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Heptagonal Shaped UWB Antenna with DGS for Wireless LTE with Enhanced Bandwidth

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Abstract*: *The paper discusses about the implementation of Heptagonal shaped compact ultra-wideband planar Microstrip patch antenna with and without defected ground plane structure (DGS) with analysis of various parameters like return loss, VSWR bandwidth etc. A substrate made up of dielectric constant FR4 epoxy is utilized and the 2D and 3D radiation pattern are also discussed. DGS has helped to fine tune and increase the bandwidth & its effects have been studied. A volume of 28x32x1.7 (1523.2 mm^3) is occupied by the size of antenna with dielectric constant of εr = 4.4, tanδ= 0.02. In order to provide fine tuning in the return loss graph, a 50Ω line with width of W=3mm direct line feeding method has been used for the micro-strip line and slots have been introduced in the ground plane structure, for achieving the good bandwidth coupling between the slots plays an important role. The antenna parameters including VSWR, Gain and return losses v/s frequency effects for the antenna with variation of slots and dimensions has been studied in this paper along with the analysis of important parameters such as return loss (dB), bandwidth, VSWR (Voltage Standing Wave Ratio) of patch antenna which has been performed using Ansoft HFSS v15 tool. The proposed design of the heptagonal shaped antenna operates as an ultra-wide band antenna ranging from 3.20 GHz to 10 GHz and beyond covering most of applications from LTE, Wimax (3.5/5.55GHz), Radio altimeter, RFID and ISM WLAN 5.2/5.8GHz etc.

Keywords*: *Microstrip Patch, heptagonal, defected ground structure, VSWR, 2D and 3D patterns, HFSS, Wireless

I. INTRODUCTION

As the advancements with technical innovation continue, the technology is bound to make things simpler and easier. The innovation in wireless communication has evolved more enormously as the lower frequency band is almost occupied and due to spectral crunch need for switching to the higher-frequency band was much needed. An accurate antenna design for greater chance to achieve higher bandwidth, especially at a high band of frequency is needed as the efficiency and performance of an antenna directly affects the overall communication system [1]. Impressive research is being carried out in the area of antenna design at different band levels like high frequency (HF) band, ultra-high frequency (UHF) band and centimeter band to name a few along with the ISM industrial, scientific and medical band [1].

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Further if we discuss about the Microstrip monopole antennas, they have the advantages of having simple & basic design and structure with ease in designing multiple operating frequencies [3]. Mst. Dilshad Jahan and etal, discuss about the MS patch antenna for applications such as RFID, WiMax and X-band Applications providing frequency of resonance at 9.968 GHz[2]. In paper titled “a multi-band LTE antenna covering LTE, GSM & UMTS”, Chen Jing Zhang and Mei Song Tong have discussed about and proposed design which can cater to the demand of various mobile terminal devices [3]. The discussed antenna by Chen Jing and etal, is a monopole micro strip patch antenna which is consisting of two conductor segments which are appropriately bent to reduce the antenna size. For commercial and military applications the research on antennas is focused primarily in many aspects with wideband, multiband and low profile antennas having a great demand. The researchers are exploring with studies on various types of antennas like as T-Shaped, E-Shaped, S-shaped, L-shaped, F shaped, inverted F-shaped and polygon shapes such as Hexagonal shaped compact sized Microstrip patch antenna for various applications in bands ranging from S to X bands such as “WLAN, GPS, GSM, mobile radio, wireless communications” etc[4,5]. In studies it has been observed that the micro strip patch antenna can perform well in WiMAX(3.5 & 5.8GHz) and X-band(8-12.5GHz) due to its elegant profile and optimal acceptable performance with ease of fabrication [4, 6]. The patch and ground plane of a Microstrip patch antenna are made of conducting metal generally such as copper whose dialectic constant is 1. The surface of the radiating patch and dielectric substrate feeding line are basically photo etched can be of any material with usual material being FR4 epoxy with dialectic constant 4.4 and tanδ= 0.02. With the proper measured selection of the Heptagonal patch shape and dimensions of the inserted slots in patch with the defected ground plane structure, good radiation characteristics and better impedance bandwidth for the wireless applications can be achieved [2]. In this paper realization of a heptagonal shaped compact planar Ultra Wide Band antenna suitable for use in the various wireless applications has been discussed [1]. The proposed antenna structure has a compact planar design and simple structure to make it flexible to design simulate and fabricate. It has a better probability to achieve a low Q-factor for the effective enhancement in the bandwidth with introduction of slots into the micro strip patch and the ground plane [4].

