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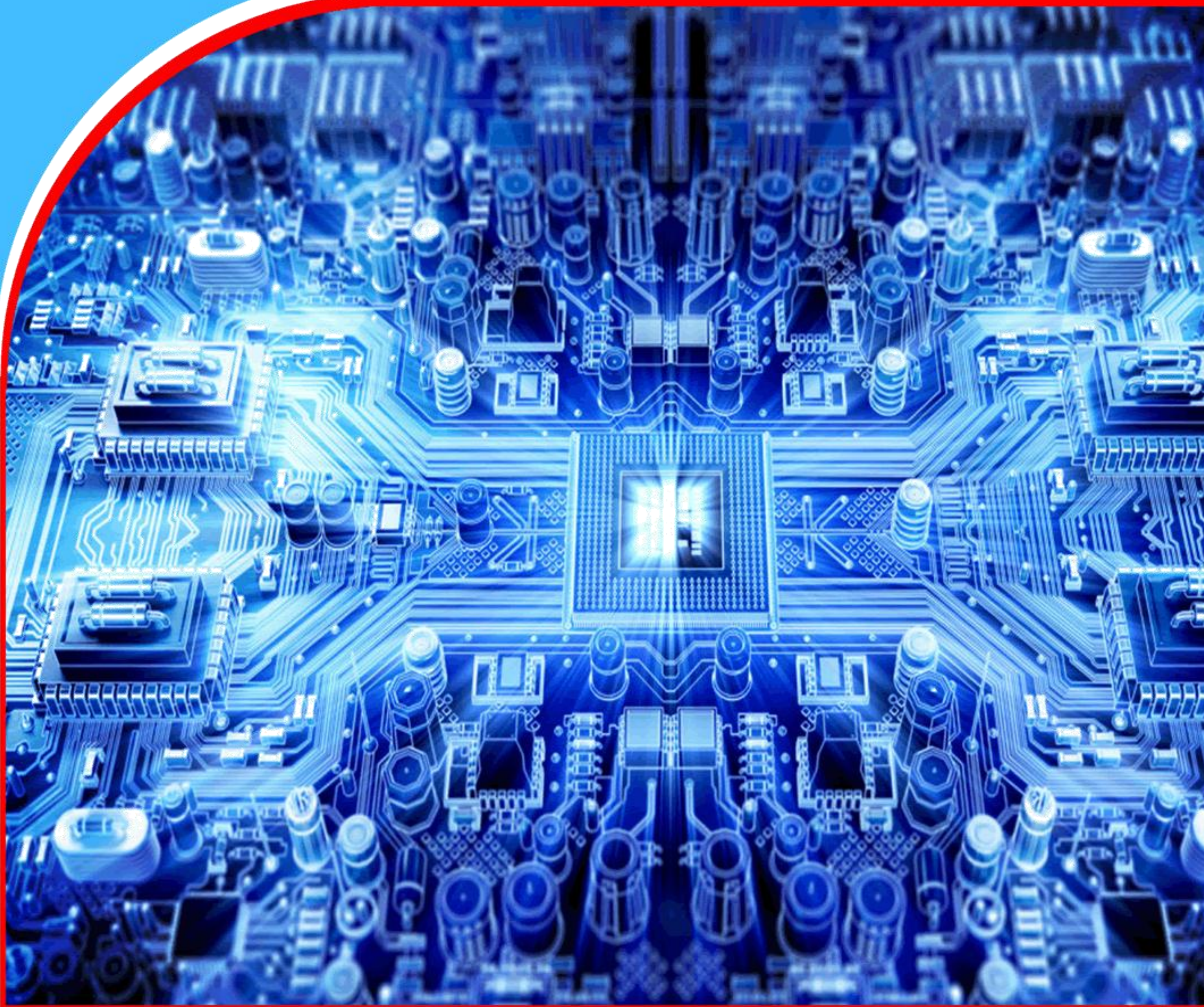

