# Electronically Steerable Antenna for WLAN Application

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***Abstract*—In wireless communication systems, interference becomes a major problem in limiting the quality of the transmitted and received signals. A common problem in wireless communications is to eliminate the interference signal that is mixed with the original signal. Thus, adaptive beamforming is proposed to eliminate the interference signal. This paper presents an adaptive antenna using a slotted patch antenna for WLANs operated at 2.4 GHz. A reactively steerable antenna concept has been applied. A downhill simplex algorithm is used to maximize the cost function. The radiation pattern of the antenna is controlled by the reactance value connected to each port. From numerical simulation, null is performed for the incoming interference.**

***Keywords—adaptive beamforming; cost function; interference; multipath fading.***

## I. INTRODUCTION

The demand for mobile communications systems has generated a considerable amount of research activities in order to cope with the requirements such as, data throughput, mobility and cost. A new technology that can cope with these requirements is smart antennas. In order to achieve a maximum reception in a specific direction, a smart antenna uses an adaptive beamforming technique. By using adaptive beamforming the direction of the arrival signal can be estimate while rejecting signals of the same frequency from other directions. This can be achieved by varying the weight of each antenna element. The main idea is that, even if there are two same signals that occupy the same frequency are transmitted from different transmitters, the signals still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interference signal. In adaptive beamforming, the optimum weights are iteratively computed using complex algorithms.

Many studies have been conducted for a steerable antenna. Harrington proposed a seven-element dipole with one active element in the middle and surrounded by several passive elements [1]. In this method, the variable reactance load is used to control the radiation pattern of the antenna. An electronically steerable passive array radiator antenna (ESPAR) has been introduced by Ohira [2,3] has the capability to steer toward the desired signal and form nulls at the interference. Various algorithm has been used in ESPAR such as steepest descent, direct search, genetic algorithm and stochastic beamforming [4,5]

In this study, an electronically steerable antenna is designed using a slotted array antenna. The downhill simplex method algorithm has been chosen because it has the fastest convergence time [6-8].

## II. ADAPTIVE BEAMFORMING

### *A. Antenna Configuration*

In this study a slotted array antenna is designed using FR-4 board with a permittivity of 4.5. The antenna is designed for 2.4 GHz and is operated in the WLAN frequency band. The array antenna consists of 5 slotted square patch antennas. The size of the square is 41.2 mm x 41.2 mm with 13.7 mm x 13.7 mm slotted in the middle of the patch. The antenna is arranged as shown in Fig. 1, with one element in the middle and surrounded by four elements. The elements are placed at a distance of 28 mm from each other.

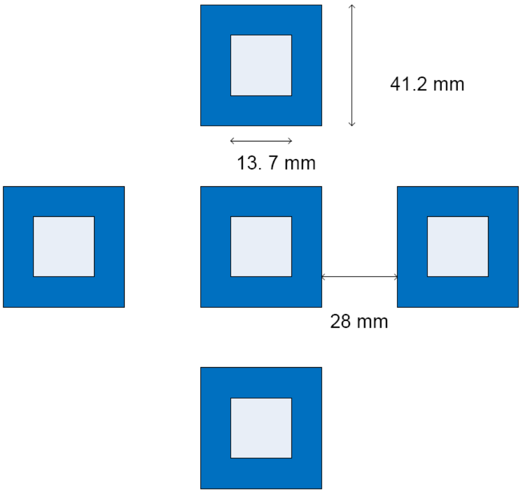

Fig. 1. Antenna structure and dimensions.

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### *B. Implementation of the Downhill Simplex Algorithm*

The application of the simplex method to the steerable antenna is discussed in this section. The cost function for this algorithm is cross correlation and therefore, it has to be maximized. After calculating the output signal, $y(t)$, the cross correlation can be calculated using equation (1). The cross correlation is a correlation between output of a signal, $y(t)$ and the reference signal, $r(t)$.

$$\rho = \frac{|y(t)r^*(t)|}{\sqrt{|y(t)y^*(t)|}\sqrt{|r(t)r^*(t)|}} \qquad (1)$$

The cross correlation represents the similarity of two signals. A large correlation indicates that the received signal (the sum of the desired signal and the delayed signal) is similar to the reference signal. Therefore, the objective of the algorithm is to determine the maximum value of the cost function. However, in simplex method algorithm, the goal is to look for the minimum value of the cost function, and for that reason, the negative value of the cross correlation is used [9].

