CHARECTERIZATION of THE RADIATION PATTERN of a GPS ANTENNA MOUNTED on a SMALL T-TAIL AIRCRAFT in LANDING POSITION

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ABSTRACT

This paper aims to characterize the radiation pattern of a Global Positioning System (GPS) antenna mounted on an aircraft at landing position. The antenna was mounted on the fuselage of the aircraft. Aircraft-level radiation pattern of a GPS antenna was simulated using the electromagnetic (EM) modeling abilities of the feldberechnung bei körpern mit beliebiger Oberfläche (FEKO) software package. An aircraft Computer-aided Design (CAD) model was created to mimic the Bombardier Global 5000 commercial aircraft. FEKO was also used to design the stand-alone microstrip patch GPS antenna. Landing aircraft position was conceived via running simulations above Perfect Electric Conductor (PEC) medium. The Pitch and Roll planes radiation pattern of the GPS antenna are presented. Statistical analysis for the three dimensions (3D) radiation patterns is provided.

KEYWORDS

GPS, Antenna, Aircraft, Pattern, Modeling.

1 INTRODUCTION

The Federal Aviation Administration (FAA) had initiated a communication protocol system between the satellite based Global Positioning System (GPS) service and ground based stations to provide accurate positioning information for approaching and landing aircraft in airports. This system is called The Local Area Augmentation System (LAAS) [1-2]. LAAS consists of a ground segment, satellite segment, and airborne segment [3]. The ground segment comprises multiple reference receiver stations and the Very High Frequency (VHF) data link, the satellite segment is the satellite constellations in space. Finally, the airborne segment is the aircraft together with the on-board GPS receiving antenna. This paper characterizes the airborne segment radiation pattern.

On-board GPS antenna performance is critical for LAAS to provide a precision approach and landing for aircrafts in view, especially for landing operations under low visibility conditions. Airborne equipment is responsible for making sufficient range measurements, monitoring their quality, and for following specific protocols to process those measurements with corrections from the ground station [3]. The GPS antenna has to meet performance requirements to achieve an acceptable level of signal detection. These requirements include upper hemispherical Right Hand Circular Polarization (RHCP) coverage from zenith down to near horizon. Below the horizon by about 10° in elevation, the gain has to start degrading significantly to eliminate undesired multipath replicas of the original transmitted GPS signal. This undesired multipath results from the aircraft platform or can bounce back to the aircraft from the ground when the aircraft is in approach or landing position. Requirements for GPS antenna are discussed in more details in [4].

The authors in [5-6] conducted a study of the GPS antenna radiation pattern on 777-300ER and 737-NG airplanes as part of an airborne segment multipath error investigation. None of the research in [5-6] conducted a study to characterize the GPS radiation pattern on a small T-tail aircraft such as the Bombardier Global 5000, whose size and body frame details are significantly different from 777-300ER and 737-NG airplanes. The study in this paper is part of a progressing study for the Impact of In-vehicle Personal privacy Device (PPD) Jammers on the airborne segment. The PPDs transmitted power may approach the aircraft from elevation angles below the horizon as it may potentially approach it from elevation angles above the horizon. The PPDs transmitted power approach aircraft from all azimuth angles. Hence, testing the full aircraft body structure is necessary. Parts of the aircraft surface in [5-6] have been eliminated.

The research in this paper studies the radiation pattern of a GPS antenna mounted on an aircraft approaching and landing in airports. The airport ground was modeled using a Perfect Electric conductor (PEC) medium. The aircraft-level antenna pitch and the Roll planes radiation pattern was compared for different polarizations to show the contributions of the vertical and the horizontal electric field component to the RHCP which is the desired polarization of the GPS signal. In addition; statistical analysis was provided for the resulting three dimensional (3D) RHCP radiation pattern. The antenna was tuned at the GPS L1 frequency (1575.42 MHz).

2 MODELING

Field computations involving bodies of arbitrary shape or Feldberechnung bei körpern mit beliebiger Oberfläche (FEKO) software package was used for the electromagnetic (EM) modeling of both, the stand-alone GPS antenna and the aircraft-level antenna radiation pattern.

A single fed microstrip patch GPS antenna mounted on 30 mm Ground plane (GP) was modeled in this research. Shown in Figure 1. The patch was printed on a 25 millimeters (mm) squared ceramic layer of 4 mm thickness. The dielectric constant of the substrate ceramic layer is 21 with a loss tangent of 0.0023. Two diagonal opposite corners of the patch antenna were truncated by 1.64 mm to generate the antenna RHCP response. The feed was located at about 2.3 mm from the antenna center along the y axis. The patch was gridded into 647 metallic triangles and 282 dielectric triangles. The triangle edge length was equal to half of the substrate thickness for fine meshing and the segment length was equal to the substrate thickness. The number of basis functions was 2479 unknowns. The antenna was mounted on the fuselage of the aircraft at about 5.76 meters (m) distance from the nose end of the aircraft. The aircraft and the antenna location is depicted in Figure 2.

