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Design, Finite Element Analysis and Implementing a Reconfigurable Antenna with Beam Switching Operating at ISM Band

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Abstract—A new radiation pattern reconfigurable antenna is designed and fabricated. The antenna is able to radiate in four orthogonal directions in the azimuth plane and sweep the whole azimuth. The radiation pattern reconfigurability is obtained using the passband and stopband characteristics of EBG surfaces which are used to form EBG panels to surround the feeding dipole centered in the structure. Switching between passband and stopband is implemented using active elements in the structure.

1. INTRODUCTION

Nowadays, reconfigurable antenna is one of the topical research subjects in the area of antennas and propagation; different approaches have recently been under investigation to add reconfigurability option to conventional antennas. So far, many reconfigurable antennas have been reported in the literature among which frequency response, polarization and radiation pattern are the main aspects of reconfigurability [1]. Radiation-pattern reconfigurability which is the subject of this paper has found many applications in base-station antennas [2]. Different techniques can be used to make an antenna radiation pattern reconfigurable. In the proposed antenna, an electromagnetic bandgap (EBG) structure is a key tool to achieve reconfiguability. EBG structures are periodic structures that have the merit of creating passband and stopband. Since EBG structures allow RF waves to go through them in their passband and avoid the RF waves to go through them in their stopband, finding a way to control the operating band of an EBG structure in a certain frequency is the main idea of using EBG structures in radiation pattern reconfigurable antennas. It is reported that creating defects in an EBG structure can change the operating band of that structure in a certain frequency [3, 4]. Using active elements as diodes in such a structure enables us to control the defects electronically and consequently controlling the behavior of the EBG structure.

In this paper, a radiation pattern reconfigurable antenna is proposed which controls the beam direction using active elements in an EBG structure. The antenna operates at 2.45 GHz. This antenna switches its radiation beam in four different directions, which scans the azimuth plane with 90 degrees steps. The dimension of the EBG structure is optimized to achieve a high gain. In order to obtain the best possible bandwidth, a wideband dipole is also designed to be used as the source of the EBG antenna. To examine the performances of the proposed antenna, simulations and experimental measurements are carried out, and they show a good agreement. In the following sections, the design of the antenna and the obtained results are presented and discussed.

2. ANTENNA DESIGN

The design process of the antenna consists of two main tasks; first designing a right feeding element and then designing a mechanism to enable the antenna reconfigure in a way to radiate in four orthogonal directions in the azimuth plane.

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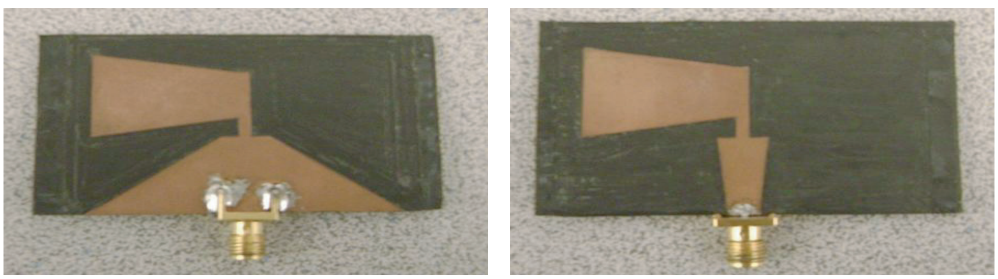
A wideband dipole is designed to fulfill the essential omnidirectionality and the required bandwidth of the excitation element. Also, a cubic cavity is designed for the reconfiguration purpose with two layers of a 2D EBG structure on four side surfaces of the cube and two PEC surfaces on the top and the bottom of the cube. PIN diodes are used as active elements to electronically implement the reconfiguration of the antenna. In the following sections, details of the two designing steps are elaborated.

