On the Generation of Truncated Airy Beams with Antenna Arrays

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***Abstract*—The objective of this work is to investigate the generation of an Airy beam at microwave frequencies with antenna arrays when the quasi-diffraction-free requirement is limited to a specific distance along with the propagation axis. In this case, it is observed that the emission aperture can be opportunely truncated in order to observe an Airy distribution at the specified distance and within a specific observation region. Furthermore, the use of directive antennas instead of simple dipoles is investigated as a methodology to increase the range of the Airy beam generation.**

I. INTRODUCTION

The concept of accelerating wave-packets emerged in the context of quantum mechanics fourty years ago [1], and became realizable when the possibility of diffraction-free optical Airy beams was proposed in 2007 based on the equivalence of Schrödinger equation with Helmholtz equation for paraxial optical beams in free space [2-3].

In [4], Chremmos described the possibility to generate a quasi-diffraction-free exponentially-truncated Airy beam within the Fresnel region by using a dipole array. In particular, the total array field provides a discretized approximation to the evolution of a paraxial beam. The generation of this quasi-diffraction-free wave beam at microwave frequencies however requires a very large array yielding this method of difficult applicability.

The objective of this paper is to investigate the generation of a quasi-diffraction-free beam with truncated antenna array. In fact, for real applications it is usually possible to define a maximum distance where the quasi-diffraction-free phenomenon has to be observed. In this case, considering a rays-optic interpretation of accelerating beams, it is found that only a portion of the array largely contributes to the generation of the Airy profile at a specific distance and within a well-defined observation region. Furthermore, directive antenna elements are used to increase the propagation distance of the Airy beam, and a comparison with the original case of a dipole array is provided.

II. THEORY

In order to facilitate the rays analysis and the derivation of the minimum emission aperture for the generation of a truncated Airy beam within the specific observation region, Fig. 1 is provided. As known from [5], a parabolic caustic (which represents the trajectory of a propagating Airy beam) governed

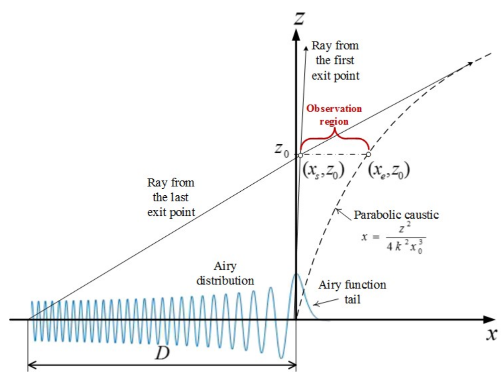

Fig. 1. Rays-optic analysis of a parabolic caustic, where x_0 is a scale factor (which is half of the Airy main lobe width), and $k = 2\pi/\lambda$.

by the law $x \propto z^2$ can be interpreted by exploiting the ray optics as the contribution of multiple rays from exit points, i.e., sources, displaced along with the *x*-axis at the coordinate *z*=0. In the case of a quasi-diffraction-free wave propagation, it is required that the emission aperture *D*, i.e., the distance from the first exit point to the last one, is taken as large as possible [4].

This theoretical consideration is obviously impractical, but can be circumvented when it is possible to specify an observation coordinate z_0 and a specific portion of the *x*-axis at which it is required to observe a quasi-diffraction-free wave propagation. In such a case, only a smaller portion of the emission aperture contributes significantly to the development of the caustic at the observation coordinate and within the observation region. In particular, only rays which pass through the observation window defined by the coordinates (x_s,z_0) and (x_e,z_0) and are tangent to the caustic have a considerable contribution. According to simple geometric elaboration, it is possible to derive the minimum emission aperture D_{min} which can generate the Airy distribution within the observation region as

$$D_{min} = 4az_0\sqrt{a^2z_0^2 - x_s}$$

where $a = 1/\sqrt{4k^2x_0^3}$.

It should be noted that since the parabolic trajectory describes the propagation of the Airy function main beam, it is important to extend the aperture dimension toward positive values of the x-axis for generating the Airy function tail. We have found that an extension of 9λ is sufficient for this purpose.

According to the previous analysis, it is now possible to design truncated antenna arrays able to radiate a quasi-diffraction-free Airy beam at least up to the observation region coordinate z_0 and within the observation region.

