

Printability study by selective laser sintering of bio-based samples obtained by using PBS as polymeric matrix

Original

Printability study by selective laser sintering of bio-based samples obtained by using PBS as polymeric matrix / Colucci, G., Piano, M., Lupone, F., Baruffaldi, D., Frascella, F., Bondioli, F., Messori, M.. - In: POLYMER TESTING. - ISSN 0142-9418. - 131:(2024). [10.1016/j.polymertesting.2024.108327]

Availability:

This version is available at: 11583/2985066 since: 2024-01-15T09:40:16Z

Publisher:

Elsevier

Published

DOI:10.1016/j.polymertesting.2024.108327

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

On the Decoupling of an On-body-matched Microwave Antenna for Head Screening

Martina Guglielmino*, David O. Rodriguez-Duarte*, Alex R. Masaquiza-Caiza*, Cristina Origlia*, Alessia Delpiano†, Maaz Khalid†, Jorge A. Tobon-Vasquez‡, Rosa Scapaticci§, Francesca Vipiana*

Dept. Electronics and Telecommunications, Politecnico di Torino, Torino, Italy

†EPF Elettronica S.r.l., Carrù, Cuneo, Italy

‡Wavision S.r.l., Torino, Italy

§Institute for Electromagnetic Sensing of the Environment, National Research Council, CNR, Naples, Italy
francesca.vipiana@polito.it

Abstract—Microwave-based head screening is a challenge that requires a sensitive and responsive antenna capable of identifying, discriminating, and sensing variations in the scattering response due to internal dielectric contrast. These variations might be degraded by external interferences from other applications, sharing the frequency band and by multipath interference caused by non-through-body traveling waves, both of which limit accuracy. This paper examines the inclusion of an immediately attached back-self and inter-element absorbing foam layer, that can be a practical, low-cost, off-the-shelf solution, in an on-body-matched-antenna array, to mitigate unwanted interferences. The study employs numerical and experimental tests and finds a suitable and industrially scalable setup. Finally, a pneumatic system is proposed as an adaptability mechanism that adjusts the antenna-to-head attachment regarding the head size, eliminating unwanted air gaps between the antenna and the head.

Index Terms—microwave antennas, biomedical diagnostics, electromagnetic propagation in absorbing media, near-field radiation, surface wave interference.

I. INTRODUCTION

Driven by the development of microwave (MW) technologies, the application of microwave-based sensing and imaging principles has currently extended to head screening scenarios in laboratory and clinical settings [1], [2]. It exploits the intrinsic penetrability of biological tissues to microwaves and the dielectric contrast displayed by pathologies compared to healthy tissues to perform sensing, discrimination, classification, and imaging tasks. Together with its low cost and harmful nature, microwave screening serves as a support diagnosis and follow-up alternative that complements well-established technologies such as magnetic resonance imaging (MRI) or computed tomography (CT-scan), being the diagnosis and monitoring of cerebrovascular diseases, including ischemic and hemorrhagic strokes, the most explored applications, even reaching clinical trial phases [1]. Moreover, its application has also been explored recently for the diagnosis of functional disorders [3], [4]. In general, MW head screening systems rely on an antenna array mounted in a helmet or ring configuration to achieve coverage that allows sensitivity to changes in the scattering response across the entire domain of interest. However, using close-by antennas near the head is a challenging scenario, not only due to the implicit complexity of the propagation scene, which involves the morphology of the head itself—a non-regular, stratified, heterogeneous, dispersive, and lossy medium, but also because it raises issues such as high

coupling between neighbor antennas, non-body penetration, and unwanted body surface currents and back radiation, that if not addressed properly, they may impair the diagnostic result. Besides, external signal interference is also harmful.

To mitigate the mentioned issues, unwanted propagation paths need to be prevented, external interferences reduced, and antenna-head matching improved. To this end, the use of absorbing and matching materials, along with back enclosures, has been proposed. For instance, [5] and [6] use a high-loss gel solution or liquid, respectively, to reduce coupling between adjacent antennas. However, this affects matching and requires a high dynamic range and very accurate measurement instrumentation. Instead, different solutions using broadband absorbing foam or lossy dielectric absorbers to suppress back radiation and self-clutter, together with metallic enclosures, have been proposed. Specifically, the Eccosorb FGM40RF, the Eccosorb LS-30, the EN-74 from Emerson & Cuming Anechoic Chambers, the Eccosorb MCS, are used in [7], [8], [9], and [10] respectively, and a radar absorbing material (RAM) in [11]. Moreover, more sophisticated and ad-hoc solutions using optimized antennas [12], [13], a metasurface [14] and a quasi-resonant metallic chamber [15], have also been proposed.

