A Multi-band Crescent shaped Microstrip Patch Antenna with Spiral shape Ground Slot for UWB applications

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Abstract: A miniaturized multi-band crescent shaped microstrip patch antenna with spiral shape ground slot for ultra wideband (3–10 GHz) applications is presented. The proposed crescent shaped antenna is developed by carving a circular hole within an elliptical patch antenna. An extensive bandwidth with added design flexibility is attained with the introduction of circular hole. High Frequency Structure Simulator is utilized for analyzing the radiation characteristics of the proposed crescent antenna. Initially, a Spiral slot on top of the ground plane is introduced in the crescent shaped antenna. This resulted in attaining Multiple-Bandwidth varying between 3-10 GHz. To further enhance the performance of the proposed crescent antenna, a U- slot on top of the crescent patch is integrated. The proposed crescent antenna shows superior performance over the Ultra-Wide Band frequency with least return loss, substantial gain, consistent radiation patterns and permissible Voltage Standing Wave Ratio. A prototype of the proposed antenna which concedes only half the area of the full elliptical patch is fabricated and analyzed. It is observed that the simulation results and the optimal fabricated prototype antenna results match closely in performance. Details of the proposed antenna design are also presented.

Keywords — Crescent Antenna, Multi-band, Patch Antenna, Return Loss, Ultra Wideband, Voltage Standing Wave Ratio.

I. Introduction

In the past few decades, the area of communication engineering has seen a tremendous growth with wireless communication systems [1]. With the growth, the complications in the field of wireless communications have also been on the rise [2]. This provides opportunities for the researchers to provide solutions to the problems associated with the field of wireless communication [3]. Need of very high data rate during data transmission in one of the major problems in wireless communication systems because most of the wireless applications such as wireless monitor, radio diagnosis etc require high date rate with low power consumption for efficient working. To achieve this, Ultra Wide Band is found to be the apt solution. Hence this research work concentrates on wireless applications in Ultra wide band region. The frequency spectrum ranging between 3.1 GHz – 10.6GHz is termed as UWB [4]

Antennas are the effective and essential tool for communication. An optimal antenna design is must for efficient transmission at ultra wide band frequencies. Researchers have designed various antennas for ultra wide band frequencies [5]. Microstrip patch antennas are good for designing UWB applications. Various researchers have devoted efforts to propose designs of such microstrip antennas. Microstrip antennas of various shapes such as disc, Fork, L-strip, Pentagon, Square ring, E-Shaped, Diamond, Reciprocal U shaped, etc have been reported for UWB [6].

There has been an increasing demand for designing antenna with reduced area, increased bandwidth and other performance characteristics. In this proposed work, a miniaturized multi-band crescent shaped microstrip patch antenna with spiral shape ground slot has been presented for UWB applications. Modifications done in its structural dimensions make it a good candidate for application in UWB. Further the design is optimized for enhancing the operating bandwidth within the UWB range. A parametric analysis of the proposed antenna in terms of Return loss, Gain, radiation patterns and Voltage Standing Wave Ratio is done through the use of High Frequency Structure Simulator. Prototype of the crescent antenna is fabricated and tested. Prototype of the optimized crescent antenna shows enhanced performance in UWB region

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II. GEOMETRY AND DESIGN OF PROPOSED ANTENNA

The proposed crescent antenna for ultra wideband applications is shown in Fig. 1. An elliptical patch having major axis a = 27mm and a minor axis b= 18mm is preferred and a circular slot of radius r = 7mm is designed on it. The center of this circular region is displaced by 5.0 mm above the center of the outer ellipse. From the assessment of the current distribution of the elliptical patch antenna, the design of carving out a circular slot is drawn [7]. The preliminary antenna design parameters are obtained using the expressions explained in the subsequent section. The antenna design parameters are optimized using HFSS simulations.

The prototype antenna is fabricated using FR4 material with relative permittivity ε_r= 4.2, loss tangent of 0.01 and with a Spiral Slot ground plane. The thickness of the substrate is chosen as 1.6 mm. The antenna is fed by a 50Ω microstrip transmission line which consists of a trace of width 2mm (50 mil), printed on the surface of the substrate that is partially backed by a ground plane. The Dimensions of ground plane are W_g =45mm and L_g=50 mm respectively. The feed width F_w and feed length F_L are 2 mm and 28 mm.

