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Optimization of Antenna Design for Gain Enhancement Using Array

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Abstract— In this paper, several designs of microstrip arrays antennas, suitable for wireless communication applications, are presented. This paper demonstrates several shapes of microstrip array antennas, such as rectangular, circular and triangular patch antennas array. Specifically, 4x1, 2x1, and single element of all shapes are designed and simulated by a full wave simulator. Moreover, this paper presents a comparison between rectangular, circular and triangular antenna arrays. Since, the resonance frequency of these antennas is 2.4 GHz; these antennas are suitable for ISM band and WLAN applications.

Keywords- microstrip antennas array, rectangular microstrip antennas, triangular microstrip antennas, circular microstrip antennas, resonant frequency of patch antennas (2.4GHz).

I. INTRODUCTION

Modern wireless communication systems require low profile, lightweight, high gain and simple structure antennas to assure reliability, mobility, and high efficiency [1]. A microstrip patch antenna is very simple in construction using a conventional microstrip fabrication technique. Microstrip antennas consist of a patch of metallization on a grounded dielectric substrate. They are low profile, light weight antennas, most suitable for aerospace and mobile applications. Microstrip antennas have matured considerably during the past 35 years, and many of their limitations have been overcome [2].

The conducting patch can take any shape, but rectangular and circular configurations are the most commonly used configurations. Among the shapes that attracted much attention lately is the triangular shaped patch antenna [3]-[10]. This is due to their small size compared with other shapes like the rectangular and circular patch antennas. In this paper, several designs of rectangular patch antennas arrays, circular antenna array and triangular patch antennas arrays are presented. Specifically, 4x1, 2x1, and single element of all shapes are designed. Moreover, these designs are simulated using IE3d (full wave simulator). Based on the simulation results, comparison between rectangular, circular and triangular patch antennas array is achieved. This paper is divided into five sections: the first section is devoted to give an overview of the microstrip antennas. Second section gives a preface of the important parameters in single element designs, for rectangular, circular and triangular. Third section discusses the patch antenna design and the necessity of the antenna array. Fourth section demonstrates the results of the paper as a whole and a comparison between the shapes (rectangular, circle and triangular) is presented. Finally, a brief conclusion is presented in the fifth section.

II. SINGLE ELEMENT DESIGN

A. Introduction

A microstrip antenna element can be used alone or in combination with other like elements as part of an array. In either case, the designer should have a step-by-step element design procedure [2]. Usually, the overall goal of a design is to achieve specific performance at a stipulated operating frequency. If a microstrip antenna configuration can achieve these overall goals, then the first decision is to select suitable antenna geometry. In this paper, rectangular, circular and triangular patch antenna arrays are designed and compared, as it will be shown in the subsequent sections.

B. Dimensions and Resonant Frequency

Figure 1 shows the geometry of single element of rectangular patch antenna. Based on the cavity model, the resonant frequency of the rectangular patch antenna, of length L and W can be calculated using the following formulas (1) and (2):

$$W = \frac{1}{2f\left(\sqrt{\varepsilon_0 \mu_0}\right)}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

$$L = \left[\frac{1}{2f\sqrt{\varepsilon_{eff}}\sqrt{\varepsilon_0 \mu_0}}\right] - 2\Delta L \qquad (2)$$

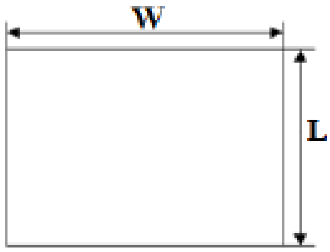

Fig.1:Geometry of rectangular patch antenna.

The design of circular patch microstrip antenna array antenna begins from a single element. From the literature review, the effective radius of circular patch is found by [4]. The calculation of length and width are found by using the equations (3) and (4),

$$r_{eff} = r\sqrt{1+\frac{2h}{\pi r \varepsilon_r}\left[\ln\left(\frac{\pi r}{2h}\right)+1.7726\right]} \quad (3)$$

The effective area of the patch is given by (4):

$$A_{eff} = \pi r^2{}_{eff} \quad (4)$$

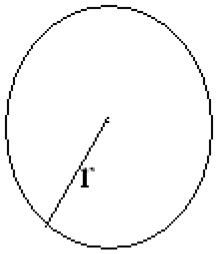

Fig.2:Geometry of Circular patch antenna

Regarding the equilateral triangular patch antenna (ETPA), of side length **a**, the resonant frequency can be calculated using the following formula (5)

