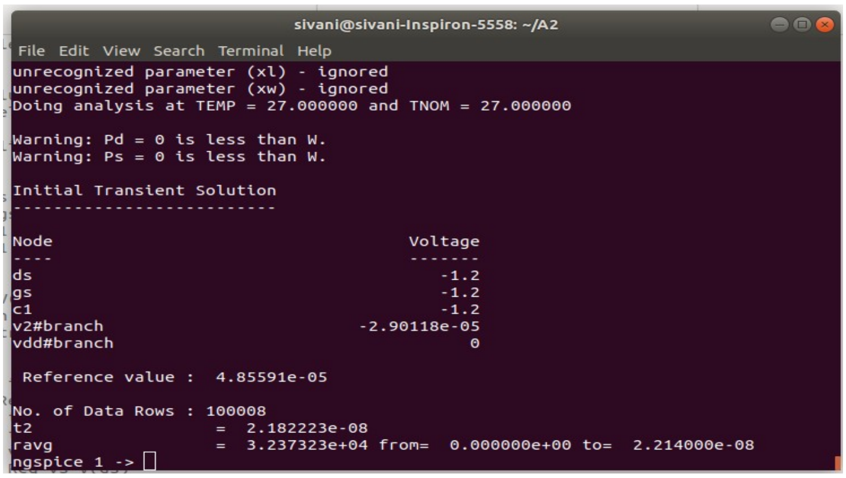
So,When Vdd=1.8V Req=16.45kΩ.

<u>For Vdd=1.5V:</u>

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
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.

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

Node                                       Voltage
----                                       -------
ds                                            -1.5
gs                                            -1.5
c1                                            -1.5
v2#branch                             -5.44996e-05
vdd#branch                                       0

 Reference value :  4.85161e-05

No. of Data Rows : 100008
t2                  =  1.454376e-08
ravg                =  2.165675e+04 from=  0.000000e+00 to=  1.464000e-08
ngspice 1 ->
```

So,When Vdd=1.5V Req=21.656kΩ.

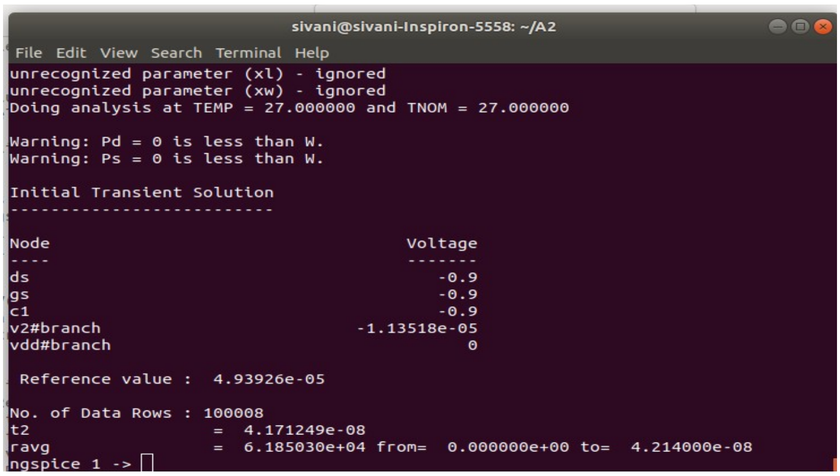
<u>For Vdd=1.2V:</u>



```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
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.

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

Node                                   Voltage
----                                   -------
ds                                        -1.2
gs                                        -1.2
c1                                        -1.2
v2#branch                         -2.90118e-05
vdd#branch                                   0

 Reference value :  4.85591e-05

No. of Data Rows : 100008
t2                  =  2.182223e-08
ravg                =  3.237323e+04 from=  0.000000e+00 to=  2.214000e-08
ngspice 1 ->
```

So,When Vdd=1.2V Req=32.37kΩ.

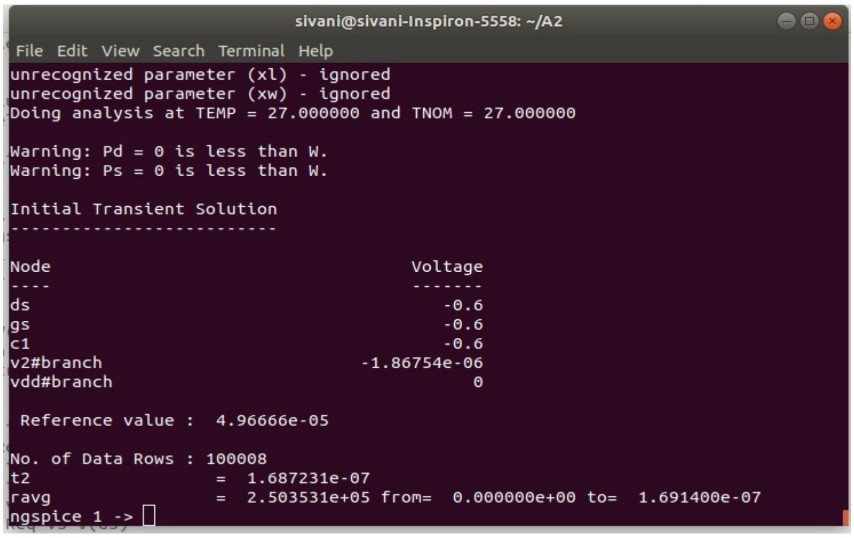
<u>For Vdd=0.9V:</u>



