SAAB

Challenges in wideband mm-wave phased arrays

Henri Kähkönen

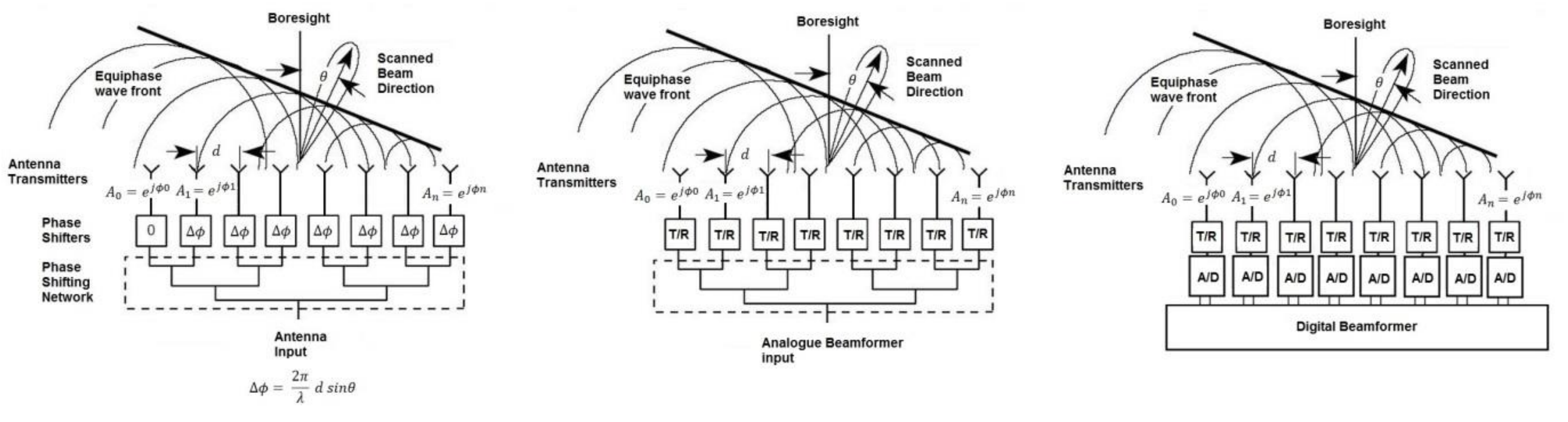
Short introduction

- Name: Henri Kähkönen
- B.Sc, M.Sc, and D.Sc at Aalto university
  - D.Sc studies in Saab-Aalto collaboration concentrated on wideband mmwave array antennas, graduated at the end of 2022
- Currently working at Saab in Tampere as an Antenna engineer

https://www.saab.com/fi/markets/finland/uutiset-ja-tiedotteet/2022/saabin-sirius-compact-tarjoaa-uudenlaista-joustavuutta-elektroniseen-sodankayntiin

Introduction on phased arrays

- An antenna array which sum pattern can be steered or shaped by modifying phase delays (and amplitudes)
- Generally phased arrays have been more common in military applications but are becoming more common in telecommunications
- Passive electronically scanned array (PESA)
  - Single amplifier connected to a feed network with phase shifters
- Active electronically scanned array (AESA)
  - Each element have dedicated amplifiers and phase shifters
  - Possibly multiple transmitters/receivers/transceivers



PESA   AESA with Analogue Beamforming   AESA with Digital Beamforming

https://blogs.plymouth.ac.uk/dcss/2017/12/06/aesa-radar-for-seapower-maritime-applications/

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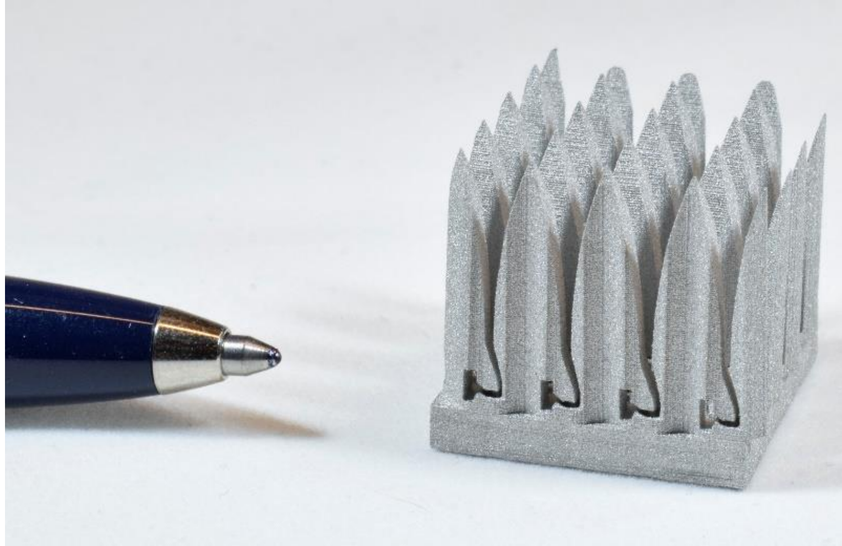
A few of the challenges

1. Moving to higher frequencies decreases the antenna element size / wavelength
   - At 40 GHz wavelength is 7.5 mm -> element spacing ~3.75 mm
2. Wideband antennas are generally more complicated
   - Manufacturing methods
3. Beam steering requires special consideration in preventing unwanted coupling between elements
4. Integrating front-end electronics close to the antenna becomes difficult due to 1. and 2.

