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Design of a Finger Ring Antenna for Wireless Sensor Networks

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***Abstract*— Body-centric communications have become very active area of research due to ever-growing demand of portability. Advanced applications such as; health monitoring, tele-medicine, identification systems, performance monitoring of athletes, defence systems and personal entertainment are adding to its popularity. In this paper, a novel wearable antenna radiating at 5 GHz for the body-centric wireless sensor networks has been presented. The antenna consists of a conventional microstrip patch mounted on a gold base and could be worn in a finger like a ring. CST Microwave Studio is used for modelling, simulation and optimisation of the antenna. The simulated results show that the proposed antenna has a -10 dB bandwidth of 90.3 MHz with peak gain of 6.9 dBi. Good performance in terms of bandwidth, directivity, gain, return loss and radiation characteristics, along with a miniaturised form factor makes it a very well suited candidate for the body-worn wireless sensor applications.**

***Keywords*— Wireless Body Area Networks, Microstrip patch, Wearable sensors, Gold ring, On-body applications, Tele-health monitoring.**

I. INTRODUCTION

In the recent years, antennas for body-centric wireless networks (BCWNs) have attracted much attention. Human body can be used as a communication channel for different low power wearable wireless devices [1]. The body centric wireless networks have a range of applications in monitoring the health of patients, surveillance and tracking, monitoring performance of athletes, and personal entertainment systems [2]-[3]. The radio transmissions in these networks can take form of three conventional types of on-body link, off-body link, in-body link and most recently and body-to-body link [4]. The antennas for the body-centric wireless networks have special requirements of small size, high reliability, continuous operation, low power consumption and body effect mitigation due to ever-changing behaviour of the communication channel. Microstrip patch antennas are a popular choice for such antennas as they offer features like low cost, low complexity, ease of integration and miniaturisation [5]. They could be made conformal to the body surface easily and hence suits the wearable applications through integration in clothing, fabrics, watches and wristbands.

Microstrip patch antennas for wearable applications are being studied by a number of researchers recently. Variety of methods including textile radiators, fabric, electromagnetic band-gap (EBG) structures and flexible substrates has been employed by the researchers to attain miniaturisation while maintaining reasonable performance of the antennas [6]-[13].

Locher et al. have presented design of purely textile patch antennas for wearable Bluetooth applications with smooth integration into clothing while preserving the typical properties of textiles [6]. The antenna uses a microstrip line as feed. Marrocco has proposed the design of a passive transponder antenna for radio frequency identification applications using the human body as the object to be monitored [7]. The antenna consists of a planar tag antenna based on a suspended patch fed via a nested slot.

In [8], the performance of a lambda/20 higher mode microstrip patch antenna operating at 2.45 GHz has been studied. The 10-mm-high antenna had an impedance bandwidth of 8.6% and offering 11-dB higher path gain compared to a fundamental-mode microstrip patch antenna. The detection of heart rate for fish has been demonstrated using a patch antenna working at 2.4 GHz, as a less-invasive alternative to surgical electrocardiogram (ECG) measurements in [9]. Chi et al. have proposed a planar, via-free, printed patch antenna for wireless medical telemetry service. The antenna is fed by a coaxial cable and looks like an adhesive bandage [10]. The measured radiation efficiency of the antenna is 89.5% in free space and 44.7% when mounted on tissue-equivalent phantom.

A patch-type slot antenna consisting of a rectangular loop for balanced feeding and patch with slots for radiating element, designed on flexible printed circuit board has been discussed in [11]. The 3-dB bandwidth of the antenna covers frequency range of 2.36-2.39 GHz with a peak gain of -4 dBi in wearable scenarios. Tak et al. have discussed design of a centre-fed textile patch antenna with an electric bandgap (EBG) structure generating the TM01 mode at the 5.8 GHz [12]. The antenna has a diameter of 1.98λ and a thickness of 0.058λ.

Design of a tapered-slot ultra wideband (UWB) band-notched antenna using ultra-thin liquid crystal polymer (LCP) substrate for wearable applications has been presented in [13]. The antenna operation covers the frequency range of 3.1 to 10.6 GHz, while rejecting the wireless local area network operation at 5.25 GHz band. Use of the LCP substrate makes the antenna to efficiently mitigate the bending effects.

