Three-Dimensional Interferometric Imaging at Terahertz Frequencies Using Three-Dimensional Spiral Array

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***Abstract*—By using a 3D interferometric array to detect point sources of equal intensity, it is possible to detect a difference in distance much more accurately. Also by tuning the depth layout of the array to be log periodic it is possible to increase the resolution of the image. The concept can be extended to image 3D objects.**

I. INTRODUCTION

The concept of using a planar spiral array for interferometric imaging of sources located on a plane parallel to the array plane has been demonstrated [1]. This paper extends the concept to three-dimensional array and three-dimensional multiple source configuration. This is demonstrated at Terahertz frequencies and shows improved image resolution as a third dimension is introduced in the array configuration.

The planar spiral array or the projection of the three-dimensional array is an Archimedean spiral with 32 detectors in the XY plane. In the Z direction, linear and log-periodic distributions are investigated to see which one gives the best resolution. Preliminary results have shown that a difference in depth between sources as small at 2cm can be detected from a range of 1m. Figure 1 shows the 3-dimensional array configuration and Figure 2 shows detected intensities of two sources at two different planes in the source domain. It shows the ability of the 3-dimensional array to detect sources in multiple planes, leading to detecting 3-dimensional objects.

Once the detector orientations that yield the best depth perception and highest resolution have been identified, the next step is to develop an algorithm to process the three dimensional raw data received to extract the desired and useful data. This processed result should yield an image that provides much more useful information about the depth, shape, and texture of the source object.

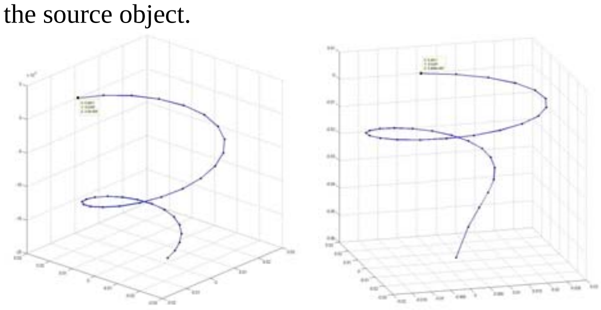

Figure 1: 3-D Spiral Array Configuration: Linear (left) and Log-Periodic (right)

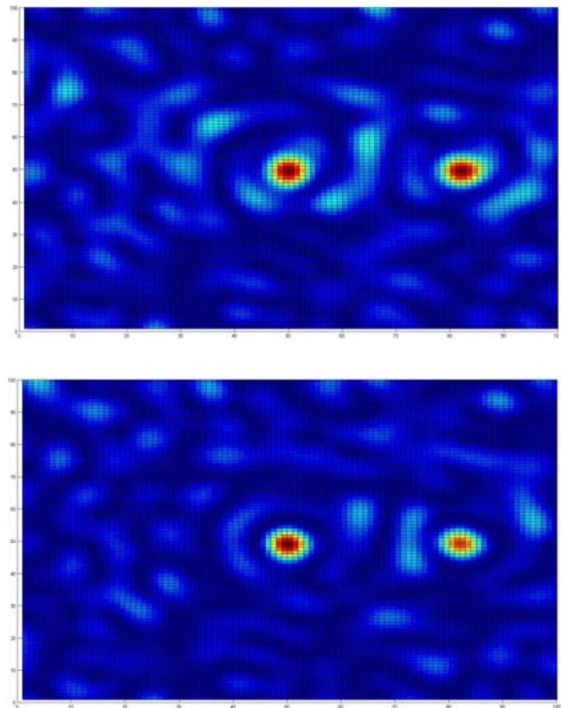

Figure 2: Detected Images of Two Sources Located at Two Different Planes. The center source is closer to the detector array than the right most source. The top image is from a 2D planar array, and the image on the bottom is from a log periodic spiral array from Figure 1.

II. THEORY

A.) ARRAY

This analysis was conducted with two different array projections in the XY plane. Experiments were made with an Archimedean spiral as well as a Log-periodic spiral. The X and Y dimensions of the array were centered around the origin and were about 0.05 meters. The depth of the array varied in the Z direction to compare how different depths affected the 3D image quality.

B.) DETECTION

For the simulation to work one of the first things that are needed is to be able to create a resultant electromagnetic field from the point sources used. This resultant electromagnetic field is what the detector array will see. The formulas below are from the paper referenced below [1]. These formulas have

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been modified to work for our three dimensional experiment. The equations representing the two sources A and B are:

$$E_A = \frac{Ae^{ikr}}{r} \text{ and } E_B = \frac{Be^{ik|\bar{r}-\bar{r}_0|}}{|\bar{r}-\bar{r}_0|}$$

The equations for the distances r and r – r0 are below,

$$q_A(n) = r_A = \sqrt{(x(n)-x_A)^2 + (y(n)-y_A)^2 + (z(n)-z_A)^2}$$
$$q_B(n) = r_B = \sqrt{(x(n)-x_B)^2 + (y(n)-y_B)^2 + (z(n)-z_B)^2}$$

