Array Antenna Design with Dual Resonators 1D-EBG for Enhancement the Directivity and the Radiation Bandwidth

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***Abstract*-A dual resonators in a one-dimensional (1D) electromagnetic band gap (EBG) application into array antenna is investigated as a means to enhance the directivity and the radiation bandwidth. The Directivity increase significantly with number of patch using 1D-EBG; a directivity of 24.44dB is reached for array of 64 patches. Moreover, the radiation band undergone a slight change, there is increase by 1.38% compared to that of the mono-source excitation using 16 patches. To increase the radiation bandwidth of the array antenna, a dual resonators is used. The proposed antenna shows 3.45% enhancement as compared with a single resonator for an excitation using 64 patches. Otherwise, with a reduced number of patches (16 or 32 patches) the directivity becomes almost stable at about 20dB for the entire operating band. In addition, the amplitude of the back lobe decreased from 5dB for conventional mono-resonator to less than -5dB using the dual resonators.**

***Index Terms*- bandwidth enhancement, electromagnetic bandgap (EBG) structures, high directivity characteristics, patch antenna array, resonator EBG.**

I. INTRODUCTION

High directive antennas have attracted considerable interest recently, due to their properties to support the information at a great distance. The array antenna was considered to moderate the problem of the low gain of the antenna [1,2]. By means of the array excitation device, the directivity increase significantly compared to the mono-source case, but the lateral lobes remain rather important, which disperses the transmitted energy and minimizes their intensity to radiate in the preferred direction [3]. An Electromagnetic bandgap (EBG) resonator is a very important way to increase the directivity of antenna; which called EBG antenna [4-7]. In these antennas, the EBG structures is typically placed a half wavelength above ground plane which carries the excitation source. The coupling between the EBG and the antenna properties create a highly directive radiation patterns. Unfortunately, there is a major disadvantage associated with EBG antenna: low radiation bandwidth, which seriously limits their usefulness [8].

In this paper, the bandwidth widening is achieved using an array antenna excitation device with a dual resonators EBG. Firstly, a high efficiency excitation antenna and the EBG resonator capable to provide a high directivity are presented. This step provides the essential information on the size of the array antenna. Secondly, the optimization resonant structure that capable to increase the radiation bandwidth is described. The method used shows that more the quality of the spatial filtering is improved, the frequency filtering is selective, i.e. the bandwidth decreases as a function of the quality factor [9]. In other, a very selective resonator cant offer these qualities over a wide frequency range. The objective is to reduce the quality factor of the resonator to increase the bandwidth radiation while keeping the quality of the spatial filtering.

II. ARRAY ANTENNA DESIGN

The antenna design is based in a micro strip technology and is chosen to operate on the WLAN band frequency, which has the advantage

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of a working frequency of 5.8GHz and which allows a realization neither too cumbersome nor too difficult to make. The antenna is printed on a FR4 substrate with a thickness of 1.6mm, a dielectric permittivity $\varepsilon_r = 4.4$ and a loss tangent $\delta = 0.02$. The antenna is excited using a 50Ω feed line, and the inset technique for adaptation. The geometry of the patch antenna with its dimensions are shown in Fig.1. The design parameters are optimized by HFSS software, there are chosen to have a real part of the input impedance in the vicinity of 50Ω around the operating frequency 5.8GHz, and an imaginary part almost nil to allow an acceptable adaptation (see Fig.2). All the parameters values are shown in the table 1.

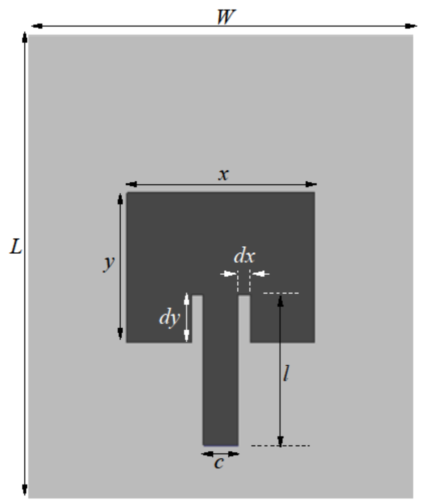

Fig.1 Geometry of mono-source patch antenna

Table 1: Design parameters and its values in mm

W	L	x	y	c	l	dx	dy
33.2	37.1	16	10	3	12	1	3.7

The antenna was designed by a set of simulation with HFSS software; the Fig.2 shows that the operating bandwidth of the antenna is 200MHz around the frequency 5.8GHz. Generally, the maximum directivity for a simple patch antenna do not exceed 7dB at the resonance frequency [10]. The array antenna is classically method used to improve the directivity.

