Wearable Sensor Antenna For Through-Body Communication In Medical Monitoring Systems

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***Abstract*—In the health care field, areliable connectivity between the Body Centric Wireless Communication (BCWC) sensor nodes is vital to patient health monitoring. Investigations in the previous studies revealed that the radiators for wearable and implantable nodes need to work efficiently even in the presence of the human body. For a wearable antenna maintaining an off-body communication, high directivity in the direction away from the body is the most important factors. To achieve this goal, real or virtual isolation from the human body is preferable, which reduces the detuning and mismatching factor due to the body. For implantable antenna the directivity is of a secondary importance, while the matching when an antenna is covered in a given tissue is vital. For a wearable sensor antenna intended for an efficient communication with an implantable antenna or another node present on any part of the body, both, the directivity as well as impedance miss-matching needs equal consideration.**

In this study, a wearable antenna for BCWC sensor node (referred to in this study as a wearable sensor antenna) is discussed, designed to work reliably for communication with an implantable antenna. This completes the link between body implant, and off-body receiver, communicating with each other via wearable node. This work presents a simulation test-bench to investigate the antenna detuning, impedance mismatch and losses in through-body communications. The results indicate that the proposed test-bench is found to be an insightful tool for antenna optimization, and reliable through body communication environment modeling.

Keywords— wearable sensor antenna, body communication, Medical Monitoring Systems

I. INTRODUCTION

An antenna designed for operation in free space, will not radiate efficiently when it operates near the human body. This phenomenon is more intense when the antenna is part of a wearable sensor establishing communication with an implantable antenna placed inside the body.

Since the main beam direction of the wearable sensor antenna (which can be a part of textile [1, 2] needs to be towards the body, reflections from the body can influence the radiation practice of the antenna. A wearable sensor antenna guided by recent progression in valuable radiators for microwave imaging [3] is given. Some of these antennas are planned on rigid substrates that are not tailored to the body curvatures, nevertheless, microwave substrates that are intended to be utilized as wearable sensor needed to be as malleable and as elastic as possible. Considering this factor, the antenna is planned on Roger's RT Duriod 5880 due to its small $\mathcal{E}_r$ and flexibility. Figure 1(a) illustrates the antenna design and schematic measurements.

