IVS Technology Coordinator Report

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Abstract Highlights of IVS technology development of the past year are summarized. This includes VGOS technology development, mixed mode observing issues, global VLBI standards, the VGOS technical committee (VTC) and its Wiki, the 2nd International VLBI Technology Workshop (IVTW), and the IVS Geodetic VLBI School.

1 VGOS Observing Plan

Over the past year, the VGOS Project Executive Group (VPEG) developed an observing plan to guide the transition from current S/X to future VGOS broadband operations. The plan spans five years. It begins with a series of test campaigns in 2015 with as many as eight sites expected to participate. IVS technology development over the next year focuses on ensuring that systems and processes are ready for the test campaigns.

Each campaign introduces a different aspect of the new VGOS mode of operation so that by 2016 the IVS will be ready to begin the VGOS pilot project. All campaigns will be roughly six weeks in duration to exercise the full "schedule to final products" operational chain in a sustained format.

- The first campaign focuses on automation of processes unique to broadband operations. It uses a single 24-hour session per week, which has the benefit of allowing six days per week to prepare for the next session. Data will be recorded and shipped after each session.
- The second campaign focuses on producing a full set of EOP products on a daily basis. It involves observing four hours per day in equispaced one-hour bursts. As with the first campaign, data will be recorded and shipped once per week.
- The final campaign focuses on producing initial EOP products within 24 hours. Observationally, it will be identical to the second campaign but with the exception that data will be e-transferred instead of being shipped.

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2 VGOS Technology Development

Development of the VGOS broadband system began in a serious way in about 2008 when the Eleven Feed was identified as a suitable candidate for use in the next generation VLBI system. As a result of work carried out in the subsequent years, the system is now in a useable state although not completely finalized. Several broadband test sessions were carried out on the ∼600 km Westford to GGAO baseline with the first 24-hour geodetic session having been carried out in late May 2013.

The new broadband system required nearly a complete reworking of the legacy S/X system including the frontend, backend, and even the connection between them. There has been significant progress over the past year in a number of areas.

2.1 Broadband Feeds

It is no surprise that active research into broadband feeds continues today because it is one of the key technological innovations that makes the new VGOS broadband system possible. The workhorse feeds for the Westford/GGAO broadband baseline are Quadridge Feed Horns (QRFH) developed at CalTech. These feeds perform at a high level, are cost effective and are easy to integrate into cryogenic front ends. So far they are the only broadband feeds that have been successfully deployed in a working VGOS system. Although the QRFH is naturally a dual linear polarization feed, circular polarization is handled more naturally by VLBI and is hence preferred. Chris Beaudoin recently suggested a method for effectively combining the QRFH linear outputs, post-LNA, into dual circular outputs. There is also an Auscope/Callisto collaboration to build a QRFH feed into a cryogenic system based on a Stirling cycle cooler. This configuration promises to be cost effective, to be very low maintenance, and to still meet the VGOS SEFD spec when used with a 12-m antenna.

Work continues on the integration of the Eleven Feed developed at Chalmers University into a cryogenic front end; a broadband feed developed in Italy is being tested at Noto, and an innovative conical feed that naturally produces circular polarized output is being proposed for the Spanish/Portuguese RAEGE antennas.

2.2 Digital-backends (DBEs)

Digital-backend (DBE) development continues in China, Europe, Japan, Russia, and the United States. A VLBI Digital-backend Intercomparison Workshop was conducted at Haystack Observatory in October 2012 to test inter-compatibility between independently developed DBE units. The results were very positive showing that in most cases the systems can operate successfully together.

In addition, to help understand the similarities and differences between various DBEs, a document named the VLBI Receiver Back End Comparison, in which the features of all known DBEs are compared in a table, was produced. The document can be found on the IVS Website and the VTC Wiki. Of the DBEs compared, the ROACH-based DBE (RDBE) and DBBC2010 were the most applicable to the VGOS system.

