**Date:** July 8, 2025

**Author:** Dustin Buccino
Planetary Radar and Radio Sciences Group
Jet Propulsion Laboratory, California Institute of Technology

**Subject:** **Processing RSC-11-11 Data into Frequency Observables**

## Purpose and Scope:

The intent of this document is to describe how to process open-loop RSC-11-11 data into frequency observables. These are sometimes called Original Data Record (ODR) files. The example file used is from the Galileo mission.

This document **does not** describe how to read the binary RSC-11-11 data; that information is covered in rsc-11-11_unpack in the Planetary Data System (PDS) Radio Science Documentation bundle, located on the Geosciences node of the PDS. The entire Radio Science Documentation bundle can be found at the following URL:

https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/

## Data File and Relevant Parameters:

The data file from the Galileo Radio Science raw data bundle (*gll.rss.raw*) with the following PDS4 logical identifier:

*urn:nasa:pds:gll.rss.raw:data.rsc_11_11_odr:gll_rss_1997127t1553_dss14_odr*

will be processed in this example. This file is a longer version of the *gll1997127sample* file included in the PDS radio science documentation bundle. This file is one of the few that cover the Ganymede-8 encounter on May 7, 1997, from Deep Space Network (DSN) station DSS-14.

The following data values are needed to perform analysis on the file:

- Time Stamp
- Programmable Oscillator Assembly (POCA) values
- Sampling
- Data Samples

The first three are found in the RSC-11-11 header. In the first record header of the file, the following information is available:

```
Primary FEA = 14
Spacecraft ID = 77
Year = 1997
Day of Year = 127
MilliSeconds Past Midnight = 57180000

POCA Status = 01110101 (normal = 01110101)
POCA Frequency Readback = 43271202.186867
POCA Readback MilliSeconds Past Midnight = 57180000
```

```
A-D Sample Rate = 1250
A55A Validator Tag = True
Conversion Mode Register = 00110101
```

These indicate that this record has a timestamp of 1997-127T15:53:00, collected at DSS-14 from spacecraft 77 (Galileo Orbiter). The POCA was operating normally and readback frequency was `43271202.186867` Hz at the same timestamp (this is typical of RSC-11-11 files). It is important to use the readback frequency, not the calculated frequency. The sampling rate was 1250 samples/sec and the conversion mode register was 00110101, indicating that it was 1 input signal sampled sequentially by 4 A-D converters (this is the simplest case, so the IQ values are already in proper time order). This makes the effective sampling rate 5000 samples/second (4*1250).

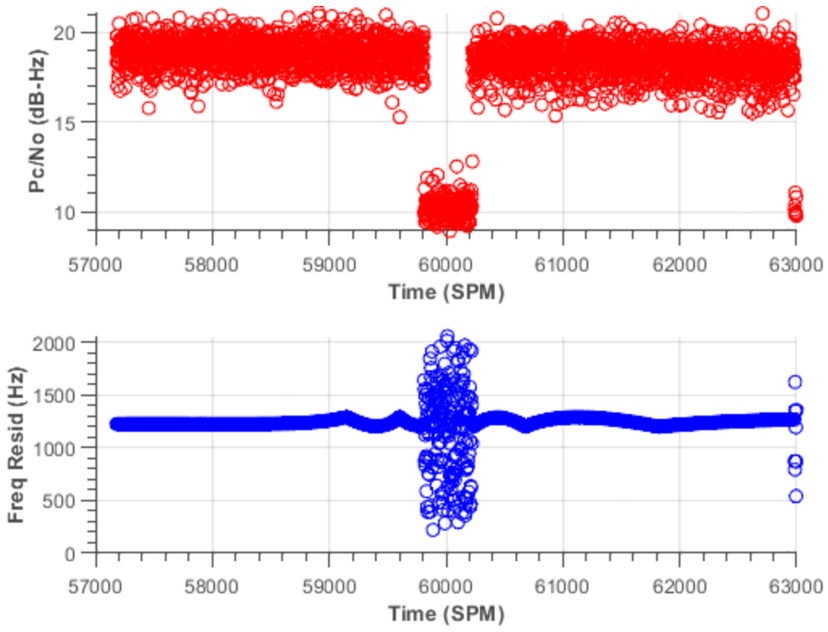
The data samples directly follow each header record.

