Impact of a simple DGS size on the radiation characteristics of an elementary MPA

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Abstract— Defected ground structures have known recently a great evolution in many systems, using the micro-strip technology, thanks to their good effects on such system performances, and their role to overcome some micro-strip structures limitations. In this regard, a parametric study of the impact of defected ground plane size on radiation characteristics is done. The study is conducted on a rectangular patch antenna adapted with notches. Simulations with various ground plane size depending on its positions, were carried out by using the electromagnetic simulator HFSS. Radiation characteristics evolution was performed to show the purpose of this work. As a result, the size decrease of a simple defect in the ground plane, can contribute to adjust the frequency behavior of an elementary patch antenna, and to improve its bandwidth and efficiency.

Index Terms— Microstrip, Antenna, ground plane, dimension, position, DGS, resonant frequency, bandwidth, efficiency, HFSS.

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1 Introduction

The antenna is one of the most important components in the wireless communication applications, in radio frequency identification applications (RFID), in microwave systems or in the mobile radio applications. [1-2].

Microstrip patch antennas (MPA) are the most used in this type of systems or applications; considering their advantages, such as: low cost, ease of implementation and compactness. [1-2]

However, most ordinary microstrip structures suffer from surface waves which are generated in the dielectric substrate when the radiating element begins to radiate. They can deny the functioning of the antenna, or even deteriorate the radiation pattern and cause the efficiency decrease of the entire system. [3-4]

Defected Ground Structures (DGS) are one of the most used technics to reduce surface waves and to improve the radiation characteristics of a MPA. In this regard, many simple and complex DGS forms have been investigated in the literature, especially for bandwidth and gain enhancement, whatever the antenna size is. [3-6]

In this paper, the study is applied on an elementary rectangular patch antenna, adapted with notches. A parametric study of the impact of a simple defect size, in the ground plane, on the MPA radiation characteristics, is completed. The defect has a rectangular shape, and the analyzed radiation characteristics are in particular: the resonant frequency, the return loss, the bandwidth and the efficiency.

The first section of this paper will be devoted to DGS structures definition, their advantages and applications. In the second section, a study of the impact of a simple DGS size on radiation characteristics will be done to show the impact of DGS on radiation characteristics of an elementary patch antenna, namely the bandwidth and the antenna efficiency.

2 Defected Grounds Structures (DGS):

Defected Ground Structures (DGS) are extracted from Electromagnetic Band Gap structure (EBG), [7-9] and are defined as an etched periodic or non-periodic cascaded configuration defect in ground of a planar micro-strip structure. [9-12]

The DGS disturbs the shielded current distribution in the ground plane, depending on the defect shape, its position and dimensions [24]. This disturbance can completely change radiation characteristics of the MPA such as radiation pattern, adaptation parameters, bandwidth, gain, and efficiency [24]. It can also change a transmission line characteristics, such as line capacitance and inductance (can give rise to increasing effective capacitance and inductance), and resulting a controlled excitation and propagation of the electromagnetic waves through the substrate layer, which can lead to surface waves suppression or reduction. [12, 24]

The defect shape can be simple or complex; it depends on the sought performance. Several forms of DGS have been studied in the literature, such as: rectangular, circular, spiral, L- shaped, U-shaped and V-shaped … etc [8, 9]

The DGS are not limited to eliminate surface waves, but also help to overcome other microstrip structures limitations, such as: antenna size reduction [4, 13, 14, 15], mutual coupling reduction [4, 15, 16, 17], harmonic suppression [4, 17, 18, 19] and cross-polarization reduction [20, 21, 22].

In addition to all the advantages listed above, the DGS can improve all radiation characteristics of a MPA. In the next section, a simple defect dimension study in the ground plane will be done to show its impact on the radiation characteristics especially on frequency range, bandwidth and efficiency.

3 Parametric study (A simple DGS size analyze):

3.1 General description of the studied antenna:

As mentioned in the previous sections, many phenomena (surface wave's propagation, cross polarization …) may prevent the defective functioning of a MPA by reducing its performance. To deal with these limitations, several methods were proposed, including the DGS technique. [13-22]

In this regard, a parametric study of the impact of a simple rectangular defect size, in the ground plane, is performed, depending of its position.

This study is applied on an elementary antenna adapted with notches and hasa rectangular shape. The radiating element and the feed line are PECs (Perfect Electric Conductor) 0.035 mm thick. They are printed on an Epoxy FR-4 substrate, with thickness of 1.6mm, relative permittivity of 4.4 and a dielectric loss tangent of 0.02.

The general dimensions of the antenna were obtained from a series of analytical equations (équations1-5) [6, 23, 25], and were adjusted to have a resonant frequency around 2.45 GHz. These equations are listed below:

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L_p = L_{eff} - 2\Delta L \tag{2}$$

$$L_{eff} = \frac{c}{2\, f_r \sqrt{\varepsilon_{re}}} \tag{3}$$

$$\Delta L = 0.412\left(\frac{\varepsilon_{re} + 0.3}{\varepsilon_{re} - 0.258}\right)\left(\frac{\frac{W_p}{h} + 0.264}{\frac{W_p}{h} + 0.813}\right) \tag{4}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{5}$$

With:

f_r: The resonant frequency;
ε_r: The dielectric constant of the substrate;
ε_{re}: The effective dielectric constant expressed (equation 5);
h: The substrate thickness
c : The speed of light in free space;
L_{eff}: The effective length given by equation 3;
ΔL: The extension of the length is given by equation 4.

