MADVLSI: Miniproject 2

Thomas Jagielski

February 2021

1 Design Files

GitHub link to design files: https://github.com/ThomasJagielski/MADVLSI-MP2.

2 Schematic

For this miniproject two conditions were considered. The first used transistors all with strength 1, and the second used strength 2 transistors in the pull down network. As shown in the simulation results section later, the strength 1 transistor circuit does not propagate the signal through the shift register properly. Thus, as discussed by Massimo Antonio Sivilotti in *Wiring Considerations in Analog VLSI Systems, with Application to Field-Programmable Networks*, the write-ability problem is present under slow transistor conditions. As a result, transistors with strength 2 in the pull down network were used in the design for increased robustness, as demonstrated through corner analysis in the simulation section. Unless indicated otherwise, the circuit being shown uses pull-down transistors of strength 2 as shown in Figure 1.

The following image shows a layout driven schematic for the CSRL positive-edge triggered D flip-flop with a ratio of 2 between the strength of the pull down transistors and the pass transistors.

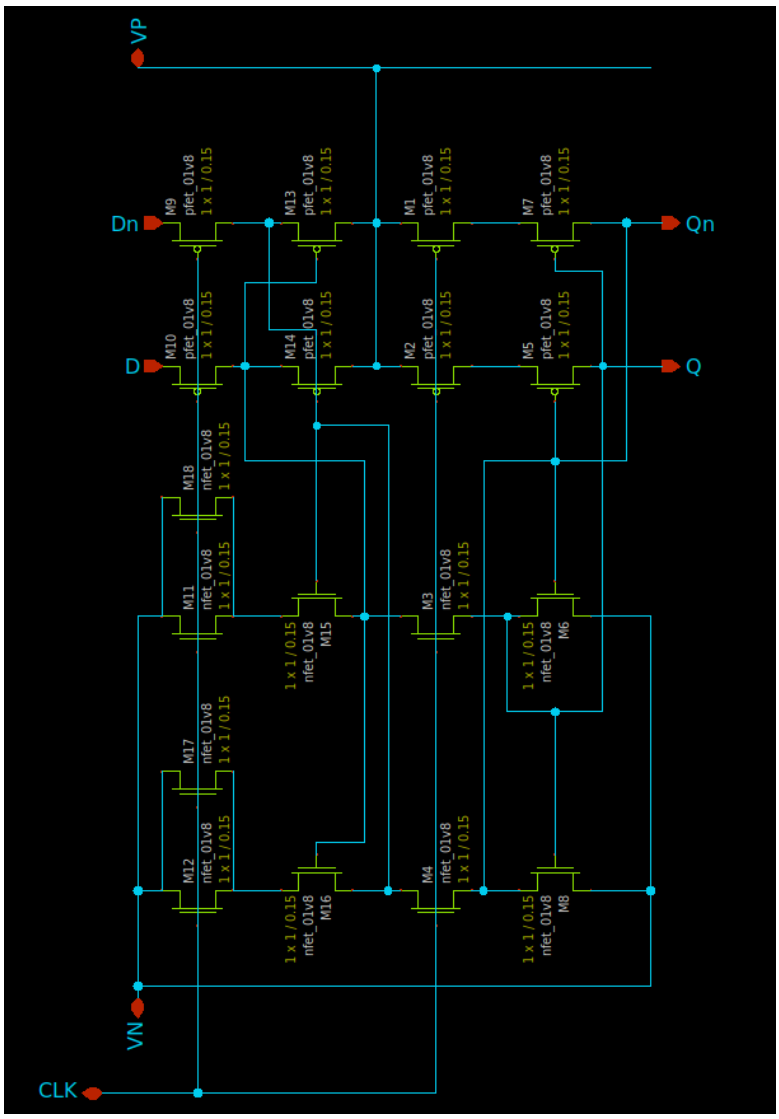

Figure 1: CSRL Positive Edge Triggered D Flip-Flop Layout Driven Schematic

3 Xschem Simulation

3.1 Schematic

The following image shows the test schematic and configuration used to simulate the circuit's function.

