Massachusetts Institute of Technology

MIT Anti-Tampering THz-ID Technology

Ruonan Han

Associate Professor

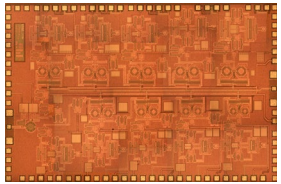
Electrical Engineering and Computer Science

Massachusetts Institute of Technology

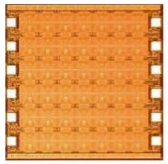
Collaborator: Anantha Chandrakasan, Dean of School Engineering, MIT

ruonan@mit.edu, https://hangroup.mit.edu

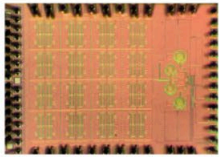
Terahertz Integrated Circuits and Systems at MIT



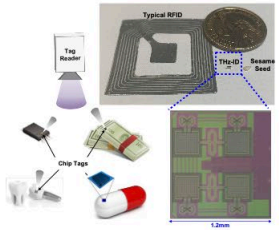
CMOS 220-320GHz Gas Spectrometer (ISSCC 2017)



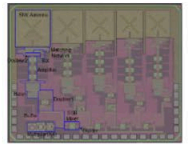
1-THz Radiator Array (JSSC 2018)



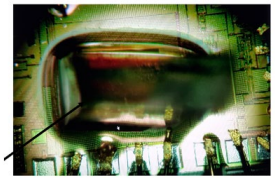
0.24-THz Heterodyne Imaging Array (JSSC 2019)



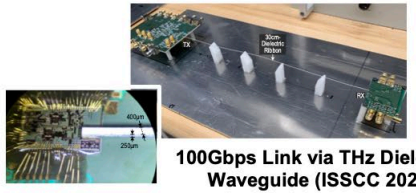
Cryptographic THz-ID (ISSCC 2020)



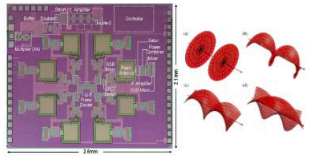
High-Resolution THz Comb Radar (ISSCC 2020)



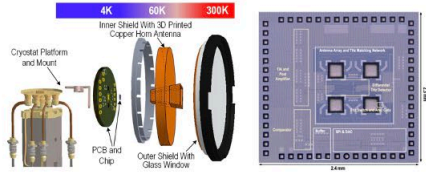
CMOS-NV Quantum Magnetometer (ISSCC 2019)



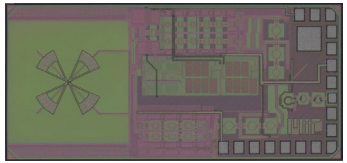
100Gbps Link via THz Dielectric Waveguide (ISSCC 2021)



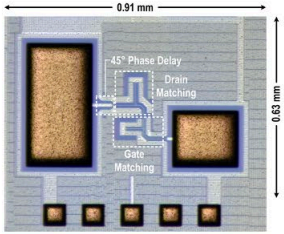
0.26-GHz Orbital-Angular-Momentum Transceiver (JSSC 2022)



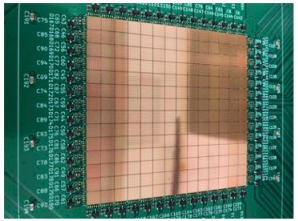
4K-300K THz Backscatter Wireless Link (ISSCC 2023)



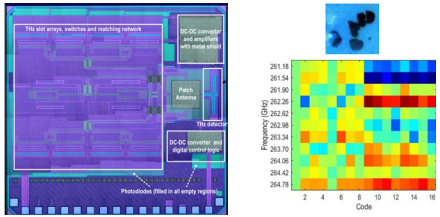
140GHz Radar with Loss-Free TX-RX Antenna Sharing (ISSCC 2022)



0.3-THz Energy Harvester (RFIC 2022)



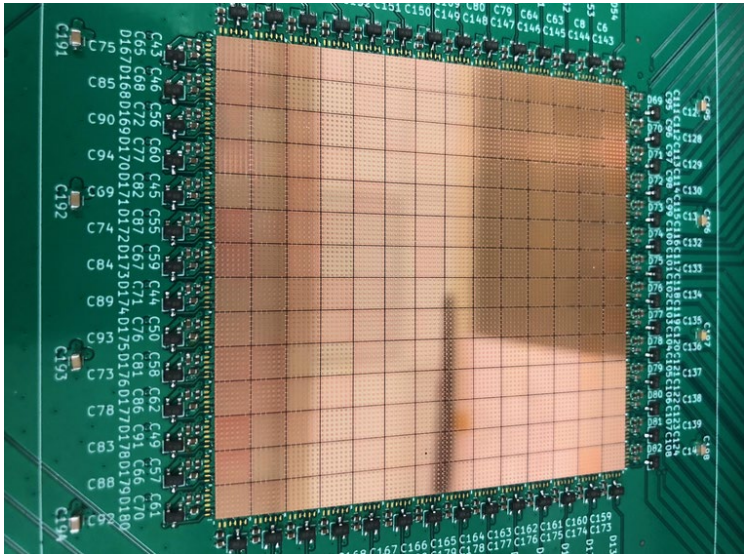
0.3-THz 98x98 Beam-Forming Array (ISSCC 2022)



Anti-Tampering THz-ID (ISSCC 2024)

What's the Missing Opportunity in THz Wireless?

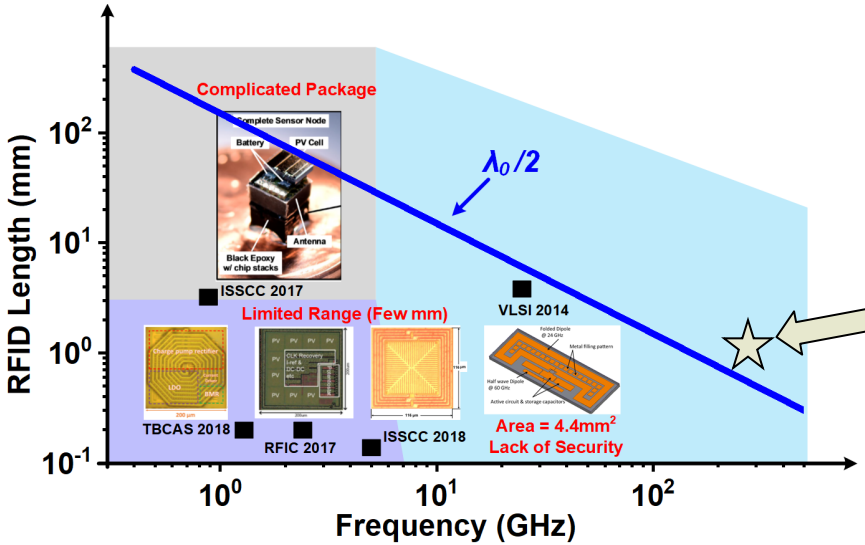
USAF PAVE-PAWS Radar (*f*=0.4 GHz)
2.2° beamwidth, 2677 antennas, 22x22 m^2

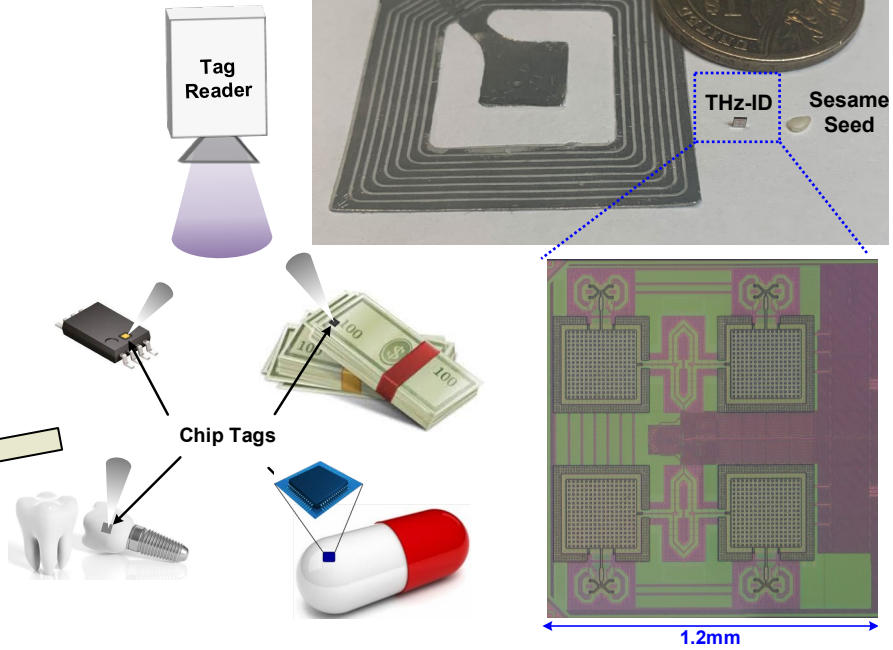


MIT-Intel CMOS Reflectarray (f=265 GHz)
1° beamwidth, 9604 antennas, 0.05x0.05 m^2

