ROLL-OUT PLAN FOR SKA1_LOW

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GLOSSARY

[Antenna Element] An individual dual-polarisation antenna, included in the antenna-array that forms a field station. The antenna element includes the LNA and other integrated electronics. When there is reference to the performance of an antenna-element, the ground plane is also included.

[Array Assembly] A package of hardware and software, characterised by the number of Dishes/Stations included in the array and by its capability as an end-to-end Telescope System with pre-defined functionality.

[Assembly] Same as Installation (see below).

[Back-End Products] The term "back-end products" refers to all products that are part of the back-end of the receive chain i.e. TM, CSP and SDP products.

[Central Area] An area 1700 m in radius with a centre at the centre of the array. This is defined mainly to be consistent with previous documentation.

[Cluster] A group of six stations placed randomly around a cluster location, defined for stations outside the core area.

[Cluster Diameter] The diameter of the area within which individual field stations are located.

[Cluster Location] The average location of the stations in cluster.

[Commissioning] All activities necessary to arrive at a working end-to-end system that can be used to perform system verification. These include setting-to-work, integration testing, system testing, and the execution and analysis of test science observations, with the aim of debugging the system. Commissioning is a collaborative, interdisciplinary activity, requiring skills in astronomy / interferometry, signal processing, control and data-analysis software, as well as hardware engineering. It is a highly iterative process, usually involving several repetitions of each test.

[Contractor] The entity carrying out a construction work package during the Construction Phase of SKA1. The definition includes Service Providers, such as System Integrators under PSC/PSSC contracts.

[Core] An area of approximately 1000 m in diameter within which the individual stations are randomly located with no overlap.

[Field Station] Array of antenna elements (256) within a circular area that has a clear physical boundary and a specific geographic location.

[Front-End Products] The term "front-end products" refers to all products that are part of the stations, including the field nodes, digitiser hardware, digital filtering/channelization products, and associated SAT and Networks products.

[Inner Spiral]	Cluster-numbers 1 to 4 on each arm, nominally within the Central Area. (Note that this definition is maintained only for historical reasons, as only the outer spirals were defined first).
[Installation]	The activities required to physically establish a product of the SKA1 Telescope System on-site. This will likely include connecting interfaces to other systems such as electrical, computer, or security systems, and may include software interfaces as well. The installed product may be verified against simulators and/or emulators.
[Integration]	The activities required to incorporate a product into the SKA1 Telescope System. Any simulators and/or emulators that might have been used during the installation process are replaced with real hardware and/or software, and the associated tests repeated, perhaps in abbreviated form.
[Outer Spiral]	Cluster-numbers greater than 4 on each arm, nominally outside the Central Area.
[Product]	A constituent part or component of the SKA1 Telescope System, including hardware, software and firmware.
[Qualification]	The determination that a Product (or System) design meets its requirements.
[Station]	A station encompasses a field station, each antenna element of which is connected to a digitiser and all signal processing equipment required to produce channelised, beam-formed signal streams. It does not include support infrastructure, such as buildings and power equipment.
[Validation]	Confirmation, through the provision of objective evidence, that the entire SKA1 Telescope System meets the needs of the stakeholders. Validation only occurs at the top level of the system hierarchy. It answers the question: “Was the right system built?”
[Verification]	Confirmation, through the provision of objective evidence, that a Product of the SKA1 Telescope System meets its specified requirements. Verification is performed at each level of the system hierarchy. It answers the question: “Was the system built right?”

1 Introduction

1.1 Purpose

The SKA LOW Roll-Out Plan is a key document aimed at the coordination and synchronization of the construction, integration and verification plans and schedules of all the components of the SKA LOW Telescope.

1.2 Scope

This document contains the Roll-Out Plan for the SKA LOW Telescope, which is located in Australia and will consist of 512 SKA LOW Stations (according to the full SKA LOW design baseline). It describes a controlled, iterative approach to the Assembly, Integration and Verification of the Telescope. It considers how the Telescope should grow and evolve over the construction phase:

- **Scale**: A working array can be established with just a few stations. Over time, as stations are added into the array, the Telescope sensitivity increases. But there may be scalability issues to be resolved. This document identifies how many stations shall be integrated into the array at various points in time.

- **Functionality**: A working array can be established with a basic level of functionality. Over time, as additional functionality is integrated and verified, the Telescope's observing capability evolves. The sequencing of functionality is based on the desire for early mitigation of major technical risks and the need to perform requirements verification.

The iterative approach, which supports the growth and evolution of the SKA LOW Telescope over time, is enumerated by the Array Assemblies, the platforms which support Integration and Verification (I&V) activities (see Chapter 3 for more information on Array Assemblies and Paragraph 1.5 on the concept of Staged Delivery, AA* and the labelling of AA4 as "optional").

The Array Assemblies are described in detail in the following chapters.

Chapter 5	Integration Test Facility Qualification Event (ITF-QE)
Chapter 6	Array Assemblies 0.5 and 1

Chapter 7	Array Assembly 2
Chapter 8	Array Assembly *
Appendix B	Array Assembly 4

Each chapter includes block diagrams, product lists, system functionality, a description of key engineering goals and a description of the major technical risks. There is a final table in each chapter which details the verification outcomes for each milestone with a list of some of the L1 Requirements being verified. There is a collection of Appendices which contain information relating to data still in need to be confirmed, and the details of the optional Array Assembly 4.

Since the configuration of these Array Assemblies is the sum of their parts and the detailed descriptions include detailed product lists, this document should help contractors to plan their Sub-system-level construction and integration roll-out and associated costs.

1.3 Roll-Out Strategy

The underlying "rationale" or strategy of the Roll-Out Plan is described in [AD2].

1.4 Construction Schedule and Roll-Out Milestone Dates

The following two terms are defined:

- T0: Start of construction for the SKAO, which took place on July 1st 2021
- C0: Start of Construction: for each component of the SKA Observatory the relevant contractor will have their own date. This is the date of the Kick-Off meeting after the contract has been awarded.

The SKA Observatory manages the Integrated Project Schedule (IPS) [AD3], which also contains the dates associated with the high-level roll-out milestones that are described in this document. Any dates or durations that are mentioned in this document need to be aligned with IPS. In case of any discrepancies, the IPS shall take precedence.

1.5 Executive Summary

As identified above, this SKA LOW Roll-Out Plan identifies the following major integration platforms:

1. Integration Test Facility Qualification Event
2. Array Assembly 0.5: 6 Stations, with early-release back-end functionality
3. Array Assembly 1: 18 Stations, with basic back-end functionality
4. Array Assembly 2: 64 Stations, with back-end located in the Central Processing Facility
5. Array Assembly *: 307 Stations, with near full back-end functionality
6. Array Assembly 4 (Optional): 512 Stations, with all back-end functionality delivered

These are shown below in Figure 1:

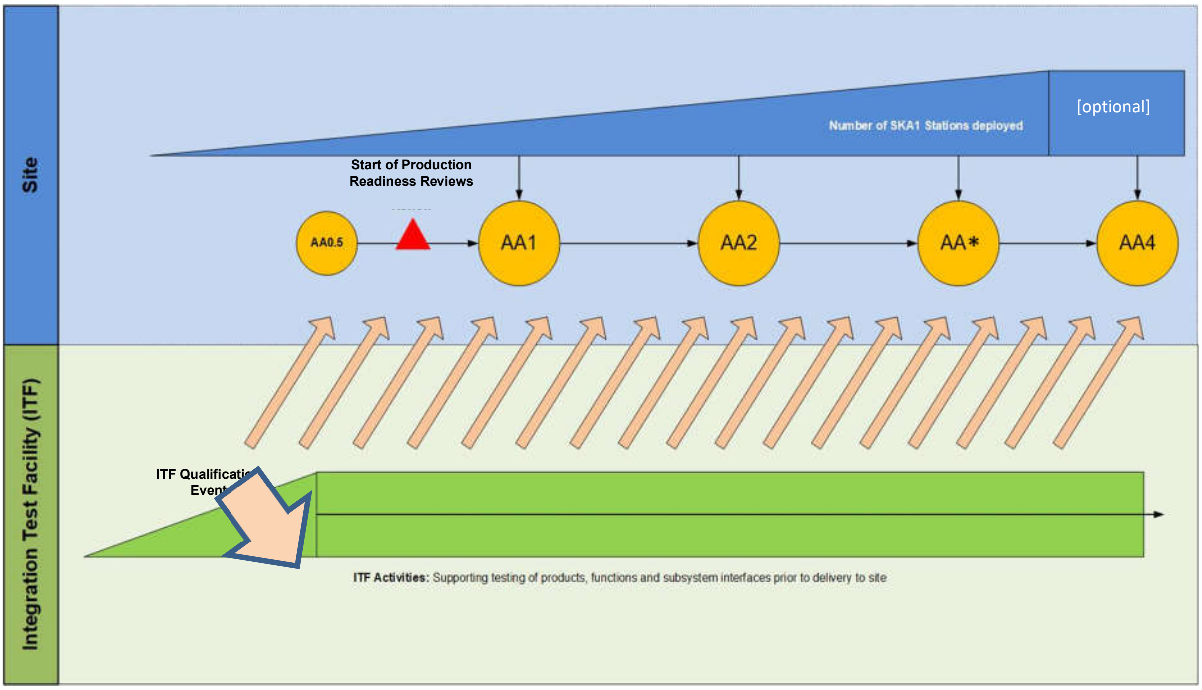


Figure 1: Overview of SKA LOW Telescope Roll-Out.

The ITF is an off-site facility allowing primary integration of products in an environment conducive to collaboration, debugging and regression testing. The integration platform established in the ITF will be set-to-work early in construction, and it will evolve over time.

In parallel to ITF Qualification Event, the early delivery of components on site (infrastructure, hardware and software) will be assembled as a minimum viable telescope. This is called Array Assembly 0.5.

Array Assembly 0.5 will comprise 6 LFAA stations plus early releases of digital electronics and software products. The firmware and software products will be very important for establishing basic functionality. These will be developed under the Scaled Agile Framework (SAFe), meaning that the AIV Team will need to be able to provide input into the feature backlog (as a part of the SAFe backlog refinement process) and will need to be able to react to changes in product and feature delivery schedules (with visibility via the PI planning process). During the integration and testing of Array Assembly 0.5 the AIV Team should also plan and execute tests from within the SAFe framework. Note that the Production Readiness Review (PRR) is described in Section 12, Roll Out Considerations.

