

## **The Effecting of Human Body on Slotted Monopole Antenna in Wearable Communications**

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### **ABSTRACT**

**I**n this paper, the characteristics of microstrip monopole antennas are studied firstly in free space. Secondly, the effects of the human body on the studied antenna's performance are investigated for wearable communications. Different patch shapes of microstrip monopole antenna are chosen to operate at two bands: industrial scientific and medical band (ISM) and ultra-wideband (UWB) for wearable applications. The studied antenna consists of a radiating element on one side of the substrate and a partial ground plane on the other side. The antenna is supposed to fabricate on cloth fabric whose relative dielectric constant is  $\epsilon_r = 1.7$ . At the same time, the pure copper could be used as the conducting part representing both the radiating monopole and the partial ground plane. The software program of Computer Simulation Technology (CST) for Microwave Studio (MWS) is utilized to simulate the studied antennas. The obtained results have illustrated that in the free space, the proposed antennas of slotted hexagonal, rectangular, and circular shapes can operate from 2-12 GHz and of the bandwidth of 10.31 GHz, 10.19 GHz, and 9.67 GHz, respectively. The hexagonal antenna is selected and proposed to investigate the effects of the human body on its performance. The human body is simulated, and its effects on the performance of the proposed antenna are studied. The reflection coefficient, Voltage Standing Wave Ratio (VSWR), gain, and efficiency are found over that frequency range. The simulated results indicate that the human body effects are significant, and the proposed antenna showed to be a good candidate for wearable communications.

**Keywords:** Hexagonal, Rectangular, Circular monopole antennas, Wearable communication, Forearm human body.

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## دراسة تأثير جسم الإنسان على هوائي احادي القطب المشقوق في اتصالات الاجهزة القابلة للارتداء

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### الخلاصة

في هذا البحث ، تمت دراسة خصائص الهوائيات أحادية القطب في الفضاء الحر أولاً ، وثانياً تم دراسة تأثيرات جسم الإنسان على أداء الهوائي المدروس في اتصالات الأجهزة القابلة للارتداء. تم اختيار أشكال مختلفة للهوائي أحادي القطب لتعمل ضمن نطاقين من الترددات: النطاق العلمي والصناعي الطبي (ISM) والنطاق العريض للغاية (UWB) للتطبيقات القابلة للارتداء. يتكون الهوائي من عنصر مشع على جانب واحد من الركيزة ومستوى أرضي جزئي على الجانب الآخر له شق مستطيل في منتصف المستوى الأرضي ومقطع في الطرفين الأيسر والأيمن. يتم تصنيع الهوائي المدروس على قماش ذو ثابت عزل  $\epsilon_r = 1.7$  ، في حين يتم استخدام النحاس النقي كجزء موصل يمثل القطب الأحادي المشع ومستوى الأرض الجزئي. يتم استخدام برنامج لتكنولوجيا محاكاة الكومبيوتر (CST) لاستوديو الميكروويف لغرض محاكاة الهوائيات المدروسة. أوضحت النتائج التي تم الحصول عليها أن الهوائيات المقترحة للأشكال السداسية والمستطيلة والدائرية ذات الفتحات لديها القدرة على العمل من 2- 12 جيجا هرتز وبعرض نطاق ترددي 10.31 جيجا هرتز و 10.19 جيجا هرتز و 9.67 جيجا هرتز على التوالي. تم اختيار الهوائي السداسي لدراسة تأثيرات جسم الإنسان على أداء هذا الهوائي. تتم محاكاة جسم الإنسان والتحقق من تأثيراته على أداء الهوائي المقترح حيث تم إيجاد معامل الانعكاس ، ونسبة الموجة الدائمة للجهد (VSWR) ، والكسب والكفاءة عبر النطاق الترددي المدروس. تشير نتائج المحاكاة إلى أن تأثيرات جسم الإنسان مهمة وأن الهوائي المقترح أثبت أنه مرشح جيد للاتصالات عبر الأجهزة القابلة للارتداء.

### 1. INTRODUCTION

Nowadays, the term communication is going to grow rapidly in the world, and different technologies and applications have been presented day by day. The newest technologies of mobile communications 5G have the advantages of improving capacity, coverage, connectivity, energy-efficient, and have the lowest cost compared to the 4G. Intensive researches have been carried out on some of these modern technologies that include the smart mobile systems (Rasheed and Al-Hindawi, 2019) and modern wearable communications (Alemaryeen and Noghianian, 2017), (Tetik and Antepi, 2018), (Liy, et al., 2019), and (Yaday, et al., 2020).

Body centric wireless communications refer to human-self and human to human networking with the use of wearable and implementable wireless sensors" (Ito, et al., 2009). Wearable devices using the ultra-low-power wireless technology can be worn comfortably. These wearable technologies such as smart watches, hearing aids, body temperature sensors, and more recently announced Google Glass is such compact ultra-low power wearable devices (Khaleel, 2015). Pacemakers, retinal prosthesis, and cochlear implants are examples of implantable devices. As these examples suggest, the users of these devices are both patients as well as healthy people.



Those devices will have some form of communication ability and permit the wearer to send information in real-time. There is a growing necessity for constant monitoring of the health of older people. Hence, these devices and sensors are increasingly being used for such purposes (Ciuti, et al., 2011), (D. Manteuffel, 2012).

