Performance Report for File
"Haigh_Farr_8310_3MD_0dB_record3_21Dec2020_442PM.dat"

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Following are notes from processing GPS L1 IF using the GNSS IF Recorder Pelican Case and a 8310-3MD Haigh-Farr antenna. Recordings were taken on 12 December 2020 with the antenna rotational assembly and setup shown in Pictures 1 and 2 below. Figures and Pictures are not particularly co-mingled with discussion. Some readers find this annoying; but, it takes less time for the writer and many apologies in that it will be required to zoom in to at least 200% to see the figure details.

The software suite developed for processing the GPS L1 IF recorded data is called "GPS_L1_Analysis_Tool_VS2019_10Jan2021_508PM" compiling under Visual Studio 2019 and last updated 5:08 P.M. on 10 January 2021 . The software is considered to be an analysis tool and not designed to be a "one button" solution for processing the recorded IF data. The software suite is being continuously updated to experiment with many different GNSS algorithms and as the writer's knowledge of GNSS expands.

The Haigh-Farr 8310_3MD antenna with 30 dB gain before the MAX2771 dev board captured six satellites, two of which were very strong, and all trackable. The MAX2771 dev board uses LNA2 with PGA gain of 55 dB. Figure 1 shows the details of acquired satellites being 4, 7, 8, 9, 27 and 30. The software performs an auto-correlation of the 32 GPS L1 PRN codes on the recorded IF data for 12 different 1 msec samples of data. Satellites 7 and 9 were considered very strong auto-correlations in that 5 to 12 samples resulted in closely matching PRN code and Doppler shift offsets. Similar auto-correlations of 2 to 4 samples out of 12 was considered a weak correlation which was the case for satellites 4, 8, 27, and 30. "Weak" or "strong", all satellites provided from ~40 to ~25 dB-Hz C/N and maintained good phase-carrier and PRN code track lock for the full ~8 minutes of record time.

Figure 2 shows GPS satellite positions during the recording from https://hilltopviews.org.uk. Navstar77 is transmitting GPS PRN code 4. Figure 3 shows the satellite positions using Google Earth generated from the recorded IF data. Figure 4 shows the acquired satellites relative to Earth and

figure 5 shows a better radial view of acquired satellites with each having ~20,200 KM distance from earth.

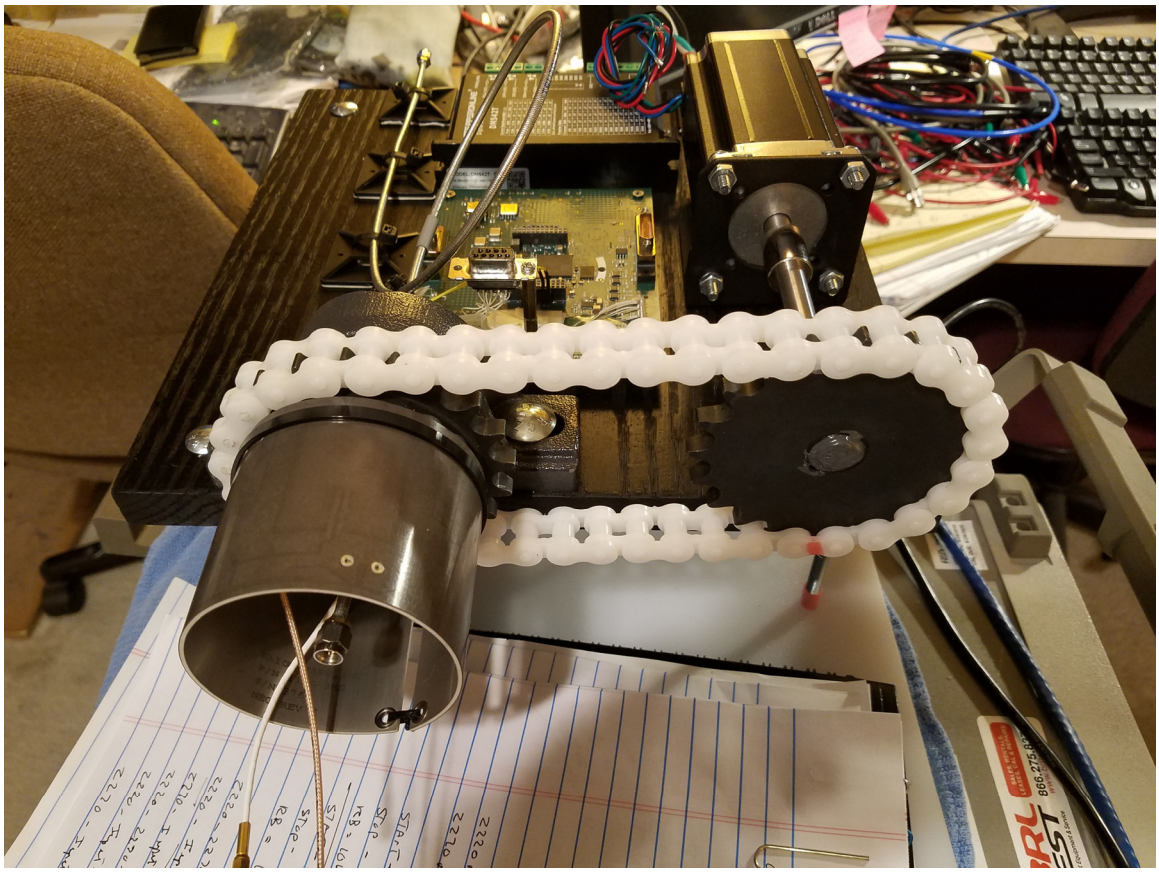
Figure 6 shows a low-pass filter function included in the software suite which helps improve noisy navigation data resulting from weak signal reception.

