SINTECHCOM: Science, Technology and Communication Journal
Vol. 5, No. 1, October 2024, pp. 15-20, DOI: 10.59190/stc.v5i1.286

Simulation and analysis of triangular structure metamaterial properties at microwave frequencies for medical sensor applications

Riska Amalia[1,*], Defrianto[1], Yan Soerbakti[1], Vepy Asyana[1,2,3], Hewa Yaseen Abdullah[4,5]
[1]Department of Physics, Universitas Riau, Pekanbaru 28293, Indonesia
[2]Department of Physics, Institut Teknologi Bandung, Bandung 40132, Indonesia
[3]Department of Physics, Kyushu University, Fukuoka 819-0395, Japan
[4]Research Center, Salahaddin University, Erbil 44002, Iraq
[5]Department of Physics Education, Tishk International University, Erbil 44001, Iraq

ABSTRACT

The development of antenna technology is increasingly developing in medical sensor applications. The medical sensor antenna can be strengthened with a split ring resonator (SRR) metamaterial structure. Metamaterial is an artificial material that has high resonance manufacturing properties and this can potentially be implemented into microstrip antenna structures. This research aims to design, simulate and analyze the characteristics of metamaterials regarding the frequency function and performance of an antenna combination of 1 – 4 metamaterials with a triangular SRR ring radius of 3.5 mm. The results of this research show that the metamaterial characteristics of permittivity, permeability and refractive index are negative. Furthermore, in the antenna application, the implementation of a 4 SRR triangular metamaterial combination structure has more optimal performance. The results show that antenna performance parameters produce return loss is -41.18 dB, the bandwidth is 3.86 GHz and gain is 3.82 dBi with an omnidirectional radiation pattern.

ARTICLE INFO

Article history:

Received Aug 9, 2024
Revised Sep 14, 2024
Accepted Oct 18, 2024

Keywords:

Antenna Parameters
Medical Sensor
Metamaterial
Resonant Frequency
Split Ring Resonator

* **Corresponding Author**
E-mail address: riska.amalia0312@student.unri.ac.id

1. INTRODUCTION

Metamaterials are engineered materials with properties not found in natural materials. Their existence is important in the development and application of this modern technology. In addition, its characteristics which have high sensitivity and amplification have the potential to be applied in antenna technology. Based on the results of previous studies, the antenna structure combined with metamaterials has increased performance compared to antennas without metamaterials [1-3]. Metamaterials are artificial materials that do not exist in nature and have negative permittivity and permeability [4, 5].

The ongoing development of technology and the application of antennas to microwave systems have been widely used for application in medical or health imaging. Antenna technology has a relatively low manufacturing cost and can be used to detect diseases in the body without significant limitations because it works in the microwave frequency range and is relatively safe to use even with certain limitations [6, 7]. Several medical imaging on antennas that work in ultra-wideband (UWB) frequencies have been carried out to detect cancer and tumors in the body [8]. As in previous studies, the antenna was designed as a brain cancer detector that has been studied by Khairani et al. (2023) [9].

The use of microstrip antennas is still the choice applied in many applications due to its low cost, high efficiency, simplicity of manufacture and easy integration into circuits [10, 11]. This antenna also has disadvantages such as narrow bandwidth. This is a serious problem faced by microstrip antennas because it is very difficult to use microstrip antennas as radar antennas that require wide bandwidth. Therefore, this deficiency is what drives a lot of research to be done to increase the bandwidth of microstrip antennas [12-14].

The use of metamaterials in antenna design can not only reduce the size of the antenna significantly, but also improve other antenna parameters, such as obtaining multi-band antennas, increasing bandwidth, increasing efficiency, and increasing gain [15, 16].

