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Designing of Triple Band Octagonal Ring Antenna for Flexible and Wearable Application

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Flexible or wearable antennas are noticing exponential rise in demand for 5G technologies, wireless sensor network, the Internet of Things (IoT) system and health monitoring. This paper focuses on the study of different substrates in the development of a compact, flexible and robust antenna. In this paper, an octagonal ring resonator antenna has been designed for tri-band terahertz application. The antenna is working on triple band characteristics at 140 GHz, 340 GHz and 396 GHz with overall dimensions of 700 × 900 × 10 μm^3. Three substrate materials Rogers R03003, polyamide and polyester are chosen for determining flexibility, durability as well as optimal antenna performance. The result and performance show that the recommended antenna will be compatible with compact flexible wireless devices. All simulation work has been done using electromagnetic software Ansoft High Frequency Structure Simulator (HFSS). The electromagnetic features like S_{11} parameters, VSWR, gain, efficiency and the radiation characteristics of such antenna are also explored.

Keywords: Flexible antenna, Ring resonator, Triple band antenna, Wearable antenna.

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1. INTRODUCTION

Next generation network requires low profile, compact size and broadband planar antennas. Flexible antennas exhibit wide adaptability due to its small size, low mass, lightweight and also suitable for curved surface [1]. Consistently, flexible electronic systems require the integration of flexible antennas operating in specific frequency bands to provide wireless connectivity which is highly demanded [2]. The efficiency of these systems primarily depends on the characteristics of the integrated antenna as well as the fabrication and manufacturing technology [3].

The flexible substrate should be highly deformable and mechanically robust and must exhibit high tolerance levels of bending repeatability to comply with flexible technologies and integrated components [4]. Researchers introduced various types of substrates, for example Rogers R03003 [5, 8], NinjaFlex substrate [6], glass epoxy [7], polyimide [9], paper [10], as well as fabrics [11]. Typically, for flexible and wearable applications antennas are printed on very thin sheets.

Many antennas with different shapes are realized in last decades, few of them are chamfered corner monopole antenna [5], square shape [6], meander line PIFA [7], Bow Tie antenna [8], ring antenna [12] and fractal antennas [13-16]. The comparison of the proposed design with the different designs existing in the literature is listed in Table 1.

In this paper, an octagonal ring resonator antenna is suggested for triple band operation for wearable application. The overall antenna dimension is 700 × 900 μm^2. To enhance the performance like gain and efficiency different conductive materials like gold and silver are also analyzed. Next different flexible substrate configurations have been discussed to improve the performance of the antenna. The designing of triple band antenna starts with the consideration of an octagonal ring microstrip antenna structure; because it is radiating over low frequency, the various iterations have been applied to make it triple band resonating antenna. The whole work is organized as follows; Section 2 describes the triple band antenna design, synthesis and analysis. Section 3 describes the result and validation of work, Section 4 describes the designing of recommended antenna on different conducting surfaces And finally the recommended antenna has also been analyzed on different flexible substrates. All the simulation work is carried using Ansys electromagnetic software HFSSv15.

Table 1 – Comparison of the proposed antenna with existing antennas

Ref. no	Substrate (ε_r)	Size	Resonant frequencies (GHz)
[5]	PDMSε_r = 3	24 × 28 mm^2	3.4-11
[6]	NinjaFlex ε_r = 3	56 × 52 mm^2	2.45
[7]	FR4 ε_r = 4.6	15 × 30 mm^2	2.45
[8]	R03003 ε_r = 3	40 × 40 mm^2	2.5
[9]	polyimide ε_r = 3.4	35 × 25 mm^2	2.45 & 5.2
Recommended antenna	polyester ε_r = 3.2	700 × 900 μm^2	140, 340 & 396

2. ANTENNA DESIGN AND ANALYSIS

For designing the flexible antenna, initially octagonal shaped ring geometry has been designed on polyester substrate with dielectric constant of 3.2 and loss tangent of 0.003. The low loss tangent gives very less power loss and better antenna gain and efficiency. Loss tangent does not have effect on resonant frequency but

