Parametric Study of Rectangular Microstrip Array Antenna at 2.2 GH

Agus Dwi Santoso[1](✉), Ferry B. Cahyono[1], H. Bambang Bagus[2], and Muh Harliman Saleh[1]

[1] Politeknik Pelayaran Surabaya, Surabaya, Indonesia
agusbp2ipsby@gmail.com
[2] Politeknik Penerbangan Surabaya, Surabaya, Indonesia

Abstract. This study aims to analyze antenna characteristics at a frequency of 2.2 GHz, including return loss, VSWR, gain, bandwidth, surface current, and radiation pattern values. Antenna characteristics were designed using simulations made with FR-4 substrates with dielectric constant $\varepsilon_r = 4.3$ and substrate thickness $(h) = 1.6$ mm and copper patches with patch thickness of 0.035 mm. Single antennas are created first to get the desired parameters and then continue the creation of antenna arrays 1×2 and 1×4, and 1×8. Feeding antenna arrays arrange using the Wilkinson power divider technique on the side of the patch. Array antenna planning aims to increase the antenna gain value as well as the antenna directivity value. The simulation results obtained consecutive values ranging from single antennas, 1×2 antenna arrays, and 1×4 and 1×8 antenna arrays, including return loss of −22 dB, 25.9 dB, −15.3 dB, and −20.2 dB. VSWR value is one each. 1, 1.1, 1.4 and 1.2. The gain values are 3.38 dB, 5.52 dB, 7.84 dB, and 9,64, respectively. Antenna bandwidth is obtained at 99.4 MHz, 110 MHz, 180 MHz, and 170 MHz. Angular widths are obtained at 99.4°, 92.2°, 80.2° and $74.\ 1^\circ$.

Keywords: Microstrip antenna · rectangular · parametric study · 1 × 2 array · 1 × 4 array · 1 × 8 array

1 Introduction

The development of microstrip antennas is very interesting for researchers because of its ease in designing and carrying out the manufacturing process [1–3]. Microstrip antennas have a basic shape on their patches that are rectangular [4, 5], circular [1, 6–8] and triangular [9–11]. Microstrip antenna technology has been applied to telecommunications and surveillance [12–14] equipment [15].

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Microstrip antennas have narrow bandwidth weaknesses, and low gain characteristics [16–18] and are better applied at high frequencies. Lack of equipment in measurements such as VNA, high-frequency spectrum analyzer, high-frequency counter frequency, and a room free from electromagnetic wave current from various electronic equipment. In its development, the telecommunications and surveillance sector isexpected to be able to adapt to the needs and developments of technology 4.0.

Parametric studies have been conducted in several previous studies, themed U-shaped split ring resonator (SRR) structure effect on the ultra-wide-band (UWB) monopole [19] a textile patch antenna designed for WBAN applications at 2.45 GHz ISM band [20], A wideband circularly polarized (CP) L-slot antenna single fed by L-shaped feed line is designed [21], a combination of dual U-slot and multiple layers is used to get multiple bands and wide bandwidth [22].

The microstrip antenna design can affect the result of transmitting a signal wave. This affects the results, especially in the number of patches used in a series of antennas. This patch serves to radiate electromagnetic waves into the air, located at the top of the entire antenna system. Contributions to this study will discuss the effect of many patches on return loss, VSWR, bandwidth, gain, and angular width. For patch shapes used, use rectangular shapes. Antenna systems are evaluated using single patch antenna designs, 1 × 2.1 × 4, and 1 × 8 antenna arrays.

2 Method

Before doing the design first the antenna dimensions are calculated using the formula below in determining the length of Peach antenna part. The working specifications used for the simulated rectangular microstrip antenna prototype are (Table 1).

Microstrip patch antennas are designed and simulated with a frequency specification of 2.2 GHz. The substrate used in this microstrip antenna is FR-4 with a permeability value of 4.3, while ground planes and patches used are coopers.

