EE224

Try to use a BSIM Model to Extract values that can be used to calculate WN for timing and Cload Specs

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Agenda

- Detail why this is important
- Develop a model for propagation delay in a CMOS inverter.
- Verify the model
- Explain why our model varies from the "book equations"
- Wrap up with proper model to use.

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Why is this important?

- We need a good solid equation to predict the propagation delay.
  - Later we will use these equations to estimate Wn and WP to meet area, timing and power specifications.
  - Later we will use this to evaluate different architectures (CLA, Ripple Carry, Serial, pipeline adder)
    - **No detailed spice simulation required!**
  - Having as good equation will save us a lot of simulation time in the lab.
  - You will have to do this at work for any new process.
- You need to know how to verify your work!

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Try the easy thing first

- Use the process data from the TSMC25 N94S run
- Using a standard propagation delay equation solve for WN for a typical CLoad
- Run the simulation and see what the error is.

$K_{PP} := 26.5 \cdot 10^{-6} \frac{A}{V^2}$ $K_{NP} := 108.6 \cdot 10^{-6} \frac{A}{V^2}$

$V_{TP} := -.51V$ $V_{TN} := .56V$ $V_{DD} := 2.5V$

$$A := \frac{1}{(V_{DD} - V_{TN}) \cdot K_{NP}} \cdot \left[\frac{2 \cdot V_{TN}}{V_{DD} - V_{TN}} + \ln\left[\frac{(1.5 \cdot V_{DD} - 2 \cdot V_{TN})}{.5 \cdot V_{DD}} \right] \right]$$

$$B := \frac{1}{(V_{DD} + V_{TP}) \cdot K_{PP}} \cdot \left[\frac{-2 \cdot V_{TP}}{V_{DD} + V_{TP}} + \ln\left[\frac{(1.5 \cdot V_{DD} + 2 \cdot V_{TP})}{.5 \cdot V_{DD}} \right] \right]$$

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$A = 6.271 \times 10^{3} \Omega$

$B = 2.453 \times 10^{4} \Omega$

$R := \frac{B}{A}$ $R = 3.912$

$C_{JSWN} := 4.44 \cdot 10^{-12} \frac{F}{cm}$ $L_D := .6 \cdot 10^{-4} cm$

$C_{JN} := 1.92 \cdot 10^{-7} \frac{F}{cm^2}$

$L_N := .24 \cdot 10^{-4} cm$

$C_{GDO} := 6.27 \cdot 10^{-12} \frac{F}{cm}$

$t_{PHL} := .05 \cdot 10^{-9} s$ $C_g := 25 \cdot 10^{-15} F$

$$W_N := \frac{C_g + C_{JSWN} \cdot 4 \cdot L_D}{\frac{t_{PHL}}{L_N \cdot A} - (1 + R) \cdot (C_{JSWN} \cdot 2 + C_{JN} \cdot L_D + 2 \cdot C_{GDO})}$$

$W_N = 1.529 \times 10^{-4} cm$

$W_P := R \cdot W_N$ $W_P = 5.984 \times 10^{-4} cm$

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Does it work?

- After running a transient simulation it was found that the propagation delay high to low had a 70% error and the low to high had a 2 percent error.
- This error is unacceptable
  - The constant A and the ration are both off by too much
  - I tried using the KEQ parameter and the correct gate length but it was still was off.

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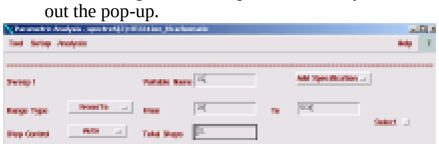
What should we try now?

- We can keep WN and WP fixed and vary the Cload and measure propagation delay
  - WN=2.4µm, WP=R*2.4µm and CLoad=50fF (run the simulation long enough to get the high to low transition.
  - Start Affirma and set all your variables.
  - In Affrima, go to tools.... parametric analysis, and fill out the pop-up.



