Advancements in Antenna Arrays

New manufacturing techniques and integration of microwave components

Matti Kuosmanen

Saab Finland Oy

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Acknowledgement

Aalto University
School of Electrical Engineering

SAAB

- This presentation is based on doctoral thesis to be defended on 11 April 2025.
  - Supervisor: Prof. Ville Viikari
  - Advisors: Dr. Juha Ala-Laurinaho and sen. univ. lect. Jari Holopainen
- The research has been conducted in Aalto University under Saab–Aalto doctoral program.

Outline

Overview of three different topics:

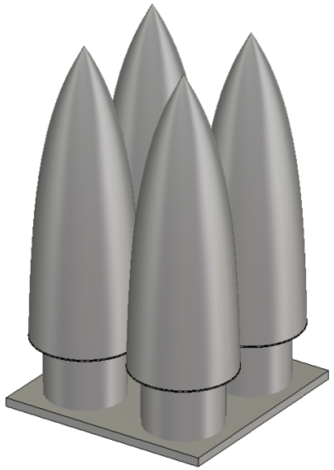
1. Inverted BoR antenna array – a new way to manufacture wideband antenna arrays
2. Filtering antenna arrays
3. Active antenna arrays

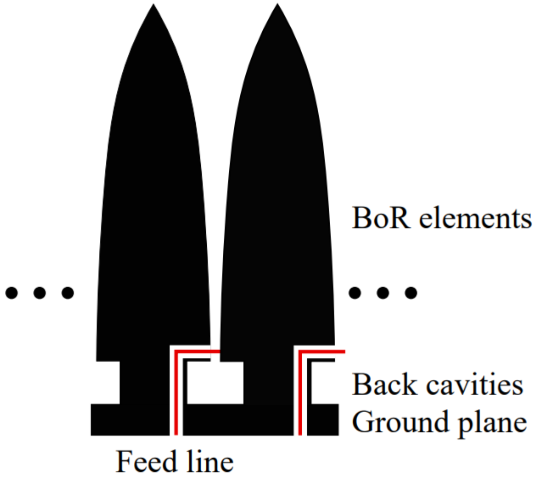
1. Inverted BoR antenna arrays

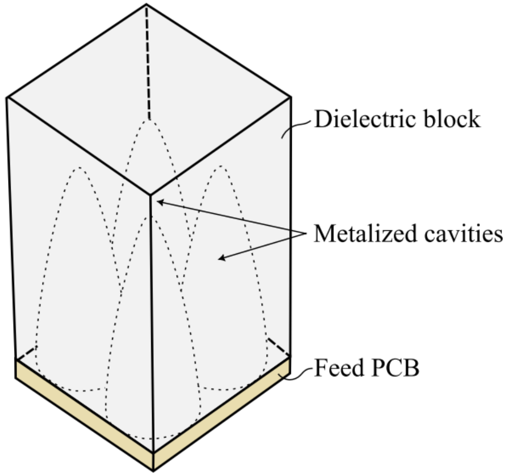
Wideband, lightweight antenna array

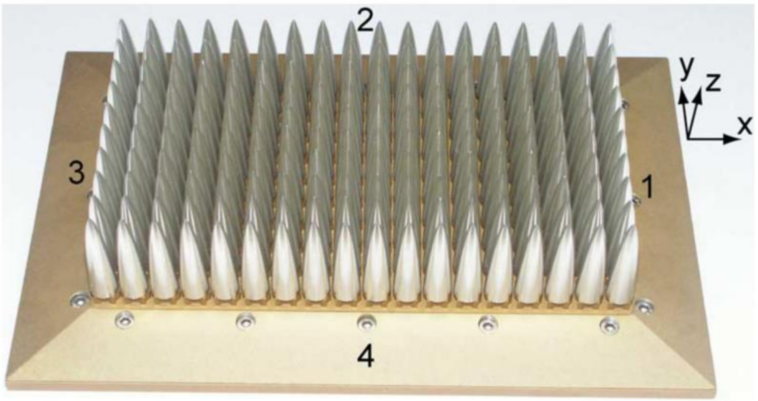
Inverted BoR antenna concept

- BoR (body-of-revolution) antenna is a wideband antenna element developed by Saab [1]
  - “Bullets” form Vivaldi elements
  - Used in various EW purposes
- Inverted BoR is electrically similar antenna with different manufacturing technique
  - Bullets replaced by metalized cavities in dielectric material
  - Lightweight structure

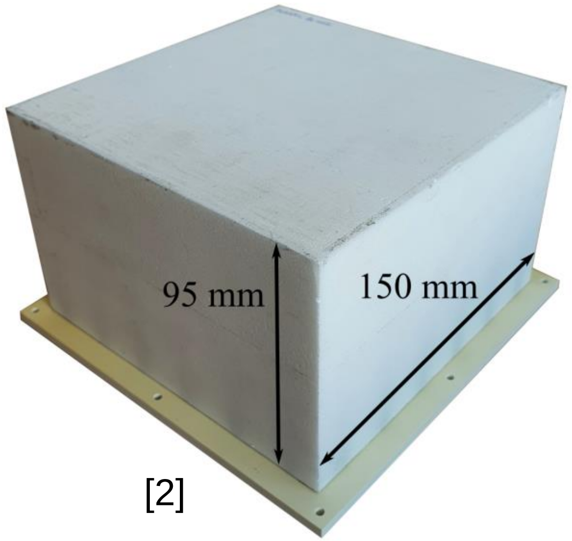








[1]



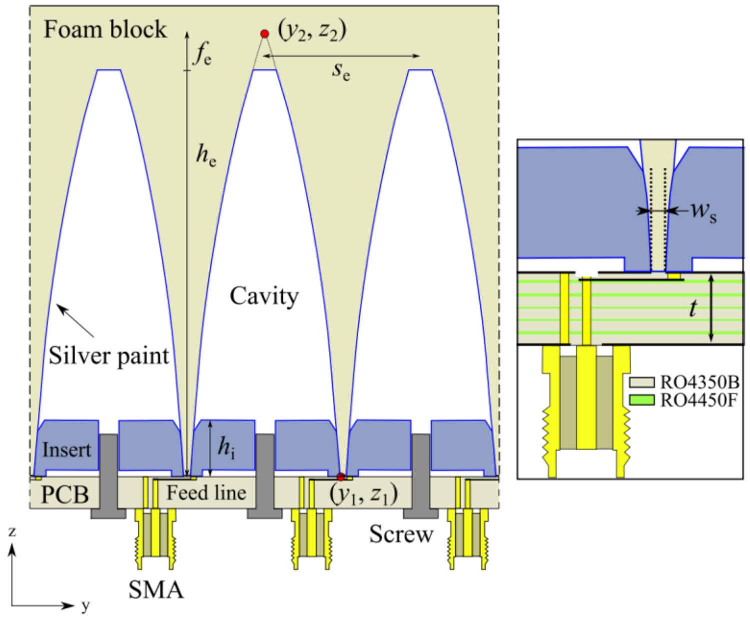
[2]

[1] H. Holter, "Dual-Polarized Broadband Array Antenna With BOR-Elements, Mechanical Design and Measurements," in *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 2, pp. 305-312, Feb. 2007, doi: 10.1109/TAP.2006.886557.

