

# Introduction to Open-Source Tools



# Free and Open-Source Software (FOSS)

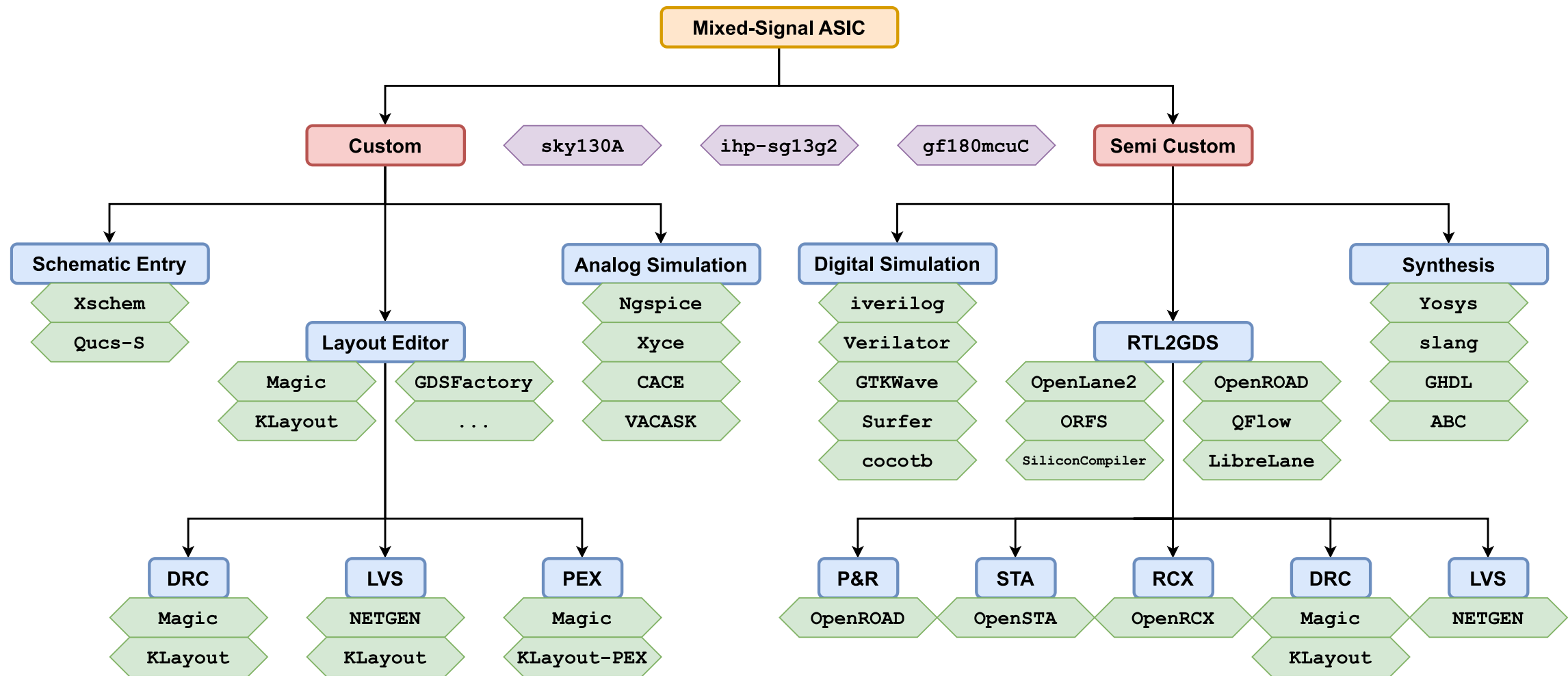
- **Verilator:** Verilog code linter
- **Icarus Verilog (iVerilog):** Verilog compiler and simulator
- **GKTWave / Surfer:** Waveform viewer
- **GHDL:** VHDL analyzer, compiler, simulator and synthesizer
- **YOSYS / ABC:** Verilog synthesis tool
- **Magic / KLayout:** Layout editor with DRC and PEX
- **NextPNR:** Portable FPGA place and route tool
- **LibreLane:** Digital RTL-to-GDS flow
- **IIC-OSIC-Tools:**

- <https://github.com/iic-jku/iic-osic-tools>

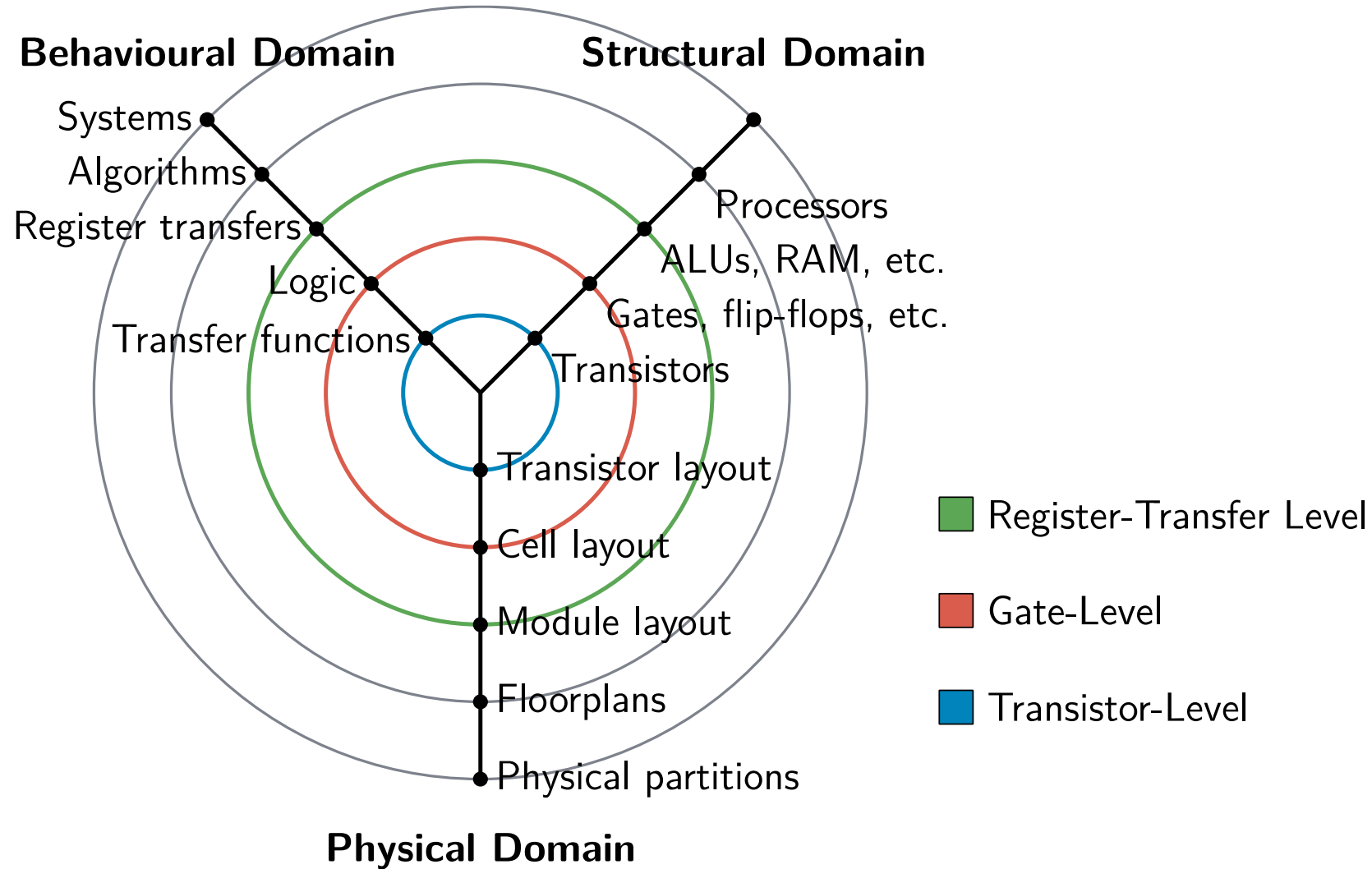
- All-in-one Docker container for FOSS based IC designs for analog and digital circuit flows



