JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 3, 03002(5pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 3, 03002(5cc) (2024)

REGULAR ARTICLE

Investigation of Complementary Metamaterial Resonators-Based Novel Dual-Band Coplanar Slotted Antenna for Wireless Communication

M. Moulay[1], M. Abri[2], M. Berka[1,3,*], T. Islam[4], S. Das[5], Ch. R. Prasad[6]

[1] *Department of Electrotechnic, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[2] *Department of Telecommunications, University Abu Bekr Belkaid of Tlemcen, 13000 Tlemcen, Algeria*
[3] *Laboratory E.P.O, 22000 Sidi Bel Abbés, University of S.B.A, Algeria*
[4] *Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204, USA*
[5] *Department of Electronics and Communication Engineering, IMPS College of Engineering and Technology, Malda, W.B, India*
[6] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India*

(Received 10 April 2024; revised manuscript received 14 June 2024; published online 28 June 2024)

The small-sized planar antenna represents a basic element for wireless communication systems. In this paper, a novel dual-band coplanar antenna is reported and designed for wireless communications applications. The proposed antenna is based on the unusual electromagnetic behavior of complementary split ring metamaterial resonators (CSRRs). In its design, the antenna comprises three CSRRs; two of them are identical in shape (circular) and size and the other has a rectangular shape. The final shape of the proposed antenna was evolved after three different stages of three models each. The designed antenna patch is printed on the top side of the chosen dielectric substrate which is the FR4_Epoxy for physical characteristics ($\varepsilon_r = 4.4$ and $tg\ \delta = 0.02$). The proposed antenna is powered by a coplanar line with an optimized length to provide the necessary adaptation. The radiating patch is printed in copper with a thickness of 0.035 mm. Simulations of the electromagnetic performances using the High Frequency Structure Simulator (HFSS) allowed us to discuss the reflection, bandwidth and gain of the studied antenna. According to the obtained outcomes, our antenna resonates at the two frequencies of 2.4 and 3.33 GHz with good adaptation and a bandwidth of around 65 and 215 MHz, respectively. All of these qualities can confirm the effectiveness of our antenna for a diversity of applications, particularly for wireless communications.

Keywords: Antenna, Coplanar, CSRRs, Gain, Metamaterial.

DOI: 10.21272/jnep.16(3).03002 PACS number: 84.40.Ba

1. INTRODUCTION

The development of antenna devices has contributed in one way or another to the development of modern wireless communication systems. The planar antenna [1, 2] with any configuration represents the basic element for the discussed systems. The miniaturization of the antenna with minimum losses is strongly requested to have compact devices with certain qualities [3, 4]. These two objectives are often hampered by design and implementation constraints. in the last few years, the design of planar antennas with metamaterial resonators of magnetic activity was able to solve these problems, in particular the problems of losses and congestion [5].

The split ring metamaterial resonators (SRRs) proposed and used for the first time by Sir John Pendry [6] have so far shown their effectiveness and importance in the design of planar antennas for the two regions; gigahertz (GHz) [7–9] and terahertz (THz) [10–11]. Depending on the size and shape of such an SRR, the electrical qualities of the metamaterial antennas are different from one antenna to another. In [12], a reconfigurable antenna was proposed for 5G applications. Thanks to metamaterial resonators, this antenna has been miniaturized up to $\lambda/8$ at a frequency of 3.5 GHz. It had a gain of around 8 dBi. A metasurface composed of an array of negative refractive index SRR resonators was exploited in [13] to improve the gain of a microwave antenna. This antenna had an average gain of 3.75 dBi for a bandwidth of 600 MHz. SRRs has also been used to improve the electrical qualities of antennas in multi-input multi-output configuration (MIMO). In [14], A four-port MIMO antenna was designed based on two different shapes (Circular and rectangular) of the SRRs. The gain achieved for the proposed antenna was around 15.79 dB for good isolation of less than −28 dB. An electromagnetic band gap (EBG) metamaterial resonator was used in [15] for the design of a MIMO antenna. The designed antenna resonated at 28/38 GHz with an isolation of around −68−90 dB.

