| Monday | **EE 671: VLSI Design** | Due on Monday |
|---|---|---|
| Sep. 04, 2023 | **Assignment 2** | Sept 11, 2022 |

The method of logical effort uses a template inverter as the reference. While using the method, we express –

- all times in units of $\tau$, which is the delay of a template inverter driving an identical inverter, excluding the parasitic delays.
- all capacitances in units of the input capacitance of this inverter
- all transistor widths in units of the width of the n channel transistor in the template inverter.

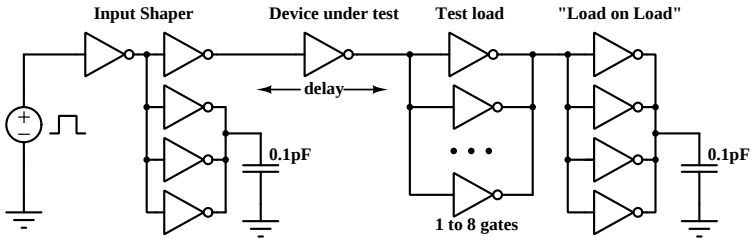
We'll use the inverter designed by you in assignment-1 as the template inverter. We want to measure $\tau$ and the parasitic delay $p_{inv}$ for this inverter. To do this, we plot the delay of the inverter when it is loaded with $1, 2, 3 \cdots 8$ template inverters in parallel. We fit a straight line to the delay data vs the number of load inverters and from the slope and intercept of this line, determine $\tau$ and $p_{inv}$

We define the delay of a logic stage as the time interval between the midpoint of input and output transitions. In practice, this delay is not independent of the rise/fall time of the input. In this simulation, we'll try to use realistic conditions for input wave shapes and output loading.

If we use a voltage source as the input signal, it has zero output impedance and does not represent realistic inputs in a VLSI circuit. Therefore, we buffer a voltage source using loaded inverters and then use the output of the buffer as the input signal.

The delay of the device under test is not independent of the load placed on the inverter(s) being used as the load. (This is because of the coupling through $C_{dg}$ of the transistors of the load inverter and miller effect). Therefore, we should put a realistic load on the inverter(s) being used as the load on the device under test. It is common to use a fan out of 4 in logic design. (Some justification for this will come after we have learnt optimization using logical effort).

Given these considerations, we use the following circuit for evaluation of $\tau$ and $p_{inv}$. It uses only inverters, so it will be convenient if you define your template inverter as a sub-circuit. Then you can instantiate it at multiple places easily.




The circuit has four parts.

1. **Input shaper:** The delay of a logic gate is influenced by the rise and fall times of the input. We would like to apply inputs which have the kinds of rise and fall times typically encountered in actual circuits, rather than the steep pulses provided by ideal voltage sources. Therefore we drive the device under test with pulses passed through a two stage inverter buffer. The first stage is a single template inverter, driving four template inverters which form the second stage. One of the four inverters in the second stage drives the device under test. The other 3 inverters present an additional dummy load to the first stage inverter. These 3 inverters drive a common load of 0.1pF.

2. **Device under test:** This is the template inverter whose delay parameters are being evaluated.

3. **Test load:** The logic gate being tested (an inverter here) will be loaded with 1 to 8 logic gates (identical to it) in parallel, to evaluate the delay as a function of the fan-out. The fanout (b) will be varied from 1 to 8.

4. **Load on Load:** The logic gates acting as load should themselves see a realistic capacitive load. Otherwise their outputs will rise too quickly, putting an unrealistic Miller capacitor load on the device under test. In this problem, we use 4 inverters in parallel driving a final output capacitance of 0.1pf as the load on load.

