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BANDWIDTH AND GAIN ENHANCEMENT OF 2×2 MICROSTRIP PATCH ANTENNA ARRAY USING METAMATERIAL AT 2.4 GHZ

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Abstract

Nowadays, in wireless communication systems, microstrip patch antennas are generally utilized since their low profile, lightweight, relatively inexpensive, and compatibility with integrated circuits. This study aimed to design and manufacture a rectangular microstrip patch antenna array inserted with metamaterial to enhance the bandwidth and gain for Wireless Fidelity (Wi-Fi) application at the frequency of 2.4 GHz. This study was conducted in two stages. In the first stage, the microstrip antenna array design was optimized. Afterward, the metamaterial was inserted into the antenna array to enhance the bandwidth and gain through simulation using CST Studio Suite. In the second stage, the microstrip antenna array was manufactured by employing the FR-4 substrate with the dielectric constant of 4.35 and the thickness of 1.6 mm. In addition, we compared the performance between microstrip antenna array minus metamaterial and microstrip antenna array inserted with metamaterial. Based on the results of simulation and measurement, the findings showed that the microstrip antenna array bandwidth with metamaterial wider than conventional microstrip antenna array. Moreover, the microstrip antenna array gain with metamaterial was higher than the conventional microstrip antenna array. Metamaterials are implemented as the antennas to boost their radiation properties utilizing the artificial magnetic conductor (AMC). By using the unique attributes of metamaterials that do not exist normally, the various microwave devices' performance can be improved. Referring to the results of simulation and measurement can be concluded that the addition of metamaterial to microstrip antenna array can enhance the bandwidth and gain.

Keywords: Bandwidth enhancement, Gain enhancement, Metamaterial, Microstrip antenna array, Wi-Fi.

1. Introduction

In a wireless communication system, an antenna has a significant role. The technology application of wireless communication requires an applicable cheap light, small antenna, but it has good quality. A patch microstrip antenna is proper for the applications. It has superiority in profile, simple, and applicable [1]. It is a metal conductor that attaches on the ground plane (found at dielectric material). It consists of three elements, namely a radiation element or patch, a substrate element, and a ground plane [2]. Patch function is as a radiation source where the electromagnetic power goes along the edge of the patch to enter the substrate. A substrate is a medium situated between patch or radiation element and the ground plane. Meanwhile, the ground plane is a base conductor layer. It gives functions as a perfect reflection element and returns the power through the substrate to the air.

The microstrip patch antenna has some weaknesses, such as limited bandwidth, low efficiency, and small gain. Wide bandwidth and high gain in an antenna are required to fulfil high demand in the wireless communication service. As a result, the frequency range is getting wider, and the coverage service is getting broader. However, in applying the microstrip, the bandwidth and the gain are one of the weaknesses [3].

Throughout the years, undoubtedly, some methods have been proposed to press the size of patch radiators and improvement in the antenna gain, while preserving their other properties of radiation [4]. The ordinary way to deal with scaling down an antenna is to put the radiator on a substrate with high dielectric constant. There are two disadvantages to this method. One issue is the remains of the electromagnetic field greatly concentrated nearby the high permittivity area. Another problem is the characteristics impedance in a medium with high permittivity that is relatively low, making adversities in the impedance matching [5]. The utilization of the metamaterials is appropriate to enhance some fundamental antenna properties (bandwidth, gain, efficiency, front-to-back, impedance matching, etc.), which has represented a new method of beating the restrictions shown by several of the notable methods for shrinking the antenna dimension [6]. A few instances of compact patch radiators have been lately proposed [7, 8].

Today, a mobile and wireless industry requires an inexpensive and straightforward implementation solution to decrease human exposure. In this way, current researches are focused on the utilization of metamaterials since they can be simply manufactured using Printed Circuit Board (PCB) processes [9].

The metamaterials are artificial construction, and the electromagnetic features of the materials given are not discovered in nature [10]. A metamaterial is a massive group of microwave structures that produce fascinating ε and μ conditions with enormous implications for various electromagnetic applications following depiction of the recent method to actualize ε-negative, μ-negative, and double-negative metamaterials [9]. Metamaterials are implemented as the antennas environment to boost their radiation properties utilizing the artificial magnetic conductor (AMC). By using the unique attributes of metamaterials that do not exist normally, the performance of sundry microwave devices can be improved [11]. The employment of AMC has solved numerous problems while defeating the typical restrictions in traditional antenna designs. Antennas are frequently placed above the reflector to enhance the radiation features of the antenna utilizing metamaterials so that radiate only in one direction, while decreasing the back-radiation [12].