In this paper, the simplex method uses the cross correlation as the cost function and produces a reactance value that will be loaded with the parasitic elements. Consider the four-dimensional coordinates $(x_1, x_2, ..., x_4)$ of the simplex corresponding to a set of reactance values.

First, an initial point of $(x_1, x_2, ..., x_4)$ is chosen. This point should be chosen carefully to prevent the algorithm falling to a local minimum. After the initial point is chosen, $\rho$ can be calculated using equation (1). The simplex method algorithm is search for a minimum point, therefore a minus sign is added to the ($\rho_a = -\rho$). After that, the process of the simplex method can be started.

The vertex with the largest $\rho_a$ provides the worst combination of $(x_1, x_2, ..., x_4)$. The largest point is reflected to the opposite as shown in Fig. 2 (a). Thus, it is expected that the reflected point provide a better coefficient.

The reflected point is compared with another vertex, if the reflected point is still high, the point is expanded further in the same direction as shown in Fig. 2(b), in order to find a better combination of points. Or else, the reflected point is contracted as depicted in Fig. 2(c).

If the expanded point provides a better coefficient than those of the previous points, the simplex is updated as shown in Fig. 2(b). Otherwise, it is updated as shown in Fig. 2(a). If the contracted point provides a poor coefficient than those of the previous points, the simplex is contracted as shown in Fig. 2(d). Otherwise, it is updated as shown in Fig.2(c). By following the simplex method sequences, the set of $(x_1, x_2, ..., x_4)$ that maximizes the cost function can be obtained.

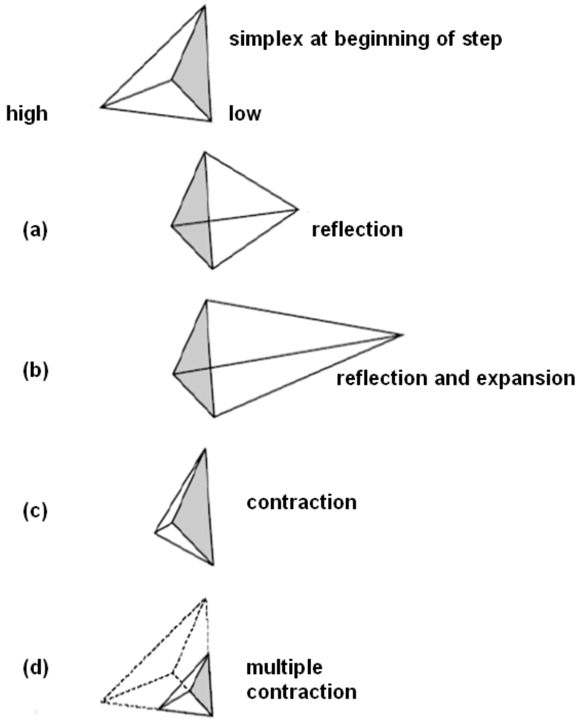


Fig. 2. Downhill Simplex Method [10].

### *C. Formulation of a Steerable Antenna*

This section briefly describes the adaptation of the antenna's configuration to the downhill simplex method. The proposed antenna consists of five slotted antennas; one is an active element surrounded by four passive elements as shown in Fig. 5. Variable reactance (denoted as $x_m$) is used to terminate the passive elements.. The vector x is represented as

$$x \cong [x_1, x_2, ......x_M]^T \qquad (2)$$

The beam pattern of the antenna is depends on the value of x. The beam pattern of the antenna is changed after the reactance value, x is varied.

