SMART LENS ANTENNA ARRAYS

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Abstract – ***This paper describes a smart lens antenna array in which a portion of the signal processing is implemented at the analog front end, resulting in reduced processing load. The design of constrained lens arrays is described, and simulations of optimal receiver placement in the array are shown. As an example, the signal-to-noise ratio (SNR) is calculated when a least-mean-square (LMS) adaptive algorithm to different-size lens arrays. The complex weight trajectories are compared to those in a standard planar antenna array, and it is shown that fewer weights are needed in the case of a lens array. Resulting adapted radiation patterns in multi-user and multi-path communication environments are calculated for realistic antenna elements, and reduction in processing load is shown as compared to standard arrays.***

I. INTRODUCTION

Smart (adaptive) antenna arrays are usually thought of in terms of the block diagram shown in Fig.1. An antenna array receives a number of signals modulated onto carriers, and the receiver front end down-converts received signals that are then sampled and processed using DSP algorithms [1]. The purpose of the algorithm is to change the complex weights (phase and amplitude) of the signals associated with each antenna element in the array, thus performing beamforming of the received radiation pattern. A standard antenna array consists of N elements, each possibly containing a LNA, followed by a feed network. In this paper, we investigate the use of a lens antenna array, in which N array elements perform a Fourier transform operation on the incoming wave, and M N receivers are placed on a focal surface sampling this image. The lens array can include integrated amplifiers in each element, and was shown to reduce multipath fading effects due to built-in angle diversity at X [2] and Ka bands [3]. A lens array was also successfully integrated with an analog holographic optical processor in an optically-smart antenna array [4]. This smart antenna demonstrated adaptive signal ordering by strength in a multi-signal space. Here we present design of lens arrays for smart antenna systems with digital signal processing, simulations of adaptive algorithm complex weights and SNR, as well as adaptive beamforming radiation patterns for cases of multi-user and multi-path communication scenarios.

As an example of the motivation to use lens arrays in the place of more standard antenna arrays, the least mean square (LMS) algorithm [5] was applied to 12-element linear array. The resulting optimal (Wiener) solution for the complex weights associated with each antenna element is shown in Fig.2. The weights all lie

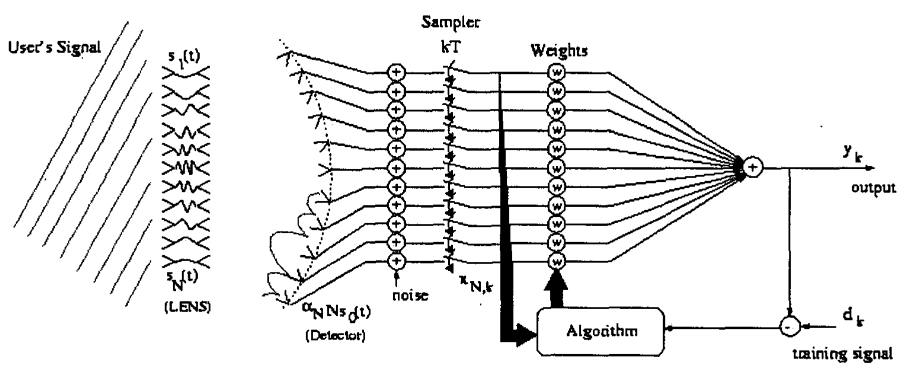

Figure 1. Block diagram of a lens antenna array front end used in a smart (adaptive) system. The received signal is sampled by several receivers, downconverted with added noise, digitized and processed according to some algorithm that determines complex weights that form the radiation pattern in receive mode. In this paper, an LMS algorithm is used for finding the optimal weights.

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on a circle, and as the antenna adapts to, eg. null an interfering user, the weights rotate in the complex plane. The simulation was then performed for an 12-element lens array with 13 receivers, and the resulting complex weight adaptation is shown in Fig.3. It is clear that the two analog front ends result in entirely different optimal solutions for the complex weights. In the standard array, the weights are distributed on a circle, and all are equally important in adapted pattern synthesis. On the other hand, in the lens array, only a few of the weights are significantly larger than 0 after adaptation, so fewer elements (receivers) in the lens can be used for beamforming (only 3, #10, #11 and #12 in the example in Fig.3). The lens, by doing a Fourier transform of the incoming wave, performs a portion of the processing and reduces the computational load of the smart antenna system.

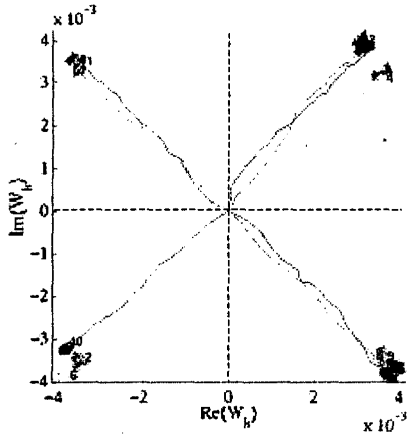

Figure 2. Trajectories of complex weights for an 12-element planar linear array as the LMS algorithm adapts to a beam in the 20^0 direction.

