

Chapter 0 - Preparations

Before the course (Optional)

Course authors (Git file)

- 1 Description
- 2 Install Option A: OpenROAD Flow Scripts (ORFS) on your computer
- 3 Install Option B: IIC-OSIC-TOOLS in a docker container on your computer
- 4 Install Option C: Guide to use an IHP server with installed EDA tools

Section 1

Description

Description

Before the course starts, you can take some optional preparations regarding the open-source EDA software tools that will be used during the course. Either you can install them locally on your own computer or get access to a preconfigured server from IHP.

Here comes a short description of the three options, followed by their detailed guides:

Option A: OpenROAD Flow Scripts (ORFS) on your computer

- A plain installation of OpenROAD, Yosys, Klayout and some flow scripts into your system.
- This option puts everything directly under your control and only installs the minimum toolset necessary for the course.
- It requires the permissions to install software on your computer.
- The guide makes use of Ubuntu Linux.

Option B: IIC-OSIC-TOOLS in a docker container on your computer

- This docker container is like a swiss knife for EDA tools. It can be configured in many ways and contains a lot of useful tools.
- All the tools for the course are in it.
- It requires the permissions to install software on your computer.
- The guide makes use of Ubuntu Linux.

Option C: IHP server with installed tools

- Working on the IHP server is the more convenient approach and does not require to install anything on your computer.
- The tools are ready to use installed on the IHP server.
- A permanent connection to the server is needed (reliable internet connection).
- This option will work on various computers and operating systems (Linux/Win/Mac).

Section 2

Install Option A: OpenROAD Flow Scripts (ORFS) on your computer

Install Option A: OpenROAD Flow Scripts (ORFS) on your computer

- This guide is a list of shell commands with some short explanations and weblinks.
- This was tested on a freshly installed Ubuntu LTS 24.04.1.
- The order of the commands is crucial and must not be skipped.
- For more explanations look into the documentations and README files of the tools. The weblinks are given.

Prerequisites:

- Ubuntu LTS 24.04.1 (should work on other Linux too, see weblink)
- Permission to install software (sudo rights)
- Reliable internet connection
- git installed: `sudo apt install git`

Weblink for detailed information:

<https://github.com/The-OpenROAD-Project/OpenROAD-flow-scripts/blob/master/docs/user/BuildLocally.md>

Your install folder

Navigate to a folder where you want the installation to reside in. The install will need some Gigabytes space.

```
1 | cd <INSERT PATH TO YOUR INSTALL FOLDER HERE>
```

Clone the ORFS repo

Clone the repository to your computer:

```
1 | git clone --recursive https://github.com/The-OpenROAD-Project/OpenROAD-flow-scripts
```

Run the setup script

Run the setup script to install the dependecies:

```
1 | cd OpenROAD-flow-scripts
```

```
1 | sudo ./setup.sh
```

Build the tools

Build all tools. This will take a while, depending on the computer:

```
1 | ./ build_openroad.sh --local
```

Verify the builds

Verify that the tools are available. You should get version informations of the tools with the following commands:

```
1 | source ./env.sh
```

```
1 | klayout -v
```

```
1 | yosys --version
```

```
1 | openroad -version
```

Section 3

Install Option B: IIC-OSIC-TOOLS in a docker container on your computer

Install Option B: IIC-OSIC-TOOLS in a docker container on your computer

- This guide is a list of shell commands with some short explanations and weblinks.
- This was tested on a freshly installed Ubuntu LTS 24.04.1.
- The order of the commands is crucial and must not be skipped.
- For more explanations look into the documentations and README files of the tools. The weblinks are given.

Prerequisites:

- Ubuntu LTS 24.04.1
- Permission to install software (sudo rights)
- Reliable internet connection

The IIC-OSIC-TOOLS docker container:

With the following steps a preconfigured docker gets installed. The docker is created and maintained by: Institute for Integrated Circuits (IIC) at the Johannes Kepler University Linz (JKU) and is available in their Github with more detailed installation instructions:
<https://github.com/iic-jku/IIC-OSIC-TOOLS>

Step 1: Install docker with apt:

Weblink for detailed informations:

<https://docs.docker.com/engine/install/ubuntu/#install-using-the-repository>

Add Docker's official GPG key:

```
1 | sudo apt-get update
```

```
1 | sudo apt-get install ca-certificates curl
```

```
1 | sudo install -m 0755 -d /etc/apt/keyrings
```

```
1 | sudo curl -fsSL https://download.docker.com/linux/ubuntu/gpg -o /etc/apt/keyrings/docker.asc
```

```
1 | sudo chmod a+r /etc/apt/keyrings/docker.asc
```

Add the repository to apt sources:

```
1 echo \  
2   "deb [arch=$(dpkg --print-architecture) signed-by=/etc/apt/keyrings/docker.asc]  
3     https://download.docker.com/linux/ubuntu \  
4     $(. /etc/os-release && echo "$VERSION_CODENAME") stable" | \  
5     sudo tee /etc/apt/sources.list.d/docker.list > /dev/null
```

```
1 sudo apt-get update
```

Install the latest version of docker:

```
1 | sudo apt-get install docker-ce docker-ce-cli containerd.io docker-buildx-plugin docker-compose-plugin
```

Step 2: Manage docker as a non-root user

Weblink for detailed informations:

<https://docs.docker.com/engine/install/linux-postinstall/#manage-docker-as-a-non-root-user>

```
1 | sudo groupadd docker
```

```
1 | sudo usermod -aG docker $USER
```

```
1 | newgrp docker
```

Step 3: Run the hello-world docker:

Run the hello-world example docker (without the need of sudo user):

```
1 | docker run hello-world
```

No errors should be displayed in running the hello-world example. The output in the shell should contain this message:

```
1 ...
2 Hello from Docker!
3 This message shows that your installation appears to be
4 working correctly.
5
6 To generate this message, Docker took the following steps:
7 1. The Docker client contacted the Docker daemon.
8 2. The Docker daemon pulled the "hello-world" image from
9    the Docker Hub. (amd64)
10 3. The Docker daemon created a new container from that
11    image which runs the executable that produces the
12    output you are currently reading.
13 4. The Docker daemon streamed that output to the Docker
14    client, which sent it to your terminal.
15 ...
```

Step 4: Clone the IIC-OSIC-TOOLS git repository to your computer:

Weblink for detailed informations about the steps 4 - 5:

<https://github.com/iic-jku/IIC-OSIC-TOOLS/blob/main/README.md>

Install git:

```
1 | sudo apt install git
```

Navigate to a folder where you want the repository to be in:

```
1 | cd <INSERT PATH TO YOUR FOLDER HERE>
```

Clone the IIC-OSIC-TOOLS:

```
1 git clone --depth=1 https://github.com/iic-jku/iic-osic-tools.git
```

Step 5: Start the docker

```
1 | ./start_x.sh
```

A shell window pops up, in which the docker runs.

Step 6: Get the OpenROAD flow scripts

- To be written
- This should be matching to option C (IHP server)
- Waiting on IHP information about their docker / server install.

Section 4

Install Option C: Guide to use an IHP server with installed EDA tools

Install Option C: Guide to use an IHP server with installed EDA tools

- This option is still in development.
- Expect updates when it is ready to use.
- Till then it is recommended to take Option A or B.



Mon

L1:
Introduction

T1:
Training

Tue

Q1, Q2:
Recap
Feedback

L3:
Verilog

T3:
Training

Wed

Q3, Q4:
Recap
Feedback

L5:
PDK

T5:
Training

Thu

Q5, Q6:
Recap
Feedback

L7:
OpenROAD
Flow scripts

T7:
Training

Fri

Q7:
Recap

L8:
Tapeout

Feedback



L2:
OpenROAD
tools

T2:
Training

L4:
OpenROAD
first run

T4:
Training

L6:
OpenROAD
GUI

T6:
Training

L7:
OpenROAD
Flow scripts 2

T7:
Training

Spare time
and
Wrap-Up

Chapter 1 - Introduction and overview

Course authors (Git file)



- 1 Welcome
- 2 Course overview
- 3 Course components
- 4 Feedback and Cheat Sheets
- 5 The Training sessions
- 6 Certificate
- 7 Open-source EDA for digital designs



Section 1

Welcome



Trainer profile

Me:

Name, Company / Uni

Why i'm here. My motivation.

What i've done before.

What interests me most.



Participants backgrounds and motivations

You:

Name, Company / Uni

Why i'm here. My motivation.

What i've done before.

What interests me most.



Section 2

Course overview



Chapter names

- 1 Introduction
- 2 OpenROAD tools
- 3 Verilog
- 4 OpenROAD first run
- 5 PDK
- 6 OpenROAD GUI
- 7 OpenROAD flow scripts
- 8 Tapeout



Schedule for the course

Mon	Tue	Wed	Thu	Fri
L1: Introduction	Q1, Q2: Recap Feedback	Q3, Q4: Recap Feedback	Q5, Q6: Recap Feedback	Q7: Recap
T1: Training	L3: Verilog	L5: PDK	L7: OpenROAD Flow scripts	L8: Tapeout
T3: Training		T5: Training	T7: Training	Feedback
				
L2: OpenROAD tools	L4: OpenROAD first run	L6: OpenROAD GUI	L7: OpenROAD Flow scripts 2	Spare time and Wrap-Up
T2: Training	T4: Training	T6: Training	T7: Training	

L : Lectures

T : Training and
Hands-On

Q : Questions

Section 3

Course components



Get the course materials here:

Course materials (Release):

<https://github.com/OS-EDA/Course/releases>

- Download the latest release
- Unpack into a directory
- There might be daily updates during the course week!



Additional course related links:

OS-EDA Github organization:

<https://github.com/OS-EDA>

Course Github repository:

<https://github.com/OS-EDA/Course>



Duplicated content versus internet links

The course slides

- contain Links to the Internet for a lot of topics.
- do not contain duplicated content (or as less as possible).

This means:

- Follow the links and read there. It is important content for the course.
- The links are carefully curated. It's not spamming.
- Don't expect all the content being duplicated into the course slides.

A brief discussion about pros and cons of this.



Lectures



Lectures:

- All the chapters start with a lecture slide deck.
- The trainer will walk you through the content of the lectures.
- Whenever you have a question inbetween: ask directly.
- The lectures contain the base knowledge of the course.



Trainings



Common training tasks:

Every training sessions starts with the common part. The tasks of the common part are sufficient to follow along the content of the course. If you're a beginner, these trainings should be your goal to reach.



Advanced training tasks:

The advanced training sessions are for those With pre knowledge. If the common training was finished fast or was just to easy, the advanced sessions get you covered.



Bonus training tasks:

Still time left to do some tasks? Want something to take with you as homework? Please enjoy the bonus rounds of the training sessions.

Questions



Questions:

- The questions are for re-visiting and remembering a previous chapter.
- They guide an interactive session between the trainer and the room:
 - Trainer: Asks the questions.
 - Room: Answers the questions.
 - Skipping a question is fine.
 - Not knowing the answer is fine.
 - This is not an exam, not a test and not a challenge.
 - It is meant as a helpfull and hoepfully enjoyable way to recap yesterdays content.
 - If no answer is found, the trainer helps with the answer.



Section 4

Feedback and Cheat Sheets



Feedback and Cheat Sheets

- We please you to give us feedback for the course.
- There is a short timeframe each day reserved for feedback.

We have two ideas about this:

- ① Developing Cheatsheets together
- ② Collecting general feedback



Cheatsheets



Some things are really hard to remember:

- Abbreviations
- Complex relations and graphics
- EDA tools workflow
- Schedule of the week
- Mathematics (joking, we're not doing math here)
- ...

- That is why we would like to develop Cheatsheets with you.
- They're made for cheating the hard parts.
- Cheatsheets work best when printed as handouts.
- One can have them nearby the computer while learning.



Cheatsheet example

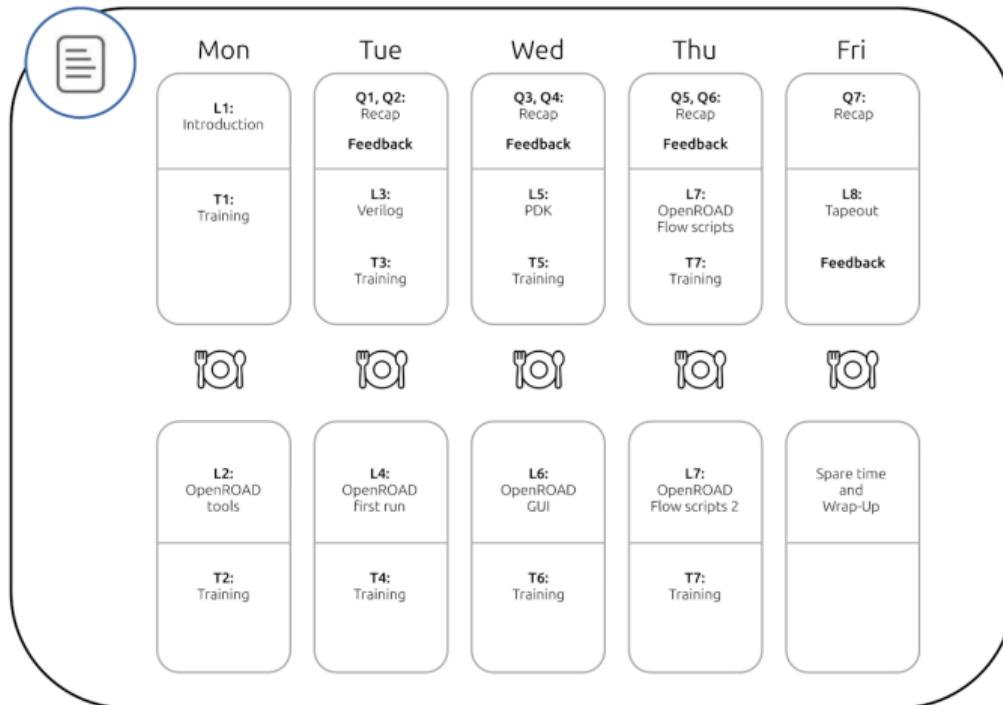


Figure 1: Cheatsheet Chapter 1

Cheatsheet example



**Cheatsheet - Chapter 5
PDK Examination**

KLayout:

.lyp	Layer properties file
.lyt	Technologies file for Layout ↔ Technology mapping

XSchema:

.sym	Schematics file

Abbreviations:

LVS	Layout versus Schematic
CDL	Circuit design language
GDS II	Graphic data system (II)
LEF	Library exchange format
techLEF	Additional info about the technology
.lib	Liberty timing file: ASCII descriptions of timing / power of cells.

Hardware Description Languages (HDL):

Verilog
VHDL

Figure 2: Cheatsheet Chapter 5



Empty Cheatsheet printversion

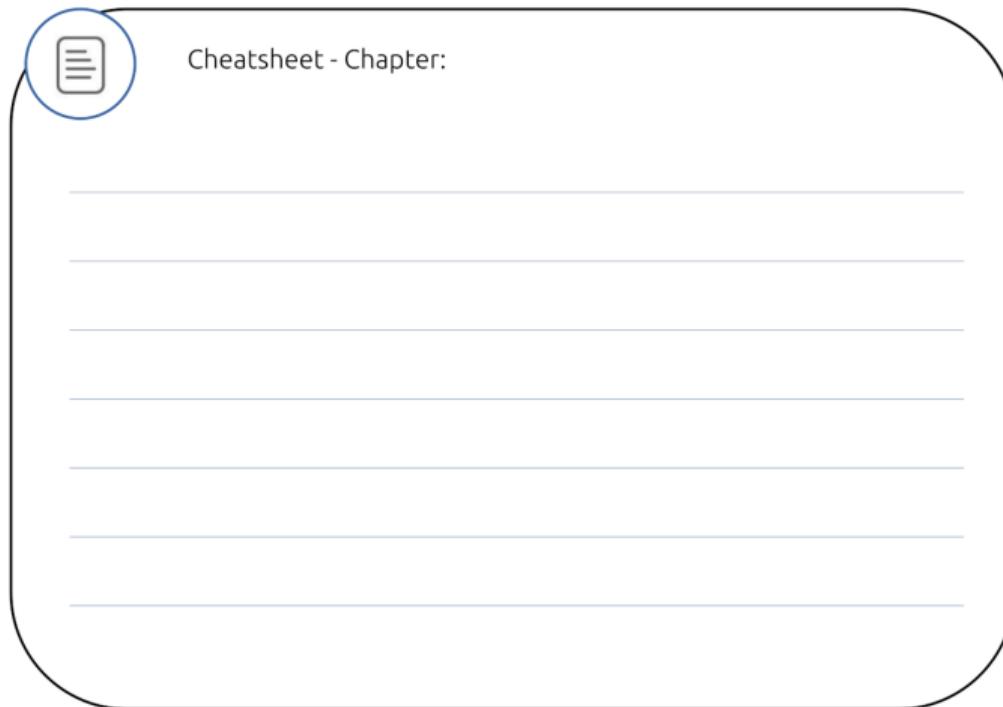


Figure 3: Cheatsheet Chapter 5

General feedback

General feedback:

- The general feedback will be collected verbally in the room.
- Everyone has the opportunity to give feedback
- We will write down the feedback, without your name.



What will happen with your feedback?

- We will put the feedback into Github issues.
- Right now, think of Github issues as some sort of tracker- or ticket system.
- Your feedback will not be connected to you (Anonymous).
- You can join a public discussion in the Github issues, if you want to.

Weblink to the issues of the course:

<https://github.com/OS-EDA/Course/issues?q=is%3Aissue>



Section 5

The Training sessions



Login at IHP

- Onboarding to the computers for everyone



Levels

- The Trainings should create success points inbetween lectures
- This is going too slow for me:
 - Try the advanced and bonus trainings (even from past chapters)
- This keeps me busy every minnute:
 - Stick to the common trainings. You will be able to follow all chapters then.



Section 6

Certificate



Certificate

We will explain live about the certificate of the course.

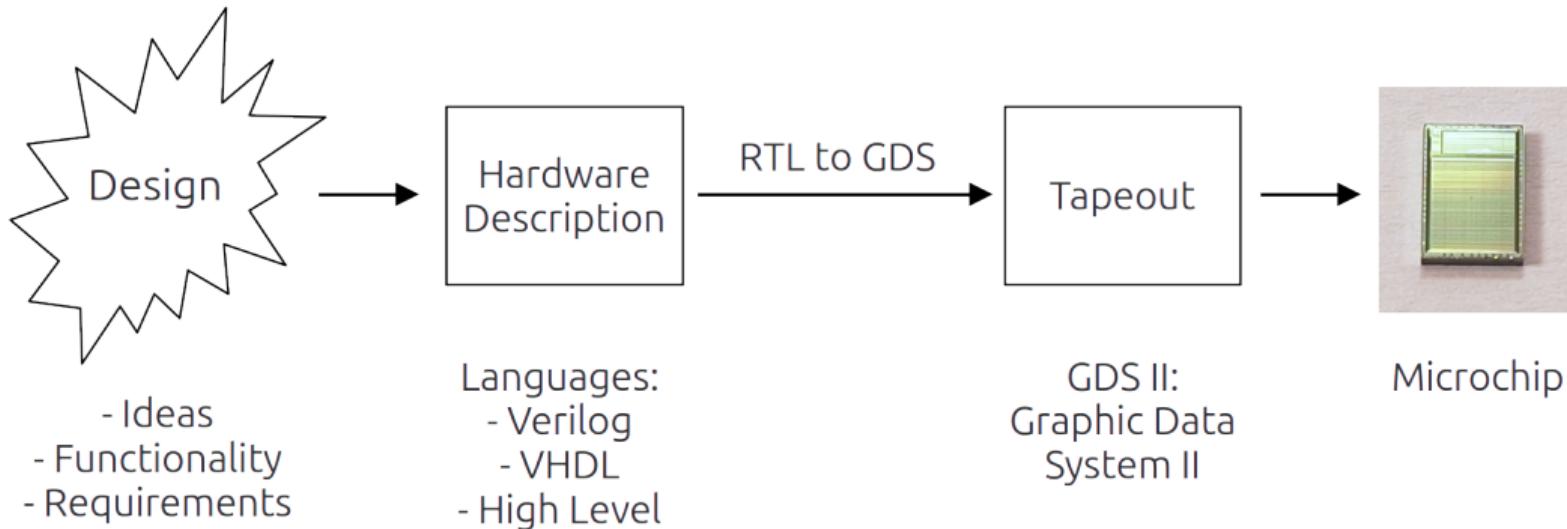


Section 7

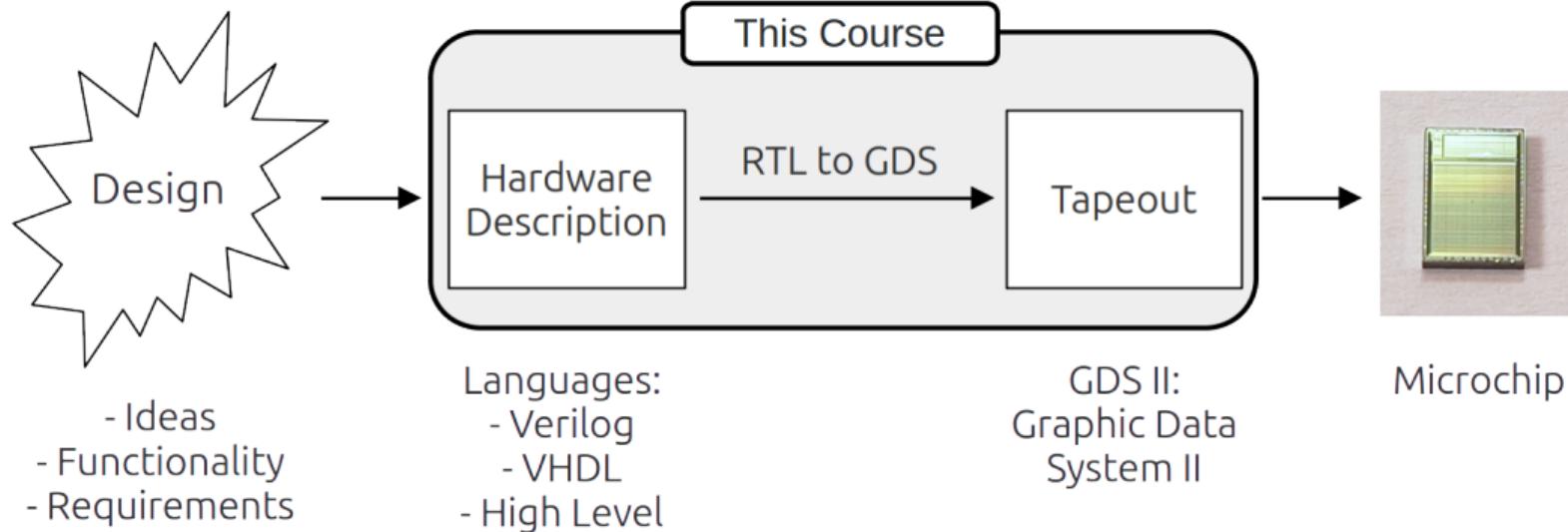
Open-source EDA for digital designs



From design to microchip



RTL to GDS toolchain



RTL: Register Transfer Level

In [digital circuit design](#), **register-transfer level (RTL)** is a design abstraction which models a [synchronous digital circuit](#) in terms of the flow of digital signals ([data](#)) between [hardware registers](#), and the [logical operations](#) performed on those signals.

Register-transfer-level abstraction is used in [hardware description languages](#) (HDLs) like [Verilog](#) and [VHDL](#) to create high-level representations of a circuit, from which lower-level representations and ultimately actual wiring can be derived. Design at the RTL level is typical practice in modern digital design.^[1]

Unlike in software compiler design, where the register-transfer level is an intermediate representation and at the lowest level, the RTL level is the usual input that circuit designers operate on. In fact, in circuit synthesis, an intermediate language between the input register transfer level representation and the target [netlist](#) is sometimes used. Unlike in netlist, constructs such as cells, functions, and multi-bit registers are available.^[2] Examples include FIRRTL and RTLIL.

[Transaction-level modeling](#) is a higher level of [electronic system design](#).

RTL description [\[edit\]](#)

A synchronous circuit consists of two kinds of elements: registers (sequential logic) and [combinational logic](#). Registers (usually implemented as [D flip-flops](#)) synchronize the circuit's operation to the edges of the clock signal, and are the only elements in the circuit that have memory properties. Combinational logic performs all the logical functions in the circuit and it typically consists of [logic gates](#).

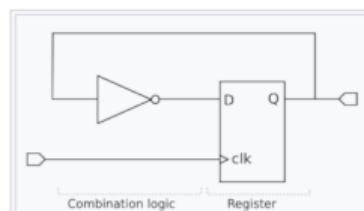


Figure 4: RTL (Screenshot from Wikipedia¹)

¹https://en.wikipedia.org/wiki/Register-transfer_level



GDS: Graphic Data System (II)

GDSII

Article Talk

From Wikipedia, the free encyclopedia

GDSII stream format (GDSII), is a binary database file format which is the de facto industry standard for electronic design automation (EDA) data exchange of integrated circuit (IC) or IC layout artwork.^[1] It is a binary file format representing planar geometric shapes, text labels, and other information about the layout in hierarchical form (two-dimensional/2D CAD file format). The data can be used to reconstruct all or part of the artwork to be used in sharing layouts, transferring artwork between different tools, or creating photomasks.

GDSII

Filename extension	.gds
Developed by	Calma
Initial release	1989; 36 years ago
Type of format	binary ^[1]
Free format?	no

History [edit]

GDS = Graphic Design System (see [GDS78])

Initially, GDSII was designed as a stream format used to control integrated circuit photomask plotting. Despite its limited set of features and low data density, it became the industry conventional stream format for transfer of IC layout data between design tools of different vendors, all of which operated with proprietary data formats.

It was originally developed by Calma for its layout design system, "Graphic Design System" ("GDS") and "GDSII".

