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Design and Simulations of a Superconducting Microstrip Antenna with a Square-Shaped Split ring Resonator (SRR) Structure at 28GHz.

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A B S T R A C T
In this research, we design and analyze a smart antenna that uses superconducting material technology by integrating the discrete ring resonator (SRR) structure into a Microstrip Patch antenna at a frequency of 28GHz, as it aims to enhance its performance in terms of gain, direction, and radiation efficiency, which is extremely important, especially in generation applications. Fifth for communications, niobium (Nb) was used as a superconducting material. It was an RT5880 substrate material with a height of 0.787 mm and a dielectric constant r 2.2. Through simulations carried out using CST Microwave Studio, the results showed significant improvements in the electromagnetic properties of the designed antenna, where the reflection value reached S11 = -3.82dB, which is close to zero, and the gain reached 40dB, the permittivity -7.260F/m, and the permeability 0.00157 H/m. Comparing the results, it was found that the frequency of the material used had a significant effect in increasing the damage.
Keywords:SRR, negative permittivity, negative permeability, Gain, Niobium (Nb)

تصميم ومحاكاة هوائي شريحي دقيقة فائق التوصيل مع هيكل مرنان حلقي مربع الشكل (SRR) عند تردد 28 جيجا هرتز.

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الملخص
في هذا البحث تصميم وتحليل هوائي ذكي يستخدم تقنية المواد فائقة التوصيل وذلك بدمج بنية المرنان الحلقي المنفصل (SRR) في هوائي من نوع Microstrip Patch عند تردد 28GHz، حيث يهدف لتعزيز أدائه من حيث الكسب والاتجاه وكفاءة الإشعاع ، وهو أمر بالغ الأهمية وخاصا في تطبيقات الجيل الخامس للاتصالات ، تم استخدام مادة النيوبيوم (Nb) كمادة فائقة التوصيل، حيث كانت مادة ركيزة RT5880 بارتفاع 0.787 ملم ، وثابت عازل r يبلغ 2.2 ، ومن خلال عمليات المحاكاة التي تمت باستخدام CST Microwave Studio ، اظهرت النتائج تحسينات كبيرة في الخصائص الكهرومغناطيسية للهوائي المصمم حيث وصلت قيمة الانعكاس الى S11=-3.82dB وهي قريبة من الصفر، وكسب يصل الى 40dB ، والسماحية 7.260H− ، والنفاذية F 0.00157 ، وبمقارنة النتائج تبين ان تاتير المادة المستخدمة له تاتير كبير في زيادة اللاذاء

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الكلمات المفتاحية: SRR، السماحية السلبية، النفاذية السلبية، الكسب، النيوبيوم (Nb)

1. Introduction

The advent of wireless communications and its associated developments have gradually influenced several scientific and engineering fields, particularly those about electromagnetic phenomena and metamaterials. The initial metamaterial is constructed with two superimposed subsystems, one imparting negative permittivity and the other negative permeability within a narrow frequency range. In particular, the structure comprises an array of thin metal wires and an array of metal rings with slits, which are known as split-ring resonators. The wires and split rings serve as miniature electrical resonant "particles," analogous to atoms in conventional materials. However, they are composed of traditional materials (highly conductive metals). Accordingly, metamaterials represent a higher level of structural organization of matter, which is man-made. [1]. The fundamental component of metamaterials has historically been the split-ring resonator (SRR), a sub-wavelength 'particle' [2]. In its most basic form, it is simply a highly conductive metal ring with a slit. The SRR and all subsequent variations, including U-particles, H-particles, Ω- or Ω-like particles, and double- and/or multi-slit SRRs, are resonant particles that effectively function as artificial "magnetic atoms") [3]. Split ring resonators (SRRs), interrogated in multiple shapes and sizes with helical, rectangular, and square forms, demonstrate highly satisfactory responses where negative amplification is effectively suppressed [4] [5]. In this research area, there has been considerable work; for example, S. Djidel and others designed and analyzed a superconducting material-based microstrip antenna for millimeter-wave applications. The results showed a reduction in return loss and a broad frequency range from 27 to 70 GHz, with favorable characteristics of the radiation pattern obtained within the operating frequency range. The proposed antenna size also reached 3 x 3 mm, which facilitates its integration into the structure of communication systems.[6]