DESIGN AND SIMULATION OF A 2.4 GHz MONOPOLE ANTENNA ARRAYS WITH PARASITIC ELEMENTS FOR WIRELESS COMMUNICATIONS

Alain François Kuate and Jean-François D. Essiben

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DESIGN AND SIMULATION OF A 2.4 GHz MONOPOLE ANTENNA ARRAYS WITH PARASITIC ELEMENTS FOR WIRELESS COMMUNICATIONS

[1]Alain François Kuate and [2]Jean-François D. Essiben

[1,2] Department of Electrical Engineering, Advanced Teachers' Training College for Technical Education, University of Douala, Cameroon

Corresponding Author's Email: kuatealainfrancois@yahoo.fr

Abstract

Purpose: This paper presents the design and analysis of a 2.4 GHz monopole antenna arrays with parasitic elements for Wireless communications using the Finite-Element Method.

Methodology: The antenna arrays are constituted of five quarter wave antenna monopoles of section1.5 mm^2 $(a = 0.691mm)$. The selected configuration is the side coupling on a plan of mass out of rectangular copper of form posed on a FR-4 substrate materiel with relative permittivity of 4.4 and the thickness of section1.6 mm. Only the central monopole is fed and the others known as parasitic are in short-circuit position by an effect of mutual coupling. The so-called CST Microwave Studio simulation software is used to simulate the design antenna.

Findings: It is shown that this array is directive with high gain.

Recommendations: To integrate this antenna arrays into wireless telecommunication systems, future research must be based on reducing its weight and dimensions. The use of printed monopole elements based on metamaterials may be a possible path for this integration.

Key words: *antenna arrays, design, monopole antenna, parasitic antenna.*

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1. Introduction

It is well known that array antennas are the solution of choice for many radar and communications applications in space and on Earth. Their advantages include the possibility of fast scanning and precise control at the radiation pattern [1]. The drawbacks of the arrays are mainly related to their weight, and the complexity, relatively high losses in the power distribution system and expensiveness of the network (which may be active or passive). Therefore, considerable interest is focused on designing a planar array with a simple feeding network [1]. Recently, the use of parasitic arrays [1, 2] illuminated by smaller active arrays has received some attention because they introduce degrees of freedom that allow patterns to be synthesized without modification of the active array feed, which can be quite simple [1, 3]. The demand for wireless communication is growing explosively making the existing communication systems inadequate. All impairments of the wireless communication systems need to be addressed as the world is moving in to the future wireless communication. In focusing on improving the performance of wireless communication, access technologies need to be taken into consideration [4]. Amongst several access technologies, radio technologies that include multiple antennas are of great interest [4]. Furthermore, whilst not overlooking the factors like cost, complexity, power consumption and practicality, parasitic arrays is the type of antenna arrays to consider for future wireless communications [4-6].

In the literature, dipoles and monopoles have been mostly considered as the parasitic array elements [5, 6]. Parasitic elements are mounted in a close proximity to the driven element; and therefore radiation field of the active element induces currents in the parasitic elements, which causes the parasitic elements to radiate in turn [7]. This interaction between antenna elements is due to mutual coupling [7]. Mutual coupling is a concept fundamental for the functioning and operation of the parasitic antenna arrays. Parasitic arrays and the concept of mutual coupling are dealt with in depth in [8, 9]. The most prevalent method for analyzing wire antennas and arrays with effects of mutual coupling is the Method of Moments (MoM) [10].

In the design of parasitic array antennas, it is required that we optimize both the structural and control parameters [11]. The authors of the article assumed that the structural parameters of the antenna are fixed, and only the control parameters will be considered. The control parameters depend on the type of antenna loading used. There are two general parasitic array antennas, namely reactive and switched parasitic antennas. The two parasitic antenna types differ in antenna loading circuitry, whereby switched parasitic antennas uses few state circuitry while reactive antennas use loading circuitry with more states [12].