Table 1. Antenna Specifications

Antenna Specifications	Description
Working Frequency	2.2 GHz
Terminal Impedance	50 Ω
VSWR	≤2
Polarization	Vertical
Gain	≥2 dB
Return Loss	≤−10 dB
Patch Shape	Rectangular

For the calculation of the formula in determining the length of each section, use the formula as follows [23]:

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

The formula (1) above can be known as follows [23]:

W = Patch length
c = Propagation of waves in the air $\left(3 \times 10^8 \frac{m}{s}\right)$
f_0 = Resonant frequency
ε_r = Permeability of materials/types of materials.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\sqrt[2]{1 + \frac{12h}{W}}} \tag{2}$$

The formula (2) above can be known as follows [23]:

ε_{reff} = Effective Permeability
ε_r = Permeability of materials/types of materials
h = Substrate thickness
W = Patch length.

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3}$$

The formula (3) above can be known as follows [23]:

L_{eff} = Effective width of the patch
f_0 = Resonant frequency
ε_{reff} = Effective Permeability.

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

The formula (4) above can be known as follows [23]:

ΔL = Patch width change
h = Substrate thickness
W = Patch width
ε_{reff} = Effective Permeability.

$$L = L_{eff} - 2\Delta L \tag{5}$$

The formula (5) above can be known as follows [24]:

ΔL = Patch width change
L_{eff} = Effective length of patch.

$$W_f = \frac{2h}{\pi}\left\{B - 1 - ln\,ln(2B - 1) + \left[ln\,ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} \tag{6}$$

$$B = \frac{6\pi^2}{Z_0\sqrt{\varepsilon_r}}$$

The formula (6) above can be known as follows.

W_f = Feeding width
B = Impedance Permeability
Z_0 = Desired impedance value
h = Substrate thickness
ε_r = Permeability of materials/types of materials.

The above formula is used to calculate the antenna patch with the insert feeding system. Performing array antenna calculations required Branching techniques using the following formula

$$Z = Z_0\sqrt{N} \tag{7}$$

The formula (7) above can be known as follows [25]:

Z = Branching Impedance Output
Z_0 = Input impedance
N = Number of branches.

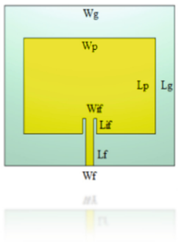
$$d = \frac{\lambda}{2} \tag{8}$$

The formula (8) above can be known as follows [25]:

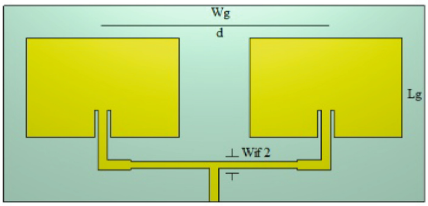
d = distance between patches
λ = Resonant frequency wavelength.

3 Antenna Design

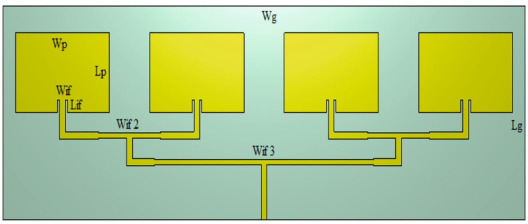
After the calculation, the results of the antenna calculation will be applied using the software. First, the antenna will be designed single using rectangular-shaped patches and an insert feeding system. The design of the single antenna is seen in Fig. 1a. After the single antenna design is carried out, the second design is carried out, namely the 1 × 2 antenna, using the calculation of the single antenna patch used. The antenna consisting of 2 patches is put together using a branched feeding system with the Wilkinson power divider technique with a combination of two impedance values of 50-Ω and 70.7 ohms.