There have been several studies on methods to increase antenna bandwidth using metamaterial. However, as explained in the literature, the addition of metamaterial is only to increase bandwidth while the gain is not a concern [13, 14]. In other research, the application of metamaterial is to increase the antenna bandwidth with bidirectional radiation patterns [15].

The purpose of this study was to design and manufacture the array of microstrip antenna for Wi-Fi application at a frequency of 2.4 GHz. Subsequently, the metamaterial was inserted into the antenna to enhance the antenna bandwidth and gain with a directional radiation pattern.

Similar to literature, the research results indicate that the bandwidth enhanced up to 50% and the gain of 8.5 dBi. They used only one patch antenna and the largest dimension was 200 mm × 200 mm [16]. Their antenna consists of a 4x4 array square ring with 135° diagonal-strips. The results were implemented as the fundamental guidelines to create the metamaterial design, which was proper to the specification of the antenna array. Our proposed antenna consists of an array 2×2 rectangular patch antenna and 3x5 square rings as metamaterial and has a smaller size for the largest dimension.

2. Method

This study was employed simulation and experimental methods consisting of designing, manufacturing, and measurement. The design of the antenna was carried out by utilizing the CST Studio Suite. The software optimized the antenna to determine a proper antenna dimension for Wi-Fi application. The microstrip antenna manufacturing was produced in PCB (printed circuit board). In this research, the antenna feeding technique implemented the feeding of the microstrip line. In conducting the feeding technique, the conductor element was connected directly to the edge of the patch distributing power to the radiation element by utilizing the conductor element directly [16-18]. Measurement of the antenna was conducted to investigate the characteristics of the antenna parameters covering return loss, VSWR, input impedance, gain, and radiation pattern. Antenna measurement employed vector network analyser (VNA) and spectrum analyser.

2.1. Antenna specifications

To meet our goal, we decided on the specification of the antenna first. Our proposed antenna in this study has the specification:

- Frequency: 2.4 GHz
- Gain: 9 dBi
- Bandwidth: 85 MHz
- Return loss: < -10 dB
- Radiation pattern: directional

2.2. Antenna design

In designing the antenna, the first step was to determine a single element antenna. To design a single microstrip patch antenna, we used formula in a good agreement with the literature [2]. We chose an inset fed rectangular patch microstrip antenna because this antenna is simple and easily matched with the microstrip line as a feeder [2]. After we got the dimension of a single element antenna, we simulated it using a CST Studio Suite and optimized it until we reached the optimum results.

The next step after getting optimum results for a single element antenna is to construct a 2×2 antenna array. Even though the performance of a single element was excellent, but when we built an array, the impedance changed as mutual impedance between antennas. Therefore, we needed to simulate and optimize it again to get optimum results. Next, the antenna was inserted by metamaterial to enhance the antenna bandwidth and gain. Subsequently, the design of the antenna array was added by metamaterial. The simulations were carried out continuously until the specification of the expected antenna was found. The next stage was the manufacturing of the antenna based on the dimension of the simulation outcome. Finally, the antenna was measured, and its parameters were compared to the simulation outcome.

3. Results and Discussion

In this section, we discussed the simulation and measurement results of both the microstrip antenna array without and with metamaterial. Afterward, we compared the simulation and measurement results between the microstrip antenna array without and with metamaterial. Then, an analysis of the performance of each antenna array was performed. The parameters were return loss, VSWR, bandwidth, gain, and radiation pattern.

The final design of the antenna array through CST Studio Suite is presented in Fig. 1, meanwhile, the dimension of this antenna array is shown in Table 1. The simulation results of return loss and gain for a 2×2 microstrip patch antenna array without metamaterial are shown in Figs. 2 and 3, respectively. The design of the metamaterial in this study was based on literature [16], presented in Fig. 4, while the dimension of the metamaterial is shown in Table 2. In the merging of metamaterial and antenna design, the metamaterial was placed on the antenna. Then, we simulated the antenna with the metamaterial as used in the last design. This metamaterial element is made into 5×3. Figure 5 is a picture of the antenna with the metamaterial in the simulation using the CST Studio Suite.

