Assembly, Integration, and Verification (AIV) Concept

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1.1	2019-01-19	AIV-WG		Reorganized document and incorporated comments and additions from v1.0; draft provided to project office per scheduled deliverable
1.2	2019-02-27	AIV-WG		Further reorganization and streamlining, implemented suggestions from WG feedback
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3	2019-07-09	M. McKinnon	All	Copyedited for clarity
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A.1	2019-07-26	R. Selina, L. Leyba-Newton	3, 8, 10.	Updating for Concepts & Stakeholder Requirements Review. Added summary, infrastructure and milestone sections.
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B	2019-08-27	A. Lear	All	Prepared PDF for approvals & release of v.B.
B.1	2019-11-05	C. Langley	Many	Incorporated RIDs from Stakeholder Readiness Review
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C	2019-12-02	A. Lenox, A. Lear	All	Prepared PDF for approvals & release of v.C.

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1 Introduction

1.1 Purpose

This document provides a concept for the Next Generation Very Large Array (ngVLA) System Assembly, Integration, and Verification (AIV). This is one of the identified lifecycle stages of the ngVLA, and this concept will be used to identify requirements relevant to this stage of the project lifecycle that must be supported by the design. The description, approach, and functions associated with key organizational interfaces during AIV will also be explored.

1.2 Scope

This document provides a qualitative view both of the overall AIV process and the activity and interactions between the System AIV Integrated Product Team (IPT) and other ngVLA construction teams. The assembly, verification, and handoff of the civil, hardware, and software deliverables will be described, along with the integration and system-level testing that will subsequently be performed.

As a concept, neither specific technical requirements, detailed product assurance requirements, permitting requirements, nor budgetary information are considered within this document's scope. These concerns will be addressed in a future AIV plan, developed to support this AIV concept.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents may not be directly referenced herein, but provide necessary context and are incorporated by reference.

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA System Engineering Management Plan	020.10.00.00.00-0001-PLA
AD02	ngVLA Operations Concept	020.10.01.00.00-0002-PLA
AD03	ngVLA System Reference Design	020.10.20.00.00-0001-REP
AD04	ngVLA Quality Assurance Plan	TBD (In prep.)
AD05	ngVLA L0 Safety Requirements	020.10.15.10.00-0004-REQ
AD06	ngVLA L0 Stakeholder Requirements	020.10.15.01.00-0001-REQ

2.2 Reference Documents

The following documents are referenced within this text or provide supporting information:

Ref. No.	Document Title	Rev/Doc. No.
RD01	ALMA Product Assurance Requirements	ALMA-80.11.00.00-001-D-GEN
RD02	B. Lopez, R. Jager, N.D. Whyborn, L.B.G. Knee, J.P. McMullin. Assembly, Integration, and Verification (AIV) in ALMA: Series Processing of Array Elements.	
RD03	R.E. Hills, A.B. Peck. ALMA Commissioning and Science Verification.	*Proc. SPIE*, *8444*, Paper 90 (2012)
RD04	D. Rabanus, M. Keating. Observatory Facility Staff Requirements and Local Labor Markets.	*Proc. SPIE*, *8449*, Paper 18 (2012)
RD05	S. Durand, ngVLA Electronics IPT Schedule.	TBD
RD06	ngVLA Change Management Plan	020.05.60.00.00-0001-PLA

3 Assembly, Integration, and Verification Concept Summary

AIV is part of the construction lifecycle stage, and starts after the design phase is completed. In this lifecycle concept document, we outline the proposed approach and guiding principles for organizing and completing the AIV of the ngVLA system. The key conclusions from this exercise are summarized below.

- There is a general *AIV process*, whereby a progressively more complex deliverable is assembled from its constituent parts into an integrated assembly with verified performance. This general process is performed by many groups at all levels of the project—from work package to IPT to system levels.
- The AIV process will be performed at the earliest level possible. Each work package group will integrate and verify their respective deliverables before delivering them to their IPT for acceptance. Each IPT will then integrate these deliverables into sub-assemblies or subsystems, verify their performance to specification, and deliver them to a *System AIV group* responsible for system-level AIV.
- The AIV process will aim for most assembly and integration taking place offsite, in controlled environments, with appropriate Quality Assurance (QA) processes. Site-based assembly and integration activities will be limited to only those required. For example, the Antenna Electronics IPT will integrate the front-end and back end assemblies prior to site installation, and the computing and software IPT will integrate the various software modules into software release packages that are delivered to AIV.
- The provider of a deliverable will be responsible for the verification testing of that deliverable. The group who receives the deliverable for integration into a higher-level element is responsible for deliverable acceptance. As part of acceptance, the receiver of the product may partially re-verify the performance of the deliverable, as in the case where shipping has occurred or parts are provided by multiple vendors. This is true for any level of the product path.
- The integration approach proposed will require a comprehensive test framework to enable validation of standalone systems as well as partially integrated systems, such as unit tests, hardware simulators, and test racks. Additionally, a complete documentation package must be formally accepted to ensure uniformity and utility. These will be deliverables of the respective IPTs.
- The System AIV group integrates the IPT deliverables into a functional system, and provides verified *functional capabilities* to a Commissioning and Science Validation (CSV) group. CSV accepts these deliverables as providing these capabilities, and then develops *observing processes* (system configuration, system and observation calibration, database pre-population, pipeline heuristics, etc.) for the required observing modes. These observing processes demonstrate how to use the functional capabilities, delivered by AIV, to achieve a scientifically useful result. The end result is the delivery of validated observing modes to Operations.
- Operations will be concurrent with the construction activities of AIV and CSV, and the associated groups will need to share array resources. Early delivery of sub-array capabilities, as well as a configuration management system and issue tracking system, will be key to managing and sharing the array resources.
- The System AIV and CSV groups will work jointly on system integration and verification during the early delivery phase of construction, bringing more resources and expertise to bear on system integration efforts. AIV and CSV will work independently once sub-array capabilities have been verified.

4 Assumptions

The items listed in this section are relevant assumptions or concepts that are not discussed elsewhere in this document.

