Differential GPS Ground Reference Antenna for Aircraft Precision Approach Operations – WIPL Design

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Abstract

This paper describes the application of the WIPL code to the design of a Differential GPS ground reference antenna for aircraft precision approach operations. This antenna has unique requirements with respect to coverage of the upper hemisphere for the reception of circularly polarized transmissions from satellites, mitigation of multipath effects, and control of group-delay variations. The antenna is part of a ground-based subsystem intended to provide sub meter accuracy corrections to aircraft on final approach to a runway. For this application the WIPL code provided the means for designing a 21-element collinear array almost completely by computer simulation.

I Introduction

The Federal Aviation Administration (FAA) is planning on utilizing the Global Positioning System (GPS) for aircraft precision approach operations. A key element for these operations is the Local Area Augmentation System (LAAS), which places subsystems on the ground at or near an airport to greatly enhance the performance of GPS receivers approaching that airport. LAAS is a local area differential system. It places a small collection of high-quality reference receivers and antennas at known, surveyed locations on the airport property. The reference measurements (or corresponding corrections) are broadcast to approaching aircraft using a VHF data link. The airborne GPS receiver uses these measurements to correct it's own, thereby achieving sub meter accuracy. This type of ground based correction system is known as differential GPS (DGPS).

GPS provides precise estimates of position based on the idea that position can be determined given the distances to objects whose positions are known. GPS has the ability to provide estimates of position, velocity and time to an unlimited number of users instantaneously and continuously. GPS satellites, which broadcast their position, are the objects at known locations. The distance between the user and the satellite is measured in terms of transit time of the signal to the user. Antenna variations of group delay (GPS code phase delay) and carrier phase delay can affect the estimates of transit time.

The ground reference antenna requirements for DGPS are unique. Multipath interference (indirect signals reflected by the ground, pavement, sea surface, roof top, vehicle body, or reflected or scattered by objects below the antenna, and sometimes above the antenna) is the chief cause of error in DGPS [1][2]. An ideal DGPS antenna should have near uniform gain in the upper hemisphere with right circular polarization and, for multipath mitigation, the vertical-plane pattern should have a sharp pattern cutoff along the horizon mask. The sharp vertical-plane pattern cutoff also facilitates the acquisition of satellites at low elevation angles. In addition to the normal low VSWR antenna requirement, code phase (group) delay and carrier phase delay are important design considerations. The sub meter accuracy of DGPS requires that the variation of code phase delay and carrier phase delay with azimuth and elevation angles be controlled or at least quantified. For LAAS the operating L1 frequency is 1575.42 ± 10 MHz, for other DGPS antennas, operation at the L2 frequency, 1227.6 ± 10 MHz, is also required. The design objective for multipath mitigation is to achieve and up-down gain ratio of more than 20 dB for elevation angles above 5°. The up-down gain ratio is the ratio of the antenna gain at a positive elevation angle to the antenna gain at the corresponding negative elevation angle.

A concept for a DGPS ground reference antenna was developed in the mid 90's [3]. The GPS LAAS community expressed interest in this concept, which provides hemispherical coverage with a single antenna. Previous solutions utilized two antennas, one for low elevation angles, and one for high elevation angles [4][5]. This paper describes the design of the single-antenna solution using the WIPL software [6][7].

II WIPL Design

The ground-reference antenna is a collinear array consisting of 21 radiating elements, an 11-way power divider located at the base, and 11 coaxial cables. The combination of the power divider and the coaxial cables is specified to have equal line length from the antenna input port to all the radiating elements. The array feed network operates at the L1 and L2 frequencies and has a wide signal bandwidth. The excitation of the array elements is given in Table 1.

The zero-amplitude elements are dummy elements required so that pattern multiplication of an element-factor pattern and an array-factor pattern is valid. WIPL was used to seek a solution that did not require the dummy elements but none was found.

The most critical part of the collinear array design is the design of the radiating element. This element, as described in [3], consists of four slanted dipoles fed with equal amplitude and with a progressive phase of 0, 90, 180, and 270 degrees. This element provides near uniform gain and circular polarization over the upper hemisphere. WIPL was used to determine a configuration that provides the desired performance in the array environment, which includes mutual coupling effects.

