

Design of A Novel Directional Microstrip-fed Super-wideband Antenna

H. M. Bernety¹, B. Zakeri², R. Gholami³

Abstract

In this paper, a novel directional super wide band micro strip antenna based on a simple and new geometry has been proposed. The antenna exhibits the widest bandwidth ever reported to the authors' knowledge from 50 GHz to 200 GHz. Its radiation pattern is approximately steady in the frequency ranges of 50 GHz to 200 GHz. The antenna consists of a club-like radiating patch, a combination of three circular patches, and a partial ground structure. Moreover, the proposed antenna has a compact volume of 24 mm × 18 mm × 0.787 mm on a RT Duroid substrate with a relative dielectric constant of 2.2. RT Duroid has very low loss characteristic and therefore the loss of the antenna will be very little. The simulation is performed by CST Microwave Studio simulator. Antenna design and the simulation results of radiation pattern and gain are presented and discussed in detail. Results show that the performance is very excellent in full band.

Keywords: Super-wideband Antenna, Reflection Coefficient, Directional Pattern, Input Impedance.

1. Introduction

In 2002, the Federal Communications Commission (FCC) of the United States officially released a regulation for ultra-wideband (UWB) technology [1]. In this regulation, the frequency span of 3.1 GHz to 10.6 GHz was allocated for unlicensed UWB measurements and communication applications. According to the released regulation, the UWB technology which is based on transmitting ultra short pulses with duration of only a few nanoseconds or less has been regarded as one of the most promising wireless technologies that promises to revolutionize high data rate transmission and enables the personal area networking industry leading to new innovations and greater quality of services to users. It is also used in medical imaging, ground-penetrating radar (GPR), positioning location and tracking. Shannon-Nyquist criterion [2] indicates that channel capacity increases linearly with bandwidth and decreases logarithmically as the signal to noise ratio (SNR) decreases. This relationship suggests that the channel capacity can be enhanced more rapidly by increasing the occupied

bandwidth than increasing the SNR. Indeed, an antenna acts like a filter for the generated ultra short pulse. Therefore, in the UWB communication systems, one of the key issues is the design of a compact antenna with an ultra-wideband characteristic over the whole operating band. Many UWB antennas have been developed to cover the ultra-wide bandwidth of the UWB systems with acceptable performance [3]-[8]. The existing wireless systems such as WLAN, WPAN, UWB and Bluetooth operate below 11 GHz, which will probably be overcrowded due to the lack of wide bandwidth in near future. However, at higher frequency, wide frequency bands can be obtained. This wide band not only meets the demands of more channels but can also provide data, voice, and video transmission at higher rates. Hence, the need thrusts us into moving towards the millimeter wave frequency. Applications involving in millimeter waves such as security sensors demand new research to achieve higher bandwidth and resolution. Sensors, which deal with super-wideband (SWB) signaling, can be appropriate options for balancing bandwidth, range and resolution. In fact, Super-wideband radio technology can be considered as a higher level of a UWB radio technology providing almost all its features and also with higher bandwidth and higher resolution for monitoring and ranging. To implement such a technology, again, an antenna plays a crucial role in the SWB systems and the choice of a specific SWB antenna design has to be based on the main application requirements.

The state of the art SWB antennas focuses mainly on the planar monopole micro strip antennas that can be directly printed onto printed circuit boards (PCBs) and show signs of being successful and are the most promising candidates. Such a PCB antenna has a low profile, a low manufacturing cost and can easily be integrated with other parts of Monolithic Microwave Integrate Circuit (MMIC). To satisfy such requirements, various types of planar antennas have been developed and several bandwidth enhancement techniques have been released such as making slots in ground plane and patch, patch tapering, reducing ground plane and defecting it [9]-[13]. In [9], a defected ground with symmetric notch in CPW feed is introduced. In [10], a circular disc patch embedded with two symmetrical C-like slots and 50 Ω coplanar waveguide feeding structure (DASCS) and also with

