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# Design of frequency reconfigurable antenna using dual band electromagnetic band gap structure

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## Abstract

**Objectives/Method:** An innovative fractal shape of Electromagnetic Band Gap (EBG) structure is proposed in this study which has dual bandgap. The proposed frequency reconfigurable antenna is integrated with the EBG structure to improve performance parameters. CST Microwave Studio Software is used for simulation. The proposed EBG has dual bandgap S-band (2 GHz to 4 GHz) and X-band (8 GHz to 10 GHz). The proposed reconfigurable antenna operates at frequencies one in S-band and another in X-band. PIN diode is used to change the structure of the antenna so that it can operate at two different frequencies (2.67 GHz and 8.8 GHz). Simulated and measured results are compared. **Findings:** When PIN diode is ON, antenna operates at 2.67 GHz and at 8.7 GHz when PIN diode is OFF. Since antenna is integrated with the proposed EBG structure, gain and bandwidth of the antenna is increased with EBG structure as compared to without EBG structure at both frequencies. Simulated and measured results are compared and found good agreement. Applications of this antenna are radar applications, satellite communication, microwave applications, space applications. **Novelty:** It is observed that most of the antennas are designed with either EBG structure for improvement in parameters or are designed as reconfigurable antennas to operate at different frequency bands. In the proposed design, reconfigurable antenna is designed along with EBG structure which gives:

- Compact structure
- Improvement in parameter viz gain, bandwidth for all frequencies.

**Keywords:** Electromagnetic band gap; reconfigurable antenna; frequency bands; dual band; dispersion diagram

## 1 Introduction

Recent trends are in development of multiband antennas, wideband antennas and reconfigurable antennas. However, reconfigurable antenna has advantage of compactness and flexibility. The radiating element which has ability to radiate more than one pattern at different frequencies and polarization by changing its design is known as reconfigurable antenna[1]. There are various techniques to design reconfigurable antenna. These techniques are: electrically reconfigurable antenna, optically reconfigurable antenna, physically reconfigurable antenna and changing structure of smart materials. PIN diodes, RF MEMS are components used as a switch to design frequency reconfigurable antenna.

Electromagnetic Band Gap (EBG) structure is defined as artificial periodic structure that averts or assists the propagation of electromagnetic waves in specified band of frequencies for all incident angles and all polarization states. The main characteristic of these structures is existence of frequency stop band. There is no propagation of electromagnetic waves in this frequency band into the structure[2].Formation of surface waves in substrate of Microstrip antenna decreases the radiation power and also destroys the radiation pattern of antenna. Surface waves also lead to decrease in gain and directivity of antenna. Using EBG structures in substrate of antenna is a very useful method to suppress the surface waves into substrate of Microstrip antenna, because EBG materials prevent the spreading of surface waves in gap band area and improve the operation of Microstrip antennas. There are different EBG structures. One of them is mushroom like structure and second is uniplanar EBG[3].The essential difference between mushroom and uniplanar EBGs is the presence or absence of shorting vias, which act as shunt inductance. In addition, a mushroom like EBG can suppress both TE and TM surface waves, whereas the uniplanar EBG can suppress only TE waves. Researchers have developed and analysed various shapes of EBG structures for enhancement of parameters of antenna[4]. Specific Absorption Rate (SAR value) must be below the specified limits as per international guidelines. Antenna design with EBG structure is effective method to reduce SAR[5].Isolation in patch antenna array can be increased with fractal EBG structure[6]. There are some additional effects of using EBG structure. EBG structure increases the gain of the antenna and reduces the surface waves. For cell phone handset geometry, high impedance electromagnetic surface is used to reduce the radiations. It reduces SAR (Specific Absorption Rate) value of the radiating elements. Patch antennas with EBG structure reduces the surface wave effects significantly and provides relatively broadband frequency performance. It also improves efficiency of the antenna.

In general, parameters in a specific frequency band are improved when EBG structure is integrated with antenna[7].For frequency reconfigurable antenna, (i.e. when antenna is operating in two different frequencies) improvement in performance parameters should be observed in both frequencies with EBG structure. Therefore, there is necessity of designing EBG structure which will operate for two different frequency bands, so that improvement in antenna parameters in both frequency bands can be observed.