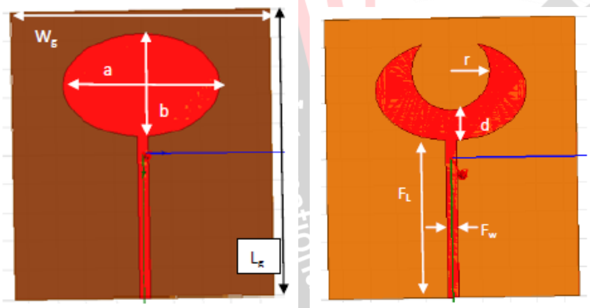

Fig.1. a) Full elliptical antenna b) Crescent antenna

III. PRELIMINARY ANTENNA DESIGN

For preliminary antenna design, simple analytical expressions are derived to obtain an initial design. For UWB design, the first resonant frequency should be slightly higher than the lower band boundary. The length of the ellipse perimeter should be around one wavelength long at the lowest in-band frequency. Practically, this frequency should be lower than 3 GHz in ultrawide band application to compensate for the environment variation [8].

The perimeter of an ellipse having a major axis (a) and a minor axis (b) can be expressed as given in equation (1).

$$P=2aE(e) \qquad (1)$$

E(e) stands for elliptic integral of the second kind with elliptic modulus , the eccentricity 'e' is given by

$$e = \sqrt{1-\left[\frac{b}{a}\right]^2} \qquad (2)$$

The perimeter of the outer ellipse should be close to one wavelength of the average medium for crescent and the elliptical antenna. If the lowest frequency in the impedance bandwidth of the antenna is f_L (GHz) and the effective permittivity of the medium of radiation can be approximated by

$$\epsilon_{eff} \approx \left(\frac{\epsilon_r+1}{2}\right) \qquad (3)$$

The relative permittivity ε_r= 4.2 is considered for the proposed antenna design. The ϵ_{eff} value is 2.6.

Then

$$f_L = \frac{300}{P\sqrt{\epsilon eff}} \qquad (4)$$

The perimeter is represented in millimeter. Using the above expressions for the proposed design, the major axis a=27 mm and minor axis b= 18 mm, perimeter p= 71.4 mm and f_L ≈2.6 GHz were obtained. For UWB applications, the inner hole of the crescent can be used for RF circuits without affecting much of the antenna operation. The overall crescent antenna area could be reduced by 50% as compared to a full elliptical patch.

IV. SPIRAL AND U SLOT DESIGN

A Spiral geometry slot structure [9] in ground plane can be used to reduce the antenna size and also to improve the performance of antenna. In this proposed work, geometries of two different slot structures are investigated, as revealed in Fig. 2(a) and 2(b). Fig 2(a) shows the one arm spiral slot on the ground plane and Fig 2(b) shows the crescent antenna with U slot on top of the patch.

Full elliptical antenna has a full ground plane as shown in Fig. 1(a). To enhance the performance of crescent antenna and to achieve multi-bandwidth, a single arm spiral is positioned on top of the grounded substrate to replace the full ground plane of the full elliptical shaped antenna as shown in Fig.3 (a).The size of the spiral slot width is 1mm.

To further augment the performance of crescent antenna and to reduce the size of the antenna, a U slot on top of the patch [10] is introduced as shown in Fig. 3(b). The width of the U slot on top of the patch is 1 mm. By realizing a spiral slot on the ground plane and U slot on top of the patch of the antenna as shown in Fig. 3(a) and (b) improves the performances, such as decreased antenna size, reduced discontinuity in bandwidth, and increased antenna gain. Table. 1 shows the dimensions of the proposed antenna used for fabrication.