E. Holdengreber et al. developed a high-sensitivity superconducting antenna to detect a frequency of 200 GHz. The antenna is designed based on electromagnetic simulation, with the Josephson bicrystalline junction detector placed as a thin layer of YBCO at the orientation point inside the antenna. The results were favorable in terms of radiation concentration systems by use of lenses. Thus, the system is simplified without a loss of sensitivity. [7]

M. ANLAGE (Member, IEEE) studied microwave superconductivity, where new technologies were explored that take advantage of the unique electrical properties of materials. The low-loss properties of microwave superconductivity enable high-quality resonant elements to handle very large flows of electric current, thereby improving performance for special applications such as super accelerators, high-performance filters, and analog electronics. By leveraging quantum properties, new generations of high-speed digital computers and highly sensitive sensors have been developed, with quantum characteristics allowing computers to operate efficiently with microwaves. [8]

Bashar A. F. Esmail (Member, IEEE) et al. provided a comprehensive overview of super materials used to improve the performance of planar antennas. The study revealed that super materials (MTMs) are synthetic materials with unique

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electromagnetic properties not found in natural materials. MTMs have raised great interest due to their peculiar electromagnetic properties, such as passive permittivity and transmittance, which allow them to be used in many practical applications such as super lenses, anonymization technology, and sensors. High-gain antennas are in high demand in modern wireless communication systems, as they contribute to improving signal strength by reducing interference and mitigating free-space path loss. [2]

This section provides a brief introduction to materials (MTMs), focusing on their operating principles. Additionally, a detailed study was conducted to enhance antenna gain based on different material properties (MTMs). ZIM, LIM, epsilon-near-zero (ENZ), and mu-near-zero (MNZ) materials are discussed in detail in the context of their ability to enhance the performance of a wide range of planar antennas. The low impedance and lens properties are enhanced by three different characteristics: high refractive index (HRI), gradient refractive index (GRIN), and negative refractive index (NRI) materials on the planar antennas to improve gain. [2]

This study presents a method for designing super materials using a deep learning database, which proved effective in solving challenges that were difficult to address with traditional methods. In the field of super materials, these technologies have significantly improved the feasibility of more complex designs and introduced new ideas for their design and analysis. [9]

The study examined the improvement of microstrip patch antenna gain using a high negative refractive index and a layer inspired by 3D super materials for wireless communication applications. The simulation results showed that the booster gain was approximately 5 dB and 3.2 dB, with the half-width of the power beam reduced to about 23°23 and 12.85° for the corrected antenna and the 2 × 2 array antenna, respectively [10].

The objective of this paper is to focus on designing and simulating a square split-ring resonator (SRR) structure operating in the 28 GHz band for metamaterial applications within 5G radiation.

2. Split Ring Resonators (SRRS) in Electromagnetic Applications

A split ring resonator (SRR) is an artificial structure that exhibits unusual electromagnetic properties compared to naturally occurring materials. SRRs are used to enable new functions in various electromagnetic applications. Over the past few decades, Figure 1 depicts the shape and construction of the SRR.

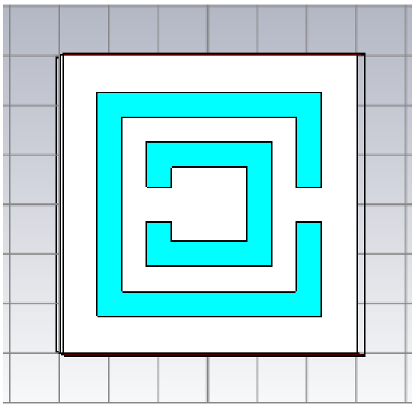

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Figure.1 The ship of the SRR

Important solutions for electromagnetic structures have been obtained through the use of split ring resonators (SRRs). For example, SRRs are the building blocks of metamaterials and are used to achieve negative transmittance and epsilon (in combination with electric ring resonators) to attain a negative index in the sub-wavelength region. A combination of squared SRRs and electrical inductors can be used to create miniature antennas [2].