With the distance between the antenna and metamaterial, we investigated the optimal range. The antenna and metamaterial were separated by air. Variation in the distance is done to produce the best return loss. In the simulation, changes in the range were 5, 10, and 15 mm. Based on the simulation results, the optimum distance between the antenna and the metamaterial was 10 mm with a return loss at a specific value, which is shown in Fig. 6.

Table 1. The antenna final dimension as the simulation result.

Parameter	Dimension (mm)
a	2.9
b	17.1
c	9.97
d	37
e	6
f	2.8
g	29
h	41
i	116.46
j	120

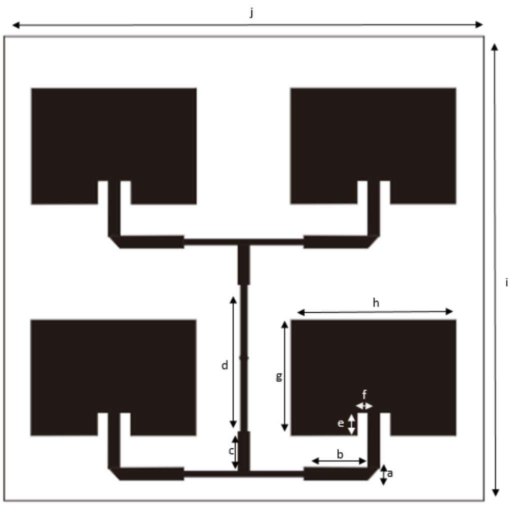


Fig. 1. The final design of microstrip antenna array.

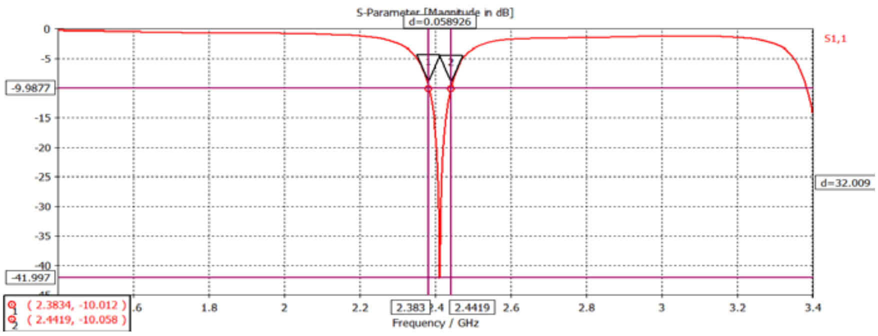


Fig. 2. The simulation result of the return loss of 2×2 microstrip patch antenna array without metamaterial.

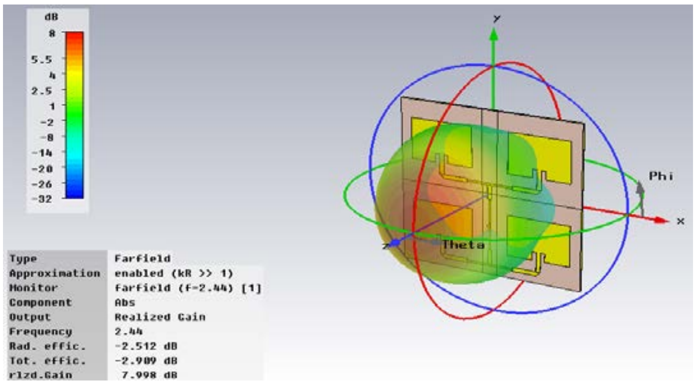


Fig. 3. The simulation result of the gain and radiation pattern of 2×2 microstrip patch antenna array without metamaterial.

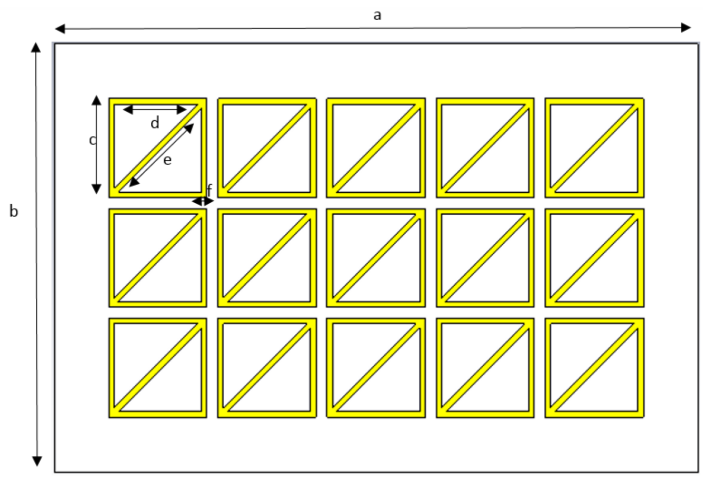


Fig. 4. The final design of metamaterial.

