Near-Field-Focused Microwave Antennas and Near-Field Shaping Of Spectrum Using Different Antennas

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ABSTRACT

Focusing the electromagnetic field radiated by an antenna at a point in the antenna near-field (NF) region is a well known technique to increase the electromagnetic power density in a size-limited spot region close to the antenna aperture. This article encompasses the basic working principles and the applications of the NF-focused (NFF) microwave antennas as well as the synthesis procedures suggested for the NF shaping around the focal point and the technologies currently used for their implementation. NFF antennas are not a new class of antennas [1]. Nonetheless, research activities in NFF microwave antennas have proliferated significantly over the last two decades. This survey encompasses the basic working principles and applications of the NFF microwave antennas as well as the synthesis procedures suggested for the NF shaping around the focal point and the relevant implementation techniques. This analysis is concentrated on NFF antennas, with the focal point located in the antenna-radiative NF region. The NFF array can increase the field amplitude in the antenna NF region while also reducing the FF radiation with respect to the corresponding FF-focused array. In this case it follows that, for an assigned maximum amplitude of the radiated field in the antenna FF region, the power density radiated by the NFF antenna around the focal point is almost 20 dB larger than that radiated by the corresponding unfocused array in its NF region.

I.INTRODUCTION

In the past, near-field focusing techniques based on lens antennas and reflectors have been extensively used at optical and mm-wave bands. Nonetheless, over the last decades, several near-field focused (NFF) antennas have been designed and characterized for applications at lower frequencies. Indeed, NFF antennas are receiving considerable attention in several applications such as RFID (Radio Frequency Identification) systems, gate access control systems, industrial microwave applications, local hyperthermia, and wireless power transfer systems. NFF microwave antennas can be implemented by a number of different technologies and layouts, which can be seen as proper modifications of those that are conventionally used to design and realize far-field (FF) focused antennas. Available solutions include ellipsoidal reflector antennas and pyramidal/conical horns with a dielectric lens in front of the antenna aperture, but they are quite bulky and heavy antennas at the microwave band. Therefore, other technologies that allow for the implementation of planar NFF microwave antennas are preferred. Most of them are array antennas, where the phase of each element current is adjusted to get constructive interference of all field contributions at the focal point.

II.MAIN FEATURES OF NFF ANTENNAS

NFF arrays essentially exploit the extreme flexibility of array antennas to control the side lobe level, shape the −3 dB focal spot, implement multi focus antennas, and electronically scan the focal point. Important features of the NFF antennas are the focus depth (or depth of focus,), the focus width at the focal plane, and the level of the secondary lobes around the focal spot region, namely, the axial lobes and the side lobes [1]. Typical parameters of conventional FF-focused antennas (radiation pattern, antenna gain) are also of interest in most of the applications, to quantify the capability of the NFF antenna to minimize the field radiated in the FF region. Indeed, in the context of short-range applications, reducing FF radiation helps to limit the interference with adjacent wireless systems, the effects of unwanted multipath phenomena, and the personnel radiation hazards. In the conjugate-phase approach the phase of the excitation of each array element is set to compensate for the phase delay introduced by the path between the array element and the assigned focal point, to achieve constructive interference of all the contributions at the focal point. If the focal distance is larger enough than the antenna size , then the above phase tapering can be approximated by a quadratic phase profile (Fresnel approximation). Actually, due to the field spreading factor, the peak of the radiated power density does not occur at the focal point where all field contributions sum in phase (focal shift).

III.NFF ANTENNAS IN ANTENNA MEASUREMENT FACILITIES

NF focusing of large-phased arrays has been proposed for performing adaptive array nulling tests by conveniently resorting to interference sources located in the antenna NF region instead of interference sources located in the FF of the unfocused phased array [17]. In the focal plane, near the antenna axis, an NFF antenna exhibits a FF-like radiation pattern that looks like the FF pattern of the unfocused version of the same antenna when the focal point moves from the FF-region toward the antenna aperture up to a distance no lower than the antenna aperture.

