CHAPTER 5

DESIGN AND PERFORMANCE ANALYSIS OF PRINTED DIPOLE ANTENNAS FOR WLAN APPLICATIONS

5.1 INTRODUCTION

MIMO wireless systems have demonstrated the potential to increase communication spectral efficiency in a rich multipath environment. From an antennas perspective, different array configurations and types of element have been proposed and analyzed for MIMO links. Nowadays in military and commercial applications there have been ever growing demands for antennas. The standard dipole antenna has an omni-directional radiation pattern; however a high directive gain is required in modern wireless communication systems due to development of broadband communication (Fan et al 2007). A printed antenna with broad operational bandwidth is preferred in many wireless applications. In this research, the printed dipole array is presented for potential use in wireless communication. Compared with traditional line antennas, printed dipole antennas have advantages like planar structure, small volume, low profile, light weight, ease of fabrication and low cost (Li et al 2009). A dual band antenna with printed balun is reported in (Chen et al 2004), but the effect of balun is not clearly explained. The CPW-fed dual band antennas discussed in Sze et al (2006), Liu (2004), Liu (2007) have simple structures but larger in size. The collocated electric and magnetic dipole antennas, E-shaped printed monopole antenna and dual broadband antennas are designed, fabricated and analyzed for MIMO system applications (Xiong et al 2012, Ali Nezhad & Hassani 2010,
Zhou et al 2012). A printed monopole antenna with neutralization line is used in MIMO system (Su et al 2012). But these antennas are complex in structure, low performance in terms of antenna efficiency and gain. Due to above drawbacks, the printed dipole antennas are fed through a microstrip balun in MIMO systems. When multiple antenna elements are used, mutual coupling is an important parameter. It is mainly caused by induced current due to the sharing of common ground and near field coupling. The coupling between the antenna elements can be reduced by modifying the geometry of printed dipole antenna (Ding et al 2007).

5.2 ANTENNA DESIGN AND STRUCTURE

A dipole antenna usually needs a balanced feed for practical operation. The electric field of microstrip lines is mainly normal to the substrate. However the electric field across the gap between the arms of the dipole is along its length, thus, the dipole cannot be fed directly from a microstrip line. This requires alternative feeding mechanisms, for example coplanar strips or microstrip to slot line cross junction. Here printed dipole antennas are excited by printed balun (Michailidis et al 2007). A balun is a device used to balance an unbalanced transmission line. The printed dipole with the integrated balun features a broadband performance (Edward & Rees 1987) and has found applications in wireless communications (Chuang & Kuo 2003). The design of printed dipole antenna involves following calculations:

**Step 1:** Calculation of effective dielectric constant

\[ \lambda_0 = \frac{c}{f_r} \]  

(5.1)

c is velocity of light (3*10^8 m/sec).

\[ f_r = \text{frequency of operation} \]

\[ \lambda_0 = \text{operating wavelength (m)} \]
Guide wavelength in dielectric is given by

$$\lambda_d = \frac{\lambda_0}{\sqrt{\varepsilon_r}}$$  \hspace{1cm} (5.2)$$

where $$\varepsilon_r =$$ dielectric constant

$$\lambda_d =$$ guide wavelength with dielectric(m)

The effective dielectric constant is given as,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ \left( 1 + \frac{12h}{W} \right)^{1/2} + 0.04 \left( 1 - \frac{W}{h} \right)^2 \right]$$  \hspace{1cm} (5.3)$$

where $$h$$ is the thickness of the substrate, $$W$$ the width of the strip and $$\varepsilon_r$$ the relative dielectric constant of the substrate used.

**Step 2:** Calculation of $$\Delta L$$

$$\Delta L = 0.412 * h \left\{ \begin{array}{c} \frac{\varepsilon_r + 0.3}{\varepsilon_r - 0.258} \\ \frac{W}{h} + 0.264 \\ \frac{W}{h} + 0.813 \end{array} \right\}$$  \hspace{1cm} (5.4)$$

$$\Delta L =$$ effective length due to $$\varepsilon_{reff}$$ (m).

