Jestr

Journal of Engineering Science and Technology Review 12 (6) (2019) 167 - 172

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

1*2 RFID-Reader Array Antenna for Narrowband Indoor Positioning Applications

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Received 16 October 2019; Accepted 27 December 2019

Abstract

This work involves two technics of MPA (Micro-strip Patch Antenna) radiation characteristics enhancement, firstly by the design of a 1*2 array antenna based on two slotted ones to enhance the gain and the directivity, secondly by the design of the same antenna with modified ground plan (DGS technic: Defected Ground structure). The 1*2 array antenna is feed by a 50-Ohm micro-strip line, set on an Epoxy FR-4 substrate, and designed to resonate at 2,45GHz frequency. Besides, simulation results of this array were performed by HFSS simulator and validated by CST, they were focused on adaptation characteristics (S11, VSWR and bandwidth) and far field radiation characteristics (Gain, Directivity and Radiation Pattern). The final proposed antenna can be used in narrowband indoor positioning application for RFID readers, using a fixed-reader-scheme.

Keywords: Narrowband, Indoor positioning systems, array, DGS, Gain, Directivity.

1. Introduction

Radio Frequency Identification (RFID) is a very attractive technology, aimed at objects contact-less detection and tracking [1, 2], it is used as a localization technic in positioning systems called also location systems [3-6].

Positioning systems can use other techniques in the localization process, such as: Global Positioning System (GPS) and A-GPS (Assisted GPS) technologies, Wireless Local Area Networks (WLAN) and WSN technologies, Ultra-Wide Band (UWB) technologies, non-RF-based techniques (Bluetooth, infrared (IR) laser localization, visual, ultra-sound, magnetic positioning, audible sounds…) [3-6]. Positioning systems include indoor and outdoor positioning systems.

Indoor positioning systems can be associated to many of these technics, it depends on the location process of the target object which can be achieved by using a defined approach. There are two general approaches used in the localization process [7, 8]:

- Lateration: estimates the tag position according to its distances from multiple non-collinear readers. The distance can be estimated by measuring Received Signal Strength (RSS), Time of Flight (ToF), Round-trip Time of Flight (RToF), time of arrival (ToA), or even time Difference of Arrival (TDoA) [5-8].
- Angulation: estimates the angle of arrival (AoA) or even direction of arrival (DoA), it is used to measure the angles of the signals arriving at the known nodes by exploiting geometric properties of triangles in the receiving array [5-8].

In addition, when the RFID technology is used in positioning systems, two kind of scheme [3, 9, 10] can be used as described in the figure 1:

- Fixed tag scheme: all tags are set to well-defined positions, with rules such as distance, antenna characteristics, and tag size [3, 9, 10]. This scheme is useful when the objects are large, while the reader must be, over time, portable with multidirectional location behavior (figure 1-(a)).
- Fixed reader scheme: readers are fixed in defined positions, while the tag is attached to the objet to be tracked [3, 9, 10]. This schema is very well known and used when many tags have to be located at the same time, in some known directions (figure 1-(b)).

(a) Fixed tag scheme

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ISSN: 1791-2377
doi:10.25103/jestr.126.21

(b) Fixed reader scheme

Fig. 1. Positioning system scheme using RFD technology

In any RFID positioning system, the antenna is the key element of the communication between the tag and the reader, it ensures emission and/or reception of necessary information for the identification process, by converting electrical energy into electromagnetic energy and vice versa. Then, overall system performances can be affected from the antenna characteristics.

In fact, many antenna characteristics have to be taken into consideration before choosing the positioning scheme, such as: the dimensions, the accuracy, the radiation characteristics (gain, radiation pattern and efficiency) and the polarization [8, 11]. In addition, the antenna bandwidth requirements in indoor positioning applications, depends on the localization techniques [8].

In RFID positioning system applications, the use of a basic antenna may, in some cases, not satisfy the desired performances in terms of gain and radiation pattern. Networking several radiating elements, which refers to array antenna, can be the judicious solution, to improve the gain and the efficiency and to reduce the side-lobes, if and only if the analysis and the array synthesis is well done [12].

This work provides a design and implementation of a 1*2 array antenna that can be used for RFID narrowband positioning system for the fixed reader scheme.