Antennas are defined as devices usually made of metal (such as rods or wires) to transmit or receive radio waves [17, 18]. Antenna quality is determined by several simulation parameters from S-parameters (scattering) such as return loss, voltage standing wave ratio (VSWR), bandwidth, gain, and directivity [19, 20]. The structure of the commonly used metamaterial type is the split ring resonator (SRR). In medical applications, SRR can be used to improve resolution and accuracy in diagnostic imaging, such as MRI. Metamaterials with SRR can help focus and amplify signals, producing clearer and more detailed images [21-24]. Computer simulation technology (CST) Studio Suite is software used to simulate electromagnetic components, devices, and systems. This device is widely used in research and development in various fields such as telecommunications and medicine [25] and processing of simulation data is carried out using MATLAB software. The use of metamaterials in currently known antenna applications has been widely applied with various types of structures such as square, circular, rod, and other SRR structures. Therefore, in this study, a 1 × 4 SRR combination triangular structure metamaterial will be used to obtain a new breakthrough in improving the performance of antenna parameters and is expected to have potential use in medical applications.

2. RESEARCH METHODS

2.1. Metamaterial Structure Design

This research was conducted by simulation, namely by designing a triangular metamaterial structure design and analyzing its characteristics as an antenna application, especially for medical applications. The results of this simulation aim to provide relative permittivity (ε_r), relative permeability (μ_r), and refractive index (n) on the metamaterial while the antenna results are focused on the return loss, VSWR and gain values. The SRR structure and microstrip antenna in this study use copper material as a metal inclusion or patch in the antenna application and the substrate material used is FR-4 (loss free). The size and design of the triangular SRR structure metamaterial can be seen in Table 1 and Figure 1.

Table 1. Size of the triangular SRR metamaterial structure.

Symbol	Size (mm)
T_S	1.6
T_P	0.035
C_1	0.50
C_2	0.50
L	7.4
W	2.14

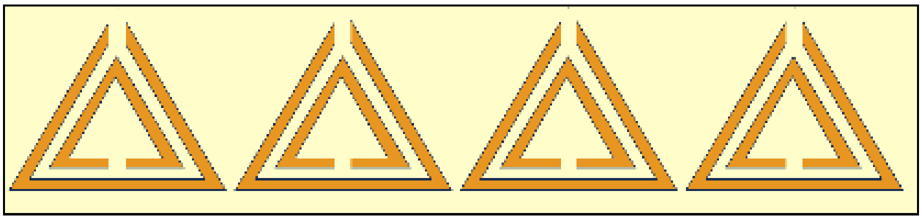

Figure 1. Triangular SRR metamaterial structure.

2.2. Antenna Structure Design

The design and simulation of the antenna with a metamaterial structure were carried out with the help of CST software to obtain antenna parameters. The antenna structure design can be seen in Figure 2.