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slightly varies the bandwidth [17]. For better impedance matching quarter wave transmission line has been designed between patch and feed line. The octagonal ring antenna is closely related to circular patch antenna. For calculating the designing equation, first circular patch design equation must be introduced. The theoretical resonance frequency of a circular patch antenna is given by [10]

$$F = \frac{8.791\times 10^9}{f_r\sqrt{\varepsilon_r}}, \quad (1)$$

$$r = \frac{F}{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]^{1/2}}, \quad (2)$$

$$re = r\left\{1+\frac{2h}{\pi r\varepsilon_r}\left(\ln\frac{\pi r}{2h}+1.7726\right)\right\}^{1/2}, \quad (3)$$

$$\pi r_e^2 = 2\left(1+\sqrt{2}\right)s^2, \quad (4)$$

where F is a constant, f_r is the resonating frequency in Hz, h is the height of the substrate, ε_r is the dielectric constant of the substrate, r is the radius of the circle and r_e is the effective radius after fringe field effect. These Equations (1)-(3) can be implemented for creating hexagonal microstrip patch antenna by relating the areas of the circular and hexagonal patch as presented in Equation (4). The side length 's' of the hexagonal can be calculated by the given formula.

Table 2 – Optimized dimensions of primary antenna

Parameter	R_1	L	W	L_1	W_1	L_2	W_2	R_2	R_3
Unit(μm)	250	900	700	200	80	154	20	215	180

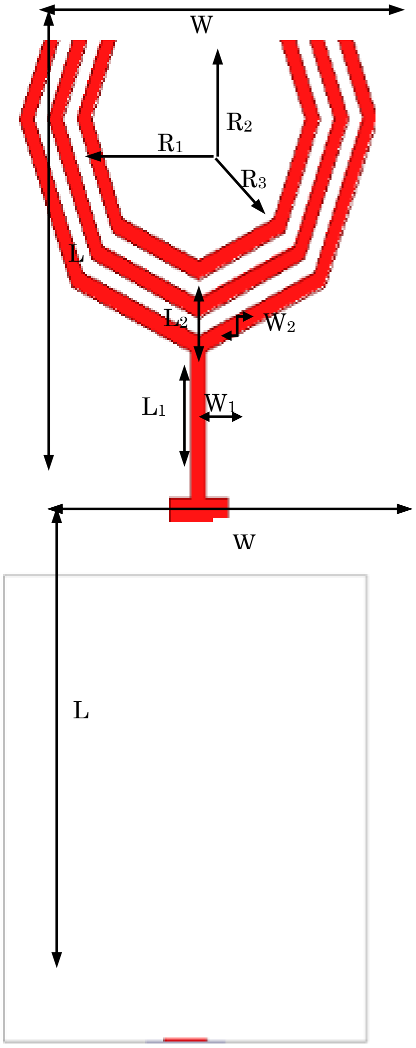
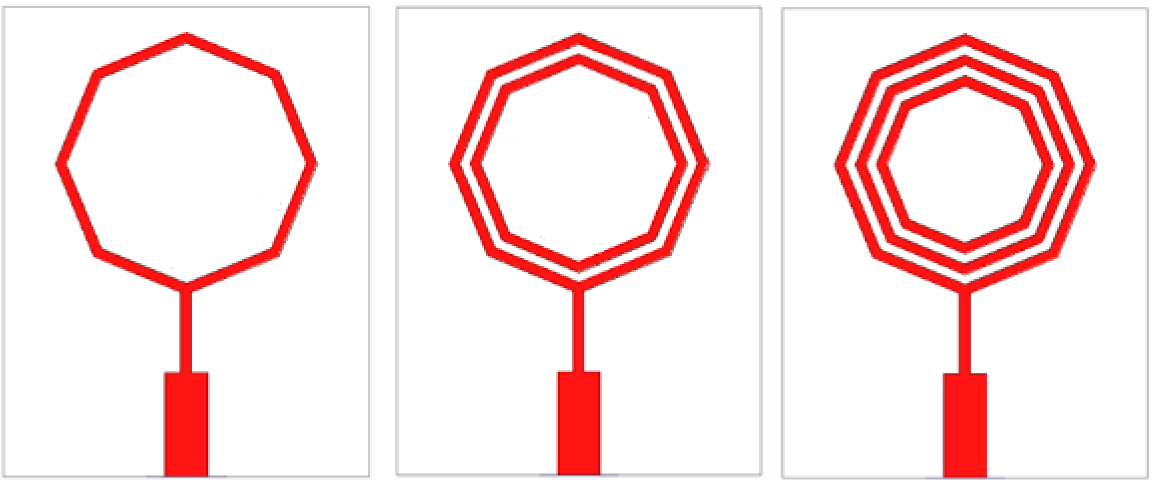