In this paper, a new EBG structure is designed which gives Electromagnetic Band Gap in two frequency bands, S-band and X-band. Also frequency reconfigurable antenna is designed to operate at frequencies 2.67 GHz (S-band) and 8.7 GHz (X-band). The effect of this EBG structure on the proposed reconfigurable rectangular patch microstrip antenna is also studied.

This paper is organized as follows: section II describes design of dual band EBG structure; dispersion diagram and simulation of the proposed EBG structure. In section III, design of reconfigurable antenna without EBG, in section IV, design of reconfigurable antenna with EBG is discussed. In section V, simulated and measured results of this antenna with and without EBG structure are observed. Conclusions are made in section VI.

## 2 Design of dual band EBG structure

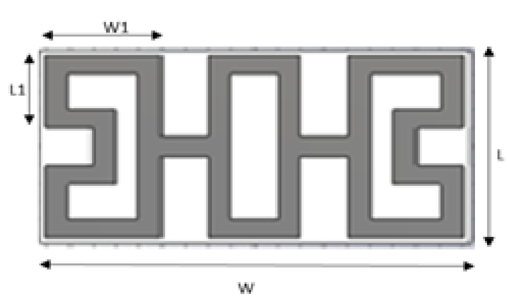


**Fig 1.** Structure of dual band EBG

Innovative fractal EBG structure is designed and simulated for dispersion diagram using CST. New structure of Dual Band EBG is shown in the Figure 1.

In this EBG structure, L=10.6mm, W=18.6mm, L1=4mm, W1=5mm. Width of the each strip of the designed structure is 1mm. Dispersion diagram for the EBG structure is as shown in the Figure 2 . The band gap for surface waves is determined by plotting the Dispersion Diagram over the irreducible Brillouin Zone (Γ-X-M-Γ).

The Path Para sweeps the entire Brillouin Zone (Γ->X->M->Γ) with a single parameter sweep.

PathPara: 0->1: Γ->X, 1->2: X->M, 2->3: M->Γ[8].Periodic boundary conditions and a parameter sweep is used with Eigen mode solver in CST. As it can be seen in Figure 3 , first band gap of dispersion curve – in EBG is between 2.25 GHz to 4.16 GHz and second bandgap is 8.5 GHz to 9.52 GHz.

Light lines can be calculated using formulae[9]:

For ΓX leg of the triangle, the line falls along,

$$f = \frac{phase2 * C}{\tau * 360} \tag{1}$$

For MΓ leg of triangle, the line falls along,

$$f = \frac{phase2 * C}{d * 360} \tag{2}$$

Values are as shown in Figure 2

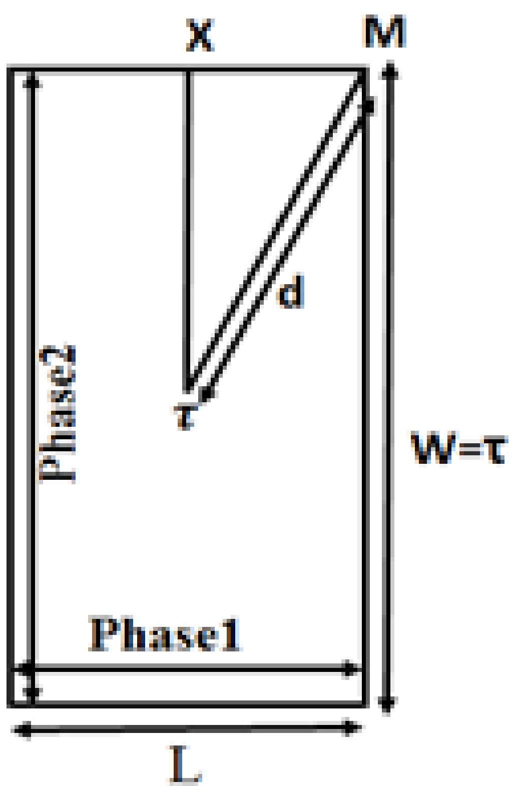


**Fig 2.** Brillouin triangle of EBG structure

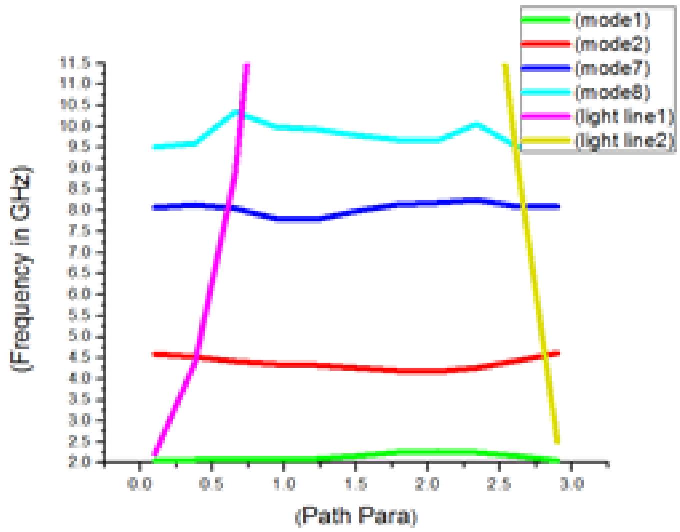


**Fig 3.** Dispersion diagram of EBG substrate with light line

# 3 Design of reconfigurable antenna without EBG

## 3.1 Design of rectangular patch in X-band

Two rectangular microstrip patch antennas are designed with inset feed and connected together with small gap for X-band as shown in Figure 4 .

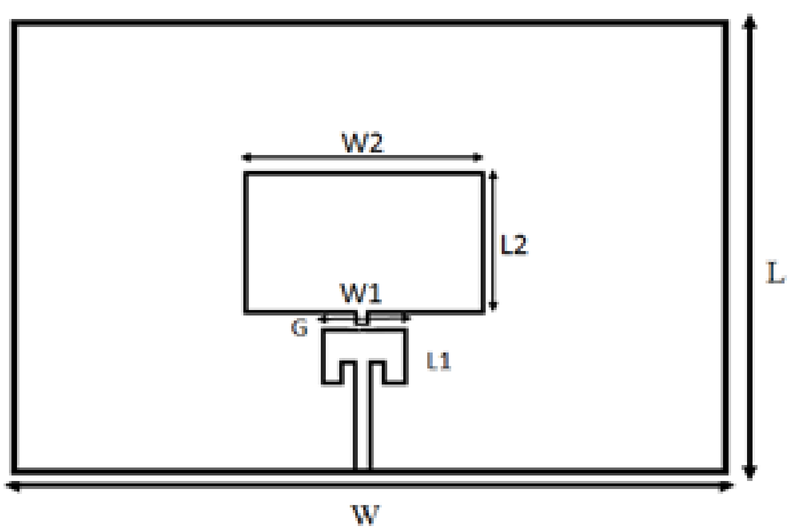


**Fig 4.** Rectangular patch antenna for X-Band

The patch is designed to operate for frequency 8.7 GHz with dimensions of substrate L=70mm, W=110mm, patch1 L1=7.5mm, W1=10.4mm. To make this antenna reconfigurable, another patch is designed with L2= 27.5mm, W2=40mm. Gap between two patches is 0.3 mm where PIN diode is to be connected. This antenna operates in second band gap of EBG structure.

### 3.2 Design of rectangular patch in S-band

A microstrip patch antenna is designed for S-band as shown in the Figure 5. The operating frequency of antenna is 2.67 GHz which constitutes S-band. Two patches are joined using PIN diode to get required frequency. For simulation, a strip of 4X2 mm (denoted by G in the figure) is used to join both of these patches.