Figure 5: GDS (Screenshot from Wikipedia ²)

²<https://en.wikipedia.org/wiki/GDSII>



The GDS II Format (Specifications)

Here are two links about the structure, format and elements of GDS II. The links are for reference reasons. It is not strictly necessary to read or learn the GDS II format for this course. But it might help understanding.

<https://boolean.klaasholwerda.nl/interface/bnf/gdsformat.html>

<https://www.rulabinsky.com/cavd/text/chapc.html>



Naming of RTL-to-GDS tools:

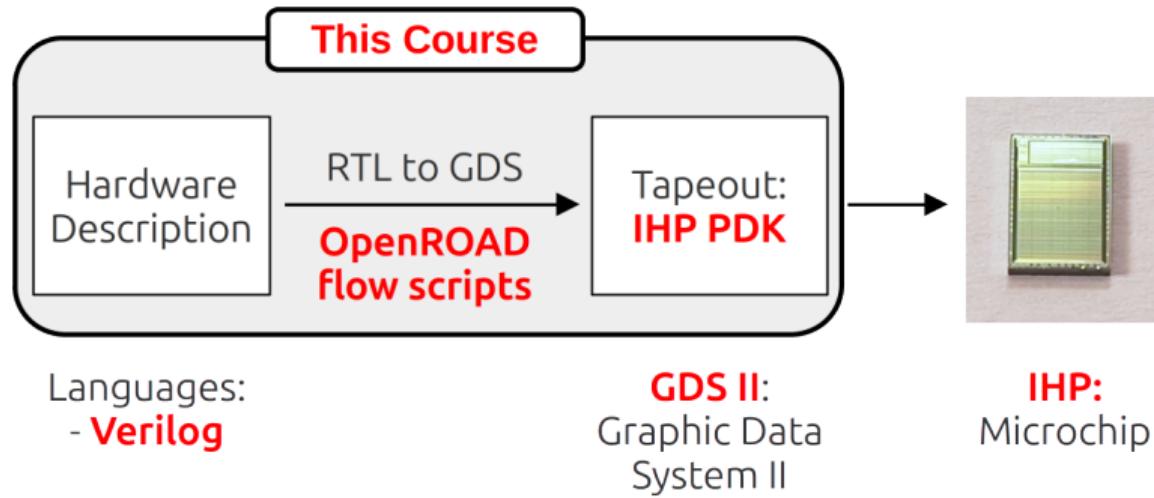
The naming of the tools is confusing:

- RTL-to-GDS
- = RTL-2-GDS
- = End-to-End-ASIC tools
- = End-to-End EDA toolchain

They all mean the same.



In this course: ORFS - OpenROAD flow scripts



Many open-Source RTL-to-GDS toolchains

Most known RTL-to-GDS toolchains:

- OpenLANE
- OpenLANE 2
- Silicon Compiler
- Coriolis

Used with IHP PDK and in this course:

- OpenROAD flow scripts

which is based on

- OpenROAD



A toolchain based on scripts and configuration files

OpenROAD flow scripts are

- based on scripts (obvious in the name)
- based on configuration files

Want most developers know from the commercial tools is:

- Graphical GUIs, used with a mouse and keyboard (shortcuts).
- Configuration through graphical masks, windows, forms.

This might feel uncomfortable at the beginning. But it still has some advantages.



Section 8

About open-source EDA



Advantages of open-source in EDA

- A word by Andrew Kahng (head of OpenROAD) about the relevance of open-source EDA

Andrews slides from the keynote speech at the Chipdesign Network June 2024. As pptx:

<https://vlsicad.ucsd.edu/NEWS24/InnovationKeynote-v6-ACTUAL-DISTRIBUTED.pptx>

Andrews news page with the link (scroll to june 2024) <https://vlsicad.ucsd.edu/>



Some aspects of open-source EDA

- Three well known PDKs are open-source and production-ready.
- Some other open-source PDKs are not that visible or prominent (MiniFab, Pragmatic(soon?), ...)
- More than one RTL-to-GDS toolchain is production tested.
- Academia starts teaching a lot with open-source EDA.
- Building microchips with open-source became easy and affordable.
- No NDAs, No licence costs, Start with a laptop and internet.



What people have done with open-source EDA

- The following slides contain some works that were made with open-source EDA tools and open-source PDKs.
- Most of this would not have been possible in closed source (because of NDAs)
- Open-source EDA drives people to experiemnt and play with the technology.





