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Comparing Mutual Coupling of Ring Metamaterial on Square and Vivaldi Array Antennas

Petrus Kerowe Goran[1], **Eko Setijadi**[2]
[1]*Telecommunication Engineering Study Program, Institut Teknologi Telkom*
[2]*Department of Electrical Engineering, Faculty of Electrical Technology, Institut Teknologi Sepuluh Nopember*
[1]*Purwokerto, Indonesia*
[2]*Surabaya, Indonesia*
email: [1]petrus@ittelkom-pwt.ac.id, [2]ekoset@ee.its.ac.id

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ABSTRACT

The antenna performance is seen from the S-parameter value. The S-parameter graph can be seen as the return loss (S11, S22) and the mutual coupling (S21, S12) value. This research focuses on analyzing mutual coupling on Square and Vivaldi array antennas using the ring metamaterial method. The value of mutual coupling is considered very important to analyze because it affects the performance of the antenna in which is arranged in an array. The simulation results of the mutual coupling value obtained on a square array antenna use a ring metamaterial is -17 dB at a frequency of 2.4 GHz. Meanwhile, the Vivaldi array antenna uses a ring metamaterial that produces a mutual coupling value of -13.840744 dB at a frequency of 3.0162 GHz. The factors that affect the square array antenna so that it becomes the best to suppress the mutual coupling value between antenna elements are a selection of metamaterial shape and proper placement between the antenna array elements is arranged horizontally.

1. Introduction

Antennas communication becomes devices in the world that will be discussed or examined before ensuring that the signal will be sent through the transmission line. Antenna becomes the final element of the sending and receiving process of a signal by a system. Antenna with a minimalist size can be flexible to use because it is easy to be carried, created, and produced massively of this type of antenna. The type of antenna discussed in this paper is the microstrip antenna. There are many kinds of microstrip antennas ranging from coplanar, cross, etc. The square and circular antennas are not commonly used because they are created according to the person who design to find an antenna model with small dimensions, small power, large beamwidth, large gain, and directivity.

The microstrip antenna has many disadvantages, one of which is the mutual coupling. Mutual coupling arises from mutual influence between one against another patch antennas, causing the S-parameter values of the antenna such as gain, return loss, radiation pattern, efficiency, channel capacity, matching impedance, and the emitted power to decrease.

This research refers to previous studies that have been investigated using microstrip antennas while regulating the value of mutual coupling (Ferendeci 2011) is obtained by giving a ring and square metamaterial between the antenna patches (Goran, Setijadi, and Hendrantoro 2018).

The value of mutual coupling is present due to interplaying electromagnetic waves in the electric and magnetic fields and surface currents between patch antennas (Malherbe 1989). Several mechanisms to reduce the value of mutual coupling are by using SIW slots between elements (Ghahramani et al. 2014), adding metamaterial absorbers (Yang et al. 2012), and adding walls (Farahani et al. 2017).

Many materials can be used as antenna materials. Antenna can have different electrical (ε_r) and magnetic (μ_r) values because of the uniqueness for each material. There is also material that does not exist on earth, which is commonly referred as metamaterial. A metamaterial is a material that is changed in such a way so that it has desired electrical (ε_r) and magnetic (μ_r) values. Metamaterial has negative electrical (ε_r) and magnetic (μ_r) values.

After selecting the type of metamaterial with appropriate electrical (ε_r) and magnetic (μ_r) values, the next problem is the creation of the metamaterial model. It has been discussed above that there are several models of metamaterials ranging from SIW slots, absorbers, and walls. This metamaterial model differs from one another in mutual coupling values influenced by the value of resistance (R), inductance (L), and capacitance (C). In the next paper, we will discuss the effect of R, L, and C on several metamaterial models. The scope of discussion in this research is the comparison of mutual coupling values and their effect on the use of the ring metamaterial model on square array antenna and Vivaldi.

2. Literature review

This research refers to previous research in reducing the value of mutual coupling with the truncated and corrugated slot method (Nurhayati et al. 2018) and research conducted with the Split Ring Resonator Metamaterial method (Hamzidah and Setijadi 2015). A Research entitled "Mutual Coupling Reduction for UWB Coplanar Vivaldi Array by Truncated and Corrugated Slot" reported mutual coupling reduction by using the truncated and corrugated slot in UWB (Ultra Wideband) Coplanar Vivaldi Array (CVA). This paper concluded that mutual coupling reduction is achieved by placing a structure between two elements. Another research entitled "Design of Microstrip Patch Antenna Based on Complementary Split Ring Resonator Metamaterial for WiMAX Applications" reported that parameters and performances of microstrip antenna with CSRR metamaterial are better than conventional microstrip antennas. In this paper, the research compares Mutual Coupling value Ring Metamaterial between Square Array Antenna and Vivaldi.

