4.2 Very Large Array (VLA)

Overview

In FY 2014 NRAO will continue to offer a suite of robust and scientifically powerful observational capabilities on the VLA, designed and tailored to address the highest priority scientific needs of the general community. Work on expanding the set of scientific capabilities to be offered will be based on users interest and planning for future large scale sky surveys, including on-the-fly interferometric mosaicking, providing more spectral channels through recirculation, a real-time transient detection mode, and the commissioning of the low frequency observing system. Many of these specialized capabilities will be enabled thanks to the continuation of the Resident Shared Risk Observing (RSRO) program, which engages experts from the astronomical community to assist with the delivery of specialized capabilities. In telescope operations much of the effort will go into ensuring that the array is calibrated, maintained and performing optimally. There will be a small number of upgrade projects chosen to improve performance in several areas including antenna pointing, receiver stability, digital sampler reliability and performance, and tropospheric weather prediction for optimal telescope scheduling.

4.2.1 Operations

Observing Programs

The NRAO VLA will continue to offer three types of observing programs to users in FY 2014: General Observing, Shared Risk Observing (SRO) and Resident Shared Risk Observing (RSRO). Observing capabilities are first offered to the community through the RSRO program, which enables the community to express their scientific interest in potential capabilities through peer-reviewed proposals, provides resources to help with testing and scientific verification, and helps to ready new capabilities for end-to-end operation. Once a capability has been demonstrated and tested, and can be dynamically scheduled, it is offered through the SRO program pending full testing and documentation. When a mode is robust and well tested, it is offered as a General capability.

The General Observing program comprises a suite of robust observational capabilities designed and tailored to address the highest priority scientific needs of the general community. An overview of the capabilities being offered for General Observing for semester 2014A is given below:

Capability	Description

8-bit samplers	• Standard Default setups for:
	  ○ 2 GHz bandwidth continuum observations at S/C/X/Ku/K/Ka/Q bands (16 x 128 MHz sub-bands)
	  ○ 1 GHz bandwidth continuum observations at L band (16 x 64 MHz sub-bands)
	• Flexible set-ups for spectroscopy, using two independently tunable 1 GHz basebands, each of which can be split into up to 16 flexibly tunable sub-bands
	• Single, dual & full polarization products
	• Up to 16,384 channels (summed over all polarization products)

3-bit samplers	• Standard Default setups for:
	  ○ 8 GHz bandwidth continuum observations at K/Ka/Q bands
	  ○ 6 GHz bandwidth at Ku band

	o 4 GHz bandwidth at C/X bands • Flexible set-ups for spectroscopy, using four independently tunable 2 GHz basebands, each of which can be split into up to 16 flexibly tunable sub-bands • Single, dual & full polarization products • Up to 16,384 channels (summed over all polarization products)
Sub-arrays	• Up to 3 independent sub-arrays using standard 8-bit continuum setups
Phased array for VLBI	• All antennas phased to simulate a single collecting area ("Y27")

The SRO program allows users access to capabilities that can be set up via the Observation Preparation Tool and run through the dynamic scheduler (without intervention), but are not as well tested as general capabilities. Shared Risk capabilities being offered for semester 2014A are correlator dump times as short as 50 ms, mixed 3-bit and 8-bit set-ups, and use of the new low frequency system in the frequency range 230 to 470 MHz for Stokes I continuum imaging.

The RSRO program will continue to provide access to more extended capabilities of the VLA in FY 2014. RSRO capabilities are those that require additional testing, and are provided to the community in exchange for a period of residence to help test and verify those capabilities. The requirements for the RSRO residency have relaxed since the completion of the EVLA Construction Project. A minimum residency is no longer required, and increased flexibility in the length and timing of visits may be implemented in the coming year. The kinds of capabilities available through the RSRO program include, e.g., correlator dump times shorter than 50 ms, data rates above 60 MB/s, use of recirculation in the correlator, use of the P-band system for polarimetry or spectroscopy, more than 3 sub-arrays or sub-arrays with the 3-bit system, on-the-fly (OTF) interferometric mosaicking, and complex phased array observations (e.g., pulsar and complex VLBI observing modes). Further details of the capabilities planned for the two shared risk observing programs can be found below.

Scientific Support for Maintenance of Receiver, Antenna, and Array Performance

The VLA has now fully transitioned to an operational state in which most of the effort goes toward maintaining array performance and ensuring that our user community has access to quality instrumentation and updated information to effectively use the VLA. Operational tasks that will be carried out by the scientific staff during FY 2014 include (but are not limited to):

- *Support Calls for Proposals:* Prepare user documentation for offered capabilities before the call goes out, provide scientific testing of user tools needed to prepare proposals (e.g., Proposal Submission Tool, General Observing Spectral line Tool, Exposure Calculator), provide technical reviews for proposals and evaluate proposals for Resident Shared Risk contributions.
- *Hardware, Software, and Operational Documentation:* Write technical documentation detailing hardware and software functionality for staff and users, develop and improve operational procedures and write documentation for the operations staff. This includes updating the VLA "Operational Status Summary" before each Call for Proposals and providing content for the "Guide to Observing with the VLA" on the NRAO web site.
- *Track and Measure VLA Performance: Sensitivity, Gain Curves, Holography, Antenna Positions, Collimation, Pointing:*
  - Characterize the sensitivity and gain response of each antenna at each band. This must be done periodically as receivers and equipment are replaced (e.g., due to failures in the field) or as software is upgraded that may change the system performance.

