

# A Wearable Flexible Loop Antenna for In-Body Beamforming

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**Abstract**—This paper presents a wearable flexible loop antenna array for use on the anterior and posterior torso. The antenna array that has been developed to assist in the detection of excess fluid in the lungs operates in the Medical Implant Communication System frequency Band. The antenna elements use a novel high-permittivity flexible substrate with dimensions of  $70.5 \text{ mm} \times 59 \text{ mm} \times 2 \text{ mm}$ . We investigate a simple beamforming technique to enable focusing the transmitted energy toward a specific lobe of the lung and also improve the low signal power at the receiver. In-body beamforming is achieved by adding proper phase shifts to the transmitter antennas. Both the return loss values of anterior antennas and the transmission coefficients between the anterior and posterior antennas are presented.

## I. INTRODUCTION

Wearable and implantable medical devices will be playing a prominent role in the future healthcare system. They will essentially enable major applications such as personal or remote health monitoring. Wearable antennas can be used to sense physical changes inside the human body both through their reflection and transmission coefficient parameters. However, monitoring these parameters presents challenges due to the high attenuation of the propagation channel inside the human body. Designing efficient wearable antennas is critical to achieve good performance with wearable health monitoring devices. In addition, it is essential to consider constraints such as bio-compatibility, usability, accuracy, and robustness, as well as regulatory restrictions such as specific absorption rate (SAR) [1].

Aside from efficient antenna design, a few methods have been considered in the literature to improve in-body radio frequency propagation, e.g., using matching mediums [2] or meta-surfaces [3]. Another potential methodology to enhance in-body propagation is using on-body antenna arrays and beamforming. It is conceivable that through beamforming, the transmitted energy can be focused towards a specific direction; leading to an increased distance in signal penetration or equivalently higher received signal power at a given distance [4]. Compared to free space propagation, in-body beamforming is more challenging due to the non-homogeneous human body environment. In this paper, we propose an on-body coplanar waveguide-fed loop antenna operating in the MICS band (i.e., [401 to 406] MHz). At these frequencies, antenna miniaturization is often required to enhance usability. Although miniaturization with meandering is a common approach, we chose dielectric loading in order to decrease the reflection of the electromagnetic waves from the air-human

body boundary. However, the flexible substrates in the market have inherently low permittivity values. Therefore, we propose utilizing a novel silicon-based flexible material as the antenna substrate. By doping RTV silicon with graphite, a substrate with a relative permittivity value of 11 can be fabricated. This high-permittivity flexible substrate (HPFS) allows us to achieve both reasonable antenna size and flexibility for the user's convenience. It also decreases the reflection at the boundary. The rest of this paper is organized as follows. The antenna design is presented in Section II. In Section III, the simulation setup and results for beamforming are discussed. Finally, concluding remarks are expressed in Section IV.

## II. ANTENNA DESIGN

To maximize propagation into the human body, magnetic antennas are typically preferred [5]. That's why in this study, we present a loop antenna which is a magnetic antenna that is directly placed on the human body surface. The antenna is optimized to operate in the MICS band on an in-house developed HPFS. Fig. 1 shows the proposed antenna and its dimensions. An HPFS with a total thickness of 2 mm is chosen to facilitate miniaturization and realize low reflection at the air-human body boundary.

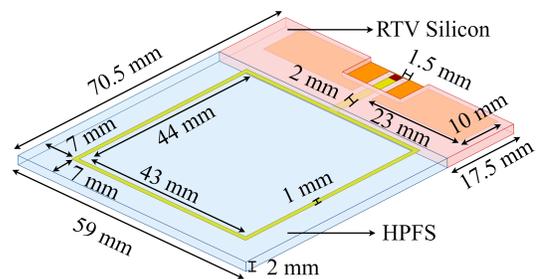


Fig. 1. The proposed loop antenna

As shown in Fig. 1, the radiating loop is located inside the HPFS, while the coplanar feed is realized on pure RTV silicon. This dual substrate usage is preferred for fabrication-related issues. If the feed was to be realized on HPFS, its width would have been as low as 0.5 mm as opposed to the dual usage which has a 2 mm width.

## III. SIMULATION RESULTS FOR IN-BODY BEAMFORMING

A simplified model of the torso is shown in Fig. 2. The model consists of a rectangular block with dielectric properties of the human muscle and two cylinders representing the human

lungs. Frequency-dependent characteristics of the tissues (i.e., muscle and lung) are considered in the numerical analysis. The dielectric properties of the lung tissue are chosen to correspond to the inhaled state [6]. The antennas are placed on the anterior and posterior of the torso model in a 2 by 2 array configuration in order to realize beamforming towards a specific lobe of the lungs.

