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A CPW-Fed Structure Shaped Substrate Wideband Microstrip Antenna for Wireless Applications

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***Abstract* - A structure shaped substrate wideband microstrip patch antenna fed by coplanar waveguide (CPW) is proposed for wireless applications. Structure shaped substrate is produced by cutting the rectangle shape substrate in the form of a semicircular disc. The radiating patch of proposed antenna is taken in the form of U-shape. The ground plane is extended towards both sides of radiator for reducing the size of the antenna. The proposed antenna is simulated by Ansoft's High Frequency Structure Simulator (HFSS). A good agreement is observed between simulated and measured results. The prototype is taken with dimensions 24 mm × 24 mm ×1.6 mm that achieves wide bandwidth, constant group delay and good radiation patterns over the entire operating bandwidth from 3.4 to 9.4 GHz (6.0 GHz) with 93.7% impedance bandwidth at 6.4 GHz center frequency. Thus, the proposed antenna is applicable for C band applications.**

Index Terms— CPW-Fed, Microstrip Antenna, Structured Substrate, Wideband.

I. INTRODUCTION

With the fast development in wireless communication, the demand for devices that can operate for wideband has increased [1-4]. A lot of research work has carried out on wideband and ultrawideband. Many different types of patch antenna shapes such as circular shape [5], U shape [6], inverted T shape [7], M shape [8], A shape [9], rhombus shape [10] etc. are used till now for getting wideband. Along with these different types of shapes researchers also work on numerous techniques and structures for getting wideband such as CPW-fed technique and defected ground structure for getting wideband [11-16]. Substrate of microstrip patch antennas also plays a major role for obtaining wideband [17]. In these types of microstrip patch antennas a common thing is that the substrate is taken either rectangular or square in shape. In these shapes the large space around the radiator is generally wasted. Small amount of work is done by the researchers till now on the structure- shaped substrate [18].

This paper is highly motivated from above reported papers and a novel wideband microstrip antenna with structure shaped substrate is proposed and designed for wireless applications. The proposed antenna uses a novel technique of cutting the substrate in place of regular shape substrates to

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achieve wide bandwidth. The advantage of structure shaped substrate is that it helps to reduce the overall size of the antenna with wide impedance bandwidth. The large space around the radiator is fully utilized by placing the ground and radiating patch on single side of the substrate. The proposed antenna is composed of U-shape radiating patch with good radiation performance from 3.4 to 9.4 GHz. The detailed antenna geometry is discussed in section 2. Section 3 covers the parametric study of proposed antenna in detail. Experimental results are discussed in section 4. Section 5 concludes the paper.

II. ANTENNA GEOMETRY

The schematic configuration of the proposed CPW-fed structure-shape substrate wideband antenna is shown in Fig. 1. The proposed antenna has overall dimensions of $L \times W$ and is designed and fabricated on a low-cost FR4 substrate of thickness h, relative permittivity $\varepsilon_r = 4.4$ and loss tangent tanδ = 0.0019. The substrate is etched in the form of semicircular disc at the centre with radius 12 mm. The radiating patch is in the shape of rectangle and a circular disc of radius (R_p) is etched in the middle of patch. The center position of circular disc is at the distance of L_{p2} from upper side of the radiator. The ground plane is on the same plane as radiator. It has two rectangular slits each having dimensions $W_g \times L_g$ and a semicircular path having thickness (R_g) . The length of gap between the radiating patch and the ground plane is taken as L_{pg}. The width of CPW- fed line is fixed at W_f to achieve 50 ohm characteristics impedance. Since the radiator is surrounded by a metal ground plane on the etched substrate it helps in reducing the size of proposed antenna. The small area between the radiator and the ground is a major factor for achieving strong capacitive coupling. The gap between the feed and ground plane is taken as 0.4mm. The detailed dimensions of the proposed defected substrate CPW- fed wideband antenna are listed in Table 1. Fig. 2 illustrates the photograph of fabricated antenna, which is connected with a 50Ω SMA connector for measurement of the parameters.

Table 1. Design parameters of the proposed CPW-fed structure-shape substrate wideband antenna.

Parameters	L	W	R_p	h	L_{p1}	L_{p2}
Units (mm)	24	24	5	1.6	7	2
Parameters	L_{pg}	W_p	W_f	L_g	W_g	R_g
Units (mm)	0.8	5.5	3	10	10.1	1

The electromagnetic solver, Ansoft HFSS (v 14.0) [19], is used to investigate and optimize the proposed antenna configuration. The various modifications of the ground plane and substrate are shown in Fig. 3. Firstly, two rectangular slots on rectangular substrate (trace (i)) is used, the simulated return loss shows that the return loss is above 10dB from 5.5 to 8.1 GHz with two

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resonating bands at 4.25 and 9.0 GHz and does not cover the entire operating bandwidth. However, when ground plane on rectangular substrate is stretched to form a circular ring shape ground (trace (ii)), the simulated return loss shows better results but not covers the entire bandwidth as return loss is above 10dB only from frequencies 5.8 to 7.6 GHz, with two resonating bands at 4.6 and 8.67 GHz. Furthermore, when substrate is etched in the form of semicircular disc (trace (iii)), the simulated return loss shows good results covering the entire bandwidth with two resonating bands at 4.4 and 8.0 GHz , having larger impedance bandwidth compared to trace (i) and (ii). Finally, it is decided to take etched substrate antenna for the proposed design because it is smaller than rest of the design with better impedance matching conditions for the entire bandwidth from 3.4 to 9.4 GHz (6.0 GHz).

