Analysis of a Singly-Fed Circularly Polarized Electromagnetically Coupled Patch Antenna

A. Hajiaboli and M. Popović

Department of Electrical and Computer Engineering, McGill University, Montreal, Canada
amir.hajiaboli@mail.mcgill.ca, milica.popovich@mcgill.ca

Abstract − This paper presents analysis of a broadband circularly polarized electromagnetically coupled patch antenna (EMCP) fed thorough a coaxial probe. The bandwidth of the antenna is investigated numerically and through experiment. The 12% bandwidth of the measured return loss implies broadband behavior considering the operating frequency and the inherent bandwidth limitations of the microstrip antenna structure. The changes in circular polarization bandwidth were investigated using finite-element-method (FEM) software and the results suggest that the increase in separation between the patches causes a decrease of 3dB bandwidth and the degradation of the minimum value of axial ratio. An axial ratio bandwidth of 2% is achieved in the reported EMCP structure. In addition, we have applied a modal analysis using finite-difference time-domain (FDTD) simulation to reveal the simultaneous excitation of TM_{01} and TM_{10} modes at around 1.3GHz. These results help explain the broadband and circular polarization characteristics of the EMCP structure under investigation.

***Keywords**:* EMCP antenna, bandwidth, return loss, axial ratio, and modal analysis.

I. INTRODUCTION

Achieving circular polarization is a challenge in microstrip antennas. Various single-layer microstrip structures have been tested for this purpose. In general, these can be categorized into two groups: multiple-feed (e.g. dual-feed) and single-feed structures (with modified patches, e.g. corner truncated structures). The noted configurations share the same principle for obtaining the circular polarization: the dimensions are modified in order to provide propagation of two orthogonal modes with close resonant frequencies. Then, the antenna is excited at a frequency between the two resonant frequencies to ensure approximately equal amplitude for both modes. The location of the feed point is chosen strategically to result in a phase difference of 90° between the two modes [1].

It has been shown [1] that, in the case of dual-feed microstrip structures, the trade-off for the wide axial ratio (AR) bandwidth is the narrow bandwidth in the return loss. Further, the feeding structure would increase the complexity and overall size of the antenna. On the other hand, in the single-feed structures, such as corner truncated configurations, the AR bandwidth is narrow (on the order of 1%) [1]. The noted antennas, therefore, cannot be considered as desirable structures with optimized characteristics for applications that necessitate circular polarization.

Electromagnetically coupled patch (EMCP) antenna was first introduced in 1983 [2] for broadband applications. Further investigations revealed its circularly polarized characteristics [3-5] and the possibility of an EMCP design with acceptable AR and return loss bandwidth. Most of the previously tested EMCP structures are based on the dual-feed excitation, truncated corner patches or the circular patch. A recent work [3] reports a systematic design procedure that results in the return loss bandwidth of 43% and the AR bandwidth of 8% in C-band. The reported procedure is based on optimizing the dimensions of a corner truncated square patch microstrip antenna.

In this paper, we analyze and report on a singly-fed coaxially fed EMCP antenna for circular polarization applications. Unlike the structure discussed in [3], the patches are not corner truncated and the feed is a coaxial probe placed off the patch diagonal. The bandwidth of the antenna has been measured and compared with the simulation results. The axial ratio has been calculated with finite-element tool (HFSS, Ansoft Co.). Our parametric study reports on the variation of the return loss and axial ratio with the change is separation between two antenna patches. Finally, a modal analysis using finite-difference time-domain (FDTD) simulation explains the broadband and the polarization characteristics of the antenna by revealing the simultaneous excitation of standing modes on the patches around 1.3GHz.

II. THE ANTENNA STRUCTURE

Three-dimensional view of the antenna is shown in Fig. 1. The antenna consists of two patches separated by a foam spacer of thickness d and ε_r=1. The patches are etched on a substrate with relative permittivity ε_r=3.38, loss tangent tan δ = 0.0027, and thickness of 0.81mm. Another substrate of identical specifications is stacked to the fed-patch. These two substrates for the fed-patch are glued together to result in total thickness of 1.74 mm. We assume a 0.12 mm thick air gap between the two glued substrates. The dimensions of interest are as follows: fed-patch 64mm×68mm, upper patch 72 mm × 72 mm, and the finite ground plane 100mm×100mm. The coaxial probe feed, modeled according to work reported in [6, 7], is placed at x=10mm and y=4mm from the lower left hand corner of the lower patch as shown in Fig. 2. To reduce the computational burden, in both the FDTD and the FEM simulations, an infinite ground plane was considered.