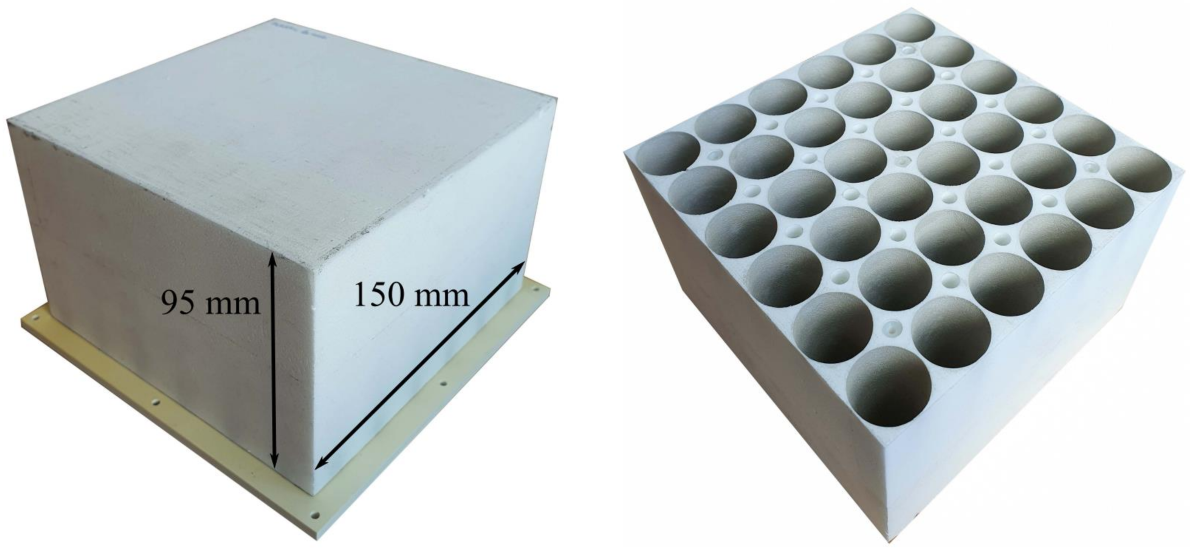
[2] M. Kuosmanen *et al*., "Dual-Polarized 2–6 GHz Antenna Array With Inverted BoR Elements and Integrated PCB Feed," in *IEEE Open Journal of Antennas and Propagation*, vol. 3, pp. 229-237, 2022, doi: 10.1109/OJAP.2022.3143993.

2–6 GHz inv. BoR array

- Rohacell 71 HF foam as a dielectric
- Metalization with silver paint
- Considerable reduction in weight
  - Feed PCB is the heaviest part



Antenna array	Parts	Mass (g)	Total (g)
This work	Foam block, height 95 mm	130	517
	3-D printed inserts	99	
	PCB	288	
Plastic array	3-D printed hollow cones	420	708
	PCB	288	
All-metal array	Solid cones (Al)	1500	1890
	Back plane (Al)	390	



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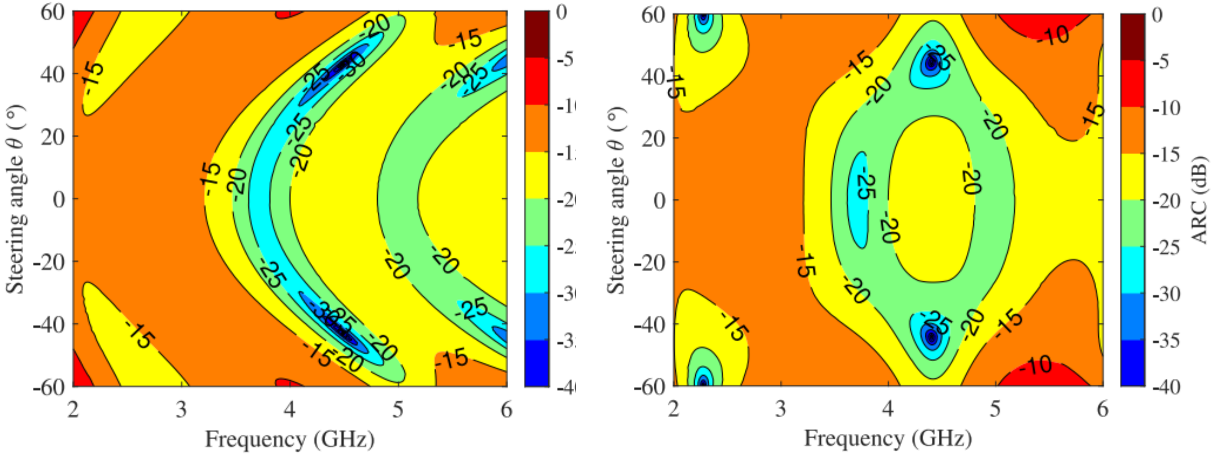
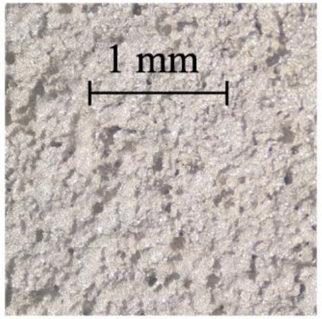
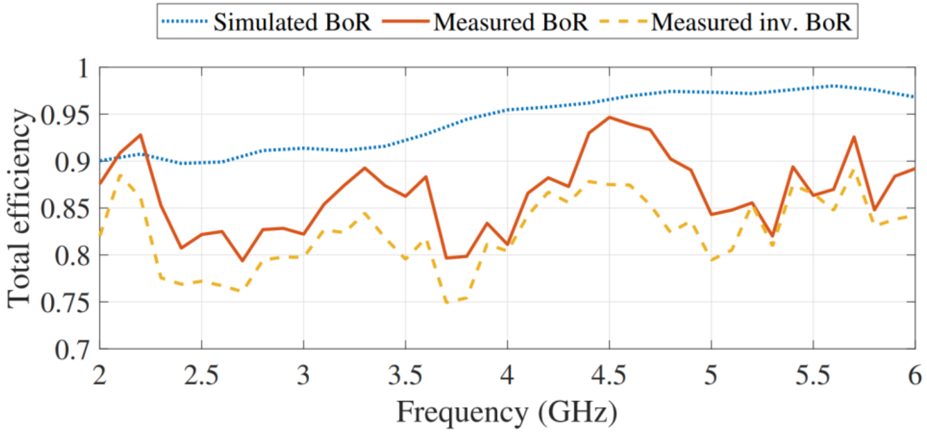
2–6 GHz inv. BoR array

- At least 50° beam steering in all planes with < -10 dB active reflection coefficient
- No scan blindness
- Radiation efficiency slightly reduced in comparison to equivalent BoR array
  - Surface roughness of the metalization
  - Moisture absorption of Rohacell
- High cross-polarization levels in D-plane
  - Typical for long Vivaldi elements







