Hindawi
International Journal of Antennas and Propagation
Volume 2019, Article ID 2431760, 7 pages
https://doi.org/10.1155/2019/2431760

*Research Article*

# A Novel Compact Microstrip Antenna with an Embedded $\lambda/4$ Resonator

**Honglin Zhang**,[1] **Dong Chen**,[1] **Ying Yu**,[1] **Chunlan Zhao**,[2] **and Guoping Tian**[2]

[1]*College of Electronic and Optical Engineering & College of Microelectronics, Nanjing University of Posts and Telecommunications, 210023 Nanjing, Jiangsu, China*
[2]*13th Research Institute, China Electronic Technology Group Corporation, 050051 Shijiazhuang, Hebei, China*

Correspondence should be addressed to Dong Chen; chendong@njupt.edu.cn

Received 16 August 2019; Revised 6 November 2019; Accepted 13 November 2019; Published 21 December 2019

Academic Editor: Hervé Aubert



In this paper, a novel design of compact microstrip antenna (MA) using an embedded $\lambda/4$ resonator is presented. By utilizing the strong coupling between the $\lambda/4$ resonator and the radiation patch of MA, the resonant frequency of MA can be decreased. Besides, the $\lambda/4$ resonator is embedded in the patch, which does not enlarge the whole size of MA. Therefore, a compact antenna can be realized. In this paper, after the principle is stated, a sample antenna has been manufactured and measured to prove the predicted characteristics of our proposed antenna. The measurement agrees well with the simulation. Hence, the proposed method in this paper is quite suitable for the design of a compact antenna.

## 1. Introduction

As the key component of a wireless communication system, transmission and reception of radio waves are accomplished by the antenna. In modern satellite communication and radar systems, the antenna and RF front-end are tightly connected or even integrated together [1]. As well known, mobile terminals increasingly require lightweight, small size, and low-power consumption. Therefore, the miniaturization of the RF front-end becomes the focus in recent years and has brought about our main challenges due to the limitations of a small antenna. Because of the peculiarity of lightweight, low profile, and easy integration with systems, microstrip antennas (MA) are widely applied in modern wireless terminals [2]. With the requirement of compact terminals, compact MA is in required indeed [3].

Several technologies of compact MA have been introduced and discussed in [4, 5] such as using a shorting wall [6, 7], shorting pin loading [8], utilizing a high permittivity substrate [9], and using a split-ring resonator (SRR) [10–13] and irregular ground plane [14].

In [15], a substrate having high permittivity or permeability is used to decrease the resonant frequency of the antenna. Nevertheless, the substrate with high permittivity or permeability might cause strong surface wave on the antenna, which will decrease the gain as well as the efficiency of the antenna. In [16, 17], the size of MAs is reduced by loading short-circuit pins. The short-circuit pin close to feeding point introduces a coupling capacitor into the resonant cavity, which realizes the miniaturization of the antenna. However, such compact MAs tend to have a narrower bandwidth, and the cross polarization level on H-plane becomes worse. In [18], the size of the MA is decreased by etching grooves on the antenna. The slotted patch causes the current to meander around the edge of the grooves, which lengthens the current path. The longer the groove, the lower the resonant frequency of the antenna. But, the cross polarization becomes worse because of the distortion of the current distribution caused by the slots.

In this paper, a compact MA is presented, which is composed of a microstrip patch and a $\lambda/4$ resonator

embedded in the patch. The patch is coupled with the $\lambda/4$ resonator by the edge. The resonant frequency of MA can be decreased by coupling between the $\lambda/4$ resonator and the patch. As the $\lambda/4$ resonator is embedded in the microstrip patch, the antenna size is not enlarged. Furthermore, the proposed compact antenna has good performance such as low cross polarization. Finally, the proposed compact antenna is manufactured and measured. The measured results are in good agreement with the predicted consequences, which prove our design method.