```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
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.

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

Node                                   Voltage
----                                   -------
ds                                        -0.9
gs                                        -0.9
c1                                        -0.9
v2#branch                         -1.13518e-05
vdd#branch                                   0

 Reference value :  4.93926e-05

No. of Data Rows : 100008
t2                  =  4.171249e-08
ravg                =  6.185030e+04 from=  0.000000e+00 to=  4.214000e-08
ngspice 1 ->
```

So,When Vdd=0.9V Req=61.85kΩ.

<u>For Vdd=0.6V:</u>



```
sivani@sivani-Inspiron-5558: ~/A2
File Edit View Search Terminal Help
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.

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

Node                                   Voltage
----                                   -------
ds                                        -0.6
gs                                        -0.6
c1                                        -0.6
v2#branch                         -1.86754e-06
vdd#branch                                   0

 Reference value :  4.96666e-05

No. of Data Rows : 100008
t2                  =  1.687231e-07
ravg                =  2.503531e+05 from=  0.000000e+00 to=  1.691400e-07
ngspice 1 ->
```

So,When Vdd=0.6V Req=250.3kΩ.

Writing these results in a table gives,

	Vdd=1.8V	Vdd=1.5V	Vdd=1.2V	Vdd=0.9V	Vdd=0.6V
NMOS(in kΩ)	6.879	7.7	9.325	14.528	63.95
PMOS(in kΩ)	16.45	21.656	32.37	61.85	250.3

2)Mosfet Capacitance

a) Given W/L=2.5

For Short channel NMOS(L=0.18um,W=0.45um)

Simulation results are

<u>Netlist file:</u>

```
*Title:Q2a-Short channel NMOS CV

.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.003183 50)
M1  0 G 0 0 nch_tt W=0.45u L=10u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)         xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Through this simulation,we will get values of C and Vgs.Then plot these points in python results in Mosfet Capacitance graph for short channel NMOS.

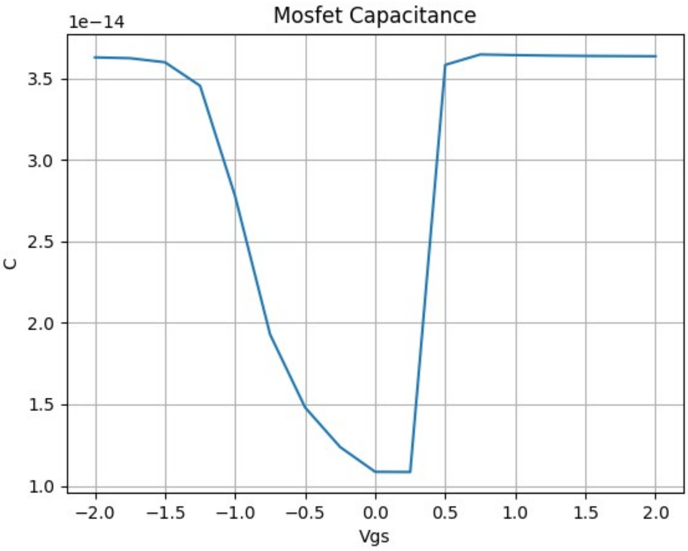


Fig-1:CV characteristics for short channel NMOS

```python
import numpy as np
import matplotlib.pyplot as plt


p1=[3.637e-14,2]
p2=[3.638e-14,1.75]
p3=[3.639e-14,1.5]
p4=[3.641e-14,1.25]
p5=[3.644e-14,1]
p6=[3.648e-14,0.75]
p7=[3.584e-14,0.5]
p8=[1.085e-14,0.25]
p9=[1.086e-14,0]
p10=[1.238e-14,-0.25]
p11=[1.481e-14,-0.5]
p12=[1.929e-14,-0.75]
p13=[2.779e-14,-1]
p14=[3.456e-14,-1.25]
p15=[3.6e-14,-1.5]
p16=[3.625e-14,-1.75]
p17=[3.63e-14,-2]


x_val=[p1[0],p2[0],p3[0],p4[0],p5[0],p6[0],p7[0],p8[0],p9[0],p10[0],p11[0],p12[0],p13[0],p14[0],p15[0],p16[0],p17[0]]
y_val=[p1[1],p2[1],p3[1],p4[1],p5[1],p6[1],p7[1],p8[1],p9[1],p10[1],p11[1],p12[1],p13[1],p14[1],p15[1],p16[1],p17[1]]
plt.plot(y_val,x_val)
plt.grid()
plt.xlabel("Vgs")
plt.ylabel("C")
plt.title("Mosfet Capacitance")
plt.show()
```