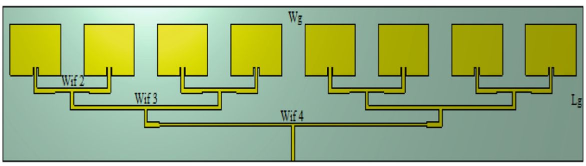
a Single Antenna



b Antenna array 1x2



c Antenna array 1x4



d Antenna array 1x8

Fig. 1. Single and array antenna 1 × 2, 1 × 4 and 1 × 8 microstrip antenna design

Table 2. Microstrip antenna calculation results

Part	Symbol	Specifications
Patch width	Lp	48 mm
Patch Length	Wp	31.2 mm
Feeding length	Lf	15.4 mm
Feeding Width	Wp	3 mm
Insert Feeding Length	Lif	10 mm
Insert Feeding Width	Wif	1 mm
Patch Length 1/2 lambda	d	70 mm
Ground width	Lg	52 mm
Ground length	Wg	62 mm
Substrate width	Ls	52 mm
Substrate length	Ws	62 mm
Insert Feeding Width 2	Wif 2	32.2 mm
Insert Feeding Length 2	Lift 2	2 mm
Insert Feeding Width 3	Wif 3	114.2 mm
Insert Feeding Length 3	Lift 3	2 mm
Insert Feeding Width 4	Wif 4	254.2 mm
Insert Feeding Length 4	Lift 4	2 mm

Figure 1c shows the design drawing of the 1 × 4 antenna array design. This design is a combination of the single antenna design and the 1 × 2 antenna array, using the Wilkinson power divider technique [26]. Antenna has three branches consisting of 2. The branches of the antenna array are 1 × 2, then the two branches are connected to one main feeding to get the power supply.

The distance between the patches is made by calculating half lambda part the closest distance to minimize interference. Figure 1d is the final drawing of this design which is the design of the 1 × 8 antenna array. This antenna consists of 8 patches and has seven feeding branches.

To get good antenna equipment performance and according to parameters, the results of simulations carried out sometimes need to be done optimization techniques on the antenna. This is because several antenna parts are not done directly, such as insert feeding and the feeding antenna length. Optimization is done by changing the shape of the size of the patch and the insert feeding until it meets the specification criteria of the antenna in general. The results of optimization result in a new antenna size (Table 3).

Table 3. Single antenna evaluation results, 1x2 array, 1x4 and 1x8 array antenna

Antenna Parameter	Single Patch	Array 1 × 2	Array 1 × 4	Array 1 × 8
Return Loss	−22 dB	−25.9 dB	−15.3 dB	−20.2 dB
VSWR	1.1	1.1	1.4	1.2
Bandwidth	90 MHz	110 MHz	180 MHz	170 MHz
Gain	3.38 dB	5.52 dB	7.84 dB	9.64 dB
Angular Width	99.40	92.20	80.20	74.10

4 Result and Discussion

In this discussion, we will evaluate the comparison of return loss, VSWR, gain, and angular width. These parameters are essential in designing the antenna. Return Loss is one parameter used to determine how much power is lost on the load and does not return as a reflection [27]. Return loss has an origin that synergizes with VSWR, which occurs due to a mixture between the transmitted wave and the reflected wave that is equally Determined by the matching between the transmitter device and the antenna.

VSWR is the ratio of comparison between the coming wave and the reflecting wave where the two waves form a standing wave [27]. A standing wave is a combination of reflection and interference, namely, a reflecting wave interfering with the coming wave so that the phase of the wave is disturbed by the reflecting wave that causing the wave to come is damaged. The higher the VSWR value means that the antenna's performance is getting better, or the waves that interact the greater.

Gain is an antenna character associated with its ability to direct its signal radiation reception from a certain direction [27]. Gain is not a quantity that can be measured in physical units, such as watts, ohms, or others, but rather a form of comparison. Therefore, the unit used for gain is decibel.