**Data Processing:**

This example loosely follows the process highlighted in Morabito and Asmar 1994, which describes data processing from the Galileo era:

Morabito, D., & Asmar, S. W. (1994). Radio-Science Performance Analysis Software. *The Telecommunications and Data Acquisition Progress Report 42-120, October–December 1994*, 121-152. https://ipnpr.jpl.nasa.gov/progress_report/42-120/120B.pdf

Firstly, one must perform signal analysis on the data samples to extract an estimate of frequency from the data samples themselves. This document will not describe how to do this analysis, as the specifics of implementation depend on the user's application. Routines such as fast-Fourier transforms (FFT) and phase-locked loops are typical. In this example, a simple FFT is used to extract signal-to-noise ratio and frequency. Note that depending on the implementation, a DC offset may need to be removed as a part of the signal analysis.



Secondly, these frequencies are at the recorded band, not sky frequency, called the "recorded frequency" ($f_{rec}$). They must be upconverted to sky frequency. The formula is in Morabito and Asmar 1994 Section II.C, where the sky frequency ($f_{sky}$) is:

$$f_{sky} = 3*poca + 1.95E9 + 3*(790/11)*1E6 - f_{samp} + f_{rec}$$

where poca is the POCA frequency at the same timestamp as the recorded frequency and $f_{samp}$ is the sampling rate. Between POCA data points in the RSC-11-11 file, one must use **linear interpolation** only to find the POCA frequency at the required timestamp.

**Validation:**

In some cases, one can compare open-loop data in the RSC-11-11 format to closed-loop data (of various types, depending on the dataset). This may not always be possible. For example, the following data file in TRK-2-25 Archival Tracking Data Format (ATDF) is used to validate the data processing for the file specified above:

*urn:nasa:pds:gll.rss.raw:data.trk225_atdf:gll_rss_1997127t0959_dssmm_tdf*

This file is the TRK-2-25 data format standard and produced after March 1997, and therefore can be read with the published code *atdf2ascii* available online through github and documented in a publication.

https://github.com/ashokverma24/atdf2ascii

Verma, A. K. (2022). A Python-based tool for constructing observables from the DSN's closed-loop archival tracking data files. *SoftwareX*, *19*, 101190. https://doi.org/10.1016/j.softx.2022.101190

From that data file, using the software set, one can extract a time-history of frequency recorded by the closed-loop receiver. A few lines from the output of *atdf2ascii* from this file are below as an example.

```
 i.   07-May-1997 15:53:00.050000,   1-Way-Doppler,    77,        S/C,
      DSS 14,     1,     S,     S,     S,        0.1,          0,       -
      1757683.2519450188,     2294997701.0000000000,        0.000000,
      0.000000,        0.000000

 ii.  07-May-1997 15:53:00.150000,   1-Way-Doppler,    77,        S/C,
      DSS 14,     1,     S,     S,     S,        0.1,          0,       -
      1757683.2319464684,     2294997701.0000000000,        0.000000,
      0.000000,        0.000000

iii.  07-May-1997 15:53:00.250000,   1-Way-Doppler,    77,        S/C,
      DSS 14,     1,     S,     S,     S,        0.1,          0,       -
      1757683.1019451618,     2294997701.0000000000,        0.000000,
      0.000000,        0.000000
```

The columns for observable (in line i, that is `1757683.2519450188`) and frequency reference (in line i, that is `2294997701.0000000000`) are then subtracted, per Verma 2022, to produce the sky frequency:

$$f_{sky} = f_{ref} - f_{obs}$$

These frequency values can then be compared against the extracted sky frequency values from the processed RSC-11-11 open-loop files. The comparison between the two, one from the ATDF and one from the ODR, is shown in the figure below. A good agreement between the two is seen, showing the data processing was successful.

**Acknowledgements:**

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).