II. ADAPTIVE LENS ANTENNA ARRAY

A lens array consists of two antenna arrays connected with transmission lines of varying electrical length, e.g. [2,3], and is similar to a Rotman lens. For example, in the experimental cylindrical X-band lens in Fig.4 [6], the patch antennas are connected with similar patches on the other side of the multi-layer substrate. The delay lines enable focusing of a received wave onto a focal surface, where receive antennas and circuitry is placed. The field distribution (image) on the focal surface is the Fourier transform of the original incident field, Nyquist-sampled by the lens.

A sketch of a lens array with a 6λ diameter and focal length to diameter ratio of F/D=1 is shown in Fig.5. The focal surface field amplitude profile for a single

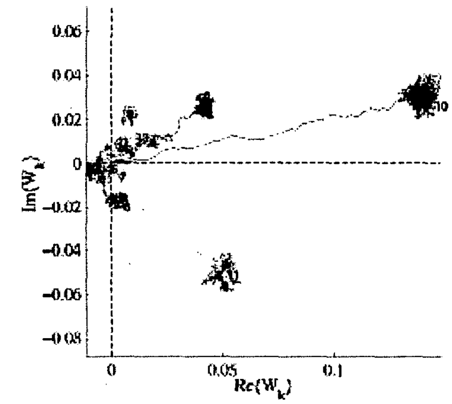

Figure 3. Trajectories of complex weights for an 12-element lens array with 13 receivers as the LMS algorithm adapts to a beam in the 20^0 direction.

source at 20 degrees off the optical axis is shown in Fig.6. The crosses represent the possible positions of 121 receivers that sample the received field distribution. In this simulation, patch antennas with a half-wavelength spacing are used and the image is found using EM wave propagation, details are given in [6].

The received amplitude at the 121 receivers can be ordered in power to show the relative received powers, Fig.7. The LMS algorithm is then applied to the received sampled signals, with noise added by the receiver taken into account. The SNR was then simulated for lenses of different sizes, and the result of these simulations is shown in Fig.8 as the number of significant receivers is increased. The arrow indicates the result for the lens from Fig.5. It can be concluded from this simulation that approximately the 10 receivers that receive most of the signal power in this 121 element array need to be taken into account to approach the optimal SNR. The same conclusion is valid for larger lenses, as can be seen from Fig.8.

III. APPLICATIONS

The performance of the lens is evaluated in a multi-user environment with a "desired" user at 30 degrees, while another user that is a potential interferer approaches from –40 degrees, to 0, 20 degrees and finally is as close as 5 degrees from the desired user in the E plane. When the LMS algorithm is applied to the 6λ lens from Fig.5, the resulting adapted radiated E-plane patterns are calculated as shown in Fig.9. In the case when the

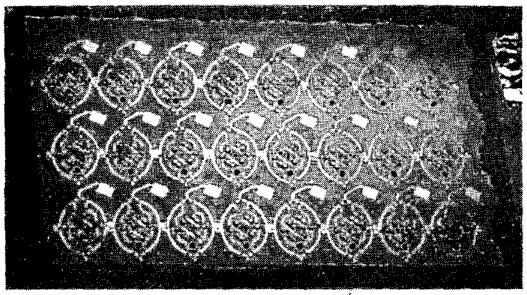

Figure 4. Photograph of one side of a cylindrical 10-GHz lens array. The antennas are spaced three quarters of a free-space wavelength apart. Identical but crosspolarized patch antennas are on the other side of the two-layer substrate and each pair of antennas is connected with a via. Each element contains a half-duplex T/R module.

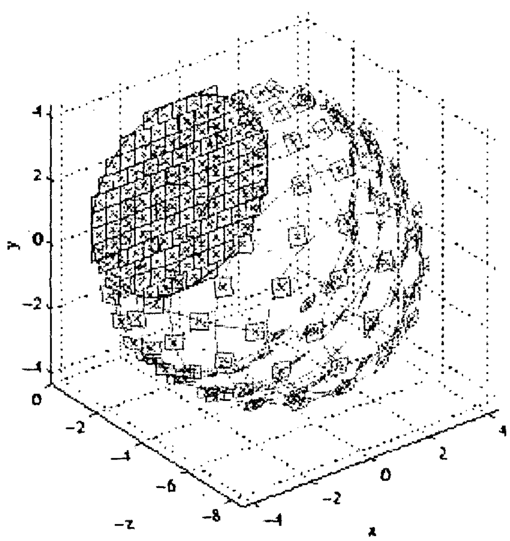

Figure 5. Geometry of a 121-element 6λ diameter lens with F/D=1 and 121 receivers (squares) placed along the focal surface used for the simulations.

interfering user is at boresight, the null is –50dB below the main lobe. These results are practically identical to beamformed patterns using a standard array, while the computational load can be reduced.