An aircraft Computer-aided Design (CAD) model was created to mimic Bombardier Global 5000 commercial aircraft structure and dimensions. As shown in Table 1, the aircraft dimensions are large and reveal unacceptable simulation time and computation memory usage using the Full- Method of Moment (MOM) solving method [7]. The number of Unknowns resulted these dimensions was about 2.5 millions. Simulation time with the antenna connected using Multilevel Fast Multipole Method (MLFMM), was more than 600 hours. The simulation was then aborted. However; hybridized solving method was optimized using Aperture Source (AP) with (MLFMM) and Physical Optics (PO) solving methods. Full aircraft radiation pattern was simulated with the GPS antenna mounted on the Aircraft's fuselage. The total simulation time was 106.738 hours with a 794.981Mega Bytes (Mb) hardware memory usage. Xeon 4-Core computing unit (CPU) with 8 Processors with 32 GByte installed Memory and 2.33 GHz Speed was used to run the simulations.

Figure 2. work plane coordinate system is defined in terms of azimuth and elevation planes as follows. In the azimuth plane, Ø = 0° in the +x direction, Ø = 90° in the +y direction. While in the elevation plane, 0° is zenith and 90° is the horizon. Pitch and Roll planes are two different cuts from the elevation planes at Ø = 90° and at Ø = 0°, respectively. This coordinate definition is needed to translate the three-dimensional polar plots and the statistical analysis going further in this paper.

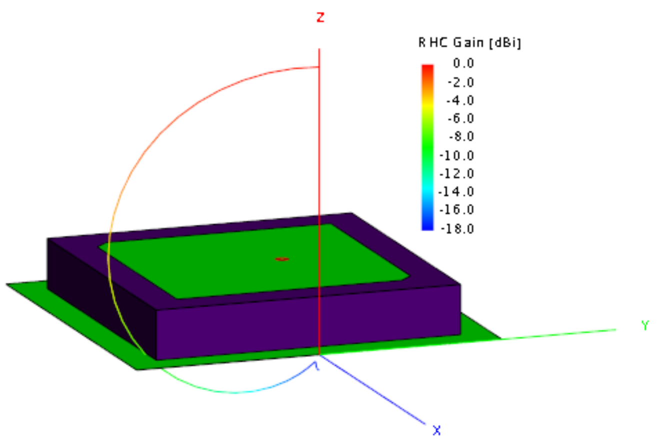

Figure 1. The GPS antenna with an azimuth cut of the resulted RHCP gain (dbi) at Phi = 0°. Note the maximum gain at the antenna Zenith, and the minimum gain below the antenna horizon.

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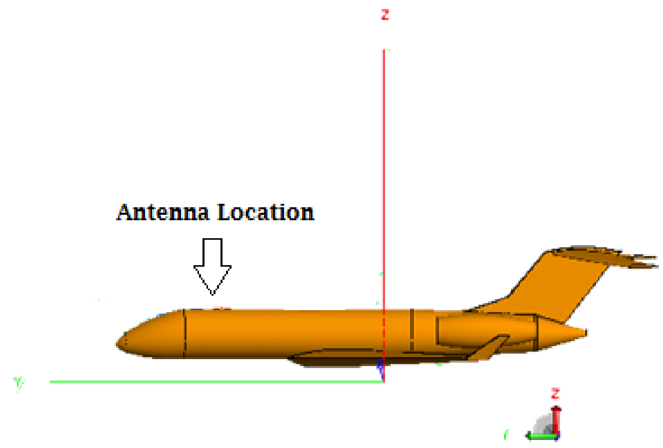

Figure 2. Aircraft Side-view with the Antenna location on the aircraft's fuselage.

Table 1. Aircraft dimensions as a function of Wavelength (λ)

Aircraft Length	Wing span	Fuselage Length	Fuselage Radius	Tail Height
155λ	151λ	66 λ	8 λ	20 λ

The RHCP is the GPS signal polarization. Aircraft-level antenna 3D radiation patterns were simulated for three polarizations, RHCP, Vertical Linear Polarization (VLP) and Horizontal Linear Polarization (HLP). Contribution from each of the three polarizations to the resulted total radiation pattern was compared. . For each polarization the 3D radiation pattern was collected in a spatial resolution of 5° in the elevation and the azimuth planes. This applies to the total radiation pattern as well. The range of angles was 0° to 90° in the elevation plane and 0° to 360° in the azimuth plane. Total of 1387 gain data points were collected for each scenario. The Far Field (FF) pitch and roll planes radiation pattern for aircraft-level antenna are shown in Figure 3 and Figure 4 respectively. All gain values in this paper were collected in (dBi).