## 2. Analysis of the Antenna

Figure 1 depicts the proposed compact MA. The proposed compact MA is composed of a rectangular patch and a $\lambda/4$ resonator embedded in the patch. The width and length of the resonator is $W_1$ and $L_1$, respectively. One end of the $\lambda/4$ resonator is opened, while the other end is shorted by a shorting pin. Probe feeding scheme is introduced in our design. The feed pin is fed by a 50 Ω SMA connector at a distance $D$ from the open end of the $\lambda/4$ resonator. By the coupling between the $\lambda/4$ resonator and the rectangular patch (i.e., gap $S$), the radiation patch of MA is driven.

Figure 2 depicts the equivalent circuit represented by a LC-J-LCR network. The radiation patch is equivalent to a lossy parallel resonator composed of $R_a$, $L_a$, and $C_a$. The coupling between the radiation patch and the $\lambda/4$ resonator can be supposed to be a $J$-inverter $J_{12}$ equivalently, while the $\lambda/4$ resonator is equivalent to a lossless shunt resonator composed of $L_r$ and $C_r$.

Seen from the equivalent circuits in Figure 2, $Y_b$ can be obtained as follows:

$$Y_b = \frac{1}{R_a} + j\omega C_a + \frac{1}{j\omega L_a}. \tag{1}$$

Based on the cavity model theorem, the patch operates under its $TM_{01}$ mode, and the closed-form formulas in [19] can be used to calculate the values of $R_a$, $L_a$, and $C_a$.

By the basic design theory of the filter [20], the admittance $Y_a$ can be obtained as follows:

$$Y_a = \frac{J_{12}^2}{Y_b}. \tag{2}$$

The input admittance $Y_{in}$ of the antenna can be established as follows:

$$Y_{in} = Y_a + Y_c, \tag{3}$$

where $Y_c$ can be obtained as follows:

$$Y_c = j\omega C_r + \frac{1}{j\omega L_r}. \tag{4}$$

The values of $L_r$ and $C_r$ can calculated by the empirical formulas based on the transmission line resonator principle [20].

By substituting (1), (2), and (4) into (3), input admittance $Y_{in}$ can be obtained a follows:

$$Y_{in} = \left\{ \frac{(1/R_a)J_{12}^2}{(1/R_a)^2 + (\omega C_a - (1/\omega L_a))^2} + j\frac{(1/R_a)^2(\omega C_r - (1/\omega L_r)) - J_{12}^2(\omega C_a - (1/\omega L_a)) + (\omega C_a - (1/\omega L_a))^2(\omega C_r - (1/\omega L_r))}{(1/R_a)^2 + (\omega C_a - (1/\omega L_a))^2}. \right. \tag{5}$$

So far, the equivalent circuit has been deduced. It can be seen from formula (5) that when the size of the radiation patch of MA and the $\lambda/4$ resonator is determined, the input admittance is related to $J_{12}$. In other words, it is related to the gap $S$ between the $\lambda/4$ resonator and the rectangular patch of MA.

From the basic knowledge of the filter design [21], the resonant frequencies of the coupled resonators deviate to low-frequency band and high-frequency band simultaneously. The stronger the coupling strength, the more obvious the deviation. Based on this principle, the resonant frequency of MA can be decreased by enhancing the coupling between the resonator and the antenna, which can realize a compact MA. In combination with the theoretical analysis above, we will verify this phenomenon by simulation.

The parameter $S$ in Figure 3 indicates the space between the antenna and the resonator embedded in the proposed antenna, which can be utilized to adjust the resonant frequency. Several simulations have been carried out to examine this phenomenon, and the results are tabulated in Table 1. Under simulation, the other dimension parameters are set as follows: $W = 25.0$ mm, $L = 35.0$ mm, $W_1 = 2.0$ mm, $L_1 = 18.0$ mm, and $D = 16.7$ mm. The substrate has a dielectric constant of 2.65 and a thickness of 1.5 mm, respectively.

