Optimization of a Broadband Discone Antenna Design and Platform Installed Radiation Patterns Using a GPU-Accelerated Savant/WIPL-D Hybrid Approach

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Abstract: Traditional design guidelines for broadband antennas do not always produce satisfactory performance for the desired frequency range of interest. In addition, the accurate prediction of the free-space antenna performance is not sufficient to determine if the antenna will meet a larger system requirement because the performance of the antenna can change significantly when it is installed on a platform. Antenna design software, such as WIPL-D, addresses the difficulties of designing antennas with broadband performance by providing optimization software that can automatically resize the various antenna dimensions until a desired performance criterion is met. At high-frequencies, the electrically large size of the platform makes it computationally difficult, or impossible, to directly consider the interactions between the antenna and the platform when designing the antenna in a full-wave solver. This paper describes an approach for the design and optimization of a discone antenna and then the subsequent installation on a large commercial aircraft. The antenna design will be optimized across a wide frequency range using WIPL-D Optimizer. The resulting discone antenna design is then imported into Savant-Hybrid, a hybrid asymptotic and full-wave solver, and the installed antenna performance is simulated using GPU acceleration at multiple potential antenna locations to determine the location that provides the least-degraded installed antenna performance.

Keywords: WIPL-D, Savant, asymptotic solvers, hybrid solver, GPU, installed antenna performance, design optimization

1. Introduction

In many applications an antenna must operate effectively over a wide range of frequencies. For example, military RF communications systems routinely operate over a decade or more of bandwidth. To avoid switching between narrowband antennas to cover the entire frequency range, broadband antennas with low return loss across the frequency range of interest are commonly employed. In this paper we outline the steps required to solve this type of broad-band antenna design and installation problem using WIPL-D and Savant-Hybrid, which is a hybridization of a full-wave solver (WIPL-D) and an asymptotic solver (Savant) [1]. The design steps are demonstrated through the use of a case study where the goal is the development of a discone antenna design that performs well over a wide frequency range of 600 MHz to 6 GHz. The antenna should have a VSWR that is below 2.0 across this range. The installed performance of the antenna is then considered at four potential locations on the bottom of the fuselage of an Airbus A320 commercial aircraft. The installed antenna pattern will be different than the free-space pattern due to interactions between the antenna and the platform. In order to determine which of the four locations to use, the installed antenna performance will be calculated for each location and compared against the free space pattern as well as a 0 dBi threshold value. We use two criteria for judging the installed performance of the antenna to show that different criteria can result in different “optimal” antenna locations.

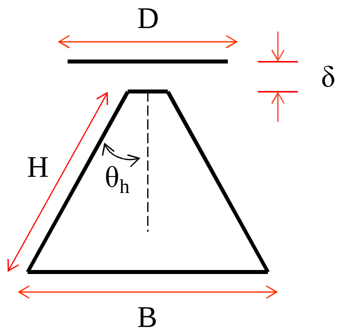
WIPL-D is a method of moments (MoM) full-wave solver with a computationally efficient solution engine that utilizes higher-order basis functions. The higher-order basis functions allow a given electrically-sized problem to be solved using many fewer unknowns, less memory and much faster than software tools that employ traditional basis functions such as RWG.WIPL-D also offers an Optimizer tool that can be used with their MoM computational engine for geometries that have been parametrically defined. In other words, the dimensions of the antenna have been defined using symbols. The Optimizer tool employs a user specified optimization technique (*e.g.*, conjugate gradient, simplex, simulated annealing, etc.) to set the values of the symbols within a user defined limit. Initial values for the symbols are determined, a computation is performed with WIPL-D and the antenna performance metric(s) of interest (*e.g.*, S_{11}, gain, *etc*) is compared with the goal metric value(s). If the goal metric is met, no further computations will be performed. If the goal metric is not met, the Optimizer varies the symbol values according to the optimization technique and performs subsequent computations until the goal is met or the number of user specified iterations has been exceeded. The optimization process with WIPL-D is made practical due to the very fast computation time per iteration that can be realized for typical antenna geometries [2].

