Parametric Analysis and Optimization on Modified Hexagon Shaped Antenna Amalgamated with Staircase to Accomplish Wide Impedance Bandwidth suitable for Wireless Portable Applications

Ria Kalra[1]. Dr.Manoj Kumar[2]
[1]*(Electronics and Communication Engineering, Research Scholar, IK Gujral Punjab Technical University, India)*
[2]*(Electronics and Communication Engineering, Principal, DAVIET, India)*

Abstract

The highlights of this paper are a detailed parametric analysis and optimization on a modified hexagon shaped antenna. Staircase is amalgamated in the designed antenna after carefully observed parametric variations in the geometry. The modified shape of the proposed antenna contributed in enhancement of Bandwidth as observed in the simulation results. The proposed modified hexagon shaped antenna amalgamated with staircase is found suitable for wireless portable applications. HFSS (Version 15.0) is used for designing and analyzing the proposed antenna and provides wide impedance bandwidth between 3 GHz to 30 GHz for VSWR < 2. Parametric analysis and optimization is done on significant design parameters to attain minimal return loss characteristic of -15.30 db obtained at 19.1 GHz and exhibiting good radiation performance over the entire frequency range. The prototype antenna is fabricated and tested to measure the experimental results. A reasonably fine agreement is observed in the simulated & measured results. The proposed antenna exhibits advantages of compact geometry and simultaneously shows minimal return loss characteristics and wide impedance bandwidth. Thus, it is considered appropriate for wireless portable applications such as GPS (1.57 GHz), GSM (1.8 GHz), Wi-Max (2.3 GHz) and WLAN (2.45 GHz).

Keywords *- Impedance bandwidth, microstrip patch antenna, microstrip line feed, reduced ground plane, ultra wide band.*

I INTRODUCTION

The advancement in Wireless Communication by the introduction of 5 G Technology has generated a contemporaneous spurt of Wireless Applications. With such a revolution in wireless technology, the necessity of designing high performance antennas adaptable with the new technology has greatly increased. As the number of users is increasing day by day in this modern era of wireless communication wide bandwidth has become an essential requirement for researchers working on designing antennas compatible with modern wireless technology. Frequency range of 3.1 to 10.6 GHz has already been approved by FCC as UWB wireless communication technology applying to civil and personal communication system. Emphasis on bandwidth enhancement is given to achieve high data rate and simultaneously miniaturization techniques has been incorporated for designing compact antennas. Low profile compact microstrip patch antennas are quite prevalent these days due to its numerous advantages such as conformability with substrate surface, low cost and ease of manufacturing and fabrication. Though there are certain disadvantages of these antennas such as low radiation efficiency, low power handling capability, narrow impedance bandwidth etc. Considering both the advantages and disadvantages researchers are trying to maintain a tradeoff between them. The major focus of researchers is to design wideband antennas. A number of techniques such as novelty in the patch antenna shapes, parametric analysis by introducing slots in the geometry, stacking of patch, meta - material loading, introduction of defects in the ground structures etc are experimented to achieve wide impedance bandwidth. From the outcome of research from the last few years by researchers, it is quite evident that a wide variety of UWB antennas have proved as potential techniques for improving the spectrum efficiency of cellular radio systems. Day by day there are growing numbers of applications, which involve the radiation or reception of electromagnetic signals over ultra-wide frequency bandwidth [1]. Therefore, the demand has swiftly risen, for compact and cheap antennas that can provide satisfactory performance in both time and frequency domains in the entire UWB Range.

In addition, the trend in modern wireless communication systems, including UWB based systems, are to build on small, low-profile integrated circuits in order to be compatible with the portable electronic devices. This resulted in numerous studies on UWB microstrip antenna, which specifically focused on the optimization techniques for designing antennas radiating in the UWB Range [2] - [5]. In the planar structure, the antenna can be easily and conveniently printed onto a piece of printed circuit board which easily satisfies the requirements for small UWB antennas and can be used for portable applications. Due to this advantage, industry and academia have been putting enormous efforts on researches to study, design and develop planar antennas for UWB communication system. Basically a printed antenna consists of a planar radiator and ground plane etched oppositely onto the dielectric substrate of the PCBs. The radiators can be fed by a microstrip line or coaxial cable depending upon the convenience. The electric currents in these antennas are distributed both on the radiating element and on the ground plane, and the radiation from the ground plane is unavoidable, which also need to be managed by doing modifications in the geometry. Therefore, the performance of the printed UWB antenna is considerably affected by the size and shape of the ground plane in terms of operating bandwidth, gain, directivity and radiation patterns.