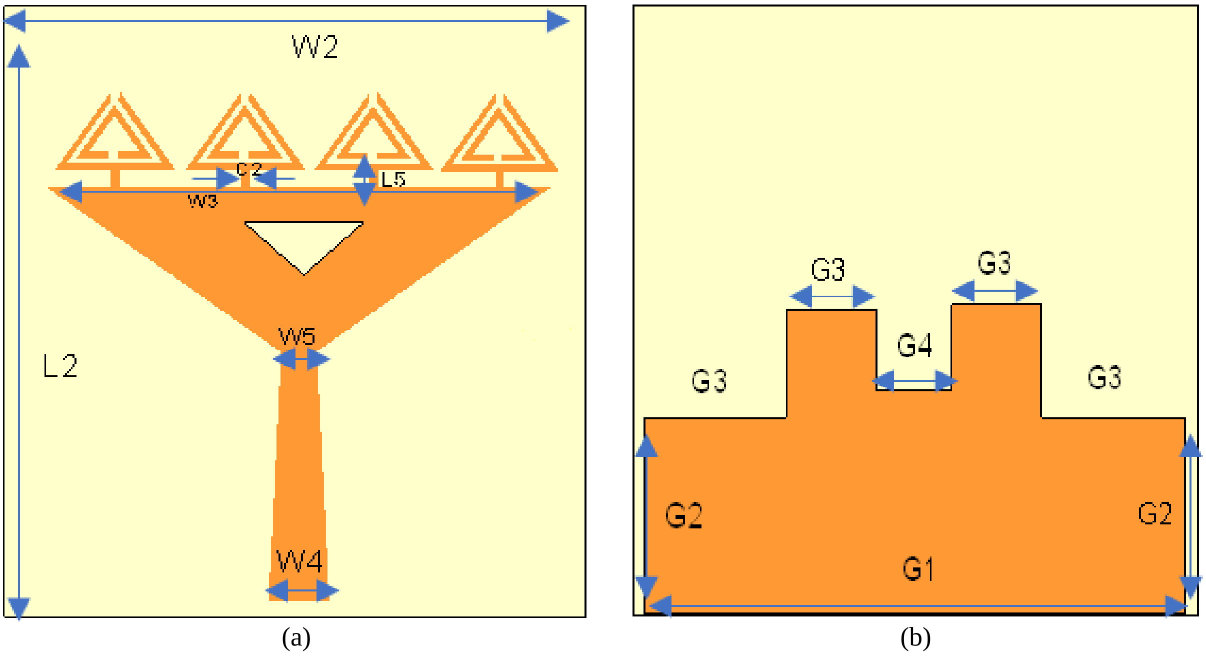

Figure 2. MTM SRR-H antenna structure: (a) front and (b) back.

The size of the metamaterial antenna structure can be seen in Table 2. The materials used consist of copper (patch and ground) and FR4 (substrate).

Table 2. Size of the triangular SRR antenna structure.

Parameter	Dimension (mm)	Parameter	Dimension (mm)
C_2	1	W_4	2.14
L_2	33.3	W_5	0.9
L_3	14.54	G_1	29.6
L_4	11.11	G_2	7.4
L_5	1	G_3	5.43
W_2	29.6	G_4	3.94
W_3	29.6	T_g	0.035

3. RESULTS AND DISCUSSIONS

3.1. Characteristics of Metamaterial Structures

The effect of the combination of 1 – 4 SRR metamaterial cells on metamaterial parameters produces ε_r, μ_r, and n with negative values, which can be seen in Figures 3 and 4. The combination of 4 triangular SRR metamaterial structures produces ε_r, μ_r, and n with greater negative values at the first resonance frequency compared to the combination of 1 – 3 SRR-H metamaterials. This occurs because the addition of dielectric medium material causes the ability to polarize electrons by the resulting E and B field moments to become smaller. So that the effect on changes in relative permittivity and permeability of the material becomes greater.

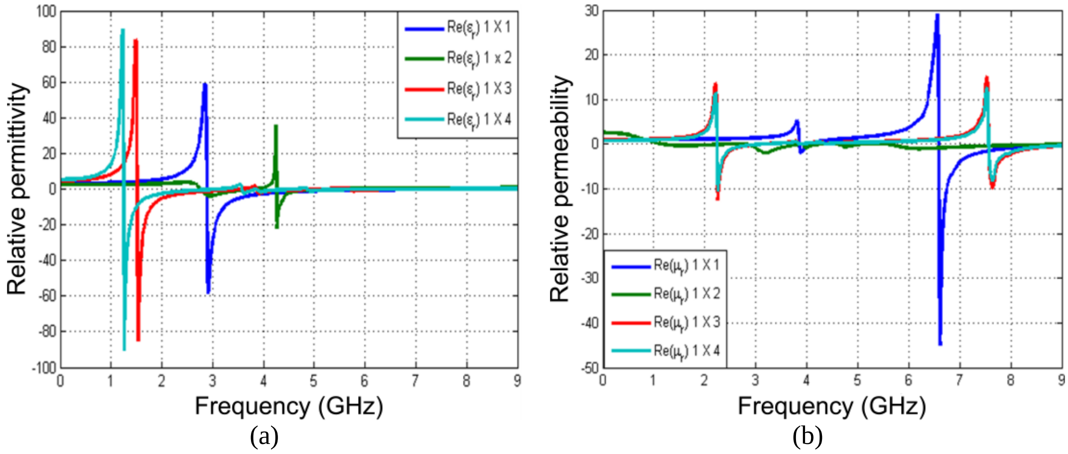

Figure 3. (a) Graph of ε_r and (b) μ_r metamaterial structures of the combination of 1 – 4 SRR.