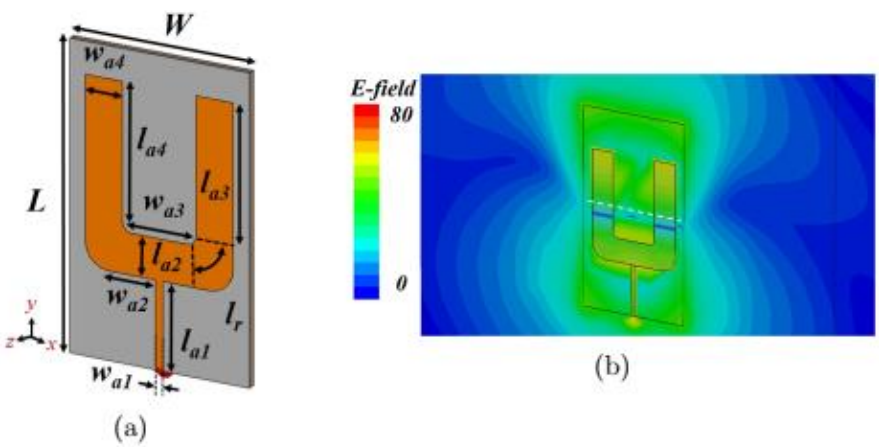


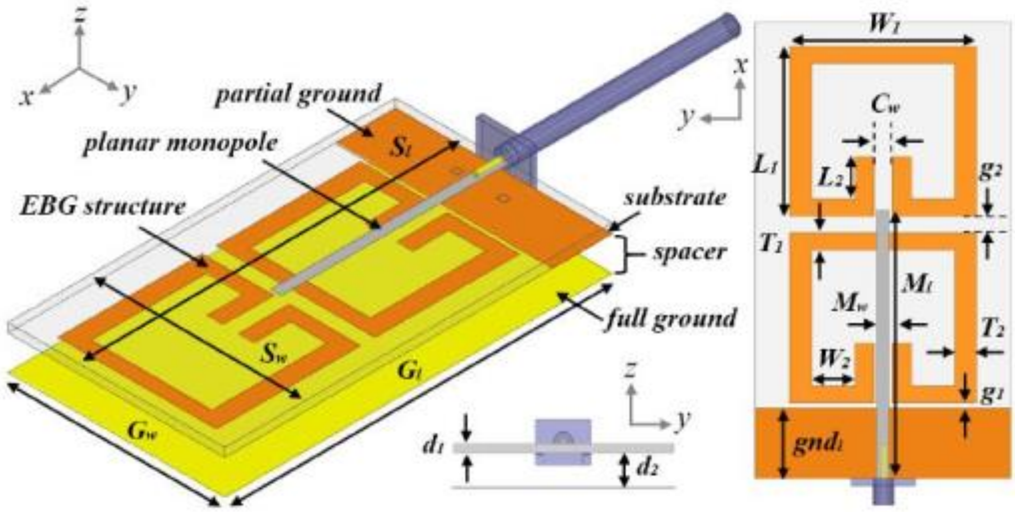
Fig. 1: (a) Diagrammatic of a wearable sensor antenna while L = 70, W = 38, w_{a1} = 2.05, w_{a2} = 10.25, w_{a3} = 7.33, w_{a4} = 8.34, l_{a1} = 22.60, l_{a2} = 10.50, l_{a3} = l_{a4} = 32.89 (all measurements are in mm) (b) Normalized E-field arrangements.

Cavity backed radiators at [3, 4, 5, 6, 7, 8] have been broadly utilized in the microwave imaging appliance due to high directivity and steady s-parameters. This is accomplished by delivering the propagating wave along the +*z*-direction.

II. MATERIALS AND METHODS

A. Antenna design

The basic point of planning was a cavity backed, fork designed antenna. It was noticed that the existence of the cavity has a strong effect on the low-profile character of an antenna working at 2.45 GHz ISM band and contributes to be wearable. To keep low-profile with the wanted directivity, a grounded planar antenna operating initially on micro-strip patch assumption was planned. It is necessary to report that the overall board measurements of the wearable sensor antenna are $G_l \times G_w$ from Figure 2. The main reason for selecting these dimensions is to be able to eventually integrate the two antennas as a single wearable sensor unit. A fork-shaped radiator is designed which is comprised of a planar base connected to two legs via curved micro-strip section.



(a) **(b)**

Fig. 2: (a) Configuration of the 2×1 EBG-backed planar monopole antenna with full ground (b) Top view of the monopole and finite sized EBG layer. The antenna is fabricated on semi -flexible Rogers RT/duroid 5880 substrates with $\varepsilon_r = 2.2$ and tanδ = 0.0009. C 2016 IEEE.

The transmission line width w_{a1} and the curvature of l_r is mainly responsible for an efficient impedance matching between the input port of the antenna and the radiating section. The principle of operation of the antenna lies in the fact that the fork-shaped radiator lengths along the *y*-axis ($l_{a2} + l_{a4}$) is 43.39*mm* which is close to $\lambda_{eff}/\ 2 \approx 44{:}75mm$. In other words, the radiator hosts a $\lambda_{eff}/\ 2$ wave, efficiently leaving the surface of the antenna. The maximum energy transmission from the antenna to the human body resides at the antenna physical center. This enables a realizable alternative of creating a cavity in the back side of a radiator. The principle of operation can further be verified by Figure 1(b) where the EM wave *E*-field null can be seen to be approximately at the physical center of the fork-shaped radiator. Figure 3(a) presents the antenna impedance matching response when it is placed almost on top of the human body phantom (initial optimization was done on chest region). Figure 4 shows the proposed system model and the device architecture for good connectivity among an external off-body transceiver and a body implant for an undisturbed patient's physiological measurement monitoring. The system consists of the EBG backed monopole antenna, transmitting/receiving signal from the off-body transceiver. The signal is to be processed at the wearable sensor node and transmitted via the wearable sensor antenna to the implantable antenna after an added (repeater) gain.

