



# TheSyDeKick

System development and verification framework in  
Python

Presenter: Marko Kosunen  
Authors: TheSyDeKick contributors

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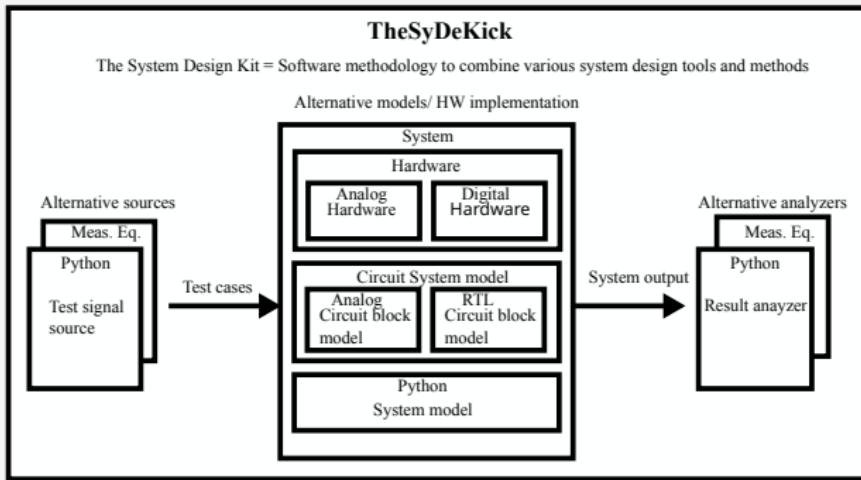
# Outline

- TheSyDeKick - What it is
- Simulator interfaces
- Principle of simulation
- Example 1: Inverter tests
- Example 3: ADC model
- Example 4: Multi-user MIMO receiver
- Example 5: Outphasing transmitter
- Example 6: A-Core RISC-V processor chip
- Example 7: EM field simulations
- Conclusion and acknowledgements

# TheSyDeKick - What it is

# What is TheSyDeKick

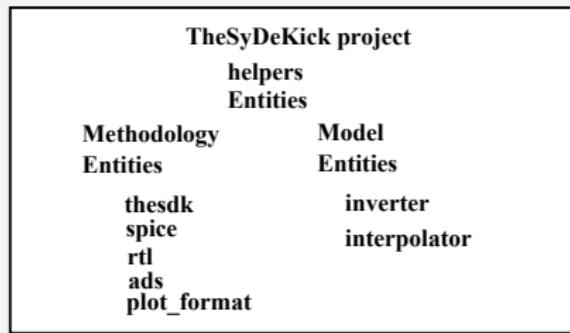
## TheSyDeKick at glance



- TheSyDeKick is a framework to enable programmatic verification of complex mixed signal systems. Contributed by multiple designers.

# TheSyDeKick project structure

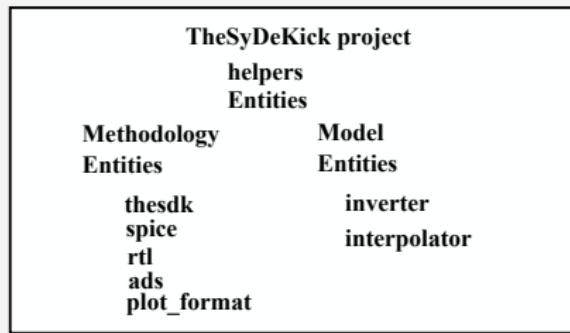
## TheSyDeKick project structure



- ▶ TheSyDeKick is a well structured container for:
  - ▶ Python packages (Entities), that provide *formalism and methods to run simulations in python, and with external simulators*
  - ▶ Python packages (Entities), that provide formalism to create and use *IO compatible models*

# TheSyDeKick project structure

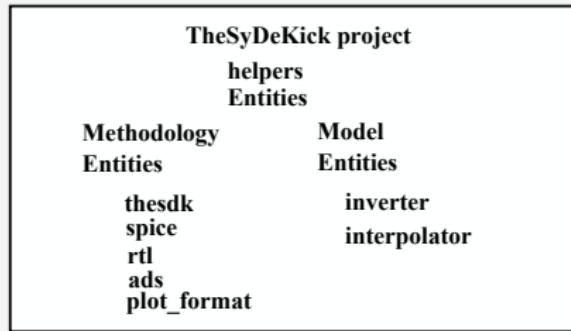
## TheSyDeKick project structure



- ▶ TheSyDeKick is a cumulative collection of Python classes and methods that help the designer to carry out the most common tasks encountered in microelectronics design. Most likely the *simulation task you have in mind has some supporting methodology available in TheSyDeKick*

# TheSyDeKick project structure

## TheSyDeKick project structure



- ▶ TheSyDeKick formalism helps the designer to:
  - ▶ Write and simulate modular, hierarchical, IO compatible hardware models with various levels of abstraction (python, spice/RTL or even EM field simulator)
  - ▶ Control the abstraction level with one parameter on chosen level of hierarchy.
- ▶ TheSyDeKick is *nothing more*

[https://github.com/TheSystemDevelopmentKit/thesdk\\_template/wiki/The-System-Development-Kit](https://github.com/TheSystemDevelopmentKit/thesdk_template/wiki/The-System-Development-Kit)

# How it is constructed?

- ▶ Minimum set of structural constraints,
  - ▶ IO definitions
  - ▶ Blocks described as connected *Entities*.
- ▶ Aims to automation of *repetitive, well structured tasks*
  - ▶ Model and modeling environment structure with init scripts
  - ▶ Running simulations
  - ▶ Defining simulator calls
  - ▶ Documentation with Docstrings see for example.

<https://thesystemdevelopmentkit.github.io/docs/index.html>

- ▶ Currently supports Python, Verilog, VHDL and three Spice variants.
- ▶ Open source simulators: Icarus for Verilog, NgSpice for analog circuits.
- ▶ Under construction: Measurement equipment.

<https://github.com/TheSystemDevelopmentKit>

# TheSyDeKick project file structure

## TheSyDeKick project structure

```
thesydekick_project/
└── Entities/
    ├── thesdk/
    ├── rtl/
    ├── spice/
    ├── ads/
    └── amplifier/
        ├── amplifier/
        │   └── __init__.py
        ├── spice/
        ├── simulations/
        └── doc/
```

[https://github.com/TheSystemDevelopmentKit/thesdk\\_template](https://github.com/TheSystemDevelopmentKit/thesdk_template)



# Simulator interfaces

# Analog simulator interface

- ▶ Calling analog simulators is handled through a common interface, the **spice** module
- ▶ Ultimate goal of **spice**: support for most industry standard simulators
  - ▶ General (w.r.t to simulator), reusable simulation testbenches
  - ▶ Centralized post processing based on open source tools and libraries.
- ▶ Save time in re-writing testbenches for different simulations and centralize effort to all-in-one testbench
  - ▶ Currently support for DC, AC, and Transient analysis. Easy to add other analysis types as IO formats are the same.

<https://github.com/TheSystemDevelopmentKit/spice>

# Digital simulator interface

- ▶ Calling digital simulators is handled the **rtl** module
  - ▶ Most commonly used simulation testbenches automatically generated for both Verilog and VHDL design under tests.
  - ▶ Automated file IO generation for strings (bit vectors), integers, and complex numbers.
  - ▶ Support for any signal type through customizable format parameter.

<https://github.com/TheSystemDevelopmentKit/rtl>

# EM field simulator interface

- ▶ Interface entity **ads** enables EM simulator Momentum from python desing environment.
- ▶ Used so far for example:
  - ▶ Together with Berkeley Analog Generator in characterization of parametrized inductors transformers.
  - ▶ In extraction of S-parameters from 3D layout structures.