In this article, we use the in-lab validated MW imaging system for brain monitoring as a starting point [16], [17], which employs microwave on-body-matched antennas, consisting of a compact printed monopole and a flexible solid matching medium as a unit, and study the integration of an immediately attached back-self and inter-element RF-absorbing foam layer to the radiating element as a mechanism to make the system more robust and clinically scalable without the need for significant design changes. The assessment is conducted using numerical full-wave simulation and experimental measurements. It employs a downscaled three-antenna configuration and a simplified mimicked head setup, allowing for a more straightforward examination of the effect of the RF-absorbing layer. Moreover, we present a pneumatic mechanism as an alternative to accommodate the antenna to the head and to avoid air gaps between the antennas and the head that would reduce the field penetration in the head.

II. ASSESSMENT FRAMEWORK

This section introduces the simplified experiment (head phantom mimicking) to evaluate the effect of a commercial RF-absorbing foam layer on the antenna performance. A sim-

plified setup is implemented to reproduce the electromagnetic (EM) interaction of the MW system with the head. It includes the phantom, the antennas, and the RF-absorbing foam.

A. Phantom

The phantom consists of a cylindrical 1 mm-thickness plastic container, as shown in Fig.1, which is filled with a liquid mixture made of alcohol, water, and salt, whose dielectric properties resemble those of average brain tissue, with $\epsilon_r = 39$ and $\sigma = 1.02$ S/m at 1.25 GHz, relative permittivity and conductivity, respectively. This phantom represents a simplified yet representative model of the human head, which allows for reproducible and controllable experimental condition.

B. Antenna Design

The antennas used in this study are based on the on-body-matched microwave design presented initially in [18] and further optimized in [17]. The antenna, hereafter referred to as Ant-MM, combines a printed monopole with a slab of semi-solid matching medium, MM, made of a mixture of 20% graphite powder and 80% urethane rubber, exhibiting a complex permittivity of $\epsilon_r = 10$ and a conductivity of $\sigma = 0.04$ S/m at 1.25 GHz. This approach provides mechanical flexibility and softness, allowing the antenna to conform to the head surface, effectively minimizing the air gap between the antenna and the skin. The Ant-MM operates in direct contact with the head surface, working at around 1.25 GHz.

C. RF-Absorbing Foam Layer

The commercial RF absorber used in this study is Eccosorb AN77, a carbon-loaded, three-layer foam designed to work at the microwave band [19]. It consists of three distinct

layers, dubbed A, B, and C in Fig. 1(a), with different attenuation each. This multilayer configuration allows a gradual absorption of incident waves, improving the suppression of back-radiation and inter-element coupling. While Eccosorb AN77 is commonly used for lining small test chambers, it is worth noting that it is not intended to be in direct contact with the antenna. Hence, motivating the assessment in this study. Their dielectric properties at 1.25 GHz are reported in Table I. Mechanically, the RF-absorbing layer is a lightweight and flexible polyurethane foam sheet capable of conforming to soft curved surfaces, such as the head. Figure 1 depicts the absorber disposition, being the Ant-MM inserted in a trimmed section, as shown in Fig. 1(b), right. In this configuration, each antenna is backed by at least two absorber layers and laterally surrounded by approximately 8 mm of absorbing material. Moreover, the relative positioning of the three antennas—two in close proximity and one placed farther apart—closely replicates the spatial distribution typically adopted in head-imaging systems, such as that described in [20].

TABLE I: Electrical properties of the RF absorbing layers at 1.25 GHz

RF-absorbing layer	ϵ_r	σ [S/m]
A	1.3	0.01
B	1.7	0.04
C	5.6	0.25

D. Numerical and Experimental Procedures

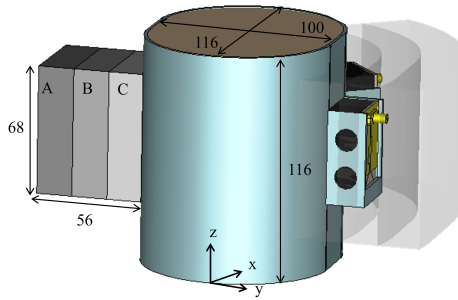
Both for numerical simulations and experimental measurements, three configurations are analyzed: (I) without the absorber, reference case, (II) with the absorber (A-B-C orientation of the RF absorber layer, in Fig.1(a)), and (III) with the absorber flipped (C-B-A orientation of the RF absorber layer).

