On-Body Antenna with Reconfigurable Radiation Pattern

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***Abstract*—On body antenna design is a challenging task due to the body being in the near-field of the antenna and the interaction between the two. The antenna should be designed to have a more application dependent gain pattern and to be less sensitive to near field effects of the body. For the case of on-body links, the antenna radiation should be directed along the body with an omni-directional pattern in horizontal plane of the antenna. It should preferably have vertical polarization. For the case of off-body links, the antenna radiation should be directed away from the body while the polarisation is not as critical as the on-body case. This paper presents a novel antenna design tackling the aforementioned challenges by exciting TM_{00} mode of a shorted rectangular patch antenna for the on-body link and exciting the TM_{01} mode for the off-body links. By means of a switching mechanism, either the on-body operation or the off-body operation is activated at 2.45 GHz with 64% and 75% efficiency respectively.**

***Index Terms*—Antenna radiation patterns, Patch antennas, Body sensor networks.**

I. Introduction

Body Area Networks (BAN) are inherently dynamic due to the mobility of people. In such dynamic scenarios, the network evolves to be more energy hungry in order to form high quality links. At the same time, battery lifetime is critical for BANs from user acceptance point of view. In order to improve the energy efficiency while maintaining the link quality, radiation pattern diversity can be exploited. For creating high quality links for both on-body and off-body operation of an on-body device or for creating dynamic links between an on-body device and an off-body device where the direction of arrival changes over time, radiation pattern can be reconfigured. The straight-forward solution of using an array of antennas for beamforming is not suitable for this case since space is a critical factor. Reconfigurability should be achieved with a single antenna; moreover, it should be unobtrusive due to ergonomic reasons. Therefore BANs are going to benefit a lot from a dual mode antenna where an on-body mode or an off-body mode which are suitable for the nature of the intended operation can be activated by means of a switch.

Placing the antenna in close proximity to human body typically distorts the radiation pattern, reduces the radiation efficiency due to absorption by the lossy tissue, shifts the resonant frequency and changes the matching [1][2]. Several different types of on-body antennas were proposed to tackle aforementioned problems. A comprehensive investigation on fabric patch antennas which are naturally suitable for body area networks was performed in [3]. A dual band wearable antenna in the shape of a button was proposed in [4]. A good examination of near body characteristics was given in [5] to investigate a PIFA near body. A disk loaded monopole was proposed in [6]. Performances of a monopole, a PIFA, a printed IFA, a printed loop and a printed dipole were evaluated in [7]. The monopole and the PIFA were found to be successful to form on-body links since they direct maximum radiation along the body surface and has the E field normal to the surface namely vertically polarized which matches to that of the surface wave [8] [6]. However all of these proposals focus on a single mode of operation. A compact multimode on-body antenna was proposed by [10]. It achieves 3 different modes in the horizontal plane, two being directional, one being omnidirectional. It utilizes a simple switching mechanism however all the modes are suitable for on-body communications only where there is no radiation in vertical direction. A multimode antenna achieving both on-body and off-body modes was proposed in [2] utilizing two radiators and a switching mechanism. It was shown to perform well near body surface although suffering from a comparatively thicker profile with three substrate layers. A similar multi-mode antenna where multiple radiators were stacked on top of each other was proposed for MIMO communications in [9]. Here a thinner profile multimode antenna exploiting two different modes of a single shorted patch radiator realizing both an on-body and an off-body mode is proposed.

TM_{00} mode of a shorted rectangular patch antenna generates an omni-directional radiation pattern. It is comparable to the TM_{01} mode that appears in shorted ring patch antennas which has been widely studied in the literature [11] [12] [13] unlike the shorted rectangular patch. The omnidirectional mode in the shorted rectangular patch antennas was studied in [14] where it was referred to as TM_m mode denoting the monopolar radiation pattern. Its application to BAN was studied in [2] and the performance of the antenna was compared with a conventional patch and a monopole antenna near body surface and shown to be suitable for the application.

Here a novel shorted rectangular patch antenna is proposed which generates the aforementioned omnidirectional mode in addition to the directional TM_{01} mode where one of which can be activated by means of a switching mechanism depending on the type of operation: on-body or off-body communications.

In Section II, the proposed antenna is detailed. The performance of the antenna is presented in Section III. Section IV illustrates the concluding remarks and future work.

