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A COMPACT OCTAGONAL PATCH ANTENNA WITH U-SHAPED SLOT AND DGS FOR UWB APPLICATIONS

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Abstract
In this article, an octagonal patch antenna with U-shaped slot for UWB application is proposed. The antenna consists of a three-layered section such as patch, Substrate and Ground. Here, Patch and Ground are the perfectly conducting foil mounted on a Flame Retardant 4 (FR -4) dielectric material whose permittivity Ɛr = 4.4 and loss tangent δ = 0.002. The radiating element and ground are fed through a microstrip line using a Lumped Port. A U- shaped slot is etched on the center of patch to disseminate the surface current throughout the patch whose sectional area is 15 x 15 mm2. Also, a Defective ground Structure is introduced in the ground plane which is provides broadened bandwidth, enriched gain, improvises the radiation characteristics of the antenna with mutual coupling between the proximate sectional areas. The complete measurement of the proposed antenna is 28 x 28 x 1.6 mm3. The antenna is design and analyzed using High Frequency Simulator software (HFSS) platform. The simulated outputs of the antenna such as Reflection Co-efficient, Voltage Standing Wave Ratio (VSWR), Fractional Bandwidth (FBW), Peak Gain, Radiating Efficiency and Impedance Matching are obtained and compare with the existing designs. Thus, the proposed antenna resonates with the bandwidth of 3.7 GHz to 13.5 GHz whose Fractional Bandwidth (FBW) is 114% with a peak gain of 5.6 dBi are obtained, which denotes that the antenna is capable of radiating for UWB applications.

Keywords:
Antenna Configuration, FR-4, Octagonal Patch, UWB Applications

1. INTRODUCTION

Microstrip Patch antennas are most useful in day-to-day life; important thing is that it can be directly printed over a circuit board. It has a wide-spread in mobile phone technologies because of its compactness. Easy manufacturing, less expensiveness and least0 profile give more advantages to this kind of antennas [1]. This makes the patch antennas much useful compared to the conventional antennas. Although limitations like narrow bandwidth, impedance mismatch, linearly polarized and poor gain are quoted on conventional patch antennas, there are various advancements made on different sections of patch antennas to overcome their constraints [2]. Mostly these patch antennas are practically implemented at microwave frequencies and applications.

Patch antennas consist of three sections - section 1 is a patch made of conducting material; section 2 is a dielectric substrate and section 3 is a ground plane which is also a conducting material. The two conducting sheets will induce resonant radio wave of one-half wavelength at the transmission line. In order to the antenna be resonant, the transmission line length should be slightly lesser than one half of the wavelength and this causes the antenna to act electrically larger than its natural dimensions [3].

Due to the "Fringing Field" effect the antenna's resonant length will become shorter and it increases the antenna's electrical length. The typical merit of patch antenna is the antenna size is inversely proportional to the resonant frequency wavelength. Octagonal design offers enhanced outcome when related to planar/conventional antenna which involves improved electrical perimeter of radiations and its efficiency. Dielectric material with higher relative permittivity (ε_r) may affect the impedance, bandwidth and radiation pattern. Hereby, increasing dielectric constant leads to decreasing in antenna bandwidth which improves the Q-factor of the antenna and also reduces the impedance [4].

FR-4 dielectric material whose permittivity ε_r = 4.4 and loss tangent δ = 0.002 is utilized for obtaining higher radio frequencies. FR-4 is a most popularly applied element in printed circuit boards (PCB) where copper clad laminates are foiled on either side of the substrate. DGS is employed for transferring electric field into patch and a lumped port induct field between patch and ground. Usage of slots in the patch will lead to attain have high gain and to spread the electric field towards the significant edges to obtain responsive fringing effect [5].

Thickness of patch and ground plane are not typically considered since they are printed in the surface of the dielectric medium; the height h should neither higher than operating wavelength nor smaller than 0.025 ($1/40^{th}$ of a wavelength). If it exceeds this parameter, it degrades the antenna efficiency [6]. Feeding power to the patch antenna is another critical process; there are different techniques used in feeding patch antenna.

In this proposed with microstrip feed is employed to yield perfect input impedance. Hereby, the surface current will be lower at the ends of the patch and this leads to have more magnitude ate the centre. If the feed is closer to mid-point, the input impedance will be lesser [7].

The antenna is designed using High Frequency Simulation Software (HFSS) Electromagnetic simulation solver version 17.2 which is adequate for impersonating intricate three-dimensional designs and results [8]. Here, a proposed monopole antenna holds an Ultra-Wide Bandwidth with an omni-directional radiation pattern through its parasitic patch.