Array Assemblies 1 to * are baselined configurations of the SKA LOW Telescope, assembled at site, defined by size and functionality as the Telescope grows and evolves over time. Each Array Assembly is subjected to a program of Integration and Verification (I&V). The purpose of these activities is to demonstrate the interoperability of the Products and the high-level functionality of the Telescope, resolve any technical and design issues and to verify the SKA LOW Telescope System (Level 1) Requirements Specification [AD1].

AA* is a schedule and commercial break point which has been included as a consequence of external factors detailed in ECP-210012 – Staged Delivery, and which substitutes the previous AA3 concept. A decision will be made at a certain point in the project schedule to stop at AA* or continue on to AA4. Array Assembly AA4 has therefore been included as an optional item, and defined in Appendix B, rather than in the main body of this document. AA* is defined as implementing the following configuration: 307 stations/78,592 antennas; maximum baseline lengths 65 km; 50-350 MHz; 250 pulsar search beams, 8 pulsar timing beams. Compared to the full Design Baseline this represents 60% stations and 75% PSS and PST. Baseline lengths are unchanged. Full (100%) infrastructure, networks, clocks and timing and correlation capabilities are delivered.

Each Array Assembly is integrated into an end-to-end SKA LOW Telescope System, with its functionality and performance targets verified and its key engineering objectives achieved. These engineering objectives enable new scientific capabilities of the array, as defined in this Roll-Out Plan, and provide an important project-wide goal.

The sizes for each integration platform are listed in Table 1.

Table 1: Size of each Array Assembly.

	ITF-QE	AA0.5	AA1	AA2	AA*	AA4
Total Number of Stations	4	6	18	64	307	512

Note that there will be a concerted effort by the AIV Team to prove the scalability of the SKA LOW Telescope to 307 stations during the course of AA* testing.

To this end, the AIV Team will add stations into the array in an opportunistic fashion during the work on AA*. The array will incorporate 64 stations at the start of AA* testing and will grow in size to 307 stations by the end of AA* testing. The decision to continue to grow towards AA4 (512 stations) will be made at a point to be defined.

For efficiency, the AIV Team will add stations in batches. The batch size will be determined by:

- The availability of stations that are ready to add,
- The maturity of the system and the absence of scalability issues with the system,
- The risk to overall system stability (and ability to roll-back if needed),
- The ability to add stations in a way that doesn't impact planned integration and verification,
- AIV Team availability

This can be assessed on a case by case basis.

1.6 Changes since the Previous Revision

This release of the Roll-Out Plan (Revision 10) contains the following updates since Revision 9:

- ECP-210012: Introduction of AA* as a separate array (based on AA3) with 307 stations (and removal of AA3 as a stand alone Array Assembly)
- ECP-190004: Addition of the L1 requirement for holography verification at AA0.5 and AA1
- ECP-200027, ECP-200074: Revised Low array co-ordinates for some of the core and spiral elements
- ECP-200039: Update of functionality and requirements to reflect Atomic COTS solution
- ECP-210037: Update of new functionality for SKA-Low in AA0.5 and AA1
- Inclusion of applicable documents for station co-ordinates and array assembly functional allocation.

- Reflection of the change from LFAA Prime Contractor to Station Integrator and impact on the handover point to AIV of this change.
- ECP-200044: Common interface CBF-Pulsar processing
- ECP-200026: Updating constraints on beams, sub-stations, bandwidth
- ECP-200036 - Perform Low.CBF VLBI beam generation on Low.PST servers
- ECP-210066: Temporary Items: Transfer from LOW AIV and FN Scopes and addition of new S-AIV HW to Infrastructure Contract 1/3 Scopes

2 References

2.1 Applicable Documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, **the applicable documents** shall take precedence.

[AD1] "SKA Phase 1 System (Level 1) Requirements Specification", SKA-TEL-SKO-0000008, Rev 11.

[AD2] "SKA1 Telescope Roll-Out Strategy", SKA-TEL-AIV-1410004.

[AD3] "SKA1 Integrated Project Schedule ", SKA-TEL-SKO-0001103.

[AD4] "Software Engineering Management Plan", SKA-TEL-SKO-0000828.

[AD5] "SKA Integrated Logistic Support Plan (ILSP)", SKA-TEL-SKO-0000104.

[AD6] "SKA Configuration Management Plan", SKA-TEL-SKO-0000120.

[AD7] "Science Commissioning and Verification Plan", SKA-TEL-SKO-0000315.

2.2 Reference Documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

[RD1] M.J. Hayes and A. MacLeod, "Functional Allocation to Roll-Out Milestones for SKA1_LOW", SKA-TEL-AIV-4410002.

[RD2] D. Gammon and R.T. Lord, "Roll-Out Plan for SKA1_MID", SKA-TEL-AIV-2410001.

[RD3] D. Liebenberg, “SKA Logistic Engineering Management Plan”, WP2-005.010.030-MP-002.

[RD4] A. MacLeod, “AIV Risk Register”, SKA-TEL-AIV-1210001.

[RD5] C. Taljaard, “SKA Support Concept”, SKA-TEL-SKO-0000103.

[RD6] M.Hayes, “Integration and Verification Plan for SKA1_LOW”, SKA-TEL-AIV-4430001.

[RD7] M.J. Hayes, “Integration & Verification Plan for SKA1_LOW – MS Project Schedule”, SKA-TEL-AIV-4430002.

[RD8] R.T. Lord, “Product Hand-Over Process”, SKA-TEL-AIV-1450001.

[RD9] SKAO Science Team, “SKA1-LOW Configuration v4”, SKA-SCI-LOW-001, Rev A, 2015-10-26.

[RD10] M.G. Labate, H. Schnetler, “SKA LOW Functional Architecture Document”, 100-000000-001.

[RD11] Scaled Agile Framework (SAFe), http://www.scaledagileframework.com

[RD12] “SKA1-Low Configuration Co-ordinates”, SKA-TEL-SKO-0000422, Rev 03.

[RD13] F. Graser, “SDP Construction and Verification Plan”, SKA-TEL-SDP-0000047, Rev 5.

[RD14] R. Brederode, “SKA1 TM Verification Plan”, SKA-TEL-TM-0000008.

[RD15] R.A.Laing, “Science Commissioning and Verification Plan”, SKA-TEL-SKO-0000315.

[RD16] A.Ahmed, A.MacLeod, “AIV Resource Plan for SKA1-Low”, SKA-TEL-AIV-4240001.

[RD17] J. McMullin and R. Laing, “Early Construction Opportunities (MeerKAT Extension + Early Production Arrays)”, SKA-BD-28.09, 12-13 November 2018.

[RD18] P. Hekman, L. Stringhetti, G. Swart, “Integration and Verification Strategy”, SKA-TEL-SKO-0001799.

[RD19] R. Anthony, P. Hekman, MG Labate, G. Swart, “SKA1 Prototype System Integration (PSI) General Framework”, SKA-TEL-SKO-0001756.

3 Roll-Out Concepts

3.1 Prototype System Integration (PSI)

Partial integration of Telescope hardware, firmware and software components is planned to be performed in one or more Prototype System Integration (PSI) facilities at convenient location(s), prior to the arrival at the System ITF. Prototype or breadboard-type hardware products may be used. The PSI facilities and the integration activities that are planned in the PSI facility are beyond the scope of this document. Refer to [RD19] for further information.

3.2 ITF Qualification Event

The ITF Qualification Event will contribute to the system-level design qualification and will verify most of the functionality and performance of the back-end products required for Array Assemblies 0.5 and 1 such as:

- Basic control and monitoring
- Basic interferometry, such as obtaining fringes and demonstrating phase and amplitude closure
- Basic phase rotation and delay compensation models
- Correlator and beamforming functionality
- Channelisation
- Bandpass calibration
- Time and Frequency reference accuracy and stability
- Gain and Phase stability
- RFI detection

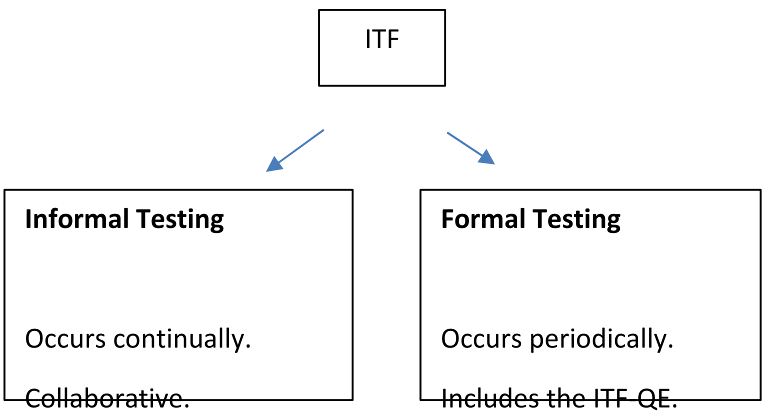
Note that to support the ITF Qualification Event, contractors should start to deliver products and perform integration and testing in the ITF approximately 6 months before the scheduled start of the Qualification Event. The ITF Qualification Event proceeds on the basis that products and functionality are stable and well tested.

The end-to-end line-up of products in the System ITF (from now on also called just ITF) would initially include:

- Noise sources, Radio Frequency (RF) power splitters and lasers to provide RF signals to test the signal path. Also, RF power combiners for providing signal plus noise test signals.
- At least 4 station LFAA digital systems including Signal Processing System (SPS) and Monitor, Control and Calibration Subsystem (MCCS).
- Pre-production CBF (Correlator and BeamFormer), supporting at least four data streams
- Early release software from Telescope Manager (TM) for telescope management
- Early release software from Science Data Processor (SDP) for visibility data capture, delay calibration, interface testing. This is likely to involve the use of CASA to capture and analyse measurement sets. Basic real-time calibration pipeline (delays) is next in priority.
- Synchronisation and Timing (SAT) and Non-Science Data Network (NSDN) systems.
- A Rubidium clock (provided by AIV) would provide a sufficiently accurate time and frequency reference source
- System Local Monitor Control systems (LMCs) as well as the monitoring functions of the different products belonging to the System.

While there will be some formal testing conducted in the ITF, including the ITF Qualification Event, a large part of the work being done in the ITF will be informal development testing. The test results obtained would contribute to product handover, as described in the Product Hand-Over Process document [RD8].

Figure 2:The ITF will host informal and formal testing



Once hardware/firmware/software has been installed in the ITF, tests will verify interfaces between products. Prior to Array Assembly 0.5, all major products of the signal chain shall be tested within the ITF and need to successfully pass the ITF Qualification Event prior to final installation on-site. Internal interfaces for any subsystem delivered by a single contractor shall be fully tested by the contractor before AIV acceptance.