Seen from the simulation in Figure 3 and Table 1, the resonant frequency of the antenna gradually moves toward the lower frequency band with the decrease of $S$. At the same time, the simulated $S_{11}$ of a traditional MA without embedded $\lambda/4$ resonator is also plotted in Figure 3 and Table 1. Obviously, compared with that of the traditional MA, the resonant frequency of the proposed MA with embedded $\lambda/4$ resonator is dramatically reduced.

Meanwhile, the matching between antenna and 50 Ω SMA connector is achieved by adjusting the feed position $D$. As depicted in Figure 4, good matching can be achieved as the feeding probe moves toward the shorting pins. In the case of simulation, the other dimension parameters are set as follows: $W = 25.0$ mm, $L = 35.0$ mm, $W_1 = 2.0$ mm, $S = 0.2$ mm, and $L_1 = 18.0$ mm.

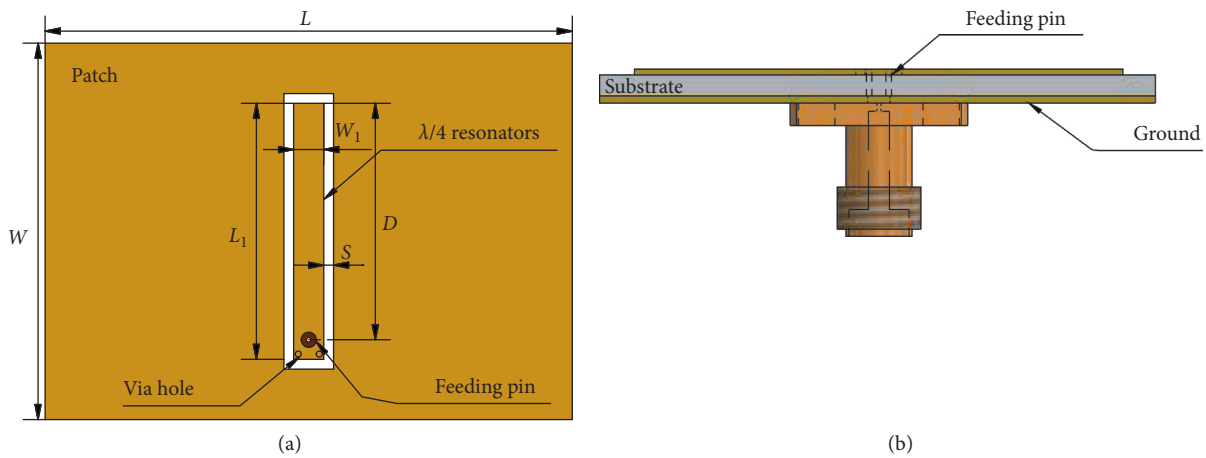


Figure 1: Physical layout of the proposed compact MA: (a) top view and (b) side view.

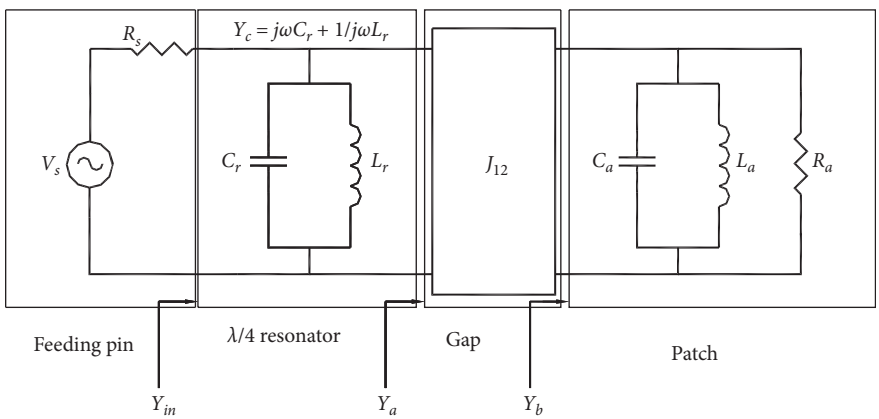


Figure 2: Equivalent circuit of the proposed compact MA.

