LeakyScatter: A Frequency-Agile Directional Backscatter Network above 100 GHz

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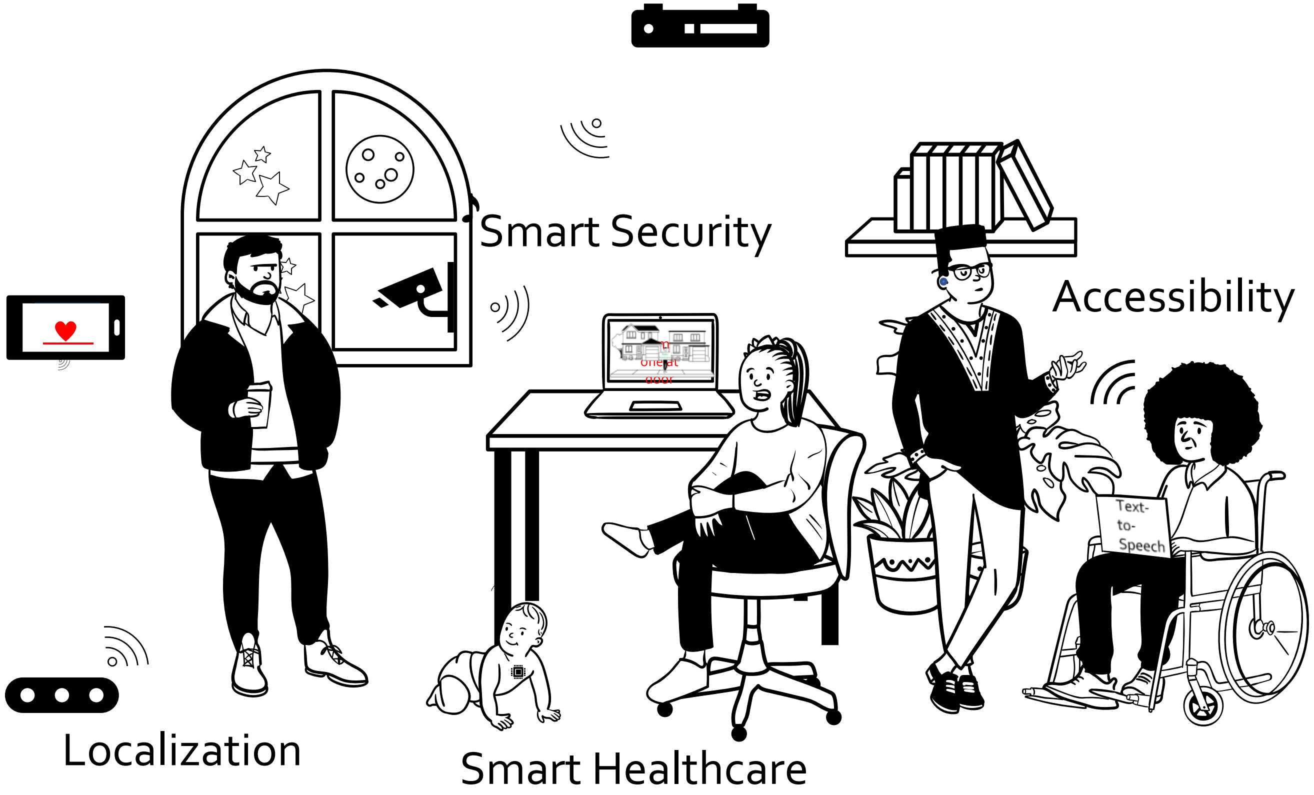
PRINCETON UNIVERSITY

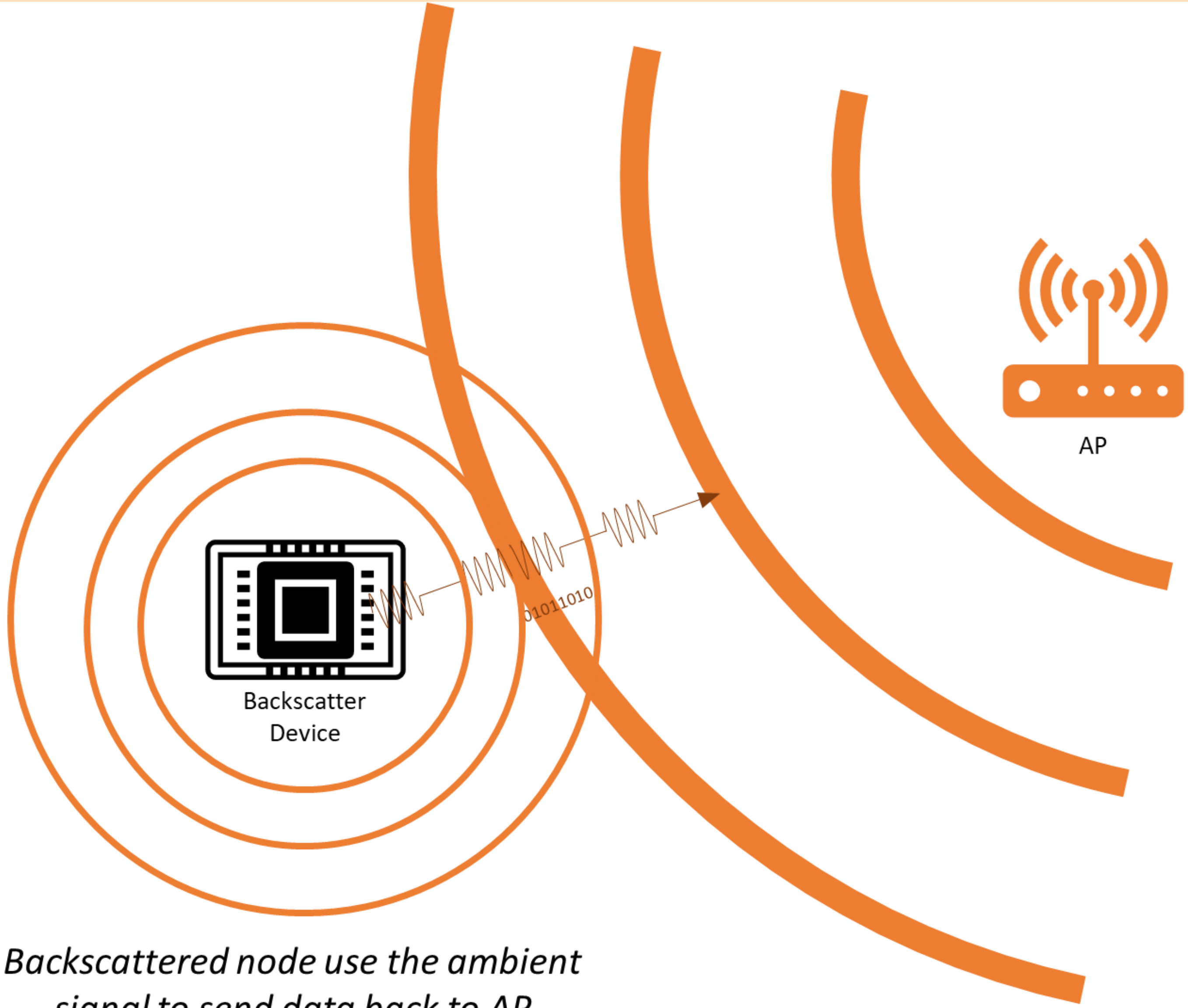
Low-Power Communication

Can be enabled by Backscattering



1. LUETH, K. L. State of the IoT 2020: 12 billion IoT Connections, Surpassing Non-IoT for the First Time. Available at https://iot-an alytics.com/state-of-the-iot-2020-12-billion-iot-con nections-surpassing-non-iot-for-the-first-time/, 2020.

Backscattering is a Promising Candidate for Low-Power Communication



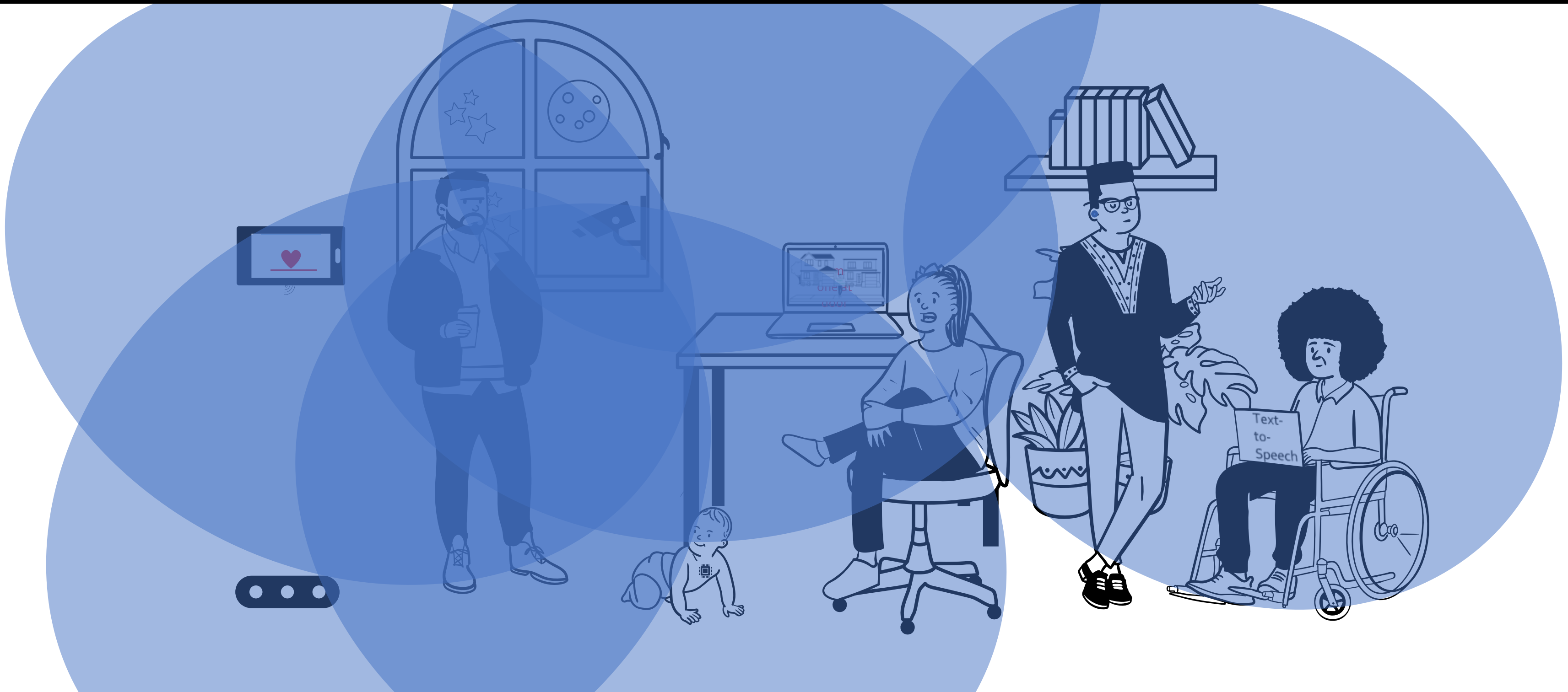
AP sends an Ambient Signal

Backscattered node use the ambient signal to send data back to AP

Today's Backscattering

Total Number of Low-Power nodes expected to increase to 41.2 billion![1]