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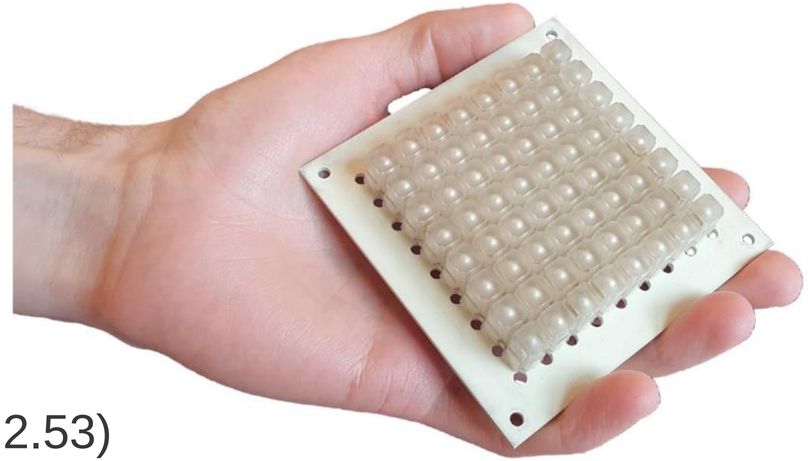
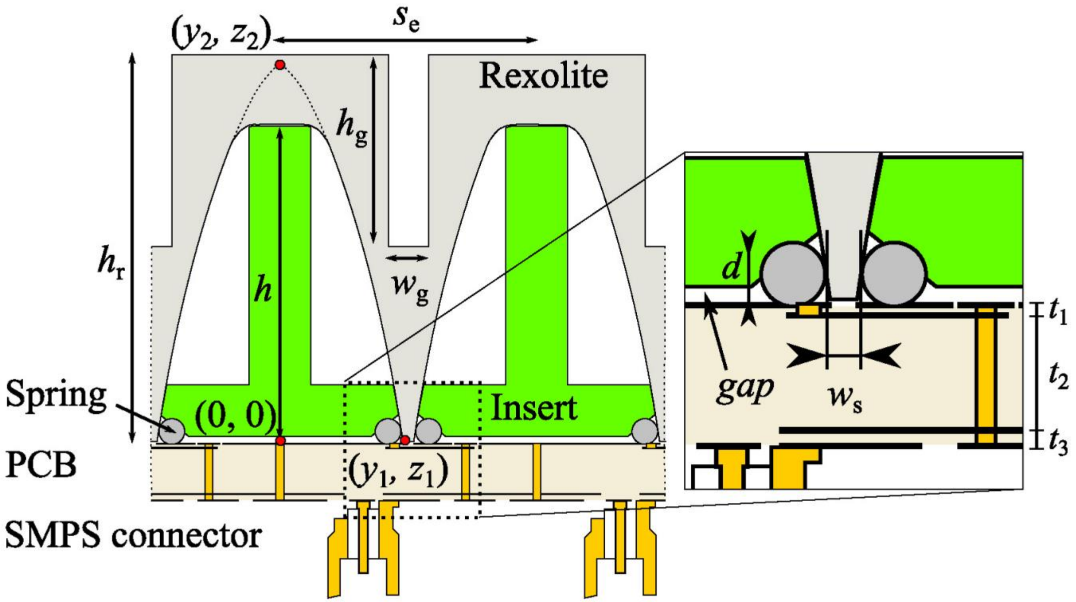
M. Kuosmanen, J. Ala-Laurinaho, J. Holopainen and V. Viikari, "Antenna Array Based on 3D-printed Plastic BoR Elements Coated with Conductive Paint," *2023 17th European Conference on Antennas and Propagation (EuCAP)*, Florence, Italy, 2023, pp. 1-5, doi: 10.23919/EuCAP57121.2023.10133144.

6–18 GHz inv. BoR array



- Higher frequency range
- Higher-permittivity dielectric material (Rexolite, Dk = 2.53)
  - Lower profile
  - Prone to surface waves and scan blindness
  - Grooves in the dielectric material reduce the effective permittivity, prevent surface waves and improve scan performance
- Better polarization performance than 2–6 GHz array due to lower profile
- Better efficiency due to improved surface roughness, lower dielectric losses, and better metalization



M. Kuosmanen, S. E. Gunnarsson, J. Malmström, J. Holopainen, J. Ala-Laurinaho and V. Viikari, "Dual-Polarized 6–18-GHz Antenna Array With Low-Profile Inverted BoR Elements," in *IEEE Open Journal of Antennas and Propagation*, vol. 4, pp. 3-11, 2023, doi: 10.1109/OJAP.2022.3227546.

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2. Filtering antenna arrays

Filter integration into wideband antenna arrays

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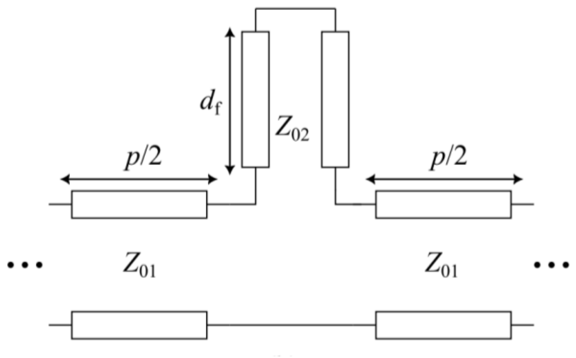
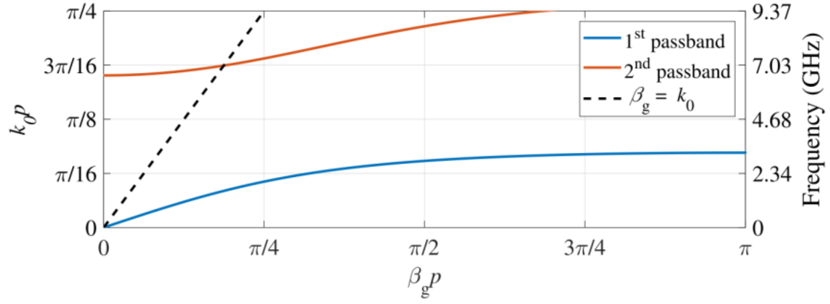
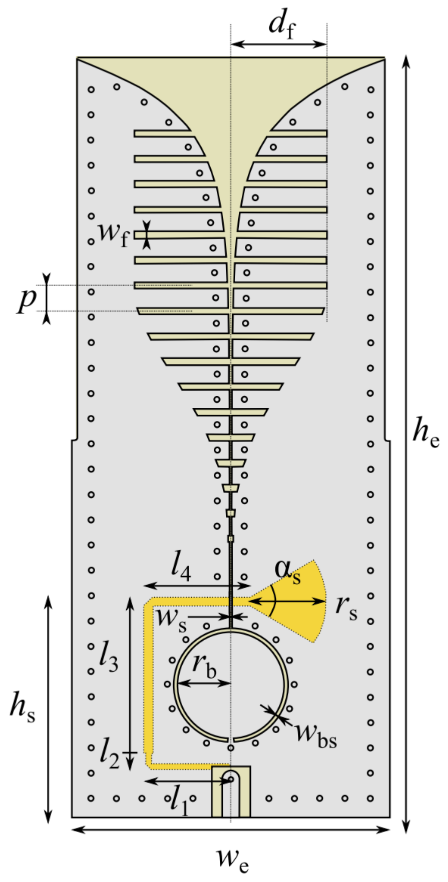
Filtering antennas based on corrugated slotlines

