JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 15 No 4, 04014(4pp) (2023)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 15 № 4, 04014(4cc) (2023)

Design of a Planar Multi-band Antenna Array based on Split Ring Resonator for WiMAX and 5G Sub-6GHz Applications

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(Received 12 June 2023; revised manuscript received 14 August 2023; published online 30 August 2023)

In this paper, a novel technique based on rectangular shaped split ring resonators (SRRs) is used to examine a new multiband antenna array design. The analysis of simulation results is shown and described in this article. The suggested antenna radiator is mounted on a low cost FR4 substrate having an overall area of 154 × 70 mm². The proposed SRRs based array antenna offers triple band resonances with high gain characteristics. The resonant frequencies, return loss, and radiation patterns are calculated concurrently using a number of simulation results that support the applicability of the created model. An electromagnetic solution based on MOM, included into ADS is used for the simulation. The full N77/N78/N79 spectrum is covered by the multiband array antenna which is validated with $S_{11} \leq -10$ dB for three operating frequency bands at 3.5 GHz, 4 GHz, and 4.22 GHz with high gains of 6.4, 6.8, and 7.25 dBi, respectively. It supports LTE, WiMAX, and WLAN wireless network systems, as well as the 5G spectrum operating below 6 GHz. The investigated antenna exhibits distinguishing qualities like a planar profile, a small footprint, symmetrized radiation behavior, and a good gain. The investigated multiband antenna can be of choice as a promising candidate to be used in modern wireless communication services within microwave S-band under sub-6 GHz spectrum.

Keywords: Antenna Array, SRR, Microstrip Patch Antenna, Triple band, High Gain, ADS, Wireless communication

DOI: 10.21272/jnep.15(4).04014 PACS number: 84.40.Ba

1. INTRODUCTION

The fifth generation (5G) cellular network is expected to support a range of new applications, including industrial automation, high speed data communication, and the Internet of Things (IoT). The design procedure for antenna or antenna arrays for mobile devices is one of the key topics for successful deployment of 5G technology [1-3]. This development is related to the constant need to improve the quality of information. The problem that arises for wireless communications is related to the fact that the non-homogeneous medium is unfavorable for the propagation of electromagnetic waves. This is due to multiple diffractions and reflections that considerably affect the propagated waves, introducing deep fading caused by multiple paths. This phenomenon is generally the result of the superposition and the constructive and destructive combination of multiple paths, which introduces disturbances in the received signal, which could generate errors in the transmission [4]. There were 5 million 5G mobile connections as of the end of 2018, and 577 million connections are anticipated by 2023. 5G wireless communications are distinguished from previous generations by unique parameters as GPS data transfer rate, millisecond latency, extremely high traffic volume density, ultra-dense connections, better spectrum energy, and cost effectiveness [5]. The following spectrum was designated for use in 5G communications by the ITU, including 3.4 – 3.6 GHz and 4 – 6 GHz bands. It brings to the design of microwave circuits characterized by small size, light weight and lower costs, as well as stringent electromagnetic characteristics. Planar structures are well suited to meet these requirements. Among the techniques used, planar microwave circuits based on metamaterials [6-13], particularly of the resonant type, have other advantages such as frequency selectivity, control of the operating frequency bandwidth as well as multi-band structures. Among these resonators, we find the association with planar antennas which allows the design of multiband antennas [14-15]. In this work, we have conducted a new study on the use of the SRR resonator to achieve multiband behavior for planar antennas. The designed antenna array is validated at 3.5 GHz, 4 GHz and 4.22 GHz by optimizing the antenna array associated with the SRR element, which allows generating distinct resonant frequency bands. Finally, we discussed the different results of the simulations in terms of radiation performance and the number of SRR cells.