Regarding the numerical part, full-wave EM simulations are performed using a frequency-domain solver, reproducing the experimental setup, and providing the corresponding scattering response and the near-field distributions. In accordance with the operation band of the Ant-MM, we run them from 0.8 to 1.8 GHz. For the measuring process, the reflection and transmission coefficients are measured using the Keysight P5003B VNA, with calibration at the antenna ports performed by an electronic calibration module [21].

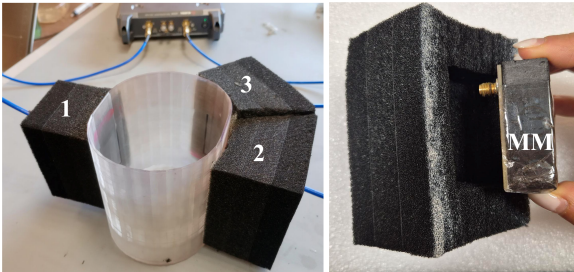
III. RESULTS AND ANALYSIS

Figures 2 and 3 compare the simulated and measured reflection and transmission scattering parameters, respectively, across the three studied configurations, demonstrating good agreement throughout the entire band. The inclusion of the RF-absorber preserves the matching, as shown in Fig. 2. Thought, in the (III) configuration, the response slightly deteriorates. On the other hand, the transmission parameters do not show a conclusive differentiation between the three configurations. As expected, the antennas placed closer to each other exhibit higher transmission, whereas those positioned farther apart show lower transmission. Since the transmission remains largely unchanged, this indicates that the internal propagation of the field is not significantly affected, as confirmed by the near field distribution at 1.25 GHz, shown in Fig. 4, and mainly depends on the through-body energy.

The first row of Fig. 4 (a-c) corresponds to (I), the reference. The second one, (d-f), to (II), with the absorber, and the last one,



(a)



(b)

Fig. 1: Assessment framework. (a) 3-D model of the system (dimensions in mm). (b) Experimental setup: on the left, the cylindrical phantom with the three antennas within the RF absorber layer; on the right, the RF absorber layer with the antenna placed inside. The thickness of the three layers is equally spaced.

(g-i), to (III), where the absorber is flipped. In the transversal view (first column), the field propagation within the phantom appears nearly unchanged across all three configurations. The back propagation, evident also in the top view (second column), is noticeably more attenuated in configuration (II). The frontal view (third column) shows that the surface field distribution remains largely consistent across the three cases. The analysis indicates that the absorber primarily affects the back propagation of the field, as seen in the transversal and top views, while leaving the internal propagation within the phantom and the surface field distribution essentially unchanged. A reduction of the field back propagation is key property of antenna arrays for medical imaging, because it allows to reduce the external interferences coupled with the antennas that can hide the signal of interest measured by the same antennas in the human body. In contrast, the external inter-element and on-body surface propagation is minimally reduced, though confined, due to the limited thickness of the lateral walls, which seems insufficient.

IV. PNEUMATIC SYSTEM

A remaining challenge in an industrial brain-monitoring system is maintaining consistent contact between the antenna and the patient head. The antenna decoupling is sensitive to the presence of air gaps [18], which is particularly challenging due to the complex and irregular geometry of the human head. To address this issue, and as a complement to the RF-absorbing material, we develop a pneumatic system capable of driving each Ant-MM perpendicularly toward the head surface, maximizing the coupling. The system, illustrated in Fig. 5, presents a maximum displacement of 2 cm, having enough degrees of freedom to conform to different head shapes. This is made of four components, A-D in Fig. 5(a): the top support plate (A) connects the pneumatic system to the device structure. The miniature SMC cylinder (B) drives the antenna motion, while the SMC fitting (C) provides the pneumatic connection. The 3D-printed PET-G L-shaped guide (D) ensures linear movement of the cylinder and prevents undesired rotation. A similar mechanical concept is presented in [22], where pneumatic micro-pistons are used to individually control antenna positioning and maintain stable contact with the head.