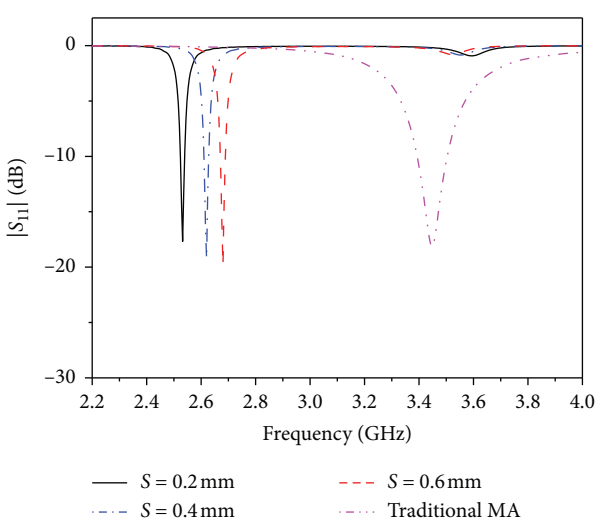


Figure 3: The simulated $S_{11}$ varies with $S$.

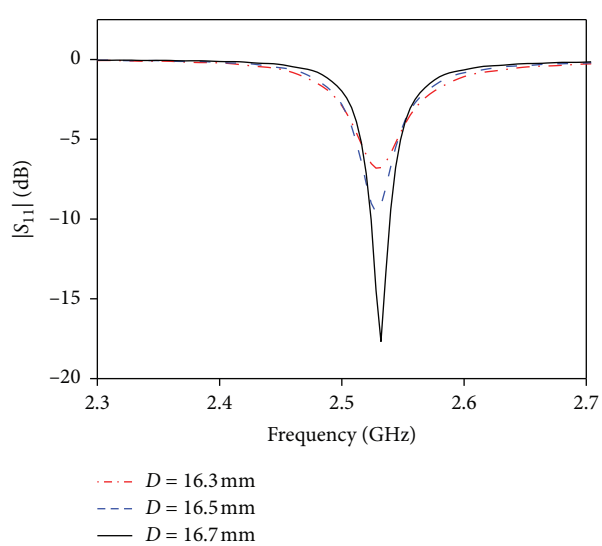


Figure 4: The simulated $S_{11}$ varies with D.

Table 1: Resonant frequency varied with S.

| The gap $S$ (mm) | Resonant frequency (GHz) | $S_{11}$ (dB) |
|---|---|---|
| 0.2 | 2.53 | −17.68 |
| 0.4 | 2.62 | −19.22 |
| 0.6 | 2.68 | −19.89 |
| Traditional MA | 3.45 | −18.15 |

Table 2: Geometric parameters of the proposed MA.

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $W$ | 25.0 mm | $L_1$ | 18.0 mm |
| $L$ | 35.0 mm | $D$ | 16.7 mm |
| $W_1$ | 2.0 mm | $S$ | 0.2 mm |

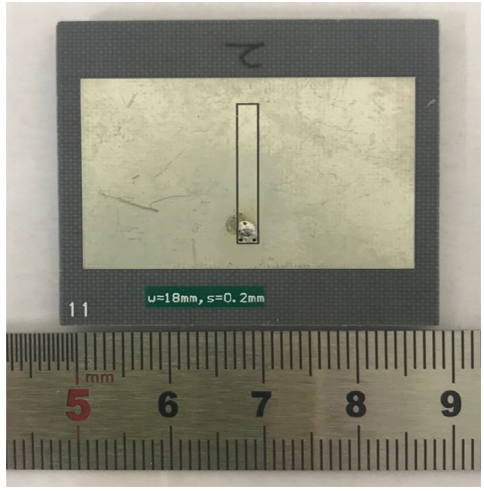


Figure 5: Photograph of the fabricated MA.