In this paper, a novel coplanar antenna for wireless communication applications is investigated. The final shape of the antenna patch is proposed according to

---

[*] Correspondence e-mail: m.barka@univ-mascara.dz

Cite this article as: M. Moulay et al., *J. Nano- Electron. Phys.* 16 No 3, 03002 (2024) https://doi.org/10.21272/jnep.16(3).03002

three design stages. The SRRs resonators are introduced in the final stage to have the desired model for a size of (50.5 × 33.97) mm^2. The patch is feeded by a coplanar line of length of 8.5 mm to have the 50 Ω matching.

2. ANTENNA DESIGN

2.1 Antenna Evolution

The proposed antenna has a patch derived from the classical rectangular shape which contains both circular and rectangular complementary metamaterial resonators CSRRs. For the first stage, the patch has a rectangular shape of length L and width W. In the second stage, we have modified the antenna shape with two half-circles on both sides. In the final stage which represents the model of the proposed antenna, we added slits in the patch using the CSRRs resonators as shown in Fig. 1.

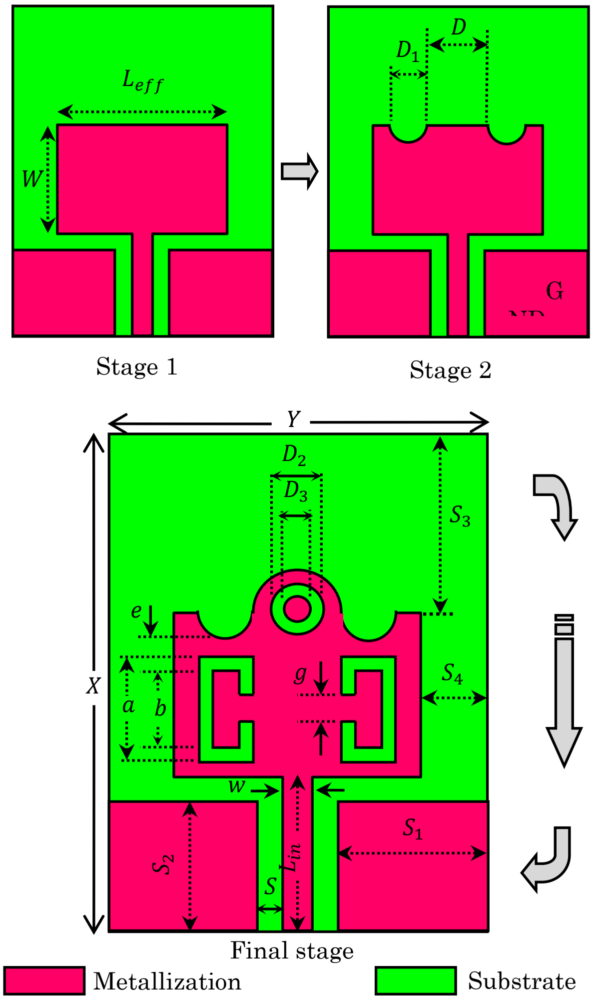


Fig. 1 – Representation of the proposed antenna, design stages and various parameters

2.2 Antenna Size

Calculating the patch surface area amounts to proposing the values of the different parameters. The sides (X, Y) of the proposed antenna are given by the following expression.

$$\begin{cases} X = L_{in} + W + S_3 = W + S + S_2 + S_3 \\ Y = L_{eff} + 2S_4 = w + 2(S + S_1) \end{cases} \qquad (1)$$

For the basic antenna shown in the first stage, the length and the width are given by the following relations [16].

$$L_{eff} = \frac{C_0}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (2)$$

$$W = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (3)$$

Here, ε_{eff} represents the effective permittivity of the inhomogeneous medium (Substrate and air), C_0 is the speed of light. The effective permittivity and the difference to the length of the patch are expressed in [16].

$$\begin{cases} \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2} \\ \frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \end{cases} \qquad (4)$$

The dimensions of the suggested antenna of sides (X = 50.5 mm, Y = 33.97 mm) are listed in Table 1.

