# Future antenna challenges and opportunities

## Finnish RF seminar "Future mobile radio frequency technologies and solutions"

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Ville Viikari, Juha Ala-Laurinaho, Jaakko Haarla, Jari Holopainen, Matti Kuosmanen, Veli-Pekka Kutinlahti, Henri Kähkönen, Anu Lehtovuori

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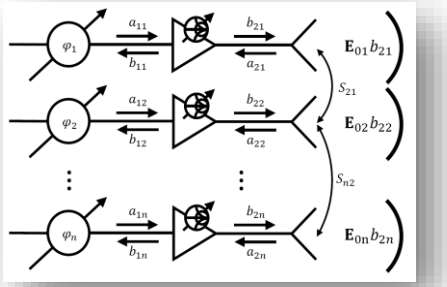
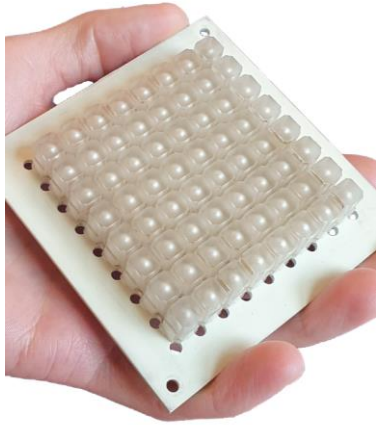
Example 1

Example 2

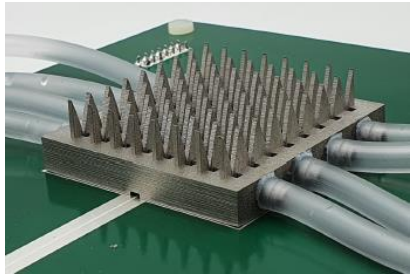



Example 3



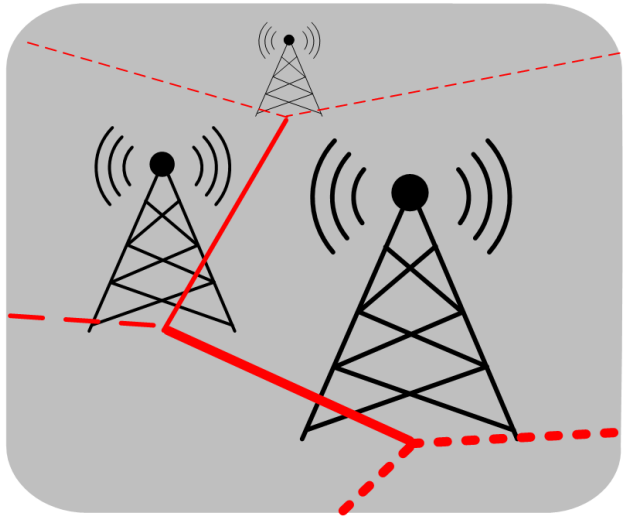
Example 4

Example 5



# Why antennas matter?

Cellular networks



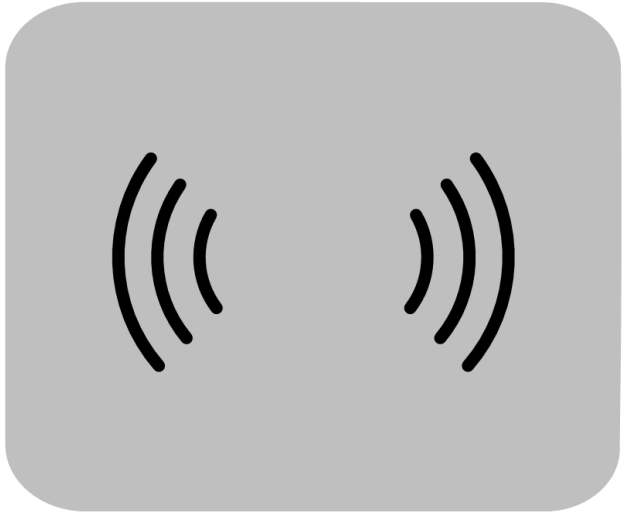
0.5 % of global electricity

Base stations

80 % of cellular networks

0.4 % of global electricity

Radio wave generation

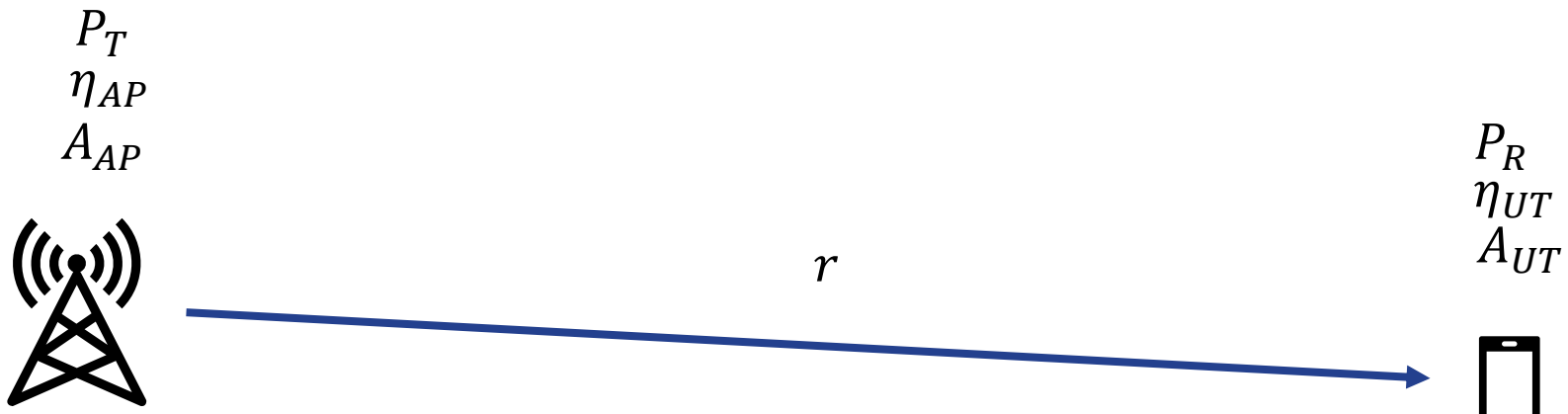


65 % of base stations

**0.26 % of global electricity**


[1] A. S. G. Andrea *et. al.*, "On global electricity usage of communication technology: trends to 2030," *Challenges*, 2015.
[2] ETSISSR05_024, NSN
[3] O. Blume *et. al.*, "Approaches to energy efficient wireless access networks," ISCCSP 2010.

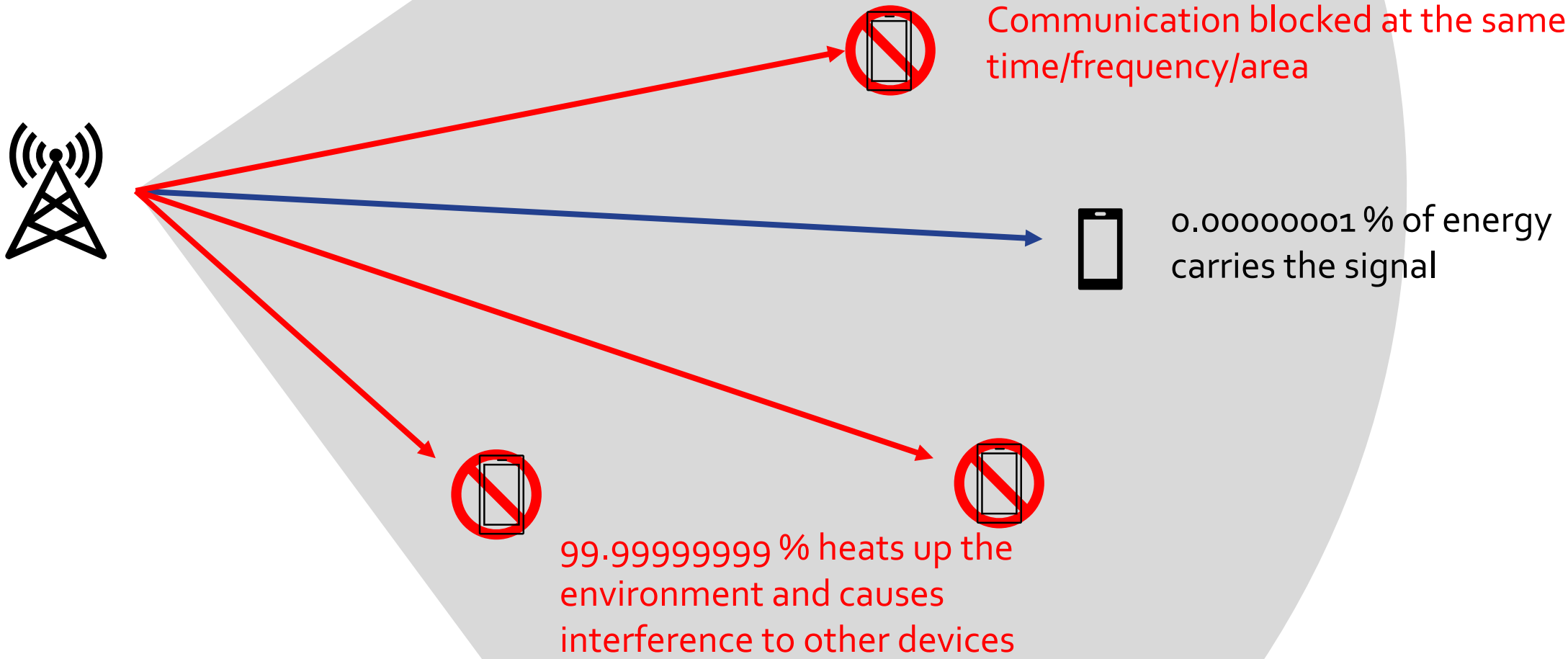
# How efficiently are microwaves used?



