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Wide-band Meta-surface Antenna for Microwave Brain Imaging systems

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Abstract

In this article, we present a broadband two-layer Meta-surface Antenna (MS) to use in Microwave brain imaging systems. The antenna element consists of an H-shaped slot antenna as a radiator and rectangular unites Meta-surface. The radiator is designed on a double side of FR4 substrate comprised of a ground plane with an H-shaped slot and the feed line radiator on top with a stub. The analysis of the operation frequency of the proposed meta-surface antennae is between 0.9- 2.7 GHz that a lower frequency supports the penetration amount of electromagnetic into tissues and the higher frequency support to obtain a high spatial resolution in the imaging algorithms. We have designed an MS antenna and optimized it inside the coupling medium. Due to the higher reflection of the electromagnetic wave from head tissues, the resonance frequency of the adjacent meta-surface antenna to the head is affected. Because of the coupling medium, reflections will be decreased and penetration of the incident wave will be increased. Furthermore, Specific Absorption Rate (SAR) is investigated in the simulation environment with 0.6 W/kg in the 1.5GHz has obtained. Also, the simulated near-field radiation pattern of the proposed antenna near the brain tissues shows that the proposed MS antenna supports the Microwave Imaging (MWI) agreements. Thus proposed MS antenna can be a good candidate for brain stroke detection.

1 Introduction

Brain stroke is admitted as the second leading cause of death and third in disability around the globe [1]. Two major types of the brain stroke are ischemic Stroke (Clots) and Hemorrhagic Stroke (Bleeds). An ischemic stroke occurs when the artery, the oxygen-rich blood supplier, is blocked [1]. A hemorrhagic stroke comes to happen if an artery ruptures or leaks blood in the brain. Brain cells are damaged by the massive pressure that leaking blood forms. Both types of stroke exhibit some typical symptoms such as; faintness, slurred speech, difficulty swallowing, and the sudden paralysis of body parts. However, from the onset of symptoms, an exclusive and timely medication is required for the treatment of each type of stroke [2].

By the means of both diagnostic and classification, an imaging test of the brain is required. The number of tests may come in handy, including computed tomography (CT) scan, magnetic resonance imaging (MRI) scan, and positron emission tomography (PET). For hemorrhagic strokes, CT scans are the fastest and most effective test [3]. Despite the fact that the mentioned techniques each have some associated constraints, however, they are well efficient and supply good resolution images of the brain. The imaging tests are all expensive, time-consuming, and immobile imaging modalities. Principally, CT acquires ionizing effects, PET involves radioactive material injection and MRI is not suitable for patients with metal biomedical implants [4]. Therefore, an alternate imaging technique is demanded that guarantees a safe, low-cost, fast, and more importantly portable imaging solution for brain stroke detection. Thus, with Microwave Brain Imaging (MWI) all the advantages along with non-ionizing, portability, and non-invasive features are supported.

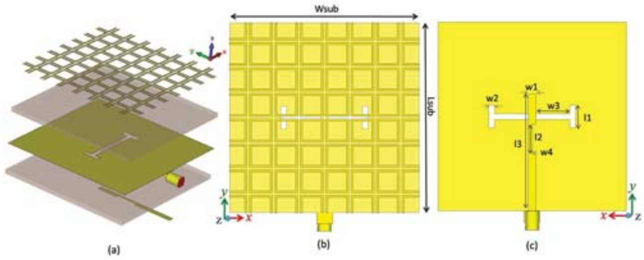

Figure 1. Proposed MS antenna with (a) perspective view, (b) top view, and (c)bottom view, Design parameters (all in mm) are given as: $Wsub = Lsub = 50$, $w1 = 2$, $w2 = 1.5$, $w3 = 10$, $w4 = 1$, $l1 = 6$, $l2 = 31$, $l3 = 8$.