In this article the authors suggested an antenna arrays with parasitic elements not very greedy in energy, where only one element says "active" is connected to the port of food or feed RF and the others known as "parasites" feed by effect of mutual coupling. For these systems, only one feeding circuit (amplifying and circuit of phase) are designed whatever the number of elements in the array. The active element radiates the fields which induce currents in the parasitic elements. This interaction between the elements of the antenna is due to the mutual coupling, which is the fundamental principle whose the operation of the antenna arrays with the parasitic elements rests. The mutual coupling, which is function of the distance between elements of the array, influences the impedances of each element and by consequence, the electrical and of radiation characteristics of the entire array.

The paper is organized as follows: the design procedure is presented in section 2. Section 3 shows numerical results, and finally, section 4 makes conclusion.

I. Antenna design

The design of the array antennas with parasitic elements is done in two stages. The first stage consists to the design of an element of an array in order to determine its electric characteristics and of radiation under isolated operation, *i.e.*, alone. The second stage consists in multiplying this element on a given level to form an array.

II.1. Design of an insulated monopole

The monopole antenna is a half-dipole whose principle is based on the theory of the images [8]. It is made up of a metal copper bit with height h placed on a plan of mass. The monopole is traversed by a sinusoidal current of amplitude I_0 in far field as shown in Figure 1.

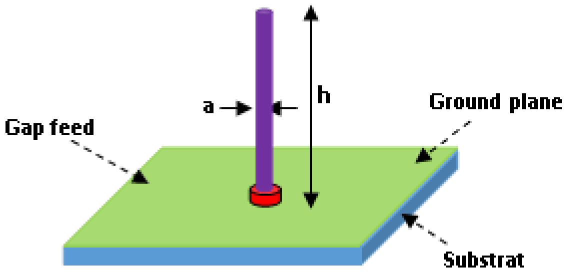

Figure 1. Geometry of the insulated monopole antenna.

It is necessary to determine the radiation characteristics of this monopole such as: the radiation pattern, the coefficient of reflexion and its gain. The geometrical and radioelectric data of the insulated monopole are presented in table 1.

Table 1. Geometrical and radioelectric data of the insulated monopole.

Height : $h = 28{,}6\ mm$
Ray : $a = 0{,}691\ mm$
Substrat : FR-4 eproxy of thickness 1,6 mm and the relative permittivity $\varepsilon_r = 4{,}4$
Dimensions of the plan of mass : $100 \times 100x0{,}035\ mm^3$
Feed : ''lumped port of impedance'' : $Z_0 = 50\ \Omega$

II.2. Design of monopole arrays

The geometry of the antenna arrays with parasitic elements proposed is shown on Figure 2. The array consists of five monopoles identical of the same length including four parasitic. They are telegraphic antennas quarter-wave $\lambda/4$ out of copper, of ray a, in parallel laid out in a configuration of side coupling on a plan of mass out of rectangular copper of form. The active element (antenna n^0 0), connected to a source of tension V_0 is in the center of the plan of mass; while the parasitic elements (antennas n^0 1, 2, 3, 4) are not fed, occupy the positions$(x_{n,}\ y_n)$. The current $I_{n\epsilon N}$ which circulates in each antenna of the induced array of the currents in all the others, fed or not.