1. As a basis for concept development, we describe the AIV of the Reference Design [AD03], with 263 antennas in the array, comprised of civil infrastructure, electronics, mechanical, and software system packages.
2. Thorough design reviews will be conducted at major project milestones. These may include a Requirements Review, Conceptual Design Review (CoDR), Preliminary Design Review (PDR), Final Design Review (FDR), Manufacturing Readiness Review (MRR), and an Operational Readiness Review (ORR). Delivery (Verification) and possibly Re-Verification reviews are also anticipated. AIV specific milestones may include a Test Readiness Review (TRR), focused on acceptance of the test plan towards AIV milestones. Safety and safe product design will be a consideration at these reviews.
3. There will be an independent configuration management process, likely developed and managed by Systems Engineering, to control significant specification or interface changes to the construction deliverables. Configuration management processes and tools that are needed for version control will be in place prior to any AIV site deployment. Changes in scope or requirements would be managed in accordance with the project-level Change Management Plan [RD06].
4. There will be a Product and Quality Assurance group (under Project Management) and associated quality assurance processes that will be in place prior to AIV activities.
5. Establishing project acceptance policy does not fall within the responsibility of AIV. Any acceptance procedures suggested or referred to in this document are superseded by procedures established by the Project Manager's office.
6. IPT construction staff are to be readily available for support during early AIV activities. This typically involves an on-site presence during the first installation of the IPT's deliverable. Some AIV expertise is intended to be drawn from the IPTs, and thus IPTs are to plan for this provision by including sufficient staff within their budget and arranging for succession planning, if needed.
7. IPTs will deliver the hardware, software, and civil/infrastructure deliverables necessary for verification and integration of capabilities on a schedule commensurate with the AIV plan. This may require partial or phased deliveries of key subsystems such as the central signal processor and signal generation and distribution system. Multiple software releases may be required with progressive functionality.
8. Management of the schedule of IPT deliveries to AIV, associated dependencies, and development of any mitigation strategies is the responsibility of the Project Management group. AIV will contribute to the integration and test task definition of the Integrated Master Schedule (IMS).
9. It is a goal to integrate software releases at cadence, and to avoid frozen software releases, as part of routine AIV activities. Enabling this regular deployment of software package releases may require additional build and test infrastructure.
10. Land use/property purchases and land use agreements will be completed prior to AIV deployments to a particular site.
11. All site civil construction activities that are needed for site system integration and verification will be in place and accepted prior to a site's AIV deployment, including outfitting of buildings with office and laboratory furnishings.
12. Logistics tools and resources (physical and human) will be in place to support efficient product flow from suppliers to antenna sites. The project will provide needed resources (physical and human) to support the planned cadence of site integrations.
13. The project will provide adequate space needed for pre-deployment activities, equipment maintenance and storage, laboratory space for an AIV test bed, and AIV staff office space.

14. A well-established integrated project master schedule that captures all AIV dependencies will be in place prior to AIV site activities.
15. There will be an issue tracking tool that tracks open action items/punch list for site activities in place prior to the start of system-level AIV and site deployments.
16. System interface testing will be executed prior to AIV site deployments. Early site integrations will be used to work out any gaps in system interface testing.
17. AIV site activities will conform to the OSHA standards for the construction industry (CFR1926). Ensuring compliance with these standards will be the responsibility of the Safety group within the Regulatory Compliance IPT.

5 Assembly, Integration, and Verification Process

AIV processes occur at multiple levels throughout the construction phase, regardless of whether a construction activity takes place entirely internally to the project or partially at an external vendor. It is important to note that AIV does not dictate acceptance criteria but carries out the process that will result in a successful handover.

For example, construction of a power supply may be formulated as the acceptance of components from external vendors, assembly and integration into a power supply module, and verification that the assembled system meets specifications. In this document, we use AIV to refer to the process through which IPT Products (defined in Section 12.2) are accepted from the construction IPTs, assembled, and integrated first into Elements and then to the Telescope System; and finally the system being verified to meet system-level technical requirements.

5.1 Process Definition

Verification is the process of evaluating deliverables to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. These conditions may include regulations, requirements, interfaces, and/or specifications that have flowed down from the project requirements. This may also include satisfying imposed documentation requirements, the successful completion of design or specification reviews, and analysis or other inspections.

During construction, verification of the individual delivered products is subject to the AIV process, regardless of whether the delivery is to the System AIV group. This process is to be carried out internally at the Work Package and IPT levels before the handover of a product to the System AIV group. This is an objective process that will help determine the overall quality of a deliverable. Throughout the construction process, best practice dictates that an overriding principle is that no group should be responsible for both the verification and acceptance of a product.

In this context, Acceptance is the declaration by the receiving party that a deliverable has been verified as defined above, and that the System AIV group may proceed to integration with reasonable expectation that the deliverable will meet the technical requirements. Prior to delivery, the IPTs shall submit a draft Verification and Validation (V&V) plan. Requirements will flow down from stakeholders and from the key science goals to the system and subsystem requirements in accordance with the ngVLA Requirements Management Plan [AD01]. These requirements will be incorporated into the subsystem Requirements Verification Traceability Matrix (RVTM), which reflects all criteria necessary for acceptance. Verification of products will occur at the IPT level, prior to delivery.

During the early delivery phase of construction, there very likely will be requirements for an IPT's deliverable that cannot practically be verified prior to integration into the larger system. In these cases, provisional acceptance or waivers will be grated, with the stipulation that these products complete their testing once the requisite capabilities exist in the integrated system.

Integration is the assembly of accepted products to form higher-level products (e.g., *articles* to *elements* or *elements* to the *telescope system*). These higher-level products provide capabilities that were not demonstrable with the lower-level products.

Finally, the integrated product must be *verified* to meet the system technical requirements, prior to delivery. The verification of system requirements will be performed on technical capabilities including interface compliance to Interface Control Documents (ICDs) and integrated functionality demonstrating that any and all technical requirements have been satisfied.

Systems with verified technical capabilities are delivered from the system-level AIV process to the CSV process. As with the acceptance from the IPTs, an agreed Capability Verification Plan will be produced prior to delivery of capabilities to CSV.

5.2 Work Package and IPT Deliverables

All IPTs (or other bodies) delivering products to the project will follow the same process. Most IPTs will have multiple types of deliverables. Deliverables include the hardware, software, firmware, test stands/equipment, test reports, civil construction, and supporting documentation.

5.2.1 Hardware

The IPTs are responsible for the design, assembly, integration, verification, and delivery of their respective hardware to the system AIV group. Upon design maturation, Line-Replaceable Units (LRUs), Articles, and Sub-assemblies may be delivered directly to the antenna assembly location, to the project warehouse for storage until such time as it is scheduled to be integrated, or to another mutually agreed upon location. Packaging for delivered hardware shall ensure the safe storage of equipment in nominal warehouse conditions.

The warehouse, which may include buildings in more than one location, is under the purview of Operations, or an operations-like entity. The warehouse building or buildings will be built early during ngVLA project construction, and may serve an alternate purpose to support construction activities prior to being transitioned to operations. A primary AIV function of the warehouse is to store electronics and other assemblies delivered by the IPTs that require safe keeping prior to antenna integration, as well as to keep an accurate inventory of these items.

5.2.2 Software

All software and firmware delivered to the project shall be version controlled and delivered with suitable automated unit, integration, and regression testing suites. Furthermore, all delivered software/firmware shall be placed under an open source license as specified by the project office. Maintenance of delivered software remains the responsibility of the delivering IPT, until the acceptance of the final product from the IPT.

The software deliverables from the IPTs will consist of subsystem software package releases, with incremental delivery of functionality. Compatibility with interfacing systems will be tested and documented for each release.

Development tools, compilers, source code, and the build system shall be delivered (as required for long-term maintenance). All delivered software and firmware products should be appropriately and uniquely identified using the native tagging process of the version control system.

AIV may perform isolated integration testing of delivered software and hardware prior to integration into elements or the full system. All external facing Application Program Interfaces (APIs) or other software interfaces must be defined in an ICD. ICDs should be documented as machine-readable interface files in the underlying programming language or languages so as to allow for automatic generation of monitor/control point interrogation, rather than in a word processing application (e.g., MS Word). The results of automated testing for conformance to the ICD should be delivered with the product.

5.2.3 Infrastructure and Buildings

Civil site construction, utility systems, buildings, and building enhancements (i.e., Radio Frequency Interference [RFI] protection, power backup and conditioning) will undergo inspection and verification equivalent to other system-level deliverables. Buildings must be delivered in a minimally outfitted condition (e.g., with planned furnishings) before integration activities start.

