A micro size terahertz wheel shaped antenna with non-defected ground structure

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ABSTRACT

A micro dimension antenna with wheel-geometrical wide-band terahertz (THz) is suggested in this research. In the circular shaped patch, concentric circle shaped slots are incorporated to form a wheel shaped patch antenna. The suggested model is designed on a polymide substrate with dielectric constant of 4.3 and thickness of 20 µm. The suggested prototype antenna is very much compact in size of 210×160 μm^2. The designed antenna achieves a wideband operation from 8.692 THz to 9.772 THz. This prototype antenna's maximum realized gain is 10.2 dBi at 9.0 THz. This high gain is important for wide range of wireless applications. The radiation pattern, radiation efficiency, reflection coefficient, surface current distribution and voltage standing wave ratio are examined through the simulation results. In future video rate imaging system, super fast close-range in-door wireless communication, biomedical picturing, homeland defence equipments, security scanning, explosive detection, and characterisation of materials in the THz level will be benefited from the suggested THz antenna.

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1. INTRODUCTION

The revolutionary advancement of wirefree technologies in recent times has necessitated boundless frequency bands to fulfil the demands of large capacity channels, efficient transit of data traffic with hassle-free connectivity [1]. So it prompted research community to investigate a modern era new frequency range band ranging from 0.1 to 10 THz and wavelength ranging from 0.03 to 3 mm known as the terahertz (THz) electromagnetic spectrum [2], [3]. A viable alternative for faster data transmission in secure high-speed wireless communication applications is 0.1 to 10 THz frequency spectrum [4], [5]. An assortment of high eventual applications exploiting THz band like spectroscopic detection and diagnostics [6], remote sensing [7], imaging system [8], and chemical detection [9], have been already reported. THz waves have various merits compare to millimetre waves, such as more spectral resolution, a wider frequency band, better interference free performance and lower diffraction, more over THz spectrum suitable for various widespread applications [10]. In THz frequency range, a substantial barrier to the commercialization of wireless communication systems is it is significant channel path loss. As a result, designing highly efficient small antennas to minimize the substantial path loss energy at terahertz frequency is a top priority [11]. THz antennas are the most important component in wave radiation and collection in THz wireless communication. The THz antennas' quality (miniaturisation, high efficiency, broad frequency band, and strong directivity) decides the terahertz system quality. It is important to emphasize that the THz antenna design process introduces numerous challenges for antenna researchers. The miniaturizing design requirements for terahertz antennas will start the new era in printed antenna technology in the coming years. The patch antenna has already proved to be an efficient antenna in GHz ranges [12], [13]. Several experts have suggested and designed several novel antenna structures for terahertz frequency applications in recent years. The antenna suggested in [14] incurs higher implementation costs due to complex design process and assembling difficulty with planar circuitry. The dielectric antenna suggested in [15] is another THz antenna option. Nevertheless, it struggles from a large surface electromagnetic wave effect in the tera hertz band, which results in massive noise and degraded antenna performance. Metamaterial structures (MTM) [16], electromagnetic band-gap (EBG) [17] and, photonic band-gap (PBG) crystal [18] are some of the innovative implementations reported in the literature. On the other side, THz antennas employing graphene as a conducting material is gaining popularity [19]–[21]. In recent years, using microstrip technology to construct THz antennas for operation in the low level THz band (0.1-1 THz) has become more popular. Varieties of innovative micro dimension antenna structures has been created to utilize in variety of terahertz applications [22], [23]. However, they have a greater physical size and a lower working bandwidth. As a result, the task is to increase the working frequency range of miniaturize THz antennas while maintaining its compactness.In this work, we suggested a novel wheel structured patch antenna for tera-hertz operation. The suggested THz antenna is very much compact in size. The dimension of the antenna is 210×160 μm^2. The antenna resonance ranging between 8.6 to 9.7 THz with a maximum possible gain of 8 dBi spoted at 9 THz. This THz antenna is designed on a polyimide substance having constant dielectric value of 4.3 with a 20 µm thickness.