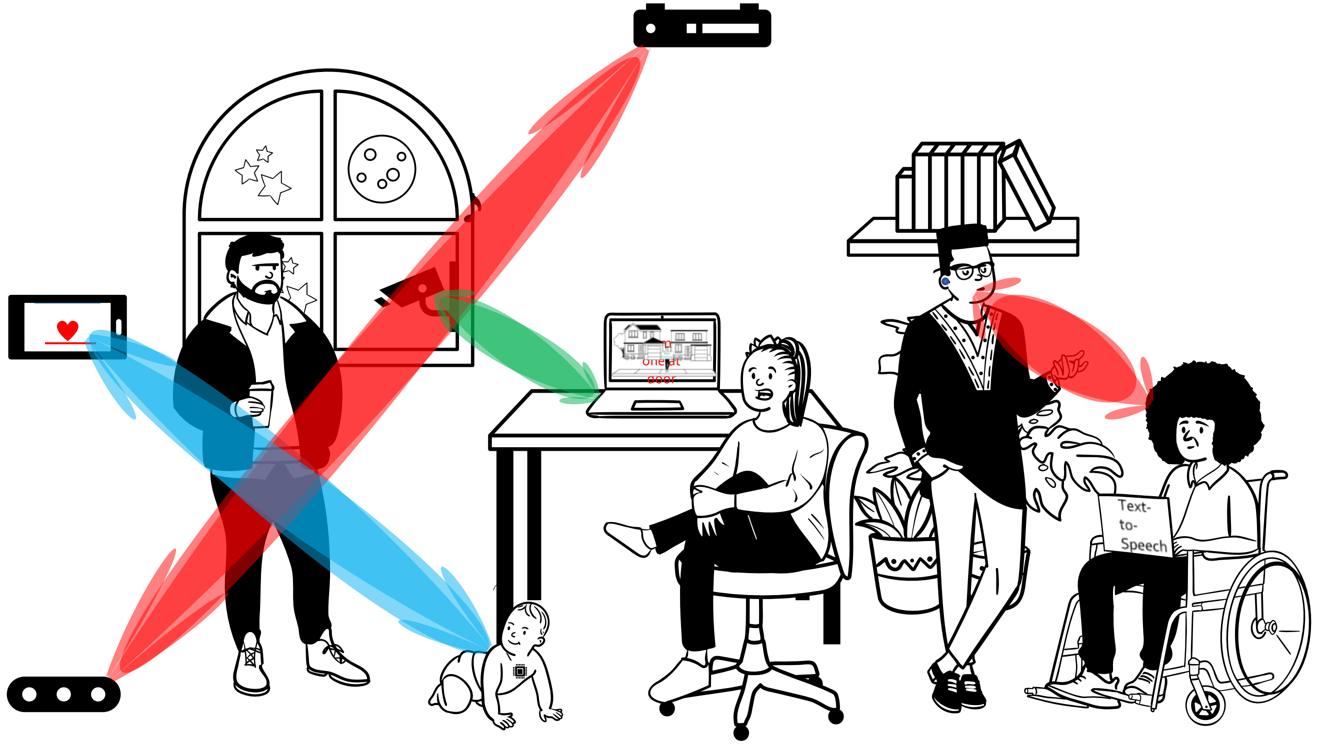
Current backscattering technology is limited in the total number of users it can support

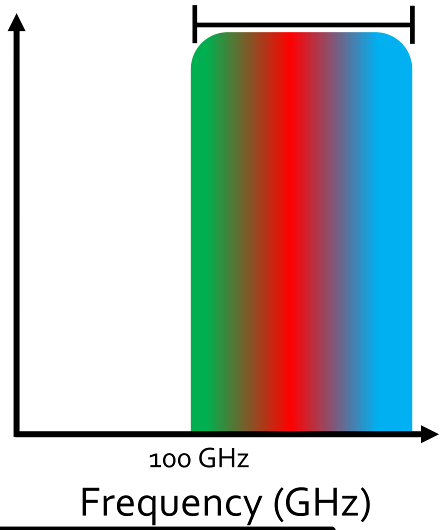


1. LUETH, K. L. State of the IoT 2020: 12 billion IoT Connections, Surpassing Non-IoT for the First Time. Available at https://iot-an alytics.com/state-of-the-iot-2020-12-billion-iot-con nections-surpassing-non-iot-for-the-first-time/, 2020.

Towards Backscattering Above 100 GHz

- Wideband – Orthogonal Frequency Division Multiple Access
- Directionality – Spectral reuse with spatial separation



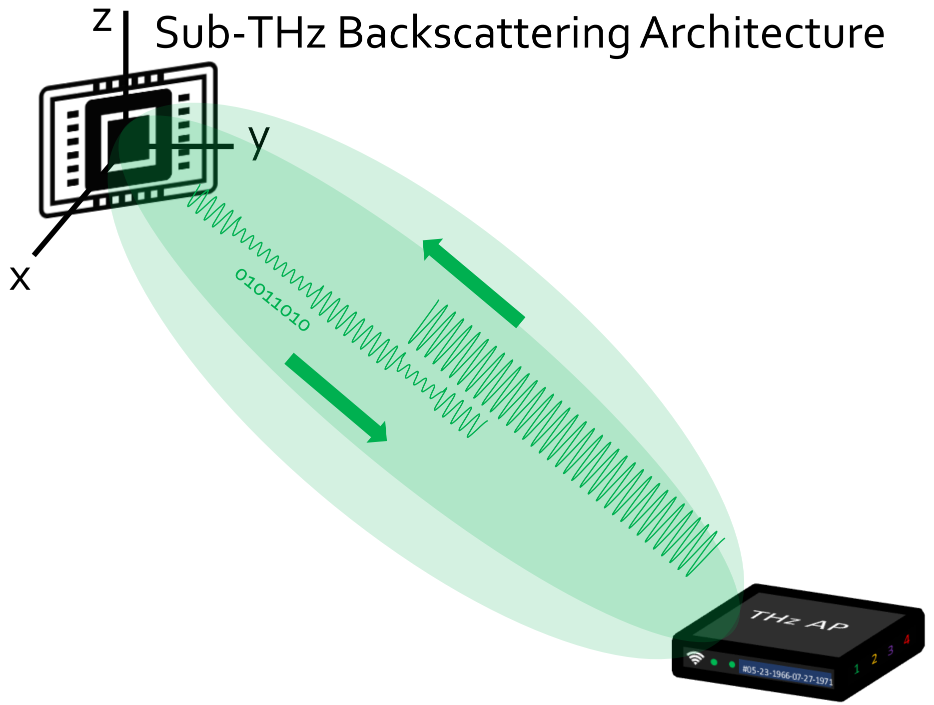


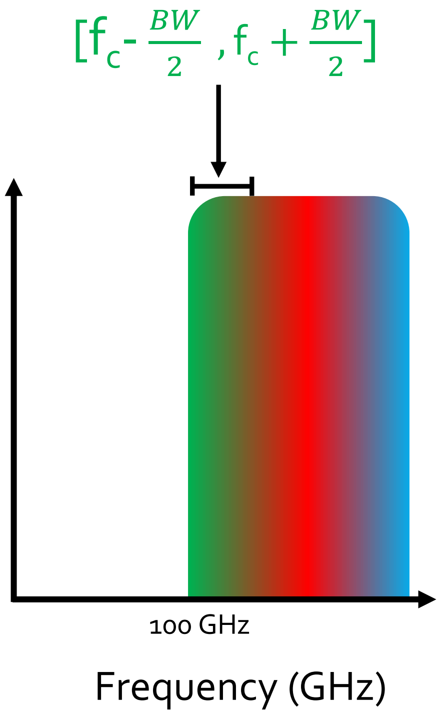
How do we enable backscattering above 100 GHz?

Key Goals

1. Enabling <u>highly directional, retrodirective links</u>
2. Enabling <u>frequency-agile operation</u> above 100 GHz
3. Enabling <u>ultra-wide bandwidth</u> (GHz-Scale)