Gino Tuccari is prototyping a new cutting edge DBE system, the DBBC3-H, in which an 8-bit 28 Gsps digitizer samples the complete VGOS 2-14 GHz RF spectrum. Unfortunately, the project has been delayed due to a requirement by the manufacturer that only very large orders will be filled. To get around this problem, Gino is looking into the possibility of a joint order with the the Square Kilometer Array (SKA). In the meantime he is moving forward with a less aggressive broadband sampler, the DBBC3-L, which needs to be coupled with external analog electronics in order to satisfy VGOS requirements.

2.3 The Mark 6 Data System

The Mark 6 data system is now ready to enter operational service. It is an excellent fit for VGOS. It can accept data at the VGOS data rate of 16 Gbps, writing it directly into a 30 s RAM buffer and then moving it from the buffer to a (single) disk pack at a sustained rate just under 8 Gbps. With proper care in the development of a schedule it should be easy to ensure that the buffer is ready to be refilled by the time the VGOS antenna has slewed to the next source. This mode of operation opens the possibility of writing a complete 24-hour VGOS session onto a single 32 Tbyte disk pack that is very efficient for media shipment.

2.4 Delay Calibrator

Phase calibration (PCAL) has always been an important aspect of geodetic VLBI, required both to account for independent local oscillator (LO) offsets and to compensate for delay and phase drifts in the system. It was hoped that the advent of DBEs, with their deterministic linear phase response, would reduce the dependence on PCAL. But for the VGOS broadband system where phase is connected between bands, the need for PCAL is as great as ever.

A modern PCAL pulse generator has recently been successfully designed and deployed. However, PCAL performance is also limited by the stability of the reference signal that drives the pulse generator. The stability of this signal is corrupted by thermal and mechanical drifts in the cable that connects the hydrogen maser frequency reference to the pulse generator (which is typically located near the receiver frontend). Although it was initially hoped that a very stable cable could be found for this purpose, tests over the past year have shown that the required stability could not be achieved.

As a result, a next generation delay calibrator system is under development at Haystack Observatory. The principle behind the new system is very similar to that of the old Mark 3 delay calibrator, although detailed implementation is significantly different. Initial tests indicate that performance of the new design already nearly meets VGOS requirements.

2.5 Correlator

Although a number of different types of correlators are currently used for geodetic VLBI, the most commonly used is the DiFX software correlator. DiFX was originally developed at Swinburne University in Australia by Adam Deller for use in astronomical VLBI. As its popularity increased, a global DiFX user group was formed to coordinate continued improvements and additions. A recent addition is an interface that allows DiFX output to be input to the Mark IV post-correlation software. This opened the door for the use of DiFX in geodetic VLBI, and since then DiFX correlators have become operational at the Bonn, Haystack, and Washington IVS Correlation Centers. Features that benefit geodetic VLBI continue to be added to DiFX, but equally important are the additions to the Mark IV post-correlation software that are needed to handle VGOS broadband modes. Some noteworthy additions include: the use of all available PCAL tones to seamlessly connect interferometer phase across the full 2-14 GHz input frequency range; the use of a total electron content (TEC) search parameter to account for the curvature of phase vs. frequency caused by the ionosphere; and the addition of the ability to form a pseudo total intensity observable out of the linear polarized outputs that are naturally produced by broadband QRFH feeds. New features continue to be added to both DiFX and the post correlation software, and these are tested using data from the Westford/GGAO broadband baseline.

3 Mixed Mode Observing

In order to establish robust geodetic ties between new broadband stations and the legacy S/X network, a series of observing sessions that include both broadband and S/X stations is required. These sessions are referred to as mixed mode sessions. There is nothing fundamental that makes these sessions difficult. However, in practice they are complicated by restrictions built into the details of the systems being used. There are a number of different types of backends that need to be considered: analog Mark IV; analog VLBA; DBBC in either digital down converter (DDC) or polyphase filter bank (PFB) mode; and RDBE in DDC or PFB mode. Beyond that, S/X stations use a number of different fixed IF down conversion schemes. This proliferation of backends and down conversion schemes makes compatibility in terms of net LO frequency, sideband, and channel bandwidth difficult to achieve. To help navigate these issues, a document was prepared entitled Mixed Mode (Broadband vs. S/X) Configuration Issues. It can be found on the VTC Wiki. Many of these incompatibilities can be handled in the correlator, but for now most of the relevant correlator features are not yet fully tested.