In fact, in some RFID positioning systems such as systems using time-of-flight approach and proximity technic, the bandwidth should be narrow in order to track the object more accurately [13-15].

In this case, the narrow bandwidth of RFID antennas seems to be an advantage, therefore a broadband is not necessarily required in RFID applications because the antenna rejects signal out of band and as a result increases the quality factor [16,17].

The bandwidth in narrowband RFID applications doesn't exceed 60MHz, that mean 4% of the 100% of the bandwidth [18, 19].

The array is based on an elementary slotted patch antenna printed on an Epoxy FR-4 substrate, and feed by a 50 Ohm feeding line.

Simulation results were performed by using HFSS simulator and validated by CST microwave.

2. The 1*2 proposed antenna design procedure

2.1. The basic antenna design

The design of the 1*2 array antenna was based on a basic slotted one, which is adapted with notches and containing three radiating slots inserted by iteration [20].

The basic antenna has a rectangular shape, its dimensions were estimated from a series of analytical equations [20, 21]. The obtained dimensions were adjusted to obtain resonance at the frequency of 2,45GHz, and was fixed at Lsub=56mm and Wsub=31mm.

The basic antenna radiating element and the 50-Ohm feed line are PEC type (Perfect Electric Conductor). They are printed on the Epoxy FR-4 substrate, with a relative permittivity of εr = 4,4 and thickness of h = 1,6 mm. This set stands on a finite size ground plan, type PEC, covering the entire bottom area of the substrate.

All details about the design steps of this antenna are described in the reference [20]. Figure 2 gives the basic antenna structure and its dimensions.

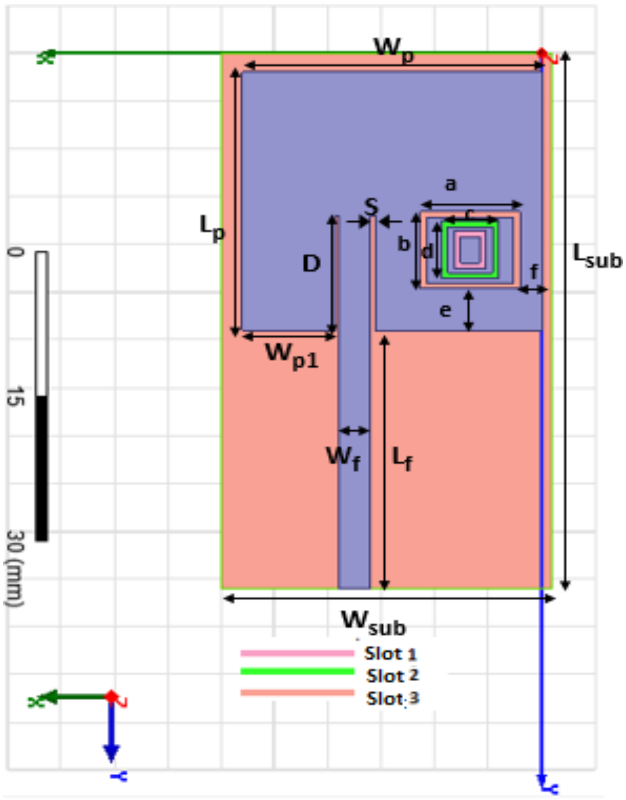


Fig. 2. The basic antenna design [20]

The simulation results of the basic antenna were obtained via HFSS simulator and supported by CST one. They are summarized in table 1 and show that the antenna is well adapted at 2.45GHz [20].

Table 1. The basic antenna radiation characteristics

Parameter	Basic antenna	
	HFSS	CST
Frequency (GHz)	2,45	2,47
S11 (dB)	-40,0	-27,1
BP (MHz)	60,30	67,30
Gain (dB)	2,37	2,06
Directivity (dB)	5,56	5,49
Efficiency (%)	42,62	37,52

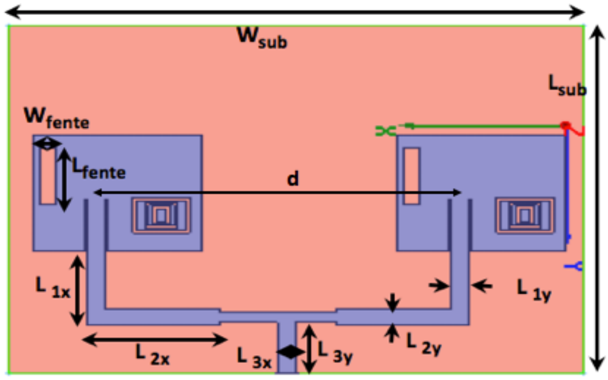
The radiation pattern of this antenna has a directional behavior, and the ratio of gain and directivity gives an efficiency of 42,62% by HFSS and 37,52% by CST.