Additionally, sportsperson and athletes monitor their vital health parameters like blood pressure, temperature, and respiration rate by using wearable devices (K. Pahlavan, 2012). Since these devices are either attached to the human body or implanted inside the body; therefore, the overall size of the device, including the size of the antenna, must be small. Moreover, the power of the electromagnetic (EM) waves radiated by these devices would be within a safe level and operating to cover the ISM /UWB frequency range (Ito, et al., 2009).

Research performed on wearable antenna includes different antenna types, like a microstrip patch antenna, monopole antenna, PIFA antenna, etc. Different shape of the patch was used, including E-shape L-shape, U-slot patch antennas. The first research on wearable antennas has been performed in 1999 (P., et al., 1999). The paper was based on a dual-band planar antenna designed for GSM and Bluetooth band applications. A U-slot was used to achieve dual-band operation in the antenna, and the possible placement of the antenna on the human body was on the sleeve. Even though the antenna was fabricated on a rigid substrate, it was considered a wearable antenna due to its size and human body placement. The author used a ground plane to minimize the effect of the human body.

In (Tronquo, et al., 2006), several new textiles-based rectangular-ring antennas for BANs operating in the ISM band (2.4 – 2.4835) GHz were investigated. The first proposed antenna was a circularly polarized antenna that covers a bandwidth of more than 190 MHz. Electro textile called Flectron is used as a conducting part (radiating element and ground plane) and Fleece fabric as an antenna's substrate.

A circular disc monopole antenna operating at the lower band of UWB was designed (Dey, et al., n.d.). Dacron fabric with permittivity ( $\epsilon_r = 3$ ) was used for the substrate, and woven copper thread as the conducting part (patch and the ground-plane) was used for the proposed design. The operating frequency of the designed circular disc monopole textile antenna is 1 GHz to 4 GHz.

In (Santas, et al., n.d., 2007), different methods of fabrications were presented and applied various material types to analyze the general antenna performance. The experimental analysis focused on the effect on the human body on the antenna reflection coefficient and the radiation pattern compared to stand-alone cases. Placing the textile antenna conformal to certain parts of the human body proved to degrade performance slightly by introducing frequency detuning and pattern deformation at the resonance frequency.

A microstrip patch with different substrate permittivity was designed in (Dey, et al., 2011). The substrate permittivity was ( $\epsilon_r = 3$ ,  $\epsilon_r = 2.2$ , and  $\epsilon_r = 1.25$ ). The operating frequency was ISM band 2.45 GHz. The authors focused on the effects of antenna bending at five different angles. The



result showed that the impedance matching for substrate permittivity ( $\epsilon_r = 2.2$ ) is better than others. And the magnitude of the main lobe radiation pattern in the azimuth plane for the antenna with ( $\epsilon_r = 1.25$ ) was better than the other higher permittivity. Also, the antenna impedance matching and radiation pattern are affected by bending. More bending of the structure gives improved impedance matching during bending conditions. However, the resonance frequency tends to deviate.

In (Hertleer, et al., 2015), the feasibility study on using textile materials for antenna by combining non-conductive textiles for substrate and conductive electro textiles for antenna patch and ground plane was demonstrated. For the manufacturing of the antenna, prototypes off-the-loom electro textiles were used for a fleece substrate. Rectangular-ring antennas were designed and operating in the ISM band. All three textile antenna prototypes showed an excellent agreement between simulated and measured characteristics, resulting in over 75% efficiency, and all the proposed antennas have circular polarization for both transmitter/receiver of the textile antennas.

A rectangular microstrip monopole antenna prototype is simulated, fabricated, and tested experimentally at frequencies lower than 6 GHz (Hamza and Al-Hindawi, 2016). The antenna performance is examined while it is fixed on different parts of the human body, such as the forearm, arm, and chest.

The present paper introduces different antenna designs aimed to enhance the bandwidth and efficiency of the ISM/UWB structure of textile antenna using slotted rings and studies the effects the human body on the suggested antennas' performance. The proposed antennas are rectangular, circular, and hexagonal shapes with slotted rings made of textile material, while the radiating element and ground-plane are made of pure copper. The antenna performance of those designs is studied at both free space and the human body.

## 2. RESEARCH METHOD

The research method for the present paper includes the basics of antenna designs for different patch shapes. It introduces how the human body is stimulated and then the effect of the human body on the studied antennas' performance.

