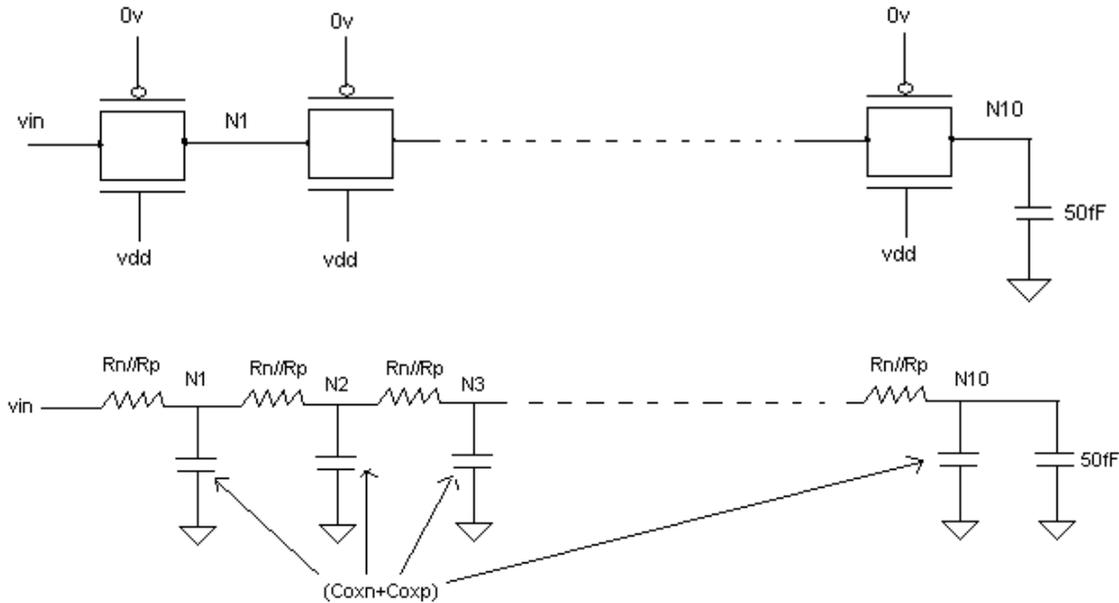


Problem 13.1)

Krishna Duvvada

Estimate and simulate the delay through 10 TG's connected a 50fF load capacitance. Use the 50nm short channel CMOS process with the parameters seen in Table 10.2.

Solution:-



From Table 10.2, for short channel (50nm) process,  $R_n=R_p=3.4K$  ohms.  
 $C_{ox,n}=0.645fF$  &  $C_{ox,p}=1.25fF$

$$t_{PHL} = t_{PLH} = [0.35 * (R_n/R_p) * (C_{ox,n} + C_{ox,p}) * 10^2] + [0.7 * 10 * (R_n/R_p) * 50fF]$$

$$= [0.35 * (1.7K) * (1.25+0.625)fF * 10^2] + [0.7 * 10 * (1.7K) * 50fF]$$

$$= (111.5625 + 595)ps$$

$$= 706.562 ps$$

$t_d = 0.7ns$

Spice net list:-

```

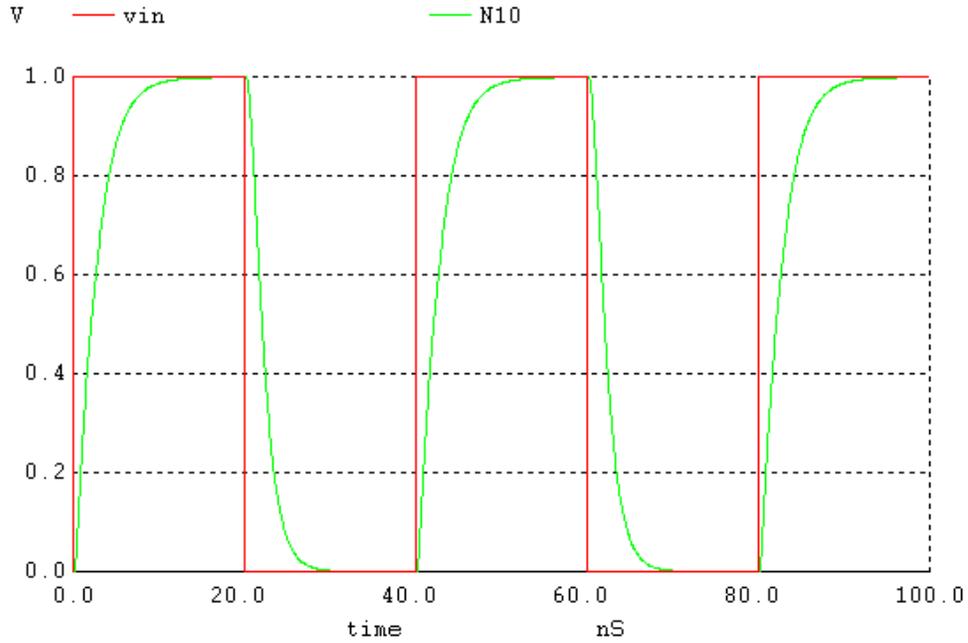
***Problem-(13.1)
.control
destroy all
run
plot vin N10 ylimit 0 1
.endc
.option scale=50n
.tran .05n 100n
    
```