Antenna Radiation Pattern is a depiction of radiation related to the strength of radio waves emitted by the antenna or the level of reception of signals received by the antenna on the antenna. Different angles [27]. In general, this Radiation Pattern is described in the form of a 3-dimensional plot. This 3-dimensional antenna radiation pattern is formed by two radiation patterns, namely elevation patterns and azimuth patterns. The shape of the radiation pattern is the Omnidirectional Pattern pattern, which is a radiation pattern that is all the same in one field of radiation, and the Directive Pattern that forms a narrow beam ball with high radiation..In the discussion below will be discussed the parameters that have been described above.

4.1 Return Loss

The return loss results to the four antennas are listed in the image below. A solid line shows a graph of a single antenna. The dashed line indicates the value of the 1 × 2 antenna array, the dotted line indicates the value of the 1 × 4 array antenna, and the dash-dot line indicates the return loss value of the 1 × 8 array antenna. The frequency value on the x-axis starts from 2 GHz to 2.4 GHz, then the value of the y-axis is the value of magnitude return loss with a value of 0 dB up to -50 d B.

In Fig. 2, there is a triangle placed at a frequency value of 2.2 GHz. As seen in triangle one, the return loss value indicates −22 dB; in triangle two, the return loss value is −26.3 dB; in triangle three, the return loss value is -15.3 dB. It can be seen that the maximum range value is not located at the frequency of 2.2 GHz. The single antenna has a frequency of 2,207 and has a return loss of −25.4 dB. While the 1 × 8 antenna array has a return loss of −45 dB at a frequency of 2.14 GHz, the 1 × 2 and 1 × 4 antenna arrays show no significant difference.

4.2 Vswr

Figure 3 shows the VSWR graph against the antenna working frequency of 2.2 GHz. A solid graph shows the value of a single antenna. Dashed graph showing the antenna array value of 1 × 2. Dot graph shows the antenna value of the 1 × 4 array, and the dash-dot graph shows the value of the 1 × 8 array antenna. There is a correlation between the relationship between return loss and VSWR value. If the return loss value is below 10 dB, then the VSWR value is below 2.

A triangle as a marker shows the VSWR value of the simulation result, obtained with consecutive values of 1.2, 1. 11.1. 4, and 1.2. This VSWR value correlates with the return loss value in Fig. 2. The higher the return loss value, the lower the VSWR value. If VSWR = 1, then all power will be emitted through the antenna.

