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Estimating a Large Phased Array Antenna Radiation Pattern by Computer Electromagnetic Simulation

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October 2018

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Introduction

The design of a conformal antenna for use on UAV's and other aircraft can be enhanced with computational electromagnetic modeling to determine the expected radiation patterns of the antenna when mounted on the aircraft. However, detailed simulation of the antenna structure and the aircraft together requires significant computational resources and time which may not be available. This paper details several methods for estimating the radiation pattern of a 50 x 50-element patch antenna.

The Conformal Lightweight Antenna Structures for Aeronautical Communication Technologies (CLAS-ACT) Program aims to build and test a 14.25 GHz (Ku-band) conformal antenna on a NASA-owned UAV. The antenna is intended for satellite communications and will enable communication between a ground station and a UAV when the separation distance is too great for line-of-sight communication. It is estimated that a 2° beamwidth will be necessary, requiring a 50 x 50 array of patch elements. The narrow beamwidth requirement, together with an element spacing of 0.6 λ, means that the array length will be 30 wavelengths, electrically very large.

Three methods of varying complexity are described for estimating the total far-field radiation pattern. The results are shown for each method in the form of a normalized power pattern.

Simulation Methods

For all three methods, the same array layout was used, the layout being the physical arrangement of the patches and the magnitude and phase of the electrical signal source fed to each patch. A 0.3 cosine taper was incorporated together with triangular spacing. The overall array shape was that of a cylinder of radius 16 inches, a shape imitating that of a possible aircraft surface. The layout is shown below in figure 1. Calculations were performed in Antenna Magus and FEKO software. Methods 1 and 2 were simpler and faster calculation methods performed on a desktop workstation, while method 3 was a much more computationally intensive and slower, but possibly more correct, method performed on the Langley Research Center (LaRC) K3 Cluster computer.

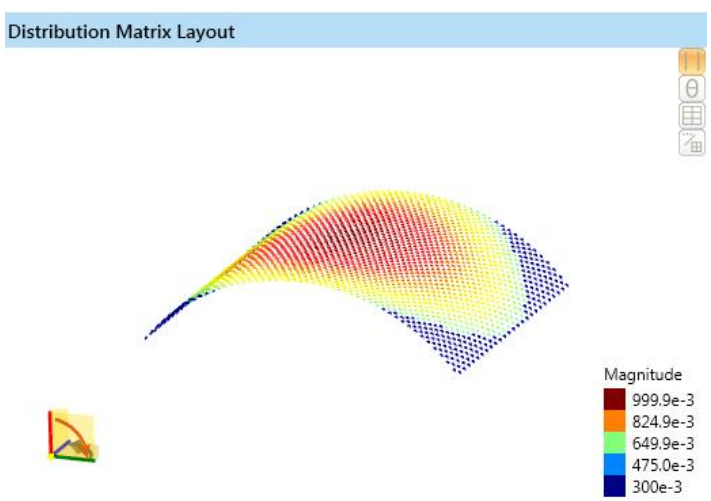

Figure 1. 50 x 50-element array layout.

Method 1

In method 1, a placeholder circular patch antenna was designed using Antenna Magus software, and the electrical far field was calculated in FEKO, by the Method of Moments, for a single patch over an infinite substrate and ground plane. The design was called "placeholder" because it was intended for the purpose of study but would not be the final design used by the Program in ground or flight measurements. Figure 2 shows the patch and its far-field pattern. Antenna Magus was used to add together the far fields radiated by all of the 2,500 patches to produce the array far-field pattern in space. Antenna Magus sums element far-fields in the arrangement specified by the layout, but ignores interactions among the patches or with the antenna platform. It is seen that the patch itself was not quite symmetrical, due to its feed being off-center. The patch asymmetry therefore resulted in an overall array pattern that was also not quite symmetrical.

