EC802
Assignment 1

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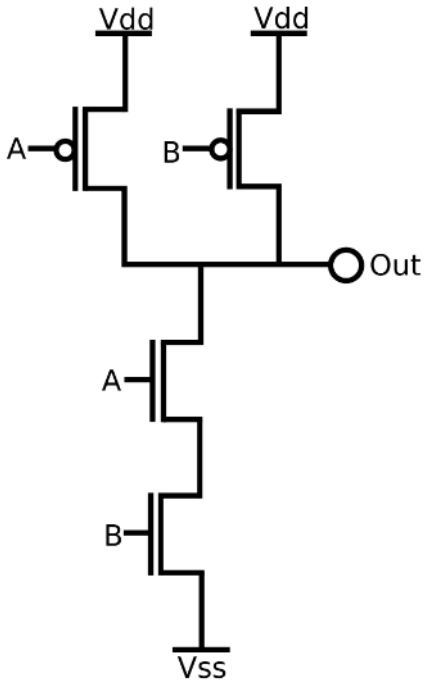
Show through simulation of NAND2 gate that VTC is data dependent and propagation delay also depends on input pattern.

Circuit Diagram



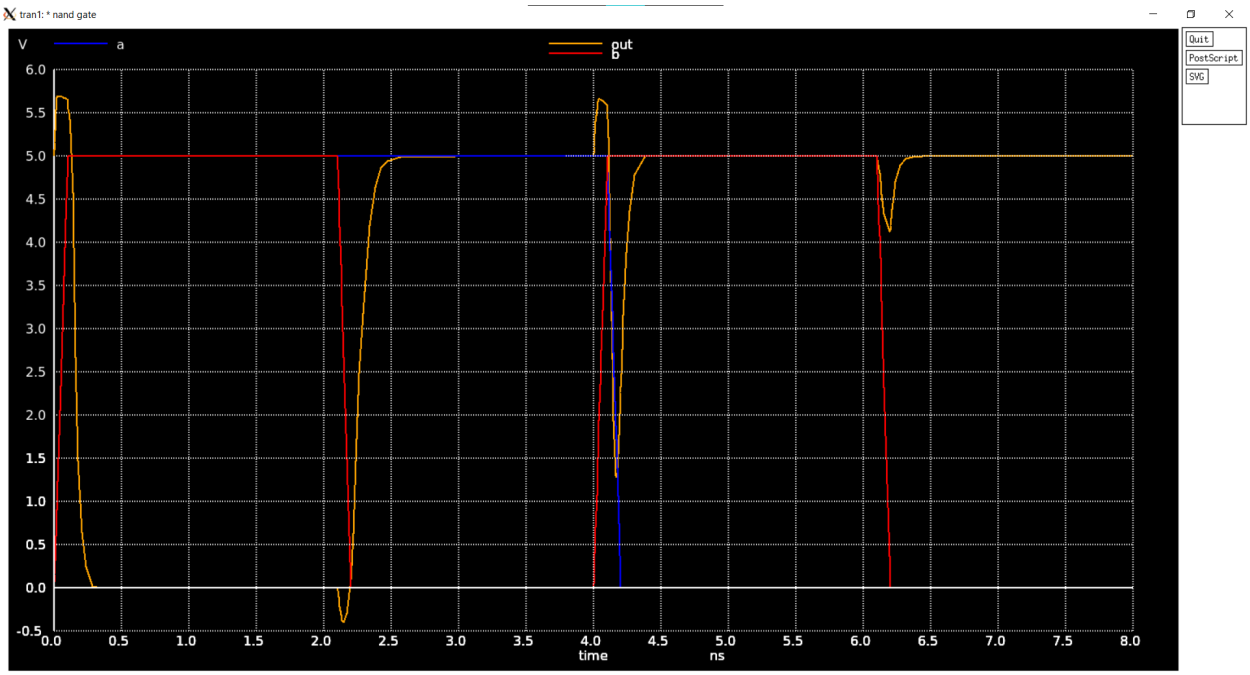
Sizing Information:
electrons have mobility ~2.7 times higher than the holes. The size of PMOS is larger than that of NMOS so to keep the resistance of NMOS and PMOS the same so we have equal rise time and fall time. This can be achieved by sizing the PMOS ~2.5 to 3 times the NMOS sizing.
So in our case, we have assumed the ratio of the width of PMOS to that of NMOS is 2.5