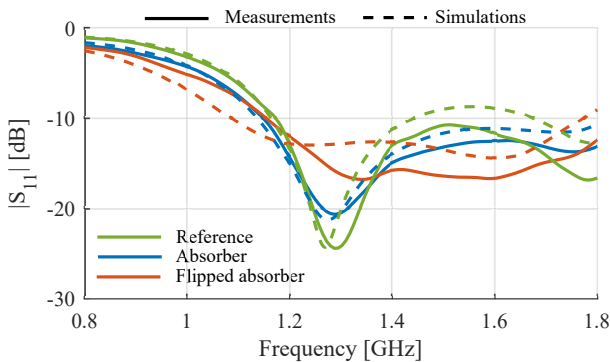


Fig. 2: Reflection parameters of Ant-MM 1. Dotted lines represent the simulations, while solid lines represent the measurements. Green lines correspond to the reference case without the absorber (I), blue lines to the case with the absorber (II), and red lines to the case with the flipped absorber (III).

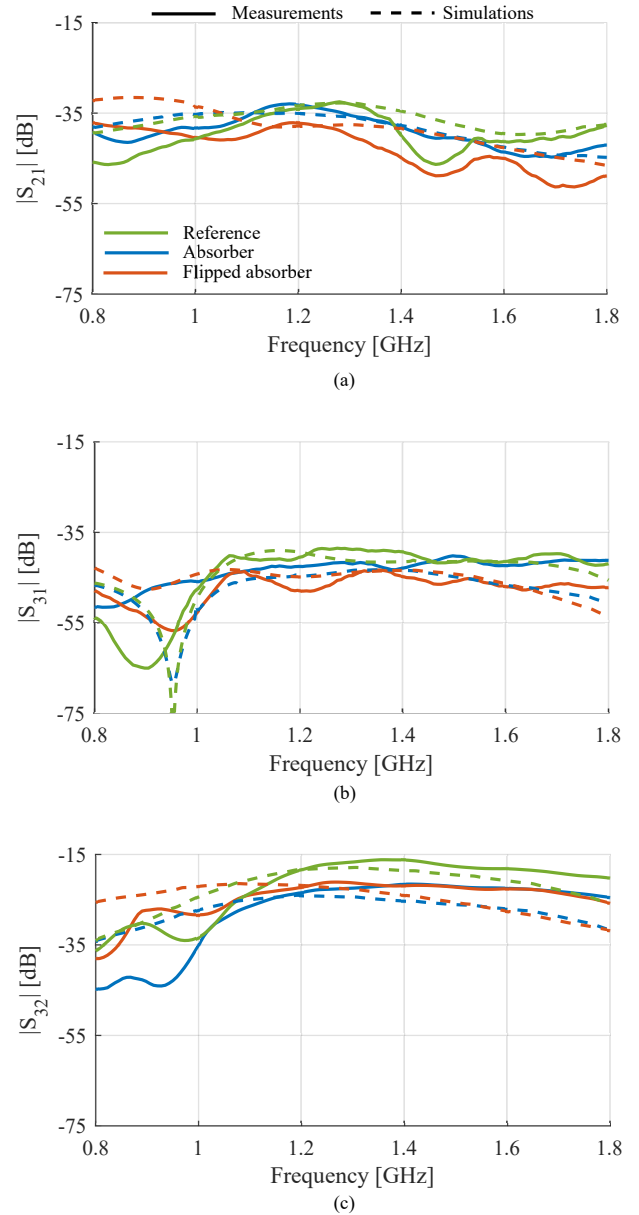


Fig. 3: Transmission parameters of the three Ant-MM. Dotted lines represent the simulations, while solid lines represent the measurements. Green lines correspond to the reference case without the absorber (I), blue lines to the case with the absorber (II), and red lines to the case with the flipped absorber (III).

V. CONCLUSION AND PERSPECTIVES

This work investigated the integration of a commercial RF-absorbing foam layer into an on-body-matched microwave antenna system designed for head screening applications, a minimally invasive solution that can be industrially scalable. Through numerical simulations and experimental measurements, it has been shown that the RF absorber preserves proper antenna matching and performance, maintaining a stable field distribution inside the phantom, while mitigating backward radiation. Besides, the RF absorber can shield against potential external interferences in a clinical environment. Finally, a pneumatic mechanism for antenna positioning was introduced as a step toward clinical translation. This adaptable system enables conformal and repeatable contact between the antennas and the head, limiting air-gap effects and improving measurement reliability.