1. M. Sc. Student, Department of Electrical Engineering, Babol Noshirvani University of Technology, hossein_mehrpourbernety@ieee.org

2. Assistant Professor, Department of Electrical Engineering, Babol Noshirvani University of Technology, (zakeri@nit.ac.ir)

3. M. Sc. Student, Department of Electrical Engineering, Babol Noshirvani University of Technology, (reza.gholami@ieee.org)

two asymmetrical C-like slots (DAACS) are introduced to operate in the frequency ranges of 3 GHz to 32 GHz and 2.6 GHz to 32.8 GHz, respectively. In [11], an asymmetrical elliptical semi-monopole antenna with optimized ground plane is used to cover frequency bands from 0.47 to 25GHz. In [12], a CPW-fed antenna with a tapered transition is proposed to achieve a super-wide frequency span from 5 GHz to 150 GHz. In [13], by embedding a fractal-complementary slot into the asymmetrical ground plane, the proposed antenna was able to operate from 1.44 to 18.8 GHz with ratio bandwidth up to 13.06: 1. In fact, all these techniques deal with surface current and the objectives are to modify it for the purpose of bandwidth increment. In [14], two printed-circuit antennas are introduced each using a hexagonal patch. The former is fed by a micro strip line. The latter is a CPW-fed antenna. The corners of the hexagon and angle of the ground plane are varied to achieve super-wide bandwidth. Both antennas operate between 3 GHz and 30 GHz.

In this paper, we propose a novel micro strip-fed SWB antenna operating in the frequency range of 11 to 200GHz, the largest bandwidth obtained until now. The structure is the simplest among super-wideband antennas ever released. Another feature of the proposed antenna is its directional behavior which makes it distinct from previous designs. The antenna is very compact and its volume is about half of the antenna proposed in [14]. Simulations were performed by using CST microwave studio package. Section 2 is allotted to antenna design and geometry. In Section 3, a parametric study for the antenna is given. Optimized parameters and simulation results of the antenna are discussed in Section 4.

2. SWB Antenna Design

The geometry and configuration of the proposed antenna is shown in Fig. 1. The gray colored part indicates the partial ground of the antenna and the black color part depicts the patch of the antenna and the feed line connected to it. It is in the x-y plane (24 mm along x-axis and 18 mm along y-axis). It has a symmetrical shape with respect to the longitudinal direction. In this design, three circular patches are combined to form a club-like patch which is fed with a microstrip line printed on a partial grounded substrate. These newly simulated structures are proposed for easy fabrication. For the proposed model, the optimization was carried out to achieve the best impedance bandwidth. The antenna has a compact size of 24 mm × 18 mm on a 0.787 mm high RT

Duroid substrate with a relative dielectric constant of 2.2. The proposed antenna model is simulated through the CST microwave studio simulator in order to evaluate its overall performance. Parametric study has been performed for different parameters of the antenna to find the optimum values. This analysis is done by varying one parameter while maintaining other parameters constant. The micro strip line feed is designed to match 50Ω characteristic impedance. The impedance matching of the proposed antenna is enhanced by correctly adjusting the dimension of the feeding structure and the patch size. A partial rectangular ground plane is used, which creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly pure resistive input impedance and resulting in bandwidth enhancement.