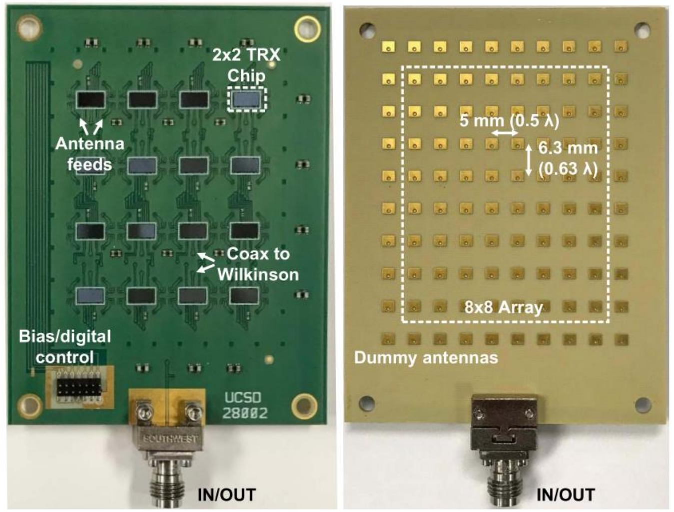
1. Decreased antenna element size

- Millimeter waves: 30-300 GHz
  - Antenna element spacing from 5 to 0.5 mm
- Assembling antenna elements or even arrays from multiple sub components is difficult
- Easier to manufacture arrays or subarrays from single piece of material
- Complex geometries with small details restricts how structures can be manufactured

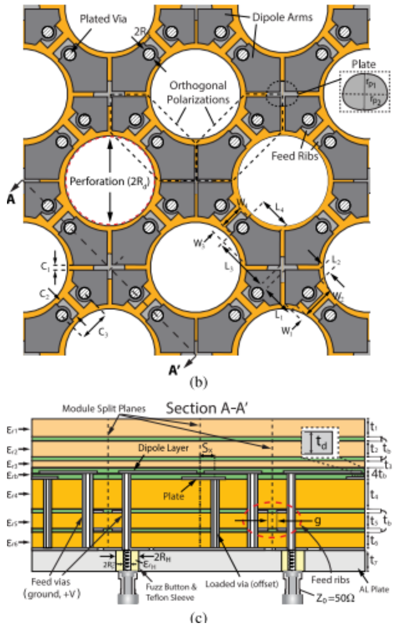


2. Wide-band antennas

- Number of antenna types are capable of wide-band operation in isolation
  - Only a few are feasible to use in arrays
- Wideband antennas are generally larger and may require more complex geometries
  - For example in thickness
  - Feeding structure
  - PCB based wide-band antennas require multiple layers and thick substrates
- An example of additively manufactured Ka-band (26–40 GHz) arrays



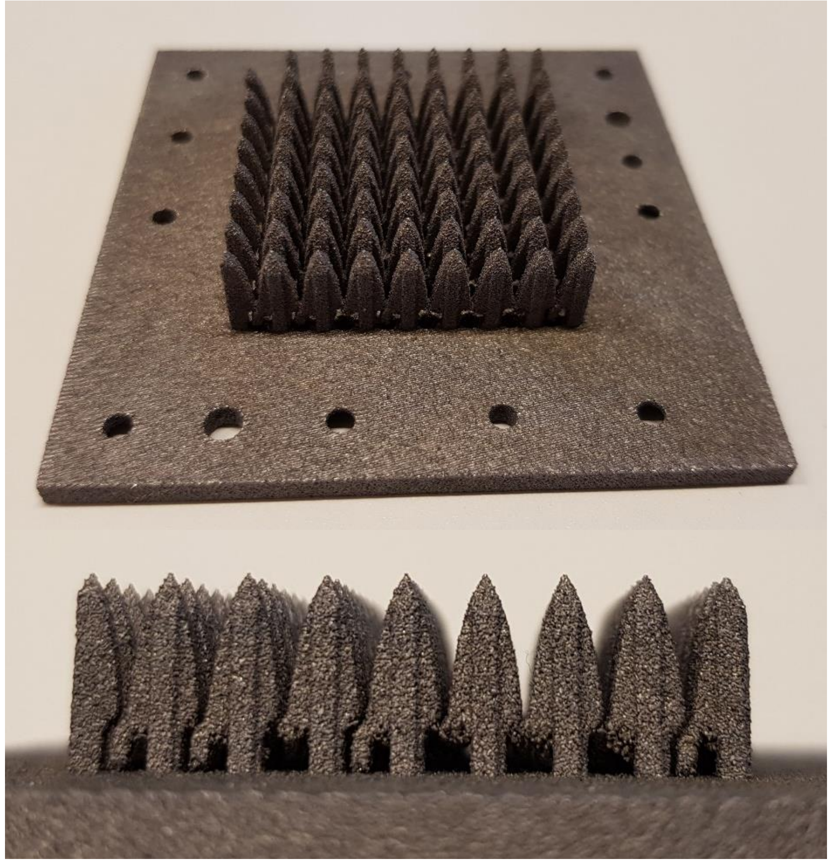
K. Kibaroglu, M. Sayginer, T. Phelps and G. M. Rebeiz, "A 64-Element 28-GHz Phased-Array Transceiver With 52-dBm EIRP and 8–12-Gb/s 5G Link at 300 Meters Without Any Calibration," in IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 12, pp. 5796-5811, Dec. 2018, doi: 10.1109/TMTT.2018.2854174.

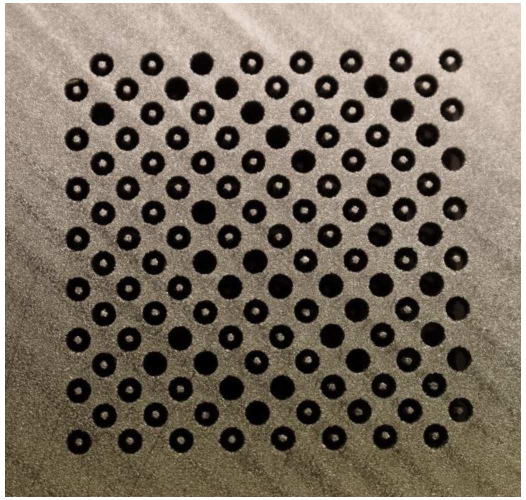


J. T. Logan, R. W. Kindt, M. Y. Lee and M. N. Vouvakis, "A New Class of Planar Ultrawideband Modular Antenna Arrays With Improved Bandwidth," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 2, pp. 692-701, Feb. 2018, doi: 10.1109/TAP.2017.2780878

