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Design and Analysis of Microstrip Patch Antenna Array using Different Substrates for X-Band Applications

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Abstract

The paper proposes a high gain narrow band array of rectangular microstrip patches. Each element of the array is rectangular in shaped. FR-4 and Rogers-3006 material with dielectric constant 4.4 and 6.51, loss tangent of 0.002 and height 1mm have been used as substrates. The feeding is done using microstrip line feed. For the current scenario proposed design of 8x1 patch array antenna using ROGERS-3006, outputs better result as far as gain of the antenna is concerned in comparison with FR-4 in X-band application at precise frequency of 10 GHz. The patch array has been targeted for the application as sensor for “Intrusion Detection”, where high gain, narrow bandwidth and higher directivity is needed, which are computed and compared in the proposed research.

Keywords: Antenna array, Microstrip antenna, gain, X-band applications, substrate material

INTRODUCTION

Antennas are one kind of transducer for converting input electrical energy into output electro-magnetic energy as a radiation [1]. Antennas are receiver to collect the electromagnetic energy from free space and converting into electrical energy. Microstrip patch antenna consists of a metallic radiating patch on upper side of dielectric substrate, which is comparably thick and conducting ground plane on the lower side of it [2]. High dielectric constants of the substrate are helpful in miniaturizing dimensions of antenna [3]. Required Gain and directivity cannot achieve with a single patch antenna so 8x1 patch antennas array has been designed to achieve high gain and directivity for ‘Intrusion Detection’ application at precise operating frequency of X-Band. Array configurations of microstrip antenna designed in different ways provide high bandwidth, high gain along with improved efficiency. Feeding network determines the distribution of voltages among the elements, which are the part of an array. The role of the suitable feeding network is to collect all the induced voltages that are made to confine into one point [4]. The corporate fed network with quarter wave transformer is used to match patch element impedance to 50 ohm input impedance. The proper impedance matching across the designed feeding array configurations deals in better result [5]. Feeding network is also responsible and thus plays an important part in proper power distribution among antenna elements. It can steer beam by leading to change of phase [6].

The choices of different microstrip antenna parameters are very important in designing. The performance of the antenna and the subsequently that of arrays are very much dependent on these parameters. The important parameters include the height (distance between patch and ground) and dielectric constant of the substrate material, and operating frequency. A proper design parameter increased the radiation performance of the array [7]. In our research we use RO3006 (duroid family) and FR4 as the substrate material for the microstrip antenna. Feeding with suitable line [8], using RO3006 as substrate material provide high gain as compared with substrate material using FR4.

DIMENSION OF ANTENNA ARRAY

In general terminology, Microstrip patch antenna consists of the patch which is mounted on the material which is known as substrate having the dielectric constant and loss tangent [9]. The Microstrip patch antenna performance is depends on and determined by its operating frequency, resonant frequency, gain, directivity, and radiation efficiency. A slot cut on the radiating patch also affects the performance of the antenna as it introduced a capacitive effect [10]. A combination of slot and notch also influences the antenna parameter [3]. In our case we have used rectangular microstrip antenna array without any slot.

The practical and efficient dimension (length and width) of the rectangular Microstrip antenna are calculated using the following set of equations [11].

The width, W, is calculated as:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{(\varepsilon_{r+1})}}$$

The length, L, is calculated as:

$$L = \frac{1}{2f_r\sqrt{\epsilon_{eff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L.$$

The correction length factor, ΔL, is calculated as:

$$\Delta L = 0.412h\left(\frac{\left(\epsilon_{eff+0.3}\right)\left(\frac{W}{h}+0.264\right)}{\left(\epsilon_{eff-0.258}\right)\left(\frac{W}{h}+0.8\right)}\right)$$

The effective dielectric, $\mathcal{E}_{eff}$, constant of the substrate material is calculated as:

$$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\sqrt{\left[1+12\frac{h}{w}\right]}$$

The better result for different antenna parameter obtained with a good impedance matching. The characteristic impedance [12] of the microstrip antenna is given as:

$$Z_c = \frac{120\pi/\sqrt{\varepsilon_{eff}}}{\frac{W}{h}+1.393+0.667\ln(\frac{W}{h}+1.444)}$$

In the above equations h is the height and $\mathcal{E}r$ is the dielectric constant of the substrate material, whereas fr is the resonant frequency.

