Exploration of Low - Cost Solutions for Sub-THz Phased Array Systems in TSMC 180nm

STUDENTS: Zhuoran Wu, Kaden Matsen, Suhail Inayatulla

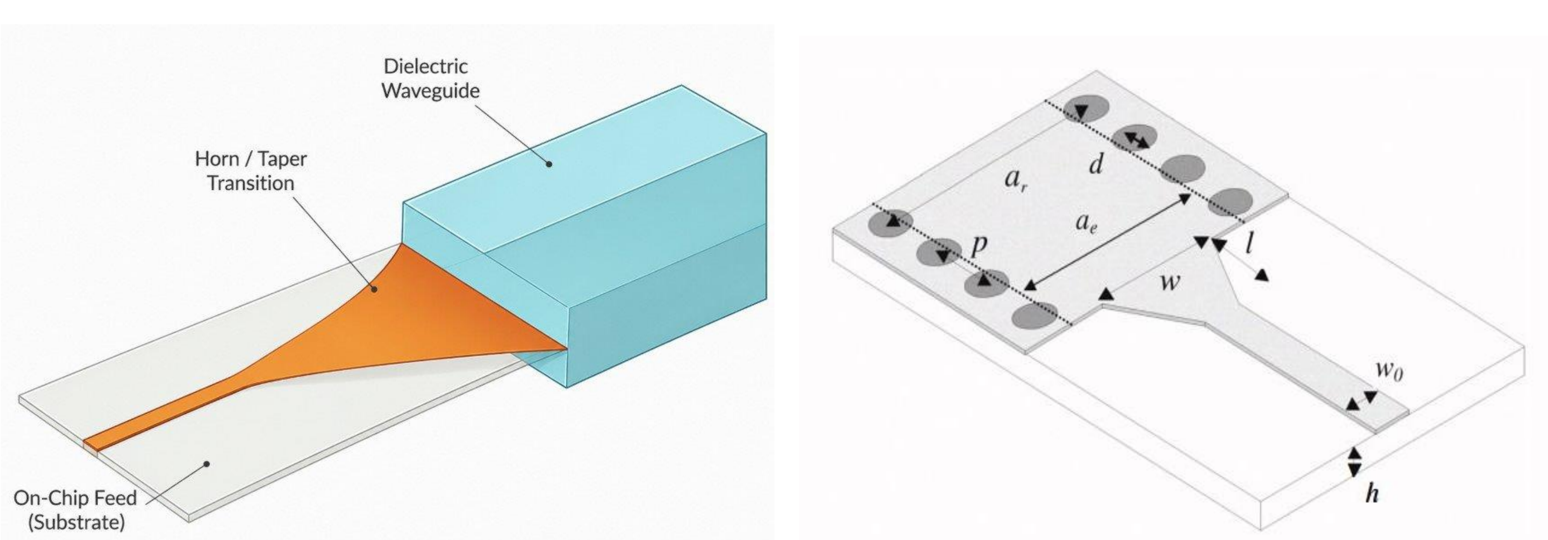
Abstract

Future 5G/6G and sub-THz wireless systems require low-loss interconnects, efficient chip-to-package transitions, and low-power control circuitry to support high-frequency beamforming. This project explores low-cost building blocks for sub-THz phased-array systems in TSMC 180 nm technology, including balun-based RF interconnects, wirebond vs E-jet transitions, dielectric waveguide coupling, and DAC/sample-and-hold control paths.

Electromagnetic simulation, post-layout extraction, PVT validation, Monte Carlo analysis, DRC, and LVS were used to evaluate performance and tapeout readiness. The design targets accepted RF and IC metrics such as low insertion loss, S11 below −10 dB, ~180° phase balance, stable 500–800 mV control voltages, and low-power operation.

The goal is to reduce barriers to practical sub-THz hardware by developing manufacturable test structures that support future wireless communication, sensing, and beamforming applications.

