Massachusetts Institute of Technology

MTL microsystems technology laboratories

Research Overview of the Terahertz Integrated Electronics Group

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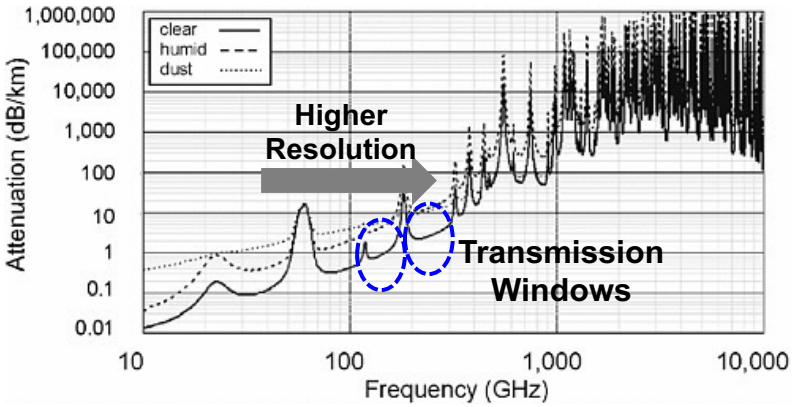
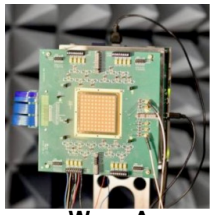
Pushing the Speed Boundary of Integrated Circuits

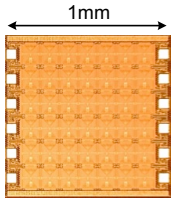


High Resolution Sensing

MHz Array
(Basketball Field Size)

GHz Array
(Table-Top Size)



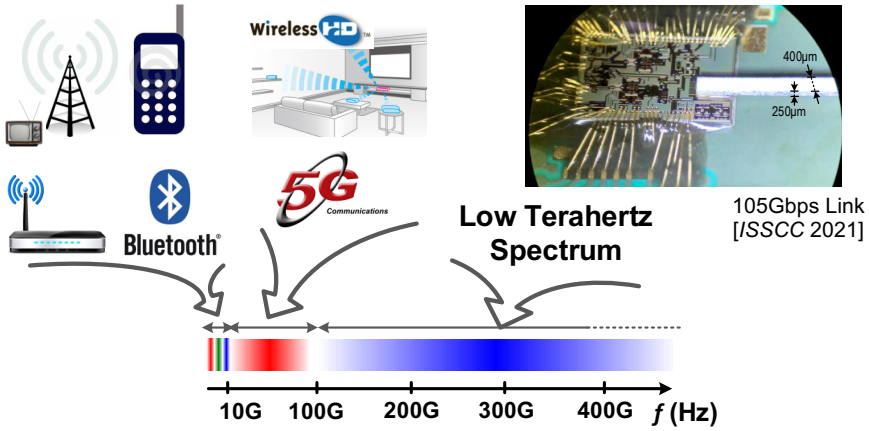


mmWave Array
(PCB-Panel Antennas)

THz Array
(Chip-Scale)

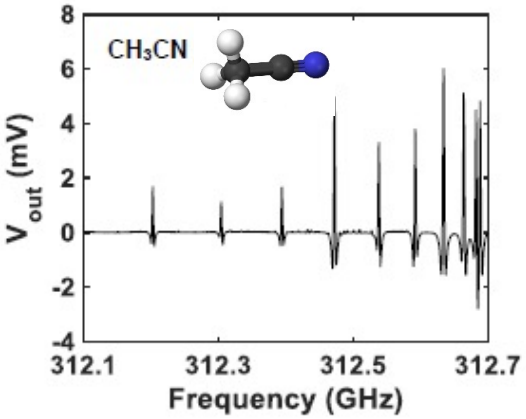
1THz Radiator
[*JSSC* 2018]

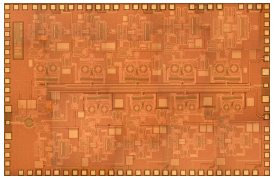
Compact Hardware



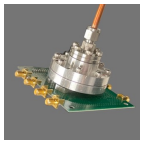
105Gbps Link
[*ISSCC* 2021]

Broadband Communication





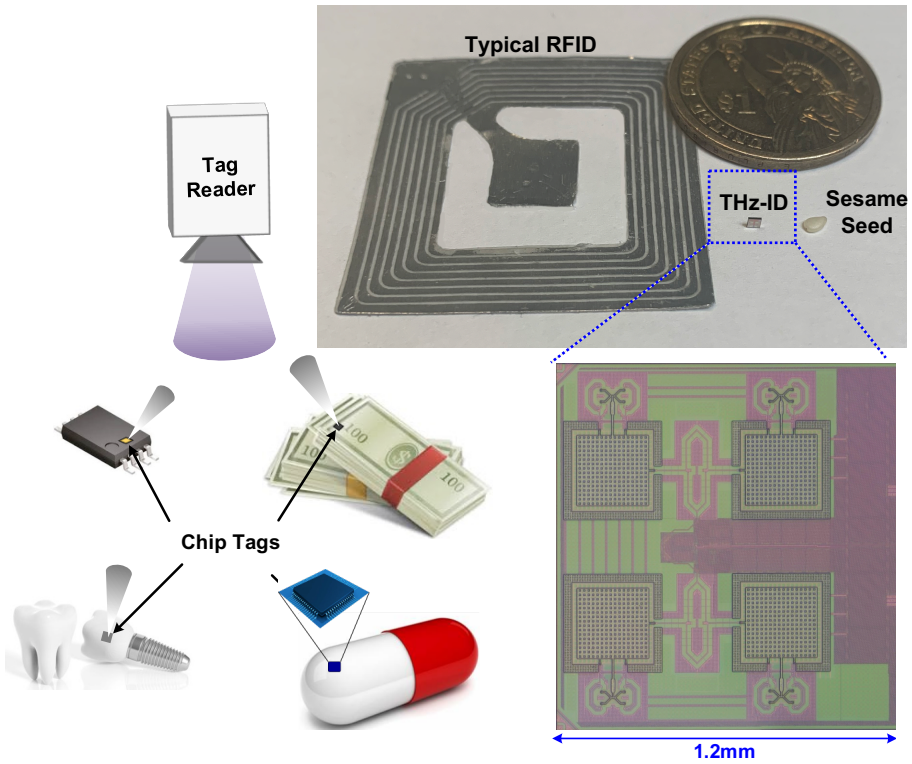
Gas Spectrometer
[*ISSCC* 2017]