The dielectric constant for the material FR4 is 4.4 whereas for RO3006 it is 6.5 in our research study here. The height of the substrate material is kept constant for the two and it is 1.0 mm. The operating frequency is the mid-point of X-band i.e. 10 GHz. The parameter observation (simulation results) of the array antenna structure with two different class of substrate material is investigated using IE3D simulator.

RESULTS AND ANALYSIS

The feeding network used in our research study is microstrip corporated feed array network. This type of array is used to offer a power splits in the order of 2n. Here n is the whole number. The values of array are thus found to be 2; 4; 8; 16; 32, etc. The microstrip corporated feed array network is done by either tapered lines or by quarter wavelength matching. These type of array are very versatile though general in use. The feed of each element is more controlled by this method of feeding and thus make it is ideal for different array structure. Some of the common array structures used in practice by the designer are multi-beam arrays, scanning phased arrays or shaped-beam arrays [13].

Case (a): Microstrip array antenna using dielectric material of FR4.

In the first case of research study the material used in designing the microstrip antenna is FR4. The patch and the full ground plane are made of copper material. FR4 material has the dielectric constant of 4.4, loss tangent of 0.02. The various value of array dimension with FR4 substrate material at 10 GHz is tabulated in table 1 below

Table 1: Design Parameter of Single Microstrip Patch Antenna @10GHz with FR-4

Width of Patch (W)	7.12 mm
Length of the Patch (L)	6.7 mm
Input Resistance of Patch	50Ω
Microstrip line width	0.15 mm
Microstrip line length	2 mm

A fully corporate feed is designed with two feeds. One is termed as main feed and the other is branch feed. This feeding type is generally used in the microstrip antenna based arrays. The design used and presented in the present research study in our research study is 8x1 array antenna. It thus provides 8 element configurations. The elements are spaced around half of wavelength.

The configuration of 8x1 arrays is shown below in figure 1 below. It is a fully corporate feeding with a main feed at the central, and the branches in the ratio of 2:1 originating from the main feed.

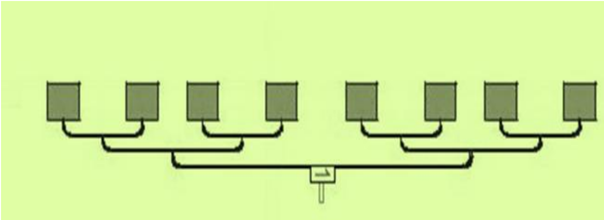

Figure 1: Design of FR4 for Microstrip feed Array.

The s-parameter (return loss) within this configuration is shown in figure 2. This antenna array has shown a good return loss of -26.4dB.return loss at 10.01GHz resonant frequency.

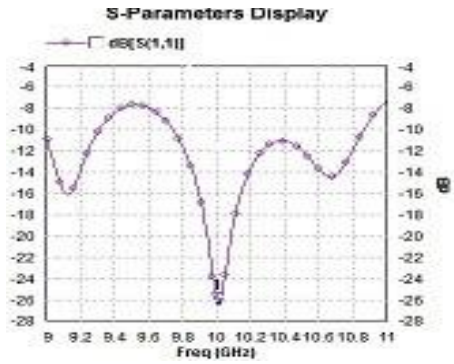

Figure 2: s-parameter plot of array.

This array gives a very high gain of 10.47 dB. The gain vs frequency plot is shown in figure 3. It shows that the gain at 9 GHz is 8 dB and with raise in frequency it also rises. At the resonate frequency (10GHz) it is maximum. Also it gives 7.2 dB at 11 GHz. Throughout the 9-11 GHz of frequency a high gain is achieved.

