HIGH GAIN ARRAY ANTENNA DESIGN OF WIRELESS COMMUNICATION APPLICATIONS

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Abstract: *This study presents a design of 4x1 rectangular microstrip array antennas operation in different applications within the context of ISM bands (specifically 2.4 and 5.8 GHz bands). High gain and radiation pattern characteristics are obtained by using parallel-fed network technique. Inset-fed and quarter-wave impedance transformer techniques are used for impedance matching. Dimensions of the radiating top conductor are taken as 250 x 90 mm^2 and dielectric constant and thickness of the substrate FR4-epoxy insulating material as 4.4 and 1.6mm respectively. Less than 2 VSWR value, 11.3dB of gain with a directivity of 12dB have been achieved. Simulation results are obtained and examined by using the microstrip antenna model ANSYS High Frequency Structure Simulator v.15.*

Key words*: microstrip antennas, array antenna, gain, directivity, quarter-wave transformer.*

1. Introduction

Due to the increase in short and long distance telecommunications in information technology with the development of wireless communication systems, array antennas with different structures draw increasing attention and interest. Therefore, low aspect, integrated and high gain antenna designs are developed. wireless communication applications There is an increasing demand for multiband antenna terminals consisting of different wireless technology networks and capable of receiving multiple services [2] Microstrip Antenna, which is used in biomedicine, satellite and missile navigations, radar systems and many applications, has a good reputation among antenna types in terms of meeting these requirements [8]. Studies are available in literature to increase gain and bandwidth values which are considered as a disadvantage in Microstrip Antenna to desired levels by selecting special insulating materials and modifying geometrical structures thereof (array antenna). Single-element antennas generally have very broad radiation patterns and relatively low directivity values. In order to overcome this problem, i.e. to increase the performance of antenna, antenna arrays created by geometric placement of multiple identical antenna elements should be used [7][13]. Each selected element of array antennas may have a different structure, but similar elements are preferred to determine overall radiation pattern of the array. Geometric structures of identical array antennas are designed as rectangular, square, triangle or round. Advantages of such geometric structures modelled for array antennas are their planar shape and coordinative operation with electronic circuit cards [1] Electrical and magnetic fields of designed array antennas are found by vector addition of radiating areas of antennas. To obtain a radiation pattern in the desired direction, areas radiating from each antenna should be added to each other in the desired direction and eliminate each other in the undesired directions. Due to their ease of design and geometric structure, microstrip antennas have been the most commonly used form of array antennas [9]. Feed network is a very important factor in array characteristics. Power distribution among radiating elements is controlled by a power divider network. Geometrical structure of rectangular microstrip array antennas is described in the method section and simulation results are analyzed and shown in the findings section of this study.

2. Methods

2.1. Design of Single-Element Microstrip Antenna

Microstrip antennas manufactured with printed circuit technology are comprised of a conductor radiating on the upper surface and a ground conductor containing an insulator on the lower surface of the insulating material having a low-loss thin layer. Microstrip line feed technique which is easy to design and generate is presented in our study. In the microstrip feed technique, an inset fed microstrip antenna that keep the planarity in an appropriate level is preferred [10]. Inset fed microstrip antenna is shown in Figure 1. Many different methods have been developed for the analysis of microstrip antennas. The most popular of these models are transmission line model, cavity model and full wave model [11].

