THzID: A 1.6mm^2 Package-Less Cryptographic Identification Tag at 260GHz

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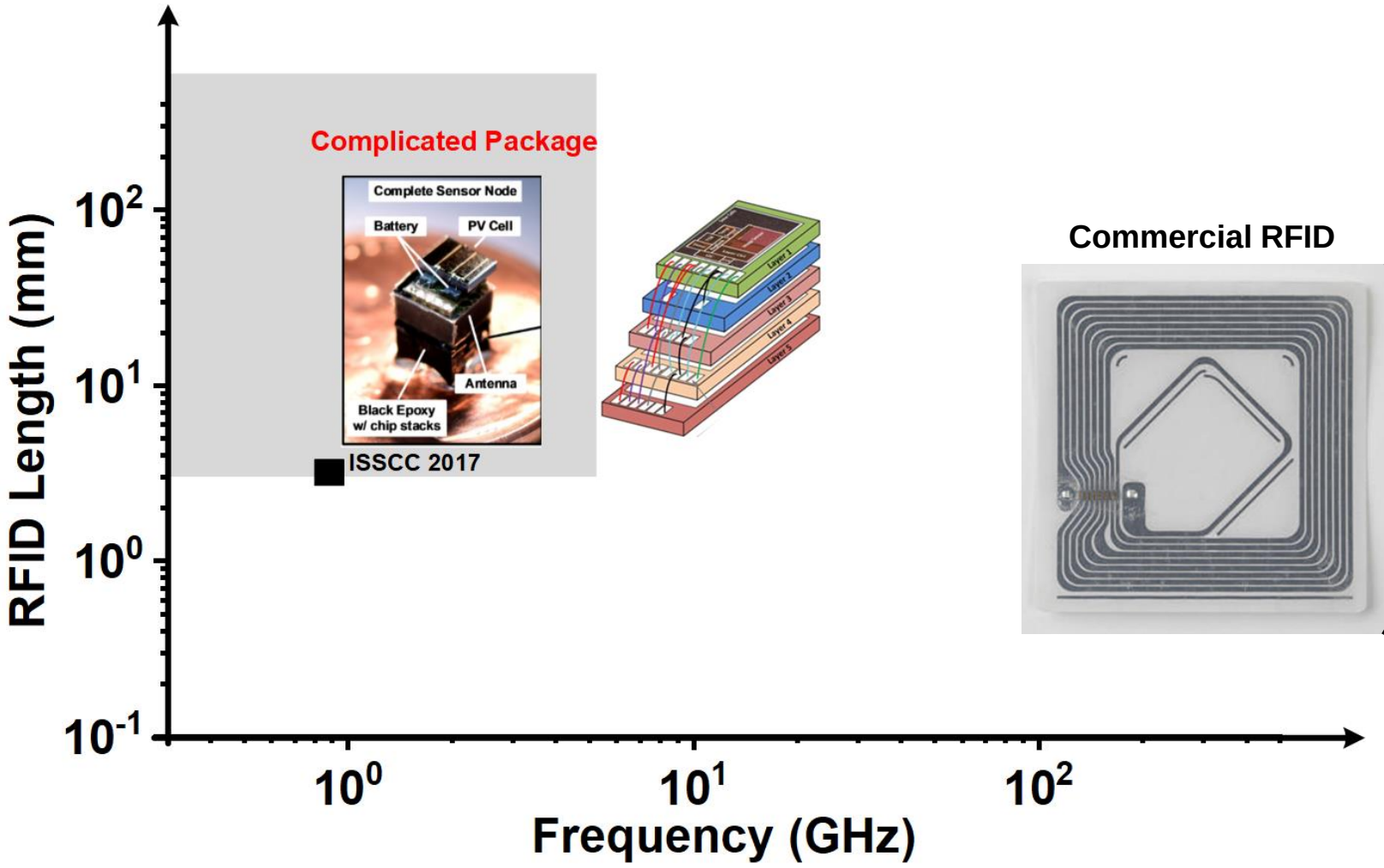
Outline

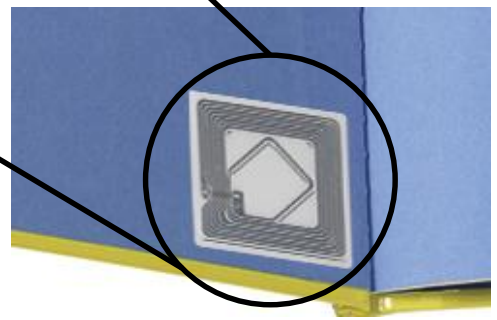
- Introduction
- 260GHz Package-Less Cryptographic THzID
  - 260GHz Backscattering Module
  - Downlink Circuitry
  - Optical-Power Harvesting
  - Cryptographic Processor
- Measurement Results
- Conclusion

Radio Frequency Identification (RFID) Tags

- **RFIDs are used in ID cards, supply chain, authentication and other applications**



Commercial RFID



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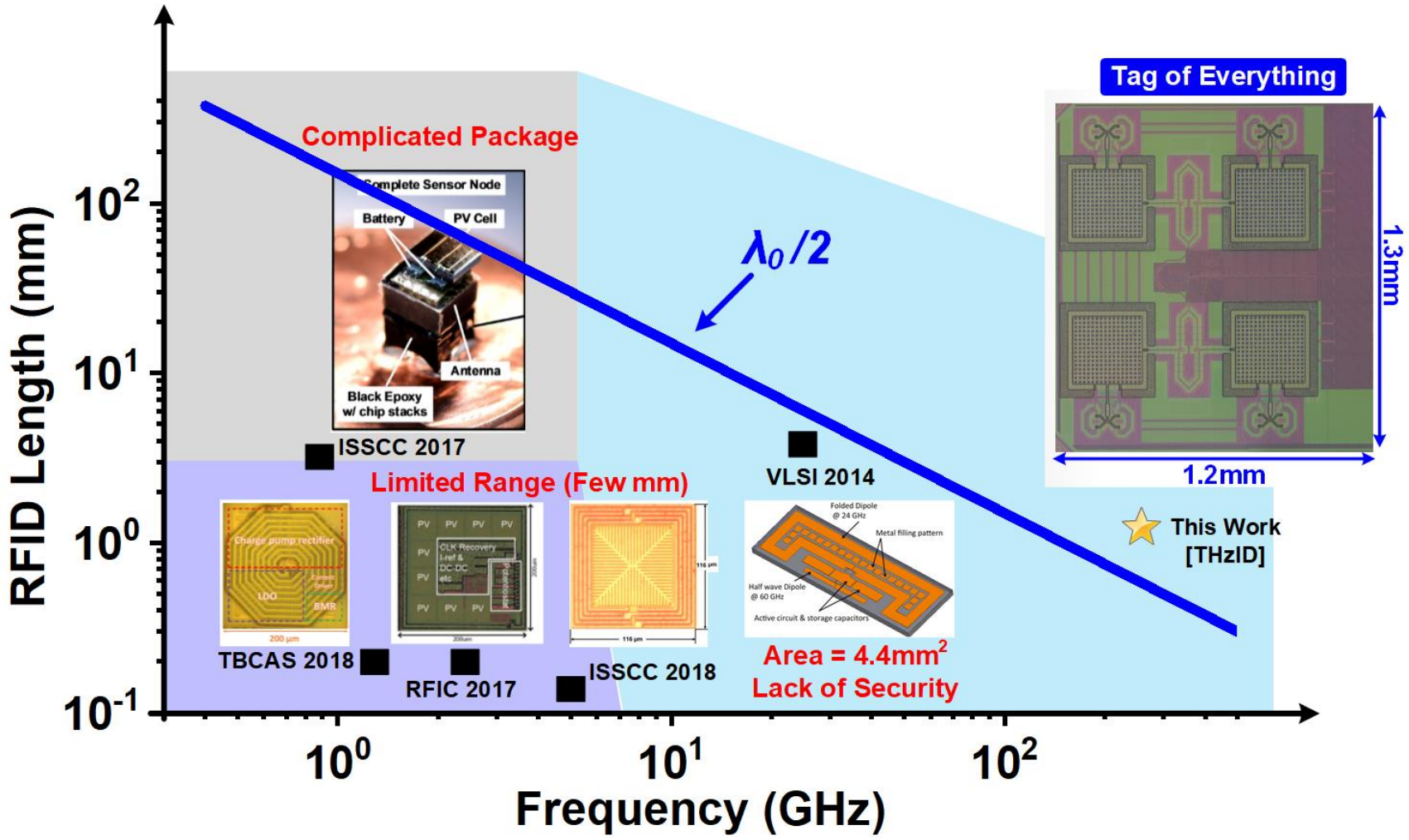
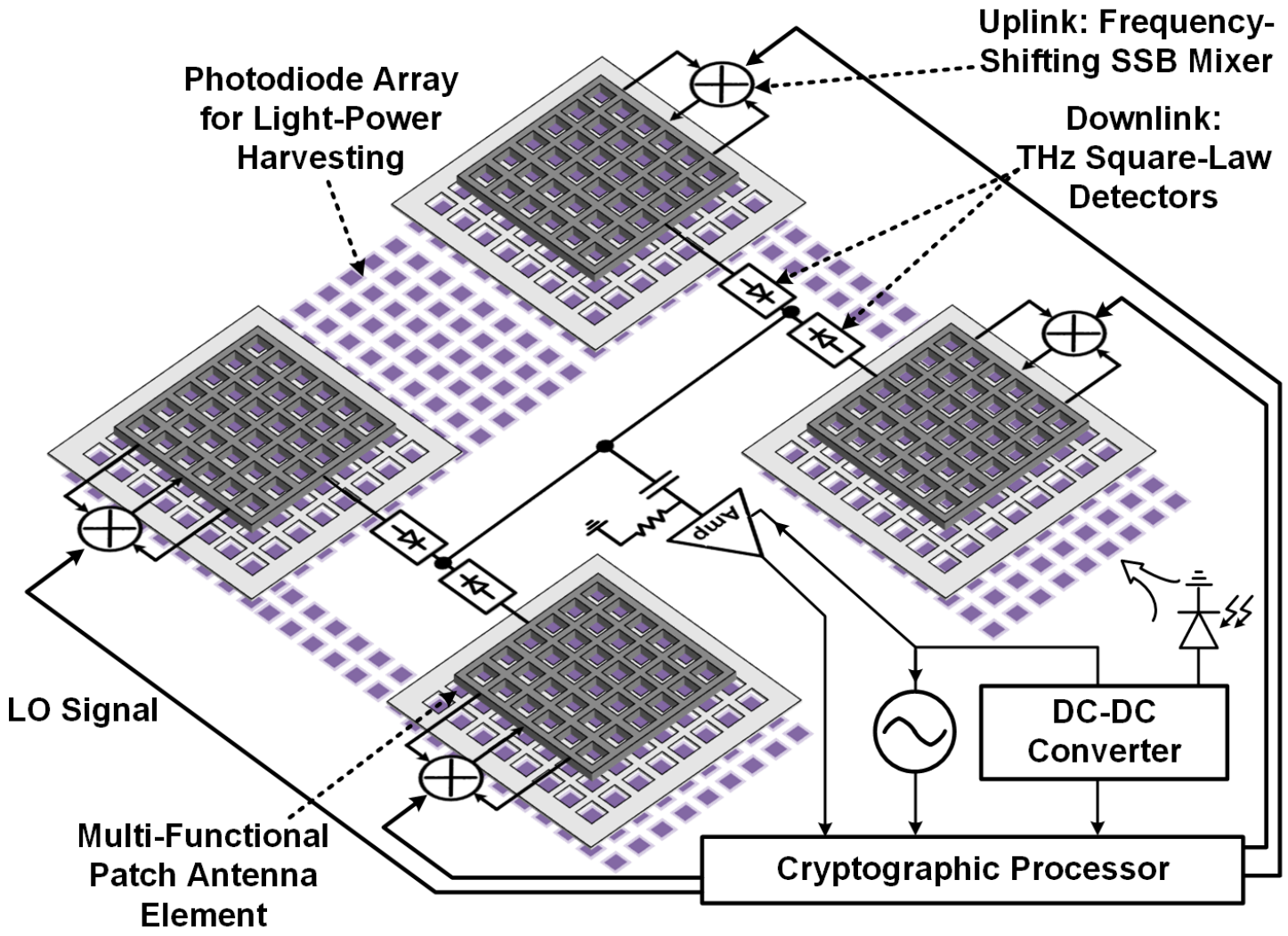


