Data Assessment of Airborne GNSS Reflectometry Experiments for Triton Satellite Mission

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Abstract

GPS receiver (GPSR) has become one of the most important navigation systems for more than two decades. Since a capable GPS/GNSS receiver is able to provide timing and navigation information for spacecraft to determine the orbit, it is one of the essential components of spacecraft. Beyond the functionality of navigation, GPS/ Global Navigation Satellite System (GNSS) is facilitated many remote sensing missions, such as GNSS radio occultation (GNSS-RO) and GNSS reflectometry (GNSS-R). In the GNSS reflectometry mission, the reflected signals are processed to form delay Doppler maps (DDMs) so that the properties including roughness, ocean wind speed, and soil moisture can be retrieved. The UK DMC, SSTL TechDemoSat-1, and NASA CYGNSS satellites have demonstrated the capability of the GNSS-R technique for the measurement of ocean surface wind speed. The design and development of National Space Organization (NSPO) in-house built GNSS-R receiver for the upcoming Triton satellite mission are introduced in the paper. Some unique features of NSPO GNSS-R receiver are described as well. In order to verify the design and performance of NSPO in-house built GNSS-R receiver, hence some airborne flight experiments have been conducted and the results of the experiment data analysis are then discussed. The conclusions and updated status of the Triton satellite mission are described in the end.

Key word: GNSS Reflectometry, TRITON, Ocean Surface Wind Speed

1. Introduction

Due to the omnipresence of GNSS signals and well-maintained infrastructure, many GNSS applications are widely explored. One of three typical GNSS space applications is using the direct GNSS signal to provide the accurate position, velocity and time (PVT) information for the precise orbit determination (Fig. 1). The other is probing the atmospheric and ionospheric profiles with the bending angle of the GNSS signal while passing through the atmosphere (GNSS radio occultation, GNSS-RO), and another is remote sensing the surface properties by receiving the reflected GNSS signals (GNSS reflectometry, GNSS-R). This paper addresses the GNSS reflectometry in which the reflected GNSS signals from the surface of the earth are measured and processed. The principle of GNSS-R remote sensing is that by using the direct line-of-sight GNSS signals as a reference and compensating for errors in the propagation path, certain surface features such as altimetry, ocean wind, seawater salinity, tsunami warning, ice-layer density, soil moisture, and underwater moving targets can be sensed remotely [1]-[4]. The National Space Organization (NSPO) has the responsibility to play an important role to promote the self-reliant technologies of the space industry in Taiwan [5], as a result, NSPO is actively engaged in the development of the Triton program which is a GNSS reflectometry mission to perform remote sensing of the ocean surface roughness and wind speed in an attempt to provide crucial data for severe weather research and prediction.