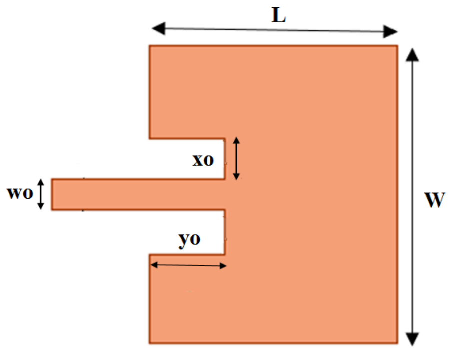

Figure 1. Inset Fed Microstrip Antenna

Antenna model is designed with transmission line model. Since the numeric values obtained as a result of theoretical calculations and simulation results are not in desired levels, some parameters are manually changed to achieve appropriate results. For simulation results, a high frequency structure simulator [14] commonly used in analysis of electromagnetic structures and based on wave finite element method is utilized. “FR4-epoxy” is selected as insulating material of the antenna designed in this study and a dielectric constant (ε_r) of 4.4, an insulating copper thickness (t) of 0.035 mm and a dielectric height (h) 1.6mm are taken. One of the important factors in the microstrip antenna design stages is the choice of insulating material. A dielectric material with an appropriate thickness (h) and an appropriate loss tangent (tanδ) affects antenna performance positively. Thick layered insulating material is mechanically strong and increases impedance bandwidth by increasing radiant power and reducing conduction loss. But dielectric loss, surface wave losses, and unnecessary radiation on the surface will increase. The substrate dielectric constant includes states similar to the substrate thickness. Selecting the dielectric coefficient of the insulating material low permits the condensation of the surface fringe areas and the increase of the spreading power [11][3]. FR4_epoxy insulation material is preferred because of the advantages such as low cost and easy availability in the design of the proposed antenna [4]. Physical parameters of the antenna designed with a center frequency of 2.4GHz are calculated with equations (1-14) used in transmission line model [8] [5][12] and demonstrated below.

$$W = c_o\sqrt{\frac{(\varepsilon_r+1)}{2}}/2f_r \tag{1}$$

$$\varepsilon_{eff} = \left[\frac{\varepsilon_r+1}{2}\right]+\left[\frac{\varepsilon_r-1}{2}\right]\sqrt{\frac{1+12h}{W}} \tag{2}$$

$$\Delta l = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

$$\lambda_r = \left[\frac{c_o}{f_r\sqrt{\varepsilon_{eff}}}\right] \tag{4}$$

$$L = \frac{\lambda_r}{2}-2\Delta l \tag{5}$$

$$L = \left[\frac{c_o}{2f_r\sqrt{\varepsilon_{eff}}}\right]-2\Delta l \tag{6}$$

Designed at the design stage of antenna input impedance *(Z_p)* ;

$$Z_p = 90\frac{\varepsilon_r^{\,2}}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \tag{7}$$

The characteristic impedance *(Z_t)* of the transmission line with the quarter-wave conversion between the 50 Ω standard microstrip feed line impedance *(Z_o)* and the input impedance of the patch *(Z_p);*

$$Z_t = \sqrt{Z_o Z_p} \tag{8}$$

($W_t/h < 1$), Line characteristic impedance (Z_t);

$$Z_t = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{8h}{W_t} + \frac{W_t}{4h}\right) \quad (9)$$

$$\varepsilon_{teff} \approx \left[\frac{\varepsilon_r + 1}{2}\right] + \left[\frac{\varepsilon_r - 1}{2}\right]\sqrt{\frac{1+12h}{W_t}} \quad (10)$$

$$L_t = \frac{\lambda_r}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon_{teff}}} \quad (11)$$

($W_t/h > 1$), Characteristic impedance of the supply line *(Z_o);*

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_r}\left(\frac{W_f}{h} + 1.393 + 0.667\ln\left(\frac{W_f}{4} + 1.44\right)\right)} \quad (12)$$

$$yo = \frac{L}{(\pi)} \arccos\sqrt{\frac{Z_o}{Z_t}} \quad (13)$$

$$xo = \frac{c_o}{\sqrt{2\varepsilon_{eff}}} \frac{4.65x10^{-12}}{f_r} \quad (14)$$

In the transmission line formula, ε_r is dielectric constant of insulating material, ε_{eff} effective dielectric value of insulating material, C_o light speed, f_r resonance frequency, h thickness of insulating material and ΔL line expansion. w_0 refers to the width of input feed line, y_0 position of feed point, x_o distance between feed point and patch, Z_t antenna input impedance present prior to adding the feed and Z_o target input impedance. In general applications, antenna input impedance is chosen as 50 Ω. Table 1 below demonstrates the output and input parameters of rectangular microstrip fed antenna.

Table 1. Inset Fed Microstrip Antenna Parameters

Inputs	
Solution Frequency (fr)	2.4GHz
Substrate Thicknes (h)	1.6mm
Loss Tangent (tanδ)	0.002
Dielectric Constant (ε_r)	4.4
Conductor thickness (t)	0.0035mm
Outputs	
Patch Width (W)	37.26mm
Patch Length (L)	28.83mm
Microstrip Line Width (w_f)	3.05mm
Inset Distance (yo)	9.57mm
Notch gap (xo)	1.59mm
Microstrip line impedanc (Z_0)	50Ω

The number of elements of microstrip antennas designed as single-element is increased to create 4x1 array antennas. In creation of 4x1 array antennas, array antenna techniques are used [8] and microstrip lines connecting the radiating patches are designed so as to have a 50Ω input port. Simulation of the 4-element antenna with HFSS is shown in Figure 2. In array designs, antennas are fed from a single input. Separated feeding of antennas is stated to be a desired method to achieve the ideally best results [8]. However, due to such reasons as practical difficulties and cost, our study aims for the power from a single central source to excite multiple antenna elements instead of using different sources.

