VLBA Sensitivity Upgrade Program and Memo Series

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Introduction

We have initiated a "VLBA Sensitivity Upgrade" program to encompass several enhancement projects currently under way, in various stages ranging from planning to implementation. These can be grouped in two major areas within the overall sensitivity-upgrade theme: expansion of the VLBA data path bandwidth to enhance continuum sensitivity at all observing bands except the very lowest; and replacement of the low-noise amplifiers in the existing receivers to increase spectroscopic sensitivity in specific observing band(s).

A new "VLBA Sensitivity Upgrade Memo" series has been launched to document developments in all these areas. This memorandum, the first in that series, provides a brief overview of current activities. Subsequent memos will be numbered following NRAO's "Hvatum Rule", with #2-9 reserved for historical documents, and current material starting at #10.

Data Path Upgrade

The overall goal of the VLBA data path upgrades is operation at 4 Gbps throughput by 2011. We anticipate that some observations, with the highest scientific priority, could be carried out in the 1-4 Gbps range within 12 to 18 months. The upgrades encompass the entire data path downstream from the IFs; the 4 Gbps target corresponds to 2-bit sampling of the entire 500-MHz bandwidth from each of the two IFs normally used. Development efforts are focussed in three separate, relatively independent areas, with several options still under consideration in each case. Only the option(s) presently considered to be most promising are described in this memo.

Sampler/Filter Module

The VLBA's existing baseband converters and samplers can be replaced by a single sampler/filter module, using modern FPGA technology to sample the entire IF bandpass and digitally filter the sample stream into distinct channels ("baseband channels" in current VLBA jargon). Preliminary specifications include two separate, program-selectable operating modes: a maximum of 16 tunable channels, with maximum bandwidth of 256 MHz each, and output sample precision up to 8 bits; and a polyphase filterbank with up to 32 channels spanning the entire passband of each IF. Each mode is subject to an overall maximum throughput of 8 Gbps. (The overdesign relative to the 4-Gbps goal is partly to allow for future expansion of the upstream equipment, and partly to accommodate the geodetic requirements described below.) The module would include output interfaces for several formats, including VSI (for Mark 5), 1G and/or 10G Ethernet (for e-VLBI and potential new recording systems), and OC-192 (for the Pie Town - VLA link).

After considering several alternatives, we believe the best option for realizing this unit is a further development of the Digital Backend (DBE) for which Haystack Observatory has already completed a preliminary version in collaboration with the Casper group at UC Berkeley. NRAO and Haystack identified the extension of that system, to include several crucial requirements for both the VLBA and for geodetic VLBI, as an extremely promising opportunity for collaborative development. The extended DBE would use a new, higher-capacity FPGA, and would exploit the design expertise developed at NRAO for the EVLA project, where quite similar equipment has already been implemented.

Recording System

A new wideband recording system will be essential for full exploitation of the DBE's 4-Gbps output capacity, but appropriate options are not readily discernible at present. Compatibility with the existing pool of disk recording media, which represents a major investment by the VLBA and by nearly all other VLBI facilities globally, is a crucial requirement. Among current disk-based systems, Mark 5B+ can record a 2-Gbps input stream, but its throughput is limited by a 1-Gbps playback rate through the VSI interface. If necessary, two such systems in parallel would allow 4-Gbps operation for at least a fraction of the time. However, recent trilateral discussions among Haystack Observatory, NRAO, and Conduant Corporation, manufacturer of the Mark 5 series of recording systems, gave grounds for some optimism that a compatible recording system with full 4-Gbps throughput may be available before 2011.

Correlator

At the endpoint of the upgraded data path, the existing VLBA correlator must be replaced. Here there are two quite different primary options. The WIDAR correlator currently being built at DRAO for the EVLA will have a 32-station configuration, and the excess capacity not required for the 27-element EVLA would be sufficient to process the 10-station VLBA at up to 16 Gbps. The signal-processing boards can accommodate VSI interfaces, for input directly from Mark 5 recordings. This approach would involve negligible additional hardware investment, but would require some software effort, potentially substantial in scope, to extend the resource-allocation subsystem to support VLBA correlation, and to do so without constraining the EVLA's capabilities. In addition to its cost, this software development is also a concern because it probably could not begin until the correlator is largely functional for EVLA-only operation.

Another attractive correlator option is a software-based system. Software correlation provides an extremely flexible trade-off among basic parameters including the number of stations and polarization states, bandwidth, spectral resolution, integration time, pulsar gating, and specialized non-standard modes, with almost no constraints beyond the available processing power. This flexibility in turn allows correlation resources to be allocated fairly, on the basis of scientific priority, in parallel with the allocation of observing time. Processing capacity can be upgraded incrementally, and matched if desired to simultaneous increases in recording capacity. A software correlator could be put into service relatively quickly, begin to support a fraction of the VLBA's correlation load, and make available a variety of capabilities beyond the limits of the existing correlator. However, the cost of the computing infrastructure necessary to support VLBA correlation at various levels is not well known at present.

Several software correlators have already been written, most of them designed to run on computing clusters in order to exploit the parallelism inherent in the application. Some such systems are in routine use, although generally on smaller arrays, and at much lower fractional observing time, than the VLBA. In a still-incomplete survey, it appears that the DiFX software correlator developed at Swinburne University would be an excellent match to the VLBA's requirements. We are developing a rudimentary processing capability to start benchmarking it as a first step toward the solid cost estimate required to decide between the two correlator options discussed here.

Receiver Upgrades

The receiver upgrades to enhance spectroscopic sensitivity concentrate on replacement of the low-noise amplifiers in some higher-frequency observing bands, where modern technology offers a significant reduction in receiver noise from the original VLBA equipment. Currently, the existing K-band (1.3 cm, 22 GHz) GaAsFET amplifiers are being replaced with units based on InP devices, designed by the NRAO Central Development Laboratory for WMAP and used in the new EVLA receivers. This project, a collaboration between NRAO and the Max Plank Institut für Radioastonomie, will be completed by the end of 2007.

The project's sensitivity goal is a 30% overall improvement. Initial results from the first two upgraded receivers, installed at the Pie Town and Los Alamos stations, are very encouraging, with system temperatures reduced approximately by half.