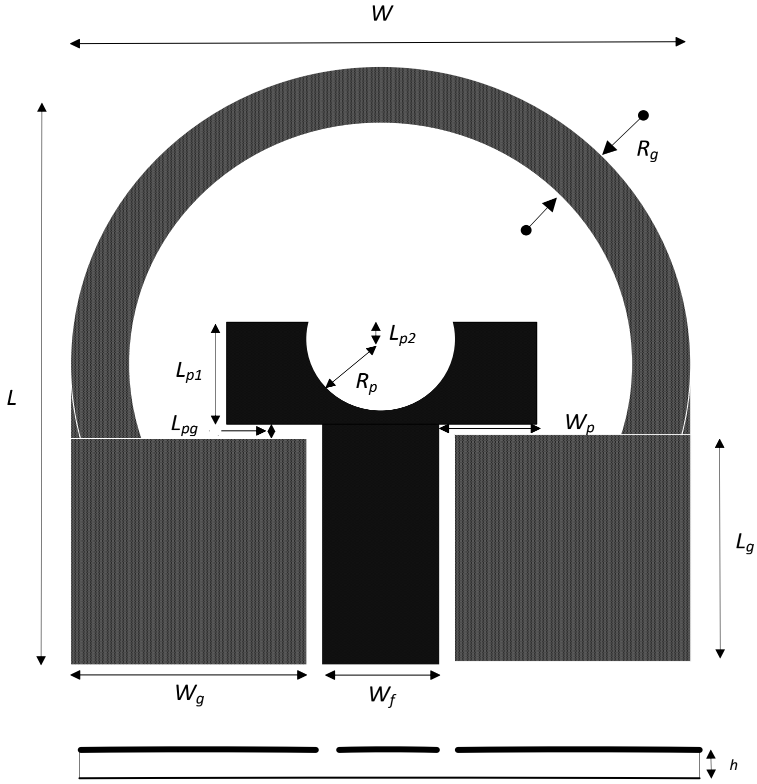

Fig. 1. Schematic configuration of the proposed CPW-fed structure-shape substrate wideband antenna.

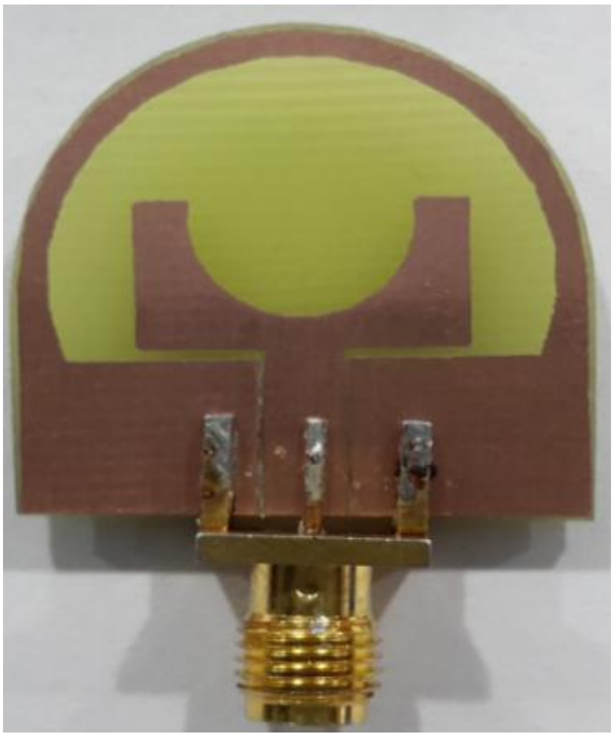

Fig. 2. Photograph of the proposed CPW-fed structure-shape substrate wideband antenna.

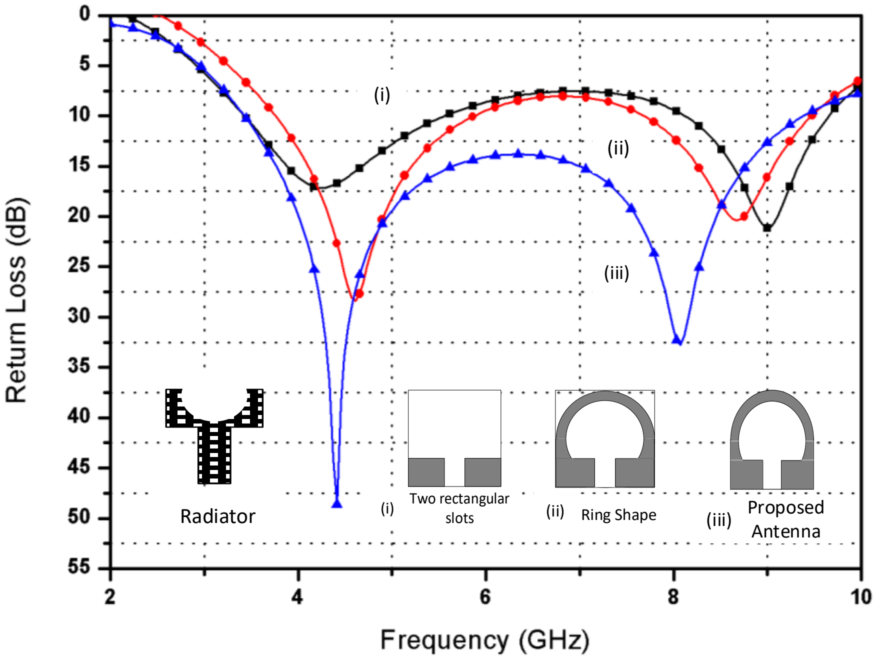

Fig. 3. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna, ring shape ground plane and two rectangular slots antenna.

III. PARAMETRIC STUDY OF THE PROPOSED ANTENNA

In this section, the influence of the different design parameters on antenna performance is studied and discussed. At a time one parameter is taken, the others are kept constant. The result of these parametric studies provides a useful strategy to optimize the design before final fabrication. The effect

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of change in radiating patch length, width, inner circle radius (L_{p1},W_p , R_p), microstrip feed line (W_f), ground plane semicircular path (R_g) and length between radiating patch and ground plane (L_{pg}) are considered for parametric study.

