Ph.D. Doctoral Meetings 2025

Ph.D. Program in Aerospace Engineering UC3M

Ultra-broadband Wireless Communications Systems Development

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Guillermo Carpintero (UC3M)

Aerospace

uc3m PHD

LEAP WAVE

Comunidad de Madrid

Outline

- LeapWave Technologies
- Motivation
- Ultra-broadband transmitter
- Communication experiments
- Conclusion & future work

Spin-off from Universidad Carlos III de Madrid

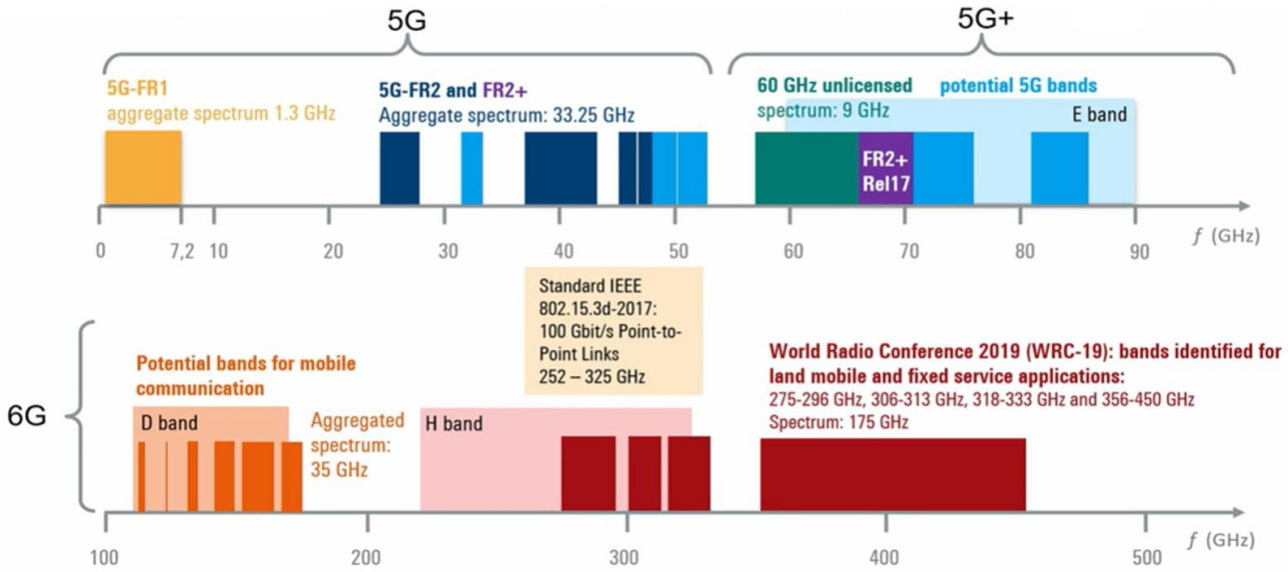
Deep-tech company with vision to bring a paradigm shift in high-speed interconnects based on dielectric waveguides.

New technology for broadband RF interconnects operating at the higher bands (mmW and THz) for IC assembly, Packaging and Test and Measurement (probing)

Applications in Wireless communications, Spectroscopy Sensing, High-speed data links, Non-destructive testing

Motivation – Why do we care about high frequencies?

New spectrum for 6G networks



T. Eichler, et al. White paper, Rohde & Schwarz.

- Higher frequencies (100 – 500 GHz)
- Broader bandwidth (over 100 GHz)

<u>High-capacity data transmission</u>

Problems – Interconnections

Bottleneck:

