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Design of a Wideband U – Slot Patch Antenna Using Spiral EBG Structure for WiMAX Applications

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***Abstract*–WiMAX technology is becoming popular for wireless communications now a days. Because of the advantages of U – slot microstrip patch antennas, they are being used for WiMAX applications very often. Hence, in this paper, a wide band U – slot patch antenna has been investigated. Spiral EBG (Electromagnetic Band Gap) structure is used to achieve wide band performance. Rogers RT/duroid 5880with dielectric constant of 2.2 & the thickness of 1.2mm is used for basic U – slot patch antenna design. Four arm spiral EBG structure having 1.2mm as the each arm width is used. Simulation results have shown that a wide bandwidth of 595MHz with 5.5GHz as the center frequency having a peak gain of 5.66dB. This is well suited for WiMAX frequency band 5.2GHz to 5.8GHz. Coaxial probe feeding has been used to feed the antenna. Simulations were carried out using Ansoft HFSS12 tool.**

Index Terms* – *U-slot patch antenna, Spiral EBG, WiMAX, Bandwidth, Gain, HFSS12.

I. Introduction

WiMAX is an importantarea of research in wireless communications present days. WiMAX (Worldwide Interoperability for Microwave Access) involves three frequency bands; 2.5GHz to 2.69GHz, 3.2GHz to 3.8GHz and 5.2GHz to 5.8GHz. WiMAX network needs widebandwidth and many operating frequencies to reach users in the differentplaces around the world [6].The microstrip patch antenna has become very popular in WiMAX communication system [3]. Due to the reliable features such as, high performance, high gain and low cost, microstrip patch antennas are used very often. Etching U – slots on the patch antenna is a very good technique to improve performance of the patch antennas. U – Slot patch antenna was first introduced in 1995 by Huynh and Lee [1]. In [1] microstrip patch antenna using U – Slot was designed at 2.5GHz for WiMAX applications. Double U – Slot patch antenna array was introduced in [2] from 5.3GHz to 5.8GHz for WiMAX. In [3], performance of differenttypes of spiral EBG structures has been studied and first resonant frequency of the spiral EBG surface was found to be 43.2% lower than the square patch EBG. In [4], a novel spiral EBG structure was discussed and the size of the spiral structure was only 30.9% of the conventional EBG structure with a 3dB of gain improvement. [5] Rectangularpatch antenna for different substrate heights was studied and increasing theheight of the dielectric substrate resulted in higher bandwidth of the antenna.

A. Previous work:

In [3], results had shown that, first resonant frequency of the spiral EBG surface was 43.2% lower than the square patch EBG. Further, they studied four arm spiral EBG structures with each spiral branches having $0.01\lambda_{12GHz}$ width&FDTD analysis technique was used. In [4], a novel spiral EBG structure was introduced where in the periodic cells were printed on a dielectric slab with permittivity 2.65 and thickness 2mm. Authors of [5] studied the performance of microstrip patch antenna with different substrate heights.Here, antennas were designed for wireless LAN applications at frequency 2.45GHz. Five antennas with different heights were designed using same substrate material (nylon (610)) having permittivity of 2.84. Coaxial probe-feed method was used and FEKO simulator with Method of Moments (MoM) technique was used. Increasing the substrate height resulted in wide bandwidth &expansion of the size of antenna, increased return loss, VSWR and better directivity.

In the proposed design, U – slot patch antenna using RT/duroid 5880 with dielectric constant, ε_r = 2.2is designed. To obtain a wideband characteristics, two layers of four arm spiral EBG structures are used. In addition, substrate height of the spiral EBG loaded antenna is increased to get optimized results. Antenna works for WiMAX frequency from 5.2GHz to 5.8GHz. Design and simulation results are discussed in the following sections.

II. Wideband U – Slot Patch Antenna Design

A. U – Slot Microstrip Patch Antenna Design:

The proposed antenna consists of a ground plane,Rogers RT/duroid5880 substrate material, U - Slot patch and coaxial feeding. Antenna geometry is as shown below and is considered as the base antenna.