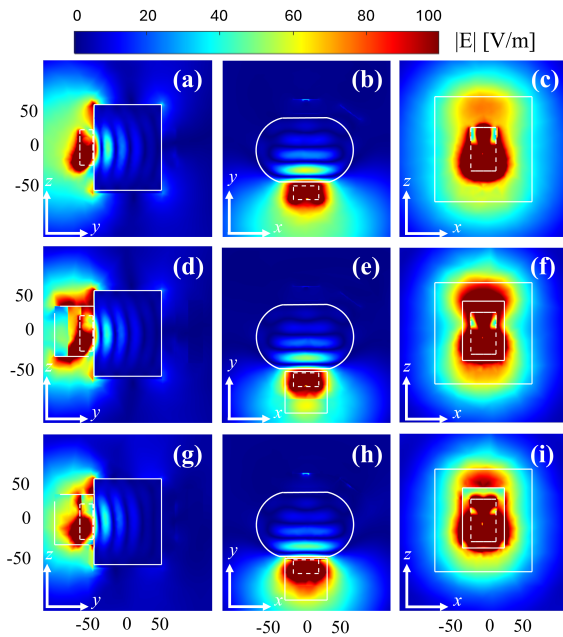


Fig. 4: Electric field Ant-MM1: (a–c) reference case without absorber (I); (d–f) case with the absorber (II); (g–i) case with the absorber flipped (III). The first column shows the transversal view, the second column the top view, and the third column the front view. The dimensions are in mm.

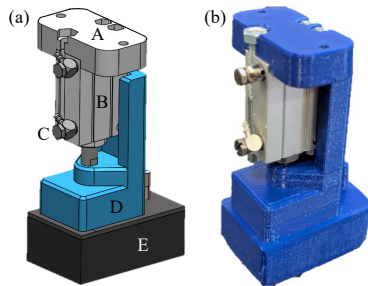


Fig. 5: The pseudo pneumatic system. (a) CAD model and (b) implemented prototype: (A) top support plate, (B) SMC cylinder, (C) SMC fitting, (D) L-shaped guide, and (E) antenna.

Future work will focus on employing the RF-absorbing material in a more realistic helmet-type head phantom configuration. In addition, a measurement system suitable for clinical environments, such as hospitals, is being developed. It integrates the pneumatic mechanism to ensure proper antenna conformity and reliable contact with different patient head shapes.

VI. ACKNOWLEDGMENT

This work was supported in part by the EU project “3Batwin” (GA: 101159623) and by the project “MedWaveImage”, funded by Interreg Central Europe (CE0200670). It was carried out partially within the Agritech National Research Center, funded by the European Union Next-Generation EU (Piano Nazionale di Ripresa e Resilienza (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022).

REFERENCES

[1] C. Origlia, D. O. Rodriguez-Duarte, J. A. Tobon Vasquez, J.-C. Bolomey, and F. Vipiana, “Review of Microwave Near-Field Sensing and Imaging Devices in Medical Applications,” *Sensors*, vol. 24, no. 14, 2024.

[2] L. Guo, A. S. M. Alqadami, and A. Abbosh, “Stroke Diagnosis Using Microwave Techniques: Review of Systems and Algorithms,” *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 7, no. 2, pp. 122–135, 2023.

[3] Y. Akazzim, C. P. Arias, M. Jofre, O. E. Mrabet, J. Romeu, and L. Jofre-Roca, “UWB Microwave Functional Brain Activity Extraction for Parkinson’s Disease Monitoring,” *IEEE Sensors Journal*, vol. 24, no. 3, pp. 3844–3852, 2024.

[4] L. Cardinali, V. Mariano, D. O. Rodriguez-Duarte, J. A. Tobón Vasquez, R. Scapaticci, L. Crocco, and F. Vipiana, “Early Detection of Alzheimer’s Disease via Machine Learning-Based Microwave Sensing: An Experimental Validation,” *Sensors*, vol. 25, no. 9, 2025.

[5] L. G. Orozco, L. Peterson, and A. Fhager, “Muscle Rupture Microwave Imaging with a Lossy Gel to Reduce Multipath Interference,” in *2023 17th European Conference on Antennas and Propagation (EuCAP)*, 2023, pp. 1–5.

[6] P. M. Meaney and K. D. Paulsen, “Addressing multipath signal corruption in microwave tomography and the influence on system design and algorithm development,” *Open access journal of biomedical engineering and biosciences*, vol. 1, no. 1, p. 102, 2018.

