Design of Graphene Annular Ring Microstrip Antenna Using Short-Pin Technique for 2.4 GHz Bands

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***Abstract*—This paper presents a design of a compact annular ring microstrip antenna using a modified graphene material with short-pin technique. The antenna design uses graphene material in parts of patch and ground plane of an annular ring antenna. The form factor of the antenna is designed for 2.4 GHz bands by adjusting the outer and inner radius using the short-pin technique to evaluate the resonant frequency. The simulation considers the return loss and directional radiation pattern in the feasibility analysis. The simulation results show that the form factor of the antenna in the proposed model can be adjusted to support 2.4 GHz bands with the return loss at −54.07 dB which is potentially feasible for various applications such as mobile phone, bluetooth, and radar in wireless communication devices**

***Index Terms*— annular ring microstrip antenna, directional radiation pattern, short-pin technique, return loss, voltage standing wave ratio**

I. Introduction

The antenna is an important part of wireless communication system for transmitting and receiving data in free space, which can be generally divided into three types: (a) slot antennas used in a high-frequency bands from 2 GHz to 24 GHz; (b) coil or wire antennas used in a frequency range between KHz-MHz; and (c) microstrip antennas used widely in a range between 1 GHz to 6 GHz [1], [2]. The design of the microstrip antenna can achieve a selective frequency band with low manufacturing costs, lightweight, and compact size. Graphene material is frequently chosen in the design instead of copper due to its structural properties. The structure of graphene material is a two-dimensional plane consisting of carbon atoms organized in a honeycomb lattice [3]. This structural property can be utilized to fabricate a very thin material which is stronger than steel around 100-300 times [4]. Graphene materials has also been integrated in the antenna design to counter problems found when using copper in the fabrication of antenna structure. Copper plate is often subjected to repetitive bending which will fatigue and break the copper [5]. Moreover, the antennas fabricated by copper material are relatively large size around 60×60 mm^2 and still have high return loss (S_{11}) about −20 to −30 dB, and high Voltage Standing Wave Ratio (VSWR) about 1 [6]-[12]. Then, graphene material has been proposed in many recent works to replace copper material. For example, works by Abdullah *et al.* presented the structure of multilayer graphene for patch antenna to reduce the resistance of the metal and improve the electric conductivity of the antenna [13]. Works by Fugto *et al.* [4] presented the patch microstrip antenna using graphene materials instead of copper for biomedical devices due to its high electric conductivity and no effect on human health. Works by Sajal *et al.* [5] also presented the suitability of graphene material in the design of microstrip antenna as same as works by Song *et al.* [14]. The properties of graphene material, i.e. high stability and good flexibility, produce the better return loss and high gain value compared with copper antenna. Moreover, its light weight and flexibility would protect the antenna from being broken.

In this paper, we design the compact annular-ring microstrip antenna by using graphene material and investigate the frequency band of the antenna by varying the form factor. The short-pin technique has been applied for the optimization of the selective frequency. The design using EMCoS software is presented including a comprehensive simulation to demonstrate an improvement in performance of the antenna.

II. Antenna Design

The schematic of annular ring microstrip antenna is illustrated in Fig. 1. The graphene microstrip antenna consists of ring-shaped patch, ground plane, and FR-4 substrate. The conductivity of graphene is σ = 1.94×10^5 S/m for a thickness of 25 μm. The substrate is placed between patch and ground plane. The FR-4 substrate used in this work has a relative permittivity, ε_r of 4.4 and a loss tangent of 0.02. The thickness of the dielectric substrate, t, is 0.5 mm.

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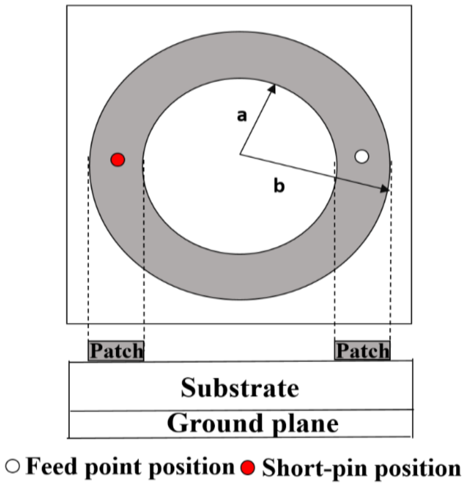

Fig. 1. Schematic of graphene annular ring microstrip antenna.

This annular ring microstrip antenna is designed to operate at the resonant frequency, f_r, of 2.4 GHz and support TM_{21} mode. Higher order modes of TM_{21} for the antenna have enhanced more radiation and bandwidth [15], [16]. The inner radius, a, of the antenna can be expressed as

$$a = \frac{3\times10^{8}\times\lambda_{21}}{2\pi f_r\sqrt{\varepsilon_r}} + \frac{3t}{4} \quad (1)$$

where λ_{21} represents 3.2825 for specific case representing for TM_{21} mode of an annular ring characteristic equation [12], [17]. The outer radius b of this antenna is given by

$$b = 2a \quad (2)$$

The inner and outer radius of the antenna calculated from (1) and (2) are 31.13 mm and 62.26 mm, respectively. The antenna size calculated by these parameters is quite large about $130\times130\times5$ mm^3. To achieve a compact size antenna with the resonant frequency of 2.4 GHz, the inner and outer radius are varied up to 10 mm and 15 mm, respectively, by using short-pin technique described in the next section.