For Long channel NMOS(L=25um,W=10um)

Simulation results are

<u>Netlist file:</u>

```
*Title:Q2a-Long channel NMOS CV

.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.003183 50)
M1  0 G 0 0 nch_tt W=25u L=10u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)          xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Through this simulation,we will get values of C and Vgs.Then plot these points in python results in Mosfet Capacitance graph for long channel NMOS.

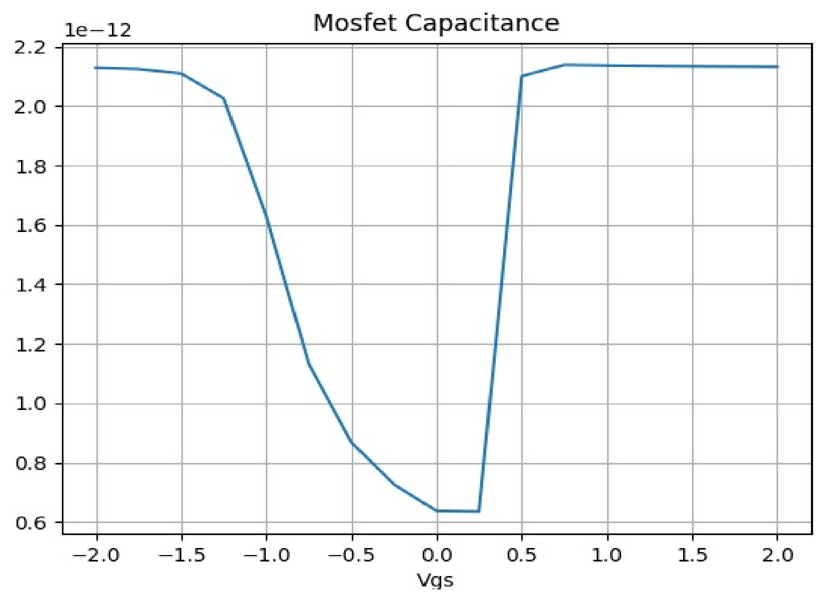


Fig-2:CV characteristics for long channel NMOS

```
import numpy as np
import matplotlib.pyplot as plt


p1=[2.13297e-12,2]
p2=[2.133627e-12,1.75]
p3=[2.134473e-12,1.5]
p4=[2.1356e-12,1.25]
p5=[2.137e-12,1]
p6=[2.139e-12,0.75]
p7=[2.101e-12,0.5]
p8=[6.35e-13,0.25]
p9=[6.37e-13,0]
p10=[7.26e-13,-0.25]
p11=[8.68e-13,-0.5]
p12=[1.131e-12,-0.75]
p13=[1.63e-12,-1]
p14=[2.027e-12,-1.25]
p15=[2.11e-12,-1.5]
p16=[2.125e-12,-1.75]
p17=[2.129e-12,-2]


