Signal-To-Noise Ratio Prediction and Validation For Space Shuttle GPS Flight Experiment

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Abstract

A deterministic method for Space Station Global Positioning System (GPS) Signal-To-Noise Ratio (SNR) predictions is proposed. The complex electromagnetic interactions between GPS antennas and surrounding Space Station structures are taken into account by computational electromagnetic technique. This computer simulator is capable of taking into account multipath effects from dynamically changed solar panels and thermal radiators. A comparison with recent collected Space Station GPS system flight experiment data is presented. The simulation results are in close agreement with flight data.

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I. Introduction

The Global Positioning System (GPS) receiver Signal-To-Noise Ratio (SNR) information has been used for spacecraft attitude determination and multipath mitigation [1,2,3]. In this paper, we propose a deterministic method for GPS SNR predictions. The method is validated by Space Shuttle flight data. Good agreement is achieved and presented in this paper.

The International Space Station (ISS) is very large in terms of physical and electrical size and is a very complex structure. The solar panels and thermal radiators are rotated dynamically to maintain a preferential orientation with respect to the sun. The Space Station GPS antennas will encounter blockage/multipath from the Space Station structures, especially the solar panels and the thermal radiators. These blockages/multipath may cause GPS signal degradation and reduce GPS measurement/performance accuracy.

The modern digital computer with its fast calculation speed and vast storage capability, in conjunction with the advance in the Computational Electromagnetics (CEM), has made accurate field strength prediction possible even in a complex environment. Accurate signal strength can be obtained by deterministic superposition of all dominant multipath signals, which is vector summation of the significant electromagnetic field contributions.

II. SOAR Flight Experiment

The Space Station has been under construction since 1998, and will be equipped with a Space Integrated GPS/INS system (SIGI) for navigation and attitude determination. The SIGI sensor is intended to be the primary navigation and attitude determination source for the ISS.

The SIGI was demonstrated on-orbit for the first time in the SIGI Orbital Attitude Readiness (SOAR) experiment during the STS-101 mission of the Space Shuttle Atlantis in May 2000. The GPS antenna mounting structure (GAMS) is installed in the payload bay of the Shuttle. Four patch antennas were mounted on multipath-suppressing choke rings in the corners and two star trackers were included to provide accurate attitude solutions. For the star trackers, the Ball CT-633 was the primary sensor and the Caltrac was the backup sensor. Two payload and general support computers (PGSC) were located in the Spacehab module to communicate with other equipment through the interface panel.

III. Simulation Tool

The Space Station GPS Signal-To-Noise Ratio analysis tool is called the Dynamic Environment Communications Analysis Testbed (DECAT) [4]. DECAT provides the capabilities to model the orbital and structural dynamics of Space Station and other vehicles and to incorporate user-written control functions to calculate communication coverage. DECAT is flexible in that it can model any number of vehicles in any configuration and include the Sun and planets in the simulation. The motion of DECAT vehicles and planets is defined hierarchically. An example is the Earth orbiting the Sun, Space Station in orbit around the Earth, and the Space Station in a fixed attitude with respect to the orbit.

Vehicle models include models for the orbital dynamics, structures, and communications system equipment such as antennas, receivers, and transmitters. Orbital dynamics models (circular or elliptical orbits, fixed attitude, etc.) are available with DECAT. When coverage analysis is required for ascent, entry, or other special trajectories, such as translunar trajectories, trajectory tapes are input into DECAT. Structures define the vehicle physically. Each segment may have some particular motion assigned to it, such as solar panels which track the Sun and radiators which anti-track the Sun. Signal strengths can be computed using the Uniform Geometrical Theory of Diffraction (UTD). The electromagnetic interactions from surrounding Space Station structures are included.

IV. Signal-To-Noise Ratio Computations

In the UTD computation, the reflected and diffracted field at a field point r', $\boldsymbol{E}^{r,d}(r')$ can be computed as

$$\boldsymbol{E}^{r,d}(r') = \boldsymbol{E}^{i}(r)\,\boldsymbol{D}^{r,d}\,\boldsymbol{A}^{r,d}(s)\,e^{-jks} \tag{1}$$

where $E^{i}(r)$ is the field incident on the reflection or diffraction point r, $\boldsymbol{D}^{r,d}$ is a dyadic reflection or diffraction coefficient, $\boldsymbol{A}^{r,d}(s)$ is a spreading factor, and s is the distance from the reflection or diffraction point r to the field point r'. $\boldsymbol{D}^{r,d}$ and $\boldsymbol{A}^{r,d}$ can be found from the geometry of the structure at reflection or diffraction point r, and the properties of the incident wave there.

