Comparative Study of Circularly Polarized Microstrip Arrays Distinguished by their Feeding System

Georgi S. Kirov[1] and Desislava P. Mihaylova[2]

***Abstract* – A comparative study of 4x4 circularly polarized microstrip arrays designed to operate within the Ku-band is accomplished. Two different feeding networks combining in-phase excitation of the sub-arrays and sequential rotation principle are investigated. For the purpose, two antenna models distinguished by their feeding system are designed and comparative simulation results are presented. The main electrical features of the arrays and the benefits due to feed line modification are estimated. The final array structures employ inexpensive substrates and have the advantage of simplicity and optimal geometry.**

***Keywords* – Aperture coupled microstrip antenna, Circularly polarized microstrip array, Sequential rotation principle, Simulation results.**

I. Introduction

A comparative study of the characteristics of two 4x4 circularly polarized (CP) microstrip arrays is presented in this paper. The arrays are designed to operate in the Ku-band at around 12 GHz. The investigated structures utilize 2x2 sub-arrays of circularly polarized antenna elements and differ with their feeding networks. The obtained simulation results for two optimized 4x4 CP arrays are summarized and compared in order to ascertain their advance features.

It should be pointed out that most scientific references emphasize on the advantages of sequentially-rotated arrays (SRA) in terms of both Axial Ratio and impedance bandwidths [1 - 5]. In the current study, however, a combination of both sequential rotation principle and in-phase excitation of microstrip sub-arrays is proposed. Thus, a more comprehensive esteem of the radiation characteristics of circularly polarized microstrip arrays and design limitations as well, is provided. The EM 3D simulator CST Microwave Studio 2008 is employed.

II. Arrays design

The arrays investigated herein consist of circularly polarized 2x2 sub-arrays with sequential rotation (CP SRA) utilizing aperture-coupled microstrip elements. The geometry of the sub-array is displayed in Fig. 1.

The coupling cross-apertures etched in the ground of the two-layer structure have unequal shoulders defined according to the middle aperture length La as $La1=2La.Ks/(1+Ks)$ and $La2=2La/(1+Ks)$, so that $2La=La1+La2$ when $Ks=1$.

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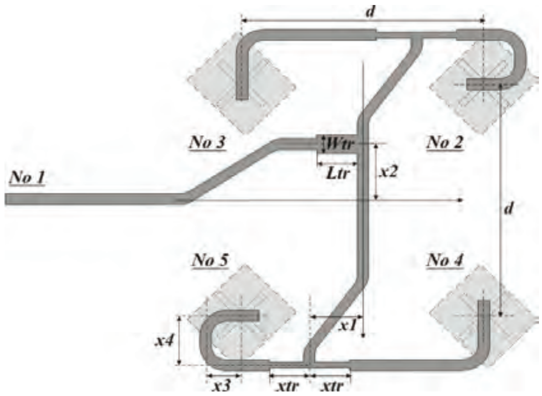

Fig. 1. Geometry of a circularly polarized 2x2 sub-array with sequential rotation (CP SRA) employing aperture-coupled microstrip elements.

Parameters of the optimized CP SRA 2x2 (Fig. 1): Antenna Size a = 53 mm, Array base d = 18 mm, Patch Length Lp = 6.1 mm, Patch Ratio Kp = Lp/Wp=1.14, Slot Ratio Ks = La1/La2 = 1.06, Stub Length Ls = 1.2 mm, Middle Aperture Length La = 4.8 mm, Impedance transformer Length Ltr(35.36Ω) = 3 mm, Impedance transformer Width Wtr = 1.3 mm, Distances xtr = 3 mm, x1 = 4 mm, x2 = 4.3 mm, x3 = 2.7 mm, x4 = 3.8 mm, Feed line Width Wf(50Ω) = 0.845 mm, Wf(70.7Ω) = 0.35 mm.

Substrates: 1) Patch substrate, Taconic TLX-7: $\varepsilon rp=2.60$, $\tan\delta p=0.0019$, Substrate thickness hp=1.575 mm, Cladding thickness tp=0.035 mm; 2) Feed substrate, Taconic RF-60A: $\varepsilon rf=6.15$, $\tan\delta f=0.0028$, Substrate thickness hf =0.635 mm, Cladding thickness tf=0.0175 mm;

The principle of sequential rotation is realized with 90^o rotation of the patches and corresponding coupling slots, and 90^o phase shift in the feeding part below the radiating patches. Particular phase shift is achieved due to different feed-line lengths, determined due to simulation so that to achieve optimal AR-bandwidth. Two types of bends 50Ω/2 x 70.7Ω and 35.36Ω/2 x 50 Ω are used in the feeding network. The choice of the first is explained with the lower susceptance, leading to a broader impedance bandwidth. The second bend is considered structurally suitable. The simulation approach as part of the current design procedure allows determination of the exact placement and dimensions of the applied transformers.