Fig. 4 depicts the effect of the length L_{p1} of the radiating patch from 5 to 9 mm. It is found that the bandwidth of antenna increases when the value of L_{p1} increases from 5 to 7 mm. With further increase in length, it deteriorates. Therefore, it is decided to take L_{p1} = 7 mm as the optimum value for the bandwidth from 3.4 to 9.4 GHz, covering the entire wideband.

The effect of the width W_p of radiating patch on the impedance bandwidth of the antenna from 5.0 to 6.0 mm is depicted in Fig. 5. It can be seen from the graph that the bandwidth of the antenna increases as the value of W_p increases from 5.0 to 5.5 mm. With further increase in width, it deteriorates. Therefore, it is decided to take W_p = 5.5 mm as the optimum value covering the entire wideband.

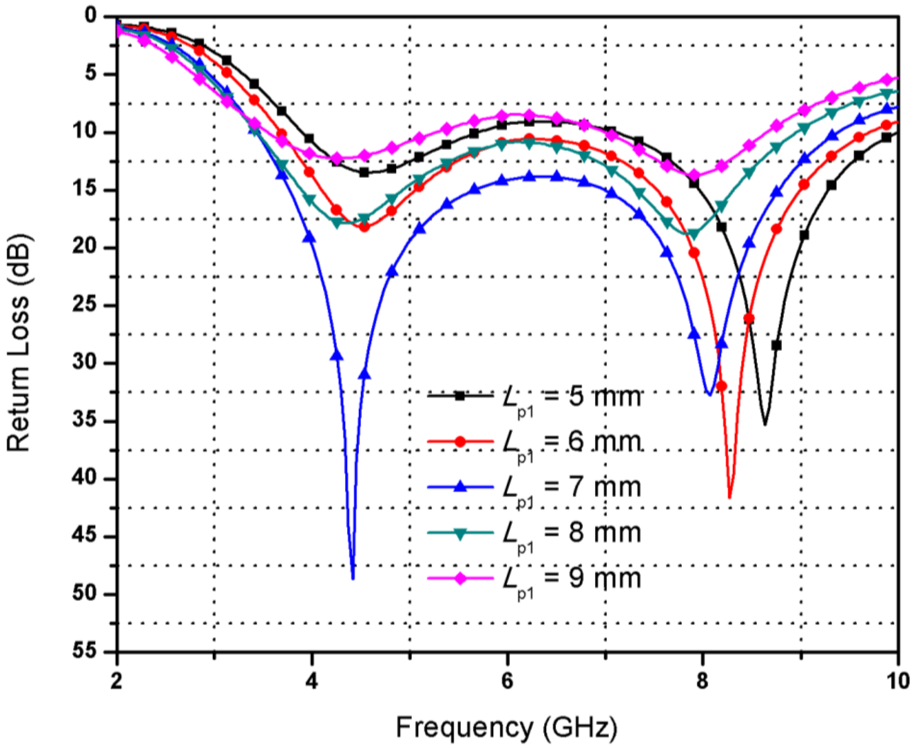

Fig. 4. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various L_{p1} ; other parameters are the same as listed in Table 1.

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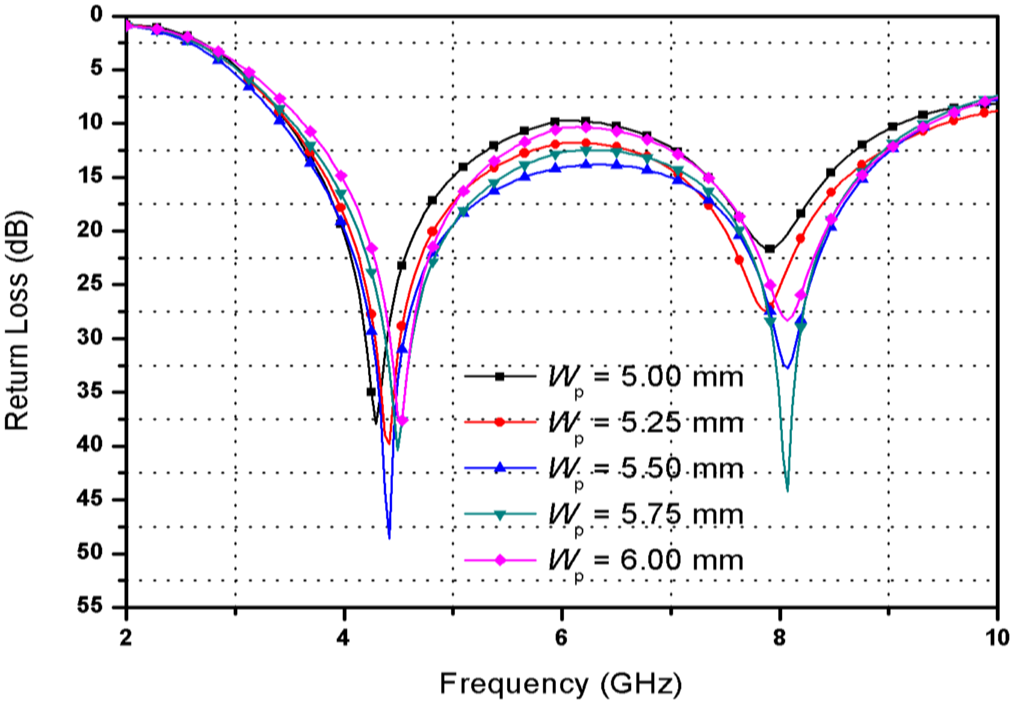

Fig. 5. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various W_p ; other parameters are the same as listed in Table 1.

Fig. 6 shows the effect on the radius of inner circle of U -shape radiating patch (R_p) on the return loss of the proposed antenna. It is keenly observed that by changing the value of R_p from 4.8 to 5.0 mm, the bandwidth of return loss increases with increase in R_p. Therefore, it is decided to take R_p = 5.0 mm as the optimum value, covering the entire wideband.

