Circularly polarized 2×2 patch antenna array at 5 GHz

Sinisa Jovanovic, Sinisa Tasic and Predrag Manojlovic

Abstract – **This paper presents a simple design procedure for obtaining a uniplanar patch antenna array with circular polarization. The feeding network of the array is carefully designed for achieving very good matching at the main antenna port as well as for obtaining a precise signal equal amplitude dividing with the required phases for all the elements of the array. An experimental example for a 5 GHz central frequency is manufactured and measured for validating the proposed method.**

Keywords – **Patch antenna, circular polarization, printed antenna array, sequential feeding, uniplanar microstrip.**

I. Introduction

Circularly Polarized (CP) antennas are employed within various communications systems whose operating comprises position or orientation change of transmitting and receiving antennas such as aircraft and satellites communication, radar, remote control, telemetry, WLAN, WiMAX, and noninvasive microwave. Their usage eliminates the influence of transmitting/receiving antennas' mutual orientation on the receiving signal level and prevents the occurrence of excessive propagation loss due to cross polarization [1, 2].

Compared to antennas with linear polarization, CP antennas have a more complex set of requirements that have to be fulfilled during the design process. Among all conceivable practical realizations of CP antennas, printed CP antennas are particularly attractive due to their low mass, simplicity, reproducibility and simple manufacturing [3].

II. Design Theory

A. Basic Concept

Generally speaking, CP can be attained either by using CP radiating elements, or by using an array in which several linearly polarized elements form CP [4]. The design described in this paper combines both techniques to achieve better axial ratio (AR) purity over a broader frequency range [5-7]. In addition, and for the same reason, the two point fed patch is used rather than the perturbed single point fed patch. In that manner, a 2x2 array, composed of square shaped patches as shown in Fig.1, is proposed.

To achieve an ideal CP with AR=1 (0 dB) the signals at all eight ports (P1-P8) of the array should have equal amplitudes and mutual phase shifts as indicated in Fig. 1. As long as this condition is fulfilled the AR value will be very close to 0 dB. However, with a realistic feeding network, the ideal CP could be achieved at a single frequency point only, while AR ≤ 3 dB, which is acceptable for practical use, could be achieved in a relatively narrow frequency range of a few percent.

B. Patch Element Initial Design

For a selected microstrip (MS) substrate (specified with ε_r and h) the optimal dimensions (W and L) of a rectangular patch having a resonance at frequency f_0 is given with the following well known equations:

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_R + 1}{2}}} \tag{1}$$

$$L = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} - 0.824h \left(\frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \right) \tag{2}$$

$$\text{where: } \varepsilon_{eff} = \frac{\varepsilon_R + 1}{2} + \frac{\varepsilon_R - 1}{2\sqrt{1 + 12\frac{h}{W}}}$$

Equation (2) gives a very good initial size ($L \times L$) for a square-shaped two point fed patch with a relative error smaller than 2%, compared to results obtained by EM analysis, which can easily be corrected in second design iteration by scaling the array's overall dimensions. The array elements are separated by approximately $2\lambda_0/3$ along both axes.

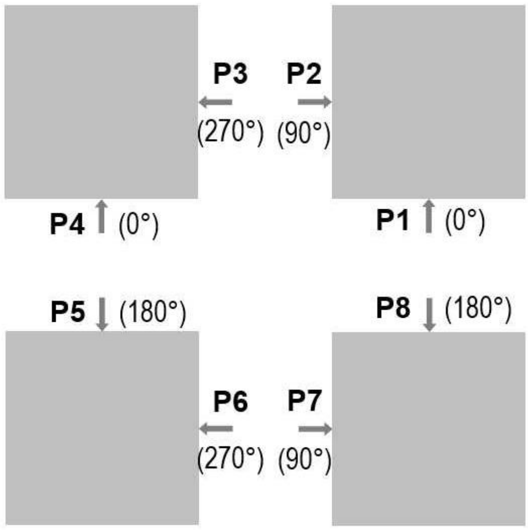

Fig. 1. Principle diagram of a circularly polarized 2×2 patch array

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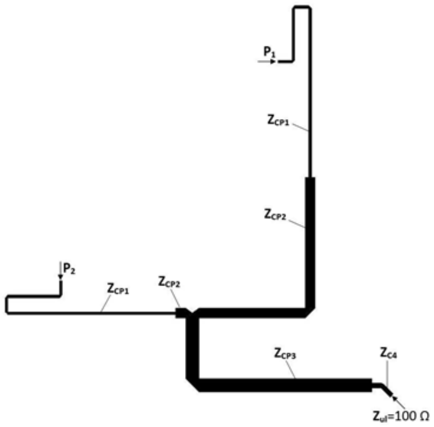