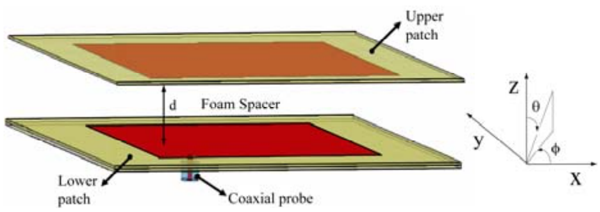


Fig. 1. Three-dimensional view of the electromagnetically coupled patch antenna.

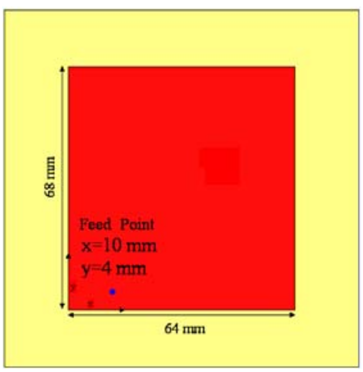


Fig. 2. Lower patch of antenna in Fig. 1, with indicated coordinates of the feed point.

III. RETURN LOSS

The measured and simulated results of input return loss (S_{11}) are shown in Figs. 3 and 4 for *d* = 22 mm and *d*=18mm. The center frequency of the -10dB return loss in simulation and experimental results is close to 1.3GHz and varies slightly with the change in *d*.

Figure 5 shows the percentage of -10dB bandwidth versus *d* both for simulation and measurement. Figure 5 demonstrates that the measured bandwidth of the antenna linearly increases with *d*, with the maximum measured bandwidth of 12% for *d*=30mm.

As it can be observed in Figs. 3, 4, and 5, around 1.25 GHz and for the foam spacer less than 24 mm, which is the focus of this paper, there is a good agreement between the simulated and the measured results. A discrepancy between the measurement and simulation can be noted around 1.8 GHz, and we suspect that it was caused by several approximations of the simulation model. First, we assume ε_r=1 for the foam layer. Second, we neglect the electromagnetic properties of the glue. Finally, the scattering effects of the finite ground plane in the constructed antenna (not modeled in the simulations to reduce the computational burden) also represent a possible source of error. As discussed in [8], by considering the finite ground plane it is possible to obtain better simulated results around 1.8 GHz.

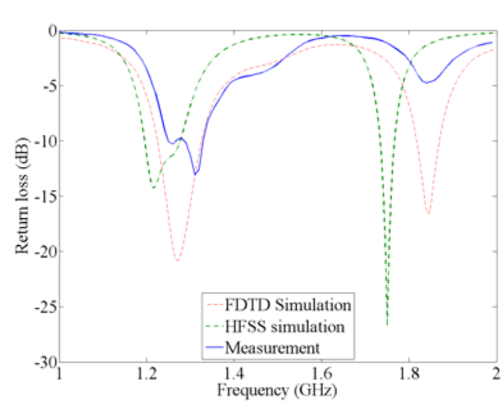


Fig. 3. Return loss for the separation between the lower and upper patch (foam spacer) *d*=18 mm.

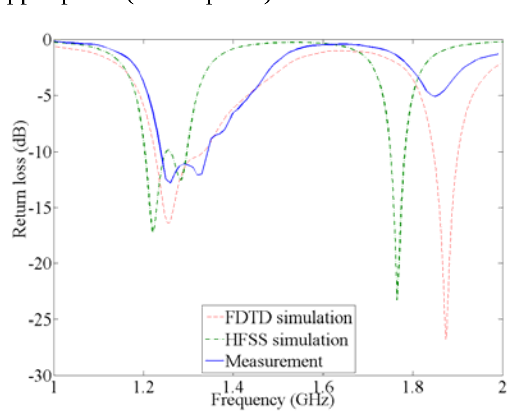


Fig. 4. Return loss for the separation between the lower and upper patch (foam spacer) d=22mm.

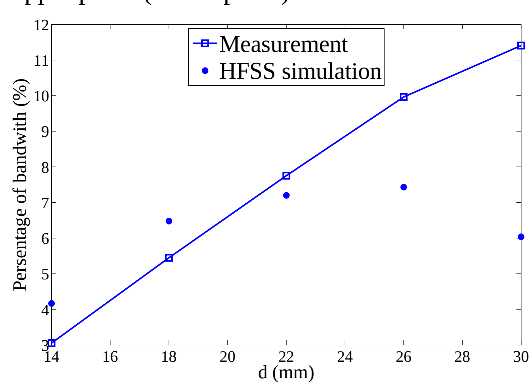


Fig. 5. Percentage of bandwidth for different values of the separation between the lower and upper patch (thickness of the foam spacer), *d*.

