



## STEERABLE ARRAY ANTENNA

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### ABSTRACT

This paper presents the design of an electronically steerable array antenna. An adaptive antenna using a slotted patch antenna for WLANs operated at 2.4 GHz is proposed. The designed antenna has five elements array, one for active elements and the remaining four are passive elements which connected to the variable reactance circuit. The variable reactance value will vary the beam pattern of the antenna. For the simulation, OFDM signal is used for the incoming signal and interference. Correlation between HGI and TGI is calculated as an objective function of the algorithm. A downhill simplex algorithm is used to maximize the cost function. From numerical simulation, null is performed for the incoming interference.

**Keywords:** Downhill simplex method algorithm • Slotted antenna • Steerable • Interference

### INTRODUCTION

In land mobile communication, there is no clear line of sight (LOS) between transmitter and receiver especially for moving systems. The receiver might receive the reflected signals instead of the original signal. The LOS is often blocked by obstacles which will lead the signal to be reflected as shown in Figure 1. The received signal is a combination of refracted signal, attenuation signal, reflected signal and diffraction signal. This effect is known as multipath fading effects. The carrier to noise ratio (CNR) is degraded because of multipath effects.

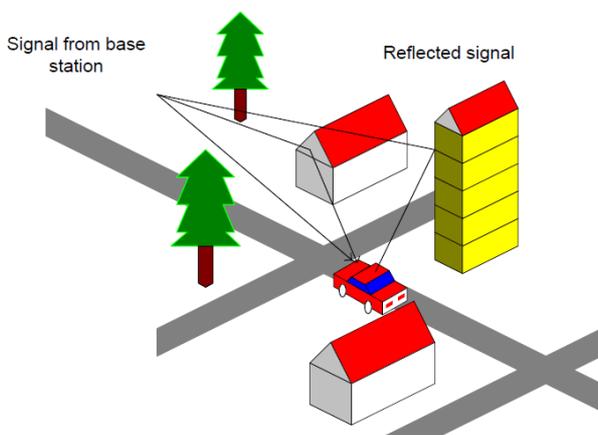


Figure 1: Multipath effects

Besides that, signal to noise ratio (SNR) also degraded because of frequency selective fading in multipath fading effects. Due to those effects, the transmission quality is definitely degraded. Therefore, Sklar has introduced several techniques to mitigate the effects of multipath fading (Sklar 1997). In order to eliminate the distortion caused by frequency selective fading, he has proposed to use an adaptive equalization, spread spectrum, and pilot signal. He also suggested several types of diversity to overcome the loss effects caused by flat fading and slow fading.

Nowadays, many researches on smart antenna has been conducted. Smart antennas are an array antenna that

can steer the beam toward the desired signal and eliminate the undesired signal (interference). There are two types of adaptive array antennas; switched beam array and adaptive beamforming antenna. Switched beam array antennas are antennas that only controlled the direction of maximum radiation. This antenna offers fixed beam direction. Meanwhile, the adaptive beamforming antennas controlled the radiation in all directions.

Adaptive array antenna is the best candidate to overcome this phenomenon (Godara 1997). Harrington has design a reactively steerable adaptive array (RSAA) using dipole antenna. This antenna is an adaptive array with single receiver. For reactively controlled antenna array, the beam pattern is controlled by varying the reactive loads. By optimizing the gain, we are able to steer the beam toward the maximum gain direction which is the desired signal (Harrington 1978). Many studies has been conducted for adaptive beamforming antenna. These array antennas are consisting of several radiating elements such as a dipole or patch. These antennas have serious problems such as a bulky structures and a large amount of calculation because of blind algorithm (Cheng (2001), Schlub (2003), Vlasits (2008) & Abdullah (2010)).

In this study, a 5-elements of slotted patch antenna has been designed. An adaptive beam is formed by maximizing the correlation coefficient between the sampled signal and sampled time interval between Head Guard Interval (HGI) and Tail Guard Interval (TGI).

### ANTENNA DESIGN

#### Antenna Configuration

The simulation for the slotted antenna is carried out by using CST. The designed antenna consists of 5 elements. The size for each element is 41.2 mm x 41.2 mm with 13.7 mm x 13.7 mm slotted at the middle of the patch as shown in Figure 2.