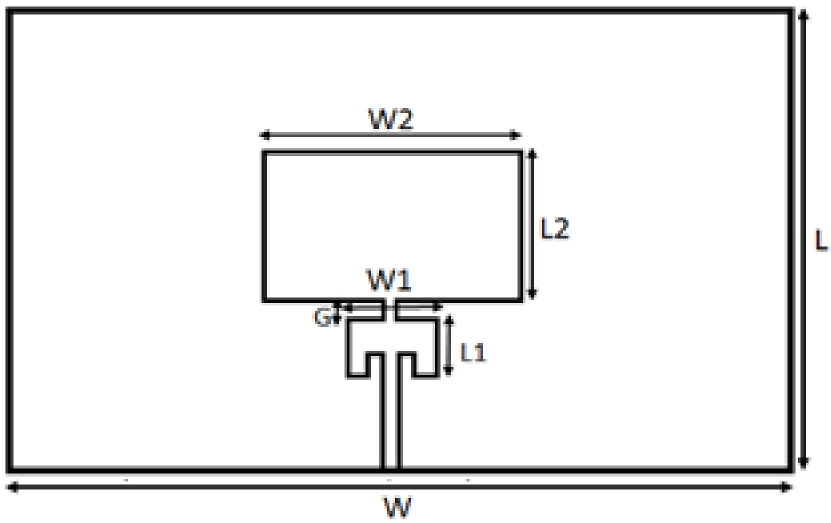


**Fig 5.** Antenna for S-band

## 4 Reconfigurable antenna with EBG structure

### 4.1 Antenna with EBG in X-band

The proposed EBG structure is integrated with antenna [10]. Antenna is simulated with EBG structure as shown in the Figure 6 . Performance parameters like gain, bandwidth are compared without EBG structure.

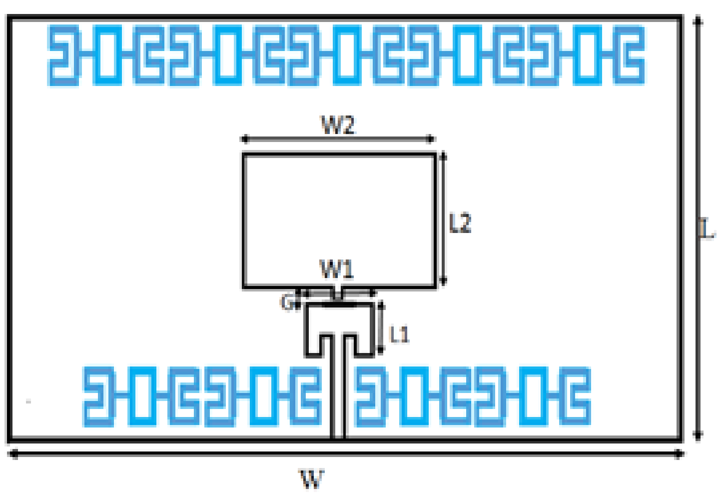


**Fig 6.** Rectangular Patch Antenna for X-Band

### 4.2 Antenna with EBG in S-band

Simulation of antenna in S-band with EBG structure is shown in Figure 7. In this band, performance parameters of the antenna are compared with antenna designed without EBG structure.

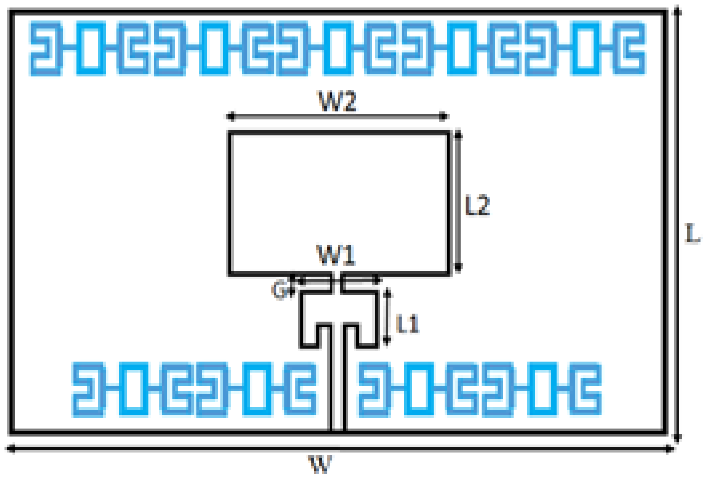


**Fig 7.** Antenna with EBG structure in S-band

## 5 Results and Discussion

### 5.1 Fabricated antenna

Antennas without and with dual band EBG structure are fabricated as shown in Figure 8 (a). PIN diode is used to reconfigure this antenna. Lumped elements like inductor (100nH) and capacitor (100pF) are used along with PIN diode MA4SPS402. Figure 8(b) shows antenna return loss measurement on network analyser.

