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Presentation to DCMS/SPF workshop

Sub-THz Antennas and Devices for 6G

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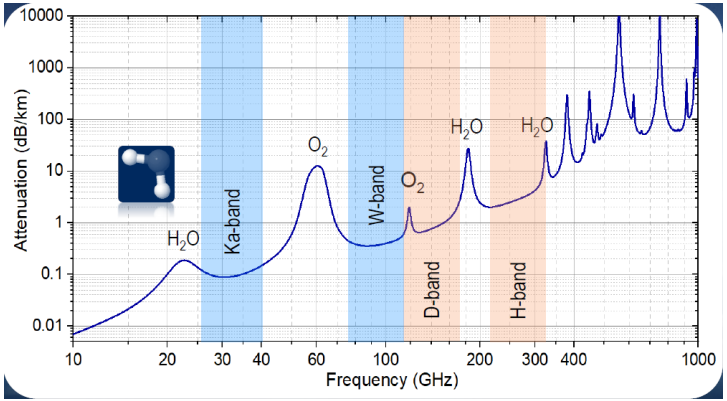
Contributions: Prof. Y. Wang, Prof. S. Hanham, Prof. M. Navarro-Cia

Communications and Sensing Research Group, School of Engineering

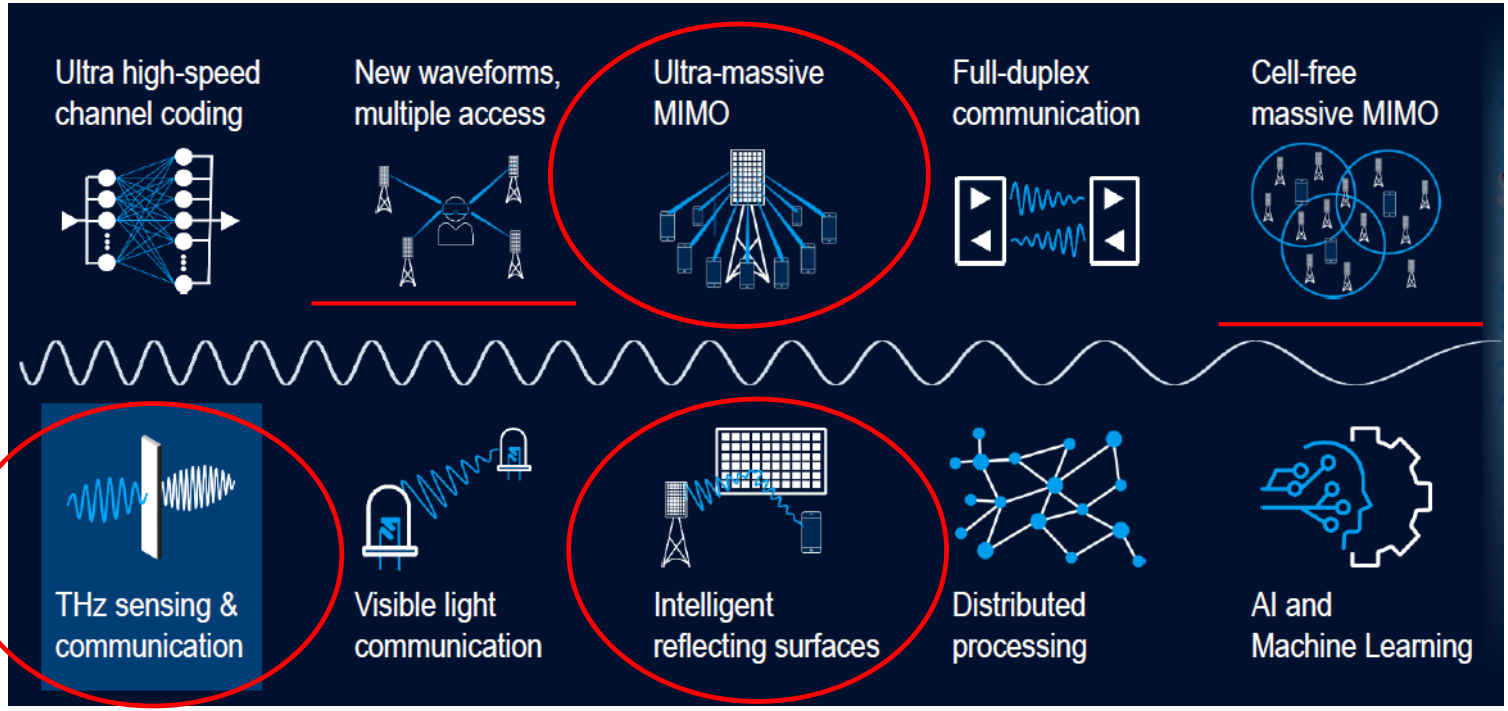
26th May 2021

- 6G promises extreme evolution of capabilities, e.g. air interface speeds >100Gbps (5G: tens of Gbps at best)
- Backhaul currently mainly optical, but wireless will also be required to accommodate the huge capacity demands, especially if small cell trend continues
- New user cases are still emerging: E-health, smart cities, cyber-physical worlds/interaction, co-operative mobile robots etc.
- Clearly, we need systems and hardware at new frequency bands with low atmospheric attenuation at mm-wave/sub-THz: D-band, H band (300GHz) and even higher (400-500GHz, and 800GHz)



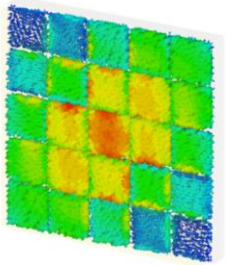
What is 6G?

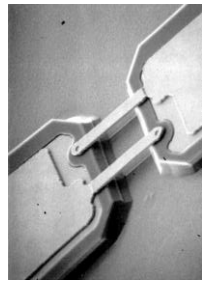
- Research challenges for the next generations beyond 5G