Cryptographic Package-Less THzID



THz frequency → Small antenna size

Antenna array → Increase gain & Beam-steering

Fully passive and compact communication module

Tightly integrated photovoltaic cells for powering

Cryptographic processor for authentication

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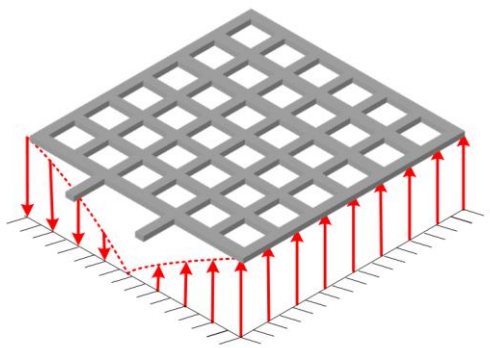
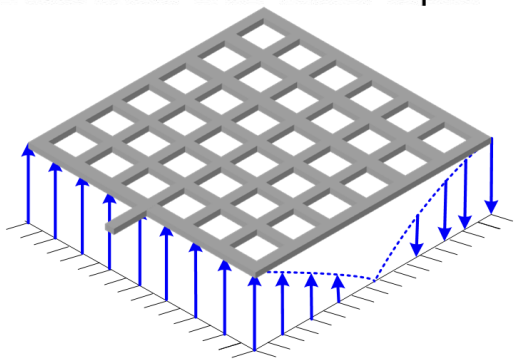
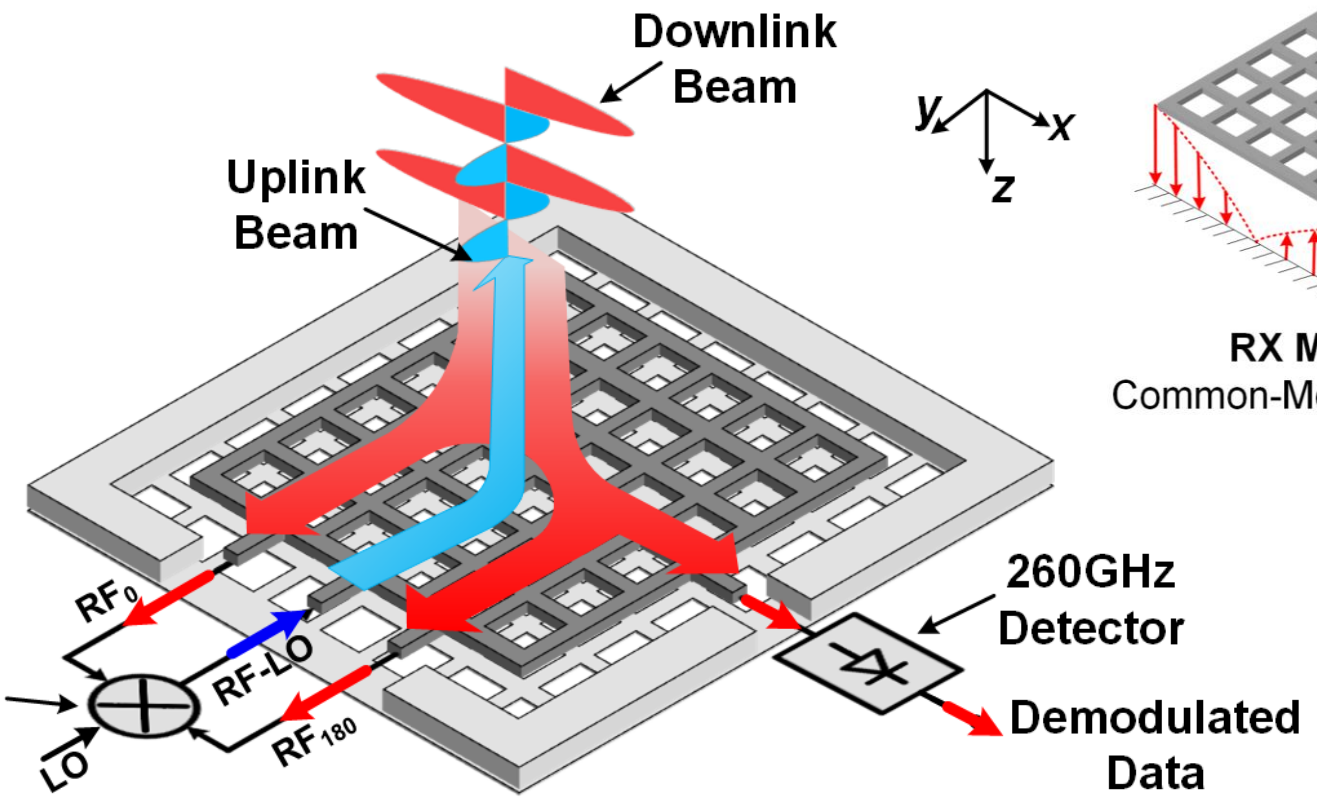
Multi-Functional Patch Antenna

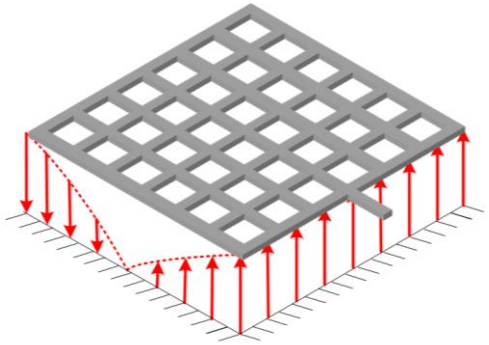


RX Mode (TM_{10})
Differential SSB Mixer Input



TX Mode (TM_{01})
Common-Mode Mixer Output

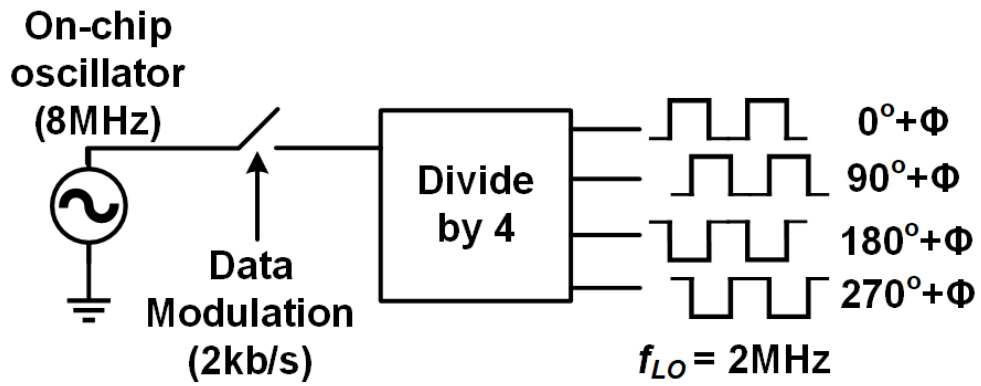


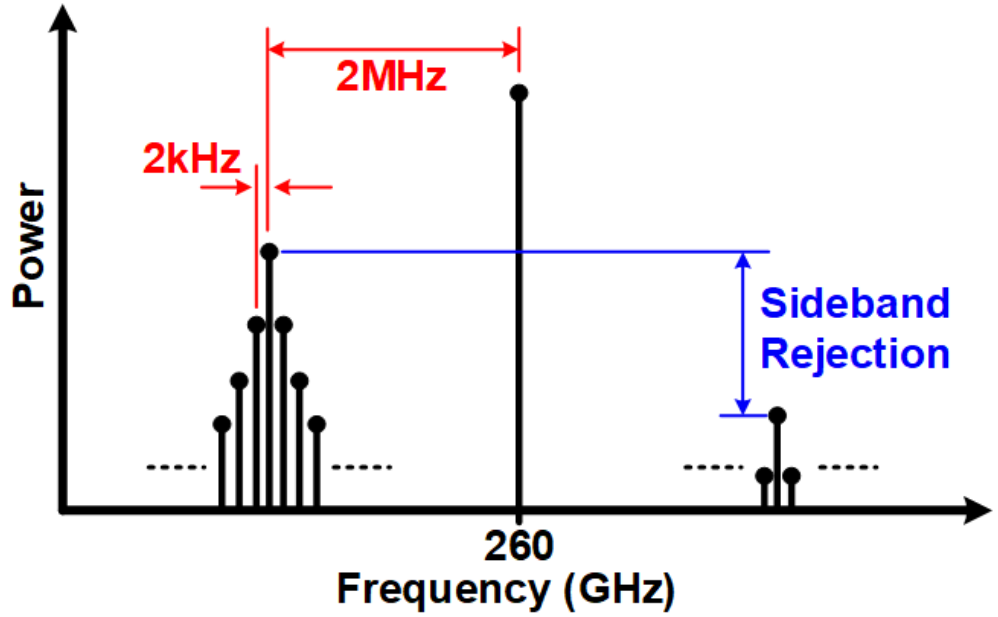


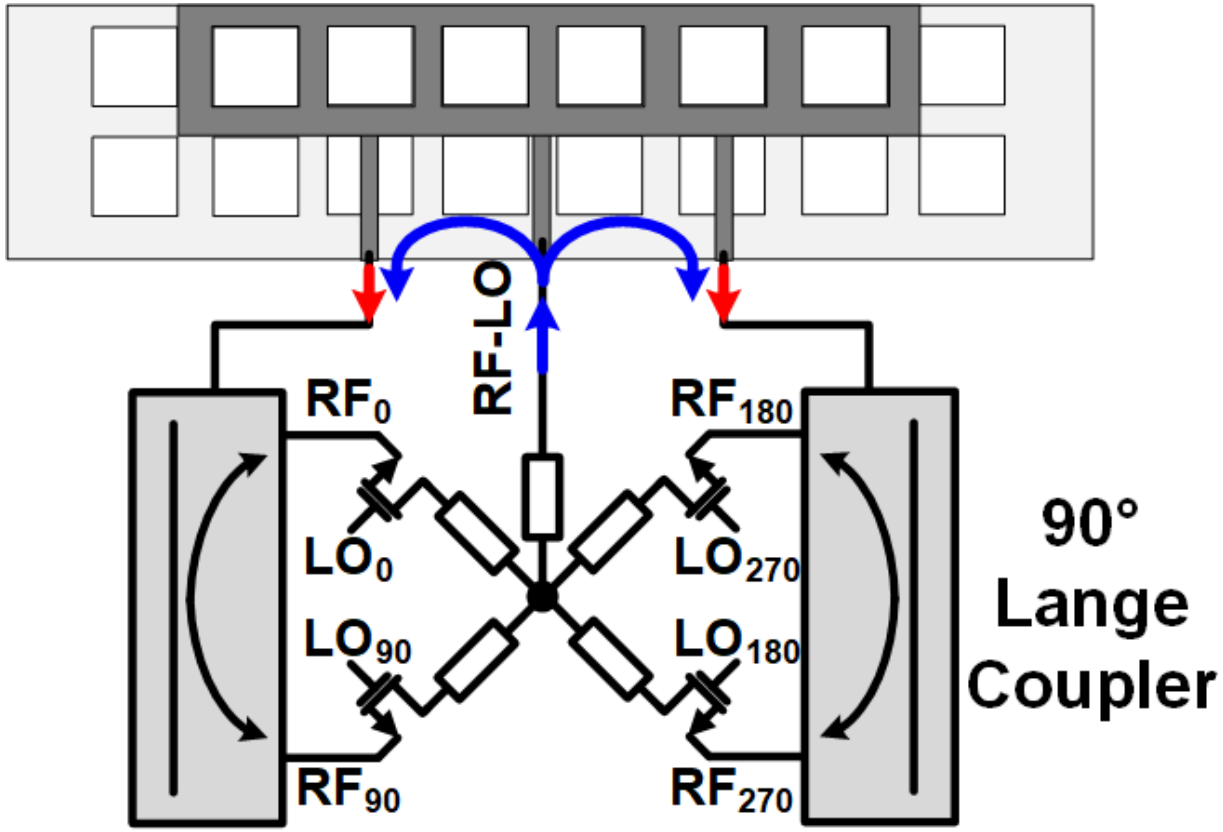
RX Mode (TM_{10})
Common-Mode Detector Input