In literature various papers have been published on printed UWB Antenna such as a broadband microstrip antenna using aperture coupling feed where dual H-shaped slots at proper angles were used to achieve the high isolation between ports and to get dual polarization [5], square patch antenna simultaneously fed on all four sides using proximity coupled feed is introduced to get broad impedance bandwidth (0.85–2.42 GHz) with circular polarization, suitable for navigation and radar applications[6], a compact patch antenna driven by shifted microstrip feed and step transformer, two parasitic patch elements are used to obtain the wide bandwidth between 4.9 and 7.05 GHz along with high peak gain of 8.9 dBi [13], defected ground plane with diagonal edges and L-Shaped slot to increase the impedance bandwidth performance (1.8–12 GHz), circular patch antenna where two shorting pins are loaded at certain angular position to achieve the broadband performance [8] etc.

In the present work detailed parametric analysis is done on the proposed antenna. The results are optimized by modifying the geometry of proposed antenna, by varying the feed length, by introducing defects in the ground structure etc. After various parametric variations, a staircase structure is introduced in the hexagon shaped antenna contributing enhancement in bandwidth. The proposed antenna provides wide impedance bandwidth between 3 GHz to 30 GHz for VSWR < 2 with a minimal return loss characteristic of -15.30 db obtained at 19.1 GHz and exhibiting good radiation performance over the entire frequency range.

Section II discusses the detail parameters calculation and geometrical model of the proposed antenna design. Section III describes the parametric study on improvised stable return loss by using modified hexagon shaped antenna. The conventional hexagon shape is modified by introducing stairs in the radiator and size reduction is done by introducing defects in the ground structure. The comparison graphs of simulated results are presented and results such as bandwidth, gain, and radiation pattern in tabular form will be discussed in Section IV. The last section will be conclusion that will conclude the entire research findings.

II PROPOSED ANTENNA DESIGN SPECIFICATIONS

The chosen substrate for designing the prototype antenna is FR4 epoxy, which is mechanically robust having dielectric constant of 4.4 and loss tangent of 0.02 and is easy available in market. The modified hexagon shaped antenna is amalgamated with staircase on one side and defects in the ground structure are provided on reverse side of substrate to enhance the impedance matching.

After computing the dimensions of the geometry by applying the formulas as given in the literature, the optimum values chosen for the antenna geometry is a length of L=22 mm and width of W=26 mm. The excitation is launched through a 50 Ohm microstrip feed line, which has the stepped feed line length of 6 mm and feed line width of 1.5 mm on one side of the dielectric substrate of thickness 2.2. Mathematical calculations are done to calculate the optimum values of width and length of the proposed antenna by taking fo = 4.5 GHZ and c = 3 x 108 m/s. The dimensions of the geometry are finalized after parametric optimization. After optimization of parameters, the final shape of radiator is chosen which results in improvement of impedance bandwidth as shown in Figure 1.A 50-Ω SMA (Sub Miniature version-A) connector is connected to provide excitation signal at the end of line feed. The ground plane is truncated by stepped geometry, in other words we can say that defects are introduced in the ground structure as shown in Figure 2.The proposed antenna is designed and simulated on 3-D electromagnetic solver named as HFSS (high frequency structure simulator) version 15.0. The dimensions of designed patch antenna are listed in Table 1.