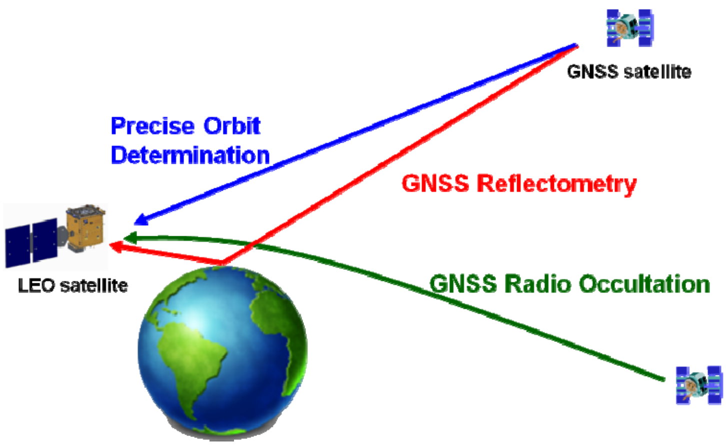

Fig. 1 GNSS space applications

2. Triton Mission

Triton mission was originally conceived as a technology demonstration mission with the goal of demonstrating some key satellite bus technologies including electrical power subsystem, attitude determination and control subsystems, on-board data handling subsystem, and communication subsystem and some associated components so as to provide a baseline design of satellite platform with self-reliant components and technologies for NSPO future missions. Since the program is conducted in parallel with the FS-7/COSMIC-2 GNSS radio occultation mission, a GNSS reflectometry experiment was planned as well as FORMOSAT-7 Reflectometry (FS-7R) is named on that time. However, due to the change of the FS-7 program (from 12+1 satellites to 6 satellites), the Triton program becomes less dependent on the FS-7 program even though the Triton satellite shares some common components with FS-7 satellites. In addition to the original technology demonstration mission, the GNSS-R mission is stressed with emphasis on the use of GNSS-R data for severe weather research. To support the mission, the GNSS reflectometry payload and data processing system are developed. Moreover, a new mission name “Triton” is coined to signify the role of revealing information of the sea

In the beginning, Triton is a part of the FS-7 program and, as a result, the exterior of the Triton satellite is similar to FS-7 satellites so that the satellites can be launched together. The Triton is a microsatellite with a wet mass less than 300 kg. The configuration of the Triton satellite is depicted in Fig. 2 [6]. In the stowed configuration to the right of the figure, the dimension is approximately 100*120*125 cm^3. In the deployed configuration, the solar panel will be deployed in space to generate an average power of 162 W. The pointing accuracy is required to be better than 0.1 deg. Although Triton and FS-7 satellites utilize some common components such as solar array, S-band transceiver, propulsion system, reaction wheel, magnetometer, coarse sun sensor, torque, and battery. Many subsystems of the Triton are designed and developed indigenously. Furthermore, some technology demonstrations including on-board computer, power control unit, H_2O_2 propulsion, fiber optical gyro, spaceborne GPS receiver, and solar array control mechanism are implemented for the Triton satellite.

As aforementioned, the motivations to conduct GNSS-R experiments are multifold. It is expected that the GNSS reflectometry data can be assimilated with radio occultation data for a better retrieval of the profiles of bending angle, refractivity, density, pressure, and temperature of the atmosphere to provide added-value to the FS-7 radio occultation mission. Furthermore, the strategy to develop the GNSS-R payload indigenously is deemed an important step in streamlining the GNSS based remote sensing science and application. Finally, a focal point in both GNSS-RO and GNSS-R is to enhance the prediction capability of the intensity and track of typhoons, which occasionally lead to devastating effects in the Asian-Pacific region. The execution of the Triton program is heavily influenced by the NASA CYGNSS mission as both share the same objectives in utilizing GNSS reflectometry technique to retrieve wind information to pave the way for severe weather research [7]-[8]. The same receiver used in the CYGNSS mission has also been used in the TechDemoSat-1 mission [9]. There are, nevertheless, some discrepancies in terms of data retrieval, assimilation model, and payload design.

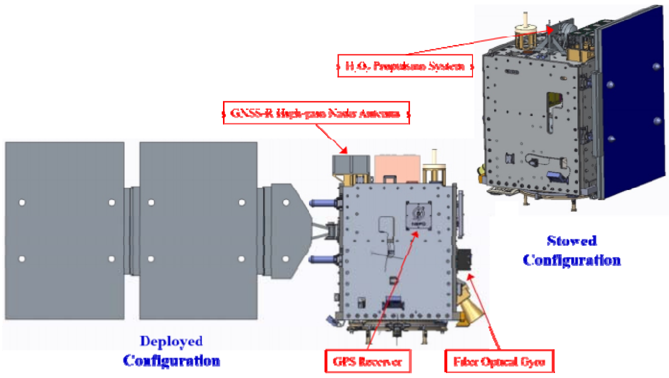

Fig. 2 Triton satellite configuration

3. GNSS-R Payload

The Triton GNSS-R payload is a scatterometric GNSS-R receiver that is designed to receive scattered GNSS signals from the surface of the Earth. As discussed in [10], the GNSS-R payload is designed to meet the following requirements.