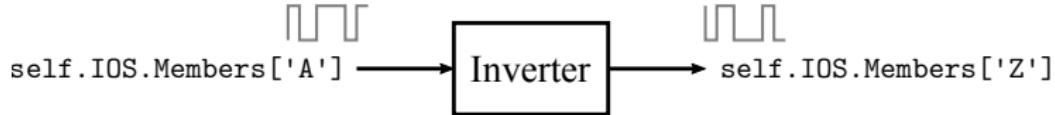
<https://github.com/TheSystemDevelopmentKit/ads>

# TheSyDeKick simulation procedure

- ① Write the testbench
  - ① Specify analysis type, inputs, outputs, supplies etc. based on TB properties
  - ② Configure simulator options, corners, etc. based on testbench properties
  - ③ Specify desired outputs, e.g. FFT of waveform, transient waveform
  - ④ Specify run cases, e.g. transient analysis for 2 different netlists, etc.
- ② Run the simulation
- ③ Analyze results
- ④ (Optional) Repeat simulation for different sets of parameters
  - Once you have one testbench, reuse for similar applications makes things faster
  - Results saved (if user chooses so), no need to repeat lengthy simulations to fix errors in post processing

# Principle of simulation

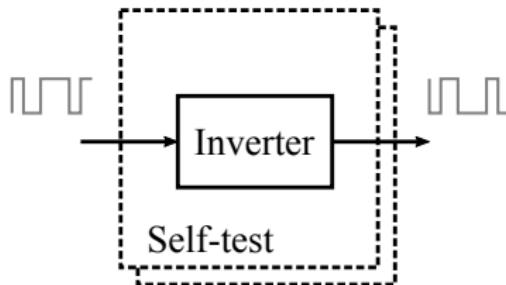
# First step: Self test



- ▶ Example: inverter
- ▶ Functional model: Inverts input signal
- ▶ IOS is a Bundle-type container for storing IO data
- ▶ Can have as many members as needed

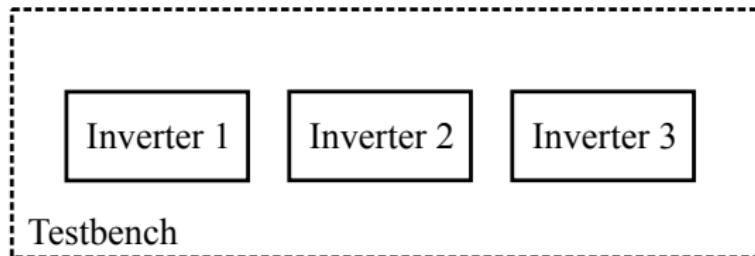
# First step: Self test

Python / VHDL / SystemVerilog / Eldo



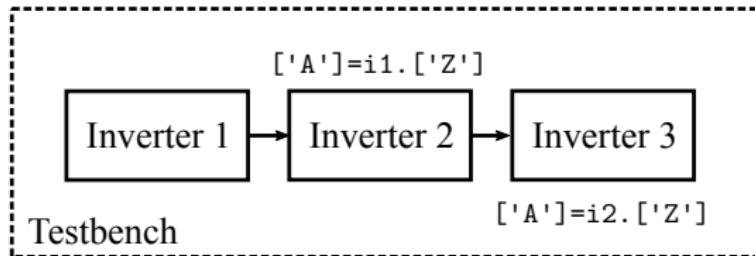
- ▶ Multiple models for the same entity: Python,spice,rtl
- ▶ Self-test is a way to verify the functionality of entity “in vacuum”
- ▶ Self-test generates and feeds the identical input data to all simulators

# Next step: Connecting Entities



- ▶ Entities care connected inside another entities, (or in a testbench).
- ▶ Chain of inverter instances can created with a for loop.

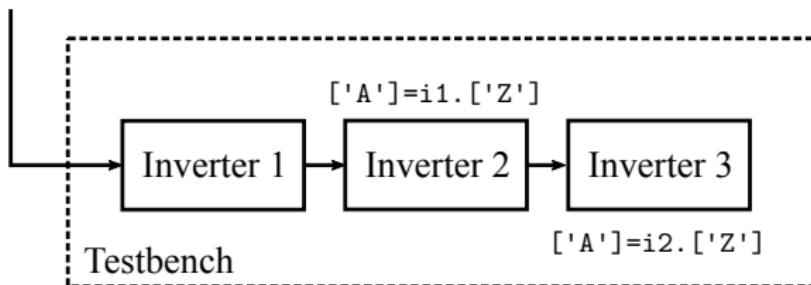
# Next step: Connecting Entities



- ▶ Entities can be connected inside another entities, (or in a testbench).
- ▶ Chain of inverter instances can be created with a for loop.
- ▶ Data flow defined by IOS connections

# Next step: Connecting Entities

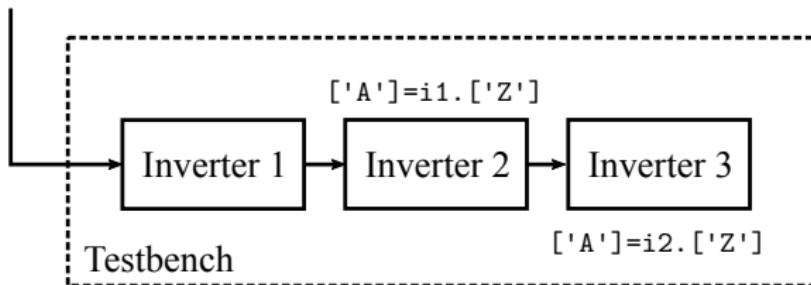
i1,['A'].Data=



- ▶ Entities care connected inside another entities, (or in a testbench).
- ▶ Chain of inverter instances can created with a for loop.
- ▶ Data flow defined by IOS connections
- ▶ Signal is assigned as input of 1st element

# Next step: Connecting Entities

i1.['A'].Data= 

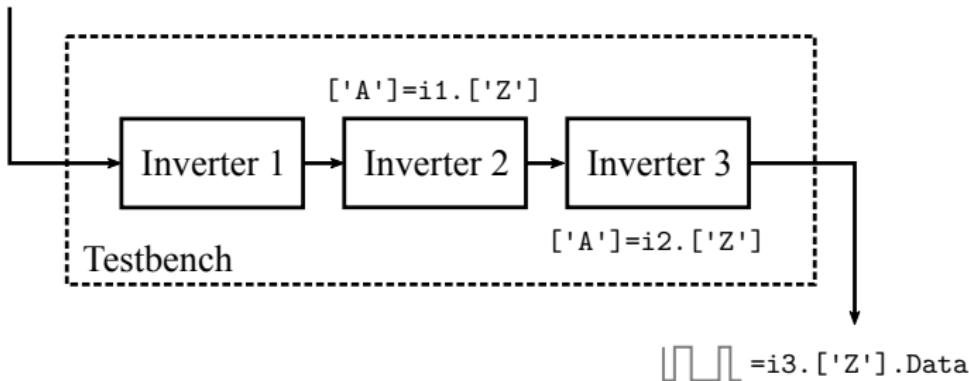


`i1.Run() -> i2.Run() -> i3.Run()`

- ▶ Entities care connected inside another entities, (or in a testbench).
- ▶ Chain of inverter instances can created with a for loop.
- ▶ Data flow defined by IOS connections
- ▶ Signal is assigned as input of 1st element
- ▶ Signal is propagated through the chain by running the entities

# Next step: Connecting Entities

i1.['A'].Data= 



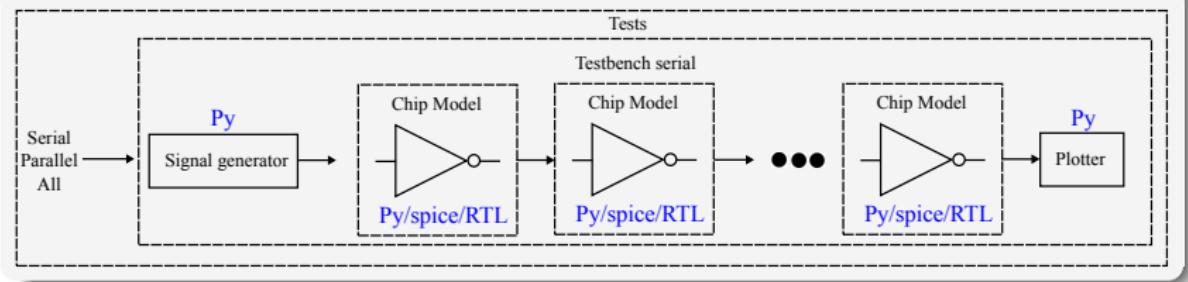
- ▶ In the end, the output of the last element contains processed data

## Example 1: Inverter tests

# Verifying inverter system

- ▶ Example of test hierarchy from bottom up: inverter, inverter testbench and inverter tests.

