Design of 4 Elements Rectangular Microstrip Patch Antenna with High Gain for 2.4 GHz Applications

Yahya S. H. Khraisat
Electrical and Electronics Department
Al-Balqa' Applied University/Al-Huson University College, Irbid, Jordan
PO box 50, Al-Huson 21510, Jordan
Tel: 962-7-7706-0985 E-mail: yahya@huson.edu.jo

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Abstract

In the recent years the development in communication systems requires the development of low cost, minimal weight and low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. This technological trend has focused much effort into the design of a microstrip patch antenna. The objective of this paper is to design, and fabricate an inset fed rectangular microstrip patch antenna. Therefore, a novel particle swarm optimization method based on IE3D was used to design an inset feed linearly polarized rectangular microstrip patch antenna with four element array. The length of the antenna is nearly half wavelength in the dielectric; it's a very critical parameter, which governs the resonant frequency of the antenna. In view of design, selection of the patch width and length are the major parameters along with the feed line depth. Desired patch antenna design was simulated by IE3D simulator program. Initially we set our antenna as a single patch and after evaluating the outcomes of antenna features; operation frequency, radiation patterns, reflected loss, efficiency and antenna gain, we transformed it to a 2x1 linear array. Finally, we analyzed the 4x1 linear antenna array to increase directivity, gain, efficiency and have better radiation patterns.

Keywords: Microstrip patch antenna, 2.4 GHz, 2x1 linear array antenna, 4x1 linear array antenna and antenna gain

1. Introduction

Antennas play a very important role in the field of wireless communications. Some of them are parabolic reflectors, patch antennas, slot antennas and folded dipole antennas. Each type of antenna is good in its own properties and usage. We can say antennas are the backbone and almost everything in the wireless communication without which the word could have not reached at this age of technology.

Patch antennas play a very significant role in today's world of wireless communication systems. A microstrip patch antenna is very simple in the construction using a conventional microstrip fabrication technique. The patch can take any shape but rectangular and circular configurations are the most commonly used configurations. These patch antennas are used as simple and for the widest and most demanding applications. Dual characteristics, circular polarizations, dual frequency operation, frequency agility, broad band width, feed line flexibility and beam scanning can be easily obtained from these patch antennas. (Garg R., Bhartia P., Bahl I. J., and Ittipiboon P., 2001)

A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. Low dielectric constant substrates are generally preferred for maximum radiation, so we used the dielectric constant substrate 2.2.

2. Antenna Array

Microstrip antennas are very versatile and are used, among other things, to synthesize a required pattern that cannot be achieved with a single element. In addition, they are used to scan the beam of an antenna system, increase the directivity, and perform various other functions which would be difficult with any one single element. The elements can be fed by a single line or by multiple lines in a feed network arrangement, so in this paper we used an array to develop the performance of this antenna.

One of the essential parameters for the design of a rectangular Microstrip patch antenna is the Frequency of operation (f_0). The resonant frequency of the antenna must be selected appropriately.

The Industrial, Scientific and Medical (ISM) Systems uses the frequency range from 2.4GHz - 2.5GHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for our design is 2.4 GHz.

In our work, we initially selected the value of the substrate parameters relative Dielectric constant (ε_r) to be 2.2 and the substrate thickness (h) to be 1.588 mm. Then, we evaluated the length, the width, the input impedance of the patch and the nested fed dimensions. After that, we changed the dimensions to get better performance of the antenna, i.e. radiation patterns, reflected loss, efficiency and antenna gain by simulating it using electromagnetic simulator IE3D.

2.1 Antenna Array Design

2.1.1 Design and Network Analysis for 2x1 Antenna Array

We used the same values of height of the dielectric substrate (h) and the same dielectric material at the design frequency so we used the same dimension of single patch antenna.

- The width of the patch W = 49.41069.
- Effective Dielectric Constant εeff of the patch = 2.11106.
- Extension of the patch length, ΔL of the patch = 0 .2885 mm.
- Actual length of the patch, L = 41.35621 mm.
- The value of the Wf = 1.41 mm.
- The value of the y0 = 10.457 mm.
- Input impedance of the patch Zin = 204 Ω.

Knowing the physical dimensions L, W and Z_{in}, the feed line network parameters can be selected by setting 50 Ω feed line Z_1 = 50 Ω, which splits into two 100 Ω ones, Z_2 = 100 Ω as shown in the Figure 1.

Then we found the width of the microstrip line at Z_1 = 50 Ω and Z_2 = 100 Ω are W_1=4.8125 mm and W_2= 1.4079 mm, respectively.