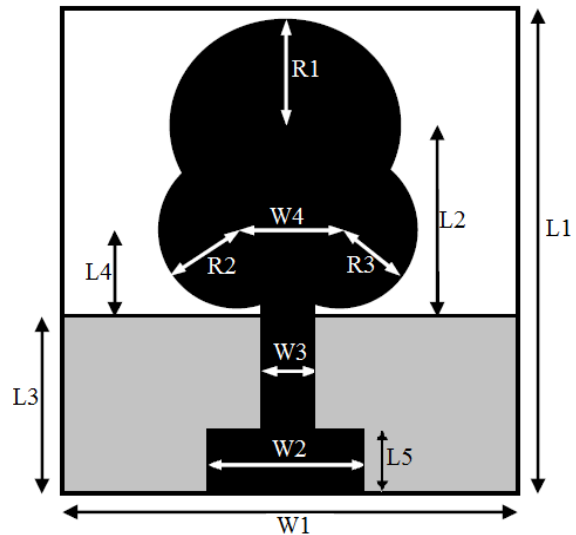


Fig. 1 Antenna Configuration

3. Parametric Study of Super-wideband Antenna

Parametric study carried out to achieve SWB characteristic using CST microwave studio simulator for the frequencies up to 150 GHz. After finding optimized parameters, the antenna was simulated for frequencies up to 200 GHz. The reason of simulating in a shorter range and then in a longer range was only to reduce simulation time because of the large number of mesh cells. Obviously, each geometrical parameter has effects on the performance of the proposed antenna. Salient parameters are R1, the radius of the greater circle, R2, the radius of two smaller circles, and L3, the length of the rectangular

partial ground, and their effects are discussed in the following subsections.

3.1 The Effect of Radius of Greater Circle (R1)

Fig. 2 shows the simulated reflection coefficient of the antenna as a function of frequency for different values of R_1 with other parameters fixed. As Fig. 2 shows, the radius of the greater circle does not have an obvious effect on the reflection coefficient curve, but when it is chosen as to be 5.25 mm can ameliorate the reflection coefficient for the frequencies around 32 GHz. Indeed, it plays the role of a controller to maintain the level of the reflection coefficient below -10 dB line for this frequency range and consequently to widen the bandwidth.

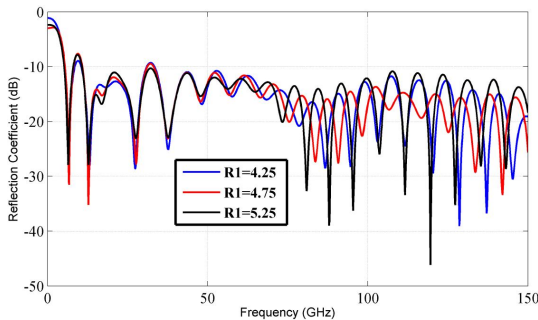


Fig. 2 Reflection coefficients for different values of R1

3.2 The Effect of Radius of Two Smaller Circles (R2)

The radius of two smaller circles (R_2) has an important effect on the impedance bandwidth. The simulated reflection coefficient curves with various R_2 are shown in Fig. 3. The simulated results are achieved by fixing other parameters. It can be seen that the radius has a crucial effect on the reflection coefficient for the frequency span of 11 GHz to 87 GHz. Actually, when the optimized value of 3.25 mm is chosen for this parameter, then it creates more intense resonances and generally decreases the reflection coefficient level.

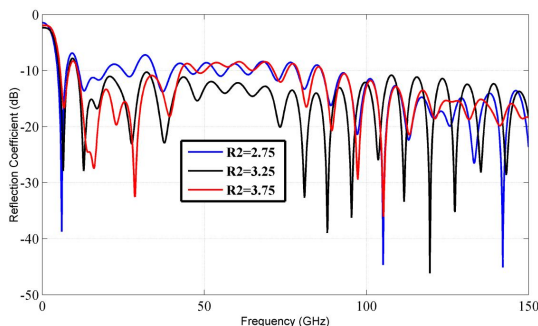


Fig. 3 Reflection coefficients for different values of R2

3.3 The effect of Length of Partial Ground (L3)

The effect of the length of the partial ground is studied by varying L_3 , as shown in Fig. 4, again with other dimensions fixed. As the L_3 changes from 4 mm to 8 mm, the reflection coefficient is not affected remarkably for the frequencies more than 54 GHz. However, the reflection coefficient of the antenna is notably related to this parameter for the frequencies below 54GHz.

4.Optimized Parameters and Simulation Results

4.1 Optimized Parameters

The dimensions of the micro strip-fed super-wideband antenna used in simulation are based on optimized dimensions using parametric analysis in Section 3. Table 1 presents the detailed dimensions of antenna parameters of the final design.