Molecular Clock
[*Nature E.* 2018]

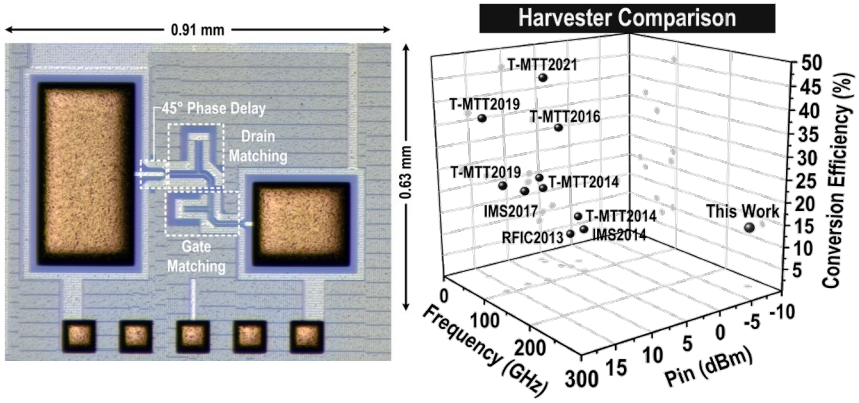
Interactions with Molecules

Miniature and Secure Tagging and Sensing Platforms



First Demonstration: THz-ID
[M. Ibrahim, et al, *ISSCC*, Feb. 2020]

① THz Energy Harvester

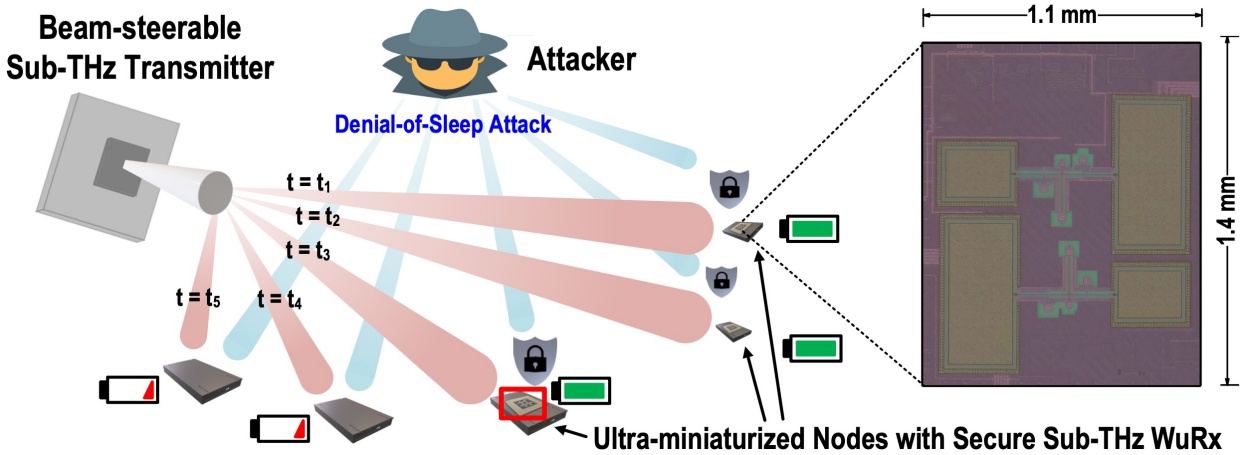


260GHz CMOS Harvester with 15% Efficiency
(PhD Student: Muhammad Ibrahim)
[M. Ibrahim, et al, *RFIC*, 2022]

② Retro-Backscatter THz-ID

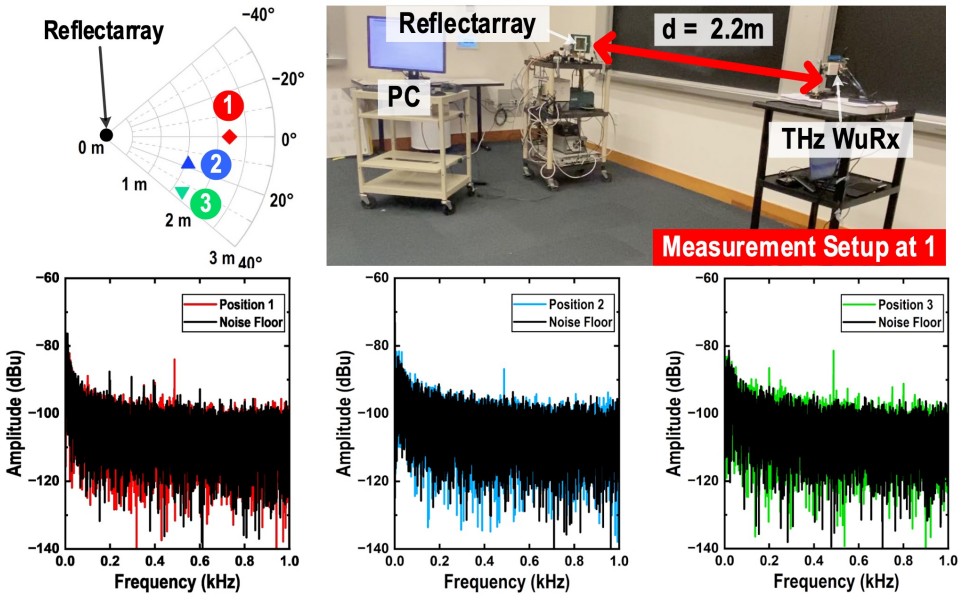
Multi-Functional Electromagnetic Design
(PhD Student: M. Jia and D. Sheen)

