AI-Assisted Automatic Ultra-Broadband Passive-Active Co-Design Workflow: A T-Coil Peaked Wireline Driver Example

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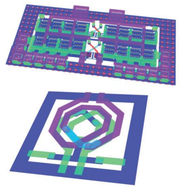
1. Introduction

Wireless Transceiver
FR1: 410 MHz – 7125 MHz
FR2: 24.25 GHz – 71.0 GHz
FR3: 7.125 GHz – 24.25 GHz
Cellular Network, Satellite Communication (SATCOM)

Wireline Link
SER – TX – RX – DES
100kHz – 50GHz
Chip-to-chip & processor-to-memory signaling

Challenges of High Frequency RFIC Design

- Variable **active** circuit topology
- Costly **passive** EM simulation
- Different frequency range configuration
- Recursive iteration for tuning & optimization

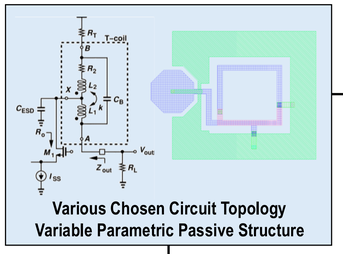


Active Circuit Cores

Recursive Iteration

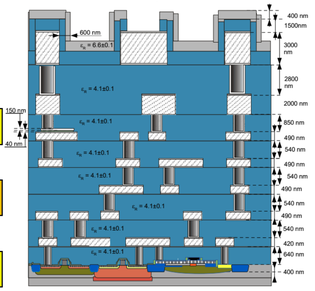
Passive 3D Structures

2. Proposed Workflow



Various Chosen Circuit Topology
Variable Parametric Passive Structure

Cluster → PDK Metal Stacks (IHP SG13G2 Open PDK Metal Stack)
→ Batch EM Generator & Simulator
GPU, Touchstone S3P Data, Geometric Parameters → Trained Artificial Neural Network for EM
Targets → Verification → SPICE Simulation → Processing & Optimization → Predicted S3P File



- OpenEMS FDTD EM Simulator
- Gdspy Python Layout Library
- Ngspice SPICE Simulator
- Optuna Python Optimizer

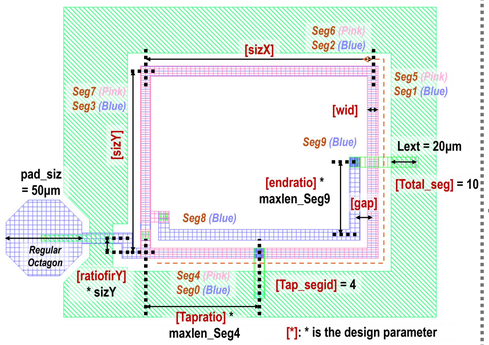
3. Design Examples: T-Coil Peaked Wireline Driver

Traditional Design Challenges

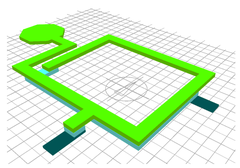
- Low-order **multi-port passive modeling**
- **Iterative design** between active & passive

AI-Driven Automatic Design Flow

- Direct **S-parameter modeling**
- **Co-designed** with given active CML core
- **9 free** geometrical parameter
- **DRC compliant** during parameter definition

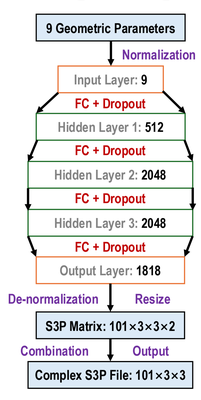


Layout View
T-coil usage
3D View
Parameter Table

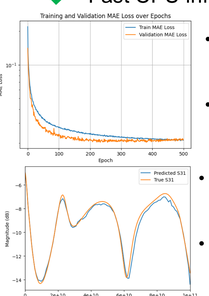


Name	Description	Unit	Range	Step
pad_siz	Diameter of the regular octagon pad	µm	50	Fixed
Lext	Feedline expansion length	µm	5	Fixed
sizX	Horizontal length of first turn	µm	[20, 200]	1
sizY	Vertical length of first turn	µm	[20, 200]	1
wid	Width of all coil segments	µm	[3, 12]	1
gap	Distance between adjacent segment center	µm	[6, 24]	1
total_seg	nummber of total segments	1	[2, 24]	1
tap_segid	# of segment that with T-coil center-tap	1	[0, total_seg)	1
tap_ratio	Percentage position of center tap	%	[30, 80]	Continuous
end_ratio	Percentage position of ending tap	%	[20, 80]	Continuous
ratio_firY	Percentage position of starting tap	%	[10, 90]	Continuous

