Hard- and Software Tools for the Education of Geodetic VLBI

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Abstract The Onsala Space Observatory hosts two 2.3-m radio telescopes called SALSA ("Such a lovely small antenna") which are utilized to bring front-line interactive astronomy to the classroom. Until now SALSA was used for astronomical educational purposes solely, in particular demonstrating the concept of single dish measurements. However, it is possible to combine both SALSAs to form an interferometer by making use of hardware which has been developed for software-defined radio. In doing so, one can utilize the SALSA antenna pair as a student demonstrator for geodetic Very Long Baseline Interferometry. Here is discussed which COTS hardware components are necessary to turn the SALSA installation into an interferometer. A simple Octave-based correlator has been written in order to process SALSA data. Results from a test run during which the Sun was tracked are presented and discussed here.

Keywords Software-defined radio, SALSA, education

1 SALSA

Two small 2.3-m radio telescopes named SALSA (cf. Figure 1) are hosted at the Onsala Space Observatory in Sweden. SALSA is the short form of "Such a lovely small antenna" or, in Swedish, "Sicken Attans Liten Söt Antenn". After free online registration, anyone may control one or both of these telescopes via the Internet and carry out his/her own experiments. SALSA is a part of the European Hands-On Universe project, EU-HOU, to bring front-line interactive astronomy to the classroom. Most SALSA users observe emissions from hydrogen in the spiral arms of the Milky Way, and all observations can be done via a Web browser. Considering the great success concerning education and outreach with the SALSA telescopes, it was studied whether it would be technically feasible to use the two antennas in interferometric mode in order to mimic a simplified VLBI setup.

Fig. 1 Webcam image of the two SALSA antennas at the Onsala Space Observatory, taken on February 22, 2016 at 11:00 UT (http://vale.oso.chalmers.se/salsa/webcam).

2 Turning SALSA into an Interferometer

In order to realize a simple and easy to handle VLBI demonstrator, it was decided to record RF signals with a single hardware tool. In doing so, one can combine both SALSA antennas to form a local interferometer which removes the need to deal with clock differences

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or drifts in post-processing. The USRP E310 standalone software defined radio (cf. Figure 2) was found to be a suitable solution for realizing such a concept. This small device has two independent RF front-ends

Fig. 2 Photo of the URSP E310 together with a pen for better illustration of the dimensions of the device.

with flexible mixed-signal baseband sections and integrated frequency synthesizers. Overall RF frequencies between 70 MHz and 6 GHz can be translated to complex baseband and sampled with up to 56 MHz of instantaneous bandwidth. Thus, the interferometer can be realized as depicted in Figure 3.

Fig. 3 Signal chain of the SALSA interferometer.

Digitized signals are sent over 1 GbE to an off-the-shelf PC where they are recorded on hard disk. Real-time signal processing is not implemented at the moment but can be realized with minimum efforts. Moreover, one can make use of the FPGA ressources and move some of the signal processing stages to the USRP and only deal with light-weight signal processing on the PC.

3 First Light

In order to test the interferometric capability, the two SALSA antennas were pointed towards the Sun on February 10, 2016. Figure 4 depicts the delay resolution function of a 20 millisecond scan observing the Sun at 1410 MHz with 1 Msps/channel around 14:00 UTC. A clear peak in the fringe plot indicates successful correlation. All data were processed with an Octave based correlator which uses a simplified delay and delay-rate model for quick fringe detection on this short baseline.

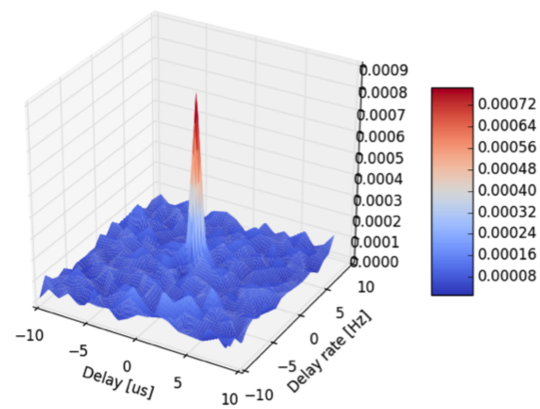

Fig. 4 Delay resolution function of a 20 ms scan of the Sun at 1,410 MHz.

4 Post-processing

A longer (i.e., 300-second) scan of the Sun was recorded a few minutes after the first fringe test. Data were post-processed with another Octave script, and phases, delays, and amplitudes were successfully obtained for accumulation periods of one second. Results are shown in Figure 5 and confirm the expected performance of the narrow-band interferometer setup. Except for an expected drift, interferometer phases appear to be very stable over time, while interferometer delays reveal a scatter of about 6 ns, which agrees well with the anticipated uncertainty corresponding to the 1 MHz bandwidth.