Complementary to current imaging-based technologies, such as MRI, PET, and CT scan, Microwave Imaging (MWI) is an emerging technology for the diagnosis and follow-up of cerebrovascular pathologies. Based on the diversity of tissues electrical properties at microwave frequencies, MWI allows to portrait the different brain tissues and to distinguish among healthy and unhealthy regions (e.g., tumor, ischemic or hemorrhagic stroke zones [5]. In MWI systems, the antenna array is the keystone, as it is essential to deliver reliable data to the algorithm in charge of issuing the image of the investigated scenario [6]. This demands a proper design of the suitable antenna in terms of the choice of an adequate working frequency band, considering that higher frequencies support better spatial resolution, while lower ones reach deeper wave penetration where the dynamic range and sensitivity of the receiver is affected [7]. Moreover, to enhance penetration within the head, a coupling medium is filled between the antenna array and the head surface (To maximize the penetration of the electromagnetic wave into the brain tissue, compact antennas operating below 2.0 GHz immersed in a lossy dielectric medium are suggested with respect to the strong attenuation of the EM waves propagating inside the head [8] [9]. When using (rigid or flexible) on-body antennas, which can improve penetration, being attached in almost direct contact with the skin, the coupling medium can be dismissed. Variety of the antennas have been proposed for biomedical imaging, for instance, a novel slot antenna [5], Low-profile aperture stacked patch antenna [10] as well as flexible antennas [11] and arrays [12]. However, if the antenna is attached to the head, the tissues in the very near field of the antenna will has an impact on the antenna reflection coefficient, e.g. turning the designed antenna resonant frequency, in an unpredictable way (based on the patient variability), with possible disadvantages for the imaging algorithm. In addition to this, the near-field effects are not pretty easy to be designed and less contribute to the reconstruction of the interior imaged domain. On the other hand, to increase the transmitted power and to improve the received signal, a meta-material (MM) film is placed in front of the skin, which can act as an anti-reflection coating [13] [14]. This approach can suppress unwanted reflections and can enhance the transmission near a specific frequency [15].

In this work, an H-shaped MS slot antenna is surveyed and studied for Microwave Brain Stroke detection. The operation frequency of the MS antenna inside the coupling medium is optimized between 0.9- 2.7 GHz in order to have an acceptable penetration rate and resolution. The remainder of the paper is organized as follows: Section 2 describes and investigate the MS antenna design for Brain Imaging Systems inside the coupling medium, performance of the MS antenna near the head tissues environment, Near-field Analysis, and Specific absorption rate (SAR) analysis. Eventually, Section 3 summarizes the concluding remarks and future steps.

2 Proposed MS antenna for Brain Imaging Systems

Figure 1 provides a detailed image of the proposed MS antenna with the parameters in the caption. As shown in Figure 1 (a), the proposed MS antenna is embodied by two FR4 substrates with the dielectric constant of 4.3, loss tangent of 0.02 and thickness of 1.6mm. Figure 1 (b) illustrates the meta-surface layer that includes square resonators on the substrate. Furthermore, an H-shape micro-strip-fed radiating slot is used to obtain a wide bandwidth, increased radiation efficiency and reduced back radiation which is printed on a FR-4 substrate. To detract from the adverse inductive behavior of the antenna, an open-ended matching stub is used to the micro-strip feed line as can be seen in Figure 1 (c). Air-gap between the radiating slot antenna and meta-surface is optimized with 2mm. Because of the non-

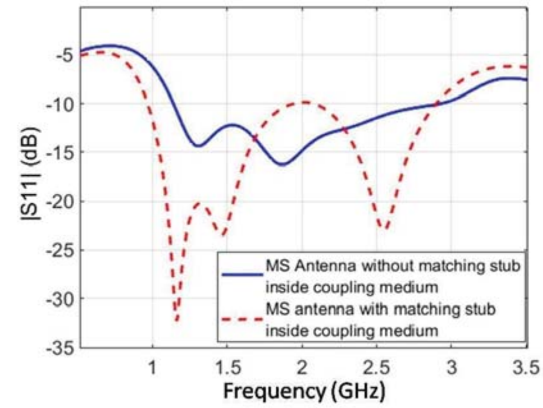

Figure 2. Simulated reflection coefficient inside of the coupling medium with and without coupling stub.

uniform shape of the brain model, it is hard to design an antenna that completely attache to the brain tissues. Thus, a coupling medium should be used in the design of the antenna for brain imaging systems and the MS antenna has been designed and optimized inside the coupling medium with a Relative Permittivity of 20 and a conductivity of 0.4 S/m at 2.5 GHz.