In the studied structure, the ground plane is a PEC, placed under the substrate, and has finite dimensions. Note D_{init}= (49mm, 66mm) the initial size of the ground plane.

The following figure shows the shape and the dimensions of the antenna on which the study is carried out :

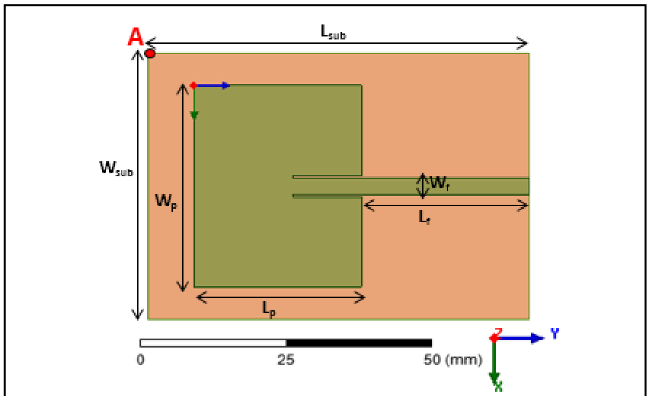


Fig. 1. Elementary patch antenna adapted with notches

The following table gives the elementary antenna dimesions:

TABLE 1
THE ELEMENTARY ANTENNA DIMENSIONS

Parameter	Dimension
L_{sub}	66
W_{sub}	49
L_p	29
W_p	37
L_f	29
W_f	3
D_{init}	x= 49 ; y= 66
A (Ground Plane Position)	(-6,-8)

"A" is the position of the ground plane, its coordinates are x=-6 and y=-8.

Simulations of the elementary antenna radiation characteristics were focused on: resonant frequency, return loss, bandwidth, and efficiency. They were carried out by the electromagnetic simulator HFSS.

As displayed in Figure 2, simulations show that the antenna resonates around the frequency 2.41GHz, and has a return loss of -12.81dB, and bandwidth at -10dB of 35.4MHz.

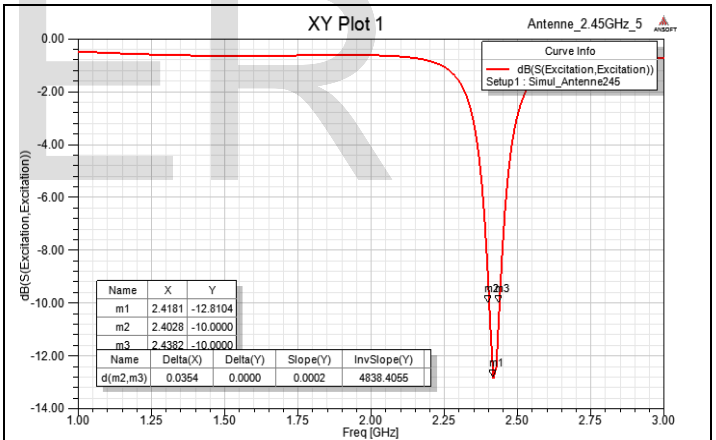


Fig. 2. Return loss of the elementary patch antenna adapted with notches

In figure 3 and 4, gain and directivity are respectively shown. We can see that the gain of this basic antenna has reached a value of 3.46dB, and its directivity has value of 6.67dB. The antenna efficiency was calculated and simulated; it reached a value of 51.87%.

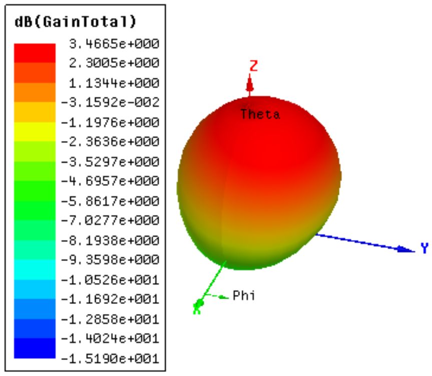


Fig. 3. Total gain of the elementary patch antenna adapted with notches

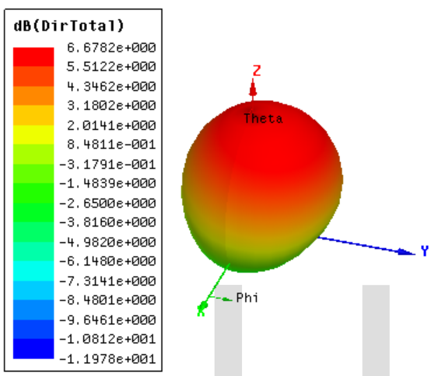


Fig. 4. Total directivity of the elementary patch antenna adapted with notches

Furthermore, from the input impedance Z_{in} and the VSWR simulation results, the antenna adaptation is verified.

3.2 The study simulation Results and Discussion:

In this part, the ground plane size will be gradually reduced, along the two axes: x-axis and y-axis (see figure 1). The two evaluated parts are:

- Size decrease according to the x-axis only,
- Size decrease along the x-axis and y-axis at the same time.

The evolution of return loss, bandwidth, and efficiency will be represented as a function of the resonant frequency.

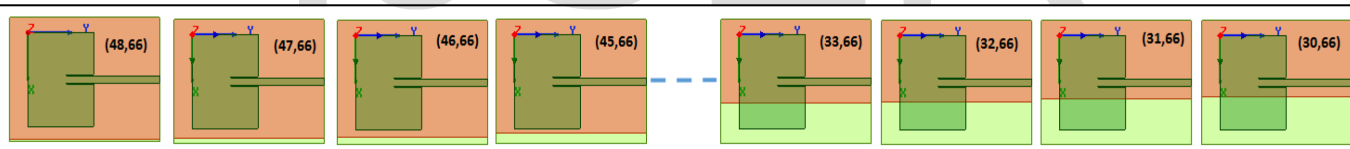
3.2.1 Size decrease according to the x-axis only:

As mentioned in the description of the adapted patch antenna, the initial size of the ground plane is D_{init} (x = 49mm, y = 66mm) beginning at the position A (-6, -8) in figure 1.