To achieve good bandwidth and desired frequency response along with the new resonances, the defected ground plane with slots made on surface of the ground plane with desired shapes are employed in [see Fig. 2(b)] but Usual case in the Microstrip patch antennas is that the structure of the ground plane will be complete [7].

The typical rectangular 'Heptagonal-shaped' and other shaped slots with a suitable size of length width and height are used [see Fig. 2(a)] inside the radiating patch to help in achieving the additional current paths generation on the patch along the new coupling paths between the slotted Microstrip patch and defected ground plane structure[4].

II. THE ANTENNA DESIGN

In the Fig. 2(a) and Fig. 2(b) the configuration of the proposed 'Heptagonal defected ground plane structure compact UWB antenna' with the antenna embedded on a height=1.6mm (thickness) substrate of FR4 epoxy with relative dielectric constant εr = 4.4 and the area of 28x32x1.7 (1523.2 mm^3) has been presented. The size of length Lg and size of width Wg of the compact rectangular defected ground plane structure of the antenna is 28mm and 14.19 mm. The dimensions used for the design has been tabulated in the Table-I. From fig 2 (a) we can observe the structure for the radiating patch. In the radiating patch design, the heptagonal shaped slot has been etched out and the slots L8, L9 and other slots has been etched out as per the given dimensions from the radiating patch as shown in Table. For feeding the heptagonal shaped antenna, Microstrip line feed of Wf=3mm width having a length L7=15mm with 50Ω direct feed line along the centerline of the radiating patch has been placed which is located in mid or the center of the radiating patch. The conducting strip's width Wf=3mm is smaller in our design, when compared to the Patch. The main advantage of Microstrip line feeding technique is that, it provides ease for fabrication and is simple to model as feed can be etched on the same substrate [7][8].

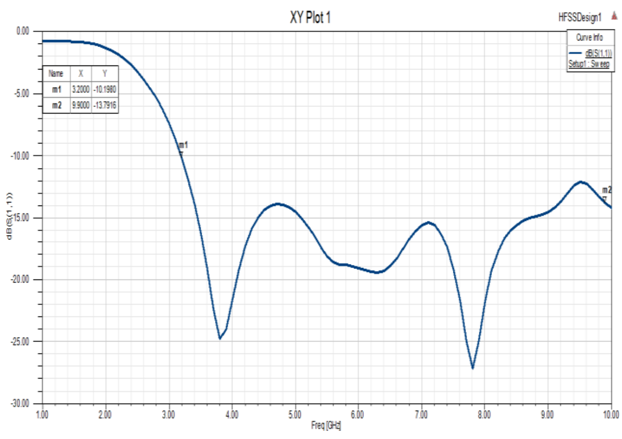

Fig. 1. 2D simulated graph of Return loss v/s Frequency from HFSS.

The designed antenna has a Heptagonal shape etched out from the patch, having seven sides with seven vertices separated with a distance of 4.908 mm. The total perimeter of the regular heptagonal shape which has been etched out from the patch is 34.356 mm.

Table- I: The Proposed Heptagonal Antenna design dimensions specifications.

