Modular 3D mmW & THz packaging

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Outline

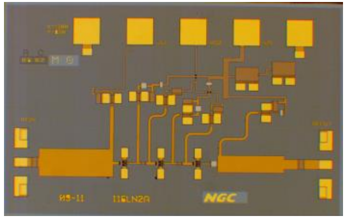
- MMIC technology comparison
- Phased-array scaling
- Modular architectures and 3D packaging
- Summary

MMIC technology comparison

MMIC technologies

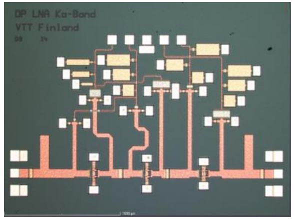
- III-V technologies
  - InP, GaAs ~ RF design with lowest noise
  - GaN ~ RF design for high power and low-noise
- Silicon technologies
  - CMOS ~ digital/analog/RF circuit design
  - SiGe BiCMOS ~ bipolar transistors for RF and CMOS for digital/analog design

W-band InP HEMT LNA
NT = 24-39 K



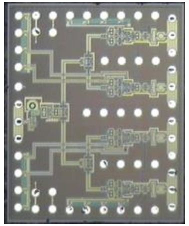
Varonen et al., IEEE TMTT

Full Ka-band GaN-on-Si LNA
NF = 1.9 dB, OCP = 22 dBm



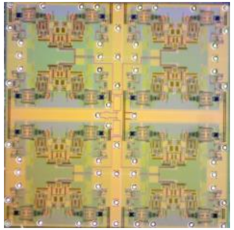
Parveg et al., EuMC

60-GHz scalable FMCW
MIMO radar



Forsten et al., IEEE TMTT

E-band 16-channel beamforming
IC in SiGe BiCMOS



Varonen et al., EuMC

Technology comparison

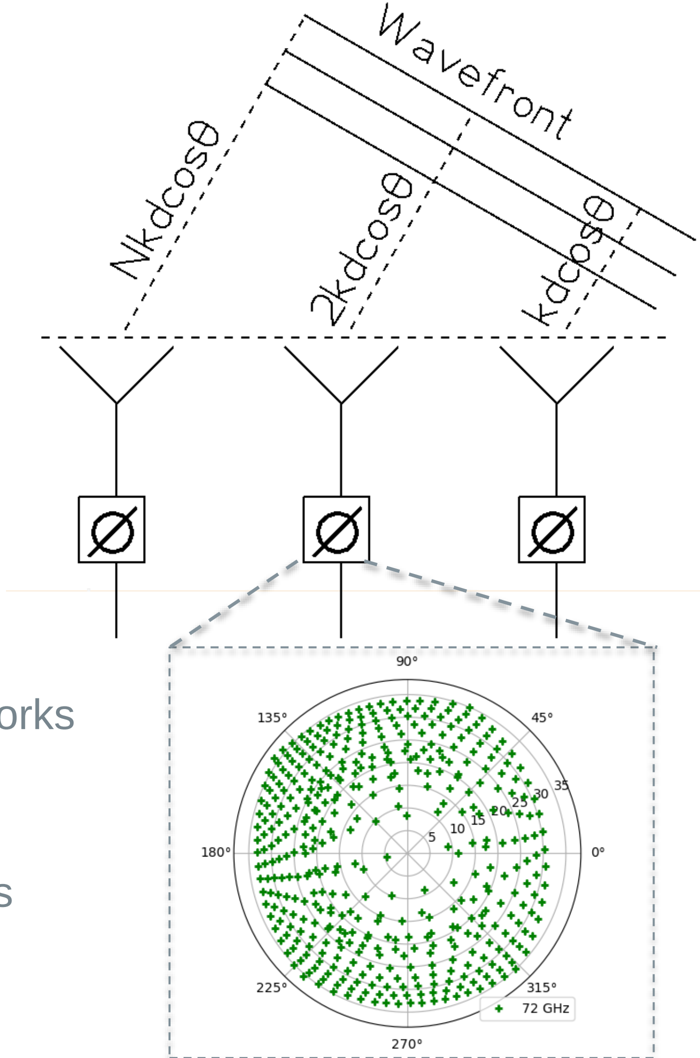
- Comparison based on amplifier performances

Technology	Freq (GHz)	Noise	Output power	Integration level
InP HEMT	~THz	☺	😐	☹
GaAs mHEMT	<700	☺	😐	☹
InP HBT	<700	😐	☺	☹
SiGe BiCMOS	<300	☹	😐	😐
CMOS	<300	☹	☹	☺
GaN HEMT	<200	😐	☺	☹