a) The GNSS-R receiver shall be able to process reflected GPS/QZSS L1 signals and generate the associated delay-Doppler map either autonomously or by schedule;
b) The resolution of the delay-Doppler map (DDM) shall be at least 128 (in code phase) × 64 (in frequency bin) and each entry of the DDM shall be at least 16 bits;
c) The GNSS-R receiver shall be capable of processing 4 DDMs (Max 8 DDMs) simultaneously;
d) The DDM update rate shall be at least one second;
e) The GNSS-R receiver shall be able to record direct line-of-sight and reflected GPS/QZSS/Galileo signals in L1 and L2 bands in raw data format at the intermediate frequency for ground post-processing purpose;
f) The GNSS-R receiver shall be designed with a process-and-record model for ground debugging purpose;
g) The GNSS-R receiver shall facilitate meta-data to support calibration and retrieval;
h) The GNSS-R receiver should potentially be extended to process reflected Galileo signals and generate DDMs of the aforementioned space, magnitude, and time resolution.

There are some distinguishable features of the GNSS-R payload in comparison with GNSS-R receiver in the TechDemoSat-1 and CYGNSS missions. The GNSS-R payload is a true GNSS receiver as it is capable of processing scattered GPS and QZSS signals. Some lessons learned in CYGNSS such as calibration are taken into account in the design.

To meet the above design requirements, several design configurations are proposed and examined in terms of complexity, resource utilization, and technical maturity. The block diagram of the GNSS-R payload is depicted in Fig. 3, which consists of zenith antenna, nadir antenna, low-noise amplifier (LNA), and a receiver. Fig. 4 depicts the photo of the GNSS-R receiver, which contains a radio frequency front end (RFFE) (containing two RF inputs), navigation unit, science unit, and power unit. The interface of telecommands (TC) and telemetry (TM) for the GNSS-R payload operation and status monitoring is the RS422. The science unit output data, including generated DDM and/or stored down-converted raw data, is transmitted to the Triton satellite bus through the SpaceWire interface. The transmitted pulse per second (PPS) signal is used for the purpose of synchronization. The zenith antenna is a dual-frequency (L1 and L2) right-handed circularly polarized (RHCP) antenna that is used to receive direct line-of-sight signals from GNSS satellites. On the other hand, the nadir antenna is a self-developed dual-frequency left-handed circularly polarized (LHCP) antenna for the reception of reflected/scattered signals from GNSS satellites (Fig. 5). The LNA installed closely to the antenna is used to provide appropriate amplification and filtering to enhance the signal-to-noise ratio (SNR). The power unit regulates the input power from Triton satellite bus for the distribution of regulated voltage to other units. The RFFE is in charge of signal conditioning, down-conversion, and analog-to-digital conversion. The incoming signals are sampled at 16.368 M samples per second and each sample is represented as a 4-bit data (2-bit in phase component and 2-bit quadrature component). The navigation unit processes the zenith antenna signal to provide position, velocity, timing information, GNSS satellite position/velocity. The core technology of the GNSS-R navigation unit and power unit is based on the NSPO space-grade GPSR.