2.1. The Excitation Element

In this design, a printed dipole is used as excitation for the EBG reconfigurable antenna. The dipole is designed by using a double-sided printed antenna etched on both sides of a dielectric substrate. Bow-tie technique is used to increase the bandwidth of the antenna [5]. So the radiator is actually a balanced radiator consisting of two triangular arms in the two different sides of a substrate. Since the feeding of the antenna is supplied by an unbalanced coaxial connector, the transition from this unbalanced connector to the balanced twin lines of the dipole is implemented using a linear microstrip taper. This taper plays the role of a balun in this structure [6]. The dipole is fabricated using both sides of the fabricated dipole and shown in Fig. 1.



(a) (b)

Figure 1. The front side and back side of the fabricated feeding dipole.

2.2. Reconfigurability Mechanism

Reconfiguration of the proposed antenna in order to radiate in different directions is implemented with the aid of the passband and stopband characteristics of EBG structures. The cubical cavity surrounding the antenna is formed of four EBG panels and two metallic surfaces. Each of the four EBG panels, which are forming the sides of the cube, consists of two parallel EBG surfaces. Each of these surfaces has thirteen parallel strip lines printed on it. These strip lines are basically discontinuous. Some PIN diodes are soldered in these discontinuities as active elements. Presence of diodes in each EBG surface guarantees two different behaviors of the structure in the operational frequency of the antenna, i.e., switching the diodes ON creates an EBG surface with stopband at the operational frequency, and switching the diodes OFF creates an EBG structure having its stopband at the same frequency. The surfaces with the stopband reflect the fields radiated by the excitation element while the surfaces having their passband in the operating frequency let the fields transmit through the surface. Now by switching the diodes ON for three EBG panels makes the antenna radiate in the direction of the fourth panels with OFF diodes. This mechanism guarantees the control of the radiation pattern electronically. In order to switch the diodes in the antenna and basically altering the radiation direction of the antenna, a control unit is designed using SCHNEIDER smart relay programmed by ZELIO [7, 8].

3. ANTENNA'S CONFIGURATION

As mentioned in Section 2, the proposed antenna has an omnidirectional feeding element in its center, which is a wideband printed dipole. Table 1 gives the dimensions of the feeding dipole. This feeding element is located in the middle of a cube-shaped structure, which is formed of four EBG panels and two metal sheets at the top and bottom as shown in Fig. 2. Each EBG panel is composed of two layers of EBG surfaces. The EBG surfaces are made of parallel discontinuous strips, where diodes are located in the discontinuities between the strips. The unit cell of the EBG surface is shown in Fig. 4. Each strip line is made of nine unit cells. The inner layer of each panel has eleven parallel strips while the outer layer has thirteen parallel strips. Table 2 gives the dimensions of the proposed antenna. The diodes used in this structure are modeled like a resistance of 2 Ω in the ON state, and they are modeled with a parallel combination of a 30 KΩ resistor and a 150 fF capacitor in their OFF state.

The unit cell of the proposed antenna is simulated by the finite element method in [9] and [10],

Table 1. Parameter values of the feeding dipole.

Parameter	Value (mm)	Description
D	50	Overall length of Dipole
W	18	Large side of triangle
W	10	Small side of triangle
$W1$	8	Balanced taper's end width
$W2$	2	Parallel strip width
Ws	49	Ground plane width
Wf	4.9	Unbalanced taper's end width
L	4	Parallel strip's length

Table 2. Parameter values of the proposed antenna.

Parameter	**Value**	**Description**
$R1$	1.6666 mm	Distance between 2 strip columns
$R2$	1.6666 mm	Distance between 2 layers
$L1$	150 mm	The Height of the structure
$L2$	200 mm	The length of the structure
Sw	2.25 mm	Width of the strip
$W1$	200 mm	Metallic plate's width
G	1.5 mm	The junction gap of the diode
Cj	150 fF	Diode's Junction Capacitance