Phased array scaling

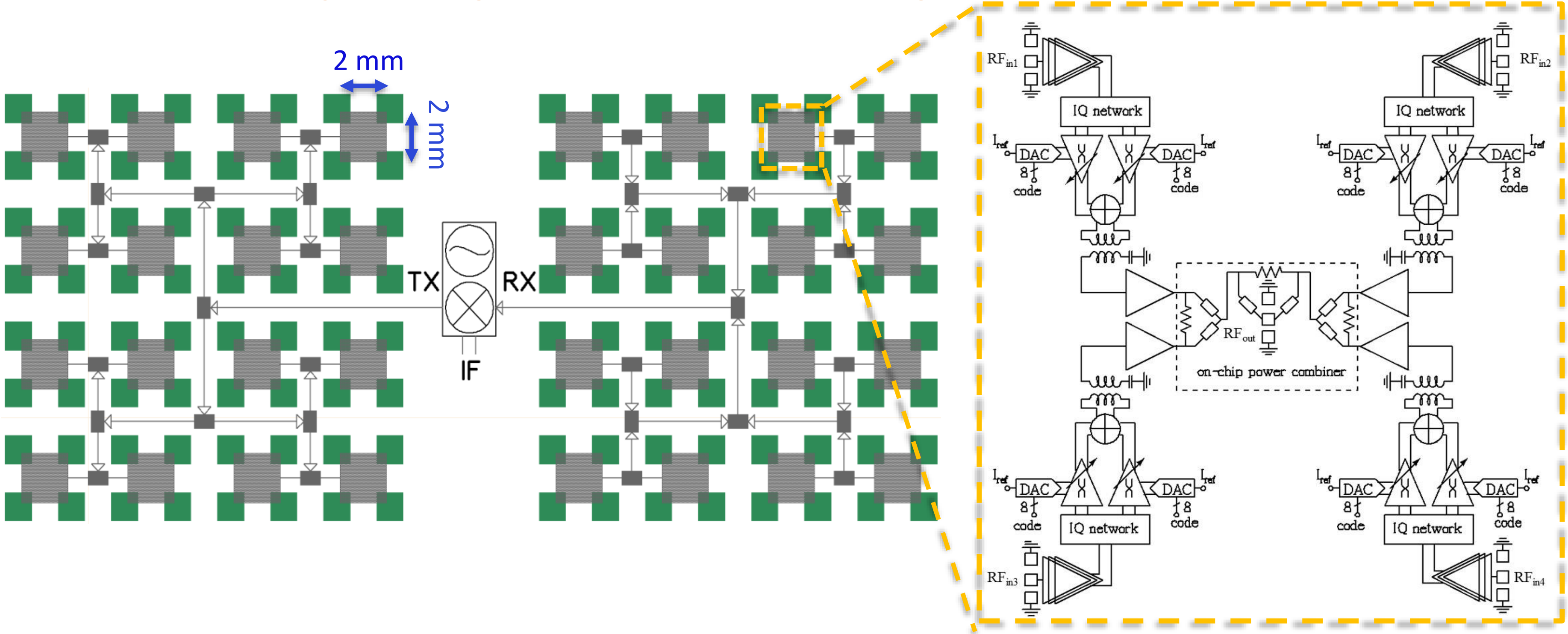
Phased array scaling

- Phased arrays with N antennas
  - 10log(N) SNR improvement
  - 20log(N) improvement in transmit EIRP
- Digital beamforming
  - scale to multiple elements and beams
  - maximum number of hardware and signal processing
- Analog beamforming
  - LO and IF phase shifting
    - Separate mixers with LO distribution networks
  - RF phase shifting
    - minimal amount of hardware
    - phase shifters in RF path -> RF signal loss
    - RF routing for large arrays challenging