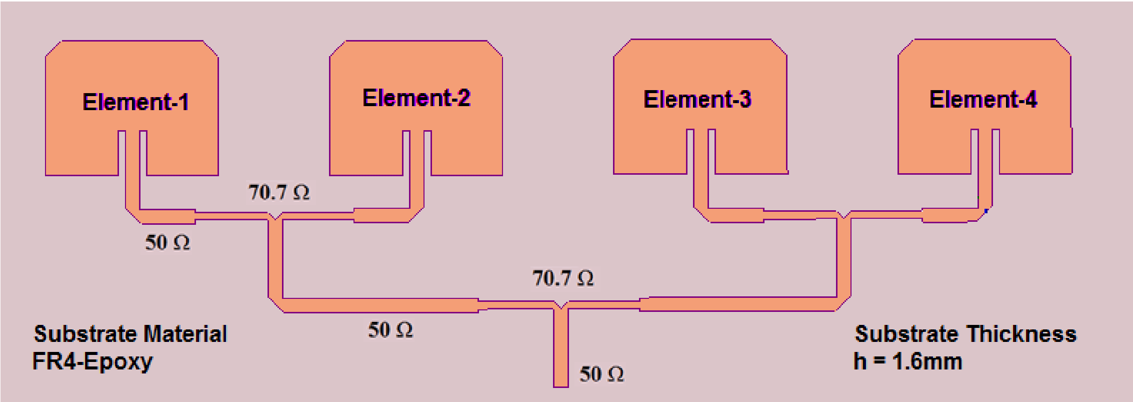

Figure 2. Simulation of the 4-Element Antenna with HFSS

Besides antenna output parameters gain and directivity are one of the criteria to be taken as reference in terms of performance. Antenna gain specified in equation (15) *(G)* is defined as a factor represented by antenna directivity *(D)* and radiation efficiency *(η)* [6].

$$G = \eta D \tag{15}$$

3. Results and Findings

Simulation results of the designed antenna obtained by using HFSS simulation program are presented in this section. Return loss (RL) characteristic of the antenna array are shown in Figure 3.

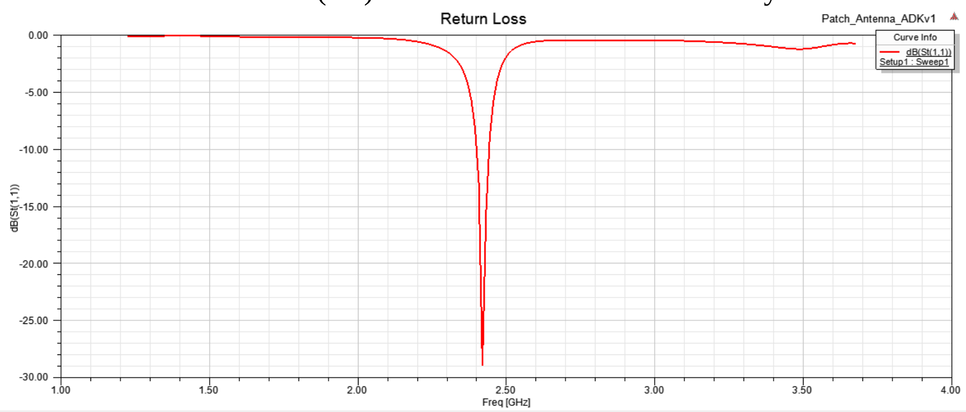

Figure 3. RL Characteristic of the Proposed Antenna

At central operating frequency of the proposed antenna VSWR value was obtained as 1.2dB and RL value was obtained as -28.91dB. 2-D gain characteristic curve and 3-D gain and directivity graphs of the proposed antenna are shown in Figure 4 and Figure 5 respectively. In addition to the simulated results, the radiation patterns in the E and H planes are illustrated in Figure 6, at the frequency of 2.4GHz. Graphics demonstrate that antenna array radiated in the same direction at mostly angles and the side lobe levels narrowed. In the graphs above, main lobe is directed towards the z-axis, maximum gain is 11.3dB and maximum directivity is 11.8dB. Efficiency (η) is 0.96 and the gain loss results from the imperfect nature of dielectric insulating material used.