III. Simulation and Discussion

In this section, the physically size of the antenna is reduced to the desired size which has the inner and outer radius of up to 10 mm and 15 mm, respectively. To operate at the resonant frequency of 2.4 GHz, the antenna is optimized by using EMCoS Antenna VLab software (EMCoS Ltd., Tbilisi, Georgia). The scattering parameter return loss (S_{11}) simulated by EMCoS is observed for performance of the power wave of the antenna, i.e. the reflection power returning from the port 1 received by the antenna port. The standard of S_{11} is required to be close to −10 dB or lower [5]. The feeding position is varied along x-axis and y-axis as shown in Fig. 2. The distance between each point is 0.25 mm.

According to Fig. 3, the minimum amount of S_{11} obtained when the feed location (f) is at 10.25 mm away from the origin. Its resonant frequency is at 4.5 GHz which does not meet the expected frequency of 2.4 GHz.

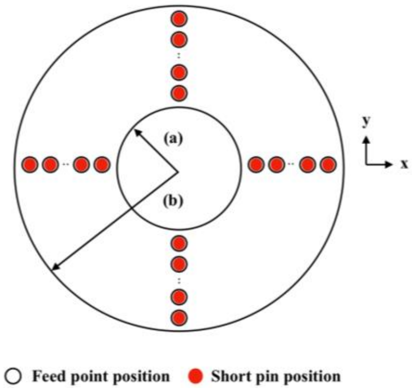

Fig. 2. Diagram of feed points and short-pin positions on graphene patch antenna.

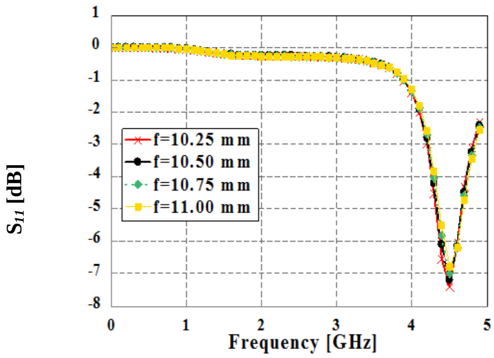

Fig. 3. Return loss of each feeding positions.

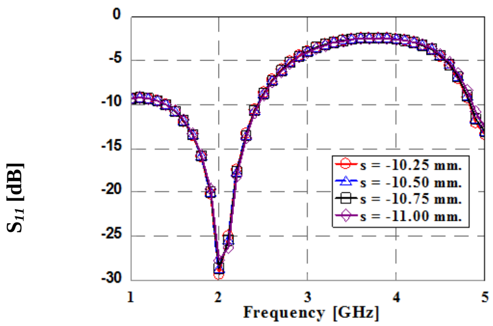

Fig. 4. Return loss of each short-pin positions with the fixed feed point of 10.25 mm.

The short-pin technique has been applied for tuning the resonant frequency to meet 2.4 GHz [18]-[20]. Firstly, the feed point is fixed at 10.25 mm, the short-pin position (s) is varied along x-axis and y-axis as shown in Fig. 2. The simulation results in Fig. 4 show that the minimum amount of S_{11} obtained when the short-pin position is at -10.25 mm.

Secondly, the inner radius is adjusted by fixing the outer radius, the feed points and short-pin positions at 15 mm, 10.25 mm and –10.25 mm, respectively. Fig. 5 shows that the inner radius (a) with the minimum amount of S_{11} is at 4 mm. Next, the outer radius is adjusted to meet the expected resonant frequency. The results are in Fig. 6.

According to Fig. 6, the resonant frequency of 2.4 GHz can be achieved by adjusting the outer radius = 11.5 mm, the inner radius = 4 mm, the feed point = 10.25 mm, and the short-pin positions = –10.25 mm. Its return loss is about –35 dB which is still not a minimum value.

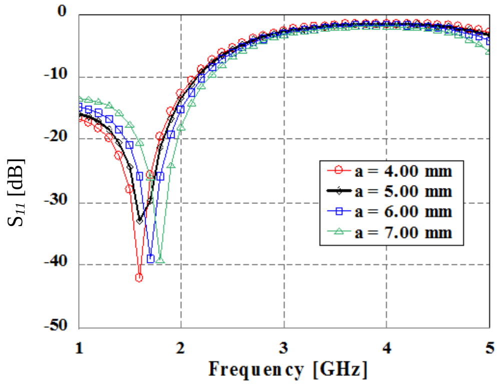

Fig. 5. Return loss of each inner radius (the outer radius = 15 mm, the feed point = 10.25 mm, the short-pin position = –10.25 mm).