The antenna works best or efficiently if the energy from the source emitted wave is completely radiated without any energy returning to the antenna and the energy source. Hence, at the beginning of designing an antenna, a single element antenna is usually used before using multiple antenna elements. This single element antenna is used as a basis for an antenna that has good parameter values before being made into two or more antenna elements. The purpose of creating an array on two or more antenna elements is to get a directional directivity and a large gain. However, mutual coupling problems arise, which have been discussed in the introduction section above. This research uses the metamaterial model that has been researched in previous research in order to be able to compare the performance of ring metamaterials on square array antenna and Vivaldi (Balanis 2005). The theory used as a basic for understanding the method of reducing the mutual coupling value of antenna are using antenna books (Gross 2011; Hansen 2009; Stutzman, Warren. L ; Thiele n.d.). The other book from Elliot (2003) told about mutual coupling can only be calculated if the element currents are known.

$$V_n = Z_{1n}I_1 + Z_{2n}I_2 + ... + Z_{nn}I_n + ... + Z_{Nn}I_N \qquad \text{1)}$$

$$Z_{an} = \frac{V_n}{I_n} = Z_{1n}\frac{I_1}{I_n} + Z_{1n}\frac{I_2}{I_n} + ... + Z_{nn} + ... + Z_{Nn}\frac{I_N}{I_n} = \sum_{i=1}^{N} Z_{1n}\frac{I_i}{I_n} + Z_{nn} \qquad \text{2)}$$

where,

V_n = Voltage of n-th element

I_n = Current of n-th element

Z_{1n} = Mutual impedance at port 1 to n-th element

Z_{2n} = Mutual impedance at port 2 to n-th element

Z_{Nn} = Mutual impedance at port N to n-th element

3. Method

This section will discuss antenna designs, including square array antenna without metamaterial, square array antenna with ring metamaterial, Vivaldi array antenna without metamaterial, and Vivaldi array antenna with ring metamaterial. Moreover, regarding the size of the antenna and the size of the ring metamaterial used in this research. This research was using software Antenna CST. Figure 1 describes all the steps of this research.

