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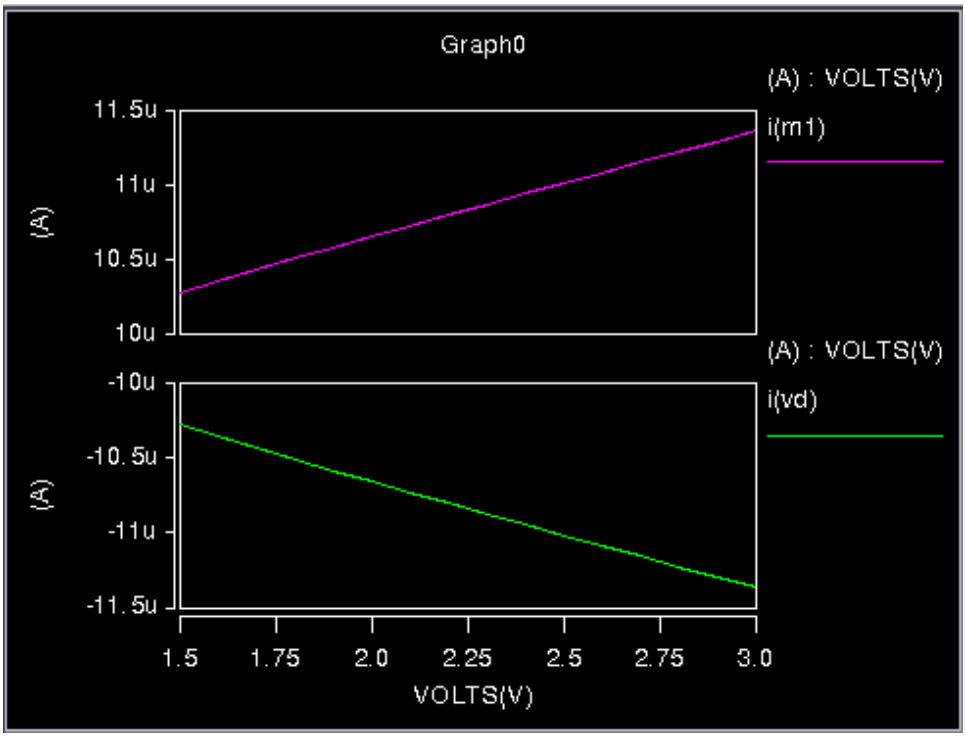
**Task:**

1.

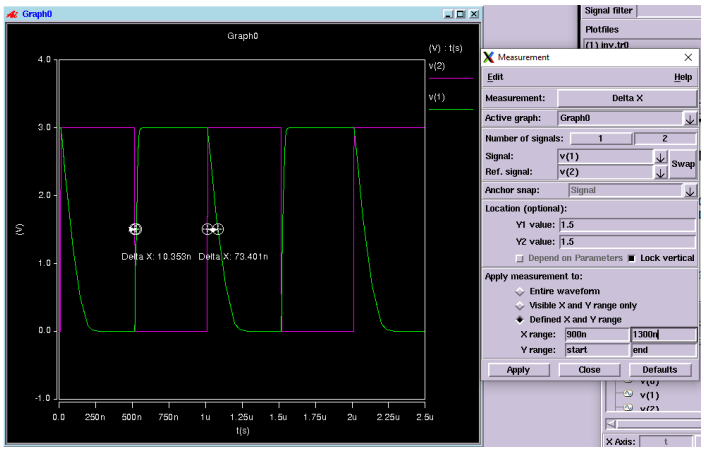
When Vgs = 3V, Vds varies from 1.5~3V, the I-V characteristics of MOSFET plotted below:




Vds = 1.5V, Imos = 10.3 uA; Vds = 3.0V, Imos = 11.4 uA.
Equivalent Rsistance = (Vdd/I1 + 0.5*Vdd/I2)/2 = (3/11.4+1.5/10.3)/2 kohm = 0.204 kohm = 204 ohm

2.

