Design of Microstrip Planar Array Antenna for Wireless Sensor Device Charging at Frequency 2300 MHz

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Abstract. In this paper, several models of planar array microstrip antennas are used for energy harvesting. This antenna is used to receive electromagnetic waves emitted by RF (Radio Frequency) sources and turn them into an electric wave. The design of planar array microstrip antennas will use a mathematical approach. For Antenna Design using a CST simulation application. The results of the design on CST will be realized in FR4 with a value of εr = 4.5 and h = 1.6 mm. The planar array microstrip antenna model designed is 1x1, 2x2, and 4x4 models. From the simulation results the three antennas are designed to work at a frequency of 2.3 GHz with a return loss value of <-10 dB and VSWR <2. The antenna realized for planar array 1x1 works at a frequency of 2.3 GHz, return loss -15.4 dB, VSWR 1.39, directional radiation pattern, elliptical polarization, gain 3.05 dB, and bandwidth 68 MHz (2,296-2,364 MHz). For 2x2 planar array antennas, this antenna works at a frequency of 2.3 GHz, return loss -17, 6 dB, 1.28 VSWR, directional radiation pattern, elliptical polarization, 7.25 dB gain and 71 MHz bandwidth (2,298-2,369 MHz). For a 4x4 planar array antenna, this antenna works at a frequency of 2.32 GHz, return loss -17.1 dB, VSWR 1.34, directional radiation pattern, elliptical polarization, gain 13.05 dB, and bandwidth of 80 MHz (2.322-2.402 MHz). Of the three antennas, a 4x4 planar array antenna is the most optimal antenna for wireless sensor device charging. The antenna gain affects the system output, the greater the antenna gain, the better the system output.

Keywords: Radio frequency, Energy Harvesting, antenna, planar array, Gain

1. Introduction

Thousands of wireless devices are now connected using wireless sensing applications. As the number of users of wireless devices increases, the energy demand for charging batteries, especially in hard-to-reach areas, will certainly increase. Currently, widely used energy sources are still limited to solar, wind, and thermal energy, but there is another abundant and untapped energy, namely electromagnetic radiation [1][2]. One of these radio energies comes from the BTS (Base Transceiver Station), Access Point (Wi-Fi), or ISM bands in the frequency range from 3 Hz to 300 GHz. If we can harness this energy properly, we will have an alternative energy source that is available anytime and anywhere. To obtain the alternative energy mentioned above, it is necessary to carry

M. U. H. Al Rasyid and M. R. Mufid (eds.), *Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023)*, Advances in Engineering Research 230,
https://doi.org/10.2991/978-94-6463-364-1_46

out energy harvesting techniques, known as energy harvesting. Energy harvesting from RF signals is meant for extracting energy from its surroundings and then converting it into some usable form. The voltage obtained from the RF energy source will be of little value because the characteristics of the RF power itself when detected are also very small along with the increase in transmission losses toward transmit distance [3]. System support devices RF energy harvesting is a power supply consisting of an antenna, rectifier, and boost converter. An antenna is an important part of building an RF power harvesting system. The antenna has the role of changing the unmanaged electromagnetic waves into guided electromagnetic waves, then can be forwarded to the rectifier circuit to produce DC voltage as an energy source. The use of antennas for mobile devices requires a small and portable dimension antenna known as a low-profile antenna. One type of low-profile antenna is a microstrip antenna that is easily integrated with other devices [4][5]. Many studies have discussed the design of microstrip antennas for this Harvesting RF application at various frequencies [6]-[9]. Priyo et al [8] designed a multiband antenna at a frequency of 900 MHz and 1800 MHz, and Cheril et al [9] designed a circular microstrip antenna with high gain at a frequency of 5.8 GHz. These antennas are designed for the needs of several different applications. In this research, a planar microstrip antenna has been successfully designed at a frequency of 2.3 GHz for wireless sensor device charging applications. There will be 3 models of microstrip antennas with a model, namely planar array with its configuration, namely 1 element, 4 elements, and 16 elements. The design and simulation of planar array microstrip antennas was carried out on the CST Microwave Studio Software.

