TU2C-2

# Embedded Near-Field Probing Antenna for Enhancing the Performance of 37-41 GHz Linear and Dual -Polarized Phased Antenna Arrays

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# Outline



- Motivation
- Recent Advances in RF Beamforming Array Calibration
- Design Details and Simulation Results
- Experimental Validation
- Conclusions
- Acknowledgement

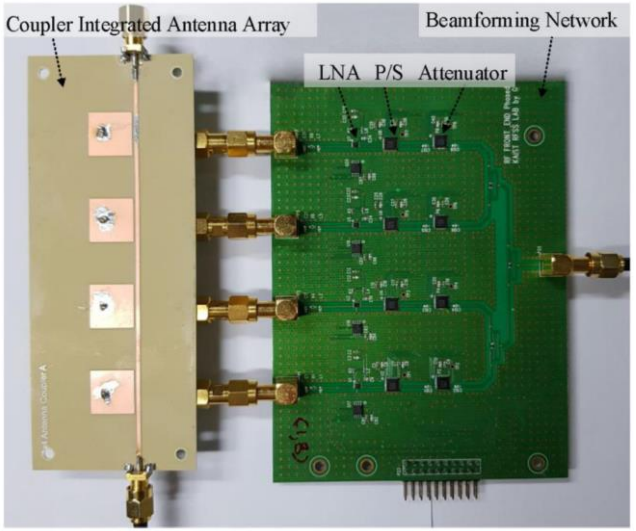
# Motivation



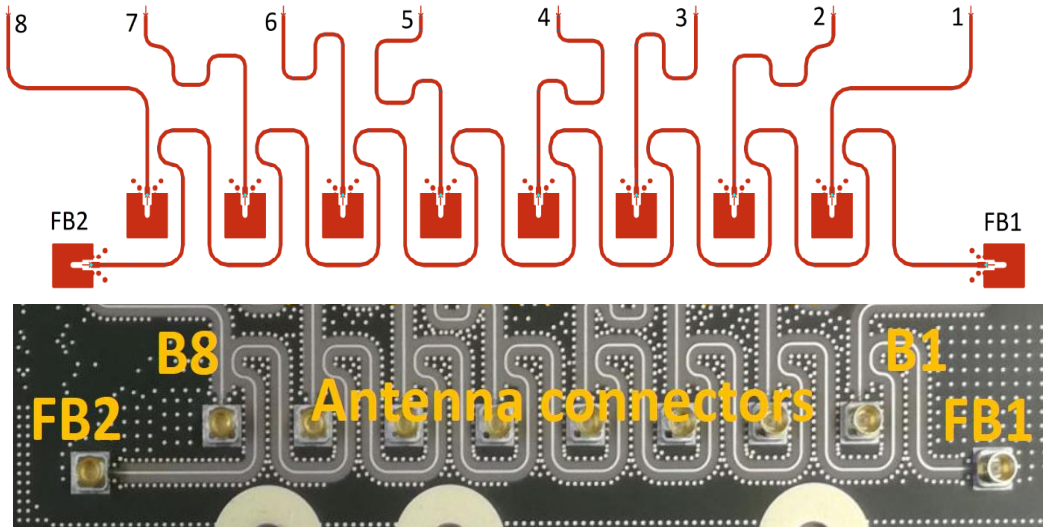
- Beamforming array calibration is a critical step before deploying array beamforming to correct for the phase and gain errors in phased arrays.
- In-field array calibration is more desirable because far-field calibration methods are not always feasible in practice.
- Digital pre-distortion (DPD) techniques are needed for enhancing the overall system performance.

# Literature Review

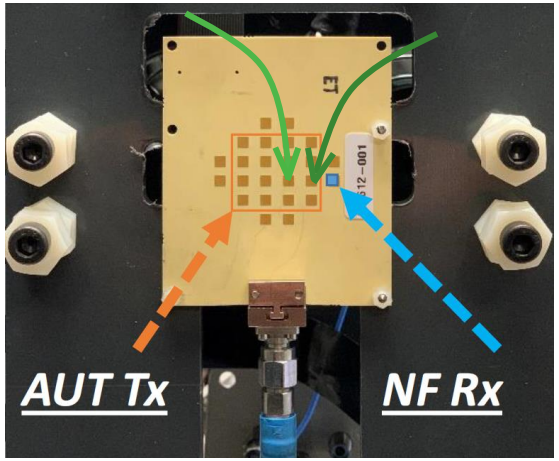




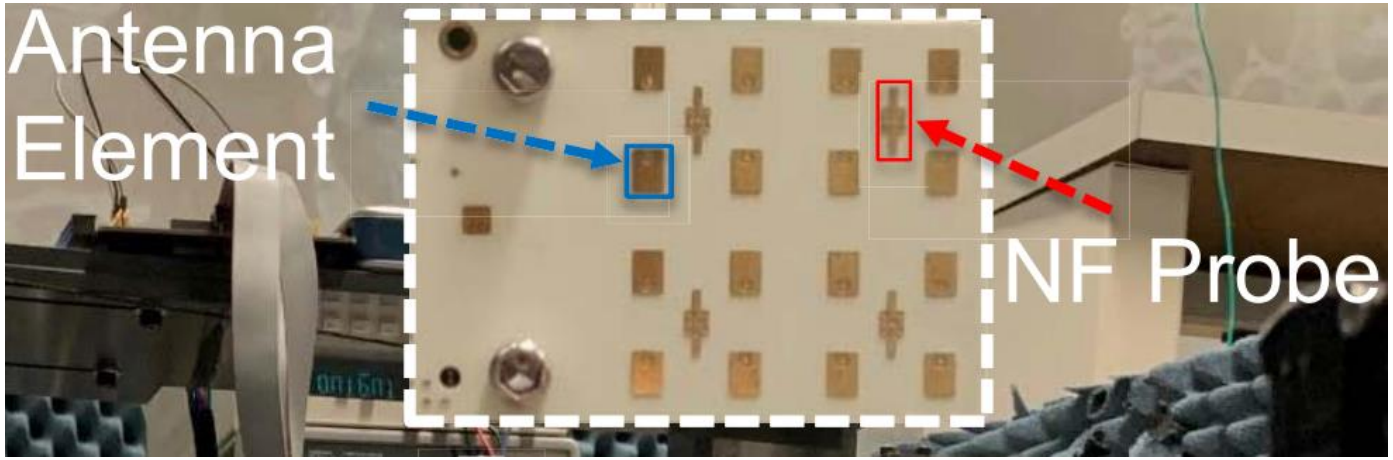

Embedded coupled line at sub-6 GHz [1]




Embedded coupled line at 28 GHz [2]




Embedded edge NF probes at 28 GHz [3]




Embedded NF probes at 28 GHz [4]