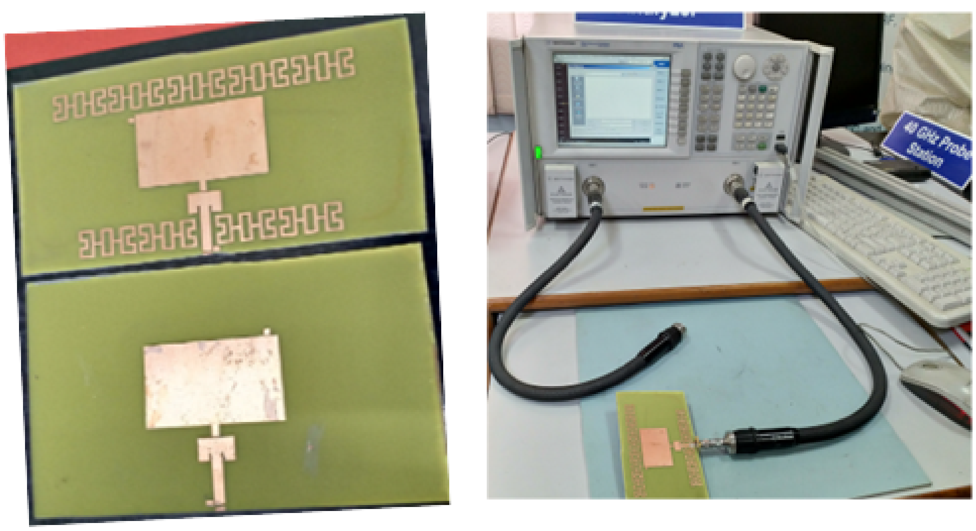

**Fig 8.** (a) Fabricated Antennas (b)Measurement of Return loss

## 5.2 Results in X band without EBG

Measured and simulated S11 parameter and Radiation Pattern for without EBG in X band are shown in Figure 9(a) and Figure 9(b) respectively. It shows operating frequency as 8.7 GHz which is X band frequency.

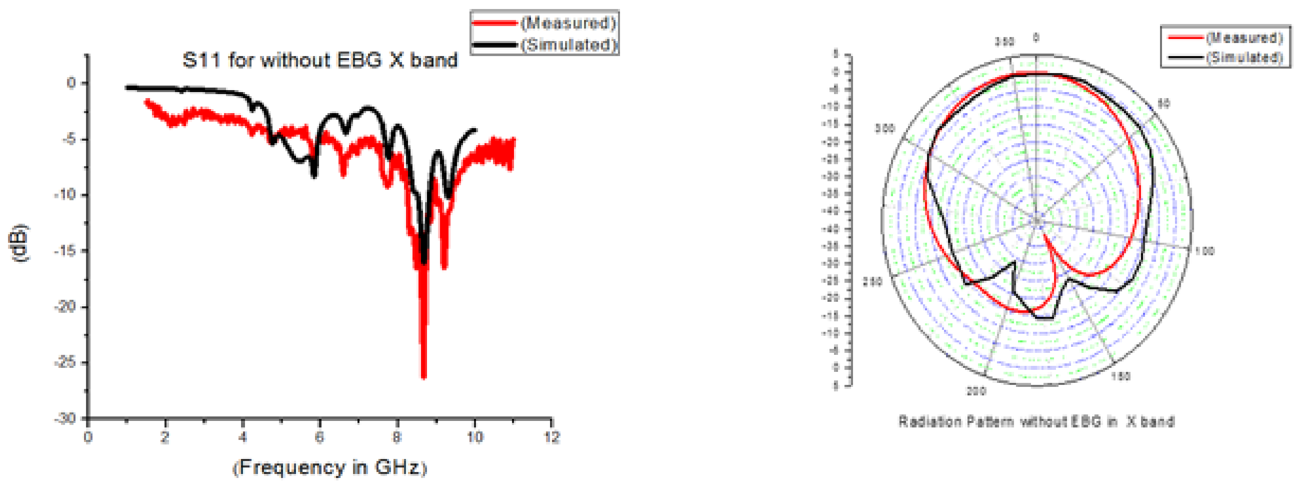


**Fig 9.** (a) Measured and simulated S11for without EBG in X band. (b) Measured and simulated Radiation Pattern for without EBG inX band