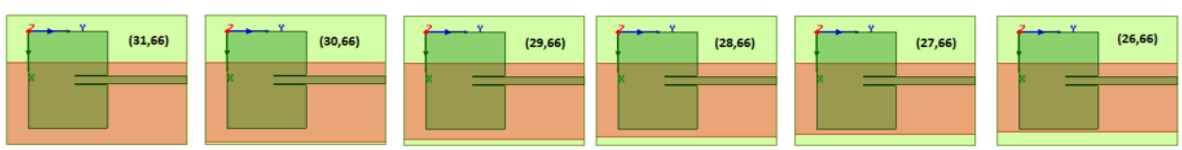
In this first part, the value of "y" is set at 66 mm and its position at -8 will be maintained, while the value of "x" varies from 49 mm to 30 mm. Then, one position is fixed and includes a number of dimensions.

In figures 5(a) and figure 5(b), different configurations in the first position A (-6, -8), which is the initial position of the ground plane and for the position (12, - 8), are displayed.

The analytical results of the radiation characteristics evolution of the elementary antenna, depending on the ground plane size, will be presented for these two positions. Positions between these two ones have been investigated and are not presented here.



(a) Configurations for the initial position (-6, -8)



(b) Configurations for the position (12, -8)

Fig. 5. The two studied cases

⇨ **<u>Position (-6, -8):</u>**

In figure 6, the studied antenna radiation characteristics evolution is presented.

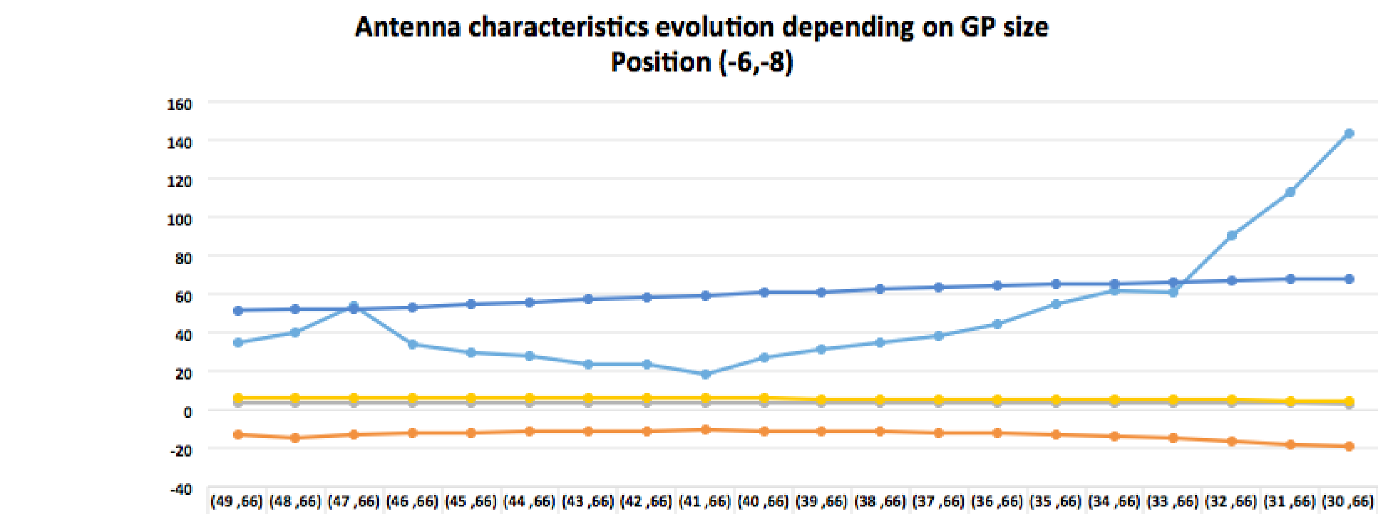
The results for each one of configurations in figure 5(a) are reported on the data table below. It shows that, as far as the ground plane dimension decreases:

- The resonant frequency moves from 2.41GHz to 2.52GHz, and the return loss goes from -12.83dB to -18.93dB reflecting the improved antenna adaptation as illustrated in figure 7,
- The bandwidth is largely improved. It grows from 35MHz to 143.5MHz,
- The efficiency of the antenna also increases from 51.87% to 68.26%.

Note that, even if the value of the directivity decreases from 6.67dB to 4.6dB, and the gain decreases relatively from 3.46dB to 3.14dB, the antenna efficiency increases.