Mixed mode observing also suffers from a sensitivity issue. VGOS broadband antennas are generally smaller than S/X antennas (which was done to make it easier for them to achieve high slew rates). For VGOS observations, this lack of sensitivity is more than compensated by the 16 Gbps instantaneous VGOS data rate. But when VGOS antennas co-observe with S/X antennas, data rate is limited to less than 1 Gbps by the S/X systems. This results in long on-source periods for mixed mode baselines, and this in turn degrades schedules and geodetic performance. The obvious solution is to increase the S/X data rate. However, this is currently not possible because the analog systems still commonly used at many S/X sites are operationally limited to 8 MHz channel bandwidths which corresponds to a maximum total data rate of about 1 Gbps. To solve this problem there is currently an effort to decommission analog systems and replace them with DBEs.

4 Global VLBI Standards

Over the past decade, the previous IVS Technology Coordinator, Alan Whitney, did a great service by coordinating the definition of a number of Global VLBI standards, including VSI-H, VSI-S, VDIF, VDIF2, and VTP. Most recently it was recognized that VEX, the pseudo-language that describes the detailed configuration of each station (as well as the schedule of observations), needs to be upgraded to handle new components that are part of the VGOS system. For obvious reasons, VEX2, the next generation VEX program, must be in place before automation of VGOS processes (which in turn is required to reduce operational costs and hence enable the VGOS goal of 24/7 operation) can begin. VEX2 is now nearly complete; its imminent release is eagerly awaited.

5 The VGOS Technical Committee (VTC) and its Wiki

The VLBI2010 Committee (V2C), was established in 2006 to encourage the realization of VLBI2010. Over the years its focus narrowed towards the technical aspects of the next generation system with the following seven main topic areas identified: system development, RFI, automation, schedule optimization, source structure, site ties, and the atmosphere. Recently, to reflect the approaching transition to the operational phase of the project, the name of the committee was changed to the VGOS Technical Committee (VTC).

As more VGOS systems are designed and built, there is an increasing need for communication and coordination between groups. To serve this purpose, the VTC established a Wiki that can be found at https://wikis.mit.edu/confluence/display/VTC/Home. Wiki contributions related to all VGOS activities are welcome. Everyone is encouraged to access the wiki to learn about VGOS developments. But its usefulness obviously depends on the quality and completeness of the information on it. So please think about what documents you have that might be of interest to the VGOS world. For more information on the Wiki, please see the related article written by Brian Corey in the April 2014 issue of the IVS Newsletter.

6 2nd International VLBI Technology Workshop (IVTW)

The 2nd IVTW was hosted by the Korean Astronomy and Space Science Institute (KASI) at Seogwipo on Jeju Island, South Korea. The workshop focused on four topics: station status reports, e-VLBI/Science, wideband developments, and frequency standards. Attendees at this very well organized workshop were treated to a field trip to the nearby 21-m Tamna radio telescope which is an element in the Korean VLBI Network (KVN).

The 3rd IVTW will be held on November 10-13, 2014 at JIVE, Groningen, Netherlands. I encourage anyone who is interested in VLBI technology to attend this very informative and useful workshop. Strong representation from the IVS will ensure that geodetic VLBI has a voice in defining a coherent direction for global multidisciplinary VLBI technology development.

7 Geodetic VLBI School at Altoo University

On March 2-5, 2013, just prior to the 21st EVGA Working Meeting, a geodetic VLBI school was held at Aalto University, Espoo, Finland. The school was sponsored by the IVS, the EGU, Onsala Observatory, the Finnish Geodetic Institute, Aalto University, and RadioNet. It was part of the activities of IVS Working Group 6, “VLBI Education”, led by Rüdiger Haas.

Lectures and exercises were prepared on a wide range of topics from Radio Telescopes, Feed Horns, and Receivers to the Terrestrial Reference Frame. It was an opportunity for young participants to get a broad introduction to the field and at the same time for technology experts to learn about analysis and vice versa. Since this was the first running of the school, an important result was the production of learning material on a broad range of topics related to geodetic VLBI. It was agreed that a school of this type should be held roughly every three years.