Figure 6: 3d cell parts³

³Picture by T.Knoll under Creative commons



Figure 7: 3d cell inverter⁴

⁴Picture by T.Knoll under Creative commons



Figure 8: 3d cell AND4_1⁵

⁵Picture by T.Knoll under Creative commons

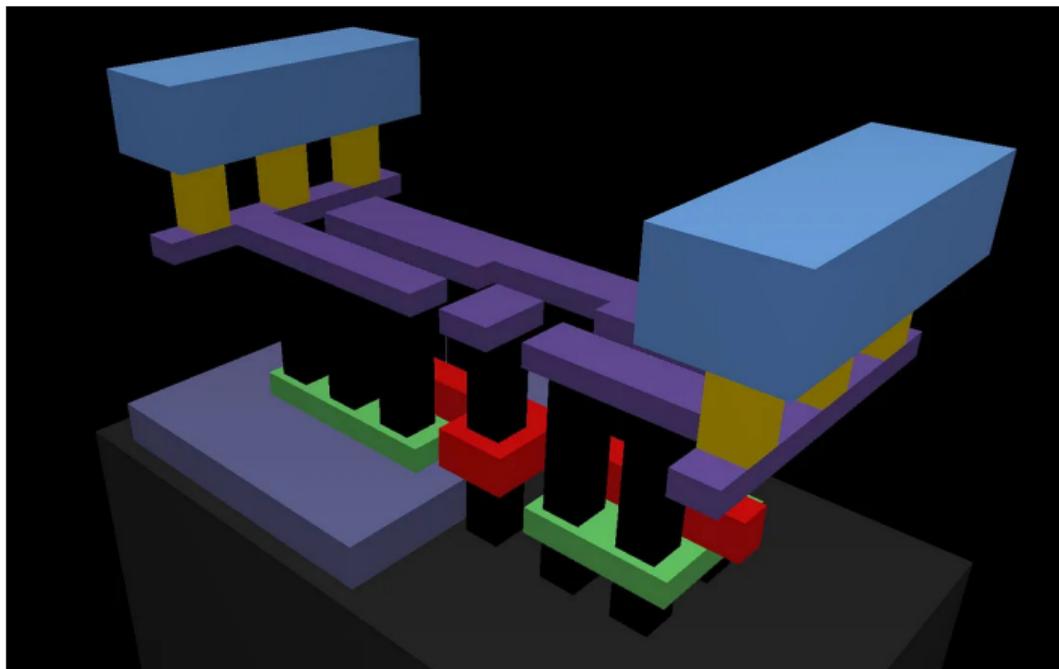


Figure 9: inverter⁶

⁶Picture by T.Knoll under Creative commons

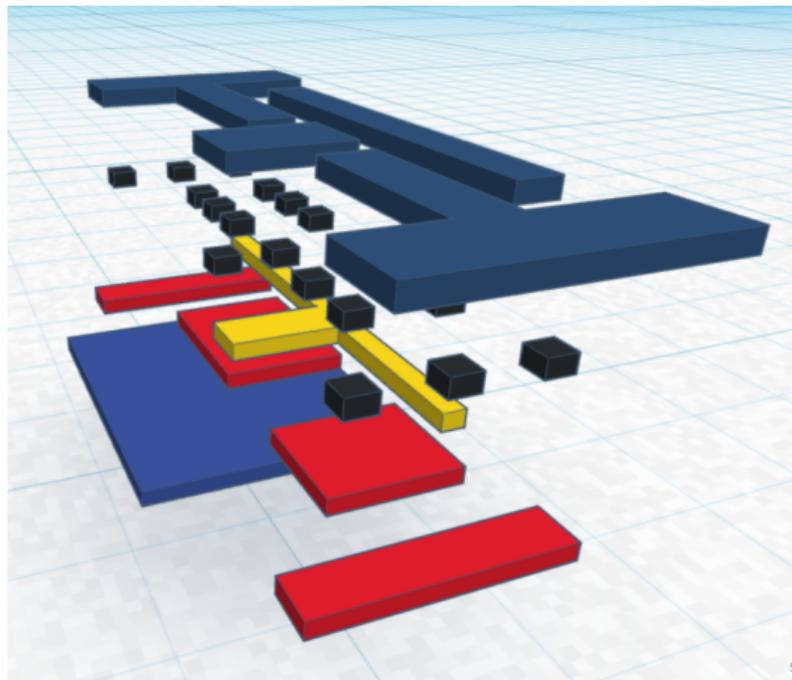


Figure 10: inverter⁷

⁷Picture by T.Knoll under Creative commons

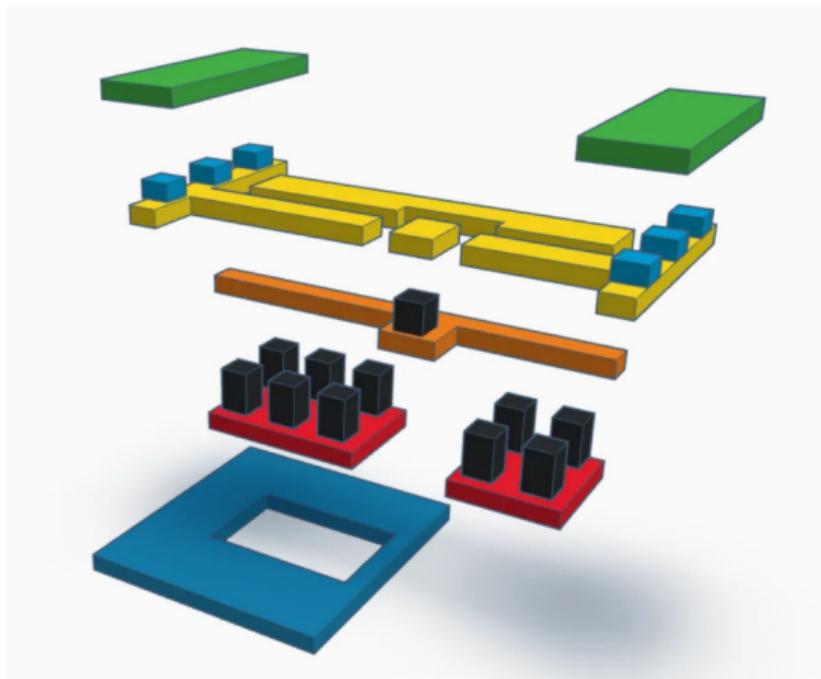


Figure 11: inverter⁸

⁸Picture by T.Knoll under Creative commons

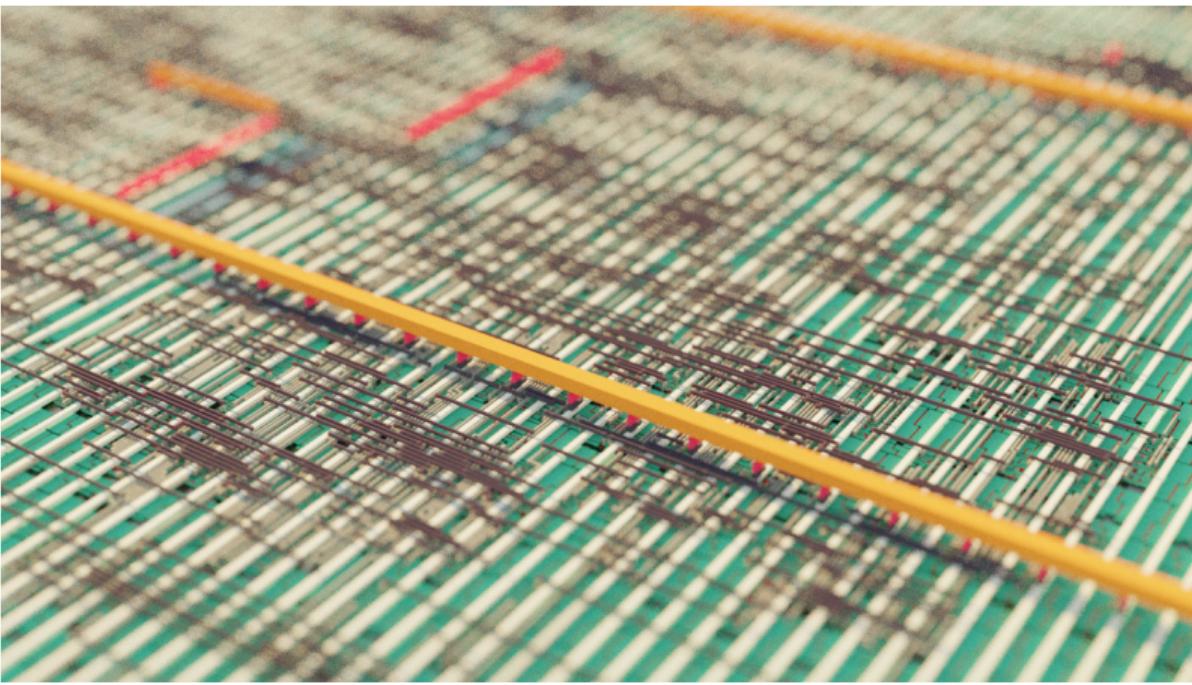


Figure 12: Maximo Borga Rendering 1⁹

⁹Picture by Maximo B. under Creative commons

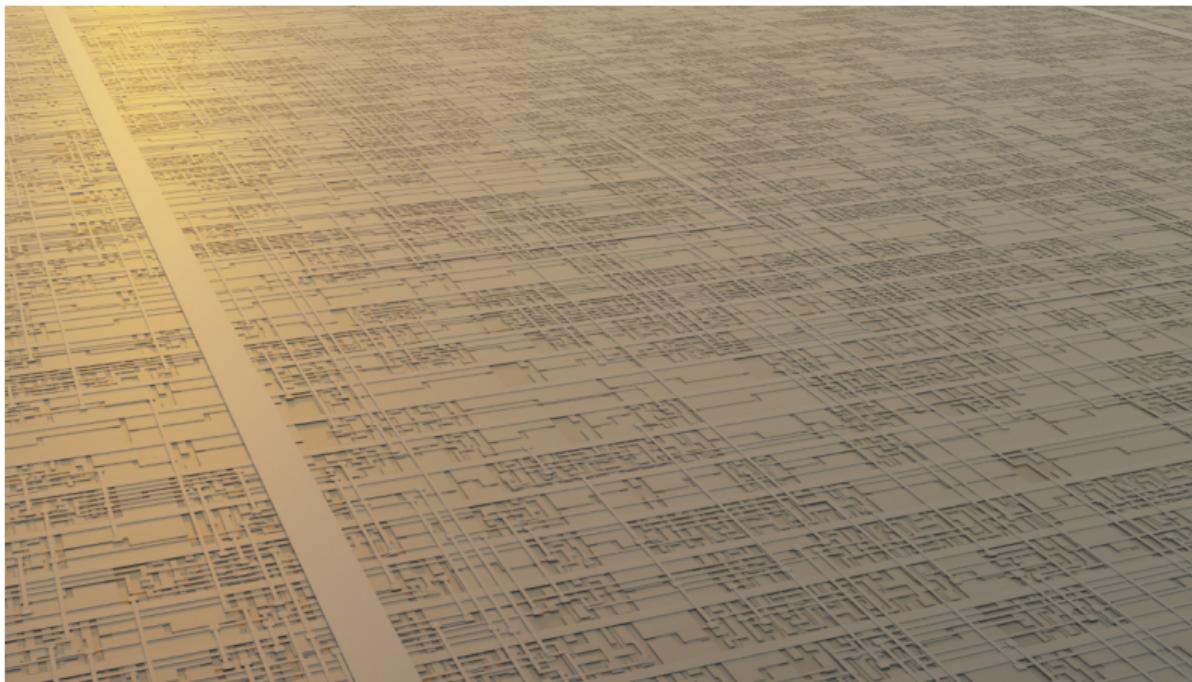


Figure 13: Maximo Borga Rendering 2¹⁰

¹⁰Picture by Maximo B. under Creative commons

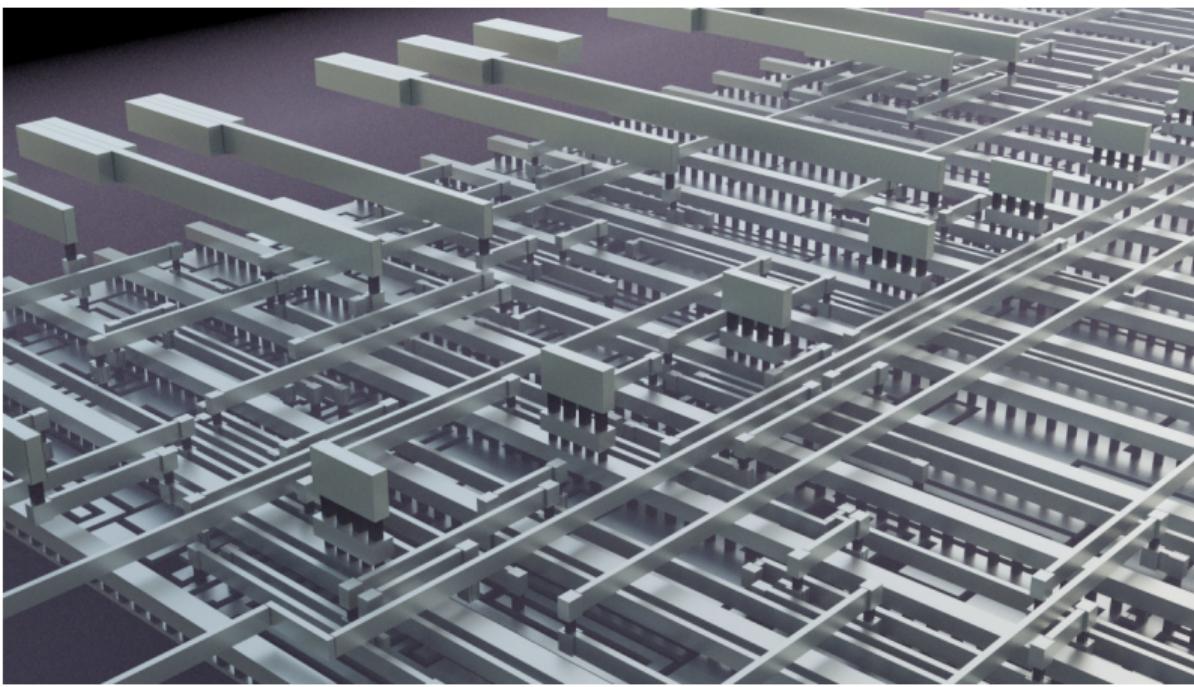


Figure 14: Maximo Borga Rendering 3¹¹

¹¹Picture by Maximo B. under Creative commons

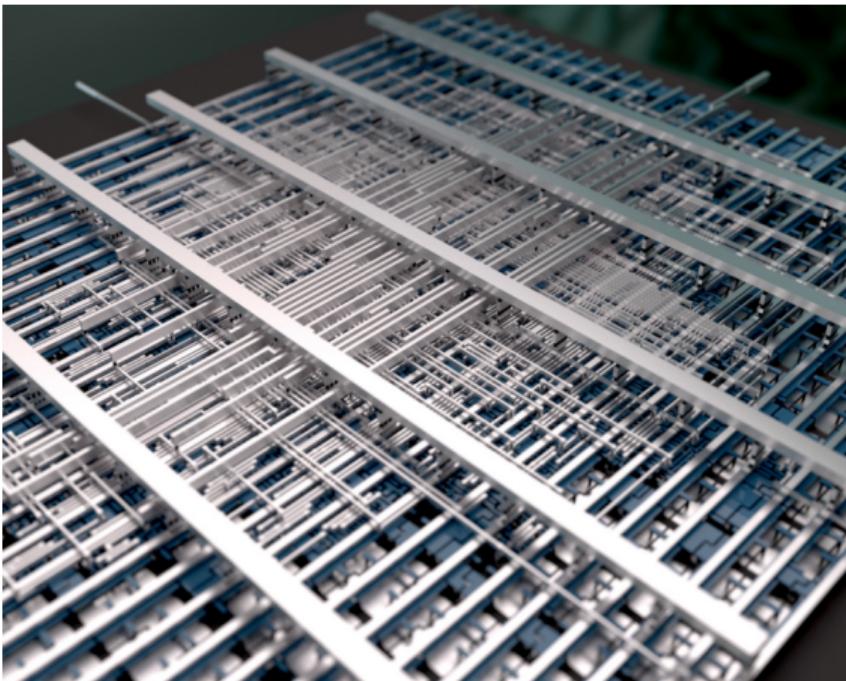


Figure 15: Maximo Borga Rendering 4¹²

¹²Picture by Maximo B. under Creative commons

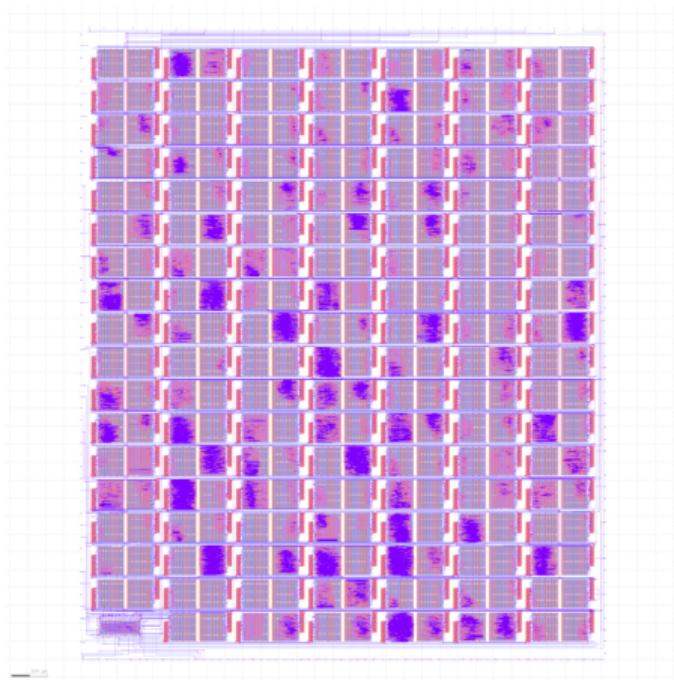


Figure 16: Tinytapeout GDS¹³

¹³Picture by T.Knoll under Creative commons



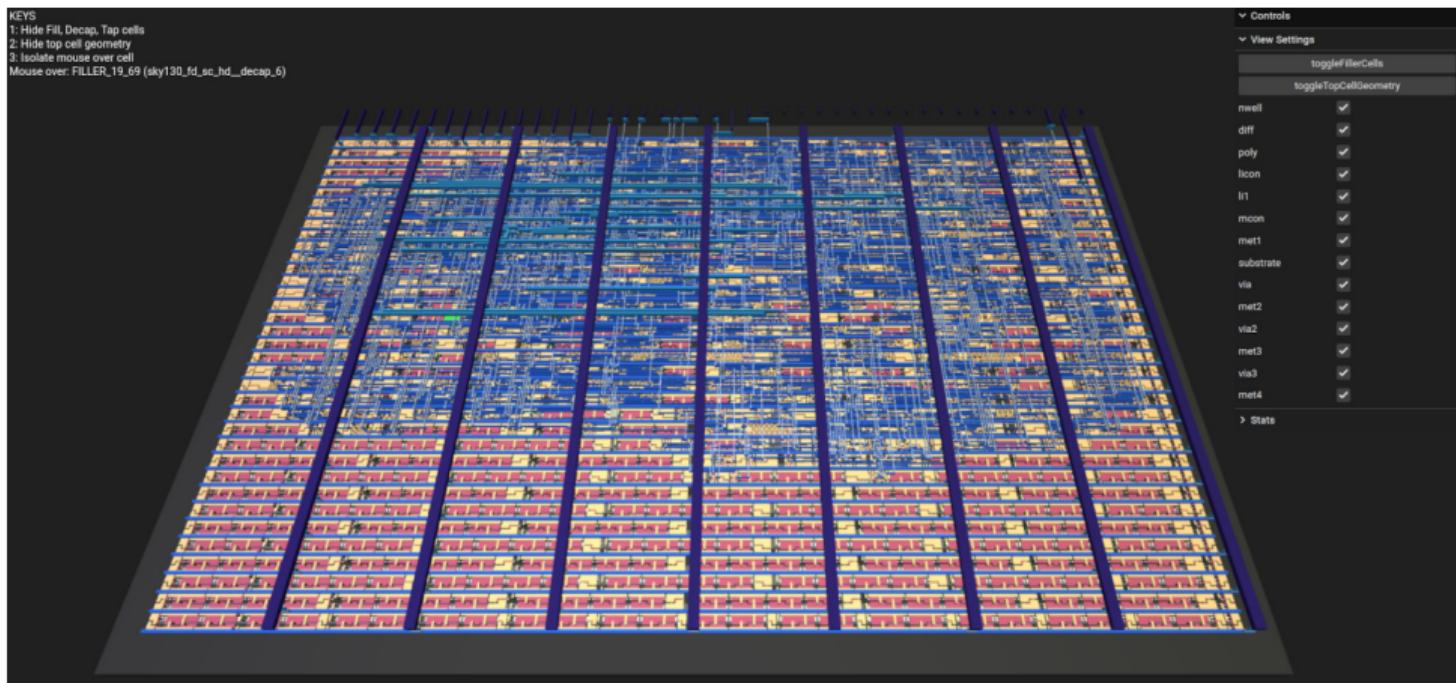


Figure 17: Webviewer Tinytapeout zoomed out¹⁴

¹⁴Picture by T.Knoll under Creative commons



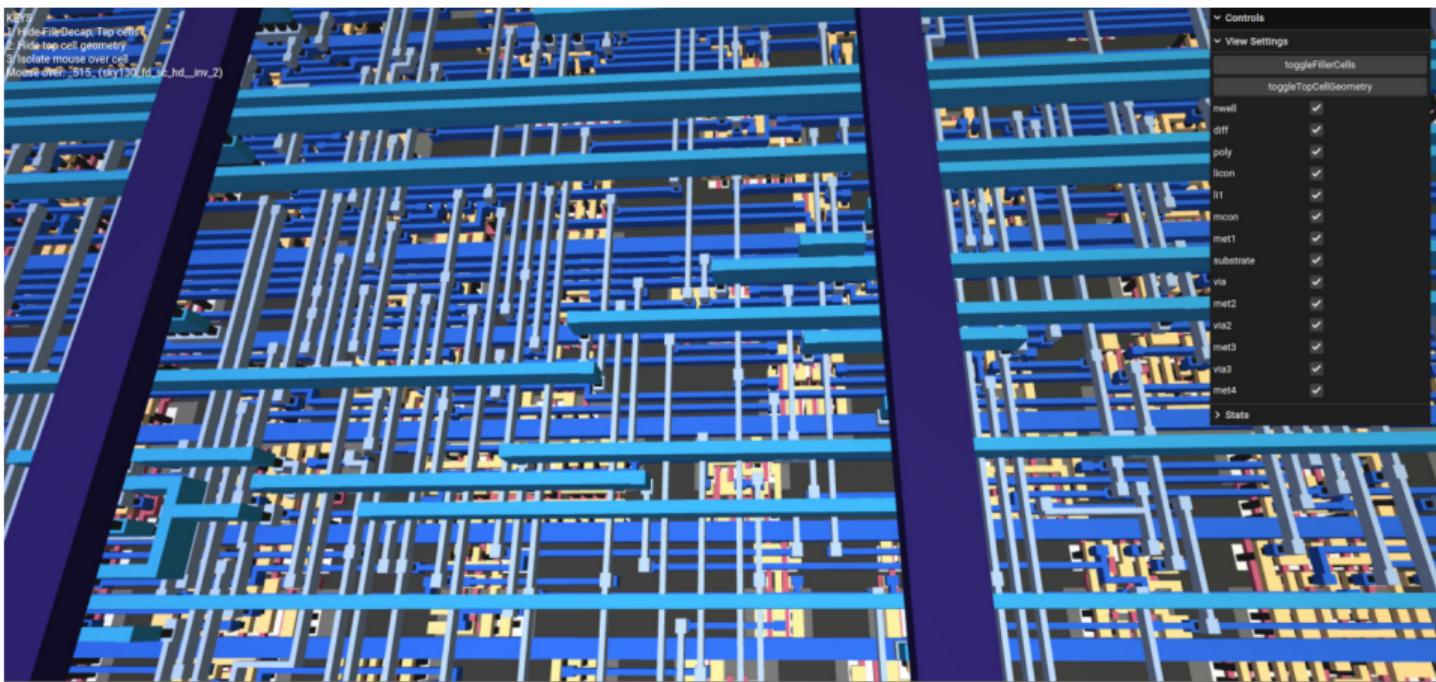


Figure 18: Webviewer Tinytapeout zoomed in¹⁵

¹⁵Picture by T.Knoll under Creative commons



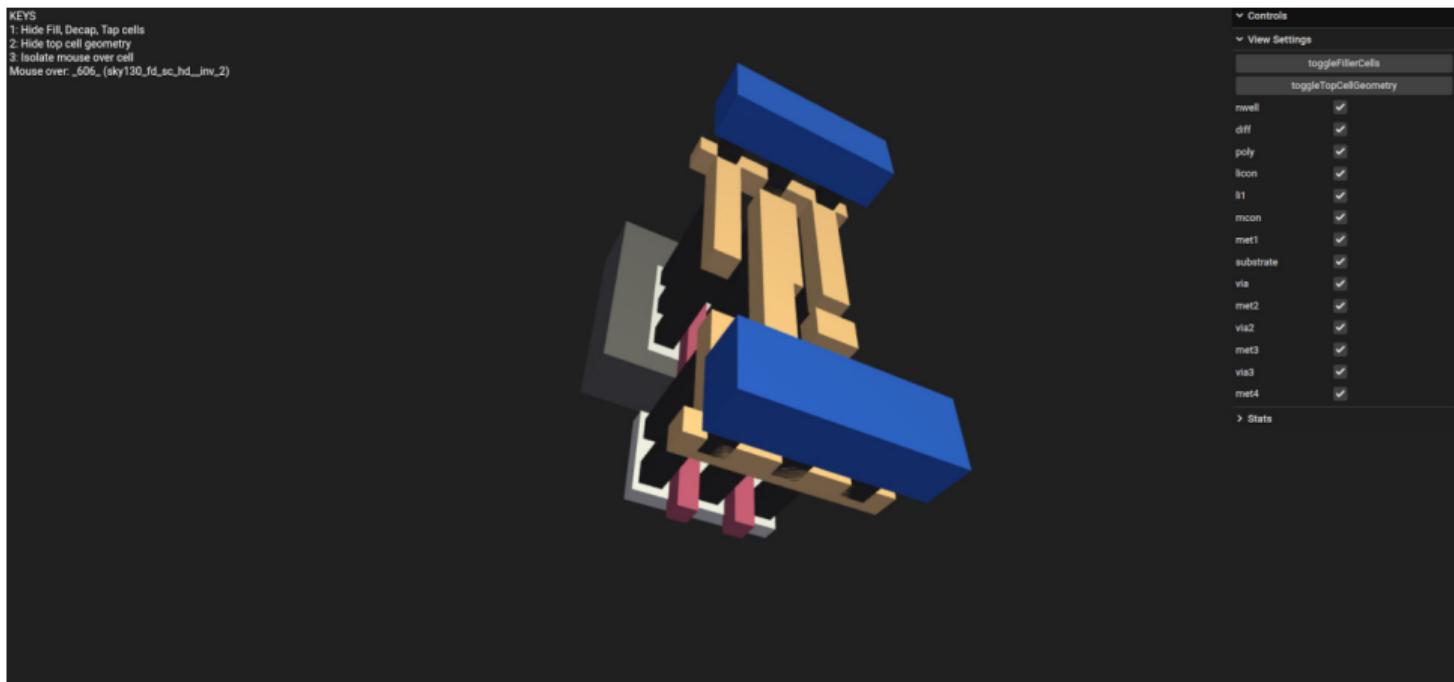


Figure 19: Webviewer Tinytapeout single cell¹⁶

¹⁶Picture by T.Knoll under Creative commons



Webviewer of Tinytapout designs with the IHP PDK

See a TinyTapeout design (GVA clock by Matt Venn) in a 3D viewer:

https://tinytapeout.com/runs/ttihp0p2/tt_um_vga_clock

It is made with the IHP open-source PDK.



Siliwiz - How do semiconductors work?

Play with Siliwiz or take the lessons:

https://tinytapeout.com/runs/ttihp0p2/tt_um_vga_clock



A few words about open-source in general

Wikipedia: Open-source

https://en.wikipedia.org/wiki/Open_source

Wikipedia: Open-source software

https://en.wikipedia.org/wiki/Open-source_software

Wikipedia: Open-source hardware

https://en.wikipedia.org/wiki/Open-source_hardware

Questions:

- Do you see the differences in the terminologies?
- Where should the article about the content of this course be in?





Chapter 1 -
Introduction
and overview -
QUESTIONS

Course authors
(Git file)

Chapter 1 - Introduction and overview - QUESTIONS

Course authors (Git file)



Chapter 1 -
Introduction
and overview -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 1



Questions

Chapter 1 -
Introduction
and overview -
QUESTIONS

Course authors
(Git file)

- What are the features of open-source software?
- RTL is an abbreviation for ... ?
- Explain RTL in your own words.
- GDS (II) is an abbreviation for ... ?
- Explaining GDS (II) in your own words.
- RTL-to-GDS (RTL2GDS) stands for? Name some bulletpoints.
- What is OpenROAD?
- How old is OpenROAD?
- Is there more OS-EDA software than OpenROAD?
- What are these? Name some?
- Since when can open-source EDA software be used to build physical microchips?

Chapter 01 - Server, Login, Shell - TRAINING - Common

Course authors (Git file)



- 1 Server and user credentials
- 2 First lookaround in Gnome
- 3 Load the course data
- 4 Linux shell



Server

- Which software to use on the Workstation
- How to connect to the server in IHP



Login

- User login on the server



Search and start a program

Tabbing between programs



Download and unpack

- Get the latest release download package:

<https://github.com/OS-EDA/Course/releases>

- Create a directory for the course.
- In Linux the home/documents is a good place to create the directory.
- Unpack the course into this directory.



Look around in the course data

The screenshot shows a GitHub repository page for the "open-source EDA course". The repository has 161 commits and 9 watching. It includes sections for About, Releases, Packages, and Languages.

About
Home of the open-source EDA course.

Releases
1 tags
Create a new release

Packages
No packages published
Publish your first package

Languages
Shell 100.0%

File/Folder	Description	Last Commit
.github/workflows	switch to pandoc:extra	3 months ago
Chapter_00_Preparations	c01 components icons	3 months ago
Chapter_01_Introduction	q8 links	3 days ago
Chapter_02_OpenROAD_tools	q8 links	3 days ago
Chapter_03_Verilog	q8 links	3 days ago
Chapter_04_OpenROAD_first_run	q8 links	3 days ago
Chapter_05_PDK	q8 links	3 days ago
Chapter_06_OpenROAD_gui	q8 training+	12 hours ago
Chapter_07_OpenROAD_flow_scripts	q8 lecture ready	12 hours ago
Chapter_08_Tapeout	q8 ready	18 hours ago
build	q8 training+	12 hours ago
icons	pandoc pic resize fixed	3 months ago
pandoc/templates	structure and content update	3 days ago
pics	structure and content update	3 days ago
LICENSE	Initial commit	last year
README.md	README slide update	1 hour ago
authors.md	structure and content update	3 days ago
generate_slides.sh	q8 lecture ready	12 hours ago

Figure 1: Course directory structure

Links from the slides

The known issue with the linux document viewer and snap browsers.

Workaround:

- Right click the link and copy
- Open browser
- Paste link to URL line



Workspace arrangement

Suggestions or Options:

- * Arrange windows next to each other
- * ALT+TAB between programs (tasks)
- * Close unwanted windows after the completion of a chapter



Short introduction to the shell

- ls
- ls -al
- cd directoryname
- cd ..
- mkdir
- touch
- mv
- cp



Online shell tutorial

To learn some Linux shell, you should find a tutorial that matches good to you.

I found this one simple and good to follow for me while learning Linux shell:

<https://community.linuxmint.com/tutorial/view/100>



Makefile

OpenROAD flow scripts use Makefiles. So you might want to learn some basics about Makefiles.
Again here is the tutorial that has helped me most:

<https://makefiletutorial.com/>



tips and tricks

- TAB for autocomplete
- 2xTAB for all choices of autocomplete
- Open a new terminal with the mouse:
- Right click on an empty space in the directory window
- Choose “open in Terminal”



Chapter 2 - OpenROAD workflow

Course authors (Git file)



1 History of OpenROAD

2 OpenROAD Flow Scripts



Section 1

History of OpenROAD



Foundations and Realization of Open, Accessible Design (OpenROAD)

At the top of the documentation:

<https://openroad-flow-scripts.readthedocs.io>

The screenshot shows the homepage of the OpenROAD Flow Scripts documentation. The left sidebar contains a navigation menu with links to "User Guide", "Build Using Pre-built Binaries", "Build Using Docker", "Build Locally", "Build Using WSL", "Environment Variables for the OpenROAD Flow Scripts", "Metrics", and "AutoTuner". Above this menu are social sharing icons for GitHub, Twitter, LinkedIn, and Stars (375). The main content area features a large title "Welcome to the OpenROAD Flow Scripts documentation!" followed by a detailed description of the project's mission and scope.

The OpenROAD ("Foundations and Realization of Open, Accessible Design") project was launched in June 2018 within the DARPA IDEA program. OpenROAD aims to bring down the barriers of cost, expertise and unpredictability that currently block designers access to hardware implementation in advanced technologies. The project team (Qualcomm, Arm and multiple universities and partners, led by UC San Diego) is developing a fully autonomous, open-source tool chain for digital SoC layout generation, focusing on the RTL-to-GDSII phase of system-on-chip design. Thus, OpenROAD holistically attacks the multiple facets of today's design cost crisis: engineering resources, design tool licenses, project schedule, and risk.

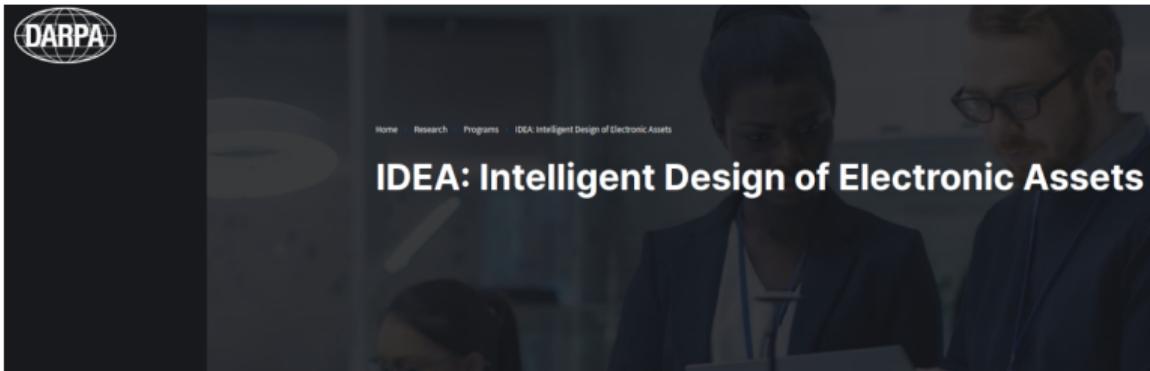
The IDEA program targets no-human-in-loop (NHIL) design, with 24-hour turnaround time and zero loss of power-performance-area (PPA) design quality.

Figure 1: Darpa IDEA¹

¹Source: Screenshot of the webpage.

Darpa IDEA

<https://www.darpa.mil/research/programs/intelligent-design-of-electronic-assets>



Program Summary

Next-generation intelligent systems supporting Department of Defense (DoD) applications like artificial intelligence, autonomous vehicles, shared spectrum communication, electronic warfare, and radar require processing efficiency that is orders of magnitude beyond what is available through current commercial electronics. Reaching the performance levels required by these DoD

Figure 2: Darpa IDEA ²

²Source: Screenshot of the webpage.

Darpa ERI

2018/2019 Darpa ERI, cadence and the people

<https://community.cadence.com/tags/openroad>

Start reading from the bottom!

ERI: OpenROAD

 Paul McLellan

If I had to summarize DARPA's Electronic Resurgence Initiative in one phrase, it would be "getting the cost of design down." As I've said several times this week, the US Department of Defense (DoD) does not have high volumes and so the cost of a part...

over 6 years ago

Cadence Blogs

Breakfast Bytes

The DARPA Electronic Resurgence Initiative (ERI)

 Paul McLellan

Many weeks ago DARPA organized a summit at the Palace of Fine Arts in San Francisco. The first day consisted of a workshop and some other presentations, including one by Cadence's Tom Beckley. Since Tom's presentation was very similar to what he presented...

over 6 years ago

Cadence Blogs

Breakfast Bytes



Figure 3: Darpa ERI ³

OpenROAD V1.0

Document with OpenROAD V1.0 Expectations:

<https://vlsicad.ucsd.edu/NEWS19/OpenROAD%20RTL-to-GDS%20v1.0%20Expectations.pdf>

OpenROAD v1.0 Expectations

Andrew B. Kahng and Tom Spyrou
The OpenROAD Project

November 22, 2019

Web: <https://theopenroadproject.org/>
GitHub: <https://github.com/The-OpenROAD-Project>

The OpenROAD v1.0 tool, to be released in July 2020, will be capable of push-button, DRC-clean RTL-to-GDS layout generation in a commercial FinFET process node. The tool is currently visible [here](#). In its v1.0 form, it will be integrated on an incremental substrate provided by [the OpenDB database](#) and [the OpenSTA static timing engine](#). It will also offer users and

Figure 4: OpenROAD v1.0⁴

V1.0 Roadmap

How to deal with these expectations:

<https://eri-summit.darpa.mil/docs/ERIsummit2019/posh/08IDEA%20UCSD%20Website.pdf>

Looking Forward (Year 2 = Phase 1B)

- V1.0 July 2020 must advance 20 years on EDA industry learning curve within next 2-3 quarters
 - 1980's file-based integration **July 2019**
 - 2000's tight integration on shared incremental substrate **July 2020**
- Next: architecture, database, build/CI/devops, CAE/PE,
 - + teaching EDA SW to the OpenROAD/FOSS community
- Professionals on the team: mandatory
 - Industry veterans who have "done this before"

Figure 5: Looking forward⁵

⁵Source: Screenshot of the webpage.

Courses for OpenROAD

A single excellent project (some of us might know):

<https://theopenroadproject.org/Courses/>

The screenshot shows the OpenROAD website with a dark blue header bar. The header contains the OpenROAD logo on the left and navigation links for HOME, ABOUT US, NEWS, RESOURCES, BLOGS, COMMUNITY, USER STORIES, and CONTACT US on the right. Below the header, the word "Courses" is centered above a table. The table has two columns: "Title" and "File/Link". A single row is visible, showing "ZeroToASIC by Matt Venn" in the Title column and a blue link "https://zerotoasiccourse.com/matt_venn/" in the File/Link column.

Title	File/Link
ZeroToASIC by Matt Venn	https://zerotoasiccourse.com/matt_venn/

Figure 6: Courses ⁶

⁶Source: Screenshot of the webpage.

Help is on the way

Kudos to this course:

<https://theopenroadproject.org/news/6455/>

The screenshot shows the OpenROAD website's homepage. At the top is a dark blue header bar with the "OpenROAD" logo in white. Below the header is a white main content area. In the center of the content area is a large, bold, dark blue banner containing the text: "Kudos to Christian Wittke (IHP) and Thorsten Knoll (HSRM) on their development of a Digital EDA Course using IHP-SG13G2 and OpenROAD!". Below this banner, there is a smaller text link: "See the video of Christian's ORConf 2024 talk at https://www.youtube.com/watch?v=Ozd_yXoExLo!"

Figure 7: This course⁷

⁷Source: Screenshot of the webpage.



Section 2

OpenROAD Flow Scripts



Flow steps

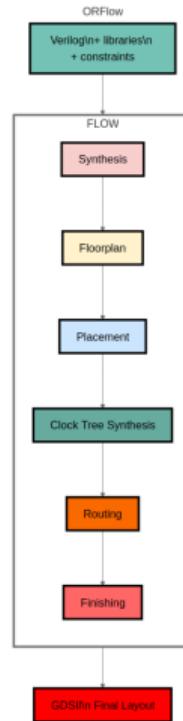


Figure 8: OpenROAD flow steps⁸

Flow components

RTL-GDSII Using OpenROAD-flow-scripts

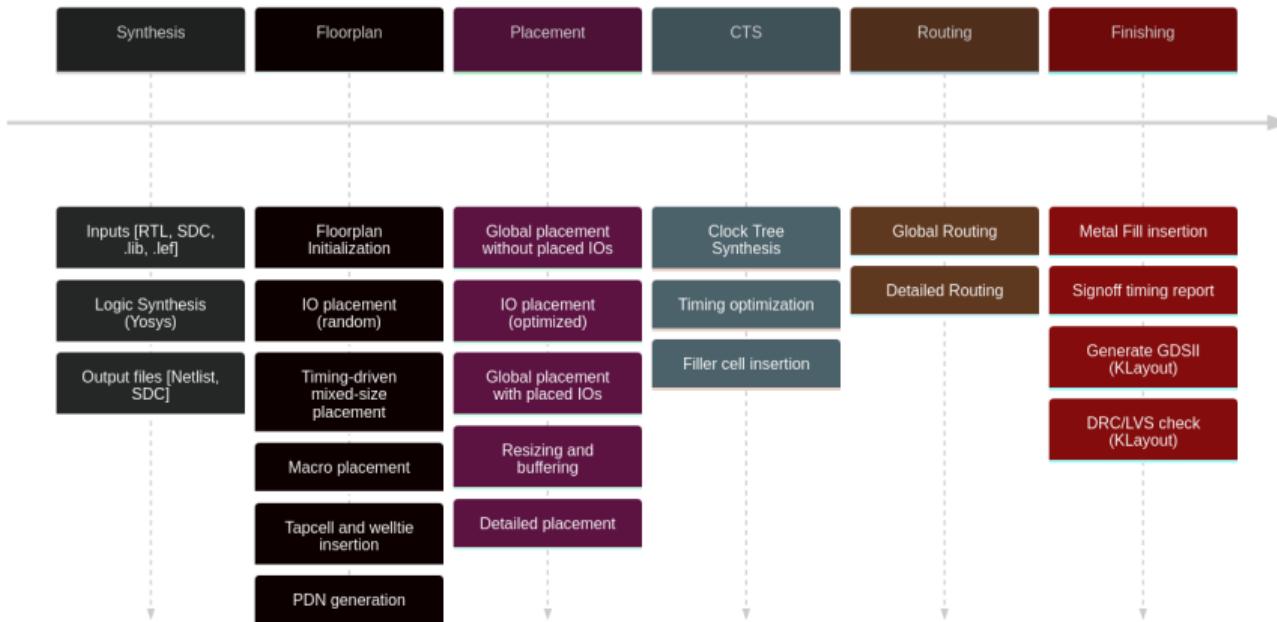


Figure 9: OpenROAD flow components⁹

Help with the terminology

Searching the terms with a standard search engine might not bring useful results. Matt Venn created a page for EDA terminology:

<https://www.zerotoasiccourse.com/terminology/>



The screenshot shows the homepage of the website. At the top right, there is a navigation bar with links: Articles, About Matt Venn, Interviews, Newsletter, Resources, Terminology (which is highlighted in blue), and Videos. Below the navigation bar, the main content area has a dark background with a collage of images related to semiconductor manufacturing. A central image shows a close-up of a metal die. To the left of the die, the text "Terminology" is visible. Below the main image, a descriptive paragraph reads: "I've collected all the ASIC jargon here and broken it down into easy to understand descriptions." The page is organized into a grid of boxes, each containing a term and its definition. The terms listed are: Antenna Report, ASIC, CMOS, Corner, Die, Doping, DRC, Floorplan, Foundry, FPGA, GDSII, Harden, and OpenROAD.

Antenna Report	ASIC	CMOS
Corner	Die	Doping
DRC	Floorplan	Foundry
FPGA	GDSII	Harden



Resources list

Awesome open-source ASIC resources:

<https://github.com/mattvenn/awesome-opensource-asic-resources>

Zero-to-ASIC resources list:

<https://www.zerotoasiccourse.com/resources/>

AIC 2025 lectures by Carsten Wullf:

<https://github.com/wulffern/aic2025>

<https://analogicus.com/aic2025/>





Chapter 2 - OpenROAD workflow - QUESTIONS

Course authors
(Git file)

Chapter 2 - OpenROAD workflow - QUESTIONS

Course authors (Git file)



Chapter 2 -
OpenROAD
workflow -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 2



Questions

Chapter 2 -
OpenROAD
workflow -
QUESTIONS

Course authors
(Git file)

- Name some of the internet resources linked in chapter 2.
- Where are the origins of OpenROAD?
- Is OpenROAD a fully from-the-scratch written toolchain?
- Can you name some of the included (used) software projects?
- How many contributors has
 - OpenROAD (OR)?
 - OpenROAD flow scripts (ORFS)?
- How many close (open) issues (pull requests) has ORFS?
- Name the flow steps in ORFS (in a relay race in the room)
- Name the flow components in ORFS (in a relay race in the room)
 - (Bonus) Can you describe what the component does?

Chapter 02 - Terminology - TRAINING - Common

Course authors (Git file)



1

Searching

Browse the resources

- Search all the flow steps in the resources
- Search all the flow components in the resources
- Try to formulate the meaning and purpose of them in your own words.



Discuss the EDA terminology

- Discuss the terminology in the room, supervised by the tutor.



What is missing?

- Did you find resources that should be added?



Chapter 3 - Verilog crash course

Course authors (Git file)



- 1 Introduction
- 2 Verilog elements
- 3 Simple circuits: Combinational
- 4 Simple circuits: Sequential
- 5 Selected feature: Parameterized counter
- 6 Selected feature: Preprocessor
- 7 Selected feature: Yosys and Systemverilog



Section 1

Introduction



Introduction

Verilog was initially developed as a simulation language in 1983/1984, bought up by Cadence and freely released in 1990.

The first standardization took place in 1995 by the IEEE (Verilog 95). A newer version is IEEE Standard 1364-2001 (Verilog 2001).

- Syntax comparable to C (VHDL was started on ADA / Pascal) with compact code
- Spread in North America and Japan (less in Europe)
- Can also be used as the language for netlists
- Support from open source tools
- The majority of the ASICs are developed in Verilog.
- Less expressive than VHDL (curse and blessing)



The proximity to C and Java may lead to confusion. In Verilog, too, lines that describe a combinatorial circuit can also be replaced.

**** Verilog is a hardware description language (HDL)****

This crash course is limited to a subset of synthesizable language constructs in Verilog.

The aim of this selection is not commercial tools, but open-source development tools such as OpenRoad¹ or Toolchains for FPGAs, i.e. we also use some language constructs from Systemverilog, which are supported by the Yosys synthesis tool.

¹<https://theopenroadproject.org/>



Literature

- Donald E. Thomas, Philip R. Moorby, *The Verilog Hardware Description Language*, Kluwer Academic Publishers, 2002, ISBN 978-1475775891
- Blaine Readler, *Verilog by example*, Full Arc Press, 2011, ISBN 978-0983497301



Contributions, mentions and license

- This course is a translated, modified and ‘markdownized’ version of a Verilog crash course from Steffen Reith, original in german language.