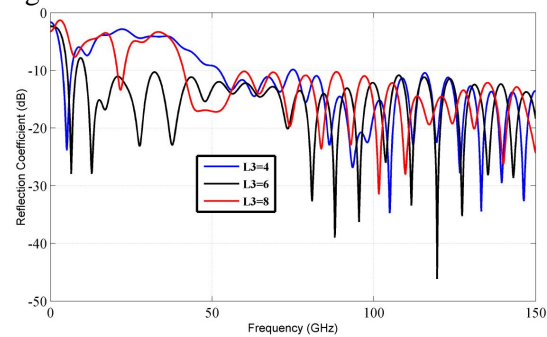


Fig. 4 Reflection coefficients for different values of L3

Table 1 Antenna parameters

Parameter	Size (mm)
L_1	18
L_2	6.5
L_3	6
L_4	3.5
L_5	5
W_1	24
W_2	2.6
W_3	2
W_4	4
R_1	5.25
R_2, R_3	3.25

4.2 Reflection Coefficient

The proposed antenna is simulated by CST microwave studio commercial software and by using Transient Solver. Simulation results confirm the super-wideband characteristic of the proposed antenna. Fig. 5 shows the reflection coefficient (S_{11}) of the antenna. The reflection coefficient is

under the -10 dB line for the frequency range of 11 GHz to 200 GHz making sure of the super-wide bandwidth. Although the antenna satisfies the super-wideband property without the larger circular part of the patch (with radius R_1), it is helpful to use this part to decrease the S_{11} level for the frequencies around 32 GHz resulting in a better reflection coefficient and a remarkable 20 GHz wider bandwidth.

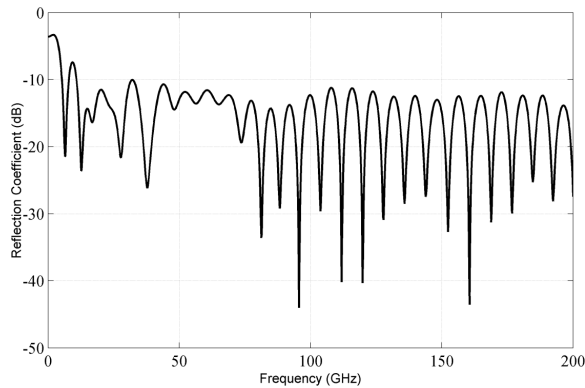


Fig. 5 Reflection coefficient

4.3 Input Impedance

The input impedance of an antenna should be well matched to transmitter and receiver in order to radiate and receive the power efficiently. Ideally, the impedance matching should be stable across the entire band. The real and imaginary parts of the proposed antenna input impedance versus frequency are illustrated in Fig. 6. The average value of the real part of the resulting input impedance is near 50Ω , while the imaginary part is slightly fluctuating around zero value.

4.4 Group Delay

Group delay is a well-known parameter in wideband antenna design and it is defined as the derivative of the far-field phase with respect to the frequency which represents the distortion of pulse signal. It needs to be constant over the entire band to avoid undesirable distortion of the radiated and received pulse. Indeed, for a good pulse transmission and in order to verify the profitability of the antenna for time-domain applications, the time-domain response of the antenna should be appropriate and the group delay should be almost small and constant through the super-wide bandwidth. Fig. 7 shows the simulated group delay time of the proposed antenna for the frequencies up to 200 GHz. The group delay time lies between -0.5 ns and 0.5 ns through the whole bandwidth except for some frequencies, which

confirms the antenna is appropriate for SWB applications.