Figure 7 shows the C/N and SNR for acquired satellite 4, considered to be a weak reception. From time 0 to 15 seconds, one of the RHCP GPS patch elements was oriented straight up and provided a C/N of ~38 dB-Hz. From 15 to 28 seconds, the RHCP GPS element was turned parallel with the ground; C/N dropped to ~32 dB-Hz. From 28 to 32 seconds, one RHCP GPS patch element was turned straight up; C/N increased back to ~38 dB-Hz. From 32 seconds to 2 minutes, the antenna was rotated from 0 to 7 Hz in 1 Hz steps with 5 seconds per each frequency step and back to 0 Hz.

Figure 8 shows the C/N and SNR for acquired satellite 9, a satellite with strong reception. Pending orientation of the RHCP GPS L1 patch elements and time, C/N ranged from ~43 to ~35 dB-Hz.

For continued discussion, please go to page 8.

Picture 1. Set up the afternoon of 12 December 2020



Picture 2. Rotational assembly with Haigh-Farr 8310-3MD antenna

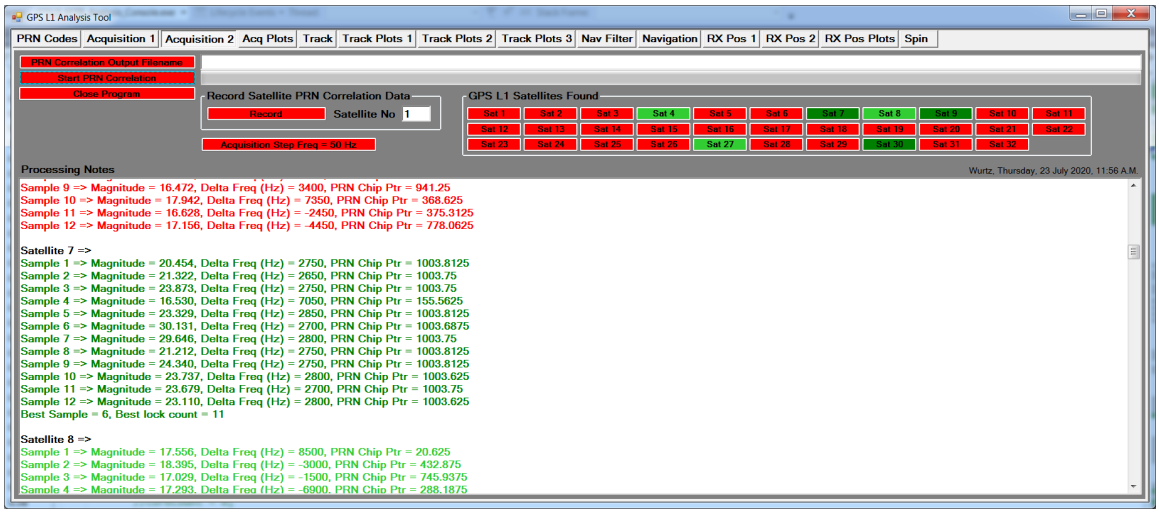


Figure 1. Acquired satellites

Figure 2. GPS satellite positions during recording from https://hilltopviews.org.uk