Civil deliverables will, by definition, be accepted in-place at the respective site. Inspection to interface requirements will be key, and critical performance requirements (e.g., thermal stability of HVAC systems or effectiveness of RFI shielding) should be demonstrated and documented by the delivering IPT prior to being accepted by the System AIV group. Document deliverables for civil construction may include, but are not limited to, as-built drawings, site maps, schematics, pneumatics, equipment specifications, and maintenance procedures.

5.2.4 Documentation

In addition to hardware and software products, IPTs (or other delivering groups) are responsible for authoring all procedures and supporting documentation associated with their delivered article and sub-assemblies. AIV will use these documents to assure an acceptable level of product support, and to confirm prior performance tests. The complete delivery package will be defined in a separate product assurance document. Required released documentation for hardware deliveries will include, but is not limited to, the following broad categories:

- Theory of Operation, including the monitoring of a device and the recovery in the case of non-normal operations.
- Product Specifications, which detail the performance and functional specifications of the deliverable.
- Interface Control Documents, which provide the interface details between the IPT's hardware and other subsystems.
- Article Test Procedures, Plans, and Results.
- Maintenance Plans and Procedures.
- Standard Operating Procedures and the associated training requirements for qualified staff.
- Safety Hazard Analysis.
- Site Protocols (environmental regulations, landowner concerns, etc.)

5.2.5 Product Test Stands and Equipment

Articles and other assemblies frequently require specialized test equipment and tools to independently verify and validate their performance outside of their subsystem environment. The design and construction of the individual product test stands, including any necessary test software (test routines or scripts), along with the procurement of specialized tooling is the sole responsibility of the delivering IPT. These will be delivered at the time of the first article so as to verify functionality during any (re-)verification process (see Figure 1).

These deliverables will be governed by the project acceptance standards, and appropriate documentation shall accompany their delivery. That is, product test stands are expected to conform to the same documentation and acceptance requirements as other hardware delivered by the IPT. Maintenance and calibration of the test stands is the responsibility of the delivering IPT during the array construction phase until acceptance of the final product delivery from the IPT. AIV is subsequently responsible for maintenance until delivery to Operations. Where appropriate and deemed useful by the Project Management Office (PMO), identical test stands shall be provided by the IPTs to production or destination facilities they use for the purpose of verification testing. In cases where a subcontractor is used, an additional test rack may be required at their location.

In some cases the IPT will be required to deliver product test stand(s) to AIV. The decision to do so for a specific product will require discussion and agreement between the PMO, AIV, and the IPT. Any test stand delivered to AIV must conform to the global project requirements that address safety, EMC/RFI, electrical, mechanical, etc., as applicable for the test stand. Test stand delivery is a special case for acceptance and shall be addressed by collaboration of the Project Engineer, AIV, and IPT Lead. AIV is responsible for procuring any other test equipment that crosses IPT boundaries and is required during antenna integration.

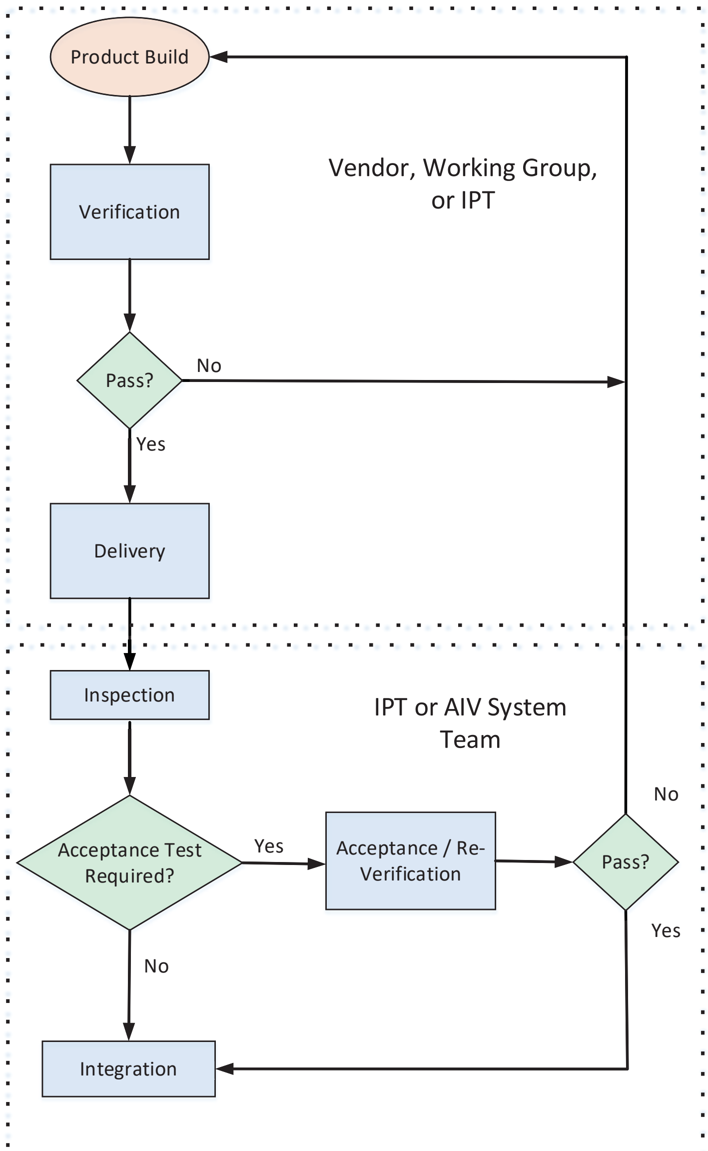

Figure 1 – Overview of ngVLA testing, verification, and acceptance processes.

5.3 General Verification and Acceptance Process

Working group and IPT-level construction and integration processes shall follow best practices. This will be achieved in part with the help of a QA team. The QA group will be a separate entity from the IPTs, although individual inspectors from the group will be embedded within each IPT to inspect workmanship, to assure all required documentation has been completed satisfactorily and all applicable standards have been addressed, and to verify that required testing prior to shipping has been successfully administered.

Each product that is provided from a vendor, a working group, or an IPT to another group will undergo functional testing and document verification milestones prior to the handoff and acceptance. Figure 2 provides a generic view of this process. The process shall remain consistent among vendors, IPT sub-groups, IPTs, and AIV. It should be noted that the process will extend between AIV and CSV as well, though this is not specifically shown in the simplified figure.