2. STRUCTURE AND EVOLUTION STAGES OF THE SUGGESTED ANTENNA

The wheel shaped antenna design is shown in Figure 1. Table lists the optimized dimensions of the wheel shaped antenna. The coplanar waveguide (CPW) feeding is used here to optimize the antenna performance. This new version of antenna has full ground structure to achieve optimum gain and stable radiation pattern. This suggested antenna is constructed using a 20 µm thick polyimide substrate with a 4.3 dielectric constant value and 0.004 loss tangent (tan) value. The antenna gets the mechanical support from the polyimide substrate. The copper material of 10 nm thickness is used as patch material for upper and lower plane patches. The copper material with a dimension of 50×15 μm^2 is used as a feed line to feed power to the suggested antenna using 50 Ω SubMiniature version A (SMA) connector. This ensures the maximum power is transferred to the antenna. The suggested antenna module is simulated using CST Microwave studio. The THz antenna's production and practical testing are difficult and time-consuming due to its small size and limited resources. THz antennas, on the other hand, are made using processes such as nano-lithography [24], printed circuit board (PCB) etching [25]and micro-machining [26]. PCB etching is a technique for removing undesirable material from the conducting layers of a circuit board. It does, however, necessitate precise and high-precision etching units. Nanolithography is a method for printing or etching microscopic objects. Micro-machining is a technology for shaping, designing, and etching materials on a micro scale. Table 1 denotes the various parameters size which has been fixed to design the suggested micro structured wheel shaped anteena.

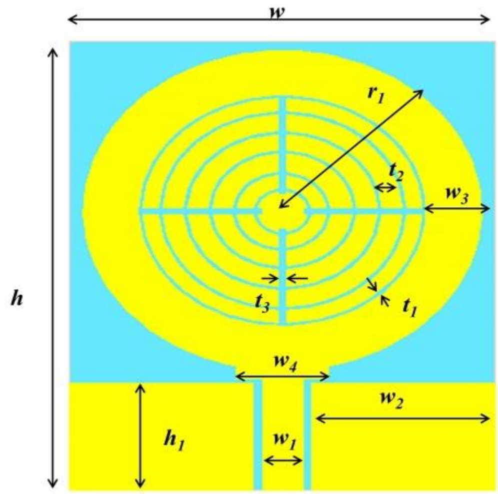


Figure 1. Structure of the suggested antenna

Table 1. Dimension optimized using CST for the designed antenna

Parameter	Dimension (µm)	Parameter	Dimension (µm)	Parameter	Dimension (µm)
h	210	w_3	20	w_4	34
w	160	t_1	3	r_1	75
w_1	15	t_2	6	h_1	50
w_2	69	t_3	3.8		

Figure 2 illustrates how the suggested antenna is developed from four steps of the design process. In the initial stage, with a full ground structure, a feed line along the circular shaped patch with the radius of 75 µm is installed on the upper side of a polyimide substrate. Figure 3 depicts the corresponding S_{11} performance. The stage 1 antenna resonates between 9 and 9.5 THz, as can be seen. Next, concentric circular slots were incorporated to form a wheel-shaped structure in the patch surface to boost performance. As shown in Figure 3, the proposed antenna's bandwidth was increased as a result of this new modification, and the second stage antenna began resonating at 8.8-9.5 THz. Next, a tapered feed is introduced in stage 3. This resulted in further improvement of operating bandwidth as seen from the S_{11} performance. Finally, CPW feeding is provided to the antenna and the resultant operating range extends from 8.65 to 9.82 THz. The CPW-feeding also resulted in high gain as discussed in the next section. Additionally, two resonant peaks at 9.03 and 9.24 THz is attained in the final stage of this antenna.