Ultra-Miniaturization of Wireless Hardware

THz-ID: Ultra-Miniaturized Tag with Built-In Security

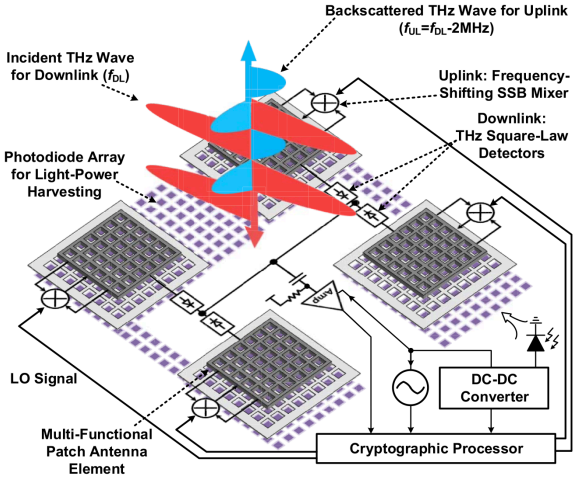


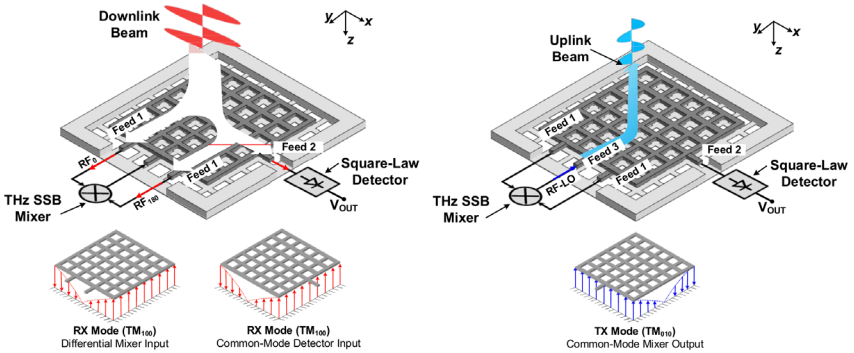


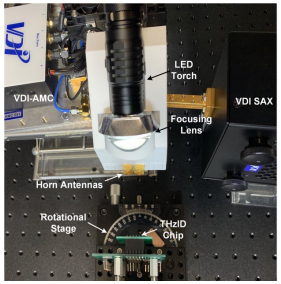
THz-ID: 1.5mm^2 Tag with 260-GHz Backscatter Communication and Built-In Security

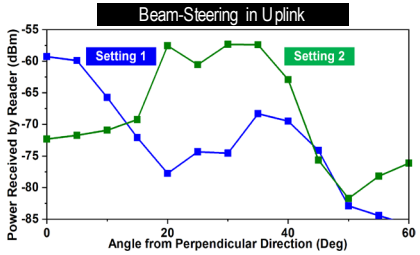
[M. Ibrahim, et al., *ISSCC* 2020, *JSSC* 2021 (Invited)]

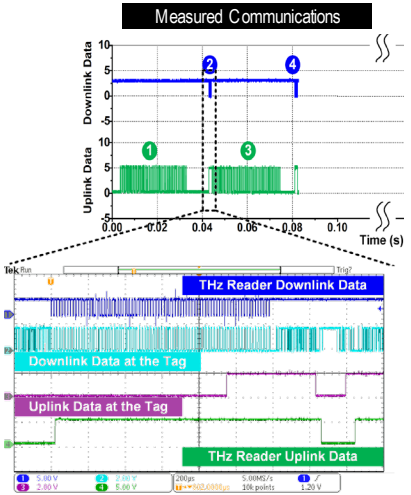
First Prototype: Principle and Experimental Results

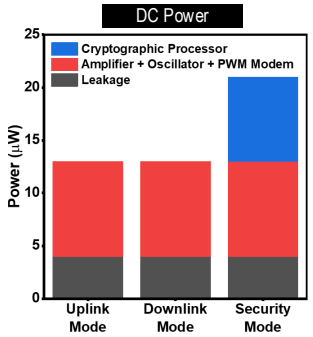








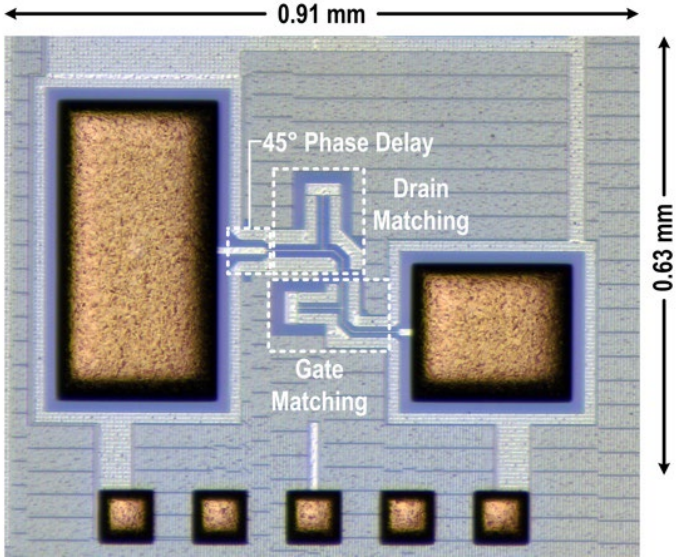


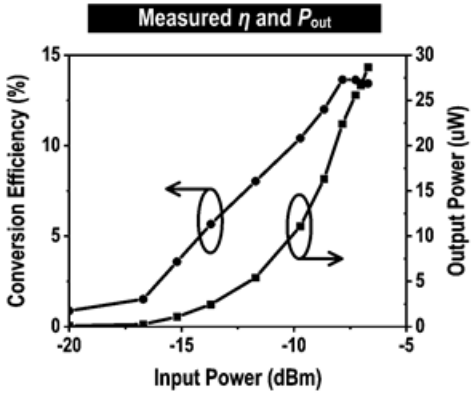


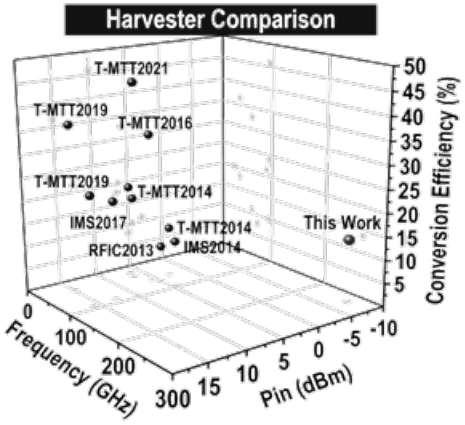
- 5-cm operation distance
- Built-in ECC authen-tication processor
- Photovoltaic powering

[M. Ibrahim, et al., *ISSCC* 2020, *JSSC* 2021]