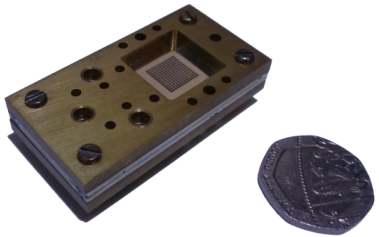


*Taken from Rohde & Schwarz webinar presentation, "**THz COMMUNICATION – A KEY ENABLER FOR BEYOND 5G?**"*

- Over 30 years of expertise in antennas, metamaterials, propagation and microwave devices
- >5M current funding from EPSRC, Industry, DSTL etc.
- Extreme massive MIMO beam-steered antennas up to 1 THz
- Sub-THz tunable metasurfaces and Intelligent reflective Surfaces for 6G
- New tuning technologies up to 300GHz
- THz sensing hardware and algorithms: accurate user location (angle of arrival algorithms), imaging techniques.
- Micromachined sub-THz circuits and transceivers
- Integrated mm-wave antennas







Communications and Sensing Research group

Design

- 14.3 TFLOP GPU computational power in-house
- EM commercial software packages - parallelised
- In-House Software

Fabrication

- Standard PCB
- Class 10,000 cleanroom
- Microfabrication down to 5 µm
- Nanoscribe's Photonic Professional GT+

Measurement

- New antenna characterisation chamber
- 1.1 THz, 4-port VNA
- THz TDS (0.2 - 3 THz)

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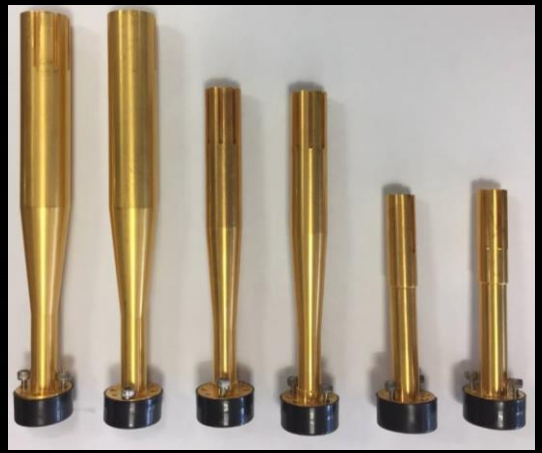
Facilities in CS group