The design antenna planar microstrip at a frequency of 2300 MHz for wireless device charging applications is the main topic of this paper. Section I explains the introduction. Section II focuses on antenna design and simulation. Discussion of measurement and result in Section III. This paper is concluded in Section IV.

2. Antenna Design And Simulation

2.1. Antenna Plannar Array 1 Element

The first design is a 1-element planar array antenna. This design consists of 1 square patch. After getting the antenna size through the next equation it is simulated on CST. This design check has fulfilled the characteristics of the designed antenna, the patch will be aligned or in the array according to the desired configuration. The description of this design can be seen in Figure 1.

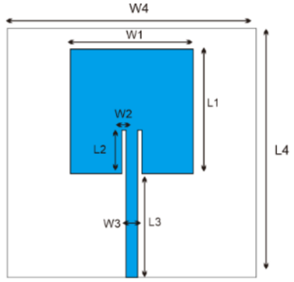


Fig. 1. Antenna design array 1 element square patch microstrip with planar technique

Table 1. Dimensions Of Antenna Array 1 Element Microstrip Patch Square With A Planar Array Technique

Parameter	Explanation	Value (mm)
W1	Patch Width	29.6
L1	Patch Length	29.6
W2	Slot Width	1
L2	Slot Length	10
W3	Impedance Width 50Ω	3
L3	Impedance Length 50Ω	25
W4	Substrate Width	60
L4	Substrate Length	60

Fig. 1. shows a simulation design of the dimensions of the calculation results that have been optimized. The results of the antenna array simulation of 1 square patch microstrip element obtained a work frequency value of 2.302 GHz with a return loss of -15.6 dB. The working frequency is fulfilled from the expected frequency of 2.3 GHz, while the resulting return loss also fulfills the expected value of <-10 dB and VSWR generated in the simulation of 1.5. The VSWR value produced is as expected, namely VSWR <2, while the radiation pattern produced is a directional radiation pattern with a gain of 1.64 dB.

2.2. Antenna Plannar Array 4 Elements

The next antenna model is a 2x2 planar array antenna. For distances between patches separated by distance as far as λ / 2. The rationing technique used is a microstrip line with impedance 50Ω and 70,7Ω. Antenna dimensions can be seen in Table 3, for antenna design can be seen in Figure 2.

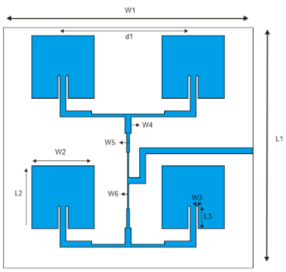


Fig. 2. Design of array antenna 4 patch square microstrip elements with planar array techniques

Table 2. Dimensions Of 4-Element Array Antennas Patch Microstrip Square With A Planar Array Technique

Parameter	Explanation	Value (mm)
W1	Substrate Width	125.2
L1	Substrate Length	115.2
W2	Patch Width	30.1
L2	Patch Length	30.1
W3	Slot Width	1
L3	Slot Length	10
W4	Impedance Width 50Ω	2.6
W5	Impedance Width 70.7 ohm	1.42
W6	Impedance Width 100 ohm	0.5
d1	Distance between Patch	62,5

The results of the antenna array simulation of 4 square patch microstrip elements obtained a working frequency value of 2.302 GHz with a return loss of -16.2 dB. The working frequency is fulfilled from the expected frequency of 2.3 GHz, while the resulting return loss also fulfills the expected value of <-10 dB and VSWR generated in the simulation of 1.35. The VSWR value produced is as expected, namely VSWR <2, while the radiation pattern produced is a directional radiation pattern with a gain of 7.29 dB.