The WIPL configuration for the element is shown in Figure 1. Each slanted dipole has a parallel resonant circuit at its feed point for achieving two-band (L1 and L2) impedance matching. Generators are located at the dipole feed points and are set to provide the progressive phase excitation.

The complete 21-element array is shown in Figure 2. This WIPL array model was configured by using the WIPL manipulation feature that allows copying, moving, rotating, and scaling of wires, plates, groups and objects. This feature also permits the setting of the excitation amplitude and phase to the desired values. For this array, 84 generator excitations were specified.

Table 1. Array Amplitude and Phase Excitation

Element No.	Excitation	
	Amplitude (Voltage Ratio)	Phase (Degrees)
1 (Bottom)	0	
2	0.0553	180
3	0	
4	0.0623	180
5	0	
6	0.1055	180
7	0	
8	0.1985	180
9	0	
1	0.6320	180
11	1.0000	90
12	0.6320	0
13	0	
14	0.1985	0
15	0	
16	0.1055	0
17	0	
18	0.0623	0
19	0	
20	0.0553	0
21 (Top)	0	

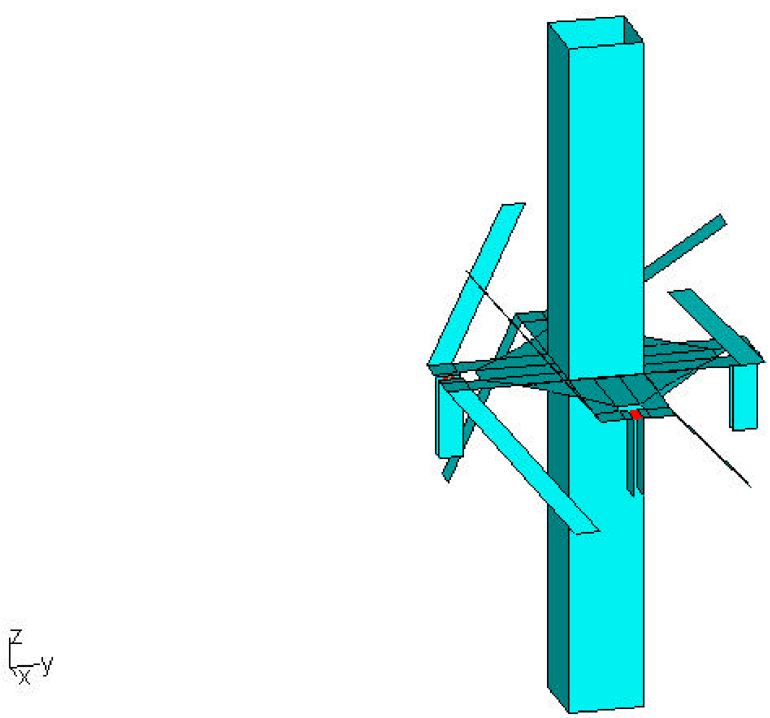


