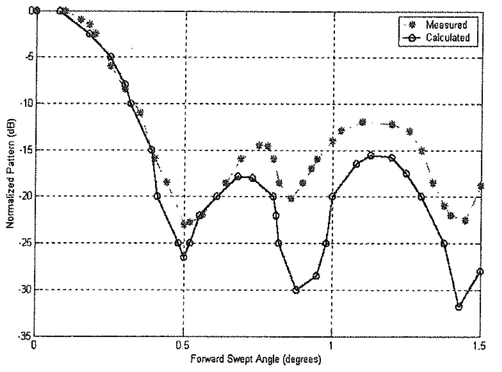

Figure (9) Calculated and measured E-plane radiation pattern of a four element Vivaldi antenna at 18 GHz.

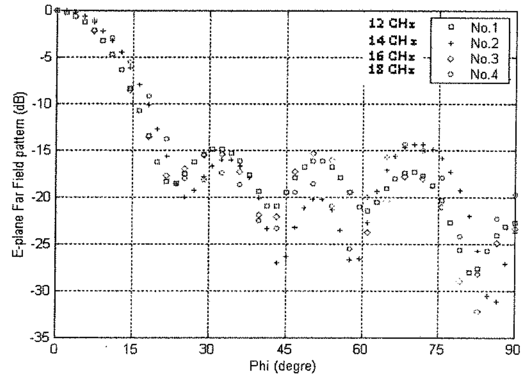

Figure (11) Optimized E-plane radiation pattern of a four element Vivaldi antenna, *at 12, 14, 16 and 18 GHz.*

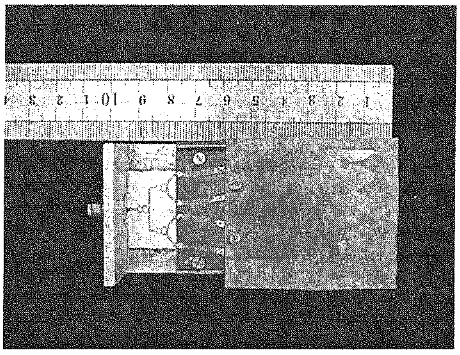

Figure (10) Constructed four element Vivaldi array and the feeding mechanism.

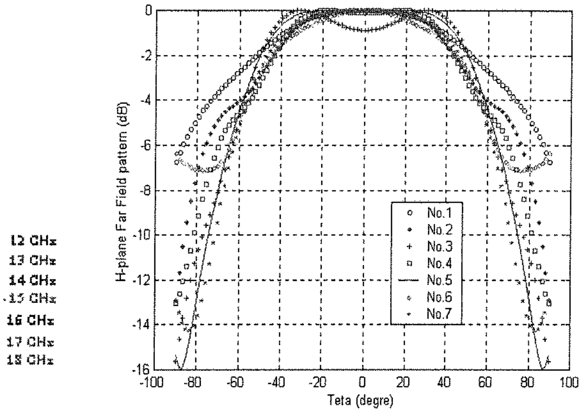

Figure (12) H-plane radiation patterns of four element array at 12-18 GHz, with 1 GHz steps.

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method, edge effects and finite ground plane are taken into account. The routine has shown to be very effective for designing complex structures microstrip array antennas. The analysis will be useful for studying Vivaldi antenna arrays to better understand why they behave as they do and to improve their performance with respect to band width and scan volume.

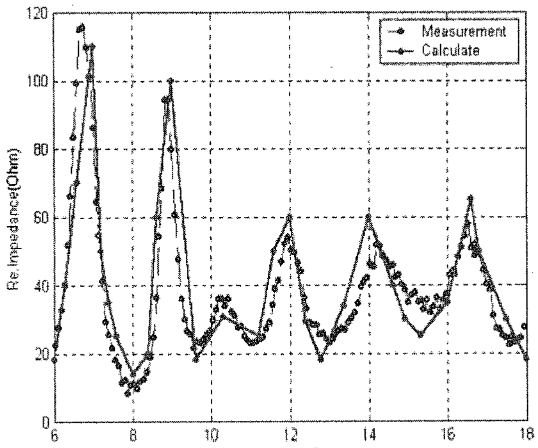

Figure (3) Calculated and measured real input impedance of a single Vivaldi antenna.

