Assembly, Integration, and Verification (AIV) Concept

020.10.05.00.00-0005-PLA-A-AIV_CONCEPT

Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
1.0	2018-12-26	S. Durand, E. Ford, C. Langley	All	Initial Draft
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
1.3	2019-03-27	AIV-WG	1.4, 6	Implemented suggestions from WG feedback
2	2019-05-30	A. Lear	All	Format and copyedit to prepare document for approvals and release
3	2019-07-09	M. McKinnon	All	Copyedited for clarity
A	2019-07-10	A. Lear	All	Prepared document for approvals & release

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1 Introduction

1.1 Purpose

This document provides a concept for the ngVLA system Assembly, Integration, and Verification (AIV). The description, approach, and functions associated with key organizational interfaces will be explored.

1.2 Scope

This document covers a qualitative view both of the overall AIV process and the activity and interactions between the AIV IPT and other ngVLA construction efforts. The assembly, verification, and handoff of the hardware and software systems will be described. Neither specific technical requirements, detailed product assurance requirements, nor budgetary information are considered within this document's scope.

1.3 AIV Working Group

A team comprised of expertise from NRAO science, technical, and program management staff has been formed to meet, discuss, outline, and produce this *Concept* for the assembly, integration, and verification of the major ngVLA construction deliverables. This qualitative document will be delivered in early 2019, and followed up with a more detailed *Plan* later in the year.

The AIV Working Group (AIV-WG) has representation from prior project teams, including ALMA, JVLA, and VLBA.

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Ex-Officio members include Rob Selina, ngVLA Project Engineer; Dana Dunbar, ngVLA Antenna IPT Lead; and Todd Hunter, ngVLA CSV-WG Lead.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents may not be directly referenced herein, but provide necessary context or supporting material.

Reference 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

2.2 Reference Documents

The following documents are referenced within this text:

Reference 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

3 Assumptions

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

1. There are on the order of 263 antennas in the array, each comprised of electronics, mechanical, and software system packages. A quantity of hardware spare components/assemblies will be provided by the IPTs with the delivered array.
2. Thorough design reviews will be conducted at major project milestones. These may include a Conceptual Design Review (CoDR), Technical Specification Review, Preliminary Design Review (PDR), Critical Design Review (CDR), Manufacturing Readiness Review (MRR), and an Operational Readiness Review (ORR). Delivery (Verification) and possibly Re-Verification reviews are also anticipated.
3. Existence of an independent Configuration Control Board (CCB).
4. Existence of a Product and Quality Assurance Role under Project Management.
5. 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.
6. IPTs will deliver the hardware necessary for verification and integration 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.
7. 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.

4 Assembly, Integration, and Verification Process

AIV processes occur at multiple levels throughout the construction process, 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 in to a power supply, 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 8.2) are accepted from the construction IPTs, assembled, and integrated first to Elements and then to the Telescope System; and finally the system being verified to meet system-level technical requirements.

4.1 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 include satisfying imposed documentation requirements, the successful completion of design or specification reviews, and analysis or other inspections. Verification of the individual delivered products is not part of the AIV process, but rather is carried out internally before the handover of a product. It is an objective process that will help determine the overall quality of a deliverable.

In this context, Acceptance is the declaration by the receiving party that a deliverable has been verified as defined above, and that the AIV team 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 for the science requirements in accordance with the ngVLA Requirements Management Plan [AD01]. These 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. Once acceptance has been achieved, the IPT's warranty period commences.[1]

Integration is the assembly of accepted products to form higher-level products (e.g., *articles* to *elements* or *elements* to the *telescope system*). Throughout the construction process, best practice dictates that an over-riding principle is that no group should be responsible for both the integration and acceptance of a product.

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 ICDs and integrated functionality demonstrating that one or more technical requirement has been satisfied.

Systems with verified technical capabilities are delivered from the 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.

1. To prevent deliverables from dwelling excessively long in the acceptance phase, some IPTs may stipulate that the warranty period automatically commences a fixed period of time after delivery.

4.2 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, supporting documentation.

4.2.1 Hardware

The IPTs are responsible for the design, verification, and delivery of their respective hardware to AIV. Upon design maturation, 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. A primary 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.

IPTs generally use the following documents to specify hardware:

1. specifications, which detail requirements of the hardware;
2. ICDs, which provide interfacing details between the IPT's Hardware and other subsystems; and
3. SOWs, which provide details about how the hardware will be produced, delivered, and warranted.

4.2.2 Software

All software and firmware delivered to the project must be version controlled and be delivered with suitable automated unit, integration, and regression testing suits. Maintenance of delivered software remains the responsibility of the delivering IPT, until the acceptance of the final product from the IPT. Development tools, compilers, source code, and the build system shall be delivered. 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 to Elements or the full system. All Application Program Interfaces (API) or other software interfaces must be defined in an ICD. Automated testing for conformance to the ICD shall be delivered with the product.

