Verification of Performances Enhancement by Array Configuration Technique in Patch Antenna Design for Energy Harvesting Applications

Saidatul Hamidah Abd Hamid, Goh Chin Hock, Nayla Ferdous

Abstract: This paper presented the analysis of element in designing a micro strip patch antenna. A single element of the circular patch antenna and 1x2 array elements of circular patch antennas were simulated, fabricated, measured, analyzed, and discussed in this work. Array configuration study is the essence of this research. In order to improve the performances of an antenna, the implementation of array configuration is one of the techniques in designing the patch antenna. Based on the results, it has been verified that an array configuration technique works in enhances and improves the patch antenna performances. This paper also discussed the fabrication process involves and comparison of performances between simulation and measurement.

Keywords: Patch, Antenna, Array, Directivity, Gain, Fabrication

I. INTRODUCTION

In a wireless communication system, an antenna plays an important role in transmitting and receiving radio signals. Without an antenna in the communication system, neither signal transmitted from the base station nor signal received at the mobile terminal will happen. An antenna also is the main component in the ambient radio frequency energy harvesting system. In between the process, there is an electromagnetic field (EMF) generated. This readily free energy can be harvest, useable and store as direct current (DC) voltage.

Designing an antenna is the state-of-art in a wireless communication system. In designing an antenna, several points need to be included in the initial state of design. Some of the points are the application of the antenna design. The antenna is designed either to be used in radio broadcasting technology, electromagnetic radiation energy harvesting system, medical or military use. The descriptions and specifications of the antenna arebased on the application of the design.

For particular applications of an antenna, there is a specific design that suits its requirement. For example, a directional antenna.

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Saidatul Hamidah Abd Hamid, College of Engineering, University Tenaga NasionalPutrajaya, Malaysia

Goh Chin Hock, College of Engineering, University Tenaga Nasional Putrajaya, Malaysia

Nayla Ferdous, College of Engineering, University Tenaga Nasional Putrajaya, Malaysia

This type of antenna is known to have high in directivity and gain that gives the perfect recipes for a transmitter. In wireless power transfer technology, in Radio Frequency Identification (RFID) for example, the RFID reader transmitted the power to the input of RFID transponder (tag) and activated the passive circuitry of the tag [1]. This is an example of the application that requires high directivity and gain performances of an antenna.

High performance in directivity and gain are quite difficult to achieve in a single element of an antenna. From previous findings, a single element of patch antenna only can be achieved around 6dBi to 7dBi [2] in directivity.

There are several methods and techniques has been discussed by the previous studiesregarding how to optimized or the technique can be implemented to improve the performance of antenna design. In [3], this paper discusses a novel design of a Genetic Algorithm (GA) technique. This method breaks the patch into several small parts and aligned them with minimum overlapped to each other. Others techniques and methods discussed in [4-6] already been discussed in [7] which is the continuity study of this work.

In this paper, the objectives are to present the comparison of performances specifically in directivity and gain improves by array configuration technique implementation, between single element and 1x2 arrays element in the form of simulation and fabrication. In this paper also will discussin the perspective of the fabrication of both designs.

II. METHODOLOGY

A. Design Philosophy

1) Array Configuration Technique

In designing the 1x2 array configuration, two identical single circular patch antenna were combined and work as a single antenna. A duplicate of a single element was aligned accordingly with the directivity of a single element, D (θ, ϕ) multiply with the array factor, ***AF***. [8]

2) Feeding Techniques

For this specific research study, the power line of the radiation patch by implementing the proximity feeding coupling technique. The advantages of using this type of feeding are less line radiation compared to microstrip feed method and it gives high in bandwidth. The drawback of these feeding methods are, this type of feeding design requires multilayer of substrates and the alignment of theradiation plate with the feed is important for the input match and it is challenging.

A 1x2 array configuration, 50Ohm input-impedance matching line was achieved by the application of Quarter-wave (QW) transformer [5] into the design. This feeding method was applied to supply the input power to the array antennas. Figure 1 shows the design structure of the antenna with the proximity feeding technique and figure 2 shows the side-view of the design.

