# Design of Graphene-Based Annular Ring Microstrip Antenna Using Short-Pin Technique for Dual Band Applications

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***Abstract*—In this paper, the design process of an annular ring microstrip antenna using graphene material for dual-band applications is proposed. The microstrip antenna is modified using graphene-based annular ring microstrip layers for patch and ground plane with FR-4 epoxy substrate in between and simulated by the EMCoS software. The design process applied the short-pin technique for the estimation of the return loss, which leads to the analysis of the resonant frequency and the dual-band directions. The evaluation shows the acceptable performance in the frequency range of two resonant positions with the return loss of -29.33 dB at 2.4 GHz in ISM-band and the return loss of -39.49 dB at 5.3 GHz in C-band. However, the modified antenna offers several advantages such as low profile, low cost and small size (40 x 40 mm$^2$).**

***Index Terms*—Dual-band, annular ring microstrip antenna, short-pin technique, return loss**

## I. Introduction

Microstrip antennas are essential parts of wireless communication applications [1]. There are lots of benefits such as inexpensive, lightweight, small size, and easy to design [2]-[4]. The structure of the microstrip antenna can be arranged into three layers. It consists of patch and ground planes which are divided by dielectric substrate [5], [6]. The microstrip antenna comes in many different shapes such as square, triangular, circular, elliptical, rectangular, annular ring, etc [7]. Especially, the annular-ring shape receives much attention from many researchers because its fundamental mode is smaller than the circular and rectangular shapes, which allows operation in $TM_{11}$ mode [8]. Nowadays, the annular-ring microstrip antenna is normally used for high bandwidth and the lower resonant frequency compared with other antennas [9]. According to these features, the major application of the annular-ring antenna is to deliver the information with compact size and low profile. The increased demand for multiband antennas due to the rapid growth of wireless communication leads to the development of the dual-band antenna which can operate with more than one frequency at a time. This is advantageous to many applications such as ISM-band applications and radar applications operating in S- and C-bands [10].

The dual-frequency microstrip antennas was first studied by Yan *et al.* They presented the microstrip antenna fed by a coaxial probe technique, which designed for wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) at the frequencies of 2.45 GHz and 5.25 GHz [2]. Later, Guo *et al.* [11] presented the selective dual-band circular microstrip shape using T-slot form to operate at the frequencies of 2.44 GHz and 5.5 GHz in ISM band and C-band applications. A compact dual-band microstrip antenna with a circular ring was also studied by Gan *et al.* aiming at the frequencies of 2.45 GHz and 5.3 GHz [12]. Another work by Katore *et al*. [13] developed the dual-band microstrip antenna for wireless applications in the frequencies of 2.4 GHz and 5.2 GHz. In addition, Chen *et al.* [14] simulated a dual-band patch antenna using an array method for wireless communications at 2.4 GHz and 5.8 GHz bands. As aforementioned, there are many alternative ways to build and tune the dual-band antenna. In this paper, the short-pin technique has been proposed.

The short-pin technique has been applied in many works since it can be easily used for tunning to the target frequency and increasing range of bandwidth [15-19]. The dual-frequency triangular microstrip antenna developed by Pan *et al*. [18] also used the short-pin technique tuning for the frequencies of 464 MHz and 2,276 MHz bands. Phonkitiphan *et al*. [19] offered the design of the graphene annular ring microstrip antenna by taking advantage of the short-pin modification to adjust the resonant frequency of the antenna to be 2.4 GHz.

Currently, graphene material has been studied and developed in many works since it is adaptable to numerous applications [20]. The basic structure of graphene material composes of two dimensions of carbon atoms in a honeycomb lattice, which possess great thermal conductivity, electric conductivity, mechanical properties and biocompatibility [21]-[24]. These properties are mainly beneficial for antenna applications.

Manuscript received November 30, 2019; revised January 15, 2020; accepted March 5, 2020.

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This research was financially supported by EMCoS Ltd., Tbilisi, Georgia as the student license program of EMCoS Antenna VLab. The authors would like to thank Silpakorn University Research, Innovation and Creative Fund for scholarship.



doi: 10.18178/ijeetc.9.4.231-236

Therefore, the graphene material is normally employed in the microstrip patch antenna instead of copper because it can handle a repetitive warping deformation [22]. This is corresponding to the research performed by Xia *et al*. [23]. They mentioned that the graphene-based films have high conductivity compared with the copper material of the rectangular dielectric resonator antenna, which was suitable for RF devices. Works by Song *et al*. applied the graphene-based films for microstrip array antenna to design for RF antennas with a distinctive performance, low profile and high flexibility [24].