- **Equal power splitting between mixer and detector**
- **Orthogonal polarization of the RX and TX modes resulting in 25dB rejection for the reflection from the surrounding**

Frequency-Shifting Backscattering Module

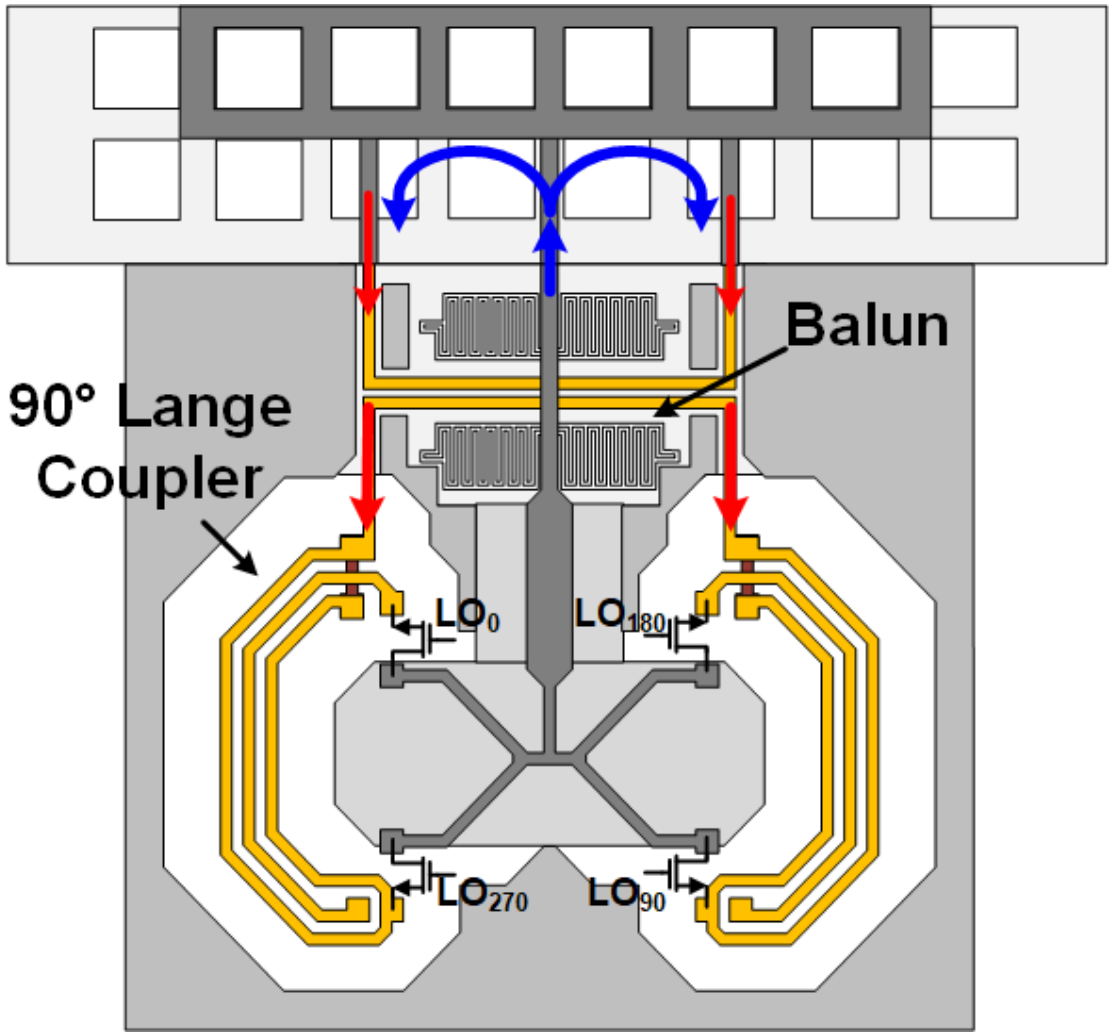


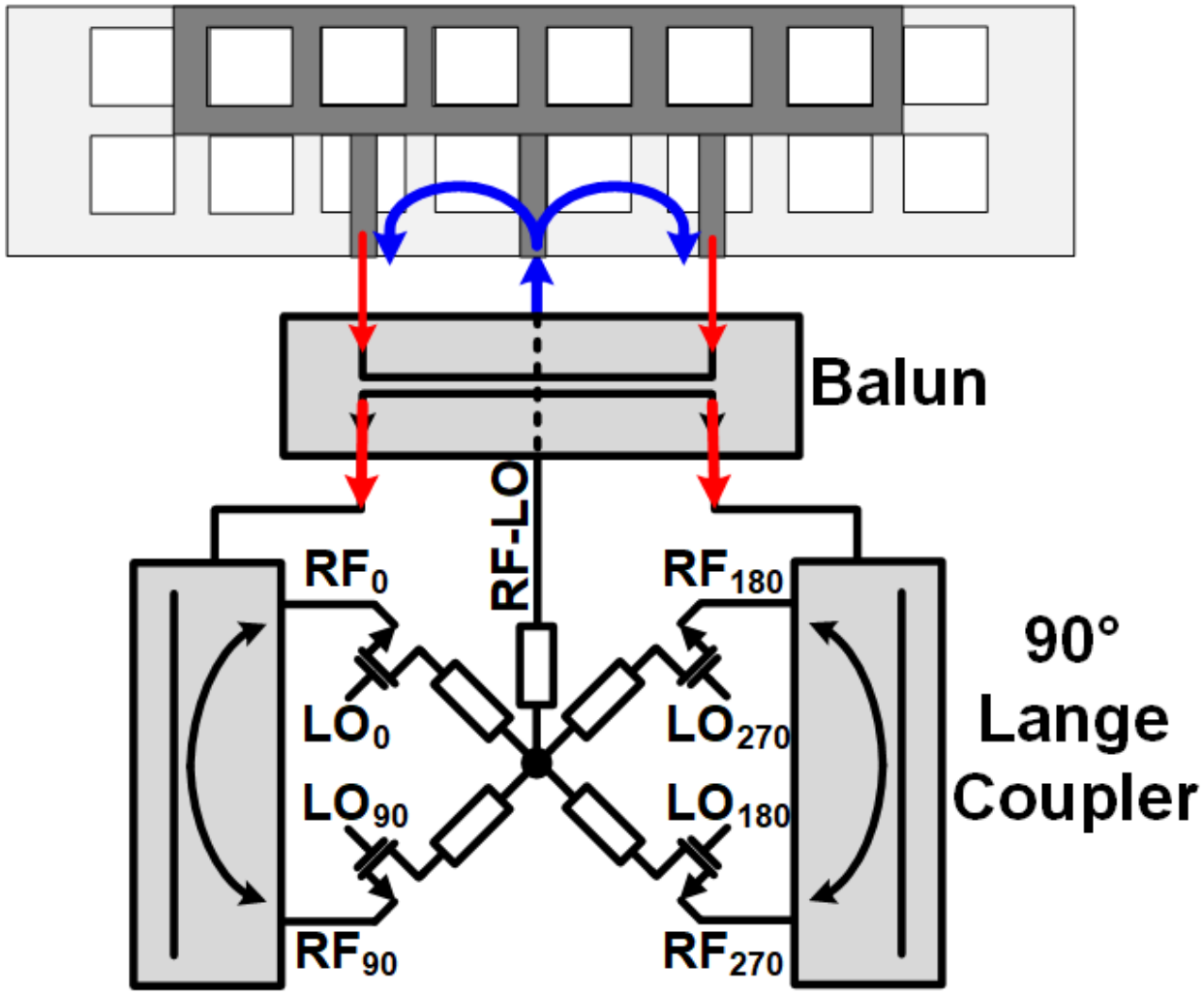




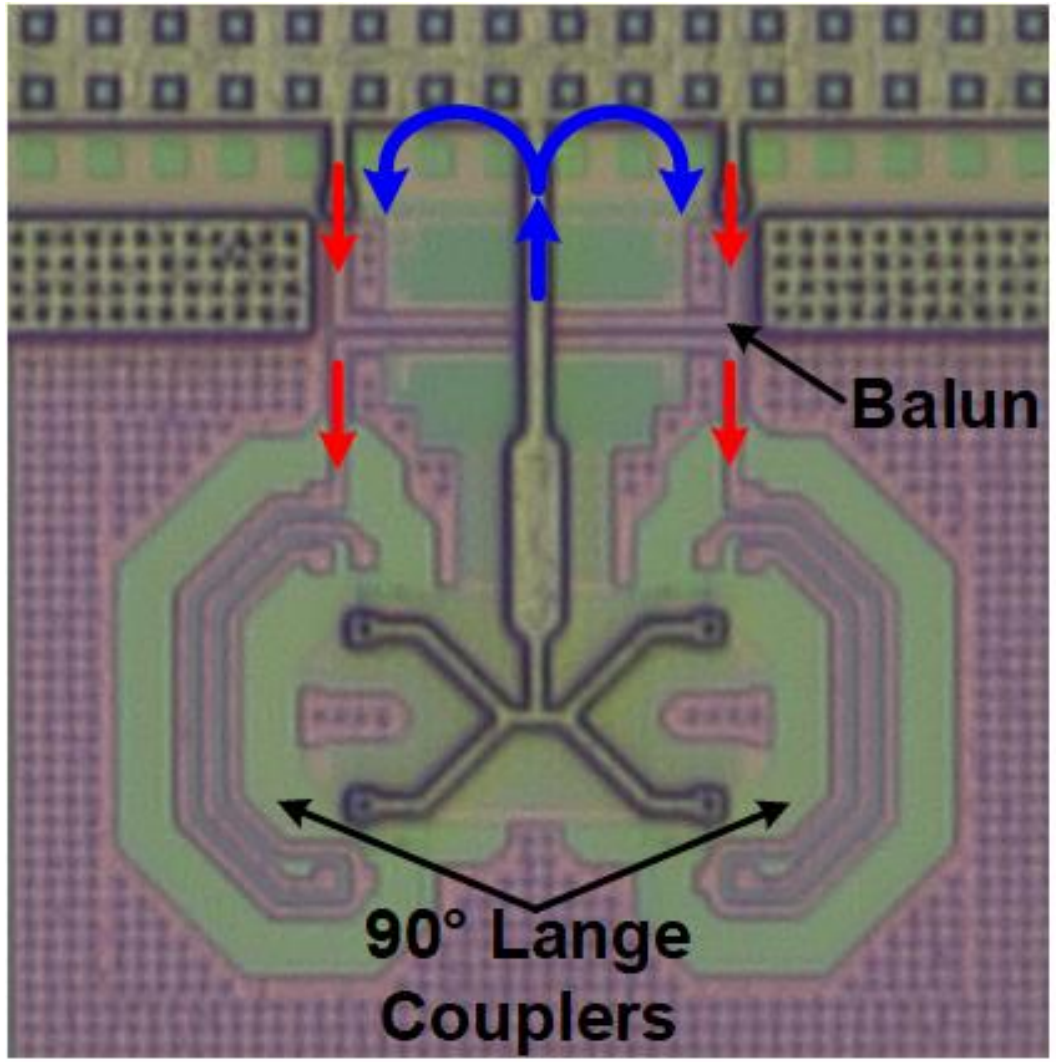
- The uplink data rate is 2kb/s
- Changing the LO phase (Φ) allows for beam-steering

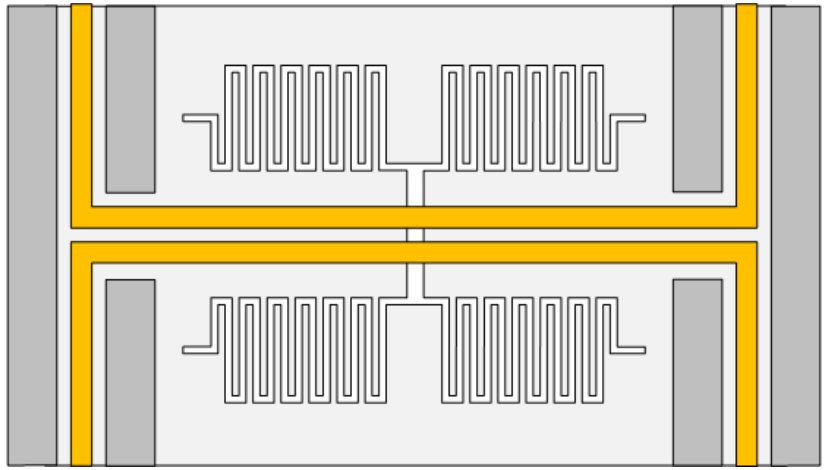
Frequency-Shifting Backscattering Module



