Graphene-Based Spiral Nanoantenna for Intrabody Communication at Terahertz

Hadeel Elayan[1], Raed M. Shubair [2], Josep M. Jornet [3], Asimina Kiourti [4], and Raj Mittra[5]
[1]Department of Electrical and Computer Engineering Khalifa University, UAE
[2]Research Laboratory of Electronics, Massachusetts Institute of Technology, USA
[3]Department of Electrical Engineering, University at Buffalo, The State University of New York, USA
[4] ElectroScience Laboratory, The Ohio State University, Columbus, OH, USA
[5] University of Central Florida, USA and King Abdulaziz University, Saudi Arabia

***Abstract*—In this paper, a graphene-based spiral nanoantenna is proposed and investigated for intrabody communication at the Terahertz (THz) frequency band (0.1-10 THz). A spiral antenna configuration is adopted as it possesses various degrees of freedom and exhibits geometries that facilitate miniaturization, which is crucial for practical deployment of nanobiosensors. Graphene is used in the design of the spiral nanoantenna since it results in the excitation of plasmonic eigenmodes, which lead to strong resonances in the lower THz band. Full wave simulation of the proposed spiral nanoantenna is carried out by COMSOL Multiphysics, to obtain the nanoantenna parameters. The desirable features attained, along with its compact size and circularly polarized characteristic, make the proposed spiral antenna design suitable for intrabody nano-communication applications.**

***Index Terms*—nanoantenna, intrabody communication, spiral, Terahertz.**

I. Introduction

Plasmonics and the emerging metamaterials are currently driving the development of a family of novel devices with unprecedented functionalities, such as subwavelength guiding structures, nanoantennas, superlenses, hyperlenses, and light concentrators. To enable communication among nanodevices for *free-space* type of Terahertz (THz) frequency band applications (0.1-10 THz), a novel graphene-based nanoantenna was first introduced by Jornet et al. in [1]. However, few publications address the issue of designing such antenna structures that are needed for in-vivo wireless nanosensor networks (iWNSNs), that offer great benefits for medical monitoring and medical implant communication [2].

In this paper, we develop a graphene-based spiral nanoantenna design for *intrabody* communication. The spiral configuration has been chosen for the problem at hand because the antenna has a number of favorable attributes including consistent gain and impedance response, as well as excellent performance in terms of circular polarization [3]. Such an antenna configuration also possesses various degrees of freedom and a geometry that facilitates miniaturization, which is crucial for practical deployment of nanobiosensors [4]. It is shown in this paper that utilizing graphene in the design of the spiral nanoantenna leads to the excitation of plasmonic eigenmodes, which in turn introduce strong resonances in the lower THz band. The use of graphene for antennas could potentially lead to very interesting features such as integration with RF active electronics [5], dynamic tuning, optical transparency and mechanical flexibility.

II. Proposed Spiral Nanoantenna Design

A. Theory

A spiral slot antenna provides a conformal design which can be used, due to its wide-band spectral response, for communication, sensing, tracking, positioning, and other such applications [6]. At the THz band, a spiral nanoantenna serves the purpose of sensing, which meets the needs for collecting and redirecting emission from localized sources. One of the most desirable attributes of the spiral-shaped antenna is that it exhibits the smallest and most compact configuration, in terms of the wavelength [7]. These features are particularly desirable for intrabody communication, especially in the context of nanobiosensing as well as cancer detection.

The proposed nanoantenna design, presented in Fig. 1, is composed of a mono-layer of graphene, mounted on a metallic surface. The graphene characteristics, namely the relative permittivity and conductivity, are obtained from [8]. The configuration involves two-arm Archimedean spiral slots. A lumped port is placed at the center of the spiral slot to excite the nanoantenna. To obtain the optimal operational bandwidth, the spiral antenna designed is self-complementary in the geometrical sense. The parameters of the proposed nanoantenna are summarized in Table I.

TABLE I
Spiral Nanoantenna Design Parameters

Outer Radius (r_{out})	47 μm
Inner Radius (r_{in})	10 μm
Number of turns (N)	3

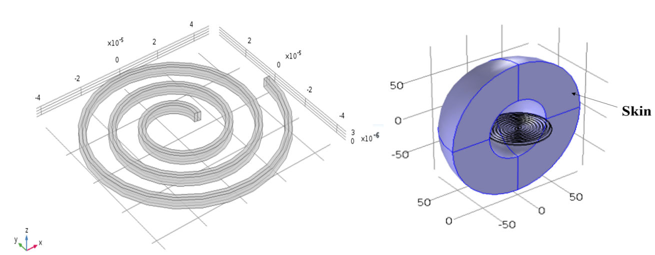

Fig. 1. Proposed graphene-based spiral nanoantenna design.