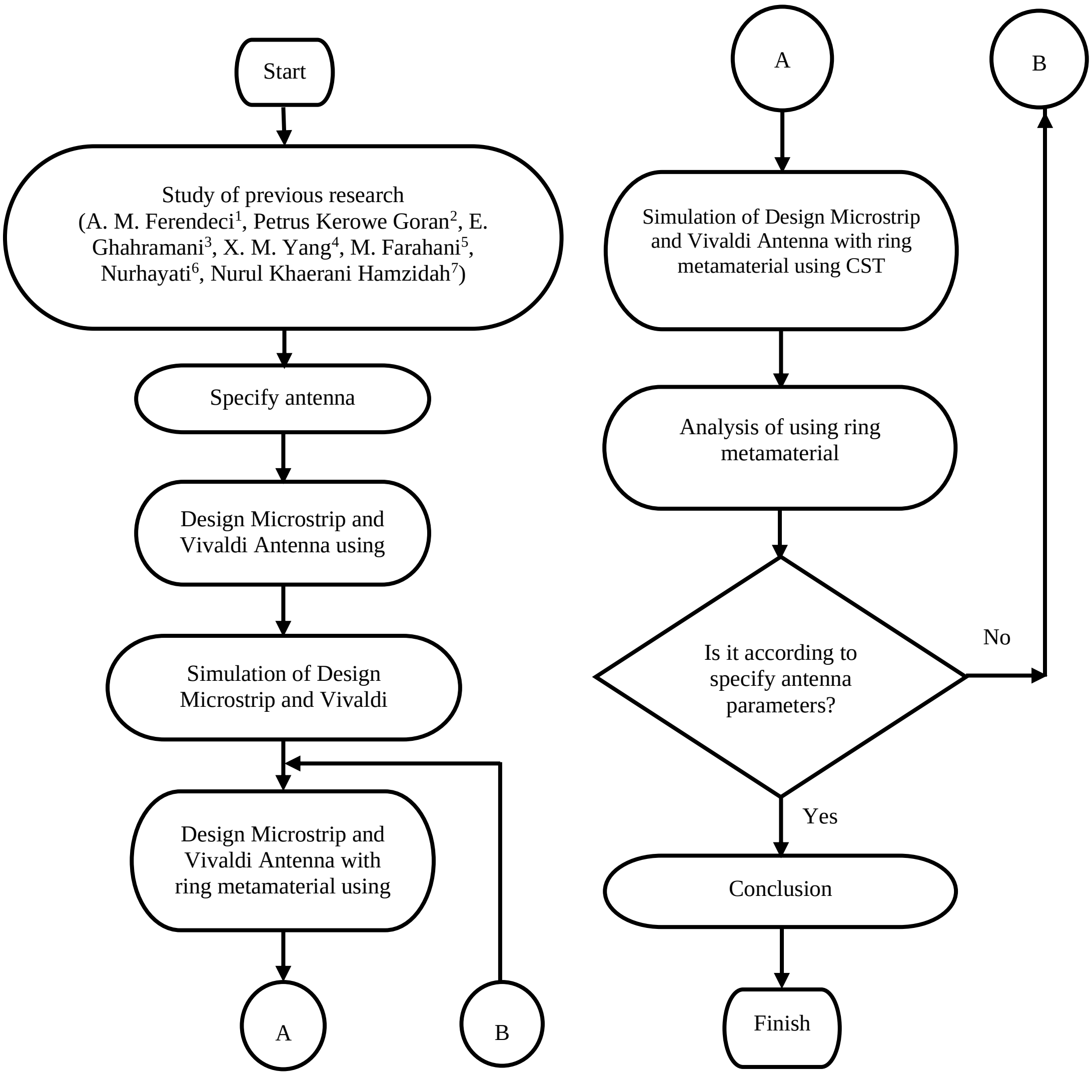

Figure 1. Flow chart of research

3.1. Square Array Antenna without Metamaterial

Figure 2 is the image of a Square Array Antenna without metamaterial with antenna dimension size criteria is 117 mm x 56 mm x 1.6 mm. The size of each antenna patch is 34.1 mm x 28.8 mm x 0.03 mm. The distance of each patch antenna is 50 mm or $0.4\lambda_0$.

3.2. Square Array Antenna with Ring Metamaterial

Figure 3 is the design of a Square Array Antenna using ring metamaterial. The ring metamaterial is placed in the middle position between two (2) patch antennas to suppress the mutual coupling value (S21), which influences each other. The ring metamaterial size of the Square Array Antenna can be seen in Figure 4. The outer diameter of the ring metamaterial is 8 mm, and the inner diameter of the ring metamaterial is 6 mm. The copper-veiled ring metamaterial diameter is 1 mm with a gap between the opening of the gap of 1 mm.

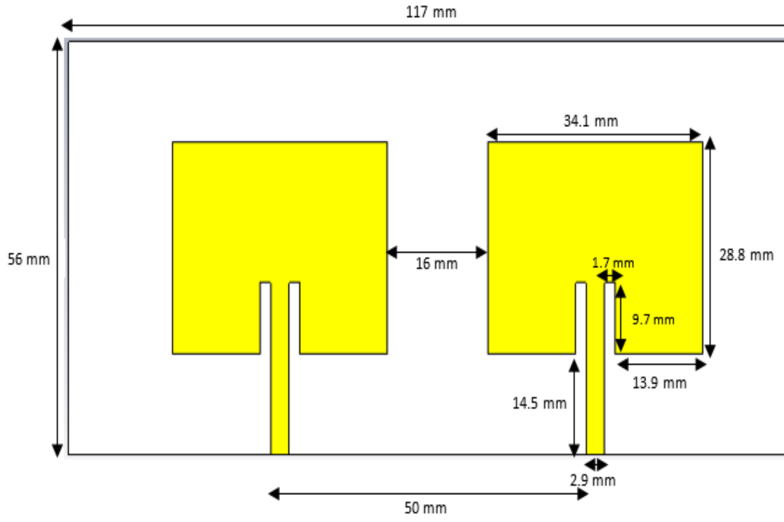

Figure 2. Square array antenna without metamaterial

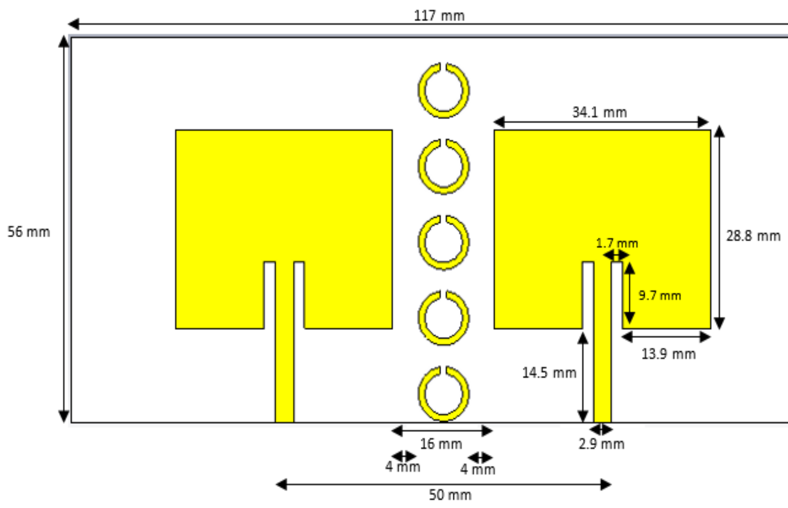

Figure 3. Square array antenna with ring metamaterial

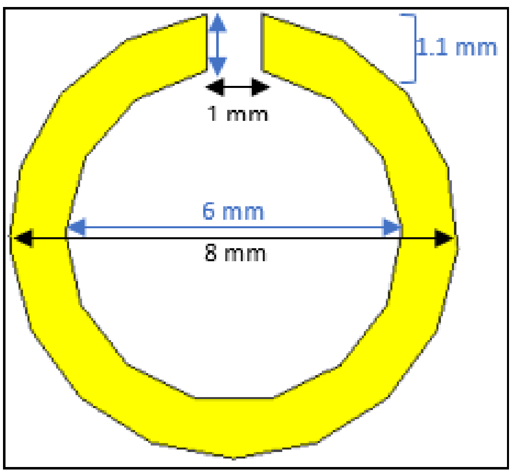

Figure 4. The size of ring metamaterial on square array antenna

Design of Square Array Antennas using ring-shaped metamaterials follows the specification values as presented in Table 1.