The slotted patch with DGS combination yields superior inductance and capacitance enables perfect absorption at all integral frequencies [9]. The coupling between slots and feed line is obtained using compact ground plane and also reduces the size [10]. An optimized tuning stub ensures the wideband matching. The structure and resonances in the designed geometry benefits increased bandwidth, wide-band capabilities and reduced electrical size.

Therefore, the structural parameters of the antenna are follows: Section 2 describes the design methodologies of the antenna. Section 3 gives the simulation outputs of the antenna; Section 4 concludes the proposed work.

2. ANTENNA DESIGN METHODOLOGY

The antenna configuration consists of three sectional layers. The radiating layer (Patch) which should be perfect conductor, Substrate made of FR-4 is the middle layer which physically supports antenna with a thickness h = 1.6 mm, Ground plane is the bottom most layer which is also a perfect conductor [11]. The design equations of the proposed antenna are given below:

$$\textit{Width of Patch } (W)\text{: } W = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where, c - velocity of light; f_r - radiating frequency; ε_r–Dielectric constant

Length of the Patch (L):

$$\Delta L = \left[\frac{c}{2f_r\sqrt{\varepsilon_{reff}}}\right] - 2\left[\frac{0.412h\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)}\right] \tag{2}$$

Effective Dielectric Constant (ε_r):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-0.5} \tag{3}$$

Substrate Width (W_s) or Ground Plane Width (W_g):

$$W_S = W_g = 6h + W \tag{4}$$

Substrate length (L_S) or Ground Plane length (L_g):

$$L_S = L_g = 6h + L \tag{5}$$

The Table.1 list the dimensions of antenna structure and Fig.1(a) and Fig.1(b) shows the Front and Back view of octagonal patch antenna with U-shaped slot [12].

Table.2. Dimensions of antenna structure

Antenna Part	Design (symbols)	Dimensions
Patch	Length (L)	15 mm
	Width (W)	15 mm
	Notch (c)	3 mm
Substrate	Length (L_d)	28 mm
	Width (W_d)	28 mm
	Thickness (t)	1.6 mm
Ground plane	Length (L_g)	5 mm
	Width (W_g)	28 mm
Feed	Length (L_f)	7.5 mm
	Width (W_f)	2.75 mm
Slot	Length (L_s)	3.5 mm
	Width (W_s)	6.5 mm

The antenna design is depicted in Fig.1(a) and Fig.1(b) shows the Front and rear portions of the octagonal patch antenna and its ground respectively. The complete dimension of the module is $25\times25\times1.6$ mm^3. In this model, the dielectric material used is FR-4, with a proportionate measurement provides a durability to the design. A ground plane is the section that typically grounds electric filed of the antenna.

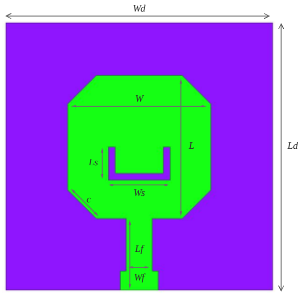

Fig.1.(a) Front view of octagonal antenna with U-shaped slot and Microstrip Feed

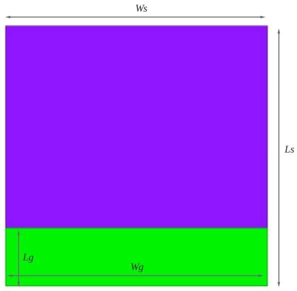

Fig.1.(b) Back view of patch antenna with Defective Ground Structure (DGS)

3. SIMULATION RESULTS

3.1 RETURN LOSS

Return loss is the quantity of EM waves which attains the transmitted antenna due to discontinuity in broadcast line. It is the proportion of energy emulated from the source to the energy catered to the source through a transmission line. It is also known as Reflection Co-efficient. Here, a minimal return loss obtained for this antenna is -45 dB at 8.7 GHz which is represented in Fig.2.

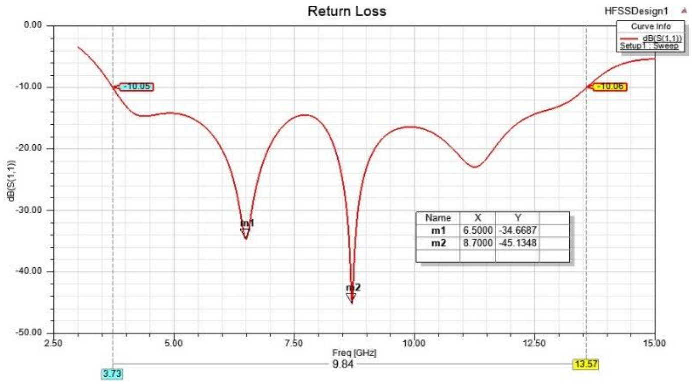

Fig.2. Return Loss and Bandwidth

3.2 BANDWIDTH

Bandwidth represents the extent of frequencies over which an antenna source can emit or admit radio wave. Insertion of slot and DGS combination will provide a noble margin of obtaining an acceptable bandwidth and gain. On taking -10dB references which is depicted in Fig.2, the antenna can radiate over the bandwidth of 3.7 GHz to 13.5 GHz which can be represented in Fractional Bandwidth as 114 % with a Bandwidth ratio of 3.6:1.