3. Design parameters of SRR structures

The SRR cell contains a pair of square rings of length (l) with a gap between them (s) and a hole or cut at the ends (g). The rings are made of niobium metal (Nb) with a width (w). When these rings are placed in a variable vertical magnetic field, as shown in Figure 2, a circular electric current is induced in the metal ring, which in turn leads to the accumulation of charges across the gaps.

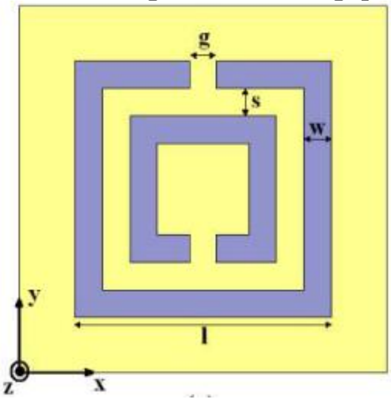

Figure .2, SRR design

The electric field created by the charge in the gap concentrates the energy of the magnetic field in the area surrounded by it. Thus, the SRR is a resonator that combines the perpendicular magnetic field with the effective capacitance and inductance determined by the loop. It can be understood in terms of resonant frequency.[4]

$$\omega^2 = \frac{1}{LC} \quad (1)$$

Where: L is the inductance and C is the capacitance of SRR

Calculate Initial Patch Dimensions is the width and length which is given by:

$$width = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (2)$$

$$Length = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right) \quad (2)$$

And the εeff equal: -

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$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}}\right] \qquad (3)$$

Calculation of the length and width of the ground level and substrate:

$$Wg = W + 6h$$

$$Lg = L + 6h$$

Figure.3, shows the flowchart of design steps

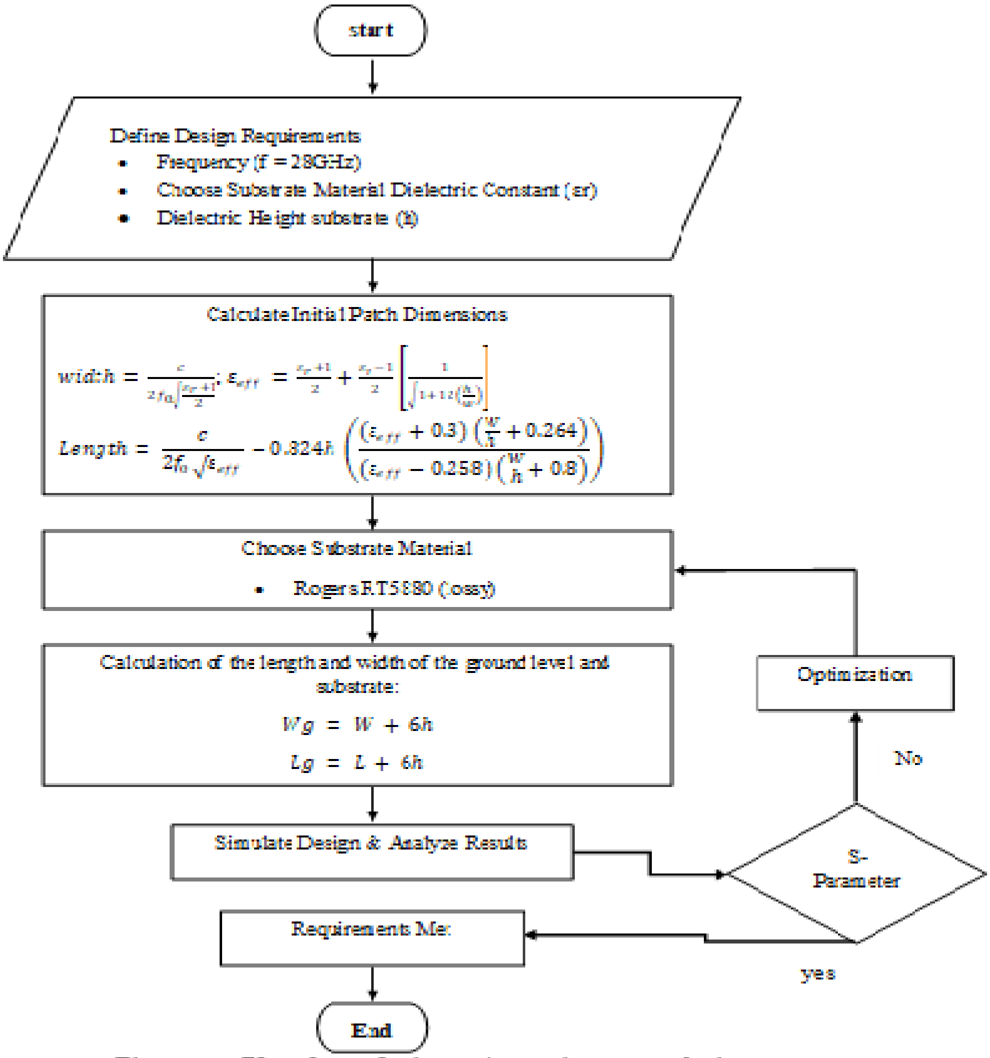

Figure 3 Flowchart of microstrip patch antenna design

The ship of design parameters is shown in Figure .4, and the Table.1, indicted the dimensions of a structure SRR

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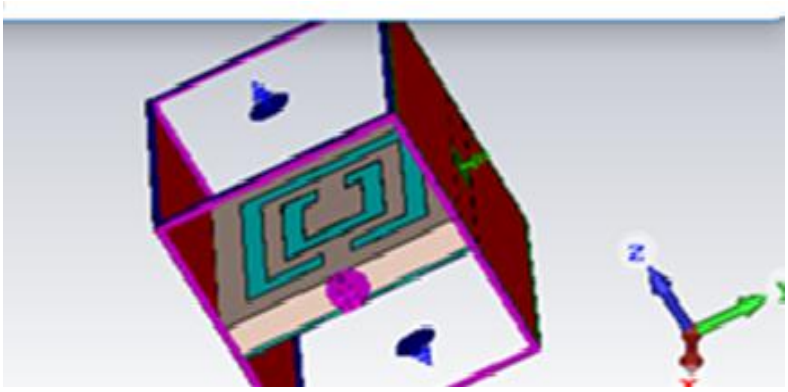

Figure .4, the design parameter's

Table .1 Design dimensions of a structure SRR

Name	type	Dimensions				
		L(mm)	W(mm)	H(mm)	S(mm)	G(mm)
material	Niobium	4.5	1	0.2	1	0.7
Substrate	RT5880	6	6	0.787	-	-
Ground	Niobium	6	6	0.1	-	-

4. Results and discussion

The CST simulation software is widely regarded as one of the premier options within the field of electromagnetic simulation. With its versatile capabilities, this software enables users to simulate nearly any scenario imaginable. Renowned for its specialized features, CST is tailor-made for effectively managing and designing projects. By leveraging the finite element method, it excels at accurately simulating intricate designs. Whether designing antennas, filters, or electronic circuits, CST offers a seamless and robust experience. Undoubtedly, it is the optimal choice for any electromagnetic project, as its dynamic and powerful mechanisms set it apart from its counterparts. [11]

The parameters listed in Table 1 were used in CST software to obtain the simulation results. Figure 5 shows the values of S-parameters in the range of 23 GHz – 33 GHz, with S1,1 = -3.82 dB. This value, close to zero, indicates that the transmitted energy is absorbed rather than reflected.

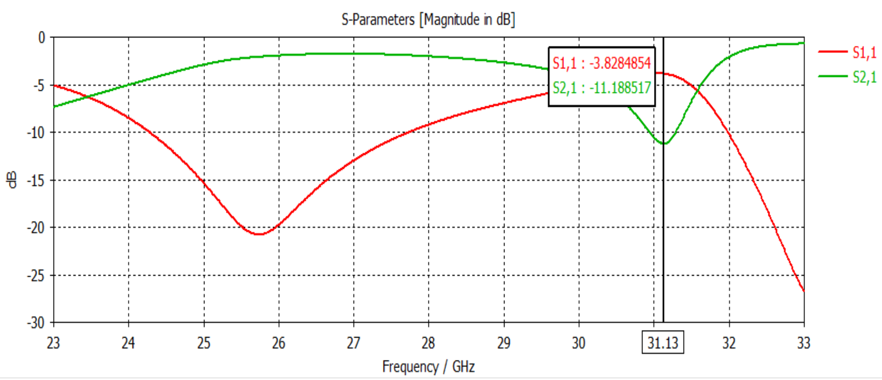

Figure.5 the S-parmeter

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Figure 6 shows that the signal outside the resonant frequency range approaches zero, which allows it to function as a filter by preventing signals outside this range from passing through.