# Design Details – Design Objectives

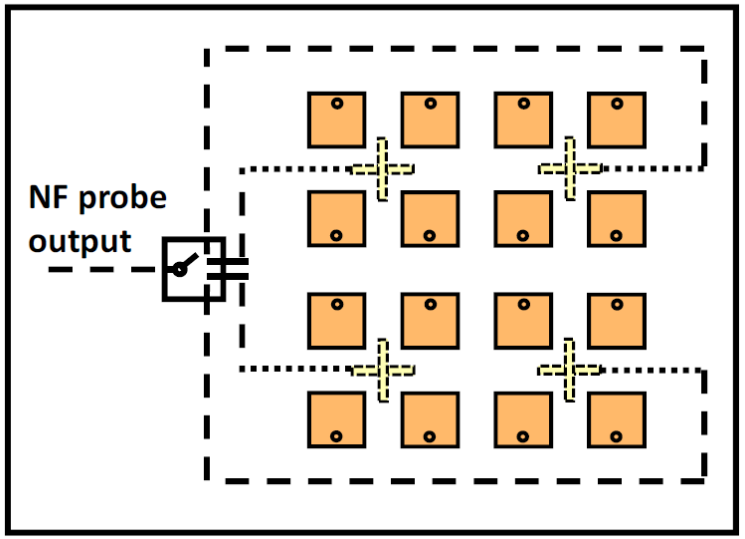


- **PCB stack-up:**
  - Accommodate **flip-chip assembly** of the beamforming chips
  - Provide **sufficient layers to support functionalities** such as antenna structures, RF transitions and shielding, power delivery, and digital control signals.
- **NF probing antenna and main antenna array integration:**
  - **The coupling magnitude/phase between each NF probing antenna and its adjacent antenna elements should be relatively constant over the design frequency.**
  - The addition of the NF probing antenna structure to the main antenna array should not negatively affect the array's beamforming performance.
- **Array size:** The design should be **scalable**.
- **Mechanical considerations:** Able to support digital signal interfacing, power delivery, thermal management, and mechanical housing.

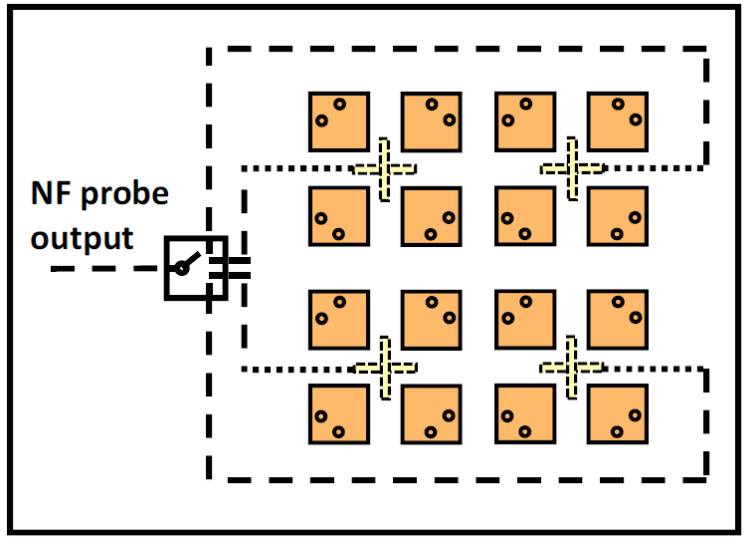
# Design Details – Block diagrams



- Conceptual block diagrams of RF beamforming arrays with proposed embedded NF probing antennas.