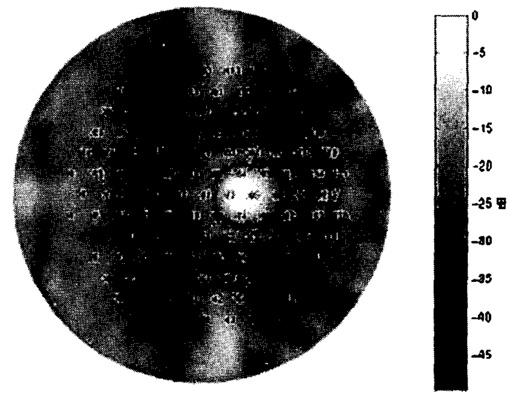

Figure 6. Image on the focal surface produced when a plane wave is incident from the direction (20 deg., 0) on the lens array from Figure 5.

In a multipath environment, the angle diversity of the lens is used to receive multiple bounced copies of the signal, adding the powers in the copies after reception. A simulation of the adapted radiation patterns of the 6λ lens for three different paths with signal losses of 0, 3,

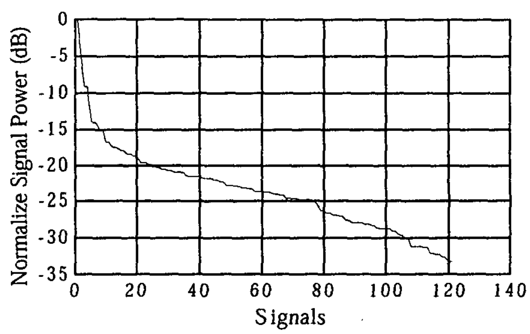

Figure 7. Signal power distribution received by the 121 receivers that sample the image from Figure 6 shows that only a very small percentage of the receivers have most of the signal power.

and 10dB is shown in Fig.8. The three respective main lobe gains (3-dB beamwidths) are inversely proportional to the received power from the corresponding direction. This means that the optimal solution for the adapted weights uses more gain in the direction of higher received power in order to increase the SNR. Again, when compared to a standard array where all the element weights would be used and computed adaptively, in the lens array only the weights corresponding to a few elements where the received signals are strongest determine the lens radiation pattern.

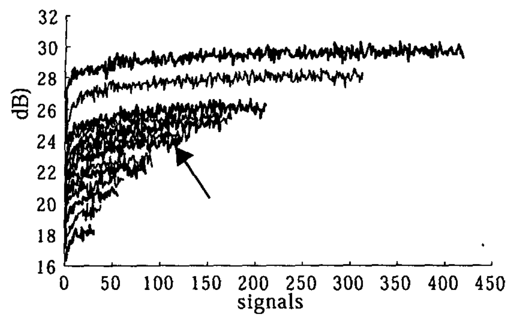

Figure 8. Calculated SNR for different sizes of lens arrays, all with F/D=1, as a function of the number of received signals that are taken weighted in the LMS algorithm. The SNR for the lens from Figure 5 is indicated with an arrow (black line).

In conclusion, this paper presents a lens array smart antenna architecture which has the property of reducing the computation load on the adaptive processing by performing analog front end processing. The front-end architechure in a *N*-element lens array reduces the number of significant complex weights in the adaptive algorithm as compared to a standard *N*-element array.

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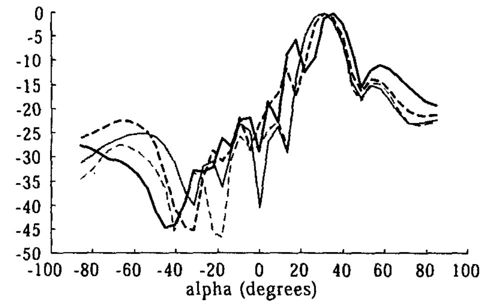

Figure 9. E-plane lens array adapted beam-formed radiation patterns in a multi-user signal space where the main beam is placed in the direction of the desired user at 30 degrees. Simultaneously, a null is placed at the interfering user when it moves towards the desired user starting from –40 deg (gray --), and moving to 0 deg (gray), 20 deg (black --) and 25 deg (black). This beamforming is very similar to that of a standard 2-dimensional planar array, but uses a much smaller number of weights.

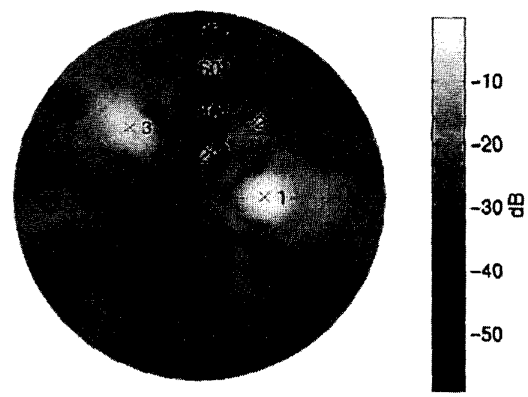

Figure 10. Adaptively beamformed pattern of lens array used in a multipath environment with 3 signal paths of relative path losses of 0 (source 1), 3 (source 3) and 10 (source 2) dB incident from the directions indicated by the x's.