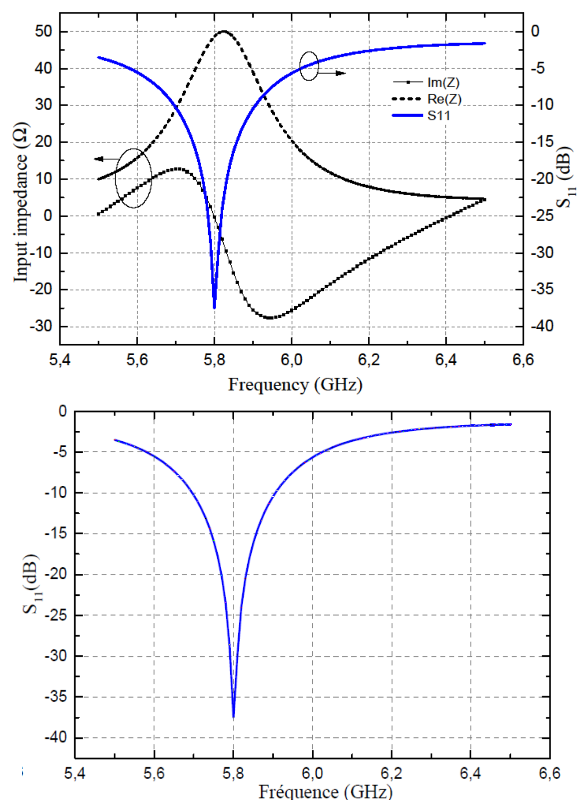

Fig.2 Reflection coefficient and input impedance

To ensure that the power is distributed in an equivalent manner in each branch of the network, the Wilkinson divisor model is used [11-13], is a typical collective supply structure designed to provide amplitude and excitation phase equivalent to each patch. The network made up of a substrate FR4 with a thickness of 1.6mm and a surface 270x270mm^2, and consists of 63 power dividers arranged to form a 64-way network. For each power divider, a quarter wavelength is used to splits an input signal into two equal phase output.

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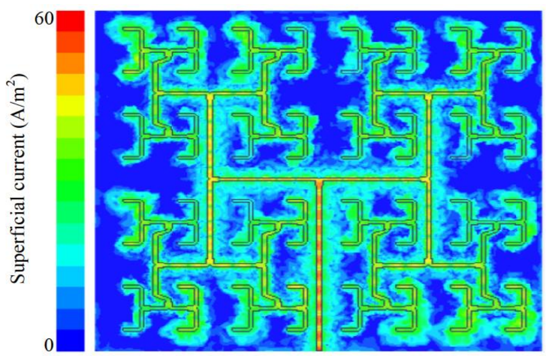


Fig.3 Surface current distribution of the network

The Fig.3 represents the surface current distribution of the network and the proposed array antenna. This figure shows that the surface current distribution is equally distributed in each branch of the network at 5.8GHz. This network is used to distribute the power to design an antenna array of 8x8 patches (see Fig.4), the patch spacing corresponds to $0.77\lambda_0$ in both directions x and y, with λ_0 is the free space wavelength at 5.8GHz. The patch sizes are shown in Table 1.

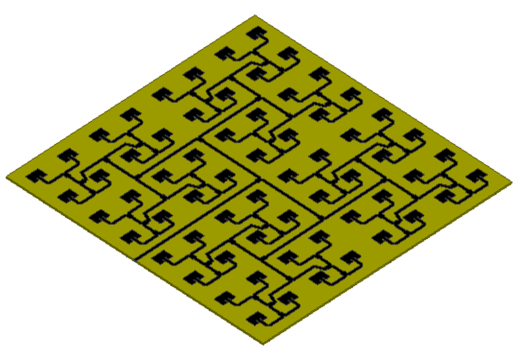


Fig.4 Array antenna design

The antenna has been designed to operate in the WLAN band for mobile phone base stations. The Fig.5 shows the reflection coefficient, it is observed that the antenna is adapted.