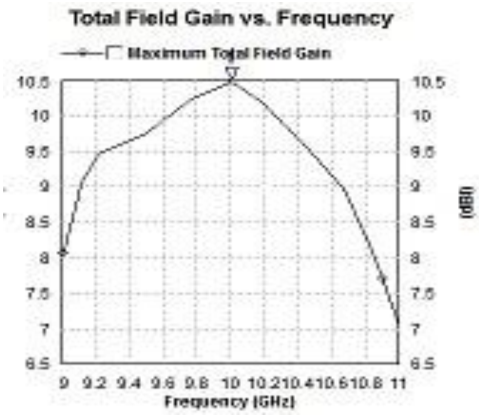

Figure 3: Gain vs frequency plot.

Next observation is that of radiation pattern at both E-plane and H-plane. This pattern with both the plane is shown in figure 4. The E-plane achieved a high relative gain of 2.24 dB and H-plane has 1 dB of relative gain at 10 GHz of frequency. The array gives a directive and uniform pattern with little back lobes.

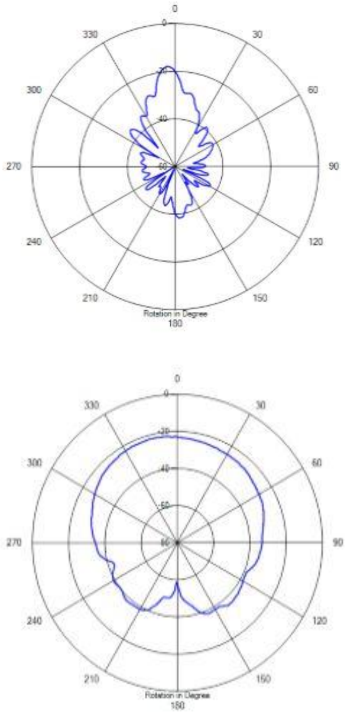

Figure 4: Radiation Pattern (E-plane and H-plane) of FR-4 of array antenna.

Case (b): Microstrip array antenna using dielectric material of RO3006:

In the second case of research study the material used in designing the microstrip antenna is RO3006. The patch and the full ground plane are made of the same copper material as used with other substrate material. RO3006 material has the dielectric constant of 6.5 and loss tangent of 0.002. the loss tangent is kept same for the two aforesaid material so that this parameter would not have nay impact on the bandwidth. The various value of array dimension with this substrate material at 10 GHz is tabulated in table 2 below

Table 2: Design Parameter of Single Microstrip Patch Antenna for 10 GHz (RO3006)

Width of Patch (W)	7.93 mm
Length of the Patch (L)	5.72 mm
Input Resistance of Patch	50Ω
Microstrip line width	0.1 mm
Microstrip line length	2 mm

The array configuration with this material of duroid family is also same as that of FR4 for similarity, and it is also made such that the configuration would not have any impact on the performance. Figure 5 shows the design array design with RO3006.

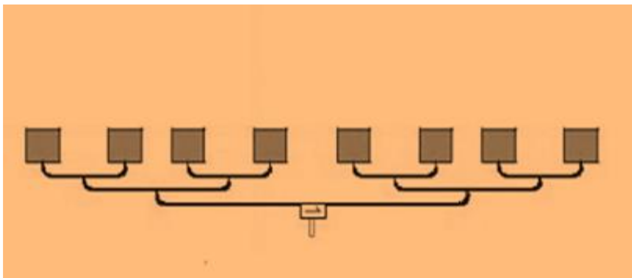

Figure 5: Design of RO3006 for Microstrip feed Array.

The s-parameter (return loss) within this configuration is shown in figure 2. This antenna array has shown a good return loss of -17.8 dB. Return loss at 9.6 GHz resonant frequency. This array design resonate from 9.4 to 10 GHz only.

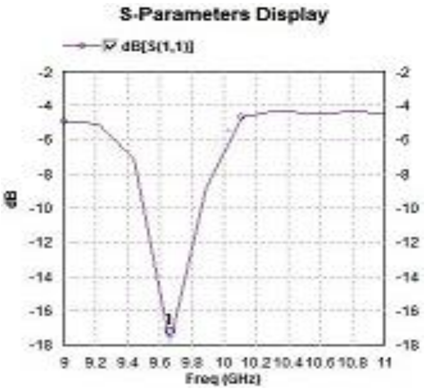

Figure 6: s-parameter plot of array.