3.3 VSWR

Voltage Standing Wave Ratio (VSWR) designates the measure of disparity obtained between a radiating antenna and impedance of the transmission line (feed) connected to it. It is also known as Standing Wave Ratio (SWR) which statistically defines how well the antenna impedance suits the transmission line. The Fig.3 shows the VSWR parameter of the proposed antenna.

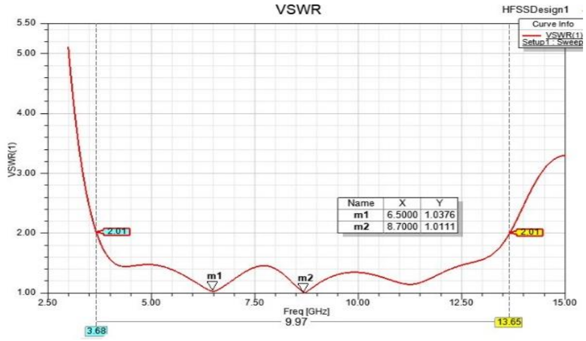

Fig.3. VSWR

3.4 GAIN AND DIRECTIVITY

Antenna Gain is the proportion of radio wave intensity in certain direction and the intensity of radiation obtained when the energy established by the antenna during its isotropic emission.

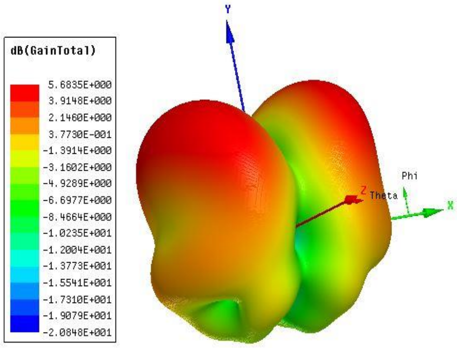

Fig.4. Gain and Directivity

The Fig.4 shows the peak gain and 3-D radiation pattern which is 5.6 dBi. This antenna provides an average gain of above 3 dBi over the range of frequencies which it operates.

3.5 RADIATION PATTERN AND EFFICIENCY

Radiation pattern is the graphical representation of the far field emission features of the antenna. It also denotes the radiation properties and direction of departure yield by the EM waves. In Fig.5(a) and Fig.5(b), the radiating field of the antenna in both E-plane and H-plane is denoted respectively.

The Fig.6 represents the radiating efficiency of the antenna which is 96.8% which proves that the proposed antenna is capable of radiating the EM wave in all 360° seamlessly.

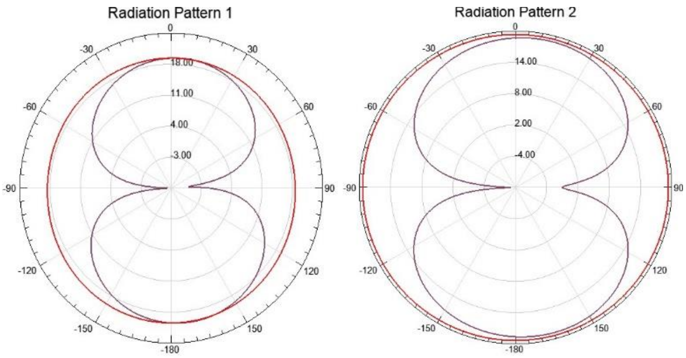

Fig.5. Radiation Pattern at (a) E Plane and (b) H Plane

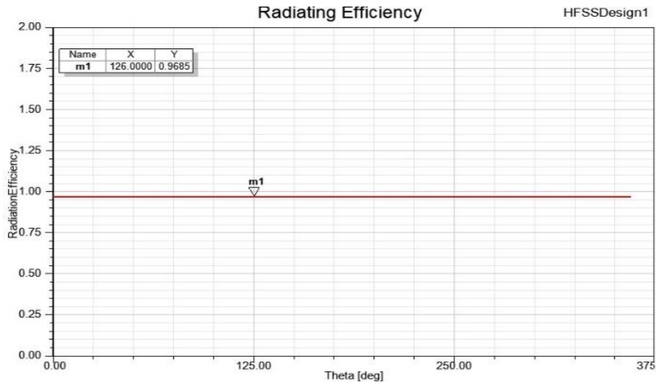

Fig.6. Radiating Efficiency

Table.2. Comparison of Proposed work with the Existing works using various Simulation parameters

