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An Ultra-Wideband One-Dimensional Plane Wave Generator Antenna Array

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Abstract

This paper presents an ultra-wideband one-dimensional plane wave generator antenna array. Tightly coupled Vivaldi antennas is used with active VSWR nearly lower than 2 across the frequency band from 1 to 7 GHz. A new plane wave excitation optimization algorithm using full wave simulation transfer matrix is proposed and compared with the traditional ideal point source plane wave optimization algorithm. One-dimensional quasi-plane waves with amplitude vibrations within ±0.75dB and phase vibrations within ±7.5° ranged from 1GHz to 6GHz is realized by carefully optimizing the feed amplitude and phase of the tightly coupled array element.

1 Introduction

The plane wave generator is a group of phased arrays, which generate quasi-plane waves in the near field by configuring the amplitude and phase of each element, which can be used for RCS testing and antenna far-field parameter testing. The plane wave generators reported by now are difficult to achieve wide-band applications due to the element bandwidth[1, 2] and space sampling rate limitations, but the wide-band operating characteristics of tightly coupled antennas can solve this problem.

The proposal of the tightly coupled array principle can be traced back to the idea of an infinite current sheet proposed by Professor Wheeler in 1965[3]. In 2003, Professor Munk proposed a capacitor-loaded dipole array[4], which was the first time physically realization of the idea of an infinite current sheet. There are many types of tightly coupled array antenna element, except for the dipole mentioned above, there are also Vivaldi-like antenna[5], helical antenna[6] and other types. The traditional idea of implementing a broadband array antenna is to design the broadband array element individually, and then group the broadband array elements. The idea of tightly coupled array antenna design is the opposite. The mutual coupling between elements is considered during element design, and the mutual coupling effect between elements is used to broaden the impedance bandwidth of the array, and the size of tightly coupled elements is small, this can guarantee the spatial sampling rate during high-frequency operation while having broadband characteristics.

The optimization method of traditional plane wave array excitation is to model the element as an ideal point source[2, 7], but due to the strong mutual coupling of the tightly coupled ultra-wideband array elements, the point source optimization is no longer applicable. This paper proposes a new method of adding full wave simulation transfer matrix. The transfer matrix based plane wave array excitation optimization algorithm solves the above-mentioned problems by adding element mutual coupling information.

In this paper, an ultra-wideband one-dimensional plane wave generator antenna array based on a tightly coupled Vivaldi antenna array is proposed. The 1-7GHz reflection coefficient of the element in the array is nearly lower than -10dB. A plane wave excitation optimization algorithm with full wave simulation transfer matrix is proposed and verified by the plane wave generator antenna array. By optimizing the plane wave array excitations, amplitude vibrations of less than ±0.75dB and phase vibrations of less than ±7.5° can be obtained in the 1-6GHz frequency band. Dimensional quasi-plane wave, comparing to the point source simulation results, the plane wave performance has been greatly improved.

2 Design and Arrangement of Array Elements

The tightly coupled Vivaldi antenna element and array structure are shown in Figure 1. The antenna substrate thickness is 0.8mm, substrate material is RO4003C with a dielectric constant of 3.5, the antenna length L = 87mm, width W = 24mm, the antenna element structure is basically the same as the ordinary Vivaldi antenna. The tightly coupled antenna array contains 8 Vivaldi elements, which are arranged along the E plane of the elements themself, and the elements are in direct contact to generate strong mutual coupling. The array aperture is Plane_l = 168mm.

Figure 2 shows the active VSWR of tightly coupled Vivaldi antenna element under period boundary condition. The active VSWR of the antenna is nearly lower than 2 in the 1-7GHz frequency band, which means the antenna has good active VSWR performance.

