Sub-Diffraction Holographic Imaging with Resonant Scatterers in Proximity of the Objects

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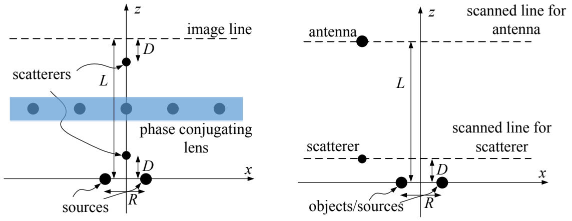
***Abstract*—To overcome the well-known "diffraction limit" in the resolution of electromagnetic imaging systems, we propose the use of resonant near-field scatterers incorporated in the holographic imaging techniques. These scatterers convert a portion of the evanescent spectrum in the proximity of the object to propagating spectrum which is measurable by the antenna in the far-field.**

Keywords—microwave and millimeter wave imaging; resonant scatterers; sub-diffraction imaging

I. INTRODUCTION

The well-known "diffraction limit" phenomenon restricts the resolution of linear far-field imaging systems. Most of the proposed techniques to overcome the diffraction limit exploit the evanescent field components in the extreme proximity of the imaged object (e.g., see [1−3]). Overcoming the diffraction limit for longer imaging distances is very challenging due to the fast attenuation of the evanescent waves. For instance, in [4], super-directivity antenna design concepts have been employed to design super-oscillatory filters and employ them to overcome the diffraction limit in the holographic imaging. This approach has limited field of view. Another technique to achieve super-resolution in the far-field is based on the projection of the near-field information to the far-field. This has been achieved in [5] using scatterers in the proximity of the imaged sources, a phase conjugating lens and a similar configuration of scatterers placed at a similar distance from the image line as shown in Fig 1(a).

Here, we propose a technique to perform sub-diffraction imaging by using scatterers in the close proximity of the imaged object as in [5]. However, unlike [5], the image reconstruction is performed via processing instead of the use of hardware components.



(a) (b)

Fig. 1. Far-field sub-diffraction imaging setups, (a) Setup proposed in [[5]] with placing scatterers at a distance D ($D \ll \lambda$) from the imaged sources and image line and also the use of phase conjugating lens. (b) Proposed setup using near-field scatterers that move together with an antenna scanning in the far-field ($L \geq \lambda$).

II. SUB-DIFFRACTION HOLOGRAPHIC IMAGING

In holographic imaging techniques, the scattering model is based on the linear Born approximation. It has been shown in [[6]] that PSF of the imaging systems can be approximated by recording the scattered field for a small object, termed as calibration object (CO), placed at the same image distance of interest. With reference to Fig. 1(b), the measured scattered field by a y-polarized antenna over the scanned line for a CO placed at the origin is denoted by $E_y^{\mathrm{sc,co}}(x)$. The measured scattered field by the antenna over the scanned line for any unknown object on z=0 line can then be approximated as [[6]]

$$E_y^{\mathrm{sc}}(x') \approx \int_x f(x)\cdot E_y^{\mathrm{sc,co}}(x'-x)dx. \qquad (1)$$

where $f(x)$ is the contrast function to be estimated. The integral over x can be interpreted as a convolution integral. Thus, (1) can be solved in the spatial frequency domain to estimate the unknown function $f(x)$.

As shown in Fig. 1(b), we assume that the antenna performs the scan on a line placed at the far-field of the object. Thus, the spectrum of the measured waves over the scanned line corresponds to only the propagating waves.

Here, we propose using a resonant scatterer moving with the antenna but in the near-field zone of the objects (as shown in Fig. 1(b)). Thus, strong evanescent components generate currents on the scatterer. These currents, in turn, produce secondary scattered components, part of which reaches the antenna in the form of propagating waves. Thus, a portion of the information related to the evanescent spectrum for the primary scattered waves can be measured by the antenna leading to resolution enhancement.