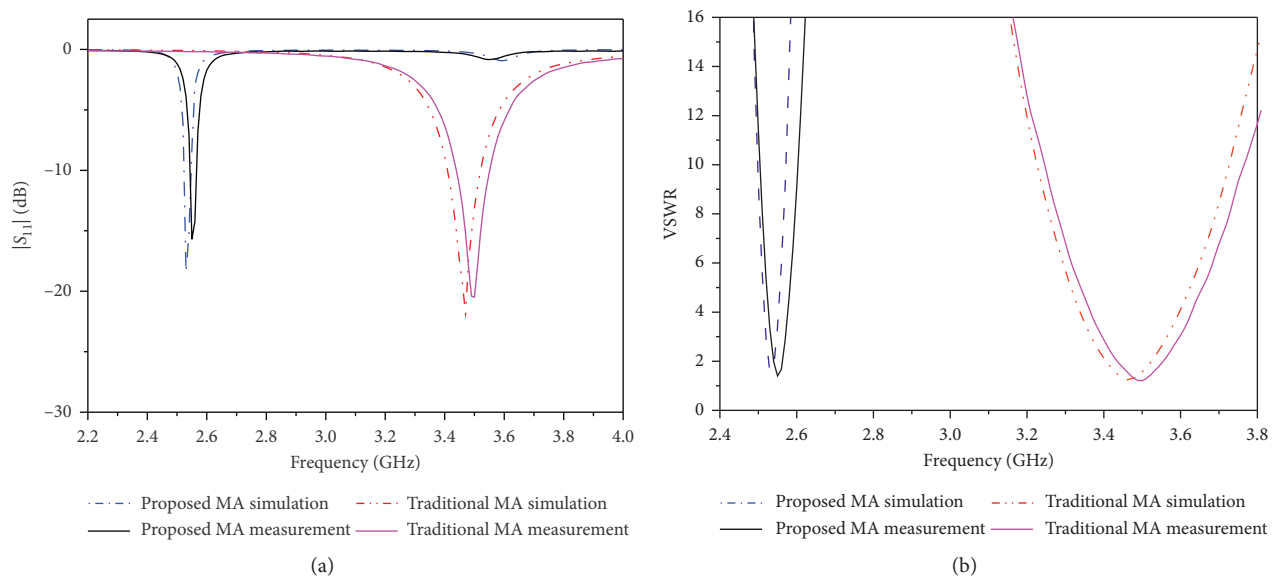


Figure 6: Simulated and measured (a) $S_{11}$ and (b) VSWR of the proposed and traditional MA.

## 3. Measured Results

After optimization carried out by electromagnetic simulation software CST STUDIO SUITE, the size parameters of a sample antenna are determined in Table 2. As mentioned above, the substrate has a dielectric constant of 2.65 and a thickness of 1.5 mm, respectively.

The sample MA is manufactured and measured to validate our design. Figure 5 displays the photograph of the proposed MA. The measurement of return loss and radiation pattern has been carried out by the Keysight E5071C vector network analyzer and SATIMO antenna electromagnetic field measurement system, respectively.

The simulated and measured $S$-parameters and VSWR are illustrated in Figure 6. The center frequency of the proposed antenna is about 2.59 GHz, and the corresponding value of $S_{11}$ and VSWR at 2.59 GHz is about −16.5 dB and 1.40, respectively. The slight difference between the simulation and measurement might be caused by the manufacture tolerance. Obviously, the resonant frequency of the proposed MA with embedded $\lambda/4$ resonator is reduced compared with that of the traditional MA (without embedded resonator and $W = 25.0$ mm and $L = 35.0$ mm), which can be observed in Figure 6. The phenomena of the preceding principle analysis are proved.

Seen from Figure 7, the measured gain in the band is around 4.0 dBi, which is in good agreement with the simulated result. Figure 8 depicts the simulated and measured radiation pattern at 2.59 GHz. The measurement is also consistent with the simulated results.

The proposed MA is also compared with the other reported compact MA in Table 3.

