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Flexible Antenna on Polymer-Conductive Textile Composite for Epidermal Electronics

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Abstract—In this paper, we investigate the applicability of polydimethylsiloxane (PDMS)-conductive textile composite for realization of a robust flexible antenna for skin-mounted applications. For this purpose, we present the design, manufacture, and testing of an ultra high frequency (UHF) 868 MHz loop antenna with the specified material. The antenna performance has been investigated through simulations and measurements on a human forearm phantom. Apart from having a low-profile implementation and being mechanically flexible, and thus comfortable for on-skin use, the novel antenna presented demonstrates a wide operating bandwidth with acceptable gain for epidermal electronics.

I. INTRODUCTION

Epidermal electronics have been emerging as one of the most promising solutions for a truly unobtrusive human-centric wireless communication system. Mimicking the relevant properties of human skin, this technology enables an intimate, seamless, and comfortable interface to the soft outer surface of a human body. This opens up possibilities for various different applications in human-centric systems, including real-time health monitoring, activity tracking, clinical diagnostics and human-machine interfaces [1]. To enable such diverse use-cases, research efforts in these various directions necessitate very different approaches in terms of complex materials and fabrication strategies required. In particular, this applies to the realization of epidermal antennas as one of the key enabling technologies for wireless epidermal electronics.

Polydimethylsiloxane (PDMS) is a class of polymer which has been seen as an attractive solution for the development of flexible and stretchable electronics including antenna, owing to its unique characteristics in terms of flexibility, biocompatibility, and dielectric properties [2]. A particular challenge associated with the use of PDMS as a microelectronics substrate is its inherently weak adhesion to metal which complicates the integration of the antenna conductive parts. Recently the authors have demonstrated a relatively simple yet effective solution to address the above issue, using a combination of commercial conductive textile and PDMS [2]. In this paper, we extend the work by investigating the possibility of applying PDMS-conductive textile composite for a simple realization of epidermal antenna for skin-mounted wireless applications.

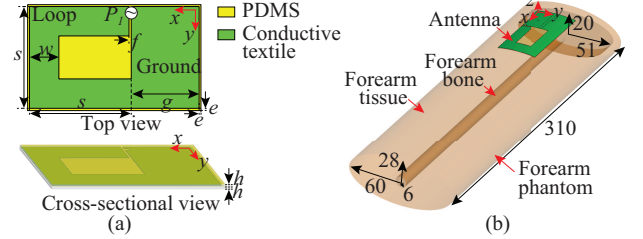


Fig. 1: (a) Antenna topology with final dimensions: $s = 45$, $g = 30$, $w = 13$, $f = 1$, $e = 0.5$, $h = 0.5$. (b) EM simulation setup with antenna placed on a forearm phantom. All units in the figure are in millimeter.

II. ANTENNA DESIGN AND PROTOTYPE

For the purpose of this study, an antenna intended for arm-worn wireless sensing applications in the emerging long-range wide area network (LoRaWAN) 868 MHz (863–870 MHz) in Europe, is designed. Fig. 1 depicts the topology of the proposed antenna, which is a modified version of a rectangular loop antenna with ground plane to enable better control on the impedance matching. The antenna is fed with an unbalanced port at P_1 . The antenna conductor ($t = 0.08$ mm) is made of a conductive textile, nickel-copper coated ripstop from Less EMF Inc., which is embedded inside a 1-mm thick PDMS dielectric layer. As the initial state of PDMS is liquid, it is feasible to further reduce the PDMS thickness during manufacturing process for an even higher mechanical compatibility to the skin. In simulation, the electrical properties of the PDMS were specified as $\epsilon_r = 2.8$ and $\tan \delta = 0.01$, while the conductive textile was modelled with a conductivity of $\sigma = 5.4 \times 10^4$ S/m derived from [2].