$$f_{1,0} = \frac{2c}{3a\sqrt{\epsilon_r}} \quad (5)$$

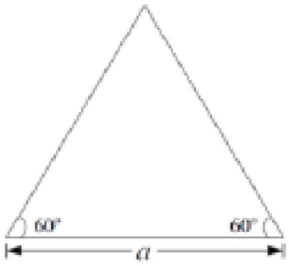

Fig.3:Geometry of Triangular patch antenna

C. Substrate Selection

One of major steps in designing a patch antenna is to choose a suitable dielectric substrate of appropriate thickness h and loss tangent. A thicker substrate, besides being mechanically strong, will increase the radiation power, reduce conductor loss, and improve impedance bandwidth. However, it will also increase the weight, dielectric loss, surface wave loss, and extraneous radiations from the feeder. The substrate dielectric constant ϵ_r plays a role similar to that of substrate thickness. A low value of ϵ_r, for the substrate, will increase the fringing field at the patch periphery, and thus, radiated power. Therefore, substrates with < 2.5 are preferred unless a smaller patch size is desired, and thus we used substrate with ϵ_r =2.2are used in our designs. An increase in the substrate thickness has similar effect on antenna characteristics as the decrease in the value of ϵ_r . A high loss tangent increases dielectric loss and therefore reduces antenna efficiency [2].

III. ARRAY DESIGN

A. Introduction

In certain applications, desired antenna characteristics may be achieved with a single microstrip element. However, as in the case of conventional microwave antenna, characteristics such as high gain, beam scanning, or steering capability are possible only when discrete radiators are combined to form arrays. The elements of an array may be spatially distributed to form a linear, planar, or volume array. A linear array consists of elements located finite distances apart along a straight line. In practice, the array type is usually chosen depending on the intended application [2]. Feeding methods, that are employed to feed microstrip array in this paper, are parallel and quarter-wave-transformer methods.

B .Design of Linear 2x1 Array

Actually, in order to make fair comparison, the same substrate used in single element (ϵ_r= 2.2 and thickness h=1.6 mm), is used in the 2x1 array. Figure 4 shows the configuration of 2x1 linear rectangular patch antenna array. To obtain 50 Ohms input impedance, feeding line with width W1=4.85. Actually, in order to make fair comparison, the same substrate used in single element (ϵ_r= 2.2 and thickness h=1.6 mm), is used in the 2x1 array. This line is split into two 100 Ohms lines, with width Wo=1.41 mm for each as shown in Figure 4. Figure 5 shows the configuration of 2x1 linear triangular patch antenna array. The same design procedure, that was used for rectangular, is used in triangular array. It is worth to mention that, the patches (rectangular , circular and triangular) dimensions used in the arrays have same dimensions used in single patches design that are shown in Figure 1,2 & 3. Figure 7 shows the reflection coefficient for both designs shown in Figures 4 and 5. Figure 8 shows the reflection coefficient for circular patch as shown in Figures 6. Obviously, all designs resonate at approximately 2.4 GHz with different levels of reflection coefficients.

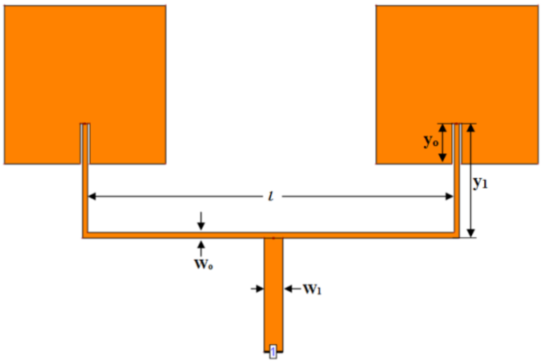

Figure 4: Configuration of 2x1 linear rectangular patch antenna array; with Wo=1.41 mm, W1=4.89 mm, yo=10.5 mm, y1=30 mm, and l=96 mm.

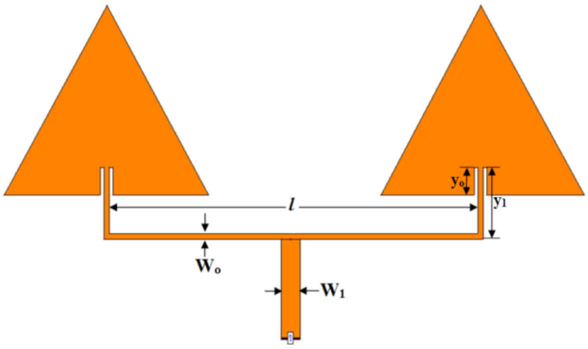

Figure 5: Configuration of 2x1 linear triangular patch antenna array; with Wo=1.41 mm, W1=4.89 mm, yo=7 mm, y1=18 mm, and l=96 mm.