# IIC-OSIC-TOOLS

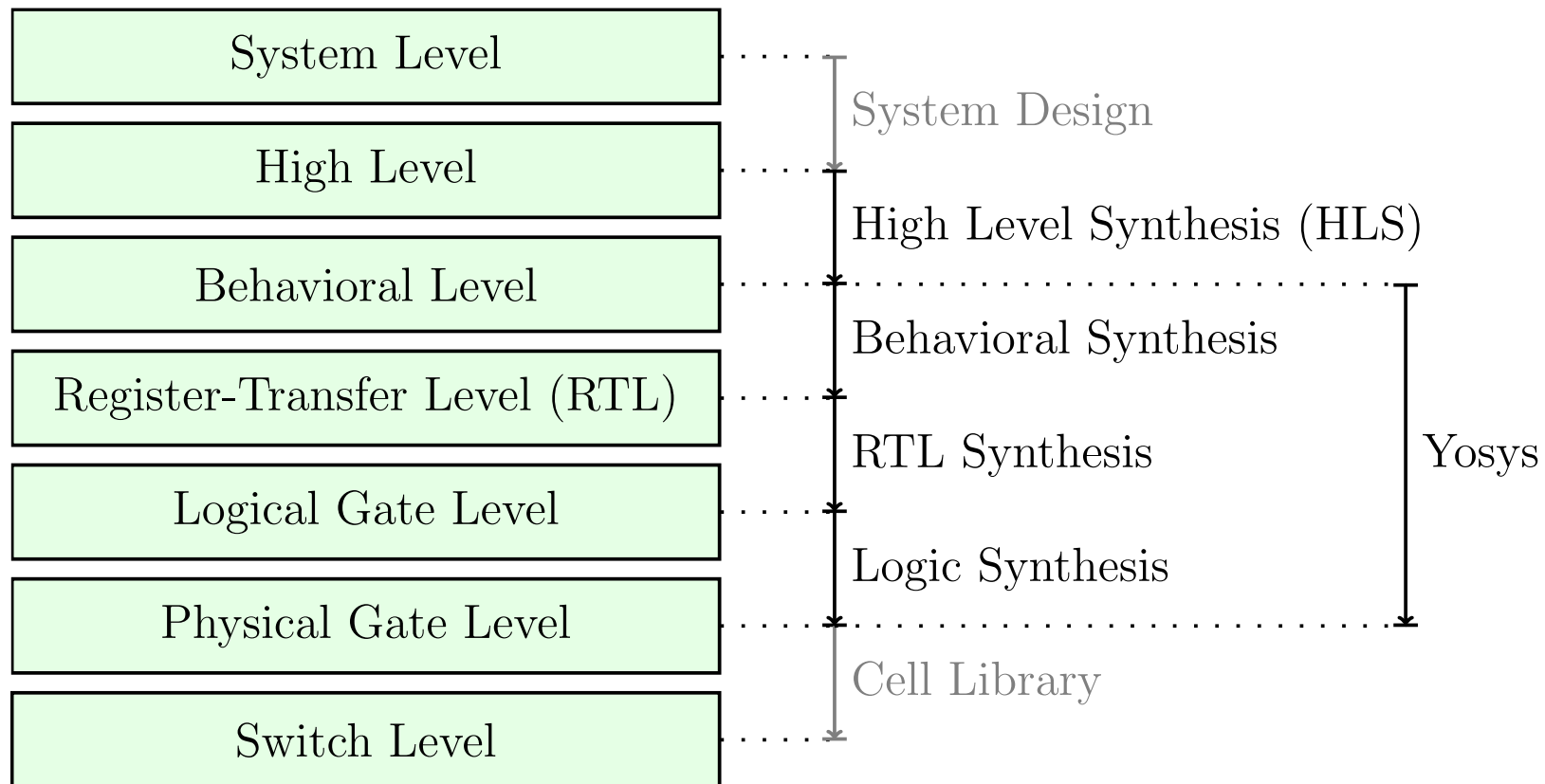


# Y-Diagramm



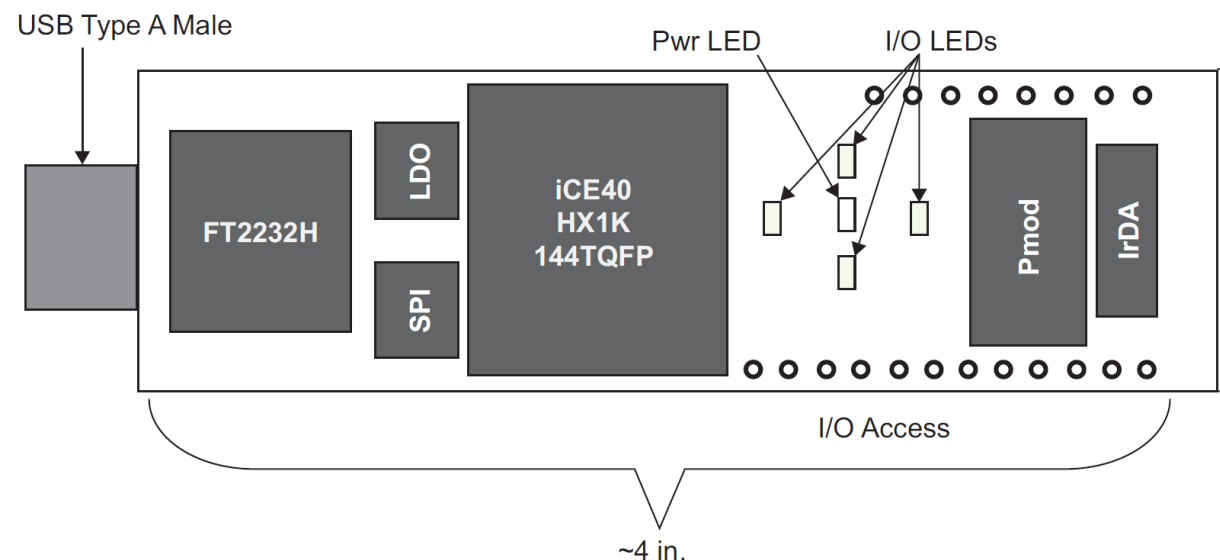
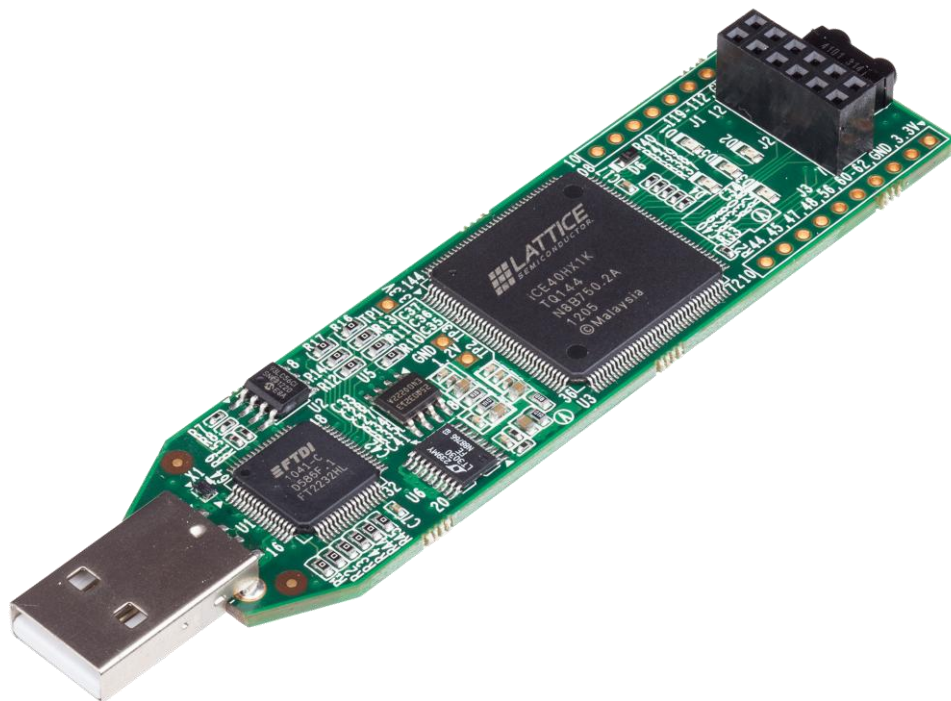
# Yosys

- Github: <https://github.com/YosysHQ/yosys>
- Documentation: <https://yosyshq.readthedocs.io/projects/yosys/en/latest/>