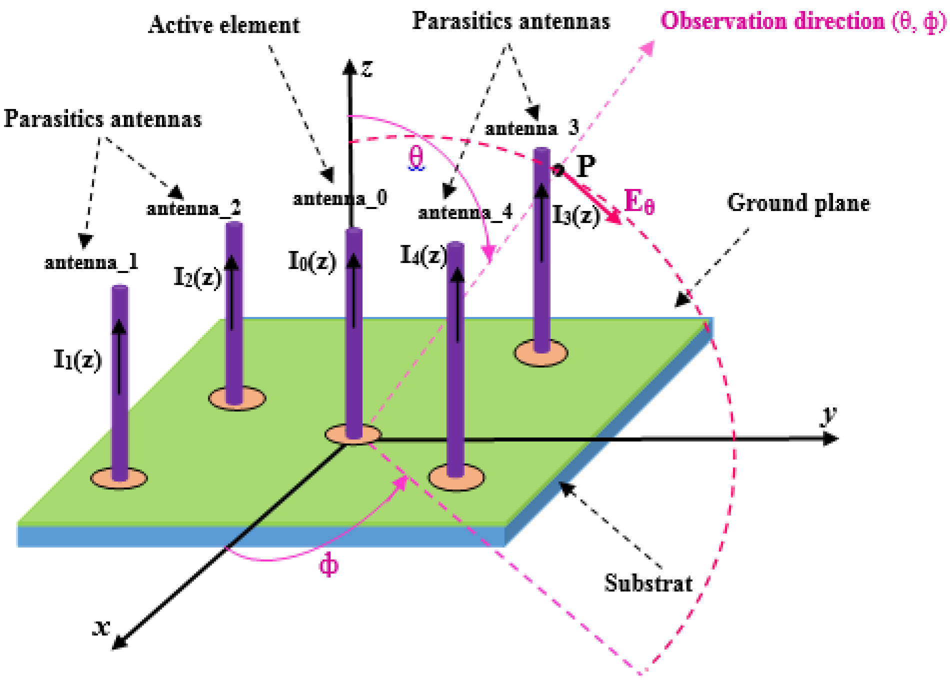

Figure 2. Geometry of the planar antenna arrays with 4 parasitic elements and an active element in the center of the plan of mass.

Table 2. Geometrical and radioelectric data of the array with parasitic monopole elements.

❖ **Elements of monopole in Copper**			
Elements	Ray of elements (mm)	Length of elements (mm)	Position (x_p, y_p) $d = n \times 0.125\lambda$ où $n \in$ □ *
#0	0,691	28,7	(0,0)
#1	0,691	28,7	$(-d;\ 0)$
#2	0,691	28,7	$(0;\ d)$
#3	0,691	28,7	(d, d)
#4	0,691	28,7	$(d; -d)$
❖ **Plan of mass**			
Name	Relative permittivity	Relative Permeability	Dimension
Copper	1	0.999991	$218x218x0{,}035\ mm^3$
❖ **Substrat**			
Name	Relative permittivity	Relative Permeability	Dimension
FR-4 eproxy	4.4	1	$218x218x1{,}6\ mm^3$
❖ **Feed of the active element** : Lumped port : $Z_0 = 50\Omega$			

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The antenna with parasitic elements is modelled by a matrix of impedance Z made up of the mutual impedances Z_{ij} and the self-impedances Z_{ii} [9]; where (i,j) represents the elements of the array. The problem would consist to solve the system of equations:

$$V = Z \times I,$$

Where= $[V_0, 0,0,0,0]$; V_0 is the supply voltage of the active element, Z is the matrix of impedance and I the currents of the array.

II.3. Parameters of monopole

The expressions of the radiation pattern, of gain and the coefficient of reflexion of the monopole traversed by a sinusoidal current of amplitude I_0 are the following:

Radiation pattern of the monopole : $U(\theta,\varphi) = \lfloor E_\theta / E_{\theta max} \rfloor$,

where $E_\theta = \left(j\eta I_0 e^{jkr}/2\pi r\right)(cos(klcos\theta) - cos(kl)/sin\theta)$ is the electric field and $E_{\theta max}$ its maximum value, $\eta = 120\pi$ is the impedance in the vacuum, j is a complex number, $k = 2\pi/\lambda$ is the number of wave, λ is the wavelength, I_0 is the amplitude of the current, r is the distance between the center of the system and the point of observation $p(\theta,\varphi)$, $l = 2h$ is the length of a dipole, h is the height of an element.

Gain of the monopole : $G_\theta = \left[\left(cos(klcos\theta) - cos(kl)\right)/sin\theta\right]^2$.

Coefficient of reflection of the monopole : $\Gamma_{in} = Z_{in} - Z_0/Z_{in} + Z_o$,

where $Z_{in} = R_{in} + jX_{in}$ is the impedance of an entry of the monopole and constitutes of an active and reactivate part $Z_0 = 50\ \Omega$.

