A Highly Compact and Highly Efficient Huygens Antenna Array

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***Abstract*-A highly compact and highly efficient Huygens 1 × 4 antenna array is reported in this paper. The Huygens array consists of two major parts: a $TE_{0.5,0}$ mode SIW waveguide with seamlessly integrated phase inverters and two folded L-shaped metallic plates being orthogonally connected to it. Four magnetic dipoles are formed on the radiating aperture of the waveguide while four electric dipoles are realized on the plates. Their moments are orthogonal to each other and naturally in phase. Thus, Huygens cardioid radiation patterns are realized. The system operates around 10 GHz. It has a 7.7% simulated overlapped –10-dB impedance and 3-dB realized gain bandwidth from 9.44 to 10.2 GHz, 760 MHz. The peak realized gain value is 10.23 dBi within this bandwidth. The realized gain pattern at 10 GHz has a narrow (25°) half-power beamwidth (HPBW) in the H-plane (ϕ = 0°) and a wide (152°) HPBW in the E-plane (ϕ = 90°). The aperture efficiency of the array reaches 97.5%.**

I. Introduction

Antenna arrays with high aperture efficiencies are highly desired in many current and future wireless applications. They are employed in base station [1], radar [2], satellite communications [3], and wireless power transfer [4] systems.

One popular approach to enhance the aperture efficiency of an antenna array is to miniaturize the size of its radiating aperture while maintaining its realized gain. Several typical examples can be found in [5] – [8]. A 60 GHz planar aperture antenna was developed in [5] to achieve an aperture efficiency of 63%. A compact linear E-shaped patch array was introduced in [6] with an enhanced aperture efficiency around 80%. Moreover, slot antenna arrays based on waveguide power divider feed networks were demonstrated in [7], [8] to achieve yet higher aperture efficiencies, above 90%.

This paper presents a new antenna array design that realizes an aperture efficiency that reaches 97.5%. Based on our previously reported Huygens antenna array with low sidelobe and backlobe levels [9], we found that the aperture efficiency of the original design could be further increased by folding its two SIW-edge-connected rectangular metallic plates into L-shaped ones. The aperture size is substantially reduced while maintaining the realized gain values. The key principle is that the current distributions on the outside edges of the plates are much weaker than their center parts. The folding of the plates does not change the operating frequency of the system and has only a minor impact on its total radiated power.

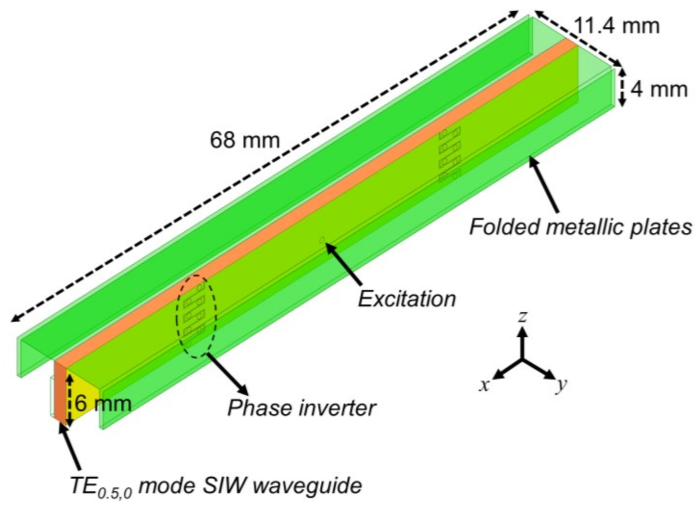

Figure 1. Configuration of the highly compact and highly efficient Huygens antenna array.

II. Designs and Operating Principles

A. *Antenna array configuration*

The configuration of the highly compact and highly efficient Huygens antenna array is shown in Fig. 1. It consists of two major parts. The first is the four-element magnetic dipole array that is formed on the radiating aperture of a $TE_{0.5,0}$ mode SIW waveguide with two seamlessly integrated phase inverters. The waveguide is about two guided wavelengths long. Each phase inverter is formed by several shorting vias distributed on two sides of a meandered slot present on one side of the SIW waveguide. A probe excitation is located in the middle of the waveguide. A natural amplitude taper of the Huygens elements thus occurs. Detailed designs and discussions can be found in our previously reported work [10]. The second major part consists of two L-shaped metallic plates that are orthogonally connected to the outside edges of the SIW aperture. The length of the vertical sections of the L-shaped plates is 4.0 mm. The gap between them, i.e., the aperture width, is 0.5 mm. The entire design is very compact with the radiating area only being 2.27 λ_0 × 0.38 λ_0 (λ_0 is the targeted design frequency, 10 GHz).