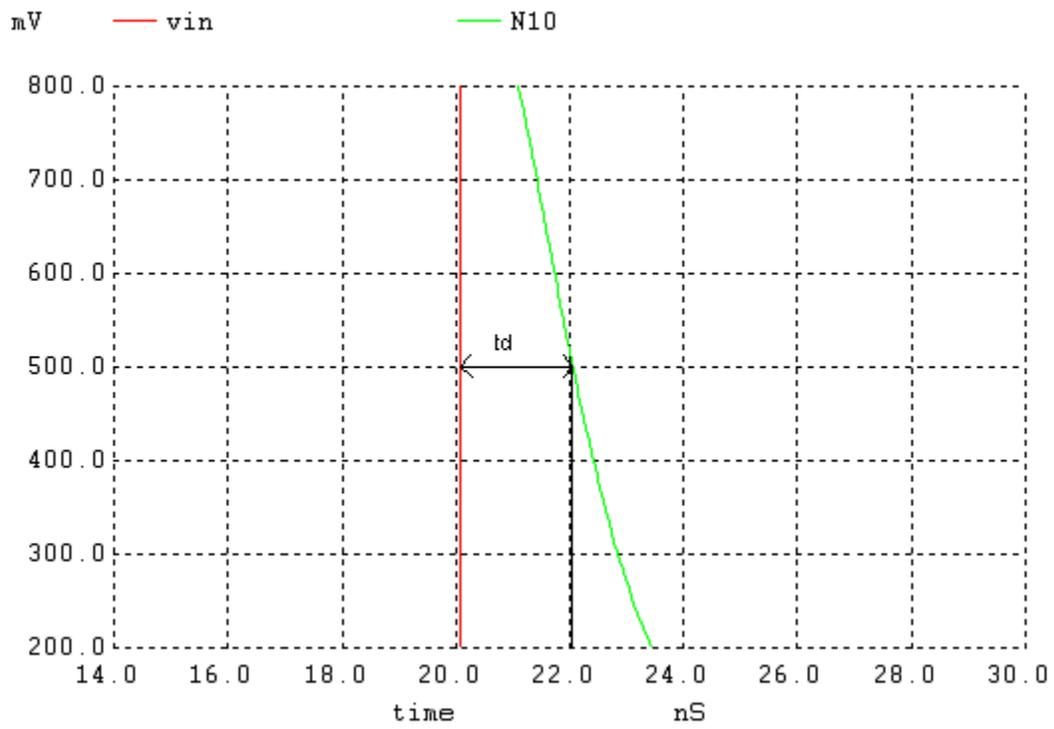
```
vdd vdd 0 DC 1
Vin vin 0 DC 0 pulse 0 1 0 0 0 20n 40n
```

```
X1 vin N1 TG
X2 N1 N2 TG
X3 N2 N3 TG
X4 N3 N4 TG
X5 N4 N5 TG
X6 N5 N6 TG
X7 N6 N7 TG
X8 N7 N8 TG
X9 N8 N9 TG
X10 N9 N10 TG
```

```
cl N10 0 50f
```

```
.Subckt TG in out
vdd vdd 0 DC 1
M1 in vdd out 0 NMOs L=1 w=10
M2 in 0 out vdd PMOS L=1 w=20
.ends
```





$t_d = (22.0 - 20.1) = 1.9 \text{ ns}$  (which is nearer to the calculated value, 0.7ns)

13.2)

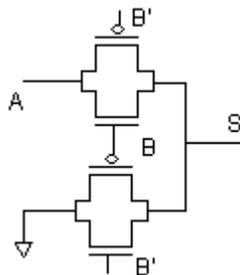
Surendranath C Eruvuru

*Design and simulate the operation of a half adder circuit using TGs.*

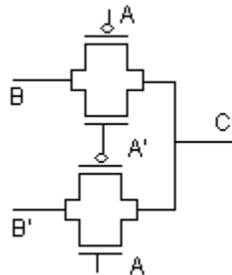
Following is the truth table of a Half Adder:

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	1	1

In the following circuit all the PMOS transistors are 20/1 and all NMOS transistors are 10/1 in measurements. Both the SUM logic and the CARRY logic have two transmission gates (TG) output capacitances to discharge through  $R_n // R_p$  resistance. So,  $T_{HL} + T_{HL}$  from hand calculations is 4.46ps.



**Circuit for SUM**



**Circuit for Carry**

**Netlist:**

```
.CONTROL
DESTROY ALL
RUN
plot A 1.25+B 2.5+S 3.75+C
.ENDC
.option scale=50n
.tran .1n 10n UIC
```

```

VA  A    0    DC    0    PULSE 1 0 1n .01n .01n 2n 4n
VAI AI    0    DC    0    PULSE 0 1 1n .01n .01n 2n 4n
VB  B    0    DC    0    PULSE 1 0 2n .01n .01n 2n 4n
VBI BI    0    DC    0    PULSE 0 1 2n .01n .01n 2n 4n
VDD VDD  0    DC    1

```

```

XTG1 B    A    AI    S    Vdd  TG
XTG2 BI   AI   A     S    Vdd  TG
XTG3 0    B    BI    C    Vdd  TG
XTG4 A    BI   B     C    Vdd  TG

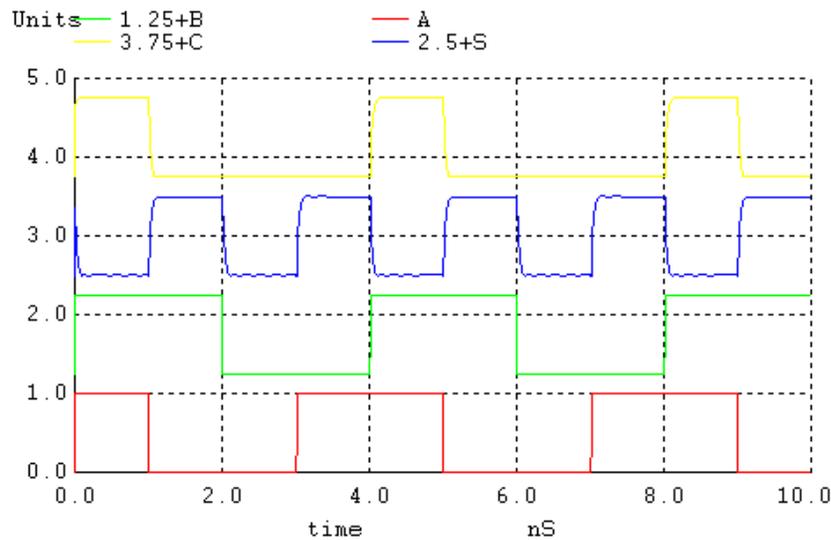
```

```

*****SUBCKT
1*****
.SUBCKT  TG  in1  in2  in3  out1  Vdd
M1  out1 in2  in1  Vdd  PMOS L=1 W=20
M2  out1 in3  in1  0     NMOS L=1 W=10
.ENDS

```

**Simulation result for Half Adder:**



Delay measured from simulations:

$T_{LH} = 20\text{ps}$ .

$T_{HL} = 19\text{ps}$ .