Table 2. The final dimension of the metamaterial as the simulation outcome.

Parameter	Dimension (mm)
a	118
b	78
c	18
d	15.25
e	21. 56676
f	2

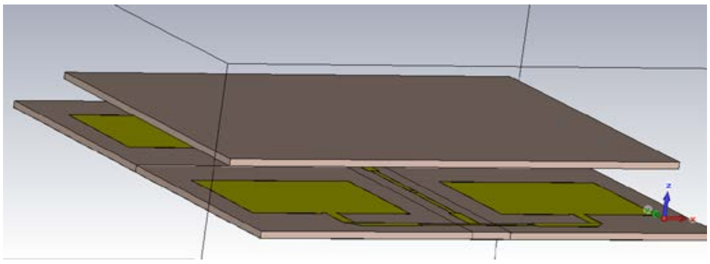


Fig. 5. The configuration between antenna array and metamaterial.

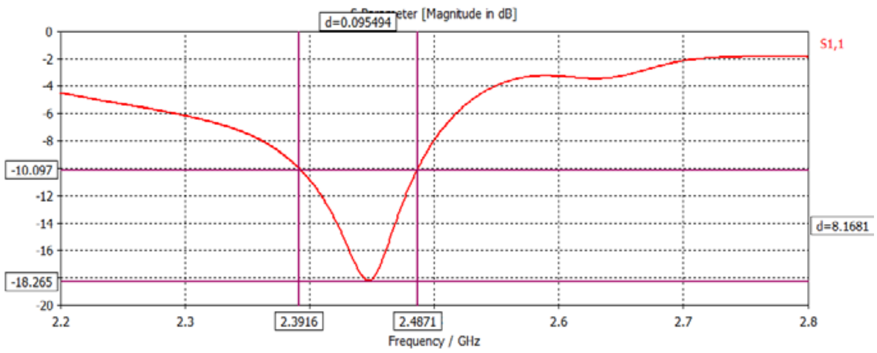
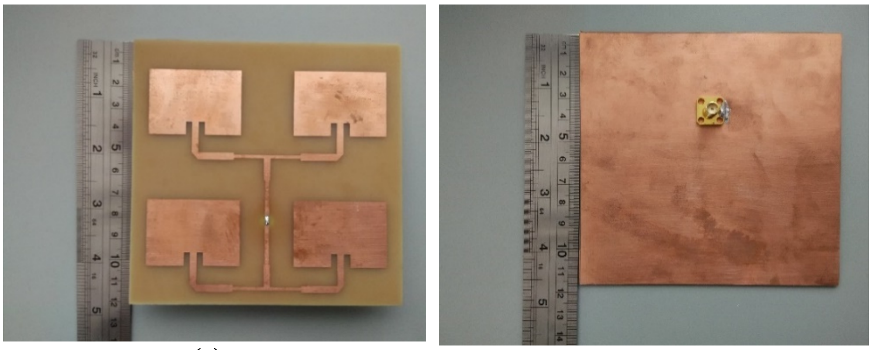


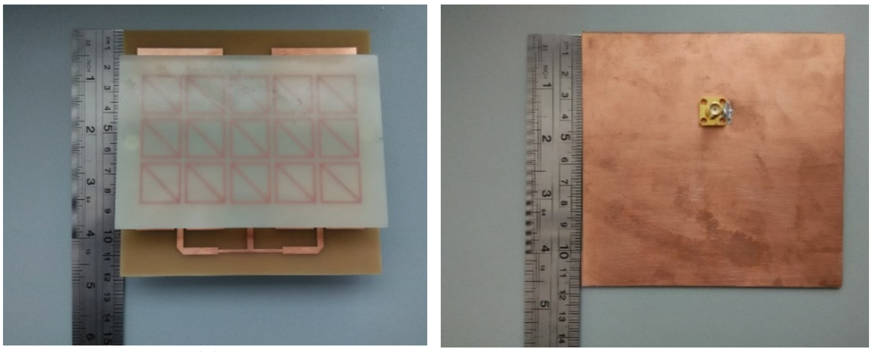
Fig. 6. The simulation result of the return loss with the distance between the antenna array and metamaterial is 10 mm.