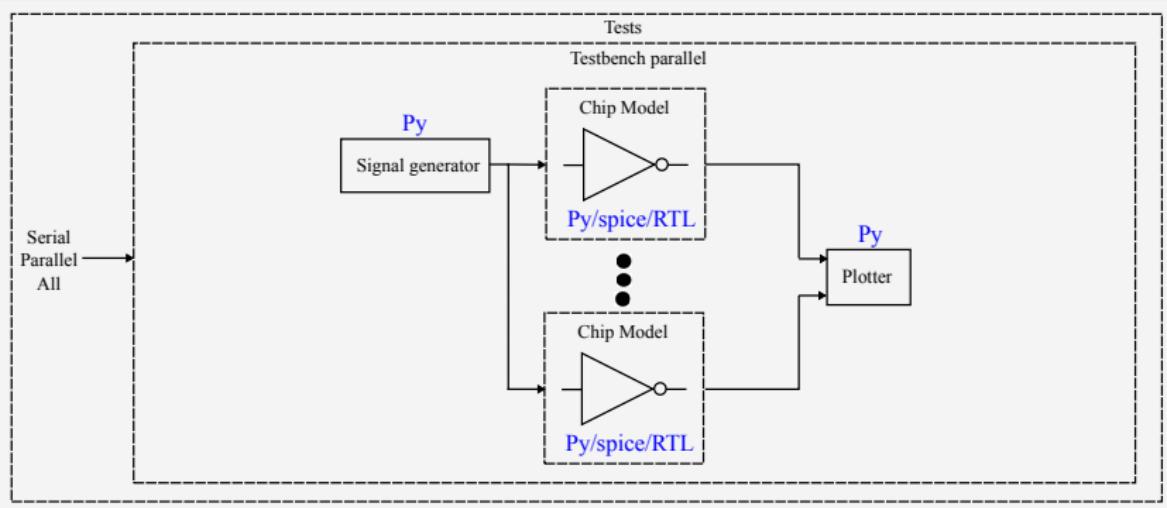
## Inverter system serial test configuration



# Multiple testbench configurations

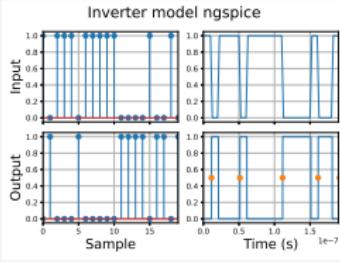
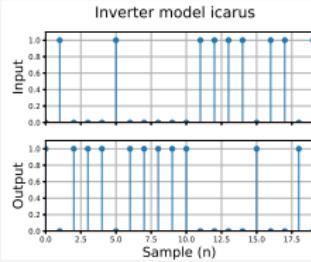
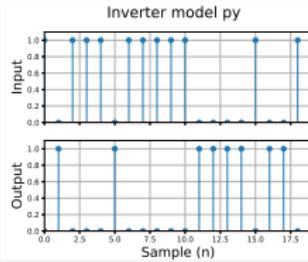
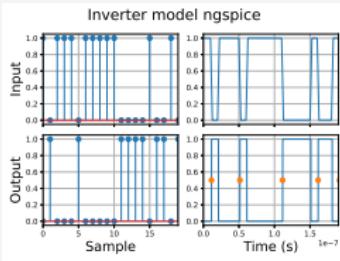
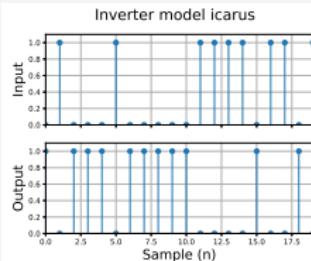
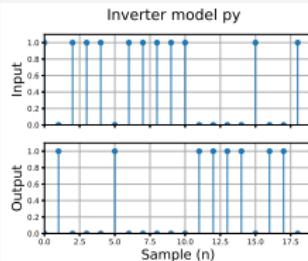
- ▶ Construction methods of testbench class enable various test configurations.
- ▶ All parallel executions can be executed in parallel threads resulting in remarkable speedup.

