Study, Design and Optimization of a New Structure of Patch Antenna Linear Array for RFID Applications

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Abstract: In this paper, we propose to study and optimize a new structure of a patch antenna linear array to four identical elements. This array is connected in parallel with a microstrip line in the form « T » having a power port adapted to 50 Ω and intended for Radio Frequency Identification applications. The insertion of slots in the structure of the patch antenna array has a direct and positive impact on improving the radiation characteristics in terms of reflection coefficient, voltage standing wave ratio, input impedance and gain over a frequency range of 2 GHz to 3 GHz. The design and optimization have been performed using the simulator HFSS (High Frequency Structure Simulator) based on the finite element method. Next, in order to validate our simulation, we use another electromagnetic simulator CST MWS (Computer Simulation Technology- MicroWaves Studio) which is based on the finite integration method. The simulation results for the four-element linear array show that the reflection coefficient reaches a level of -25.49 dB, the standing wave ratio is strictly less than 2 and the gain is approximately 14.50 dB for the same frequency resonance of 2.4 GHz.

Key-Words: linear array, patch antenna, microstrip line, RFID application, simulateurs HFSS and CST.

1 Introduction

Wireless technology advancements have given birth to Radio Frequency Identification (RFID) systems, which have generated significant interest and hype among scientists, researchers and industry. RFID technology enables identification, location and information exchange of distant objects via radio waves [1]. It has been commercialized in areas of logistics, manufacturing, transportation, health care, and mobile communications [2]. Basically, RFID system is a tag or transponder and a transceiver or reader. The tag consists of an antenna combined with an application specific integrated circuit chip. In order to activate and detect a tag, a base station (reader) transmits a modulated signal with periods of unmodulated carrier.

The microstrip patch antenna is one of the most exciting and fascinating development in antenna and electromagnetic history [2]. It falls into the category of printed antennas such as dipoles, slots and tapered slots. This is due to their distinguished features including ease of integration, good radiation control and low cost of production. This antenna is a resonant style radiator so one of its dimensions must be $\lambda/2$ where λ is a guided wavelength taking into accounts the surrounding environment of the printed antenna. The resonant dimension depends on the shape of the patch conductor. It is obvious that the substrate properties such as dielectric constant ε_r and its height play vital role in the antenna performance. The main advantage of patch antenna is its size, which is relatively small compared to other radiators. The minimal thickness of the material or profile allows microstrip patch antenna to be easily integrated into the skins of various objects [3].

Integrating microstrip patch antenna with RFID technology achieves significant performance and cost advantage due to its light weight, low fabrication cost, and the ability to fabricate feed lines and matching networks simultaneously with the antenna structure.

One of the major disadvantages of patch antenna is its narrow bandwidth, however, RFID applications do not need much bandwidth, and it turns out to be an advantage, because the antenna rejects the signals that are out of the band and accordingly the quality factor increases [4].

The gain of the microstrip antenna unit generally is only 6 ~ 8 dB [5-7]. So in order to obtain a larger gain or specific directivity, a microstrip radiating elements

are often used to consist of a microstrip array antenna [8-12].
In this paper, we propose to study and optimize a new structure of a patch antenna linear array to four identical elements. This array is connected in parallel with a microstrip line in the form « T » having a power port adapted to $50\,\Omega$ and intended for radio frequency identification applications.
In the first part of this work, we focus on modeling and optimization of radiation characteristics of the new patch antenna structure (a single element) in terms of reflection coefficient, standing wave ratio, input impedance and gain over a frequency range of $2\ GHz$ to $3\ GHz$.
In the second part, we are interested in the analysis and improvement of radiation characteristics of an antenna array to four identical elements while using the same patch element optimized in the first part of this work in order to increase the gain.

