A Switched Beam HSRR-Like Antenna for On/Off-Body Communication

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***Abstract*—This paper presents a dual-band electrically small antenna consisting of a one half of a split ring resonator (HSRR-like) which is located on a square ground. The antenna design allows the radiation pattern to switch between two orthogonal directions with respect to the ground plane depending on the frequency of the excitation signal at 950 MHz (lower resonance) and 2.25 GHz (upper resonance). The matching of the antenna to a 50-Ω line is reasonably acceptable where the measured reflection coefficients are better than -13 dB at both resonance frequencies. The simulated efficiency of the antenna at the lower and upper resonance frequencies are approximately 80% and 95%, respectively. Additionally, an estimation of the antenna gain (realized) obtained from simulation shows -0.5 and 1.2 dB, respectively for the lower and upper resonance, which are acceptable for a small antenna. The robustness of the radiation characteristics of the antenna is also investigated while situating the antenna on different parts of a volunteer's body when the reflection coefficients are measured over a frequency band ranging from 1 to 4 GHz.**

I. Introduction

Recently, wearable health monitoring devices have become widespread and are currently used in telemedicine [1]. Generally, health monitoring devices comprises a number of vital signs sensors (e.g., ECG, EEG and EMG) which are placed on different parts of patients' body, as schematically shown in Fig. 1. Usually, the sensors communicate the measured vital signs with a wearable device which is comfortably carried by patients. Typically, such wearable devices consist of essential components such as transceiver and microcontroller in addition to an antenna which is the bulkiest one. Therefore, the main obstacle in developing miniaturized wearable devices encounters the challenges associated with designing low-profile antennas without compromising the gain and efficiency. To date, a variety of small antenna prototypes comprising the modified microstrip patch [2], planar inverted-F (PIFA) antennas [3] in addition to a variety types of dielectric resonator antennas [4], were designed and reported in literature for off/on-body communication. In [5], an antenna consisting of a PIFA and a top-loaded monopole antenna for achieving on/off-body communication was realized where two perpendicular radiation modes are achieved.

Presented here is an antenna incorporating a one half of a split ring resonator (HSRR-like) operating at two orthogonal radiation modes which are controlled by the frequency of the excitation signal. In the proposed design, a single antenna is used to obtain off/on-body radiation unlike the design reported in Ref. [5]. Also, the proposed antenna uses a single excitation scheme as opposed to the antenna design reported in Ref. [6] in which a dual delta-patch antenna with two excitations is used for achieving on/off-body communication where the isolation between the radiation modes is a concern.

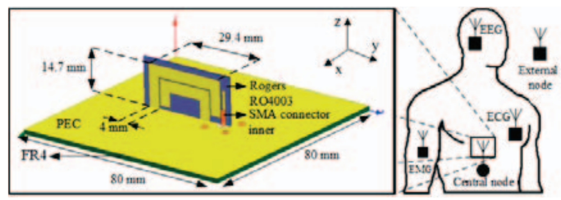


Fig. 1. Schematic showing the proposed HSRR-like antenna.

II. The Proposed HSRR-Like Antenna Design

Fig. 1 represents the schematic of the proposed antenna which is designed for achieving a switched beam capability. As it can be seen in Fig. 1, the antenna includes a one half of a split ring resonator operating at two different frequencies. At the lower resonance, the antenna radiates toward the broadside direction with respect to the ground plane, whereas an end-fire radiation is obtained at the upper resonance which is desired for on-body communication. In Fig. 2, the simulated and measured reflection coefficient results of the HSRR-like antenna in addition to a photograph of the antenna realization are shown. The resonance frequencies of the HSRR-like antenna are 950 MHz and 2.25 GHz, which have been selected slightly different from the ISM (Industrial, Scientific and Medical) frequencies of 915 MHz and 2.45 GHz to avoid interference with nearby devices operating at the mentioned ISM frequencies. The agreement between the simulation and measurement is acceptable, however, an approximate frequency shift of 10 MHz and 12 MHz, respectively, from the lower and upper resonance can be observed. The frequency shifts are mainly due to uncertainties in the fabrication of the antenna. It is also noteworthy to mention that the continuous reduction in the reflection coefficients in both simulation and measurement results (as shown Fig. 2) is believed to be due to the loss associated with the FR4 dielectric substrate used in the fabrication of the antenna. In Fig. 3, the radiation pattern