The main electrical characteristics of the optimized 2x2 CP sub-array are listed in Table 1. The bandwidth of the sub-array is limited by Directivity and ranges up to 10.98 %.

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TABLE I

SUB-ARRAY ELECTRICAL CHARACTERISTICS

Electrical characteristic	**2x2 Sub-array**
Impedance Bandwidth	
fmin / fmax [GHz]	10.66 / 12.55
fo [GHz]	11.6
bw %	16.29
Directivity Bandwidth	
fmin / fmax [GHz]	10.75 / 12
fo [GHz]	11.375
bw %	10.98
AR-bandwidth and characteristics within it	
$fmin_{AR}$ / $fmax_{AR}$ [GHz]	10.73 / 12.65
fo_{AR} [GHz]	11.69
bw_{AR} %	16.42
BRmin / BRmax [dB]	-25.0 / -11.76
Gmin / Gmax [dB]	8.15 / 11.15
Dmin / Dmax [dB]	8.9 / 11.9

Using the above mentioned sub-array another two 4x4 CP arrays distinguished by their feeding system are designed – Fig. 2 and Fig. 3. The first one is fully constructed on the sequential rotation principle, adjusting the radius r4 for appropriate phase shift. In the second in-phase feeding is used.

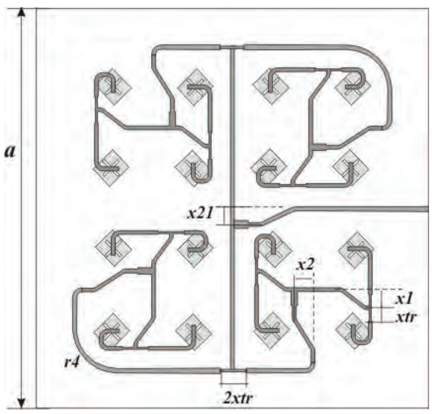


Fig. 2. Geometry of the circularly polarized microstrip array with sequentially rotated sub-arrays (CP ARRAY 1).

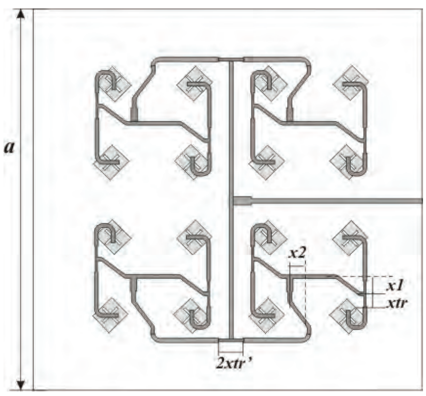


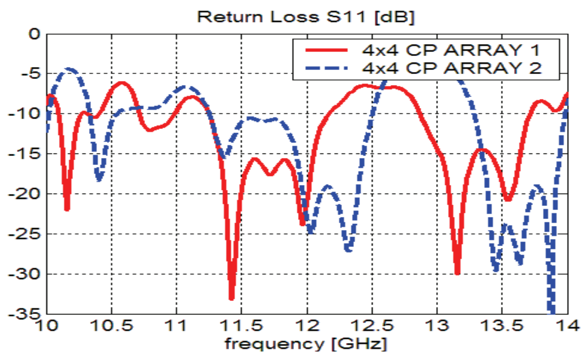
Fig. 3. Geometry of the circularly polarized microstrip array with in-phase excited sub-arrays (CP ARRAY 2).

Parameters of 4x4 CP ARRAY 1 (Fig. 2): Antenna Size a = 89 mm, Patch Length Lp = 6.1 mm, Patch Ratio Kp = 1.14, Slot Ratio Ks = 1.06, Stub Length Ls = 1.2 mm, Middle Aperture Length La = 4.8 mm, Transformer Length Ltr = 3 mm, Transformer Width Wtr = 1.3 mm, Distances xtr = 3 mm, x1 = 4 mm, x2 = 4.3 mm, x21 = 3.4 mm, x3 = 2.7 mm, x4 = 3.8 mm, radius r4 = 10 mm.