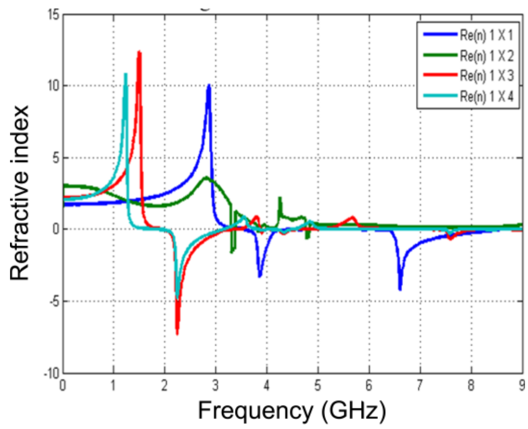

Figure 4. Graph of refractive index (n) of metamaterials 1 – 4 SRR-H.

The maximum negative value of refractive index n is -4.78 at a frequency of 2.21 GHz. The frequency shift is increasingly down towards low frequencies with the addition of the SRR metamaterial structure combination is shown in Figure 4.

3.2. SRR Metamaterial Combination Antenna

The characteristics of metamaterial parameters have been carried out and then the metamaterial structure combination of 1 – 4 triangular SRRs will be applied in the form of an antenna for medical applications. Antenna parameter are in the form of return loss, VSWR, and gain.

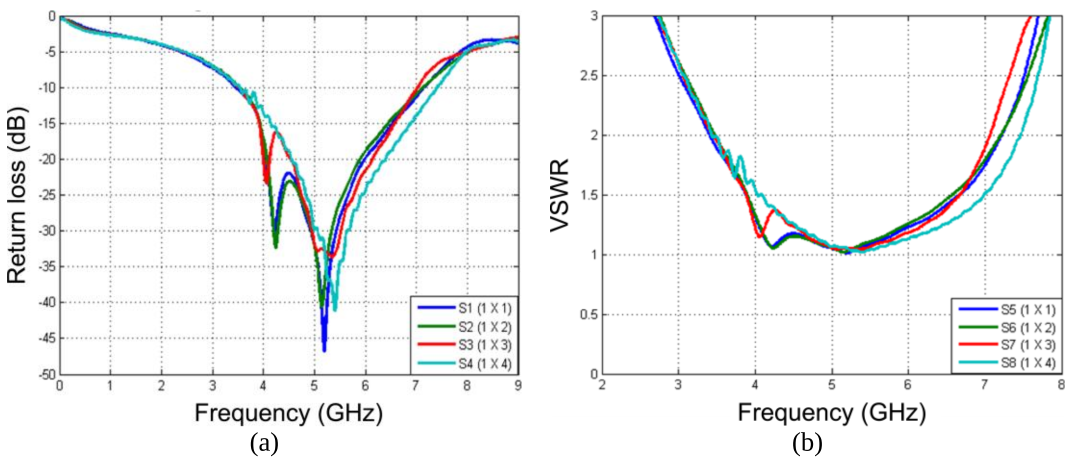

Figure 5. (a) return loss and (b) VSWR of the 1 – 4 SRR combination antenna with a radius of 3.5 mm.

Based on the simulation results, the addition of metamaterial cells affects the RL value. The lower the RL value indicates that the power received by the antenna is greater and makes the antenna work more optimally. In this study, the best RL value is found in the combination of 1 triangular SRR metamaterial with a value of -46.72 dB. This causes the VSWR frequency range and BW width to be larger. This is proven by 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.