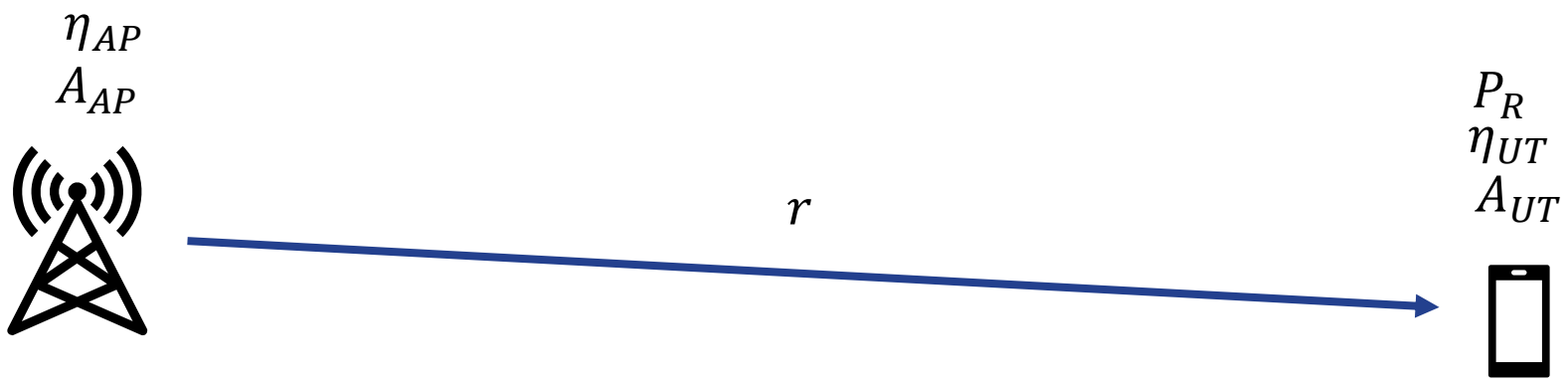

$$\eta_{UT} = 0.5$$
$$\eta_{AP} = 1$$
$$A_{UT} = 8\ \text{cm}^2$$
$$A_{AP} = 80\ \text{cm}^2$$
$$r = 2000\ \text{m}$$

$$\text{@ 3 GHz: } \frac{P_R}{P_T} = \frac{\eta_{UT}\eta_{AP}A_{UT}A_{AP}}{\lambda^2 r^2} \approx 10^{-10}$$

# How efficiently are microwaves used?



# Effect of higher frequency with constant antenna size

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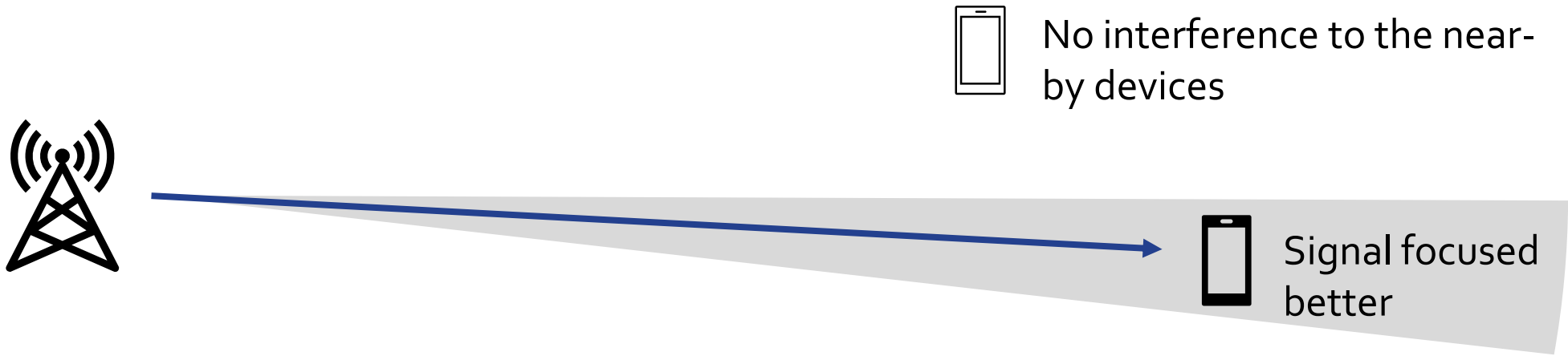
$A_{AP} = 80\ \text{cm}^2$
$r = 2000\ \text{m}$

@ 3 GHz: $\frac{P_R}{P_T} = \frac{\eta_{UT}\eta_{AP}A_{UT}A_{AP}}{\lambda^2 r^2} \approx 10^{-10}$

100 times better use of radio wave energy

@ 30 GHz: $\frac{P_R}{P_T} = \frac{\eta_{UT}\eta_{AP}A_{UT}A_{AP}}{\lambda^2 r^2} \approx 10^{-8}$

# Higher frequencies enable better use of space




Effect of reduced interference:

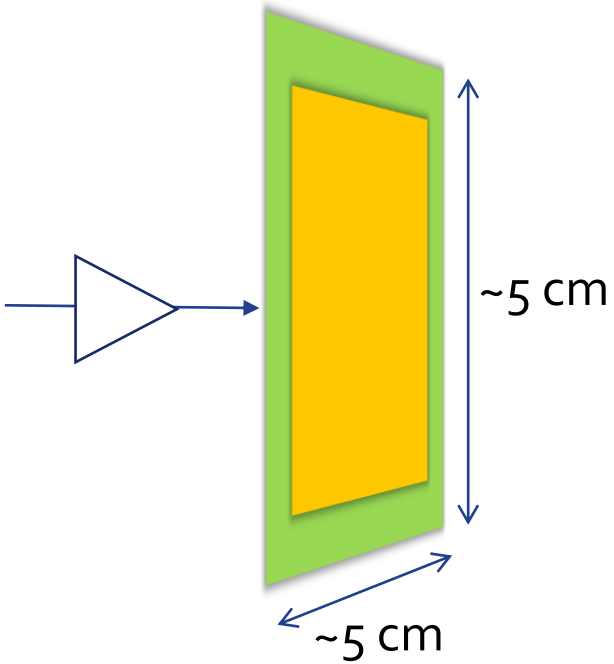
$$C = BW \log_2(1 + SNR)$$

Reduced interference allows equal reduction in transmit power (until the noise floor is reached)

