Circular Patch Array of Microstrip Antenna for 2.4GHz

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Abstract - **This paper presents the design and analysis of circular patch for linear microstrip array antenna with four elements. The antenna has been designed and fabricated at resonant frequency of 2.4 GHz for digital wireless system applications. The performance of the designed antenna was analyzed in term of return loss, VSWR, percentage bandwidth, radiation pattern, and directivity. The antenna was fabricated on FR-4 laminate with having dielectric constant of 4.9 and substrate thickness is 1.6mm respectively. The antenna characteristics were then measured using vector network analyzer (VNA) and compared with the simulated results using CST software. The results show that the array antenna outperformed in many ways when compared to the single antenna.**

***Keywords** –Circular Patch for Linear Microstrip Antenna with 4 elements, Computer Simulation Technology (CST), Vector Network Analyzer (VNA)*

I. INTRODUCTION

Microwave equipments require low profile and light-weight to assure reliability, an antenna with these characteristics is essentially required and a microstrip antenna satisfies such requirement. The key features of a microstrip antenna relative of construction, light weight, low cost and either conformability to the mounting surface or, at least an extremely thin protrusion from the surface [1]. There are also have major operational disadvantages such as low efficiency, low power, poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth [2]. Besides that, Microstrip arrays also are limited in that they tend to radiate efficiently only over a narrow band of frequencies and they can't operate at the height power levels of waveguide, coaxial line, or even stripline [1]. However, there are methods such by increasing the height of the substrate that can be used to extend the efficiency as large as 90 percent if surface waves are not included and bandwidth up to about 35 percent. However, as the height of the substrate increase, surface waves are introduced which usually are not desirable because they extract power from the total available for direct radiation (space waves) [3].

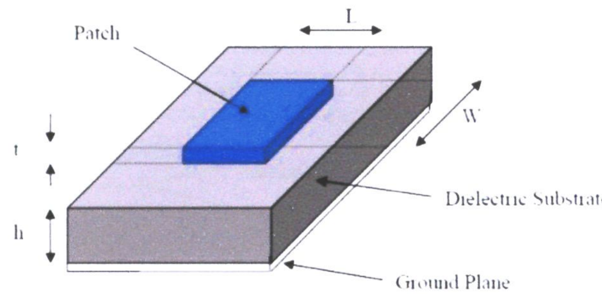

Fig.1: Basic structure of microstrip patch [4].

There are various types of patch antenna that used in communication systems. The radiating patch may be square, rectangular, dipole, circular, elliptical, triangular or any other configuration. Circular patch is used in this antenna design.

A. Circular Patch Microstrip Antenna

Other than the rectangular patch, circular or disk is the next most popular design of the microstrip antenna. Nowadays, it's not designed for only as a single element, but also in arrays. For the circular patch, there is only one degree of freedom to control (radius of the patch) unlike the rectangular patch (width and length of the patch). By control the radius of the patch, it does change the absolute value of the resonant frequency.

The circular or disk patch antenna can only be analyzed conveniently using the cavity model. The cavity is composed of two perfect electric conductors at the top and bottom represent the patch and the ground plane, and by a cylindrical perfect magnetic conductor around the circular periphery of the cavity. The dielectric material of the substrate is assumed to be truncated beyond the extent of the patch [3].

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B. *Wi-Fi overview*

Wi-Fi, which stands for wireless fidelity is a wireless networking technology used across the globe. Wi-Fi refers to any system that uses the 802.11 standard, which was developed by the Institute of Electrical and Electronic Engineers (IEEE) and released in 1997. The IEEE sets standards for a range of technological protocols, and it uses a numbering system to classify these standards.

The first standard is 802.11a. It transmits at 5 GHz and can move up to 54 Mbps. Then, 802.11b is the slowest and least expensive standard. It transmits in the frequency band of the radio spectrum. Next, 802.11g is the standard that transmits at 2.4 GHz like 802.11b, but it's a lot faster and it can handle up to 54 Mbps. It's faster because it uses the same OFDM coding as 802.11a. Lastly is 802.11n and is the newest standard that is now widely available. This standard significantly improves speed and range. Reportedly, it can achieve speeds as high as 140 Mbps [5].

II. SCOPE OF WORKS

The work was limited to design linear microstrip array antenna with four elements using commercial simulation software; *CST Microwave Studio*. The microstrip patch antenna was designed and fabricated using FR4, with dielectric constant and height of 4.9 and 1.6 mm. The antenna was designed at resonant frequency of 2.4 GHz. Finally the microstrip antenna is measured using VNA (Vector Network Analyzer) and the measured values are compared with the simulated values.