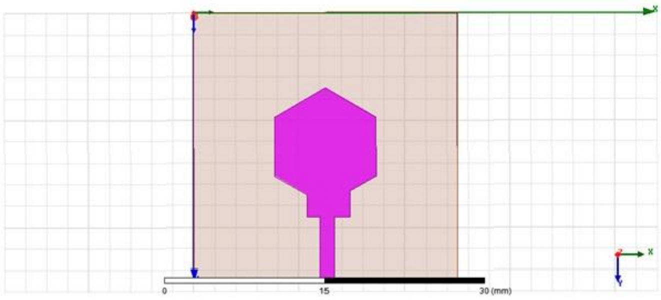

Fig. 1 Modified hexagon-shaped patch antenna radiator

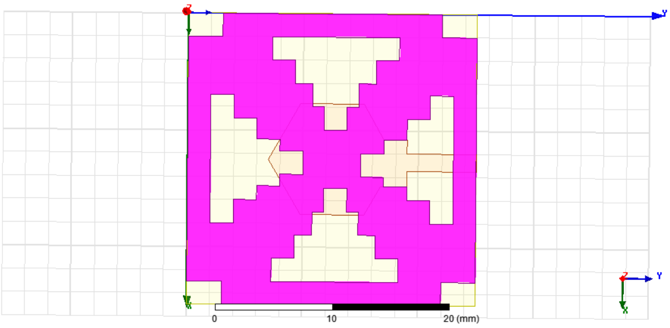

Fig. 2 Modified hexagon-shaped patch antenna ground plane

Table 1 Dimensions of Modified hexagon shaped patch antenna

Design Parameters	Dimensions (mm)
Feed Length	6
Feed Width	1.5
Hexagon side Length	5.5
Substrate side length	22
Substrate side width	26
Substrate thickness	2.2
Dielectric Constant	4.4

III OPTIMIZATION OF PARAMETERS

Simulation to the proposed antenna is carried out using High Frequency Structure Simulator to determine the performance of Antenna. For designing a patch antenna optimization of parameters is an important technique for optimum antenna realization. The proposed antenna is designed to provide ultra wideband performance for upper L band and lower S band applications including GPS (1.57 GHz), GSM (1.8 GHz), Wi-Max (2.3 GHz) and WLAN (2.45 GHz) and useful for covering the entire UWB range of 3.1 to 10.6 GHz. To achieve ultra wideband performance, optimizations of dimensions of the parameters involved in the designing of the antenna are required. The optimum values are chosen by performing parametric variation of these design parameters. Five design parameters i.e. feed width (Fw), feed length (Fl), side of hexagon (a), material used for the antenna and defects in the ground plane have substantial impact on antenna return loss performance. Proper impedance matching is required so that signal doesn't reflect back from the feeding location and will be able to radiate properly through desired antenna. The return loss below − 10 dB at desired resonating frequency is considered as an acceptable standard.

- Variation in the Feed Width (Fw)

In addition to the feed length, feed width is also varied to find the optimum values of antenna design. The feed width is varied from 0.5 mm to 2 mm with an interval of 0.5 mm to observe the results. It can be figured out from Figure 3 that for feed width of 0.5 mm and 2 mm, return loss of -10 db is not achieved. On increasing the feed width to 1 mm, there is improvement observed in the return loss vs frequency graph. The maximum wide bandwidth is obtained with feed width of 1.5 mm. Thus feed width of 1.5 mm is the optimum value for maximum bandwidth and minimum return loss.

- Variation in Feed Length (Fl)

The feed length is varied and analyzed to attain optimum performance. The feed length is varied from 4 mm to 6.5 mm. The inferences from the simulation graph as shown in Figure 4 can be drawn that if we take the feed length as 4 mm or 4.5 mm, the entire operating band is above -10 db. As the value of feed length is increased to 5mm, there is a shift observed in the graph. The optimum result is observed, when the feed length is taken as 6 mm, thereby resulting a satisfactory performance in the entire frequency band of 3.1 to 10.6 GHz. It can also be observed that on increasing the feed length beyond 6 mm, deterioration in the result is observed.

- Variation of hexagon side length (a)

Value of ‘a’ is varied from 4 mm to 6 mm. Great impact is observed on the bandwidth and return loss by the variation of this parameter. Initially the bandwidth is increasing with the increase of length of hexagon from 4 mm to 5.5 mm, but beyond 5.5 mm, the bandwidth starts decreasing. Peak of return loss graph is very sensitive to the variation of this parameter. Thus the optimum value for the side of hexagon is 5.5 mm as observed in Figure 5.