IV.NFF TRANSIENT

S is classified into one of two categories: the conjugate-phase approach and the multi objective optimization techniques. As already stated in the “Main Features and Basic Metrics” section, in the conjugate-phase approach, the phase of the excitation of each antenna radiation source is set to compensate for the phase delay introduced by the path between the source and the assigned focal point, to achieve a constructive interference of all the contributions at the focal point. Additionally, a proper tapering of the amplitude of the source excitation can be chosen to control the level of the secondary lobes around the focal spot region. Otherwise, if a multi objective optimization technique is applied, it means that both the amplitude and phase of the source excitations are simultaneously determined through ad hoc optimization techniques. The conjugate-phase approach has a clear physical meaning based on a ray-optics model (Figure 1). The optimization based approaches are much more general and flexible in that they allow concurrent optimization of many NFF antenna parameters for almost arbitrary antenna configurations and complex application scenarios. For example, optimization-based approaches can be applied to the synthesis of NFF arrays with unequal elements, NFF antennas radiating in lossy and/or non-homogeneous media, antennas radiating in presence of scatterers in their NF region, NF/NF or NF/FF multi focus antennas, and plane-wave generators.

V.CONCEPT OF NEAR-FIELD DIRECT ANTENNA MODULATION

In the past, directly modulating the antenna has been used for different purposes in the literatures. For instance, in [11], a micro strip patch antenna is fabricated directly on a silicon-substrate forming a distributed Schottky diode between the patch and the ground plane. In the same paper, a CW microwave carrier is modulated by applying a dc bias control between the patch and the ground. In [12], a patch antenna is integrated with Schottky diodes which are driven by modulating signals. The switches are able to shut off and turn on the antenna's radiating edges directly to overcome the patch antenna's bandwidth limitation. In this paper, [12], a patch antenna with a resonance frequency of 2.4 GHz and a 30 MHz bandwidth is used to transmit a digitally modulated signal with 400 MHz bandwidth. It is noteworthy that although the scheme in [12] shares the same.

VI.NFF THEORY

For reasons of space reduction, we will work towards the design of a linear array. Figure 1 shows part a linear array antenna, positioned in the xy-plane of a rectangular coordinate system.

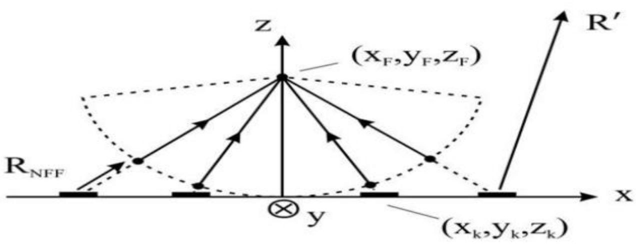

Fig. 1 – Part of a linear array antenna to be focused at (x_F,y_F,z_F).

The required phase shift for an element *k* for focusing the power (adding the signals in-phase) in the focal point ($\mathbf{x_F}$,$\mathbf{y_F}$,$\mathbf{z_F}$) is given by [4].

$$\varphi_k = kR_{NFF_k} = \frac{2\pi}{\lambda}\left[\sqrt{(x_k - x_F)^2 + (y_k - y_F)^2 + (z_k - z_F)^2} - \sqrt{x_F^2 + y_F^2 + z_F^2}\right]. \qquad (1)$$

The electric field at any position (*x*,*y*,*z*) in the far-field region of the individual (N) array elements is given by

$$\vec{E}(x,y,z)=\sum_{k=1}^{N}\frac{\vec{E}_k(\vartheta_k,\varphi_k)}{4\pi R'}e^{-jk(R_{NFF_k}-R')}, \tag{2}$$

Where (□k,□k) describes the local orientation of the element and where

$$R'=\sqrt{(x-x_k)^2+(y-y_k)^2+(z-z_k)^2}\ . \tag{3}$$

A similar expression may be derived for the magnetic field and the time averaged power density is then obtained from the vector (cross) product of the electric field and the complex conjugate of the magnetic field.