Fig. 2. Patch Feeding Network

C. Patch Feeding Network Design

Every element of the array has an identical Patch Feeding Network (PFN) which is shown in Fig. 2. It provides two equal signals at the patch's ports (P1 and P2), with a phase difference of π/2. Another function of the PFN is to match the patch ports' input impedances (of about 220 Ω) to the impedances of the output ports of the Array Feeding Network (AFN), which is adopted to be $Z_{ul} = 100\ \Omega$. Fig. 2 shows one possible PFN configuration composed of microstrip lines (MSL) having characteristic impedances: $Z_{CP1} = 122\ \Omega$, $Z_{CP2} = 68\ \Omega$ and $Z_{CP3} = 58\ \Omega$, with the respective widths (in mm): $w_{CP1} = 0.12$, $w_{CP2} = 0.46$ and $w_{CP3} = 0.6$ for the selected MS substrate ($\varepsilon_r = 2.17$, $h = 0.254$ mm, $\tan\delta = 0.0009$ and $t = 0.017$ mm). The electrical length of MSL with Z_{CP1} and Z_{CP3} is π/2, which is also the difference of the longer and shorter MSL having Z_{CP2}.

D. Array Feeding Network Design

A layout of the AFN is shown in Fig.3. The feeding coaxial SMA connector is placed in the centre of the symmetry of the array, vertically to the MS ground layer. The central part of the AFN (shaded in grey) divides the input signal into four equal amplitude samples shifted successively by π/2. It consists of a short 50-ohm MSL followed by a cascade of λ/4 transformers

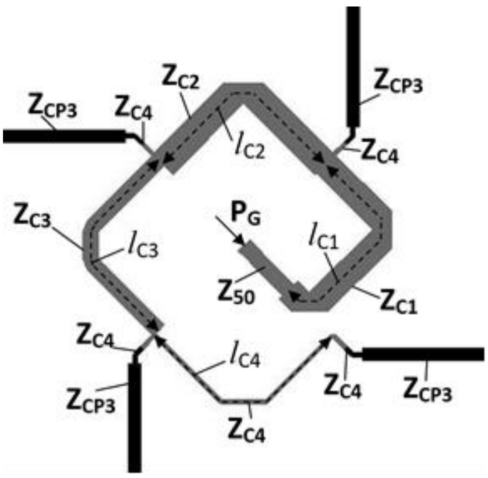


Fig. 3. Array feeding network

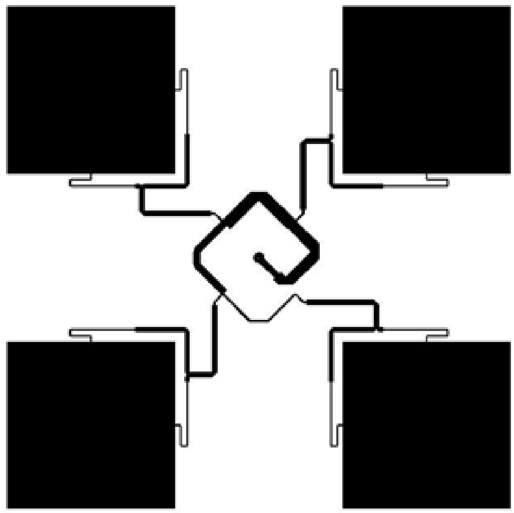


Fig. 4. Antenna Array Layout

with characteristic impedances: $Z_{C1} = 35.35\ \Omega$, $Z_{C1} = 33.33\ \Omega$, $Z_{C3} = 50\ \Omega$ and $Z_{C4} = 100\ \Omega$. The corresponding MSL widths (in mm) are $w_1 = 1.26$, $w_2 = 1.35$, $w_3 = 0.77$ and $w_4 = 0.21$. Each section of the cascade is followed by a short parallel MSL having $Z_{C4} = 100\ \Omega$, that connects AFN and one of the four PFNs. The MSL of AFN are meandered using an appropriate combination of 90° or 45° bends in order to accommodate MSL of different widths and slightly different lengths (l_{C1} to l_{C4}) into the available space between the patches as well as to precisely align the connections between AFN and four PFNs,. A complete layout of the proposed antenna array having right-handed (RH) CP is shown in Fig. 4, while its flipped version (either around x or y axes) corresponds to a left-handed (LH) CP antenna array. The layout is designed for a central frequency of 5 GHz which gives the patch dimension of 20 × 20 mm, patch spacing of 40 mm and overall array dimensions of 60 × 60 mm.