## 5.3 Results in X band with EBG

Simulated and measured S11 and Radiation Pattern for with EBG in X band are shown in Figure 10 (a) and Figure 10(b). Operating frequency is 8.7 GHz.

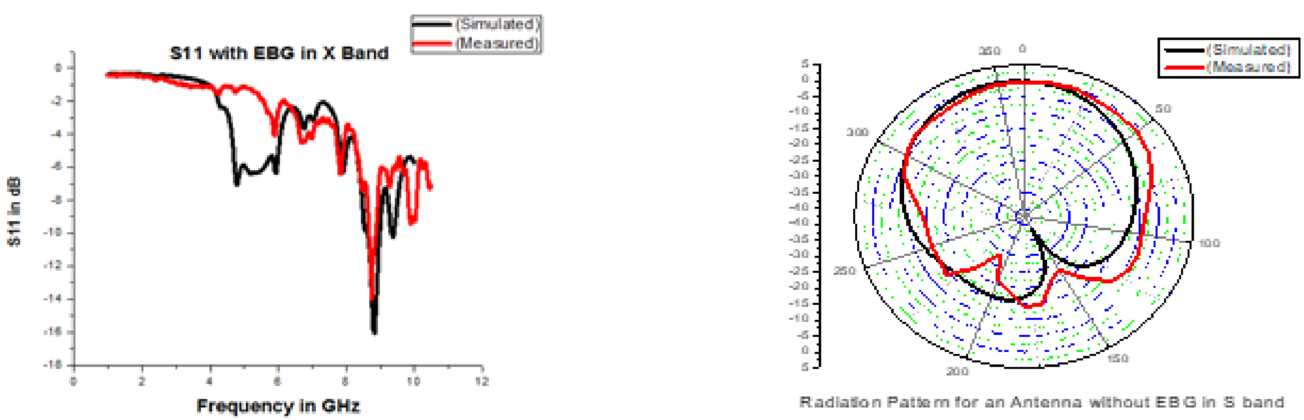


**Fig 10.** (a) Measured and simulated S11 for with EBG in X band. (b) Measured and simulated radiation pattern for with EBG in X band

## 5.4 Results in S-band without EBG:

Simulated and measured S11 and Radiation Pattern for without EBG in S band (at 2.67 GHz) as shown in Figure 11 (a) and Figure 11(b).