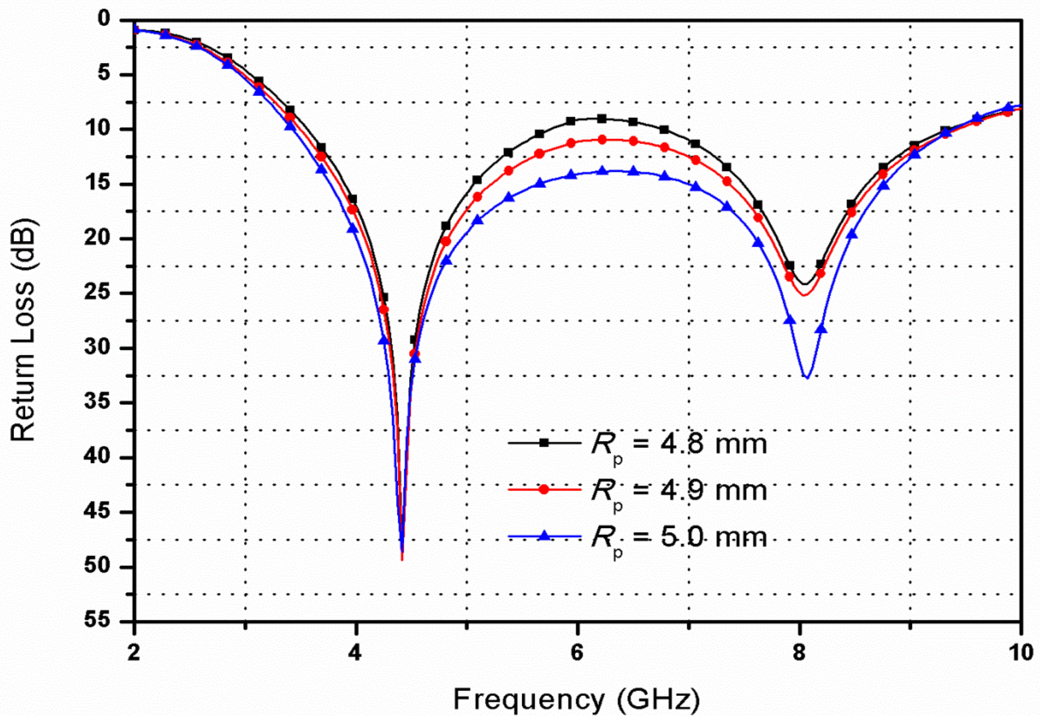

Fig. 6. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various R_p ; other parameters are the same as listed in Table 1.

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Fig. 7 illustrates the effect of the microstrip feed line width W_f on the return loss of the proposed antenna from 2.8 to 3.2. It is observed that by changing the value of W_f from 2.8 to 3.0 mm, the impedance matching improves at 5 to 7 GHz. With further enhancement in microstrip feed line width (W_f), it deteriorates. Therefore, it is decided to take W_f = 3.0 mm as the optimum value.

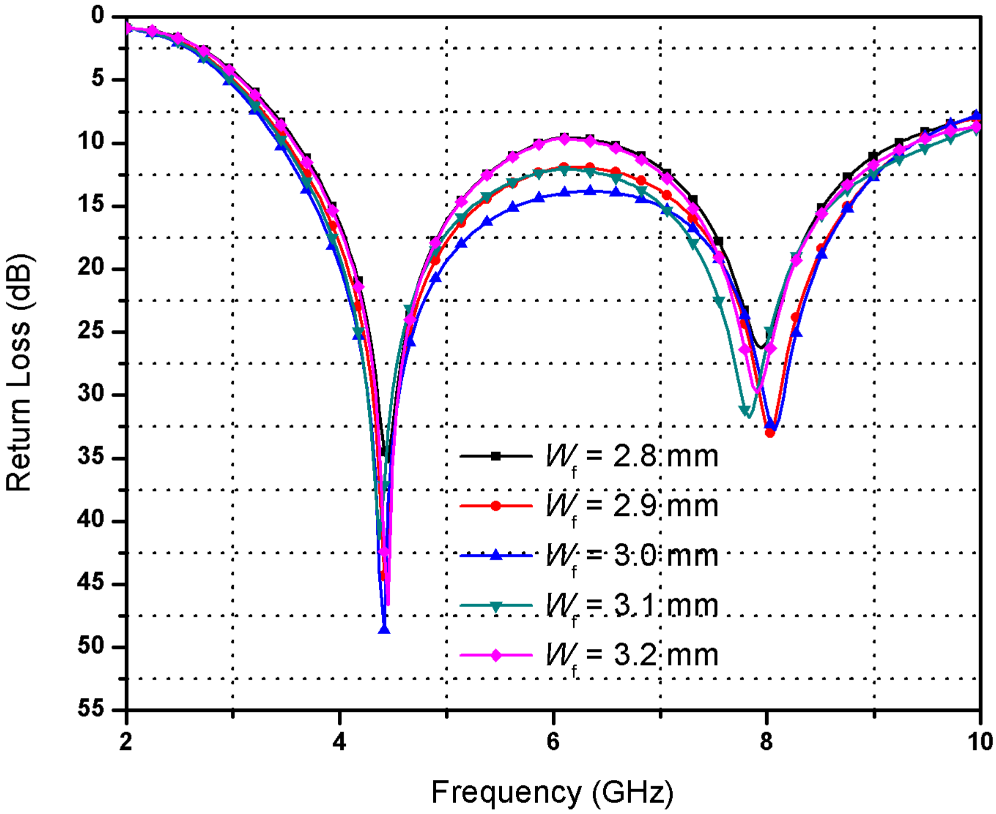

Fig. 7. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various W_f ; other parameters are the same as listed in Table 1.