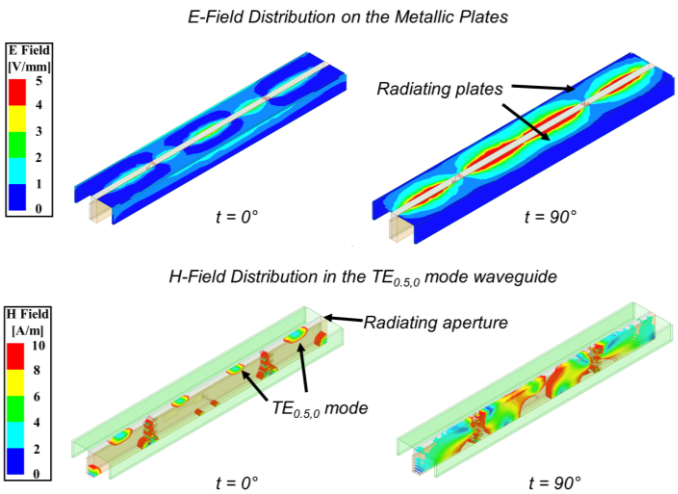

Figure 2. Electric field magnitude distributions on the folded, L-shaped metallic plates and the magnetic field distributions in the SIW waveguide at quarter periods of time corresponding to its resonance frequency, 10.0 GHz.

B. *Operating Principle*

The operating principle of the developed Huygens array can be explained with the electric and magnetic current moments on the array. Fig. 2 shows the magnitude of the electric field distributions on the folded metallic plates and of the magnetic field distributions in the SIW waveguide at quarter periods of time corresponding to its resonance frequency, 10.0 GHz. It is clearly seen that electric fields and the magnetic fields are resonating with a phase difference of 90°. Because the magnetic dipole current moment has a 90° phase delay from the magnetic fields that generate it, the electric and magnetic dipoles radiate in-phase and are orthogonal to each other [11]. Thus, a broadside Huygens cardioid radiation pattern are produced. A similar concept has been extensively developed in [12] – [14] as magnetoelectric (ME) dipole antennas.

III. Simulated Performance

The design model was simulated with ANSYS Electromagnetics Suite (HFSS), v. 18. Fig. 3(a) shows the simulated $|S_{11}|$ and realized gain values as functions of the source frequency. The system operates around 10 GHz as designed and has a 7.7% overlapped –10-dB impedance and 3-dB realized gain bandwidth from 9.44 to 10.2 GHz, 760 MHz. The peak realized gain value at 10 GHz is 10.23 dBi within this bandwidth. The aperture efficiency reaches 97.5% thanks to the compact aperture size and to the fact that the currents are very small on the vertical sections of the L-shaped metallic plates as shown in Fig. 2.

The realized gain patterns at 10 GHz are shown in Fig. 3(b). Broadside radiation patterns are realized even without a ground plane underneath. As a 1 × 4 array, it has a narrow (25°) half-power beamwidth (HPBW) in its H-plane (φ = 0°) and a wide (152°) HPBW in its E-plane (φ = 90°). The 1 × 4 array can be used as the element of a much larger scale array that attains a similar, very high aperture efficiency.

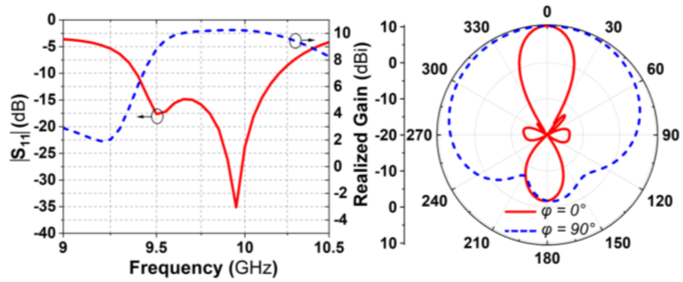

Figure 3. Simulated performance characteristics of the antenna array. (a) $|S_{11}|$ and realized gain values as functions of the source frequency. (b) Realized gain patterns at 10 GHz.

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