Hexagonal Shaped Microstrip Patch Antenna for Satellite and Military Applications

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Abstract: In this work, investigation of the effect of different slots in a hexagonal shaped microstrip patch antenna is presented. The proposed antenna is designed on FR4-epoxy substrate and the performance is obtained by using CST Microwave Studio. The antenna has been analyzed for various dimensions of slots and the optimum design has been chosen. By increasing the number of slots, the gain, bandwidth and return loss of the structure has been improved. The simulated antenna structures also show dual band characteristics. The antenna offers application in WiFi IEEE802.11n (2.4 to 5 GHz) and UWB range especially for X-band uplink satellite system (7.9–8.4GHz). As the designed structures resonate in C-band (4-8 GHz), it offers applications in Fixed Satellite Services (FSS) and military also.

Index Terms: Microstrip Patch Antenna, Ultra Wide Band, Fixed Satellite Services, Return Loss.

I. INTRODUCTION

As the demands of wireless systems have increased day by day, low profile systems have drawn the interest of the researchers towards the Microstrip Patch Antennas [1]. The growing wireless communication systems require small size and compact antennas which have wider bandwidth than conventional antenna design [2]. In the design of communication systems of low-profile, size of antenna is a most critical factor. Therefore, miniaturization techniques are used for the design of different kinds of antennas [2].

Multiband antennas provide an effective integration of several communication standards, in addition to low-cost and high data rate features. Multiband antennas can be designed by feeding techniques [1–3], etching slots [4–6], adding multi-branched strips, fractals etc. Slots create some sort of discontinuity in the electric current path leading to positive impact on input impedance thereby creating additional resonance frequencies. Research shows that cutting slots and slits in radiating patch and ground plane [8-12] shift the operating frequency and increase resonating frequencies.

The proposed antenna works in the WiFi IEEE802.11n (2.4 to 5 GHz) and UWB range especially for X-band uplink satellite system (7.9–8.4GHz). This structure can also be used for C-band (4-8 GHz) applications in Satellite communication and also for medical uses to detect cancers and tumors where the safe frequency range for human tissues is 4 GHz - 9.5 GHz. A small-size hexagonal patch antenna is made using circular slots. By increasing the number of slots and decreasing the size of the slots, we can observe that the gain of the proposed antenna has been increased. The paper is divided into three more sections. Section II shows the antenna design, Section III shows the parametric study of hexagonal patch antenna and Section IV shows the parametric study of proposed antenna. A comparative study of hexagonal patch antenna with the proposed antenna with slots is discussed in Section V.

II. ANTENNA DESIGN

The microstrip antenna consists of a very thin patch placed above a ground plane. The patch can be of any shapes such as rectangular, circular, triangular.

In this work, the hexagonal patch with slots is selected for the analysis. Although the transmission line model yields less accurate results, it is a very simple model and provides a good physical insight of the basic antenna performance. Among the various feeding methods, microstrip line feed is chose as it is simple to model and easy to fabricate.

A. Design of Rectangular Patch

The model of Microstrip Antenna can be represented by two slots of width (W) and height (h) separated by transmission line of length (L).

The width of the patch can be calculated from the following equation [7].

$$W = \frac{v_0}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}$$

(1)

The effective dielectric constant of the substrate can be calculated as follows,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12\frac{h}{W}}}$$

(2)

The actual length of the antenna is different from the calculated L since the fringing field also needs to be considered here. The actual length is calculated by subtracting the excess lengths from both the sides of the patch. The length of the Patch Antenna L is given by,

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$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 0.824h\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \quad (3)$$

Higher values of permittivity allow a shrinking of the Patch Antenna. Particularly in cell phones, the designers are given very little space and want the antenna to be a half-wavelength long. One technique is to use a substrate with a very high permittivity. The actual length of the Patch Antenna is given by,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

The length (Lg) and the width (Wg) of a ground plane are calculated using the following equations,

$$Lg = 6h + L \quad \text{and} \quad Wg = 6h + W \quad (5)$$

Hence, if the permittivity is increased by a factor of 4, the length required decreases by a factor of 2. Using higher values for permittivity is frequently exploited in antenna miniaturization. The height of the substrate h also controls the bandwidth - increasing the height increases the bandwidth.