The delay of the logic gate under test will be measured from 50% of input transition to 50% of the output transition. We shall use the average of delays measured with the input rising and falling as the gate delay. Use the parameterized pulse generator statement suggested in assignment 2.

```
* pulse with time period of Trep, rise and fall times = Trep/20
.param Trep= 5n
.param Trf = {Trep/20.0}
.param Tw = {Trep/2.0 - Trf}
.param hival=1.8
.param loval=0.0
Vpulse pgen 0 DC 0 PULSE({loval} {hival} {Tw} {Trf} {Trf} {Tw} {Trep})
.tran 1pS {3*Trep} 0nS
```

The delays can be measured using meas constructs in the post-processing part of simulation.

```
meas tran invdelay1 TRIG v(dutin) VAL=0.9 RISE=2 TARG v(dutout) VAL=1.65 FALL=2
```

This measures the time between the instants when the voltage at dutin reaches $V_{DD}/2 = 0.9$V during the second rising transient and when the voltage at dutout reaches $V_{DD}/2 = 0.9$V during the second falling transient. Similar constructs can be used for evaluating the delay for a falling input.

Simulate the circuit above with different number of inverters (from 1 to 8) as load on the inverter under test. Make sure you give a short enough time step in your .tran statement ($\leq$ 1ps) so that you can evaluate delays of the order of tens of ps accurately.
(Don't be alarmed if your rise and fall times do not match very closely in this simulation).

As mentioned earlier, the delay here is the average of delays observed for input falling/output rising and input rising /output falling. Plot the delay of the inverter-under-test versus fan-out, fit a straight line to this data and Find the slope and intercept of this line. Using the

slope and intercept, find the values for $\tau$ and $p_{inv}$. Also, report the value of $\gamma$, the ratio of the width of p and n channel transistors required to give equal rise and fall times. (This was done in assignment-1).

Use a supply voltage of 1.8V and use the same model file as was used for all the previous assignments.