**Step 3:** Calculation of length and width of dipole

$$L = \left\{ \frac{C}{2f_r \sqrt{\varepsilon_{reff}}} \right\} - 2\Delta L$$  \hspace{1cm} (5.5)$$

$$W = L / 3$$

$$L =$$ Length of dipole (m)

$$W =$$ Width of dipole (m)
The length of the dipole L is the function of strip width W, substrate parameters h and $\varepsilon_r$ and thickness of the air dielectric. The length of the dipole is adjusted to get optimum result. The designed printed dipole antenna is shown in Figure 5.1.

![Figure 5.1 Configuration of the printed dipole antenna](image)

For simulation of the designed antenna, Length = 35 mm, Width = 55 mm and space between dipole arm (g)=1mm is considered. The length(L1) and width(W1) of each arm of the printed dipole antenna is 23mm and 11mm respectively, the length(L2) of dipole arm is 12mm and the width(W) of arm is 16mm. The printed dipole antenna is designed on a FR4 substrate of thickness, h = 1mm with dielectric constant $\varepsilon_r$ =2.65.

The design of balun is based on Marchand balun (Fan et al 2007), which essentially a microstrip to Co-Planar Strip line (CPS) transition with associated $\lambda$/4-stubs. In this design, this stub is replaced with a true open circuit. The CPS line, with characteristic impedance $Z_{CPS}$ rotates the impedance of the radiating element into the values with input resistance ($R_{L+CPS}$) closed to 50Ω using design equation as follows:
\[
Z_{L \cdot CPS} = Z_{CPS} \frac{Z_L + jZ_{CPS} \tan(\beta l)}{Z_{CPS} + jZ_L \tan(\beta l)} \quad (5.6)
\]

Suppose if the reactance \( X_{L \cdot CPS} \) is about \( jX_0 \Omega \), the open microstrip stub (MS1), with characteristic impedance \( Z_{MS1} \) and electrical length \( \beta l_{MS1} \), adds the impedance \( Z_{in,MS1} = -jZ_{MS1} \cot(\beta l_{MS1}) \) to \( X_{L \cdot CPS} \), moving the entire band closer to 50\( \Omega \). Subsequently, at the upper frequency band, \( Z_{MS2} \) and \( \beta l_{MS2} \) are determined to compensate reactance according to Equation (5.7),

\[
Z_{in} = Z_{MS2} \left( \frac{Z_{in,MS1} + Z_{L \cdot CPS}}{Z_{MS2} + j(Z_{in,MS1} + Z_{L \cdot CPS}) \tan(\beta l_{MS2})} \right) \quad (5.7)
\]

The complete balun structure is shown in Figure 5.2. The geometrical size of dipole antenna and balun is given in Table 5.1. The designed antenna element is suitable for 5.8GHz application. This antenna element can be arrayed for use in MIMO application.

![Figure 5.2 Configuration of the balun feed for printed dipole antenna](image)
Table 5.1  Designed geometrical parameters of dipole antenna with balun feed

<table>
<thead>
<tr>
<th>Dipole arm</th>
<th>Balun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Value (mm)</td>
</tr>
<tr>
<td>L1</td>
<td>23</td>
</tr>
<tr>
<td>L2</td>
<td>12</td>
</tr>
<tr>
<td>W1</td>
<td>11</td>
</tr>
<tr>
<td>W2</td>
<td>16</td>
</tr>
<tr>
<td>g</td>
<td>1</td>
</tr>
<tr>
<td>Overall dimension</td>
<td>35*55mm²</td>
</tr>
</tbody>
</table>

Figure 5.3 shows the simulated current distribution of two element array at 5.8 GHz. In each case, the spacing between the array elements is calculated as 25 mm and the mutual coupling between the antennas can be obtained from $S_{ij}$ of the scattering matrix. Changes in the position, pattern, and polarization of the elements results in different mutual coupling. The antenna array configurations investigated in this work are: side by side, collinear, Echelon and H shaped array antennas for WLAN applications. The side by side and echelon configurations have their elements oriented in the vertical direction and provide only space diversity. The H shaped arrays are dual polarized. The 6 element side by side, Echelon, collinear and H-shaped printed dipole antenna arrangements are shown in Figures 5.4 to 5.7 respectively. These figures show the simulated electric current distribution at 5.8GHz frequency. Red color indicates strong electric current distribution and weak current distribution is indicated by blue color.
Figure 5.3  Simulated electric current distribution of two element printed dipole antenna

