Application of the Savant/WIPL-D Hybrid Solver to Analyze the Installed Performance of a Monopulse Antenna Array Mounted on a Widebody Aircraft

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Abstract: Amplitude comparison monopulse antenna arrays produce a sum pattern and a difference pattern, which allow for highly accurate angular measurements to be performed with tracking radars. When a monopulse antenna array is mounted on a platform such as an aircraft, the radiation pattern of the antenna array can change relative to the free space pattern. In particular, the angle and depth of the null of the difference pattern can be significantly different from the free space pattern. It is critical for system designers to understand the changes in the null of the difference pattern as the array is steered (electronically or mechanically). Often, the installed patterns are simulated with computational electromagnetic (CEM) software tools given the cost of measurements and the insight provided by simulation tools. The simulation of monopulse antenna arrays as installed on electrically large platforms can greatly benefit from a hybrid CEM approach. A hybrid approach that combines method of moments (WIPL-D) and shooting and bouncing rays (Savant) is used to predict difference pattern null characteristics for a linear array of Yagi-Uda elements mounted on an Airbus A320 aircraft. Hybrid solutions are compared with WIPL-D solutions and excellent agreement is achieved. A graphics processing unit (GPU) acceleration feature for the hybrid approach is used to rapidly generate installed null characteristics for many orientations of the linear array as mounted on the A320 aircraft. This null error information can then be used to either directly generate calibration tables for downstream signal processing or to identify particularly problematic array orientations for which pure full-wave solutions or measurements are required.

Keywords: Hybrid, PO, SBR, MoM, WIPL-D Pro, Savant, GPU

1. Introduction

Tracking a target with radar requires a feedback system that will direct the radar’s antenna beam to the target’s angular direction when there is a difference between the reference direction and the actual target direction. The difference signal derived from the tracking antenna provides information to drive the antenna boresight axis toward the target direction and also provides a correction factor in the angular estimate when boresight direction leads or lags target direction [1]. There are generally three types of tracking techniques used for target angular estimation: conical-scan, sequential-lobe comparison and
simultaneous-lobe comparison (or monopulse). For this paper, the monopulse approach is considered. In monopulse implementations, two signals are formed. One of the signals is the sum of two beams, and the other is the difference of two beams. For example, consider a linear array with an even number of antenna elements. By applying a phasing of 0˚ to half of the elements and a phasing of 180˚ to the other half of the elements, a difference pattern is generated with a deep null occurring broadside to the linear array. If a phasing of 0˚ is applied to all of the elements of the array, a peak in the pattern occurs broadside to the linear array. The ratio of the sum and difference beams normalizes the difference signal and allows the direction of arrival of the signal to be calculated. The shape of the antenna beams must be known very precisely and hence the accuracy can be affected by unwanted platform interactions [2].

Installed radiation patterns of antennas can be significantly different from their free-space performance due to interactions with the platform. These interactions include multi-path reflections, diffraction, creeping wave, blockage and propagation through penetrable materials such as radomes. As previously indicated, it is critical to understand the installed performance of antennas used for monopulse radar applications such that changes in radiation patterns (relative to free space performance) can be addressed in downstream signal processing of measured data. If the installed radiation patterns are not taken into consideration, the radar system performance will be degraded. There are typically two methods for characterizing the installed performance of antennas: measurement and simulation. Measurements can be very accurate but they are time consuming, very expensive and often not practical to perform. CEM software tools have matured greatly over the past two decades. Due to this maturity, they are now commonly used to supplement and/or guide measurements. In some cases, CEM software has almost completely replaced measurements given the accuracy of the simulated data and the insight to physical phenomena that can be gained from such tools.

There are generally three types of CEM software tools for predicting installed antenna performance: full-wave, asymptotic and hybrid solvers. Full-wave tools solve Maxwell’s equations exactly and can provide very accurate solutions. However, there are limits to the electrical size of problems that can be solved with full-wave techniques. Asymptotic techniques can very efficiently solve electrically large problems spanning thousands of wavelengths in dimension, but they are not capable of directly modeling the antenna structure itself. Hybrid solvers try to combine the strengths of full-wave and asymptotic solvers by dividing the problem into two parts: Part A is the antenna structure and Part B is the remainder of the platform. The full-wave solver is used for Part A and the solution of Part A drives the asymptotic solution of Part B. This is a first-order hybridization scheme where information is passed from the full-wave solver (Part A) to the asymptotic solver (Part B) [3].