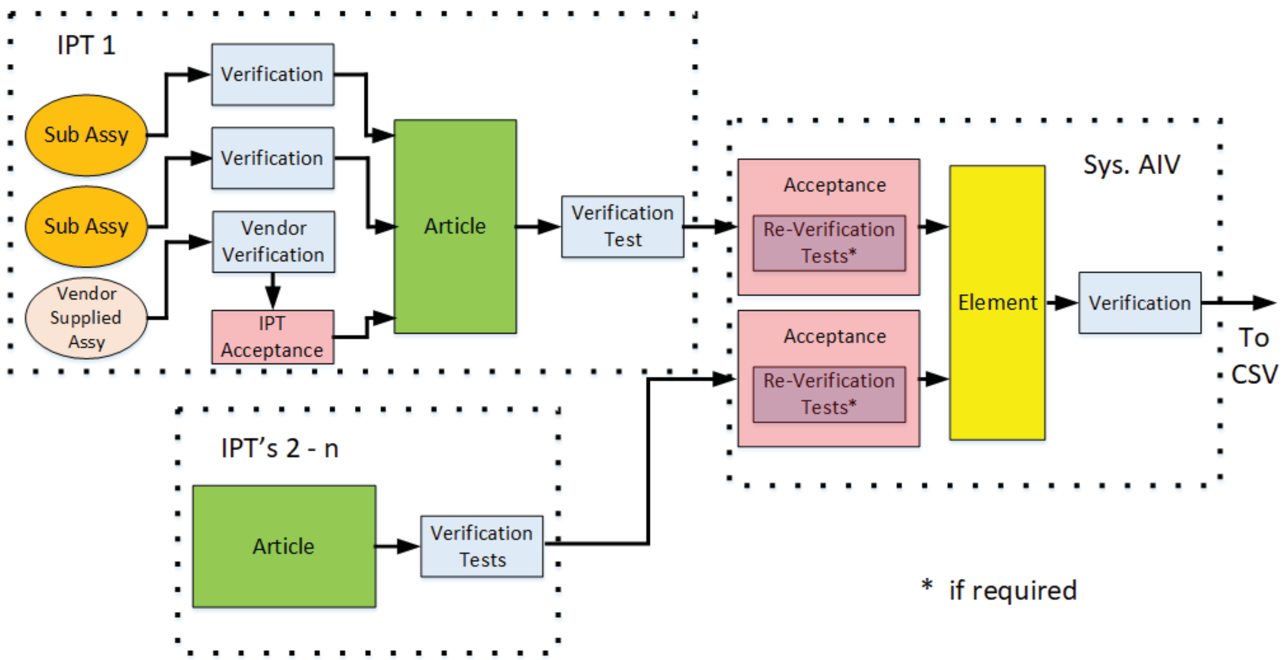

Figure 2 – Overview of ngVLA product flow.

A successful verification or acceptance, defined as when all responsible parties sign off on the verification document, must be achieved prior to handoff of a product to the receiving group. To assure no damage has occurred during transit, all deliverables must undergo an inspection. In cases where an item is shipped from one working group to another, the assembly may be required to undergo a limited re-verification. Verification and re-verification, or acceptance procedures and documents may be similar, but not necessarily identical.

Products are delivered to the System AIV group by the individual IPTs. The general product flow is depicted in Figure 2. IPTs will collaborate and work on system integration testing in a laboratory/testbed setting, prior to delivering their products to the AIV System team for deployment. Though a collaborative effort with the greater project, it is the responsibility of the delivering IPT to perform delivery verification. Within an IPT, verification testing may occur more than one time along the product assembly path prior to product handoff from the IPT to the AIV System team (or to another other receiving IPT), depending on the nature of the products and the location at which they are constructed.

Possible acceptance or re-verification on site may be required based on the Quality and Product Assurance plans. This preliminary acceptance is a milestone where the System AIV group agrees that the product has been verified and is ready to take responsibility for it. Once the Telescope system is verified by the System AIV group to support a previously defined set of Capabilities, the system is delivered to CSV. Final acceptance may take place after integration, when the product has been demonstrated to meet all technical requirements.

6 System AIV Group Activities

The AIV process described above is fundamentally a project-level activity with direction and contributions from the project office (e.g., Quality Assurance and Systems Engineering activities). The System AIV group is also required to execute many of the tasks associated with the AIV process at the system level.

The System AIV group is responsible for:

- Producing procedures for their activities during assembly, integration, and verification.
- Participating in the Product Acceptance process (this process is led from a different group, likely Systems Engineering).
- Integration of these products into a Telescope System with defined technical capabilities.
- Performing the verification process to demonstrate that the Telescope System meets the system-level technical requirements.

The System AIV group has completed their charge when all technical capabilities and elements are delivered to the CSV group. This is expected to be near the end of the project construction phase. Delivery of the Telescope System to Operations is the responsibility of the CSV group after completion of commissioning and scientific validation.

Figure 3 illustrates the System AIV group's role during ngVLA construction and the interactions with the IPT and CSV groups. Design and development will typically take place within each construction group, but during the early delivery phase the major groups will necessarily work closely together to assure system requirements are met and handover processes are fully defined. Once these procedures are established, construction shall enter the delivery phase; the groups will then return to their separate identities and be subject to the handover process as illustrated in the previous figures.

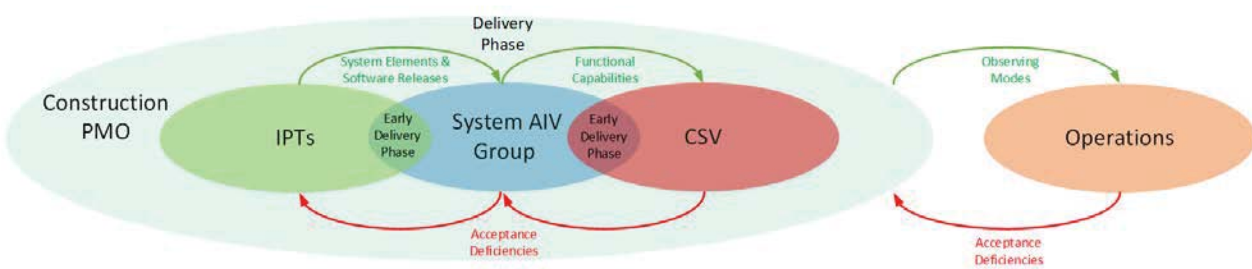

Figure 3 – System AIV Group and CSV interaction.

6.1 Design and Development Phase

To assure performance and schedule success, AIV will fill key staffing roles prior to the integration and testing of the first antenna, as described in Section 7.

Responsibility for the creation of an ICD lies with the delivering group or IPT. This is not to say that the delivering entity will work in a vacuum. Prior to element integration, the AIV and CSV groups will contribute to ICD development through review, and work with the IPT to ensure that all testing plans adhere to the project requirements and specifications.

Also during this period, AIV engineering and technical staff will specify, develop, and/or procure any test equipment that does not fall within the responsibility of the individual IPTs but will be necessary during integration and verification. At this time, AIV, with IPT technical assistance, will design and develop a laboratory testbed for the integration of early deliverables and to assist with future evaluation and troubleshooting of LRUs. Testing software will be developed in conjunction with this equipment.

The test framework shall conform to the concept of a standard integrated test environment. The goal is to provide a common framework, adopted by both the hardware and software groups, to test systems with representative hardware, software, and interfacing systems. This environment will also enable AIV to perform integration tests prior to the delivery of final production systems. The framework will be developed incrementally as prototypes are developed and tested, ultimately migrating to the early delivery phase with production or pre-production hardware and software.

In the latter stages of IPT design and development, a prototype antenna will be assembled on site well before the commencement of formal array construction. The prototype antenna subsystem will be installed on a close-in pad or dedicated test pad near the center of the future array. The IPTs, working closely with AIV, will initially install their prototype hardware on the antenna, with upgrades to pre-production hardware as it becomes available. This will allow the IPTs the opportunity to refine interfaces, better understand the environment, and perform initial performance testing, while giving the System AIV group hands on training. The IPTs will use this information to finalize the test requirements to be transferred to AIV for formal construction. The IPTs will have an opportunity to remove and replace hardware as needed on the test antenna. Should project funding and schedule constraints not allow for one or more prototype antennas to be outfitted and tested prior to formal construction, these activities will necessarily take place on the first antenna during the beginning of the production, or pre-production, phase.

