First Signal in Space Analysis of GLONASS K-1

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BIOGRAPHY

Steffen Thoelert received his diploma degree in Electrical Engineering with fields of expertise in high-frequency engineering and communications at the University of Magdeburg in 2002. The next four years he worked on the development of passive radar systems at the Microwaves and Radar Institute at the German Aerospace Centre (DLR). In 2006 he changed to the Department of Navigation at German Aerospace Centre (DLR), Institute of Communications and Navigation. Now he is working within the topics of calibration, civil security and automation of technical processes.

Stefan Erker received his diploma degree in Communication Technology at the Technical University of Kaiserslautern, Germany in 2007. In the same year he joined the Institute of Communications and Navigation of the German Aerospace Center (DLR) at Oberpfaffenhofen. He mainly works on the topics of GNSS verification and corresponding signal analysis

Johann Furthner received his diploma degree in Physics with fields of expertise of laser physics at the University of Regensburg in 1990. In 1994 he finalized his Ph.D. work in laser physics at the University of Regensburg. Since 1995 he is scientific staff at the Institute of High Frequency, since 2000 of the Institute of Communication and Navigation, both at German Aerospace Centre (DLR). In 2008 he stayed half year at ESA/ESTEC in the Galileo Project Team as Navigation Performance Engineer. Johann Furthner is working since 1995 on the development of navigation systems in a number of areas (systems simulation, timing aspects, GNSS analysis, signal verification, calibration processes).

Michael Meurer received the diploma in Electrical Engineering and the Ph.D. degree from the University of Kaiserslautern, Germany. After graduation, he joined the Research Group for Radio Communications at the Technical University of Kaiserslautern, Germany, as a senior key researcher, where he was involved in various international and national projects in the field of communications and navigation both as project coordinator and as technical contributor. Since 2005 he has been an Associate Professor (PD) at the same university. Additionally, Dr. Meurer joined the German Aerospace Centre (DLR), Institute of Communications and Navigation in 2006. Since June 2008 he is the director of the Department of Navigation.

Grace Xingxin Gao is a research associate in the GPS Lab at Stanford University. She received a B.S. in Mechanical Engineering in 2001 and her M.S. in Electrical Engineering in 2003, at Tsinghua University, Beijing, China. Her current research interests include GNSS signals, GNSS receiver architectures, and interference mitigation.

Liang Heng is a Ph.D. candidate under the guidance of Professor Per Enge in the Department of Electrical Engineering at Stanford University. He received his B.S. and M.S. degrees in electrical engineering from Tsinghua University, Beijing, China. His current research interests include GNSS integrity and modernization.

Todd Walter is a Senior Research Engineer in the Department of Aeronautics and Astronautics at Stanford University. Dr. Walter received his PhD. in 1993 from Stanford and is currently developing WAAS integrity algorithms and analyzing the availability of the WAAS signal. He is a fellow of the ION.

Per Enge is a professor of aeronautics and astronautics at Stanford University, where he is the Kleiner-Perkins, Mayfield, Sequoia Capital Professor in the School of Engineering. He directs the GPS Research Laboratory, which develops satellite navigation systems based on the Global Positioning System (GPS). He has been involved in the development of Federal Aviation Administration's GPS Wide Area Augmentation System (WAAS) and

Local Area Augmentation System (LAAS) for the FAA. Enge has received the Kepler, Thurlow, and Burka Awards from the Institute of Navigation. He received his Ph.D. from the University of Illinois.

ABSTRACT

Russia's global navigation satellite system starts the upgrade to a new level. The first GLONASS space vehicle with a CDMA coded signal was launched in February 2011.
The article gives a short overview about all transmitted GLONASS-K1 signals. The main focus of this article is the new GLONASS CDMA signal L3. The signal quality is assessed by analysing the purity and symmetry of the spectrum. The modulation quality and possible distortions are analyzed with the help of scatter plot and analysis of the time domain signal. In a final step the primary and secondary Pseudo-Random-Noise Code of GLONASS-K1 L3 signal are retrieved out of the sampled signal itself and compared to the theoretical expected code. Finally tracking results of the GLONASS-K1 L3 signals by using a software receiver are presented.

