A Frequency Reconfigurable E-shaped Antenna with Fork-like EBG Structure

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Abstract- In this paper, a frequency reconfigurable E-shaped Patch antenna with fork like Electromagnetic Band Gap (EBG) structure is proposed. PIN diode is used to achieve the frequency reconfiguration mechanism. The proposed antenna resonates at 3.8 GHz when the PIN diode is ON and resonates at 2.2 GHZ when the PIN diode is OFF. Fork like EBG structure is integrated with antenna in order to enhance performance parameters like Gain, Radiation Pattern, Directivity, Return Losses and Specific Absorption Ratio (SAR). HFSS software is used to simulate antenna design. Simulated and measured results are compared and found with good agreement. Gain is improved by 2.88 dB with EBG structure as compared to without EBG. Further, by calculating the average SAR value of the antenna, it is observed that the proposed antenna radiation is under the radiation limits and hence not hazardous for the human beings.

Keywords – Patch Antenna, Electromagnetic Bandgap Gap Structure, Reconfigurable Antenna, PIN Diode, VSWR, Specific Absorption Rate.

I. INTRODUCTION

The electromagnetic-bandgap (EBG) structures are defined as artificial periodical structures that prevents propagation of electromagnetic waves in a specific frequency bands. Due to bandgap structure of EBG, surface wave propagation gets suppressed when antenna is integrated with EBG structure. Since surface waves suppress, antenna gain increases and also back radiation reduces [1]. Different shapes of EBG structures are integrated with antenna to improve parameters [2]. Also, now a days, reconfigurable antennas are in demand. The reconfigurable antenna dynamically adjusts its characteristics like Polarization, frequency, Radiation pattern or the combination of either [3]. Reconfigurable antenna has ability to change its operating frequency or frequency bands by changing its structure. The structure can be changed by using switches like PIN diodes, Varactor diodes and MEMS switches. A reconfigurable antenna is the most suitable option to obtain the wide bandwidth by using its ON and OFF switching conditions. In this paper, E-shaped antenna is designed at 2.2 GHz frequency. Fork like EBG structure is designed and integrated with the proposed antenna [4]. Fork like EBG structure is designed as it is simple to design and compact in size. Due to EBG structure, gain, bandwidth, efficiency of the antenna is improved. SAR (Specific Absorption Rate) is reduced when EBG structure is integrated with antenna. The proposed antenna with EBG structure is reconfigured to operate it at another frequency 3.8 GHz. PIN diode is used to achieve frequency reconfiguration [5]. Advantages of the proposed antenna are miniaturization of structure, improved gain and reduced SAR value.
The sessions are organized as follows:
In section 2, design considerations of Fork like EBG structure and E-shaped antenna is discussed, in section 3, simulation results of the proposed antenna is presented, in section 4, measured results of the antenna are discussed followed by conclusion in section 5.

II. Design Considerations

2.1 *Design of E-shape Antenna*

With E shaped antenna, better bandwidth can be achieved than Rectangular and H-shaped Patch antenna [6]. Nowadays, the world is becoming very smart. Mobile phones, Communication systems are smart systems. To achieve this smartness, a compact size of the communication system is needed. To compact the structure of antenna, E-shaped antenna is used for various applications [7], [8], [9].

The expression for ε_{reff} is given by [10]

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

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given by

$$\Delta L = 0.412\,\frac{(\varepsilon_r + 0.3)(\frac{W}{h}+0.264)}{(\varepsilon_r - 0.258)(\frac{W}{h}+0.8)} \quad (2)$$

The effective length of the patch L_{eff} now becomes

$$L_{eff} = L + 2\,\Delta L \quad (3)$$

For a given resonance frequency f_o, the effective length is given by

$$L_{eff} = \frac{c}{2\,f_o\sqrt{\varepsilon_{reff}}} \quad (4)$$

For efficient radiation, the width W is given by

$$W = \frac{c}{2\,fo\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (5)$$

(a) (b) (c)

Figure. 1. a) E-shaped Proposed Antenna b) Simulation in HFSS c) Fork shaped EBG structure

E-shaped antenna is designed for 2.2 GHz with ground plane length 76mm and width 88mm.

