TAFA: Design Automation of Analog Mixed-Signal FIR Filters Using Time Approximation Architecture

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The Speaker’s Biography

Shiyu Su received the B.S. degrees from BUPT and QMUL in 2011, and the M.S. and Ph.D. degrees from USC in 2013 and 2019, all in electrical engineering.

His research interests include data converters, all digital PLL, RF/millimeter-wave transceivers, and analog/mixed-signal design automation, micro-unmanned vehicles.

Dr. Su was the recipient of IEEE SSCS Predoctoral Achievement Award for 2017–2018, IEEE SSCS Student Travel Grant Award for 2019–2020. He is a Ming Hsieh Institute Scholar from 2019 to 2020.

POSH Team at USC

Outline

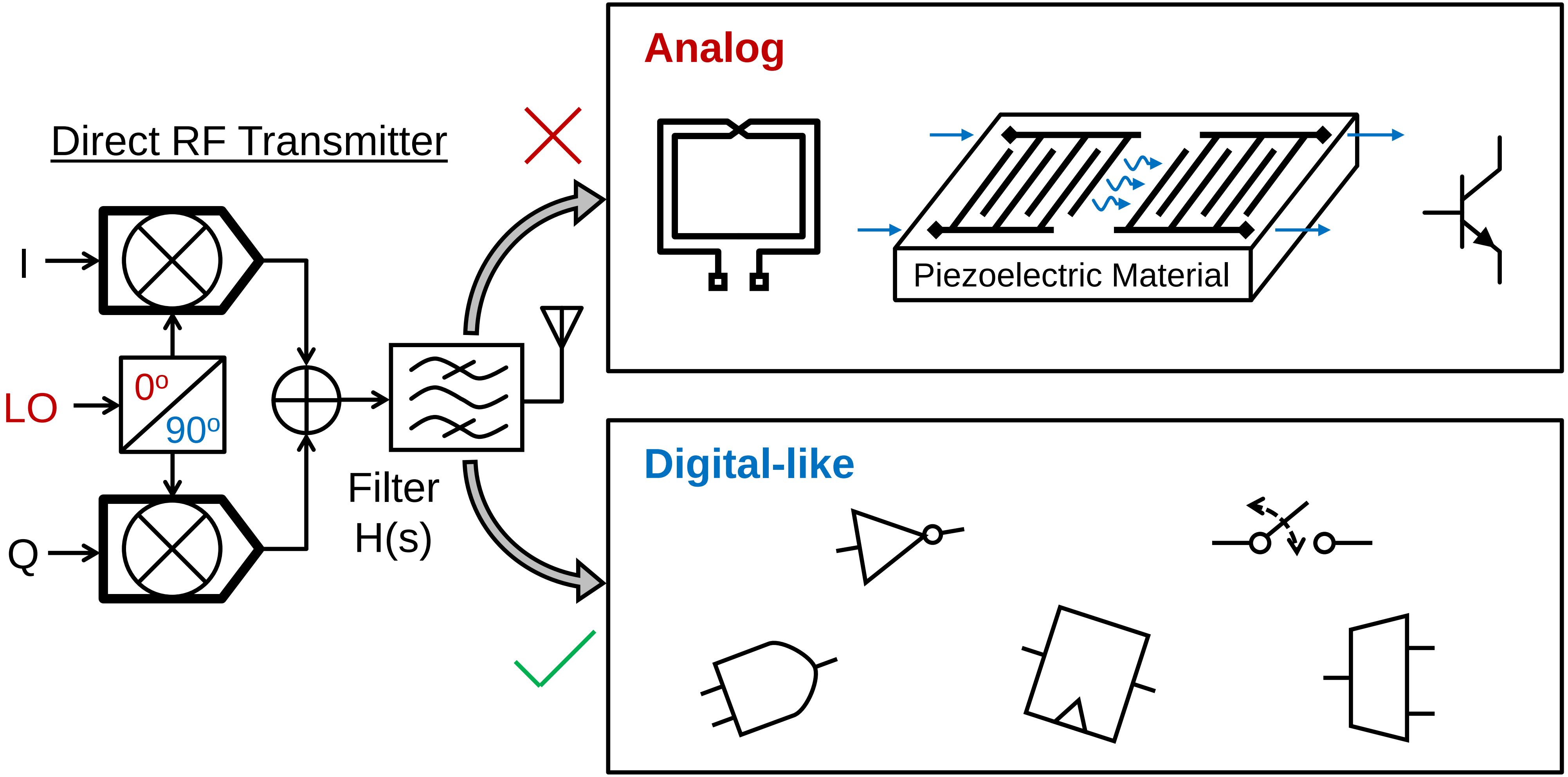
- Introduction
- Proposed AMS filter design flow
  - **Hybrid TAF pattern generation**
  - **NN-based parameter search**
- Experimental results
- Conclusion

AMS: Analog/mixed-signal

TAF: time-approximation filter

NN: Neural network

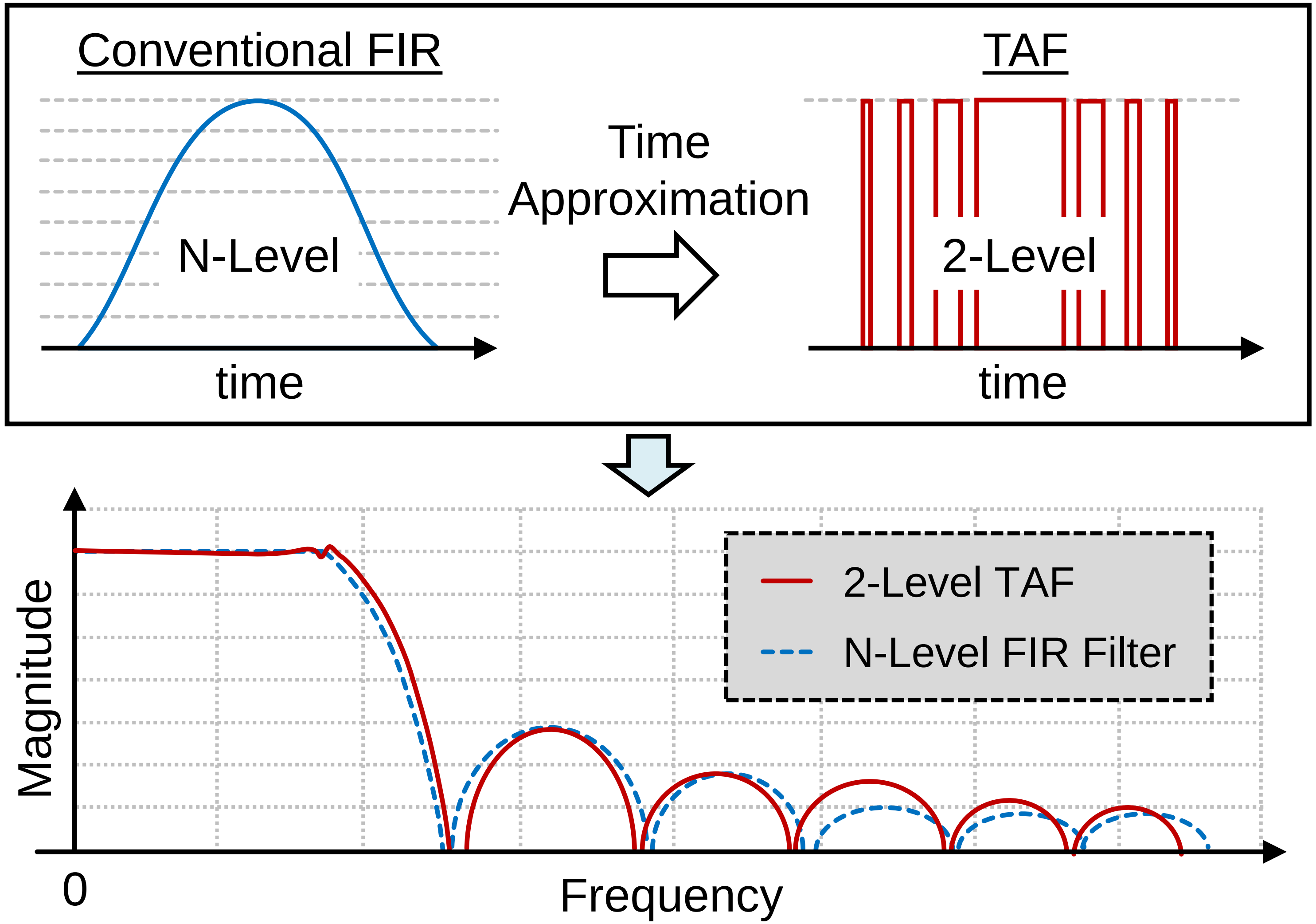
Motivation – Towards "Digital-Like" Design



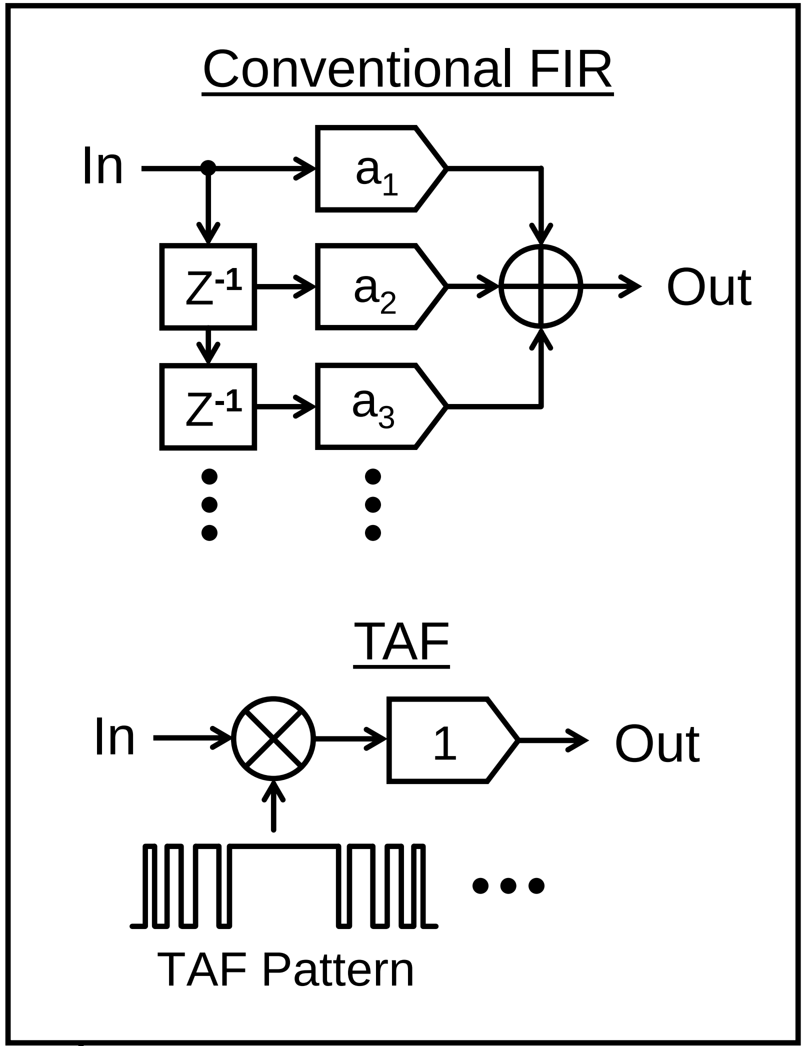
- X Bulky
- X Manual design
- X Not scalable