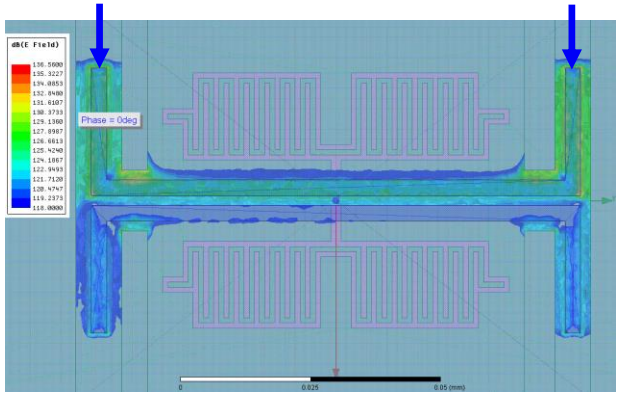


Differential Slot Balun Performance

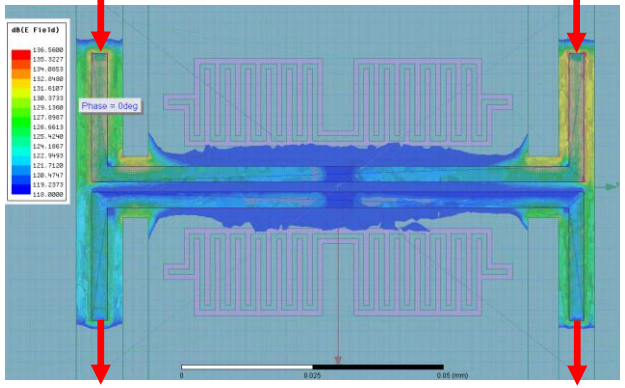




Common Mode

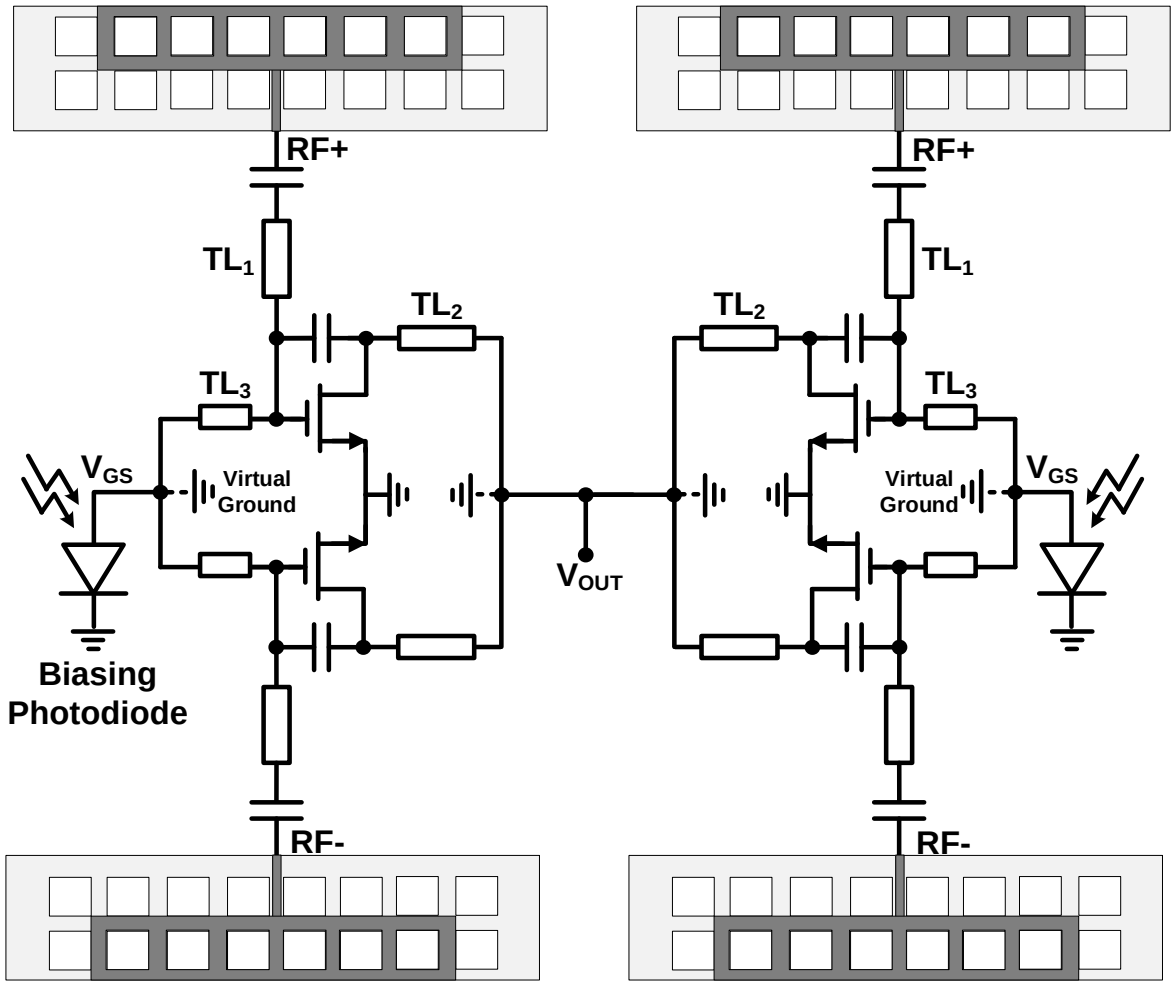


Differential Mode

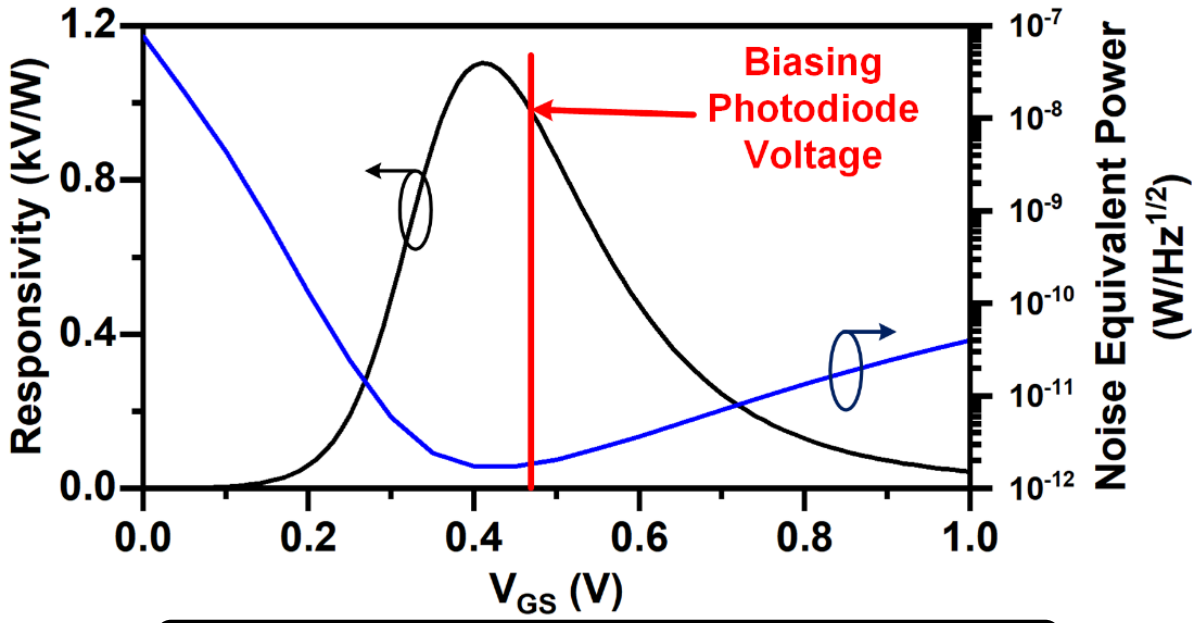


- Diff. to common mode isolation is 10dB

260GHz Square-Law Detector

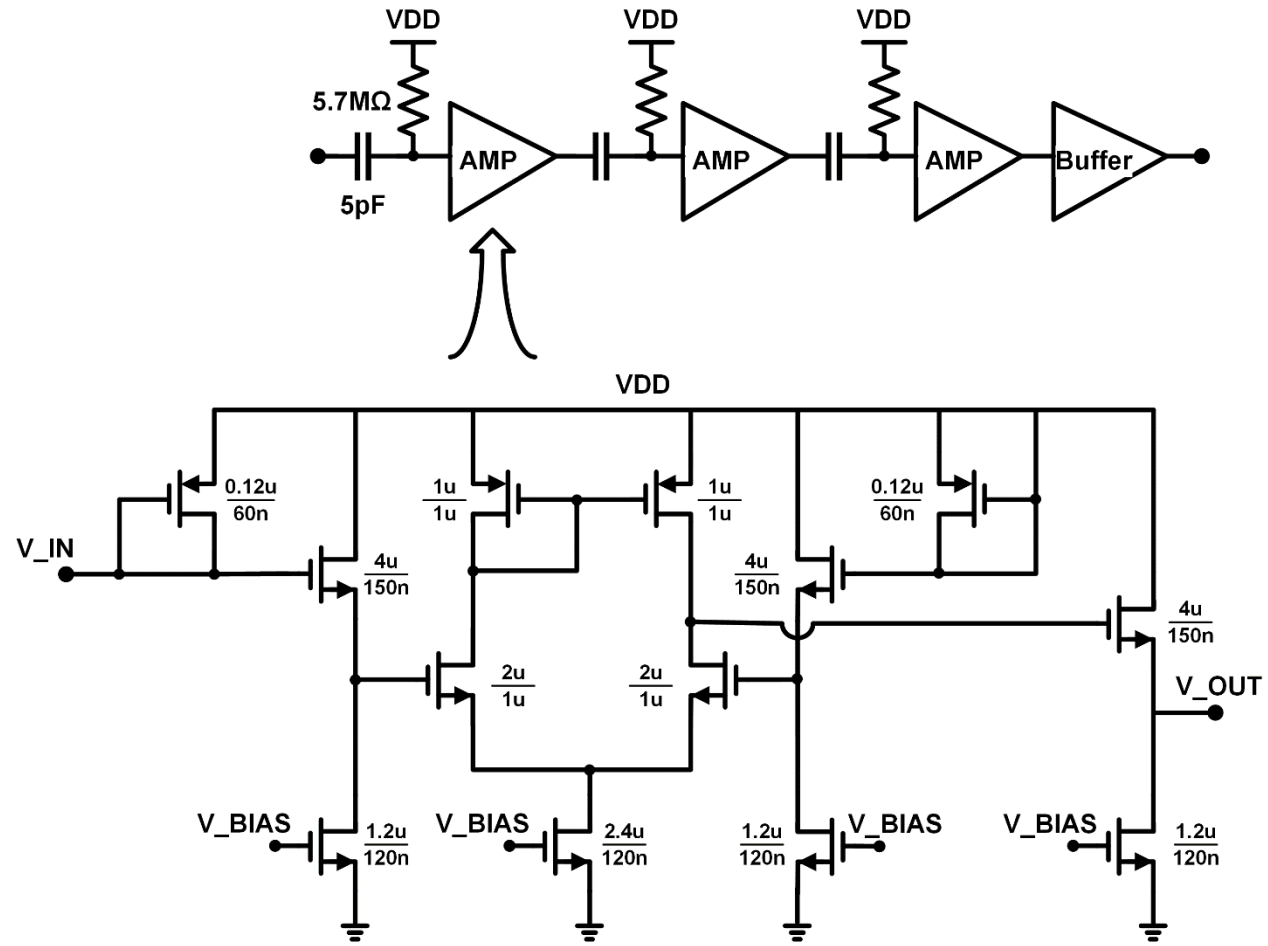


- RF+ and RF- are coming from two antennas facing each other
- Photodiode is used for biasing
- Responsivity ≈ 1kV/W, and NEP ≈ 32pW/√Hz