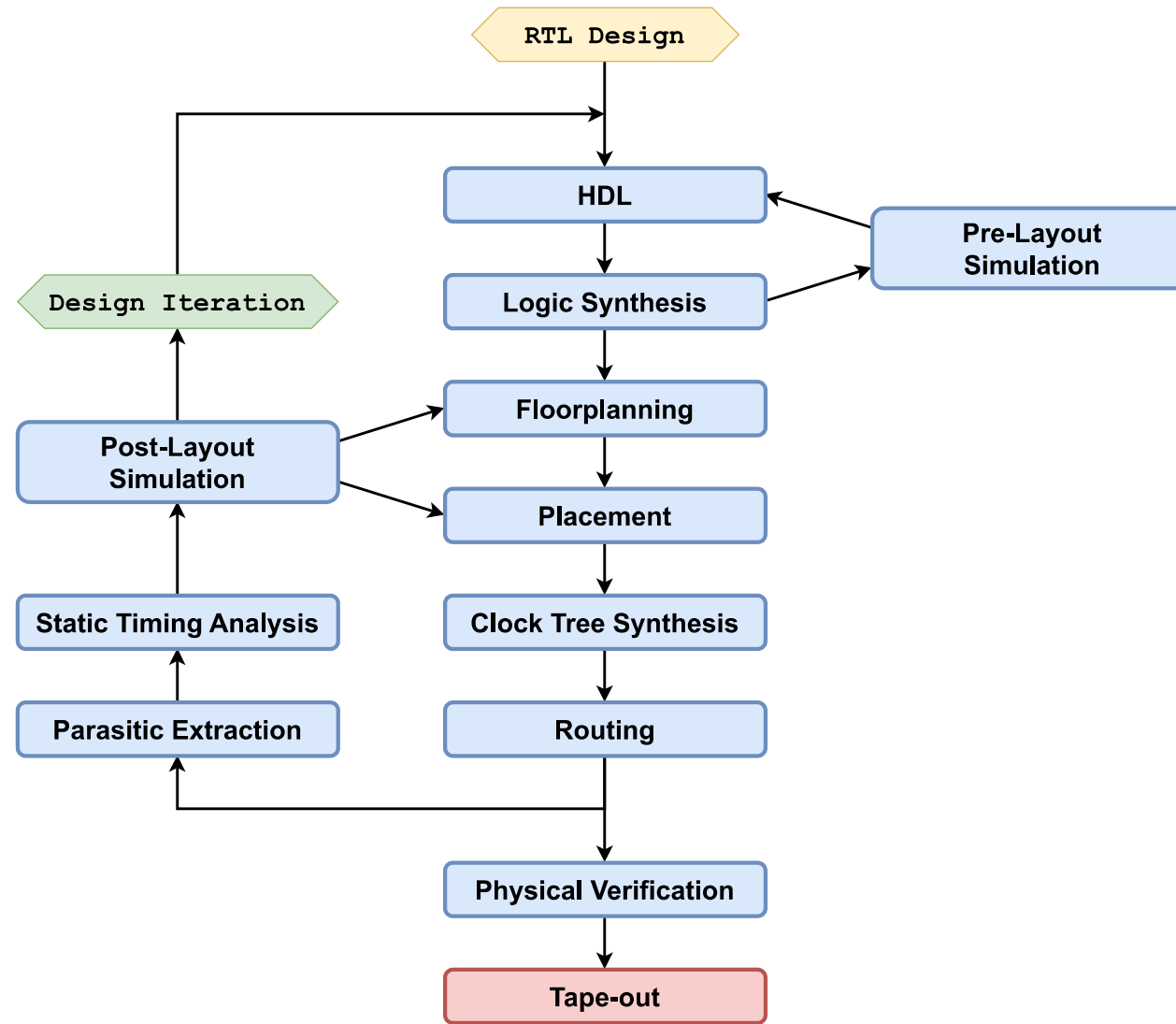


# NextPNR & Lattice iCE40 FPGA Board

- Github: <https://github.com/YosysHQ/nextpnr>
- Lattice iCE40 FPGA Board: <https://www.latticesemi.com/icestick>
- If you want to test your design on this FPGA board, write me an email.