II. Antenna Model

A novel on-body antenna is designed to operate at 2.4 GHz ISM band using HFSS and prototyped for validation. Its size

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is less than 0.5λ by 0.5λ and can be further miniaturized by dielectric loading. Fig. 1 shows the top, front and side views of the antenna. The patch is shorted to the ground plane at two symmetrical points. A microstrip line feed is located under its ground plane comprising a T junction of which branches excite the patch at two symmetrical points with a phase difference. By changing this phase difference between the excitation points hence the length of one leg using two switches as seen in Fig. 1, the modes are shifted in frequency domain.

The described structure generates two modes: TM_{00} and

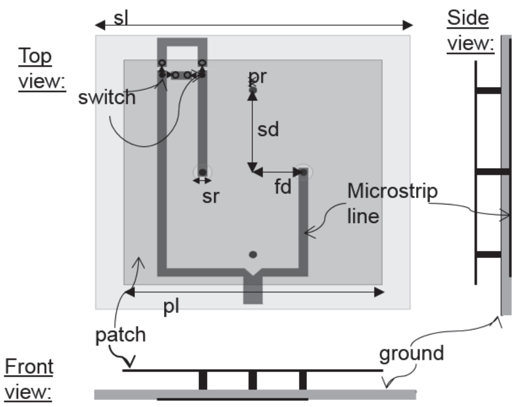
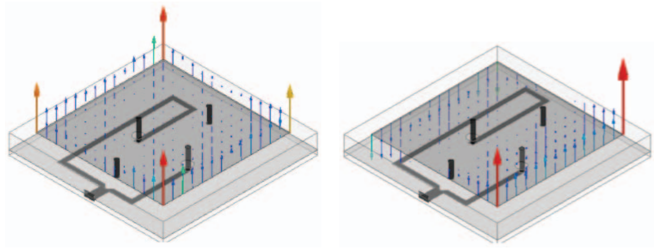


Fig. 1. Top, front and side view if the proposed dual mode antenna which comprises a switching mechanism to switch between two radiation modes: horizontally omnidirectional and broadside radiation

TM_{01} as seen in Fig. 2. Both modes exist simultaneously but they are not active at the same time. As seen in Fig. 2(b) the E field vectors are in opposite directions at the excitation points. Therefore in order to activate TM_{01} mode, the inputs from the symmetrical excitation points should be out of phase. Ideally the phase difference should be 180^0 and practically it should at least be more than 90^0 to activate the off-body link. During off-body operation, TM_{01} mode is resonant within 2.4 GHz ISM band while TM_{00} mode is detuned and at a lower frequency. Once the phase difference is less than 90^0, TM_{00} mode is resonant within 2.4 GHz ISM band whereas TM_{01} mode is at a higher frequency. The length of the longer branch should be at least $\lambda/4$ shorter so that the phase difference between the excitation points is less than 90^0. As the phase difference approaches 0^0, the radiation pattern gets more uniform along ϕ. For the on-body operation, there is minimal radiation in the vertical direction of the antenna which is a big advantage for on-body links. The energy is directed along the body so that the links between on-body devices are boosted. On the other hand, the antenna has a directive radiation pattern for off-body operation which is optimum for connecting to off-body gateways.

III. Performance Analysis

Parametric analysis have been performed in order to find the optimum dimensions for the antenna to operate at 2.4 GHz ISM band. As labelled in Fig. 1, the optimum dimensions are found to be as follows: patch length (pl) = 45 mm, substrate length (sl) = 50 mm, feed distance (fd) = 8 mm, short distance (sd) = 15 mm, pin radius (pr) = 0.64 mm and slot radius (sr) = 0.9 mm.



(a) (b)

Fig. 2. Vector E field distributions of TM_{00} (a) and TM_{01}(b) modes which support on-body and off-body operations respectively

The radiating patch is printed on 0.127 mm RT/duroid 5880 with $1/2$ oz (17μm) electro-deposited copper. The feeding is printed on 1.6 mm thick FR4 substrate with 1 oz (35μm) copper cladding. A 4.8 mm thick Eccosorb (polyethylene foam) by Emerson and Cuming is sandwiched between the two structures. Two different versions of the antenna were manufactured to generate the two modes. Note that the switching mechanism in order to realize the change in length is left out of the scope of this paper.