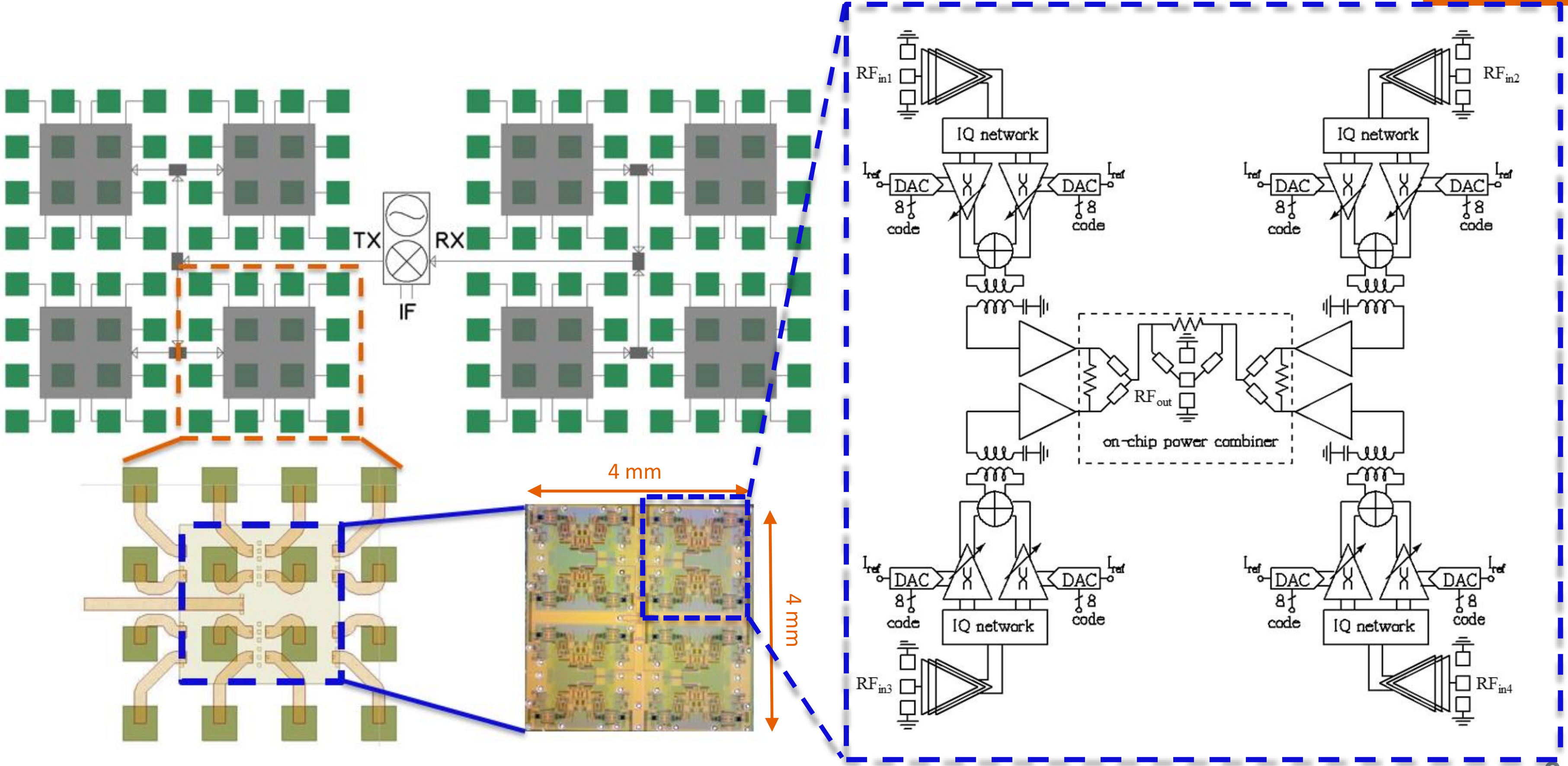
E-band RF beamforming

- More scalability utilizing 4-channel beamforming MMICs



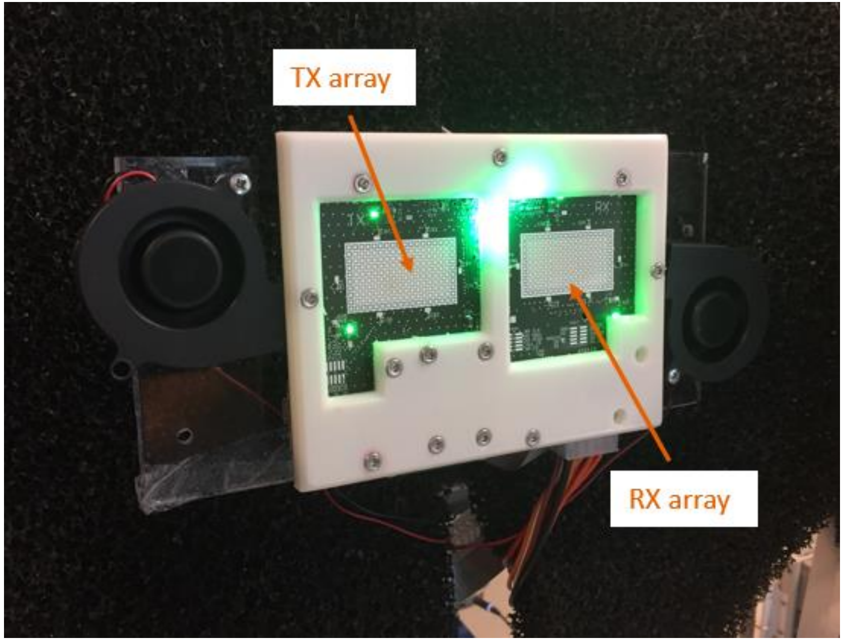
M. Varonen et al., ”Receive and Transmit Beamforming SiGe BiCMOS ICs for Scalable E-Band Phased Arrays”, EuMC 2021.