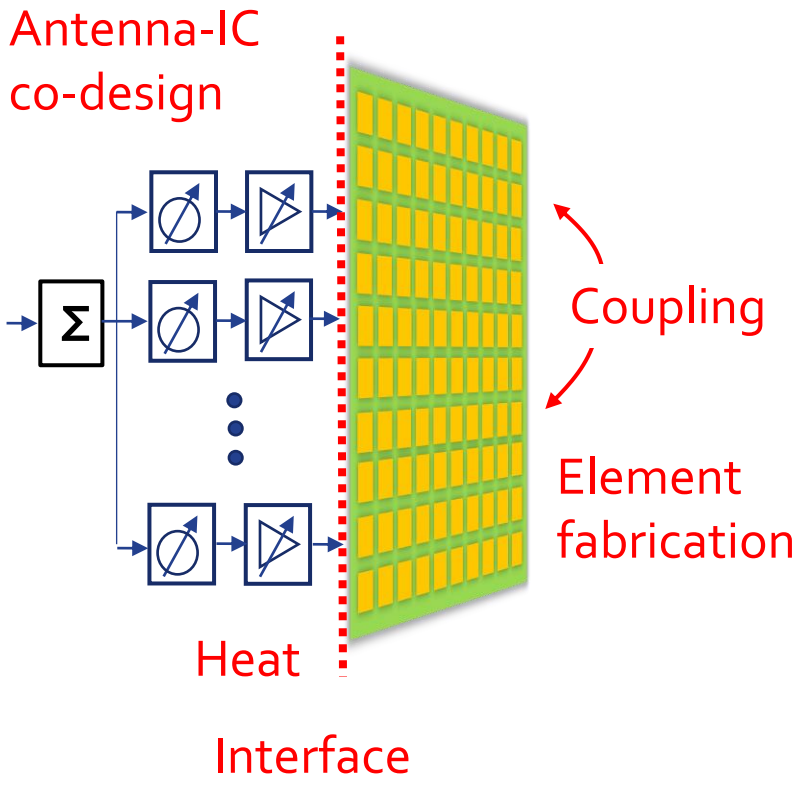
→ Better than **100x** improvement

# Challenges of higher frequencies

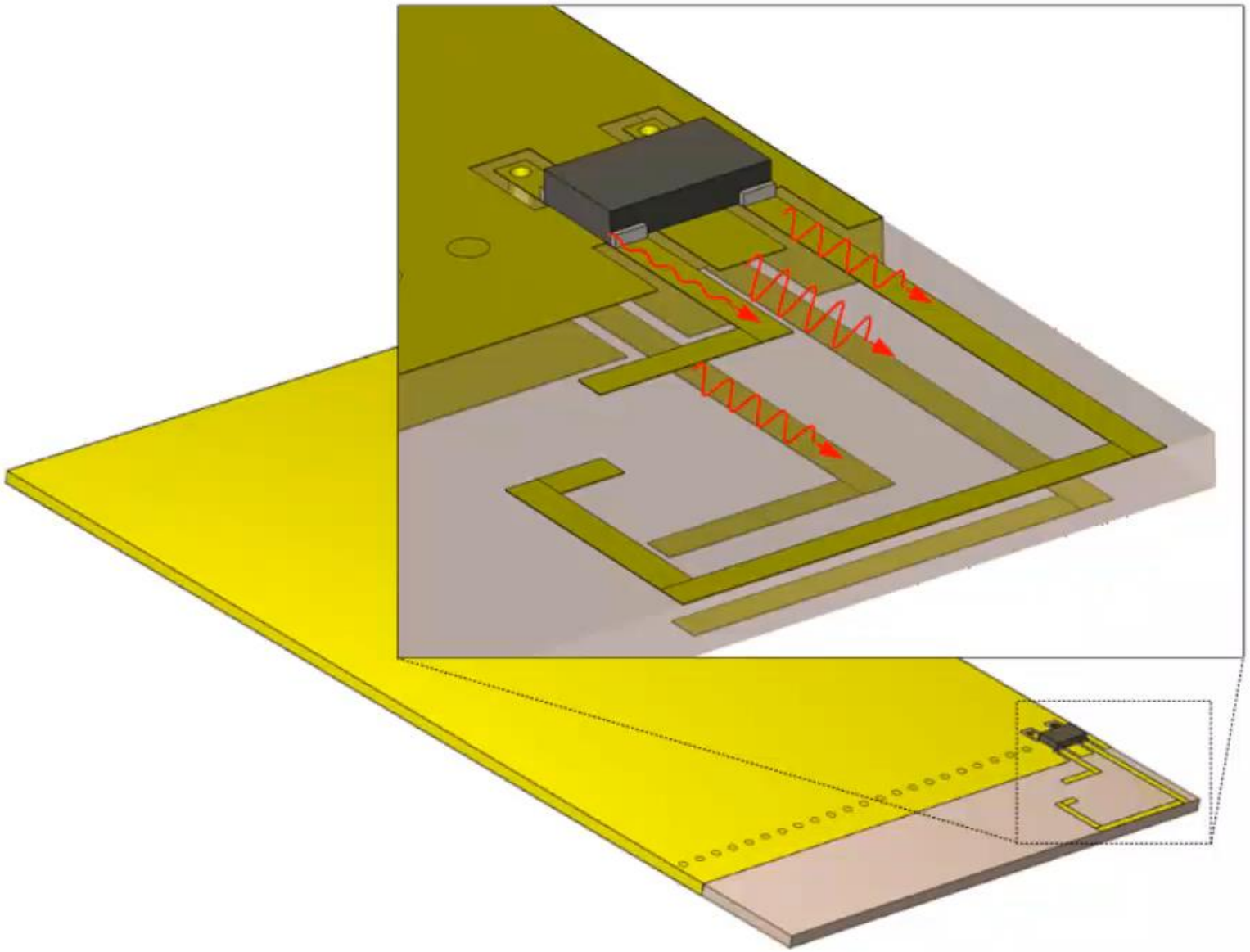
3 GHz
1 element




30 GHz
100 elements



# Example 1: Antenna cluster concept



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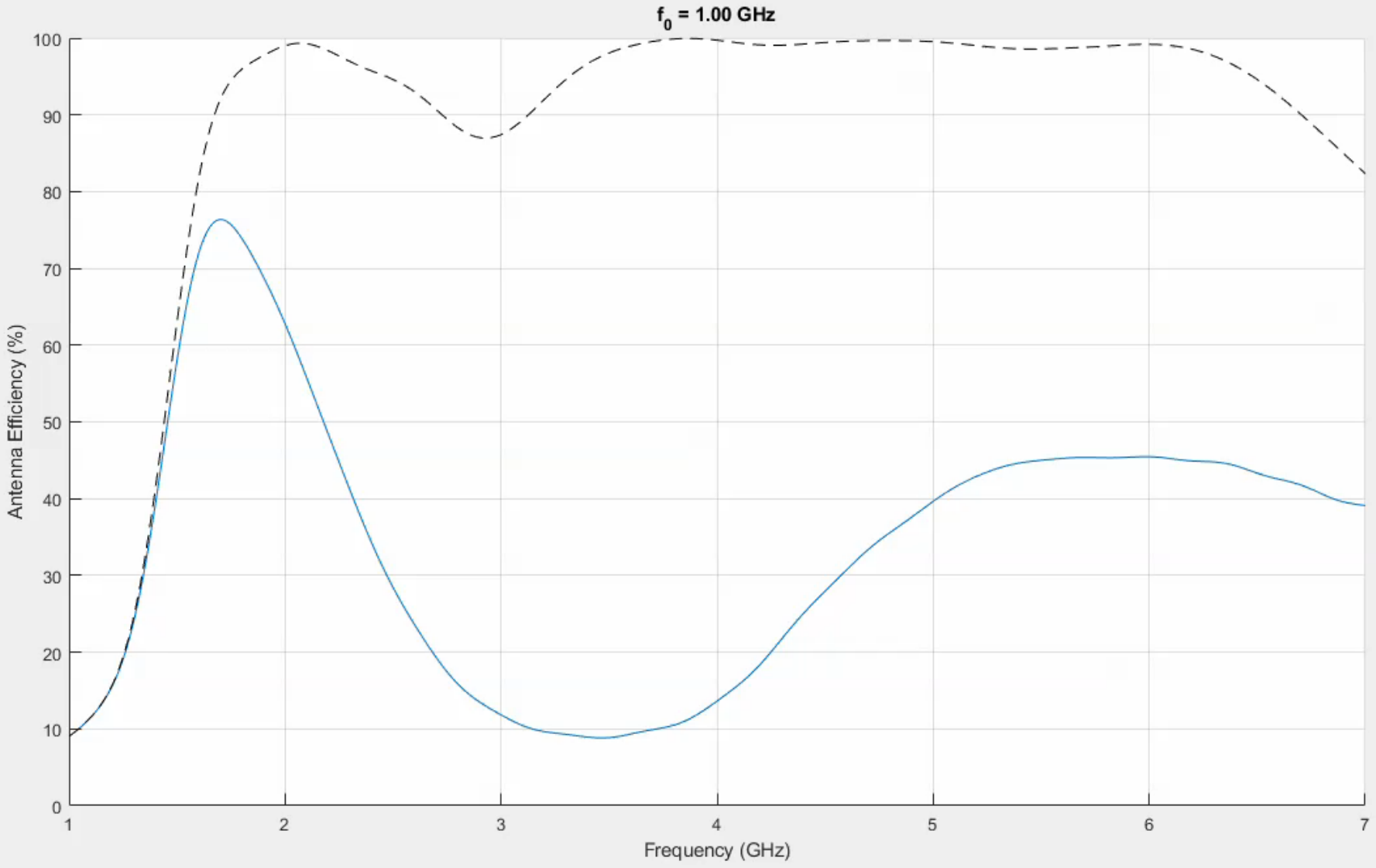
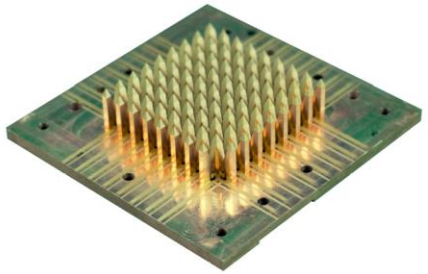


# Antenna arrays and clusters

## Antenna array



Ideally:
Feeding affects the beam
Orthogonal element patterns
No coupling

## Antenna cluster

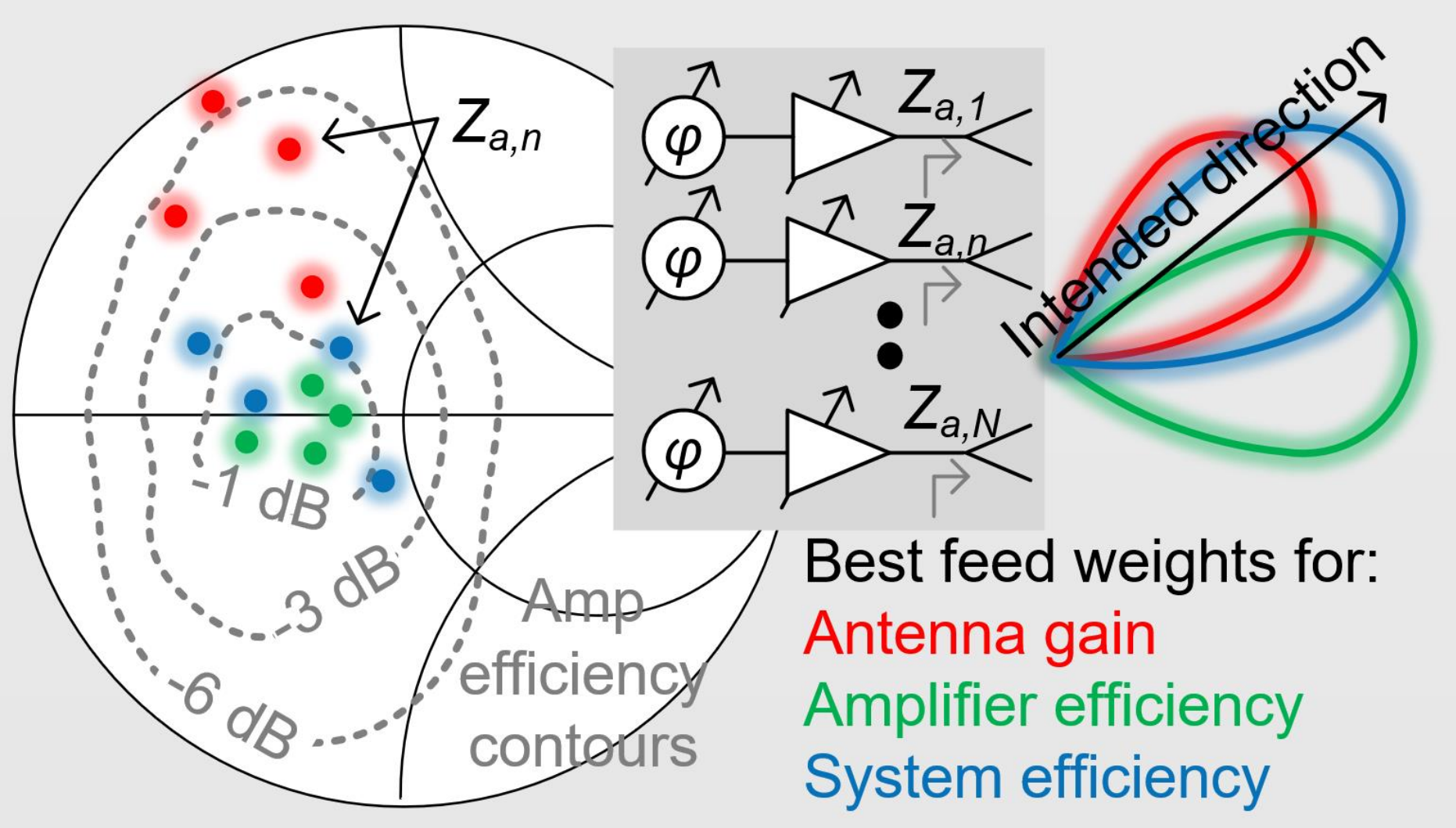
Ideally:
Feeding affects the impedance
Non-orthogonal element patterns
Coupling

In practice: Feeding affects the beam and the impedance and efficiency, polarization etc.