The current vector *i* and the voltage vector *v* are related as follows

$$i = Yv \qquad (3)$$

The vector voltage, v can be calculated using equation (4),

$$\begin{bmatrix} v_0 \\ v_1 \\ \vdots \\ \vdots \\ v_m \end{bmatrix} = \begin{bmatrix} 1 - R_{i0} \\ -jx_1 i_1 \\ \vdots \\ \vdots \\ -jx_m i_m \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ \vdots \\ \vdots \\ 0 \end{bmatrix} - Xi \tag{4}$$

where

$$i = [i_0, i_1, i_2, \ldots\ldots, i_M]^T \tag{5}$$

$$X = diag[50, jx_1, jx_2, \ldots\ldots jx_M] \tag{6}$$

The reactance matrix is represented by equation (6), X is known as a diagonal matrix .

Equation (7) is used to calculate the beam pattern of the antenna,

$$fA(\varphi) = wa(\varphi) \tag{7}$$

where w is a weighted vector and $a(\varphi)$ is a steering vector. Weighted vector can be obtained using equation (8)

$$w = (I + jYX)^{-1} y_0 \tag{8}$$

where I is the identity matrix, Y is the admittance and X is the diagonal matrix depicted by (6) and the vector $y_0$

$$y_0 = [y_{00}, y_{10}, y_{20}, \ldots\ldots, y_{M0}]^T \tag{9}$$

The cross correlation for the output signal and the reference signal is defined in Equation (1). This cross correlation is used as the cost function. The aim of this simulation is to determine the maximum value of the cross correlation. However, the downhill simplex method is a search for the minimum. Therefore, a minus is added to the cross correlation to make it a negative value.

In the downhill simplex algorithm, we begin with an initial value of the reactance, which is denoted as x. This initial reactance value can be chosen arbitrarily. Sequences number of the cross correlation is calculated using this initial value of the reactance. This initial sequence of the cross correlation will be used to determine the highest point, the second highest point and the lowest point.

## III. RESULTS AND ANALYSIS

### A. *CST Simulation*

The CST software was used to perform the simulation of the antenna. The $S_{11}$ obtained from the simulation is depicted in Fig. 3. This figure shows that $S_{11}$ is -22.03 dB with a 1.44% bandwidth at 2.4 GHz. The gain of this antenna is 3.75 dB as indicated in Fig. 4.

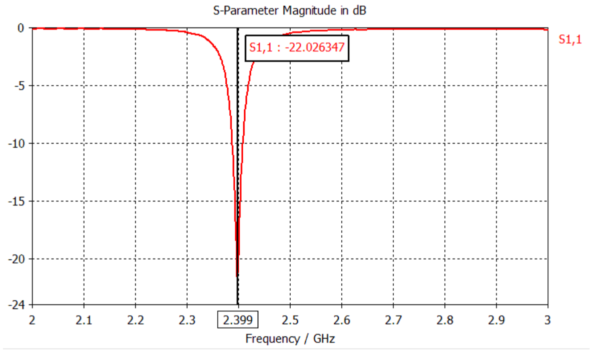
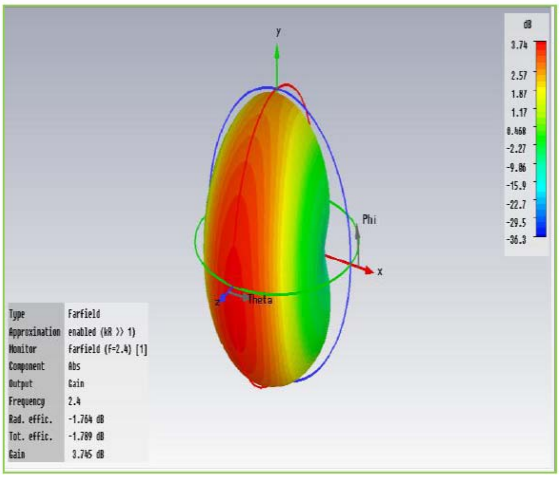


Fig. 3. Return loss for slotted array antenna.



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=2.4) [1] |
| Component | Abs |
| Output | Gain |
| Frequency | 2.4 |
| Rad. effic. | -1.764 dB |
| Tot. effic. | -1.789 dB |
| Gain | 3.745 dB |

Fig. 4. 3D radiation pattern for slotted array antenna.