Fig. 1 – Octagonal ring antenna: (a) front side; (b) back side



(a) Antenna-I (1st iteration) (b) Antenna-II (2nd iteration) (c) Antenna-III (3rd iteration)

Fig. 2 – Development of a triple band ring antenna

The intermediate antenna design steps are examined and depicted in Fig. 2 and all dimensions are also listed in Table 2. It is observed that for the 1st iterations the resonant frequency shifted towards a lower frequency band due to increase in gap capacitance and resonating on 140 GHz with reflection coefficient of – 34 dB. By applying the 2nd ring in the radiating patch, the recommended antenna is operating on dual frequency of 140 GHz and 340 GHz with reflection coefficient of – 23.4 dB and – 20.3 dB, respectively. Finally, the increase in iterations makes the operating frequencies shifted at higher frequency band. The insertion of 3rd ring gives an extra resonance on 396 GHz. These characteristics are shown in Fig. 3.

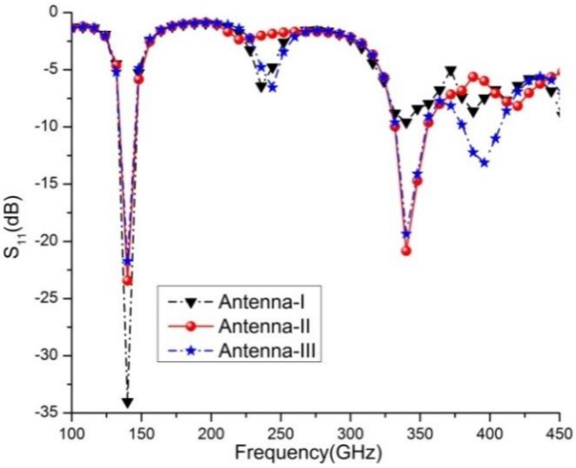


Fig. 3 – Simulated S_{11} (dB) of suggested antenna

3. SIMULATED RESULTS AND DISCUSSION

By applying the triple ring in the above-described antenna, the desired triple band pass characteristics have been achieved. The graph depicted in Fig. 3 shows that antenna produces resonance on 140 GHz, 340 GHz and 396 GHz. The mentioned antenna produces triple band characteristics at 140 GH, 340 GHz and the third resonance at 396 GHz with S_{11} of – 21.74 dB, – 19.34 dB and – 13.4 dB. Fig. 6 displays that this suggested design shows very good band-pass characteristics at 140/340/396 GHz.

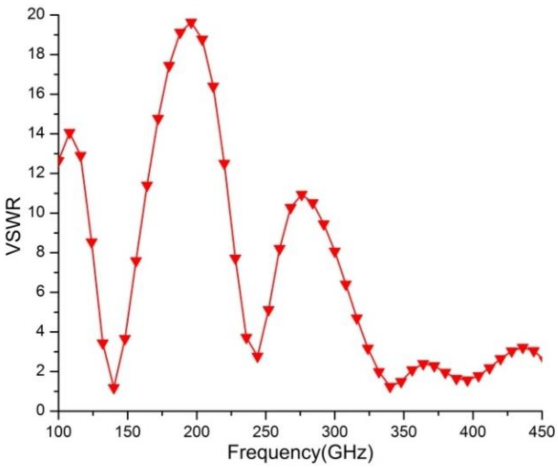


Fig. 4 – Simulated VSWR of suggested antenna

The graphical representation of the VSWR versus frequency plot is shown in Fig. 4, which concludes that at the simulated frequency 992GHz, the obtained value of VSWR is less than 2.