2.1 Characteristics of the MS Antenna

With the intention of validating the proposed MS antenna in the microwave brain imaging, the antenna should be immersed in the coupling medium. in Figure 2, the perspective view of the MS antenna is shown with the simulated reflection coefficient with and without an open-ended coupling stub. As can be seen from figure 2, the proposed antenna operates in the frequency range of 0.97 to 2.8 GHz when the $|S11 \leq -10|$. It is clear that there will be reflections in presence of a head phantom and the reflection coefficient will be affected. Thanks to the coupling medium, this effect will be minimized. In order to obtain more realistic results of the proposed antenna, a headband array is designed and illustrated in figure 3. The array consists of 8 MS antenna with 45^o placement to each other in front of the Austin man brain head model [16]. The antenna is covered by the coupling medium with the mentioned features previously. Besides, expected that the reflection coefficient

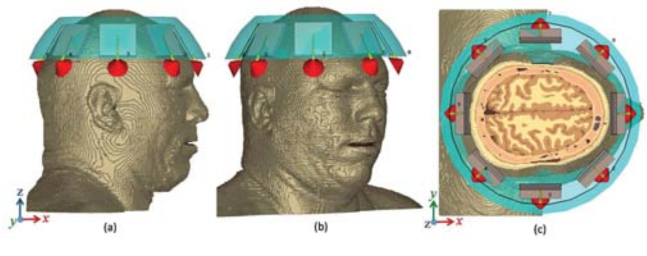

Figure 3. (a) Side view of the MS Antenna array system with Austin-Man head Model [16], (b) perspective view and (c) top slice view plane at Z = 150mm.

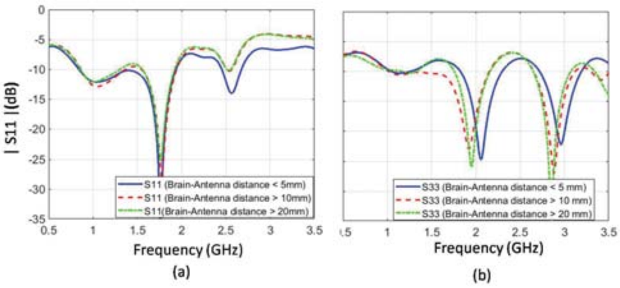

Figure 4. Simulated reflection coefficient of the (a) first MS antennas in different distance from head tissues, and (b) third MS antenna in the array.

should have less affection in terms of antenna and tissue distance as the head size of the different individuals is different. To validate this, we simulate different distances of the antenna in presence of the realistic brain head phantom in the simulation environment. Figure 4(a) illustrates the reflection coefficient of the first antenna with the different distances of the head phantom and operates between 0.7 to 2.6 GHz when the $|S11 \leq -8|$. Figure 4(b) it can be seen that the third antenna in the array operates between 0.9 to 3.5 GHz when the $|S11 \leq -8|$. We can realize from figure 4 that the differences in the size of an individual's brain will not affect the antenna's performances. We also analysand the radiation pattern of the proposed MS antenna inside the coupling medium without a head phantom. As the coupling medium is dispersive and lossy medium, it is not expected to have a positive Gain. In figure 5, the radiation characteristic of the MS antenna is depicted in the 3D form. It is evident that nearly a unidirectional radiation is obtained. Back lobes of the radiation are emerged mainly due to the coupling medium and it can be reduced in future work.

2.2 Near-field Analysis

To investigate the MS antenna in brain imaging systems, it is placed at three different distances from the brain head phantom and simulated in CST Microwave Studio software [17]. The 3-D Austin man phantom model with 1 mm resolution is used which consists of all the body tissues. The dispersive feature of each tissue is considered in the simulation environment. Figure 4 shows the average electric field intensity for the three different distances of the antenna with the brain in the frequency of 2.5 GHz. As can be seen, the electric field intensity is penetrated inside the head with the different distance of the antenna. In all three scenarios, a maximum of the electric field intensity can be switched inside the brain tissues efficiently. But, in the third scenario, (the average distance of the antenna with the head model is higher than 20 mm) penetration of the signals is almost plate and cover in wider tissues range. It is clear that we will have a more penetration amount of electric field in the 1.5 GHz also.