The efficiency values were calculated by using the formula (6), and were approved by the direct simulation of the absolute efficiency in HFSS.

$$\text{Eff} = \left(\frac{\text{Gain}}{\text{Directivity}}\right) * 100(\%) \qquad (6)$$



	(49 ,66) 2,4181	(48 ,66) 2,4114	(47 ,66) 2,4181	(46 ,66) 2,4181	(45 ,66) 2,4181	(44 ,66) 2,4147	(43 ,66) 2,4147	(42 ,66) 2,4181	(41 ,66) 2,4135	(40 ,66) 2,4135
Bandwidth (Mhz)	35	40,4	54	34,46	30	27,9	24	24	18,2	27
S11 (dB)	-12,83	-14,16	-12,34	-12,04	-11,7	-11,31	-10,97	-10,76	-10,42	-10,88
Gain	3,46	3,5	3,43	3,46	3,55	3,58	3,65	3,59	3,61	3,62
Directivity	6,67	6,69	6,54	6,48	6,45	6,37	6,33	6,15	6,04	5,93
Efficiency	51,87	52,32	52,45	53,40	55,04	56,20	57,66	58,37	59,77	61,05

	(39 ,66) 2,4185	(38 ,66) 2,4236	(37 ,66) 2,4336	(36 ,66) 2,4386	(35 ,66) 2,4436	(34 ,66) 2,4536	(33 ,66) 2,4637	(32 ,66) 2,4737	(31 ,66) 2,4937	(30 ,66) 2,5238
Bandwidth (Mhz)	31,9	35,3	38,6	44,7	55,3	61,6	61,5	90,3	113,3	143,5
S11 (dB)	-11,16	-11,33	-11,51	-11,92	-12,91	-13,35	-14,14	-16,43	-18,26	-18,93
Gain	3,58	3,66	3,62	3,58	3,59	3,57	3,47	3,42	3,33	3,14
Directivity	5,82	5,8	5,69	5,54	5,51	5,43	5,24	5,11	4,9	4,6
Efficiency	61,51	63,10	63,62	64,62	65,15	65,75	66,22	66,93	67,96	68,26

Fig. 6. Radiation characteristics Evolution in the initial position (-6, -8) as a function of the ground plane dimension decrease

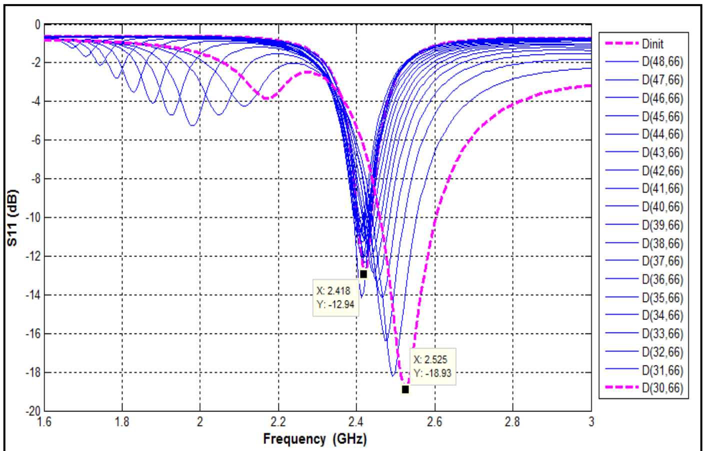
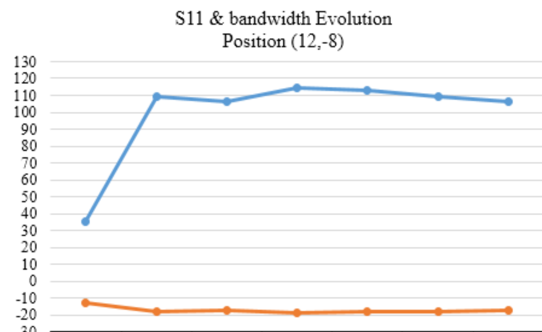


Fig. 7. Return loss & resonant fréquency evolution as a function of the ground plane size decrease of the initial position (-6, -8)

⇨ **Position (12, -8):**

In this position, six configurations were analyzed (figure 5(b)). The same evolution of the radiation characteristics is observed (figure 8 and figure 9):

- The resonant frequency increases from 2.41GHz to 2.49GHz, and the return loss from -12.83dB to -17.13dB. (See figure 10),
- The bandwidth is improved to 106.5MHz,
- The antenna efficiency also increases from 51.87% to 69.85%.



	Dinitial	(31 ,66) 2,4436	(30 ,66) 2,4386	(29 ,66) 2,4916	(28,66) 2,4983	(27 ,66) 2,4916	(26 ,66) 2,4916
S11 (dB)	-12,83	-17,9	-17,14	-19,01	-18,24	-18,11	-17,13
Bandwidth (Mhz)	35	109,6	106	114,8	113,2	109	106,5

Fig. 8. S11 and bandwidth evolution in the position (12, -8) as a function of the ground plane dimension decrease

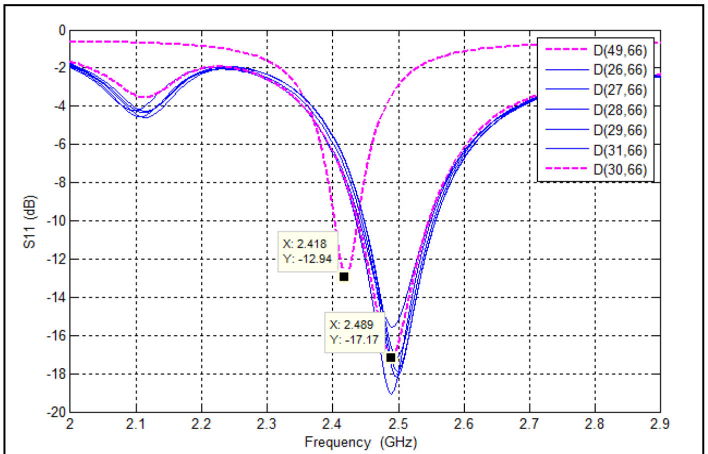
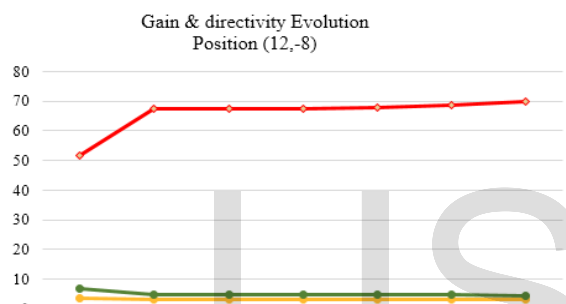