<https://github.com/SteffenReith>

- The initial rework (translate, modify and markdownize) was done by:

<https://github.com/ThorKn>

- The build of the PDF slides is done with pandoc:

<https://pandoc.org/>

- Pandoc is wrapped within this project:

<https://github.com/alexeygumirov/pandoc-beamer-how-to>

- License:

GPLv3



Synthesis tool: Yosys

One should also deal with the peculiarities of the synthesis tool. The well-known open source synthesis tool Yosys writes about this

Yosys is a framework for Verilog RTL synthesis. It currently has extensive Verilog-2005 support and provides a basic set of synthesis algorithms for various application domains. Selected features and typical applications:

- Process almost any synthesizable Verilog-2005 design
- Converting Verilog to BLIF / EDIF / BTOR / SMT-LIB / simple RTL Verilog / etc.
- ...



Section 2

Verilog elements



Structure of a verilog module

```
1  module module_name (port_list);
2  // Definition of the interface
3  Port declaration
4  Parameter declaration
5
6  // Description of the circuit
7  Variables declaration
8  Assignments
9  Module instantiations
10
11 always-blocks
12
13 endmodule
```

Port list and port declaration can be brought together in modern verilog.

// introduces a comment.



Example: A linear shiftregister

```

1 module LSFR (
2   input wire load,
3   input wire loadIt,
4   input wire enable,
5   output wire newBit,
6   input wire clk,
7   input wire reset);
8
9   wire      [17:0]  fsRegN;
10  reg       [17:0]  fsReg;
11  wire      taps_0, taps_1;
12  reg       genBit;
13
14
15  assign taps_0 = fsReg[0];
16  assign taps_1 = fsReg[11];
17
18  always @(*) begin
19    genBit = (taps_0 ^ taps_1);
20    if(loadIt) begin
21      genBit = load;
22    end
23  end

```

```

1   assign newBit = fsReg[0];
2   assign fsRegN = {genBit,fsReg[17 : 1]};
3
4   always @(posedge clk) begin
5     if(reset) begin
6       fsReg <= 18'h0;
7     end else begin
8       if(enable) begin
9         fsReg <= fsRegN;
10      end
11    end
12  end
13
14 endmodule

```

input and **output** define the directions of the ports.



Constants and Operators

There are four values available for constants and signals:

- 0 / 1
- X or x (unknown)
- Z or Z (high impedance)

One can specify the width of constants:

- Hexadecimal constant with 32 bit: 32'hDEADBEEF
- Binary constant with 4 bit: 4'b1011
- For better readability you can also use underscores: 12'B1010_1111_0001

To specify the number base use

- b (binary)
- h (hexadecimal),
- o (octal)
- d (decimal)

The default is decimal (d) and the bit width is optional, i.e. 4711 is a valid (decimal) constant.



There is an array notation:

- wire [7:0] serDat;
- reg [0:32] shiftReg;
- Arrays can be sliced to Bits:
 - serDat[3 : 0] (low-nibble)
 - serDat[7] (MSB).
- {serDat[7:6], serDat[1:0]} notes the concatenation.
- Bits can be replicated and converted into an array, i.e $\{8\{\text{serData}[7 : 4]\}\}$ contains eight copies of the high-nibble from serDat and has a width of 32.

Arithmetic operations, relations, equivalences and negation:

- $a + b$, $a - b$, $a * b$, a / b und $a \% b$
- $a > b$, $a \leq b$, und $a \geq b$
- $a == b$ und $a != b$,
- $!(a = b)$



** Attention: ** If x or z do occur, the simulator determines false in a comparison. If you want to avoid this, the operators === and !== exist. So the following applies:

```
1 if (4'b110z === 4'b110z)  
2 // not taken  
3 then_statement;
```

```
1 if (4'b110z == 4'b110z)  
2 // not taken  
3 then_statement;
```

Boolean operations exist as usual:

bitwise operators: & (AND), | (OR), ~ (NOT), ^ (XOR) und auch ~^ (XNOR)

logic operators: && (AND), || (OR) und ! (NOT)

Shiftoperations: a « b (shift a for b positions to the left) und a » b (shift a for b positions to the right). A negative number b is not permitted, empty spots are filled with 0.



Parameters (old style)

In order to be able to adapt designs easier, Verilog offers the use of parameters.

```
1 module mux (
2     in1 , in2 ,
3     sel ,
4     out);
5
6     parameter WIDTH = 8; // Number of bits
7
8     input [WIDTH - 1 : 0] in1 , in2 ;
9     input sel;
10    output [WIDTH - 1 : 0] out;
11
12    assign out = sel ? in1 : in2;
13
14 endmodule
```



Instances and structural descriptions

If you describe a circuit through its (internal) structure or if a partial circuit is to be reused, an instance is generated and wired.

```
1 module xor2 (
2   input wire a,
3   input wire b,
4   output wire e);
5   assign e = a ^ b;
6 endmodule
```

```
1 module xor3 (
2   input wire a,
3   input wire b,
4   input wire c,
5   output wire e);
6
7   wire tmp;
8   xor2 xor2_1 // Instance 1
9   (
10     .a(a),
11     .b(b),
12     .e(tmp)
13   );
14   xor2 xor2_2 // Instance 2
15   (
16     .a(c),
17     .b(tmp),
18     .e(e)
19   );
20
21 endmodule
```



Code for sequential circuits

A flip-flop takes over the input of the rising or falling edges of the clock. For this, the block entry is used with the *@-symbol* and *always* blocks:

```
1 module FF (input  clk ,
2             input  rst ,
3             input  d,
4             output q);
5
6   reg q;
7
8   always @ ( posedge clk or
9             posedge reset)
10  begin
11    if ( rst )
12      q <= 1'b0;
13    else
14      q <= d;
15  end
endmodule
```

The list of signals after the *@-symbol* means sensitivity list. The reset is synchronized when you remove or *posedge reset*.



Section 3

Simple circuits: Combinational



Combinational circuits correspond to pure boolean functions and therefore do not contain the key word *reg*. No memory (flip-flops) gets generated and assignments are done with *assign*.

```
1 module mux4to1 (in1, in2, in3, in4, sel, out);
2
3 parameter WIDTH = 8;
4
5 input [WIDTH - 1 : 0] in1, in2, in3, in4;
6 input [1:0] sel;
7 output [WIDTH - 1 : 0] out;
8
9 assign out = (sel == 2'b00) ? in1 :
10      (sel == 2'b01) ? in2 :
11      (sel == 2'b10) ? in3 :
12      in4;
13 endmodule
```



Priority encoder

Similarly to the VHDL version, we describe the priority encoder as follows:

```
1 module prienc (input wire [4 : 1] req,
2                 output wire [2 : 0] idx);
3
4     assign idx = (req[4] == 1'b1) ? 3'b100 :
5                 (req[3] == 1'b1) ? 3'b011 :
6                 (req[2] == 1'b1) ? 3'b010 :
7                 (req[1] == 1'b1) ? 3'b001 :
8                 3'b000;
9
10    endmodule
```



Priority encoder (alternative version)

For a priority encoder you can use the *don't care* feature from Verilog.

```
1 module prienc (input [4:1] req,
2                 output reg [2:0] idx);
3
4     always @(*) begin
5         casez (req) // casez allows don't-care
6             4'b1????: idx = 3'b100; // Also: idx = 4;
7             4'b01???: idx = 3'b011;
8             4'b001?: idx = 3'b010;
9             4'b0001: idx = 3'b001;
10            default: idx = 3'b000;
11        endcase
12    end
13
14 endmodule
```



Section 4

Simple circuits: Sequential



Synchronous design

Contrary to combinational circuits, sequential circuits use internal memory, i.e. the output not only depends on the input.

In the synchronous method, all memory elements are checked / synchronized by a global clock. All calculations are carried out on the rising (and/or) falling edge of the clock.

The synchronous design enables the draft, test and the synthesis of large circuits with market tools. For this reason, it is advisable to remember this design principle.

Furthermore, there should be no (combinational) logic in the clock path, as this can lead to problems with the distribution times of the clock signals.



Synchronous circuits

The structure of synchronous circuits is idealized as follows:

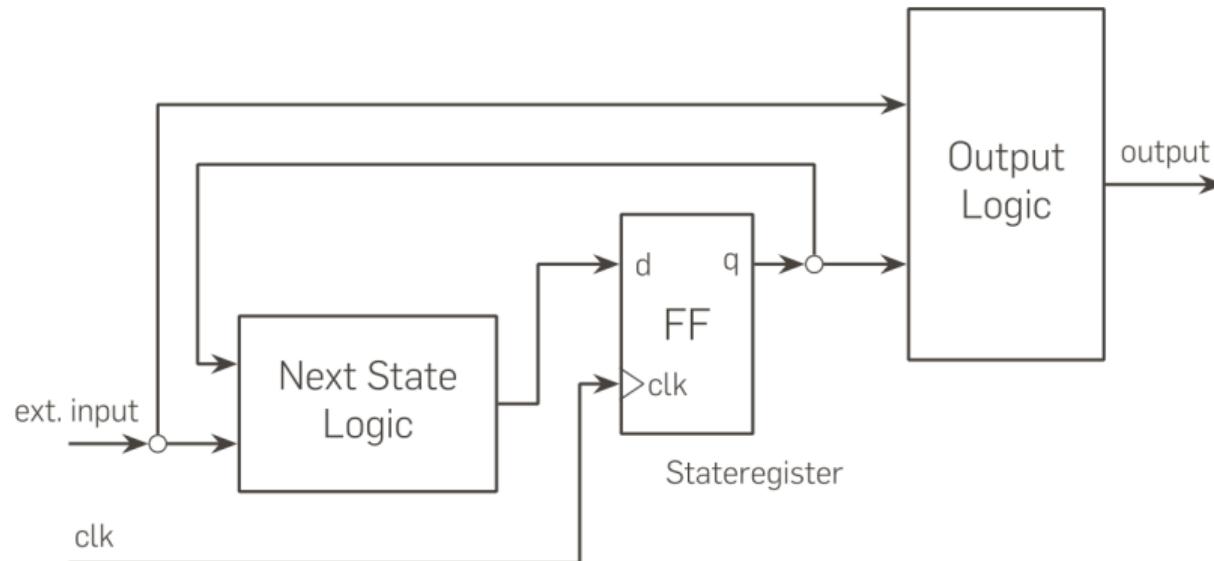


Figure 1: Idealized diagram of a synchronous circuit



A binary counter

According to the synchronous design, a free running binary counter can be realized:

```
1 module freecnt (value , clk , reset);
2
3     parameter WIDTH = 8;
4
5     input  wire  clk;
6     input  wire  reset;
7     output wire [WIDTH - 1 : 0] value;
8
9     wire [WIDTH - 1 : 0] valN;
10    reg   [WIDTH - 1 : 0] val;
11
12    always @ (posedge clk) begin
13
14        if (reset) begin // Synchron reset
15            val <= {WIDTH{1'b0}};
16        end else begin
17            val <= valN;
18        end
19
20    end
21
22    assign valN = val + 1; // Nextstate logic
23    assign value = val; // Output logic
24 endmodule
```



Synthesis result of the binary counter

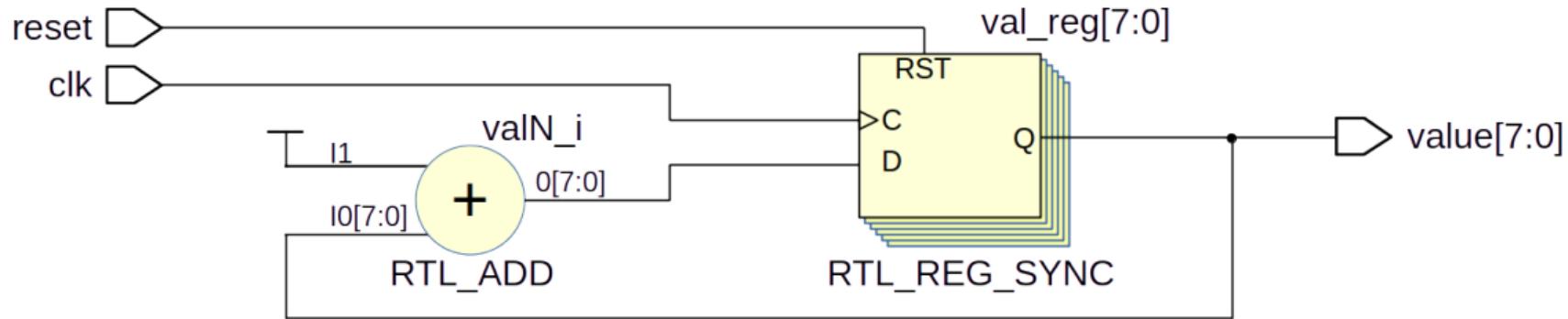


Figure 2: Synthesis diagram of the binary counter

At this point you can see that the result follows the diagram of the synchronous design.

RTL_REG_SYNC corresponds to the stateregister and *RTL_ADD* corresponds to the next state logic.



Some remarks

So far we use three assignment operators:

- assign signal0 = value
- signal2 <= value
- signal1 = value

The *assign* instruction is known as the continuous assignment and corresponds (roughly) to an ever active wire connection. It is used for signals of the type *wire* and is not permitted for *reg* (register).

The operator *<=* means non-blocking assignment. This assignment is used for synthesized registers, i.e. in *always-blocks* with *posedge clk* in the sensitivity list.

The variant *=* is called blocking assignment and is used for combinational *always-blocks*. Attention: Not allowed for signals of the type *wire*. So use the type *reg*.



A modulo counter

According to the synchronous design, a freely running modulo counter can be realized:

```

1 module modcnt (value , clk , reset , sync);
2
3   parameter WIDTH  = 10,
4           MODULO = 800,
5           hsMin  = 656,
6           hsMax  = 751;
7
8   input  wire  clk;
9   input  wire  reset;
10  output wire [WIDTH - 1 : 0] value;
11  output wire sync;
12
13  wire [WIDTH - 1 : 0] valN;
14  reg   [WIDTH - 1 : 0] val;
```

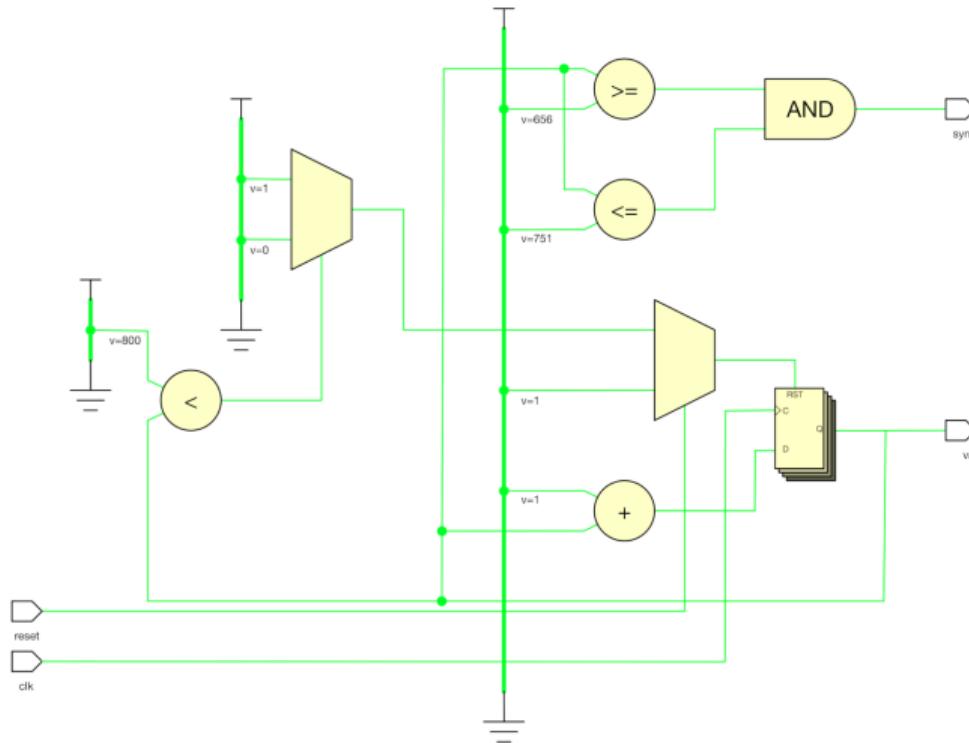
```

1   always @ (posedge clk) begin
2
3     if (reset) begin // Synchron reset
4       val <= {WIDTH{1'b0}};
5     end else begin
6       val <= valN;
7     end
8
9   end
10
11  // Nextstate logic
12  assign valN = (val < MODULO) ? val + 1 : 0;
13
14  // Output logic
15  assign value = val;
16  assign sync = ((val >= hsMin) && (val <= hsMax)) ? 1 : 0;
17
18 endmodule
```



Synthesis result of the modulo counter

In this case, next state logic and output logic are of course more complex:



A register file

RISC-V processors have a register file with a special zero register. Reading always provides 0 and writing operations are ignored.

```
1 module regfile (input clk,
2                  input [4:0] writeAddr, input [31 : 0] dataIn,
3                  input wrEn,
4                  input [4:0] readAddrA, output reg [31:0] dataOutA,
5                  input [4:0] readAddrB, output reg [31:0] dataOutB);
6
7 reg [31 : 0] memory [1 : 31];
8
9 always @ (posedge clk) begin
10
11   if ((wrEn) && (writeAddr != 0)) begin
12
13     memory[writeAddr] <= dataIn;
14
15   end
16
17   dataOutA <= (readAddrA == 0) ? 0 : memory[readAddrA];
18   dataOutB <= (readAddrB == 0) ? 0 : memory[readAddrB];
19
20 end
21
22 endmodule
```



Section 5

Selected feature: Parameterized counter



Selected feature: Parameterized counter

The newer variants of Verilog offer an improved version of the parameter feature:

```

1 module cnt
2 #(parameter N = 8,
3   parameter DOWN = 0)
4
5   (input clk,
6    input resetN,
7    input enable,
8    output reg [N-1:0] out);
9
10  always @ (posedge clk) begin
11
12    if (!resetN) begin // Synchron
13      out <= 0;
14    end else begin
15      if (enable)
16        if (DOWN)
17          out <= out - 1;
18      else
19        out <= out + 1;
20    end
21
22  end
23
24 endmodule
25
26

```

```

1 module doubleSum
2 #(parameter N = 8)
3   (input clk,
4    input resetN,
5    input enable,
6    output [N : 0] sum);
7
8   wire [N - 1 : 0] val0;
9   wire [N - 1 : 0] val1;
10
11 // Counter 0
12 cnt #(.N(N), .DOWN(0)) c0 (.clk(clk),
13 .resetN(resetN),
14 .enable(enable),
15 .out(val0));
16
17 // Counter 1
18 cnt #(.N(N), .DOWN(1)) c1 (.clk(clk),
19 .resetN(resetN),
20 .enable(enable),
21 .out(val1));
22
23 assign sum = val0 + val1;
24
25 endmodule

```

Synthesis result of the parameterized counter

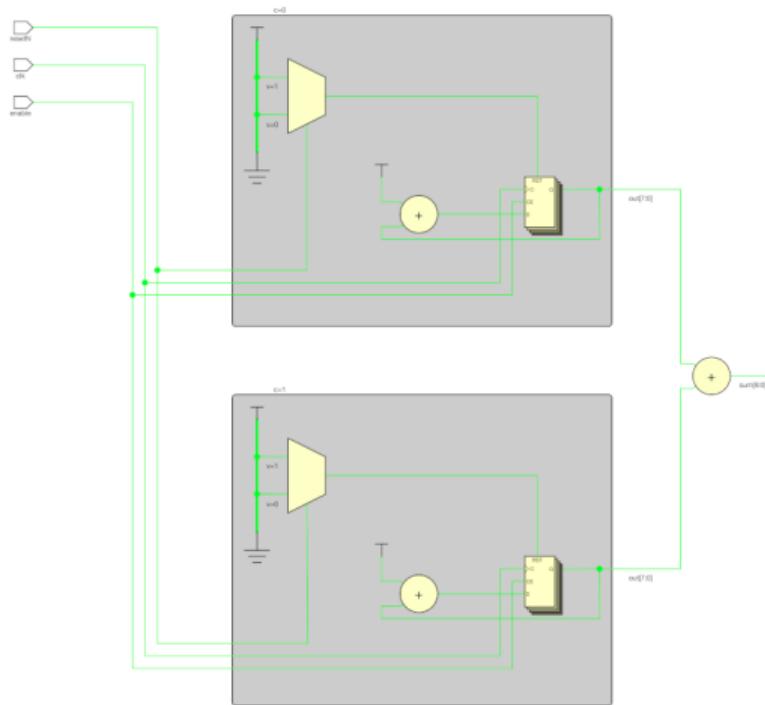


Figure 4: Parameterized counter



An alternative version

Verilog still offers a (older) possibility for the parameterization of a design:

```
1 module double
2   #(parameter N = 8)
3   (input clk,
4    input resetN,
5    input enable,
6    output [N : 0] sum);
7
8   wire [N - 1 : 0] val0;
9   wire [N - 1 : 0] val1;
10
11  // Counter 0
12  defparam c0.N = N;
13  defparam c0.DOWN = 0;
14  cnt c0 (.clk(clk),
15           .resetN(resetN),
16           .enable(enable),
17           .out(val0));
```

```
1 // Counter 1
2 defparam c1.N = N;
3 defparam c1.DOWN = 1;
4 cnt c1 (.clk(clk),
5          .resetN(resetN),
6          .enable(enable),
7          .out(val1));
8
9 assign sum = val0 + val1;
10
11 endmodule
```

This variant leads to the same synthesis result.



Section 6

Selected feature: Preprocessor



Selected feature: Preprocessor

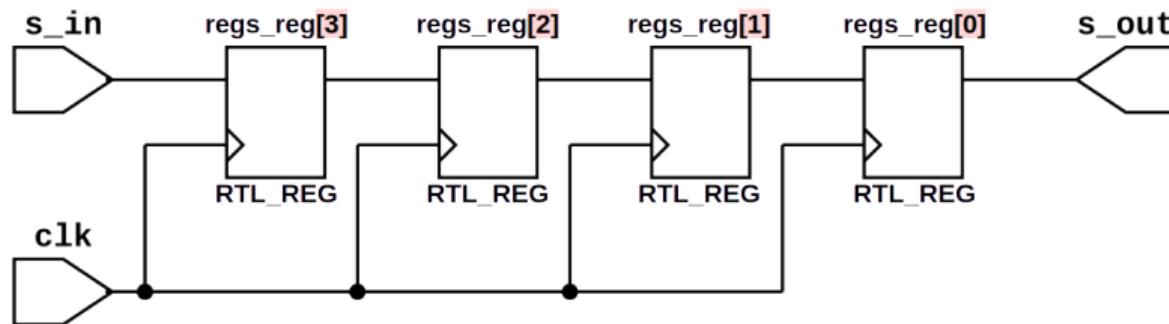
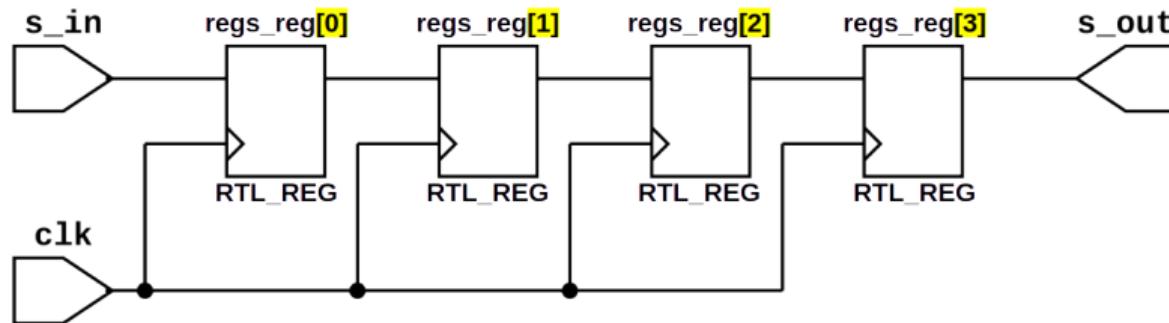
Verilog knows a preprocessor (cf. C/C++) with ‘define’, ‘include’ and ‘ifdef’. A *parameter* defines a constant and ‘define’ a text substitution.

```
1  `define SHIFT_RIGHT
2  module defineDemo (input clk, s_in,
3                      output s_out);
4
5    reg [3:0] regs;
6
7    always @ (posedge clk) begin // next state logic in always-block
8      `ifdef SHIFT_RIGHT
9        regs <= {s_in, regs[3:1]};
10       `else
11         regs <= {regs[2:0], s_in};
12       `endif
13   end
14
15  `ifdef SHIFT_RIGHT
16    assign s_out = regs[0];
17  `else
18    assign s_out = regs[3];
19  `endif
20
21 endmodule
```



Two results of the synthesis

The conditional synthesis gives you two different shift registers:



Modularisation

Comparable to the include mechanism of C/C++, Verilog offers the possibility of primitive modularization with ‘include’.

The tick symbol ‘ is again the marker for a preprocessor command, comparable to # at C/C++.

With ‘include headers_def.h, for example, configuration settings from the file headers_def.h can be included. Since a pure text replacement is carried out, the file extension is basically arbitrary. It is meaningful to use .h analogous to C.

If a ‘define is arranged in front of a ‘include, the text replacement is also carried out in the included header file, i.e. a ‘define applies globally from the definition on. However, this can happen comparable to C unintentionally.



Section 7

Selected feature: Yosys and Systemverilog



Selected feature: Yosys and Systemverilog

The open source synthesetool Yosys provides some selected extensions from SystemVerilog.

