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Analysis and modelling of the characteristics of telecommunication antennas utilising metamaterials with a circular structure

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ABSTRACT

The development of telecommunication antenna technology is increasingly being considered with the need for high and practical antenna performance. The antenna technology can be realized by using the split ring resonator (SRR) metamaterial structure. SRR metamaterial is a periodic material that has minimal manufacturing dimensions and is able to work at high frequencies. The ability of this metamaterial has the potential to be implemented in microstrip antenna structures as telecommunication applications. This study aims to design, simulate and analyze the characteristics of SRR-Circle metamaterials against the frequency function and application performance as a telecommunication antenna. The process is carried out using the Computer Simulation Technology (CST) Studio Suite Software which is operated at a working frequency of 0.009 – 9 GHz. The metamaterial structure is combined from 1 – 4 SRRs in the shape of a Circle with a fixed radius of 3.5 mm. The results of this study indicate the characteristics of metamaterials with negative values in relative permittivity (ε_r), relative permeability (μ_r) and refractive index (n) with the highest values in the metamaterial structure of the combination of 4 SRR-Circles, each with values of -144.33 Farad/m, -9.29 H/m and -9.07. In its application as a telecommunications antenna, metamaterials have succeeded in improving antenna performance. The highest antenna performance was obtained in the combination structure of 4 SRR-Circles with a return loss value of -34.37 dB, and a bandwidth of 1.00 GHz at a VSWR of 6.77 – 7.77 GHz. The results of this antenna performance have the potential to be applied to telecommunications antenna technology such as satellites, radars and 5G networks.

Keywords: Antennas, metamaterials, resonance, split ring resonator, telecommunications

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INTRODUCTION

The development of information technology and the application of antennas has caused the need for information to continue to increase and has been widely used for applications in the field of telecommunications, one of which is satellites. Satellites are communication devices placed in outer space [1]. Metamaterials are artificial structures that have the characteristics of negative refractive index values and high resonance sensitivity. As a sophisticated technological breakthrough, the use of metamaterials has a very large impact with high and broad potential because the material and structure can be renewed [2]. The metamaterial material used is copper because of its good conductivity and electromagnetic response properties, allowing better control [3].

The use of microstrip antennas on metamaterials is the choice that is applied because it has high efficiency, low cost, simplicity of manufacture and easy integration into circuits. Microstrip antennas are metal conductive antennas mounted on a base plate used as microwaves in various modern telecommunications systems. The main components of a microstrip antenna consist of a ground connection plane, a substrate and a radiation patch. However, this antenna also has several disadvantages, such as low gain and narrow bandwidth [4]. The quality of an antenna can be determined by several simulation parameters from the S-parameter (scattering) such as return loss, VSWR (voltage standing wave ratio), gain and directivity. The metamaterial surface used can improve the characteristics of antenna parameters for communication applications, remote sensing and medical imaging [5].

Telecommunication is a technology and science of communication that involves the transmission of information over long distances using electromagnetic signals [6]. The use of antennas in communication technology can transmit communication signals without being blocked by obstacles. The technology used is satellite. Satellite technology is one of the wireless telecommunications technologies besides cellular communication systems. Satellite technology is expected to be able to reach a wide area even though there are hills, mountains or forests where the area is difficult to reach with cable telecommunications or cellular technology [1].

In this article, it is done by designing and simulating telecommunication antennas based on the characteristics of the circle structure using computer simulation technology (CST) Studio Suite. As a comparison, several simulation parameters from the S-parameter (Scattering) antenna with gain and bandwidth that will be used to obtain new breakthroughs in improving antenna performance and are expected to have potential use in satellite applications.

MATERIALS AND METHODS

Structure Design

The design of the SRR metamaterial structure was carried out using the CST Studio Suite 2019 software. The SRR unit consists of two concentric rings with the radii of the outer ring R_1, R_2 and the inner ring R_3, R_4. Where the size of the inner ring R_1 and the outer ring R_2 are designed with different sizes [2]. The material used in the SRR patch structure and microstrip antenna is copper as a metal inclusion or patch in the antenna application. Expected antenna parameters.

