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THE INFLUENCE OF INTER-ELEMENT PHASE DIFFERENCE ON THE BEAMFORMING AND SPATIAL ELECTROMAGNETIC FIELD DISTRIBUTION OF A QUAD MICROSTRIP PATCH ANTENNA ARRAY IN THE X BAND

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Abstract: *A simple model of 1x4 linear array of microstrip antennas was used to analyse the influence of phase difference between antenna elements on the performance of beamforming at 8.9 GHz. Simulations with full wave CST Studio were performed over a number of phase sets. Among them we identified the most constructive and the most destructive cases based on the maximum gain, the total efficiency and the polarization. It resulted that [0;0;0;0] phase case provided 10.6 dB higher gain, 46.5% higher efficiency and much more spatial uniformity of polarization along the propagation path than the [0;180;0;180] case. Field strength computations and vector representations proved the complexity of beamforming when one also takes into account the mutual coupling of the elements.*

Keywords: microstrip patch, delta phase, beamforming, vector field, 8.9 GHz

1. Introduction

Microstrip patch antenna arrays are intensively used today in wireless communications and radar applications for their beamforming capabilities [1]. By modification of the delta phase (phase difference) between two adjacent element antennas in an array, the angle of the beam can be changed as desired. One accompanying and inherent problem of these adaptive beamforming antenna arrays is the specific influence that mutual couplings between the elements has on the main antenna characteristics [2]–[5]. The mutual coupling might have a constructive or a destructive effect on the desired beam, on the maximum gain of the antenna, on the radiation pattern and on the efficiency. Some researchers found solutions for diminishing this coupling [6].

Current approach aimed at analysing the effect that the phase difference between the elements of a 1x4 patch array antenna has on the overall characteristics of the emitted field. By full wave computations in CST Studio which also calculates the coupling we followed the complete behaviour of the emitted field at a resonance frequency of 8.9 GHz in the near- and far-field of the array, emphasizing the complete impact of the phases combinations by means of vector field distributions.

2. Materials and Methods

The model of the quad microstrip patch antennas array and its dimensions are shown in Fig. 1 (left). Its total area is 5 x 3 cm^2 making it operable in the X-band of microwaves. The yellow areas correspond to the four patches which are made of copper, as well as the ground surface (opposite face, not seen). The white areas represent the dielectric substrate which was FR4. The width of the copper surfaces was 0.035 mm while that of the substrate was

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1.6 mm. FR4 had a relative permittivity ε_r=4.3 and a loss tangent tgδ=0.025 and were considered constant over the entire frequency range of interest. The real antenna array was also built afterwards by using a CNC machine (Fig. 1 – right). Voltage standing wave ratio (VSWR) presented a minimum at 8.9 GHz, VSWR = 1.66, therefore this frequency was used in the present simulations.

The input continuous wave power was 2W, while the four ports were overlapped in the simulation. Table 1 shows the 11 cases considered in the analysis regarding the phases applied at the patch elements. They are indicated in rectangular brackets. Per each situation the maximum gain, the radiation efficiencies and the total efficiencies were computed. The most constructive and destructive situations were further analysed by representing the radiation patterns and the electric (E) – field strength distributions in significant planes. A receiving plane situated parallel to the transmitting antenna at 72 cm distance away was considered indicative for the far-field observations.

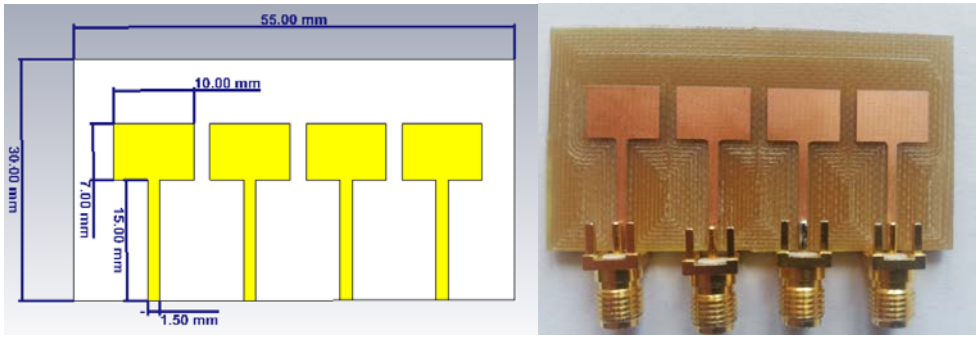


Figure 1: The quad model of patch linear array antenna used in the simulation (left) and the built (right)