## Inverter system parallel test configuration



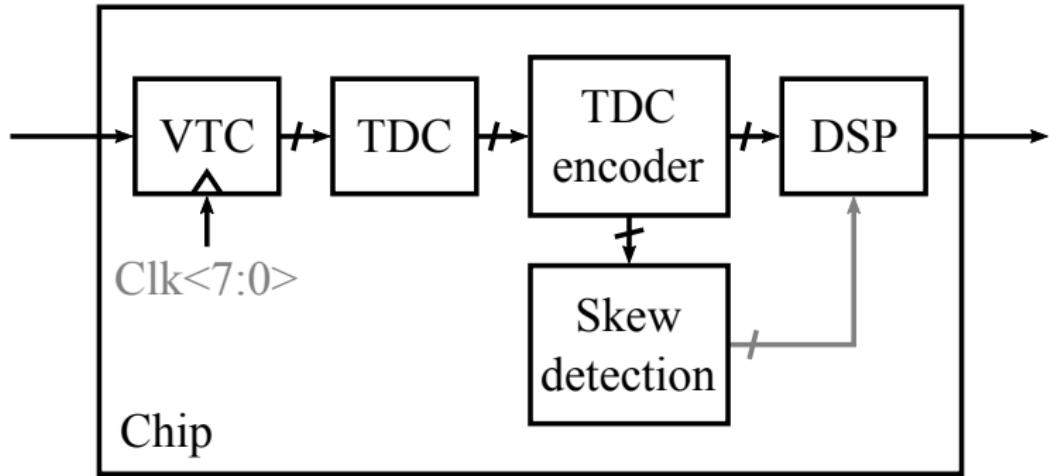
# Inverter system verification results

## Inverter system results

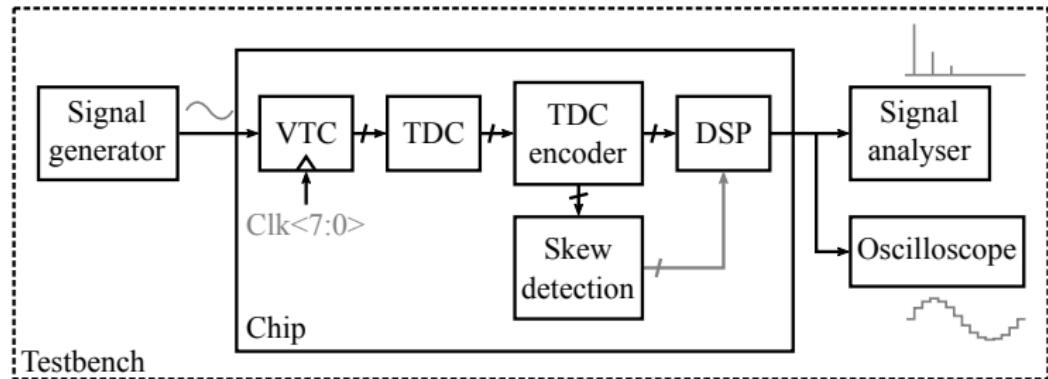


## Example 3: ADC model

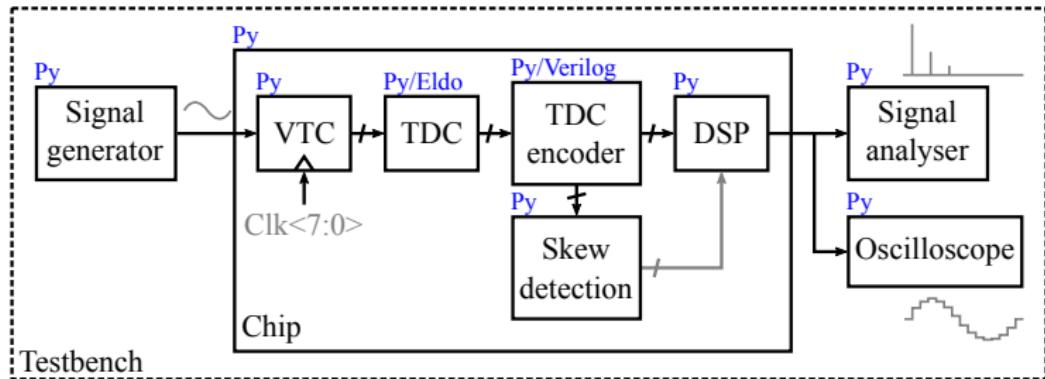
## Example 3: ADC Model



# Example 3: ADC Model

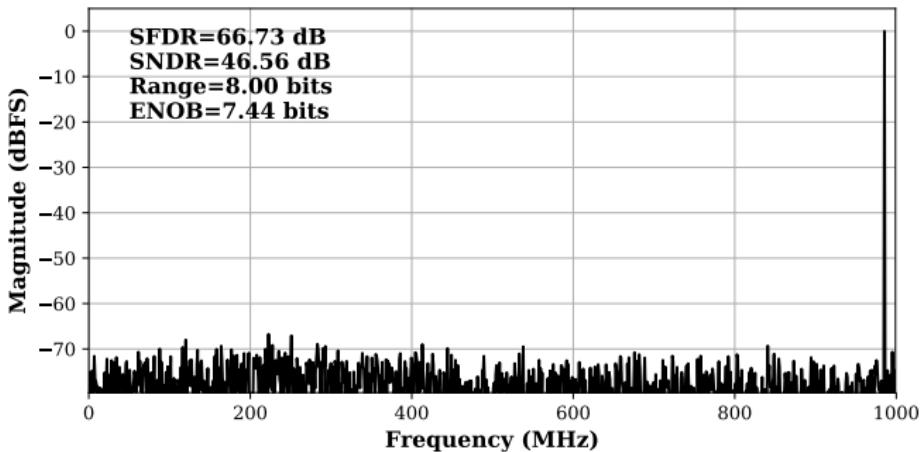


# Example 3: ADC Model



## Example 3: ADC Model

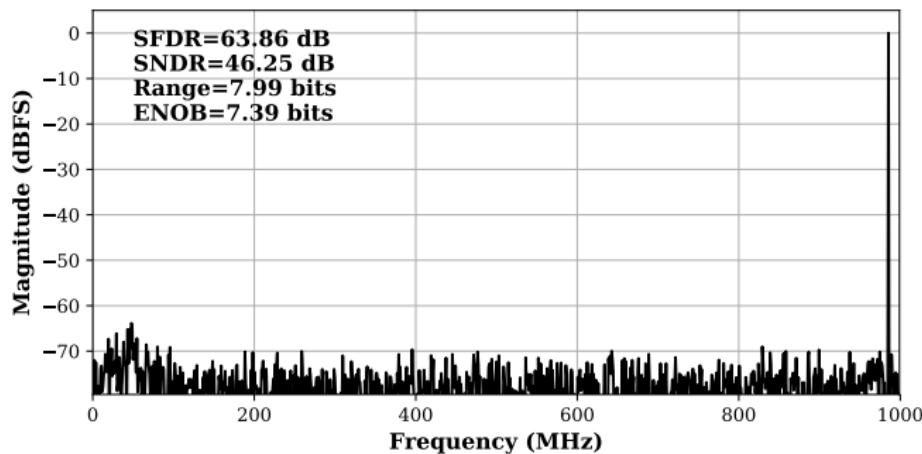
Full ADC Model in Python



- Spectrum plotted by signal\_analyser -module, which also calculates SNDR etc.

## Example 3: ADC Model

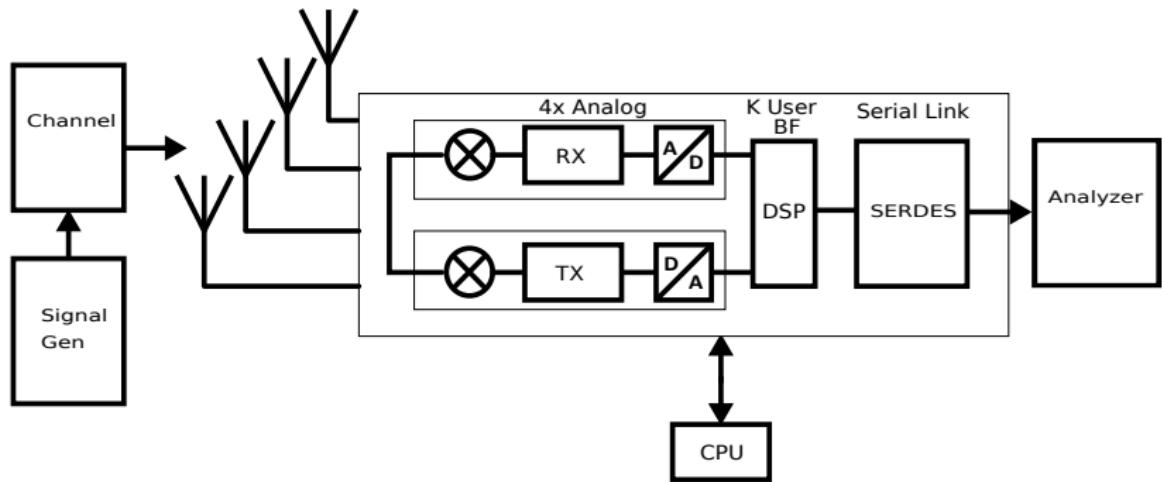
Full ADC Model in Python with Transistor-level TDC Model



- ▶ Same exact simulation as before, except the TDC block is simulated as a spice-netlist in Eldo

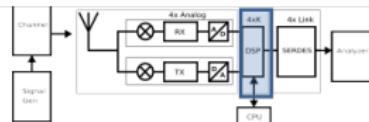
## Example 4: Multi-user MIMO receiver

# Example 4: Multi-user MIMO receiver



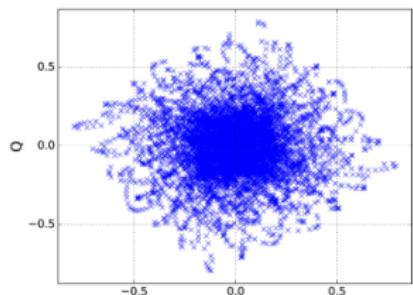
## ► Goals:

- ▶ First, model the receiver of a single chip with python
- ▶ Python models swappable to RTL and analog models
- ▶ Generated sub-blocks verified at the system level
- ▶ Control the HW generators of the block (emerging feature)

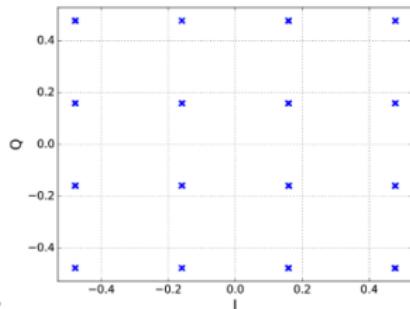


### Channel 802.11n C

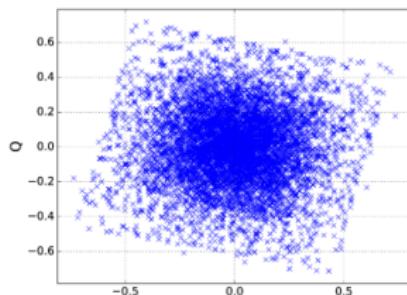
DSP, Ant=0, Usr=0, py, EVM=0.19 dB, BER= 0.364



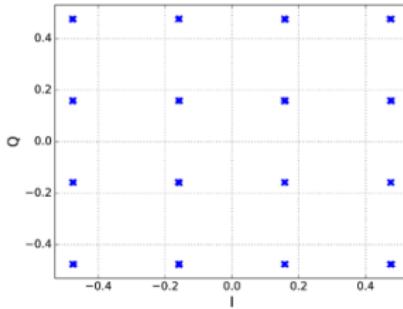
Postproc, Usr=0, py, EVM=-55.09 dB, BER= 0



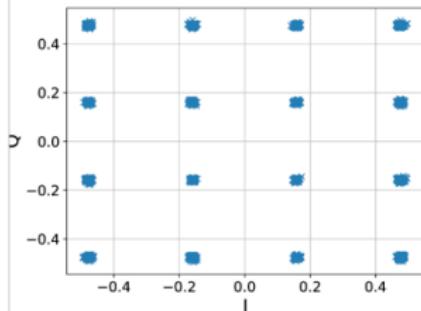
DSP, Ant=0, Usr=1, py, EVM=2.09 dB, BER= 0.453