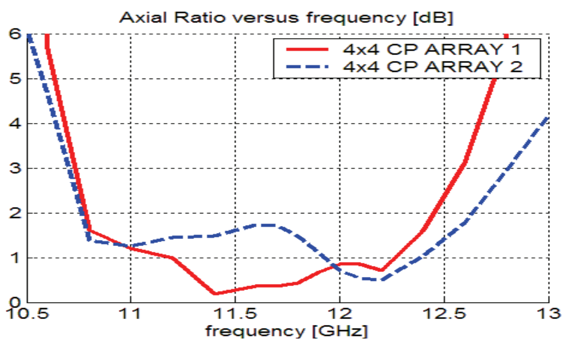
Parameters of 4x4 CP ARRAY 2 (Fig. 3): Antenna Size a = 89 mm, Patch Length Lp = 6.1 mm, Patch Ratio Kp = 1.17, Slot Ratio Ks = 1.06, Stub Length Ls = 1.2 mm, Middle Aperture Length La = 4.8 mm, Transformer Length Ltr = 3 mm, Ltr1 = 4 mm, Transformers Width Wtr = 1.3 mm, Distances xtr = 3 mm, xtr' = 2 mm, x1 = 4 mm, x2 = 4.3 mm, x3 = 2.7 mm, x4 = 3.8 mm.

III. COMPARATIVE STUDY OF ARRAYS

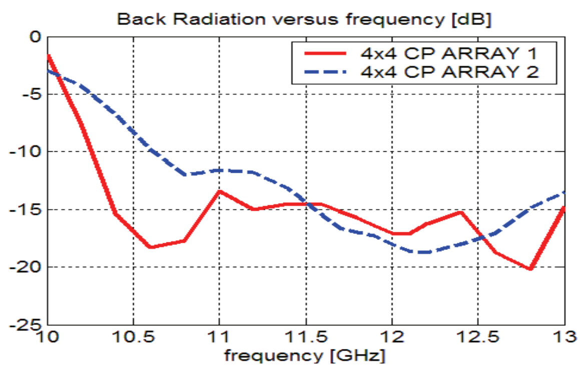
Comparative simulation results for the two 4x4 CP arrays are shown in Fig. 4. The arrays have been optimized in terms of AR-bandwidth due to CST Microwave Studio 2008 [6].



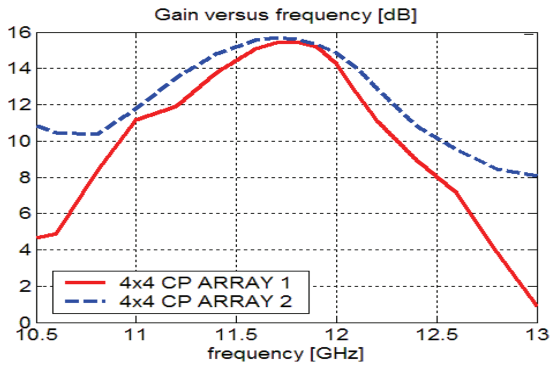
a) Return loss S11 [dB].



b) Axial ratio [dB].



c) Back radiation [dB].



d) Gain [dB].

Fig. 4. Characteristics of the CP sequentially rotated 2x2 sub-array: a) Return loss S11 [dB]; b) Axial ratio AR [dB]; c) Back radiation BR [dB]; d) Gain [dB] versus frequency.

TABLE II
ELECTRICAL CHARACTERISTICS OF ARRAY 1

Electrical characteristic	4x4 CP Array 1
Impedance Bandwidth	
fmin / fmax [GHz]	11.25 / 12.19
fo [GHz]	11.72
bw %	8.0
Directivity Bandwidth	
fmin / fmax [GHz]	11.25 / 12.13
fo [GHz]	11.69
bw %	7.52
AR-bandwidth and characteristics within it	
$fmin_{AR}$ / $fmax_{AR}$ [GHz]	10.73 / 12.6
fo_{AR} [GHz]	11.665
bw_{AR} %	16.0
BRmin / BRmax [dB]	-17.0 / -14.5
Gmin / Gmax [dB]	11.22 / 12.14
Dmin / Dmax [dB]	11.25 / 12.13

