Smart Patch Antenna Array for Uplink in 4G Mobile Communication Based on LMS Algorithm for DS-CDMA Technique

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Abstract

There are many ways in which antennas can be used smartly. This improves the overall performance of mobile communications. Third generation communication system needs huge quantum of data transfer and it is ever increasing furthermore. Thus, there is a need for an antenna system of higher efficiency to facilitate data transfer at high speed. This paper is focused on to develop an array of 8 antennas to form a highly directional beam to maximize the power transfer for DS-CDMA wireless communication for mobile applications. The array is optimized by using adaptive algorithm. Each of the patch antenna elements is designed in such way that the bandwidth for uplink is exactly matched. Finally an array of eight tested patch antennas is used in DS-CDMA wireless mobile communication system and a BER performance analysis was done subsequently. An ADALINE algorithm is applied to maximize the received power from antenna array. The BER analysis showed an improvement by a factor of 10⁴ for uplink antenna array at an efficiency of 73.8% and gain of 6.17dB.

Keywords: Patch Antenna Array, DS-CDMA, Wireless Mobile Communication, BER, Radiation Polarization, Uplink

1. Introduction

The 4G mobile system is evolving fast and will provide much higher data rates. It is based on integration of existing wireless communication systems with increased frequency range and decreased cell radius of base station [1]. The 4G communication will need specifically designed and miniaturized patch antenna to meet bandwidth needs and power ratings [2]. The direct sequence code division multiple accesses (DS-CDMA) based mobile communication system has been optimized for various performance parameters. The optimization techniques include software based and hardware implementations. Quite often intelligent circuits are employed to maximize the efficiency of antenna systems. Intelligent and smart antenna systems were developed with adaptive properties and use of digital signal processing. This led to the higher directional gain and efficiency [1]. Analysis includes users at different power level at different direction of arrival. We, in our earlier work implemented DS-CDMA system using adaptive linear (ADALINE) neural networks to improve efficiency [3]. Here, our focus was on reducing BER and improving MAI cancellation. We observed that channel efficiency was improved considerably. The throughput has been improved by numerous approaches by forming smart beams for mobile applications at high speed [4] [5]. Directional array gain was improved by using signal processing techniques with an additional advantage of reduced interference in the same direction [5]. This can ultimately be concluded as a better system capacity and higher throughput. Based on various research results, it is obvious that DS-CDMA communication system has undergone a tremendous improvement due to incorporation of intelligent techniques into it. Many algorithms have been developed to make it more robust and adaptable [6]. The coding techniques and error control designs have also been used to improve the performance of mobile communications [7]. Algorithms have advantages and disadvantages both for different situations and applications. This may be attributed to the constraints of system dependency and frequency limitations. The operating conditions and ambience also plays vital role for end results. At times, hardware design may have more advantages than what algorithm and software based systems have. If intelligent techniques are incorporated along with hardware design then the system becomes more precise and provides better...
efficiency. Adaptive techniques are far superior to many other techniques for variable conditions [8]. The variable conditions are far difficult to predict and may have very high randomness. This may affect the overall efficiency of the system. Yet another research work was focused on a design of omnidirectional and adaptive antennas arrays for better rate control. It produced higher SINR with better throughput and less interference [8].

Minimal trellis module based on convolutional codes has shown with efficiency improvement in the OFDM-CDMA based mobile radio communications. The authors used BER as a main parameter to measure the system performance. Kashwan et al reported up to 10% reduction in BER [7]. The position and type of feeding techniques also plays role in overall efficiency of the mobile communication system [9]. Most of the research shows improved system capacity. A novel way of hardware based design implemented on FPGA for CDMA mobile communications system has shown higher speed with low complexity involved. It also indicated for better channel utilization [10].