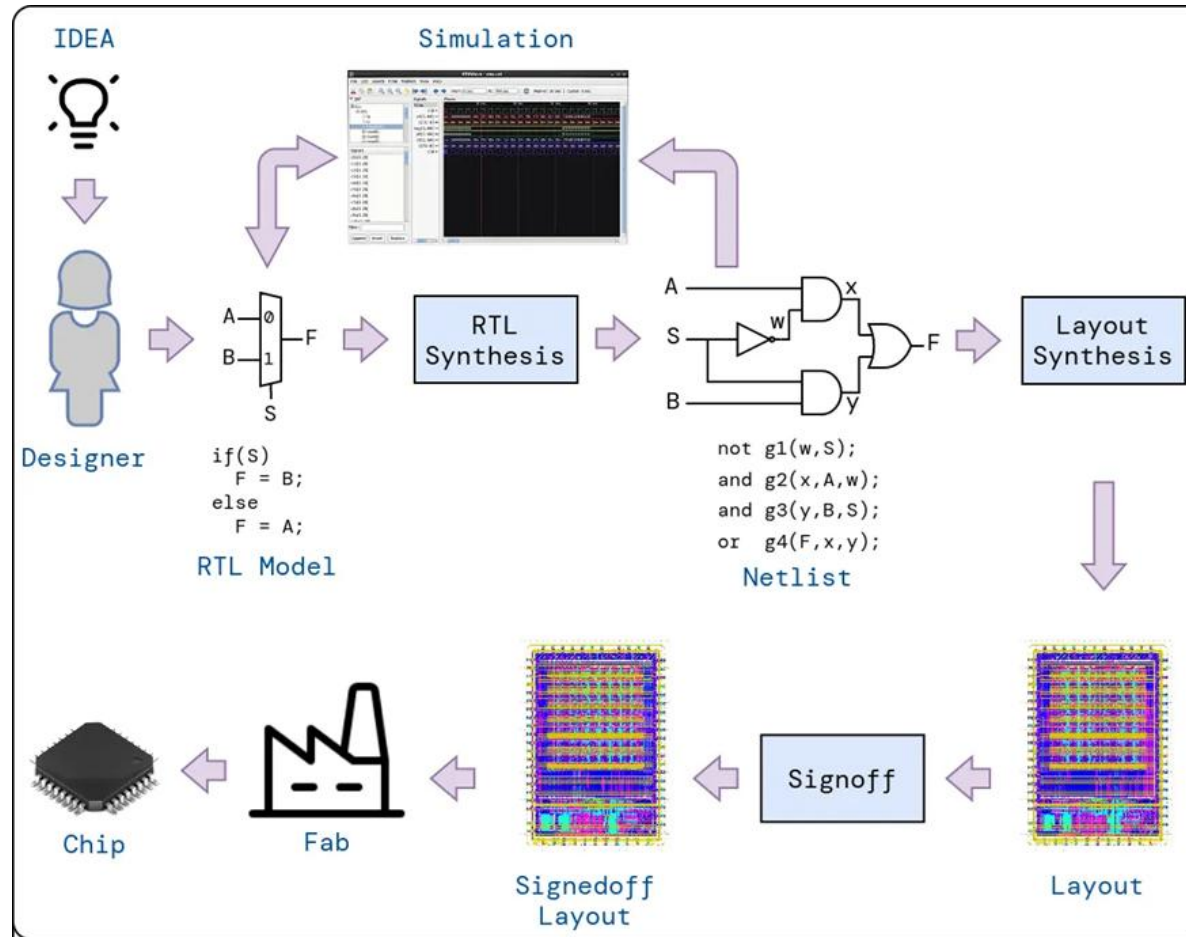


# RTL to GDS Flow



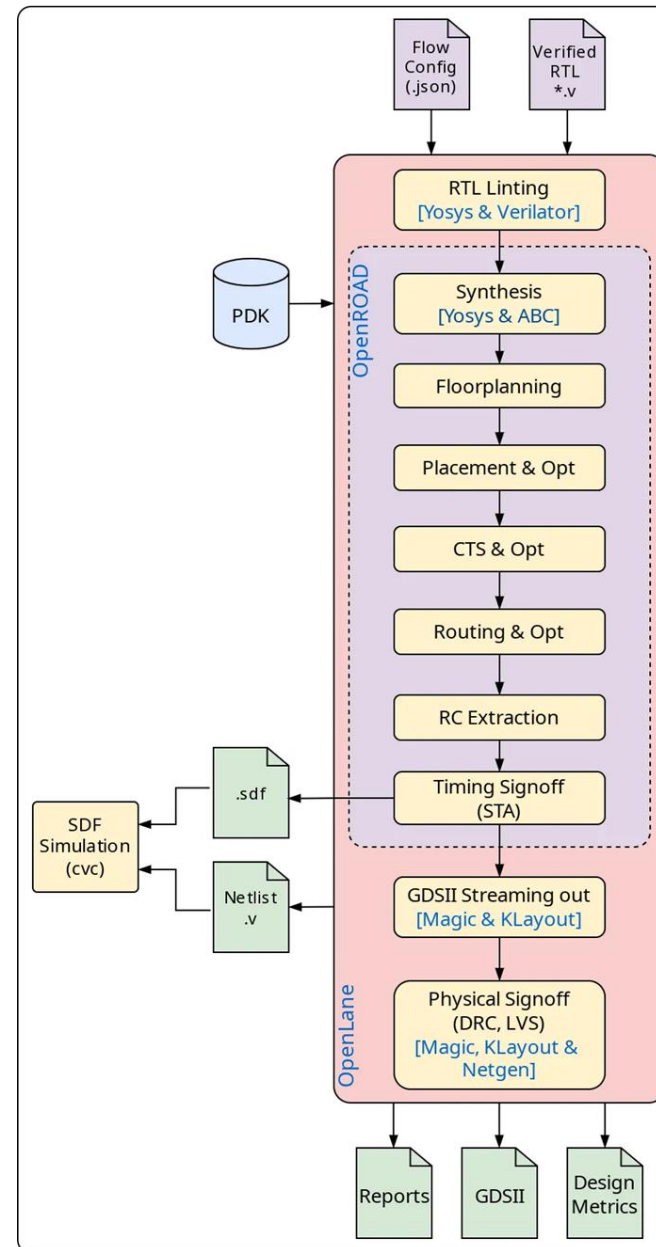
# LibreLane – Intro

- Github: <https://github.com/librelane/librelane>
- Documentation: <https://librelane.readthedocs.io/en/latest/>





# LibreLane – Flow Diagram



# LibreLane – Design Stages

## 1. Synthesis

1. `yosys/abc` - Perform RTL synthesis and technology mapping.
2. `OpenSTA` - Performs static timing analysis on the resulting netlist to generate timing reports

## 2. Floorplaning

1. `init_fp` - Defines the core area for the macro as well as the rows (used for placement) and the tracks (used for routing)
2. `ioplacer` - Places the macro input and output ports
3. `pdnngen` - Generates the power distribution network
4. `tapcell` - Inserts welltap and decap cells in the floorplan

## 3. Placement

1. `RePLace` - Performs global placement
2. `Resizer` - Performs optional optimizations on the design
3. `OpenDP` - Performs detailed placement to legalize the globally placed components

## 4. CTS

1. `TritonCTS` - Synthesizes the clock distribution network (the clock tree)

## 5. Routing

1. `FastRoute` - Performs global routing to generate a guide file for the detailed router
2. `TritonRoute` - Performs detailed routing
3. `OpenRCX` - Performs SPEF extraction

## 6. Tapeout

1. `Magic` - Streams out the final GDSII layout file from the routed def
2. `KLayout` - Streams out the final GDSII layout file from the routed def as a back-up

## 7. Signoff

1. `Magic` - Performs DRC Checks & Antenna Checks
2. `KLayout` - Performs DRC Checks
3. `Netgen` - Performs LVS Checks
4. `cvc` - Performs Circuit Validity Checks

OpenLane integrated several key open source tools over the execution stages:

- RTL Synthesis, Technology Mapping, and Formal Verification : [yosys + abc](#)
- Static Timing Analysis: [OpenSTA](#)
- Floor Planning: [init\\_fp](#), [ioPlacer](#), [pdn](#) and [tapcell](#)
- Placement: [RePLace](#) (Global), [Resizer](#) and [OpenPhySyn](#) (formerly), and [OpenDP](#) (Detailed)
- Clock Tree Synthesis: [TritonCTS](#)
- Fill Insertion: [OpenDP/filler\\_placement](#)
- Routing: [FastRoute](#) or [CU-GR](#) (formerly) and [TritonRoute](#) (Detailed) or [DR-CU](#)
- SPEF Extraction: [OpenRCX](#) or [SPEF-Extractor](#) (formerly)
- GDSII Streaming out: [Magic](#) and [KLayout](#)
- DRC Checks: [Magic](#) and [KLayout](#)
- LVS check: [Netgen](#)
- Antenna Checks: [Magic](#)
- Circuit Validity Checker: [CVC](#)

# Installed Open-Source PDKs

- **PDK:** Process-Design Kit
  - [https://en.wikipedia.org/wiki/Process\\_design\\_kit](https://en.wikipedia.org/wiki/Process_design_kit)
  - Set of files used within the semiconductor industry to model a fabrication process for the design tools used to design an IC
  - Symbols, Device Parameters
  - Simulation models for components (e.g. BSIM, PSP, ...)
  - Design Rule Check (DRC), Layout vs. Schematic (LVS), Electrical Rule Check (ERC)
- IHP 130nm BiCMOS Technology (IHP130): <https://www.ihp-microelectronics.com/de>
- Skywater 130nm CMOS Technology (SKY130): <https://www.skywatertechnology.com/>
- Global Foundries 180nm CMOS Technology (GF180): <https://gf.com/de/>



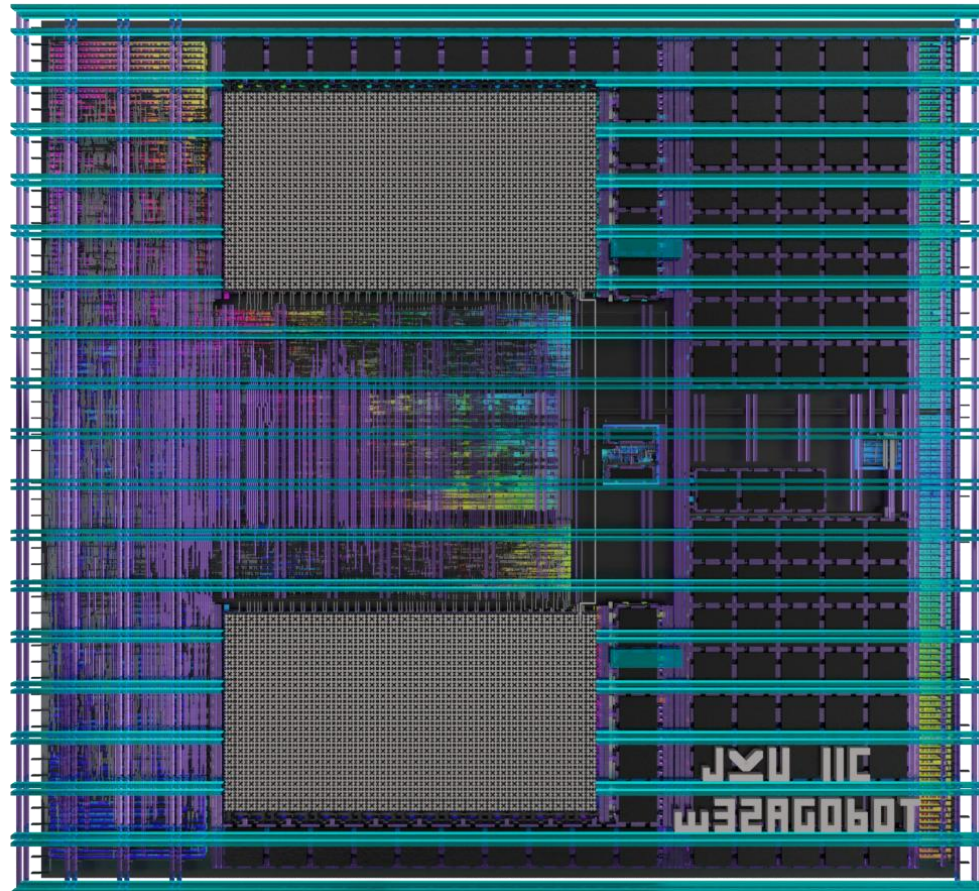
# Where to Tape out?