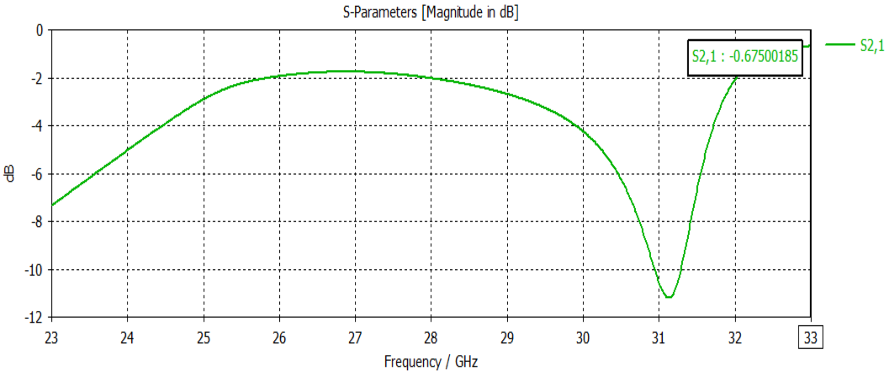

Figure 6 Signal outside the resonant frequency

Figure 7 shows a gain value of 40 dB in all directions, represented in the form of a circle for a superconducting SRR structure. This indicates very distinctive properties, including:

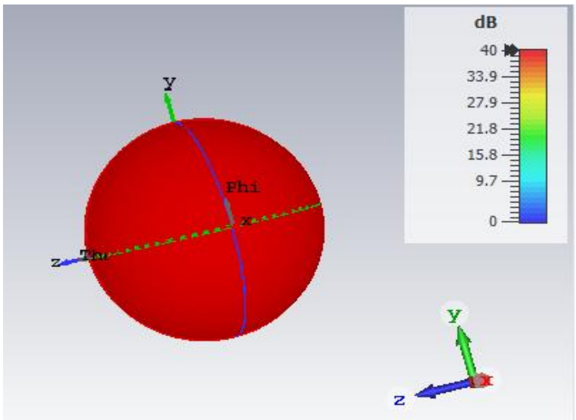

Figure 7 shows the gain value.

- **High Efficiency**: This refers to the high efficiency in converting electromagnetic energy into visual signals or processed signals within the system.
- **Uniform Distribution of Gain**: The gain being equal in all directions indicates that the structure acts as a continuous radiator, with no specific direction preferred for transmission.
- **Strong Resonance**: The presence of high gain in all directions indicates strong resonance in the design structure, meaning that the structure absorbs significant energy within a specific frequency range.

Figure 8 shows the far-field radiations at the design frequency.

High efficiency, refers to high efficiency in converting electromagnetic energy into visual signal or processed signal in the system. Uniform distribution of gain, The gain being equal in all directions indicates that the structure acts as a continuous radiator and no specific direction is preferred for transmission, Strong resonance, The presence of high gain in all directions indicates the presence of “strong resonance” in the design structure. This means that the structure absorbs significant energy in a

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specific frequency range, Figure .8, shows the far-field radiations in the design frequency.

