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Tunable Graphene-Based Rectangular Nano Patch Antenna for 5.5THz WLAN Applications: Design, Simulation, and Analysis

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Abstract

The demand for high-speed and reliable Wireless Local Area Networks (WLAN) has driven the exploration of efficient antenna designs in the THz frequency band. This study presented the design and simulation results of a rectangular nano patch antenna constructed from graphene for Wireless Local Area Network (WLAN) applications with a resonating frequency of 5.5THz. The antenna was designed using HFSS software, considering FR-4 Epoxy as the dielectric material with a constant of 4.4 and varying thicknesses (3µm, 5µm, 7µm, 10µm, and 15µm). The study explored design considerations and provided comprehensive simulated results. The findings indicate a decreasing trend in resonating frequency as the substrate height increased. Acceptable Voltage Standing Wave Ratio (VSWR) values of 1.5347 and 1.4815 were achieved at substrate heights of 7µm and 10µm, respectively. The most acceptable VSWR value of 1.4815 corresponds to a substrate height of 10µm, aligning with the resonant frequency of 5 THz. The return loss initially increases with substrate height, reaching a maximum value of -21.4037 dB at H=10µm, resonating at 5 THz, and then exhibits a decreasing trend. Furthermore, the gain and directivity of the antenna show an increasing trend with an augmentation in substrate height. These outcomes suggest the potential for tuning the antenna's operating frequency across the THz band by adjusting the antenna height. In conclusion, the graphene-based rectangular nano patch antenna offers tunability and desirable performance characteristics, making it a promising candidate for high-frequency WLAN applications

***Keywords*:** Re-configurable, Graphene, Substrate, Terahertz Frequency, Directivity

Antenne rectangulaire nano-patch à base de graphène accordable pour applications WLAN à 5,5 THz : Conception, simulation et analyse

Résumé

La demande de réseaux locaux sans fil (WLAN) rapides et fiables a motivé l'exploration de conceptions d'antennes efficaces dans la bande de fréquences THz. Cette étude présente les résultats de conception et de simulation d'une antenne rectangulaire nano-patch en graphène destinée aux applications WLAN, avec une fréquence de résonance de 5,5 THz. L'antenne a été conçue à l'aide du logiciel HFSS, en utilisant de la résine époxy FR-4 comme matériau diélectrique avec une constante de 4,4 et des épaisseurs variables (3 µm, 5 µm, 7 µm, 10 µm et 15 µm). L'étude explore les considérations de conception et fournit des résultats simulés détaillés. Les résultats indiquent une tendance à la baisse de la fréquence de résonance avec l'augmentation de la hauteur du substrat. Des valeurs acceptables du Taux d'Ondes Stationnaires (VSWR) de 1,5347 et 1,4815 ont été obtenues pour des hauteurs de substrat de 7 µm et 10 µm, respectivement. La valeur VSWR la plus acceptable, 1,4815, correspond à une *hauteur de substrat de 10 µm, coïncidant avec une fréquence de résonance de 5 THz. La perte de retour augmente initialement avec la hauteur du substrat, atteignant un maximum de -21,4037 dB pour H=10 µm à 5 THz, puis présente une tendance à la baisse. Par ailleurs, le gain et la directivité de l'antenne augmentent avec l'épaisseur du substrat. Ces résultats suggèrent la possibilité d'ajuster la fréquence de fonctionnement de l'antenne dans la bande THz en modifiant la hauteur de l'antenne. En conclusion, l'antenne rectangulaire nano-patch à base de graphène offre une accordabilité et des performances prometteuses, en faisant un candidat idéal pour les applications WLAN haute fréquence.*

Mots-clés : Reconfigurable, Graphène, Substrat, Fréquence Térahertz, Directivité

١٣. هوائي رقعة نانوية مستطيلة قابل للضبط يعتمد على الجرافين لتطبيقات الشبكات اللاسلكية (WLAN) عند تردد 5.5 تيراهرتز: التصميم، والمحاكاة، والتحليل

