

Wideband P-Shaped Dielectric Resonator Antenna with Coaxial Probe Feed

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Abstract: In this paper, design of wideband Coaxial Probe feed P-Shaped Dielectric Resonant Antenna is proposed. The proposed structure has bandwidth of 4.1GHz ($S_{11} < -10\text{dB}$) ranging from 5.05GHz to 9.15GHz which is 85.4% of total bandwidth from 4.5GHz to 9.3GHz. Antenna has return loss of -61.29dB that is only a micro part of input power is reflected back resulting to a highly efficient antenna. Designed antenna is a low profile antenna with height of 10mm. Resonant frequency of proposed antenna is 6.14 GHz, suitable for wireless system like WiMAX, WLAN, C-band applications. Simulation and parametric analyses of proposed P-shaped antenna is done using CST (Computer Simulation Technology) Microwave Studio Suite 10.

Keywords: Dielectric resonator antenna (DRA), Impedance bandwidth (IBW), Perfect conductor, Resonant frequency, Return loss (S_{11}).

I. Introduction

Recently extensive research has been done to achieve wide bandwidth and high radiation efficiency for DRA using different configuration and design aspects. DRAs are low profile antennas means they have light weight, low cost and compact size. Moreover, they offer greater design flexibility and mechanical simplicity [1-3]. DRAs have zero conduction losses thus a major problem of conductor losses in metallic antennas is overcome by dielectric resonators antennas [4]. Additionally, they offer primary features like different methods of excitations such as coaxial probe feed, micro-strip feed, ease of coupling to almost all type of transmission lines, low temperature coefficient and high radiation efficiency [3]. DRAs are available in rectangular, triangular, spherical, conical and cylindrical shapes, where rectangular DRA offer maximum design flexibility (have two aspect ratios width/height and length/height) [5]. One more advantage of rectangular DRA is reduction of mode degeneracy problem which offer optimized bandwidth [6]. Over the last decades, main area of interests is to broaden the bandwidth of DRA. For the same, compact DRAs such as embedded DRA or DRAs with different configuration and shapes (L-shaped [7], T-shaped [8], tetrahedron [9], stair case [10] and so on) with different feeding mechanism were introduced. By using these DRAs bandwidth was increased up to only 50%-60% [7-10]. Recently P-shaped DRA with micro-strip feed was introduced which offers bandwidth of 80% [11]. This paper presents designing of P-shaped DRA excited by coaxial probe which enhances the bandwidth of DRA up to 85.4% from 5.05GHz to 9.15GHz. This paper is organized in different sections as basic theory is explained in Section II, Antenna configuration and Parametric Study/Results are in Section III and Section IV respectively. Paper is concluded in Section V.

II. Theory

To design proposed structure rectangular DRA is chosen. Field inside rectangular DRA is similar to rectangular dielectric waveguide and the propagation modes are divided into TE and TM modes but due to mounting of DRA over ground plane only TE modes- TE^x , TE^y and TE^z are excited [12]. The resonant frequency of these modes is a function of DRA dimensions. By using equation of magnetic wall waveguide model, initial dimensions of DRA are calculated considering $m=n=1$ and dielectric in x-z direction [13-14]. To calculate wave number equations are derived after implying magnetic wall boundary conditions, these equations are-

$$k_x = \frac{m\pi}{a} \quad \dots (1)$$

$$k_y = \frac{n\pi}{b} \quad \dots (2)$$

$$k_z \tan\left(\frac{hk_z}{z}\right) = \sqrt{(\epsilon_x - 1)(k_o^2 - k_z^2)} \quad \dots (3)$$

$$k_x + k_y + k_z = \epsilon_r \quad \dots (4)$$

Where k_x , k_y and k_z are wave numbers in x, y and z directions respectively and k_o denotes wave number in free space, defined as:

$$k_o = \frac{2\pi f_o}{c} \quad \dots (5)$$

Thus, resonant frequency can be calculated using equation:

$$f_o = \frac{c}{2\pi} \sqrt{\left\{ \frac{1}{(\epsilon_r - 1)} \left[k^2 \tan^2 \left(\frac{dk_x}{2} \right) + k_x \right] \right\}} \dots (6)$$

There is trade-off between bandwidth and Q-factor. Higher Q-factor lowers the bandwidth whereas Q-factor increases with increase in dielectric constant. Thus to achieve greater bandwidth material with lower dielectric constant should be used [15-17]. By removal of a part from rectangular DRA also reduces Q-factor resulting increase in bandwidth.