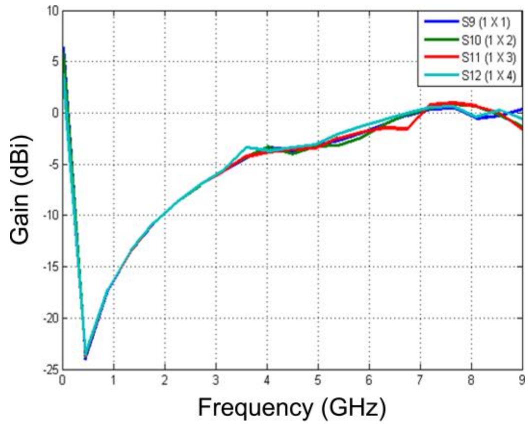

Figure 6. Gain graph of combination of 1 – 4 triangular SRR cells.

Changes in gain on metamaterial antennas with variations of combinations of 1 – 4 triangular SRRs and a fixed radius of 3.5 mm can be seen in Figure 6. The graph clearly shows that the metamaterial structure affects the performance of the antenna. The resonance frequency of the antenna appears to be the same at the point of occurrence. However, after that, the movement of the gain graph of each antenna becomes different. This is due to the interaction caused by the metamaterial structure with the combination of triangular SRRs applied to the antenna when electric current or power has entered and flowed into the attached material structure.

4. CONCLUSION

In the combination antenna 1 – 4 SRR triangle according to the specifications of the medical sensor field antenna application. Good antenna results are obtained on a triangular structure antenna with a return loss of -41.18 dB, a working frequency of 3.53 – 7.39 GHz, a bandwidth of 3.86 GHz and a gain of 3.82 dBi which can be applied to the medical sensor field antenna.

REFERENCES

[1] Saktioto, Soerbakti, Y., Syahputra, R. F., Gamal, M. D. H., Irawan, D., Putra, E. H., Darwis, R. S., & Okfalisa. (2022). Improvement of low-profile microstrip antenna performance by hexagonal-shaped SRR structure with DNG metamaterial characteristic as UWB application. *Alexandria Engineering Journal*, **61**(6), 4241–4252.

[2] Kumar, P., Ali, T., & Pai, M. M. (2021). Electromagnetic metamaterials: A new paradigm of antenna design. *IEEE Access*, **9**, 18722–18751.

[3] Ahmad, I., Tan, W., Ali, Q., & Sun, H. (2022). Latest performance improvement strategies and techniques used in 5G antenna designing technology, a comprehensive study. *Micromachines*, **13**(5), 717.

[4] Lestari, A. N., Hakim, W. A. N., Nur, L. O., & Edwar. (2021). Pengaruh left-handed metamaterial (LHM) terhadap bandwidth antena mikrostrip patch triangular untuk teknologi 5G. *SinarFe7*, **4**(1), 10–14.

[5] Kumar, R., Kumar, M., Chohan, J. S., & Kumar, S. (2022). Overview on metamaterial: History, types and applications. *Materials Today: Proceedings*, **56**, 3016–3024.

[6] Chishti, A. R., Aziz, A., Qureshi, M. A., Abbasi, M. N., Abbasi, D., Iqbal, S. S., Zerguine, A., Algarni, A. M., & Hussain, R. (2023). Advances in antenna-based techniques for detection and

monitoring of critical chronic diseases: A comprehensive review. *IEEE Access*, **11**, 104463–104484.

[7] Karthikeyan, T. A., Nesasudha, M., Saranya, S., & Sharmila, B. (2024). A review on fabrication and simulation methods of flexible wearable antenna for industrial tumor detection systems. *Journal of Industrial Information Integration*, **41**, 100673.

[8] Tayel, M. B., Abouelnaga, T. G., & Desouky, A. F. (2018). UWB high gain antenna array for SAR based breast cancer detection system. *2018 5th International Conference on Electrical and Electronics Engineering, ICEEE 2018*, 311–316.