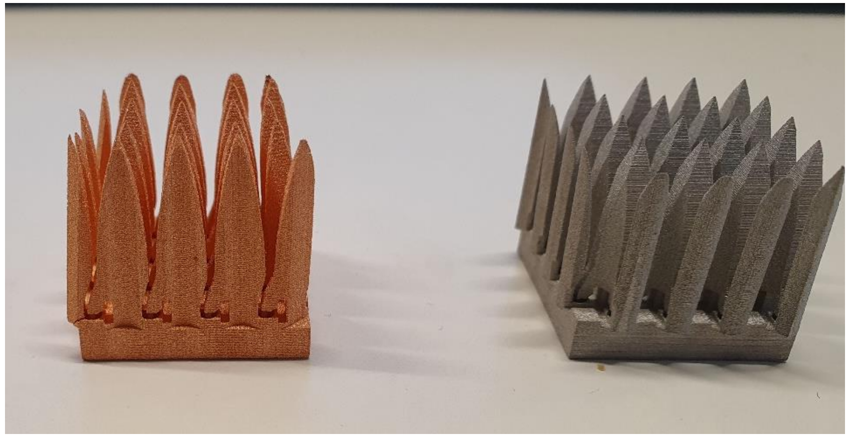
Some manufacturing failures

SLM: aluminum, 3.8 mm element spacing, 8x8 dual polarized array up to 40 GHz





Binder jetting: copper vs stainless steel, 5 mm element spacing, 4x4 dual polarized array module up to 30 GHz



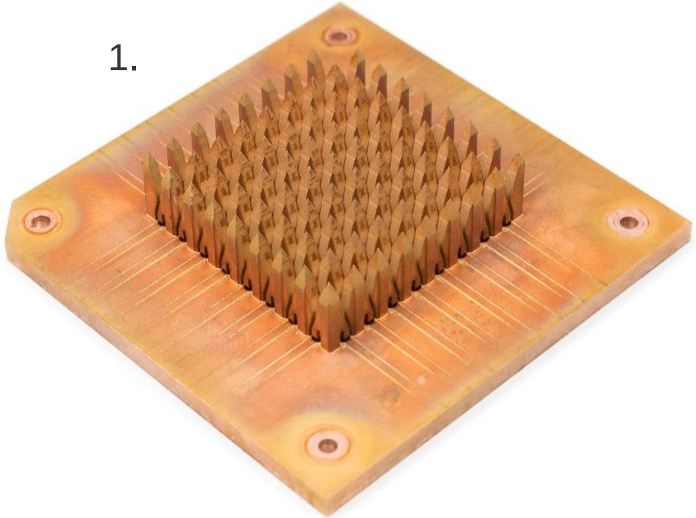
Succesfully manufactured arrays

1.

2.

3.

1.



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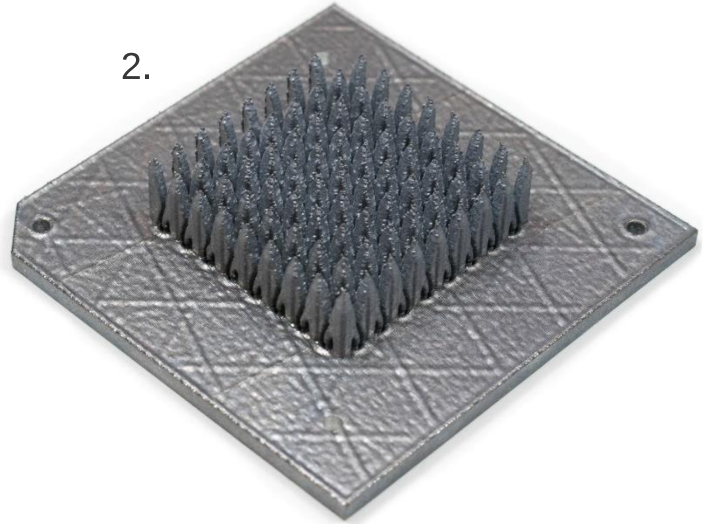
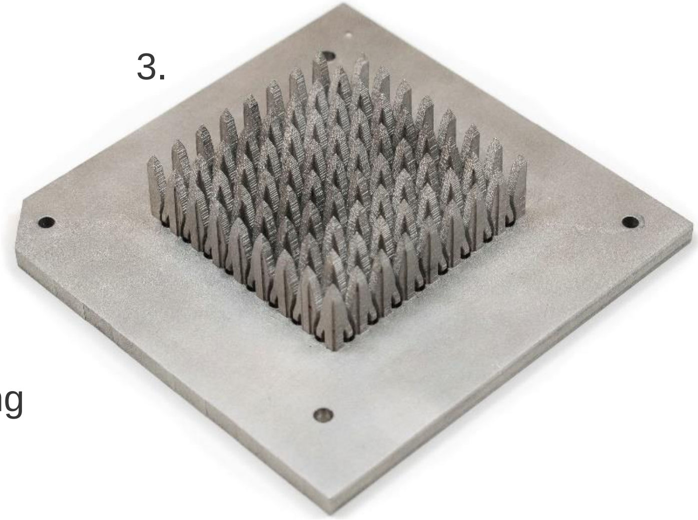
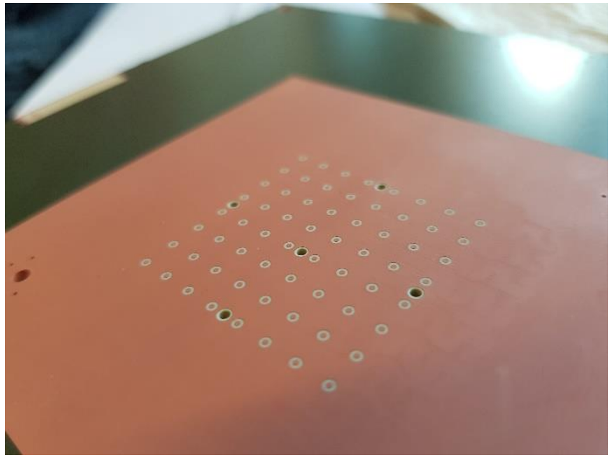


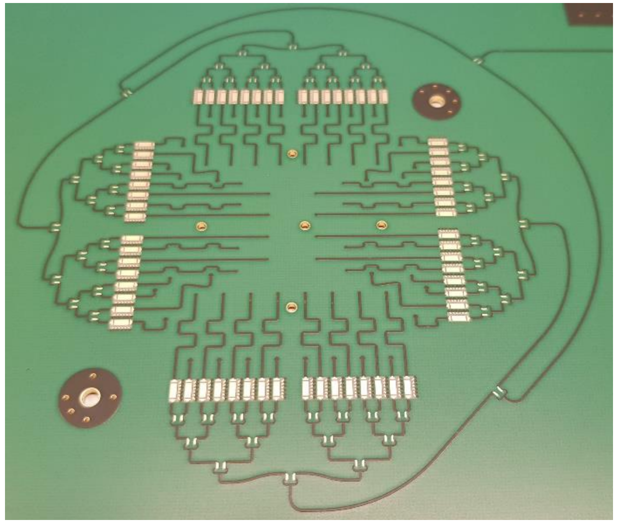
3.