2.2 *Fork shaped EBG structure*

The Tuning Fork shape of EBG structure gives better performance with respect to simplicity, compactness and band gap, hence it is used in proposed antenna design [11],[12]. The rectangular block for EBG has a dimension of 10 x10 mm. The prongs for this fork shaped EBG structure shown in figure 1(c) are 5mm in length and 1mm wide. Both the prongs are connected by a strip of the length 1.25 mm. The base line down to the prongs is 2 mm in length.

The central frequency of the bandgap is given in Equation 6 [13].

$$fo = \frac{1}{2\pi\sqrt{LC}} \quad (6)$$

Where $L=\mu_0\mu_r h$

$$C = \omega\varepsilon_0 \frac{\varepsilon_r + 1}{\pi} cosh\left[\frac{a}{g}\right] \quad (7)$$

where h - thickness of the substrate in mm, L - inductance in Henry, C - capacitance in Farad, ‘b’ is the period of the EBG structure, i.e., b=a+g, ‘g’ is the gap between two adjacent EBG patches, ‘a’ is the grid of the EBG patch as shown in figure 1 (c), h is the thickness of the substrate, L is the inductance, and C is the capacitance. Parameters μ0 and ε_0 are the permeability and permittivity of free space, respectively.

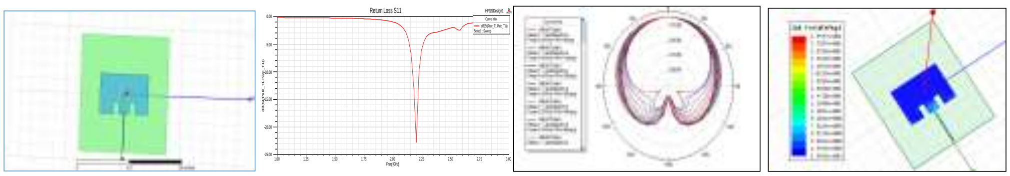
The bandwidth of the electromagnetic bandgap is given in equation 8.

$$BW = \frac{1}{\eta}\sqrt{\frac{L}{C}} \quad (8)$$

With these formulae, f_0 = 2.2 GHz and bandwidth is 2 GHz.

III. Simulated Result

3.1. *Design of E-shape antenna without EBG:*

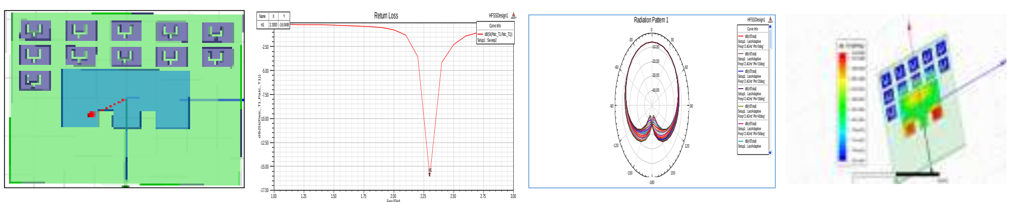


(a) (b) (c) (d)

Figure 2. (a) Simulated E-Shaped Antenna (b) Return Loss (c) 2-D Radiation Pattern (d) SAR value

E-shape antenna without EBG is simulated as shown in the figure 2 (a) and its SAR value

3.2 *E-shaped Antenna with EBG Structure:*

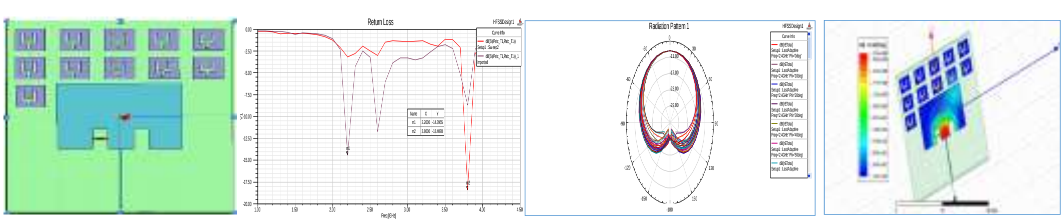


(a) (b) (c) (d)

Fig 3. (a) Simulated E-shaped Antenna with EBG (b) Return Loss (c) 2-D Radiation Pattern (d) Simulated value of SAR

Simulation results of E-shaped antenna without EBG and with EBG is shown in figure 2 and figure 3 respectively. SAR (specific absorption rate) is also simulated using HFSS. SAR is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue) [14]. Depending upon the SAR value, it can be observed whether the designed antenna is hazardous or not and also can conclude whether the radiation level are under limits as prescribed by TEC which should be less than 1.6 W/Kg. SAR value is 0.92W/Kg without EBG whereas it is reduced to 0.52W/Kg when integrated with EBG.