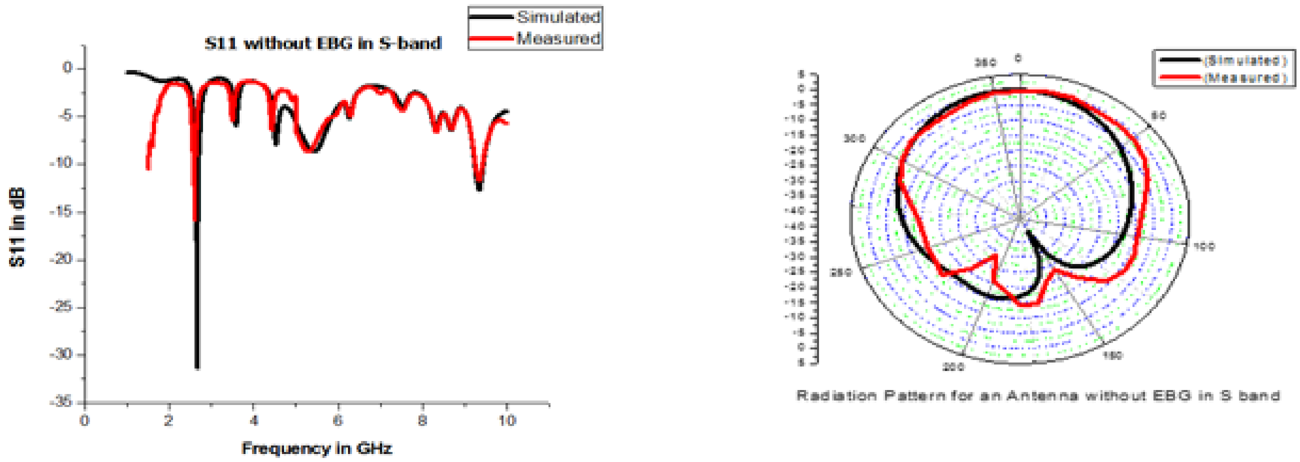


**Fig 11.** (a) Measured and simulated S11 without EBG in S band. (b) Measured and simulated radiation pattern without EBG in S band

### 5.5 Results in S band with EBG

Simulated and measured S11 and Radiation Pattern for with EBG in S-band is shown in Figure 12 (a) and Figure 12(b). Operating frequency of the antenna is 2.67 GHz. In Table 1, simulated and measured gain and bandwidth is shown and are with good agreement.

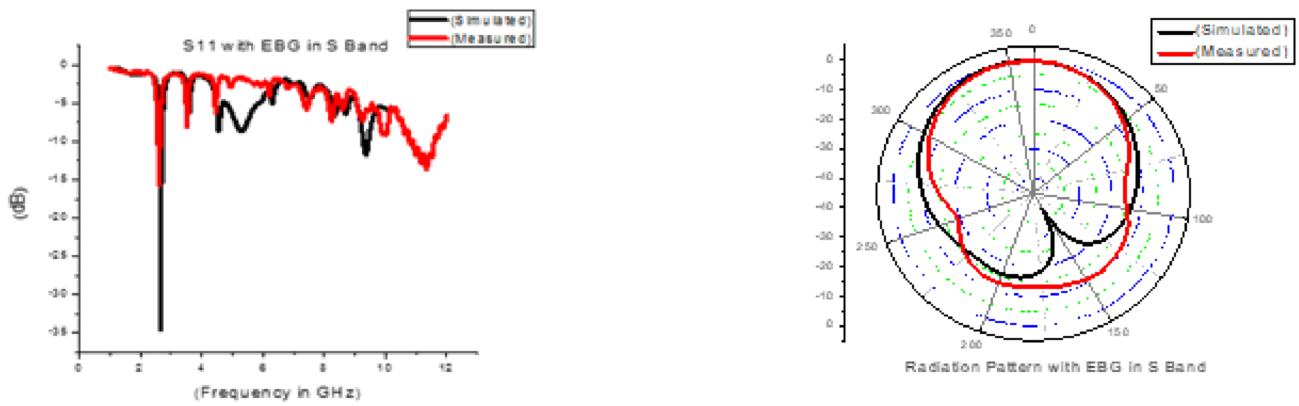


**Fig 12.** (a) Measured and simulated S11for with EBG in S band (b) Measured and simulated radiation pattern for with EBG in S band

**Table 1.** Simulated and measured results of gain and bandwidth

| Specification | Gain | | Bandwidth | |
|---|---|---|---|---|
| | Simulated | Measured | Simulated | Measured |
| Without EBG in S Band (2.67 GHz) | 2.63 dB | 2.52 dB | 80 MHz | 70 MHz |
| With EBG in S Band (2.67 GHz) | 3.45dB | 3.3 dB | 50 MHz | 40 MHz |
| Without EBG in X Band (8.7 GHz) | 4.3 dB | 3.12 dB | 290 MHz | 270 MHz |
| With EBG in X Band (8.7 GHz) | 6.18 dB | 4.62 dB | 350 MHz | 330 MHz |

Performance of antenna has been improved when integrated with EBG structure. From Table 1, it is observed that in S band for antenna with EBG structure, gain is increased by approximately 1 dB and bandwidth is increased by 30 MHz whereas in X band for antenna with EBG, gain is increased approximately by 1.88 dB in simulated result and 1.5 dB in measured result.

