Broadband Microwave Antenna for Imaging and Sensing in Biomedical Applications

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***Abstract*—Thanks to their operation band, broadband antennas demonstrate applicability and versatility in biomedical sensing and imaging. This work presents the numerical validation of a microwave broadband monopole antenna aimed for work in close proximity to biological tissues, such as the human head. An iterative design starting from an elliptical patch antenna reduces geometry dimensions and enhances bandwidth efficiency. The final design achieves a compact 48×38 mm antenna with a dielectrically custom-made 3 mm-thickness matching layer covering a -10 dB frequency band from 1 to 6 GHz, which is assessed on top of a simplified multi-layer head phantom.**

I. Introduction

The need for cost-effective and accessible systems without ionizing radiation exposure has driven the use of microwave-based solutions for biomedical issues. Applications include microwave imaging for stroke and breast cancer diagnosis, blood glucose monitoring, and pleural effusion detection [1]–[5]. The success of these microwave-based alternatives hinges significantly on the design of the radiating element, a critical factor influencing resolution and penetration, as well as determining factor on the selection of the data processing algorithm.

Various antenna architectures have been proposed for biomedical applications, with wide band antennas standing out as versatile solutions. However, a notable technical challenge lies in their realistic close-body operation conditions impacting directly on antenna performance.

In this study, we present a broadband monopole antenna design, stressing the reduction of antenna dimensions and improving bandwidth efficiency while works near biological tissues. We investigated an elliptical patch antenna, techniques for enhancing bandwidth and the integration of a manufacturable custom-made matching medium (MM).

II. Design process

A multi-purpose monopole antenna featuring an operating band from 1 to 6 GHz is proposed, covering the bands used by microwave imaging and sensing applications [2]–[5]. The ground design incorporates a slot antenna with a clipped ground plane printed on a 1.59 mm Rogers RT5880 substrate [6]. Moreover, it considers the antenna's surrounding effects on the near-field and performance. For this purpose, a layered model —comprising skin, bone, cerebrospinal fluid (CSF), and brain— is employed, assigning their respective dielectric properties [7]. The thickness of each layer was selected according to [8], resulting in a block of homogeneous layers that size is 96×76×161.7 mm, as shown in Fig. 1(a).

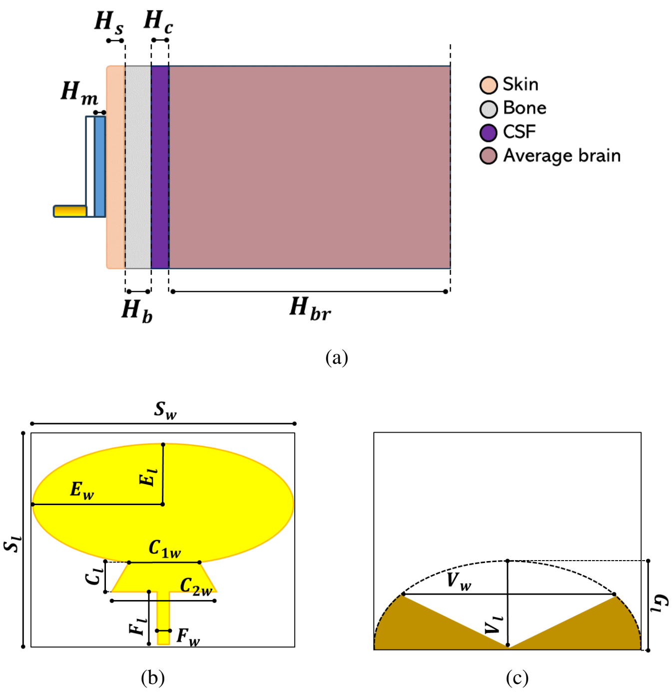

Fig. 1. Numerical models. (a) Head model and antenna setup, including the matching medium in blue. (b-c) Proposed antenna, front and back view, respectively.