In this paper, a first-order hybridization of WIPL-D Pro, a method of moments (MoM) code, and Savant, a shooting-and-bouncing-rays (SBR) code, is used to determine the installed difference pattern of a monopulse linear array of Yagi-Uda elements as installed above the fuselage of an Airbus A320 aircraft for several orientations of the array. At 400 MHz, the A320 is electrically large but can still be solved directly with WIPL-D. Comparisons are made between the hybrid solutions and WIPL-D solutions and good agreement is realized. GPU acceleration of the hybrid solution is used to rapidly compute the error in the null location of the difference pattern as the array is mechanically rotated 180˚ (nose to tail) in 1˚ steps.

2. Modeling the Stand-Alone Yagi-Uda Monopulse Antenna Array (WIPL-D, MoM)

The monopulse linear array is composed of twenty Yagi-Uda antennas with one-half wavelength spacing between elements. A wire model for a single Yagi-Uda antenna element of the monopulse array is shown in Figure 1. The lengths of the driven, reflector and director elements are 0.348838, 0.355814, and 0.279070 meters respectively. The spacing between the driven and reflector elements is 0.1875 meters and the spacing between the driven and director elements is 0.1350 meters. To create the difference pattern for the monopulse array, a 0˚ phase was applied to the first ten elements of the array and a 180˚ phase was applied to the other ten elements of the array. The difference pattern was simulated with WIPL-D in 0.27 seconds on a laptop computer and required 100 unknowns. The results of the
WIPL-D simulation are shown in Figure 1 with the array geometry model overlaid on top of the difference pattern. As can be seen, there is a deep null located broadside to the axis of the linear array.

![Figure 1](image)

**Figure 1.** WIPL-D is used to simulate the performance of a single Yagi-Uda antenna and the difference pattern for a 20-element linear array of Yagi-Uda elements.

Since the antenna array is entirely perfectly electrically conducting (PEC), only electric currents will be computed for the array. The currents computed by WIPL-D are current densities and the Savant tool requires current moments. Further, a WIPL-D computation may produce more currents than are necessary for the Savant computation. To streamline the current source generation process, the hybrid solver performs the conversion from current densities to current moments and resamples the WIPL-D current sources according to user specified parameters. For the linear array of Yagi-Uda elements, 216 current sources are computed by the hybrid solver as shown in Figure 2. The current sources are colored and scaled according to their magnitudes. These currents are used to compute the free space pattern of the array and the 3-D pattern is overlaid with the current sources in the figure. The free space pattern as computed directly by WIPL-D and with the current sources match extremely close.

![Figure 2](image)

**Figure 2.** Current sources for the linear array created by converting WIPL-D current densities to Savant current moments. The 3-D far-field pattern of the 216 current sources is shown in the background.

### 3. Modeling the Platform Interaction (Savant, SBR) and Hybridization

With the current sources for the linear array determined in the previous step, we can now turn to computing the installed pattern of the array as a function of the orientation of the array. The monopulse array is mounted 1.524 meters above the top of the fuselage and 20.52 meters back from the nose of the Airbus A320 aircraft. At the simulation frequency of 400 MHz, the aircraft is approximately 50 x 45.5 x 14.7 wavelengths in dimension. The axis of the fuselage of the aircraft is along the x-axis and the default orientation of the array is pointing towards the vertical stabilizer (azimuth = 180°). For all WIPL-D and Savant simulations, the entire aircraft is treated as PEC surfaces. In Figure 3, the WIPL-D and Savant models for the default orientation of the array are shown.

![Figure 3](image)
Three orientations of the array were selected for comparing the results from the WIPL-D solution with the Savant solution. The array was rotated 6°, 90° and 180° from the default orientation previously described. For the 6° rotation, there are strong interactions with the vertical stabilizer of the aircraft. For the 90° rotation, the array is effectively pointing across the wing of the aircraft and for the 180° rotation, the array is pointing along the nose of the aircraft. For each of these orientations, computations were performed with WIPL-D and then with Savant using the current sources as computed by WIPL-D for the linear array.

Savant employs the shooting and bouncing rays (SBR) method [4],[5] to predict the performance of antennas as installed on electrically large structures [6],[7]. In the SBR method, geometrical optics (GO) rays are launched in all directions towards the platform model to determine the surfaces that are directly illuminated by the antenna. The GO rays are weighted according to the polarimetric antenna representation (far-field pattern or current sources) and are used to “paint” surface currents on the platform according to principles of physical optics (PO). The GO rays are allowed to propagate until they exceed the maximum number of bounces as specified by the user or until they escape the problem space. Then, all of the PO currents that were painted by GO ray tracing are radiated to observation points (far-field, near-field, or receive antenna points) to compute the scattered field. The scattered field is summed with the incident field of the antenna to yield the total field. Savant also includes higher order phenomena such as creeping way, curved surface divergence factor, and physical theory of diffraction (PTD) wedge correction for improved accuracy over a basic SBR implementation.

