Co-locations of Space Geodetic Techniques on Ground and in Space

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Abstract Systematic error sources are of great concern in space geodesy. Subtle in nature, they are currently limiting the performance of all the major techniques—GNSS, VLBI, and SLR. Co-locations of these techniques on fundamental stations provide the chance to identify such systematic errors. In order to provide a better tie between GNSS, SLR, and VLBI, we have designed and implemented a fully calibrated receiver unit that allows GNSS observations with the 20-m Radio Telescope Wettzell (RTW). The Wettzell 20-m antenna is equipped with S- and X-band receivers, which cannot be used for receiving the GNSS L1 signal without significant changes. We are reporting the design and construction of the new receiving chain and enabling observation of the GNSS L1 signal together with the required changes in the NASA Field System using the satellite tracking module. The receiver was installed in the 20-m RTW, and the first common observation with Onsala Space Observatory was performed. Finally, we give a rough estimation of the expected signal strength and also outline suitable observation scenarios.

Keywords GNSS, VLBI, co-locations, L1 receiver

1 Introduction

All the major measurement techniques of space geodesy are characterized by a very high measurement sensitivity, which resolves the measured quantities, such as the range to satellites or signal delays from quasar sources between radio telescopes to about one part in 10^9. While all the different observing stations have impressive precision, the accuracy still carries biases well in excess of estimated measurement precision.

Within each of the techniques, these errors are minimized by a non-linear data fitting process. Fundamental stations on the other side are important, because they provide a link from one measurement technique to the other. However, this is also the link where discrepancies between precision and accuracy become evident. There are several co-location strategies between GNSS, SLR, and VLBI. One possibility is to observe GNSS satellites with all relevant techniques at the same time. Unfortunately, until now there has been no real chance to observe GNSS satellites at the Geodetic Observatory in Wettzell, because the 20-m RTW is equipped only with an IVS-compatible S/X receiver. But the previous work at Onsala and Medicina [2, 3] was a driving motivation to make required upgrades of the Wettzell S/X receiver chain.

2 Wettzell 20-m S/X Receiver

The Wettzell 20-m Radio Telescope is equipped with a classical IVS-compatible S/X receiver. However, the GNSS signals are well below the lowest S-band frequency. In order to receive GNSS signals using this in-

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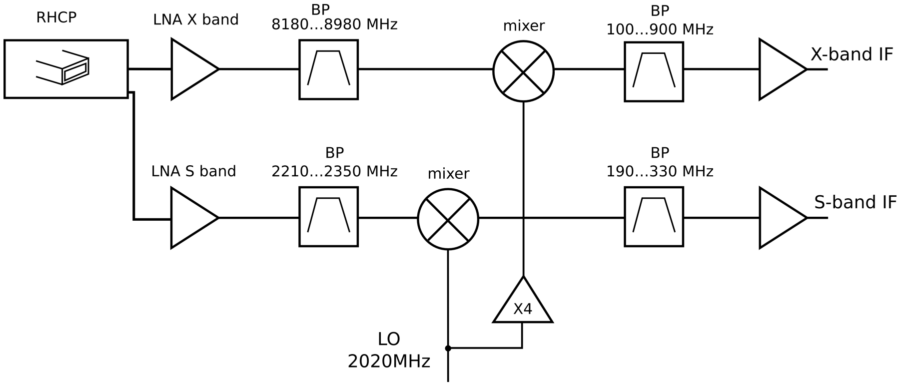

Fig. 1 Simplified block diagram of the Wettzell 20-m S/X receiver.

strument, it is necessary to revise the frequency passband and to adjust the signal levels. The GPS L1 signal is transmitted at a frequency of 1575.42 MHz, and GLONASS satellites transmit L1 signals in the band of 1592–1609 MHz, while each satellite transmits at a different frequency. According to the specification, the received RF signal level at the output of a 3 dBi linearly polarized antenna is not less than -160 dBW for GPS C/A code and -161 dBW for GLONASS in the L1 sub-band[1]. The maximum differential power level from different satellites is affected by the distance of the satellites. The shortest distance is at zenith and the longest distance to the satellite is at the horizon. Because the power level is inversely proportional to the distance square, the difference in power level can be written as

$$\Delta = 10log_{10}\left(\frac{R^2_{zenith}}{R^2_{horizon}}\right) , \qquad (1)$$

where R_{zenith} is the distance to the satellite at zenith and $R_{horizon}$ is the distance to the satellite at the horizon. Using the above equation, one obtains a maximum differential power level of ~ 2 dB for GPS and of ~ 3 dB for GLONASS [1].

Reviewing the Wettzell 20-m S/X Receiver, which is shown in Figure 1, one can divide the receiving chain into three main parts. At first the signal passes through the antenna dish with the feed horn and the wave-guides. Then the signal is fed into the low noise amplifier (LNA) in the cryo-box, followed by the bandpass filters and S or X receiver mixers. The wave-guide of the X-band receiver has dimensions which do not allow the GNSS L1 signal to be received. The S-band wave-guide system uses the wave-guide type WR430 with a cut-off frequency of 1.375 GHz, so that L1 transmission is possible. For this reason we focused on the S-band receiver part[2] in order to detect the L1 GNSS signal.