This paper is focused on an antenna element design for uplink channel for future 4G communications standards for DS-CDMA. The antennas, specifically strips or patches type, are very important element and is critical for high speed data rates [11]. There are not many thoughtful designs of antenna dedicated to DS-CDMA. In this paper, we report a specific design of antenna optimized for DS-CDMA mobile communications for high speed data rates in near future. Mobile communications mostly use DS-CDMA for many advantages. The compact devices find a patch antenna more suitable since these are miniaturized and optimized for low power applications. We have designed and characterized a patch antenna element for uplink channel applications at 2.119 GHz frequency band. The paper also describes a systematic approach how to replicate the design for different dimensions and materials. It also provides measurement of performance parametric. Variable signal strengths at different geographical locations and with time variation, it becomes quite difficult to design a miniaturized patch. Miniaturized patches and strips have many advantages such as shape and weight apart from being power efficient. Changes in feed positions and types of feeds have been used to optimize the design for a given application.

Figure 1 shows an antenna array for general representation of experimental setup for optimization of the data rates. We used a uniform linear array of 8 antennas for better beam forming under the conditions of spatial variations. This can best be explained as, in real time, the users and interferers are
located geographically at different locations. To overcome spatial diversity, an adaptive antenna system suits far better than any other combination. Adaptive antenna system consists of a patch array and digital signal processing unit to adapt directional requirements. This can be used to change the beam forming patterns. Also adaptive array maximizes gain for desired signals and minimizes interference. As shown in Figure 1, signals received from individual micro-strip antenna are used to form desired signal with maximum gain and same time minimum interference. The weights are updated jointly by ADALINE algorithm and digital signal processing unit. The algorithm is implemented on FPGA board. The signal summation and error estimation are implemented on digital processors. ADALINE algorithm works in such a way that updated weights tend to reduce the error in outputs by comparing with desired signals.

2. Design of single element patch antenna

Generally a patch antenna, also called as micro-strip, is build on a support called substrate by depositing thin film of metal of various shapes and sizes. The other side of substrate has uniform same metal film which acts as a ground plane. The antenna is mounted with a varying thickness of substrate. The substrate is places as sandwich in between patch and ground plane. The thickness and dielectric constant (type of substrate material) of substrate affects performance of antenna. Normal criterion for selection of length of the patch is 

\[ 0.33 \lambda_0 < l_0 < 0.5 \lambda_0 \]

where \( \lambda_0 \) is wavelength in free space. The film thickness, \( t \), of patch is normally kept less than \( \lambda_0 \). The thickness of substrate may be chosen as 

\[ 0.003 \lambda_0 < h < 0.5 \lambda_0 \]

where \( h \) is substrate thickness. The selection of a particular substrate also is a function of

![Figure 2. Physical views of antenna design (a) Isometric view of 4 slotted structures with feed location indicated, (b) Cross sectional view with feed location on the patch and (c) Physical structure of substrate layers with dimensions given in mm.](image)
dielectric constant associated with the substrate as it affects antenna design parameters. Figure 2 shows a general structure of a micro-strip antenna. Figure 2 (a) and (c) shows feed position and layers of films and substrate respectively.

Normally a linear array is used to match the optimization for spatial diversity. There are other arrays, such as circular with ease of scanning for 360° without moving or changing orientation of antenna elements. This gives very flexible and directionally adaptive property [12]. Figure 1 illustrates how the antennas are placed in a linear manner but for real hard designs, antennas may be placed in a circular fashion on the substrate [13]. Smart antenna designs have shown very intelligent and adaptively monitoring of unpredictable and random variations in received signals [14].

The analysis for the current research is based on linearly placed 8 element antenna array on a substrate. We have chosen Rogers RT Duroid 5880 as a substrate with dielectric constant of 2.20, since it is available in the library of Advanced Design System (ADS) software from Agilent. It was easy to carry out simulations tests and optimizations with Duroid. The patch size was selected as 45 × 45 mm and slot size of 20 × 4 mm. The centre slot was placed at (7, 7) in the Cartesian coordinate system with a size of 4.535 × 1.667 mm. Our main aim was to achieve frequency at about 2 GHz for uplink applications in DS-CDMA communications.

3. Performance analysis of a single antenna element

The simulations were carried out on ADS software for the antenna elements described above for various performance parameters. Main focus was on resonance frequency matching with about 2 GHz. Figure 3 shows the gain and efficiency at resonance frequency. Figure 3 (a) shows gain at about 6.176

Figure 3. Patch antenna performance (a) Gain vs. frequency (b) Directivity vs. frequency (c) Efficiency vs. frequency and (d) Power radiated vs. frequency
dB and Figure 3 (b) illustrates directivity 7.5 dBi. Figure (c) shows and efficiency about 73.8 % and Figure 3 (d) demonstrates the power radiated which is about 1 mW.