Spice Simulations showing that with the  $(S3, S2, S1) = (0, 0, 0)$  the output node A followed the node Z and when  $(S3, S2, S1) = (1, 0, 0)$  the output node e followed the node Z.

```
*Prob 13.3 DEMUX

.control
destroy all
run
plot VZ   Vs1+2 vs2+4 vs3+6 va+8 Vb+10 Vc+12 vd+14 ve+16 vf+18 vg+20
.endc

.option scale=50n
.tran 100p 24n UIC
.IC V(va)=0 V(vb)=0 V(vc)=0 V(vd)=0 V(ve)=0 V(vf)=0 V(vg)=0

vdd      vdd      0      DC      1
VZ       VZ       0      DC      0      pulse 0 1 5n 0 0 5n 10n

VSEL1    VSEL1    0      DC      0      pulse 0 1 14n 0 0 7n 14n
VSEL2    VSEL2    0      DC      0
VSEL3    VSEL3    0      DC      0

XINV1    VSEL1    Vs1bar vdd     0      INV
XINV2    Vs1bar Vs1     vdd     0      INV
XINV3    VSEL2    Vs2bar vdd     0      INV
XINV4    Vs2bar Vs2     vdd     0      INV
XINV5    VSEL3    Vs3bar vdd     0      INV
XINV6    Vs3bar Vs3     vdd     0      INV

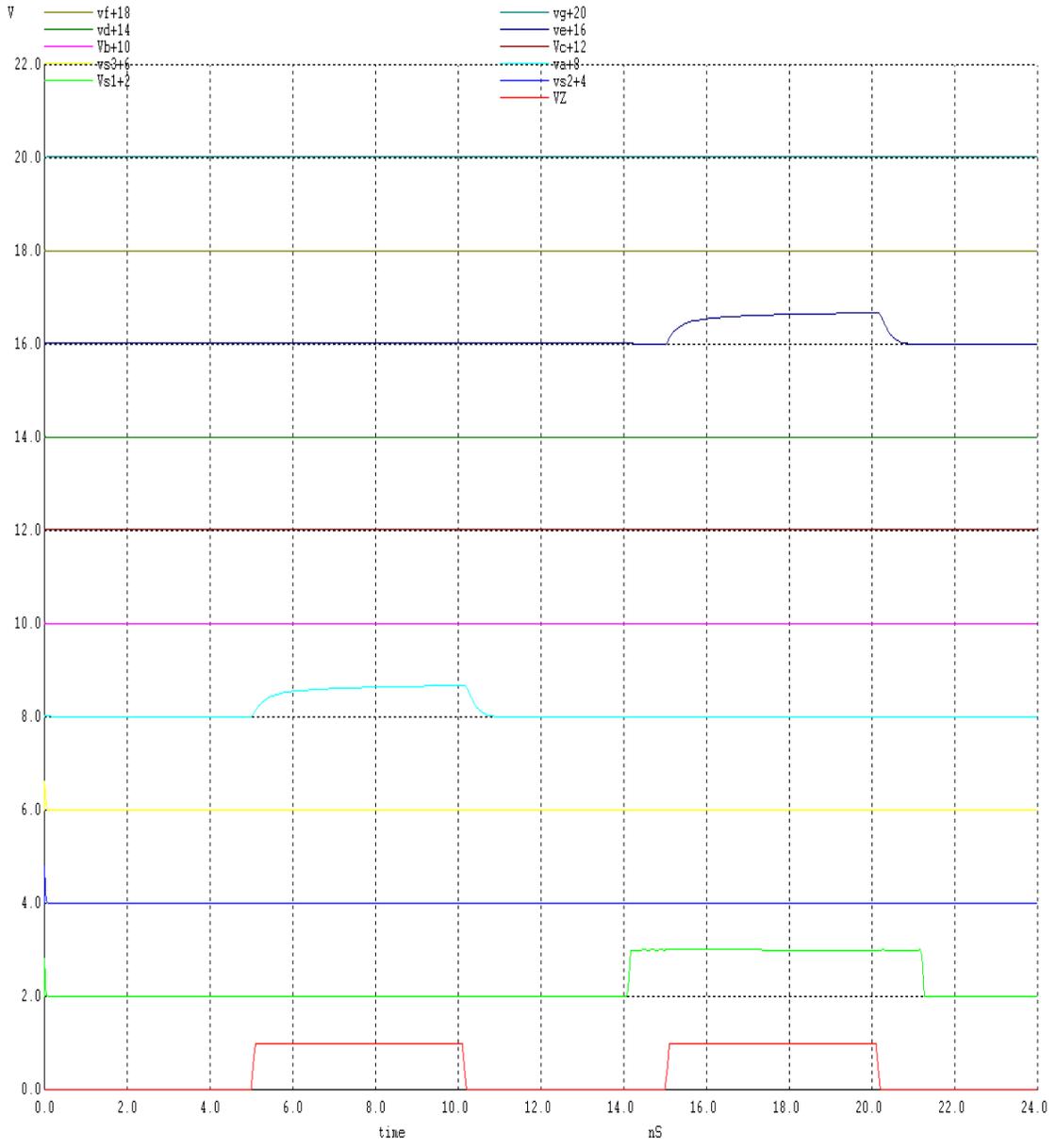
M1       Va      Vs3bar temp1  0      NMOS L=1 W=10
M2       Vb      Vs3     temp1  0      NMOS L=1 W=10
M3       Vc      Vs3bar temp2  0      NMOS L=1 W=10
M4       Vd      Vs3     temp2  0      NMOS L=1 W=10
M5       temp1  Vs2bar temp3  0      NMOS L=1 W=10
M6       temp2  Vs2     temp3  0      NMOS L=1 W=10
M7       temp3  Vs1bar VZ     0      NMOS L=1 W=10

M8       Ve      Vs3bar temp4  0      NMOS L=1 W=10
M9       Vf      Vs3     temp4  0      NMOS L=1 W=10
M10      Vg      Vs3bar temp5  0      NMOS L=1 W=10
M11      Vh      Vs3     temp5  0      NMOS L=1 W=10
M12      temp4  Vs2bar temp6  0      NMOS L=1 W=10
M13      temp5  Vs2     temp6  0      NMOS L=1 W=10
M14      temp6  Vs1     VZ     0      NMOS L=1 W=10

Cloada  va      0      50f
Cloadb  vb      0      50f
Cloadc  vc      0      50f
Cloadd  vd      0      50f
Cloade  ve      0      50f
Cloadf  vf      0      50f
Cloadg  vg      0      50f
Cloadh  vh      0      50f

.SUBCKT INV  INV_in  INV_out  INV_Vdd  INV_gnd
Minv1  INV_out  INV_in  INV_vdd  INV_vdd  PMOS  L=1  W=20
Minv2  INV_out  INV_in  INV_gnd  INV_gnd  NMOS  L=1  W=10
.ENDS

* 50nm BSIM4 models
```



Vinay Dindi

13.4) Verify, using SPICE, that the circuit seen in Fig. 13.12 operates as an XOR gate.

