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

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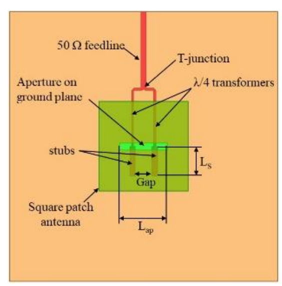
Abstract—**This paper describes a methodology for designing feed networks for single-polarized aperture-coupled microstrip patch (ACMP) antennas with dual-offset microstrip feedlines. The method involves characterizing the effective series impedance of the antenna when it is fed in a balanced manner as a function of the distance between the dual feedlines. Fitting equations were generated from the data to relate the effective series impedance to the feed geometry, allowing the design of the matching network for any effective impedance. This work demonstrates 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. A 10 GHz single-polarized ACMP antenna was designed and implemented obtaining satisfactory impedance matching.**

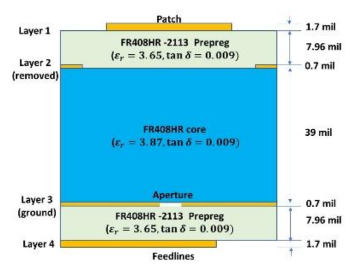
I. Introduction

Microstrip patch antennas find numerous applications in both government and commercial sectors due to their simplicity and versatility. These antennas can easily meet various requirements such as size, weight, cost, performance, manufacturing, and installation. To ensure the proper functioning of microstrip antennas, several feeding methods can be employed. Common configurations include microstrip line, coaxial probe, aperture coupling, and proximity coupling [1]. Among these, the aperture coupling feeding method stands out with its ability to isolate feed radiation from the antenna using a ground plane [2] [3]. In this configuration, the radiating element (antenna) and the feedline are not directly connected. Instead, substrates are employed to create separation through the previously mentioned ground plane. To establish coupling between the antenna and the feedline, it is necessary to have an aperture in the ground plane, positioned beneath the patch [2]. Optimization of the coupling level can be achieved by adjusting the size and position of the aperture, while any reactance introduced by changes in the aperture can be fine-tuned using the stub length in the case of a single offset feedline [2]-[4]. Both single and dual offset feedlines can be utilized for antenna coupling, but the latter generally yields lower cross-polarization levels [5].

In recent years, several aperture-coupled microstrip (ACMP) antennas with dual offset feedlines have been reported. The feedlines can be implemented using: 100 Ω lines [3] or λ/4 transformer [6]. Despite these works, there is limited literature on the design of the feed network to appropriately match the antenna impedance to the dual offset feedline.

In this paper, the steps required to design the feed network for an ACMP antenna featuring dual-offset feedlines is discussed. Although the method is demonstrated for a specific antenna substrate, it could be applied for any substrate materials. The geometry and the PCB stack-up of the ACMP antenna used in this work are shown in Fig. 1. A four-layer pcb is used, but with the inner layer 2 removed. The radiating microstrip patch element is etched on the top of the antenna substrate (made from FR408HR core and prepreg laminates), the coupling aperture etched in layer 3, and the feed network etched on the bottom of the feed substrate (FR408HR prepreg). The feed network has two feedlines, each having a tuning stub to tune the excess reactance of the effective impedance, Z_{eff}, seen at the aperture, and a λ/4 transformer to transform the real part of Z_{eff} into 100 Ω. The reactive T-junction matches the two 100 Ω impedances delivered by the transformers to 50 Ω. In this configuration, the effective impedance and coupling level between the antenna and the dual offset feedline are influenced by the spacing between the two feedline offsets. Regression equations are derived to establish the relationship between effective impedance and the feed geometry. Employing the methodology outlined in this paper, a 10 GHz aperture-coupled antenna was successfully designed and implemented.





a) b)
Figure 1. ACMP antenna with feed network. a) Geometry. b) PCB stack-up

II. Design Process

A. Element Characterization

The resonant frequency of the antenna is assumed to be 10 GHz for the purpose of demonstration. Both the length of the patch antenna and the length of the coupling aperture (L_{ap}) are initially obtained through HFSS simulations using a single centered feedline to set the required resonant frequency at 10 GHz. Once the patch and aperture dimensions are obtained, the centered feedline is replaced by a pair of 50 Ω feedlines as shown in Fig. 2a.

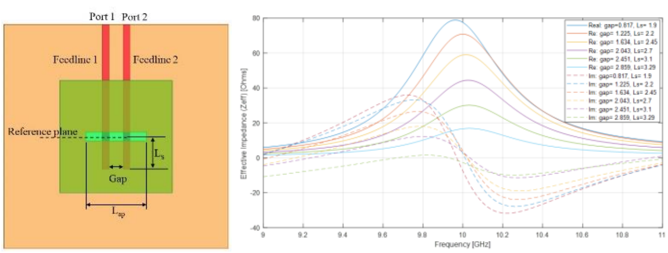
When an ACMP antenna is fed in a balanced manner, two equal waves in phase are applied to the coupling aperture, creating an effective series impedance at each feed line that depends on the mutual coupling between ports. This impedance cannot be directly measured, but it can be derived from S-parameters measurements by considering the dual-fed ACPM antenna as a two-port network and taking the data at the reference plane indicated in Fig. 2a. The effective impedance can be found as [3]

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

Since this impedance depends on the coupling level between antenna and feedlines, which is controlled by the gap between the dual feedlines, the characterization of Z_{eff} as function of the gap is required for design purposes. However, when the gap is varied, the length of stub must be adjusted to compensate for the increase in the reactance of Z_{eff}. The length and width of the patch remain unchanged throughout this process. Fig. 2b shows Z_{eff} for a resonant antenna at 10 GHz versus frequency for various separation distances between the dual-offset feedlines and the required stub length to keep $Im(Z_{eff}) = 0$.