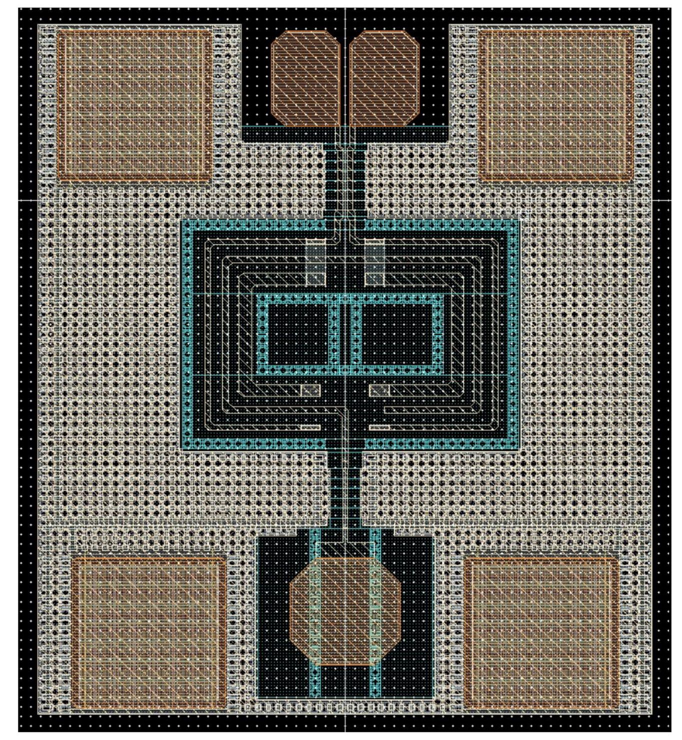
Chip to Dielectric Waveguide Transition

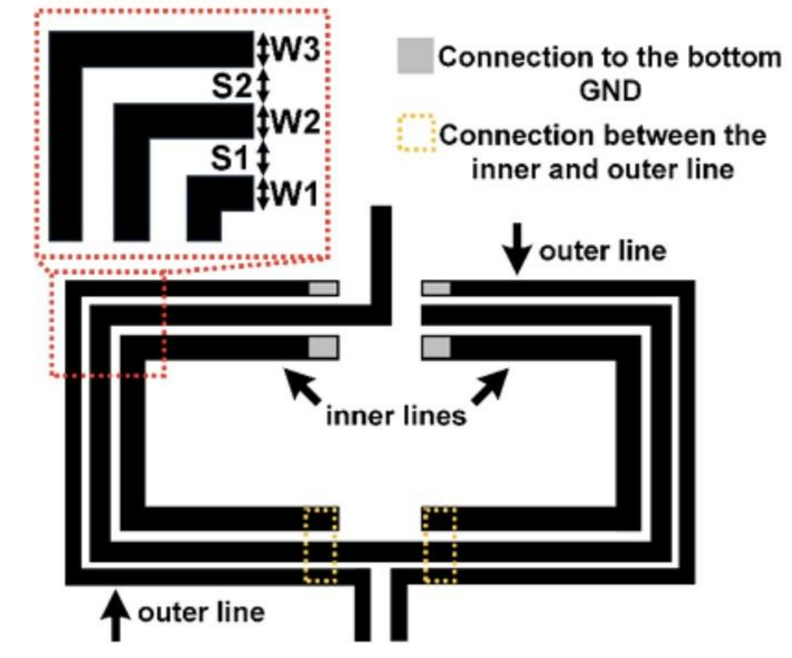


[1]

- An off-chip dielectric waveguide receives energy from the on-chip edge horn/taper and guides it forward with low loss, supporting a stronger guided mode than a weak on-chip antenna could radiate directly.
- A tapered transition improves mode matching between the chip feed and the guide, reducing interface reflections and moving the radiating structure out of lossy silicon while keeping a compact planar form factor.
- Two transition designs are fabricated and compared: a surface-launch coupler and a slotted substrate-integrated-waveguide (SIW) feed, both meeting >40 GHz bandwidth.
- Using a dielectric guide instead of a bulky metal horn or silicon lens supports lower-cost sub-THz packaging, easier fabrication, and scalable integration with future phased arrays.