[9] Khairani, H. S., Nur, L. O., & Edwar, E. (2023). Perancangan dan realisasi antena planar ultra wideband patch berbentuk triangular untuk deteksi kanker otak. *eProceedings of Engineering*, **10**(5).

[10] Bhomia, Y., Kajla, A., & Yadav, D. (2010). V-slotted triangular microstrip patch antenna. *Int. Journal of Electronics Engineering*, **2**(1), 21–23.

[11] Karim, R., Iftikhar, A., Ijaz, B., & Mabrouk, I. B. (2019). The potentials, challenges, and future directions of on-chip-antennas for emerging wireless applications—A comprehensive survey. *IEEE Access*, **7**, 173897–173934.

[12] Permatasari, D. P. (2015). Pelebaran bandwidth antena mikrostrip dengan struktur pentanahan tiruan. *Fakultas Teknik Industri Institut Teknologi Sepuluh Nopember, Surabaya*.

[13] Singh, S., Sethi, G., & Khinda, J. S. (2022). A historical development and futuristic trends of microstrip antennas. *Int. J. Com. Dig. Sys*, **12**(1).

[14] Sharma, V. (2020). Microstrip antenna-inception, progress and current-state of the art review. *Recent Advances in Electrical & Electronic Engineering*, **13**(6), 769–794.

[15] Ashyap, A. Y. I., Inam, M., Kamarudin, M. R., Dahri, M. H., Shamsan, Z. A., Almuhanna, K., & Alorifi, F. (2023). Multi-band metamaterial antenna for terahertz applications. *Computers, Materials and Continua*, **74**(1), 1765–1782.

[16] Banerjee, S., Dutta, P., Basu, S., Mishra, S. K., Appasani, B., Nanda, S., Abdulkarim, Y. I., Muhammadsharif, F. F., Dong, J., Jha, A. V., Bizon, N., & Thounthong, P. (2023). A new design of a terahertz metamaterial absorber for gas sensing applications. *Symmetry*, **15**(1).

[17] Parthasarathy, H. (2022). *Select Topics in Signal Analysis*. CRC Press.

[18] Abdullah, S., Xiao, G., & Amaya, R. E. (2021). A review on the history and current literature of metamaterials and its applications to antennas & radio frequency identification (RFID) devices. *IEEE Journal of Radio Frequency Identification*, **5**(4), 427–445.

[19] Bakır, M., Karaaslan, M., Karadağ, F., Ünal, E., Akgöl, O., Alkurt, F. Ö., & Sabah, C. (2018). Metamaterial-based energy harvesting for GSM and satellite communication frequency bands. *Optical Engineering*, **57**(08), 1.

[20] Manage, P. S., Naik, U., & Rayar, V. (2023). Optimization algorithms for mimo antennas: A systematic review. *Wireless Personal Communications*, **131**(1), 105–139.

[21] Selvi, N. T., Selvan, P. T., Babu, S. P. K., & Pandeeswari, R. (2020). Multiband metamaterial-inspired antenna using split ring resonator. *Computers and Electrical Engineering*, **84**, 106613.

[22] Guo, Z., Xu, Y., Hu, S., Wang, Y., Sun, Y., & Chen, H. (2024). Metamaterial-enhanced magnetic resonance imaging: A review. *Advanced Photonics Nexus*, **3**(5), 054001.

[23] Alrayes, N., & Hussein, M. I. (2021). Metamaterial-based sensor design using split ring resonator and Hilbert fractal for biomedical application. *Sensing and Bio-Sensing Research*, **31**, 100395.

[24] Shin, M., Seo, M., Lee, K., & Yoon, K. (2024). Super-resolution techniques for biomedical applications and challenges. *Biomedical Engineering Letters*, **14**(3), 465–496.

[25] Raj, R. (2022). *Hyperthermic procedure to treat cancer using biomedical antenna*. Doctoral dissertation, Ph. D. dissertation, Dept. Electron. Telecommun. Eng., Int. Inst. Inf. Technol. Bhubaneswar, Bhubaneswar, India.