Ring antennas are considered a good option for the body-mounted sensors. Arakwa et al. have presented circular loop finger ring antenna for UWB operation in 7.25 GHz-10.25 GHz [14]. This antenna however has a large diameter of 22 mm that makes it not suitable for wearable body-centric applications. A 6 mm high monopole antenna for finger ring has been proposed in [15]. The antenna operates in UWB band (7.25 GHz–10.25 GHz). Size and performance of these antennas are however less attractive for body-mounted sensors and necessitates novel solutions.

In this paper, a novel finger ring antenna for body-centric wireless networks has been discussed. The antenna employs a simple and low profile patch structure fed by a microstrip line mounted on top of a gold finger ring. Following the introduction, the paper is organised in three sections. Section 2 explains the antenna design and structure. Section 3, discusses the performance of the antenna in terms of free space simulated results. Finally the paper is concluded in Section 4.

II. Antenna Design and Structure

The proposed finger ring antenna was designed for 5 GHz frequency band. CST Microwave Studio software package has been used for modelling and simulating the antenna. The design process involves use of the conventional microstrip rectangular patch antenna as a template and then embedding this antenna into a gold finger ring. Hence, the microstrip rectangular patch antenna was designed first for operation at 5 GHz frequency. A quarter wavelength transformer was employed to match the antenna impedance with a 50 Ω feeding port.

After accomplishing the design of the conventional microstrip rectangular patch antenna for 5 GHz frequency, the next step was to model a finger ring. The finger ring was selected to be made of gold as gold rings are most widely used ornament. Finally, the designed microstrip rectangular patch antenna along with the feeding line and matching network was bent to conform the shape it with the finger ring and embed on top of the ring.

The top view of this finger ring antenna is shown in Fig. 1. The optimised design of the proposed antenna has a length of 22 mm and width of 21.6 mm. The radiator is a conventional microstrip patch antenna having 35 µm thick layer of copper fed through a 50 Ω microstrip feed. The substrate is Rogers RT6006 with a thickness of 0.8 mm. It has a permittivity of 6.15 and *tan δ* of 0.0027. The ground plane is sandwiched between the 2 mm thick golden finger ring and the Rogers RT6006 dielectric substrate.

The quarter wavelength transformer used in the matching network has the dimensions of 0.24×4.765 mm^2. The dimensions of the microstrip feed line are 2.9×4 mm^2. Fig. 2 shows the side view of the antenna structure using a cutting plane.

