Design of Compact Z Shape Slot Graphene Antenna for 2.4 GHz Wireless Fidelity Applications

Shreya Sharad, Madhur Deo Upadhayay

Department of Electrical Engineering,Shiv Nadar University G.B Nagar, Uttar Pradesh

Corresponding author: Shreya Sharad , Email: ss984@snu.edu.in

This paper describes the design and simulation of a compact CPW fed graphene patch antenna with Z shape slot. Antenna design is enhanced by the introduction of a 'Z' shaped slot in the patch of the antenna, that make it compact. Antenna resonates at the frequency of 2.4 GHz, for Wi-Fi uses. Polyamide Kapton tape of thickness 100μm and relative permittivity of 3.5 is used as the substrate. Graphene is used to make the conducting patch, feed and grounds of the antenna design. Various antenna parameters including reflection coefficient, radiation patterns and surface currents and parametric study of a physical parameter related to antenna design are discussed. The proposed antenna is ~20% smaller than the patch antenna at the same resonance frequency.

Keywords: CPW, Graphene, Slot, Kapton.

2021. In Prashant Singh Rana, Deepak Bhatia & Himanshu Arora (eds.), *SCRS Proceedings of International Conference of Undergraduate Students*, 153–160. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.52458/978-81-95502-01-1-17

1. Introduction

Situations encountered during pandemic times have emphasized on the need of having highly efficient, consistent, and economic Wi-fi networks. Keeping in mind the demands of current and future situations, this paper discusses a CPW fed graphene slot antenna on the basis of different antenna parameters. The antenna is designed to facilitate economic Wi-fi communications for which miniaturization is also tried to achieve [1].

Graphene and Kapton tape are the materials chosen for making the antenna. Graphene is chosen since metals show less conductivity at higher frequencies. Moreover, metallic thin films are prone to micro-cracks and require self-healing techniques such as electro pulsing [3]. To overcome this problem graphene, an allotrope of carbon, comprised of a single layer of carbon atom is used. It is an attempt to effectively use the extraordinary electrical and mechanical properties of graphene. Graphene's honeycomb-like '2D' structure is highly flexible and easy to fabricate also [4]. Due to the '2D' structure, one electron per carbon atom is free to conduct electricity in '3D' space. Mathematically graphene's total conductivity is the sum of its inter band and intra band conductivities. The relation between frequency and conductivity of graphene is described in terms of inter band and intra band equations.

The total conductivity,

$$\sigma(\omega)=\sigma intra(\omega)+\sigma inter(\omega) \qquad (1)$$

The intra band conductivity,

$$\sigma intra(\omega)=\frac{qe^2 KBT}{\pi h^2(\omega-j2\Gamma)}\left[\frac{\mu c}{KBT}+2\ln(e^{-\mu C/KBT}+1)\right] \qquad (2)$$

The inter band conductivity,

$$\sigma inter(\omega)=\frac{qe^2}{4h}\left[H\left(\frac{\omega}{2}\right)+i\frac{4\omega}{\pi}\int_0^\infty d\delta\,\frac{H(\delta)-H(\frac{\omega}{2})}{\omega^2-4\delta^2}\right] \qquad (3)$$

In the above equations, qe is the electron charge KB is the Boltzmann's constant, h is the reduced Plank constant, T is the temperature μc is the chemical potential, and ω is the operating angular frequency. Scattering rate Γ=1/2τ constitutes the loss mechanism and τ the relaxation time.

$$H(\delta)=\frac{\sinh(\frac{h\delta}{KBT})}{\cosh\left(\frac{\mu c}{KBT}\right)+\cosh(\frac{h\delta}{KBT})} \qquad (4)$$

Effect of intra band conductivity dominates at a frequency less than 1THz. Above 1THz inter band conductivity becomes dominant. For this discussion, it is assumed that the conductivity of graphene is only influenced by the intra band conductivity.Graphene conducting patch is fabricated on top of a polyamide substrate, Kapton. Kapton has great dielectric strength and it is highly resistant to organic solvents, acids, and moisture absorption. It can withstand high temperatures and is self-extinguishable [6]. A frequency range of 2.4GHz is chosen to make the antenna fabrication easy and possible with available resources of measurement. The size of the antenna is of the order of millimetres. Both Graphene and Kapton complement each other in terms of flexibility and durability hence these two were used for antenna fabrication. Graphene antenna has also facilitated complex design including arrays and printable antennas [2,5].

This paper includes a thorough discussion of a slotted CPW fed graphene antenna based on antenna parameters. The research paper is divided into four sections. In section one an overview of the research problem with a hypothesis is given. In section two, the design of the proposed antennas is given. In sections three and four, parametric study and results are included respectively. Finally, in section five, salient features of the design are concluded along with the scope of future work.