Savant is a software tool for predicting the installed performance of antennas as mounted on electrically large platforms. In particular, Savant focuses on modeling the interaction of the antenna with the installation platform using an asymptotic methodology known as shooting-and-bouncing rays (SBR) [3,4]. Asymptotic methods are widely used to efficiently compute the scattering by objects whose overall size and features are electrically large. At high frequencies (or short wavelengths), propagation of electromagnetic (EM) waves can be approximated by ray bundles, and EM scattering is dominated by local conditions of the scattering body. SBR was originally developed to efficiently model radar cross section (RCS) for electrically large cavities [3] and later extended for radar signature modeling on realistic targets [5]. It was subsequently adapted to installed antenna applications [6-8]. In recent years, additional physics models have been developed for SBR to address creeping wave, which is an important physical effect to capture for certain classes of problems.

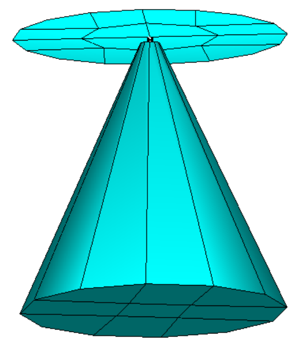
A hybrid full-wave and asymptotic solver has recently been developed based on WIPL-D and Savant. In general, hybrid solvers try to combine the strengths of full-wave and asymptotic solvers by dividing the problem into two parts: Part A is the antenna structure and Part B is the remainder of the platform. The full-wave solver is used for Part A and the solution of Part A drives the asymptotic solution of Part B. As described, this is a first-order hybridization scheme where information is passed from the full-wave solver (Part A) to the asymptotic solver (Part B) [1]. The Savant-Hybrid software automates many of the technically challenging aspects of importing an antenna design from WIPL-D into Savant. Savant-Hybrid makes use of WIPL-D to generate current moments from the antenna geometry. These currents are then imported into Savant as a current source antenna and used to drive the Savant simulation in order to determine the installed antenna performance. Savant can produce three different types of results: far-field radiation patterns, near-field distributions and antenna-to-antenna coupling.

2. Antenna Design and Optimization (WIPL-D, MoM)

The initial discone antenna design was constructed using the design rules provided by Stutzman and Thiele [9]. The initial design was constructed for 3.3 GHz, the center of the operating frequency range of 600 MHz to 6 GHz. A CAD model of this initial antenna design was parametrically constructed in WIPL-D, as shown in Figure 1.



$H = 0.7\lambda$
$B = 0.6\lambda$
$D = 0.4\ \lambda$
$\theta_h = 25^\circ$
$\delta << D$



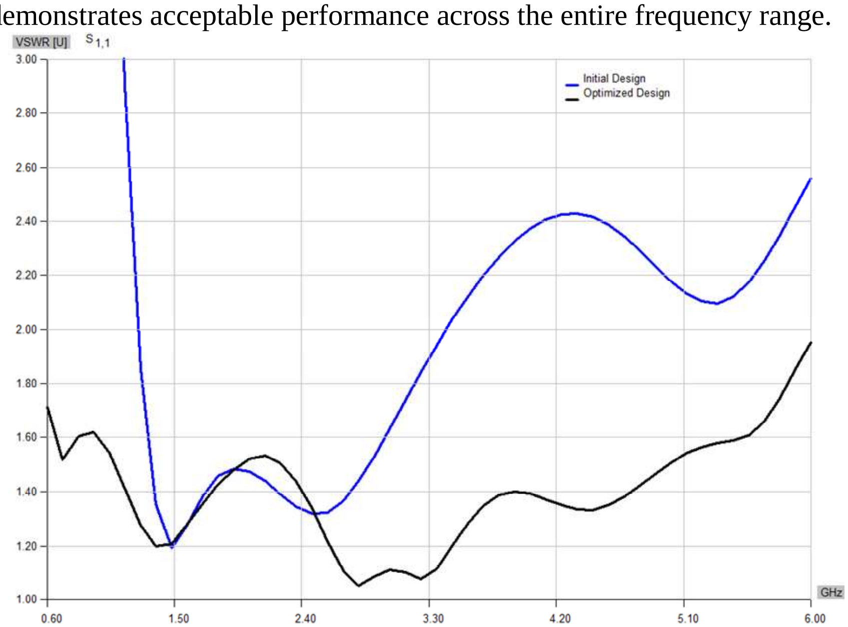
a) b)

Figure 1: a) Discone antenna design rules used to create the initial antenna design at 3.3 GHz, the center of the operating frequency range. b) WIPL-D model of the discone antenna.