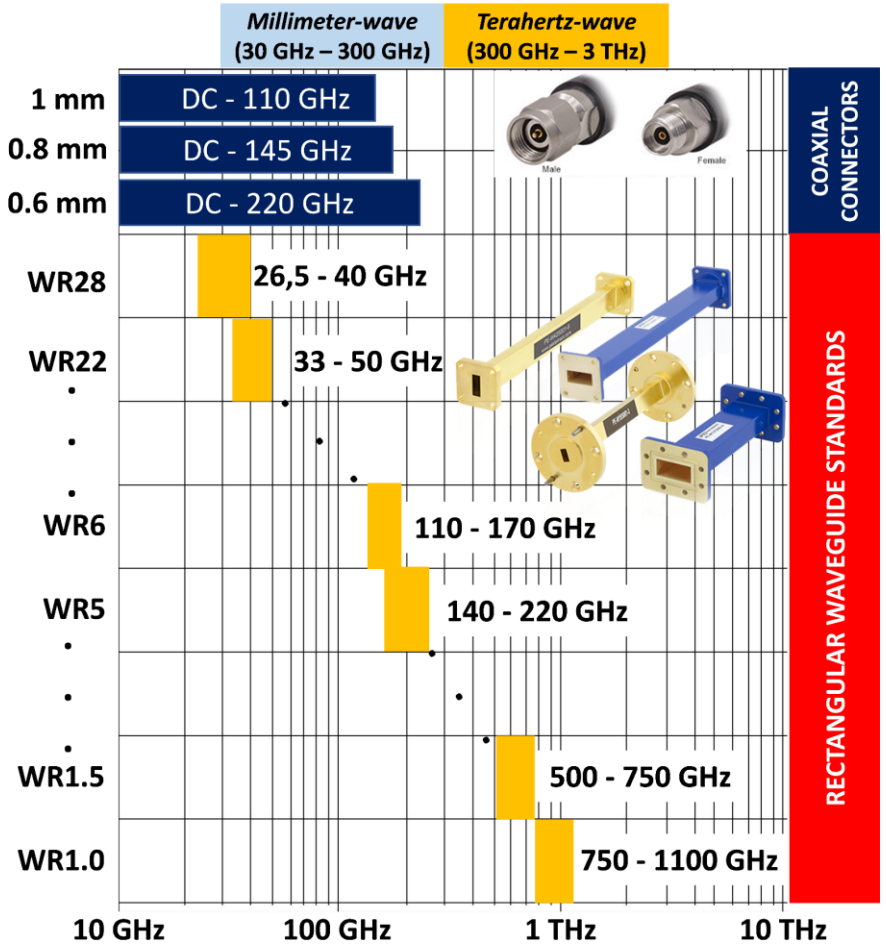
Interconnections

Coaxial cables/connectors

- ☺ Wide bandwidth
- ☹ High loss at high frequencies

Rectangular waveguides

- ☺ Low loss (e.g. 0.14 dB/cm @330 GHz)
- ☹ Bulky
- ☹ Narrow bandwidth



Solution – Silicon dielectric waveguides

Dielectric Rod Waveguide (DRW) technology

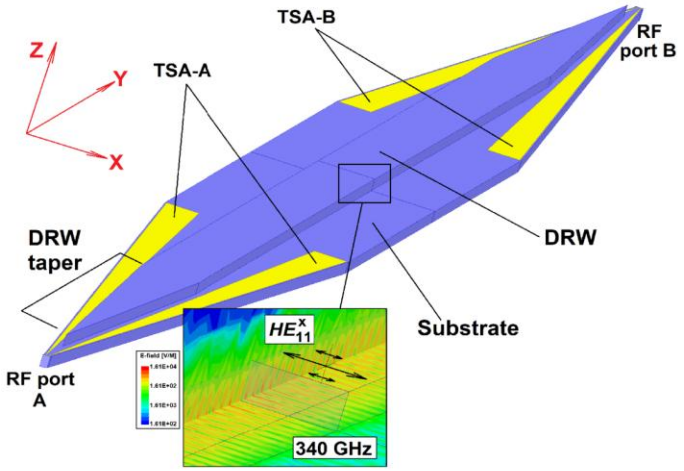
Silicon wafer

Etching process

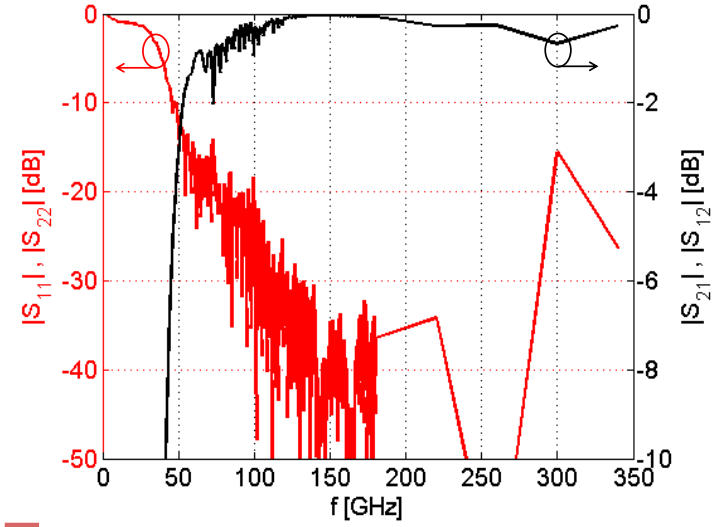
- Low loss (0.06 dB/cm @ 300 GHz)
- Broadband
- Low cost
- Versatile (functional devices)

State-of-the-art technology

Structure

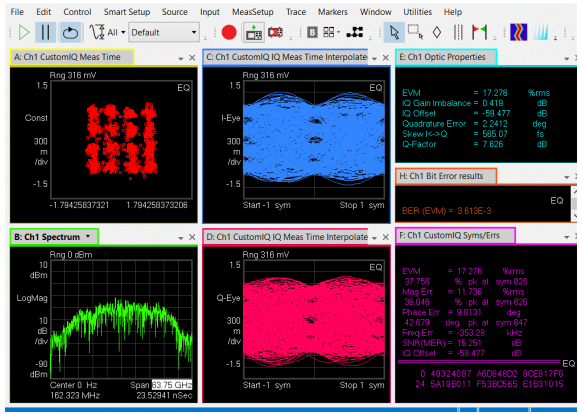


Simulated *S*-parameters

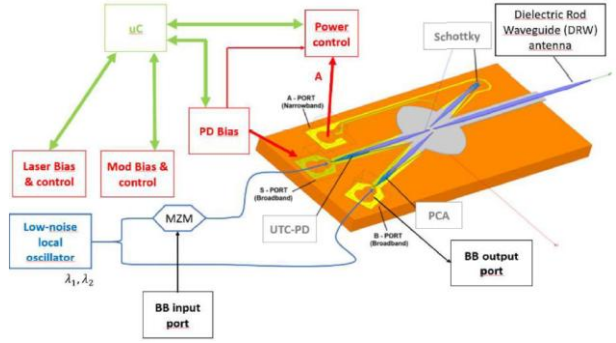


Ultra-broadband systems (50 – 500 GHz)