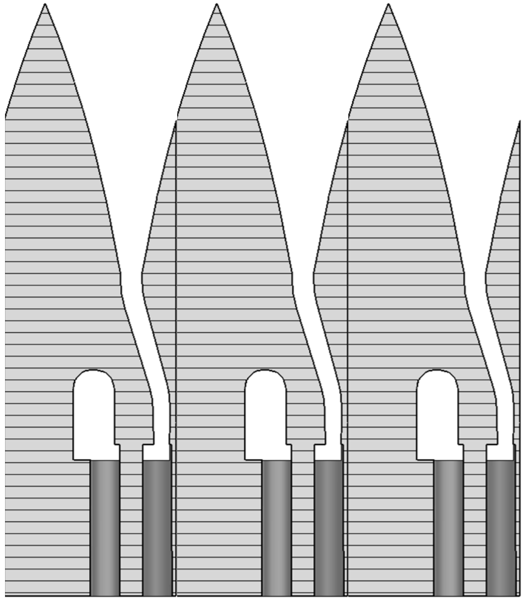


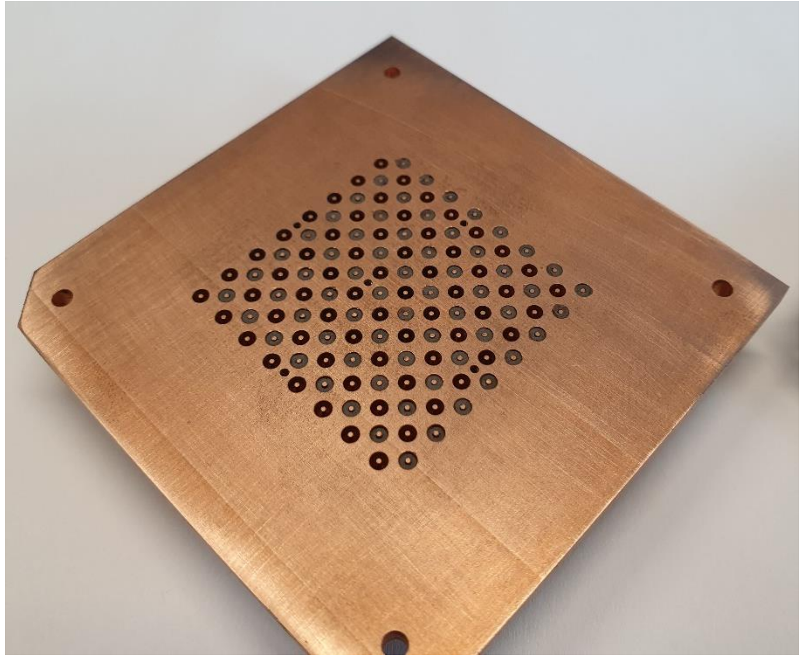
1. Copper, wire electric discharge manufacturing
2. Aluminum alloy, selective laser melting
3. Stainless steel, binder jetting

