On-Off Body Performance of A Multiband Antenna for Wireless Health Monitoring

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Abstract—**Performance of a multiband antenna for on/off body applications is evaluated and analysed in this paper. This compact microstrip patch antenna employs a combination of two rings and semi-circular slot to generate multiband resonances. Overall size of the antenna is 50 $\times$ 50 mm^2. The presented results show that this compact multiband antenna operates excellently in the vicinity of the human body making it a potential contender for wireless health monitoring systems providing simultaneous data transmission/reception at at- least three distinct frequency bands.**

Keywords*—*Patient health, multiband antenna, on/off body, Wireless body area networks.

I. INTRODUCTION

Field of wireless communications is growing day by day and it is predicted by the Wireless World Research Forum (WWRF) that by 2017, over 7 trillion wireless devices will serve 7 billion people [1]. This rapid growth of wireless technology has increased the demand of mobile terminals offering multiple features including coverage of different cellular frequencies, availability of navigation and positioning, and inclusion of Wi-Fi [2]. The basic idea behind the emergence of Body Centric Wireless Networks (BCWNs) was the health monitoring of the patients remotely but its applications also span navigation and positioning, entertainment, security and surveillance, space exploration and military [3], [4]. This system requires inter-connectivity between body mounted sensors, body mounted access point and remote processing unit. Efficient real time monitoring, high data rate and continuity of the service with high level of mobility and flexibility could be facilitated by using a single low profile antenna having a multi-band operation at different communication frequencies [4]–[7].

The human body is an inherent part of the BCWN applications. The antennas operating in the close proximity of the human body are vulnerable to electromagnetic distortions caused by the varying electric properties of the lossy human body tissues. Efficient deployment of the BCWN systems necessitates the evaluation of the interaction between the human body and body-worn antennas.

Researchers have put a huge amount of interest to study the performance of the antennas in on/off body scenarios. It is established theoretically and experimentally that the human tissues causes high level of losses over the communication spectrum. As a result, it effects the antenna performance by distorting the radiation pattern, reducing the radiation efficiency and detuning the antenna input impedance [3], [8], [9].

Commercially used Planar Inverted F Antenna (PIFA) and meander line antenna have been used to study various factors affecting on-body communication links including handset-to-body separation and presence of blocking objects have been studied in [8]. Two dual-band textile antennas having a higher conductivity-based textile material and a large-sized ground plane have been analysed for on-body performance by Boyes *et al.* [10]. The authors conclude that larger ground plane makes the antennas more resilient when placed on-body undergoing about a 20% degradation in radiation efficiency as compared with free-space levels (which is much less than the lower conductivity textile material). A multiband textile-based body-worn antenna performance covering the GSM/PCS/WLAN frequency bands is discussed in [11]. The antenna is made of densely embroidered metal-coated polymer fibers of 15 m thickness. Dierck *et al.* have proposed a wearable multiband circularly polarised active antenna for use in GPS and Iridium satellite phone applications [12]. The antenna is constructed using flexible foam and fabric substrates and conductors etched on thin copper-on-polyimide films.

These antennas employ either complex geometries, have low gain or use fabrics. It limits their applicability due to cost and complexity. A new design of a microstrip patch antenna for multi-band operation has been proposed in [13]. The antenna covers four popular communication bands including GPS (1.575 GHz), 4G/LTE/CDMA (2.1 GHz), and Wi-Fi (3.6/5 GHz). The structure and dimensions of the antenna are depicted in Figure 1. The radiating element of the antenna is a combination of a microstrip patch, two rings and a slot. The antenna is printed on a commonly used FR4 substrate having a relative permittivity of 4.4. The thickness of the substrate is 1.6 mm. The size of the ground plane is $50mm \times 50mm$. The antenna is fed using a 50 ohm coaxial line. The antenna performance in free space is excellent at the four frequency bands. Good impedance matching (of more than -10 dB), good omni-directional coverage in both azimuth and elevation, high peak gain values of more than 5.1 dBi planes is observed for this multiband antenna. Good performance, simple configuration and low profile makes this antenna particularly attractive for wireless health monitoring systems.