2. MULTIBAND ANTENNA ARRAY DESIGN PROCEDURE

The goal of this research is to create an antenna array based on a narrowband radiating element and then

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The results were presented at the 3rd International Conference on Innovative Research in Renewable Energy Technologies (IRRET-2023)

integrate well-optimized SRR cells. This antenna array can be designed for multi-band operations that can be matched to many standards of communication like the WiMAX band, and 5G applications. The basic antenna element is the is validated at the center frequency 3.5 GHz, then by associating a T-junction power divider, the required antenna array structure has been formed. The T-power which may be implemented in a variety of ways, including microstrips, waveguides, and SIWs. For a perfect power divider, initially, the two output ports have identical amplitudes and phases. The antenna array geometry is shown in Fig. 1.

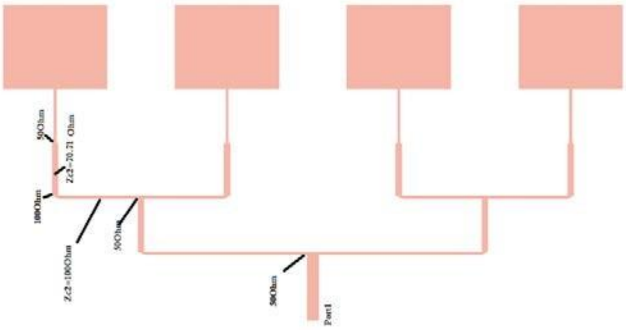

Fig. 1 – The antennas array designed at 3.5 GHz.

After the simulation of the antennas array with 4 antenna elements by using ADS simulation tool, we could validate an array operating in a narrow band centered at 3.5 GHz as depicted in Fig. 2. The proposed array is simulated by taking into account a high mesh density in order to cover the whole circuit. As shown from the reflection coefficient, we have obtained a good input impedance matching suitable for WiMAX Applications.

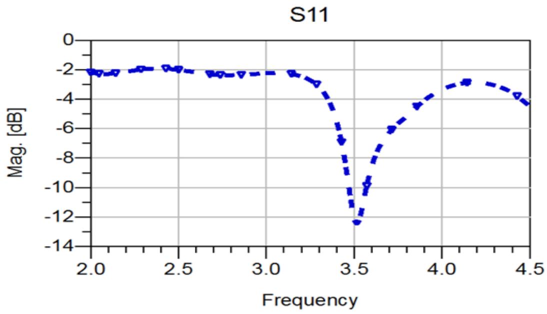

Fig. 2 – Reflection coefficient versus frequency

So, The SRR cell was connected across the breadth of the antenna. Following several optimizations and a parametric analysis on the dimensions of the SRR resonator, an antenna array has been obtained which is multiband as shown in Fig. 3.

Table 1 – SSR optimization parameters

Parameter	Unit (mm)
L1	4
W1	0.5
W2	4
g1	0.15
g2	0.2

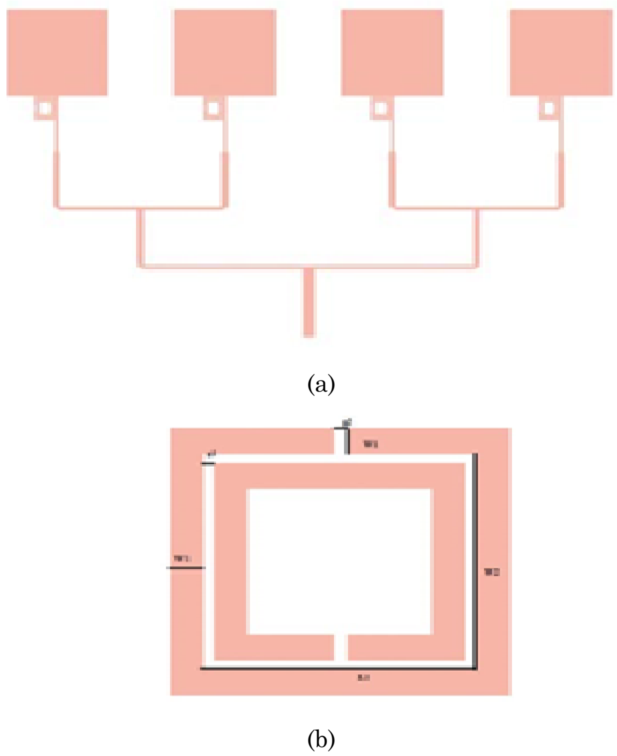

Fig. 3 – The proposed multiband antenna array associated to SRR resonator (a), The optimizedSRR cell (b).