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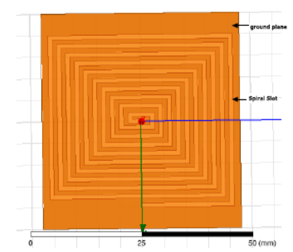


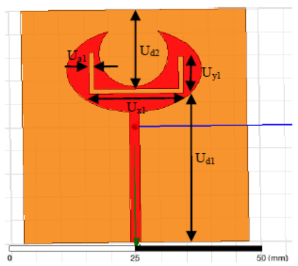
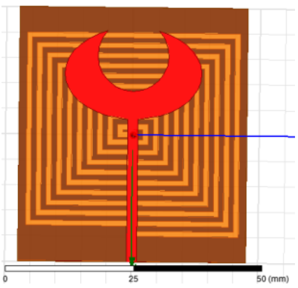


Fig.2a.One arm spiral ground slot 2b. Crescent Antenna U slot



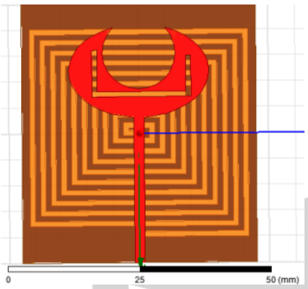


Fig. 3a. Crescent-shaped antenna with spiral ground plane. **3b.Crescent-shaped antenna with U slot in the patch**

Table – 1

Dimensions of the proposed antennas (Unit: mm) ground Plane Size: 45 mm x 50 mm

Antenna	W_s	L_s	d	U_{a1}	U_{d1}	U_{d2}	U_{x1}	U_{y1}
Crescent antenna with U slot	45	50	5	1	32	16.5	19	8

V. Simulation Results

Case I: Full elliptical antenna with full ground plane

Simulations required for the design realization of the proposed antenna were done using the High Frequency Structure Simulator, version. 14 and measurements of the prototype antenna were done by using a vector network analyzer. The simulation was initiated by designing a full elliptical antenna and its parameters were calculated by using the expressions given in section III. The full elliptical antenna is simulated with a major axis 'a' = 27mm, a minor axis 'b'= 18mm and with ground plane of 45 x 50 mm. The simulation results in terms of return loss and VSWR are shown in Fig. 4(a) and 4(b) respectively

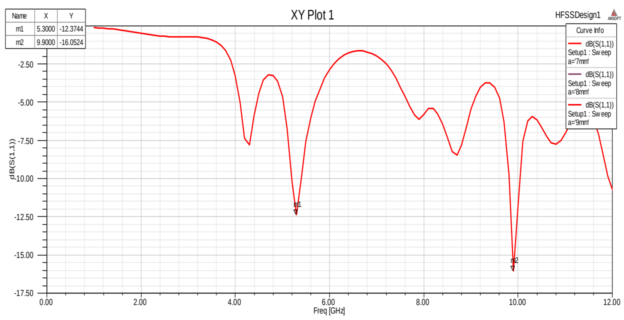


Fig.4 (a). Simulated return loss for the full elliptical antenna

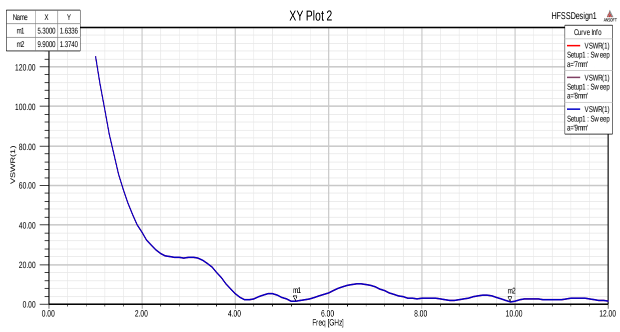


Fig.4 (b). Simulated VSWR for the full elliptical antenna

For efficient operation of antenna, the value of return loss should be less than -10db [11]. From the simulation results of return loss characteristics, an impedance bandwidth for return loss less than -10 db from 5 GHz – 9.9 GHz. The return loss for full elliptical antenna at 5.3 GHz is -12.37 db and at 9.9 GHz is -16 db. For perfect impedance matching the value of VSWR should be between unity and two. In Fig.4 (b), the VSWR value for the full elliptical antenna satisfies the requirements well.