III. SIMULATION RESULTS

For this study, we employ FEKO software. All simulations are performed with air background and at 1 GHz. The antenna is a y-polarized half-wavelength dipole scanning along $z=\lambda$ line. Also, for implementing the holographic imaging, in all examples, PSF, i.e. $E_y^{\mathrm{sc,co}}(x)$ in (1), is obtained approximately by scanning a CO which is a PEC sphere with diameter of $\lambda/40$.

First, we study the effect of the distance D in Fig.1(b) on the resolution. The scatterer is a half-wavelength wire along the y axis. The imaged objects are two PEC spheres with diameter of $\lambda/40$ and center-to-center distance of $R=0.18\lambda$. Fig. 2(a) shows the reconstructed images without using scatterer as well as when using scatterer and with decreasing D from $\lambda/10$ to $\lambda/30$. Significant improvement in the resolution is observed with decreasing D. Fig. 2(b) shows the results when the scatterer is a quarter-wavelength. It is observed that this non-resonant scatterer does not improve the resolution as much as the resonant scatterer in Fig. 2(a).

Next, we study the effect of having two scatterers aligned along the z axis. Fig. 3(a) shows the images for this configuration compared with the cases when using a single scatterer or no scatterer. It is observed that when using two scatterers along the z axis, the resolution is improved significantly compared to the use of one scatterer. Further improvement in the resolution in this example indicates that a portion of the evanescent spectrum for the secondary scattered wave due to the scatterer is also converted to propagating spectrum which is measurable by the antenna.

As the last example, an imaging configuration is studied in which three scatterers are aligned along the x axis and they move together with the antenna. Fig. 3(b) shows the reconstructed images with these scatterers as well as for the cases that only one scatterer or no scatterer is used. It is observed that, in contrast to the previous example (adding additional scatterer along the z axis), adding scatterers along the x axis does not improve the resolution.

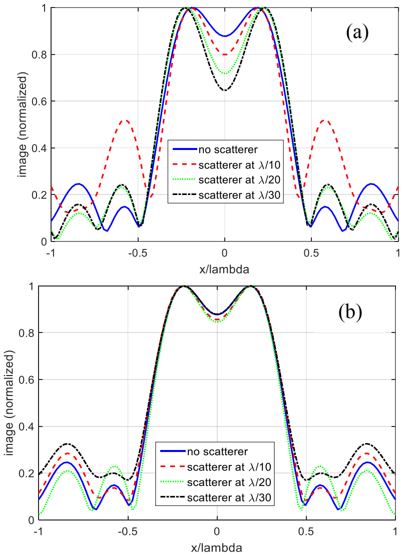


Fig. 2. Images when changing D in Fig. 1(b) with (a) resonant scatterer, (b) non-resonant scatterer.

IV. CONCLUSIONS

We proposed a technique to overcome the diffraction limit in the resolution for the far-field holographic imaging. In this technique, although the antenna performs scanning at the far-field, a resonant scatterer is moving together with the antenna but in the near-field of the object. We studied the improvement in the resolution as the scatterer-object distance decreases. We also showed that using more scatterers along the range direction further improves the resolution.

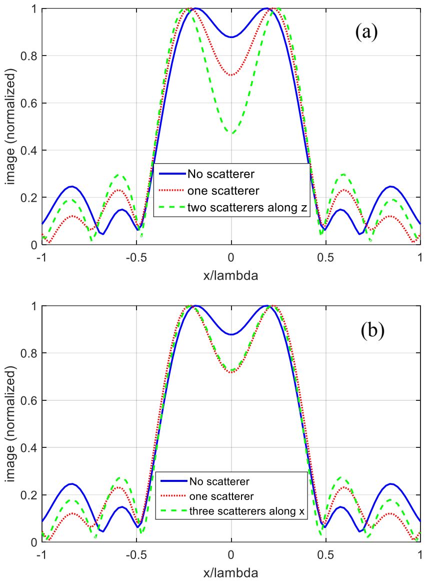


Fig. 3. Effect of using multiple scatterers, (a) two scatterers along z axis, (b) three scatterers along x axis.

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