Scientific Research Publishing

Open Journal of Antennas and Propagation, 2023, 11, *-*
https://www.scirp.org/journal/ojapr
ISSN Online: 2329-8413
ISSN Print: 2329-8421

Modeling and Simulation of High Frequency Electromagnetics Wave Propagation on Vivaldi Antenna Using Finite Element Method

Jean Ndoumbe, Nelly Tchuenbou, Charles Hubert Kom

Laboratory of Energy, Materials, Modeling and Method (E3M), National Higher Polytechnic School of Douala, University of Douala, Douala, Cameroon
Email: jndombe02@gmail.com

How to cite this paper: Author 1, Author 2 and Author 3 (2023) Paper Title. *Open Journal of Antennas and Propagation*, **11**, *-*.
https://doi.org/10.4236/***.2023.*****

Received: **** **, ***
Accepted: **** **, ***
Published: **** **, ***

Abstract

The simulation of the electromagnetic wave propagation plays an important role in predicting the performance of wireless transmission and communication systems. This research paper performs a numerical simulation using the finite element method (FEM) to study electromagnetic propagation through both conductive and dielectric media. The simulations are made using the COMSOL Multiphysics software which notably implements the finite element method. The microwave is produced by a Vivaldi antenna at the respective frequencies of 2.6 and 5 GHz and the propagation equation is formulated from Maxwell's equations. The results obtained show that in the air, strong electric fields are observed in the slot and the micro-strip line for the two frequencies, they are even greater when the wave propagates in the glass and very weak for the copper. The 3D evolutions of the wave in air and glass present comparable values at equal frequencies, the curves being more regular in air (dielectric). The radiation patterns produced for air and glass are directional, with a large main lobe, which is narrower at 5 GHz. For copper, the wave propagation is quite uniform in space, and the radiation patterns show two main lobes with a much larger size at 2.6 GHz than at 5 GHz. The propagation medium would therefore influence the range of values of the gain of the antenna.

Keywords

Radiated Field, Propagation Medium, Microwave, Vivaldi Antenna, Finite Element Method, COMSOL Multiphysics

1. Introduction

The advancements in the wireless communication industry have revolutionized how societies exchange information, particularly with the telecommunications systems. The mobile communications, especially cell phone ones, are realized through the signal transmission antennas which play the role of electromagnetic signal generators, as mediator of these signals or conductors of this signal among antennas and other transmission systems of information. The current challenge in this field of telecommunications is to ensure an increase in transmission rates. For this, several techniques are envisaged, among which the rise in frequency. For this reason, high frequency electromagnetic fields (*i.e.*, frequencies from 300 MHz to 3 GHz, which are mainly human-produced, are increasingly present in the environment [1] because of the active development of wireless technology, including cell phones, Wi-Fi, and various kinds of connected devices. One of the prerequisites for the development of telecommunication services is the understanding of the propagation of the electromagnetic waves, which are used for the transmission of information. Electromagnetic waves propagate in space according to several different physical mechanisms such as free-space propagation, reflection, transmission, diffraction, scattering and wave guiding. The behavior of electromagnetic fields in a given medium corresponds to the description given by Maxwell's equations and the constitutive relations.

Over the decades, many computational techniques have been developed to solve the wave propagation problems. Šesnić and Poljak [1] used the antenna model to represent the horizontal grounding electrode, and used the analytical method and the boundary element method (BEM) to solve the electromagnetic equations. Sarkar [2] studied the effects of various parameters on the performance of the Vivaldi antenna. The paper uses the finite difference time domain (FDTD) method to model and simulate the electromagnetic behavior of the antenna, and analyzes the results in terms of return loss, radiation pattern, gain, and bandwidth. The paper also compares the proposed antenna with other existing designs, such as tapered slot antenna (TSA), exponential tapered slot antenna (ETSA), and elliptical tapered slot antenna (ELTSA). They conclude the performance of Vivaldi antenna is sensitive to the parameters across the frequency range of 3.1 to 10.6 GHz. Diao and Hirata [3] proposed and demonstrated a novel method for assessing the millimeter wave exposure from an antenna using the transformation of spherical wave expansion (SWE) to plane wave expansion (PWE). Their paper used the SWE to represent the near-field radiation of the antenna, and used the PWE to calculate the far-field radiation and the specific absorption rate (SAR) of the human body. They also compared the proposed method with other methods, such as finite-difference time-domain (FDTD) and finite element method (FEM).