2.3. Antenna Plannar Array 16 Elements

In this design, the rationing technique used is the microstrip line with impedance 50Ω, 70,7Ω, and 100 Ω. Antenna dimensions can be seen in Table 3, for antenna design can be seen in Figure 3.

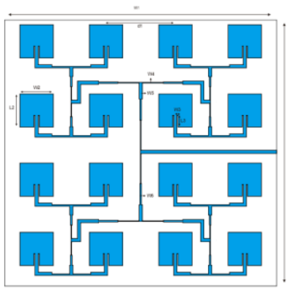


Fig. 3. Antenna array design 16 elements square patch microstrip with planar array techniques

Table 3. Dimensions Of Antenna Array 4 Elements Patch Microstrip Square With Planar Array Techniques

Parameter	Explanation	Value (mm)
W1	Substrate Width	242.9
L1	Substrate Length	255.9
W2	Patch Width	29.8
L2	Patch Length	29.8
W3	Slot Width	1
L3	Slot Length	10
W4	Impedance Width 50Ω	2.6
W5	Impedance Width 70.7 ohm	1.42
W6	Impedance Width 100 ohm	0.5
d1	Distance between Patch	62,5

The antenna array simulation results of 16 square patch microstrip elements obtained a working frequency value of 2.304 GHz with a return loss of -16.2 dB. The working frequency is fulfilled from the expected frequency of 2.3 GHz, while the resulting return loss also fulfills the expected value of <-10 dB and VSWR generated in the simulation of 1.36. The VSWR value produced is as expected, namely VSWR <2, while the radiation pattern produced is a directional radiation pattern with a gain of 12.4 dB.

3. Antenna Measurement And Result

Realization of the antenna is done in the PCB, namely FR4. The hardware results of the planar antenna array are shown in Figure 4-6.

Fig. 4. Realization of 1 element microstrip antenna array with a square patch planar array technique

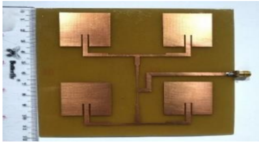


Fig. 5. Realization of 4 elements microstrip antenna array with a square patch planar array technique

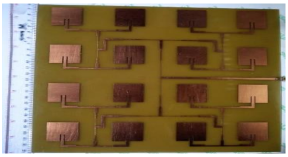


Fig. 6. Realization of 16 elements microstrip antenna array with a square patch planar array technique

3.1. Return Loss, VSWR, and Bandwidth

Simulation results and work frequency measurements for 1-element planar array antennas are shown in Figure 7.

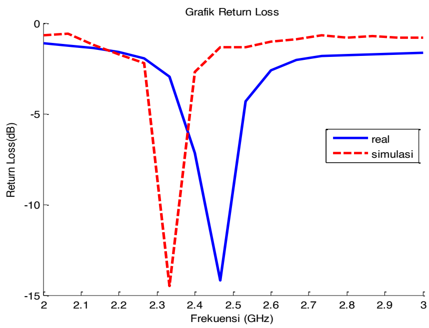


Fig. 7. Comparison of Simulation and Measurement Return loss of 1 element planar array antenna.

Based on simulation results and measurement data then compared as shown in Figure 8. Then it is obtained for the work frequency produced when the test experiences a shift that is equal to 0.125 GHz. When simulating a patch square microstrip antenna 1 element produces a working frequency value of 2.302 GHz while the results of testing a microstrip antenna 1 square patch element produces a working frequency value of 2.427 GHz. This happens because the difference in the value of εr is designed with a real value of εr. The value of εr is very important because it affects the size of the patch. The size of the patch affects the working frequency of the antenna. Therefore here the new design will be redesigned using the new εr value. The value of εr is sought by using the patch antenna length range. From the calculation results, the new value of εr is 4.15.

The simulation results and measurements of work frequency for planar arrays of 1 element array using the new εr are shown in Figure 9.