In this research, the design process of a graphene-based annular ring microstrip antenna for dual-band applications based on $TM_{11}$ mode is presented. The short-pin technique has been applied to adjust the antenna size and tune to an optimal frequency for the ISM band and C-band using the EMCoS software to simulate within the form factor design.

## II. Antenna Design

Fig. 1 illustrates the structure of the graphene-based annular ring microstrip antenna. This design has been developed from previous work [19] for dual bands. Its structure consists of a patch and a ground plane with a substrate layer (FR-4) placed in between. The graphene material has been used for the layers of patch and ground planes, which has conductivity ($\sigma$) of $1.94\times10^5$ S/m. The thickness of each layer ($t_g$) is 25 μm.

The antenna size has been defined at 40 x 40 mm$^2$ [19]. The relative permittivity ($\varepsilon_r$) and thickness ($t_{FR\text{-}4}$) of FR-4 substrate are 4.4 and 0.5 mm, respectively, with the loss tangent at 0.02.

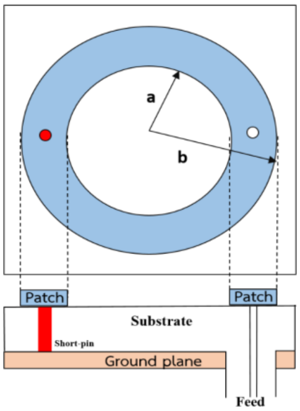


Fig. 1. Schematic of the graphene-based annular ring microstrip antenna.

The inner ($a$) and outer ($b$) radii of the antenna have been calculated along x-axis aiming to the first ($f_{fr}$) and second ($f_{sr}$) resonant frequencies at 2.4 GHz and 5.3 GHz, respectively. The constant property ($K$) and the inner radius ($a$) can be calculated by

$$K=\frac{8.791\times10^9}{f_{sr}\sqrt{\varepsilon_r}} \tag{1}$$

$$a=\frac{K}{\{1+\frac{2t_{FR-4}}{\pi\varepsilon_r K}[\ln(\frac{\pi K}{2t_{FR-4}})+1.7726]\}^{\frac{1}{2}}} \tag{2}$$

The outer radius ($b$) is then given by

$$b=\frac{3\times10^8\times\lambda_{11}}{2\pi f_{fr}\sqrt{\varepsilon_r}}+\frac{3t_{FR-4}}{4} \tag{3}$$

where $\lambda_{11}$ is equal to 1.841 in the case of $TM_{11}$ mode of an annular ring characteristic [12], [25].

The outer radius ($b$) is evaluated using (3) at the first resonant frequencies ($f_{fr}$) of 2.4 GHz to support at $TM_{11}$ mode.

According to the above equations, the calculated results are $a$ = 8 mm and $b$ = 17.5 mm. These results were set as a preliminary design to find out the suitable parameters for achieving the frequencies required. Later, the feed point ($f$) and the short-pin technique ($S$) are employed with respect to the target resonant frequencies of 2.4 GHz and 5.3 GHz.

## III. Simulation and Discussion

EMCoS software (EMCoS Ltd., Tbilisi, Georgia) was employed to simulate the antenna design aiming for the resonant frequencies of 2.4 GHz and 5.3 GHz. The return loss ($S_{11}$) describes the input electromagnetic power of a reflected back signal, which measures the amount of power returning to the analyzer on antenna port. It is an important parameter to achieve the antenna yield. This parameter should not exceed -10 dB to ensure that the antenna works efficiently with high radiation and clear propagated waves [26]. Another important parameter is bandwidth ($B_p$) which is simply known as a percentage of the center frequency [24]. Bandwidth can be determined by

$$B_p=\frac{f_U-f_L}{f_C}\times100\% \tag{4}$$

where $f_U$ is upper frequency, $f_L$ is lower frequency and $f_C$ is center frequency.

