Graphene Reconfigurable Antenna for GPS and Iridium Applications

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Summary
A frequency reconfigurable antenna based on graphene and used for multi-band wireless communications is presented in this article. The proposed antenna, which consists of two radiating rectangular loops with a graphene extension, is analyzed for Global Positioning System (GPS) and Iridium applications. Its operating frequency is tuned through the implementation of a layer of graphene and thereby adjusting the applied gate bias. Furthermore, the results show a novel use of graphene for microwave frequencies while achieving a frequency reconfiguration with an improvement of the impedance matching and the gain. The results also prove the importance of graphene, with its exceptional properties, for a promising future in nano-electronics.
Keywords:
Graphene, Reconfigurable antennas, GPS, IRIDIUM, loop dipole, frequency reconfiguration.

1. Introduction

Thanks to the rapid development in electronics and wireless communications, the demand for mobile devices operating at different standards or for different applications is increasing and it is no longer useful to deploy an antenna for each standard, hence the idea of an antenna capable of supporting more than one standard [1]. This will result in antenna size and cost reduction, as well as higher performance.

The reconfiguration of an antenna is generally achieved by changing its frequency, radiation or polarization characteristics. This change can be determined by different methods that redistribute the antenna currents and therefore, modifies the electromagnetic fields of the antenna's effective aperture, which results in reversible changes in the antenna impedance and/or the radiation properties [2]. Thus, a single reconfigurable antenna could perform the job of multiple antennas while occupying less space.

Since the rise of the reconfigurable antennas, several techniques have been proposed. The tunability can be achieved electrically by disturbing the antenna current using active elements such as PIN diodes [3-4], varactors [5] or by micro electromechanical systems (RF-MEMS) [6] or mechanically by altering the structure of the antenna [7]. Otherwise, tunablity can be obtained by implementing smart materials on the antenna structures such as ferrites, liquid crystals [8- 9] and graphene plasmonic materials [10].

However, numerous factors have to be taken into consideration when designing frequency reconfigurable antennas, such as making a considerable gain, stable radiation, and good impedance match throughout all the antenna operation states. In the past decades, the implementation of graphene has risen as another technique to achieve reconfigurability for different properties. Different research areas has gained much interest in graphene thanks to its particular chemical, mechanical, electronic, thermal and optical proprieties [11]. Its unique band structure is especially exploited in nano-electronics to achieve novel high-speed devices [12], such as field effect transistors [13], frequency multipliers [14] and optical devices [15]. High speed can be achieved by the special energy of the band structure and ultra-high electron mobility in the grapheme material [16-17].

The remarkable characteristics of graphene, namely its high sensitivity and electron mobility, its thermal conductivity, and its tunability [18], [19], can bring significant benefits to the field of antenna technology. Among these we can mention the miniaturization, the working in microwave [20], the THz domains [21] and the tuning of the resonant frequency. When compared with some conventional materials commonly adopted for the synthesis of antennas such as the copper or the silver, the graphene was found to be more advantageous due to its powerful characteristics [22]. "Although it has other advantages, we chose to focus mainly on its tunability which can be easily obtained by an applied external electric or magnetic bias field (i.e., affecting graphene chemical potential), and mechanical properties.

In this paper, a frequency reconfigurable antenna is presented. In the first part, the simulated antenna without any added components is operating at 1.54 GHz to notice the antenna response. Then, by exchanging the cooper used for the loops with a layer of graphene implemented on the FR4 substrate without changing the geometrical parameters. The proposed graphene-based antenna can switch between the GPS and the Iridium frequencies through the adjustment of the applied gate bias. The obtained results were

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impressive and showed a novel use of graphene for microwave frequencies.