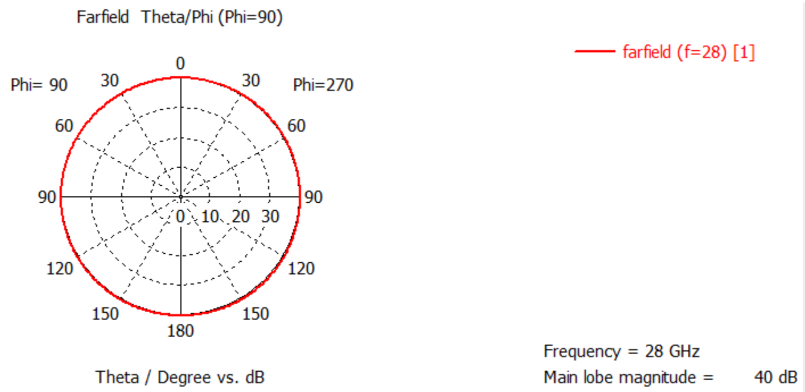

Figure.8 The far-field radiations in 28GHz

Figure 9 presents the simulation results that examine the material properties of the SRR structure made of superconducting niobium. The graphs depict the real values of both relative permittivity (Epsilon_r) and relative permeability (Mu_r) of the material. It is observed that the relative permittivity starts at a low value and gradually increases with frequency, reaching its peak before declining again. At the specified point of 30.84 GHz, the value is (-7.26e-05). These negative values in Epsilon_r indicate that the material functions as a metamaterial, which can exhibit unusual behavior in controlling electromagnetic waves.

As for the relative permeability, a similar but inverse curve is observed compared to the relative permittivity. Mu_r starts at a low value, increases to its peak at 30.84 GHz, and then decreases again, approaching zero. This suggests that the material reduces the absorption of the magnetic field. The use of a superconducting material such as niobium can significantly enhance antenna performance by reducing energy loss due to superconductivity, increasing radiation efficiency, and improving frequency stability.

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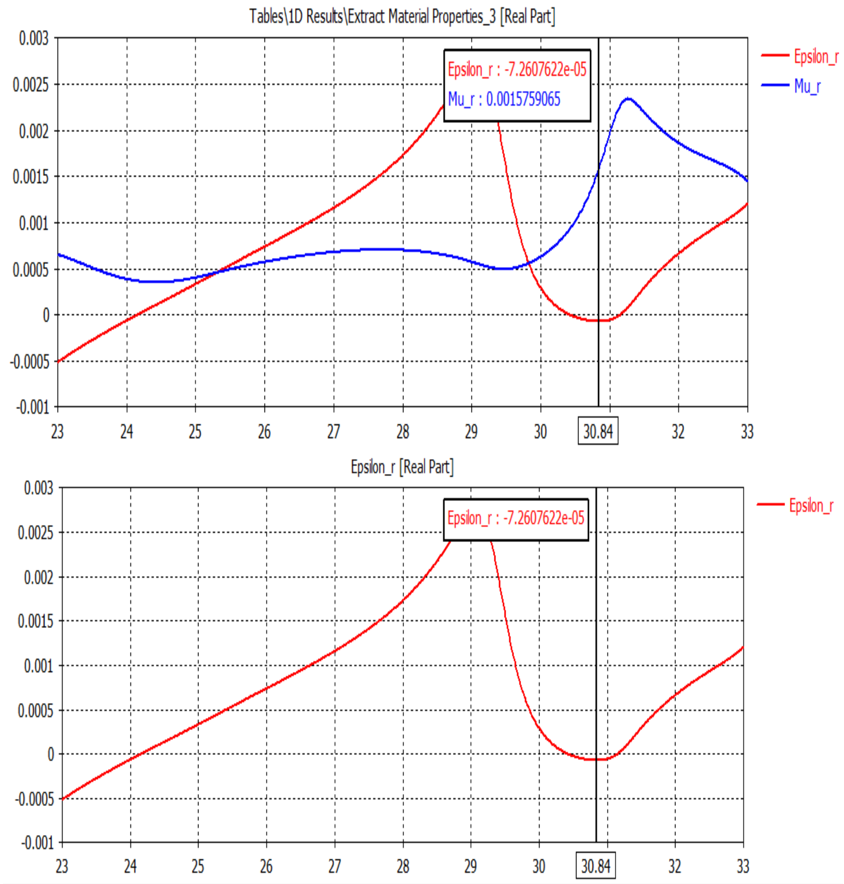

Figure 9, the value of the negative permittivity and permeability of the SRR structure

