Development of a Pattern Simulator for Benchmarking a Near-field Holographic Image Processor

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Abstract

Deformations of the reflector optics comprising a radio telescope can introduce station position errors that are significant in the context of VLBI2010. Radio holographic imaging is a technique that can be utilized to detect such deformations. In experiments involving large reflector antennas at relatively high frequencies, geosynchronous satellites are observed to conduct far-field radio holography since the stand-off ranges satisfy the far-field requirement. However, these sources are relatively fixed with respect to the radio telescope and this limitation does not facilitate the ability to characterize the deformations over the telescope's full field-of-view. The near-field holographic imaging technique overcomes this limitation of the satellite-based far-field technique since the source is under the control of the observer and may be placed in close proximity to the radio telescope in question. Additional complexities arise in this near-field scenario but these considerations have been addressed in the literature. In this report, a near-field antenna pattern simulator was developed to facilitate testing of a near-field holographic image processor. The results of this simulator have been compared against independent expectations to validate the simulator.

Holography

The process of generating a holographic image involves: (1) measurement of the radio telescope's complex (i.e. real and imaginary components) antenna pattern and (2) processing the Fourier transform of the radio telescope's complex antenna pattern. This project comprised of part (1) leaving the second part for a future development.

$$f = e^{ikr(x,y,\phi,\theta)} \quad \text{Equation 1}$$

$$F(\phi,\theta) = \int e^{ikr(x,y,\phi,\theta)}\, dxdy \quad \text{Equation 2}$$

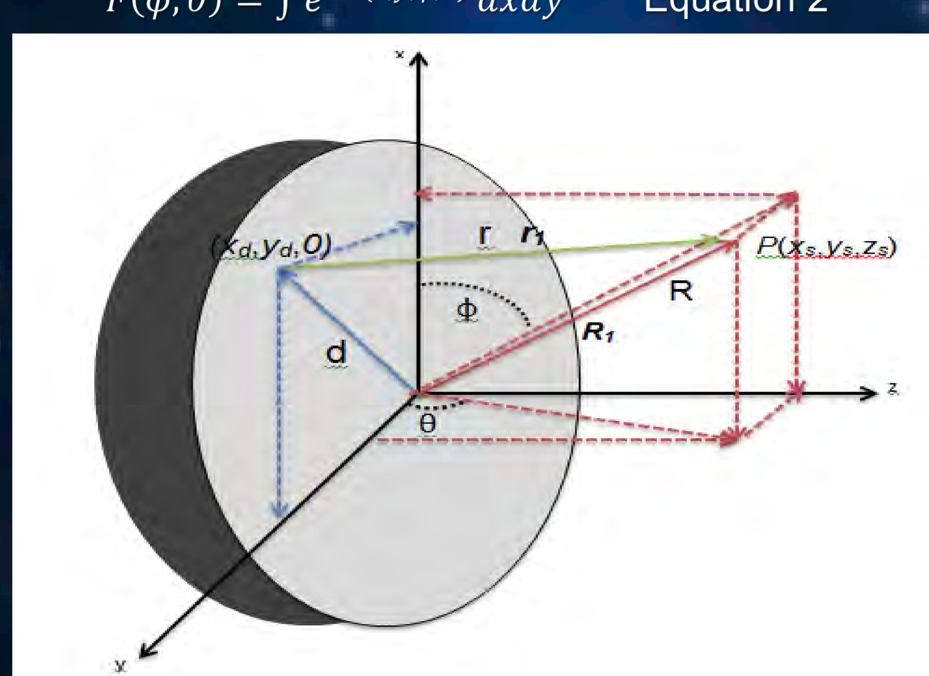

Figure 1: The aperture coordinate system where R is the distance from the origin to the source, d is the distance from the origin to the differential aperture point, and r is the distance from the aperture point to the source.