B. Electrical Properties of Human Tissues in the THz Band

The dielectric response in the frequency domain of tissues having high water content can be characterized by the Debye Relaxation Model [9]. In particular, to provide the best approximation of complex permittivity for polar liquids at frequencies up to 1 THz, the double Debye formulas are used [10]

$$\epsilon = \epsilon_\infty + \frac{\epsilon_1 - \epsilon_2}{1 + jw\tau_1} + \frac{\epsilon_2 - \epsilon_\infty}{1 + jw\tau_2}. \tag{1}$$

Using the values in Table II, ϵ' and ϵ'' are computed. Also, the naoantenna structure is enclosed by a perfectly matched layer (PML) which mimics the electrical properties of the human skin at THz.

TABLE II
PERMITTIVITY AND RELAXATION TIME VALUES OF SKIN

Model	ϵ_∞	ϵ_1	ϵ_2	τ_1(ps)	τ_2(ps)
Skin [9]	3.0	60.0	3.6	10.6	0.2

C. Simulation Results

To assess the performance of the proposed spiral nanoantenna, the return loss $|S_{11}|$, voltage standing wave ratio (VSWR), and far field radiation pattern have been computed using COMSOL Multiphysics software.

Fig. 2 plots the variation of the return loss $|S_{11}|$ as a function of frequency between (0.1-1 THz). It can be observed that the return loss satisfies the -10 dB requirement over the entire simulated THz band. This favorable feature allows the proposed spiral nanoantenna design to be simultaneously used for multiple functions. The efficiency and suitability of the proposed nanoantenna design are further verified by computing the VSWR, as depicted in Fig. 3. It can be noted that the VSWR spectral response over the simulated THz band satisfies the 1:2 upper limit. The 3D far-field visualization in Fig. 4 shows a bi-directional radiation pattern and a maximum radiation along the z-axis. The preference of such radiation pattern stems from the fact that power is radiated in all directions, which is desirable for nanobiosensing applications.

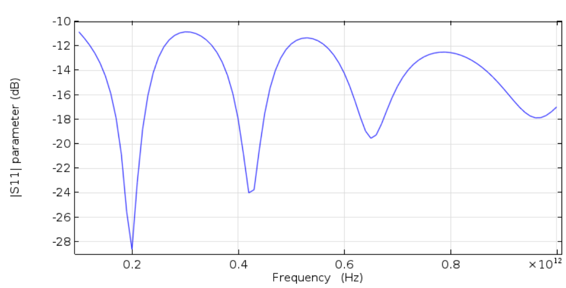

Fig. 2. The S_{11} parameter plot shows better than -10 dB S_{11} over the simulated frequency.

III. CONCLUSION

The design of a graphene-based Terahertz (THz) spiral slot nanoantenna for intrabody communication was presented and investigated in this paper. The antenna structure selected was a spiral one, because it possesses various degrees of freedom and exhibits geometries that facilitate miniaturization, which is essential for practical deployment of nanobiosensors. The desirable features of the proposed nanoantenna along with its compact size and circularly polarized characteristic, make the proposed design suitable for intrabody nano-communication applications.

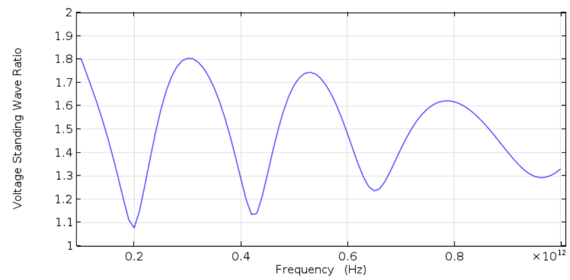

Fig. 3. The VSWR plot satisfies the 1:2 upper limit over the simulated frequency.

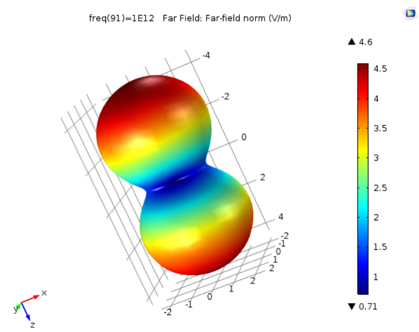

Fig. 4. 3D far-field radiation pattern at 1 THz. The direction of the maximum radiation is along the z-axis.

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