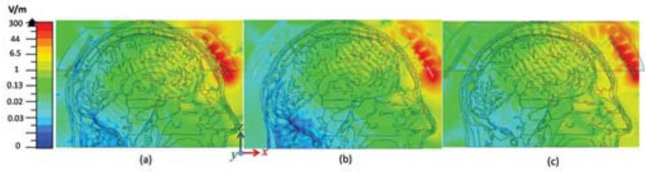

Figure 5. A cross-section (xz plane) view at the E-plane for (a) average distance of the antenna with the head model is lower than 5 mm, (b) larger than 10 mm, and (c) larger than 20 mm when the first antenna (Ant1) is radiated in 2.5 GHz.

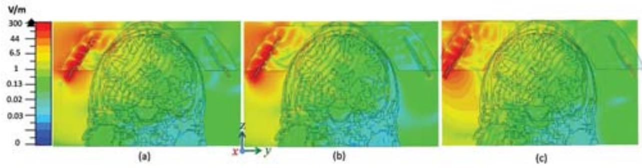

Figure 6. A cross-section (yz plane) view at the E-plane for (a) average distance of the antenna with the head model is lower than 5 mm, (b) larger than 10 mm, and (c) larger than 20 mm when the Third antenna (Ant3) is radiated in 2.5 GHz.

2.3 Specific absorption rate (SAR) analysis

Specific Absorption Rate (SAR) is one of the most important parameters in near-field imaging and must be taken into account which is arises from the exposure of microwave signals to the human tissues. SAR is defined as the amount of power dissipated per unit mass and calculated using Eq. (1) in watts per kilogram [W/kg] and must be lower than 1.6 W/kg over the 1 g of tissues [18]. In the Eq.(1) E is the induced electric field intensity norm value [V/m], ρ and σ points out both the density $[kg/m^3]$ and electric conductivity [S/m] of the tissues, respectively. In this work, we have investigated three scenarios to validate the usefulness of the proposed MS antenna in terms of SAR that is illustrated in Figure 7. In figure 7(a), the maximum SAR of 0.6 W/kg has occurred when the antenna's average distance is lower than 5 mm from the brain tissue. by increase the antenna with the head phantom, the amount of SAR is decreased as can be seen from figure 7(b) and (c). the results show that the proposed MS antenna is acceptable for the brain image systems due to the lower distributed amount of SAR in the brain tissues.

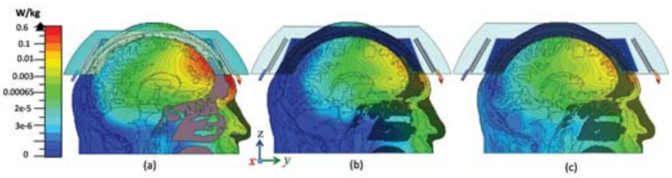

Figure 7. SAR value (W/kg) inside the head phantom at 1.5 GHz when (a) the average distance of the antenna with the head model is lower than 5 mm, (b) larger than 10 mm, and (c) larger than 20 mm.

$$SAR = \frac{\sigma E^2}{2\rho}. \quad (1)$$

3 Conclusion

This paper introduces a design of the MS antenna inside the coupling medium for microwave brain imaging systems. In order to reach a wide bandwidth and more suitable coupling, an H-shaped radiating slot antenna with an open-ended stub has been designed in the simulation environment. The proposed MS antenna operates between 0.9- 2.7GHz. Performance of the antenna has been investigated in presence of the head phantom model and obtained acceptable reflection of the signals due to the coupling medium. Moreover, the E-field intensity of the proposed antenna at the different distance from the head phantom model is investigated which acceptable penetration of the signals inside the brain tissues is observed. Besides these, one of the most significant parameters of patient safety has been investigated. The maximum amount of the SAR(0.6 W/kg) has occurred over the 1 g of tissue when the distance of the antenna and the head phantom is lower than 5 mm.

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