Parameters	**SPECIFICATIONS**	**DIMENSIONS(mm)**
Ground Plane	Ground Plane	WgxLgxH = 28x14.19x0.05
Substrate	FR4 Epoxy (εr = 4.4)	WxLxH= 28x32x1.6
Patch	Patch Width	Wp = 20.5
Patch	Patch Sides L8 and L9	L8=6 and L9=6
Patch	Patch Sides Slots WxH	L1=1x5 and L2=1x5, L3=2x3 and L4=2x3, L5=3.625x1 and L6=2.875x1
Patch	Patch Sides Width	w1=2.375 and w2=2.625
Feeding	Inset feed LengthxWidth	L7=15 Wf=3
Patch	Heptagon Sides	H1=4.908
Ground Plane	Slots in Groundplane(defected)	S1=S2=S3=5x0.7

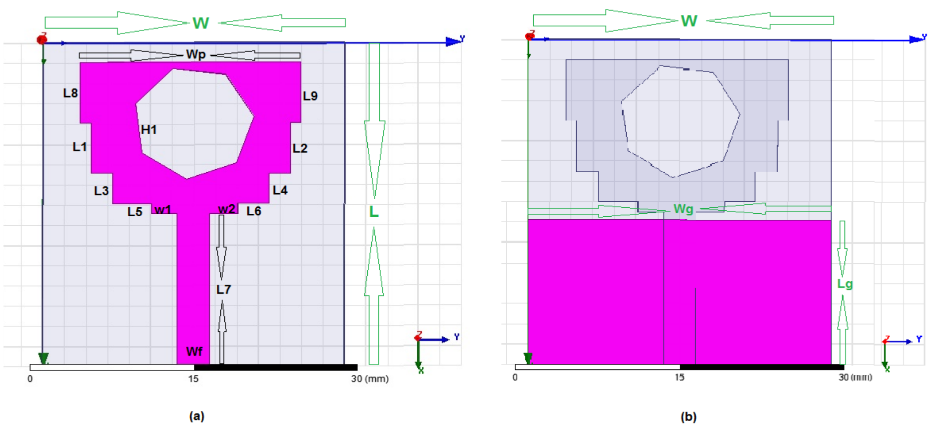

Fig. 2. The proposed design of Heptagonal shaped antenna with (a) Patch and (b) Ground plane with dimensions.

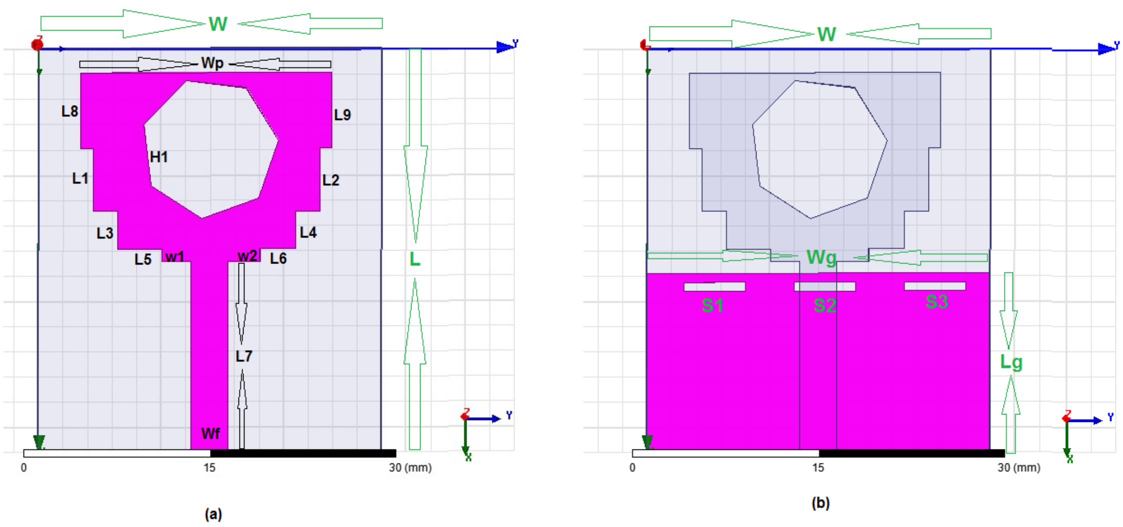

Fig. 3. The proposed design of Heptagonal shaped antenna with (a) Patch and (b) Defected Ground plane Structure with dimensions.

The figure-3 shown displays the heptagonal shaped antenna with defected ground structure with dimensions for comparison of the defected ground structure shape before finalizing the final shape & structure for discussion. There are slots of size S1=S2=S3=5x0.7 mm^2 which has been etched in the ground plane of size Wg=28mm and Lg=14.19mm which has been termed as defected ground plane structure (DGS).