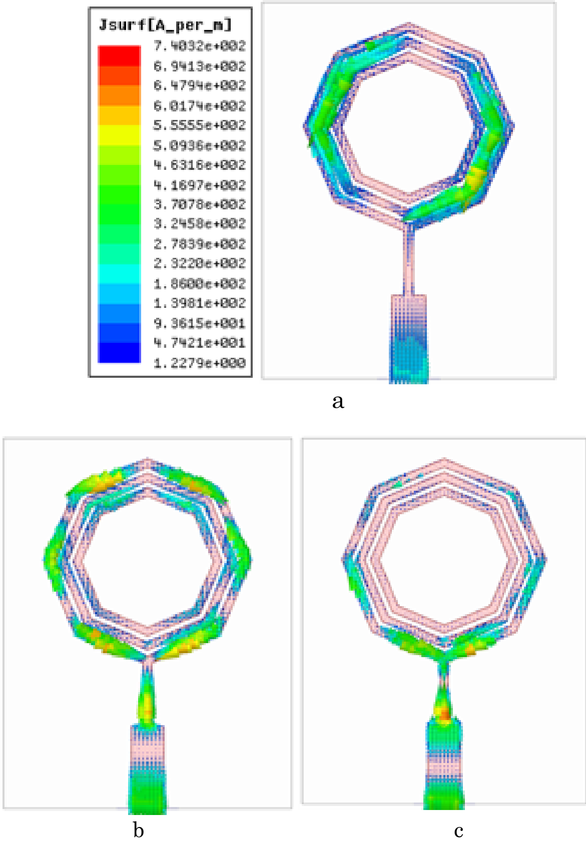
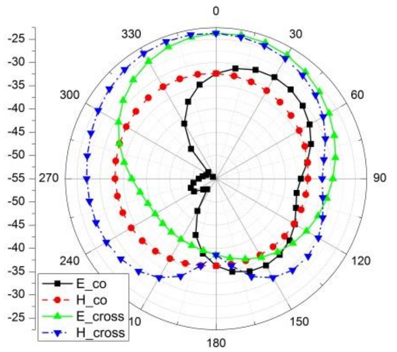
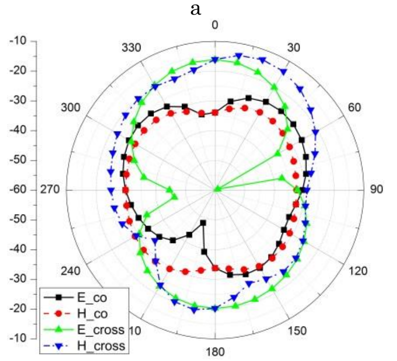


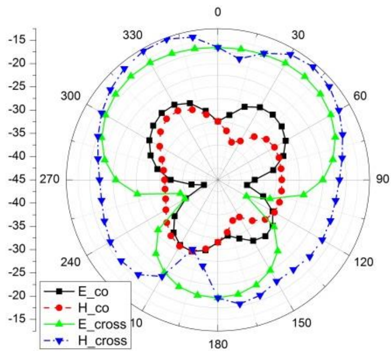
Fig. 5 – Current distribution of the proposed antenna: (a) 140 GHz; (b) 340 GHz; (c) 396 GHz



a



b



c

Fig. 6 – Radiation pattern of the proposed antenna: (a) 140 GHz; (b) 340 GHz; (c) 396 GHz

The effect of surface current on the proposed antenna geometry has been presented in Fig. 5. At desired resonating frequencies of 140 GHz, 340 GHz and 396 GHz, the distribution of vector current is uniform and is concentrated at slot edges as shown in Fig. 5 which looks like passband for antenna structure.

