IVS Technology Coordinator Report

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Abstract The main focus of IVS technology development over the past year was to achieve operational readiness for broadband observing. This includes not only the development and proliferation of broadband systems but also the development of software and processes to enable efficient, and eventually automatic, operation of the VGOS stations and correlators. Already, a number of fully compliant (or nearly compliant) VGOS antennas have been constructed (many of these having already achieved first light and first fringes) with several more expected to come on line in the next year or two. The looming challenge is to ensure: that signal chains are available for these antennas; that operating modes of the various systems are VGOS compliant, interoperable, and sufficiently robust against RFI, and that systems can be controlled and thoroughly monitored remotely.

1 VGOS Compliant Signal Chain

Although the definition of the official VGOS signal chain has never been formalized in a single document, it has been discussed in some detail in the collection of talks presented at the IVS VLBI2010 Workshop on Technical Specifications held at Bad Koetzting/Wettzell on March 1-2, 2012. Earlier discussions can also be found in the talks presented at the IVS VLBI2010 Workshop on Future Radio Frequencies and Feeds held at Wettzell/Hollenstein on March 18-20, 2009 and in the reports "Design Aspects of the VLBI2010 System: Progress Report of the IVS VLBI2010 Committee", June 2009, and "VLBI2010: A Vision for Geodetic VLBI", 2005. Links to all of these talks and reports can be found on the IVS Web site.

So that there is no confusion about the expectations for a VGOS system, the most important system parameters are summarized below:

- The input frequency range is 2.2—14 GHz. But because it is expected that there will be stations that have RFI in the 2.2—3 GHz range that is strong enough to saturate their front ends, VGOS frequency sequences will typically use only the 3—14 GHz range. Use of the full 2.2—14 GHz range will however be important to allow interoperability with legacy S/X systems and stations with S/X/Ka-band receivers.
- There will be four 1024 MHz bands in a system, each of which can be situated anywhere within the input frequency range. [Resolution for setting the frequency will be 400 KHz or a sub-multiple.] Because most systems will operate in an RFI environment, a digitizer with at least 8-bit resolution should be used to provide adequate dynamic range.
- Each of the four 1024 MHz bands will be divided into channels. This is required to protect against RFI within the band. Although there has been no formal discussion of acceptable channel bandwidths, all channelized systems incorporate a 32 MHz option making this, in practice, the standard. VDIF output format is expected with 2-bit requantization of either real or complex data. It will be possible to select any subset of the channels for output.

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- The instantaneous output data rate will be 16 Gbps. But because VGOS observing involves short integrations (less than about 15 s) and frequent slewing between sources, the sustained data rate is not expected to be greater than about 4 Gbps. Provided that a RAM buffer of at least 30s at 16 Gbps is available, sustained record or e-transfer rates greater than about 4 Gbps will not be required.
- To minimize systematic effects, calibration systems are required:
  - A phase calibration (Pcal) signal needs to be injected into the receiver frontend so that interferometric phases between bands can be aligned. The same signal is also be used to calibrate the downlink delay through the signal chain and transmission lines. For optimal performance the Pcal signal should be a series of very narrow pulses with pulse repetition rate of 5 or 10 MHz.
  - The delay of the cable carrying the maser reference signal to the Pcal generator needs to be calibrated because that delay is reflected directly in the measured interferometric delay once Pcal has been applied. This is referred to as cable cal. It needs to achieve a stability roughly equal to that of the maser in order to avoid degradation of the time scale.
  - The total power of the receiver needs to be accurately measured in order to support investigations into source structure. This is done by measuring the change in receiver power as a calibrated noise signal is coupled into and out of the signal chain. In order for this to be done simultaneously with observing, it is necessary that the noise signal be relatively weak, and in order to track rapid changes in power, it is necessary that the switching be done several times per second. A switching rate of 80 Hz is common in astronomy.

Although there are many other detailed recommendations, systems that include these basic characteristics have a very good chance of working successfully together.

2 Automation and Remote Control

Automation and remote control are very important aspects of VGOS. With the expectation of 24/7 operations and a sharp rise in the number of observations per day, it is necessary (to keep operating costs at a reasonable level) to make all processes (including schedule generation, station operation, correlation, fringe processing, and analysis) as automated as possible.

A necessary step to achieve automation and remote control is to have a language to concisely and completely describe the instrumentation, operating modes, and schedule for a session. This has been the role of the VEX language over the past decades. But, with the advent of VGOS and the new broadband systems, instrumentation and operating modes which had not been conceived of when the original version of VEX was developed now need to be handled. As a result, over the past few years, a new version of VEX, VEX2, was developed. VEX2 was completed this year; it went through a brief period of community consultation, and it is now being used to write software to control instrumentation and processes in the complete VGOS operational chain.

The real workhorse for monitor and control at the stations has always been the Field System. This will continue to be true in the future, but, with the growing emphasis on automation and remote control, a significantly larger amount of data will need to be collected continuously at the stations. This is needed to evaluate remotely whether or not all systems are working optimally or perhaps to even indicate when systems are just beginning to show signs of failure. As a result, processes are being put in place to monitor continuously and store locally a wide variety of parameters including such things as temperatures throughout the site, motor currents, Pcal, total power, stream stats, raw data captures, plus much more. These data can be accessed remotely to get a detailed view of the state of all station equipment.