THz-to-DC Energy Harvester in CMOS

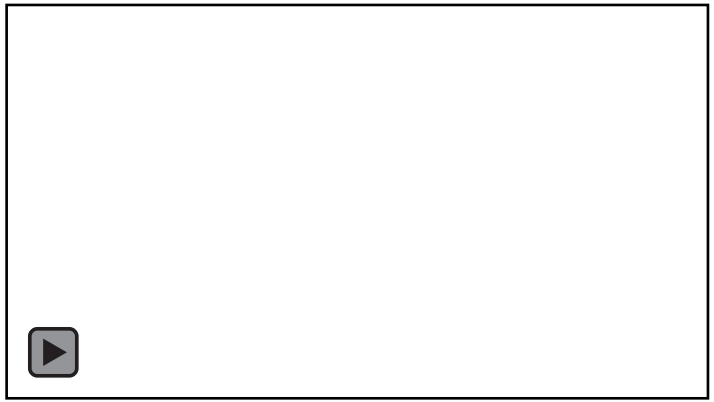




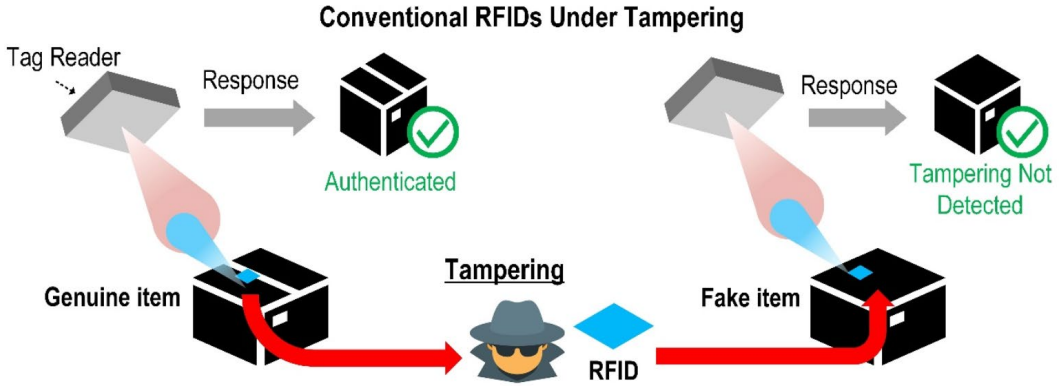


- **Recent progress: 260-GHz energy harvesting in CMOS (22nm FinFET)**
  - 15% THz-to-DC efficiency @ -8dBm input power
  - 25μW output DC power
  - *Highest frequency* of CMOS RF harvester

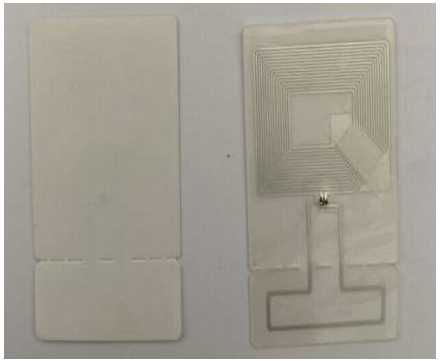
[M. Ibrahim, et al., *RFIC* 2022]