6.2 Early Delivery Phase

The Early Delivery phase begins with the acceptance of the first products from the IPTs and continues through, at minimum, the delivery to CSV of the first Telescope System with sub-array capabilities (through milestone AIV6.1). Throughout the Early Delivery phase, the AIV and CSV groups will work jointly to achieve the early integration milestones and to refine the processes, verification tests, and procedures that will be used to verify future product deliveries. Since these are AIV milestones and activities, the CSV team will be formally integrated into the System AIV group during this phase (i.e., AIV is lead), providing organizational clarity while leveraging the experience and skills of the CSV team for these early integration steps.

Products delivered to the AIV Team will have already been verified by the IPT. AIV may complete spot checks or re-verification as required by the project Quality Assurance Plan (AD04). The primary AIV tasks during this phase are to assemble and integrate the products into a functional and safe telescope or small set of telescopes (although not yet capable of meeting all specifications), establish the initial technical performance, and ensure the stated technical requirements and capabilities are met by the respective subsystems.

The System AIV and CSV teams are responsible for developing and maintaining the software necessary to perform and automate verification tests for products that span IPT boundaries. Standardized testing technologies will be developed across the project, including the definition of testing plans, software test frameworks, and a standard integrated test environment. These programming environments may include application code, scripts, or similar diagnostic tools. These tools shall use the APIs delivered by the CSW IPT.

6.3 Delivery Phase

For early deliveries, past experience indicates that a portion of system-level requirements will not be fully verified prior to array construction. These may include environmental requirements, such as RFI emissions, that cannot be fully tested until a product is integrated into the greater system. For this reason, provisional or pre-production deliverables are to be expected. These deliverables will arrive with deficiencies which will be recorded in their handover documentation and re-visited once all requirements can be verified.

As array elements come online, it is also reasonable to expect hardware, firmware, or software modifications to be recommended based on the results of early AIV test results. These changes will be subject to the formal review process offered by the change control board. Any changes made to pre-production deliverables must result in an identical version of product to all future deliverables of that product.

Once the first Telescope System with sub-arraying capabilities has been delivered, the System AIV and CSV teams will begin to work independently. At that time, the ngVLA will be a functional telescope, although with limited capabilities. As production increases and multiple antennas are undergoing assembly and integration, AIV will necessarily expand to several antenna integration teams. The AIV team will continue to integrate products to the system, integrating and delivering to CSV a system with increased capabilities. Some capabilities will continue to require progressive refinement or development of the verification procedures (increasing baseline length, new correlator modes or capabilities) while others (such as the verification of integrated antenna elements) should become a routine and efficient process. Routine processes may be streamlined to improve efficiency at the discretion of the Project Engineer.

During the construction phase, should IPT hardware be identified as deficient after having been delivered to CSV, AIV will be responsible for addressing these problems and engaging the originating IPT. Routine maintenance (both preventive and corrective) responsibilities will transfer to Operations as part of the respective handover from CSV to Ops.

6.4 Late Construction and Project Closeout

Only after all products have been delivered from the IPTs can the final integration and verification be completed. During this period, where AIV is verifying the performance of the full ngVLA system, it may be efficient to have AIV and CSV again work closely together. In this case, the primary activities pertain to system commissioning, so AIV would support these CSV-led activities.

Once all technical capabilities of the full array have been verified, the AIV team will have completed its primary mission. AIV will continue to exist for some time (approximately one year) after all deliveries to CSV are complete. This will assure the group has adequate time to complete any remaining documentation requirements, and that they are present to support commissioning of the final elements. All procedures, test equipment, and test software shall be delivered to the Operations and Maintenance staff as part of project closeout. It is expected that many key individuals from the AIV team will transition to the Operations and Maintenance staff to preserve the expertise and institutional knowledge developed during the construction project. An acceptance review of the AIV materials to Operations may be held independently or as part of the project-wide closeout review process.

7 AIV Group Organization

During the Design and Development phase, AIV will not be fully staffed and may only consist of the AIV manager and a few support staff. The AIV Lead should be in place two years prior to the first antenna article delivery in order to participate in AIV planning, with the second-tier managers in place the following year. A detailed ramp-up (and down) staffing plan will be described in the AIV plan, and the overall timing of this ramp is tied to the delivery of sufficient products to begin assembly and integration of the first antenna element.

7.1 Staff Duties and Responsibilities

Multiple teams of engineers and technicians will be required to outfit and verify the various system elements. While the number of teams is not yet determined and will be set by other timetables in the project, the following roles are expected to be required within the AIV team. Additional specialists may be called upon to support AIV activities.

Position	Minimum Requirements	Responsibilities
AIV Lead	Advanced Engineer or Scientist	Process-centered individual responsible for managing System AIV group, including hiring, budget, and reporting status. Has signature authority over the AIV budget.
AIV Commissioning Scientist	Scientist/Research Engineer	Responsible for ensuring AIV is testing to specification. Interfaces with CSV and the AIV test staff.
AIV Software Lead	Software Engineer IV	Responsible for managing the team that integrates software and hardware deliverables. Upholds the standards set forth by the CSW IPT and oversees the development of AIV test software and integrated test framework.
AIV Software Engineer(s)	Software Engineer II	Responsible for development, maintenance and updates of V&V tools through production and installation. Performs tests of software and hardware integration.
AIV Site Engineer	Civil or Mechanical Engineer IV	Responsible for ensuring all ngVLA elements interface successfully with the site buildings and infrastructure. Interfaces with Buildings & Infrastructure IPT staff.
AIV Electronics Lead	Electronics Engineer IV	Responsible for development, maintenance, and updates to V&V tools and processes within the electronics domain. Contribute to development of integrated test framework. Manage the RFI test chamber and emission test processes.
AIV Mechanical Lead	Mechanical Engineer IV	Responsible for development, maintenance, and updates to V&V tools and processes within the mechanical domain. Contribute to development of integrated test framework.

Position	Minimum Requirements	Responsibilities
AIV Team Lead(s)	Electronics or Mechanical Engineer IV	Responsible for managing a team that integrates LRU/Sub-assemblies and articles. Performs tests, ensures testing reliability, calibration and documentation.
AIV Mechanical Engineer(s)	Mechanical Engineer II–III	Responsible for the installation of the LRU/ Sub-assemblies and articles. Perform tests.
AIV Electronics Engineer(s)	Electronics Engineer II–III	Responsible for the installation of the LRU/ Sub-assemblies and articles. Perform tests.
AIV Electronics Technician(s)	Electrical Technical Specialists II–IV	Responsible for the installation of the LRU/ Sub-assemblies and articles.
AIV Mechanical Technicians(s)	Mechanical Technical Specialist II–IV	Responsible for the installation of the LRU/ Sub-assemblies and articles.
Safety Officer(s)		Responsible for enforcing compliance to all safety regulations. Embedded in AIV, but the individual remains accountable to ES&S.

8 AIV Infrastructure

The AIV approach described here implies the need for significant supporting infrastructure (including related safety equipment) within the construction project scope. The following list is not intended to be comprehensive but is provided for context.

8.1 Antenna Assembly

The Antenna IPT will be responsible (either directly or via contract) for erecting the antenna at each site, after acceptance of the site foundations and infrastructure. Assembly will require a crane and other heavy equipment for a nearly eight-year period. Metrology and/or photogrammetry equipment may be required to align the mechanical axes and reflectors.

In addition to the site assembly equipment, additional integration areas may be required at the VLA site depending on the chosen antenna concept. For example, construction of single-piece composites would require a thermally controlled building with large bay doors and a gantry crane. A paint shop would also be required.