Table 1 – Various parameters of the proposed antenna

Parameter	Value (mm)	Parameter	Value (mm)
a	16.5	D_3	3.6
b	14.9	S	0.8
g	1.2	S_1	15.58
W	28.5	S_2	7.7
L_{eff}	21.97	S_3	13.5
D	9.97	S_4	6
D_1	4	w	1.2
D_2	5.2	e	4

3. RESULTS AND DISCUSSION

3.1 Antenna Reflection

On the top face of the FR4_Epoxy substrate with a thickness $h = 1.5$ mm, we have printed the patch of the proposed antenna with metallization in copper with a thickness $t = 35$ μm. Around the resonance of 3.2 GHz (a frequency chosen in the C- band), the dimensions of the rectangular base antenna are ($L_{eff} = 21.97$ mm, $W =$ 28.5 mm) for ($\varepsilon_{eff} = 4.03$ and $\Delta L = 0.69$ mm). So the dimensions of the antenna of the final model proposed are determined according to L_{eff} and W and they are summarized in Table 1. To simulate the proposed antenna using the digital calculator, we set the band conditions. A radiation box which represents free space is used to shield the antenna from the radiated electromagnetic field. The proposed antenna is illustrated in the 3D-Modeler of the simulator and represented in Fig. 2.

The antenna reflection of the first two models is shown in Fig. 3.

As shown in Fig. 3, the reflection of the antenna for the first two stages is almost the same for an identical resonance of around 3.4 GHz, which is the working frequency proposed to find the dimensions of the patch. We also note that the antenna has a good matching for both models with a reflection of around – 20.45 dB.

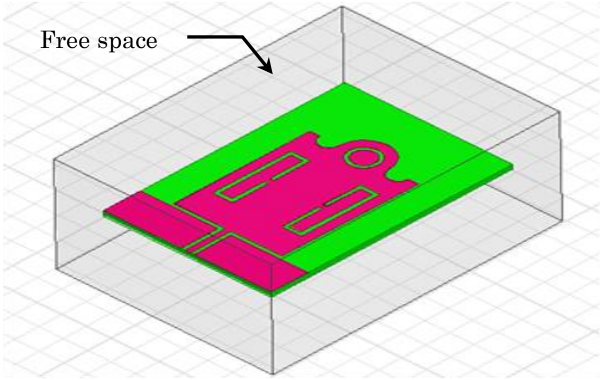


Fig. 2 – Simulation setup of the proposed antenna

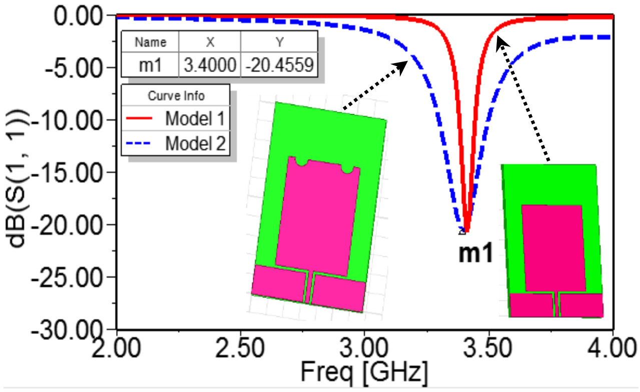


Fig. 3 – Reflection of the antenna for model 1 and 2

As shown in Fig. 3, the reflection of the antenna for the first two stages is almost the same for an identical resonance of around 3.4 GHz, which is the working frequency proposed to find the dimensions of the patch. We also note that the antenna has a good matching for both models with a reflection of around – 20.45 dB.

The antenna reflection for the proposed model is shown in Fig. 4.

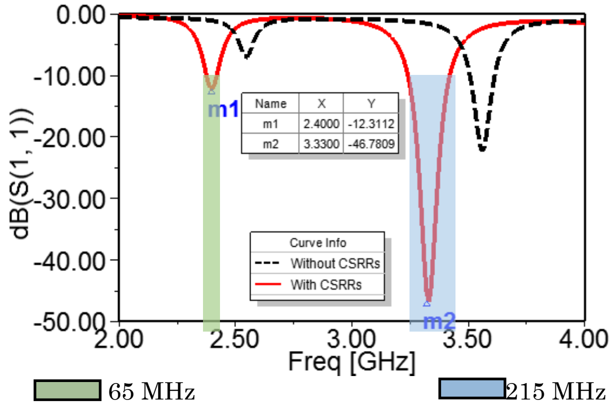


Fig. 4 – Reflection of the proposed antenna

Fig. 4 represents the proposed antenna reflection for the final stage. In order to show the impact of the complementary metamaterial resonators, we have represented the two cases; without and with CSRRs. We notice for the case of the patch without CSRRs that the two semi-circle slots created a rejection in terms of the antenna response (with poor adaptation) for the first configurations. The etching of complementary CSSR resonators in the patch also created a considerable rejection band with good adaptation (reflection around – 46.78 dB). This characteristic allowed our antenna to radiate on two frequency bands of 65 and 215 MHz at resonances of 2.4 and 3.33 GHz, respectively.