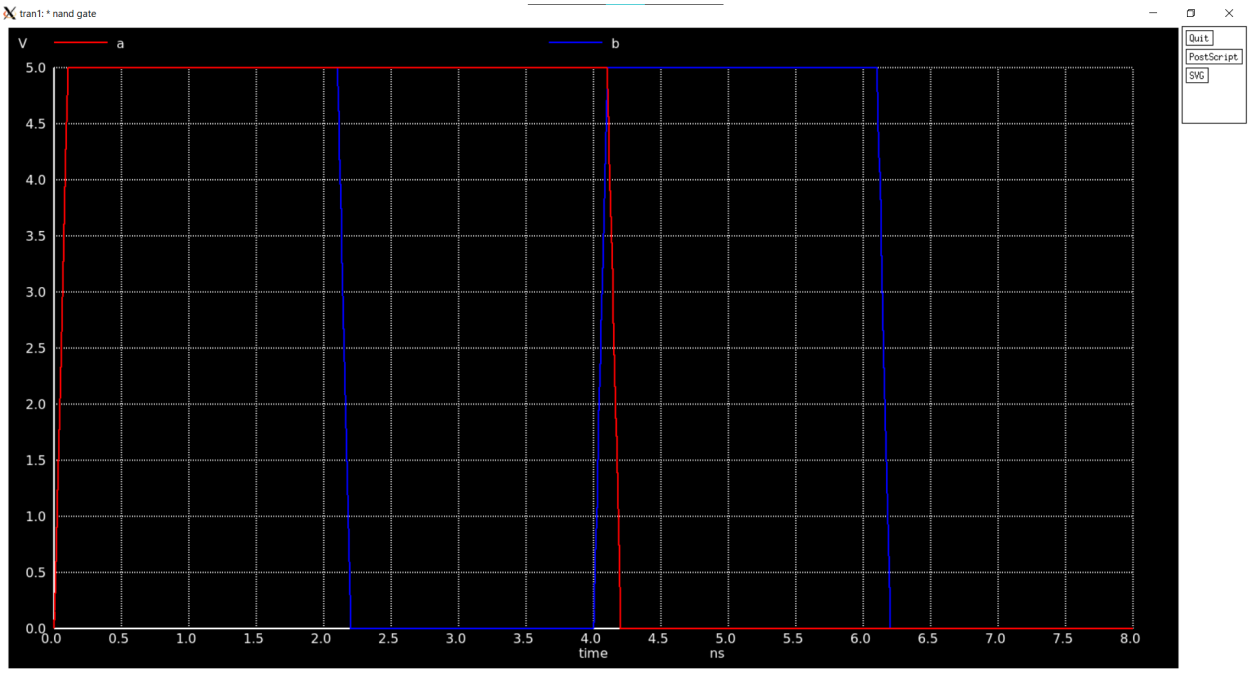
Netlist

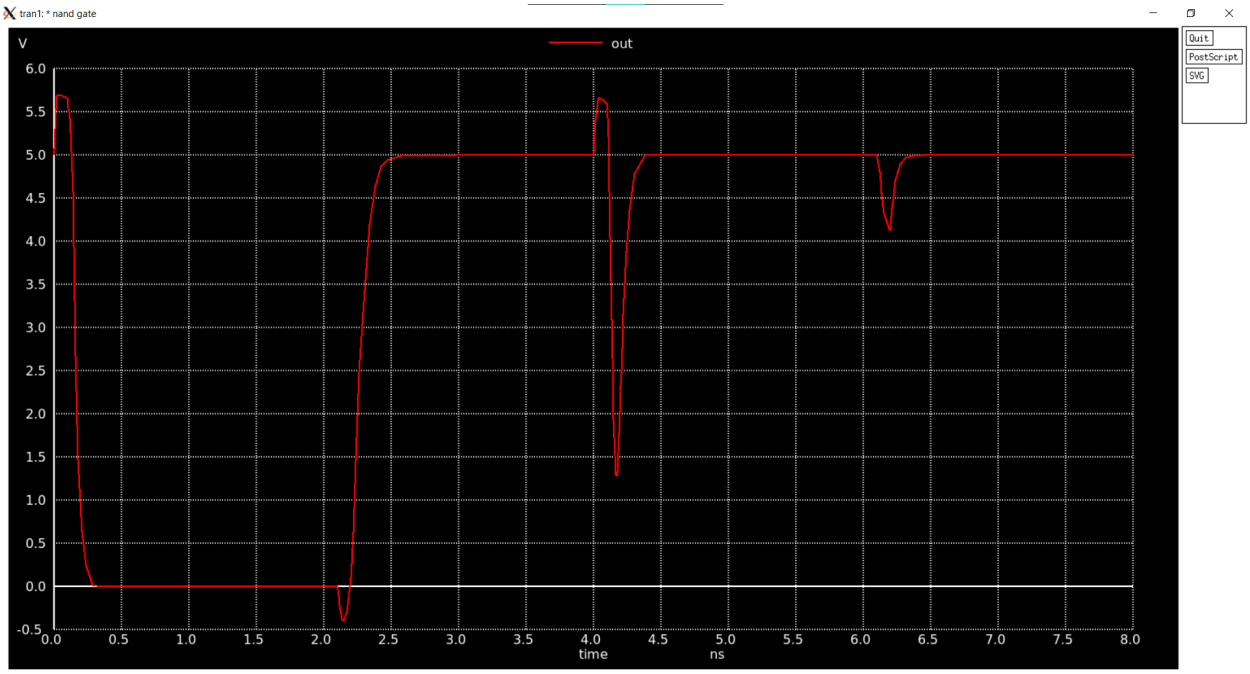
```
* NAND gate
* model file
.include ./t14y_tsmc_025_level3.txt
**Pull up network**

m2 vdd a out vdd cmosp w=25u l=1u
m3 vdd b out vdd cmosp w=25u l=1u

**Pull down network**
m0 out a x 0 cmosn w=10u l=1u
m1 x b 0 0 cmosn w=10u l=1u

v_dd vdd 0 5
v_a a 0 5 pulse(0 5 0 0.1n 0.1n 4n 8n)
v_b b 0 5 pulse(0 5 0 0.1n 0.1n 2n 4n)

* output
* VTC Characteristics

.control
dc v_a 0 5 1 v_dd 0 5 1
run
setplot dc1
plot -v_dd#branch

dc v_b 0 5 1 v_dd 0 5 1
run
setplot dc2
plot -v_dd#branch
.endc

.control
tran 0.1n 8n
setplot tran1
* plot a b
* plot out
* plot b a out

meas tran Vmax MAX out from=6.2n to=7.8n
meas tran Vmin MIN out from=6.2n to=7.8n
let v10 = Vmin + 0.1*(Vmax-Vmin)
let v90 = Vmin + 0.9*(Vmax-Vmin)
let v50 = Vmin + 0.5*(Vmax-Vmin)

* print v10, v50, v90

meas tran trise trig out val=v10 rise=1 targ out val=v90 rise=1
* print trise
meas tran tfall trig out val=v90 fall=1 targ out val=v10 fall=1
* print tfall
```