    - Check the surface accuracy with holography periodically to ensure optimal efficiency at the highest frequency bands.
    - Determine antenna positions, collimation offsets and pointing accuracy when the array is moved into a new configuration.
- *Scientific Testing of Antennas Completing Major Maintenance:*
    - Determine antenna positions, collimation offsets and pointing accuracy each time an antenna comes out of the Antenna Assembly building after a maintenance overhaul.
    - Evaluation of new Antenna Control Units (ACU): Two antennas are scheduled to be outfitted with new ACUs during FY 2014 during major maintenance overhauls (see "Upgrade Projects" below). As new ACUs are installed they will undergo testing and evaluation by scientific staff.
- *System Health and Maintenance Feedback:* Run routine health checks to determine if there are any hardware failures that must be followed up with maintenance tickets. Troubleshoot problems found and confirm fixes are implemented. Run RFI tests to characterize and help mitigate RFI contamination in the bands.
- *Data Quality Assurance Checks:* Evaluate data quality based on the Pipeline results and run test observations to identify and diagnose problems that are not caught by the standardized tests and engineering checks.
- *Calibration Data:*
    - Flux calibrator models, flux density run: Develop and maintain the infrastructure needed by users to establish an accurate absolute flux density calibration scale for the VLA at each observing frequency. Extensive, multi-configuration observations of calibrators are made to develop models that can be applied during the data calibration process.
    - Polarization stability and service calibration tests: Develop and maintain optimal polarization calibration infrastructure and tools for our users. In FY 2014 this includes documentation, full polarization source models and measurements of the polarization stability of the system. Service observations are also made for VLBA polarization observations to enable better calibration of VLBA data.
- *Stabilize New Additions to the VLA:* "Y27" phased array observations with the VLBA, sub-arrays, fast dumps. Although observing with the VLA phased array with all available antennas (Y27) is possible, there are still issues that arise occasionally as this new capability is exercised. Similarly, sub-arrays and fast dumps may continue to have issues that need to be worked out. These issues will be trouble-shot and solved as they arise.
- *Evaluation of a New Atmospheric Phase Interferometer (API):* The API is used to continuously measure the atmospheric stability, providing a means to estimate the needed observation cycle times when using fast switching phase calibration at the highest frequency bands and to guide the dynamic scheduler as to when the weather conditions are appropriate for high frequency observations. The existing API is beginning to fail and a new system will be ready for testing and evaluation during FY 2014.

Support for the Calls for Proposals and associated documentation updates and software testing have milestones on a cyclic time scale that is matched to the proposal cycle. Understanding and characterizing, e.g., antenna positions, gain curves, collimation and pointing have a high impact during and just after each array re-configuration and then decrease to a lower level of effort that is needed to support antennas coming back to the array after major maintenance. ACU evaluation will be linked to when those antennas return to the array after maintenance (one is expected to be installed during Q2 and one during Q4). Thus, these tasks have milestones after each configuration as well as a base of continuing effort. System health and data QA evaluation along with polarization service observations and support of phased-array observations require an on-going level of effort that is expected to remain relatively constant through out the year.

Array Operations

Array Configurations: Over a 16-month period the VLA cycles between 4 primary configurations, and 3 "hybrid" configurations, in order to provide sensitivity to different spatial scales as needed to achieve various science goals. Re-configurations occur every four months, to ensure that a particular configuration cycles through all the seasons averaged over multiple configuration cycles. These antenna moves require most of the site staff (typically 10 persons for each of two transporters), and can require anywhere from one to three weeks each, depending on which configuration is being set. Array configuration changes along with transportation for antenna overhauls results in approximately 60 antennas being relocated annually. All moves require track crew, antenna mechanics, transporter operators, electricians, and receiver, cryogenic, fiber optic, and LO/IF technicians. Personnel involved in the array reconfigurations are used to perform maintenance activities (antenna overhauls, track maintenance, electrical infrastructure maintenance, receiver, fiber optic, and LO/IF maintenance) at other times, and are highly integrated with the rest of operations.

VLA Reconfigurations

To Config	B	BnA	A	D	DnC	C
Start	9/23/2013	1/13/2014	2/3/2014	5/27/2014	9/8/2014	9/29/2014
Complete	10/4/2013	1/17/2014	2/14/2014	6/13/2014	9/12/2014	10/10/2014

Operating Model: Currently, the VLA is manned 24 hours per day, seven days per week from the VLA site by six array operators on rotating shifts. Along with his supervisory duties, the VLA supervisor also acts as the scheduler for major maintenance and overhauls for the VLA and the VLBA. Additionally, custodians and security guards are present for all evening and night shifts as well as weekend day shifts. VLA Operations continues to explore the possibility of moving operator control to Socorro for the evening and night shifts in order to achieve savings in vehicle use and to reduce the number of operators needed to maintain full operational coverage. The staff that provides custodial and security services will continue to work at the site. Maintaining appropriate levels of safety for site personnel and equipment will be a major factor in whether this plan will move forward.

4.2.2 Upgrade and Enhancement Projects

VLA Antenna Control Unit (ACU) Replacement Project: The electronics parts to repair the existing ACUs are no longer available. Antennas with failed ACUs would no longer be able to participate in observations, posing a serious operational risk. All of the legacy VLA antenna control units must be replaced with newer technology units, which enables a more supportable ACU, as well as eliminating some inherent problems with the original design and greatly improving the pointing and tracking capabilities of the antennas. The first new VLA ACU was installed in antenna 21 during the last quarter of FY13. The 2nd and 3rd ACU replacements will occur in FY 2014, in Q2 and Q4. Additional ACUs will be replaced as funding permits. Once an antenna has been outfitted with a new ACU its performance will be evaluated by scientific staff.

4-Band Feed Development Project: To date, 4-band observations on the VLA require special dipoles, designed by W. Erickson, that cross under the subreflector and attach to the quadrupod legs. Although these dipoles are adequate for observing at 4-band, their presence reduces the sensitivity at L and S-bands, and the dipoles must be mounted temporarily for observing "campaigns," requiring manpower both to mount and remove the dipoles. A new design is being explored in collaboration with Steve

Ellingson of Virginia Tech that would "strut straddle" the quadrupod legs in a square shape with minimal blockage of the subreflector, and so could be left up permanently. The new 4-band feed development project will be completed by the end of FY 2013. At the time of writing tests indicate that the feed has not yet met sensitivity requirements, but additional testing continues. In the event that the new feed design does not meet the required sensitivity with minimal blockage then the legacy Erickson dipoles will be refurbished for use in the next 4-band observing campaign, and will undergo testing and scientific verification by scientific staff.

VLA Solar Retrofit: The present receivers that were installed as part of the EVLA Construction Project do not support solar observing. The long-term plan is to add solar capability to the L, S, C, X and Ku-Band receivers. In FY 2013 three C-band receivers were modified. In FY 2014 three additional C-band receivers will be modified completing the C-band solar modifications. Six L-band receivers and six Ku-band receivers will also be modified with solar capability. Performance of these receivers for solar observing will be evaluated by scientific staff in conjunction with participants from the RSRO program.