**Figure 4.** Patch antenna performance on polar plots (a) Gain (b) Radiated power (c) Efficiency (d) Electric and magnetic fields (e) Absolute fields (f) Axial ratio and (g) absolute fields
Figure 4 illustrates the performance parameters’ of Figure 3 but in polar plot format. Additionally it illustrates effective area in $m^2$ and axel ration in Figures 4 (c) and 4 (f) respectively. Performance parameters of radiation pattern, impedance matching, return loss and phase information are given in Figures 5 (a) to (d) respectively. Impedance matching at resonance frequency is depicted in Figure 5 (b) indicated by marker $m_1$ on smith chart. The details of impedance matching circuits for this antenna design are not included in this paper.

![Figure 4](image1.png)

![Figure 5](image2.png)

**Figure 5.** Performance measures of simulation tests (a) $\Phi$-model diagram (b) Smith chart for impedance matching (c) Return loss and (d) Phase variations vs. frequency

Figure 5 (c) illustrates coefficient of return loss. Our simulation results indicate about $-1.2$ dB losses at resonance frequency of 2.119 GHz. Figure 5 (d) concludes with phase information. All parameters are summarized in Table 1. The radiated power was not very encouraging for the design simulated to match a given resonance frequency and patch size. The power can be further changed for a
given application as each of the applications need different scales. Efficiency also need to be improved. The main area of concern for the element antenna is return loss. This may be due to fact that we used a given substrate for fixed dimensions. Our next focus of this research is to analyze the various parameters with variations of thickness and dielectric constant of the substrate. The patch antenna designed and tested for the various parameters is then used as a single element for an array of 8 such elements.

### Table 1. Simulated performance values achieved for antenna array

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Performance Value</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonance Frequency</td>
<td>2.119 GHz</td>
<td>Frequency choice is based on 4G requirements</td>
</tr>
<tr>
<td>Gain</td>
<td>6.17 dB</td>
<td>Gain of first design and may be further refined</td>
</tr>
<tr>
<td>Directivity</td>
<td>7.49 Db</td>
<td>--</td>
</tr>
<tr>
<td>Efficiency</td>
<td>73.8 %</td>
<td>Efficiency is reasonably good but may be improved</td>
</tr>
<tr>
<td>Radiated Power</td>
<td>1 mW</td>
<td>Any rating may be achieved depending on application</td>
</tr>
<tr>
<td>Return Loss</td>
<td>- 1.2 dB</td>
<td>Return loss is currently high, working on improving</td>
</tr>
<tr>
<td>Impedance Matched</td>
<td>(0.2 – j1.368)</td>
<td>Matching is shown but circuits not designed</td>
</tr>
<tr>
<td>Effective Area</td>
<td>7 × 10³ mm²</td>
<td>Effective area is average</td>
</tr>
<tr>
<td>Axial Ration</td>
<td>26</td>
<td>Axial ratio is good</td>
</tr>
<tr>
<td>BER (single element)</td>
<td>75 × 10⁻³</td>
<td>BER is estimated at SNR of about 4</td>
</tr>
<tr>
<td>BER (array of 8 elements)</td>
<td>0.8 × 10⁻⁶</td>
<td>BER is estimated at SNR of about 4 for array antenna</td>
</tr>
</tbody>
</table>

5. **Performance analysis of antenna array**

We have simulated the single antenna element for different parametric values. After having done optimization of a single element, we performed simulation test for an array of 8 such antenna elements. The antenna elements are used as shown in Figure 1. Antenna elements’ output signals are fed to the weight correction circuits. Outputs from each element are summed up to produce the final single output. The output is then compared with desired signal and if there is any difference in the output produced and desired one, then an error is generated. The error is routed to the adaptive linear (ADALINE) neural network based intelligent adaptive algorithm circuits, implemented on FPGA. The ADALINE algorithm execution steps are illustrated in Table 2. The various symbols used in Table 2 are self explanatory from Figure 1. The current inputs from antenna array are represented by \( y_n \) as shown in Figure 1.