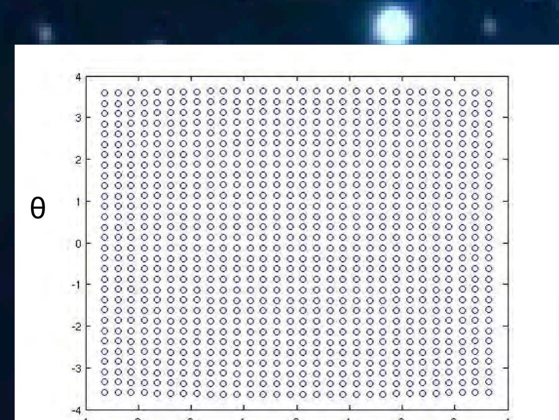

Figure 2: This image shows the number of points scanned in the raster

Test Cases

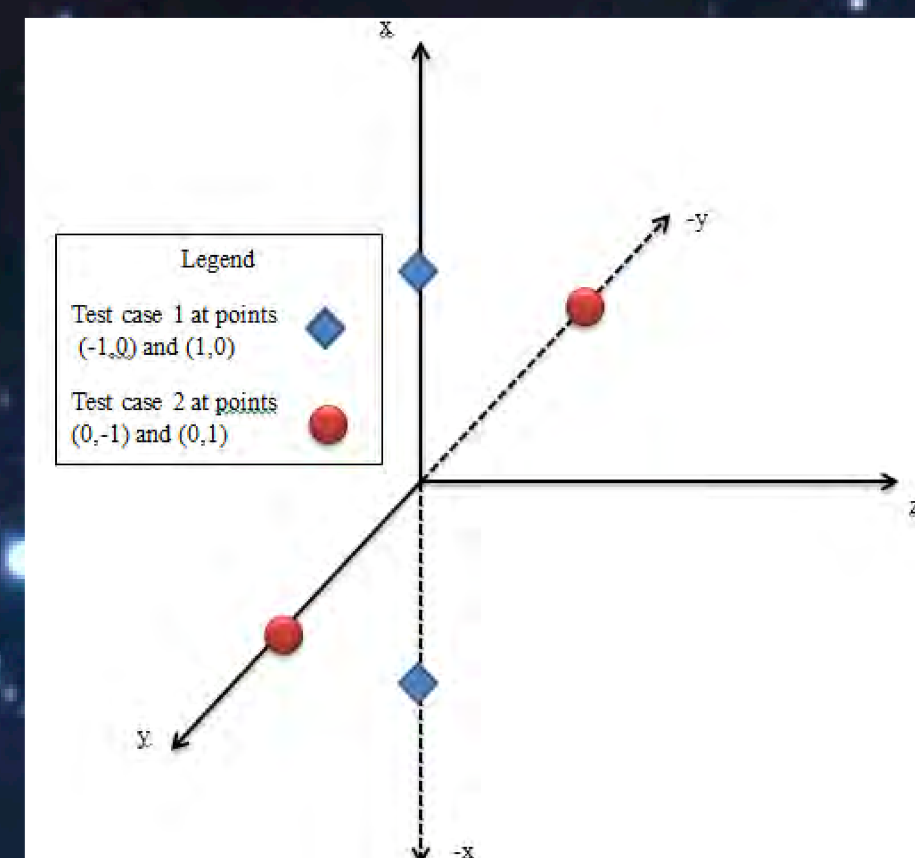

Figure 3: This diagram represents the location of the differential receiving elements (aperture points) in each test case.

In this project, MATLAB code was developed and tested to simulate the complex near-field receiving pattern of an idealized antenna aperture for the purpose of benchmarking a near-field holographic image processor. This software allows the operator to define the antenna aperture as an array of idealized unit-amplitude differential isotropic receiving elements as well as the span of the source scan parameters (ϕ,θ) through which the aperture is rotated to "observe" the complex receiving pattern. Once this software was developed and gave seemingly accurate results, the results needed to be verified. Test cases 1 and 2 helped to do that by qualitatively and quantitatively checking the complex receiving pattern and that the calculation of r was accurate. In the case of the former an analysis of the pattern was examined. The nonlinear phase variation across the aperture causes a "blurring" out of the pattern at closer distances of R because of the wavefronts presenting more phase curvature. For the variation of r, the law of cosines was used to independently verify that the values of r the code was calculating were correct for each angle they were being computed against.