Fig. 10. Return loss & resonant fréquency evolution as a function of the ground plane size decrease of the initial position (12, -8)



	Dinitial	(31 ,66) 2,4436	(30 ,66) 2,4386	(29 ,66) 2,4916	(28,66) 2,4983	(27 ,66) 2,4916	(26 ,66) 2,4916
Gain (dB)	3,46	3,33	3,31	3,24	3,31	3,3	3,22
Directivity(dB)	6,67	4,94	4,92	4,8	4,89	4,8	4,61
Effeciency	51,87	67,41	67,28	67,50	67,69	68,75	69,85

Fig. 9. Efficiency evolution in the position (12, -8) as a function of the ground plane dimension decrease

⇨ **Symmetric cases :**

The same parametric study according to the decrease of the ground plane surface by varying x-dimension, but in the opposite side as illustrated in figure 11, has been conducted.

We can see in this figure, that the ground plane takes symmetrical positions on either side of the x-axis median, with the same dimensions.

The evolution of radiation characteristics for these cases is almost the same as presented in figures 12 and 13 respectively for the resonant frequency and the efficiency. The same evolution is obtained for the other characteristics (S11, Bandwidth, Gain and directivity) not presented here. This means that the defect position and its symmetrical relatively to x-axis median, does not present difference in the radiation characteristics.

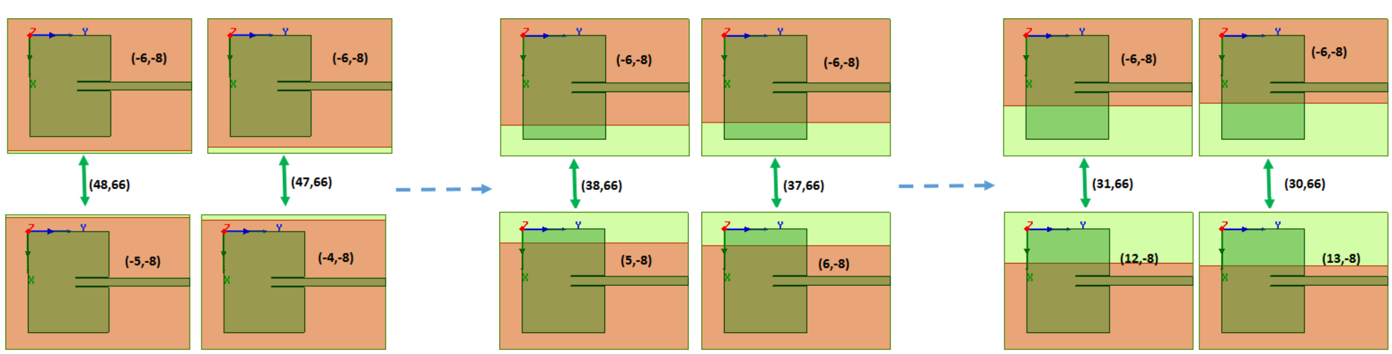
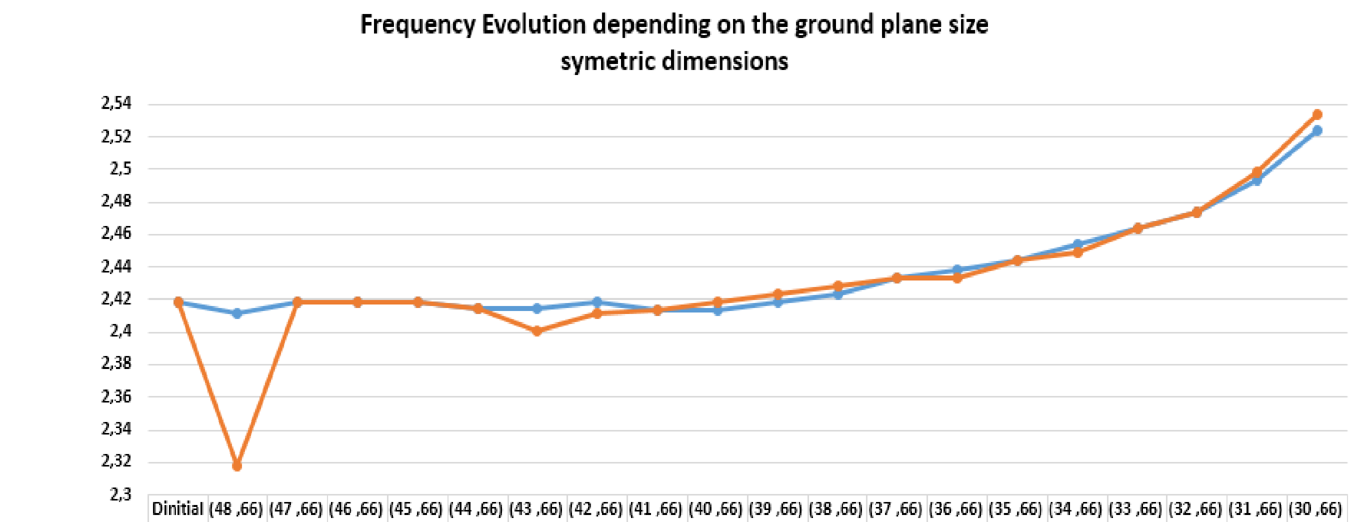
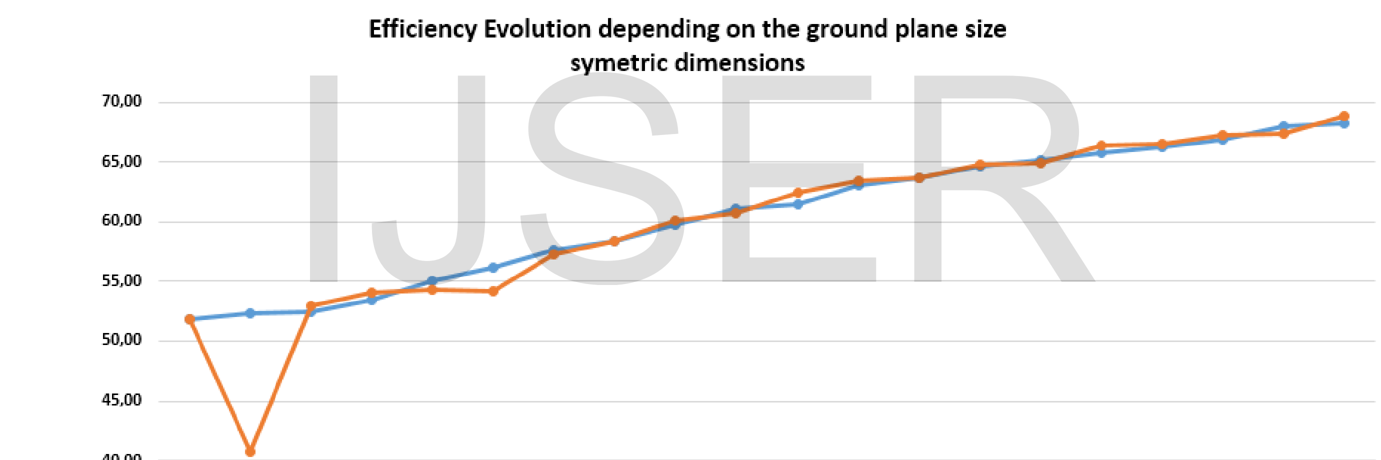