The FEM is the most popular method for electromagnetic simulation. It can be implemented using various software tools, such as COMSOL Multiphysics, MATLAB, or ANSYS HFSS, which provide user-friendly interfaces and powerful features for antenna design and optimization. Constantinescu, *et al.* [4] studied the effects of various parameters on the performance of the Vivaldi antenna at high frequencies. Their paper used the FEM to model and simulate the electromagnetic behavior of the antenna, and analyzes the results in terms of reflection coefficient, radiation pattern, gain, directivity, and bandwidth. Their paper also compares the proposed antenna with other existing designs, and shows that it achieves better results in terms of bandwidth and gain. Zhou, *et al.* [5] used the FEM to model and simulate the electromagnetic and thermal behavior of the antenna array, and analyzed the results in terms of return loss, radiation pattern, gain, efficiency, and temperature distribution. They compared the proposed antenna array with a conventional one, and showed that the proposed antenna array has better heat dissipation performance and higher efficiency. Ostadrahimi, *et al.* [6] performed the FEM to model and simulate the electromagnetic behavior of the antenna, and uses the transmission line theory to analyze the input impedance and the radiation efficiency of the antenna. The paper also applies the proposed technique to design a microstrip patch antenna and a Vivaldi antenna, and compares the results with other methods. Xue and Jin [7] proposed and compared different domain decomposition methods (DDMs) for solving large-scale electromagnetic problems using the FEM. They used the FEM to discretize the electromagnetic domain into subdomains, and used the DDMs to couple the subdomains and solve the resulting linear system. They also evaluate the performance of the DDMs in terms of accuracy, convergence, scalability, and parallel efficiency. Calò, *et al.* [8] propose and demonstrate a novel integrated Vivaldi antenna for optical wireless communication on chip. With the increasing in transmission rate on the field of wireless communication, the development of a simple and effective model for simulating the EM waves propagation on different environments is strongly demanded.

The present study deals with a fully 3D simulation of the propagation of an electromagnetic wave in different dielectric and conductive environments, in the microwave frequency range. We will examine the effects of different mediums in order to be able to determine the physical quantities which characterize the state of electromagnetic systems, in particular around the transmitting antenna. This work uses the FEM to design and optimize the antenna, and uses the photolithography and lift-off techniques to design the antenna on a silicon substrate. The performance of the antenna in terms of return loss, radiation pattern, gain, and bandwidth is also investigated. This paper therefore aims to provide better knowledge on the radiation of high-frequency antennas with the related electromagnetic field propagation and helpful guidance for antennas design.

2. Materials and Methods

2.1. FEM Formulation

The equations that define the fundamental relationships between electromagnetic quantities are Maxwell's equations. These equations allow us to fully describe all electromagnetic phenomena. It is shown that the wave propagation equation is written as follows:

$$\nabla \times \mu^{-1}{}_{r}\left(\nabla \times \vec{E}\right) - k_0^2\left(\varepsilon_r - j\sigma / \omega\varepsilon_0\right)\vec{E} = \vec{0} \qquad (1)$$

2.2. Vivaldi Antenna Modeling

Figure 1 shows the Vivaldi antenna modeled in COMSOL Multiphysics. The slot has one end exposed to the air and the other end closed by a circular slot. The substrate's bottom has a 50 Ω microstrip feed line that is short-circuited and modeled as perfect electrical conductor surfaces. The whole model is bounded by a perfectly matched layer. A lumped port is used to feed the antenna. **Table 1** presents the parameters of the Vivaldi antenna used in this study. **Figure 2** illustrates the FEM model obtained mesh.

3. Results and Discussions

3.1. Propagation Medium: Air

Figure 3 represents the values of the power of the field radiated around the

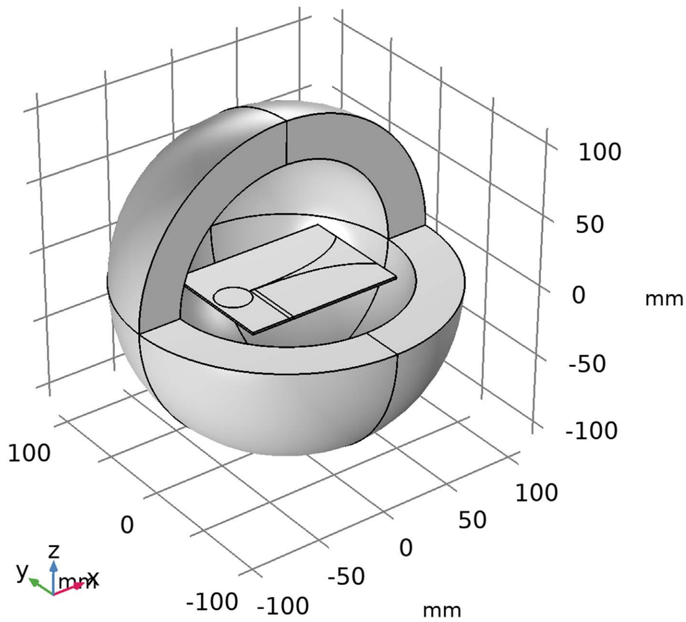

Figure 1. Vidalvi antenna model.

Table 1. Specifications adopted for the simulated inverter.