These features can also be proved from far field radiation characteristics. The radiation patterns of the presented antenna shown in Fig. 6 proclaim the suitable matching results with passband characteristics. The recommended antenna has also been compared with various octagonal ring antennas that are mentioned in kinds of literature [18-21] as listed in Table 3.

Table 3 – Recommended antenna comparison with other octagonal ring antennas

Ref. no	Substrate material (ε_r)	Ring radius	Resonant frequency	Bandwidth
[18]	FR4 $\varepsilon_r = 4.4$	14.4 mm	7.5 GHz	7 GHz
[19]	FR4 $\varepsilon_r = 4.4$	10 mm	3 GHz	8.4 GHz
[20]	RT5880 $\varepsilon_r = 4.2$	9.5 mm	14.5 GHz	150 GHz
[21]	FR4 $\varepsilon_r = 4.4$	17 mm	1.8 GHz	0.28 GHz
Recommended antenna	polyester $\varepsilon_r = 3.2$	0.25 mm	140, 340 & 396 GHz	20 GHz

4. DIFFERENT CONDUCTING MATERIAL ANALYSIS

After designing the triple band flexible antenna, some other conducting materials like silver and gold are also used to analyze antenna characteristics. The frequency of the antenna is highly dependent on the conductivity of the material. The effect of gold and silver materials on the reflection coefficient has been plotted in Fig. 7.

Silver is used as conducting material with the conductivity of 0.61×10^8 siemens/m and mass density of 10500. After applying the silver in place of copper, the resonating frequency has shifted towards a higher frequency band. After that, gold is used as a conducting material with a conductivity of 0.41×10^8 siemens/m and mass density of 19300. Therefore, an analysis of different materials can be a good choice for wide range of frequency tuning. Comparison of radiation efficiency is demonstrated in Fig. 8. The radiation efficiency is defined according to IEEE Std 145-1993 "The ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter". Fig. 8 realizes that the proposed antenna has good radiation efficiency of around 80 %.