The elements of the array being identical and the currents sinusoidal; the radiation pattern, the coefficient of reflexion and the gain of the array are determined by the same formulas taking into account the contribution of each element.

II. Results and discussion

Figure 3 presents the coefficient of reflection in entry of the monopole antenna. Taking into consideration this figure, we can say that it resounds to 2,5152 GHz for a band-width to -10 dB of 0,36541 GHz going of 2,3474 GHz to 2,7275 GHz, thus, covering all the frequencies of the Wi-Fi array at 2,4 GHz. This coefficient of reflection is -14,145717 dB and shows that this monopole antenna is adapted with an impedance of entry $\mathrm{Z_{in}} = 35{,}193684 + \mathrm{j}7{,}9116023\ \Omega$ to the frequency of 2,5151 GHz.

Figure 4 presents the radiation patterns in polar co-ordinates in the horizontal and vertical planes, respectively. In the vertical plane or plane E (solid-red line), we obtain a gain of 2,79 dB in the main lobe direction at 304^0 for a maximum level of secondary lobes equal to -4 dB. In the horizontal plane or plane H (dashed-blue line), the gain is nearly constant to -0,279 dB; thus justifying the omnidirectivity of this monopole antenna in this plan.

Figure 5 shows the coefficient of reflection to the port #0 (element # 0) of the array with parasitic monopoles elements for $d = 0{,}25\lambda$. We note that for this value, the S_{11} parameter at this port #0 is lower by -10 dB and has a band-width ranging between 2,2612 to 2,7454 GHz; showing that this port is well adapted. Simulations has shown that, that is valid for $0{,}25 \leq d \leq 0{,}5\lambda$. On the other hand, for values of $d \leq 0{,}25\lambda$; the port #0 is made unsuitable due to the fact that its coefficient of reflection is equal to or higher than -4,98697 dB.

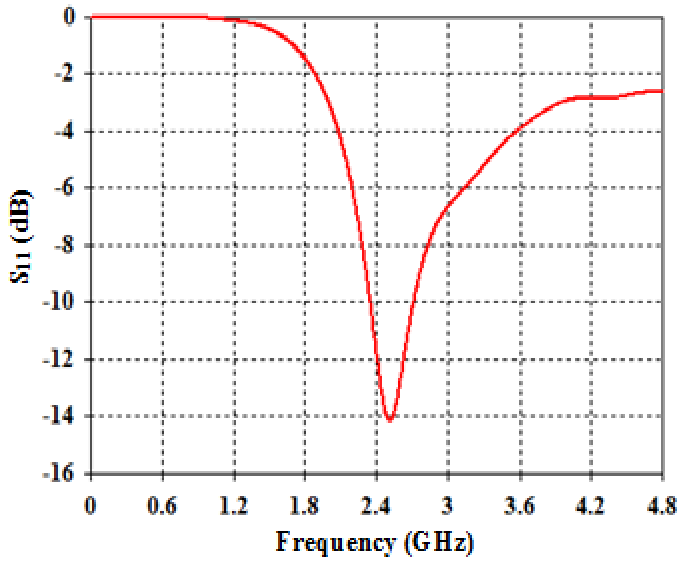

Figure 3. Coefficient of reflection of a monopole.