Table 1. Expected antenna parameters.

Parameters	Antenna characteristic
Working frequency	6 – 30 GHz [1]
Return loss	< -10 dB [7]
Bandwidth	≥ 1 GHz [8]
VSWR	≤ 2 [7]
Gain	≤ 3 dBi [1]

Figure 1. Combination structure 1 – 4 SRR-Circle with a fixed radius of 3.5 mm.

The number of cells is designed from one cell then varied into four circular metamaterial cells as in Figure 1 is a metamaterial structure with a combination of 1 – 4 SRR- Circles with a fixed radius of 3.5 mm to be analyzed. The selection of the design in this cell variation is intended to obtain a comparison in the relative permittivity constant (ε_r) relative permeability (μ_r) and refractive index (n) of the structure as in the following equation:

$$\mu_r = \frac{2}{jk_0 t_m}\frac{1 - V_2}{1 + V_2} \quad (1)$$

$$\varepsilon_r = \mu_r + j\frac{2S_{11}}{k_0 t_m} \quad (2)$$

$$n = \pm\sqrt{\varepsilon_r \mu_r} \quad (3)$$

The values of relative permittivity, relative permeability and refractive index of the structure can be determined by applying the NRW method to the S-parameters and phase values obtained during the simulation in CST Studio Suite [9].

The addition of circular metamaterial cells experiences a shift in the resonance frequency which causes a change in the E and B field induction to be lower for each structure. The constants ε_r and μ_r increase based on Maxwell's equations explained in the Literature review section. The relationship between **D** and **E** and **B** and **H** that occurs in linear, non-dispersive, and isotropic materials can be written as [10].

$$\boldsymbol{D} = \varepsilon \boldsymbol{E} = \varepsilon_r \varepsilon_0 \boldsymbol{E} \tag{4}$$

$$\boldsymbol{B} = \mu \boldsymbol{H} = \mu_r \mu_0 \boldsymbol{H} \tag{5}$$

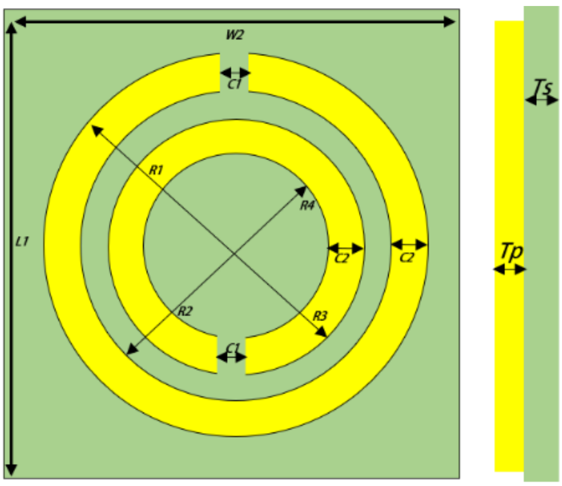
Antenna Dimensions and Design

The dimensions of the SRR ring structure are T_s (substrate thickness), T_p (patch thickness), C_1 (gap and separation distance between rings) and C_2 (patch width) with variations in the number of combination structures 1 – 4. The dimensions of the structure used in this study can be seen in Table 2.

Table 2. SRR structure size.

Symbol	Size (mm)	Description
T_s	1.6	Substrate thickness
T_p	0.035	Patch thickness
C_1	0.43	Ring gap width
C_2	0.6	Patch width

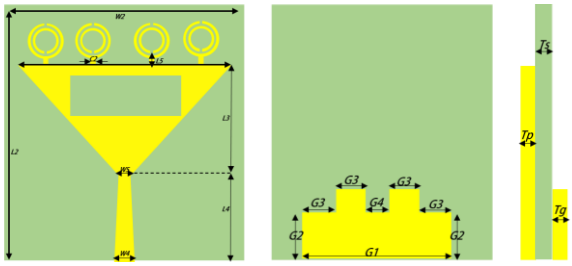
The dimensions of the SRR structure can be seen in Table 1 The SRR structure to be designed is shown in Figure 3.