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Running the parametric simulation

- In the parametric analysis window, go to analysis... start
- Once this is done add a horizontal marker at VDD/2 and show the results.
- Save the results to a text file and ftp to a computer with excel.
- Read in the data delimited with spaces and tabs
- Search and replace p with e-12, n with e-9 and f with e-15.
- Plot propagation delay vs load capacitance

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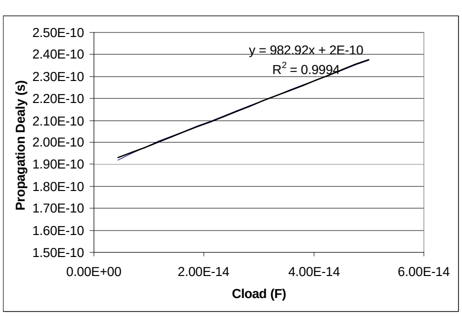

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Linear Fit

$$\tau_{PHL} := \frac{L_N \cdot A}{W_N} \cdot (C_{Internal} + C_{LOAD})$$

$$\tau_{PHL} := \frac{L_N \cdot A}{W_N} \cdot C_{Internal} + C_{LOAD} \cdot \frac{L_N \cdot A}{W_N}$$

Y= B + X M

M=982.9*LN/WN, LN/WN=1/10 A:9829ohms

This still gave me values that were off by quite a bit!

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What's next?

- Find the value of R experimentally (WN constant) that produce symmetric propagation delays.
- Then using the equation for WN vary A until the equation gives you the propagation delay from the simulation
- Then test the new values of a range of delays and loads. Anything below 20% is acceptable.

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So what values should we use?

$$R := 2.327$$

$$A := 11400\Omega$$

$$W_N := \frac{C_g + C_{JSWN} \cdot 4 \cdot L_D}{\frac{\tau_{PHL}}{L_N \cdot A} - (1 + R) \cdot (C_{JSWN} \cdot 2 + C_{JN} \cdot L_D + 2 \cdot C_{GDO})}$$

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Taking in to account that the junction capacitance is not contestant

$$W_N := \frac{C_g + C_{JSWN} \cdot 4 \cdot L_D \cdot K_{EQ}}{\frac{\tau_{PHL}}{L_N \cdot A} - (1+R) \cdot \left(C_{JSWN} \cdot 2 \cdot K_{EQ} + C_{JN} \cdot L_D \cdot K_{EQ} + 2 \cdot C_{GDO}\right)}$$

$R := 2.399$

$A := 12385\Omega$

$\Phi := .99V \quad V_2 := -2.5V \quad V_1 := 0V$

$$K_{EQ} := \frac{-2 \cdot \sqrt{\Phi}}{V_2 - V_1} \cdot \left(\sqrt{\Phi - V_2} - \sqrt{\Phi}\right)$$

$K_{EQ} = 0.695$

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Two Questions

- Which method was most accurate?
  - Since the constants of A and R are back fit to simulation they have about the same accuracy.
- Why do we have to play with the constant A and the ratio so much?
  - The ratio from the MOSIS website was almost 4, the A constant is off by a factor of two?
  - Even our linear fir of propagation delay and Cload was off.
    - This will take some thinking

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Why do we have to back fit A and R

- Clue 1: The pmos seemed to work OK for delay
- The nmos seemed really off.
  - I have never seen a R of around 4 before

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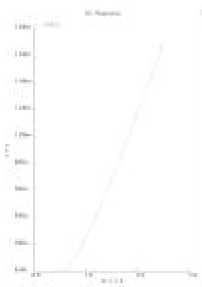
NMOS in Saturation



Note: It does not look parabolic!

Re-derive A

$$K_{np\_usat} := \frac{.24 \cdot 151}{.36} \cdot 10^{-6} \frac{1}{\Omega}$$

$$A := \left[\frac{2V_{TN}}{(V_{DD} - V_{TN}) \cdot K_{np\_usat}} + \frac{1}{(V_{DD} - V_{TN}) \cdot K_{NP}} \cdot \ln\left[\frac{(1.5 \cdot V_{DD} - 2 \cdot V_{TN})}{.5 \cdot V_{DD}} \right] \right]$$

$$A = 9.266 \times 10^{3} \Omega$$

$$\frac{B}{A} = 2.648$$

delay 50p, CL 25f WN=2.021u
low to high 57p high to low 65

This was still off but by only 30%. I scaled R to 2.322 and A to 11950 ohms.

So what do I really use?

$$W_N := \frac{C_g + C_{JSWN} \cdot 4 \cdot L_D \cdot K_{EQ}}{\frac{\tau_{PHL}}{L_N \cdot A} - (1 + R) \cdot (C_{JSWN} \cdot 2 \cdot K_{EQ} + C_{JN} \cdot L_D \cdot K_{EQ} + 2 \cdot C_{GDO})}$$

R=2.322
A=11950

Is our reasoning correct?

- It seems to work for now, so we go forward.
  - Possible problems:
  - After further research I discovered that Knp and Kpp are different in the linear and saturation regions
  - In the linear region Kpp and Knp are constantly changing.
  - The problem is in the mobility

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