### Table 2. Execution steps of ADALINE net based on LMS algorithm

1. Get the input, \( x(t) \), to ADALINE network.
2. Determine square of the errors computed by \( e(t) = [d(t) – W(t) x(t)]^2 \).
3. Determine gradient by differentiating \( e(t) \) which is determined in step 3.
4. Approximately determine average of values in step 3.
5. Update the weights by \( W(n+1) = W(n) + [\text{Average error} \times x(n)] \)
6. Repeat steps 1 to 4 until \( e(t) \) is universally minimum.

The ADALINE neural network is based on least mean square error (LMS) algorithm. It is also called as LMS learning rule or Widrow-Hoff learning rule. It has advantages compare to perceptron as it always converges to the least squares of the error. ADALINE is also useful for the noisy signals as it can correct continuous errors easily. It is normally applied for arbitrary and complex decisions in the matter of real time online signals. We have used LMS learning rule as a dynamic system as it adapts to the ever changing conditions of the channel and random noise associated with it. The weights get adapted to the changing conditions easily based on the error estimates done.

The performance of array patch antenna is analyzed based on the Bit Error Rate (BER) of the transmitted signal for various noises to signal ratio. The simulation for the BER estimation was carried out using MATLAB and Communication toolbox. We used DS-CDMA communication by generating pseudo noise sequence and QPSK modulation technique for digital transmission. We added white noise and simulated the BER estimation of the array antenna.
Gaussian noise to simulate the real-time channel conditions. Figure 6 illustrates the BER performance of the antenna array compared to a single element antenna. The error is quite significantly reduced when an array is used. It is observed that error is about $75 \times 10^{-3}$ for a noise to signal ratio of 4 for a single element antenna, as shown in Figure 6 (a). If an antenna array of 8 elements is used then the error is about $0.8 \times 10^{-6}$, as shown in Figure 6 (b). It is improved by a factor of $10^4$. This has proven that array antenna has better performance compared to the single element antenna.

![Figure 6](image)

**Figure 6.** BER performance (a) Single element antenna (b) An array antenna of 8 elements

### 6. Conclusion and future scope

We have introduced an array of 8 element antennas for reducing interference and increasing capacity in CDMA communication. This, however, needs additional hardware and software resources, thereby increasing the cost for implementation. We have reported our research work in this paper, first for a single antenna element design and results of simulation tests for various performance parameters for the same. Next, we carried out simulation tests for the patch antenna array to be used for CDMA communications specially, wireless and mobile ones. Our design performances are comparable with most of the performances available for the literature review. The design has focused on only uplink application for a resonance frequency at about 2 GHz. At this frequency, we measured the various parameters of gain, directivity, efficiency, return loss and radiated power. These are listed in Table 1. The channel modeling was simulated on MATLAB for BER analysis. It shows that BER of DS-CDMA wireless digital communication has improved by a factor of $10^4$ if an array antenna, instead of a single element antenna, was used.

We used ADALINE neural network for adaptation of dynamic conditions for the antenna array as the receiving users and interfering users are located spatially at diverse positions. Learning rate for the training of neural network was based on LMS algorithm. The training sessions for the ADALINE neural networks are estimated and optimized for the convergence and delay requirements to suit the applications in DS-CDMA.

Future work will focus on the improving the performance of various parametric values and design of matching circuits for impedance and ADALINE neural network based LMS and X-LMS algorithms. The performance of BER may be further done for more dense users and interferers. Different types of noises are to be simulated and different types of receivers are to be analyzed for combating better with noise. There are many adaptive algorithms available for specific advantages for particular use. One can see opportunities in developing new algorithms and learning rules for training of adaptive neural networks. The orientation of patch antenna array makes significant effect on the final performance of
the transceiver circuits. The analysis on reverse and forward link is essentially important for real time applications. The antenna arrays may be effectively used for handling increased traffic for reverse and forward links. This is expected to offer good results for DS-CDMA mobile communication systems. Quite predictably, 4G requirements in near future will need rigorous research to enhance data rates and reliable quality of service for data transfer.

7. References