INTRODUCTION

On 26th February the Russian Space Forces launched the first satellite of the new GLONASS-K generation. With this new satellite the Russian system is able to provide for the first time a CDMA signal in addition to the traditional FDMA signals to the users. This upcoming CDMA signal is located at the L3 frequency band with the center frequency at 1202.025 MHz and will be used for test purposes only. As future steps Russia plans to implement further CDMA signals at L1, L2 and later L5 frequencies at their navigation satellites to achieve compatibility and interoperability to GPS and Galileo[1][4].
To verify the new signal of the GLONASS-K1 satellite the signals were recorded independently from the Institute of Communications and Navigation of the German Aerospace Center (DLR) and the Stanford University in the United States. DLR used a 25m high gain antenna at Raisting, Germany. This high gain antenna allows a very precise and detailed analysis of the navigation signals since the signal is raised high above the noise floor. Doing so a wide range of the signal analysis can be performed allowing to characterize signal power, spectra, signal IQ constellation, sample analysis, correlation functions etc [3]. The Stanford team used their GNSS Monitoring System (SGMS) for recording and analyzing signals of the new GLONASS-K1 satellite. The SGMS includes a 1.8m steerable parabolic dish antenna that delivers 25dB gain in the L-band.

Figure 1 Site at Raisting with Radom of the 25m Antenna (left)

MEASUREMENT CAMPAIGN

With the help of the high gain antenna several complete GLONASS-K1 passes were recorded and analyzed. The 25m dish at Raisting amplifies the signals from space with approximately 47dB in the L-band. Two low noise amplifiers (LNA) provide around 70dB gain in the receiving chain of the installed setup. In addition a broadband filter is used preventing the saturation of the first LNA by out-of-band interference. The amplified signal is digitized using a state-of-the-art vector signal analyzer.
Results of the GLONASS-K1 path over Europe during the night of May 5th are presented. During this path the space vehicle was observed with a maximum elevation angle of 84 degree. The measurements at this time showed that GLONASS-K1 transmitted navigation signals on three different frequencies.
The traditional FDMA signals L1 and L2 have a center frequency of 1599.1875 MHz and 1243.812 MHz, whereas the new L3 CDMA signal is centered at 1202.025 MHz. In Figure 2, Figure 3 and Figure 4 the derived spectra are depicted.

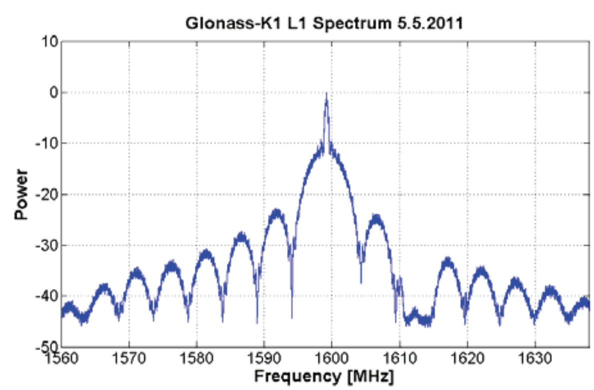

Figure 2 Normalized spectrum of GLONASS-K1 L1 signal recorded at maximum elevation at 05-05-2011

The L1 and L2 signal show the typical shape of the classical GLONASS FDMA signals. In the L1 spectra the signal suppression at the important radio astronomical band for measurements of the characteristic OH-line (1610.6 – 1613.8 MHz) from stellar sources is clearly visible.

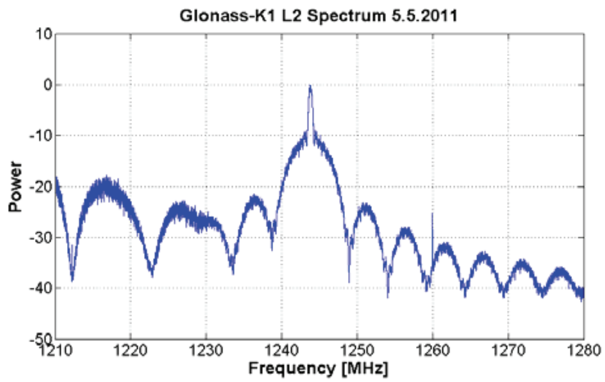

Figure 3 Normalized spectrum of GLONASS-K1 L2 signal recorded at maximum elevation at 05-05-2011