$$r = \sqrt{d^2 + R^2 + 2dRsin(\phi)} \quad r = \sqrt{d^2 + R^2 + 2dRsin(\theta)}$$

Equations 3,4

Test Case #1

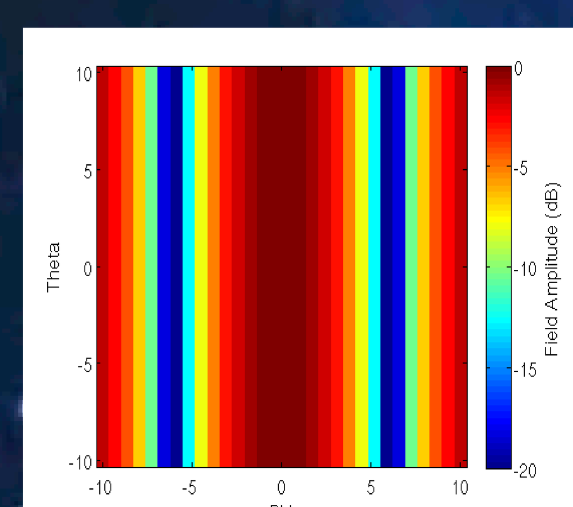

Figure 4a: Complex radiation pattern of points at (-1, 0) and (1,0) and R=1

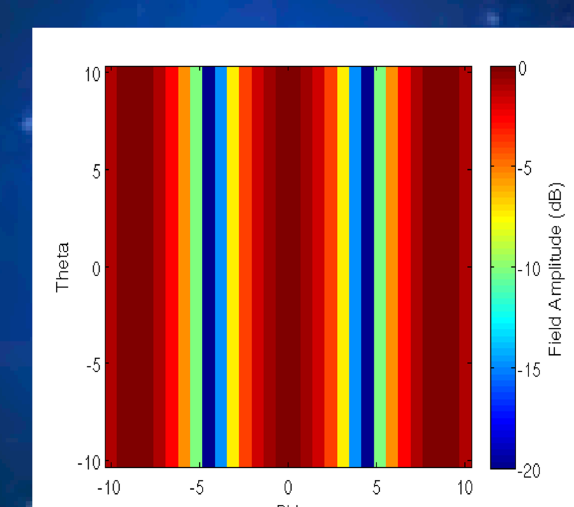

Figure 4b: Complex radiation pattern of points at (-1, 0) and (1,0) and R=100

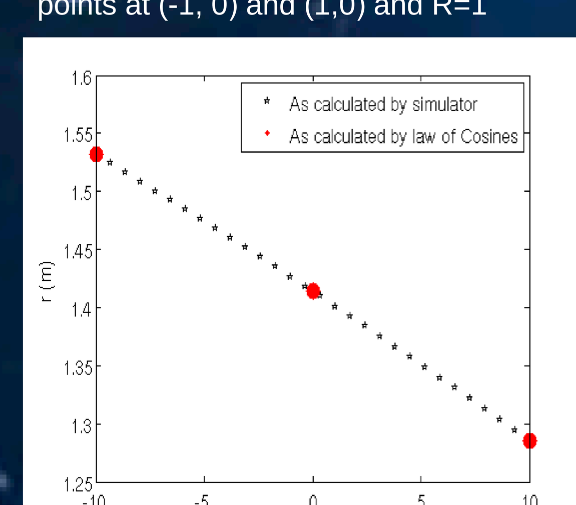

Figure 5a: A plot of phi v. r where R=1 and the point is (-1,0)