**Model Files**

```
.MODEL CMOSN NMOS LEVEL=8 VERSION=3.3.0
+TNOM    = 27              TOX     = 4.1E-9
+XJ      = 1E-7            NCH     = 2.3549E17      VTH0    = 0.3662473
+K1      = 0.5864999       K2      = 1.127266E-3    K3      = 1E-3
+K3B     = 0.0294061       W0      = 1E-7           NLX     = 1.630684E-7
+DVT0W   = 0               DVT1W   = 0              DVT2W   = 0
+DVT0    = 1.2064649       DVT1    = 0.4215486      DVT2    = 0.0197749
+U0      = 273.8094484     UA      = -1.40499E-9    UB      = 2.408323E-18
+UC      = 6.504826E-11    VSAT    = 1.355009E5     A0      = 2
+AGS     = 0.4449958       B0      = 1.901075E-7    B1      = 4.99995E-6
+KETA    = -0.0164863      A1      = 3.868769E-4    A2      = 0.4640272
+RDSW    = 123.3376355     PRWG    = 0.5            PRWB    = -0.197728
+WR      = 1               WINT    = 0              LINT    = 1.690044E-8
*+XL      = 0               XW      = -1E-8
+DWG     = -4.728719E-9    DWB     = -2.452411E-9   VOFF    = -0.0948017
+NFACTOR = 2.1860065       CIT     = 0              CDSC    = 2.4E-4
+CDSCD   = 0               CDSCB   = 0              ETA0    = 2.230928E-3
+ETAB    = 6.028975E-5     DSUB    = 0.0145467      PCLM    = 1.3822069
+PDIBLC1 = 0.1762787       PDIBLC2 = 1.66653E-3     PDIBLCB = -0.1
+DROUT   = 0.7694691       PSCBE1  = 8.91287E9      PSCBE2  = 7.349607E-9
+PVAG    = 1.685917E-3     DELTA   = 0.01           MOBMOD  = 1
*+RSH     = 6.7
+PRT     = 0               UTE     = -1.5           KT1     = -0.11
+KT1L    = 0               KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18       UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0               WLN     = 1              WW      = 0
+WWN     = 1               WWL     = 0              LL      = 0
+LLN     = 1               LW      = 0              LWN     = 1
+LWL     = 0               CAPMOD  = 2
*+XPART   = 0.5
+CGDO    = 8.23E-10        CGSO    = 8.23E-10       CGBO    = 1E-12
+CJ      = 9.466429E-4     PB      = 0.8            MJ      = 0.3820266
+CJSW    = 2.608154E-10    PBSW    = 0.8            MJSW    = 0.102322
+CJSWG   = 3.3E-10         PBSWG   = 0.8            MJSWG   = 0.102322
+CF      = 0               PVTH0   = -2.199373E-3   PRDSW   = -0.9368961
+PK2     = 1.593254E-3     WKETA   = -2.880976E-3   LKETA   = 7.165078E-3
+PU0     = 6.777519        PUA     = 5.505418E-12   PUB     = 8.84133E-25
+PVSAT   = 2.006286E3      PETA0   = 1.003159E-4    PKETA   = -6.759277E-3
+NOIMOD=2.0E+00 NOIA=1.3182567385564E+19
+NOIB=144543.977074592 NOIC=-1.24515784572817E-12 EF=0.92 EM=41000000
*
```

```
*
* flicker noise parameters above added manually from some other process
*
.MODEL CMOSP PMOS  LEVEL=8 VERSION=3.3.0
+TNOM    = 27              TOX     = 4.1E-9
+XJ      = 1E-7            NCH     = 4.1589E17      VTH0    = -0.3906012
+K1      = 0.5341312       K2      = 0.0395326      K3      = 0
+K3B     = 7.4916211       W0      = 1E-6           NLX     = 1.194072E-7
+DVT0W   = 0               DVT1W   = 0              DVT2W   = 0
+DVT0    = 0.5060555       DVT1    = 0.2423835      DVT2    = 0.1
+U0      = 115.6894042     UA      = 1.573746E-9    UB      = 1.874308E-21
+UC      = -1E-10          VSAT    = 1.130982E5     A0      = 1.9976555
+AGS     = 0.4186945       B0      = 1.949178E-7    B1      = 6.422908E-7
+KETA    = 0.0166345       A1      = 0.4749146      A2      = 0.300003
+RDSW    = 198.321294      PRWG    = 0.5            PRWB    = -0.4986647
+WR      = 1               WINT    = 0              LINT    = 2.94454E-8
+XL      = 0               XW      = -1E-8          DWG     = -2.798724E-8
+DWB     = -4.83797E-10    VOFF    = -0.095236      NFACTOR = 2
+CIT     = 0               CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0               ETA0    = 1.035504E-3    ETAB    = -4.358398E-4
+DSUB    = 1.816555E-3     PCLM    = 1.3299898      PDIBLC1 = 1.766563E-3
+PDIBLC2 = 7.728395E-7     PDIBLCB = -1E-3          DROUT   = 1.011891E-3
+PSCBE1  = 4.872184E10     PSCBE2  = 5E-10          PVAG    = 0.0209921
+DELTA   = 0.01            RSH     = 7.7            MOBMOD  = 1
+PRT     = 0               UTE     = -1.5           KT1     = -0.11
+KT1L    = 0               KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18       UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0               WLN     = 1              WW      = 0
+WWN     = 1               WWL     = 0              LL      = 0
+LLN     = 1               LW      = 0              LWN     = 1
+LWL     = 0               CAPMOD  = 2              XPART   = 0.5
+CGDO    = 6.35E-10        CGSO    = 6.35E-10       CGBO    = 1E-12
+CJ      = 1.144521E-3     PB      = 0.8468686      MJ      = 0.4099522
+CJSW    = 2.490749E-10    PBSW    = 0.8769118      MJSW    = 0.3478565
+CJSWG   = 4.22E-10        PBSWG   = 0.8769118      MJSWG   = 0.3478565
+CF      = 0               PVTH0   = 2.302018E-3    PRDSW   = 9.0575312
+PK2     = 1.821914E-3     WKETA   = 0.0222457      LKETA   = -1.495872E-3
+PU0     = -1.5580645      PUA     = -6.36889E-11   PUB     = 1E-21
+PVSAT   = 49.8420442      PETA0   = 2.827793E-5    PKETA   = -2.536564E-3
+ NOIMOD=2.0E+00           NOIA=3.574569933176E+18  NOIB=2500
+ NOIC=2.612600202858E-11  EF=1.1388                EM=41000000
*
*
* flicker noise parameters above added manually from some other process
*
```