- ✓ Favors scaling
- ✓ Developed tools
- ✓ High abstraction

Digital-Like Time-Approximation Filter (TAF)



[Su VLSI 2019]



→ Implementation

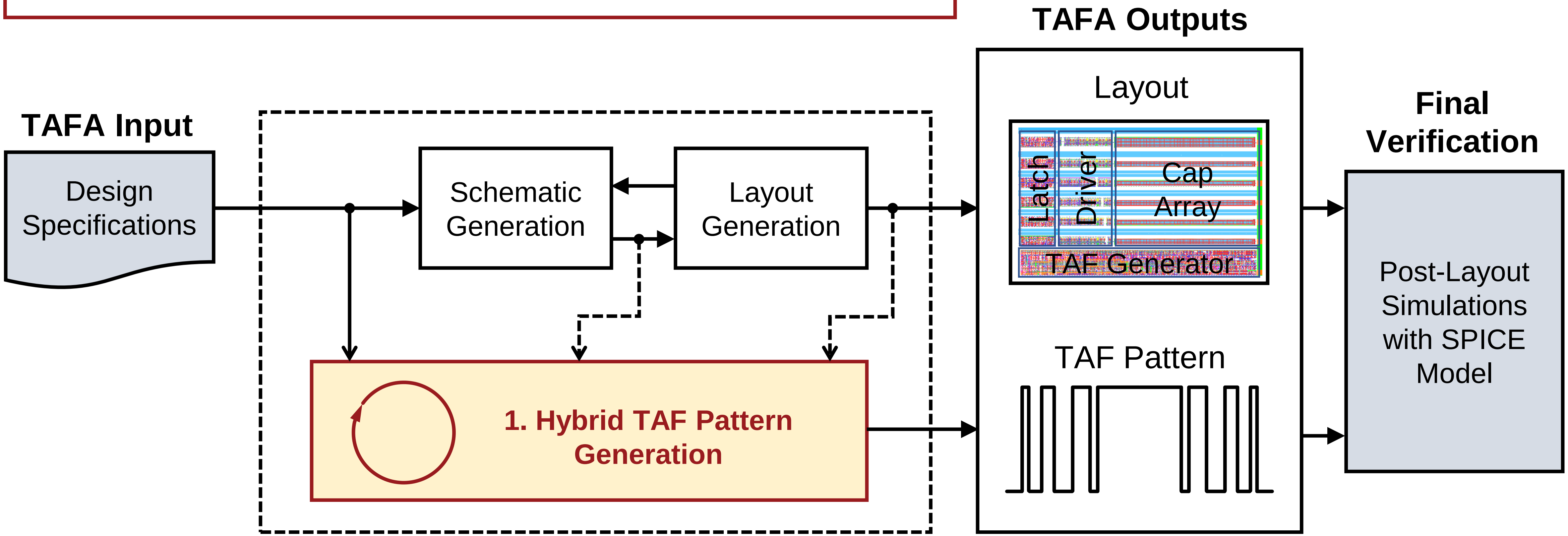
Challenges of TAF Design

1. The **time resolution** for time approximation is limited by the system clock rate.

2. There are remaining analog circuits that require intensive **hand-crafted design**.

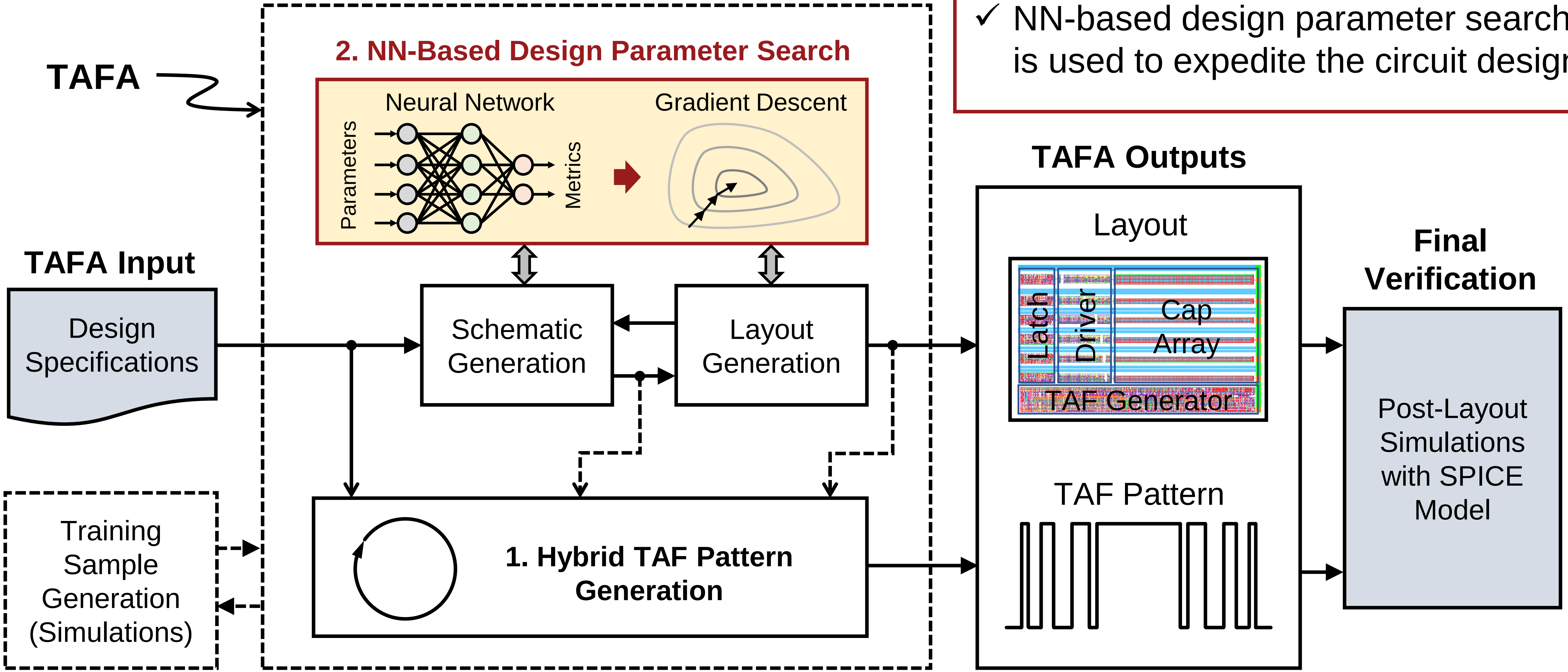
Hybrid TAF Pattern Generation

✓ Hybrid TAF pattern generation is proposed to derive a nearly optimum impulse response for a TAF



NN-Based Design Parameter Search

✓ NN-based design parameter search is used to expedite the circuit design.



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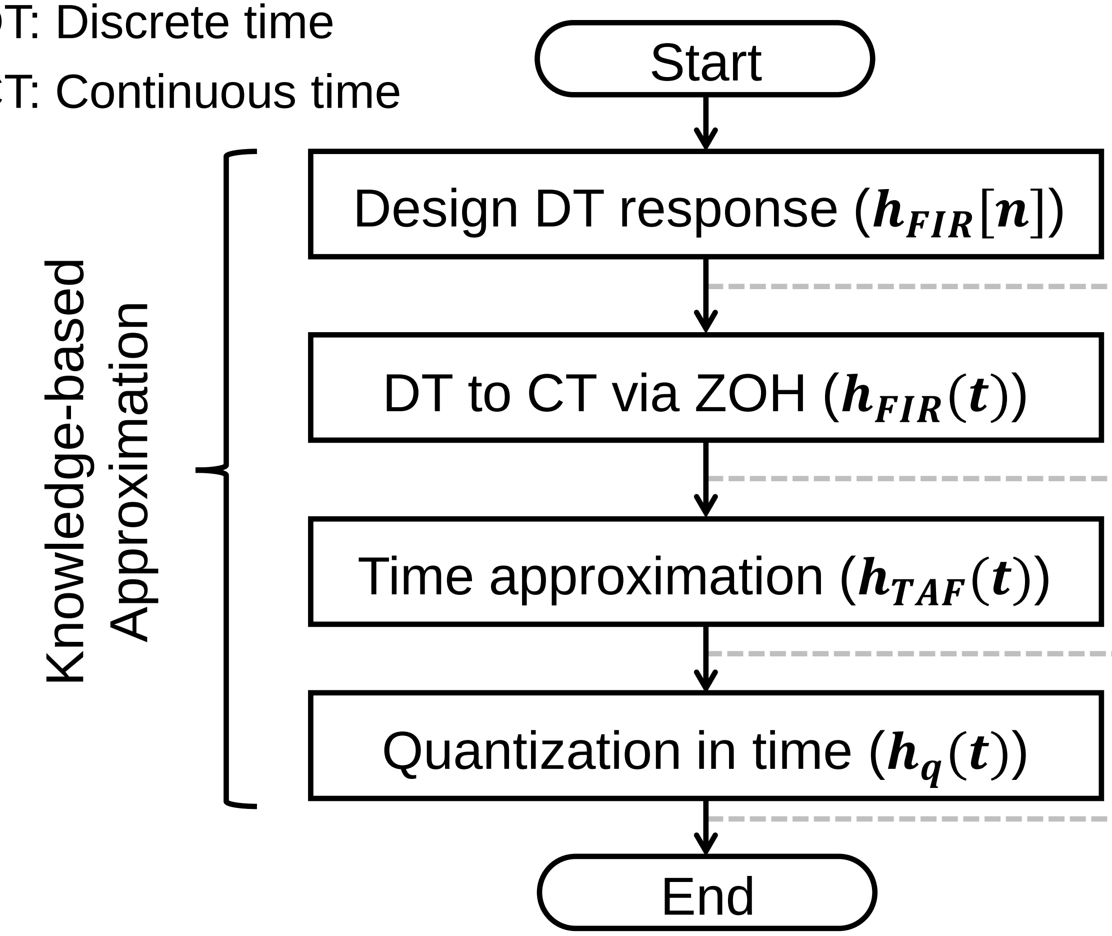
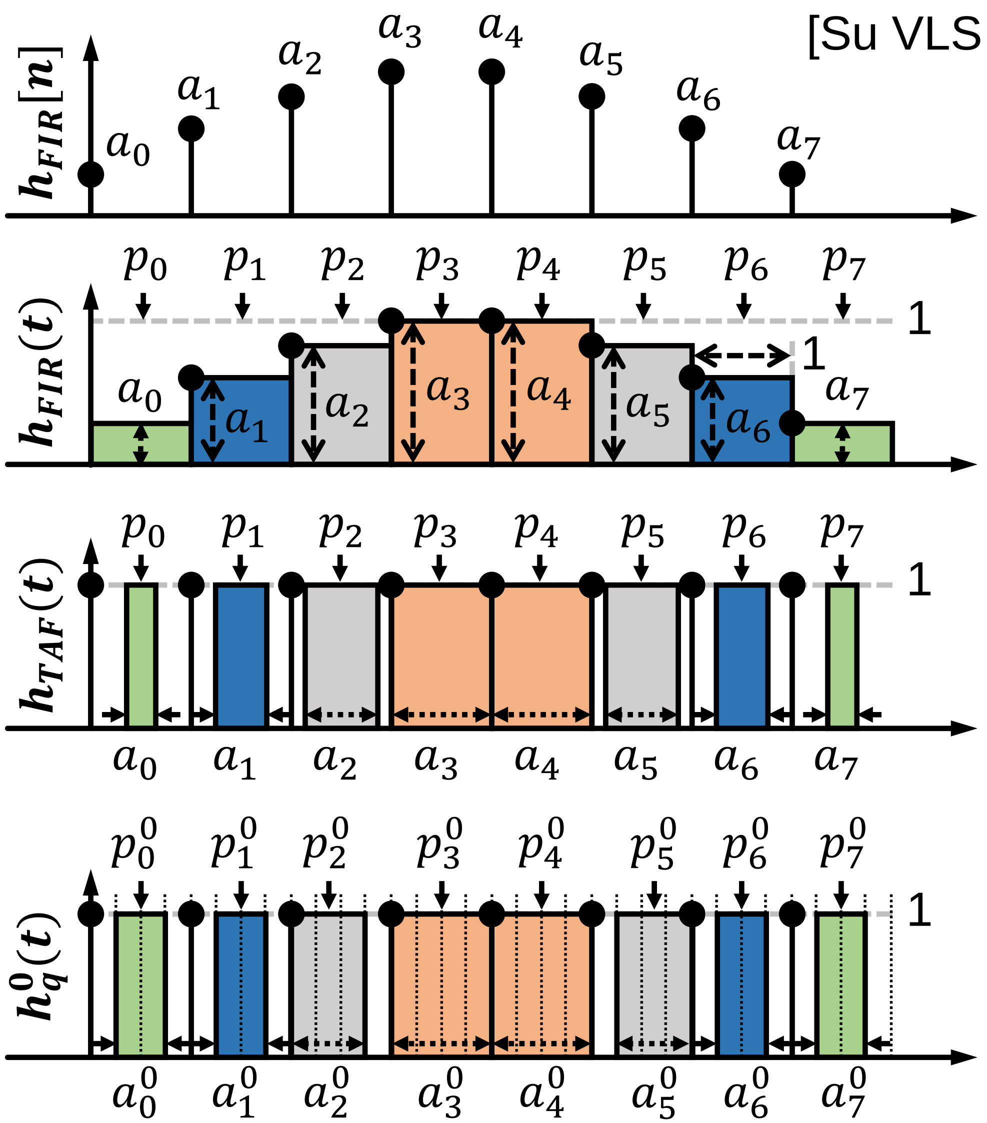
Traditional TAF Pattern Generation