Name description	Expression	Value	Description
thickness	60 [mil]	0.001524 m	Substrate thickness
w_slot	0.5[mm]	5E−4 m	Slot width
f_min	2.0 [GHz]	2.E9 Hz	Minimum frequency in sweep
f_max	6.0 [GHz]	6.E9 Hz	Maximum Frequency in sweep
f0	6.0 [GHz]	6.E9 Hz	Current frequency in sweep
llda0	c_const/f0	0.115384 m	Current wavelength, air
h_max	0.2*lda0	0.0230768 m	Maximum element size, air

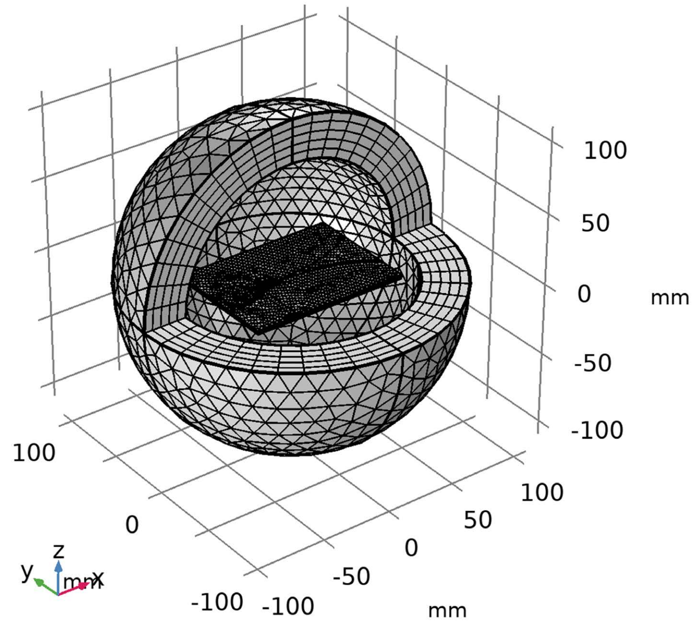

Figure 2. FEM model mesh.

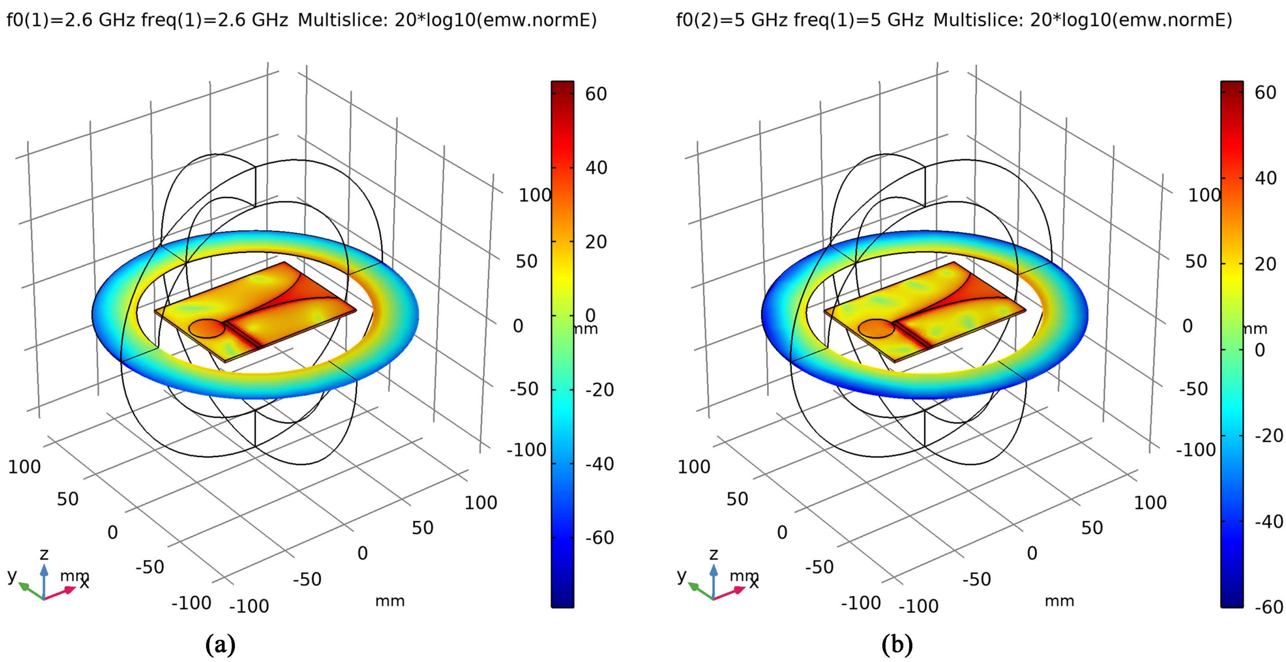

Figure 3. Multicut diagram of the field for a frequency in the air of: (a) 2.6 GHz; (b) 5 GHz.

antenna for the frequencies 2.6 and 5 Ghz. It appears that in the air, strong electric fields are observed in the slit and the microstrip line.

Figure 4 illustrates the propagation of the wave in space, the evolution of the field is represented in 3D around the radiating element.

In the air, at the 5 GHz frequency, the field is more directional (narrower main lobe) than at the 2.6 GHz frequency.

The radiation or emission diagrams (graphical representation of the angular distribution of the energy emitted by an antenna) in the air for the two frequencies are superimposed on the following **Figure 5**, in order to better compare them.

Indeed, in the air, the field simulated at the 5 GHz frequency is more directional than that simulated at the 2.6 GHz frequency. We also note the presence of several secondary lobes for the higher frequency.