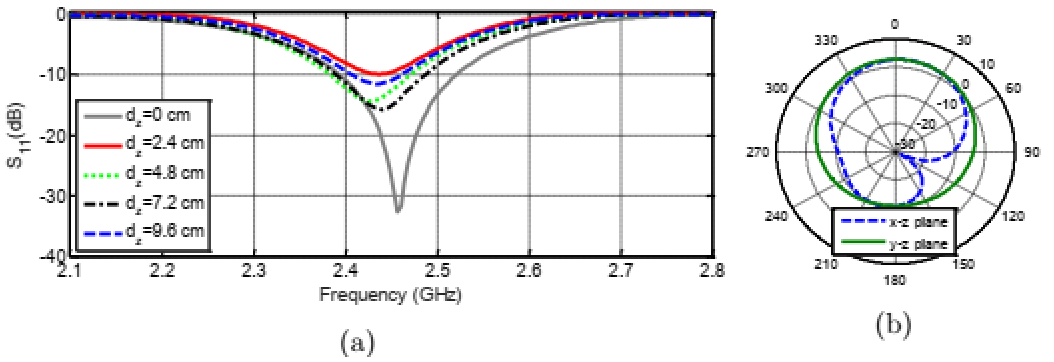


Fig. 3: (a) Simulated S_{21} when the antenna is placed on the chest and moved away from the body. (b) 2D gain plot

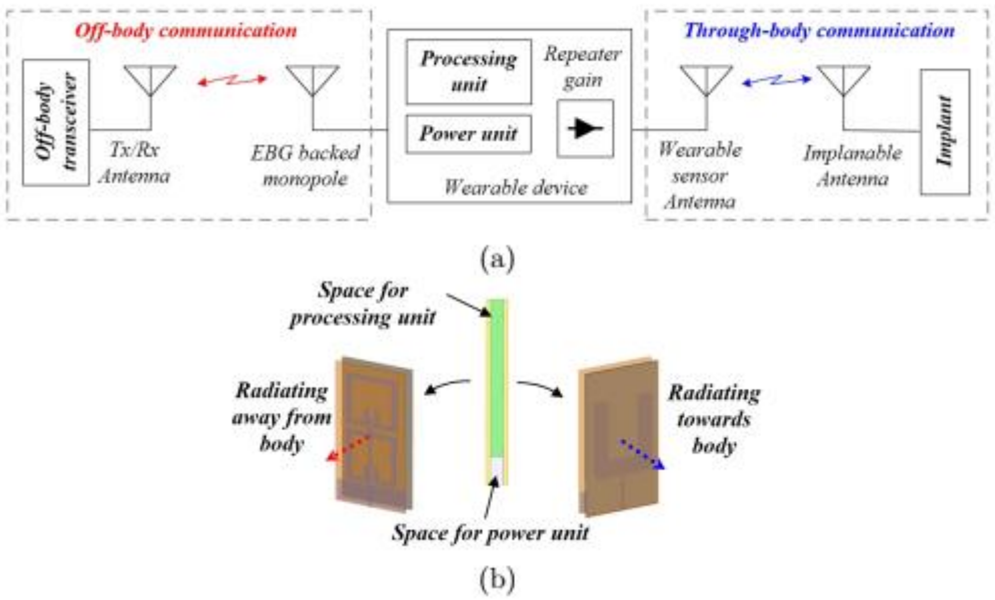


Fig. 4: (a) System level block diagram of implantable to outside-body transceiver connectivity via wearable node (b) Wearable device architecture representing the operational principle when two antennas radiate in the opposite directions.

The EBG backed monopole antenna is efficient for off-body communication and it needs a full ground plane to operate effectively. This full ground plane is to host a wearable sensor antenna facing towards the opposite direction as compared to the EBG backed monopole antenna forming the proposed wearable sensor architecture. The spacer between EBG surface and the full ground plane can be readily used to host the electronic components of a sensor node (which may include a power management unit, processing unit and circuit board hosting electronic components). It is advised to keep the power unit among the 2 metallic ground plates ($G_l \times G_w$ and $gndl \times S_w$) so that it has a minimum impact on the radiation performance of both antennas. An important condition that must apply in the implementation of the proposed architecture is that both the antennas should be re-optimized in the presence of the entire system governed by the principles of operation in their respective design guideline sections.

B. Methodology

The simulated results indicate the antenna covers an entire 2.45 GHz ISM band when placed at the right upper part of the body. An inevitable mismatch can be observed when the antenna is moved away from the human body, however, it is not severe. Most importantly, the antenna detuning factor is negligible when it is moved away from the body ($dz > 0mm$). The antenna gain patterns simulated by normalizing the input impedance port to 50 Ω are given in Figure 3(b). The reason of normalizing is that when the antenna is placed on body phantom and simulated in EM simulator, the background material in the antenna surroundings are considered a part of a radiator, which impacts the accuracy of the simulations. A reliable method is to calculate far field patterns in free space without considering the impedance mismatch impact which will occur when the given antenna is moved away from the body. The patterns are very close to standard micro-strip patch antenna while the peak gain is 3.41 dBi. The mentioned properties make the proposed antenna fit for through body communication with an implant at 2.45 GHz even at a distance of multiple centimeters from the body.