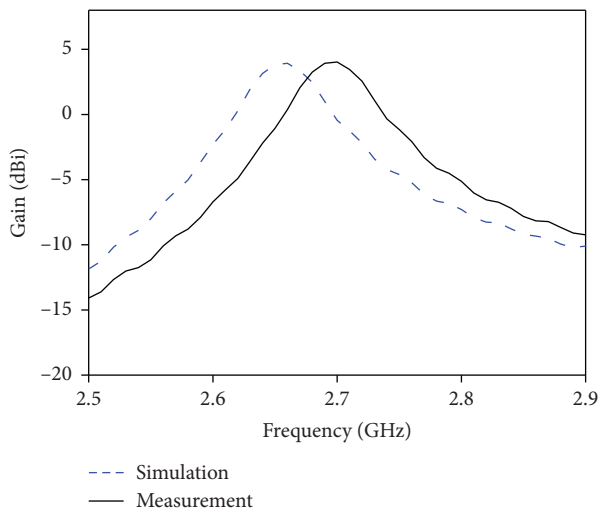


Figure 7: Simulated and measured radiation gain of the proposed MA.

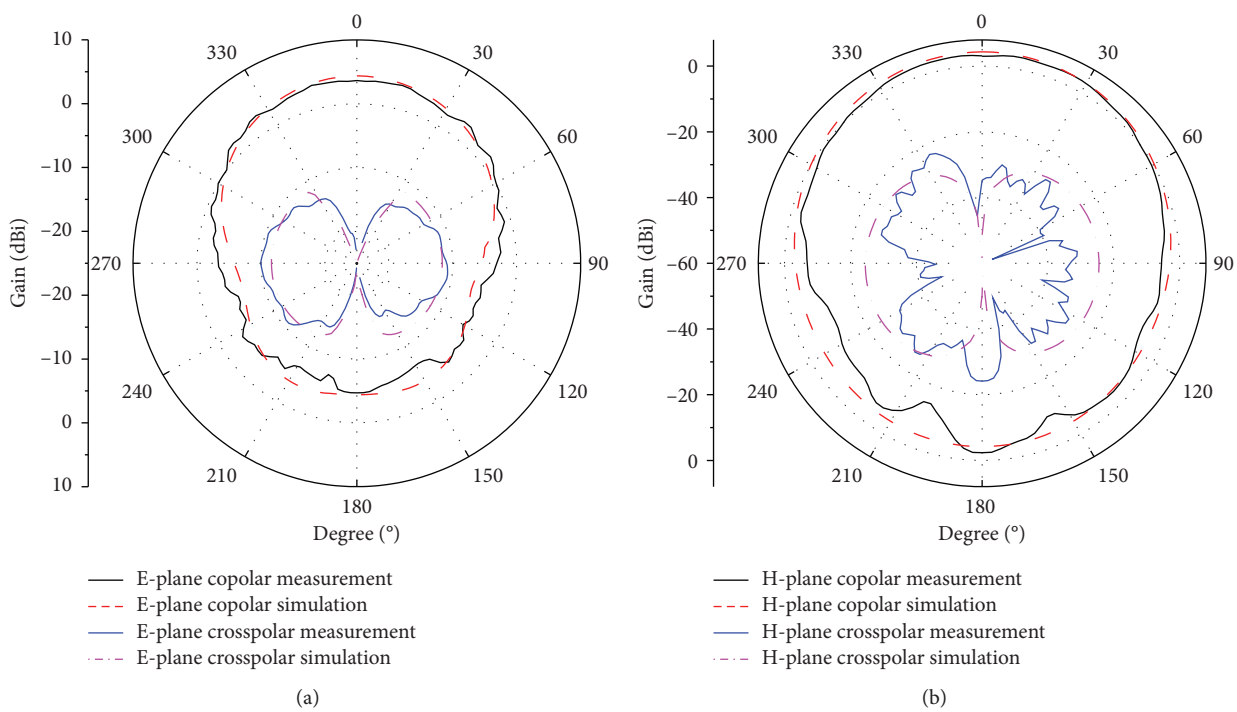


Figure 8: Simulated and measured radiation patterns of the proposed MA at 2.59 GHz (a) E-plane (b) H-plane.

