Design and Implementation of Single band Array Antenna for Wireless Applications

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Abstract—This work proposes the design and analysis of single band array antenna with rectangular patch using polymide substrate. Performance analysis was carried out for return loss, VSWR, radiation characteristics and impedance matching. This antenna is implemented on polymide substrate with $\varepsilon_r = 4.3$, $h=1.6\text{mm}$ and operating frequency of 5.25 GHz. By this design it is also shown that single band operation is possible with proper position of the feed line and proper determination of inset size. Designed antennas is simulated by Ansoft High Frequency Structural Simulator (HFSS) by using the FEM (Finite element method).

Keywords—HFSS simulation, Polymide substrate, Single band array antenna, VSWR, WLAN.

I. INTRODUCTION

Wireless communication system requires low profile, light weight, high gain, and simple structure antennas to assure reliability and high efficiency characteristics. Microstrip antenna satisfies such requirements. The key features of a microstrip antenna are relative ease of construction, light weight, low cost and conformability to the mounting surface. This antenna provides all of the advantages of printed circuit technology. These advantages of microstrip antennas make them popular in many wireless communication applications such as satellite communication, radar, medical applications, etc [1].

The limitations of microstrip antennas are narrow frequency band and disability to operate at high power levels of waveguide, coaxial line or even stripline. Therefore, the challenge in microstrip antenna design is to enhance the bandwidth and gain [2]. Different array configurations of microstrip antenna can give high gain, wide bandwidth and improved efficiency. The distribution of voltages among the elements of an array depends on feeding network. Suitable feeding network accumulates all of the induced voltages to feed into one point [3].

The proper impedance matching throughout the corporate and series feeding array configurations provides high efficiency microstrip antenna [4]. Power distribution among antenna elements can be modified by corporate feed network. The corporate feed network can steer beam by introducing phase change [5]. The choosing of design parameters (dielectric material, height and frequency, etc) is important because antenna performance depends on these parameters. Radiation performance can be improved by using proper design structures [6]. The use of high permittivity substrates can miniaturize microstrip antenna size [7].

Thick substrates with lower range of dielectric provide better efficiency, and wide bandwidth but it requires larger element size [8]. Microstrip antenna with superconducting patch on uniaxial substrate gives high radiation efficiency and gain in millimeter wave lengths [9]. The width discontinuities in a microstrip patch reduces the length of resonating microstrip antenna and radiation efficiency as well [10]. This article provides a way to choose the design parameters of antennas to achieve the desired dimensions as well as the characteristics for the effective radiation efficiency.

II. MICROSTRIP ANTENNA DESIGN

Microstrip patch antennas consist of very thin metallic strip (patch) placed on ground plane where the thickness of the metallic strip is restricted by $t << \lambda_0$ and the height is restricted by $0.0003\lambda_0 \leq h \leq 0.05\lambda_0$ [11-12]. The microstrip patch is designed so that its radiation pattern maximum is normal to the patch. For a rectangular patch, the length $L$ of the element is usually $\lambda_0 / 3 < L < \lambda_0 / 2$. There are numerous substrates that can be used for the design of microstrip antennas and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$ [12]. The Performance of the microstrip antenna depends on its dimension. Depending on the dimension the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced. For an efficient radiation, the practical width of the patch can be written as [12-13].

$$W_p = \frac{c}{2f_\text{ref}(\varepsilon_r^{0.5})}$$

and the length of the antenna becomes

$$L_p = L_{\text{eff}} - 2\Delta L$$

Where $\Delta L = 0.412 \left( \frac{\varepsilon_r^{0.3} + 0.264}{\varepsilon_r^{0.25} - 0.8} \right)$

$$\text{Ref.}$$
Effective length of patch $L_{eff} = \frac{c}{2f \sqrt{\varepsilon_{reff}}}$

Effective dielectric constant

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + \frac{12h}{W_p}}} \right)$$

where $\lambda$ is the wave length, $f_r$ is the resonant frequency, $L_p$ and $W_p$ are the length and width of the patch element respectively and $\varepsilon_r$ is the dielectric constant. Based on above equations the design dimensions of the antenna are calculated and are shown in Table I.

Table I. Design dimensions for single band antenna

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Length(mm)</th>
<th>Width(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate and Ground plane</td>
<td>22.9</td>
<td>27.2</td>
</tr>
<tr>
<td>Patch</td>
<td>13.33</td>
<td>17.6</td>
</tr>
<tr>
<td>Notch</td>
<td>5.478</td>
<td>3.52</td>
</tr>
<tr>
<td>Feed line</td>
<td>7.904</td>
<td>1.85</td>
</tr>
<tr>
<td>Wave port</td>
<td>1.85</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Figure 1 shows an antenna that has been designed to cover operating frequency of 5.25 GHz by introducing the inset feed method. Microstrip antenna mainly contains three types of elements they are patch, substrate and ground plane. Perfect electric conductor is used as a patch material and polymide substrate material. Where $L_p$, $W_p$ are length and width of patch and $h$ is the thickness of the substrate.

III. RESULTS AND DISCUSSION

The characteristics of proposed antenna are investigated through a parametric study. Frequency and time domain results were measured and are presented in terms of VSWR and radiation pattern. The antenna was excited using a rectangular edge-fed micro strip line. A partial conducting ground plane was used to enhance the bandwidth of the antenna. The simulated results of the return loss $|S_{11}|$ and the standing wave ratio (VSWR) of the antenna for frequency 5.25 GHz are discussed.