16-channel TX and RX phased-array MMICs

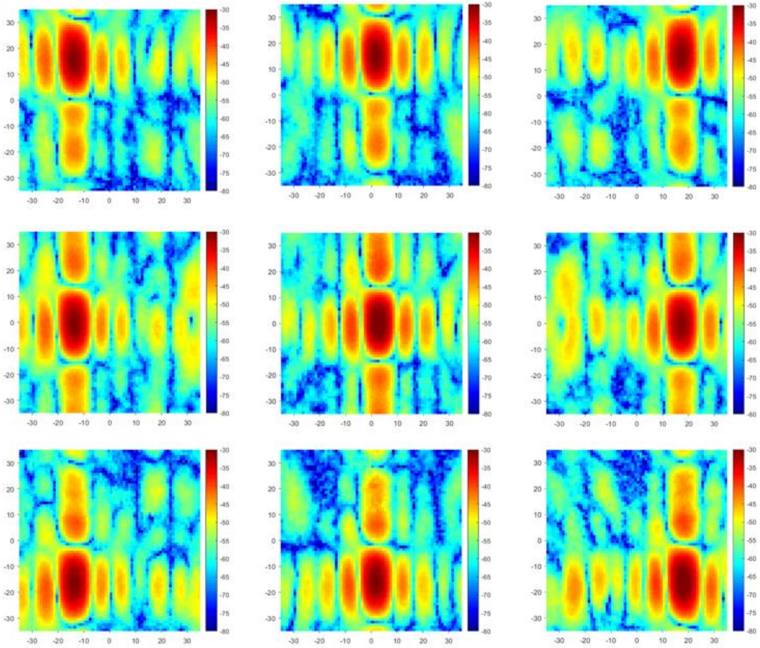


E-band 5G development

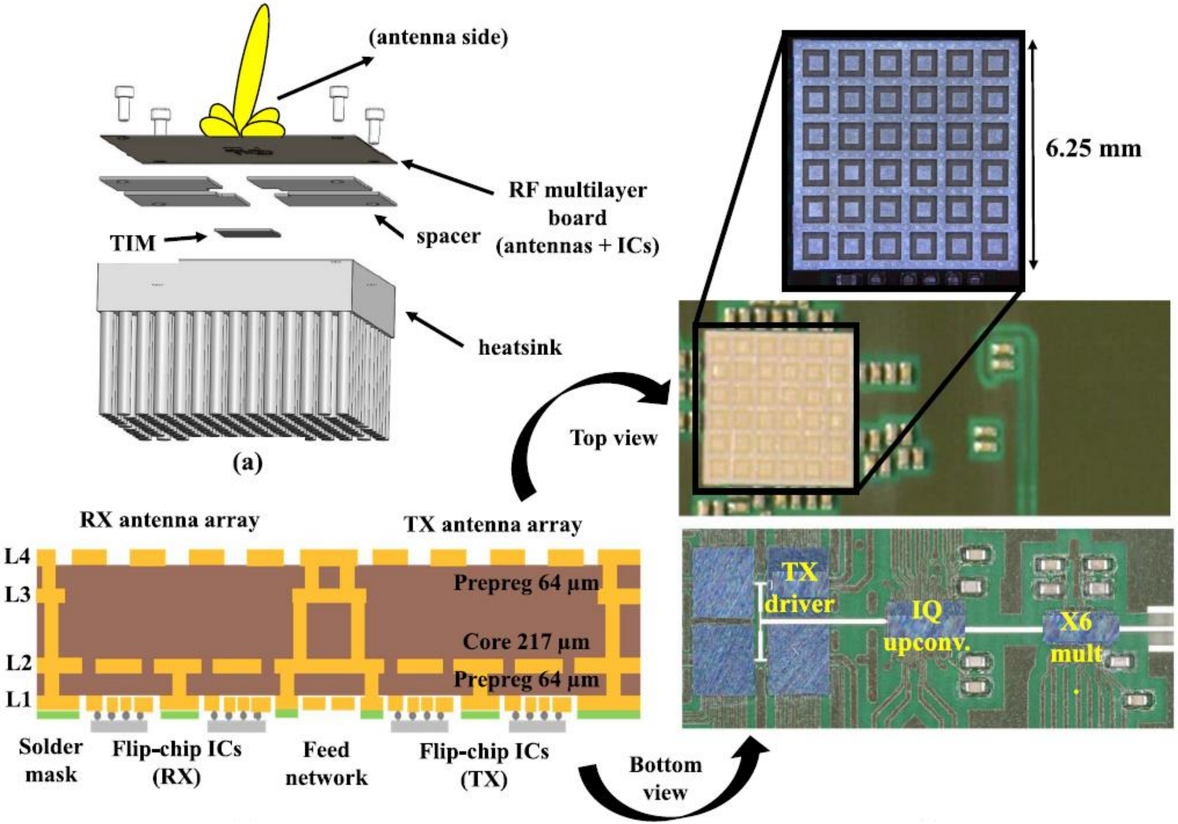
- 128 element TX and RX beam steering phased array using 16-channel SiGe BiCMOS beamforming ICs



