A Frequency Reconfigurable Antenna based on Few Layer Graphene

Sheng-lan Wang, Jing-Song Hong, Yan Deng, and Zhi-jian Chen

Institute of Applied Physics
University of Electronic Science and Technology of China, Chengdu, 610054, China
wsl_0317@hotmail.com

***Abstract* —** In this paper, a frequency reconfigurable antenna was presented. This antenna is made up of a square loop and a microstrip line with a gap, in which the few layer graphene (FLG) sheet is located to achieve frequency reconfigurable. FLG is likes a lumped resistor with resistance. And the surface impedance can be adjusted by applying a direct current bias voltage, which obtains two work modes that imitate switch. Additionally, the experimental evidence show the proposed frequency reconfigurable antenna can provide a tunable bandwidth.

***Index Terms* —** Few layer graphene, frequency tunable, microstrip structure.

I. INTRODUCTION

Reconfigurable antenna, with its advantages of improving integration and space utilization, has been widely used in the modern wireless communication system. According to their functions, a reconfigurable antenna can be designed in resonant frequency, radiation pattern, and polarization. The method is usually achieved by switches, such as PIN diodes [1], varactor diodes [2], and micro-electromechanical systems (MEMS) [2].

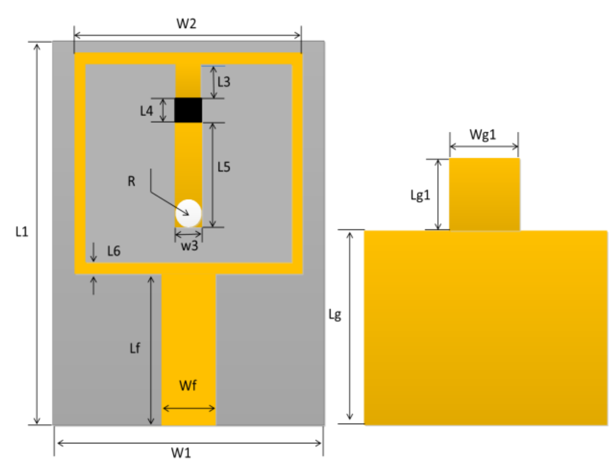
Graphene, a flat monoatomic layer of carbon atoms distributed in a 2-D honeycomb like lattice, which has excellent electrical and thermal properties, will emerge as a leading material for communication technologies [3, 4]. And with changing the bias voltage across graphene, the resonant frequency of the antenna changes significantly [5, 6]. In Ref. [7], Huang et al. studied the performance of wearable antennas made of graphene ink from 1 to 5GHz. In Ref. [8], Rajni studied the wearable Graphene Based Curved Patch Antenna. However, the performance of antenna may be affected by bending. Fortunately, many scholars carry out some basic research on the optimal design method and radiation efficiency of the few layer graphene (FLG) [9, 10]. As experimental evidence in Ref. [11], it is verified that the application of a proper voltage through two bias tees changes the surface resistivity of FLG. In Ref. [12], analyze the optimization of the shorted microwave stub. Few layer graphene was synthesized by CVD deposition techniques, which the thickness less than 5 nm.

In this paper, a novel frequency reconfigurable antenna was presented. This antenna is made up of a square loop with a microstrip structure, in which the FLG sheet is set. This letter is structured as follows. Section II will introduce the design and analyze of the proposed antenna. And Section III will introduce the Fabrication and measurement of the proposed antenna.

II. ANTENNA DESIGN AND ANALYZE

A. Configuration of antenna

The geometry of the presented antenna is shown in the Fig. 1. The antenna has three layers, which are a ground plate, a dielectric substrate, and a radiation layer. As the Fig. 1 (a) shown was the front of antenna, which is the radiation layer. The radiation patch comprised a rectangular loop and a microstrip stub. The stub consists of two microstrip lines and an FLG, which is connected to the ground by a shorting pin. The gray part was the dielectric substrate. The dielectric substrate is Duride 5880 with h=1.6mm, $\varepsilon_r = 2.2$, $\tan\delta = 0.0009$. As the Fig. 1 (b) shown was the back of antenna, which is the ground plate. As shown in Fig. 1 (c), it is the voltage connection method on the FLG. One port of bias DC voltage connects the FLG sheet, the other port connects the ground of antenna.