لقد أدى الطلب المتزايد على شبكات المناطق المحلية اللاسلكية (WLAN) عالية السرعة والموثوقية إلى دفع جهود البحث نحو تصميم هوائيات فعالة في نطاق تردد التيراهرتز (THz). وتعرض هذه الدراسة تصميم ومحاكاة لهوائي رقعة نانوية مستطيلة مصنوع من الجرافين لتطبيقات الشبكات اللاسلكية (WLAN) بتردد رنين يبلغ 5.5 تيراهرتز. وقد تم تصميم الهوائي باستخدام برنامج HFSS ، مع اختيار مادة FR-4 Epoxy كعازل كهربائي بثابت عزل قدره 4.4 وسماكات مختلفة (3 ميكرومتر، 5 ميكرومتر، 7 ميكرومتر، 10 ميكرومتر، و15 ميكرومتر).

استعرضت الدراسة اعتبارات التصميم وقدمت نتائج محاكاة شاملة. وتشير النتائج إلى اتجاه تنازلي في تردد الرنين مع زيادة ارتفاع الطبقة العازلة. وقد تم تحقيق قيم نسبة الموجة الراجعة (VSWR) المقبولة وهي 1.5347 و1.4815 عند ارتفاعات للطبقة العازلة قدرها 7 ميكرومتر و10 ميكرومتر على التوالي. وكانت أفضل قيمة لـ VSWR هي 1.4815 عند ارتفاع 10 ميكرومتر، متوافقة مع تردد الرنين 5 تيراهرتز.

أما فقد الإرجاع (Return Loss) فقد أظهر زيادة أولية مع ارتفاع الطبقة العازلة، حيث بلغ أقصى قيمة له -21.4037 ديسيبل عند ارتفاع 10 ميكرومتر، متوافقًا مع تردد 5 تيراهرتز، ثم بدأ في الانخفاض. علاوة على ذلك، أظهرت الكسب (Gain)والقدرة التوجيهية (Directivity) للهوائي اتجاهًا تصاعديًا مع زيادة ارتفاع الطبقة العازلة.

تشير هذه النتائج إلى إمكانية ضبط تردد تشغيل الهوائي داخل نطاق تيراهرتز من خلال تعديل ارتفاع الهوائي. وفي الختام، فإن هوائي الرقعة النانوية المستطيلة القائم على الجرافين يتمتع بقابلية للضبط وخصائص أداء مرغوبة، مما يجعله مرشحًا واعدًا لتطبيقات WLAN عالية التردد.

الكلمات المفتاحية: **قابلية إعادة التكوين، الجرافين، الطبقة العازلة، تردد التيراهرتز، القدرة التوجيهية.**

Introduction

An antenna that can have at least one of its attributes changed by applying a command after it has been manufactured is called a reconfigurable antenna. There are numerous classification schemes for reconfigurable antennas. This can be accomplished, for instance, in accordance with the physical attribute that renders them reconfigurable (such as altering current lines, altering the dielectric/diamagnetic properties of antenna elements, or undergoing geometric deformation), in accordance with the kind of reconfigurable components that are employed (such as diodes, transistors, or MEMS), or in accordance with their geometric structure (such as the type of reconfigurable structure, the antenna's a priori geometry). Different methods can be used to reconfigure the antenna. Some methods rely on mechanical modification, while others use localized active components to modify quasi-punctual lines of current or impedance (Cai *et al.,* 2010). And some depend on mechanically changing the antenna's structure (Piazza et al., 2009), while others make use of substrates with adjustable properties (Chang *et al.,* 2015). Certain methods depend on the power supply networks' capacity to be reconfigured (Mazlouman *et al.,* 2011) or appropriately excite the antenna arrays (Surface *et al.,* 2012). The development of microelectronics has made it possible to create re-configurable structures through the use of varactors and electrically operated switches. In fact, when introduced into the antenna's structure, they allow for controlled modifications to the radiating element's size, shape, and/or effective electrical length, as well as the creation of switchable slots or short circuits and the addition of spurious elements. It can be changed continuously (tunability) or selectively (switching). On the other hand, using these components result in significant traffic jams and higher manufacturing costs. Other methods of altering an antenna's electromagnetic characteristics without adding more parts include using "intelligent" or "agile" materials, whose dielectric characteristics (permeability and/or permittivity) can be altered externally by the action of an electric or magnetic field, respectively. Their primary use is as a substrate layer or patch, upon which antennas are constructed. The most amazing of these materials is graphene (Geim *et al.,* 2007). This material has the remarkable optical (Falkovsky *et al.* 2008; Loh *et al.* 2010) and electrical (Castro Neto *et al*., 2009) properties, with the added benefit that these properties may be altered by applying an external voltage (Ajlani *et al* . 2016; Zhan *et al*. 2016). The shape of the radiating element is to make short circuits or slots which can be switched, to add spurious elements and this in a controlled manner. Its modifications are carried out discretely (switching) or continuously (tunability).