V(2) stands for input, V(1) stands for output.
The Tphl and Tplh of the inverter can be measured by cscope:



Or measured by hspice simulation:

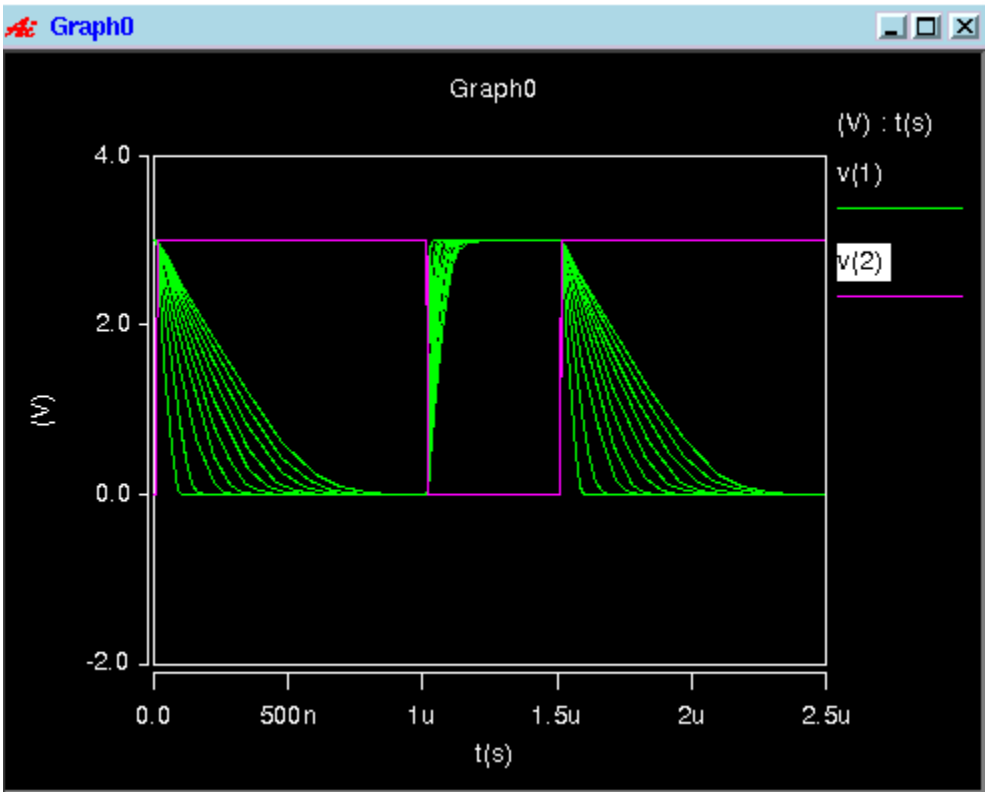
```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tphl=  10.3533n  targ= 527.8533n   trig= 517.5000n
tplh=  73.4014n  targ=   1.0859u   trig=   1.0125u
```

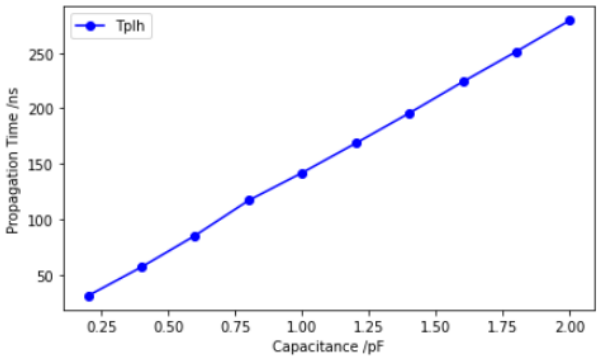
Tphl = 10.4 ns, Tplh = 73.4 ns.

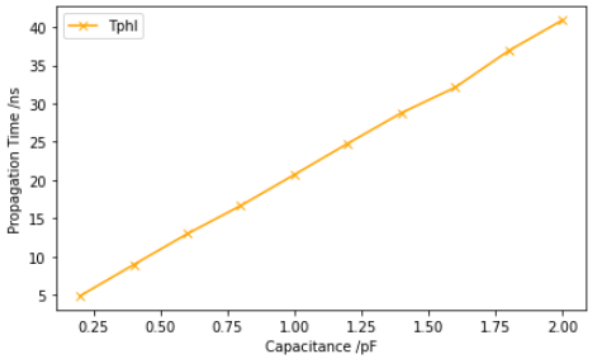
3.