- Corrugated slotline: a slotline, which has short-circuited series-stubs densely spaced along the slotline
- Due to dense spacing (w.r.t. wavelength), the corrugated slotline appears homogenous for the incident wave
- Corrugation causes dispersion that leads to **low-pass** behavior with very steep transition band
- Dispersion model can be derived from the ABCD parameters of the equivalent circuit

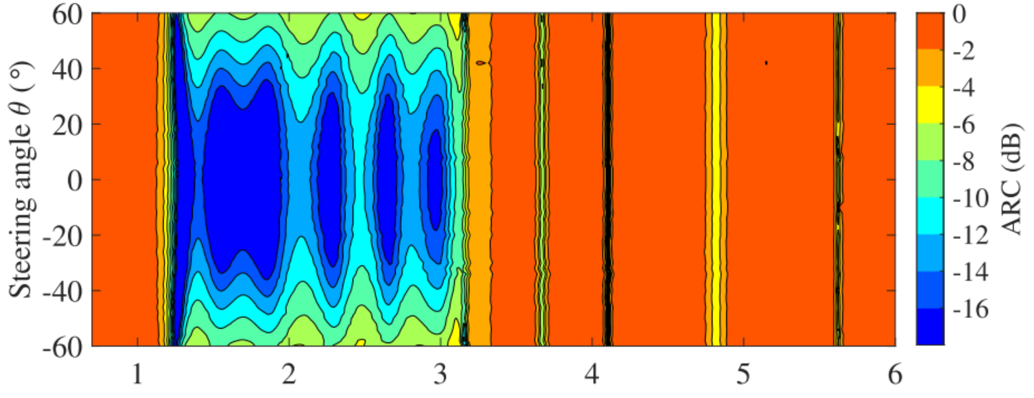




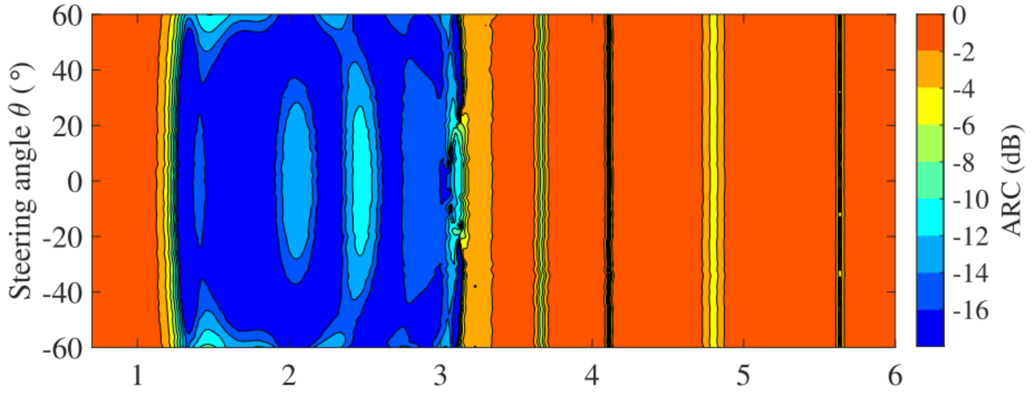


M. Kuosmanen, J. Holopainen, J. Ala-Laurinaho, T. Kiuru and V. Viikari, "Filtering Antenna Array Based on Corrugated Vivaldi Elements," in *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 8, pp. 6546-6557, Aug. 2023, doi: 10.1109/TAP.2023.3278879.

1.2–3.1 GHz filtering array

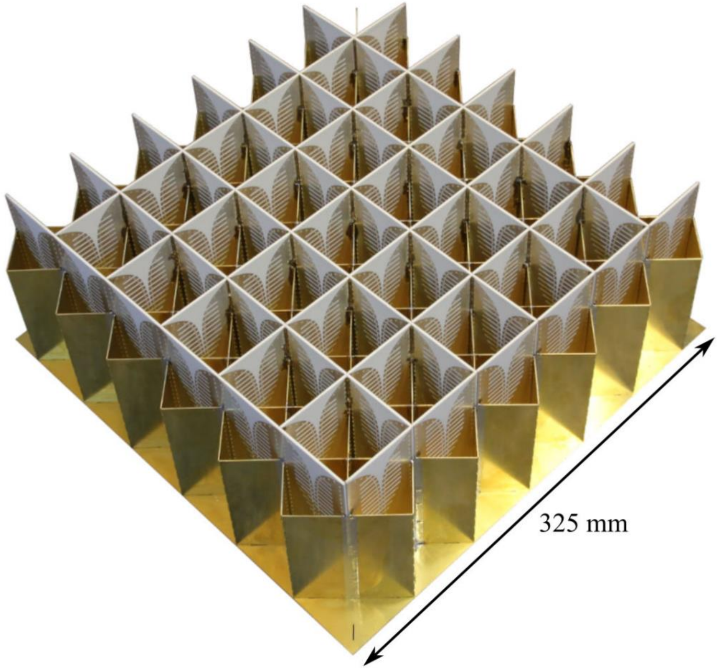


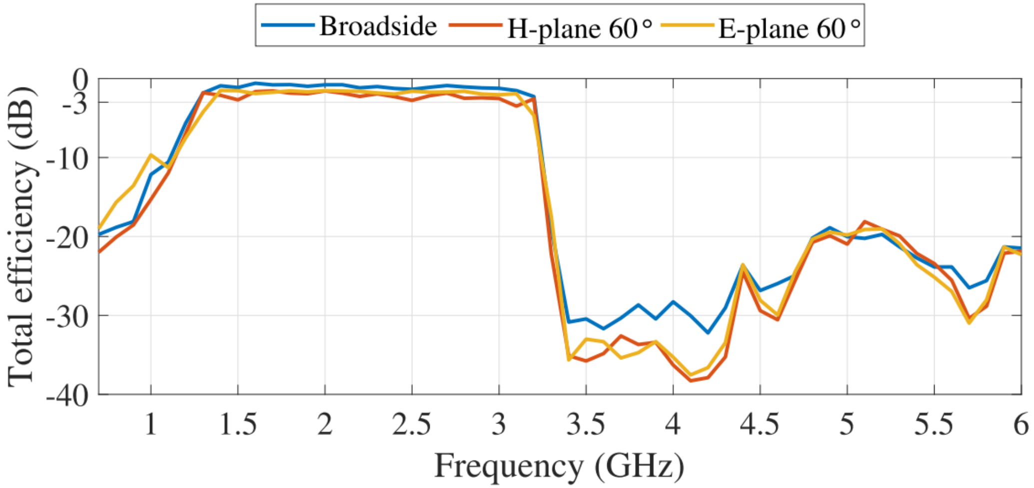
(a)



(b)

Simulated active reflection coefficient of the antenna array in (a) H-plane and (b) E-plane.