Table 1. Parameter of square array antenna using ring metamaterial

Parameter	Value
Operational frequency	2.4 GHz
Type of Substrate	FR-4
Kind of Substrate	Copper
Dielectric Constant	4.4
Patch Height (PH)	0.03 mm
Substrate Height (SH)	1.6 mm
Patch Length (PL)	28.8 mm
Patch Width (PW)	34.1 mm
Gap Patch (GP)	50 mm
Substrate Length (SL)	56 mm
Substrate Width (SW)	67 mm
Outer radius	4 mm
Inner radius	3 mm
Ring Spacing	11.02 mm

3.3. Vivaldi Array Antenna without Metamaterial

Figure 5 is the Vivaldi Antenna array design without metamaterial, which has the antenna patch dimensions of 125 mm x 60 mm x 0.03 mm. The antenna's dimensions, including patch antenna, substrate, and ground plane, are 125 mm x 60 mm x 1.6 mm and designed at operational frequency 2.4 GHz. The distance between the antenna patches from one feeding to the other is 1.923λ_0 or 65 mm.

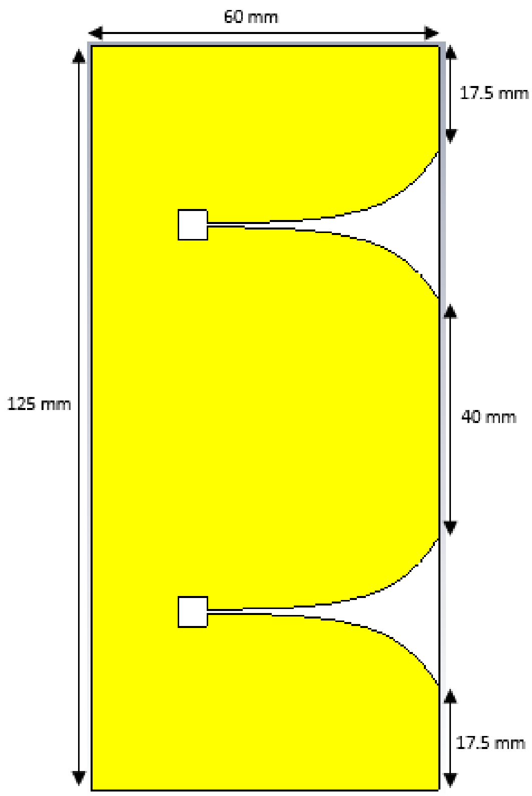

Figure 5. Vivaldi array antenna without metamaterial

3.4. Vivaldi Array Antenna with Ring Metamaterial

Figure 6 is a design drawing of an Antenna Vivaldi Array using a ring metamaterial. The ring metamaterial size in the Vivaldi Array Antenna follows the measurements in Figure 7. Figure 7 is the metamaterial size of the ring used in the Vivaldi Array Antenna, which is used to suppress the value of mutual coupling.