DT: Discrete time

CT: Continuous time



[Su VLSI 2019]

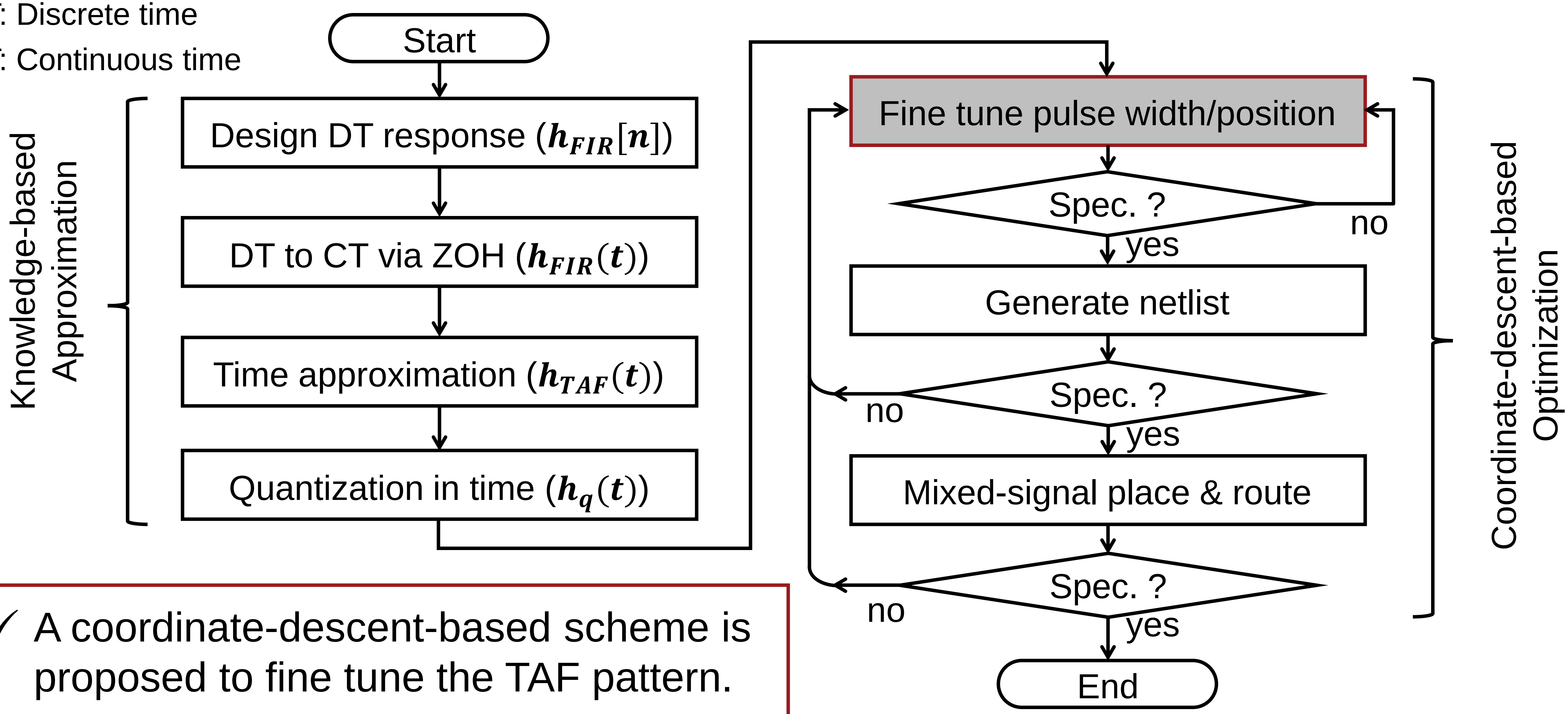


- Time quantization error limits the time approximation accuracy.

Hybrid TAF Pattern Generation Flow

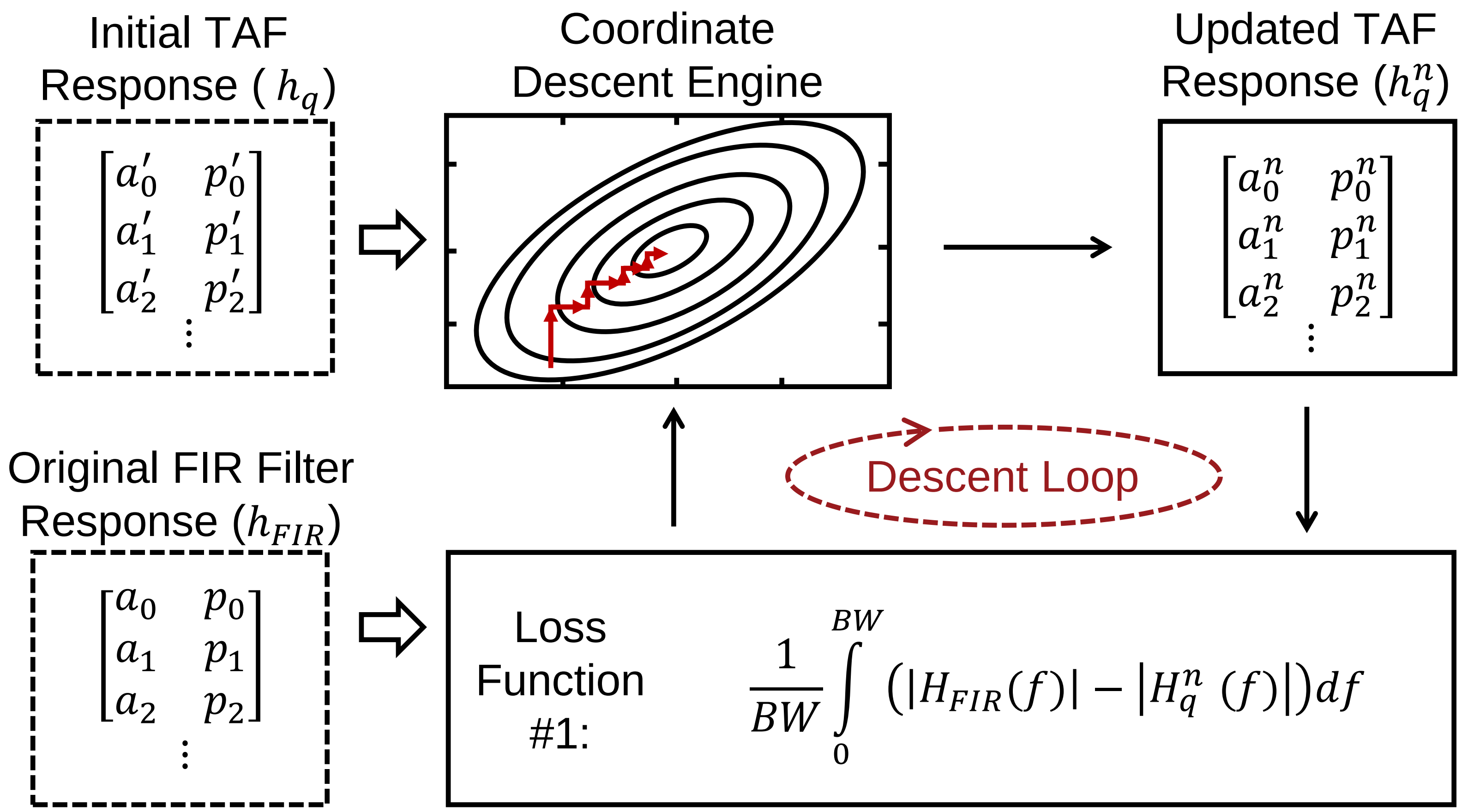
DT: Discrete time

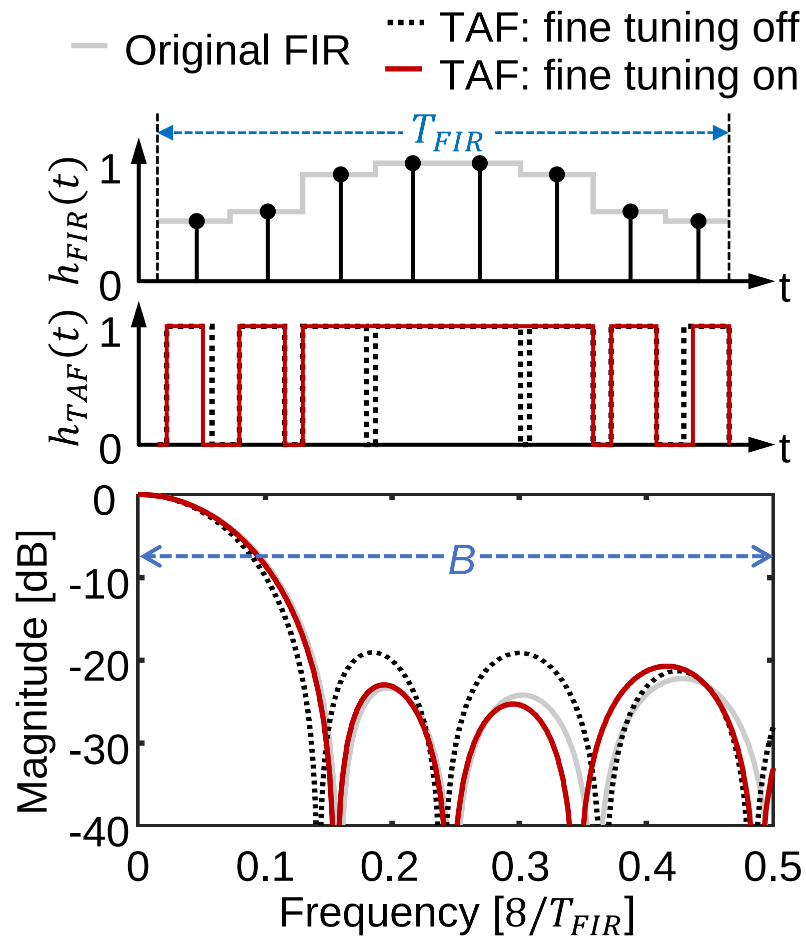
CT: Continuous time



✓ A coordinate-descent-based scheme is proposed to fine tune the TAF pattern.