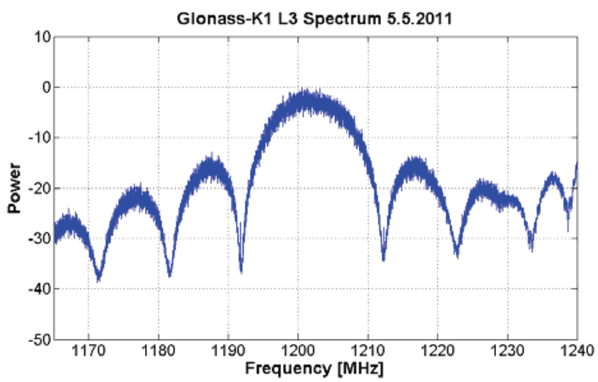

Figure 4 Normalized spectrum of GLONASS-K1 L3 signal recorded at maximum elevation at 05-05-2011

Figure 3 and Figure 4 illustrate how close the L2 and L3 signals are in the frequency band (overlapping side-lobes, clearly visible at around 1230MHz).

ANALYSIS OF THE NEW GLONASS L3 SIGNAL

The major milestone of the GLONASS K1 satellite is the new L3 CDMA signal. In this chapter the CDMA signal is analyzed based on measurements gathered by described DLR and Stanford facilities.

According to [1] the new L3 CDMA signal can be characterized by the scheme of Figure 7. The signal has a chip rate of 10.23 MChips and is modulated using quadrature-phase-shift-keying (QPSK) modulation. The signal contains a pilot signal on the in-phase (I) and a data signal on the quadrature-phase (Q) component.

After removing the Doppler offsets of the complex signal I and Q components are separated and analyzed in detailed. For an initial assessment of the L3 modulation quality the scatter plot is plotted and shows the IQ signal constellation diagram. Figure 5 shows that I and Q components are clearly separated. The four possible states are clearly visible and the transitions between the states show that pilot and data channel use the same chip rate. A minor expansion and distortion of I and Q states is visible which might be related to band limitations and saturation effects of K1´s RF components.

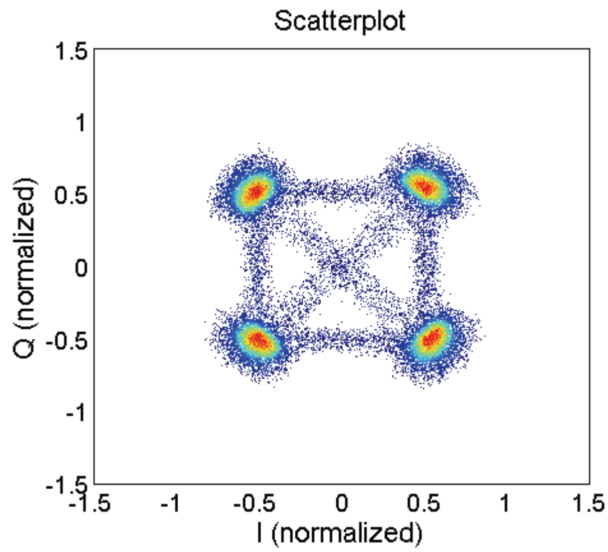

Figure 5 Scatter plot of GLONASS-K1 L3 showing the IQ signal constellation histogram

Since the received signal is raised high above the noise floor using a high gain antenna the transitions of the individual code chips can be clearly observed and precise code analysis is possible by analyses in the time domain. In the results of Figure 6 a degradation of the amplitude level for the pilot and data channel during code chips having the same state can be observed. Further investigations on this effect are ongoing.