Fig. 11. Examples of symetric positions of some ground plane dimensions



	Dinitial	(48 ,66)	(47 ,66)	(46 ,66)	(45 ,66)	(44 ,66)	(43 ,66)	(42 ,66)	(41 ,66)	(40 ,66)	(39 ,66)	(38 ,66)	(37 ,66)	(36 ,66)	(35 ,66)	(34 ,66)	(33 ,66)	(32 ,66)	(31 ,66)	(30 ,66)
fr	2,4181	2,4114	2,4181	2,4181	2,4181	2,4147	2,4147	2,4181	2,4135	2,4135	2,4185	2,4236	2,4336	2,4386	2,4436	2,4536	2,4637	2,4737	2,4937	2,5238
fr_Symetric	2,4181	2,3177	2,4181	2,4181	2,4181	2,4141	2,4007	2,4114	2,4135	2,4185	2,4236	2,4286	2,4336	2,4336	2,4436	2,4486	2,4637	2,4737	2,4987	2,5338

Fig. 12. Resonnant frequency evolution of symetric positions as a fonction of the ground plane dimension decrease



	Dinitial	(48 ,66)	(47 ,66)	(46 ,66)	(45 ,66)	(44 ,66)	(43 ,66)	(42 ,66)	(41 ,66)	(40 ,66)	(39 ,66)	(38 ,66)	(37 ,66)	(36 ,66)	(35 ,66)	(34 ,66)	(33 ,66)	(32 ,66)	(31 ,66)	(30 ,66)
Eff	51,87	52,32	52,45	53,40	55,04	56,20	57,66	58,37	59,77	61,05	61,51	63,10	63,62	64,62	65,15	65,75	66,22	66,93	67,96	68,26
Eff_Symetric	51,87	40,77	52,96	54,05	54,29	54,22	57,21	58,43	60,07	60,71	62,44	63,39	63,73	64,82	64,97	66,42	66,48	67,24	67,41	68,88

Fig. 13. Efficiency evolution of symmetric positions as a function of the ground plane dimension decrease

3.2.2 Size decrease along the two axes x and y:

In this part, different values for the y-axis dimension are investigated. For each value of y, the x-axis dimension changes from 49mm to 37mm. Note that the variation of the ground plane dimension according to y-axis can be only done on the opposite side to the supply line.

Only results for y values (65mm and 58mm) are presented. Intermediate ones are not displayed here since they give the same evolution of the two ones above.

Figure 14 present the two studied configurations respectively for y = 65mm (figure 14(a)) and y = 58mm (figure 14(b)) by varying x from 49mm to 37mm.

⇨ **Case 1:**

In this first case, x-dimension change from 49mm to 37mm, while y-dimension is fixed at 65mm (see figure 14-(a)). Reminding that the initial values of the ground plane dimension are x=49mm and y=66mm.