4.2.3 Documentation

In addition to hardware and software products, IPTs (or other delivering groups) are responsible for authoring all procedures 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 documentation for hardware deliveries will include, but is not limited to, the following broad categories:

- Theory of Operation, including Hardware Design Document Package
- Product Specifications
- Interface Control Documents
- Article Test Procedures, Plans, and Results
- Maintenance Plans and Procedures

4.2.4 Product Test Stands and Equipment

Articles and other assemblies frequently require specialized test equipment 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 (LabView executables and other test routines or scripts), 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 the (re-)verification process.

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 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. Identical test stands shall be provided by the IPTs to any production or destination facilities they use for the purposes of verification testing. In cases where a subcontractor is used, an additional test rack may be required at their location.

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.

4.3 General Acceptance Process

IPT-level construction and integration processes will follow best practices. This will be achieved in part with the help of a quality assurance (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 one group or IPT to another will undergo functional testing and document verification prior to the handoff (Figure 1). A successful verification, 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, in cases where an item is shipped from one working group to another, the assembly may be required to undergo a re-verification. Verification and re-verification procedures and documents may be similar, but not necessarily identical.

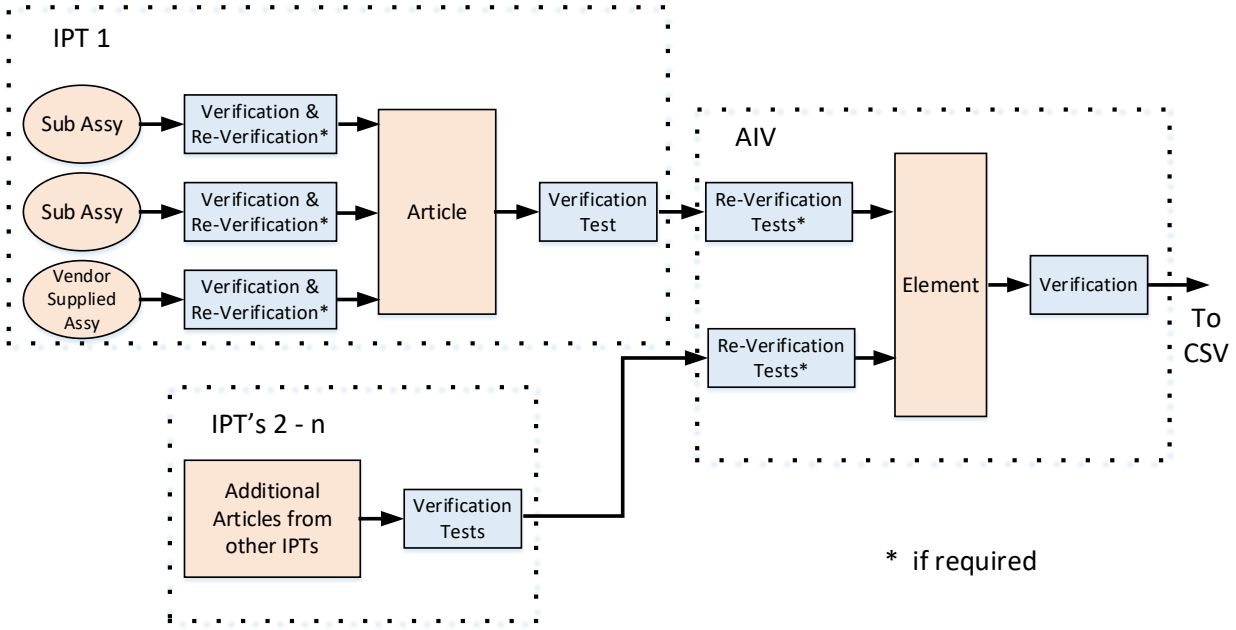

Figure 1 - Overview of ngVLA testing, verification, and acceptance processes.

Products are delivered to AIV by the individual IPTs. The delivering IPT will perform delivery verification. Within an IPT, this testing may occur more than one time along the product assembly path prior to product handoff from the IPT to AIV (or other receiving IPT), depending on the nature of the products and the location at which they are constructed. Possible re-verification on site may be required based on the Quality and Product Assurance plans. This preliminary acceptance is a milestonewhere AIV agrees that the product has been verified and is ready to take responsibility for it. Once the Telescope system is verified 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.

5 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 System Engineering activities). An AIV Group is also required to execute many of the tasks associated with the AIV process.

The AIV group is responsible for:

- 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.

Delivery of the Telescope System is the responsibility of the CSV team for commissioning and scientific validation. Additionally, the AIV team has the responsibility to produce procedures for their activities during assembly, integration, and verification.

The AIV group is finished 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.

5.1 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 later in this document.