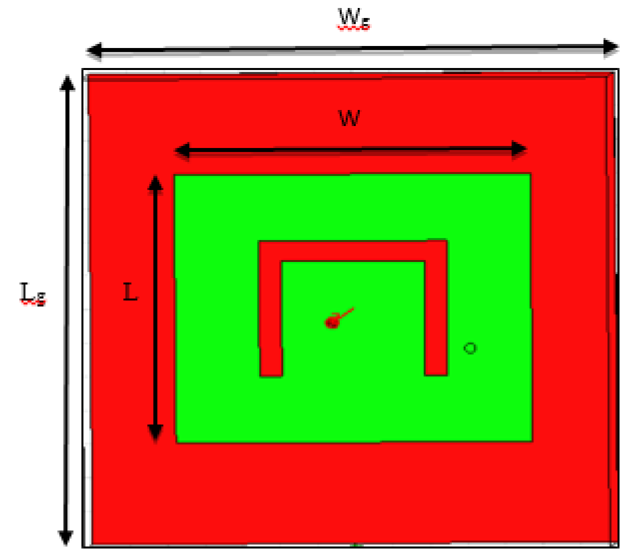

Fig. 1 U – Slot microstrip patch antenna.

TABLE I
SPECIFICATIONS OF THE BASE ANTENNA

Parameters	Description
Substrate height	1.2mm
Substrate material	Rogers RT/duroid 5880 (tm)
Dielectric constant, ε_r	2.2
Substrate: Length, L_g Width, W_g	70mm 70mm
Patch: Length, L Width, W	39.89mm 47.43mm
U-Slot – vertical arms: Length Width	20mm 3mm
U-slot – horizontal arms: Length Width	25mm 3mm
Probe feed location, (X,Y)	(6,15.5)

1) Design Equations:

$$\text{Patch width, } W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad \text{.......................................} (1)$$

$$\Delta L = h \times 0.412\left[\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right] \quad \text{.......................} (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right] \quad \text{..............................} (3)$$

$$Patch\ Length, L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad \text{...........................} (4)$$

c = Speed of light
ε_r = Dielectric constant of the substrate
ε_{eff} = Effective dielectric constant
f_r = Design frequency
h = Height of the substrate
ΔL= Extension of the patch length

B. Base Antenna with Spiral EBG (Electromagnetic Band Gap) structures:

Electromagnetic Band Gap structures improve the performance of patch antennas by eliminating surface waves. This paper proposes a four arm spiral EBG structure with each spiral branches having $0.01\lambda_{2.5GHz}$ width, split from the center and rotate outwards. Since the geometry is symmetric in both*x*-and*y*- directions. The scattering responses to the *x*- and *y*-polarized fields are identical. As a result, the cross polarized components can be canceled [3].Basic geometry of four arm spiral EBG structure is shown next:

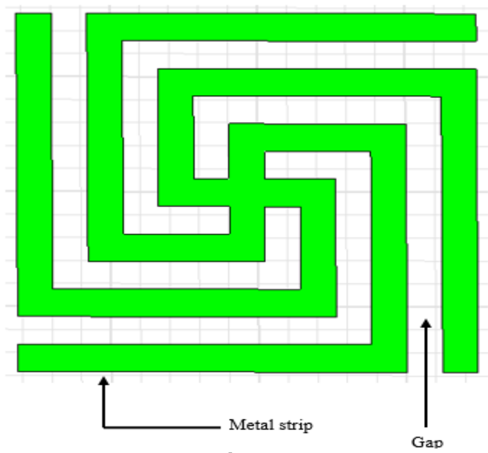

Fig. 2 Spiral EBG structure

TABLE II
SPECIFICATIONS OF THE SPIRAL EBG STRUCTURE

Parameters	Description
Spiral width	$0.01\lambda_{2.5GHz}$ = 1.2mm
Gap b/w metal strips	$0.01\lambda_{2.5GHz}$ = 1.2mm
Separation b/w EBGs	$0.01\lambda_{2.5GHz}$ = 1.2mm
Length*Width of EBG	15.6*15.6 (in mm)

Two layers of spiral EBG structures have been loaded on U – Slot patch antenna to achieve wide bandwidth and higher gain.In order optimize the performance of the antenna substrate height is incremented to 3.2mm.Probe feed location, (X, Y) is chosen as (0.75, 14.5). Geometry of the U - Slot antenna using spiral EBG is shown below:

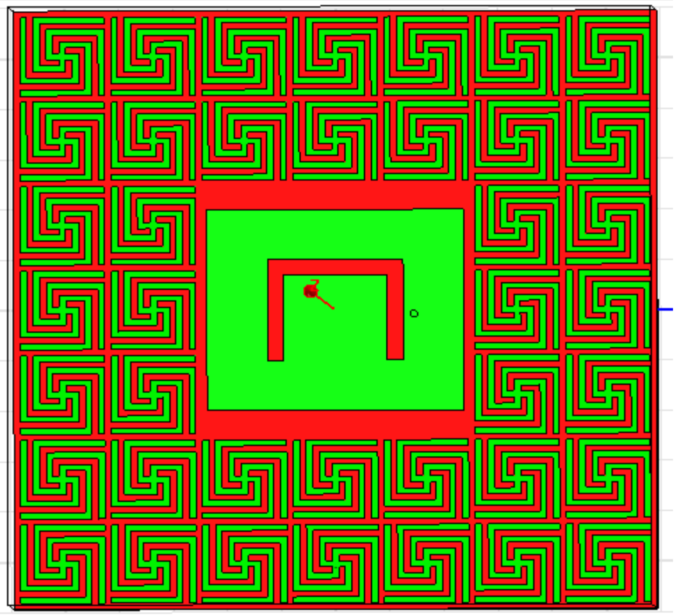

Fig. 3 Base antenna with Spiral EBG structure

III. Simulation Results

Simulations were carried out using Ansoft HFSS12 simulation tool which is a high performance full wave electromagnetic (EM) field simulator.Ansoft HFSS can be used to calculate parameters such as return loss, gain, band width and VSWR etc.

A.U – Slot Patch Antenna:

Plots of return loss, gain and radiation pattern of the base antenna are shown below:

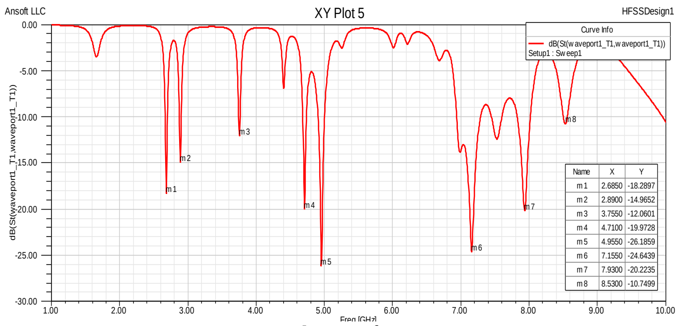

Fig. 4 Return loss v/s frequency

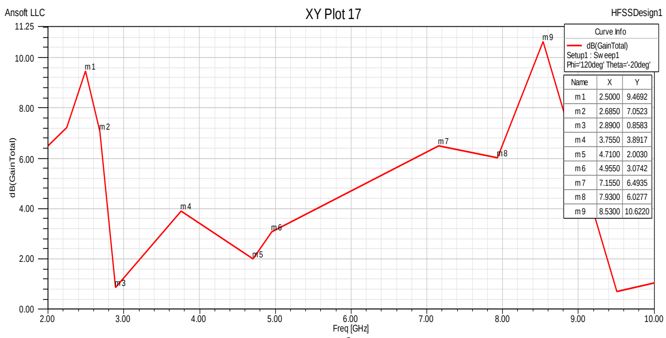

Fig. 5 Gain v/s frequency

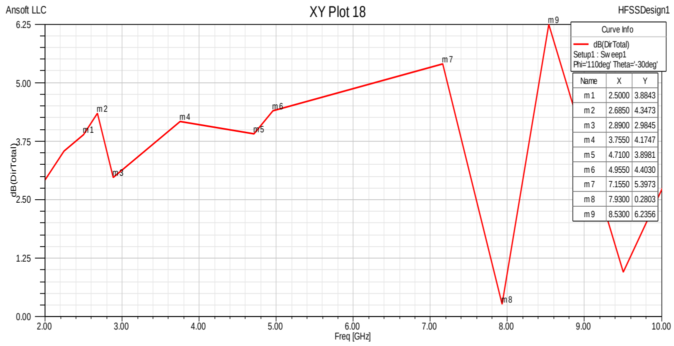

Fig. 6 Directivity v/s frequency

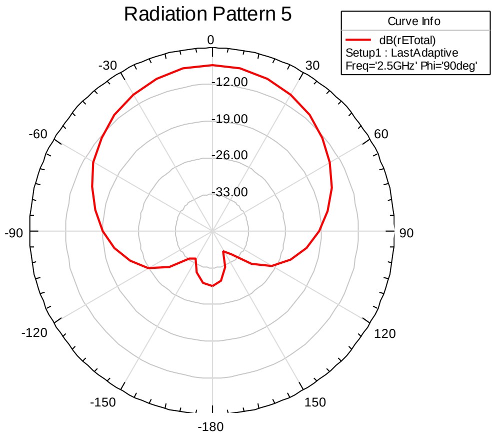

Fig. 7 Radiation Pattern

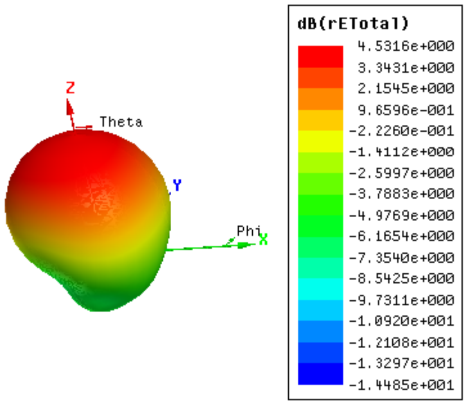

Fig. 83D polar plot

The results show that, we get five resonances at 2.685GHz, 2.89GHz, 3.755GHz, 4.71GHz and 4.955GHz with return loss/S11 of -18.28dB, -14.96dB, -12.06dB, -19.97dB and -26.18dB respectively. The peak gains (in dB) at these frequency are: 7.05, 0.85, 3.89, 2.00 and 3.07 respectively. This design can be used for the WiMAX frequency ranging from 2.5GHz to 5GHz for narrowband applications.

B. U – Slot Patch Antenna with Four Arm Spiral EBG:

To improve the performance of the antenna in terms of bandwidth with good gain, spiral EBG structures are loaded and substrate height is increased. Wide band performance of the base antenna loaded with spiral EBG structures are as shown below:

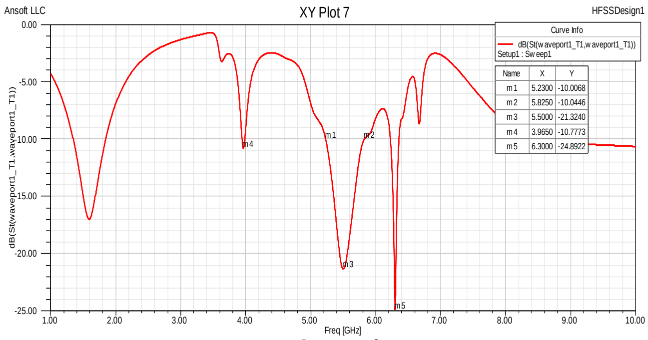

Fig. 9 Return loss v/s frequency

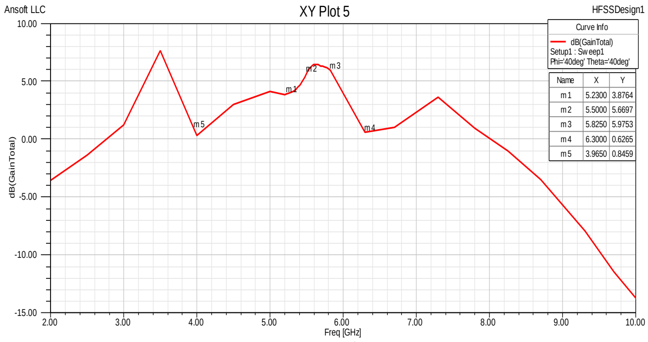

Fig. 10 Gain v/s frequency

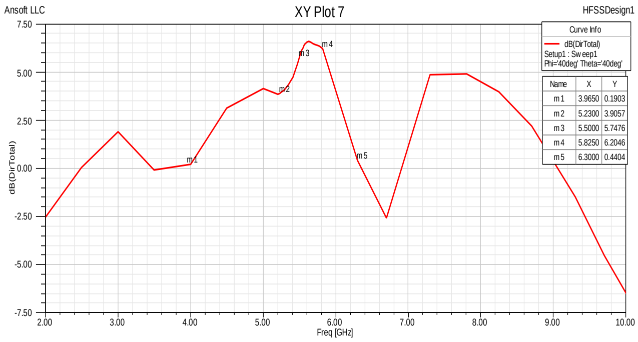

Fig. 11 Directivity v/s frequency

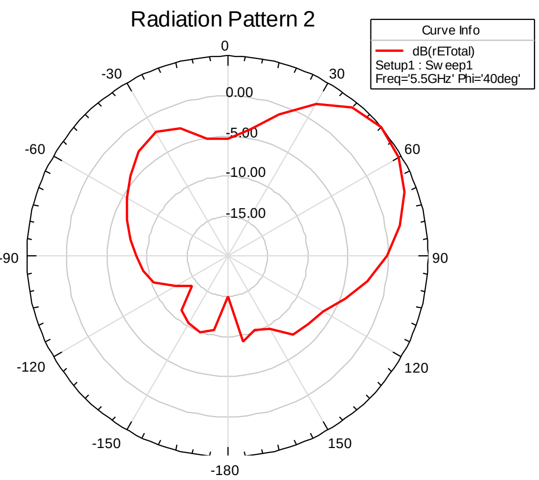

Fig. 12 Radiation Pattern

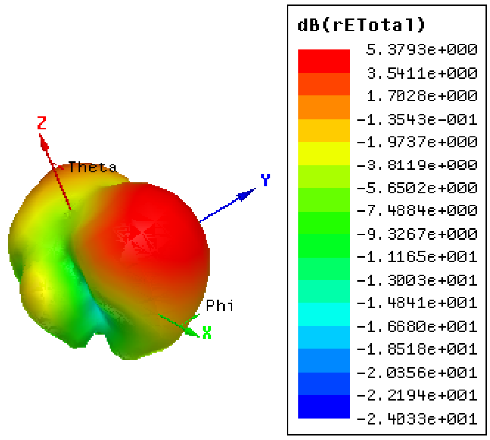

Fig. 133D polar plot

As we can see, a -10dB bandwidth of 595MHz from 5.23GHz to 5.825GHz is obtained. A maximum gain of 5.66dB is obtained at the center frequency 5.5GHz with a return loss of -21.32dB &the VSWR is 1.18. The overall gain inside the bandwidth is almost constant with a values around 5dB as shown in fig. 9. Hence, it gives well satisfied performance characteristics for use in WiMAX applications in the frequency band 5.2GHz to 5.8GHz.

TABLE III
COMPARISON OF SIMULATION RESULTS OF BASE ANTENNA WITH & WITHOUT EBG STRUCTURE:

Antenna	Resonant Frequency (GHz)	Reflection coefficient (dB)	VSWR	Gain (dB)	Directivity (dB)
Base antenna	2.685 2.89 3.755 4.71 4.955	-18.28 -14.96 -12.06 -19.97 -26.18	1.27 1.65 1.66 1.46 1.10	7.05 0.85 3.89 2.00 3.07	4.34 2.98 4.17 3.89 4.40
Base antenna with Spiral EBG	3.965 5.50	-10.77 -21.32	1.81 1.18	0.84 5.66	1.19 5.74

IV. COMPARATIVE STUDY

As the above table shows,in the base antenna, we obtained a very narrow bandwidth & satisfactory gain. In the case of antenna without EBG structures, it cannot be used for wide bandwidth applications in because of its narrow band.Use of spiral EBG structures has improved the performance of the U – Slot antenna/base antenna considerably. But, there is huge improvement in bandwidth, gain & directivity of the base antenna after applying spiral EBG structures. But, with spiral EBG structures, antenna resulted in huge -10dB bandwidth of 595MHz with gain of 5.66dB & directivity of 5.74dB. Here, the antenna with EBG structure can be used for WiMAX applications in 5.2GHz to 5.8GHz range because its gain & are constant around 5dB in that range.

V. CONCLUSION

This paper proposes a wideband antenna with a bandwidth of 595MHz with 5.5GHz as the center frequency.Maximum gain of 5.66dB at 5.5GHz is obtained. Return loss and VSWR at 5.5GHz are -21.32dB and 1.18 respectively. Peak directivity at 5.5GHz is 5.74dB. These characteristics satisfy the requirements of WiMAX applications and hence can be used for WiMAX in 5.2GHz – 5.8GHz range. These characteristics of the antenna are achieved by the use of four arm spiral EBG structures to the U – Slot microstrip patch antenna and increasing the substrate height. Proposed antenna will be fabricated, tested and practical results will be compared with the simulation results for further analysis in the future.

VI. SCOPE FOR FUTURE WORK

The proposed antenna model can be further improvised for better results in the low frequency band of WiMAX; that is, from 2.5GHz – 2.69GHz & 3.2GHz – 3.8GHz. Different feeding methods such as, line feed, proximity feed etc. can be used. Since the introduction of spiral EBG structures increased the antenna size, space filling curve EBG structures [3] such as hilbert curve & piano curve can be applied to patch antenna for antenna size miniaturization. Other improvising techniques such as use shorting pins, etching slits on the patch can be used.

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