2 Microstrip Antenna Theory

At present, the basic theory of the research and analysis of microstrip antenna can be divided into three categories: firstly, the transmission line model theory, secondly, cavity model theory, thirdly, the full-wave theory analysis.
Analysis of microstrip antenna is the most simple and suitable for the application of the theory of general engineering model is the transmission line model [13-16]. The model will rectangular microstrip patch as field laterally (Wside) and there is no change of the transmission line resonator.
Field only along the longitudinal direction (L side) into the standing wave changes, the radiation is mainly generated by the two open ends at the edge field.
Antenna patch width W affects the bandwidth, radiation efficiency, input impedance. In order to prevent the higher mode produce field distortion, width W generally is no more than the type :

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Due to the upper edge of the field effect, value of length L is generally

$$L = \frac{c}{2\ f_r . \sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (2)$$

Among them, the elongation is

$$\Delta L \ = 0.412h\,\frac{(\varepsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_r - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (3)$$

Relative effective dielectric constant is

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right] \qquad (4)$$

c is the speed of light, f_r is the resonant frequency of the patch antenna and ε_r is the dielectric constant of the substrate.

3 Theory of Linear Array

3.1 Principle

This type of antenna is composed of a multitude of identical and independent elements. The energy is distributed between the various sources according to a given law through a distributor which distributes the signal on each element with a known phase and amplitude. The controllable phase shifters are insertable between the radiating elements and the dispatcher to form a phased array [17].

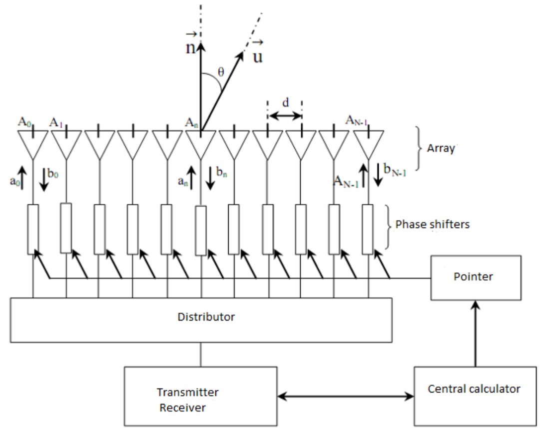

Fig.1 : General structure of a linear array

The antenna arrays can produce radiation patterns having a desired shape. The radiation characteristics of the system depends on both :

- the radiation pattern of the base element multiplied by the array factor,
- the excitation coefficients into amplitude and phase of each of the sources,
- the distance between the elements.

The networking of the radiating elements also allows a gain increase. Indeed, the use of N elements in N multiplies the gain of the basic element. The weighting relative phase serves to direct the main lobe in a given direction. The amplitude weighting reduces the sidelobe level and conform the shape of the beam. However, this type of stopovers requires an important number element to minimize grating lobes or to form a beam with extreme precision.

The antenna arrays may have different geometries: linear arrays, circular arrays and planar arrays (figure 2). The total field radiated by the array is determined by the vector addition of the fields radiated by the different elements. If one wants make a very directive modelit is essential that the fields interfere constructively in the required directions and interfere destructively in the remaining space [18].

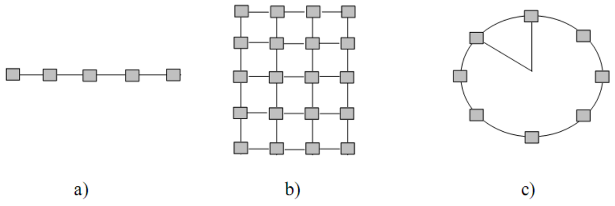

Fig.2 : Different geometric configurations of the arrays, linear (a), two-dimensional (b) and circular (c)

The antenna feed network will aim to bring energy to the different sources within the law weighting. The simplest technique is to feed the radiating elements by microstrip lines. Two types of power supply are commonly used :

- series feed : a transmission line excites the radiating elements in series (figure 3). The law imposes a phase length given line between two consecutive elements. The network is said to resonant when the elements are excited in phase, this length is a multiple of the wavelength guided in the line.
- parallel feed : the power supply circuit has an input and output n radiating elements (figure 3). The power is divided between the n elements, with the desired distribution.

