

# Generation of Radiation Patterns Equivalent to In-Flight Measurements

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**Abstract**—Comparison of in-situ measured antenna radiation patterns (RPs) to modeled ones is vital for validation of both. In-flight measured RPs do not always produce a standard conic or elevation cut (constant  $\theta$  or  $\phi$  angle, respectively), but rather Great Circle (GC) cuts at the aircraft bank angle of interest. WIPL-D's post-processing routines, on the other hand, do not produce GC cuts in normal setups. A manipulation of the aircraft orientation in xyz-coordinates is required to accomplish this task. Under standard conditions in WIPL-D, the fuselage is positioned parallel to the x-axis and the wings parallel to the y-axis. A model rotation of  $90^\circ$  with respect to the y-axis allows for the generation of GC cuts, where  $\theta$  and  $\phi$  swap roles. This makes comparison between in-flight measurements and computed data cumbersome. This paper investigates several options to produce non-standard RPs in WIPL-D and MATLAB (using WIPL-D results) that are equivalent to those of in-flight measurements.

**Keywords**—Great circle, in-flight measurements, radiation pattern, WIPL-D.

## I. INTRODUCTION

In-flight Radiation Pattern (RP) measurements for in-situ antennas are normally collected by flying the aircraft in a circular flight path at a distance from the data collection tower. As the aircraft executes its flight path, collected points that are away from the aircraft's centerline will be above the aircraft's horizon on one side and below the aircraft's horizon on the opposite side. The collected data points form a great circle (GC) cut at a bank angle  $\gamma$  with respect to the aircraft's horizon, as shown in Fig. 1.

For a single simulation run, the WIPL-D Pro graphing utility provides the ability to plot standard conic and elevation cuts, assuming the aircraft is oriented in standard position (x-axis is parallel to the fuselage, y-axis is parallel to the wings, and positive z-axis towards zenith). Multiple runs would be required to produce both standard and non-standard cuts. A simple rotation of the aircraft along the x-axis for each  $\gamma$  angle will produce the desired data. However, this approach may be prohibitive if data sets for a large number of cases (frequencies and/or bank angles) are being analyzed. This is especially true for models with very large number of unknowns. This effort provides a description of how to achieve non-standard GC cuts, in WIPL-D, using various methods.

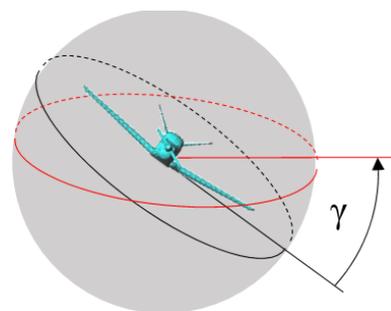


Fig. 1. Great circle illustration at angle  $\gamma$ .

## II. CEM MODELING DETAILS

A half-wave cross-dipole antenna, arbitrarily designed to operate at 300 MHz, was constructed in WIPL-D. Its dipole elements were fed in quadrature, to produce right-hand circular polarization (RHCP). The antenna was then placed a quarter-wavelength above the surface of a Beechcraft Bonanza aircraft WIPL-D model, as shown in Fig. 2. The model was run at 300 MHz in WIPL-D using the standard position to produce standard elevation and conic cuts. The model was subsequently run in various orientations to generate GC cuts for each of the methods, as described below.

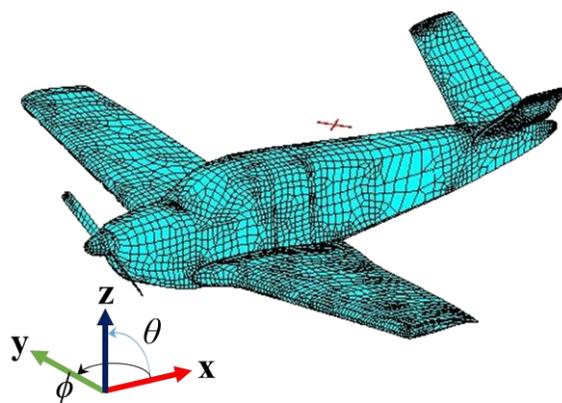


Fig. 2. Cross-dipole onboard Beechcraft Bonanza WIPL-D model.

### A. Rotation about x-axis

For each bank angle  $\gamma$  of interest, rotate the model about the x-axis accordingly and re-run the model individually. This is the reference case, since it emulates real world in-flight measurements.

### B. Sampling Discrete Points on Full Sphere

Generate a dense three-dimensional (3-D) RP over the entire  $4\pi$  steradian space. Rotate the  $\gamma = 0^\circ$  cut, [1], to the bank angle of interest. Run a MATLAB post-processing routine to interpolate the gain values from the original 3-D RP file to generate the GC cut of interest.

### C. Matrix Inversion Avoided

Run the CEM model in the standard position and save a copy of the WIPL-D generated current distribution “.dis” file, as well as the WIPL-D input “.IWP” file, [2]. Open the “.IWP” and modify it by rotating the model by the bank angle  $\gamma$ . Turn on the “Matrix Inversion Avoided” option in WIPL-D. Set the RP output to provide only the principal azimuth cut, re-run the model to generate the corresponding GC cut quickly. This process is repeated to generate GC cuts for other bank angles of interest.

