Modeling and Design of Dual-Polarized Aperture Coupled Microstrip Patch Antennas with Dual-Offset Microstrip Feedlines

R1 – Microwaves and Millimeter-wave Systems

Jan Claudio – Department of Electrical and Computer Engineering

Dr. Rafael Medina – Department of Electrical and Computer Engineering

Abstract

This poster outlines a methodology for designing feed networks for single and dual-polarized aperture-coupled microstrip patch (ACMP) antennas with dual-offset microstrip feedlines. The challenge to be addressed is matching the antenna effective impedance (Zeff) to the feedline, which is an area with limited literature. This study demonstrated that ACMP antennas can be coupled to dual-offset feedlines with λ/4 transformers and T-junctions with infinite combinations of impedance for the λ/4 transformer [1], [2]. Equations were developed to relate the effective impedance to the feed geometry, allowing the design of the patch antenna's feedlines. Using this approach, two ACMP antennas, with single and dual-polarization, were designed and implemented obtaining satisfactory impedance matching.

Problem and Hypothesis

- While the ACMP antennas are widely utilized in advanced phased array antennas, there is limited literature addressing the process of matching the antenna's effective impedance to the feedline [3]. Impedance matching is critical for optimizing antenna performance, as it ensures maximum power delivery, eliminates reflections in the system, enhances signal-to-noise ratio, and reduces amplitudes and phase errors.
- The typical design approach involves parametric optimization within an electromagnetic simulator to align the outcomes with the desired impedance. This makes the design phase longer as it requires sequentially running a parametric assessment for each variable in order to meet the intended specifications.
- Earlier studies have demonstrated that the antenna's effective impedance depends on the level of coupling between the antenna and the feedlines, and this coupling is influenced by the separation between the two feed line offsets [4], [5]. As a result, there is likely a mathematical connection between Zeff and Gap that can be employed for designing the impedance matching network transformer. Zeff can be derived from the scattering parameters.

Objectives

- Define a theoretical model for the effective input impedance of an aperture coupled microstrip patch antenna with dual-offset microstrip feedlines as a function of the scattering parameters.
- Model the antenna effective input impedance and stub length as a function of offset-between feedlines using an electromagnetic field solver.
- Perform isolated simulations to design, fabricate, and test a single-polarized ACMP antenna using the proposed methodology.
- Utilize the suggested approach to design, manufacture, and test a dual-polarized ACMP antenna in an array configuration.

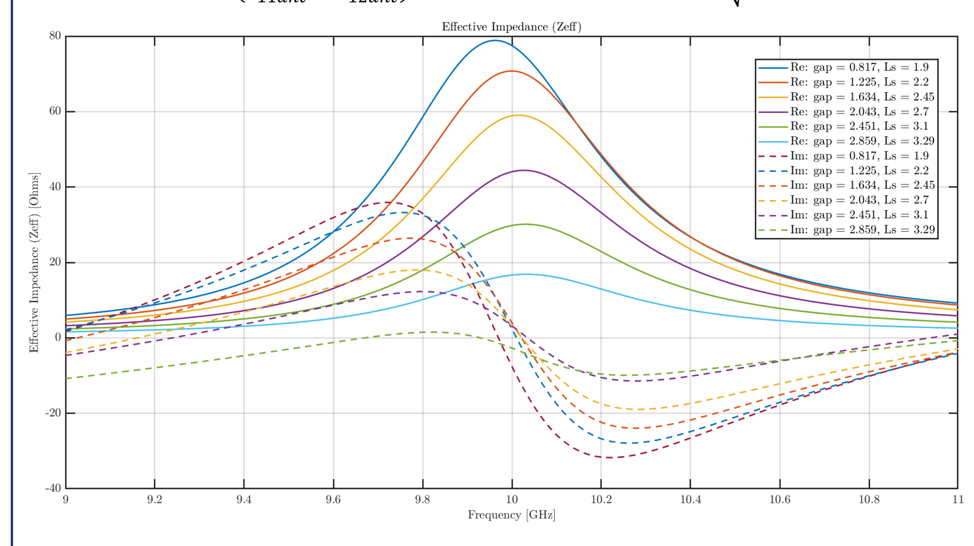
Methodology

10GHz Single-Polarized ACMPA Design (Isolated)