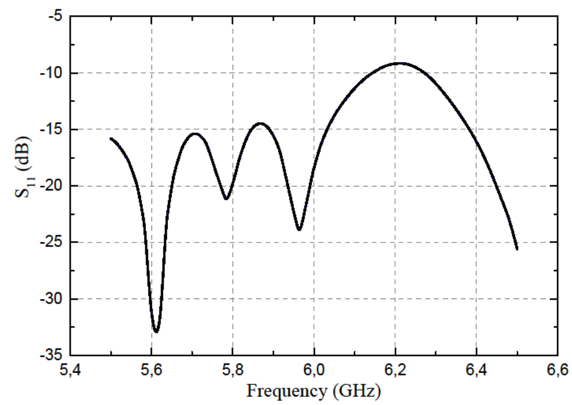
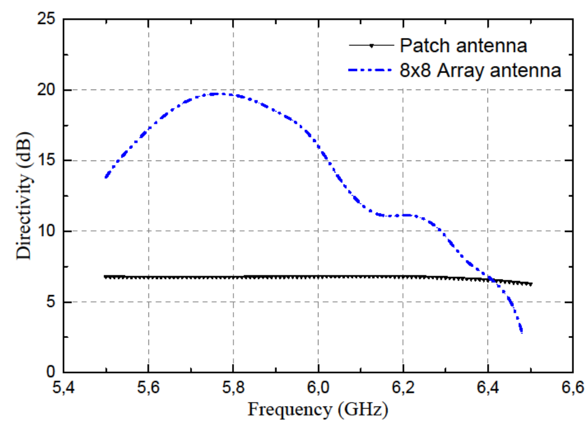
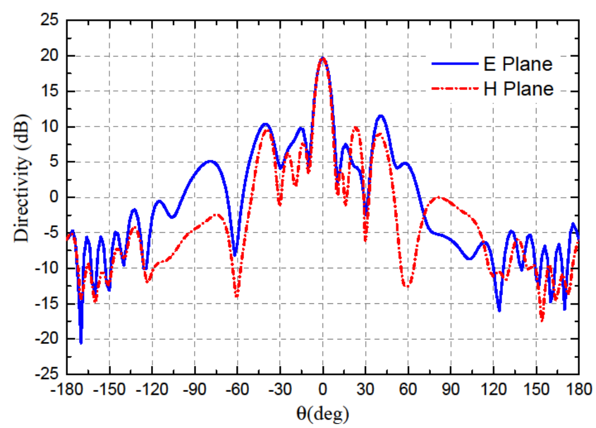


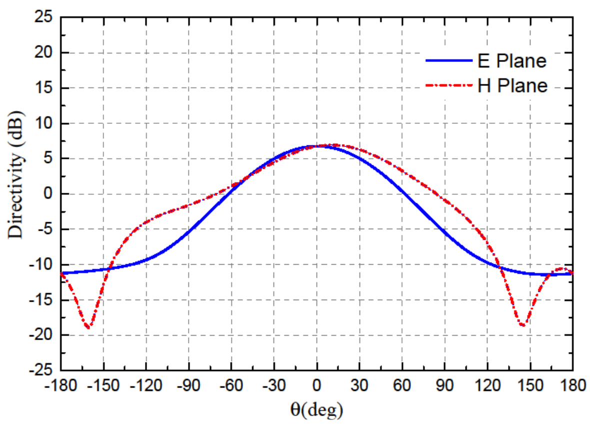
Fig.5 Array antenna characteristics: S_{11}



(a) Directivity



(b) Array antenna (5.8GHz)



(c) Conventional patch antenna (5.8GHz)

Fig.6 Radiation pattern characteristics

The radiation pattern of the proposed array antenna for the elevation and the azimuth planes are illustrated in Fig.6. The directivity of the antenna can be increased in a significant way with multi-source excitation, a 20dB is obtained with 64 patches. As a large number of sources generate mutual couplings between these radiating sources, which are responsible for high side lobes and surface waves. So, the radiation pattern exhibits dispersive behavior because of the antenna sensitivity described by the higher power of the side lobes.