Case II: Crescent antenna with spiral ground plane

To reduce the size of the antenna, the elliptical antenna is transformed into crescent antenna by carving a circular hole inside the full ellipse antenna and simulations were done to analyze its performance. The analysis was done for three different values of 'r', radius of circular hole (7mm, 8mm and 9mm). A spiral slot in the ground plane of the crescent antenna is also introduced. The simulation results are shown in Fig. 5(a) and 5(b) respectively. Figures 5(e) and 5(f) show the simulated radiation pattern and gain for the crescent antenna.

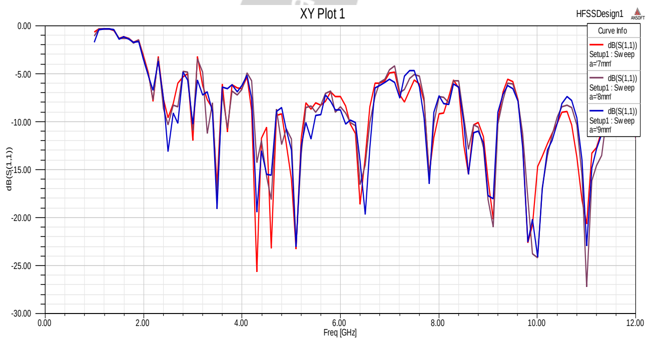


Fig.5 (a).Simulated return loss for the proposed crescent antenna with variation in circular slot size and spiral slot in the ground plane

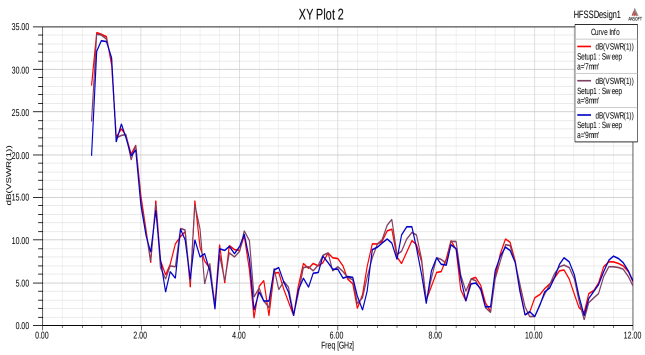


Fig.5 (b).Simulated VSWR for the proposed crescent antenna with variation in circular slot size and spiral slot in the ground plane

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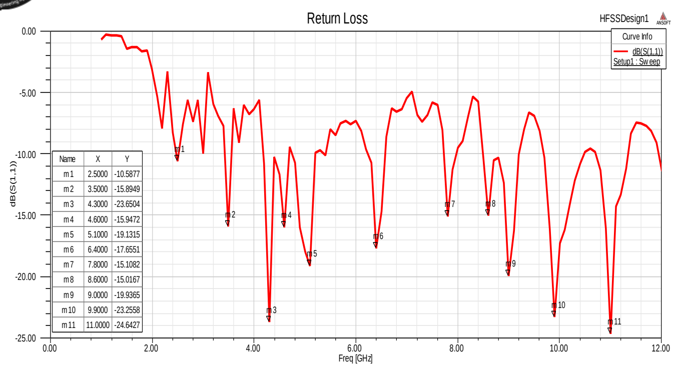

Fig.5(c).Simulated returns loss for the proposed crescent antenna with 7mm circular slot and spiral slot in the ground plane

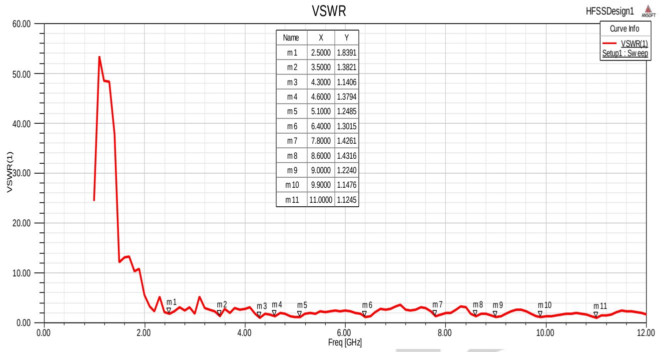

Fig.5 (d).Simulated VSWR for the proposed crescent antenna with 7mm circular slot and spiral slot in the ground plane