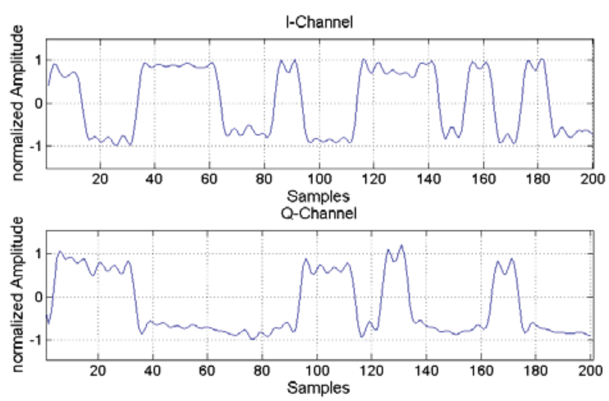

Figure 6 Time samples of I and Q channel of GLONASS-K1 L3

For a detailed code analysis a synthetic replica of the GLONASS-K1 pseudo random sequences (PRS-P Initial State n= 30 for the I channel and PRS-D Initial State n=62 for Q channel) is generated and correlated with the recorded satellite signal with an implementation of the GLONASS L3 code generator shown in Figure 7. The GLONASS L3 ranging codes base upon truncated Kasami sequences with a length of 2^{14}-1 symbols. The used codes are truncated after 10,230 symbols. The duration of one navigation symbol is 10 code chips which equals 10 milliseconds. Both signals have an overlaid secondary code, the data channel a 5-bit Barker code (BC=00010) and the pilot signal a 10-bit Neuman-Hoffman code (NH=0000110101). The symbol rate of both secondary codes is 1ms per code symbol.

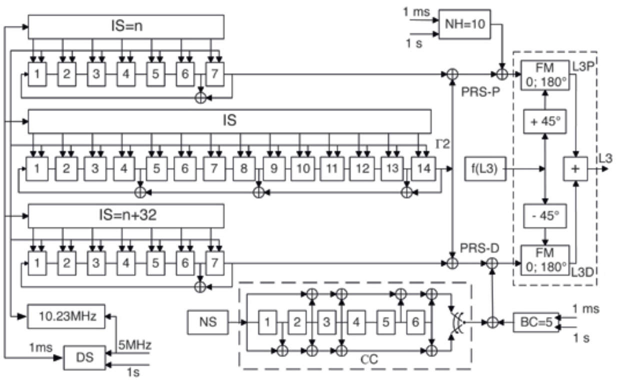

Figure 7 Scheme of GLONASS-K1 L3 CDMA signal generation according to [1];
Abbreviations: BC=Barker Code, CC=Convolutional Code, NH=Neuman-Hoffman Code, NS=Navigation message symbol, IS=Initial State

In Figure 8 a snapshot of 100ms of the GLONASS L3 data channel is correlated with a short segment of 5000 samples (approx. 48µs) of the synthetic code. The code rate of the signal can be determined by correlation peaks every 1ms. The rate and the change of the polarity of the correlation peaks verify the repetition rate of 5ms for the secondary code (Barker Code).

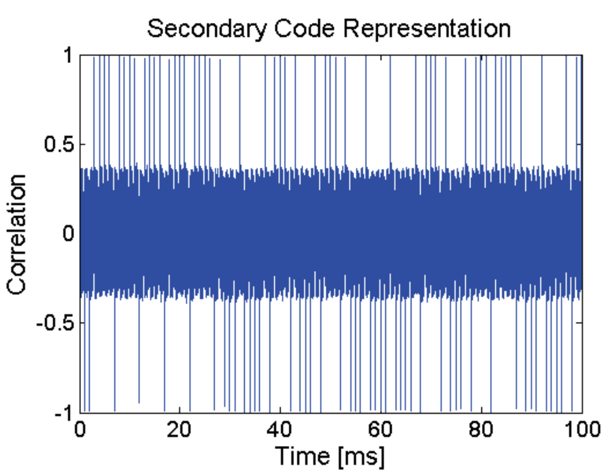

Figure 8 Secondary code at the data channel (IS n=62)

The used pseudo random sequences for both channels are verified by the comparison of the synthetic generated codes with the received signals.
In Figure 9 short segments of the recorded pilot and data signal are overlaid with the corresponding theoretical expected code. The comparison illustrates that both signals are inline with respect to the pseudo random sequences based on the Initial State n=30, respectively n= 62.