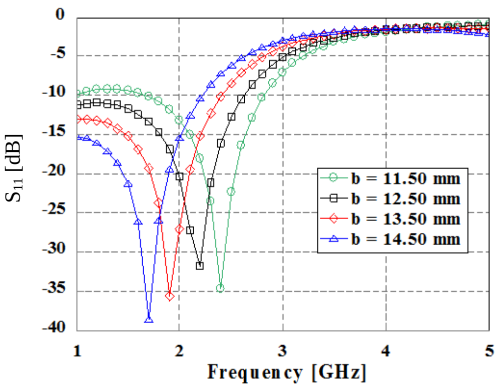

Fig. 6. Return loss of each outer radius (the inner radius = 4 mm, the feed point = 10.25 mm, the short-pin position = –10.25 mm).

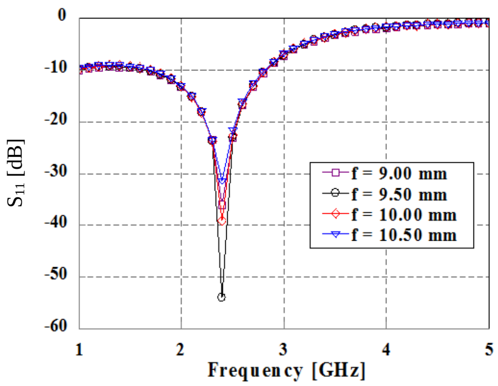

Fig. 7. Return loss of each feed points (the inner radius = 4 mm, the outer radius = 11.5 mm, the short-pin positions = –10.25 mm).

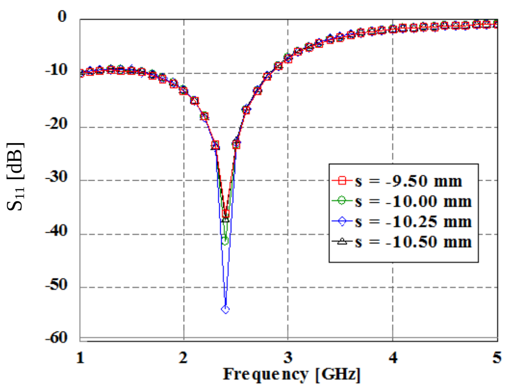

Fig. 8. Return loss of each short-pin positions (the inner radius = 4 mm, the outer radius = 11.5 mm, the feed position = 9.5 mm).

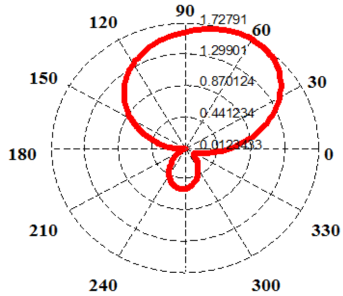

Fig. 9. Directional radiation pattern.

TABLE I. SUMMARY OF THE ANNULAR RING MICROSTRIP ANTENNAS

The research	Parameters		
	S_{11} (dB)	Resonant frequency (GHz)	Size (mm^3)
This work	–54.07	2.4	40×40×5
Baek *et al*. [6]	–31.73	2.68	60×60×0.787
Sharma *et al*. [10]	-33	2.4	24×33×1.6
Gan *et al*. [11]	–20.96/–12.823	2.45/5.3	160×160×0.8

To minimize the return loss, the feed and short-pin positions are adjusted. The feed point is varied first with the fixed short pin position of –10.25 mm. Fig. 7 shows that the minimum return loss of –54.07 dB obtained when the feed position is at 9.5 mm.

Next, the short-pin position is varied with the fixed feed point of 9.5 mm. Fig. 8 shows that the minimum return loss of –54.07 dB obtained when the short-pin position is at –10.25 mm.

According to the simulation results, the optimized parameters are the inner radius of 4 mm, the outer radius of 11.5 mm, the feed position of 9.5 mm, and the short-pin position of –10.25 mm. The form factor of the proposed antenna can be adjusted to support 2.4 GHz bands with the return loss at –54.07 dB. The directivity result of the antenna is a directional pattern as shown in Fig. 9.

The variation of the outer radius, the inner radius, the feed point, and the short-pin position has an influence on the amount of S_{11} parameter and the operating frequency of the antenna. The designed antenna in this work is compared with other works as shown in Table I.

According to Table I, this work shows the lowest value of the return loss S_{11} of –54.07 dB which is in an acceptable range for sending the information in wireless bands and mobile applications. The form factor of the antenna can be optimized using short-pin technique to meet the required frequency of 2.4 GHz with the compact size of 40×40×5 mm^3 obtained.

IV. CONCLUSION

The design of graphene annular-ring microstrip antenna was studied in this work. The designed antenna has an inner and outer ring of 4 mm and 11.5 mm respectively, giving a compact size of 40×40 mm^2. The operating range of frequency covers 1.6 GHz to 2.83 GHz with the minimum return loss of –54.07 dB. Tuning the resonant frequency of the antenna by using the feed point and short-pin technique provides an effective solution for 2.4 GHz bands. This work can be developed using the short-pin technique to be a dual band antenna operated at 2.4 GHz and 5.2 GHz, respectively.

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