The verification of Level 1 Requirements is an outcome of the planned AIV activities. There are other outcomes as well including delivery of a working SKA LOW Telescope to Science and Operations. The strategy, which is an iterative cycle of Assembly Integration and Verification, has the aim of minimising cost and schedule while delivering the SKA LOW Telescope to full scope. The ITF is a key part of that iterative process.

The initial line up of products mentioned above will evolve over time, i.e. later releases of products will be used within the ITF when they become available. The line-up in the ITF will be upgraded and maintained with new releases of hardware so that further releases of firmware and software may be tested in the ITF, before being released on site.

Further ITF testing may include additional formalised Qualification Events, in order to evaluate the readiness of products being released for AA2 and AA*. These have not yet been planned.

3.3 Array Assembly 0.5

Array Assembly 0.5 is an early integration platform on site, to be assembled and tested as a collaborative effort between AIV, product contractors and service providers, working with iterative, adaptive processes similar to the software SAFe framework. It will comprise 6 pre-production LFAA stations and plus:

- Early infrastructure
- Early releases of back-end products, possibly including prototype hardware[1].

SKA LOW receive-chain components and products that are used in AA0.5 should have been integrated and tested within integration test platforms (e.g. the PSI, the ITF) prior to their deployment to site. However, they will not need to have been fully verified against low-level requirements prior to deployment.

[1] Note that results from tests done on prototype hardware will not be suitable for input to PRR.

"Early Production Arrays" were originally noted in SKA-BD-25 and SKA-BD-26 as a means of verifying the SKA1 system design and reducing the risk on the construction phase through the deployment of a minimal array, capable of demonstrating both compliance and production capabilities for both the LOW and MID facilities. The need for such a system as early as possible was uniformly recognised. However, the timing of such a deployment during the pre-construction or construction phases faced distinct challenges. At SKA-BD-26, the Board approved the effort to develop planning for the AA0.5 integration activity. The current proposed early construction is essentially a minimum viable telescope, which is directly on the path towards Array Assembly 1 and is therefore referred to as Array Assembly 0.5 or AA0.5 in order to distinguish it from earlier (EPA) concepts.

The following text, describing the objectives of AA0.5, has been copied from [RD17]:

> *"Three different objectives were identified for AA0.5. These are:*
>
> a. *Early deployment of infrastructure. Given the advanced state of planning for infrastructure in both host countries, it would be possible to commence construction earlier than originally planned (subject to permitting and the availability of funds). This could potentially reduce the risks of late delivery and interference with other aspects of construction.*
>
> b. *Early evaluation of pre-production equipment and preparation for industrialisation. Many components of SKA must be manufactured in large quantities, and it makes sense to carry out extensive tests on a small pre-production run before committing to full production. A related activity is extended use in the field to test the design and the reliability under realistic environmental conditions. The need for a pre-production series is particularly clear for equipment associated with LOW Stations, but similar arguments apply to individual scalable sub-systems such as the Correlator/Beam Formers. The evaluation phase will end in a formal Production (or Manufacturing) Readiness Review.*
>
> c. *Early commissioning and verification. The key aim is to assemble, integrate, commission and verify a minimal system, using a mixture of dedicated engineering tests and astronomical observations. Early commissioning increases the time available to identify and fix system issues, thereby massively reducing risk. It also contributes to training of the commissioning team and to the development of robust and automated test procedures, scripts and documentation. An essential prerequisite is integration and test of as many components as possible in a laboratory environment, i.e. the Integration Test Facility.*
>
> *The principal commissioning and verification objectives are as follows:*
>
> - *Carry out astronomical and engineering tests to:*

- *Commission the AA0.5 LOW Telescope System.*
    - *Perform functional testing at an early stage of all Telescope Sub-systems performing astronomical observations (interferometry).*
    - *Verify performance at Level 1 to the extent that this is feasible with the available hardware and software (requirements scaled to a 4-element array).*
    - *Identify hardware and software components which do not meet requirements, need rework or are unreliable.*
    - *For pre-production components, provide test results as input to a formal Production Readiness Review.*
    - *Debug, optimise and improve the system.*
- *Develop methods and working practices for full production:*
    - *Hire, organise and train the nucleus of the commissioning team.*
    - *Establish effective collaborative working between array operators, astronomers, engineers (hardware and software) and host organisations.*
    - *Write, refine and document (automated) test scripts and analysis software.*
    - *Establish (short functional) tests that can be used as a benchmark during construction and during operation."*

3.4 Array Assemblies 1 to *

Array Assemblies are defined as "A package of hardware and software delivered to the AIV Team for the purposes of verification". An Array Assembly is characterised by the number of Stations included in the array, and by its capability as an end-to-end Telescope System with pre-defined functionality. It is the "required products installed" (i.e. after Assembly; the input to the Integration and Verification process). Five Array Assemblies are planned, as outlined in Table 1. Each Array Assembly has the following attributes:

- Number of Stations.
- Array capability, which limits the amount of engineering verification work and on-sky observations that can be performed with the array.
- A date, which is the date at which all required products have been *installed*, i.e. not necessarily *integrated*. The system-level integration and verification activities commence after this date. This date is contained within The SKA Integrated Project Schedule [AD3].

The Array Assembly concept is further illustrated in Figure 3 and Table 2, which show:

- The number of verified stations (including field nodes, pre-processing hardware, remote processing facilities etc.) ramps up over time.
- The capability of an Array Assembly determines the functionality that is required from the back-end products (CSP, TM, SAT, Networks and SDP).
- The hand-over to Science and Operations teams, initially with a proven set of verified high-priority observing modes. Operational Support (i.e. maintenance) needs to ramp up from the beginning.

Array Assemblies will be used by the AIV Team to commission the Telescope and to verify it against Level-1 Requirements. A key objective of the Science Commissioning & Verification Team is to validate the Telescope against the User (Level-0) Requirements. This delineation according to Level-1 and Level-0 Requirements is not very rigid, since many of the Level-1 Requirements can only be verified by the Science Commissioning & Verification Team. Furthermore, the task-level boundary between these two teams is not always obvious, since both teams will perform interferometric and beamforming testing and on-sky observations with the entire array. However, the Science Commissioning & Verification Team will spend more time characterising the array and optimising calibration procedures, since these require more in-depth observations with longer integration times. It is expected that both teams will work closely together during the Construction Phase. Refer to the Science Commissioning and Verification Plan [RD15] for further detail.

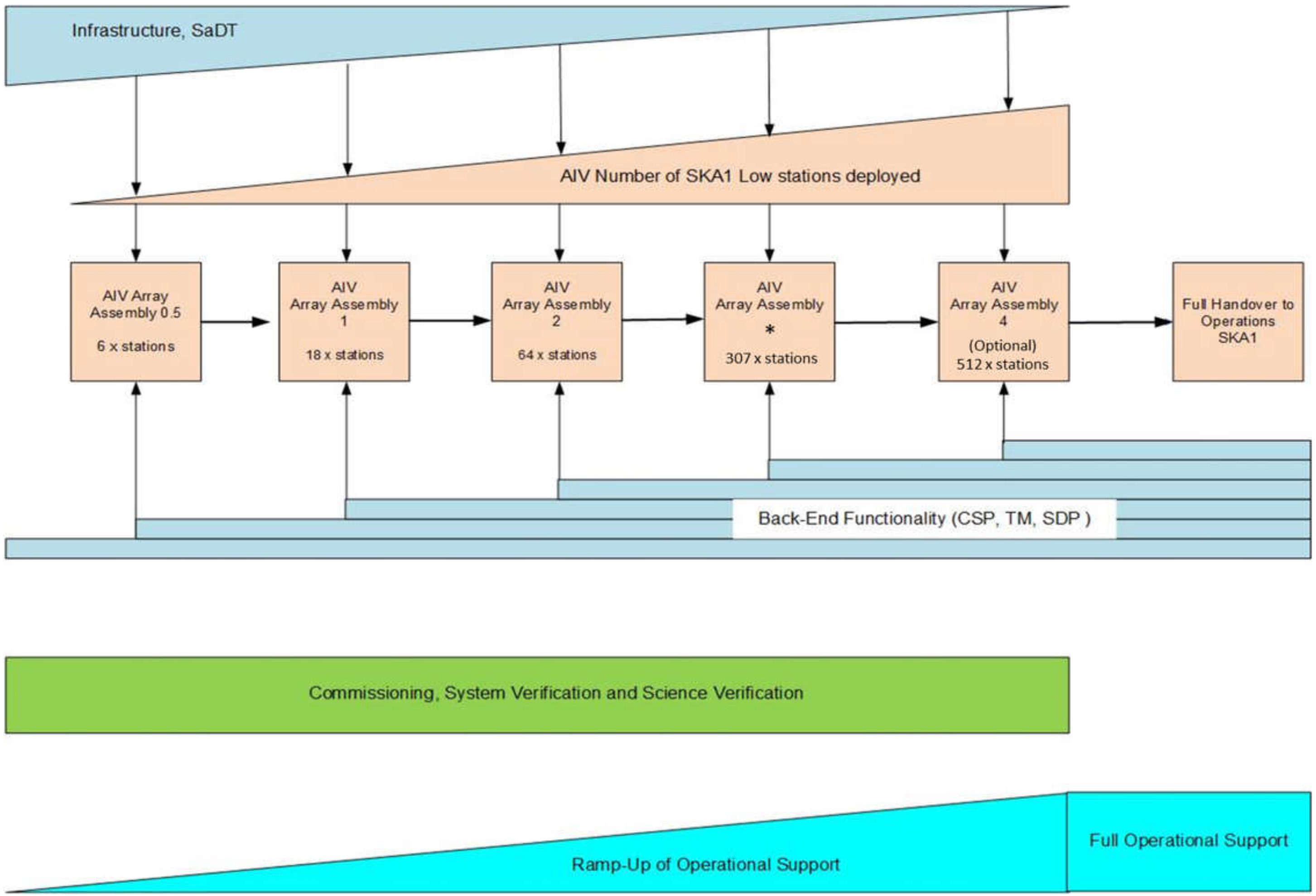


Figure 3: The Array Assembly concept of the Roll-Out Plan. Update to show AA* with 307 stations whilst preserving AA4 (512) as optional

Table 2: SKA1-LOW Observing Modes.