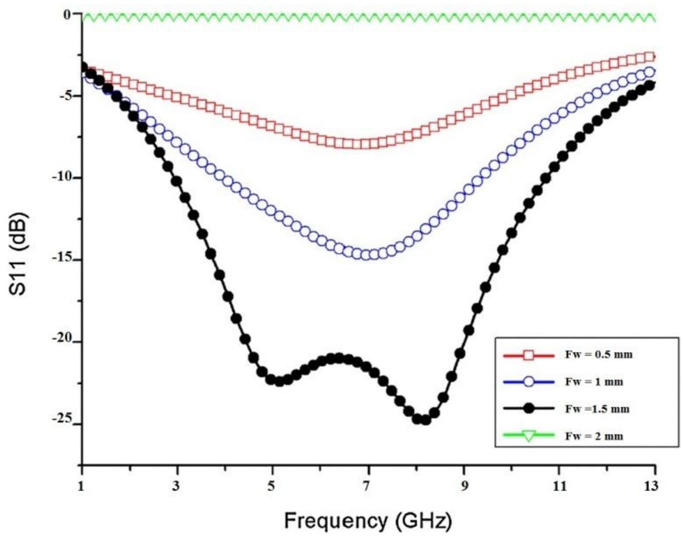

Fig. 3 Return loss for parametric variation of feed width

- Use of different material

The different material used for analyzing the performance of the proposed antenna are FR4, Rogers [4003] and Teflon as shown in Figure 6 and their simulation results in Figure 7. It is observed that FR4 proves to be the best materials for the proposed design to achieve an enhanced BW and better mechanical characteristics. The material FR4 is not only cheap but is readily available in market