5. Conclusion

1. The integration of the split-ring resonator (SRR) into the antenna design has demonstrated exceptional electromagnetic properties that are unattainable with conventional materials. The negative values of permittivity (ε_r) and permeability (μ_r), as observed at 30.84 GHz, confirm the material's behavior as a metamaterial capable of efficiently controlling electromagnetic waves.
2. The SRR structure significantly enhances antenna performance by absorbing transmitted energy and preventing reflection. This is evident from the simulated reflection coefficient (S11 = -3.82 dB), which indicates excellent impedance matching and minimal reflection losses.
3. The use of superconducting niobium (Nb) in the SRR design contributes to higher radiation efficiency and improved frequency stability. The results show a gain value of 40 dB, uniformly distributed in all directions, highlighting the SRR's role in enhancing antenna efficiency and resonance characteristics.
4. The antenna demonstrates strong resonance characteristics and maintains efficient operation within the designed frequency range, making it highly suitable for high-frequency applications, particularly in the 5G band.
5. **Recommendations:**
    1. **Application in 5G Networks**: With its high gain, uniform radiation pattern, and excellent impedance matching, the designed SRR-integrated antenna is well-suited for next-generation 5G communication systems.

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2. **Experimental Validation**: To ensure real-world feasibility, it is recommended to fabricate and experimentally test the SRR-integrated antenna to validate the simulation results and refine the design.
3. **Exploration of Alternative Superconducting Materials**: Investigating other superconducting materials alongside niobium may reveal additional enhancements in performance and broaden the scope of potential applications.

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7. References

[1] W. Adepoju, I. Bhattacharya, M. Sanyaolu, et al., "Critical review of recent advancement in metamaterial design for wireless power transfer," IEEE, 2022. ieee.org

[2] R. Imani, S. Chouhan, J. Delsing, "A Fully Additive Approach for the Fabrication of Split-Ring Resonator Metasurfaces," 2022 IEEE 72nd Electronic Components and Technology Conference (ECTC), 2022. oulu.fi

[3] LitchinitserN.M. et al. Photonic metamaterials Laser Phys. Lett(2008) .

[4] Koray Aydin and Ekmel Özbay," Experimental and Numerical Analyses of the Resonances of Split Ring Resonators ", WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 22 March 2007. IVSL

[5] PendryJ.B. et al. Magnetism from conductors and enhanced nonlinear phenomena IEEE Trans. Microw. Theory Tech. (1999

[6] M. Belazzoug, and D. Khedrouche, "Design and Analysis of a Microstrip Antenna Based on Superconducting Material for Millimeter Wave Applications," Acta Physica Polonica A, vol. 129, no. 1, pp. 12-15, Jan. 2016.

[7] A. G. Holdengreber, M. V. Kovetz, S. E. Shafran, and E. E. Yucht, "High Sensitivity High Tc Superconducting Josephson Junction Antenna for 200 GHz Detection," Journal of Electromagnetic Waves and Applications, vol. 22, no. 10, pp. 1354-1364, Oct. 2018.

[8] S. M. Anlage, "Microwave Superconductivity," IEEE Journal of Microwaves, vol. 1, no. 1, pp. 5-15, Jan. 2021.

[9] Q. X. Huang, W. Xiaoshu Zhou, "Metamaterials Design Method Based on Deep Learning Database," Journal of Physics: Conference Series, vol. 2171, no. 1, Dec. 2022.

[10] H. Khourser, Y. K. Chok, B. Guntupalli, "Gain Enhancement in Microstrip Patch Antenna with High Negative Refractive Index 3D-Metamaterial Inspired Superstrate for Wireless Applications," IEEE Access, vol. 12, pp. 13532-13543, Jan. 2024.

مجلة جامعة فزان العلمية
Fezzan University scientific Journal
Journal homepage: wwwhttps://fezzanu.edu.ly/

[11] K. Singh, M. U. Afzal, and K. P. Esselle, "Designing Efficient Phase-Gradient Metasurfaces for Near-Field Meta-Steering Systems," IEEE Access, vol. 9, pp. 3432-3440, Dec. 2021

[12] S. Djidel, M., Bouamar, and D. Khedrouche, "Design and Analysis of a Microstrip Antenna Based on Superconducting Material for Millimeter Wave Applications", ACTA PHYSICA POLONICA A, Vol. 131 (2017), No. 1.