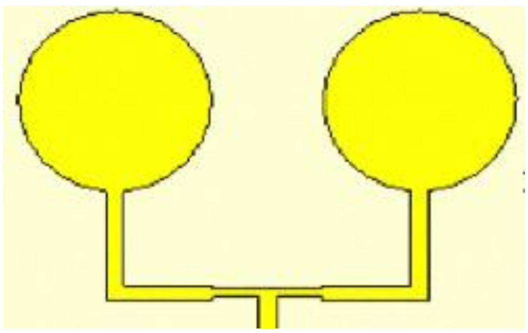

Figure 6: Configuration of 2x1 linear Circular patch antenna array; with r_0=1.41 mm

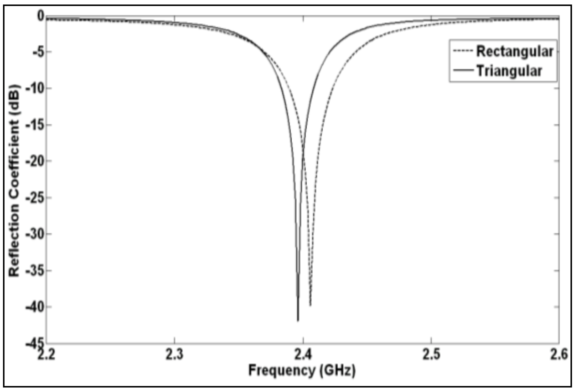

Figure 7: Simulated reflection coefficient (in dB) of the designs shown in Figures 4 and 5.

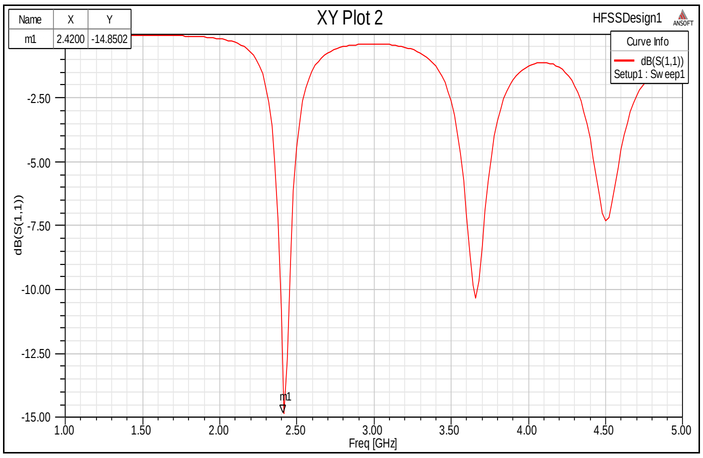

Figure 8: Simulated reflection coefficient (in dB) of the designs shown in Figures 6.

C. Design of 4x1 Array

In an attempt to design 4x1 array, for both rectangular and triangular, quarter wave transformer is used to feed the elements. Figure 9 shows the configuration of 4x1 rectangular patch antenna array. All dimensions are shown in the figure. The dimensions of quarter wave transformer are based on calculations. Figure 10 shows the configuration of 4x1 triangular patch antenna array, as well. In order to compare between circular, rectangular and triangular 4x1 array, the reflection coefficient of all designs (shown in Figures 12 and 13) are shown in Figure. It can be seen both designs resonate approximately at 2.4 GHz.

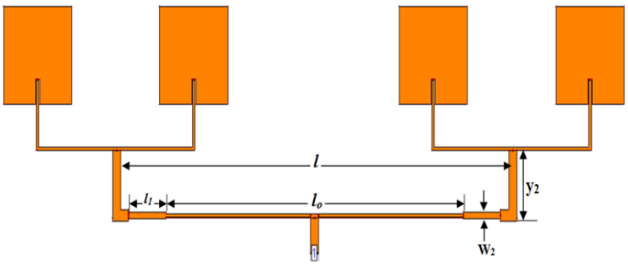

Figure 9: Configuration of 4x1 rectangular patch antenna array; with W2=2.85 mm, y2=30 mm, l= 201.2 mm, lo=185 mm and l1= 23.1 mm.

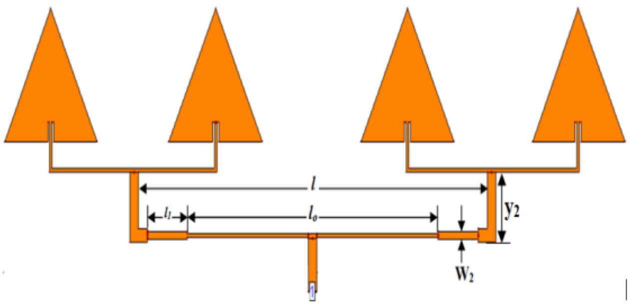

Figure 10: Configuration of 4x1 triangular patch antenna array; with W2=2.85 mm, y2= 25 mm *l*= 201.2 mm, *lo*=185 mm and *l1*= 23.1 mm.