Figure 1. Basic radiating element

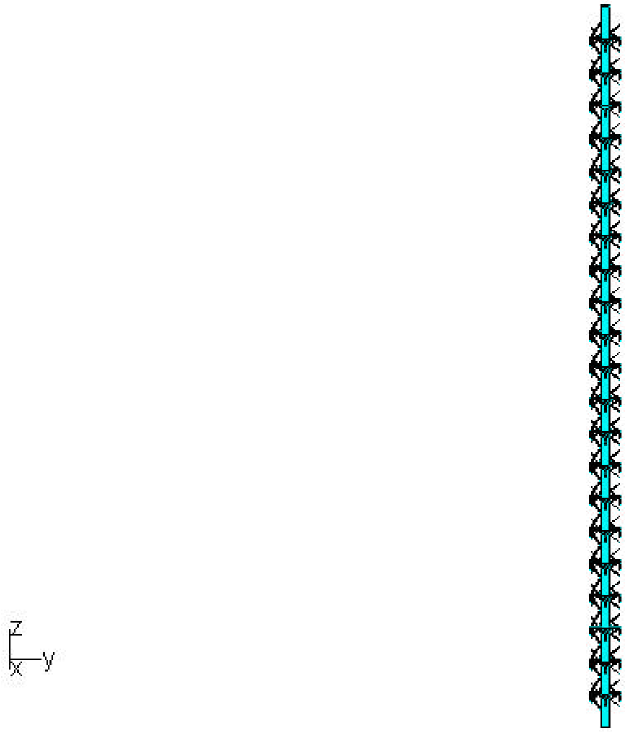
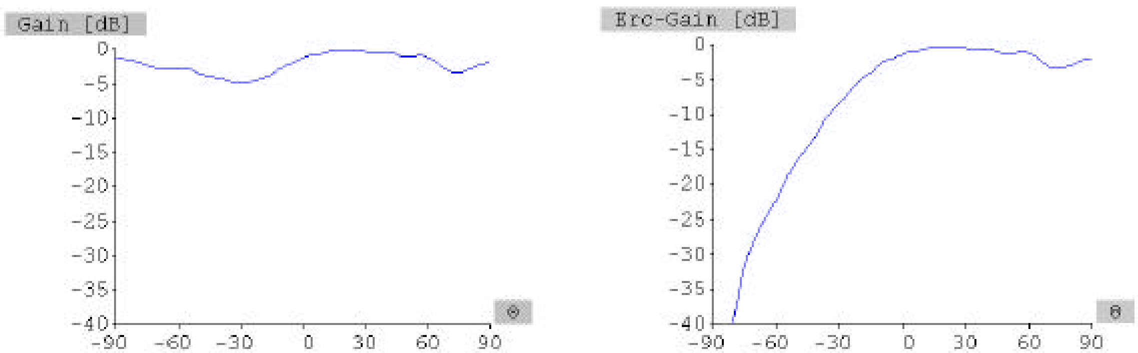


Figure 2. WIPL model for 21-element array

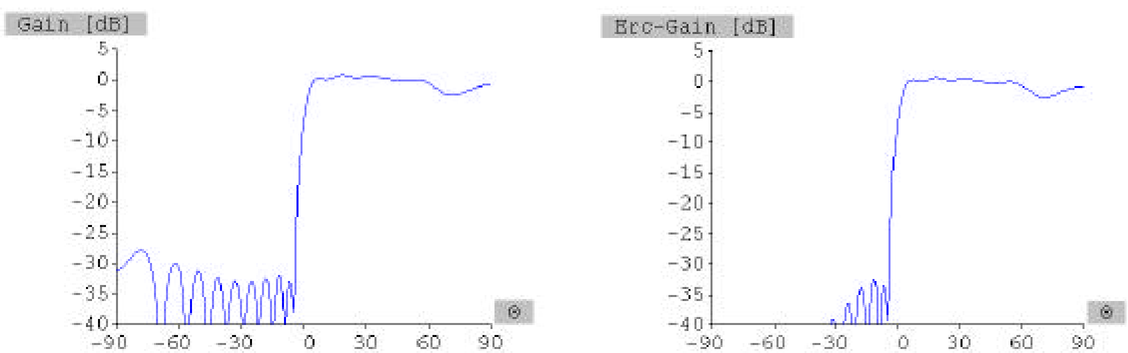
Figure 3. Photographs of prototype 21-element array antenna

The WIPL element configuration was adjusted to achieve the desired radiation pattern and impedance matching characteristics. A printed-circuit impedance matching circuit and progressive-phase exciter was incorporated in the horizontal plate supporting the four slanted dipoles. The progressive-phase exciter consisted of two 90° directional couplers and a 2-way power divider. A coaxial connector is located at each active element for connection to the array feed network. The array feed network consists of an 11-way power divider and 11 coaxial cables. The 11-way power divider and the connecting coaxial cables provide equal path lengths from the power divider input port to the coaxial connectors on the elements. Photographs of a prototype antenna are presented in Figure 3.