This paper investigates the performance of this multiband antenna for on/off body applications using numerical studies and considering various body-mounting scenarios. Following the introduction, this paper is organised in four sections. In Section II, details of the numerical design of the human body

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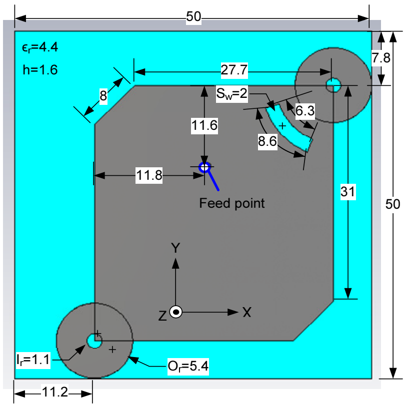

Fig. 1. Geometry and dimensions of the slot-ring microstrip patch multi-band antenna operating at GPS/4G/Wi-Fi frequencies (all units are in mm [13])

are discussed. Section III analyses the antenna performance in different on-body and off-by configurations while conclusions are drawn in Section IV.

II. Numerical Modelling of the Human Body

CST Microwave Studio® which is based on the Finite Integration Technique (FIT) for the solution of Maxwell's equations [14] has been used to develop the realistic numerical model of the human body which is based on MRI scans [15]. The complexity of the human body composition compelled to design this model as a single layer homogeneous structure.

To reduce the overall number of cell volumes (voxels) in the computational domain that subsequently reduces the computation and time requirements, an adaptive meshing scheme is used. This scheme employs finer cell sizes around the vital parts of the body. The Perfectly Matched Layer (PML) absorbing boundary conditions are used [14]. It resulted in a maximum mesh cell size of 10 mm near the boundaries of the computational domain and a minimum mesh cell size of 0.08 mm at the edges of the solids in the computational domain. The high level discretisation of the whole-body model represents an average built human subject standing tall with a height of 1755 mm, as shown in Figure 2.

Accurate modelling of the multiband antenna in the presence of the human body requires careful determination of the dielectric properties. For the single layer human body model, 2/3 muscle dielectric properties are considered that are well characterised up to 20 GHz [16]. The antenna operation at multiple frequencies in the range from 1.5 GHz to 6 GHz lead to the adoption of the Debye dispersion equation to express the complex dielectric properties of the numerical human body [17]:

$$\varepsilon^* = \varepsilon_o(\varepsilon^{'} - j\varepsilon^{''}) = \varepsilon_o(\varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}) \qquad (1)$$

where ε_o, is the free space permittivity, ε_s represents the static permittivity, ε_∞ is the optical permittivity, ω depicts the angular frequency and τ is the relaxation time. The values used in this paper for these parameters to obtain best fit are $\varepsilon_s = 37.1$, $\varepsilon_\infty = 12.2$ and $\tau = 12.5 \times 10^{-12}$ [18].

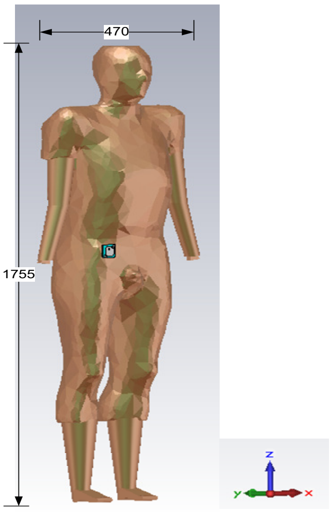

Fig. 2. Structure of realistic high-resolution numerical model of the human body (all lengths are in mm)

III. Antenna Performance Evaluation

The performance of the multiband antenna is evaluated in various on-body configurations as discussed in the following sections.

A. On-body Antenna

For the on-body scenarios, the antenna is mounted on-body keeping a separation of 10 mm between the antenna and the body to replicate the space for the covering assembly of the wireless device. The antenna performance is analysed in terms of reflection coefficient response and Specific Absorption Rate (SAR) distributions.