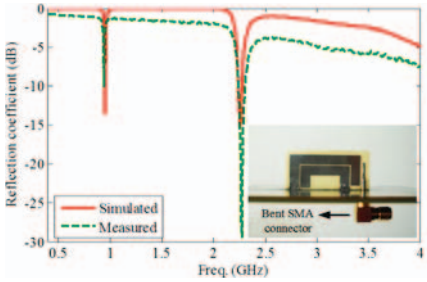
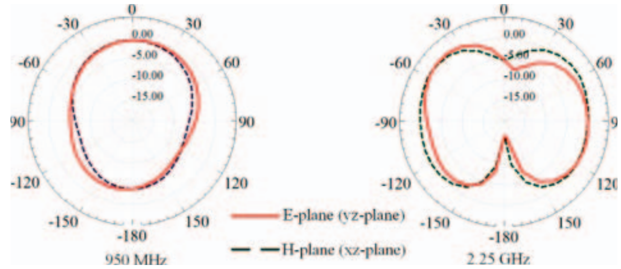
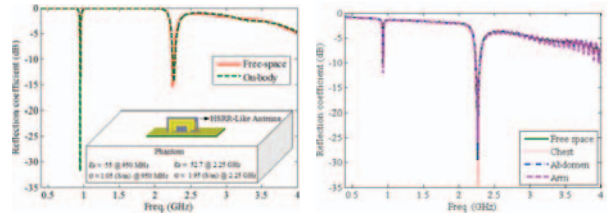


Fig. 2. Reflection coefficient of the HSRR-like antenna. Photograph of the fabricated antenna (side view) is shown in the inset figure.



(a) (b)

Fig. 3. Radiation pattern of the HSRR-like antenna, (a) 950 MHz, (b) 2.25 GHz.



(a) (b)

Fig. 4. Reflection coefficient of the HSRR-like antenna in the proximity of a volunteer's body, (a) Simulated, (b) Measured.

of the antenna for E-plane (yz-plane) and H-plane (xz-plane) is shown. The results indicate that the HSRR-like antenna at the resonance frequency of 950 MHz has the maximum total gain of approximately -.5 dB, while the estimated gain at 2.25 GHz is as high as 1.2 dB.

III. Evaluation Of The HSRR-Like Antenna In The Proximity Of The Human Body

In order to evaluate the performance of the antenna in the proximity of the human body, a phantom showing a similar electromagnetic characterization to the human body was used, as it is shown in the inset of Fig. 4(a). The phantom is a block of $20\times20\times5$ cm^3 having a relative permittivity and conductivity of 55 and 1.05 S/m, and 52.7 and 1.95 S/m, respectively, for 950 MHz and 2.25 GHz [7]. The results obtained from the simulation reveal that the proposed HSRR-like antenna is nearly insensitive to the loadings due to the proximity of the antenna to the phantom. Also, it can be seen in Fig. 4 that the resonance frequencies are seemingly unchanged compared to the measured ones in free-space. However, an improved level of the matching of the antenna to a 50-Ω line is observed which is due to loss of power in the human body model. As opposed to the lower resonance, the antenna matching condition at upper resonance remains similar to the its free-space counterpart, since the antenna shows a null in the broadside direction due to its radiation pattern (Fig. 3(b)). Lastly, the antenna reflection coefficient was measured when it was situated on different parts of a volunteer's body as it is schematically shown in Fig. 1. Figure 4(b) shows the measured reflection coefficient of the antenna when it is placed on the human body. As the obtained results reveal, the antenna resonances maintained unchanged compared to the measurement performed in free-space.

IV. Conclusions

In this paper, a HSRR-like antenna featuring beam switching characteristic, which is controlled by the excitation frequency, was introduced. The antenna radiation pattern can be switched for off/on-body communication at 950 MHz (lower resonance) and 2.25 GHz (upper resonance), respectively. At the lower resonance, the antenna radiates the fields perpendicular to its ground plane (off-body mode) where the measured reflection coefficient is better than -13 dB. Whereas, the radiation pattern at the resonance frequency of 2.25 GHz is along the ground plane (on-body mode), perpendicular to its counterpart at 950 MHz. The matching of the antenna to a 50-Ω line is approximately -15 dB which is close to the value obtained from simulation. The simulated values of the antenna efficiency at the lower and upper resonances are approximately 80% and 95%, respectively. The performance evaluation of the antenna in the vicinity of the human body was numerically and experimentally investigated. The obtained results revealed that the antenna is almost robust to the loading of the human body at the both resonances. It is also noteworthy to mention that due to the perspective application for the proposed antenna, it can be protected from physical damage and deformations by adding a miniaturized radome to its structure, however, the antenna needs to be redesigned.

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