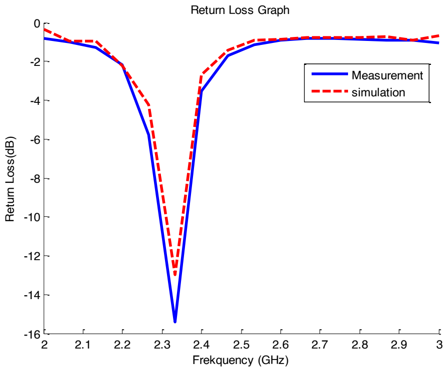


Fig. 8. Comparison of Simulations and Measurements Return loss of planar array 1 element array using new εr

The results for the new design have a return loss value of -15.32 with a working frequency of 2296 MHz. So this εr value will be used for the design of the next antenna.

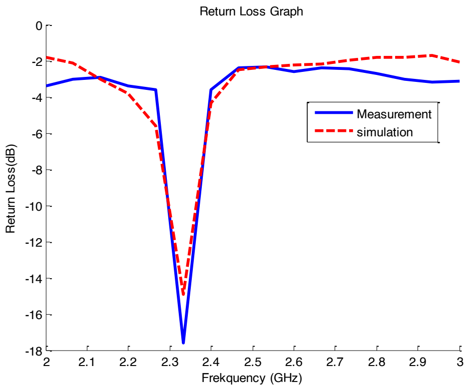


Fig. 9. Comparison of Simulation and Return Measurement Loss of 4 element planar array antenna

The simulation results and measurement data are then compared as shown in Figure 10. Obtained for the working frequency produced when testing and simulation have almost the same results. When simulating a patch square microstrip 4-element antenna, it produces a working frequency of 2.302 GHz while the microstrip antenna 4-element patch square test results in a working frequency value of 2.28 GHz.

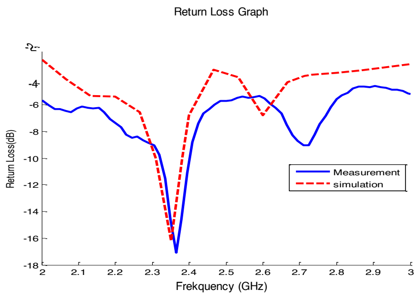


Fig. 10. Comparison of Simulation and Return Measurement of 16-element planar array antenna

The simulation results and measurement data, it is then compared as shown in Figure 10. Then it is obtained for the working frequency produced when testing and simulation have different results. To simulate a patch square microstrip antenna 16 elements produce a working frequency of 2302 MHz while the measurement produces a working frequency of 2322 MHz so that a shift of 20 MHz occurs to the right. This is due to the incorrect distance between patches and repetitive connector changes.

Testing the working frequency of the three antennas has been done, from the results of this measurement can be known several parameters such as return loss, VSWR, and bandwidth. A comparison of the performance of the three antennas and the comparison between the measurement results and simulations is shown in Table 4.

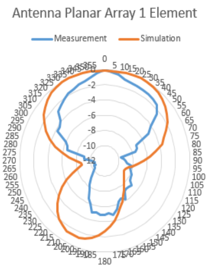
Table 4. Comparison Of Parameters Of Simulation Antennas With Measurements

Type of Antenna	Parameters					
	Return Loss(dB)		*VSWR*		*Bandwidth*(MHz)	
	Simulation	Measurement	Simulation	Measurement	Simulation	Measurement
Antenna Planar Array 1 element	-15.2	-15.4	1,5	1,39	50,3 (2.302 - 2.3523)	68 (2296 - 2364)
Antenna Planar Array 4 elements	-16.25	-17.6	1,35	1,28	54,6 (2.302 - 2.357)	71 (2298 - 2369)
Antenna Planar Array 16 elements	-16.2	-17.1	1,36	1,34	61,7 (2.304 - 2.3657)	80 (2322 - 2402)

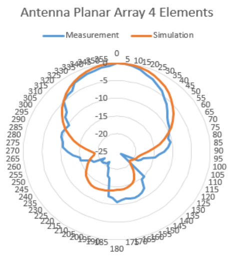
3.2. Radiation Pattern

Testing of antenna radiation patterns is carried out in the Chamber room, using a Signal generator as a source and a horn antenna as a transmitting antenna. The tested microstrip antenna is on the side of the receiver. The distance between the transmitter and receiver antennas is 2.7 m. The measurement results of the three antenna models can be seen in Figure 11.

