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A Wide Band EBG Based Microstrip Patch Antenna with Reduced SAR for WiMAX Communication

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Abstract: A compact wideband mushroom like Electromagnetic band gap (EBG) structure with slots and "via" is elaborated in this research paper for Specific Absorption Rate (SAR) reduction. The proposed EBG is coupled with a coaxial fed modified square patch antenna that works in 3.5GHz band for Wimax applications. The designed EBG integrated with patch antenna shows significant reduction of 82% in SAR value in CST microwave studio. The EBG unit cell size is 10mm×10mm with size reduction of 2mm from that of conventional mushroom type EBG structure. The percentage bandwidth of slotted patch antenna has enhanced to 4.27% as compared to 2.86% of simple patch antenna. The overall dimensions of patch antenna are 45mm×45mm×1.6mm. A dual band EBG is also presented which covers the 3.5GHz and 5.8GHz bands for Wimax applications with SAR reduction of 51.5% and gain enhancement of 12.8%.

Keywords: Return Loss, Bandwidth, Gain, VSWR and Ku-Band

1. INTRODUCTION

With numerous advancements in telecom sector and designing technology of smart phones, the use of mobile phones is increasing with every passing day. The 3G and 4G technology, new mobile apps and social media are all contributing to high usage of handsets. A portion of RF radiations transmitting from mobile phones is directed towards user body. Research has proved that prolonged exposure to these RF radiations is harmful for human body specially head region. There is a greater risk of brain tumor, man infertility and ear impairment in those who are mobile addicts than others (Suhag *et al.,* 2008). So there is a need to minimize the hazardous effects of these radiations.

The harmful effect of these radiations is calculated by using a parameter called SAR. It is defined as "the power absorbed per mass of tissue and has SI unit of Watt/Kg" (Kwak, *et al.,* 2008). Mathematically,

$$SAR = \frac{\sigma E^2}{\rho} \qquad (1)$$

Where σ is the conductivity of tissue, E is the electric field intensity and ρ is the mass density. SAR is generally measured over a small sample volume. According to American FCC standards, SAR is averaged over one gram of tissue and maximum permissible value is 1.6 Watt/Kg In European IEC https://www.fcc.gov/general/specific-absorption-rate-sar-cellular-telephones standards, SAR is averaged over ten gram of tissue with maximum permissible value of 2 Watt/Kg https://webstore.iec.ch/publication/25336

Microstrip patch antennas are very popular due to its compact size, low cost and ease in fabrication. SAR value of patch antenna can be minimized by improving front to back ratio and blocking surface waves (Kwak, *et al.,* 2011). Various techniques have been proposed for SAR reduction in past. In one technique RF shield made of ferromagnetic material is attached to antenna to suppress surface waves (Ragha, and Bhatia, 2010.). But inserting such conductors on back side of antenna reverses phase of incoming electromagnetic waves. Some studies have proposed the usage of highly directive antenna as it will reduce the back radiations (George, and Anoop. 2015) however antenna with high directivity reduces reception of signal from other directions. Researchers have found that EBG structures are very effective in SAR reduction. These are periodic structures which acts as LC filter and suppress surface waves in a particular band (Yang and Rahmat, 2015). The inductance is due to current flow through "via" while capacitance is introduced by gap effect between adjacent patches. EBG structures behave as perfect magnetic conductors i-e have zero reflection phase in the operating band. In this manuscript a unique design of EBG is presented to minimize SAR. The proposed EBG

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is integrated with a slotted square patch antenna which works in 3.5 GHz for Wimax (worldwide wireless interoperability for microwave access). Wimax is a last mile broad band wireless communication alternative for DSL and cable based on 802.16 standard of IEEE. As patch antennas are narrow band inherently, a slotted patch is used to enhance its bandwidth. A total of 12 EBG unit cells are arranged around the patch and 82% reduction in SAR value is observed. A dual band EBG is also proposed coupled with a dual band patch antenna for 3.5 GHz and 5.8 GHz which are the mostly used bands for wimax applications.