3.3 *E-shaped Reconfigurable Antenna with EBG Structure:*



(a) (b) (c) (d)

Figure 4. (a) Simulated E-shaped Reconfigurable Antenna with EBG (b) Return Loss (c) 2-D Radiation Pattern (d) Simulated value of SAR

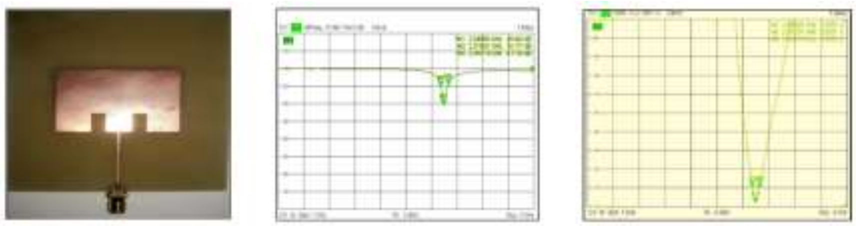
Reconfigured antenna with PIN diode is simulated as shown in figure 4. It is observed that antenna operates at 2.2 GHz when PIN diode is OFF and operates at 3.8 GHz when PIN diode is ON.

IV. Measured Results

Fabricated E-shaped antenna is shown in figure 5. Measured results of S11 and VSWR are shown in figure 5(b) and 5(c).

The proposed antenna is fabricated with fork shaped EBG and measured results are shown in figure 6 (a, b and c respectively). Reconfigurable antenna is fabricated with PIN diode and measured results S11 and VSWR are shown in figure 7 (a, b and c). The PIN diode so used to achieve the reconfiguration in frequency is BAP65-02.

4.1 *Fabricated E-Shaped Antenna:*



(a) (b) (c)

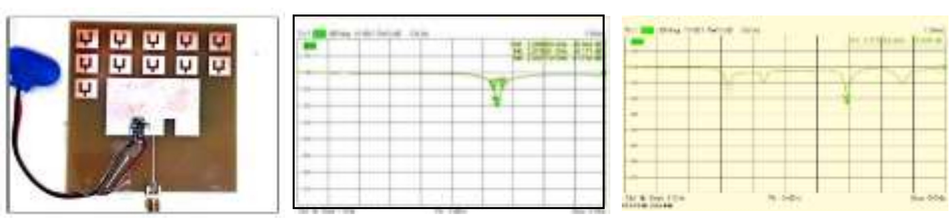
Figure 5. (a) Fabricated E-shaped Antenna (b) S11 Parameter (c) VSWR

4.2 *Fabricated E-shaped Antenna with EBG:*

(a) (b) (c)

Figure 6. (a) Fabricated E-shaped Antenna with EBG structure (b) S11 Parameter (c) VSWR

4.3 *Reconfigurable E-shaped Antenna with EBG:*



(a) (b) (c)

Figure 7 (a) Fabricated Reconfigurable antenna (b) PIN diode is OFF (c) PIN diode is ON

Table 1. Simulated and Measured values of E-shaped Antenna with and without EBG

Sr. No.	Parameter	Simulated Value without EBG	Simulated Value with EBG	Measured Value without EBG	Measured Value with EBG
1.	Frequency	2.2 GHz	2.2 GHz	2.29 GHz	2.29 GHz
2.	Return Loss	-22.56 dB	-16.24 dB	-20.84 dB	-15.6 dB
3.	VSWR	1.23	1.12	1.20	1.15
4.	Gain	1.81 dB	4.69 dB	-	-
5.	Bandwidth	40MHz	100MHz	38MHz	58MHz

From above table, it is observed that, measured results and simulated results are with good agreement. Gain of the antenna is increased by 2.88 dB in simulated value. Also, efficiency is increased by 30% and SAR value is decreased to 0.56 W/Kg (with EBG) as compared to 0.92W/Kg (without EBG). Bandwidth is also increased by 60 MHz (simulated value) whereas is increased by 20 MHz (measured value). When PIN diode is integrated with the proposed antenna, it operates at 2.2 GHz when diode is OFF, and at 3.8 GHz when PIN diode is ON. Efficiency is nearly 80% and SAR value is reduced to 0.56W/Kg.