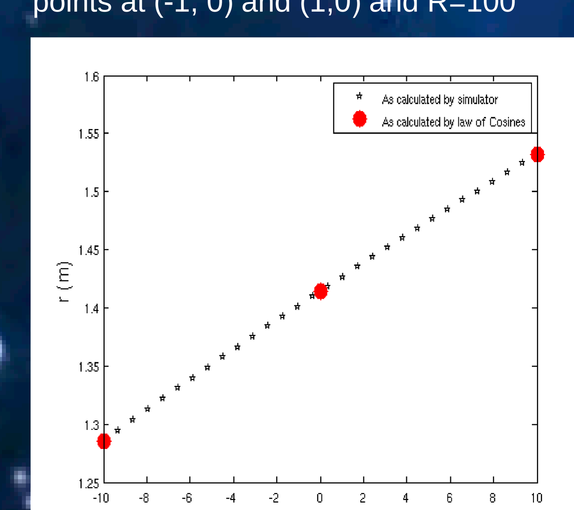

Figure 5b: A plot of phi v. r where R=1 and the point is (1,0)

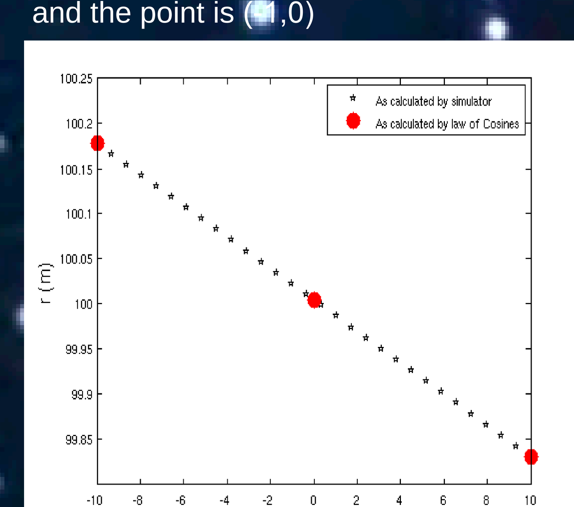

Figure 5c: A plot of phi v. r where R=100 and the point is (-1,0)

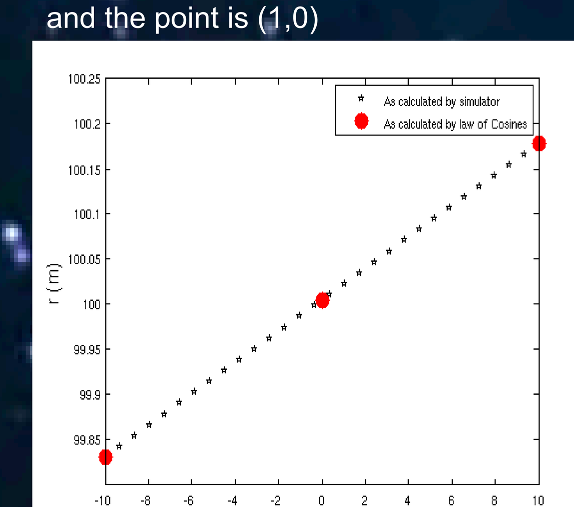

Figure 5d: A plot of phi v. r where R=100 and the point is (1,0)

