Chapter 7 - OpenROAD flow scripts

Course authors (Git file)

Section 1

Introduction

Introduction

What happend 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)

NOW:

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

Section 2

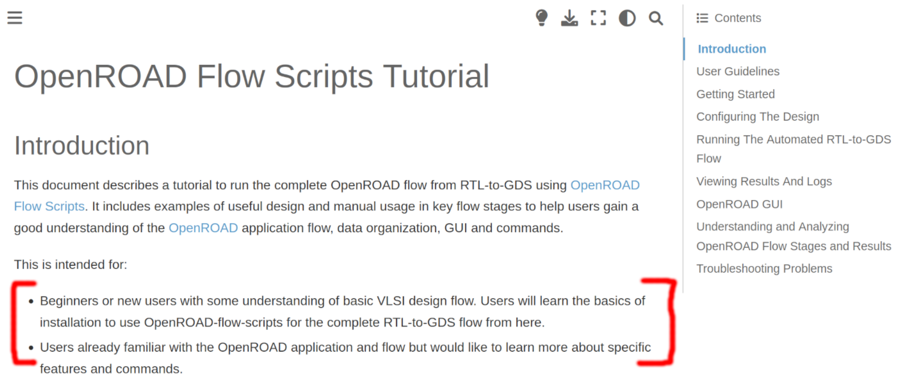
ORFS Tutorial

ORFS Tutorial

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.



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

Section 3

Multiple runs

Caveats of multiple runs in ORFS

- 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.

Workaround for saving the design data

1. After a design run:
   - Rename the results directory to something different:
     - flow/results/ihp-sg13g2/designname/base
     - flow/results/ihp-sg13g2/designname/base_old_1
   - Rename the reports directory to something different:
     - flow/reports/ihp-sg13g2/designname/base
     - flow/reports/ihp-sg13g2/designname/base_old_1
2. With the start of the next run (make):
   - The original directory gets created again.
3. Repeat that before every new run of the same design.

Reviewing the older design data

- The command `make gui_final` only works on the enabled design (Makefile, DESIGN_CONFIG)
- To load an older design from a renamed folder, run `openroad −gui`
- This opens an empty GUI and you can load a GDS into it.
- This can be done multiple times in parallel.

Section 4

Structure of flow directories

Structure of flow directories

Inside the flow directory:

```
flow$ ls

Makefile     platforms  test
designs      reports    tutorials
results      util       logs
objects      scripts
```

- **Makefile**: Runs the RTL-2-GDS toolchain with a design
- **platforms**: Technology nodes and PDKs
- **designs**: Source and configuration files of the designs
- **reoprts**: Generated report files from the design runs
- **results**: Generated result files from the design runs

Section 5

TCL Console and commands

TCL Console and commands

At the bottom of the OpenROAD GUI is the TCl command console.

Type `help` into the console to get a list of the avaiable commands and their syntax.

Some commands that were already used in this couse:

- save_image
- report_design_area
- report_power
- report_worst_slack

Section 6

Reports

Reports

- Reports get generated for each design run.
- The reports are stored in the reports directory.
- These are the report files for the gcd example:

```
reports/ihp-sg13g2/gcd/base$ ls

2_floorplan_final.rpt  6_finish.rpt           final_resizer.webp
3_detailed_place.rpt   congestion.rpt         final_routing.webp
3_resizer.rpt          cts_core_clock.webp    grt_antennas.log
4_cts_final.rpt        drt_antennas.log       synth_check.txt
5_global_place.rpt     final_clocks.webp      synth_stat.txt
5_global_route.rpt     final_ir_drop.webp     VDD.rpt
5_route_drc.rpt        final_placement.webp   VSS.rpt
```