E. Simulation Results

The configuration from Fig. 4 is analysed with a full wave electromagnetic simulation (EMS) program. Fig. 5 shows the obtained results for the return loss (RL) at the input port of the array, which is better than 30 dB at a central frequency. RL better than 10 dB is obtained from 4.94 GHz to 5.07 GHz.

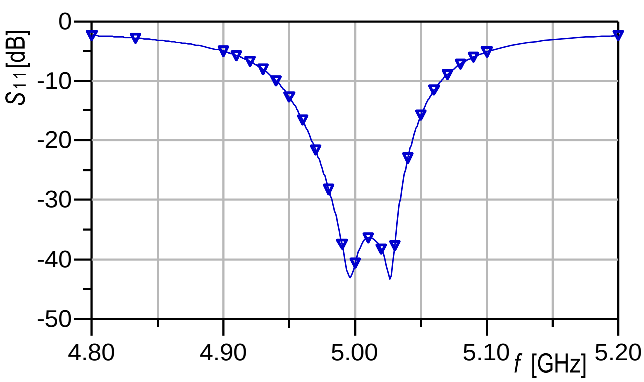


Fig. 5. Return loss at the input of antenna array (EMS results)

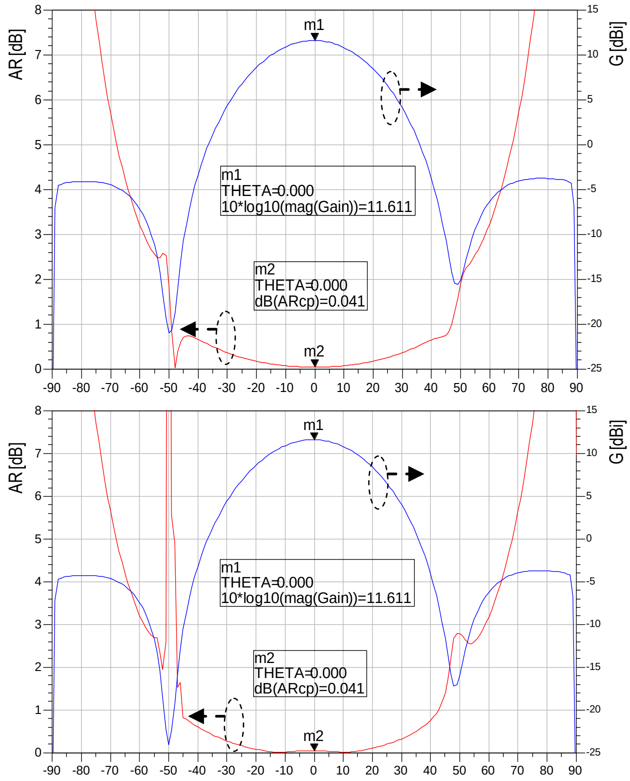


Fig. 6. Radiation pattern and AR in two orthogonal planes at 5.01 GHz (EMS results)