- The logic datatype is particularly interesting, which simplifies allocations with *reg* and *wire*. With *logic signed* you declare signed numbers.
- The special block *always_ff* was introduced for sequential logic. Only non-blocking assignments (\leftarrow) are used for assignments.
- For combinatorial logic, *always_comb* replaces the construct *always @()*. Only blocking assignments ($=$) are used in *always_comb* blocks.



Another counter

Now the free running counter is to be re-implemented:

```
1 module freecnt2
2
3 #(parameter WIDTH = 8)
4   (input logic clk,
5    input logic reset,
6    output logic [WIDTH - 1 : 0] value);
7
8   logic [WIDTH - 1 : 0] valN;
9   logic [WIDTH - 1 : 0] val;
10
11  always_ff @(posedge clk) begin
12
13    if (reset) begin // Synchron reset
14      val <= {WIDTH{1'b0}};
15    end else begin
16      val <= valN;
17    end
18
19  end
20
21  always_comb begin
22
23    valN = val + 1; // Nextstate logic
24    value = val; // Output logic
25
26  end
27
endmodule
```

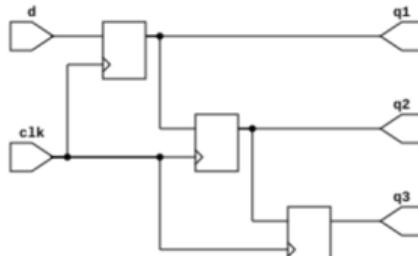
Blocking and Non-blocking assignments in always_ff

Caution with false assignments in *always_ff*:

```

1 module demoOk (input clk,
2   input d,
3   output q1,
4   output q2,
5   output q3);
6   always_ff @(posedge clk) begin
7     q1 <= d;
8     q2 <= q1;
9     q3 <= q2;
10    end
11 endmodule

```

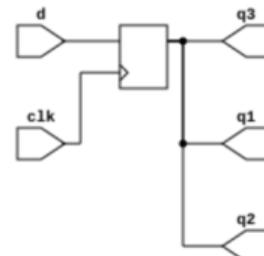


Okay:

```

1 module demoWrong (input clk,
2   input d,
3   output q1,
4   output q2,
5   output q3);
6   always_ff @(posedge clk) begin
7     q1 = d;
8     q2 = q1;
9     q3 = q2;
10    end
11 endmodule

```



Wrong:





Chapter 3 -
Verilog crash
course -
QUESTIONS

Course authors
(Git file)

Chapter 3 - Verilog crash course - QUESTIONS

Course authors (Git file)



Chapter 3 -
Verilog crash
course -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 3



Questions

Chapter 3 -
Verilog crash
course -
QUESTIONS

Course authors
(Git file)

- What are HDL?
- What is Verilog?
- Are there other HDL?
- What is the main difference between HDL and programming languages?
- List and describe the structure of a simple Verilog file.
- Yosys is ... ?
- How to define ports in Verilog?
- Describe the concept of module instantiation in Verilog.
- What is the difference between combinational and sequential circuits?
- Try to explain the synthesized schematic of the parameterized counter in your own words.
- WHat is the problem with the assignements on the right side of the last slide?

Chapter 3 - Verilog - TRAINING - Advanced

Course authors (Git file)



1

LSFR

Analyse parts of the Verilog source

Find combinational and synchronous parts in

- Code
- Schematic



Generate schematic and JSON

Generate * Schematic * JSON



yosys file

Read the .ys file



Chapter 3 - Verilog - TRAINING - Common

Course authors (Git file)



1

ORFS examples

GDC example

- Find the Verilog file of the gcd example in ORSF
- Open the Verilog file with an editor

Questions about the code: - What are the port definitions - How many inputs and outputs will the chip have? - Can you identify other parts of the code?



IBEX example

- Find the top level Verilog file of the ibex example in ORSF
- Open the top level Verilog file with an editor

Questions about the code: - What are the port definitions? - How many inputs and outputs has the top level module? - Can you identify other parts of the code?



Chapter 04 - OpenROAD first run

Course authors (Git file)



1 Doing this chapter

2 Basic ORFS

3 Example pick



Section 1

Doing this chapter



Doing this chapter

- This chapter is mostly a training.
- We will try to get our first results.
- Example projects are available.



Section 2

Basic ORFS



Find the flow directory



Checking the tools





Section 3

Example pick



Example: gcd (from the OpenROAD-flow-script examples)

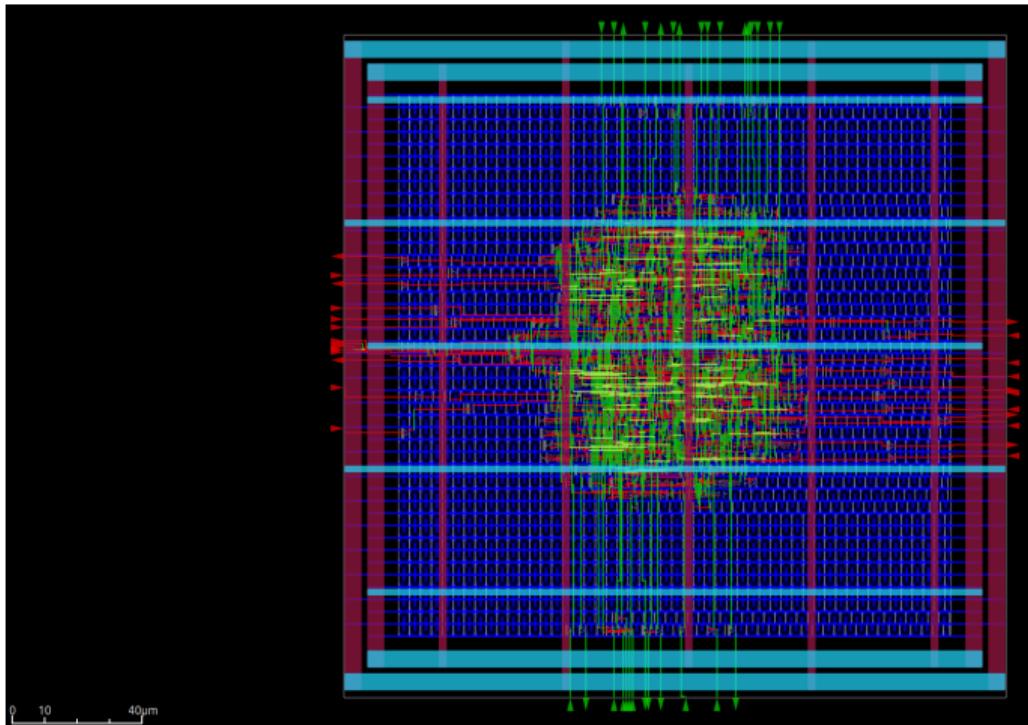
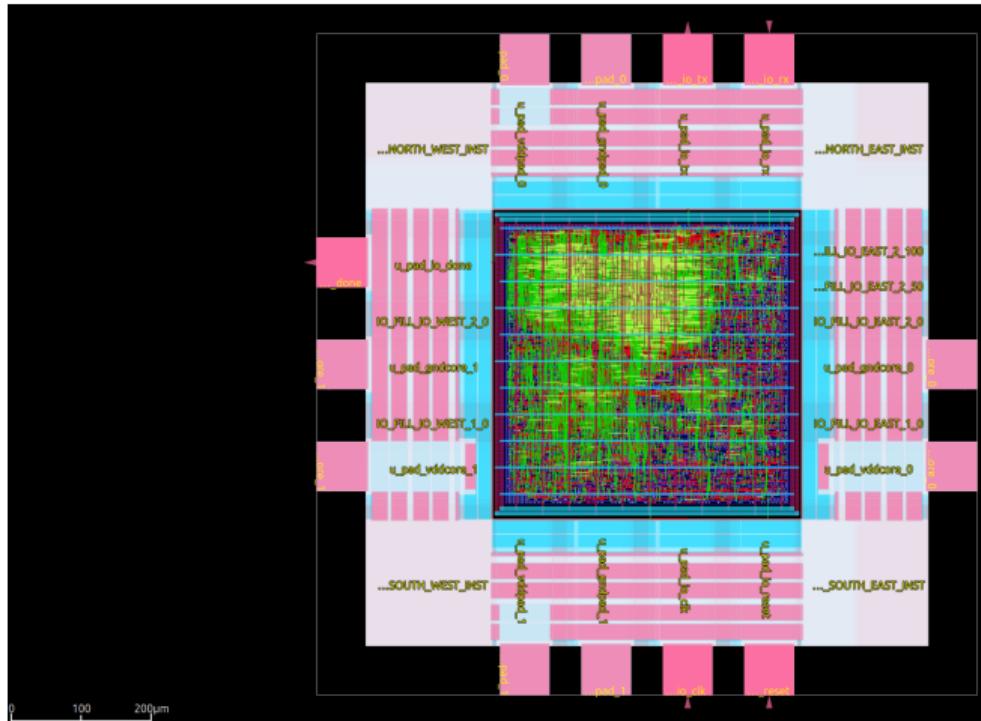


Figure 1: GDS gcd



Example: masked_aes (from the Sign:HEP research project)

HEP Alliance - Masked AES





Chapter 04 -
OpenROAD first
run -
QUESTIONS

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(Git file)

Chapter 04 - OpenROAD first run - QUESTIONS

Course authors (Git file)



Chapter 04 -
OpenROAD first
run -
QUESTIONS

Course authors
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Recap questions for Chapter 4



Questions

Chapter 04 -
OpenROAD first
run -
QUESTIONS

Course authors
(Git file)

- How to choose the design for a run?
- How to do a run of ORFS?
- What is expected for a succesfull run?
- Name some of the steps in the console output that gets created during the run.
- What is the content of the final table?

Chapter 04 - OpenROAD first run - TRAINING - Advanced

Course authors (Git file)



1

Build an external example

EDA tools

- One of the options of chapter 0 (preparations) is needed.
- Navigate to the `/flow` folder



Clone the design “masked AES” from the HEP Alliance

Clone the masked AES design from Github. Use the tutorial from the HEP Alliance Repository:

<https://github.com/HEP-Alliance/masked-aes-tapeout>

In a nutshell (clone via https):

```
1 | git clone https://github.com/HEP-Alliance/masked-aes-tapeout.git <ORFS-Root>/flow/designs/ihp-sg13g2/masked_aes
```



Enable the design in the Makefile

- Edit the Makefile:
 - Uncomment the line with your chosen DESIGN_CONFIG from ihp-sg13g2. In this case the cloned masked_aes:

```
1 DESIGN_CONFIG=./designs/ihp-sg13g2/masked_aes/config.mk
```

- Re-comment the previous uncommented line with DESIGN_CONFIG. For example the gcd on SKY130 design:

```
1 # DESIGN_CONFIG=./designs/asap7/gcd/config.mk
```

- The line with the default design does not need to be commented. This only applies when no previous line with DESIGN_CONFIG is set.



Run the flowscript

- Run `make` from inside the `/flow` folder.



Success

- The chosen design should finish after a while and a lot of console output with a table (time/memory) like this:

	Log	Elapsed	seconds	Peak	Memory/MB
1					

CONGRATS! Your design got build to a GDS!



Chapter 04 - OpenROAD first run - TRAINING - Bonus

Course authors (Git file)



1. Build the IBEX RISC-V design
2. Integrate a new design into OpenROAD flowscripts



1. Build the IBEX RISC-V design

Build another example from the flow script designs: - The IBEX RISC-V example. - Modify and follow the steps from the common training for this task.



2. Integrate a new design into OpenROAD flowscripts

In this training session you will integrate a new design for using it with OpenROAD flowscripts. You can either:

- * Have your own design ready.
- * Take an opensource design from someone else.



Pick a design to integrate

- LSFR from earlier?
- Pre-selected TinyTapeOut designs?



Run the flowscript

Todo.



Success

Todo. * The chosen design should finish after a while and a lot of console output with a table (time/memory) like this:

	Log	Elapsed	seconds	Peak	Memory/MB
1					

CONGRATS! Your first(?) design got build to a GDS!



Chapter 04 - OpenROAD first run - TRAINING - Common

Course authors (Git file)



1

Start the first run



EDA tools

- One of the options of chapter 0 (preparations) is needed.
- Navigate to the `/flow` folder



Enable the design in the Makefile

- Edit the Makefile:

- Uncomment the line with your chosen DESIGN_CONFIG from ihp-sg13g2. For example the gcd design:

```
1 DESIGN_CONFIG=./designs/ihp-sg13g2/gcd/config.mk
```

- Re-comment the previous uncommented line with DESIGN_CONFIG. For example the gcd on SKY130 design:

```
1 # DESIGN_CONFIG=./designs/asap7/gcd/config.mk
```

- The line with the default design does not need to be commented. This only applies when no previous line with DESIGN_CONFIG is set.



Run the flowscript

- Run `make` from inside the `/flow` folder.



Success

- The chosen design should finish after a while and a lot of console output with a table (time/memory) like this:

Log	Elapsed seconds	Peak Memory/MB
1_1_yosys	0	24
1_1_yosys_canonicalize	0	17
1_1_yosys_hier_report	0	12
2_1_floorplan	0	110
2_2_floorplan_io	0	106
2_3_floorplan_tdms	0	98
2_4_floorplan_macro	0	106
2_5_floorplan_tapcell	0	105
2_6_floorplan_pdn	0	108
3_1_place_gp_skip_io	0	108
3_2_place_iop	0	107
3_3_place_gp	0	320
3_4_place_resized	0	289
3_5_place_dp	0	112
4_1_cts	1	379
5_1_grt	0	340
5_2_route	93	899
5_3_fillcell	0	111
6_1_fill	0	113
6_1_merge	1	368
6_report	1	292



Cheatsheet - Chapter 5 PDK Examination

KLayout:

.lyp	Layer properties file
.lyt	Technologies file for Layout ↔ Technology mapping

xScheme:

.sym	Schematics file

Hardware Description Languages (HDL):

Verilog
VHDL

Abbreviations:

LVS	Layout versus Schematic
CDL	Circuit design language
GDS II	Graphic data system (II)
LEF	Library exchange format
techLEF	Additional info about the technology
.lib	Liberty timing file: ASCII descriptions of timing / power of cells.

Chapter 5 - Process Design Kit (PDK)

Course authors (Git file)



1 What is a PDK?

2 Open-Source PDK and GitHub

3 Content of the PDK ihp-sg13g2

4 File formats

5 Ruleset documents



Section 1

What is a PDK?



Wikipedia definition

A process design kit (PDK) is a set of files used within the semiconductor industry to model a fabrication process for the design tools used to design an integrated circuit. The PDK is created by the foundry defining a certain technology variation for their processes. ...

... The designers use the PDK to design, simulate, draw and verify the design before handing the design back to the foundry to produce chips. The data in the PDK is specific to the foundry's process variation and is chosen early in the design process, influenced by the market requirements for the chip. An accurate PDK will increase the chances of first-pass successful silicon.

Source: https://en.wikipedia.org/wiki/Process_design_kit



Open-source viewpoint

ToDo: Image of the border between development and production



In the context of this course



Section 2

Open-Source PDK and GitHub



Difference from closed source

With publishing a PDK under a open-source license, the development from there on becomes a worldwide visible joint effort. The number of contributors and authors of the PDK can only increase from here on.



Collaborative workflow in GitHub

Some of the main principles of open-source are the permissions to use, study, change and re-distribute the published code and data according to the license. This leads to a open collaboration in which everyone can participate.

GitHub enables a workflow that was designed and build with these principles and opportunities in mind. A good starting point to explore the open collaboration in the IHP PDK are

- **Issues (open and closed)**
- **Pull requests (open and closed)**

The topics and discussions that you can read and study there will draw a picture of how the process of open collaboration works for the PDK.



Issues openss

👉 Want to contribute to IHP-GmbH/IHP-Open-PDK?
If you have a bug or an idea, read the [contributing guidelines](#) before opening an issue. Dismiss ▾

Filters ▾ Labels (9) Milestones (0) New issue

Clear current search query, filters, and sorts

	Author ▾	Label ▾	Projects ▾	Milestones ▾	Assignee ▾	Sort ▾
① 35 Open ✓ 55 Closed						
② [bug] ifnone state-dependent path delay #209 opened 2 weeks ago by likeamahoney		5				
③ [bug] LRM specify block delay path restrictions bug #208 opened 2 weeks ago by likeamahoney		3				
④ Simulation of MOSFET noise with ngspice #207 opened 2 weeks ago by 0y8w1x		2				
⑤ .spiceinit seems to produce errors in AC simulation bug #205 opened 3 weeks ago by olsnr		2				
⑥ how to use tolerances in LVS? #203 opened 3 weeks ago by olsnr		5				
⑦ DRC seem to miss error on GatPoly Gat.b or Gat.b1 bug #201 opened 3 weeks ago by olsnr		24				



Figure 1: Issues open

Issues closed

💡 Want to contribute to IHP-GmbH/IHP-Open-PDK?
If you have a bug or an idea, read the [contributing guidelines](#) before opening an issue. Dismiss ▾

Filters Labels (9) Milestones (0) New Issue

Clear current search query, filters, and sorts

Author ▾	Label ▾	Projects ▾	Milestones ▾	Assignee ▾	Sort ▾
35 Open	✓ 55 Closed				
<p><input checked="" type="checkbox"/> .spice net for LVS 11 #197 by olisnr was closed 3 weeks ago</p> <p><input checked="" type="checkbox"/> a question to LVS from .spice 2 #196 by olisnr was closed last month</p> <p><input checked="" type="checkbox"/> Resistor parameter <code>b</code> usage? question 5 #191 by hpreti was closed 3 weeks ago</p> <p><input checked="" type="checkbox"/> sram: missing .lib files 5 #177 by dnlitz was closed on Aug 12</p> <p><input checked="" type="checkbox"/> Any Recommended Python Versions? question 12 #169 by redpanda3 was closed 3 weeks ago</p> <p><input checked="" type="checkbox"/> Routing issue in <code>dfrbp_1</code> flop bug invalid 2 #166 by sergeiandreyev was closed on Aug 5</p>					

Figure 2: Issues closed

Pull requests closed

First time contributing to IHP-GmbH/IHP-Open-PDK?Dismiss 

If you know how to fix an [issue](#), consider opening a pull request for it.
You can read this repository's [contributing guidelines](#) to learn how to open a good pull request.

Filters   Labels (9)  Milestones (0) New pull request

 Clear current search query, filters, and sorts

Author 	Label 	Projects 	Milestones 	Reviews 	Assignee 	Sort 
 3 Open	 115 Closed					
<p> iho-sg13g2: libs.ref: sg13g2_io: verilog: Fix specify syntax ✓  #215 by dnltz was merged last week</p> <p> Update KLayout DRC scripts ✓  #214 by akrinke was merged last week</p> <p> PyCell Klayout integration ✓  #213 by ThomasZecha was merged last week</p> <p> LVS rule decks: Fix GF180 remnants in log strings ✗  #212 by martinjankoheler was merged last week</p> <p> Updated procedure to avoid constant opening cmd window on Windows to... ✓  #211 by adatsuk was merged last week  2 tasks</p>						

Figure 3: Pull requests closed

Resources for you



Contributing?

Wiki



Section 3

Content of the PDK ihp-sg13g2



The README

The Readme file in the PDKs repository is the starting point for information about the content of the PDK.

<https://github.com/IHP-GmbH/IHP-Open-PDK/blob/main/README.md>

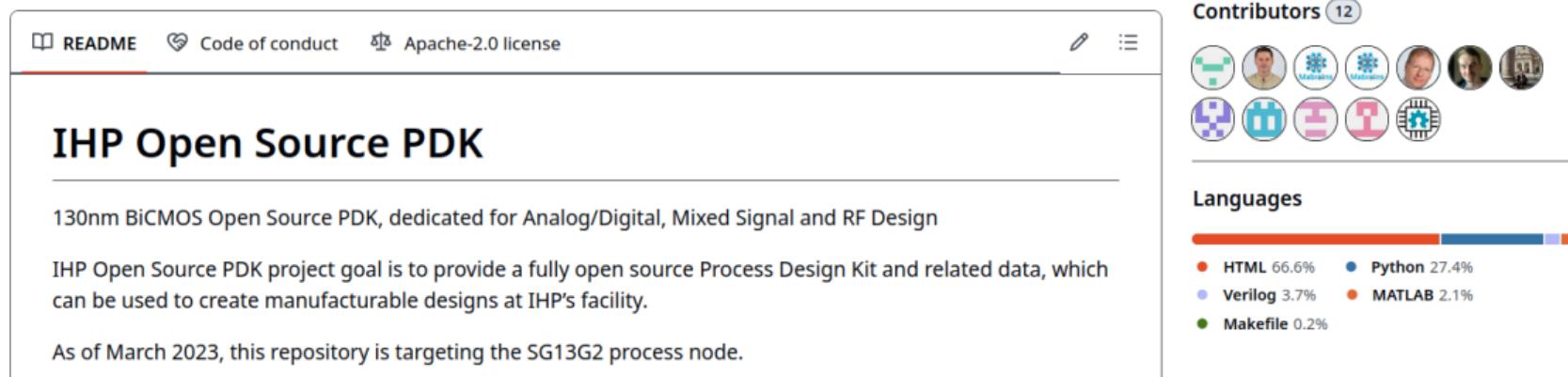


Figure 4: Readme

Project roadmap

A GANTT chart of the roadmap for the open-source PDK is available under this weblink. It shows the projects timeline (2022 - 2026):

https://github.com/IHP-GmbH/IHP-Open-PDK/blob/main/ihp-sg13g2/libs.doc/roadmap/open_PDK_gantt.png

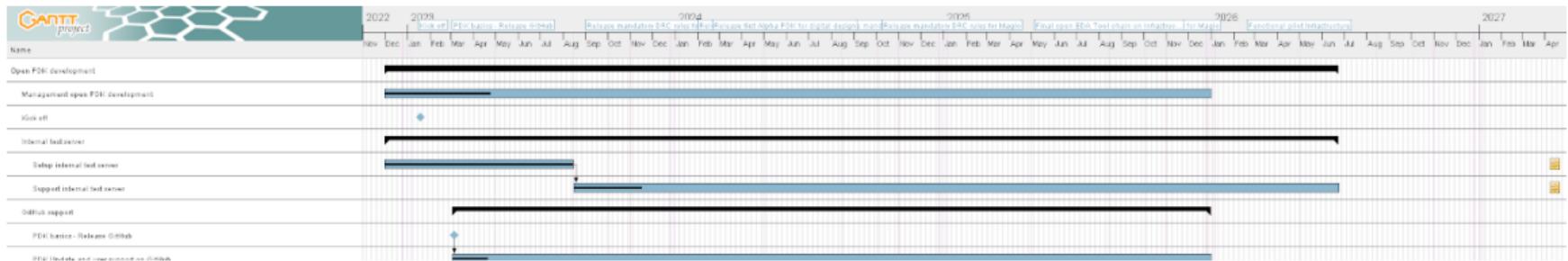


Figure 5: Gantt chart

Cells in the PDK

There are four different sets of cells (or devices) in the PDK:

- Base cellset with limited set of standard logic cells
 - CDL, GDSII, LEF, Tech LEF
 - Liberty, SPICE Netlist, Verilog
- IO cellset
 - GDSII, LEF, Liberty (dummy), SPICE Netlist
- SRAM cellset
 - CDL, GDSII, LEF, Liberty, Verilog
- Primitive devices
 - GDSII



Other data in the PDK

- KLayout tool data:
 - layer property and tech files
 - DRC rules (minimal set)
 - PyCells
 - initial version of the wrapper API
 - sample cells
- Pcells (for reference only) libs.tech/pycell
- MOS/HBT/Passive device models for ngspice/Xyce
- xschem: primitive device symbols, settings and testbenches
- OpenEMS: tutorials, scripts, documentation
- SG13G2 Process specification & Layout Rules
- MOS/HBT Measurements in MDM format
- Project Roadmap Gantt chart



Standard cell library

ToDo:

- Where in the RTI-to-GDS is the cell library needed?
- Design to cells to GDS and Tapeout
- Naming of the cells



A single cell from the library

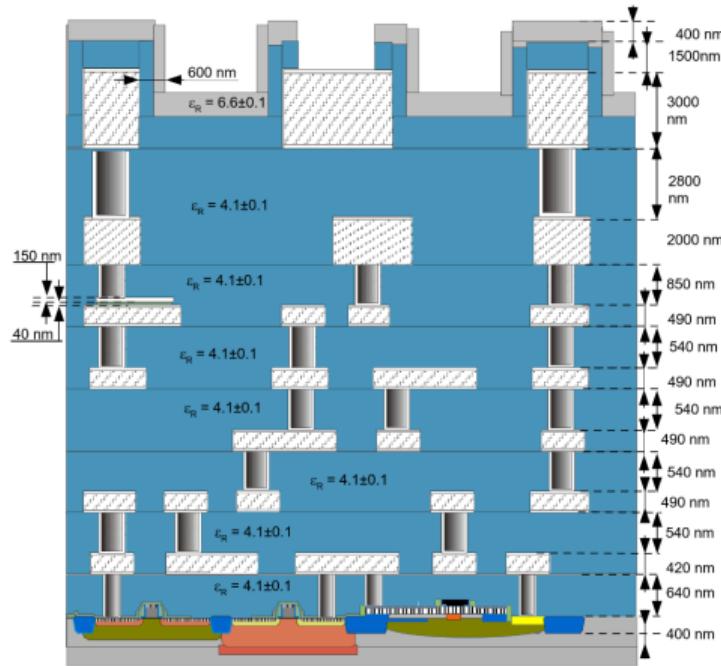
ToDo:

- Pick one cell
- Pictures of the layers of the cell
 - Klayout
 - 3D Rederings?
- Schematic of the cell



Layer stack

IHP sg13g2 Layers in a picture.