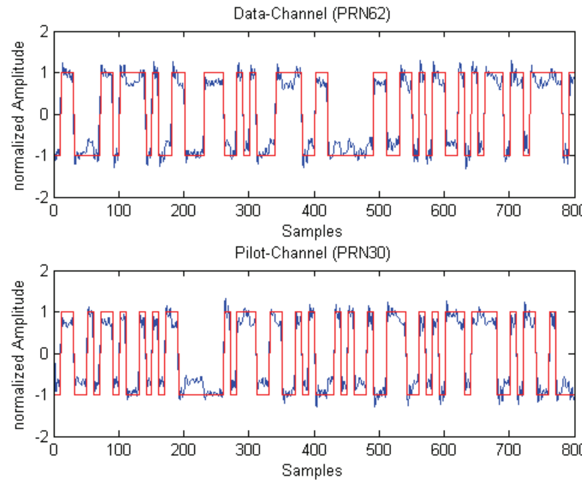

Figure 9 Time Sample Snapshots for data and pilot channel overlaid with ideal code

For further code analyses the shape of the correlation function retrieved by the cross correlation of the received data channel signal and the ideal code sequence is studied, (see Figure 10). By this results one gets a first coarse impression if signal deformations exist, which could effect tracking accuracy and performance of GLONASS CDMA receivers. The normalized correlation peak shows a typical symmetric shape. Detailed analyses of tracking performance are realized using a software receiver (see Chapter 4).

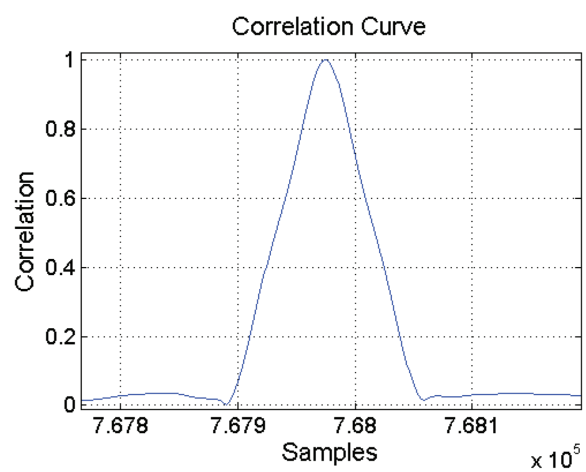

Figure 10 Exemplary correlation function – cross correlation of theoretical code with samples of data channel

TRACKING RESULTS

For analysing the tracking performance in detail the Stanford GNSS Software Receiver [2] is used. The processed GLONASS L3 data was recorded at 22:10 PDT on 13.04.2011 (14.04.2011 05:10 UTC) using a Trimble

Zephyr geodetic antenna and an Agilent 89600 VSA with a sampling frequency 47.5 MHz. Figure 11 and Figure 12 show the tracking results of the pilot channel and the data channel, respectively. The GNSS software receiver has two working phases. In the first 750 ms, the software receiver is in a transient state of achieving frequency/ carrier-phase/code-phase synchronization and data bit alignment. From 750 ms, the software receiver enters a steady state of coherent code-phase tracking and data bit demodulation. The steady state also features longer integration period and narrower tracking loop to suppress noise.

Each of Figure 11 and Figure 12 includes eight subplots showing the decoded navigation data bits, scatter plot, correlator output power (blue – early gate, red – late gate, green – prompt gate, all in a linear scale), Doppler frequency, code-phase, and smoothed C/N0. In the navigation data plot, the red curve shows the normalized I output and the blue curve shows the decided data bits. Please note that the decided data bits before 750 ms may be incorrect because the carrier-phase synchronization and bit alignment has not been fully achieved yet. In the scatter plot, I and Q outputs in the transient state and the steady state are in light blue and dark blue, respectively. In the code-phase plot, an upward curve implies that the pseudo range was increasing.