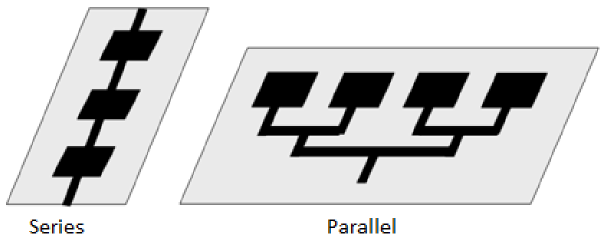

Fig.3 : Feeding of a one-dimensional array

The choice of type feed is based on different parameters which are :

- the desired weighting law, amplitude or phase,
- the bandwidth desired. A serial network will have a lower bandwidth to the extent the law weighting will be more sensitive to the frequency in the case of a parallel feed. Indeed, the phase errors are cumulative,
- the maximum clutter. A parallel network will be bigger than a serial network.

Moreover, it is noted that a network has parallel upper lines lengths and a greater number bends which generates in more losses, particularly in the millimeter domain.

3.2 Choice of a Array Antenna

The total field of the array is determined by the vector addition of the fields radiated by the individual elements. This assumes that the current in each element is the same as that of the isolated element (neglecting compling). This is usually not the case and depends on the separation between the elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space [19]. Ideally this can be accomplished, but practically it is only approached. In an array of identical elements, there are at last five controls that can be used to shape the overall pattern of the antenna. These are :

- the geometrical configuration of the overall array (linear, circular, rectangular, spherical, etc),
- the relative displacement between the elements,
- the excitation amplitude of the individual elements,
- the excitation phase of the individual elements,
- the relative pattern of the individual elements.

Theoretically, the gain value is multiplied by two when we double the number of array elements. However, this relation does not take into account any loss (coupling, phase error, etc). On the other hand, the study of the spacing between the elements is primordial because the latter acts directly on the gain and shape of the radiation. It has been shown [20] that the ideal gap between the sources to obtain maximum gains is between 0.25 and 2λ. Indeed, a shorter distance results in a coupling phenomenon between the sources and a greater distance reveals array lobes.

3.3 One-Dimensional Array

A uniform one dimensional array geometry is most frequently used in the design of antenna arrays.

Either identical N radiating sources disposed in a regular manner on an axis ox, and equidistant by a distance not called array, as indicated in figure 4.

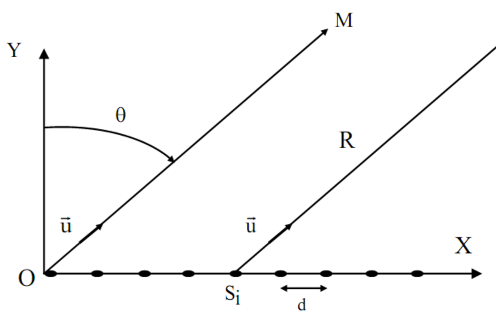

Fig.4 : One-dimensional Array

In order to simplify the calculations, it is generally assumed that there is no coupling between sources and each other in the presence radiates the same pattern $f(\theta)$.

The total radiated field into the far zone one dimensional array is the sum of different contributions radiated by each weighted by coefficients excitation w_i those of their geometric phase shifts source fields. The expression of the directivity pattern is given by :

$$F(\theta) = f(\theta) \sum_{i=0}^{N-1} w_i e^{j(k_0 i\, d \sin\theta)} \qquad (5)$$

One can still write in the form :

$$F(\theta) = f(\theta)\, F_R(\theta) \qquad (6)$$

i : index of the source.

N : total number of sources.

$F(\theta)$: elementary diagram of a single source.

$k_0 = \frac{2\pi}{\lambda}$: propagation constant and λ: wavelength.

where F_R is a array specific function, called factor of the array. It not only depends on the array and its excitation law w_i. Physically, it represents the gain provided by the association array [20].

4 Design Procedure

4.1 Antenna Element Design

In this section, we focus only on the modeling and optimization of radiation characteristics of the new microstrip patch antenna structure proposed in terms of reflection coefficient, standing wave ratio, input impedance and gain over a frequency range of 2 GHz to 3 GHz.