According to Figs. 2 and 6, we found out that the bandwidth of the microstrip antenna array without and with metamaterial is 59 MHz and 95.5 MHz, respectively. Thus, there is an increment in the bandwidth around 62%, which this different from the antenna array before adding metamaterial. The manufacturing of the antenna was based on the simulation outcome through the CST Studio Suite. The antenna was produced in PCB (printed circuit board). The feeding method of the antenna implemented the feeding of the microstrip line. The results of the manufacturing of the antenna are presented in Figs. 7 and 8. Figure 7 shows the top view and bottom view of the antenna array without metamaterial. At the same time, we can see the top view and bottom view of the microstrip patch antenna array with metamaterial, as presented in Fig. 8.



(a) (b)

Fig. 7. The microstrip patch antenna array resulted from manufacturing (a) Top view (b) Bottom view.



(a) (b)

Fig. 8. The microstrip patch antenna array inserted by metamaterial resulted from manufacturing (a) Top view (b) Bottom view.

3.1. Return loss and bandwidth

Return loss is a measure of the portion of available power that is not delivered by a source to a load [19]. Figure 9 presents the comparison of return loss between the simulation and the measurement outcomes of the antenna. Based on the measurement results, the findings showed that at a frequency of 2.41 GHz, the return loss was -34 dB. Moreover, at the frequency range of between 2.361 and 2.436 GHz, the return loss was under -10 dB. Meanwhile, as we found on the simulation results, at a frequency of 2.4 GHz, the highest value of return loss was at -25.252 dB.

Additionally, at the frequency range of between 2.3834 and 2.4419 GHz, the return loss was less than -10 dB. There are differences between the simulation and the measurement results in the return loss. It is the effect of dielectric constant in the manufacturing process, which is insignificantly different from the simulation.

The antenna bandwidth is defined as "the frequencies range within which the antenna performance, regarding some characteristics, following predetermined standard." The bandwidth is shown as the frequencies range, on either side of a center frequency (usually the resonance frequency), where the antenna properties (such as pattern, radiation efficiency, polarization, input impedance, beam width, gain, beam direction, sidelobe level) are inside a suitable value at the center frequency [2].

For narrowband antennas like in this study, the bandwidth is a percentage of the frequency difference (higher minus lower) to the center frequency of the bandwidth. For instance, a 10% bandwidth demonstrated that the frequency range of proper operation was 10% of the bandwidth center frequency [2]. The bandwidth of the simulation outcome was 59 MHz (2.446%), and the bandwidth of measurement outcome was 75 MHz (3.193%). This bandwidth was slightly wider than that reported in literature Steer [20], reaching a value of 56 MHz.

Figure 10 discusses the comparison of the return loss between the simulation and measurement results of the antenna array inserted by metamaterial. As we found in the measurement results, the return loss at the frequency of 2.44 GHz is -27.294 dB. Moreover, at the frequency range of between 2.380 and 2.488 GHz, the return loss was lower than -10 dB and the bandwidth was 108 MHz. Meanwhile, based on the simulation results, the return loss was -17.7477 dB. Additionally, at the frequency range of between 2.3916 and 2.4871 GHz, the return loss was less than -10 dB and the bandwidth was 95.5 MHz. There is a dissimilarity in the return loss and bandwidth between the results of simulation and measurement. It is the effect of dielectric constant value in the manufacturing process slightly different from the simulation.

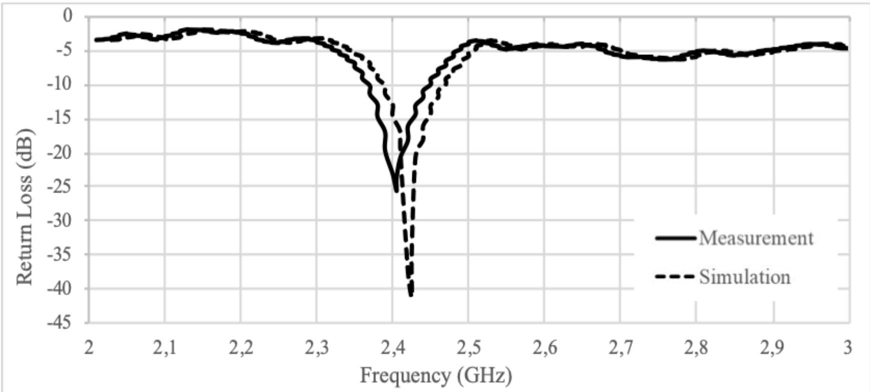


Fig. 9. The return loss comparison between simulation and measurement results of the antenna array.