x_val=[p1[0],p2[0],p3[0],p4[0],p5[0],p6[0],p7[0],p8[0],p9[0],p10[0],p11[0],p12[0],p13[0],p14[0],p15[0],p16[0],p17[0]]
y_val=[p1[1],p2[1],p3[1],p4[1],p5[1],p6[1],p7[1],p8[1],p9[1],p10[1],p11[1],p12[1],p13[1],p14[1],p15[1],p16[1],p17[1]]
plt.plot(y_val,x_val)
plt.grid()
plt.xlabel("C")
plt.ylabel("Vgs")
plt.title("Mosfet Capacitance")
plt.show()
```

b)CV characteristics with change of frequency

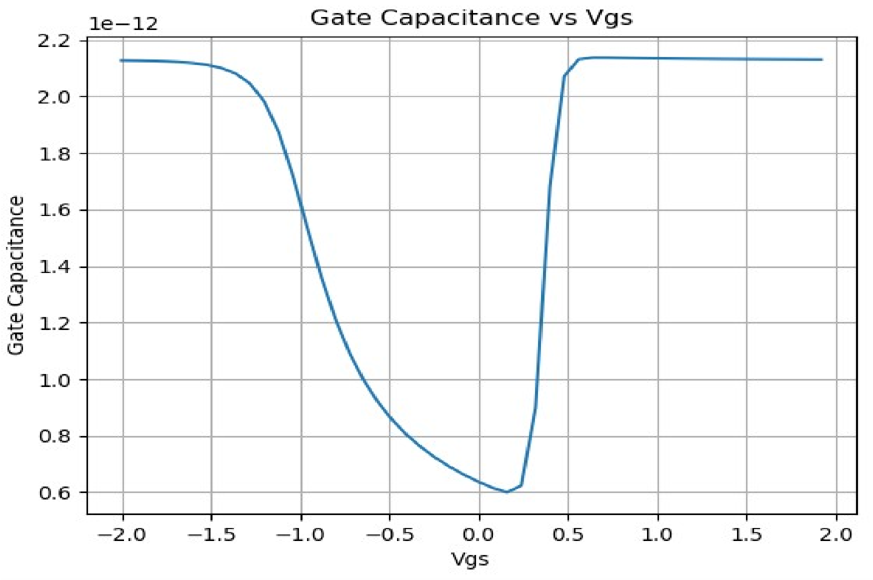
For long channel nmos,

with f=10M Hz

<u>Netlist file:</u>

```
*Title:Q2b-Long channel NMOS CV

.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.159e-7 1e7)
M1  0 G 0 0 nch_tt W=25u L=10u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)          xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Plotting these simulation points in python yields mosfet capacitance graph as

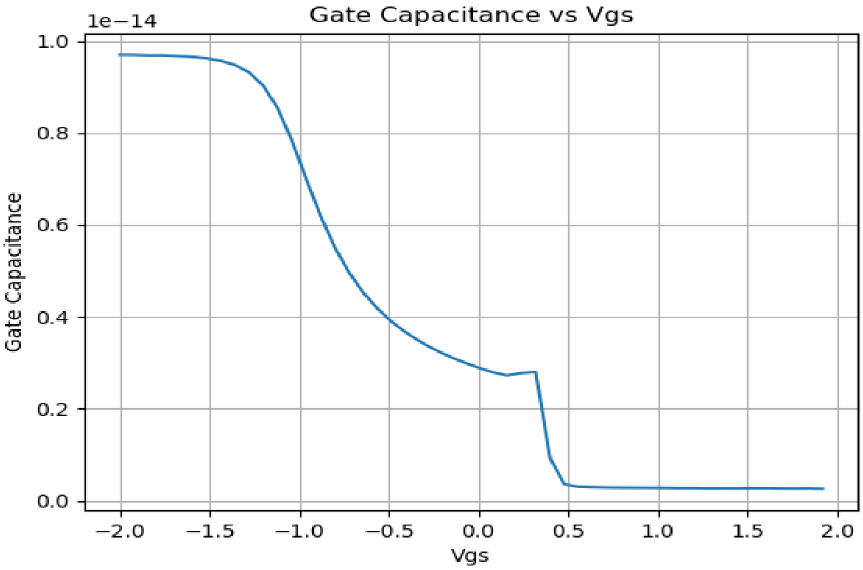


With f = 10GHz,

<u>Netlist file:</u>

```
*Title:Q2b-Long channel NMOS CV

.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.159e-10 10e9)
M1  0 G 0 0 nch_tt W=25u L=10u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)         xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Plotting these simulation points in python yields mosfet capacitance graph as



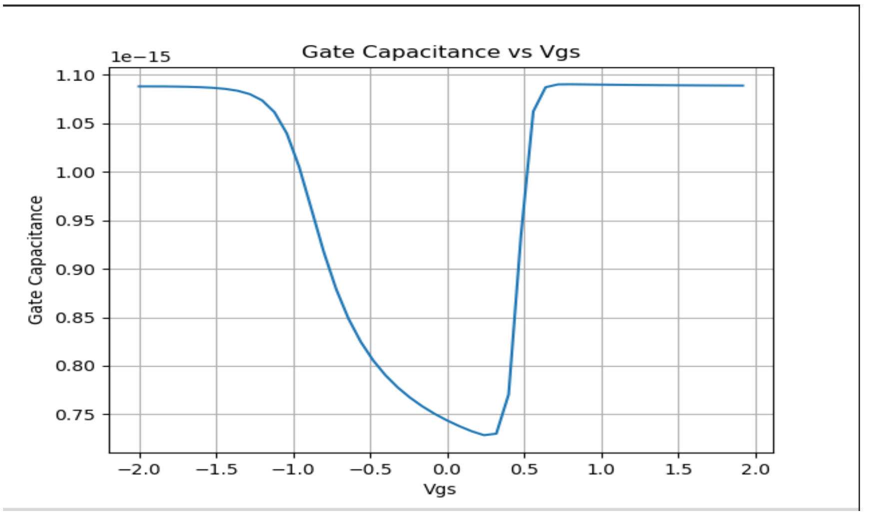
For short channel NMOS,

with f=10M Hz,

<u>Netlist file:</u>