III. METHODOLOGY

Fig.2 shows the flowchart of the workflow from the initial starting to the end of the project. Literature review was done to obtain information of the design antenna. CAD is used to design, simulate and evaluate the resonant frequency of the antenna at 2.4GHz.

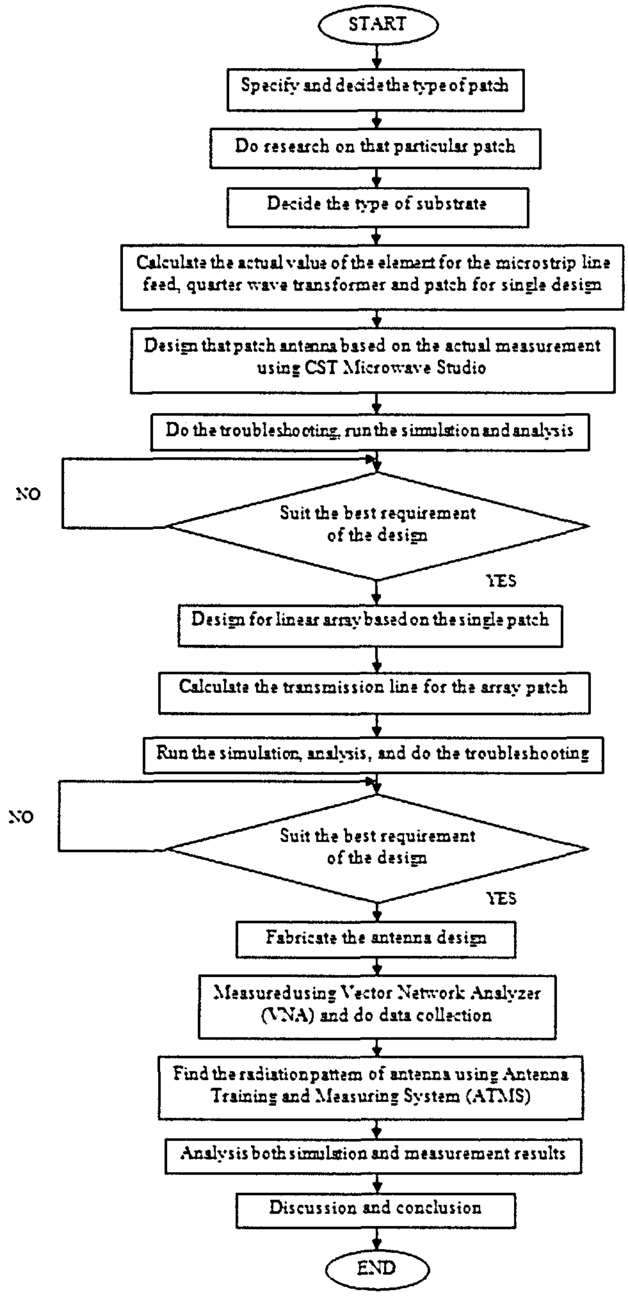

Fig.2: Design flowchart

A. Design Procedure

For microstrip antenna, the dielectric constant is usually in the range of $2.2 \leq \varepsilon_r \leq 12$. Dielectric constant in the lower end of the range can give better efficiency, large bandwidth, and loosely bound electric field for radiation pattern into space, but at the expense of large element size of an antenna. In microwave circuit that requires tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element size. In some application, small size of antenna is needed and substrate with high dielectric constant is a better choice in this application. High dielectric constants have greater losses so they are less efficient and have relatively small bandwidth [3]. In this design, all these things have been considered and finally FR4 was chosen to achieve best responses at 2.4 GHz.

The design of a circular microstrip patch antenna usually starts with a set of parameters that will satisfy the requirements of an application needed. Table 1 shows the specification of FR4 substrate used in the project.

Table 1: FR4 Substrate properties

Dielectric constant, ϵ_r	4.9
Substrate height	1.6 mm
Loss tangent	0.025
Metal Thickness	0.035 mm
Resonant frequency	2.4 GHz

Single Patch Antenna Design

The first step is to design a single patch antenna and then determine the width and length of the microstrip line feeder and quarter wave transformer. Then, proceed with the radius of the circular patch.