Measured total efficiency of the antenna array with three different beam-steering directions.

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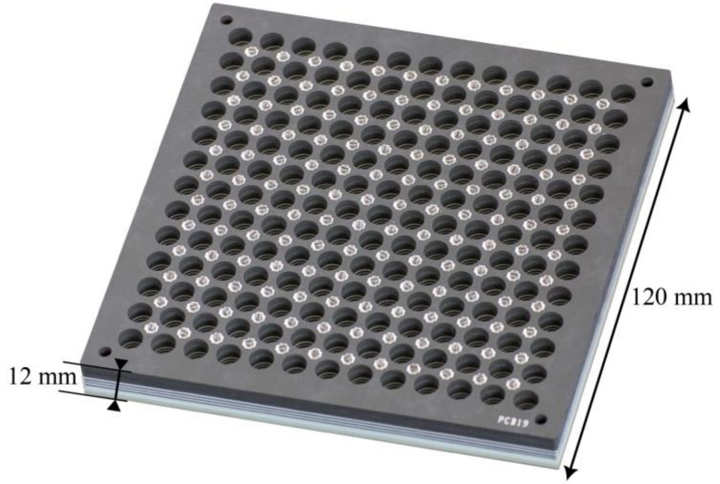
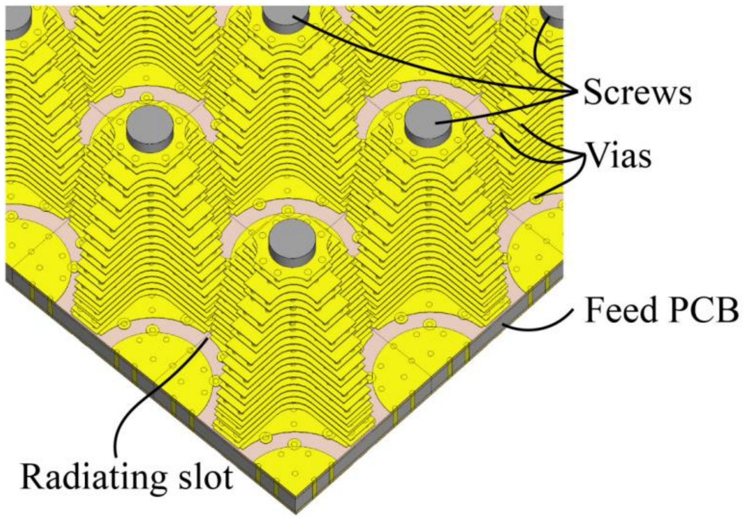
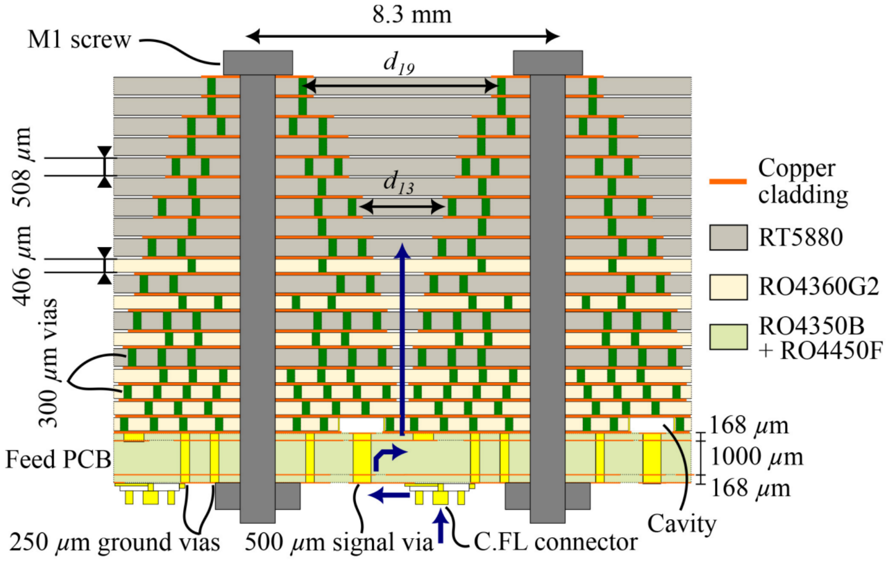
6–18.5 GHz filtering array based on stacked PCBs

- Traditional Vivaldi with crossed PCB (egg-crate lattice) is difficult to manufacture due to manual work
- In stacked-PCB structure the copper layers of the PCB stack construct the antenna elements
- Corrugation can be added -> low-pass filtering functionality
- Prototype constructed of separate 2-sided PCBs but also multilayer stack up is possible