To quantify the aircraft-level antenna RHCP radiation pattern performance, the maximum gain, minimum gain, Maximum to Minimum Gain Ratio (MMGR) and the linear average gain (LAG) were computed at each of the 19 elevation cuts as illustrated in Figure 5. At each elevation cut, the aforementioned statistical analysis was implemented on the RHCP gain values of the 73 azimuth angles.

At each of the 19 elevation angles (θ_M), the LAG of the RHCP gain is computed by taking the average of the RHCP gain values at the desired 73 azimuth angles ($\emptyset_K$) as mathematically represented in (1).

$$\text{LAG} = \left(\frac{1}{73}\right) \sum_{K=1}^{73} \text{Gain}_{\text{RHCP}}(\theta_M, \emptyset_K) \qquad (1)$$

While the MMGR is the minimum gain subtracted from the maximum gain values for the desired 73 azimuth gain values, and it tracks the distribution consistency of the gain values over the full 3D coordinate system, and is computed using (2).

$$MMGR = Max\left(Gain_{RHCP}(\theta_M, \emptyset_K)\right) - Min\left(Gain_{RHCP}(\theta_M, \emptyset_K)\right) \qquad (2)$$

3 RESULTS

In Figure 3 and Figure 4, the upper hemispherical RHCP coverage radiation pattern from the antenna horizon and up toward its zenith is included. Roll and Pitch planes radiation pattern Lower hemispherical coverage below earth surface was not practical since the aircraft wheels are on Earth's ground. Using PEC medium to represents Earth is consistent in this case as it does not allow radiation patterns beneath it. The RHCP gain reaches the maximum at zenith and start degrading to be eliminated at and below the horizon. The aircraft fuselage length provides the ground plane for the antenna pitch plane radiation pattern, while the wings-span and the fuselage radius extensions provide the ground plane for the roll radiation pattern. This explains the difference in the two cuts radiation pattern above the same PEC medium.

Figure 5, statistically, quantifies the 3D RHCP radiation pattern. As noticed from the MMGR values, the RHCP radiation pattern starts fluctuating as the elevation angle moves from the zenith down to the horizon. As the elevation angle moves from the zenith to the horizon the VLP contribution to the RHCP increases because the aircraft body frame and the PEC medium starts

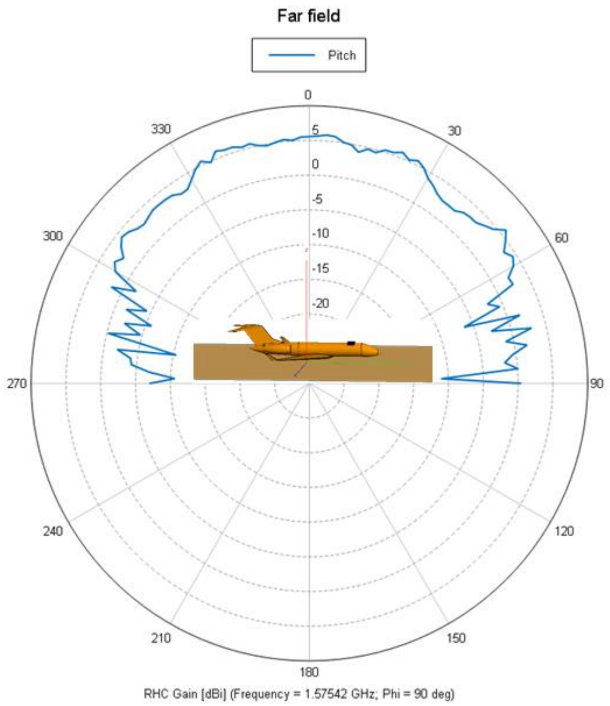

Figure 3. Aircraft's Pitch RHCP radiation pattern above PEC medium.

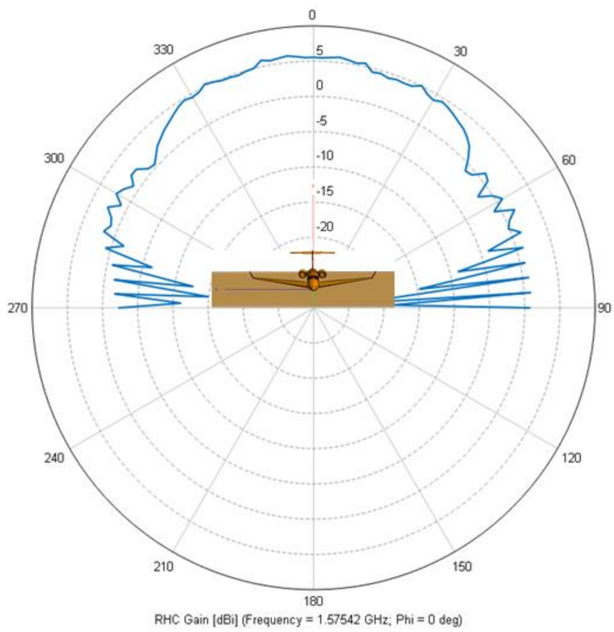

Figure 4. Aircraft's Roll RHCP radiation pattern above PEC medium.

