Measuring GPS EIRP in Real-Time with a Spaceborne GNSS-Reflectometry Remote Sensing System

Tianlin Wang
Dept. of Electrical Engineering and Computer Science
University of Michigan
Ann Arbor, MI, USA
wangtl@umich.edu

Christopher Ruf
Dept. of Climate and Space Sciences and Engineering
University of Michigan
Ann Arbor, MI, USA
cruf@umich.edu

***Abstract*—This paper presents a unique technique which uses a spaceborne GNSS receiver system to measure GPS EIRP in real time and then uses it to improve the calibration of NBRCS for GNSS-Reflectometry observations. It includes two steps: precise gain calibration of satellite GNSS antenna using on-orbit measurements, and dynamic GPS EIRP calibration with a spaceborne system. For the CYGNSS mission, it successfully recovers the flagged measurements (~37% of the entire dataset) to be included in the standard science data products and further improves the mission's science data quality.**

I. Introduction and Motivation

GNSS-Reflectometry (GNSS-R) is a bistatic radar that uses the reflected signals of the Global Navigation Satellite System (GNSS) to remotely sense the ocean, land and cryosphere of the Earth [1]. It has broad applications for measurements of ocean surface wind speed, sea ice, sea surface altimetry, land soil moisture, flood inundation, etc. Past and current GNSS-R satellite missions or missions with GNSS-R payloads include UK Disaster Monitoring Constellation (DMC), TechDemoSat-1 (TDS-1), NASA Cyclone Global Navigation Satellite System (CYGNSS), BuFeng-1 A/B, and several CubeSats. All of these missions use the Global Positioning System (GPS) as the active transmitter. Therefore, GPS effective isotropic radiated power (EIRP), defined as the product of transmit power and antenna gain, is the key parameter that determines the power incident on the Earth's surface and its knowledge is required for calibration of the normalized bistatic radar cross section [2].

The major challenges in the estimate of the GPS EIRP include 1) the variation of the transmit power; 2) limited knowledge of the transmit antenna gain pattern; 3) the gain uncertainty due to pattern asymmetry and yaw maneuver [3]. One major issue is caused by the flex power mode of the Block IIR-M and IIF GPS satellites was developed and implemented to redistribute the transmit power between the individual signal components of the C/A, P(Y), and M codes [4]. For the NASA CYGNSS mission, this uncertainty of transmit power results in 37% of entire dataset being flagged out and thus significantly reduces the mission's daily measurement coverage. To address this issue, a dynamic EIRP calibration approach is developed to use the CYGNSS zenith navigation channel to detect power fluctuations in all GPS transmitters and correct the calibration of science measurements. However, to accurately estimate the GPS EIRP using the zenith signal, the first step is to precisely calibrate the gain pattern of the CYGNSS zenith antenna.

II. Precise Gain Calibration of Satellite GNSS Antenna Using On-orbit Measurements

The gain pattern of a satellite GNSS antenna is often impacted by coupling and multipath from nearby satellite structures. In certain scientific applications, the GNSS antenna gain must be known very accurately, but circumstances can limit measurement of its gain pattern prior to launch. In this case, on-orbit calibration becomes necessary. An iterative antenna calibration approach is proposed to estimate the gain pattern using multiple GNSS transmitters and a constellation of satellite (CYGNSS) receivers, as shown in Fig. 1. The raw measured counts I^2+Q^2 are converted into power in watts based on an end-to-end calibration experiment. Based on the Friis equation, the received power is used to solve each zenith antenna pattern with measurements of 7 independent GPS signals. Similarly, each GPS antenna pattern is solved using measurements made by 8 CYGNSS zenith channels. The iterative process converges after about 30 iterations.

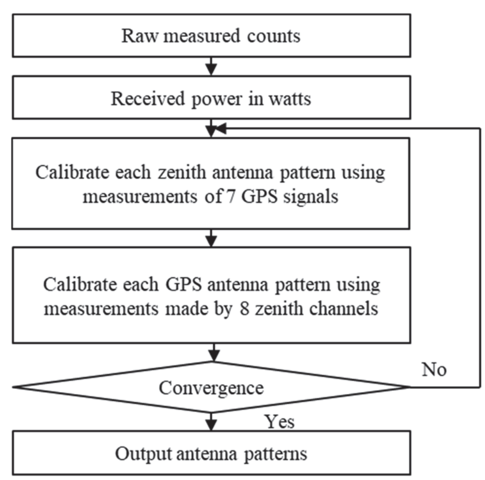

Fig. 1. Iterative antenna calirabtion approach.

The unique advantage of this iterative approach includes 1) it identifies and removes errors existing in the calibration and propagation modeling as well as the systematic differences between satellite platforms; 2) actual on-orbit data is used to demonstrate that it provides very precise and highly accuracy gain pattern of a set of satellite GNSS antennas and also the GPS transmit antennas in its operational environment.

III. Spaceborne Dynamic EIRP Calibration

The idea originates from a GPS flex power event observed simultaneously in the navigation signal of the CYGNSS zenith channel and the reflected signal of the science channel. As shown in Fig. 2, the dynamic EIRP calibration approach uses the measurements made by the direct signal to solve the GPS EIRP in the direction of the zenith antenna (E_Z), then to estimate the EIRP in the direction of specular point (E_S), and finally make a correction to the NBRCS.