3.2 Antenna Performance

In this section, we discuss the performance of the proposed metamaterial antenna (gain, radiation pattern and surface current). The gain of the antenna with the three CSRRs and shown in Fig. 5.

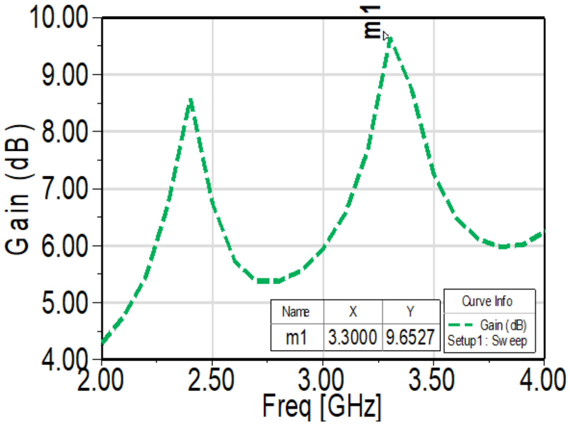


Fig. 5 – Gain of metamaterial antenna

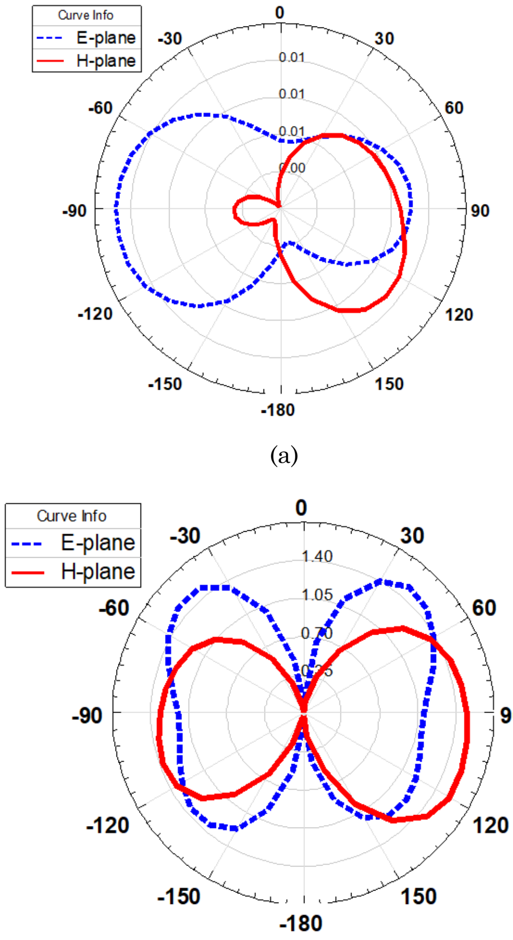
Fig. 5 represents the gain of the proposed metamaterial antenna. It is noted that the gain characteristic has two peaks of maximum values corresponding to the two resonances of the antenna. Around the second resonance of 3.33 GHz, the gain achieved is of the order of 9.65 dB which represents a significant value for the desired applications. The radiation pattern of our antenna is shown in Fig. 6.

As shown in Fig. 6, radiation patterns are presented in the *E*- $(\emptyset = 90^{\circ})$ and *H*-planes $(\theta = 90^{\circ})$ for the first resonance. We note that the antenna provides a nearly omni-directional *E*-plane pattern and a bi-directional *H*-plane radiation. This performance can justify the importance of our antenna for C-band applications. For the second resonance, we confirm the same radiation characteristics.

To show the impact or influence of the complementary metamaterial resonators CSRRs on the electrical qualities of the designed antenna, it is better to represent the distribution of the magnetic field and surface current on the patch.