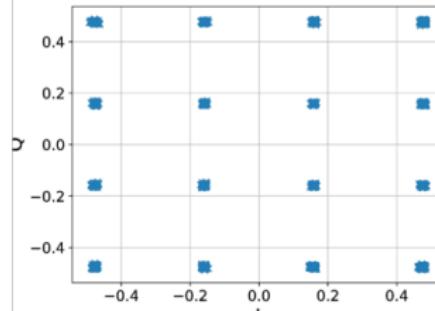
Postproc, Usr=1, py, EVM=-52.50 dB, BER= 0



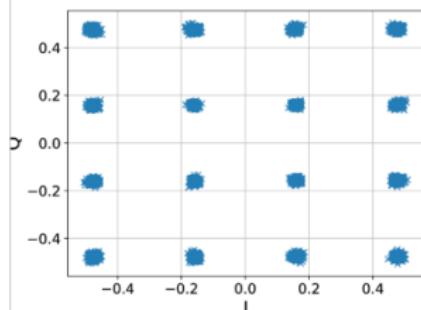
Postproc, Usr=0, py, EVM=-40.96 dB, BER= 0



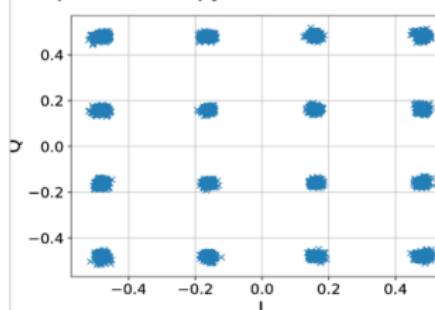
Postproc, Usr=1, py, EVM=-41.39 dB, BER= 0



Postproc, Usr=0, py, EVM=-34.47 dB, BER= 0



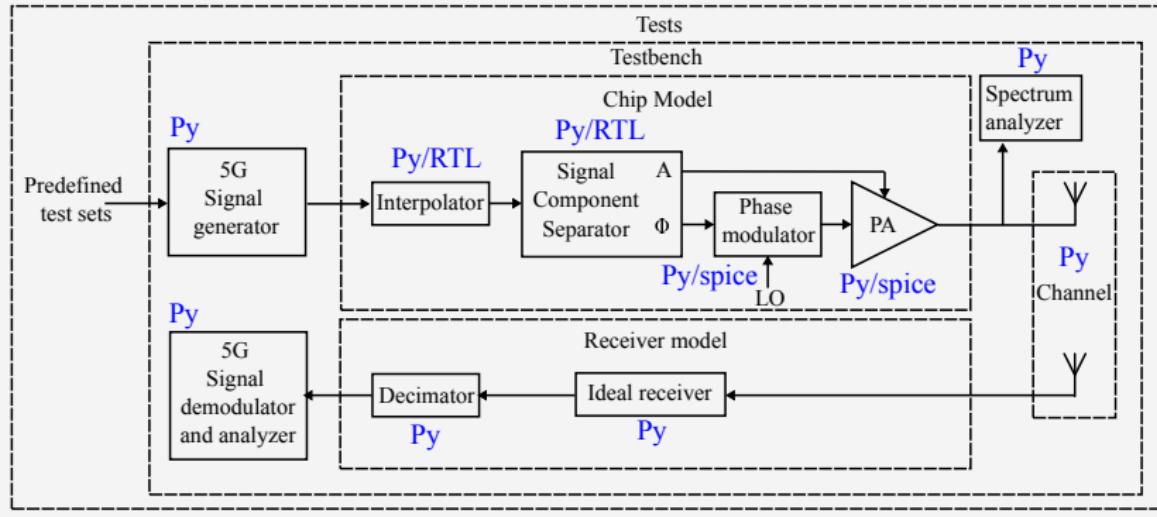
Postproc, Usr=1, py, EVM=-33.41 dB, BER= 0



## Example 5: Outphasing transmitter

# Outphasing transmitter system

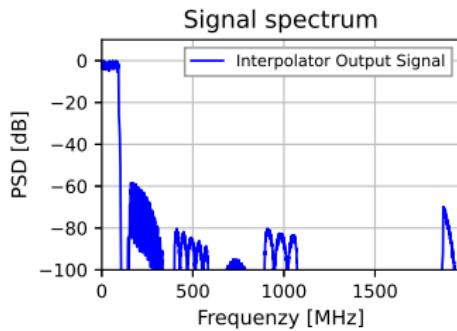
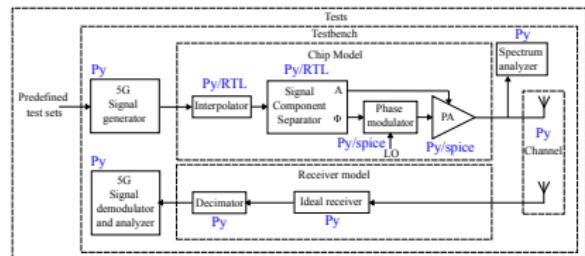
## Outphasing system simulation



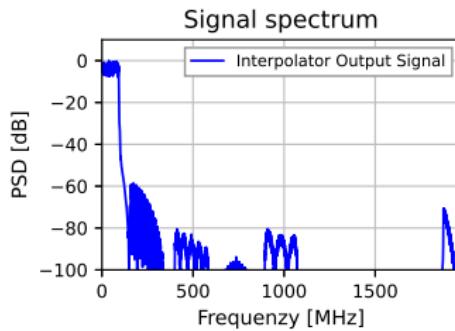
### ► System development

- Model the transmitter chip with python
- Model the ideal receiver in python
- Simulate the functionality

# Interpolator frequency response

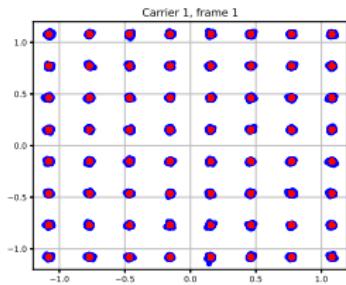
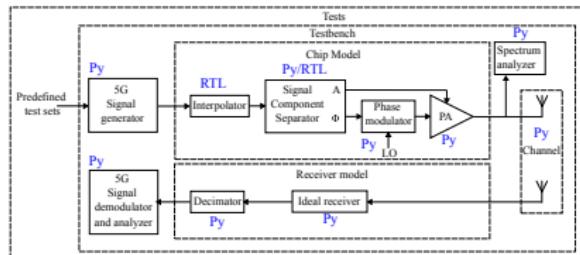


(a) Interpolator SW

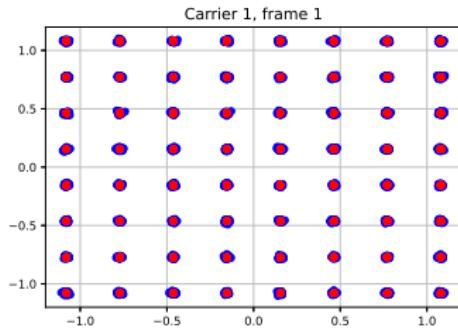


(b) Interpolator HW

# Interpolator EVM simulation



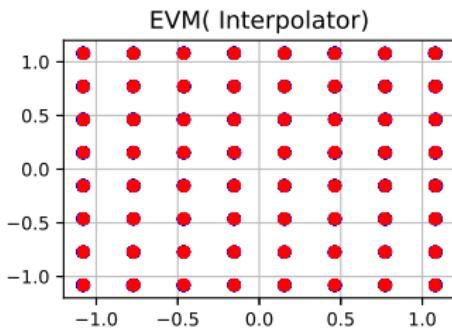
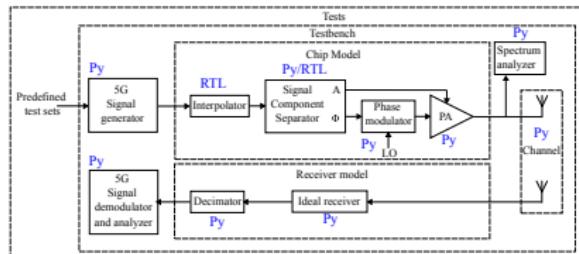
(c) Interpolator HW  
(EVM, 16-bit)