**→Conventional methods fail**

**→Convergence of antenna arrays and clusters**

# Example 2: Active antenna array

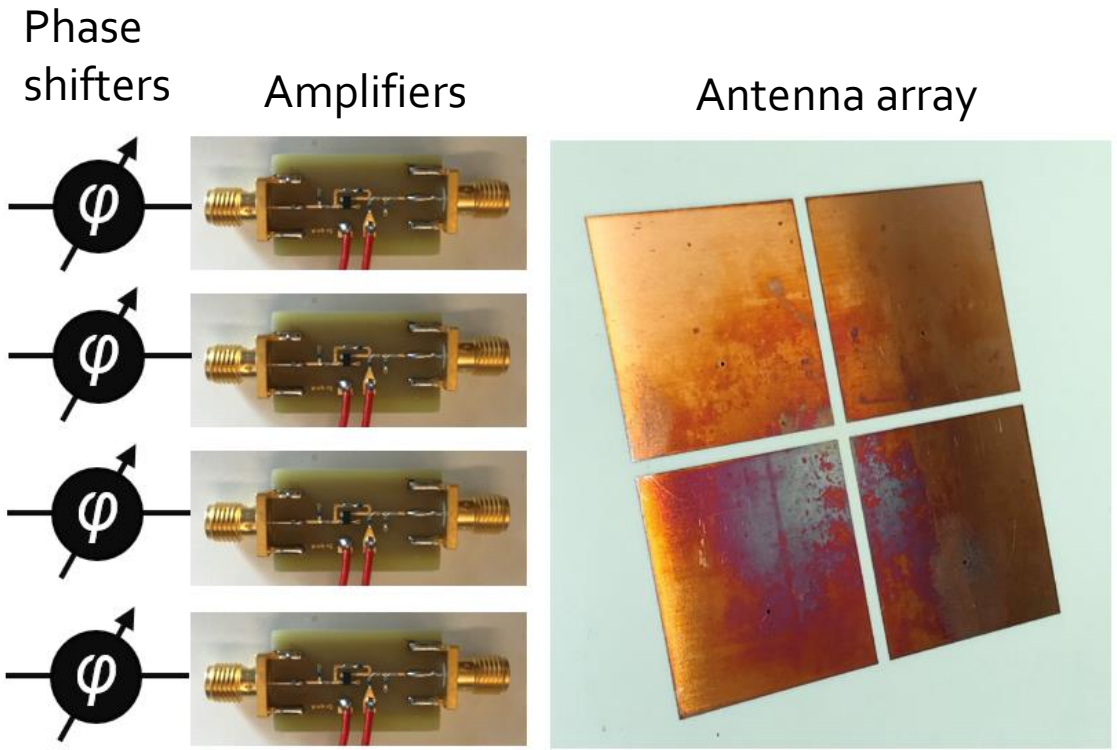




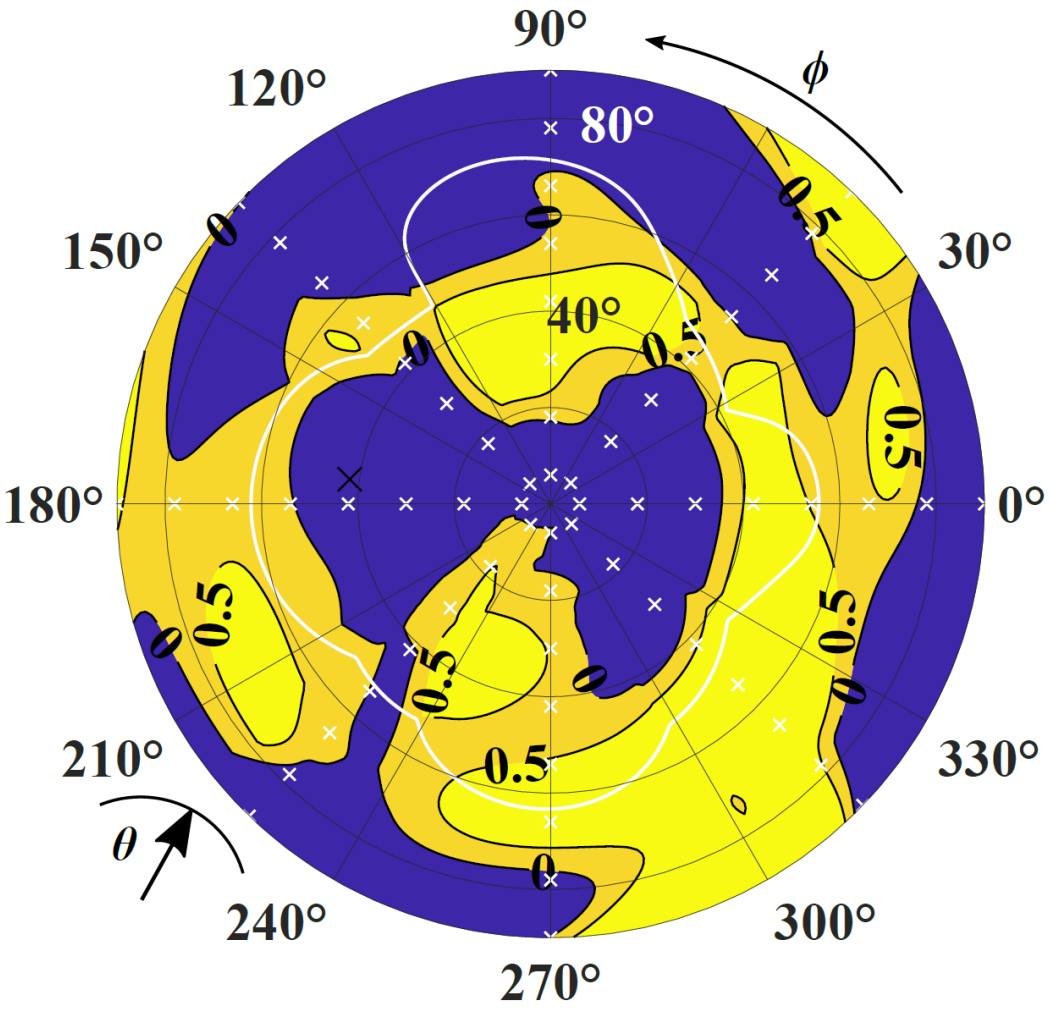
V.-P. Kutinlahti et al. ”Optimizing RF efficiency of a vector-modulator-driven antenna array,” *IEEE AWPL* 2020

V.-P. Kutinlahti et al. ”Amplifier-antenna array optimization for EIRP by phase tuning,” *EuCAP* 2022

# Measured improvement in radiated power (compared to the case where coupling is ignored)

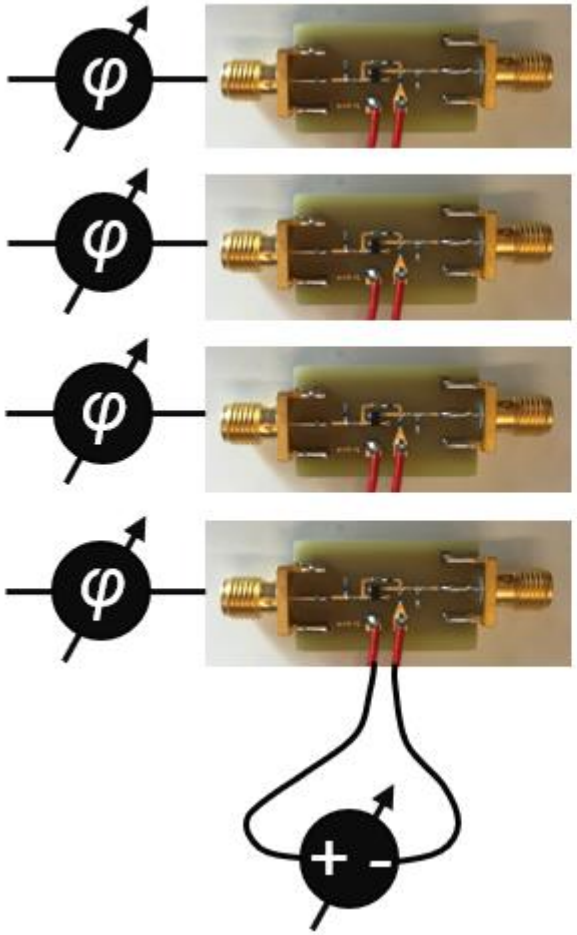



V-P Kutinlahti et. al., "Analyzing and optimizing the EIRP of a phase tunable amplifier-antenna array," submitted to IEEE Journal of Microwaves




Angular plot across hemi-sphere

# Coupling could also be used for other purposes




Find the best phases and bias voltages for:

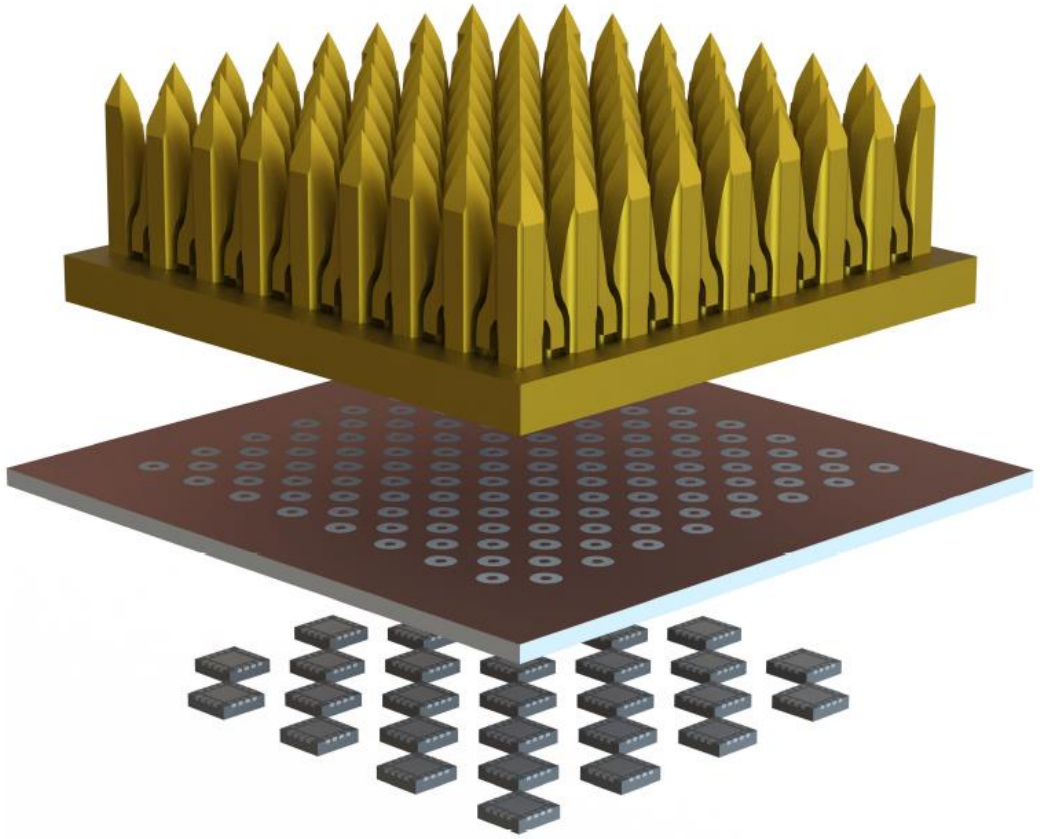
- Linearity
- Polarization
- Error vector magnitude
- Efficiency
- Sidelobes

# Surface-mountable 3D antenna arrays

Surface-mount antenna array

Single multi-layer PCB

Active components on a PCB



High efficiency (>90%)

Two polarizations

Broadband (26-40 GHz)

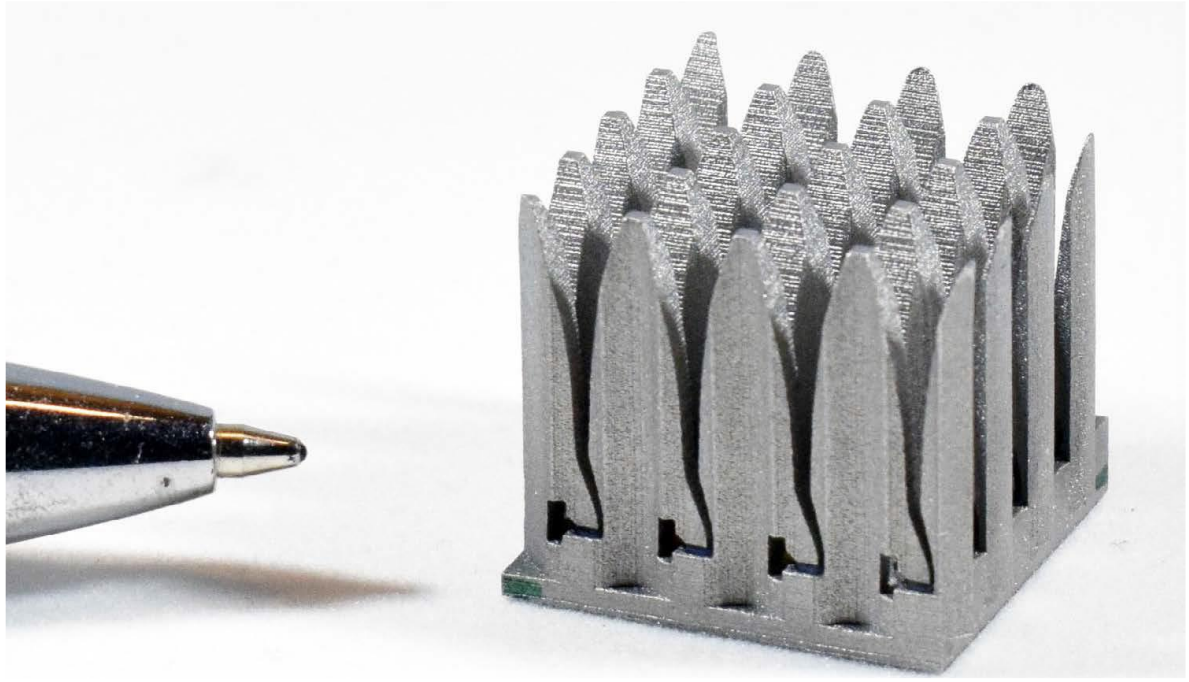
Wide beam steering ($\pm 60°$)

Low active reflection (<-10 dB)

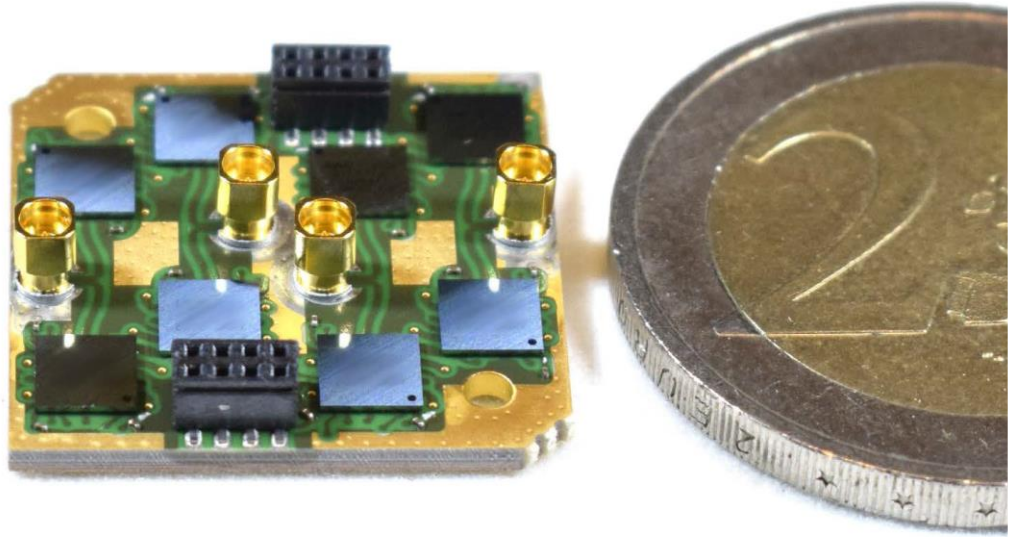

H. Kähkönen et. al, "Dual-polarized Ka-band Vivaldi antenna array," *IEEE TAP*, 2020
H. Kähkönen et. al, "A Modular Dual-Polarized Ka-Band Vivaldi Antenna Array," *IEEE Access*, 2022
H. Kähkönenet. al, "Comparison of additively manufactured and machined antenna array performance at Ka-band," *IEEE AWPL* 2022
H. Kähkönen et. al, "Surface-mounted Ka-band Vivaldi antenna array," *IEEE OJAP*, 2021

# Example 3: Modular dual-pol 18-30 GHz array

3D-printed array module
4x4 dual-pol elements



PCB module with beam former chips



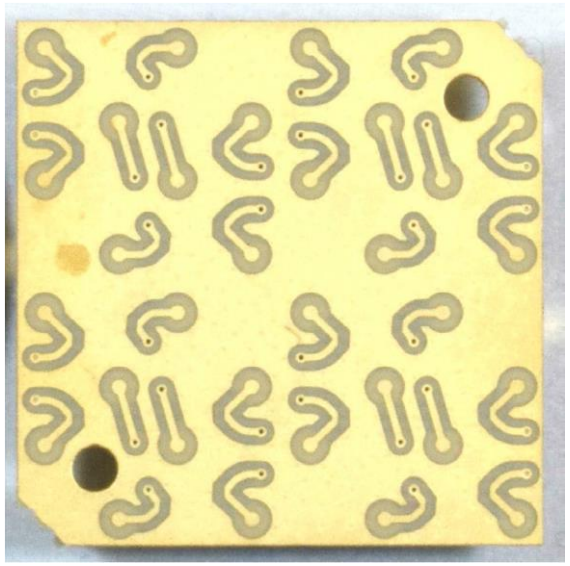
H. Kähkönen et. al, "A Modular Dual-Polarized Ka-Band Vivaldi Antenna Array," *IEEE Access*, 2022