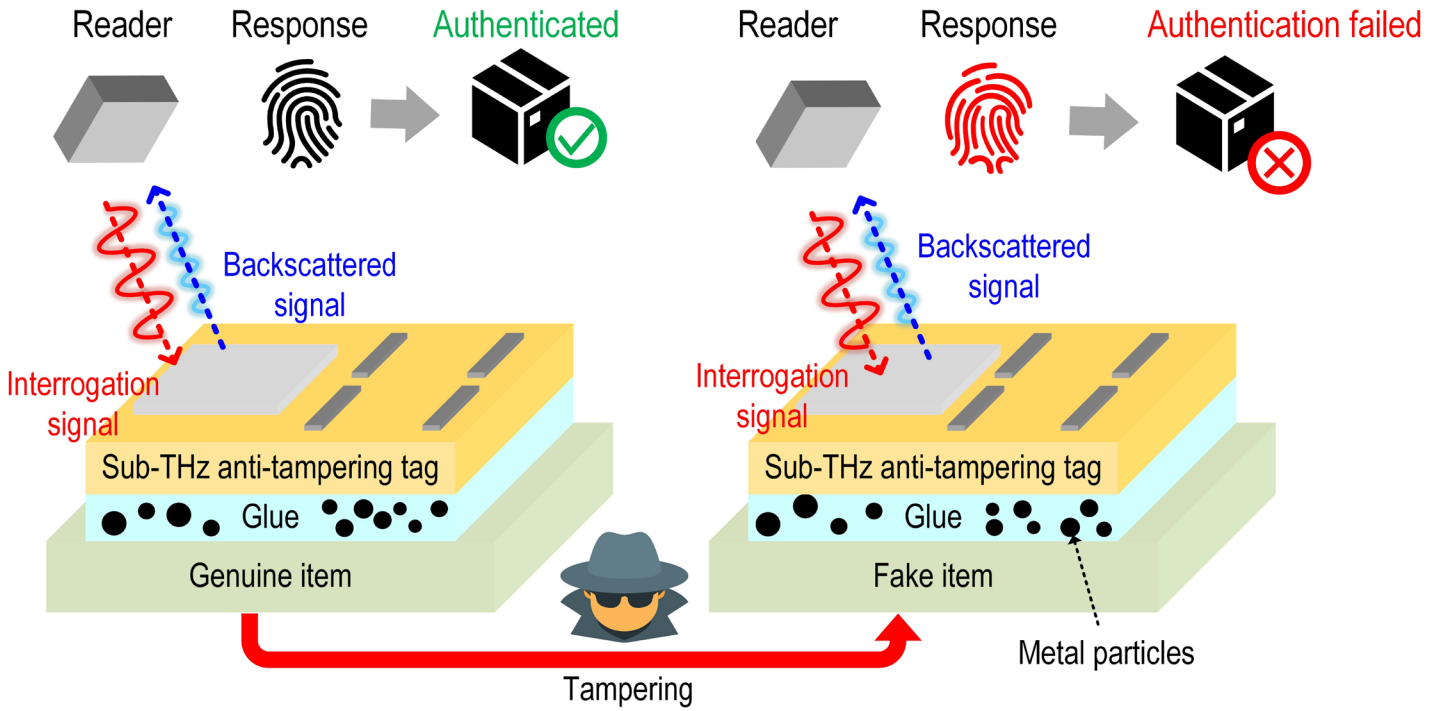
Anti-Tampering Function



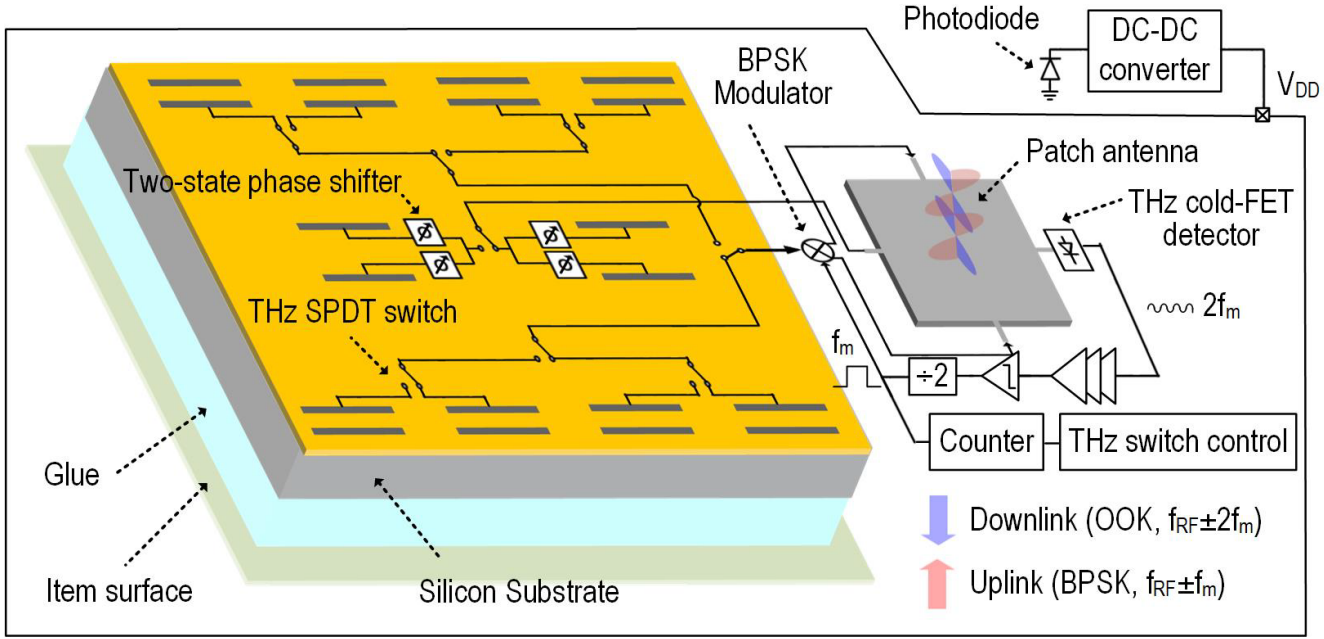
Conventional Anti-Tampering Approach



Sub-THz Anti-Tampering ID Using THz Backscattering



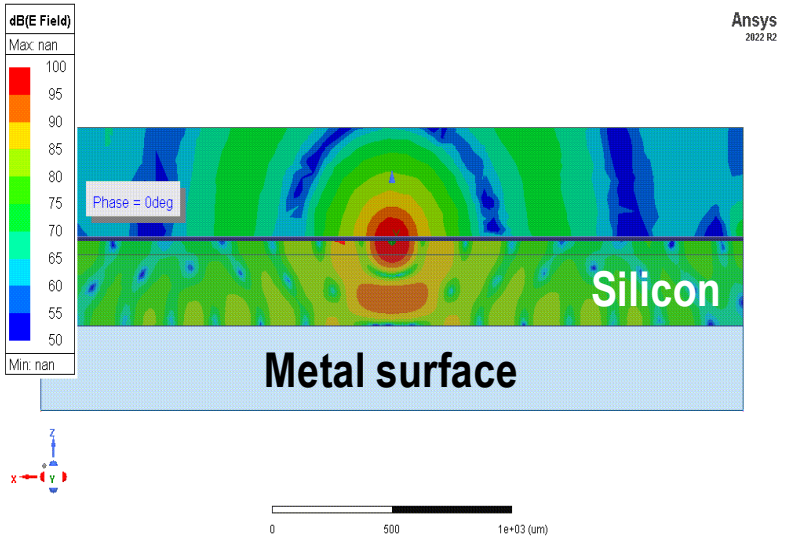
System Architecture

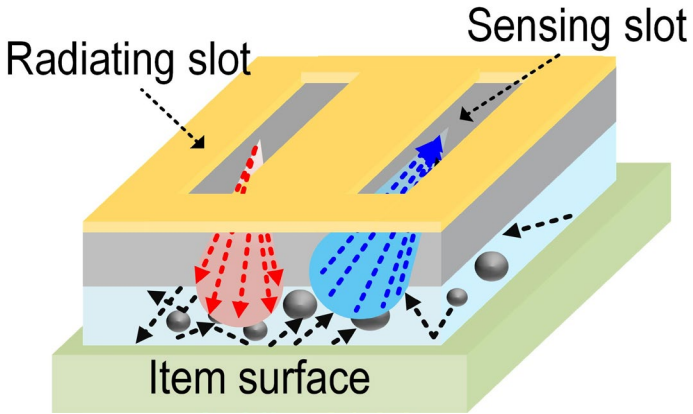


- **Sub-THz Wave Scattering Detection**
  - Slot pairs
- **Communication**
  - Downlink (OOK)
  - Uplink (BPSK)
- **Self-powering**
  - Photovoltaic harvesting

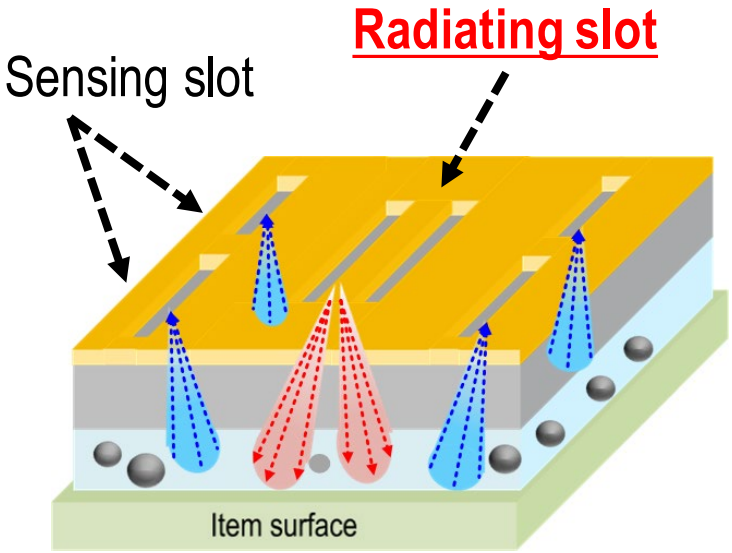
Sub-THz Fingerprinting at Chip-item Interface

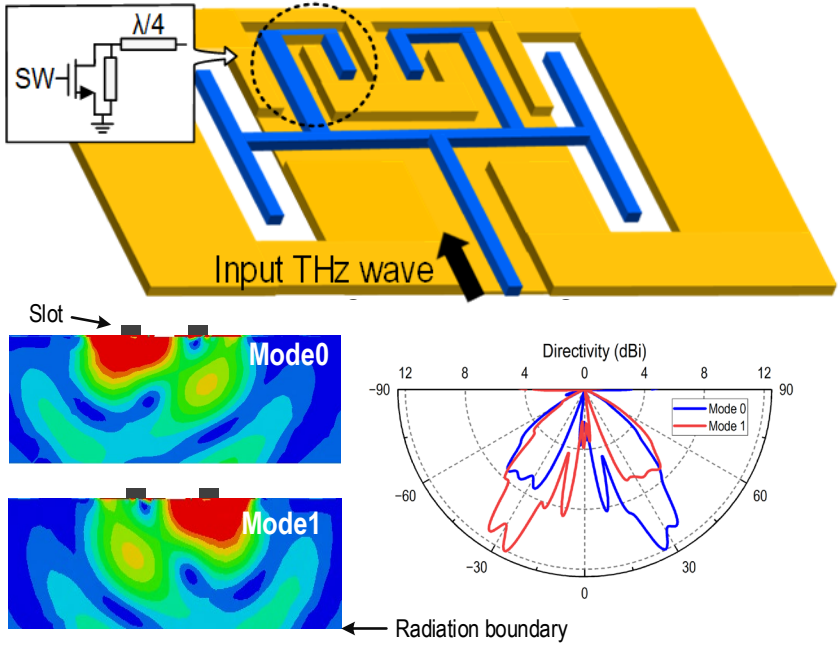
- Substrate-mode wave radiation below the chip using slot
- Sub-THz waves scattering varies with 3D material distribution under chip.
- Scattering detection using radiating & sensing slot pair





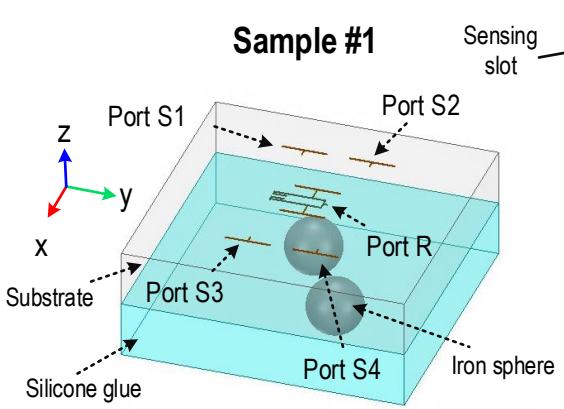
Two-State Beam-Reconfigurable Radiating Slot