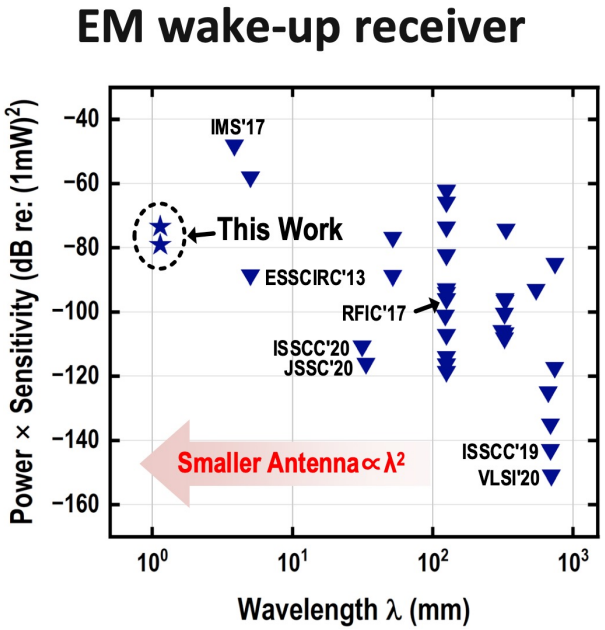
Ultra-Miniaturized Sub-THz Wake-Up Receiver



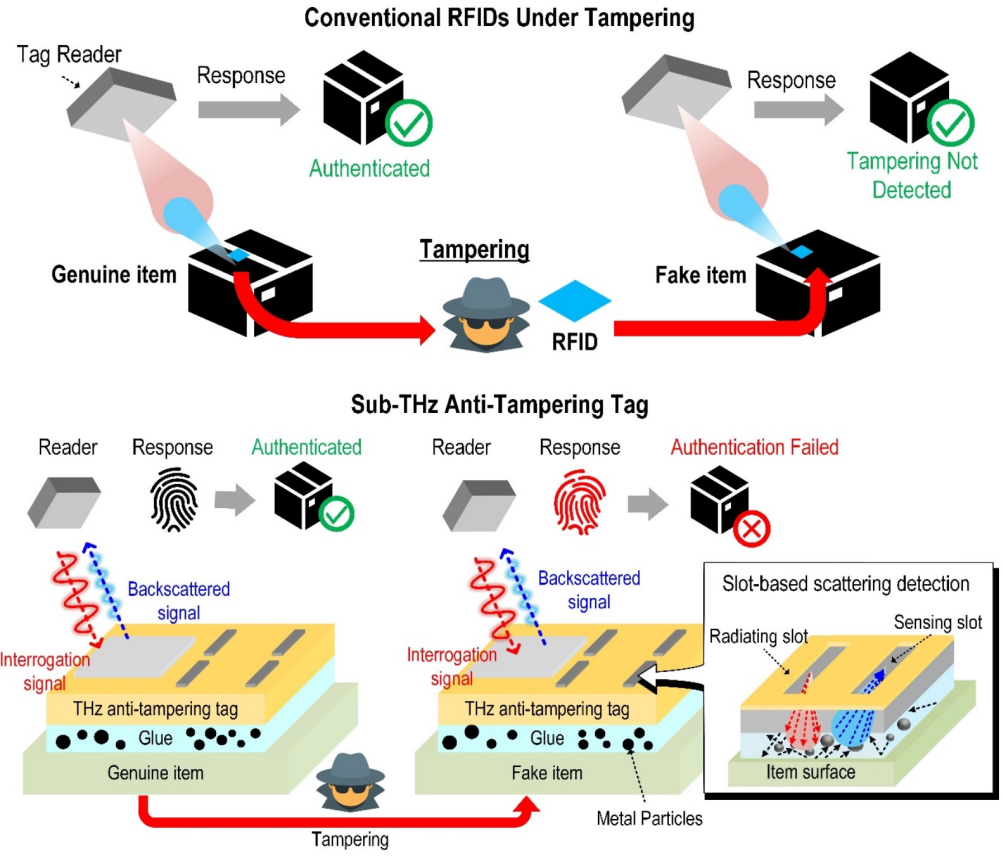
③ 260GHz Wake-Up Receiver with 1.5mm² Size, 0.7μW and Lightweight Cryptography

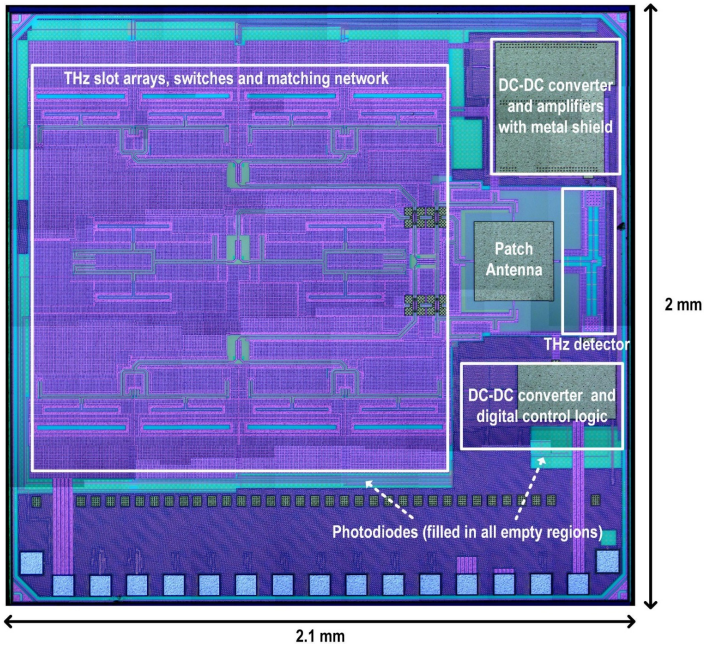
[E. Lee, et al, *CICC*, *JSSC* (Invited) 2023]