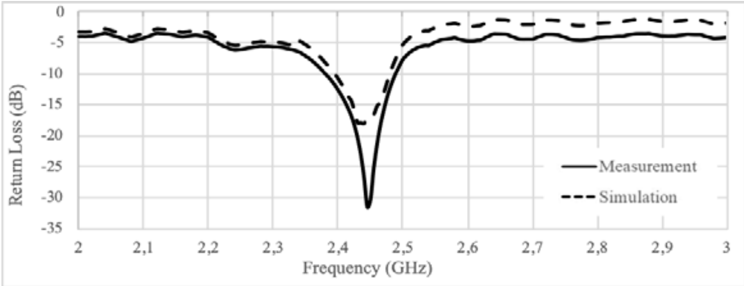


Fig. 10. The comparison of the return loss between the simulation and measurement results of the antenna array inserted by metamaterial.

3.2. VSWR

The power reflected back to the transmitter influences the performance of the RF transmitter [2, 19]. Standing waves were determined by the proportion of the maximum and minimum voltage amplitudes of the wave in the transmission line, so-called VSWR (Voltage Standing Wave Ratio) [21]. Actually, between VSWR and return loss are interrelated. If the return loss is functional, the VSWR is excellent, and vice versa. The correlation between return loss and VSWR is explained in literature [2, 19]. Figure 11 enlightens the VSWR comparison between the simulation and the measurement results of the antenna arrays. We found in the simulation outcomes that at the frequency of 2.4 GHz, the VSWR is 1.2.

Moreover, at the frequency range of between 2.385 and 2.442 GHz, the VSWR of the antenna array reached near 1. Meanwhile, based on the results of measurement, at the frequency of 2.4 GHz, the VSWR was 1.1. Additionally, at the frequency range of between 2.395 and 2.452 GHz, the VSWR was less than 2. Referring to the findings, the frequency ranges of VSWR increased 10 MHz to the lower frequency. It indicated that the difference of dielectric constant between the simulation and measurement process influenced the VSWR of the antenna. Since in the simulation process, the dielectric constant was 4.3, whereas in the manufacturing process, it is 4.35.

Figure 12 explains the VSWR comparison between simulation and measurement results of the antenna array inserted by metamaterial. According to the simulation outcomes, at the frequency of 2.44 GHz, the VSWR was 1.3. Additionally, at the frequency range of between 2.391 and 2.487 GHz, the VSWR of the antenna array inserted by metamaterial was less than 2. Meanwhile, we found according to the measurement results, at the frequency of 2.44 GHz, the VSWR was 1.091. Moreover, at the frequency range of 2.380-2.488 GHz, the VSWR of the antenna array inserted by metamaterial was less than 2. Referring to the outcomes can be concluded that the VSWR of the measurement result was better than that in the simulation results. The prediction of a standing wave reflected in the simulation process is similar to the realistic situation after the antenna was implemented. Moreover, the VSWR of the antenna designed has qualified the initial design, it was < 2, and the reflected wave resulted in the process is in a good position and acceptable scope.

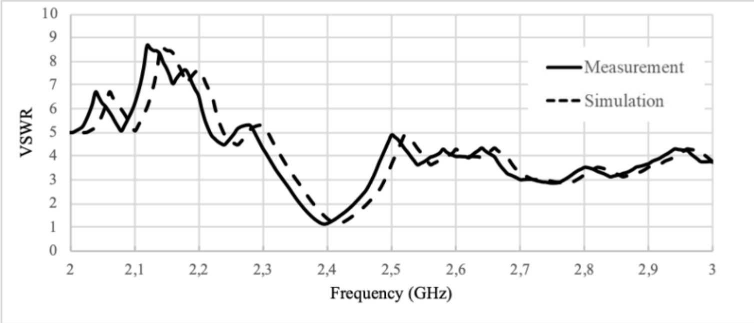


Fig. 11. The VSWR comparison between the simulation and measurement results of the antenna array.