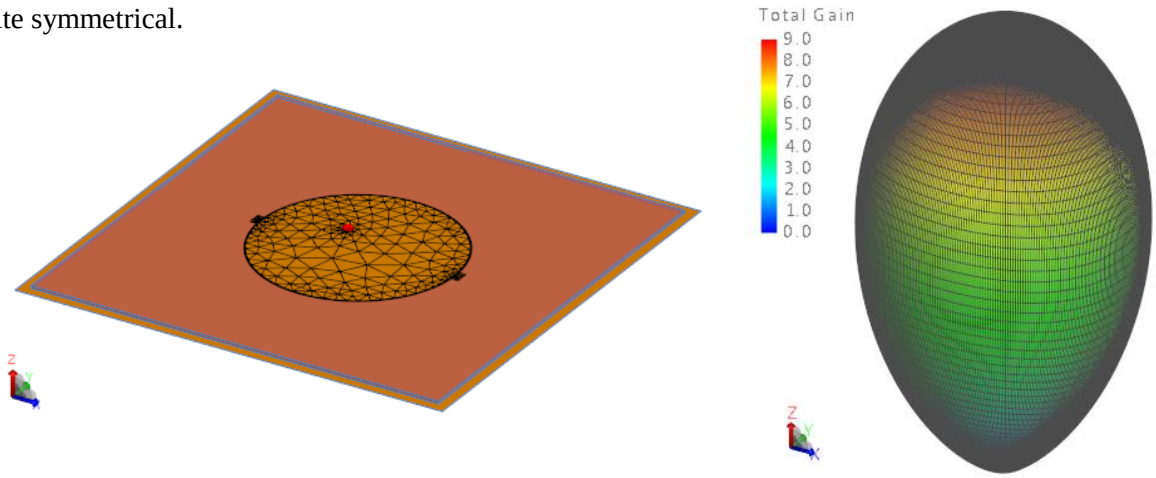

Figure 2. Placeholder circular patch antenna with infinite substrate and groundplane. a) Meshed drawing of the patch with a red dot indicating the feed point. b) Far-field radiation pattern for a single patch.

Method 2

In method 2, the ideal cavity-backed patch built into Antenna Magus was chosen as the array element. Its far-field pattern is shown in figure 3. The array far-field pattern was then calculated by using this element together with the array layout shown in figure 1. Again, the total 50 x 50 array radiation pattern was calculated without regard to interactions among the patches or with the antenna platform. However, the cavity-backed patch design simulated a metal surface behind the individual patches, and the use of a precalculated element far field simplified the process of finding an array pattern.

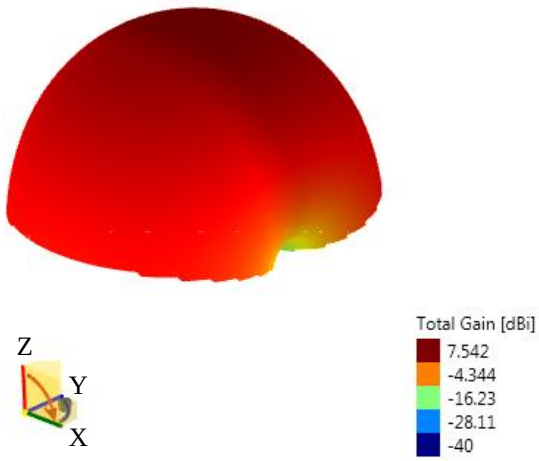

Figure 3. Far-field pattern for a single cavity-backed patch.

Method 3

In method 3, the placeholder circular patch antenna was selected. Its electrical and magnetic near fields were computed in a hemispherical pattern in FEKO, assuming that the patch was given an infinite substrate and ground plane. The near-field data were then used as equivalent sources to replace the array elements in the array simulation. The 50 x 50 array of near-field sources was placed over a perfectly electrical conducting (PEC) cylinder of radius 16 in. and length 48 in., as shown in figure 4. The figure shows the arrangement of one out of the 12 groups of near-field sources with respect to the PEC cylinder.

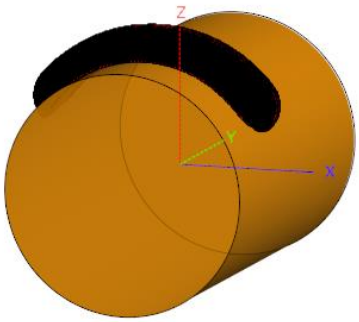

Figure 4. Closed PEC cylinder together with one of 12 groups of near-field equivalent sources.

Because of the large size of the simulation, it was performed on the LaRC K3 Cluster computer; however, the entire problem could not be solved in one run due to memory and time limitations. The array was divided into 12 sections whose far-field patterns were calculated separately using the Multilevel Fast Multipole Method (MLFMM) technique. Then the 12 sets of resulting fields were added together. In this way, the interactions of close-together patches and the platform were accounted for, but the simulation could not account for interactions among the far-apart patches.