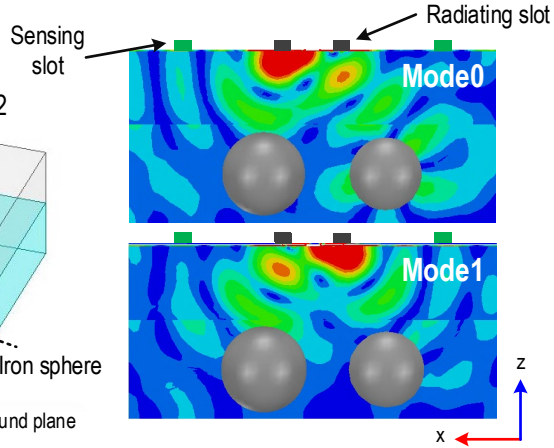


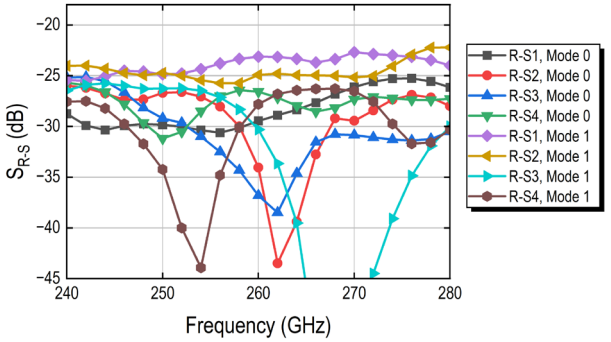


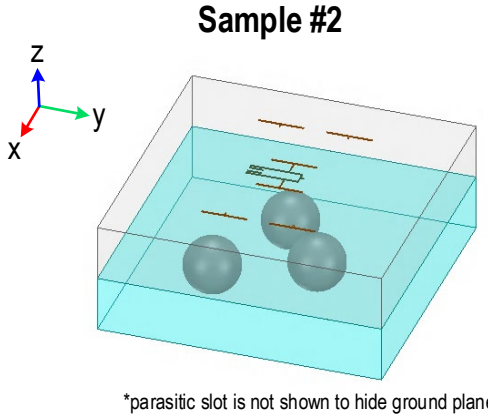
- Two-state phase shifter for beam-reconfigurability
- Beam-steered towards the upper/lower side of the chip substrate