	# Stations	Imaging	Pulsar Timing	Pulsar Search	Dynamic Spectrum	Transient Capture	VLBI
AA0.5	6	• Basic Continuum and Spectral Line imaging • Standard Channelization • 1 Station beam • 75 MHz bandwidth	• 4 beams	• 9 beams			
AA1	18	• Basic Continuum and Spectral Line imaging • Standard Channelization 75 MHz bandwidth • 8 station beams • Substations mode up to 512-substations	• 4 beams	• 30 beams			

AA2	64	• Basic Continuum and Spectral Line imaging • Standard Channelization • 16 zoom windows, zoom of 1808Hz • 150 MHz bandwidth • 8 station beams • Substation mode up to 720-substations	• 4 beams	• 30 beams	• Supported by PST		
AA*	307	• Basic Continuum and Spectral Line imaging • Standard Channelization • 32 zoom windows, zooms down to 226Hz • 300 MHz bandwidth • 8 station beams • Substation mode up to 1440-substations	• 8 beams	• 250 beams • Pulsar de-dispersion and acceleration processing	• Supported by PST	• Transient response and commensal observing	• Full capabilities

AA4	512	• Basic Continuum and Spectral Line imaging • Standard Channelization • 64 zoom windows, zooms down to 14Hz • 300 MHz bandwidth • 8 station beams • Substation mode up to 2880-substations	• 16 beams	• 500 beams • Pulsar de-dispersion and acceleration processing	• Supported by PST	• Transient response and commensal observing	• Full capabilities

3.5 On-Site Activities

The Infrastructure contractors will be the first to work on-site. The planning foresees infrastructure work to be completed as early as possible, in order not to be a bottleneck for the LFAA contractors for the roll-out of antenna stations.

It is intended that the AA0.5 / AA1 array be located away from the centre of the LOW Central Area [RD9] to allow the roll-out of infrastructure, stations and the construction of the Central Processing Facility (CPF) to proceed unimpeded. Note that the AA1 configuration is a superset of AA0.5.

It is intended that the AA1 array would comprise three 6-field node "clusters" (described in [RD9] and [RD12]) in a triangular configuration with baselines in the order of 3-5 km. Each field node will comprise 256 SKALA antennas. This field node configuration is described further in Section 13. Each of these field node clusters will have a dedicated Remote Processing Facility (RPF) housing the digital frontends for each field node. The back-end products of AA0.5 and AA1 will be housed close by in a fourth RPF – the "SKA LOW Temporary CPF". It will consist of pre-production hardware and be of the same build and capacity as the ITF correlator. The CSP-LOW correlator contractor will supply a 6-station correlator for AA0.5. This correlator is intended for re-use with AA1 although it will be subject to changes as required.

By the time of AA2 array assembly, it is assumed that the infrastructure and power/optical fibre installation at the LOW Central Area would be completed and the AA2 array assembly could use some of the field nodes located at the LOW Central Area. The AA1 field nodes would be incorporated into the AA2 array, with an additional field node cluster located at the end of the Southern Spiral Arm (S15) - see Section 13.3 for the AA2 configuration. It is assumed that the AA2 array assembly would see the construction and fit-out of the permanent Central Processing Facility (CPF) in the LOW Central Area and the installation of the AA2 correlator.

The configurations of AA2 and AA* have been proposed and are shown below in Sections 13.3 and 13.4. In brief:

- AA2 should be a superset of AA1. AA* should be a superset of AA2.
- The configurations should incorporate a mixture of short and long fibre runs.
- The configurations should incorporate a mixture of short and long baselines.
- The configurations should be confirmed as early as possible and should take into account the constraints of construction contractors and the potential needs of science verification.

The station integrator contractor will conduct Short Functional Tests (SFT) prior to handover to the AIV Team. This will be done using groups of stations (one or more clusters in the spiral arm, a group of agreed stations in the core). Each group will comprise:

- Fully integrated and deployed field nodes (in quantities and arrangements as agreed).
- Populated signal processing system racks for the field nodes under test.
- MCCS simulator software with agreed minimum monitoring and control functionality.
- Temporary/final CPF (depending on the AA).

All Station Level 2 LFAA Requirements and station functionality (forming beams, checking beam shape and beam steering, etc) will be verified on each station by the station integrator before handover to the AIV Team.

3.5.1 Delivery of Partial LFAA Stations during Construction

There will not be a prime contractor delivering LFAA stations but rather a Station Integrator who delivers partially integrated stations.

AIV will need to accept groups of stations from the station integrator. The groups of stations handed over will include field nodes and associated digital systems (SPS, TPMs etc) but may exclude the MCCS. These groups of stations will have completed and passed an SFT before handover to AIV.

The stations will have been tested and calibrated (to the extent of functionalities provided by the Partial LFAA Station Construction) before being accepted.

Integration and Verification of the stations into the array with the MCCS product will be the responsibility of the AIV Team.

The integration of the Networks and Signal And Timing Sub-systems will have not occurred before station handover.

3.5.2 Logistic Support Roll-Out

The AIV Team and Science Commissioning & Verification Team will be using the Logistic Support System extensively during the Construction Phase. An initial Logistic Engineering Management Plan (LEMP) was presented to the SKA Office (see [RD3]). This is now incorporated in the SKA Integrated Logistics Support Plan (see [AD5]). It provides guidance regarding Logistic Support and Resources, such as:

- Workforce and Personnel
- Maintenance
- Spare Parts
- Training
- Support Publications
- Packaging, Handling, Storage and Transportation (PHS&T)
- Support & Test Equipment
- Support Facilities
- Support Data
- Product Supplier Support (PSS)
- etc

The Logistic Support Roll-Out is the responsibility of the SKAO, but this roll-out process should be supported by all contractors. The reader is also referred to [RD5].

3.5.3 Roles and Responsibilities

During the Construction Phase, many groups of people will be accessing various resources on site and working on various overlapping jobs. All contractors and individuals directly or indirectly involved with the production, construction or maintenance activities for SKA will be responsible for a healthy and safe working environment. These must be compliant with the health and safety regulations.

3.6 ITF-QE Simulators and Diagnostic Tools

The provision of simulators to help the AIV Team during the various AIV verification phases (particularly the ITF) will save time in the setup and conduct of integration test activities. Specific simulators will be provided to simulate missing sub-systems (e.g. Antennas for LOW ITF) and to help overall test coverage and test repeatability.

Desirable simulators include:

- A simulator able to replicate/simulate sky signals. It can be as simple as fixed frequency tones embedded within a wide band noise signal, or a recording (a “Golden Sample”) of targeted sky noise that could be replayed into SKA LOW digitisers.
- SKA LOW digitiser cards supporting digital test signal generators that can be programmed to produce arbitrary waveforms (tones, chirps, correlated noise, sky noise) as needed and synchronised within and between stations in some way.
- A correlated pair of RF sources with a programmable delay, injected into the I/O interfaces of the TPMs for fringe rotator testing.

What will also be required are suitable “tap-in points” and “data spigots” in the LOW Sub-systems that the AIV Team can use. E.g.:

- The ability to generate engineering test scripts to allow low level control and monitor of individual hardware products would require “tap-in points” accessible through I/O controllers provided by TM. Using these tap-in points, AIV will be able to develop and control any monitoring, simulation and analysis software that is needed during integration and verification.
- Data “spigots” throughout the digital system for capturing raw data from the receive chain data path.
- The provision and use of SDP post-processing tools and algorithms to analyse the data from these data spigots.

These tap-in points will need to be part of the Sub-system designs and they will need to be available to AIV throughout all the AIV activities (i.e. they are not applicable only to the ITF). These tap-in points and spigots will need to be designed by the Sub-system suppliers, be defined by L2 requirements and be recognised as a requirement by the SKAO. In their turn, AIV needs to make sure that the minimal spigots for expected control/monitoring/simulation/data capture are included.

3.7 Science Commissioning and Verification

Science Commissioning activities are executed in conformance with the Science Commissioning and Verification Plan [AD7] to formally verify the Telescope System against its System Level 1 Requirements. Many Level 1 Requirements are verified by performing astronomical observations and dedicated engineering tests.

Science Verification is used to denote all activities that are executed to verify the Telescope System against its User and Science Requirements (Level 0 Requirements), i.e. to ensure that the Telescope System meets the needs of the science and operational users.

Throughout the construction phase, the *Consultant* collaborates with Science Commissioning teams on a daily basis to verify that the Array Assemblies meet their Engineering and Science performance requirements.

The relationship is described in the Science Commissioning and Verification Plan [RD15], while the roles and responsibilities of the AIV Team and the Science Commissioning and Verification team are described in the RASCI table of the AIV Resource Plan for SKA LOW [RD16].

1 Software Roll-Out

1.1 Introduction

The SKA1 project has adopted the Scaled Agile Framework (SAFe®)[2] approach for rolling out software in a lean-agile manner during construction (see [AD4] and [RD11]).

It is not the intention of this document to describe SAFe in detail. Rather, a few of the key concepts and principles of this approach are described, since the roll-out of software is an important part of rolling-out the entire SKA LOW Telescope.

The AIV Team will be accepting products (software configuration items) that have been developed under SAFe. It is therefore important that the AIV Team understands the SAFe development process and is involved in the Program Increment (PI) planning sessions. The AIV Team is an internal **Customer**[3] in the SAFe context, which includes participating as a business owner in the planning events. As a **Customer**, the responsibilities of the AIV Team include (but are not limited to) participation in PI planning sessions, and helping to define the roadmap, milestones and releases.

1.2 Large Solution SAFe®

Various configurations of SAFe® exist (see [RD11]). The configuration adopted by SKAO is called "Large Solution SAFe®", see Figure 4. It coordinates Agile Release Trains (ARTs) with a Solution Train, and aims to:

- Synchronize alignment, collaboration and delivery for large numbers of teams.
- Synchronize multiple ART value streams.
- Manage solution intent.
- Integrate suppliers as partners.
- Deliver value via capabilities.

[2] SAFe® is a copyright trademark of © Scaled Agile Inc.