The width of microstrip line feeder and quarter wave transformer is using (1) and (2) [6].

$$W/d = \frac{8e^A}{e^{2A}-2} \text{ ....for } W/d < 2 \quad (1)$$

$$W/d = \frac{2}{\pi}\left[B-1-\ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \text{ ....for } W/d > 2 \quad (2)$$

Where,

$$A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \quad (3)$$

$$B = \frac{377\pi}{2Z_o\sqrt{\varepsilon_r}} \quad (4)$$

The length of microstrip line feeder and quarter wave transformer is using (5) [6].

$$L = \frac{\emptyset c}{2\pi f\sqrt{\varepsilon_e}}, \quad (5)$$

Where,

$\emptyset c$ is the phase shift of the microstrip element and,

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12d/W}} \quad (6)$$

Based on the cavity model formulation, a design procedure is outlined which is leads to practical design of circular patch microstrip antennas for the dominant TM^z_{110} mode. The procedure assumes that the specified information includes the dielectric constant of the substrate (ϵ_r), the resonant frequency (f_r) and the height of the substrate h. The procedure is as follows [3]:

Specify ϵ_r , f_r (in Hz), and h (in cm). The actual radius, a of the patch is using equation (7) [3].

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (7)$$

Where,

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\epsilon_r}} \quad (8)$$

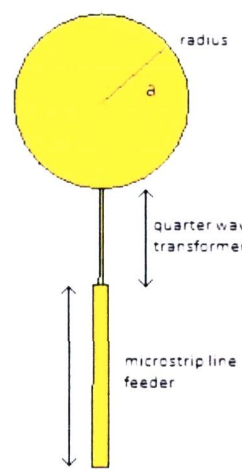

Fig.3: Single patch microstrip antenna design

Next, proceed to the design of array circular patch microstrip antenna. The antenna design is consist of four patch array that arrange in corporate feed that show in Fig.4.

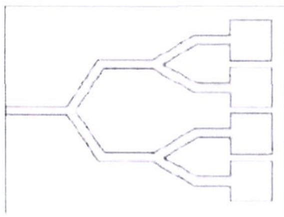

Fig.4: Corporate feed network of array patch antenna [3]

Array Patch Antenna Design

The function of array design is to synthesize a required pattern that cannot be achieved with a single element. Other than that, it's used to scan the beam of an antenna system, increase the directivity, and perform various other functions which would be difficult with any single element. The element can be fed by a single line or by multiple lines in a feed network arrangement. Corporate feed arrays are generally versatile. With this method the designer has more control of the feed of each element and it is ideal for scanning phased arrays, multibeam arrays, or shaped-beam arrays. The phase of each element can be controlled using phase shifters while the amplitude can be adjusted using amplifiers or attenuators [3].

In this design, corporate feed network is chosen for designing four element array networks. The array antenna consists of a branching network of two-way power dividers. Quarter wave transformer, 70Ω are used to match the 100Ω lines to the 50Ω lines. Figure below show how the quarter wave transformer it's done.

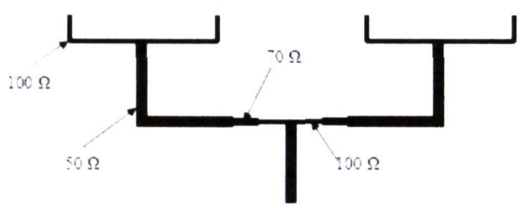

Fig.5: 70Ω quarter wave transformer of the microstrip line for corporate feed design [7]

The array calculation consists of two parts. First is the patch calculation and then for 50Ω, 70Ω and 100Ω transmission lines.

Patch Calculation

The patch radius is similarly obtained as single patch antenna design using (7).

Calculation of the Impedance for Quarter Wave Transformer

Calculation for impedance to match the 100Ω to 50Ω transmission lines is shown below. Using (9) [8], where Z_o = 50Ω and R_{in}= 100Ω, the transformer characteristic impedance:

$$Z_1 = \sqrt{50(100)} = 70\Omega \quad (9)$$

Dimension of Circular Patch, 50Ω, 70Ω, 100Ω Transmissions Line for the Array Design

As a single patch, the different impedance dimension is obtained by using (1), (2) and (3). The dimensions of the array design are shown in the Table 2 below.

Table 2: Dimension for the array antenna design

Patch	
Radius	16 mm
100 Ω Feedline	
Width	0.621675421686 mm
Length	34.429438028 mm
70 Ω Feedline (Quarter Wave Transformer)	
Width	1.49951007804 mm
Length	16.7641847541 mm
50 Ω Feedline	
Width	2.81972838665 mm
Length	32.7238492234 mm

B. *Fabricated Design*

Figure below shows the fabricated antenna after the antenna design was simulated using *CST Microwave Studio* and being optimized to achieve the best response.