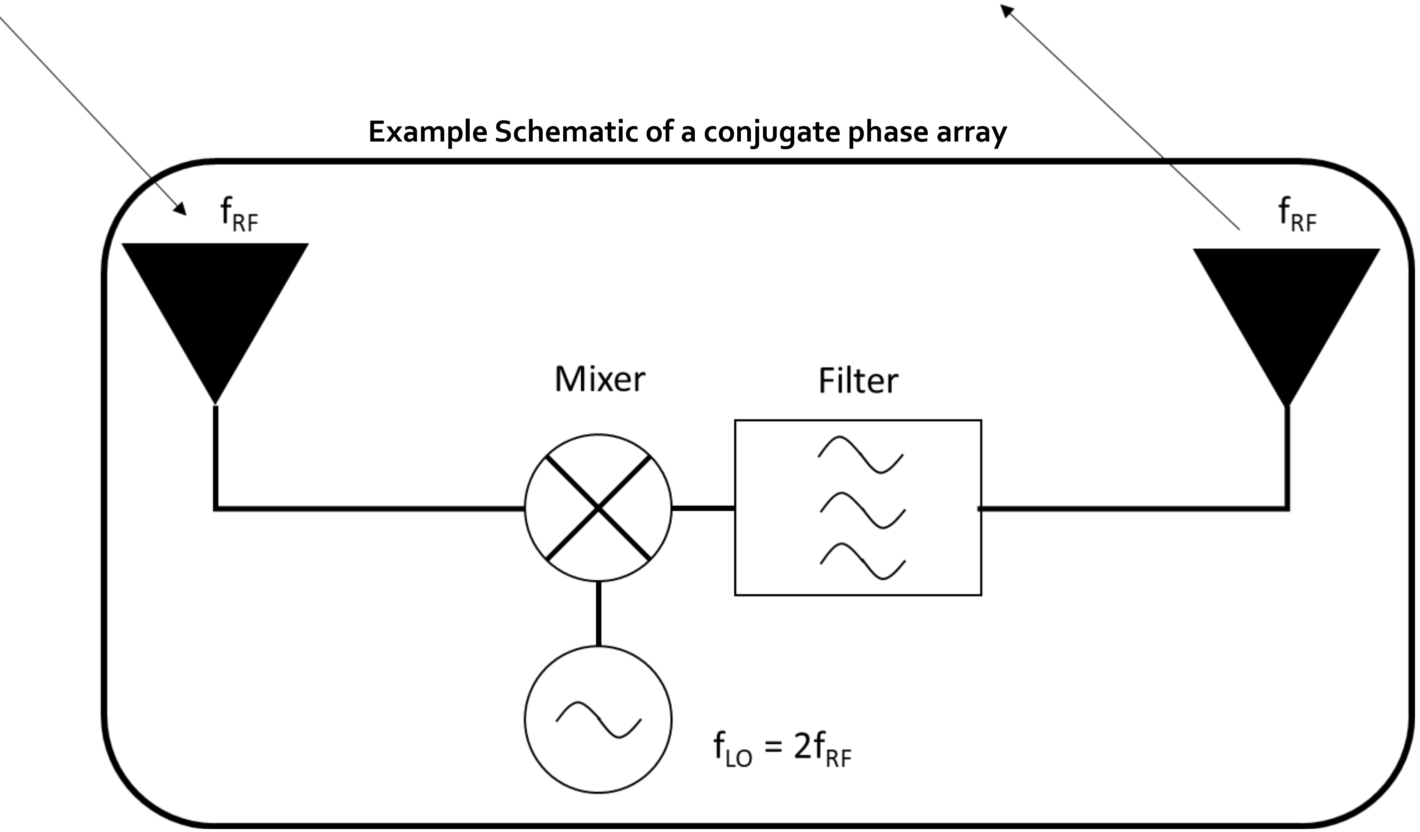
All performed at zero-power cost





Prior Work: Phase Arrays

Example Schematic of a conjugate phase array

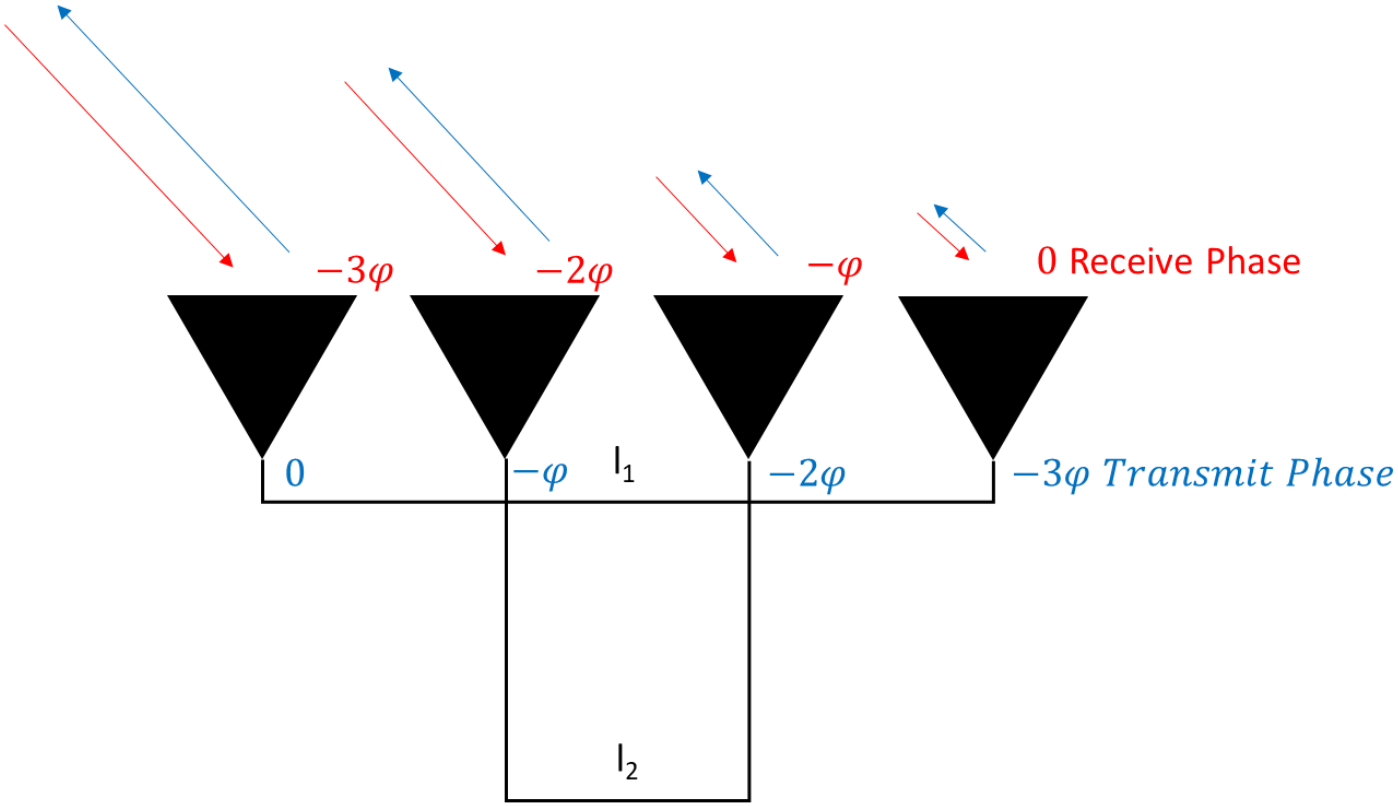


Requires Active Components

Key Goals

1. Retrodirective ✓
2. Frequency-agile ✓
3. Wideband ✓
4. Low-power ✗

Prior Work: Van Atta Arrays



Antenna size ∝ λ

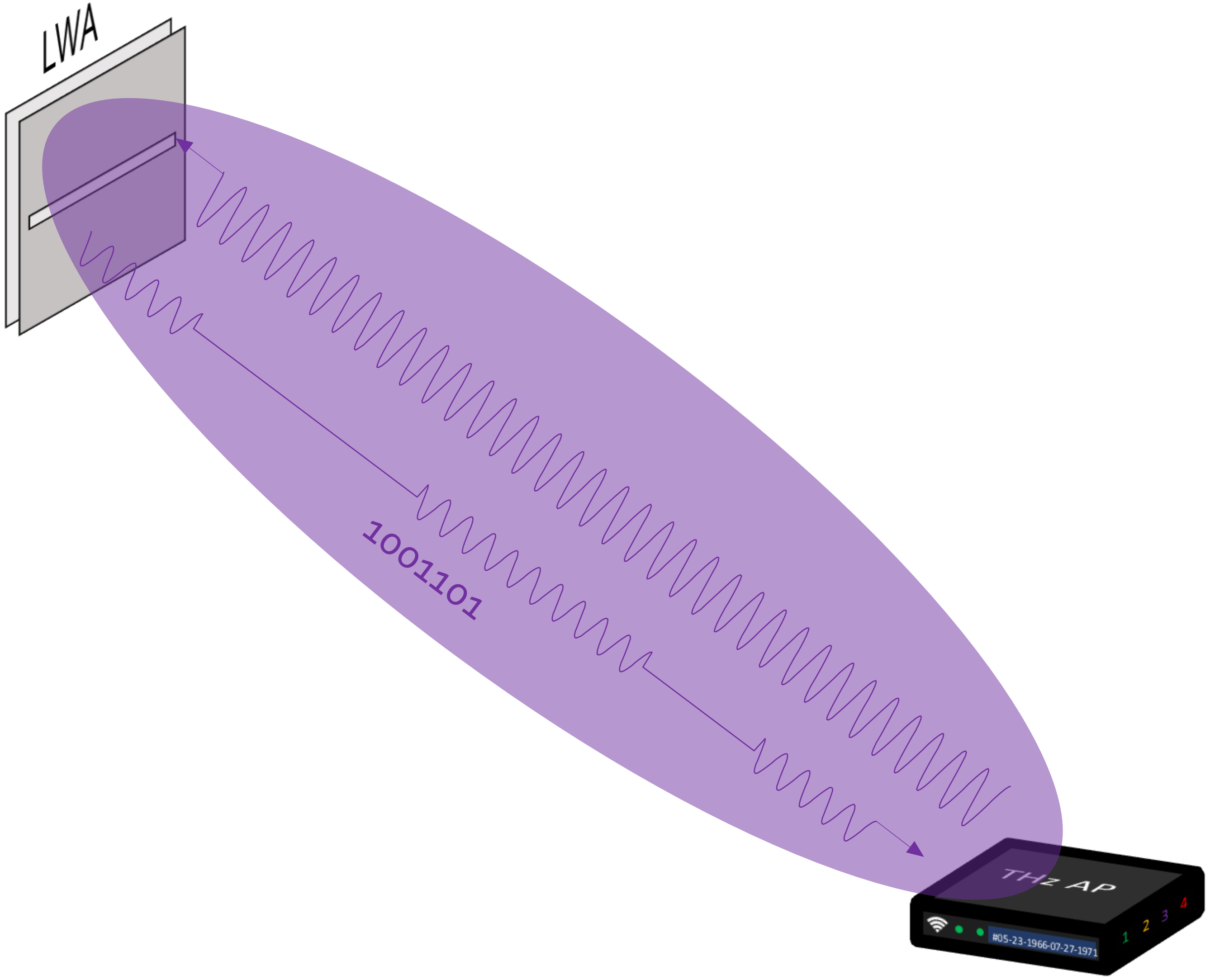
Transmission Line Length ∝ λ

Key Goals

1. Retrodirective ✓
2. Frequency-agile ✗
3. Wideband ✗
4. Low-power ✓

Presenting **LeakyScatter**: The first frequency-agile sub-THz Backscatter Architecture

Key Idea: Create a New PHY-Layer Architecture based on Leaky Wave Antennas (LWAs)



Key Goals

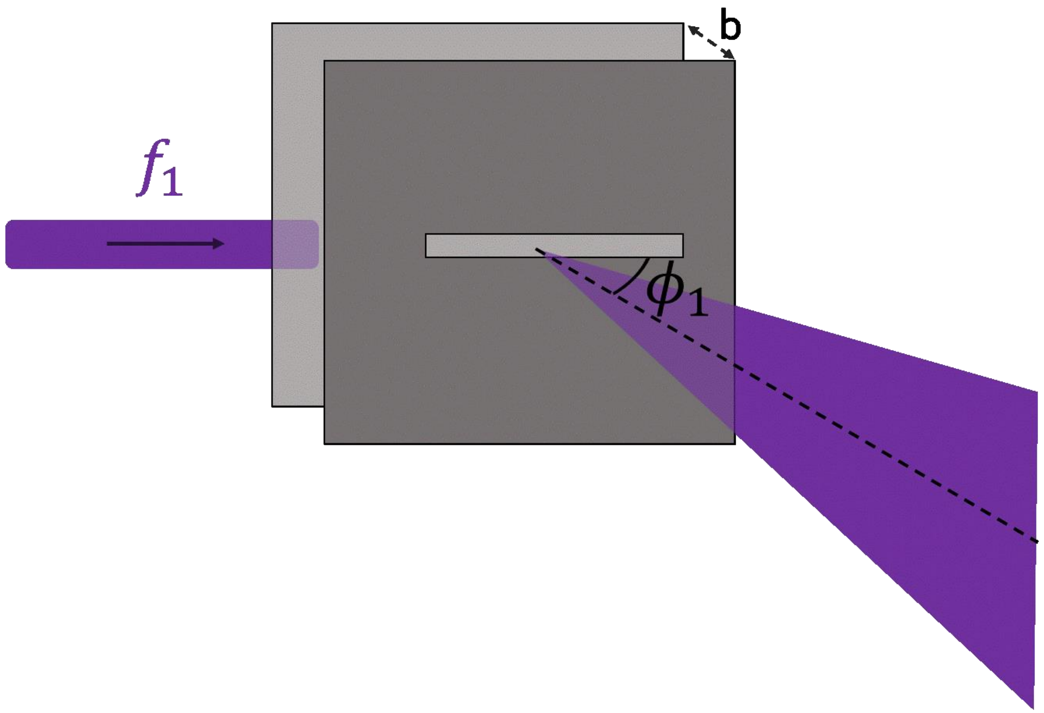
1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power

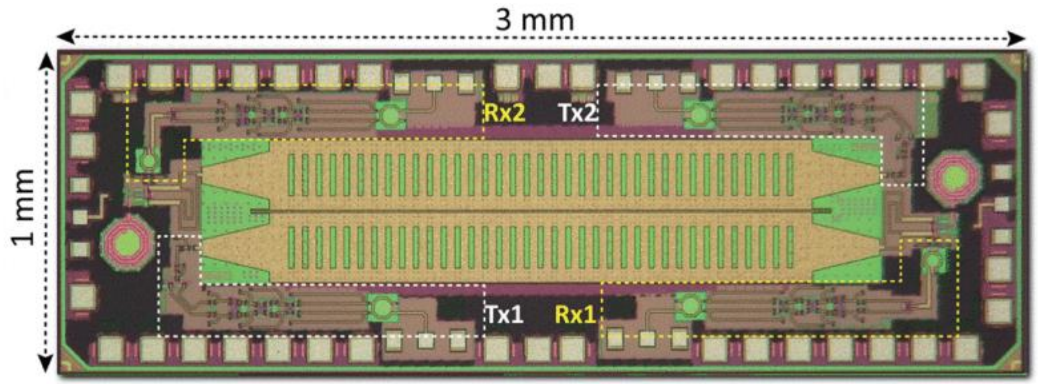
Key Idea: Design a new PHY-layer architecture that supports directionality at low-power cost and is ultra-wideband

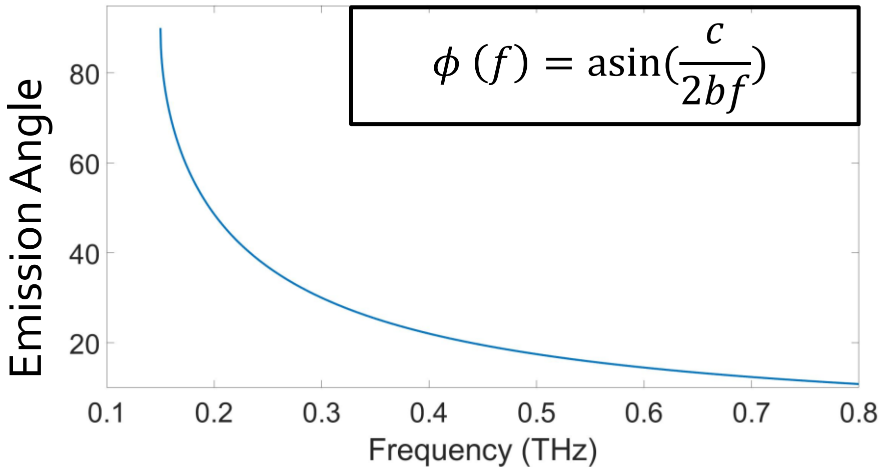
Method: Using Leaky Wave Antennas (LWAs) as the foundational architecture