Cleanroom Facility

- New 10,000 class clean room (>£1.5M)
- Microfabrication of THz Devices
- Spin coating of polymers
- Evaporative and Sputter Coating
- Photolithography
- IBM
- Large scale sputter
- DRIE

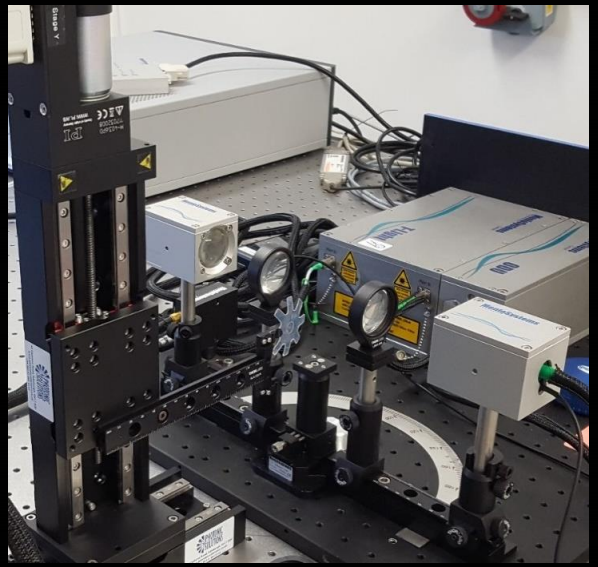
THz VNA and quasi-optical Facility

- 1.1 THZ VNA – EPSRC equipment grant (£1.2M) EP/P020615/1
- Terahertz quasi-optical system for metasurfaces and materials property measurements
- Frequency range: 200 GHz to 1.1 THz



THz spectroscopy and imaging

- TERA K15 all fibre-coupled time-domain (pulsed) spectrometer
  - [Temperature-controlled] spectroscopy & imaging
  - Scattering measurements
  - Near-field with TeraSpike microprobe (80 μm spatial resolution)
  - Frequency range: 0.2 THz to 3 THz
- 142 and 292 GHz IMPATT diodes
- TeraSense Tera-1024 and Ophir Pyrocam IV cameras



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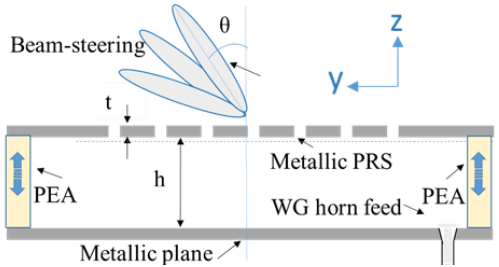
Facilities in CS group

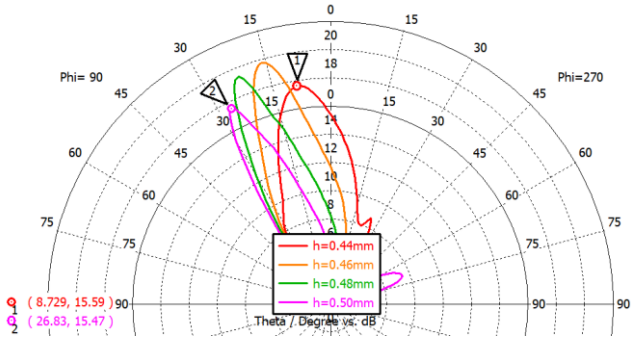
Sub-THz low loss beam-steered antennas

- Developed under **EPSRC project EP/P008380/1**, April 2017-Sept 2021
- Design of beam steered metasurface-based antennas at 280GHz
- Electro-mechanical tuning based on piezo-electric actuators
- Continuous beam scanning up to ±30 degrees from our most recent results
- Simulated max gain >26dBi with 90% efficiency