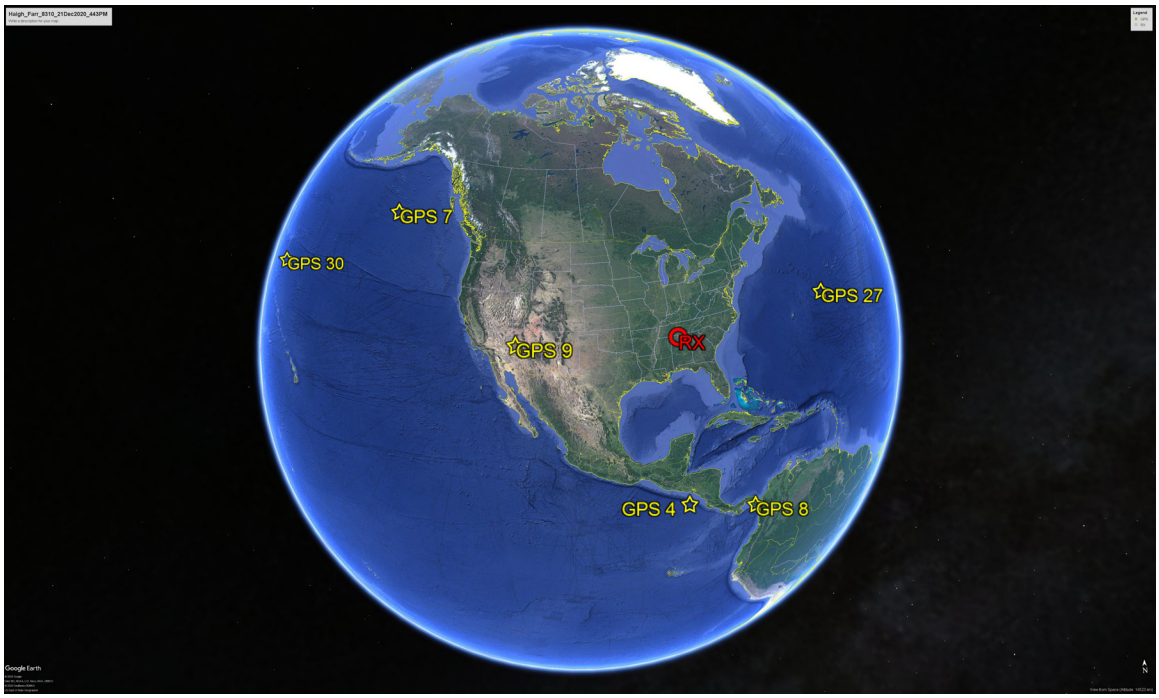


Figure 3. Satellite positions generated from recorded IF data

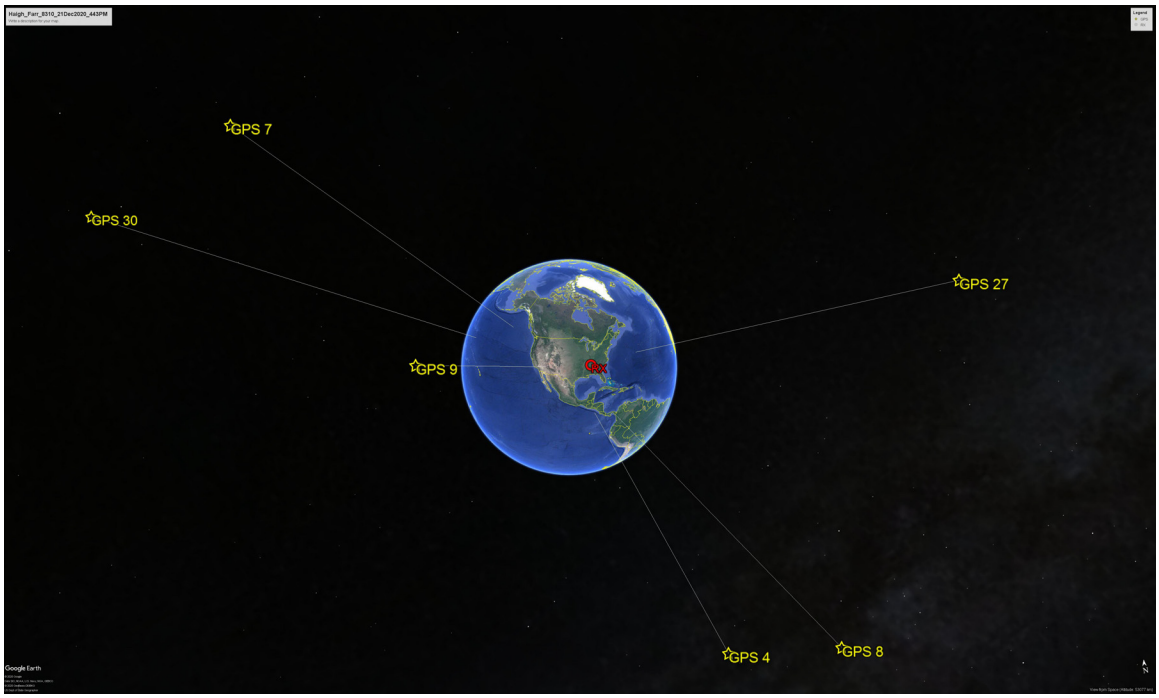


Figure 4. Acquired satellites relative to Earth generated from recorded IF data

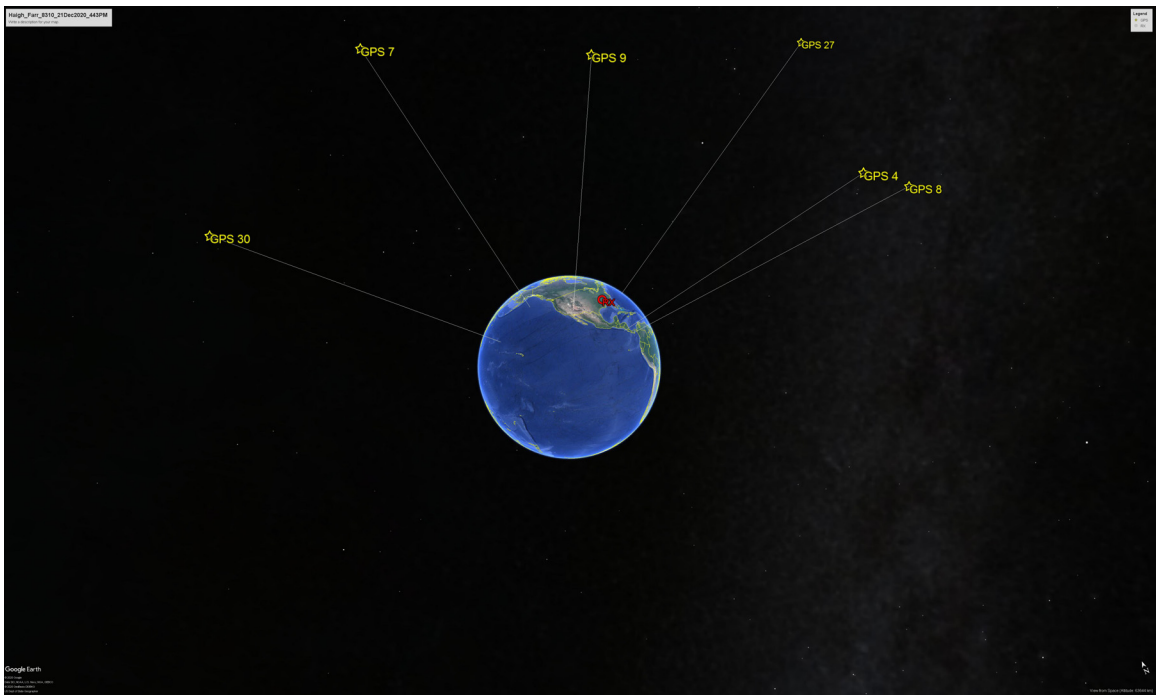