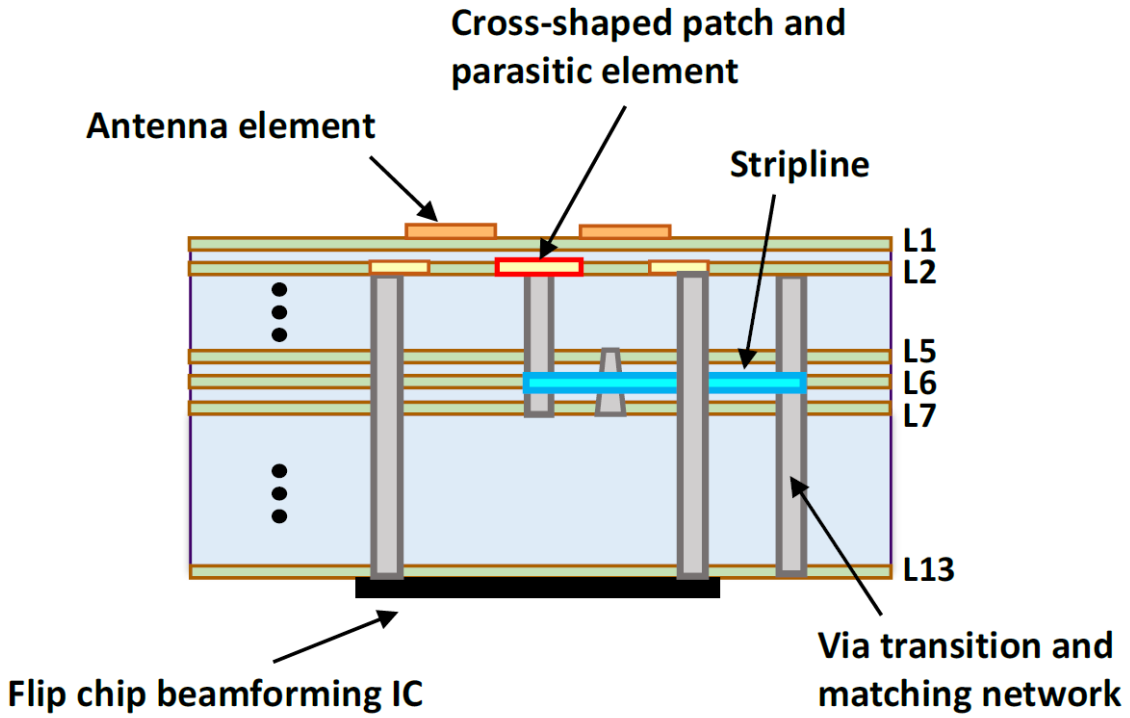


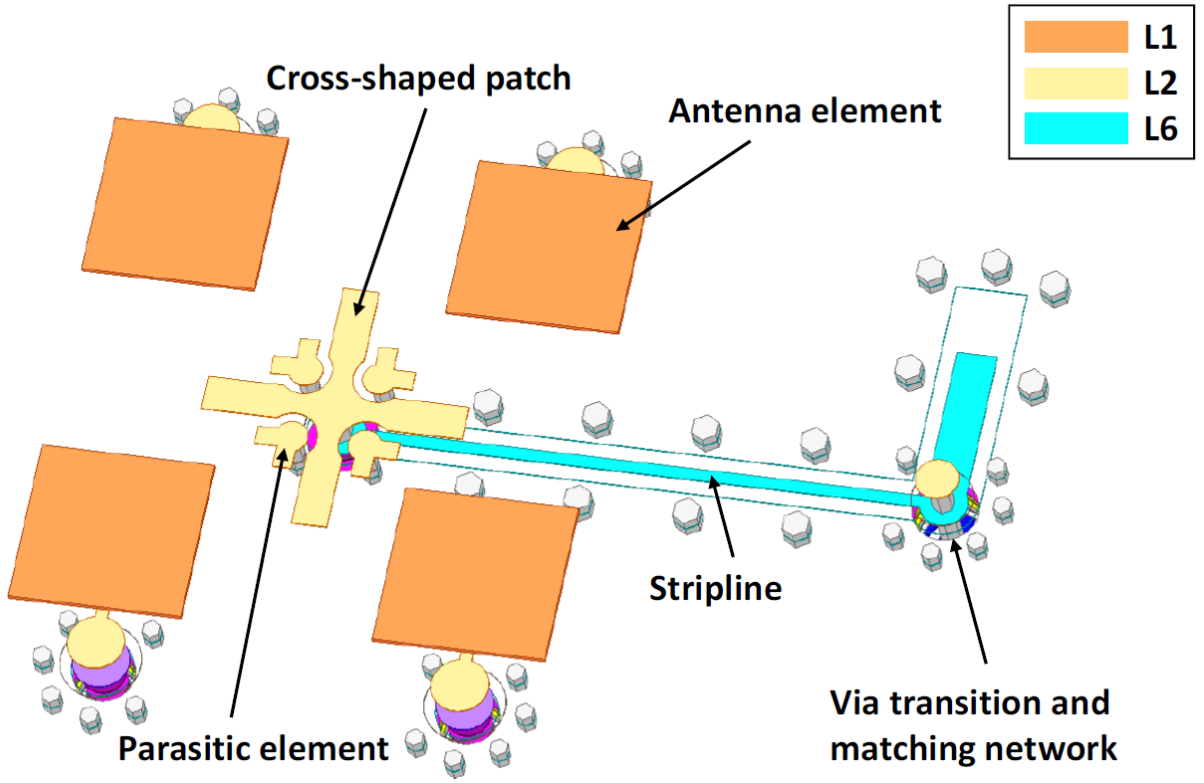

A 4x4 linear-polarized RF beamforming arrays




A 4x4 dual-polarized RF beamforming arrays

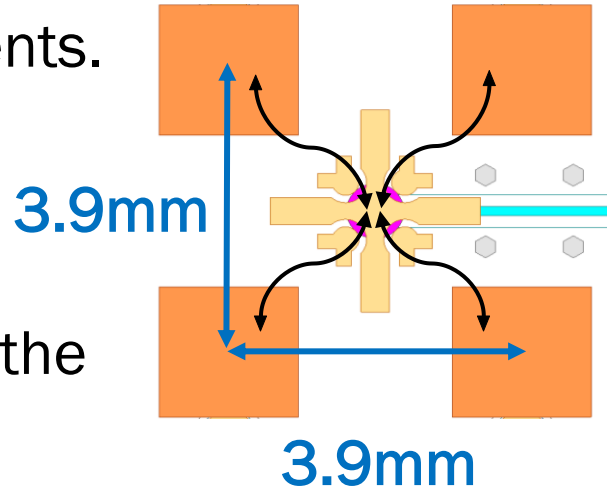
# Design Details – NF probing antenna structure



# Design Details – NF probing antenna highlights

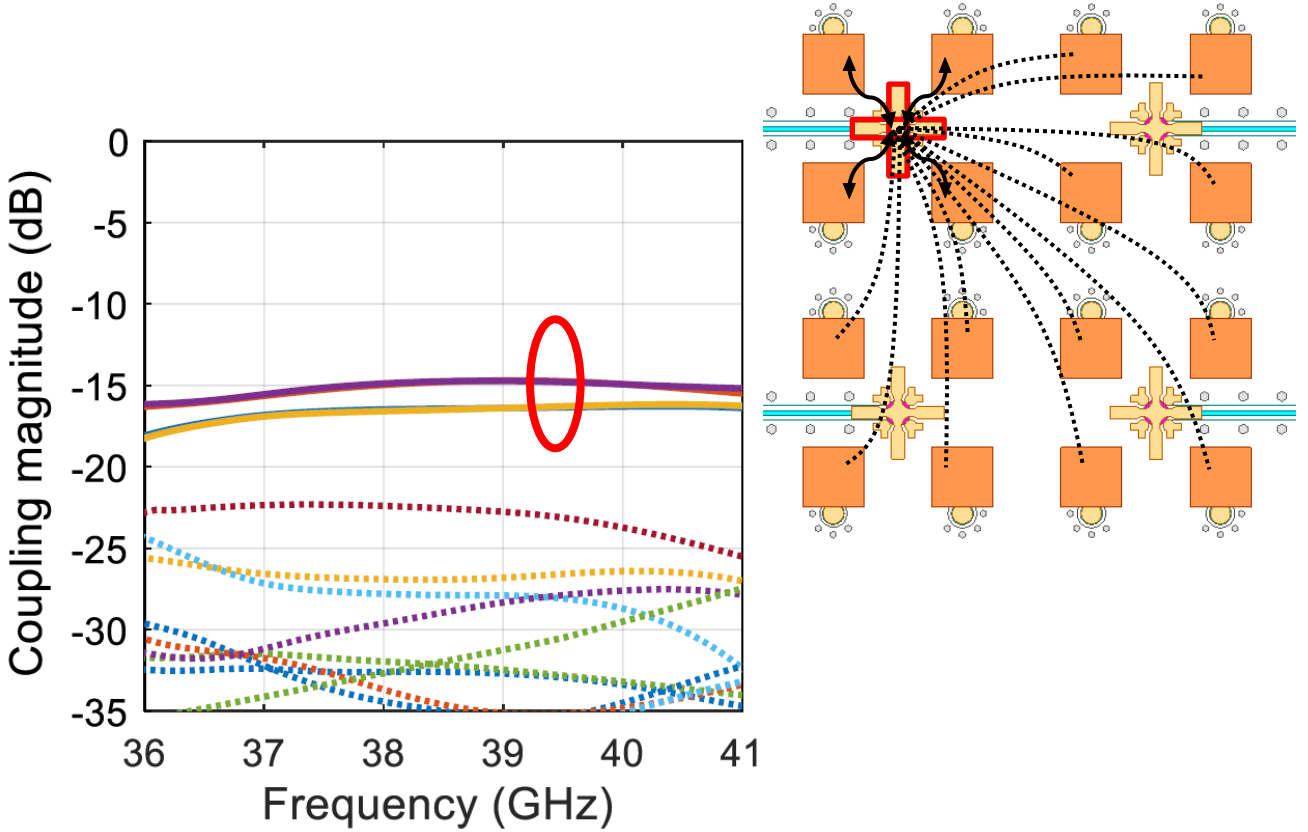
- **Symmetry:**
  - The proposed symmetrical NF probing antenna provides **flat coupling magnitude and constant group delay** between each NF probing antenna and its nearest four radiating antenna elements.




- **Compact size & Scalability:**
  - **Optimized size** to cope with the constrained spacing between the antenna elements ($\lambda/2$ = 3.9mm at 38.5 GHz).