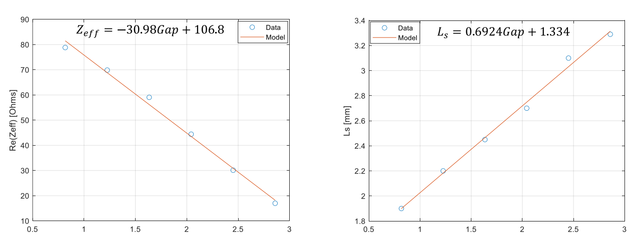
B. Equations Development

The equations derived from the characterization process enable the design of the feed network for any desired effective impedance. These equations yield output values for the λ/4 transformer impedance, spacing (gap) between the two feedline offsets, and stub length (L_s) required to match the antenna impedance to the dual offset feedline. To achieve this, the real part of Z_{eff} at the resonant frequency obtained from Fig. 2b is plotted as a function of gap in Fig. 3a. Then a regression equation was developed to establish a relationship between both variables, $Z_{eff} = -30.98gap + 106.8$ Consequently, for any desired Z_{eff}, this equation provides the necessary spacing between the two feedlines. Similarly, the required length of the stub to keep $Im(Z_{eff}) = 0$ and its model are plotted versus gap in Fig. 3b. Notice that both parameters Z_{eff} and L_s varies linearly with the spacing between feedlines.



a) b)

Figure 2. (a) Dual-fed ACPM antenna. b) Z_{eff} versus frequency for various gaps, units in mm



a) b)

Figure 3. (a) Re (Z_{eff}) at 10 GHz versus gap. b) Length of the stub versus gap

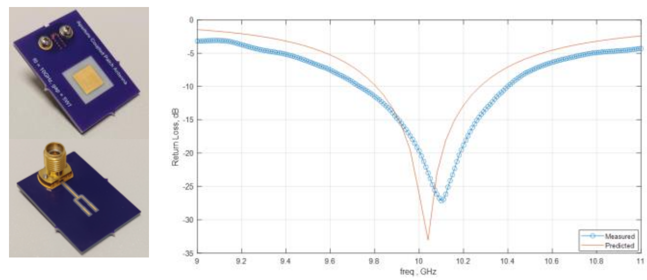
III. Design of a Prototype Element

An ACMP antenna was designed at 10 GHz for an effective impedance of 44.4 Ω. To achieve such impedance, the dual feedline is spaced by gap = 2.02 mm. This value also yields a length of stub L_s = 2.72 mm according the regression equation. The characteristic impedance of λ/4 transformers is obtained as

$$Z_{\lambda/4} = \sqrt{100 \times Z_{eff}(Gap)} \quad (2)$$

which gives an impedance of 66.6 Ω.

Fig. 4a shows the top and bottom layers of the fabricated prototype. Fig. 4b shows the comparison between the simulated and measured return loss for the antenna. The simulations yielded a return loss of -37.9dB @ 10.03 GHz, while the measured return loss was -27.1dB @ 10.1 GHz. Although a slight shift in frequency can be observed that may be due to the manufacturing process and material tolerances.



a) b)

Fig 4. a) Fabricated prototype. b) Simulated and measured return loss.

IV. Conclusions

A single-polarized antenna was designed and implemented at 10GHz using the proposed method, resulting in favorable overall performance and successful impedance matching. The characterization demonstrated that both effective impedance of the antenna and the length of the stub to keep the $Im(Z_{eff}) = 0$ varies linearly with the spacing between feedlines.

Acknowledgment

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References

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

[2] D. M, Pozar, "Microstrip antenna aperture-coupled to a microstripline," *Electron. Lett.*, vol. 21, pp. 49-50, Jan. 1985.

[3] S. D. Targonski and D. M. Pozar, "Design of wideband circularly polarized aperture-coupled microstrip antennas," *IEEE Trans. Antenna Propagat.*, vol. 41, pp. 214 – 220, Feb. 1993.

[4] A. A. Serra, P. Nepa, and G. Manara, "A wide-band dual-polarized stacked patch antena," *IEEE Antennas and Wireless Propag. Lett.*, vol. 6, pp. 141-143, 2007.

[5] S. D. Targonski, R. B. Waterhouse, and D. M. Pozar, "Design of wide-band aperture-stacked patch microstrip antennas," *IEEE Trans. Antenna Propagat.*, vol. 46, pp. 1245 – 1251, Sep. 1998.

[6] M. Yamazaki, E. T. Rahardjo, and M. Haneishi, "Construction of a slotcoupled planar antenna for dual polarization," *Electron. Letter*, vol. 30