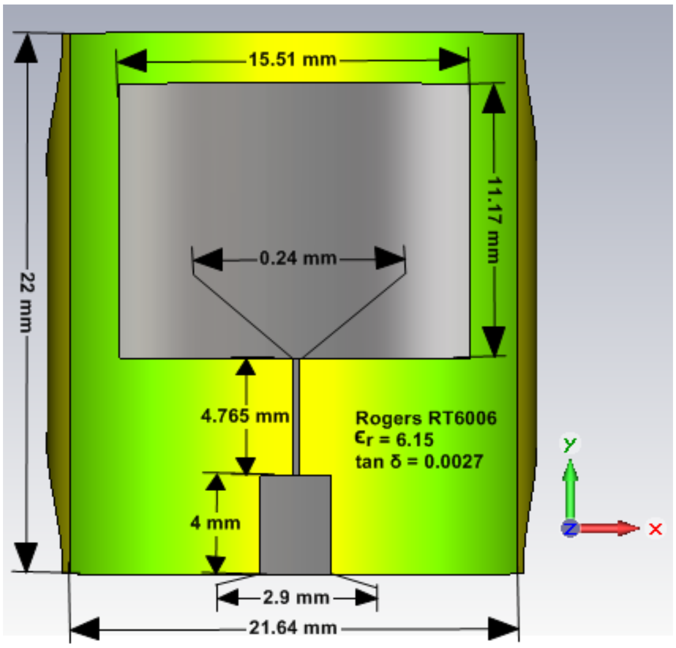


Fig. 1 Top view of the proposed finger ring antenna

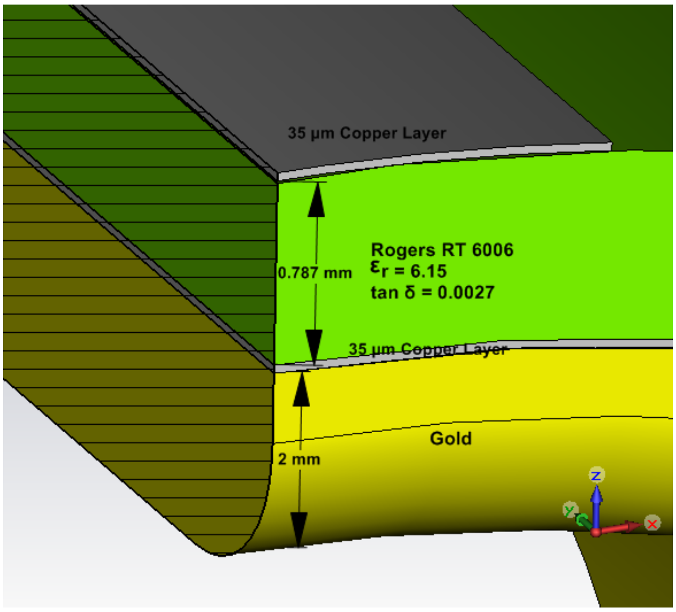


Fig. 2 Side view through a cut-plane of the proposed finger ring antenna

Fig. 3 illustrates the side view and dimensions of the golden finger ring. The inner diameter of the finger ring is 18 mm while the outer diameter is 20 mm. Multiple layered structure can also be observed in this figure. Fig. 4 displays the 3D model of the optimised structure with three key components. The overall structure of the antenna is very compact. The design is simple and can be worn in a finger just like a traditional golden ring. The antenna can be used as stand-alone or being integrated with a sensor chip.

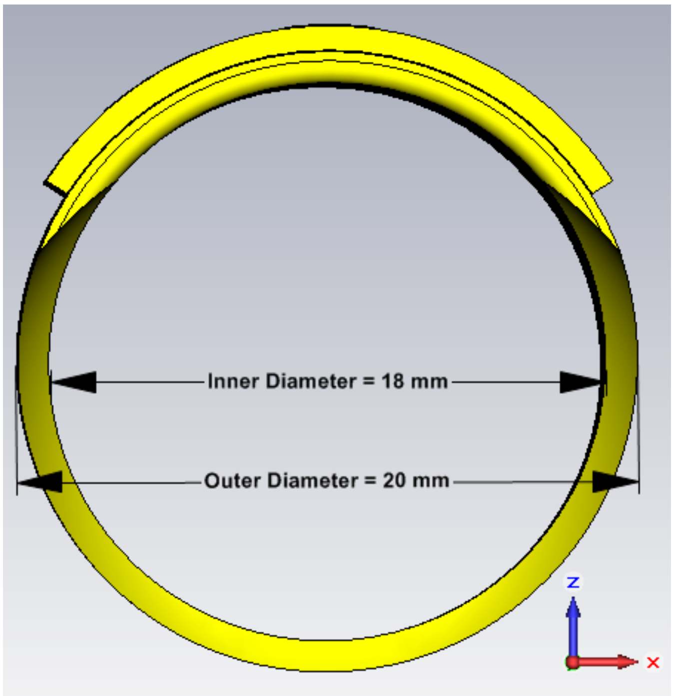


Fig. 3 Dimensions of finger ring

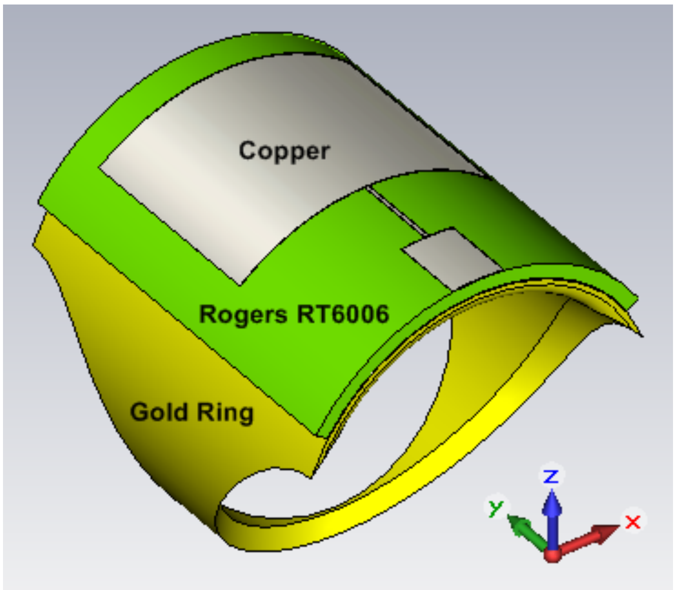


Fig. 4 Optimised 3D model of the proposed finger ring antenna

III. Results and Discussion

The antenna performance is analysed in terms of the simulated free space parameters. The S_{11} response of the proposed antenna is presented in Fig. 5. It is observed that the finger ring antenna resonates at 5.04 GHz with a return loss of -21.5 dB. It exhibits a -10 dB impedance bandwidth of 90.4 MHz. It is evident from these results that the antenna is covering the Wi-Fi frequency band with excellent impedance match.