2. RELATED WORK

In one study a mushroom type EBG integrated with a dipole antenna shows up to 42% reduction in SAR value (Mishra, and Wagadre, 2015) A square metamaterial (SMM) is proposed in (Farooq, and Islam, (2013) and 53% reduction in SAR is observed. In another study (Kamlash, and Sameena, 2014), circular shaped EBG structures are integrated with a dipole array oand SAR reduction up to 31% is observed. A cross-hair type EBG was proposed in (Vishwanth, and Santhosh, 2015) which reduced SAR by 52%. Other variants of EBG such as jureslam JC-EBG and double spiral EBG have been proposed in (Alam, and Islam, 2013) respectively.SAR reduction up to 53% is present in past studies. This study combines the goals of SAR reduction and bandwidth enhancement.

3. PROPOSED ANTENNA WITH SLOTTED PATCH:

The substrate material is FR4 with permittivity of 4.3 and dimensions of 45mm×45mm×1.6mm. Dimensions of the patch can be found by using the following formulas (Constantine A. Balanis, 2015) . The width of patch is given by:

$$W = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (2)$$

Where C=speed of light, f_r = resonant frequency and ε_r = permittivity of substrate.

Length of the patch is given by:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \qquad (3)$$

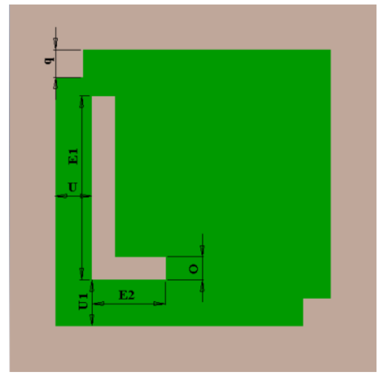
Where

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \qquad (4)$$

And

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (5)$$

This formulas are approximate so there is need of slight adjustment in patch dimensions. The square shaped radiating patch (19mm×19mm) with thickness of 0.035 mm, is made up of copper. Ground plane thickness is 0.035mm with dimensions of 45mm×45mm.An L-shaped slot is made in the patch along with two square slots at the edges as shown in **(Fig. 1)**.



Fig, 1. Slotted patch antenna

These slots introduce second resonance and by adjusting the parameters properly, the two resonance merge together to give wide band. Coaxial probe with 50Ω impedance is used for feeding the antenna. The best matching point is obtained to be at a vertical distance of 3.8 mm from the center of patch.

The suggested EBG unit cellhas cross slots and via of diameter 0.5mm at the center as shown in **(Fig.2).** The unit cell size is 10mm×10mm.

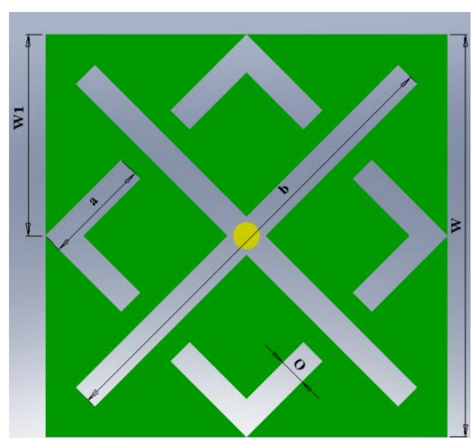


Fig. 2. Modified EBG unit cell

The center frequency of EBG is given by (Yang and Rahmat 2015)

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (6)$$

Where,

$$C = \frac{W\varepsilon_0(\varepsilon_r+1)\cosh^{-1}{}^{(W+g)}/_{g}}{\pi} \qquad (7)$$

And

$$L = \mu_0 h \qquad (8)$$

Twelve unit cells are arranged around the patch with 0.3 mm gap between adjacent unit cells. The width of all slots is 0.2mm. The arrangement of EBG cells is shown in **(Fig. 3)**. These EBG structures provide high surface impedance and thus are helpful in suppressing the surface waves. The gap width (g) and number of EBG unit cells used are important parameters and affect the performance of EBG structure.