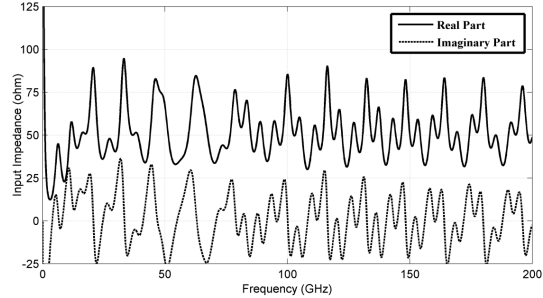


Fig. 6 Input impedance

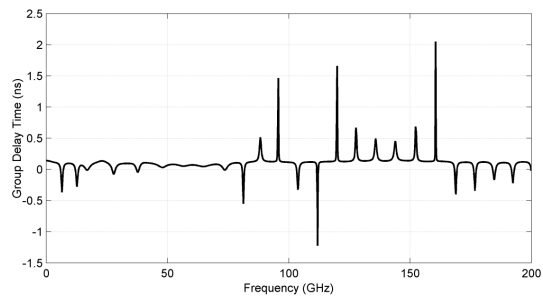


Fig. 7 Group delay time

4.5 Radiation Pattern and Antenna Gain

Fig. 8 shows the simulated far-field azimuth ($\theta=90^\circ$) and elevation ($\varphi=90^\circ$) radiation patterns for 7 different frequencies at 20 GHz, 50 GHz, 80 GHz, 110 GHz, 140 GHz, 170 GHz, and 200 GHz, respectively. The antenna exhibits a directional pattern through the bandwidth. In [12], the radiator pattern is stable over the frequency range from 5 GHz to 50 GHz, but the radiation pattern of our proposed antenna is stable in a larger frequency span of 50 GHz to 200 GHz with the simplest geometry in comparison to the antennas in [9] – [13].

Fig. 9 shows the simulated maximum gain of the proposed antenna. It confirms that the antenna has a directional radiation pattern especially for the frequencies more than 50 GHz. To emphasize that this directional pattern is steady across the antenna super-wide bandwidth, antenna gain in Y direction is also illustrated in Fig. 9. As illustrated, the antenna gain is not constant during whole frequency band but this variation is acceptable for super wideband frequency span. Indeed, maximum gain occurs almost near Y direction within the frequency range from 50 GHz to 200 GHz. Consequently, the proposed super-wideband antenna radiates directionally in a frequency range more than all antennas reported in the past, with an interesting steady pattern.