III. RESULTS DISCUSSION

The designed 'Heptagonal Shaped Ultra Wide Band Antenna with Defected Ground Structure for Wireless LTE with Enhanced Bandwidth' design utilizes the simulation power of Ansys High Frequency Structure Simulation (HFSS) v15 [13] (full-wave simulation software) to design and simulate & analyze the simulation data. The proposed Heptagonal shaped patch Antennas prototype has been etched out on a substrate namely FR4 epoxy (4.4). Antenna parameters like gain(dB), S11 (return loss patterns), Voltage Standing wave Ration - VSWR, radiation patterns, Magnetic field , Current & Electric field density plots have been simulated and the data has been extracted in .csv files from HFSS design tool [13-14] . These patterns and graphs have been plotted in the up-coming sections in respective figures. When we analyze the plots of S11 v/s frequency graphs results plotted as shown in figure Fig-1 and Fig-4, there is a continuous UWB band obtained in the plot. From the observation we can confirm that the proposed antenna has achieved a -10dB return loss bandwidth of 3.2–10 GHz with the peak resonance at 3.8GHz having -24.42 dB and 7.77GHz peak resonance with -26.82dB return losses with most of the continuous UWB band below -15dB throughout. The UWB band has VSWR < 2 continuity from 3.2GHz up till 10 GHz range of frequency. Theoretically for the VSWR <= 2, resonant frequency known to have return loss less than -10dB. Thus when with a reference point of 2.5 the VSWR value is considered, then the bandwidth coverage will imporve enormously. In figure Fig.4 the comparison Graph of Return loss v/s frequency comparisons for the heptagonal shape with and without DGS is shown. The bandwidth, VSWR Gain comparisons for proposed design with and without DGS has been tabulated in the table-II below. The overall size is same for both the designs except the defected ground structure. The overall bandwidth has improved for design with DGS and slight improvement in the Gain and directivity is also observed. The efficiency of the antenna can be calculated as per equation 1.

Table-II: Bandwidth VSWR comparison for proposed design with and without DGS with same dimensions

Characteristics	Antenna With DGS	Antenna Without DGS
Dimensions of the antenna (W/L), mm	28x32	28x32
Return loss (S11), dB at 8GHz	-21.88	-20.44
Bandwidth, GHz	7	6.8
VSWR	1.2176	1.2264
Directivity, dB	2.4212	2.3872
Gain, dB	2.2941	2.2304
Total Efficiency,%	94.75	93.43

Efficiency = Gain/Directivity …………(1)

The efficiency of the antenna has improved by 1.4% at 94.75. The improvement in the Gain is 2.85% and Directivity is 1.42% at 8GHz resonance for the antenna design with DGS.