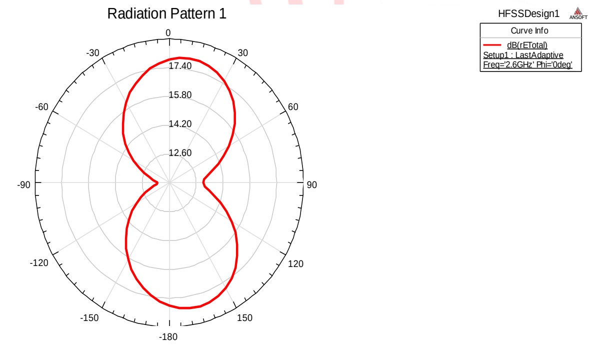

Fig. 5(e) Simulated radiation patterns for Crescent antenna

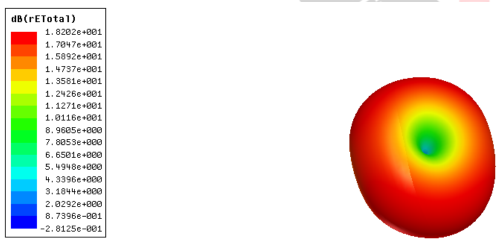

Fig. 5(f) Simulated gain for Crescent antenna

The above figures show the variation of return loss, VSWR, radiation pattern and gain by changing the size of circular slot above the patch as well as by introducing spiral slot in the ground plane. From the simulated outputs, the circular slot with 7mm radius has lower return loss and permissible VSWR when compared with other circular slot antennas with 8mm and 9mm radius. Fig. 5(c) shows the simulated return loss for the proposed crescent antenna with 7mm circular slot and spiral slot in the ground plane. The proposed antenna with 7mm circular slot and spiral slot in the ground plane gives multiple bands having low return loss. The radiation pattern illustrates how the antenna directs the energy it radiates. The radiation pattern at 2.6 GHz is shown in Fig.5 (e). The gain value illustrates the efficiency and directional capabilities of the antenna. For the proposed crescent antenna with spiral slot in the ground plane, the simulated gain is 8.9605 db.

Case III: Crescent antenna with U slot on top of the patch

In an attempt to further enhance the performance of Crescent antenna with spiral ground plane, a U slot with 1mm is made on the top of the patch of the Crescent antenna with spiral ground plane. This resulted in size reduction of the patch and the performance of the antenna is also improved. The simulated return loss, VSWR, radiation pattern and gain for this case are shown in Figures 6(a)-6(d) respectively. From the analysis of simulated results, it has been observed that the Crescent antenna with U slot on top of the patch provides optimal performance with multi-band. This final proposed Crescent antenna with U slot on top of the patch is used for preparing the prototype and the corresponding performance parameters are measured to validate its performance.