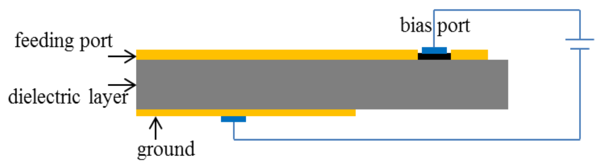


(a) (b)

Submitted On: November 28, 2018
Accepted On: June 28, 2019

https://doi.org/10.47037/2020.ACES.J.360508

1054-4887 © ACES



(c)

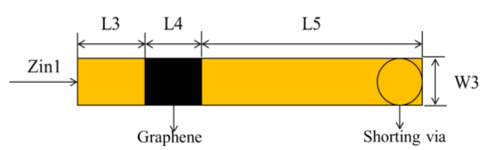
Fig. 1. Geometry of presented frequency tunable antenna: (a) the front geometry of antenna; (b) the back of geometry antenna; (c) the DC voltage connection method on the FLG. (L1=25, Lg=13, L2=11, Lg1=4.5, L3=1.5, W1=20, L4=0.7, W2=12, L5=4.5, W3=1, L6=0.6, Wf=4.8, Lf=13, Wg1=3.5) (unit: millimeter).

B. The analysis of frequency reconfigurable structure

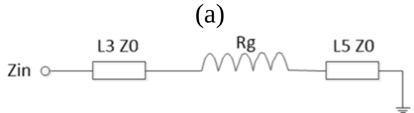
Based on existing research on few layer graphene, the graphene flake can be modeled as an infinitely thin resistive flake with a sheet resistance ρ (Ω/sq), which is likes a lumped resistor with resistance. And:

$$R = \rho L_4 / W_3 . \tag{1}$$

R is the resistance of the FLG, L, and W is the length and width, ρ is the resistivity. According to the Ref (2), the ρ is 1360 (Ω/sq) when the DC voltage is loaded to 0 V (mode1), the ρ is 49.6 (Ω/sq) when the DC voltage is loaded to 5.5V (mode2).



(a)



(b)

Fig. 2. The microstrip stub: (a) geometry of microstrip structure; (b) circuit equivalent model of microstrip structure.

The microstrip stub is shown in Fig. 2 (a). It includes microstrip line, graphene fleet and shorting via which connects the ground. As shown in Fig. 2 (b), the microstrip stub is equivalent to the transmission line circuit model. The input impedance of the transmission line can be calculated by formula (2):

$$Z_{inc} = Z_0 \frac{Z_L + jZ_0 \tan(\beta L)}{Z_0 + jZ_L \tan(\beta L)}, \tag{2}$$

$$Z_{in} = Z_0 \frac{\rho L_4 / W_3 + jZ_0 \tan(\beta L_3) + jZ_0 \tan(\beta L_5)}{Z_0 + \left(\rho L_4 / W_3 + jZ_L \tan\left(\beta L_5\right)\right) \tan\left(\beta L_3\right)}. \tag{3}$$

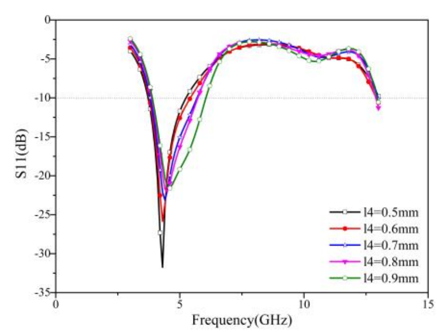
For this model, the input impedance Z_{in} of antenna can be obtained by two calculations of Equation (2). In Equation (3), Z_0 is the characteristic impedance of microstrip line, β is propagation constant. And the following conditions (4) should be met:

$$L_3 + L_4 + L_5 \le 10 . \tag{4}$$

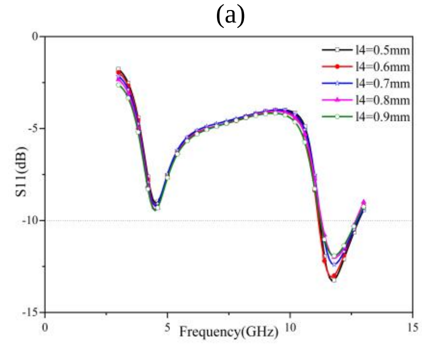
In order to achieve the impedance matching of the entire antenna, the ranges of L3, L4, and L5 is initially estimated by equations (3) and (4) and (5).