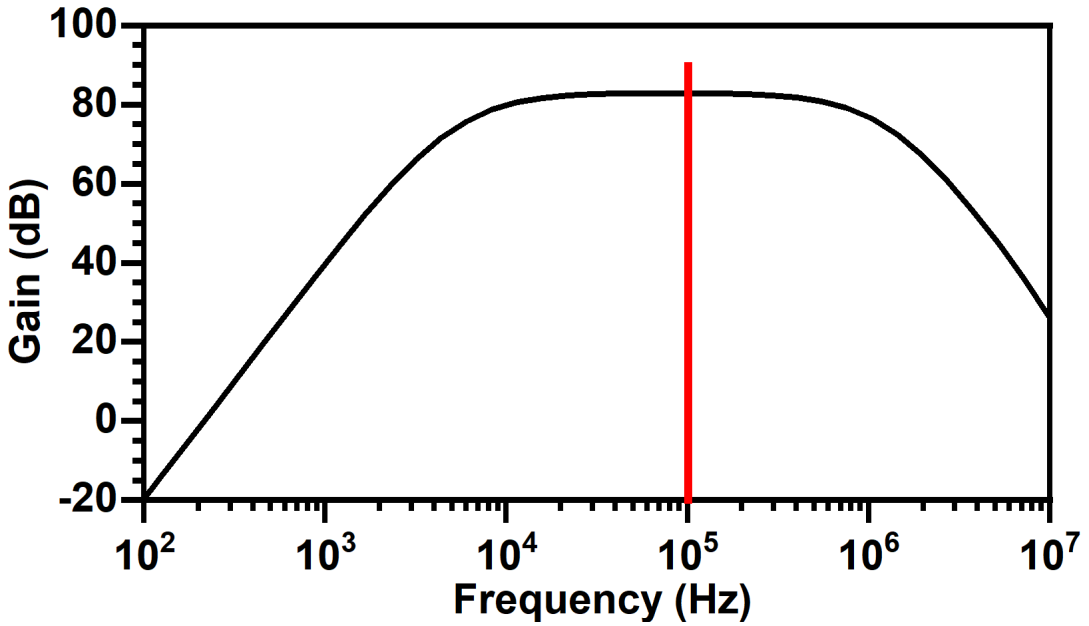


Simulated Detector Responsivity and NEP

Ultra-Low Power Amplifier Chain

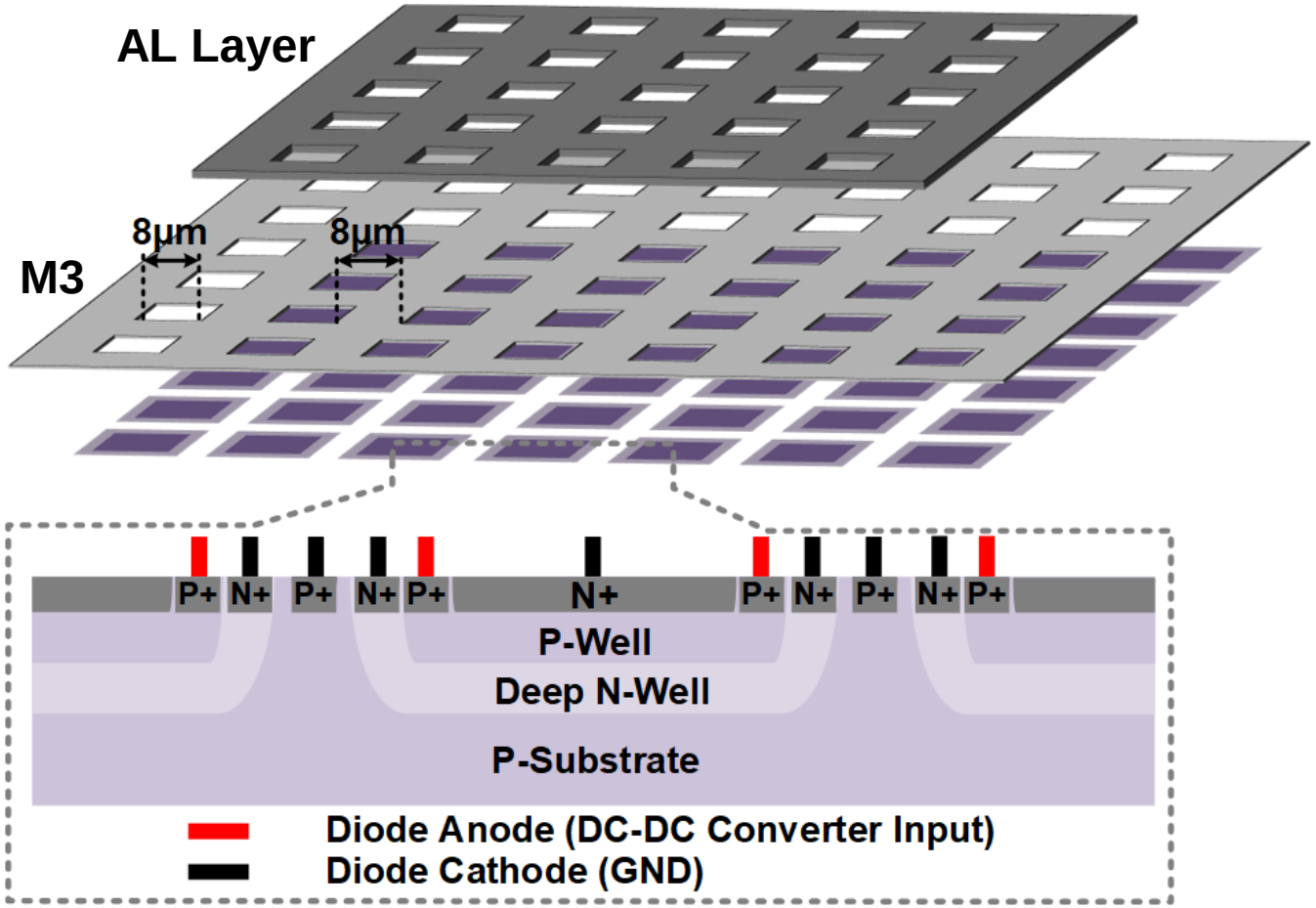


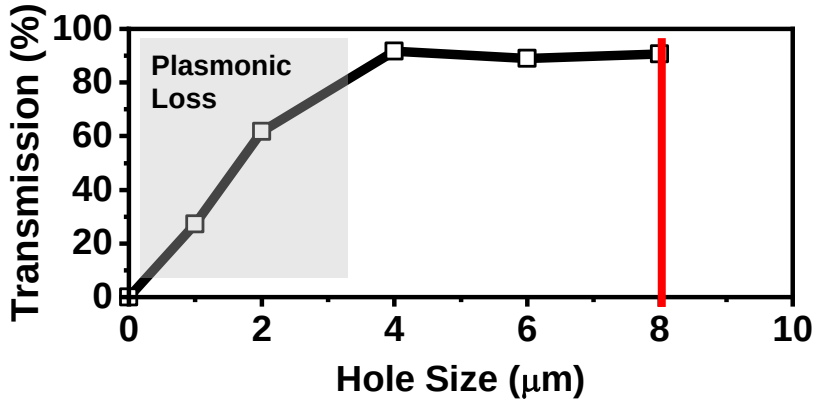
- **Subthreshold low power design**
  - **Simulated gain of 80dB**
  - **Simulated DC power of 1.5μW**
- **Downlink data rate is 100kb/s**