III. Design And Antenna Configuration

To design P-shaped DRA, first of all a rectangular part of dimension $(p \times q \times h)$ is removed from a rectangular DRA of dimension $(w \times d \times h)$ as shown in Fig. 1(b). In second step another rectangular part of dimension $(u \times v \times h)$ is separated from the structure obtained in first step, final structure is shown in Fig. 1(c) [2].

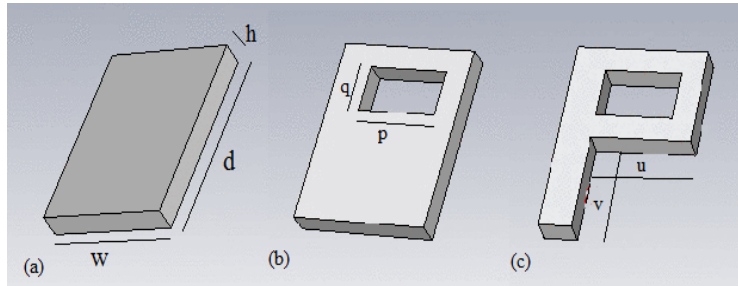


Figure 1 (a) Rectangular DRA (b) DRA with hole (c) P-shaped DRA

To reduce the value of Q-factor a hole of $(p \times q \times h)$ is drilled where $p=6\text{mm}$ and $q=4\text{mm}$, same as values of other removed section is $u=v=8\text{mm}$. Fig. 2 shows 3D and back view of proposed P-shaped DRA with coaxial probe feed. DRA is mounted over ground plane which is a perfect conductor. This ground plane has dimensions- width-16mm, length-18mm and height-1.5mm. Proposed antenna is designed using material Beryllia of dielectric constant $\epsilon_r=6.5$. Beryllia has thermal conductivity 330 W/K/m, Young’s modulus 345 kN/mm², Poisson’s ratio of 0.26 and thermal expansion of 7 [1e⁻⁶/K]. Dielectric resonator is characterized by dimensions w, d and h having values 12mm, 16mm and 10mm respectively. DRA is excited by a z-directed coaxial probe whose radius is $r=0.5\text{mm}$ which is insulated by Teflon coating having inner radius of $r=0.5\text{mm}$ and outer radius $R=1.67\text{mm}$ to have matching impedance of 50 ohm. Values of r and R are calculated using line impedance calculator to have optimum matching. Coaxial probe is inserted from the back side of the ground plane at the lower end of DRA as shown in Fig. 2(a).

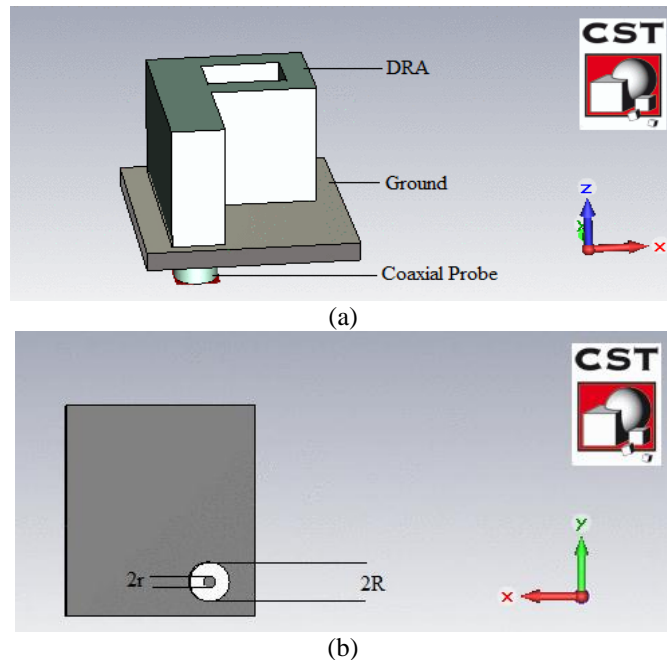


Figure 2. (a) 3D view and (b) back view of proposed P-shaped DRA

As in Fig. 2(b) ground and probe is insulated by Teflon whose material density is 2200 kg/m^3 , $\mu_r=1$, $\epsilon_r=2.1$, thermal conductivity is 0.2 W/K/m , Young's modulus 0.5 GPA , thermal expansion coefficient $140[10^{-6}/\text{K}]$ and Poisson's ratio of 0.4 . Design presented in [2] has been enhanced and the simulated results are presented. To design proposed structure material with lower dielectric constant is used which is cheaper and easy to machine. Probe is a PEC and its length is 11.5mm out of which 8mm is inserted into the DRA and 2mm is below to the ground. Only 3.5mm length of probe is coated by Teflon.