- **Tiny Tapeout:**
  - <https://tinytapeout.com/>
  - PDKs: SKY130 & IHP130
  - Multi-Project Chip (MPC), Multi-Project Wafer (MPW)
    - Cheap, since more projects are put on one chip
  - Development board
- **ChipFoundry:**
  - <https://chipfoundry.io/>
- **Europractice:**
  - <https://europractice-ic.com/services/fabrication/>
  - Supports also commercial PDKs (e.g. TSMC)



# Examples – IICQC

- SAR-ADC: [https://github.com/iic-jku/SKY130\\_SAR-ADC1](https://github.com/iic-jku/SKY130_SAR-ADC1)
- Synthesizable Digital Temperature Sensor: <https://github.com/iic-jku/tt03-tempsensor>





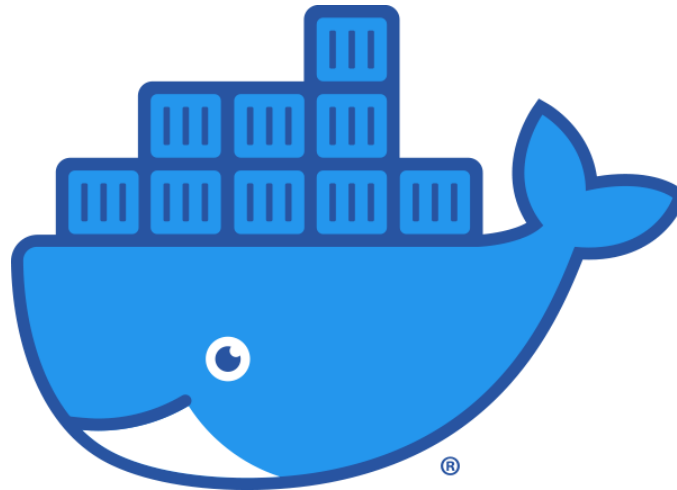
# Examples – Tiny Tapeout

- Tiny Tapeout 3 projects: <https://tinytapeout.com/runs/tt03/>



# Tutorial – Setting up Docker container (WIN11)

- Install Docker: <https://docs.docker.com/desktop/install/windows-install/>
- Download IIC-OSIC-TOOLS: <https://github.com/iic-jku/iic-osic-tools>
- Start Docker & enter “.\start\_x.bat” in command line in IIC-OSIC-TOOLS folder
- Set up “.designinit” file for used PDK
- **Alternatively, access to a virtual machine (VM) can be requested by email.**



# Tutorial – Linux Cheatsheet

- The most useful commands for the Linux command line are:
  - `ls` to list files and directories
  - `cd` to change directory (e.g. `cd analog-circuit-design/xschem`)
  - `cd ..` to move one directory level down
  - `mkdir` to create a new directory (e.g. `mkdir my_directory`)
  - `touch` to create an empty file (e.g. `touch file.txt`)
  - `rm` to remove files (e.g. `rm file.txt`)
  - `rm -r` to remove recursively, for example a directory (e.g. `rm -r my_directory`)
  - `cp` to copy files (e.g. `cp file.txt destination`)
  - `cp -r` to copy recursively a directory (e.g. `cp -r directory destination`)
  - `mv` to rename files (e.g. `mv file.txt new_name.txt`)
  - `mv` to move files into other directories (e.g. `mv file.txt directory`)
  - `cat` to view the contents of a file (e.g. `cat file.txt`)
  - `find` to search for files and directories (e.g. `find /path -name "*.txt"`)
  - `nano` to edit file (e.g. `nano file.txt`)
  - `Ctrl + C` to forcefully terminate a running process
  - `htop` to open the “task manager”
- More advanced commands can be found under <https://www.geeksforgeeks.org/linux-commands-cheat-sheet>



# Tutorial – Recommended Workflow

1. Write Verilog Design
2. Simulate Verilog Design in **GTKWave / Surfer**
3. Synthesize Verilog Design with **Yosys**
4. Test Verilog Design on Lattice iCE40 FPGA board with **nextpnr (optional)**
5. GDS generation with **LibreLane** or **Tiny Tapeout GitHub Actions**
6. Take PDK-dependent Verilog netlist and simulate the design again (**Post-Layout Simulation**)

# Tutorial – Compilation / Linting / Simulation

- If the architecture is finished, it should be compiled and checked for **syntax errors**.
- This can be done with the command `"iic-vlint.sh <file.v>"`
- After the architecture is without syntax errors, it should be simulated with its according **testbench**.

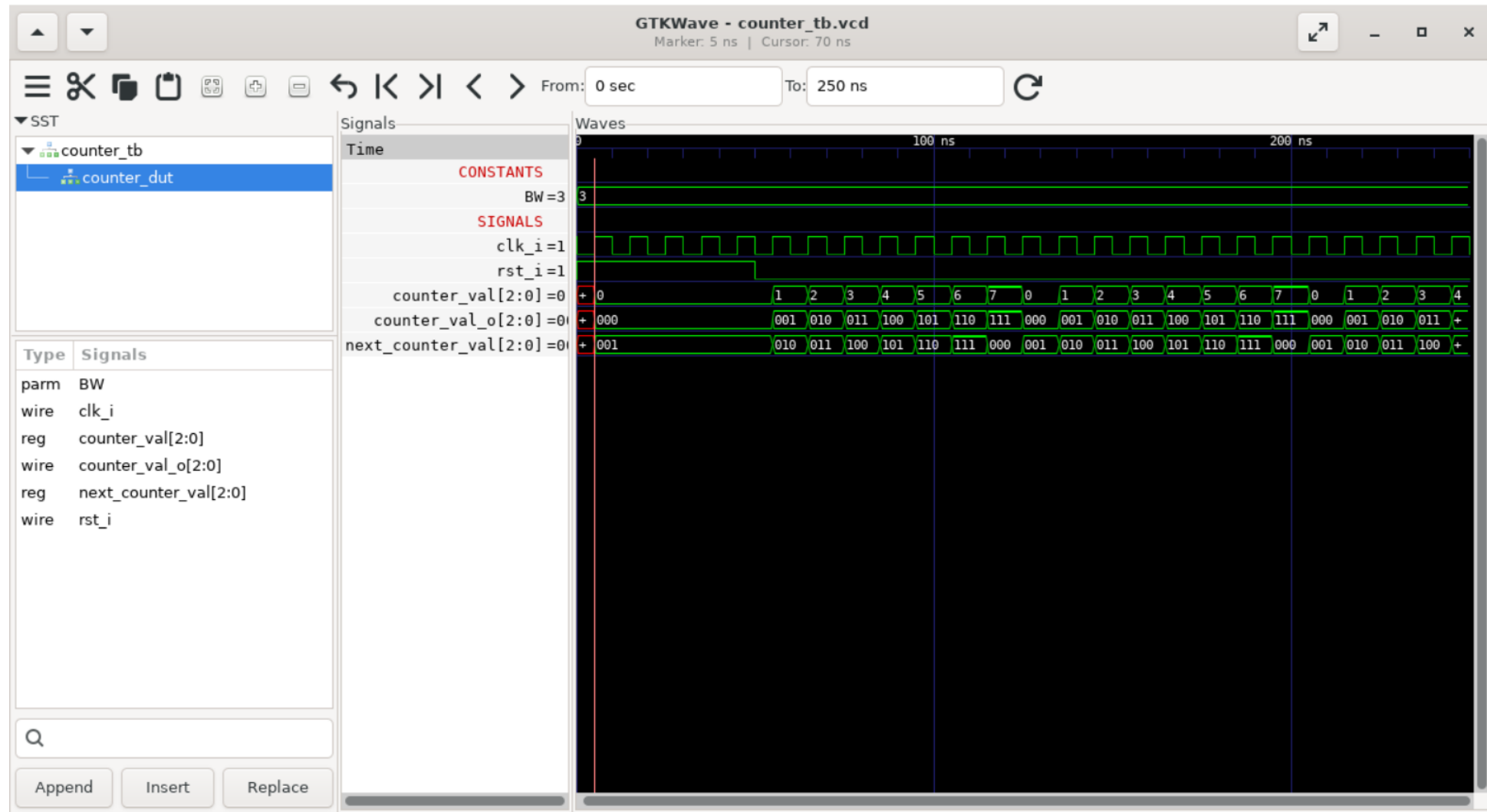
```
/foss/designs/kvic_336007_ws25/verilog/tb > iverilog -g2005 ../src/counter.v counter_tb.v  
/foss/designs/kvic_336007_ws25/verilog/tb > ./a.out  
VCD info: dumpfile counter_tb.vcd opened for output.  
counter_tb.v:38: $finish called at 250 (1ns)  
/foss/designs/kvic_336007_ws25/verilog/tb > gtkwave counter_tb.vcd
```

- With the self-written script, this can be done very easily, just call `"./simulate.sh <file>"`.
- After a simulation is set up it can be saved with CTRL+S and re-loaded with CTRL+O again.
- A simulation file is saved as `"<wave>.gtkw"` by default.
- Alternatively, open Surfer with the `"surfer"` command and load `"<file.vcd>"`.