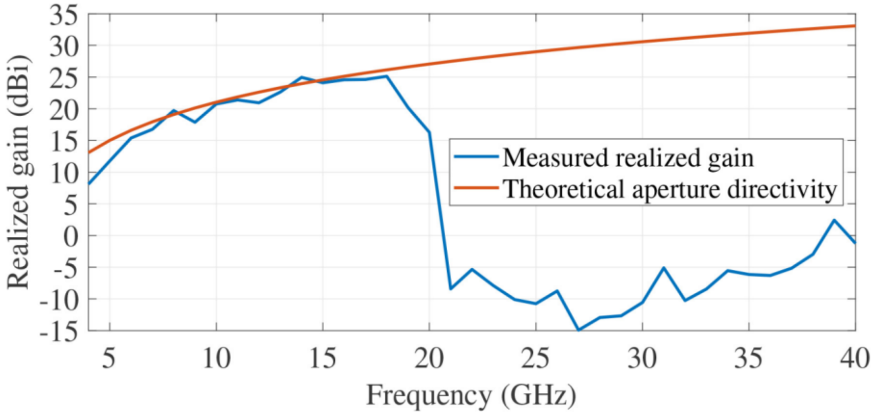


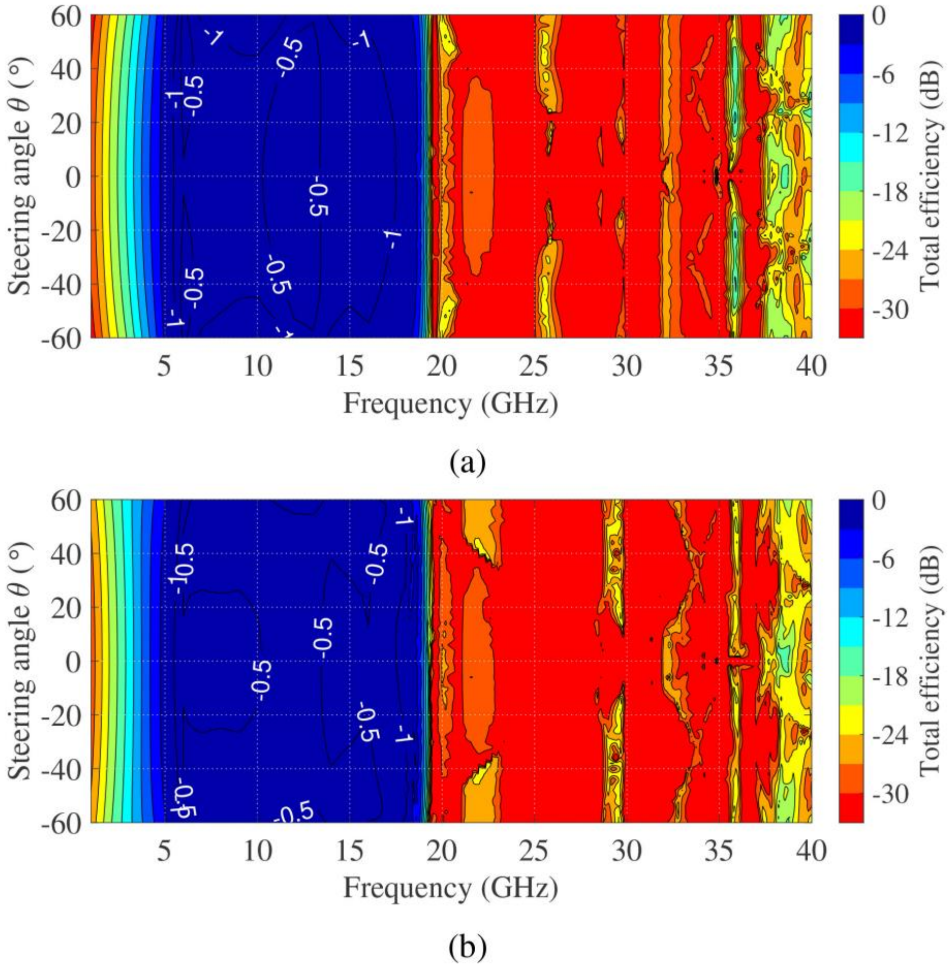


M. Kuosmanen, S. E. Gunnarsson, J. Malmström, J. Ala-Laurinaho, J. Holopainen and V. Viikari, "Dual-Polarized Wideband Filtering Antenna Array Based on Stacked-PCB Structure," in *IEEE Open Journal of Antennas and Propagation*, vol. 6, no. 1, pp. 38-50, Feb. 2025, doi: 10.1109/OJAP.2024.3466234.

6–18.5 GHz filtering array – electrical performance

- Integrated low-pass filter based on corrugated slotlines
  - Steep transition band
  - Beam-steering independent performance
- Beam-steering ranges ±60° in E-plane (ARC < -10 dB) and ±55° in H-plane (ARC < -6 dB)





Simulated total efficiency in (a) H- and (b) E-planes.

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3. Active antenna arrays

Integration of amplifiers into antenna arrays – opportunities and challenges

Opportunities

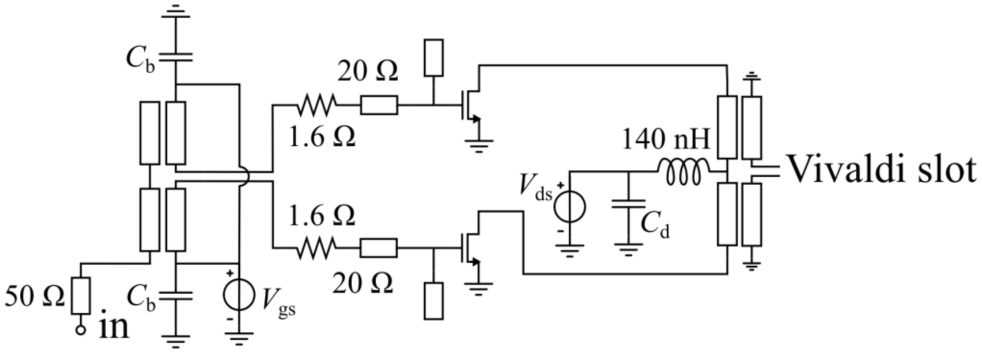
- Avoid restrictions due to 50 Ω impedance interfaces
  - Direct matching without matching network
  - Improved bandwidth
  - Improved efficiency
- Compact size
  - Amplifiers integrated into antenna array. In best case, no extra space required

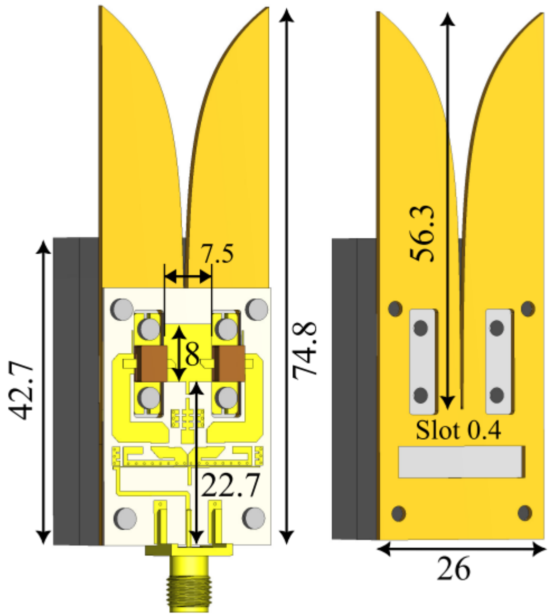
Challenges

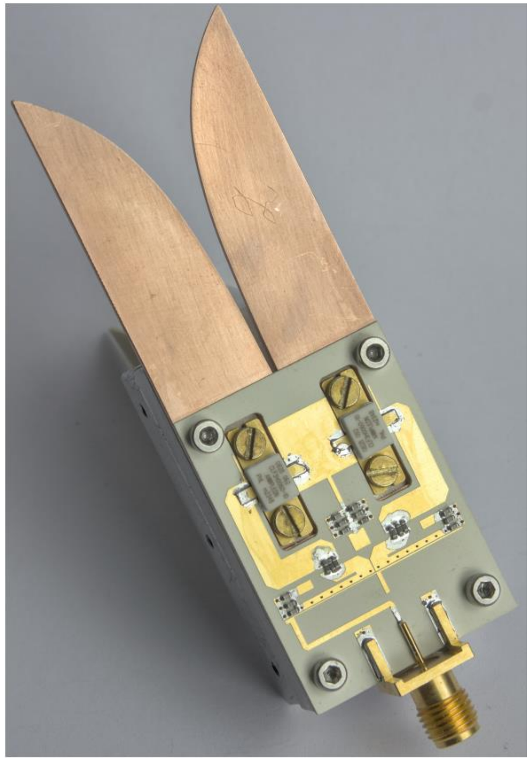
- Integration of both high-power amplifier and low-noise amplifier
  - Isolation, different impedance requirements, space restrictions
- Design of (stable) amplifier with desired properties for a coupled antenna array
  - Excitation-dependent active impedance can lead to detrimental load-pull effects

Vivaldi antenna array with integrated push–pull amplifier

- Push–pull amplifier: two high-power discrete GaN transistors are fed in opposite phases
  - Cancellation of second harmonic
  - High power
  - Ideal for balanced antennas
- Class AB amplifier without load modulation
- Integration into codesigned Vivaldi antenna



