OPTIMAL DESIGN OF SMART ANTENNA ARRAY

Gao Feng Liu Qizhong Shan Runhong* Zhang Hou
(Institute of Antenna and EM Scattering, Xidian University, Xi’an 710071)
* (Institute of Computer, National University of Defense Technology, Changsha 410073)

Abstract This letter investigates an efficient design procedure integrating the Genetic Algorithm (GA) with the Finite Difference Time Domain (FDTD) for the fast optimal design of Smart Antenna Arrays (SAA). The FDTD is used to analyze SAA with mutual coupling. Then, on the basis of the Maximal Signal to Noise Ratio (MSNR) criteria, the GA is applied to the optimization of weighting elements and structure of SAA. Finally, the effectiveness of the analysis is evaluated by experimental antenna arrays.

Key words Genetic Algorithm(GA); Finite Difference Time Domain (FDTD); Mutual coupling; Weighting element; Beam-forming

I. Introduction

The rapid increase in the number of users of cellular phones and personal communication devices poses certain challenges for mobile communication, such as limited frequency spectrum and co-channel interference. With an antenna array and proper array signal processing techniques, a smart antenna system can alleviate these problems by suppressing the interference and reducing the effect of multi-path fading.

Commonly used adaptation methods in smart antenna system are based on simplified model of antenna array, in particular mutual coupling among the radiating elements is not included. Recently much attention is paid to mutual coupling [1-3], these methods generally analyze simple Linear Equally Space (LES) array or circular array made up of ideal simple dipole antenna. On the other hand, the genetic algorithm is used to simulate adaptation of smart antenna, but these methods do not analyze electromagnetic effects such as mutual coupling and polarization characteristics [4,5].

In this letter, the coaxial collinear microstrip antenna that is desirable as an element of the arrays is used to constitute the LES array and the circular array. Based on the Maximal Signal to Noise Ratio (MSNR) criteria, this letter investigates an efficient design integrating the Genetic Algorithm(GA) with the Finite Difference Time Domain (FDTD) for the optimal design of smart antenna. This approach analyzes mutual coupling completely and optimizes weighting elements and structure of antenna arrays. Finally, the experimental smart antenna circular array is manufactured to demonstrate its effectiveness.

II. Model of Antenna Array

1. Element of antenna array
An element of the antenna array is shown in Fig.1, which is coaxial collinear microstrip antenna. When twelve dipoles are presented, the gain of an element is as high as 11 dBi.

2. LES array
Equally relation between signal impinging on the linear antenna array with equal el-
element space and received signal can be expressed in the form of conventional radiation characteristics.

\[ f(\theta, \phi) = \sum_{m=0}^{M} I_m w_m \exp(j \beta d_m (\cos \phi \sin \theta - \cos \phi_0)) \tag{1} \]

where \( \beta = 2\pi/\lambda \) is the phase propagation factor, \( d_m \) is the space between elements. \( I_m \) is the complex amplitude at each element. \( \phi_0 \) is the incident signal angle.

3. Circular array

An eight-element circular array of radius \( r \) is spaced equally around the circumference. Then the array factor in the direction \((\theta, \phi)\) is

\[ f(\theta, \phi) = w^H a(\theta, \phi) \tag{2} \]

where \( a(\theta, \phi) \) is the steering vector, and \( w \) is the weighting vector.

III. Integration of Genetic Algorithm with FDTD

1. Signal to Noise Ratio(SNR)

During the adaptation process, weights \( w \) supplied by algorithm and covariance matrices are calculated for given signal and interference angle of incidence. Based on the niche technique, each chromosome represents array phase-shifter settings. In order to improve power and reduce cost of system in practice, only the phase of weights is shifted in algorithm and amplitude is constant. The task for GA in smart antenna system to find optimum weight settings will be minimizing the given cost function. The SNR is given by\(^{[5]}\)

\[ \text{SNR} = \frac{w^H R_{ss} w}{w^H R_{nn} w} \tag{3} \]

where \( R_{ss} \) and \( R_{nn} \) are signal and noise covariance matrices.

2. Finite Difference Time Domain(FDTD)

FDTD is the direct method to solve Maxwell differential equations, so parameters of antenna arrays calculated by the FDTD include mutual coupling. Firstly the electromagnetic parameters of an array element are calculated. The voltage source excitation is Gaussian impulse.

\[ E_z = f_s(t) = e^{-(t-t_0)^2/T^2} \tag{4} \]

The normal time and second-order space difference FDTD formula\(^{[6]}\) is used in the letter. The absorbing boundary is Mur's second-order approximate absorbing boundary condition. Therefore we can obtain input impedance and patterns of an array element.

If the relation between each element is regarded as a multi-port network, the network equation of voltage to current can be easily given\(^{[7]}\).