It is worth mentioning that the configuration of the ground plane also affects the characteristics of patch antenna. Thus, the semicircular path (R_g) of the structure shape substrate is also considered for the parametric study. Fig. 8 shows the simulated return loss as R_g varies from 0.6 to 1.4 mm in step of 0.2 mm. It can be seen that the bandwidth of return loss increases as R_g varies from 0.6 to 1.0 mm and decreases with further increase in R_g. It is also observed that impedance mismatch of the total band also improved as R_g varies from 0.6 to 1.0 mm and decreases further. Therefore, it is decided to take R_g = 1.0 mm as the optimum value with the bandwidth from 3.4 to 9.4 GHz, covering the entire wide band.

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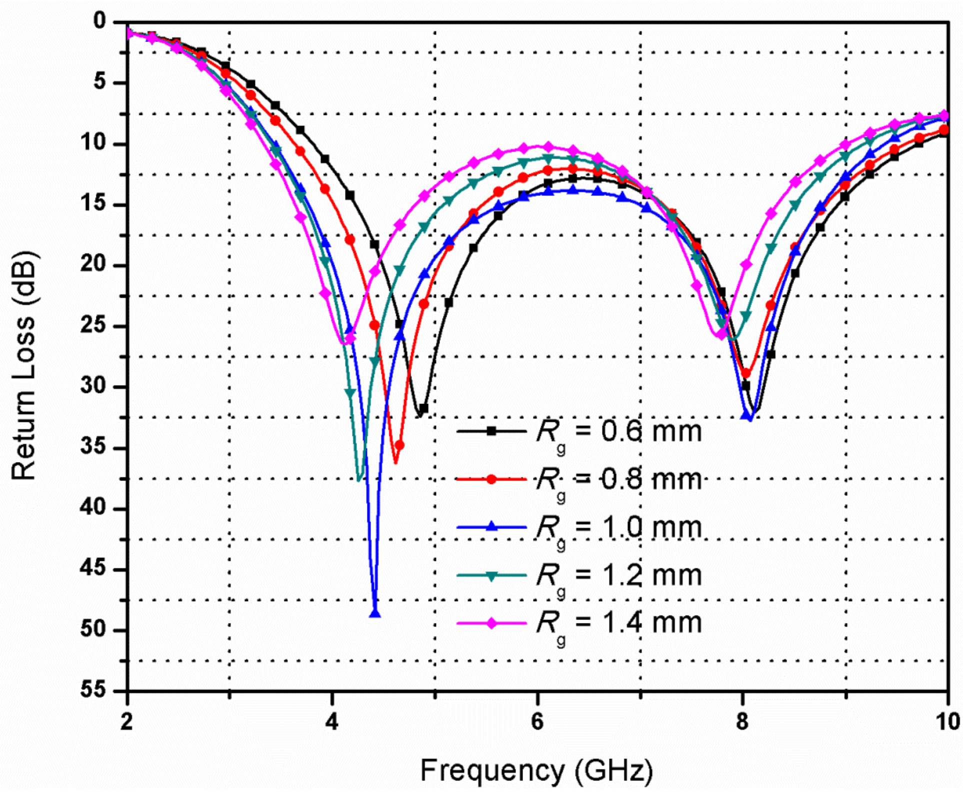

Fig. 8. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various R_g ; other parameters are the same as listed in Table 1.

Fig. 9 shows the effect of length between patch and ground L_{pg} from 0.6 to 1.4 mm on antenna performance. The bandwidth of return loss increases as the value of L_{pg} increases from 0.6 to 0.8 mm. As the value of L_{pg} increases further, the bandwidth of return loss degrades. Thus, the optimum value of the length between patch and ground (L_{pg}) of the proposed antenna is chosen to be 0.8mm.

The results obtained from the variation of different parameters, it is clear that due to structure shape substrate, the proposed antenna has wide impedance bandwidth performance without increasing the overall dimensions of the antenna.

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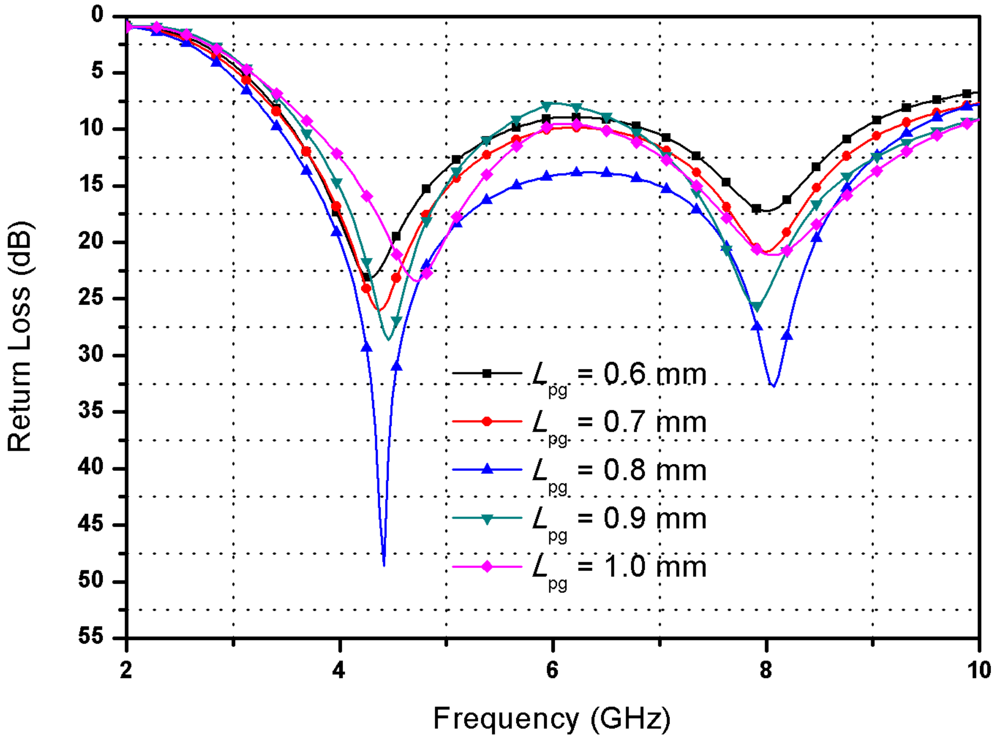

Fig. 9. Simulated return loss against frequency for the proposed CPW-fed structure-shape substrate wideband antenna with various L_{pg} ; other parameters are the same as listed in Table 1.