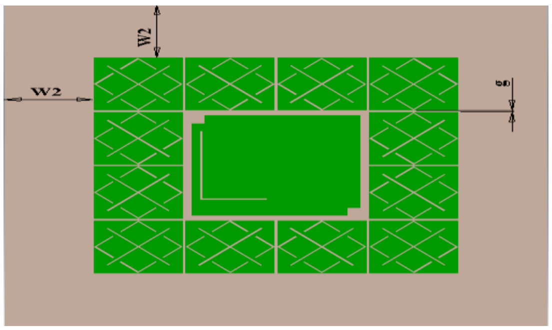


Fig. 3. EBG cell arrangements

To calculate SAR value, a cylindrical head model is designed having properties close to the human head. The outer layer comprises of skin material, the middle layer represents bones and the inner layer behave as brain material. The properties assigned to these layers are given in **(Table 1).**

Table 1. Head model properties

Layer	Correspond to	permittivity
Layer 1	Skin	31.3
Layer 2	Bone	12.6
Layer 3	Brain	38

4. DUAL BAND ANTENNA AND DUAL BAND EBG:

A square patch antenna with double L slotted patch is designed to work in frequently used 3.5GHz and 5.8 GHz bands for Wimax applications. The overall dimensions of antenna are same as the previous one. The slotted patch is shown in **(Fig. 4).**

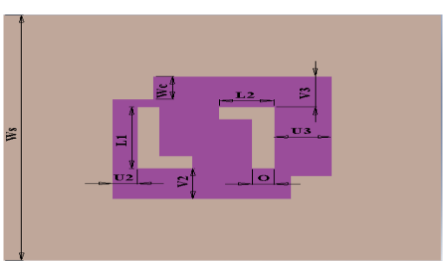


Fig. 4. Dual band patch antenna

A dual band EBG is proposed to couple with this antenna for SAR reduction. The proposed EBG has double E shaped slots with unit cell size of 10mm×10mm as shown in **(Fig 5).** Via of diameter 0.5mm is present at center of unit cell**.**

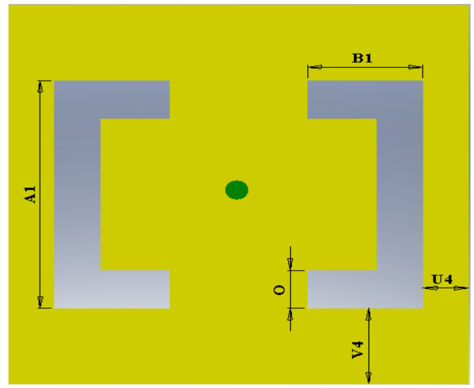


Fig. 5. Dual band EBG unit cell

Again a total of 12 unit cells are arranged in single layer around patch with a gap of 0.3mm between adjacent cells. All the parameters are given in **(Table 2)**.

Table 2. Table of dimensions

Table 3Parameter	Value (mm)	Parameter	Value (mm)
Ws	45	W_2	2.05
Wp	19	g	0.3
h	1.6	Wc	1
q	1.5	L_1	13
E_1	13	L_2	2.2
E_2	7.5	U_2	1
U	1	V_2	2.7
U_1	3	U_3	7
O	0.2	V_3	3.3
W	10	A_1	7
W_1	5	B_1	3.4
a	3.3	U_4	1.1
b	10	V_4	1.5

5. RESULTS AND DISCUSSION

The proposed antenna was simulated in CST microwave studio and various key properties were investigated.

A) SLOTTED PATCHANTENNA

The return loss graph with and without EBG is shown in Figure 6. The resonant frequency of simple antenna is 3.51 GHz with bandwidth of 150MHz. A typical patch antenna has 2-3% impedance bandwidth (Singh *et al.*, 2012). This antenna has 4.27% impedance bandwidth. Antenna with EBG has center frequency of 3.59 GHz with bandwidth of 150MHz.

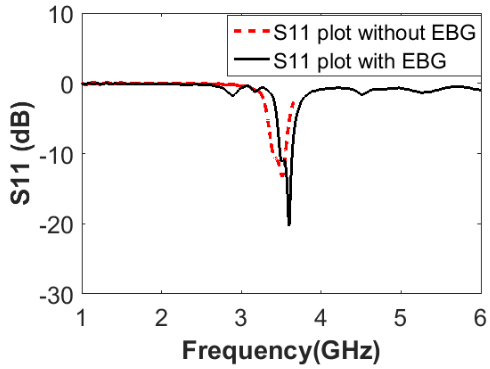


Fig. 6. Return loss graph

The peak gain of antenna with and without EBG are 4.46dB and 3.92 dB respectively. The gain versus frequency curve is shown in **(Fig.7).**