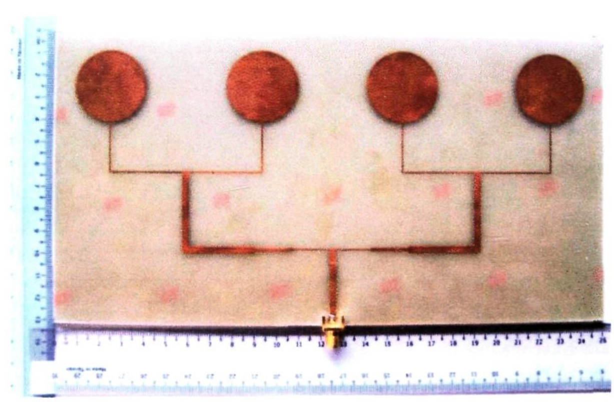

Fig.6: Fabricated antenna (250 mm x 130 mm)

IV RESULTS AND DISCUSSION

A. *Simulated Single and Array Circular Patch Antenna*

Table 3: Comparison of simulation results between single and array elements within the range 2-3 GHz

	Single antenna	Array antenna
Return Loss, S11 (dB)	-27.836 dB	-37.0263dB
VSWR	1.098	1.0339
Directivity (dBi)	6.010 dBi	10.53 dBi
Gain (dB)	0.3303 dB	4.258 dB
Percentage Bandwidth	2.28%	3.668%

Table 3 describes the performance of single and array circular patch antenna. From the results, it shows that the performance of the array circular patch antenna outperformed the single circular patch antenna in term of return loss, VSWR, directivity, antenna gain and percentage bandwidth.

Simulated Radiation Pattern (3D)

Figure 7 shows a 3D view radiation pattern of single patch antenna and array patch antenna respectively from *CST Microwave Studio* software.

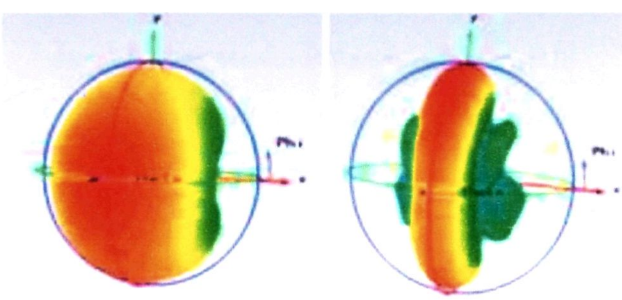

Fig.7: Radiation pattern for single and array patch of microstrip antenna

Based on the radiation pattern above, the array design give more focus on the center site of the radiation pattern form. It's confirmed with the theory of the array itself which is to increase the directivity of the antenna. The simulation results also show that the directivity of array antenna is increased.

From the above simulation results, the array circular patch antenna was further optimized for fabrication

B. *Simulated and Measured Array Circular Patch Antenna*

Simulated and Measured Return Loss

Below are the comparisons for the measurement and simulation results of the 4 elements linear circular patch array microstrip antenna. From the figure below, it is observed that the return loss for the simulated result at resonant frequency 2.4 GHz is -37.02632 dB while for the measured result is -36.7905 dB at the frequency of 2.6003 GHz. The result is not as expect as the simulation process. It is maybe due to the flaw during the fabrication process. As a result, the resonant frequency has been shifted around 8.323 % from its original state.

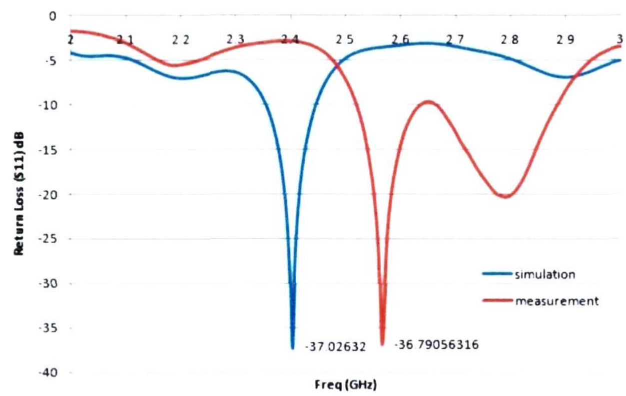

Fig.8: Measurement and simulation for the Return Loss results

Simulated and Measured VSWR

Figure 9 and 10 below shows the comparison results of VSWR between simulation and measurement. It is observed that VSWR for the simulation result is 1.0339 at 2.4 GHz while for the measurement result is 1.1933 at 2.6033 GHz.