```
.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.159e-7 1e7)
M1  0 G 0 0 nch_tt W=0.45u L=0.18u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)         xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Plotting these simulation points in python yields mosfet capacitance graph as

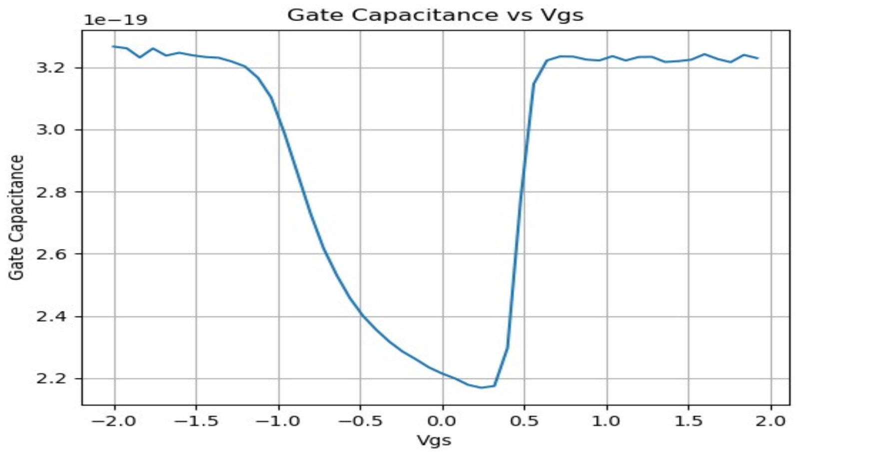


With f =10GHz,

<u>Netlist file:</u>

```
*Title:Q2b-Short channel NMOS CV

.include "TSMC180.lib"
.model nch_tt nmos

*Netlist
Vgs1 n1 0 DC 2
Vgs2 T n1  DC 0 AC 1 SINE(0 0.159e-10 10e9)
M1  0 G 0 0 nch_tt W=0.45u L=0.18u
Vt T G DC 0

.control
run
let vgs1 = 2
while vgs1 >= -2
        alter @Vgs1 vgs1
        tran 10u 20m
        meas tran c1 FIND i(Vt) AT = 20m
        print vgs1
        plot i(Vt)         xlabel "Current waveform at VCM $&vgs1"
        let vgs1 = vgs1 - 0.25


end
.endc
.end
```

Plotting these simulation points in python yields mosfet capacitance graph as



5)NMOS Inverter

Results obtained analytically in question-4 are:

V_{OH}=2.5V V_{iL}=0.3837 V Noise margin low=0.3597 V

V_{OL}=24.08mV V_{iH}=0.684 V Noise margin high=1.816 V

V_M=0.6403 V Peak gain=-10.399

Now we shall compare these with simulations

a) Simulating the given circuit

<u>Netlist File:</u>

```
*Title:Q5a-Gain of NMOS Inverter

.include TSMC180.lib
.model nch_tt nmos

*Netlist
Vdd 1 0 2.5
Rl 1 out 75k
Vin in 0 1
M1 out in 0 0 nch_tt W=0.54u L=0.18u

.control
dc Vin 0 3 0.01
let gain = deriv(V(out))
plot gain
meas dc Vol find V(out) at=2.5 cross=1
meas dc Voh find V(out) at=0
meas dc Vm find V(out) when V(out)=V(in)
meas dc Vil when gain=-1 cross=1
meas dc Vih when gain=-1 cross=2
let NMh = Voh-Vih
let NMl = Vil-Vol
print NMh
print NMl
meas dc peakgain MIN gain
plot V(out)

.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help

No. of Data Rows : 2008
c1                  =  -4.381621e-30
vgs1 = -2.00000e+00
ngspice 1 -> Q5a.net

Circuit: *title:q5a-gain of nmos inverter

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.


No. of Data Rows : 301
vol                 =  3.174192e-02
voh                 =  2.499998e+00
vm                  =  6.731995e-01
vil                 =  3.871599e-01
vih                 =  7.738449e-01
nmh = 1.726153e+00
nml = 3.554180e-01
peakgain            =  -9.515716e+00 at=  6.500000e-01
ngspice 1 ->
```

From these simulations we obtained,

V_{OH}=2.499V V_{iL}=0.3871 V Noise margin low=0.3554 V

V_{OL}=31.7mV V_{iH}=0.7738 V Noise margin high=1.726 V

V_M=0.673 V Peak gain= -9.515

So,These simulation results are similar to analytical values.