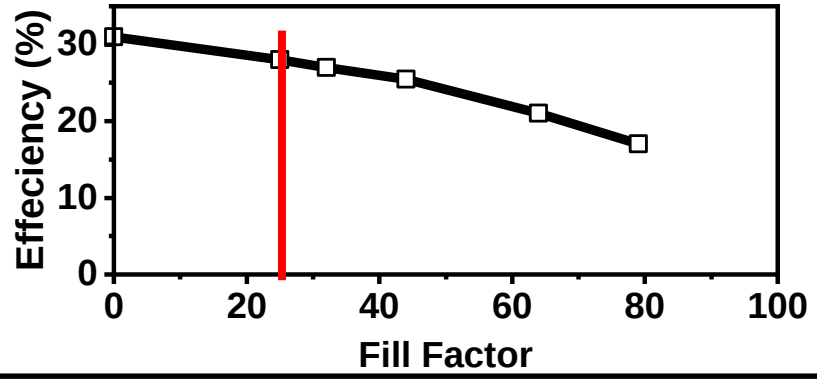
Simulated Amplifier Gain

Optical-Power Harvesting





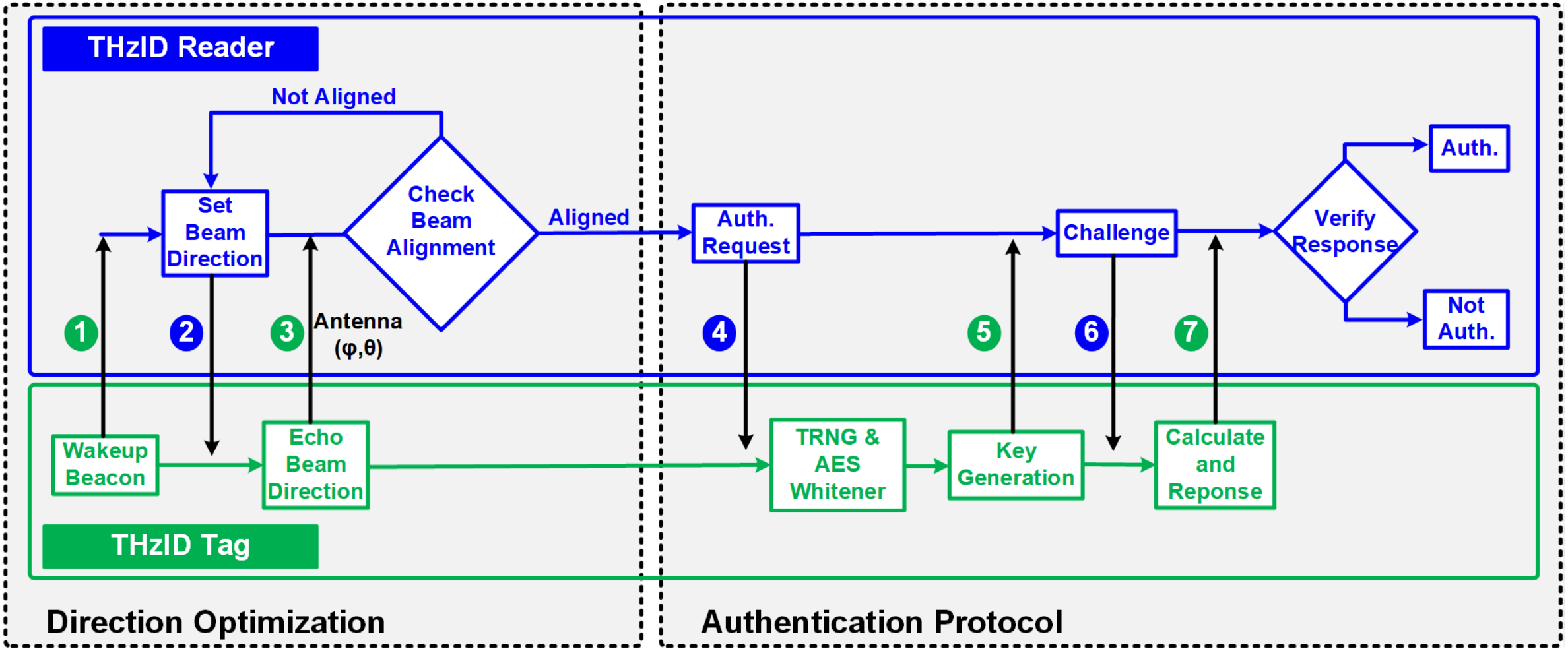
Light Transmission with Hole Size



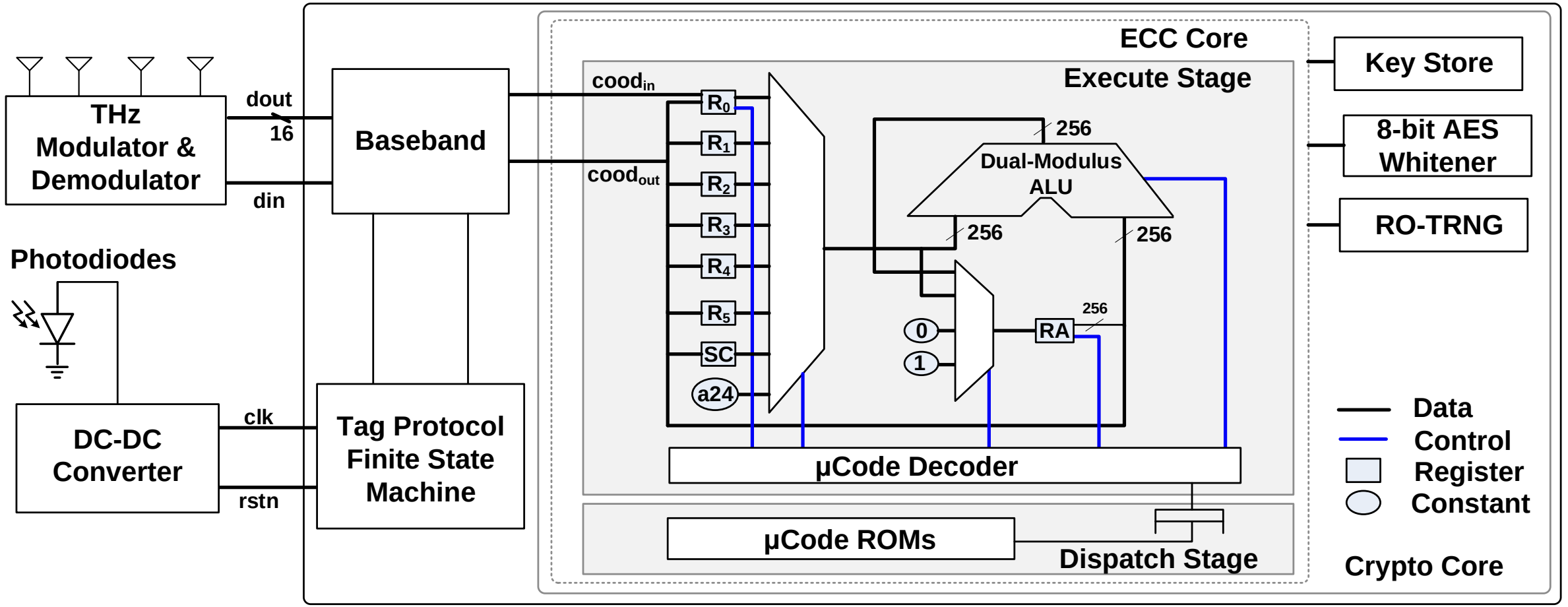
Antenna Efficiency with Fill Factor (8µm Hole Size)

- N+/P-well/Deep-N-well diode is used to create an isolated anode terminal
- The simulated light transmission through the antenna fishnet pattern is 22%

Communication Protocol



Cryptographic Processor



- **Elliptic curve cryptography (ECC) with 22% lower area and 18% lower cycle count compared to state-of-the-art**

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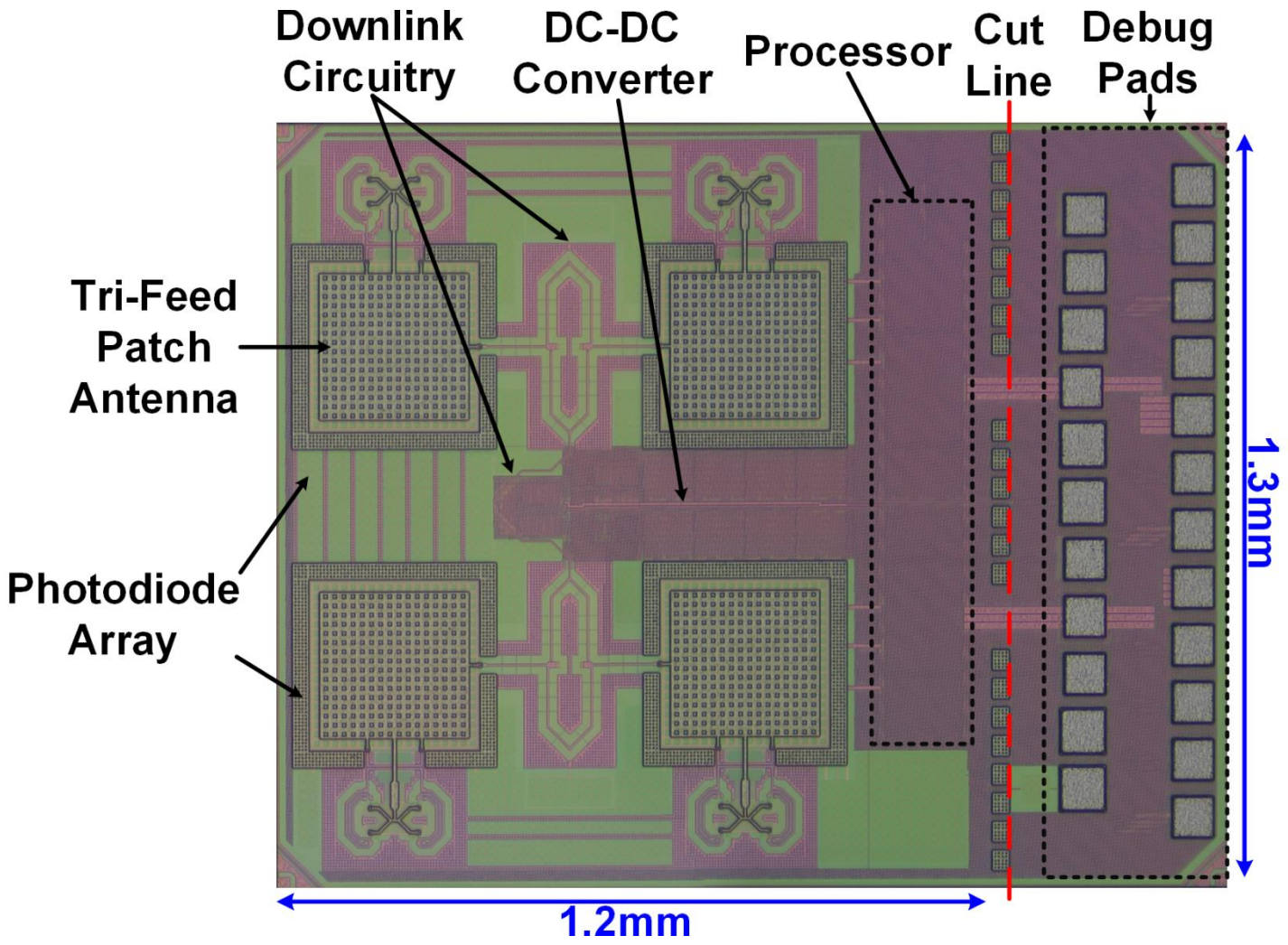
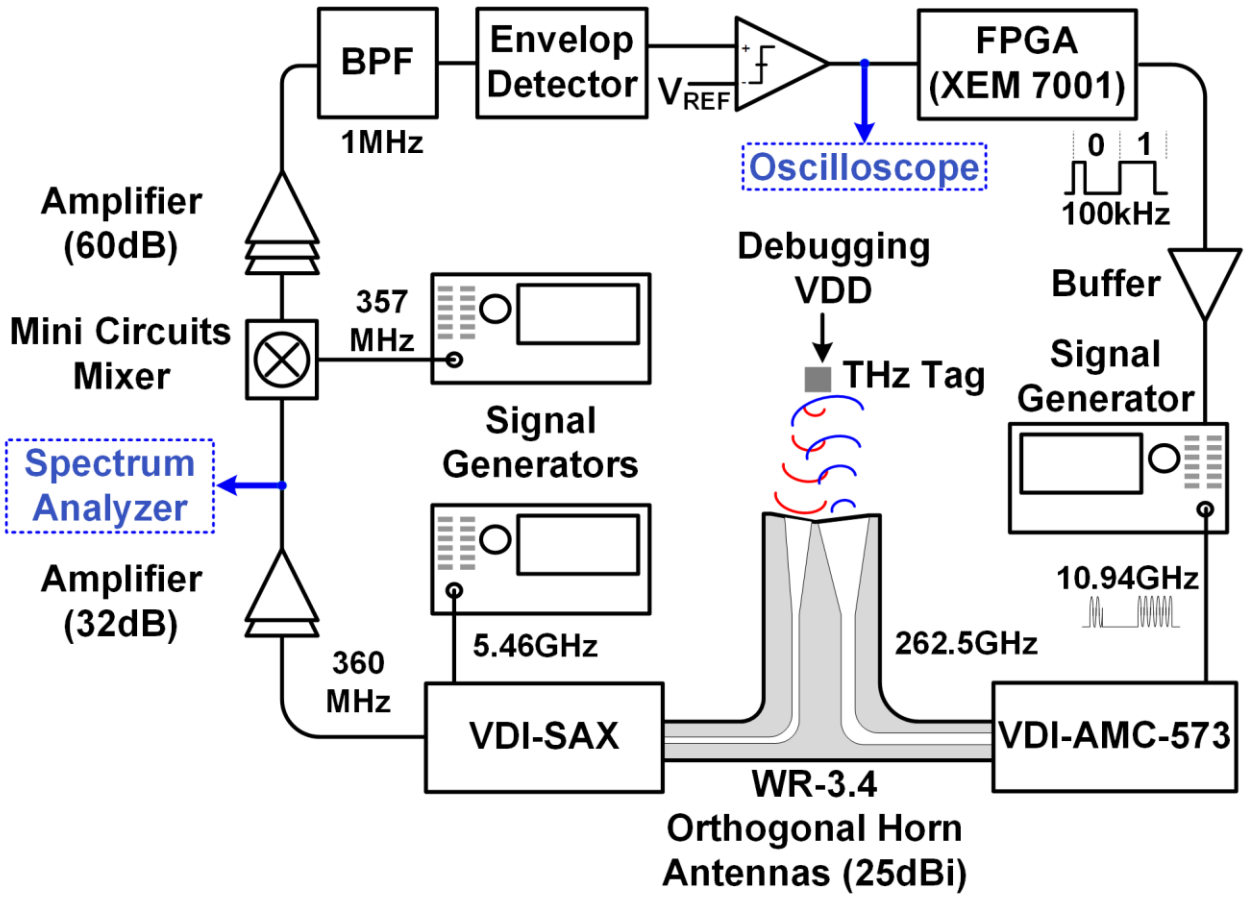
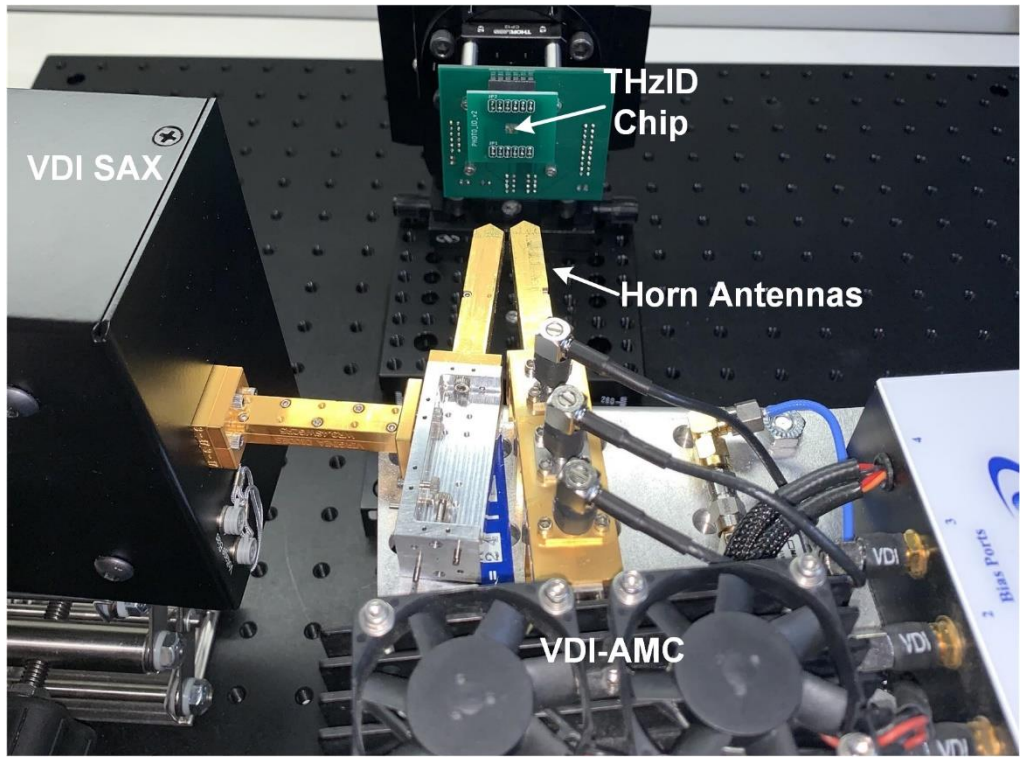
Chip Micrograph