Section 4

File formats



Cell AO21: VERILOG HDL language

```
1 // type: AO21
2 `timescale 1ns/10ps
3 `celldefine
4 module sg13g2_a21o_1 (X, A1, A2, B1);
5   output X;
6   input A1, A2, B1;
7
8   // Function
9   wire int_fwire_0;
10
11  and (int_fwire_0 , A1, A2);
12  or (X, int_fwire_0 , B1);
13
14 // Timing
15 specify
16   (A1 => X) = 0;
17   (A2 => X) = 0;
18   if (A1 == 1'b1 & A2 == 1'b0)
19     (B1 => X) = 0;
20   if (A1 == 1'b0 & A2 == 1'b1)
21     (B1 => X) = 0;
22   ifnone (B1 => X) = 0;
23 endspecify
24 endmodule
`endcelldefine
```

Cell AO21: SPICE Netlist

```
1 * Library name: sg13g2_stdcell
2 * Cell name: sg13g2_a21o_1
3 * View name: schematic
4 * Inherited view list: spectre cmos_sch cmos.sch schematic veriloga ahdl
5 * pspice dspf
6 .subckt sg13g2_a21o_1 A1 A2 B1 VDD VSS X
7 XN0 net1 A1 net2 VSS sg13_lv_nmos w=640.00n l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
8 XN1 net2 A2 VSS VSS sg13_lv_nmos w=640.00n l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
9 XN2 net1 B1 VSS VSS sg13_lv_nmos w=640.00n l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
10 XN3 X net1 VSS VSS sg13_lv_nmos w=740.00n l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
11 XP0 net1 B1 net3 VDD sg13_lv_pmos w=1.000u l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
12 XP1 net3 A1 VDD VDD sg13_lv_pmos w=1.000u l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
13 XP2 net3 A2 VDD VDD sg13_lv_pmos w=1.000u l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
14 XP3 X net1 VDD VDD sg13_lv_pmos w=1.12u l=130.00n ng=1 ad=0 as=0 pd=0 ps=0 m=1
15 .ends
* End of subcircuit definition.
```



Cell AO21: Circuit design language

```
1 ****
2 * Library Name: sg13g2_stdcell
3 * Cell Name:    sg13g2_a21o_1
4 * View Name:   schematic
5 ****
6
7 .SUBCKT sg13g2_a21o_1 A1 A2 B1 VDD VSS X
8 *.PININFO A1:I A2:I B1:I X:O VDD:B VSS:B
9 MN0 net1 A1 net2 VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
10 MN1 net2 A2 VSS VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
11 MN2 net1 B1 VSS VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
12 MN3 X net1 VSS VSS sg13_lv_nmos m=1 w=740.00n l=130.00n ng=1
13 MP0 net1 B1 net3 VDD sg13_lv_pmos m=1 w=1.000u l=130.00n ng=1
14 MP1 net3 A1 VDD VDD sg13_lv_pmos m=1 w=1.000u l=130.00n ng=1
15 MP2 net3 A2 VDD VDD sg13_lv_pmos m=1 w=1.000u l=130.00n ng=1
16 MP3 X net1 VDD VDD sg13_lv_pmos m=1 w=1.12u l=130.00n ng=1
17 .ENDS
```



Section 5

Ruleset documents





Chapter 5 -
Process Design
Kit (PDK) -
QUESTIONS

Course authors
(Git file)

Chapter 5 - Process Design Kit (PDK) - QUESTIONS

Course authors (Git file)



Chapter 5 -
Process Design
Kit (PDK) -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 5



Questions

Chapter 5 -
Process Design
Kit (PDK) -
QUESTIONS

Course authors
(Git file)

- What is a PDK?
- Define the border between development (design) and production of a microchip.
- Where is the (actual) border of open- to closed-source in this?
- Name as many parts of the IHP open-source PDK as you can (round robin)
- What are layers?
- What is a layer stack?
- Can you name some layers and their purpose?
- Try to explain the picture on page XXX of the layout rules document.
- Describe the content of the process specification document.
- Name some of the important file formats from the PDK. What are they used for? (round robin).

Chapter 5 - PDK Examination - TRAINING - Advanced

Course authors (Git file)



1. Open Klayout
2. Matchmaking a cell
3. Examining cell GDS
4. Logic function of the cell



1. Open Klayout

- Execute `klayout` in console shell.
- Klayout starts in viewer mode.
- Edit mode can be started with `klayout -e` but is not needed for this training.



1. Open KLayout

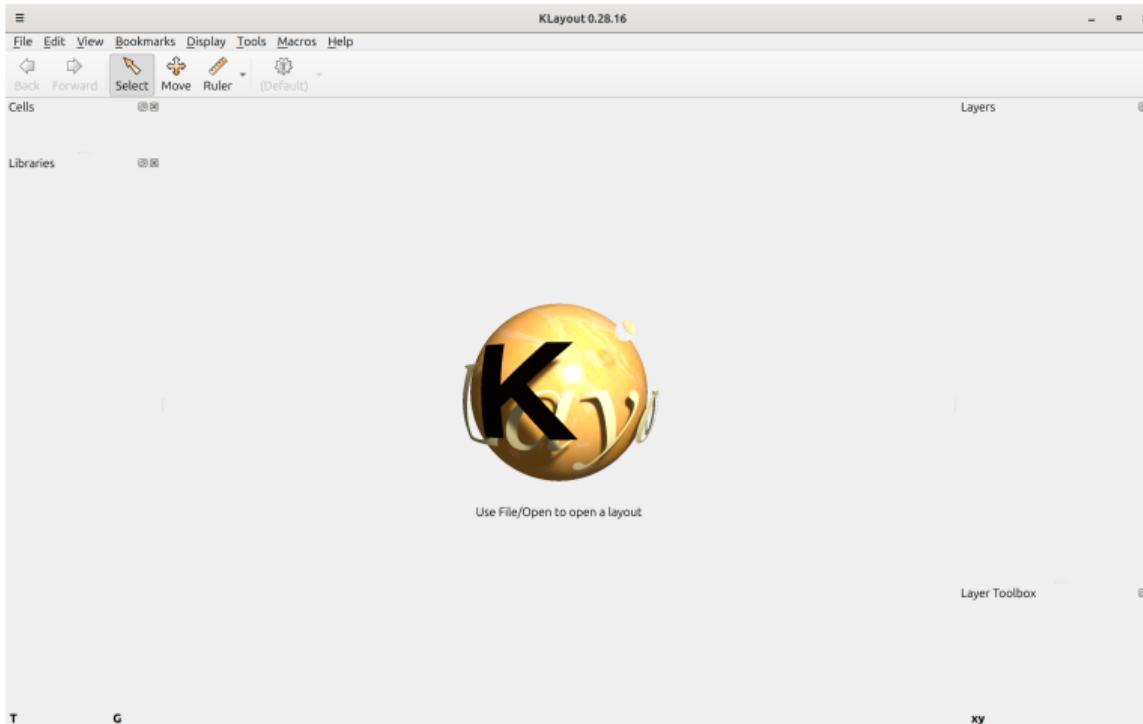


Figure 1: Start KLayout

2. Matchmaking a cell

- Here is a 3D rendering of a standard cell (Insert name? Or find name?)
- ToDo: Insert cell picture
- Can you identify the layers and their order from the cell?



2. Matchmaking a cell

ToDo.



3. Examining cell GDS

Todo. * Search for the cell GDS and examine the layers and their order.



3. Examine cell GDS

Todo. - Picture of



4. Logic function of the cell

- Find the schematic of the cell.



4. Logic function of the cell

- Match the schematic and the logic function of the cell.



Chapter 5 - PDK Examination - TRAINING - Bonus

Course authors (Git file)



- 1 1. Transistor count
- 2 Next slide: Solution Spoiler!
- 3 Solution: Transistor count
- 4 Solution: Transistor count in file



1. Transistor count

- Load the gds of the standard cell AND4_1.
- How many transistors are in the cell?
- How to verify this with the use of another file from the PDK?



Next slide: Solution Spoiler!

SPOILER ALERT:

- The next slide contains the solution.
- Only proceed to the next slide if you want to see the solution right now!



Solution: Transistor count

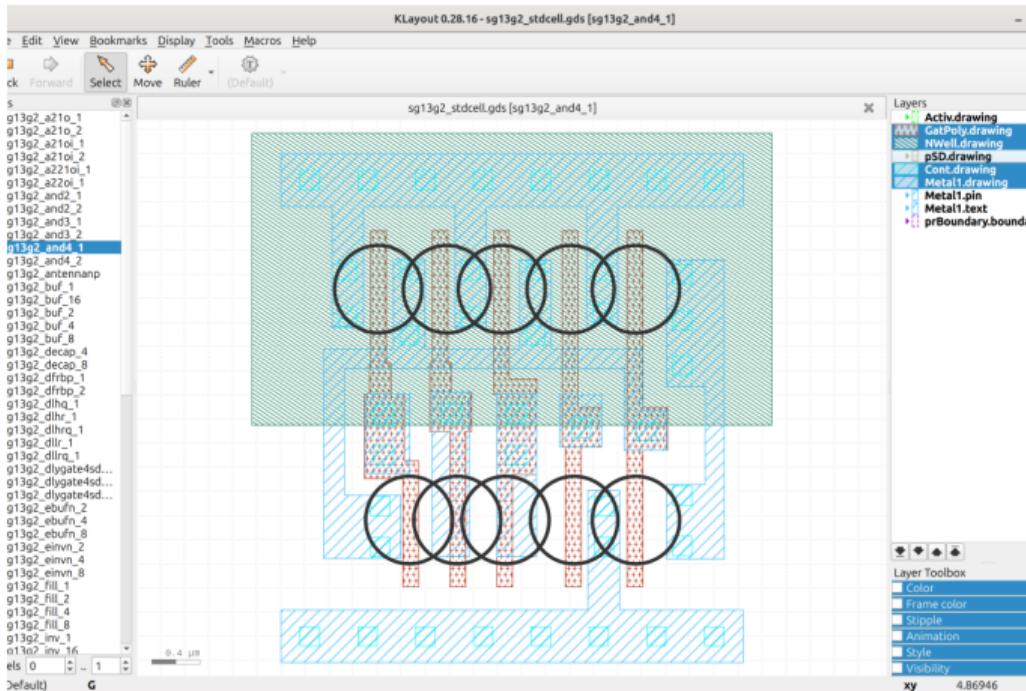


Figure 1: AND4_1

Solution: Transistor count in file

File: sg13g2_sdtcell.cdl

```
1 MN4 net17 D VSS VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
2 MN3 net16 C net17 VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
3 MN2 net15 B net16 VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
4 MN1 net1 A net15 VSS sg13_lv_nmos m=1 w=640.00n l=130.00n ng=1
5 MNO X net1 VSS VSS sg13_lv_nmos m=1 w=740.00n l=130.00n ng=1
6 MP0 net1 A VDD VDD sg13_lv_pmos m=1 w=840.00n l=130.00n ng=1
7 MP4 X net1 VDD VDD sg13_lv_pmos m=1 w=1.12u l=130.00n ng=1
8 MP3 net1 D VDD VDD sg13_lv_pmos m=1 w=840.00n l=130.00n ng=1
9 MP2 net1 C VDD VDD sg13_lv_pmos m=1 w=840.00n l=130.00n ng=1
10 MP1 net1 B VDD VDD sg13_lv_pmos m=1 w=840.00n l=130.00n ng=1
```



Chapter 5 - PDK Examination - TRAINING - Common

Course authors (Git file)



1 1. Open Klayout

2 2. Load example GDS

3 3. Use a LYP file

4 4. Navigate Layers and GDS

5 5. Load cell library GDS

6 6. Pick a cell



1. Open Klayout

- Execute `klayout` in console shell.
- Klayout starts in viewer mode.
- Edit mode can be started with `klayout -e` but is not needed for this training.



1. Open KLayout

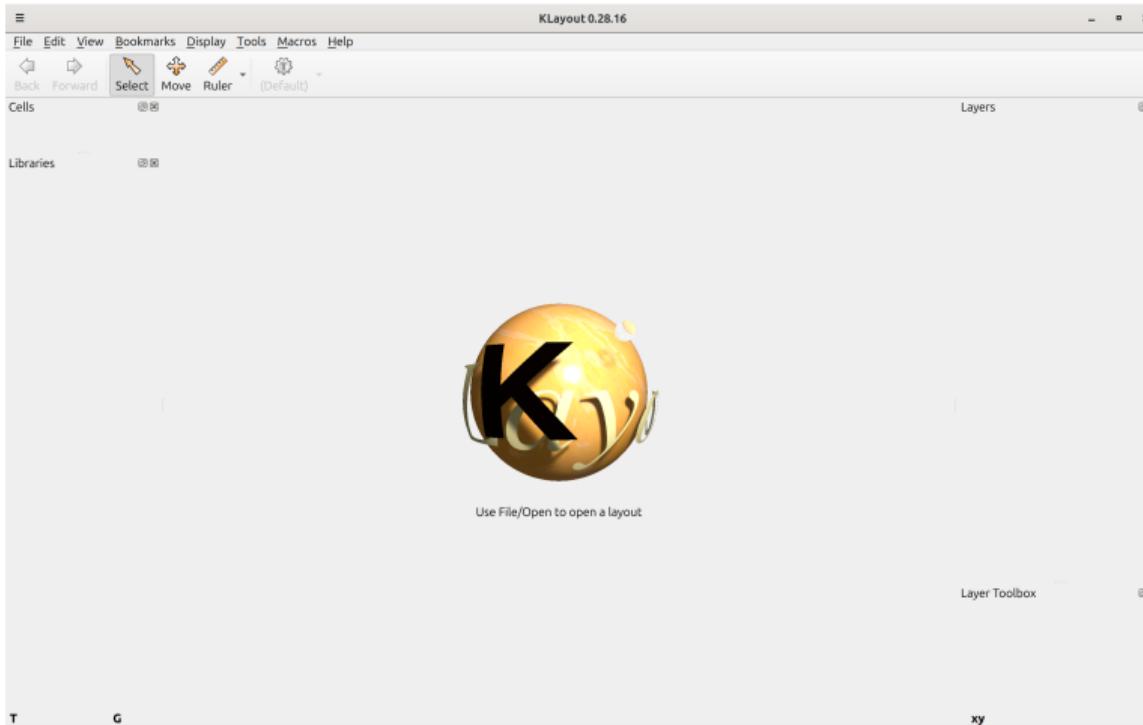


Figure 1: Start KLayout

2. Load example GDS

- Search for the final GDS from your example run and load it into Klayoutv



2. Load example GDS

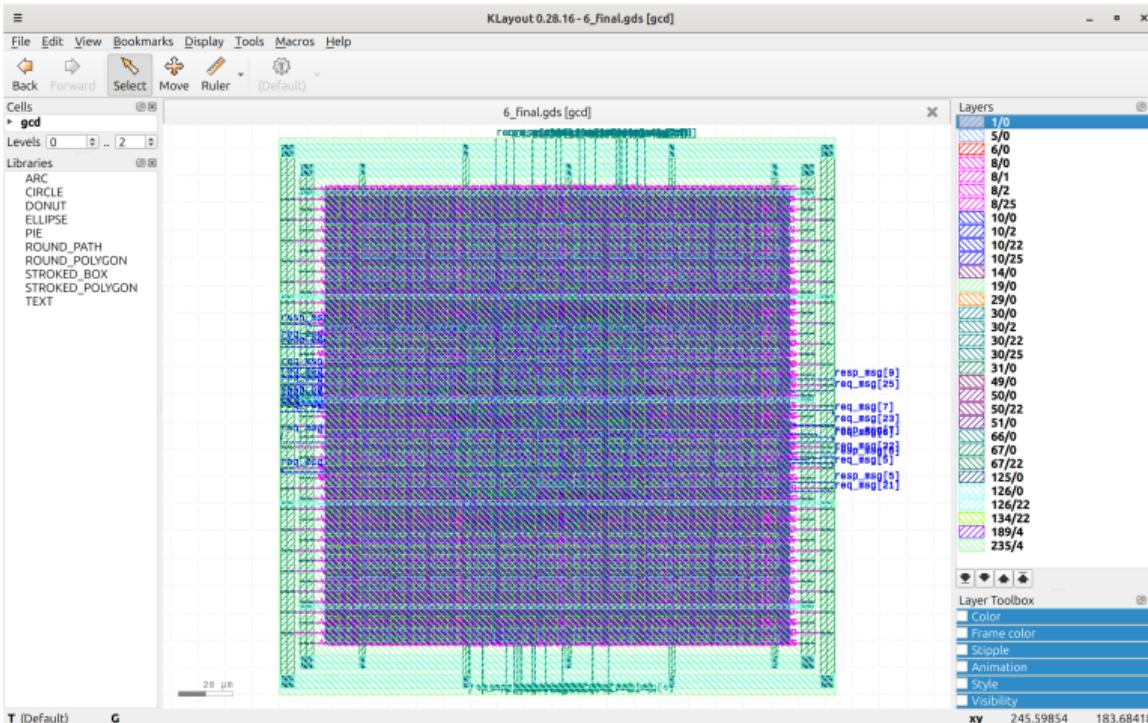


Figure 2: Load GDS

3. Use a LYP file

- Recall: What are layer properties and the .lyp file?
- Search the sg13g2 lyp-file from the PDK and enable it in Klayout.
- Make it the default lyp in Klayout.
- Look for changes in the layer list and the GDS.
- What has changed?



3. Use a LYP file

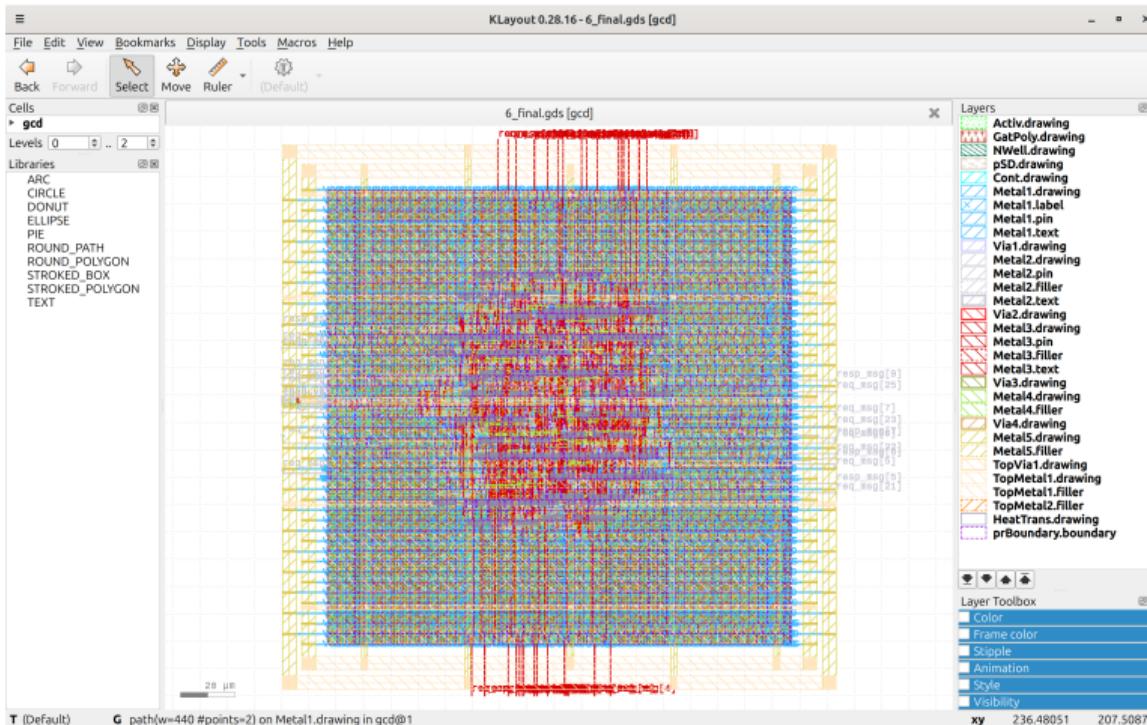


Figure 3: Use LYP file

4. Navigate Layers and GDS

- In the layer list:
 - Enable “Hide empty layers”.
 - Enable “Visibility follows selection”.
 - De-/Select multiple layers and see the changes.
- Zoom out to see the complete GDS and de-/select layers.
- Zoom into details and de-/select layers.
- Move the GDS file while zoomed in.
- Try to find interesting views.
- Discuss with neighbours what might be of interest.



4. Navigate Layers and GDS

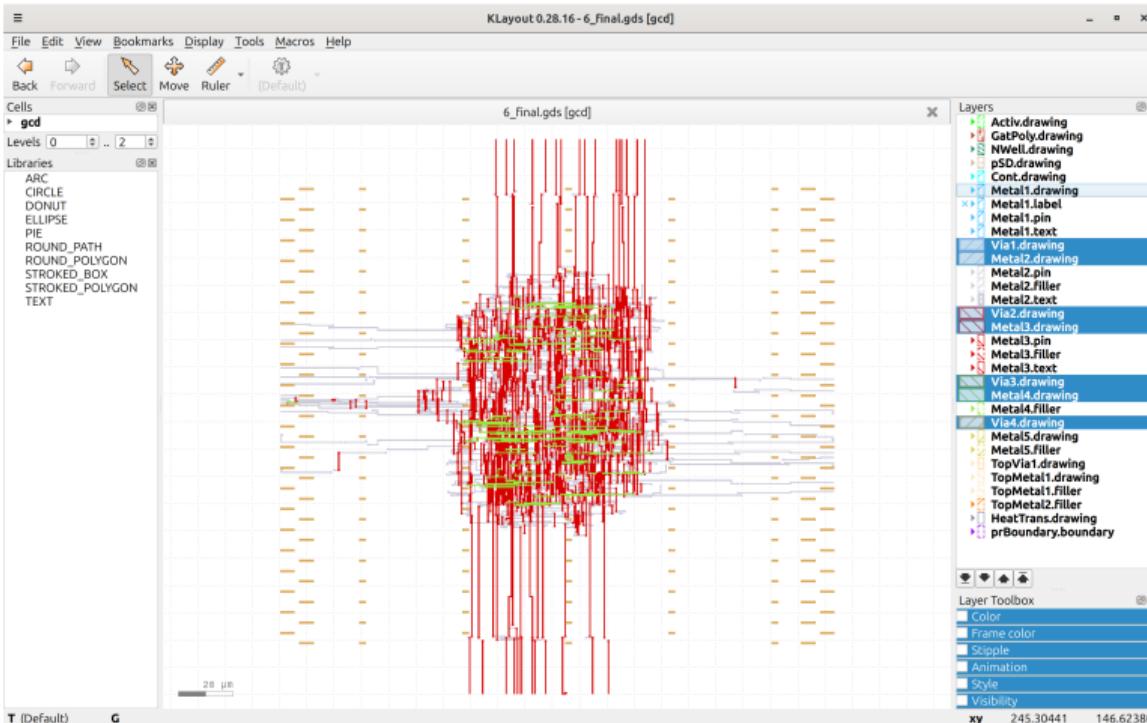


Figure 4: GDS zoomed out

4. Navigate Layers and GDS

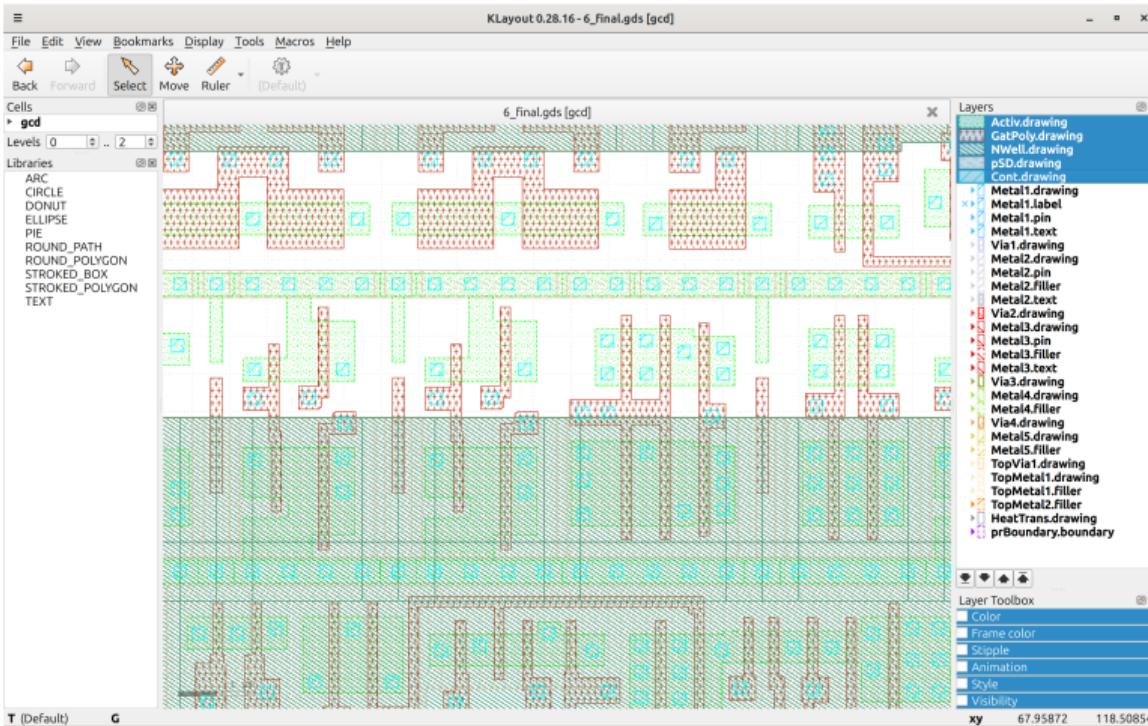


Figure 5: GDS zoomed in

5. Load cell library GDS

- Now open another GDS: the standard cell library from the sg13g2 PDK.
- The standard cell library is a single GDS file. Search and load the library file.



