Near and Far Field Focusing Patterns for a 2D Sparse MIMO Array

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***Abstract*—A generic topology, namely, circular array, for two dimensional (2D) sparse multiple-input-multiple-output (MIMO) array, geometrically simple, is proposed. The focusing and imaging properties of the array at millimeter-wave range with narror-bandwidth are studied by simulation. The results for the focusing property show that the array has decent sidelobe levels over a wide field of view within near and far field. Imaging capability of the array presents that point-like targets are well reconstructed with a high dynamic range.**

***Index Terms*—MIMO, array, imaging, focusing property.**

I. Introduction

With great interest of millimeter-wave (MMW) due to its fine cross-range resolution, and ability to penetrate through most dielectric materials as well as poor weather conditions such as smoke and fog, there are many researches regarding to MMW imaging performed [1]-[3].

For three-dimensional (3D) imaging in many applications, the wide field of view imaging and real-time operation are ultimate goals that are usually unreachable with mechanical scanning methods. In order to achive the goals, two-dimensional (2D) array architecture is a suitable solution [4].

The major problem facing the development of 2D arrays for imaging is the complexity arising from the large number of elements required. in such systems, if the region of interest requres the scanning of a wide field of view, the element spacing must not exceed one half of the wavelength. The cost of the 2D array is not thus affordable for any commecial applications. Aside from this, at MMW range, another problem arises from the manufacturing point of view becasue of transmission line-width. As the operating wavelength becomes smaller, the narrow sampling distance is required.

In order to solve these dificulties, sparse multiple-input-multiple-output (MIMO) arrays which employ spatially distributed multiple transmitters and receivers have huge interest due to array thinning and reducing the manufacturing cost [4], [5].

In spite of advantages of MIMO arrays, for the wide field of view applications, conventional MIMO array topology suffers from grating lobes due to its sparsity when the sampling distance between two adjacent virtual array elements is larger than one half of the wavelength [6]. The autors in [5] offer sparse MIMO array topologies which exhibit better angular properties. Nevertheless, the manufacturing complexity of these topologies at MMW range is almost prohibitive because of the complex spatial geometric distribution of transmitters and receivers.

In medical imaging MIMO array topologies are also interested in [7], [8]. The autors in [8] proposes different dual-ring arrays in order to reduce the system complexity in forward-looking (FL) cathered-based imaging systems. In this paper, focusing and imaging properties for a modified dual-ring array, called as circular array which is supposed to bring simplicity in terms of manufacturing complexity, is thus studied.

This paper is organized as follows. Section II presents the geometry for the array and the simulation method. In section III, point focusing patterns and 3D image obtained for point-like targets are analyzed. Finally, section VI summarizes the results and concludes this paper

II. Simuation Model

A. Array Description

The focusing properties for the MIMO array, circular array, are investigated within near and far fields. The proposed circular array has 20 transmitters and 20 receivers. In order to simplify the manufacturing complexity, the transmit and receive arrays are seperated from each other and both of them are arranged on ring structures in Fig. 1. In order to achive $1cm$ cross-range resolution at 1m range for the center frequency of $120GHz$ with $5GHz$ bandwidth, the physical aperture for each array is $11.6cm$. The closest projcted distance along X-axis between the transmit and receive elements is $6mm$.

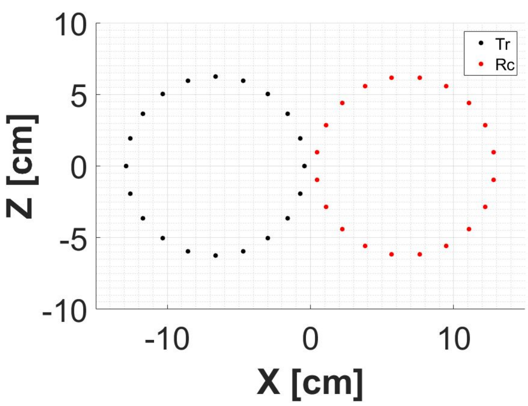

Fig. 1. 2D circular MIMO array topology.