Materials and method

In designing an antenna, the first thing to consider is to choose an appropriate substrate. The substrates in microstrip antennas or Nano patch antennas were principally needed for the mechanical support of the antenna. To provide this support, the substrate should consist of a dielectric material, which may affect the electrical performance of the antenna, circuits and transmission line. A substrate must, therefore, simultaneously satisfy the electrical and mechanical requirements, which is sometimes difficult to find. The substrates materials considered in this work is FR-4

Design Requirements

HFSS model was created with graphene patch of 30 × 22 μm, thickness (t) of 0.345 nm as shown in Figure 1. The analysis was performed with graphene patch on FR4-epoxy substrate material having thicknesses of (3μm, 5μm, 7μm, 10μm, and 15μm) and dielectric permittivity, εr = 4.4. The wave propagation velocity for graphene material depends on the patch dimensions, its resonant frequency and the Fermi energy of the structure. Based on graphene's ability to support plasmonic resonant frequency in the THz regime (0.1 - 10THz), we consider the frequency range from 1THz to 10 THz, with fundamental frequency of 5.5 THz.

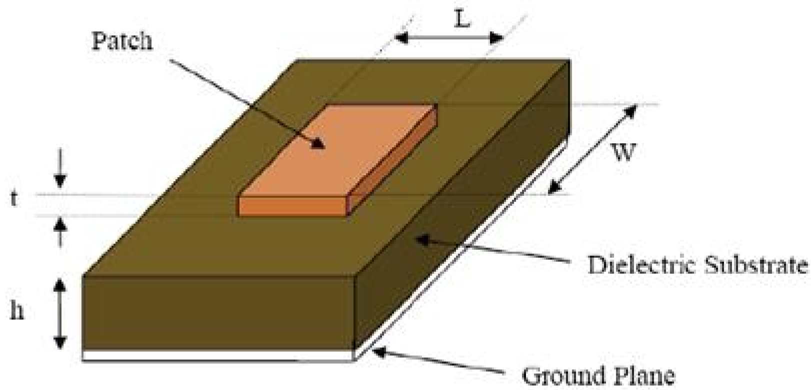


Figure 1. Structure of the Rectangular Patch Antenna (Kokila *et al*., 2016)

Varying Substrate Height (H)

In this section, the height (h) of the substrate is varied for various values of h = 3µm, 5µm, 7µm, 10µm, and 15µm, keeping the other dimensions of antenna model as given in Table1. Detailed comparative analysis performed on various substrate height and the best suitable height determined for graphene based nano patch antenna in THz regime

Table 1: Design Parameters for Nano Patch Antenna.

Design parameters	measurement
Patch thickness (t)	0.345 nm
Length of the Patch	22 µm
Width of the Patch	30 µm
Height of Substrate (H)	3,5,7,10 and 15µm
Length of Substrate	100 µm
Width of Substrate	63 µm
Length of feed line	21 µm
Width of feed line	6.0 µm