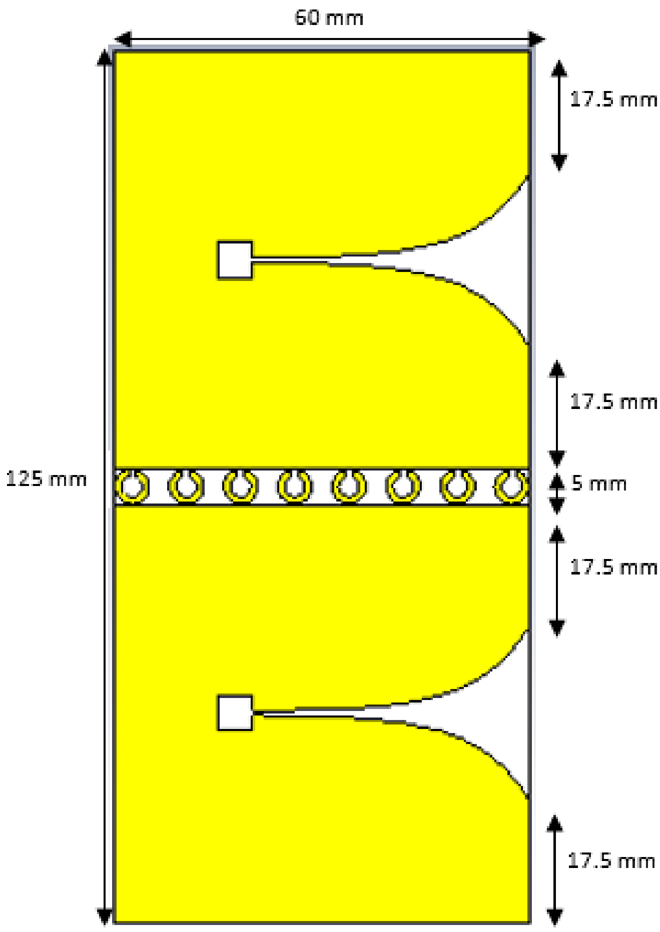

Figure 6. Vivaldi array antenna with ring metamaterial

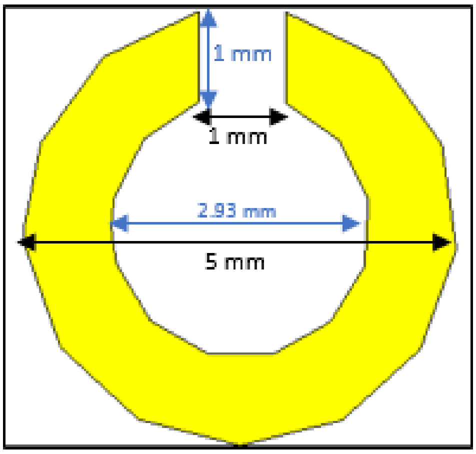

Figure 7. The size of ring metamaterial on vivaldi array antenna

Vivaldi array antenna design with ring metamaterial uses parameters presented in Table 2.

Table 2. Parameter of Vivaldi array antenna using ring metamaterial

Parameter	Value
Operational frequency	2 GHz – 4 GHz
Type of Substrate	FR-4
Kind of Substrate	Copper
Dielectric Constant	4.4s
Substrate Length (Lsub)	60 mm
Substrate Width (Wsub)	60 mm
Tapered Length (LT)	40 mm
Tapered Width (WT)	25 mm
Strip Width (Wstrip)	2 mm
Slot Width (Wsl)	0.6 mm
Balun Width (Wb)	5 mm
Substrate Height (Tsub)	1.6 mm
Patch Height (Tpatch)	0.035 mm
Balun Length (Lb)	5 mm
Distance between Vias (dxvias)	1.1 mm
Distance vias field Y (YV)	54 mm
Distance vias field X (XV)	15 mm
RO	0.5 mm
RI	0.13 mm
Strip Height from the bottom (Ostrip)	15 mm
Strip Length Horizontal (Lstrip)	25 mm
Strip Height Vertikal (Hstrip)	28 mm
Ring Cell Gap	1 mm
Outer radius	5 mm
Inner radius	2.93 mm
Outer and Inner Ring Spacing	1 mm
Ring Spacing	7.83 mm

4. Result and Discussion

The result of the Square Array antenna simulation without metamaterial shows that the value of mutual coupling (S21) at the operational frequency of 2.3 GHz, as in Figure 8, is equal to -18.221 dB. This result is for the distance of two elements as far as $0.4\lambda_0$ or 50 mm. This distance is used because it is the limit to see the effect of mutual coupling. If the distance is less than 50 mm, the mutual coupling effect is more obvious (in this research, we see that the distance limit's final threshold is 24 GHz frequency). In contrast, if the distance is more than $0.4\lambda_0$ or 50 mm, the mutual coupling effect will be negligible. Otherwise, this research discusses the effect of mutual coupling and how to overcome it by using a ring metamaterial.

The design of the square array antenna with ring metamaterial and the selection of metamaterial follow the parameters in Table 1. The simulation results are displayed in Figure 9. As we can see in the figure, the value of mutual coupling (S21) of Square Array Antennas with ring metamaterial is -17 dB. This value is obtained from the shape of the ring metamaterial displayed in Figure 4. The ring metamaterial has an inner circle diameter of 6 mm and an outer circle diameter of 8 mm. These values affect both the equivalent value of inductance (L) and capacitance (C).