III. EBG STRUCTURE ANALYSIS AND CONFIGURATION

The one-dimensional electromagnetic band gap structure consists of stacking two layers of materials with different permittivities with the periodicity in one direction [14-17]. There are forbidden bands if the thicknesses of each layer are equal to a quarter of the guided wavelength. The proposed EBG structure consists of alternating NELTEC layers whose relative constant is $\varepsilon_r = 2.6$, the loss tangent $tg\delta = 0.002$ and others of air. This structure is illustrated in Fig.7.

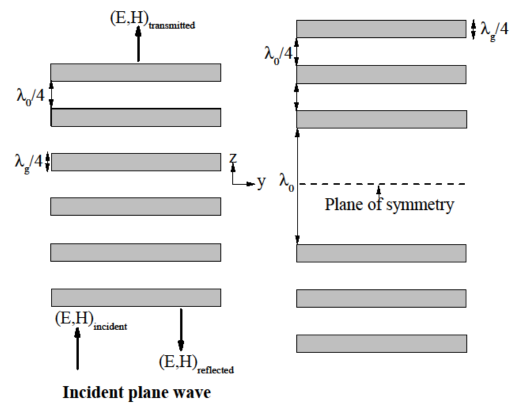


Fig.7 The 1-D periodic EBG structure

Generally, For a linear medium, according to the resolution of Maxwell's equations, it is found that for the i^{th} layer:

$$\begin{bmatrix} E_{i-1} \\ B_{i-1} \end{bmatrix} = \begin{bmatrix} cos(\delta_i) & j\dfrac{sin(\delta_i)}{\gamma_i} \\ j\gamma_i sin(\delta_i) & cos(\delta_i) \end{bmatrix} \begin{bmatrix} E_i \\ B_i \end{bmatrix} \quad (1)$$

Thus,

$$\begin{bmatrix} E_{i-1} \\ B_{i-1} \end{bmatrix} = M_i \begin{bmatrix} E_i \\ B_i \end{bmatrix} \quad (2)$$

$(\vec{E}_i, \vec{H}_i)$ the incident electromagnetic field in i^{th} layer.

The global transfer matrix corresponding to the entire structure (an N-layers stack, see Fig.7) is the product of the particular transfer matrices M_i of each layer:

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \prod_{i=1}^{n} M_i \quad (3)$$

Therefore,

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$$M_i = \begin{bmatrix} cos(\delta_i) & j\dfrac{sin(\delta_i)}{\gamma_i} \\ j\gamma_i sin(\delta_i) & cos(\delta_i) \end{bmatrix} \qquad (4)$$

Where $\delta_i = ak_i$ and $\gamma_i = \dfrac{k_i}{\omega}$.

In the case of the normal incidence $k_i = (\dfrac{\omega}{c})n_i$, where $n_i = \sqrt{\varepsilon_{r,i}}$ is the refraction index of the i^{th} layer, a is its thickness and c is the celerity of the light in the vacuum.

In this stack:

$$\begin{bmatrix} E_0 \\ B_0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} E_n \\ B_n \end{bmatrix} \qquad (5)$$

The tangential components of the electromagnetic field are continuous in the last interface of the periodic structure. Therefore,

$$\begin{cases} E_n & = E_{n+1} \\ H_n & = H_{n+1} = \dfrac{1}{\eta_{n+1}} E_t \end{cases} \qquad (6)$$

Since the structure is excited only from one side, the field after the last interface will contain only the transmitted component (E_t, H_t).

$$\begin{cases} E_{n+1} & = E_t \\ H_{n+1} & = H_t = \dfrac{1}{\eta_{n+1}} E_t = \dfrac{1}{\eta_0} E_t \end{cases} \qquad (7)$$

At the incidence interface, the tangential component of the electric and magnetic fields are continuous:

$$\begin{cases} E_0 = E_{i0} + E_{r0} \\ H_0 = \dfrac{1}{\eta_0}(E_{i0} - E_{r0}) \end{cases} \qquad (8)$$

According to the equations (eq.7 and eq.8), the matrix (eq.5) is written as follows:

$$\begin{bmatrix} E_{i0} + E_{r0} \\ \Gamma_0 (E_{i0} - E_{r0}) \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} E_t \\ \Gamma_0 E_t \end{bmatrix} \qquad (9)$$

Where $\Gamma_0 = \dfrac{n_0}{c}$, n_0 is the refractive index of medium at the edges of the unit cell. In the studied case, $n_0 = 1$. And $\eta = \sqrt{\dfrac{\mu}{\varepsilon}}$ the characteristic impedance of the medium.