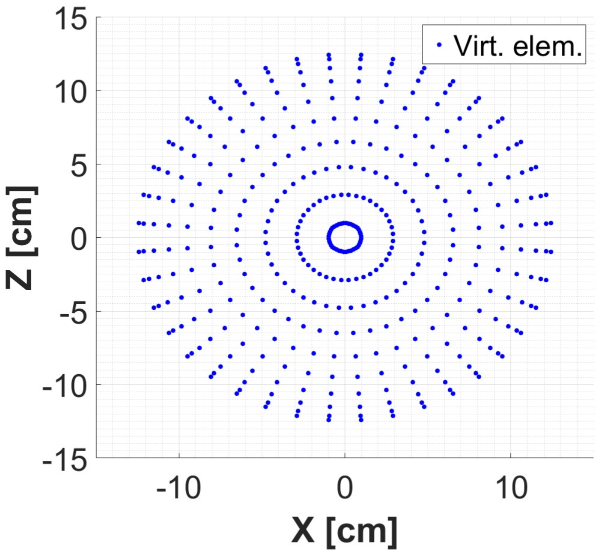

Fig. 2. Its virtual array

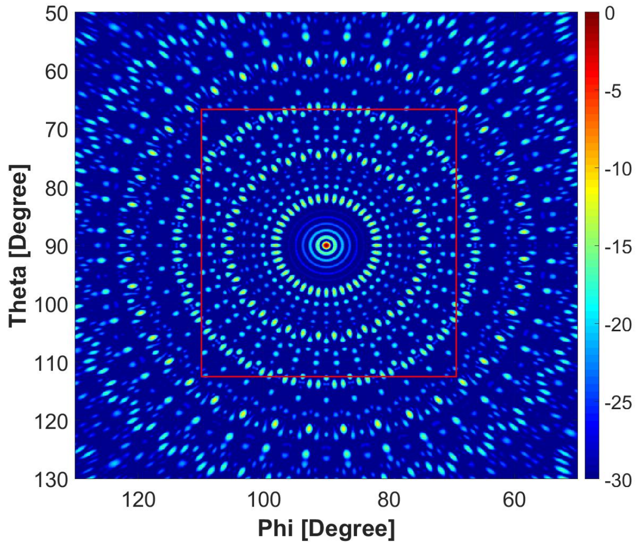

Fig. 3. Far field focusing pattern in [dB]

Circular array has 400 virtual elements in its virtual array and they are distributed on many ring structures as seen in Fig. 2.

B. Point Spread Function and Focusing Algorithm

Point spread function (PSF) is able to show focusing characteristics of arrays such as grating lobes, side lobes and main lobe. PSF is mainly defined by the center frequency, the signal bandwidth, the weighting of the array elements and the array aperture. In simulations, PSF is determined in the following way. Because, the far field condition for the array is satisfied about 8m away from the center of $X-Z$ plane [9], a point-like scatter is located in front of the array in certain distance as the center focal point $(x=0m, y=10m, z=0m)$ for the far field simulation, and $(x=0m, y=1m, z=0m)$ and $(x=0.5m, y=1m, z=0.5m)$ as center and edge focal points, respectively, for the near field simulations. The signal simulated in frequency domain is then transfered into the time domain by the inverse fast Fourier transform (IFFT). The data obtained is focused by using modified Kirchhoff migration algorithm (MKMA). Here, MKMA is selected due to its linear formulation which allows MKMA to be appied to all array configurations and not to bring distortion, caused by the focusing algorithm, to the focused data. Thus, the three-dimensional (3D) PSF is generated over both, cross-range and range. The maximum value along its range dimension is selected to present the focusing pattern of the array in the near and far fields. For 1D focusing pattern for the center focal point, the maximum projection along the angular dimension is calculated. More detail regarding the simulation is given in [6].

III. Simulation Results

In this section, the performance of the proposed array in terms of grating and, side lobes level and its main lobe is to be analyzed within near and far fields. Then, its 3D imaging performance is to be investigated.

The region of interest is between 1m and 10m in the range. In both cross-ranges, the array should illuminate at least 1m cross-range width at 1m range. The counterpart of the cross-range width of interest is $[63.5^o, 116.5^o]$ along polar angle θ and $[63.5^o, 116.5^o]$ along azimuthal angle φ within the far field. Omni-directional antennas are used as transmitter and receiver. The scattered signal is computed in frequency domain at 120GHz center frequency with 5GHz bandwidth.

A. Far Field Focusing Pattern

We start the analysis with 3dB beamwidth. For a MIMO array, 3dB beamwidth is defined by virtual array aperture.

