Where are we?

- Lots of Layout issues
  - Line of diffusion style
  - Power pitch
  - Bit-slice pitch
  - Routing strategies
  - Transistor sizing
  - Wire sizing

Layout - Line of Diffusion

- Very common layout method
  - Start with a "line of diffusion" for each transistor type
  - Cross with poly to make transistors
  - This is the "type 2" NOR gate
Line of Diffusion in General

- Start with lines of diffusion for each transistor type
- Cross with Poly to make transistors

- Now break and connect diffusion
  - There’s our NOR gate
Now break and connect diffusion
   There’s our NOR gate

Stick Diagrams
   You can plan things with paper and pencil using Stick Diagrams – Great for sketchbooks!!!!
   You’ll need colored pencils
   Draw lines for layers instead of rectangles
   Then you can translate to layout
Layout can be very time consuming
- Design gates to fit together nicely
- Build a library of standard cells

Standard cell design methodology
- \( V_{DD} \) and GND should abut (standard height)
- Adjacent gates should satisfy design rules
- nMOS at bottom and pMOS at top
- All gates include well and substrate contacts
Example: Inverter

- Horizontal N-diffusion and p-diffusion strips
- Vertical polysilicon gates
- Metal1 V_DD rail at top
- Metal1 GND rail at bottom
- 32 λ by 40 λ
- 9.6μ x 12μ

Example: NAND3
**Stick Diagrams**

- *Stick diagrams* help plan layout quickly
  - Need not be to scale
  - Draw with color pencils

![Stick Diagrams](image)

**Wiring Tracks**

- A *wiring track* is the space required for a wire
  - 1.2µ width, 1.2µ spacing from neighbor results in 2.4µ pitch
- Transistors also consume one wiring track

![Wiring Tracks](image)

In our rules M1 and M2 width & spacing is 3λ, so pitch is 1.8µ
Well spacing

- Wells must surround transistors by 1.8\(\mu\)
  - Implies 3.6\(\mu\) (12\(\lambda\)) between opposite transistor flavors
  - Leaves room for one wire track

Area Estimation

- Estimate area by counting wiring tracks
  - Multiply by 8 to express in \(\lambda\), or by 2.4 to express in microns
Example: O3AI

Sketch a stick diagram for O3AI and estimate area

\[ Y = (A + B + C) \cdot \overline{D} \]
Example: O3AI

Sketch a stick diagram for O3AI and estimate area

\[ Y = (A + B + C) \cdot D \]

[Diagram of O3AI circuit with labeled inputs and outputs]
Example: O3AI

Sketch a stick diagram for O3AI and estimate area

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Example: O3AI

- Sketch a stick diagram for O3AI and estimate area
  - \( Y = (A + B + C) \cdot \overline{D} \)

![Stick Diagram and Truth Table](image-url)
Example: O3AI

- Sketch a stick diagram for O3AI and estimate area
  - \[ Y = \left( A + B + C \right) D \]

Euler Paths

- A graphical method for planning complex gate layout
  - Take the transistor netlist and draw it as a graph
  - Note that the pull-up and pull-down trees can be duals of each other
  - Find a path that traverses the graph with the same variable ordering for pull-up and pull-down graphs
  - This guides you to a line of diffusion layout
Simple example: NOR

- Euler path is a tour of all edges
- Find a path that has the same ordering for pull-up and pull-down, i.e. A B
  - Vdd A 1 B Out
  - GND A Out B GND

Another great bit of sketchbooking...

This Path Translates to Layout

- Find a path that has the same ordering for pull-up and pull-down, e.g. A B
  - You can also include all the internal nodes
    - Pull-up: Vdd A 1 B Out
    - Pull-Down: GND A Out B GND
  - Line of diffusion layout
Examples

- Switch to chalkboard for examples
  - Hopefully with colored chalk…

Layout Example: Flip Flop

- Simple D-type edge triggered flip flop
Need two copies of this for a full D flip flop
Need two copies of this for a full D flip flop

First add the gates
- Note where outputs can be shared
- Ignore details of signal crossings for now…
Stick Diagram of Latch

- First add the gates
- Note where outputs can be shared
- Ignore details of signal crossings for now…
First add the gates
- Note where the signals are relative to the schematic
- Note where additional connections are needed

Start With First Enabled Inv
- I’m using 5u power wires, 29u vertical pitch based on a C5x standard cell model from AMI
  - Probably overkill…
- Add DIF for N- and P-type transistors
  - Note 2x standard size because of series connection
Add Next Enabled Inverter

- Add two more poly gates for second enabled inverter
- Note that the two enabled inverters share an output (not connected yet)
- Note that I’ve added vdd! and gnd! For DRC
- I’ll deal with C-Cb crossover later…

Aside: Multiple Contacts

- Look at a model of transistor resistance
Contact Option #1

- Total equivalent resistance = 56.1 Ohms
  - Metal resistance = 0.05 Ω/square
  - Contact resistance = 5 Ω/contact
  - Active resistance = 70 Ω/square
  - Gate resistance = 50 Ω/square
  - Active resistance 7Ω - contact to gate

Contact Option #2

- Total equivalent resistance = 105.1 Ohms
Contact Option #3

- Total equivalent resistance = 24.7 Ohms
- So, put in as many contacts as will fit along side a wide gate...