Anti-Tampering THz-ID

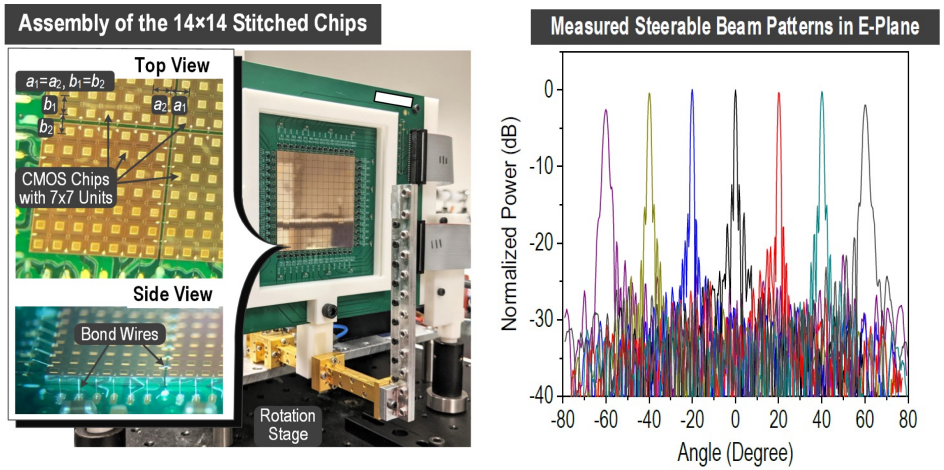




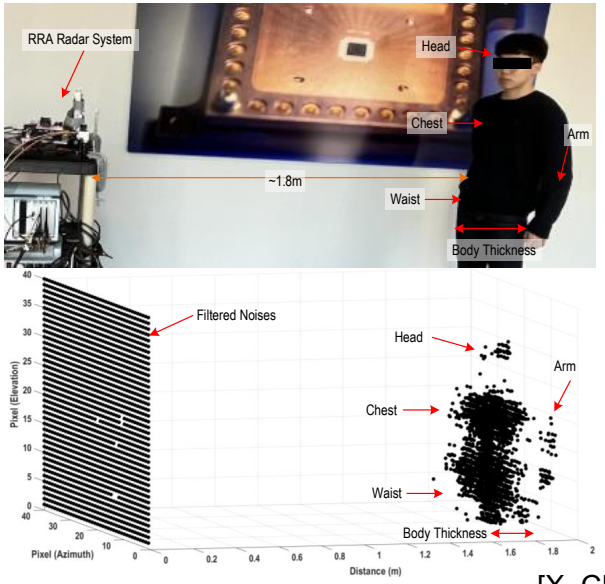
E. Lee, X. Chen, M. Ashok, J. Won, A. Chandrakasan and R. Han, "A Packageless Anti-Tampering Tag Utilizing Unclonable Sub-THz Wave Scattering at the Chip-Item Interface," *IEEE Intl. Solid-State Circuit Conf. (ISSCC)*, San Francisco, CA, Feb. 2024.

④ Physical Unclonable Function Based on the THz Backscattering of the Glue Interface

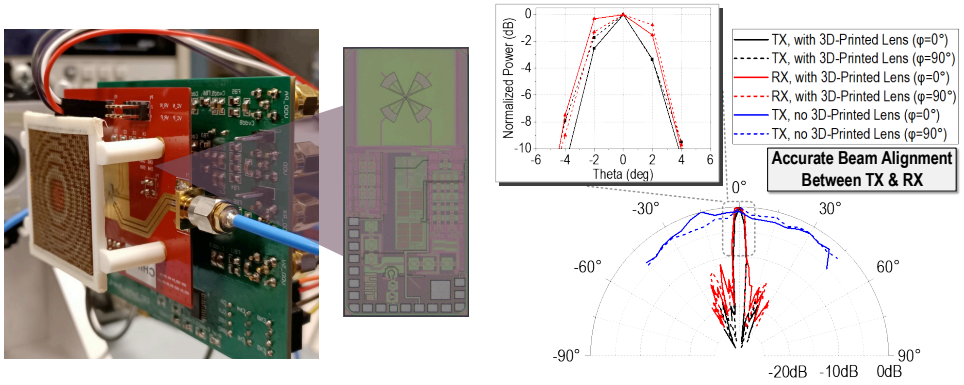
High-Angular-Resolution Imaging



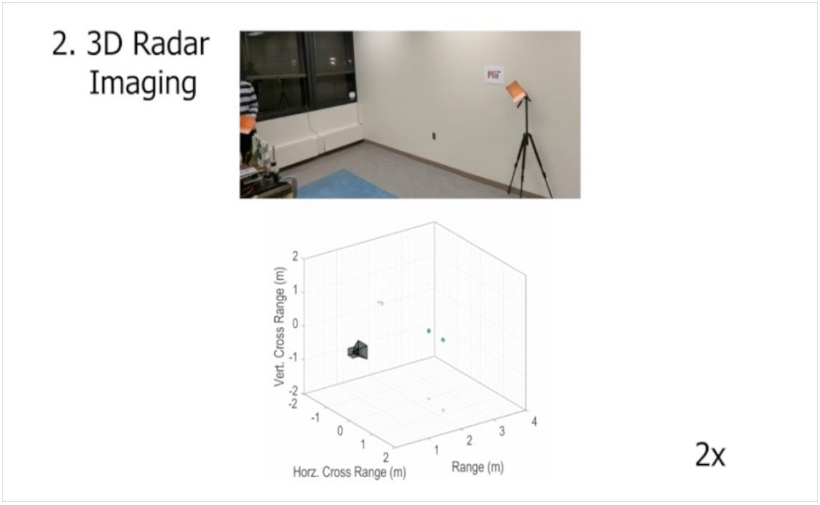
98x98 Reflectarray for Beam Forming at 260GHz
[N. Monroe, et al, *ISSCC*, Feb. 2022]