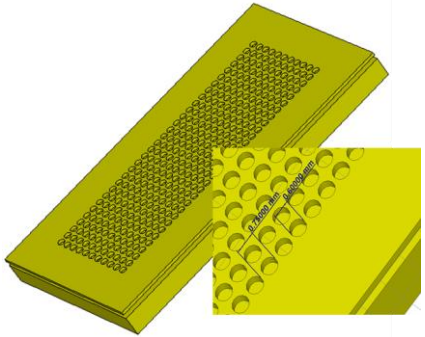
Operating principle of antenna



Beam-scanning Radiation patterns at 280 GHz



Metasurface based antenna at 280 GHz



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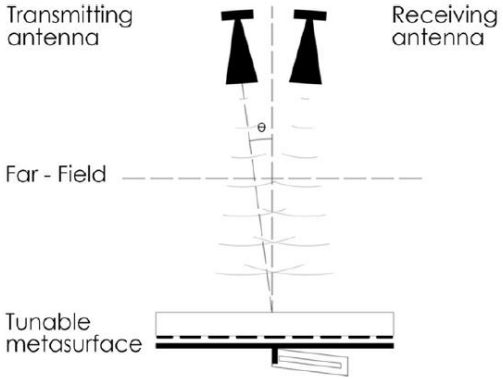
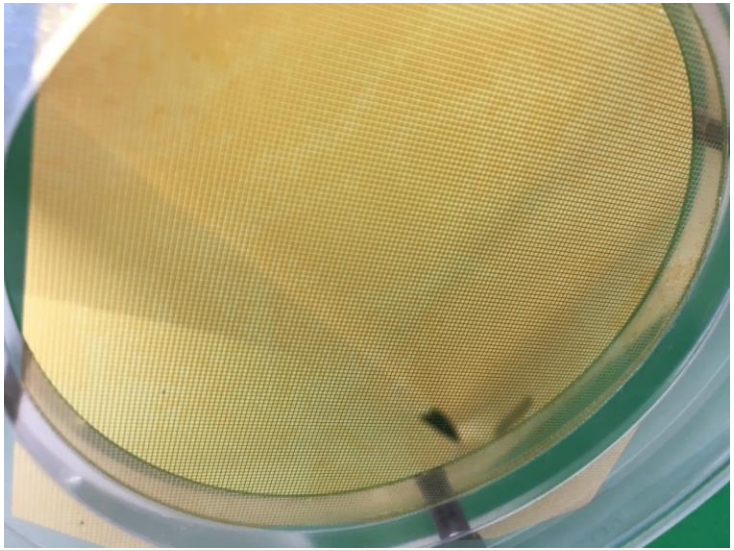
THz Research projects

Reflecting MetaSurfaces with phase shift and polarisation control

- Design and fabrication of static and tunable reflecting metasurfaces at 50GHz and 300GHz
- <3 dB reflection losses
- Full 360˚ tunable phase shift
- *Scientific Reports volume 10, 15679 (2020)*

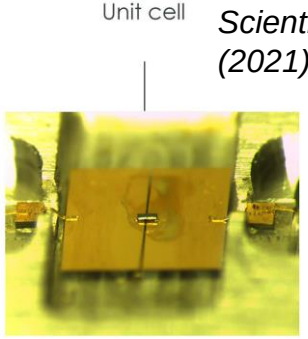


300 GHz metasurface prototype
Clean room photolithography - gold elements on quartz substrate

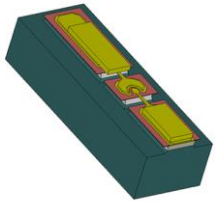


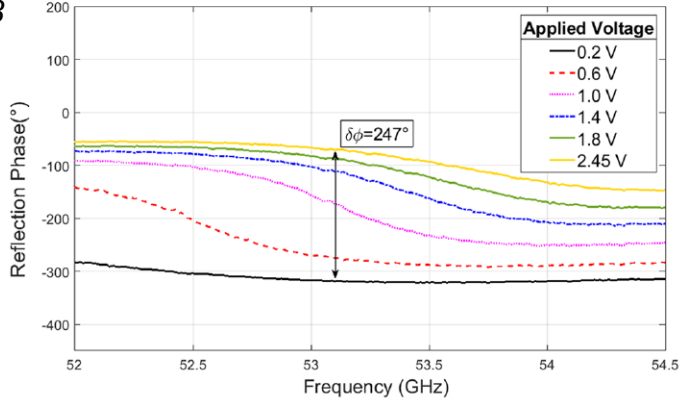
Air-bridged Schottky diode based dynamically tunable metasurface