The application of UTD to a space vehicle requires first to decompose the space vehicle structure into simple geometrical shapes such as plates and cylinders, and given that the reflection and diffraction coefficients for these are known. Next, all field components contributing to the radiation intensity in the field point must be traced, and the individual contributions must be determined. The resultant field is given by summing all the complex contributing components:

$$E^{tot} = E^{inc} + \sum_{n=1}^{N} E_{n}^{ref} + \sum_{m=1}^{M} E_{m}^{dif} \tag{2}$$

where E^{tot} : Total field at the observation point, E^{inc} : Direct incident fields from antennas, E^{ref} : Reflected fields from plates and cylinders, E^{dif} : Diffracted fields from plates and cylinders. Detailed information on the theory of this method can be found in [5,6].

V. Flight Data Comparisons

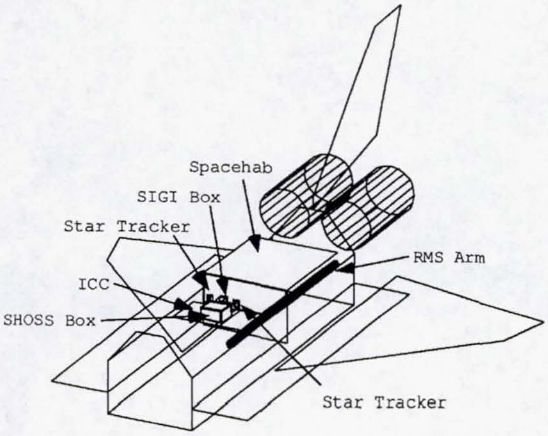

Fig.1. Space Shuttle STS-101 model.

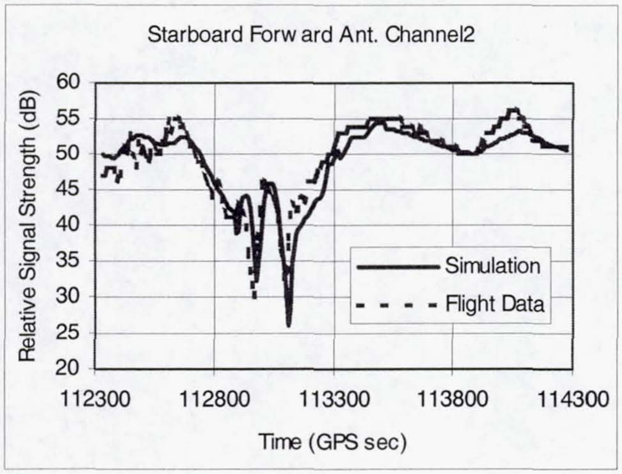

Fig.3. Starboard forward antenna SNR for receiver Channel 2 with Space Station module blockage.

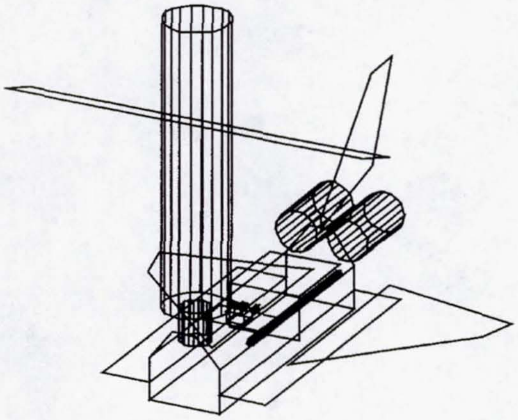

Fig.2. Space Shuttle STS-101 docked to Flight 2A Space Station model.

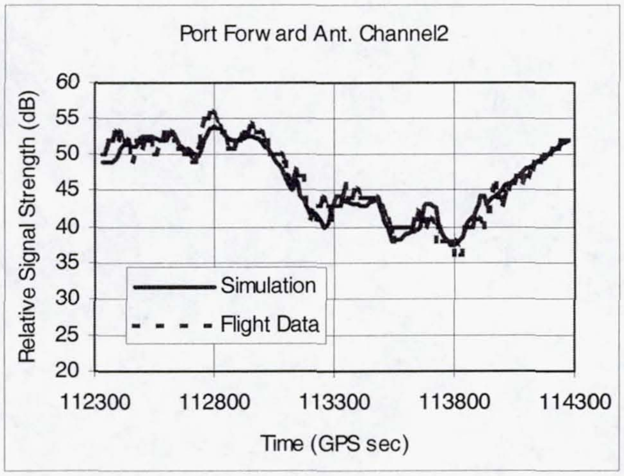

Fig.4. Port forward antenna SNR for receiver Channel 2 with Space Station module blockage.

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