Full 128-element TX array measurement



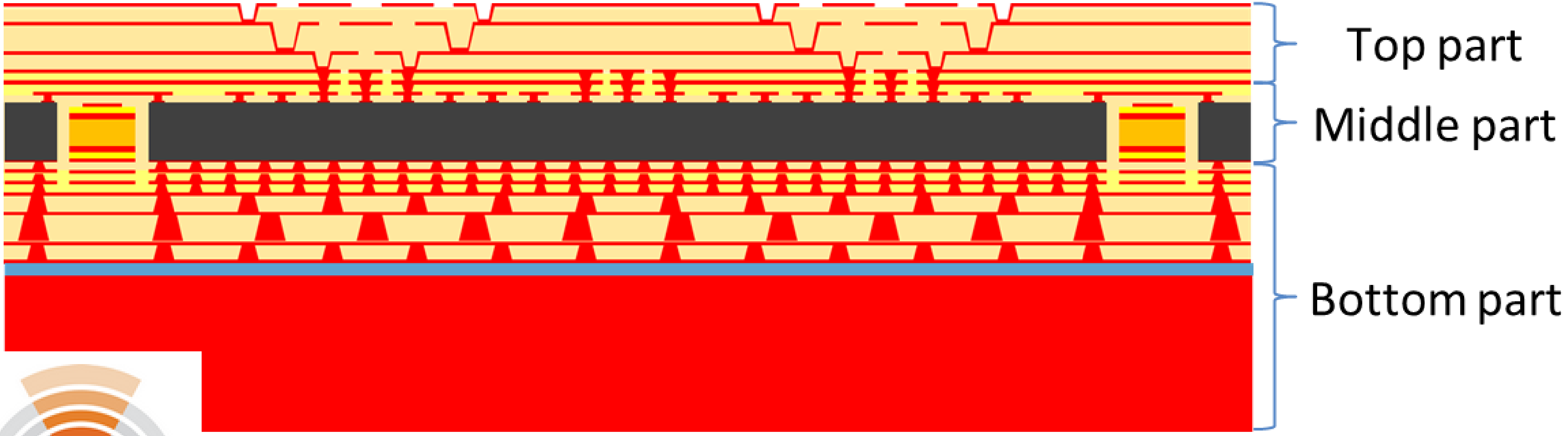
D-band 5G/6G development



D. del Rio *et al.*, “A D-Band 16-Element Phased-Array Transceiver in 55-nm BiCMOS,” *IEEE TMTT 2023*

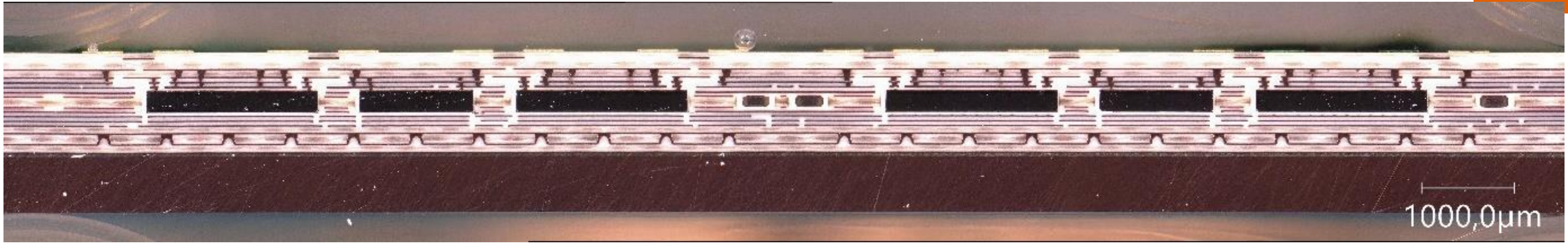
Phased-array scaling

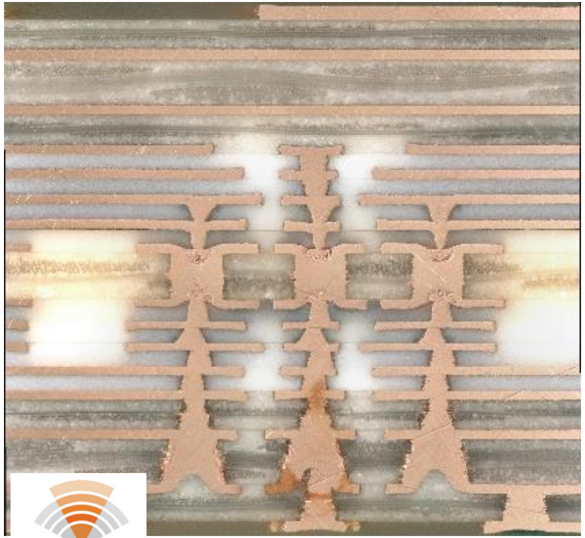
- Embedded component packaging for efficient heat handling

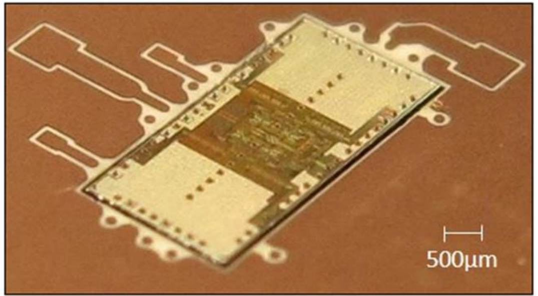


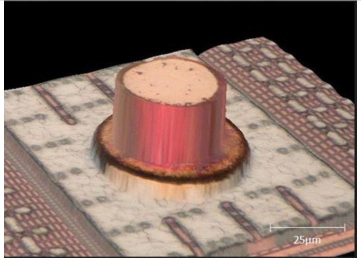
M. Schober et al., "Embedded component packaging for D-band radio systems," *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*

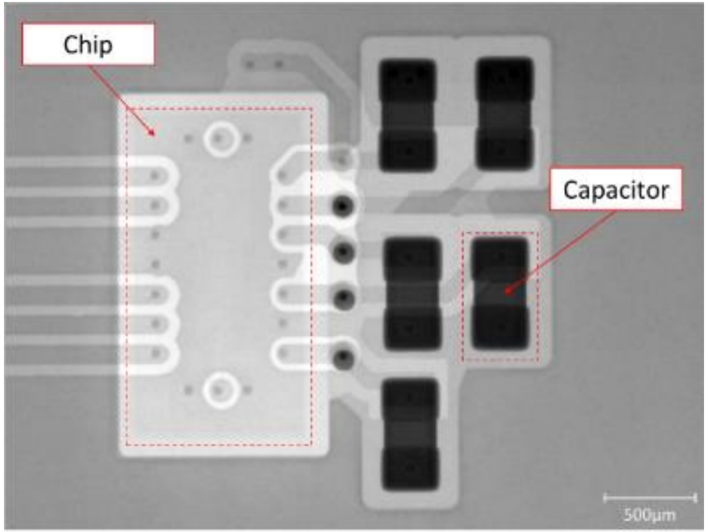
D-band embedded component packaging









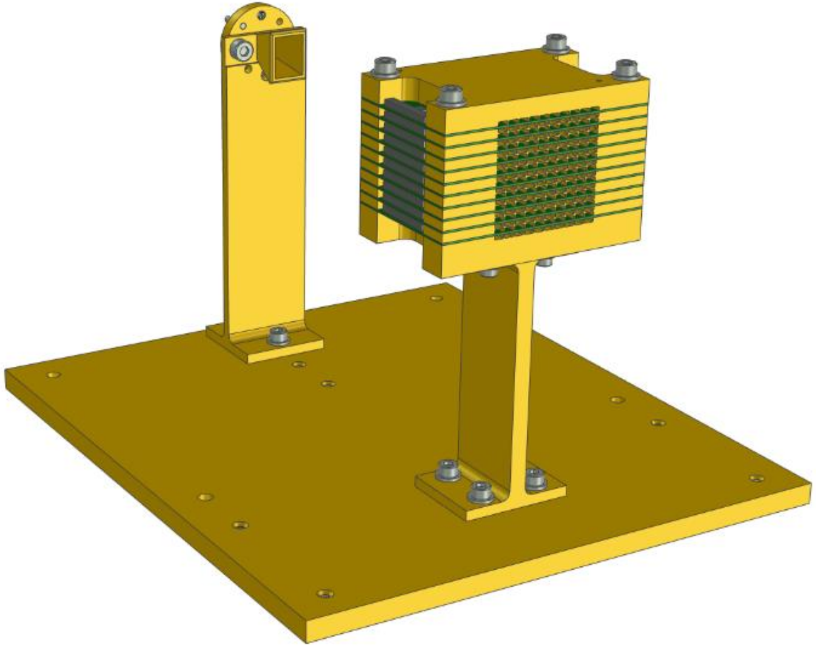


M. Schober et al., "Embedded component packaging for D-band radio systems," *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit).*