Table 3: Comparison of various compact MAs.

| Ref. | Methods | Freq. (GHz) | Size | Gain (dB) | Substrate $\varepsilon_r$ | FBW (%) |
|---|---|---|---|---|---|---|
| [22] | Defected ground structure | 2.45 | $0.2\lambda_g \times 0.32\lambda_g$ | 2.35 | 4.4 | 6.12 |
| [23] | Magneto-dielectric metasubstrate | 2.35 | $0.13\lambda_g \times 0.17\lambda_g$ | 1.34 | 3.5 | 0.89 |
| [24] | Sierpinski carpet slot | 2.45 | $0.19\lambda_g \times 0.28\lambda_g$ | 2.69 | 4.7 | 2.85 |
| [25] | Loaded split-ring resonators | 2.406 | $0.27\lambda_g \times 0.27\lambda_g$ | −2.02 | 4.02 | 1.04 |
| The proposed antenna | Embedded $\lambda/4$ resonator | 2.59 | $0.22\lambda_g \times 0.30\lambda_g$ | 4.0 | 2.65 | 1.16 |

FBW: fractional bandwidth; $\lambda_g$: guide wavelength.

Compared with the other antennas tabulated in Table 3, our proposed MA provides better performance in terms of gain and size.

## 4. Conclusion

A novel compact MA with an embedded $\lambda/4$ resonator is proposed in this paper. By using the coupling between the $\lambda/4$ resonator and the patch, the resonant frequency of the MA can be decreased. Since the resonator is implanted in the MA, the whole size of the antenna does not increase. Furthermore, the proposed compact antenna also has good performance, such as loss cross polarization and easy input matching. Finally, a prototype MA is designed, manufactured, and measured. The simulation agrees with the measurement, which further proves the design method proposed in this paper.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Acknowledgments

This work is supported by the National Natural Science Foundation of China under project no. U1636108, the Key University Science Research Project of Jiangsu Province under project no. 17KJA470005, and SATIMO near-field antenna measurement system supplied by Nanjing University of Posts and Telecommunications.

## References

[1] T. S. Rappaport, J. N. Murdock, and F. Gutierrez, "State of the art in 60-GHz integrated circuits and systems for wireless communications," *Proceedings of the IEEE*, vol. 99, no. 8, pp. 1390–1436, 2011.

[2] K. M. Luk, K. F. Tong, S. M. Shum, K. F. Lee, and Q. Lee, "FDTD analysis of U-slot rectangular patch antenna," in *Proceedings of the IEEE Antennas and Propagation Society International Symposium Digest*, pp. 1390–1436, London, UK, 2011.

[3] R. Li, G. De Jean, M. M. Tentzeris, and J. Laskar, "Development and analysis of a folded shorted-patch antenna with reduced size," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 2, pp. 555–562, 2004.

[4] S. K. Patel, M. Ladumor, V. Sorathiya, and T. Guo, "Graphene based tunable grating structure," *Materials Research Express*, vol. 6, no. 2, Article ID 025602, 2018.

[5] S. K. Patel, M. Ladumor, J. Parmar, and T. Guo, "Graphene-based tunable reflector superstructure grating," *Applied Physics A*, vol. 125, no. 8, p. 574, 2019.

[6] S. Pinhas and S. Shtrikman, "Comparison between computed and measured bandwidth of quarter-wave microstrip radiators," *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 11, pp. 1615-1616, 1988.

[7] R. Chair, K. F. Lee, and K. M. Luk, "Bandwidth and cross-polarization characteristics of quarter-wave shorted patch antennas," *Microwave and Optical Technology Letters*, vol. 22, no. 2, pp. 101–103, 1999.

[8] R. Waterhouse, "Small microstrip patch antenna," *Electronics Letters*, vol. 31, no. 8, pp. 604-605, 1995.