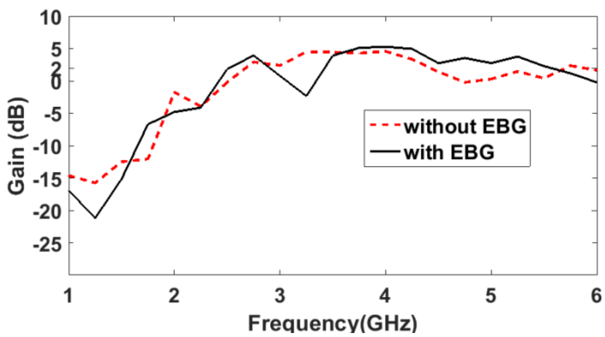


Fig. 7. Gain versus frequency graph

The VSWR value of antenna is well within the acceptable range of 2. VSWR value for simple antenna and antenna coupled with EBG are 1.5 and 1.21 respectively as shown in **(Fig. 8).**

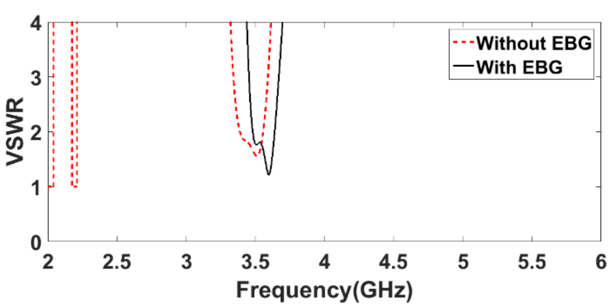


Fig. 8. VSWR Versus frequency plot

Radiation efficiency of antenna is the ratio of radiated power to the power present at the antenna terminal. Typically microstrip patch antenna have very low efficiency. The radiation efficiency plot of proposed antenna is given in Figure 9. The radiation efficiency of antenna is 0.615 while after integration with EBG, it becomes 0.632 showing slight increase.

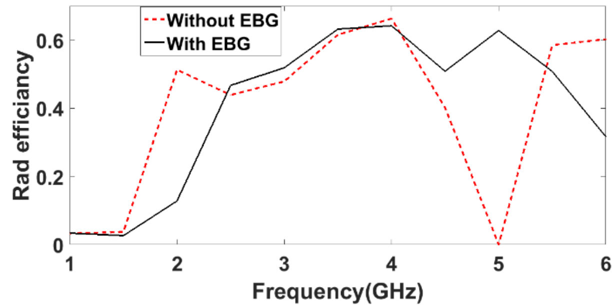


Fig. 9. Radiation efficiency plot

Total efficiency is the ratio of radiated power to input power. Total efficiency also consider the mismatch losses and thus it is always less than the radiation efficiency. The total efficiency plot with and without EBG is shown in Figure 10. The total efficiency of antenna without EBG is 0.58 while with EBG it is 0.475.

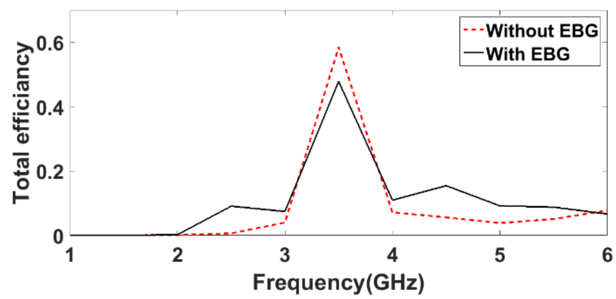


Fig.10. Total efficiency plot

To evaluate SAR value, the head model was placed at a distance of 10mm from antenna. SAR value of antenna averaged over 10g tissue without EBG is 0.166 Watt/Kg while after coupling with EBG it reduces to 0.03Watt/Kg showing82% reduction in SAR value as shown in **(Fig.11).**

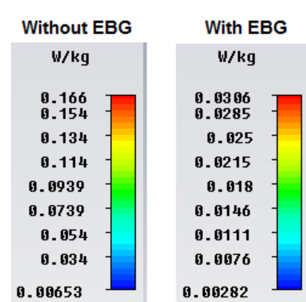


Fig.11. SAR value with and without EBG

The reduction in SAR value is due to the fact that the back lobe radiations has been significantly reduced by the EBG structure. This is clearly evident from the electric field pattern plot in **(Fig.12).**