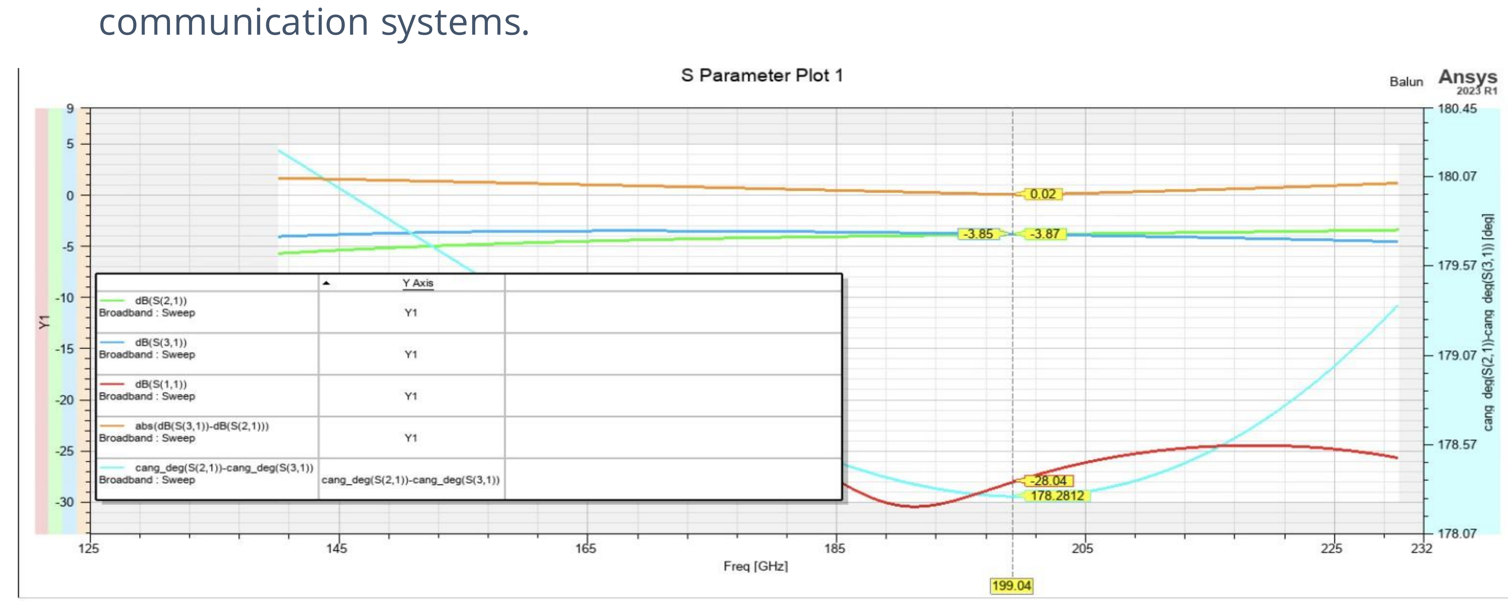
Balun



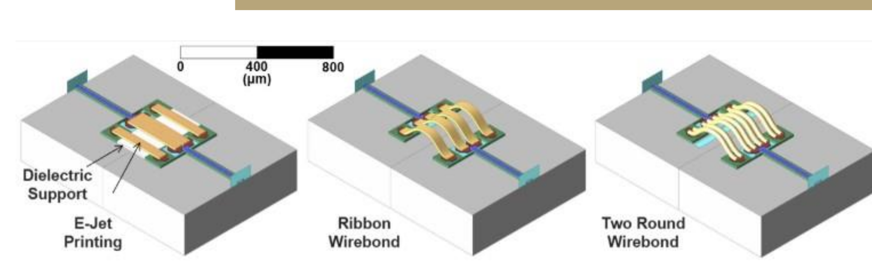


[2]