2.2.2 Design and Network Analysis for 4x1 Antenna Array

We used the same values of height of the dielectric substrate (h) and the same dielectric material at the design frequency.

- Effective Dielectric Constant εreff of the patch = 2.11106.
- Extension of the patch length, ΔL of the patch = 0.2885 mm.
- Actual length of the patch, L = 41.35621 mm.
- The value of the Wf = 1.41 mm.
- The value of the y0 = 10.457 mm.

Setting 50 Ω feed line Z_1 = 50 Ω, which splits into two 100Ω ones, Z_2 = 100 Ω. Then solve for impedance of quarter-wave transformer, Z_c. Setting $Z_c = \sqrt{Z_1 Z_2}$, impedance of quarter-wave transformer, and solve for the width, W_c of quarter- wave transformer as shown in the Figure 2. This yields Z_c = 70 Ω.

After that, we found the width of the microstrip line at Z_c = 70 Ω is, W_c = 2.81689 mm.

Solving for the length of quarter-wave transformer by dividing the effective wavelength λ_{reff}, by four.

λ_{reff} = 92.5331 mm.

The Length of quarter-wave transformer is, $\lambda_{reff}/4$ = 23.1333 mm.

3. Testing and Validation

In this paper we tested our design by using electromagnetic simulator (IE3D). IE3D is an integral equation, method of moment, full-wave electromagnetic simulator. It includes layout editor, electromagnetic simulator, schematic editor and circuit simulator, near field calculation program, format converter, current and field display program. IE3D employs a 3D non-uniform triangular and rectangular mixed meshing scheme. It solves the current distribution, slot-field distribution, network s-parameters, radiation patterns, near field on an arbitrarily shaped and oriented 3D metallic structure in a multi-layered dielectric environment.

3.1 Simulation Output for 2x1 Antenna Array

After finishing our design for 2x1 antenna array, we tested it by IE3D. We obtained Figures: 3, 4 and 5.

3.2 Simulation Output for 4x1 Antenna Array

Again, after finishing our design for 4x1 antenna array, we tested it by IE3D and we got Figures: 6, 7 and 8.

The summary of outcomes is shown below in Table 1.

4. Conclusions

1) Wide bandwidth of microstrip patch antenna can be achieved by

- Increasing the substrate thickness.
- Optimizing impedance matching.
- Reducing the substrate effective permittivity.

2) In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape; In addition other shapes are complex to analysis and need heavy numerical computations.

3) Microstrip antennas have a wide beam that make it suitable in building antenna.

4) Inset fed rectangular microstrip patch array antenna having a heavy number of advantages that make it designer's choice through small size, light weight, approximately using in all wireless application fields.

5. Future Work

As a future work, we will make comparison between our proposed design for rectangular patch antenna with different design of triangular patch antennas.

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Table 1. Summary of Outcomes

Number of elements	S_{11} (dB)	Gain (dB)	Side lobes (dB)
Single	-16.624	5.1877	No side lobes
(2x1) Array	-9.5	9.186	1.856
(4x1) Array	-22	13.2	2.931