Feeding structure

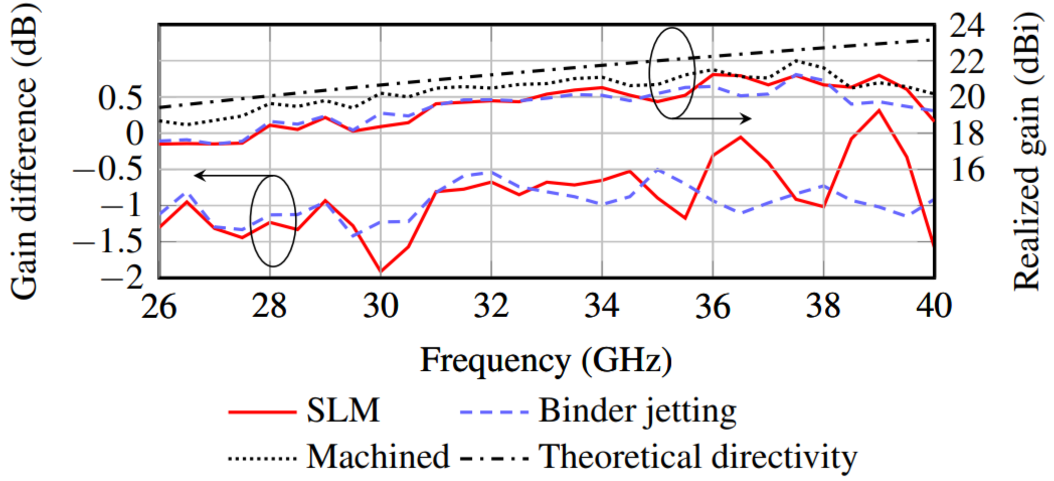


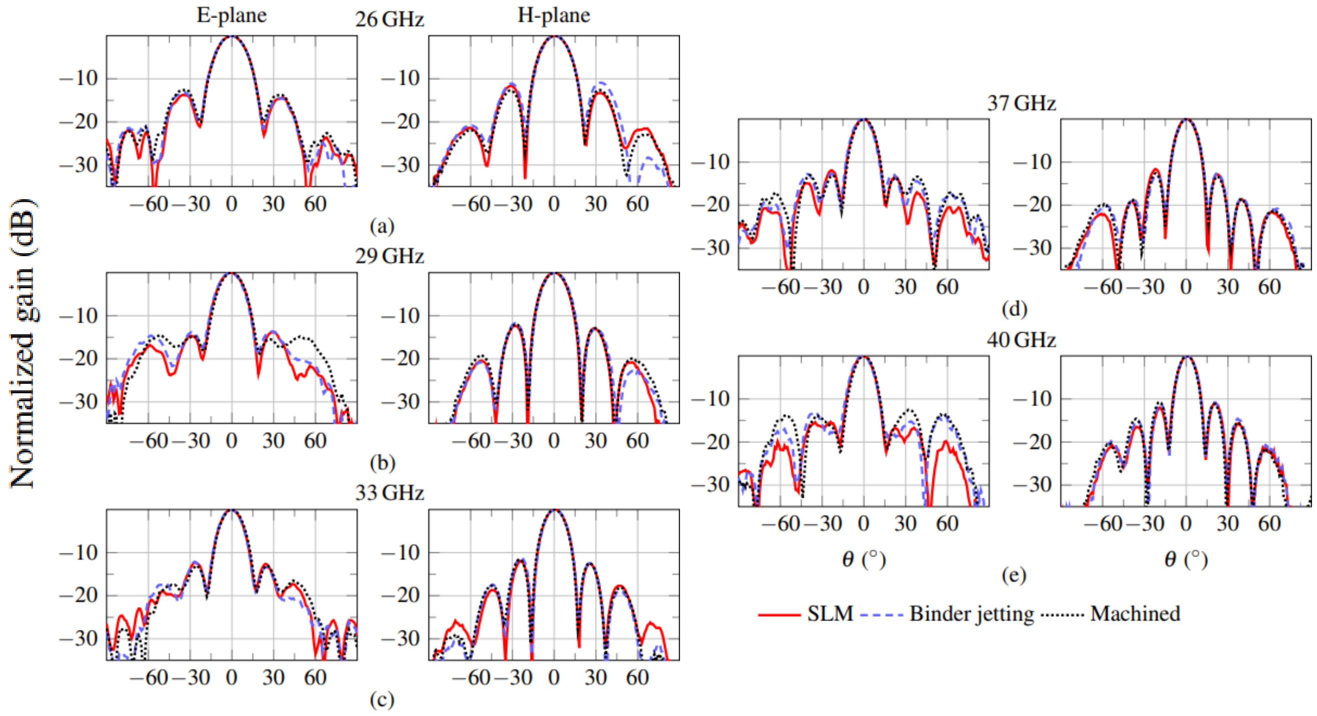






Comparison between previous arrays





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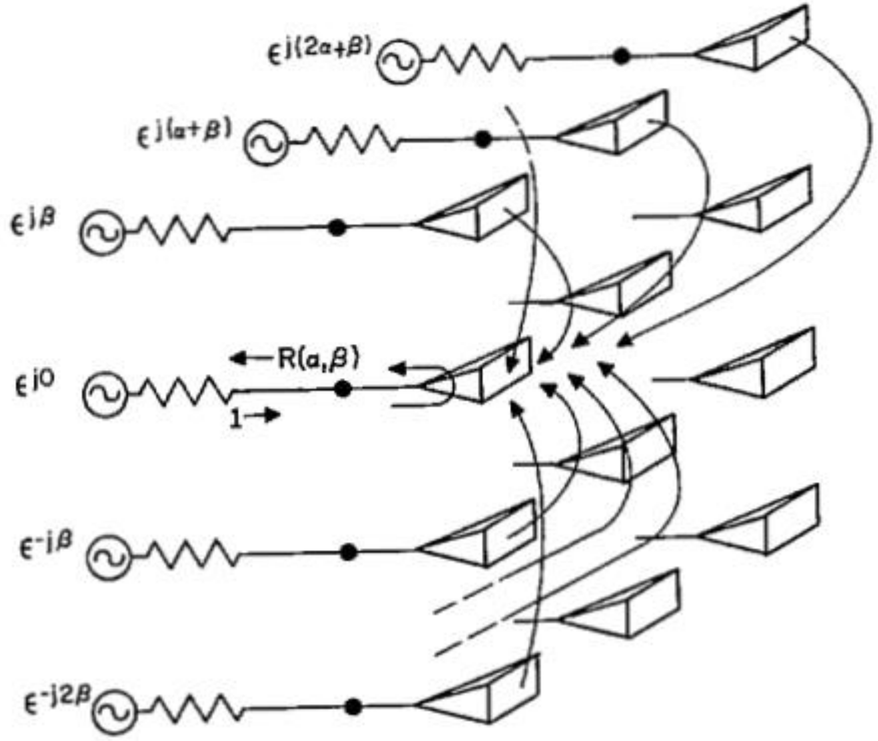
3. Beam steering and antenna coupling

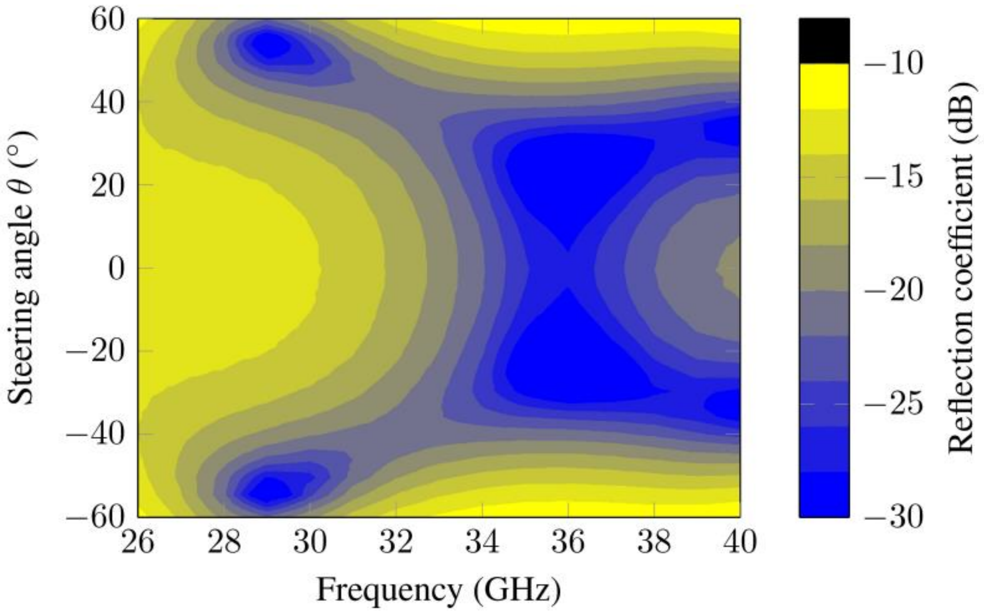
- Closely spaced antenna elements will couple energy to neighboring elements
  - Element design can be simulated to minimize issues
  - Not taking the coupling into account can lead to ”scan blindness”
- Behavior can be efficiently simulated in unit cell
  - Single element simulation with boundary conditions simulating infinite array
  - Active reflection coefficient / scan impedance / active impedance
- Measurement of the complete coupling matrix is rather laborious