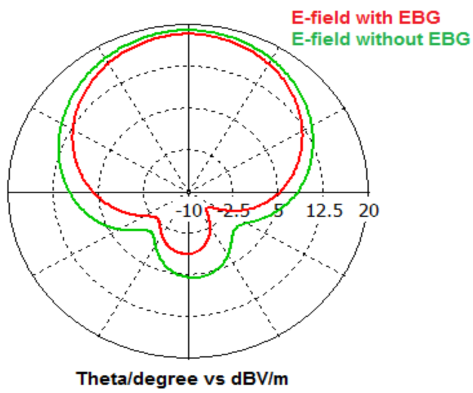


Fig. 12. E-field pattern

(B) DUAL BAND EBG AND DUAL BAND ANTENNA RESULTS:

The return loss graph of dual band antenna shows two resonances at 3.5GHz and 5.8 GHz which are two mostly deployed bands for Wimax applications. After coupling with EBG the resonant frequencies remains at almost the same point as shown in **(Fig. 13).**

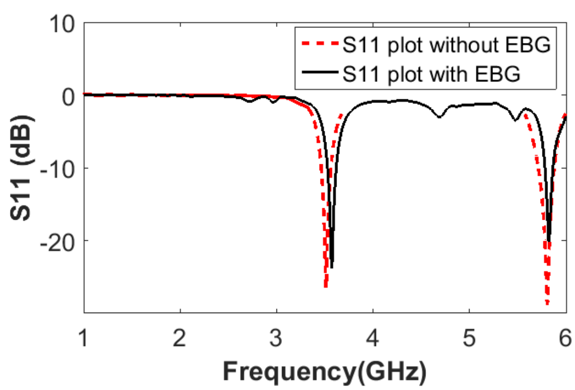


Fig. 13. Return loss graph of dual band antenna

The dual band antenna has bandwidth of 100 MHz at 3.5 GHz and 150 MHz at 5.8 GHz The dual band antenna has good matching at both resonances as evident from its VSWR of 1.10 and 1.08 at 3.5 GHz and 5.8 GHz respectively as shown in **(Fig. 14).**

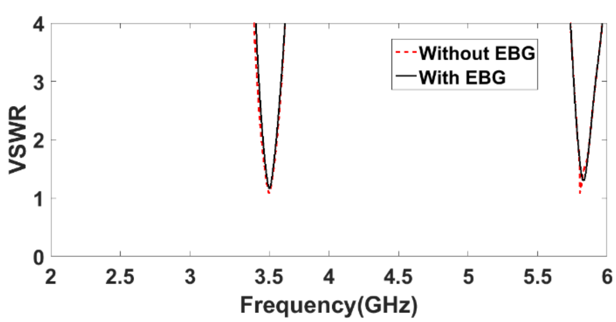


Fig. 14. VSWR versus frequency plot

The proposed dual band EBG has also enhanced the gain of antenna from 4.43 dB to 5 dB at 3.5 GHz showing 12.8% increase in gain. The gain versus frequency graph is shown in **(Fig.15).**

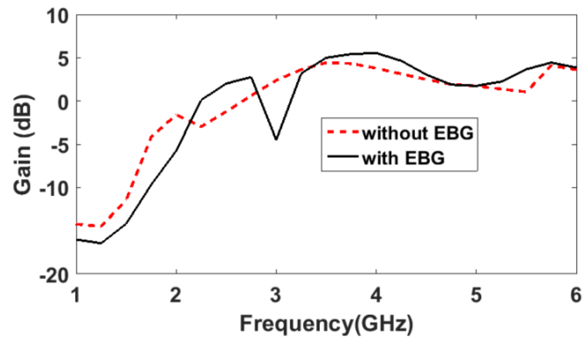


Fig. 15. Gain versus frequency plot of dual band antenna

The radiation efficiency of dual band antenna is 0.62 and 0.58 at 3.5GHz and 5.8 GHz respectively as clear from **(Fig.16)**. The coupling of EBG has almost no effect on the radiation efficiency of dual band antenna.