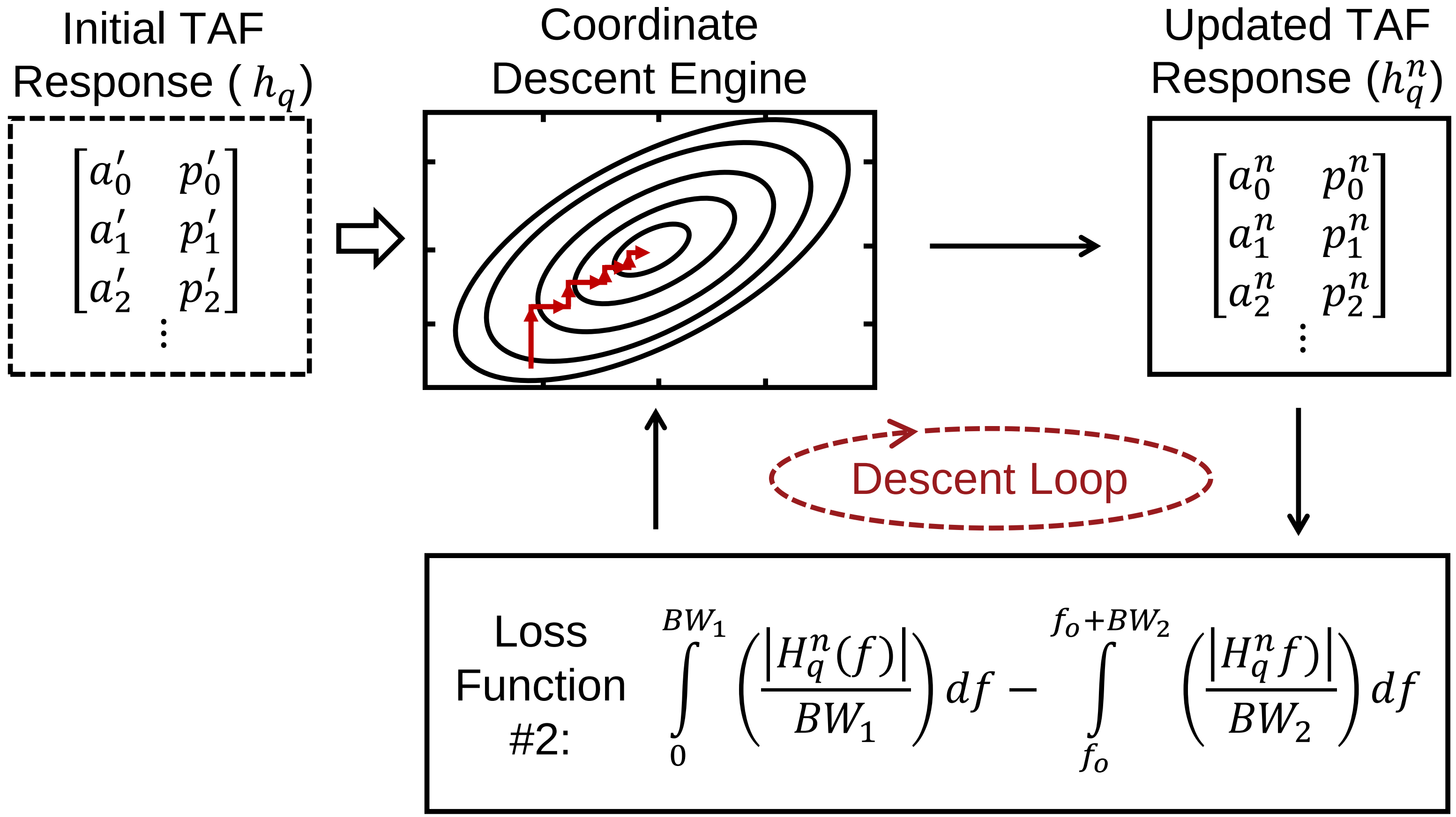
Fine Tuning with Custom Loss Functions

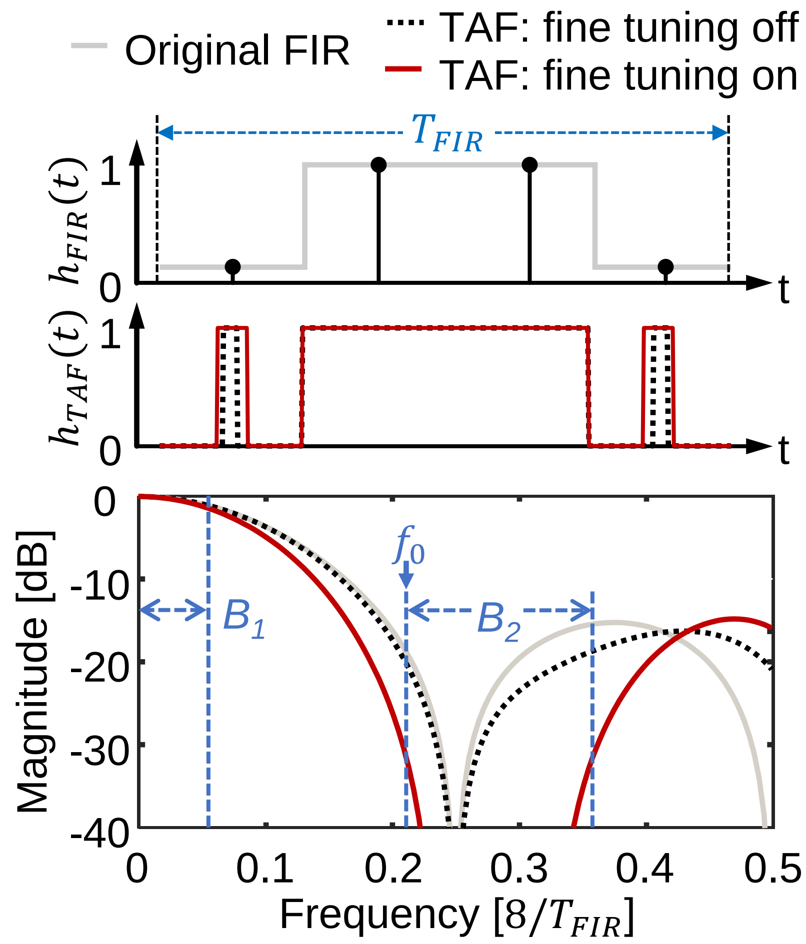




- ✓ Fine tune the width (a) and position (p) of each pulse in the TAF pattern using different loss functions. For example, loss function # 1 is used to **better approximate the original or target FIR filter response**.

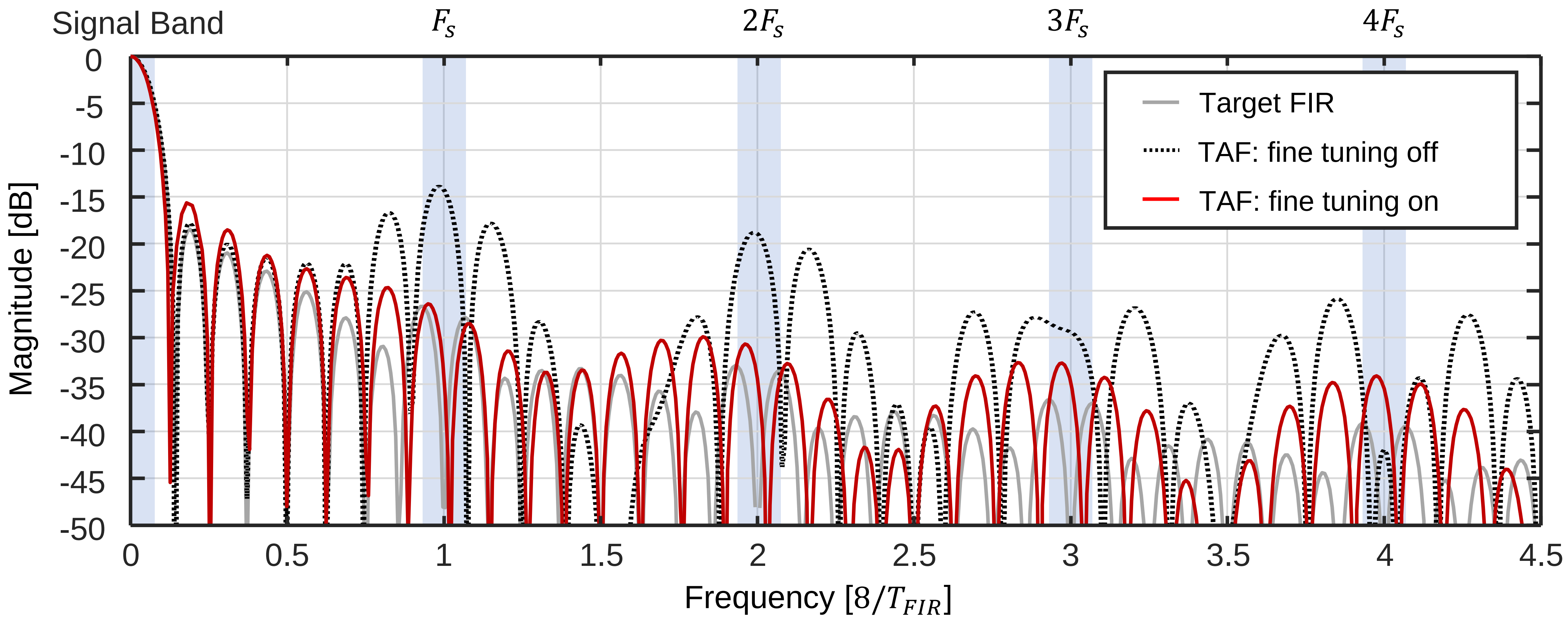
Fine Tuning with Custom Loss Functions





✓ Starting from the original FIR filter response, loss function # 2 is used to **enhance the filter attenuation at specific band of interest** instead of approaching to the original FIR filter response.