B. Design of Hexagonal Patch

The aim is to design a patch shape other than rectangle; a rectangular patch for the particular frequency is designed initially. The parameters of rectangular patch are modified to obtain the dimensions of the other patch shapes like circular, hexagonal etc. The radius 'a' of a circular patch whose resonant frequency is *fr* is given by,

$$a = \frac{X_{mn}c}{2\pi f\sqrt{\varepsilon_r}} \quad (6)$$

$Xmn = 1.811$ for $TM11$ mode

The effective radius of the patch can be calculated as,

$$a_e = a\left[1 + \frac{2h}{\pi\varepsilon_r a}\left(\ln\left(\frac{\pi a}{2h}\right)+1.7726\right)\right]^{\frac{1}{2}} \quad (7)$$

If the patch is hexagonal, then the sides of the hexagon can be calculated using the effective radius of the circular patch. The side of the hexagonal patch S is given by,

$$S^2 = \frac{2\pi a_e^2}{3\sqrt{3}} \quad (8)$$

C. Design Specifications

All of the parameters in a Rectangular Patch Antenna design (L, W, h, permittivity) control the properties of the antenna. Table I gives the design specifications of the standard rectangular patch and hexagonal patch.

Table I. Design Specifications of Patch

Substrate material used	FR4 (εr=4.3)
Thickness between ground and fed patch (h)	1.6 mm
Length of the rectangular patch (L)	9.698 mm
Width of rectangular patch (W)	13.163 mm
Radius of the circular patch (a)	6.056 mm
Width of the ground plane (Wg)	22.763 mm.

The length of the ground plane (Lg)	19.298 mm.
The side of the Hexagonal Patch (S)	6.0 mm

## III. PARAMETRIC STUDY OF HEXAGONAL ANTENNA

There are various parameters, which can be used to tune the antenna. The major among them are the slot length, slot width, feed line width and position of the patch relative to the slot. The performance parameters such as return loss, bandwidth and radiation patterns of the hexagonal antenna are discussed below. The basic structure is that of a Hexagonal Patch Antenna shown in Fig.1.

6 mm
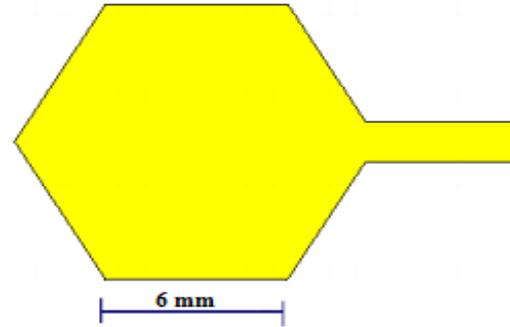
Fig.1. Hexagonal Patch Antenna

1. Return Loss

The response S (1, 1) shows in Fig.2 and the antenna resonates at 7.38 GHz with a Return Loss of -14.6 dB. The antenna has a bandwidth of 0.701 GHz. The area of hexagonal patch is 99.47 mm.sq.
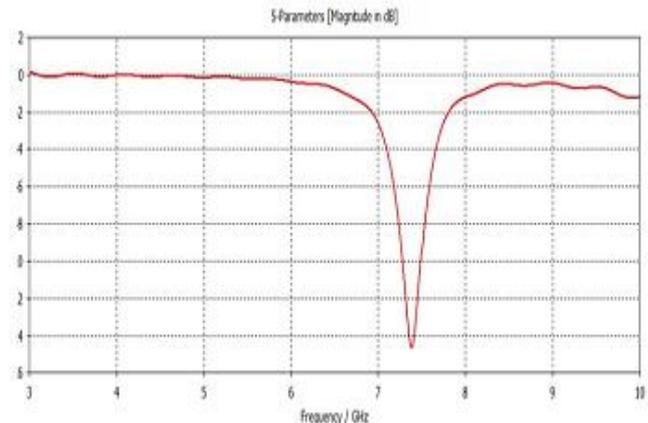
Fig.2. Plot of S Parameters versus Frequency