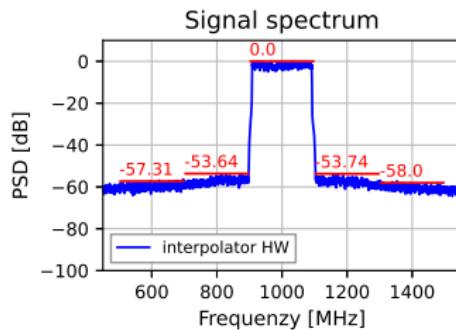
(d) Interpolator HW (EVM,  
20-bit)

- ▶ EVM(16-bit): 1.6 - 1.52%
- ▶ EVM(20-bit): 1.3 - 1.08%

# Interpolator EVM and ACLR



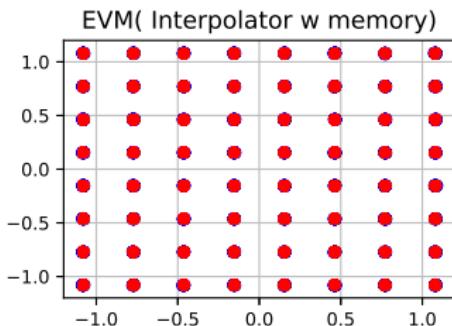
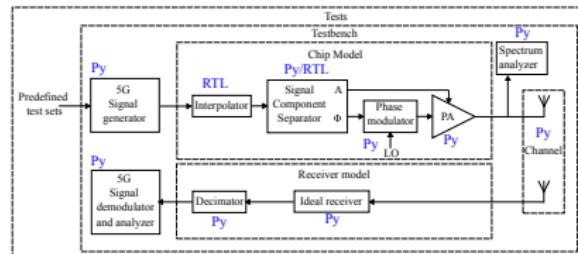
(e) Interpolator (HW, EVM)



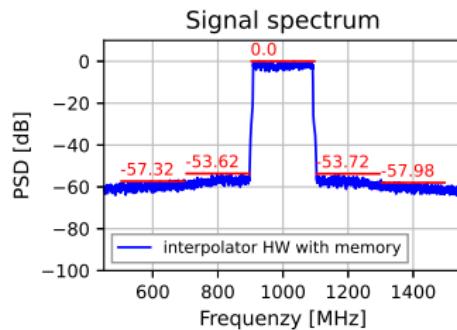
(f) Interpolator (HW, ACLR)

- ▶ EVM : 0.338%
- ▶ ACLR:  $-53.64, -53.74$  dB

# Interpolator hardware EVM and ACLR



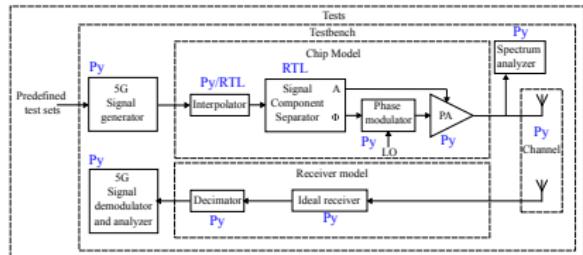
(g) Interpolator (HW, EVM)



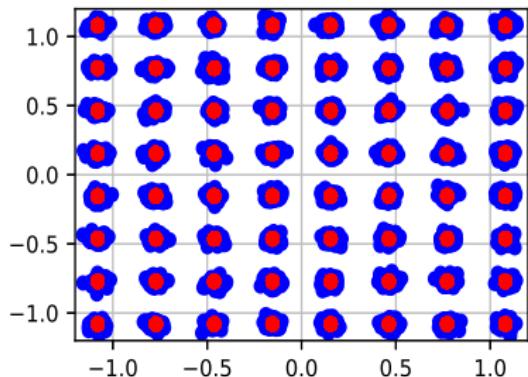
(h) Interpolator (HW, ACLR)

- ▶ EVM : 0.339%
- ▶ ACLR:  $-53.62, -53.71$  dB

# SCS 6-bit resolution EVM

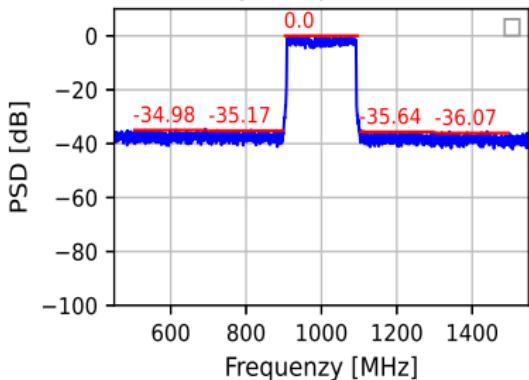


EVM (3.32%)



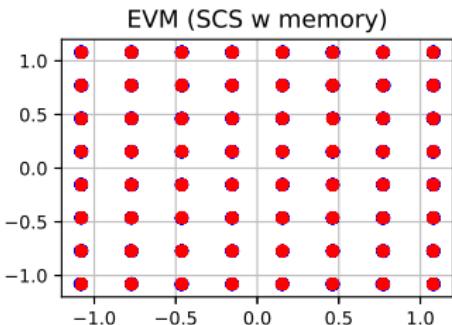
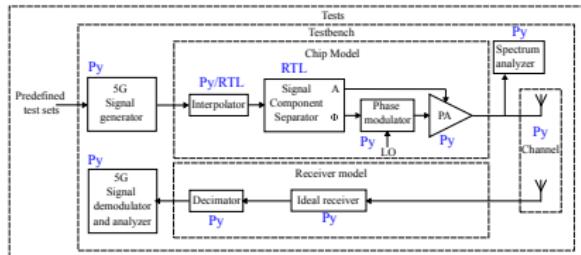
(i) EVM, SCS RTL simulation)

Signal spectrum

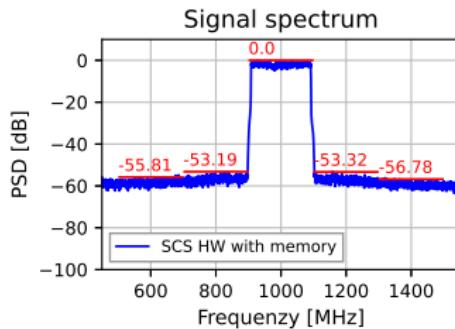


(j) ACLR, SCS RTL simulation)

