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A Compact Wearable Slot Antenna for LTE and WLAN Applications

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Abstract**—**In this paper, a compact wide-band, ultra-thin and flexible slot antenna intended for wearable applications is presented. The presented antenna is designed to provide Wireless Local Area Network (WLAN) and Long Term Evolution (LTE) connectivity. The presented design exhibits a relatively wide bandwidth (1600-3500 MHz below -6 dB impedance bandwidth limit). The antenna is positioned on a 33 mm x 30 mm flexible substrate with a thickness of 50 µm. Antenna properties, such as the far-field radiation patterns, scattering parameter S_{11} are provided. The presented compact, thin and flexible design along with excellent radiation characteristics are deemed suitable for integration into flexible and wearable devices.

Keywords**—**Wearable Electronics, Slot Antenna, LTE, WLAN.

I. INTRODUCTION

RECENT years have witnessed significant research activities in the field of wearable computing. It has been recently estimated that there are around 1500 worldwide research groups working on diverse topics related to wearable technology [1]. The unique characteristics of wearable computers and electronics have tremendously expanded the spectrum of modern electronics and digital systems. Obviously, the success of wearable electronic systems is heavily dependent on the integrated wireless communication component since one of the most important attributes of wearable computers is mobility and portability. Hence, most wearable computers require antennas operating in specific frequency bands to ensure continuous wireless connectivity [2]. Obviously, the efficiency of such systems directly depends on the properties of the integrated antenna which is typically required to be compact, light-weight, flexible, and mechanically robust. Moreover, they are desired to exhibit high radiation efficiency with specific directivity characteristics [3].

In most of current wearable computing systems, different types of sensors and actuators are connected to a low power microprocessor which in turn communicates with a network through a radio module which is usually low-power and is based on one of the short range wireless schemes such as Bluetooth and ZigBee [4]. On the other hand, WLAN is recognized as the most common solution for wireless connectivity. In addition to WLAN, the relatively new technology in mobile wireless communication is operated at the LTE which is dedicated for voice and data transmissions [5].

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In the past decade, numerous design approaches for wearable antennas have been reported in the literature which are based on different platforms. Antennas based on electro-textiles seem to be a reasonable solution for wearable computers, especially for integration within garments. However, their substrate materials are subject to discontinuities and fluid absorption [6]. The same is true for paper-based platforms since they have high loss factor which compromises the efficiency of the antenna [7].

In [8], a 50 mm × 19 mm textile based Printed Inverted F Antenna prototyped using an electrically conductive textile is proposed for Wireless Body Area Network (WBAN). The presented antenna exhibited a relatively large impedance bandwidth, and good radiation efficiency; however, its relatively high-profile attribute is considered high for the targeted application. Furthermore, it consists of multiple layers which complicates the manufacturing process. It is also worth mentioning that planar monopole radiators have gained much attention over other antenna platforms due to their large bandwidth, low thickness, easy manufacturing process, and omni-directionality [9]. Conventional microstrip antennas, on the other hand, are not the optimal choice for wearable computers since their bandwidth is a function of the substrate's thickness [10].

In this paper, an ultra-thin, compact, and flexible slot antenna is presented. The antenna exhibits a wide bandwidth which covers the LTE and WLAN bands (1600-3500 MHz).

As a substrate for the antenna presented in this paper, Kapton Polyimide film was selected due to its desirable physical and chemical characteristics, and electromagnetic properties with a low loss tangent across a wide frequency spectrum (tan δ =0.002). Moreover, Kapton Polyimide substrates are available at very low thicknesses and offer a tensile strength of 165 MPa at 73 °F. It also exhibits a dielectric tolerance of 3500-7000 volts/mil, and a thermal endurance of -65 to 150 °C [11].

In Section II, the design of the presented slot antenna is presented. In Section III, detailed description of the antenna`s performance is discussed. Finally, conclusions are given in Section IV.

II. ANTENNA DESIGN

Design and simulation of the presented wearable slot antenna have been carried out using the 3D full wave electromagnetic simulation package CST Microwave Studio which is based on the Finite Integration Technique (FIT) [12].

Slot antennas have received attention by the wireless design community due to their planar platform and large bandwidth

[13]. Hence, it has been adopted in this research since it would be a reasonable candidate for wearable and flexible applications. For WLAN and LTE technologies, slot antennas are preferred due to their relatively wide impedance bandwidth, low profile, reduced fabrication complexity due to their single layer deposition.

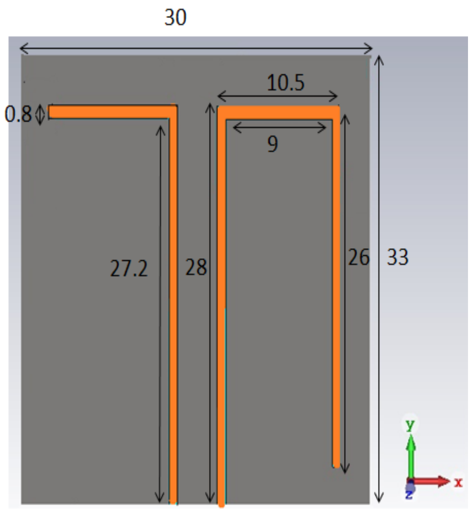

Fig. 1 Geometry and dimensions of the proposed wideband slot antenna (the grey shaded area represents the metallization)

As shown in Fig. 1, the antenna consists of a winding slot (represented by the orange shade), etched out from a single layer metallization (grey shade). This winding gives rise to a miniaturized structure since it lengthens the current path. The antenna structure is positioned over a 30 mm × 33 mm polyimide substrate with permittivity of 3.4, loss tangent of 0.002, and thickness of 50.8 µm.