C. Parameters optimization

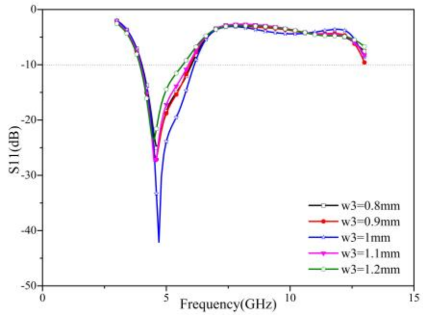
According to the theoretical calculation results, several parameters optimization have been carried out to improve the performances of the proposed reconfigurable antenna. Because of the diverse combination of parameters, the better value was selected by multiple simulation optimization tests, and the simulation result of optimization was shown in Fig. 3. The simulation was completed by 3D electromagnetic simulation software HFSS17. Four parameters are optimized to improve bandwidth of mode1 and mode2. One of them is L_4, which represents the length of the graphene flake that connect with the microstrip line. Figure 3 (a) and Fig. 3 (b) intimate that with the variation of L_4 from 0.5mm to 0.9mm, in two modes, S11 achieves the best value at L_4=0.7mm. The other are W_3, L_3, and L_5, they represent the width and length of two microstrip line. Figures 3 (c)-(h) show that with the variation of W_3 from 0.8mm to 1.2mm, L_3 from 1mm to 3mm, and L_5 from 4mm to 6mm. Consider the balance of the two modes, the values of the three parameters were L_4 = 0.7mm, W_3 = 1mm, L_3 = 1.5mm and L_5 = 4.5mm respectively.



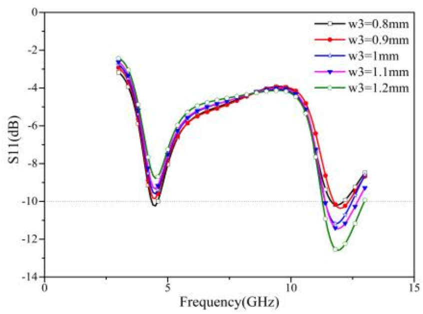
(a)



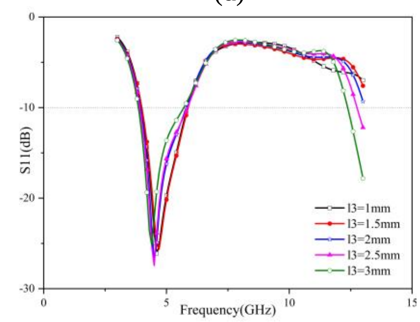
(b)



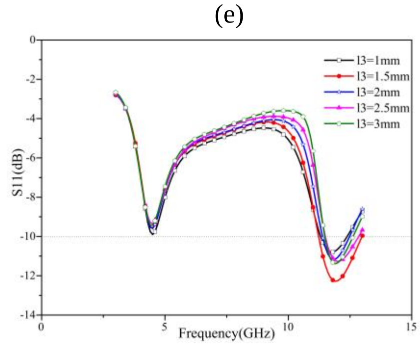
(c)



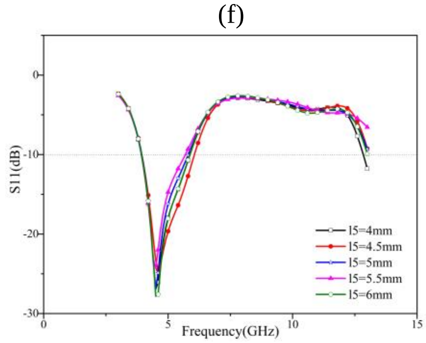
(d)