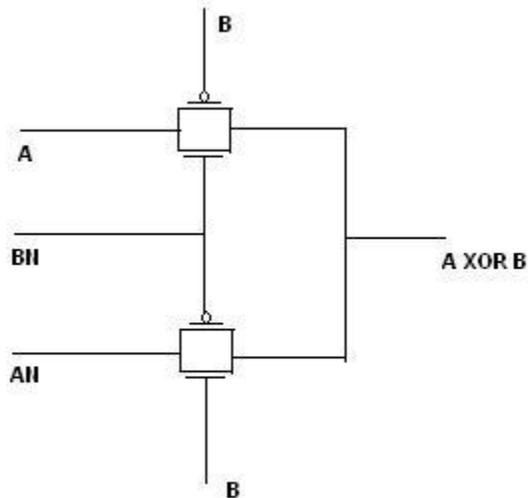


Fig 13.12

The circuit is simulated in winspice with PMOS and NMOS sizes as 20/1 and 10/1 respectively. Netlist is as shown below..

```
Prob13_4 - Notepad
File Edit Format View Help
*** Problem 13.4 CMOS: Circuit Design, Layout, and Simulation ***
.control
destroy all
run
plot vin1 vin2+1.2 out+2.3
.endc
vdd      vdd      0      DC      1
Vin1     vin1     0      DC      0      pulse    0 1 200p 0 0 2n 3n
Vin2     vin2     0      DC      0      pulse    1 0 200p 0 0 1n 2n

x1       vin1     out      vin2bar  vin2     vdd      TG
x2       vin1bar out      vin2     vin2bar  vdd      TG
x3       vin1     vin1bar  vdd      INV
x4       vin2     vin2bar  vdd      INV
c1       out      0        10f

.subckt  TG      in      out      s        sbar      VDD
M1       in      s        out      0        NMOS L=1 W=10
M2       in      sbar     out      vdd      PMOS L=1 W=20
.ends

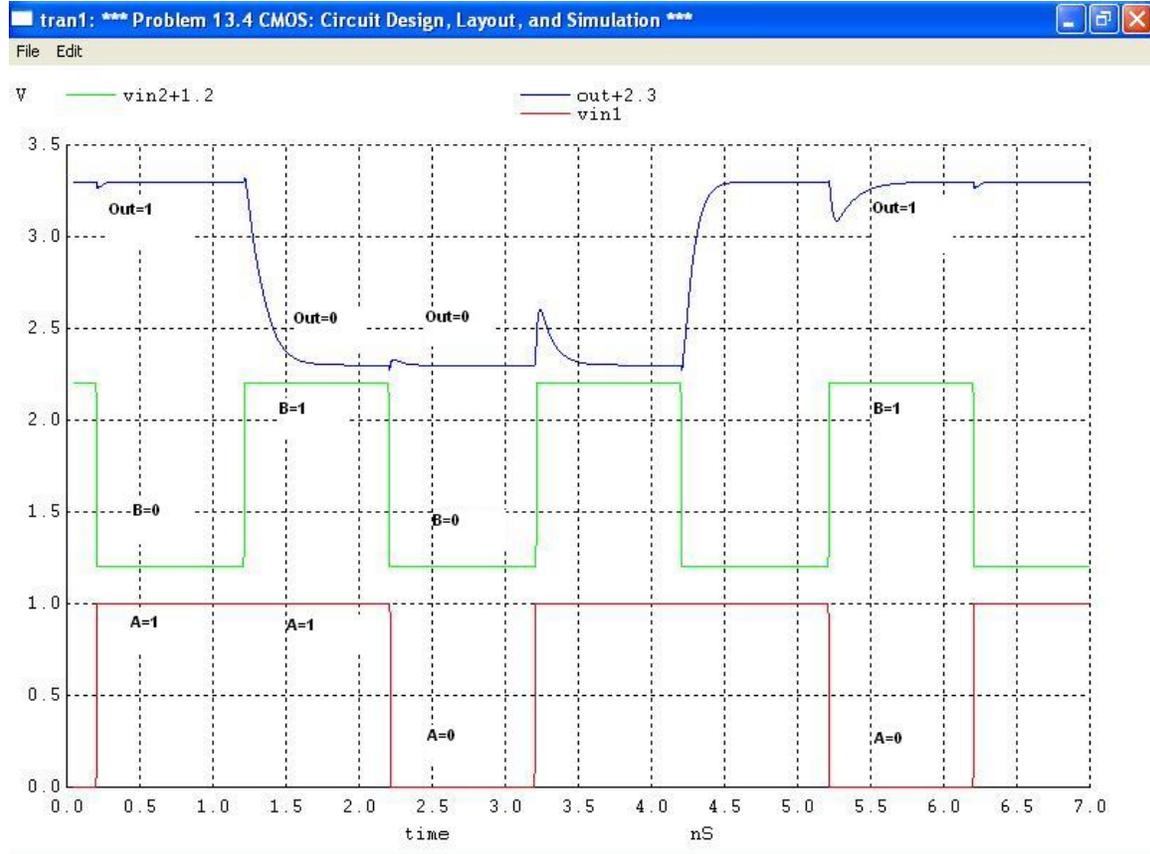
.subckt  INV     A        out1     VDD
M1       out1    A        0        0        NMOS L=1 W=10
M2       out1    A        VDD     VDD     PMOS L=1 W=20
*c2      out1    0        20f
.ends

|option scale=50n
```

Truth table of an XOR gate

A	B	Out
0	0	0
0	1	1
1	0	1
1	1	0

Note: In the netlist A=Vin1, Abar=Vin1bar, B=Vin2, Bbar=Vin2bar. The output of the simulation is as shown below



**Problem 13.5 :- Simulate the operation of an SR latch made with NAND gates. Show all four possible combinations.**

**Solution:-**

```
*netlist for the circuit
.control
destroy all
run
plot vr vS+1.5 vQ+3 vq1+4.5 VQ1+4.5 ylimit 0 6
.endc
.option scale=50n
.tran .01n 4n
```