III. Performance

As can be seen in Fig. 2, the maximum simulated return loss for the antenna is around 16.8 dB at 2.05 GHz, with a -10 dB bandwidth of 900 MHz ranging from 1600 to 3500 MHz. The principal planes (E and H) were also simulated using CST microwave studio package. E-plane (*YZ* cut) and H-plane (*XZ* cut) far-field radiation patterns for the proposed antenna at 2.45 GHz are depicted in Fig. 3. It can be seen that the radiation pattern is omni-directional at 2.45 GHz (which can be considered as the central frequency. The antenna achieved gains of 3.28 dBi at 2.45 GHz, which is slightly larger than a typical value for antennas with omni-directional radiation pattern. It is also worth noting that the antenna is intended for low-power applications, hence, the user is not expected to be exposed to harmful levels of thermal effects due to electromagnetic radiation.

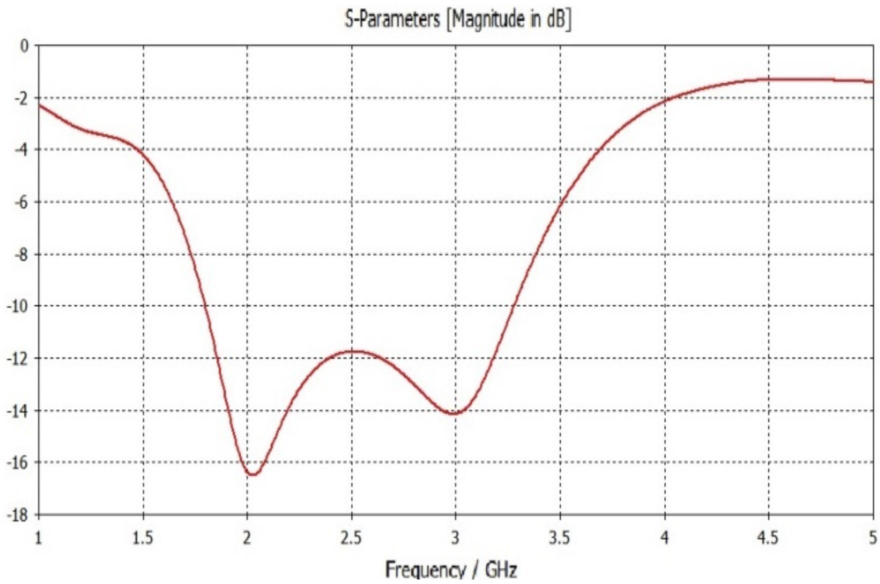

Fig. 2 Simulated reflection coefficient S11 for the proposed slot antenna

Previously, we proposed an Artificial Magnetic Conductor (AMC) antenna design based on the same material used in the current design (Kapton Polyimide). The design was intended for integration within wearable cellular-based telemedicine systems [10]. The main objective of the design was to reduce Specific Absorption Rate (SAR) which is crucial to minimize the potentially hazardous exposure to electromagnetic waves in applications that use moderate to high transmission power [14]-[21]. The antenna design for these systems presents a particularly challenging task due to the orientation of the antenna on the human body [22], [23]. In typical antenna designs, the designer is not constrained by such requirements as Specific Absorption Rate (SAR), substrate flexing, and impedance changes due to human body proximity. The human body is also difficult to model. Each tissue layer, each muscle, bone, and blood vessel presents a heterogeneous lossy structure that is difficult to model [24]-[26]. Humans are also unique, so one antenna that is designed to be a pace-maker