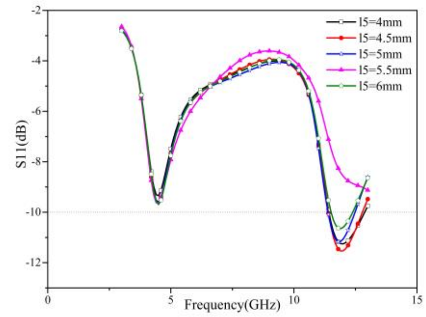
(e)



(f)



(g)



(h)

Fig. 3. The S11 of parameters optimization: (a) mode1, the variation of L4; (b) mode2, the variation of L4; (c) mode1, the variation of W3; (d) mode2, the variation of W3; (e) mode1, the variation of L3; (f) mode2, the variation of L3; (g) mode1, the variation of L5; (h) mode2, the variation of L5.

III. FABRICATION AND MEASUREMENT

A prototype of the frequency tunable antenna is shown in Fig. 4. The scattering parameter is measured using an Agilent N5230C vector network analyzer to analysis impedance matching. Because of the processing technology, the FLG sheet is large than the gap area. The simulated and measured scattering parameter is shown in Fig. 5. The measured resonance frequency is 4.9GHz (from 3.9GHz to 5.45GHz) in mode1 and 11.58GHz (from 11.1GHz to 12.75GHz) in mode2. The S-parameter in different modes verifies that it is feasible to achieve frequency reconfigurable.

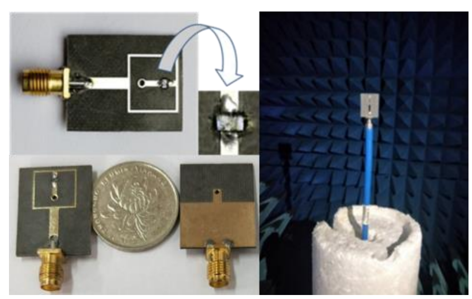
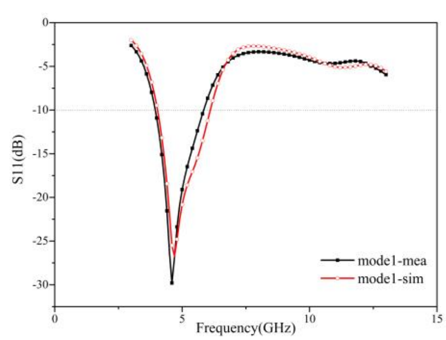
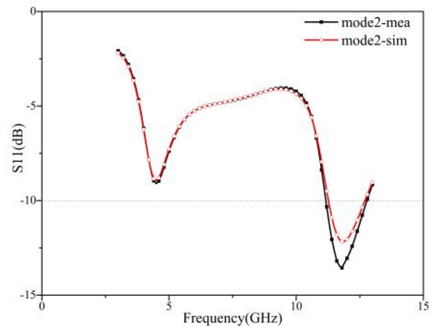


Fig. 4. The prototype of the proposed antenna.

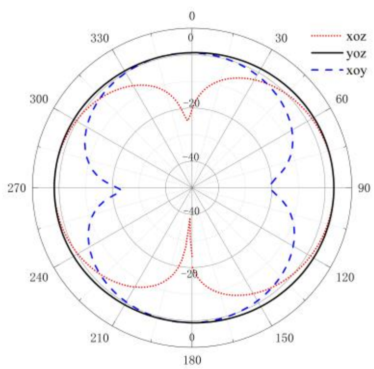


(a)

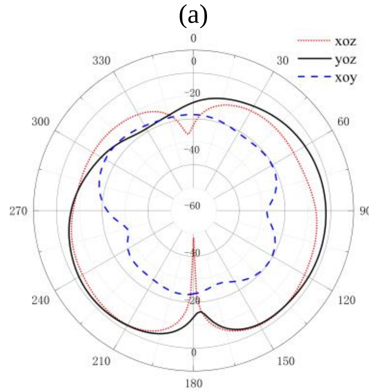


(b)

Fig. 5. Simulated and measured S-parameter of the proposed antenna: (a) mode1, simulated and measured S-parameter, and (b) mode2, simulated and measured S-parameter.