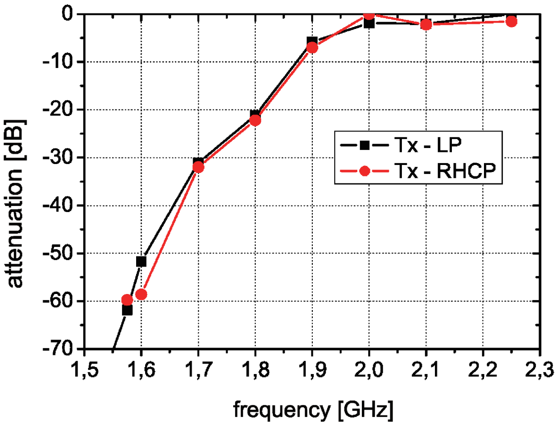

Fig. 2 Dependency of the attenuation on frequency in the S-band receiver chain.

In a first approach, we tested the antenna dish, feed horn, and microwave guides with artificially generated signals. Linear Polarization (LP) and Right Hand Circular Polarization antennas were used and were mounted in Wettzell TWIN radio telescope at a distance of 136 m. The dependency of the 20-m RTW

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[1] Expressed in Jansky: GPS ∼4900 Jy and Glonass ∼7800 Jy.

[2] It should be noted that the cut-off frequency of the 20-m RTW is 1.375 GHz, and hence L2 is outside of this pass-band.

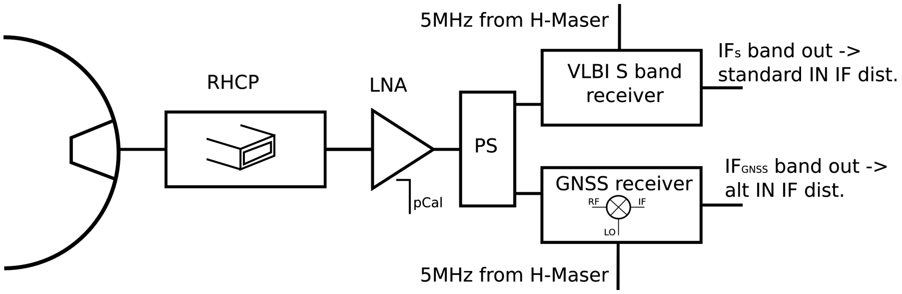

Fig. 3 The simplified diagram of the Wettzell 20-m S/X receiver upgrade.

gain on frequency is shown in Figure 2. One can see that the attenuation of the receiving chain up to the input of the LNA is 60 dB in the GNSS L1 band. On the other hand, the 20-m parabolic dish antenna has 47 dBi gain in this band. The GNSS signal power level at the input of the LNA in a bandwidth of 1 MHz[3] is

$$P_{LNAin} = P_{GNSS} + G_a - A = -144 dBm \, , \qquad (2)$$

where P_{GNSS} is the GNSS signal power level on the ground, G_a is the antenna gain and A is the attenuation. That means that the GNSS signal power is approximately 30 dB below the noise floor. This fact precludes the detection of the GNSS signal with spectrum analyzers, as would be possible with a complete L-band feed chain.

The next part in the receiver chain is the S-band LNA, which has a gain of 35 dB in S-band. In the L1 band, the gain of the LNA is slightly lower and was measured to be 33 dB. Behind the LNA there is a bandpass filter with a passband of 2210–2350 MHz, which completely blocks the L1 GNSS signal.

3 Wettzell 20-m S/X Receiver Upgrade

The previous section showed that the bottleneck of the complete receiver chain is located in the electronic section of the heterodyne receiver. In order to overcome this problem we are bypassing the main receiver by adding a power splitter behind the initial S-band LNA. One part of the signal is used for the standard S-band receiver chain, and the second part of the signal path is used for the newly developed L1-band VLBI receiver, which will be referred to as the VLBI(GNSS) receiver in the text below. The block diagram of the updated 20-m RTW S-band receiver is shown in Figure 3. Splitting the signal behind the LNA will not influence the standard VLBI observation, because the system temperature is defined mainly by the noise temperature of the LNA. In order to avoid additional losses, it is necessary to adjust the power level by changing the attenuation of the IF band. Another advantage of connecting the VLBI(GNSS) receiver behind the LNA was that the phase calibration tones are now also present in the GNSS observations.

The photograph of the receiver is presented in Figure 4. The VLBI(GNSS) hardware is installed in a metal box and comprises a classical heterodyne receiver. The local oscillator can be locked to the 5 or 10 MHz reference frequency[4]. We are using a VBF-1575 image filter with a pass-band of 1530–1620 MHz, which defines the receiver bandwidth. Behind the passive mixer (MiniCircuits ZX05-C42), an IF band filter BFP-A410 is inserted. In order to compensate for cable losses of the cable guiding the IF band signal from the 20-m RTW antenna to the VLBI control room, the overall gain of the receiver was set to 71 dB.