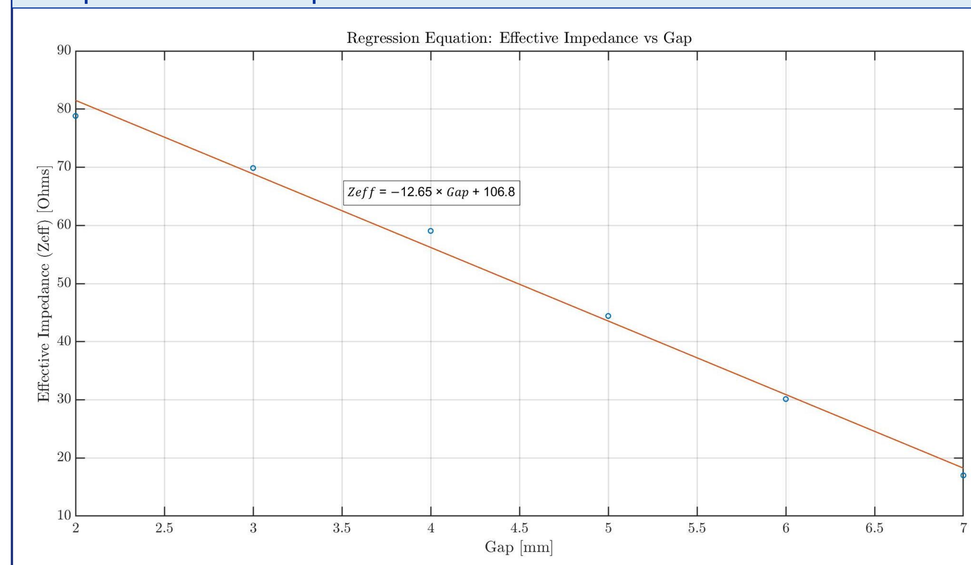
1. Element Characterization

$$Z_{eff}(Gap) = \frac{1 + (S_{11ant} + S_{12ant})}{1 - (S_{11ant} + S_{12ant})}$$

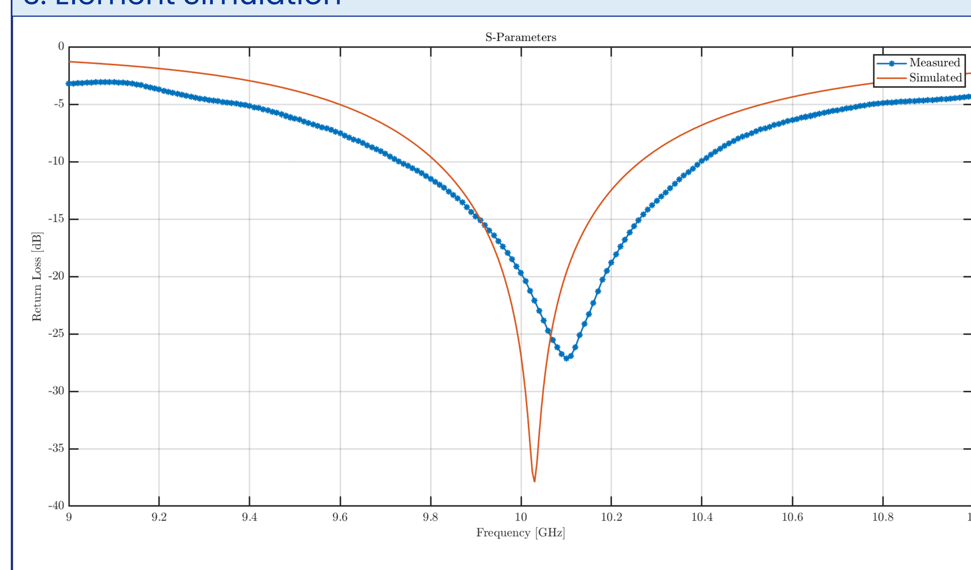
$$Z_{\lambda/4} = \sqrt{2 \times Z_0 \times Z_{eff}(Gap)}$$



