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# A Novel Indoor UWB Antenna Array Design by GA

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***Abstract*—In this paper, a new ultra wideband circular antenna array (UCAA) combining genetic algorithm(GA) to minimize the bit error rate (BER) is proposed. The novelties of our approach is not only choosing BER as the object function instead of sidelobe level of the antenna pattern, but also consider the antenna feed length effect of each array element. The strong point of the genetic algorithm is that it can find out the solution even if the performance index cannot be formulated by simple equations. In other words, the receiver can increase the received signal energy to noise ratio. The synthesized array pattern also can mitigate severe multipath fading in complex propagation environment. As a result, the BER can be reduced substantially in indoor UWB communication system.**

***Keywords-UWB;GA;BER;feed length;circular antenna array***

## I. INTRODUCTION

Ultra wideband (UWB) technology is an ideal candidate for a low power, low cost, high data rate, and short rang wireless communication systems. According to the Federal Communication Commission (FCC), UWB signal is defined as a signal having fractional bandwidth greater than 20% of the center frequency [1]. Ultra wide bandwidth of the system causes antenna design to be a new challenge [2]-[5]. This is because the multipath fading and interferences become more apparent than in narrow band system. In order to overcome these phenomenon, smart antenna technology are envisaged as one of possible solutions.

Smart antennas employ arrays of antenna elements and can integrate multiple antenna elements with a signal processing. These smart antennas combine the signals from multiple antennas in a way that mitigates multipath fading and maximize the output signal-to-noise ratio. It can dramatically increase the performance of a communication system. The smart antenna technology in wireless communication can apply to the receiver [6],[7] and the transmitter [8],[9]. The smart antenna technique at receiver is to perform combining or choosing in order to improve the quality of the received signal. When using the smart antenna to be transmitter, it can focus the synthesized antenna array pattern to optimize available processing gain to the receiver by adjusting the excitation phase delay and amplitude of each antenna array element and so on.

When synthesizing the antenna array pattern to minimize the BER. The excitation problem is reformulated as optimization problem and the constraint conditions are often highly nonlinear and non-differentiable. Thus, we use the genetic algorithm to regulate the antenna feed length of each array element to minimize the BER performance. As a result, the receiver can increase the received signal energy to noise ratio. Moreover, it can mitigate severe multipath fading and reduce the effective delay spread of the channel.

In this paper, the genetic algorithm is used to regulate the antenna feed length of each array element to minimize the BER performance of the communication system. The remaining sections of this paper are organized as follows: section II briefly explains the formulation of the problem which include antenna pattern, channel modeling and the BER calculation. Section III describes the genetic algorithm. The propagation modeling and numerical results are then presented in section IV and conclusion is made in section V.

## II. SYSTEM DESCRIPTION

The entire link can be described in terms of the block diagram in Fig. 1. It shows the B-PAM UWB modulator, equivalent baseband impulse response $h_b(t)$ which includes the effect of the circular antenna array, a correlate receiver and feed length controller (regulated by Genetic algorithm to minimize BER).

### A. Circular array pattern

We consider a circular array of N UWB printed dipole antenna, as shown in Fig. 2. Each element is apart along a circle of radius $\Gamma$ with spaced 5cm which is

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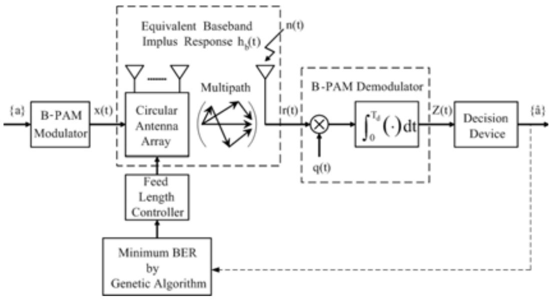