The position of the antenna as the access point is selected to be right belly which is the common location if the device is placed in the user's pocket (as shown in Figure 2). The reflection coefficient (S_{11}) performance is compared to that observed in the absence of the human body model and illustrated in Figure 3. The results show that the human body detunes the antenna and brings a shift in the resonance frequency. However, the antenna still manages to give good performance at 2.1 GHz and 5.3 GHz frequency bands. The two bands can be used simultaneously for transmission/reception of body monitored data.

The Specific Absorption Rate (SAR) is used as a measure to determine the health hazards posed by the RF signal to the human body. The SAR is expressed as follows:

$$SAR = \frac{\sigma}{\rho}|E|^2 \qquad (W/kg) \qquad (2)$$

Where, σ is conductivity of the tissue in S/m, ρ is mass density of the tissue in kg/m^3 and E is total RMS electric field strength in V/m.

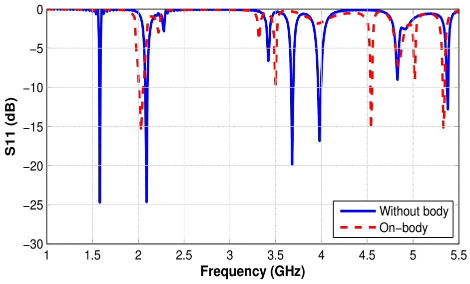

Fig. 3. Reflection coefficient response of the multiband microstrip patch antenna with and without human body presence

Different standardisation bodies use certain SAR limits for wireless devices to guarantee the safety of the user. The Federal Communications Commission (FCC) uses 1.6 W/kg SAR value averaged over 1 g of tissue volume as a public safety standard while International Commission on Non-Ionising Radiation Protection (ICNIRP) and The Institute of Electrical and Electronics Engineers (IEEE) have adopted 2 W/kg SAR value averaged over 10 g of tissue volume [19], [20].

The 1 g averaged SAR for the multiband antenna at different operating frequencies are summarised in Table I. The results show that the level of energy absorption is different at different frequencies. Overall, the SAR values are well below the required threshold.

TABLE I. COMPARISON OF THE 1 G AVERAGED SAR VALUES AT DIFFERENT FREQUENCIES OF OPERATION FOR THE ON-BODY MULTIBAND ANTENNA

Frequency (GHz)	SAR (W/kg)
1.575	1.65×10^{-12}
2.45	5.7×10^{-11}
3.68	2.02×10^{-11}
5.37	2.65×10^{-11}

Performance of the antenna is also evaluated for different on-body mounting positions. Most logical placements at left belly, right belly, left chest, right chest and centre chest are studied. Reflection coefficient responses are compared and presented in Figure 4. The results show that varying position changes the antenna performance in terms of impedance matching due to change in the underlying body physique. However, the antenna maintains its operation successfully at 2.1 GHz and 5.3 GHz bands. Left and right placements at the similar position (i.e. belly and chest) brings no significant variation in the antenna performance.

B. On-body Channel Characterisation

In this section, the antenna performance is evaluated considering various on-body channels. The similar multiband antenna is used both as the transmitter and the receiver. The transmitter position is fixed at the right belly while the receiving antennas are rotated among left belly, right chest, centre chest, left chest, right knee and left knee as illustrated in Figure 5.

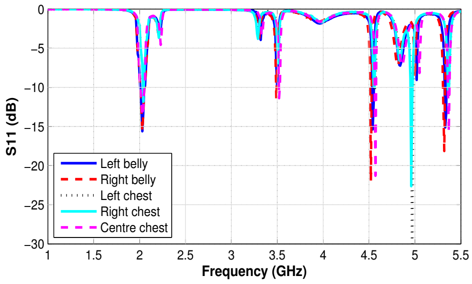

Fig. 4. Reflection coefficient response of the multiband microstrip patch antenna while placed at different on-body positions