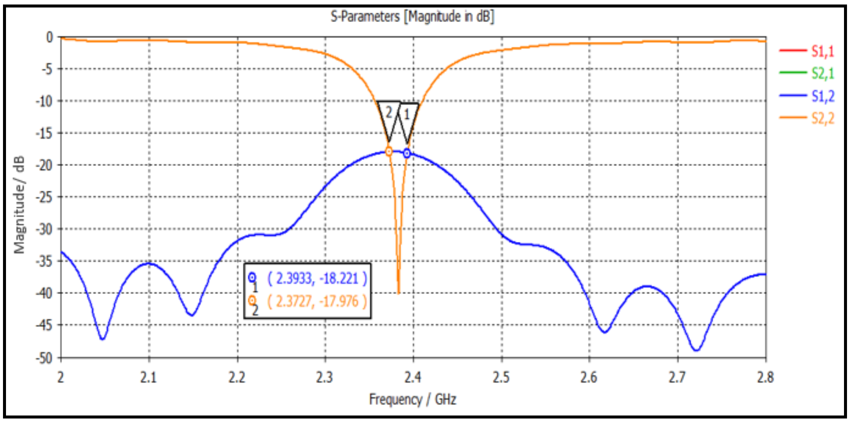

Figure 8. S-Parameter of square array antenna without metamaterial

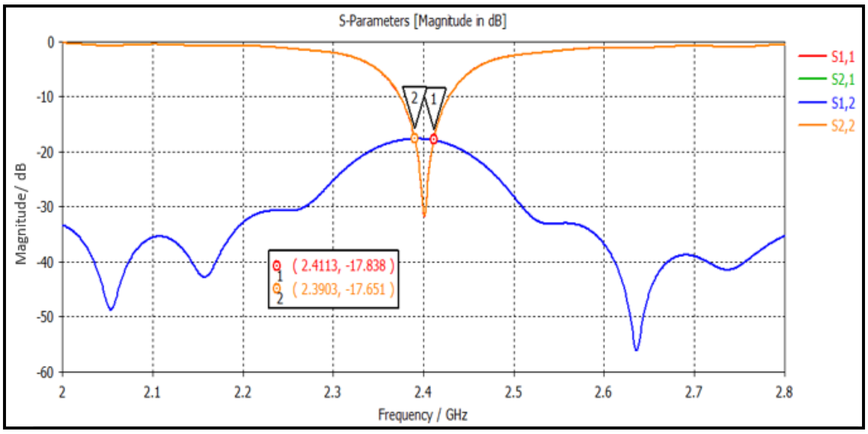

Figure 9. S-Parameter of square array antenna with ring metamaterial Metamaterial

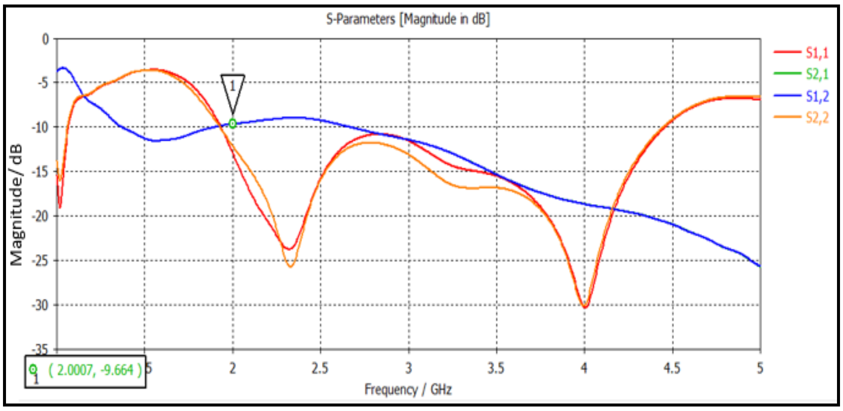

Figure 10. S-Parameter of vivaldi array antenna without metamaterial

Figure 10 shows the S-Parameter of the Vivaldi array antenna without metamaterial. The mutual coupling (S21) decrease starting at the operational frequency of 2.5 GHz to the final frequency. The Vivaldi array antenna's bandwidth is unknown because it does not have a graph that intersects from S12 or S21 to S11 or S22 graph at the magnitude of -10 dB, a high threshold value of the antenna performance. This result can be explained that the distance is $1.923\lambda_0$ or 65 mm, the threshold for mutual influence between the elements. Thus, if there is nothing block radiation between elements, it will result in mutual influence between the elements.

By following the Parameters shown in Table 2, S-Parameter values of Vivaldi antenna array using ring metamaterial are displayed in Figure 11. The S-parameter graphic in Figure 11 shows the performance of Vivaldi antennas in the range of 2 GHz to 4 GHz. In that range, a good value of S21 is obtained when the frequency is above 2.5 GHz, namely less than -10 dB, at the bandwidth value of the antenna is 0.5 GHz. These results were obtained from the antenna design presented in Figure 7. The diameter size of this ring metamaterial affects the inductance (L) and capacitance (C) values of this metamaterial so that it can block the effect of mutual coupling between elements on the Vivaldi antenna array.