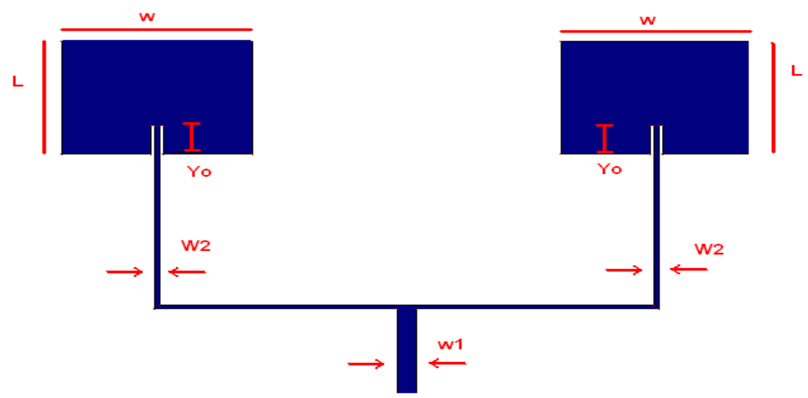

Figure1. 2x1 Array Network

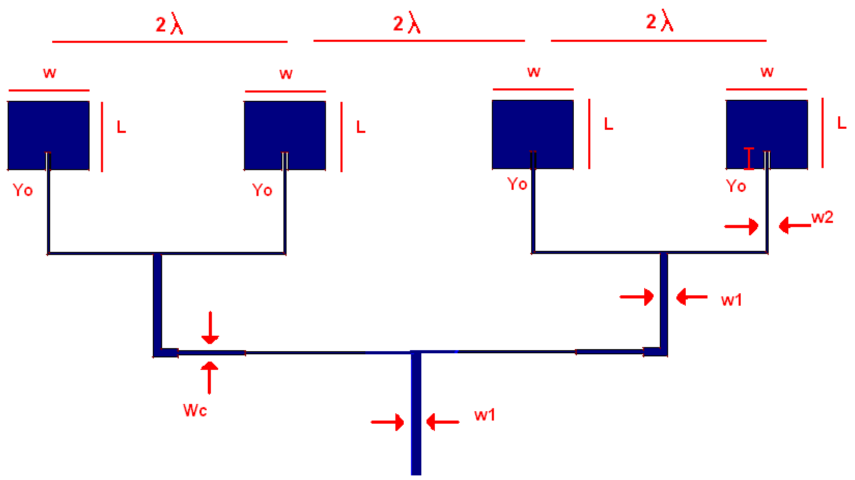

Figure 2. 4x1 Array Network

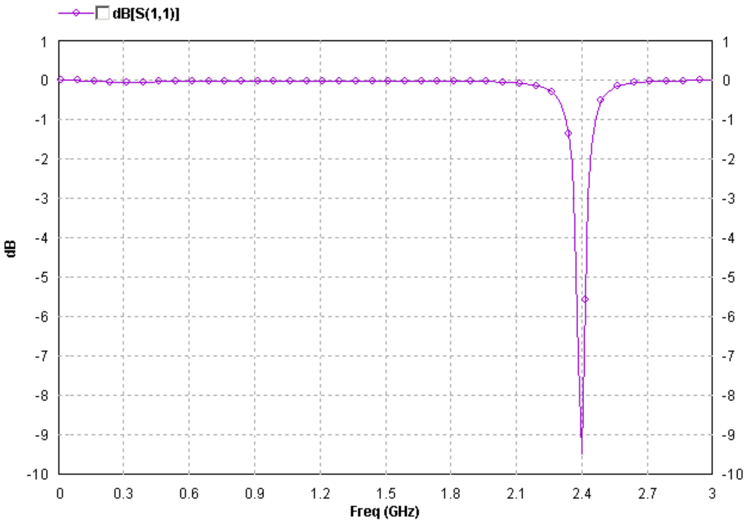

Figure 3. S parameter for 2x1 Antenna Array

From Figure 3, we can see that the return loss equals –9.5 dB at 2.4 GHz.

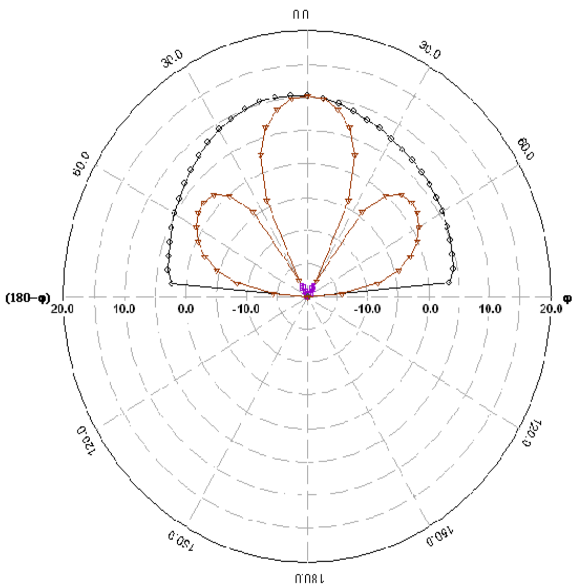

Figure 4. 2-D Radiation pattern for 2x1 Antenna Array

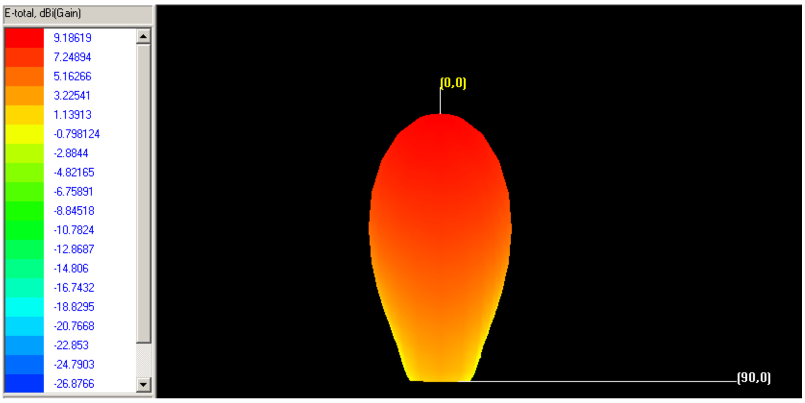

Figure 5. 3-D Radiation Pattern 2x1 Antenna Array

From Figure 5, it can be noticed that the gain for 2X1 antenna array equals 9.186 dB.