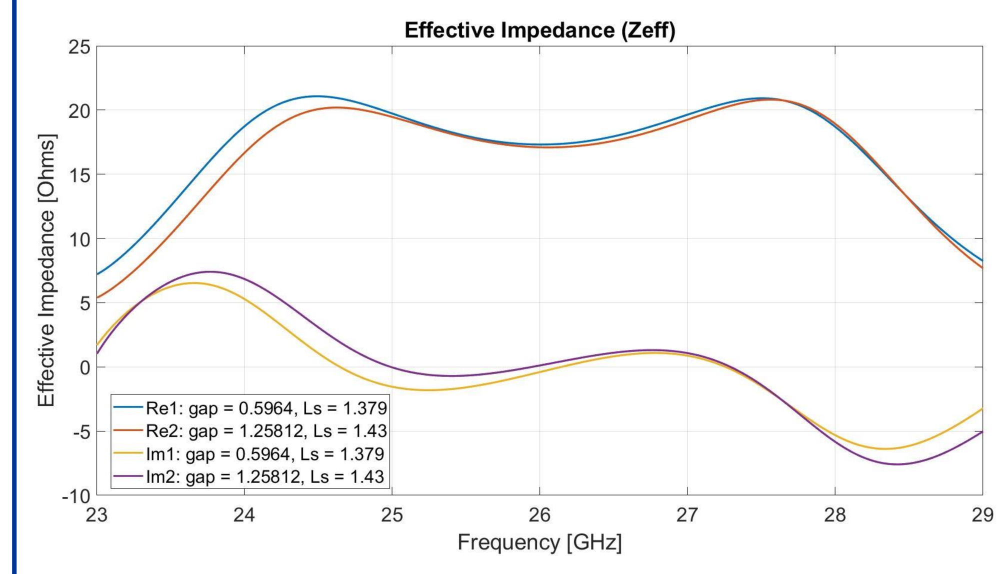
2. Equations Development

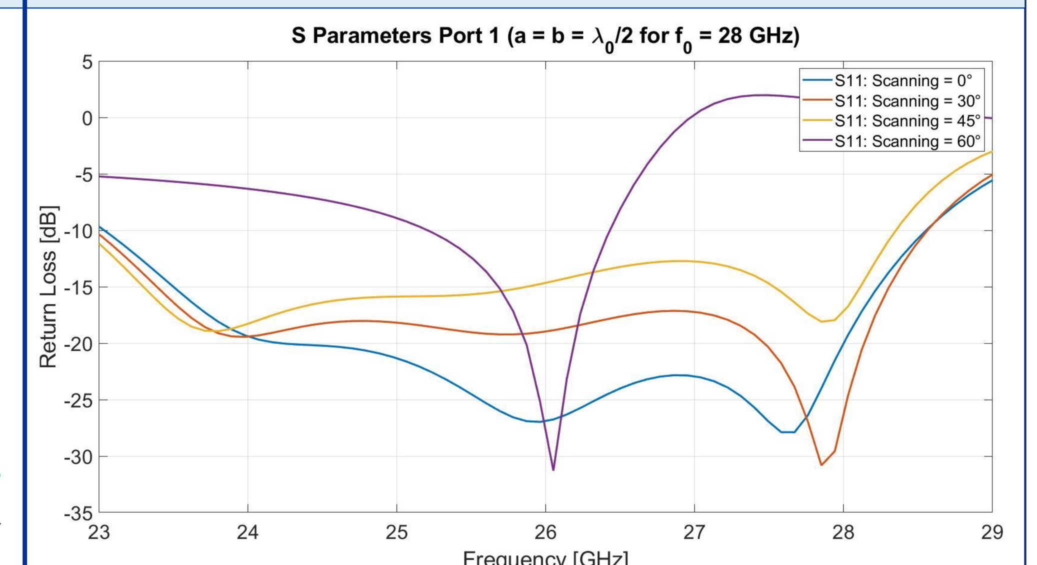


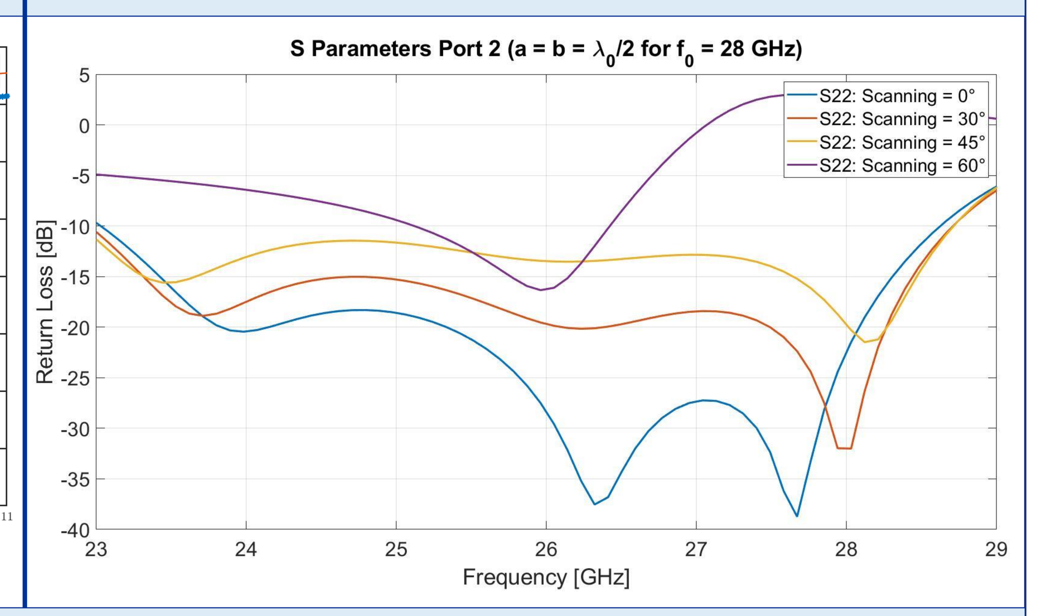
3. Element Simulation



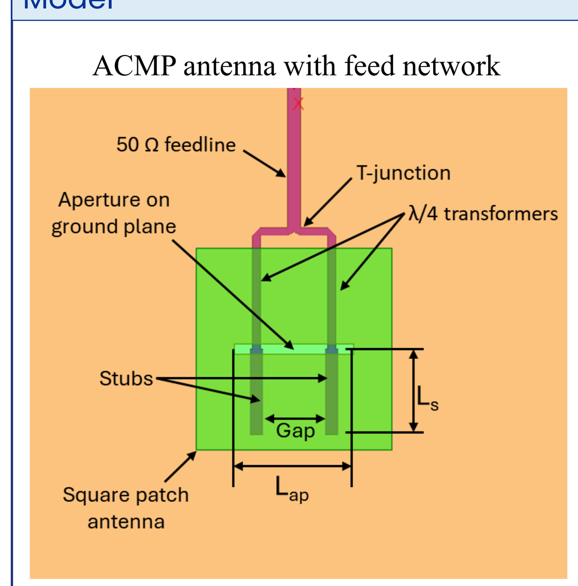
K/Ka Band Dual-Polarized ACMPA Design (Array)