# Example 3: Modular dual-pol 18-30 GHz array

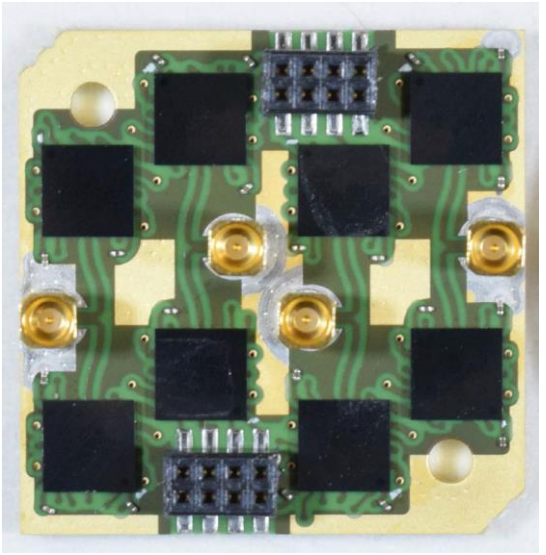
Array module side

Array module bottom

PCB module top



PCB module bottom



H. Kähkönen et. al, "A Modular Dual-Polarized Ka-Band Vivaldi Antenna Array," *IEEE Access*, 2022

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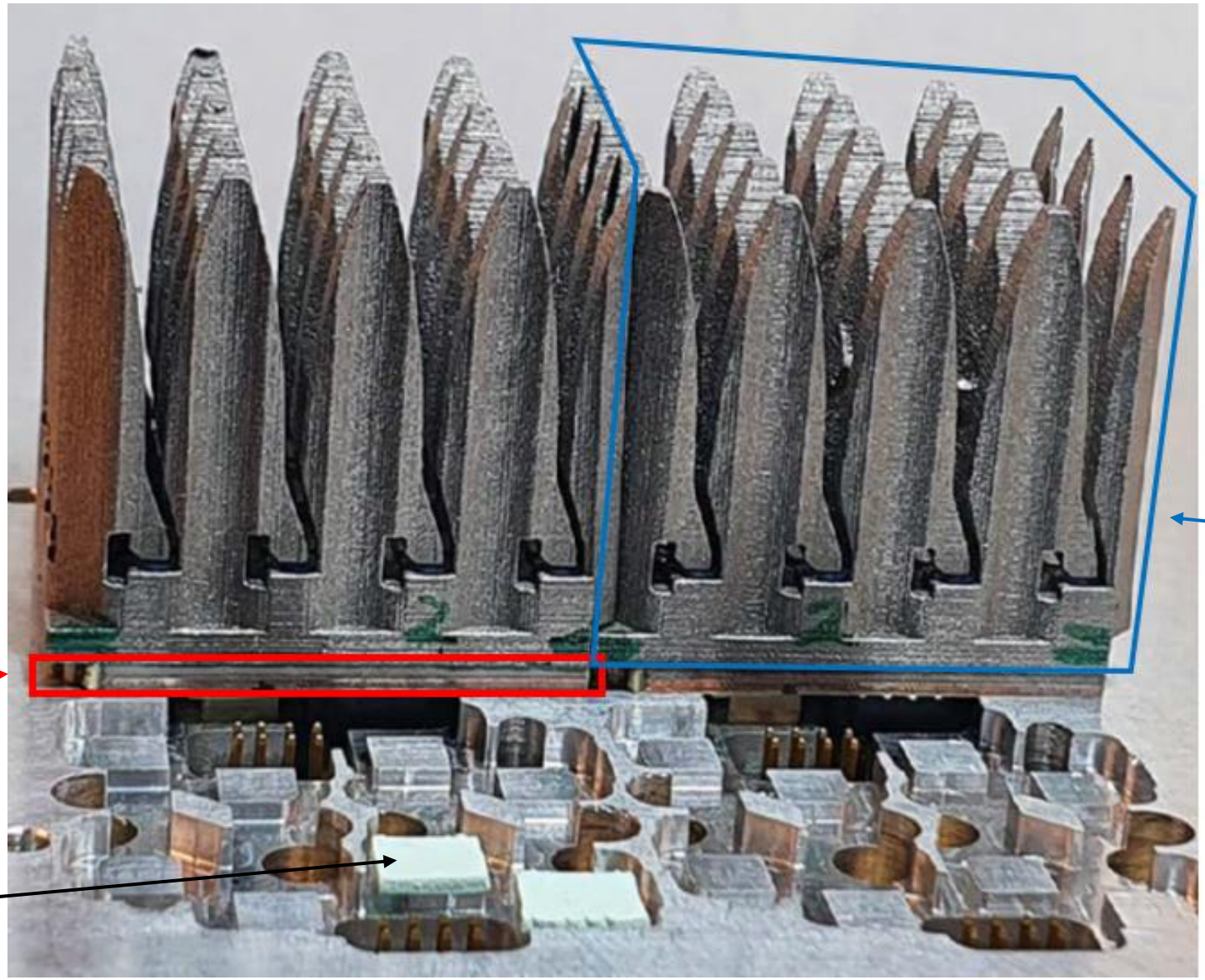
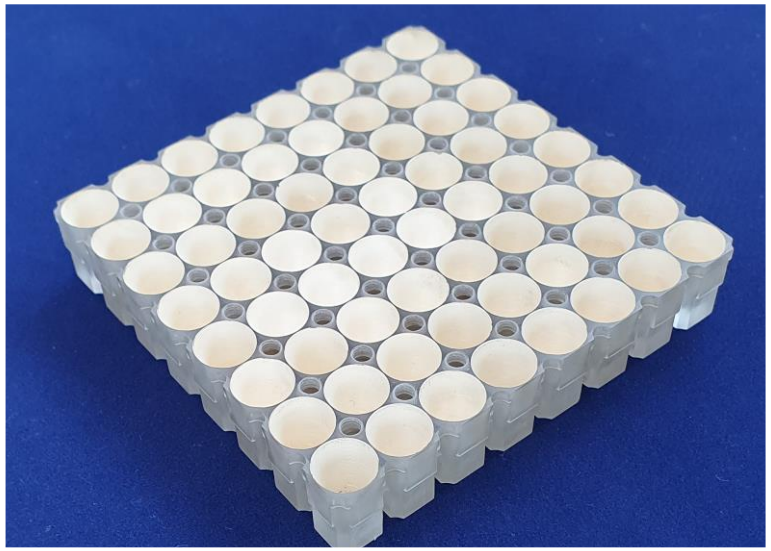


# Example 4: New fabrication methods

## Traditional BoR-antenna

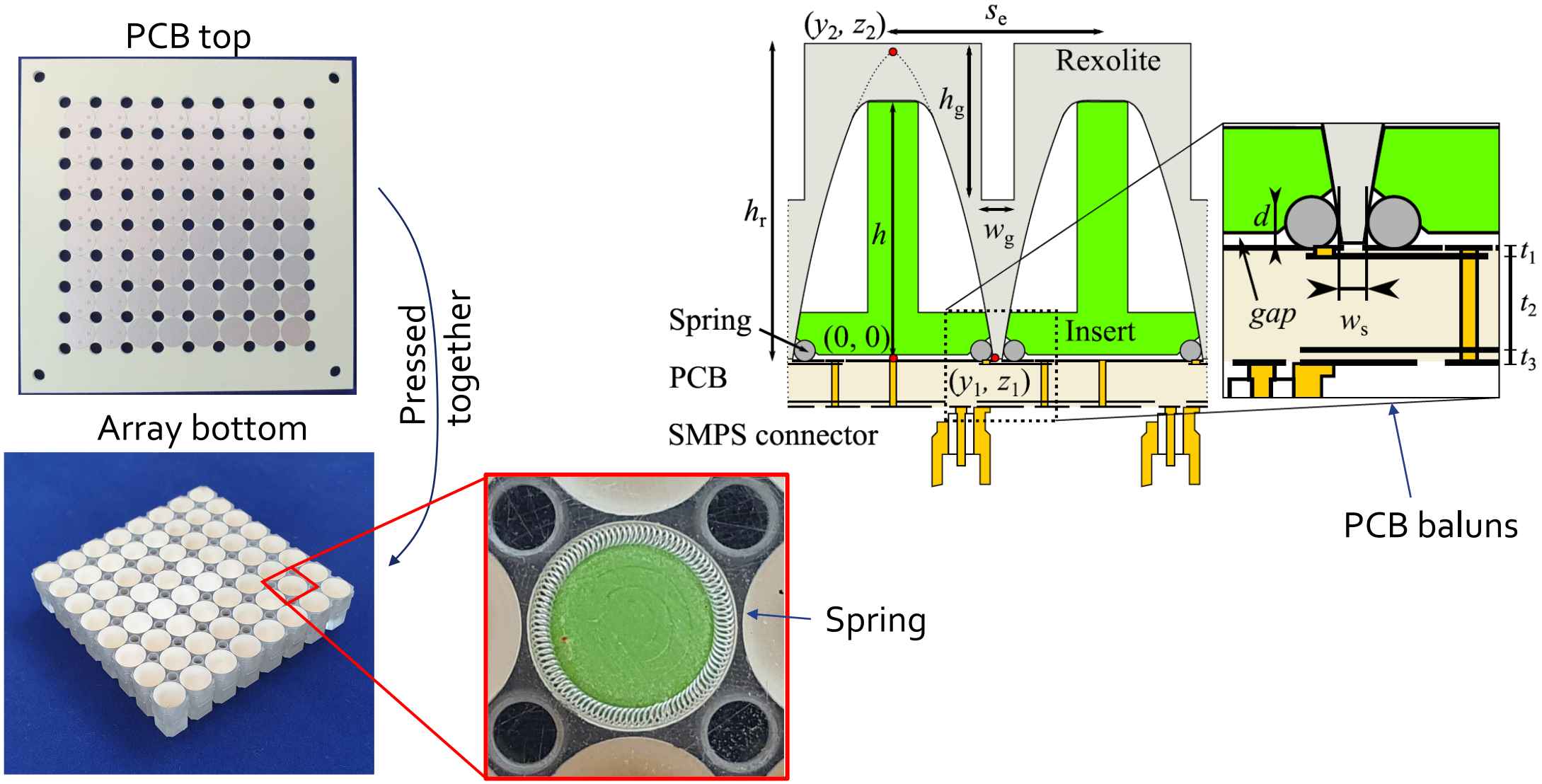

- Excellent electrical performance
- Solid metal – heavy and expensive (at lower frequencies)
- Costly fabrication