Fine Tuning with Custom Loss Functions



- ✓ In addition, loss function # 2 can be also used to **optimize the far-out spectrum**, avoiding unwanted peaks at high frequencies.

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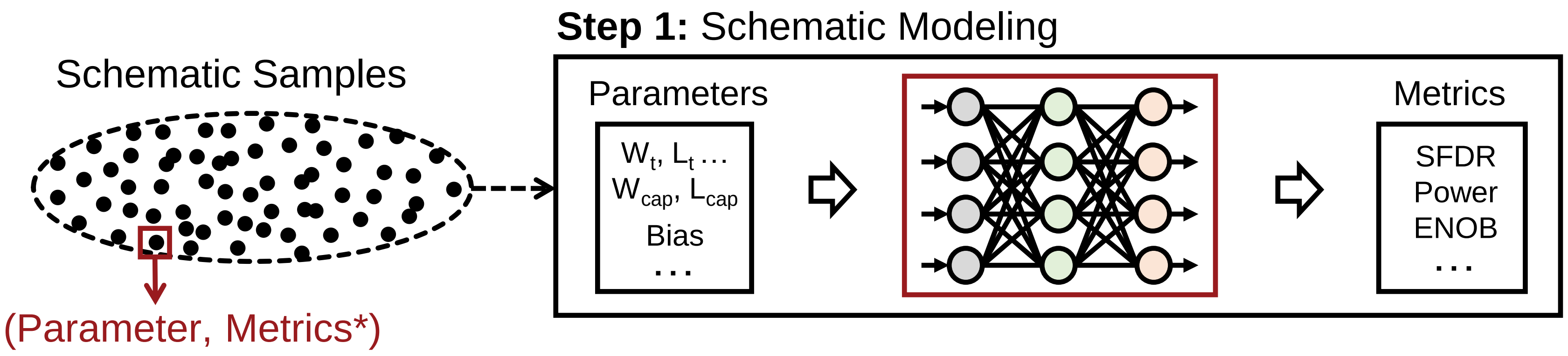
NN-Based Surrogate Model for AMS Circuits

Human in Loop (Developer)



✓ An NN-based Surrogate model is used to imitate the parameters-to-metrics (P2M) relationship of the AMS circuit.

* Obtained from schematic simulations; ** Obtained from post-layout simulations;

Pros:

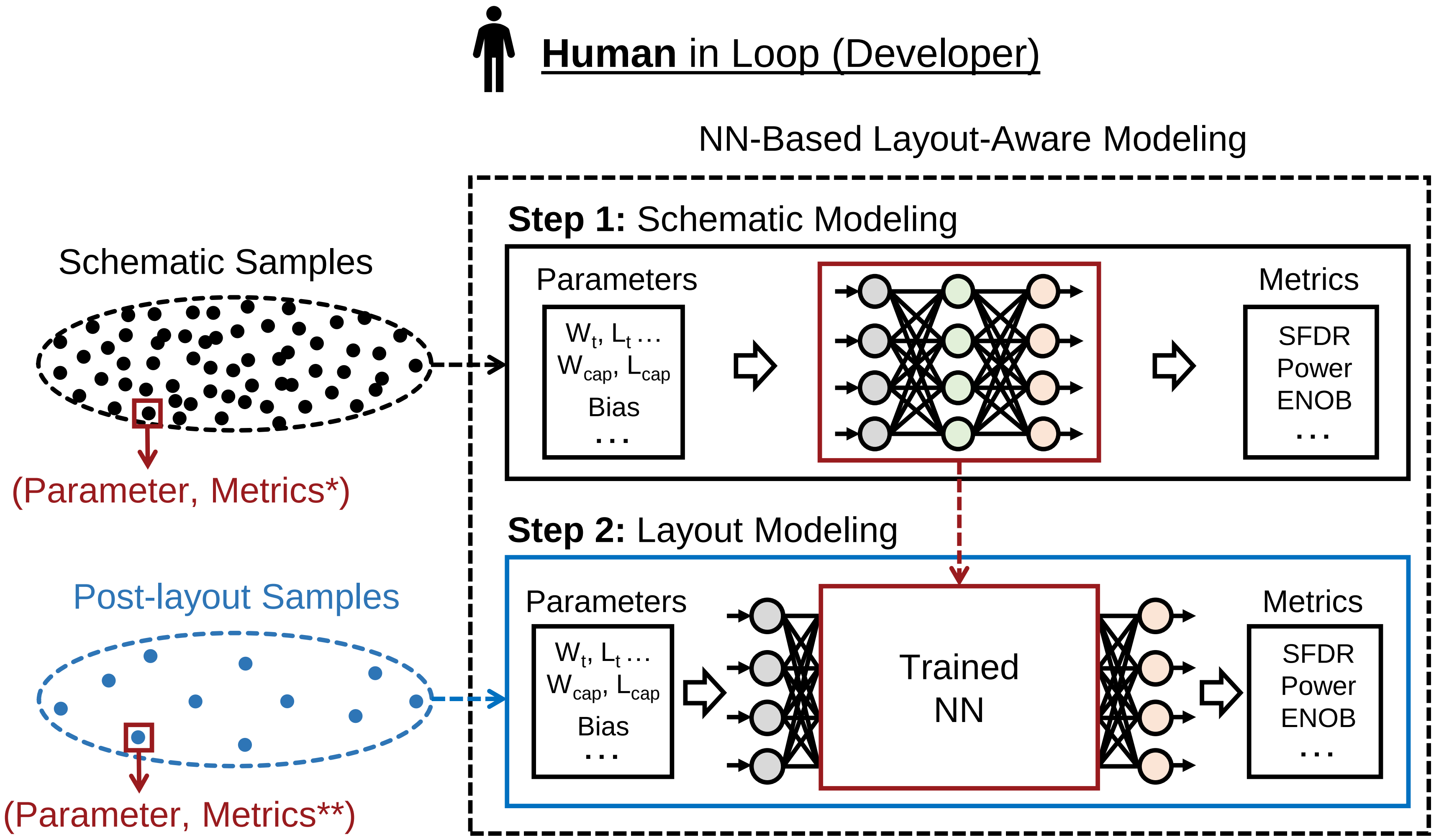
1. Well-developed
2. Fast inference
3. Reusable
4. Low computational cost

Con:

Required sufficient training data. (**Post-layout** simulations of AMS circuits using SPICE model can be extremely expensive!)

Given a target model accuracy, how to reduce the required training data?

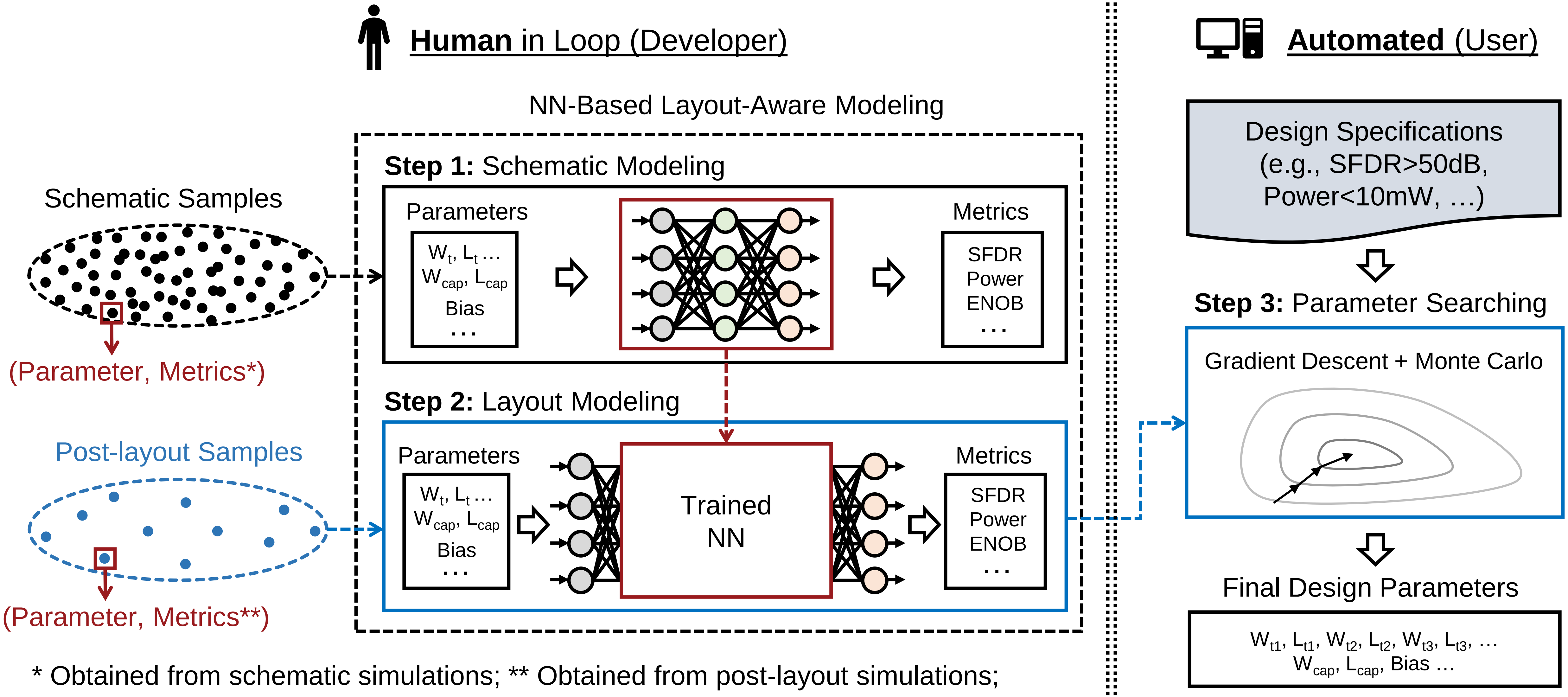
Layout-Aware Model Using Transfer Leaning



* Obtained from schematic simulations; ** Obtained from post-layout simulations;