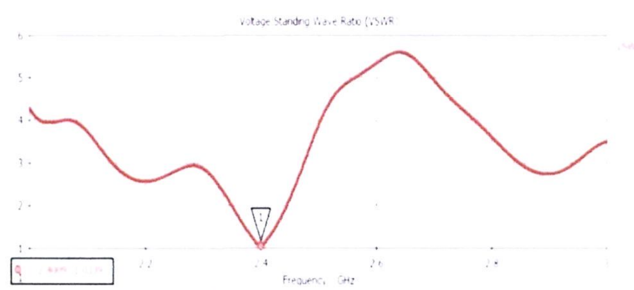

Fig. 9: Simulation result for VWSR

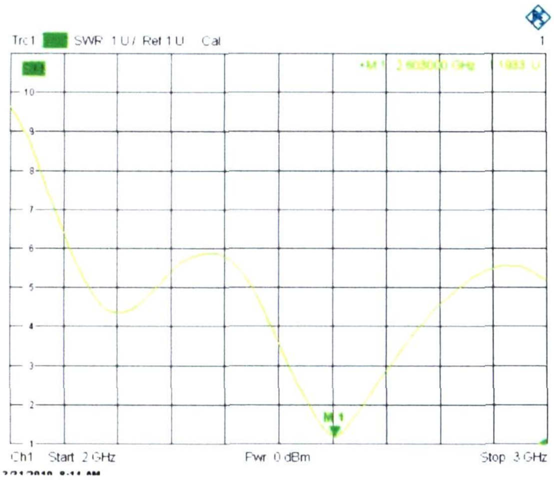

Fig. 10: Measurement result for VSWR

Table 4: Comparison of the simulation and measurement results for the array circular patch antenna

	Simulation results	Measurement results
Center frequency(f_c)	2.4005 GHz	2.6033 GHz
VSWR	1.0339	1.1933
Return loss (S_{11})	-37.0263 dB	-36.7905 dB

Simulated and Measured Radiation Pattern (2D)

Figure 11 and 12 shows the different between radiation pattern of the 4 elements linear array microstrip antenna from the simulation and measurement results. The degree of Half Power Beam Width (HPBW) of the simulation result is 24.4° and for the measurement result is 30°. Radiation pattern from the measurement shows that it is not smooth at all. This is because of the noise floor from the equipment itself and maybe because of done in the open space instead using a chamber to reduce the noise.

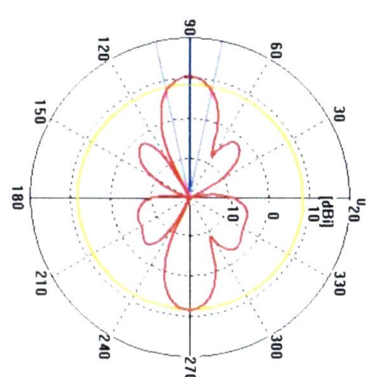

Fig.11: Radiation pattern of the simulation result

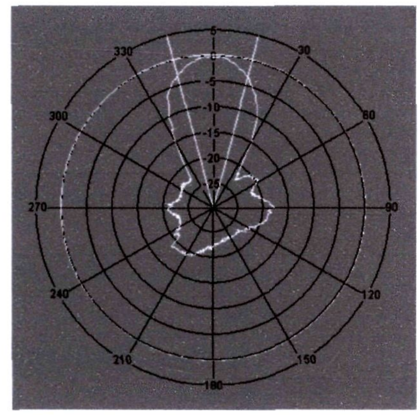

Fig.12: Radiation pattern of the measurement result at E-plane

V. CONCLUSION

This paper presented the design of the linear circular array microstrip antenna with good return loss, gain, directivity and wider bandwidth compared to the single patch circular antenna. From the simulation, it is observed that the return loss of array design is -37.0263 dB and VSWR is 1.0339 at the resonant frequency of 2.4 GHz. For the measurement result, it is observed that the return loss is equal to -36.7905 dB and VSWR of 1.1933 at the resonant frequency of 2.6003 GHz.

The more elements are being used, the better and higher directivity could be obtained but a cost to mutual coupling. In microstrip arrays, mutual coupling between elements can introduce scan blindness which limits, for a certain maximum reflection coefficient, the angular volume over which the arrays can be scanned. For microstrip antennas, this scan limitation is strongly influenced by surface waves within the substrate. This scan angular volume can be extended by eliminating surface waves [1].

VI. FUTURE RECOMMENDATION

The results can be improved in future using many ways. Another option is to design the array antenna in a circular topology instead of linear topology. The circular array design topology could be such a good solution in order to reduce the mutual coupling effects between two adjacent edges or the patch itself [9].

Next method is by using multi-layer substrate. It is related to the theory of the antenna which is by increasing the height of substrate or using multi-layer substrate, it can increase the efficiency of the antenna design. Dielectric constant also plays an important role in order to get the better efficiency to the antenna [3].

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