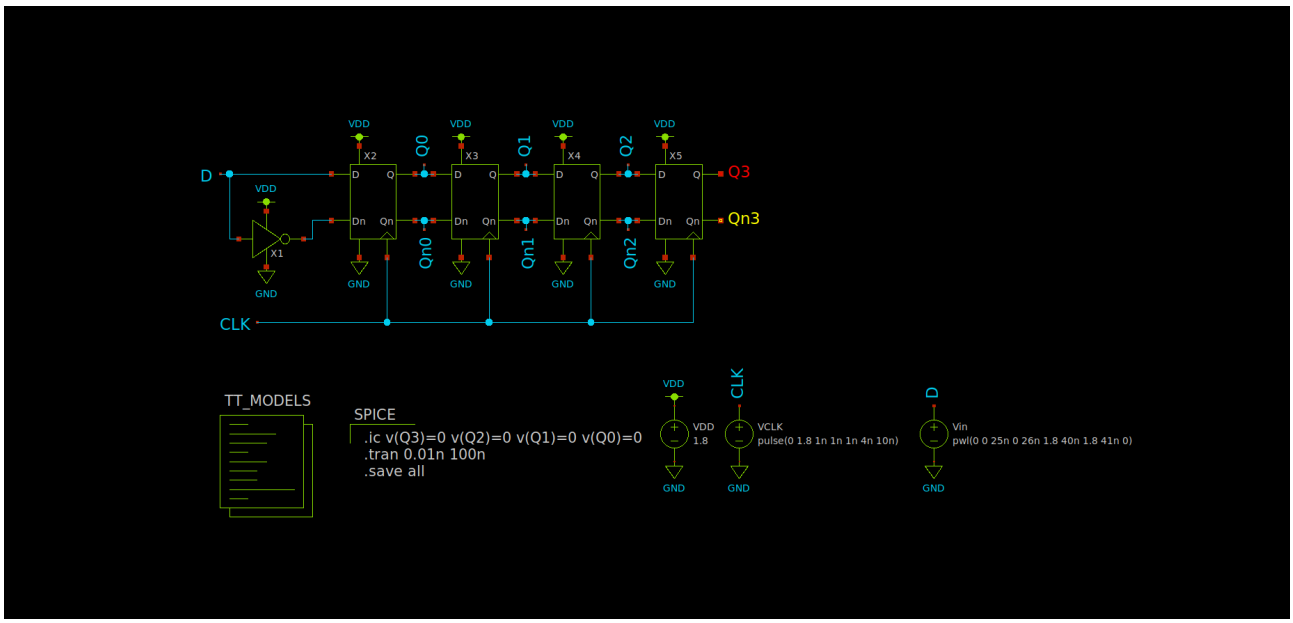

Figure 2: Simulation Schematic for Width 1 and Width 2 Cases

3.2 Simulation Results

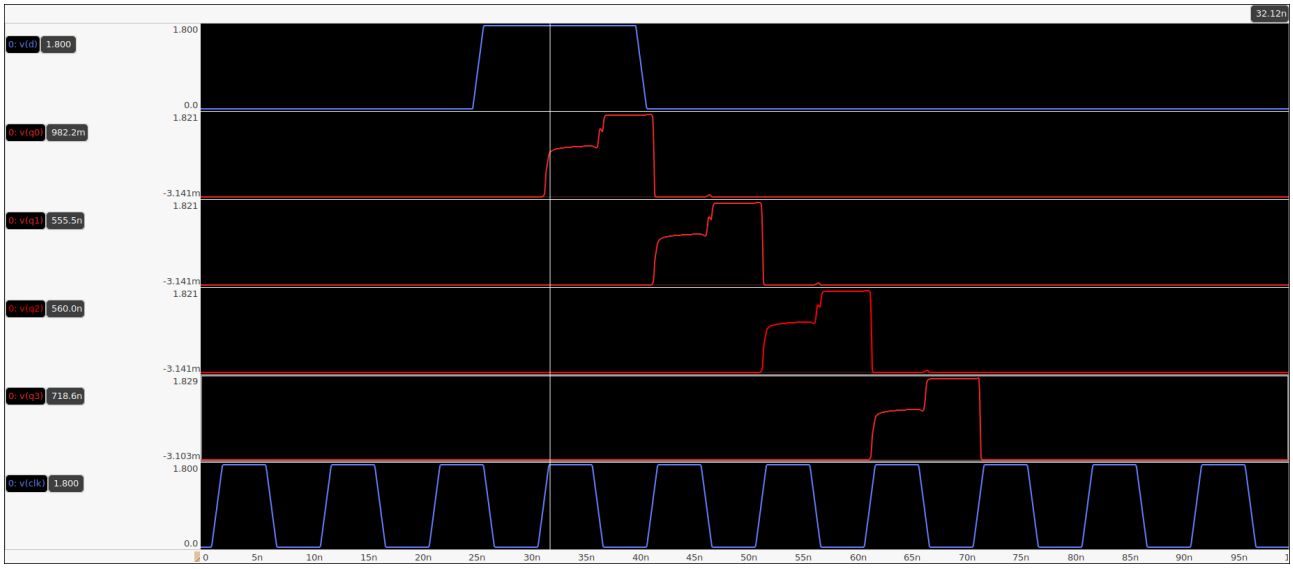

Figure 3: TT Model Simulation for Circuit Shown in Figure 1

We find that through corner analysis that the circuit functions as expected and similarly to what is shown in the figure above under all edge case considerations. Figures showing each of the corner case results can be seen at the following link https://github.com/ThomasJagielski/MADVLSI-MP2/tree/main/images/width_2_simulations.