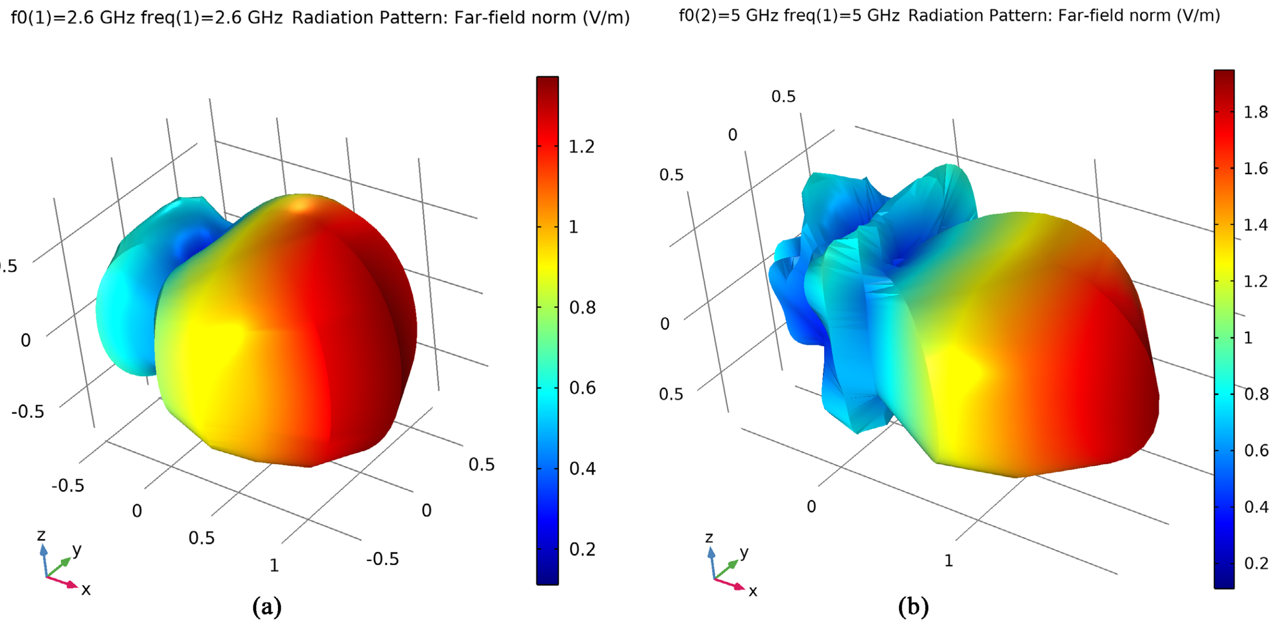

Figure 4. 3D evolution of the field in the air for (a) 2.6 GHz; (b) 5 GHz.

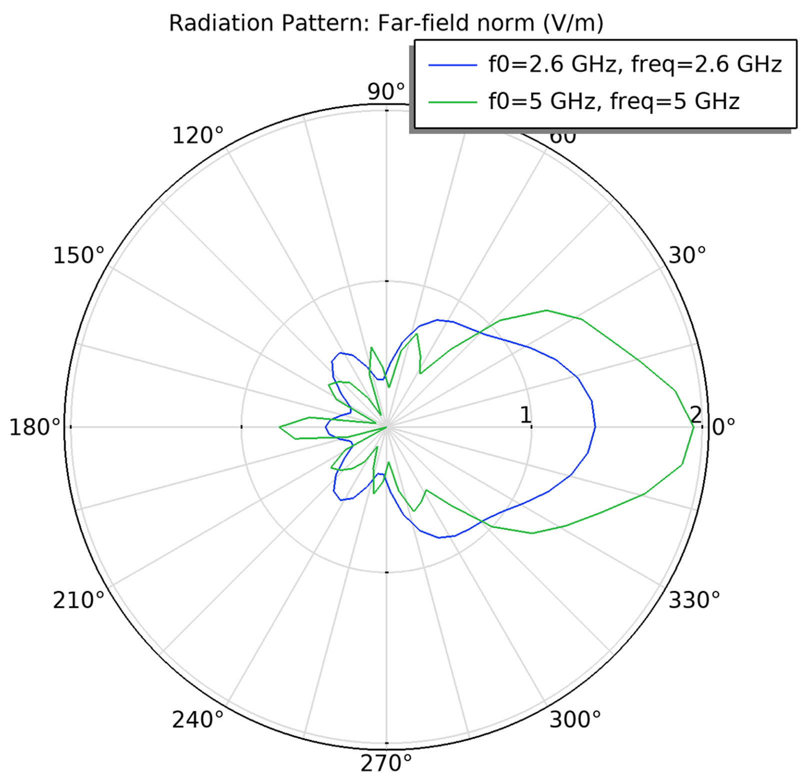

Figure 5. 2D far field radiation patterns (xy plane) in air for frequencies 2.6 and 5 GHz.

3.2. Propagation Medium: Glass

Glass was chosen to emulate transmission over optical fiber, a medium widely used by operators on their transport and backhaul networks. The values of the power of the radiated field are represented by the following **Figure 6**:

The electric fields are even greater in the slit and the microstrip line, as well as on the substrate, compared to those observed when the propagation medium is air.