[3] https://www.scaledagileframework.com/customer/

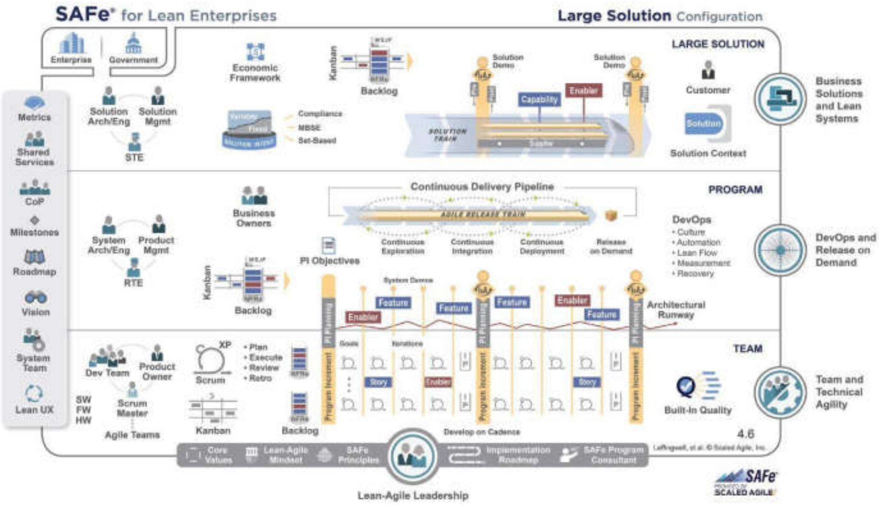


Figure 4: Large Solution SAFe® (see [RD11]).

1.3 Key Concepts

SAFe is:

- Flow and cadence based.
- Continuously builds value and reduces risk.
- An agile process that allows scalability of overall team size by having “teams of teams”.

Consequently, SAFe does not have:

- Fixed product definitions.
- Fixed requirements.
- A definite work breakdown structure.

Instead it has:

- An evolving architectural runway.
- A working product demonstrated frequently.
- A building block of 5-10 person long-lived teams.
- A 3-level hierarchy to scale these teams.

1.4 Release on Demand, Develop on Cadence

Software development is planned on a 3-month “cadence” called a Program Increment (PI). At each Program Increment Planning session the progress to date is reviewed, and the plans for the next 3-month cycle are confirmed. There needs to be agreement and buy-in from the various agile teams in terms of the features they commit to in the PI planning sessions. It is important for the AIV Team to be involved in the PI planning sessions and, more importantly, to contribute towards the development of the roadmap, to help align the development of software functionality from a particular contractor with the development and hand-over of other telescope products. The AIV Team is also likely to be involved as feature owners or product owners within the SAFe teams.

Importantly, the *release* of software is not governed by the PI cadence, as illustrated in Figure 5. Once a specific feature has been implemented, it should become feasible to release a “stable” branch at short notice. Software releases do not need to coincide with Array Assembly dates, but nevertheless need to be managed in order to enable the Array Assembly to be formed, and to ensure that the required functionality is available at the Array Assembly date.

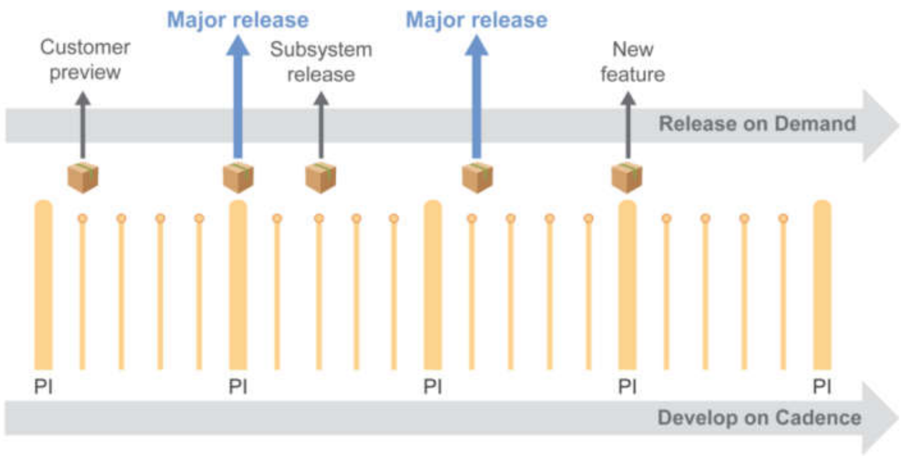


Figure 5: Release on Demand, Develop on Cadence.

1.5 Continuous Integration and Deployment

Continuous Integration and Deployment is a key concept of the SAFe approach. It is a development practice that requires a Software Solution Test Environment that enables software developers to build, integrate and verify (through automated testing) their code with simulators and emulators on a continuous (usually daily) basis, before they are ready for deployment and release to the System ITF or On-Site. This allows teams to detect problems early.

Integration and deployment to the System ITF and On-Site happens less frequently (compared to the Software Solution Test Environment), and is constrained by the existence of other products and interfacing items, and by verification teams requiring a stable system with known configuration for the duration of a particular test.

The *release* of software features in the System ITF and On-Site happens *even less* frequently and is driven by the demand for these features by the system users (e.g. the commissioning and verification teams). The release of software needs to consider what will be released, when will the release happen, who will be affected by the release, and whether the engineering support for this release is available. In reality, controlled releases of parts of the system will happen frequently, otherwise development flow will stall and schedules will slip.

It is not possible at this time to plan and predict the frequency or the dates at which software will be integrated, deployed and released at the System ITF and On-Site[4]. The 3-monthly PI cadence provides the mechanism by which certain features can be prioritised, so that the development of software can support the actual delivery of hardware products in an agile manner, thereby supporting the efforts of the commissioning and verification teams. As soon as the sub-arraying capability has been released, more options with regard to software deployment and releases will become available.

1.6 Software Platforms

Three primary software platforms will exist during construction (in addition to the Software Development Environment, which may be distributed all over the world):

1. The Software Solution Test Environment (mentioned in the previous subsection).
2. The System ITF, where real pre-production hardware is available for integration testing.
3. The on-site SKA LOW Telescope system.

[4] In the experience of ASKAP, software was deployed every 2-4 weeks. A similar deployment frequency is expected for SKAO.

The Agile Teams will first perform extensive testing of their software within the Software Solution Test Environment, prior to deploying software to the System ITF or On-Site. Whereas continuous integration will occur in the Software Solution Test Environment, software will only be released to the System ITF or On-Site on a release-on-demand basis, as shown in Figure 6.

Integration, testing and deployment of software occurs continuously, but new features are not activated or available until they are released (using feature toggles). Continuous integration, testing and deployment onto the System ITF or On-Site requires software automation infrastructure and therefore may not be possible in the early phases of construction, until the necessary software automation infrastructure is in place.

Any issues that are found on any of these software platforms are fed back to the Software Development Environment, so that appropriate tests can be implemented to reflect these issues, and so that the software will be corrected in a future release.

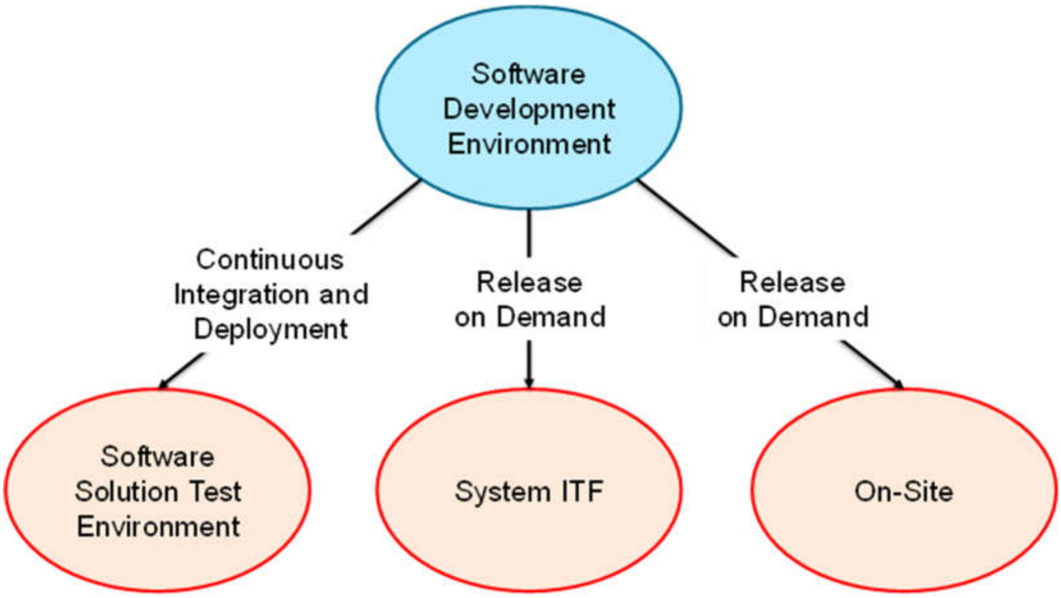


Figure 6: Software being released to the three primary software platforms.

1.7 Role of the PSI and System ITF

Whilst the Software Solution Test Environment might contain some representative hardware for testing interfaces, the PSI and System ITF will include subsets of the complete SKA LOW Telescope. The System ITF therefore makes it possible to verify new software in a laboratory environment, but with an intermediate level of system complexity, representative of the full Telescope.

As far as possible, software should first be released to the System ITF, before it is released on-site. The on-site system is used for end-to-end verification testing and needs to be as stable as possible. However, it is important that the System ITF does not become a bottleneck for software development, and therefore it is indeed possible that new software functionality is released on-site, before it has been tested in the ITF. It is also important to note that the ITF will not have full-scale hardware and may not be useful for some later tests.

With regard to Figure 7:

- The Software Development Environment can be located anywhere in the world.
- In the beginning, un-qualified software may be released into the PSI and ITF environments, in order to encourage the early release of software for early integration. However, the ITF Qualification Event requires the release of qualified software, which has been qualified against simulators in the Software Solution Test Environment. Change Control would be introduced at this time[5].
- An important milestone in the ITF is the ITF Qualification Event (ITF-QE). The ITF will, however, remain active for the entire duration of the Construction Phase.
- The intention is to release software on a regular basis to site as the assembly, integration and verification process proceeds.
- Software is released often into the PSI and ITF environments, and less often into the On-Site Environment.
- Releases on-site do not need to align with Array Assembly dates.
- The PSI and ITF environments are also used to verify new functionality of all back-end products. This means that on-site released software needs to be maintained, while new functionality comes on-line. This can be done with the use of Virtual Machines (VMs). A new VM

[5] Note that software will always be under source code configuration control in the sense that it is developed using a system such as GitLab or similar. The source code will never be placed in a system such as eB, rather, a set of release notes and a pointer to the source code configuration control system will be inserted into the configuration management system.

is used for verifying new functionality, and older VMs can be booted up, as needed. Note that older VMs can be discarded, once the new functionality is released on-site.

Figure 7 should not be interpreted to imply that software has to be released to the System ITF first, before being released on-site (although this should always be the first option, as described above).

The reader is also referred to SAFe's scalable Definition of Done (see Table 1 here: https://www.scaledagileframework.com/built-in-quality/).