Bandwidth is increased by 60 MHz in both simulated and measured result. Antenna is compact in size as PIN diode is used as a switch for reconfiguration [11,12]. Following are the observations from research papers listed in the Table 2,

**Table 2.** Comparison with Other research work

| Ref. | Design techniques of reconfigurable antenna | Operating frequency range | Gain (dB) | Bandwidth |
|---|---|---|---|---|
| [13] | Four PIN Diodes | Mode 1: 5.74GHz,<br>8.822GHz,<br>Mode 2: 5.76GHz,<br>6.35 GHz,<br>7.54 GHz,<br>9.8 GHz<br>Mode 3: 5.70 GHz,<br>7.23 GHz,<br>9.52 GHz<br>Mode 4: 3.436 GHz,<br>5.811 GHz,<br>6.51 GHz,<br>7.363 GHz,<br>8.91GHz | 2.488<br>4.93<br>4.8<br>4.6<br>2.20<br>5.46<br>3.62<br>5<br>5.02<br>5<br>3.60<br>3.03<br>2.24<br>3.02 | - |
| [14] | Varactor Diode | 1.04 GHz to 1.52 GHz (Left Polarized to Right Polarized) | - | 40% increase in Bandwidth |
| [15] | Six PIN Diodes | 2 GHz to 9 GHz | | |
| [16] | Five PIN Diodes | 0.83 GHz and 2.5 GHz | $7.6 \pm 2.4$ dB | |
| [17] | Different techniques of design of Reconfigurable Antenna | 3.2 GHz to 11 GHz | - | |
| This Paper | One PIN Diode | 2.67 GHz (without EBG)<br>2.67 GHz (with EBG) 8.7 GHz (without EBG)<br>8.7 GHz (with EBG) | 2.52 dB<br>3.3 dB<br>3.12 dB<br>4.62 dB | Simulated Measured<br>80 MHz 70 MHz<br>50 MHz 40 MHz<br>290 MHz 270 MHz<br>350 MHz 330 MHz |

Four PIN diodes are used for frequency reconfiguration. Using reconfiguration concept, the proposed antenna can resonate at approximately ten different resonant frequencies in all the modes. In the Table 2, frequency of operation and gain is observed for all four modes [13]. Six varactor diodes are used to get frequency and polarized reconfigurable antenna with EBG structure. The configuration will switch between LHCP and RHCP, realizing the polarization reconfigurability. Also it configures for six different frequencies and increases 40 % bandwidth [14]. Six PIN diodes are used to reconfigure antenna in the frequency range from 2.2 GHz to 9.9 GHz. The proposed antenna operates at 10 different frequencies. The antenna design is complicated. No observations about other performance parameters are discussed in this paper+. Four PIN diodes are used for frequency reconfiguration. Four narrow band modes can be achieved at 1.05 GHz, 1.2 GHz, 1.5 GHz and 2.1 GHz, respectively with the proposed antenna. But disadvantages of the antenna is high losses, low efficiency and complicated design [16]. In this paper, different techniques to design reconfigurable antenna are discussed. These antennas are designed at frequency range from 3.2 GHz to 11 GHz [17].

In the research papers discussed:

- More than one PIN diodes are used to operate antenna for two or more than two frequencies.
- Antenna structures are more complex since four, five and six diodes are used.

In the proposed research work, reconfigurable antenna is designed only with one diode and is used for switching frequency from S-band (2.67 GHz) to X-band (8.8 GHz). Gain and bandwidth are improved with EBG structure in S-band as well as in X-band.

## 6 Conclusion

The proposed EBG structure gives two different frequency band gaps which is an innovative part of this study. The dual band EBG structure has bandgap in two frequency bands S band and X band. In S band (frequency at 2.67 GHz) antenna with EBG structure, gain is increased which results in by 0.8 dB and bandwidth is increased by 30 MHz; whereas in X band (frequency at 8.7 GHz) also antenna with EBG, gain is increased by approximately by 1.88 dB in simulated gain but it is increased by 1.5 dB in measured gain. Simulation and measured bandwidth is 60 MHz in this band. The reconfigurable antenna is simple but innovative in structure with PIN diode as switch.

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