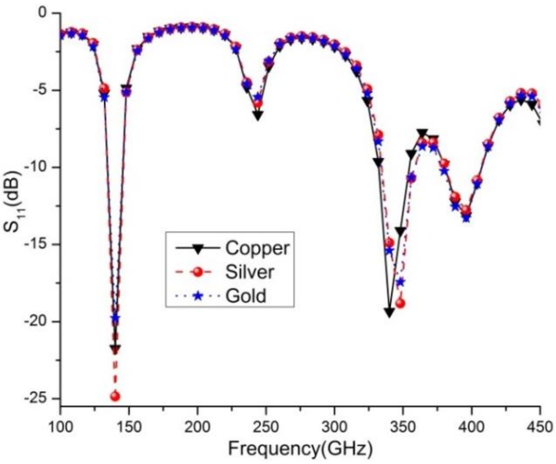


Fig. 7 – Comparative reflection coefficient at different conductive materials

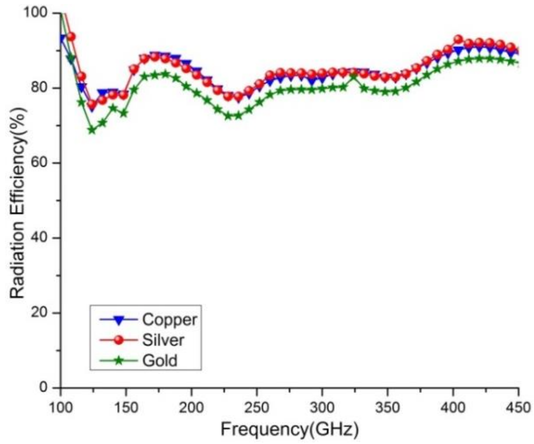


Fig. 8 – Comparative radiation efficiency at different conductive materials

5. DIFFERENT FLEXIBLE MATERIAL CHARACTERIZATION

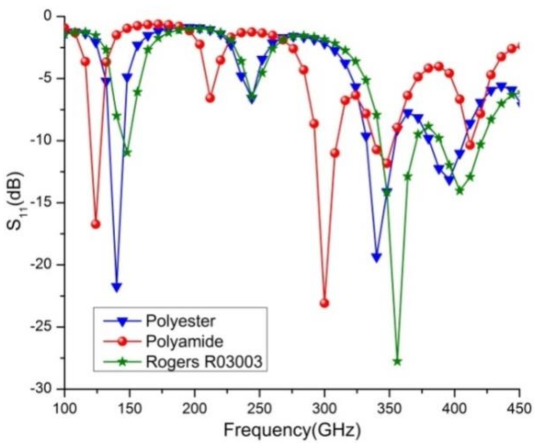


Fig. 9 – Reflection coefficient at different substrates

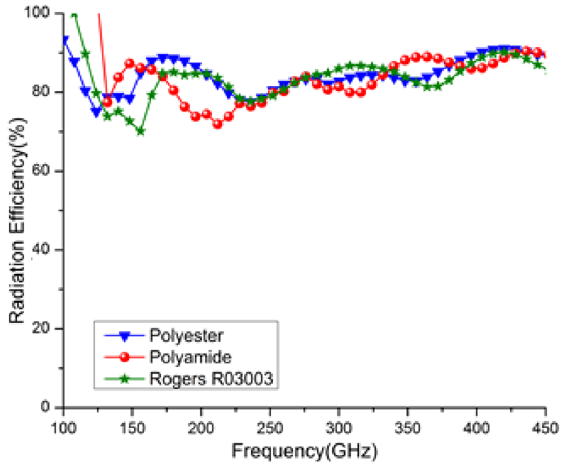


Fig. 10 – Radiation efficiency at different substrate

As we had discussed earlier while determining the most optimal substrate material, properties including flexibility, durability, thickness, frequency bandwidth, and dielectric losses, were of the highest consideration. Therefore, R03003 from Rogers Corporation and polyamide substrate have also been chosen as the substrate material.

The result shown in Fig. 9 reveals that while applying the polyimide substrate the resonant frequency is shifted towards lower frequency bands. Also, the efficiency plot in Fig. 10 depicts that the polyester substrate has very good efficiency around 80-85 %.

6. CONCLUSIONS

The proposed antenna covers triple band resonance characteristics. Initially, an octagonal-shaped microstrip is designed for wireless application, and then the octagonal slots are cut to make octagon ring shaped geometry. The recommended antenna has a simple structure and a compact size of 700 × 900 μm². All results of this antenna specify that proposed antenna can be a good applicant for the triple band antenna operation at the optical frequency band in various applications like Nano antennas, indoor communications, miniaturized devices and WPAN. Finally, some gold and silver are used as conducting surfaces on the patch antenna, which may be used to fine-tune the frequency characteristics of the antenna.

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Проектування трисмугової восьмикутної кільцевої антени для гнучких та портативних застосувань

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Спостерігається експоненціальне зростання попиту на гнучкі або портативні антени у зв'язку з розповсюдженням стандарту 5G, бездротових сенсорних мереж, системи Інтернет (IoT) та моніторингу стану здоров'я. Стаття фокусується на дослідженні різних підкладок при розробці компактної, гнучкої та надійної антени. У роботі восьмикутна кільцева резонаторна антена була спроектована для трисмугових терагерцових додатків. Антена працює у трьох діапазонах частот 140 ГГц, 340 ГГц та 396 ГГц і має загальні розміри 700×900×10 мкм^3. Три матеріали підкладки Rogers R03003, поліамід та поліестер були вибрані для визначення гнучкості, довговічності, а також оптимальних характеристик антени. Результати та характеристики показують, що рекомендована антена буде сумісна з компактними гнучкими бездротовими пристроями. Вся робота з моделювання проводилася з використанням електромагнітного програмного забезпечення Ansoft High Frequency Structure Simulator (HFSS). Також досліджуються такі електромагнітні характеристики антени як коефіцієнти S_{11}, VSWR, коефіцієнт підсилення, ефективність та радіаційні параметри.

Ключові слова: Гнучка антена, Кільцевий резонатор, Трисмугова антена, Портативна антена.