Although this additional data will be invaluable for evaluating the health of stations, the volume of data will be too large for a remote operator to continuously scan it. As a result, intelligent software and display processes will be required to study the data and inform the operator through warnings, alarms, and displays when significant performance deficiencies or dangerous conditions are detected.

3 VGOS Innovation

As the operational phase of VGOS approaches, focus is shifting to the deployment of signal chains at stations. But significant VGOS related innovation continues at IVS Technology Development Centers. A few significant highlights are listed below:

- Circular polarized conical feeds are being developed at Yebes. Up until this year, all broadband feeds considered for use in VGOS have used dual linear polarization. This is in spite of the fact that linear polarization has complications for VLBI due to inhomogeneity of parallactic angles caused by the wide separation of antennas in the network. Although a solution to the parallactic angle problem has been found, there continues to be interest in circular polarized feeds because they are a more natural fit for VLBI. If the conical feeds being developed at Yebes can achieve low noise, high efficiency, and good polarization separation, they may become a preferred solution for the VGOS community.
- Progress continues to be made at Noto on the DBBC3L. The DBBC3L is a data acquisition system that, due to its digitizers with wide bandwidth and high clock frequency, can direct sample 4 GHz chunks of data. Although each sampler of the DBBC3L is not capable of directly sampling the entire 2—14 GHz VGOS bandwidth (as was the intention with the DBBCH), when eight of these are combined with fixed frequency down converters, the full 2—14 GHz band can be sampled in both polarizations. This enables optimal placement of each channel anywhere within the full VGOS range, which is an added capability beyond currently used band-constrained systems.
- The Mark 6 data systems developed at Haystack are entering operational service. These data systems are ideally suited for use in VGOS observing. Their large input RAM buffers allow data to be input at the full VGOS data acquisition rate of 16 Gbps and then recorded at a slower rate as the antenna slews to the next source. This capability along with the advent of disk packs based on 4 Tbyte or larger individual disks opens the possibility of efficiently recording a complete VGOS 24-hour session onto a single disk pack.
- A new cooled broadband front end based on a Sterling cycle refrigerator is the joint project of Auscope and Callisto. Sterling cycle refrigerators are small and light; they require very little maintenance and have long times between failures. Although these systems cannot achieve as low physical temperatures as the usual GM-refrigerators, calculations indicate that Tsys for the new front end system meets the VGOS recommendation while at the same time being less expensive, lighter, and more operationally efficient. Collaborative funding strategies have left sufficient funds to also acquire a full VGOS back end for Auscope.
- A new cable delay measurement system was developed at Haystack to replace the old Mark III cable cal units. Although based on similar principles, the new units are in detail very different and perform with significantly better stability, matching roughly the performance of a maser. Initially it had been thought that an ultra-stable Pcal uplink cable could be found, but experience has shown that a back-up monitoring system is prudent to guarantee the specified VGOS temporal performance.
- Significant work was done in the past year to move the DiFX correlator and fringing software towards an operational configuration for VGOS. In the correlator itself several compatibility features have been implemented to allow correlation of data streams with incompatible characteristics, e.g. different bandwidths, different LO settings, real vs. complex encoding, etc. In addition, the fringing software has been extended to combine multiple bands (including the use of a TEC search to handle the phase curvature of the ionosphere) and polarizations. With these capabilities in place, the focus has moved to improving the operational efficiency of the correlator so that correlator runs become easier to set up and extraction of data from Mark 6 units into native correlator storage is less time consuming. When this development phase is complete, it will be important to export the VGOS enhancements to other correlators so that experience can be gained with processing VGOS sessions.
- A cost effective direct sampling digital back end is being developed at NICT. This system uses a broadband sampler along with a lower rate sample clock. Using aliasing, a number of bands can be overlapped onto the same frequency region. Al-

though very cost effective, this system does not currently support channelization and hence is incompatible with the VGOS recommendation. It has been used successfully on the baseline between Kashima and Ishioka for broadband tests but is mainly intended for internal use with the NICT time transfer project.

4 VGOS Observing Plan

During 2013, 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 and begins with a series of test campaigns in 2015. In 2014, the plan was accepted by the IVS Directing Board and presented to the IVS membership at the IVS GM in Shanghai. In the meantime the plan was augmented by a Data Transmission and Correlation Plan.

Two main initiatives are underway to support the test campaigns of 2015.

First, a number of VGOS antennas have now been constructed and have achieved first light and first interferometric fringes. Westford and GGAO have implemented front and back end receivers that are very nearly VGOS compliant. At the same time, a number of other international sites are working hard to put in place VGOS signal chains, with Wettzell, Yebes, and Kokee expected to be ready before the end of the year.

Second, a series of bi-weekly VGOS sessions have been initiated between Westford and GGAO, the goal being to establish a fully operational VGOS methodology. To support this, a so-called "parallel universe" has been put in place at Goddard that completely imitates the Master Schedules, ops mailing list, etc. that have been used for years for the legacy S/X-band operations. In addition, processes are being put in place to automate as much as possible the full operational chain from schedule generation to analysis. The importance of this effort cannot be overemphasized in the quest to move from a VGOS test footing to a full VGOS operational capability.

With these two initiatives underway, the IVS can be optimistic that it will be ready for the VGOS Pilot Project planned for 2016.