Using A Dynamic Channel Emulator for CubeSat GNSS Receiver Test and Integration

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***Abstract* — Insufficient system-level integration and testing has been cited as one reason why failure of the communication subsystem has been responsible for approximately 20% of small satellite mission failures over the period between 2000 and 2019. However, the cost of accessing wireless test facilities designed for testing spacecraft systems is often far beyond the reach of CubeSat designers. In previous work, we have shown how a GTEM cell can be adapted for use as a key part of a dynamic channel emulator will permit designers of CubeSats operating at frequencies up to 20 GHz to evaluate their spacecraft's communications subsystem over multiple simulated passes with the spacecraft in as close to flight condition as possible including fully deployed antennas. Such tests can confirm that the communications subsystem will function correctly while experiencing path loss, Doppler shift, fading and other impairments. The GNSS receiver subsystem is another critical component of a CubeSat that operates in a far more challenging environment than it would in a terrestrial environment. Moreover, the small size of a CubeSat also limits: 1) the options for implementing the GNSS antenna and 2) the size of the antenna ground plane. Here, we show how our dynamic channel emulator can also be used to evaluate the performance of the GNSS receiver subsystem in as close to flight condition as possible including fully deployed antennas with account taken for the position, speed, and orientation of the CubeSat with respect to a simulated GNSS constellation.**

***Index Terms*— channel emulator, CubeSat, GNSS, satellite test and integration**

I. INTRODUCTION

In recent years, universities, governments, and industry have taken increasing advantage of the opportunity to use CubeSats to launch sensors and other small payloads at very low cost compared to conventional platforms. However, past studies of the reliability of small satellite missions launched between 2000 and 2018 show that failure of the communications system accounted for 17% of mission failures between 2000 and 2012 [1] and 26% of failures between 2009 and 2018 [2]. In each case of failure, lack of preflight testing was identified as the reason that the deficiencies in the communications subsystem weren't identified and corrected. Although a 2017 MIAW study concluded that realistic system-level testing of the communications link between their satellite and their ground station is essential [3], few universities or other organizations involved in CubeSat development have access to the facilities required to perform such tests. Too often, the tests that are conducted are either necessary but not sufficient, or an afterthought and performed in haste.

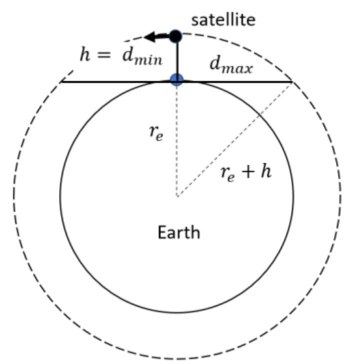

Fig. 1 - A LEO satellite orbiting the Earth.

A typical Earth-LEO communications scenario is presented in Fig. 1. Here, r_e is the radius of the Earth, h is the altitude of the satellite and d is the range from the satellite to the Earth station which changes rapidly as the satellite passes from horizon to horizon, resulting in rapid changes in path loss and Doppler shift during the pass. In previous work [4], we introduced a GTEM-based dynamic channel emulator that can be used to perform over-the-air system-level testing of CubeSat communications links through ultra-realistic simulation of the wireless channel during such passes far less expensively than other test systems.

The GNSS (Global Navigation Satellite System) receiver subsystem is another critical wireless component of a CubeSat. For example, UBC's ALEASAT requires precise orbit determination (POD) using GNSS in order to achieve accurate Earth imaging. However, the high speed and rapidly changing orientation of the satellite with respect to the GNSS constellation is far more challenging environment than what would be encountered in terrestrial deployments. The small size of a 1U CubeSat like ALEASAT also limits: 1) the options for implementing the GNSS antenna and 2) the size of the antenna ground plane. Careful assessment of alternative ground plane designs is often required. For these reasons, CubeSat GNSS testing with a simulator is considered essential [5].

Here, we show how our dynamic channel emulator can also be used to evaluate the performance of the GNSS receiver subsystem in as close to flight condition as possible including a flight ready GNSS antenna. The simulated GPS signals account for the position, speed, and orientation of the CubeSat with respect to a simulated GNSS constellation.