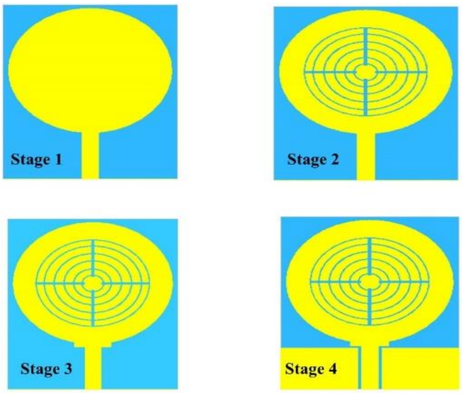


Figure 2. Stages of the suggested antenna

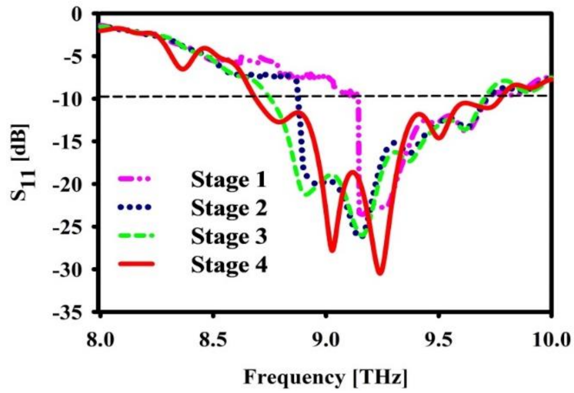


Figure 3. S_{11} performance of the proposed antenna during it is evolution stages

3. SIMULATION RESULTS AND DISCUSSION

In this section, extensive investigation of the proposed antenna has been made. The CST microwave studio 2016 simulation tool is used for analysing the proposed antenna. The final simulated radiation characteristic in terms of S_{11} of the wheel shaped antenna is plotted in Figure 4. The antenna operates from 8.692 to 9.772 THz with an impedance bandwidth of 11%. Additionally, two resonant peaks with S_{11} less 25 dB are observed at 9.03 and 9.24 THz frequencies.

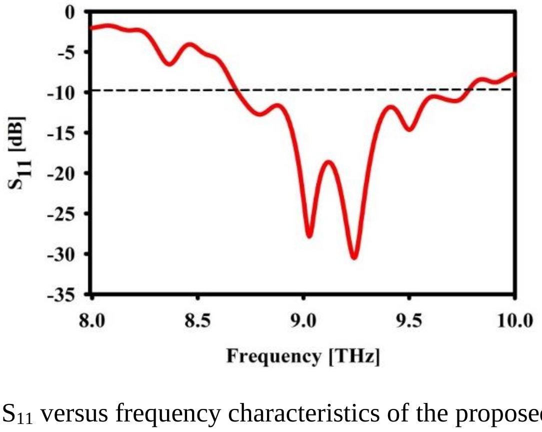


Figure 4. S_{11} versus frequency characteristics of the proposed antenna

Parametric analysis was used to examine the impact of various parameters, and the results are shown below. To begin, simulations were run for various CPW heights in order to better understand the impact of CPW feeding height. Figure 5 depicts the proposed antenna's radiation performance as a function of CPW height change. The height ranges from 20 to 50 µm. Figure 5 shows that when h_1=20 µm, 30 µm, and 40 µm, the resultant bandwidth of operation is less when compared to h_1=50 µm. Hence, we have chosen the 50 µm as a height of CPW feeding.

In order to depict the effect of r_1 on the radiation characteristics, we have performed the simulation by varying the values of r1 from 55 to 75 µm in steps of 10 µm which is shown in Figure 6. Eventhough the lower resonant peaks are obtained for the radius of 55 and 65 µm there is a reduction in operating bandwidth. However, on choosing the radius as 75 µm, the trade-off between the resonant peak and bandwidth is compromising. Hence, 75 µm is considered in the proposed antenna.

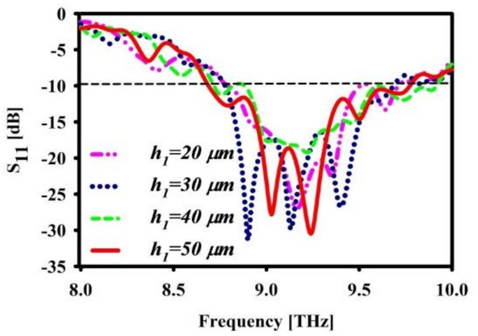


Figure 5. Effect of h_1 on S_{11} performance of the proposed antenna

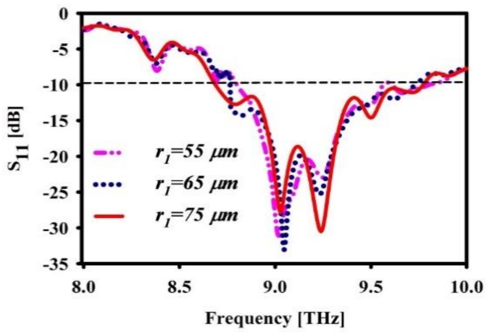


Figure 6. S_{11} versus frequency for different values of r_1

To verify the impedance matching condition, another key parameter taken in to consideration is voltage standing wave ratio (VSWR) which is used to calculate the quantity of signal reflected from the receiving antenna due to mismatch of impedances between the source and destination antenna. The VSWR values for a perfectly designed antenna should have less than 2 VSWR value to achieve adequate impedance matching to avoid stading waves henceforth less loss recorded and more quality reception is achieved. The VSWR of this antenna is shown in the Figure 7.