Figure 1. Block diagram of the simulated system

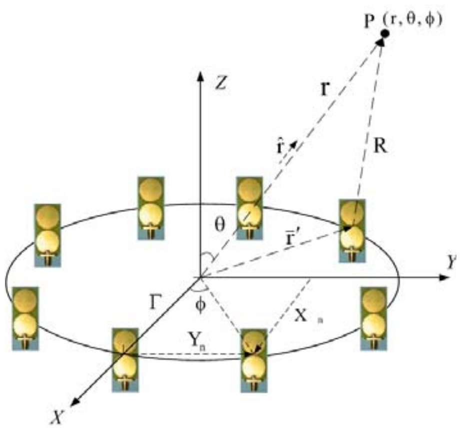


Figure 2. Geometry of a circular antenna of 8 UWB printed dipole antennas

corresponding to the half wavelength of 3 GHz. The radiation pattern between 3GHz and 6GHz is omnidirectional in the azimuth plane, which is interesting for communications between objects having undefined position in relation to each other. According to this advantage, we use this kind of antenna for circular array element. The array factor of this circular antenna array can be written as

$$AF(\theta,\phi,f) = \sum_{n=0}^{N} F_n \exp\left[-j\left(k\cdot X_n \sin\theta\cos\phi + k\cdot Y_n \sin\theta\sin\phi + \psi_n\right)\right] \quad (1)$$

where $\theta$ and $\phi$ are the spherical coordinate angles from the origin to the viewpoint in the elevation plane and azimuth plane. F is the frequency of sinusoidal wave. N is the element number. $k = 2\pi/\lambda$ is the wavenumber, where $\lambda$ is the wavelength of sinusoidal wave. $\psi_n$ is the excitation current phase delay of the n-th element and $F_n$ is the element excitation current amplitude of the n-th element. In this paper, all $F_n$ are set to 1. $X_n$ and $Y_n$ are the position of n-th array element. Thus the total radiation vector can be expressed as

$$\vec{N}(\theta,\phi,f) = AF(\theta,\phi,f)\cdot \vec{N}_e(\theta,\phi,f) \quad (2)$$

Where $\vec{N}_e(\theta,\phi,f)$ is the radiation vector of individual element which can be obtained by the HFSS software based on the finite element method.

## B. *UWB Channel modeling*

Because the UWB communication span a wide bandwidth in the frequency domain, the channel impulse response variations are significant for different type antennas [10],[11]. As a result, we do not only describe the antenna radiation pattern which varies with different frequencies but also use the SBR/Image technique to calculate the channel impulse response which includes angular characteristics of radiation patterns and the variation between different frequencies of wave propagation.

SBR/Image techniques are good techniques to calculate channel frequency response for wireless communication [12],[13]. In this paper, we develop SBR/Image techniques including antenna pattern to model our simulation channel. It can performed the identification of major scattering objects causing reflection, diffraction and penetration in our simulation environment. The SBR/Image technique conceptually assumes that many triangular ray tubes (not rays) are shot from a transmitter. Here the triangular ray tubes whose vertexes are on a sphere are determined by the following method. First, we construct an icosahedron which is made of 20 identical equilateral triangles. Then, each triangle of the icosahedron is tessellated into a lot of smaller equilateral triangles. Finally, these small triangles are projected on to the sphere and each ray tube whose vertexes are determined by the small equilateral triangle is constructed. Then each ray tube will bounce and penetrate in the simulate environments. If the receiver falls within the reflected ray tube, the contribution of the ray tube to the receiver can be attributed to an equivalent source (image). Using these images and received fields, the channel frequency response can be obtained as following

$$H(f) = \sum_{i=1}^{N_i} \left|a_i(f)\right| e^{j\theta_i(f)} \quad (3)$$

Where f is the frequency of sinusoidal wave, i is the path index, $\theta_i$ is the i-th phase shift, $|a_i|$ is the i-th receiving magnitude which depend on the radiation vector of the transmitting and receiving antenna in (2). Note that the receiving antenna in our simulation is only one omnidirectional UWB dipole antenna and the transmitter is the UWB circular antenna array (UCAA) which has been described in above section. The channel frequency response of UWB can be calculated by equation (3) in the frequency range of UWB.

The frequency response are transformed to the time domain by using the inverse fast Fourier transform with the

Hermitian signal processing [14]. Therefore the time domain impulse response of the equivalent baseband can be written as follows

$$h_b(t) = \sum_{m=1}^{M} \alpha_m \delta(t - \tau_m) \quad (4)$$

Where M is the number of paths observed at time. $\alpha_m$ and $\tau_m$ are the channel gain and time delay for the n-th path respectively.