C and L-Band Thermal Gap Retrofits: The new thermal gap designs were completed in late FY 2012. These thermal gaps have been shown to decrease the noise temperature of both the C and L-band receivers and significantly improve performance. At the end of FY 2013 three C-Band and six L-band receivers had been retrofitted. Three additional C-band and six L-band receivers will be modified in FY 2014.

Card Cage Upgrades: Approximately 3-4 receiver card cage failures are reported each week for the VLA, which make the receiver involved unusable. A revised Front End card cage design to address these reliability issues was completed in FY 2013. The rollout of upgrades will begin in FY 2014 Q1, with 12 upgrades completed each quarter.

VLA 3-bit Sampler Upgrade: There are 224 3-bit sampler boards installed in the VLA, which provide the widest bandwidths. Some of the boards do not perform as well as others, and installation of all the best performers in the array has reduced the number of good spare sampler boards below a comfortable level. The current 3-bit sampler chip is obsolete, so a board that uses a commercially available chip is being designed and tested. The new Data Transmission System (DTS) transmitter module 3-bit sampler boards will be installed in 2 modules in the array by end of Q2. An analysis and presentation on performance will be given to senior staff in Q3.

VLA Atmospheric Phase Interferometer (API) Hardware Upgrade: A major upgrade to the API was started in FY 2013 to address technical issues that make the existing system prone to failure, and which also includes installing two additional dishes (for a total of four) to provide 2-dimensional information about the structure function of the troposphere. A complete new set of electronics and software has been installed. The installation of the new API system at the VLA will be completed in FY 2014 Q1, with testing by scientific staff continuing into Q2. If the performance of the API meets specifications its output will be incorporated into the VLA dynamic scheduling system by the end of Q3.

Capability Enhancements for Semesters 2014A, 2014B, and 2015A

The VLA continues to provide new capabilities to our user community to optimize and enhance the science that can be done with the array. This strategy has proven to be effective in keeping our users engaged, and it is a critical factor in keeping the scientific productivity of the VLA high. To this end, we continue to provide incremental capability enhancements above and beyond our operational efforts. During the EVLA project, development and commissioning of new capabilities were a top priority. Now, however, Operations has taken center stage and the pace of development of new capabilities is now matched to the available FTEs who are not fully engaged with daily operations.

Enhancements in a number of areas are identified in the table below. Note that the rate at which a capability moves from RSR to SR to a General Observing mode depends upon the complexity of the task, the available manpower of RSRO participants, funding for hardware (in some cases) and the available FTEs within NRAO. Some assumptions about effort from participants in the RSRO program have been made in the schedule below; since these resources lie outside NRAO's control, the delivery schedule for these capabilities may vary from that outlined below.

Enhanced Observing Mode Capability	**2014A**	**2014B**	**2015A**
Mixed 3/8-bit samplers for increased flexibility to observe mixed line and continuum projects	SR	General	General
P-band Stokes I observations	SR	SR	General
Dump times below 1 s (but greater than 50 ms)	SR	SR	General
Recirculation x 4 in the correlator to increase the spectral resolution	RSR	SR	General
8 spectral windows (VLBA channels) recording mode for Y27 to match VLBA PFB/DDC-8	RSR	SR	General
Sub-arrays using the 3-bit samplers	RSR	RSR	SR
On-the-fly interferometric mosaicking	RSR	RSR	SR
Single antenna sub-array for VLBI while observing a standard VLA program with remaining antennas ("Y1")	RSR	RSR	SR
Dump times below 50 ms and/or data rates above 60 MB/s	RSR	RSR	RSR
Pulsar de-dispersion mode	RSR	RSR	RSR
Real-time transient detection mode	RSR	RSR	RSR
New 4-band system (58-84 MHz)	RSR	RSR	RSR
P-band spectral line and/or polarimetry	RSR	RSR	RSR
Pulsar phase binning	RSR	RSR	RSR
Increase # sub-bands per 8-bit baseband from 16 to 32	RSR	RSR	RSR

Installation of the new low frequency system for the VLA that has been developed in collaboration with the Naval Research Laboratory will be completed in FY 2013. Scientific testing and verification will continue into FY 2014, and development of polarimetry and spectroscopic capabilities with these receivers at P-band are noted in the table above. At 4-band the potential use of new strut-straddling feeds depends on the outcome of tests taking place towards the end of FY 2013. If the new design does not meet specifications some effort may be required to re-commission the Erickson dipoles, including scientific verification tests.

<u>Operational Enhancements</u>

Several enhancements to VLA calibration procedures and scheduling are planned for FY 2014:

- *<u>Implement Referenced Pointing Using Multiple Spectral Windows:</u>* Referenced pointing has been implemented using a relatively narrow bandwidth associated with a single spectral window, with that window being at a fixed relative position in the baseband. In addition, the reference antenna is currently fixed. Options for selecting the reference antenna, and the use of more complex combinations of spectral windows allowing for mitigation of RFI and pointing on weaker sources will be tested.
- *<u>Implement Tipping Scans for Opacity Correction:</u>* When it is not possible to observe an absolute flux density calibrator within the same elevation range as that spanned by the science target, it is necessary at high frequencies to estimate the difference in atmospheric opacity between the calibrator and the science target. A tipping scan can be used to derive the zenith opacity during

an observation to characterize elevation-dependent gain terms, improving the accuracy of the absolute flux density scale. Although this was possible with the old VLA system, it has not yet been implemented with the EVLA, and is currently potentially limiting the absolute flux density calibration accuracy at high frequencies.

- *Develop a Method to Use Switched Power Values for Improved Calibration:* The switched power calibration values can be used to remove gain variations as a function of time if the measured system power is stable. Thus, it has the potential to decrease observing overhead and simplify the post-processing steps in several observing bands. Several problems remain to be solved with respect to the use of switched power calibration, and commissioning of the switched power system and development of the best practices for how to use the values will continue into FY 2014.
- *Pipeline Heuristic Development:* The VLA Calibration Pipeline currently delivers calibrated visibility data for continuum experiments. Heuristics will continue to be developed during FY 2014 to extend the use of the pipeline to those experiments using "weak" calibrators (relative to the fractional bandwidth, including spectroscopy), and to improve the flagging heuristics for L-band.
- *High Frequency Scheduling Improvements:* Currently the VLA dynamic scheduler uses only the "current" weather conditions and tropospheric phase stability to determine whether the conditions are suitable to observe at high frequencies. During FY 2014 some effort will go into investigating the extent to which weather predictions can be incorporated into the dynamic scheduler.