3.2.1 Simulation with All Strength 1 Transistors

We will find that under the TT model, a circuit configuration with all transistors being strength 1 works as we expect. The output waveform for this model is shown below.

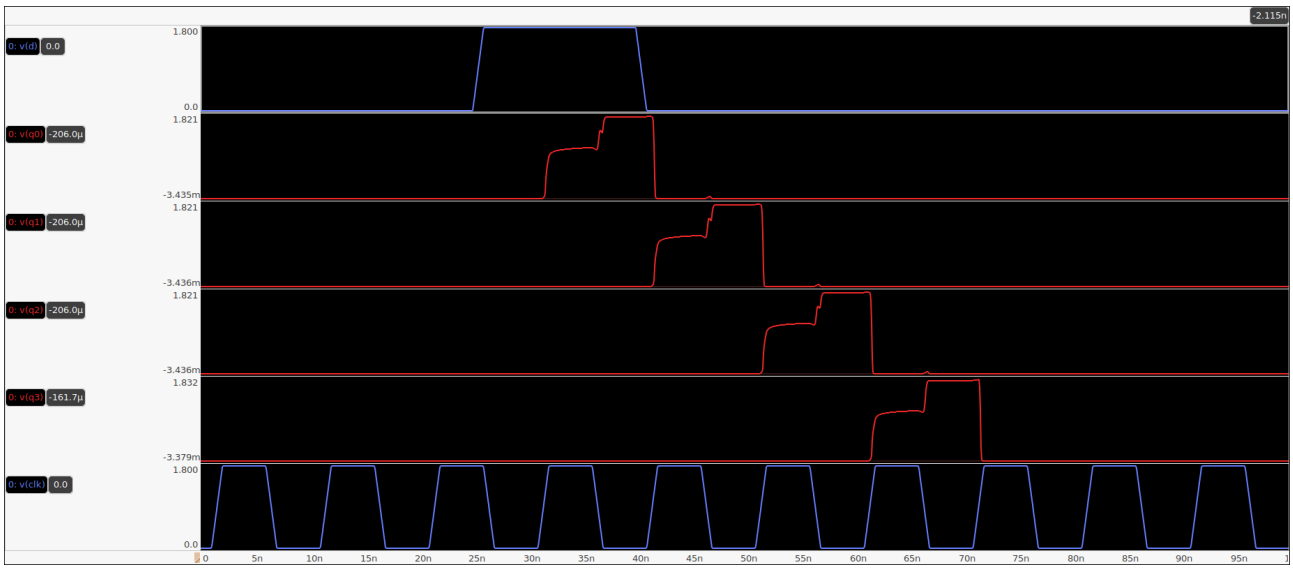

Figure 4: TT Model Simulation Strength Ratio 1 Transistors

However, we will find that through corner analysis this circuit does not function as expected using the SF and SS models. The output waveform shown below demonstrates the write-ability issue mentioned by Sivilotti with the SS models,