Figure 7 represents the 3D evolutions of the field in the glass. It has characteristics

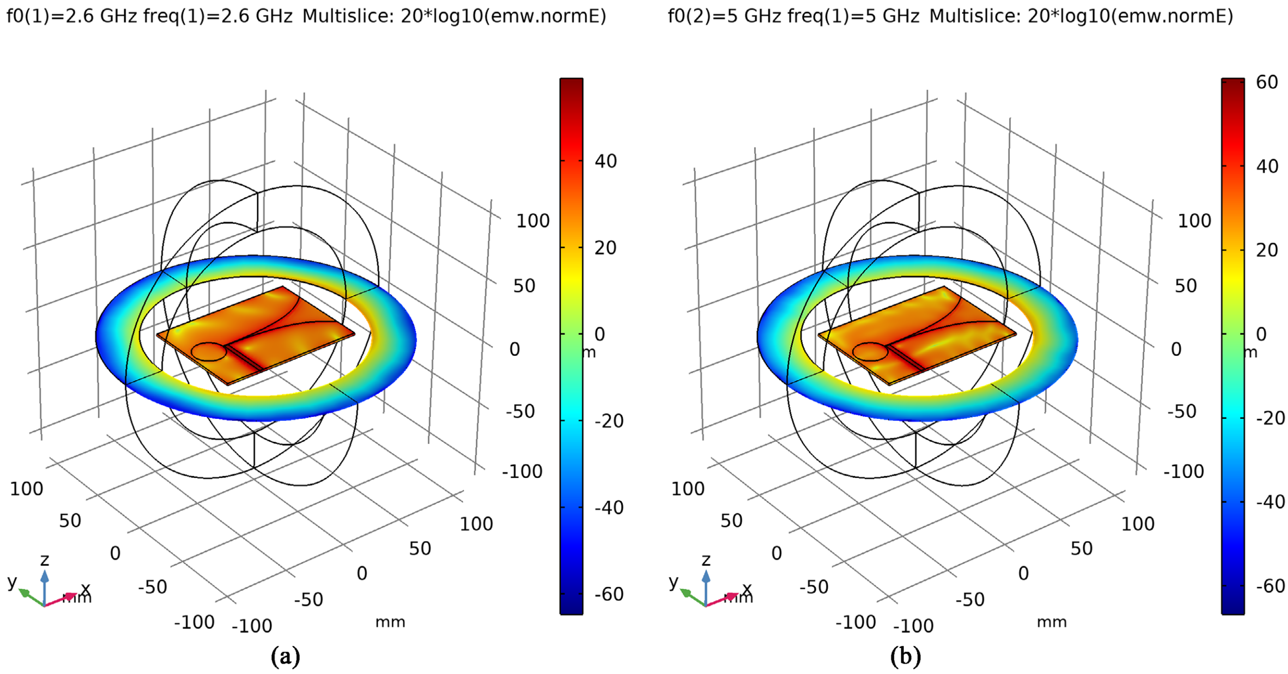

Figure 6. Multicut diagram of the field for a frequency in the glass of: (a) 2.6 GHz; (b) 5 GHz.