Similarly, the simulations results of each configuration are made and compared with those in the initial dimension. According to the figure 15, as far as the x-dimension decreases, we notice that:

- The resonant frequency increases from 2.41GHz to 2.43GHz,
- The return loss increases negatively from -12.83dB to --14.13dB,

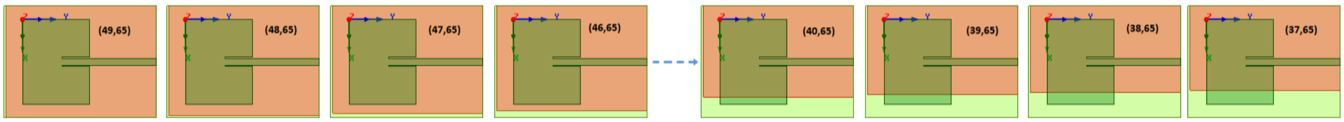
- The bandwidth is improved and changes from 35MHz to 55MHz,
- The antenna efficiency also increases from 51.87% to 63.80%.

⇨ **Case 2:**

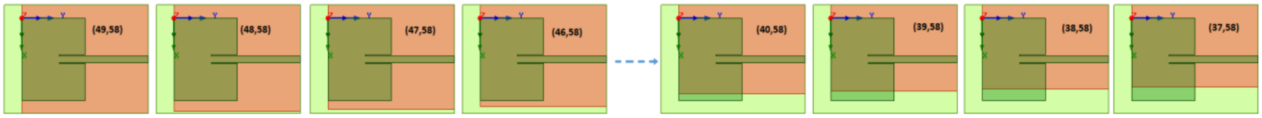
In this case, the ground plane size along y is fixed at 58mm for y-dimension, and x-dimension varies from 49mm to 37mm (see figure 14-(b)).

The evolution of radiation characteristics is reported in the figure 16, and almost the same evolution as in the first case is observed:

- The resonant frequency increases from 2.41GHz to 2.46GHz,
- The return loss increases negatively from -12.83dB to -16.66dB,
- The bandwidth is improved and changes from 35MHz to 59.9MHz,
- The antenna efficiency also increases from 51.87% to 68.80%

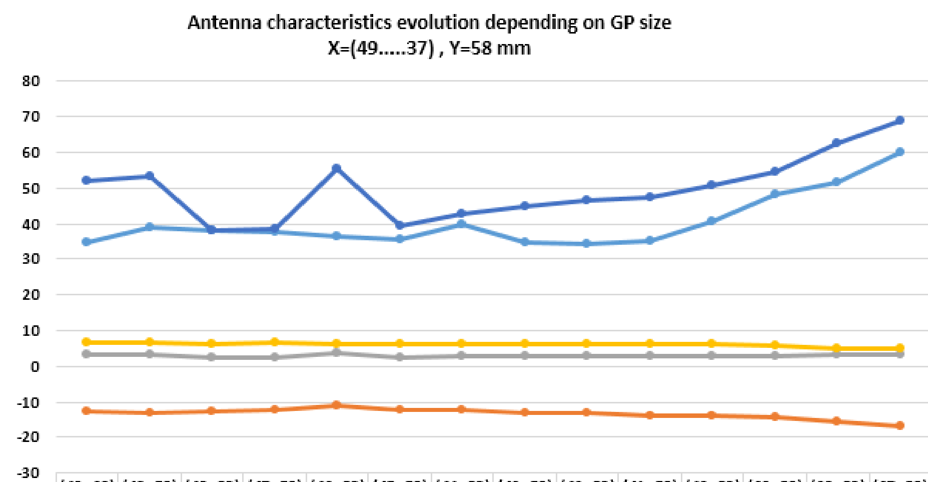


(a) Configurations for y=65mm at the position (-6,-7)



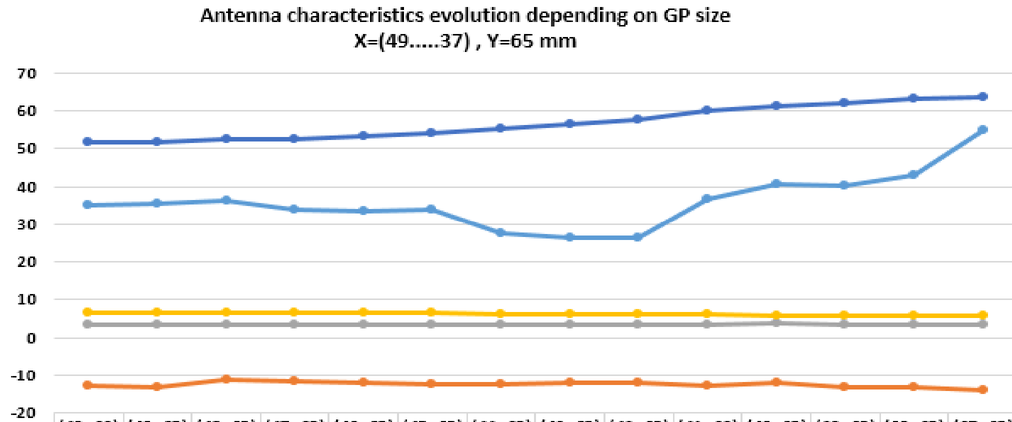
(b) Configurations for y=58mm at the position (-6,0)

Fig. 14. The two studied configurations in a fixed y-dimension and x-dimension changing from 49mm to 37mm