IV. Results And Parametric Analysis

Proposed structure is examined and simulated using CST Microwave Studio-10, S_{11} parameter is shown in Fig. 3. According to this simulation resonant frequency is at 6.14GHz and bandwidth of 4.1GHz ($S_{11} < -10\text{dB}$) from 4.5 to 9.3GHz . Fig. 3 shows that maximum dip is at 6.14GHz and at this frequency return loss is -61.29dB . Gain of the antenna is 2.4dB and its Far-field radiation pattern is shown in Fig. 4. Impedance bandwidth of antenna is calculated using equation $IBW = \frac{f_h - f_l}{f_c}$, where f_h is higher cut-off frequency, f_l is lower cut-off frequency and f_c is center frequency. It is found that impedance bandwidth is 65% . Voltage standing wave ratio (VSWR) is the measure of how perfectly antenna is matched with transmission line. It is expressed as $VSWR = (1 + \Gamma) / (1 - \Gamma)$, where Γ is reflection coefficient or return loss. From Fig. 5 it is found that VSWR is 1.001 , which is way below 2 .

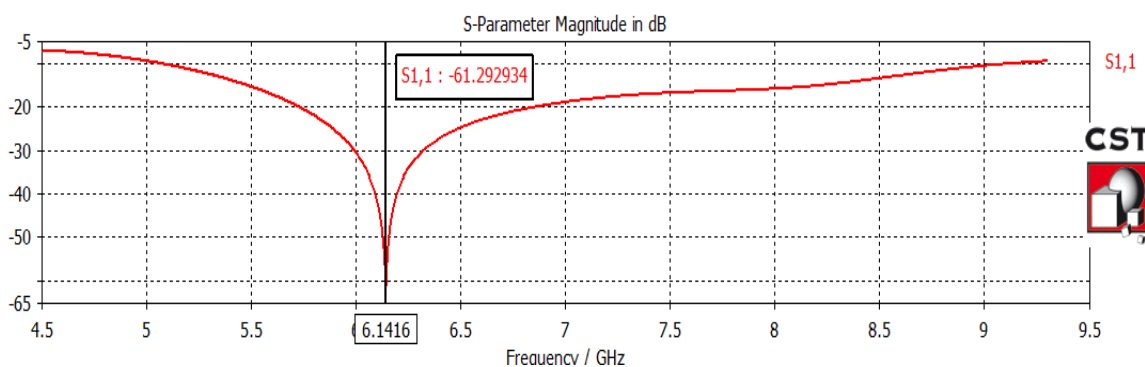


Figure 3. S_{11} Parameter of proposed antenna.

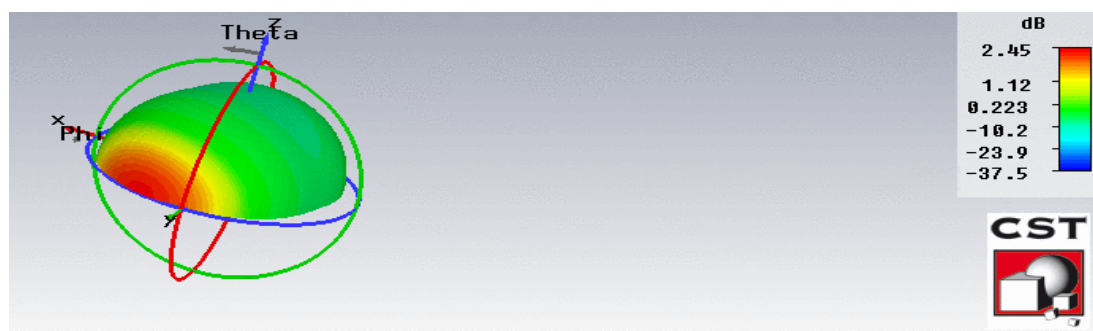


Figure 4. Far-field radiation pattern.