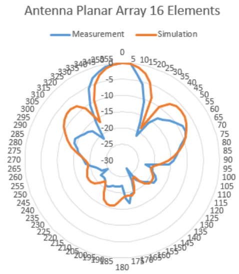
From Figure 11, it can be seen that there are differences in the radiation pattern between the measurement and simulation results. This is due to several factors, among others: error readings of the received power level measured in the spectrum analyzer due to fluctuations, manual angular direction so that errors may occur and other waves from outside that affect the measurement time. From the comparison of three radiation patterns, the more the number of patches, the direction of the radiation pattern from the other antenna narrows towards one direction, which results in the antenna gain getting better. By looking at the simulation results and measurements, show that the three results of this type of radiation pattern are directional because the greatest power leads to one direction only.



(a)



(b)



(c)

Fig. 11. Comparison of Simulation and Measurement of Radiation Patterns

(a) Antenna array 1 element patch square microstrip with planar array technique.
(b) Antenna array 4-element patch square microstrip with planar array technique.
(c) Antenna array 16-element patch square microstrip with planar array technique.

3.3. Gain Antenna

Antenna gain is defined as the ratio of the radiation intensity of an antenna in a primary direction to the radiation intensity of an isotropic antenna as a reference using the same input resource. Calculating the gain of an antenna is done by comparing the received power between the standard antenna and the antenna to be measured from the same transmitter antenna with the same power. Measuring the gain of the three antennas is carried out in the chamber, from which the gain parameters can be known. Third performance comparison antennas and comparisons between measurement results and simulations are shown in Table 5.

Table 5. Comparison Of Gain Antenna Simulation Parameters With Measurements

Type of Antenna	**Parameter**	
	***Gain*(dB)**	
	Simulation	**Measurement**

Antenna Planar Array 1 element		1,75	3,05
Antenna Planar Array 4 elements		7,29	7,65
Antenna Planar Array 16 elements		12,4	13,05

From Table 5. you can see the performance comparison of the three planar array microstrip antennas. Of the three designs made antenna array designs, 16 square patch microstrip elements with planar array techniques show better performance compared to 2 other planar antenna forms. This 16-element planar array antenna has a gain of 13.05 dB. The value of this gain is very much needed for the RF energy harvesting system. It is expected that the greater Gain value will increase the output of the RF energy harvesting system.

3.4. Application of Microstrip Antenna

In this test, direct measurement of the transmitting power of BTS (Base Transceiver Receiver) at the frequency of 2300 MHz, using a microstrip antenna that was made in this study. This test is carried out at several points with different distances. Tests were carried out in the D3 building 3rd Floor of the Surabaya State Electronic Polytechnic. The purpose of this test is to determine the ability of microstrip antennas to harvest radio frequencies emitted by BTS. To calculate the acceptability of microstrip antennas you can use the equation, namely:

$$Pin(dBm) = Pr(dBm) - Gx\ (dB) + Lx(dB) \quad (1)$$

Where : Pin = Antenna Receipt
Pr = Readable power in Spectrum
Lx = Cable Losses
Gx = Receiving Antenna Gain

So, by using the formula in Equation 1, the value of receiving power is obtained at the receiver antenna as shown in the table below and the average cable losses value is around 3dB to 4 dB. The first test is to use a 1-element array planar microstrip antenna.

