Illumination Properties of Multistatic Planar Arrays in Near-Field Imaging Applications

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***Abstract*— The achievable illumination quality in microwave and millimeter-wave images using multistatic planar arrays is discussed. The geometrical relations between the array effective aperture and the illumination boundaries caused by the specular reflections are introduced. Afterwards, the variations in the processing gain due to diffuse and specular reflections are analyzed and verified experimentally.**

I. Introduction

Microwave and millimeter-wave imaging have received an increasing attention since the last decade due to their utilization in security, industrial, and medical applications. This is supported by a continuous enhancement in the semiconductor technology which allows building of imaging arrays with large number of RF modules governed mainly by the system cost rather than the design producibility. For real time active electronic scanning, multistatic planar arrays combined with digital beamforming (DBF) is a promising technology. The performance of this type of array configuration for near-field imaging has been investigated by the authors in [1] and [2] and has proven a good functionality. Using active imaging in personnel scanning and nondestructive testing (NDT) applications, the images often suffer from specular reflections which appear in the produced image as bright spots beside dark regions [3][2]. Therefore near-field operation is required in which the distance to the imaged object is comparable to the dimensions of the scanning physical aperture. Besides a good resolution and reduced artifacts, a good illumination quality achieved by the scanning system is a primary objective.

In this work, the effects of specular reflections on the images made using multistatic planar array configurations are investigated quantitatively. In section II, the geometrical relations leading to the illumination boundaries will be introduced. This extends in section III to the calculations of the processing gain produced by the reconstruction algorithm for multistatic as well as monostatic planar arrays. In section IV, an experimental verification in W-band is presented, followed by the conclusion in section V.

II. Illumination boundaries

Multistatic planar arrays include a distribution of transmitters a_t and receivers a_r on a planar physical aperture. The performance of the array in far-field is given by the double convolution $a_t{**}a_r$, namely the array effective aperture [1][4]. The array performance deviates in the near-field operation and can be considerably restored by increasing the redundancy in its effective aperture. While DBF is used, the reflections measured by each Tx-Rx pair are recorded in magnitude and phase. The measured data is afterwards synthetically focused using a reconstruction algorithm based on the backpropagation algorithm either in its space integral form [2] or in a numerically optimized form.

For discrete transmitter and receiver physical apertures located on $[n, m]$ grid, the effective aperture a_e is given by

$$a_e\left[n,m\right] = \sum_{\forall d_n}\sum_{\forall d_m} a_t\left[d_n, d_m\right]\cdot a_r\left[n-d_n, m-d_m\right]. \quad (1)$$

For redundancy-free multistatic arrays, a_e is flat, otherwise proper weighting of the measurements from each Tx-Rx pair can restore the flatness of the effective aperture which is important for the focusing quality as introduced in [1]. The image at position $\overrightarrow{r_v}$ is hence given by

$$I(\overrightarrow{r_v}) = \sum_{\forall k}\sum_{\forall tx}\sum_{\forall rx} M(k, tx, rx)\cdot \underbrace{e^{+jk\left(|\overrightarrow{r_v}-\overrightarrow{r_t}|+|\overrightarrow{r_r}-\overrightarrow{r_v}|\right)}}_{\text{Focusing term } O}, \quad (2)$$

where $M(k, tx, rx)$ is the measured data at wavenumber k, transmitter tx at position $\overrightarrow{r_t}$, and receiver rx at position $\overrightarrow{r_r}$. Using unfocused low gain antennas, the radiation patterns of the used antennas are not considered here. It is to be noticed that for monostatic configuration $\overrightarrow{r_t}$ and $\overrightarrow{r_r}$ are identical.

While imaging a smooth surface, specular reflections occur where the angles of incidence and reflection are equal. This is illustrated in Fig. 1 for the simple case of a single transmitter and receiver placed on a line parallel to a large metal plate. For the transmitter at position l_t and the receiver at position l_r, the specular point is located at $(l_t + l_r)/2$. From (1), the effective position is located, however, at $(l_t + l_r)$. For the general case of a metal plate placed parallel to a multistatic planar array with an effective aperture $a_e[n, m]$, the illuminated region is given by the area occupied by $a_e[2n, 2m]$. We thus define the array illumination effective aperture as the area occupied by $a_e[2n, 2m]$, which physically indicates the illuminated portion in the resultant image of an infinitely large metal plate placed