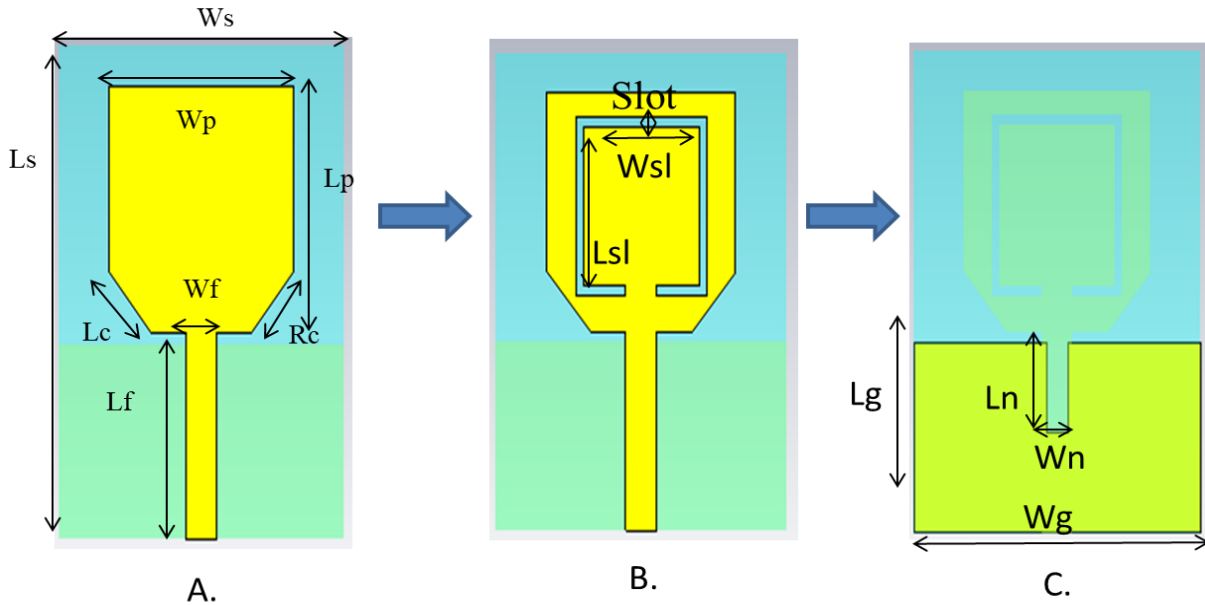
### 2.1 Antenna Designs

Three different antenna designs of geometries, hexagonal, rectangular, and circular monopole, are investigated operating at ISM/UWB frequency band. The antenna dielectric substrate is of jean fabric type, with a height of 1 mm, a relative permittivity of 1.7, and loss tangent 0.025, which is fixed in between the radiating monopole element and the partial ground plane. The transmission line with dimensions of  $4.1 \times 27 \text{ mm}^2$  is used to obtain 50 Ohm input impedance when a middle notch, right, and left cuts are made at the radiating monopole. The length and width of the dielectric substrate and ground-plane are respectively  $48 \times 40 \text{ mm}^2$ ,  $19 \times 40 \text{ mm}^2$ . The suggested antennas are studied and optimized using the EM simulation tool, CST. The effects of both slotted rings in the radiating patch and the human body on the antenna performance are investigated.

Three design groups of study antennas are suggested; the first group is of rectangular shapes, and the second one is of circular shapes while the third group is of hexagonal shapes. All of these designs are investigated with and without slotted rings as follows .

a) Rectangular Monopole Antenna

**Fig. 1** shows the antenna designs with and without slotted rings and all the dimensions of the antennas are illustrated in **Table 1**.



**Figure 1.** Antenna designs A. front view, B. front view with one slot and C. back view.

**Table 1.** Dimensions of rectangular monopole with and without slotted rings.

Parameter	Dimension without a slotted ring (mm)	Dimensions with slotted ring (mm)
Ws	40	40
Ls	48	48
Wg	40	40
Lg	19	19
Ln	9	9
Wn	3	3
Wp	26	26
Lp	24	24

Wf	4.1	4.1
Lf	20	20
Lc, Rc	Chamfer 6mm with 45° angle	Chamber 6mm with 45° angle
Slot	-	1 mm
Lsl	-	8
Wsl	-	8

b) Circular Monopole Antenna

Fig. 2 shows the antenna designs with and without slotted rings, and all the dimensions of the antennas are illustrated in Table 2.

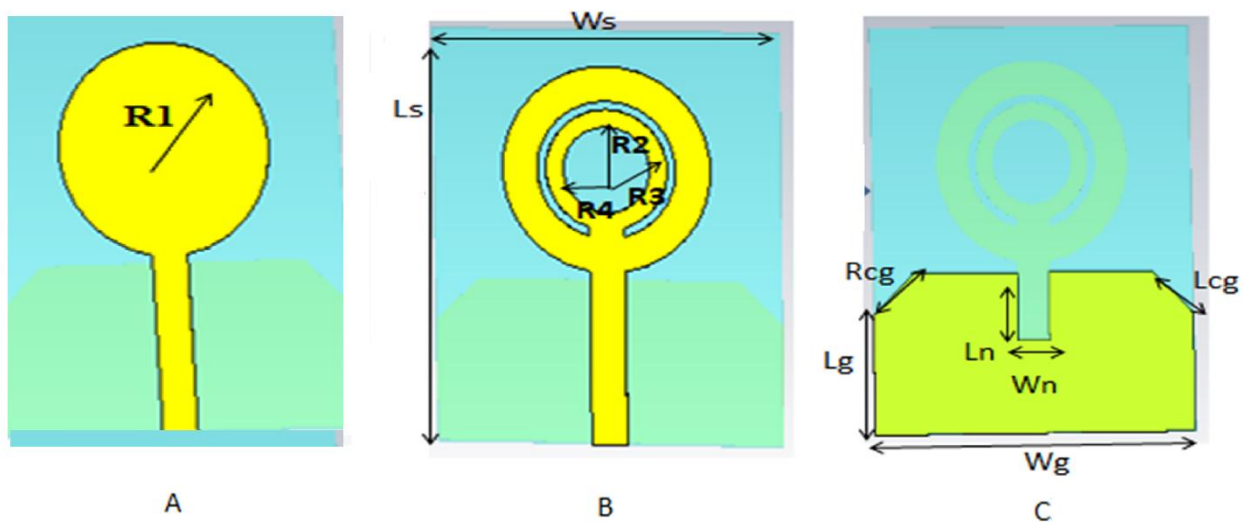


Figure 2. Antenna designs: A. Front view, B. Front view with two slots, and C. Back view

Table 2. Dimensions of circular monopole with and without slotted rings.