Milestones of my Ph.D. thesis

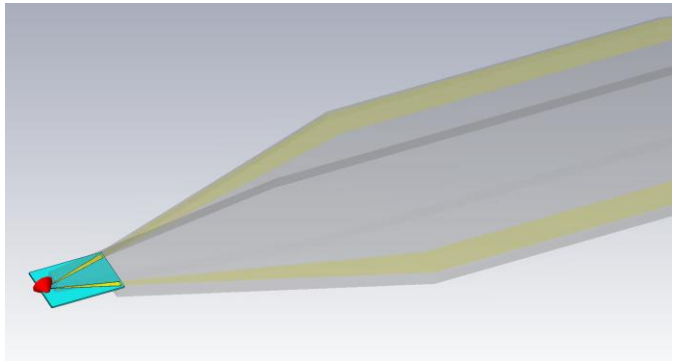


Demonstration

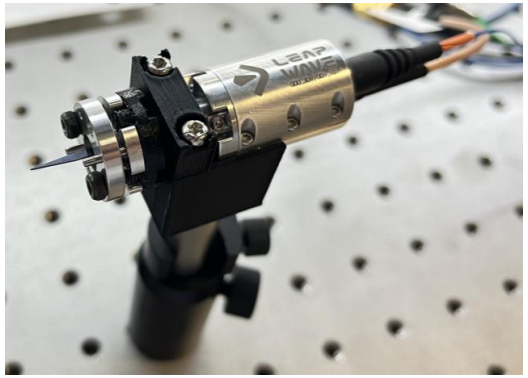


Communication systems

Receivers

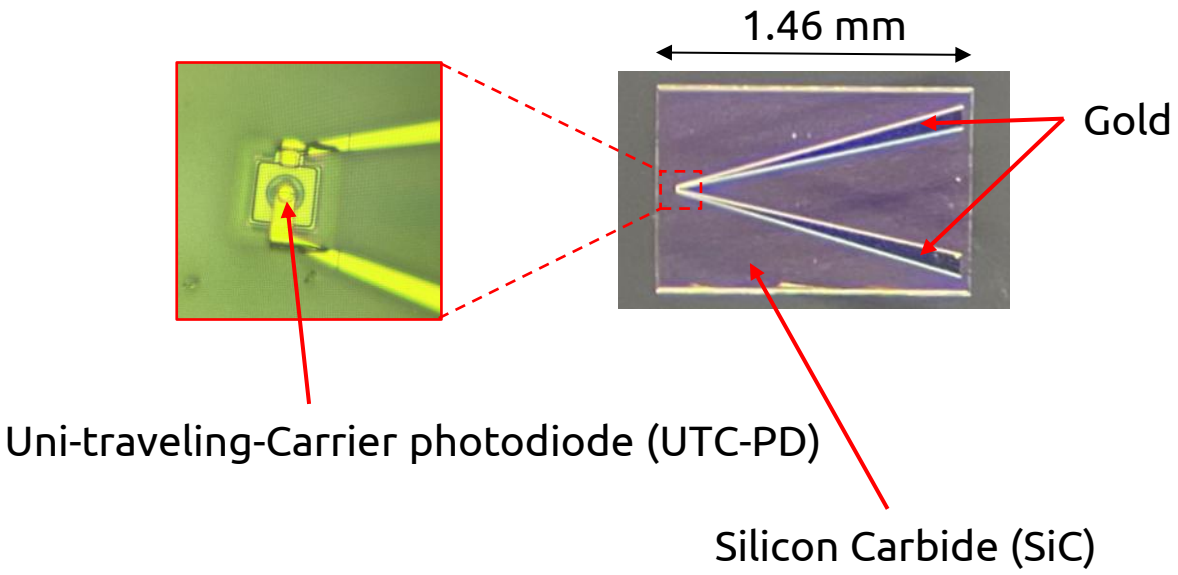


Transmitters



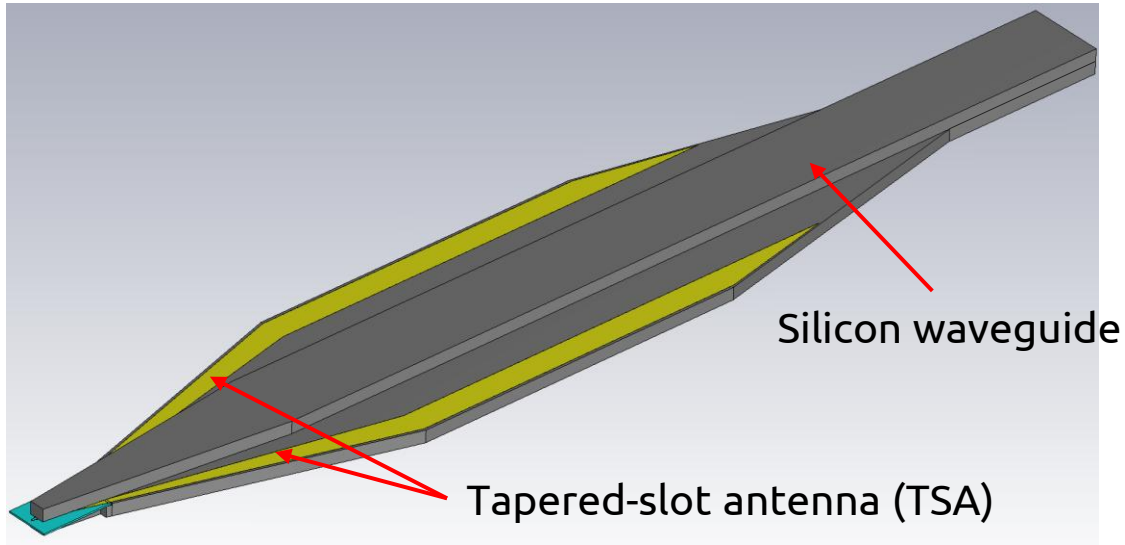
Ultra-broadband transmitter (High-speed photodiode)