Optimization of the antenna dimensions was conducted through full-wave electromagnetic (EM) simulation using ANSYS HFSS to maximize the antenna gain and impedance matching across the 868 MHz band. The final dimensions of the antenna are listed in the caption of Fig. 1(a). The optimization process was carried out with the antenna placed directly on a forearm phantom, structured as a double-layer cylinder as shown in Fig. 1(b), mimicking the SHO-GFPC-V1 forearm phantom from SPEAG [3] used in the antenna measurement. The forearm tissue was modeled with $\epsilon_r = 30$ and $\sigma = 0.7$ S/m, whereas the forearm bone was modeled with $\epsilon_r = 30$ and $\sigma = 2.5$ S/m. Both values are based on the averaged



Fig. 2: Fabricated antenna prototype: (a) Top view. (b) Folded antenna demonstrating its flexibility.

electrical properties of forearm at 868 MHz according to the SPEAG phantom datasheet [3]. It was observed in the simulation that the antenna gain is mainly determined by the overall aperture of the loop (s); while the antenna matching is mainly controlled by the width of the loop and ground (w and g). However, counter intuitive to the case of a loop antenna in free space, a bell-shaped characteristic was observed in the gain performance as the loop aperture progressively increases. Such phenomenon was also reported recently in [4], indicating counteracting phenomenons between the radiation resistance and power dissipation of an epidermal antenna as the antenna size increases.

Fig. 2 shows the photograph of the antenna prototype, which was developed by means of a layer-by-layer process as described in [2]. For measurement purposes, a U. FL connector is used at the feed point, attached with a conductive silver epoxy after partly removing the top PDMS layer to expose the conductive element.

III. ANTENNA PERFORMANCE

Fig. 3(a) shows the simulated and measured reflection coefficient ($|S_{11}|$) of the antenna placed on the forearm phantom, with results in good agreement showing a 10-dB return loss bandwidth of greater than 1 GHz. Slight discrepancy in the results is likely due to manual fabrication inaccuracies. The simulated far-field performance of the antenna at 868 MHz (Fig. 3(b)) shows a peak realized gain of -13.7 dBi with 2% radiation efficiency, which is within the typical performance range of an epidermal antenna with the radiator located 0.5 mm distance from the body [4].

Transmission measurement between the fabricated antenna placed on phantom and a commercial UHF whip antenna [5] was also conducted as illustrated in Fig. 4(a). To demonstrate the applicability of the developed epidermal antenna, the results are compared with the case when an identical commercial whip antenna was used on the phantom replacing the epidermal antenna. The measured S-parameter results are given in Fig. 4(b). As can be seen, with the epidermal antenna, the transmission coefficient ($|S_{12}|$) level at the resonance of the whip (i.e., 950 MHz) is only 4.1 dB lower. Concurrently, the developed epidermal antenna comes with many mechanical advantages (e.g., being very thin, highly flexible, water resistant, biocompatible, and lightweight), which makes it more suitable for direct integration to skin for epidermal electronics.

IV. CONCLUSION

This paper presents the design, implementation, and testing of PDMS-conductive textile composite for epidermal antenna.

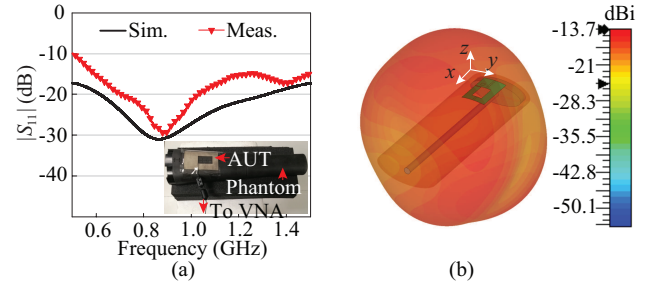


Fig. 3: (a) $|S_{11}|$ of the antenna when placed on phantom. The inset shows the antenna measurement setup with SPEAG forearm phantom. (b) Simulated radiation pattern of the antenna at 868 MHz.

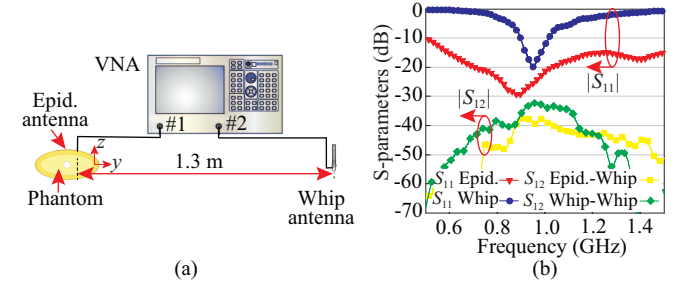


Fig. 4: (a) Transmission measurement setup. (b) Measured S-parameters.

The antenna performance, including the transmission tests with a commercial whip antenna, demonstrates the applicability of the developed antenna for epidermal electronics. Further studies incorporating the epidermal antenna with a wireless module to evaluate its performance in real wireless scenario are planned as a future work.

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