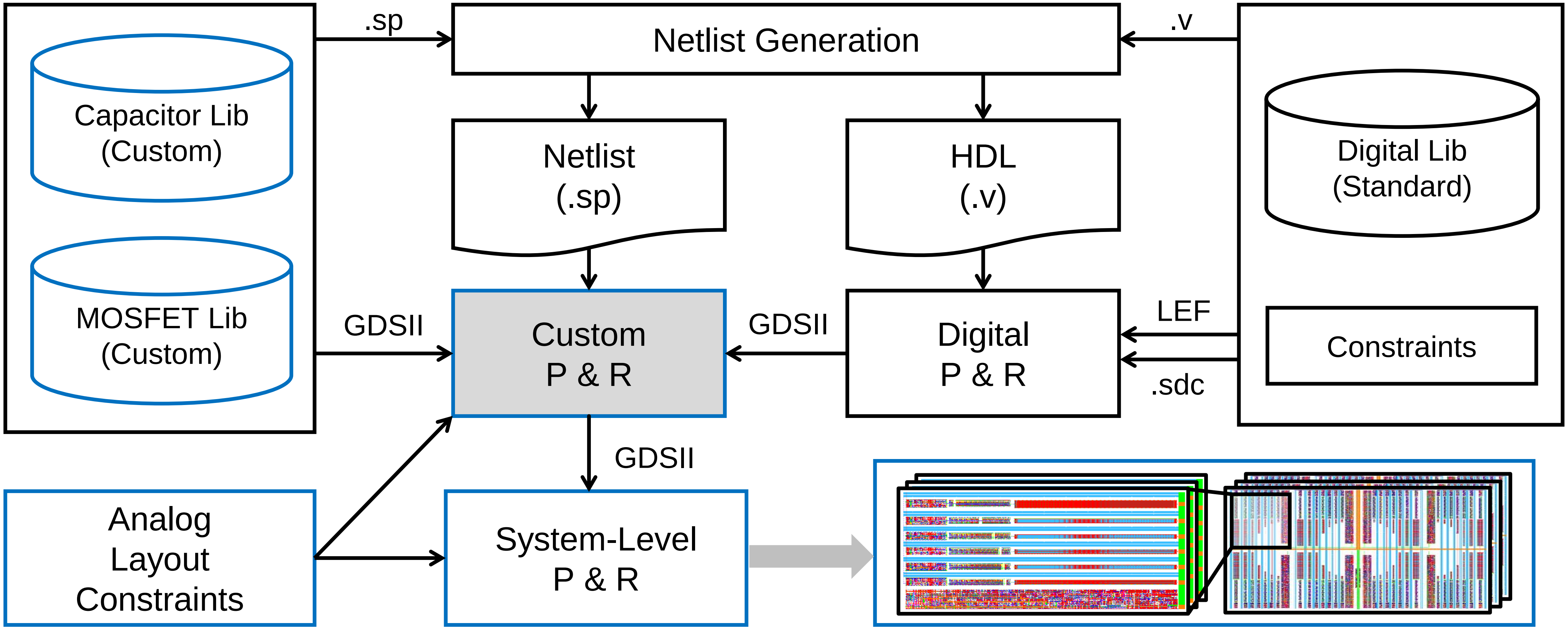
- ✓ Leverage the knowledge learned from schematic simulations via transfer learning.
- ✓ Note that the model training including the training sample generation only needs to be done **once**.

Rapid Design Parameter Search



* Obtained from schematic simulations; ** Obtained from post-layout simulations;

Custom AMS Layout Flow



✓ Customize the P&R for performance-sensitive blocks and top-level integration while maximally leverage standard digital flow.

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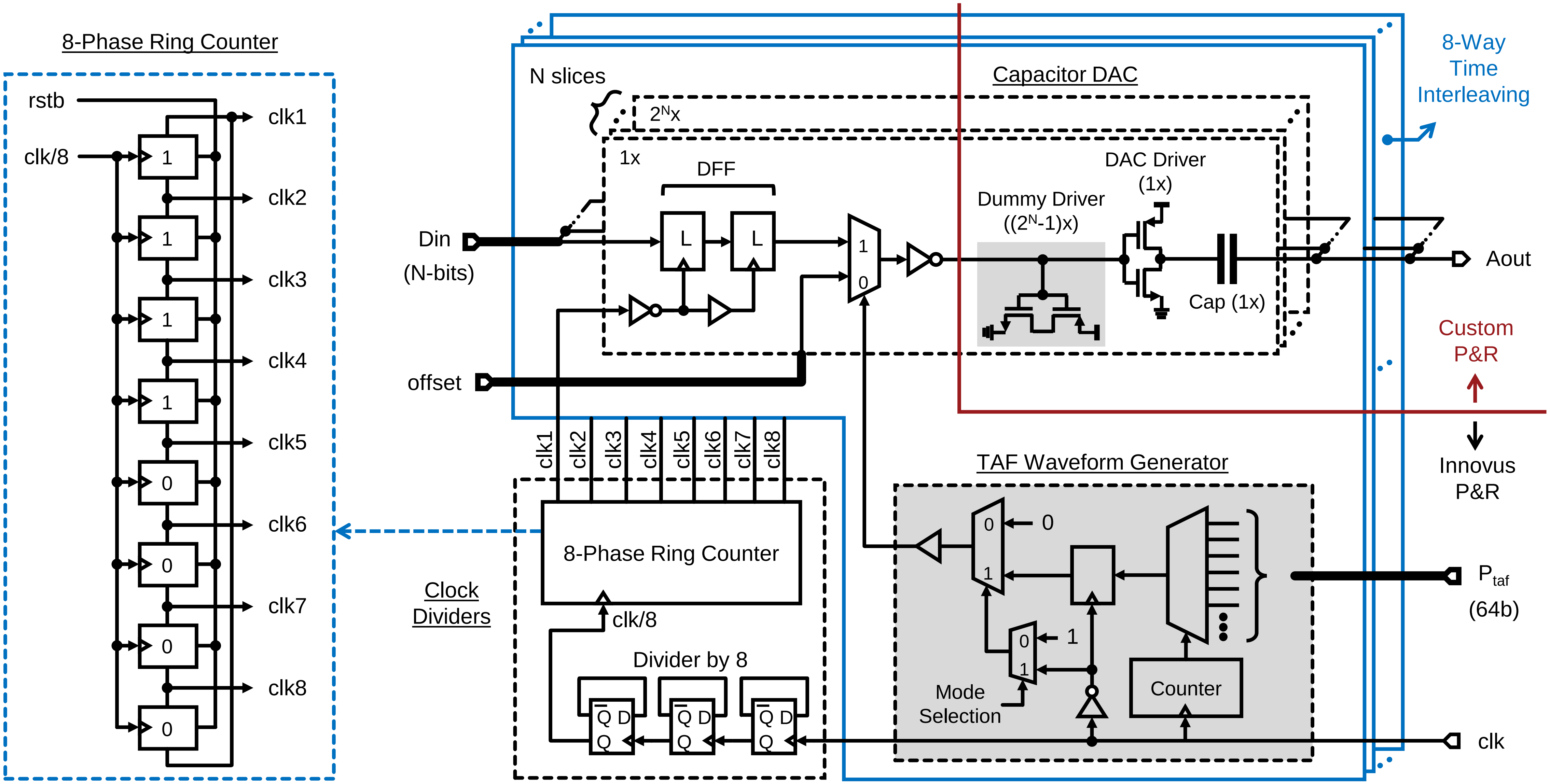
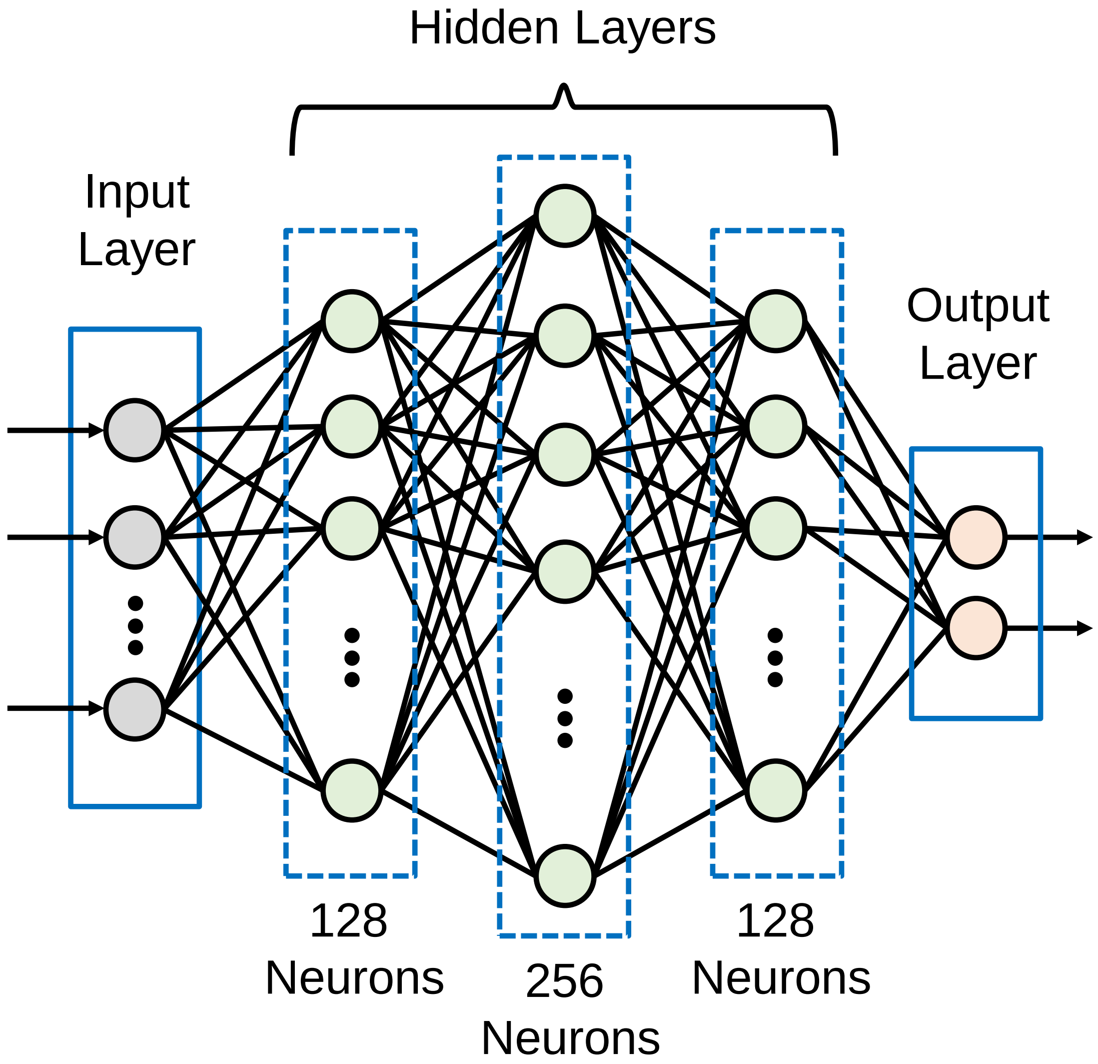
Fully Synthesizable Circuit Implementation



Design Parameters & Performance Metrics

Input

Design Parameters (Size)
Data latch (stage 1)
Data latch (stage 2)
Mixing MUX
Driver of the Mixing MUX
Clock driver
DFF for the ring counter
PMOS of the DAC driver
NMOS of the DAC driver
Capacitor