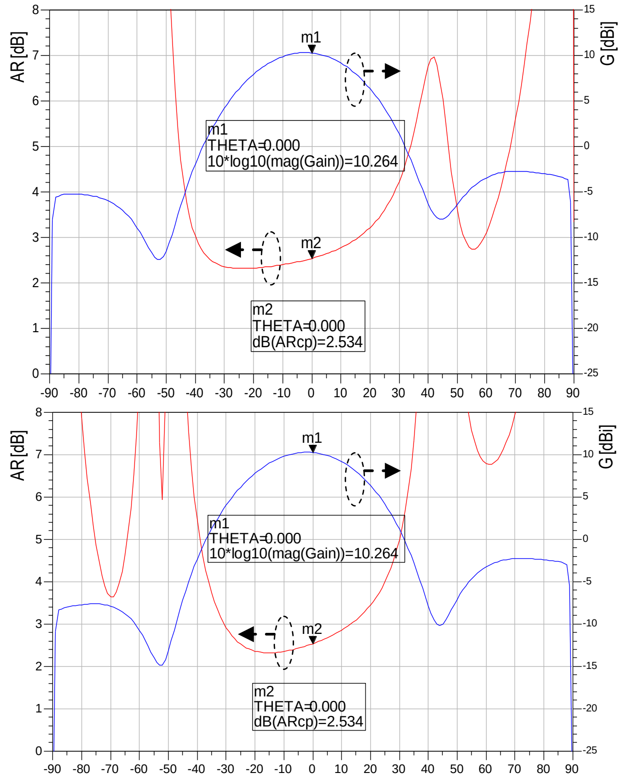


Fig. 8. Radiation pattern and AR in two orthogonal planes at 5.05 GHz (EMS results)

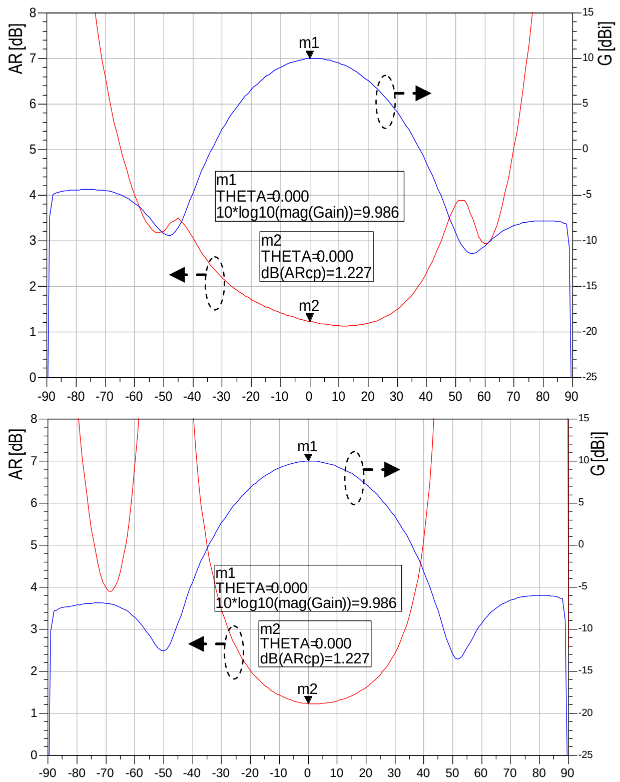


Fig. 7. Radiation pattern and AR in two orthogonal planes at 4.98 GHz (EMS results)

Figs. 6 to 8 show the radiation pattern and AR of the antenna array from Fig. 4 in two mutually orthogonal planes that are also normal to the plane containing the array. Fig. 6 shows that the best results for both gain (G = 11.6 dBi) and AR ≈ 0 dB are obtained at a frequency of 5.01 GHz. At 4.98 GHz and 5.05 GHz, which frame the useful frequency range, the gain reduces to 10 dBi, while AR increases to 1.2 dB and 2.5 dB, respectively. The narrow range is caused by the selection of a relatively thin MS substrate that was required for MSLs with low Z_c within AFN. Radiation patterns at a central frequency have very good axial symmetry, which becomes slightly deformed toward framing working frequencies.

Fig 9 shows the frequency characteristics of AR and the maximum gain and AR.

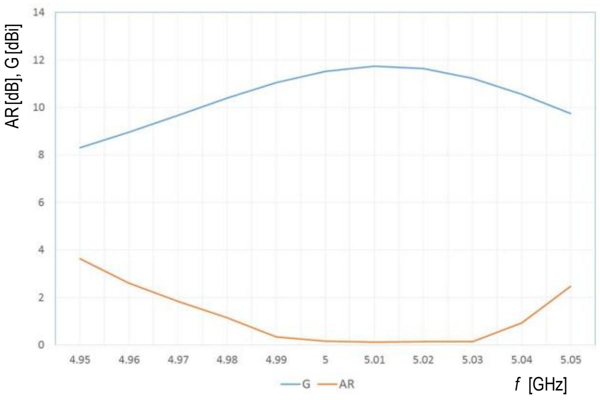
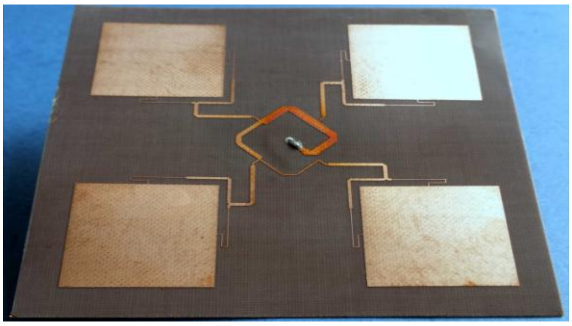