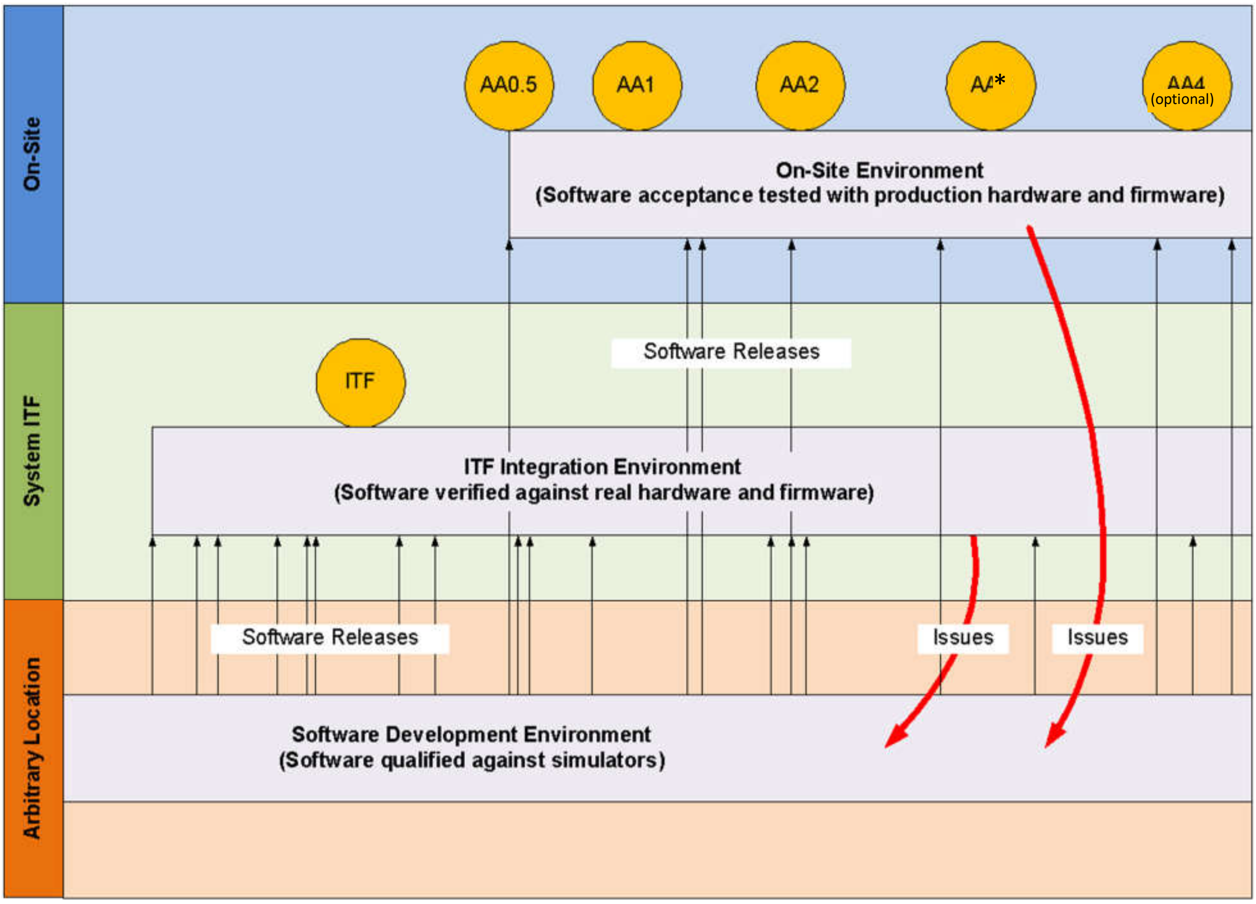


Figure 7: Software release management process.

1.8 Configuration Management

A software Configuration Management system is required to allow careful management of the version of released software, so that there is always visibility as to which software is installed where. There is a need to maintain information about the various releases of software deployed in an agile manner in each single environment at every point in time. Refer to the SKA Configuration Management Plan [AD6], which describes document, hardware and software configuration management.

Furthermore, it is important that released software can be rolled-back to a previous stable version, in order to avoid long periods of system down-time.

1.9 Interaction between SAFe and AIV

As stated in the I&V Strategy document [RD18], the system AIV Team will participate in the Scaled Agile Framework (SAFe®) approach for rolling out software. Several Software Support engineers are also part of the system AIV Team, giving the team the capability to provide the first line-of defence in identifying and resolving on-site SW integration issues. During the run-up to the ITF and site integration, the Software Support engineers and several other AIV engineers perform some of the system AIV work within the SAFe framework, to help align software development and s-AIV efforts.

In addition, the Telescope Delivery Team (TDT) Program Increment planning integrates the whole of facility delivery planning (including SAFe) for alignment across the systems. Through the Program Increment (PI) planning sessions, the AIV team can highlight the integration and verification needs during the construction period, in order to roll-out the Telescope in the quickest and most cost-effective manner. The 3-monthly Program Increment (PI) cycle makes it possible to assess what has been achieved in the previous cycle, and to plan and prioritise the activities for the following cycle.

The processes of system verification and validation are applied throughout the construction phase, with the primary objective of reducing risk as early as possible. This means that the system-under-test changes over time, with constituent components providing more and more functionality over time, as managed by an overall roll-out plan. This concept is epitomised by the roll-out of software functionality. The SAFe approach is built on the concept of *DevOps*, which aims to apply agile and lean approaches to operations work. It is based on a deep appreciation of the value of collaboration between development teams and operations staff, throughout the entire construction period and even into operations.

For the AIV Team, this raises the following type of questions:

- How often will new software be released?

- Who decides when new software will be released?
- Who decides what features the new software release should contain?
- How much system downtime can be expected when new software releases are being installed?
- What is the turnaround time for fixing bugs?
- What are the communication channels for reporting bugs?
- etc.

Although the concept of "Continuous Integration" might sound alarming for the AIV Team, which relies on the system-under-test to remain stable for the duration of a particular test, it should be remembered that the very foundation of the SAFe approach is to work collaboratively with the end-user, who is embodied by the AIV Team and the Science Commissioning and Verification team throughout the construction period.

As mentioned above, software releases happen *on demand*. New features should already be deployed prior to release and should only be toggled to be activated when they are released. Early on, before automated continuous integration and deployment is achieved, the software system may need to be restarted in order to release certain functionality, but system downtime should be very minimal.

The feature set of new software releases is planned collaboratively with the AIV Team at the PI planning sessions, as part of the development of the SAFe roadmap. The AIV Team can therefore be seen as an internal **Customer** in the SAFe context, which includes participating as a business owner in the planning events. As a customer, the responsibilities of the AIV Team include (but are not limited to) participation in PI planning sessions, interacting with analysts and subject matter experts during specification workshops, and helping to define the roadmap, milestones, and releases.

As described in [RD1] (SKA1 TM Verification Plan), the development approach of SAFe is based on continuously delivering value in the form of an evolving, tested, working system, throughout the construction period. This makes it possible for system-level verification activities to commence earlier, and it facilitates regular feedback in terms of the system's fitness for use. Newly developed capabilities and features will be demonstrated at each increment boundary, providing an opportunity for stakeholder feedback to influence the next increment. A set of criteria will be defined for each feature that defines when it is done, and product managers and owners will be responsible for accepting these features.

The agile approach of rolling-out software features should therefore be seen as assisting System-level AIV activities to reduce risks early and should not be seen as a disruptive process that changes the configuration of the System-Under-Test without the knowledge or agreement of the AIV Team.

2 ITF Qualification Event (ITF-QE)

The Integration Test Facility (ITF) may be used by contractors throughout construction for interface testing between products and for product verification. The tests will be coordinated by AIV and will culminate in on-going periodic ITF Qualification Events, to be performed by the AIV Team, to verify function and performance of a line-up of products that represent the on-site SKA LOW Telescope system. The first of these ITF Qualification Events (simply referred to as the ITF-QE) is the most important. It will be planned in detail and scheduled to happen in a similar timeframe to AA0.5.

Products integrated for the ITF Qualification Event will include MCCS, and SPS subsystems (suitable for 4 Field Nodes), SAT, Networks, CSP, TM and SDP products. The tables and diagrams below provide the following information for ITF-QE:

- Block Diagram.
- Product List.
- Functionality.
- Key engineering goals for the ITF-QE, referenced to Integration, Risk Reduction and Verification strategies.