As shown in Fig. 6, radiation patterns are presented in the *E*- $(\emptyset = 90^{\circ})$ and *H*-planes $(\theta = 90^{\circ})$ for the first resonance. We note that the antenna provides a nearly omni-directional *E*-plane pattern and a bi-directional *H*-plane radiation. This performance can justify the importance of our antenna for C-band applications. For the second resonance, we confirm the same radiation characteristics.

To show the impact or influence of the complementary metamaterial resonators CSRRs on the electrical qualities of the designed antenna, it is better to represent the distribution of the magnetic field and surface current on the patch.



(a)

(b)

Fig. 6 – Radiation patterns of the proposed antenna for (a) 2.4 GHz and (b) 3.33 Ghz

The distribution of the magnetic field and surface current (for both resonances) on the patch and the ground plane of our antenna are shown in Fig. 7. In Fig. 7 (a) which represents H-distribution at the 2.4 GHz resonance, we notice that the magnetic field is relatively concentrated in the patch in the area located between the CSRRs. A strong concentration is also noticed between the coplanar feed line and the ground plane of the antenna. At the 3.33 GHz resonance shown in Fig. 7 (b), we notice that the concentration of the magnetic field has become greater, which justifies the coupling effect between the CSRRs to create the necessary rejection.

Discussing the surface current distribution for the two resonances, Fig. 7 (c) which represents this distribution at 2.4 GHz shows that the current is concentrated in the same places where the magnetic field exists. In Fig. 7(d), the current flows in the surface of the patch and the coplanar ground plane with considerable values. We also notice that the current is considerably suppressed around the three CSRRs. This characteristic can justify the creation of magnetic dipoles responsible for the two resonances.

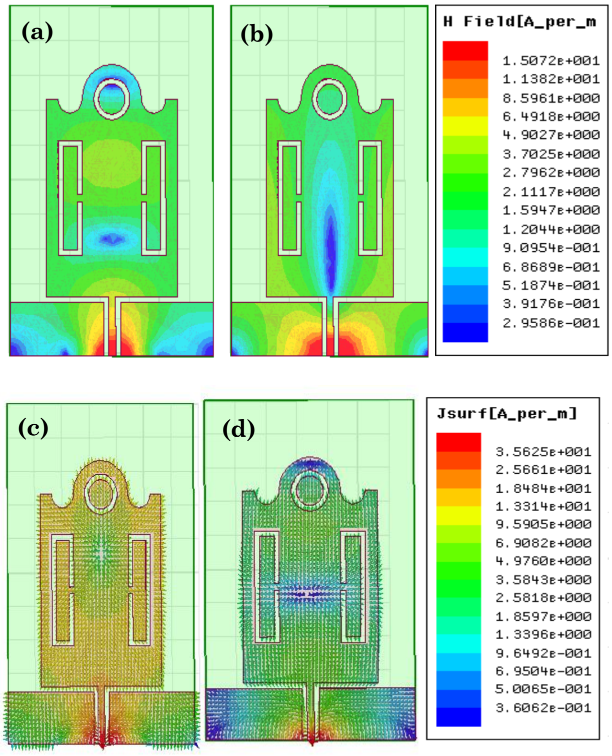


Fig. 7 – H-field distribution at (a) 2.4 and (b) 3.33 GHz, and Surface current distribution on the antenna at (a) 2.4 and (b) 3.33 GHz (with A/m scale).

4. CONCLUSIONS

To sum up, a dual-band coplanar metamaterial antenna has been successfully reported and designed for operation in wireless communications systems. The proposed antenna has an overall size of (50.5 × 33.97) mm^2 and it was fed by a coplanar line with a length of 8.5 mm. The final shape of the antenna patch is derived by the conventional rectangular patch with slots introduced in the form of complementary metamaterial resonators CSRRs. These metamaterial resonators contributed directly to the creation of two resonances corresponding to two separated bandwidths with a significant rejection band. The simulation results carried out show that the proposed antenna has good electrical qualities. Two bandwidths of the order of 65 and 215 MHz in the C-band, a significant gain of the order of 9.65 dB, radiation in both planes for the two resonances and good adaptation for a reflection of the order of – 46.78 dB. The performance of our antenna with a simple design makes our structure highly recommended for various applications of wireless communication systems.

ACKNOWLEDGEMENTS

This work was supported by the Algerian Ministry of Higher Education and Scientific Research and the General Directorate for Scientific Research and Technological Development (DGRSDT) via funding through the PRFU Project No. A25N01UN220120200001.