ANTENNA DESIGNED IN HFSS

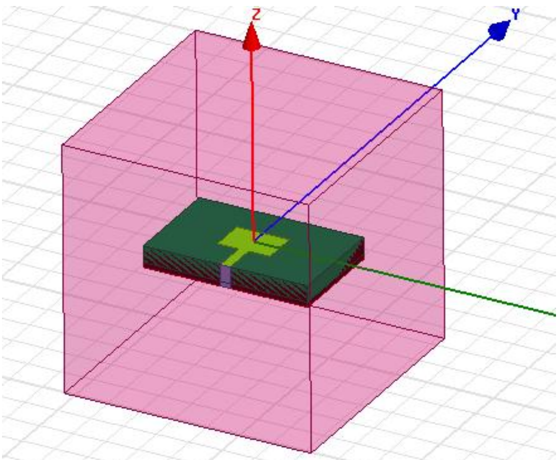
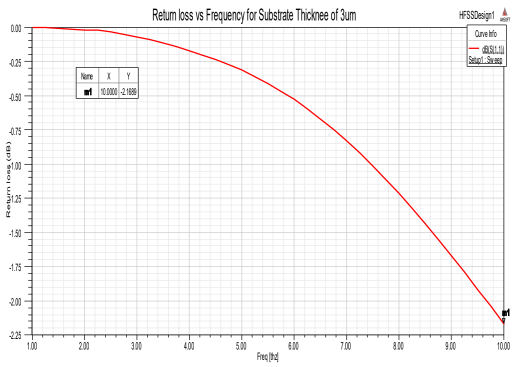


Figure.2: Proposed rectangular patch antenna using HFSS Software

Figure 2 shows the completed design of the proposed antenna. The simulated results of the antenna which includes return loss (S11 parameter), VSWR, 2D radiation pattern as well as 3D radiation pattern were obtained and presented in figure.3 to 7

Simulated Results for Varying Substrate Height



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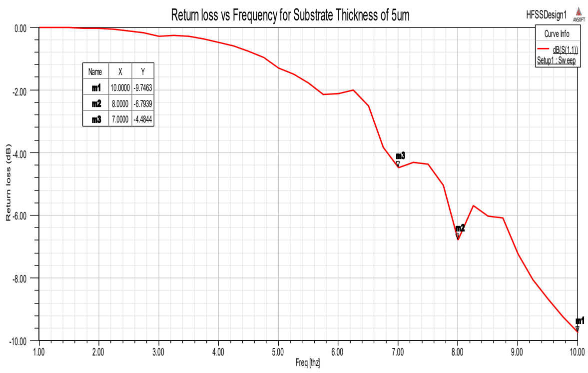

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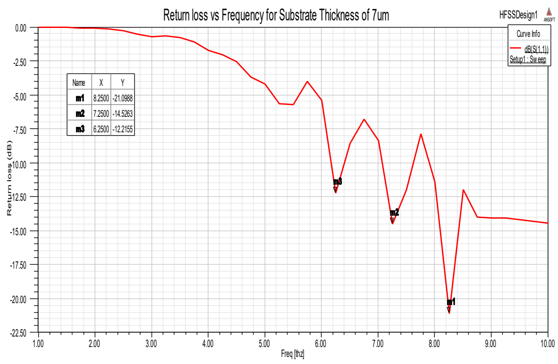

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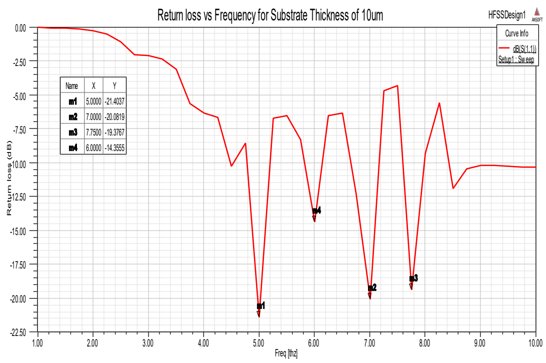

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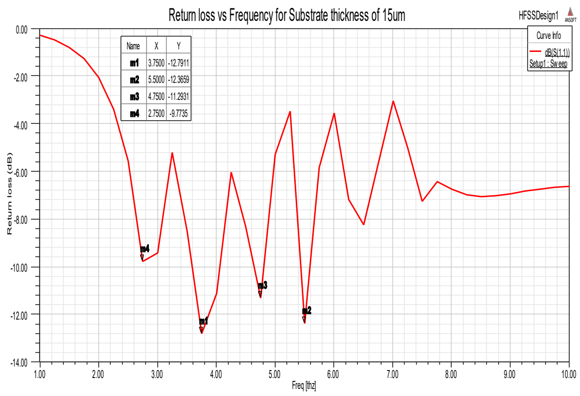