Table 1 Influence of the phase difference between the elements on some significant parameters of the array

Phase of the elements (degrees)	Antenna max gain (dBi)	Radiation efficiency (%)	Total efficiency (%)
[-30;0;0;30]	8.01	61.2	56
[-60;0;0;60]	7.67	59.0	52.2
[-180;0;0;180]	3.28	47.6	37.2
[0;0;0;0]	8.14*	61.9	57.3*
[0;30;0;30]	7.89	60.3	54.2
[0;30;60;90]	7.95	61.3	56.6
[0;30;90;270]	4.68	52.5	43.0
[0;60;120;180]	7.52	58.7	52.8
[0;60;180;240]	6.49	54.9	47.1
[0;90;0;90]	5.88	46.6	34.1
[0;180;0;180]	-2.51*	19.9	10.8*

3. Results and Discussion

Table 1 emphasizes that there are two extreme cases: phase angles [0;0;0;0] and [0;180;0;180], noted by stars, for which the highest and the lowest gains and efficiencies were obtained. It is seen that a

π delta phase alternatively present between two adjacent elements destroys practically the usability of the antenna.

Fig. 2 shows the E-field distribution in the plane of the array at these two phase differences. No very significant differences are observed for [0;0;0;0] and [0;180;0;180] phases, and field strength covers the same range 52-92 dBV/m in both cases.

Fig. 3 provides the E-field strength distribution at a receiving plane situated at 72 cm distance from the emitting array. Notable differences are observed this time, both as spatial distribution and as range values. At [0;0;0;0] the field covers the range (6.5-10) V/m while at [0;180;0;180] it is in the range (0.65-1.25) V/m. A ten-fold decrease is obtained for anti-phase sequence at a virtual receptor placed there.

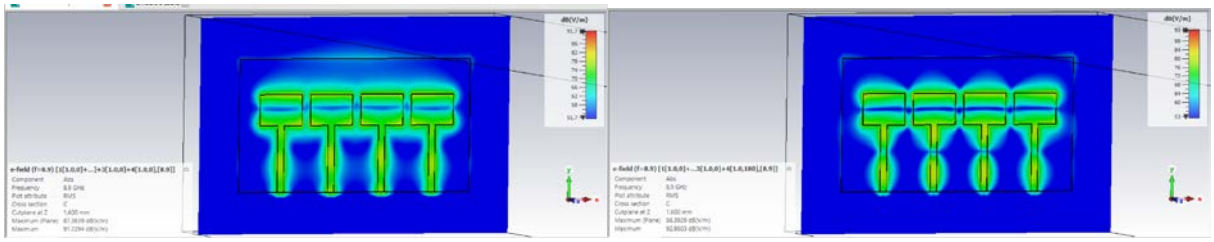


Figure 2: E-field strength in the plane of the array antenna in case of [0;0;0;0] phase (left) and [0;180;0;180] phase (right)

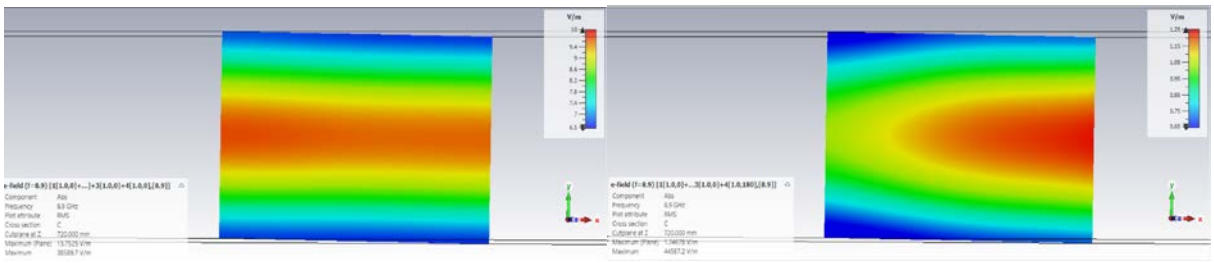


Figure 3: E-field strength in a receiving plane parallel to the array antenna at 72 cm away, in case of [0;0;0;0] phase (left) and [0;180;0;180] phase (right)