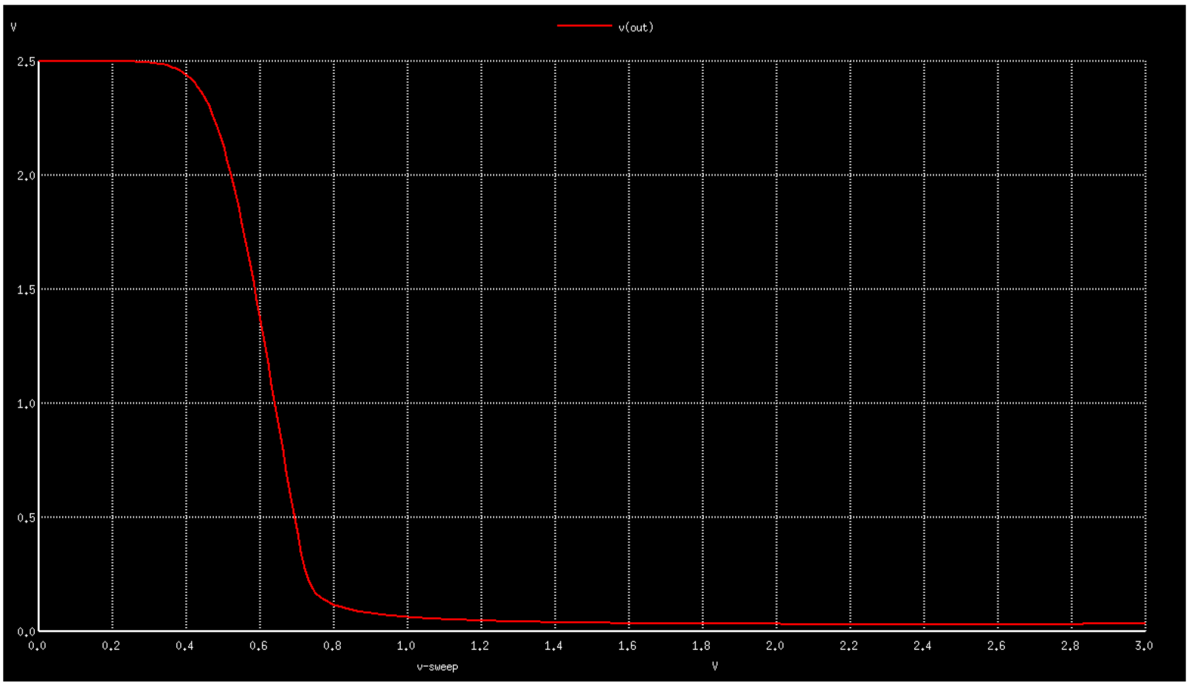


Fig:Graph of Vout

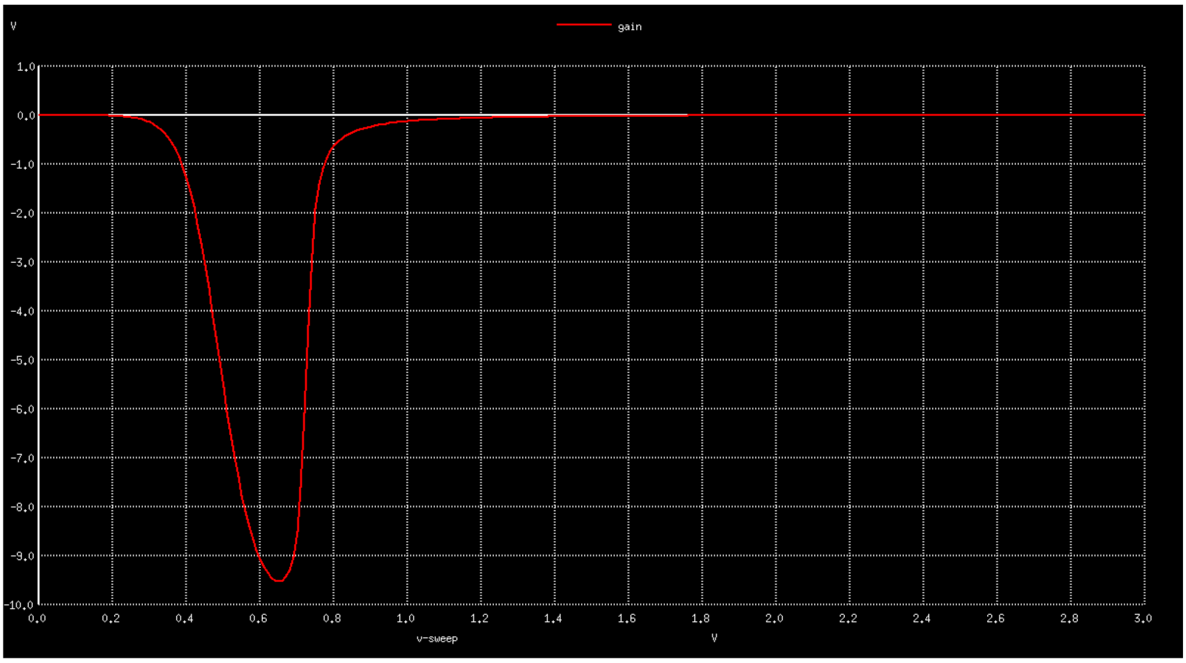


Fig:Plot of Gain of Inverter

b)Impact of load resitance on threshold(V_M) and peak-gain of Inverter.

Let us consider R_L=6kΩ and simulate

Netlist file:

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

*Netlist
Vdd 1 0 2.5
Rl 1 out 6k
Vin in 0 1
M1 out in 0 0 nch_tt W=0.54u L=0.18u

.control
dc Vin 0 3 0.01
let gain = deriv(V(out))
plot gain
meas dc Vol find V(out) at=2.5 cross=1
meas dc Voh find V(out) at=0
meas dc Vm find V(out) when V(out)=V(in)
meas dc Vil when gain=-1 cross=1
meas dc Vih when gain=-1 cross=2
let NMh = Voh-Vih
let NMl = Vil-Vol
print NMh
print NMl
meas dc peakgain MIN gain
plot V(out)

.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
Error(parse.c--checkvalid): vil: no such vector.
Error(parse.c--checkvalid): nmh: no such vector.
Error(parse.c--checkvalid): nml: no such vector.
peakgain              =  -3.092402e-01 at=  1.220000e+00
ngspice 1 -> Q5a.net

Circuit: *title:q5b-gain of nmos inverter

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.


No. of Data Rows : 301
vol                   =  4.285629e-01