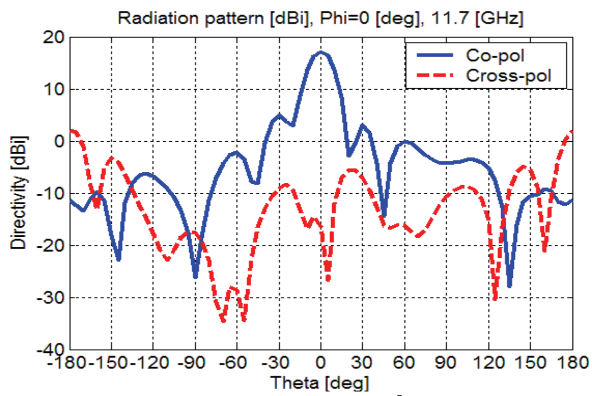
TABLE III
ELECTRICAL CHARACTERISTICS OF ARRAY 2

Electrical characteristic	4x4 CP Array 2
Impedance Bandwidth	
fmin / fmax [GHz]	11.25 / 12.5
fo [GHz]	11.875
bw %	10.53
Directivity Bandwidth	
fmin / fmax [GHz]	11.12 / 12.23
fo [GHz]	11.675
bw %	9.5
AR-bandwidth and characteristics within it	
$fmin_{AR}$ / $fmax_{AR}$ [GHz]	10.7 / 12.81
fo_{AR} [GHz]	11.75
bw_{AR} %	17.87
BRmin / BRmax [dB]	-18.7 / -12.0
Gmin / Gmax [dB]	12.6 / 15.6
Dmin / Dmax [dB]	14.15 / 17.15

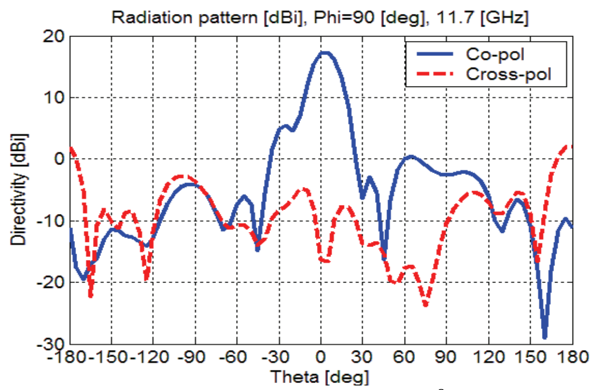
The obtained electrical characteristics can be compared by using Tables 2 and 3.

As seen in Fig. 4 a) the matching of the CP Array 2 is better within particular frequency range, but in the meantime it suffers at lower frequencies. Observing the Gain characteristic it is seen that the array with in-phase feeding (CP Array 2) has an advantage by means of Gain maximum and bandwidth (measured at level -3 dB from the maximum). The operational bandwidth of this antenna is fixed by the overlapping areas of impedance and Directivity bandwidths and reaches 8.3 %, while the relevant value of the other array is calculated 7.52 %. The Back radiation of the CP Array 2 distinguishes with one minimum, which equals -17 dB. The same characteristic of the CP Array 1 is broader with its values below -13 dB in the whole operational bandwidth.

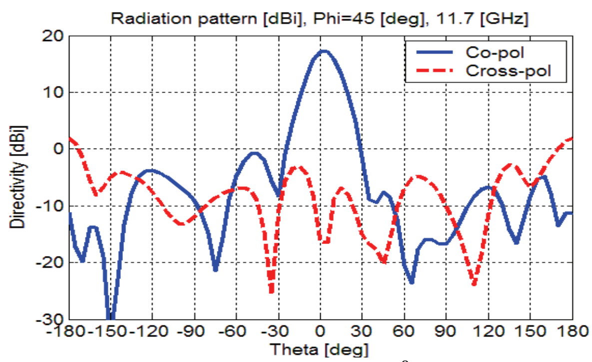
Co- and Cross-polarization patterns of the 16-element circularly polarized microstrip arrays are illustrated in Fig. 5 and Fig. 6.



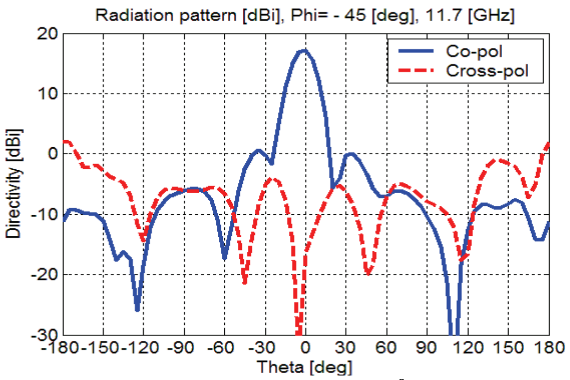
a) Patterns at phi=0°.



c) Patterns at phi=90°.