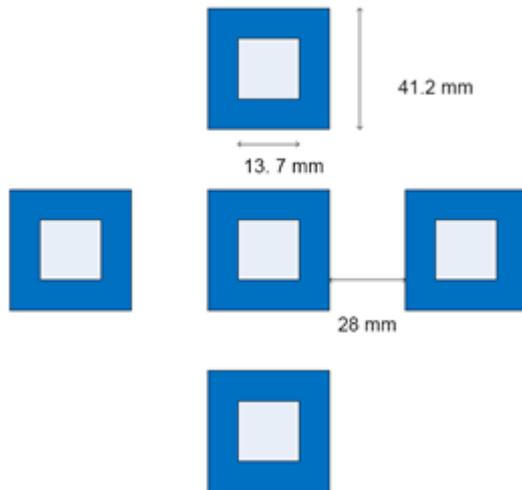


Figure 2: Antenna dimensions

### Description of Simplex Method

This section will describe about the downhill simplex method. It is an iterative search technique to minimize a function that is nonlinear in parameters. This method also known as Nelder-Mead method. The advantage of using Simplex method is it can be used to solve N-dimensional geometry. Simplex is a geometrical figure consisting N dimensions of N+1 points and all interconnecting line segments and polygonal faces. For example, in two dimensional, simplex is viewed as triangle.

Simplex method starts with defining,  $P_0$  which is consists of N+1 points. After that all points in  $P_0$  will be classified to highest point ( $x_h$ ), second highest point ( $x_{sh}$ ) and lowest point ( $x_l$ ). Simplex method has several possible steps such as reflection, expansion, contraction and multiple contractions as shown in Figure 3. All this steps are required in order to discard the highest point.

The process starts by reflecting the highest point,  $x_h$  to a new point denoted as,  $x_r$ . Point  $x_r$  is defined as

$$x_r = (1 + \alpha)\bar{x} - \alpha x_h \quad (1)$$

Where,  $\alpha$  is a reflection coefficient, and  $\bar{x}$  is a centroid point defined as

$$\bar{x} = \frac{1}{M} \sum_{i=1}^M x_i \quad i \neq h \quad (2)$$

If  $P_l < P_r < P_{sh}$ , then replaced  $x_h$  with  $x_r$  and start the new process again. If  $P_r < P_l$ , then there is possibility to find new minimum point. Therefore, the  $x_r$  point is expanded along the same direction using the following equation,  $x_e$

$$x_e = \bar{x} + \beta(x_r - \bar{x}) \quad (3)$$

Where,  $\beta$  is an expansion coefficient and greater than one ( $\beta > 1$ ). If  $P_e < P_h$ , then replaced  $x_h$  with  $x_e$  and repeat the process again. However, if  $P_e$  is greater or equal to  $P_h$ , then new simplex is formed by replacing  $x_h$  by  $x_r$  and continue the process.

If the reflection process leads the  $P_r$  to be greater than  $P_h$ , then contraction is performed using the following equation,

$$x_c = \bar{x} + \gamma(x_h - \bar{x}) \quad (4)$$

Where,  $\gamma$  is a contraction coefficient lies between 0 and 1. If  $P_c > P_h$ , the highest point cannot be discard, therefore contracted again around the lowest point. Otherwise, replaced  $x_h$  with  $x_c$  and restart the process again until the minimum value of P. Nelder has defined the best value for reflection, expansion and contraction coefficient is -1, 2 and 0.5, respectively (Nelder 1965).

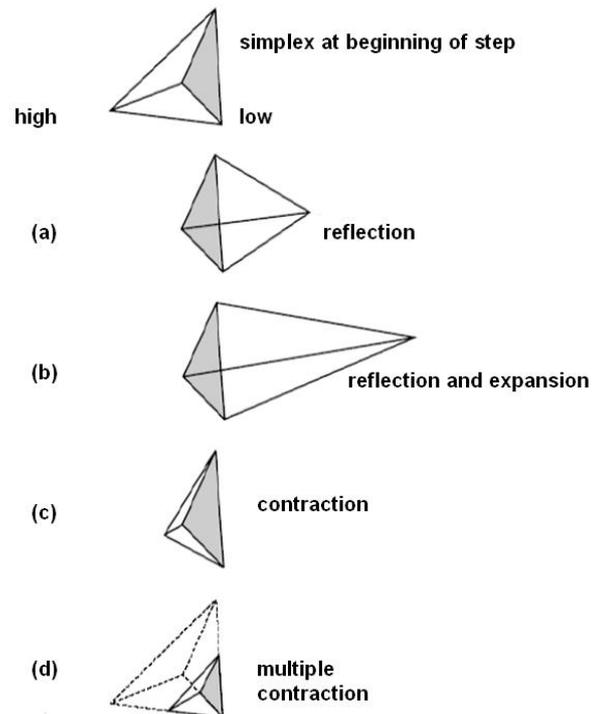


Figure 3: Downhill Simplex Method (Press).

### Implementation of Simplex Method

In this study, Orthogonal Frequency Division Multiplexing (OFDM) signal is used as an incident and delayed signal. HGI is placed at the head of the symbol. The correlation between HGI and TGI should be one because HGI is a copy of TGI.