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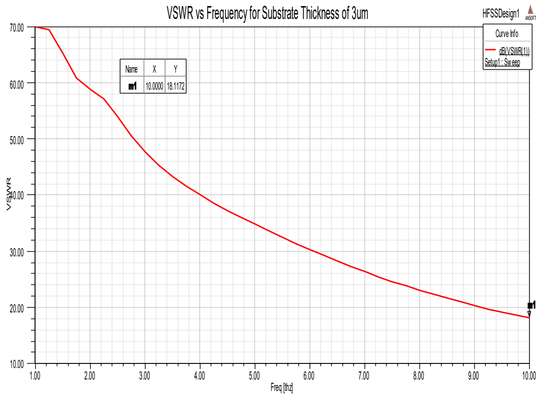
Figure3a-e, Return loss (in dB) curve for substrate height of 3μm, 5μm, 7μm, 10μm and 15μm respectively.



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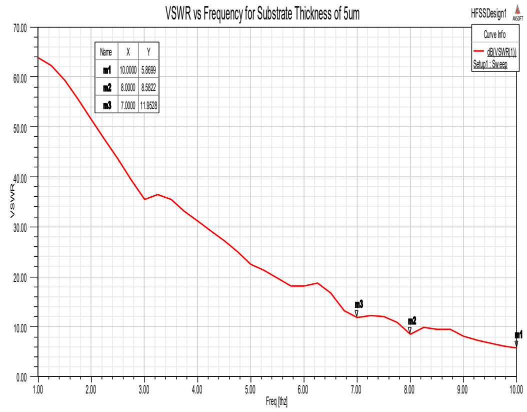

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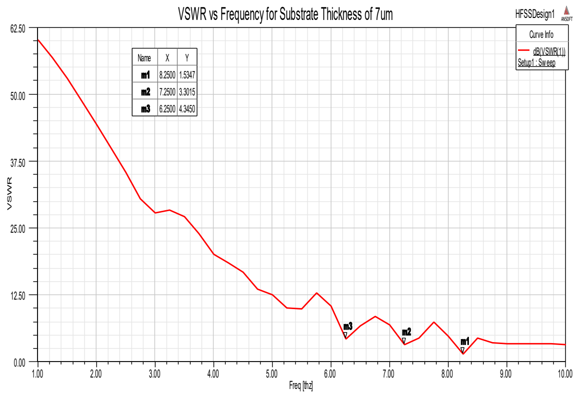

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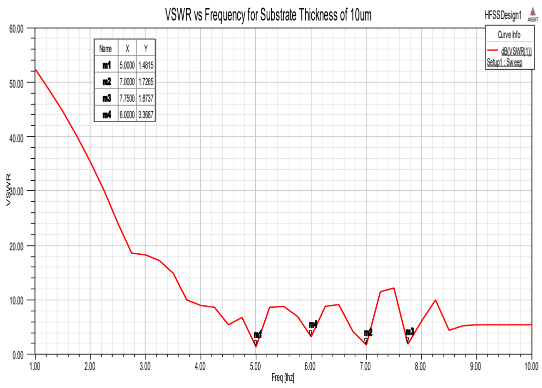

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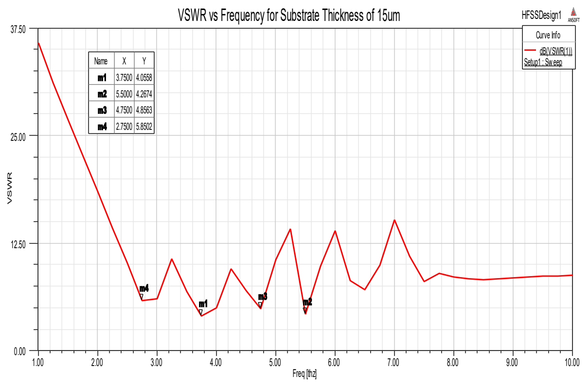

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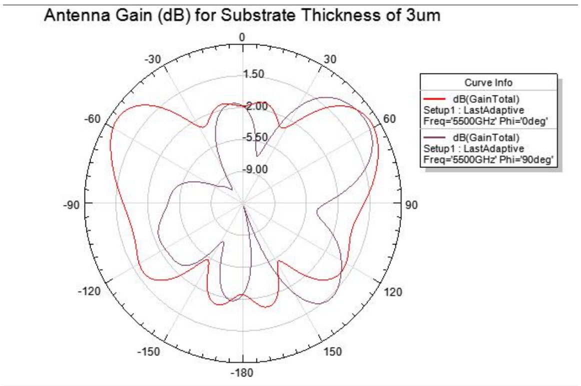
Figure 4a-e. VSWR Curve for Substrate Height, 3µm, 5µm, 7µm, 10µm and 15µm respectively