High-speed photodiode chip



- UTC-PD
  - ☺ High-frequency operation (> 500 GHz)
- SiC substrate
  - ☺ High thermal conductivity (490 W/m·K)

Integration with a Si waveguide

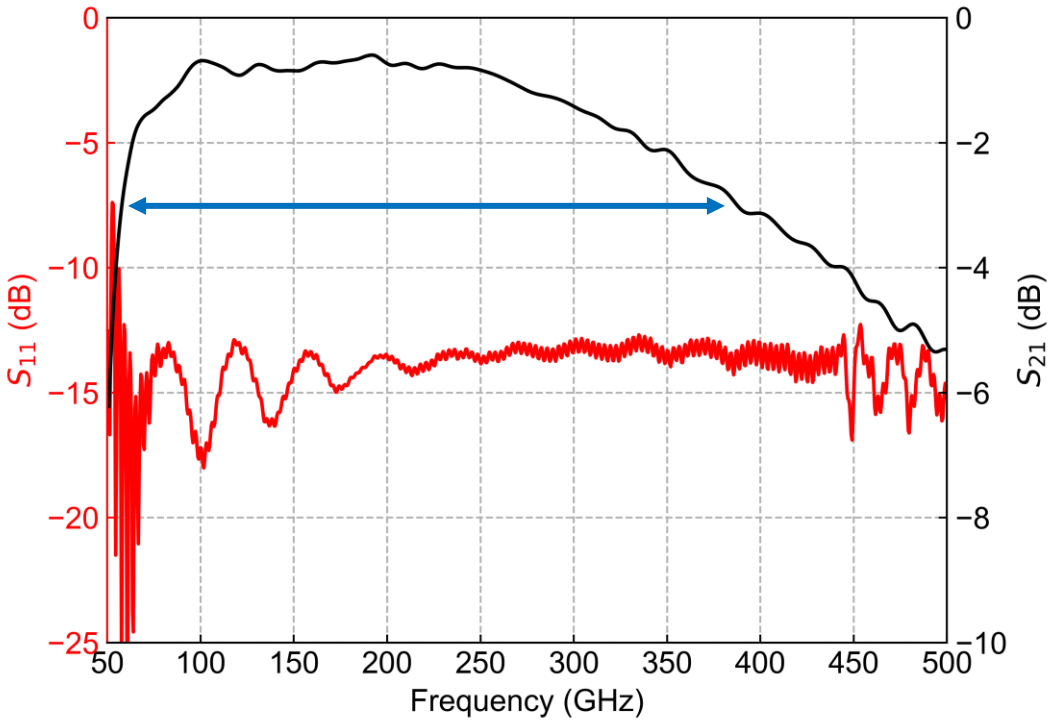


UTC-PD chip

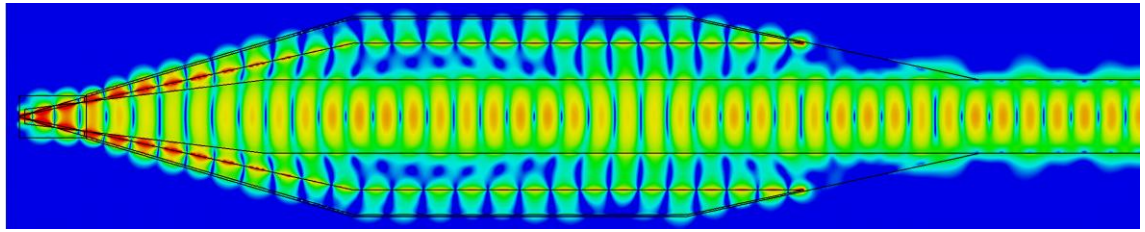
Efficient coupling between **a TSA** and **a Si waveguide**

Ultra-broadband transmitter (High-speed photodiode)