Figure 5. Acquired satellites relative to Earth showing better radial view generated from recorded IF data

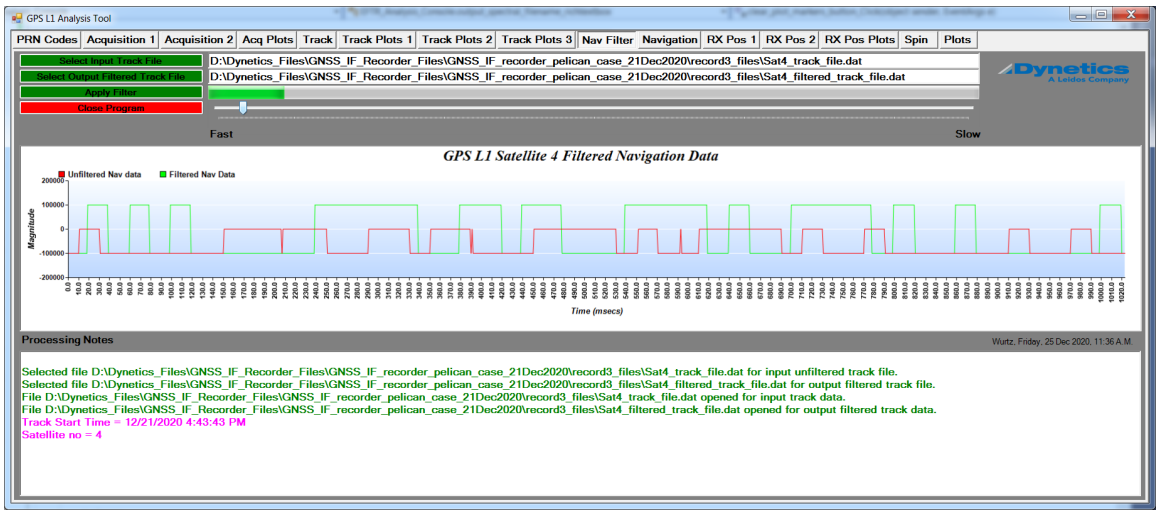


Figure 6. Navigation data low-pass filter function to reduce the effects of noise