Parameter	Dimensions without a slotted ring (mm)	Dimensions with slotted ring (mm)
Ws	40	40
Ls	48	48

Wg	40	40
Lg	19	19
R1	12	12
Wf	4.1	4.1
Lf	20	27
R2	-	8
R3	-	7
R4	-	5
Wn	-	4
Ln	-	8
Lcg, Rcg	-	Chamfer 5mm with 45° angle

c) Hexagonal Monopole Antenna

Fig. 3 shows the antenna designs with and without slotted rings and all the dimensions of the antennas are illustrated in Table 3.

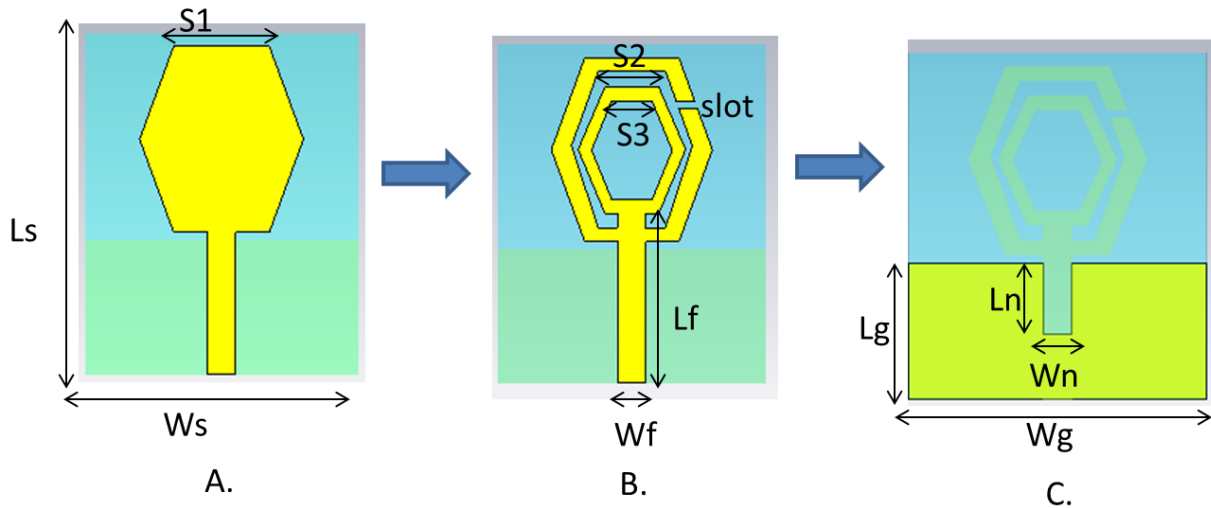


Figure 3. Antenna designs A. front view, B. front view with two slots, and C. back view.

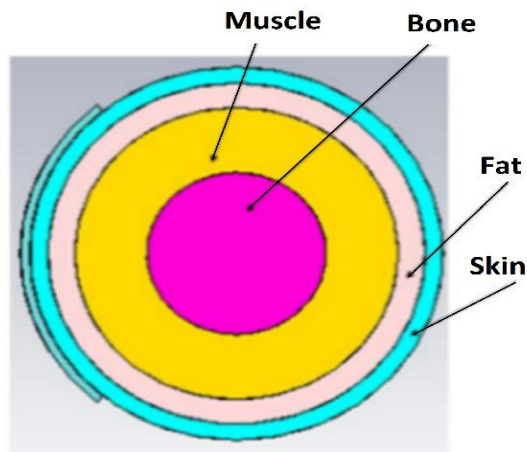
**Table 3.** Dimensions of hexagonal monopole with and without slotted rings.

Parameter	Dimensions without a slotted ring (mm)	Dimensions with slotted ring (mm)
Ws	40	40
Ls	48	48
Wg	40	40
Lg	19	19
S1	14	14
Wf	4.1	4.1
Lf	20	26
S2	-	10
S3	-	7.6
Wn	-	3.6
Ln	-	10
Slot	-	3 x 1 mm <sup>2</sup>

## 2.2 Human Body Simulation

The dielectric properties of a human body change with the frequency, displaying the dispersive demonstrating of tissues for the evaluation of on-body execution. In narrowband frameworks, the properties can be basically characterized for the single recurrence focuses. In the case of a broadband width, a frequency-dependent method must be checked. Due to the variety of the tissue properties with the frequency, the definitions of phantom tissue models must be determined in the design of the UWB WBAN antenna (Tommi, 2014). To study the proliferation of electromagnetic waves inside the body, a layered tissue model is regularly used. In this paper, the model can be chosen to be composed of four distinctive tissue layers; skin, fat, muscle, and bone to simulate the forearm body, as shown in Fig 4. The cylindrical shape can represent a forearm body with a length of 60 mm due to the running simulation timer. In most cases, the model can be chosen to compose of three distinctive tissue layer, skin, fat, and muscle, which are defined as the following:





**Figure 4.** Human forearm model.

### **Skin tissue**

The skin layer is made from two layers, the dermis, and epidermis. The general thickness of skin fluctuates between 1.5 mm to 4 mm. It is important to note that the thickness fluctuates in the distinctive body part between males and females and with age. These differences are usually related to the water content of the skin (Yvanoff, 2008).

### **Fat tissue**

Underneath the dermis is found the hypodermis, which converges with the Subcutaneous Fat Tissue (SAT) containing a specific amount of fat. The SAT's greatest values 23.2 mm for people with a normal body (Yvanoff, 2008).