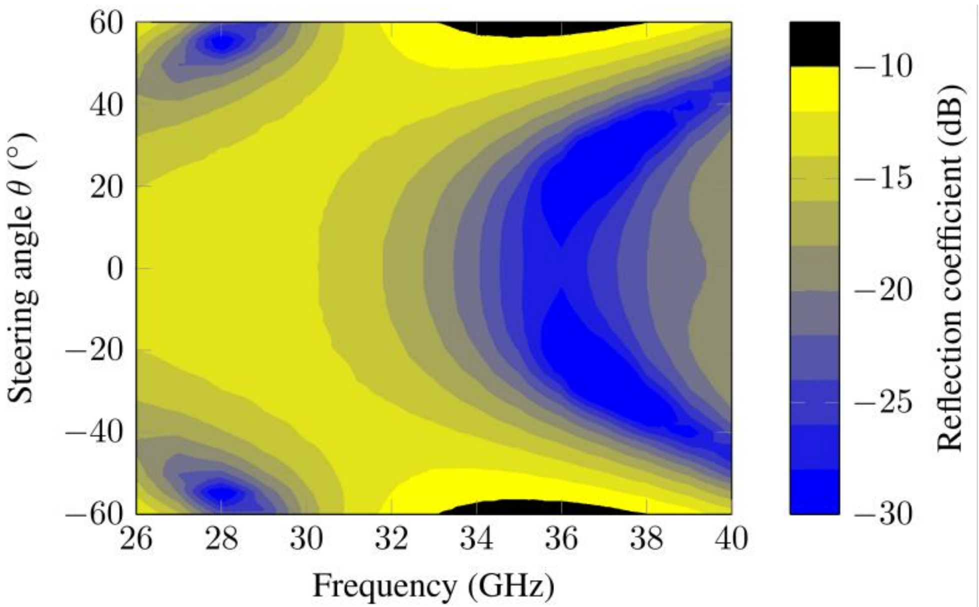
P. Hannan, "The element-gain paradox for a phased-array antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 12, no. 4, pp. 423-433, July 1964, doi: 10.1109/TAP.1964.1138237.