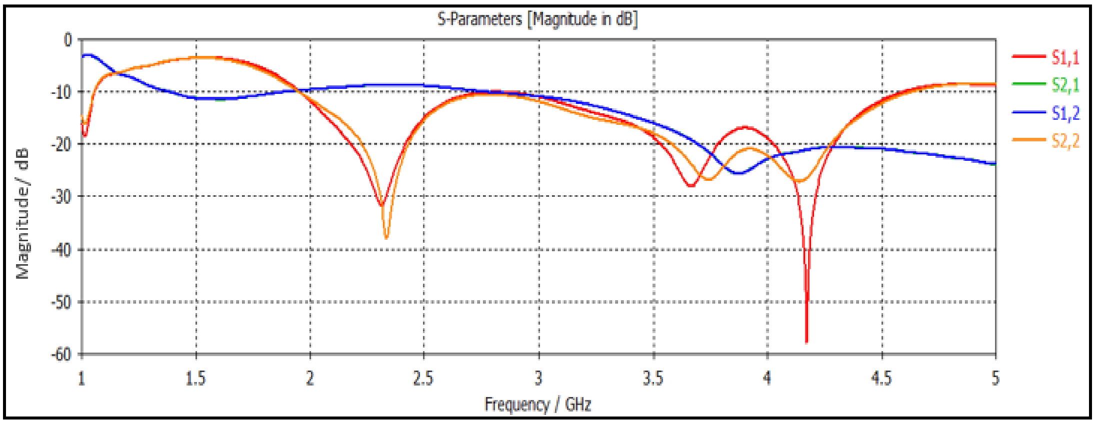

Figure 11. S-Parameter of Vivaldi Array Antenna with Ring Metamaterial

4.1. Comparison of Mutual Coupling between Square Array Antenna without metamaterial and with Ring Metamaterial

Figure 12 compares the Square array antenna's mutual coupling values when using and not using metamaterial. The value of mutual coupling (S21) antenna without metamaterial is -18.4 dB. In comparison, the value of mutual coupling (S21) of the Square array antenna using ring metamaterial is -17.8 dB at the operational frequency of 2.4 GHz. There is a difference of -0.6 dB between the two results. The determination of the minimum boundary distance between one element and another of a square array antenna is determined by each antenna's radiation pattern, which is a simulation of the presentation of the radiation pattern. Based on these, the input can be given to provide a method to suppress the effect of mutual coupling between antennas. The results can be seen in the radiation pattern and the graph of the mutual coupling value of -0.6 dB.

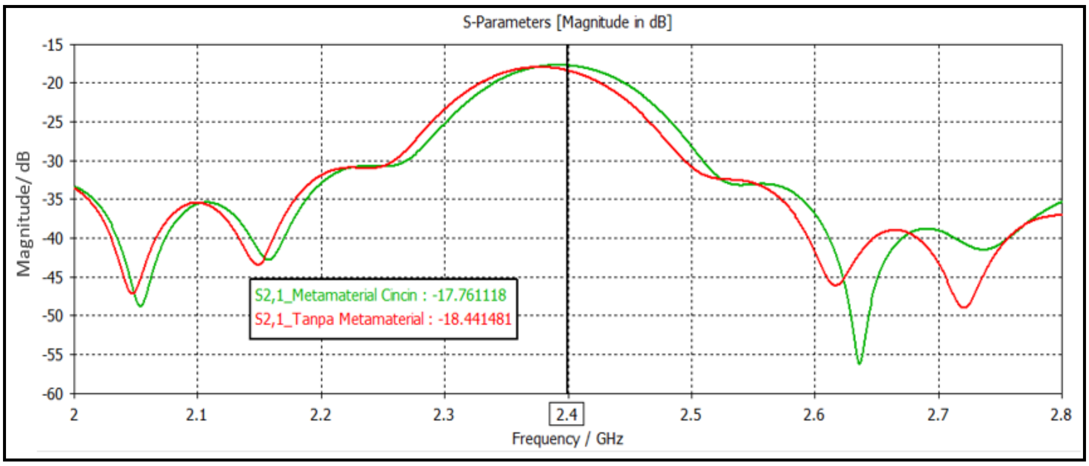

Figure 12. Comparison of mutual coupling between square array antenna without metamaterial and with ring metamaterial

4.2. Comparison of Mutual Coupling between Vivaldi Array Antenna without Metamaterial and with Ring Metamaterial

Figure 13 compares the mutual coupling values of the Vivaldi Array Antenna without a metamaterial and with a ring metamaterial. The value of mutual coupling (S21) antenna without metamaterial is -11.538206 dB at the operational frequency of 3.0162 GHz. In comparison, the value of mutual coupling (S21) of the Vivaldi array antenna using ring metamaterial is -13.840744 dB, which works at 3.0162 GHz operational frequency. The two results differ by about -2.302538 dB. The analysis in Figure 13 has been partially explained in the graphs of Figure 10 and Figure 11. The ring metamaterial is made in such a way that it functions to suppress the effect of mutual coupling between elements of the Vivaldi array antenna. The correct placement and the ring metamaterial size between the Vivaldi antenna elements in the array can suppress the effect of the mutual coupling value by -2.302538 dB.