IV. AXIAL RATIO

Figure 6 shows the axial ratio computed with the finite-element software (HFSS) for different values of *d*. The minimum value of the axial ratio (0.7dB) occurs at *d*=20mm at the center frequency of 1.24 GHz. Considering the frequency shift between the measurements and simulations noted in Figs. 3 and 4, we can anticipate the minimum axial ratio value in the measurement at approximately 1.3GHz – the center frequency of the -10dB bandwidth. The maximum 3dB bandwidth of axial ratio (2.2 %) is observed for *d*=16mm at the center frequency of 1.23GHz. We note that the increase in *d* results in a reduction of the axial ratio bandwidth. As can be seen in Fig. 6, for *d* > 22 mm, the 3dB bandwidth of axial ratio is negligible.

Figure 7 shows the variation of axial ratio at φ=0°(*x*-*z* plane) versus θ at 1.24 GHz and for different values *d*. Again, it can be observed that, as *d* increases, the beamwidth of the 3-dB axial ratio decreases. For *d*>22mm, the beamwidth is zero. At *d* = 20 mm the 3-dB beamwidth of axial ratio is around 90°.

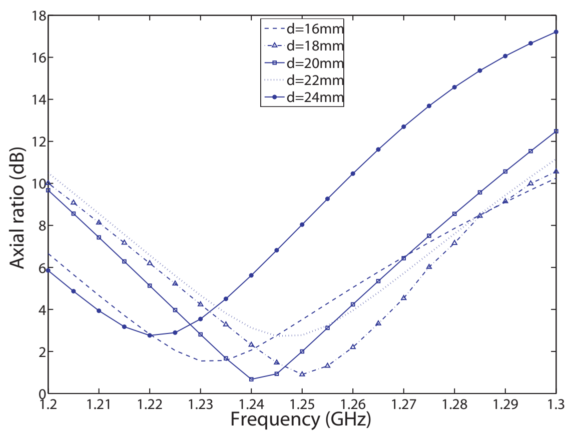


Fig. 6. Axial ratio vs. frequency for different values of *d*.

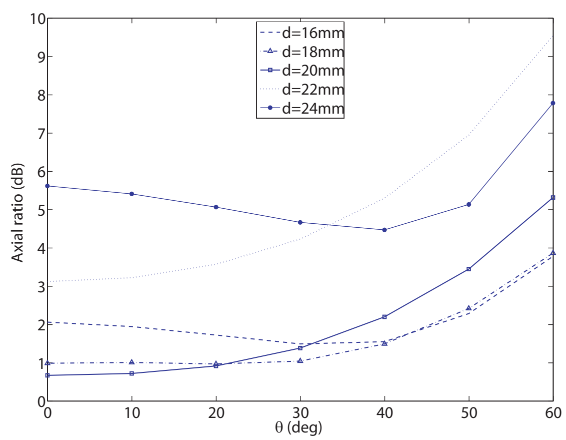
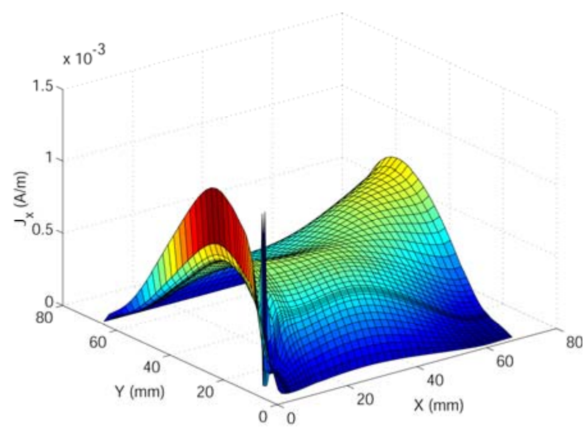


Fig. 7. Axial ratio at φ=0° vs. θ for different values of *d* at 1.24 GHz.

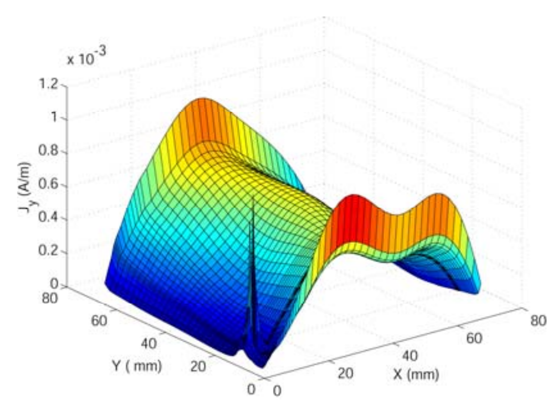
V. MODAL ANALYSIS

In order to explain the broadband behavior and the circular polarization of the antenna, we simulate the antenna using finite-difference time domain (FDTD) method and extract the current distribution on the patches at different frequencies.

