Paper ID: 33098
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23rd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Small Spacecraft for Deep-Space Exploration (8)

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ORBIT DETERMINATION OF FEMTOSATELLITES USED IN PLANETARY EXPLORATION MISSIONS

Abstract

Over the past 15 years, there has been a growing interest in femtosatellites, a class of tiny satellites having mass less than 100 grams. Research groups from Peru, Spain, England, Canada, and America have proposed femtosat designs and novel mission concepts for them. Peru made history in 2013 by releasing the first, and still only, femtosat tracked from LEO. Femtosatellite applications in interplanetary missions have yet to be explored in detail. An interesting operations concept would be for a space probe to release numerous femtosatellites into orbit around a planetary object of interest, thereby augmenting the overall data collection capability of the mission. One challenge after such a deployment would be how to determine the locations of the femtosats over time. That is, any measurements that the femtosats provide are only useful if their corresponding locations can be determined.

Position determination for a femtosatellite poses a unique problem. Such a tiny form factor inherently imposes limited power constraints on its transmitted radio signal. We can assume that a larger host satellite would deploy the femtosats and then maintain an observation orbit, with position and velocity states obtained via methods used in prior interplanetary voyages. As the host satellite receives signals from the entire constellation of femtosats, their relative positions can be determined using a classical technique: Doppler curves.

In this paper, we propose a method of position determination for femtosatellites operating beyond Medium Earth Orbit and therefore beyond the help of GPS. Specifically, we show that Kalman filter techniques applied to Doppler shift measurements allow for orbit determination. To demonstrate the usefulness of this method, we present a mission case study where femtosats are deployed from a satellite orbiting Titan. The conceptual mission objective is to observe Titan's dynamic ionosphere. In this context, we model the orbital dynamics of the satellites and generate synthetic Doppler shift measurements. We then apply a Kalman filter orbit determination algorithm to solve for the femtosatellites' positions over time.

Our goal for this effort is to advance the field of miniature spacecraft-based technology and to highlight the advantage of using femtosatellites in future planetary exploration missions. A planetary probe releasing hundreds of femtosats could complete an in-situ, simultaneous 3D mapping of a physical property of interest, achieving scientific investigations not possible for one probe operating alone. By presenting our position determination method, such a femtosat mission concept is one step closer to being feasible.