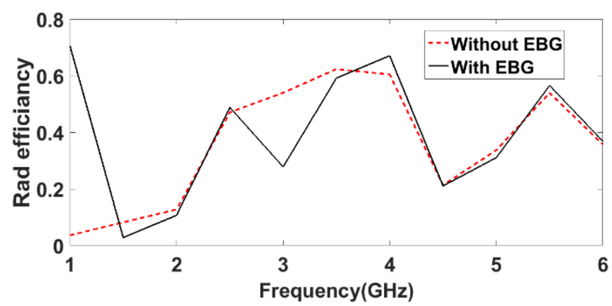


Fig. 16. Radiation efficiency plot

The dual band antenna has total efficiency of 0.52 and 0.49at 3.5 GHz and 5.8 GHz respectively as evident from **(Fig.17).** After coupling with EBG, there is a slight decrease in the total efficiency of proposed dual band antenna.

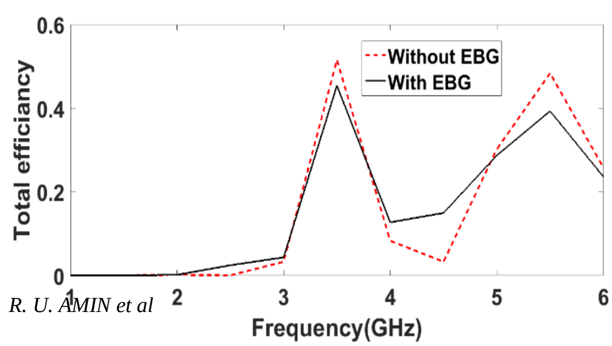


Fig. 17. Total efficiency plot

To calculate SAR value averaged over 10g, the head model was placed on the back side of antenna at a distance of 10mm from the antenna. SAR value of dual band antenna is 0.173Watt/Kg while after coupling with dual band EBG it reduces to 0.084Watt/Kg showing 51.5% reduction as shown in **(Fig.18).**

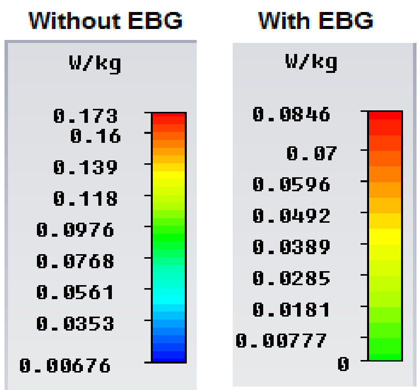


Fig. 18. SAR value of Dual band antenna with and without EBG

This SAR reduction is observed due to suppression of back lobe radiation as visible from the polar plot **(Fig. 19)** of electric field pattern of antenna with and without EBG structures.

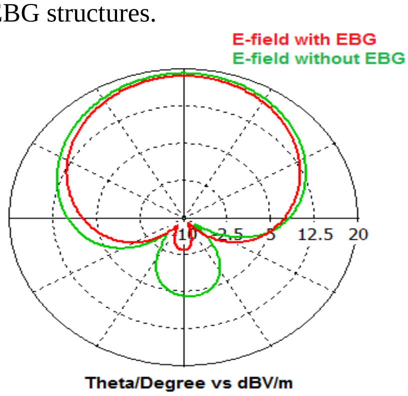


Fig. 19. E-field pattern of Dual band antenna with and without EBG

6. PARAMETRIC STUDY

Various parameters of dual band patch antenna has been varied and its effect on return loss of antenna has been investigated.

a) Variation with U_3

U_3 is the distance of inverted "L" slot from the edge of patch. It controls the upper band center frequency. The default value of U_3 is 7.Increasing the value of U_3 results in increase in upper band frequency while the lower band frequency remains unaffected. The variation of return loss for different values of U_3 has been shown in **(Fig. 20).**