Modular architectures and 3D packaging

Modular 3D packaging

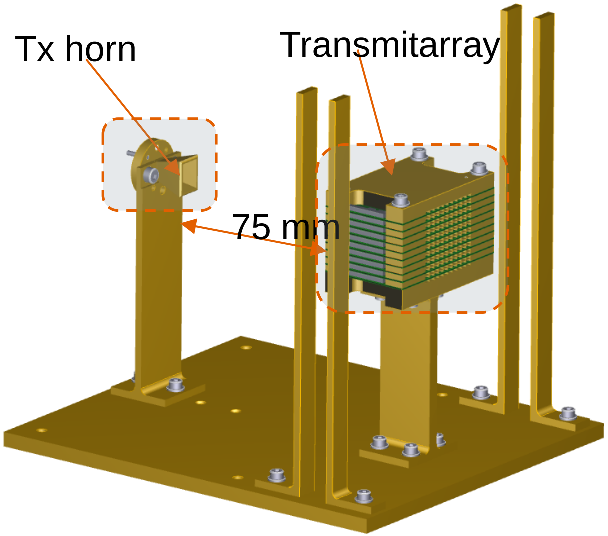
- Transmitarray topology
  - Scalable solution for large phased array antennas
  - Low feeding losses
  - Excellent thermal management due to open 3D structure
  - Heterogenous integration of III-V and silicon technologies
    - InP LNAs and GaN PAs
    - SiGe/CMOS phase-shifter ICs

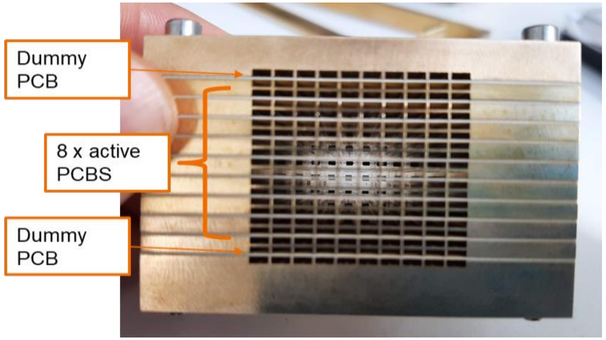


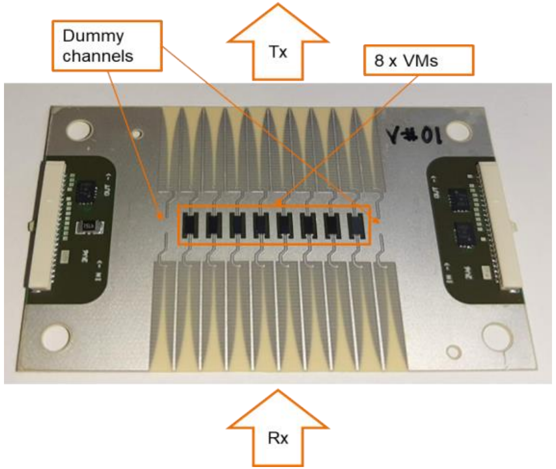
A. Lamminen et al., *ESA 1st Space Microwave week 2023.*

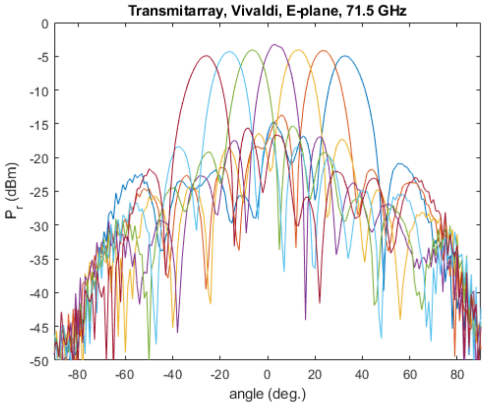
Modular 3D packaging

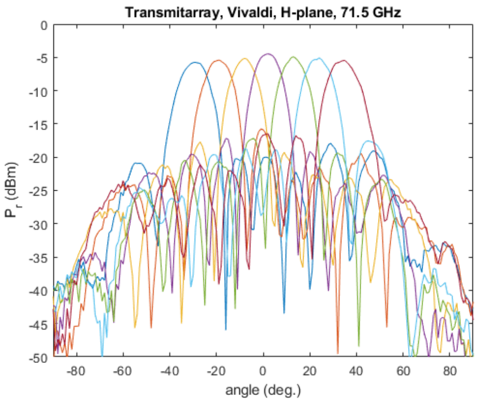
- EIRP up to +40 dBm demonstrated with 64-element array at 71-76 GHz