Primer: Leaky Wave Antennas (LWAs)

- LWAs are traveling wave structures
- Injected signal will leak out into free-space in a **specific angle**

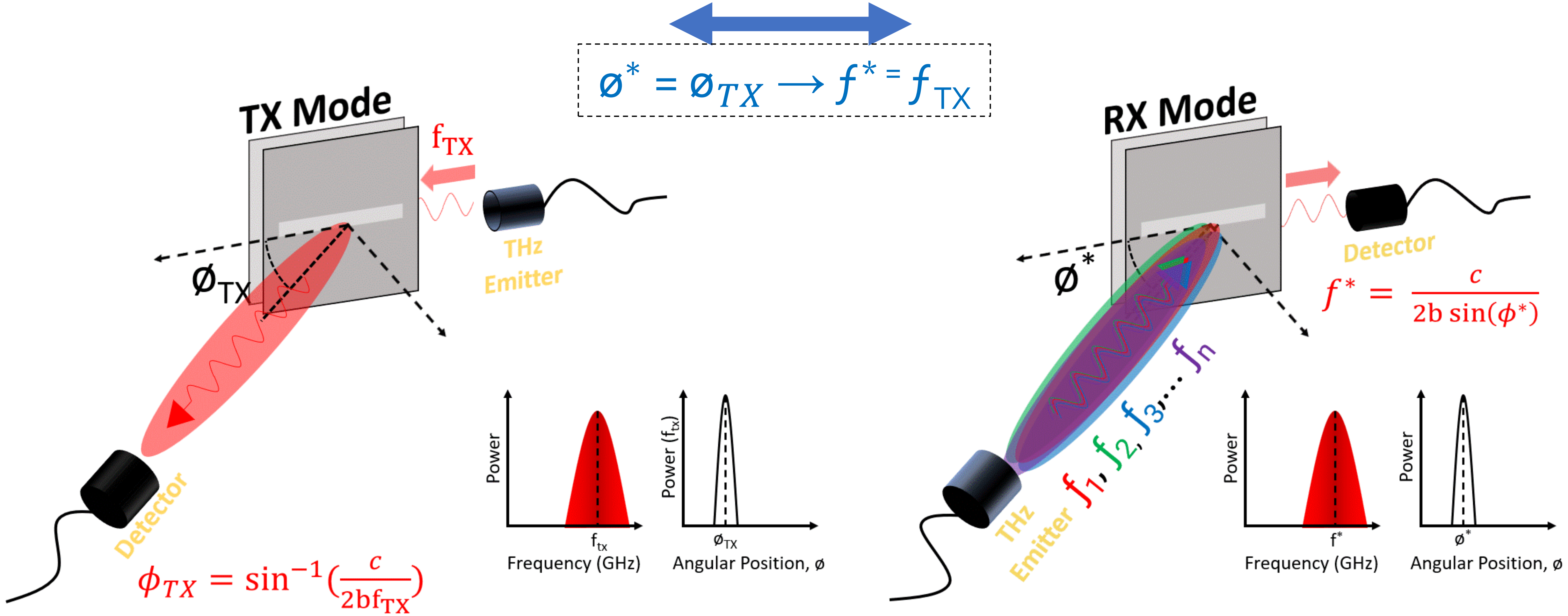






2. Yasaman Ghasempour, Rabi Shrestha, Aaron Charous, Edward Knightly, and Daniel M. Mittleman. 2020. Single-Shot Link Discovery for Terahertz Wireless Networks. Nature Communication 11, 1 (2020), 2017.
3. Hooman Saeidi, Suresh Venkatesh, Xuyang Lu, and Kaushik Sengupta. 2021. 22.1 THz Prism: One-Shot Simultaneous Multi-Node Angular Localization Using Spectrum-to-Space Mapping with 360-to-400GHz Broadband Transceiver and Dual-Port Integrated Leaky-Wave Antennas. In 2021 IEEE International SolidState Circuits Conference (ISSCC), Vol. 64. 314–316

Reciprocal Properties of a Leaky Wave Antenna



We can leverage reciprocity to create retrodirective links

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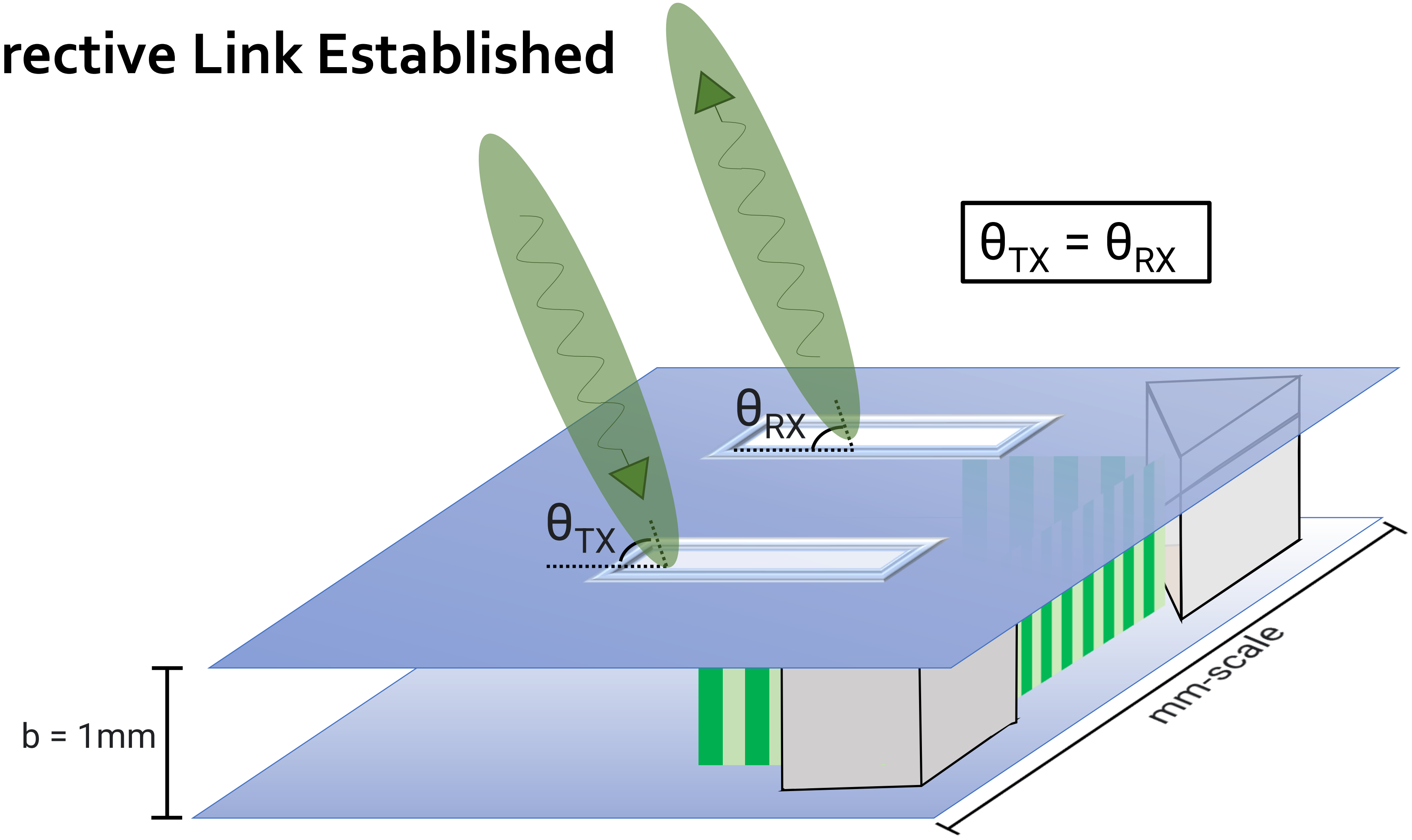
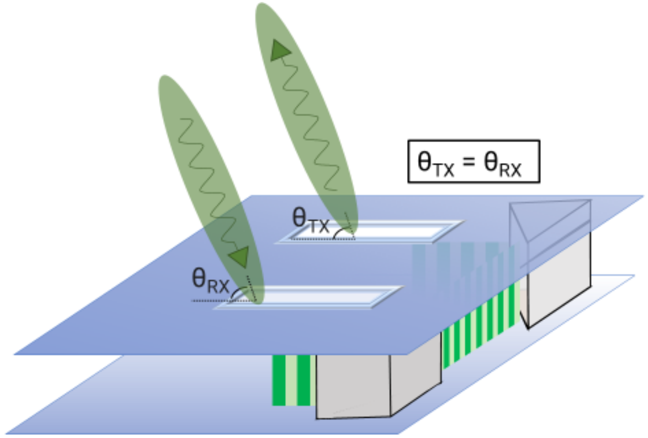
Dual Slit Architecture

Retrodirective Link Established



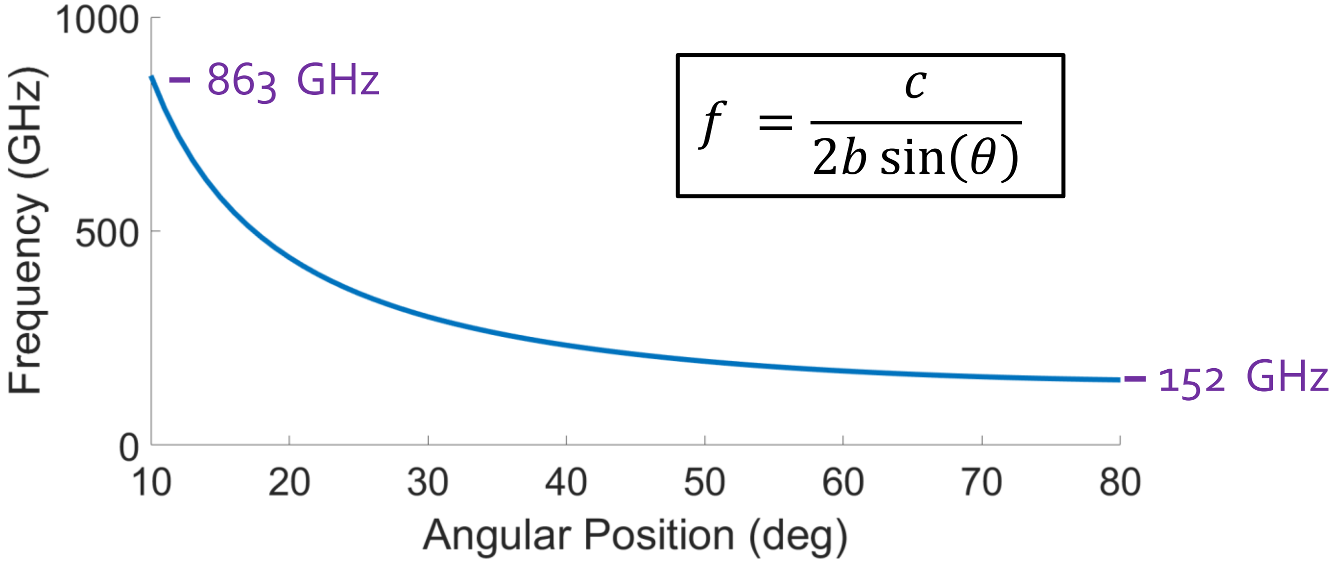
Frequency Agile and Wideband Operation

- Angle-dependent center frequency and bandwidth
- Bandwidth always on a GHz-scale