## Inverted 6-18 GHz BoR-antenna



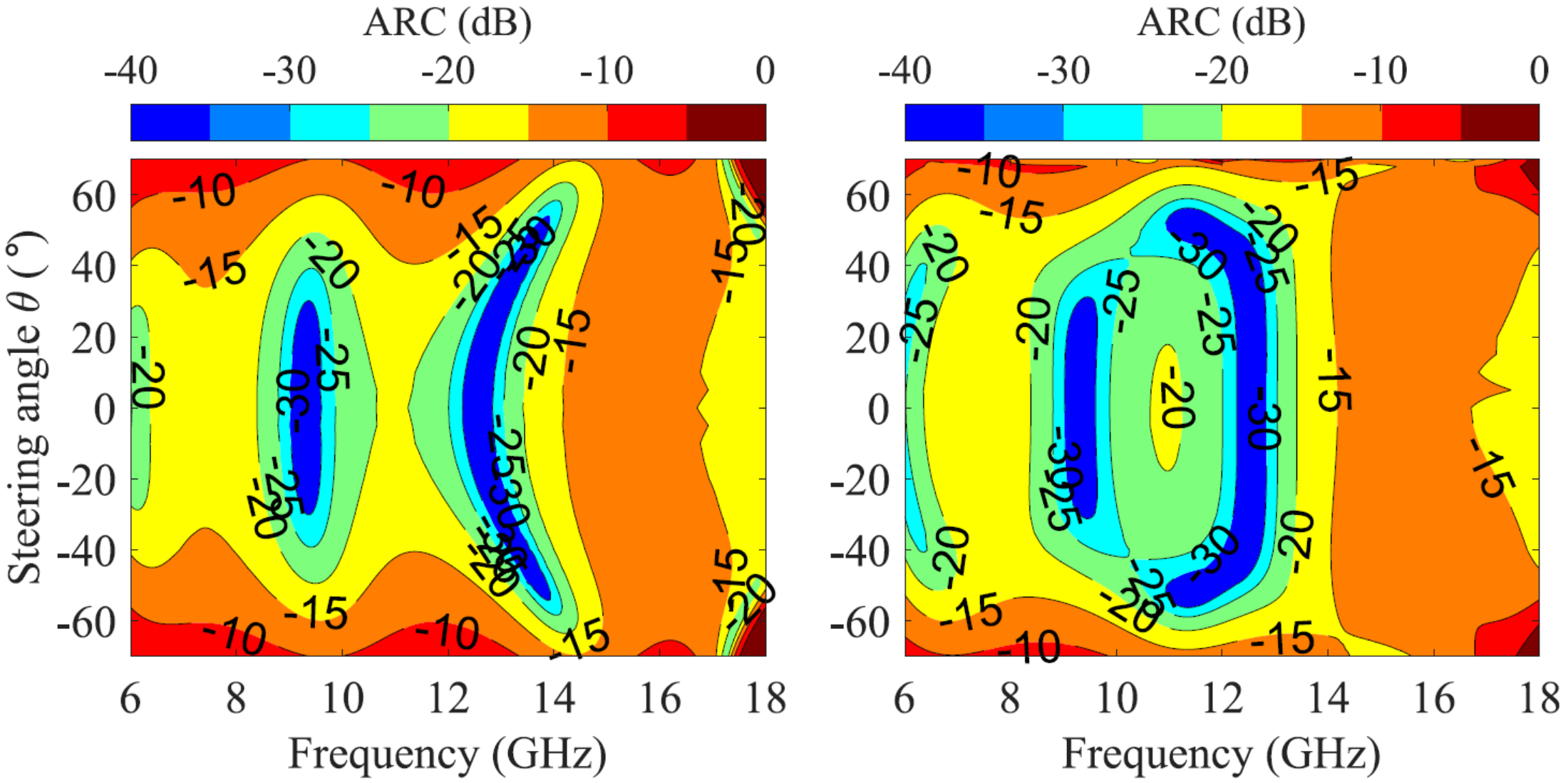
- Metal-coated plastic shell
- Lightweight, minimal use of materials
- Excellent electrical performance
- Inexpensive fabrication processes available

# Inverted BoR structure




M. Kuosmanen et. al., "Dual-Polarized 6–18 GHz Antenna Array with Low-Profile Inverted BoR Elements," IEEE OJAP 2022

# Simulated (infinite array) active reflection coefficient

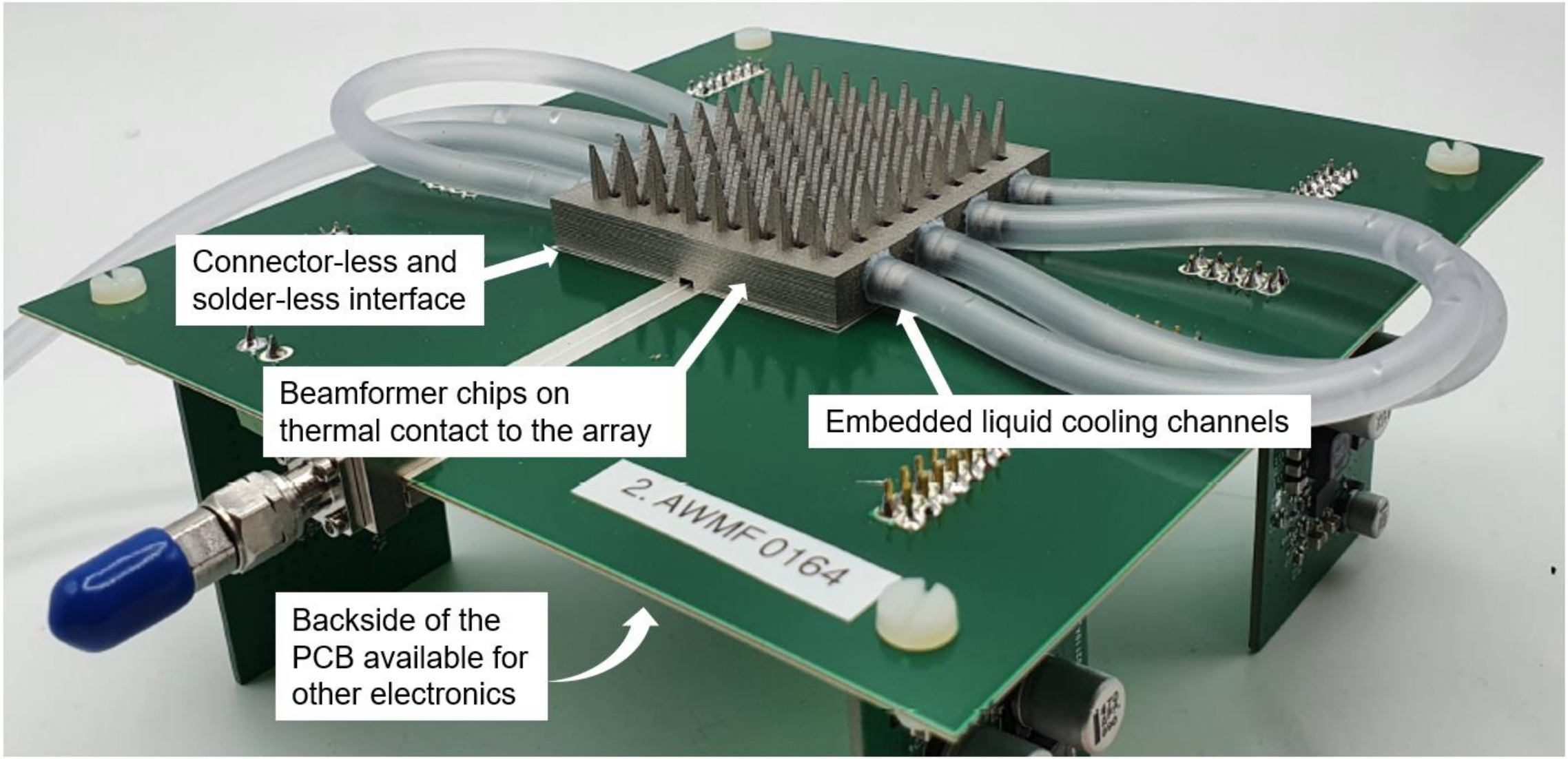


# Challenge: cooling

4-channel beamformer chip
1.5 W, 3.6 x 3.6 mm²
~0.12 W/mm²

One heating element in sauna stove
1500 W, 60 000 mm²
~0.025 W/mm²

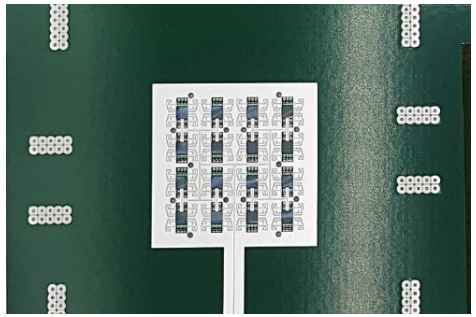
# Example 5: Scalable 8x8 24-29.5 GHz liquid-cooled array



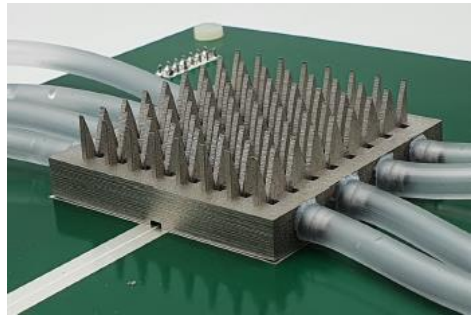

J. Haarla et. al., "Scalable 3D-printable antenna array for 28 GHz with liquid cooling," accepted with major revision to IEEE TAP

# Different cooling approaches

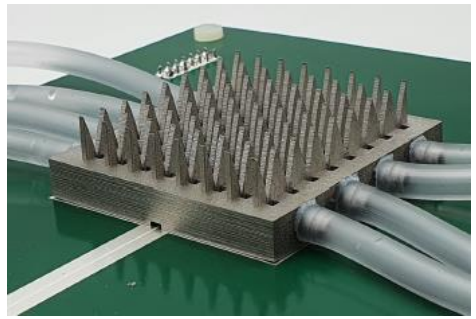
**No fan**
**No liquid cooling**
- No continuous use of receiver or transmitter