Table 6. Receipt Of Planar Microstrip Antenna Array Of 1 Element In The Horizontal Position

Antena *Planar array* 1 Element				
Gain (dB)	**Distance (meter)**	**Power Receive (dBm) Position: Horizontal**		
		10 Minutes	**20 Minutes**	**30 Minutes**
3.05	55.16	-63.34	-63.305	-62.25
	33.26	-47.68	-46.572	-46.574
	65.21	-41.835	-41.296	-41.82

Table 7. Receipt Of Planar Microstrip Antenna Array Of 1 Element In Vertical Position

Antenna *Planar array* 1 Element				
Gain (dB)	**Distance (meter)**	**Power Receive (dBm) Position: Vertical**		
		10 Minutes	**20 Minutes**	**30 Minutes**
3.05	55.16	-52.075	-51.566	-51.322
	33.26	-41.494	-41.374	-41.443
	65.21	-41.796	-40.813	-41.109

The second test is using a 4-element planar array microstrip antenna. In the same way as before, the results of -

Table 8. Receiving Planar Microstrip Antenna Array Of 4 Elements In Horizontal Position

Antenna *Planar Array* 4 Elements				
Gain (dB)	**Distance (meter)**	**Power Receive (dBm) Potition : Horizontal**		
		10 Minutes	**20 Minutes**	**30 Minutes**
7.65	55.16	-51.41	-53.261	-53.408
	33.26	-37.985	-37.332	-37.754
	65.21	-34.831	-34.772	-33.807

Table 9. Receipt Of 4-Element Planar Microstrip Antenna At Vertical Position

Antena *Planar array* 4- Elements				
Gain (dB)	**Distance (meter)**	**Power Receive (dBm) Position: Vertical**		
		10 Menit	**20 Menit**	**30 Menit**
7.65	55.16	-43.457	-42.069	-42.606
	33.26	-37.546	-36.947	-37.076
	65.21	-32.761	-32.58	-32.665

The third test is to use a 16-element planar array microstrip antenna. In the same way as before, the results of measurements are shown in Table 10 and Table 11.

Table 10. Receipt Of Planar Microstrip Antenna Array Of 16 Elements In The Horizontal Position

Antenna *Planar Array* 16 Elements				
Gain (dB)	Distance (meter)	Power Receive (dBm) Position: Horizontal		
		10 Minutes	20 Minutes	30 Minutes
13.05	55.16	-50.724	-52.398	-51.95
	33.26	-33.381	-32.657	-32.793
	65.21	-31.87	-31.396	-31.52

Based on the measurement results of the antenna receiving power based on time, the result is relatively the same. This is because the transmit power of the BTS is fixed every time. In addition, the distance affects the antenna receiving power. Based on the theory, the closer the transmitter and receiver are, the better the receiving antenna will receive. But in this measurement, the farthest distance has the best-received power. This is caused by the building barrier that is at the first point, so that the waves that come from the BTS signal turn after having collisions with the barrier, causing the receiving power at that point to be small. In addition, the antenna position also affects the antenna receiving power. The best position measurement is vertical.

Table 11. Receipt Of Planar Microstrip Antenna Array Of 16 Elements In Vertical Position

Antenna *Planar Array* 16 Elements				
Gain (dB)	Distance (meter)	Power Receive (dBm) Position: Vertical		
		10 Minutes	20 Minutes	30 Minutes
13.05	55.16	-41.944	-41.012	-41.571
	33.26	-31.285	-31.218	-31.086
	65.21	-31.496	-30.025	-29.873

4. Conclusion

Based on the results of testing and discussion, the best antenna model is a 16-element square planar array microstrip antenna compared to 2 other antenna models. In RF energy harvesting, an antenna that has a large gain is needed, in testing the best antenna gain is 13.05 dB. Besides that, the antenna position also needs to be considered, in testing the best position for the antenna is vertical.

Acknowledgment

The author would like to thank the Research Center of Politeknik Elektronika Negeri Surabaya for its support of this research.

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