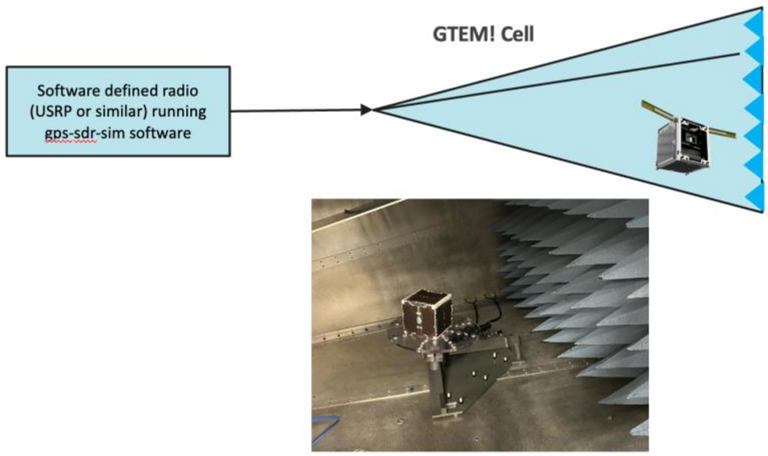

Fig. 2 - Reference design for the dynamic channel emulator as configured for GNSS testing.

II. System Design

The reference design for the UBC dynamic channel emulator is based upon the use of an ETS-Lindgren Model 5407 GTEM (Gigahertz Transverse Electromagnetic) cell to simulate a free space environment and is shown in Fig. 2. A CubeSat placed inside the GTEM cell experiences a signal comparable to what it would experience in the far field of a transmitting antenna. The compact size of a GTEM cell compared to a full-size anechoic chamber and an open area test site are significant advantages [5].

The GPS signal simulator *gps-sdr-sim* is used to generate the signals required for testing purposes [6]. The signal will be applied directly to the input port of the GTEM cell. All adjustments to the frequency and power of the signal will be made in software. The *gps-sdr-sim* software is only designed to generate signals for use with terrestrial receivers so it must be modified to account for the fast-moving trajectories of LEO satellites relative to the GPS satellites in their higher orbits. The software requires the location and movement across time of the GNSS receiver under test. While it can accept two formats for this motion file, orbital motion is better represented by Earth-Centered Earth-Fixed (ECEF) coordinates as opposed to latitude, longitude, and height (geodesic) coordinates.

The software assumes that the simulated GNSS antenna is always optimally oriented towards the zenith and neglects any GPS satellites below the astronomical horizon of the receiver. In the case of ALEASAT, many pointing strategies are required to fulfill its mission, including but not limited to nadir pointing during earth observation and corner-sun pointing while idle. These common pointing strategies necessitate that our model accounts for the relative orientation to GNSS constellations. Furthermore, the boresight axis – representing the direction of maximum radiation – can extend below the astronomical horizon as the orbital height increases. Hence, the modified software allows for pointing of the antenna below the astronomical horizon. As a result, the software should also support the configuration of a radiation pattern in a 360-degree sphere as opposed to the previously implemented zenith-pointing and radially symmetric hemisphere.

Most vendors supply utility software to display both the location returned by the receiver and supplementary data for diagnostic purposes. Typical results obtained using a uBlox GNSS receiver with the GPS simulator generating signals consistent with a location over Japan are shown in Fig. 3.

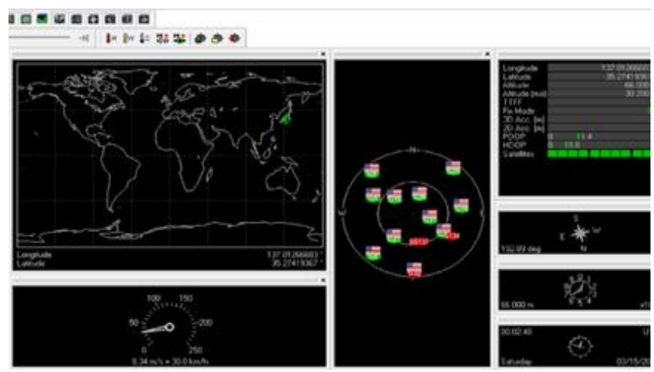

Fig. 3 – Typical results obtained using a uBlox GNSS receiver.

III. Discussion

The GNSS receiver subsystem is a critical wireless component of a CubeSat that operates in a far more challenging environment than it would in a terrestrial environment. Our dynamic channel emulator can be used to evaluate the performance of the GNSS receiver subsystem in as close to flight condition as possible, including fully deployed antennas with account taken for the position, speed, and orientation of the CubeSat with respect to a simulated GNSS constellation, and thereby provide confidence that the subsystem will function as intended after the CubeSat is launched.

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