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Future Directions on the VLBA

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Abstract

Over the next few years, incremental improvements are expected on the VLBA. The Mark 5 recording system will be installed, raising the sustainable bandwidth by a factor of eight. Improvements in both receivers and optics should significantly improve the sensitivity at high frequencies. And, the VLBA may begin to contribute to the navigation of interplanetary spacecraft. But the big changes ahead for the VLBA relate to the Expanded VLA (EVLA) project, and especially the proposal to extend the resolution of the VLA by a factor of 10 by building eight new antennas and upgrading two VLBA antennas. These 10 antennas are referred to as the New Mexico Array (NMA). The correlator for the EVLA/NMA can also correlate VLBI data and will replace the current VLBA correlator, providing a significant increase in capability. Also the additional antennas will provide excellent, and much needed, short spacing coverage for the VLBA for improved imaging. The sharing of the correlator and some antennas will require a tight integration of the VLA and VLBA. In time, the VLBA may lose its separate identity and become the long baseline component of a single instrument that covers baselines from 25 m to 8600 km.

1. Introduction

The Very Long Baseline Array (VLBA) is a dedicated instrument for VLBI. It includes ten 25 m antennas that are used at frequencies between 327 MHz and 96 GHz. The antennas are operated remotely and are unattended most of the time. The VLBA also includes a 20 station correlator. Both the correlator and the stations are operated from the same room in the Array Operations Center (AOC) in Socorro, New Mexico. The AOC is also where much of the maintenance, software development, user support, and scientific staff for both the VLBA and the Very Large Array (VLA) are located.

The VLBA and VLA are run by the National Radio Astronomy Observatory (NRAO) which is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc. Observing time is allocated on the basis of refereed scientific proposals. Anyone, regardless of national or institutional affiliation, may propose for time.

Much of the geodetic/astrometric observing being done on the VLBA has been folded into the RDV projects for which all VLBA antennas and up to 10 other stations observe for 24 hours, 6 times per year. Because of the large number of baselines in these observations (up to 190), these projects are starting to contribute a significant fraction of the overall geodetic data base.

Plans for future enhancement of the VLBA fall into two categories. Over the next few years, improvements in recording systems and high frequency performance are expected. Spacecraft navigation may get added to the types of observations done on the array. There will also be ongoing improvments in software that should enhance usability but that won't be discussed here. The longer term outlook is dominated by the Expanded VLA project (EVLA) and especially the portion of that project that will add new antennas to extend VLA baselines to 350 km. Since those antennas are scattered across New Mexico, that portion of the project is called the New Mexico Array (NMA). The VLBA is expected to share the correlator and two antennas with the EVLA/NMA so tight integration of operations is required. The long range goal, although not part of any current proposal, is to upgrade the VLBA equipment to full EVLA standards and operate the EVLA/NMA/VLBA as one instrument with baselines from 25 m to 8600 km.

2. Near Term Projects

Perhaps the most important of the near term projects is to replace the VLBA tape system with the Mark 5 disk system. This replacement is well under way at other observatories, but is difficult for the VLBA because so many record and playback units (36) and so many disks are needed to sustain full time operation. The expected cost is around $3 million and an effort to find the necessary funds is underway.

For the VLBA, the Mark 5B system is required in order to reach 1 Gbps operation. With Mark 5A, the formatters limit the recorded bit rate to 512 Mbps and the correlator playback is limited to 256 Mbps per station input. The samplers, however, can generate 1 Gbps and the correlator could handle 512 Mbps per station (in a maximum of 8 baseband channels) after the deformatters. For 1 Gbps observations, 10 station data can be processed by using all 20 station inputs. Larger observations would would require 2 pass processing.

There is interest in improved high frequency performance because much of the interesting science being done on the VLBA is at high frequencies. The receivers at 22 and 43 GHz could be improved significantly by upgrading their amplifiers to current standards. This would not require major alterations to the receivers as long as no attempt is made to reach the very wide bandwidths of the EVLA receivers. As with Mark 5, funding for this project still needs to be identified.

In the last few years, receivers at 80-96 GHz have been installed on the 8 VLBA antennas where they are usable (St. Croix is too wet and the Brewster subreflector needs work). Funding for the receivers was supported to a significant degree by the Max-Planck-Institut für Radioastonomie. The VLBA antennas were specified to work well at 43 GHz with a goal of working at 86 GHz. The current efficiencies, before any post-construction surface adjustments, are near 50% at 43 GHz and 10-20% at 86 GHz. It should be possible to improve the 86 GHz efficiency by adjusting panels on the main reflectors and by improving the subreflector surfaces. A project is under way to do both.