Noted $E_i = E_{i0}$ and $E_r = E_{r0}$, the expressions of E_t and E_r are given by the following equation:

$$\begin{cases} E_t & = \dfrac{2\Gamma_0}{m_{11} + \Gamma_0^2 m_{12} + m_{21} + \Gamma_0 m_{22}} E_i \\ E_r & = \dfrac{\Gamma_0 m_{11} + \Gamma_0^2 m_{12} - m_{21} + \Gamma_0 m_{22}}{\Gamma_0 m_{11} + \Gamma_0^2 m_{12} + m_{21} + \Gamma_0 m_{22}} E_i \end{cases} \qquad (10)$$

The diffracted waves are characterized by the transmission and the reflection coefficients. The Fig.7 illustrates the method used to calculate the transmission coefficient T and the reflection coefficient Γ. To calculate the transmission coefficient, the observation point is placed in the area of the transmitted field behind the periodic structure. In addition, to obtain the reflection coefficient, the observation point is placed in the area of the reflected field between the excitation and the structure as shown in Fig.7.

The transmission coefficient of a periodic structure corresponds to the ratio between the amplitude of the transmitted and the incident waves:

$$T = \frac{E_{transmitted}}{E_{incident}} \qquad (11)$$

And the reflection coefficient is the ratio between the amplitude of the reflected and the incident waves:

$$\Gamma = \frac{E_{reflected}}{E_{incident}} \qquad (12)$$

According to (eq.12) the transmission and the reflection coefficients for the entire stack of layers are written:

$$T = \frac{2\Gamma_0}{\Gamma_0 m_{11} + \Gamma_0^2 m_{12} + m_{21} + \Gamma_0 m_{22}} \qquad (13)$$

$$\Gamma = \frac{\Gamma_0 m_{11} + \Gamma_0^2 m_{12} - m_{21} + \Gamma_0 m_{22}}{\Gamma_0 m_{11} + \Gamma_0^2 m_{12} + m_{21} + \Gamma_0 m_{22}} \qquad (14)$$

If a resonator (or defect) of λ_0 corresponding to the operating frequency (5.8GHz) is created in the middle of the EBG structure as shown in Fig.7, a narrow transmission band is formed at the center of the band gap as shown in Fig.8. This property of transmission is used to create the directive antenna.

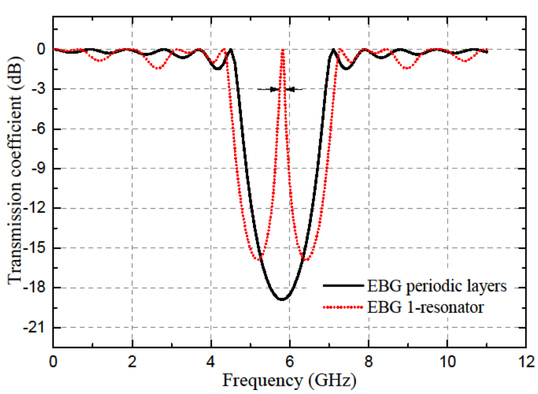
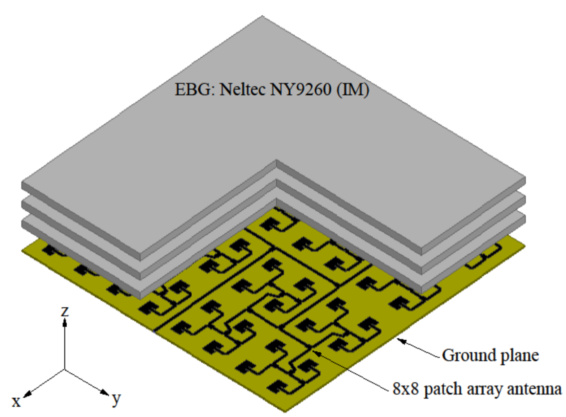