- Developed under **EPSRC project EP/S007903/1**, March 2019-March 2022
- World leading air-bridged Schottky diode provided by our industrial partner (Teratech components- spin out of RAL)
- Design and fabricated prototype at 50GHz, scalable to sub-THz
- Over 200˚ phase shift. Full 360˚ phase shift metasurface has been designed.
- To be applied on fully electronically controlled IRSs

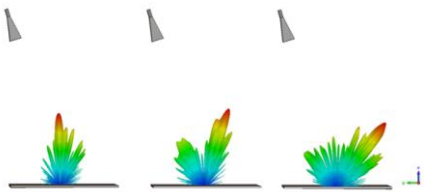


Scientific Reports 11, 5988 (2021)





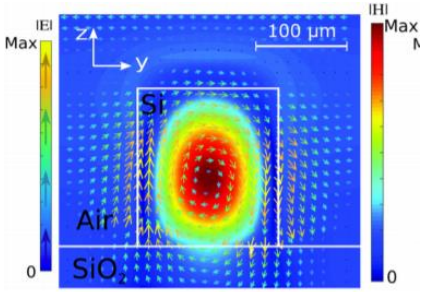
Example of IRS response



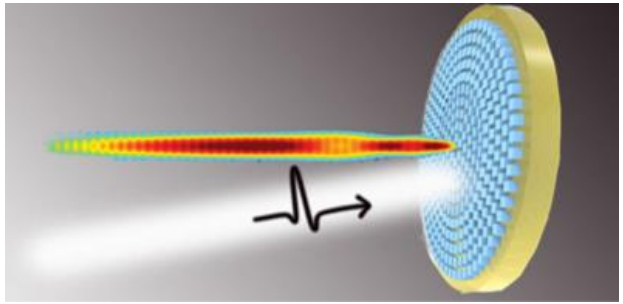
All-dielectric Metasurfaces

- Terahertz silicon-based metasurfaces allow arbitrary control over a reflecting wave's amplitude and phase distribution
- Applications:
  - 'Perfect' dielectric mirrors
  - Vortex and diffraction-less Bessel beam generation
  - Half-wave plate for CP conversion

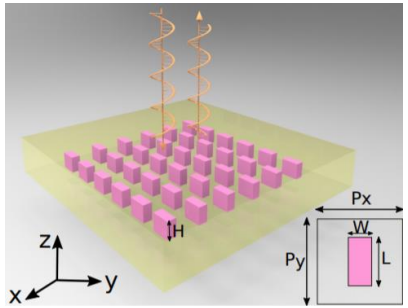
ACS Photonics 2016, 3, 1010−1018
Optics Letters, vol. 43, no. 4, 4, pp. 911-914, 2018