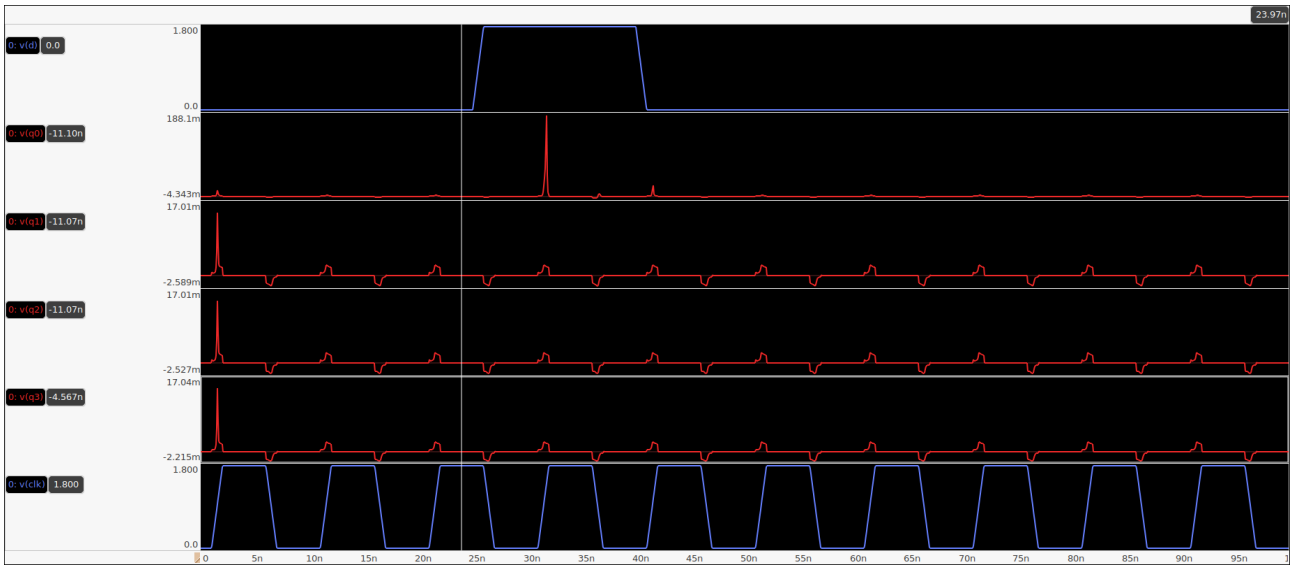

Figure 5: SS Model Simulation Strength Ratio 1 Transistors

For the output waveforms in each of the cases please refer to the following link, https://github.com/ThomasJagielski/MADVLSI-MP2/tree/main/images/width_1_simulations.

As a result of the write-ability issue demonstrated above, the pull down network was sized with a strength ratio of 2 transistors to ensure robust designs that are run invariant.