2. Graphene Behavior

In this paper, an attempt has been made to accurately model a graphene-based antenna operating in the gigahertz (GHz) regime. When we compared the metallic antenna with the graphene-based antenna, we observed a notable agreement.
In literature, it is known that the electromagnetic fields of the metallic antenna are managed by Maxwell's equations. Therefore, graphene antenna is described in terms of its surface conductivity that is expressed by the Kubo formula as a function of frequency f, temperature T, chemical potential µc and scattering rate Γ.
However, the graphene is a flat mono-atomic layer of carbon atoms arranged in the form of two-dimensional honeycomb crystal lattices. Graphene can be modeled as an infinitely thin surface with the complex conductivity σ. Its surface conductivity can be determined by using Kubo formula as follows:

$$\sigma(\omega) = \frac{jq_e(\omega - j2r)}{\pi h^{-2}} \left[\frac{1}{(\omega - j2r)^2} \int_0^\infty \left(\varepsilon \frac{\delta f_d(\tau) - \delta f_d(-\tau)}{\delta\varepsilon}\right) \delta\varepsilon - \int_0^\infty \frac{f_d(-\tau) - f_d(\tau)}{(\omega - j2r)^2 - 4(\frac{\tau}{h})^2} \delta\varepsilon \right] \quad (1)$$

Where ω is the radian frequency, is the scattering rate, ε is the energy, q_e is the electron charge, T is the temperature, h is Planck's constant and fd is the Fermi-Dirac distribution which is described as follows:

$$f_d = (e^{\frac{\varepsilon - \mu_c}{K_B T}} + 1)^{-1} \quad (2)$$

Where µc is the chemical potential and K_B is the Boltzmann's constant.

3. Antenna Design

3.1 Structure of the antenna

Fig. 1 shows the 3-D structure of the proposed rectangular bi-loop single-feed antenna printed on an FR-4 epoxy substrate with a size of 90*90mm², a relative permittivity 4.4 and a thickness of 0.8mm [8]. The proposed antenna consists of two radiating loops printed on the top of the substrate with LL =70mm, WL =35mm and e=1mm. The substrate is mounted at a height of 55mm above the ground plane by a coaxial single-feed antenna.

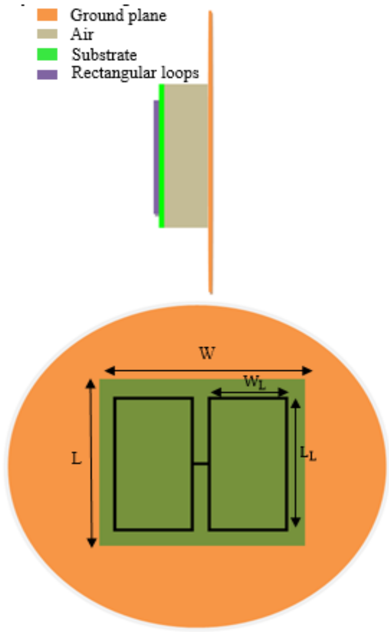

Fig. 1. Schema of the dipole antenna

3.2 Results

In this section, the proposed antenna is simulated without any added components. To validate the results of the proposed design, we used two software simulators HFSS and CST. The simulated reflection coefficient magnitude of the proposed bi-loop antenna is shown in Fig. 2. It can be noticed that the loop antenna operates at 1.54 GHz with a maximum peak value of -29.02 dB for this simple configuration.

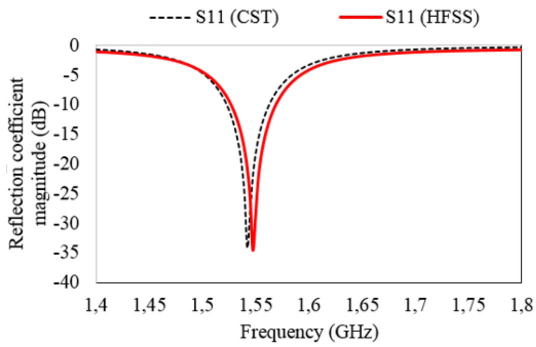

Fig. 2. S11 of the initial antenna

Through the optimization of the antenna shown in Fig; 1, the antenna operates at 1.54 GHz. Also, Fig. 2 shows that the bandwidth of the antenna for this initial configuration is around 420MHz for -10dB going from 1.525 to 1.567 GHz for -10dB. Fig. 3 presents the VSWR of the antenna that describes how well the antenna gets its impedance matched. The VSWR value should be less than 2 for a more efficient antenna.