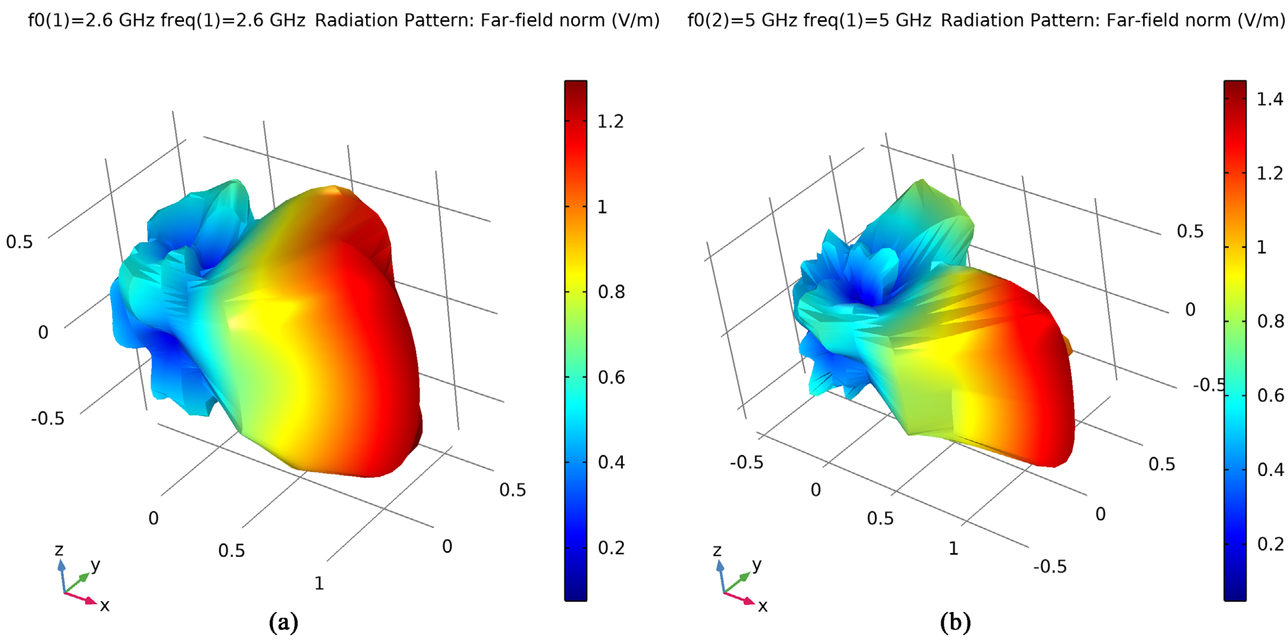

Figure 7. 3D evolution of the field in the glass for (a) 2.6 GHz; (b) 5 GHz.

comparable to those obtained for **Figure 4**, but they are less regular.

The radiation patterns of the two frequencies are laid out in **Figure 8**.

When the wave propagates in glass, the 5 GHz radiation pattern is more directional than that of 2.6 GHz, as in the case of propagation in air. However, here the main lobes are narrower for both frequencies.

3.3. Propagation Medium: Copper

The values of the power of the field radiated around the antenna are represented for the different frequencies by **Figure 9**. The electric fields are very weak in the slot and the microstrip line for copper, compared to the values obtained in the air and glass propagation media. Since copper is a good conductor, the field evolves fairly uniformly in the surrounding medium. **Figure 10** illustrates the 3D evolution of the field in the copper. For 5 GHz there is a clear convexity around the antenna, we note the existence of 2 lobes, directional on both sides, almost symmetrical or even equal.

The far-field radiation patterns for propagation in copper, at frequencies 2.6 and 5 GHz, respectively are depicted first separately by **Figure 11**. In a copper medium, the radiation pattern of the Vivaldi antenna is greatly affected by its frequency.

4. Conclusions

Controlling the propagation of electromagnetic waves is a key point in predicting

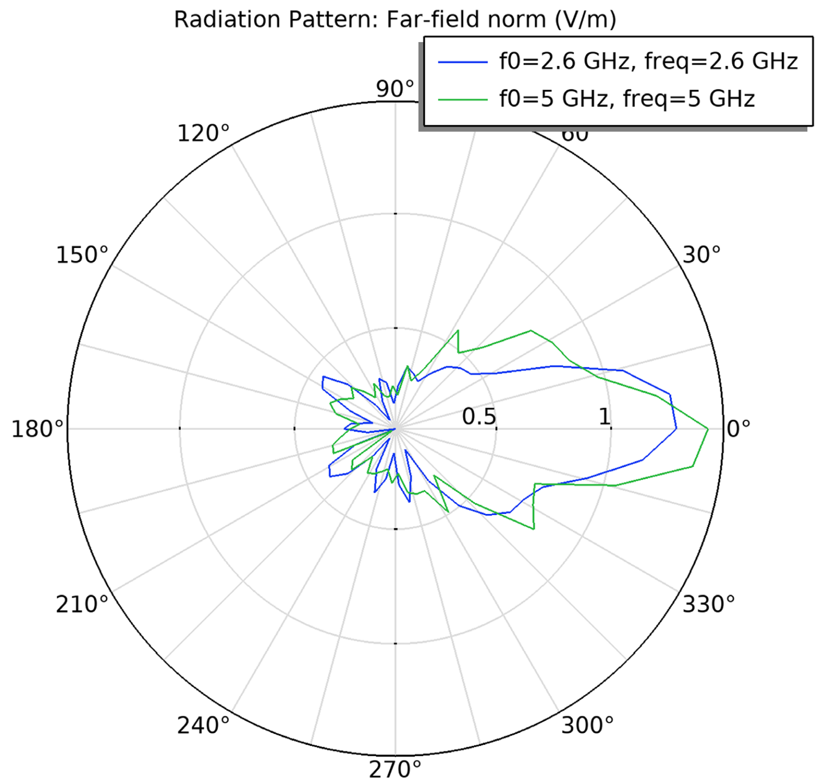

Figure 8. 2D far-field radiation patterns (xy-plane) in glass for frequencies 2.6 and 5 GHz.

