Ultra-Thin Uniform Linear Array of Electrically Small Huygens Dipole Antennas

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***Abstract*—A uniform linear array of electrically small Huygens dipole antennas (HDAs) that is realized on a single ultra-thin substrate is presented in this paper. The HDA consists of a pair of near-field resonant parasitic (NFRP) elements and a simple driven antenna element. The NFRP elements are metamaterial-inspired electrically small structures – the Egyptian axe dipole (EAD) and the capacitively loaded loop (CLL). They are excited by an electrically small dipole antenna connected to a 50-Ω source by a twin-line microstrip line. This HDA generates a cardioid radiation pattern with a high realized gain (5.4 dBi) and wide beamwidth (151° in its H-plane). A uniform 1×4 linear array formed with four of these HDAs operating at 2.45 GHz with a center-to-center spacing of 0.45 λ_0 has been developed to achieve higher directivity. The array is excited by a 1-to-4 microstrip feed network. The entire system is realized on a single piece of 0.0042 λ_0 thick PCB substrate. The –10 dB impedance bandwidth covers 70 MHz, from 2.415 to 2.485 GHz. The realized gain is stable over it with a 8.7 dBi peak value. A very broad beamwidth (162°) is realized in the H-plane. The array is an ideal candidate to act as the base station antenna for 5G and beyond wireless power transfer (WPT) applications.**

***Index Terms*—Antenna array, beamwidth, directivity, electrically small antenna, Huygens antenna, IoT, WPT.**

I. INTRODUCTION

Linear antenna arrays are attractive because they are conducive to many applications and have attractive performance characteristics, including high directivity and broad beamwidth in the plane orthogonal to their axis. These features enable wireless applications that require both long distance and large area coverage. In particular, base station antennas for emerging wireless power transfer (WPT) applications for 5G and beyond sensor networks [1] should have both high gain and large half-power beamwidth (HPBW) to broadcast and deliver wireless power to a large number of widely distributed Internet-of-Things (IoT) elements.

Linear antenna arrays have been extensively studied. Various single radiating elements have been employed including microstrip patch antennas [2], slot antennas [3], modified dipoles [4], horn antennas [5], and magnetoelectric (ME) dipole antennas [6]. Nonetheless, it remains very challenging to achieve both high gain and large HPBW beamwidth (greater than 150˚) from a compact, ultra-thin array that can be fabricated by a low-cost process. To the best of our knowledge, only one 1×4 single-substrate linear Huygens (ME-dipole) array has been reported in [7], but with electrically large radiating elements. We present a uniform linear 1×4 array formed with four electrically small Huygens dipole antennas (HDAs). The size (area above ground plane) of this array is more than four times smaller than the design in [7].

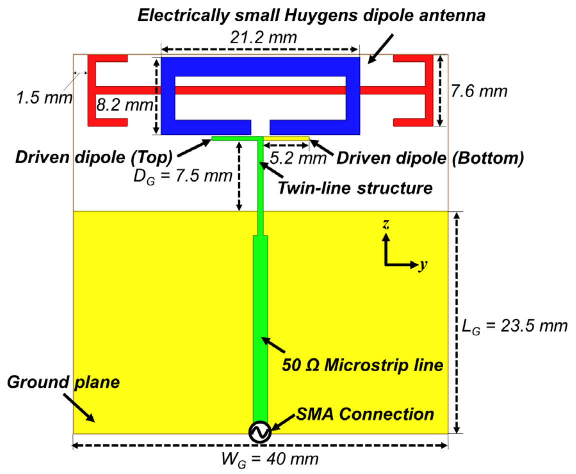

Fig. 1. Configuration of the ultra-thin electrically small Huygens dipole antenna.

II. ULTRA-THIN ELECTRICALLY SMALL HDA

The single radiating element of the array, an ultra-thin, electrically small HDA, is shown in Fig. 1. The HDA consists of an Egyptian axe dipole (EAD) and a capacitively-loaded loop (CLL) excited by a driven dipole element. These near-field resonant parasitic (NFRP) elements are etched on opposite sides of a PCB substrate. The EAD acts as an electric dipole radiator and the CLL acts as a magnetic one. The very subwavelength driven dipole is fed directly with a microstrip twin-line structure. Its two arms are printed on opposite sides of the substrate. The twin-line structure is an extension of a

50-Ω microstrip line and its ground plane. The EAD lies on the same surface as the ground plane. The entire structure is simple, compact and all together designed on a single piece of thin Rogers Duroid™ 5880 substrate whose relative permittivity, loss tangent and thickness are, respectively, 2.2, 0.0009 and 0.508 mm (0.0042 λ_0 at 2.45 GHz).