# SCS 10-bit resolution hardware EVM and ACLR



(k) EVM SCS RTL simulation



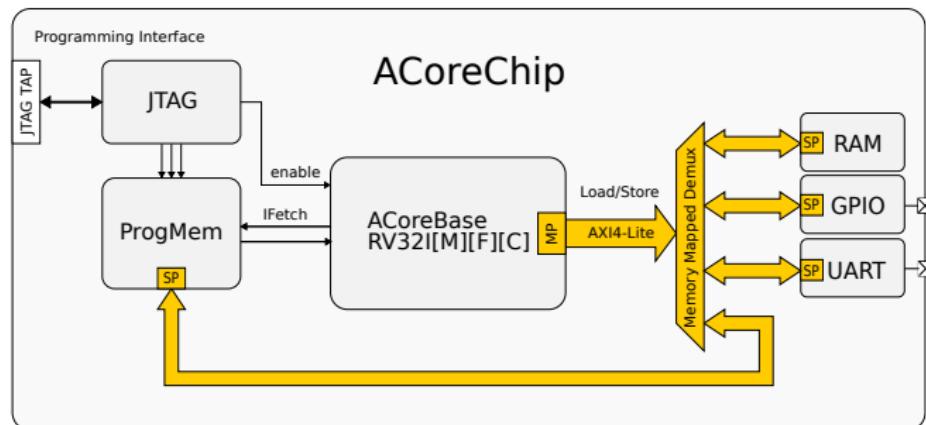
(l) ACLR SCS RTL simulation

- ▶ EVM: 0.336%
- ▶ ACLR: -53.18, -53.31 dB

## Example 6: A-Core RISC-V processor chip

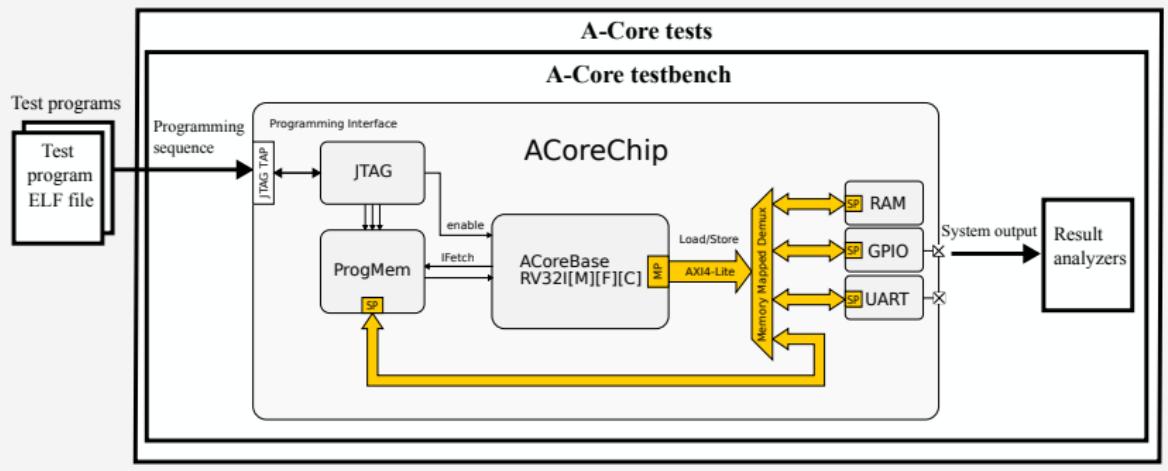
# A-Core RISC-V processor chip

- ▶ SoC built with ACoreBase
- ▶ AXI4-Lite on-chip interconnect
- ▶ Memory mapped peripherals
  - ▶ Random Access Memory (RAM)
  - ▶ Read-only access to instruction memory (ProgMem)
  - ▶ General Purpose Input/Output (GPIO)
  - ▶ Custom accelerator IP



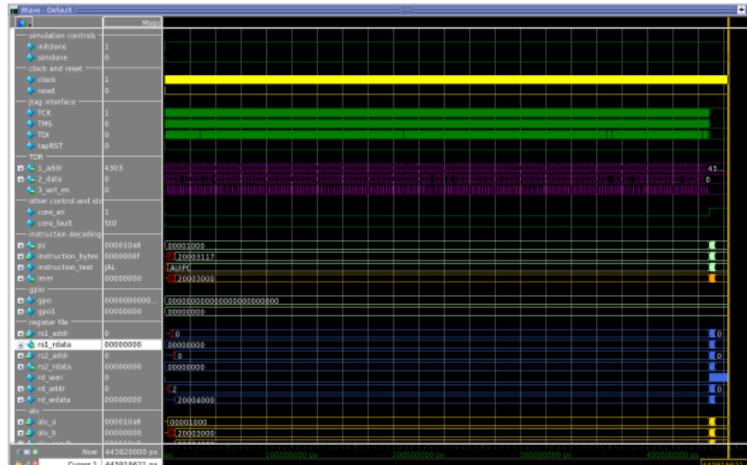
# A-Core chip verification

## A-Core test setup



# TheSyDeKick simulations

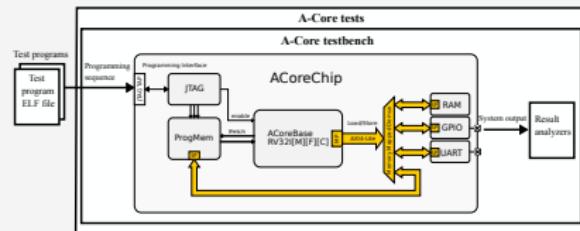
- ▶ For system-level simulations
- ▶ TheSyDeKick automates the following verification tasks
  - ▶ Generate a simulation test vector
    - ▶ JTAG programming waveform from ELF file
    - ▶ Chip control signals (e.g. core enable)
  - ▶ Generate a verilog testbench
  - ▶ Invoke a digital simulator (ModelSim)



# ACoreChip Entity

- ▶ Represents a simulatable model of ACoreChip
- ▶ Submodules
  - ▶ ACoreChip Chisel generator **chisel/**

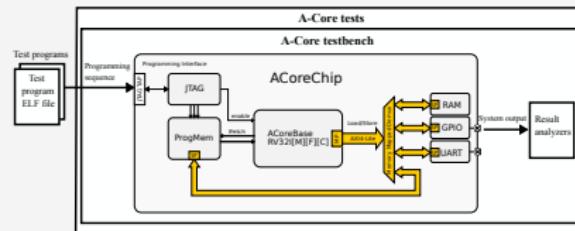
## A-Core test setup



# ACoreTestbenches

- ▶ ACoreTestbenches instance represents a test bench configuration.
- ▶ Testbench configuration is selected with appropriate `define*` method
  - ▶ For example, `define_acorechip_sim testbench(**kwargs)` configures test-bench as a acorechip simulation.
  - ▶ Software, jtag config., etc. are provided as keyword arguments to `define*`

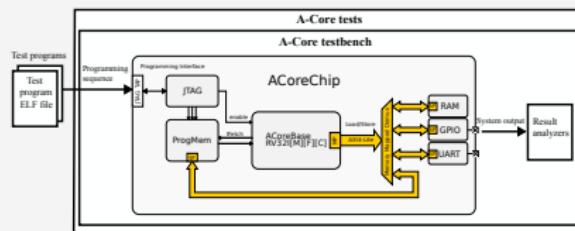
## A-Core test setup



# ACoreTestbenches

- ▶ A testbench configuration is a general combination of entities and related configuration for representing a unique test setup.
- ▶ The simulation testbench has two options: The SyDeKick and cocotb
  - ▶ The SyDeKick uses its own structures to generate the Verilog testbench, IO's and run with modelsim
  - ▶ Cocotb runs a cocotb test - can be used to create interactive debug environments in the future

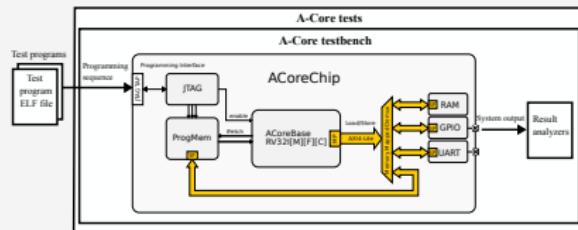
## A-Core test setup



# ACoreTests

- ▶ ACoreTests contains different concrete parameterizations of ACoreTestbenches and their dependencies:
  - ▶ Test software live under **sw**
  - ▶ Simulation specific do-files live under **interactive\_control\_files/modelsim**
- ▶ Each test is defined as a method under ACoreTests class.
- ▶ For example, sim\_f\_tests configures a testbench with
  - ▶ F-extension enabled
  - ▶ test program for f-extension

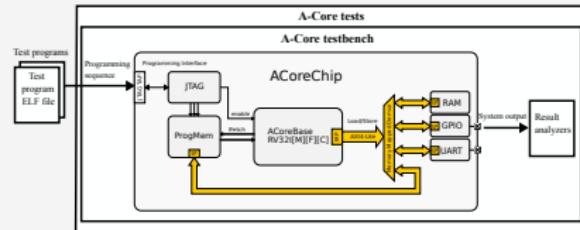
## A-Core test setup



# ACoreTests

- ▶ The test to be executed is selected with a command line argument. For example,  
`$ ./configure && make sim test_target=sim_f_tests` runs the simulation defined as `sim_f_tests`
- ▶ The simulator option can be selected with `simulator` argument for `make`, for example  
`$ make sim test_target=sim_f_tests simulator=cocotb`