Figure 5.4  Simulated electric current distribution of printed dipole antenna in side by side array configuration at 5.8GHz
Figure 5.5  Simulated electric current distribution of collinear dipole array configuration at 5.8GHz

Figure 5.6  Simulated electric current distributions of multiple printed dipole antennas in Echelon configuration at 5.8GHz
Figure 5.7  Simulated electric current distribution of printed dipole antenna in H-shaped configuration

5.3 PERFORMANCE ANALYSIS

The simulation of the design is carried out by the method of moment’s technique using ADS software (ADS 2011). Figure 5.8 gives the simulated return loss of the single printed dipole antenna which is -34dB at 5.8 GHz. Figure 5.9 shows return loss of 6 elements echelon array which is less than -25dB in the frequency range 5.4 - 5.6GHz. When the number of antenna elements increases it was found that the mutual coupling tends to shift down the operating frequency of the printed dipole antenna from 5.2-6 GHz to 5.4-5.8GHz. The operating frequency shift down is reasonable because the neighboring elements of an antenna tend to effectively increase the size of the antenna. The return loss of H-shaped array antenna is less than -30dB in the frequency range of 5.6- 6 GHz is shown in Figure 5.10. WLAN utilize the frequency ranges between 5.2 - 5.9 GHz (Gupta et al 2011). The return loss of the proposed antennas are low in this frequency range and hence it can be used for WLAN applications. The return loss of different antenna configurations is given in Table 5.2.
Figure 5.8 Simulated return loss of single printed dipole antenna

Figure 5.9 Simulated return loss of the 6 element echelon array configuration
The radiation pattern of the printed dipole array antenna is shown in Figure 5.11. The radiation intensity of an antenna is indicated in red color which offers omni-directional pattern.
The normalized co-polarized and cross-polarized E-plane radiation pattern of echelon and H-shaped array antenna is shown in Figure 5.12. It can be observed that the E-plane co-polar and cross polar radiation pattern is in the shape of omnidirectional pattern at 5.8 GHz. Figure 5.13 shows echelon and H shaped absolute electric field radiation component at 5.8GHz. Radiation field pattern is similar to that of a conventional half-wavelength
dipole antenna which has a figure eight radiation pattern. Figure 5.14 shows circularly polarized electric field pattern of echelon and H shaped array antennas. The pattern shape is purely omni-directional at the two frequencies and its level is in between -10 dB and 10 dB. Table 5.3 shows the absolute electric field, linearly polarized and circularly polarized electric field pattern of different antenna configurations.

Figure 5.13  Absolute electric field components of Echelon and H-shaped array antenna

Figure 5.14  Circularly polarized electric field pattern of echelon and H-shaped array antenna
Table 5.3 Antenna parameters of different array configurations

<table>
<thead>
<tr>
<th>Antenna configuration</th>
<th>Absolute Electric Field (dB)</th>
<th>Linearly polarized electric field pattern</th>
<th>Circularly polarized electric field pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Co-polar</td>
<td>Cross-polar</td>
</tr>
<tr>
<td>2 element array</td>
<td>0.35 -4.5</td>
<td>-9</td>
<td>-20</td>
</tr>
<tr>
<td>6 element Side by side</td>
<td>1.2 , 0.792</td>
<td>-4</td>
<td>-24</td>
</tr>
<tr>
<td>6 element Echelon</td>
<td>2.1,3.22</td>
<td>8</td>
<td>-40</td>
</tr>
<tr>
<td>6 element Collinear</td>
<td>2.3,3.62</td>
<td>10</td>
<td>-22</td>
</tr>
<tr>
<td>6 element H shaped array</td>
<td>2.5,3.98</td>
<td>-7</td>
<td>-16</td>
</tr>
</tbody>
</table>

Figure 5.15 shows the peak gain of the proposed antenna, existing C shaped slot antenna and printed monopole antenna. The gain of the proposed H shaped antenna varies from 7-8 dB across the frequency from 4.5-5 GHz and 10-10.5 dB across the frequency from 5.2-6.0 GHz band. The gain, directivity, radiated power, maximum intensity and efficiency of different antenna configurations are shown in Table 5.4.