voh                   =  2.500000e+00
vm                    =  1.282686e+00
vil                   =  5.615429e-01
vih                   =  1.716112e+00
nmh = 7.838880e-01
nml = 1.329800e-01
peakgain              =  -1.680549e+00 at=  1.150000e+00
ngspice 1 ->
```

Let us consider R_L=1G Ω and simulate

<u>Netlist file:</u>

```
*Title:Q5b-Gain of NMOS Inverter

.include TSMC180.lib
.model nch_tt nmos

*Netlist
Vdd 1 0 2.5
Rl 1 out 1e9
Vin in 0 1
M1 out in 0 0 nch_tt W=0.54u L=0.18u

.control
dc Vin 0 3 0.01
let gain = deriv(V(out))
plot gain
meas dc Vol find V(out) at=2.5 cross=1
meas dc Voh find V(out) at=0
meas dc Vm find V(out) when V(out)=V(in)
meas dc Vil when gain=-1 cross=1
meas dc Vih when gain=-1 cross=2
let NMh = Voh-Vih
let NMl = Vil-Vol
print NMh
print NMl
meas dc peakgain MIN gain
plot V(out)

.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
vih                   =  1.716112e+00
nmh = 7.838880e-01
nml = 1.329800e-01
peakgain              =  -1.680549e+00 at=  1.150000e+00
ngspice 1 -> Q5a.net

Circuit: *title:q5b-gain of nmos inverter

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: Pd = 0 is less than W.
Warning: Ps = 0 is less than W.