4.2.3 Maintenance and Renewal

New Mexico Operations also supports over 3,300 modules, power supplies, and receivers for the VLA, VLBA, and the ALMA Back End, as well as all mechanical parts in the antennas, such as motors, gears, and structural elements. Support work includes addressing the over 3000 maintenance forms generated yearly and requires engineers and technicians to investigate, diagnose, trouble shoot and ultimately resolve these reports. To this end, there is a daily maintenance meeting attended by the group leads of all electronics and engineering service personnel to review all new problem reports to assure all problems are assigned to the proper group. Older forms are reviewed to avoid stagnation of those issues and to identify recurring issues that may require an improvement or redesign of a module or procedure. Technicians are also available for after-hours callouts to address problems that seriously impact the safety of the array, such power failures, electrical problems, antennas stuck in un-safe positions. Callouts also occur if there are more than three antennas unusable for astronomy due to problems that may not be safety related, such as warmed receivers following a power glitch. Specific maintenance activities are described further below.

Antennas: VLA antennas are routinely cycled through the Antenna Assembly Building for checkout and overhaul throughout the year. Under normal maintenance circumstances, up to eight antennas per year could be cycled through the assembly building. In FY 2014, several antennas will be upgraded with new control circuitry (ACU), and as such each will require roughly double the period of time given that these will be the first antennas which undergo this retrofit. In FY 2014, we plan to perform overhauls on six antennas. In addition to the mechanical work associated with the ACU upgrade, the overhaul process includes (1) structural inspections that may reveal existing and potential problems; (2) the installation of upgrades to mechanical parts, electrical systems and electronic equipment; (3) addressing maintenance issues that require the Antenna Assembly Building resources, such as azimuth gear and bearing replacement; (4) inspecting and changing oil in gear boxes; (5) carrying out touch-up painting on the structure; and (6) repairing and replacing parts as needed.

After a one-year hiatus, the process of replacing one antenna azimuth bearing per year will resume in FY 2014.

Preventive maintenance is conducted in the field to inspect, clean, and lubricate each antenna's Focus Rotation Mount (FRM) and azimuth and elevation bearings. Antenna mechanics routinely check grease for metal chips on all antennas in the field so as to be alerted for potential failure of moving parts. This is especially important for the sustainability of the azimuth gears. The goal is for each antenna to undergo this maintenance every six months. The antenna mechanics will continue to respond to mechanical/structural problems that occur regularly, such as inoperative motors, water leaks into the antenna, equipment rooms, broken anemometers located on the dish lip, realigning misaligned FRMs, and addressing other antenna issues brought to their attention. The two transporters used to move the antennas during reconfigurations undergo maintenance and repair between move periods. Maintenance on the almost forty year old transporters includes servicing the motors, checking the generators that keep critical power to the antenna during a move, lubricating the moving parts, checking on the twenty-four wheel axles and wheels and maintaining electrical and hydraulic systems. Antenna mechanics also inspect the 72 concrete antenna pads to ensure their structural integrity and to measure for signs of shifting. If the tripod legs of the pad were to shift too far apart, the antenna would not be able to be bolted to the pad.

Track: During FY 2014, inspection of the VLA railroad tracks will continue, checking for problems that could compromise the safety of the transporters that carry the antennas during array reconfigurations and other antenna moves. These inspections also guard against problems that could jeopardize the safety of the maintenance rail vehicles that are used by technicians to service the antennas.

Maintaining track integrity requires specialized railroad repair vehicles and equipment, as well as ballast, rails and track sections. The supply of ballast purchased with ARRA stimulus funding in FY 2010 is quickly being exhausted, so a line item for this has been added back into the operations budget. The VLA track contains approximately 200,000 ties. With a nominal life expectancy of 25 years for pine railroad tie, ideally we would replace on the order of 8000 ties per year, or more given the dry conditions at the site. This task alone would require the constant attention of 7 FTE over the course of a year. Given that the track crew is comprised of 6 FTE, and that there exists other necessary maintenance tasks to keep the tracks in reasonable shape, our goal is to locate and replace only 2500 ties along the approximate 44 miles of track in FY 2014.

73 intersections to antenna pads are included in the VLA Wye. As with the track cross-ties, the ties which make up these intersections must be replaced on a regular basis. Due to the complexity of rebuilding an intersection, the decision was made to replace failing intersections with fabricated concrete ties rather than wooden ones. This requires more time to accomplish than working with wooden ties, but the payoff is extended life and less maintenance. To date, approximately 10 of the 73 intersections have been replaced. Another 3 will be fabricated and replaced in FY 2014.

Site Infrastructure: The VLA site buildings, utility systems, and grounds will continue to undergo routine annual inspection and preventive maintenance in FY 2014. This includes annual road grading; roof repairs; heating and cooling systems maintenance; pest and weed control; fire brigade and emergency medical response team training; and the routine servicing of gas pumps, sewer and water supply systems, backup generator power, electrical lines, switches, and transformers, and other related systems.

In FY 2014 a plan will be developed to recommend the best course of action to take for the site's original VAX building. Also referred to as the SLOB, this building most recently housed the site's Track Crew and Fiber Group, which have since been relocated to upgraded facilities. Also, a campaign will be carried out to replace the failing transformer which supplies the VLA Activity Center, Visitor's Center, and soon to be decommissioned ALMA Test Facility.

Vehicle Support: The VLA continues to operate more than 50 vehicles and heavy equipment items, such as forklifts, cranes, loaders, tampers, backhoes, trenchers, and buses. Many of these are used daily and will continue to be routinely serviced and repaired to remain in safe, efficient working condition through FY 2014 and on.