[7] M. Klemm, I. J. Craddock, J. A. Leendertz, A. Preece, and R. Benjamin, “Radar-Based Breast Cancer Detection Using a Hemispherical Antenna Array—Experimental Results,” *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 6, pp. 1692–1704, 2009.

[8] P. Serano, J. W. Adams, L. Chen, A. Nazarian, R. Ludwig, and S. Makaroff, “Reducing Non-Through Body Energy Transfer in Microwave Imaging Systems,” *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 7, no. 2, pp. 187–192, 2023.

[9] M. S. R. Bashri, T. Arslan, W. Zhou, and N. Haridas, “Wearable device for microwave head imaging,” in *2016 46th European Microwave Conference (EuMC)*, 2016, pp. 671–674.

[10] O. Karadima, M. Rahman, I. Sotiriou, N. Ghavami, P. Lu, S. Ahsan, and P. Kosmas, “Experimental validation of microwave tomography with the DBIM-TwIST algorithm for brain stroke detection and classification,” *Sensors*, vol. 20, no. 3, p. 840, 2020.

[11] S. Rana, J. Davis, K. Khalil, M. O’Toole, S. Watson, S. Liang, A. Parry-Jones, D. Daniels, and A. Peyton, “Microwave imaging for human brain stroke detection using frequency domain inverse modelling & phantom experiments,” *Scientific Reports*, vol. 15, no. 1, p. 34801, Oct. 2025, © 2025. The Author(s).

[12] S. M. Pishnamaz, X. Zeng, H. D. Trefná, M. Persson, and A. Fhager, “Reducing Waves on the Body Surface in Near-Field Medical Diagnostics by a Dielectric Rod Antenna,” *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 10, pp. 7958–7969, 2023.

[13] M. Mokhtari and M. Popović, “Surface Wave and Back Radiation Suppression in Microwave Breast Screening,” *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 8, no. 3, pp. 245–250, 2024.

[14] Z. Liu, N. Bayat, and P. Mojabi, “On the Use of Absorbing Metasurfaces in Microwave Imaging,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 12, pp. 9026–9031, 2021.

[15] L. Banting, J. LoVetri, and I. Jeffrey, “Microwave Imaging on S-Parameters Using FEM Thin-Wire Subcell Models,” *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 9, no. 3, pp. 263–269, 2025.

[16] D. O. Rodriguez-Duarte, C. Origlia, J. A. T. Vasquez, R. Scapaticci, L. Crocco, and F. Vipiana, “Experimental Assessment of Real-Time Brain Stroke Monitoring via a Microwave Imaging Scanner,” *IEEE Open Journal of Antennas and Propagation*, vol. 3, pp. 824–835, 2022.

[17] M. Guglielmino, D. O. Rodriguez-Duarte, C. Origlia, J. A. T. Vasquez, R. Scapaticci, J. C. Bolomey, L. Crocco, and F. Vipiana, “On the Use of an Electromechanical and a Solid-State Switching Matrix for a Portable Microwave-Based Brain Stroke Scanner,” *IEEE Antennas and Wireless Propagation Letters*, vol. 23, no. 11, pp. 3342–3346, 2024.

[18] D. O. Rodriguez-Duarte, J. A. T. Vasquez, R. Scapaticci, L. Crocco, and F. Vipiana, “Brick-Shaped Antenna Module for Microwave Brain Imaging Systems,” *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 12, pp. 2057–2061, 2020.

[19] “Eccosorb AN datasheet,” Available at <https://www.laird.com/sites/default/files/2021-01/RFP-DS-AN%2006242020.pdf>.

[20] D. O. Rodriguez-Duarte, C. Origlia, J. A. T. Vasquez, R. Scapaticci, L. Crocco, and F. Vipiana, “Experimental assessment of real-time brain stroke monitoring via a microwave imaging scanner,” *IEEE Open Journal of Antennas and Propagation*, vol. 3, pp. 824–835, 2022.

[21] “Keysight datasheet,” Available at <https://www.keysight.com/us/en/product/N7551A/electronic-calibration-module-e-cal-dc-6-5-ghz-2-port.html>.

[22] A. Cuccaro, A. Dell’Aversano, B. Basile, M. A. Maisto, and R. Solimene, “Subcranial Encephalic Tomograph-Shaped Helmet for Brain Stroke Monitoring,” *Sensors*, vol. 24, no. 9, 2024.