Test Case #2

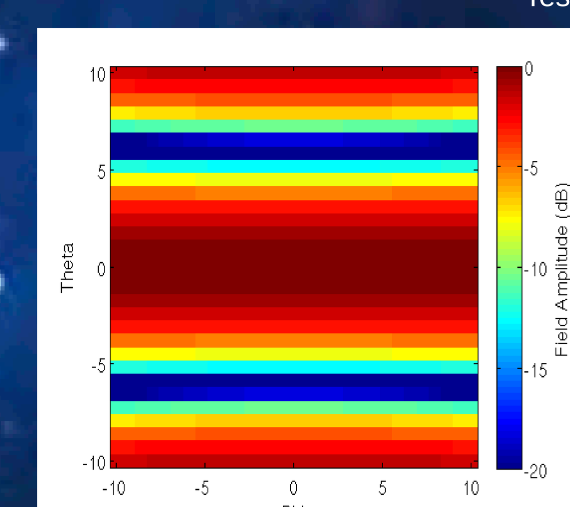

Figure 6a: Complex radiation pattern of points at (0,-1) and (0,1) and R=1

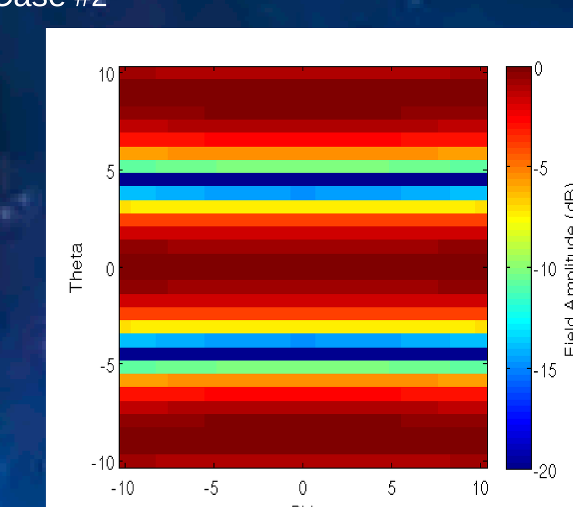

Figure 6b: Complex radiation pattern of points at (0,-1) and (0,1) and R=100

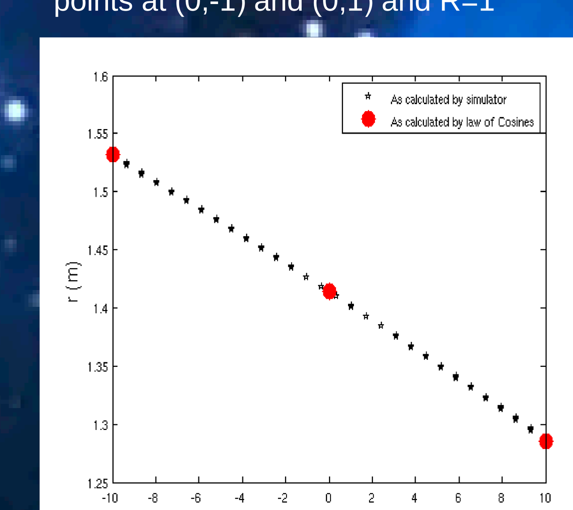

Figure 7a: A plot of theta v. r where R=1 and the point is (0,-1)

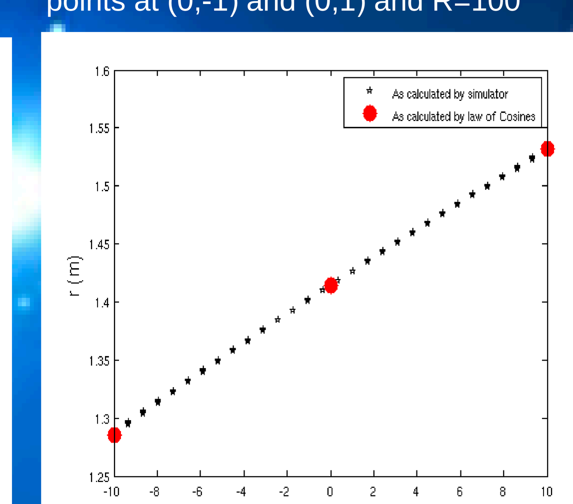

Figure 7b: A plot of theta v. r where R=1 and the point is (0,1)