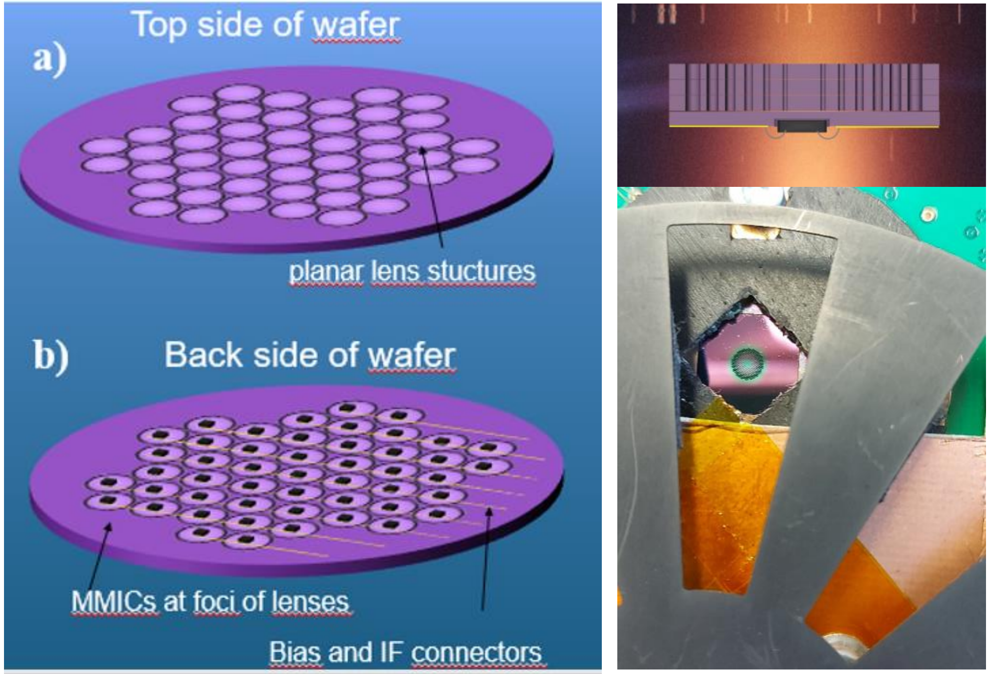




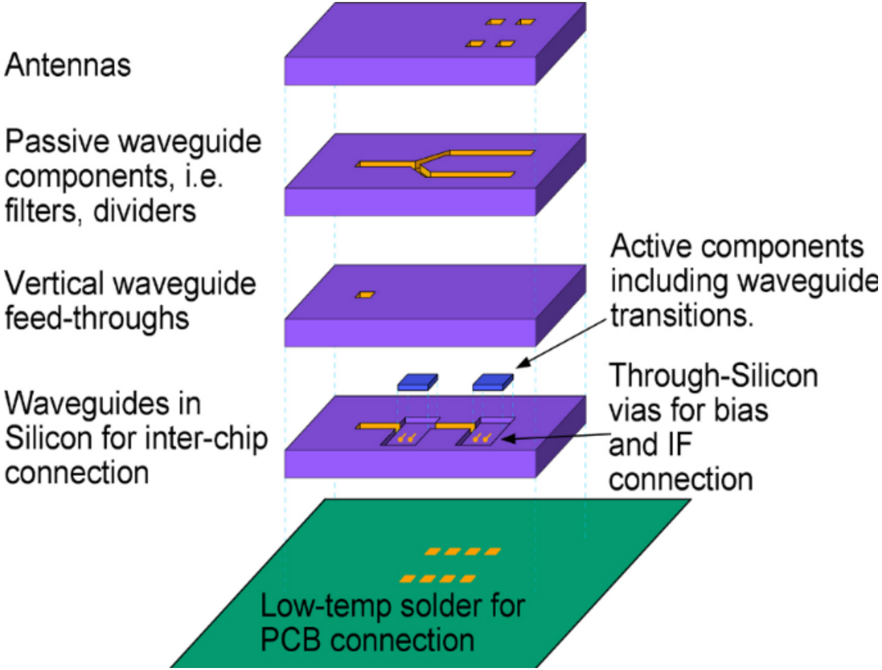
A. Lamminen et al., *ESA 1st Space Microwave week 2023.*

Wafer level packaging for THz large arrays

- Light-weight and low-cost packaging technique for heterogeneous MMIC integration



P. Pursula et al., *IEEE TMTT 2024*



Antennas

Passive waveguide components, i.e. filters, dividers

Vertical waveguide feed-throughs

Waveguides in Silicon for inter-chip connection

Active components including waveguide transitions.

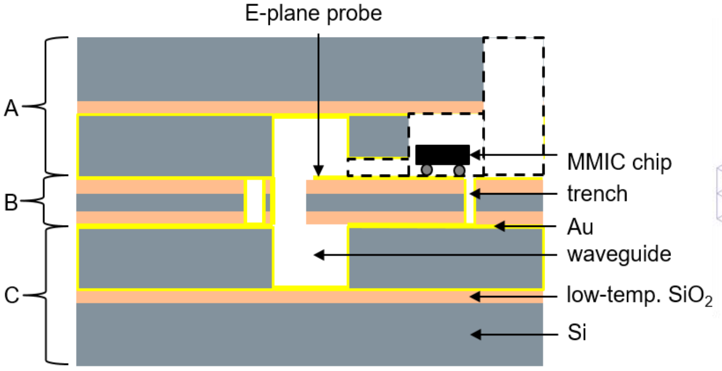
Through-Silicon vias for bias and IF connection