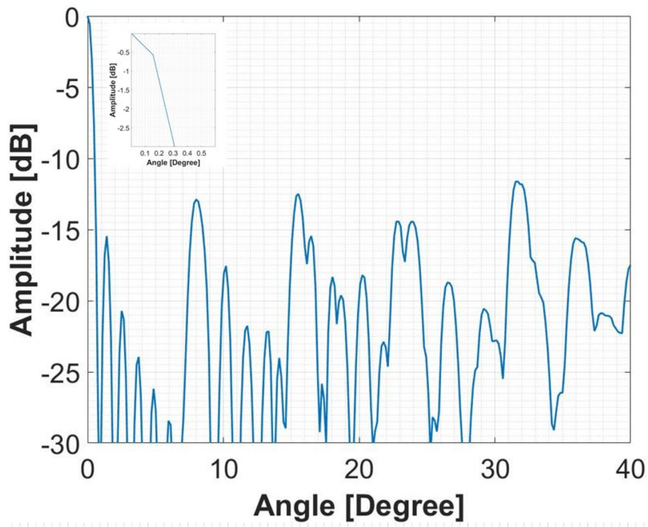

Fig. 4. Far field 1D focusing pattern

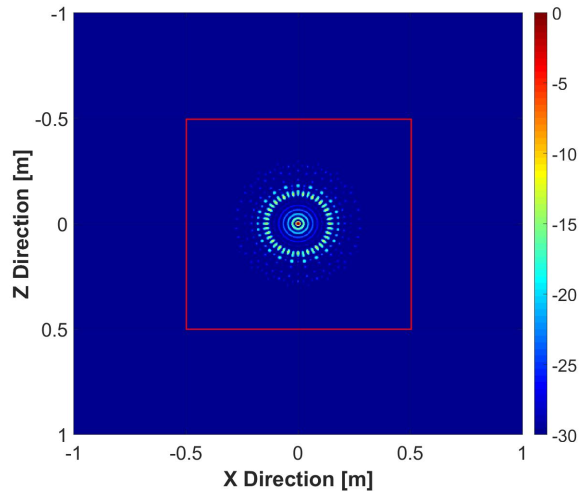

Fig. 5. Near field focusing pattern for the center focal point in [dB]

The array given in Fig. 1 provides a virtual array which has the same aperture on each projection angle on $X-Z$ plane as seen in Fig. 2. Circular array has 0.6^o beamwidth within the far field in Fig. 4. The beamwidth is consistent with the expected resolution, $10cm$ at $10m$ range distance.

In a circular array, grating lobes are supposed to have annual forms due to the fact that the array sparsness exists between circulary distributed array elements. Here, circular array does not have any grating lobes in the region of interest. Firstly, its topology spreads the radiation energy into whole region of interest as seen in Fig. 3. Another reason is that the inter-element spacing in the virtual array is not same on each projection angle. Thus, the unequal distribution of virtual elements also results in no grating lobes.

As seen in Fig. 3, sidelobes are distributed, concentrically. This is because the virtual elements are cocentrically distributed in its virtual aperture. This provides the same element shadowing along each projection angle on $X-Z$ plane. As a result of this, the radiation energy is spreaded, equally, on each projection angle. It is also worth noticing that the maximum sidelobe level (MSLL) is $12.5dB$ which is desirable for many imaging applications.

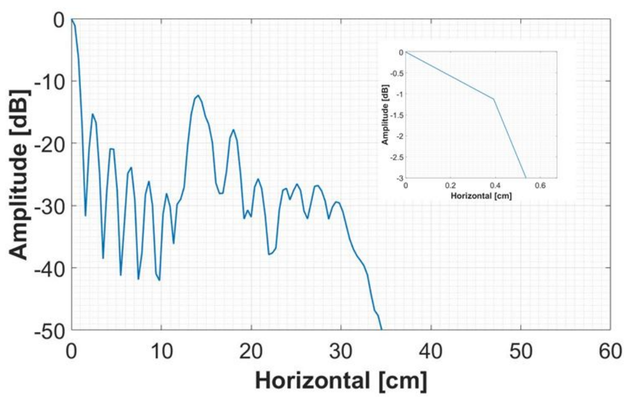

Fig. 6. Near field 1D focusing pattern

B. Near Field Focusing Pattern

The analysis continues with the evaluation of center and edge focuing patterns wihtin the near field for the MIMO array.

First of all, as seen in Fig. 6 and Fig. 7, the array provides 1.08cm and 1.3cm of 3dB resolution at 1m range for the center and edge focal points, respectivelly. The 3dB resolution obtained for the near field center focal point is in agreement with the expected resolution. One should notice that the 3dB resution becomes worse as the focal point is steered to the edge position. When the focal point is within the near field, the array aperture in both cross-ranges begins to play a role in the focusing pattern. The total aperture on one of projection angles on the focal point space becomes smaller. This leads to a lower 3dB resolution.

There is no grating lobe formed in the region of interest due to its concetrically distributed virtual elements. This makes the wide field of view imaging available by employing the sparse MIMO array based on this topology.