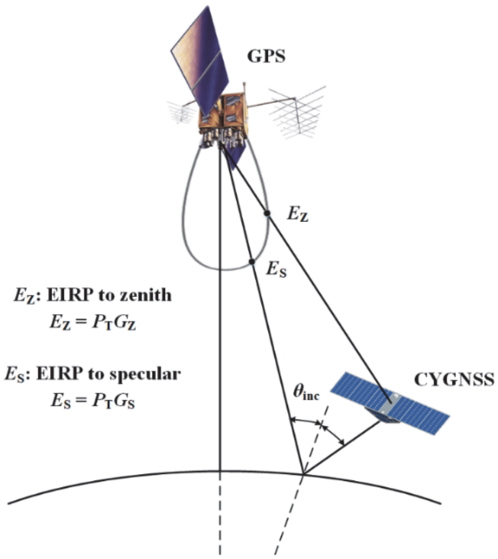

Fig. 2. Concept of the dynamic EIRP calibration algorithm.

The first step to examine if the estimated EIRP reflects the different transmit power levels. Fig. 3 shows the global map of estimated GPS EIRP to the specular point E_S for a Block IIF GPS transmitter (PRN 9) based on one month's data. The different levels of EIRP over different regions are caused by the geographically driven flex power mode, as demonstrated by independent measurements made by DLR [4]. The map is averaged for all incident angles, resulting in the variation of EIRP.

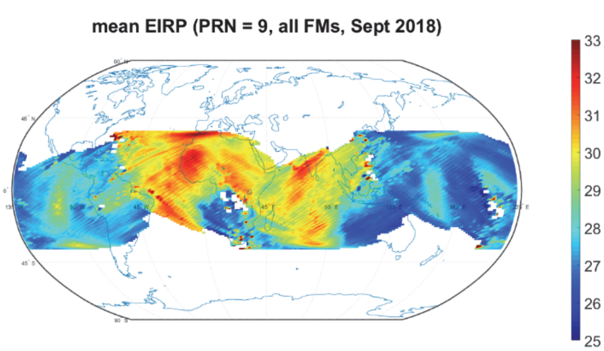

Fig. 3. Global map of estimated EIRP to the specular point.

An example of the flex power event is illustrated in Fig. 4 to demonstrate how this approach improves the calibration of NRBCS. The GPS transmit power increased for ~ 2.5 dB, as shown in the zenith received power calibrated at the DMR input port. The red line shows version 2.1 NBRCS calibrated with a static transmit power, resulting in the similar abrupt change seen in the zenith power. The blue line shows version 3.0 NBRCS using the dynamic ERIP calibration, which is physically reasonable with regard to the real situation of an open ocean with ~7 m/s wind speed.

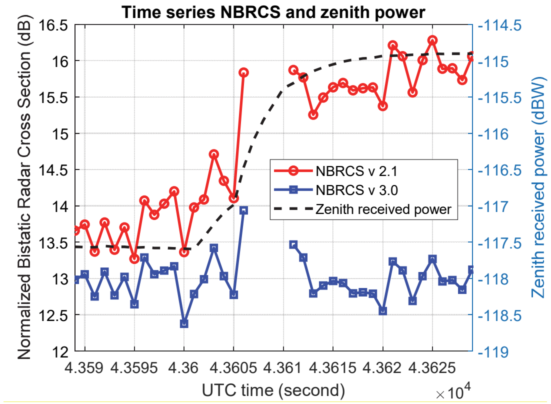

Fig. 4. Case study of improved calibration with the flex power.

The unique advantage of this approach includes: 1) it can instantaneously detect the power fluctuations and correct the calibration of science measurement; 2) it minimize the error incurred by azimuthal asymmetry in the GPS antenna patterns without requiring additional information about GPS yaw attitude. This dynamic EIRP calibration approach brings back flagged observations with Block IIF transmitters (~37% of the entire dataset) to be included in the standard data products. It will also help improve the accuracy of wind speed retrieval.

IV. Summary

This paper presents a an iterative approach for precise antenna gain calibration of a satellite GNSS antenna and a spaceborne GPS real-time EIRP calibration approach for GNSS-R remote sensing. The research contributes significantly to the CYGNSS mission and will also be very useful to the system design, engineering calibration, and scientific investigation of future GNSS-R missions.

Acknowledgement

The authors would like to sincerely thank our colleagues Dr. Scott Gleason, Dr. Andrew O'Brien, Dr. Darren McKague, Mr. Bruce Block, and Mr. Anthony Russel for their beneficial discussions and technical support.

References

[1] V. U. Zavorotny, S. Gleason, E. Cardellach and A. Camps, "Tutorial on Remote Sensing Using GNSS Bistatic Radar of Opportunity," *IEEE Geosci. Remote Sens. Mag*, vol. 2, no. 4, pp. 8-45, Dec. 2014.

[2] S. Gleason, C. S. Ruf, A. J. O'Brien and D. S. McKague, "The CYGNSS Level 1 Calibration Algorithm and Error Analysis Based on On-Orbit Measurements," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 12, no. 1, pp. 37-49, Jan. 2019.

[3] T. Wang, C. Ruf, B. Block and D. McKague, "Characterization of the Transmit Power and Antenna Pattern of the GPS Constellation for the CYGNSS Mission," *IGARSS 2018*, pp. 4011-4014, 2018.

[4] P. Steigenberger, S. Thölert, S. and O. Montenbruck, "Flex Power on GPS Block IIR-M and IIF," *GPS Solutions*, vol. 23, no.8, pp. 1-12, Nov. 2018.