It is clearly illustrated VSWR is subsided to less than 2 for the entire operating range starts from 8.692 to 9.772 THz with a centre frequency of 9.232 THz. Also, the minimum VSWR value of 1.08 and 1.06 is observed at resonant peaks of 9.03 and 9.24 THz, respectively. Additionally, this antenna achieves the stable gain throughout the entire range of operation. The radiation efficiency versus frequency is also visualized in Figure 8. It can be witnessed that the antenna achieves comparably higher radiation efficiency. Simulated gain and radiation efficiency of the modified antenna is depicted in Figure 8. A significant achievement by the optimized design can be observed in Figure 8 that maximum obtained gain is 10.2 dBi spotted at 9.02 THz.

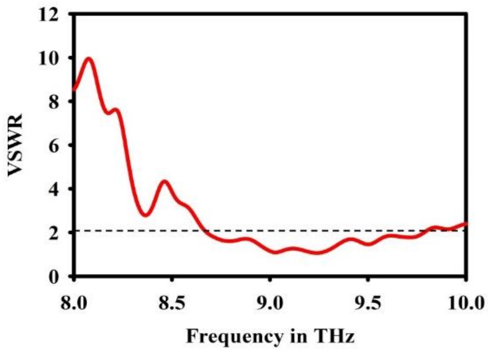


Figure 7. VSWR of the proposed antenna

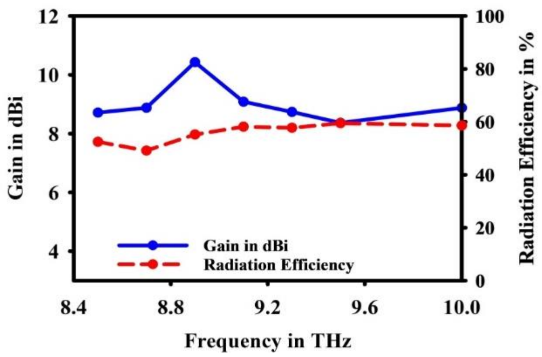
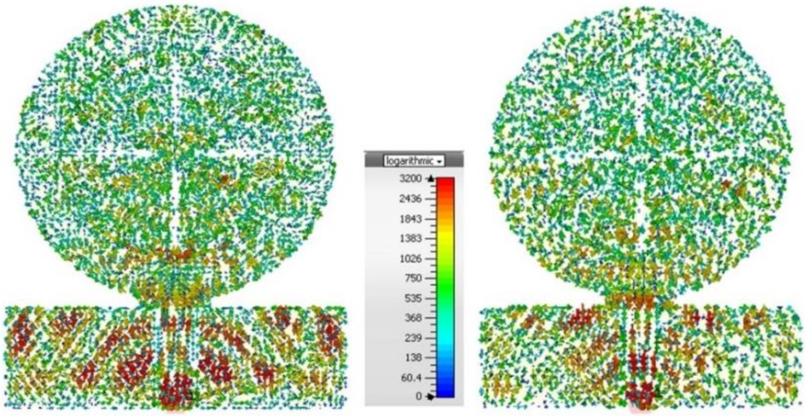


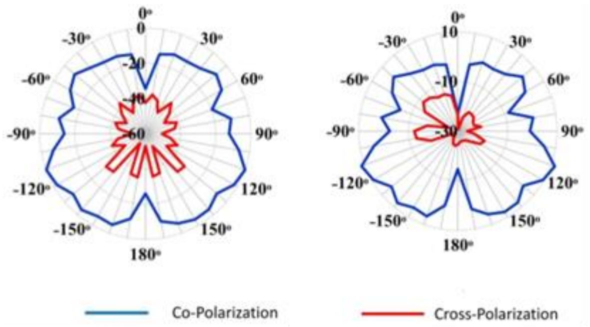
Figure 8. Simulated radiation efficiency and gain