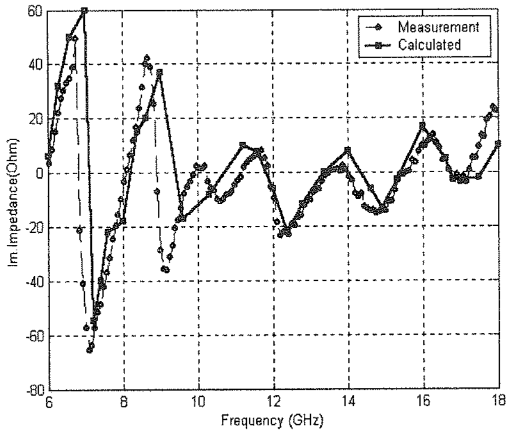

Figure (4) Calculated and measured imaginary input impedance of a single Vivaldi antenna.

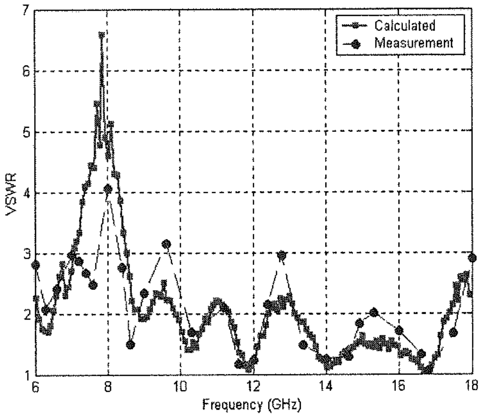

Figure (5) Calculated and measured VSWR of a single Vivaldi antenna.

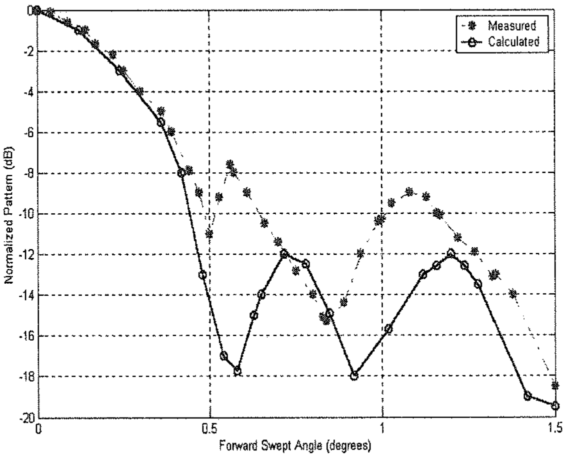

Figure (6) Calculated and measured E-plane radiation pattern of a four element Vivaldi antenna at 12 GHz.

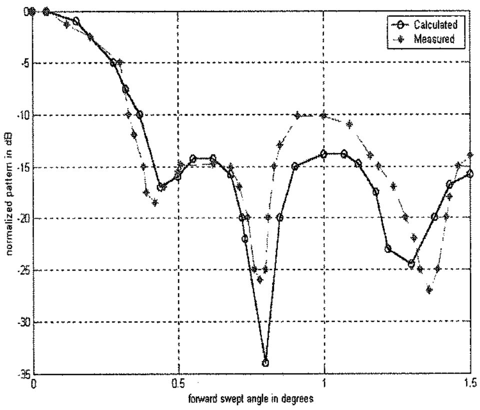

Figure (7) Calculated and measured E-plane radiation pattern of a four element Vivaldi antenna at 14 GHz.