### **Muscle tissue**

Muscle tissue thickness varies significantly depending on the location and person. Up to 60mm of muscle tissue thickness has been reported (Yvanoff, 2008).

In this simulation, the body part's curvature has been approximated to a conical shape with top and bottom radiuses. Each layer's thickness was taken as skin = 2 mm, fat = 3 mm, muscle = 8 mm, and bone = 10 mm (radius) as given in (Waddah A. M, et al, 2015), and listed in **Table 4**.

**Table 4.** Human forearm model dimensions.

<b>Tissues</b>	<b>Dimensions in (mm)</b>
Skin	2
Fat	3
Muscle	8
Bone	10

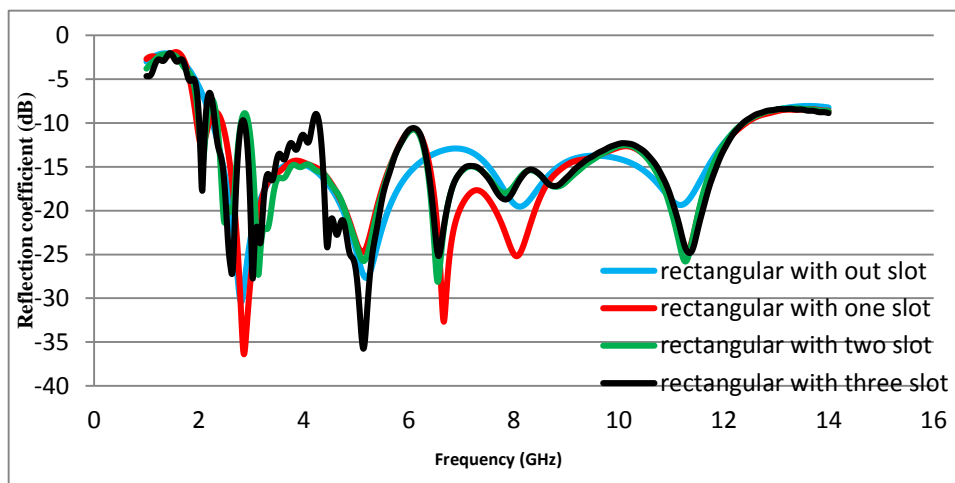
### 3. RESULTS AND DISCUSSION

In the following sections, the effects of slot rings on the antenna designs are presented and compared with each other for rectangular, hexagonal, and circular monopole antenna. In the last section, the effects of the human body on the hexagonal monopole antenna is studied.

#### 3.1 Effects of Slotted Rings on antenna Performance

##### a) Effects of slotted rings on rectangular monopole

The characteristics of the reflection coefficient for the studied antennas are plotted in **Fig 5**. It is noticed that the best result is obtained when the rectangular monopole has one slotted ring and the impedance bandwidth, which is below -10 dB, is 10.19 GHz (from 2.25 GHz to 12.44 GHz), while the VSWR is less than 2 for all frequencies.



**Figure 5 .** Reflection characteristics of rectangular monopole with different slotted rings

##### b) Effects of slotted rings on circular monopole

The reflection coefficient characteristics of the studied antennas are plotted in **Fig 6**. It is noticed that the best result is obtained when the circular monopole has two slotted rings, and the impedance bandwidth is 9.67 GHz from 2.25 GHz to 11.92 GHz below -10 dB, and the VSWR < 2 for all frequencies.

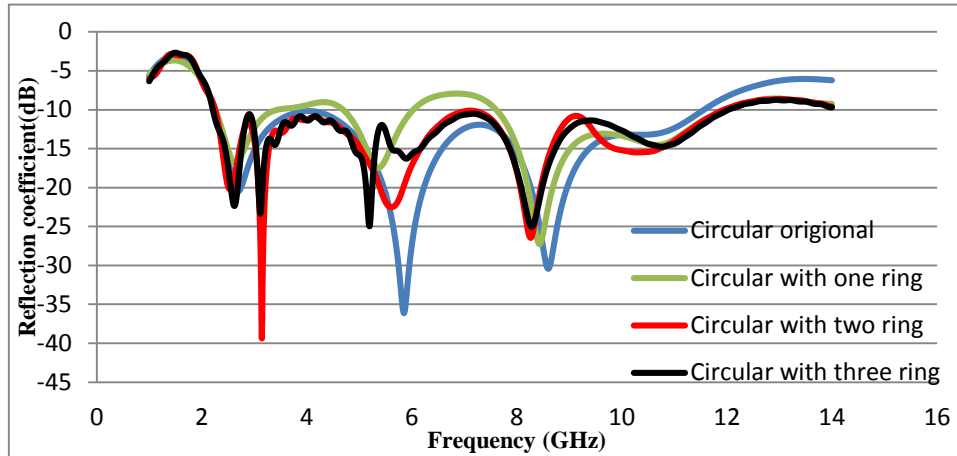


Figure 6 . Reflection characteristics of circular monopole with different slotted ring.

c) Effects of slotted rings on hexagonal monopole

The reflection coefficient characteristics of the studied antennas are plotted in Fig 7. It is noticed that the best result is obtained when the circular monopole has two slotted rings, and the impedance bandwidth is 10.31 GHz from 2.39 GHz to 12.7 GHz below -10 dB, and the VSWR < 2 for all frequencies.