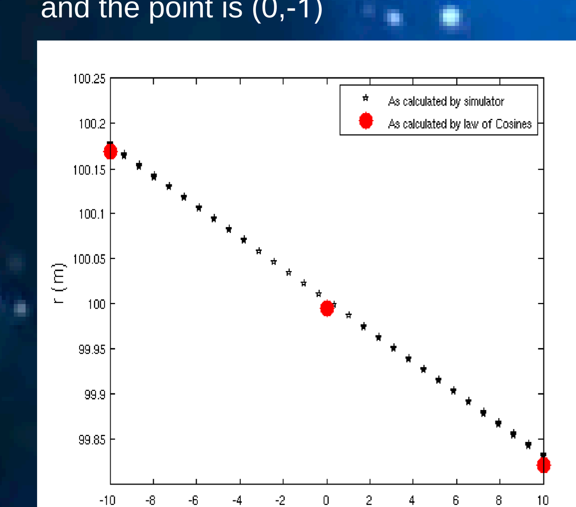

Figure 7c: A plot of theta v. r where R=100 and the point is (0,-1)

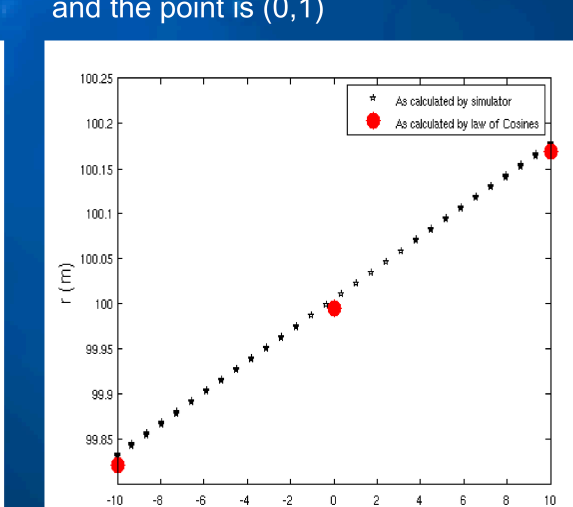

Figure 7d: A plot of theta v. r where R=100 and the point is (0,1)

Applications

Antenna structures undergo both thermal and gravitational deformations. Both bias the effective position of the antenna. The development of a stable, externally accessible set of reference marks is necessary for decoupling geophysically interesting site motions from intrinsic antenna deformations, for enabling comparisons and combinations of VLBI with other techniques, and for providing more general access to the VLBI frame.[3]

Conclusion & Future Works

The test cases proved that the complex aperture simulator is working correctly. Since the impetus for this project is the development of a near-field holographic image processor, the next logical step is to develop such a software utility. The software developed in this project would serve as a benchmark radiation pattern for such a processor. Given the confidence in the accuracy of the results that were reported regarding the complex receiver pattern simulator, this software tool may be used to establish the integrity of the imagery generated by the near-field image processor during software development.

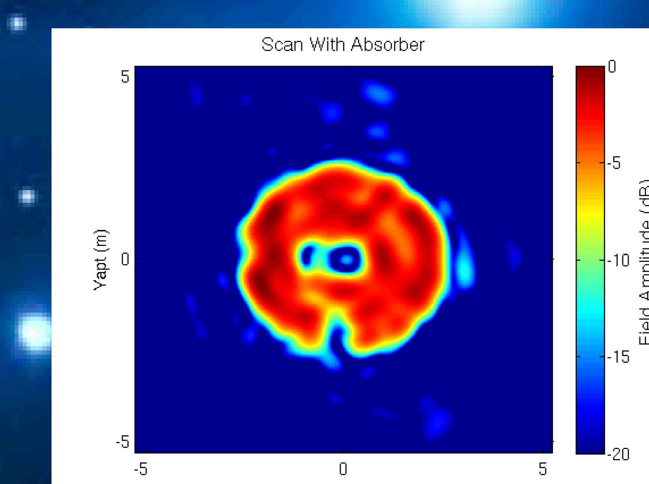

Figure 8: Sample of what a completed holographic image would look like with the developed near-field processor. This is what is hoped to be developed for the near-field case. This image comes from a previously designed image processor for the far-field case.[4]

Figure 9: What the dish that took figure 8 image looks like. It has a microwave absorber unit on the bottom, a equipment case cover on center left and the feed structure in the center.[4]

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Sources

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