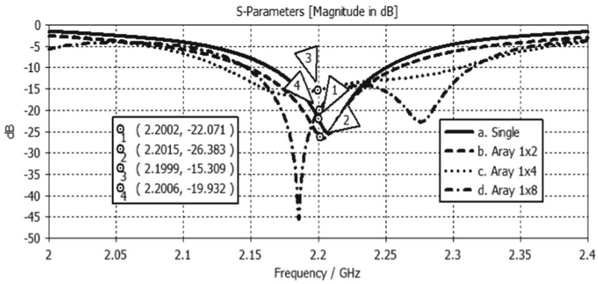


Fig. 2. Single antenna returnloss value and 1 × 2,1 × 4, and 1 × 8 antenna array

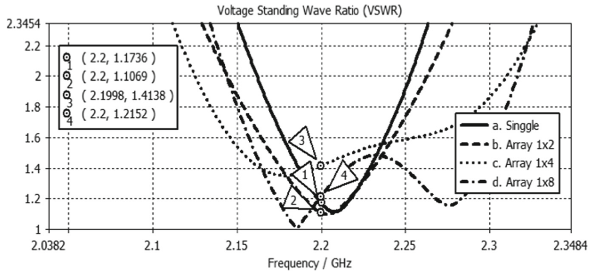


Fig. 3. VSWR value of single antenna, 1 × 2,1 × 4, and 1 × 8 array antenna

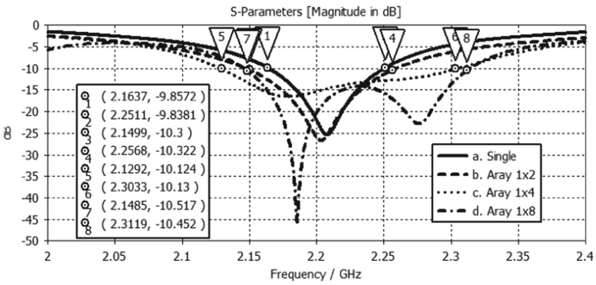


Fig. 4. Single antenna bandwidth values, 1 × 2.1 × 4 and 1 × 8 array antennas

4.3 Bandwidth

Figure 4 shows the frequency value against the antenna's magnitude return loss value. The bandwidth value is obtained by taking a working frequency greater than 10 dB. The chart value indicates that the solid chart is for a single antenna. Dashed graphics for 1 × 2 array antennas. Grafik dot shows antenna 1 × 4, and the dash-dot graph shows antenna array value of 1 × 8.

Triangular marker in Fig. 4. The antenna shows a working frequency below 10 dB. After marking each graph obtained bandwidth values of 90 MHz, 110 MHz, 180 MHz, and 170 MHz, respectively. There is a shift in value in this antenna design in each design. The smallest bandwidth value is 90 MHz, and the largest is 180 MHz.

4.4 Gain

Figure 5 shows the gain value of each antenna, and the solid chart shows the gain value of the single antenna. Dashes graph showing the antenna array value of 1 × 2. Grafik dot indicates the value of the 1 × 4 array, and the dash-dot graph shows the value of the 1 × 8 array antenna gain. Gain relates to the value of the antenna patch created into the antenna array design. In the feeding array series, the more number of antenna patches, the higher the gain magnitude.

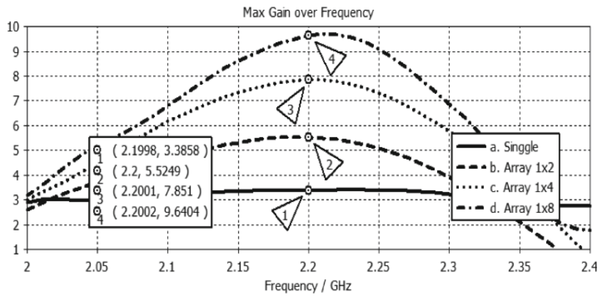


Fig. 5. Single antenna gain value, 1 × 2, 1 × 4, and 1 × 8 array antenna

In Fig. 5, four triangles indicate the gain value in each antenna design with a value of 3.38 dB, 5.52 dB, 7.81, and 9.64 dB, respectively, so that it shows one proof that the more the number of arrays, the greater the value of the antenna gain.

4.5 Radiation Pattern

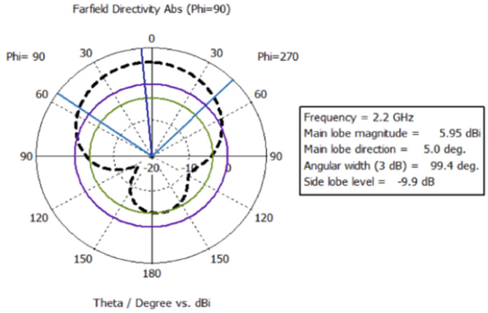
Figure 6 are the results of simulations of radiation patterns. The image shows the main lobe magnitude, main lob direction, angular width (3 dB), and sidelobe level. The main lobe magnitude is indicated by a broken dash that intersects with the main lobe direction located in the middle. The inner circle indicates the value of isotropic radiation, and the center circle is a reference to the position of the circle. The mark of the slice of the circle forming the pizza slice indicates the angular width value, and the centerline between the slices indicates the value of the main lobe direction.

The value of the radiation pattern of each antenna can be seen in Figs. 6a, 6b and 6c. in this discussion, highlighted angular width values in a row 99.4 0.92. 2 0.80.2 0, and 74.10. The value indicates the effect of the patch on the linear arrangement of the array affects the reactivity of the antenna.