The initial discone antenna design was imported into the WIPL-D antenna Optimizer module to create an optimal free-space antenna design with a design goal of S_{11} of less than -10 dB across the frequency range of 600 MHz to 6 GHz. The WIPL-D optimizer, using the Simplex method, produced a new antenna design in 439 seconds on a laptop computer. The dimensions of the initial and final designs are shown in Figure 2a. The VSWR for the initial and optimized antennas is shown in Figure 2b. The blue trace indicates the performance of the initial design across the frequency range. The antenna design guidelines from [9] resulted in a VSWR of less than 2.0 for the design frequency of 3.3 GHz, but the performance was larger than 2.0 across the majority of the range of operating frequencies. The optimized design, shown in the black trace, demonstrates acceptable performance across the entire frequency range.

Parameter	Initial
H	6.36 cm
B	5.45 cm
D	3.64 cm
θ_h	25˚

Parameter	Optimized
H	12.64 cm
B	10.9 cm
D	11.6 cm
θ_h	25.6˚



a) b)

Figure 2: a) Initial and optimized antenna design parameters for the discone antenna. b) VSWR for the initial and optimized discone antenna designs across the range of operating frequencies.

3. Installed Antenna Performance Optimization (Savant, SBR)

The optimized discone antenna produced by WIPL-D was then imported into Savant-Hybrid in order to compute the installed antenna performance at the four candidate locations on the lower fuselage of the A320 aircraft. The four positions are shown in Figure 3. Three different frequencies were selected for analysis based on the operating frequency range of this antenna: 600 MHz, 3 GHz and 6 GHz, producing a total of twelve different scenarios to be solved using Savant-Hybrid. Savant-Hybrid has two phases of computation. In the first phase, WIPL-D is used to compute the current source representation of the discone antenna. In the second phase, Savant is used to compute the installed antenna pattern of the discone antenna from the current source representation.

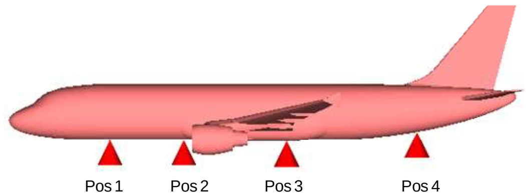


Figure 3: Four candidate locations for the installation of the antenna on the lower fuselage of the A320.

This study focused on the installed performance over the lower hemisphere by computing the installed pattern from 0 to 180˚ in azimuth at 1˚ intervals, and from -180˚ to 0˚ in elevation at 0.25˚ increments, for a total of 130,501 angular samples. This dense sampling of the radiation pattern yielded a precise characterization of the installed performance, allowing for the selection of the location that gave the best performance relative to the free-space antenna pattern and the 0 dBi criteria. A representative example showing the installed pattern and the free space pattern is shown in Figure 4 for the four antenna positions at 3 GHz and for a single cut in elevation. The installed-antenna performance data was then used to determine which of the four potential locations of the discone antenna gave the best overall installed performance across all frequencies.