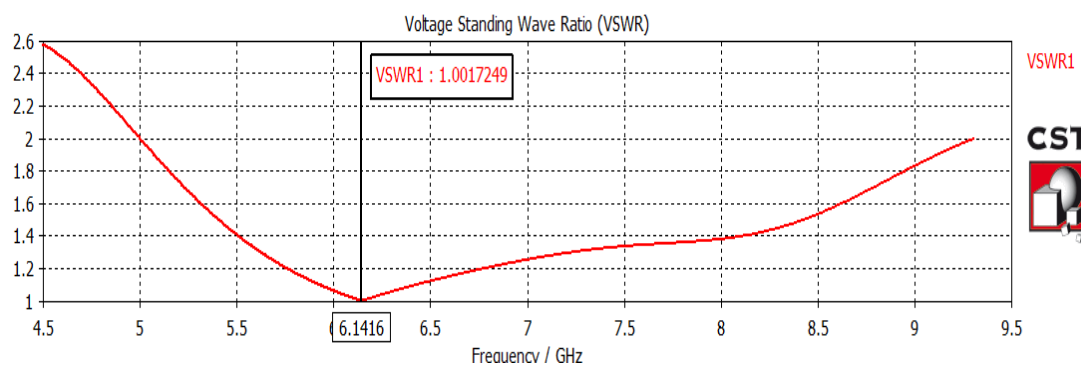


Figure 5. VSWR Representation at Resonant frequency.

E-field should have a regular converging pattern, form Fig. 6(a) it can be analyze that E-fields are converging at the center of Probe. Fig. 6(b) shows H-field radiation pattern.

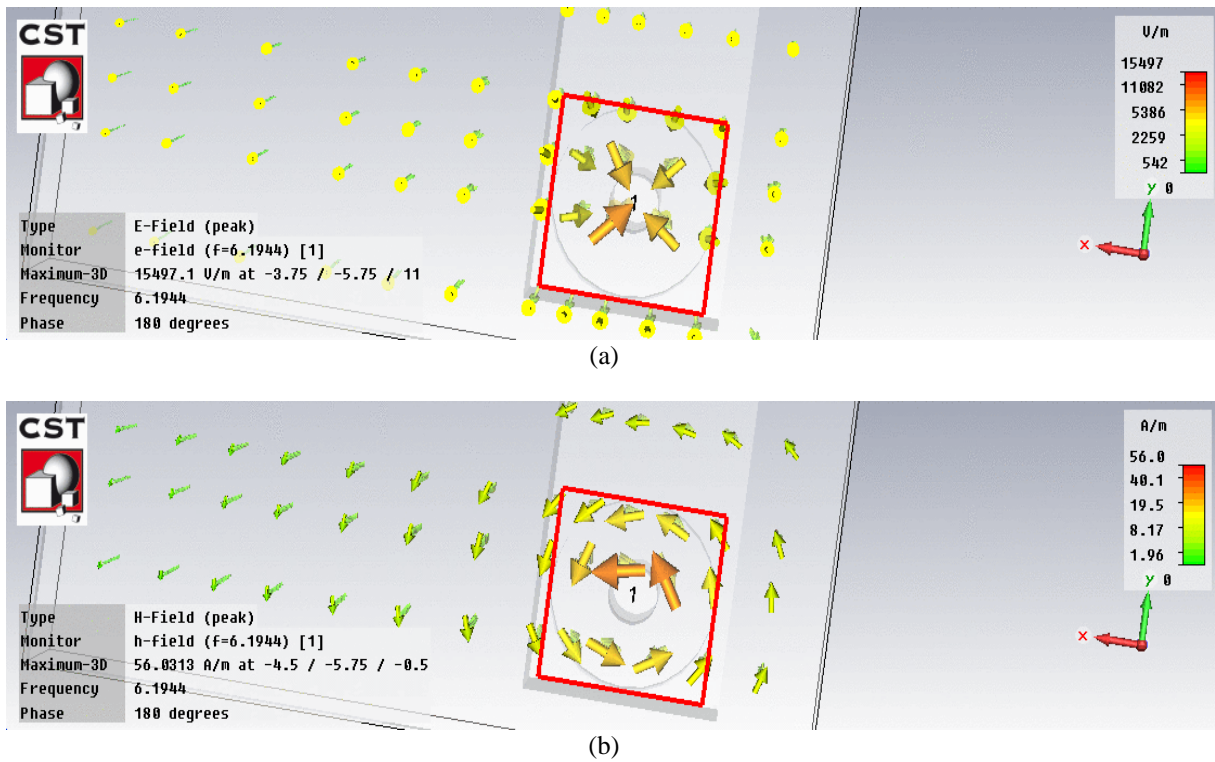


Figure 6. (a) E-field pattern (b) H-field pattern.