These heavy equipment and building costs could be direct expenses to the Antenna IPT or contractor expenses, depending on the antenna contract structure. These details should be addressed in a future IPT-level AIV plan.

8.2 Antenna Electronics Integration

The electronics deliverables from each antenna electronics work package would be integrated by the Antenna Electronics IPT prior to antenna installation. It is preferable to integrate the front-end electronics at the secondary focus and the back end electronics in the pedestal rack in a controlled environment off site to improve quality control and reduce the risk of site errors. This approach will require an integration facility near the site. The requirements are similar to the repair center envisioned for the operations phase, so early construction of this facility could meet both needs.

8.3 Warehouse

This concept generally calls for delivery of tested subsystems by IPTs to the central warehouse. It is possible that this warehouse could be the same as the one envisioned for the operations phase, so early construction of this facility could meet both needs.

8.4 Office Space, Test Stands, and Test Area

The schedule for AIV requires multiple AIV teams as described in Section 7.1. These individuals will require office space adjacent to a test area with access to test stands and associated test equipment. Proximity to the warehouse would be desirable, so the maintenance center described in the Operations Concept may be a suitable location if constructed on an appropriate timeline. Thought should be given to the concurrent AIV and operations phase as early science starts, and the building should be sized accordingly.

Test stands for major subsystems and to check conformance with key performance standards must be provided in this area. A key example is a central RFI emission test chamber and associated equipment.

8.5 Vehicle Fleet

As described in Section 7.1, the schedule for AIV requires multiple AIV teams working on site installation. These teams will require an appropriate number of fleet trucks to transport system hardware and test equipment to the respective installation sites.

8.6 Software Integration and Test

The quantization of the software deliverables generally requires that a full software package be delivered concurrently from the respective IPT. This delivery mode places the integrated testing responsibility upon the delivering IPT, suggesting that the project must provide a software integration suite, unit test and regression test suite, hardware simulators, and test racks.

While most software packages will initially be developed and tested with hardware simulators, these packages will need to be re-tested with actual hardware. It may be advantageous to perform these tests on representative test setups before being integrated into the operational system. Therefore, a concept for a standard integrated test environment must be developed and deployed by the AIV group as part of design and development phase activities (Section 6.1). This test environment will be adopted by the hardware groups for the purpose of testing their products with realistic software and interfacing hardware systems, and by the software groups for the purpose of testing with representative hardware. This environment will also enable AIV to perform integration tests.

8.7 Communications Infrastructure

The nature of remote site work can complicate communications with remote teams. Establishing data and voice service at each antenna site should be a priority in the AIV of each site. The feasibility of providing 3G/4G data at the construction sites, connecting to the fiber-optic infrastructure, or even using the Iridium network should be considered.

8.8 Equipment Inventory and Configuration Tracking

A number of computerized tracking systems will be required to track inventory in the warehouse, equipment configuration and test data, the status of maintenance teams and the system configuration. The needs of AIV seem similar to the needs for long-term maintenance, so early delivery and deployment of these systems may satisfy both needs.

9 AIV Interactions with CSV

The primary deliverables from AIV to CSV are integrated telescope systems with verified system functional capabilities. To accomplish this, integrated and characterized antennas elements with supporting signal generation and transport must be integrated and verified. As discussed above, during the Early Delivery Phase CSV will support the System AIV group by developing procedures and tests to clearly define expectations for future handoffs. During this time, the two groups will collaborate on the execution of test plans and achieve several common milestones (AIV0.1 through AIV6.1) as described in Section 11.

Finally, by working essentially as a single group during these early deliveries, a path for efficient knowledge transfer between AIV and CSV will be established. Once subarray capabilities have been verified, CSV and AIV will begin independent operations.

10 AIV Interactions with QA

A Quality Assurance (QA) group will also reside within the SE IPT (or possibly the Project Management IPT). Individual inspectors from the QA group will be embedded within each IPT to inspect workmanship, to assure all required documentation has been completed satisfactorily and all applicable standards have been addressed, and to verify that required testing prior to shipping has been successfully administered.

A similar relationship is expected with the AIV group, with embedded inspectors ensuring that project standards are satisfied. A key aspect of this relationship is that the QA group provide an independent assessment of compliance to project standards, and does not execute work directly. The AIV group will be responsible for acceptance of the IPT deliverables (as described in Section 5), execution of AIV activities, and remediation of any deficiencies in process or documentation identified by the QA group.

11 AIV Milestones

The following milestones describe the incremental integration of IPT deliverables into a functioning system, and the resultant verification of system-level functionality. Milestones AIV0.1 through AIV6.1 would be conducted in collaboration with CSV. After this milestone, each group would continue independently as described in Section 9. The overall flow of these milestones is as follows.

1. Integration of infrastructure systems necessary to support the AIV process.
2. Single dish integration and test.
3. Basic interferometer integration and test.
4. High-level M&C integration and test.
5. First functional interferometer delivered to CSV.
6. First functional interferometer for early science operations delivered to CSV.
7. Incremental delivery of the full system capabilities to CSV.

The ordering of milestones after the delivery of the first functional interferometer for early science operations (AIV30.0) is notional, and is not intended to suggest a priority of science capability. That is not the purview of this document, and the order will be determined through discussions with the community on early and legacy science, as well as the needs of the commissioning team. This document only aims to define technical antecedents, not milestone priority, beyond AIV30.0.

Additional milestones are also likely required for ancillary systems and services, for example, integration and commissioning of the maintenance and operations facilities, and the data/computing center.

The sequence of AIV and CSV activities must strike a balance between (1) providing a commissioned capability to users as early as practical, and (2) retiring technical risks as early as practical during the AIV and commissioning activities. Milestones are sequenced with these competing goals in mind.

The milestones are described in qualitative terms in this AIV Concept, and will be defined in detail as part of the AIV Plan. These milestones are not intended to prescribe design decisions—the final AIV milestones (documented in the AIV plan) must reflect input from the IPTs and the natural quantization of their deliverables based on their respective design architectures. Milestones are expected to be refined, added, or combined as the plan and the system design mature.

11.1 AIV0.1: AIV Infrastructure

Predecessor: None.

Description: This milestone provides verification that infrastructure systems to support AIV are in place. In particular, an early release of the Monitor and Control (M&C) system, configuration management, and issue tracking system are implemented and tested.

Pass Criteria: The milestone would be passed with the M&C supervisory system deployed and recording data in the engineering database. The configuration management system is deployed, tested, and ready to ingest subsystem calibration coefficients by serial number. The issue tracking system is deployed, tested, and pre-populated with the system product tree.

11.2 AIV1.1: Single Dish Integration

Predecessor: AIV0.1

Description: This milestone demonstrates the functional integration of a single antenna's analog signal path using Band 3. It also demonstrates antenna integration with the M&C system.

Band 3 is selected since it is presently the lowest-frequency axially corrugated feed horn. Spot checks in Band 3 of System Equivalent Flux Density (SEFD) will be performed. The lower fractional bandwidth, reduced sidelobe level, and quieter RFI environment at Band 3 are expected to make this band easier to commission than the wideband Band 1 or Band 2 receivers in the reference design.

Pass Criteria: Acceptable SEFD. Antenna points and tracks to RA/dec coordinates when commanded through a console/terminal M&C interface to the Antenna Control Unit (ACU). Signal read-out confirms on-source status using the Band 3 signal chain, using the Integrated Receiver Downconverter and Digitizer (IRD) module as a (continuum) power detector for each sub-band.