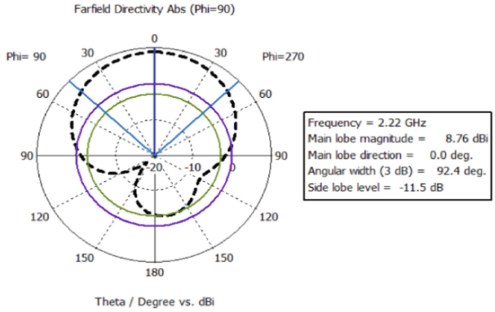
4.6 Current Analysis

Figure 7 is the result of the simulation surface current. The current moves through the feeding, then pass through the patch and spreads to the ground. The largest current is found in most antenna patches and on the side of the insert feeding antenna. Next to the current distribution, there is a graph of the rod with here maximum current of 31.5 A/m.

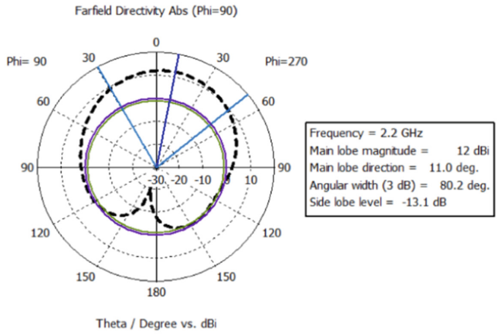
In Fig. 7, there is only a picture of the current distribution of the 1 × 2 antenna array. For single antennas, 1 × 4 array antennas, and 1 × 8 array antennas, the current flow is almost the same, distinguishing only at maximum current values—passing through the antenna. The maximum current values of the four antennas are 44.6 A/m,31.5 A/m,27 A/m, and 25.5 A/m. The current magnitude indicates the highest indigo single antenna and the lowest value of the antenna array 1 × 8. Following Kirchhoff's Law, I state that the amount of current entering a branch equals the amount of outflow of the branch [28].



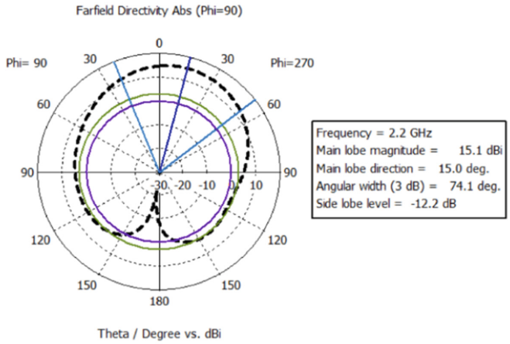
a single antenna



b antenna array 1x2



c Antenna array 1x4



d antenna array 1x8

Fig. 6. Single antenna radiation pattern values, 1 × 2.1 × 4 and 1 × 8 array antennas

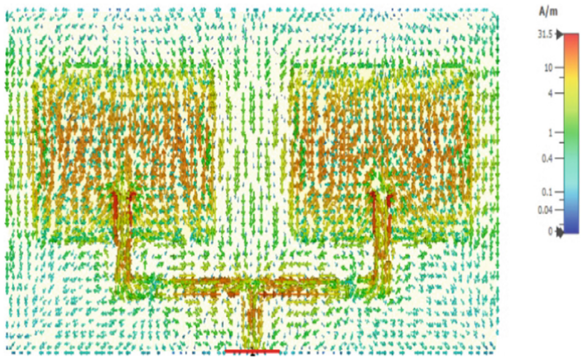


Fig. 7. Current distribution on 1 × 2 array antennas

5 Conclusion

This paper successfully designed a rectangular patch-shaped microstrip antenna that works at a frequency of 2.2. The frequency lies in the S-band. This study uses four antenna designs: a single patch, 1 × 2 array, 1 × 4 array, and 1 × 8 array. The results of the simulation evaluation have obtained the results shown in Table 2.

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