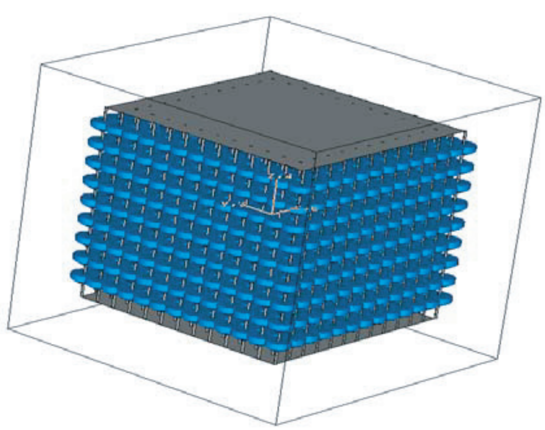


Figure 2. The overall shape of the proposed antenna.

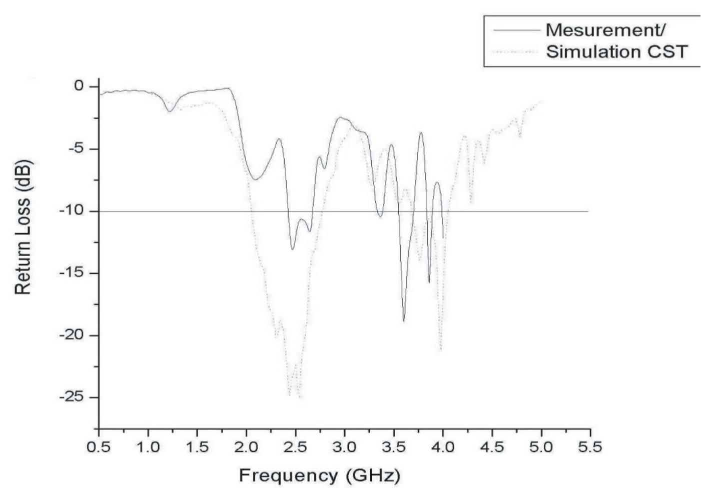


Figure 3. Simulation and measurement result for there turn loss of the proposed antenna.

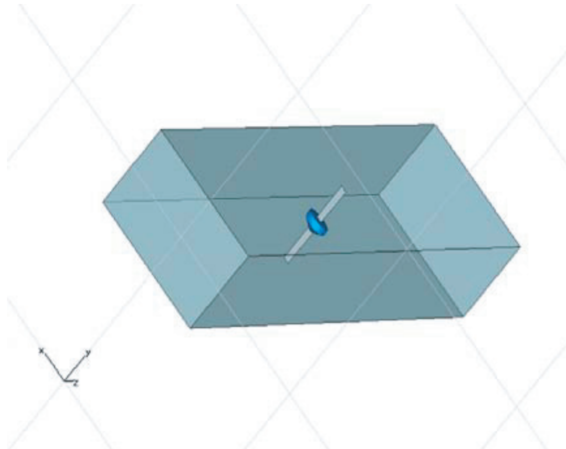


Figure 4. A unit cell of the proposed EBG structure.

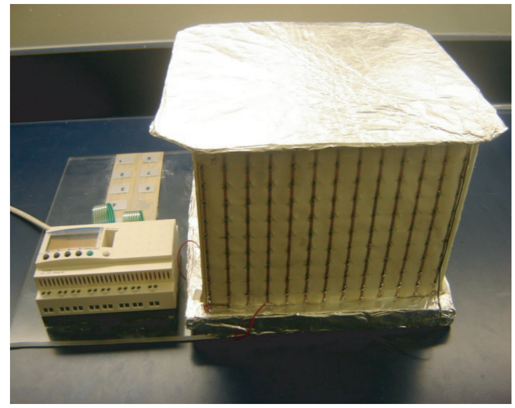


Figure 5. The fabricated EBG antenna.