11.3 AIV1.2: DSP Signal Path

Predecessor: AIV1.1

Description: This milestone demonstrates the functional integration of the single dish Digital signal Processing (DSP) signal chain to the central signal processor, and associated M&C integrated. This milestone may be achieved with a single sub-band (expected to be ~200 MHz, depending on final CSP design) to allow progressive AIV of the CSP.

Pass Criteria: Autocorrelation total power is read out over an M&C interface at the correlator F-engine.

11.4 AIV2.0: First Fringes

Predecessor: AIV1.2

Description: This milestone demonstrates the functional integration of a two-antenna interferometer by generating on-sky fringes using two antennas in Band 3 on a ~1-km baseline, with fringe tracking, in a (limited flexibility) spectral line mode.

One-km baselines are selected based on perceived difficulty. Very long baselines are hard due to the decorrelation introduced by the troposphere, but very short baselines can also be difficult during these early stages due to common RFI, or coupled signals between antennas. One km is a notional value where these short baseline and long baseline effects are believed to be minimized.

Visibilities would be recorded in the Correlator Back End (CBE), with no averaging outside the CBF (either in frequency or time), or other formatting for a full science data model or archive data format. Configuration, control and monitoring of the system would be through consoles and scripted interfaces.

Pass Criteria: Stable on-sky fringes (amplitude and phase) are demonstrated on a 1-km baseline while pointing at an astronomical calibrator (point source) using the limited-flexibility spectral line mode.

11.5 AIV3.0: Phase Closure

Predecessor: AIV2.0

Description: This milestone demonstrates fringe tracking for three antenna elements and determination of closure error(s) using Band 3.

Pass Criteria: All baseline-based complex residuals within 1% in amplitude and within 1 degree of phase for all (~1 km) baselines on a high SNR (~1 Jy) point source.

11.6 AIV6.0: Six-Element Array with Commissioning Interfaces

Predecessor: AIV3.0

Description: This milestone demonstrates functional integration of a six-element array at Band 3. It also demonstrates functional integration of the high-level graphical user interfaces (GUIs) for array operation. A six-element array is considered the practical limit for console/terminal based interfaces, so high-level interfaces are required early in the AIV process. However, operation is still expected to be scripted (rather than through scheduling blocks).

Pass Criteria: Determination of closure phase residuals, to same spec as AIV3.0, for all baselines. Functional demonstration of the operator control and monitoring through GUI interfaces for scripted operations. Fringe amplitude and phase plotted in near-real-time using graphical tools for each baseline.

11.7 AIV6.1: Continuum and Spectral Line Data Averaging and Formatting

Predecessor: AIV6.0

Description: This milestone demonstrates the functional operation of the CSP back end for averaging in time or frequency space, providing both continuum and spectral line flexibility. This is a necessary precursor to detailed receiver band characterization. CBE ingest and recording at the associated higher data rates is also demonstrated.

Visibilities should be stored in the standard science data model, with associated metadata aggregation and formatting.

Pass Criteria: High spectral resolution (~100 kHz) visibilities recorded in the CBE. Data integrated over time and bandpass plots are generated for each baseline. Averaging over frequency or time approximates radiometer assumptions for noise.

11.8 AIV6.2: Sub-Arrays

Predecessor: AIV6.1

Description: This milestone demonstrates the functional division of the system into sub-arrays. Pointing, Local Oscillator (LO) tuning, and other key parameters should be demonstrated for a minimum of two sub-arrays. It is desirable also to demonstrate separate instantiation of software systems within each sub-array. This milestone marks the split between AIV and CSV into separate teams.

Pass Criteria: Division of the system into two sub-arrays with independent configurations. Corrections for sampler and clock offsets in the correlator. GUI display of status for both sub-arrays.

11.9 AIV6.3: Functional Band Verification

Predecessor: AIV6.1

Description: Using the new high spectral resolution mode provided by AIV6.1, verify functionality and key performance parameters at all bands.

Early band validation will be functional in nature and can start immediately after AIV6.1. Adding correlator bandwidth for this milestone is desirable in order to render this process efficient.

Pass Criteria: Acceptable SEFD, bandpass structure, and closure phase residuals at all bands for the six-element array.

11.10 AIV30.0: VLA C Configuration Analog

Predecessor: AIV6.2

Description: This milestone aims to demonstrate comparable performance to the VLA in C Configuration, in Band 3. The full bandwidth of Band 3 (~8 GHz) should be processed for a 30-element array of approximately 5 km in extent.

Integration with the proposal management system should be demonstrated, with scheduling blocks generated from proposal files (though hand editing may still be required). CBE interfaces should provide data in the correct format for calibration and imaging (including metadata aggregation), and data should be ingested into the archive. Both continuum and spectral line modes must be demonstrated. This milestone, after subsequent actions by the commissioning team (e.g., implementation of pipeline heuristics), will enable the beginning of science validation.

A 30-antenna array is chosen for this milestone as being roughly equivalent in both sensitivity and (u,v) coverage to the VLA at the same RF frequencies. The bandwidth processed by the CSP also matches VLA continuum capabilities.

Pass Criteria: Integration of 30 antennas into a functional array at Band 3, operating at full bandwidth and recording in the correct data format for calibration and imaging. Scheduling blocks generated from proposal management system, and data ingested into the archive.

11.11 AIV30.1: Full Band Verification

Predecessor: AIV30.0, AIV6.3

Description: This milestone aims to duplicate the functional testing of the VLA-C analog at all bands (1 through 6). The system would still be limited to 8 GHz of Bandwidth.

While bands have been functionally verified at the antenna level in AIV6.3, this milestone aims to verify performance with wider bandwidths and a full end-to-end system. Additional performance requirements, such as gain and phase stability must be demonstrated. Switched power system functionality to be verified.

Pass Criteria: Acceptable SEFD, bandpass structure and closure phase residuals at all bands for 30 antennas. Acceptable gain and phase stability, and switched power system functionality demonstrated. Scheduling blocks generated from proposal management system. Data recorded in the correct data format for calibration and imaging, and data ingested into the archive.

11.12 AIV31.0: Incremental Antenna Integration

Predecessor: AIV30.1

Description: After AIV30.1, the 30-element array has been verified to work at all frequencies and the antennas are considered fully deployed/verified. Each additional antenna added to the array will subsequently have its performance verified at all bands. This milestone will be repeated for each additional element added to the array after completion of the AIV30.1 milestone.

Pass Criteria: Acceptable SEFD, bandpass structure, and closure phase residuals at all bands for each new antenna.

11.13 AIV60.0: VLA C+D Configuration Analog

Predecessor: AIV30.1 (also AIV130.0, AIV140.0 for risk reduction)

Description: This milestone aims for comparable (u,v) coverage to the VLA in C+D Configuration. System now extended to full bandwidth (20 GHz/pol).

Pass Criteria: Integration of 60 antennas into a functional array at all bands. Demonstration of data recording for the full 20 GHz/pol bandwidth on all baselines.

11.14 AIV90.0: VLA B+C+D Configuration Analog

Predecessor: AIV60.0

Description: This milestone aims for comparable (u,v) coverage to the VLA in B+C+D Configuration.

Pass Criteria: Integration of 90 antennas into a functional array at any/all bands. Demonstration of data recording for the full 20 GHz/pol bandwidth on all baselines while mitigating time/bandwidth smearing.