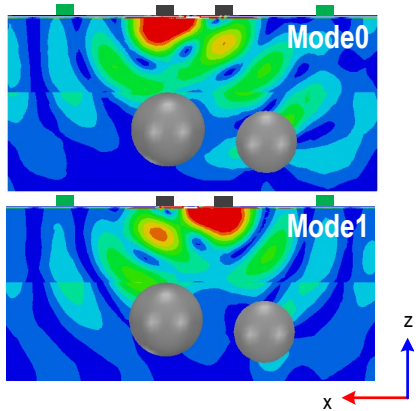
Simulated Inter-Slot Coupling Responses

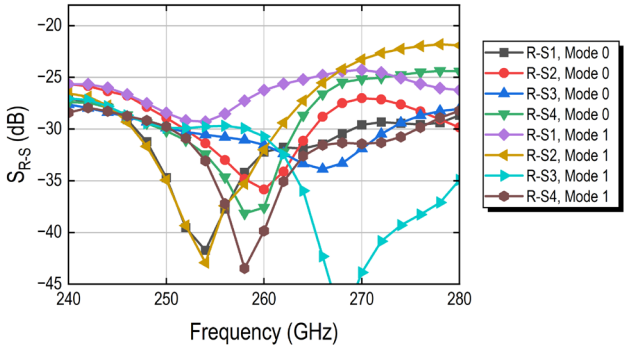




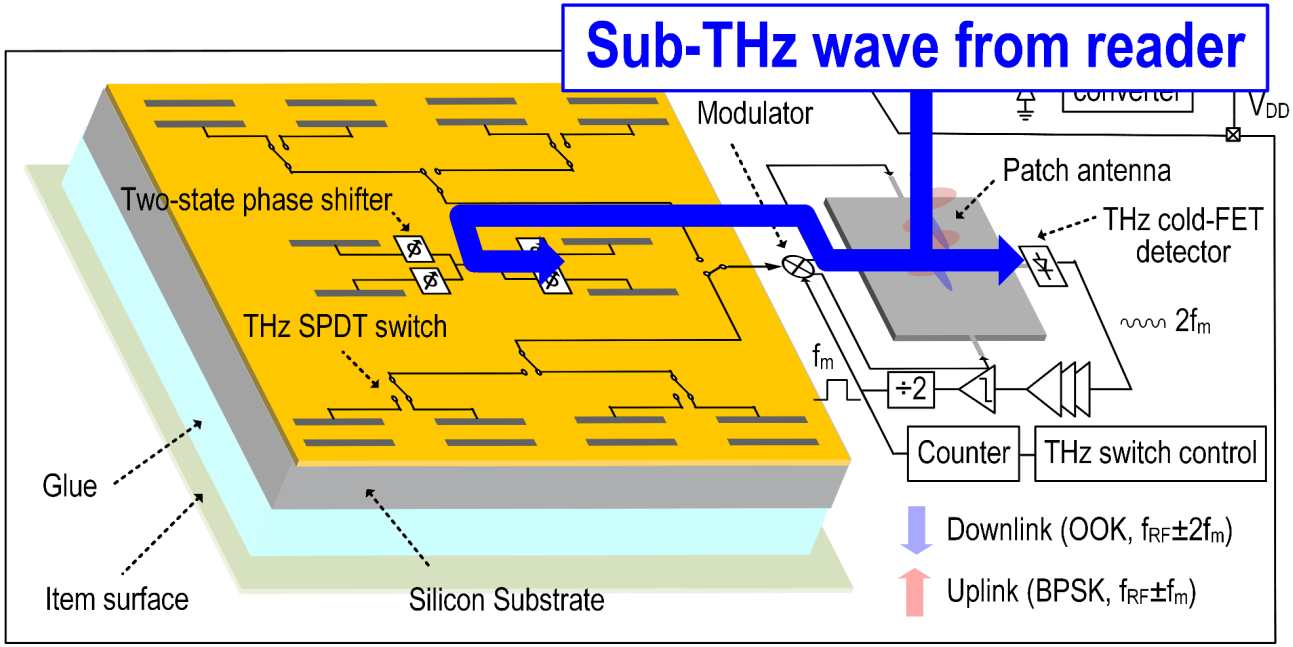






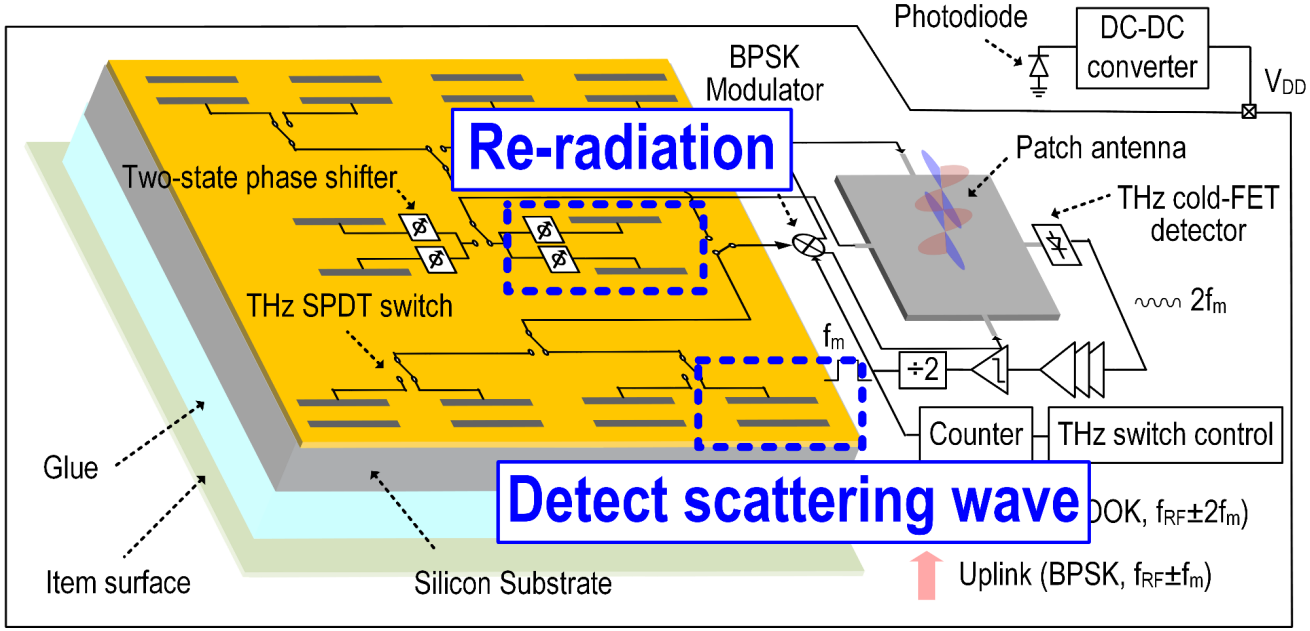


Tag Operation (1) – Downlink



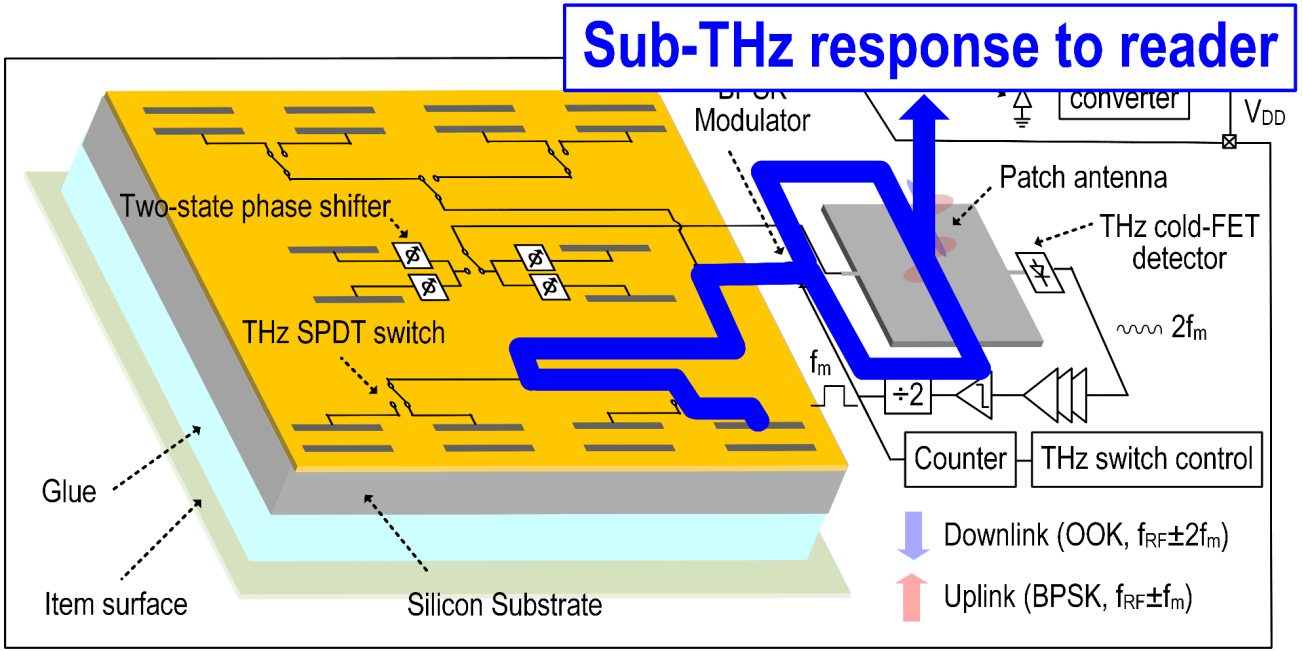
- Sub-THz wave captured by patch antenna
- 1:1 power splitting between THz square-law detector and slot pairs

Tag Operation (2) – Sub-THz Scattering Detection



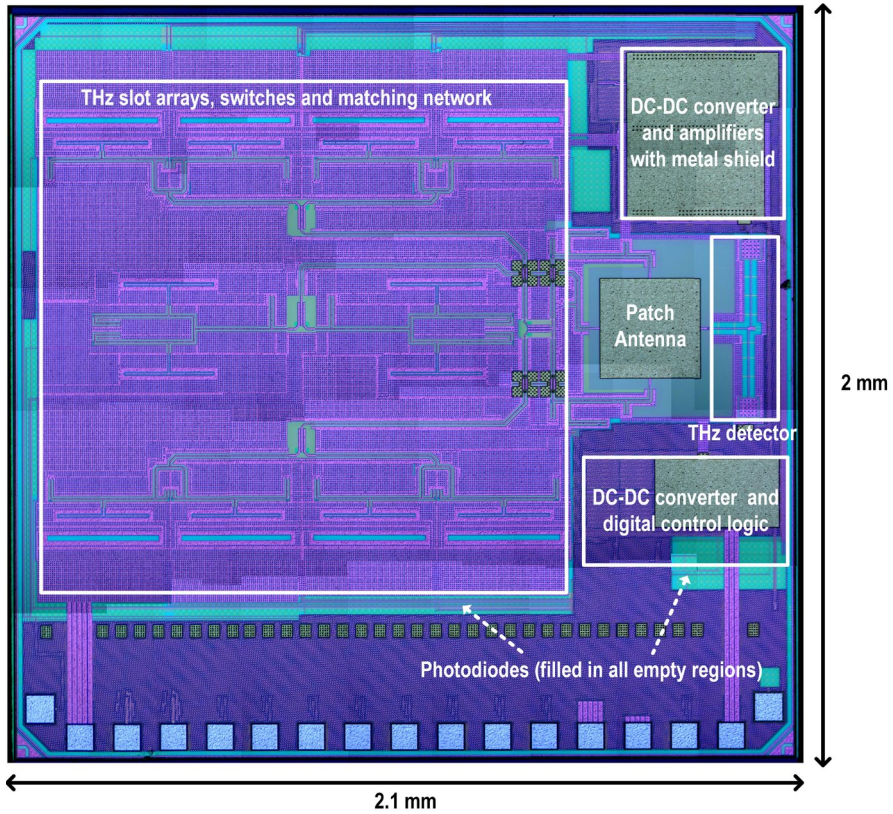
- Sub-THz signal is re-radiated by metal slot
- Injected to the silicon substrate and 3D distribution below the chip

Tag Operation (3) – Uplink



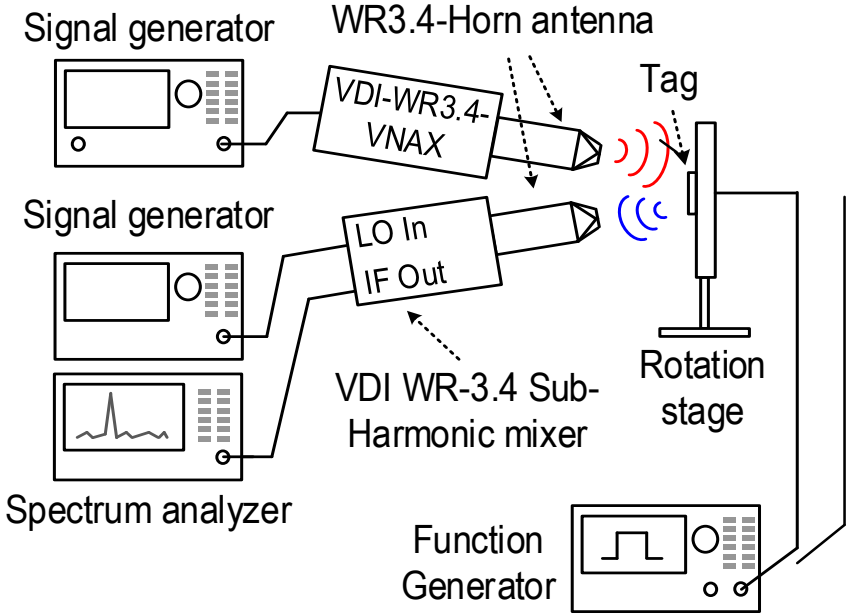
- Probed Sub-THz wave backscattered back to reader (at $f_{RF} \pm f_m$)
- LO for backscatter - f_m signal is frequency divided ($\div 2$) from the THz detector

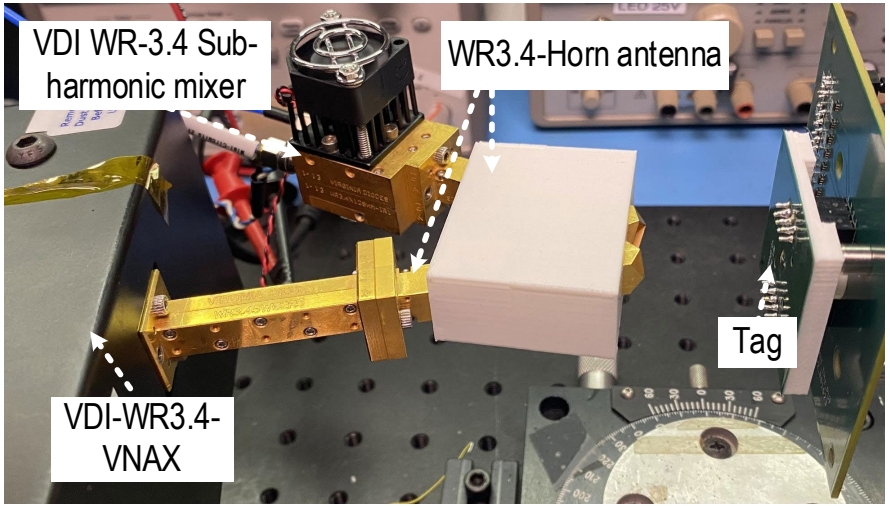
Die Micrograph



- 65nm CMOS process
- Metal shield for optical insensitivity on downlink circuits
- Photodiodes filled in all empty regions