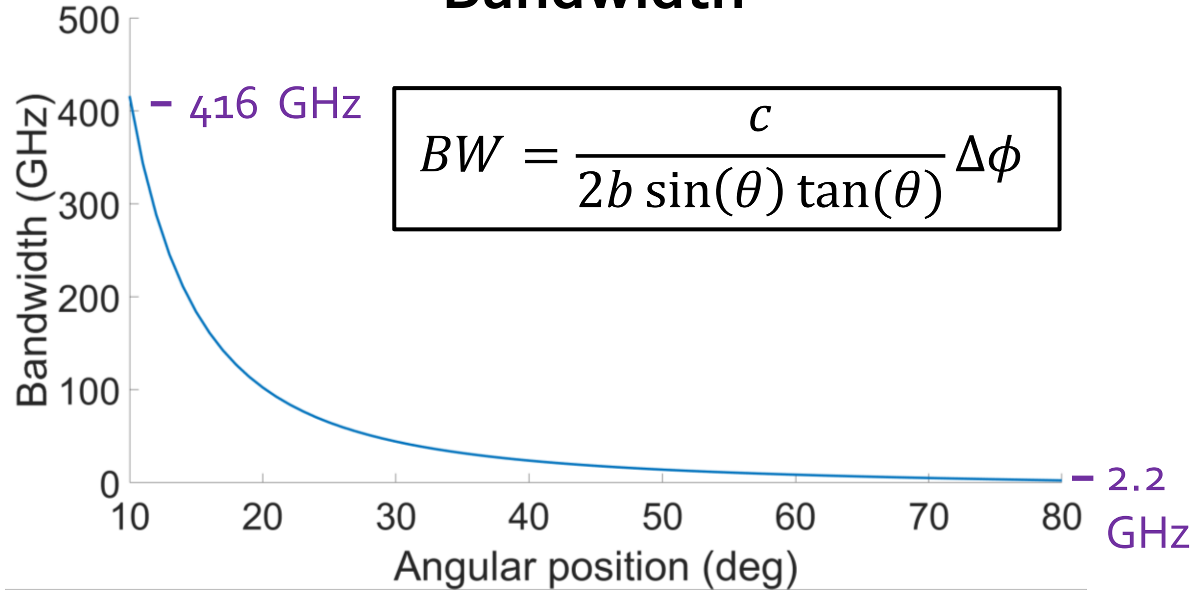
Center Frequency

$$f = \frac{c}{2b\sin(\theta)}$$



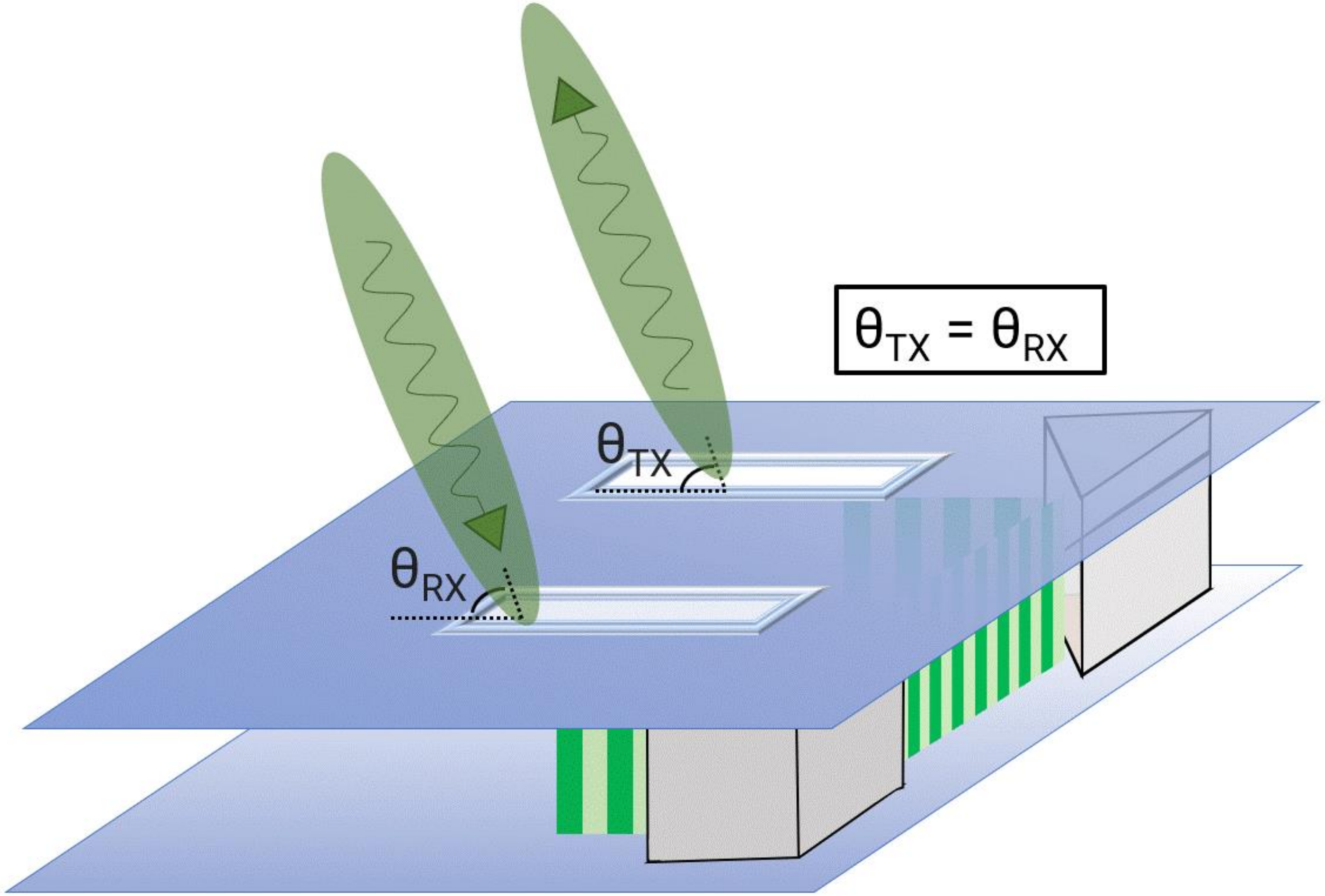
Bandwidth

$$BW = \frac{c}{2b\sin(\theta)\tan(\theta)}\Delta\phi$$



Recap of Key Goals with LWA Architecture

Key features performed at **zero-power cost**!