Light-weight MLP-based EM Emulator



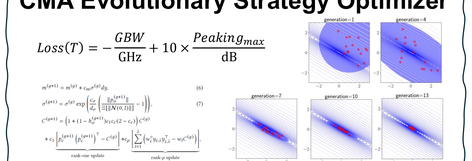
- ✓ 10k data collected
- ✓ < 9M parameter
- ✓ Efficient GPU training
- ✓ Fast CPU inference



- Converge within 20min on A400 4GB
- Normalized MAE < 0.02
- S-parameter matches EM simulator well
- > 50 infer/s @ Zen4 3.7GHz

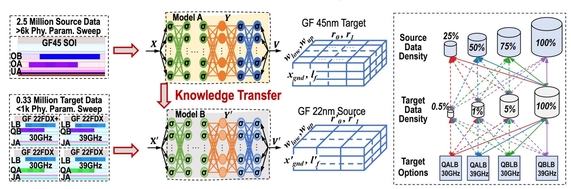
CMA Evolutionary Strategy Optimizer

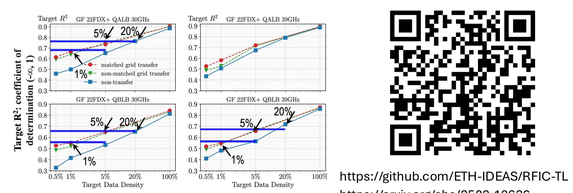
$$Loss(T) = -\frac{GBW}{\text{GHz}} + 10 \times \frac{Peaking_{max}}{\text{dB}}$$



4. *ETH IDEAS Group* AI4RF Work

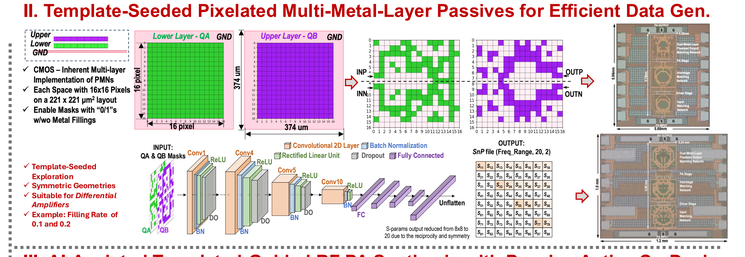
I. RFIC-TL: End-to-End Transfer Learning Assisted RFIC Passives





https://github.com/ETH-IDEAS/RFIC-TL
https://arxiv.org/abs/2502.18636

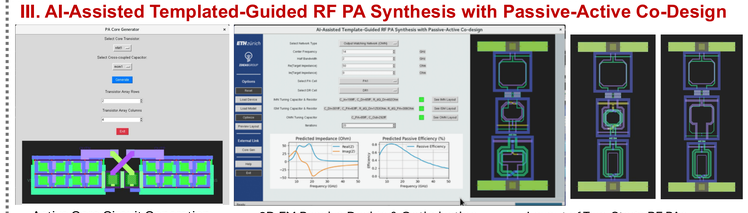
II. Template-Seeded Pixelated Multi-Metal-Layer Passives for Efficient Data Gen.



- ✓ CMOS – Inherent Multi-layer implementation of PMNs
- ✓ Each Space with 16x16 Pixels on a 221 x 221 µm² layout
- ✓ Enable Masks with "0/1"s w/wo Metal Fillings

- ✓ Template-Seeded Exploration
- ✓ Symmetric Geometries
- ✓ Suitable for *Differential Amplifiers*
- ✓ Example: Filling Rate of 0.1 and 0.2

III. AI-Assisted Templated-Guided RF PA Synthesis with Passive-Active Co-Design



Active Core Circuit Generation | 3D EM Passive Design & Optimization | Layout of Two-Stage RF PAs

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[2] B. Razavi, "The Design Of Broadband I/O Circuits [The Analog Mind]," in IEEE Solid-State Circuits Magazine, vol. 13, no. 2, pp. 6-15, Spring 2021.
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[4] Nomura, Masahiro, and Masashi Shibata. "cmaes: A simple yet practical python library for cma-es." arXiv preprint arXiv:2402.01373 (2024).

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[2] C. Chu et al., "Deep Learning-Assisted RFIC Design With Dual-Metal-Layer Passive Matching Networks: A 15-22 GHz CMOS PA for 6G in 22nm FDX+," 16th German Microwave Conference, GeMiC 2025.
[3] C. Chu, Y. Mao, and H. Wang, "Transfer Learning Assisted Fast Design Migration Over Technology Nodes: A Study on Transformer Matching Network," 2024 IEEE/MTT-S International Microwave Symposium, IMS 2024.