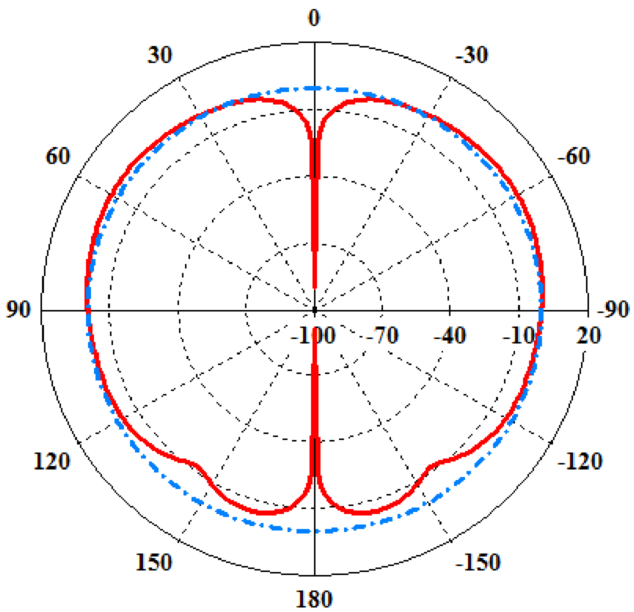

Figure 4. Radiation pattern of the monopole in the vertical plane (solid-red line) and horizontal (dash-red line).

Figure 6 compares the radiation patterns in gain of the array with parasitic elements (solid-red line) and of the array with uniform feed (dashed-blue line) for $d = 0{,}25\lambda$ and $\phi = 90^0$. The comparative table of the radiation characteristics of the various arrays at the work frequency equal to 2,4 GHz are summarized in table 3. The analysis of the numerical results has shown that with the distance $d = 0{,}25\lambda$, the radiation pattern of the array with parasitic elements is similar to the one of the array with uniform feed but, with a variation of 19^0 between the directions of the main lobes; from -10,1 dB between the secondary levels of lobes, from 0,49 dB between the gains and of $7{,}4^0$ betweem the apertures.

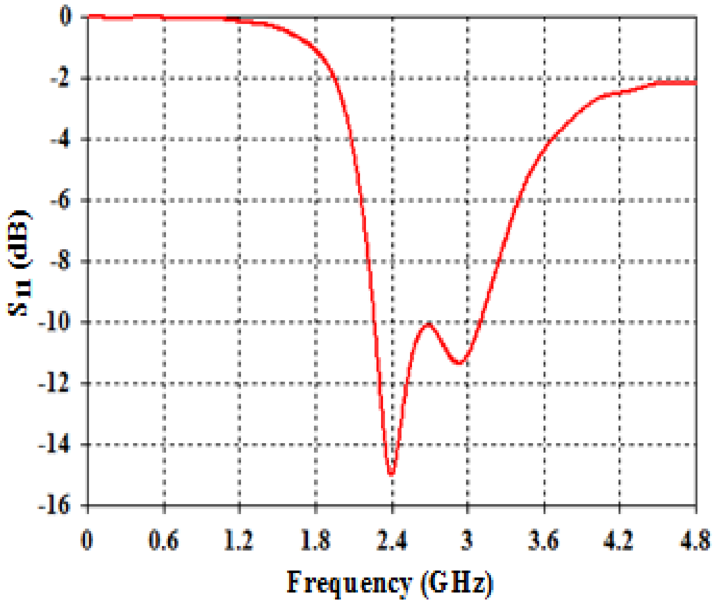

Figure 5. Parameter S_{11} of the monopole array for $d = 0{,}25\lambda$.

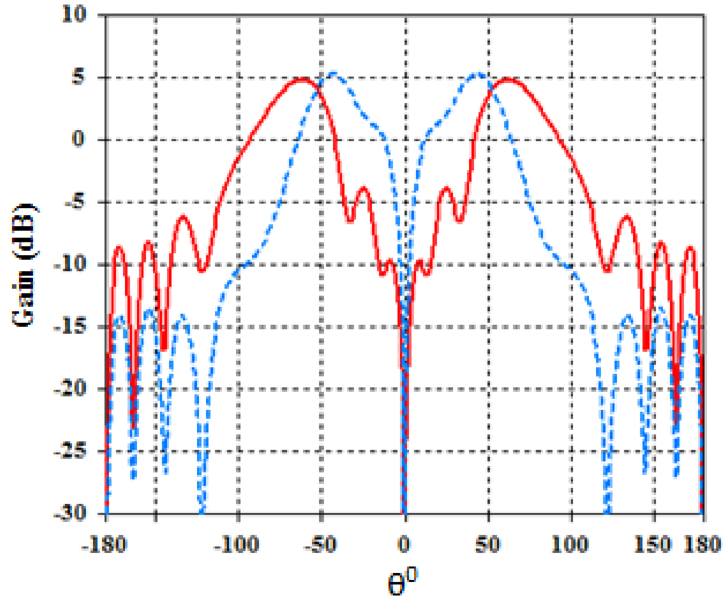

Figure 6. Comparison of the radiation pattern in gain at 2,4 GHz of the parasitic element arrays (solid-red line) and of the array with uniform feed (dashed-blue line). $d = 0{,}25\lambda$.