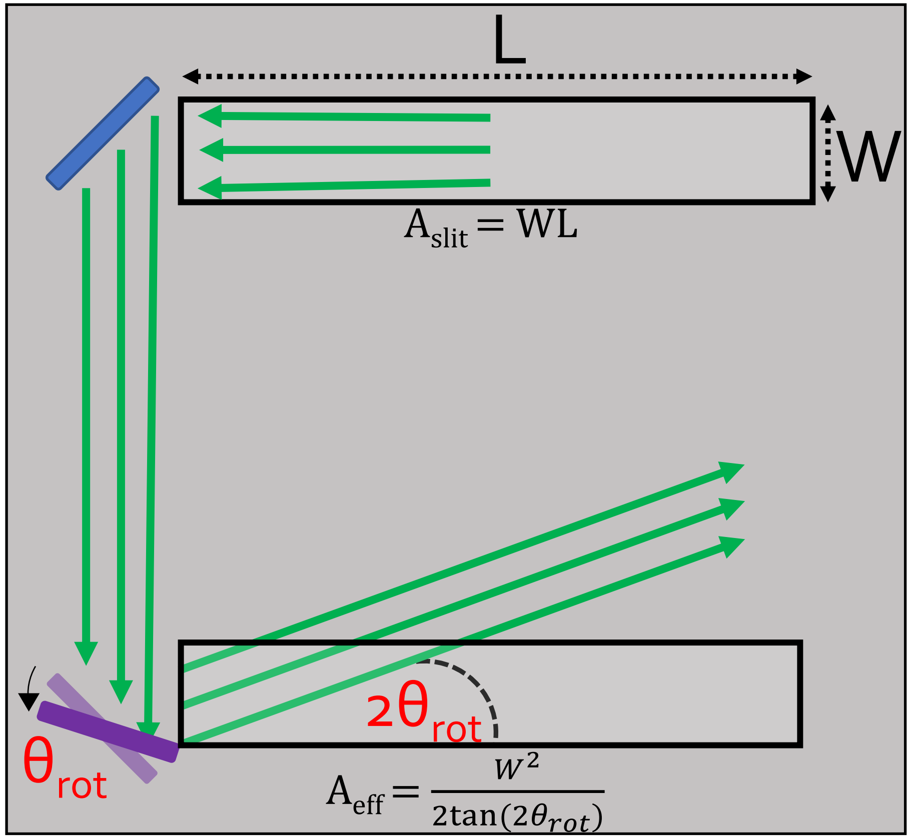


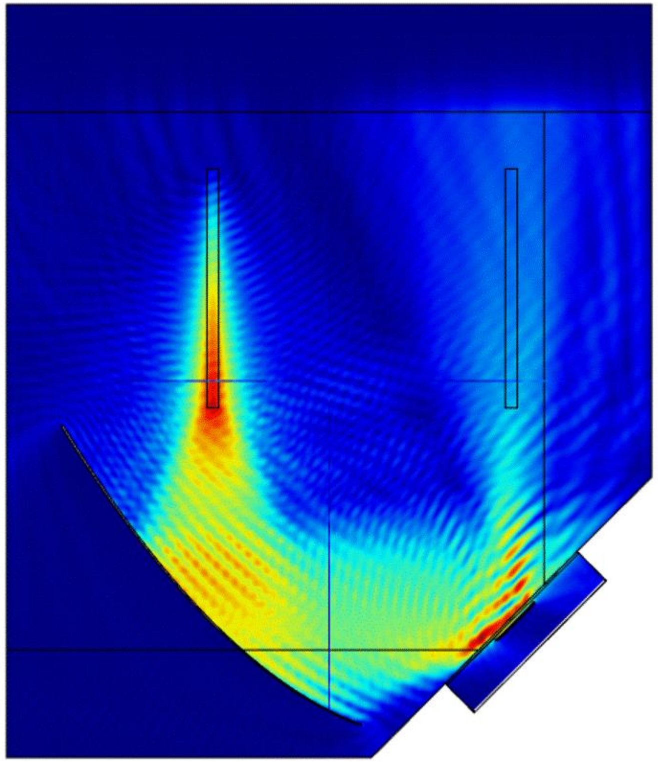
Key Goals

1. Retrodirective
2. Frequency-agile
3. Wideband
4. Low-power

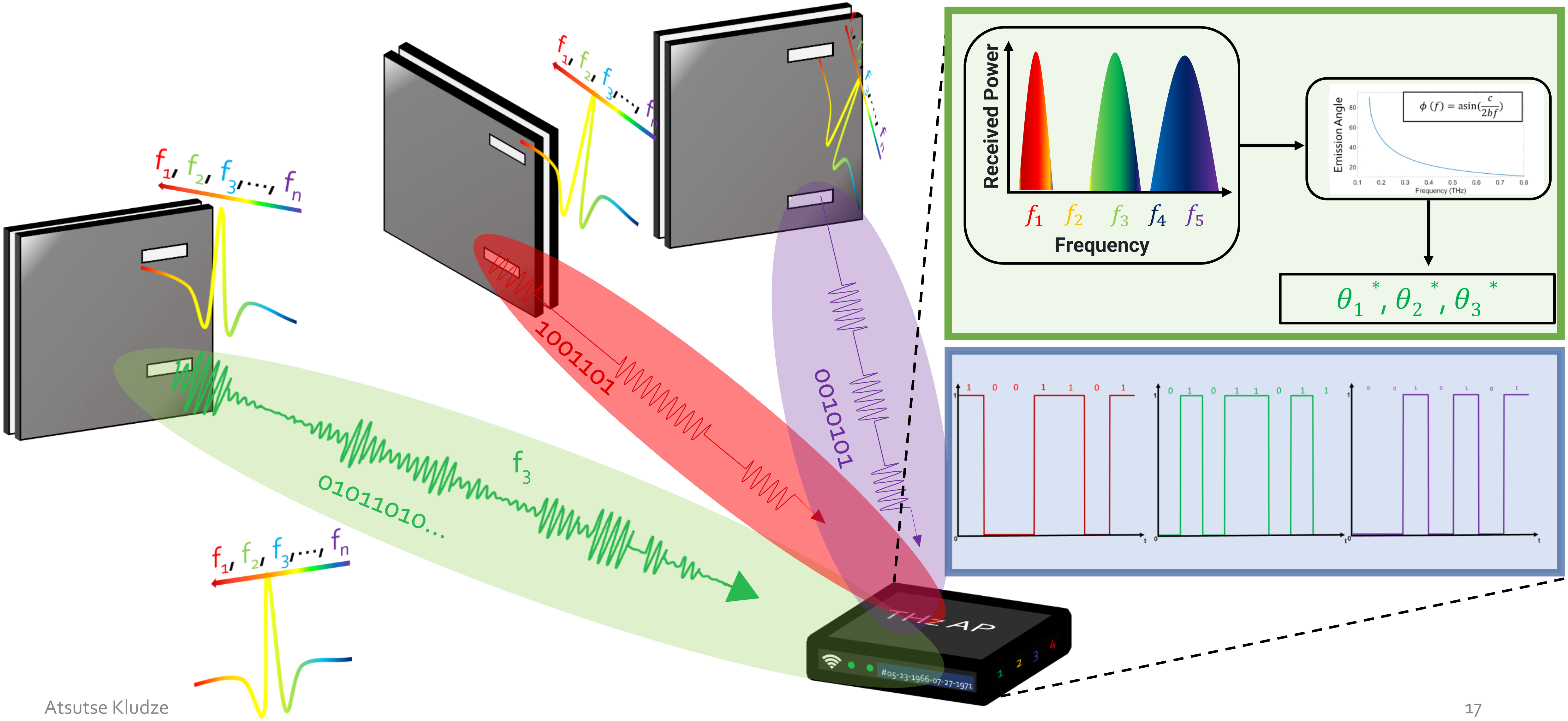
Aperture-Based Data Modulation for AM

- Backscattered power ∝ aperture size
- Changing guided waves' trajectory ⟶ changing aperture