Section 7

Logs

Logs

- Logs get generated for each design run.
- The logs are stored in the logs directory.
- These are the log files for the gcd example:

```
logs/ihp-sg13g2/gcd/base$ ls

1_1_yosys_canonicalize.log   2_6_floorplan_pdn.json      4_1_cts.log
1_1_yosys_hier_report.log    2_6_floorplan_pdn.log       5_1_grt.json
1_1_yosys.log                3_1_place_gp_skip_io.json   5_1_grt.log
2_1_floorplan.json           3_1_place_gp_skip_io.log    5_2_route.json
2_1_floorplan.log            3_2_place_iop.json          5_2_route.log
2_2_floorplan_io.json        3_2_place_iop.log           5_3_fillcell.json
2_2_floorplan_io.log         3_3_place_gp.json           5_3_fillcell.log
2_3_floorplan_tdms.json      3_3_place_gp.log            6_1_fill.json
2_3_floorplan_tdms.log       3_4_place_resized.json      6_1_fill.log
2_4_floorplan_macro.json     3_4_place_resized.log       6_1_merge.log
2_4_floorplan_macro.log      3_5_place_dp.json           6_report.json
2_5_floorplan_tapcell.json   3_5_place_dp.log            6_report.log
2_5_floorplan_tapcell.log    4_1_cts.json
```

Section 8

Results

Results

- Results (mostly odb, GDS) get generated for each design run.
- The results are stored in the results directory.
- These are the result files for the gcd example:

```
flow/results/ihp-sg13g2/gcd/base$ ls

1_1_yosys.v                3_3_place_gp.odb        6_1_fill.sdc
1_synth.rtlil              3_4_place_resized.odb   6_1_fill.v
1_synth.sdc                3_5_place_dp.odb        6_1_merged.gds
1_synth.v                  3_place.odb             6_final.def
2_1_floorplan.odb          3_place.sdc             6_final.gds
2_2_floorplan_io.odb       4_1_cts.odb             6_final.odb
2_3_floorplan_tdms.odb     4_cts.odb               6_final.sdc
2_4_floorplan_macro.odb    4_cts.sdc               6_final.spef
2_5_floorplan_tapcell.odb  5_1_grt.odb             6_final.v
2_6_floorplan_pdn.odb      5_2_route.odb           clock_period.txt
2_floorplan.odb            5_3_fillcell.odb        keep_hierarchy.tcl
2_floorplan.sdc            5_route.odb             mem.json
3_1_place_gp_skip_io.odb   5_route.sdc             route.guide
3_2_place_iop.odb          6_1_fill.odb            updated_clks.sdc
```

Section 9

Basic design initialization

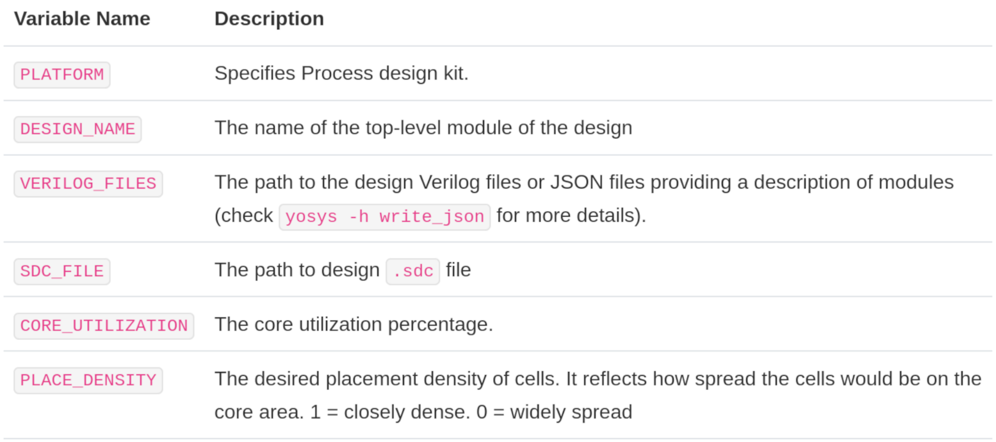
Design configuration (config.mk)

config.mk from the ibex example:

https://github.com/The-OpenROAD-Project/OpenROAD-flow-scripts/blob/master/flow/designs/sky130hd/ibex/config.mk

Tutorial about the design configuration;