Between the frequencies of 9.02 and 9.23 THz, the surface current distribution is examined and presented in Figures 9-11. Figures 9(a) and 9(b). High surface current is noticed at the CPW feeding at 9.02 THz whereas at 9.23 THz, the frequency corresponds to other resonant peak shows more current in the feed line. This shows that the CPW feeding is responsible for the resonant peaks. The radiation pattern is found to be stable and omni-directional at all frequencies. Also, the cross polarization is minimum as desired which can be seen from Figures 10(a) and 10(b). However, the cross polarization is increasing slightly at 9.23 THz. The E-plane and H-plane far-filed radiation pattern is depicted using polar plots in Figures 11(a) and 11(b). The radiation pattern is plotted at two frequencies, i.e. at 9.02 and 9.23 THz.



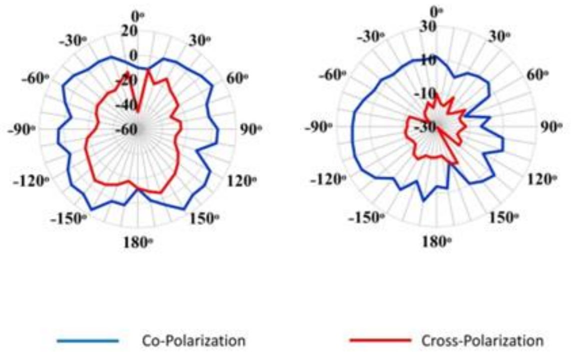
(a) (b)

Figure 9. Surface current density of the proposed antenna at (a) 9.02 THz and (b) 9.23 THz



(a) (b)

Figure 10. Radiation Pattern of the proposed antenna (a) E-Plane and (b) H-Plane at 9.02 THz



(a) (b)

Figure 11. Radiation pattern of the proposed antenna (a) E-Plane and (b) H-Plane at 9.23 THz

Finally, the comparison in table justifies the propose antenna achieves high gain when compared to the existing antennas. The bandwidth of operation is also significantly improved in this antenna. In Table 2, the proposed micro-wheel shaped anteena performance is compared with other recently proposed antennas.

Table 2. Comparison of the proposed antenna with the recently proposed antennas

Reference	Dimension of the antenna in µm	-10 dB BW (THz)	Fractional BW in %	Gain in dBi	Radiation efficiency in %	Substrate material
Kushwaha *et al.* [22]	800×600	0.04	5.73	7.93	85.93	Polyimide
Hocini *et al.* [23]	600×600	0.2	33	9.19	90	Polyimide
Younssi *et al.* [27]	1,000×1,000	0.155	22.4	10.4	Not Reported	RT/Duroid 6006
Nejati *et al.* [28]	500×500	B.W not reported	Not Reported	6.2	Not Reported	pyrex
Sharma and Singh [29]	1,000×1,000	0.15	19.35	3.502	55.88	RT/Duroid 6006
Mahmud [30]	700×600	0.15	19.35	9.7	75	RT/Duroid 6006
This work	210×180	1.08	11	10.2	68	Polyimide

4. CONCLUSIONS

In this manuscript, a novel wheel shaped patch antenna with full ground structure has been analysed. This antenna is implemented on a polyimide substrate with a thickness of 20 µm. The copper material is used as a patch with a thickness of 10 µm. This antenna is very much compact in size of about 210×160×20 µm^3. The antenna achieves a wideband response i.e. S_{11}<-10 dB from 8.692 to 9.772 THz with a 1.08 THz bandwidth of operation. The two resonant peaks at 9.03 and 9.23 THz present in the wideband of operation has a maximum gain of 10.2 and 10 dBi, respectively. The radiation efficiency is maximum at the resonant peaks of about 68 %. Furthermore, the anticipated radiation pattern and VSWR is observed in the operating region. This wide-band THz antenna can be used for a variety of applications, including video rate imaging system, high-speed shorter distance indoor wireless communication, biomedical imaging, sensing, security scanning, material characterization, homeland defence system and explosive detection, thanks to the merits of all these results.

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