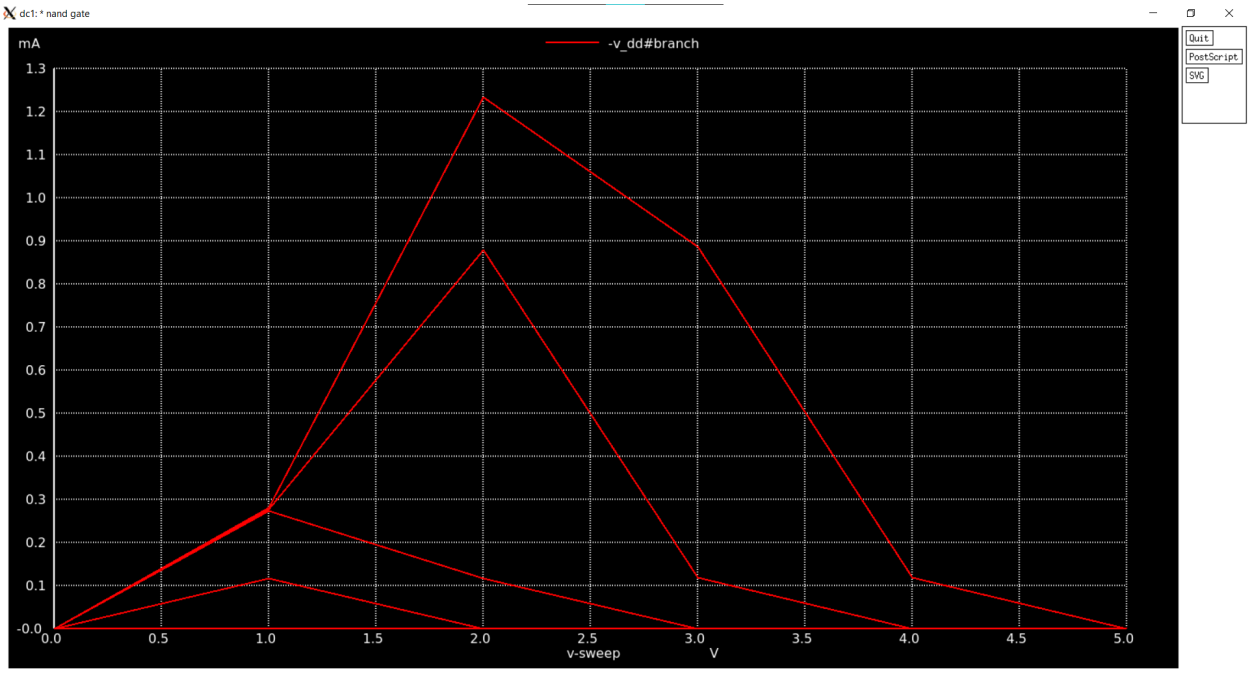
```
meas tran tphl_a trig a val=2.5 rise=1 targ out val=v50 fall=1
meas tran tplh_a trig a val=2.5 fall=1 targ out val=v50 rise=1
let tp_a = (tphl_a+tplh_a)/2


meas tran tphl_b trig b val=2.5 rise=1 targ out val=v50 fall=1
meas tran tplh_b trig b val=2.5 fall=1 targ out val=v50 rise=1
let tp_b = (tphl_b+tplh_b)/2


meas tran tphl_out trig out val=2.5 rise=1 targ out val=v50 fall=1
meas tran tplh_out trig out val=2.5 fall=1 targ out val=v50 rise=1
let tp_out = (tphl_out+tplh_out)/2
print tp_out, tp_a, tp_b

.endc
.end
```