2.Antenna Design

CPW fed antenna comprises of a conducting rectangular patch of dimension Lp xWp and a CPW feed, placed over a dielectric substrate. Graphene powder of conductivity 2.4*10^5 S/m and thickness 0.02mm is used for the conducting patch, feed, and grounds whereas Kapton tape of relative permittivity 3.5 and thickness 0.1mm is used as the dielectric substrate. 3 layers of Kapton tape are used to keep the antenna intact and durable.

The proposed antenna design includes a basic CPW fed rectangular patch antenna with the introduction of a 'Z' shaped slot. Figure 1 depicts the proposed antenna design including the Z-shaped slot.

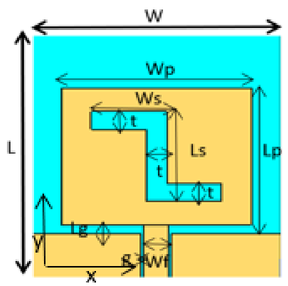


Fig. 1 Antenna Design

CPW fed antenna is used over the microstrip patch antenna since it has low dispersion, wider bandwidth, and low radiation loss. Moreover, in CPW fed antenna grounds are present on the same side as the conducting patch, this makes it possible to use graphene itself for the grounds as well. Additionally, the absence of grounds below the substrate allows the possibility of making the antenna stickable. All these add to the economic advantages of the antenna design.

S11 parameter or reflection coefficients of an antenna are the measure of the power returned or reflected from the antenna as per impedance matching level. S11 parameter of the slotted antenna is around -54dB at 2.4GHz and bandwidth ~2GHz whereas the antenna without slot showed an S11 value of -22dB at 2.66GHz. Figure 2 depicts the graphs corresponding to the s11 parameter of both, Z shape slot and without slot antenna having same dimensions. It is clear from the graph and the values that the introduction of slot not only improves the S- parameter value but also decreased the frequency that too without increasing the overall antenna dimensions. Hence it is concluded that introduction of slot enabled miniaturization as well. Table 1 contains the antenna design parameters and slot design parameters.

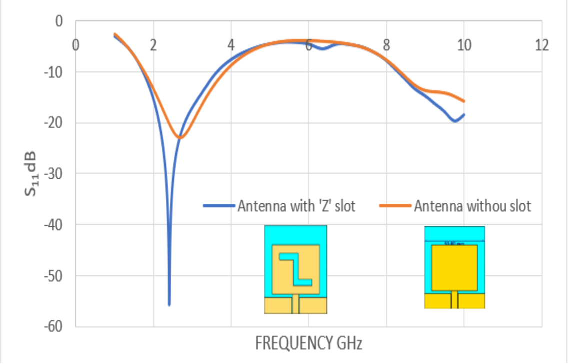


Fig. 2 Simulated S_{11} Parameter

Table 1 Physical parameters of proposed antenna

Parameters	Symbols	Values (in mm)
Substrate polyimide	L x W x h	54x50x0.3
Patch Graphene	Lp xWp xTp	30x38x0.02
Feed width	Wf	5
Gap between patch and grounds	Lg	2
Gap between feed and grounds	G	0.5
Slot length	Ls	20
Sloth length horizontal	Ws	15
Slot width	T	4

3. Parametric Study

To study slot dimension sensitivity; the effect of variation of antenna parameters on S11, two parametric studies are performed. The horizontal length of Z shaped slot and width of Z shape slot are varied.

(a) Effect of changing the horizontal slot length Ws.

The horizontal length of slot Ws is varied from 13 mm to 17 mm in the step of 2mm and other parameters are kept constant. It is observed from figure3 that when the slot horizontal length Ws is increased from 13 to 17mm resonating frequency has decremented. However, the S11 value degrades to the almost same amount at Ws = 13 & 17 mm. This shows that Ws=15mm gives the best results as far as the S11 value is considered.

(b) Effect of changing slot width t

The width of slot t is varied from 2 mm to 6mm in the step of 2mm and other parameters are kept constant. Figure 4 shows that frequency does not vary much upon increasing the value of t from 2mm to 6mm. However, the S11 value degrades in both of the cases t=2 & t=6mm, but degradation upon increasing the width is more as compared to that on decreasing the thickness. Hence, the optimum value of Z-shaped slot width is t=4mm.