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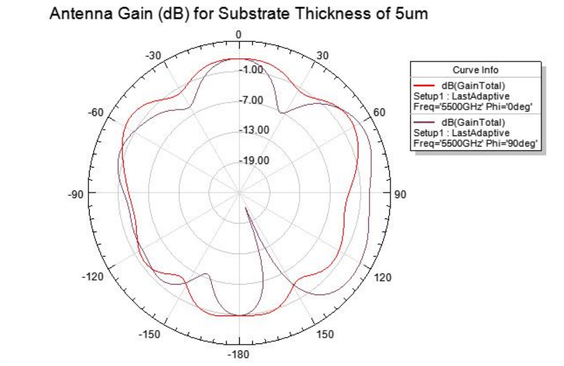

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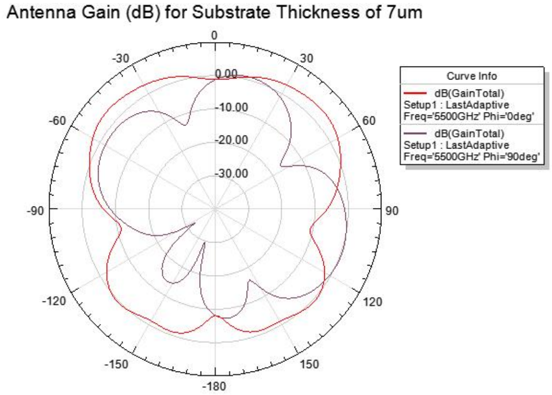

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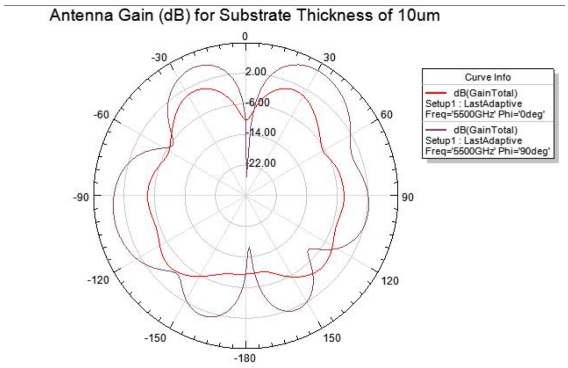

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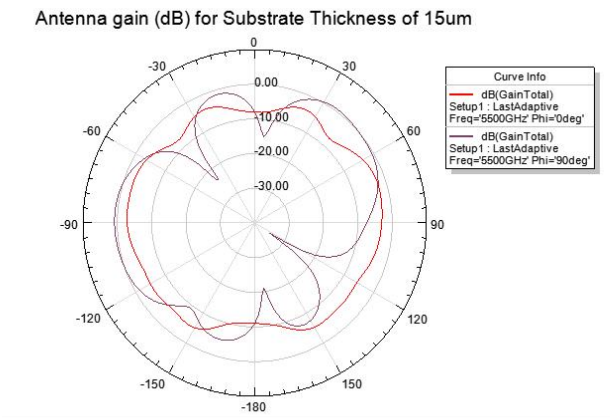

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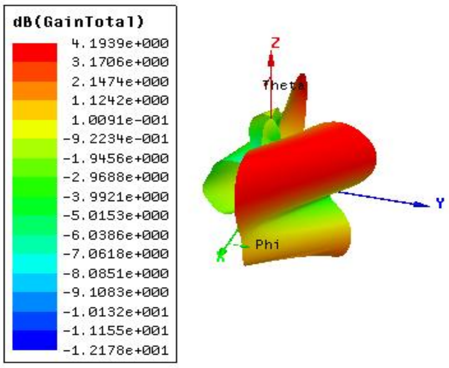
Figure 5a-e. 2D Polar Plot of Gain (dB) in Azimuth Plane $\phi = 0^o$ (red) and $\phi = 90^o$ (purple) for Substrate Height 3µm, 5µm, 7µm, 10µm and 15µm respectively.