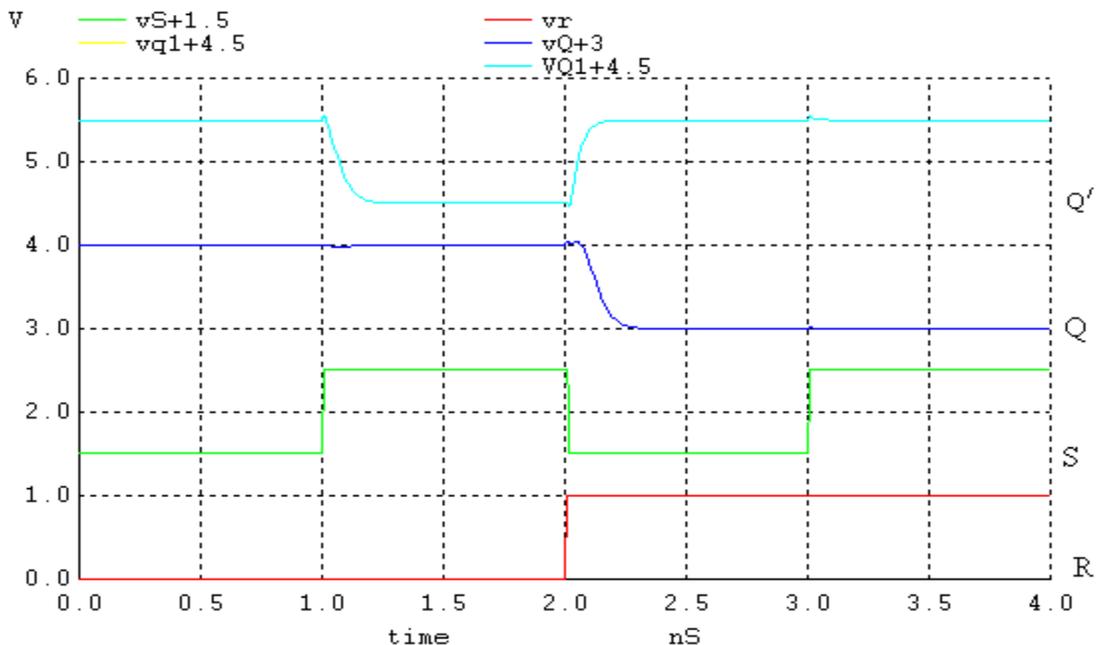
```
vS vS 0 DC 0 pulse(0 1 1n 0 0 1n 2n)
vR vR 0 DC 0 pulse(0 1 2n 0 0 2n 4n)
```

```
x1 vSvQ vQ1 NAND
x2 vRvQ1 vQ NAND

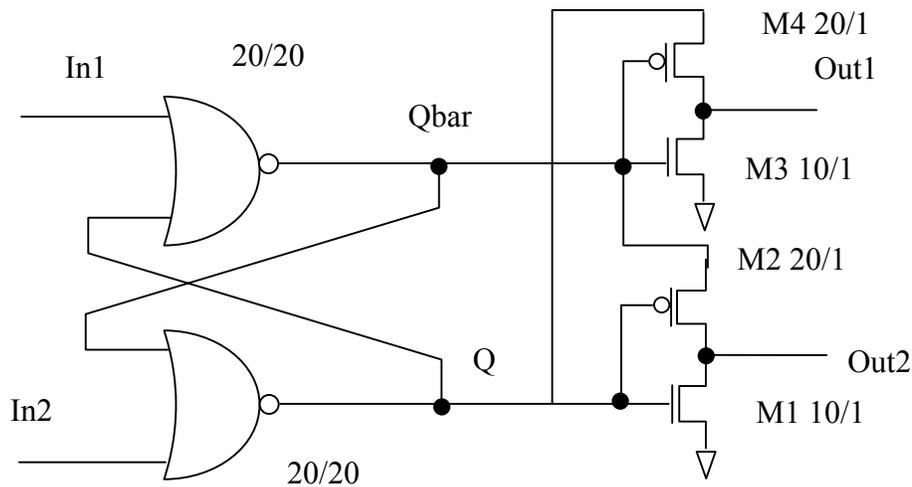
.subckt NAND ina inb out
vdd vdd 0 DC 1
M1 out ina vdd vdd PMOS L=1 W=20
M2 out inb vdd vdd PMOS L=1 W=20
M3 out ina n1 0 NMOS l=1 W=10
M4 n1 inb 0 0 NMOS l=1 W=10
.ends
*models attached
.end
```

Truth table  
for SR latch

S	R	Q	Q'
0	0	1	1
1	0	1	0
0	1	0	1
1	1	Q	Q'



13.6 Simulate the operation of the Arbiter seen in Fig. 13.15. Show how two inputs arriving at the same time results in only one output going high.



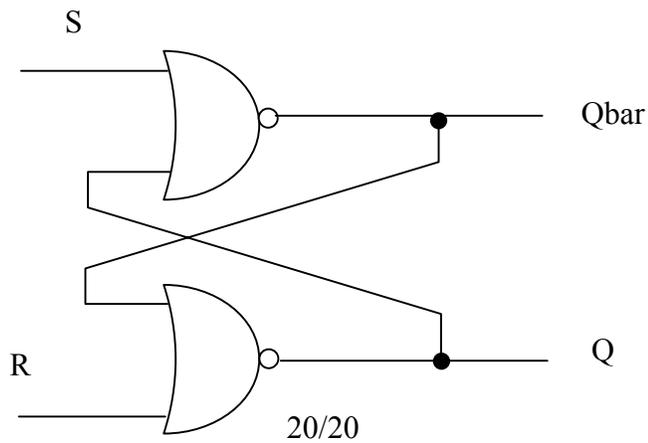
**Figure 13.15** An arbiter made using NAND gates.

**Solution**

The input stage is a SR NAND latch as seen in the figure below. The output of the NAND latch powers the inverters.

Truth Table

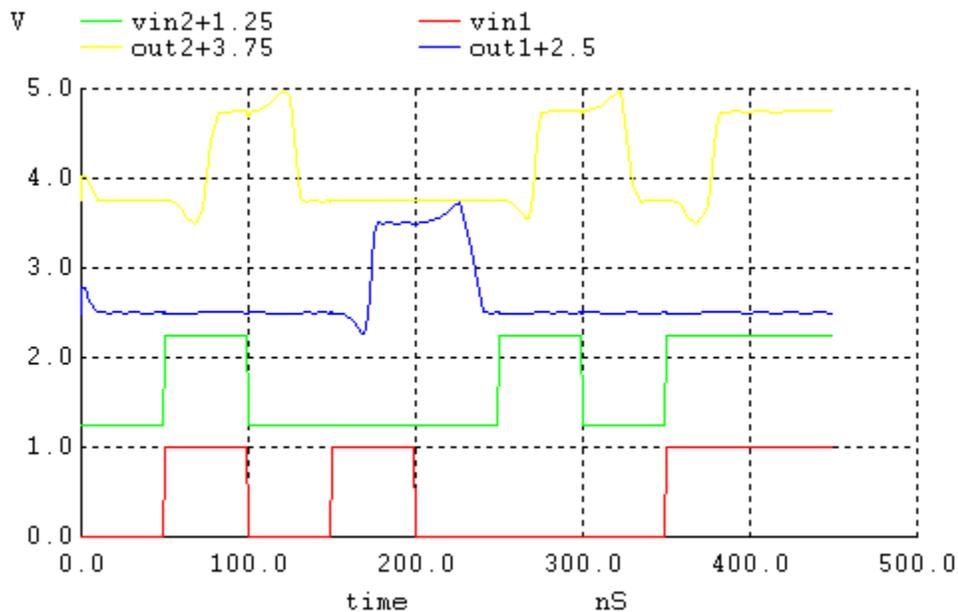
S	R	Q	Qbar
0	0	1	1
0	1	1	0
1	0	0	1
1	1	Q	Qbar



**Figure 13.6.1** Set-reset NAND latch.

The truth table for the NAND latch is shown in Figure 13.6.1. So if S (In 1) is high, Q is low. As a result Out 1 is high, because it has a low input and is powered by Q. This can be seen in the simulation results of Figure 13.6.2.

Out 2 is low because of the similar reason. Similarly if R is high, Qbar is low, and Out2 is high and Out1 is low. When both the arbiter inputs go low, both the arbiter outputs are also low. This is also observed in the simulations of Figure 1.6.2.



If, the arbiter is in steady state (one output high and the other low), and both the inputs are high, the arbiter maintains its steady state because of the latch action of the NAND latch (Q and Qbar maintain their states if both the inputs are high, as seen in the Truth table). This is seen in the simulation Figure 13.6.2. The simulation shows the outputs Out1 and Out2 for all combinations of inputs Vin1 and Vin2 (namely 00, 01, 10 and 11).