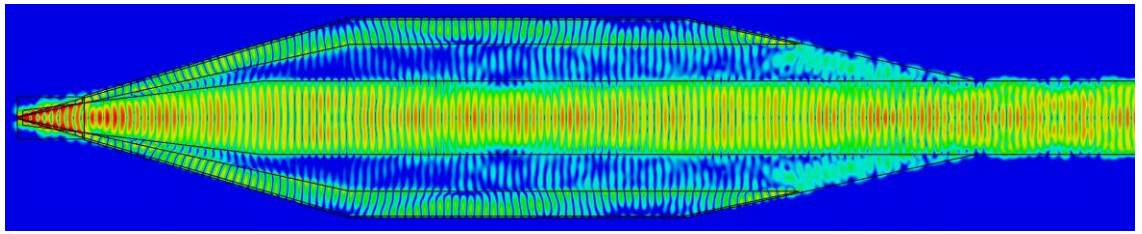
Simulated *S*-parameters



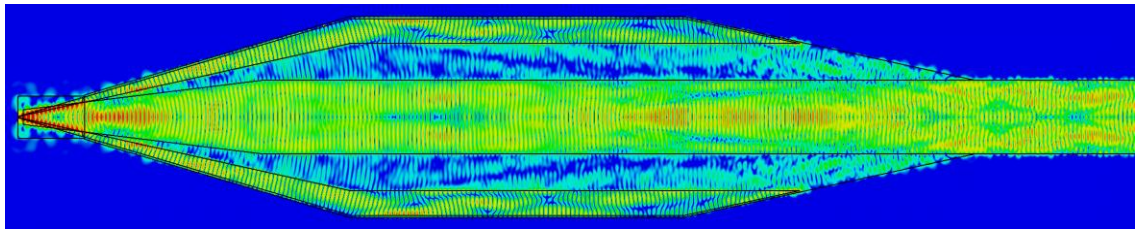
Simulated *E*-field distribution @ 100 GHz