The dimensional parameters of the optimized SRR are presented in the following Table 1.

Fig. 4 shows the variations of the reflection coefficient as a function of "g". As illustrated in this figure, it can be seen that the more the value of "g" is getting smaller, the SRR cell is close to the width of the patch and due to this, a second resonance with a very good matching is obtained.

After the various parametric studies carried out in relation to the radiating element, a multi-band patch antennas array (Fig. 4) is validated with two application bands one centered at 3.5 GHz with a significant gain of 6.4 dBi for WiMAX applications and a second band centered at 4.25 GHz for Aeronautical Radio navigation. The radiation patterns of this dual band antenna structure are presented in the Fig. 5 for the two operating frequency bands and which are directives in natures.

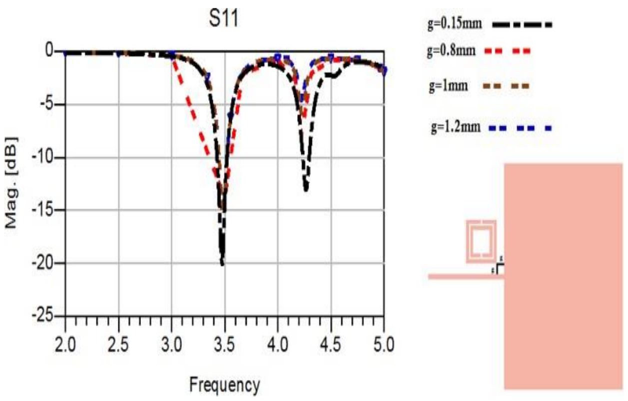

Fig. 4 – The reflection coefficient versus frequency in GHz for different values of "g".

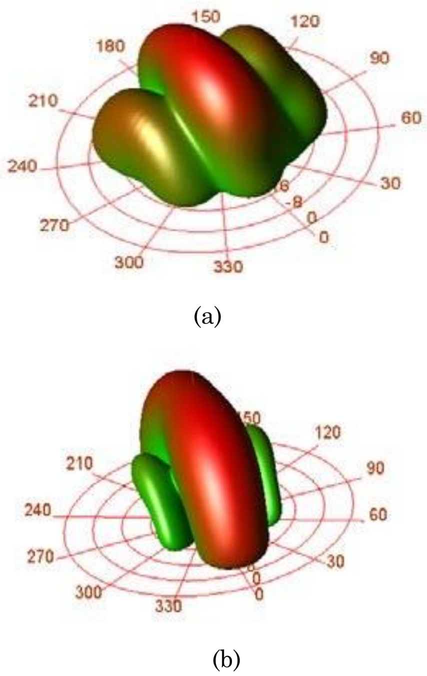

Fig. 5 – Radiation patterns of the dual band single SRR integrated array antenna at 3.5 GHz (a), 4.25 GHz (b)

After the validation of this antenna structure, another study is conducted to see the influence of number of SRR cells on patch antenna's resonance. Then it is found that for two SRR cells are coupled with the patch antenna as indicated in Fig. 6. The antenna becomes multiband with another frequency band centered at 4 GHz as shown in Fig. 6. It can be concluded that the increase in the number of cells makes the antenna multi-band with resonating frequencies at 3.5 GHz, 4 GHz, 4.25 GHz. By consequent, the increase of the SRR cells demonstrated the feasibility of designing and building multiband antennas while associating a well-optimized SRR cells coupled with the radiating element. Additionally, the dual SRR cells integrated antenna shows increased gain values. The peak gains of 6.4, 6.8 and 7.25 dBi are obtained at triple resonances. The performance of the proposed antenna is compared with other references and outlined in Table 2. It's observed that the proposed array antenna provides a greater number of resonating bands with better gains as compared with other reported designs [5, 16-18].