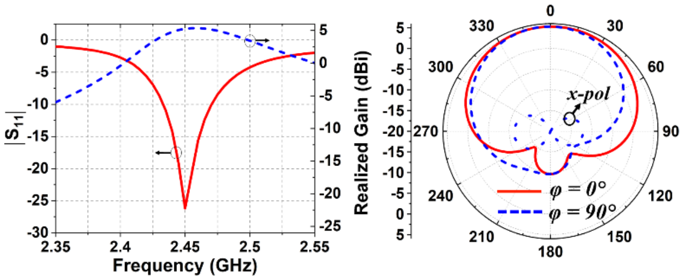

Fig. 2. Simulated performance. (a) $|S_{11}|$ and realized gain values as functions of the source frequency. (b) Realized gain patterns at 2.45 GHz in the two vertical planes.

Fig. 2(a) shows its simulated $|S_{11}|$ and realized gain values as functions of the source frequency. The antenna is resonating at 2.45 GHz with a 5.4 dBi peak realized gain. Fig. 2(b) shows its unidirectional Huygens realized gain patterns in both principal vertical planes at 2.45 GHz. The beamwidth in the H-plane (φ = 0°) is broad, covering 151° from -74° to 77°. Note that the E-plane pattern is not as symmetrical as the H-plane one because the driven dipole design is asymmetric along the y-axis. This asymmetry is reduced by an optimized design of the HDA array.

III. Ultra-Thin Linear Huygens Dipole Antenna Array

Thanks to the simplicity and compactness of the ultra-thin HDA, a uniform linear HDA array (HDAA) is readily achieved on a single substrate. To make a performance comparison with the 4-element ME dipole array design in [7] fair, a 4-element HDAA excited with a 1-to-4 microstrip power divider was developed; it is shown in Fig. 3. The center-to-center spacing between adjacent elements is 0.45 λ_0.

Fig. 4(a) shows the simulated $|S_{11}|$ and realized gain values as functions of the source frequency. The –10 dB impedance bandwidth covers 70 MHz, from 2.415 to 2.485 GHz. The realized gain values are stable over it with a 8.7 dBi peak value. Fig. 4(b) presents the radiation patterns at 2.45 GHz in the two vertical planes. A narrow beamwidth (28°, from -13° to 15°) is observed in the E-plane and a very broad beamwidth (162°, from -77° to 85°) is achieved in the H-plane. The sidelobe levels in the E-plane are less than –13.2 dB and the front-to-back ratio (FTBR) is 12.8 dB. The simulated antenna efficiency is 95%. Compared with the 1×4 fixed-beam single-substrate ME dipole array design in [7], our 1×4 HDAA is more compact in size, i.e., the area of the HDAA above the ground plane ($L \times W$ in Fig. 1) is only 1.9 $\lambda_0 \times 0.13\ \lambda_0$, which is more than four times smaller than 2.7 $\lambda_0 \times 0.4\ \lambda_0$. Moreover, our H-plane HPBW, 162°, is much wider. Although the bandwidth of the design in [7] is much wider, the narrowband design in this work is most appropriate for the intended WPT applications. In particular, it is an ideal candidate to become a WPT base station antenna, i.e., it could readily deliver wireless power from one point to multi-points in the same elevation plane [8].

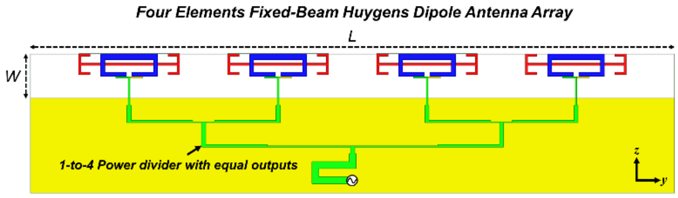

Fig. 3. Configuration of the broadside fixed-beam HDAA whose HDA elements are excited with equal amplitude and zero phase progression by twinline feed structures integrated with a microstrip power-divider feed network.

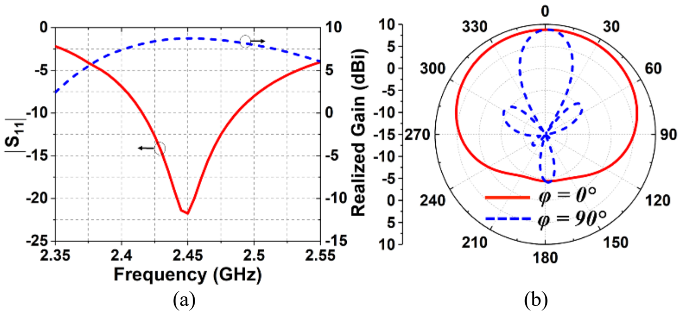

Fig. 4. Simulated results. (a) Input impedance of the electrically small Huygens antenna; and (b) Radiation patterns at 2.45 MHz.

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