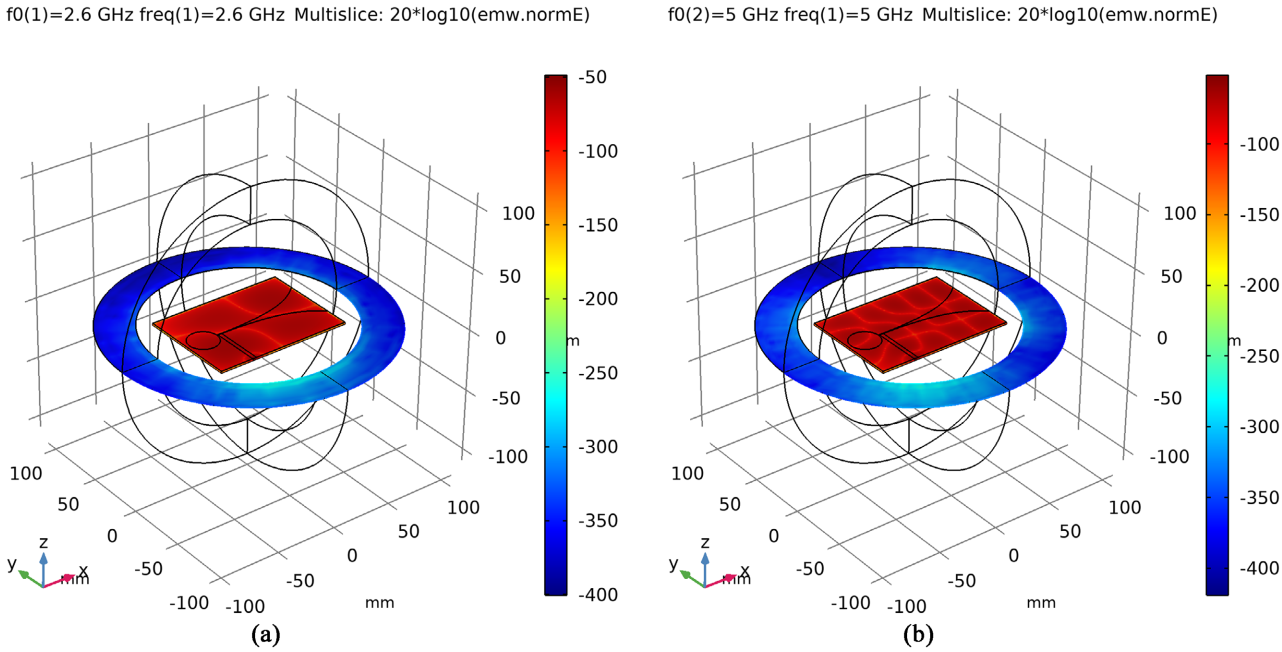

Figure 9. Multicut diagram of the field for a frequency in the copper of: (a) 2.6 GHz; (b) 5 GHz.

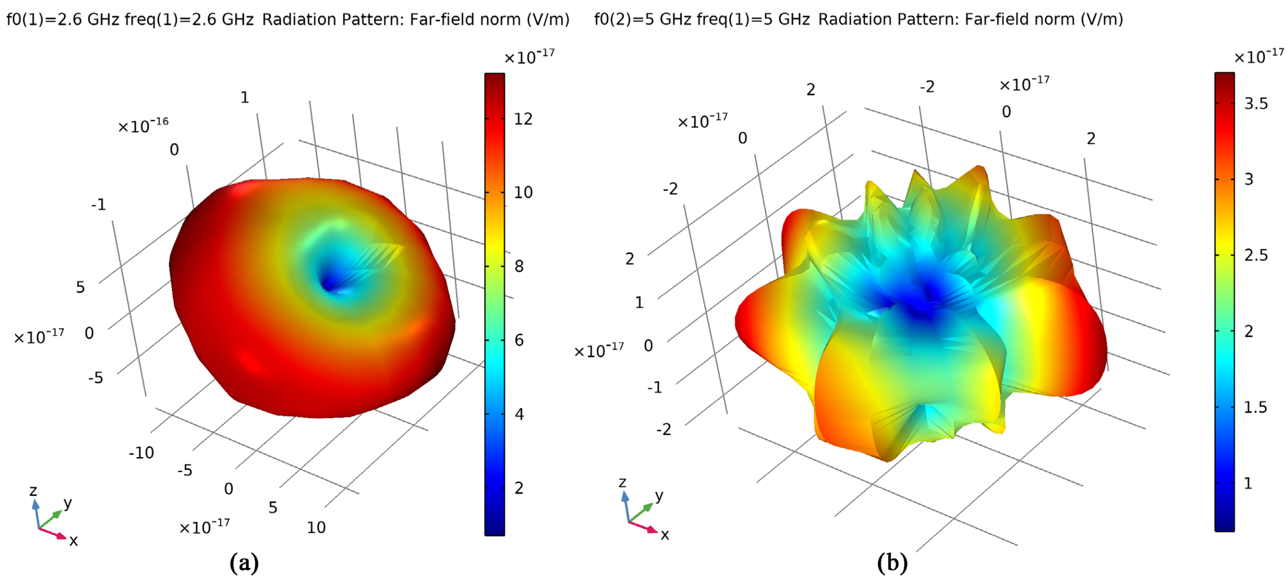

Figure 10. 3D evolution of the field in the copper for (a) 2.6 GHz; (b) 5 GHz.

the performance of electromagnetic systems such as wireless network, hence the importance of a prelude to their deployment. It is necessary to improve their design, but also to help decision-making in an operational context. This work deals with the modeling of the three-dimensional propagation of microwaves, in different conductive and dielectric media. For this, we used the Comsol Multiphysics 5.1 tool, a Vivaldi antenna radiating at 2.6 and 5 GHz frequencies.