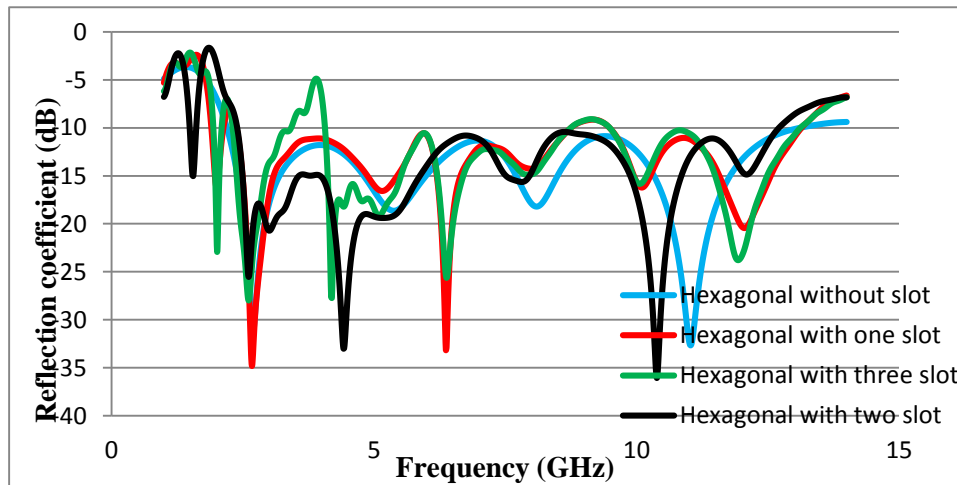


Figure 7 . Reflection characteristics of hexagonal monopole with different slotted ring.

3.2 Results Comparison for Different Antenna Shapes

Fig. 8 compares the rectangular monopole antenna's reflection coefficient with one ring, circular monopole with two rings and hexagonal monopole with two rings.

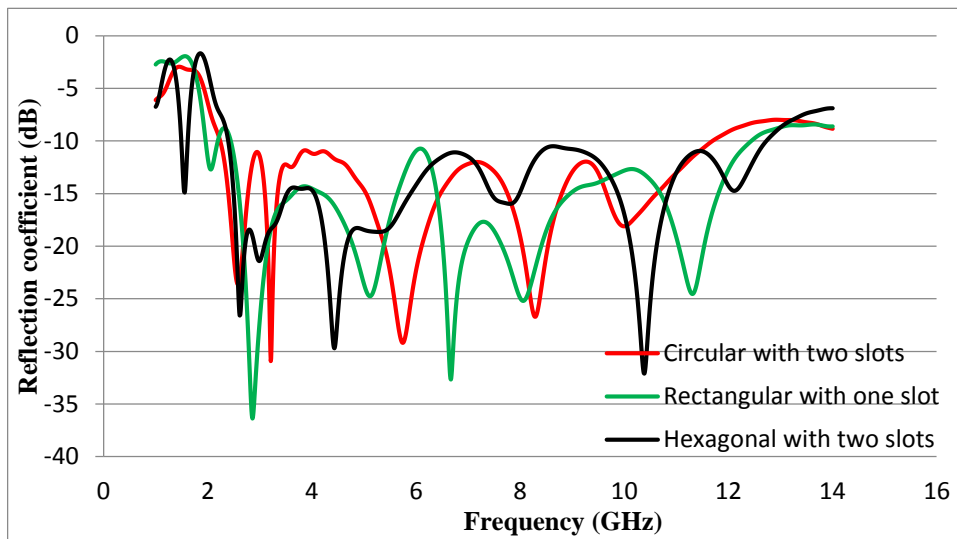


Figure 8. Reflection characteristics of the rectangular, circular, and hexagonal monopole with different slotted ring.

Fig. 9 shows the comparison of efficiency for rectangular, hexagonal, and circular monopole antenna. It is observed that the rectangular monopole antenna has a good gain characteristic (average of 87.5%) and better than the others. At the same time, the average efficiency of the slotted hexagonal is 84%, which is greater than that of the slotted circular one.

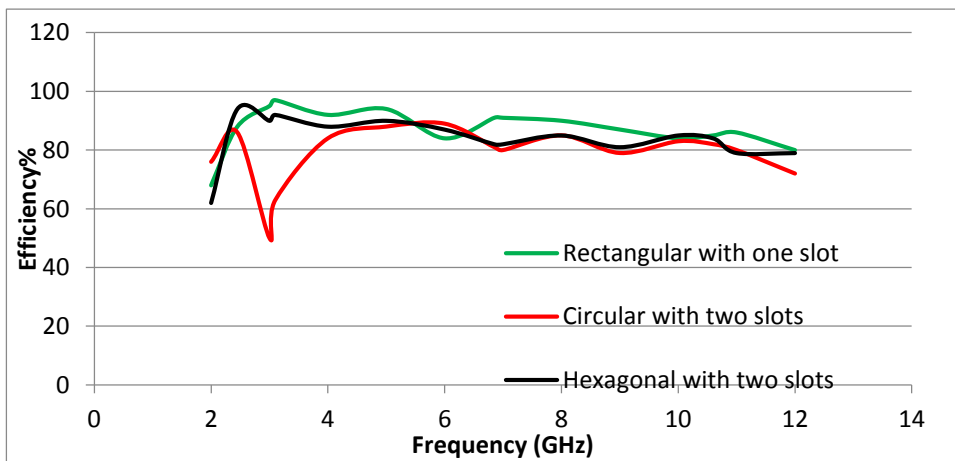


Figure 9 . Efficiency of the rectangular, circular, and hexagonal monopole with different slotted rings.