Electric Dipolar Resonance

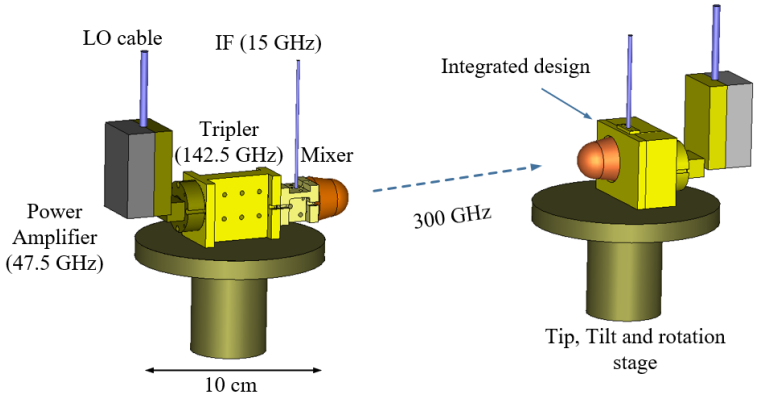


Bessel Beam Generation



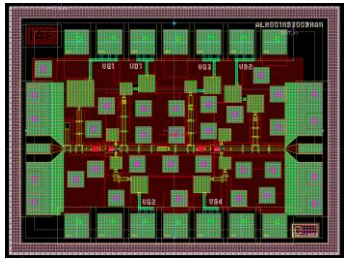
Half-wave Plate

THz link based on micromachined waveguides and Schottky technology



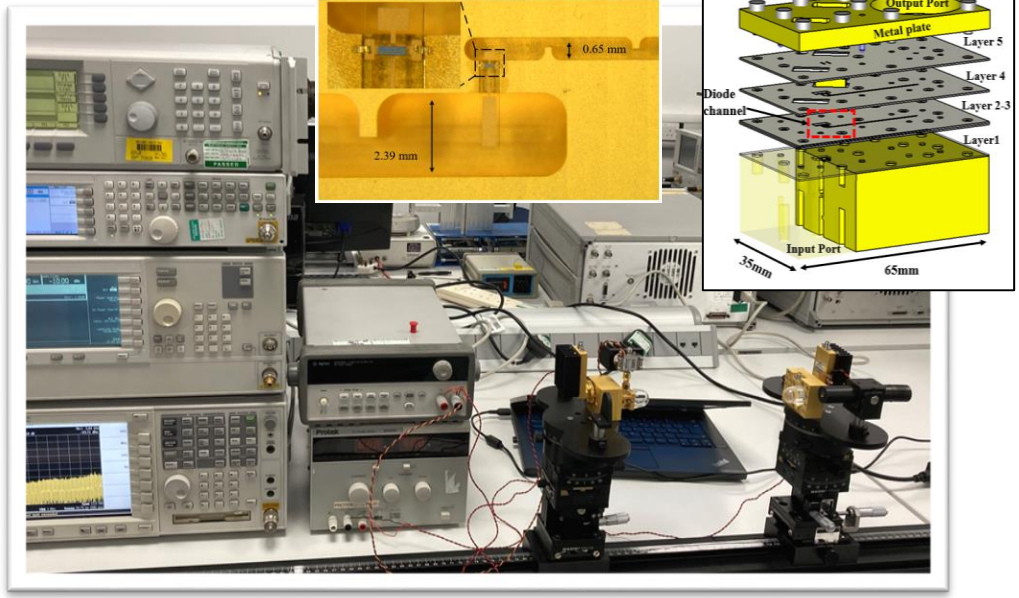
Developed under **EPSRC project EP/M016269/1**, June 2015-Dec 2018

A 300 GHz amp based on IAF 35nm 3M MHEMT process has been designed, prototyped but not implemented.



CNC machined housing

Micromachined housing



All device technologies demonstrated and published in IEEE Trans.: source (multiplier), mixer, filters, antennas