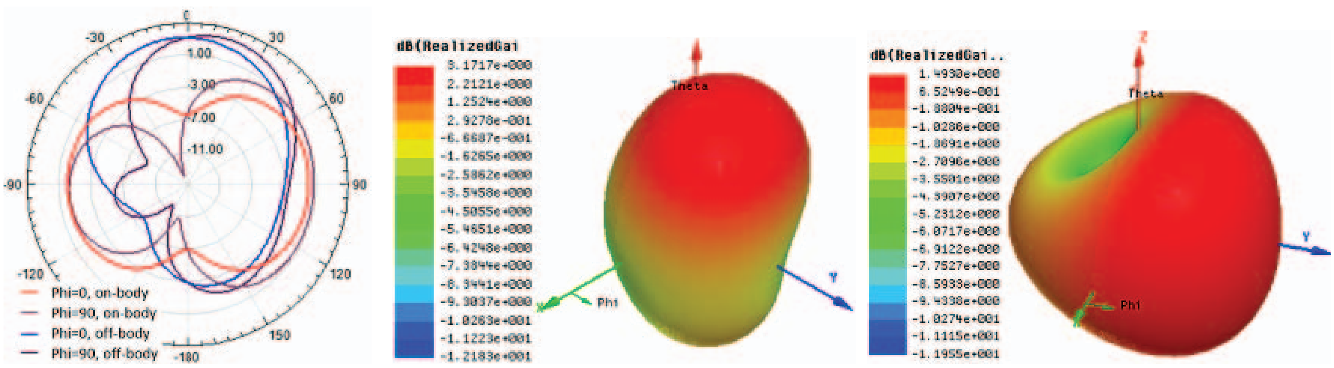
Simulated and measured frequency characteristics are plotted in Fig. 3. Although both modes cover 2.4 GHz ISM band in simulations, prototypes show that the operating frequencies are approximately 50 MHz higher than the simulated values. This could be due to manufacturing errors. Yet, good agreement between simulations and measurements has been observed in terms of matching and the occurrence of the modes in relation to each other.

The simulated 3D radiation patterns at the centre frequency of 2.45 GHz for each mode are plotted in Fig. 4. Realized maximum gain for the off-body operation is 3.1 dB and the half power beamwidth is approximately 100 degrees. On-body operation achieves an omnidirectional pattern with maximum 1.8 dB variation in the maximum directivity at $\theta = 90^0$.

IV. Conclusion and Future Work

A novel on-body antenna with switch-able radiation pattern is presented here. The antenna is capable of generating two distinct modes which can be activated using a switching mechanism in order to form an off-body or an on-body link efficiently. Radiation characteristics of the modes were analysed through HFSS simulations and shown to have good performance. In addition, better than 60% efficiency is predicted for each mode. The simulations are validated by measurements in terms of the frequency response. More than 10 dB Return Loss is measured for both modes with 100 MHz bandwidth.

The antenna is going to be further investigated by radiation pattern and efficiency measurements of the antenna in vacuum as well as on human body. The effects of human body on the performance will be explored in the future.



(a) (b) (c)

Fig. 4. Radiation patterns of different modes of the antenna in isolation at the resonant frequency: Fig.4(a) 2D Radiation Pattern of each mode at ϕ=0, Fig.4(b) 3D Radiation Pattern of the off-body mode, Fig.4(c) 3D Radiation Pattern of the on-body mode

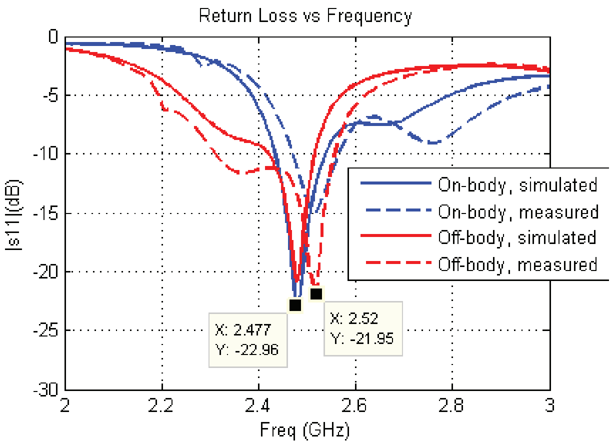


Fig. 3. $|s11|$ vs. frequency of the proposed antenna with 100 MHz Bandwidth for the off-body mode and 120 MHz Bandwidth for the on-body mode

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