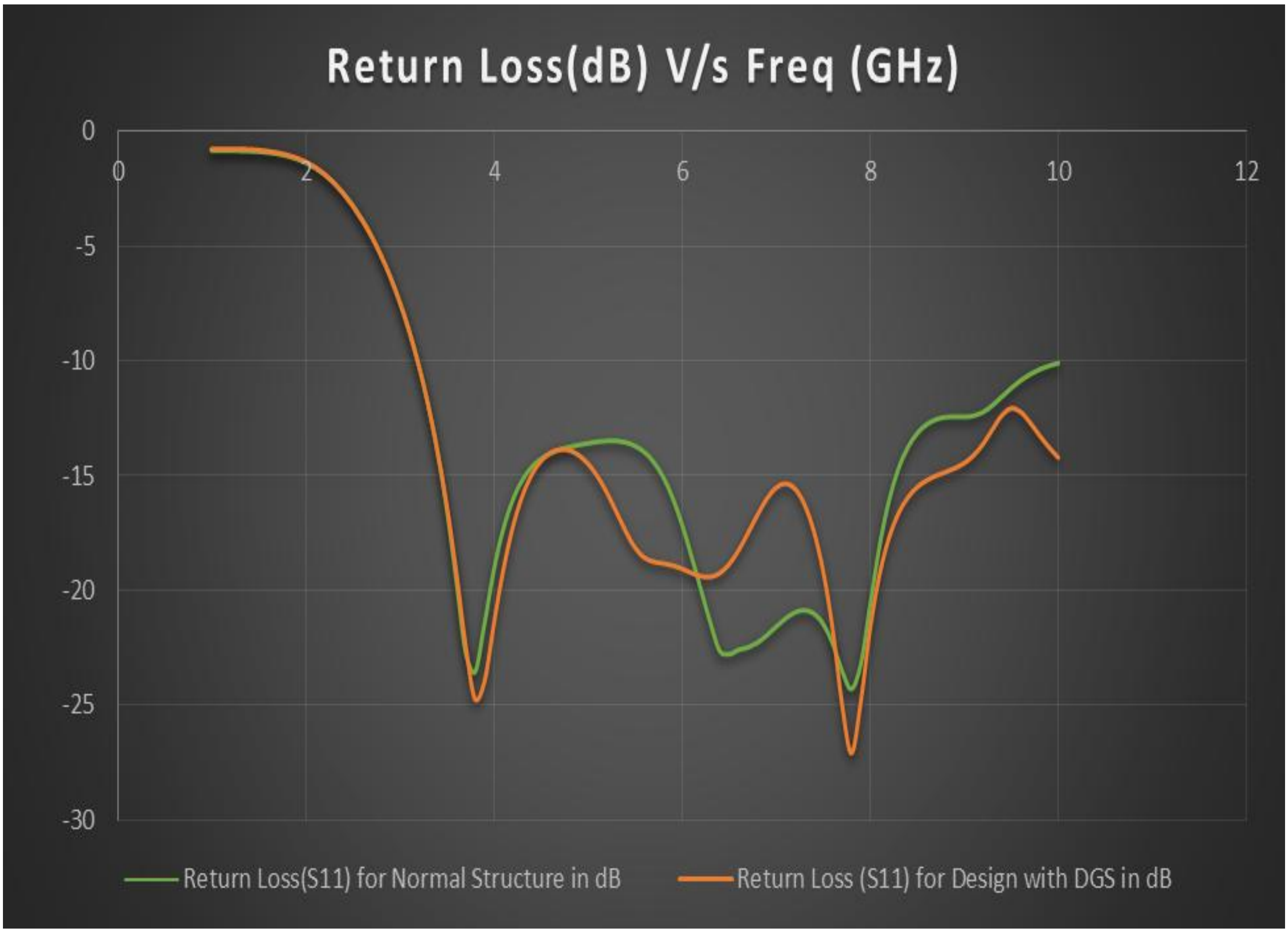

Fig. 4. Return loss v/s frequency Graph - comparisons for the design with and without DGS.

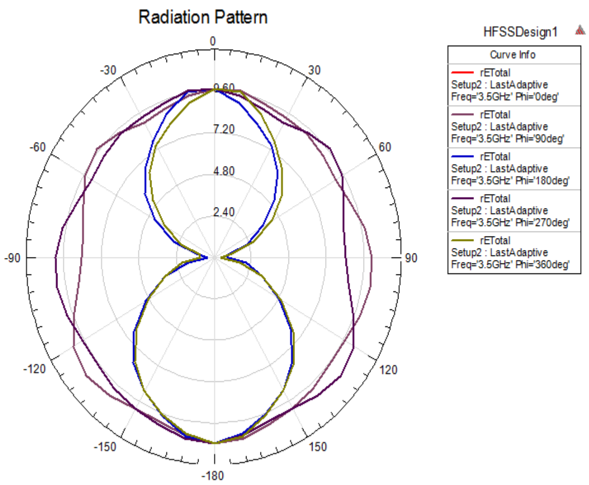

Fig 5. Radiation pattern Plot at phi = 0, 90,180 and 270 degrees for 3.5 GHz.