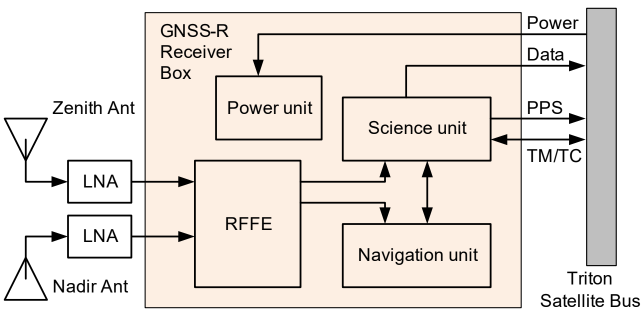

Fig. 3 GNSS-R payload block diagram

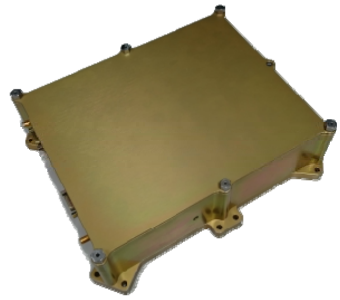
Fig. 4 Photo of the GNSS-R receiver

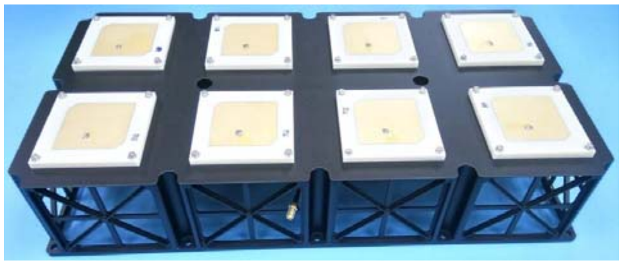
Fig. 5 Nadir antenna of the GNSS-R payload

The kernel of the GNSS-R receiver, science unit, is responsible for the reception and processing of reflected GNSS signals. Hence, a reflection management routine is used to determine the specular reflection point with respect to each GNSS satellite based on the provided information of the navigation unit. The relative code shift and Doppler shift are also computed to properly assign the bins for DDM processing. The relative code shift is the delay of code from the specular reflection point to receiver. The relative Doppler shift is the change in frequency of GNSS signal for receiver moving relative to the specular reflection point and GNSS satellite moving relative to the specular reflection point. The science unit relies on the reflected scenario to adjust the code phase and Doppler frequency in the generation. In addition, special code and carrier generation schemes are developed to process the data in parallel to form DDMs. The science unit of the NSPO self-developed GNSS-R receiver is implemented by using a reprogrammable FPGA coprocessor, Zynq-7045, to meet the demand of real-time processing. Compared with SGR-ReSI used in the TechDemoSat-1 and CYGNSS missions, both reflectometry receiver designs are similar in terms of major functions. However, there are still some distinguishable features of the NSPO self-developed GNSS-R payload, such as QZSS reflected signal processing. The key improvement of the NSPO self-developed GNSS-R receiver is the higher resolution of DDM.

3. Airborne GNSS-R Experiments

The prototype of the GNSS-R payload had been developed in 2016. Despite several ground tests have been conducted to validate the prototype of the GNSS-R payload in the early development phase (Fig. 6), two airborne tests have been performed with Aerospace Industrial Development Corporation (AICD) airplane in later 2016 to verify the functionality of the GNSS-R payload. Fig. 7 and Fig. 8 depict two actual flight test paths as well as one snapshot of the aircraft position and the corresponding DDMs, respectively. The two flight tests essentially verify that the design requirements of the GNSS-R receiver are fulfilled. Additional test results can be found in [11]-[14]. Thereafter, the engineering model (EM), engineering qualification model (EQM) and flight model (FM) of the GNSS-R payload have been produced from 2017 to 2019. Some tests pertaining to its performance including conducted electromagnetic compatibility (EMC) test, radiated EMC test, vibration test, thermal vacuum test, and shock test have been completed. The unit is then integrated with the Triton satellite bus for verification and validation.

Owing to the successful validation of the prototype flight test, NSPO conducted further airborne GNSS-R experiments during GNSS-R EM/EQM/ FM development. In the beginning, due to the flexibility of the unmanned aerial vehicle (UAV) several airborne GNSS-R experiments were performed by UAV (Fig. 9). It is capable to validate the GNSS-R operation scheduling, link budget analysis, data collection, calibration mode operation, and so on (Fig. 10). Since the limitation of the UAV flight altitude, the airborne GNSS-R experiments by AIDC airplane is planned to perform (Fig. 11). The data retrieval of the AIDC airborne GNSS-R experiment would be compared with the measurements of the Central Weather Bureau (CWB) buoys.