In order to enhance the basic antenna far field characteristics and the efficiency parameters, a 1*2 array antenna is designed.

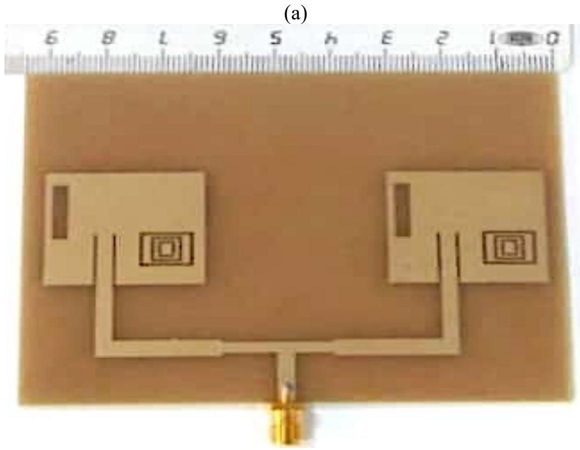
2.2. The 1*2 array antenna design.

The 1*2 array antenna design started by estimating the feeding lines dimensions and the spacing distance between the two radiating elements.

Figure 3-(a) and figure 3-(b) gives the 1*2 array shape and its implementation by PCBWay which is a Chinese (Shenzhen) manufacturer specializing in PCB prototyping, low-volume production and PCB Assembly service. Table 2 summarize all its dimensions.



(a)



(b)

Fig. 3. The 1*2 array antenna design, (a) The 1*2 Array Antenna designed on HFSS and b) The implemented 1*2 Array Antenna

Table 2. The 1*2 array antenna parameters

Parameter	Dimension (mm)
L_{sub}	80
W_{sub}	95
L_{fente}	13
W_{fente}	2,7
L_{1x}	17
L_{1y}	2,9
L_{2x}	18,85
L_{2y}	3,8
L_{3x}	3
L_{3y}	13,8

Note that in the design of the 1*2 array antenna, a vertical slot was inserted in each radiating element of the elementary antenna in order to get the resonant frequency around 2,45GHz.

The distance between the two elements was set at d= 59mm at 2,45Ghz. in fact, the spacing between two successive elements in any array antenna have to be less than λ/2, in order to avoid the mutual coupling between the elements and grating lobes [22,23].

Simulation results of the 1*2 array antenna were obtained by HFSS, validated and compared to those in CST, and concern the return loss (S11), the Voltage Standing Wave Ratio (VSWR), the gain (G), the directivity (D) and the radiation pattern (RP).

- <u>Return Loss, VSWR and Bandwidth:</u>

The return loss variation is given by figure 4, which translate directly the antenna adaptation at 2,46GHz. It shows that, at this frequency, S11 reaches a value of -11,33dB and the bandwidth a value of 62,10MHz using HFSS, CST simulator gives a value of -18,59dB for S11 and 66,50MHz for the bandwidth.

In comparison with the basic slotted antenna, adaptation parameters remain in the same interval, and the bandwidth was maintained nearly between 60MHz and 67MHz.

The S11 measurement were performed in STRS (Système de Télécom, Réseau et Services) Laboratory in INPT of Rabat in Morocco. According to the figure 4, the measured S11 gives value of -29,52dB at 2.455GHz. the bandwidth obtained from measurement is in about 65,90MHz.