(a) (b)

Figure 3. SRR structure: (a) front and (b) side.

The structure type is applied to the design of a microstrip antenna from a combination of SRR structures. First, the formed SRR structure is analyzed to identify the properties of the metamaterial. Then, the placement of the feeding port and ground is used in the antenna.



(a) (b) (c)

Figure 4. (a) Front SRR antenna structure after adding the feeding port, (b) rear ground structure, and (c) side.

Table 3. Design parameters of the SRR combination microstrip antenna.

Symbol	Dimension (mm)	Symbol	Dimension (mm)
C_2	0.5	W_4	2.14
L_2	33.34	W_5	1.8
L_3	14.46	G_1	24
L_4	11.20	G_2	7.4
L_5	0.54	G_3	5.43
W_2	29.60	G_4	3.94
W_3	27.84	T_g	0.035

RESULTS AND DISCUSSION

Testing of the metamaterial structure of the combination of 4 SRR-Circles in the form of relative permittivity values (ε_r), relative permeability (μ_r), and refractive index (n). While in the metamaterial structure antenna combination of 4 SRR-Circles focused on the resonance frequency values on return loss, VSWR, bandwidth, and gain obtained from the simulation results by applying the Nicolson-Ross-Weir (NRW) Equation. The working frequency used is 0.009 – 9 GHz.

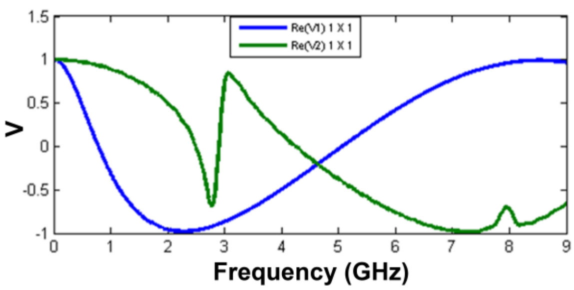
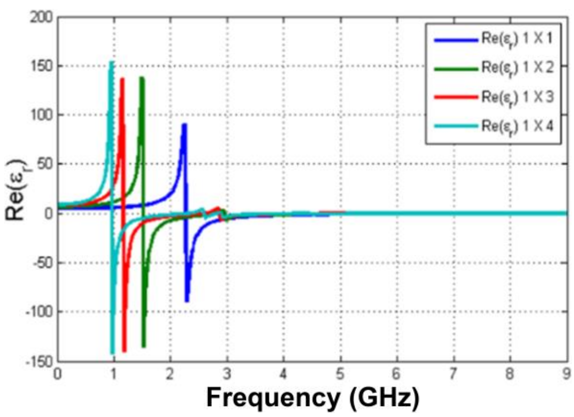
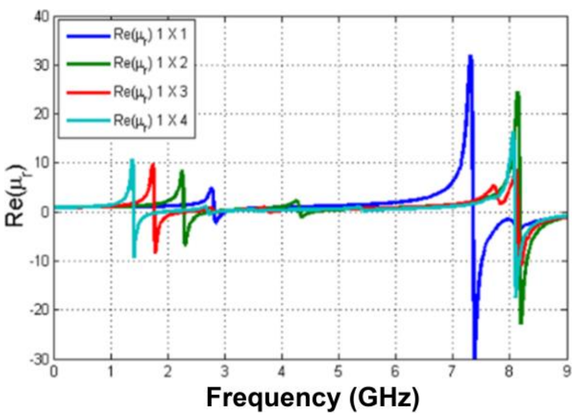


Figure 5. Graph of the real part V1 and V2 of the FR4 substrate (ε = 4.3).