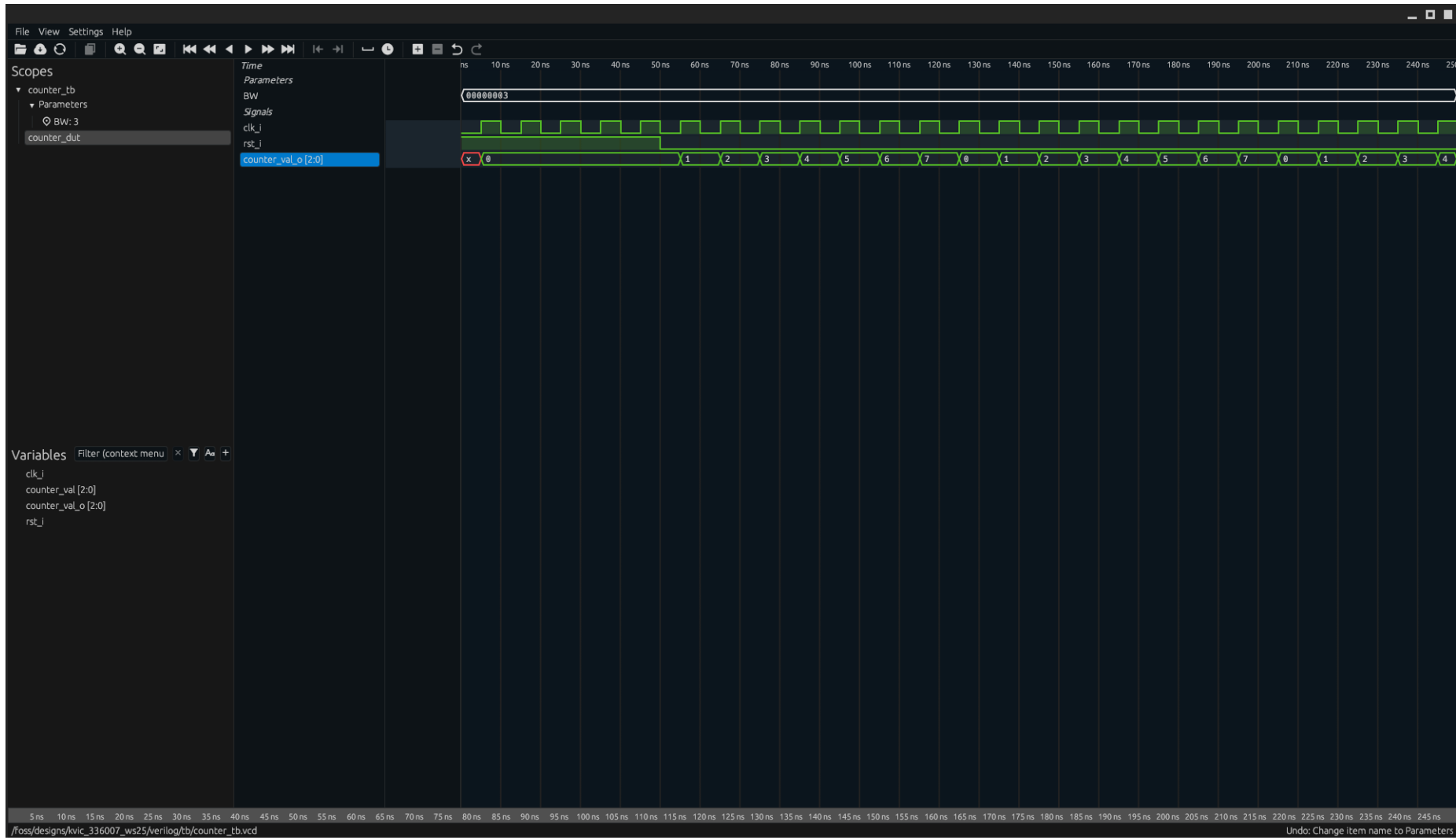
# Tutorial – Compilation / Linting / Simulation

```
1  #!/usr/bin/env bash
2
3  # =====
4  # Author: Simon Dorrer
5  # Last Modified: 02.10.2025
6  # Description: This .sh file verifies and simulates a verilog testbench with Verilator, IVerilog and GTKWave.
7  # =====
8
9  set -e -x
10
11  cd "$(dirname "$0")"
12
13  GREEN='\033[1;32m'
14  NC='\033[0m'
15
16  name=$1
17
18  RTL=${RTL:-../src}
19  SRC_FOLDER=${SRC_FOLDER:-.}
20
21  echo -e "${GREEN}Verilator:----- ${NC}"
22  verilator --lint-only -I"$RTL" "$RTL"/"$name".v # -I"$RTL" for multiple Verilog file dependencies in "src" folder
23
24  echo -e "${GREEN}IVerilog:----- ${NC}"
25  iverilog -g2005 -I"$RTL" "$RTL/$name.v" "$SRC_FOLDER/${name}_tb.v" # -I"$RTL" for multiple Verilog file dependencies in "src" folder
26
27  echo -e "${GREEN}a:----- ${NC}"
28  ./a.out
29
30  echo -e "${GREEN}GTKWave:----- ${NC}"
31  if [ -e "$SRC_FOLDER"/"$name"_tb.gtkw ]
32  then
33      gtkwave "$SRC_FOLDER"/"$name"_tb.gtkw
34  else
35      gtkwave "$SRC_FOLDER"/"$name"_tb.vcd
36  fi
37
38  # Clean
39  rm -f a.out
40  # rm -f *.vcd
41
42  echo -e "${GREEN}Generated files were removed----- ${NC}"
```

# Tutorial – GKTWave



# Tutorial – Surfer



# Tutorial – Showing Stats

- To show the stats with “yosys” the following commands are needed.

```
/foss/designs/kvic_336007_ws25/verilog/src > yosys
yosys> read_verilog counter.v
yosys> proc
yosys> stat
3. Printing statistics.
=== counter ===
      +-----Local Count, excluding submodules.
      |
      9 wires
      44 wire bits
      4 public wires
      18 public wire bits
      3 ports
      10 port bits
      3 cells
      1 $add
      1 $dff
      1 $mux
```

# Tutorial – Showing Stats

- To show the stats with “yosys” after “techmap” a script is provided.
- Just run `<./yosys_stats.sh counter>`

```
1  #!/usr/bin/env bash
2
3  # =====
4  # Author: Simon Dorrer
5  # Last Modified: 02.10.2025
6  # Description: This .sh file loads the Verilog file and outputs stats, such as cells, AND, OR, NOT, XOR, MUX, and registers.
7  # =====
8
9  set -e -x
10
11  cd "$(dirname "$0")"
12
13  # Name as input parameter (counter)
14  name=$1
15
16  yosys -p "read verilog "$name".v; proc; opt; flatten; techmap; stat"
```

```
6. Printing statistics.

=== counter ===

+-----Local Count, excluding submodules.
|
55 wires
1330 wire bits
4 public wires
18 public wire bits
3 ports
10 port bits
77 cells
24 $ _AND_
8 $ _MUX_
8 $ _NOT_
12 $ _OR_
8 $ _SDFF_PP0_
17 $ _XOR_
```

# Tutorial – Showing Stats

- add... adder
  - sub... subtractor
  - mul... multiplier
  - eq... equality
  - dff... D-Type Flip-Flops with synchronous reset (register)
  - adff... D-Type Flip-Flops with asynchronous reset
  - lt...  $Y = A < B$  (lower than)
  - le...  $Y = A \leq B$  (lower equal)
  - shl...  $Y = A \ll B$  (logical left shift)
  - sshl...  $Y = A \lll B$  (arithmetic left shift)
  - gt...  $Y = A > B$  (greater than)
  - ge...  $Y = A \geq B$  (greater equal)
  - shr...  $Y = A \gg B$  (logical right shift)
  - sshr...  $Y = A \ggg B$  (arithmetic right shift)
  - memrd... read port of memory
  - memwr... write port of memory
- The \$memwr cells have a clock input CLK, an enable input EN (one enable bit for each data bit), an address input ADDR and a data input DATA.
  - The \$memrd cells have a clock input CLK, an enable input EN, an address input ADDR and a data output DATA.
  - More informations can be found in the yosys manual, just search for „\$abbreviation\_name“.