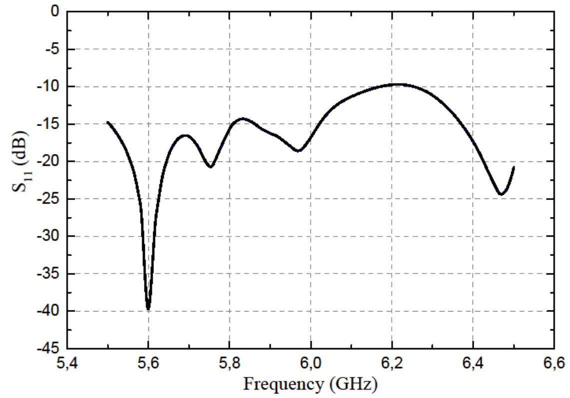
Fig.8 Transmission coefficient of the EBG structure

IV. EBG ANTENNA CONFIGURATION

The plane of symmetry presented in Fig.7 can be replaced by a metallic plane (or a ground plane), because the mapping of the electric field shows a cancellation of the tangential E field component at this plane of symmetry [18]. Thus, by applying the theory of electrical images, the behavior of the half-structure above the ground plane is equivalent to that of the EBG structure with defect.
At the level of the ground plane, a source of excitation is placed; that can be one or more patches, dipoles, slots, a horn, a waveguide or also an array of that one. The antenna obtained is called a EBG antenna. The EBG antenna consists of a ground plane containing a excitation array patch is placed at the symmetry plane of the EBG structure in middle of the defect which is described by Thevenot et al. [8]. The Fig.9(a) illustrates the 1-D EBG array antenna, it's composed of an excitation source shown in Fig.4 accompanied by three dielectric layers of Neltec NY9260 with thickness of 8mm positioned at height of 26.4mm from the ground plane.



(a)



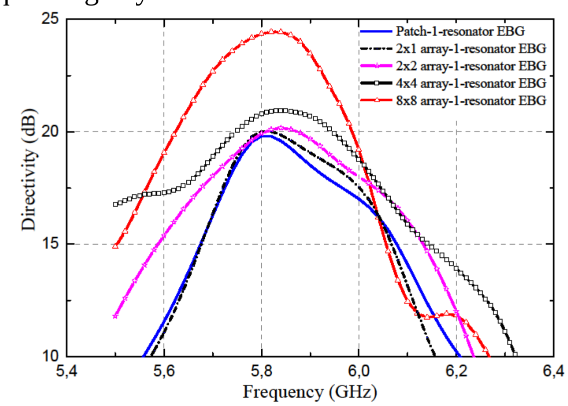
(b)

Fig.9 1-D EBG array antenna: (a) antenna de configuration, (b) reflection coefficient

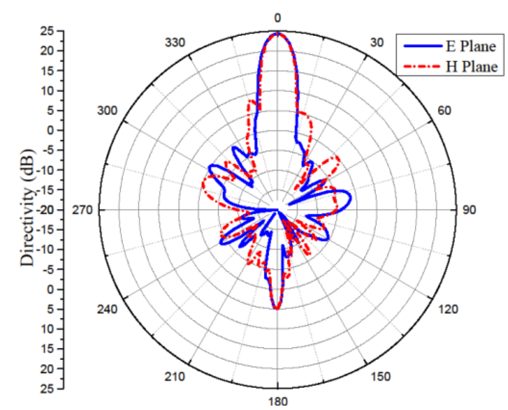
The Fig.9(b) shows the reflection coefficient of the EBG array antenna, it shows that the antenna is adapted and covers the entire objective WLAN band.

The Fig.10(a) shows that the EBG resonator accompany with array antenna increases the directivity significantly. It has been shown that there is a relationship between the maximum gain value and the gain bandwidth that depends on the properties of the EBG material (number of layers, dielectric constant and nature of resonator [19]). It can be seen that for the same inter-source distance, the directivity increases when the number of sources increase, a value of 24.5dB is achieved using 64 patches. The results show that the global antenna has a very narrow radiation bandwidth, which limits their utilization.
However, the radiation bandwidth increases by 1.4% using 16 patches compared with that of a mono-source excitation which does not exceed 5%. The radiation bandwidth is represented by the percentage of band at -3dB with respect to the maximum directivity at the operating frequency.