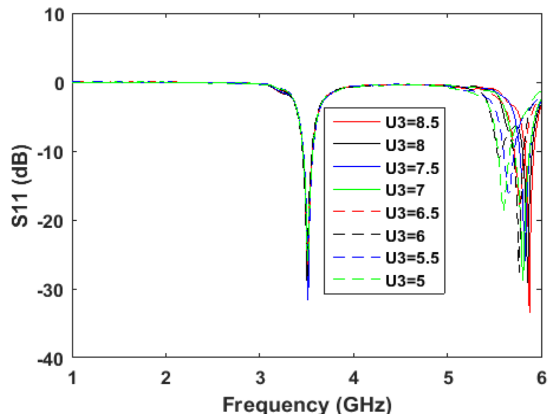


Fig. 20. Variation with U_3

b) Variation with U_2

$U_2$is the distance of "L" slot from the edge of patch. Increasing value of U_2 has the effect of decrease in upper band center frequency while decrease in U_2 increases the upper band frequency. Changes in U_2 has no effect on lower band. The default value of U_2 is 1. The variation of return loss with U_2 is shown in **(Fig. 21).**

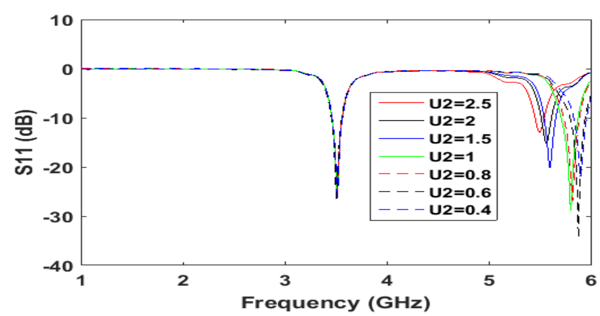


Fig. 21. Variation with U_2

c) Variation with L_1

L_1 is the length of long arm of both "L" slots. Its default value is 13. Increasing L_1 results in increasing lower band frequency and decrease in upper band frequency. Return loss for different values of L_1 is shown in **(Fig. 22)**.

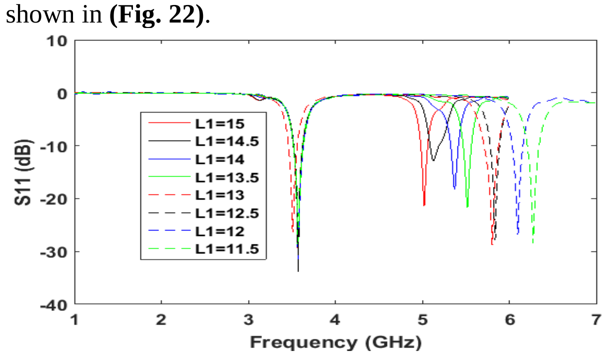


Fig. 22. Variation with L_1

d) Variation with L_2

L_2 is the length of short arm of both "L" slots. Its default value is 2.2. By decreasing L_2, the upper band frequency increases and lower band frequency remains unaffected. On the other hand increase in L_2 results in decrease in upper band frequency and increase in lower band frequency. The variation is shown in **(Fig. 23).**

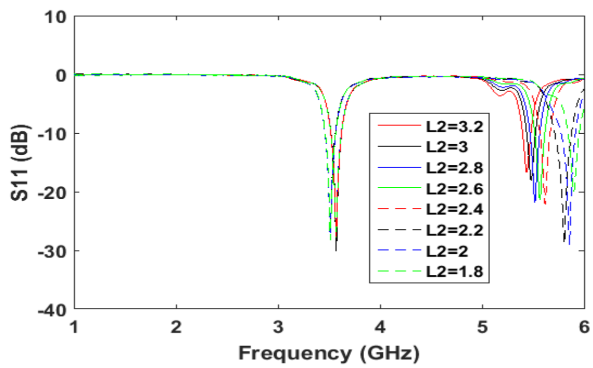


Fig. 23. Variation with L_2

7. CONCLUSION

This research combines the goals of bandwidth enhancement and SAR reduction. A SAR reduction of 82% is very impressive along with the increase in bandwidth from 100MHz to 150MHz. In addition to this, a dual band antenna is presented with reduced SAR and enhanced gain for 3.5 GHz and 5.8 GHz. The dual band antenna has very good matching for 3.5GHz and 5.8GHz. The dual band EBG, relatively simple in design, has achieved 51.5% reduction in SAR and 12.8% increase in gain. The antennas presented in this article are good candidates to be applied for Wimax applications.

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