5. Load cell library GDS

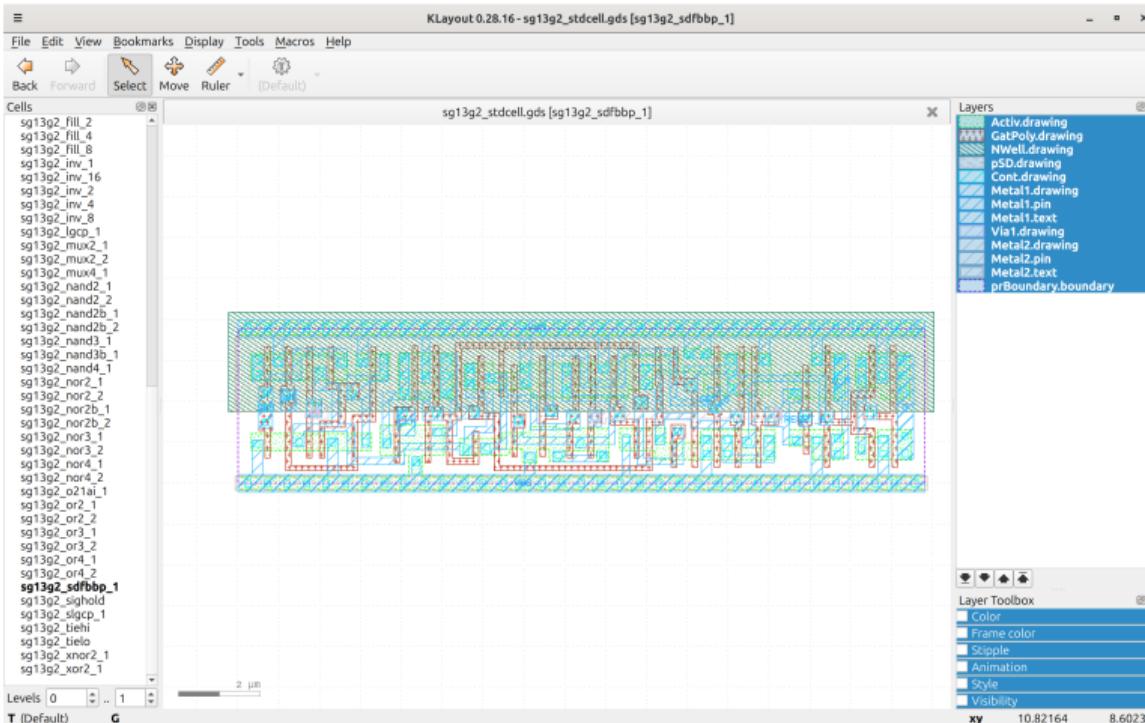


Figure 6: Cell library

6. Pick a cell

- All the cell names are displayed in a window to the left. One cell is selected (displayed in bold). The GDS of this cell is viewed. Try to bring another cell “to the top” to see that cells GDS.
- Repeat the layer navigation like in the eaxmple GDS.



6. Pick a cell

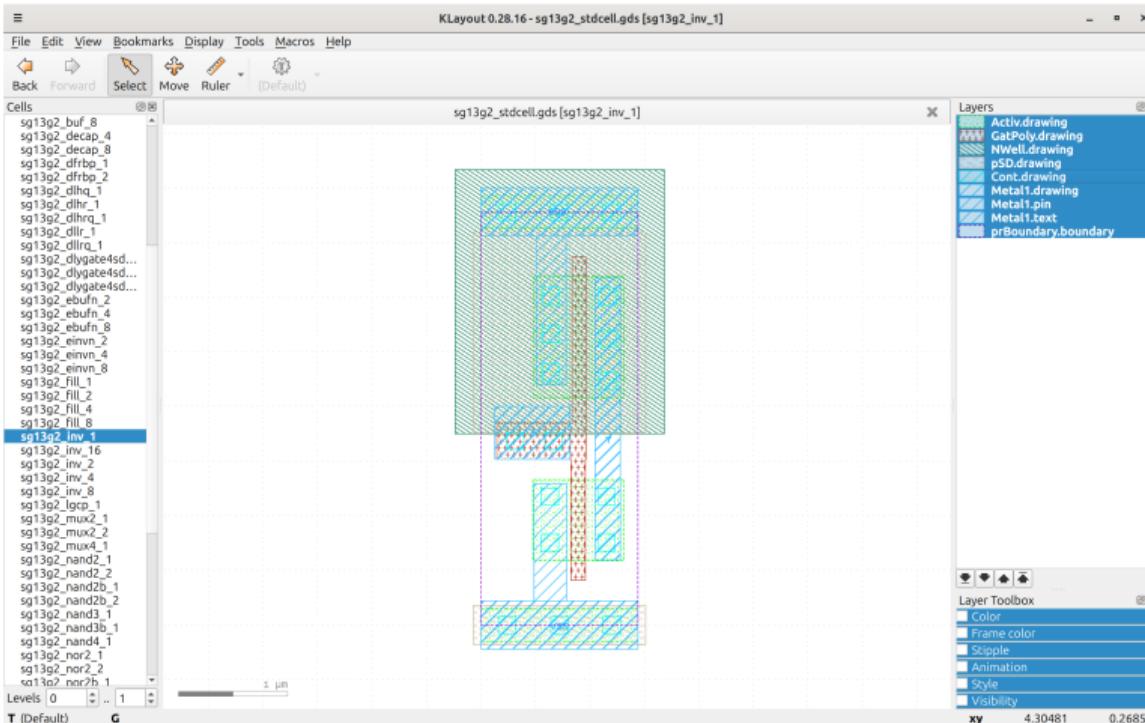


Figure 7: Single cell

Chapter 6 - OpenROAD GUI

Course authors (Git file)



1 Analysing designs with the GUI



Section 1

Analysing designs with the GUI



View layout

Viewing Layout Results

The `make gui_final` command target successively reads and loads the technology `.odb` files and the parasitics and invokes the GUI in these steps:

- Reads and loads `.odb` files.
- Loads `.spf` (parasitics).

The figure below shows the post-routed DEF for the `ibex` design.

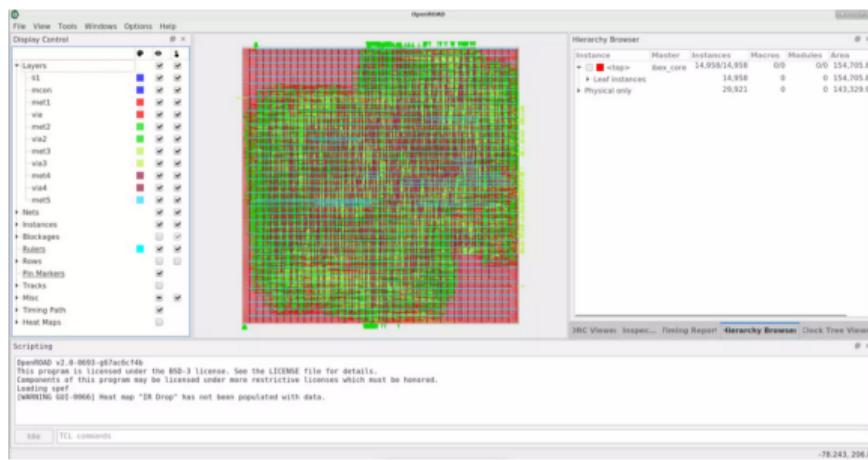


Figure 1: View layout

View objects

Visualizing Design Objects And Connectivity

Note the **Display Control** window on the LHS that shows buttons for color, visibility and selection options for various design objects: Layers, Nets, Instances, Blockages, Heatmaps, etc.

The Inspector window on the RHS allows users to inspect details of selected design objects and the timing report.

Try selectively displaying (show/hide) various design objects through the display control window and observing their impact on the display.

Figure 2: View objects



Clock tree

Tracing The Clock Tree

View the synthesized clock tree for `ibex` design:

- From the top Toolbar Click `Windows` -> `Clock Tree Viewer`

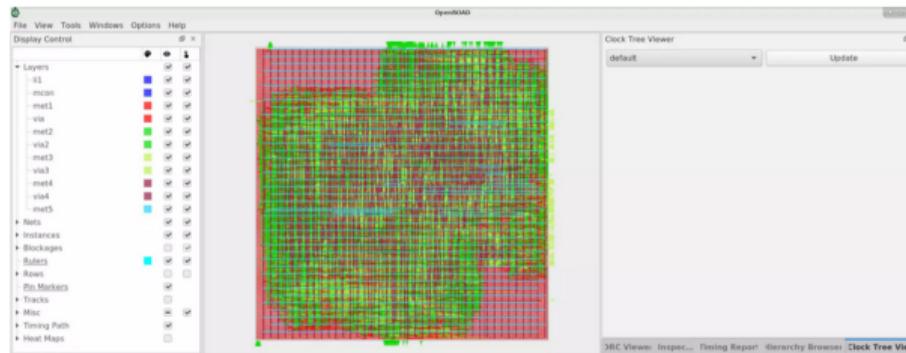


Figure 3: Clock tree



Heat maps

Using Heat Maps

From the Menu Bar, Click on **Tools** -> **Heat Maps** -> **Placement Density** to view congestion selectively on vertical and horizontal layers.

Expand **Heat Maps** -> **Placement Density** from the Display Control window available on LHS of OpenROAD GUI.

View congestion on all layers between 50-100%:

In the **Placement density** setup pop-up window, Select **Minimum** -> **50.00%** **Maximum** -> **100.00%**

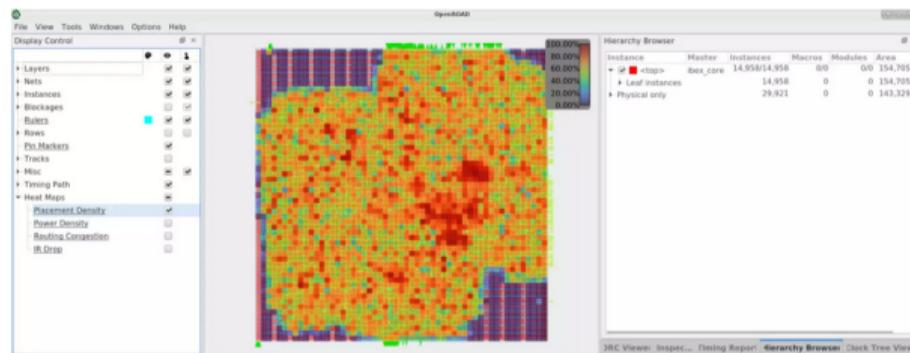


Figure 4: Heat maps

Timing report

Viewing Timing Report

Click **Timing** -> **Options** to view and traverse specific timing paths. From Toolbar, click on the **Timing** icon, View **Timing Report** window added at the right side (RHS) of GUI as shown below.

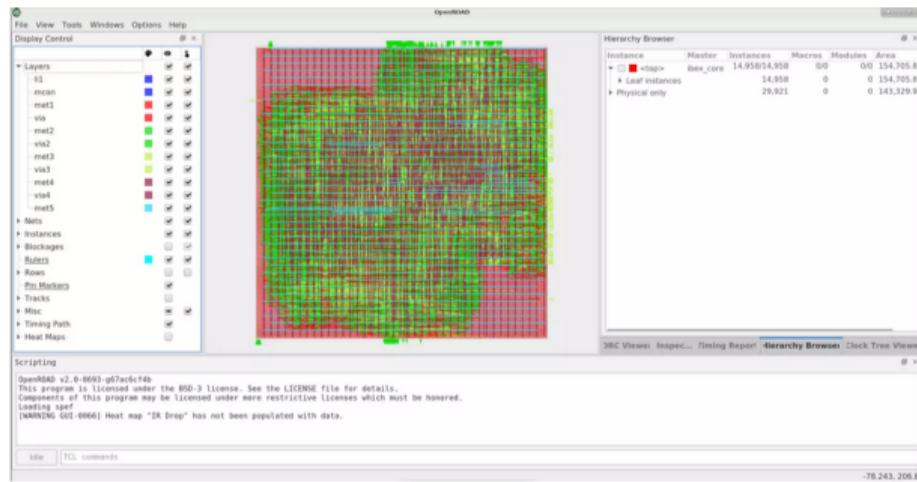


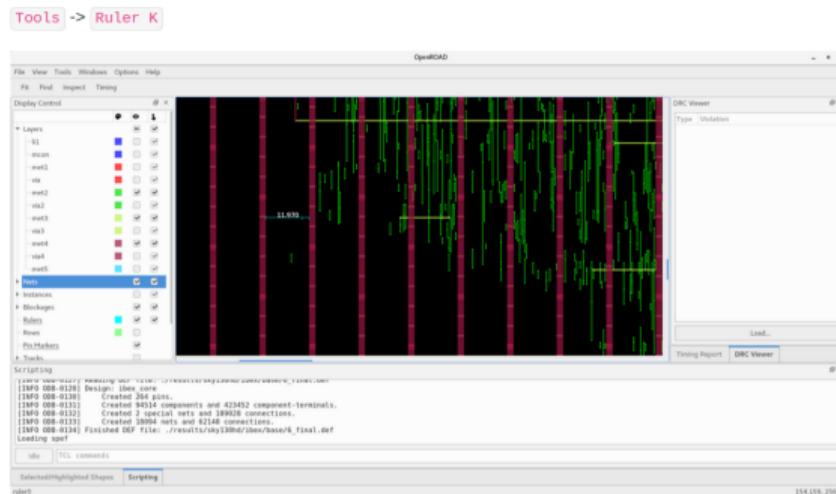
Figure 5: Timing report

Rulers (measure distances)

Using Rulers

A ruler can measure the distance between any two objects in the design or metal layer length and width to be measured, etc.

Example of how to measure the distance between VDD and VSS power grid click on:



Distance between VDD and VSS layer is **11.978**

Figure 6: Rulers

TCL command interface

Tcl Command Interface

Execute OpenROAD-flow-scripts Tcl commands from the GUI. Type `help` to view Tcl Commands available. In OpenROAD GUI, at the bottom, `TCL commands` executable space is available to run the commands. For example

View `design area` in the `Tcl Commands` section of the GUI:

```
report_design_area
```

Try the below timing report commands to view timing results interactively:

```
report_wns  
report_tns  
report_worst_slack
```

Figure 7: TCL interface



Area report

Area

View design area and its core utilization:

```
make gui_final
```

In the [Tcl Commands](#) section:

```
report_design_area
```

View the resulting area as:

```
Design area 191262 u^2 30% utilization.
```

Figure 8: Area report



Timing slack report

Timing

Users can view flow results using the command interface from the shell or the OpenROAD GUI to visualize further and debug. Learn more about the [GUI](#).

```
make gui_final
```

Use the following commands in the [Tcl Commands](#) section of GUI:

```
report_worst_slack  
report_tns  
report_wns
```

Note the worst slack, total negative slack and worst negative slack:

```
worst slack -0.99  
tns -1.29  
wns -0.99
```

Figure 9: Timing slack report



Power report

Power

Use the report command to view individual power components i.e. sequential, combinational, macro and power consumed by I/O pads.

In the [Tcl Commands](#) section:

```
report_power
```

The power output is as follows:

Group	Internal Power	Switching Power	Leakage Power	Total Power
Sequential	5.58e-03	6.12e-04	1.67e-08	6.19e-03 19.0%
Combinational	9.23e-03	1.71e-02	4.90e-08	2.63e-02 81.0%
Macro	0.00e+00	0.00e+00	0.00e+00	0.00e+00 0.0%
Pad	0.00e+00	0.00e+00	0.00e+00	0.00e+00 0.0%
Total	1.48e-02 45.6%	1.77e-02 54.4%	6.57e-08 0.0%	3.25e-02 100.0%

Figure 10: Power report



Chapter 6 -
OpenROAD GUI
- QUESTIONS

Course authors
(Git file)

Chapter 6 - OpenROAD GUI - QUESTIONS

Course authors (Git file)



Chapter 6 -
OpenROAD GUI
- QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 6



Questions

Chapter 6 -
OpenROAD GUI
- QUESTIONS

Course authors
(Git file)

- Is the OR-GUI a HDL code editor?
- Is the OR-GUI a full RTL-2-GDS graphic tool?
- What is OR-GUI instead?
- If you have a ready-build project (GDS), what can you do with it in OR-GUI?
- Explain heatmaps
- How to make better chip designs with the analysis in OR-GUI?

Chapter 6 - OpenROAD GUI - TRAINING - Common

Course authors (Git file)



1

Guess and rebuild

Challenge 1

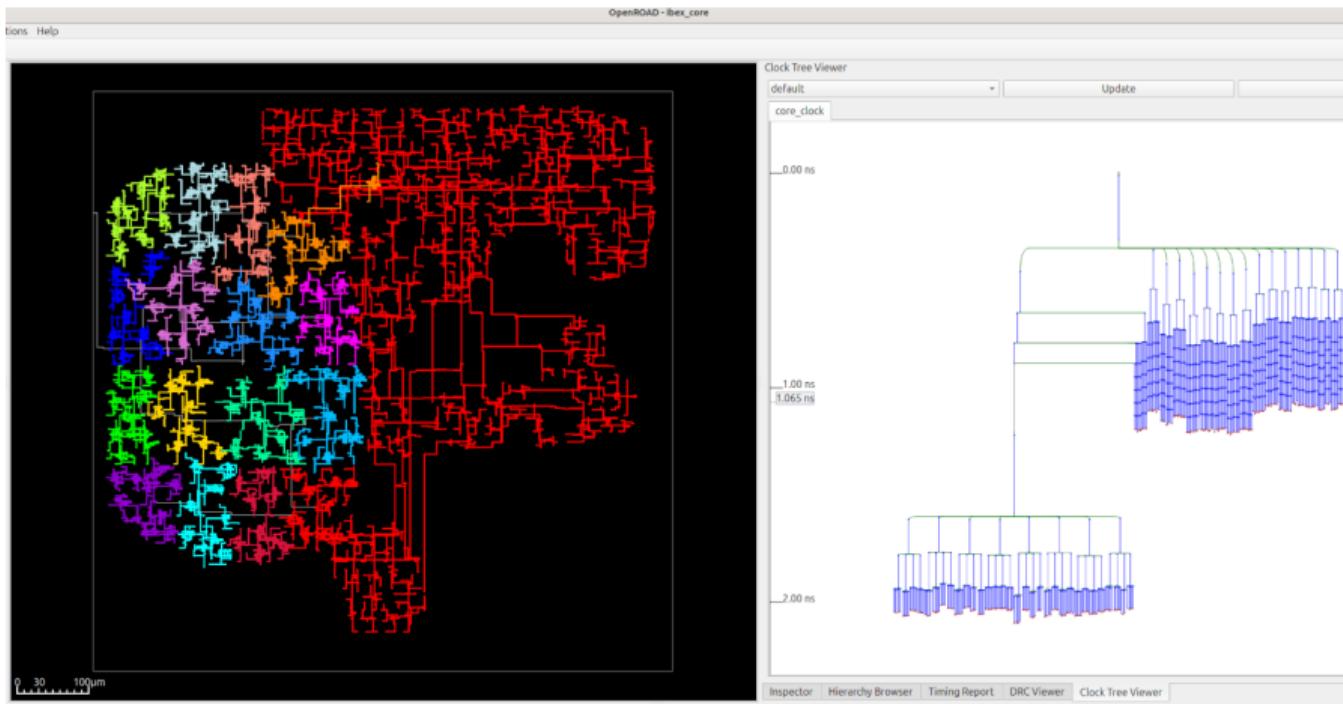


Figure 1: What is this?

Challenge 2

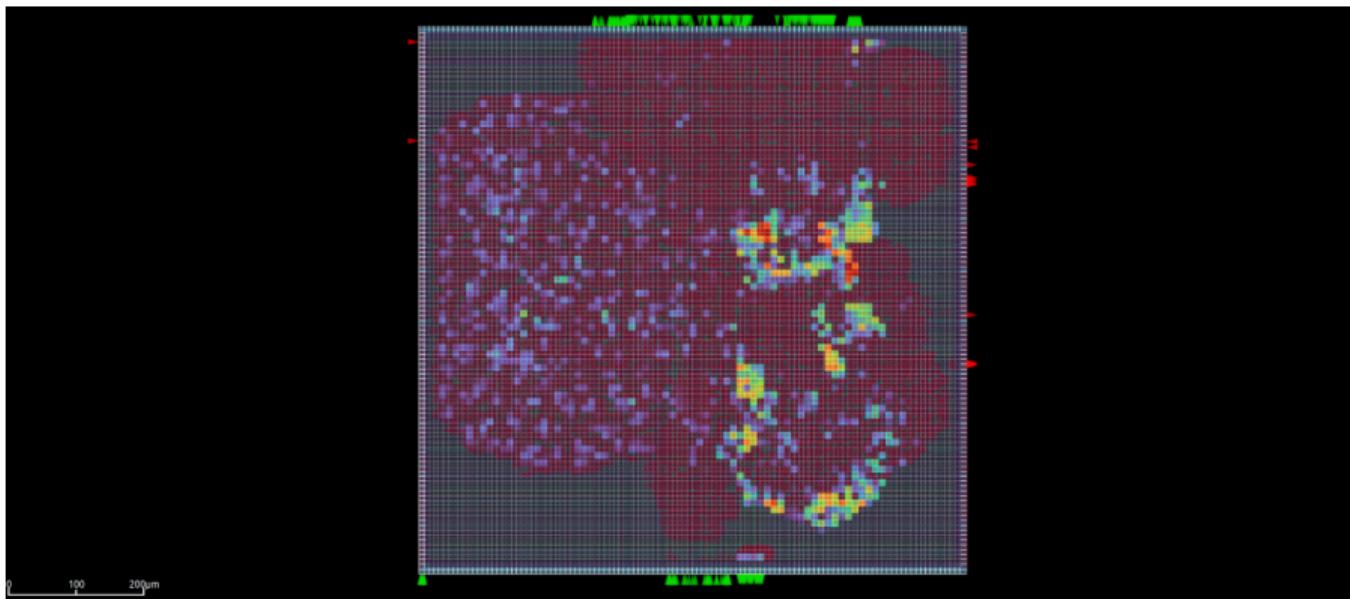


Figure 2: What is this?

Rebuild the picture with any design!

Challenge 3

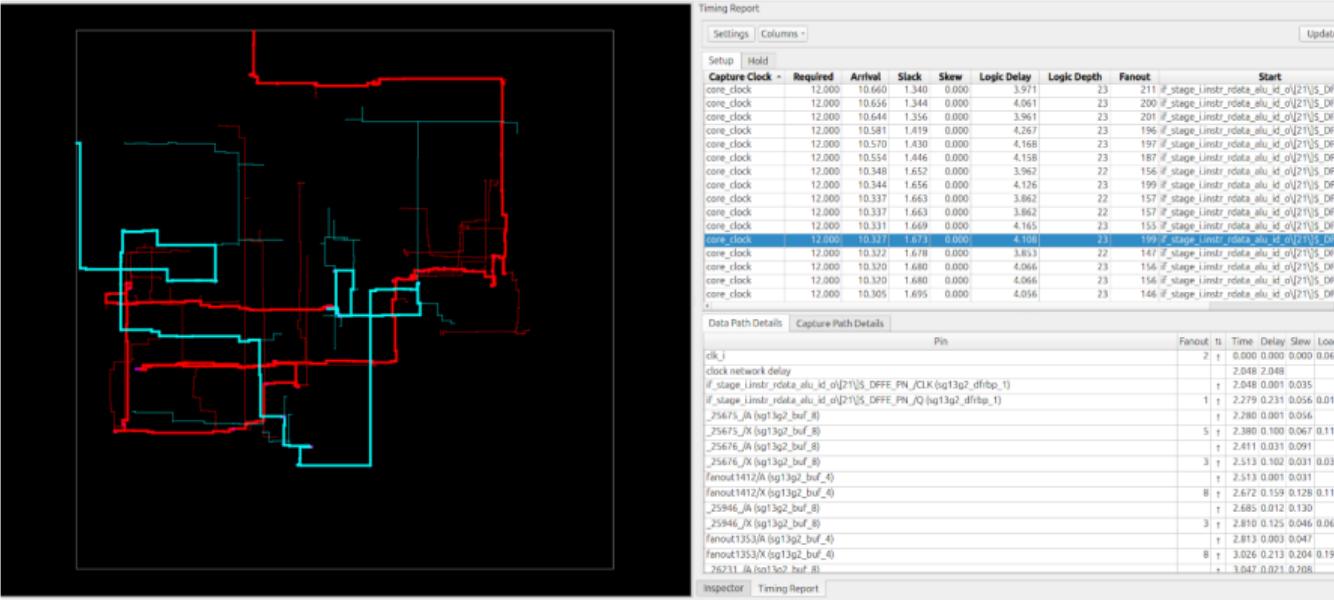


Figure 3: What is this?

Rebuild the picture with any design!