The radiation patterns of the antenna at $\phi=0^o$ and $\phi=90^o$ planes are shown in Fig. 6. It can be seen that antenna has a very good radiation profile with the peak gain value of 6.9 dBi. The 3 dB angular beamwidth is 111.5°. The antenna coverage is also good spanning the whole upper hemisphere. Back lobe levels are also minimal.

The simulated radiation efficiency of the antenna is noted to be 78% showing acceptable amount of losses and good radiation performance. The simulated free space parameters of the proposed finger ring antenna are summarised in Table I. These excellent radiation characteristics again make this antenna to fulfil most of the desired parameters for the body-centric wireless networks.

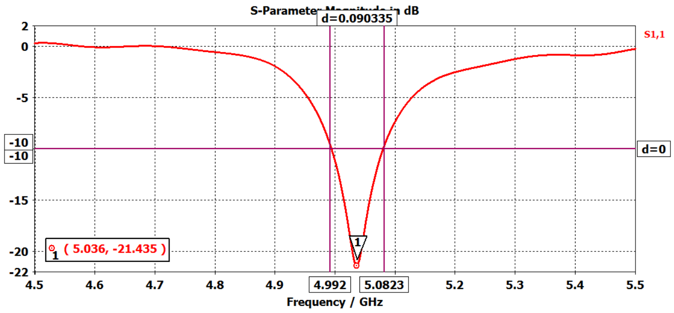
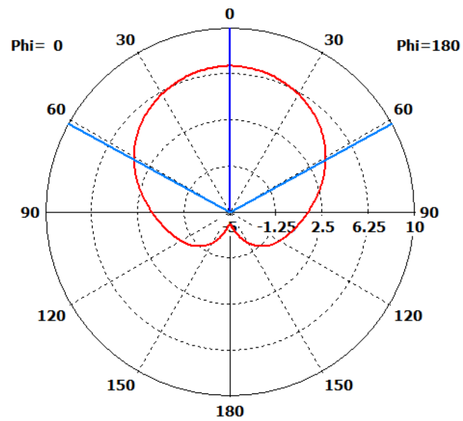
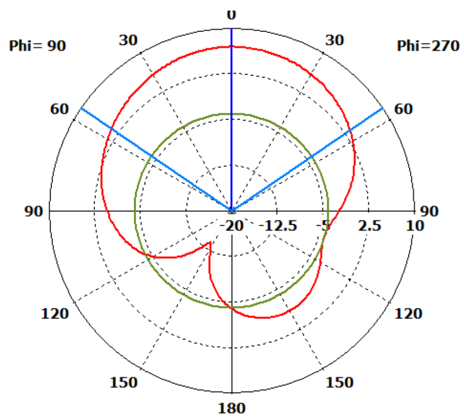


Fig. 5 S_{11} response of the proposed finger ring antenna



(a) $\phi=0^o$



(b) $\phi=90^o$

Fig. 6 Radiation patterns of the proposed antenna at 5 GHz

TABLE I

SUMMARY OF THE FREE SPACE ANTENNA PERFORMANCE AT 5 GHZ

Antenna Parameters	Free Space Simulated Results
S_{11}	-21.5 dB
-10 dB Bandwidth	90.4 MHz
VSWR	1.2:1
Gain	6.9 dBi
Total Efficiency	82 %
Radiation Efficiency	78 %
Input Impedance	53 Ω

IV. CONCLUSION

Design of a novel antenna for body-worn wireless applications has been presented with an analysis of antenna performance and radiation characteristics in free space. The antenna structure was formed in the shape of a finger ring. The antenna has used a simple conventional microstrip patch antenna bent on a gold finger ring to provide conformity. The performance of the antenna has been studied using numerical analysis. The simulated results have shown that the proposed antenna has high value of peak gain of 6.9 dBi with a good -10 dB impedance bandwidth of 90.4 MHz. The antenna has also exhibited good radiation coverage and minimal back radiation. Small size and good radiation characteristics make this antenna a suitable candidate for body-centric wireless communications and body-mounted sensors. It is an ongoing research where the performance of the proposed antenna in body-worn scenarios and validation through measurements are in progress.

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