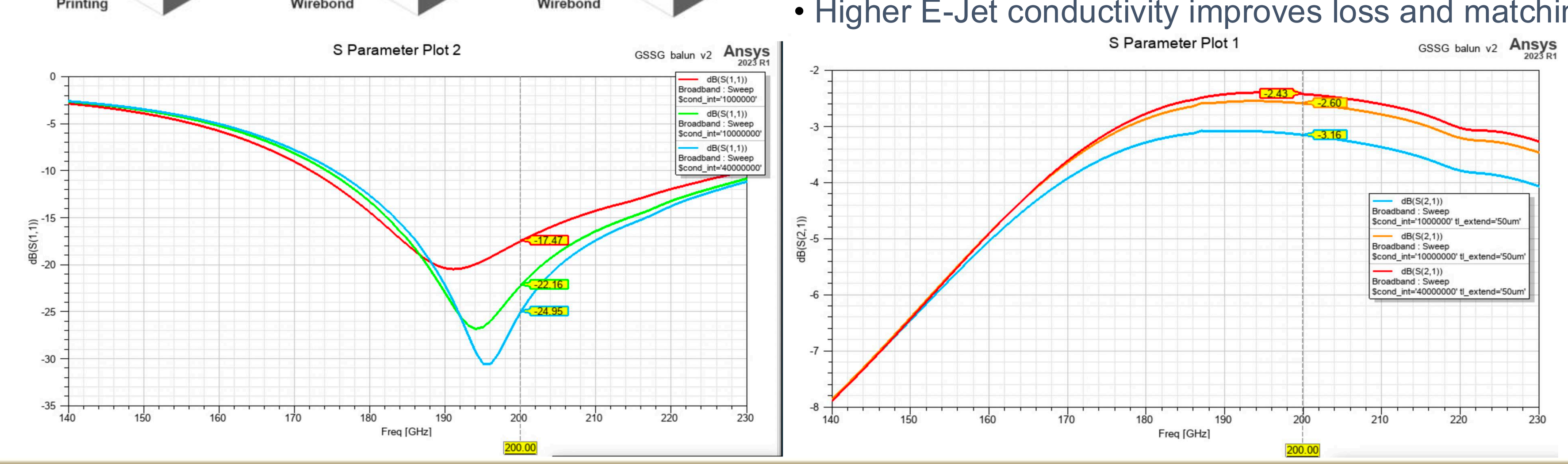
- Converts a single-ended RF signal to balanced differential (~180° phase difference), enabling standard RF probes to interface with differential sub-THz blocks.
- Edge-coupled transmission-line structure gives wide bandwidth, low insertion loss, and good amplitude/phase balance.
- A key building block for phased-array, beamforming, and high-frequency communication systems.



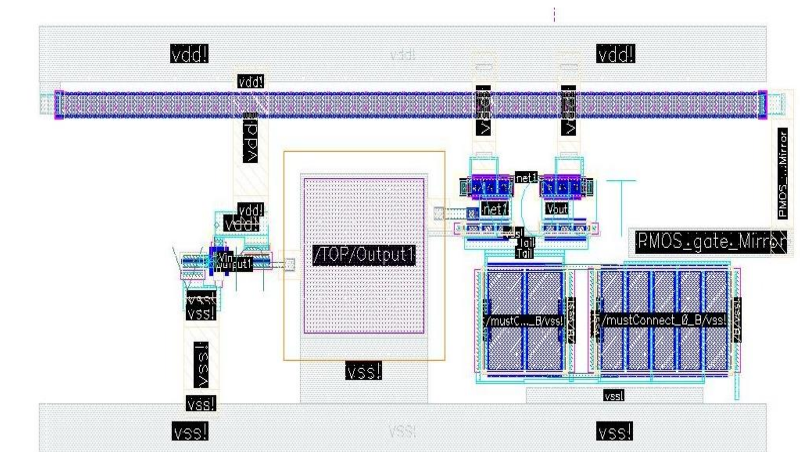
Wirebond Vs E-Jet Printing



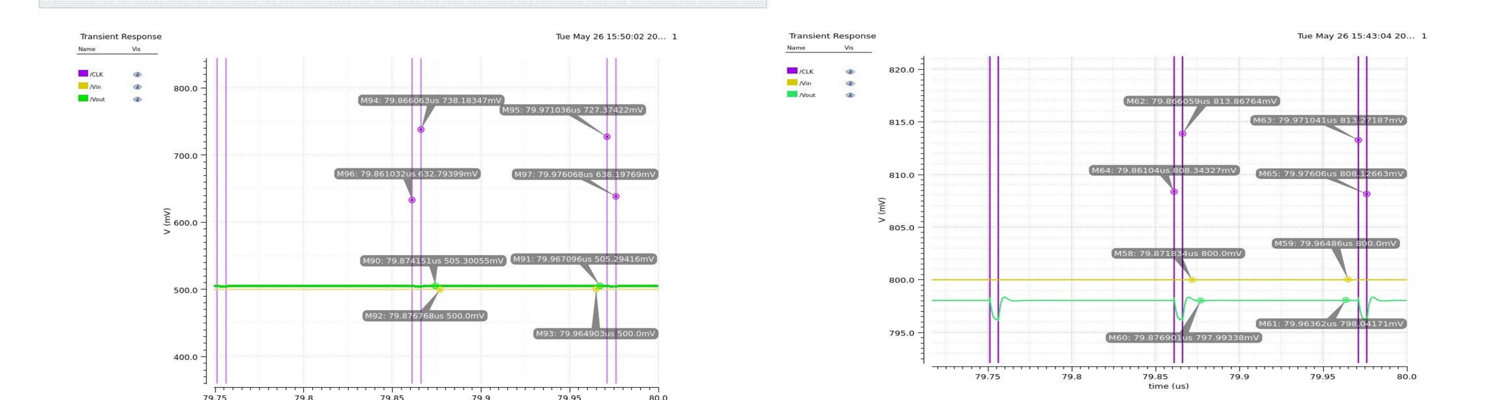
- At 200 GHz, interconnects directly affect RF performance.
- Wirebonds add height, inductance, and loss.
- E-Jet offers a shorter, controlled RF path.
- We compare S21 transmission and S11 matching.
- Higher E-Jet conductivity improves loss and matching.