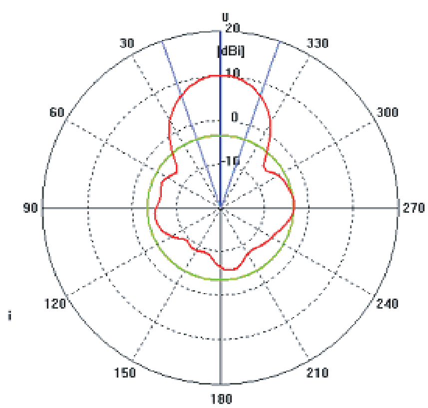


Figure 6. Radiation pattern — H-plane (simulation).

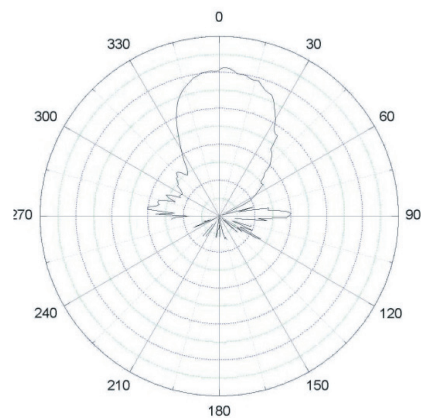


Figure 7. Radiation pattern — H-plane (measurement).

and the overall structure is simulated by the full wave FE solver of CST software [11]. The simulation results for return loss and radiation pattern are depicted in Fig. 3 and Fig. 6, respectively. Fig. 3 shows that the antenna has an impedance bandwidth from 2.4 GHz to 2.7 GHz, which covers the whole ISM band. Fig. 7 shows the radiation pattern of the antenna in the H-plane at 2.45 GHz. A gain of 10.2 dB is achieved. The experimental results for the proposed antenna are presented in the next section.

The radiation pattern which is reported either for the simulation or for the measurement results belongs to the state in which the diodes on one side are all switched off when all the other diodes on the three other sides are all staying on. The symmetry in the cubic periodic structure guarantees the reconfigurability of the radiation pattern which makes the reporting on one of the four possible situations enough to prove the point in characterizing the beam scanning merit of the structure.

4. EXPERIMENTAL RESULTS

The proposed antenna is fabricated in an RF Lab at INRS. A substrate with a thickness of 0.05″ and permeability of 3 is used to build the EBG surfaces. The diodes used in this structure are GMP4201-GM1. The reason for using this model of diode is its low junction capacitance, which is as small as 150 fF. The small junction capacitance of the diode guarantees the transparency of the radiating side of the antenna, which has diodes in OFF state [3]. Fig. 5 shows the fabricated structure and designed control unit to switch the diodes between ON and OFF states. The feeding element is placed at the middle of the structure and is not visible in this picture.

The S parameters of the fabricated prototype are measured with 8722ES Agilent Network Analyzer. Fig. 3 shows the measured return loss of the antenna. As seen, the bandwidth of the antenna is wider in measurement than in the simulations. The reason for this phenomenon is that in the simulations the junction capacitance of the diode is considered 150 fF, which is the worst case, and in reality it is between 50 fF and 150 fF. As reported in [3], the effect of the junction capacitor in PIN diodes used in EBG structures has been investigated.

The radiation pattern of the structure is measured in an anechoic chamber at an RF lab, INRS, and the measured pattern at 2.45 GHz in the H-plane is shown in Fig. 7. From this, it can be observed that the proposed antenna can provide a directive pattern.

5. CONCLUSION

In this paper, a reconfigurable antenna which operates at ISM band is proposed, which is based on EBG materials. The antenna scans the elevation plane with a 90-degree step. The antenna is composed of an omnidirectional feeding element surrounded by a two-layer EBG structure. The configurability in the proposed antenna is achieved by using diodes in the EBG surfaces of the EBG structure. Switching the diode creates a defect in the EBG surfaces, which changes the functionality of EBG surfaces from stopband to passband. The antenna radiates in the direction of the EBG surface with OFF diodes. The antenna is simulated and fabricated. The simulated and experimental results show a good agreement.

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