For better understanding of proposed DRA, parametric study is performed to see the effect on the reflection coefficient and impedance bandwidth. In Figure 7, height of antenna (h) is varied and related impedance bandwidth is calculated and presented in Table I.

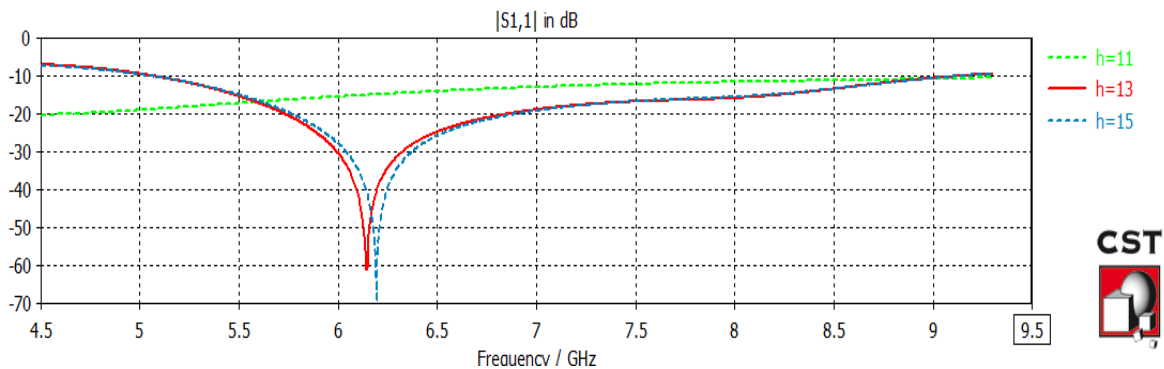


Figure 7. S_{11} Parameter representation with variation in DRA height.

TABLE I. Impedance Bandwidth for Different Heights of DRA.

Height of DRA (h)	Range (f_h - f_l)	Resonant frequency (GHz)	Bandwidth (GHz)	IBW
11	-	-	-	-
13	9.15-5.05	6.14	4.1	66.77%
15	9.05-5.25	6.23	3.8	60.99%

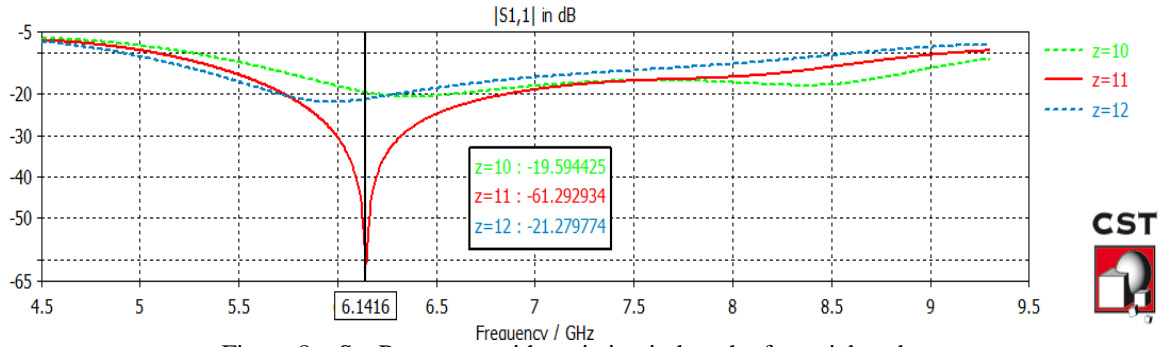


Figure 8. S_{11} -Parameter with variation in length of coaxial probe.

In Fig. 8 z is representing the co-ordinate from -0.5 to 11 with ground plane having z co-ordinate ranging from 1.5 to 3, it can be seen in Fig. 1(a) that probe is z -directed. It is clear from Fig. 8 that when probe length is varied, reflection coefficient is also varying; best result comes when the probe is inserted into the DRA up to the length of 8mm. Fig. 9 presents simulated result of S_{11} Parameter when point of feeding is varied (in y direction which can be seen in Fig. 1(b)). Results are taken at three positions, at lower end ($y=-6$), at upper side ($y=6$) and at middle ($y=0$) with x co-ordinate at -4 taking center of antenna ($x=0, y=0$). We have best result when probe is at lower end.