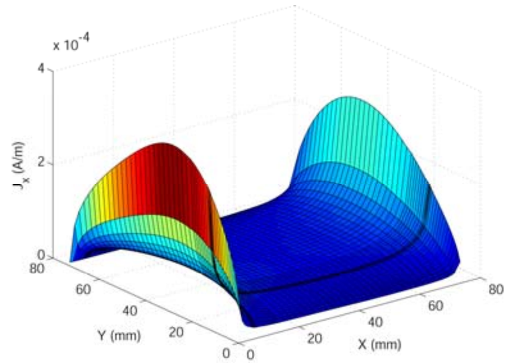
In order to obtain the current distribution (J_x and J_y) we calculate and save the current distribution at each time step at the late simulation time to ensure the higher order modes have diminished and only dominant modes exist on the patches. We then apply the Fourier transform on these current distributions to obtain the current distributions in frequency domain. As depicted in Fig. 8, the current distribution at 1.3 GHz corresponds to TM_{01} and TM_{10} modes with approximately the same amplitude. The simultaneous excitation of these two modes matches with the broadband behavior obtained at around 1.3GHz. Further, since the modes are spatially orthogonal this explains the circular polarization when the appropriate phase conditions are met for certain values of the separation between the upper and lower patch (*d*).



(a)



(b)



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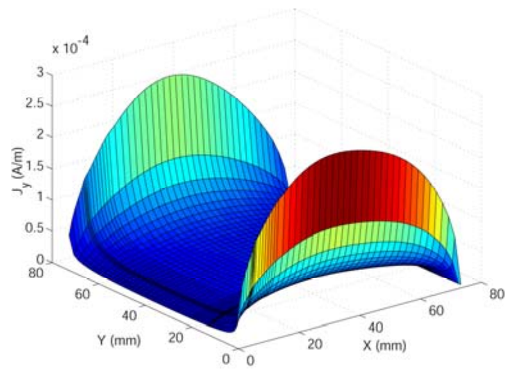

(d)

Fig. 8. Current distribution at 1.3GHz on the patches, illustrating the simultaneous excitation of TM_{01} and TM_{10} modes. a) J_x on lower patch, b) Jy on lower patch, c) J_x on upper patch, and d) J_y on upper patch.

VI. CONCLUSION

A broadband circularly polarized electromagnetically coupled patch antenna has been analyzed through simulation and experiment. The measured bandwidth increases linearly with the separation between the lower and upper antenna patch *d* and the maximum bandwidth of 12% around 1.33 GHz (L-band) occurs for *d*=30mm. Through FEM simulations, we observed that the 3-dB bandwidth of axial ratio degrades as the separation of the patches *d* increases. A modal analysis on the current distributions obtained by FDTD has been performed and the current distribution at 1.3GHz clearly shows the simultaneous excitation of TM_{01} and TM_{10} modes with nearly equal amplitudes on the lower and upper patches. This can explain the broadband and circular polarization characteristics of the antenna.

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Amir Hajiaboli obtained a B.Sc. from University of Tehran in 2000 and a M.Sc. with highest distinction from Iran University of Science and Technology in 2003 both in electrical engineering. Since Sept. 2004, he has been pursuing his Ph.D. in electrical engineering with the Department of Electrical and Computer Engineering at McGill University in Montreal Canada. His research interests focus on computational electromagnetic for antennas and bio-medical applications. He has extensive experiences in developing computational electromagnetic codes using finite-difference time-domain method. He is currently working on simulating the electrodynamics of light interaction with retinal photoreceptors.

Milica Popović received her B.Sc. (1994) from University of Colorado (Boulder, Colorado, USA) and M.Sc. (1997) and Ph.D. (2001) degrees from Northwestern University (Evanston, Illinois, USA), all in electrical engineering. She is currently an associate professor with the Department of Electrical and Computer Engineering at McGill University in Montréal, Canada. Her research interests focus on numerical methods in computational electromagnetics for bio-medical applications, in particular: breast cancer screening with microwaves, wireless implants for physiological research and light interaction with retinal photoreceptor cells. On the teaching side, her efforts include improvement methods for instruction of introductory electromagneticss courses.