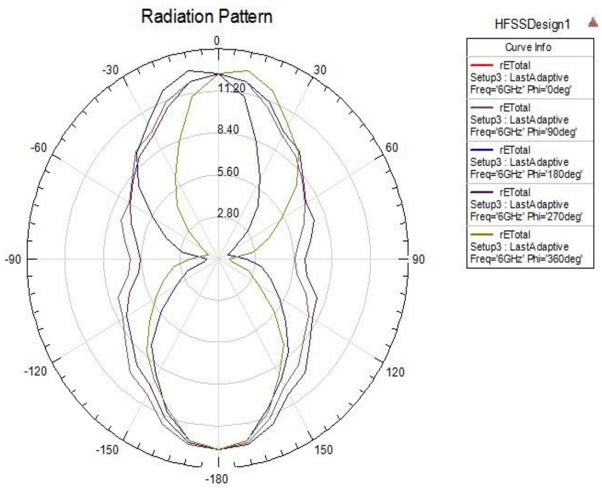

Fig. 6. Radiation pattern plot at phi = 0, 90,180 and 270 degrees for 6GHz.

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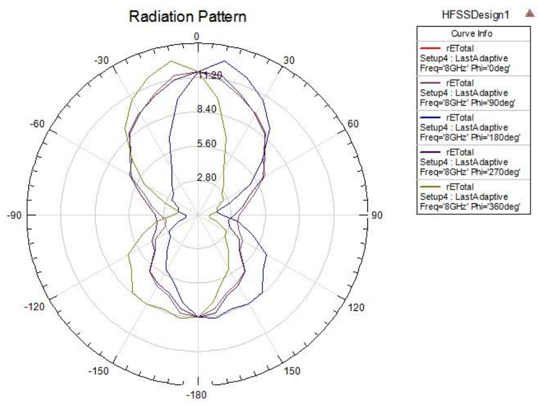

Fig. 7. Radiation pattern plot at phi = 0, 90,180 and 270 degrees for 8GHz.

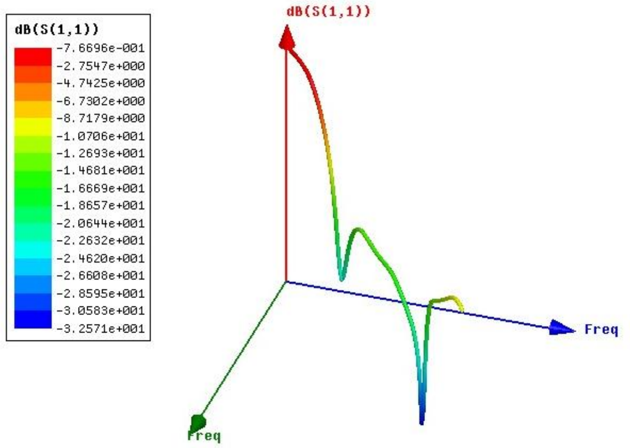

Fig. 8. Plot for the simulated 3D Rectangular pattern for return loss v/s freq

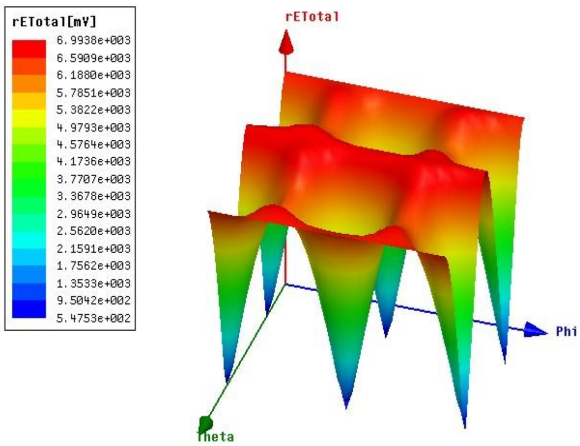

Fig. 9. Simulated 3D Rectangular pattern plot

As per the comparison plot of fig 4, the proposed heptagonal UWB antenna is covering S, C and X bands and the figure Fig.4 displays the plots comparing the graph for return loss v/s frequency plots between the defected ground plane structure and the normal heptagonal shaped antenna design with FR4-epoxy substrates in HFSS tool. As shown in the figures Fig.5, Fig.6 and Fig.7 the radiation patterns plots [7] has been studied which have been simulated at 3.5 GHz, 6 GHz and 8GHz frequencies at phi=0,90,180,270 degrees respectively in the E-plane and H- plane in HFSS software [13]. From the graph plots, it can be inferred the omnidirectional behavior of the radiation patterns. In fig 8 and fig 9, the plots of 3D rectangular patterns have been discussed and it depicts a good polarization for the discussed heptagonal shaped ultra wide band antenna.