V(2) stands for input, V(1) stands for output.
The propagation time of both high to low and low to high is increasing linearly as the capacitance of load capacitor increases, and low to high takes more time to travel through inverter.

```
capacitance:  [0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0]
Tplh:  [30.9194, 56.9062, 85.3044, 116.9992, 141.9983, 168.5988, 195.7995, 22
4.0765, 251.3581, 279.5669]
Tphl:  [4.8732, 8.9452, 12.9735, 16.6661, 20.7048, 24.7919, 28.7802, 32.0963,
 36.8888, 40.8792]
```

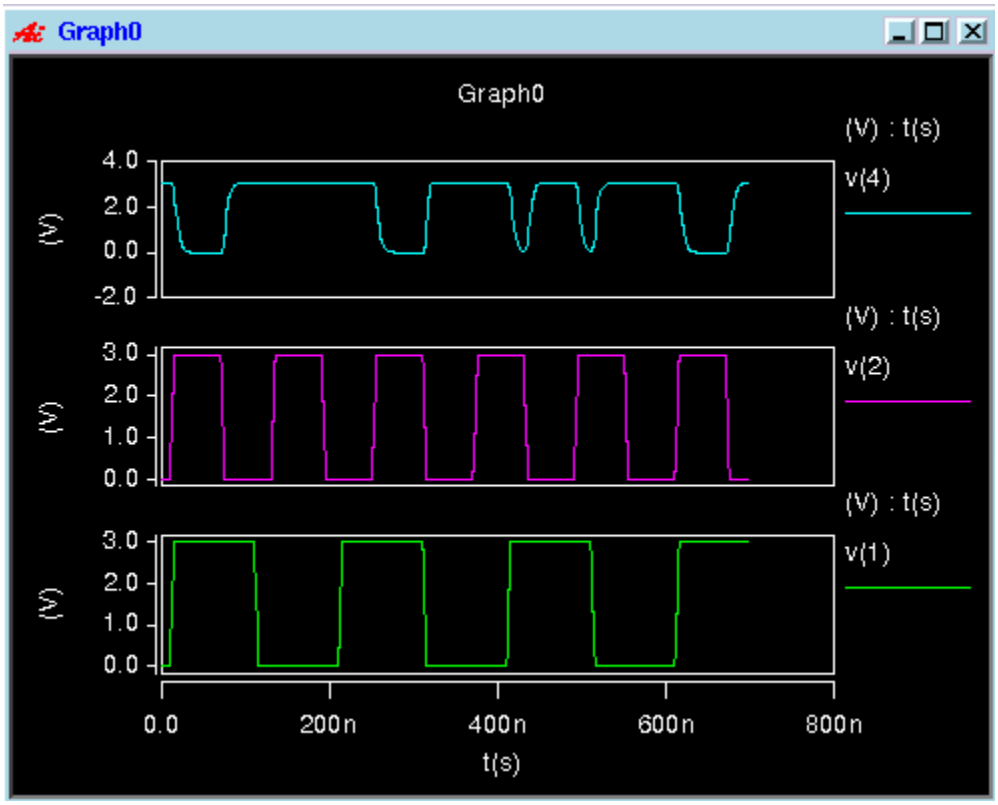





4.

V(1) stands for the input of A, V(2) stands for the input of B, V(4) stands for the output.
There are three ways to switch output from low to high, the “11->00” have the least propagation delay, is 2.95ns, comparing to Tf=Tp=5ns of input signal.