The results obtained show that at equal frequency, the values of the field in the air and the glass are comparable in terms of intensity and shape of the radiation diagram, indeed we note in the far field the same order of extremal values. In

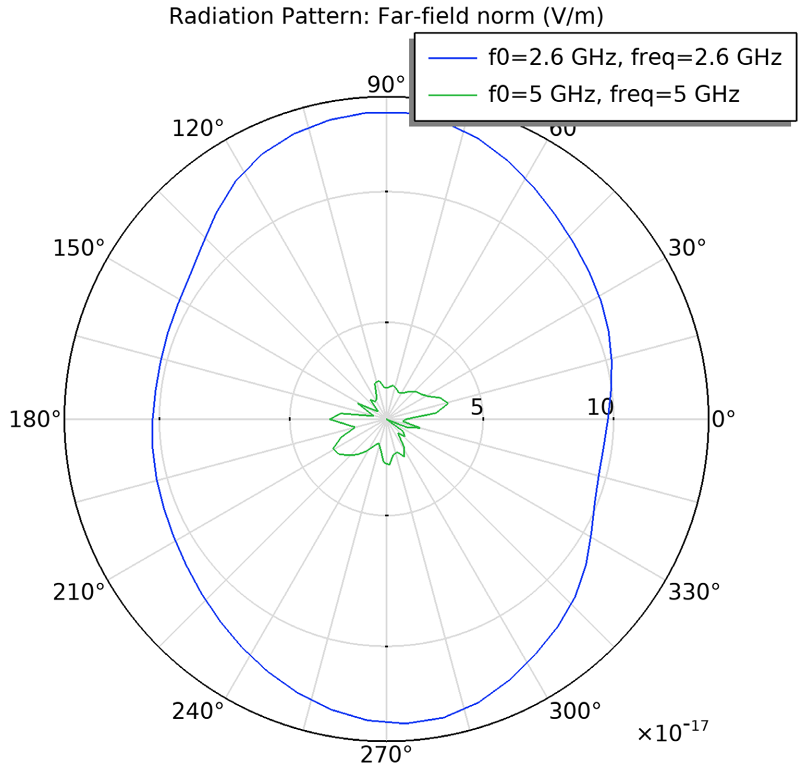

Figure 11. 2D far-field radiation patterns (xy-plane) in copper for frequencies 2.6 and 5 GHz.

general, lower values of the field are obtained, in terms of power and intensity for copper. It was also observed that the radiation diagrams produced for air and glass are directional, and those obtained for copper are bidirectional. Copper being a good conductor, the field evolves fairly uniformly. The propagation medium would therefore influence the range of antenna gain values. Thus, the results corroborate with the fact that this material is used to model and produce waveguides (zero field inside), stealth planes, electromagnetic barriers, Faraday cages and other shielding.

Future work and directions may include other constraints such as the types of soil and relief, the propagation of electromagnetic waves in different wave guides (rectangular, circular), as well as specific phenomena guided waves, resonances and experimental validation also.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Šesnić, S. and Poljak, D. (2013) Antenna Model of the Horizontal Grounding Electrode for Transient Impedance Calculation: Analytical Versus Boundary Element Method. *Engineering Analysis with Boundary Elements*, **37**, 909-913. https://doi.org/10.1016/j.enganabound.2013.03.008

[2] Sarkar, C. (2014) Some Parametric Studies on Vivaldi Antenna. *International Journal of u-and e-Service, Science and Technology*, **7**, 323-328. https://doi.org/10.14257/ijunesst.2014.7.4.29

[3] Diao, Y. and Hirata, A. (2021) Assessment of mmWave Exposure from Antenna Based on Transformation of Spherical Wave Expansion to Plane Wave Expansion. *IEEE Access*, **9**, 111608-111615. https://doi.org/10.1109/ACCESS.2021.3103813

[4] Constantinescu, C., *et al*. (2020) High Frequency Analysis of the Vivaldi Antenna Parameters. 2020 *International Conference and Exposition on Electrical and Power Engineering* (*EPE*), Iasi, 22-23 October 2020, 376-381. https://doi.org/10.1109/EPE50722.2020.9305674

[5] Zhou, L., Tang, M., Qian, J., Zhang, Y.-P., and Mao, J. (2021) Vivaldi Antenna Array with Heat Dissipation Enhancement for Millimeter-Wave Applications. *IEEE Transactions on Antennas and Propagation*, **70**, 288-295. https://doi.org/10.1109/TAP.2021.3091625

[6] Ostadrahimi, M., Noghanian, S., and Shafai, L. (2012) A Novel Antenna Design Technique Using Finite Element Method and Transmission Line Theory. *Microwave and Optical Technology Letters*, **54**, 126-133. https://doi.org/10.1002/mop.26516

[7] Xue, M.-F. and Jin, J.-M. (2015) Domain Decomposition Methods for Finite Element Analysis of Large-Scale Electromagnetic Problems. *The Applied Computational Electromagnetics Society Journal*, **29**, 990-1002.

[8] Calò, G., *et al*. (2018) Integrated Vivaldi Antennas, an Enabling Technology for Optical Wireless Networks on Chip. *Proceedings of the* 3*rd International Workshop on Advanced Interconnect Solutions and Technologies for Emerging Computing Systems*, Manchester, January 2018, 1-4. https://doi.org/10.1145/3186608.3186609