The Fig.10(b) shows that the EBG structure properties creates a highly directive radiation pattern compared to the conventional antenna, the of role EBG resonator is to realize both the frequency and the spatial filtering. But the radiation pattern shows that the back lobe remains quite high by 5dB.



(a)



(b)

Fig.10 1-D EBG array antenna characterization: (a) directivity and (b) radiation pattern for 8x8 patches at 5.8GHz

V. RADIATION BANDWIDTH ENHANCEMENT USING DUAL RESONATORS EBG

In this section, the dual resonators array antenna with high directivity and a wide radiation bandwidth is presented.
The proposed antenna has been designed to operate at the WLAN band for mobile phone base stations.

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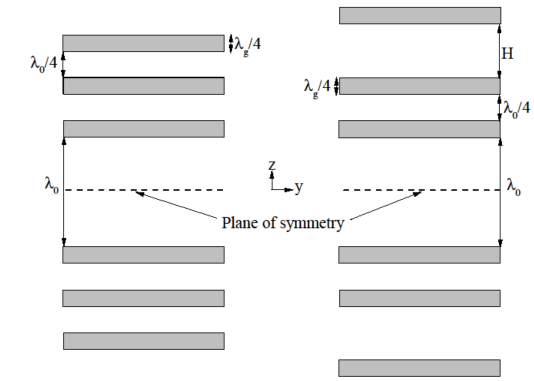
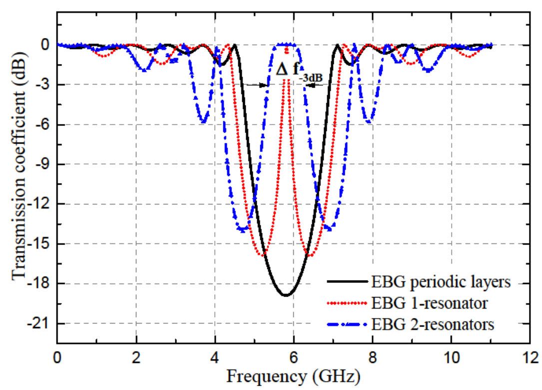
The design is dedicated to the antenna which have low side lobes, good impedance matching and a directivity reasonably constant with high value over the specified operating bandwidth.

A method to increase the bandwidth radiation by means of the dual resonators EBG instead of a single resonator is described here. Therefore, by changing the quality factor of the resonator through the properties of the EBG structures (number of dielectric layers, material dielectric constant or interlayer distance), the width of the bandwidth will be modified. To explain the improvement of the bandwidth, the transmission coefficient in normal incidence on the EBG structure using a dual resonators configuration is compared to that of a mono-resonator EBG structure. If a resonator of λ_0 corresponding to the operating frequency (5.8GHz) is created in the middle of the EBG structure as shown in Fig.7, a narrow transmission band is formed at the center of the band gap. The Fig.11(a) represents a new configuration of the EBG structure where a second resonator is added at the extremities of the structure. The external resonator controls the external coupling, while the middle resonator is used to control the spatial and frequency filtering at the operating frequency. The transmission coefficient through the two structures is shown in Fig.11(b), it shows that through the use of multi-resonators, the transmission bandwidth at 3dB increases from 1.97% (mono-resonator) to 16.13% (multi-resonator), while the quality factor Q (Eq. 15) decreases from 294.4 to 35.95.

$$Q = \frac{f_r}{\Delta f_{-3dB}} \qquad (15)$$



(a)



(b)

Fig.11 Dual 1-D EBG characterization: (a) design (b) S-parameters

In the same way, this dual-resonators structure has a plane of symmetry, where the tangential electric field is nil (see Fig.11(a)). The ground plane, which carries the multi-sources excitation is introduced at this plane of symmetry, the dual resonators EBG array antenna is obtained and illustrated in Fig.12.