Results

The results of the three simulation methods appear in figures 6-8. In each case, normalized total far-field radiation patterns are shown for the principal planes phi = 0° and phi = 90°. It is seen that the antenna points at theta = 0°. For methods 1, 2, and 3, the 3-dB beam widths were 2.0, 2.0, and 2.2 degrees, respectively. The first side lobes appeared at -24.0, -24.0, and -29.7 dB, respectively. In each case it is seen that, in the phi = 0° plane, which cuts through the curve of the cylinder, the radiation pattern occupies a larger theta extent than in the phi = 90° pattern, which cuts through a flat portion of the cylinder. In the phi = 0° plane, radiation may be observed at theta = ±140° for methods 1 and 2 and ±180° for method 3, which incorporates the metal cylinder into the model. In the phi = 90° plane, radiation may be observed to theta = ±90°, ±82°, and ±132° for methods 1, 2, and 3, respectively.

Therefore, two general observations may immediately be made: 1) greater curvature of the antenna causes radiation over a larger angular extent and 2) inclusion of a metallic platform also causes radiation over a larger angular extent compared to simply modeling the antenna in space. We see that the MLFMM (method 3) produces more fluctuations than simply adding far fields together (methods 1 and 2). However, there is a similarity in all three sets of plots if we examine the tops of the fluctuating curves. From theta = 0 to ±100° in the phi = 0° plane and 0 to ±50° in the phi = 90° plane, all three sets of plots show the same power levels.

However, if one is interested in radiation levels at theta more than 50° off boresight, the platform should be included in the simulation. For a conducting platform, we expect currents to travel along the platform surface and radiate in all directions; therefore method 3 agrees more than the other methods with what we expect. For the same reason, method 1 appears more correct than method 2. Finally, we note that the

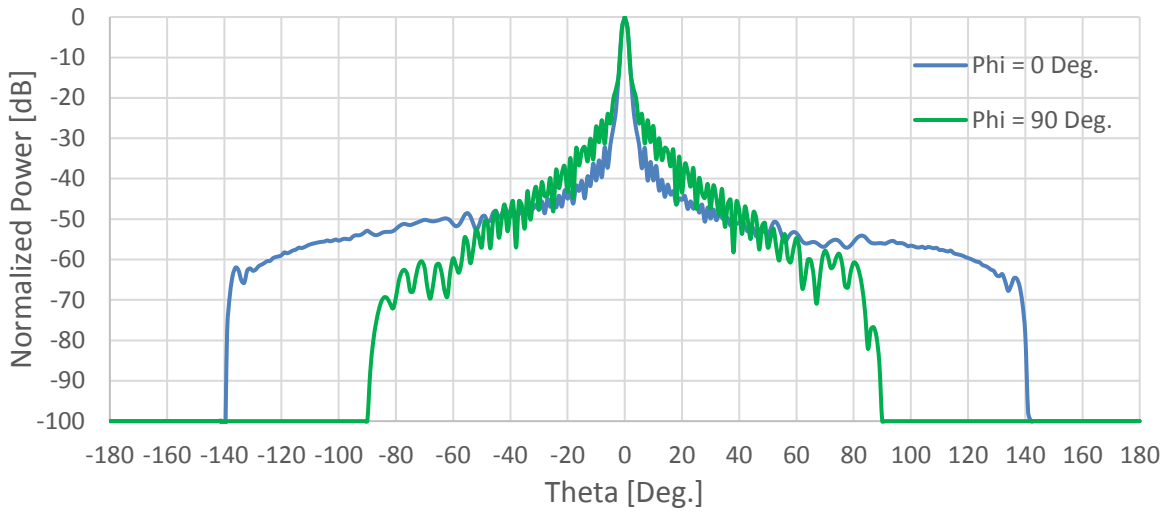

Figure 6. Method 1 far-field power plots in two principal planes.