Figure 7 compares the radiation patterns in gain of the array with parasitic elements at the work frequency of 2,4 GHz in the plan $\phi = 90^0$ for various values of $d = 0{,}25\lambda$ (solid-red line) and $d = 0{,}50\lambda$ (dashed-blue line). Simulations show a maximum gain of 4,83 dB for $d = 0{,}25\lambda$, which is explained by the fact that the array is perfectly adapted and the inter-elements coupling is better contrary to the value $d = 0{,}50\lambda$. Note that with $d = 0{,}50\lambda$, the operate currents of the parasitic elements are very weak because of the low coefficient of coupling between the parasitic elements and the active element.

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Table 3. Comparison of the radiation characteristics at 2,4 GHz between the array with parasitic elements and the array with uniform feed for $d = 0{,}25\lambda$.

	Direction of the main lobe	Angle of aperture (3dB)	Gain (dB)	Level of the secondary lobe (dB)
Array with uniform feed	$317{,}0^0$	$32{,}4^0$	5,32	-18,8
Array with parasitic elements	$298{,}0^0$	$39{,}8^0$	4,83	-8,7

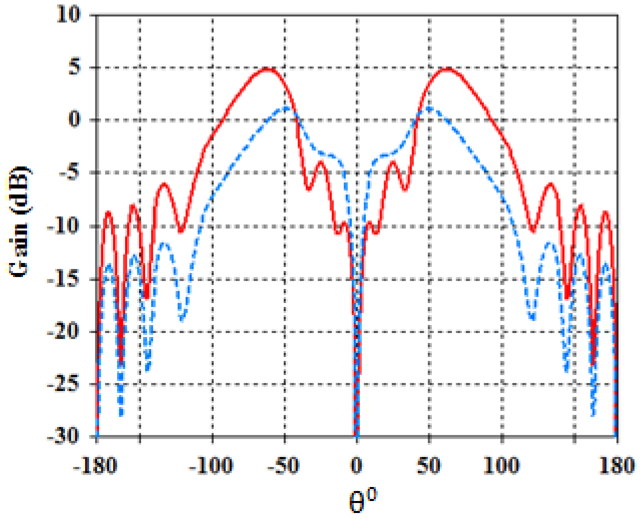

Figure 7. Comparison of the radiation pattern in gain at 2,4 GHz for $d = 0{,}25\lambda$ (solid-red line) and $d = 0{,}50\lambda$ (dashed-blue line) of the array with parasitic elements.

III. Conclusion

Thus, we designed an antenna arrays with parasitic elements for the Wi-Fi applications at 2,4 GHz. We compared its radiation characteristics such as the gain, the coefficient of reflection and the radiation pattern to those of the array with uniform feed. This reveals that the coupling inter-element affects the impedances of entry of the antennas and obviously their adaptation is disturbed. This coupling degrades the level of adaptation between the elements of the array compared to only one insulated element.

Finally, it is clear that the design of a planar antenna with parasitic monopole elements is a compromise between the level of adaptation of the antenna and the radiation characteristics in terms of gain.

Recommendations: The current trend is converging towards communicating systems that are less bulky, less heavy and have very low energy consumption. The designers of radiating systems must develop tools allowing the miniaturization of the antenna. Research must be based on reducing the weight and dimensions of our monopole antenna arrays with parasitic elements. The use of printed monopoles based on metamaterials as arrays elements can be envisaged for its integration into wireless telecommunications systems.

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