Table 2. Simulated and Measured values of Reconfigurable E-shaped Antenna

Sr. No.	Parameter	Simulated Value (PIN diode ON)	Measured Value (PIN diode ON)	Simulated Value (PIN Diode OFF)	Measured Value (PIN Diode off)
1.	Frequency	2.2 GHz	2.29 GHz	3.8 GHz	3.77 GHz
2.	Return Loss	-22.56 dB	-23.6 dB	-18.4 dB	-15.6 dB
3.	VSWR	1.21	1.14	1.12	1.3
4.	Gain	4.62 dB	-	4.69 dB	-
5.	SAR	0.57 W/kg	-	0.56 W/kg	-

When PIN diode is integrated with the proposed antenna, it operates at 2.2 GHz when diode is OFF, and at 3.8 GHz when PIN diode is ON. Efficiency is nearly 80% and SAR value is reduced to 0.56W/Kg.

4.4 *Comparison with previous work*

Table 3. Comparison with Previous Work

References	Frequency (GHz)	Methodology	Parameters Obtained
[9]	2.468 GHz and 4 GHz	• Fork like EBG structure is designed. • With change in dimension, bandgap is changed. • With antenna array, frequency of operation can be switched to 4 GHz using MEMS.	A comparison has been carried out between the new structure and the conventional mushroom-like EBG structure and verified that the area of the fork-like structure is less than 40% of the latter
[10]	5.25 GHz and 5.8 GHz	• E-shaped antenna is designed. • By changing dimensions, frequency of operation is changed..	Gain=7.5dB, Bandwidth=830 MHz;
[11]	6.5 GHz	• Rectangular and E-shaped antenna is designed at 6.5 GHz frequency. • Performance parameters are improved in E-shape antenna.	Rectangular Patch: Gain: 2.65dB; Bandwidth:50 MHz; Return Loss:-16.7dB E-shaped Patch: Gain = 5.52 dB, Bandwidth = 440 MHz Return Loss:-34.28dB
[12]	2.4 and 5 GHz	• One E-shaped antenna and two element E-shape antenna are designed. • Photoconductive material is used for reconfiguration. Rectangular patch array • Four configurations are used to increase directivity.	At 2.4 GHz: Gain is increased from 1dB to 6.8dB as I to IV configuration is considered. At 5 GHz: Gain is increased from 5.1 dB to 12.5 dB from I to IV as I to IV configuration is considered.
[13]	3.027 GHz, 7.243 GHz and 9.189 GHz	• E-shaped microstrip notched antenna structure is designed. • Width of the patch is varied to operate it at different frequencies.	At 9.189 GHz: Gain = 7.28 dB Return Loss=-37dB
[14]	Different EBG structures are designed.	• Fractal Type EBG • Fork Type EBG • Spiral Type EBG	Among three EBG structures the fork type EBG structure gives better performance in terms of simplicity, compactness and band gap.
Proposed work	2.2 GHz and 3.8 GHz	• E-shaped patch antenna is designed at 2.2 GHz. • Fork shaped EBG structure is integrated with the antenna. • PIN diode is used to reconfigure antenna at 3.8 GHz.	Gain: improved by 2.88 dB when integrated with EBG. Bandwidth: Improved by 60 MHz (simulated) and 20 MHz (Measured) when integrated with EBG. Efficiency: Improved to 81% with EBG. SAR value: Reduced from 0.96W/Kg to 0.56W/kg when integrated with EBG.

From above table, it is observed that E-shaped antenna gives better gain and bandwidth as compared with rectangular antenna [11]. In previous research, E-shaped antenna is proposed with two element array for improvement of gain of the antenna and other parameters [12] and dimensions of the E-shaped antenna is varied manually to operate it at other frequency [10], [13]. Fork like EBG structure is designed and observed that it gives better performance in case of simplicity, compactness and bandgap [9], [14]. In the proposed work, parameters like gain, bandwidth and efficiency are improved when integrated with fork like EBG structure. SAR value is reduced which is one of the major application of EBG structure. Also when reconfigured, parameters are improved at another frequency as well. Structure is miniaturized because only one PIN diode is used to reconfigure it at another frequency and also improvement in parameters like gain, bandwidth and efficiency is observed at reconfigured frequency as well.