*C. Formulation of BER*

As shown in Fig. 1, {a} is the input binary data stream and $\{\widehat{a}\}$ is the output binary data stream after demodulator and decision device. When {a} passing through the B-PAM modulator, the transmitted UWB pulse stream is expressed as follows:

$$x(t) = \sqrt{E_t} \sum_{n=0}^{\infty} p(t - nT_d) d_n \quad (5)$$

The average BER for B-PAM IR UWB system can be expressed as

$$BER = \sum_{n=0}^{N} P(\bar{d}_n) \cdot \frac{1}{2} erfc\left[ \frac{V(t = nT_d)}{\sqrt{2}\sigma} \cdot (d_N) \right] \quad (6)$$

## III. GENETIC ALGORITHM

Genetic algorithms are the global numerical optimization methods based on genetic recombination and evaluation in nature [15],[16]. They use the iterative optimization procedures, which start with a randomly selected population of potential solutions. Then gradually evolve toward a better solution through the application of the genetic operators. Genetic algorithms typically operate on a discretized and coded representation of the parameters rather than on the parameters themselves. These representations are often considered to be "chromosomes", while the individual element, which constitutes chromosomes, is the "gene". Simple but often very effective chromosome representations for optimization problem involving several continuous parameters can be obtained through the juxtaposition of discretized binary representations of the individual parameter.

When analyzing the circular antenna array, the feed length of each array element provides the phase delay of excitation current which varies with different frequencies. The relationship between n-th antenna feed length $\ell_n$ and the excitation current phase delay $\psi_n$ can be expressed as follows:

$$\psi_n = \frac{2\pi}{\lambda} \ell_n \quad (7)$$

Where $\lambda$ is the wavelength. Thus, we regulate the antenna feed length of each array element to get a optimal radiation pattern which can minimize the BER performance. The feed length of each array element can be decode by the following equation：

$$\ell_n = Q_{min} + \frac{Q_{max} - Q_{min}}{2^M - 1} \sum_{i=0}^{M-1} b_i^{\ell_n} 2^i \quad (8)$$

where $b_0^{\ell_n}, b_1^{\ell_n}, \cdots, b_{M-1}^{\ell_n}$ (genes) are M-bit strings of the binary representation of $\ell_n$ .The $Q_{min}$ and $Q_{max}$ are the minimum and the maximum values admissible for $\ell_n$ , respectively. In practical cases, $Q_{min}$ and $Q_{max}$ can be determined by the prior knowledge of the objects. Therefore, we set the $Q_{min}$ = 0.0 cm and $Q_{max}$ = 10.0 cm which is according to the minimum frequency 3GHz. Then the unknown coefficients in (8) are described by a $N \times M$ bit string (chromosome). The genetic algorithm starts with a population containing a total of $N_p$ candidates (i.e., $N_p$ is the population size). Each candidate is described by a chromosome. Then the initial population can simply be created by taking $N_p$ random chromosomes. GA iteratively generates a new population, which is derived from the previous population through the application of the reproduction, crossover, and mutation operators.

The genetic algorithm is used to maximize the following fitness function (FF):

$$FF = \left\{ \sum_{n=0}^{N} P(\bar{d}_n) \cdot \frac{1}{2} erfc\left[ \frac{V(t = nT_d)}{\sqrt{2}\sigma} \cdot (d_N) \right] \right\}^{-1} \quad (9)$$

Where FF is the inverse of the average BER for B-PAM IR UWB system. Through repeated applications of reproduction, crossover, and mutation operators, the initial population is transformed into a new population in an iterative manner. New populations will contain increasingly better chromosomes and will eventually converge to an optimal population that consists of the optimal chromosomes. In our simulation, when the fitness function is bigger than the threshold value or GA do not find a better individual within 300 successive generations. The genetic algorithm will be terminated and a solution is then obtained.