Challenge 4

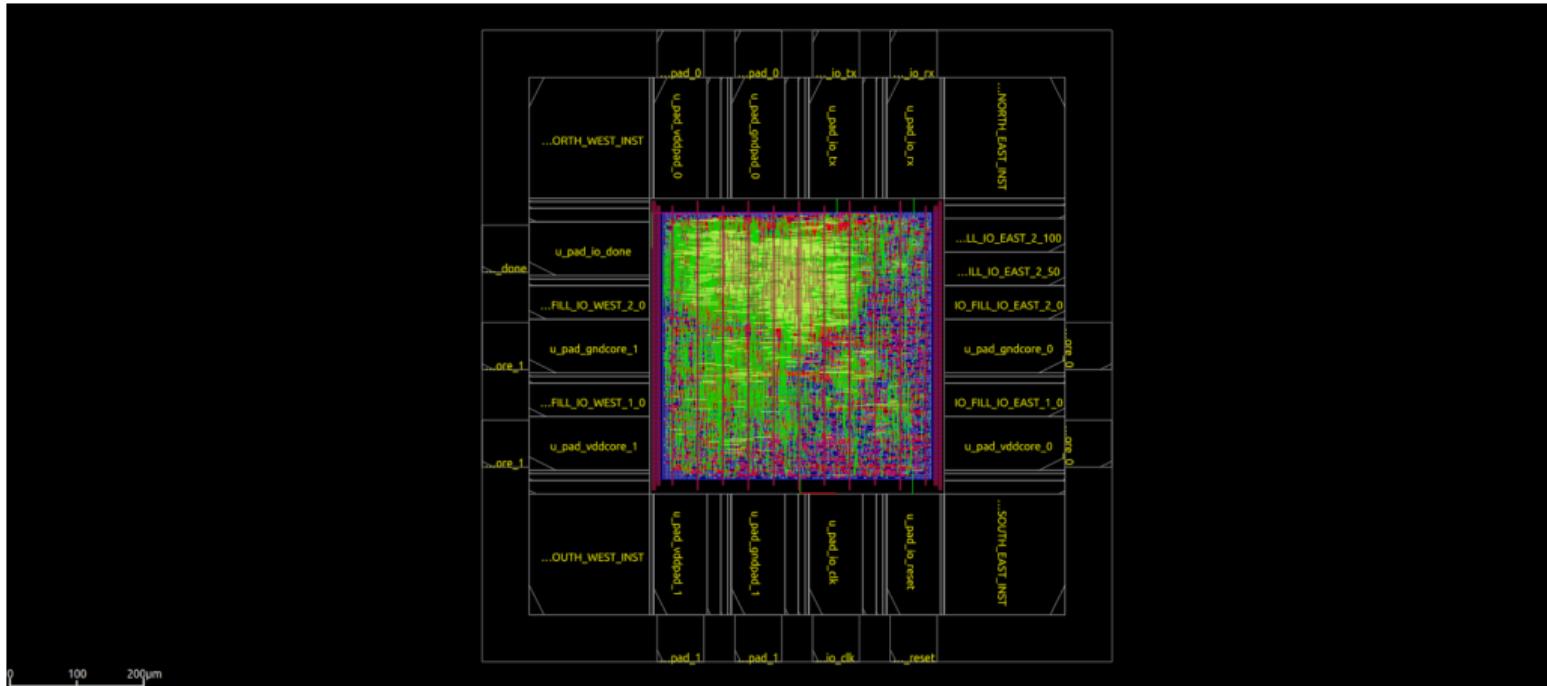


Figure 4: What is this?

Solutions (of the challenges)

- ① Ibex clocktree without most other layers (IHP PDK)
- ② Ibex power density >15 uW (IHP PDK)
- ③ Ibex single clock path with all layers off, but the timing paths (IHP PDK)
- ④ Masked aes without most metals and only pins names (IHP PDK)



Chapter 7 - OpenROAD flow scripts

Course authors (Git file)



- 1 What are we going to do now?
- 2 The tools in ORFS
- 3 Structure of flow directories
- 4 Important data locations
- 5 Design config variables



Section 1

What are we going to do now?



Previous chapters

What happened on the way to here:

- GDS-2-RTL: OpenROAD
- OpenROAD flow scripts (ORFS) overview
- ORFS flow steps and flow components
- First run of the flow scripts
- A Dive into the PDK (Klayout)
- Analysing: Heatmaps and more (ORFS GUI)



This chapter

NOW:

- One day of using ORFS
- Getting a hands on with important data and features.



Idea of today

There is a good tutorial about ORFS in the official documentation:

<https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html>

The ORFS online-tutorial was not written for the use with the IHP PDK especially, but we can adopt this easily.



**Introduction**[User Guidelines](#)[Getting Started](#)[Configuring The Design](#)[Running The Automated RTL-to-GDS Flow](#)[Viewing Results And Logs](#)[OpenROAD GUI](#)[Understanding and Analyzing](#)[OpenROAD Flow Stages and Results](#)[Troubleshooting Problems](#)

OpenROAD Flow Scripts Tutorial

Introduction

This document describes a tutorial to run the complete OpenROAD flow from RTL-to-GDS using [OpenROAD Flow Scripts](#). It includes examples of useful design and manual usage in key flow stages to help users gain a good understanding of the [OpenROAD](#) application flow, data organization, GUI and commands.

This is intended for:

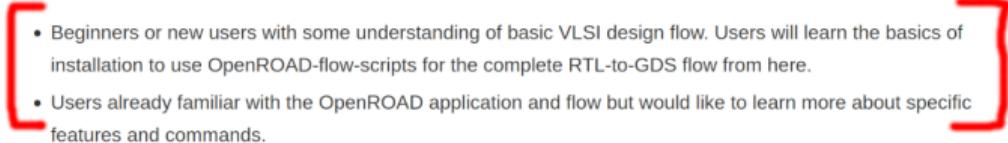
- 
- Beginners or new users with some understanding of basic VLSI design flow. Users will learn the basics of installation to use OpenROAD-flow-scripts for the complete RTL-to-GDS flow from here.
 - Users already familiar with the OpenROAD application and flow but would like to learn more about specific features and commands.

Figure 1: ORFS Online Tutorial



Lecture and trainings more interactive



Caveats

- ORFS does not handle multiple runs for a single design.
- The design run must be cleared with make clear_all, before a new runs can be started.
- !!! The previous data from the previous run will be lost.

Side feature:

- A run can start over where you left it.

My opinion:

- Both should be possible:
 - Keep data
 - Start over where left behind

But it is not.



Workaround for this

We have to:

- Manually save the previous data.
- Maybe just be renaming the directory.
- make gui_final only works on the actual design data.

Training: Multiple design runs



Section 2

The tools in ORFS



Section 3

Structure of flow directories



Section 4

Important data locations



Logs

- Where to find?
- How to read?

Training: Design logs

Training: Design logs



Results

- Where to find?
- How to read?

Training: Design results

Training: Design results



Reports

- Where to find?
- How to read?

Training: Design reports

Training: Design reports



Section 5

Design config variables



Design config variables

- Where to find?
- How to change?
- See the changes in the design data

Training: Changing the density

Training: Changing the density





Chapter 7 -
OpenROAD
flow scripts -
QUESTIONS

Course authors
(Git file)

Chapter 7 - OpenROAD flow scripts - QUESTIONS

Course authors (Git file)



Chapter 7 -
OpenROAD
flow scripts -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 7



Questions

Chapter 7 -
OpenROAD
flow scripts -
QUESTIONS

Course authors
(Git file)

Questions about:

- Power
- Performance
- Area
- How to change?
- Configuration of a design:
 - pdk specific configs
 - design specific configs
- Structure of a design project in ORFS?

Chapter 7 - OpenROAD flow scripts - TRAINING 1 - Common

Course authors (Git file)



1

Platform configurations

Platform configurations

Make use of the ORFS tutorial, platform configuration:

<https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#platform-configuration>



Compare two platforms

- Open the config.mk files for two platforms in parallel, so you can compare them.
- Platforms: ihp-sg13g2 and sky130hd

Questions:

- How are they similar and different?



Structure of the config.mk

- Open the config.mk of the platform ihp-sg13g2
- Name the sections of the config.mk

Questions:

- Where have you seen the titles (comments) of the sections before?



Variables

- Open the config.mk of the platform ihp-sg13g2
- Identify the following variables and find out their meanings / purpose.
- Variables:
 - DONT_USE_CELLS
 - IO_PLACER_H
 - CORE_MARGIN and CORE_UTILIZATION
 - KAYOUT_TECH_FILE
 - KAYOUT_DRC_FILE

Questions:

- Where is the information about the variables?
- The meanings and purpose of the variables.
- Is CORE_UTILIZATION in the config.mk? Why?
- Any other variables you looked up out of interest?



Chapter 7 - OpenROAD flow scripts - TRAINING - Common

Course authors (Git file)



Chapter 8 - Tapeout

Course authors (Git file)



1 Open-source Tapeout informations from IHP

2 READMEs

3 Read-the-docs

4 The last steps to a successful Tapeout

5 Contribute to open-source



Section 1

Open-source Tapeout informations from IHP



Open-source Tapeout informations from IHP

This chapter provides information about the Tapeout at IHP. Please follow the links to tag along with the chapter.



IHP - Repositories structure

- The designs for the open-source Tapeouts are collected as the “Open DesignLib”.
- During the process of each Tapeout there are dedicated repositories by the names TO_monthyear.
- After Tapeout these designs shall be merged into the Open DesignLib repository.



PDK and Open DesignLib

- Open.source PDK:

<https://github.com/IHP-GmbH/IHP-Open-PDK>

- Open DesignLib:

<https://github.com/IHP-GmbH/IHP-Open-DesignLib>



TapeOut repositories (TO)

- Tapeout May 2024:

https://github.com/IHP-GmbH/TO_May2024

- Tapeout Nov 2024:

https://github.com/IHP-GmbH/TO_Nov2024

- Tapeout Dec 2024:

https://github.com/IHP-GmbH/TO_Dec2024



Section 2

READMEs



README file in TO repositories

Important notes:

- Always look for the most actual and stable information
- Tools and workflows change fast
- Design rules don't change fast (if ever)
- Most parts of the PDK are long term stable



Submission process

Screenshot from the [README TO_DEC2024](#):

Submission process

To submit for our OpenMPW run you have to have a valid github account. Make a fork of this repository and then create a separate directory for your design next to the `ExampleDesign` (you can also make a copy and rename it). Structure your data according to our recommendations, update the documentation and push your files to your fork, then make a pull request.

ⓘ Caution

On each PR a github action will be triggered to run a minimal DRC precheck (rejection test). Please consider it and do not upload many `gds` files.

Once you make a PR a github action will run a minimum set of DRC checks on each `gds` and `gds.zip` file. If the test passes it means that your design is manufacturable at our pilot line not ensuring the reliability. An example of a failure is shown on the following figure

Figure 1: Submission process



Physical constraints

Screenshot from the [README TO_DEC2024](#):

Physical design constraint

1. Please align with the layout design rules which can be found [here](#)
2. The area granted to a community member is 2 mm^2 It includes the sealring.
3. The sealring can be found among KLayout PyCells.

Figure 2: Physical design constraints

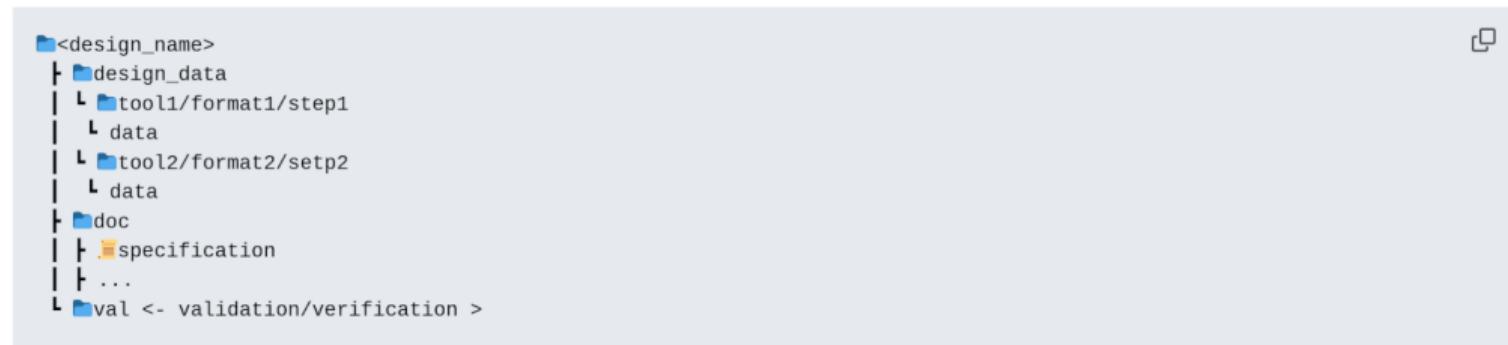


Project structure

Screenshot from the [README TO _DEC2024](#):

Directory structure

If you are a designer, we propose the following directory structure, which we and the community would appreciate you using. Please ensure that the design you submit is reproducible, meaning it should include all the information necessary to replicate the design.



```
<design_name>
├── design_data
│   ├── tool1/format1/step1
│   │   └── data
│   └── tool2/format2/step2
│       └── data
├── doc
│   ├── specification
│   └── ...
└── val <- validation/validation >
```

The first segmentation separates the `design data` from a `documentation` and `verification/validation data`.

Figure 3: Directories in a project



Design data structure

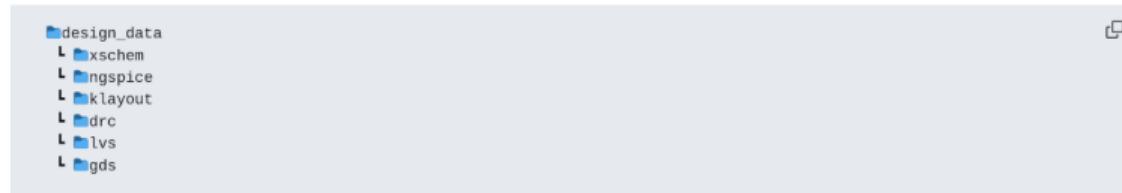
Screenshot from the **README TO _DEC2024:**

Design data directory structure

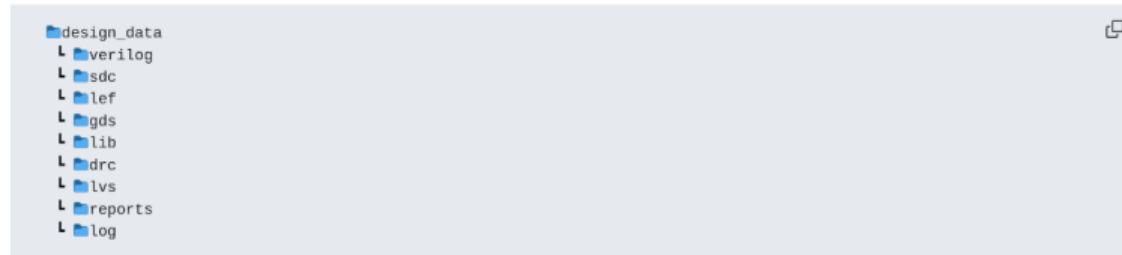
The `design_data` should be structured using tool/format/step specific scheme.

Here you can find some examples:

Example1



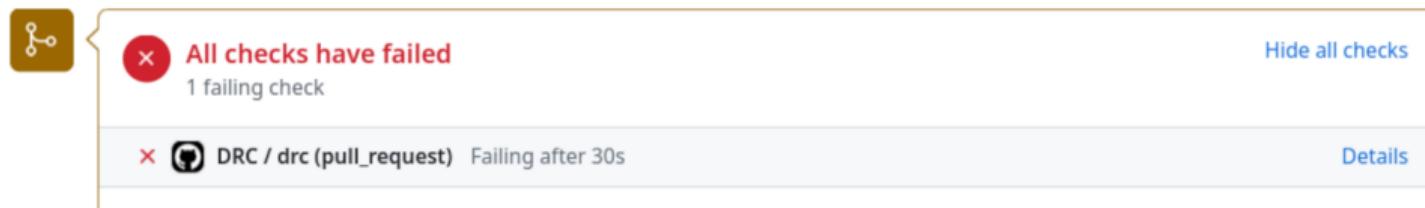
Example2



DRC

During a submission to a Tapeout the design gets checked with a DRC via Github Actions.

Once you make a PR a github action will run a minimum set of DRC checks on each `gds` and `gds.zip` file. If the test passes it means that your design is manufacturable at our pilot line not ensuring the reliability. An example of a failure is shown on the following figure



The detailed report can be downloaded from a link, which can be found at the end of the section `Details->Archive DRC Results` as show on the image:



Figure 5: DRC via Github actions

Section 3

Read-the-docs



Read-the-docs

- Open PDK Docu:

<https://ihp-open-pdk-docs.readthedocs.io/en/latest/index.html>

- Open DesignLib Docu:

<https://ihp-open-ip.readthedocs.io/en/latest/>



README versus Read-the-docs

- The README version is a extract of the full documentation (read-the-docs) for the DesignLib.
- The read-the-docs version contains the Tapeout calender and further info



Tapeout calendar

Welcome to IHP-Open-DesignLib documentation!

IHP-Open-DesignLib is repository, which contains open source IC designs using IHP SG13G2 BiCMOS processs. It is also a central point for design fabrication under the concept of IHP Free MPW runs funded by a public German project [FMD-QNC \(16ME083\)](#). Project funds can be used exclusively to produce chip designs for non-commercial activities, such as university education, research projects, and others. In the project, a continuation for the provision of free area for the open source community is to be worked out.

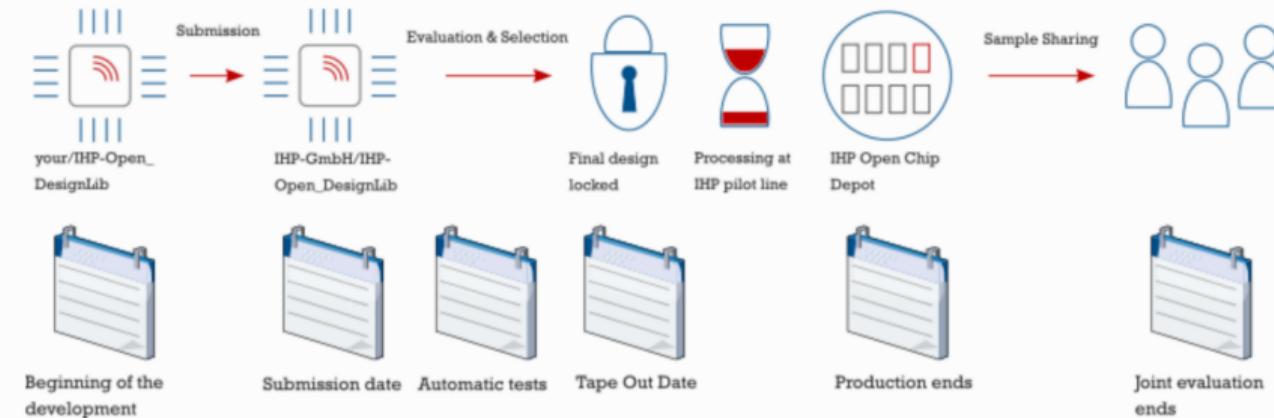
Tape In date	10 May 2024	11 Nov 2024	22 Nov 2024	07 Apr 2025	09 May 2025
Technology	SG13G2	SG13CMOS	SG13G2	SG13G2	SG13G2
Area available [mm ²]	10	220	20	140	30
11 Nov 2024	22 Nov 2024	07 Apr 2025	09 May 2025	18 Jul 2025	15 Sep 2025
SG13CMOS	SG13G2	SG13G2	SG13G2	SG13G2	SG13CMOS
220	20	140	30	30	220

Figure 6: Open DesignLib Tapeout Calendar



More submission information

The overview of the submission process is shown on the following figure.



The submission process contains a few steps, where some of them are mandatory and crucial:

1. Project development phase. At the beginning specifications and criteria will be defined by PDK status, later specifications from sponsors might be possible

Figure 7: Submission process detailed



Section 4

The last steps to a successful Tapeout



The last steps to a successful Tapeout

A few words about the finish of a Tapeout-ready GDS:

- A successfull Tapeout for a producable, correct and working micorchip contains more steps and knowdledge. It is out of scope of the course to explain and tutor these all details about this knowledge.
- Most of these steps will integrate into ORFS soon in a easy-to-use way eventually.



Topic to watch in design

Till then, here is a (not complete) list of important topics:

- Placement and instantiation of the Input-Outputs.
- Metall fills
- Sealring construction
- Automated DRC free



Github Actions

- Tapeout Nov 2024 Actions drc.yml:

https://github.com/IHP-GmbH/TO_Nov2024/blob/main/.github/workflows/drc.yml

- Tapeout Nov 2024 Actions runs:

https://github.com/IHP-GmbH/TO_Nov2024/actions



Active development in ORFS

Pull requests in ORFS with the search IHP in it:

<https://github.com/The-OpenROAD-Project/OpenROAD-flow-scripts/pulls?q=IHP+>

The screenshot shows a GitHub repository page for 'OpenROAD-flow-scripts'. The 'Pull requests' tab is selected, showing 53 results. A search bar at the top right contains 'Type [] to search'. Below the tabs are filters for 'Labels (44)', 'Milestones (0)', and a 'New pull request' button. A search bar also contains 'IHP'. The main list displays the following pull requests:

- #2744 Reverted AT mods in config.mk's ✓ (merged 3 days ago)
- #2730 update metrics for ppl fix ✓ (merged 4 days ago)
- #2726 ibex autotuner updates for gf180, ihp-sg13g2 and sky130hd ✓ (merged 5 days ago)
- #2723 update Yosys to version 0.49 ✓ (merged 4 days ago)
- #2722 AES AutoTuner updates ✓ (merged 5 days ago)
- #2721 flow: designs: ihp-sg13g2: i2c-gpio-expander: Fix missing IO pwr/gnd ✓ (merged last week)



Issues in ORFS (open and IHP in it):

<https://github.com/The-OpenROAD-Project/OpenROAD-flow-scripts/issues?q=is%3Aissue%20state%3Aopen%20IHP>

The screenshot shows the GitHub Issues page for the repository "The-OpenROAD-Project / OpenROAD-flow-scripts". The search bar at the top contains the query "is:issue state:open IHP". Below the search bar, there are filters for "Issues" (88), "Pull requests" (53), "Discussions" (0), "Actions", "Projects", "Security", and "Insights". The main list displays eight open issues:

- #2616 - [ERROR] LEF Cell 'spi_DEF_FILL' has no matching GDS/OAS cell. Cell will be empty when running ihp-sg13g2 examples (waiting on op)
- #2574 - Min metal area ignored by ORFS (DRC error) (drt) (waiting on op)
- #2553 - Honor Cell Footprint in sky130hd, sky130hs and ihp (rsz)
- #2536 - Change CI to only run relevant checks (syndace)
- #2473 - make command fails inside the docker during detail routing (vijayank88)
- #1953 - Bug in ihp-sg13g2 jpeg flow (luarss)

Figure 9: ORFS issues, open and IHP in it

Workarounds (example masked_aes)

The README of the design example from earlier (masked_aes) gives some basic, but sufficient information about the actual state and the workarounds.

<https://github.com/HEP-Alliance/masked-aes-tapeout/blob/main/README.md>

The ASIC

To build the ASIC, set up OpenROAD-flow-scripts, clone this repository as `<ORFS-Root>/flow/designs/ihp-sg13g2/masked_aes` and run the build like any other ORFS design.

Sealring

The sealring was generated using a script included with IHP's open PDK.

Clone the PDK and set up the technology in KLayout. The following command creates the sealring:

```
$ klayout -n sg13g2 -zz -r <IHP-repo-root>/ihp-sg13g2/libs.tech/klayout/tech/scripts/sealring.py -rd width=1065.0 -rc ↗
```

The generated sealring has to be moved by -60 in both directions, which can be done in KLayout.

Caveats

Information on steps that are not fully automated yet as well as known issues.

Metal Fill

Metal fill has to be performed on the output GDS using a KLayout script provided as part of the IHP PDK. The script is currently work-in-progress here: [IHP-GmbH/IHP-Open-PDK#229](#)

DRC Violations



Before your Tapeout

If you plan to do a Tapeout with open-source to a Shuttlerun at IHP:

- Get in touch with the people at IHP before submitting a GDS.
- Inform yourself about the actual changes in the tools, the PDK and the submission repositories.
- Look for recent examples from the CoreExpert Group.



Non public and non open-source designs

IMPORTANT NOTICE:

- Using open-source doesn't mean you have to publish your work in open-source!

With using the open-source EDA tools and the open-source IHP PDK it is possible

- to design and fabricate closed source microchips at IHP.
- to not make a design public.

If you plan to do this: Talk to IHP!



Section 5

Contribute to open-source



Contributing with Git

If you want to start contributing to open-source (maybe to this course?):

- Create a Git account
- Join a discussion about an issue.
- When you discover an error, write an issue yourself.

It is really not much more than a ticket-system via email.



The Feedback to this course

Your feedback will become issues in the course repository. Join in the discussion if you want to contribute:

<https://github.com/OS-EDA/Course/issues?q=is%3Aissue>

A screenshot of a GitHub repository interface. The top navigation bar shows 'OS-EDA / Course'. Below it, the 'Issues' tab is selected, showing a count of 1. Other tabs include 'Code', 'Pull requests', 'Actions', 'Projects', 'Wiki', 'Security', 'Insights', and 'Settings'. A search bar at the top right contains the placeholder 'Type / to search'. Below the tabs, there's a 'New issue' button. The main area displays two issues under the heading 'is:issue':

- Tutorial for the slides** (opened by ThorKin last week)
- Which pandoc version is needed to compile/build slides?** (closed by sergeiandreyev last week)

Filtering options like 'Open', 'Closed', 'Author', 'Labels', 'Projects', 'Milestones', 'Assignees', 'Types', and sorting by 'Newest' are available.

Figure 11: Issue tracking in the course repository



Chapter 8 -
Tapeout -
QUESTIONS

Course authors
(Git file)

Chapter 8 - Tapeout - QUESTIONS

Course authors (Git file)



Chapter 8 -
Tapeout -
QUESTIONS

Course authors
(Git file)

Recap questions for Chapter 8



Questions

Chapter 8 -
Tapeout -
QUESTIONS

Course authors
(Git file)

- How to submit a Tapeout at IHP?
- What parts are still in the making of ORFS to come soon?
- Explain Sealring, IO-Cells, Filler-Cells, PDN?
- Reference these to the designs of this course.
- How to contribute to this course?
- How to contribute to the PDK?
- What to do in case you discovered an error in ORFS?

Chapter 8 - Tapeout - TRAINING - Common

Course authors (Git file)



1

The IHP repos

OpenLib

PDK

TO_XYZ



Read the docs

Github Actions

- Look at some Github Actions in the Tapeout repositories
- What is a yaml workflow?