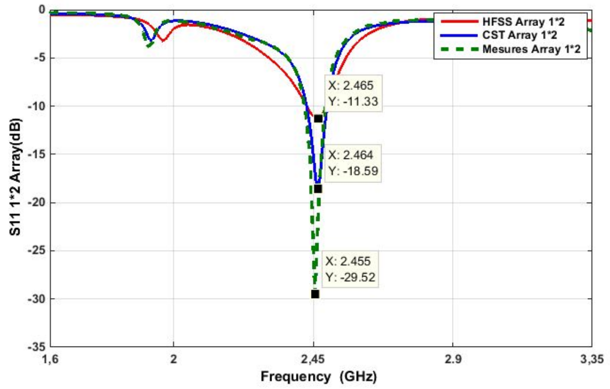


Fig. 4. The 1*2 array antenna return loss variations

VSWR is one of the parameters that support the antenna adaptation. For this array antenna, VSWR values are less than 2 either by HFSS or CST at 2,45GHz, these values prove the antenna adaptation. Figure 5 gives the VSWR variations.

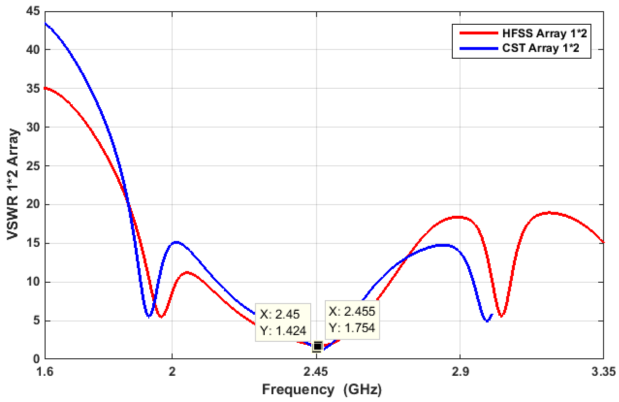
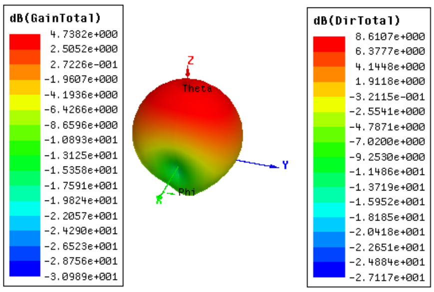


Fig. 5. VSWR variation of the 1*2 array antenna

- <u>Gain and directivity</u>

The total gain and the total directivity of the array were visualized in 3D at 2,45GHz. their shapes are illustrated in figure 6, which shows that their values were enhanced.

In fact, by adding another radiating element, the gain was enhanced from 2,37dB to 4,73dB (figure 6-(a)), and the directivity from 5,56dB to 8,61dB (figure 6-(b)) by HFSS simulations. The same evolution is obtained by CST, the gain goes from 2,06dB to 3,14dB, and the directivity from 5,49dB to 7,89dB.



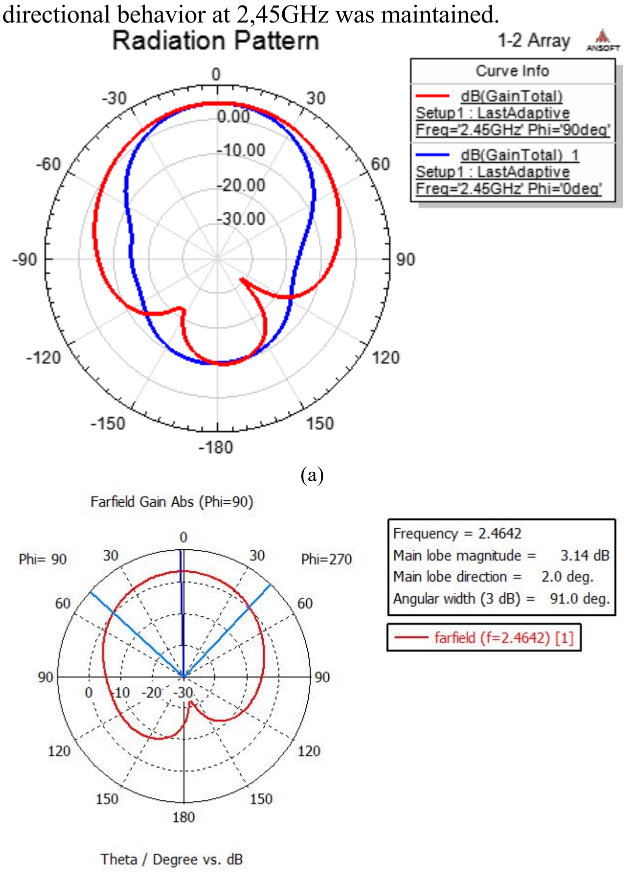
a) b)

Fig. 6. Total gain and total directivity of the 1*2 array antenna. (a) The 1*2 array antenna Gain and (b) The 1*2 array antenna Directivity

The 1*2 array antenna efficiency at 2,45GHz was calculated and validated by HFSS simulation, it's around 55,05% (the basic antenna efficiency is only 42,62%).