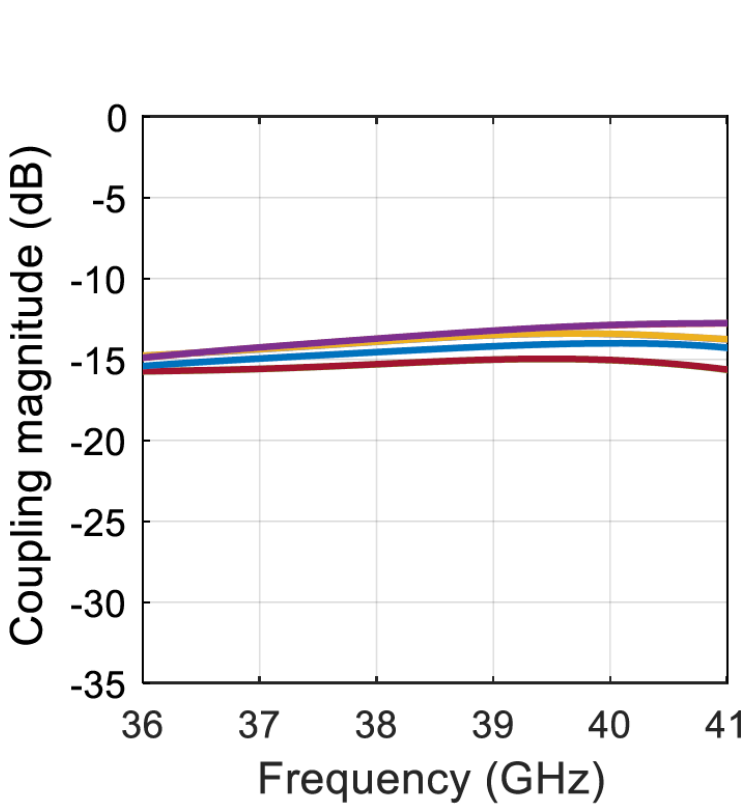
- **Capable for linear and dual -polarized phased arrays**

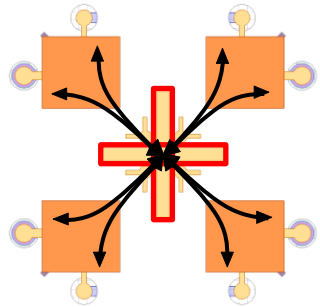
# Simulation Results – NF probing antenna performance





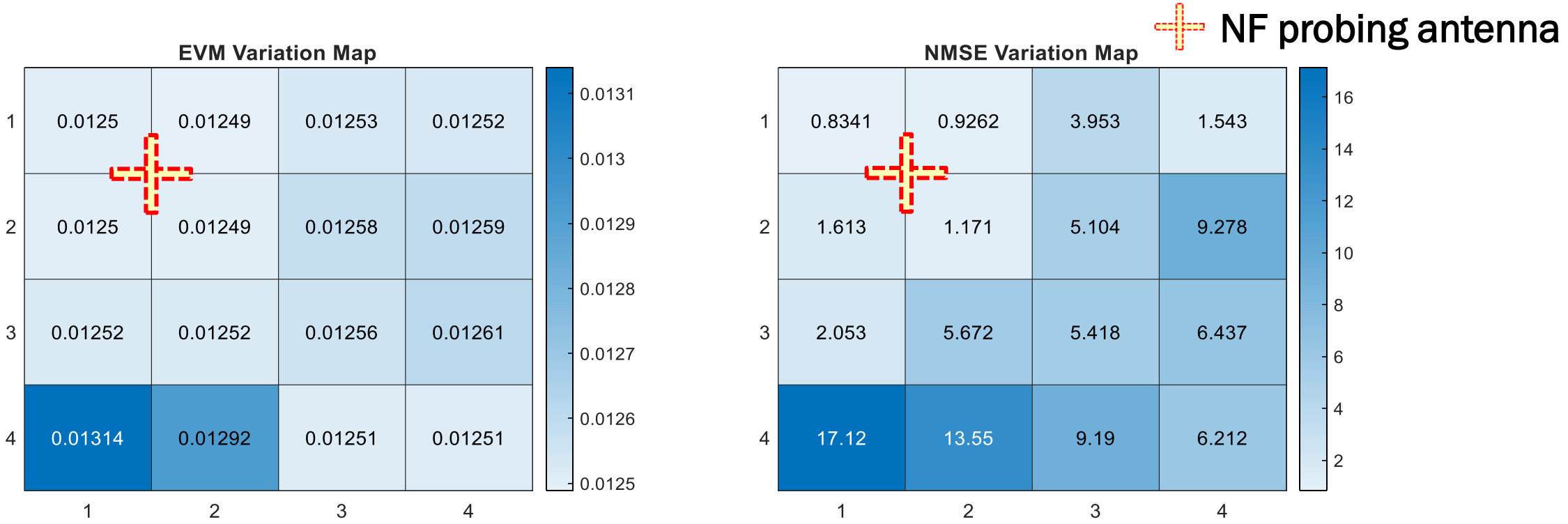

NF probing antennas embedded in 4×4 linear-polarized phased array



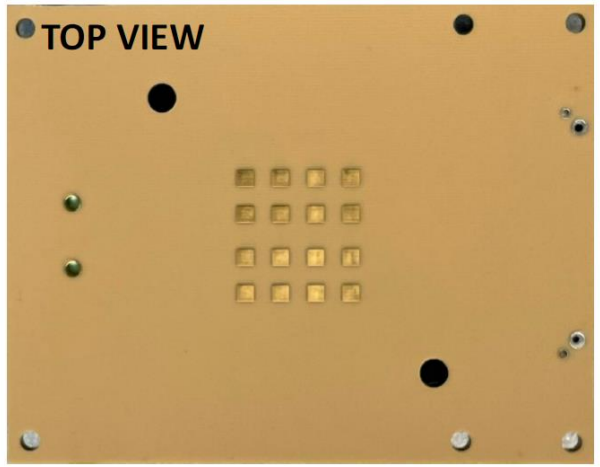
NF probing antenna embedded in 2×2 dual-polarized phased array

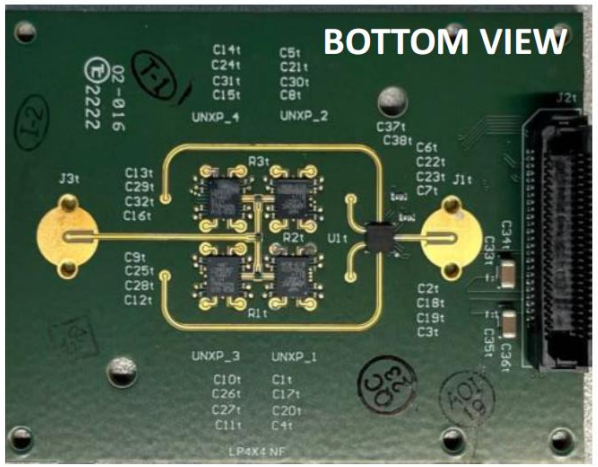
# Simulation Results – NF probing antenna in 4x4 linear-pol array



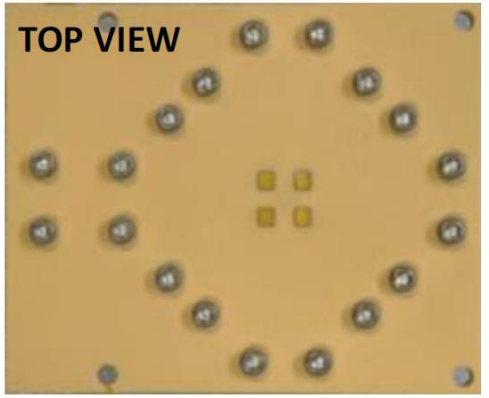

- Simulation with 800 MHz, 256 QAM OFDM signal at 38.5 GHz.
- The low EVM and NMSE values indicate flat coupling and constant group delay between the NFP and the adjacent antenna elements.