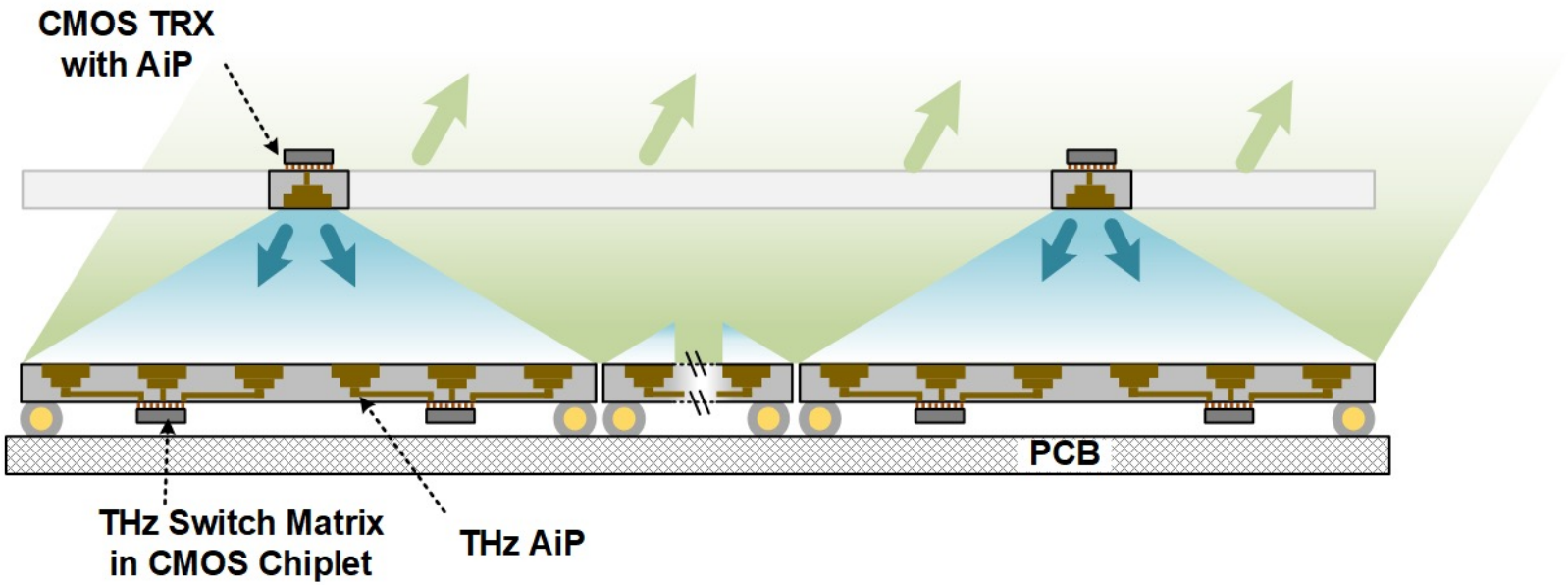
[X. Chen, et al, to be submitted to *JSSC*]



140GHz Radar with Shared TX-RX Antenna
[X. Chen, et al, *ISSCC*, Feb. 2022]