Consider a scenario that during the initial power up, both the inputs go high at the same time. Because of the propagation delay mismatch in the feedback paths of the NAND gates in the latch, (delays depend upon layout), either Q or Qbar, but not both, goes high. Accordingly, either Out1 or Out2 will be high. This is also observed in the simulation of Figure 13.6.2. Thus, the circuit act as an arbiter for the two inputs.

The spice simulation file is as given below.

\*\*\* Problem 12.6 CMOS: Circuit Design, Layout, and Simulation \*\*\*

```
.control
destroy all
run
plot vin1 vin2+1.25 out1+2.5 out2+3.75
```

```

.endc

.option scale=1u
.tran 10n 450n 0n UIC

vdd vdd 0 DC 1
vin1 vin1 0 DC 0 PWL(0 0 49n 0 50n 1 99n 1 100n 0 149n 0 150n 1
199n 1 200n 0 349n 0 350n 1)
vin2 vin2 0 DC 0 PWL(0 0 49n 0 50n 1 99n 1 100n 0 249n 0 250n 1
299n 1 300n 0 349n 0 350n 1)

x1 vin1 n2 n1 vdd NAND_2
x2 n1 vin2 n2 vdd NAND_2

x3 n1 n2 out1 vdd INV
X4 n2 n1 out2 vdd INV

cout1 out1 0 5f IC=0
cout2 out2 0 5f IC=0

.subckt NAND_2 A B out VDD
M1 n1 A 0 0 NMOS L=1 W=20
M2 out B n1 0 NMOS L=1 W=20
M3 out A VDD VDD PMOS L=1 W=20
M4 out B VDD VDD PMOS L=1 W=20
.ends

.subckt INV A B OUT VDD
M5 OUT A 0 0 NMOS L=1 W=20
M6 OUT A B VDD PMOS L=1 W=10
.ends

* 1 um Level 3 models
*
* Don't forget the .options scale=1u if using an Lmin of 1
* 1<Ldrawn<200 10<Wdrawn<10000 Vdd=5V

* Long Channel NMOS and PMOS models

.end

```

Problem 13.7

Indira

Show using simulations, how making the feedback inverter in Fig. 13.18 stronger (decreasing the lengths) can result in the output having either a long delay or not fully switching?

Solution:

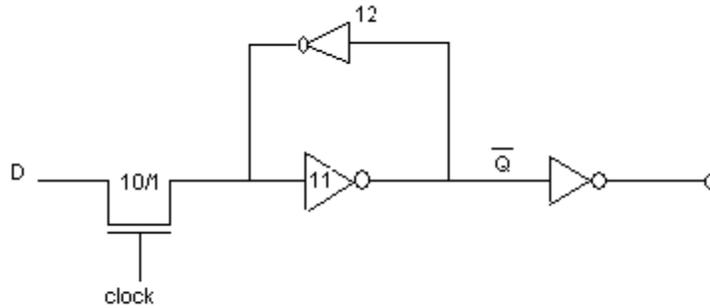
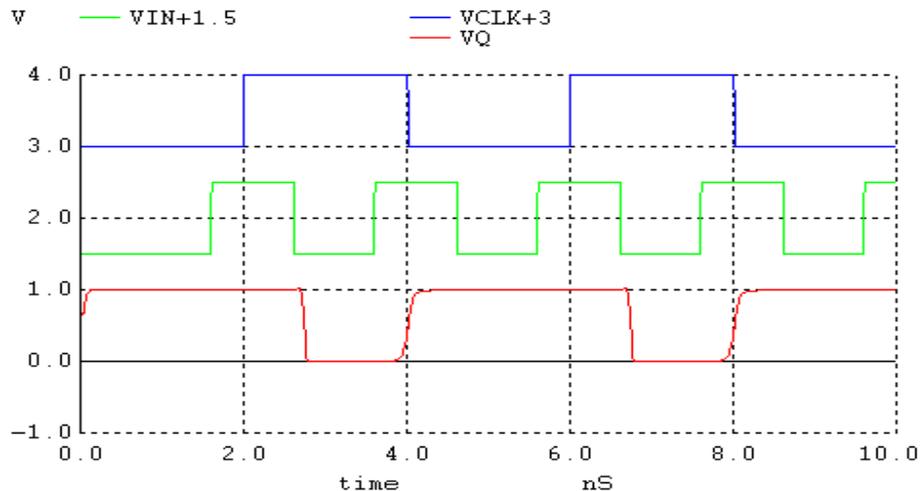


Figure 13.18

\*\*\*\*problem 13.7\*\*\*\*

```
.control
detroy all
run
plot VQ VIN+1.5 VCLK+3
.endc
.option scale=50n
.tran 10p 10n 10P UIC
VDD VDD 0 DC 1
VIN VIN 0 DC 0 PULSE 0 1 1.6N 0 0 1N 2N
VCLK VCLK 0 DC 0 PULSE 0 1 2N 0 0 2N 4N
```

```
M1 VOUT1 VCLK VIN 0 NMOS L=1 W=10
M2 VQ1 VOUT1 0 0 NMOS L=1 W=10
M3 VQ1 VOUT1 VDD VDD PMOS L=1 W=20
M4 VOUT1 VQ1 0 0 NMOS L=10 W=10
M5 VOUT1 VQ1 VDD VDD PMOS L=10 W=10
M6 VQ VQ1 0 0 NMOS L=1 W=10
M7 VQ VQ1 VDD VDD PMOS L=1 W=20
```

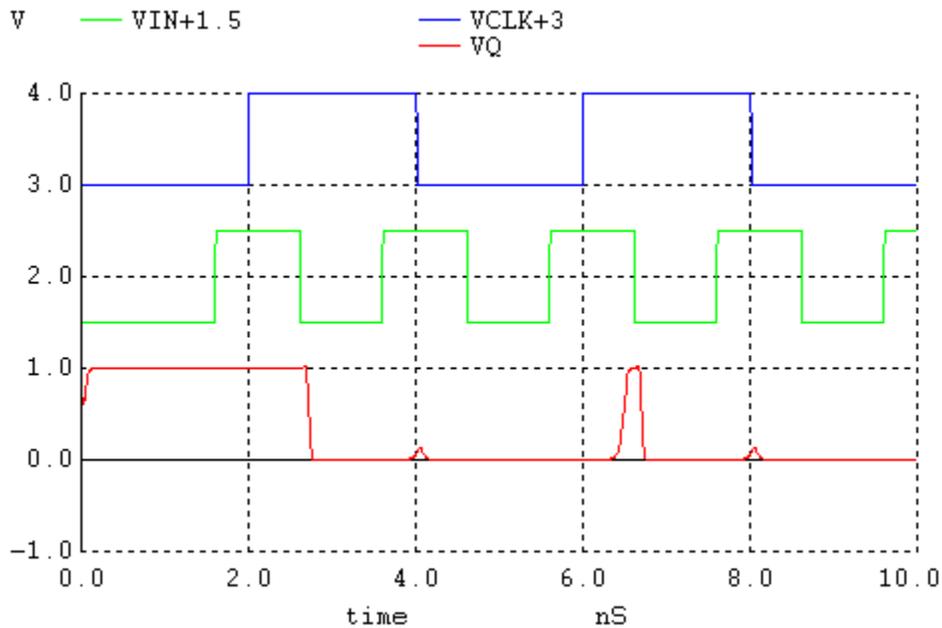


Using L=10 for the inverter 12 will give an output which is fully switching as shown in the above simulation.