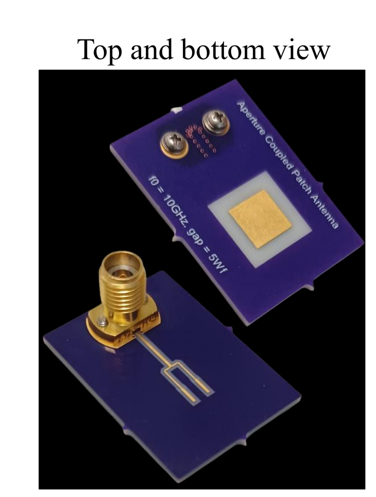


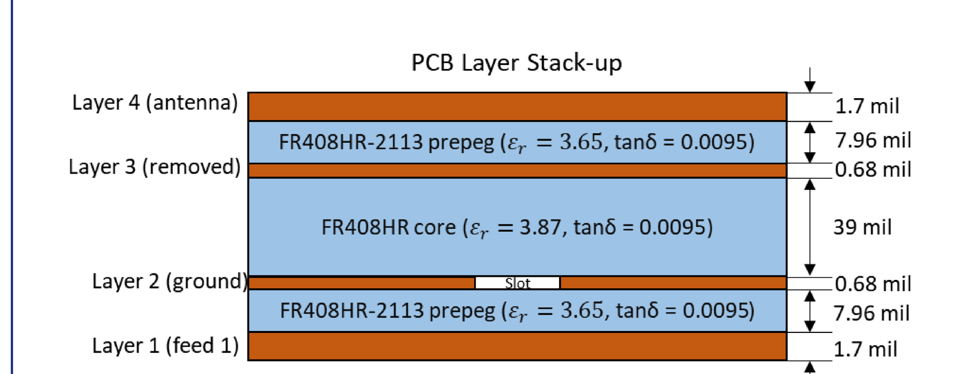


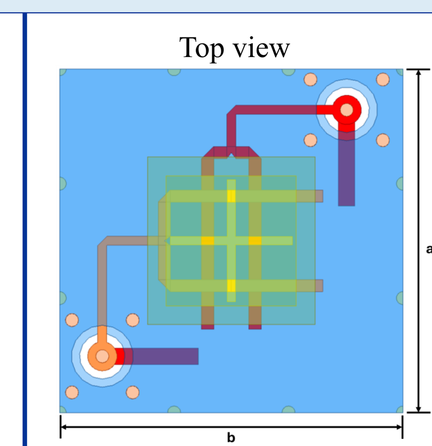


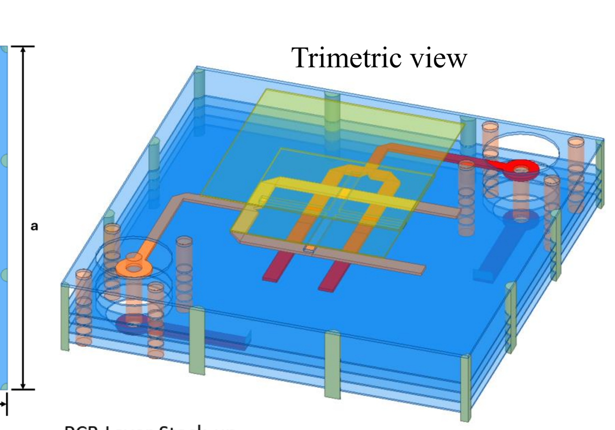
Model

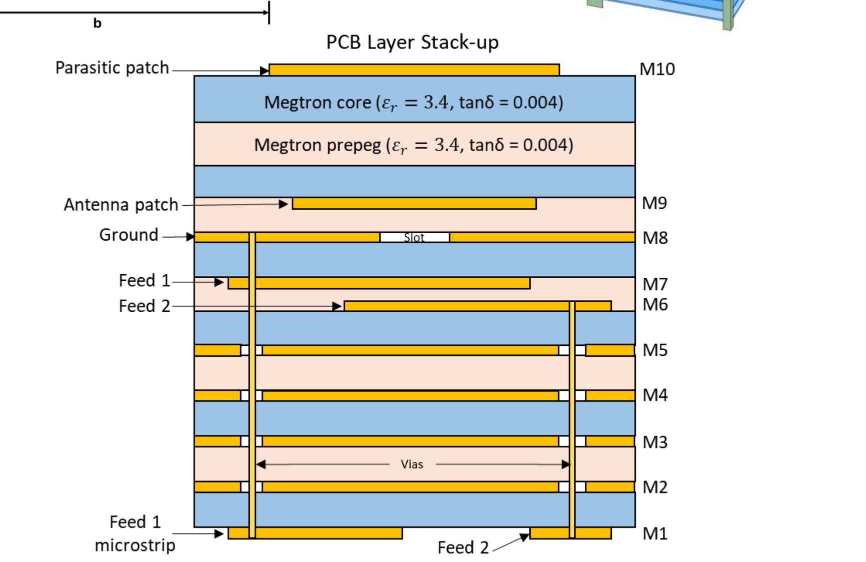












Results

- The characterization process resulted in the derivation of equations relating the effective impedance and stub's length to the offset-distance between feedlines allowing the design of the feed network for any desired input impedance value of the ACMP antenna.
- A single polarization ACMP antenna was designed for Zeff = 44.4Ω. To achieve such impedance a λ/4 transformer of Zo = 66.6Ω and a stub's length of 2.7 mm were required. Both simulation and measurements resulted in a return loss under -15 dB with a fraction bandwidths of about 4.5% and 6.6% respectively.
- Following this approach, a dual-polarized K/Ka band ACPM antenna was designed and simulated for Zeff = 18.6Ω in both ports. This simulation was conducted in an infinite array configuration achieving a return loss within a bandwidth of approximately 5.5 GHz, ranging from 23 GHz to 28.5 GHz, with the capability to scan up to an angle of 45 degrees. The stacked patch and substrate height led to an increase in bandwidth.

Conclusions