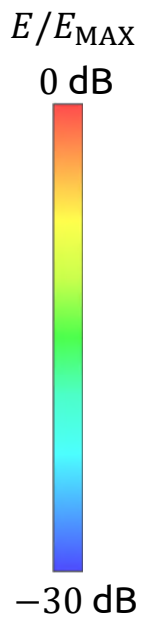


@ 300 GHz



@ 500 GHz

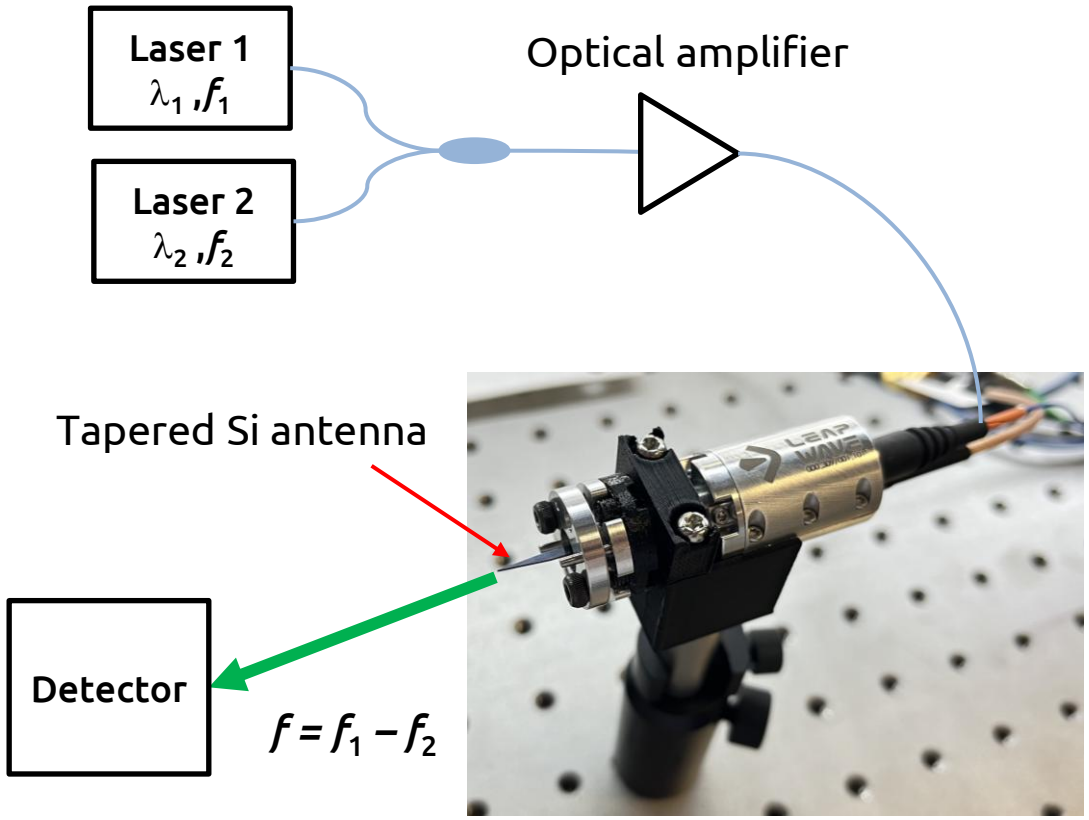




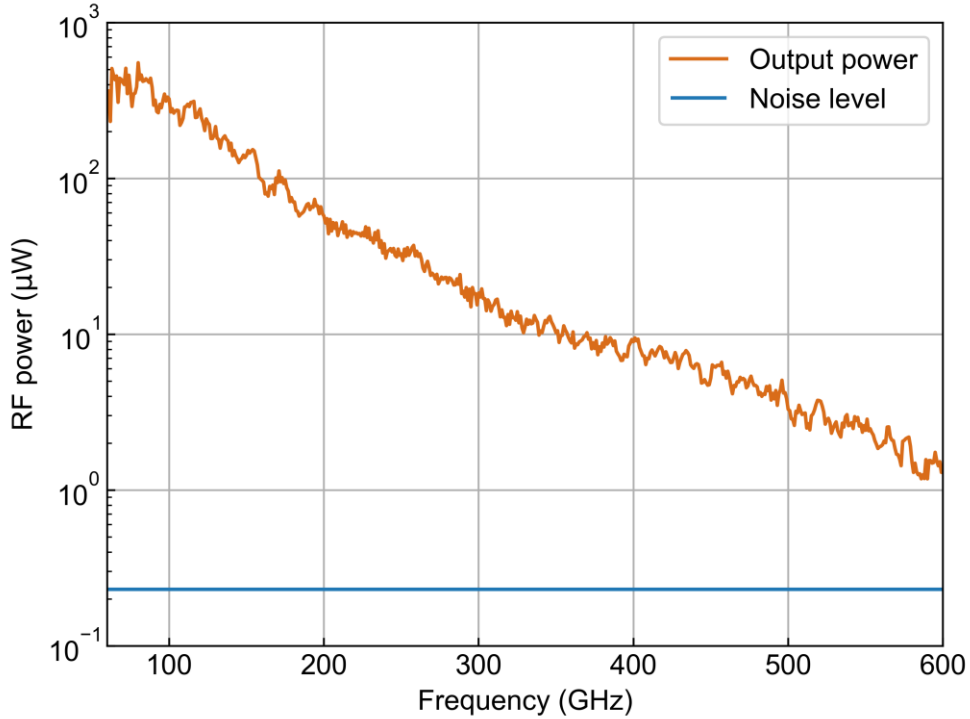
High-frequency interconnection ***beyond 350 GHz***

Ultra-broadband transmitter (High-speed photodiode)

Frequency response measurement



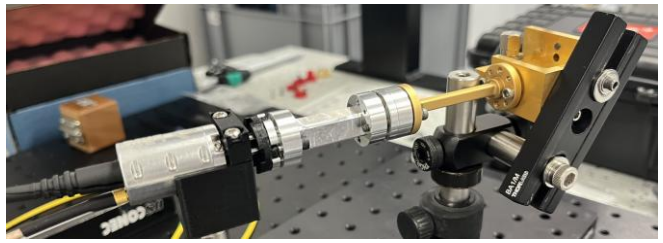
Measured results



Output signals > 500 GHz in one single interface!

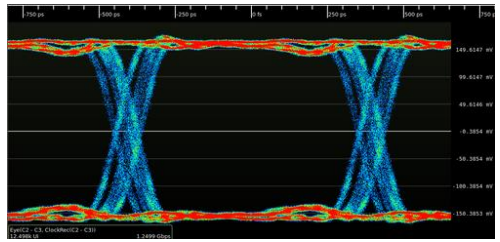
Communication experiments

Experimental Setup

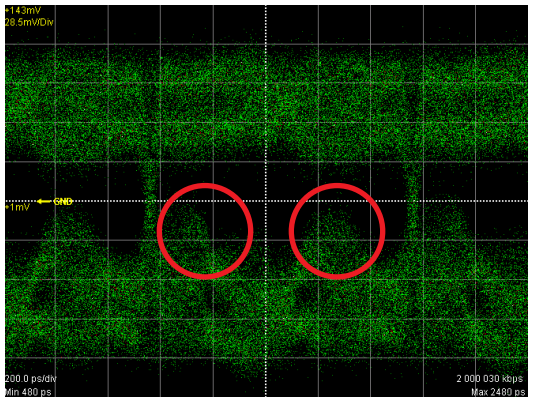


Results

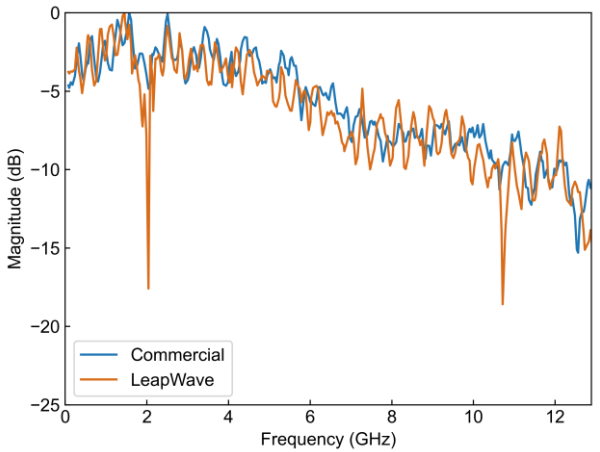
Eye diagram (On-off keying)