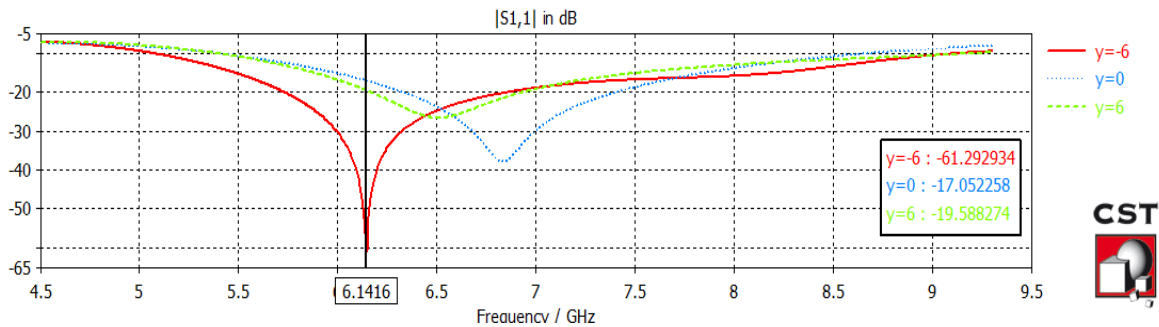


Figure 9. S_{11} -Parameter representation when feeding position is varied.

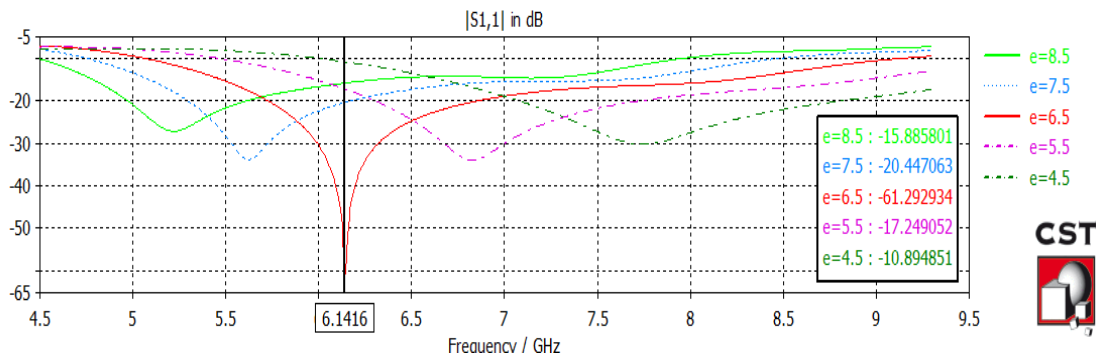


Figure 10. Variation of S_{11} -Parameter with variation in dielectric constant of DRA.

When dielectric constant is varied it is observed that either dielectric constant value is increased or decreased return loss increases. At $\epsilon_r = 6.5$ return loss is -61.29dB and impedance bandwidth is maximum. Table II shows the change in impedance bandwidth and S_{11} parameter as dielectric constant is varied.

Table II. Reflection Coefficient and Impedance Bandwidth when Dielectric Constant is varied.

Dielectric Constant	Reflection Coefficient(dB)	Resonant frequency(GHz)	Bandwidth(GHz)	IBW
4.5	-30	7.72	3.42	44.30%
5.5	-34	6.82	3.75	54.98%
6.5	-61.29	6.14	4.10	66.77%
7.5	-32	5.62	3.62	64.44%
8.5	-28	5.23	3.30	63.0%

V. Conclusion

Proposed P-shaped antenna is examined which is excited by a coaxial probe and it is found that proposed structure is a low profile antenna, widely applicable for wireless application systems like WLAN, WiMAX and C-band. From simulated result it is observed that proposed antenna is a wideband antenna of bandwidth 4.1GHz (where $S_{11} < -10\text{dB}$). Resonant frequency is calculated using an approximate equation which is 6.14GHz and gain at this frequency is 2.45dB. VSWR is found 1.001. 85.4% frequency is useful from total supplied frequency with impedance bandwidth of 66.77%, which makes it an ultra-wideband antenna.

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