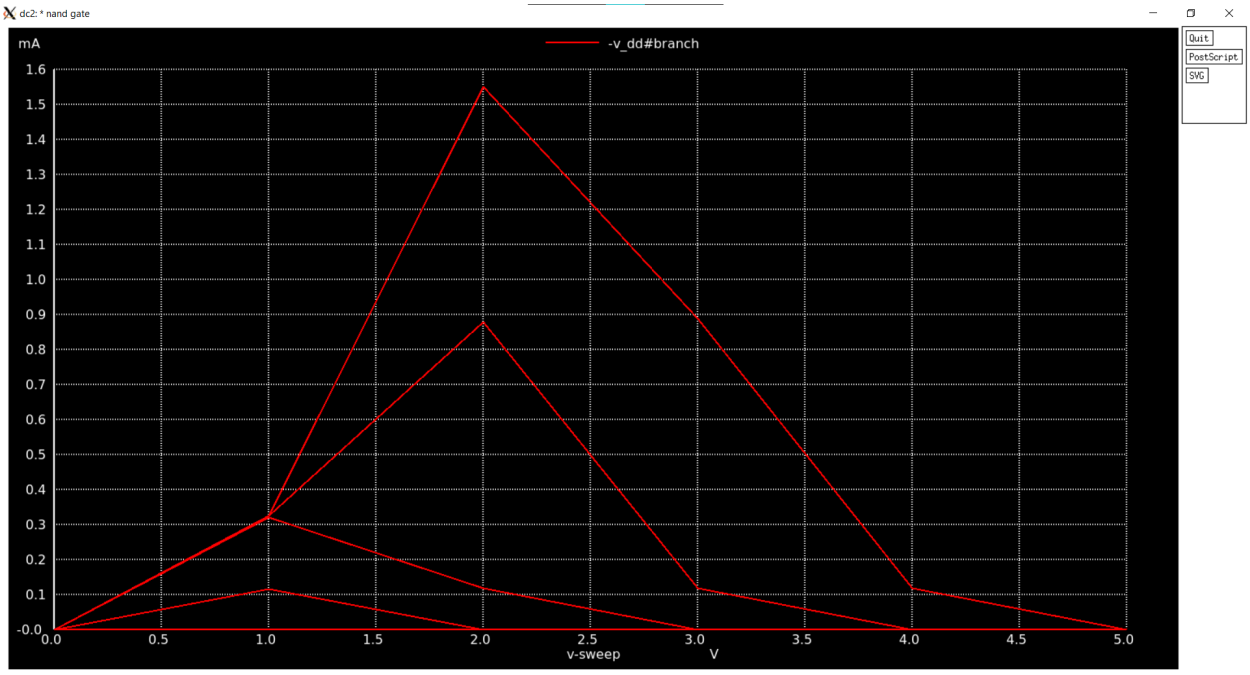
Voltage Transfer Characteristics:




tran1: * nand gate
V
a
b
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
time
ns
Quit
PostScript
SVG


tran1: * nand gate
V
out
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0
time
ns
Quit
PostScript
SVG





From the above waveforms, we can observe the output characteristics changes based on given inputs to a and b.

Propagation Delay:

Initial Transient Solution
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```
Node                                   Voltage
----                                   -------
vdd                                          5
a                                            0
out                                          5
b                                            0
x                                    0.0140853
v_b#branch                                   0
v_a#branch                                   0
v_dd#branch                        -2.15962e-11
```

From t=0 to t= 2n
a = 1, b = 1

```
No. of Data Rows : 208
vmax                =  5.696929e+00 at=  2.476925e-11
vmin                =  -9.458493e-04 at=  3.471568e-10
trise               =  -2.210019e-09 targ=  2.587975e-12 trig=  2.212607e-09
tfall               =  8.670607e-11 targ=  2.097099e-10 trig=  1.230038e-10
tphl_a              =  1.037169e-10 targ=  1.537169e-10 trig=  5.000000e-11
tplh_a              =  -1.876083e-09 targ=  2.273917e-09 trig=  4.150000e-09
tphl_b              =  1.037169e-10 targ=  1.537169e-10 trig=  5.000000e-11
tplh_b              =  1.239175e-10 targ=  2.273917e-09 trig=  2.150000e-09
tphl_out            =  -2.107262e-09 targ=  1.537169e-10 trig=  2.260979e-09
tplh_out            =  2.115540e-09 targ=  2.273917e-09 trig=  1.583774e-10
tp_out = 4.139000e-12
tp_a = -8.86183e-10
tp_b = 1.138172e-10
```

From t=2n to t= 4n
a = 1, b = 0