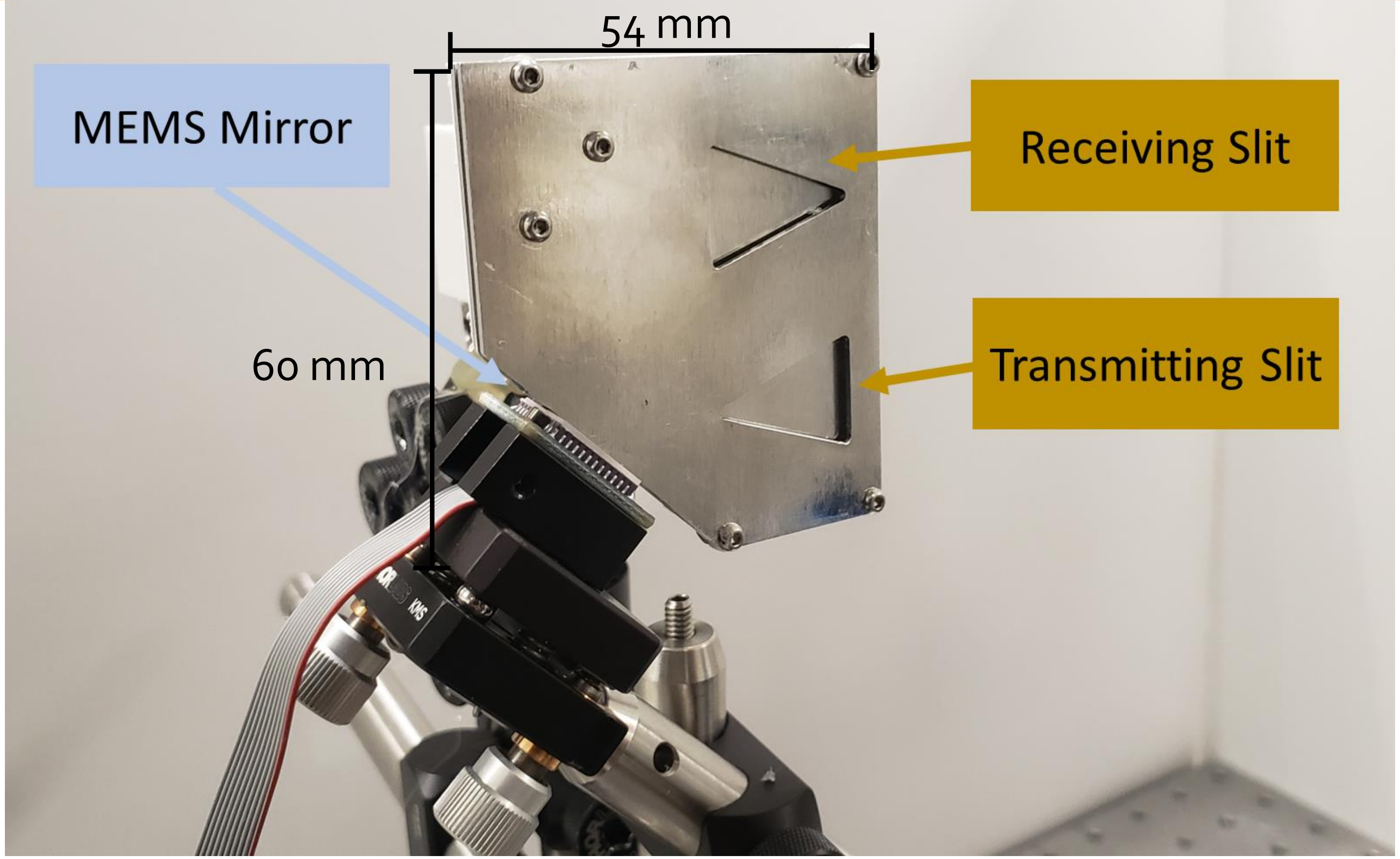


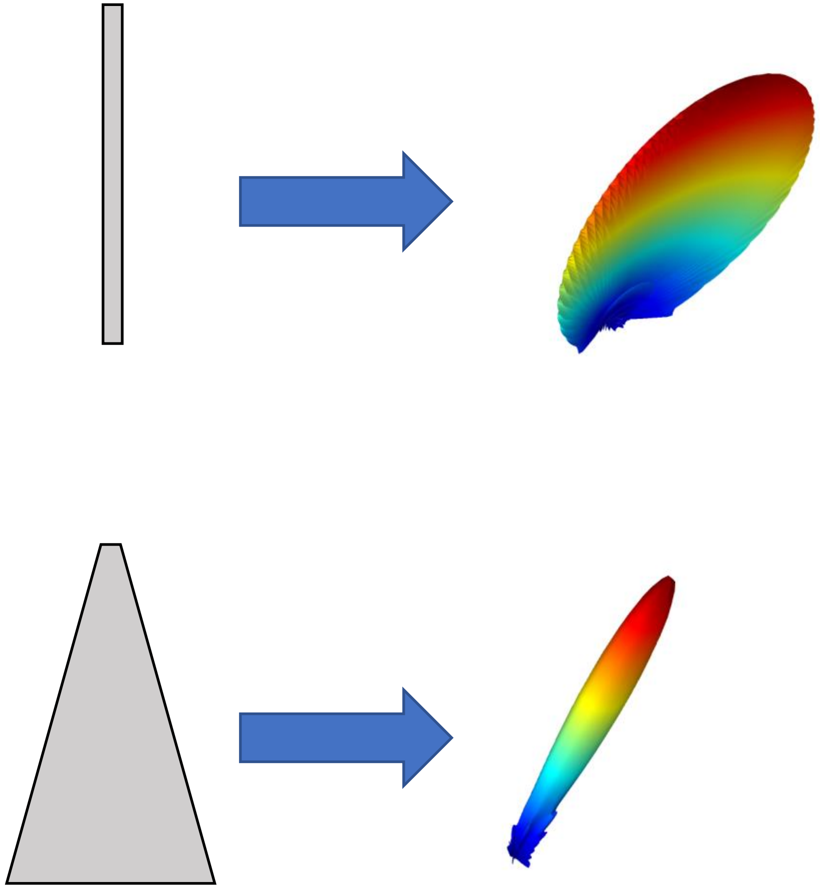


Scaling to Multi-Users



Fabricated LeakyScatter

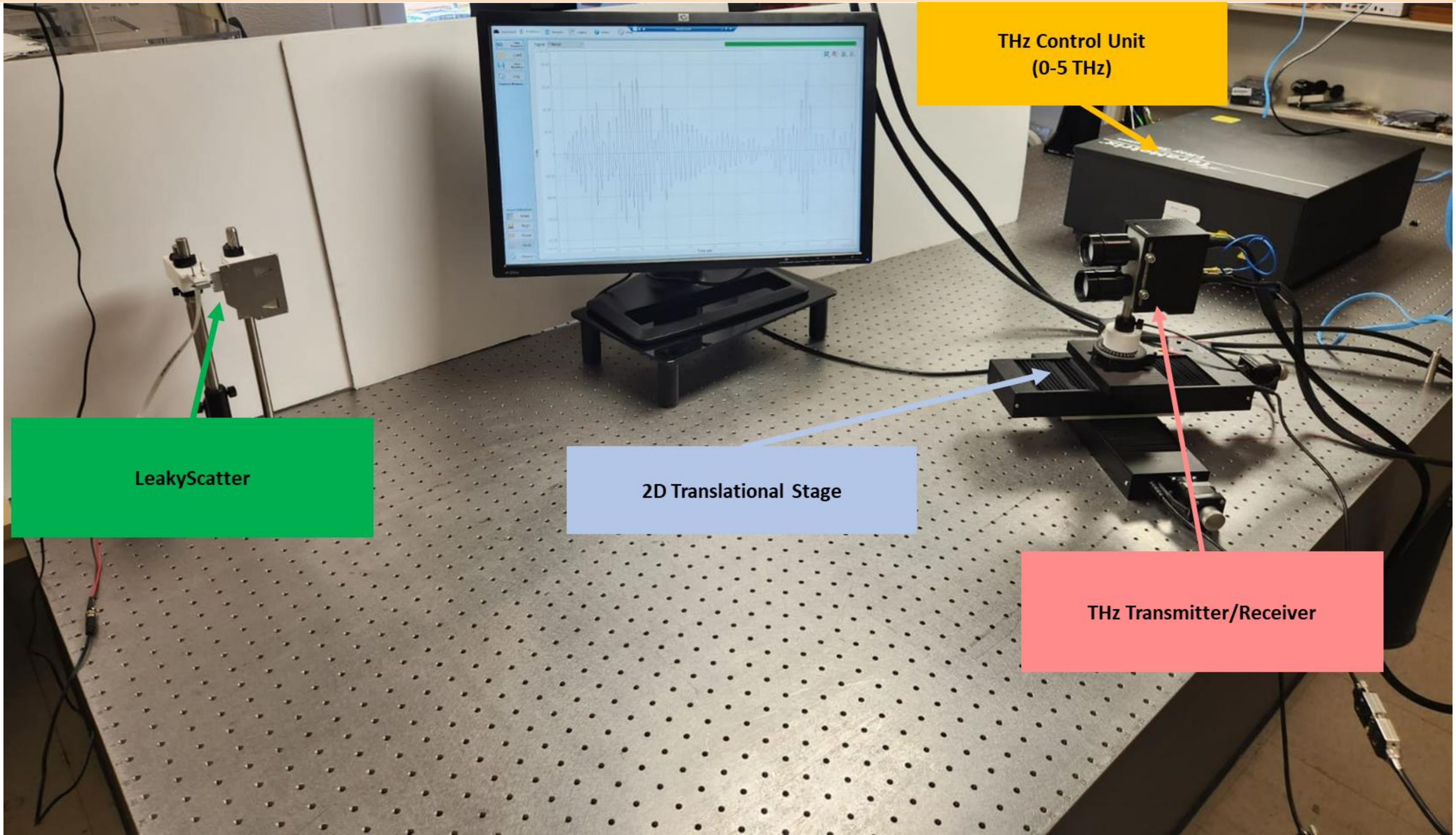




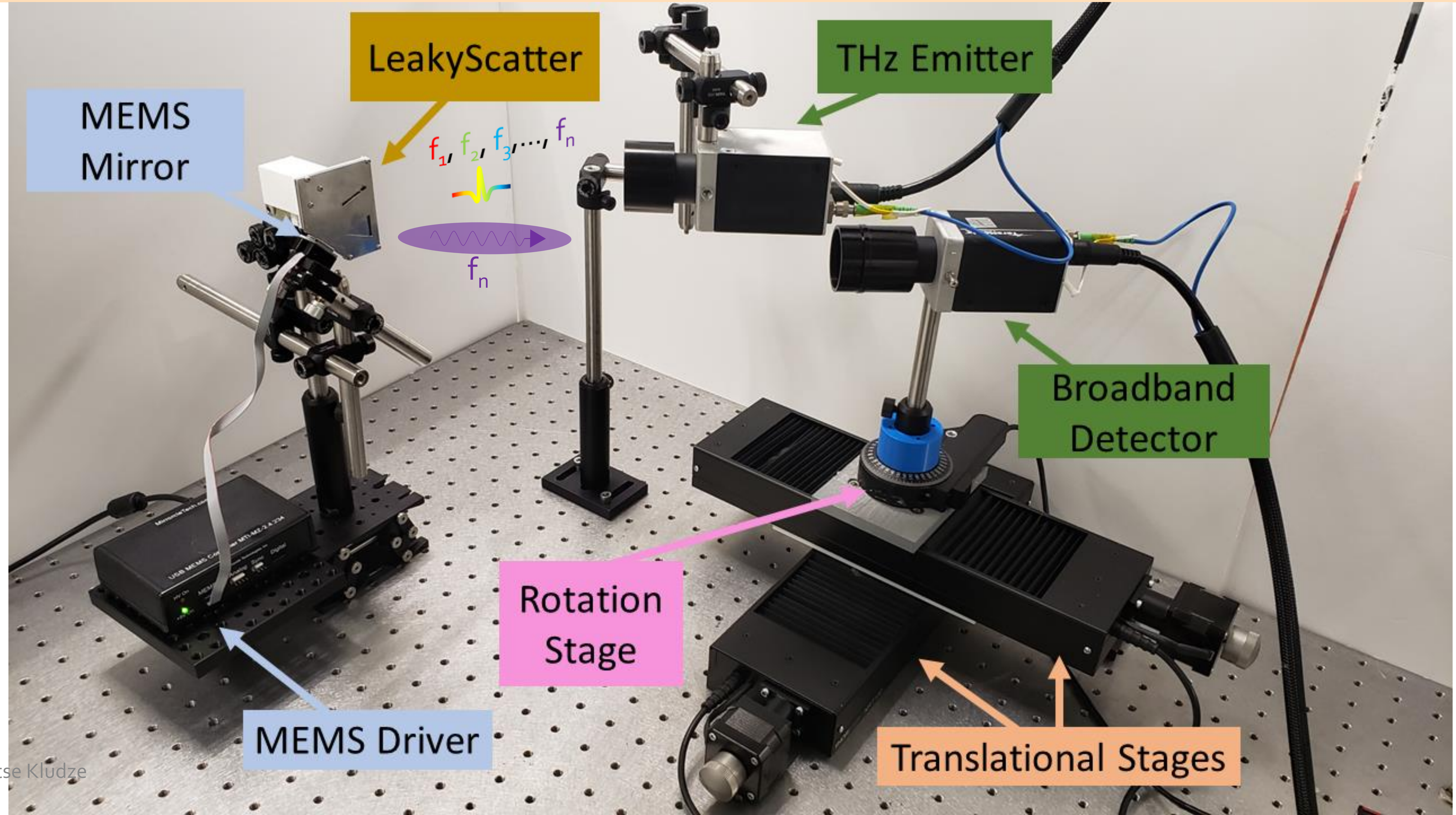
- Trapezoidal shape slits used to increase coupling efficiency

4. GUERBOUKHA, H., SHRESTHA, R., NERONHA, J., RYAN, O., HORNBUCKLE, M., FANG, Z., AND MITTLEMAN, D. M. Efficient Leaky-Wave Antenna for Terahertz Wireless Communications. In Conference on Lasers and Electro-Optics (2021), Optical Society of America.