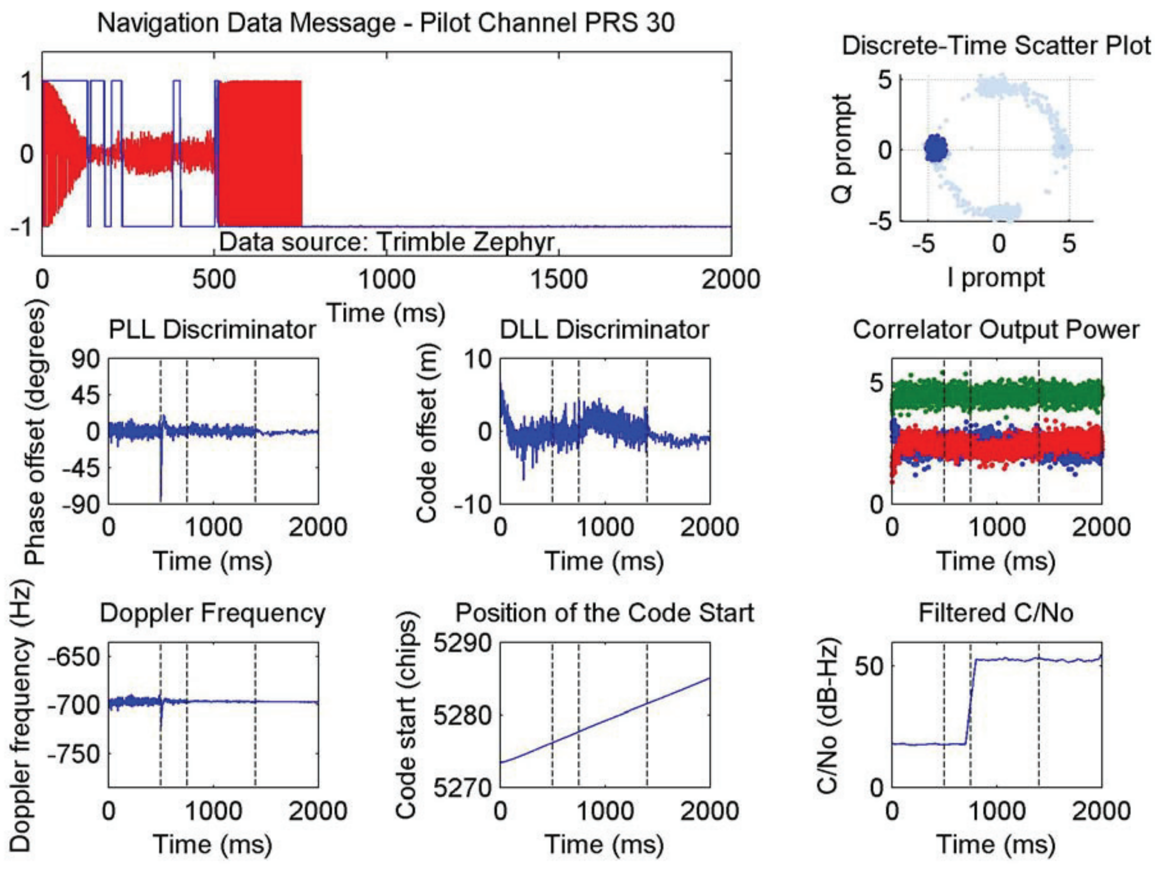

Figure 11 Tracking results of GLONASS-K1, L3 pilot channel, 2011-04-13 22:10 PDT (14.04.2011 05:10 UTC)

Figure 11 and Figure 12 demonstrate that the PLL and DLL tracking loops both converge, and the navigation data can be demodulated. The success of acquisition, tracking, and demodulation gives an agreement with results in chapter 3 which is again a verification for the signal specification (the primary code polynomials and the secondary codes) given in [1].

Another interesting observation is that the C/N0 of the data channel is always 0.5 ~ 1.5 dB higher than the pilot channel, which is not directly visible from the IQ signal constellation and time domain diagram in chapter 3. This indicates that the C/N0 difference between both channels can be related to different correlation losses of I and Q channel. The described degradation of the signal amplitude level in the time domain might be a reason for this observation.

Besides, the transmitting power of GLONASS-K1 on L3 is approximately 5 dB higher than GPS IIF-1 on L5 at a similar elevation.