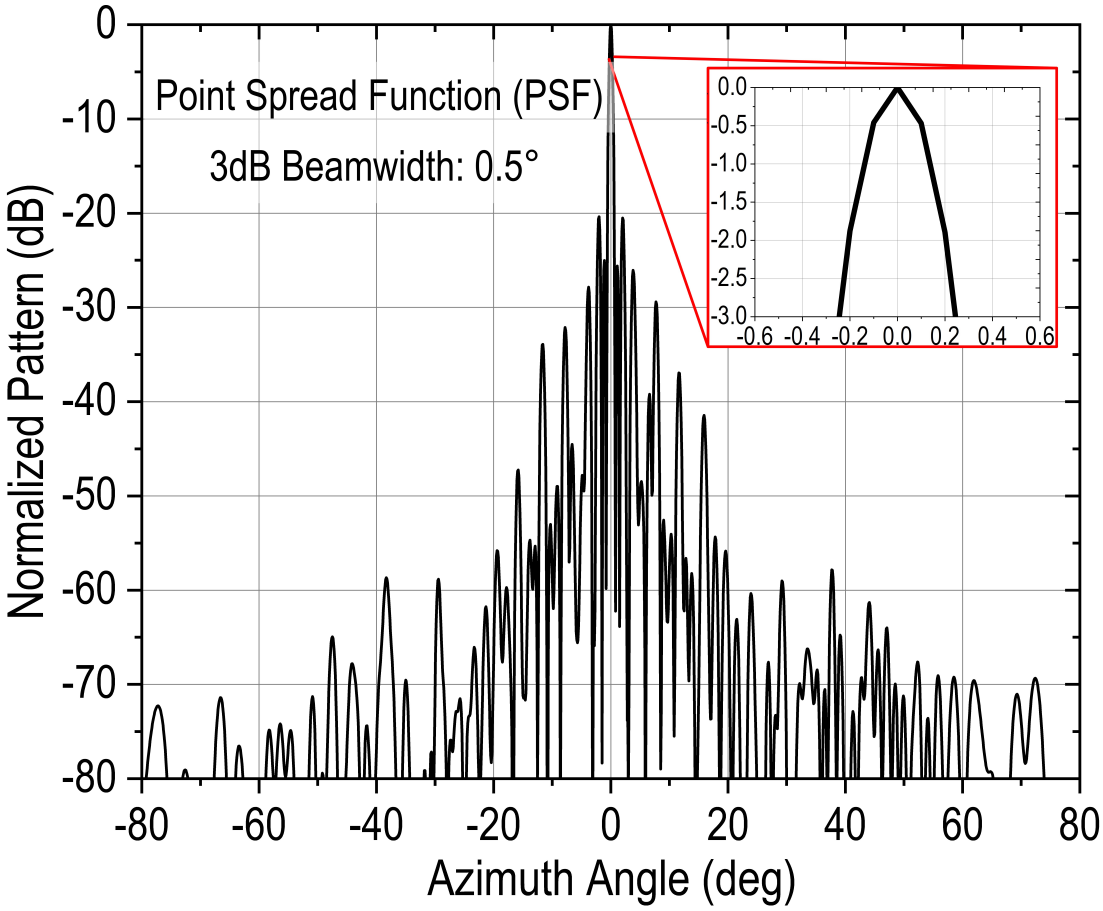


Full Imaging System Using AiP and Chiplet Integration



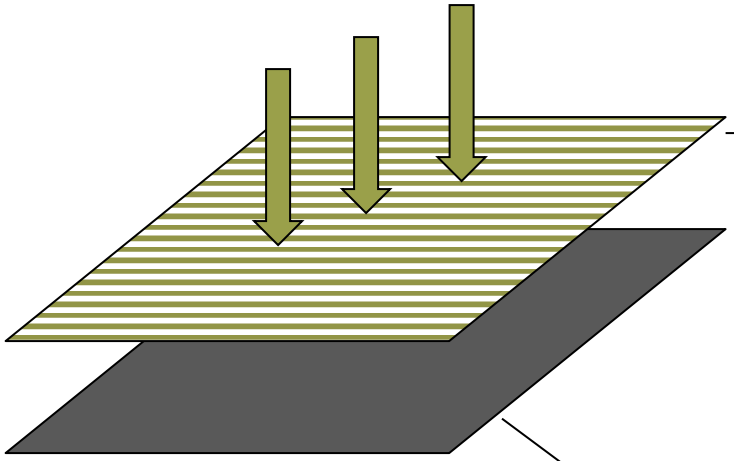
- All-silicon implementation for a low-cost imaging system
- Antenna-in-Package and chiplet-based integration (~400 chiplets on package)
  - Silicon area reduction: >10x
  - Antenna radiation efficiency: 20%→80%
  - Quasi-optical transmitter power combining
  - Overall link budget improvement: >1000x

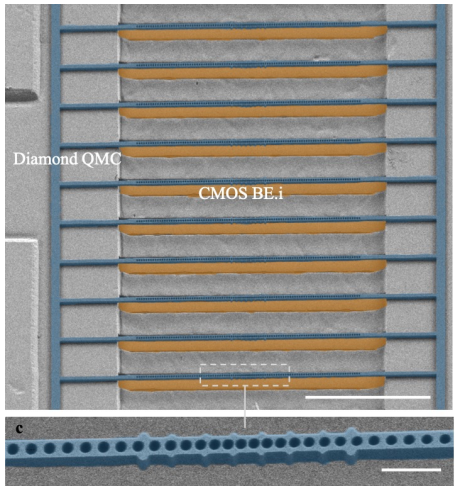
Radiation Pattern at 260GHz



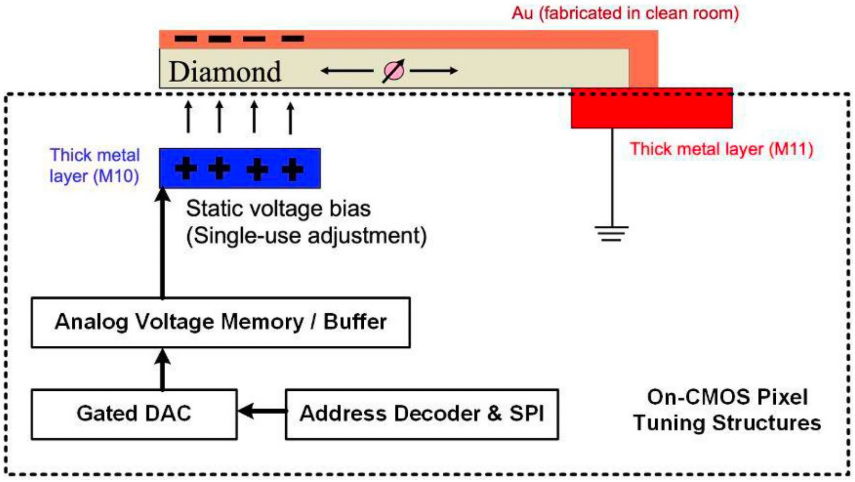
- Physical size: 7.5x7.5 cm^2
- Expected imaging angular resolution: $0.5/2=0.25^o$ → Already similar to LiDARs!

Scalable Photonic-Electronic Quantum Processor

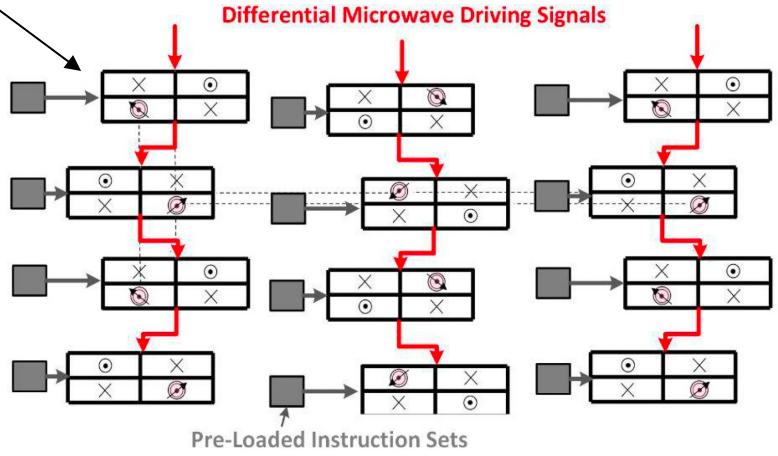




Diamond Quantum Microchiplets
[L. Li, et al, CLEO 2023]