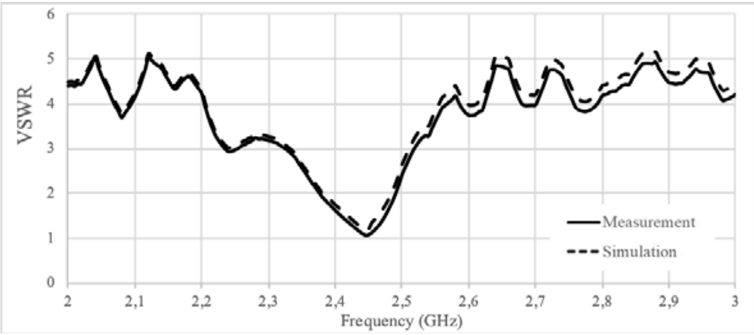


Fig. 12. The VSWR comparison between simulation and measurement result of the antenna array inserted by metamaterial.

3.3. Antenna gain

The antenna gain (in a provided direction) is defined as the proportion of the strength, in a provided direction, to the radiation strength that would be acquired if the power received by the antenna were radiated isotopically [2]. The gain achieved through simulation and manufacturing process is different. The gain of manufacturing is slightly higher than the gain of simulation. It is the consequence of an unstable received signal in the measurement [22]. Moreover, the existence of the interference signal in the measurement area was caused the measurement results different from simulation results. However, the insertion of metamaterial in the antenna array enhanced the antenna gain. The result of the gain measurement is shown in Table 3.

Table 3 - The result of the gain measurement.

Types of antenna	Frequency (MHz)	Simulation	Measurement
Antenna array	2400	7.998 dB	8.04 dBi
Antenna array inserted by Metamaterial	2440	8.498 dB	9.11 dBi

3.4. Radiation pattern

The comparison between the results of simulation and measurement in the antenna radiation pattern of the azimuth plane is presented in Figs. 13 and 14. Generally, the antenna radiation pattern resulted from the simulation and the measurement has similarity [23]. In the simulation process, it resembled the perfect system because of the ideal space assumption. In the measurement process, although it is untidy, the system is almost complete. It was caused by the carefulness factor in setting the antenna and the angle dimension in the measurement process.

The antenna radiation pattern comparison between the simulation and measurement outcomes in the elevation plane is illustrated in Figs. 15 and 16. Generally, the antenna radiation patterns resulted from the simulation and the measurement process are identical. However, it moves faintly. It is the effect of inaccurate setting between antennas and the existence of reflected wave, which is caused by the objects in the space in the measurement process. The insertion of metamaterial has little influence on the antenna radiation pattern. In the before and after inserting the metamaterial, the antenna array still has directional radiation pattern.

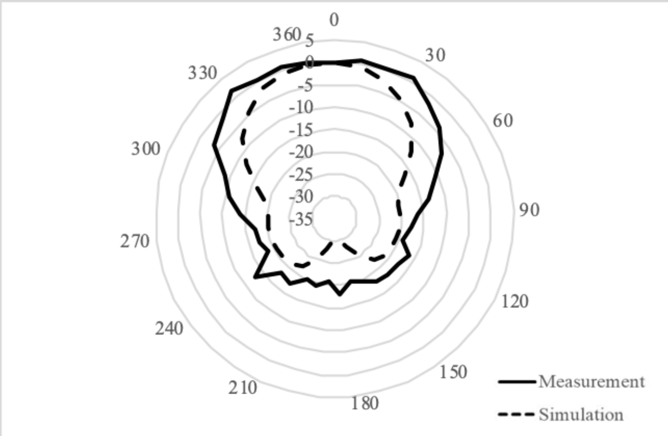


Fig. 13. The comparison between the microstrip patch antenna array radiation pattern in the azimuth plane resulted from simulation and measurement.

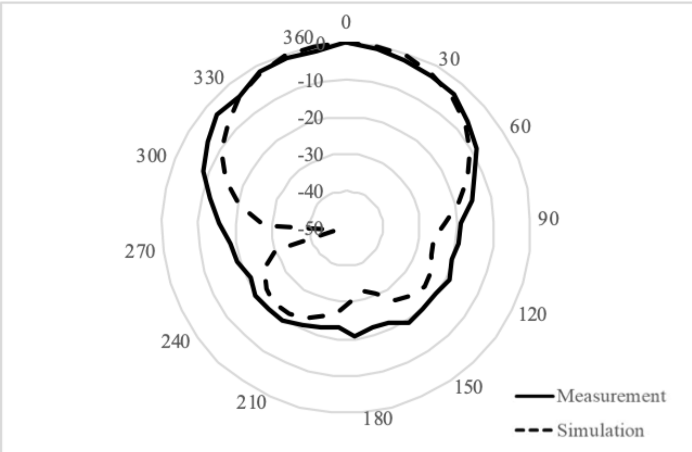


Fig. 14. The comparison between the radiation pattern of the microstrip patch antenna array located in the elevation plane resulted from simulation and measurement.