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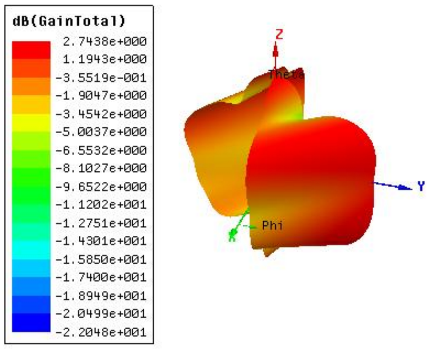

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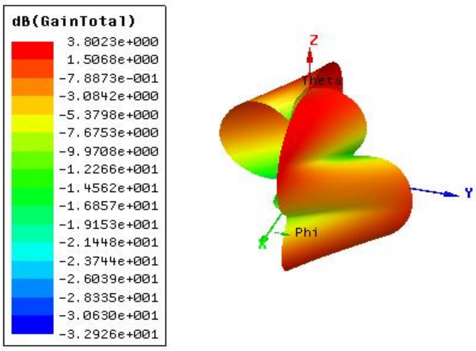

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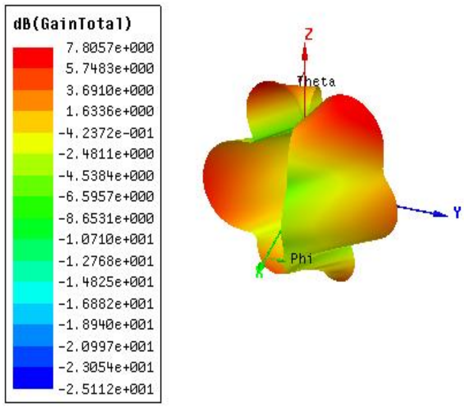

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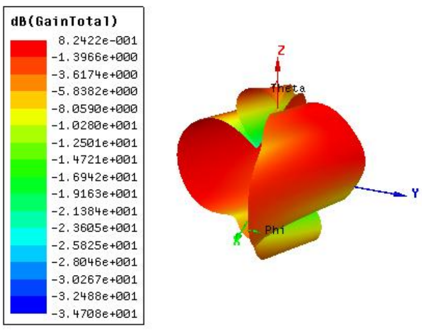

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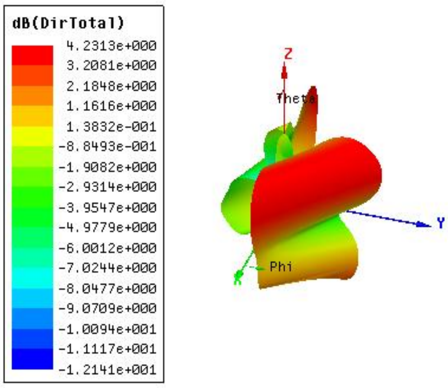
Figure 6a-e. 3D Radiation Pattern of Gain (dB) for Substrate Height, 3µm, 5µm, 7µm, 10µm and 15µm respectively



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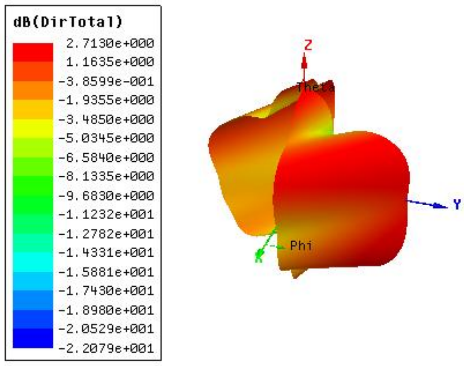

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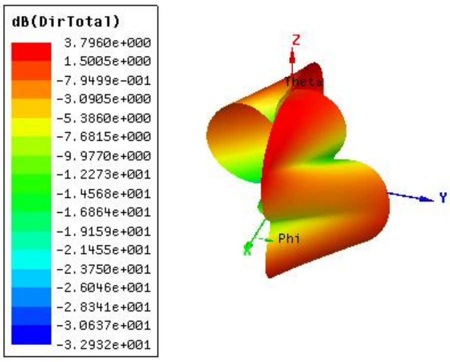