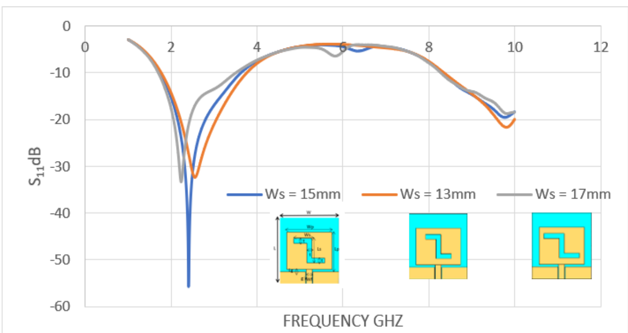


Fig. 3 Effect of variation of horizontal slot length Ws

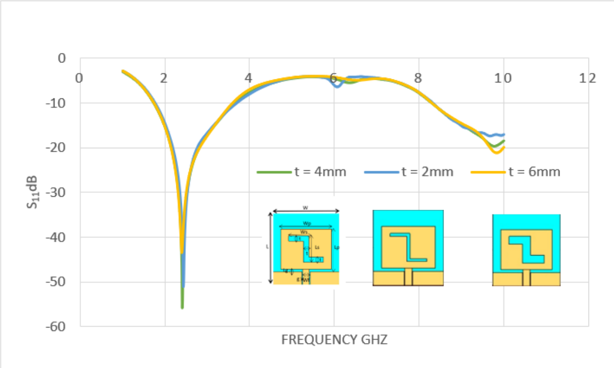
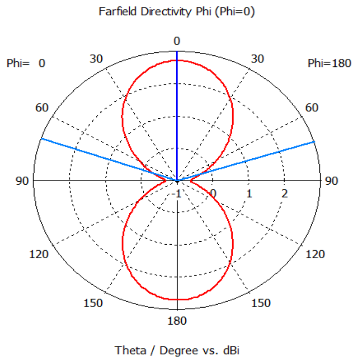


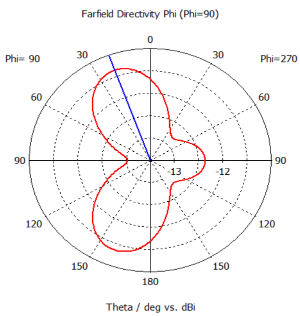
Fig. 4 Effect of slot width variation t

4. Results and Discussions

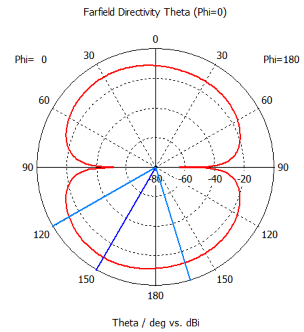
The designed Z-shaped slot antenna with CPW feed resonates at 2.4 GHz, with S11 value -54dB and approximately 2 GHz bandwidth. Radiation patterns are the graphical representation of the radiation of an antenna in different directions.