Electronics Division Support: In addition to the upgrade projects described above, the New Mexico Electronics Division is responsible for maintaining all VLA electronic components and the WIDAR Correlator. Routine work for FY 2014 will consist of the following:

- Overhaul at least 30 receiver cold heads per quarter to keep Front Ends operating.
- Replace LNAs in 12 L-band receivers (1 per month) to correct wire bond breakage problem.
- Recondition and replace receiver desiccant in each of 240 units twice per year.
- Perform preventive maintenance on 25 VLA compressor lines twice per year.
- Overhaul two EVLA compressors due to normal wear-and-tear.
- Perform preventive maintenance on 4 helium circuits to maintain cryogenic performance.
- Repair and replace 24 Front End receivers per year.
- Perform checks on the Correlator boards, replace as needed.
- Perform checks of the fiber optics system to ensure proper operations, reset as needed.
- Build 20 fiber optic cables for the Computing Division and replace 20 fiber optic cables on the EVLA antenna infrastructure per quarter.
- Investigate issues with locking, fringing, output power, and general communication dropouts.
- Perform routine power supply and battery maintenance.
- Retrofit upgrades or additions to enhance equipment safety.
- Perform bench work on modules for repair or assembly.
- Monitor modules responsible for array timing, adjusting as needed.
- Perform maintenance on Antenna control units and FRM controllers.
- Replace 10 SCR driver cards in the VLA antenna servo cabinet.
- Maintain monitor for local RFI at the VLA site.
- Swap out the site weather station twice yearly for preventive maintenance.

RFI Mitigation: Plans for reducing and mitigating RFI for FY 2014 include:

- Reduce or eliminate HF & VHF RFI originating from Transporter Building florescent lighting. Current lighting interferes with the VLA low band observing and LWA observing.
- Re-enable the W8, L-band automated spectrum monitor. The legacy W8 monitor was found to produce ripples in the L-band spectrum during early EVLA observations and was disconnected.

4.2.4 VLA Major Milestones

Table XX: VLA Major Milestones

		FY 2014			
Program	**Project**	**Q1**	**Q2**	**Q3**	**Q4**
Scientific Support for Operations	Support the 2014B semester (2014 Feb 1) Call for Proposals		1		
	Support the 2015A semester (2014 Aug 1) Call for Proposals				2
	Support reconfiguration to B-config	3			
	Support reconfiguration to BnA and A-configs		4		
	Support reconfiguration to D-config			5	
	Support reconfiguration to DnC-config				6
	Stabilize VLA capabilities: Y27, sub-arrays, & fast dumps			7	
Array Operations	Array Configuration Changes	8	9	10	11
	Complete evaluation of array ops move to Socorro			12	
VLA Prototype ACU	Critical Design Review prior to 2nd installation	13			
	Install 2nd ACU		14		
	Scientific evaluation of ACU performance			15	
	Install 3rd ACU				16
VLA Solar Retrofit	Solar modification of 3 C-band receivers				17
	Solar modification of 6 L-band receivers				18
	Solar modification of 6 Ku-band receivers				19
VLA Thermal Gap Retrofit	Thermal gap modification of 3 C-band receivers				20
	Thermal gap modification of 6 L-band receivers				21
VLA Card Cage Upgrade	Install 48 card cage upgrades for VLA front ends				22
VLA 3-Bit Sampler Upgrade	Install 3-bit sampler PCB in 2 VLA DTS modules		23		
	Present 3-bit sampler performance analysis to NRAO staff			24	
VLA API Upgrade	Install final 2 API dishes	25			
	Incorporate API output into VLA dynamic scheduler			26	
Capability Enhancements	Define and demonstrate new capabilities for 2014B	27			
	Define and demonstrate new capabilities for 2015A			28	
Operational Enhancements	Improved referenced pointing				29
	Tipping scans implemented		30		
	Improved switched power calibration			31	
	Pipeline heuristic development				32
	High frequency scheduling improvements				33
Infrastructure Maintenance and Renewal	Antenna overhauls	34	35	36	37
	Replace azimuth bearing on one antenna				38
	Replace 2500 cross-ties				39
	Replace 3 intersections				40
	Develop proposal for VLA VAX building				41
	Replace VLA Activity Center transformer			42	
	Preventive maintenance on 90 VLA site transformers				43
	Preventive maintenance on hatch gear		44		45

Milestones:
1,2. Scientific Support for the 1 Feb and 1 Aug calls for proposals, including software testing and updating documentation.
3,4,5,6. Support array reconfigurations (e.g., antenna position, collimation and pointing determinations).
7. Stabilize operation of Y27, sub-arrays, and fast dumps.
8. Re-configurations to B config.
9. Re-configurations to BnA and A configs.
10. Re-configuration to D config.
11. Re-configuration to DnC config.
12. Complete evaluation of whether evening and nighttime array operations can be moved to Socorro.
13. Critical Design Review of ACU prior to 2nd installation.
14. Install 2nd ACU.
15. Scientific evaluation of ACU performance.
16. Install 3rd ACU.
17. Install solar modifications on 3 VLA C-band receivers.

Deliverables:
[1,2] Documentation and software testing.
[3,4,5,6] Arrays ready for science observing.
[7] Capabilities stabilized, with sub-arrays and fast dumps dynamically schedulable.
[8,9,10,11] Arrays ready for scientific validation prior to observing.
[12] Decision on implementation of move of evening and nighttime operations to Socorro.
[13] CDR documentation.
[14] Operational antenna hardware.
[15] Report on pointing performance of antenna with new ACU.
[16] Operational antenna hardware.
[17,18,19] Operational antenna hardware.
[20,21] Operational antenna hardware.
[22] Operational antenna hardware.
[23] Operational antenna hardware.
[24] Presentation.