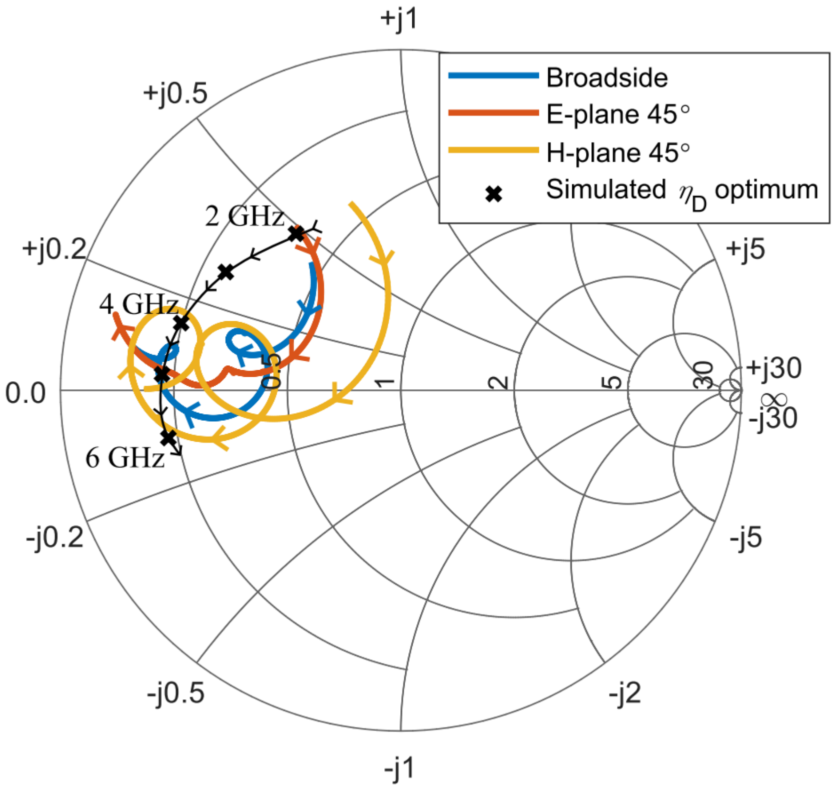




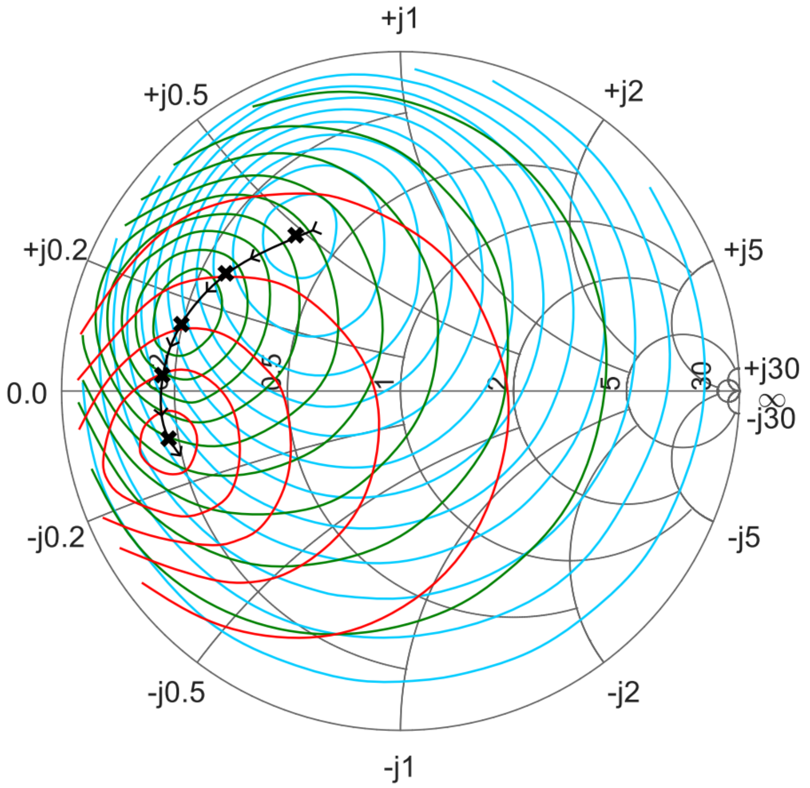
One antenna element of the active antenna array

M. Kuosmanen, doctoral thesis, to be published in April 2025.

Direct matching



Simulated active antenna impedance and optimal load impedance for GaN transistors.



Drain efficiency contours at 2 GHz (blue), 4 GHz (green), and 6 GHz (red). Corresponding maximal drain efficiencies are 62%, 49%, and 27%. Contour interval is 5%.