Figure 5 illustrates the new proposed patch antenna structure. This structure is composed of a rectangular microstrip patch of the length $L_p = 50\ mm$ and the width $W_p = 56\ mm$, printed on a substrate of Rogers RT/duroid 5880 (tm), of the relative permittivity of 2.2, a thickness of 3.2 mm, the length $L_{sub} = 70\ mm$ and width $W_{sub} = 100\ mm$. The antenna is fed by microstrip line having a power port adapted to 50 Ω, of the length $L_m = 41\ mm$ and the width $W_m = 3.8\ mm$, the assembly is placed on a ground plane of dimension $(100x70)\ mm^2$. The inserted at slot patch antenna having a width of $W_s = 30\ mm$ and the length $L_s = 15\ mm$, allows to improve the performance of the antenna. A slot antenna has special advantages such as less conductor loss, wider bandwidth, and better isolation between the radiating element and fed network [21].

The table 1 below shows all dimensions of proposed patch antenna.

Table 1 : Dimensions of patch antenna proposed

Parameters	Values (mm)
L_{sub}	70
W_{sub}	100
L_g	70
W_g	100
L_p	50
W_p	56
L_m	41
W_m	3.8
W_s	30
L_s	15
L_1	34.10

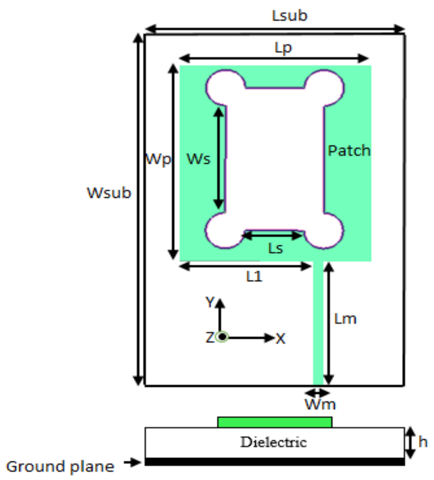

Fig.5: Geometry of the single antenna element proposed

The various simulation results for the single patch element in terms of the reflection coefficient, standing wave ratio, input impedance and gain over a frequency range of 2 GHz to 3 GHz are presented respectively in figures 6, 7, 8 and 9.