eliminating the tangential component to their surface $E_{\emptyset}$. As a result VLP gain becomes dominant. However; both VLP and HLP phase contributes to the RHCP gain phase even at higher elevation angles. The LAG of the aircraft-level antenna radiation pattern shows that the antenna can still perform in the upper hemisphere.

The results in Figure 6, demonstrate the vertical and the horizontal electric field components E_{θ} and $E_{\emptyset}$ contributions to the RHCP. Note the agreement between the total gain and the VLP gain (Resulted from E_{θ}). The GPS antenna responses to the VLP gain more than it does for the RHCP gain. This gives an idea about the dominance of the electric field vertical component in existence of the PEC medium. PEC medium is one of different medium that represents Earth random proprieties such as sea water and dielectric mediums.

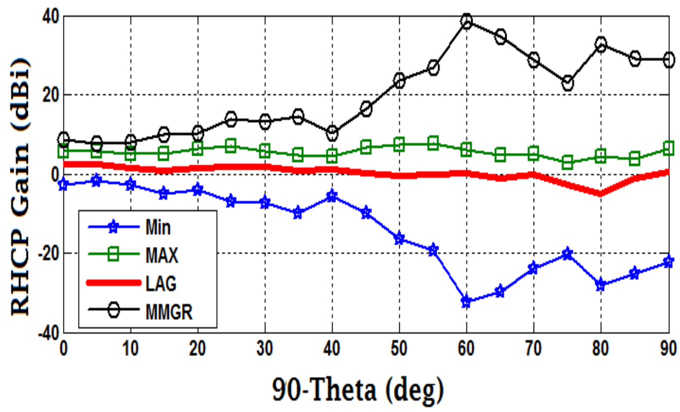

Figure 5. MMGR, LAG, Minimum and Maximum RHCP gain (dBi) vs elevation angle. Note that 0° is Zenith while 90° is the horizon.

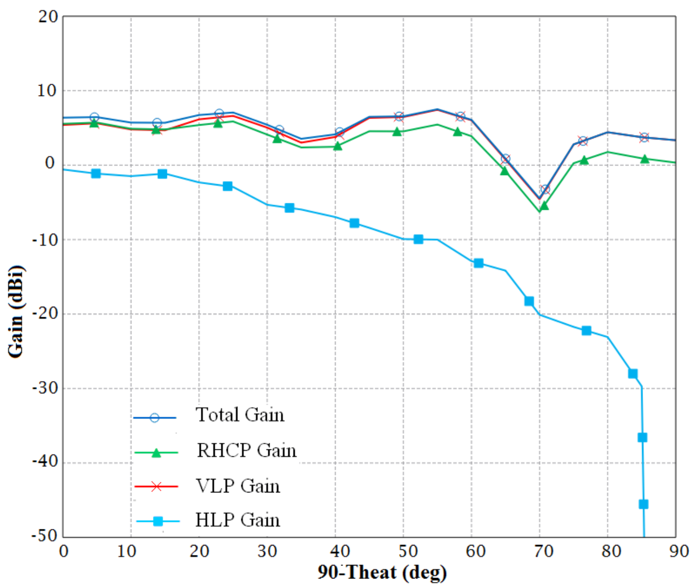

Figure 6. Total, RHCP, VLP and HLP gain values vs elevation angle . Note that 0° is Zenith while 90° is the horizon.

The airborne segment approaches airport in a 3° glide slope, which results in changing the aircraft elevation from the ground of the airport. This polarization loss impacts the antenna performance as the aircraft approaches the airport's ground.

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4 CONCLUSIONS

The 3D RHCP radiation pattern of the GPS antenna mounted on a small T-tail aircraft was simulated, and results were characterized. Simulation time was reduced significantly without results accuracy trade. Polarization loss as a function of elevation angle was investigated, and results of different signal gain polarizations were compared. The contribution of the horizontal component of the electric field component to the RHCP gain decreases as the elevation angle moves from zenith toward horizon, while the vertical component of the electric field becomes dominant. This work will continue to investigate the impact of the different airports facility environments on the approaching and landing aircrafts.

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