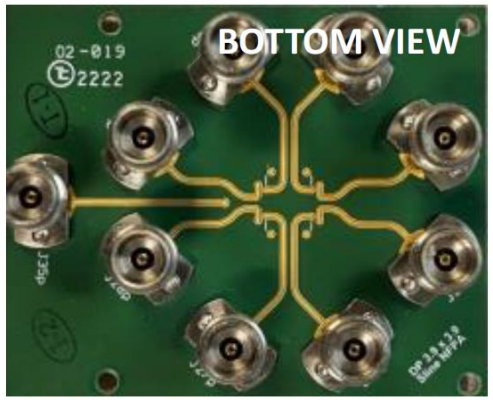
# Experimental Validation – Fabricated PCBs



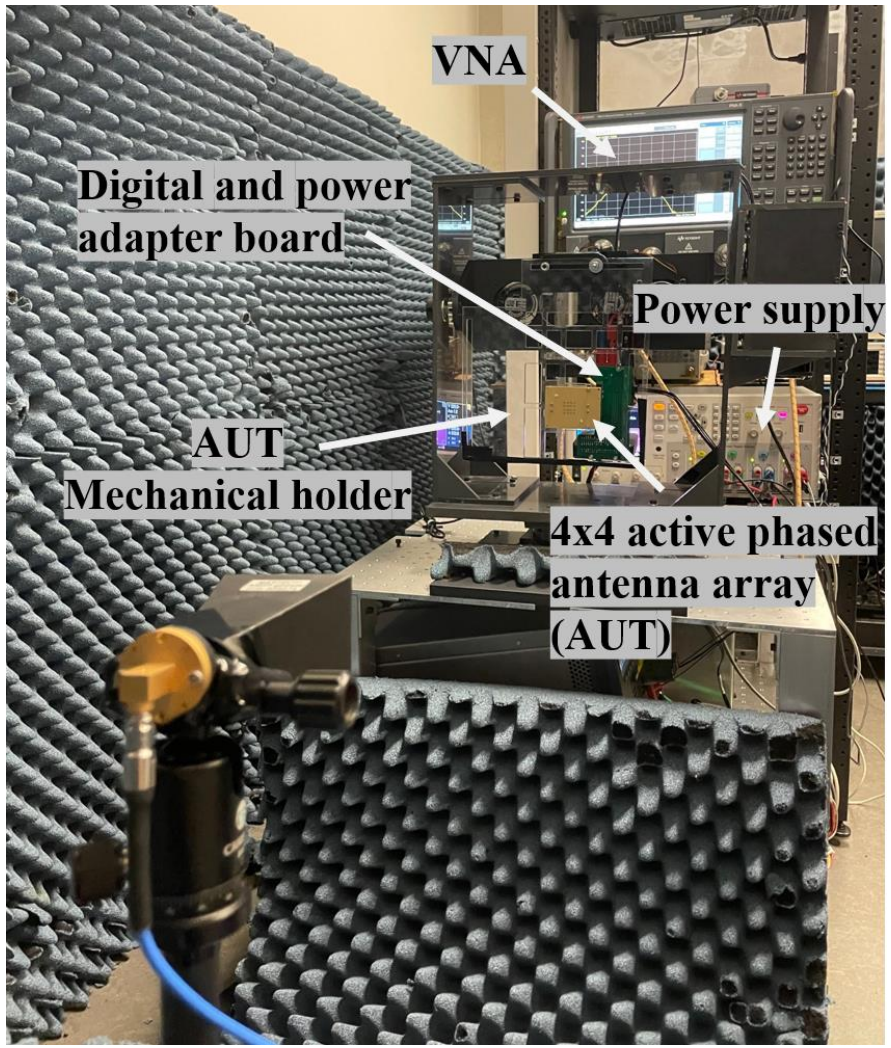

4×4 linear-polarized active array
65mm*50mm

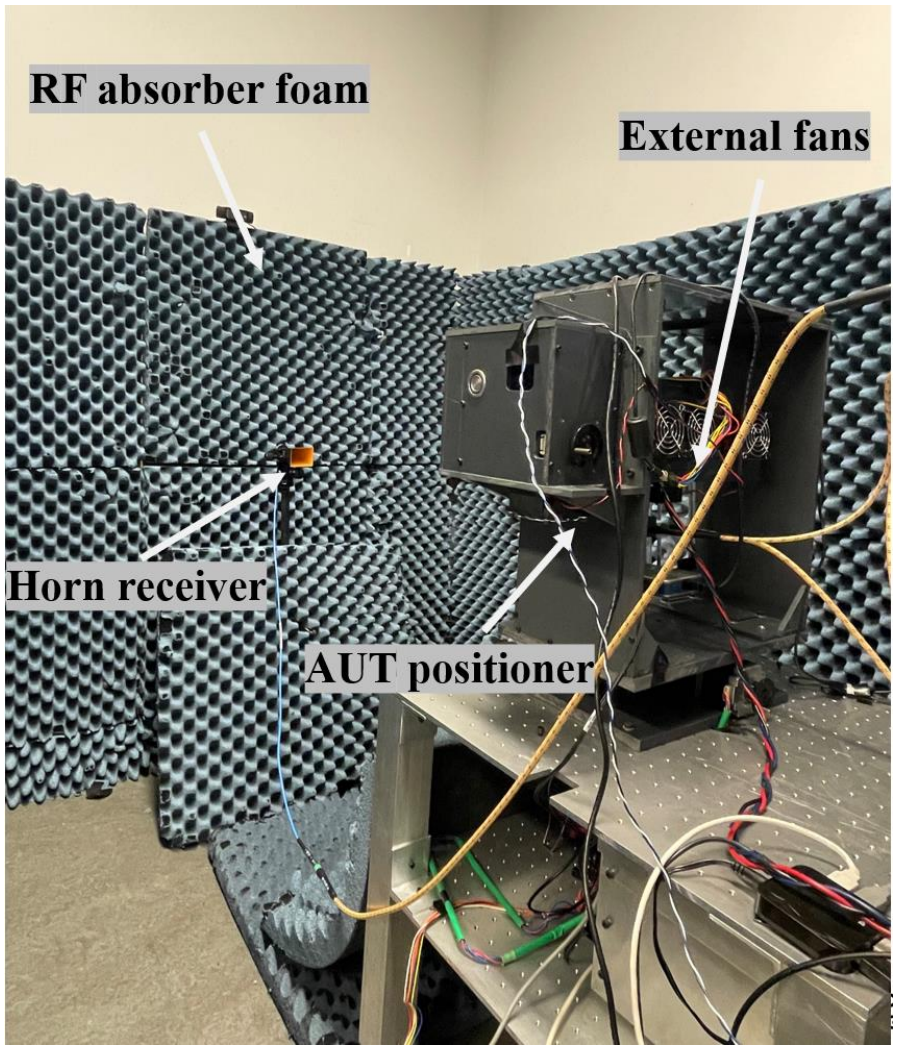



2×2 dual-polarized passive array
51mm*42mm