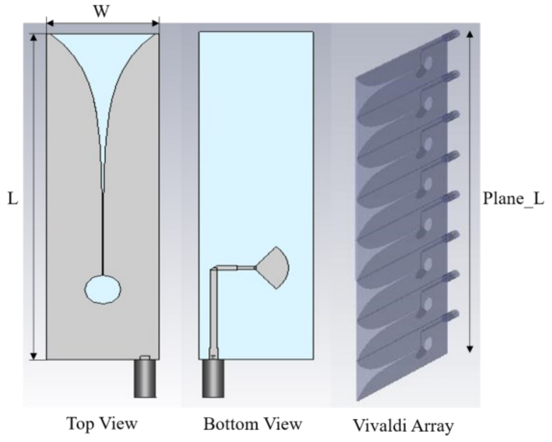

Figure 1. Tightly coupled Vivaldi element structure and array structure

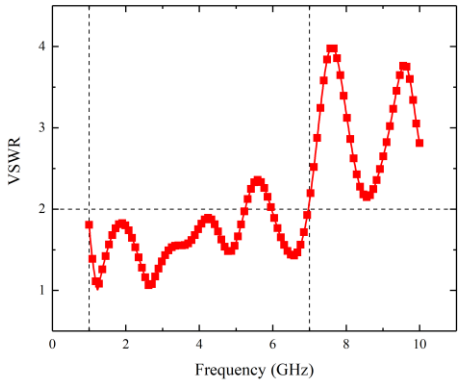

Figure 2. Tightly coupled element active VSWR

3 Improved Plane Wave Array Excitations Optimization Method

For non-tightly coupled plane wave generator, whose elements can be modeled as ideal point sources. The electric field in near field observation region generated by antenna element can be calculated by complex excitation multiplying propagation factor e^{-jkr}/r where r is the distance from the element to the observation point. However, for tightly coupled antenna array which has strong mutual coupling between elements, the method above doesn't work, but the whole plane wave generator system is still a linear system, the system transfer matrix can be constructed by exciting every element and sampling electric field of near field observation region at the same time, the specific procedure is showed in Figure 3. Multiplying the full-wave simulation transfer matrix and the elements' complex excitation vector can more accurately calculate the electric field of the sampling points in the near field plane wave region.

The optimization method proposed in this paper using classical genetic algorithm, as Figure 4 shows, the only difference is that the method mentioned above is used when calculating the near-field electric field. Let the transfer matrix extracted from the full wave simulation electric field result be $\mathbf{H}$, element complex excitation vector be $\mathbf{e}$, then electrical field in near field observation $\mathbf{E}=\mathbf{H}\cdot\mathbf{e}$. Plane wave amplitude vibration fit_amp, phase vibration fit_phase, let the algorithm fitness function $fitness = 1/(10 * fit\_amp + fit\_phase)$ which can reflect flatness of the plane wave.

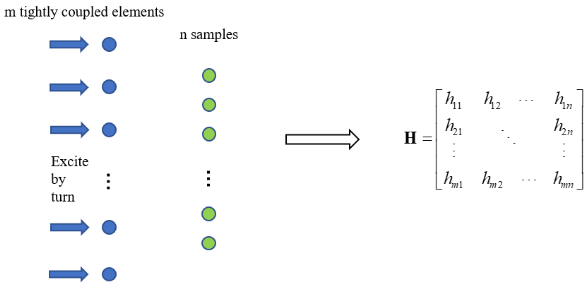

Figure 3. Extraction of full wave simulation transfer matrix

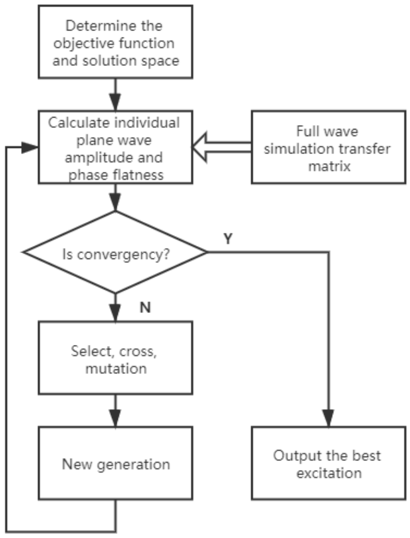

Figure 4. Plane wave excitation genetic optimization algorithm with full wave simulation transfer matrix

For the ultra-wideband array proposed in this paper, the distance between the plane wave observation surface and the array Plane_Obser_Z = Plane_l = 168mm, the electric field sampling point spacing d_Obser = W/2 = 12mm is half of the cell spacing, the number of samples n = 12, the sampling range [-66mm, 66mm].

4 Simulation Results and Discussion

This paper uses CST electromagnetic simulation software to simulate the ultra-wideband plane wave generator antenna array. With 1GHz frequency interval, the full-wave simulation transfer matrix at each frequency of 1-7GHz is extracted and be used for the plane wave generator antenna array excitations optimization. The plane wave results above are compared with ideal point source optimization plane wave results.

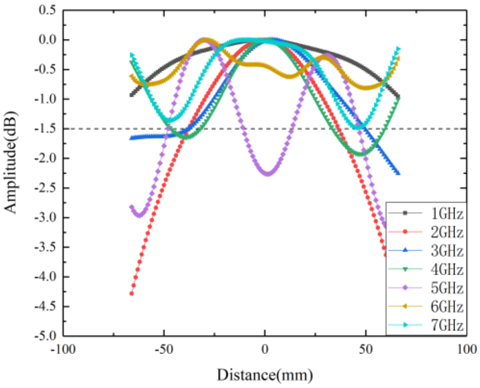

Figure 5. Ideal point source optimization plane wave amplitude vibrations at specified frequencies