******
nand_gate_2_input *2 input nand cmos

****** transient analysis tnom=  25.000 temp=  25.000 ******
tphl0011=   5.7595n  targ=  18.2595n   trig=  12.5000n
tplh1110=   4.8748n  targ=  77.3748n   trig=  72.5000n
tplh1101=   4.7355n  targ= 517.2355n   trig= 512.5000n
tplh1100=   2.9470n  targ= 315.4470n   trig= 312.5000n

         ***** job concluded

**APPENDIX A**

```
 *** parameter cap =    2.000E-13 ***

******
mosinverter

****** transient analysis tnom=  25.000 temp=  25.000 ******
tphl=   4.8732n  targ=   1.0224u   trig=   1.0175u
tplh=  30.9194n  targ=   1.5434u   trig=   1.5125u

      ***** job concluded
******
mosinverter

****** transient analysis tnom=  25.000 temp=  25.000 ******
 *** parameter cap =   400.0000f      ***

tphl=   8.9452n  targ=   1.0264u   trig=   1.0175u
tplh=  56.9062n  targ=   1.5694u   trig=   1.5125u

      ***** job concluded
******
mosinverter

****** transient analysis tnom=  25.000 temp=  25.000 ******
 *** parameter cap =   600.0000f      ***

tphl=  12.9735n  targ=   1.0305u   trig=   1.0175u
tplh=  85.3044n  targ=   1.5978u   trig=   1.5125u

      ***** job concluded
******
mosinverter

****** transient analysis tnom=  25.000 temp=  25.000 ******
 *** parameter cap =   800.0000f      ***

tphl=  16.6661n  targ=   1.0342u   trig=   1.0175u
tplh= 116.9992n  targ=   1.6295u   trig=   1.5125u

      ***** job concluded
******
mosinverter

****** transient analysis tnom=  25.000 temp=  25.000 ******
 *** parameter cap =     1.0000p      ***

tphl=  20.7048n  targ=   1.0382u   trig=   1.0175u
tplh= 141.9983n  targ=   1.6545u   trig=   1.5125u

      ***** job concluded
```

******
mosinverter

****** transient analysis tnom= 25.000 temp= 25.000 ******
*** parameter cap = 1.2000p ***

tphl= 24.7919n targ= 1.0423u trig= 1.0175u
tplh= 168.5988n targ= 1.6811u trig= 1.5125u

***** job concluded
******
mosinverter

****** transient analysis tnom= 25.000 temp= 25.000 ******
*** parameter cap = 1.4000p ***

tphl= 28.7802n targ= 1.0463u trig= 1.0175u
tplh= 195.7995n targ= 1.7083u trig= 1.5125u

***** job concluded
******
mosinverter

****** transient analysis tnom= 25.000 temp= 25.000 ******
*** parameter cap = 1.6000p ***

tphl= 32.0963n targ= 1.0496u trig= 1.0175u
tplh= 224.0765n targ= 1.7366u trig= 1.5125u

***** job concluded
******
mosinverter

****** transient analysis tnom= 25.000 temp= 25.000 ******
*** parameter cap = 1.8000p ***

tphl= 36.8888n targ= 1.0544u trig= 1.0175u
tplh= 251.3581n targ= 1.7639u trig= 1.5125u

***** job concluded
******
mosinverter

****** transient analysis tnom= 25.000 temp= 25.000 ******
*** parameter cap = 2.0000p ***

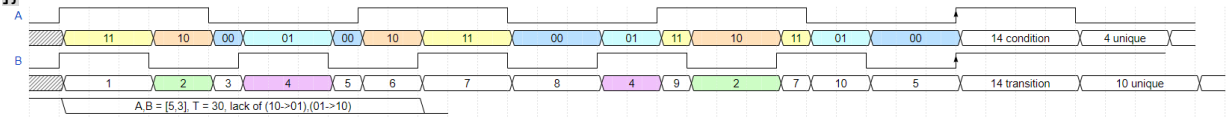
tphl= 40.8792n targ= 1.0584u trig= 1.0175u
tplh= 279.5669n targ= 1.7921u trig= 1.5125u