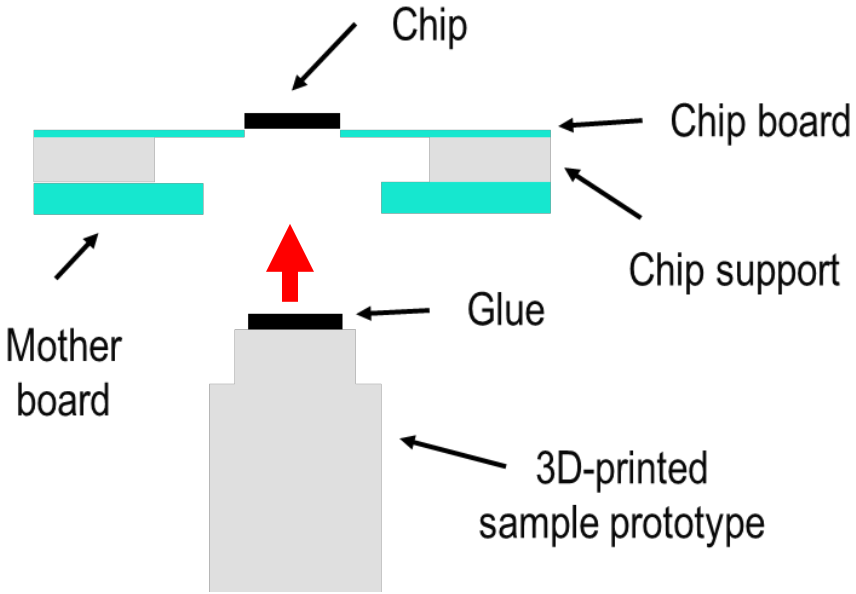
Measurement Setup for Fingerprint Acquisition



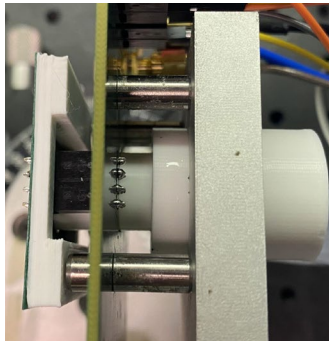


Measurement Setup for Fingerprint Acquisition

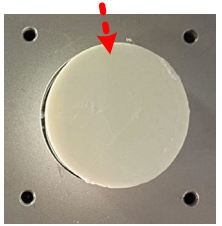
- Experimental setup for modifying the glue distribution under the chip



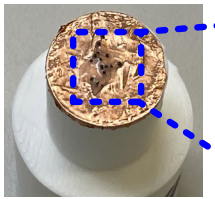
PCB upper view



PCB backside sample surface prototype



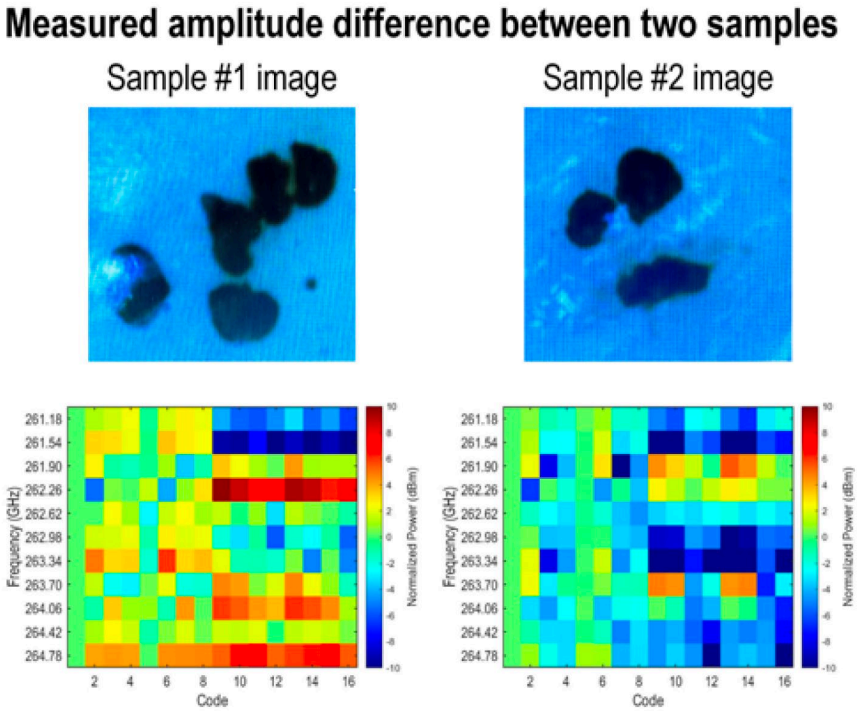
Sample surface prototype

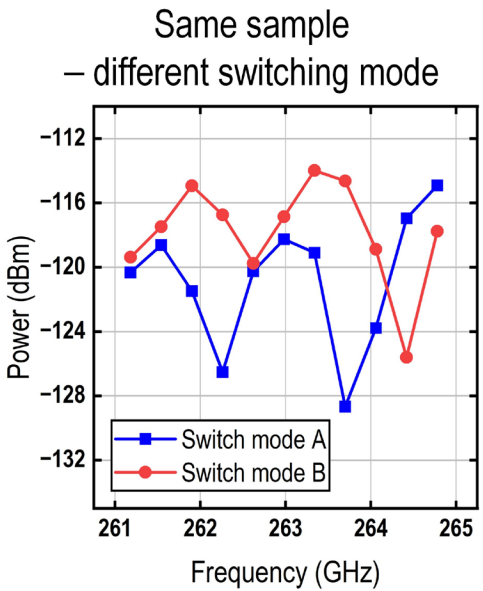


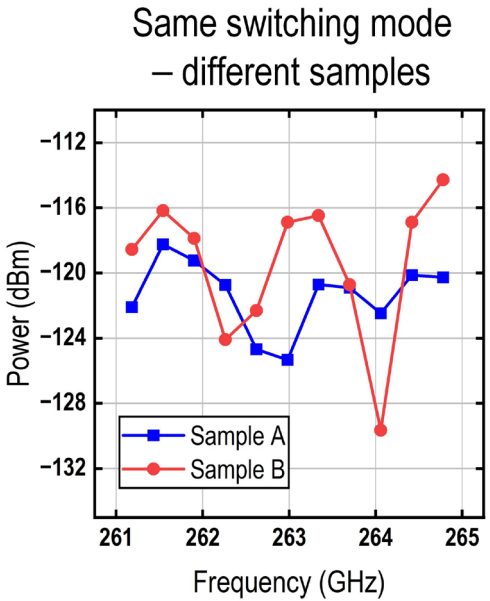
Iron particle (250-380um)