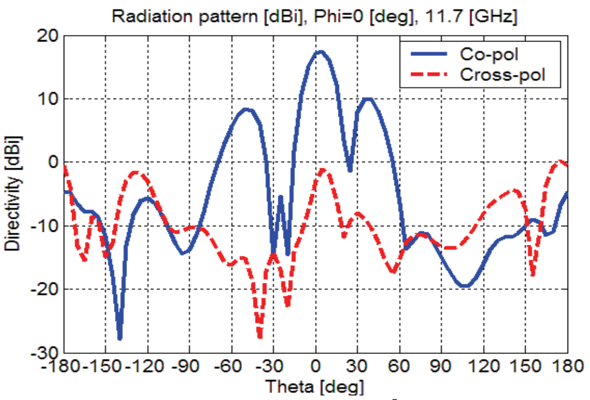


c) Patterns at phi=45°.

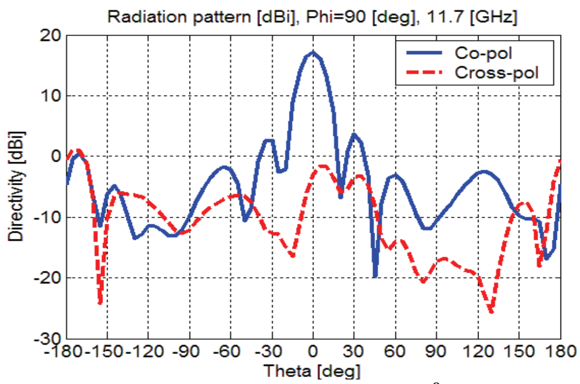


d) Patterns at phi= - 45°.

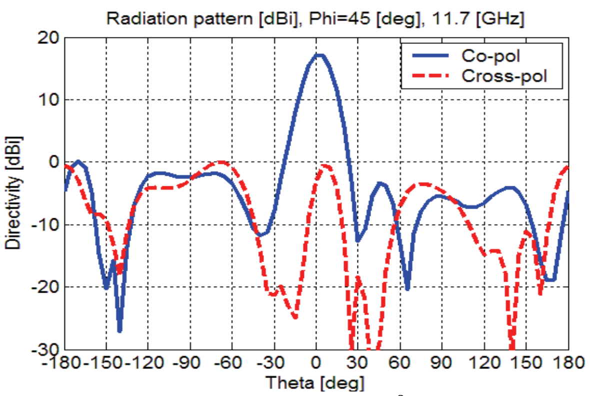
Fig. 5. Co- and cross-polarization patterns of the 4x4 CP ARRAY 1: a) Patterns at phi=0°; b) Patterns at phi=90°; c) Patterns at phi=45°; d) Patterns at phi= - 45°.



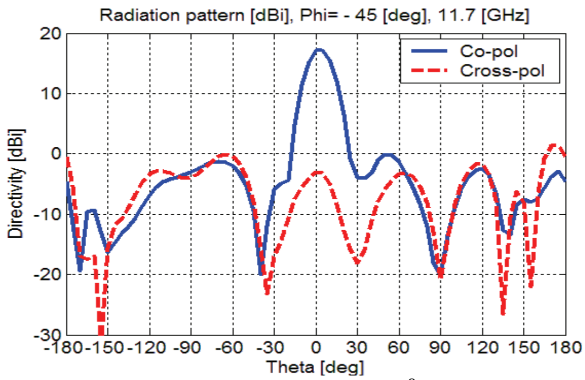
a) Patterns at phi=0°.



d) Patterns at phi=90°.



c) Patterns at phi=45°.



d) Patterns at phi= - 45°.

Fig. 6. Co- and cross-polarization patterns of the 4x4 CP ARRAY 2: a) Patterns at phi=0°; b) Patterns at phi=90°; c) Patterns at phi=45°; d) Patterns at phi= - 45°.

Both arrays exhibit right-hand circular polarization and have satisfying Co- and Cross-polarization characteristics in the principal planes (phi =0°, 90 °, 45 °, -45 °). Generally, the suppression of cross-polarization is more than 15 dB in comparison with the main lobe maximum.

IV. Conclusion

The characteristics of two circularly polarized 4x4 micrstrip arrays distinguished by their feeding system have been reported and compared. The simulation results show the advantage of the in-phase fed sub-array in terms of bandwidth and Gain. Both arrays are structurally simple and acquire good polarization properties. These arrays may be applied as receiver antennas in wireless communication systems.

Acknowledgement

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