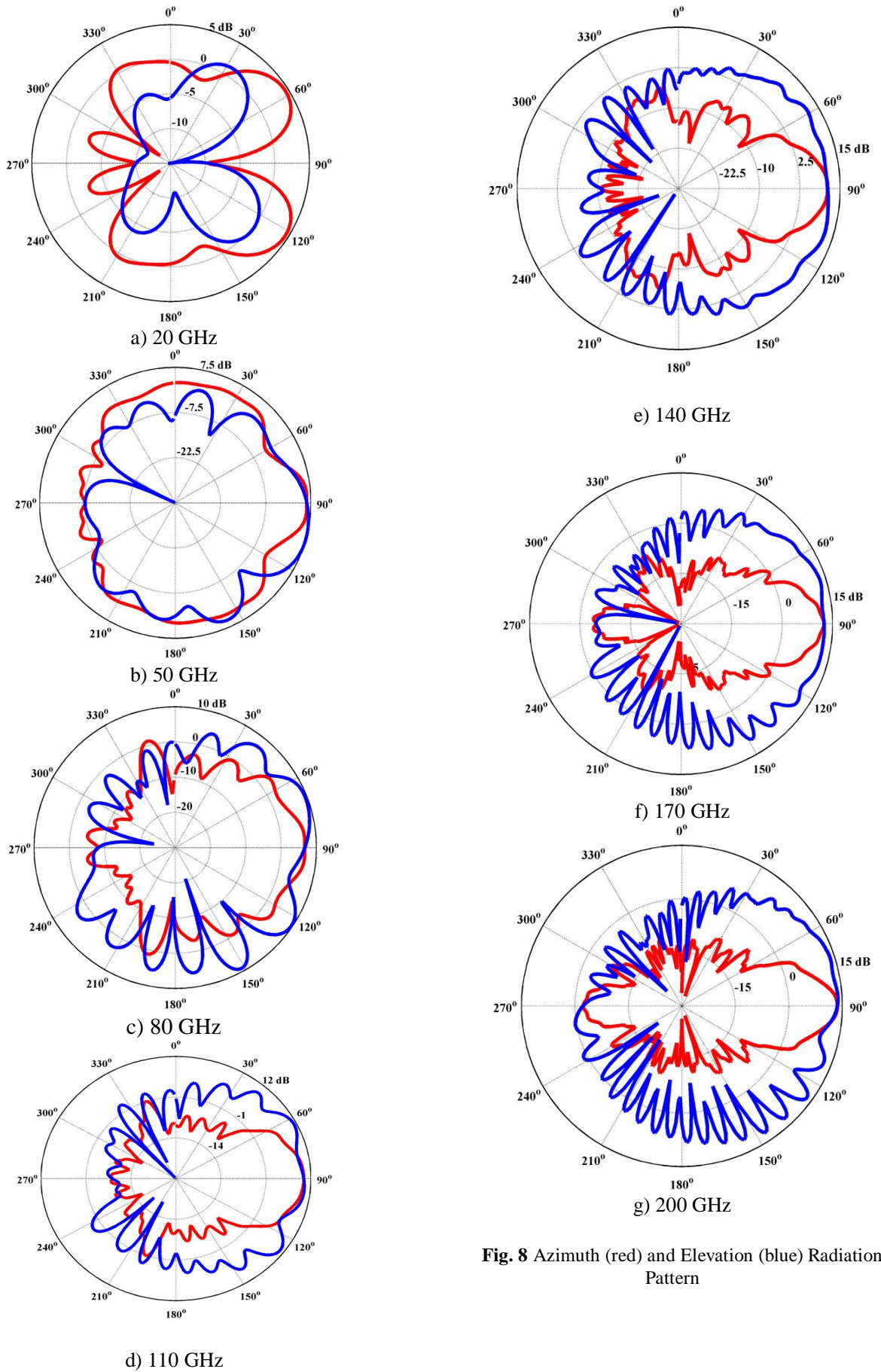


Fig. 8 Azimuth (red) and Elevation (blue) Radiation Pattern

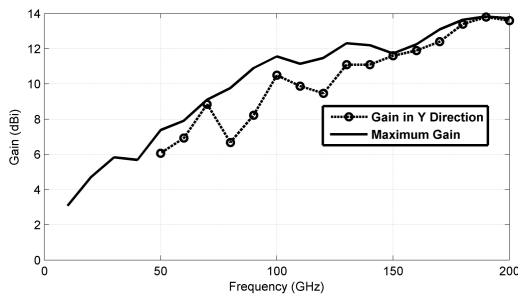


Fig. 9 Antenna Maximum Gain and Gain in Y direction

5. Conclusion

A novel super-wideband micro strip antenna with a simple structure has been proposed in this paper. This paper describes the design in detail and provides sufficient parametric study, as well as simulation results to investigate the antenna performance. The simulated results are obtained by using CST microwave studio simulator. The proposed antenna has a compact volume of $24 \text{ mm} \times 18 \text{ mm} \times 0.787 \text{ mm}$. Indeed, using a club-like patch, which is consisted of three combined circular patches, is the novel technique to enhance the bandwidth of the antenna. The simulated results indicate that the proposed antenna yields the largest super-wide bandwidth ever released from 50 GHz to 200 GHz. Another interesting feature of the antenna is its radiation pattern stability across a very large bandwidth of about 150 GHz from 50 GHz to 200 GHz. In addition, the gain of the antenna confirms the directional behavior in this frequency span. In sum, appealing properties of the antenna such as super-wide bandwidth, stable pattern, high gain and directional behavior, compact size, and acceptable group delay time distinct the antenna from all other previous designs and makes it available for wireless systems such as MVDDS (12.2 GHz-12.7 GHz), LMDS (27.5 GHz-29.5 GHz), and any applications pertained to high resolution screening and extremely high data rate sensors.

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