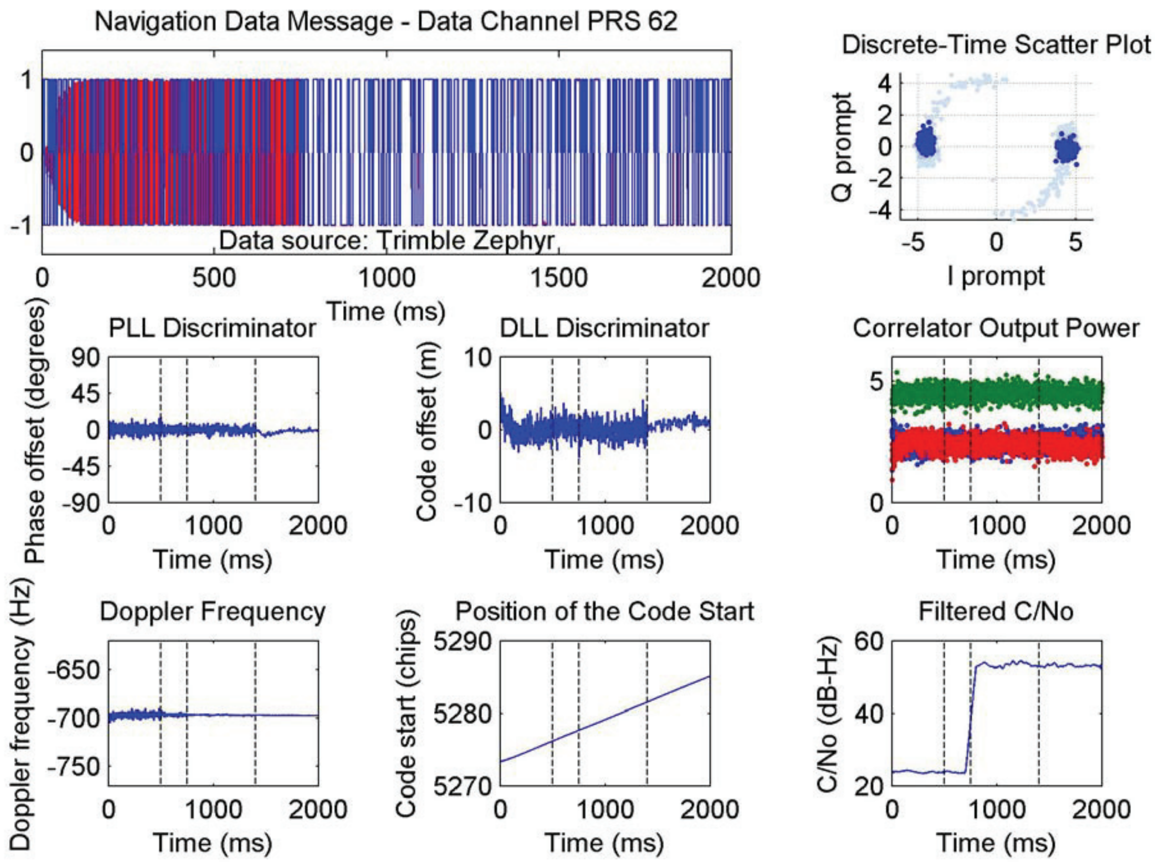

Figure 12 Tracking results of GLONASS-K1, L3 data channel, 2011-04-13 22:10 PDT (14.04.2011 05:10 UTC)

SUMMARY & OUTLOOK

The paper documents an initial measurement and analysis campaign for characterizing the signals transmitted by the first satellite of the new GLONASS K satellite generation. A special emphasis is given to the new L3 CDMA signal. The presented results allow an early assessment of the quality and the potential of the CDMA signal.

In general, the first results are in well agreement with the expected signal already published in literature [1], i.e. spectral shape, chip rates, primary and secondary codes and code rates etc. match with [1]. However, minor imperfections and deviations between the analysis results and the expected signal have been identified including especially sporadic analogue signal deformations. Such effects may trace back to imperfections, frequency-selectivity and non-linear saturation effects in the satellite RF transmission chain and need further research for clarification. Overall, the good performance of the new signal was proven using a GNSS software receiver for signal tracking. Some indications to imbalances between data and pilot channel were obtained which may also trace back to the aforementioned signal deformations.

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