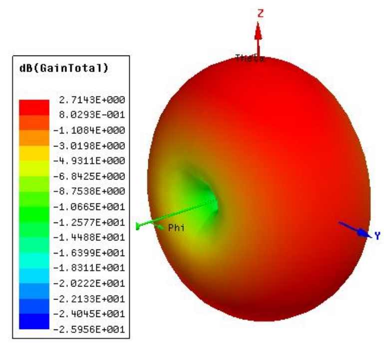
(a)



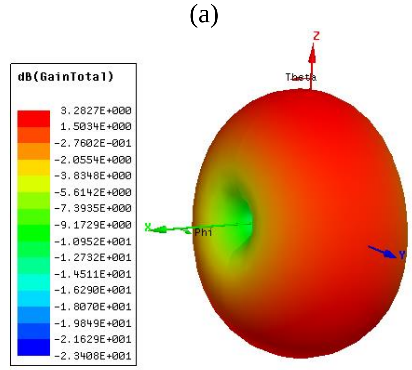
(b)

Fig. 6. Far filed radiation patterns of the proposed antenna: (a) mode1, measured radiation pattern at 4.9GHz, and (b) mode2, simulated radiation pattern at 11.6GHz.

Far filed radiation patterns of proposed antenna which was measured in the satimo OTA system as shown in Fig. 6. Figure 6 (a) was the measured radiation pattern at 4.9GHz of mode 1. Figure 6 (b) was simulated radiation pattern at 10.6GHz of mode 2. For both 4.9 GHz and 11.6 GHz, the antenna manifests a good performance in radiation patterns. Comparing the two radiation patterns, it is found that the changes in different modes were acceptable. The gain of the antenna is also improved of the mode 2. The 3D radiation patterns are shown following (Fig. 7). In mode 1, the maximum gain of the antenna is 2.71dB. In mode 2, the maximum gain of the antenna is 3.28dB. Compared to mode 1, 3D radiation patterns of mode 2 have some variations.



(a)



(b)

Fig. 7. 3D radiation patterns of antenna: (a) mode 1 3D radiation patterns, and (b) mode2 3D radiation patterns.

Efficiency of the proposed antenna was shown in Fig. 8. At 4.9 GHz, the efficiency of the antenna is 58%. At 11.6 GHz, the efficiency of the antenna is about 41%. The lower efficiency of the proposed antenna may be due to the smaller radiation area of rectangular loop. In mode 2, the electromagnetic wave radiation was affected to some extent, and the efficiency was also reduced.

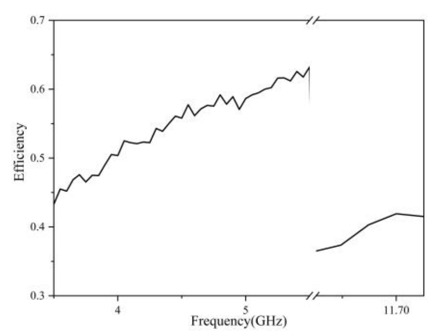


Fig. 8. Efficiency of the proposed antenna.

IV. CONCLUSION

This letter presents a frequency tunable antenna. It was made up of a square loop with a microstrip structure based on the few layer graphene, which the surface impedance can be adjusted by applying a direct current bias voltage. As experimental evidence, the resonant frequency of the antenna can be modified from 4.9GHz to 10.6GHz. The proposed frequency reconfigurable antenna may be great candidate for wireless communication system in the future.

REFERENCES

[1] I. Lim and S. Lim, "Monopole-like and boresight pattern reconfigurable antenna," *IEEE TAP*., 2013. doi: 10.1109/TAP.2013.2283926.

[2] L. Zhong, "A novel pattern-reconfigurable cylindrical dielectric resonator antenna with enhanced gain," *IEEE AWPL*, 2015. doi: 10.1109/LAWP. 2015.2504127.

[3] I. Llatser, C. Kremers, A. Cabellos-Aparicio, J. M. Jornet, E Alarcon, and D. N. Chigrin, "Graphene-based nano-patch antenna for terahertz radiation," *Photonics and Nanostructures – Fundamentals and Applications*, 10, pp. 353-358, 2012. doi: 10.4236/anp.2014.33010.