IV. EXPERIMENTAL RESULT AND DISCUSSION

The performance of the proposed antenna such as return loss, group delay and radiation pattern are measured using Agilent 8757E scalar analyzer. For manufacturing the proposed antenna, dielectric substrate FR4 (Fire Retardant) having relative permittivity $\varepsilon_r = 4.4$ is used. The value of loss tangent for this dielectric material is tanδ= 0.0019. FR4 is a composite material composed of woven fiber glass cloth with an epoxy resin binder that is flame resistant. The proposed antenna was printed through milling technique done with the help of MITS, Eleven Lab machine. In milling process the removal of extra copper on FR4 sheet is done through machine without using any chemical. Milling process is typically a non-chemical process and it can be completed in a lab environment without exposure to hazardous chemicals.

The measured and simulated return loss curves of the proposed are shown in Fig. 10. A good agreement is observed between simulated and measured results. The small difference between measured and simulated result is due to the effect of SMA (sub miniature version A) connector soldering and fabrication tolerance. This small difference is also due to the impingement of the electromagnetic wave radiated from the antenna on the receptacle and the outer conductor of the connector [20].

The influence of the SMA connector on the proposed antenna can be understood with the help of equation 1.

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$$S'_{11} = S_{11} exp(2j\beta h_s) \quad (1)$$

where $\beta = \omega\sqrt{\mu\varepsilon}$ is the phase constant. The μ, ε and ω are the permittivity, permeability in the SMA connector, and the angular frequency, respectively.

SMA connectors are commonly used for microwave measurements. Connectors are necessary to connect cables in such systems. The modeling of SMA connectors is either neglected in the simulation of microwave components or approximated by an inaccurate model to model its characteristics [20]. The outer structure and receptacle of the SMA connector are modeled because the electromagnetic field affects them. A lumped port with 50Ω characteristic impedance is used for excitation in the simulation. The designed antenna offers a bandwidth of 6.0 GHz (3.4 to 9.4 GHz) which meets the bandwidth requirements for C band applications.

The proposed antenna illustrates good radiation pattern characteristics as shown in Fig. 11(a) to 11(b). The radiation patterns in H and E planes are at sampling frequencies of 4.4 and 8.0 GHz respectively. Patterns are distorted because the ground plane is a part of loop path, the surface current on the radiating plane changes the effective current distribution of the loop and results in distortion. These patterns are suited for application in almost all wireless communication equipment, as expected. Measured and simulated of radiation patterns shows good agreement.

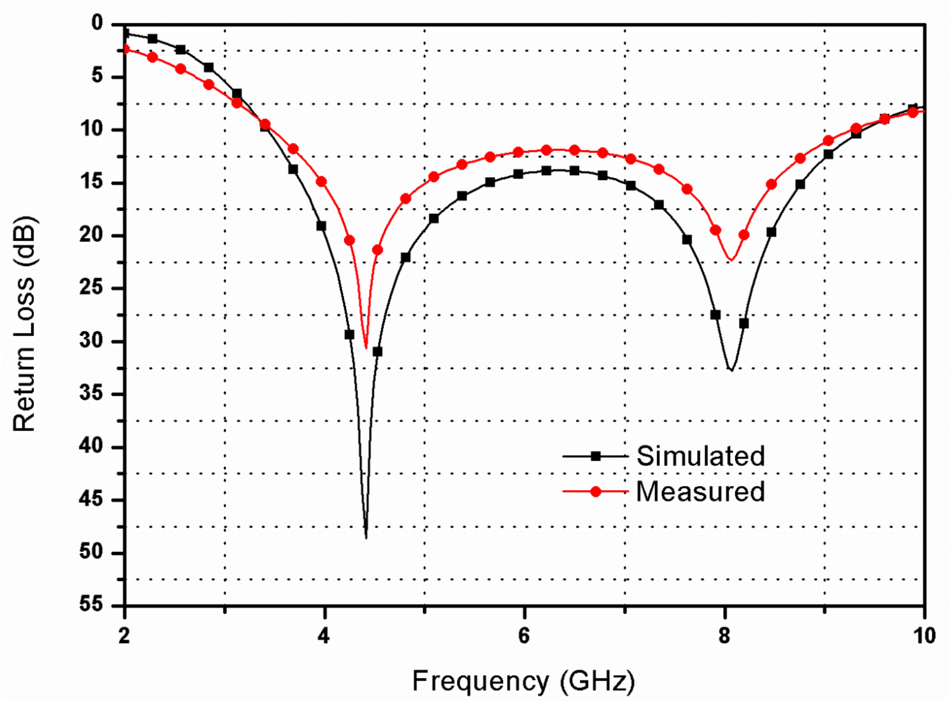

Fig. 10. Simulated and measured return loss for the proposed CPW-fed structure-shape substrate wideband antenna.