A single-polarized antenna was designed and implemented at 10GHz using this approach, resulting in favorable overall performance and successful impedance matching. These identical steps were then applied to develop a dual-polarized ACMP antenna at K/Ka band, leading to satisfactory outcomes in simulations. The dual-polarized antenna was simulated in an infinite array configuration, considering the mutual coupling among the elements.

References

[1] C. Balanis, "Antenna Theory: Analysis and Design", 4th ed. New York, John Wiley, 2016.

[2] S. Targonski, R. Waterhouse, and D. Pozar, "Design of Wide-Band Aperture-Stacked Patch Microstrip Antennas", IEEE Trans on Antennas and Propagation, vol. 46, Sept. 1998.

[3] K. Ghorbani and R. Waterhouse, "Dual Polarized Wide-Band Aperture Stacked Patch Antennas", IEEE Trans on Antennas and Propagation, vol. 52, Aug. 2004.

[4] A. Serra *et al.*, "A Wide-Band Dual-Polarized Stacked Patch Antenna", IEEE Antennas and Wireless Propagation Letters, vol. 6, 2007.

[5] J Lu, Z. Kuai, X. Zhu, and N. Zhang, "A High-Isolation Dual-Polarization Microstrip Patch Antenna With Quasi-Cross-Shaped Coupling Slot", IEEE Trans on Antennas and Propagation, vol. 59, July 2011.

Acknowledgements

This work was supported in part by the NSF Center for Advanced Radio Sciences and Engineering, under Cooperative Agreement Award AST-2132229.