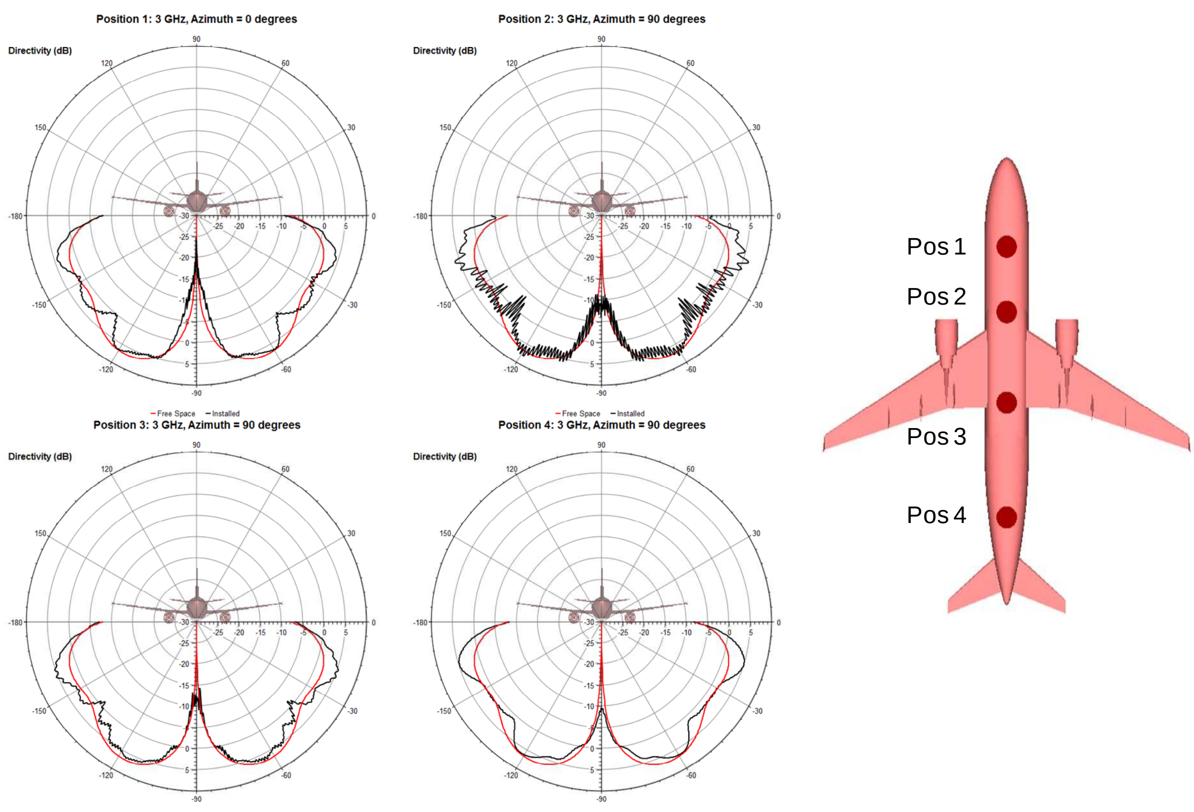


Figure 4: Comparison of installed and free-space performance of the discone antenna at 3 GHz for each of the four locations.

The installed radiation patterns for the 12 Savant-Hybrid computations were compared with the free space patterns and with a 0 dBi or greater directivity threshold. Two different criteria were used because system level requirements for antenna performance often vary between applications. For some scenarios, the system designer would like the installed gain to be equal or greater than the free-space pattern while in other scenarios, the installed pattern needs to achieve a minimum directivity for a specific percentage of coverage over a specific sector. These different criteria can result in different "best" installation locations for an antenna.

The results of the comparison with free-space performance and the 0 dBi threshold are shown in Table 1. In this table, we show the percentage of angles for which the installed pattern was equal or greater than a) the free-space directivity or b) 0 dBi. There is no clear optimal location for either performance metric. For the comparison with free-space performance, location 4 yields slightly better performance than the other three locations. For the comparison with the 0 dBi or greater directivity metric, location 1 yields slightly better performance than the other three locations.

Table 1. Coverage analysis for free-space and 0 dBi directivity metrics.