Fig. 10 shows the gain comparison of rectangular, hexagonal, and circular monopole antennas with slotted rings. The slotted hexagonal monopole's gain characteristics behave better than the others for all the studied frequency bands. In contrast, the slotted rectangular monopole's gain characteristics behave better than those for the slotted circular antenna.

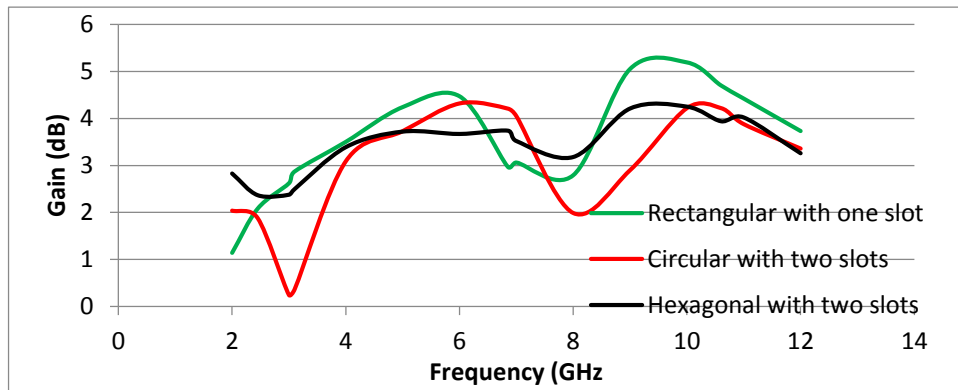


Figure 10 . Gain of the rectangular, circular, and hexagonal monopole with different.

The above properties of studied antennas can be summarized in Table 5.

Table 5. Summary of studied antennas.

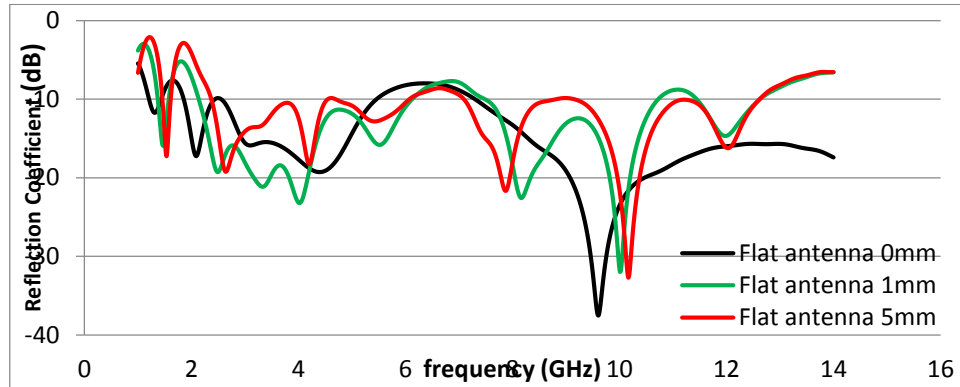
	Monopole antenna	Average S11 (dB)	Bandwidth (GHz)	Average Efficiency (%)	Average Gain (dB)
1	Rectangular with one slotted ring	-17.2	10.19	87.5	3.522
2	Hexagonal with two slotted rings	-15.3	10.31	84	3.399
3	Circular with two slotted rings	-15.61	9.67	78.533	2.967

It is noticed that the best result is obtained for hexagonal monopole antenna with two rings, which has a greater impedance bandwidth and return loss below -10dB, compared to the rectangular and circular monopole antennas. The rectangular monopoles have better reflection characteristics than those of circular shape.

### 3.3 Human Body Effects on Performance of Slotted Hexagonal Monopole Antenna

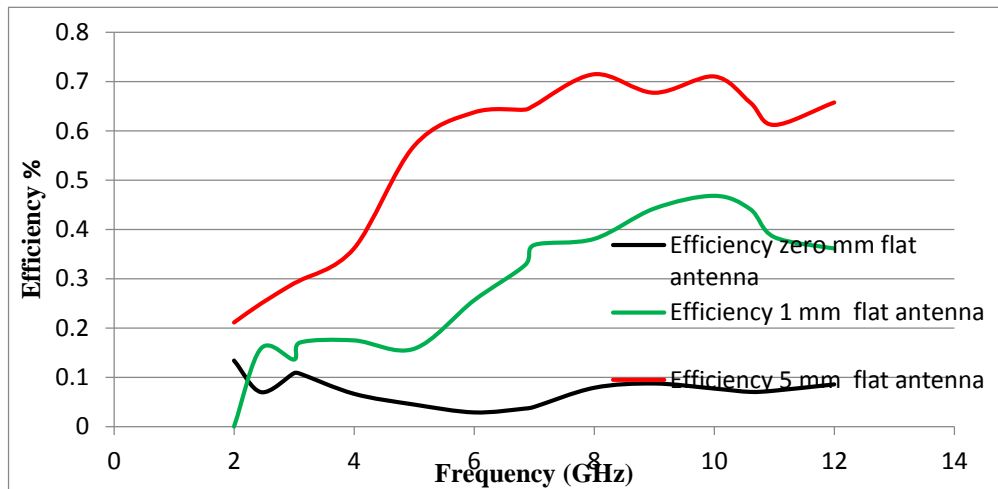
The human body's effects on the antenna performance are studied, and the hexagonal monopole antenna with two slots is selected as a case study. The antenna is placed on the body at different spaces (0 mm, 1 mm, and 5 mm) at a flat position (without bending the antenna's surface). Fig. 11 shows its reflection characteristics. In the real case, the antenna may be placed on the clothes and may not be in direct contact with the skin. It is noticed that the bandwidth of the proposed

antenna at the body increased compared to the free space results because of the lowering Q factor of the antenna's proximity to the body. The return loss for all spacing shifted to lower frequencies because a body is exceptionally lossy at UWB frequencies. For all spacing, the antenna has a better S11 below -10 dB except the region between 5 to 7 GHz. It is noticed that the antenna has better reflection characteristics at 0 mm spacing.