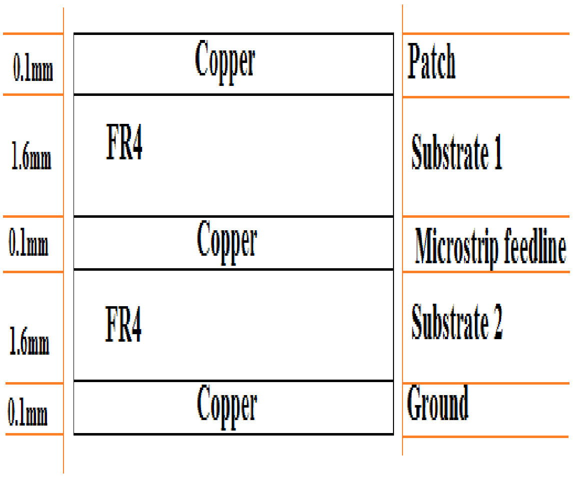


Fig. 1 Structure of design of antenna with proximity feedline

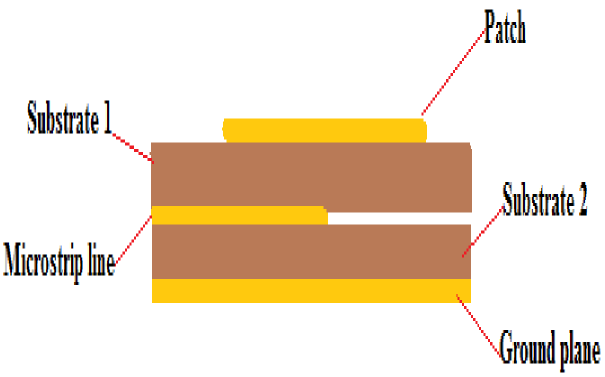
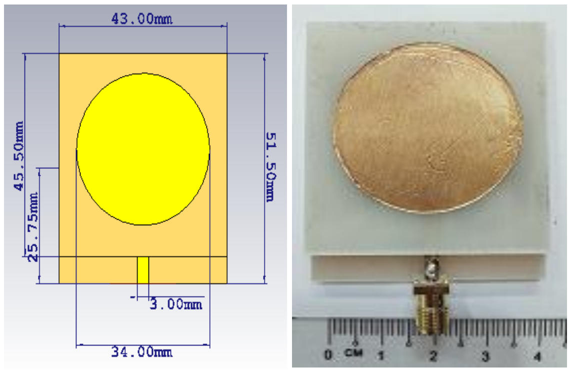


Fig. 2 Side view of the antenna design

B. Design Structures

In the simulation and fabrication of this research study, the material used in designing and fabricating the antenna is theFR-4(Lossy) as the substrates with permittivity equal to 3.95. The thickness of the substrate is equal to 1.6mm. Basic structures of proximity feeding antenna design are consisting of five layers. The top layer is the radiation patch plane followed by the first layer of the substrate, also known as the antenna substrate. Microstrip line placed in betweenthe antenna substrate and feed substrate. Feed substrate is the second layer of the substrate placed on the ground plane. Figure 3 to figure 5show the design's parameters by CST and fabricated antenna accordingly.

1) **Case 1: Single Element Circular Patch Antenna**



(a) (b)

Fig. 3 (a) single circular patch antenna design by CST (b) fabricated antenna

2) **Case 2: 1x2 Array Element Circular Patch Antennas**

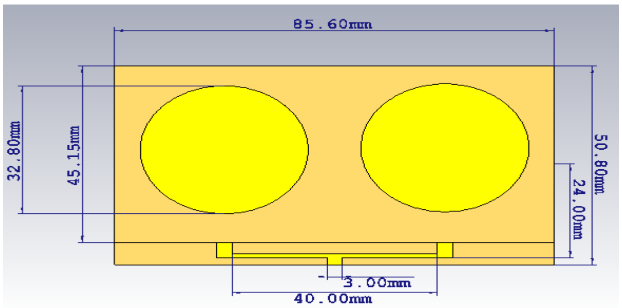


Fig. 4 1x2 array circular patch antenna design by CST

Fig. 5 1x2 array fabricated antenna

III. DESIGN VALIDATION

Verification for simulation of the design performances was done using Computer Simulation Technology (CST) while all the measurements were verified with Vector Network Analyzer (VNA) equipment. Operation frequency was set to be at 2.4GHz for Wi-Fi application.

IV. DESIGN FABRICATION

As stated earlier, the process of fabrication for 1x2 Array Circular patch Antenna was quite challenging. Antenna design with proximity coupled feed method is not easy to fabricate. Its fabrication is not as simple as microstrip feed technique and other feeding methods. Alignment of the feeding sandwiched in between two layers of substrates and placed centered position with the radiating patch is important according to the design in CST. Since the FR-4 (Lossy) is not a transparent material, this will make the alignment of all the layers become more challenging. Proper measurements of each edge and center-coordinates are very important to have the right position of every element. Cutting, handling, and positioning of the 0.1mm thin matching line also quite a very difficult process. A 0.1mm thin strip-line is very difficult to position and aligned.