Ringing observed @ 1 Gbit/s

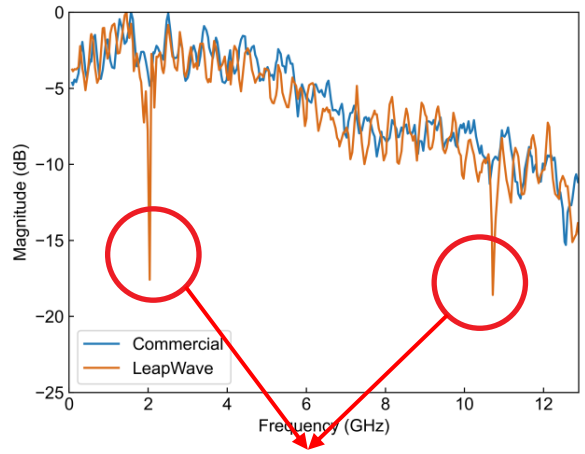


Frequency response of the system

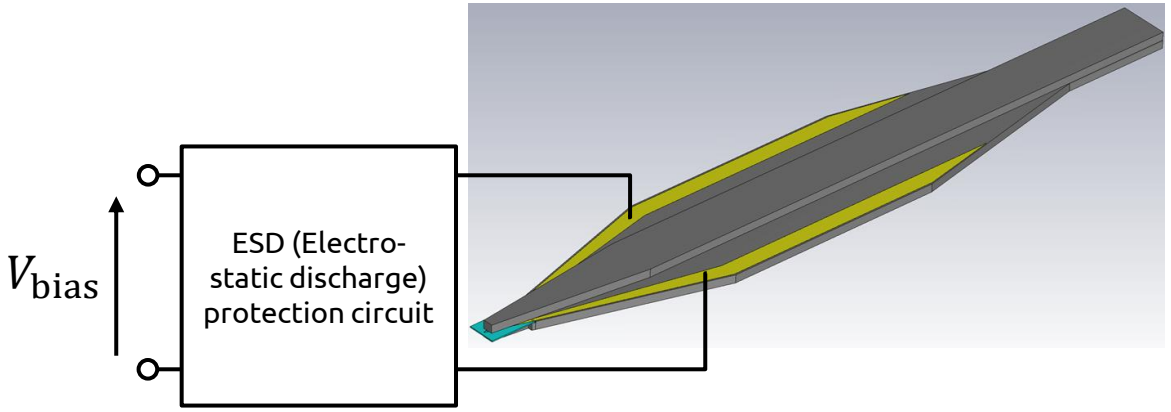


Hypothesis and solutions

Potential



Resonances…?



Solutions

- Simulations at lower frequencies
- Introduce a high inductance (a coil) to isolate the device from the ESD protection circuit
- ► If this doesn't work, the issue can be in the TSA structure.
- Introduce a damping resister to reduce the ringing

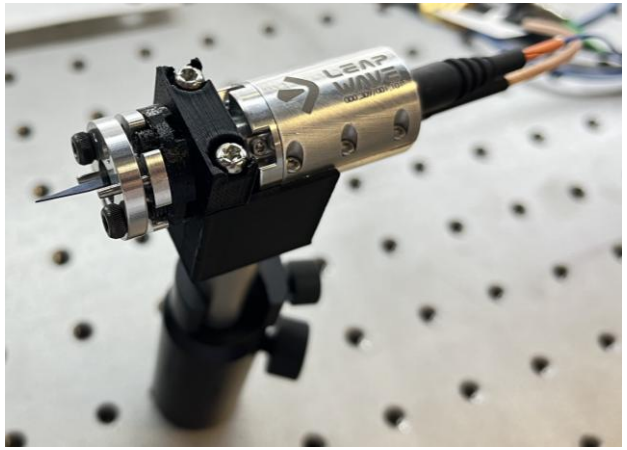
Conclusion & future work

Conclusion

- We developed an ultra-broadband transmitter based on a photodiode, operating at more than 500 GHz.
- In communication experiments, signal distortion was observed.
- The potential cause of the signal distortion is the resonance in the internal structure of the device.

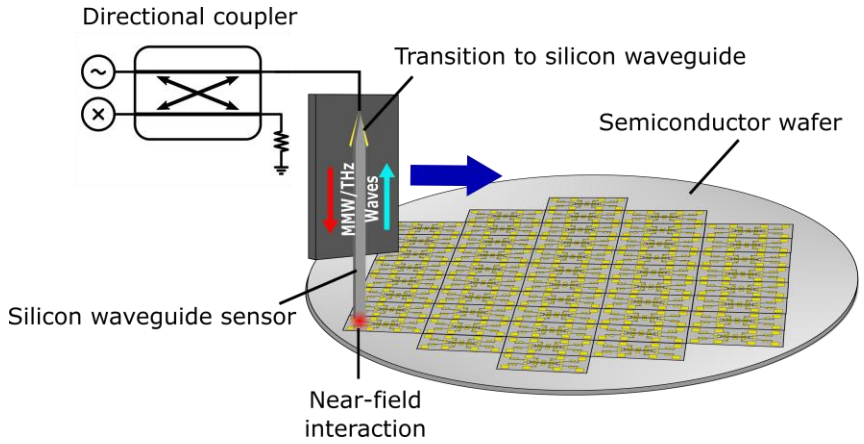
Future work

- Investigate and rework the structure to suppress the resonance
- Complex modulation in communication experiments
- Develop a broadband receiver