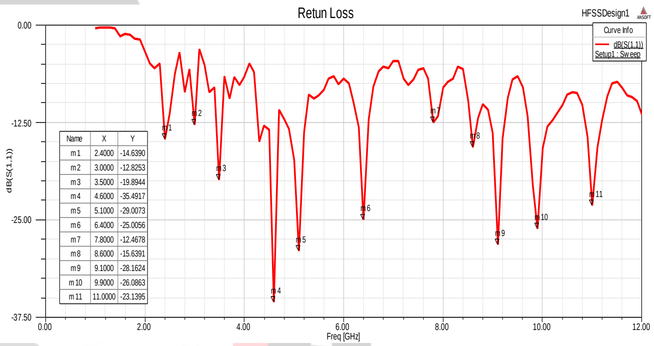

Fig.6 (a).Simulated return loss for the proposed crescent antenna with U slot

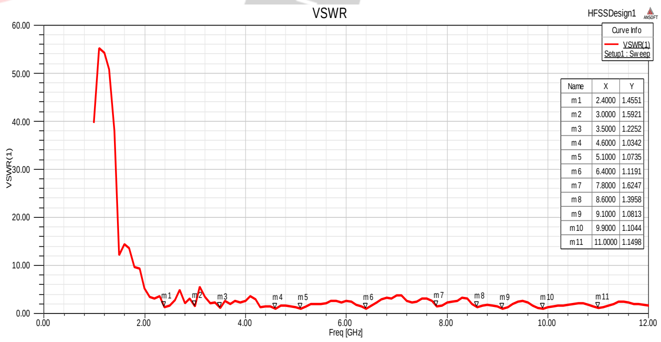

Fig.6 (b).Simulated VSWR for the proposed crescent antenna with U slot

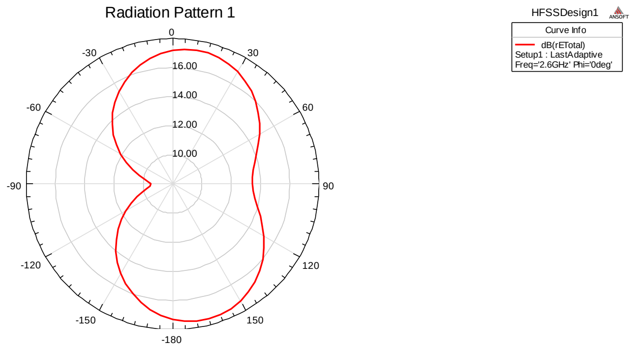

Fig.6(c).Simulated radiation pattern for Crescent antenna with U slot

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Fig. 6(d).Simulated gain for Crescent antenna with U slot

VI. Experimental Results

The multi-band crescent antenna with spiral ground plane and with U slot above the patch as shown in Fig. 7(a) and 7(b) are fabricated using Photolithography techniques and measured using network analyzer. There is a good agreement between the measured and simulated results.

Fig.7 (a). Bottom view of Prototype Crescent-shaped antenna with spiral ground plane.

Fig.7 (a). Top view of Prototype Crescent-shaped antenna U slot

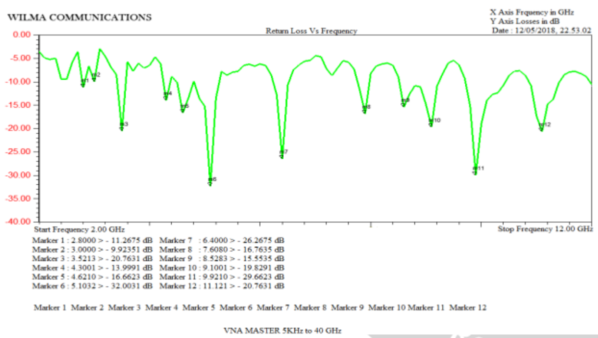

Fig.7 (c) .Measured return loss of the prototype crescent antenna

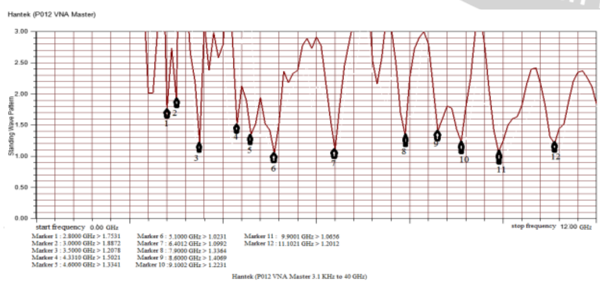

Fig.7 (d).Measured VSWR of the prototype crescent antenna

VII. Conclusion

In this paper, a new crescent antenna for UWB applications has been designed and tested successfully. It includes a spiral shaped slot in the ground plane and a U slot on top of the patch. This proposed crescent shaped antenna has been designed to be suitable for UWB applications. The spiral slot in the ground plane provides multiple bandwidths. The U slot design reduces the antenna size but the performance characteristics are not degraded when compared with its original structure. Return loss, VSWR, radiation pattern and gain of the crescent antenna with U slot were almost identical to the original full size geometry. HFSS tool is employed for the analysis of the proposed crescent antenna. Prototype of the optimal crescent antenna is made. The prototype is found similar in terms of its performance characteristics. This leads to the suitability of the proposed crescent antenna with U slot on the top of patch for Ultra-Band wireless applications.

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