(a) Total radiation (b) Response to right hand circular polarization

Figure 4. Radiation patterns, gain versus elevation angle, for center element of array antenna



(a) Total radiation (b) Response to right hand circular polarization

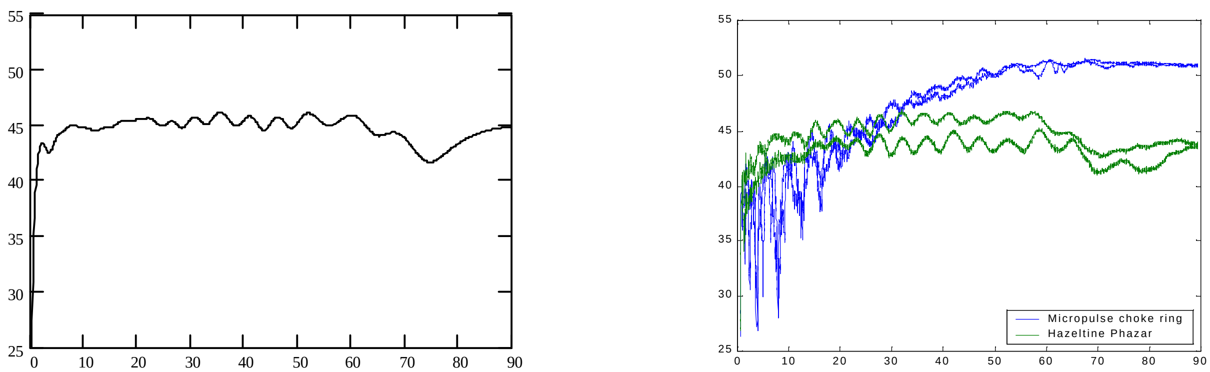
Figure 5. Radiation patterns, gain versus elevation angle, for array antenna

III Antenna Performance

For an array antenna the key component is the radiating element. WIPL was utilized to determine the 4-dipole configuration that would provide the desired radiation and impedance matching characteristics in the array environment. The WIPL generated radiation patterns for the center element in the array environment are shown in Figure 4.

The radiation patterns for the complete array are presented in Figure 5. It is noted from Figures 4 and 5 that the center element and the complete array have essentially right hand circular polarization over the complete upper hemisphere. The computed azimuth-plane patterns are omni directional ± 0.6 dB.

One breadboard and three prototype antennas were fabricated. The measurement of the radiation patterns was difficult. One set of measurements was performed for an installed antenna. The breadboard antenna was located at a test site with the center of the antenna located 1.3 meters above the local ground. The WIPL pattern was converted to an installed pattern by assuming that the local ground is a perfect reflector. The ground reflected component is combined with the direct component assuming that the ground image is located 2.6 meters directly below the center of the array antenna. The GPS satellites provide near constant power density at the user site independent of satellite location. GPS receivers can measure carrier-to-noise-density ratio. Therefore, a measurement of carrier-to-noise-density ratio versus satellite elevation angle should be in agreement with the predicted installed pattern. A comparison is shown in Figure 6. The two green traces in Figure 6(b) are for the 21-element breadboard array. One trace corresponds to the satellite ascending from the horizon to zenith; the other trace is for the satellite descending from zenith to the horizon. Included in the figure for comparison is the same measurement for another type of DGPS ground reference antenna.



(a) (b)

Figure 6. Carrier-to-noise-density ratio (dBHz) versus elevation angle, (a) WIPL prediction, (b) satellite measurement; green trace, 21-element array; blue trace, choke ring antenna for comparison

IV Conclusion

This paper describes the application of the WIPL software to the design of a Differential GPS ground reference antenna. WIPL provided the means for designing a 21-element collinear array almost completely by computer simulation. One cycle of physical modeling of the array element was required to achieve the desired impedance matching. The new Windows version, WIPL-D [7], greatly enhances the software's capability.

Currently, the WIPL software is being used to estimate the array antenna code phase (group) delay and carrier phase delay variation with angle. These estimates and measurements will be used to determine calibration data for the ground reference antenna to achieve centimeter accuracy for the DGPS corrections broadcast to approaching aircraft

V References

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