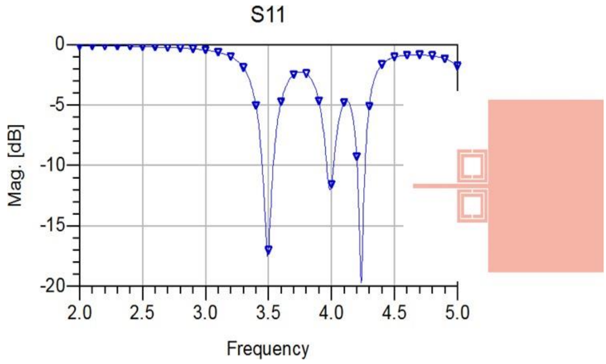

Fig. 6 – The reflection coefficient versus frequency.

Table 2 – A comparison between the proposed antenna and earlier works

References	**Operating Frequencies (GHz)**	**Peak Gain (dBi)**
[16]	3.9	4.7
[17]	2.92	4.31
[18]	2.493	3.2
[19]	2.77	2.45
This work	3.5 4 4.22	6.4 6.8 7.25

3. CONCLUSION

In this work, we have presented a study of multiband antenna array based on the use of SRR resonators. The integration of SRRs with the patch antenna permits it to achieve multiband operations. The dimensions of the SRRs are optimized in order to achieve best characteristics parameters. The suggested array antenna array operates at 3.5, 4, and 4.25 GHz frequency bands, which are suitable for Wi-MAX, 5G, and Aeronautical Radio navigation applications. The suggested array configuration offers high gain with directional patterns. The suggested array is designed on a low cost FR4 substrate with a physical area of 154×70 mm^2. This same design methodology can be implemented for designing other antenna structures to support other standards of wireless communication systems.

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Розробка планарної багатодіапазонної антенної решітки на основі розділеного кільцевого резонатора для додатків WiMAX і 5G для 6 ГГц

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У цій статті запропонована техніка, заснована на прямокутних кільцевих резонаторах (SRR), яка використовується для дослідження нової багатодіапазонної конструкції антенної решітки. Проаналізовані результати моделювання. Запропонований випромінювач антени встановлений на недорогій підкладці FR4 загальною площею 154 × 70 мм². Антенна решітка на основі SRR забезпечує трисмуговий резонанс із високими характеристиками підсилення. Резонансні частоти, зворотні втрати та діаграми спрямованості обчислюються одночасно з використанням низки результатів моделювання, які підтверджують застосовність створеної моделі. Для моделювання використовується електромагнітне рішення на основі MOM, включене в ADS. Повний спектр N77/N78/N79 охоплює багатодіапазонна антенна решітка, перевірена за S11 ≤ – 10 дБ для трьох робочих частотних діапазонів 3,5; 4 і 4,22 ГГц з високим коефіцієнтом підсилення 6,4, 6,8 і 7,25 дБі, відповідно. Вона підтримує бездротові мережі LTE, WiMAX і WLAN, а також спектр 5G, що працює на частотах нижче 6 ГГц. Антена демонструє переваги, такі як плоский профіль, невелика площа, симетризована поведінка випромінювання та хороший коефіцієнт підсилення, може бути обрана як перспективний кандидат для використання в сучасних послугах бездротового зв'язку в мікрохвильовому S-діапазоні в діапазоні нижче 6 ГГц.

Ключові слова: Антенна решітка, SRR, Мікросмугова патч-антена, Потрійний діапазон, Високий коефіцієнт підсилення, ADS, Бездротовий зв'язок.