![Figure 5.15 Simulated gain of H shaped and existing antennas](image-url)
Table 5.4 Simulated results of printed dipole antenna in different configuration

<table>
<thead>
<tr>
<th>Antenna type</th>
<th>Gain  (dBi)</th>
<th>Directivity (dBi)</th>
<th>Radiated power (mW)</th>
<th>Max intensity (mW/ster)</th>
<th>η(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Printed dipole</td>
<td>3.56</td>
<td>3.57</td>
<td>1.20</td>
<td>1.112</td>
<td>89</td>
</tr>
<tr>
<td>2 element array</td>
<td>5.92</td>
<td>5.92</td>
<td>4.38</td>
<td>1.514</td>
<td>94</td>
</tr>
<tr>
<td>6 element side by side array</td>
<td>8.82</td>
<td>8.85</td>
<td>24.5</td>
<td>14.8</td>
<td>94</td>
</tr>
<tr>
<td>6 element Collinear array</td>
<td>9.56</td>
<td>9.56</td>
<td>27</td>
<td>16.2</td>
<td>94</td>
</tr>
<tr>
<td>6 element Echelon array</td>
<td>10.1</td>
<td>10.15</td>
<td>35.6</td>
<td>31</td>
<td>94</td>
</tr>
<tr>
<td>H-shaped array</td>
<td>10.4</td>
<td>10.4</td>
<td>45.8</td>
<td>37.8</td>
<td>95</td>
</tr>
</tbody>
</table>

In general, the multiple antenna parameter results are better than single printed dipole antenna. Due to dual polarization of H shaped array antenna the gain, directivity, radiated power and efficiency are better than other array configurations. The percentage efficiency of different antenna types varied from 89 to 95 and the highest was observed in H-shaped array which might be due to high radiated power.

5.4 PERFORMANCE ANALYSIS OF PROPOSED ANTENNAS IN MIMO SYSTEM MODEL

The performance of an antenna array suitable for MIMO application is based on various parameters such as envelope correlation, mutual coupling and MIMO system capacity. The use of MIMO technology in small terminals causes high degree of coupling and spatial correlation between antenna elements and thus affecting the channel capacity. One of the
critical parameter affecting mutual coupling and correlation is the spacing between the elements, spatial diversity. Analytical studies have shown that for minimal or no mutual coupling, the distance between typical antenna element need to be at least half wavelength.

5.4.1 Envelope Correlation

The envelope correlation can be computed from the S-parameters using the following formula:

\[ \rho_e = \frac{|S_{11}^*S_{21} + S_{12}^*S_{22}|^2}{(1-|S_{11}|^2)(1-|S_{21}|^2)(1-|S_{22}|^2)(1-|S_{12}|^2)} \]  (5.8)

The envelope correlation coefficient is an important parameter for a MIMO antenna system, which can be calculated through the S parameters under the assumptions that the incoming signals are uniformly distributed and the antenna elements are lossless and well matched.

5.4.2 Mutual Coupling

Since coupling between antenna elements is one of the most important properties to consider in an antenna design. Several closely spaced elements at the transmitter and receiver experience mutual coupling, thus, including this effect at both transmitter and receiver, the expression for the channel becomes

\[ H_{mc} = C_b HC_m \]  (5.9)

where the coupling matrix at the BS \( C_b \) is \( N_R \times N_R \) and the corresponding matrix at the MS \( C_m \) is \( N_T \times N_T \). The coupling matrix of an array element is derived from the simulated S parameter values.
5.4.3 MIMO Channel Capacity

The capacity is computed for a large number of channel realizations. The capacity of 2 element array antenna is plotted in Figure 5.16. The effect of mutual coupling also included using S matrix of array which shows that the capacity is about 11bits/sec/Hz for 12dB SNR value. Figure 5.17 shows the envelope correlation of the two element array structure. For the antenna diversity, the practically acceptable envelope correlation is less than 0.5. The calculated envelope correlation of the proposed antenna array structure is less than 0.05.