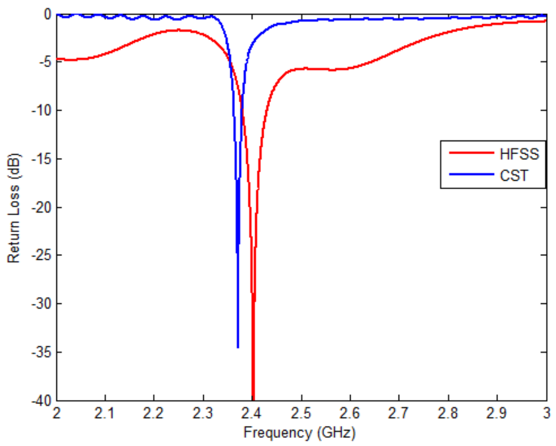

Fig.6: Return loss of the single antenna element

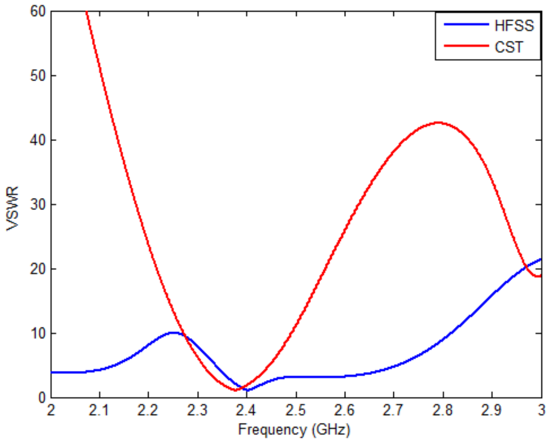

Fig.7: Voltage standing wave ratio of the single antenna element

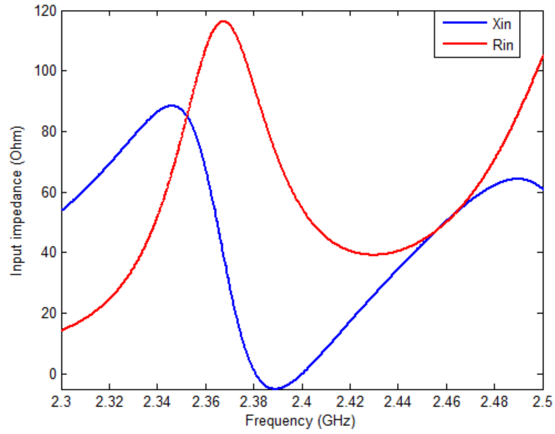

Fig.8: Input impedance of the single antenna element

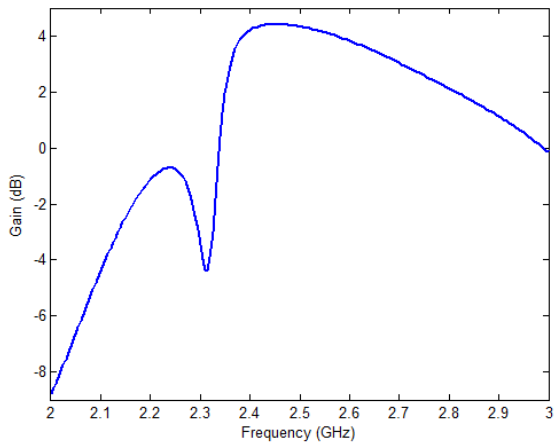

Fig.9: Gain of the single antenna element

From figure 6 is found that the reflection coefficient reaches a minimal level of -39.90 dB at a resonance frequency of 2.4 GHz and this is achieved by using the electromagnetic simulator HFSS.
With the aid of simulator CST, we found a somewhat minimal level about -34.55 dB relative to that found by HFSS for a resonant frequency 2.37 GHz. This slight difference in resonant frequencies and levels of reflection coefficients is due to the simulation steps and the mesh used for each simulator.
Figure 7 represents the standing wave ratio as a function of frequency. We notice that the VSWR equal to 1.05 for a resonant frequency 2.4 GHz and that VSWR less than 2 for all frequencies ranging from 2.38 GHz to 2.43 GHz. This shows that the microstrip antenna is given clearly adapted.
As shown figure 8, the input impedance of the microstrip antenna patch is equal to $Z_{in} = (50.93 - j0.03)\ \Omega$ at the resonance frequency of 2.4 GHz. This means that it is adapted to the power source.
From figure 9, we note that the maximum value of the gain of the patch antenna is approximately 4.22 dB for the resonance frequency of 2.4 GHz. This result is clearly acceptable to ensure the proper operation of this antenna.
Finally, one can conclude that this type of patch antenna studied presents significantly better results in terms of reflection coefficient, standing wave ratio, input impedance and gain. For this, we propose the following to form a patch antenna array with four identical elements using the same patch previously optimized to increase the gain.

4.2 Antenna Array Design
In the second part, we are interested in the analysis and improvement of radiation characteristics of a patch antenna array to four identical elements while

using the same patch element optimized in the first part of this work in order to increase the gain.
Figure 10 shows the geometry of the proposed antenna array. This structure is composed of four identical radiating elements, as shown in figure 5 and connected by a feeding network. Distances between the patches are $0.48\lambda_0$ at $2.4\ GHz$. The area of the proposed array is $(252\ x100\ x\ 3.2)mm^3$.

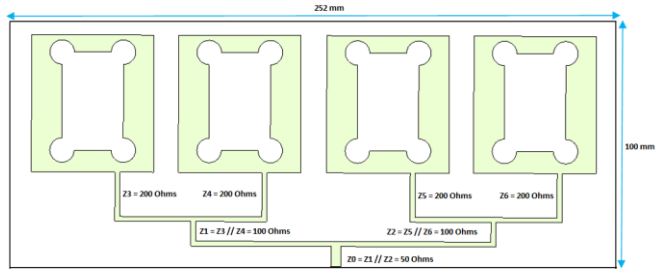

Fig.10: Geometry of the antenna linear array

The simulation results obtained for the patch antenna linear array to four identical elements in terms of reflection coefficient, the standing wave ratio and gain over a frequency range of $2\ GHz$ to $3\ GHz$ are respectively presented in figures 11, 12 and 13.