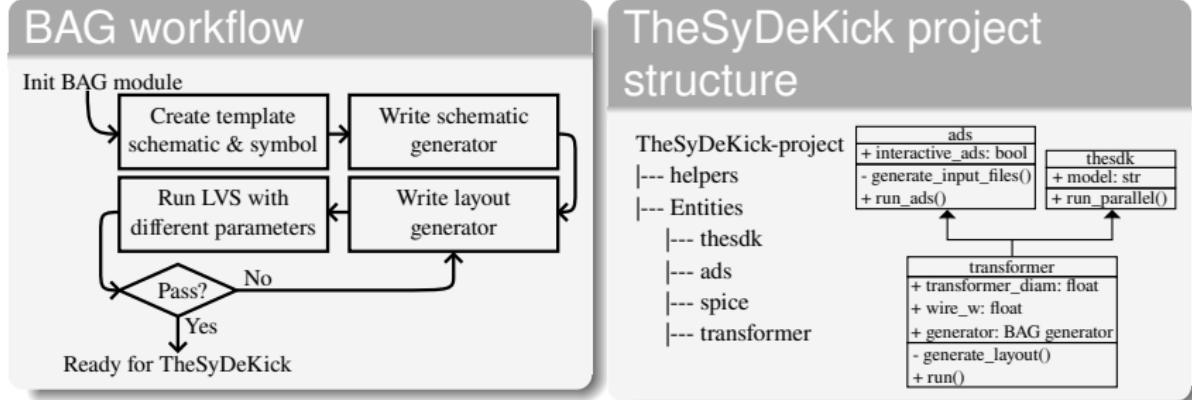
## A-Core test setup



## Example 7: EM field simulations

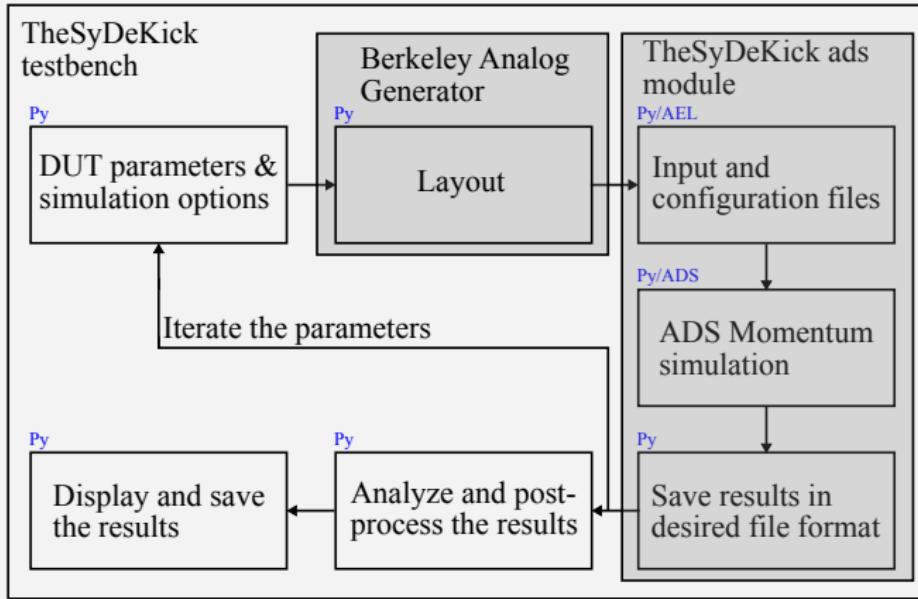
# Layout preparation

- ▶ Preparations: Constructing the layout from TheSyDeKick with Berkeley Analog Generator.
- ▶ Active development of BAG2 currently ongoing at [https://gitlab.com/mosaic\\_group/mosaic\\_BAG](https://gitlab.com/mosaic_group/mosaic_BAG)



# Transformer design flow diagram

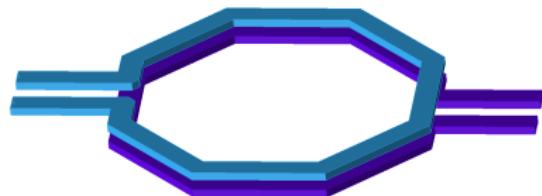
## Design flow



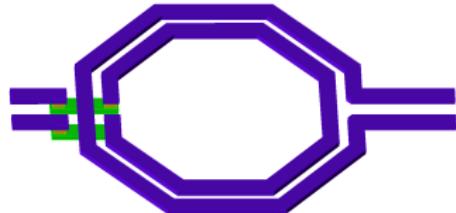
# Transformer structures

- Parameters: Wire width, transformer diameter.

A stacked transformer

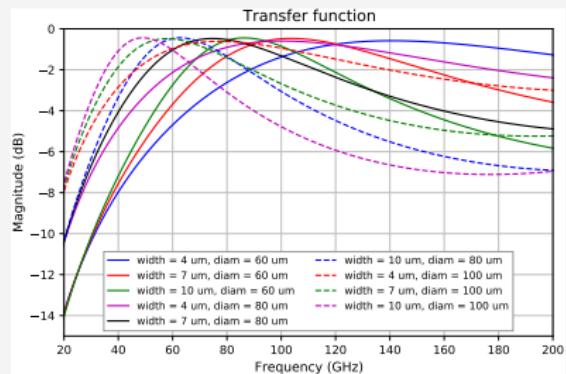


An Interwound transformer

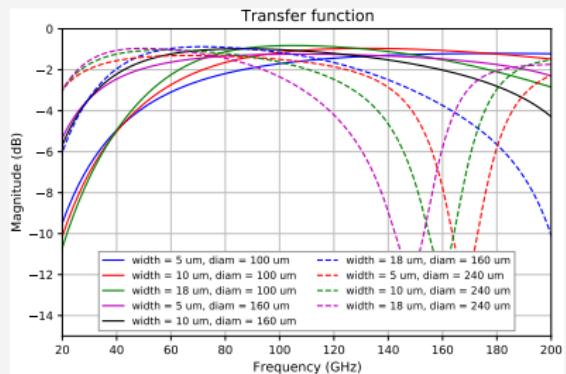


# Transfer functions

## Transfer function of a stacked transformer

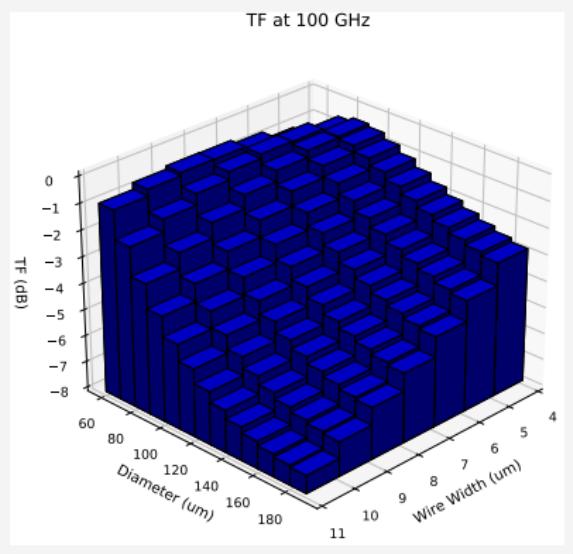


## Transfer function of an interwound transformer

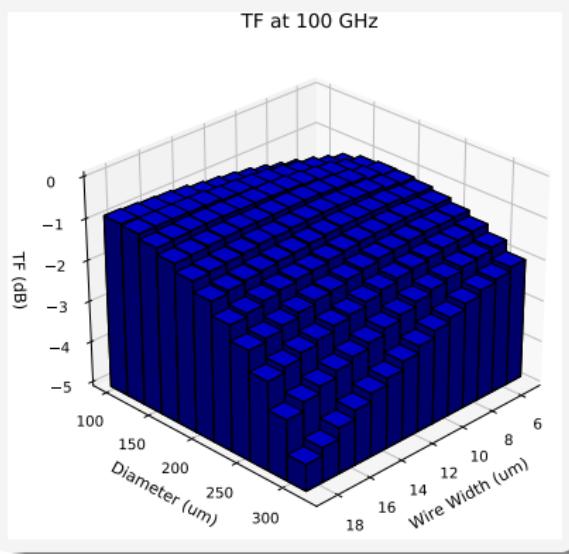


# Insertion loss

## Insertion loss of a stacked transformer



## Insertion loss of an interwound transformer



# Conclusion and acknowledgements

# Conclusion

- ▶ Modular design environment through well defined IO boundaries and *Entity* definitions.
- ▶ Open Source
- ▶ Automates repetitive verification tasks and provides means for programmatic verification with various simulators
- ▶ Support for measurement equipment under development.
- ▶ *Enables* co-development by multiple designers using various verification tools.
- ▶ *Enabled* by utilization of programming methodology and version control in hardware design context.

# Acknowledgement

- TheSyDeKick framework has been initiated during 2017-2019 under Marie Skłodowska-Curie project *ADVANTAG5*, in collaboration with Aalto University and University of California, Berkeley. (See licences, <https://github.com/TheSystemDevelopmentKit/thesdk> )
- Since the end of *ADVANTAG5* 2019, Lot of valuable development work has been carried out by several students of Aalto University, Finland.

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