4 Layout

4.1 Single Flip-Flop Cell

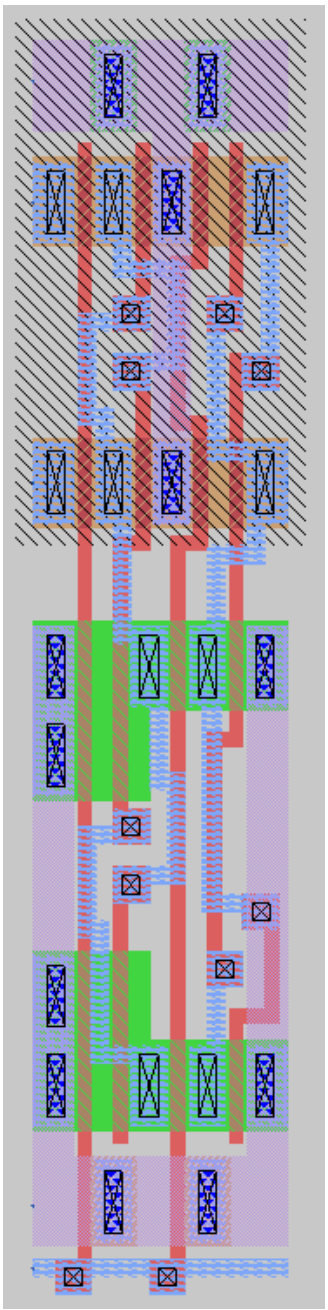

Figure 6: Single Positive Edge Triggered Flip-Flop Cell

4.2 Inverter

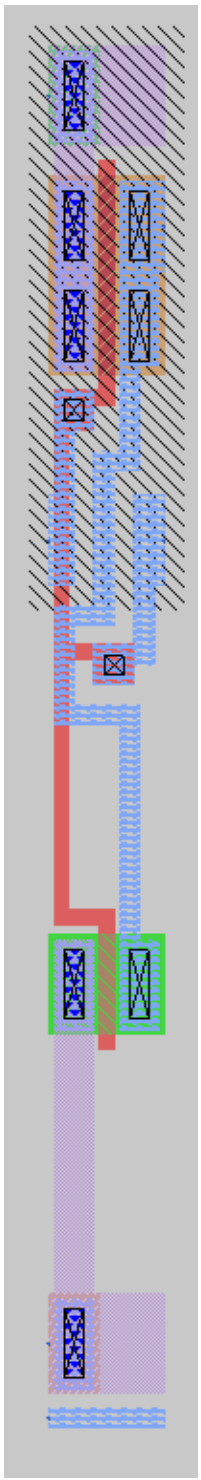

Figure 7: Inverter Cell for Dn Input from D

4.3 4-Bit Shift Register

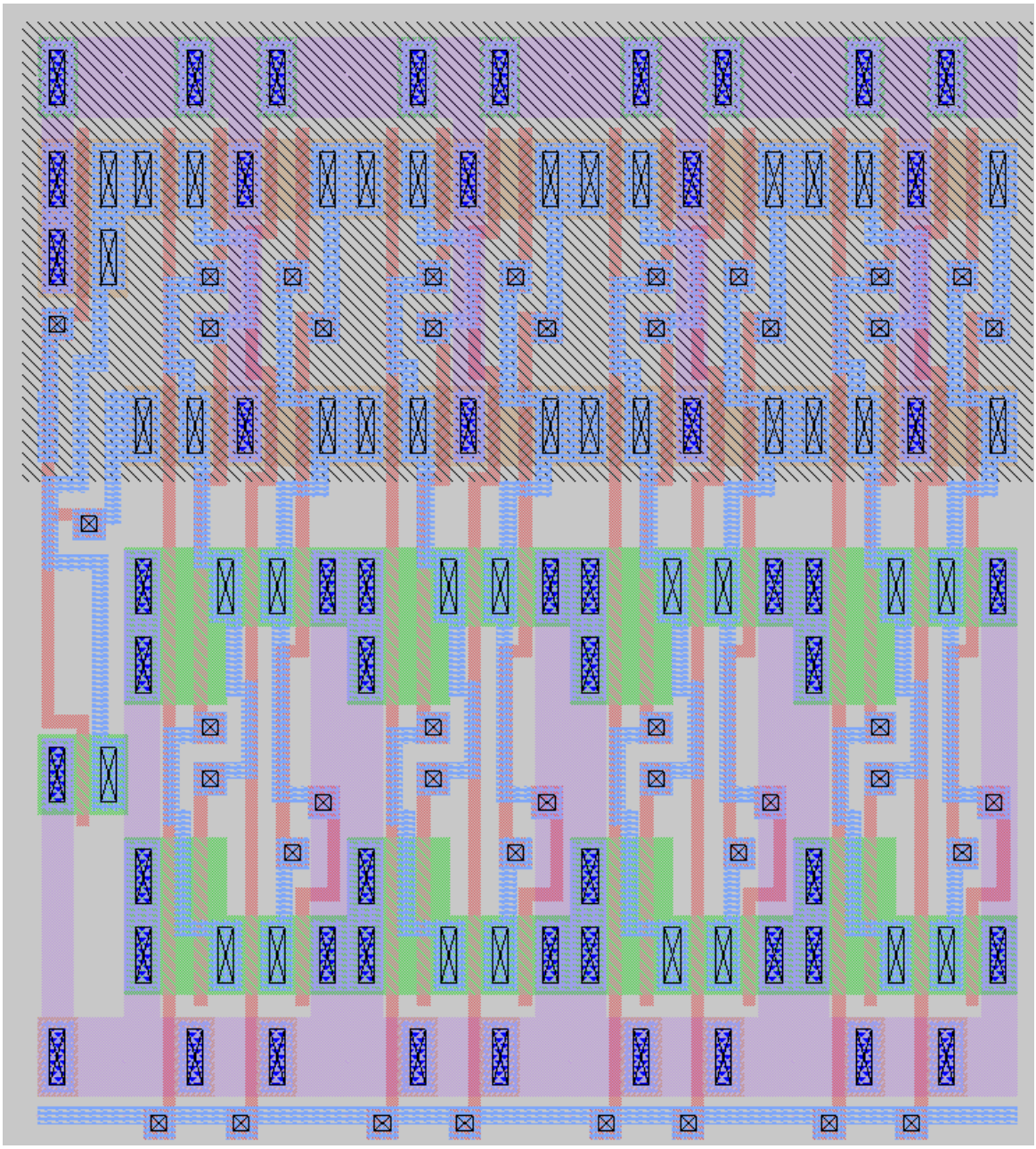

Figure 8: 4-Bit Shift Register Comprised of Latches Shown in Figure 6 and an Inverter as Shown in Figure 7

Cell Dimensions		
Case	**Width [Microns]**	**Height [Microns]**
Without Inverter	11.40	14.05
With Inverter	12.50	14.05

5 Layout Verses Schematic

The following comp.out file shows the LVS output for the width 2 pull-down transistor schematic and layout. The "mismatches" at the top refer to the use of VP and VDD as well as VN and GND. We find at the end that when checking for net equalities the schematic and layout match.

```
Equate elements:  no current cell.
Equate elements:  no current cell.

Cell inverter disconnected node: CLK

Subcircuit summary:
Circuit 1: inverter                        |Circuit 2: inverter
-------------------------------------------|-------------------------------------------

sky130_fd_pr__pfet_01v8 (1)                |sky130_fd_pr__pfet_01v8 (1)
sky130_fd_pr__nfet_01v8 (1)                |sky130_fd_pr__nfet_01v8 (1)
Number of devices: 2                       |Number of devices: 2
Number of nets: 4                          |Number of nets: 4
-------------------------------------------------------------------------------------------

Circuits match uniquely.
Netlists match uniquely.

Subcircuit pins:
Circuit 1: inverter                        |Circuit 2: inverter
-------------------------------------------|-------------------------------------------

Y                                          |Y
A                                          |A
VP                                         |VDD **Mismatch**
VN                                         |GND **Mismatch**
-------------------------------------------------------------------------------------------

Cell pin lists are equivalent.
Device classes inverter and inverter are equivalent.
Class CSRL_D_FF:  Merged 2 devices.

Subcircuit summary:
Circuit 1: CSRL_D_FF                       |Circuit 2: CSRL_D_FF
-------------------------------------------|-------------------------------------------

sky130_fd_pr__pfet_01v8 (8)                |sky130_fd_pr__pfet_01v8 (8)
sky130_fd_pr__nfet_01v8 (8)                |sky130_fd_pr__nfet_01v8 (8)
Number of devices: 16                      |Number of devices: 16
Number of nets: 13 **Mismatch**            |Number of nets: 15 **Mismatch**
-------------------------------------------------------------------------------------------

NET mismatches: Class fragments follow (with fanout counts):
Circuit 1: CSRL_D_FF                       |Circuit 2: CSRL_D_FF

-------------------------------------------------------------------------------------------

Net: CLK                                   |Net: CLK
  sky130_fd_pr__nfet_01v8/2 = 4            |  sky130_fd_pr__pfet_01v8/2 = 4
  sky130_fd_pr__pfet_01v8/2 = 4            |  sky130_fd_pr__nfet_01v8/2 = 4
                                           |
(no matching net)                          |Net: VDD
                                           |  sky130_fd_pr__pfet_01v8/4 = 8
                                           |
(no matching net)                          |Net: GND
                                           |  sky130_fd_pr__nfet_01v8/4 = 8
-------------------------------------------------------------------------------------------