2. Radiation Pattern

The Radiation property of any antenna can be analyzed to understand the distribution of power around the orientation. The simulated gain pattern of the antenna can be studied at various resonant frequencies.
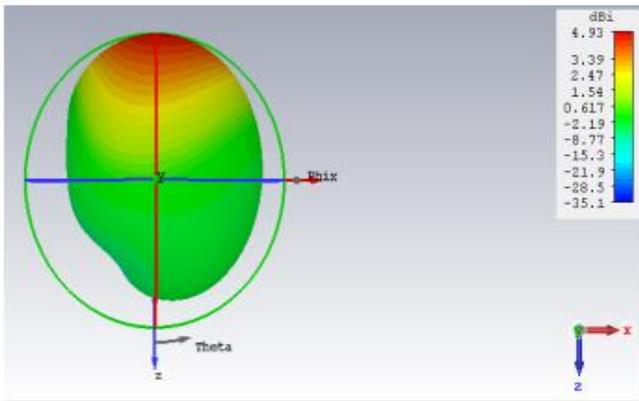
Fig.3. Radiation Patterns at 7.38 GHz

The Radiation pattern of the antenna shows (Fig. 3) that the antenna has a gain of 4.93 dBi.

IV. PARAMETRIC STUDY OF PROPOSED ANTENNA

The performance parameters such as return loss, bandwidth and radiation patterns of the proposed antennas are discussed below. In slotted hexagon antennas, a basic hexagon is designed at 7.38 GHz. Different kinds of slots are incorporated in the patch and the results are studied.

A. Structure 1

The basic structure is that of a Hexagonal Patch Antenna. Circular slots were incorporated in the antenna and are shown in Fig.4. A larger circular slot of diameter 2 mm was created in the center of the patch. Four smaller circles of diameter 0.5 mm were also generated around the central slot.
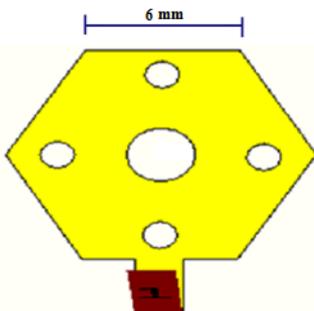

Fig.4. Structure1

1. Return Loss

The response S (1, 1) shows in Fig.5, that antenna resonates at two different frequencies. The antenna provided a return loss of -22.266 dB at 4.8 GHz with a bandwidth of 0.48633 GHz. At 7.98 GHz, the antenna radiated with a return loss of -19.113 dB and a bandwidth of 0.8263 GHz.
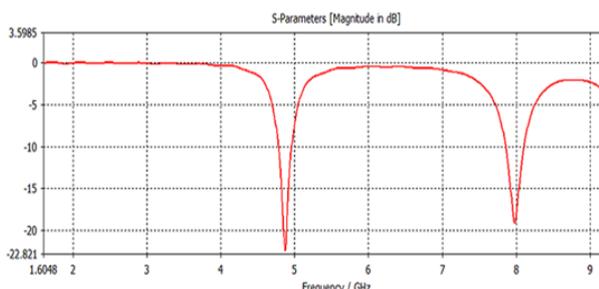