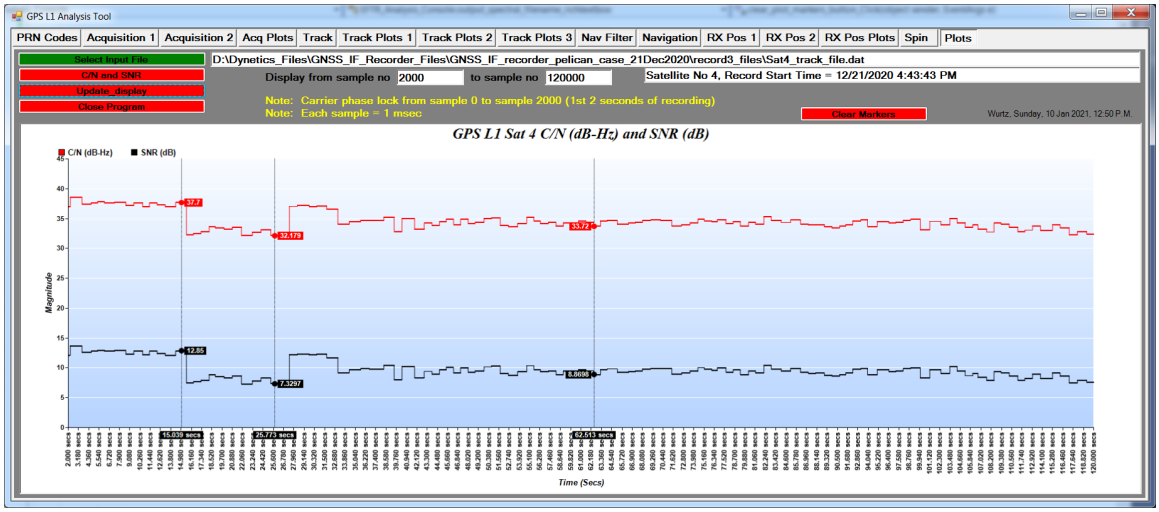


Figure 7. GPS Satellite 4 C/N (dB-Hz) and SNR (dB)

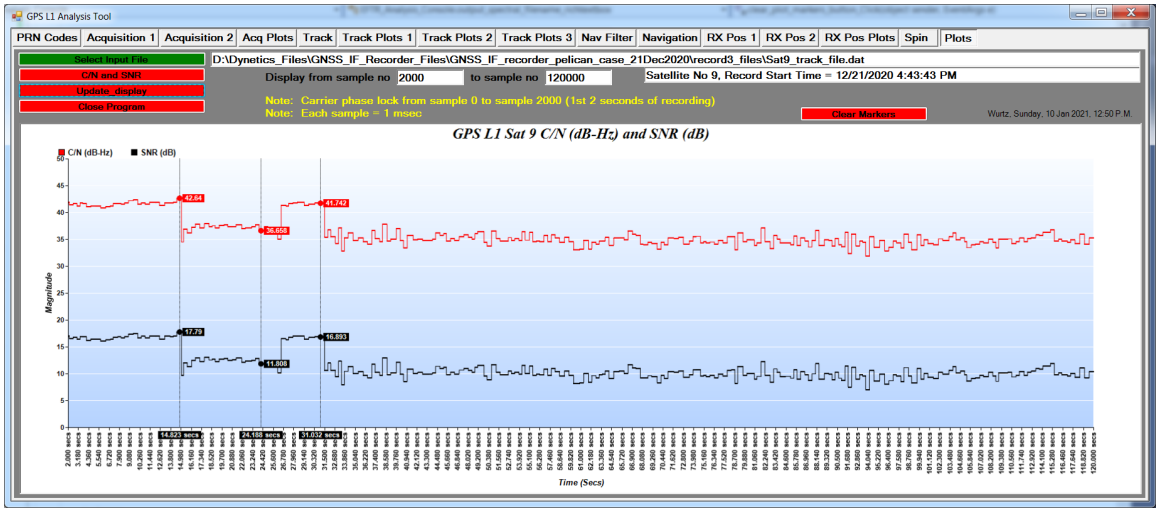


Figure 8. GPS Satellite 9 C/N (dB-Hz) and SNR (dB)

The primary purpose of the Haigh-Farr antenna setup with a rotational assembly was to determine performance as the antenna is rotated.

Figure 9 shows a feature of the software suite to recover antenna spin information from the antenna's radiation pattern. Between the markers is the radiation pattern from the antenna for one complete revolution. The software updates the rotation information with each complete rotation. Accordingly, a spin rate of 1 Hz has spin information reported every 1 second. A spin rate of 20 Hz has spin information updated every 50 msecs. Figure 10 shows the spin profile from satellite 7 track data from 2 seconds to 2 minutes.

The test setup has a fixed position with varied rotation; accordingly, relative position error is reported. Figures 11, 12, and 13 show the position error along the X-axis, Y-axis, and Z-axis to be +/- 0.8 inches, +/- 2.5 inches, and +/- 2.5 inches, respectively.

For the modulation enthusiast, Figure 14 shows an IQ scatter plot from Satellite 4 from 2 to 17 seconds record time. Figure 15 shows the IQ scatter plot from satellite 7. As expected, GPS L1 follows a BPSK modulation format. The signal strength of satellite 7 is stronger than satellite 4 since the associated IQ scatter concentrations are further from the I-axis zero point. C/N is derived as a ratio of the IQ scatter plot mean square over variance.