# Experimental Validation – In-lab setup (CW measurements)

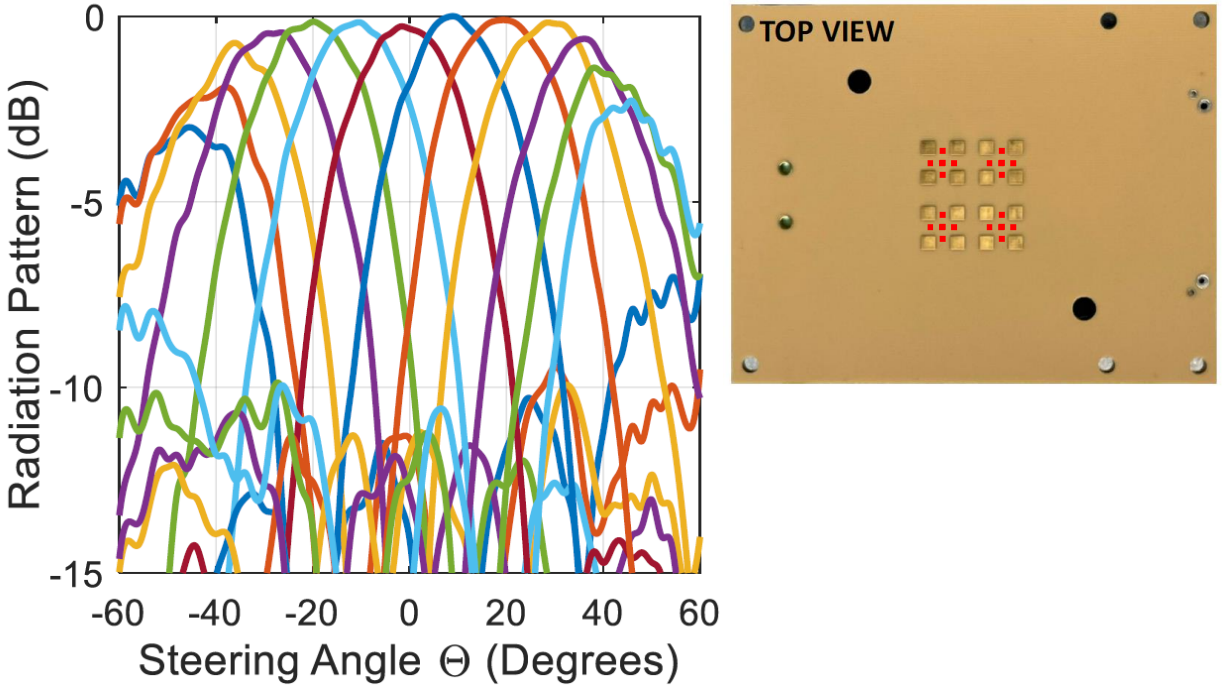


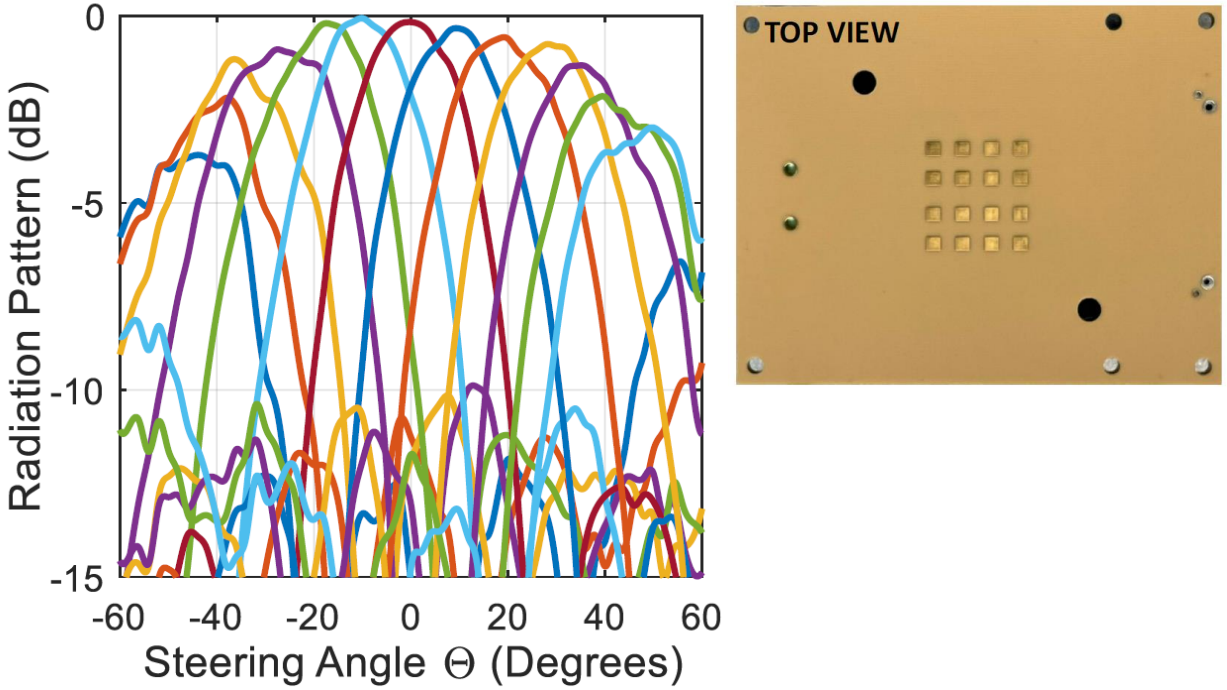
# Experimental Validation – Radiation patterns



- Measured radiation patterns versus different steering angles at 38.5 GHz.
- Measured boresight gain of 16.5 dBm.