Low-temp solder for PCB connection

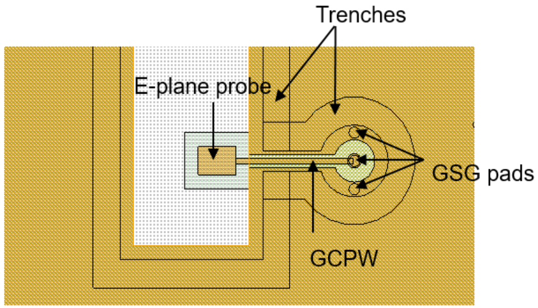
P. Pursula et al., *EuMW 2017*

Wafer level packaging for THz large arrays

- Fabrication process based on silicon micromachining and flip-chip technologies

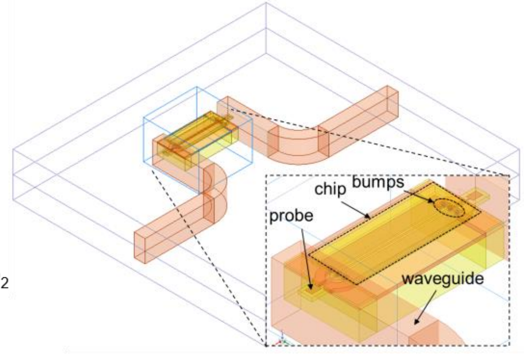


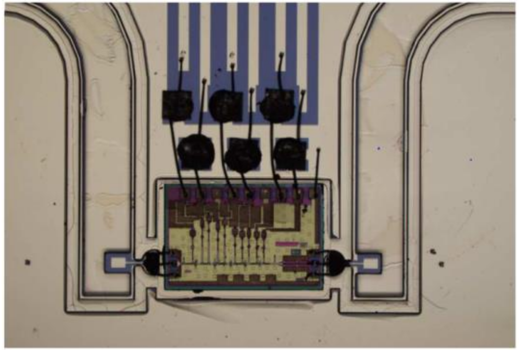
(a)

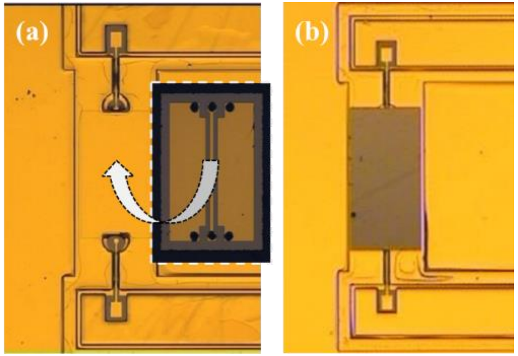


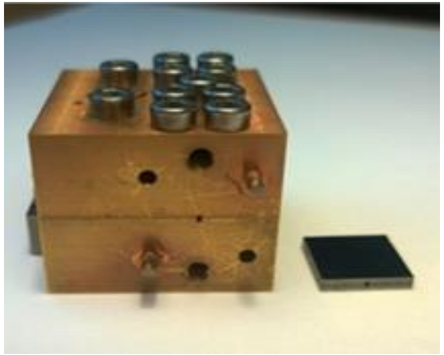
(b)

V. Ermolov et al., *IEEE MWTL 2023*





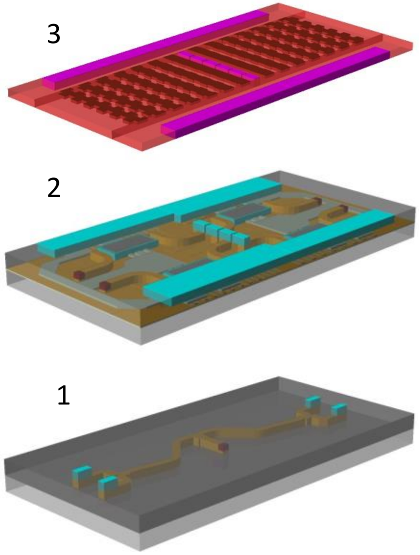




V. Ermolov et al., *EuMW 2024*

Wafer level packaging for THz large arrays

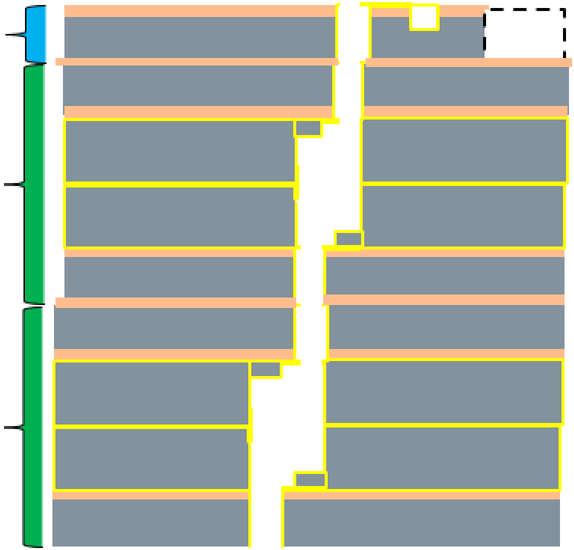
- 3-D hybrid module integration

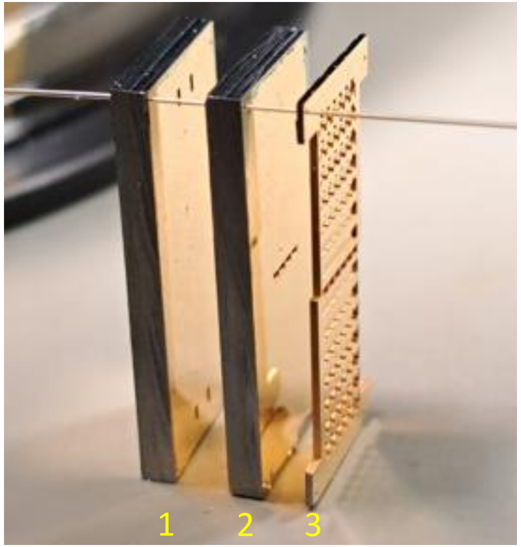


3 Antennas

2 Active phase shifters

1 Power splitter





V. Ermolov et al., *IEEE APMC 2024*

Conclusions

- Challenges in mmw/sub-THz phased array scaling
  - Low-loss feed networks for 2-D phased array scaling
  - Space limitations due to decreased antenna separation at sub-THz and beyond
  - Heat management
  - Heterogeneous integration
    - ➢ ***New architectures and novel 3D packaging technologies needed***

Thank you!