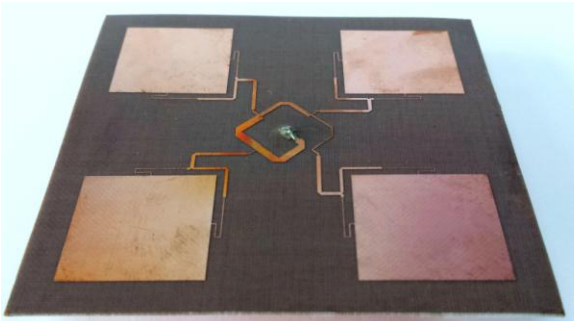
Fig. 9. Gain and AR of antenna array (EMS results)

III. Realization and Measured Results

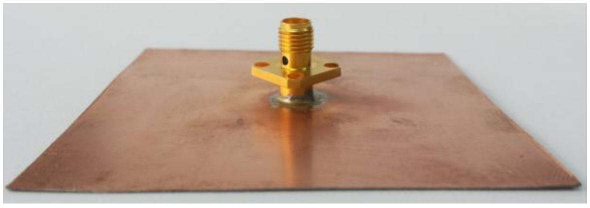
As shown in Fig. 10, both the RH and LH versions of the antenna layout from Fig. 4 are fabricated using the standard lithographic procedure, for experimental validation of the proposed design. An identical pair of the RH version is realized for gain valuation by free space loss measurement, which showed a maximum gain of 10.5 dBi at 4.95 GHz,



(a)



(b)



(c)

Fig. 10. Photo of realized 2×2 antenna array: (a) front side - RHCP; (b) front side - LHCP; (c) back side

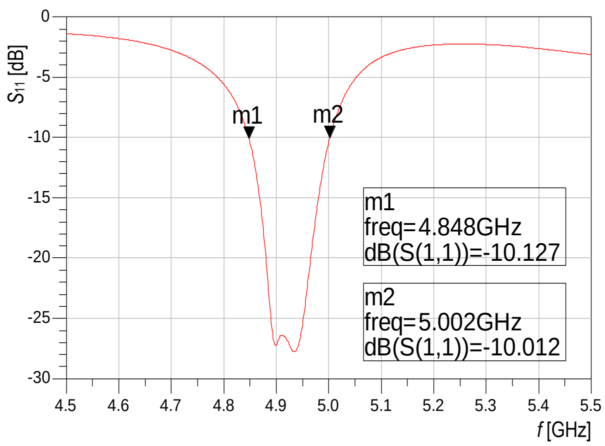


Fig. 11. Measured Return Loss of realized antenna array

while the LH antenna is used for cross-polarization isolation measurement, which was about 25 dB. AR is estimated from receiving signal level variation due to the rotation of one of the tested antennas, which showed the AR value of about 1dB in a 70 MHz wide range around the central frequency.

As shown in Fig. 11, the measured RL is better than 10 dB from 4.848 GHz to 5.002 GHz, whereas at the range centre, the RL is better than 25 dB. The measured frequency characteristics are shifted for about 1.5% toward lower frequencies relative to EM simulation results, which can be corrected in the next design iteration by suitable layout scaling.

IV. Conclusion

The presented solution enables the realization of circularly polarized antennas as a printed array realized in uniplanar microstrip technology. The parasitic radiation of the array feeding network is significantly mutually canceled due to its center-symmetric shape which prevents AR degradation. The proposed design and structure of the array feeding network, allows the achievement of excellent matching at the main input of the array with an RL better than 25 dB at the central working frequency. The selected values of λ/4 transformers' characteristic impedances allowed keeping the widths of the transmission lines within the available technological limits. The measured results are in very good agreement with the theoretical predictions with a slight frequency characteristics shift of 1.5% toward lower frequencies.

Acknowledgement

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