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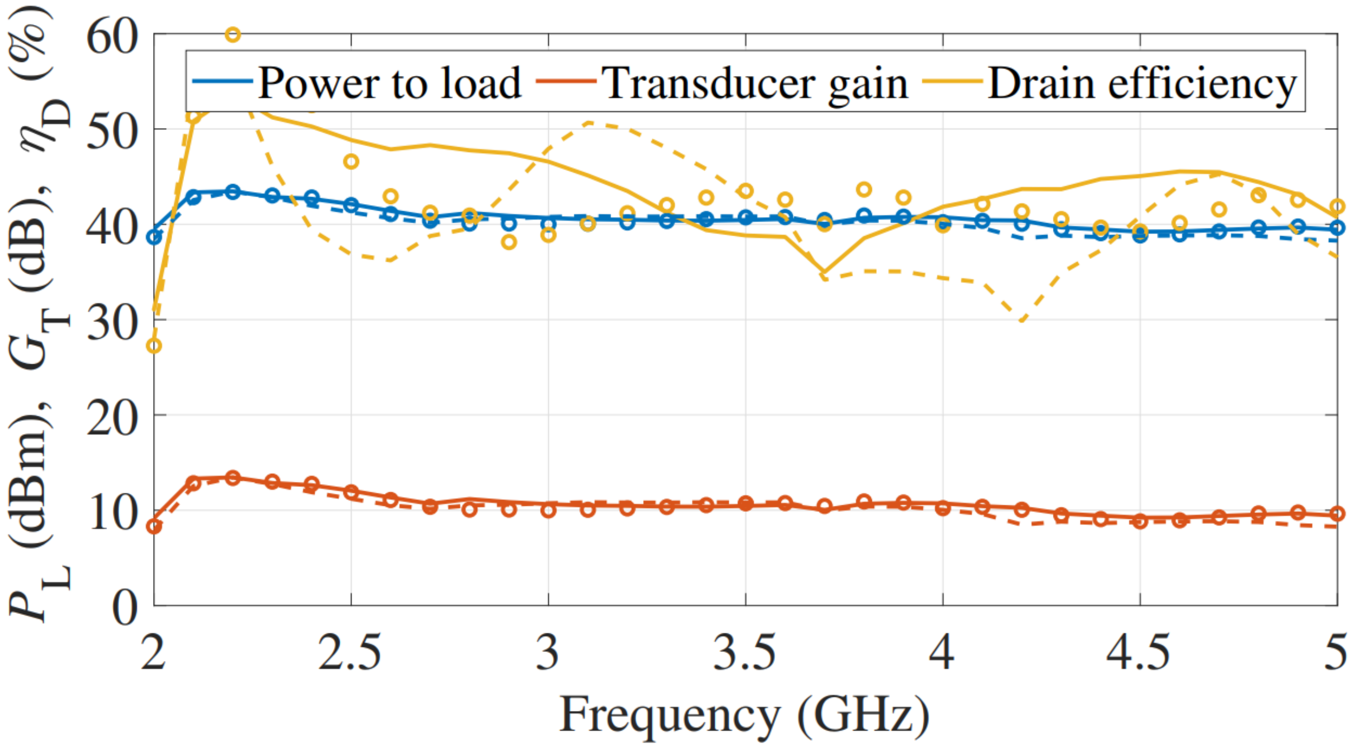
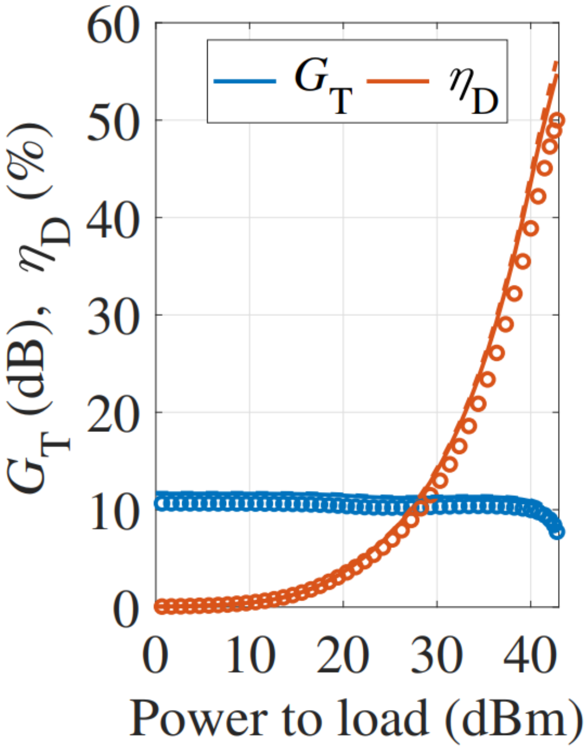
Electrical performance



Simulated frequency response of the active antenna array with broadside scan (solid line), E-plane 45° scan (o), and H-plane 45° scan (dashed line) at 1-dB compression point.



Power response at 3 GHz

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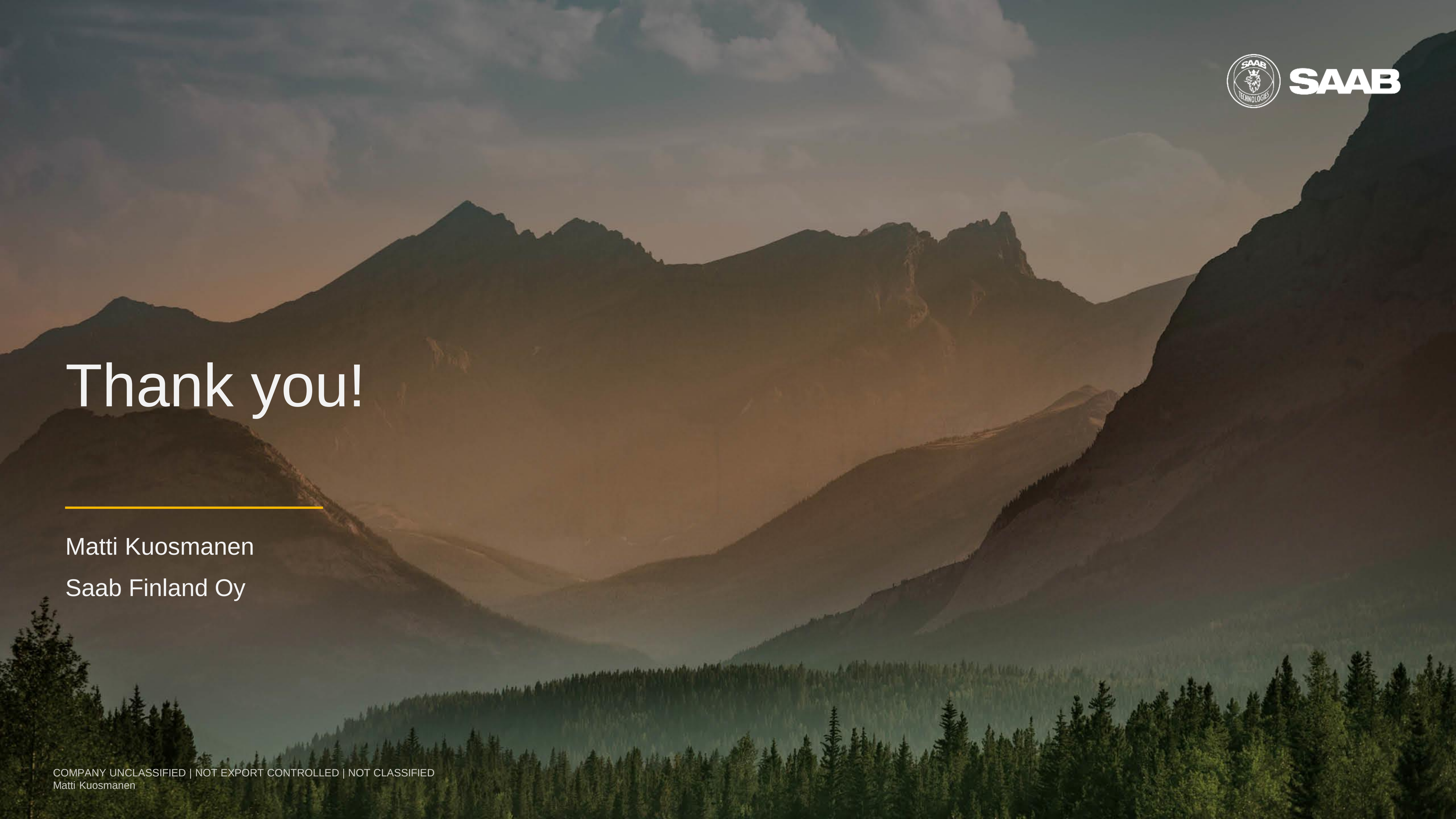
M. Kuosmanen, doctoral thesis, to be published in April 2025.

Conclusion

- Inverted BoR antenna array provides a new, lightweight way to fabricate antenna arrays
  - Radome integration also possible
- The integration of microwave components can lead to more compact and efficient antenna arrays
  - 50 Ω interface is avoided
  - Direct matching of amplifiers and integration of filters into antenna aperture save space
- Integration leads to complicated antenna arrays which require skills in many fields
  - Antenna design, amplifier design, thermal design…



Thank you!

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