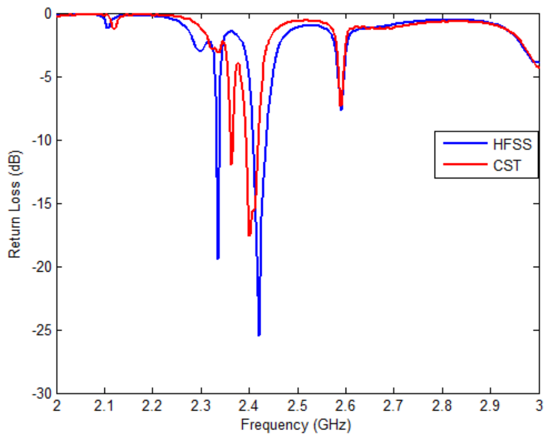

Fig.11: Return loss of the antenna linear array

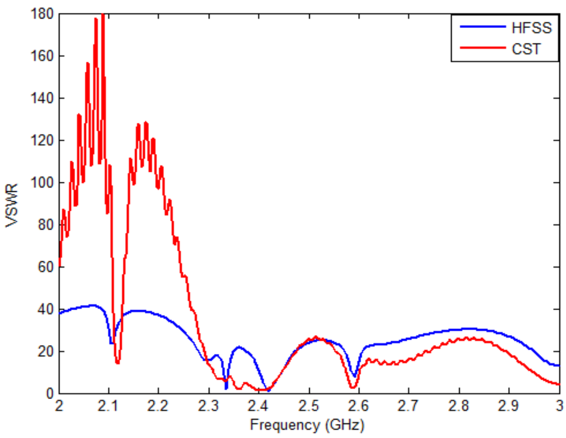

Fig.12: Voltage standing wave ratio of the antenna linear array

Table 2: Comparison of simulation results obtained by HFSS and CST

Simulators	Frequency (GHz)	S_{11}(dB)	VSWR
HFSS	2.42	-25.49	< 2
CST	2.40	-17.53	< 2

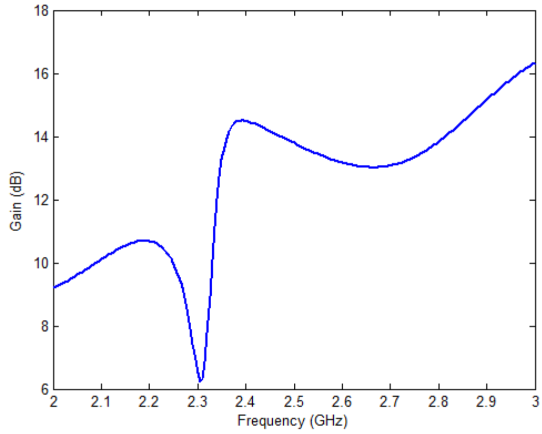

Fig.13: Gain of the antenna array

After inserting of the linear array of patch antennas at four identical elements connected in parallel, we got two operating bands on the frequency range of $2\ GHz$ to $3\ GHz$ (figure 11).
It can be observed in figures 11-12 and table 2, a slight difference between the results obtained by HFSS and by those CST in terms of resonance frequencies and levels of reflection coefficients. This difference is due to the simulation steps and the mesh used for each simulator.
Figure 13 represents the gain of our patch antenna linear array to four identical elements. It is noted that the resonant frequency of $2.4\ GHz$, the maximum value of the gain is about $14.50\ dB$.
Indeed, the more one increases the number elements of the array, the total gain increases for the array. But against, we can not increase the number of elements at infinite number, it is important to consider the size of the network.

5 Conclusion

In this paper, we have presented a new structure of a patch antenna linear array to four identical elements connected in parallel and intended for Radio Frequency Identification applications.
The results presented throughout this work are optimized in terms of reflection coefficient, standing wave ratio, input impedance and gain over a frequency range of $2\ GHz$ to $3\ GHz$.

The proposed linear antenna array is a simple structure which can be easily manufactured with a low cost. It is a good solution for many wireless applications.

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