Fig. 4 shows on the left [0;0;0;0] and right [0;180;0;180] columns: a) the 3D radiation pattern; b) the E-field distribution along the propagation distance of 72 cm in a vertical plane sectioning the antenna in the center; c) the E-field distribution along the propagation distance of 72 cm in a horizontal plane sectioning the antenna in the center. The in-phase elements array provide a single and narrow beam directed perpendicular to the antenna surface. The maximum gain is 8.14 dBi. Because of the good total efficiency of 57.3%, the E-field maintains higher values over distance. On the contrary, the opposite-phase elements conduct to a double beam antenna, but with a much lower maximum gain of -2.51 dBi. While its total efficiency is also very low, of only 10.8 %, this situation conducts to a much lower field strength observed in Fig. 3 (right), at distance from the antenna.

Fig 5 consists in three representations of the E-field vectors distributed on two columns: a) the vectors in a vertical cutting plane, with their distribution in the receiving plane at 72 cm from the emitting antenna; b) the vectors in a horizontal cutting plane with the final receiving plane emphasized; c) the vectors distribution in the whole volume of the parallelepiped of propagation. If comparing left to right columns, respectively the situations [0;0;0;0] and [0;180;0;180], we observe large differences. The field vectors orientation is important from the perspective of polarization and may impose supplementary problems at

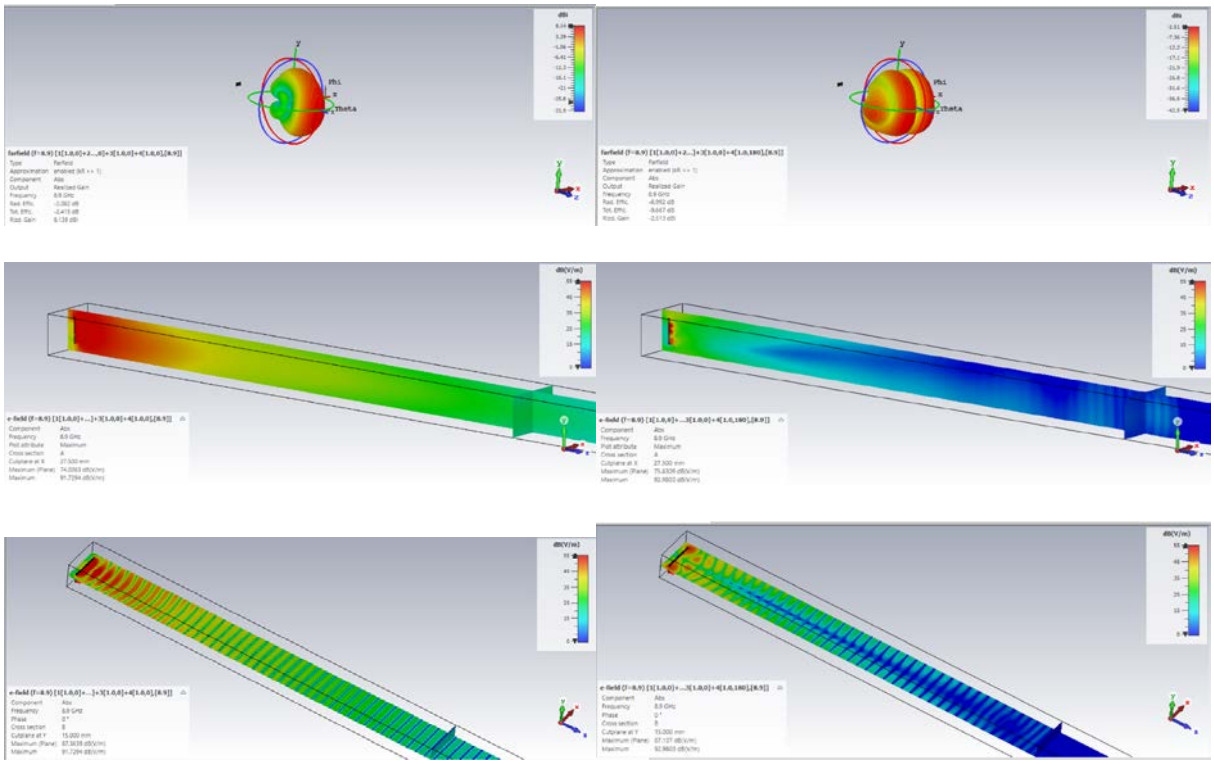


Figure 4: Column figure representing comparatively: the 3D radiation pattern (up), E-field attenuation in a vertical section plane (middle) and E-field attenuation in a horizontal section plane (down) for the two cases of phase distribution in the quad array elements: [0;0;0;0]- left and [0;180;0;180]- right