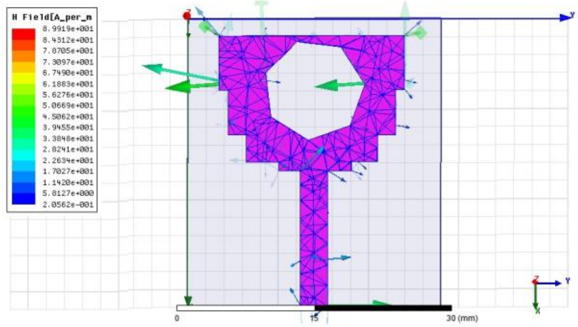

Fig. 10. Vector Magnetic field distribution

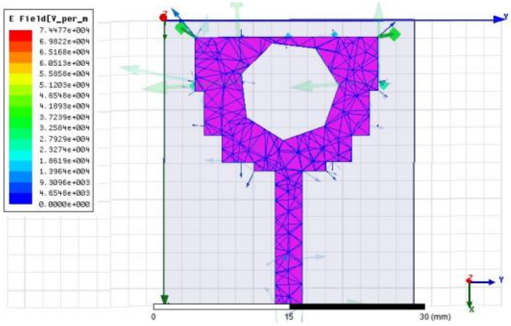

Fig. 11. Vector Electric field distribution

Using the Ansoft HFSS design tool [13], the vector surface current density, electric field and magnetic field distribution plots have been simulated for the designed Heptagonal shaped patch design with DGS UWB antenna for range of frequencies of operation including 3.5GHz, 5.2GHz etc. These simulated graphs are as shown in figures Fig. 10, Fig.11 and Fig.12 respectively. As per the figure Fig-12, the surface current density for the antenna is observed maximum at the edges of the radiating heptagonal patch whereas at the centre it is observed as low or minimal. Graph for the simulated results for the VSWR (Voltage Standing Wave Ratio) are shown in Fig.13 plots. The value of VSWR is very important in determining of the various parameters including the antenna return loss. As per figure Fig.13, we can conclude that the VSWR value for the proposed 'Heptagonal-shaped' slotted micro-strip patch antenna with DGS and without DGS is less than 2 and theoretically as well to get return losses below -10dB, VSWR<2 is a must, which is enough to satisfy one of the primary conditions to achieve the bandwidth requirement for required or specified frequency ranges [1]. If we consider the value of VSWR below 2.5, we can see wider coverage with bandwidth of up to 7GHz with good return loss. From the study, we can state that the overall VSWR is better than 2.5 throughout ultra wide band from 3.2 GHz up to 10GHz.

The continuity in band from 3.2GHz to 10GHz equips the available bandwidth to have the maximum coverage of requirement of an UWB frequency of operation. The graph of Fig.14 is the plot for the Gain and fig 15 is the graph for plot of Directivity simulated from the HFSS tool for the proposed antenna for 8 GHz frequency of resonance at phi= 0, 90, 180, 270 and 360 degrees.

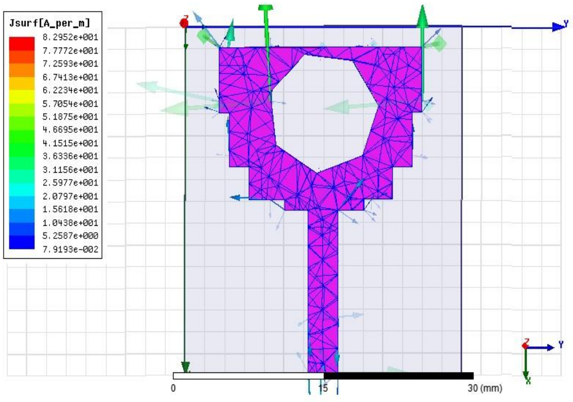

Fig. 12. Vector distribution of surface Current density distribution.