The preliminary design parameters ($a$ = 8 mm and $b$ = 17.5 mm) obtained from the previous section were simulated by EMCoS software to observe the return loss of the antenna as shown in Fig. 2. The resonant frequencies were still at 1.4 GHz and 4.6 GHz with -35 dB, and –12 dB, respectively. This result does not meet the requirement.

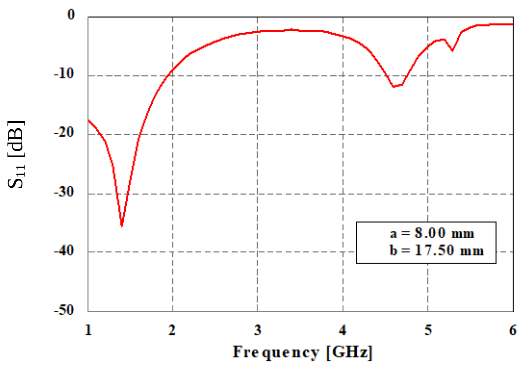


Fig. 2. Return loss of the antenna using the inner radius ($a$ = 8 mm.) and outer radius ($b$ = 17.5 mm.) as calculated from antenna design.

The resonant frequencies in Fig. 2 did not meet the expected frequencies (2.4 and 5.3 GHz) due to improper radius ($a$ and $b$) applied. Then, the radius of the antenna was varied to observe the change of the resonant frequency. In this step, the short-pin position ($s$) and the feed points ($f$) were fixed at –12.75 mm and 12.75 mm, respectively. The outer radius ($b$) was varied from 12.5 mm to 16.5 mm with a fixed inner radius, $a$=8 mm. The results show that the resonant frequencies decrease with the increase of the outer radius as illustrated in Fig. 3.

According to Fig. 3, the first resonant frequencies ($f_{fr}$) of the outer radius $b$ = 13.5 mm and $b$ = 14.5 mm were 2.2 GHz and 2 GHz, respectively. Although the first resonant frequencies ($f_{fr}$) given by $b$ = 13.5 mm is closer to the expected frequency ($f_{fr}$ = 2.4 GHz) than that given by $b$ = 14.5 mm, the second resonant frequencies ($f_{sr}$) given by $b$ = 13.5 mm is not applicable. So, the outer radius $b$ = 14.5 mm was chosen instead even though its second resonant frequency was still at 5.4 GHz. In order to reach the expected frequencies ($f_{fr}$ = 2.4 GHz and $f_{sr}$ = 5.3 GHz), the inner radius ($a$) was varied from 9 mm to 12.5 mm by fixing the outer radius at $b$ = 14.5 mm. The results show that the first resonant frequency increases with the increase of the inner radius while the second resonant frequency remains steady at 5.3 GHz as shown in Fig. 4. Fig. 4 shows that the optimal inner and outer radius of the antenna are at $a$ = 12 mm and $b$ = 14.5 mm, respectively. The resonant frequencies of 2.4 GHz and 5.3 GHz can be achieved with the return losses of -28.74 dB and –27.69 dB.

In order to improve the antenna performance, the return loss has to be minimized using the short-pin technique. The feeding and short-pin positions are varied along x- and y-axes as in Fig. 5. The distance between each point was set to be 0.25 mm.

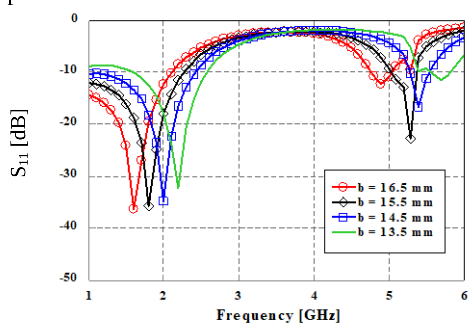


Fig. 3. Return loss of each outer radius (the inner radius = 8 mm, the feed point = 12.75 mm, the short-pin position = -12.75 mm).

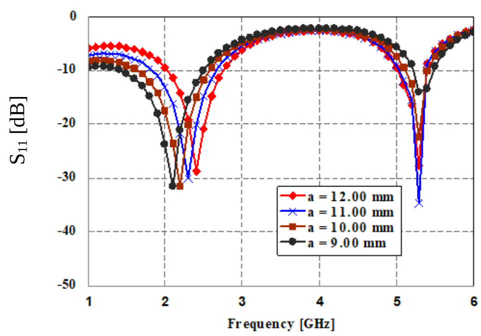


Fig. 4. Return loss of each inner radius (the outer radius = 14.5 mm, the feed point = 12.75 mm, the short-pin position = -12.75 mm).