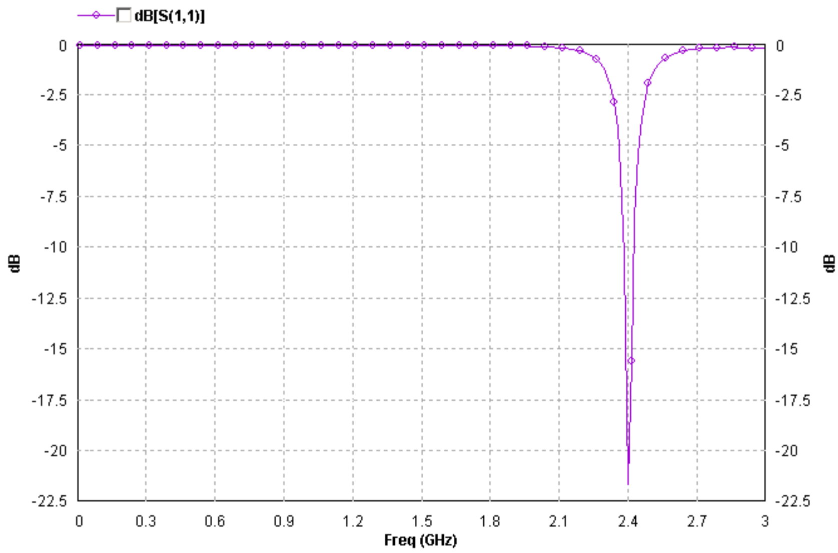

Figure 6. S- prameter for 4x1 Antenna Array

From Figure 6, we can notice a signifigant improvement in 4X1 array, the return loss becomes arround -22 dB.

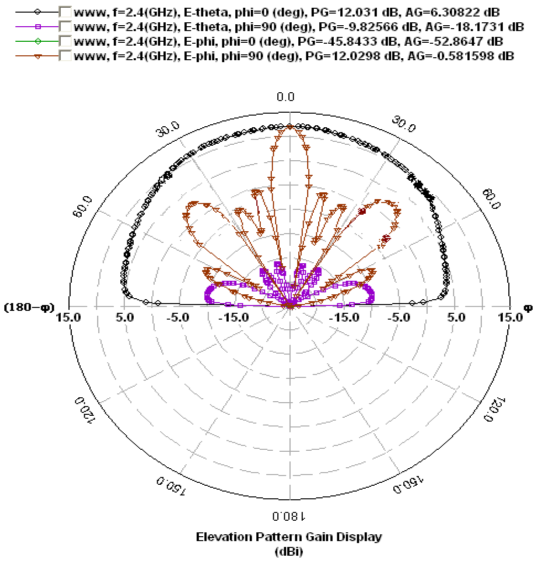

Figure 7. 2D radiation pattern for 4x1 Antenna Array

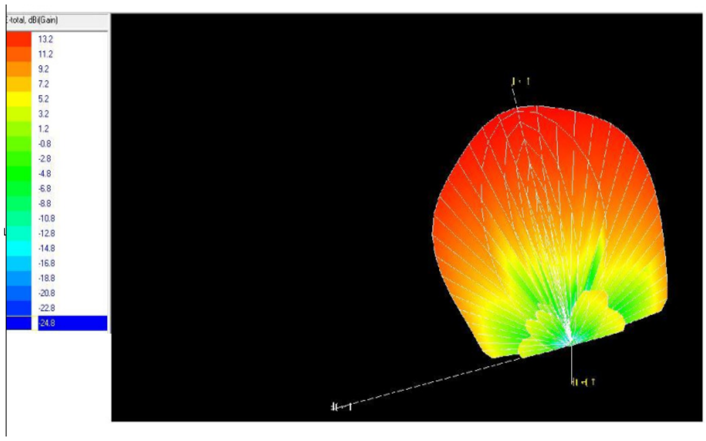

Figure 8. 3-D Radiation Pattern 4x1 Antenna Array

From Figure 8, we can notice a high improvement in the gain compared to 2X1 array.