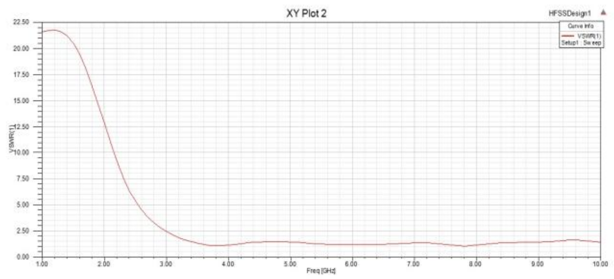

Fig. 13. Simulated VSWR v/s frequency for the antenna graph.

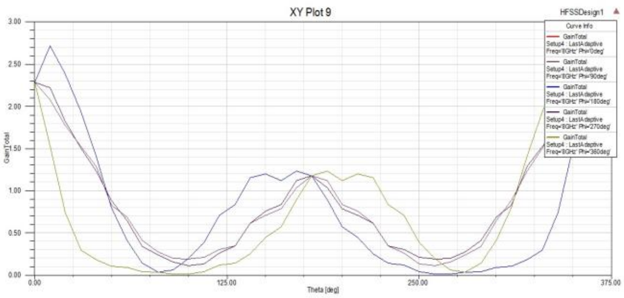

Fig. 14. Simulated gain v/s frequency at 8 GHz graph.

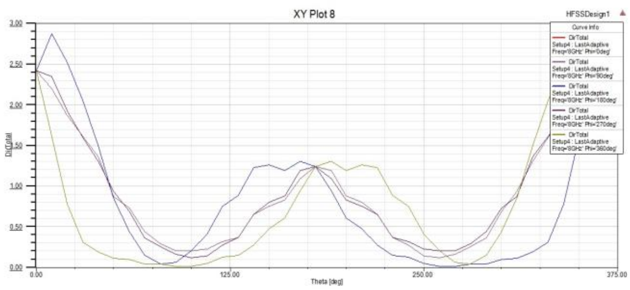

Fig. 15. Simulated Directivity v/s frequency at 8 GHz graph.

IV. CONCLUSION

The “Heptagonal Shaped antenna with defected ground plane” paper discusses about the Heptagonal shaped micro strip patch designed on a FR4 substrate in HFSS simulation software using Microstrip line feeding techniques. A 50 Ω line feed with width 3mm has been utilized for direct feeding of the antenna. Various antenna parameters have been studied by using the 2D and 3D patterns extracted from the tool. From the results discussions of rectangular micro-strip patch antenna for ground plane without DGS and with DGS, we can observe an increase in the bandwidth and fine tuning of the results. The paper also discusses about the effects of the variation in the patch by analyzing the slots variations on the results of return loss & bandwidth. As the proposed heptagonal shaped antenna covers S(2-4GHz), C(4-8GHz) and X bands(8-12.5GHz) through its continuous UWB band, the paper discusses about the multiple applications where this designed patch antenna can be used in such as various wireless applications like “LTE, Wi-Fi, RFID, Radio altimeter and WLAN/WiMax applications” [7] to be named few. Looking at the plot of the VSWR plot, we can infer that the overall VSWR is better than 2 and has been maintained VSWR<2 throughout the UWB band from 3.2GHz to 10GHz and beyond it which puts the antenna at an added advantage to cover the complete bandwidth available to have most of the requirement and applications of an frequency of operation of UWB band met [1]. The proposed heptagonal antenna design specification utilizes the defected ground plane DGS with ‘Heptagonal-shaped’ slots etched out on the radiating patch elements. Along with the heptagonal shaped design rectangular shaped slots are etched on the copper plated etched radiating patch having a compact volume. Overall the size of the antenna is small with the antenna having compact size of volume of 28x32x1.7 (1523.2 mm^3). For the purpose of validation of the parameters such as VSWR, radiation patterns; return loss, Gain, Current & Electric field distribution Ansys HFSSv15 software has been used for simulation and analysis of the results.

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