***** job concluded
******
mosinverter

****** job statistics summary tnom=  25.000 temp=  25.000 ******

**APPENDIX B**

```
{signal: [
  {name: 'A', wave: 'lh....l....h....l....h....l....H...l...'},
  {name: '', wave: 'x3..4.56..54.3..5..6.34..36.5..=...=..=', data:
["11","10","00","01","00","10","11","00","01","11","10","11","01","00","14 condition","4 unique"]},
  {name: 'B', wave: 'lh..l..h..l..h..l..h..l..h..l..H......'},
  {name:'', wave: 'x=..7.=8..==.=..=..8.=7..==.=..=...=...=', data:
["1","2","3","4","5","6","7","8","4","9","2","7","10","5" ,"14 transition","10 unique"]},
  {name: '', wave: '1=..........0', data: ["A,B = [5,3], T = 30, lack of (10->01),(01->10)"]}
]}
```




```
NAND_GATE_2_INPUT *2 input nand cmos
.option post
.lib './mosfet.lib' MOS
Vdd 3 0 DC 3V
VA 1 0 DC PULSE 0 3 10NS 5NS 5NS 95NS 200NS
VB 2 0 DC PULSE 0 3 10NS 5NS 5NS 55NS 120NS
* output node is 4, A1 B2
Map 4 1 3 3 pmos L=0.5U W=1.0U
Mbp 4 2 3 3 pmos L=0.5U W=1.0U
Man 4 1 5 5 nmos L=0.5U W=1.0U
Mbn 5 2 0 0 nmos L=0.5U W=1.0U
Cload 4 0 0.2pf
.TRAN 10PS 700NS
.MEAS tran tphl0011 trig V(1) td=5ns val='1.5' cross=1
+                   targ V(4) td=5ns val='1.5' cross=1
.MEAS tran tplh1110 trig V(2) td=60ns val='1.5' cross=1
+                   targ V(4) td=60ns val='1.5' cross=1
.MEAS tran tplh1101 trig V(1) td=500ns val='1.5' cross=1
+                   targ V(4) td=500ns val='1.5' cross=1
.MEAS tran tplh1100 trig V(1) td=300ns val='1.5' cross=1
+                   targ V(4) td=300ns val='1.5' cross=1

.END
```

**APPENDIX C CODE**

```
Inv.sp
mosinverter
.option post
.lib './mosfet.lib' MOS
VG 2 0 DC PULSE 0 3 10NS 5NS 5NS 1000NS 1500NS
VDD 3 0 DC 3V
M1 1 2 3 3 pmos L=0.5U W=1.0U
M2 1 2 0 0 nmos L=0.5U W=0.5U
.param cap = 0.2pf
cload 1 0 cap
.TRAN 10ps 2500ns sweep cap 0.2pf 2pf 0.2pf
.meas tran tphl trig v(2) td=1000ns val = '1.5' cross=1
+               targ v(1) td=1000ns val = '1.5' cross=1
.meas tran tplh trig v(2) td=1500ns val = '1.5' cross=1
+               targ v(1) td=1500ns val = '1.5' cross=1
.END
```

```
Mosfet.sp
*MOS OUTPUT CHARACTERISTICS
.lib './mosfet.lib' MOS
.OPTIONS post
VD 3 0
VG 2 0 DC 3.0
M1 3 2 0 0 nmos L=0.5U W=0.5U

.DC VD 1.5 3.0 0.1
.PROBE DC i(M1)
.END
```

```
Nandcmos.sp
NAND_GATE_2_INPUT *2 input nand cmos
.option post
.lib './mosfet.lib' MOS
Vdd 3 0 DC 3V
VA 1 0 DC PULSE 0 3 10NS 5NS 5NS 95NS 200NS
VB 2 0 DC PULSE 0 3 10NS 5NS 5NS 55NS 120NS
* output node is 4, A1 B2
Map 4 1 3 3 pmos L=0.5U W=1.0U
Mbp 4 2 3 3 pmos L=0.5U W=1.0U
Man 4 1 5 5 nmos L=0.5U W=1.0U
Mbn 5 2 0 0 nmos L=0.5U W=1.0U
Cload 4 0 0.2pf
```

```
.TRAN 10PS 700NS
.MEAS tran tphl0011 trig V(1) td=5ns val='1.5' cross=1
+           targ V(4) td=5ns val='1.5' cross=1
.MEAS tran tplh1110 trig V(2) td=60ns val='1.5' cross=1
+           targ V(4) td=60ns val='1.5' cross=1
.MEAS tran tplh1101 trig V(1) td=500ns val='1.5' cross=1
+           targ V(4) td=500ns val='1.5' cross=1
.MEAS tran tplh1100 trig V(1) td=300ns val='1.5' cross=1
+           targ V(4) td=300ns val='1.5' cross=1

.END
```