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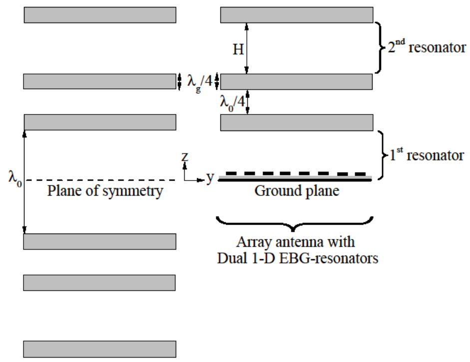


Fig.12 Dual 1-D EBG array antenna

The reflection coefficient of the proposed antenna is illustrated in Fig.13. There is a good agreement between the simulated results obtained by CST and HFSS software.

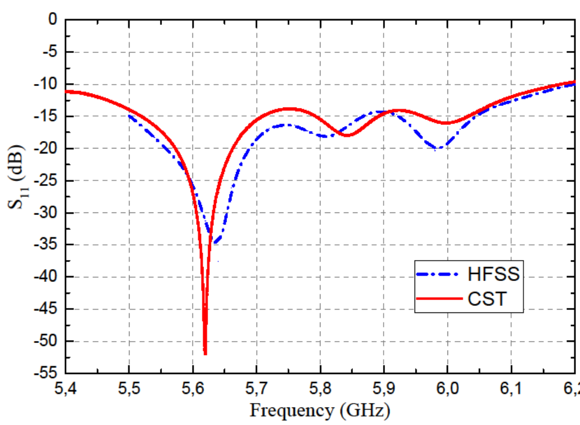
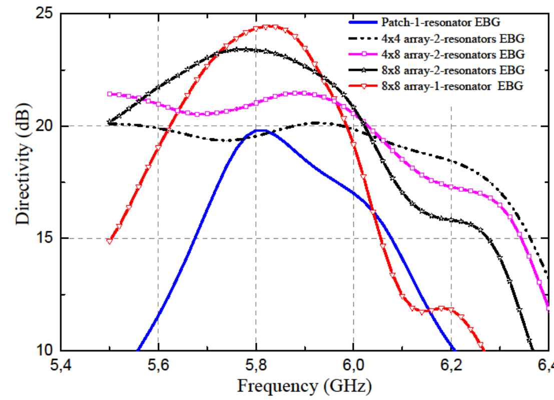
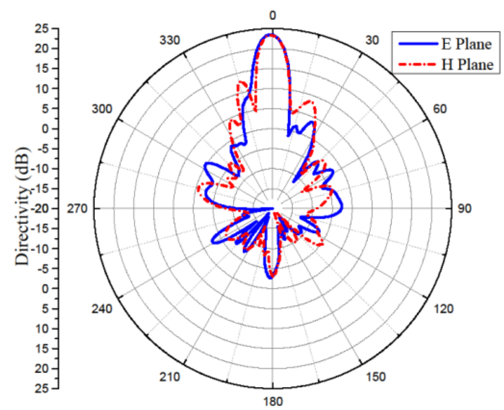


Fig.13 S-parameters of dual 1-D EBG array antenna

The Fig.14(a) shows that the use of the dual-resonators increases the directivity significantly, we achieved a value of 23.5dB and at the same time the radiation bandwidth increases by 3.45% for an excitation composed of 64 patches compared to that of a single resonator. However, for a reduced number of patches (16 or 32 patches), we have shown that approximately at 20dB, the directivity becomes almost stable for the entire operating band.



(a) Directivety



(b) Radiation pattern

Fig.14 Dual 1-D EBG characterization

In Fig.14(b), it can be seen that the back lobe amplitude is decreased by 10dB compare with that used the conventional mono-resonator. So, the dual-resonator has a typically required additional advantage that makes it better used.

VI. CONCLUSION

In this paper, the enhancement method of the directivity and the radiation bandwidth is disrobed and discussed. Its shows that possible to obtain a high directivity using electromagnetic band gaps with mono-source excitation, but remaining in a limited application because of the very narrow bandwidth. The resonators EBG array antenna is advantageous for simultaneously increasing the directivity and the radiation bandwidth. This increase depends on the number of sources and their spacing. Thus the dual resonators structure has a typically required additional advantage which makes it better used with respect to conventional mono-resonator EBG structure by means the directivity approximately stable into all the operating frequency.

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