2.1 ITF-QE Block Diagram & Product List

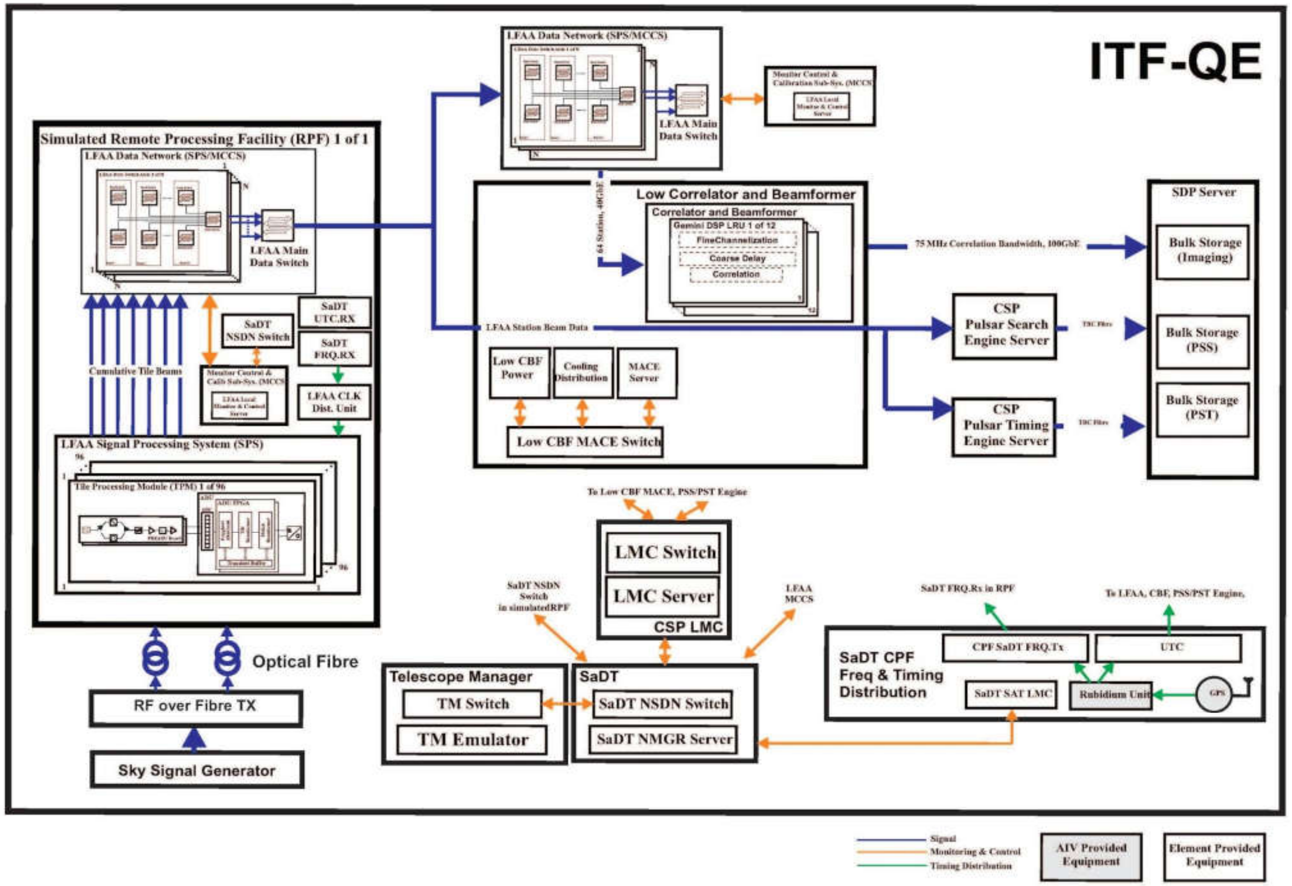


Figure 8: Typical Configuration of Products under Test in the System ITF.

Table 3: ITF-QE Product List.

CMN	Product name	Quantity Required (ITF-QE)
101-000000	**LOW Frequency Aperture Array (LFAA) LOW**	
160-000000	Field Node	N/A
163-010000	Signal Processing System (SPS) Cabinets (populated)	3
164-010000	Monitor Control and Calibration Sub-system (MCCS) High Performance Computing Units	1
	LOW Frequency Aperture Array Data Network (LFAADN)	1
102-000000	**Central Signal Processor (CSP) LOW**	
110-000000	**Local Monitoring and Control (LMC)**	
110-020000	LMC Server	1
110-030000	LMC Switch	1
111-000000	**Correlator and Beamformer (CBF)**	
TBC	Alveo Cards	20
TBC	Monitoring and Control Environment (MACE) Server	1
TBC	Monitoring and Control Environment (MACE) Switch	1
TBC	P4 Switch	1
113-000000	**Pulsar Search Engine (PSS)**	
113-010000	Compute Node	N/A
TBC	Control Network	N/A
TBC	Data Network	N/A
114-000000	**Pulsar Timing Engine (PST)**	
114-010000	Management Server	N/A
114-020000	Beam Server	N/A
103-000000	**Telescope Manager (TM) LOW**	
103-000001	Sub-Array Coordinator LOW	1
103-000002	SDP Master Leaf Node LOW	1
103-000003	CSP Master Leaf Node LOW	1

103-000004	INFRA-AU Leaf Node	1
103-000005	LFAA Master Leaf Node	1
103-000006	SADT Leaf Node LOW	1
124-000000	Local Infrastructure for TM	10U Rack space
TBC	External Information Manager	1
700-000004	Central Alarm Handler	1
700-000005	TM Alarm Handler	1
700-000006	Engineering Data Archive	1
700-000007	Central Coordinator	1
700-000010	Telescope Information Manager	1
700-000019	TM Monitor	1
700-000020	Logging Service	1
700-000021	Software System Monitor	1
700-000022	Life Cycle Manager	1
104-000000	**Science Data Processing (SDP) LOW**	
TBC	SDP Commissioning and AIV Support System	1
105-000000	**Networks LOW**	
140-000000	Local Infrastructure (LINFRA) LOW	N/A
142-000000	Non-Science Data Network (NSDN)	1
143-000000	Network Manager	1
146-000000	CSP – SDP	N/A
141-000000	**Synchronisation and Timing (SAT)**	
141-011000	SAT.STFR.FRQ.THU	1
141-030000	SAT.STFR.UTC_SKA1-LOW	1
141-040000	SAT.Timescale.SKA1-LOW	N/A
141-060000	SAT.LMC.SKA1-LOW	1
TBC	GPS & Rubidium Unit	1 (AIV)

500-000000	**Infrastructure Australia (INFRA-AU)**	
TBC	Remote Processing Facility (RPF)	N/A
TBC	Central Processing Facility (CPF)	N/A

2.2 ITF-QE Hardware to be supplied by AIV

AIV provides a GPS-disciplined Rubidium for the ITF for LOW. AIV understands that the SAT supplier will provide the interface hardware for the Rubidium to interface with the SAT FRQ and UTC systems.

2.3 ITF-QE Functionality

This table details the required functionality for ITF-QE. The function name, description and function number are derived from the SKA1_LOW Functional Architecture Document [RD10]. A more detailed breakdown of Sub-system functionality required for each AIV milestone and a complete list of the SKA1_LOW functions derived from [RD10] is detailed in the Functional Allocation to Roll-Out Milestones for SKA1_LOW [RD1].

Table 4: Description of ITF-QE Functionality.

ITF-QE Functionality	Function Name	Function Description	Function No.	Function allocated to Sub-system	Comments
Operational Functionality	Configure visibilities	Configure the station and visibility resources involved in the generation of station beams and visibilities.	F.2.3.3.2, F.2.3.3.2.1, F.2.3.3.2.2	TM, LFAA, SDP, CSP	Configure and Control station beams, configure and select visibilities
	Provide Time and Frequency reference	Provide the time and frequency reference necessary to ensure that all the data are properly time-stamped and can be synchronised.	F.6 F.6.1 F.6.2 F.6.3 F.6.4	SAT and Networks	Generate and distribute time and frequency reference
	Execute Observation	Execute the overall observation, from the reception of the simulated electromagnetic signals to the generation of the data products	F.4, F.4.1, F.4.1.2, F.4.1.3, F.4.2, F.4.2.1, F.4.2.2 F.4.3.1	LFAA, CSP, SDP	Front to back process incorporating all parts representative of the telescope system (excluding the LFAA field nodes)

	Monitor Telescope	Monitor the health of the Telescope and the quality of the data.	F.7, F.7.1, F.7.1.1, F.7.1.10, F.7.1.11	TM, LFAA, CSP, SDP, SAT and Networks	Monitor telescope resources and faults across the system
	Manage Telescope Resources	Interpret and react to deviations in the required health of the telescope system	F.7.4	TM, LFAA, CSP, SDP, SAT and Networks	Response to faults and changes in system performance
	Form Visibilities	Produce visibility data and generate autocorrelation spectra from simulated RF signals.	F.4.3.1	CSP	Produce cross-correlation and auto-correlation data

2.4 ITF-QE Key Engineering Goals, Integration and Risk Reduction

The table below details the Key Engineering Goals for the first ITF Qualification Event and the Risks being mitigated through specific Test Cases.

Some of the system risks are to be partially retired at ITF-QE, and completely retired by Array Assembly * (AA*). This table is to act as a guide for the Sub-system suppliers on what testing and risk mitigation is to be performed at the ITF-QE.

Table 5: Description of ITF-QE Key Engineering Goals

ITF-QE Key Engineering Goals	Test Cases (Type)	System/Subsystem Function Check	Demonstrating/Mitigating Risk
Correct operation of POST (Power On Start-up Test), BIT (Built In Test) and alarm handling	Power Cycle Test	System	• This test shall mitigate the risk of the ITF system returning to a non-defined state after a shutdown cycle and also mitigate the risk of "infant mortality" in subsystem components. • The ITF system will be powered up and powered down a number of times to check correct initialisation and recovery of the system. • For a successful test, the system shall successfully return to an idle state after powering up after a shutdown cycle. • In addition, different ways of starting up the system may be investigated to uncover any power sequencing issues. • A peak load requirement will need to be specified (TBC) and the test equipment will need to have sufficient time resolution to measure the transient peaks at start-up (TBC). • This test may require a UPS for all subsystems to stop the transients killing power supplies.
	Steady State Soak Test	Subsystems/ components	• This test would mitigate the risk of "infant mortality" in components and subsystems and also the risk of overheating due to incorrect or inefficient cooling systems. • Power consumption could also be monitored by logging the current consumed during the test. • Note: The load could be variable, dependent upon which components are being utilised. The load will need to be representative of a scaled (AA1) system (TBC).

	System Failures Test	System	● This test introduces planned "Faults" into the ITF system including signal loss, data packet loss and thermal/cooling issues. ● This test mitigates the risk of missing monitor points in the monitoring system and alarms that may be missed due to incorrect mapping of monitoring points by User Interfaces. ● This test would also simulate System failures - blackout, brownouts and would demonstrate what state the system returns to. ● This test would mitigate the risk of unknown/undefined states and modes the system may enter into during fault conditions. ● It also demonstrates what alarms are generated and how the alarms are handled. ● Power consumption could also be monitored by logging the current consumed during the test. ● A stress test of the interfaces by ramping up the data rates to full bandwidth/utilisation could also be included. Also test boundary conditions of analog interfaces. ● This test also tests "failsafe" functions which have been designed into the system - e.g. that the TM will shut down a piece of equipment before actual serious damage is caused. ● The Line Replaceable Units (LRUs) of all products need to be “fail safe” with each rack being “fail safe” - this is independent of TM. These also need to be tested.

	Power Consumption Test	System and Sub-system	• This test measures the power consumed by the system by logging the current consumed during operation. • This test mitigates the risk of overconsumption of power by the system/subsystem due to either faults conditions or design errors - i.e. power consumption outside the specifications of the system. • This test may be incorporated as an add-on or an overhead to the above tests, where a number of operating conditions are tested implicitly. • This test is to be conducted for power up transients and steady state conditions.
Basic operational Interface (TM)	Demonstration	TM LMC interfaces to other products	• Mitigates the risk of data/communications problems between TM LMC and the other Sub-system LMCs in the ITF system. • This demonstration also verifies the operation of the Network NMGR. The NMGR is essentially the LMC for the NSDN and CSP-SDP data pipeline. As all TM/LMC traffic uses NSDN, then the NSDN functionality is also tested/verified. • Correct data communications are essential for setting fringe rates, delay corrections and zoom functions in the correlator as well as setting correct beamformer weights and ACM retrieval in the LFAA TPMs. • May also serve as a stress test of the various digital interfaces within the system (bandwidth and utilisation) to ensure that data isn't lost and that the system can keep up with data demand.
Test Time and Frequency reference accuracy and stability	Test	SAT System	• Mitigates the risk of noisy or unstable reference tones from the SAT system. • Coherent reference signals are essential for the coherent, low-noise sampling of the input data and the efficient production of accurate visibility products in the Correlator.