- TSMC 65nm CMOS process



Measurement Setup



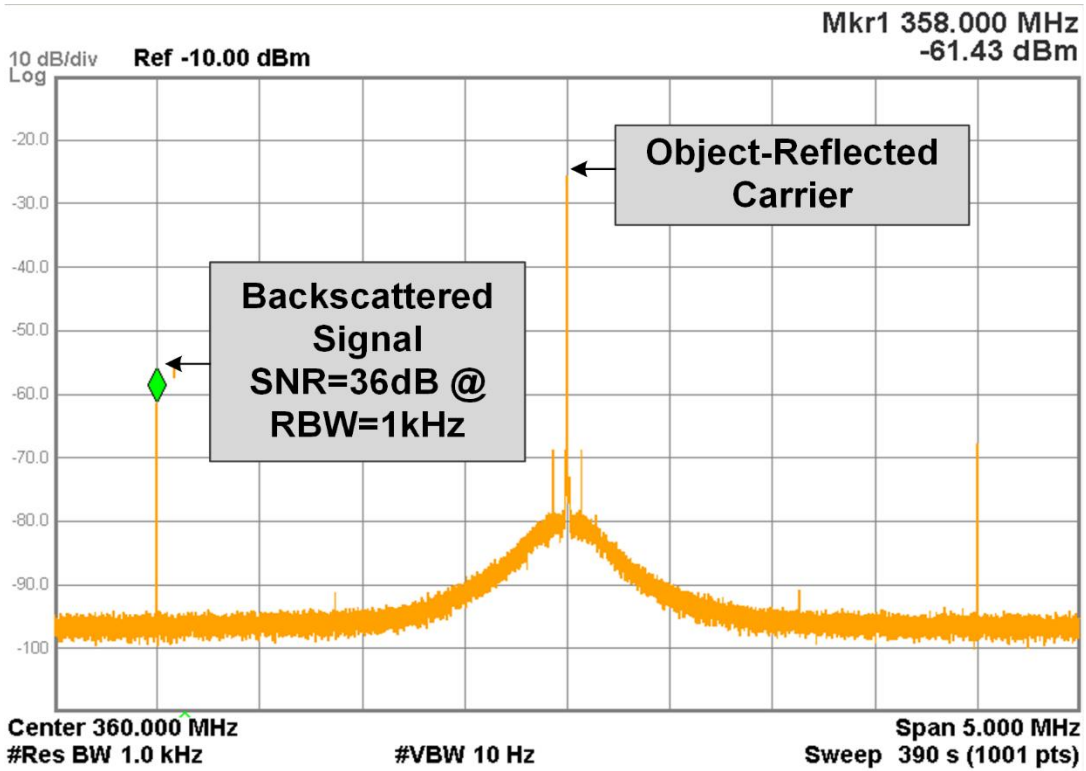


Measurement Setup Schematic

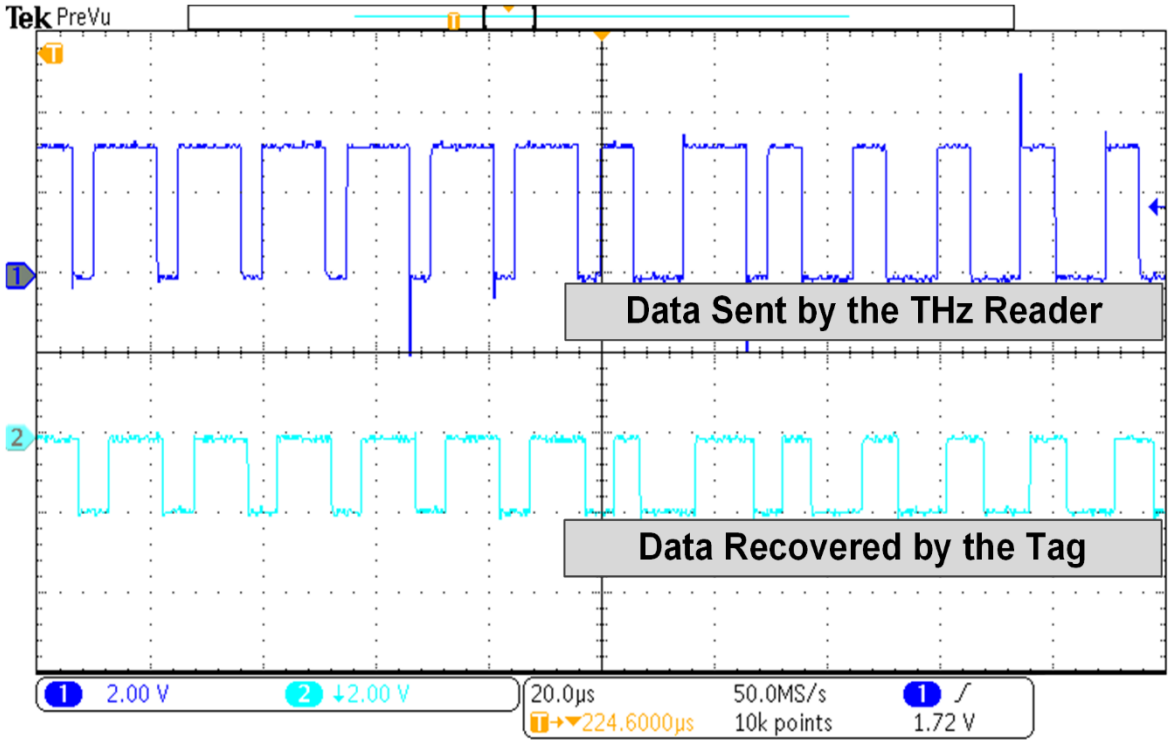
Chip Testing Setup Photograph

260GHz Front-End Performance

Measured Backscattered Spectrum

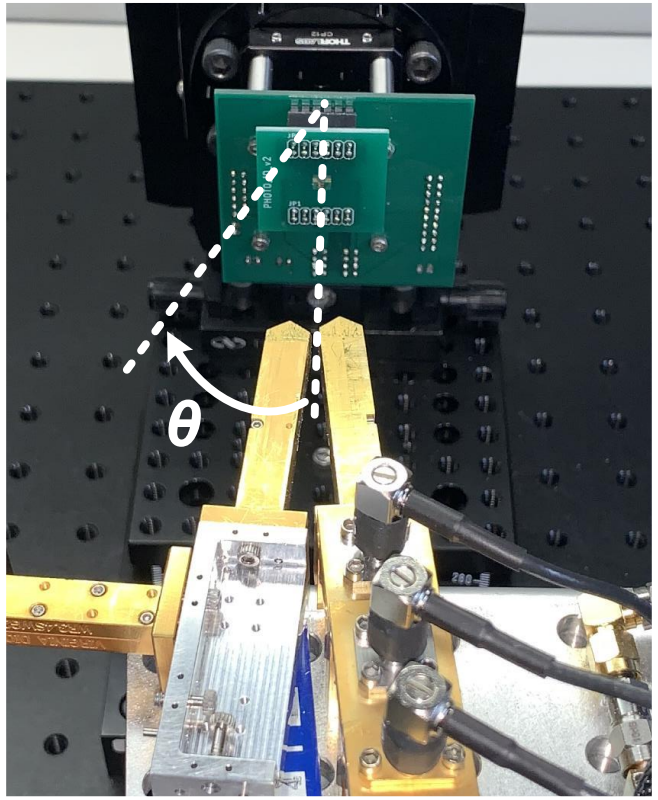


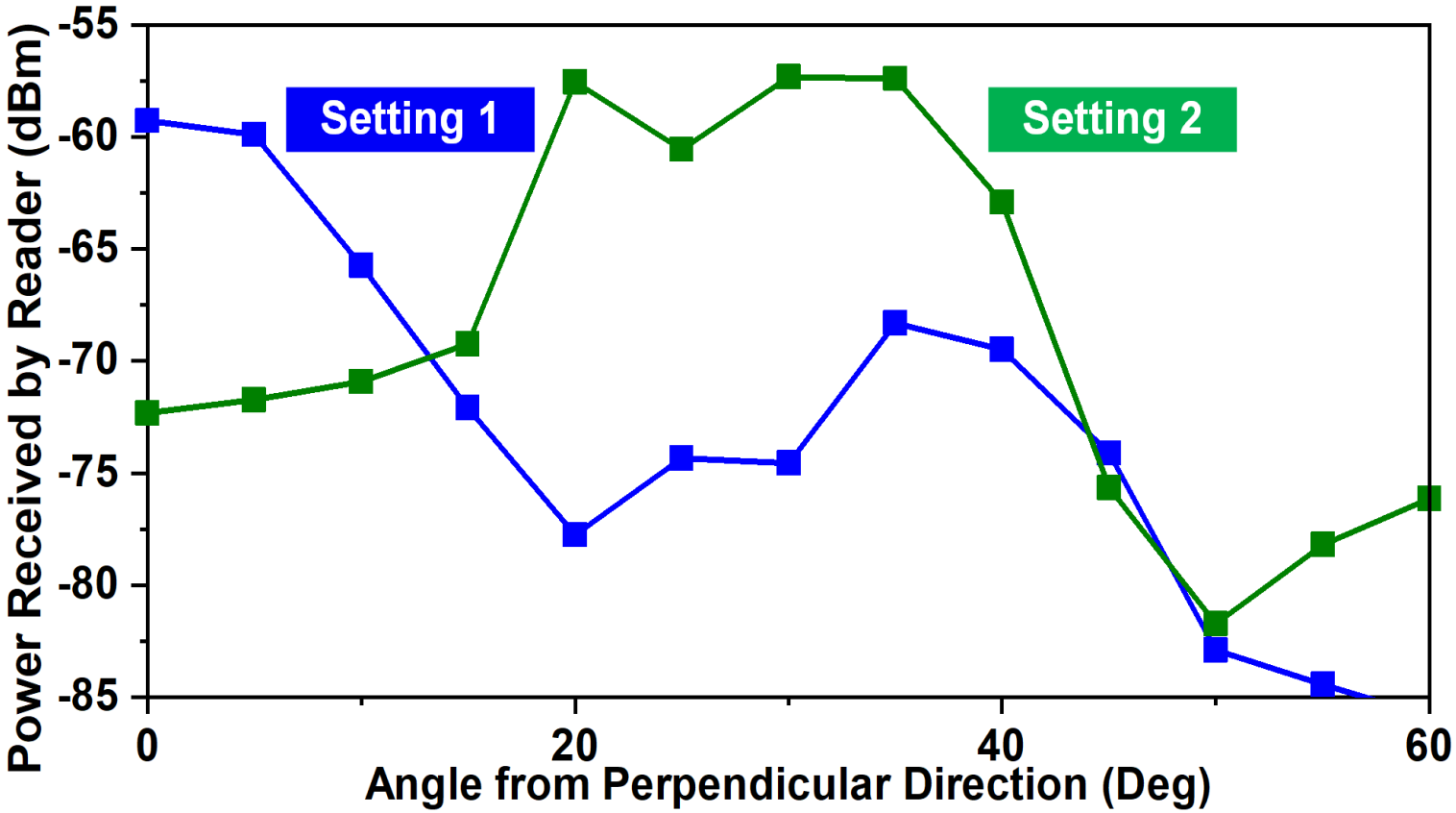
Measured Downlink Data



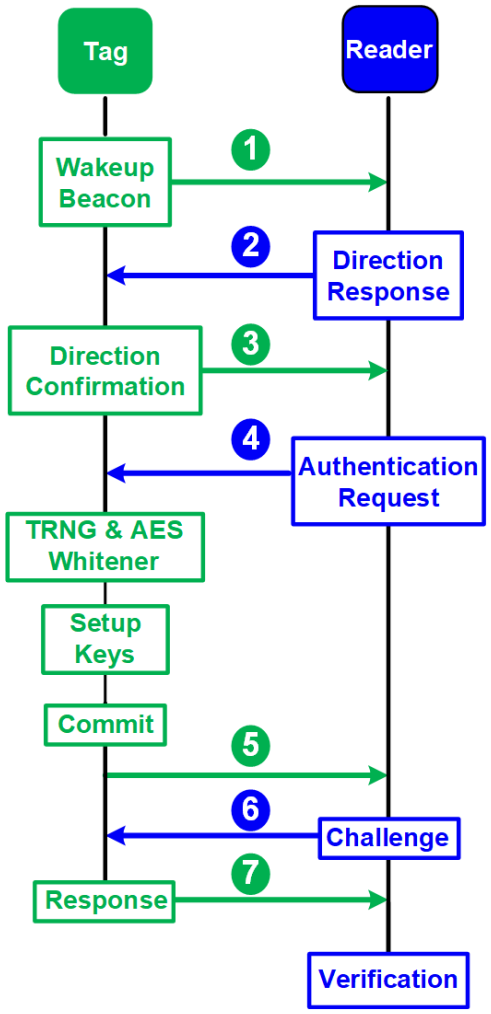
Beam-Steering Measurements

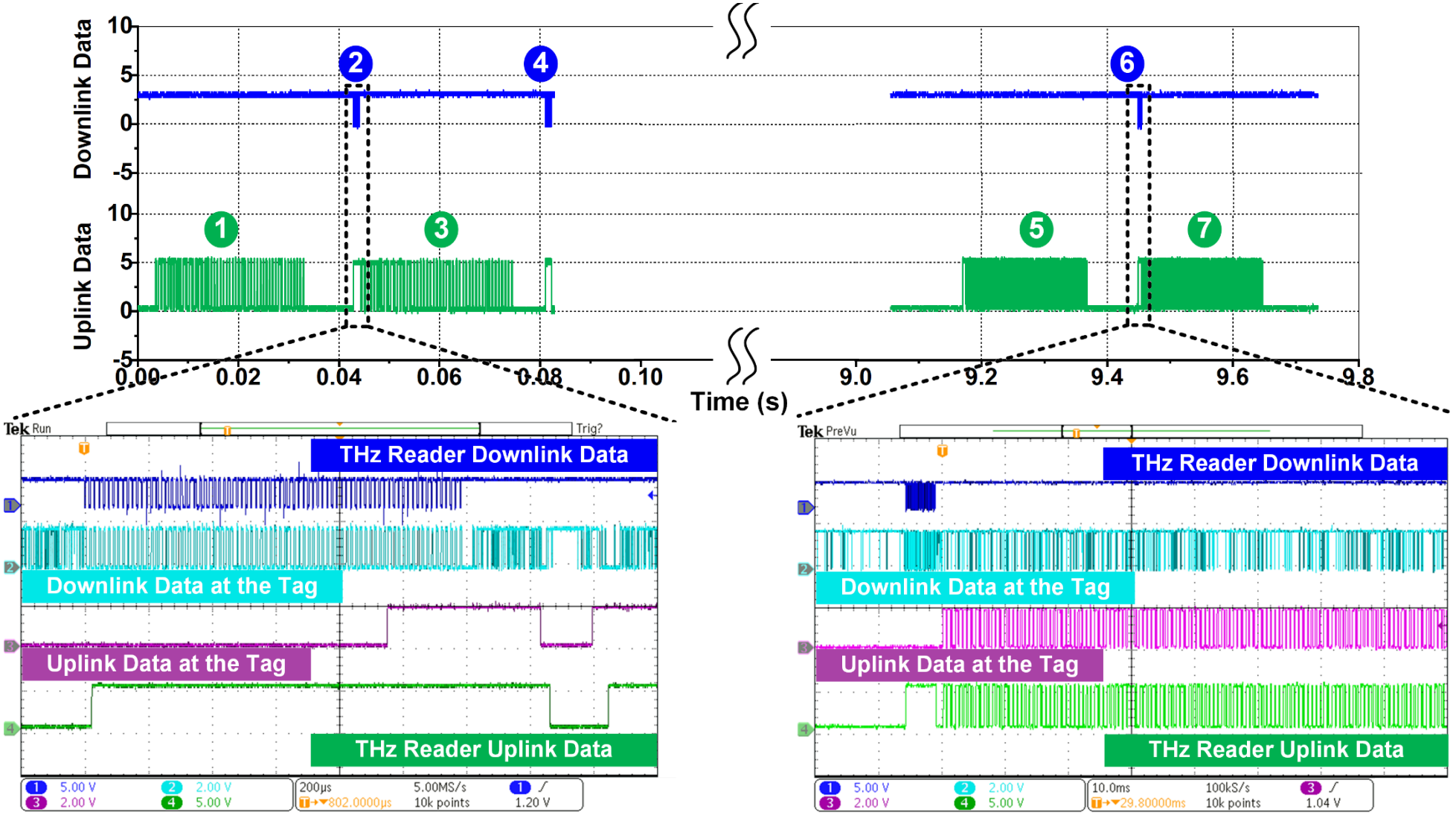
- **Backscattered signal detected by the reader at non-perpendicular positions by sweeping the angle (θ)**



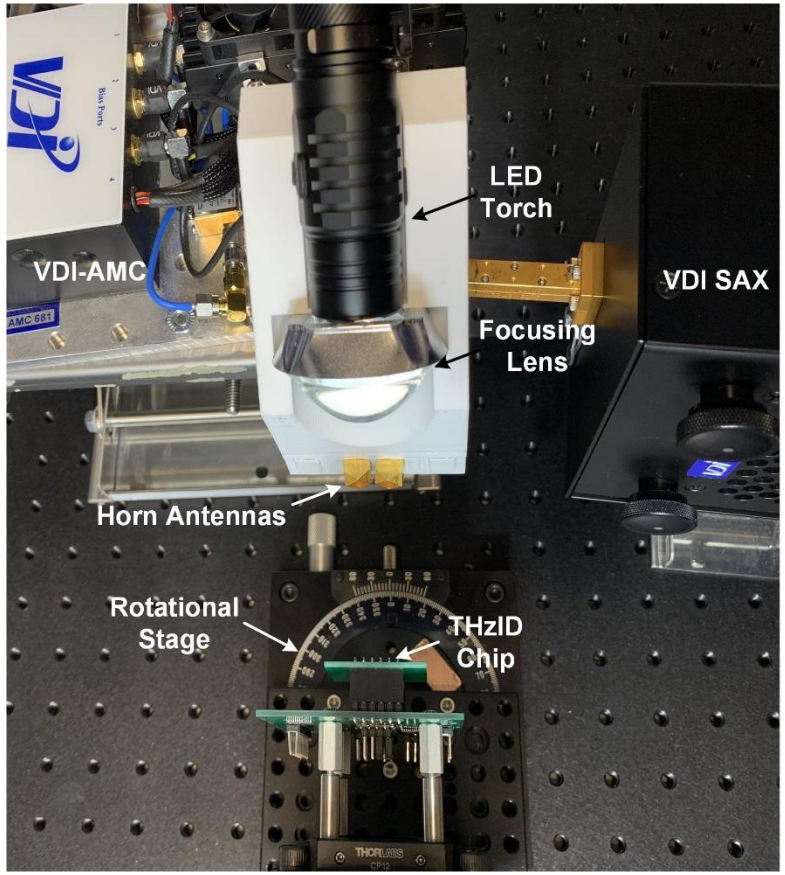


Measured Time Domain Communication

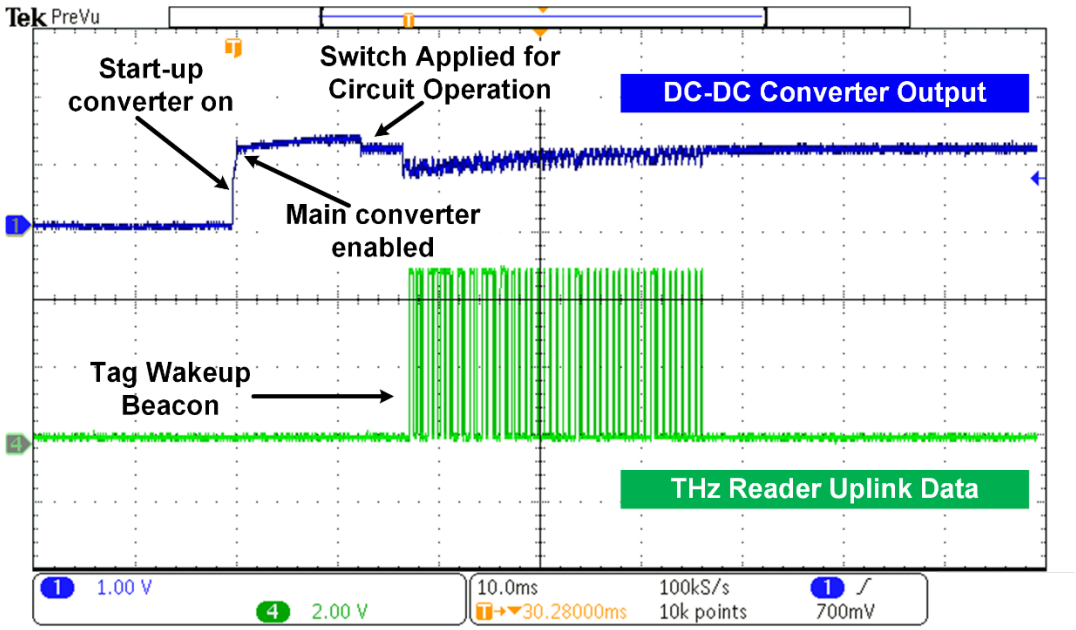




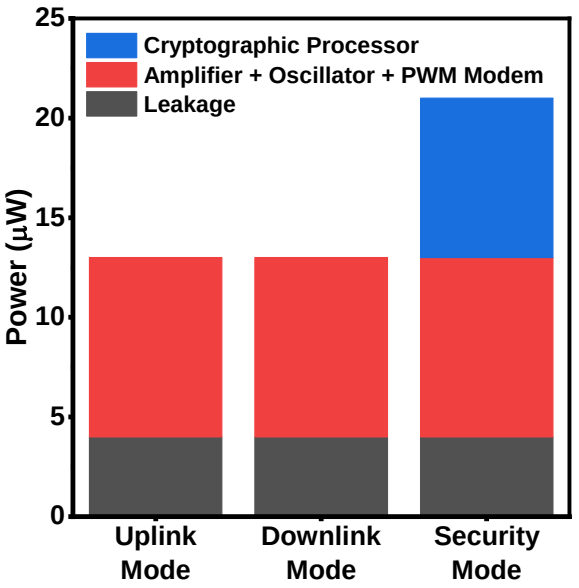
Light Powering Performance



Chip Testing Setup Photograph with LED Torch



Chip Start-up with Light Power



Power Budget Breakdown

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Performance Comparison

References	Process	Carrier Frequency (GHz)	Data Rate	Peak Power	Security	Range	Beam-Steering	Area (mm^2)