```

```
--------------------------------------------------------------------------------

(no matching net)                          |Net: VN
                                           |   sky130_fd_pr__nfet_01v8/(1|3)
    = 4
                                           |
(no matching net)                          |Net: VP
                                           |   sky130_fd_pr__pfet_01v8/(1|3)
    = 4
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

Net: D                                     |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 1        |
                                           |
Net: Dn                                    |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 1        |
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

(no matching net)                          |Net: Dn
                                           |   sky130_fd_pr__pfet_01v8/(1|3)
    = 1
                                           |
(no matching net)                          |Net: D
                                           |   sky130_fd_pr__pfet_01v8/(1|3)
    = 1
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

Net: a_30_1320#                            |(no matching net)
  sky130_fd_pr__nfet_01v8/(1|3) = 2        |
  sky130_fd_pr__pfet_01v8/2 = 1            |
  sky130_fd_pr__pfet_01v8/(1|3) = 2        |
  sky130_fd_pr__nfet_01v8/2 = 1            |
                                           |
Net: a_30_1950#                            |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 2        |
  sky130_fd_pr__pfet_01v8/2 = 1            |
  sky130_fd_pr__nfet_01v8/(1|3) = 2        |
  sky130_fd_pr__nfet_01v8/2 = 1            |
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

(no matching net)                          |Net: net3
                                           |   sky130_fd_pr__nfet_01v8/(1|3)
    = 2
                                           |   sky130_fd_pr__pfet_01v8/(1|3)
    = 2
                                           |   sky130_fd_pr__pfet_01v8/2 = 1
                                           |   sky130_fd_pr__nfet_01v8/2 = 1
                                           |
```

```
(no matching net)                          |Net: net4
                                           |  sky130_fd_pr__nfet_01v8/(1|3)
   = 2
                                           |  sky130_fd_pr__pfet_01v8/(1|3)
   = 2
                                           |  sky130_fd_pr__pfet_01v8/2 = 1
                                           |  sky130_fd_pr__nfet_01v8/2 = 1
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

Net: VN                                    |(no matching net)
  sky130_fd_pr__nfet_01v8/4 = 8            |
  sky130_fd_pr__nfet_01v8/(1|3) = 4        |
                                           |
Net: VP                                    |(no matching net)
  sky130_fd_pr__pfet_01v8/4 = 8            |
  sky130_fd_pr__pfet_01v8/(1|3) = 4        |
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

Net: a_290_1950#                           |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 2        |
                                           |
Net: a_290_1320#                           |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 2        |
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

Net: a_30_710#                             |(no matching net)
  sky130_fd_pr__nfet_01v8/(1|3) = 2        |
                                           |
Net: a_30_n30#                             |(no matching net)
  sky130_fd_pr__nfet_01v8/(1|3) = 2        |
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

(no matching net)                          |Net: net5
                                           |  sky130_fd_pr__pfet_01v8/(1|3)
   = 2
                                           |
(no matching net)                          |Net: net6
                                           |  sky130_fd_pr__pfet_01v8/(1|3)
   = 2
--------------------------------------------------------------------------------


--------------------------------------------------------------------------------

(no matching net)                          |Net: net1
                                           |  sky130_fd_pr__nfet_01v8/(1|3)
   = 2
                                           |
```

```
(no matching net)                              |Net: net2
                                               |  sky130_fd_pr__nfet_01v8/(1|3)
   = 2
-------------------------------------------------------------------------------


-------------------------------------------------------------------------------

Net: Qn                                        |(no matching net)
  sky130_fd_pr__pfet_01v8/(1|3) = 1            |
  sky130_fd_pr__nfet_01v8/2 = 1                |
  sky130_fd_pr__pfet_01v8/2 = 1                |
  sky130_fd_pr__nfet_01v8/(1|3) = 2            |
                                               |
Net: Q                                         |(no matching net)
  sky130_fd_pr__pfet_01v8/2 = 1                |
  sky130_fd_pr__nfet_01v8/(1|3) = 2            |
  sky130_fd_pr__pfet_01v8/(1|3) = 1            |
  sky130_fd_pr__nfet_01v8/2 = 1                |
-------------------------------------------------------------------------------


-------------------------------------------------------------------------------

(no matching net)                              |Net: Q
                                               |  sky130_fd_pr__nfet_01v8/(1|3)
   = 2
                                               |  sky130_fd_pr__pfet_01v8/(1|3)
   = 1
                                               |  sky130_fd_pr__pfet_01v8/2 = 1
                                               |  sky130_fd_pr__nfet_01v8/2 = 1
                                               |
(no matching net)                              |Net: Qn
                                               |  sky130_fd_pr__nfet_01v8/(1|3)
   = 2
                                               |  sky130_fd_pr__pfet_01v8/2 = 1
                                               |  sky130_fd_pr__nfet_01v8/2 = 1
                                               |  sky130_fd_pr__pfet_01v8/(1|3)
   = 1
-------------------------------------------------------------------------------

DEVICE mismatches: Class fragments follow (with node fanout counts):
Circuit 1: CSRL_D_FF                           |Circuit 2: CSRL_D_FF

-------------------------------------------------------------------------------

Instance: sky130_fd_pr__nfet_01v83             |(no matching instance)
  (1,3) = (12,2)                               |
  2 = 8                                        |
  4 = 12                                       |
                                               |
                                               |
Instance: sky130_fd_pr__nfet_01v85             |(no matching instance)
  (1,3) = (12,2)                               |
  2 = 8                                        |
  4 = 12                                       |
                                               |
-------------------------------------------------------------------------------