![Figure 5.16 Mean capacity of 2 element antenna](image)

![Figure 5.17 Simulated correlation coefficient of two element printed dipole array](image)
The capacity loss induced by the correlation can be expressed for a case of high Signal-to-Noise Ratio (SNR) as

\[ C(\text{loss}) = -\log_2 \det(\psi^R) \]  

(5.10)

where \( \psi^R \) is a 2×2 correlation matrix. The elements of the correlation matrix can be obtained by the following (Blanch et al 2003)

\[ \begin{align*}
\psi_{aa} &= 1 - \left( |S_a|^2 + |S_y|^2 \right) \\
\psi_{ay} &= -\left( S_a^* S_y + S_y^* S_y \right)
\end{align*} \]  

(5.11)

The capacity loss of the developed MIMO antenna system is plotted in Figure 5.18. The capacity loss is less than 0.8 bits/s/Hz in the frequency band (5.1–6 GHz). The channel capacity of a 2×2 uncorrelated MIMO system is about 11 bits/s/Hz. Therefore, a capacity of less than 0.8 bits/s/Hz is acceptable for practical MIMO systems.

![Figure 5.18 Capacity loss of 2×2 array antenna for SNR=12dB](image)

\textbf{Figure 5.18} Capacity loss of 2×2 array antenna for SNR=12dB
The channel capacity with mutual coupling for different array configuration has been evaluated based on Monte Carlo realizations by constructing the channel matrix with Gaussian distributed uncorrelated random variables. The mutual coupling between antenna elements is computed from the measured S parameters. The SNR is varied from 3 to 12dB and the corresponding capacities over this SNR range, for different antenna configurations with and without mutual coupling are plotted in Figure 5.19. The number of elements on the transmit side and the receive side is taken to be six which shows that the H-shaped dipole configuration performs well compared to echelon, collinear and side by side configurations. This is possibly due to the fact that the H-shaped configuration has very little mutual coupling than the others. The mean capacity of H-shaped antenna is $15.99 \text{ b/sec/Hz}$ at 12dB SNR, but the existing C shaped slot antenna provides only $11\text{ b/sec/Hz}$ at 20dB SNR. The use of multiple antennas in a communication link greatly improves the spectral efficiency of the system.

Figure 5.19  Mean capacity as a function of SNR for different antenna configurations
Table 5.5 shows the mean capacity of different antenna configuration. The collinear, echelon and H shaped array configurations show more capacity as compared to side by side array. The H shaped antenna provides better capacity compared to all other antenna configurations.

<table>
<thead>
<tr>
<th>SNR in dB</th>
<th>Printed Dipole Antenna Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Side by side array</td>
</tr>
<tr>
<td>3.0</td>
<td>3.56</td>
</tr>
<tr>
<td>3.8</td>
<td>3.87</td>
</tr>
<tr>
<td>4.6</td>
<td>4.19</td>
</tr>
<tr>
<td>5.4</td>
<td>4.55</td>
</tr>
<tr>
<td>6.2</td>
<td>4.91</td>
</tr>
<tr>
<td>7.0</td>
<td>5.26</td>
</tr>
<tr>
<td>7.8</td>
<td>5.67</td>
</tr>
<tr>
<td>8.6</td>
<td>6.07</td>
</tr>
<tr>
<td>9.4</td>
<td>6.52</td>
</tr>
<tr>
<td>10.2</td>
<td>6.93</td>
</tr>
<tr>
<td>11.0</td>
<td>7.39</td>
</tr>
<tr>
<td>11.8</td>
<td>7.90</td>
</tr>
</tbody>
</table>

### 5.5 SUMMARY

A printed dipole with an adjusted integrated balun is developed. The antenna has small size and easy to integrate with circuit on the same dielectric, resulting in the reduction of size, fabrication cost and required volume of whole system. With a help of printed antenna an side by side array, collinear, echelon and H-shaped array antenna has been developed and
analyzed. This array antenna nearly produces an omnidirectional radiation pattern, so this array seems to be a good antenna for wireless LAN applications. The antenna parameters such as gain, directivity, radiated power and efficiency are compared and concluded that H shaped array provides better results. The capacity of MIMO antenna array with and without mutual coupling is also evaluated using Monte Carlo simulations and compared with the Single Input Single Output antenna (SISO) system. The H- shaped dipole array configuration shows less mutual impedance and dissimilar radiation patterns than side by side configuration and hence they offer better capacity than side by side case.