When comparing the Savant and WIPL-D solutions for the three orientations of the array on the A320, we focused on the details of the difference pattern null (e.g., null angular location and depth) but we also considered the data on a global scale across a 360° azimuthal cut. For the monopulse radar application, the details of the difference pattern null are arguably the most important features to accurately capture with CEM software, but we hope to also see a good global comparison. The WIPL-D data is treated as the reference data and studies were performed with WIPL-D to show that the solutions had converged as a function of mesh size, integral accuracy and current expansion. The WIPL-D simulations required 159,485 unknowns and 245 minutes per orientation to run on a desktop computer equipped with one NVIDIA GTX 570 GPU card. Given the electrical size of the problem, it is very impressive that WIPL-D could solve such a problem with the stated number of unknowns in 245 minutes on a desktop computer. The Savant simulations required less than 1 minute to run per orientation on a desktop computer equipped with one NVIDIA GTX 580 GPU card. As expected, Savant run times are much less than WIPL-D given the asymptotic nature of the Savant solver.

Table 1 contains the errors for the null angular location and the null depth for the three orientations of the linear array. Again, the WIPL-D solution for the composite problem (array + A320) is treated as the reference data. In general, the error in the Savant solution for the location and depth of the null are quite
small. However, the error requirements for such CEM simulations vary from one application to another. In some applications, these errors are acceptable and the Savant/WIPL-D hybrid approach would be a very efficient solution for understanding installed system performance. Of course, for other applications the error values shown in Table 1 are not acceptable. In Section 4 of this paper, we will show that the Savant/WIPL-D hybrid approach can still yield useful information for problems requiring accuracy that can only be attained through measurements or pure full-wave solutions.

Table 1. Null errors as predicted by Savant and compared to WIPL-D.

<table>
<thead>
<tr>
<th>Angular Error</th>
<th>Depth Error</th>
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<tbody>
<tr>
<td>6˚ Rotation</td>
<td>0.1˚</td>
</tr>
<tr>
<td>90˚ Rotation</td>
<td>0.16˚</td>
</tr>
<tr>
<td>180˚ Rotation</td>
<td>0.0˚</td>
</tr>
</tbody>
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In Figure 4, polar plots for the WIPL-D, Savant and Free Space results for the three array orientations are shown. The trace for the free space pattern is included to show that there are substantial changes in the radiation pattern for some orientations when the array is mounted on the A320. In general, the WIPL-D and Savant solutions match quite well.

Figure 4. Polar plots for the three array orientations as mounted on the A320 aircraft. WIPL-D, Savant and free space results are shown.

4. Utilizing GPU Acceleration to Generate Results for Many Array Orientations

Given the extremely rapid computation time realized through GPU acceleration of the Savant engine, another useful mode of operation for the hybrid solver is for quickly identifying array orientations that produce the largest errors in the null location. To demonstrate this concept, we used a script to generate Savant jobs where the orientation of the linear array is varied from pointing along the nose of the aircraft (azimuth = 0˚) to pointing towards the vertical stabilizer (azimuth = 180˚). The array orientation is changed in 1˚ steps resulting in 181 total Savant jobs. Note that it is not necessary to run a full 360˚ of array orientations as the aircraft model is symmetric in this scenario.

The 181 orientations required 120 minutes to run on a desktop computer with an NVIDIA GTX 580 GPU card. Through Matlab post-processing, the error in the null location relative to the free space null location was computed and the results are plotted in Figure 5. As can be seen, there are a number of peaks in the error values. This information can be used by analysts in a number of ways. In particular, it can help to quickly identify particularly problematic array orientations early in a system design. Further, a rapid computational capability such as the hybrid solver can allow analysts to very quickly study trade
spaces and help focus the full-wave simulations and measurements that need to be performed.

Figure 5. The difference pattern null error as a function of array orientation as predicted by Savant.

5. Conclusion

The WIPL-D/Savant hybrid is a useful tool for engineers designing and analyzing monopulse antenna arrays mounted on platforms. The hybrid solver combines the accuracy of a full-wave solver (WIPL-D) with the scalability and efficiency of an asymptotic solver (Savant). It is shown that the hybrid solver can very accurately predict the null location and depth of a monopulse difference pattern for three array orientations. It is further shown that the hybrid solver can very rapidly consider many array orientations and generate null error data as a function of orientation. The hybrid solver can be used directly to generate calibration data for monopulse radar systems or it can help reduce the number of measurements and full-wave simulations that are required.

References

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