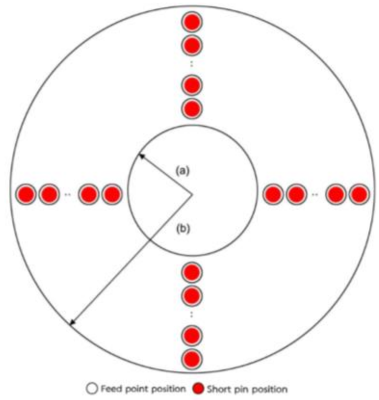


Fig. 5. Diagram of feed points and short-pin positions on graphene patch antenna [19].

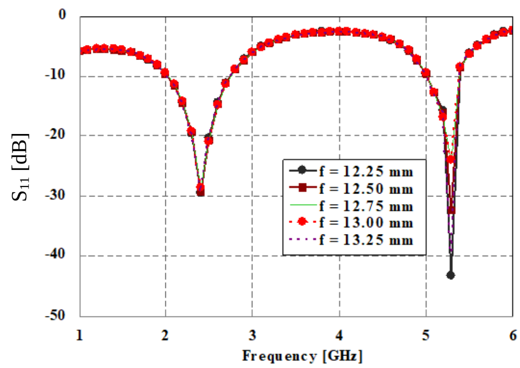


Fig. 6. Return loss at different feed points (the inner radius = 12.00 mm, the outer radius = 14.50 mm and the short-pin position = -12.75 mm).

In this process, the inner ($a$) and outer ($b$) radii were fixed at 12 mm and 14.5 mm, respectively. The feed point ($f$) was varied first from 12.25 mm to 14.25 mm with the fixed short-pin positions ($s$)=–12.75 mm. The simulation results are in Fig. 6.

The return losses can be minimized from –28.74 dB to –29.17 dB at 2.4 GHz and from –27.69 to –43.82 dB at 5.3 GHz when the feed point is at 12.25 mm as shown in Fig. 6. After that, the short-pin position was varied from –14.25 mm to –12.25 mm with the feed point fixed at 12.25 mm in order to obtain minimum return loss. The simulation results in Fig. 7 shows that the optimal return losses of –29.33 dB and –39.49 dB can be obtained at the short-pin position of –12.50 mm and provided sufficient bandwidth at 30.23 % and 7.35 %, respectively.

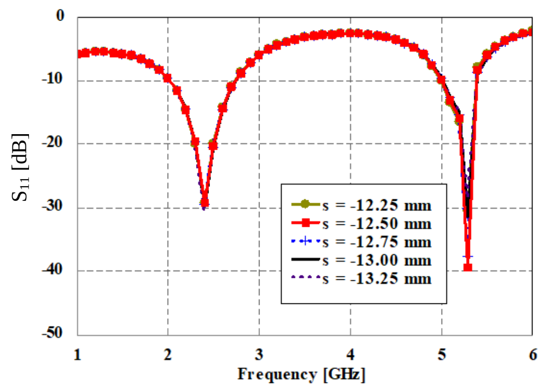


Fig. 7. Return loss of different short-pin positions (the inner radius = 12.00 mm, the outer radius = 14.50 mm and the feed point = 12.50 mm).

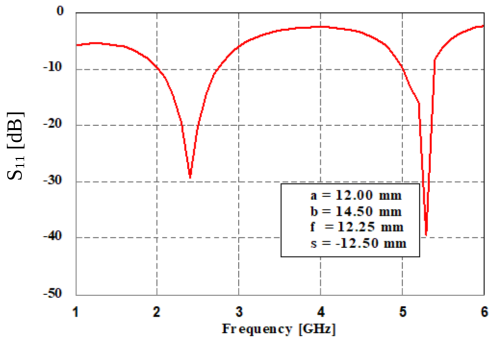


Fig. 8. Simulated result for the dual-band of the microstrip antenna.

According to all simulation results, the optimal parameters are the inner radius of 12.00 mm, the outer radius of 14.50 mm, the feed position of 12.25 mm and the short-pin position of –12.50 mm. The form factor of the antenna design can support 2.4 GHz and 5.3 GHz bands with the return losses of –29.33 dB and –39.49 dB as shown in Fig. 8.