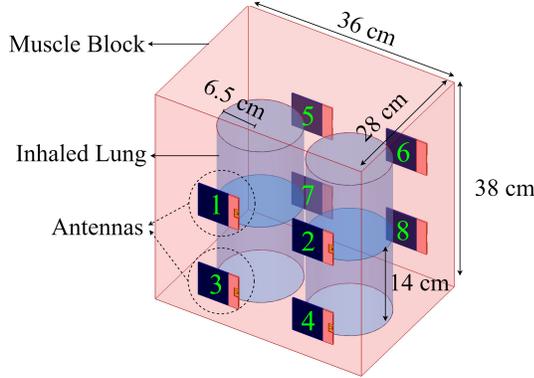


Fig. 2. The simulation setup: Four-element antenna array covering the lungs inside the torso model

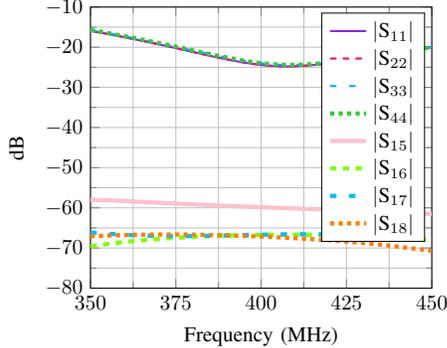


Fig. 3. Reflection performance of the antennas on the anterior torso and transmission responses for different channels

The values of the return loss for the four anterior antennas and the forward transmission coefficient ( $|S_{1n}|$ ) between antenna number 1 and the four posterior antennas are presented in Fig. 3. The  $|S_{15}|$  value of  $-59$  dB is the largest transmission coefficient since the antenna pair directly face each other with a distance of 28 cm. At the same time,  $|S_{16}|$ ,  $|S_{17}|$ , and  $|S_{18}|$  values are approximately around  $-70$  dB. This is mostly due to the increased antenna separation in these propagation channels. As observed, the proposed antenna has a larger bandwidth for the frequency of operation (i.e., 350 MHz to 450 MHz). This is useful in tackling detuning caused by changes in dielectric load or bending.

In Fig. 4, in-body beamforming is illustrated through Poynting Vector and SAR plots. Initially, no beamforming is performed as seen in 4(a) and 4(d), respectively. Then, proper phase shifts are introduced to the transmit ports of the antennas to form and steer the beam towards the lower section (i.e., lower lobes of the lungs). This steering is presented in 4(b) and 4(e). Finally, the beam is steered towards the right bottom lobe as seen in 4(c) and 4(f). (Note: the simulated 1 g average SAR value at the resonant frequency for an incident power

of 10 mW is 0.292 W/kg. This value is under the maximum limit of 2 W/kg set in the European regulatory Standards).

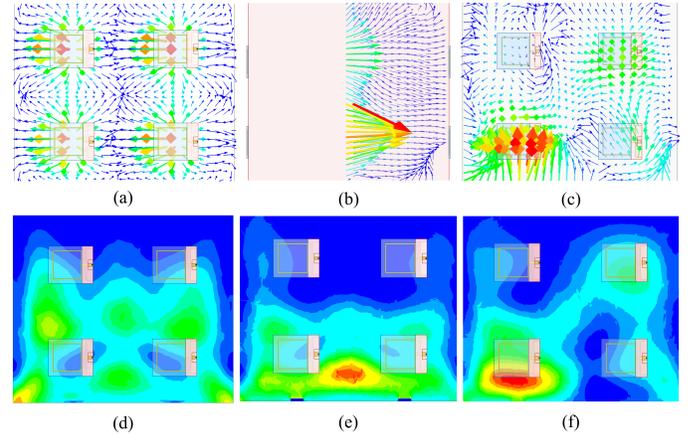


Fig. 4. In-body beamforming demonstrated by Poynting Vector (PV) and SAR plots: (a) & (d): No beamforming (front views), (b) & (e): Beamforming to lower lobes (PV side view, SAR front view), (c) & (f): Beamforming to right bottom lobe (front views)

#### IV. CONCLUSION

In this paper, an antenna array operating in the MICS band is proposed for in-body beamforming. The antenna is produced on a novel HPFS with a relative permittivity value of 11. The reflection and transmission responses prove that the proposed design could be suitable for in-body propagation. The beamforming capability is demonstrated with Poynting vector and SAR plots. To the best of the author's knowledge, there is no other work in the literature performing in-body beamforming with a microwave flexible antenna. Further research with a higher number of antenna elements and a more detailed study of phase shift strategies to achieve optimal beamforming are required.

#### ACKNOWLEDGEMENT

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