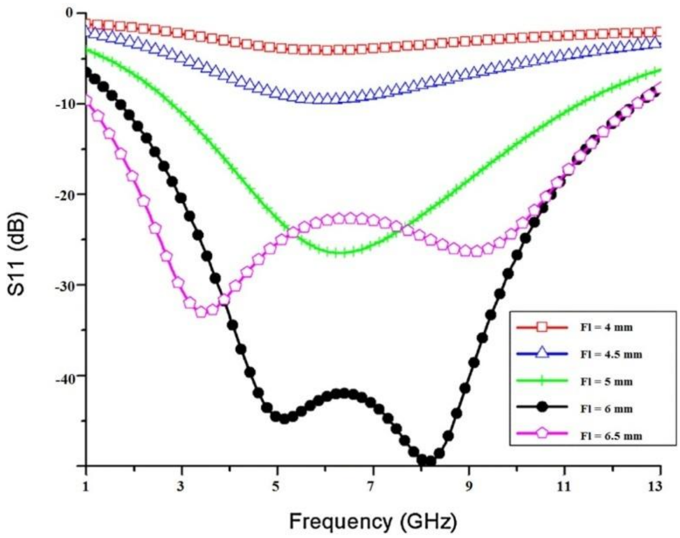

Fig. 4 Return loss for parametric variation of feed length

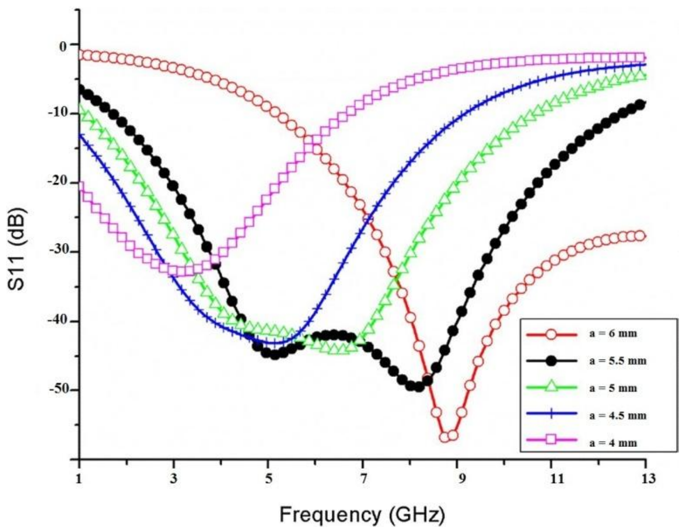

Fig. 5 Return loss for parametric variation of hexagon side length

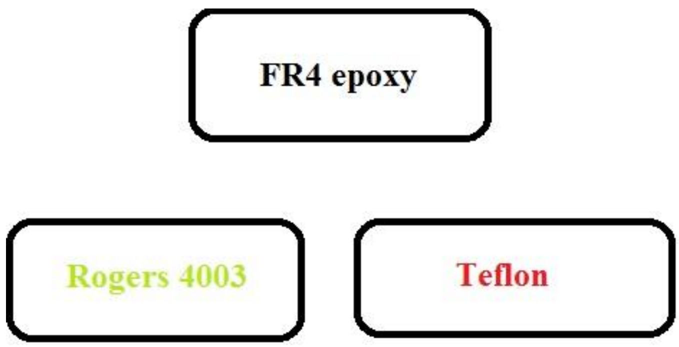

Fig. 6 Different Material used for simulations

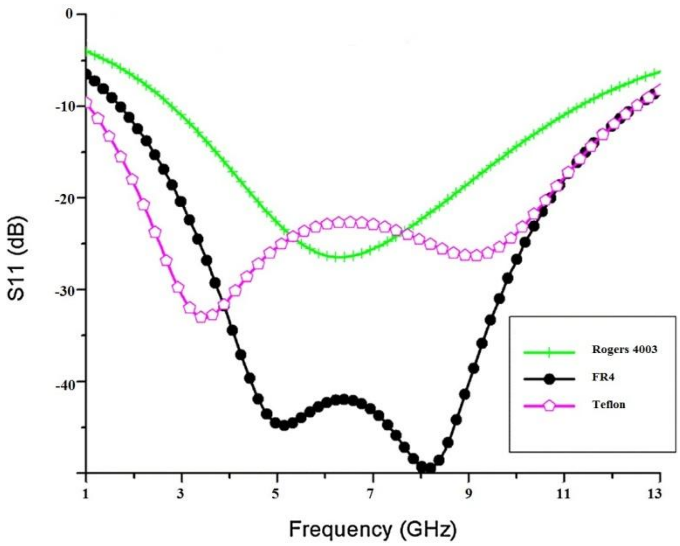

Fig. 7 Return loss for different material

- Introduction of defects in the ground structure

The proposed antenna is backed with defects in the ground structure on reverse side of the substrate. The defects introduced in the geometry have a substantial impact on the bandwidth performance of the antenna. The ground structure is truncated from all the four sides of the geometry to observe the variations in the return loss graph. It is observed in Figure 8 that when the defects are introduced in all the four sides of the ground plane, optimum wideband performance is achieved with minimum return loss characteristics. It is also observed that poor return loss performance is achieved without defects in the ground structure. It is observed that defects in the ground plane results in reduced cross coupling effects and wide impedance bandwidth.