III. NUMERICAL EXAMPLES

A. Reduced size antenna arrays

Assuming an initial field distribution as $U(x) = Ai(x/x_0)$, where $Ai(x)$ is the Airy function and x_0=3λ, we have compared the normalized electric field amplitude at the distance z_0=260λ within the observation region x_s=1.39λ, x_e=15.86λ for the ideal case of an infinitely large continuous aperture launcher and the minimum emission aperture D_{min}=61λ array (the starting point of the array is taken at x=9λ as discussed before). The minimum emission aperture D_{min}=61λ has been realized with a dipole array of N=77 elements spaced by 0.8λ. The electric field distribution at the coordinate z_0 has been evaluated numerically as in [4], and compared with the full electromagnetic simulator Ansoft HFSS results (where the dipole array has been implemented for a working frequency of 5.8 GHz).

Normalized electric field distributions are shown in Fig. 2 (a) where a great correspondence between the continuous

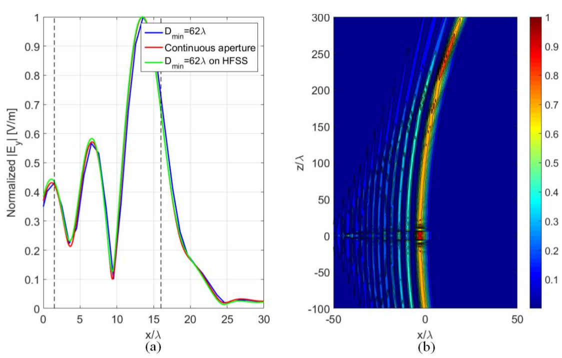

Fig. 2. (a) Normalized electric field distribution at the observation coordinate z_0 with dipole array; (b) Evolution of the time-averaged electric field energy density $\epsilon_0 |E_y|^2/4$ scaled to its maximum value.

aperture launcher and the minimum emission aperture array results can be observed. Furthermore, the time-averaged electric field energy density scaled to its maximum value depicted in Fig. 2 (b) for the minimum emission aperture array confirms that the propagating beam can reach the distance z_0 with a quasi-diffraction-free behavior.

B. Use of directive antennas for generating Airy beams

The theory in [4] has been originally developed for dipole arrays. In this paper, the use of directive antenna elements for generating the Airy field distribution shown in Fig. 2 is considered and, in particular, an array configuration constituted by dipoles with a reflector placed at $\lambda/4$. As before, the number of elements is taken as N=77, the inter-element space is 0.8λ, with working frequency 5.8 GHz.

Simulation results of the electric field distribution obtained with the full electromagnetic simulator Ansoft HFSS are shown in Fig. 3 for the two arrays above described. As it can be seen, the dipole with reflector array is also able to generate the Airy field distribution within the observation region. Moreover, the dipole with reflector array provides larger amplitude values than the dipole array, and this is coherent

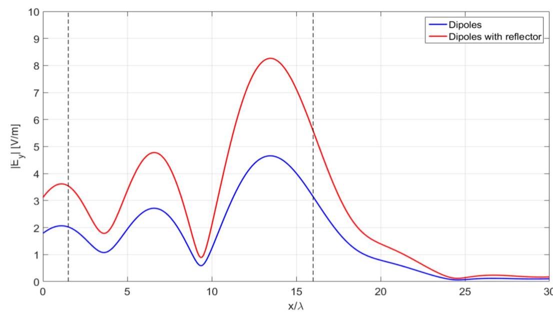

Fig. 3. Electric field distributions at the observation coordinate z_0 for the dipole array and the dipole with reflector array.

with far-field pattern behaviors of the two antennas (the dipole with reflector has a broadside gain of 8 dBi, whereas the simple dipole 2.2 dBi).

IV. CONCLUSIONS

This paper discusses the generation of quasi-diffraction-free Airy beam with antenna array. The minimum antenna array size is derived when the quasi-diffraction-free behavior is required to be observed up to a limited propagation distance. Numerical results demonstrate the capability of such array to generate the Airy beam, and the use of directive antennas instead of simple dipoles is proposed as a valid alternative to increase the Airy beam propagation distance.

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