Spire Level 0 Raw RO Product Description

Spire Global Inc.

Issue/Revision	Date	By	Description
1.0	2021-08-19	Spire	Initial version

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1 Overview

Spire's low-earth orbit (LEO) satellite constellation continuously collects data from occulted GNSS signals to derive profiles of atmospheric variables using the radio occultation (RO) technique. Each satellite designed to collect RO data is equipped with a custom receiver that tracks GNSS signals at two different frequencies through multiple antennas. The high gain RO antennas (known as "antBRO" and "antFRO"), approximately aligned with the Spire satellite velocity direction, are designed to collect GNSS signals that pass through the atmosphere. Each occulted signal is nominally tracked at 50 Hz sampling using a state-of-the-art, open-loop tracking technique, which employs an *a priori* model of the atmosphere to aid in the tracking of a GNSS signal. This technique is necessary to track the signal as it passes through the lowest portion of the atmosphere where signal dynamics are large and received signal amplitudes are degraded. In addition to the limb-facing antennas, an upward-facing antenna is utilized to collect simultaneous, dual-frequency signals from multiple GNSS satellites at 1 Hz sampling for precise orbit determination (POD), ionospheric data collection, and reference satellite tracking.

The a priori phase model and 50 Hz in-phase and quadrature correlator accumulations collected during each occultation event are stored in Spire's custom netCDF format. These files are denoted as either *rocObs* and *rocRef* files. The *rocObs* files contain the raw data collected from the primary occulted GNSS signal traversing through the atmosphere and observed through the high-gain RO antennas. The *rocRef* files contain simultaneously collected raw data originating from a reference GNSS satellite observed by the zenith POD antenna, which is intended to mitigate the effects of receiver clock error through the single differencing technique in downstream processing. Each *rocObs* or *rocRef* file contains measurements pertaining to only one signal frequency/type (i.e., GPS L1 versus GPS L2). In general, for a given successful occultation event observed on a single Spire satellite, there should be two *rocObs* files containing raw measurements from the occulting GNSS satellite (one for each signal frequency) and two or more files *rocRef* containing raw data from one or more reference GNSS satellites.

2 Product Content

2.1 Overview

The following describes the content of Spire's *rocObs* and *rocRef* data products.

2.2 Naming Convention

Both *rocObs* and *rocRef* files have the following naming convention:

spire_gnss-ro_L0_{DATA_TYPE}_{VERSION}_{OCC_TIME}_{FM}_{ANTENNA}_{RINEX_ID}_{SIGNAL}_{TRACKING}.nc

where

DATA_TYPE: rocObs or rocRef

VERSION: Product version (e.g. v6.02)

OCC_TIME: Occultation time of event (i.e 2020-01-01T00-00-00). Occultation time is equivalent to the first time stamp of the file.

FM: Spire satellite id (e.g. FM103)

ANTENNA: Virtual antenna id (e.g. antBRO)

RINEX_ID: GNSS RINEX ID (i.e G01)

SIGNAL: RINEX signal code (i.e L1C)

TRACKING: 'O' for open loop tracking, 'C' for closed-loop tracking

3.3 File Observational Coverage

The nominal observed straight line tangent altitude range of each occultation event spans from less than -150 km to approximately 170 km. There are several cases where a smaller or larger altitude range is observed, which are listed below:

- A spacecraft attitude maneuver during an occultation event causes the event to be cut short.
- A receiver collection window terminates and truncates an occultation event.

- A high ionospheric scintillation event is triggered by the receiver onboard detector, which causes all 50 Hz data spanning from orbit altitude (~400-650 km) to below the Earth's surface to be downlinked. These high altitude data are intended for ionospheric data analysis, but can still be used for radio occultation retrieval.

3.4 Notable Variables

Format: NETCDF

Variable	Dimension	Description	Unit
time		Time since the start time of the occultation event. The observation time of each *model_phase* sample in GPS seconds is calculated as: *Time + reference time(ref_gps_week,ref_gps_sow) + ref_gps_fos* The observation time of each *i* and *q* sample in GPS seconds is calculated as: *Time + reference time(ref_gps_week,ref_gps_sow) + ref_gps_fos + time_add_offset*	sec
tap		The receiver correlator tap. The location of the prompt tap is int(n_taps/2).	
model_phase	time	Phase model used during open loop tracking if *tracking_type* = "OPEN_LOOP". For closed loop tracking, this variable is the accumulated Doppler range.	cycles
i	time, tap	In-phase component of correlator accumulation	
q	time, tap	Quadrature component of correlator accumulation	

Notable Global Attributes

Attribute	Description
gnss_system	GNSS system code as per RINEX 3: “G”, “R”, “E”, “C”, “J”
gnss_band/gnss_attribute	GNSS signal band and attribute codes as per RINEX 3: “1C”, “2L”, “2C”, “7Q”, etc.
virtual_antenna_id	“RISING”, “SETTING” or “PRIMARY” (virtual antenna differs from the physical antenna due to satellite orientation)
tracking_type	“CLOSED_LOOP” or “OPEN_LOOP”
noise_floor	Used to derive SNR in V/V

Appendix A - Computation of SNR [V/V] from Raw Correlator Accumulation

The following table summarizes the variables Spire uses to estimate SNR in V/V. These variables are raw observables provided by the open-loop correlation channels on the Spire GNSS-RO payload when observing an RO event.

Magnitude	**Units**	**Description**	**Typical value**
T_i	[s]	Correlator coherent accumulation time. It is the sampling period of the RO signals, and hence as well that of the SNRv estimations.	0.02
$I = S_I + N_I$	[c.c.]*	Real part of a correlator coherent accumulation, of duration T_i. S_I and N_Ii represent the signal and background noise, respectively, of this in-phase component.	From many 10's of counts when there's no signal, to 1000's of counts when there is
$Q = S_Q + N_Q$	[c.c.]*	Imaginary part of a correlator coherent accumulation, of duration T_i. S_Q and N_Q represent the signal and background noise, respectively, of this quadrature component.	
σ_{N_I}	[c.c.]*	Square root of the time-average of the power of real-part of the correlator accumulation, when there is no signal. Namely: $\sigma_I = \sqrt{< \lvert I \rvert^2 >}$ when $S_I = 0$	Noise floor values are typically between 50 and 200, and are dependent on Spire satellite, frequency and antenna. These values are included in each rocObs/rocRef file in order to compute SNR V/V.
σ_{N_Q}	[c.c.]*	Square root of the time-average of the power of the imaginary part of the correlator accumulation, when there is no signal. Namely: $\sigma_Q = \sqrt{< \lvert Q \rvert^2 >}$ when $S_Q = 0$	

*c.c. = correlator counts
** Both real and imaginary components of the background noise have same statistics, so that it is always true that $\sigma_{N_I} = \sigma_{N_Q} \equiv \sigma_N$

Based on the magnitudes observed at the correlator output, summarized on the table above, Spire defines the SNRv at every sampling period, and for every GNSS signal being tracked, as:

$$SNRv \equiv \frac{1}{\sigma_N} \cdot \sqrt{\frac{(I^2+Q^2)}{Ti}},$$

where σ_N is the power of the background noise of either the in-phase or the quadrature component. These values are included as a global attribute ('noise_floor') in each rocObs and rocRef file in order to compute SNR V/V using the formula above.