\*\*\*\*problem 13.7\*\*\*\*

```
.control
detroy all
run
plot VQ VIN+1.5 VCLK+3
.endc
.option scale=50n
.tran 10p 10n 10P UIC
VDD VDD 0 DC 1
VIN VIN 0 DC 0 PULSE 0 1 1.6N 0 0 1N 2N
VCLK VCLK 0 DC 0 PULSE 0 1 2N 0 0 2N 4N
```

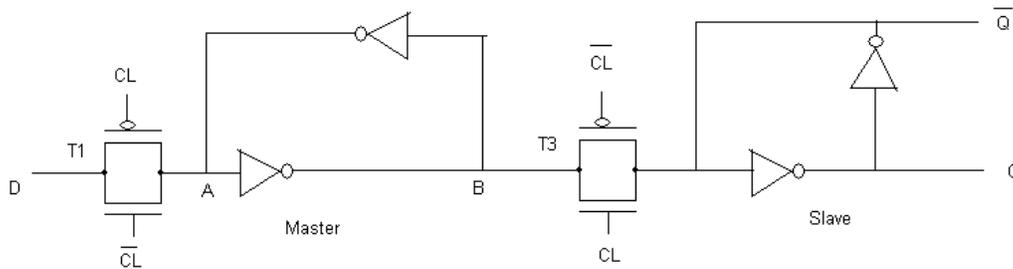
```
M1 VOUT1 VCLK VIN 0 NMOS L=1 W=10
M2 VQ1 VOUT1 0 0 NMOS L=1 W=10
M3 VQ1 VOUT1 VDD VDD PMOS L=1 W=20
M4 VOUT1 VQ1 0 0 NMOS L=5 W=10
M5 VOUT1 VQ1 VDD VDD PMOS L=5 W=10
M6 VQ VQ1 0 0 NMOS L=1 W=10
M7 VQ VQ1 VDD VDD PMOS L=1 W=20
```



Using L=5 for the inverter 12 will result in an output which is not switching completely as shown in the above simulation. Therefore decreasing the length of the feedback inverter 12 will cause the output not to switch fully or either an output having longer delay.

## KRISHNAM RAJU KURRA

Q:13.8: Redesign the FF in Fig.13.22 without T2 and T4 present. Simulate the operation of your design. Show, by using a limited amplitude on the D input, how point B can have a metastability problems.



\*\*\* KRISHNAM ELECTRONIC Q13.8\*\*\*

```
.control
destroy all
run
plot CL D+1 Q+2 ylimit 0 5
.endc
```

```
.option scale=50n
.tran 100P 18n UIC
```

```
vdd      vdd      0      DC      1
Vin      D        0      DC      0      pulse  0 1 300p 0 0 .7n 1.9n
VCL      CL       0      DC      0      pulse  0 1 0 0 0 1n 2n
```

```
M17     CL1     CL      VDD     VDD     PMOS L=1 W=20
M18     CL1     CL      0       0       NMOS L=1 W=10
M19     CL2     CL1     VDD     VDD     PMOS L=1 W=20
M20     CL2     CL1     0       0       NMOS L=1 W=10
M21     CL1     CL2     VDD     VDD     PMOS L=1 W=20
M22     CL1     CL2     0       0       NMOS L=1 W=10

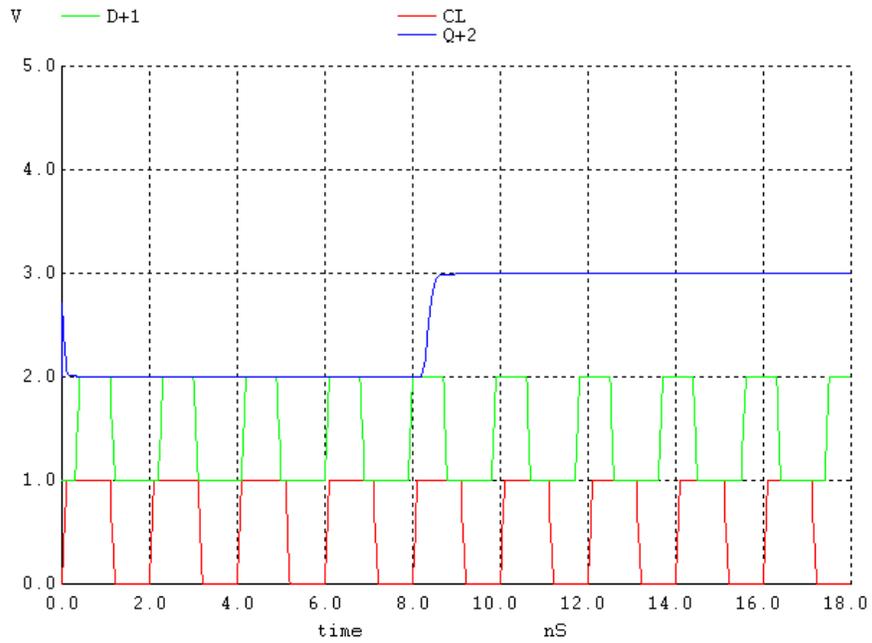
M1      D       CLI     A       0       NMOS L=1 W=10
M2      D       CL      A       vDD     PMOS L=1 W=20

M3      B       A       VDD     VDD     PMOS L=1 W=20
M4      B       A       0       0       NMOS L=1 W=10
M5      A       B       VDD     VDD     PMOS L=10 W=20
M6      A       B       0       0       NMOS L=10 W=10

M7      B       CL      C       0       NMOS L=1 W=10
M8      B       CLI     C       vdd     PMOS L=1 W=20

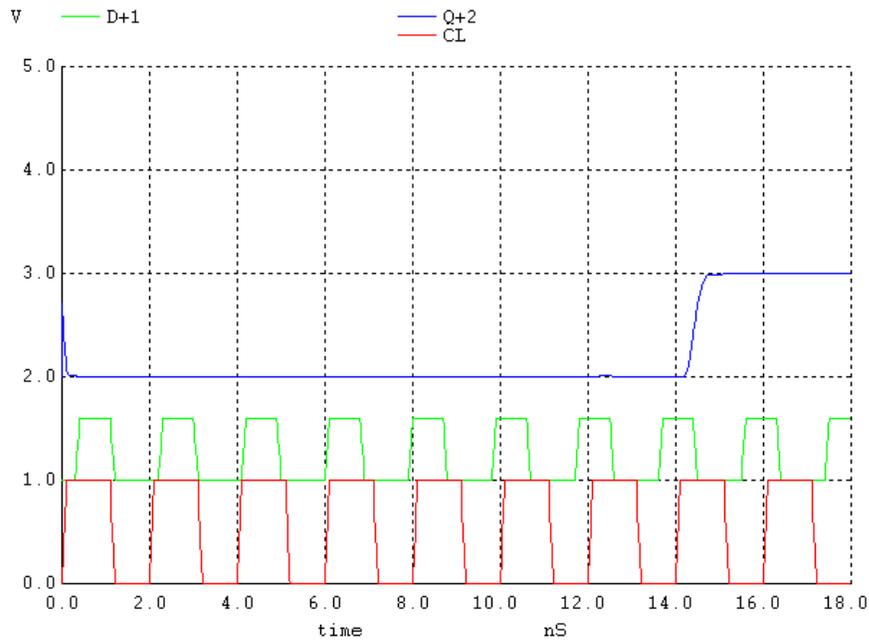
M9      Q       C       VDD     VDD     PMOS L=1 W=20
M10     Q       C       0       0       NMOS L=1 W=10
M11     QI      Q       VDD     VDD     PMOS L=10 W=20
M12     QI      Q       0       0       NMOS L=10 W=10
```

```
.model nmos nmos level = 14
.end
```