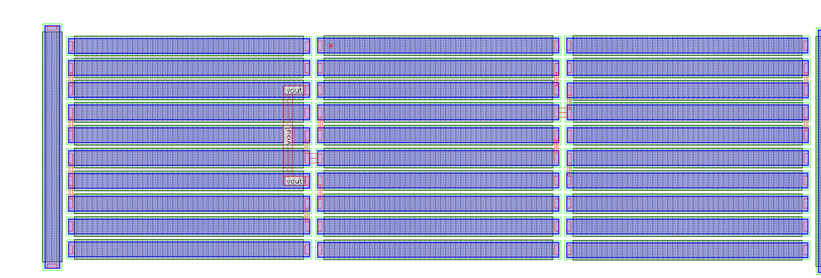
S&H



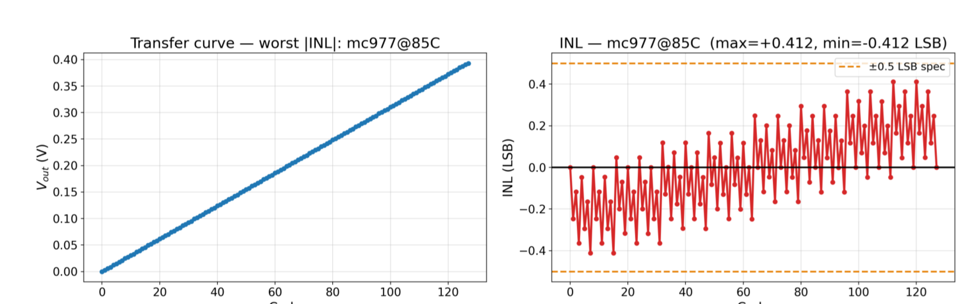
- Samples and holds the analog control voltage for the phased array
- Inverter + T-gate front end with an OTA buffer driving the output.
- Holds 500–800 mV stably with negligible droop, verified across process and temperature corners (TT/SS/FF); ~22 µW total.



R-2R Digital to Analog Converter



- 7-bit R-2R DAC generating the phased array's DC reference voltages
- ~3 mV steps, scan-chain input to minimize pad count.
- Matched ladder with dummy-resistor perimeter holds INL/DNL within ±0.5 LSB across process, mismatch, and temperature
- < 250µW total power



Future Work, References, and Acknowledgments

- **Measure and correlate:** probe with GSG/VNA and compare measured S-parameters, DAC linearity, and S&H stability against simulation to confirm the models near 200 GHz.
- **Down-select the interconnect:** confirm on silicon whether E-jet beats wirebonds, establishing a low-cost chip-to-package path.
- **Validate sub-THz transition:** verify low-loss off-chip dielectric coupling, allowing sub-THz packaging without bulky horns or lenses.
- **Toward integration:** combine the validated blocks into a complete beamforming front end for low-cost 5G/6G and sensing.

Faculty: Hossein Naghavi, Chris Rudell
Sponsors: Apple, TSMC
UW TIME Lab, Analog IC Capstone

[1] D. Deslandes, "Design Equations for Tapered Microstrip-to-Substrate Integrated Waveguide Transitions," IEEE MTT-S International Microwave Symposium Digest, pp. 704–707, 2010.

[2] Anyi Tian, Chenxin Liu, Hiroyuki Sakai, Kazuaki Kunihiro, AtsushiShirane, and Kenichi Okada, "A Low-Loss 220GHz–325GHz MarchandBalun in 65nm CMOS Technology," Proceedings of the 54thEuropean Microwave Conference, Paris, France, 2024.

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of WASHINGTON

ADVISERS: Hossein Naghavi - Terahertz Integrated MicroElectronics Lab
SPONSOR: Chris Rudell - IC Capstone (Spring 2026) - TSMC / Apple