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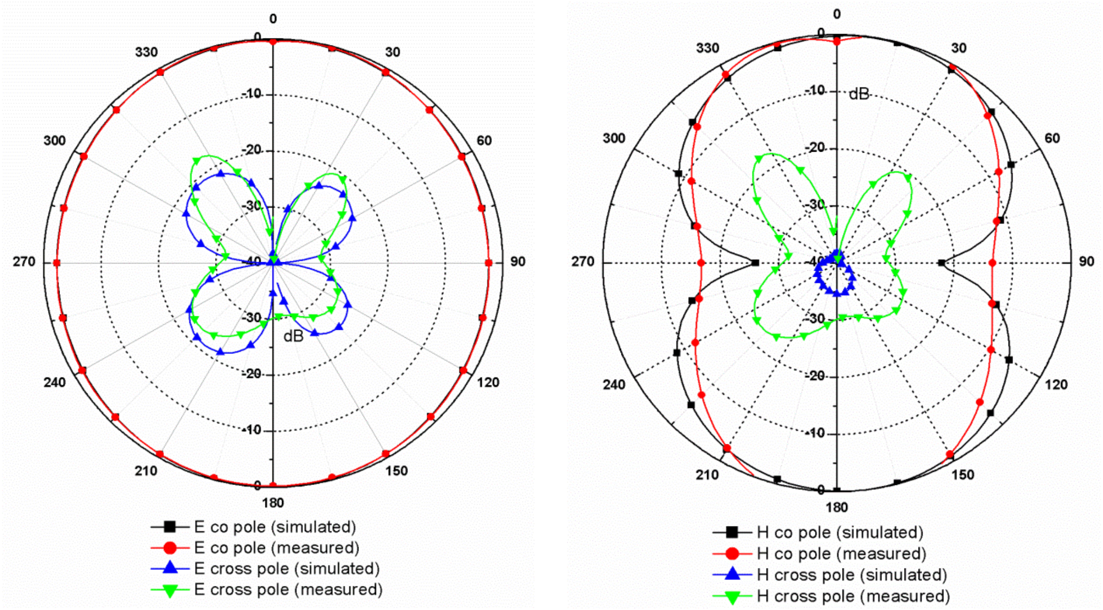
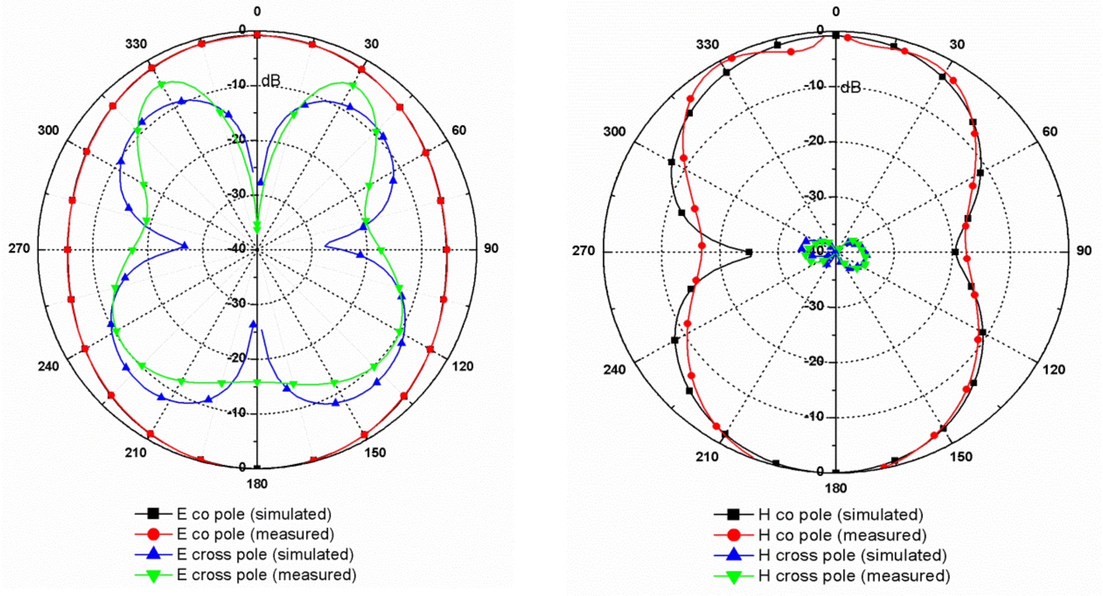


(a) 4.41 GHz



(b) 8.0 GHz

Fig. 11. Radiation patterns at various frequencies of proposed CPW-fed structure-shape substrate wideband antenna (a) 4.4 GHz and (b) 8.0 GHz

The antenna gain variation with frequency is shown in Fig. 12 for the proposed antenna. Antenna gain varies from 0.8 to 2.1 dBi over the entire operating band. Simulated result of gain shows good agreement with the measured results.