Analysis of Figure 5 explains that Graphs V1 and V2 are the results of the sum of the S11 and S21 values. Graph V1 experiences resonance at a frequency of 2.27 GHz, while Graph V2 experiences two resonances located at frequencies of 2.81 GHz and 7.22 GHz. The resonance frequency is a characteristic of metamaterials based on the spectrum and transmission according to a certain phase magnitude depending on the shape of the metamaterial structure, Graphs V1 and V2 also experience a deflection of the polarization direction by the application of electric fields and magnetic fields given so that dispersion anomaly events (scattering interference) occur when the increase in relative permittivity (ε_r) and relative permeability (μ_r) decrease towards negative values. In addition, the resonance frequencies located on Graphs V1 and V2 also show the location of the resonance frequency on the permittivity and permeability as in Figure 6.



(a)



(b)

Figure 6. Graphs (a) ε_r, and (b) μ_r of metamaterial combination 1 – 4 SRR-Circle.

The effect of the combination of metamaterial cells 1 – 4 SRR-Circle on the metamaterial parameters in Figure 6 explains that the combination of 4 SRR-Circle metamaterial structure cells produces ε_r, μ_r, and n with negative values and the resonance frequency is greater than the metamaterial combination 1 – 3 SRR-Circle. This happens because the addition of the structure affects the properties of the material which is getting stronger (constructive) and the dielectric medium in the material causes the ability to polarize electrons by the resulting E and B field moments to become smaller. So that the influence on relative changes in permittivity and permeability of the material becomes greater.

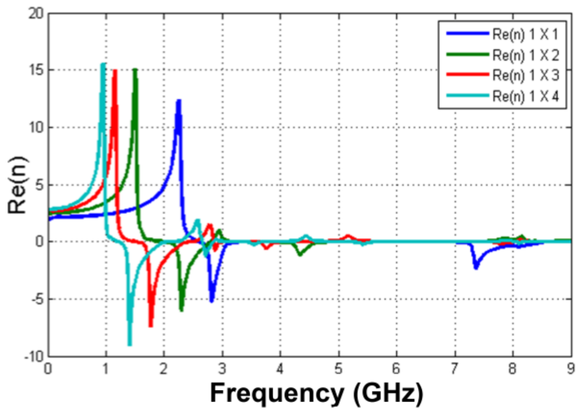
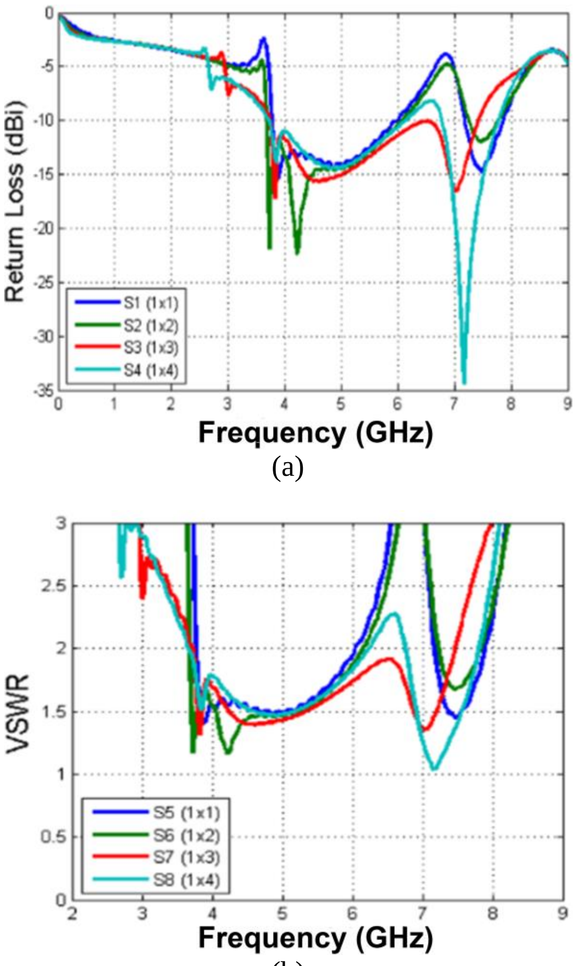


Figure 7. Refractive index graph metamaterial 1 – 4 SRR-Circle.