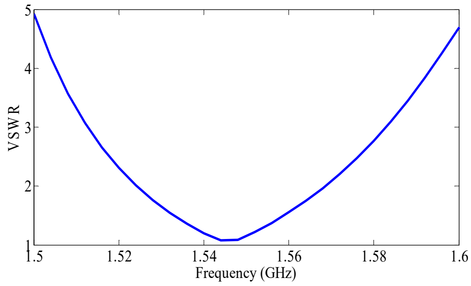

Fig. 3. VSWR

Fig. 4 illustrates the 3-D simulated gain of the proposed antenna at its operating frequency. It can be seen that the maximum gain of the proposed antenna simulated at 1.54 GHz is 4.59 dB.

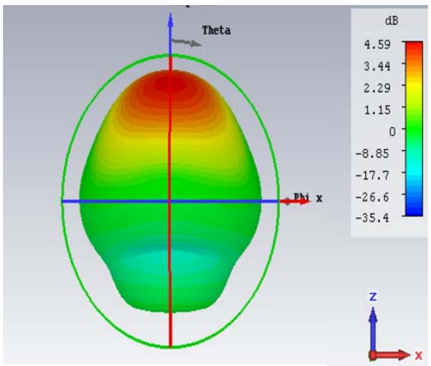

Fig. 4. Simulated 3D- Gain of the antenna

3. Reconfigurable antenna

One of the remarkable disadvantages of metallic antennas is that they are not tunable. Because of its conductive properties, graphene could be a promising material for the reconfiguration of the antenna. The major property of graphene consists in its electromagnetic wave propagation speed which can be up to 100 times lower than the free space or that of conventional materials. The antenna structure is simulated and investigated using the CST Microwave Studio and validated by Ansoft HFSS simulator. In the first part, a loop antenna printed on the top layer of an FR4 epoxy substrate is simulated without any added components. Then, we have modified the initial structure by replacing the cooper used for the loops by a layer of graphene without changing any of the geometrical parameters of the antenna, as shown in Fig. 5.

In the first part of the paper, the initially designed structure resonates at a frequency of 1.54 GHz. By replacing the metal-based loops with loops based on graphene, an alteration in the antenna's resonant frequency occurs while keeping the same dimensions. Fig. 6 shows the corresponding frequency of reconfiguration which is reached by the adjustment of the chemical potential. This latter affects the phase velocity, characteristic impedance and propagation constant.

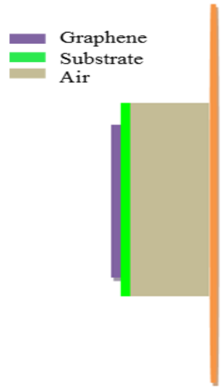

Fig. 5. Structure of the antenna with the graphene-based Switch

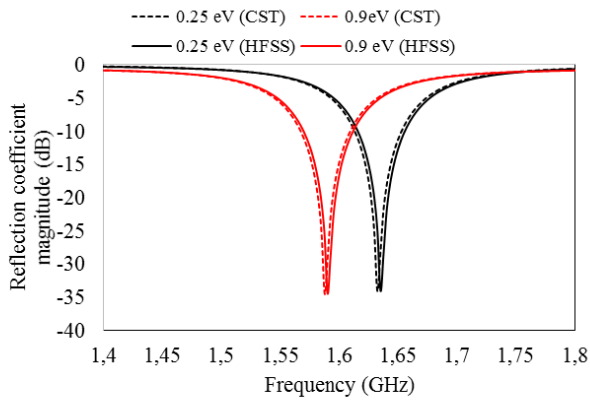

Fig. 6. S11 of the graphene antenna for diffe0rent chemical potentials

In the case where the chemical potential is μ_c=0.25 eV, the resonant peak appears at 1.587 GHz. When the chemical potential is changed to 0.9 eV, the antenna resonates at 1.622 GHz, as shown in Fig. 6. These results show that the proposed antenna can be useful for GPS and Iridium applications. As a result, each time the chemical potential of the graphene is changed, the resonant frequency of our antenna changes as well.