Where $x(n)$, $y(n)$, $z(n)$ are the coordinates of the n-th detector and x_A, y_A, z_A and x_B, y_B, z_B are the x, y, z coordinates of the sources A and B respectively. Combining the above equations yields E the resultant electromagnetic field

$$E = E_A + E_B = \frac{Ae^{ikq_A(n)}}{q_A(n)} + \frac{Be^{ikq_B(n)}}{q_B(n)} = Mag\ e^{i\ phase}$$

In the three-dimensional spiral array, each detector is able to measure the amplitude and phase of the resultant electromagnetic field. The amplitudes and phases received by each detector are then correlated and processed with the Fourier equation below:

$$\sigma_E(\xi,\eta) = \sum_{l=1}^{N(N-1)/2} \left[\mathrm{Re}\left(A_l e^{i\Delta\phi_l}\right)\cos\left(k\left(u_l\xi + v_l\eta + w_l\Theta\right)\right) - \mathrm{Im}\left(A_l e^{i\Delta\phi_l}\right)\sin\left(k\left(u_l\xi + v_l\eta + w_l\Theta\right)\right)\right]$$

where σ_E is the time-averaged intensity of the source, u_l is $(x_n - x_m)$ and v_l is $(y_n - y_m)$ are the x and y baselines for two detectors located at the points (x_m,y_m) and (x_n,y_n), k is the wave number, N is the number of detectors in the array, A_l is the product of E_mE_n, $\Delta\varphi_l$ is $\varphi_m - \varphi_n$. The variables ξ is x'/Z_0 and η is y'/Z_0 represent the ratio of the source located at (x',y') and Z_0 which is the distance from the detector array to the source plane [1].

III. RESULTS

By utilizing a 3D array similar to layouts shown in Figure 1, it is possible to detect differences in distances of equal or different intensity sources. This should allow this technique to detect the surface texture of an object. Also by altering the depth of the array between linear depth to log periodic, it may be possible to achieve improved resolution of the detected sources.

Although 2D imaging with some adjustments to detector layout can be made to show a difference of brightness between two equal intensity sources that are located at different distances from the imaging array, 3D imaging yields more information about the objects being imaged. With 3D imaging a volume that contains the sources can be imaged. By looking at the various cross sections of this volume, valuable information can be obtained about the distribution, density and locations of the sources.

Figures 3 and 4 show two images of the same two sources in Figure 2, taken with an array similar to Figure 1. The sources are of equal intensity. Source A is located 96 cm above the origin, and Source B is located 8 cm to the right of Source A and at 108 cm above the XY plane. The detection array starts at the XY plane and has a depth of 0.05 m.

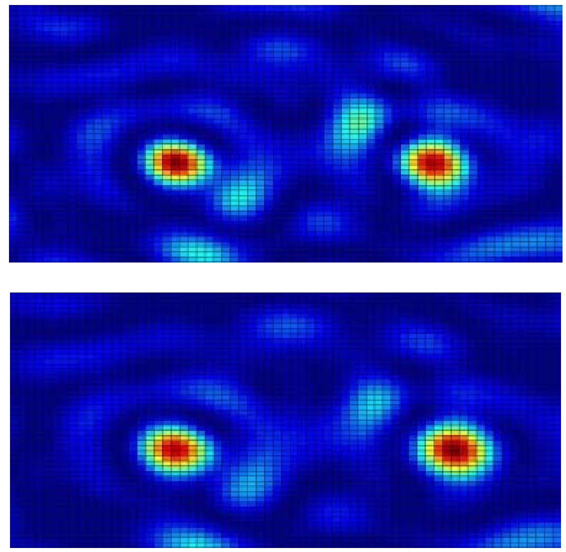

Figure 3: The sources mentioned earlier are imaged with an Archimedean spiral array with a depth of 0.05m and the differences in distance in the negative Z direction are log periodic. (top) Source A on the left is more prominent than Source B on the right. The peak colors on Source A are darker in the center of the oval. (bottom). Source B has become more prominent than Source A. Source B is now darker. The top image is of the part of the imaged volume closest to the array; and the bottom image is of the part of the volume farthest from the array.

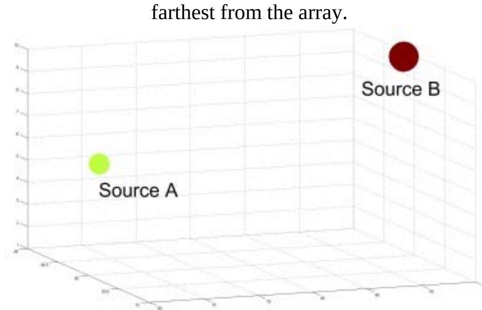

Figure 4: Graphical representation of the imaged volume showing where each of the two sources are at a maximum and relatively where they are located in space.

IV. CONCLUSION

The use of 3D spiral arrays as detectors is shown to produce 3D images. The additional information provided by taking a 3D image may yield valuable information for detecting and imaging 3D objects. It could yield more information about object distribution, shape, and orientation. This advantage over 2D imaging may prove valuable in security applications.

V. REFERENCES

[1] A. Sinyukov, R. Barat, D. Gary, Z. Michalopoulou, I. Zorych, D. Zimdars, and J. Federici, "Terahertz interferometric imaging of RDX", *Proc. of SPIE Vol. 6549, 654909, (2007).*

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