A comprehensive numerical body pattern was utilized in the simulations to practically resembling an actual life scenario for the examination of the wearable sensor antenna act. Because the wearable sensor antenna is an assumed to always operate towards the body, and is principally segregated from the EBG backed monopole antenna, just the procedure of wearable sensor antenna is explained in this research, supposing that it will behave the same way as a part of entire system presented in Figure 4. The performance of wearable sensor antenna was optimized when it was placed on top of the realistic body phantom in the thoracic region. Note that the metallic antenna layer was not in direct contact with the tissue muscles. This study presents a simulation test-bench to investigate the antenna detuning, impedance mismatch, and losses in through-body communications. These parameters are relevant to the efficient design of wearable and implantable antennas for biomedical sensors.

The study was carried out using finite-difference-time-domain electromagnetic simulations using realistic high-resolution numerical human body Cirs phantom models presented in Figure 5 a, and b.

(a) (b)

Fig. 5: (a), and (b), realistic high-resolution numerical human body Cirs phantom models

Fig. 6: The realistic human body phantom

S-parameter measurement corresponding to the simulation setup was carried out when an implantable antenna connected to port two was placed in the armpit of a realistic human body phantom (figure 6), and communication was established with an external wearable antenna connected to port 1.

The 1st benefit of this setup is the suitability of situation an electrically small antenna. The 2nd benefit is that the axillary area incorporates a mixture of tissues (muscle, vessels, lymph nodes, fat, and skin) with specific dielectric characteristics which are haphazardly distributed, and thus, insightful for the work of through-body wave propagation. The disadvantage is the requirement of high computational resources needed for the simulations.

III. RESULTS and DISCUSSION

Kiourti et al. [9] discussed in his study that the initial antenna testing was done in minced pork meat as its electrical properties resemble human muscle, and skin tissue between 100 MHz and 3 GHz [9]. In this study, the implantable antenna was placed in the axilla section on the realistic human body phantom while the wearable sensor antenna was placed at d_z = 1 cm from the arm's surface. The results presented in Figure 7 indicate a small frequency shift, which disturb the impedance bandwidth of both the antennas, nonetheless the simulated S_{11} and S_{22} remained below -10 dB at 2.45 GHz ISM band.

The time-varying electric fields in the full-wave simulator depicted valuable information of the wave propagation through the complex heterogeneous tissues. It was observed that the communication between the wearable sensor antenna and the implantable antenna mainly relied on the diffracted and reflected signals propagating through the tissues. Even though the wave propagation was almost blocked by the presence of the bone tissues in the arm, however, the wave diffracting and creeping along the bone tissues reached the implantable antenna.

VI. CONCLUSIONS

The results indicate that the proposed test-bench is found to be an insightful tool for antenna optimization and reliable through body communication environment modeling. Future work will optimize the test-bed to be representative of the broad range of human tissue compositions of the human population, which impact the antennas and propagation performance of wearable wireless sensor systems.

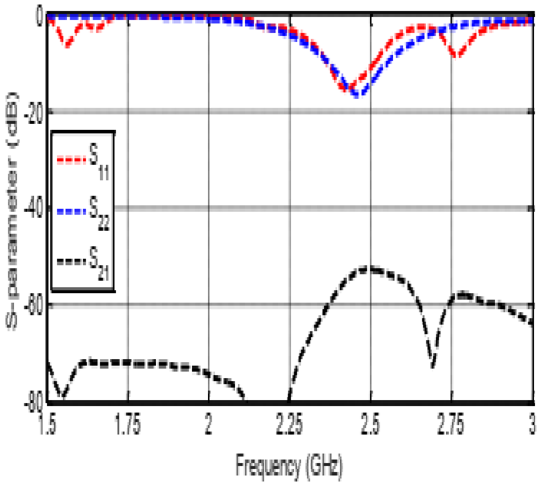


Fig. 7: Small frequency shift, which disturbs the impedance bandwidth of both the antennas, the simulated S_{11} and S_{22} remained below -10 dB at 2.45 GHz ISM band

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