```
No. of Data Rows : 208
vmax                =  5.002308e+00 at=  3.567208e-09
vmin                =  1.037124e-01 at=  2.200000e-09
trise               =  1.522508e-10 targ=  2.365498e-09 trig=  2.213248e-09
tfall               =  7.130622e-11 targ=  2.078706e-10 trig=  1.365644e-10
tphl_a              =  1.074890e-10 targ=  1.574890e-10 trig=  5.000000e-11
tplh_a              =  -1.887050e-09 targ=  2.262950e-09 trig=  4.150000e-09
tphl_b              =  1.074890e-10 targ=  1.574890e-10 trig=  5.000000e-11
tplh_b              =  1.129498e-10 targ=  2.262950e-09 trig=  2.150000e-09
tphl_out            =  -2.103490e-09 targ=  1.574890e-10 trig=  2.260979e-09
tplh_out            =  2.104572e-09 targ=  2.262950e-09 trig=  1.583774e-10
tp_out = 5.410000e-13
tp_a = -8.89780e-10
tp_b = 1.102194e-10
```

From t=4n to t= 6n
a =0, b = 1

```
No. of Data Rows : 208
vmax                =  5.000050e+00 at=  4.549262e-09
vmin                =  2.262998e+00 at=  4.200000e-09
trise               =  1.318545e-10 targ=  2.394198e-09 trig=  2.262343e-09
tfall               =  2.540886e-11 targ=  1.577623e-10 trig=  1.323534e-10
tphl_a              =  9.564247e-11 targ=  1.456425e-10 trig=  5.000000e-11
tplh_a              =  -1.841374e-09 targ=  2.308626e-09 trig=  4.150000e-09
tphl_b              =  9.564247e-11 targ=  1.456425e-10 trig=  5.000000e-11
tplh_b              =  1.586258e-10 targ=  2.308626e-09 trig=  2.150000e-09
tphl_out            =  -2.115336e-09 targ=  1.456425e-10 trig=  2.260979e-09
tplh_out            =  2.150248e-09 targ=  2.308626e-09 trig=  1.583774e-10
tp_out = 1.745600e-11
tp_a = -8.72866e-10
tp_b = 1.271341e-10
```

From t=6n to t=8n
a=0, b=0

```
No. of Data Rows : 208
vmax                =  4.999955e+00 at=  7.634084e-09
vmin                =  4.130587e+00 at=  6.200474e-09
trise               =  1.137830e-10 targ=  2.452224e-09 trig=  2.338441e-09
tfall               =  1.160487e-11 targ=  1.396037e-10 trig=  1.279988e-10
tphl_a              =  8.602007e-11 targ=  1.360201e-10 trig=  5.000000e-11
tplh_a              =  -1.779656e-09 targ=  2.370344e-09 trig=  4.150000e-09
tphl_b              =  8.602007e-11 targ=  1.360201e-10 trig=  5.000000e-11
tplh_b              =  2.203445e-10 targ=  2.370344e-09 trig=  2.150000e-09
tphl_out            =  -2.124959e-09 targ=  1.360201e-10 trig=  2.260979e-09
tplh_out            =  2.211967e-09 targ=  2.370344e-09 trig=  1.583774e-10
tp_out = 4.350400e-11
tp_a = -8.46818e-10
tp_b = 1.531823e-10
```

Tp = propagation delay

Input a	Input b	tp_a	tp_b	tp_out
1	1	-8.86e-10	1.13e-10	4.13e-11
1	0	-8.89e-10	1.10e-10	5.41e-11
0	1	-8.72e-10	1.27e-10	1.74e-11
0	0	-8.46e-10	1.53e-10	4.3e-11

We can clearly observe from the above table that propagation delay is dependant on the input pattern.