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



Variable Name	Description
`PLATFORM`	Specifies Process design kit.
`DESIGN_NAME`	The name of the top-level module of the design
`VERILOG_FILES`	The path to the design Verilog files or JSON files providing a description of modules (check `yosys -h write_json` for more details).
`SDC_FILE`	The path to design `.sdc` file
`CORE_UTILIZATION`	The core utilization percentage.
`PLACE_DENSITY`	The desired placement density of cells. It reflects how spread the cells would be on the core area. 1 = closely dense. 0 = widely spread

Figure 2: Design config variables

Clock constraints (constraints.sdc)

constraints.sdc from the ibex example:

```
current_design ibex_core

set clk_name  core_clock
set clk_port_name clk_i
set clk_period 10.0
set clk_io_pct 0.2

set clk_port [get_ports $clk_port_name]

create_clock -name $clk_name -period $clk_period $clk_port

set non_clock_inputs [lsearch -inline -all -not -exact [all_inputs] $clk_port]

set_input_delay  [expr $clk_period * $clk_io_pct] -clock $clk_name $non_clock_inputs
set_output_delay [expr $clk_period * $clk_io_pct] -clock $clk_name [all_outputs]
```

https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#timing-constraints

Design Verilog input

https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#design-input-verilog

These are the Verilog files of the ibex design example:

```
flow/designs/src/ibex$ ls

ibex_alu.v                 ibex_ex_block.v          ibex_register_file_ff.v       prim_ram_1p.v
ibex_branch_predict.v      ibex_fetch_fifo.v        ibex_register_file_fpga.v     prim_secded_28_22_dec.v
ibex_compressed_decoder.v  ibex_icache.v            ibex_register_file_latch.v    prim_secded_28_22_enc.v
ibex_controller.v          ibex_id_stage.v          ibex_wb_stage.v               prim_secded_39_32_dec.v
ibex_core.v                ibex_if_stage.v          LICENSE                       prim_secded_39_32_enc.v
ibex_counter.v             ibex_load_store_unit.v   prim_badbit_ram_1p.v          prim_secded_72_64_dec.v
ibex_cs_registers.v        ibex_multdiv_fast.v      prim_clock_gating.v           prim_secded_72_64_enc.v
ibex_csr.v                 ibex_multdiv_slow.v      prim_generic_clock_gating.v   prim_xilinx_clock_gating.v
ibex_decoder.v             ibex_pmp.v               prim_generic_ram_1p.v         README.md
ibex_dummy_instr.v         ibex_prefetch_buffer.v   prim_lfsr.v
```

Section 10

Design tweaking

Design tweaking

- OpenROAD is build on many different tools
- It does not feel consistent to configure the tools.
- To find and understand the possiblities of improving a design via tweaking one must read the documentation of the tools.
- It might take some time to become comforatable with tweaking.
- Don't give up!

In the following we present

- some easy tweaking possibilities to start with

Synthesis AREA or SPEED

https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#area-and-timing-optimization

In a nutshell:

- Set ABC_SPEED=1 or ABC_AREA=1 in the config.mk
- Rerun.

DIE_AREA and CORE_AREA

- Set DIE_AREA and CORE_AREA in the config.mk
- Rerun

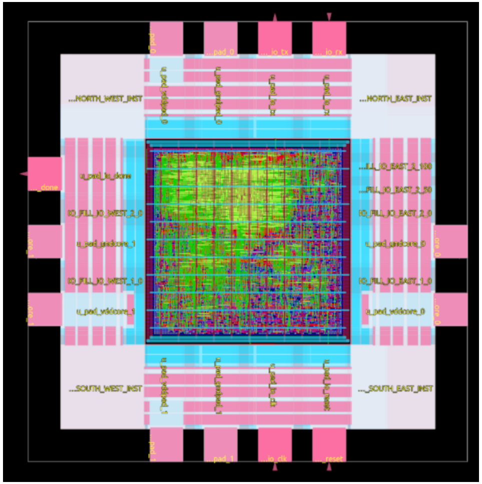
This is an examplefor the two variables, taken from the config.mk in the masked_aes example earlier. The comments contain a list of added spaces around the core area.