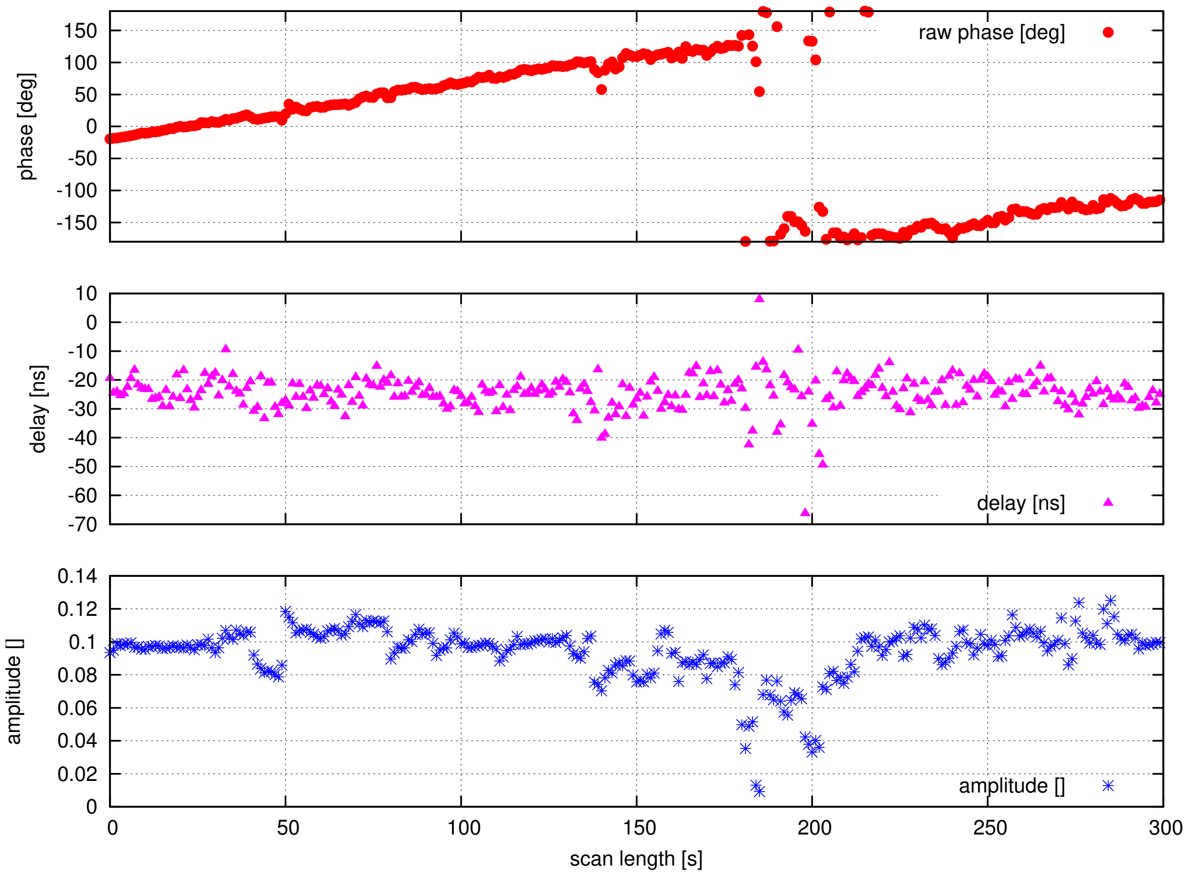

Fig. 5 Phases (upper plot), delays (middle plot), and amplitudes (lower plot) as obtained from a scan of the Sun on February 10, 2016 at 14:03 UT.

5 Next Steps

In order to use the SALSA installation more efficiently for demonstrating the basic concepts of interferometry, a few hard- and software changes are necessary. First, one needs to upgrade the front-ends in order to be able to receive other frequency ranges as well. This goes along with a firmware upgrade of the USRP E310 which enables receiving and processing of a much wider bandwidth. Limitations here are caused by the CPU which runs the embedded system rather than the FPGA processing capabilities. Thus, moving signal processing stages from the USRP to the PC will enable the handling of a wider RF bandwidth. However, one can also think about moving dedicated signal processing steps on the FPGA when dealing with narrow-band signals and thus supporting real-time operations. The USRP E310 supports this by means of RF Network on Chip (RFNoC) which can be developed, implemented, and tested in the form of undergraduate projects or theses. In general, such a feature can be of special interest for satellite observations, for example GNSS and other communication satellites transmitting in S-band. However, for such applications, one needs to implement also a satellite tracking module in the SALSA control system and make use of two-line element orbit information in order to steer the antennas towards the object of interest.

The post-processing software discussed in the previous section relies on Octave and can also run on Matlab. However, it is necessary to improve the existing software in order to obtain more precise observables. Delay tracking, fringe rotation, and other features have to be considered thoroughly even though the baseline is very short. Thus, longer integration times and correspondingly longer scans can be processed homogeneously while maintaining a high coherence over time. In addition, an interface to standard geodetic observation formats (VGOSDB, NGS) needs to be created so that data can be handled easily with geodetic analysis software packages.

Considering that all these implementations and developments will be available in the near future, it is anticipated that the SALSA installation can be used as an educational enviroment that mimics all stages of VLBI, including antenna control, RF processing, sampling, correlation, and analysis. Moreover, undergraduate and graduate thesis projects are expected to complement and extend the possibilities of the SALSA configuration and pave the way towards prototyping and testing of new observational concepts.