Fig. 6 Ground test with GNSS-R prototype

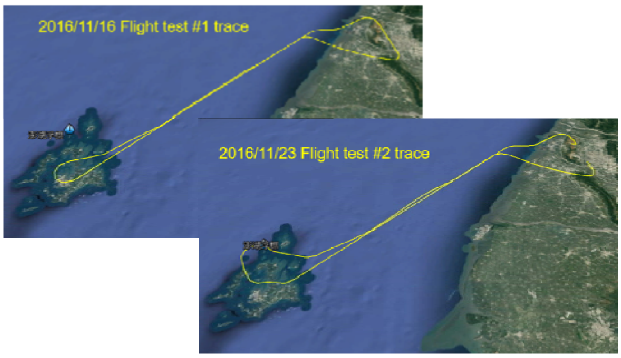

Fig. 7 Actual flight paths of test #1 and #2

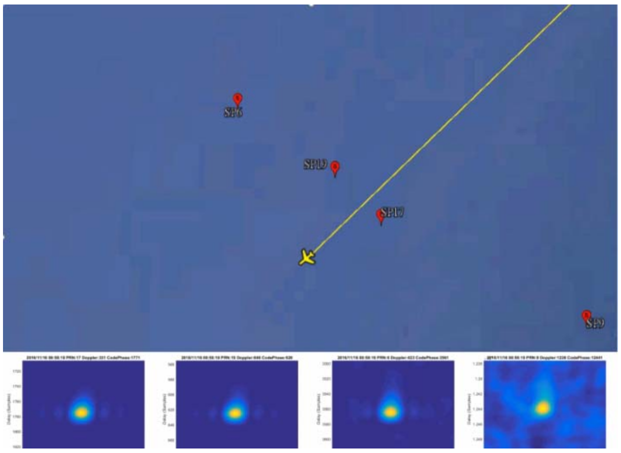
Fig. 8 One epoch resulting DDMs @ flight test #2