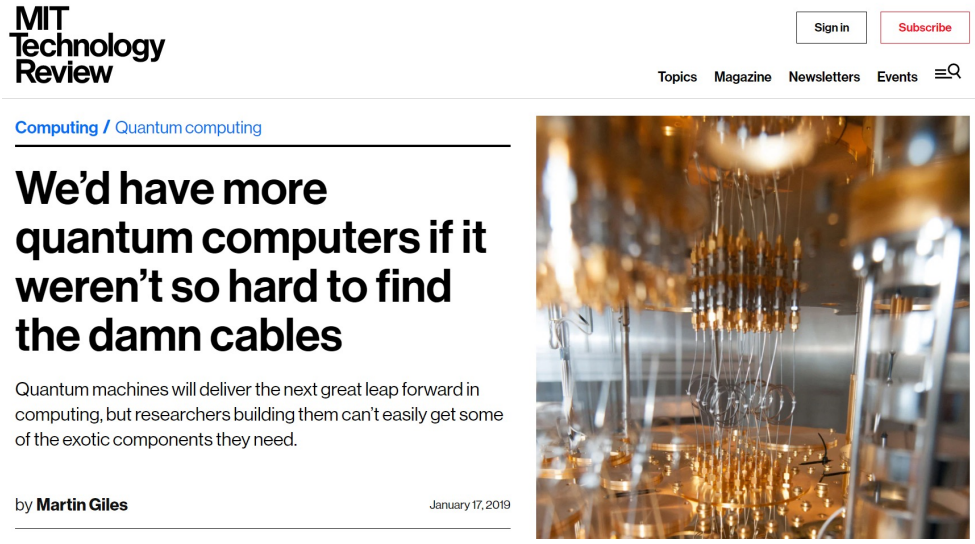


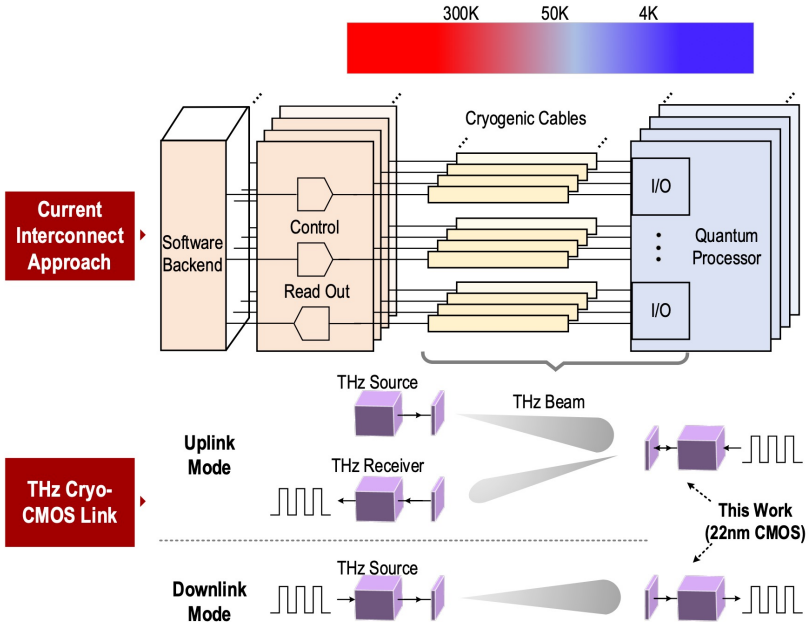
High-Precision Strain Tuning



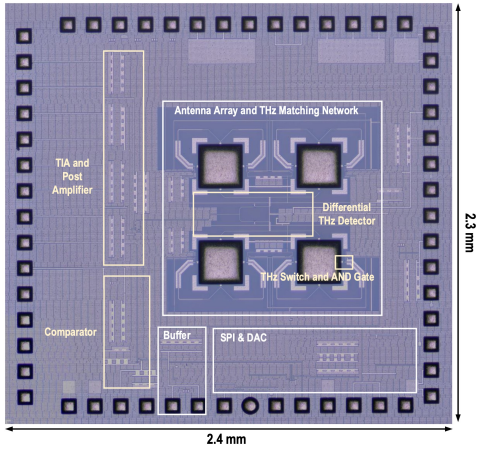
Low Crosstalk Microwave Control

THz Cryogenic Backscatter Transceiver



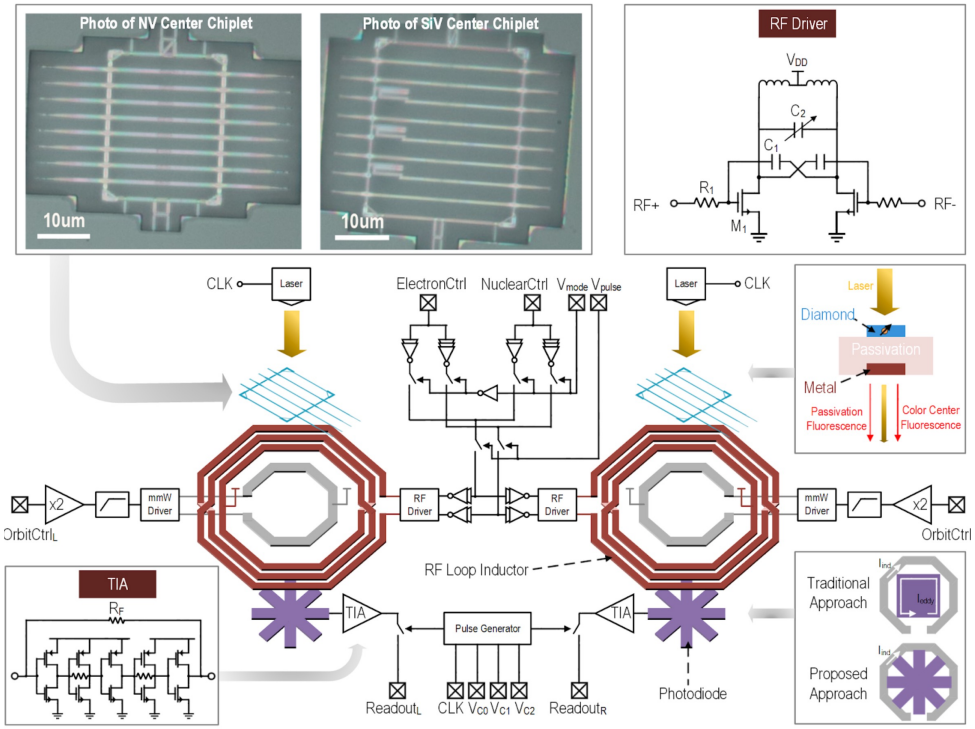


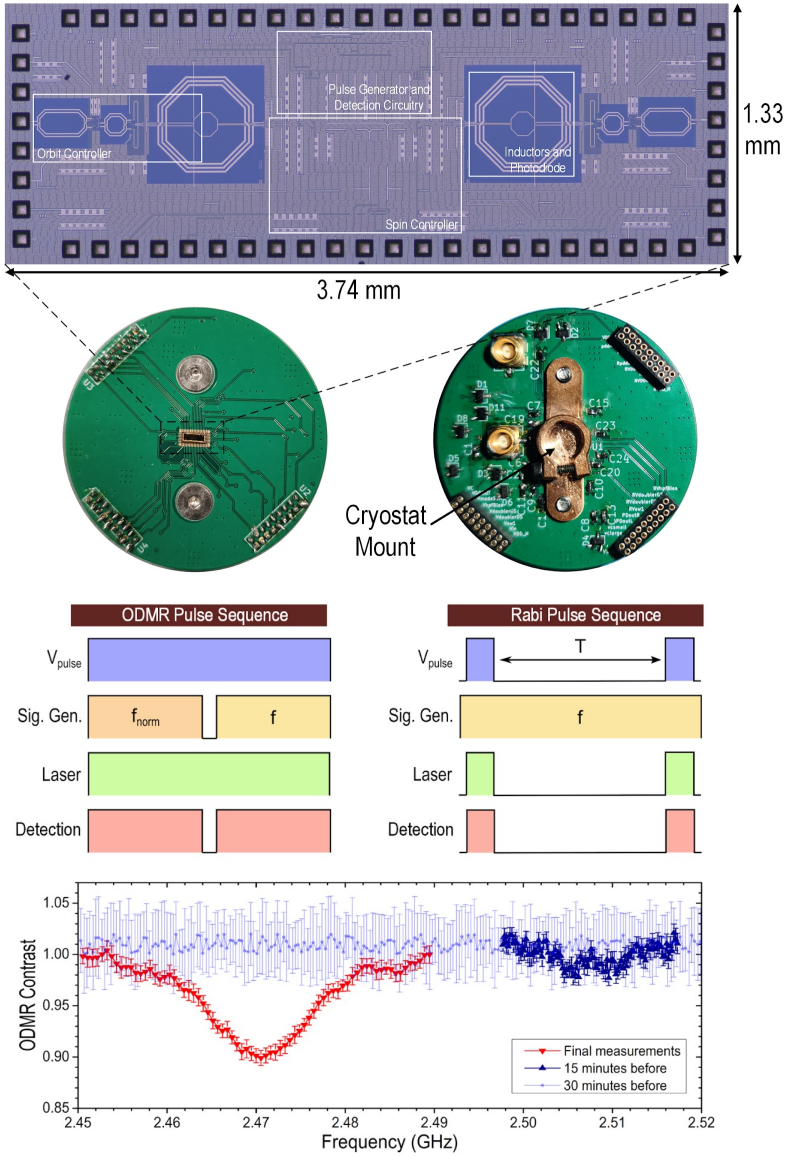
- Current metal RF/data cables pose large thermal load to the cryogenic platform of quantum system
- Proposal: non-contact wireless up/down links using THz waves
  - Uplink: 176fJ/bit @ 4Gbps
  - Downlink: 34fJ/bit @ 4.4Gbps



J. Wang, R. Han, *ISSCC* 2023, *Nature Electronics* (Under Review).

Cryogenic CMOS Pulse Control of Color Centers





- **Pulse control is critical for quantum information processing**
- **NV and SiV center chiplet on CMOS (from D. Englund's team)**
- **Intel-16 FinFET technology**
- **Demonstration at 5K**

Other Active Projects

- **CMOS- control for optical quantum transfer**
  (J. Wang, Y. Hu (D. Englund))
- **Under-epidermis THz-ID**
  (M. Jia (co-advised with A. Chandrakasan))
- **LLM-assisted electronic design**
  (Y. Xu, M. Cox, L. Skelic, W. Lu (ADI), T. Yu (ADI))
- **Ultra-low-noise radio-astronomical receiver with built-in calibration**