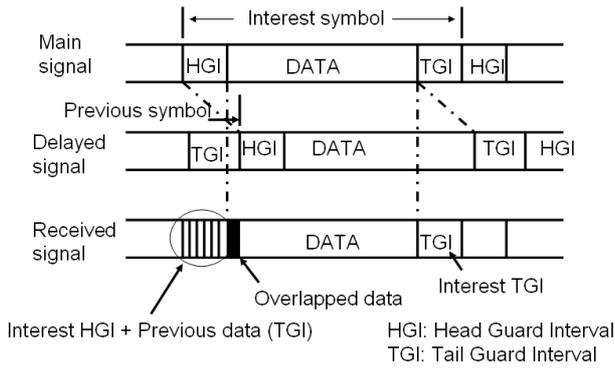


Figure 4: OFDM signal

Figure 4 shows the main signal, delayed signal, and received signal. The correlation between HGI and TGI is calculated using equation (5).

$$\rho = \frac{|\sum_n y(n)y(n+m)^*|}{\sqrt{|\sum_n y(n)y(n)^*|} \sqrt{|\sum_n y(n+m)y(n+m)^*|}} \quad (5)$$

where  $y(n)$  denotes the sampled signal of  $y(t)$ , and  $m$  denotes the sampled time interval between HGI and TGI.

If the correlation between HGI and TGI of the received signal becomes large, the delayed signal has to be cancelled. The correlation between HGI and TGI is used as an objective function.

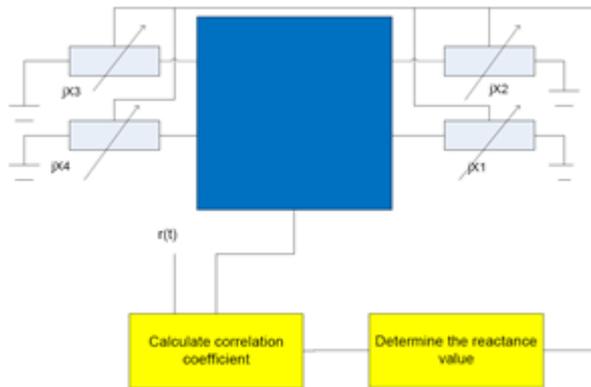


Figure 5: Concept of proposed antenna

**RESULTS AND ANALYSIS**

**Spatial Cross Correlation**

Spatial cross correlation (SCC) is calculated by using equation 6 using MATLAB. The SCC must be less than 0.5 in order to ensure the capability of the antenna to operate as diversity antenna. From simulation, the SCC for each pair of ports are less than 0.5 as tabulated in Table 1.

$$SCC = \frac{\left| \int_0^{2\pi} \int_0^\pi A_1^*(\theta, \varphi) A_2(\theta, \varphi) d\theta d\varphi \right|^2}{\sqrt{\int_0^{2\pi} \int_0^\pi A_1^*(\theta, \varphi) A_1(\theta, \varphi) d\theta d\varphi} \sqrt{\int_0^{2\pi} \int_0^\pi A_2^*(\theta, \varphi) A_2(\theta, \varphi) d\theta d\varphi}} \quad (6)$$

Table 1: Simulated Spatial Cross Correlation

Port	1	2	3	4	5
1		0.1058	0.0982	0.1128	0.2062
2	0.1058		0.0495	0.0397	0.1112
3	0.0982	0.0495		0.0079	0.0857
4	0.1128	0.0397	0.0079		0.0570
5	0.2062	0.1112	0.0857	0.0570	

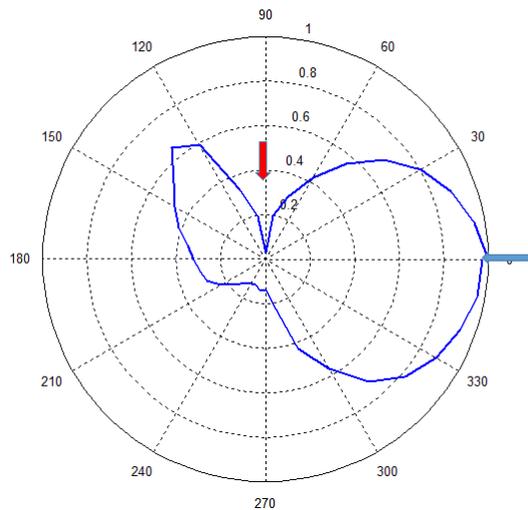
**Adaptive Beamforming**

Adaptive beamforming simulation is done using MATLAB. As mentioned in previous part, the designed antenna has five-elements. One element is set to be active element (the middle patch as depicted in Figure 2). The other four elements that surround the active elements are set as passive elements (denoted by  $jx_1 - jx_4$ ). There are connected to the variable reactance. The overall concept of the designed antenna is depicted in Figure 5. The simulation starts by calculating the correlation coefficient between HGI and TGI. 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 reactance value will changed the beam pattern of the antenna. The parameter listed in Table 2, are used in the simulation. For the modulation schemes, OFDM signal 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.