Methods	Normalized Size (mm^3)	Dielectric Material	Frequency Range (GHz)	Fractional Bandwidth (%)	Peak Gain (dBi)	Bandwidth Ratio
Triangular	24×22×1.57	FR-4	3.1 to 10.9	111.42	4.1	3.406
Fractal Shaped	18.5×39×1.59	FR-4	3.2 to 12	113.78	4	3.66:1
Minkowski Fractal	40×30×3	Alumina	2.23 to 3.1	32.64	3.62	1.39:1
Hexagonal	20×18×0.08	Polyamide	3.2 to 10.6	107.2	-5	3.3:1
Pentagonal	66×55×1.6	FR-4	1.7 / 2.74 / 3.25	65.2	4	-
Sierpinski Gasket	41×99.4×3.245	FR-4	4.3 to 11.6	91.8	4.7	2.6:1
Metamaterial	30×30×1.6	FR-4	5.8 to 15	98.6	5.5	2.5:1
Minkowski Resonator	50×50×1.6	FR-4	5.52 to 10.72	64.5	4	1.94:1
Proposed Work	28×28×1.6	FR-4	3.7 to 13.5	114.38	5.6	3.6:1

3.6 IMPEDANCE MATCHING

Impedance matching is employed to denote that the load impedance of the source should match the transmission line which will ensures that the antenna is capable of transmitting and receiving radio waves without any signal reflection. Since, co-axial cable with 50 ohms resonant is used to supply input to the antenna, the antenna should also match with the respective value. Thus, Fig.7 depicts the impedance matching plot of the proposed antenna which is at 50 ohms.

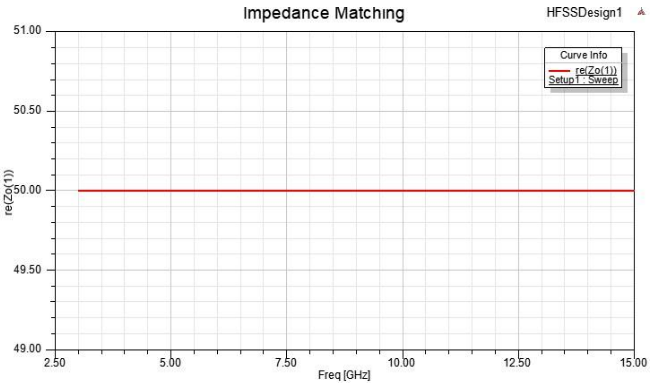

Fig.7. Impedance matching

3.7 CURRENT DISTRIBUTION

The current distribution is depicted in the Fig.8. It depicts the intensity of the surface current at internal and external edges. The U-shaped slot placed in the radiating material distributes the fields along the radiating edges.

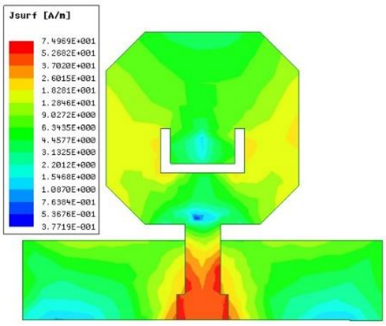

Fig.8. Current Distribution

4. CONCLUSION

An octagonal patch antenna is designed with U-shaped slot and DGS for UWB applications. The octagonal structure and the slot in it will enhance the effective length of the radiating patch. The entire measurement of the proposed antenna is 28×28×1.6 mm3 which is fed using a microstrip transmission line to attain acceptable impedance between the source and the transmission line. The structural design and simulated outputs of the proposed antenna are analysed using HFSS tool and the parameters such as Fractional Bandwidth, Gain, Dimensions and Bandwidth ratio are compared with the recent existing works. Among the comparison, the proposed antenna provides good output characteristics like Fractional Bandwidth of 114% with peak gain of 5.6 dBi in the miniaturized design of 28×28×1.6mm^3. Since, the proposed octagonal patch antenna is designed with U-shaped slot and DGS is capable of handling radio frequencies from 3.7 GHz to 13.5 GHz, the antenna may well suits for Ultra-wide Band applications (3.1 GHz to 10.6 GHz).

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