### B. *MATLAB Simulation*

The simulation for the steerable antenna is performed using MATLAB. In this simulation, a five-element antenna was employed. One element is the active element and the remaining four elements (denoted by $jx_1 - jx_4$) are passive elements which surround the active element, and there are connected to the variable reactance circuit (refer Fig. 4). Fig. 5 shows the overall concept of the proposed antenna. The system begins its operation by calculating the correlation coefficient of the reference signal and the output of the slotted array antenna. Then, it searches for the minimum value of the cost function and sends the new reactance value to each port of the passive elements. The beam pattern changes if the reactance value varies. The parameter listed in Table I, are used in the simulation. For the modulation schemes, Binary Phase Shift Keying (BPSK) is used. In this simulation, two signals (the desired signal and the interference) are used, both signals are assumed to have same amplitude and incident from random directions.

TABLE I. SIMULATION CONDITIONS

| Modulation | BPSK |
|---|---|
| No. of signals | 1 desired signal<br>1 interference |
| Amplitude | 1 |
| Direction of arrival (DOA) | Random |

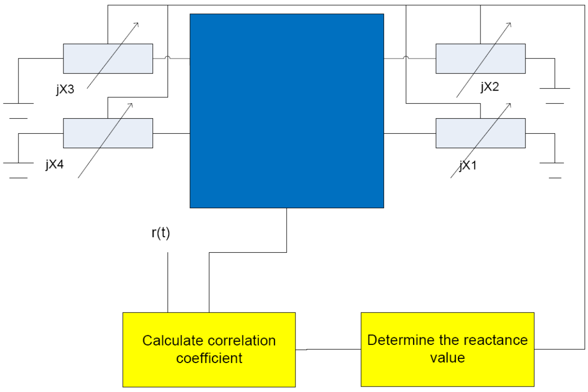


Fig. 5. Basic antenna configuration for adaptive beamforming.

Fig. 6 shows the beam pattern obtained from two scenarios where the desired and interference are randomly selected. The red arrow represents the incoming interference and the desired signal is represented by the black arrow. The simulation demonstrates that the proposed antenna can eliminate the incoming interference. As can be observed, null is performed for the interference coming from 30° and 120°.

By varying the reactance values, the interference can be eliminated. The reactance values are different for each incoming DOA. The reactance value for two DOAs can be referred to Table II. For the direction of arrival (DOA) 90°, it took 0.0362 s to convergence the signal with 64 iterations, and for the DOA 0° the time required to converge the signal is 0.0335 s with 51 iterations.

TABLE II. SIMULATION RESULTS

| DOA | Convergence time (s) | Iteration number | Reactance values(Ω) | | | |
|---|---|---|---|---|---|---|
| 90°, 30° | 0.0632 | 64 | -220.1 | 34.8 | 214.8 | -75.0 |
| 0°, 120° | 0.0335 | 51 | 28.9 | 9.4 | 31.1 | 54.3 |

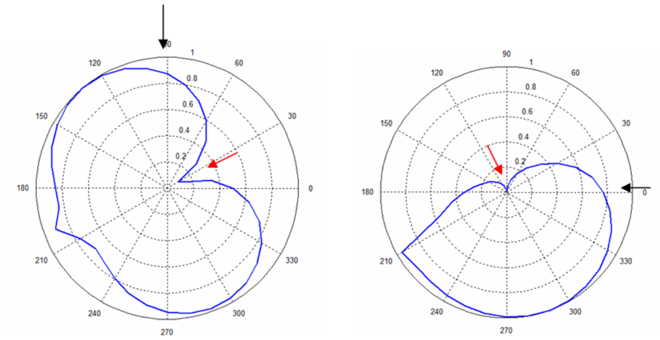


Fig. 6. Beam pattern for two incoming signals.

## IV. CONCLUSION

A smart antenna using adaptive beamforming has been designed in this paper. The antenna is modeled using a slotted patch antenna. The designed antenna is capable to steer at the desired signal and eliminate the interference. From the MATLAB simulation, null is performed for the incoming interference while retaining a high gain for the desired signal. The designed antenna is suitable for a moving system because it has the fastest convergence time.

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