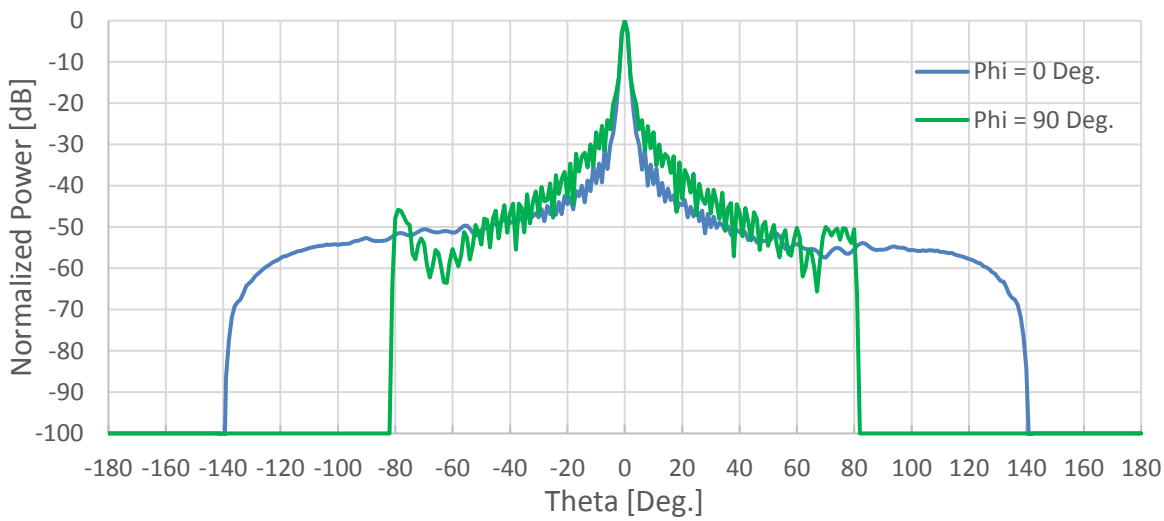

Figure 7. Method 2 far-field power plots in two principal planes.

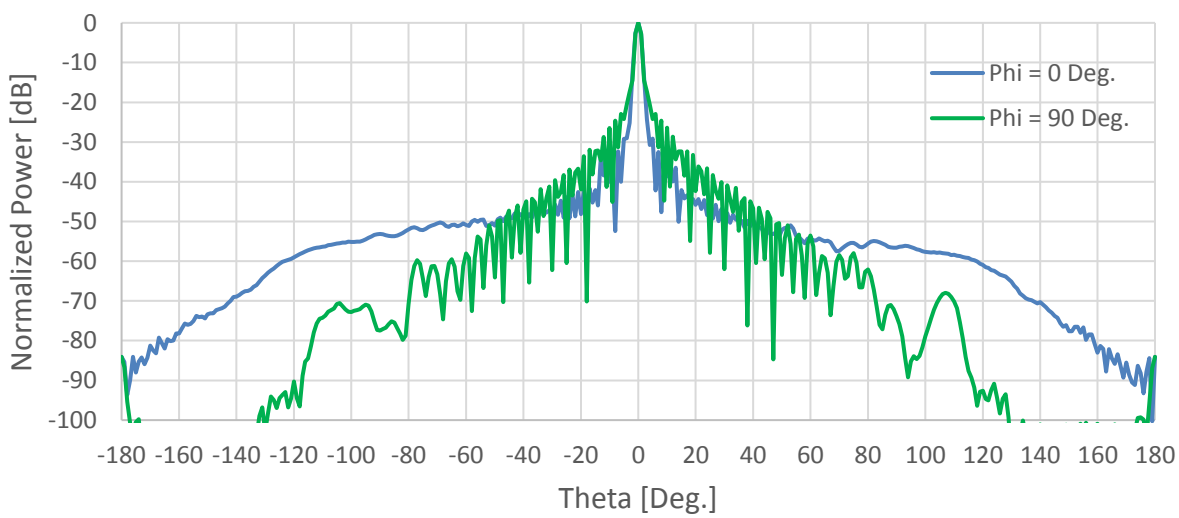

Figure 8. Method 3 far-field power plots in two principal planes.

first side lobe in method 3 appears smaller than in the other 2 methods, -29.7 compared to -24.0 dB. Inclusion of the platform in the simulation has resulted in a 5.7 dB reduction of the first side lobe. Given that not all of the elements could be included in a single simulation, there will still be some error in the method 3 results.

Conclusions

Three simulation methods have been compared in the calculation of radiation patterns for a large conformal patch array antenna. With the knowledge that a full simulation of the aircraft and antenna may not be feasible, it was desired to test some quicker and computationally less demanding methods. It has been shown that, for the radius of curvature 16 in. and at the frequency 14. 25 GHz, acceptable results may be obtained in the theta = 0 to 100° region of the phi = 0° plane and the theta = 0 to 50° region of the phi = 90° plane by any of the methods. However, for theta greater than 50°, the platform should be included in the simulation.

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