No. of Data Rows : 301
vol                   =  2.363255e-06
voh                   =  2.472216e+00
vm                    =  2.298608e-01
vil                   =  1.381283e-02
vih                   =  2.597311e-01
nmh = 2.212485e+00
nml = 1.381047e-02
peakgain              =  -1.884902e+01 at=  2.100000e-01
ngspice 1 ->
```

So,from above considered simulations of load resistance range we can conclude that Threshold(V_M) decreases with increase in load resistance where as Peak gain increases with increase in load resistance.

c)Simulating the circuit

<u>Netlist file:</u>

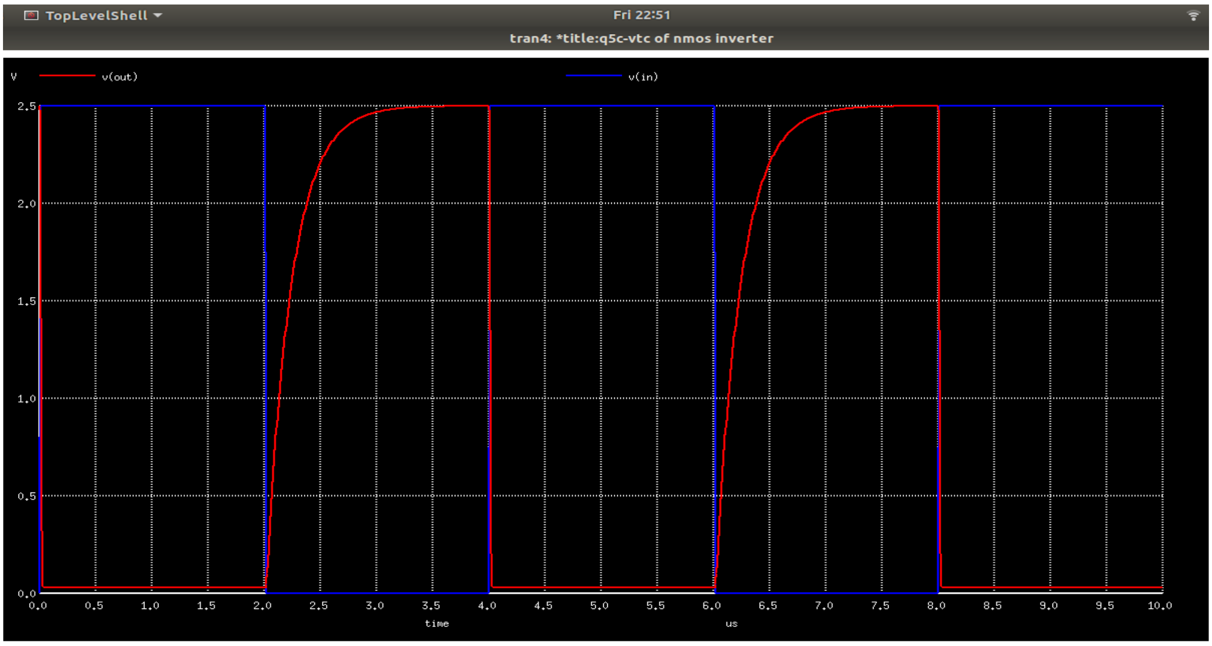
```
File: /home/sivani/A2/Q5c.net                                   Page 1 of 1

*Title:Q5c-VTC of NMOS Inverter

.include TSMC180.lib
.model nch_tt nmos

*netlist

Vdd 1 0 2.5
Rl 1 out 75k
Cl out 0 3p
Vin in 0 PULSE(0 2.5 0 0 0 2u 4u)

M1 out in 0 0 nch_tt W=0.54u L=0.18u

.control
tran 0.01u 10u 0u
plot V(out) V(in)
meas tran Voutpeak MAX V(out)
meas tran Vinpeak MAX V(in)
let v1 = Voutpeak/2
let v2 = 0.1*Voutpeak
let v3 = 0.9*Voutpeak
let v4 = Vinpeak/2
meas tran T1 when V(in)=v2 cross=1
meas tran T2 when V(in)=v3 cross=1
meas tran T3 when V(in)=v2 cross=2
meas tran T4 when V(in)=v3 cross=2
meas tran T5 when V(in)=v1 cross=1
meas tran T6 when V(out)=v4 cross=1
meas tran T7 when V(in)=v1 cross=2
meas tran T8 when V(out)=v4 cross=2
let Tpl = T5-T6
let Tph = T7-T8
let Tr = T2-T1
let Tf = T3-T4
print Tr
print Tf
print (Tpl+Tph)/2
.endc
.end
```

```
sivani@sivani-Inspiron-5558: ~/A2
File  Edit  View  Search  Terminal  Help
----                                         -------
1                                                2.5
out                                              2.5
in                                                 0
vin#branch                                         0
vdd#branch                               -2.82365e-11


No. of Data Rows : 1050
voutpeak            =  2.500021e+00 at=  8.000000e-10
vinpeak             =  2.500000e+00 at=  1.000000e-05
t1                  =  1.000008e-09
t2                  =  9.000076e-09
t3                  =  2.019000e-06
t4                  =  2.011000e-06
t5                  =  5.000044e-09
t6                  =  1.282583e-08
t7                  =  2.015000e-06
t8                  =  2.169378e-06
tr = 8.000068e-09
tf = 8.000000e-09
(tpl+tph)/2 = -8.11019e-08
ngspice 1 ->
```

Here t_r and t_f both are equal to 8x10^-9 approximately.So,both rise and fall time are equal. T_p =8.11x10^-8

- We know that maximum operating frequency depends on Tp.Tp is inversely proportional to f(since Ron increases with decrease in W/L).So,Maximum frequency is also inversely proportional to W/L.

  The maximum frequency depends on W,L of mosfet(geometric parameters).



Vin-Vout Graph