# Tutorial – LibreLane

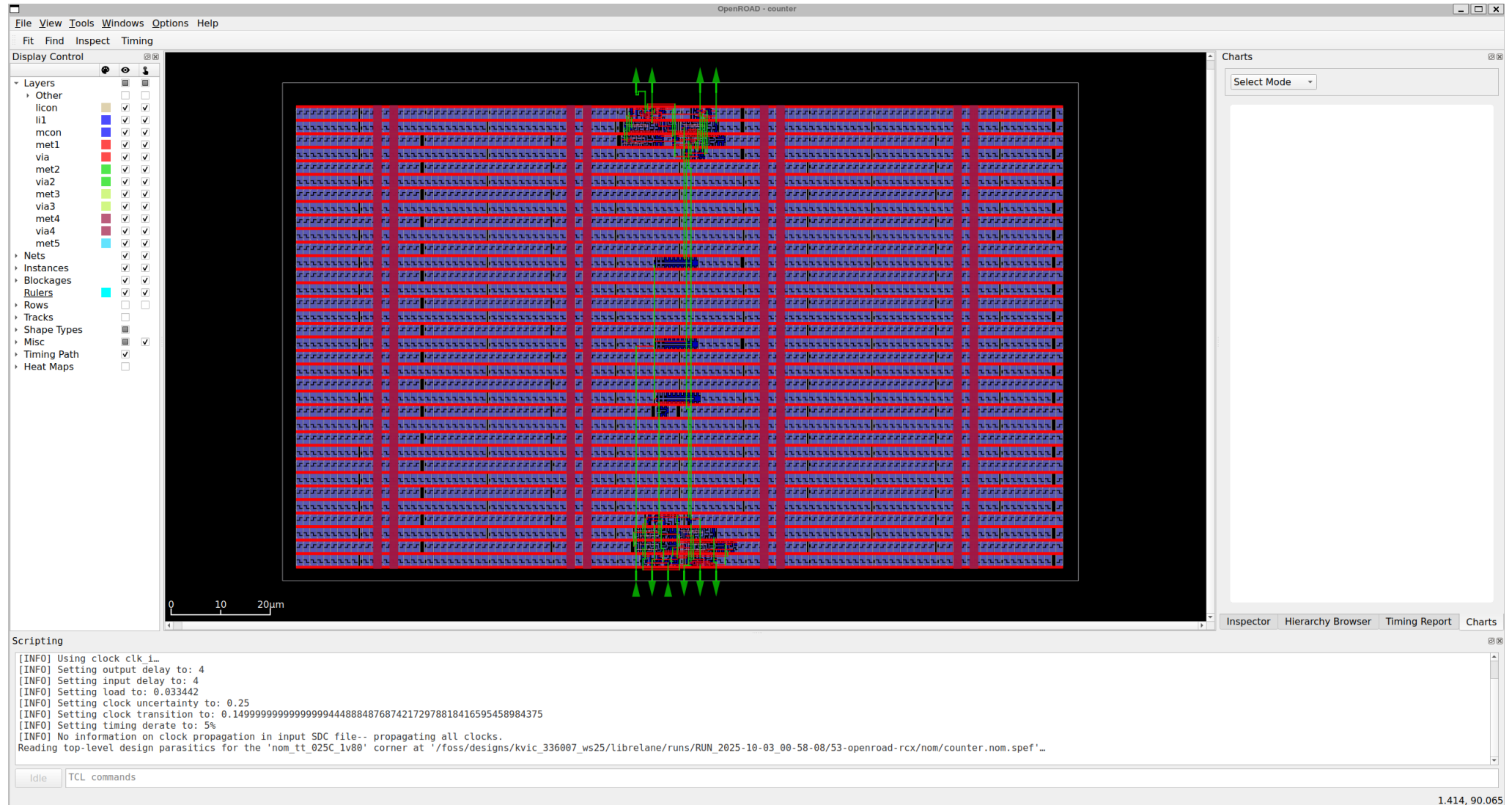
- In the „config.json“ file the Tiny Tapeout parameters for the digital layout are set.
  - CLOCK\_PERIOD, CLOCK\_PORT, ...
  - DIE\_AREA, PL\_TARGET\_DENSITY\_PCT, ...
- In order to create the layout, one must navigate to the folder with the config file and execute the command “*librelane --manual-pdk config.json*”.
- After some minutes / hours, the design should be created, and it can be viewed in 2D with the tools „***magic***“ or „*klayout*“ or in 3D with “*GDS3D*” or the **Tiny Tapeout GitHub actions**.
- Alternatively, the built-in **OpenROAD GUI** can be used.
- More information (HeiChips 2025 LibreLane Workshop): <https://github.com/FPGA-Research/heichips25-workshop?tab=readme-ov-file>

# Tutorial – LibreLane

- To switch to the sky130A PDK, run the LibreLane flow and open the layout in the OpenROAD GUI, an additional script is provided.
- Just run `<./run_librelane.sh>`

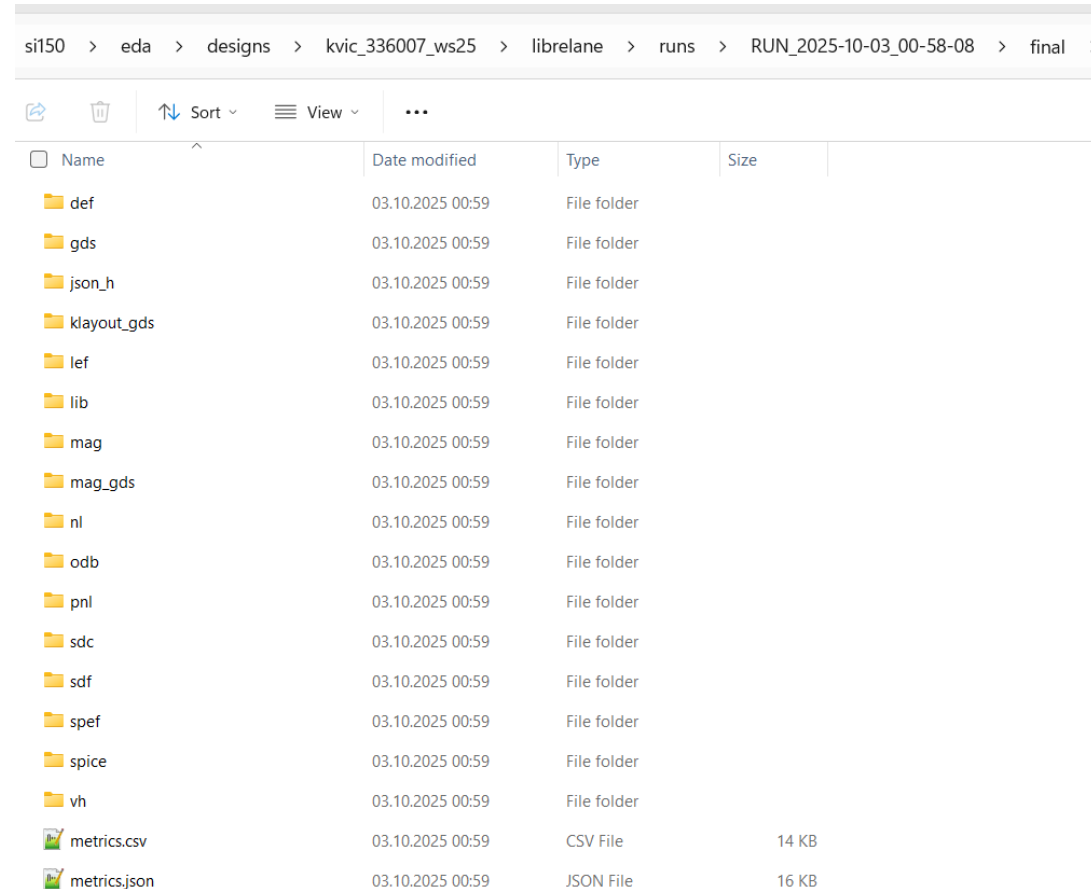
```
1  #!/usr/bin/env bash
2
3  # =====
4  # Author: Simon Dorrer
5  # Last Modified: 02.10.2025
6  # Description: This .sh file switches to the SKY130 PDK, runs the LibreLane flow and opens the layout in the OpenROAD GUI.
7  # =====
8
9  set -e -x
10
11  cd "$(dirname "$0")
12
13  # Switch to sky130A PDK
14  source sak-pdk-script.sh sky130A sky130_fd_sc_hd > /dev/null
15
16  # Run LibreLane
17  librelane --manual-pdk config.json
18
19  # Open Layout in OpenROAD GUI
20  librelane --manual-pdk config.json --last-run --flow OpenInOpenROAD
```

# Tutorial – LibreLane – OpenROAD GUI



# Tutorial – LibreLane

- All output data is placed in “*librelane/runs/ RUN\_XYZ/final*” by default:

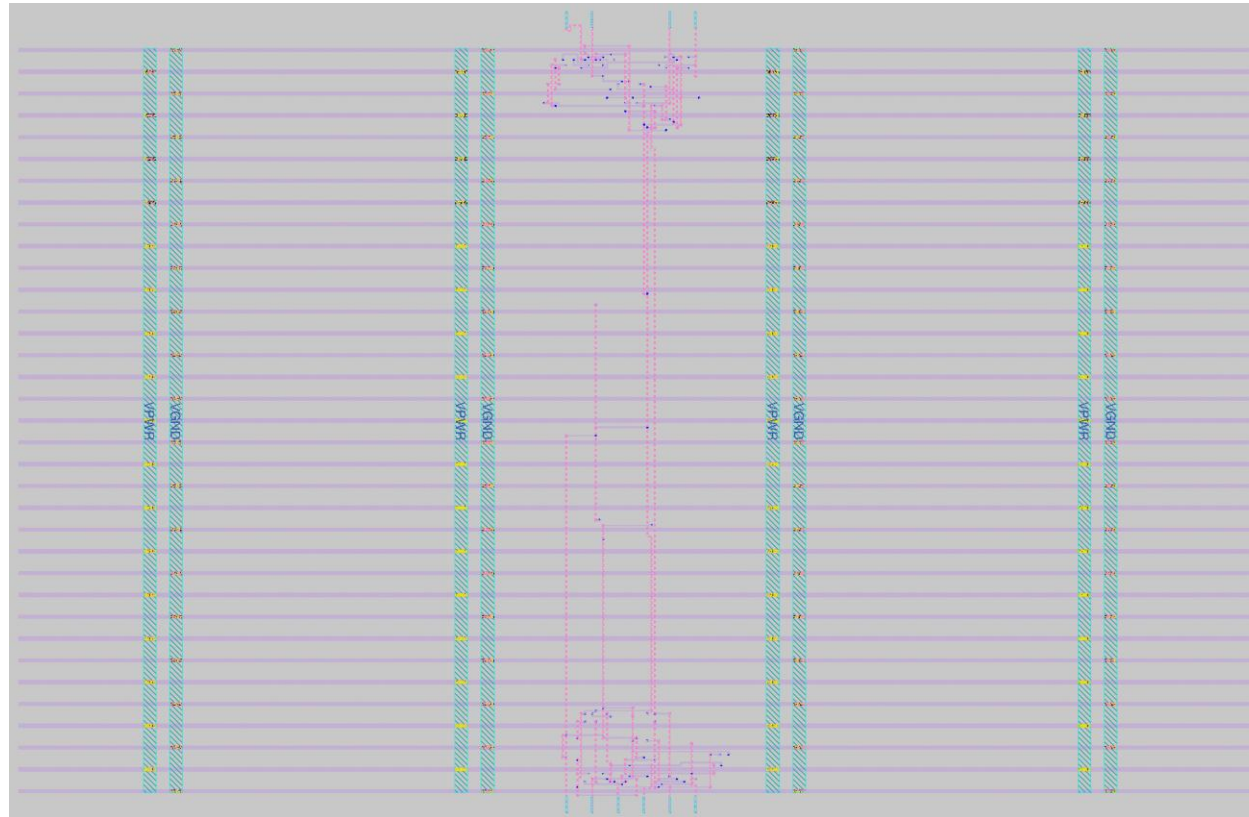


si150 > eda > designs > kvic_336007_ws25 > librelane > runs > RUN_2025-10-03_00-58-08 > final >				
Sort View ...				
<input type="checkbox"/> Name	Date modified	Type	Size	
def	03.10.2025 00:59	File folder		
gds	03.10.2025 00:59	File folder		
json_h	03.10.2025 00:59	File folder		
klayout_gds	03.10.2025 00:59	File folder		
lef	03.10.2025 00:59	File folder		
lib	03.10.2025 00:59	File folder		
mag	03.10.2025 00:59	File folder		
mag_gds	03.10.2025 00:59	File folder		
nl	03.10.2025 00:59	File folder		
odb	03.10.2025 00:59	File folder		
pnl	03.10.2025 00:59	File folder		
sdsc	03.10.2025 00:59	File folder		
sdf	03.10.2025 00:59	File folder		
spcf	03.10.2025 00:59	File folder		
spice	03.10.2025 00:59	File folder		
vh	03.10.2025 00:59	File folder		
metrics.csv	03.10.2025 00:59	CSV File	14 KB	
metrics.json	03.10.2025 00:59	JSON File	16 KB	

- Furthermore, each flow cycle will output a folder in “*librelane/runs/RUN\_XYZ*”.

# Tutorial – Magic

- Go to “*librelane/runs/RUN\_XYZ/results/final/mag*” & enter “*magic counter.mag*”
- Please see the “*magic\_cheatsheet.pdf*” for Magic commands!



- For a nice 3D view, use the GDS viewer of the Tiny Tapeout GitHub actions!

# Tutorial – Wokwi to Verilog Template

- Rename the existing repo
- Create a new repo from ttsky-Verilog-template with the same name as the original repo
  - <https://github.com/TinyTapeout/ttsky-verilog-template>
- Get docs and GDS green
- Go to <https://app.tinytapeout.com/> and click on your project name, then click on the big blue **“SUBMIT A NEW REVISION”** button
- Detailed description: <https://moodle.jku.at/mod/forum/discuss.php?d=151162>

# Tutorial – Wokwi to Verilog Template



## Wokwi to Verilog Repo

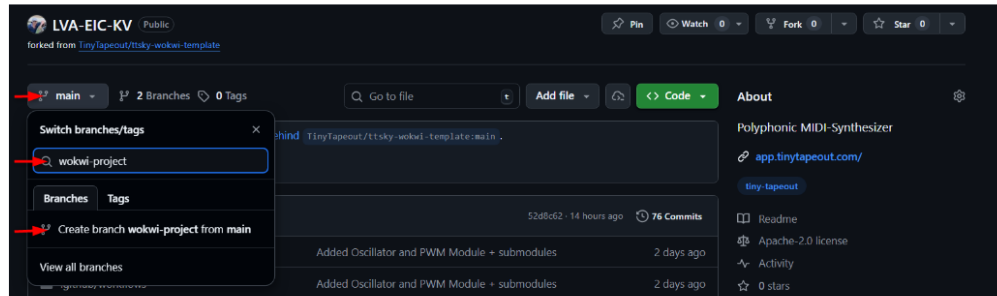
von Simon Grundner - Donnerstag, 2. Oktober 2025, 18:49

### Vorraussetzungen

- Git installiert<sup>1</sup>
- SSH Key aufgesetzt (siehe Folien)

### Backup Wokwi Design

Wenn du das Wokwi projekt behalten möchtest, erstelle einen neuen Branch:



### Neues Template Hochladen

Öffne ein Terminal und navigiere in der Kommandozeile zu deinem Wokspace (z.B. Dokumente) und clone dort die Verilog Template Repository:

- `git clone https://github.com/TinyTapeout/ttsky-verilog-template <my-project-name>`

Git Remote auf die eigene URL umstellen (git am ende nicht vergessen). Gib hier deine bereits existierende Wokwi Repo an:

- `git remote set-url origin https://github.com/<username>/<repository>.git`

main Branch in deiner GitHub Repo überschreiben:

- `git push --force origin main`

Danach nur noch die GitHub Seite neuladen und überprüfen ob es geklappt hat. Mit `git pull` kann noch der alte wokwi-project Branch auf den Rechner heruntergeladen werden.

### Repo Umbenennen (wenn gewünscht)

Die Repository kann in *Settings* -> *Dangerzone* (ganz unten) umbenannt werden. Die Verbindung zu [app.tinytapeout.com](https://app.tinytapeout.com) besteht danach weiterhin und es kann wie gewohnt eine neue Revision Submitted werden.

GitHub leitet URLs mit dem alten namen dauerhaft auf den aktuellen namen der Repository um, bis eine neue Repository mit dem alten Namen erstellt wird<sup>2</sup>. Daher sollte auch das Tutorial in den Folien funktionieren. Es könnte jedoch eine weile dauern bis GitHub zulässt, dass eine neue Repository mit einem alten Namen erstellt werden kann.

1. [Git for Windows - Downloads](#)
2. [How long does github forward renamed/moved repos?](#)
3. [Git Reference](#)

[Dauerlink](#) [Bearbeiten](#) [Löschen](#) [Antworten](#)



**JOHANNES KEPLER  
UNIVERSITY LINZ**