Following the establishment of the initial patch antenna model, iterative simulations achieve the goal of a wide bandwidth starting from 1 GHz. The first iteration involves modifying the radiator element into an elliptical shape and introducing slots in the ground plane, following the approach proposed in [9]. This enhanced matching at lower frequencies. Subsequently, a slot is added to the ground plane, improving higher frequencies as suggested in [10], resulting in an enhanced coupling across the full band.

As the antenna dimensions are reduced, operating frequencies tend to increase, requiring new strategies for adapting coupling at the desired points. Then, the addition of stubs to the feed line is explored, initially with a single stub, leading to an overall low-frequency performance increment. The introduction of a second symmetrical stub revealed a second resonance point at 1 GHz, emphasizing the importance of a smooth transition from the feed line to the radiator. The final structure was triangular, seamlessly transitioning between the strip line and the ellipse.

Additional simulations were conducted to determine the optimal size of the ground plane, revealing that a slightly larger ground plane with a deeper slot enhances coupling across the entire bandwidth. The resulting design, achieved through this iterative process, has dimensions of 61×43 mm, representing a significant reduction compared to the initial design, but falling behind the goal of a minimum size of 50×40 mm.

Finally, a triangular structure was integrated into the feed line and radiator to achieve a compact antenna design. Moreover, as the last iteration, a MM is introduced between the antenna and the head phantom, which reduces the dimensions and improves the physical coupling between the antenna and the application zone. For the MM, the degrees of freedom are the thickness and permittivity, ϵ, being 3 mm the reached optimal, and $\epsilon = 17.876 + j2.345$ at 2 GHz, respectively. Here, it is worth notice that the used values correspond to real custom-made dispersive materials, which are made with a mixture of urethane rubber and graphite [11]. The final antenna design yields a 48×38 mm antenna, including its radiating element and ground plane as depicted in Fig.1b and 1c, and reported in Table I.

TABLE I
DIMENSIONS OF PROPOSED ANTENNA AND MULTI-LAYERS PHANTOM

Index	[mm]	Index	[mm]	Index	[mm]
S_w	48	G_l	20	S_l	38
V_w	42.72	S_h	1.6	V_l	19
C_l	4	F_l	11	C_{1w}	14.76
H_m	3	C_{2w}	20	H_s	3
F_w	4	H_b	6.5	E_w	23
H_c	3.2	E_l	10.5	H_{br}	150

III. RESULTS

The iterative process successfully met the bandwidth requirements, with a wide bandwidth covering from 1 to 6 GHz, positioning it as an attractive choice for applications in body microwave imaging and sensing. The $S_{1,1}$ parameter results at each step of this procedure are illustrated in Fig. 2, demonstrating progressive enhancement design requirements throughout the iteration process. Notably, although the first iterations performed well, the final design achieved size advantages, particularly crucial for the body microwave imaging application with multiple antennas as in [5].

IV. CONCLUSIONS AND FUTURE WORK

An ultra-wideband elliptical monopole antenna with partial ground plane clipping is specifically designed for microwave imaging and sensing applications, operating effectively in the frequency range from 1 to 6 GHz. Incorporating a realistic matching medium has been validated, reducing the antenna's size and facilitating better structural adaptation around the area of interest. Considering the promising results of the proposed antenna, in future work is planned to validate it experimentally.

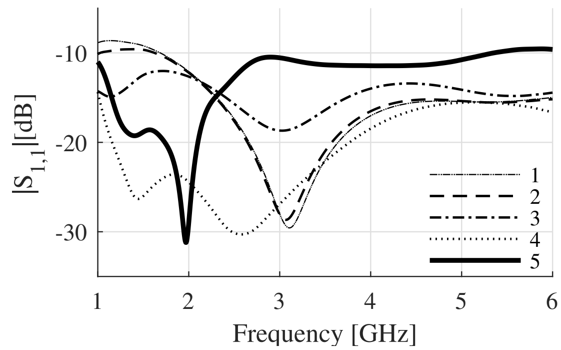

Fig. 2. Reflection coefficient amplitude of the proposed antennas for the different design iterations. The numbers indicate different design iterations.

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