```

```
190 ------------------------------------------------------------------------------------------
191 Instance: sky130_fd_pr__nfet_01v81          |(no matching instance)
192   (1,3) = (6,5)                            |
193   2 = 8                                    |
194   4 = 12                                   |
195                                            |
196                                            |
197 Instance: sky130_fd_pr__nfet_01v811         |(no matching instance)
198   (1,3) = (6,5)                            |
199   2 = 8                                    |
200   4 = 12                                   |
201                                            |
202 ------------------------------------------------------------------------------------------
203
204 ------------------------------------------------------------------------------------------
205 Instance: sky130_fd_pr__nfet_01v813         |(no matching instance)
206   (1,3) = (6,2)                            |
207   2 = 6                                    |
208   4 = 12                                   |
209                                            |
210                                            |
211 Instance: sky130_fd_pr__nfet_01v814         |(no matching instance)
212   (1,3) = (6,2)                            |
213   2 = 6                                    |
214   4 = 12                                   |
215                                            |
216 ------------------------------------------------------------------------------------------
217
218 ------------------------------------------------------------------------------------------
219 Instance: sky130_fd_pr__nfet_01v86          |(no matching instance)
220   (1,3) = (12,5)                           |
221   2 = 5                                    |
222   4 = 12                                   |
223                                            |
224                                            |
225 Instance: sky130_fd_pr__nfet_01v815         |(no matching instance)
226   (1,3) = (12,5)                           |
227   2 = 5                                    |
228   4 = 12                                   |
229                                            |
230 ------------------------------------------------------------------------------------------
231
232 ------------------------------------------------------------------------------------------
233 (no matching instance)                      |Instance:
       sky130_fd_pr__nfet_01v8M3
234                                            |  (1,3) = (6,5)
235                                            |  2 = 8
236                                            |  4 = 8
237                                            |
238                                            |
239 (no matching instance)                      |Instance:
       sky130_fd_pr__nfet_01v8M4
240                                            |  (1,3) = (6,5)
```

```
                                          |  2 = 8
                                          |  4 = 8
                                          |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M6
                                          |  (1,3) = (5,4)
                                          |  2 = 5
                                          |  4 = 8
                                          |
                                          |
(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M8
                                          |  (1,3) = (5,4)
                                          |  2 = 5
                                          |  4 = 8
                                          |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M11
                                          |  (1,3) = (4,2)
                                          |  2 = 8
                                          |  4 = 8
                                          |
                                          |
(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M12
                                          |  (1,3) = (4,2)
                                          |  2 = 8
                                          |  4 = 8
                                          |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M15
                                          |  (1,3) = (6,2)
                                          |  2 = 6
                                          |  4 = 8
                                          |
                                          |
(no matching instance)                    |Instance:
   sky130_fd_pr__nfet_01v8M16
                                          |  (1,3) = (6,2)
                                          |  2 = 6
                                          |  4 = 8
                                          |
------------------------------------------------------------------------------------------