## IV. NUMERICAL RESULTS

A realistic environment is investigated. It consists of a living room with dimensions 10mx10mx3m, housing one metallic cupboard and three wooden bookcases. Both of the cupboard and bookcase are 2 meter in height. The radio wave can penetrate through the wooden bookcase and total reflect by the metallic cupboard. The plan view of the simulated environment is shown in Fig. 3. Tx and Rx1, Rx2 antennas were all mounted 1 meter above the floor. The transmitter Tx position is (7m,5m,1m). Scenario has no line-of-sight path to the Rx2(5m,1m,1m), since the wooden bookcase was higher than the Tx and Rx2. The Tx - Rx2 distance on the horizontal plane is 4.3 meter in Scenarios. Scenario using three kinds of transmitting antennas: (a) Only one UWB printed dipole antenna (OUA) (b) A circular

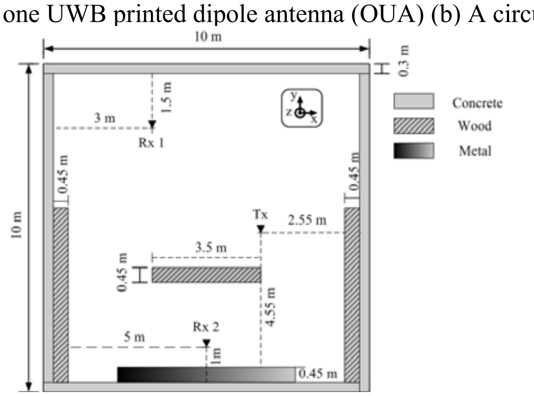


Figure 3. Block diagram of the simulated system

array of eight UWB printed Dipole antenna, each element antenna has the same feed Length without GA regulating (NOGA-UCAA) (c) A circular array of eight UWB printed dipole antenna , each element antenna feed length was regulated by GA(GA-UCAA). A three-dimensional SBR/Image technique combined antenna radiation pattern has been presented in this paper. This technique is used to calculate the UWB channel impulse response for each location of the receiver.

Furthermore, we use the impulse response to calculate the BER. The frequency range for the UWB channel is simulated from 3GHz to 6GHz, because the array element has the omnidirectional characteristic in this frequency range [11]. Other simulation specifications are summarized in table I.

Fig. 4 shows the BER V.S. SNR for Scenario using three kinds of transmitters. The results show that the BER curve decrease when using the GA-UCAA to be transmitter.

All of the above results demonstrate the GA-UCAA which present in this paper is powerful. When applying this antenna array NLOS propagation environment, it can increase the ratio of combined receiving signal energy to noise. It also can mitigate severe multipath fading in complex propagation environment. For these reasons, the BER can be reduced substantially in indoor UWB communication system.

TABLE I

SPECIFICATIONS OF THE ANTENNA AND GENETIC ALGORITHM

| | |
|---|---|
| Antenna | UWB circular antenna array |
| Number of array element (N) | 8 |
| Circle of radius $r$ | 6.75 (cm) |
| Polarization of Tx - Rx | Vertical - Vertical |
| Transmitted signal to noise ratio | At least 20 dB |
| GA population size | 200 |
| Binary string length | 10 |
| Search range of the feed length | 0.0 to 10.0 (cm) |
| The probability of crossover and mutation | 0.5 and 0.02 |

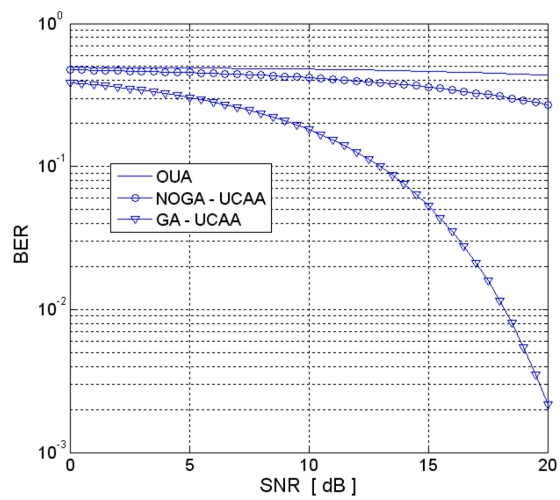


Figure 4. BER V.S. SNR over Scenario for three kinds of transmitter

## V. CONCLUSIONS

Using the smart UWB circular antenna array to minimize the BER performance in indoor wireless local loop is presented. The impulse response of the channel is computed by SBR/Image techniques, inverse fast Fourier transform and Hermitian processing. By using the impulse response of the multipath channel and the genetic algorithm synthesizing optimal antenna radiation pattern, the BER performance of B-PAM IR UWB communication system is investigated. Base on the BER formulation, the synthesis problem can be reformulated into an optimization problem.


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