The tactic adopted to improve the surfaces is to first work on the subreflector and then to adjust the main antenna panels based on holographic measurements. The fact that the subreflector is rotated to select the observing frequency band means that large subreflector errors cannot simply be compensated for by panel adjustments. One could end up improving one frequency at the expense of another. However using panel settings to compensate for small residual subreflector errors when the subreflector is at the 86 GHz position is probably acceptable because the other frequencies are not as sensitive to surface errors.

Adjustment of the subreflector surfaces requires filling and/or sanding and is best done off the antenna. The work is being done at the VLA on what at any given time is the spare subreflector. Once adjusted, that subreflector is mounted on the next antenna that will receive holographic measurements. That antenna's subreflector then becomes the spare and is adjusted in turn. The subreflector tuning process is done with the help of a Faro Arm, a device with an instrumented, jointed arm that can measure the position of a sensing head in 3 dimensional space with a repeatability of about 75 microns. With this arm, it is possible to iterate very rapidly between sanding and measuring. An adjusted subreflector was recently put on Pie Town but the benefit will not be clear until the main reflector panels are adjusted.

A holography system has been developed that can be mounted without disturbing the normal receivers and can be used at a variety of subreflector rotation positions. This system has a 12 GHz satellite receiver with a feed aimed at right angles to the normal feeds. There is a 45 degree reflector in the right place to deflect the beam to the subreflector. The whole assembly can be mounted above the normal feeds, and can be positioned at several locations around the feed circle. The reference horn is mounted on the back side of the antenna apex to minimize any effects from pointing shifts. By making measurements at multiple subreflector rotations, it is possible to partially separate subreflector and main antenna offsets. The data handling and correlation are handled in a PC. The whole system is portable. So far it has been under test at Pie Town and the first round of panel adjustments should happen soon.

There is a project, in cooperation with the JPL, to explore the use of the VLBA for spacecraft navigation. The value of VLBI observations to constrain the position of deep space probes has been demonstrated using the Delta-DOR technique on the DSN. But such observations require special setups and special signals from the spacecraft to provide the multiple tones needed to obtain a delay. Phase referencing techniques commonly used in VLBI astronomy could allow observations to be made without special signals and at any time that the transmitter is on. They would have no impact on normal communications activities with the satellite. It is likely that the observational data would be delivered to the navigators as total delays so that they can be treated like any other VLBI data. But those delays would be derived from the phases after phase referencing to a background source of known position has been used to remove any phase ambiguities. Such a capability would provide an additional, and perhaps paying, "customer" for the VLBA and aid some of the most publicly visible projects in all of astronomy.

3. The EVLA Connection

The EVLA project is a major upgrade to the VLA. There are two phases to the project. The first is already funded and under construction. That phase includes several items to improve the sensitivity and capability of the 28 current antennas. Most of the receivers will be replaced by new wide-band systems that, with 8 receivers, will provide continuous coverage between 1.0 and 50 GHz. The LO/IF system will break the signals from a receiver into 4 analog channels of 2 GHz each in each polarization for a total sampled bandwidth of 16 GHz. Each sample will be encoded with 3 bits to help with RFI tolerance (8 bits for narrower bandwidths) and sent to the correlator over optical fiber. The total bit rate from each antenna is 96 Gbps. The correlator will provide 16384 channels per baseline over all IFs in the wide band modes and more for narrower bandwidths. The correlator is being built at the Dominion Radio Astrophysical Observatory in Canada and is being funded by Canada. Mexico has also contributed financially to the EVLA project. In both cases, these are indirect contributions to the Atacama Large Millimeter Array, which is under construction by NRAO and partners from Europe and Japan. Much of the fiber has already been buried and the first antenna to be converted to EVLA electronics is nearly finished.

The EVLA "WIDAR" correlator has a design that can support VLBI correlation. And it is possible to use the inputs that would normally be allocated to one EVLA antenna to correlate 4 GHz from 2 antennas or 1 GHz from 4 antennas. The design also naturally comes in blocks of 8 stations. The phase 1 correlator will have 32 station inputs to have enough capacity to handle the 27 active VLA antennas. This leaves 5 unused station inputs that could be used for 10 VLBI stations at 4 GHz (16 Gbps with 2 bit samples) or 20 antennas at 1 GHz (4 Gbps). With these bandwidths and with the channelization capabilities of the new correlator, the extra stations have significantly greater capability than the current VLBA correlator. The plan is to shift to using the EVLA correlator for the VLBA and probably to shut down the current VLBA correlator.