Fig.5. Plot of S Parameters versus Frequency

2. Radiation Pattern

The Radiation property of any antenna can be analyzed to understand the distribution of power around the orientation. The simulated gain pattern of the antenna can be studied at various resonant frequencies.
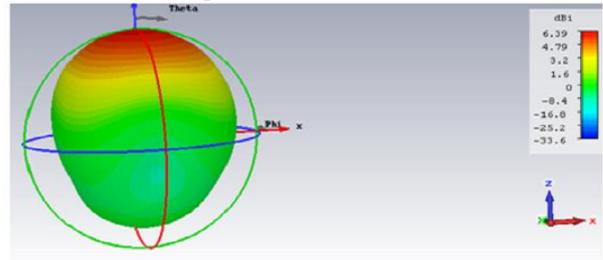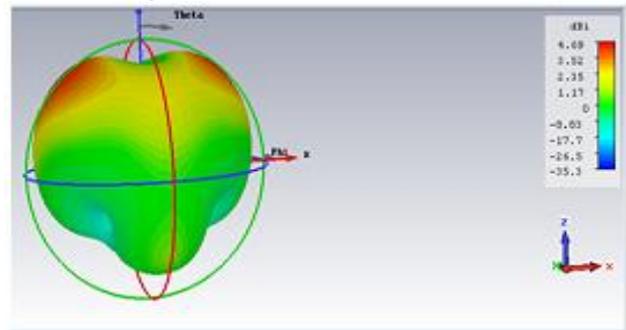

Fig.6. Radiation Patterns at 4.8 GHz

Fig.7. Radiation Patterns at 7.98 GHz

The Radiation patterns of the antennas at both the frequencies are as shown in Fig.6 and Fig.7. The gain at 4.8 GHz is 6.39 dBi and the gain at 7.98 GHz is 4.69 dB. The area of the patch is 83.76 mm.sq. The improvement in bandwidth when compared to basic hexagonal patch at 4.8 GHz and 7.98 GHz are -44.1 % and 15.1 % respectively. The reduction in area of the patch when compared to basic patch is 18%.

B. Structure 2

The larger circular structure at the center is of diameter 2 mm and twelve smaller circular structures of diameter 1 mm are placed around the larger circle as shown in Fig.8.
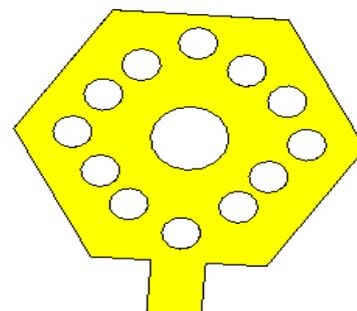

Fig.8. Structure 2

1. Return Loss

The response S (1, 1) shows in Fig.9, that antenna resonates at two different frequencies. The antenna provided a return Loss of -22.69 dB at 4.8 GHz with a bandwidth of 0.521 GHz. The antenna also resonates at 7.91 GHz with a Return Loss of -19.227 dB and a bandwidth of 0.795 GHz.

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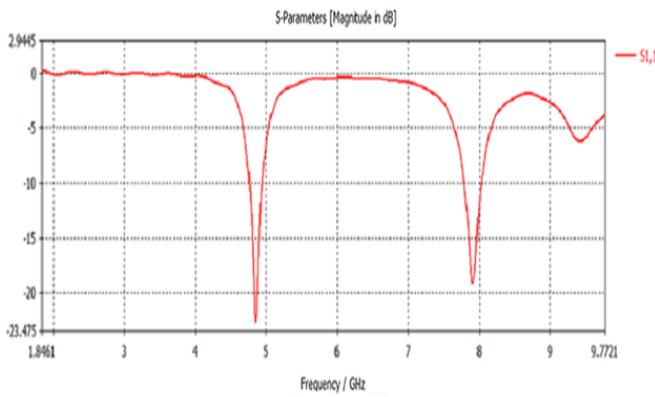
Fig.9. Plot of S Parameters versus Frequency