VII.NFF ANALYSIS RESULTS

An example of the possibilities of NFF for a (0.5W) EIRP limited system consisting of a linear array of eight short dipoles, spaced apart one wavelength, is shown in Figure 2 for a frequency of 2.45GHz. Figure 2(a) shows that the power density around the focal spot at *z*=1m, produced by the NFF array is 5.5dB higher than that of a single element. The Figure also shows that that in this case the array antenna focused at infinity underperforms by -11dB compared to a single element. Figure 2(b) Shows the power density at a distance *z*=1m parallel to the face of the array. Figure 2(c) shows that the normalized far-field power density of a near-field-focused array is more diffuse than that of an array focused at infinity, leading to a lower directivity and thus allowing to transmit more power before the EIRP limit is reached.

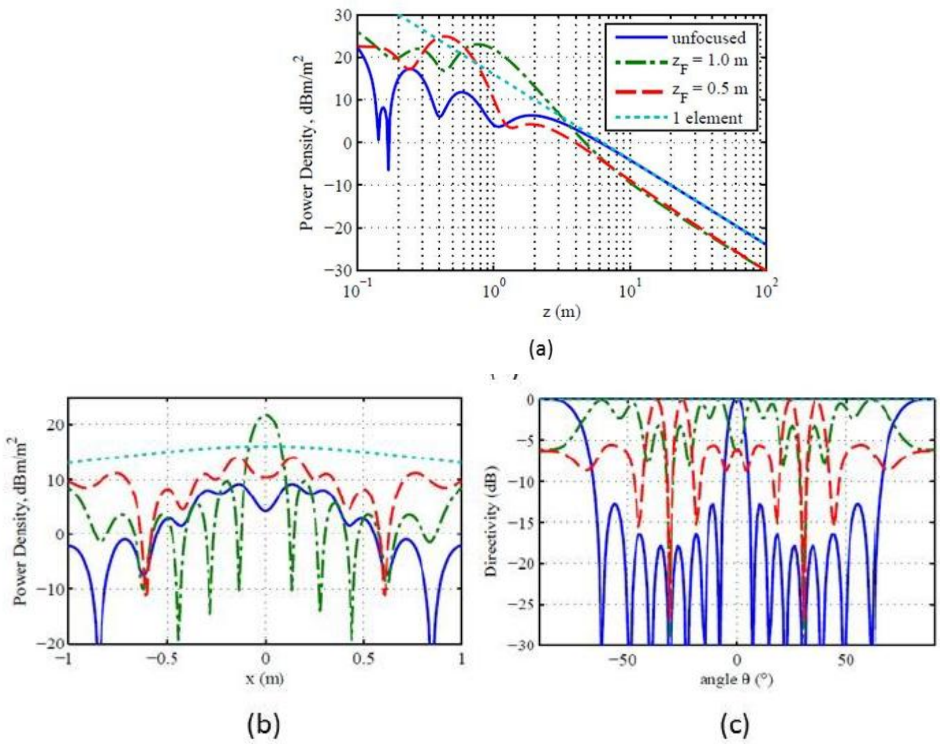

Figure. 2 Power densities along the axis perpendicular to the array face (a), parallel to the array face at a distance z=1m (b) and the normalized far-field in the xz-plane (c).

For practical applications we do not need a sharp focal point but rather a focal area or volume in which a desired power density level can be guaranteed. Figure 3 shows the variation in power density averaged over a volume of $10x10x10cm^3$ centered around z=1m for an eight-elements linear short dipole array having different uniform element spacings.

VIII.IMPROVEMENTS

Although the results obtained with a 'standard' NFF array (employing realistic radiating elements) are satisfactory, we have been looking for ways to increase the focused power level. Several of the investigated methods, like amplitude tapering, the creation of multiple focal points, employment of orthogonal polarizations, and employment of non-planar arrays resulted in the proposal to employ *rotated, highly directive array elements*.

IX.CONCLUSION

Through near-field focusing, employing a (linear) array antenna, more power can be transferred over intermediate distances than will be possible by RF far-field power transfer when obeying the limitations in allowed EIRP. NFF array antenna optimization is currently going on.

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