18. Install solar modifications on 6 VLA L-band receivers. 19. Install solar modifications on 6 VLA Ku-band receivers. 20. Install thermal gap on 3 VLA C-band receivers. 21. Install thermal gap on 6 VLA L-band receivers. 22. Install 48 card cage upgrades for VLA front ends. 23. Install 3-bit sampler PCB in 2 VLA DTS modules. 24. Present performance analysis to NRAO staff. 25. Install final 2 API dishes. 26. Incorporate API output into VLA dynamic scheduler. 27. Define and demonstrate new SR and general capabilities for 2014B. 28. Define and demonstrate new SR and general capabilities for 2015A. 29. Improved referenced pointing. 30. Tipping scans implemented. 31. Improved switched power calibration. 32. Pipeline heuristic development. 33. High frequency scheduling improvements. 34,35,36,37. Overhaul total of 6 antennas. 38. Replace azimuth bearing on one antenna (probably EA21). 39. Replace 2500 ties. 40. Replace 3 intersections. 41. Develop proposal for VLA VAX building. 42. Replace VLA Activity Center transformer. 43. Preventive maintenance on 90 VLA site transformers. 44,45. Preventive maintenance on hatch gear.	[25] Operational antenna hardware. [26] API incorporated into operations following scientific evaluation. [27,28] New capabilities for SR and General observing documented and demonstrated operational through the dynamic scheduler. [29] Robust referenced pointing. [30] Tipping scan capability ready for testing. [31] Robust switched power calibration. [32] Pipeline operational for weak calibrators. [33] Include cloud camera and weather predictions in dynamic scheduler. [34,35,36,37] Antennas overhauled and returned to array. [38] Azimuth bearing replaced and returned to array. [39] Railroad hardware. [40] Railroad hardware. [41] Proposal. [42] Electrical hardware. [43] Electrical hardware maintenance. [44,45] Electrical hardware maintenance.

4.3 Very Long Baseline Array

Overview

In FY 2014 the VLBA Sensitivity Upgrade will be completed and the VLBA will transition to a fully operational state whose science will be dominated by large observing programs. New capabilities will continue to be added for our user community but the emphasis in telescope operations for FY 2014 will be to stabilize and document existing capabilities, as well as increase the ease of use and reliability of the array. Incremental capability enhancements include implementing the use of a single VLA antenna in a sub-array for VLBI, the development of a rapid response for triggered VLBA observations, and demonstrating a narrow bandwidth, quasi-real-time correlation capability that would be suitable for real-time fringe checks and spacecraft tracking. Due to manpower limitations, implementing some of these new capabilities will require community participation in the VLBA version of the Resident Shared Risk Observing (RSRO) program. In addition to a regular program of infrastructure maintenance and renewal, there will be several upgrade projects primarily focused on retiring legacy hardware and software systems to ease operational loads.

4.3.1 Operations

Observing Programs

The NRAO VLBA will offer three types of observing programs for our users: General Observing, Shared Risk Observing (SRO) and Resident Shared Risk Observing (RSRO). The VLBA General Observing program comprises access to well-tested observing modes using the new Sensitivity Upgrade equipment that provides data rates up to 2 Gbps. For semester 2014A two observing systems are available within the "RDBE" digital backend units: the relatively limited Polyphase Filterbank (PFB) and the more flexible Digital Down-Converter (DDC). Two RDBEs using the DDC observing system offer 8-channel modes that are equivalent to what was available with the legacy system. The new C-band receivers provide wider bandwidth coverage than previously possible and allows for observations of the excited OH line at 6.0 GHz and the methanol line at 6.7 GHz. In addition, it is possible to combine the VLBA with the phased VLA (phasing all VLA antennas together, "Y27"), GBT, Arecibo and Effelsberg. The observing system that can be used for General Observing depends upon what is available for each station (e.g., Arecibo and Effelsberg only support the PFB mode while Y27 only supports a limited, 4-channel DDC General observing mode). The Calls for Proposals identify explicitly what the available options will be for each semester.

The SRO program allows users access to capabilities that can be set up via the standard VLBA software packages and run without intervention, but are not as well tested as General capabilities. The Shared Risk capabilities being offered for semester 2014A comprise any narrow bandwidth observing modes used in conjunction with the phased VLA ("Y27").

The RSRO program provides users with early access to new capabilities in exchange for a period of residence to help test and verify those capabilities. As an example, the phased VLA system was developed through the VLA RSRO program. For FY 2014 NRAO is encouraging additional RSRO participation to expand the phased VLA and High Sensitivity Array (HSA) capabilities, implement the use of a single VLA antenna in a sub-array for VLBI observing while the remaining VLA antennas perform VLA observations ("Y1"), develop a rapid response (5 to 10 minutes latency) for triggered VLBA observations, and develop a narrow bandwidth, quasi-real-time correlation capability that would be suitable for real-time fringe checks and spacecraft tracking.

Scientific Support for Maintenance of Receiver, Antenna, and Array Performance

As the VLBA Sensitivity Upgrade is almost completed the telescope is now transitioning to an operational state in which a significant fraction of the effort goes toward maintaining array performance and ensuring that our user community has access to quality instrumentation and updated information to effectively use the VLBA. Operational tasks that will be carried out by the scientific staff during FY 2014 include (but are not limited to):

- *Support Calls for Proposals:* Prepare user documentation for offered capabilities before the call goes out, provide scientific testing of user tools needed to prepare proposals (e.g., Proposal Submission Tool, EVN Sensitivity Calculator), provide technical reviews for proposals and evaluate proposals for Resident Shared Risk contributions.
- *Hardware, Software, and Operational Documentation:* Write technical documentation detailing hardware and software functionality for staff and users, develop and improve operational procedures and write documentation for the operations staff. This includes updating the VLBA "Operational Status Summary" before each Call for Proposals.
- *Track and Measure VLBA Sensitivity, Pointing, Focus:* Characterize the sensitivity, pointing and focus of each antenna at each band. This must be done periodically as receivers and equipment are replaced or as software is upgraded.
- *Clock Maintenance:* Accurate time keeping is central to VLBI, and is provided by hydrogen masers and reference signals inserted into the astronomical data. Scientific staff and data analysts perform quality assurance checks periodically.
- *RFI Characterization and Mitigation:* Run RFI tests to characterize and help mitigate RFI contamination in the observing bands.
- *System Health and Maintenance Feedback:* Run routine health checks and critically analyze the data to determine if there are any hardware failures that must be followed up with maintenance tickets.
- *Data Quality Assurance Checks:* Evaluate data quality and run test observations to identify and diagnose problems that are not caught by engineering checks. In particular, potential issues with the new DDC observing modes will require continued vigilance during FY 2014.
- *Calibration of the RDBEs:* New switches will be installed by the end of FY 2013 to enable the use of two RDBEs simultaneously, providing the 8-channel observing mode with the DDC. Scientific verification of the dual RDBE operation will continue into FY 2014, along with establishing calibration procedures for the new equipment.
- *Stabilize VLBA+Y27/GBT Operations:* Although observing with the VLA phased array with all available antennas (Y27) is possible, there remain occasional issues as these capabilities are exercised with the new Sensitivity Upgrade hardware. A significant effort will be made during FY 2014 towards stabilizing operation of these observing modes.
- *Coordination with Other Observatories for Global mm VLBI and the HSA:* The VLBA occasionally observes in parallel with other observatories, as requested by users whose scientific goals require the inclusion of baselines to large-aperture and/or distant facilities. Scheduling and correlation of these observations requires coordination with local schedulers at each participating observatory, a significantly more complex process than normal VLBA-only observations require.