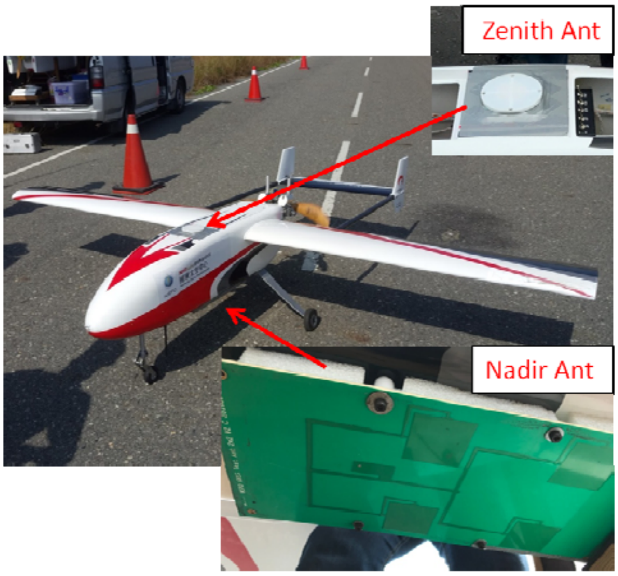

Fig. 9 Airborne GNSS-R experiment by UAV

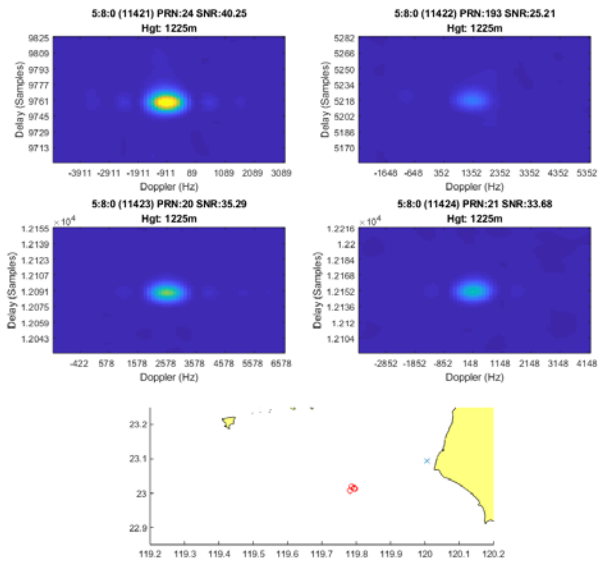

Fig. 10 Flight test route and the corresponding DDMs

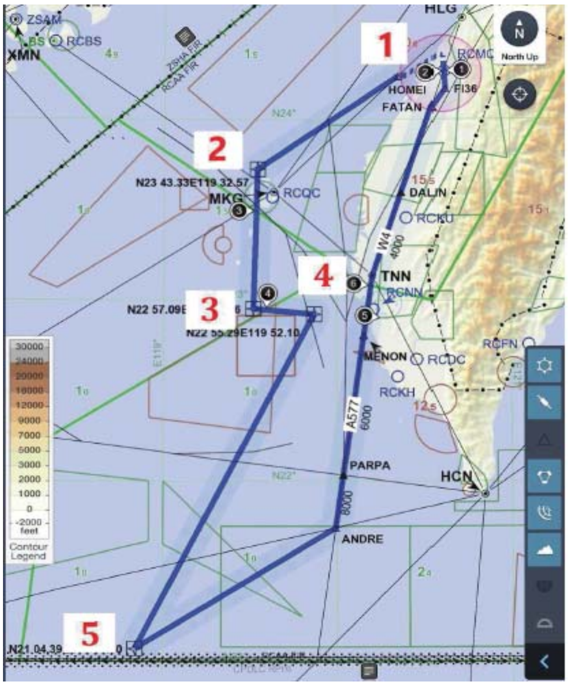

Fig. 11 Planned flight path of airborne GNSS-R experiment by AIDC airplane

4. Conclusion

To support the Triton mission, a science team has been formed to perform the tasks of data calibration, data archiving, data retrieval, and data utilization. Fig. 12 depicts the science data processing of Triton's GNSS-R payload, which will be done by domestic universities and research centers. The Triton program started in 2012 and its development milestones are listed as follow.

- System design review (SDR), 2013.05
- Preliminary design review (PDR) 2014.06
- Critical design review (CDR) 2015.11
- Integration & test review (ITR), 2017.11

The Triton satellite is expected to be launched in 2022. With the GNSS-R payload in which QZSS reflected signals are processed, the Asian Pacific region can be better emphasized and information from the sea as manifested in terms of Typhoons can be monitored.

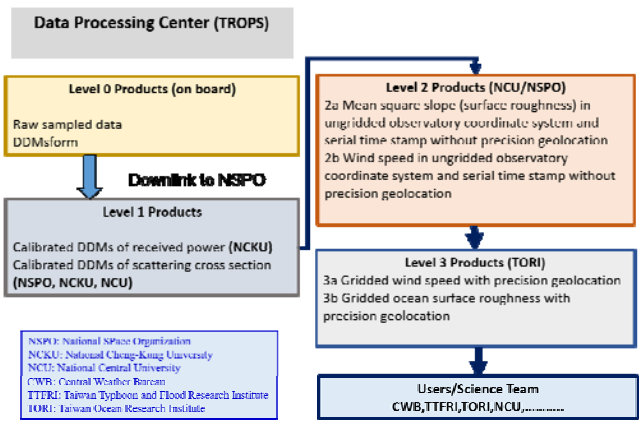

Fig. 12 Science data processing chain

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