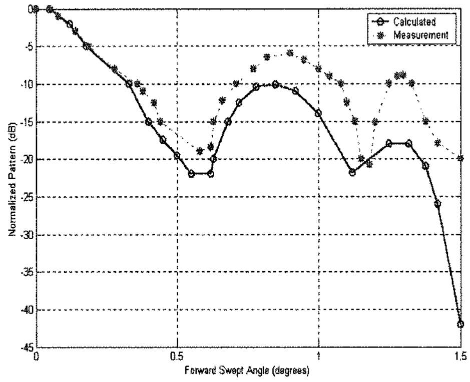

Figure (8) Calculated and measured E-plane radiation pattern of a four element Vivaldi antenna at 16 GHz.

B- Genetic Algorithm

The GA is a stochastic search technique that explores a given search space in parallel using a population of design candidates. Each member of this population is encoded into a chromosome, which is composed of genes, each of which represents a single design parameter. Here, a binary representation of the design parameters of section II is used for encoding chromosomes. The program is written by randomly creating an initial population of chromosomes. SLL is the objective function for optimization in the GA routine. Finally, after several iterations the optimum design is achieved [12].

3- Comparing Results

The input impedance of a single Vivaldi antenna was calculated by the FDTD method and also experimentally measured. The design parameters are:

ε_r=2.33, thickness substrate (t) =0.787 mm;
L=9 mm, H=6.5 mm, W_{SL}=0.5 mm;
W_{ST} =0.8 mm, A_R=70, R_R=2mm;
Taper opening rate=0.3 cm^{-1};
Time period =D_t=0.83 ps;
FDTD cell size =D_x=D_y=D_z=D=0.5 mm;
Computational domain =100 D*120D*40D;

Comparison between theoretical and experimental real and imaginary input impedance is represented in figures 4 and 5 respectively. There is a very good agreement between the measurement and FDTD simulation which shows that the computer code is functioning properly. Figure 6 displays the measured and calculated VSWR for a single Vivaldi antenna. The results show that the designed Vivaldi antenna element is wide band. A four element Vivaldi array with the single antenna dimensions mentioned above and 11 mm spacing (a in Fig.2.) was analyzed using FDTD method. The simulation and experimental E-plane radiation patterns at 12, 14, 16 and 18 GHz are compared with each other in figures 6 through 9 respectively. A wide band Wilkinson power divider on alumina (ε_r=9.6) is used for feeding the array in the Co-phase mode as shown in figure 10. The variation between calculated and measured results shown in figures 6 to 9 clearly indicates the deviation caused by the conductor and dielectric loss, as well as imperfect SMA connectors. Furthermore, part of the deviation is caused by residual slotline-mode field, which is not completely eliminated. It has been shown in [13] that the slotline-mode field as bounced back and forth, which may cause a noticeable error in measurements.

The simulated SLL of the array varies from -12 to -15 dB. Afterward, GA method was used for optimization of the array, as shown in figure 11, the SLLs of the optimized radiation patterns at 12, 14, 16 and 18 GHz are improved by 3 dB. This 3 dB improvement is due to reduction of the effects of some unwanted phenomena on antenna dimensions like as diffraction and residual slotline mode field and mutual coupling, which occurred after implementing the optimization algorithm. The H-plane radiation pattern of four element arrays at Frequency band 12-18 GHz with 1GHz steps is shown in figure.12. This similarity is clear in E-planes radiation pattern too, which results a wide band nature of the designed arrays.

4- Conclusion

A hybrid method of FDTD and GA was used to analyze and optimize a broad band Vivaldi antenna array. It is shown that there is the capability for modification of all design parameters to optimize the array radiation pattern in a wide range of frequencies. In the numerical FDTD