- <u>Far field Simulation results: Radiation pattern</u>

The figure 7 present the simulated far-field Radiation Pattern of the 1*2 array antenna, in the two plans E (φ=0°) and H (φ=90°). This figure shows that, either in HFSS or CST, the directional behavior at 2,45GHz was maintained.



(a) b)

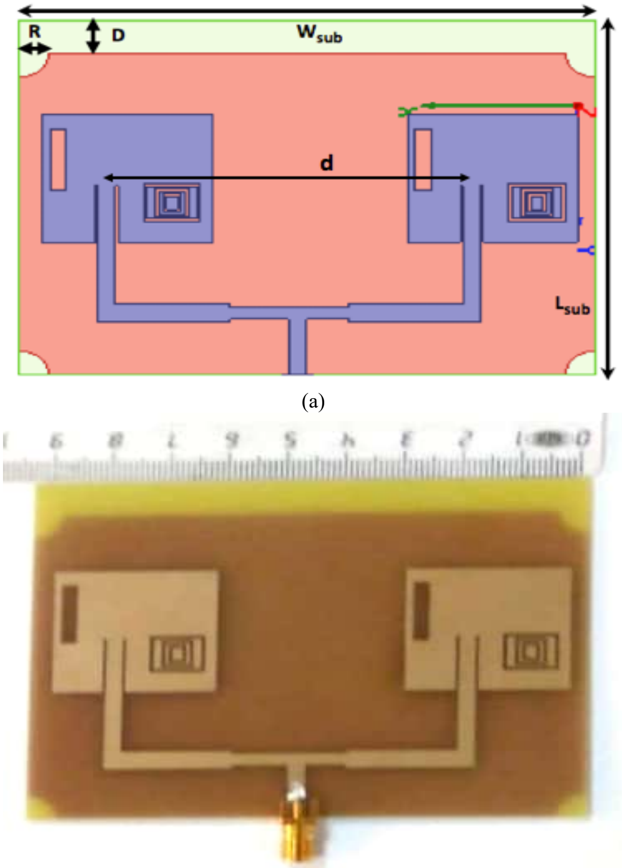
Fig. 7. The 1*2 array patch Radiation Pattern, (a) The 1*2 array antenna radiation pattern in HFSS and (b) The 1*2 array antenna radiation pattern in CST

2.3. The 1*2 array antenna adaptation characteristics enhancement by DGS application

The 1*2 array antenna present acceptable far field radiation characteristics, but the resonant frequency is not exactly at 2,45GHz and the bandwidth is too narrow. In fact, broadening the bandwidth is one of RFID applications challenges to ensure high data transfer rate and to enhance the read rang, but as mentioned before, positioning in indoor environment can use narrow band antennas and ultra-wide band antennas, it depends on the scenario and the used technique.

In this part, through the application of the DGS technique (Defect Ground Structure) [24, 25], it is possible to change the frequency behavior of the designed and implemented 1*2 array antenna, and to increase the bandwidth, to a better value, for the purpose to keep the trade-off between gain and the narrowband application.

The structure of the 1*2 array antenna with DGS is given in figure 8, which shows the shortening of the ground plane size from its upper part, and then the addition of four cylindrical slots with radius R = 5mm.



(a) (b)

Fig. 8. The 1*2 array antenna structure with DGS, (a) 1*2 Array Antenna designed with DGS on HFSS and (b) The implemented 1*2 Array Antenna with DGS

Note, as mentioned in the table 3, that the substrate length was reduced in order to get the exact resonant frequency. All the other dimensions were maintained.

Table 3. The 1*2 array antenna dimensions with DGS

Parameter	Dimension (mm)
L_{sub}	75
W_{sub}	95
D	7
R	5

In the same way, adaptation parameters and far field radiation characteristics simulations were performed by using HFSS simulator and validated and compared to those obtained by CST and by measurement.