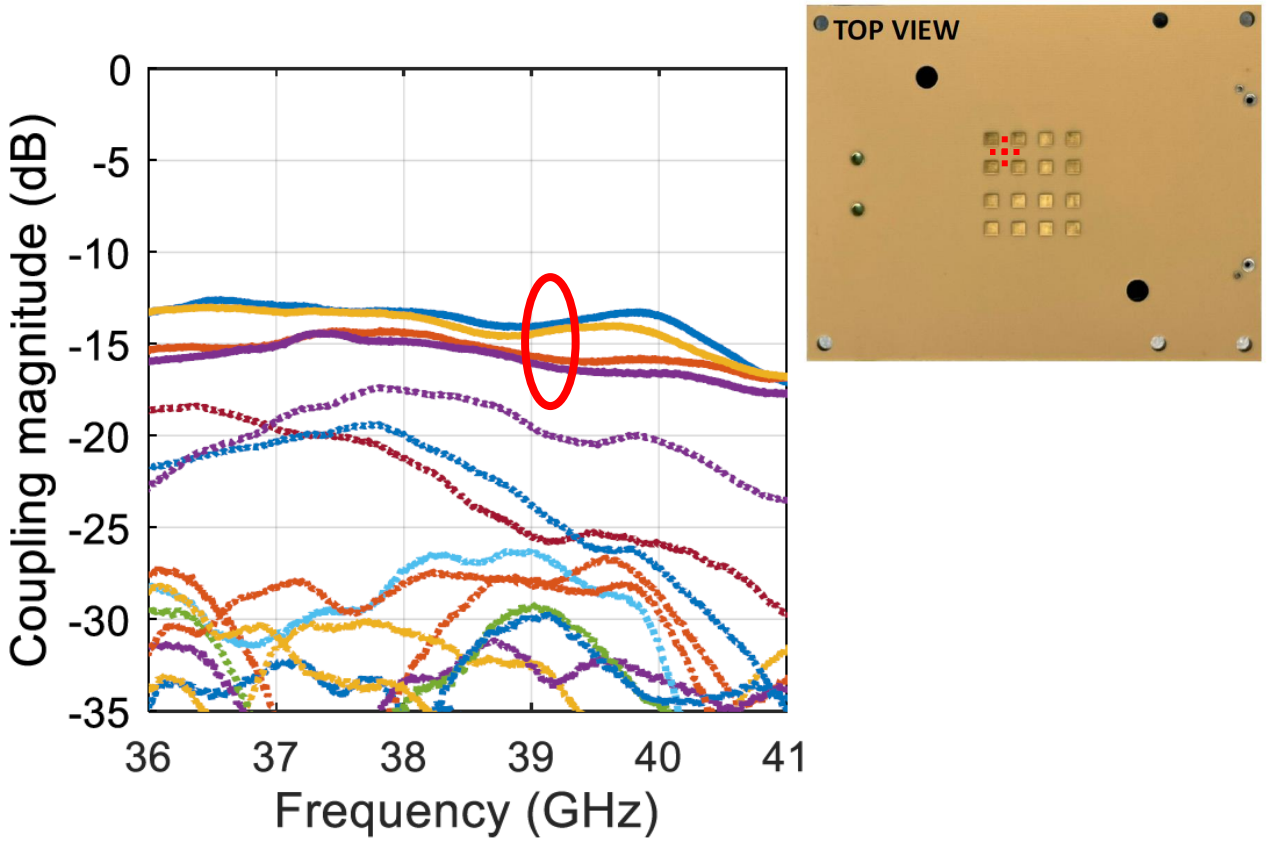



4x4 linear-polarized active array with four proposed NF probing antennas




4x4 linear-polarized active array without NF probing antennas (as reference)

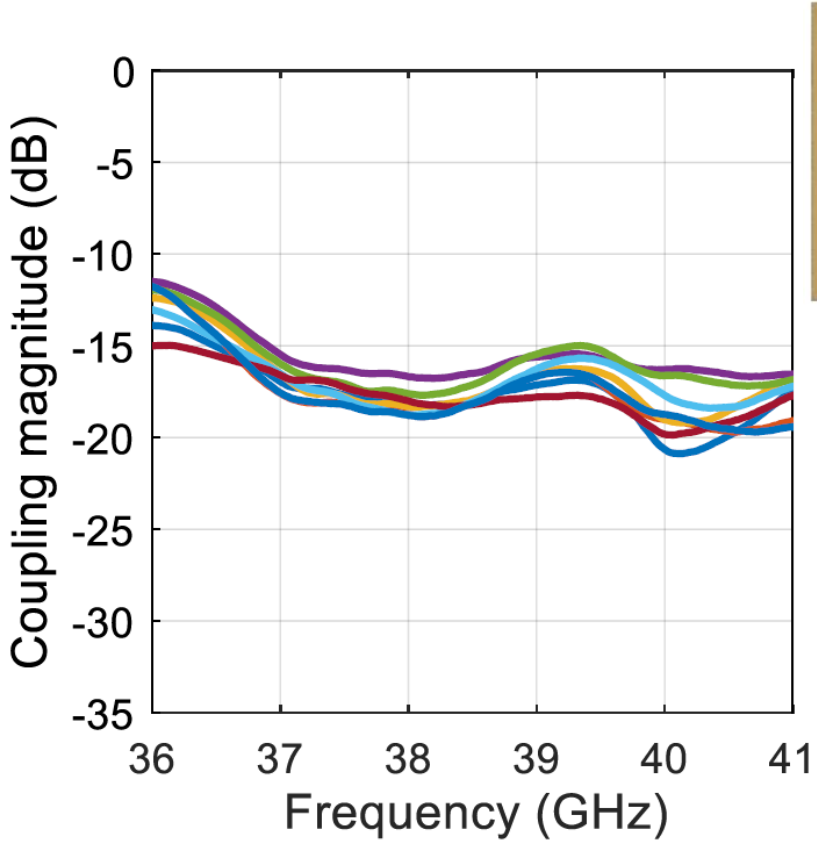
# Experimental Validation – NF probing antenna performance

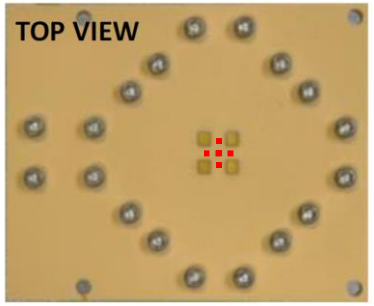






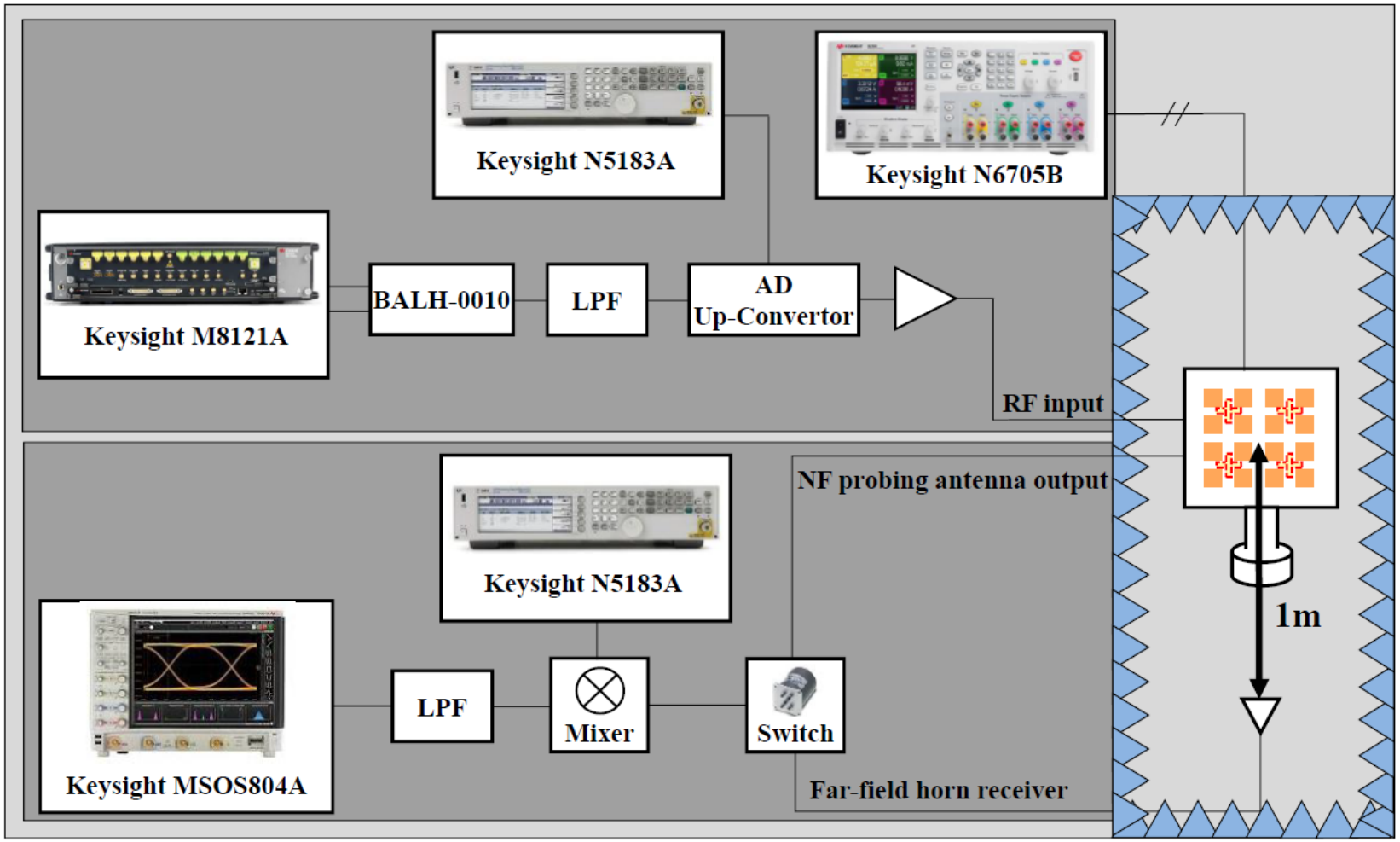
NF probing antennas embedded in 4×4 linear-polarized phased array