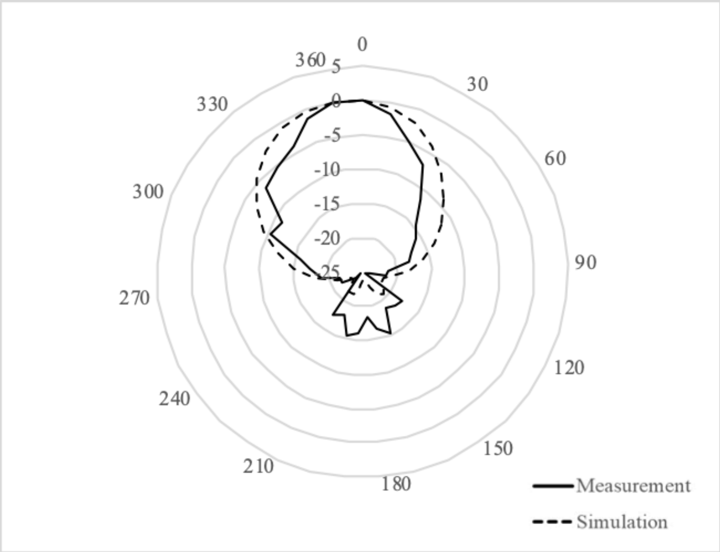


Fig. 15. The comparison between the radiation pattern of the microstrip patch antenna array inserted by metamaterial in the azimuth plane resulted from simulation and measurement.

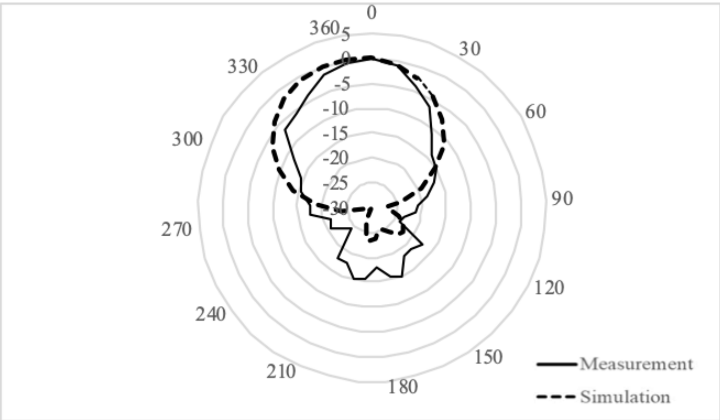


Fig. 16. The comparison between the radiation pattern of the microstrip patch antenna array situated in the elevation plane resulted from simulation and measurement

4. Conclusions

In this study, the designing and manufacturing of rectangular microstrip antenna array were conducted for Wi-Fi application at a frequency of 2.4 GHz in dimension 106.4 mm × 1.6 mm. We found on the measurement results, the antenna has the frequency range of between 2.361 and 2.436 GHz with the return loss less than -10 dB, the VSWR of less than 2, the bandwidth of 75 MHz, and the gain of 8.04 dBi at a frequency of microstrip antenna measurement. Moreover, the antenna had a directional radiation pattern. Besides, the microstrip antenna array was inserted by metamaterial between elements having distance 10 mm, in which each of them is to improve the antenna array bandwidth and gain. The metamaterial had composition 3x5 in dimension 108 mm × 77 mm × 1.6 mm. Referring to the results of measurement through antenna array inserted by metamaterial, the findings indicate that the antenna is active at the frequency range of between 2.380 and 2.488 GHz with a return loss of less than -10 dB, VSWR of less than 2, bandwidth of 108 MHz and the gain of 9.11 dBi at a frequency of microstrip antenna measurement. The microstrip patch antenna array inserted by metamaterial enhances the bandwidth of 44% and the gain of 1 dBi.

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