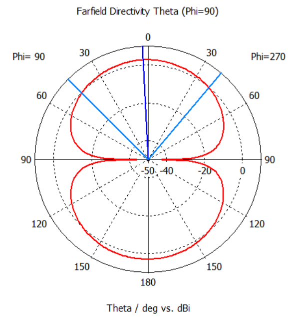
(a) XZ Plane Co polarised



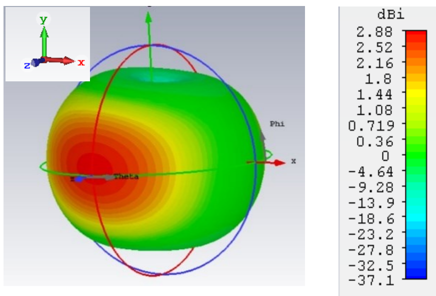
(b) YZ Plane cross polarised



(c) XZ plane cross-polarized



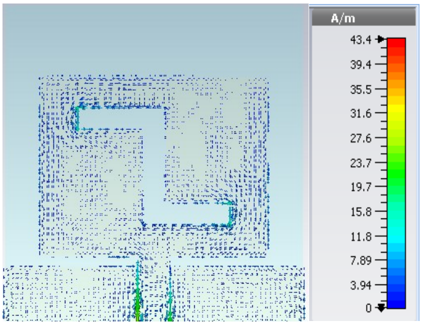
(d) YZ Plane co polarised



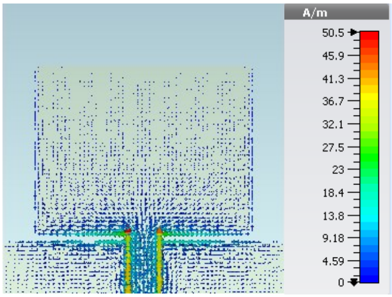
(e) 3-D Radiation Pattern

Fig. 5 Simulated radiation patterns of the proposed antenna

Figure 5(a) shows the radiation pattern along with phi(phi=0) direction, main lobe magnitude and direction are 2.7dBi and 0.0deg respectively with an angular beamwidth of 143.4deg. A squinted beam radiation pattern appears in the phi(phi=90) plane as shown in Figure 5(b), main lobe magnitude and direction are -11.4dBi and 20deg respectively. Figure 5(c) shows radiation pattern for theta(phi=0) plane, main lobe magnitude is -9.82dBi, main lobe direction is 150deg and angular beamwidth is 77deg. Figure 5(d) shows the pattern in the theta(phi=90) plane, main lobe magnitude is 2.72dBi, main lobe direction is 3deg and the angular beamwidth is 85.1deg. A 3-D radiation pattern shown in figure 5(e) is direction.The surface current of the proposed antenna at 2.4 GHz is depicted in Figure 6. The majority of surface current is centered on the Z-shaped slot. That increases the path length hence decreases the resonance frequency from 2.66 GHz to 2.4GHZ. This leads to an approximately 20% reduction in area size.

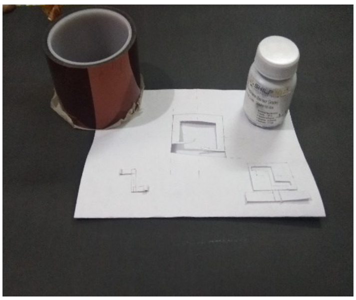


(a) Proposed antenna

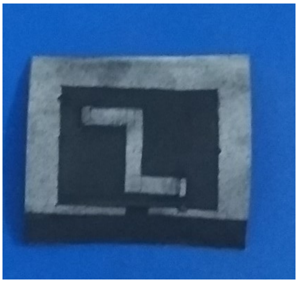


(b) Antenna without slot

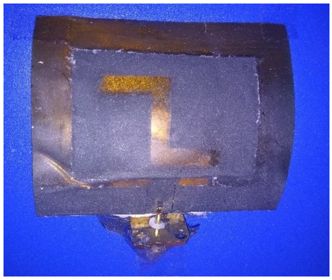
Fig. 6 Surface Currents at 2.4GHz



(a) Materials and stencils used



(b)After stencilling and sprinkling graphene powder



(c) After removing stencils and fixing connector

Fig. 7 Manual Fabrication of the proposed antenna

5. CONCLUSION AND FUTURE WORK

Design and simulation of a CPW fed rectangular patch antenna with a 'Z' shaped slot have been demonstrated successfully. The proposed antenna exhibits an S11 value of -54dB at 2.4GHz, 2.7dBi gain, and bandwidth of around 70%. Parametric studies show that the dimensions of the proposed antenna are the best fit for the 'Z' shaped slot at 2.4 GHz. Compact in size concerning patch antenna by approximately 20%. The proposed antenna is useful for Wi-Fi applications. Future work includes hardware prototyping and further miniaturization of the antenna.

REFERENCES

[1] O. Staub, J. -. Zurcher, A. K. Skrivervik and J. R. Mosig, "Miniaturizing Antennas for Personal Communication Systems (PCSs)," 2000 30th European Microwave Conference, Paris, France, 2000, pp. 1-6, doi: 10.1109/EUMA.2000.338732.

[2] K. Pan et al., "Graphene Printed UWB Monopole Antenna for Wireless communication applications," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA, 2019, pp. 1739-1740, doi: 10.1109/APUSNCURSINRSM.2019.8888805.

[3] Hui Song, Zhong-jin Wang, Xiao-dong He & Jie Duan, "Self-healing of damage inside metals triggered by electropulsing stimuli", Sci. Rep.7: 7097, doi:10.1038/s41598-017-06635-9.(2017)

[4] Ömer Güler, Nihal Bağcı, "A short review on mechanical properties of graphene reinforced metal matrix composites",Journal of Materials Research and Technology,Volume 9, Issue 3,2020

[5] Siti Nor Hafizah Sa'don 1,Mohd Haizal Jamaluddin 1,*OrcID,Muhammad Ramlee Kamarudin 2,Fauzan Ahmad 3,Yoshihide Yamada 3,Kamilia Kamardin 3 andIzni Husna Idris "Analysis of Graphene Antenna Properties for 5G Applications" Sensors 2019, 19(22).

[6] https://www.dupont.com/content/dam/dupont/amer/us/en/products/ei-transformation/documents/EI-10142-Kapton-Summary-of Prop erties.pdf

.