[4] J. Perruisseau-Carrier, "Graphene for antenna applications: Opportunities and challenges from microwaves to THz," *2012 Loughborough Antennas & Propagation Conference*, 2012. doi: 10.1109/ LAPC.2012.6402934.

[5] Z. Xu, X. Dong, and J. Bornemann, "Design of a reconfigurable MIMO system for THz communications based on graphene antennas," *IEEE TTHZ*, vol. 4, no. 5, Sep. 2014. doi: 10.1109/TTHZ.2014. 2331496.

[6] M. Akbari, M. W. A. Khan, M. Hasani, and T. Bjorninen, "Fabrication and characterization of graphene antenna for low-cost and environmentally friendly RFID tags," *IEEE AWPL*, vol. 15, 2016. doi: 10.1109/LAWP.2015.2498944.

[7] R. Bala and R. Singh, "Wearable graphene based curved patch antenna for medical telemetry applications," *Applied Computational Electromagnetics Society*, 2016.

[8] X. Huang, T. Leng, M. Zhu, X. Zhang, J.-C. Chen, K.-H. Chang, M. Aqeeli, A. K. Geim, K. S. Novoselov, and Z. Hu, "Highly flexible and conductive printed graphene for wireless wearable communications applications," Scientific Reports, 2015. doi: 10.1038/srep18298.

[9] C. Núñez Álvarez, R. Chheung, and J. S. Thompson, "Performance analysis of hybrid metal–graphene frequency reconfigurable antennas in the microwave regime," *IEEE TAP*, vol. 65, no. 4, Apr. 2017. doi: 10.1109/TAP.2017.2670327.

[10] G. Deligeorgis, M. Dragoman, D. Neculoiu, and D. Dragoman, "Microwave propagation in graphene," *Phys. Rev. Lett*., vol. 95, pp. 073107-1–073107-3, 2009. doi:10.1063/1.3202413.

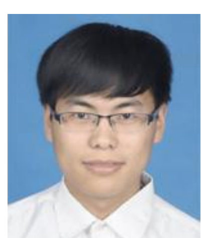
[11] L. Pierantoni, D. Mencarelli, M. Bozzi, R. Moro, S. Moscato, L. Perregrini, F. Micciulla, A. Cataldo, and S. Bellucci, "Broadband microwave attenuator based on few layer graphene flakes," *IEEE TMTT*, vol. 63, no. 8, Aug. 2015. doi: 10.1109/TMTT.

[12] 2015.2441062.

[13] M. Yasir, P. Savi, S. Bistarelli, A. Cataldo, M. Bozzi, L. Perregrini, and S. Bellucci, "A planar antenna with voltage-controlled frequency tuning based on few-layer graphene," *IEEE AWPL*, vol. 16, 2017. doi: 10.1109/LAWP.2017.2718668. CST Microwave Studio, ver. 2008, Computer Simulation Technology, Framingham, MA, 2008.

Sheng-lan Wang was born in Henan, China. She received her B.S. degree in Electronics Information and Engineering from Northwest A&F University, China, in 2016. She is now working toward her M.S. degree in Radio Physics from the University of Electronic Science and Technology of China (UESTC). Her research interests include antennas for wireless communication and the graphene application in antenna.

Jing-Song Hong received the B.S. degree in Electromagnetic from Lanzhou University, China, in 1991, and the M.S. and Ph.D. degrees in Electrical Engineering from the University of Electronic Science and Technology of China (UESTC), in 2000 and 2005, respectively. He is now a professor with UESTC. His research interest includes the use of numerical techniques in electromagnetic and the use of microwave methods for materials characterization and processing.



Yan Deng was born in Jiangsu, China. He received his B.S. degree in New Energy and Electronic Engineering from Yancheng Teaching University, China, in 2017. He is now working toward his M.S. degree in Radio Physics from the University of Electronic Science and Technology of China (UESTC). His research interests include antennas for wireless communication and microwave power transmission.

Zhi-jian Chen was born in Sichuan, China. He received his B.S. degree in School of Electronic Engineering from Chengdu University of Information Technology, China, in 2017. He is now working toward his M.S. degree in Radio Physics from the University of Electronic Science and Technology of China (UESTC). His research interests include antennas for wireless communication and metamaterial antennas.