It is recommended to have a good soldering's skill in order to fix the SMA connector to the antenna structure. Figure 6 shows the example of misaligned and out ofmeasurement errors duringthe fabrication process for 1x2 array antenna design.

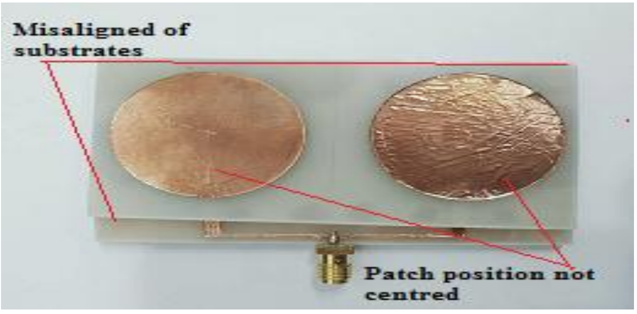


Fig. 6Example of a fabricated 1x2 array circular patch antenna

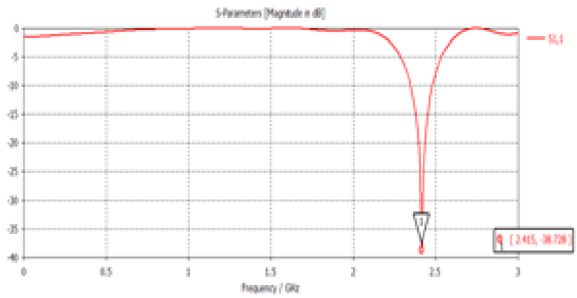
V. RESULT AND MEASUREMENT

Results from the CST simulation and VNA measurement were observed, recorded, and compares. Figure 7(a) and figure 8(a) shows the return loss S11 for simulation and Figure 7(b) and figure 8(b) shows the measurement results, respectively. Figure 9(a) and figure 9(b) shows the directivity performances in polar form for both designs. The gain performances in polar form for both designs is shown in figure 10(a) and figure 10(b) respectively.

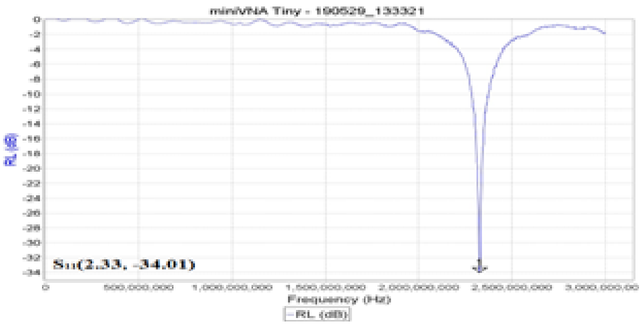
A. Return Loss S_{11}

Figure 6 shows the result achieved from the single element circular patch antenna design. Figure 7(a) is the resultsimulation from CST and figure 7(b) is the result measured from VNA. Figure 7 referred to the 1x2 array element circular patch design and the results show accordingly.

1) Single Element



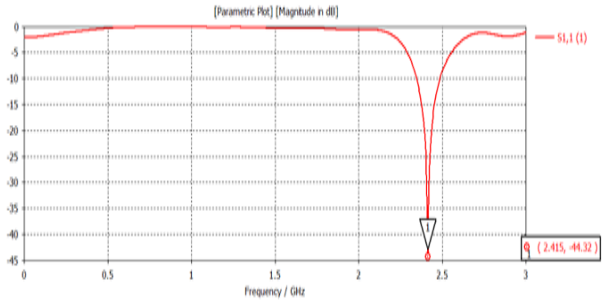
(a)



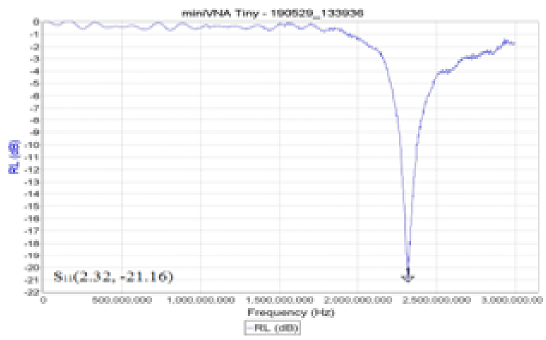
(b)