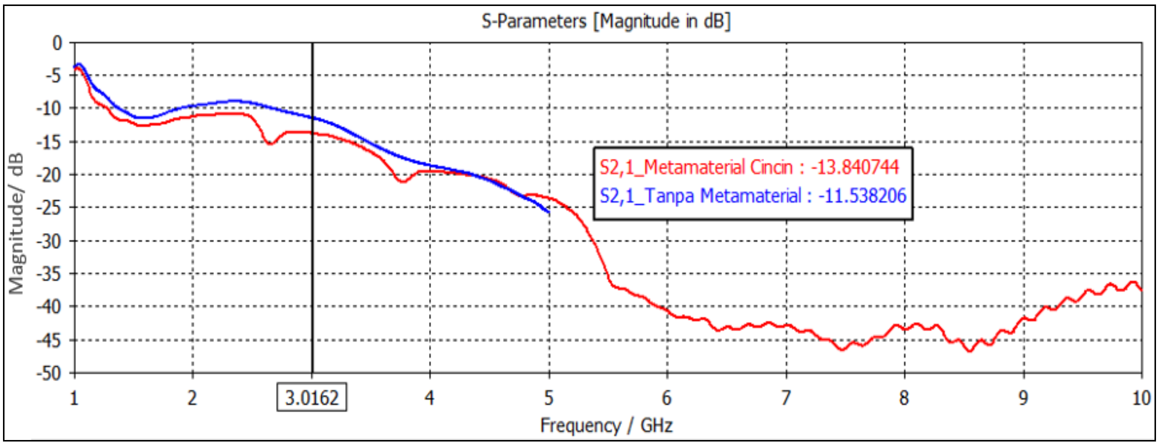

Figure 13. Comparison of mutual coupling between Vivaldi array antenna without metamaterial and with ring metamaterial

4.3. Comparison of Mutual Coupling between Square Array Antenna and Vivaldi Array Antenna using Ring Metamaterial

Figure 14 compares the mutual coupling value of square array antenna and Vivaldi array antenna using ring metamaterial. The performance of the two antennas is compared at the middle of operational frequency, namely 3 GHz. At this point, the square array antenna with ring metamaterial has a mutual coupling (S21) value of -53.521557 dB. In comparison, the Vivaldi array antenna with ring metamaterial has a mutual coupling of -10.963974 dB. Thus, the two antennas have a different value of -42.557583 dB. Metamaterial has a function to keep electromagnetic waves from crossing into other antenna elements. Suppose there exists an influence of electromagnetic waves between antenna elements, then it will affect

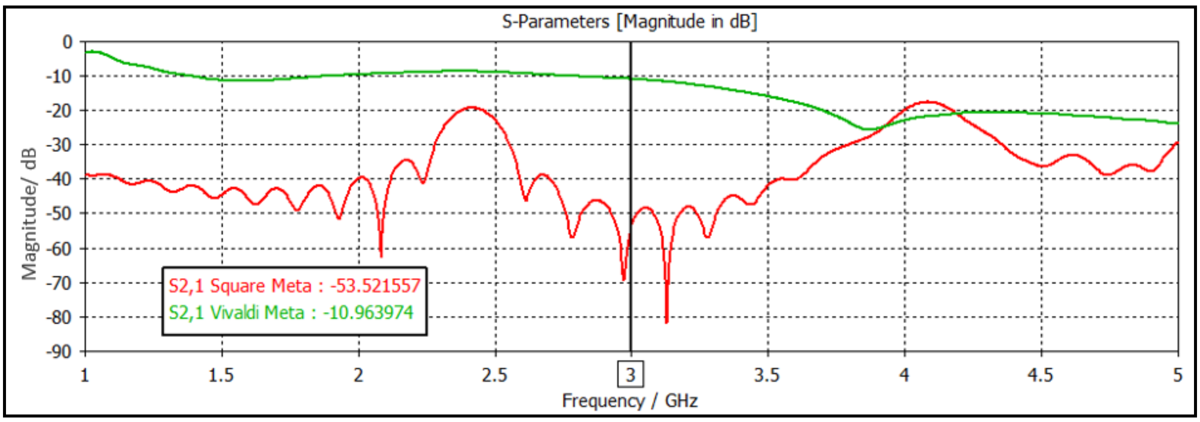

Figure 14. Comparison of Mutual Coupling between Square Array Antenna and Vivaldi Array Antenna using Ring Metamaterial

the value of mutual coupling (Ren, Gong, and Jiang 2018). The ring metamaterial is used because it is one of the best metamaterials. It has an advantage of showing resonance polarization transmission response and direction insensitive (Yu et al. 2012). Thus, the results show that the Square Array Antenna is better than the Vivaldi Array Antenna. The factors that influence the best square array antenna in this research to suppress the mutual coupling value between antenna elements are the function of the metamaterial selected and used and the proper placement between the antenna array elements that are arranged horizontally.

5. Conclusion

All comparisons between S-Parameters mutual coupling (S21) of Square Array Antenna and that of Vivaldi with ring metamaterial show that the best performance is demonstrated by ring metamaterial on Square Array Antenna with a magnitude of -53.521557 dB. The magnitude differs by -42.557583 dB from using ring metamaterial on Vivaldi Array Antenna. The factors that affect the square array antenna so that it becomes the best in this research in suppressing the mutual coupling value between antenna elements are selecting the metamaterial shape and the proper placement between the antenna array elements that are arranged horizontally. From this research, it can also be concluded that the ring-shaped metamaterial is very suitable to suppress mutual coupling in a square array antenna. This research can be further developed in the analysis of the relationship between voltage (V), current (I) on the mutual coupling value and proof of formula reduction that can strengthen the simulation results and analyze the effect of inductance (L) and capacitance (C) values on the performance of ring metamaterials.

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