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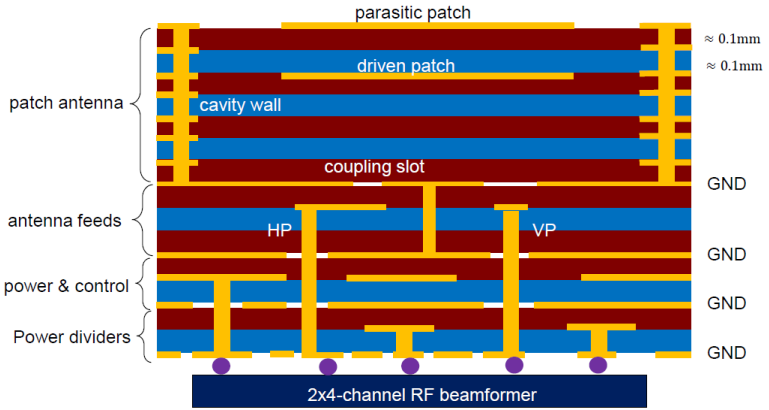
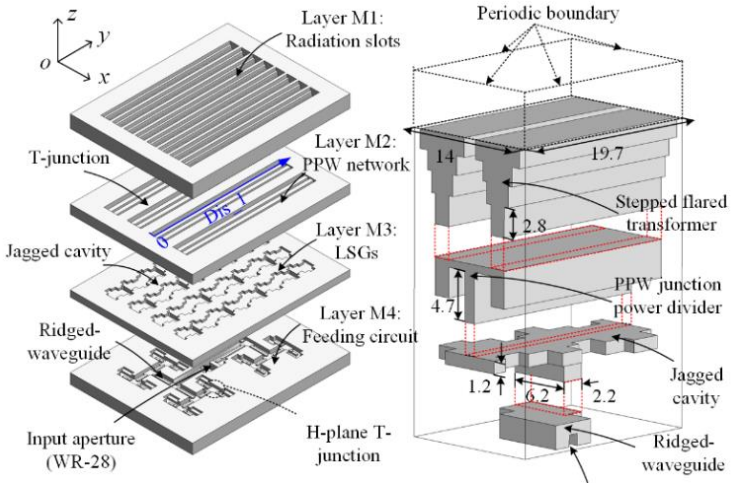
THz communication system

- 5G beamforming antenna module for **base station**



multi-layer stackup: HDI/LTCC antenna-in-package (AiP) + mm-wave chips

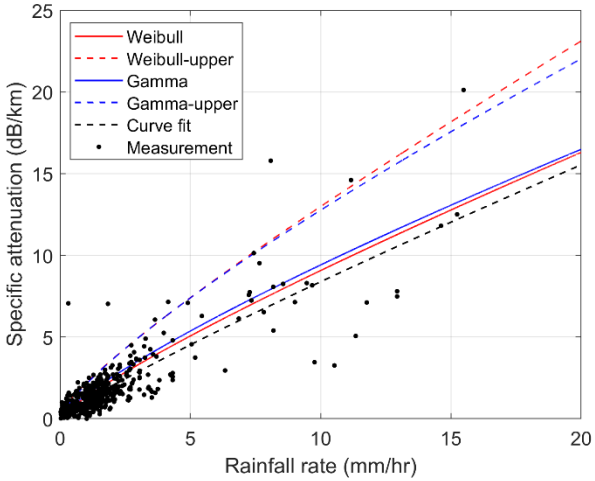
- High-gain low-profile waveguide antenna array for **backhaul**

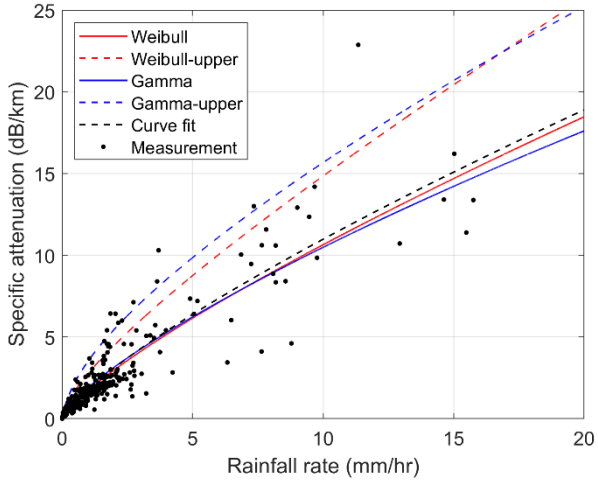


Up to 80 GHz demonstrated, high-efficiency ~80%

THz propagation for communications

A new physics-based "upper bound" specific attenuation model: Norouzian F., Marchetti E., Gashinova M., Hoare E., Constantinou C., Gardner P. and Cherniakov M., 'Rain Attenuation at Millimeter Wave and Low-THz Frequencies,' *IEEE Transactions on Antennas and Propagation*, **68**(1), pp. 421-431, 2020; doi: 10.1109/TAP.2019.2938735





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THz Research projects

Thank you