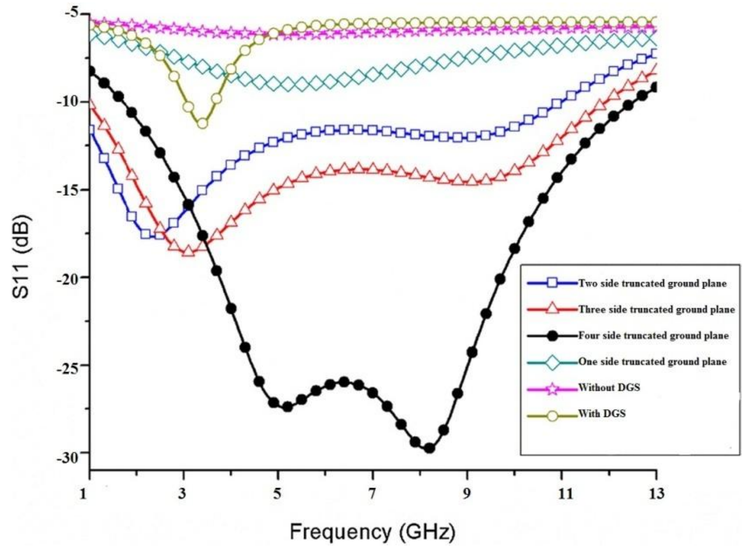

Fig. 8 Return loss for parametric variation of ground

IV RESULTS AND DISCUSSION

The prototype of optimized modified hexagon shaped antenna amalgamated with staircase is fabricated. Testing of the antenna is also done to validate the simulated results. Figure 9 provides top and bottom view of fabricated prototype antenna. A comparison in the simulated and measured return loss performance of the proposed antenna can be seen in Figure 10.The simulation and measured results are found satisfactory with each other. Although as compared to the simulated results there is minor upper shift observed in resonant frequency for the measured results. Sometimes due to fabrication inaccuracies of prototype antenna design, soldering process or temperature while connecting SMA connector to the antenna may slightly affect the measured results from the simulation results.

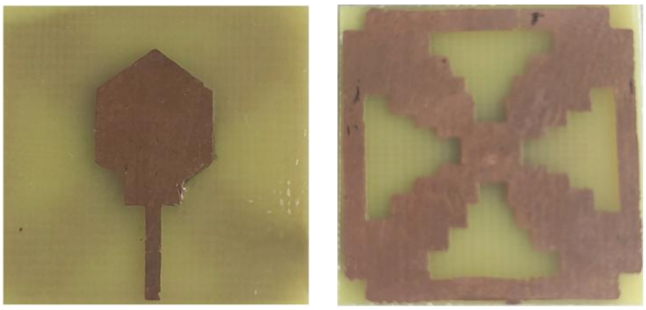

Fig. 9 Top and Bottom view of fabricated prototype antenna

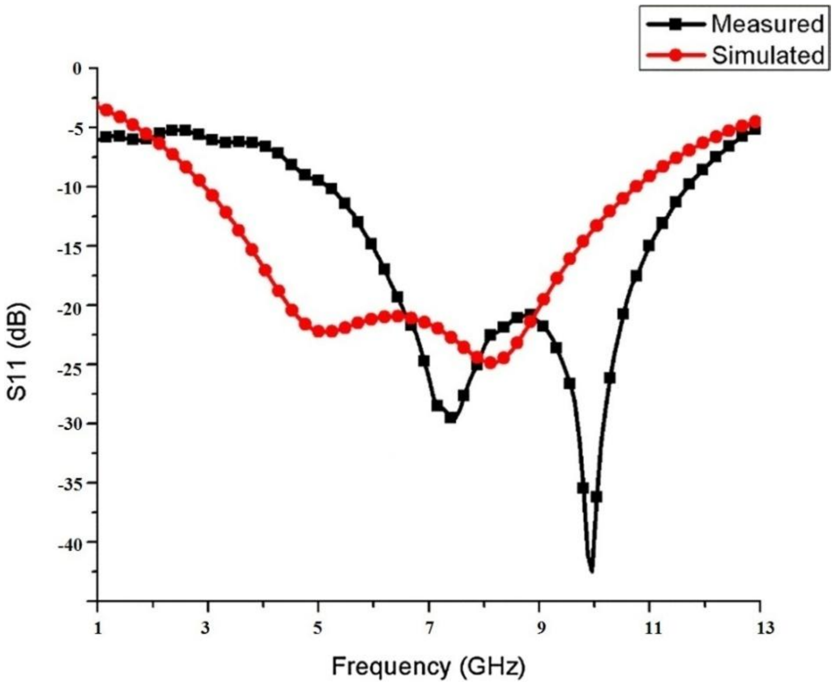

Fig. 10 Return loss w.r.t frequency for designed patch antenna

VSWR is another imperative measure to reflect the impedance matching between radiating antenna and signal excitation. VSWR plot for the proposed antenna is shown in Figure 11.The ideal value of VSWR is 1 for perfect impedance matching although value below 2 is considered acceptable for various applications. From Figure 11, it can be seen that there is conformity observed in the measured and simulated results of the proposed antenna as for the frequency range between 1.7 and 2.61 GHz, VSWR measured is less than 2. The reflection coefficient and VSWR characteristics are measured using 20 GHz Rohde & Schwarz vector network analyzer.