```

```
------------------------------------------------------------------------------------------

Instance: sky130_fd_pr__pfet_01v84          |(no matching instance)
  (1,3) = (12,2)                            |
  2 = 8                                     |
  4 = 12                                    |
                                            |
                                            |
Instance: sky130_fd_pr__pfet_01v88          |(no matching instance)
  (1,3) = (12,2)                            |
  2 = 8                                     |
  4 = 12                                    |
                                            |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

Instance: sky130_fd_pr__pfet_01v80          |(no matching instance)
  (1,3) = (5,2)                             |
  2 = 5                                     |
  4 = 12                                    |
                                            |
                                            |
Instance: sky130_fd_pr__pfet_01v89          |(no matching instance)
  (1,3) = (5,2)                             |
  2 = 5                                     |
  4 = 12                                    |
                                            |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

Instance: sky130_fd_pr__pfet_01v82          |(no matching instance)
  (1,3) = (12,6)                            |
  2 = 6                                     |
  4 = 12                                    |
                                            |
                                            |
Instance: sky130_fd_pr__pfet_01v810         |(no matching instance)
  (1,3) = (12,6)                            |
  2 = 6                                     |
  4 = 12                                    |
                                            |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

Instance: sky130_fd_pr__pfet_01v87          |(no matching instance)
  (1,3) = (6,1)                             |
  2 = 8                                     |
  4 = 12                                    |
                                            |
                                            |
Instance: sky130_fd_pr__pfet_01v812         |(no matching instance)
  (1,3) = (6,1)                             |
  2 = 8                                     |
  4 = 12                                    |
```

```
                                                |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M1
                                                |  (1,3) = (4,2)
                                                |  2 = 8
                                                |  4 = 8
                                                |
                                                |
(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M2
                                                |  (1,3) = (4,2)
                                                |  2 = 8
                                                |  4 = 8
                                                |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M5
                                                |  (1,3) = (5,2)
                                                |  2 = 5
                                                |  4 = 8
                                                |
                                                |
(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M7
                                                |  (1,3) = (5,2)
                                                |  2 = 5
                                                |  4 = 8
                                                |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------

(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M9
                                                |  (1,3) = (6,1)
                                                |  2 = 8
                                                |  4 = 8
                                                |
                                                |
(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M10
                                                |  (1,3) = (6,1)
                                                |  2 = 8
                                                |  4 = 8
                                                |
------------------------------------------------------------------------------------------


------------------------------------------------------------------------------------------
```

```
(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M13
                                                |  (1,3) = (6,4)
                                                |  2 = 6
                                                |  4 = 8
                                                |
                                                |
(no matching instance)                          |Instance:
   sky130_fd_pr__pfet_01v8M14
                                                |  (1,3) = (6,4)
                                                |  2 = 6
                                                |  4 = 8
                                                |
--------------------------------------------------------------------------------

Netlists do not match.
  Flattening non-matched subcircuits CSRL_D_FF CSRL_D_FF
Subcircuit summary:
Circuit 1: shift_register_final.spice           |Circuit 2:
   shift_register_lvs_xschem.spice
-------------------------------------------------|------------------------------

inverter (1)                                    |inverter (1)
sky130_fd_pr__pfet_01v8 (32)                    |sky130_fd_pr__pfet_01v8 (32)
sky130_fd_pr__nfet_01v8 (32)                    |sky130_fd_pr__nfet_01v8 (32)
Number of devices: 65                           |Number of devices: 65
Number of nets: 37                              |Number of nets: 37
--------------------------------------------------------------------------------

Circuits match uniquely.
Property errors were found.
Netlists match uniquely.
There were property errors.
CSRL_D_FF_3/sky130_fd_pr__nfet_01v813 vs. CSRL_D_FF5/
   sky130_fd_pr__nfet_01v8M15:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_3/sky130_fd_pr__nfet_01v814 vs. CSRL_D_FF5/
   sky130_fd_pr__nfet_01v8M16:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_2/sky130_fd_pr__nfet_01v813 vs. CSRL_D_FF4/
   sky130_fd_pr__nfet_01v8M15:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_2/sky130_fd_pr__nfet_01v814 vs. CSRL_D_FF4/
   sky130_fd_pr__nfet_01v8M16:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_1/sky130_fd_pr__nfet_01v813 vs. CSRL_D_FF3/
   sky130_fd_pr__nfet_01v8M15:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_1/sky130_fd_pr__nfet_01v814 vs. CSRL_D_FF3/
   sky130_fd_pr__nfet_01v8M16:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_0/sky130_fd_pr__nfet_01v813 vs. CSRL_D_FF2/
   sky130_fd_pr__nfet_01v8M15:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
CSRL_D_FF_0/sky130_fd_pr__nfet_01v814 vs. CSRL_D_FF2/
   sky130_fd_pr__nfet_01v8M16:
 w circuit1: 2   circuit2: 1   (delta=66.7%, cutoff=1%)
Cells have no pins;  pin matching not needed.
Device classes shift_register_final.spice and shift_register_lvs_xschem.
   spice are equivalent.
```

```
Circuits match uniquely.
Property errors were found.
The following cells had property errors: shift_register_final.spice
```