Glue

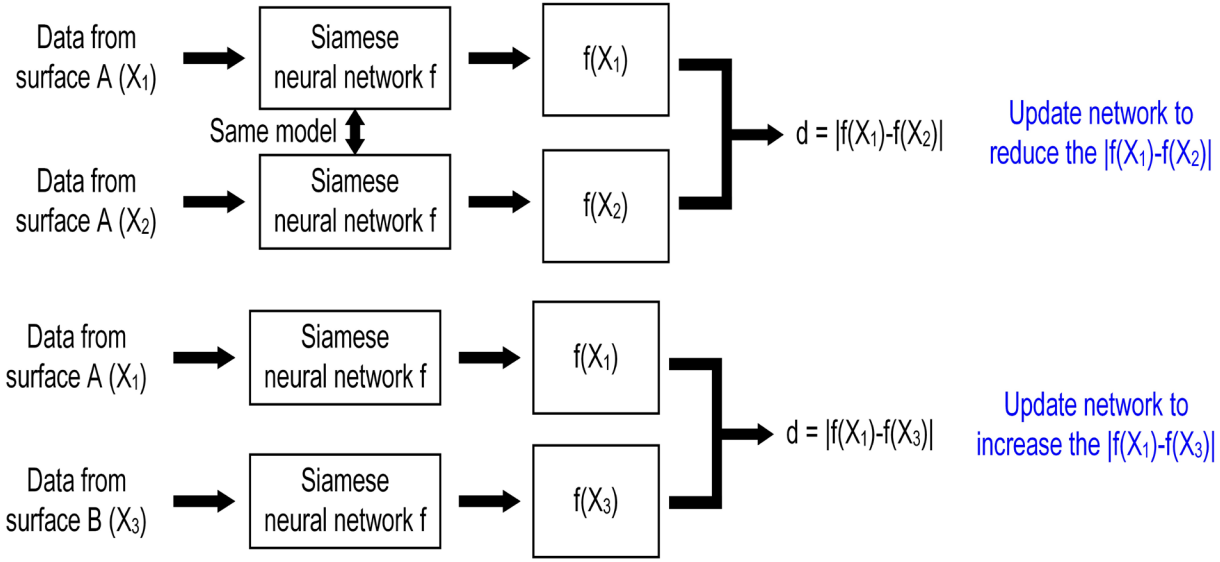
Measured Sub-THz Fingerprint

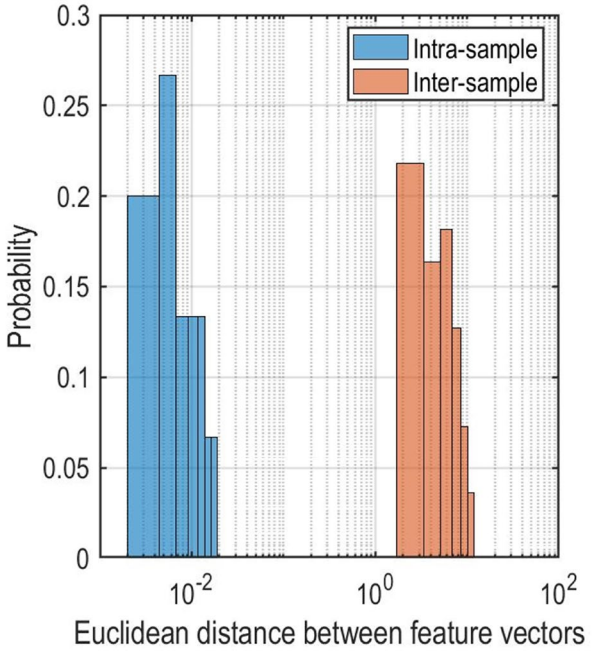






Neural Network Based Fingerprint Authentication





Conclusions

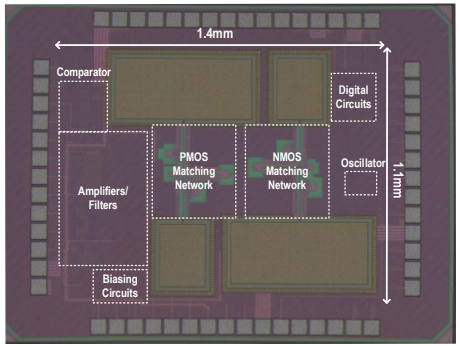
- This work shows first sub-THz packageless anti-tampering tag
- Slot-based sub-THz wave scattering detection technique
- Beam-steering technique is used to provide spatial diversity
- Sub-THz BPSK backscatter to suppress cross-polarization leakage from patch antenna
- Neural-network-based authentication algorithm is demonstrated for fingerprint authentication

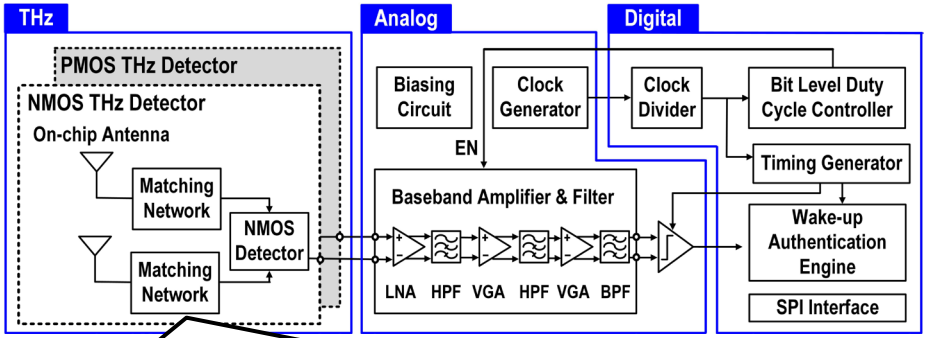
System performance

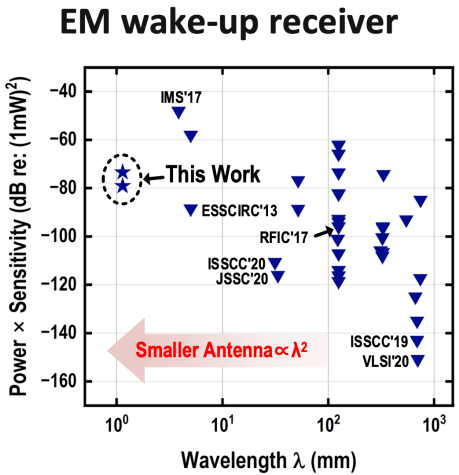
Technology	65nm CMOS
Carrier frequency	261 – 265 GHz
Main feature	Tamper-evidence
Modulation	Downlink: OOK Uplink: BPSK
Analog power	5.1uW
Digital power	0.92uW
Harvesting method	Photovoltaic energy
Die area	4.2 mm^2

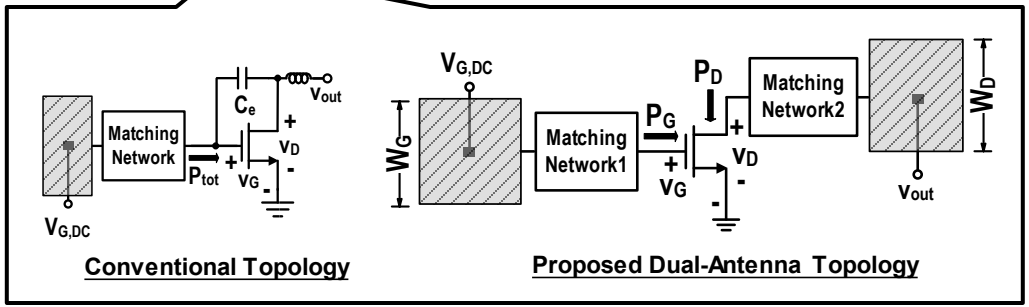
A Packageless Anti-Tampering Tag Utilizing Unclonable Sub-THz Wave Scattering at the Chip-Item Interface
E. Lee, X. Chen, M. Ashok, J. Won, A. Chandrakasan and R. Han
IEEE Intl. Solid-State Circuit Conf. (ISSCC), San Francisco, CA, Feb. 2024.

THz Wake-Up Receiver for Ultra-Miniaturized Sensing Platform



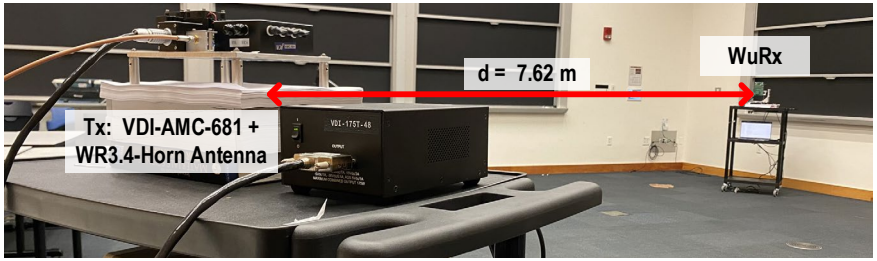






- **260-GHz CMOS wake-up receiver** [E. Seok, et al., *CICC* 2023, JSSC 2024 (Invited)]
  - The smallest RF wake-up receiver (1.5mm²)
  - 750nW DC power
  - Built-in security authentication against denial-of-sleep attack

Demonstrations



Tx - WuRx Distance	Bit Error Rate (BER)
5.1 m	5.7×10^{-3}
7.6 m	1.7×10^{-2}