3. Beam steering and antenna coupling

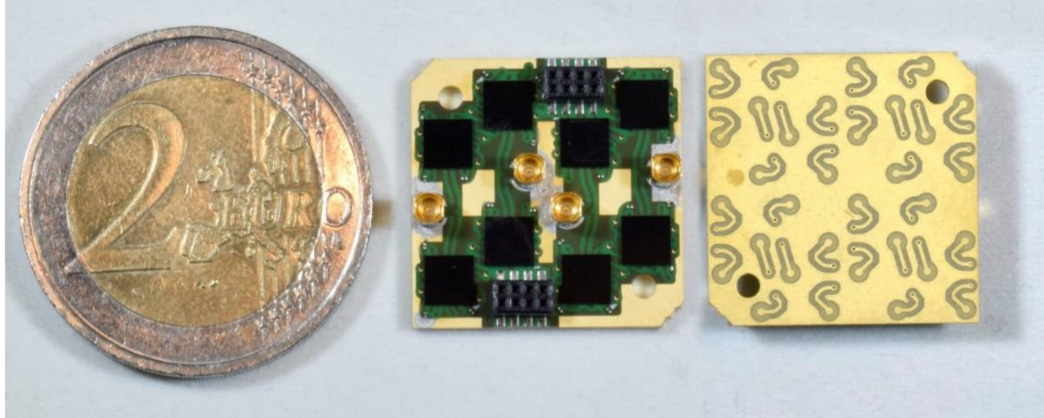
E-plane steering

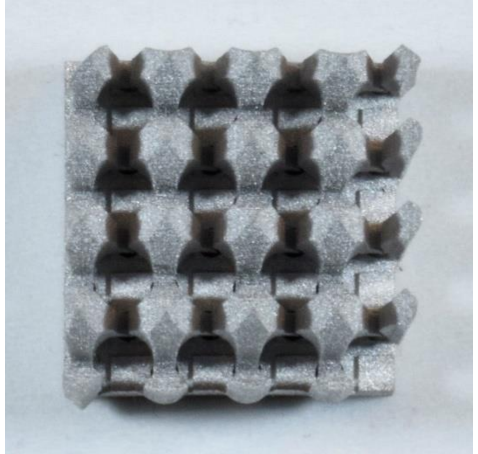


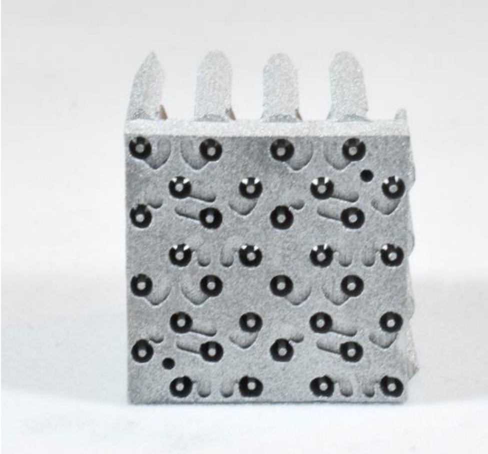
H-plane steering

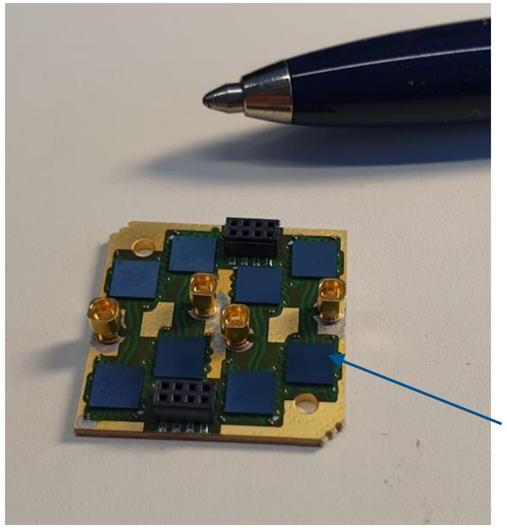


4. Integrating front-end electronics in dual-polarized 30 GHz array

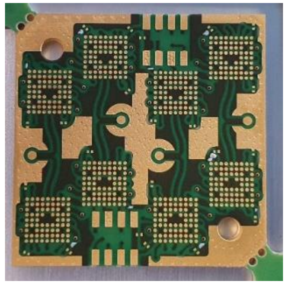


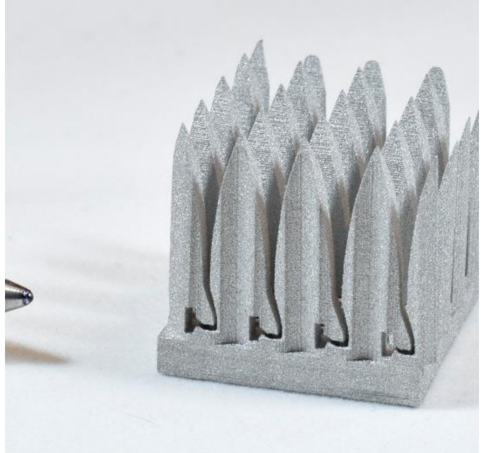






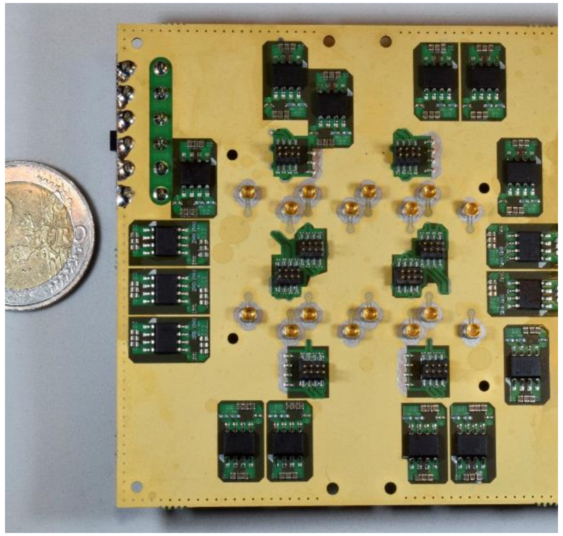
Anokiwave AWMF-0158





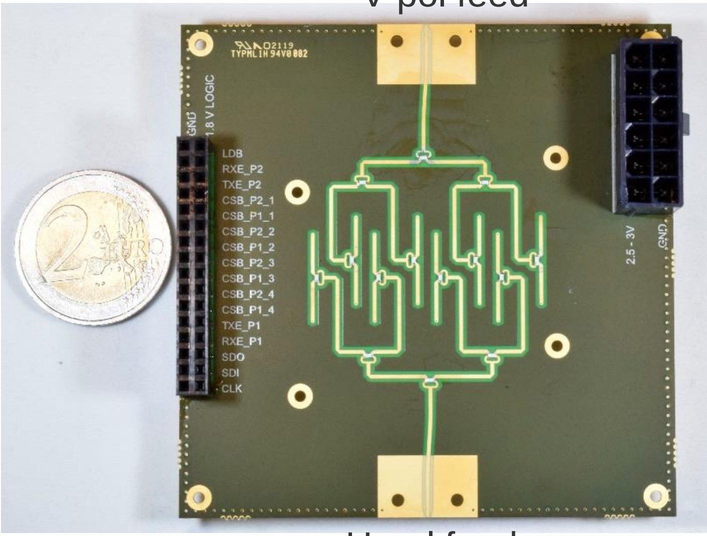
4. Integrating front-end electronics in dual-polarized 30 GHz array

- Very little space to integrate all the required front-end ICs in a ”planar” structure
- Cooling, up to 2W per chip
- Measurements
  - Characterization partially based on simulations
  - Measuring the antenna separately is difficult due to the small antenna spacing
  - Near-field scanner measurements are useful for element level observations



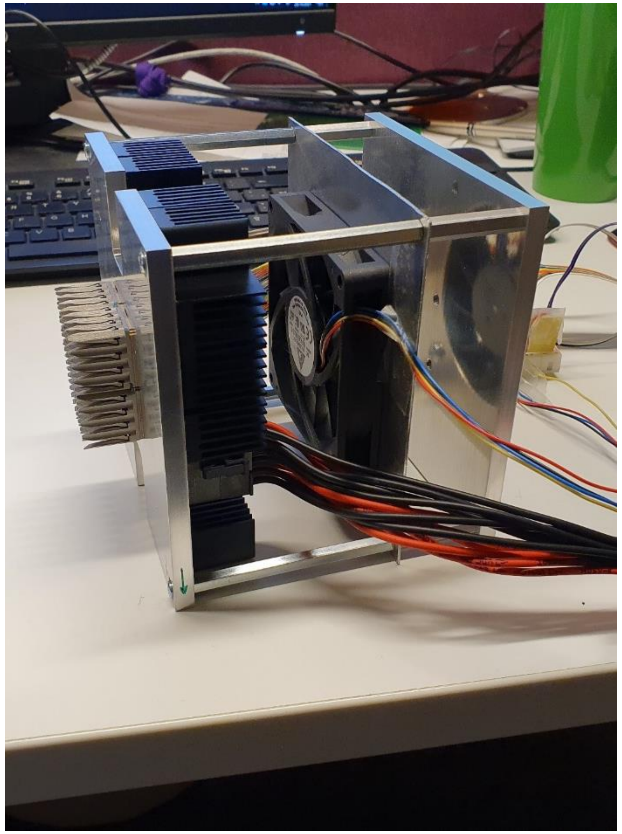
Voltage regulation, RF- and control connectors for four modules