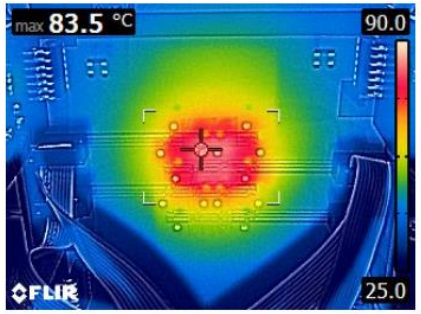
**Fan**
**(forced convection)**
- No continuous use of transmitter

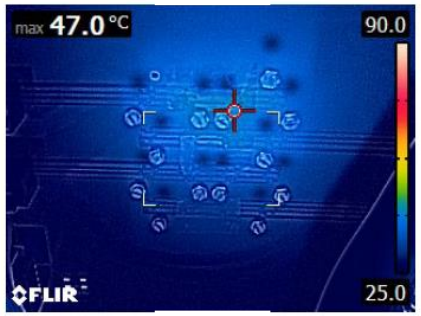


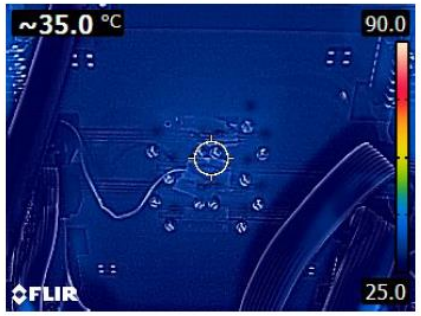
**Liquid cooling**
- Continuous use of receiver and transmitter



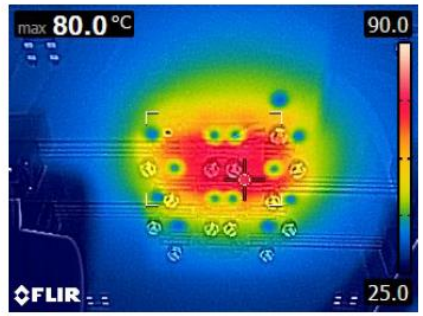
**Receiver on**



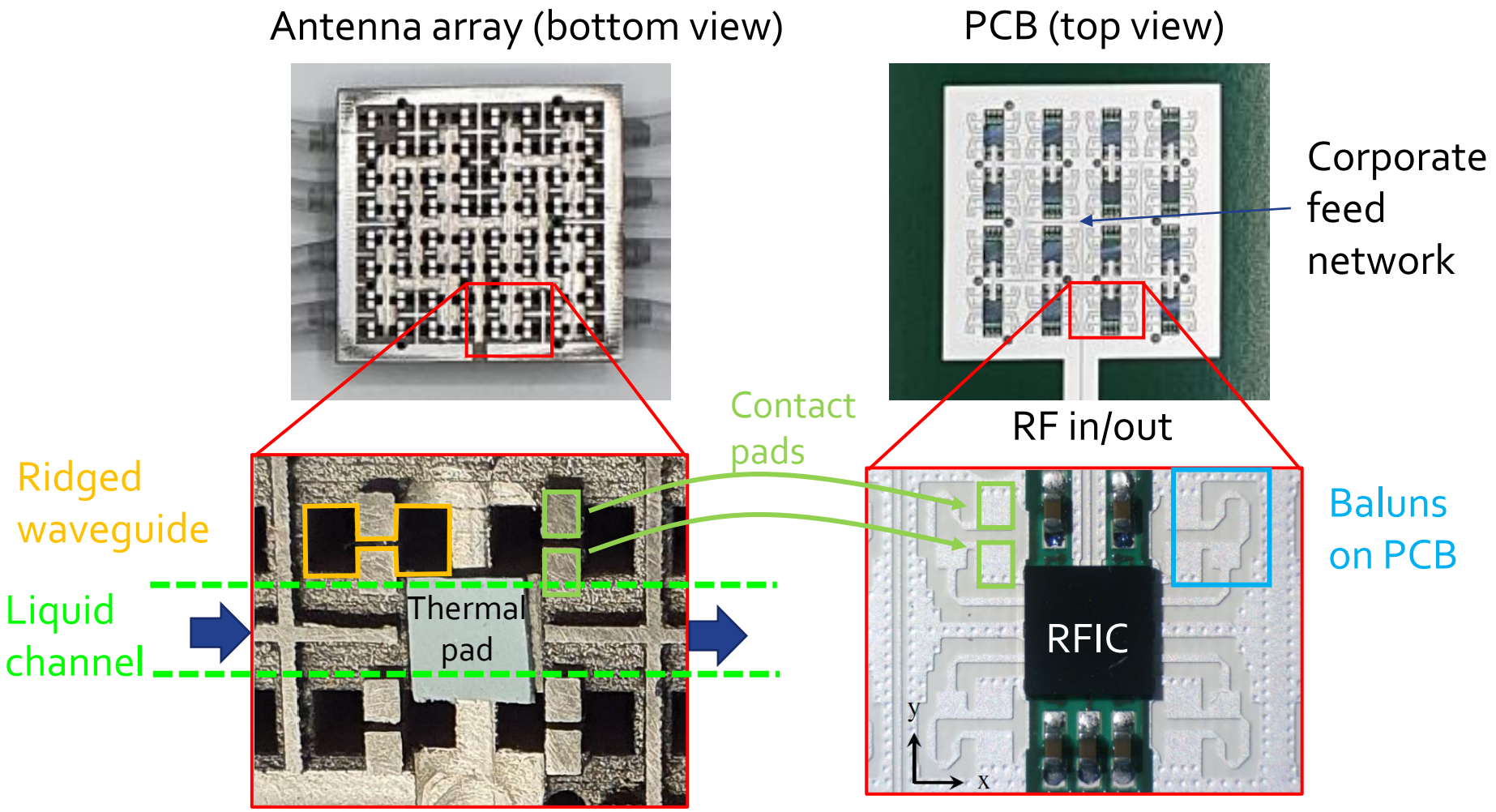



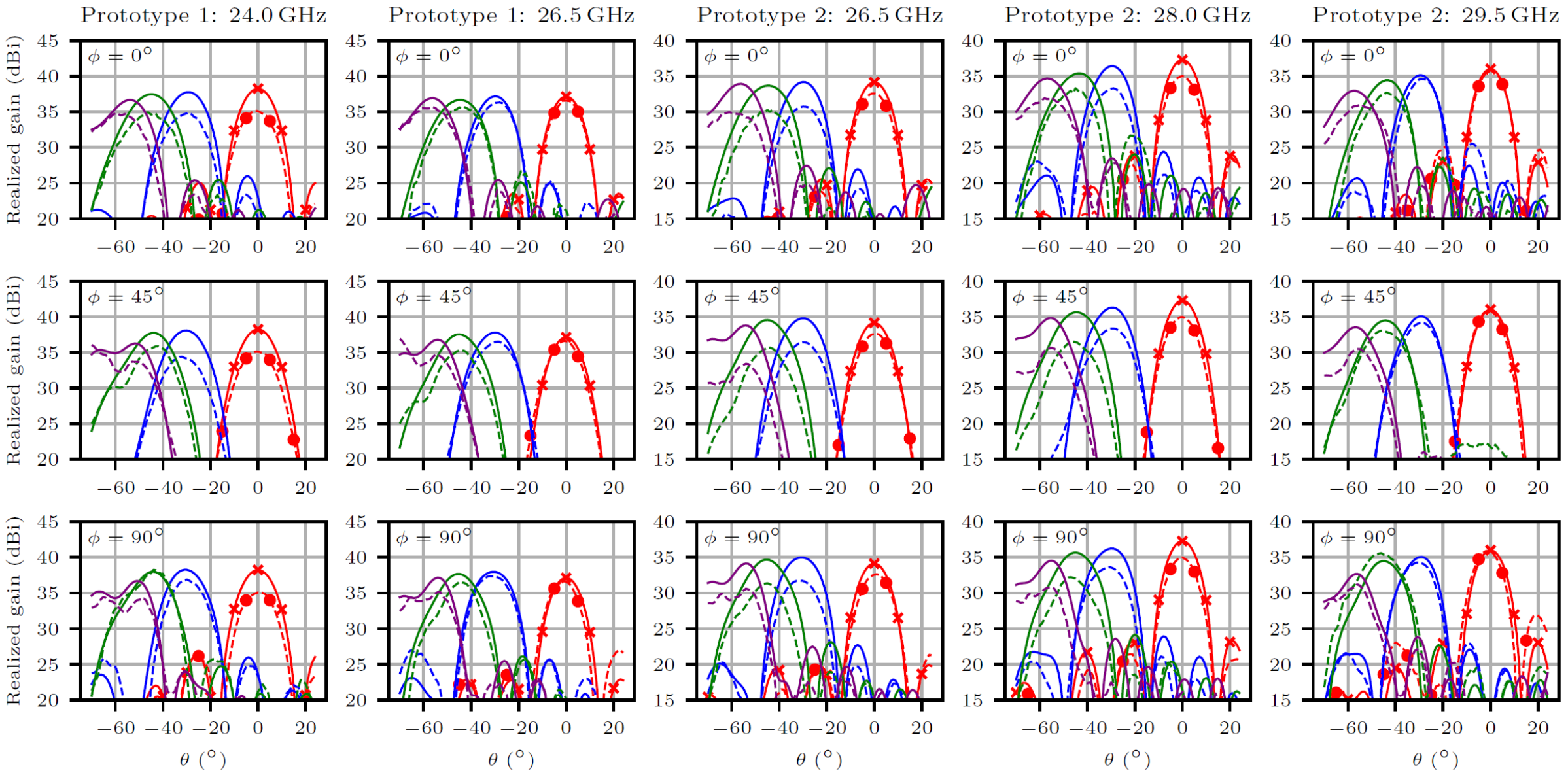

**Transmitter on**




# Antenna PCB interface



# Simulated (solid) and measured (dashed) gain



# Summary

- mm-wave frequencies may provide much better use of radio wave energy
- Mutual coupling always exist and can be used for benefit
- 3D surface-mountable arrays can provide superior performance
- Thermal performance becomes vital

# Thank you!

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