A- FDTD Method

A FDTD program was written explicitly for analysis of single and the array of Figure 2. A rectangular box surrounding the array is taken as the computational domain. Then, the total volume is subdivided to small unit cells with dimensions D_x, D_y and D_z in the x, y and z directions respectively. Following the set up of the simulation domain and subsequent Gaussian pulse excitation according to equation (1), the boundary conditions are applied. Then Yee algorithm is used as a central difference approximation of Maxwell curl equations [9]. The solution is iterated until the fields are convergent. Subsequently the field distribution in whole computational region is evaluated. The electric and magnetic difference equations for a lossless media (excluding the source) are given by:

$$H_Z^{n+1/2}(i+\frac{1}{2},j+\frac{1}{2},k)=H_Z^{n-1/2}(i+\frac{1}{2},j+\frac{1}{2},k)-\frac{\Delta t}{\mu}\times \left(\frac{E_Y^n(i+1,j+\frac{1}{2},k)-E_Y^n(i,j+\frac{1}{2},k)}{\Delta x}-\frac{E_x^n(i+\frac{1}{2},j+1,k)-E_x^n(i+\frac{1}{2},j,k)}{\Delta y}\right) \tag{2}$$

$$E_X^{n+1}(i+\frac{1}{2},j,k)=E_X^n(i+\frac{1}{2},j,k)+\frac{\Delta t}{\varepsilon}\times \left(\frac{H_Z^{n+1/2}(i+\frac{1}{2},j+\frac{1}{2},k)-H_Z^{n+1/2}(i+\frac{1}{2},j-\frac{1}{2},k)}{\Delta y}-\frac{H_Y^{n+1/2}(i+\frac{1}{2},j,k+\frac{1}{2})-H_Y^{n+1/2}(i+\frac{1}{2},j,k-\frac{1}{2})}{\Delta z}\right) \tag{3}$$

In these equations, superscript n is the time step index and subscripts i, j and k are the spatial indices corresponding to the x, y and z directions respectively. An absorbing boundary is assumed around the whole computational boundary to take into account the radiation of the antenna [10]. From the field distribution on the absorbing boundary, the radiation pattern of the antenna is calculated [11]. These time domain results were then Fourier transformed to obtain the frequency dependence of the radiation pattern.

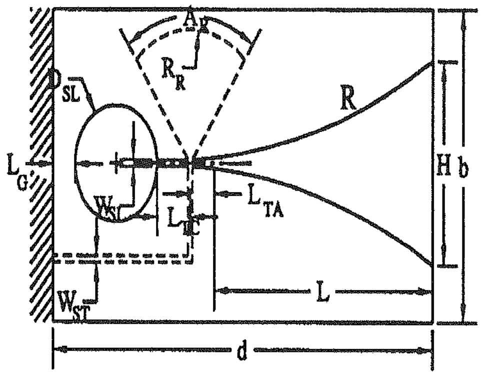

Figure (1) Single Vivaldi antenna configuration.

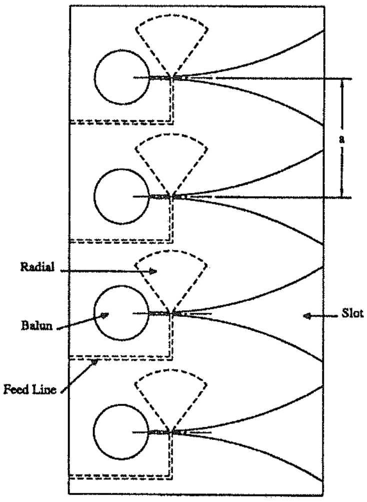

Figure (2) Four element Vivaldi antenna structure.

In section II, the design parameters are discussed. Section III presents the method of analysis. Finally, section IV includes the numerical and experimental results that are compared with each other.