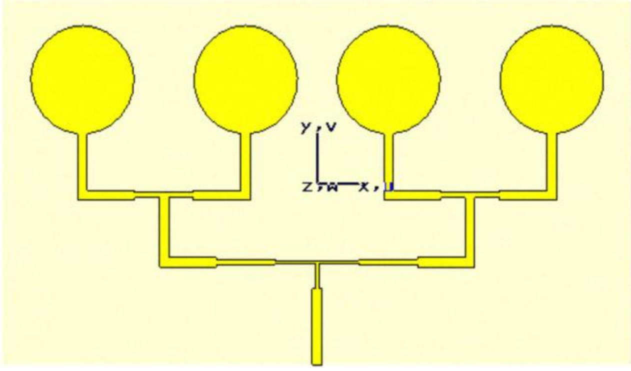

Figure 11: Configuration of 4x1 linear Circular patch antenna array; with r_0=1.41 mm

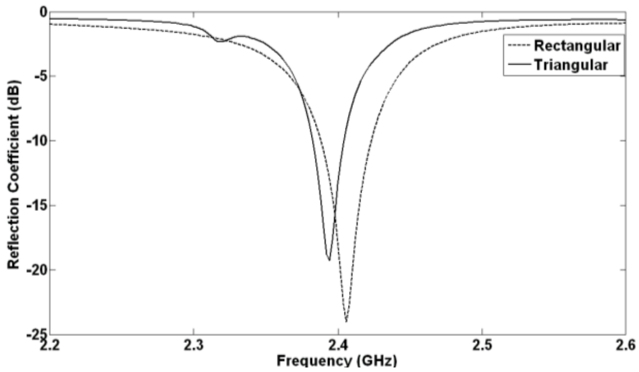

Figure 12: Simulated reflection coefficient (in dB) of the designs shown in Figures 7and 8.

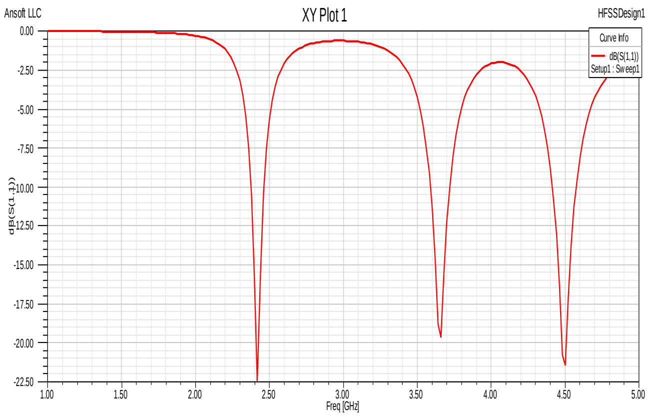

Figure 13: Simulated reflection coefficient (in dB) of the designs shown in Figures 7and 8.

IV. COMPARISON

Table 1 shows the obtained simulated results. As shown in the table, the results obtained from rectangular patch are very close to those obtained from circular and triangular patchs. The reflection coefficient is best in single and 2x1 array for all shapes (Rectangular, circular and Triangular). It could be because good matching is obtained in those cases. Both gain and directivity, for all shapes (Rectangular, circular and Triangular), are increasing as the number of elements are increased, which is expected. Finally, the side lobe level is increasing as the number of elements are increased .over rectangular patch antenna.

Table:1 Comparison between rectangular (Rect), Circular(Cir) and triangular (Tri) patch antenna arrays.

No. of elements	S11(dB)			Gain(dB)		
	Rect	Tri	Cir	Rect	Tri	Cir
Single	-40	-35	-33	6.7	6.3	6.2
2 x 1	-39	-41.4	-38	9.6	9.5	9.3
4 x 1	-23.6	-19.2	-23	12.5	12.4	11.9

From the Table 1, the performance microstrip four-patch array antenna is better than single microstrip antenna and two-patch array antenna. The return loss four-patch array antenna for rectangular at 2.45GHz is -23.6dB. Here, for a good antenna should indicate a return loss of less than 10dB.

V. CONCLUSION

In this paper, triangular, circular,rectangular patch antenna arrays were studied, for first time up to our knowledge. Several shapes of all circular, rectangular patch antennas and triangular patch antennas arrays were designed, specifically, 4x1, 2x1 and single element. All designs are compatible for WLAN and ISM application. Good enhancement, on both gain and directivity, is obtained by employing the array techniques. In this paper, we proved the ability of using triangular patch antenna array with same performance of rectangular approximately. Moreover, using triangular patch antenna array, we could obtain better suppression for side lobe level than that obtained using rectangular patch antenna array, especially in 4x1 array.

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