The following features will be added to the software suite over the next couple of weeks:

1. Reporting of velocity and acceleration error with a moving receiver.
2. Enhanced track modifications to report all performance metrics from time 0 (missile launch) with no delay due to satellite acquisition and track lock times.

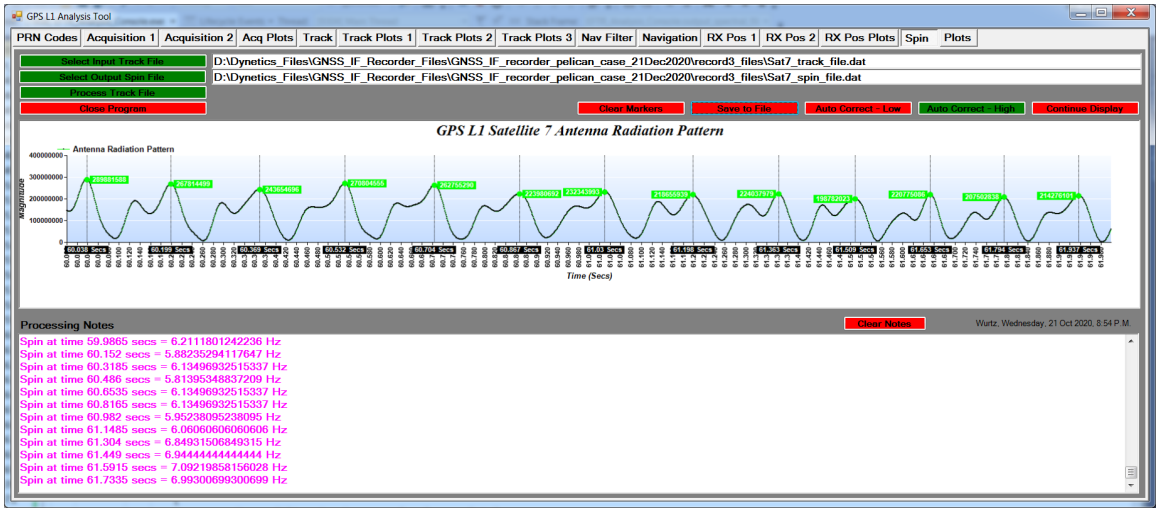