As for the VLA, support for the Calls for Proposals and associated documentation updates and software testing have milestones on a timescale matched to the proposal cycle. Unlike the VLA, the VLBA does not reconfigure its antennas so the measurement and characterization of system health, gain curves, receiver collimations, etc., is a continuous effort tied to the regular maintenance activities.

Array Operations

The VLBA is operated twenty-four hours a day, seven days a week, supported by five operators stationed at the operations center in Socorro and by two site technicians per station living within driving distance of each site. The array operators also concurrently operate the DiFX Correlator. Two Data Analysts prepare the proper scripts for the correlation and perform quality checks on the correlated data. The supervisor for the VLBA operators also dynamically schedules the array from a list of approved projects, and manages the software to log maintenance and problem reports for both the VLA and the VLBA. A Media Specialist ensures that recording media are available at the sites and manages the software used to track the media. Data are recorded at the VLBA sites on the disk packs on the Mark 5A/C recorders as appropriate, and shipped to the Correlator for processing. The media are then returned to the sites. The VLBA site techs perform all manner of maintenance and diagnostics tasks, as well as ensuring the recording media is loaded and then shipped to the appropriate Correlator. These techs are available for after-hours call-outs to address failures that impact antenna performance as well as issues related to the safety of the antenna (power outages, severe weather conditions, etc.).

Possible changes to this operation model may take place during FY 2014 that may include combining the VLBA and VLA operator pools, if it becomes feasible to move the VLA operators to the Socorro center for some shifts.

4.3.2 Upgrade and Enhancement Projects

Retirement of the VLBA VMEs: The legacy VME computers that control the operation of the VLBA antennas are reaching end-of-life. As part of the Sensitivity Upgrade project, new hardware has been installed at the VLBA stations; all of this new hardware is controlled with a modified version of the EVLA Executor. The computer which hosts the Executor will be used to replace the VMEs, but is not currently able to communicate with the legacy VLBA hardware. An interface box will be designed, built, and installed in the laboratory for software development in FY 2014 Q1. An operational unit will be installed at a VLBA site in Q3 for further testing.

Retirement of VLBA Legacy Recording System: As part of the ongoing process to retire the legacy VLBA recording system and transition to the new Sensitivity Upgrade equipment, NRAO will complete the transition of any VLBA observing projects still requiring the legacy recording system to using the DDC in Q3. As soon as this transition is complete, the Mark 5A recording units will be re-integrated into the correlator to increase the number of available playback units.

C-Band Receiver System Completion: Ten 4-8 GHz C-band receivers were installed in the VLBA in FY 2012 but some work still needs to be done. The Electronics Division needs to complete and test the spare VLBA C-band receiver (Q2) and upgrade two of the early C-band receivers (Q4). Scientific staff will then evaluate system performance.

Capability Enhancements for Semesters 2014A, 2014B, and 2015A

The VLBA continues to provide capability enhancements to our user community in an effort to increase the ease of use and the science that can be done with the array. To this end, we continue to provide incremental capability enhancements above and beyond the operational efforts outlined above. The pace of development for capability enhancements is matched to the available FTEs who are not fully engaged with daily operations.

The VLBA can be operated as a stand-alone interferometer, in combination with other NRAO telescopes (phased VLA and the GBT) and as the foundation to the High Sensitivity Array (HSA) in combination with the collaborating observatories (Effelsberg and Arecibo). We therefore split the planning for future enhancements into two categories: 1) those internal to NRAO (where the priorities are uniform across the observatory); and 2) those that depend on effort from (and priorities of) other observatories.

Enhancements that can be managed solely within the NRAO are identified in the table below. The rate at which a capability moves from being an RSRO to SRO to a General Observing capability depends upon the complexity of the task, the available manpower of visiting, resident experts, funding for hardware (in some cases) and the available FTEs within NRAO. Some assumptions about effort from participants in the RSRO program have been made in the schedule below; since these resources lie outside NRAO's control, the delivery schedule for these capabilities may vary from that outlined below.

Enhanced Observing Mode Capability	**2014A**	**2014B**	**2015A**
Develop Y27 mode to match VLBA PFB and 8-channel dual-RDBE DDC mode ("PFB/DDC-8").	RSR	SR	General
Develop single antenna sub-array for VLBI while observing a standard VLA program with remaining antennas ("Y1").	RSR	RSR	SR
Implement ultra-rapid response capability.	RSR	RSR	RSR
Develop a narrow BW, quasi-real-time correlation capability to support real-time fringe checks and spacecraft tracking.	RSR	RSR	RSR

In addition to the enhancements described above, it is a high priority to enable a spectroscopic mode for the non-NRAO HSA antennas, to make available the full collecting area of the HSA for spectroscopic projects. This requires a DDC-compatible observing mode on Effelsberg and Arecibo, and although new instrumentation has been developed with similar general specifications to those of the DDC, detailed compatibility of both operation and control between the VLBA and these other stations has yet to be established. NRAO staff will work with these external observatories during FY 2014 to define a development path to complete this process.