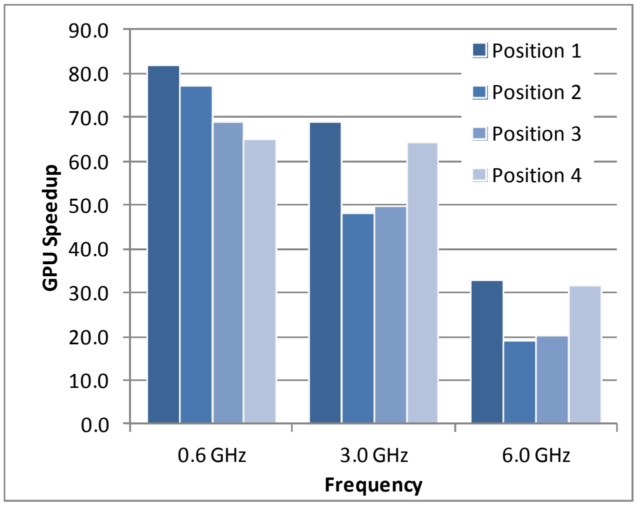
	Free Space				0 dBi Directivity			
	Loc 1	Loc 2	Loc 3	Loc 4	Loc 1	Loc 2	Loc 3	Loc 4
600 MHz	90.31%	76.83%	76.36%	87.37%	52.96%	52.02%	52.56%	53.38%
3 GHz	40.37%	40.90%	43.67%	45.27%	78.65%	76.83%	77.69%	80.65%
6 GHz	37.41%	39.70%	35.43%	48.30%	84.60%	77.52%	81.92%	80.32%

5. GPU Acceleration

The twelve Savant simulations were computed using the GPU-accelerated version of Savant on a desktop computer with a quad-core CPU and two NVIDIA GTX 480 GPUs. GPU acceleration has been shown to provide significant speed-ups for typical Savant simulations [10], often achieving more than a 25x speedup per GPU when compared to the four core CPU solution time. The total runtime for the twelve Savant-Hybrid simulations performed here was 50.1 minutes when run on a desktop computer with two GPU cards and four CPU cores. The twelve simulations required over 26.1 hours when computed using only the four CPU cores. The aggregate speedup for the GPU-based solution of the twelve simulations was more than 31.2 times faster than the four core CPU-only solution. Run times and speedup factors vary for each of the twelve experiments, as shown in Figure 5. The run times increase frequency because the number of rays required to sufficiently sample the platform increases as a function of decreasing wavelength. The variations in GPU speedup across the runs are due to differences in the costs of intersecting the rays with the platform due to changes in the antenna position and ray sampling rate which changes the relative cost of the CPU and GPU computations. At higher frequencies, the CPU computational costs become a larger fraction of the total run time, and the relative impact of the GPU acceleration decreases and the total run time speedup decreases.

6. Conclusions

In this paper, we demonstrated how the WIPL-D and Savant-Hybrid software tools could be used to optimize the free-space design of a broadband antenna and how the installed antenna performance could be efficiently computed for multiple potential installation locations on an Airbus A320 aircraft. The Savant-Hybrid software combines the benefits of full-wave and asymptotic solvers to allow users to accurately and quickly study installed antenna performance on electrically large platforms. While there was not a clear optimal installation location for the four locations considered and the performance metrics selected, the process for using a hybrid solver and different performance metrics to identify an optimal installation location is demonstrated. GPU acceleration of the Savant-Hybrid simulations reduced the solution time from over one day to less than one hour, providing a significant increase in productivity to engineers who are performing antenna design studies like the one presented here.



a)

Freq (GHz)	Position	Run Time (s)		Speedup
		CPU	GPU	
0.6	1	2224.4	27.1	82.1
0.6	2	1731.8	22.4	77.3
0.6	3	1192.1	17.3	68.9
0.6	4	1040.2	16.0	65.0
3.0	1	6448.0	93.2	69.2
3.0	2	3690.0	76.6	48.1
3.0	3	4102.0	82.4	49.8
3.0	4	5505.0	85.8	64.2
6.0	1	21958.0	667.7	32.9
6.0	2	11565.0	602.0	19.2
6.0	3	13085.0	640.9	20.4
6.0	4	21346.0	674.9	31.6

b)

Figure 5: Speedup for GPU runs for each of the twelve frequency/position combinations. GPU system consisting of two NVIDIA GTX 480 GPUs. Both GPU and CPU runs were based on four CPU cores.

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