11.15 AIV120.0: VLA A+B+C+D Configuration Analog

Predecessor: AIV90.0

Description: This milestone aims for comparable (u,v) coverage to the VLA in A+B+C+D Configuration.

Pass Criteria: Integration of 120 antennas into a functional array at any/all bands. Demonstration of data recording for the full 20 GHz/pol bandwidth on all baselines while mitigating time/bandwidth smearing.

11.16 AIV130.0: 50-km Baselines

Predecessor: AIV6.3

Description: This milestone demonstrates the performance of frequency transmission, data transmission and phase calibration on long baselines, with the maximum baseline in excess of 50 km.

Pass Criteria: Stable fringe tracking on a 50-km baseline, using the full available (deployed) bandwidth of the correlator.

11.17 AIV140.0 500-km Baselines

Predecessor: AIV130.0

Description: This milestone demonstrates the performance of frequency transmission, data transmission and phase calibration on long baselines, with the maximum baseline in excess of 500 km.

Pass Criteria: Stable fringe tracking on a 500-km baseline, using the full available (deployed) bandwidth of the correlator.

11.18 AIV700.0: Functional Phased Array Mode

Predecessor: AIV6.3

Description: This milestone demonstrates the basic functionality of the phased array mode over a 5-km aperture with limited bandwidth.

Pass Criteria: Phased array time series is recorded in the CBE.

11.19 AIV700.0: Full Phased Array Mode

Predecessor: AIV30.1

Description: This milestone demonstrates the functionality of the phased array mode over a 30-km aperture and 8 GHz of bandwidth. Also demonstrate multiple phase centers.

Pass Criteria: Two or more phased-array time series are recorded in the CBE. Acceptable summed beam SEFD.

11.20 AIV701.0: Pulsar Timing Mode

Predecessor: AIV700.0

Description: This milestone demonstrates the functionality of the pulsar timing mode.

Pass Criteria: Singe phased array beam ingested by pulsar engine in Pulsar Timing (PT) mode, generating a PSRFITS output.

11.21 AIV702.0 Pulsar Search Mode

Predecessor: AIV701.0

Description: This milestone demonstrates the functionality of the pulsar search mode.

Pass Criteria: Singe phased array beam ingested by pulsar engine in Pulsar Search (PS) mode, generating a PSRFITS output.

11.22 AIV801.0: First SBA Antenna

Predecessor: AIV30.1

Description: This milestone functionally tests the first Short Baseline Array (SBA) antenna, with first fringes to three antennas in the main array.

Pass Criteria: Stable fringes in Band 3 on an astronomical calibrator.

11.23 AIV801.1: SBA Band Validation

Predecessor: AIV801.0

Description: This milestone aims to validate the performance of an SBA antenna at all bands.

Pass Criteria: Acceptable bandpass structure and closure phase residuals at all bands.

11.24 AIV819.0: SBA Sub-Array

Predecessor: AIV801.1

Description: This milestone demonstrates deployment of the full SBA as a sub-array. 20 GHz of processed bandwidth.

Pass Criteria: Full SBA antenna complement tested at all bands and operated as an independent sub-array.

11.25 AIV850.0: TP Mode Verification

Predecessor: AIV819.0

Description: Demonstrate functional operation of an 18m antenna and the CSP in Total Power (TP) mode.

Pass Criteria: TP observation triggered through proposal management system and data recorded to CBE in standard data format.

11.26 AIV903.0: First LBA Cluster

Predecessor: AIV140.0

Description: This milestone demonstrates the deployment of the first Long Baseline Array (LBA) cluster (three antennas) and first fringes with the Main Array.

Pass Criteria: Short baseline cross-correlation within the cluster, and long baseline cross-correlation with core antennas. Short baseline and long baseline fringes on a calibrator source.

11.27 AIV930.0: LBA Sub-Array

Predecessor: AIV903.0

Description: This milestone demonstrates the deployment of full LBA and operation as a sub-array.

Pass Criteria: Full LBA antenna complement tested at all bands. Full bandwidth to correlator as a stand-alone sub-array.

11.28 AIV999.0: Full Array Deployed

Predecessor: (All)

Description: This final AIV milestone demonstrates concurrent operation of all 263 elements as a single array.

Pass Criteria: Full array demonstrated cross correlation at the highest specified time resolution (~500 msec) and 100k+ spectral channels (i.e. the maximum permitted data rate).

12 Appendix

12.1 Abbreviations and Acronyms

Acronym	Description
ACU	Antenna Control Unit
AIV	Assembly, Integration, and Verification
ALMA	Atacama Large Millimeter/submillimeter Array
API	Application Program Interface
AE	Antenna Element
FE	Front End
BE	Back End
CBE	Correlator Back End
CCB	Change Control Board
CDR	Critical Design Review
CoDR	Conceptual Design Review
CSP	Central Signal Processor
CSV	Commissioning and Science Validation
CSW	Computing Software
DSP	Digital Signal Processing
EMC	Electromagnetic Compatibility
ES&S	Environment, Safety, and Security
FDR	Final Design Review
GUI	Graphical User Interface
HVAC	Heating, Ventilation, and Air Conditioning
ICD	Interface Control Document
IMS	Integrated Master Schedule
IPT	Integrated Product Team
IRD	Integrated Receiver/Downconverter and Digitizer
L0	Level Zero, i.e. top-level requirements
LBA	Long Baseline Array
LO	Local Oscillator
LRU	Line Replaceable Unit
M&C	Monitor and Control
MRR	Manufacturing Readiness Review
ngVLA	Next Generation VLA
OSHA	Occupational Safety and Health Administration
ORR	Operational Readiness Review
PA	Product Assurance
PDR	Preliminary Design Review
PMO	Project Management Office
PS	Pulsar Search
PSRFITS	Standard for pulsar data storage using Flexible Image Transport System
PT	Pulsar Timing
QA	Quality Assurance
RA	Right Ascension
RFI	Radio Frequency Interference

Acronym	Description
RSD	Reference Signal and Distribution
RVTM	Requirements Verification Traceability Matrix
SBA	Short Baseline Array
SE	Systems Engineering
SEFD	System Equivalent Flux Density
SOW	Statement of Work
TBD	To Be Determined
TP	Total Power
TRR	Test Readiness Review
V&V	Verification and Validation
VLA	Jansky Very Large Array
WG	Working Group
WP	Work Package
WVR	Water Vapor Radiometer

12.2 Glossary

Element: A functioning collection of Articles. A fully functioning and verified antenna, comprised of various articles and subsystems, is an ngVLA Array Element (AE).

Hardware Article: Delivered as a complete package to AIV, an integrated collection of LRUs and Sub-assemblies that are designed for a specific function.

Integrated Product Team (IPT): An organizational group responsible for the design and delivery of a product.

IPT Product: An integrated subsystem designed for a specific function. Products are the fundamental deliverables of the IPTs, either to the AIV process or, less frequently, to another construction IPT.

Line Replaceable Unit (LRU): A modular component that typically fits into a larger assembly, with an ability to be replaced quickly with no required software/firmware modifications.

Scientific Capability: Integrated functionality meeting one or more of the system-level scientific requirements.

Sub-assembly: A separately assembled unit designed to be incorporated into a larger manufactured product or article.

Technical Capability: Integrated functionality meeting one or more of the system-level technical requirements.

Telescope System: An integrated combination of software and hardware that is capable of performing one or more [Technical/Scientific] capabilities.