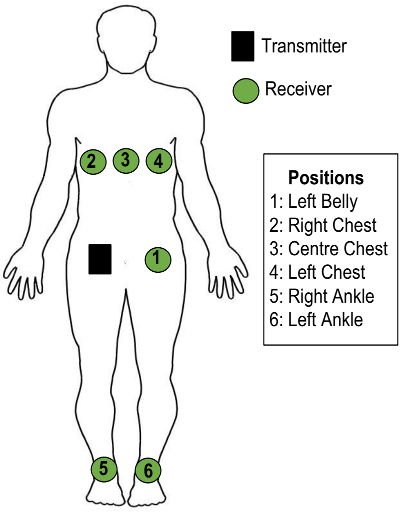

Fig. 5. On-body placements of the transmitting and receiving antennas for the characterisation of antenna performance in different on-body channels

The path gain curves are plotted and compared by observing S_{21} values. Figure 6 illustrates the path gain values for different on-body channels.

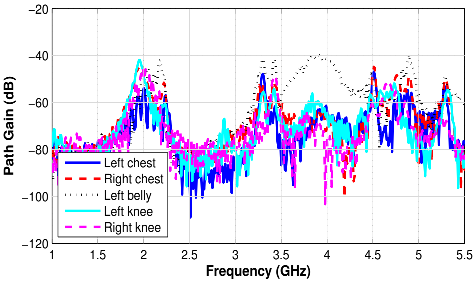

Fig. 6. Path gain response of the multiband microstrip patch antenna in different on-body channels

The results show that the path gain values lie between -42 dB to -50 dB for different on-body channels when the antenna is operating at 2.1 GHz. Path gain values are between -50 dB to -55 dB for the antenna operation at 5.3 GHz. It is evident from these results that the antenna establishes quite strong link at the two frequencies guaranteeing continuous and robust working of the overall monitoring system.

C. On-Off Body Channel Characterisation

Patient health monitoring systems require efficient channel performance between on-body and off-body antennas. Characterisation of on-off body channel is considered in this section. Both Line-of-sight (LOS) and Non-line-of-sight (NLOS) scenarios are studied which could happen if the patient moves. In LOS configuration, the two antennas are in a straight line, one transmitting while mounted on-body at right belly while the other receiving at a distance of 50 cm in front of the human body. In NLOS configuration, the receiving antenna is located in front of the centre chest. Distance between the body-mounted transmitter and the receiver is again 50 cm. The path gain values for the two scenarios are plotted in Figure 7.

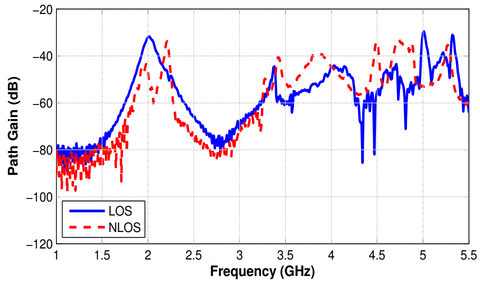

Fig. 7. Path gain performance of the multiband microstrip patch antenna in on-off body LOS and NLOS configurations

The presented results indicate that the performance of the antenna is good in both LOS and NLOS on-off body channels. For the LOS link, path gain value is observed to be -31 dB while this value is -42 dB for the NLOS link at 2.1 GHz. At 5.3 GHz, path gain value for LOS link appears to be -32 dB while for NLOS, this value is -37 dB. It shows that for on-off body channel, the antenna has potential to establish excellent link, much stronger than the on-body links.

IV. CONCLUSION

Performance of a multiband microstrip antenna is studied for on-off body scenarios. The results show that this simple antenna works well for different on-body placements, in different on- and on-off body channels. The antenna undergoes detuning when placed on-body. However, it maintains good performance at 2.1 GHz and 5.3 GHz frequency bands. The link performance at the two frequency bands of 2.1 GHz and 5.3 GHz lies between -42 dB to -55 dB for different on-body channels and between -31 dB to -42 dB for LOS and NLOS on-off body channels. The antenna also effectively meets the SAR limits set by the FCC. Consequently, this low profile antenna is a well-suited option for wireless health monitoring systems.

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