Fig. 7 (a) CST simulation result, (b) Fabricated antenna performance by VNA measurement

2) 1x2 Array Element



(a)

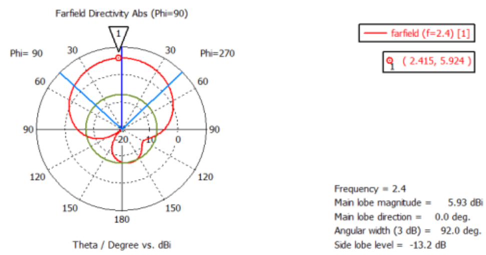


(b)

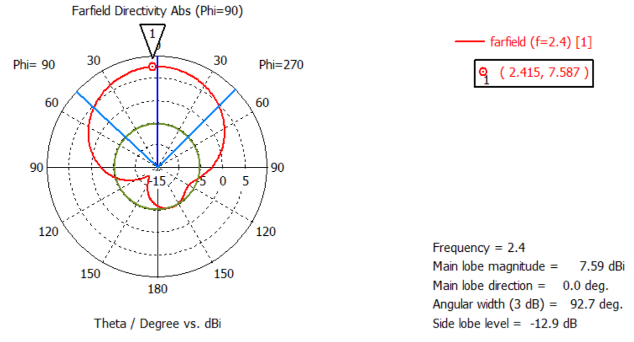
Fig. 8 (a) CST simulation result, (b) Fabricated antenna performance by VNA measurement

B. Directivity

Figure 8(a)shows the result achieved for directivity performance usingsimulation CST for the single element circular patch antenna design. Figure 8(b) shows the result achieved for the 1x2 array element circular patch design.



(a)

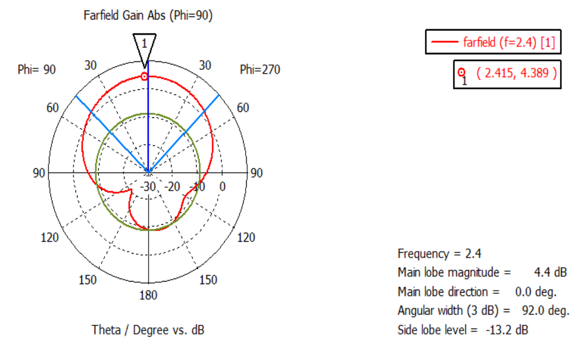


(b)

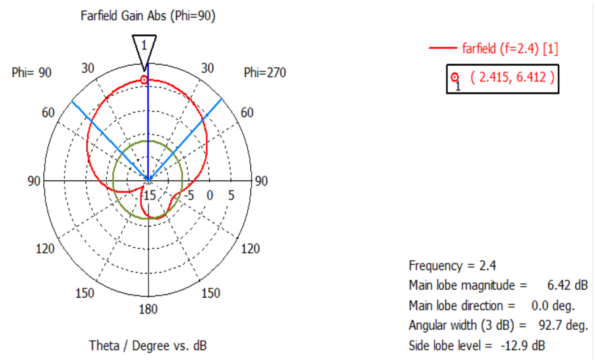
Fig. 9 Directivity performance of the antennas in polar form (a) Single Element, (b) 1x2 Array Element

C. Gain

Figure 9(a) shows the result achieved by simulation CST of the single element circular patch antenna design. The result achieved for the 1x2 array element circular patch design is shown in figure 9(b) for gain performance in polar form.



(a)



(b)

Fig. 10 Gain performance of the antenna in polar form (a) Single Element, (b) 1x2 Array Element

VI. DISCUSSION

In table 1 and table 2, the results from the CST simulation and VNA measurement were tabulated and compares. Results of Return loss S_{11}<-10dB, impedance matching, bandwidth, directivity, gain, radiation efficiency, total efficiency, and VSWR were observed and recorded. As shown in Table 1 and Table 2, by simulation verification, all related performances show improved results. On the other hand, the fabrication results for a single element and array configuration technique of the patch antenna were slightly shifted and not closely the same as simulation. For the return loss S_{11} performance, the single element gives -38.73dB and -44.32dB were achieved by array configuration design. Both antennas were resonated at frequency 2.415GHz by simulation. For the bandwidth's performance, the results achieved by both design was 0.14GHz. Others performances values attained as tabulated in Table 2. On the other hand, for fabrication measurements, the return loss S_{11} for single element and array configuration design achieved at -34.01dB at 2.33GHz resonance frequency and -21.16dB at 2.32GHz resonance frequency, respectively.