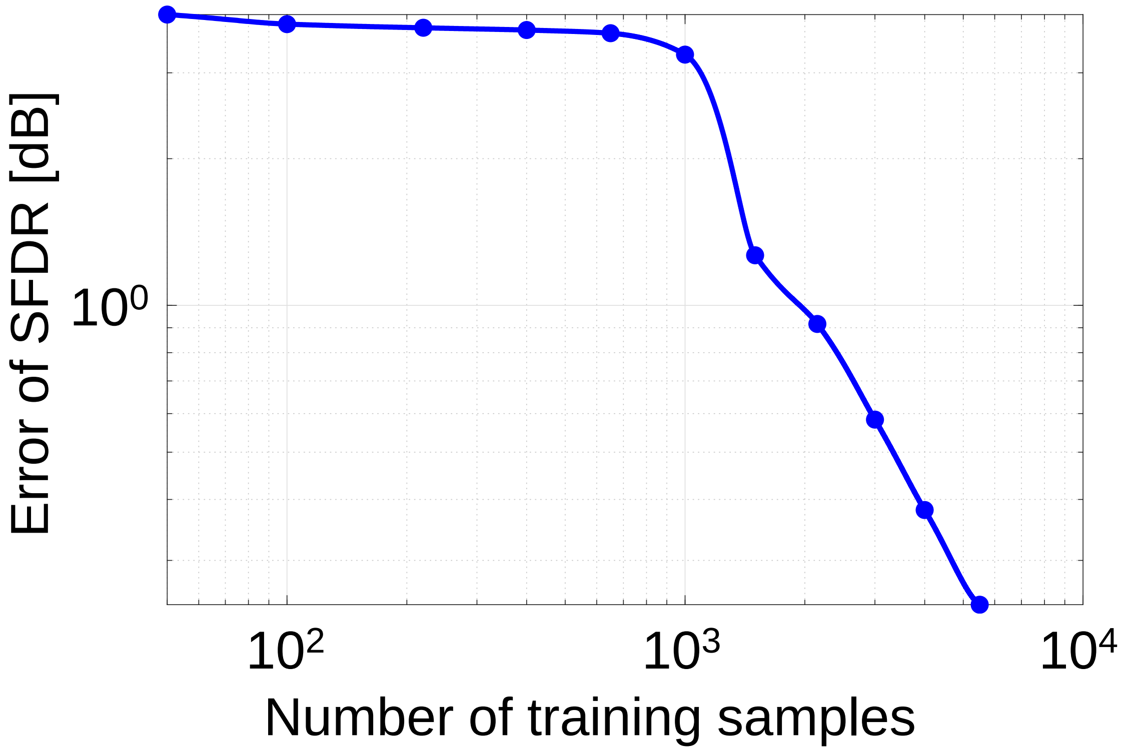
Output

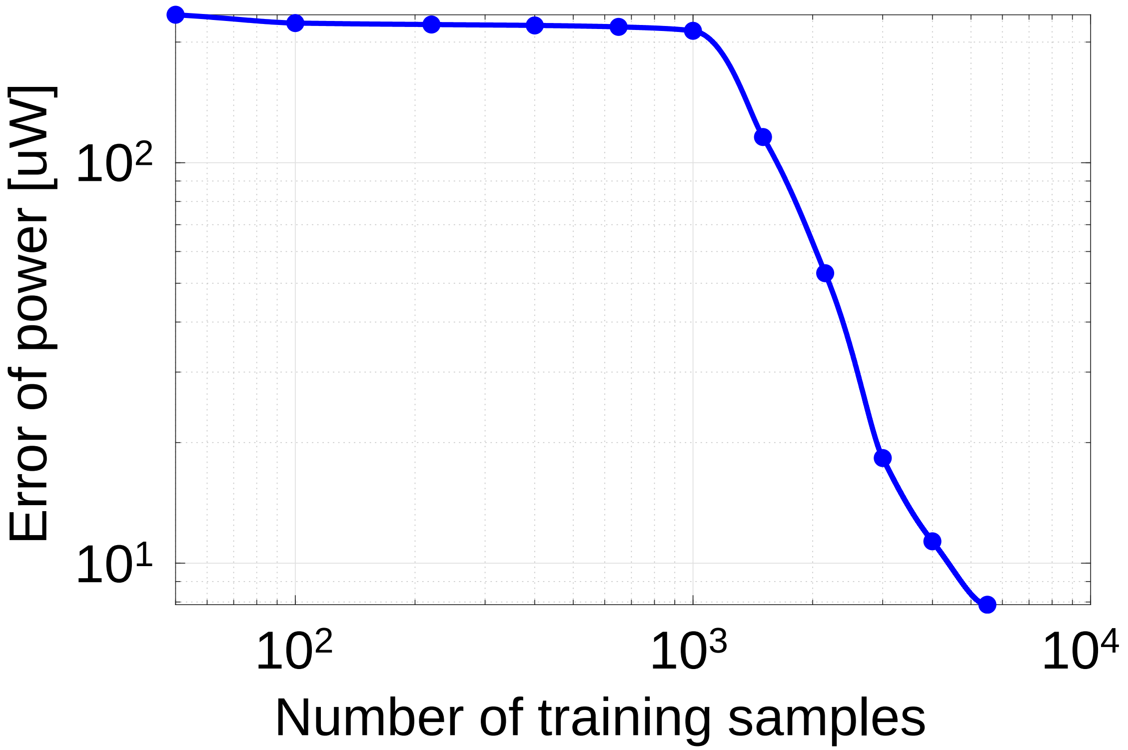
Performance Metrics
SFDR
Power

SFDR: Spurious Free Dynamic Range

Training Errors versus Number of Samples

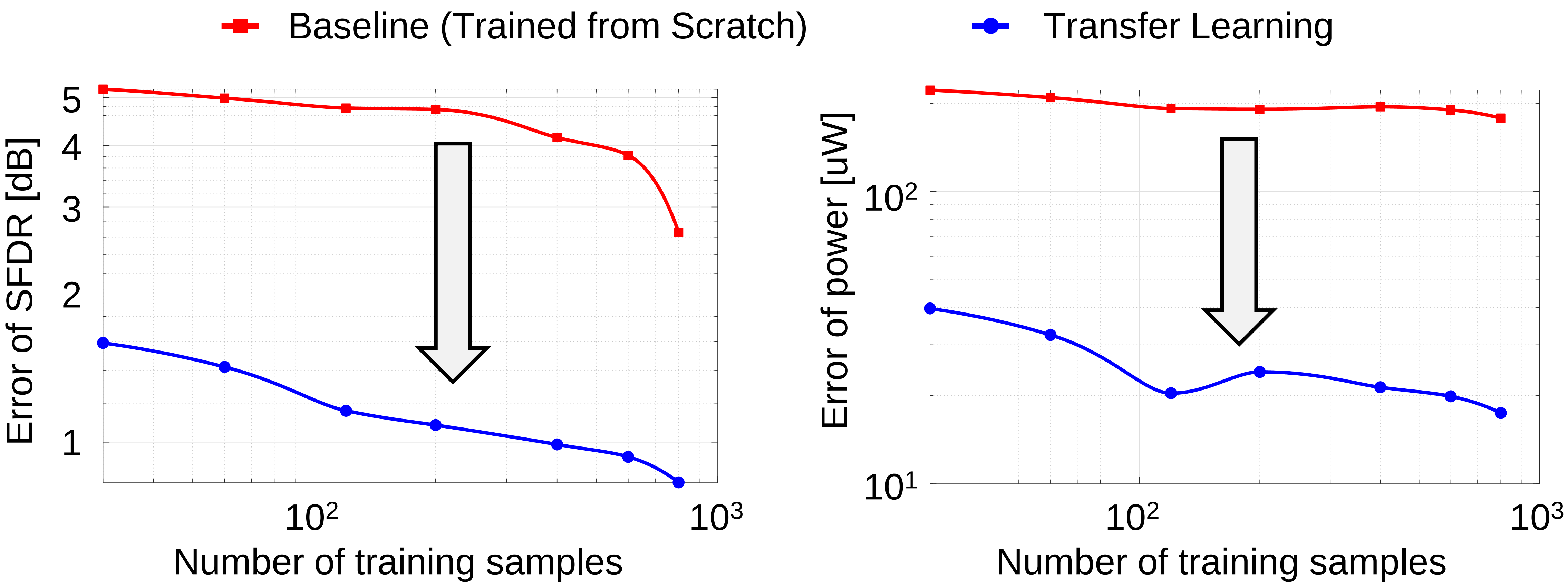
Schematic Model





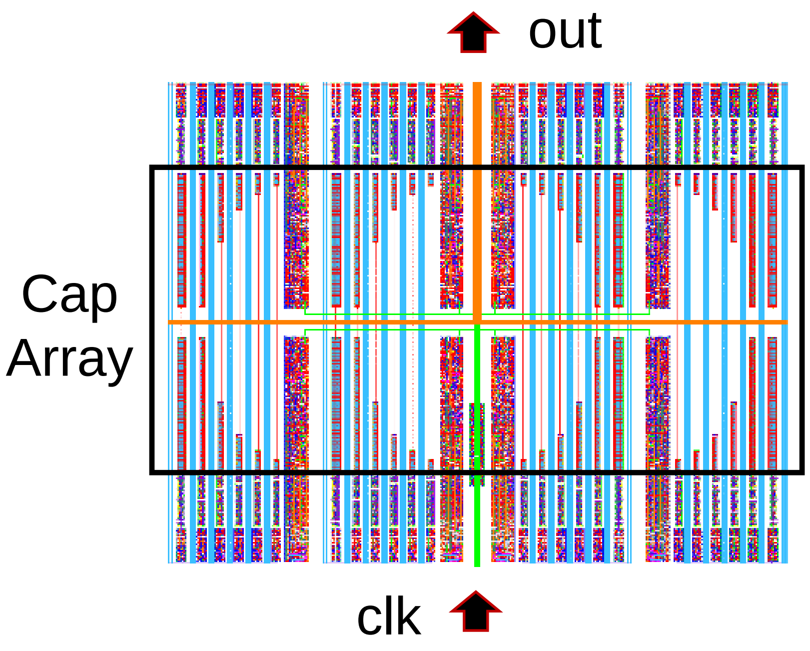
Model Improvement via Transfer Learning

Post-Layout Model

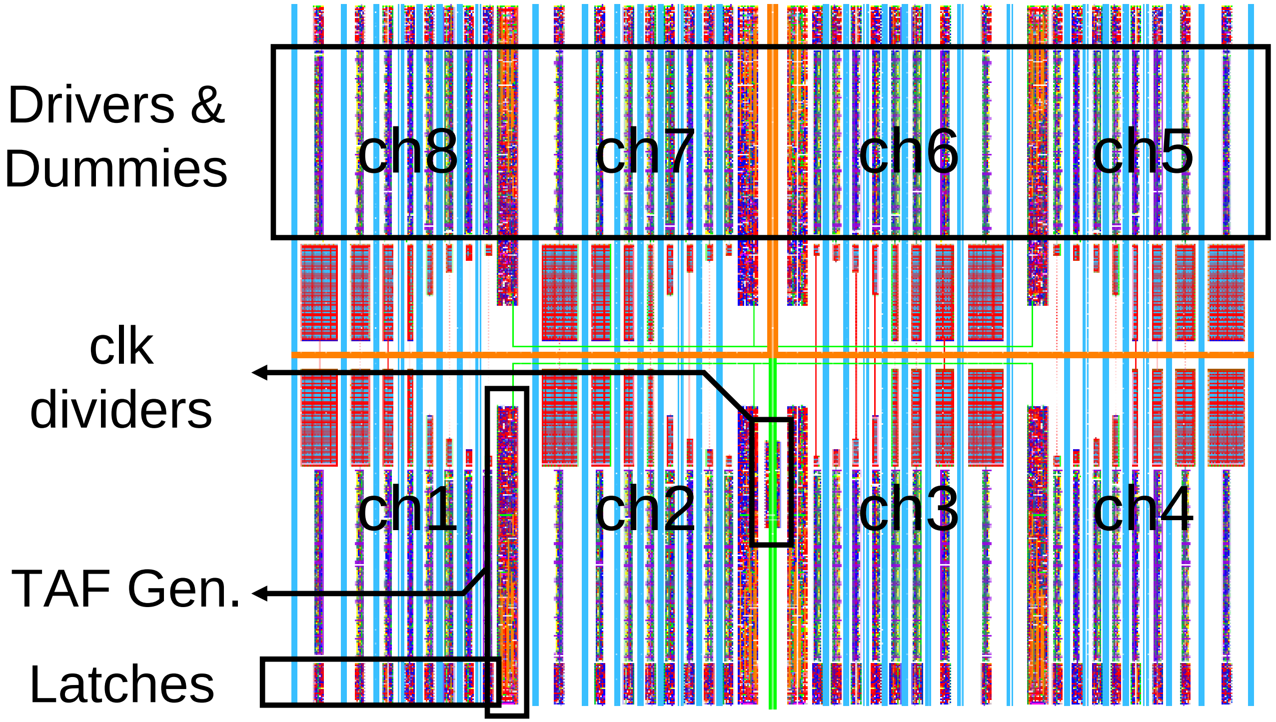


Filter Layout

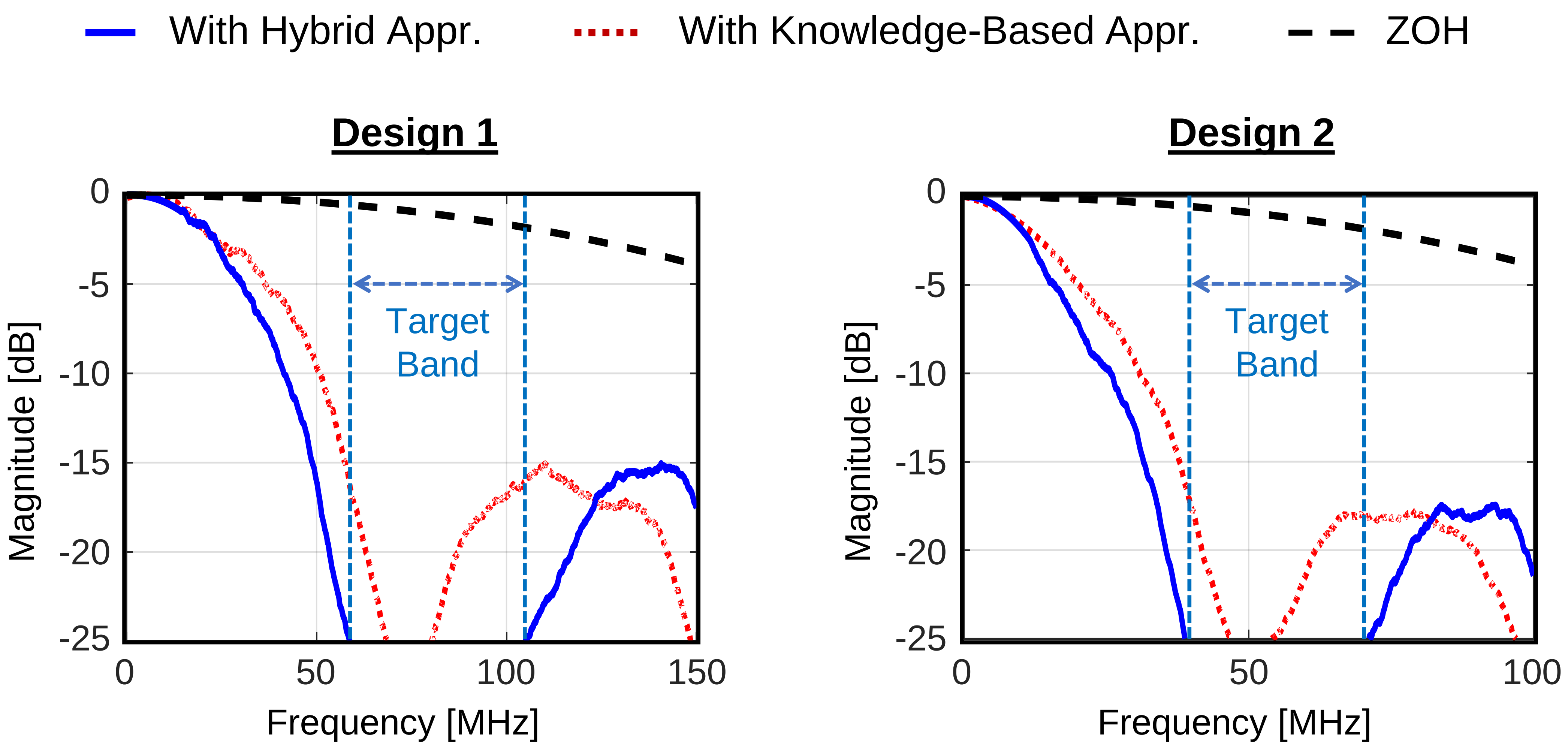
Design 1: w/ a 6-bit DAC



Design 2: w/ an 8-bit DAC



Simulated Filter Responses



Performance Summary

	DAC Res. [bits]	F_s [MHz]	BW [MHz]	F_{TAF} [GHz]	DAC SFDR [dBc]	Corner Freq.* [dBc]	Atten.** [dB]	Power [mW]	Area [mm^2]
Design 1	6	300	20	2.4	49	21	20	6.9	0.044
Design 2	8	200	10	1.6	51	14	18	5.2	0.089

* Corner frequency of the TAF's frequency response.

** Stop-band attenuation of the TAF.

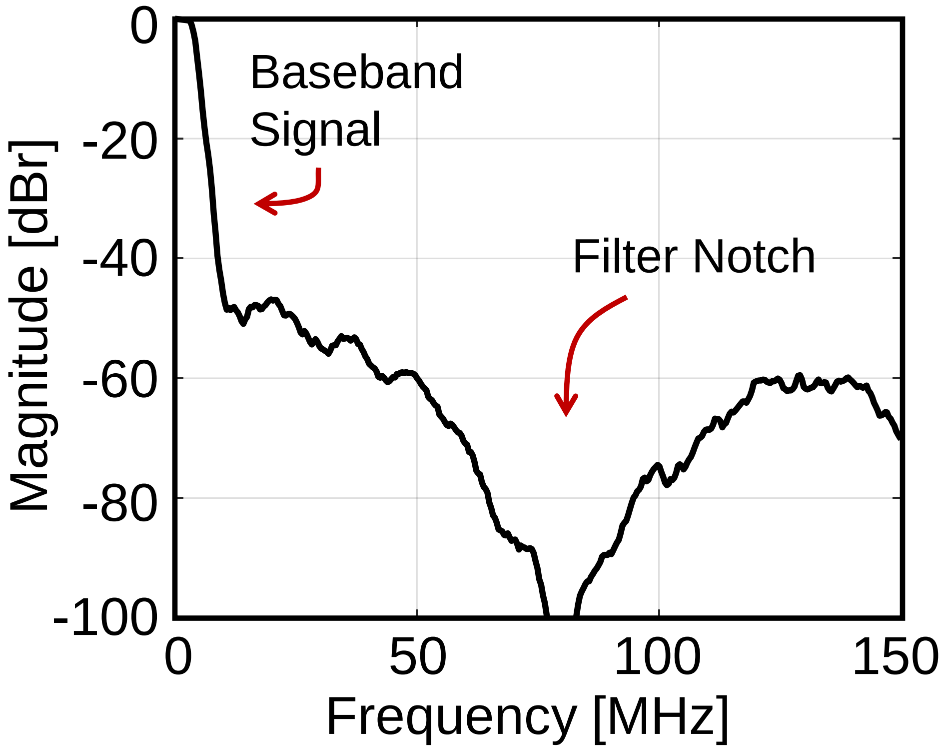
Performance Comparison

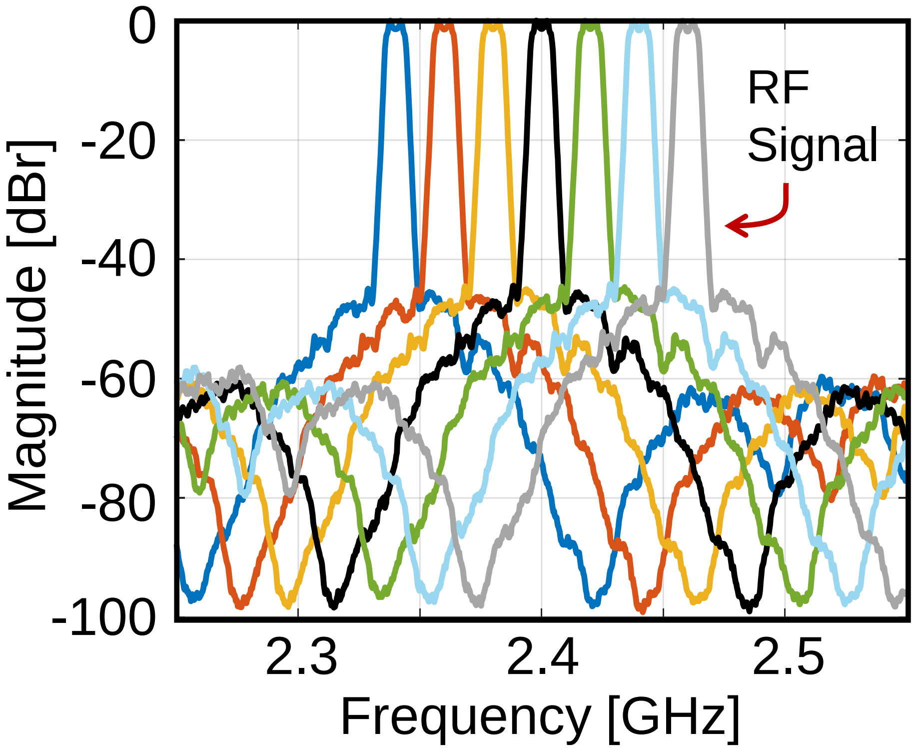
	Design 1		Design 2	
	KB**	**Hybrid Appr.**	KB*	**Hybrid Appr.**
Attenuation* [dB]	21.3	**28.8**	21.7	**31**
BW with >20dB attenuation [MHz]	24.1	**63.5**	19.7	**42.7**
BW with >25dB attenuation [MHz]	12	**46.58**	7.62	**32.7**

* Average attenuation of the TAF at the target band.

** Knowledge-based time approximation scheme proposed in [Su VLSI 2019].

Bandpass Mode Responses





Conclusion

- TAFA demonstrates a complete design automation flow for FIR AMS filters based on the time-approximation filter (TAF) technique.
- The hybrid pattern generation scheme significantly improves the TAF's performance for various applications.
- The NN-based search algorithm expedites the filter synthesis by orders of magnitude during schematic and layout stages.

Acknowledgement

- This work is supported in part by **DARPA ERI POSH** program and in part by **GlobalFoundaries**.

- The authors also would like to thank Professor **Anthony F. J. Levi** and Professor **Sandeep Gupta** from USC for technical discussions and supports.

POSH