In the referenced work [4], the reconfiguration process is based on PIN diode in spite of its disadvantages, namely its high-power consumption. Also, the incorporation of switches increases not only the complexity of the antenna structure but also its price due to the need for additional shunt capacitors and inductors. On the other hand, the activation of the switch requires lines of polarization that can adversely affect the radiation pattern of the antenna and add more losses.

Although graphene is not widely used since it is a newly discovered technology, it is nowadays seen as one of the most reliable mechanism for reconfiguration. When we compare the results found in [4] with the results of this study, we notice the various advantages that distinguish graphene from other methods. Among these; its high performance, good matching and efficiency. Despite the interesting findings of the recent research into nanotechnology, we found that graphene could be a better solution thanks to its ability of miniaturization. There is a difference between the use of initial methods in [4] and the graphene to achieve the reconfiguration process. For the usual methods, the designer of the antenna focuses on the surface current distributions then puts the switchers whose number (one or more) can be determined through optimization. The reconfiguration is realized by turning the switchers on or off, whereas for graphene the procedure is much simpler, as only one layer of graphene is used to reach reconfiguration. By replacing the metal loops with a layer of graphene, the resonant frequency of the antenna changes each time the chemical potential is changed, which shows the efficiency of the graphene.

Our results show that this modification improves the adaptation of the antenna and helps to attain reconfiguration by a simple alteration of the chemical potential. Similarly, it is clear from the results shown in Figure 6 that graphene could be a perfect solution to realize reconfiguration through altering the chemical potential of the antenna. The simulation results prove that graphene has an important role in the reconfiguration of the antenna thanks to its electronic proprieties that can be tuned by its chemical potential, hence the production of a tunable antenna. Contrary to the usual techniques employed to modify the surface reactance such as the use of printed elements, pins of different heights or dielectric slabs with variable thickness, we propose in this study the use of graphene to create the required impedance modulated surface.

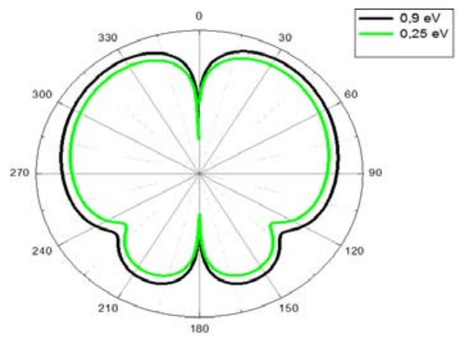

Fig. 7. Radiation pattern of the graphene antenna for different chemical potential

Fig. 7 shows the radiation pattern of the graphene antenna, which slightly changes for different chemical potentials. For μ_c=0.25 eV, the graphene antenna resonates at a bandwidth of 430MHz and at -10dB, while for μ_c =0.9 eV, it resonates at a bandwidth of 440 MHz and at -10dB. An increase in the gain of the antenna has been noticed after including graphene, which demonstrates the powerful role of graphene to increase the gain.

4. Conclusion

In this paper, we investigated a novel use of the graphene antenna for microwave frequencies. The proposed antenna that is based on graphene can switch from GPS to Iridium through a simple adjustment of the applied gate bias. We notice that graphene is different from all the usual techniques of reconfiguration due to its particular properties. Therefore, the designer does no longer need an indefinite number of switchers to achieve reconfiguration due to the integration of a layer of graphene on the antenna. The results show that the proposed loop antenna has a better adaptation than the initial metallic structure that is based on PIN diode, which proves the potential role of graphene for a rising future in nano-electronics.

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