Figure 9. Recovery of spin rate from antenna radiation pattern

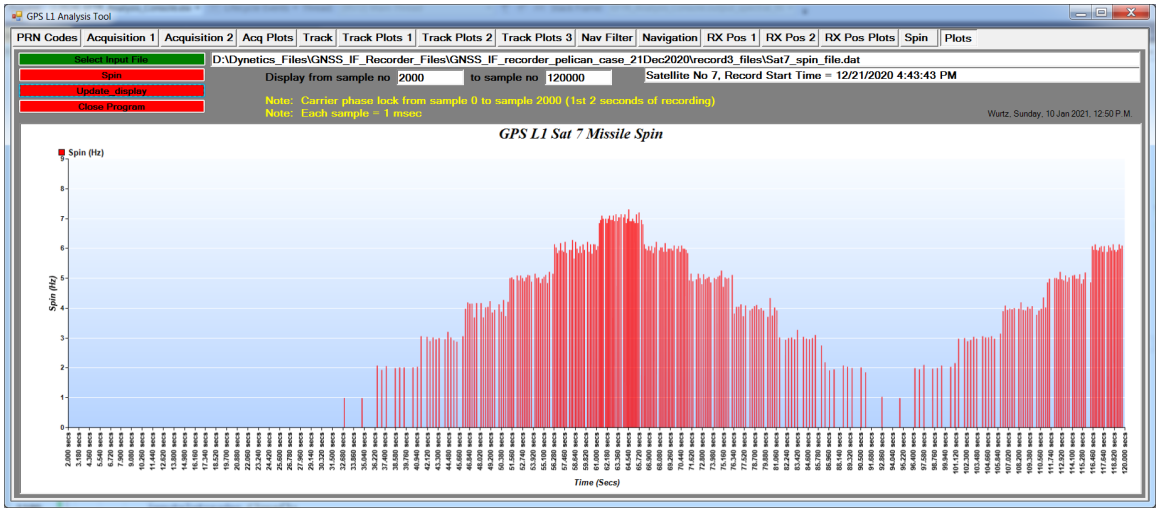


Figure 10. Spin profile from satellite 7 track data for 2 minutes record time

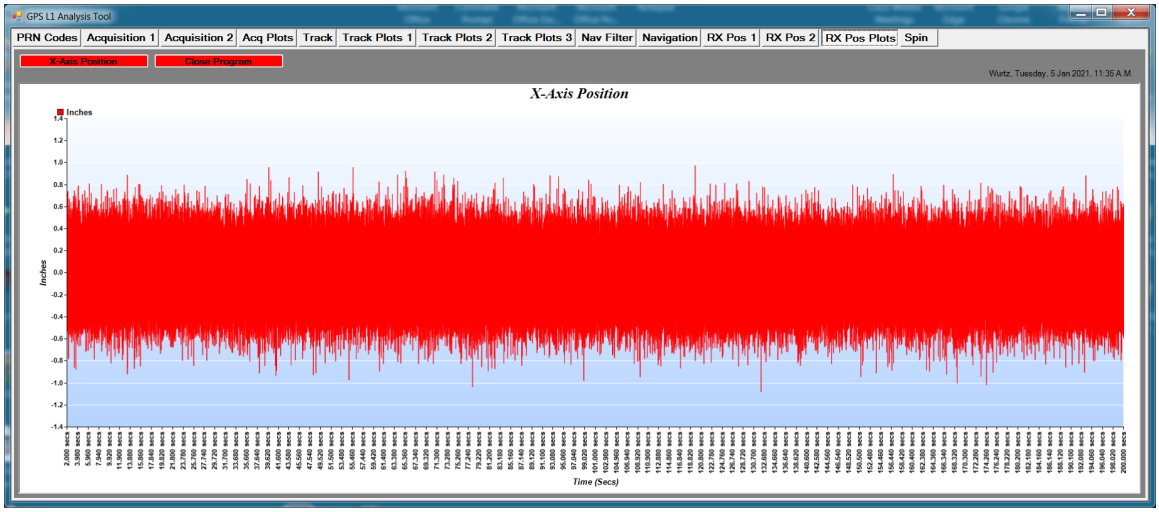


Figure 11. X-axis position error for 2 minutes record time

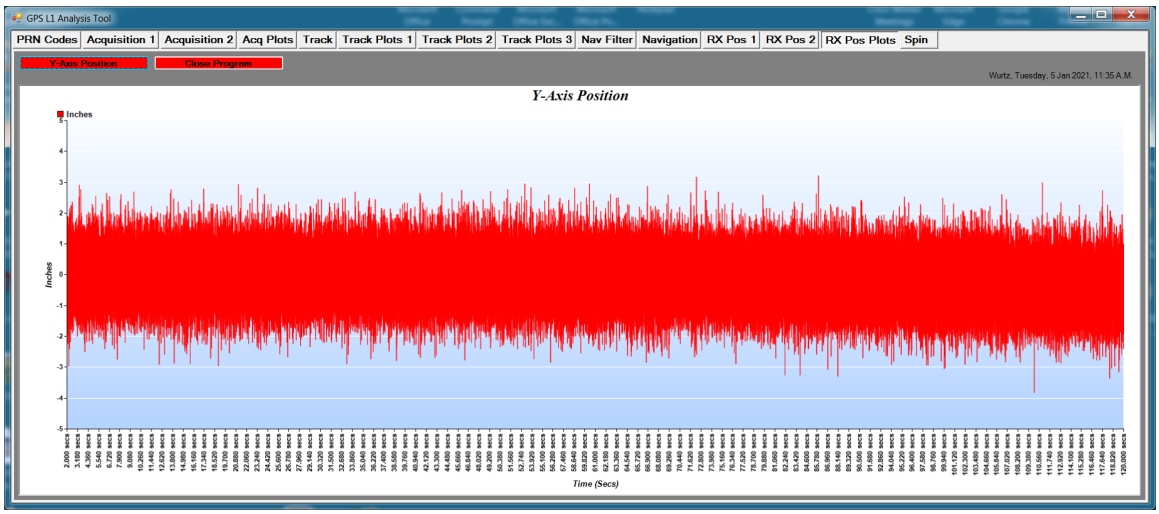