REFERENCES

1. I. Khadhraoui, T. Ben Salah, T. Aguili, *J. Comput Electron.* **21**, 713 (2022).
2. D. El Hadri, A. Zugari, A. Zakriti, *Australian Journal of Electrical and Electronics Engineering* **18**. 2 (2021).
3. J. Liu, C. Xu, H. Yu, J. Su, *Sci. Rep.* **11**, 12499 (2021).
4. Y. Fan, X. Liu, J. Li, T. Chang, *Micromachines* **10**, 1 (2019).
5. Y.S. Faouri, S. Ahmad, N.O. Parchin, C.H. See, R. Abd-Alhameed, *Electronics* **11**, 5 (2022).
6. R. Marquez, F. Medina, R. Raffi, *Phys. Rev. B* **65**, 144440 (2002).
7. M. Berka, U. Özkaya, T. Islam, *et al. Opt. Quant. Electron.* **55**, 699 (2023).
8. M. Berka, B. Fellah, T. Islam, *et al. Opt. Quant. Electron.* **55**, 1223 (2023).
9. M. Berka, A. Bendaoudi, K. Benkhallouk, *et al. Appl. Phys. A* **128**, 1112 (2022).
10. M. Tal, S. Keren-Zur, T. Ellenbogen, *ACS Photon.* 7, 12 (2020).
11. A. Kumar, D. Saxena, *Opt. Quant. Electron.* **55**, 1043 (2023).
12. T. Saba, *et al. Micromachines* **14**, 131 (2023).
13. Md. Moniruzzaman, M. Mobarak, A. Alqahtani, *Opt. Mater.* **148**, 114777 (2024).
14. M. Berka, et al., *J. Nano- Electron. Phys.* **14** No 6, 06018 (2022).
15. R. H. Elabd, A.J. Abdullah Al Gburi, *J Infrared Milli. Terahz. Waves* **45**, 35 (2023).
16. A.C.A. Balanis, *3rd Edition, John Wiley and Sons* (2011).

Дослідження нової дводіапазонної копланарної щілинної антени на основі додаткових метаматеріальних резонаторів для бездротового зв'язку

M. Moulay[1], M. Abri[2], M. Berka[1,3], Tanvir Islam[4], Sudipta Das[5], Ch Raghava Prasad[6]

[1] *Department of Electrotechnic, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[2] *Department of Telecommunications, University Abu Bekr Belkaid of Tlemcen, 13000 Tlemcen, Algeria*
[3] *Laboratory E.P.O, 22000 Sidi Bel Abbés, University of S.B.A, Algeria*
[4] *Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204, USA*
[5] *Department of Electronics and Communication Engineering, IMPS College of Engineering and Technology, Malda, W.B, India*
[6] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India*

Малогабаритна планарна антена є базовим елементом для систем бездротового зв'язку. У статті описано нову дводіапазонну копланарну антену, дія якої заснована на незвичайній електромагнітній поведінці комплементарних резонаторів з метаматеріалів з розділеним кільцем (CSRR). За своєю конструкцією антена складається з трьох CSRR; два з них однакові за формою (круглі) і розміром, а інший має прямокутну форму. Остаточна форма запропонованої антени була розроблена після трьох різних етапів по три моделі на кожній. Розроблена накладка антени надрукована на верхній стороні обраної діелектричної підкладки - епоксидної смоли FR4 для фізичних характеристик ($\varepsilon_r = 4.4$ and $tg\,\delta = 0.02$). Антена живиться від компланарної лінії з оптимізованою довжиною для забезпечення необхідної адаптації. Випромінююча накладка надрукована на міді товщиною 0,035 мм. Моделювання електромагнітних характеристик за допомогою симулятора високочастотної структури (HFSS) дозволило дослідити відображення, смугу пропускання та посилення антени. Згідно з отриманими результатами, антена резонує на двох частотах 2,4 і 3,33 ГГц з хорошою адаптацією та смугою пропускання близько 65 і 215 МГц відповідно. Усі ці параметри можуть підтвердити ефективність антени для різноманітних застосувань, зокрема для бездротового зв'язку.

Ключові слова: Антена, Компланар, CSRRs, Підсилення, Метаматеріал.