masked_aes config.mk:

```
# (Sealring: roughly 60um)
# I/O pads: 180um
# Bondpads: 70um
# Margin for core power ring: 20um
# Total margin to core area: 270um
export DIE_AREA  =   0   0 940 940
export CORE_AREA = 270 270 670 670
```

masked_aes areas

The area calculations from the masked_aes config.mk in a GDS:



Density

In a nutshell:

- Change the PLACE_DENSITY value in the config
- Value between 0.2 and 0.95
- Rerun

```
export PLACE_DENSITY ?= 0.88
```

CORE_UTILIZATION

In a nutshell:

- Change the CORE_UTILIZATION value in the config
- Value between 20 and 80
- Rerun

export CORE_UTILIZATION = 45

Example for Utilization and Density with the ibex design

In the ORFS tutorial is a tweak example with these two variables:

https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#defining-placement-density

Read how this should change the GDS.

Further reading on the topic

- The chapters in the ORFS tutorial starting here:

https://openroad-flow-scripts.readthedocs.io/en/latest/tutorials/FlowTutorial.html#understanding-and-analyzing-openroad-flow-stages-and-results

- Synthesis Explorations
- Floorplanning
- Power Planning And Analysis
- Macro or Standard Cell Placement
- Timing Optimizations
- Clock Tree Synthesis
- ...

Section 11

Finishing a design

Footprint for IOPads

- A TCL script is needed to arrange the IOPads around the core design area.
- This TCL script must be referenced in the config.mk:

```
export FOOTPRINT_TCL = $(DESIGN_HOME)/$(PLATFORM)/$(DESIGN_NICKNAME)/footprint.tcl
```

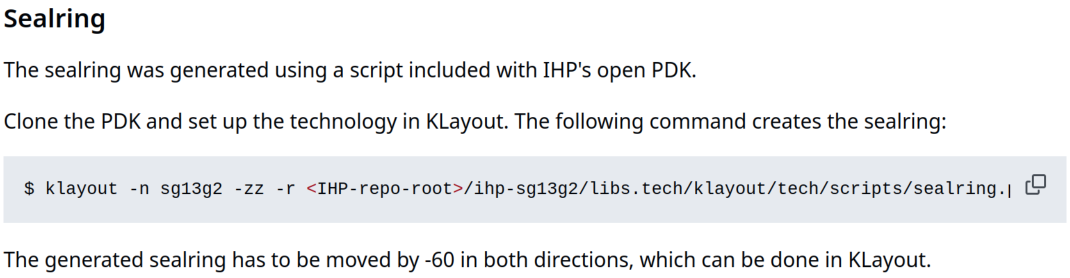
A working example of such a footprint.tcl can be found inside the masked_aes example:

masked_aes footprint.tcl:

https://github.com/HEP-Alliance/masked-aes-tapeout/blob/main/footprint.tcl

Sealring

- A sealring GDS must be generated and merged with the design GDS.
- Information about how to create a sealring is available as an example in the masked_aes README:



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.|
```

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

Figure 4: Sealring Information masked_aes

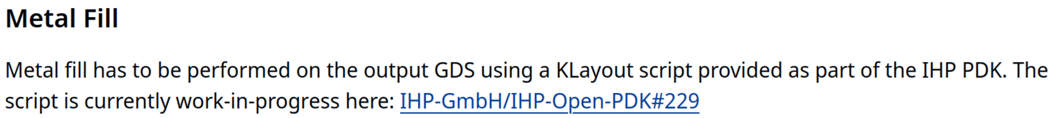
https://github.com/HEP-Alliance/masked-aes-tapeout/tree/main?tab=readme-ov-file#sealring

Metal fill

- Ongoing issue discussion about the Metall fill:

https://github.com/IHP-GmbH/IHP-Open-PDK/pull/229

It is solved and merged to the repo, but the issue is kept open for enhancement reasons.



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

Figure 5: Metal fill information masked_aes