Meanwhile, Add inverter

- Note that it’s back to standard size
- Shares vdd/gnd connection with enabled inverter
- Minimum spacing for all transistors so far
  - Incremental DRC at EVERY step!
Finish Inverter (mostly)

- Make inverter output connections
  - Don’t connect yet
  - I’m going to use M1 as a horizontal layer
  - Which means being careful about vertical use of M1

Make Feedback Connections

- Output of inverter (connected in M1 for now) goes to input of 2nd enabled inverter
- Output of enabled inverters goes to input of inverter
  - Note that output of enabled inverters goes through POLY
Deal With C/Cb Crossover

- Start by cutting the “select” gates of the enabled inverters

Connect the C Input

- Prepare for M1 crossover in C wire
  - C is N-type in first enabled inverter, P-type in second enabled inverter
  - Use M1PLY contacts
- PROBLEM! We need to squeeze a poly wire inbetween those contacts...
  - Use design rules to plan for space
Look at Gap

- You need to have enough space for minimum width poly to fit through gap

Start Making Room

- Push D-signal poly out of the way with minimum spacing to DIF
  - We’ll move it back later
- Make sure to continue to DRC at every step!
- Jog the poly around and through the gap with minimum spacing to M1PLY contact on both sides

Fit Things Back Together

- Now put big D-poly jog back as close as you can
Add M1PLY contacts for future connections

- Need to get Cb, C, D signals into the latch in the future
- Those will most likely be routed on some type of metal
- So we need the M1 metal connection at the bottom

Plan For Clock Routing

- Break M1 output connection on inverter to leave room for horizontal M1 routing
  - I'll eventually route C and Cb through the cell horizontally on M1
Bit Slice Plan

- Plan is to stitch these together to make a register
  - Inputs on top in M2
  - Outputs on bottom in M2
  - Clock and Clock-bar routed horizontally in M1

Need Second Latch

- Basically a copy of the first latch
  - But with reversed C and Cb connections
  - Copy the first layout…
Expand from Latch to F/F

- Select and copy the first latch
- Now I need to reverse the C and Cb connections

C/Cb Routing Plan

- Remember my C/Cb routing plan
  - Plan for where those wires can go
Remember my C/Cb routing plan

- Plan for where those wires can go

Connect Clocks to 1\(^{\text{st}}\) Latch

- Adjust contact positions for the first enabled inverter
Connect Clocks to 2nd Latch

- Now shift the contacts the other way for the second latch
  - Makes the complementary C/Cb connection
Connect the Two Latches

- Q of first goes to D of second
- Don’t really need both top and bottom connections, but it doesn’t hurt
- Lower resistance paths

Note Extra Routing Channels

- Note that this vertical pitch, and this cell contents have left two additional M1 horizontal routing channels through the middle of the cell
Now Consider Output Inverters

- Two more inverters
  - Make them 2x size for output drive

Output Inverters

- Add the DIF for the output inverters
  - Remember I want to make them 2x size
Make Output Connections

- Add vdd, gnd and output contacts
- Add poly gates
- Make output connections in M2
- Connect to 2\textsuperscript{nd} latch and to 2\textsuperscript{nd} inverter

Now Squeeze Inverter

- Select regions of the layout and stretch to move it all to a new spot
Now squeeze power supply contacts

Output inverters squeezed together

Note that D, Q, And Qb are routed vertically in M2
Final D-Type Flip Flop

- Squeeze vertically since I don’t need extra routing channels, and I don’t need to match with standard cells
- Add long NWELL and SUB contacts

Put Four of them Together

- Add instances that abut
  - Or use the “array” feature of the instance dialog
- Note that C and Cb are routed in horizontal M1
Put Four of them Together

D3 → D2 → D1 → D0 → C

Q3 → Q2 → Q1 → Q0 → Cb

D2 → D1 → D0 → Vdd → C → Cb → Vss

Qb2 → Q2 → Qb1 → Q1 → Qb0 → Q0

Zoom in to Cell Boundary

- There's a little extra space
  - Caused by wanting each latch to DRC on its own
  - Could close this up by overlapping cells