4.3.3 Maintenance and Renewal

The VLBA is approaching the twentieth anniversary of the end of its construction phase. Some critical components are becoming more problematic as they reach the end of their normal lifespan. These items include the masers, the azimuth track and the grouting, elevation bearings, and rust problems at the Hancock and Saint Croix sites. Maser issues are likely to continue in 2014 – two masers failed in FY 2013. Symmetricom, the supplier of these masers, will only consider repair of the newer models, and not the older ones. We are currently renting one maser and will probably rent another in FY 2014. One of the two failed masers is repairable, but the other cannot be repaired. The Saint Croix and Hancock sites, due to their local weather conditions, will soon require extensive re-painting to control rust on the structure. The local technicians perform spot painting on areas showing signs of rust, but more extensive painting is likely to be needed at some point. The grout on the rails of the azimuth track deteriorates with time and typically one antenna per year has needed re-grouting, patching of the concrete, and/or replacement of the rail, making it probable that this may be needed in FY14. Other electronic components are also on the verge of becoming unsupportable due to obsolete repair parts and/or incompatibility with recent electronic updates. Those potential failures that pose the most serious risk to operations are being addressed through upgrade projects.

Antennas: In FY 2014, the North Liberty and Hancock VLBA stations are scheduled to receive major maintenance visits by the VLBA Tiger Team comprising personnel from the antenna mechanics and servo groups. The number of visits will remain at 2 per year for FY 2014 (compared with 3 per year in FY 2012 and earlier) in order to reduce operations costs. We will continue to monitor the impact of the reduced Tiger Team visits to VLBA stations. The Tiger Team will inspect, repair, and upgrade mechanical and electronic components, as needed. Gears will be greased and checked for early signs of potential failure, and elevation bearings checked. Most, if not all, of the VLBA antennas will likely need both elevation bearings replaced over the next five years. Detailed descriptions of past VLBA Tiger team tasks are documented in the Antenna memo series available on the VLBA web site.

Electronics Division Support: Each VLBA antenna contains eight cooled receivers, two compressors and numerous other electronics components. Although some of these components are supported in the Socorro labs, for efficiency, many are sent to the 20 VLBA site techs for repair and maintenance. In FY 2014 sites techs will continue to carry out the bulk of the routine maintenance tasks of:

- Inspecting and lubrication of FRM, Az/El drive motors, encoder and pintle bearings, elevation gears, elevation hoist, change gearbox oil, etc.
- Check/test encoder motor tachometers, servo limits, ACU, vacuum pumps, all HVAC systems, dry air system, weather station equipment, etc.
- Ensure safety equipment such as UPS's and generators, emergency power, fire alarm systems, fire extinguishers, security systems, etc. are operating normally.
- Ensure all other preventive maintenance tasks such as checking motor brushes and commutators are checked and replaced, check of Azimuth wheel position, check for metal in grease samples, cable wrap maintenance, replace oil filters, etc., completed in a timely fashion.
- Repair some VLBA specific modules to relieve some of this task from the technical staff at the DSOC and the VLA sites.
- Maintain the grounds and building infrastructure.
- Other diagnostic and repair tasks as needed.

Other tasks performed by the Electronic Division personnel include support for the Front Ends. Because some of the VLBA receivers still use old-style LNAs (e.g., S-band) that are no longer serviced by CDL, occasionally an entire receiver may have to be rebuilt with new LNAs in order to maintain full operational functionality. The Division is also responsible for the repair of 24 VLBA recording and playback modules, and repairs 100 Mark 5 disk packs per year.

The maser lab is also part of the Electronics Division. It is currently in need of modernization, and NRAO will develop a plan for addressing the long-term support of the VLBA and VLA masers during FY 2014.

RFI Mitigation: RFI mitigation efforts in FY 2014 will address the Brewster, WA 6cm RFI problem by working with the "USEI-Teleport" engineers to reduce the effects of their 6676 MHz satellite uplink signal on VLBA-BR C-band Methanol line observing.

4.3.4 *VLBA Major Milestones*

Table XX: VLBA Major Milestones

		FY 2014			
Program	**Project**	**Q1**	**Q2**	**Q3**	**Q4**
Scientific Support for Operations	Support the 2014B semester (2014 Feb 1) Call for Proposals		1		
	Support the 2015A semester (2014 Aug 1) Call for Proposals				2
	Complete verification tests of VLBA dual RDBE system		3		
	Define and document calibration procedures for VLBA dual RDBEs				4
	Stabilize VLBA + Y27/GBT operations		5		
Retirement of VLBA VMEs	Design, build, and install VLBA Control Computer Interface Box in laboratory	6			
	Install VLBA Interface Box in VLBA Antenna			7	
Retirement of Legacy Recording System	Complete transition of projects using legacy system to DDC			8	
	Re-integrate Mark 5A recorders from sites into correlator			9	
C-band Receivers	Complete construction of spare VLBA C-band receiver		10		
	Upgrade 2 pre-production VLBA C-band receivers				11
Capability Enhancements	Define and demonstrate new capabilities for 2014B	12			
	Define and demonstrate new capabilities for 2015A			13	
Infrastructure Maintenance and Renewal	Tiger Team maintenance campaigns			14	15

Milestones:
1,2. Scientific Support for the 1 Feb and 1 Aug calls for proposals, including software testing and updating documentation.
3. Complete verification tests of VLBA dual RDBE system.
4. Define and document calibration procedures for VLBA dual RDBEs.
5. Stabilize VLBA + Y27/GBT operations.
6. Design, build, and install VLBA Control Computer Interface Box in laboratory.
7. Install VLBA interface box in VLBA antenna.
8. Complete transition of projects using legacy system to DDC.
9. Re-integrate Mark 5A recorders from sites into correlator.
10. Complete construction of spare VLBA C-band receiver.
11. Upgrade 2 pre-production VLBA C-band receivers.
12. Define and demonstrate new SR and general capabilities for 2014B.
13. Define and demonstrate new SR and general capabilities for 2015A.
14. Tiger Team maintenance visit to North Liberty.
15. Tiger Team maintenance visit to Hancock.

Deliverables:
[1,2] Documentation and software testing.
[3] Operational dual RDBE system.
[4] Documentation.
[5] Capabilities stabilized.
[6] Operational hardware.
[7] Operational hardware.
[8] Complete transition of projects using legacy system.
[9] Operational hardware and software replacement.
[10,11] Operational hardware.
[12,13] New capabilities for SR and General observing documented and demonstrated operational.
[14,15] Antenna and receiver maintenance.