[9] B. Lee and F. J. Harackiewicz, "Miniature microstrip antenna with a partially filled high-permittivity substrate," *IEEE Transactions on Antennas and Propagation*, vol. 50, no. 8, pp. 1160–1162, 2002.

[10] S. K. Patel and Y. Kosta, "Triband microstrip-based radiating structure design using split ring resonator and complementary split ring resonator," *Microwave and Optical Technology Letters*, vol. 55, no. 9, pp. 2219–2222, 2013.

[11] S. K. Patel and Y. Kosta, "Liquid metamaterial based microstrip antenna," *Microwave and Optical Technology Letters*, vol. 60, no. 2, pp. 318–322, 2018.

[12] S. K. Patel and Y. P. Kosta, "Split-ring resonator metamaterial-loaded parallel-plate structure for performance enhancement," *Journal of Modern Optics*, vol. 61, no. 15, pp. 1282–1289, 2014.

[13] S. K. Patel, C. Argyropoulos, and Y. P. Kosta, "Broadband compact microstrip patch antenna design loaded by multiple split ring resonator superstrate and substrate," *Waves in Random and Complex Media*, vol. 27, no. 1, pp. 92–102, 2016.

[14] D. Wang, H. Wong, and C. H. Chan, "Small patch antennas incorporated with a substrate integrated irregular ground," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 7, pp. 3096–3103, 2012.

[15] H. Mosallaei and K. Sarabandi, "Antenna miniaturization and bandwidth enhancement using a reactive impedance substrate," *IEEE Transactions on Antennas and Propagation*, vol. 52, no. 9, pp. 2403–2414, 2004.

[16] A. Chapari, A. Z. Nezhad, and Z. H. Firouzeh, "Analytical approach for compact shorting pin circular patch antenna," *IET Microwaves, Antennas & Propagation*, vol. 11, no. 11, pp. 1603–1608, 2017.

[17] V. Gonzalez-Posadas, D. Segovia-Vargas, E. Rajo-Iglesias, J. L. Vazquez-Roy, and C. Martin-Pascual, "Approximate analysis of short circuited ring patch antenna working at," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 6, pp. 1875–1879, 2006.

[18] D. E. Brocker, D. H. Werner, and P. L. Werner, "Dual-band shorted patch antenna with significant size reduction using a meander slot," in *Proceedings of the 2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, pp. 289-290, Memphis, TN, USA, July 2014.

[19] R. Garg, P. Bhartia, and I. Bahl, *Microstrip Antenna Design Handbook*, Artech House, Norwood, UK, 2001.

[20] D. M. Pozar, *Microwave Engineering*, Wiley & Sons, Hoboken, NJ, USA, 4th edition, 2011.

[21] S. B. Cohn, "Parallel-coupled transmission-line-resonator filters," *IRE Transactions on Microwave Theory and Techniques*, vol. 6, no. 2, pp. 223–231, 1958.

[22] R. Wang, J. Wang, R. Xie, X. Wang, Z. Xu, and S. Zhu, "A novel miniaturized microstrip antenna using interdigital capacitor based on defected ground structure," in *Proceedings of the 2016 Progress In Electromagnetic Research Symposium (PIERS)*, Shanghai, China, August 2016.

[23] S. Kumar and D. K. Vishwakarma, "Miniaturisation of microstrip patch antenna using an artificial planar magneto-dielectric meta-substrate," *IET Microwave, Antennas & Propagation*, vol. 10, no. 11, pp. 1235–1241, 2016.

[24] S. Shrestha, J. J. Park, S. K. Noh, and D. Y. Choi, "Design of 2.45 GHz sierpinski fractal based miniaturized microstrip patch antenna," in *Proceedings of the 2012 18th Asia-Pacific Conference On Communications (APCC)*, Jeju, South Korea, October 2012.

[25] Y. Dong, H. Toya, and T. Itoh, "Design and characterization of miniaturized patch antennas loaded with complementary split-ring resonators," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 2, pp. 772–785, 2011.