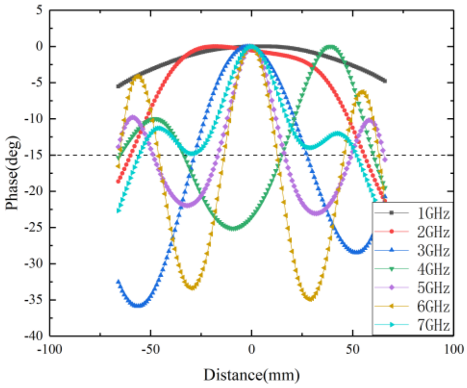

Figure 6. Ideal point source optimization plane wave phase vibrations at specified frequencies

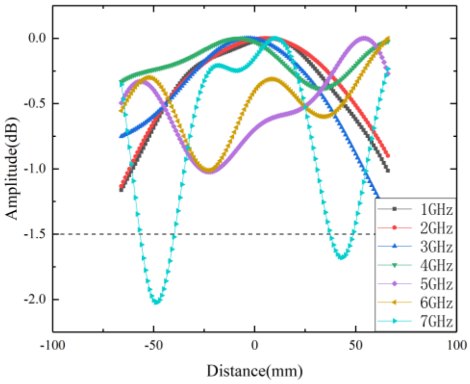

Figure 7. Full wave simulation matrix optimization plane wave amplitude vibrations at specified frequencies

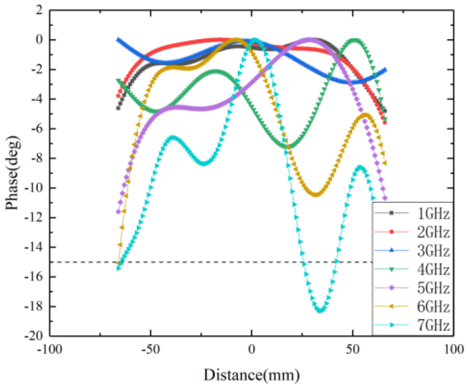

Figure 8. Full wave simulation matrix optimization plane wave phase vibrations at specified frequencies

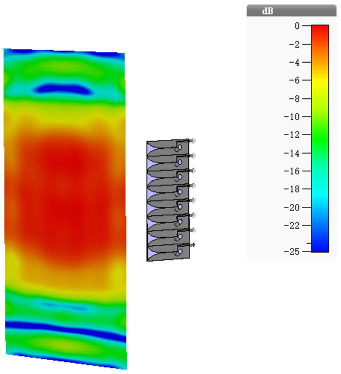

Figure 9. Full wave simulation matrix optimization plane wave 2D amplitude distribution at 4GHz

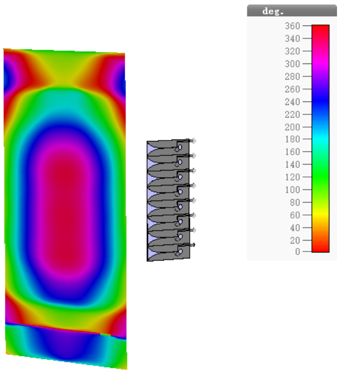

Figure 10. Full wave simulation matrix optimization plane wave 2D phase distribution at 4GHz

Ideal point source optimizes plane wave amplitude vibration is above ±2dB, phase vibration is above ±17.5° , as shown in Fig 5 and Fig 6. On the contrary, the plane wave optimized by the method with full wave transfer matrix amplitude vibration within ±0.75dB, phase vibration within ±7.5° in 1-6GHz. Comparing the two results, because the optimization of the full-wave simulation transfer matrix takes the mutual coupling effect between the tightly coupled array elements into account, the quality of the plane wave has been improved a lot. These figures also show that with the increase of frequency, the quality of the plane wave generally deteriorates. This is because the high-frequency plane wave requires a higher spatial sampling rate. In the 1-6 GHz frequency band, the tightly coupled plane wave generator antenna array can generated one-dimensional quasi-plane wave with amplitude vibrations of ±0.75dB and phase vibrations of ±7.5°, which meets the design requirements of actual plane wave generator antenna arrays.

5 Conclusion

This paper proposes a tightly coupled plane wave generator antenna array. The optimization method of plane wave generator antenna array excitations under tightly coupled conditions is studied. The transfer matrix containing the mutual coupling information of the elements is obtained by stimulating each element in the array in sequence and sampling the electric field in the observation area, then using the linearity of the plane wave generator antenna array system to calculate the plane wave amplitude and phase flatness as the optimization fitness function. Finally, the optimal excitations of the tightly coupled plane wave generator antenna array are obtained through multiple iterations of the genetic algorithm. A plane wave generator with amplitude vibrations less than ±0.75dB, and phase vibrations less than ±7.5° in the near-field quiet zone area across 1 to 6 GHz bandwidth achieved. The proposed array provides much wider bandwidth than waveguide array and diploe array.

6 Acknowledgements

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