It is acknowledged that in fabricating an antenna with proximity coupled feed technique, the fabrication is not as easy asthe stripline feeding method. For the fabrication of both antennas, since it is required multilayers of substrates, the alignment of both layers was very crucial. Air-gap between sandwiched layers needs to be as minimum as possible so that the best return loss can be achieved. Alignment between the feeding line and the radiating patch also important. Slightly shifted in the position of the feed or the patch will cause defective in antenna's performance. Positioning and soldering of the SMA connector also affected the performances.

The essence of this research study is to verify the array configuration technique in order to be used to optimizes and enhances the antenna performances especially, in this case, the optimization of the directivity and gain. By simulation, it is shown that all the performances were effected and improved in values by the array configuration technique.

Table. 1 Simulation Vs Measurement results

parameters performances	Simulation		Measurement	
	Single	1x2 array	Single	1x2 array
Resonant Frequency(GHz)	2.415	2.415	2.33	2.32
Return loss (dB)	-38.73	-44.32	-34.01	-21.16
Impedance matching (Ω)	51.1+j 0.36	50.5 +j0.34	48.5-j1.3	47.4 +j8.1
Bandwidth (GHz)	0.14	0.14	0.18	0.08

Table. 2 Simulation Results

Variable parameters performances	Element types		% of improvement
	Single	1x2 array	
Directivity (dBi)	5.93	7.59	*28*
Gain (dB)	4.4	6.46	*47*
VSWR	1.0234	1.0136	*1*
Rad. Efficiency (%)	70.22	77.07	*10*
Total Efficiency (%)	69.97	75.23	*8*

Figure 11 and figure 12 shows the comparison between simulation and measurement of the antenna design for Return Loss S11 performance according to cases. However, the directivity and gain of the fabricated antenna cannot be compared and verified in this study due to the equipment limitation in the laboratory.

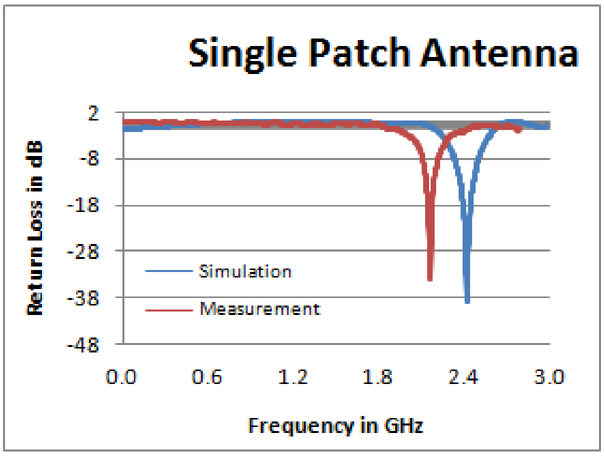


Fig. 11Comparison Return Loss S11 performance between simulation and measurement of single-element antennas

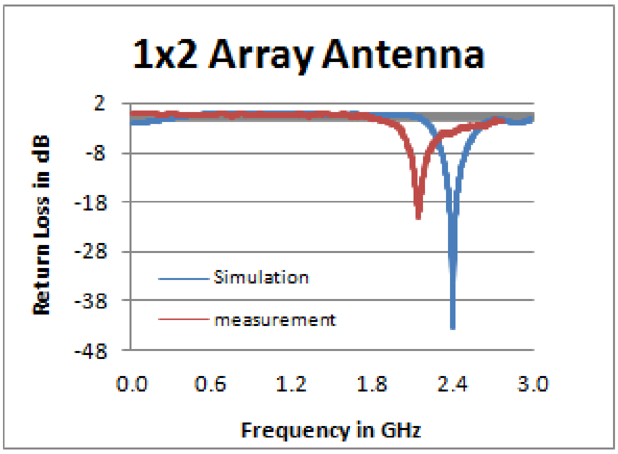


Fig. 12Comparison Return Loss S11 performance between simulation and measurement of 1x2 arrays antennas

VII. CONCLUSION

In this paper, a single element of circular patch antenna design and 1x2 array element of circular patch antennas design has been designed, simulated, fabricated, and measured. Based on the simulation-wise, the array configuration technique proved to optimize and enhances the antenna performances especially for directivity and gain compared to a single element in this research work. On the other hand, for fabrication-wise, many factors require extra attention in fabricating patch antenna, especially when using a specific feeding technique such as proximity coupled feed method. Alignment is the crucial point in this fabrication's work. Nevertheless, the fabricated antenna design's performances were within the standard and prove that the antennas working as expected.

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