### D. Rotation About y-Axis

Rotate the standard position model by  $90^\circ$  along the y-axis, as shown in Fig. 3. Set up and run the model to generate elevation cuts that actually represent the GC cuts of interest. However, the equivalent  $\theta$ -range must be  $-90^\circ$  to  $270^\circ$ , to match the  $\phi$ -range of  $0^\circ$  to  $360^\circ$  for the standard position, respectively.

Comparison of GC gain, for  $\gamma = 20^\circ$ , in Method B to the reference case is provided in Fig. 4. Comparison of Methods C and D, for  $\gamma = 20^\circ$ , to the reference case is provided in Fig. 5. Comparison of unwrapped GC phase in Method D, for  $\gamma = 20^\circ$ , to the reference case is shown in Fig. 6.

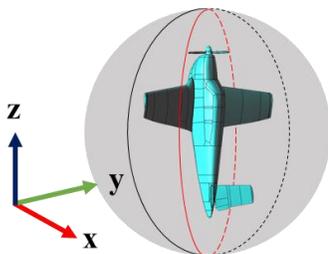


Fig. 3. Beechcraft Bonanza WIPL-D model rotated  $90^\circ$  about y-axis.

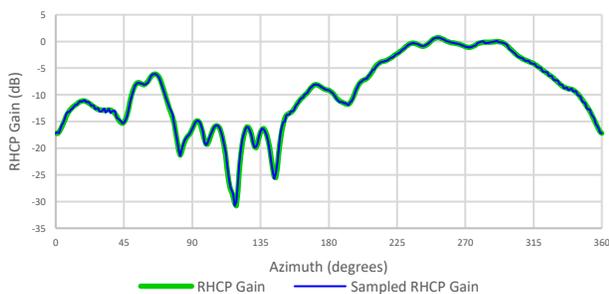


Fig. 4. Gain comparison of discrete sampling to reference case.

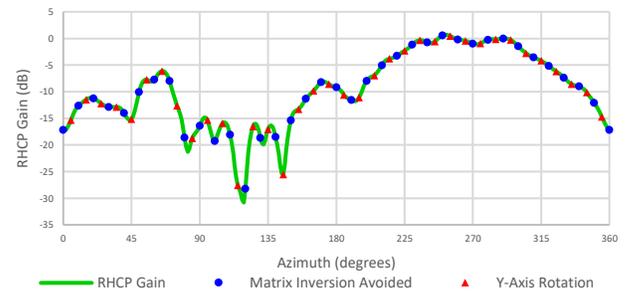


Fig. 5. Gain comparison of matrix inversion avoided and y-axis rotation to reference case.

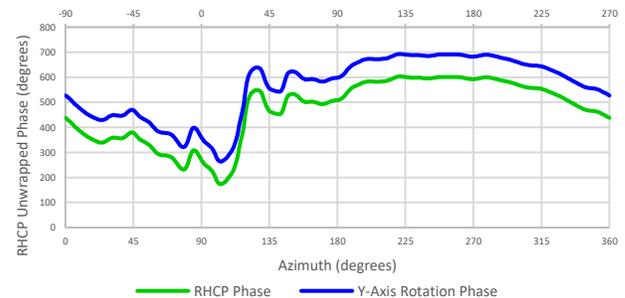


Fig. 6. Phase comparison of y-axis rotation to reference case.

## III. CONCLUSIONS

Even though it is equivalent to in-flight measurements, the reference case has the major drawback of having to run the model multiple times. This is not an issue when the WIPL-D model has a very low number of unknowns, and runs in a few minutes. However, that is not the case when there are many frequencies to study and the model grows into the hundreds of thousands of unknowns, taking hours to days to run each case individually.

The discrete sampling method, Method B, requires very small increments in  $\theta$  and  $\phi$  to yield acceptable results, especially for linear polarization components where the error increases with the increase in  $\gamma$ . This requires a significant amount of additional post-processing to overcome. The Matrix Inversion Avoided method (Method C) is ideally suited for this purpose. However, when WIPL-D automatically internally remeshes the model, this could lead to a mismatch between the stored current coefficients and the respective surfaces to which they belong, thus producing erroneous results. The rotation about the y-axis method (Method D) generates identical GC gain results to the reference case. However, all the unwrapped GC phase results shifted by  $90^\circ$ , even though the RHCP feature of the cross-dipole is preserved. The root cause for this phase shift must be investigated further, but is suspected to mainly be due to the contrasting ways  $\theta$  and  $\phi$  are incremented.

## REFERENCES

- [1] G. Strang, Linear Algebra and its Applications. 4th Edition, Belmont, CA: Thompson Corporation, 2006, pp. 130-132.
- [2] WIPL-D Pro, Software and User's Manual, WIPL-D d.o.o., Belgrade, Serbia 2019.