A. Return loss

Figure 2 shows the simulated result of return loss and resonance occurs at 5.25 GHz with $S_{11}$ value of -19dB.

B. Voltage Standing Wave Ratio

The voltage standing wave ratio (VSWR) of the proposed microstrip antenna has VSWR value of 1.3 for 5.25 GHz is shown in the Figure 3.

C. Radiation characteristics of $E$ and $H$-plane

The proposed microstrip patch antenna shows an omni directional radiation pattern and antenna has a wide frequency over the operating band and it radiates electromagnetic energy equally in all directions. The obtained radiation patterns including the co polarization and cross polarization. Figure 4 shows radiation characteristics of $E$-plane for all values of $\varphi$, and $0=90$ degree, where $\varphi$ is magnetic field angle.
and θ is electric field angle. It is observed that E-plane is perfectly symmetric along both sides along φ.

![Figure 4. Radiation characteristics of E-plane](image)

Figure 4. Radiation characteristics of E-plane

Figure 5 shows the radiation characteristics of H-plane for all values of θ and φ=0 degree and the result shows that H-plane is almost symmetric on both sides.

Figure 5. Radiation characteristics of H-plane

Figure 6 illustrates the 3D radiation patterns of proposed antenna in polar form. It shows omni directional characteristics, hence the proposed design is capable of transmitting or receiving signals in all directions.

![Figure 6. 3D-Polar plot for single element antenna](image)

IV. PROPOSED SINGLE BAND ARRAY ANTENNA DESIGN IN HFSS

Microstrip antennas are used in arrays as well as single elements. By using array in communication systems we enhance the performance of the antenna like increasing gain, directivity scanning the beam of an antenna system, and other functions which are difficult to do with the single element. An antenna array consists of identical antenna elements with identical orientation distributed in space. The individual antennas radiate and their radiation is coherently added in space to form the antenna beam. For a linear array, the antennas are placed along a line called the axis of the array.

The corporate-feed network is used to provide power splits of $2^n$ (i.e., n = 2; 4; 8; 16; 32, etc.). This is accomplished by using either tapered lines or using quarter wavelength impedance transformers [5]. In a uniform array the antennas are equi-spaced and are excited with uniform current with constant progressive phase shift. Spacing between any two adjacent elements of the array is d and its value will vary $\lambda/2 \leq d \leq \lambda$. Where, $\lambda$ = Wavelength and d = spacing between two antennas.

<table>
<thead>
<tr>
<th>Impedance(Ω)</th>
<th>Length(mm)</th>
<th>Width(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>7.904</td>
<td>3.11</td>
</tr>
<tr>
<td>100</td>
<td>8.295</td>
<td>0.72</td>
</tr>
<tr>
<td>200</td>
<td>8.642</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Figure 7 shows an microstrip array antenna that has been designed to cover operating frequency of 5.25 GHz by introducing the corporate feed method. Microstrip array antenna also mainly contains three types of elements they are patch, substrate and ground plane. Perfect electric conductor is used as a patch material and polymide substrate material.

![Figure 7. Schematic view of proposed Microstrip array antenna in HFSS tool](image)
V. RESULTS AND DISCUSSION
The characteristics of proposed microstrip array antenna are investigated through a parametric study. Frequency and time domain results were measured and are presented in terms of VSWR and radiation pattern which is more efficient to single element antenna. The antenna was excited using a rectangular edge-fed micro strip line. A partial conducting ground plane was used to enhance the bandwidth of the antenna. The simulated results of the return loss $|S_{11}|$ and the standing wave ratio (VSWR) of the antenna for frequency 5.25 GHz are discussed.

A. Return loss
Figure 8 shows the simulated result of return loss and resonance occurs at 5.25 GHz with $S_{11}$ value of -14dB for microstrip array antenna which provided the better bandwidth as compare single element antenna.

![Figure 8. S11-characteristics for microstrip array antenna](image1)

B. Voltage Standing Wave Ratio
The voltage standing wave ratio (VSWR) of the proposed microstrip array antenna has VSWR value of 1.5 for 5.25 GHz is shown in the Figure 9.

![Figure 9. VSWR characteristics for microstrip array antenna](image2)

C. Radiation characteristics of E and H-plane
The proposed microstrip array antenna shows an omni directional radiation pattern and antenna has a wide frequency over the operating band and it radiates electromagnetic energy equally in all directions with improvement in gain as compare to single element antenna.

Figure 10 shows radiation characteristics of E-plane for all values of $\phi$, and $\theta=90$ degree, where $\phi$ is magnetic field angle and $\theta$ is electric field angle. It is observed that E-plane is perfectly symmetric along both sides along $\phi$.

![Figure 10. Radiation characteristics of E-plane](image3)

Figure 11 shows the radiation characteristics of H-plane for all values of $\theta$ and $\phi=0$ degree and the result shows that H-plane is almost symmetric on both sides.

![Figure 11. Radiation characteristics of H-plane](image4)

Figure 6. 3D-Polar plot for micro strip array antenna
VI. CONCLUSION AND FUTURE WORK

Single element microstrip antenna is designed by using HFSS and their parameters are analyzed. To improve the performance in gain and bandwidth of antenna, a 1 x 4 microstrip array antenna is designed and its parameters are studied. The performance of the designed antenna in terms of their parameters is compared. Microstrip array antenna is more efficient as compared to the single element antenna. In future by introducing active devices such as pin diode or varactor diode, a phased antenna array with beam steering can be achieved with improvement in gain and bandwidth.

ACKNOWLEDGEMENT

We sincerely thank SRM University for providing the framework to accomplish our work.

REFERENCES


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