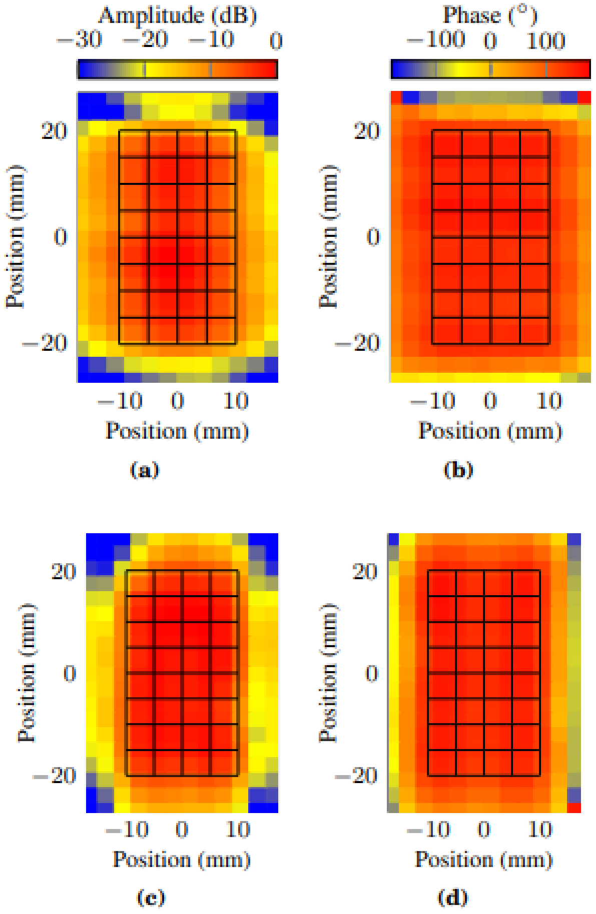
V-pol feed

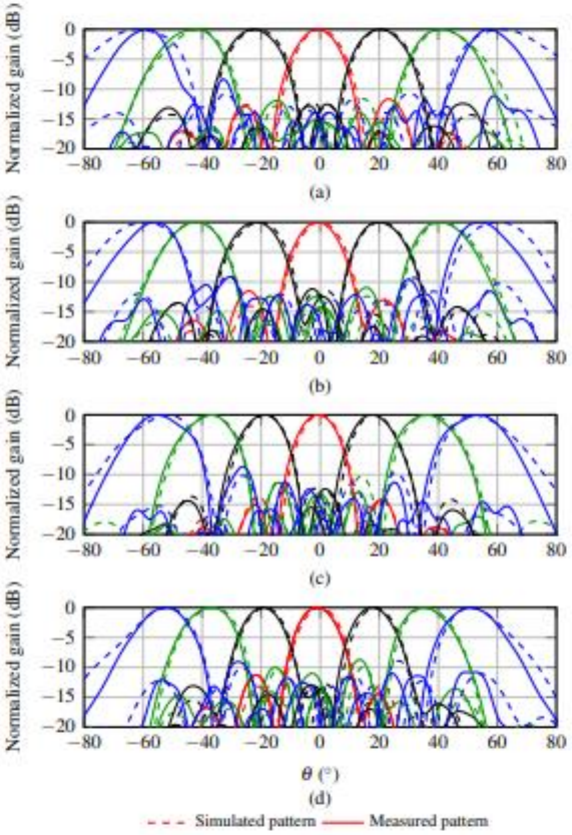


H-pol feed

4. Integrating front-end electronics in dual-polarized 30 GHz array







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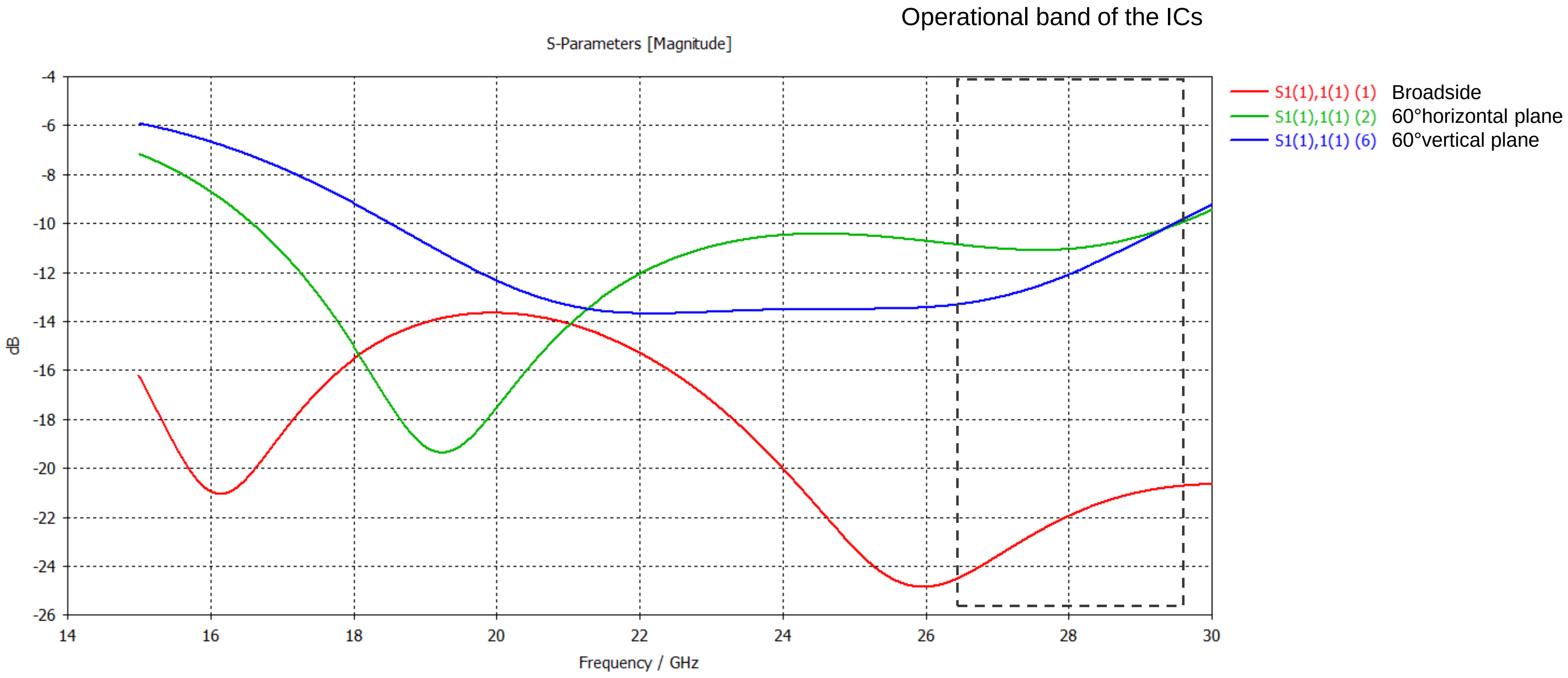
Prototyping and wide-band array antenna systems



Conclusion

- Phased arrays at mmwaves become increasingly more difficult to manufacture and characterize when moving to higher in frequencies
  - Simulations will play higher role than before
- Wide-band arrays at mmwaves are possible but are difficult to implement on a single PCB with electronics
  - Integration possible with narrow band solutions with more simple antennas
- Additive manufacturing can be succesfully used at least up to 40 GHz with complex antenna array geometries with a small impact on performance
- Advances in ICs enable compact mmwave AESAs
  - Wide-band operation may still require more custom solutions