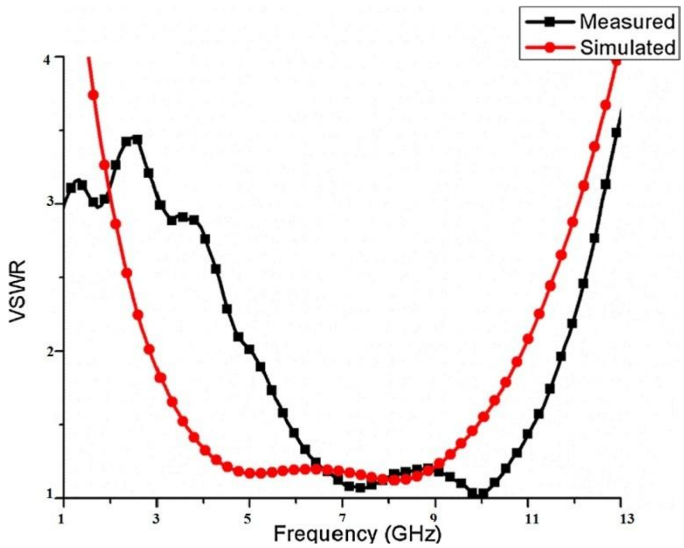

Fig. 11 VSWR w.r.t frequency plot for designed patch antenna

Simulated and measured gain with respect to frequency spectra for the proposed prototype antenna can be observed in Figure 12. A maximum measured gain of 3.4 dBi is observed experimentally using anechoic chamber and it is observed that the simulated gain confirms well with the measured gain. Moreover, larger gain is observed for higher resonating frequencies.

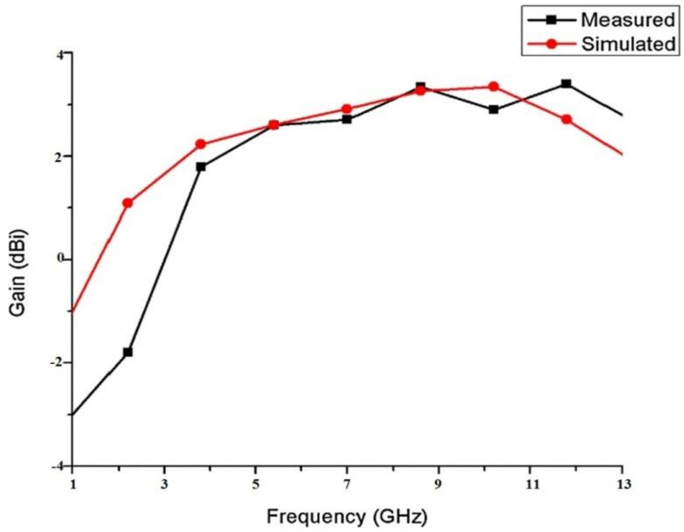

Fig. 12 VSWR w.r.t frequency plot for designed patch antenna

V CONCLUSION

The highlights of this paper are a detailed parametric analysis and optimization on a modified hexagon shaped antenna. Staircase is amalgamated in the designed antenna after carefully observed parametric variations in the geometry. The modified shape of the proposed antenna contributed in enhancement of Bandwidth as observed in the simulation results. The proposed modified hexagon shaped antenna amalgamated with staircase is found suitable for wireless portable applications. HFSS (Version 15.0) is used for designing and analyzing the proposed antenna and provides wide impedance bandwidth between 3 GHz to 30 GHz for VSWR < 2. Parametric analysis and optimization is done on significant design parameters to attain minimal return loss characteristic of -15.30 db obtained at 19.1 GHz and exhibiting good radiation performance over the entire frequency range. The prototype antenna is fabricated and tested to measure the experimental results. A reasonably fine agreement is observed in the simulated & measured results. The proposed antenna exhibits advantages of compact geometry and simultaneously shows minimal return loss characteristics and wide impedance bandwidth. Thus, it is considered appropriate for wireless portable applications such as GPS (1.57 GHz), GSM (1.8 GHz), Wi-Max (2.3 GHz) and WLAN (2.45 GHz).

VI. ACKNOWLEDGEMENTS

The authors would like to thank JCDM college of Engineering,Care Lab at Indian Institute of Technology, Delhi and IK Gujtal Punjab Technical University.

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