2. *Radiation Pattern*

The Radiation property of any antenna can be analyzed to understand the distribution of power around the orientation. The simulated gain pattern of the antenna can be studied at various resonant frequencies.
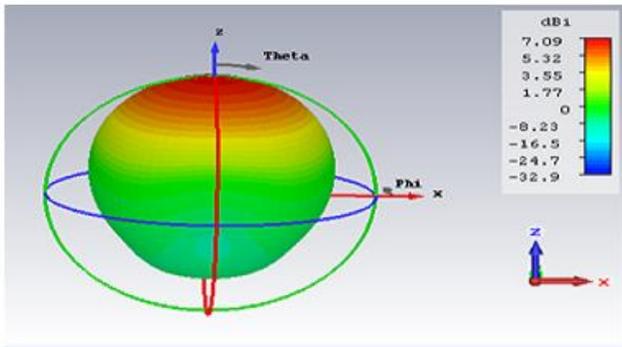
Fig.10. Radiation Patterns at 4.8 GHz
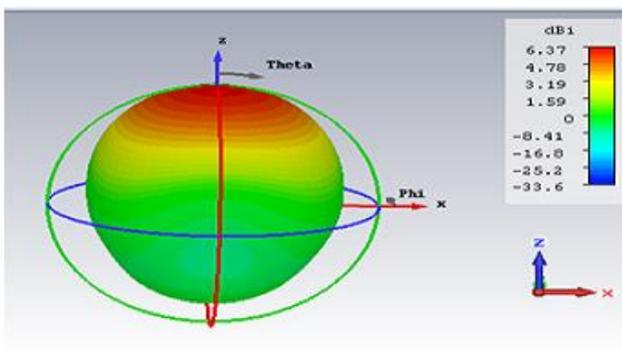
Fig.11. Radiation Patterns at 7.91 GHz

The Radiation patterns of the antennas at both the frequencies are as shown in Fig.7 and Fig.8. The gain at 4.8 GHz is 7.09 dBi and the gain at 7.91 GHz is 6.37 dBi. The improvement in bandwidth when compared to the basic hexagonal patch is -34.5 % at 4.8 GHz and is 11.823 % at 7.91 GHz. The area of the patch is 61.7 mm. sq. The reduction in area when compared to the simple hexagonal patch is 61.2 %.

V. COMPARATIVE STUDY

Table II shows the comparison of conventional hexagonal patch antenna and the hexagonal patch antenna with slots in terms of operating frequency, return loss, gain and bandwidth.

Table II. Comparison of Antenna Parameters

	Resonating Frequency (GHz)	Return Loss (dB)	Band width (GHz)	Area (mm. sq.)	Gain (dBi)
Hexagonal Patch Antenna	7.38	-14.6	0.701	99.47	4.93
Hexagonal Patch Antenna with slots					
Structure 1	4.8	-22.26	0.486	83.76	6.39
	7.98	-19.11	0.826		4.69
Structure 2	4.8	-22.69	0.521	61.7	7.09
	7.91	-19.22	0.795		6.37

The proposed Hexagonal Patch Antenna with slots shows multiband behavior characteristics with improved bandwidth. By increasing the slots, the gain of the antenna is also improved and reduction in area is also achieved.

VI. CONCLUSION

In this work, the proposed antenna works in the WiFi IEEE802.11n (2.4 to 5 GHz) and UWB range especially for X-band uplink satellite system (7.9–8.4GHz) applications. The designed antenna structures can also be used for C-band (4-8 GHz) applications in Satellite communication and also for medical uses to detect cancers and tumors where the safe frequency range for human tissues is 4 GHz - 9.5 GHz. By introducing slots in standard hexagonal patch antenna, it is observed that the gain and the bandwidth have been improved. The proposed structure shows dual band characteristics with a lower value of return loss. From the analysis, it is observed that introduction of slots create some sort of discontinuity in the electric current path leading to positive impact on input impedance thereby creating additional resonance frequencies. In Structure 1, the improvement in bandwidth when compared to basic hexagonal patch at 4.8 GHz and 7.98 GHz are -44.1 % and 15.1 % respectively. The reduction in area of the patch when compared to basic patch is 18%. In Structure 2, the improvement in bandwidth when compared to the basic hexagonal patch is -34.5 % at 4.8 GHz and is 11.823 % at 7.91 GHz. The area of the patch is 61.7 mm. sq. The reduction in area when compared to the simple hexagonal patch is 61.2 %.

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