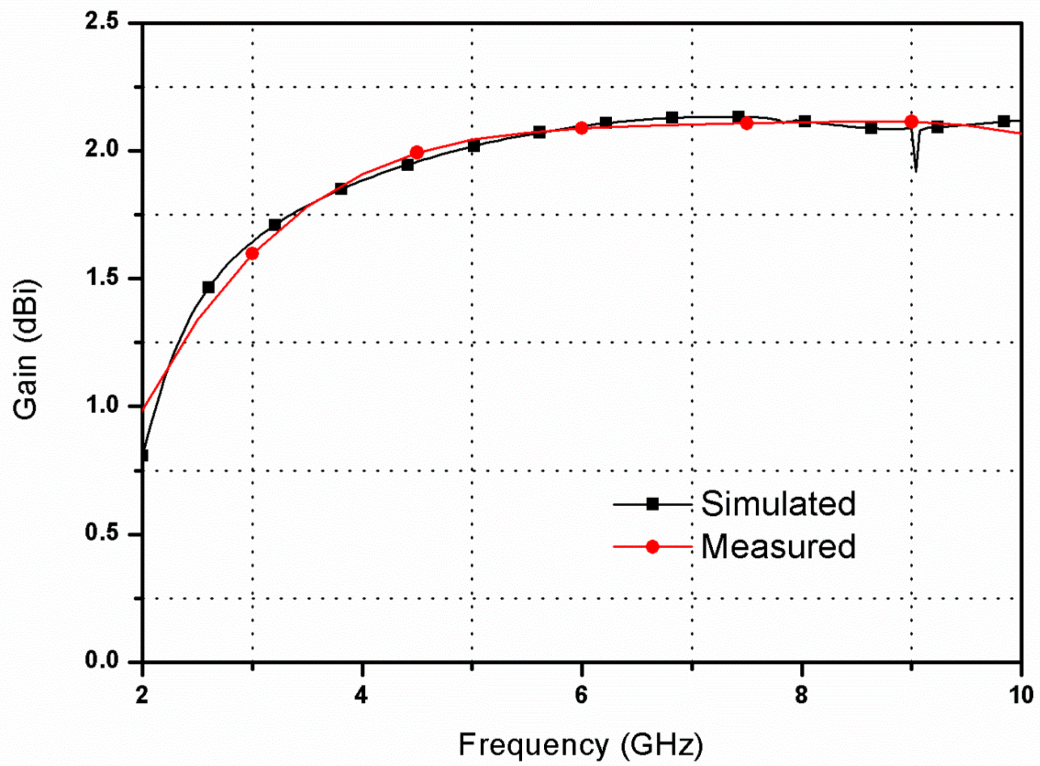


Fig. 12. Simulated and measured gain against frequency for the proposed CPW-fed structure-shape substrate wideband antenna.

Fig. 13 illustrates the group delay of the proposed antenna. Group delay is an important parameter in the designing of wideband antenna as it shows about the distortion of the transmitted pulses in all wireless communications. The group delay is obtained from the derivative of the phase variation with respect to angular frequency [21]. The group delay of the proposed antenna is simulated and calculated through electromagnetic solver, Ansoft HFSS (v 14.0). It is observed that the group delay for the proposed antenna is constant and less than 1 ns for entire operating bandwidth from 3.4 to 9.4 GHz. For distortion less transmission, group delay should be less than 1 ns in the wideband antenna.

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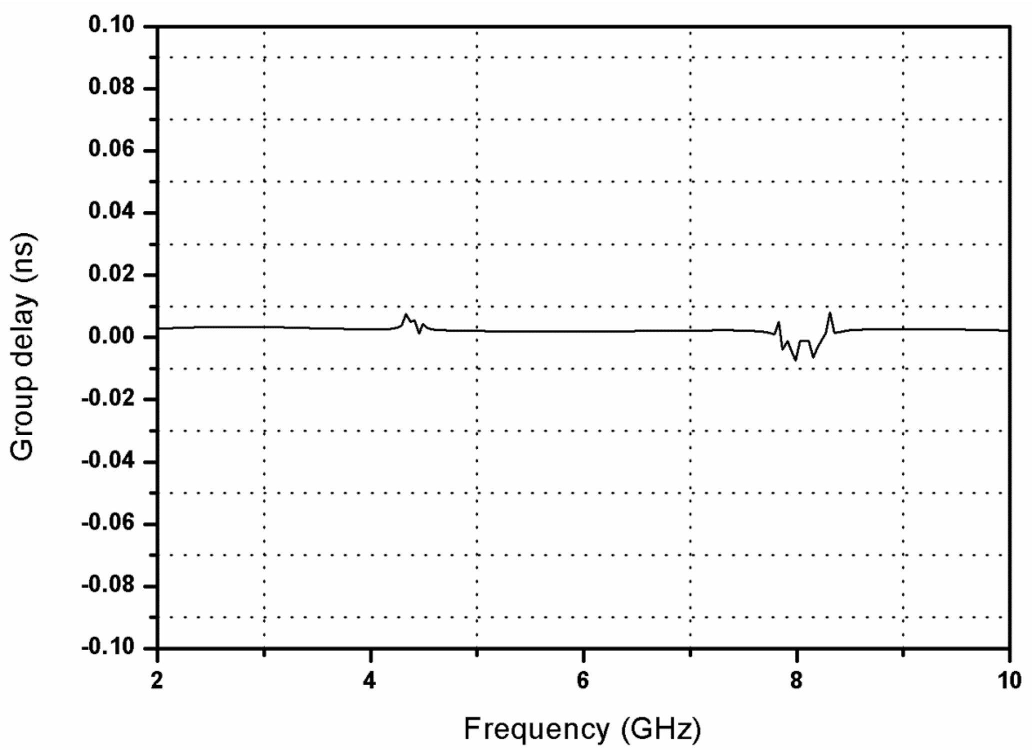

Fig. 13. Group delay for the proposed CPW-fed structure-shape substrate wideband antenna.

Table 2 shows the comparison of proposed (structure-shaped substrate) antenna with some other existing antennas in terms of the antenna purpose, antenna size, operating frequency band, Impedance bandwidth and applications. The comparative chart shows that the proposed antenna has small size, structure-shaped substrate and wideband applications with respect to other antenna of different dimension and shapes.

Table 2: Comparison of Reference antennas in term of size and bandwidth

Reference No.	Antenna purpose	Antenna Size (mm^2)	Operating frequency band (GHz)	Impedance Bandwidth (%)	Applications
[5]	UWB	39×40	2.6 - 12.3	129.35	UWB
[10]	UWB	19×21	2.78 – 12.92	129	UWB
[11]	Wideband	38×25	2.4 – 6.0	85.71	WLAN/WiMAX
[12]	Dual Band	35.24×26.4	3.424 – 6.274	19.44 & 33.19	WLAN/WiMAX
[18]	UWB	18×25	4.5-13.5	100	C and X band
Proposed Antenna	Wideband	24×24	3.4 -9.4	93.7	C band

V. CONCLUSION

A CPW-fed structure-shape substrate wideband antenna is presented in this study. The proposed antenna shows wideband performance in operating band from 3.4 to 9.4 GHz (6.0 GHz). The simulated and measured results of the proposed antenna show a balanced agreement in terms of return

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loss, antenna gain and radiation patterns. The radiation patterns are satisfactory over the entire operating bandwidth. Also, almost constant group delay is achieved. The proposed antenna gives impedance bandwidth of about 93.7% which helps its use in various wireless applications.

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