V. Conclusion

It can be easily observed that, designed E-shaped antenna improves gain with EBG structure 2.88dB. Bandwidth is improved by 60 MHz (simulated value), 20 MHz (measured value) when antenna is integrated with fork like EBG structure. It has been also observed that antenna can be reconfigured at 3.8 GHz frequency using PIN diode. Improvement in parameters are also observed when the antenna is reconfigured at 3.8 GHz frequency. SAR value of 0.56 W/Kg is observed with EBG as compared with 0.92W/Kg without EBG.

REFERENCES

[1] Md. Shahidul Alam, Norbahiah Misran, Baharudin Yatim, and Mohammad Tariqul Islam, "Development of Electromagnetic Band Gap Structures in the Perspective of Microstrip Antenna Design", International Journal of Antennas and Propagation, Hindawi Publishing Corporation, Volume 2013.

[2] Nagendra Kushwaha, Raj Kumar, "Study of Different Shape Electromagnetic Band Gap (EBG) Structures for Single and Dual band Applications", Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 13, No. 1, June 2014.

[3] Christos G. Christodoulou, Youssef Tawk, Steven A. Lane, Scott R. Erwin, "Reconfigurable Antennas for Wireless and Space Applications", Proceedings of the IEEE | Vol. 100, No. 7, July 2012.

[4] M. Kapoor, "Electromagnetic Bandgap Structures" Shodhganga, Chapter-3, 2012.

[5] B. Liang, B. Sanz-Izquierdo, E. A. Parker, and J. C. Batchelor, "A Frequency and Polarization Reconfigurable Circularly Polarized Antenna Using Active EBG Structure for Satellite Navigation", IEEE Transactions on Antennas and Propagation,2014.

[6] Constantine A. Balanis, Antenna Theory, Analysis and Design, John Wiley & Sons Inc. 4th edition.

[7] Mobile Communication- Radio Waves & Safety, Department of elecommunications, Ministry of communications and IT, Government of India (2013).

[8] H. R. Cheng, Q. Y. Song, Y. C. Guo, X. Q. Chen and X. W. Shi, "Design of A Novel EBG Structure and its Application in Fractal Microstrip Antenna", Progress In Electromagnetics Research C, Vol. 11, 81–90, 2009.

[9] Li Yang, Student Member, Mingyan Fan, Fanglu Chen, Jingzhao She, and Zhenghe Feng, "A Novel Compact Electromagnetic-Bandgap (EBG) Structure and its Applications for Microwave Circuits", IEEE Transactions on Microwave Theory and Techniques, Vol. 53, No. 1, January 2005.

[10] B.-K. Ang, B.-K. Chung, "A Wideband E-Shaped Microstrip Patch Antenna for 5–6 GHz Wireless Communications", Progress in Electromagnetics Research, PIER 75, 397–407, 2007.

[11] Prof. Jaikaran Singh, Prof. Mukesh Tiwari, Ms. Neha Patel, "Design and Simulation of Microstrip E-Shaped Patch Antenna for Improved Bandwidth and Directive Gain", International Journal of Engineering Trends and Technology (IJETT) – Volume 9 Number 9 - Mar 2014

[12] Arismar Cerqueira Sodré Junior, Igor Feliciano da Costa, Leandro Tiago Manera, José Alexandre Diniz, "Optically Controlled Reconfigurable Antenna Array Based on E-Shaped Elements", Hindawi Publishing Corporation International Journal of Antennas and Propagation Volume 2014.

[13] Sunil Kumar Sharma, Dr. Yadwinder Kumar, "E - Shaped Microstrip Notched Patch Antenna for Wireless Applications", EasyChair Preprint, October 17, 2019.

[14] Shiva Chauhan1, P.K. Singhal, "Comparative Analysis of Different Types of Planer EBG Structures", International Journal of Scientific and Research Publications, Volume 4, Issue 6, June 2014.