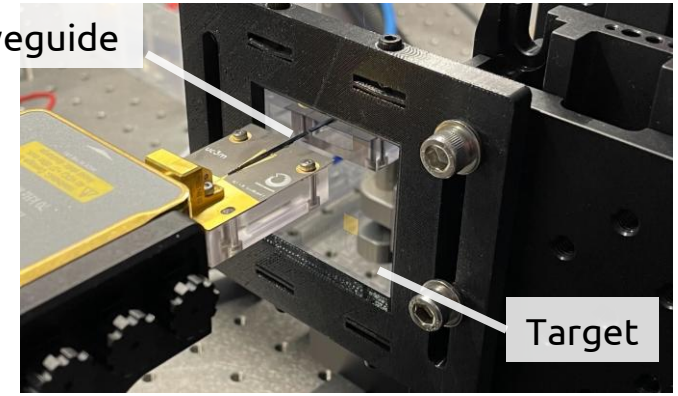


Other applications: Semiconductor near-field imaging

Compact imaging module in deployment

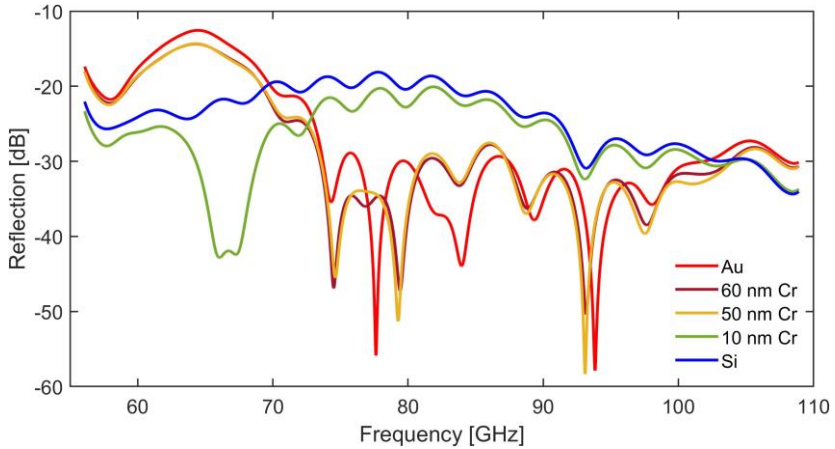


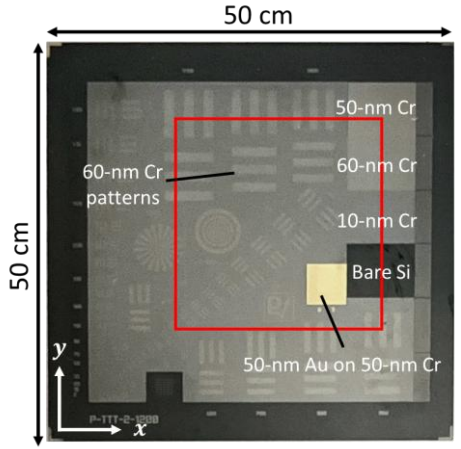
Truncated Si waveguide

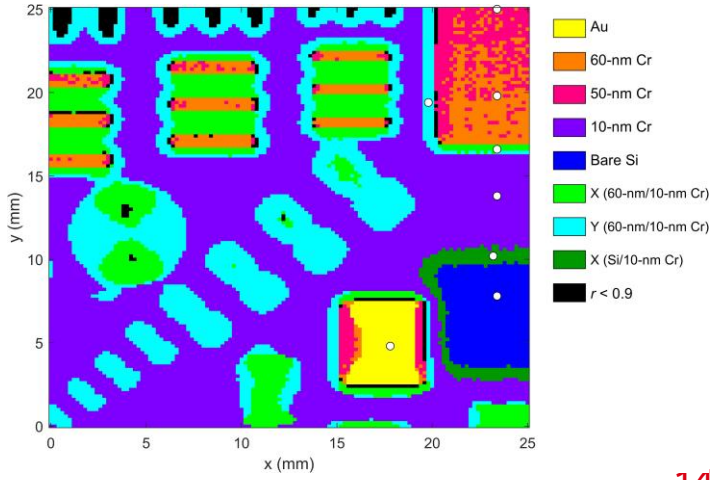


Y. Kawamoto, et al. *IEEE Sensors Journal* (2025).

Frequency response of the reflection from different materials







Research activities

Activities

- Photonics Packaging Course at Tyndall National Institute, March 25th – 27th, 2025.

Conference papers

- **Y. Kawamoto**, W. Gao, T. Ishibashi, H. Ito, and T. Nagatsuma, "200-Gbit/s sub-terahertz communications with I/Q receiver based on Fermi-level managed barrier diodes," 2024 49th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), pp. 1–2, Sep. 2024, doi: 10.1109/irmmw-thz60956.2024.10697835.

Journal papers

- **Y. Kawamoto**, D. C Gallego, A. Rivera-Lavado, T. Nagatsuma, M. Nagel, D. Headland, G. Carpintero, "Near-field Semiconductor Imaging and Classification Enabled by Signal Cancellation using Truncated Mm-wave Silicon Waveguide," *IEEE Sensors Journal*, 2025, doi: 10.1109/jsen.2025.3562280.

Others

- Contribution to the deployment of LeapWave's intelectual property (IP) strategy.

Surfing the waves on silicon

Thank you for your attention!
Any questions?

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