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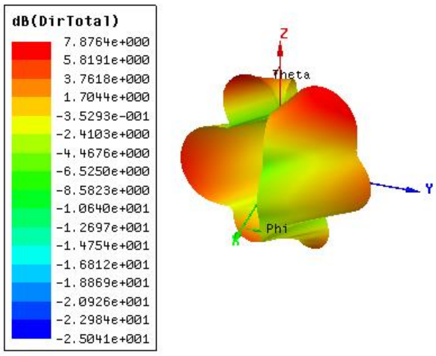

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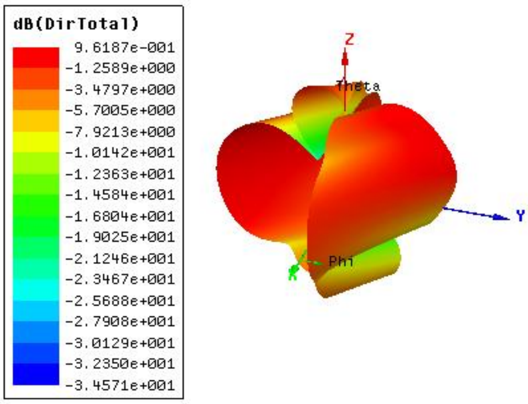

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Fig.7a-e, 3D Radiation Pattern of Directivity (dB) for Substrate height, 3µm, 5µm, 7µm, 10µm and 15µm respectively

Results and discussion

Results for Varying Substrate Height

Table 2: Simulated Results of Graphene Nano Patch Antenna for Different Substrate Height

	Substrate Height (µm) (FR4-epoxy) / Parameter	3(µm)	5(µm)	7(µm)	10(µm)	15(µm)
1	Resonating frequency (THz)	10.0000	10.0000	8.2500	5.0000	3.7500
2	Return loss (dB)	-2.1689	-9.7463	-21.0988	-21.4037	-12.7911
3	VSWR	18.1172	5.8699	1.5347	1.4815	4.0558
4	Gain (dB)	4.1939	2.7438	3.8023	7.8057	8.2422
5	Directivity (dB)	4.2313	2.7130	3.7960	7.8764	9.6187
6	Lower frequency at (-10dB)	-	-	7.9000	4.7783	3.5872
7	Upper frequency at (-10dB)	-	-	10.0000	5.19339	4.0572
8	Bandwidth (GHz)	-	-	2100	415.6	470.0

Table 2 shows the summary of the analysis obtained for different substrate heights. The height, H was a variable and was varied for various values of H= 3µm, 5µm, 7µm, 10µm, and 15µm, keeping the other dimensions of antenna model as given in Table 1. The result showed that the resonating frequency decreases as the substrate height increases. The acceptable VSWR value of 1.5347 and 1.4815 was achieved at substrate height of 7 and 10µm respectively. The substrate height of 10µm leads to the must acceptable VSWR value of 1.4815 at the corresponding resonant frequency of 5 THz. It is evident from VSWR plot as shown in figure 4d. The height of the substrate affects the bandwidth of the antenna. It shows that, substrate height is proportional to the bandwidth. The return loss value can be seen to increase with substrate height up to certain limit and then shows reducing trend. It can be observed that return loss attains maximum value of -21.4037 dB at H=10µm resonating at 5 THz which is closer to the operating frequency of 5.5 THz. The gain and directivity also increased with increase in substrate height. These results suggest that the antenna operating frequency can be tuned over the THz band by adjusting the antenna height.

Conclusion

In conclusion, the design and simulation of a graphene-based rectangular nano patch antenna for WLAN applications at a resonating frequency of 5.5 THz demonstrated promising results. The study revealed that by adjusting the substrate height, it is possible to tune the antenna's resonating frequency within the THz band. Specifically, a substrate height of 10µm yielded the most favourable performance, with a VSWR of 1.4815 and a return loss of -21.4037 dB at 5 THz. Additionally, the antenna's gain and directivity improve as the substrate height increases. These findings highlight the tunability and efficiency of the antenna, making it a viable solution for high-frequency WLAN applications.

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