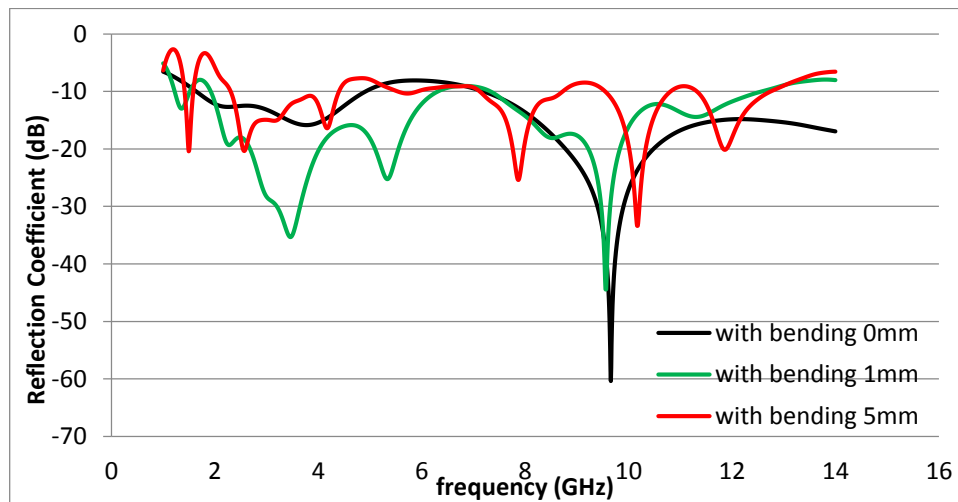
**Figure 11.** Reflection coefficient for different spacing at a flat position on the body.

**Fig. 12** shows the hexagonal monopole antenna's efficiency at the flat position on the human body for different spacing. The efficiency is low at lower frequencies, but for higher frequencies, the efficiency becomes well also, by increasing the space between the antenna and body, the efficiency is becoming large.



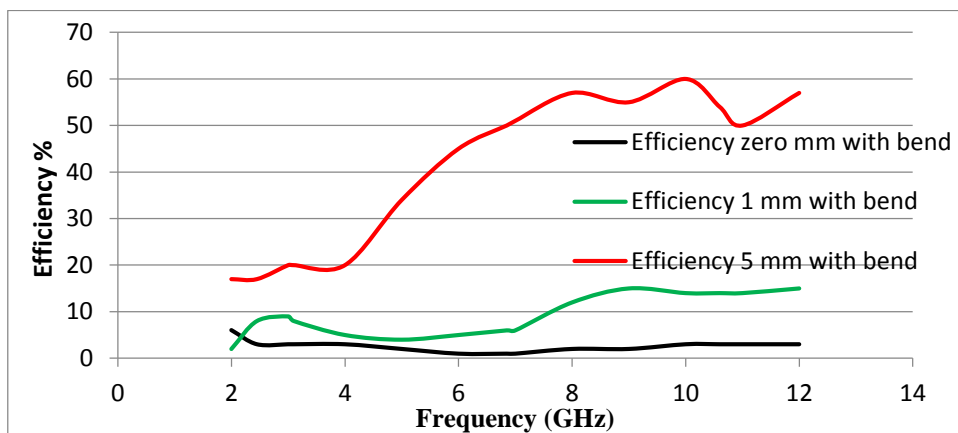
**Figure 12 .** Efficiency characteristics for different spacing for flat position along the body.

**Fig. 13** shows the comparison of the slotted hexagonal monopole antenna's reflection coefficient when it is placed on the human body with bending at different spaces (0 mm, 1 mm, and 5 mm). Also, the antenna's bandwidth increased due to the above reason because of the lossy body bending; all return loss shifted to the lower frequencies. It is seen that the antenna of spacing 1 mm behaves better and has a lower reflection coefficient from the others.



**Figure 13.** Reflection coefficient for different spacing for bending along the body.

**Fig. 14** shows the hexagonal monopole antenna's efficiency when bent along the human body for different spacing. The efficiency is low at lower frequencies, but for higher frequencies, the efficiency becomes well also, by increasing the space between the antenna and body, the efficiency is becoming large.



**Figure 14.** Efficiency characteristics for different spacing for bending along the body.

#### 4. CONCLUSIONS

In this study, different patch shapes of microstrip monopole antenna are investigated at ISM and UWB for wearable applications. The studied antenna is considered as a radiating microstrip patch with a partial ground plane. The obtained results have illustrated that the proposed antennas of slotted hexagonal, rectangular, and circular shapes have the ability to operate from 2-12 GHz with a bandwidth of 10.31 GHz, 10.19 GHz, and 9.67 GHz, respectively. The hexagonal antenna is selected as a case study to investigate the effects of human body on the antenna performance. The human body is simulated, and its effects on the proposed antenna performance that includes reflection coefficient, gain, and efficiency are investigated over that frequency range. The



simulated results indicate that the human body effects are significant, and the proposed antenna showed to be a good candidate for wearable communication.

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