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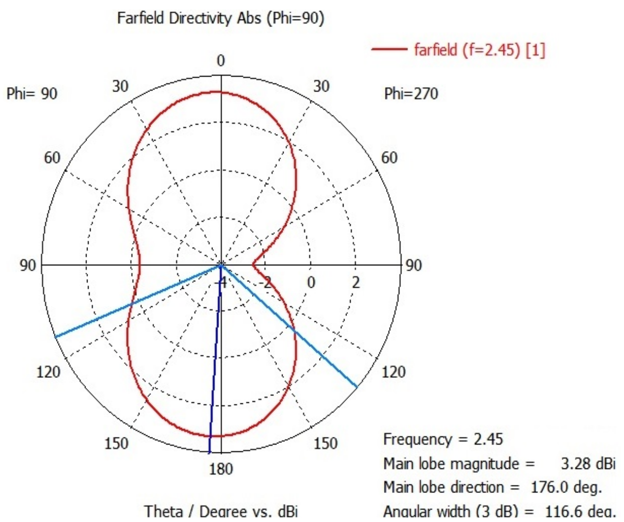
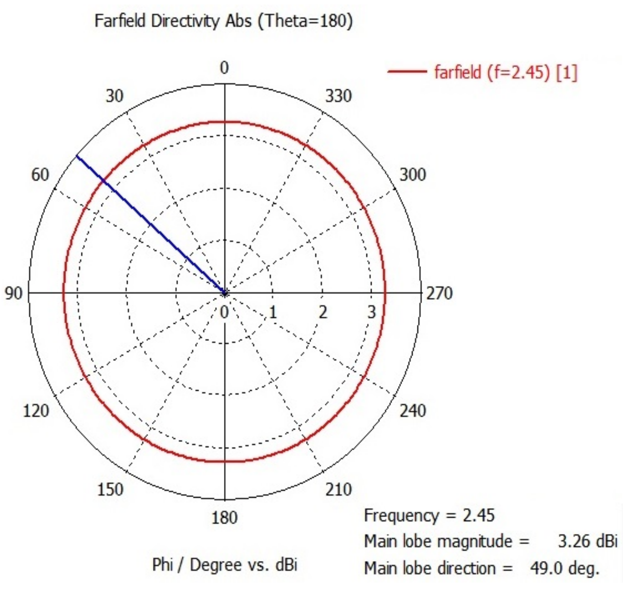
communication radio for one human may work differently than another, based on differences in weight, gender, or other physiological differences. In order to be completely thorough, each layer of tissue should be accounted for in the antenna model. This may not be realistic to accomplish or feasible in real world scenarios and sometimes there is no replacement for empirical results, however, Lim et al have looked closely at developing a human body model that is useful for characterization of communication radio systems for WBANs [27], [28]. Their work demonstrates that for propagation along the surface of tissues such as down an arm, the differences in a numerical model that take into consideration such features as skin, fat, muscle, etc. do not have such a profound effect on the outcome.



(a)



(b)

Fig. 3 Simulated (a) E-plane (*YZ*) and (b) H-plane (*XZ*) radiation patterns for the proposed slot antenna at 2.45 GHz

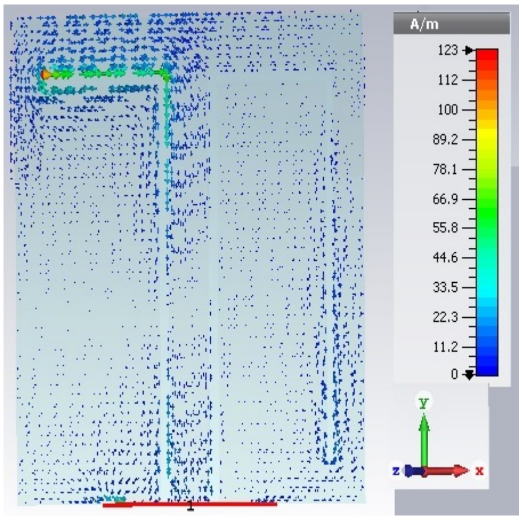


Fig. 4 Simulated surface current distribution for the proposed slot antenna at 2.45 GHz

The presented antenna was simulated for SAR using the HUGO numerical human model for 10 mW and the exhibited SAR was 0.327 W/Kg which is below the limit (1.6 W/Kg) specified by the FCC.

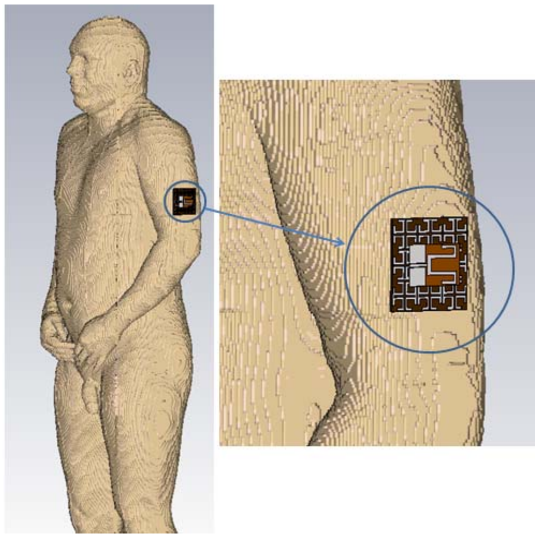


Fig. 5 Numerical Human model (HUGO) used for Specific Absorption Rate assessment of the proposed wearable slot antenna design [10]

IV. Conclusion

In this paper, the design of flexible and compact printed wide-band slot antenna is discussed in details. The reported design is based on an ultra-thin substrate. Flexibility, compactness, mechanical robustness, and relatively easy fabrication, in addition to desirable radiation characteristics exhibited by the antenna suggest that the proposed design is a reasonable candidate for integration within wearable computing devices that support WLAN and LTE connectivity. Moreover, the calculated SAR values for the proposed wearable slot antenna were very low (0.327 W/Kg) which is

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below the limit (1.6 W/Kg) specified by the Federal Communications Committee requirements.

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