1- Design parameter of Vivaldi antenna array

The design parameters of Vivaldi antenna array are in figures 1 and 2 can be classified into four categories substrate parameters (relative dielectric constant, ε_r, and thickness, array grid parameter (element spacing), antenna element parameter are as follows:

R_R	radius of radial strip line stub;
A_R	angle of radial strip line stub;
D_{SL}	diameter of circular slot line cavity;
L_G	offset of slot line cavity from the ground plane;
L_{TC}	distance from the transition to the slot line cavity;
L_{TA}	distance from the transition to the taper;
L	Taper length;
W_{SL}	slot line width;
W_{ST}	strip line width;
R	opening rate;
H	width of Vivaldi antenna;

In this paper, the excitation function is described by:

$$E_X(x,t) = E_o \frac{e^{-((t-t_o)/T)^2}}{\sqrt{1-\left(\frac{x-x_o}{L}\right)}} \tag{1}$$

Where t_0 is the time shift, T controls the width of the Pulse, x_0 is the center of the slot, and L is the half width of W_{SL}. The pulse has a Gaussian variation in time and a singular function in space to account for the edge condition.

The excitation is applied to stripline, which is terminated in a radial stub. This radial stub simulates a RF short circuit at the transition between the stripline and the slotlines. This is done to allow maximum coupling electromagnetic energy to the slot lines at the feed point.

Parameters such as strip line stub and slotline cavity have a large impact on performance at the upper and the lower ends of frequency band and that the antenna flare(opening rate) have an impact in-band SWR. The parameters for a desired band width (12-18 GHz) are calculated in [7].

Parameters like as L_G, D_{SL}, L, H, W_{ST}, R_R, W_{SL}, distances between elements and excitation-phases, are the variables of optimization. These parameters are the most important factors in displacement of scan blindness of the array, and variations in gain, SLL and bandwidth [8].

2- Method of Analysis

Initially, a preliminary design is analyzed by FDTD method and SLL is calculated. Then the design variables and the computed SLL results are given as input to the GA which generates new design parameters .Then new parameters are fed back to the FDTD algorithm. This process is iterated until an optimum design is achieved. FDTD and GA methods are explained below.

Side Lobe Reduction in Vivaldi Array Radiation Pattern Using Genetic Agorithm and FDTD

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Abstract

In this paper, we describe the design and evaluation of Vivaldi elements optimization for operation in the array environment over a wide range of frequency (12-18GHz). The Finite Difference Time Domain (FDTD) is used in design and analysis of finite Vivaldi array and genetic algorithm (GA) for optimization of its radiation pattern. The hybrid method is used to find maximum side lobe level (SLL) over a range of frequency (12-18GHz) by adjustment of the antenna and array parameters. An array SLL improvement of 3dB was attained by optimization. Here a single Vivaldi antenna and a four element array are analyzed and compared with measurements. Theoretical and experimental results show good agreement with each other.

Keywords

Wideband Array Antenna, Vivaldi Antenna, Finite Difference Time Domain & Genetic Algorithm

Introduction

Tapered-slots are traveling wave antennas that produce a broad band end-fire radiation. An exponentially tapered slot line antenna (Vivaldi) was introduced by Gibson in 1979[1]. These antennas are not resonant; as a result they can operate over a much wider bandwidth than dipoles or microstrip patch antennas. Theoretical and experimental results show that a single Vivaldi antenna has a VSWR of less than two over two octaves which is limited by the feed structure. The feed problem can be overcome by a broad band balun. Microstrip fed Vivaldi arrays are efficient integrated phased array antenna.

Since these antennas are not resonant, the dimensions could vary to achieve desired radiation characteristics, although, the relationship between antenna design parameters and array performance are not well defined [2]. It is possible to achieve desired main lobe beam width and SLL by different array parameters.

The Vivaldi array antenna is an important member of integrated circuit antennas in millimeter wave and microwave frequency [3]-[5]. These efficient wide-band widths, wide-scanning phase arrays are suitable for satellite communications, remote sensing and radio astronomy.

The FDTD method is used to analyze this antenna where the effect of diffraction due to finite ground planes, variation in phase velocity, frequency-dependant impedance and coupling between elements are taken into account [6]. Since GA escapes form local minima and maxima and consequently it rapidly searches a large solution space, it is used for optimization. The hybrid method is used to analyze and optimize a four element Vivaldi array antenna for maximum side lobe level.