- <u>Return Loss, VSWR and Bandwidth</u>

By modifying the ground plan of the 1*2 array antenna and minimizing its dimensions, the resonant frequency changes to 2,45GHz either in HFSS or CST or even by measurement.

Besides, the return loss variation given by figure 9, shows that S11 is less than -10dB (-18,59dB for HFSS and -11,33dB for CST and -33,35dB by measurement), these values translate the adaptation of the antenna after DGS application. The bandwidth of this antenna was enhanced, it changes from an average value of 63,5MHz to a value of à 88,70MHz by HFSS and 68,80MHz by CST and 78MHz by measurement.

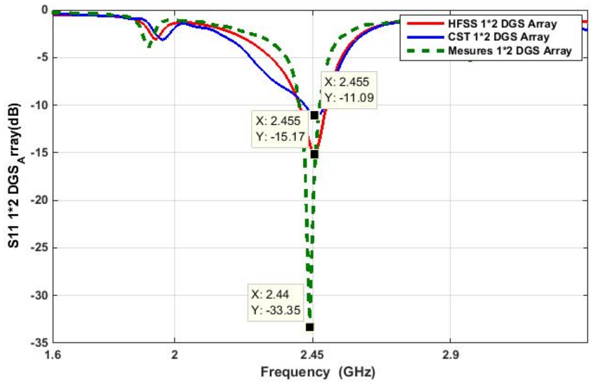


Fig. 9. S11 variation of the 1*2 array antenna with DGS

VSWR of the array with DGS was also simulated, its value is less than 2 at 2,45GHz, 1,42 for HFSS and 1,77 for CST. The variation of this parameter is given by figure10.

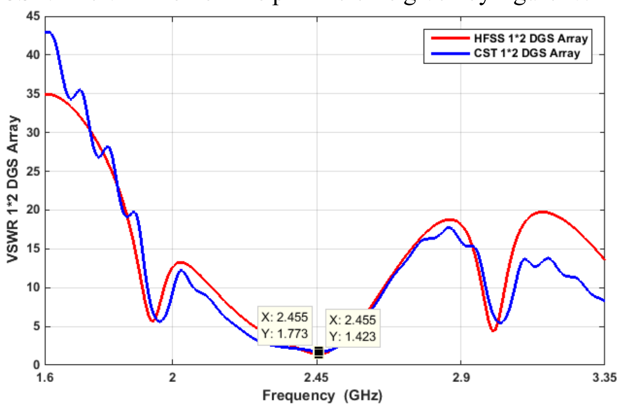
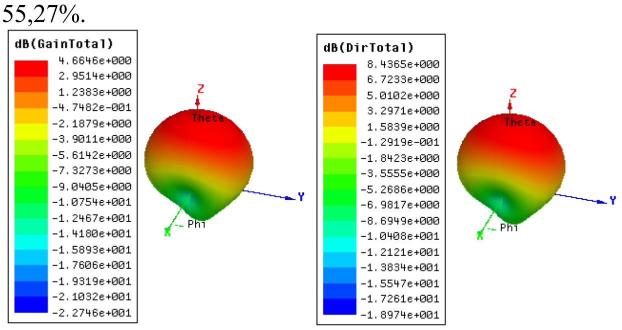


Fig. 20. VSWR variation of the 1*2 array antenna with DGS

- Gain and directivity
  The total gain and the total directivity after applying the DGS to the 1*2 array antenna structure had kept almost the same values. These values are given by figures 11-(a) and 11-(b).

In addition, the efficiency at 2,45GHz was calculated and validated by direct simulation via HFSS, its value is about 55,27%.