The second phase of the EVLA project, which has not yet been funded, has two components, a new compact configuration and the NMA. The new configuration just requires construction of new pads and some rail. It is meant for use when observing very large sources. The NMA is a much more expensive component. The concept is to increase the resolution of the current VLA by a factor of 10 using 10 antennas in New Mexico with baselines of up to 350 km. Eight of those antennas will be new, probably 25 m antennas of the VLBA design. Two will be the existing VLBA antennas currently at Pie Town and Los Alamos. The Los Alamos antenna will be moved for reasons related to land use priorities at the Los Alamos National Lab and independent of the EVLA project. Both the Pie Town and Los Alamos antennas will have their electronics upgraded to EVLA standards.

The NMA antennas will have the same bandwidth and bit rate capabilities as the Phase 1 EVLA. This will require sending 96 Gbps per antenna over distances of several hundred kilometers. The current plan is to lease dark fibers from the local rural telephone companies and to have NRAO provide all the electronics, lasers etc. This appears to be cost effective at the rates that these subsidized companies are willing to charge. So far it has not proven possible to get anywhere near as good rates from the larger companies that don't benefit from the rural subsidies. While the rates are affordable for the EVLA project, scaling them up by mileage to what it would take to connect the VLBA suggests that this model for e-VLBI would not be viable without totally dominating the VLBA operating budget.

The NMA will require that the correlator be increased by another 8 stations to 40 total. The EVLA/NMA needs 37 leaving 3 which is adequate for 1 GHz VLBA observations. During VLBA observations that use at least the two VLBA antennas that are part of the NMA, there will be at least 5 extra correlator stations which would handle VLBA observations with 4 GHz bandwidth. These concepts of moving antenna inputs to the correlator between EVLA and VLBI playback and moving antennas between NMA and VLBA make it clear that operations of the EVLA/NMA and the VLBA need to be tightly integrated. The eventual hope is that the cost of long range data transission will come down sufficiently that all 45 antennas can be correlated in real time. Then there will be a single instrument capable of providing whatever combination of baselines between 25 m and 8600 km that the observers need. A correlator expansion may be required to facilitate this once high bit rates can be obtained from the VLBA.

Until real time signals can be sent from the VLBA and other VLBI antennas, all NMA antennas will be equipped with recording systems for VLBI. The recorders will be located at the correlator so that all required disk changes can be handled by a single operator and the antennas can run unattended.

There are 3 primary ways in which the NMA antennas will be used. When the VLA is in the largest, or "A" configuration, the NMA will usually be used as the outer EVLA antennas, extending the EVLA resolution and utilizing the short spacings and high sensitivity provided by the VLA. The NMA can be used alone for various types of observations for which its resolution is appropriate or for projects such as flux density monitoring that take advantage of the lack of the configuration changes that make such projects very hard on the VLA. Finally the NMA can be used to provide short spacings for VLBI observations with the VLBA or global arrays. The latter two modes will actually dominate simply because the VLA is likely to be in the A configuration less than half the time. Thus the NMA is expected to have a major impact on VLBI science.

4. The Geodesy/Astronomy Connection on the VLBA

The impacts of the VLBA on geodesy and astrometry can be seen in a number of other presentations at this meeting. The uniformity and sensitivity of the antennas, the careful design to insure phase stability, and the ability to support very large observations (up to 20 stations), has allowed the VLBA to produce some of the best available data. It has also allowed large surveys to be made to increase the number of sources with well determined positions. The expected upgrades will improve the sensitivity and hence the quality of the results. The high frequency capabilities and improvements make the VLBA the logical instrument on which to explore alternative frequencies for future geodetic VLBI.

The results from the geodesy community have, and will continue to have, a major impact on VLBA astronomy. Without high quality reference frames and geometric models, VLBI is limited to observing sources that can be detected with a fringe fit in a coherence time. With the well understood geometry provided by the geodesy community, it has been possible to use phase referencing on frequencies between 1 and 50 GHz. This allows observations of sources of less than 1 mJy that can be detected only with many hours of data on many baselines. It has increased the effective sensitivity of the VLBA by more than an order of magnitude. It also allows a variety of astrometric projects with significant impact, such as paralax measurements to pulsars. When last checked, about half of all VLBA observations used phase referencing.

The ongoing efforts by the geodetic community to improve their results have the potential to significantly improve astronomy results too. For example, the global ionospheric models provided by the GPS community are already proving to be valuable to improve VLBA phase referencing at least to 8 GHz and maybe higher and are in common use. We are also interested in GPS tropospheric results and in the efforts reported at this meeting to improve tropospheric models. We look forward to continuing fruitful interaction between the geodetic VLBI community represented by the IVS and the astronomical community that is the VLBA's main user base.

5. NRAO Web Sites

For more information about the NRAO, see the home page at http://www.nrao.edu.
For specific information on the VLBA, see http://www.aoc.nrao.edu/vlba/html/.
For EVLA information, see http://www.aoc.nrao.edu/evla.