Experimental Platform

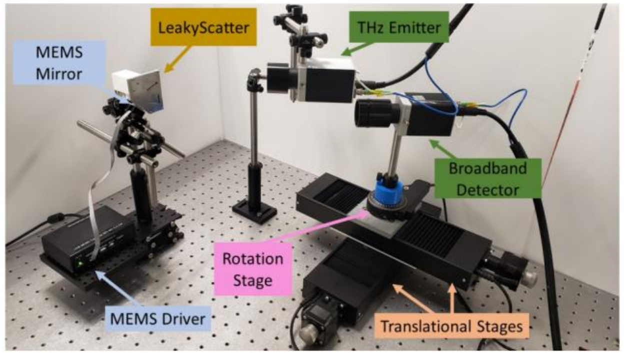


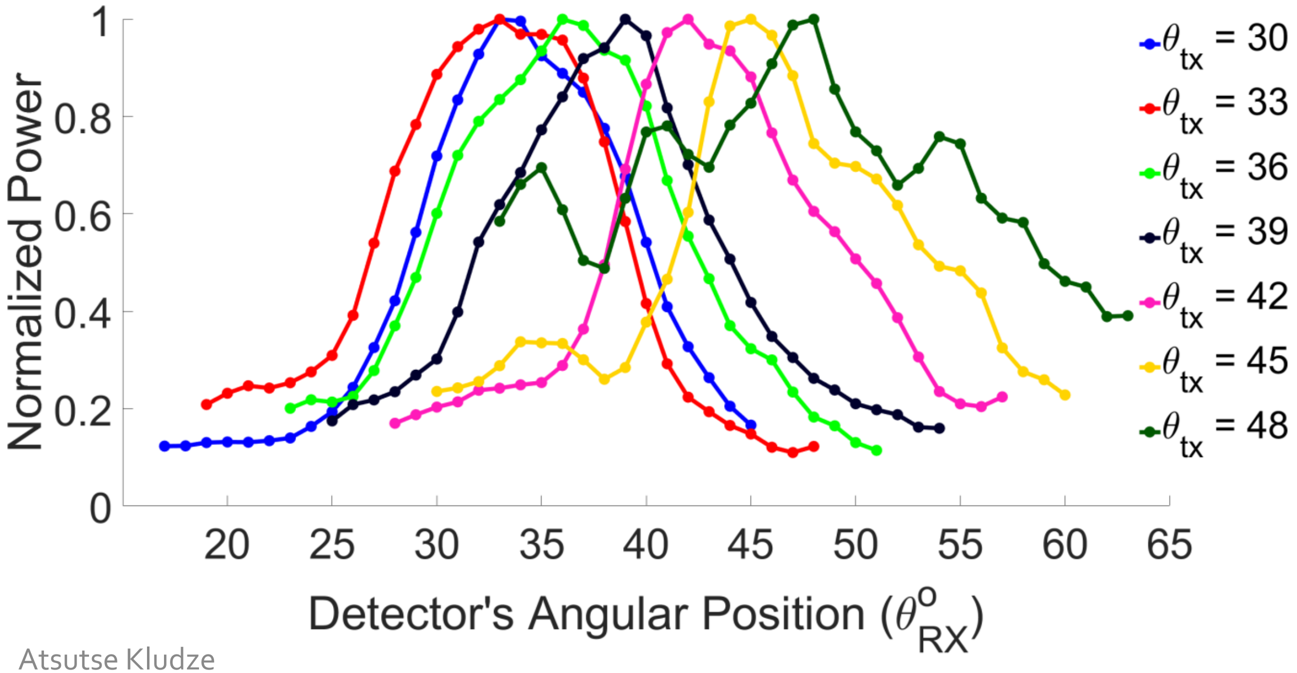
Experimental Platform



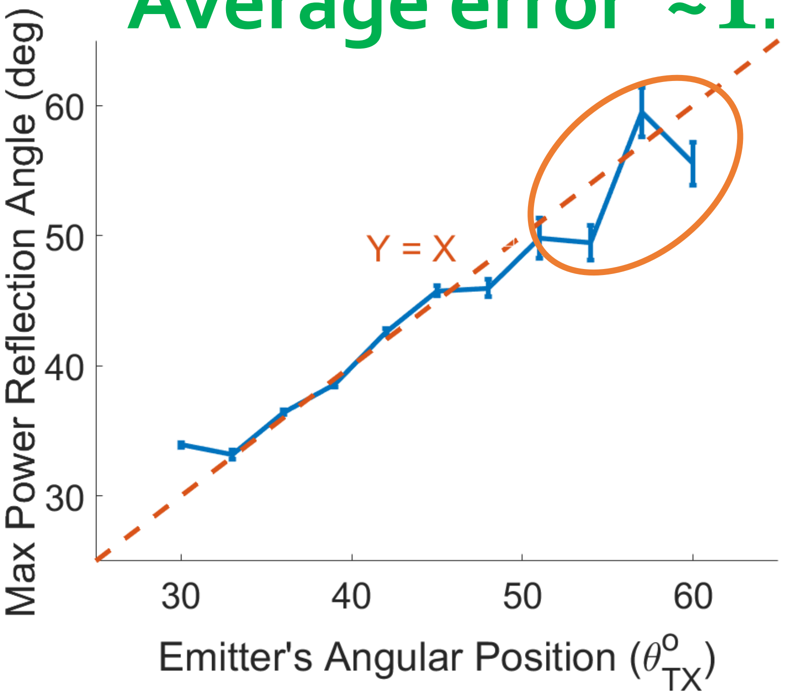
Highly Directional Retrodirective Links

- We observe an increase in errors and fluctuations at higher impinging angles



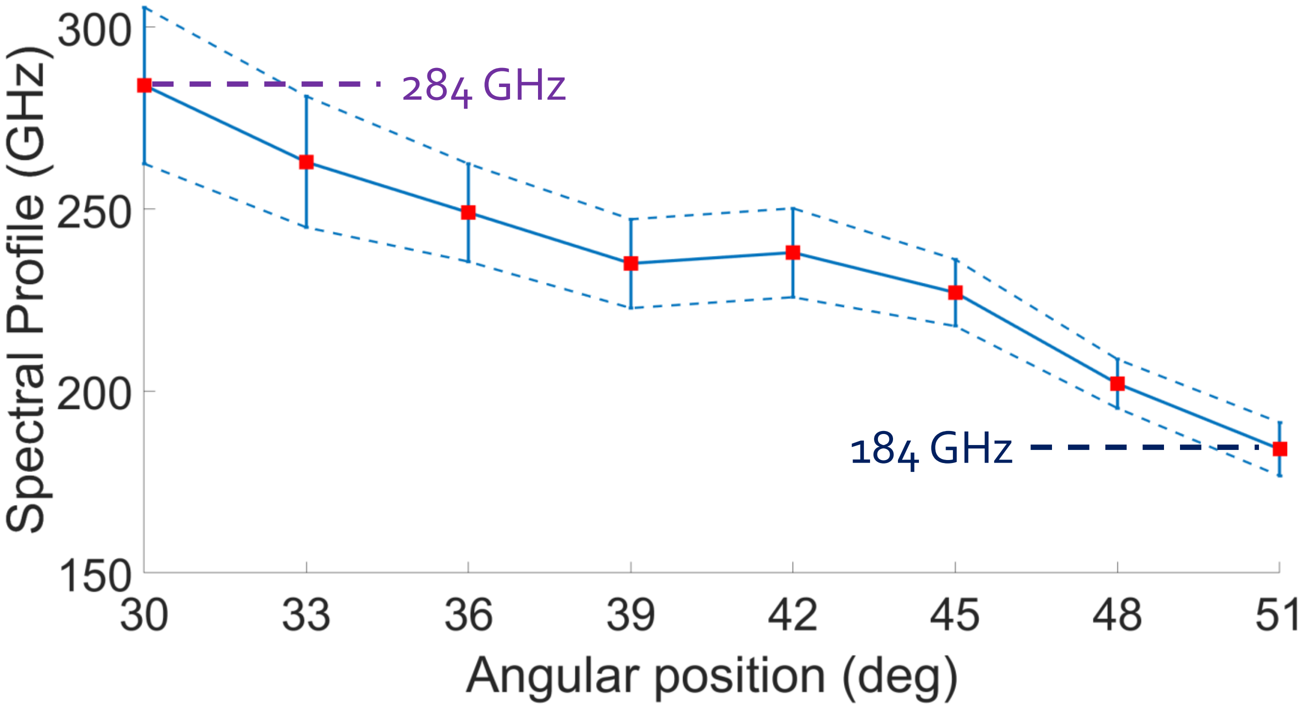


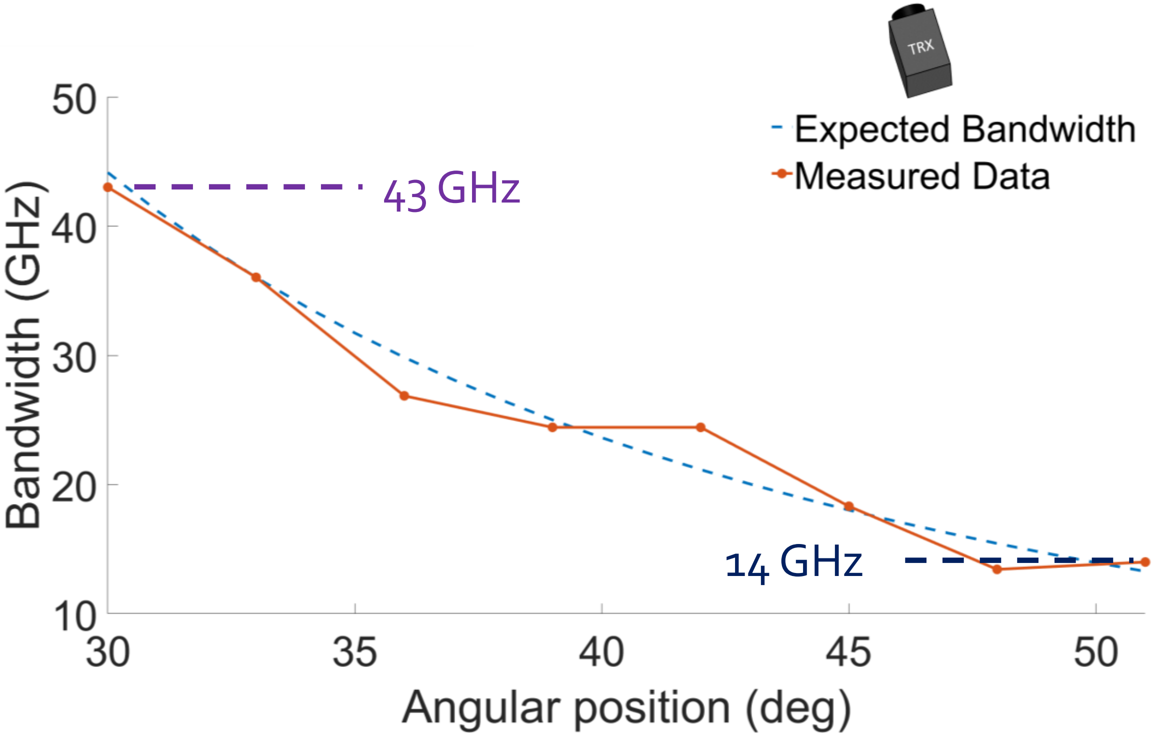
Average error ~1.9°



LeakyScatter is Frequency-Agile

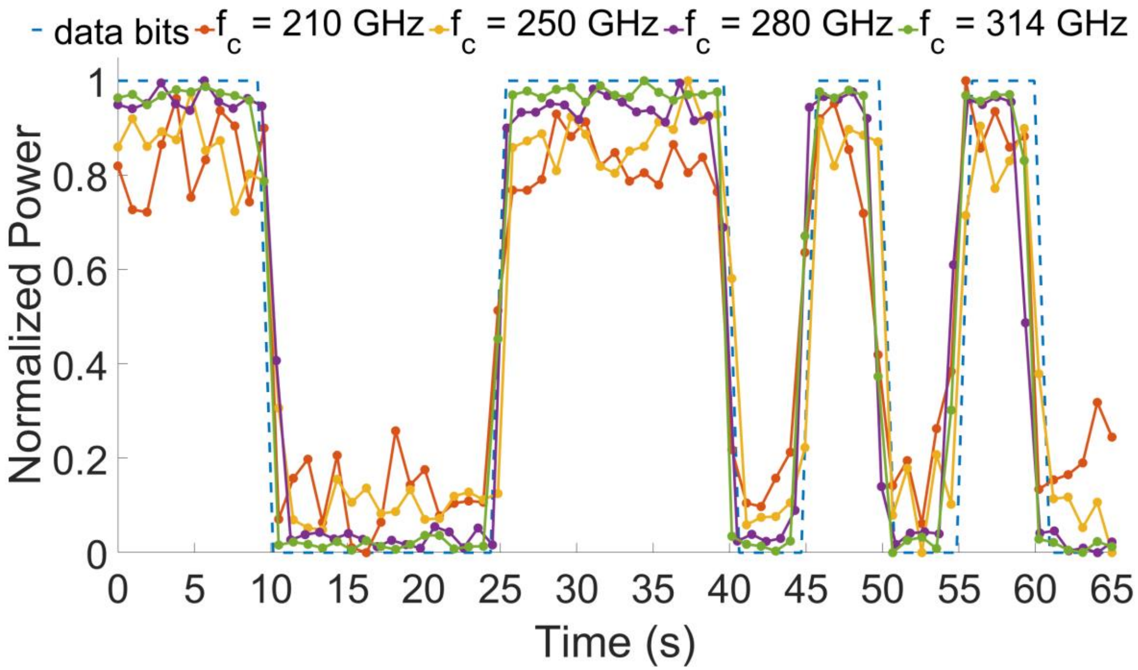
- Frequency-Agile achieve across 100 GHz
- GHz-Scale bandwidth achieved across space

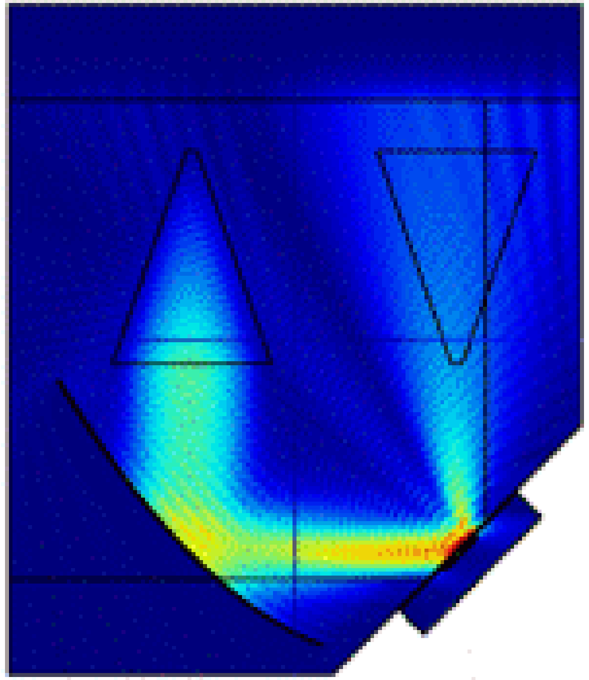




ASK Demonstrated across 100 GHz !

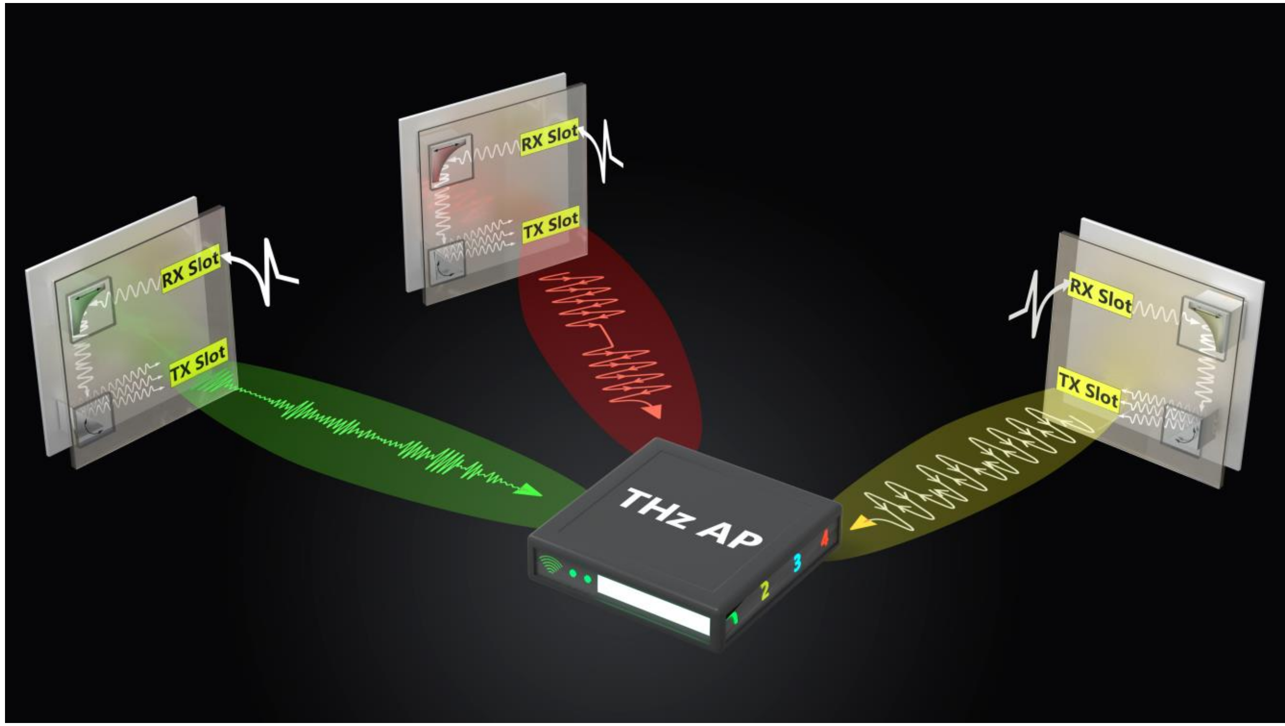
- Bit stream successful demonstrated up to 314GHz
- Data rate limited by mechanical components and data acquisition rate of our broadband detection
- Ongoing work: Achieving higher order schemes (i.e. QAM) and higher data rate (using electronic components)





Summary and Contributions

- A novel architecture for backscattering above 100 GHz
- Scaling backscattering to multiple users by frequency-space division multiple access
- First work that experimentally demonstrate backscattering above 100 GHz



Thank you