Prior to element integration, the IPTs, AIV, and CSV will work concurrently to produce formal ICDs and to assure 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 which will be necessary during integration and verification. Testing software will be developed in conjunction with this equipment.

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 install their prototype hardware on the antenna. This will allow the IPTs the opportunity to refine interfaces, better understand the environment, and perform initial performance testing, while giving AIV 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, the planned activities will necessarily take place during the beginning of the production, or pre-production, phase.

5.2 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. Throughout the Early Delivery Phase, the AIV and CSV teams will work together to refine the processes, verification tests, and procedures that will be used to verify future product deliveries.

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 (RD when it gets written).

The primary AIV tasks during this phase are to assemble and integrate the products into a functional 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.

AIV and CSV are responsible for developing and maintaining the software necessary to perform and automate verification tests. These programming environments may include LabView code, scripts, or similar diagnostic tools. These tools shall use the APIs delivered by the CSW IPT.

5.3 Delivery Phase

Once the first Telescope System with sub-arraying capabilities has been delivered, the CSV and AIV teams will begin to work more independently. At that time, the ngVLA shall be a functional telescope, although with restricted capabilities. As production increases and multiple Telescope Systems are undergoing assembly and integration, AIV will necessarily expand to several construction teams. When an antenna's integration approaches completion of the AIV process, CSV resources may be diverted to those systems that are close to the time of handoff. 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 refinement or development of the verification procedures (increasing baseline length, software 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 process, should IPT hardware suffer a failure after having been delivered to CSV, AIV will intervene to solve these problems by engaging the originating IPT.

5.4 Late Construction and Project Closeout

Only after all products have been delivered from the IPTs can the final assembly 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.

Once all technical capabilities of the full array have been verified, the AIV team will have completed its primary mission and complete a project closeout. AIV will continue to exist for 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. 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.

6 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 three years prior to the first antenna article delivery, with the second-tier managers in place the following year. A detailed ramp up (and down) staffing plan is 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.

6.1 Staff Duties and Responsibilities

Multiple teams of engineers and technicians may 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.

Position	Minimum Requirements	Responsibilities
AIV Lead	Advanced Engineer or Scientist	Process centered individual responsible for managing AIV including hiring, budget and reporting status. Has signature authority over the AIV budget.
AIV Commissioning Scientist	Scientist/Research Engineer	Responsible for insuring 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. Oversees the development of AIV test software.
AIV Software Engineer	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 Electronics Lead	Electronics Engineer IV	Responsible for managing the team that integrates LRU/Sub-assemblies and articles. Performs tests, ensures testing reliability, calibration and documentation.
AIV Electronics Engineer	Electronics Engineer II	Responsible for the installation of the LRU/Sub-assemblies and articles. Performs tests.
AIV Electronics Technician	Electrical Technical Specialists II & III	Responsible for the installation of the LRU/Sub-assemblies and articles.
AIV Mechanical Lead	Mechanical Engineer IV	Responsible for the installation of the LRU/Sub-assemblies and articles.
AIV Mechanical Technicians	Mechanical Technical Specialist III & IV	Responsible for the installation of the LRU/Sub-assemblies and articles. Performs tests.

7 AIV Interactions with CSV

The primary deliverables from AIV to CSV are integrated telescope systems with verified system capabilities. Of course, to accomplish this integrated and characterized antennae elements, the supporting signal generation and transport must be verified and integrated. As discussed above, during the Early Delivery Phase of the project AIV and CSV will work closely together to develop procedures and tests to clearly define expectations for future handoffs. During this time, the two groups will co-develop the test plans and other handoff requirements and will achieve several common milestones, which may include the following (capabilities will be further detailed in the AIV plan):

- Initial tests of delivered components (prior to antenna availability), including WVR
- Single dish operations I: Pointing, tracking, focus
- Interferometry operations I: Two-element interferometry
- Simultaneous interferometry in multiple subarrays

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 multiple subarray capabilities have been verified, CSV and AIV will begin independent operations.

8 Appendix

8.1 Abbreviations & Acronyms

Acronym	Description
AIV	Assembly, Integration, and Verification
API	Application Program Interface
RFI	Radio Frequency Interference
AE	Antenna Element
FE	Front End
BE	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
ES&S	Environment, Safety, and Security
ICD	Interface Control Document
IPT	Integrated Product Team
IRD	Integrated Receiver/Downconverter and Digitizer
LRU	Line Replaceable Unit
MRR	Manufacturing Readiness Review
ngVLA	Next Generation VLA
ORR	Operational Readiness Review
PA	Product Assurance
PDR	Preliminary Design Review
PS	Pulsar Search
PT	Pulsar Timing
RA	Right Ascension
RSD	Reference Signal and Distribution
RVTM	Requirements Verification Traceability Matrix
SE	Systems Engineering
V&V	Verification and Validation
VLA	Jansky Very Large Array
WVR	Water Vapor Radiometer

8.2 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 which 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.