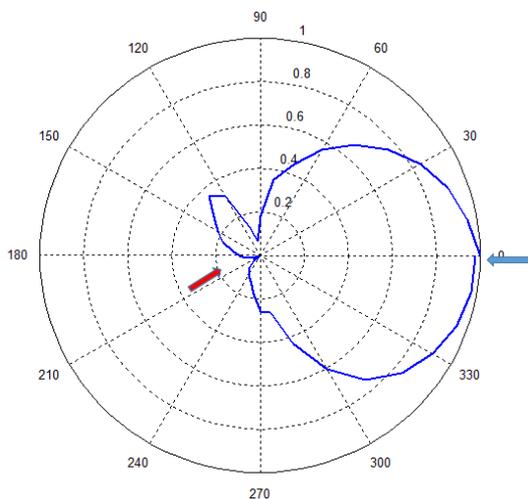
Table 2: Simulation parameters

Modulation	OFDM
No. of signals	1 desired signal 1 interference
Amplitude	1
Direction of arrival (DOA)	0°, 90° 0°, 210°

Figure 6 shows the beam pattern 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 blue 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 90° and 210°.



(a) DOA 0°, 90°



(b) DOA 0°, 210°

Figure 6: Beam pattern from MATLAB simulation

By varying the reactance values, the interference can be eliminated. The reactance values are different for each interference. The reactance value for two DOAs can be referred to Table 3. For the interference coming from 90°, it took 0.0623 s to convergence the signal with 51 iterations, with SINR 15.1 dB. For the interference coming from 210° the time required to converge the signal is 0.0494 s with 38 iterations with SINR 33.76 dB.

Table 3: Simulation Results

DOA	Convergence time (s)	Iteration number	Reactance values( $\Omega$ )			
0°, 90°	0.0623	51	-21.49	15.88	25.84	-20.65
0°, 210°	0.0494	38	-13.65	4.61	29.17	59.4

## CONCLUSIONS

A steerable antenna has been designed, modelled in this paper. The simulated results have been presented and discussed. The antenna is modelled using a slotted patch antenna. This designed antenna has SCC less than 0.5 for a better diversity performance. From MATLAB simulation, the designed antenna is capable to eliminate incoming interference and steer towards the desired signal. The beam of the antenna is controlled by reactance value which was calculated using downhill simplex method algorithm.

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## REFERENCE

Sklar B.(1997). Rayleigh fading channels in mobile communication systems Part 2: Mitigation, *IEEE Communication Magazine*, July 1997, pp.102-109.

Godara L. C.,(1997). Application of antenna array to mobile communications, part 1: Performance improvement, feasibility, and systems considerations, *Proc. IEEE*, Vol. 85, No. 7, July 1997, pp. 1031-1060.

Harrington R. F (1978), Reactively controlled directive arrays, *IEEE Transaction on Antennas and Propagation*, Vol. AP-26, No. 3, pp. 390-395, May 1978.

Cheng. J, Kamiya Y., and Ohira T.(2001), Adaptive beamforming of ESPAR antenna based on steepest descent gradient algorithm, *IEICE Transaction on Communication*, Vol. E84-B, No.7, pp. 1790-1800, July 2001.

Schlub R., Wei J., and Ohira T.(2003), Seven-element ground skirt monopole ESPAR antenna design from a genetic algorithm and the finite element method, *IEEE transaction on Antennas and Propagation*, Vol. 51, No. 11, pp. 3033-3039, Nov. 2003.

Vlasis B., Athanasios G. K., Antonis K., and Constantinos P. A.(2008), Stochastic Beamforming algorithm for ESPAR Antennas, *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, pp. 745-748, 2008.

Abdullah N., and Kuwahara Y.(2010), A Study of ESPAR Antenna, *International Conference on Microwave and Millimeter Wave Technology 2010*, pp 1999-2002, 2010.

Nelder J. A., and Mead R.(1965). A simplex method for function minimization, *Computer Journal*, Vol. 7. No. 4, pp. 308-313, 1965.

Press W. H., Teulkolsky S. A., Vetterling W. T., and Flannery B. P., Numerical recipes in C; The Art of Scientific Computing, *Cambridge University Press*, Second Edition, pp.408-411.