4 The First Experimental Results

The VLBI(GNSS) receiver was tested in several experiments. The biggest obstacle is that the GNSS signal is well below the noise floor; therefore, a standard spectrum analyzer cannot be used to check whether the VLBI antenna is detecting the satellite or not.

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[3] Valid for GLONASS.

[4] The SNM-H201 low phase noise programmable frequency synthesizer from Serenum, a.s. was used. The programmable synthesizer has a custom firmware version allowing it to generate frequencies up to 2.2 GHz.

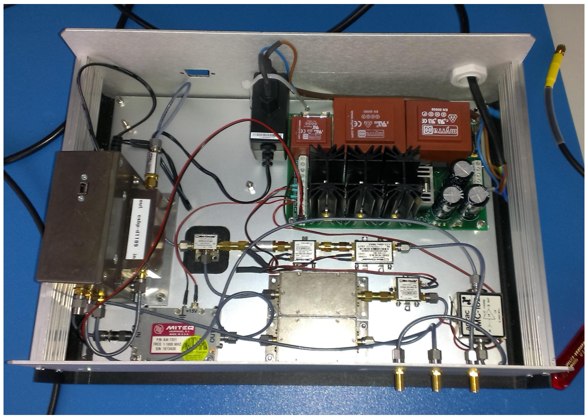

Fig. 4 Photograph of the VLBI(GNSS) receiver suitable for the split S-band receiver channel of the RTW.

For the first acquisition test, we have used a standard GNSS antenna in connection with VLBI(GNSS) receiver. The data was stored for the correlation process, using the MIT Mark 5A/B recording systems. In Matlab, we have developed correlation software which implements a parallel code phase search algorithm of the GPS and the GLONASS signals[5]. The sensitivity of the search algorithm is improved by coherent and non-coherent integration. Once this test was successfully completed, we installed the receiver in the 20-m RTW. Using the Vienna VLBI Software (VieVS) and an additional implementation allowing the scheduling of satellite targets, we were able to create schedules for the observation of satellites with different telescopes. With an additional program extension of the NASA Field System, it was possible to track the GNSS satellites successfully in a continuous way. For more details please refer to [4].

Based on the described sessions, we have demonstrated that we are able to adequately receive the GNSS L1 signal. Therefore, we have organized a series of common observations of GLONASS signals together with the Onsala Space Observatory. The first common observation, Wettzell—Onsala, was recorded in January 2013 (G130128), and the details of the experiment were reported in [5]. At this time the first observation schedules were provided and correlation was performed by the Joint Institute for VLBI in Europe (JIVE). The latest progress in VLBI satellite observing was made in January 2014. During several observation days, the (VieVS) satellite tracking capability and the entire system settings were optimized. The fact that we could look at the observed signal by using our Matlab search algorithm almost in real-time played one major role for the optimization process for the Wettzell station. Figure 5 shows an example of GNSS data analysis for a data set of GLONASS 735 made with the Matlab search algorithm. One can obtain the carrier-to-noise ratio and account for the system noise temperature. Considering the GNSS signal power level, we were able to confirm the calculated signal transmission of the receiving chain. The observed attenuation resulted in $-62dB$, which is in a good agreement with the earlier measurements using an artificial signal from a signal generator.

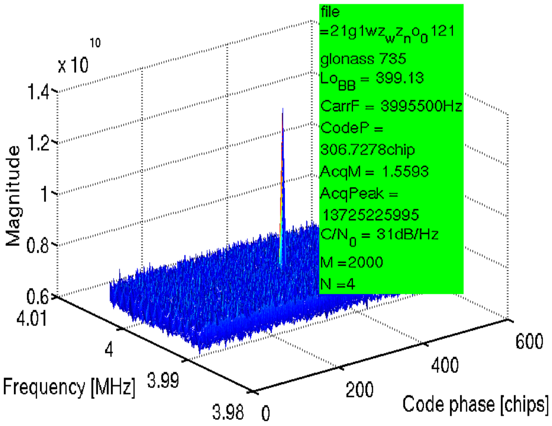

Fig. 5 The obtained GNSS signal data acquisition extracted by a Matlab script.

5 Conclusions

The Global Geodetic Observing System (GGOS) requires both a reduction in measurement errors and a considerable reduction of systematic errors within the measurement techniques of space geodesy. Co-locations of these techniques on fundamental core stations provide the chance to identify such systematic errors. One of the possible ways to tie GNSS, SLR, and VLBI is to perform common observations of the GNSS satellites using all these space techniques.

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[5] The purpose of this proceedings paper is not to describe basic algorithms used for acquisition of the GNSS signals, in detail. For further information see [1].

We have designed and implemented a receiver unit called the VLBI(GNSS) receiver, that allows GNSS observations with the 20-m RTW in Wettzell. With that hardware we are able to overcome the problem that the 20-m RTW was only equipped with a classic S/X receiver. The functionality of the updated receiver was demonstrated in several experiments at the Wettzell Observatory and in common observations with the Onsala Space Observatory.

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