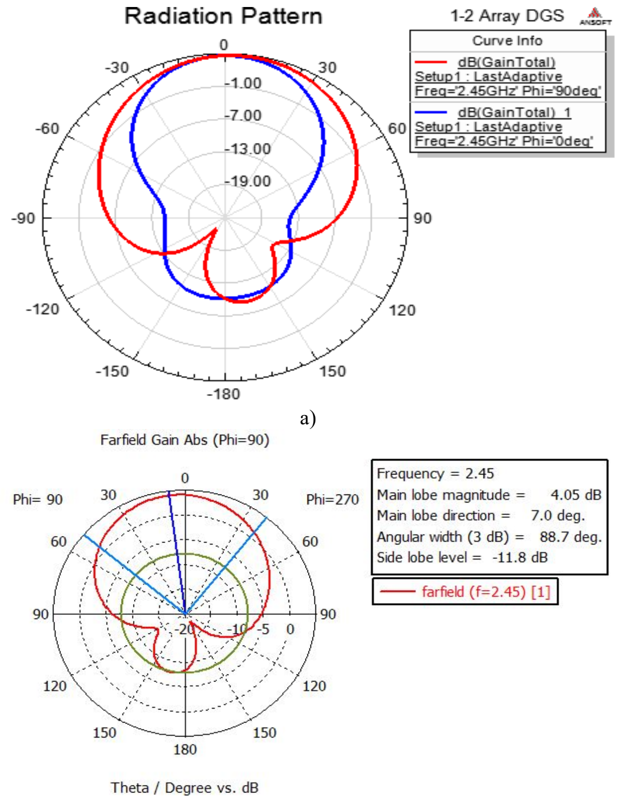


a) b)

Fig. 31. Total gain and total directivity of the 1*2 array antenna with DGS, (a) Gain of 1*2 array with DGS and (b) Directivity of 1*2 array with DGS

- Far field Simulation results: Radiation pattern

After ground plan modification and DGS application, the 1*2 array antenna maintained the directional behavior, as illustrated in figure 12-(a) and 12-(b).



a)

b)

Fig. 42. Radiation pattern of the 1*2 array antenna with DGS, (a) The 1*2 array antenna radiation pattern in HFSS using DGS and (b) The 1*2 array antenna radiation pattern in CST using DGS

3. Discussion, Comparison and summary of simulation results

Table 4 regroups and summarize all simulation results of the basic antenna and the 1*2 array antenna with total ground plan and with DGS. From this table, some conclusions can be set out:

- The return loss values weren't improved in the 1*2 array patch antenna with and without DGS, but their values were maintained to less than -10dB, which prove the antenna adaptation. All VSWR simulations gives values less than 2, this parameter can prove the antenna adaptation.
- The bandwidth of the 1*2 array antenna with total ground plan, was maintained to around 62MHz, but enhanced to 88MHz in the same structure with DGS. These results lead to a narrow-band positioning application.
- The gain and the directivity was improved by multiplying the number of radiating elements, this achieved values can respond to the positioning systems applications requirements.

Table 4. Comparison and summary of Simulation results

	The basic antenna		The 1*2 array antenna		The 1*2 array antenna with DGS	
Simulator	**HFSS**	**CST**	**HFSS**	**CST**	**HFSS**	**CST**

Fr (GHz)	2,45	2,47	2,465	2,464	2,455	2,455
S11 (dB)	-40,00	-27,10	-11,33	-18,59	-15,17	-11,09
Bandwidth (MHz)	60,30	67,30	62,10	66,50	88,70	68,80
VSWR	1,02	1,14	1,75	1,42	1,42	1,77
Gain (dB)	2,37	2,06	4,73	3,14	4,66	4,06
Directivity (dB)	5,56	5,49	8,61	7,89	8,43	8,10

4. Conclusion

The adaptation parameter optimization of single patch antenna containing slots were performed in this work, by a 1*2 array antenna.

As a result, the array gives an enhanced gain and directivity, however, the bandwidth wasn't improved and the frequency was slightly deviated from the desired one which is 2,45GHz.

The ground plan dimensions decreasing and the DGS application had a direct impact on adjusting the frequency behavior and enhancing the bandwidth.

Thanks to the two technics involved in this paper, which are: networking micro-strip patch antennas (array antenna) and DGS technic, the designed antenna lead to wide scenario applications in indoor positioning systems, by using serval approaches, such as DoA, KNN, or even proximity approach.

In future works, other kind of antennas used in localization system will be studied and designed, to get a multidirectional behavior or a signal maximization in specified directions.

Acknowledgements
This work is partially supported by Pr. Abdelwahed Tribak from STRS Laboratory (Système de Télécom, Réseau et Services) in INPT of Rabat in Morocco.

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