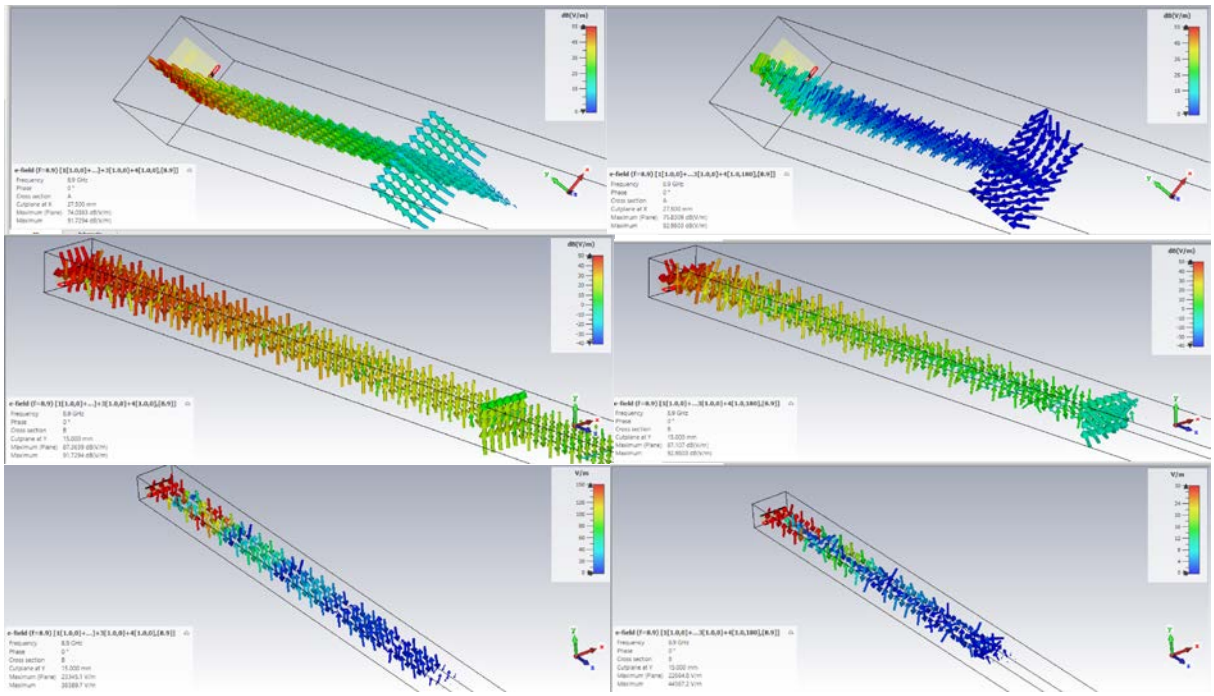


Figure 5: Column figure representing comparatively vector fields: E-field evolution in a vertical section plane (up), E-field evolution in a horizontal section plane (middle) and total spatial E-field evolution for the two cases of phase distribution: [0;0;0;0]- left and [0;180;0;180]- right

reception. Therefore, this type of representation emphasizes the whole complexity in approaching beamforming antennas functionalities. For example, in the [0;0;0;0] situation field vectors in the vertical cut plane have completely different orientation than in the [0;180;0;180] situation.

It is worth mentioning that vectors orientations are much more stochastic along the propagation path in the case of opposite delta phases in comparison with the same phase of the elements at emission. Also, even in the near field of the array, E-field strength is at least 5 times lower in one case than in the other.

Observing the values of the gains and efficiencies in Table 1 for different delta phase situations conduct to the conclusion that beams oriented in different directions are always accompanied by losses due to either efficiency diminution or to performance degradation due to polarization losses. Mutual coupling of the elements is an extra contributor to the degradation of the beam.

5. Conclusions

Using a simple model of a quad microstrip patch antenna array radiating at 8.9 GHz we quantified the effect of the phase difference between the elements on the performance of beamforming. The characteristics mostly influenced by the phases distribution in the array are the maximum gain, the total efficiency and the polarization. It results that radiation pattern dynamic shaping techniques need careful analysis and mitigation of mutual coupling between the element antennas.

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