With limited D input

Vin D 0 DC 0 pulse 0 0.6 300p 0 0.7n 1.9n



The delay in the case when we used 0-0.6 pulse for the D input is more then the case when we used 0-1 pulse for D input.

***In your own words describe setup and hold times. Use D-FF in Fig. 13.22 and simulations to help support your clear descriptions.***

Setup time is the least amount of time necessary for the data to be present prior to applied clock signal in order to capture valid data input. Hold time is the least amount of time necessary for the data to be present after clock signal in order to capture valid data.

Figure 1 shows simulation results for circuit (D-FF) in fig. 13.22. The results are obtained by applying logic 1 to data input and decreasing delay of the clock compared to data signal to the border point of getting invalid data. Setup time was found to be 45 psec approximately. Once setup time point was found, hold time was obtained by decreasing width of data pulse to the border point of getting invalid data. Hold time was found to be about -1psec. Also, from the figure we can estimate delay through flip flop at about 150 psec.

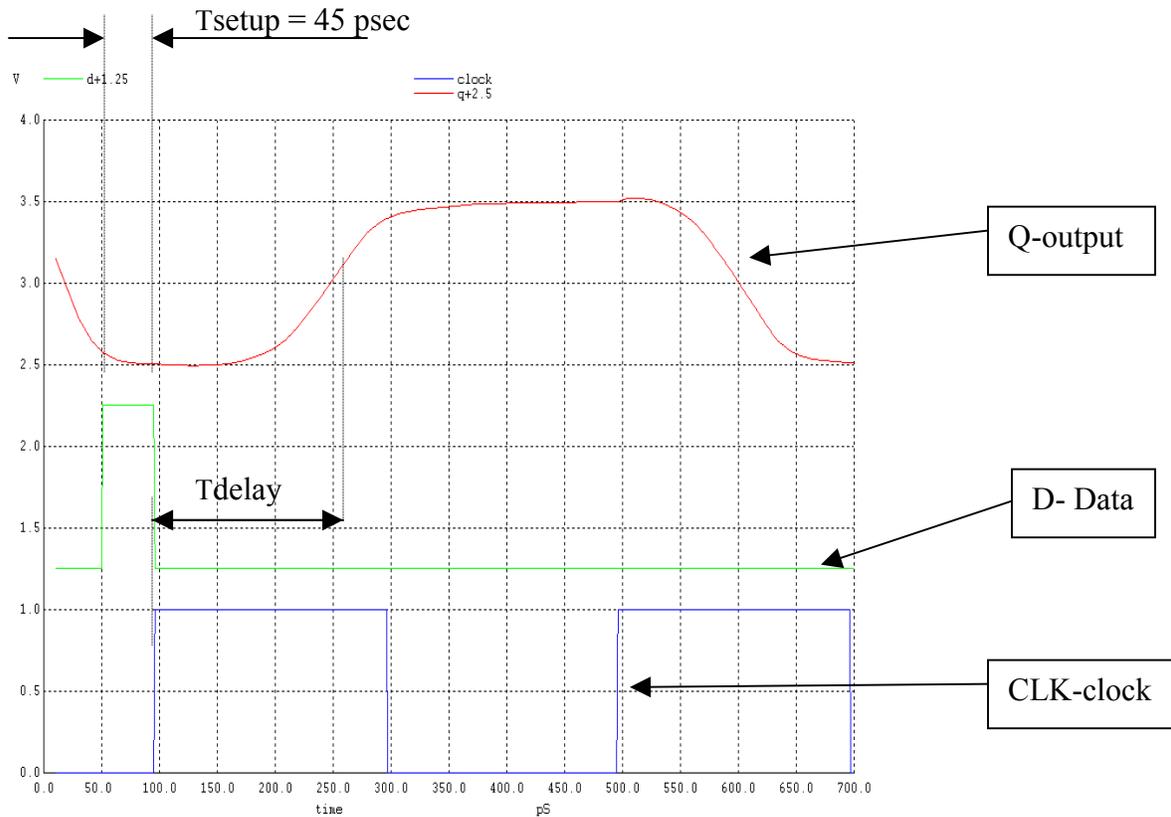


Figure 1. Simulation results for circuit in fig. 13.22 to illustrate setup and hold times

```

.control
destroy all
run
plot q+2.5 d+1.25 clock
.endc

.option scale=50n
.tran 10p 0.7n 10p UIC

vdd    vdd    0    DC    1
Vin    d      0    DC    0    PULSE 0 1 50p 1p 1p 44p 0.7n
Vclock clock  0    DC    0    PULSE 0 1 95p 1p 1p 0.2n 0.4n
Vclockb clockb 0    DC    0    PULSE 1 0 95p 1p 1p 0.2n 0.4n

x11    in1    qbar1  vdd    inv
X21    qbar1  q1     vdd    inv
X31    d      in1    clockb clock  vdd    tg
X41    q1     d      clock  clockb vdd    tg

x12    in2    q      vdd    inv
X22    q      qbar   vdd    inv
X32    qbar1  in2    clock  clockb vdd    tg
X42    in2    qbar   clockb clock  vdd    tg

.subckt inv    in    out    VDD
M1    out    in    0    0    NMOS L=1 W=10
M2    out    in    vdd  vdd  PMOS L=1 W=20
.ends

.subckt TG    in    out    s    sbar    VDD
M1    in    s    out    0    NMOS L=1 W=10
M2    in    sbar out    vdd  PMOS L=1 W=20
.ends

```