The patterns of the dual-band antenna are shown in Fig. 9 and Fig. 10. The directional radiation patterns at 2.4 GHz and 5.3 GHz are both directional shapes in the XZ plane.

The variation of the inner radius, the outer radius, the feed point and the short-pin position has an influence on the return loss, bandwidth and the operating frequencies of the antenna. The output results of the designed antenna are then compared with the previous works as summarized in Table I.

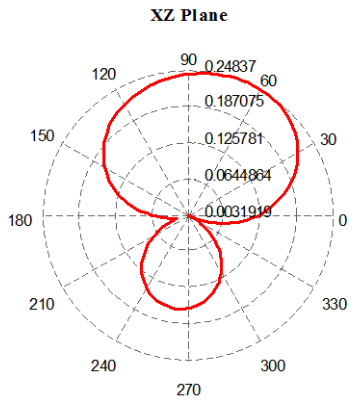


Fig. 9. Directional radiation pattern of 2.4 GHz in the XZ plane.

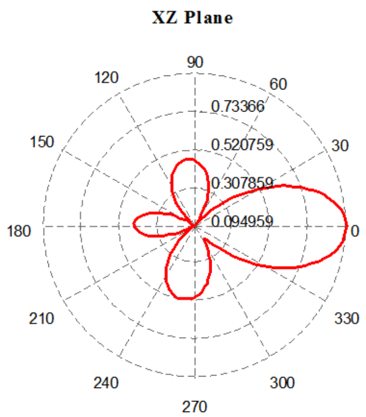


Fig. 10. Directional radiation pattern of 5.3 GHz in the XZ plane.

TABLE I: SUMMARY OF THE ANNULAR RING MICROSTRIP ANTENNAS.

| Research | Parameters | | | |
|---|---|---|---|---|
| | $S_{11}$ (dB) | Resonant frequencies (GHz) | Size (mm$^3$) | Bandwidth (%) |
| This work | -29.33/-39.49 | 2.4/5.3 | 40×40×5 | 30.23/7.35 |
| [2] | -16.33/-12.66 | 2.45/5.25 | 63×86.6×1.6 | < 5 |
| [12] | -20.96/-12.823 | 2.45/5.3 | 160×160×0.8 | 2.61/ 2.02 |
| [13] | -24/-27 | 2.44/5.25 | 36.7×24.7×1.6 | 2.46/7.62 |
| [14] | ≈-35/-30 | 2.45/5.5 | 142×98×6 | 4/12.73 |

Compared with others in Table I, the return loss of this work is quite low (–29.33 dB at 2.4 GHz and –39.49 dB at 5.3 GHz) which ensures that the proposed antenna can efficiently operate in an acceptable range for sending the information in ISM bands and C bands. This work shows that the target frequencies of 2.4 GHz and 5.3 GHz can be reached with a compact-size antenna of 40 mm × 40 mm × 5 mm by using the short-pin technique.

## IV. CONCLUSION

The design of a graphene-based annular ring microstrip antenna using the short-pin technique is presented in this work for dual-band applications. It can operate in the range of frequencies from 2.02 to 2.74 GHz and 5.02 to 5.4 GHz with the minimum return loss of –29.33 dB and –39.49 dB respectively, which is suitable to support wireless communication devices of ISM band and C band. Using the feed point and short-pin technique provides an effective solution to achieve the desired frequencies while keeping the antenna size as compact as possible. Finally, our design is optimum for dual-band frequency range between 2.4 GHz to 5.3 GHz, that it was developed from single band at 2.4 GHz [19]. Continuously, it can be modified for serving many of frequency range such as 2.4 GHz in ISM-band [19], 3.5 GHz in S-band [10], and 5.3 GHz in C-band [10] with triple-bands or wide-band, respectively. In case of improvement of the user flexibility to cover multi-band and wide-band microstrip antenna design will be a challenge for the further work.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

P. Phongchit conducted the research and analyzed the data; P. Phonkitiphan and R. Kaewon wrote the paper; all authors had reviewed and approved the final version.

## ACKNOWLEDGMENT

The authors would like to give gratitude to Lect. Pornchai Pliamsup from Silpakorn University, and Prof. Atsushi Saito from Yamagata University for their kind support.

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