Figure 7 explains the occurrence of frequency shifts down towards low frequencies with increasing combinations of SRR- Circle metamaterial structures. The refractive index value in metamaterial 1 – 4 SRR- Circle produces a positive resonance frequency originating from the permittivity resonance frequency and vice versa at a negative frequency originating from the permeability resonance frequency so that the maximum refractive index value (n) is -9.07 at a frequency of 1.40 GHz as seen from metamaterial 4 SRR-Circle. The shift in resonance frequency cannot be separated from the contribution of the addition of circle metamaterial cells which causes changes in the E and B field induction to be lower for each structure. So that the constants ε_r and μ_r increase based on Maxwell's equations (4) and (5) explained in the Literature review section.

Identification of the characteristics of metamaterial parameters will be applied to the combination metamaterial structure 1 – 4 SRR-Circle in the form of an antenna as a telecommunications application. The standard quality of the antenna to be used as a detector in a telecommunications network that is good for wide coverage. Return loss and VSWR are one of the parameters that influence each other. The minimum RL value for the antenna application to work is -10 dB or 10% of the power transferred. The VSWR parameter is determined by the RL value obtained. VSWR has a value between 1 and 2 or $1 \leq VSWR \leq 2$. If RL has a value of -10 dB then VSWR will be equal to 2 and has a value of ≥ 1 when the RL value is lower -10 dB.



(a)

(b)

Figure 8. Graph (a) return loss and (b) VSWR of the antenna combination 1 - 4 SRR- Circle.

The graphs shown in Figure 8 (a) and (b) are changes in RL and VSWR of metamaterial antennas with variations in the combination of 1 – 4 SRR- Circle with a fixed radius of 3.5 mm. The difference in the combination of SRR-Circle causes the RL antenna parameters to change. As in the combination antenna 1 – 4 SRR- Circle which has a different resonant frequency and RL value.

Based on the simulation results, the RL value will be lower when the SRR- Circle metamaterial structure increases on the antenna. A lower RL indicates that the power received by the antenna is greater and makes the antenna work more optimally. RL increases from the addition of 1 SRR- Circle to 4 SRR- Circle with a value of -14.75 dB to -34.37 dB. This causes the VSWR frequency range and BW width to increase. It is proven from previous studies that the use of metamaterials in antennas can improve antenna parameters and also reduce the size of the antenna dimensions to be smaller and cheaper.

CONCLUSION

The design and simulation of metamaterial structures with cell variations of 1-4 Split Ring Resonator Circle (SRR-Circle) have been carried out with a geometry of less than 1/4 of the minimum wavelength. In the cell variation of 4 metamaterials with a 1 X 4 array arrangement, the relative permittivity (ε_r), relative permeability (μ_r) and refractive index (n) values are large, each with values of -144.33, -9.29, and -9.07 compared to the values in the 1-3 SRR-Circle structure. The application of metamaterials as antennas from the results of the analysis of the characteristics of metamaterials of cell variations obtained results that the return loss value was higher when the cell arrangement on the antenna increased. Return loss on the 4 SRR-Circle antenna structure has a large resonance frequency of 7.16 GHz with a return loss value of -34.37 dB compared to the 1-3 SRR-Circle structure which each have return loss values of -14.78 dB, -11.97 dB and -16.58 dB. In the 4 SRR-

Circle antenna structure with a 1 X 4 array arrangement in accordance with the specifications of the telecommunications antenna application, the antenna results on the circle structure antenna with a high frequency of 7.16 GHz, a return loss of -34.37 dB, and a bandwidth of 1.00 GHz at a VSWR of 6.77 - 7.77 GHz which can be operated on radar telecommunications antennas (satellites), 5G networks and IoT devices.

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