The MSLL's are -$12.5dB$ and -$12.7dB$ for the center and edge focal points, respectivelly, which are also favorable for many imaging appilcations.

It is worth noticing in Fig. 3 and Fig. 5 that the dynamic range for the near field focusing pattern is higher than that for the far field focusing pattern due to the fact that the sampling distance between two adjacent virtual elements becomes smaller on the projection of focal point space with the shorter focal point range. This results in lower grade/side lobe levels and high dynamic range.

C. The Reconstruction of Point-like Targerts

The proposed array in Fig. 1 is employed in the simulation in order to see its imaging performance. 8 point-like targets are distributed as seen in Fig. 8 between 1m and 10m range. The

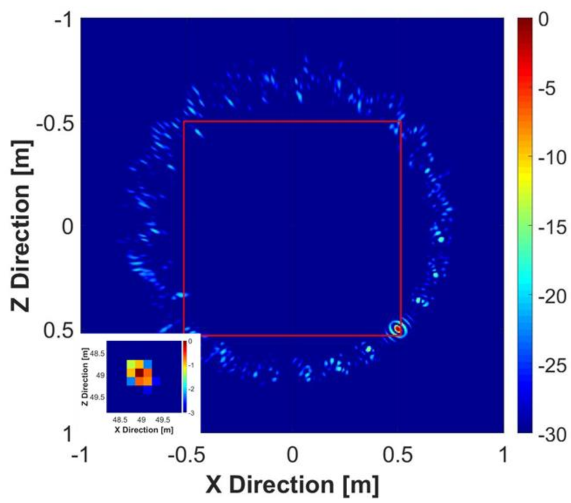

Fig. 7. Near field focusing pattern for the edge focal point in [dB]

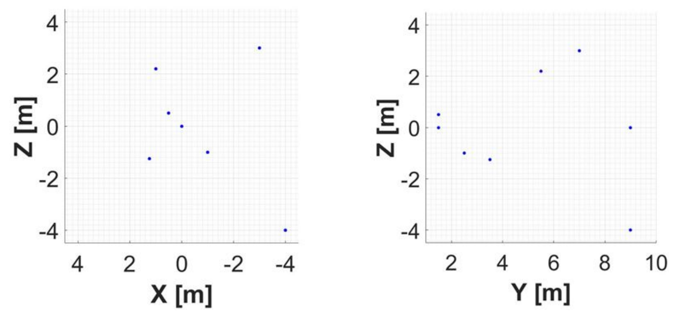

Fig. 8. Positions of point-like targets

simulation is calculated at the center frequency of 120GHz with 5GHz frequency bandwidth. The MKMA algorithm is used to reconstructe 3D image.

As given in Fig. 9, the point like targets are well reconstructed without grating and sidelobes in the region of interest within near and far fields by 12dB iso-value which is desirable in many radar imaging applications.

3dB cross-range resolution is better as the targets are closer to the array aperture due to a linear propotion between 3dB cross-range resolution and target distance to the array aperture.

As a result, the proposed array is suitable to be employed in imaging applications.

IV. Conclusion

We have proposed a sparse 2D MIMO array for MM-wave applications to decrease the manufacturing complexity and number of array elements. The array has a decent sidelobe level without grating lobes in the region of interest. Its imaging capability is also shown by simulation data that it is able to image point-like targets in the wide field of view.

Consequently, the array is convenient for imaging applications of the wide field of view within near and far ranges.

Acknowledgment

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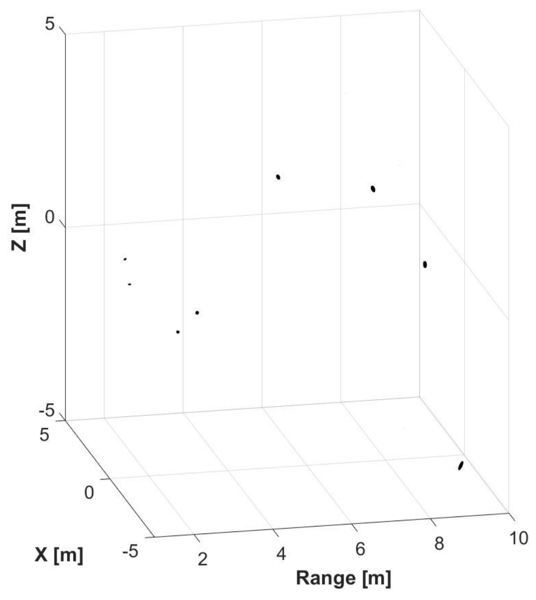

Fig. 9. 3D Image obtained for 12dB Iso-value