Figure 12. Y-axis position error to 2 minutes record time

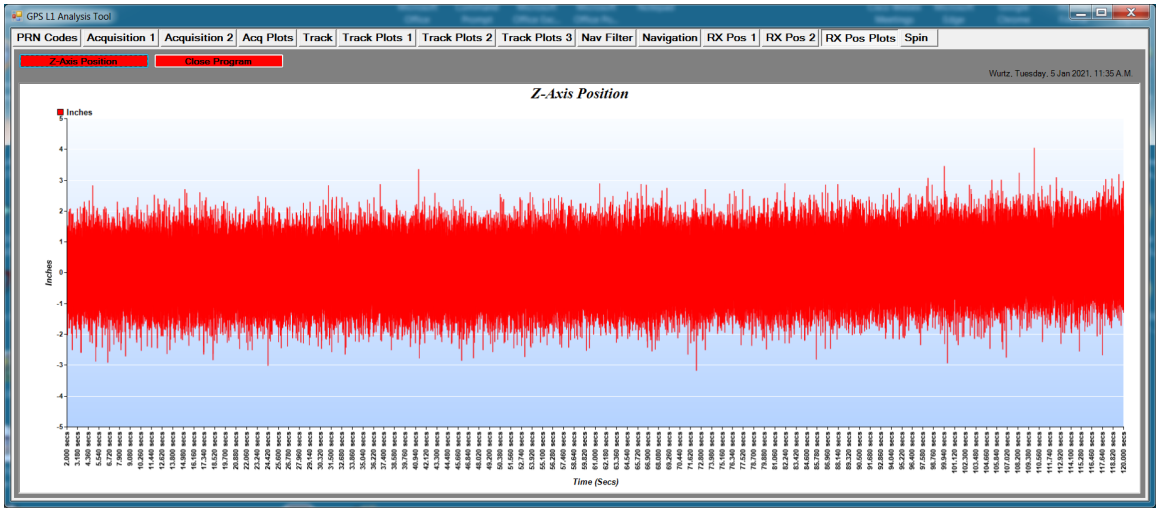


Figure 13. Z-axis position error to 2 minutes record time

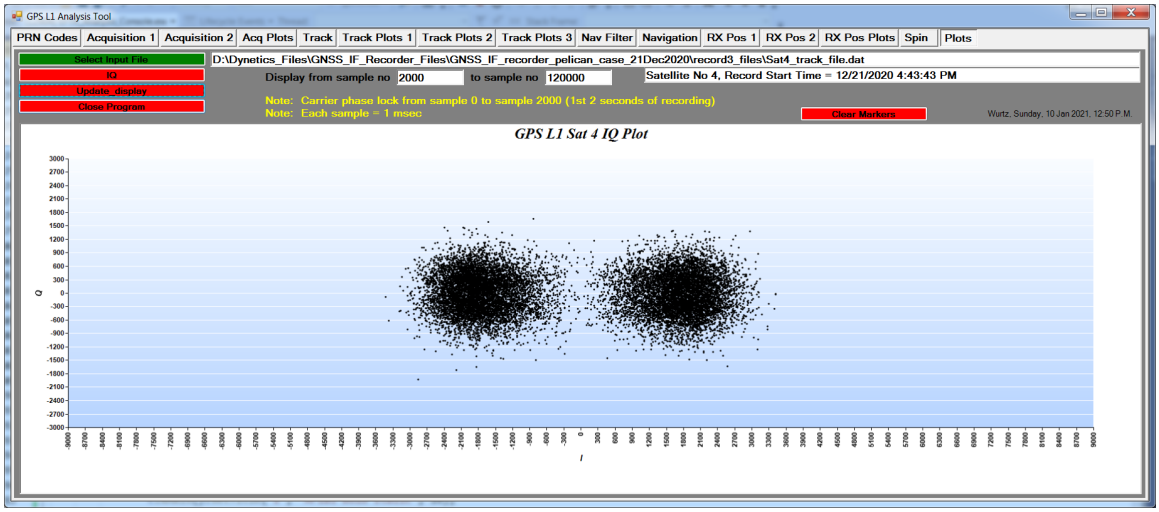


Figure 14. Satellite 4 IQ scatter plot from 2 to 17 seconds record time

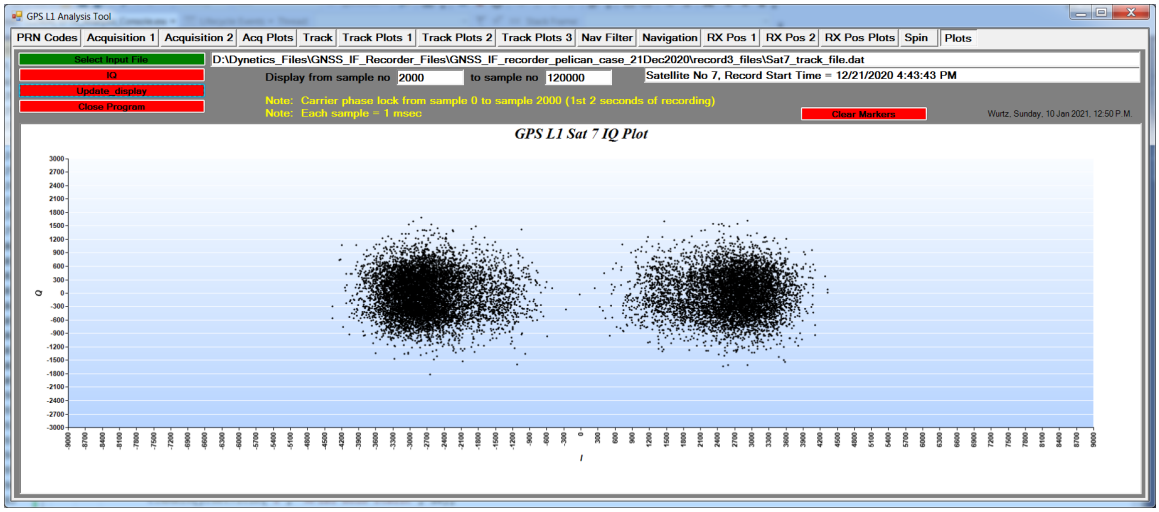


Figure 15. Satellite 7 IQ scatter plot from 2 to 17 seconds record time