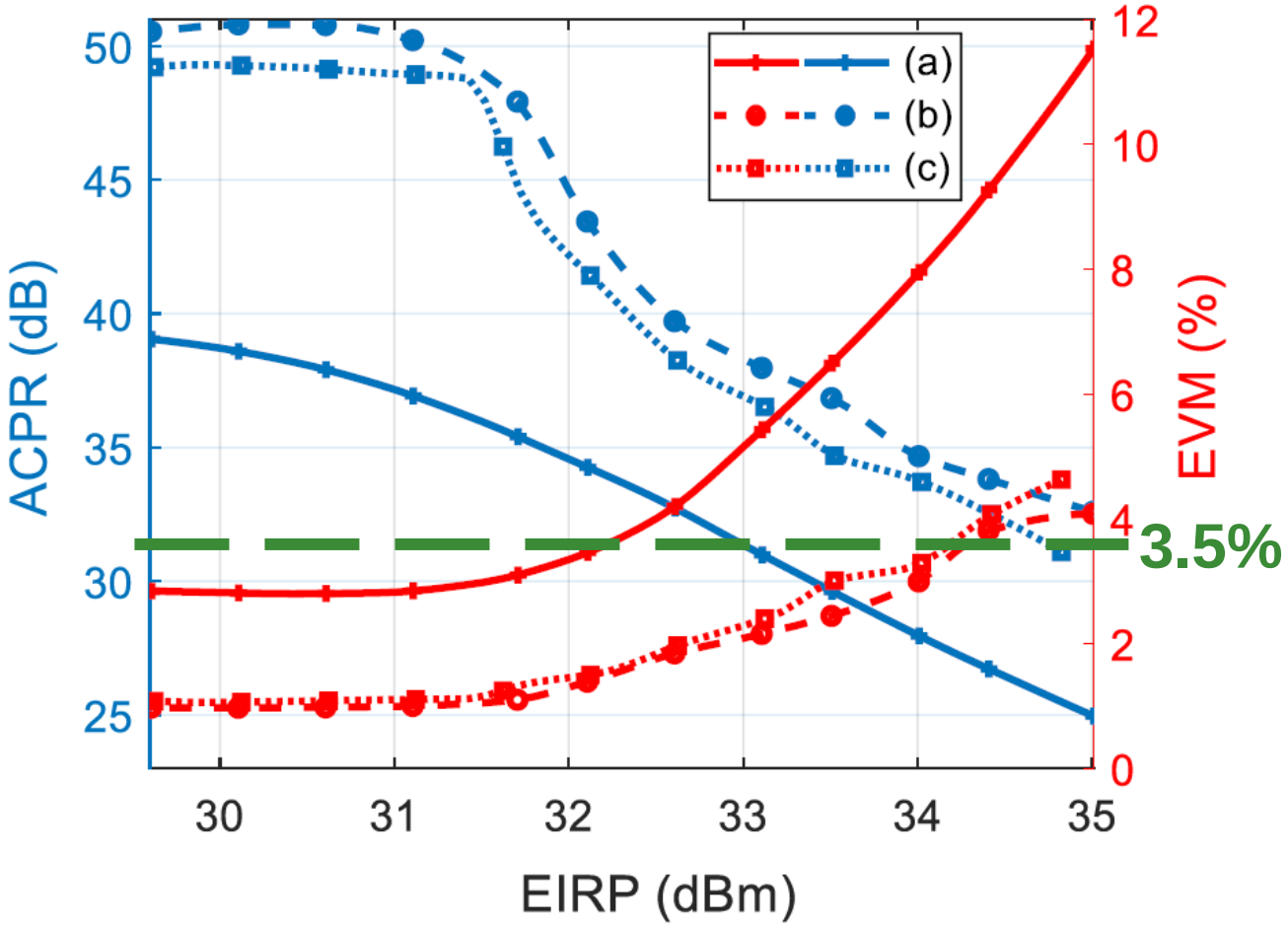




NF probing antenna embedded in 2×2 dual-polarized phased array

# Experimental Validation – In-lab setup (modulated signal measurements)



# Experimental Validation – DPD training on a 4x4 active phased array




- Modulated signal:
  - 400 MHz, 256 QAM OFDM signal
- Center frequency: 37.5 GHz

- (a) prior to DPD
- (b) after DPD trained at the FF in the main beam direction
- (c) after DPD trained using NF probing antennas

# Conclusions



- The simulation/experimental validation inferred the proposed NF probing antenna is
  - able to meet the constrained spacing at 38.5 GHz and scalable for any large-scale linear and dual –polarized phased arrays.
  - effective in providing a feedback path for array calibration and DPD training.

- The experimental validation of the 4x4 active phased array with four embedded NF probing antennas
  - beam steerability from −50 deg to 50 deg on the H-plane.
  - negligible impact of the NF probing antennas on the phased array's radiation pattern.
  - successful DPD training; enabled the EIRP to be increased from 32 dBm to 34.1 dBm while maintaining an EVM below 3.5%.

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  - Canadian Microelectronics Corporation (CMC) for providing EDA tools for designs and simulations.
  - Gorilla Circuits for array fabrication.
  - NXP Semiconductors for supplying the integrated circuits used in the fabricated active arrays.

# References


- [1] S. -C. Chae, H. -W. Jo, J. -I. Oh, G. Kim and J. -W. Yu, "Coupler Integrated Microstrip Patch Linear Phased Array for Self-Calibration," in IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 9, pp. 1615-1619, Sept. 2020, doi: 10.1109/LAWP.2020.3011862.
- [2] N. Tervo et al., "Digital Predistortion of Millimeter-Wave Phased Array Transmitter With Over-the-air Calibrated Simplified Conductive Feedback Architecture," 2020 IEEE/MTT-S International Microwave Symposium (IMS), Los Angeles, CA, USA, 2020, pp. 543-546, doi: 10.1109/IMS30576.2020.9224083.
- [3] A. B. Ayed, G. Scarlato, P. Mitran and S. Boumaiza, "On the Effectiveness of Near-Field Feedback for Digital Pre-Distortion of Millimeter-Wave RF Beamforming Arrays," 2020 IEEE/MTT-S International Microwave Symposium (IMS), Los Angeles, CA, USA, 2020, pp. 547-550, doi: 10.1109/IMS30576.2020.9223791.
- [4] A. Ben Ayed, Y. Cao, P. Mitran and S. Boumaiza, "Digital Predistortion of Millimeter-Wave Arrays Using Near-Field Based Transmitter Observation Receivers," in IEEE Transactions on Microwave Theory and Techniques, vol. 70, no. 7, pp. 3713-3723, July 2022, doi: 10.1109/TMTT.2022.3174857.