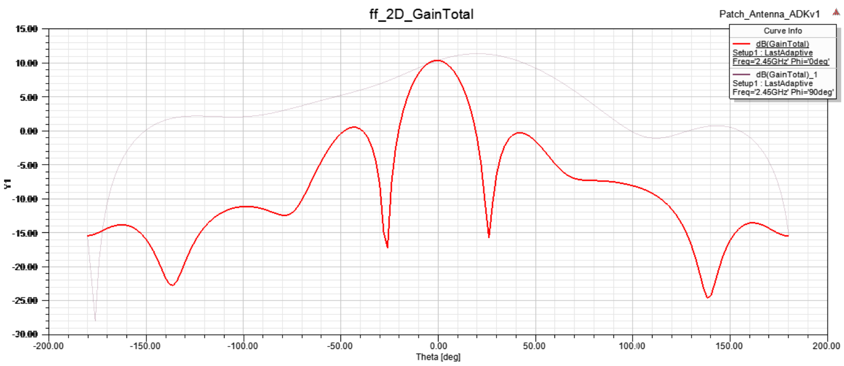

Figure 4. 2-D Gain Characteristic of Proposed Antenna

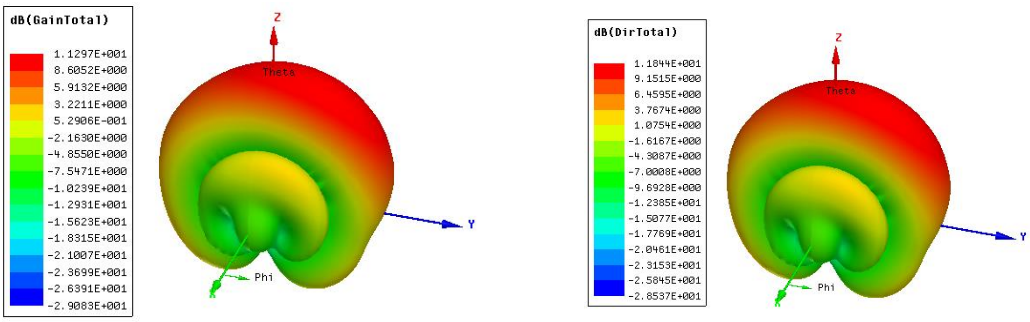

Figure 5. 3D Gain (Left) and Directionality (Right) Graphs for the Proposed Antenna

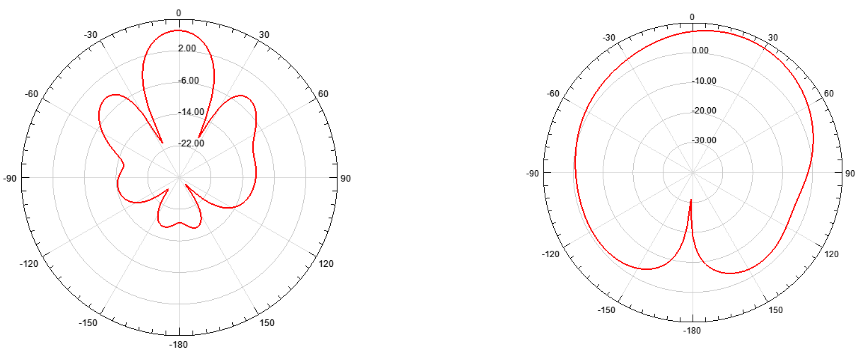

Figure 6. Radiation Pattern E-Plane (Left) and H-Plane (Right) Graphs

4. Conclusion

In this study, a linearly polarized, high gain array antenna that can operate in the ISM band is designed and simulated. The gain and directivity graphs of 4x1 (four elements) array antenna shows very low loss of efficiency of the design. The loss of efficiency between gain and directivity is minimized by selection of low dielectric substrate material. The antenna shows the best radiation pattern when catches the appropriate high gain. In our study, 11.3dB gain is obtained from 4x1 array antenna. The designed microstrip antenna is small size and high gain and suitable for today's wireless communication devices. It is aimed to fabricate the designed antenna and add measurement results in the next stage.

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