This Work	65nm	260	DL:100kbps UL:2kbps	21μW	Yes (Elliptic Curve)	5cm	Yes	1.6
ISSCC'17 [1]	180nm	0.915	DL:62.5kbps UL:30.3kbps	2mW	No	20m	No	9*
ISSCC'18 [2]	65nm	5.8	DL:5Mbps UL:4kbps	10μW		1mm		0.01
VLSI'14 [3]	65nm	DL:24 UL:60	DL:6.5Mbps UL:1.2Mbps	11mW**		50cm		4.4
ISSCC'16 [4]	130nm	0.433	125kbps	16μW	Yes (Symmetric)	5mm		64***

* Volume is $27mm^3$
** Calculated data according to [1]
*** The area includes off-chip antenna (chip area is $0.8x0.8mm^2$)

[1] L. Chuo, et al., *ISSCC*, 2017.
[2] B. Zhao, et al., *ISSCC*, 2018.
[3] M. Tabesh, et al., *VLSI*, 2014.
[4] C. S. Juvekar, et al., *ISSCC*, 2016.

Acknowledgement

- National Science Foundation (SpecEES ECCS-1824360)
- Virginia Diodes Inc. (VDI) for providing testing instruments
- Prof. Donhee Ham and Dr. Houk Jang at Harvard University for their support during the testing
- Prof. Nicholas Fang and Xinhao Li at MIT for their support during the testing

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