Homework Assignment 5
(Due Feb. 26th at the beginning of the class)

***** Submission policy: Please zip your source code and waveform screenshots into a single file and send it to daehyun@eecs.wsu.edu. The file name should be *firstname_lastname*.zip (or .tar.gz or .tar …)

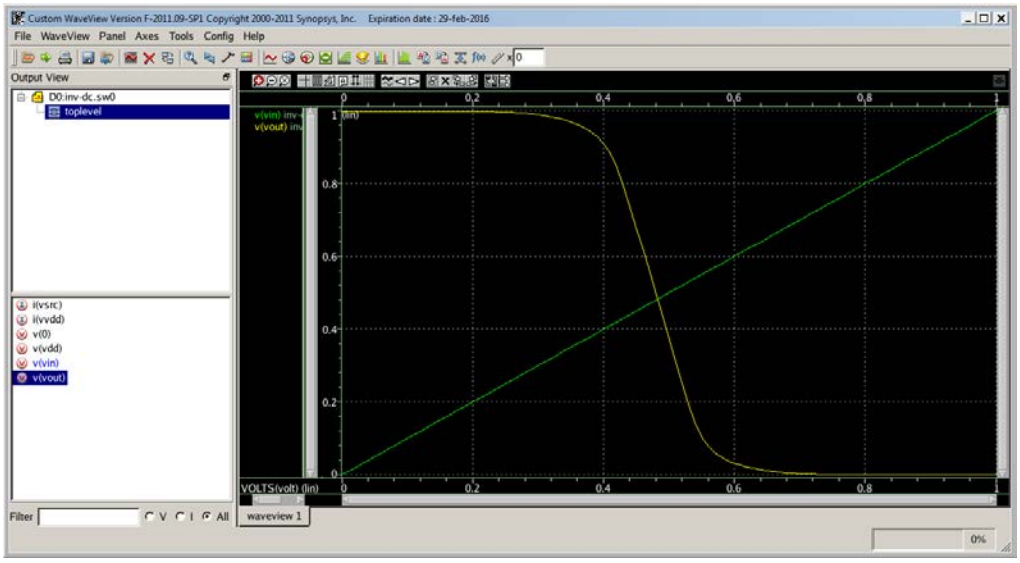
(1) **[Switching Characteristics of a CMOS Inverter, 10 points]** First, go to "Labs" and see "tut-hspice.pdf". It shows how to use HSPICE. Once you are done with it, download the following file into your working directory.

- http://eecs.wsu.edu/~ee434/Homework/hw05.zip
- Unzip it.
  - > unzip hw05.zip
- You will see the following files.
  - 45nm_PTM_HP_v2.1.pm (HSPICE transistor models)
  - inv-ac.sp (an HSPICE netlist for the simulation of switching characteristics of an inverter)
  - inv-dc.sp (an HSPICE netlist for the simulation of DC characteristics of an inverter)
- The size of the 1X inverter is (Wn, Wp) = (45nm, 70nm). The rise/fall time of the 1X inverter is 216ps as shown in the tutorial.
- Upsize the inverter to 2X, i.e., (Wn, Wp) = (45nm * 2, 70nm * 2) = (90nm, 140nm). Measure the rise and fall times again.
- [**Submit**] Fill the following table.

Inverter size	Rise time (ps)	Fall time (ps)
1X	216ps	216ps
2X	101ps	101ps
3X	66.6ps	67.4ps
4X	50.1ps	49.2ps
8X	25.7ps	25.5ps
16X	14.2ps	14.6ps
32X	8.54ps	8.80ps

(2) **[DC Characteristics of a CMOS Inverter, 20 points]** Open "inv-dc.sp" in a text editor and see the contents of the file. We use ".DC" for DC simulation.

- Run HSPICE for the DC simulation.
  - > hspice inv-dc.sp
- Open the DC simulation result.
  - wv inv-dc.sw0
- Double-click v(vin) and v(vout) to visualize the DC characteristics of the inverter.
- Drag and drop one of the graphs into the other one as follows:



- Measure V_{IL}, V_{IH}, V_{OL}, V_{OH} (use "Difference" in the measurement tool).
- In my window, $V_{IL} = 375mV, V_{IH} = 580mV, V_{OL} = 45mV, and\ V_{OH} = 950mV$.
- $NM_L = 375mV - 45mV = 330mV, NM_H = 950mV - 580mV = 370mV$.
- [**Submit**] Use ($W_n = 90nm, W_p = 70nm$) and run DC sweep analysis again. Compute and submit NM_L and NM_H.
  - $V_{IL} = 336mV, V_{IH} = 540mV, V_{OL} = 48mV, and\ V_{OH} = 950mV, NM_L = 288mV, NM_H = 410mV$
- [**Submit**] Use ($W_n = 45nm, W_p = 140nm$) and run DC sweep analysis again. Compute and submit NM_L and NM_H.
  - $V_{IL} = 409mV, V_{IH} = 620mV, V_{OL} = 48mV, and\ V_{OH} = 952mV, NM_L = 361mV, NM_H = 332mV$
- [**Submit**] Use ($W_n = 90nm, W_p = 140nm$) and run DC sweep analysis again. Compute and submit NM_L and NM_H.

- $V_{IL} = 370mV, V_{IH} = 578mV, V_{OL} = 52mV, and\ V_{OH} = 953mV, NM_L = 318mV, NM_H = 375mV$