	(49 ,66) 2,4181	(49 ,58) 2,4448	(48 ,58) 2,4515	(47 ,58) 2,4486	(46 ,58) 2,4486	(45 ,58) 2,4424	(44 ,58) 2,4386	(43 ,58) 2,4436	(42 ,58) 2,4436	(41 ,58) 2,4486	(40 ,58) 2,4486	(39 ,58) 2,4586	(38 ,58) 2,4586	(37 ,58) 2,4687
S11	-12,83	-12,97	-12,74	-12,15	-11,12	-12,15	-12,37	-13,07	-13,18	-14	-14,04	-14,37	-15,42	-16,66
BW	35	38,8	38,1	37,6	36,5	35,8	39,7	34,9	34,4	35,3	40,6	48,4	51,5	59,9
Gain	3,46	3,46	2,47	2,53	3,53	2,52	2,69	2,79	2,89	2,9	3,08	3,07	3,13	3,44
Directivity	6,67	6,49	6,44	6,53	6,38	6,36	6,31	6,21	6,18	6,11	6,09	5,64	5	5
Efficiency	51,87	53,31	38,35	38,74	55,33	39,62	42,63	44,93	46,76	47,46	50,57	54,43	62,60	68,80

Fig. 15. Radiation characteristics Evolution in the seconde case [Changing x-dimension from 49 mm to 37 mm with y-dimension fixed at 58mm]



	(49 ,66) 2,4181	(49 ,65) 2,4181	(48 ,65) 2.4181	(47 ,65) 2.4181	(46 ,65) 2,4185	(45 ,65) 2,4185	(44 ,65) 2,34	(43 ,65) 2,4085	(42 ,65) 2,4035	(41 ,66) 2,4035	(40 ,65) 2,4185	(39 ,65) 2,4185	(38 ,65) 2,4236	(37 ,65) 2,4286
S11	-12,83	-13,07	-11,09	-11,56	-12	-12,3	-12,34	-12,06	-12,03	-12,65	-12,13	-13,03	-13,14	-14,13
BW	35	35,59	36,2	34,1	33,4	33,9	27,7	26,3	26,6	36,8	40,8	40,4	42,9	55
Gain	3,46	3,47	3,48	3,45	3,46	3,5	3,5	3,54	3,51	3,63	3,67	3,62	3,64	3,63
Directivity	6,67	6,7	6,63	6,55	6,5	6,47	6,33	6,25	6,1	6,05	5,99	5,85	5,76	5,69
Efficiency	51,87	51,79	52,49	52,67	53,23	54,10	55,29	56,64	57,54	60,00	61,27	61,88	63,19	63,80

Fig. 16. Radiation characteristics Evolution in the first case [Changing x-dimension from 49 mm to 37 mm with y-dimension fixed at 65mm]

In all discussed parts in this parametric study, either along only the x-axis, or along the two axes x and y, the ground plan size has an impact on:

- The resonant frequency variation, which in one hand, varies in a large band [2.41GHz-2.52GHz] by acting on the x-dimension only, in the other hand, it varies slightly between 2.41GHz and 2.46GHz in the x and y axes dimensions analysis.
- The bandwidth, which has been significantly increased to a value above 100MHz in the first part of the study and up to 59MHz in the second part.
- The efficiency evolution, which is the same in both parts of the study. The value achieved is around 69%.

Moreover, the ground plane size was reduced to 60% from its initial size, consequently; we can talk about ground plane miniaturization.

4 Results Synthesis:

The main purpose of the study presented in this work, is:

- First, to approve and support the role of a DGS in improving radiation characteristics and adjusting the frequency behavior,
- Second, demonstrate that the DGS does not require complex periodic structures to achieve the desired antenna performances, and that the ground plane size reduction along the x-axis or both axes x and y may result in significant changes in radiation characteristics.

This parametric study was applied on an elementary patch antenna, adapted with notches and intended to operate in the microwave band [2.45GHz].

However, the antenna adaptation was reached at 2.41GHz with a return loss of -12.81dB and a bandwidth of 35MHz, and an efficiency around 50%.

In order to act on the frequency behavior to reach the exact frequency 2.45GHz, bandwidth and the other radiation characteristics, we reduced gradually the ground plane size.

In this regard, the ground plane size reduction was evalated in two parts:

⇨ **<u>The analysis according to the x-axis only:</u>**

In this section, many configurations were studied, by decreasing the x-dimension only.

Through analyzing the simulations results, as far as the size of the ground plane decreases according to the x-axis, the adaptation of the antenna (S11), bandwidth and efficiency were significantly enhanced.

It should be noted that, one of the aims of this study, was to bring back the desired resonant frequency to 2.45GHz. However, the resonant frequency was speedily increased from 2.41GHz to a value around 2.5GHz.

Therefore, we can note that the change in a rectangular ground plan size, according to x-axis can be widely used, if the rapid increase in the resonant frequency is set as the primary purpose of a given set of specifications.

⇨ **<u>The analysis according to the x and y axes at the same time :</u>**

In the second part of the study, we acted on the two dimensions x and y. Many configurations were studied.

As a result, the improvement of the antenna adaptation, bandwidth and efficiency is less significant in comparison with the first part of this parametric study. Whereas, in terms of frequency analysis, we notice that dimension reduction according to x and y-axes, can increase very slightly the resonant frequency reaching the correct frequency value (in our case 2.45GHz).

5 Conclusion

The impact of the size reduction of a DGS, on the MPA radiation characteristics has been studied in this work.

The increase of the resonant frequency from the initial size of the ground plane to a smaller size is significant for size decrease according to the x-axis only, and is quite significant along the two axes x and y.

Furthermore, the studied radiation characteristics, namely, the return loss, the bandwidth and the efficiency are improved as far as the DGS dimension decreases.

Hence, the use of DGS in the MPA structure broadened remarkably their field of application. Simple or complex DGS forms may adjust the antenna characteristics to the market requirements.

This study was applied on a MPA adapted with notches, and can be complemented by studying the effect of DGS dimension when slots are inserted in the radiating element.

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