  (D. Sheen, F. Llnd (MIT Haystack Observatory))
- **High-stability THz signal synthesizer for CMOS molecular clock**
  (J. Jung (co-advised with A. Chandrakasan))
- **Intensity-detection-only, large-scale THz array with 3D sensing capability**
  (C. Brabec (co-advised with D. Englund))

Acknowledgements

- **Research Group Members:**
  Jinchen Wang
  Eunseok Lee (co-advised w/ Chandrakasan)
  Xibi Chen
  Daniel Sheen
  Mingran Jia (co-advised w/ Chandrakasan)
  Cole Brabec (co-advised w/ Englund)
  Jaehong Jung (co-advised w/ Chandrakasan)
  Yan Xu, Matthew Cox, Lejla Skelic

- **Ph.D. & Postdoc Alumni:**
  Cheng Wang (University of Electronic Science and Technology of China), Zhi Hu (Apple), Jack Holloway (Raytheon), Xiang Yi (South China University of Technology), Mohamed Ibrahim (Cornell University), Mina Kim (Apple), Muhammad Wasiq Ibrahim (MediaTek), Nathan Monroe (Cambridge Terahertz)

- **Collaborators:**
  G. Dogiamis (Intel), S. Coy, R. Field (MIT Chemistry), A. Chandrakasan, H. Lee, D. Englund (MIT EECS), L. Yi (JPL NASA), M. Kaynak (IHP), R. Yazicigil (Boston Univ.), B. Perkins, K. Kolodziej (MIT LL), W, Lu (ADI), T. Yu (ADI), X. Zhang (IBM)…

- **Sponsors:**

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