This array gives a very high gain of 12.3 dB. The gain vs frequency plot is shown in figure 3. It shows that the gain at 9 GHz is 11 dB and with raise in frequency it also rises. At the resonate frequency (10GHz) it is 9 dB. The maximum is at 9.6 GHz of frequency. Also it gives 5.5 dB at 11 GHz. Throughout the 9-11 GHz of frequency a high gain is achieved.

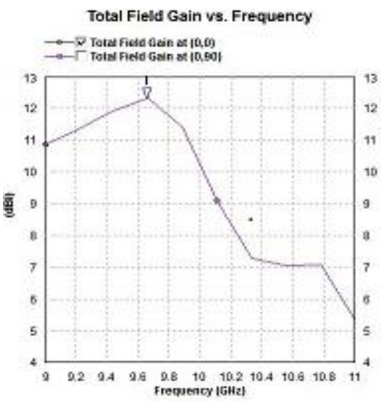

Figure 7: Gain vs frequency plot.

The last observation is that of radiation pattern at both E-plane and H-plane. This pattern with both the plane is shown in figure 8. The E-plane achieved a high relative gain of 5.8 dB and H-plane has 1.2 dB of relative gain. The array gives a more omnidirectional pattern with little back lobes.

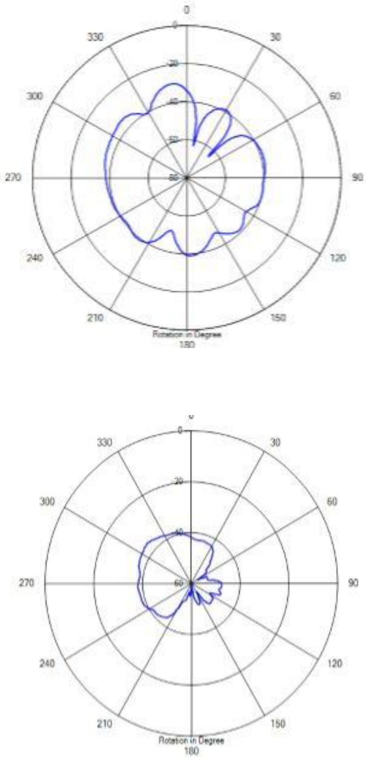

Figure 8: Radiation Pattern (E-plane and H-plane) of FR-4 of array antenna.

Table 3 below summarizes a comparison of different parameters with the two aforesaid materials.

Table 3: Comparison of Basic Parameter Results with Two Dielectric Material.

Substrate Material	Return Loss (dB)	Gain (dB)	VSWR
FR 4	-26.4	10.47	1.10
RO3006	-17.61	12.30	1.30

Table 3 above shows that both the array (with different sets of material) provides a high gain. But with FR4 (lower dielectric) the return loss is more and it also has little deviation of operating frequency from the resonant frequency. The shift in resonant frequency with respect to operating frequency is observed with duroid material. The effective dielectric constants of the two materials are different. High values of this in RO30006 give lower dimension and thus coupling gets deviated with quarter wavelength impedance matching.

CONCLUSION

We see that changing the geometry of antenna and array element spacing gives us different result. These things should be consider in array antenna designing system. In designing of 8x1 antenna arrays for X band application Rogers RO3006 gives encouraging result in comparison of FR4 substrate. Microstrip feed has better match is achieved resulting in better gain. Rogers RO3006 is performing better among the two substrates used in the research in terms of return loss and gain, whereas FR4 provides better result in terms of bandwidth and smoothens sin return loss. Patch 8x1 patch antenna arrays has been designed in corporate feed network and it has been concluded that such proposed antenna arrays are suitable for applications in X-band. The array finds usefulness in using as a sensor for intrusion detection. When the number of elements has been increased in the corporate feed network then performance parameters also increases efficiently including the Gain.

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