Test Gain and Phase stability	Spectral Stability Test	Front-to-back RF chain	● The gain and phase stability of the end-to-end RF system will be measured but is likely to be affected by analog components upstream of the ADC, particularly the laser diodes and the fibres. ● This test mitigates the risk of noisy LNAs, noisy/inefficient lasers and o/e interfaces and optical fibre connector reflections. ● Checks for phase coherence through the RF chain and checks for amplitude jumps and/or dropouts. ● Note: May require a pre-calibration phase and gain stability requirement (TBC)
Verify Channelisation performance	Channelisation Test	CSP-CBF	● These tests mitigate risk in the operation of the Filter banks in the CBF Beamformer and the LFAA TPMs. ● They check for channel leakage into adjacent and non-adjacent channels. (May be a confirmation of a CSP L2-Requirement, and to check LFAA TPM beamformer functionality). ● This test can be combined with the "Perform Bandpass Calibration" test by sweeping a test tone across the entire receive band and viewing the output spectrum.
Correlator visibility products and functionality	Correlator Efficiency Correlator Signal to Noise Correlator Integration Rate	CSP-CBF	● This test firstly mitigates the risk to the correlator function caused by incorrect weighting/operation/connection of the Correlator and cross-connects. (This test may be the confirmation of a CSP L2 Requirement). ● The risks being mitigated here also include the performance aspects of the correlator relating to Correlation Signal to Noise and the Correlation Integration Rate. These function and performance parameters also need to be operating correctly for correct visibilities to be produced. ● These tests require two test tones of known coherence and power and would require injecting correlated digitised noise - maybe using a simulator of the TPM interface (TBC).

Delay Tracking, Baseline delay and phase calibration	Baseline Delay Solution	Coarse Delay unit (CSP-CBF)	• The Coarse Delay unit removes the coarse delays due to the geometric differences in signal path length. • The risk mitigated is errors in calculation of coarse delays in the Coarse Delay Unit and the inaccurate removal of these delays. • This test checks the operation of the coarse delay unit by injecting reference noise signals with a changing delay. • This could be done by replacing the TPMs with simulators on at least two inputs. • This test rig could also be used to test Correlator efficiency (above). This test may already be required by CSP to sign-off L2 Requirements (TBC).
Perform Bandpass Characterisation and Calibration (test channel with swept frequency tone - gain flatness over frequency)	Instantaneous BW Test	Front-to-back RF Chain.	• These tests confirm the basic operation of the RF path from the TPM inputs to the output of the Correlator. The basic shape of the Bandpass is confirmed. • Risks that are mitigated include possible problems with sampling of the ADC in the TPMs, beam weights in the TPM beamformer, filter banks in the CBF, and the autocorrelation and cross-correlation functions in the Correlator. • Input test signal into TPM. Sweep tone across a single 5.4kHz channel measuring the aliased power into all adjacent channels. Use analysis to extend results from the single channel to all other channels in RX Pass band and determine total effect of aliased power. Tests may be done for Autocorrelations with single tone and also cross-correlations with two separate tones. Tests can be repeated at spot frequencies across the RX band. Tests can be repeated for Zoom Mode. For Zoom mode also sweep channels at the Zoom band edges and band centre. • Also a very useful initial end-to-end test of the RF path from the ADC inputs to the TPMs to the output of the Correlator.

			● This test can be used to check the boundary conditions of the overall receive frequency range, checking that signals out of the receive frequency range do not propagate through the system (e.g. 30MHz). ● An impulse response test may be considered (TBC) ● Note: There no present L1 requirement on the independence of adjacent time samples (possible L2 requirements - TBC).
Confirmation of system synchronisation	Demonstration	Front-to-back RF Chain	● Correct end-to-end data synchronisation is essential for proper operation of an Aperture Array. ● Data streams/packets need to be aligned in time for correct operation and correct delay alignment is essential for accurate correlation. This test mitigates the risk of delay aberrations like delay jumps occurring in the data streams that would otherwise corrupt visibility products. It also determines how sensitive is the system to the start-up sequence (TBC) and how easy the system is to "break". ● This test requires testing the delay tracking of the correlator as well as the RF chain. The correlator will be adding samples and performing a fractional sample delay. Also, checks should be made on the effect of changing the beamformer setting in the TPM.
Fringes	Fringes Test - ITF	Front-to-back RF chain, Data timing	● Fringes and Phase Closure basically implement the successful testing of system synchronisation, baseline delay and phase calibration. The risks (which are all related) are progressively retired. ● The Fringes test in the ITF also mitigates the possible risk of incoherent or inaccurate time and frequency signals from the SAT STFR system distributed to the ADCs in the LFAA TPMs, and the CSP Correlator.

			● "Fringes" are simulated in the ITF using optical/RF input signals injected into the LFAA TPMs with a known delay between them. This delay is varied with time to produce "fringing". The TPMs beamformer weightings are set to ""1"" for the TPM input channels used.
	Fringe Rotation & Stopping	Front-to-back RF chain Fine delay Tracking (CSP-CBF) Data timing	● The Fine Time Delay units in the Correlator are essential to the proper alignment of time domain input signals prior to correlation. ● This demonstration mitigates the risk of unexpected delay/phase jumps in the Fine delay process. ● It also confirms the operation of the Coarse Delay unit as well as overall correlator function and CSP-TM LMC interfaces. ● It is also an essential Front-to-back interferometric test. As above, the test jig comprises a correlated pair of RF sources with a programmable delay, injected into the e/o interfaces of the TPMs. Otherwise they may be simulated by a pair of TPM simulators interfaced to the correlator.
	Baseline/ Frequency Mapping of Visibilities	Front-to-back RF chain, Correlator Interconnects	● This test confirms that the output visibility products correspond to the correct input baselines, polarisation product and frequency. ● This test mitigates the risk of incorrect connections in the correlator interconnects and is an essential test before attempting Phase Closure
Phase closure	Phase Closure - ITF Demonstration	Synchronisation, Front-to-back RF Chain, CSP-CBF	● Phase Closure is a test that may be used often and progressively throughout the testing program. ● It is a system test that mitigates risk with Front-to-end synchronisation/timing and data interface problems between LFAA and CSP products.

			● It also mitigates the risk of timing and programming problems with fine delay units and Correlator function in the CSP CBF as well as the operation of the TPMs to form beams. ● For testing phase closure at the ITF (without the sky), 3 correlated inputs are required.
Amplitude closure	Amplitude Closure - ITF Demonstration	Correlator, LFAA/CSP Interfaces, End-to-end system test	● Amplitude closure is an end-to-end test checking for stability of the ITF RF chain and the stability of the Correlator. ● This test mitigates the risks of instability in inter-Sub-system interfaces (primarily LFAA to CSP) and also any instability in the production of cross-correlation visibilities by the Correlator. ● For testing amplitude closure at the ITF (without the sky), 4 correlated inputs are required.
RFI detection (TBC - ITF to have EMC chamber?)	Test	LFAA Antenna and Field Node	● This test mitigates the risk of RFI radiation from the LFAA Antenna/LNA system, PASD and power distribution systems. ● Other tests may include subsystems that are to be housed in the CPF. ● These products should be thoroughly tested at the product level and may be a construction requirement on LFAA - meeting emissivity requirements may be an LFAA L2 requirement (TBC).

2.5 ITF-QE Verification Outcomes

The table below details the Key Engineering Goals for the first ITF Qualification Event and the outcomes at this Roll-Out Milestone (including some L1 Requirements). Many of the requirements are partially verified at ITF-QE, with increasing numbers verified as more stations are added in subsequent Array Assemblies. This table is to act as a guide for the Sub-system suppliers on what verification is to be performed at this ITF-QE milestone.

Table 6: Description of ITF-QE Verification Outcomes.

ITF-QE Key Engineering Goals	Test Cases (Type)	System/Subsystem Function Check	Verification Outcomes
Correct operation of POST (Power On Start-up Test), BIT (Built In Test) and alarm handling	Power Cycle Test	System	• This test verifies the ITF system returns to a defined state after a shutdown cycle and also mitigates the risk of "infant mortality" in subsystem components. • The ITF system will be powered up and powered down a number of times to check correct initialisation and recovery of the system. • For a successful test, the system shall successfully return to an idle state after powering up after a shutdown cycle.
	Steady State Soak Test	Subsystems/ components	• Verify and measure the steady state operation of the ITF system • Power consumption could also be monitored by logging the current consumed during the test.
	System Failures Test	System	• This test introduces planned "Faults" into the ITF system including signal loss, data packet loss and thermal/cooling issues. • Verifies what alarms are generated and how the alarms are handled. • Verifies "failsafe" functions which have been designed into the system - e.g. that the TM will shut down a piece of equipment before actual serious damage is caused. • CSP: The "failsafe" functions of the Line Replaceable units (LRUs) and each CSP rack are verified.
	Power Consumption Test	System and Sub-system	• Verifies the steady state and power-on power consumption (L2 Requirements?). • Verifies correct power-on/power-off sequencing

Basic operational Interface (TM)	Demonstration	TM LMC interfaces to other products	• Verifies correct data communications for setting fringe rates, delay corrections and zoom functions in the correlator as well as setting correct beamformer weights and ACM retrieval in the LFAA TPMs. • Verifies the operation of the Networks NMGR. The NMGR is essentially the LMC for the NSDN and CSP-SDP data pipeline. As all TM/LMC traffic uses NSDN, then the NSDN functionality is also tested/verified. • Verifies the robustness of various digital interfaces within the system (bandwidth and utilisation) to ensure that data isn't lost and that the system can keep up with data demand.

Test Time and Frequency reference accuracy and stability	Test	SAT	• Verifies the stability of the reference tones from the SAT system.
			• System parameters being verified include:
			  ○ SKA1_LOW coherence losses 1s
			  ○ Frequency reference phase drift
			  ○ SKA1_LOW Frequency reference phase drift
			  ○ Pulse per second precision
			• Pulse per Second synchronisation

Test Gain and Phase stability	Spectral Stability Test	Front-to-back RF chain	• System parameters being verified include: ○ Spectral stability, Instantaneous bandwidth, Linearity, Clipping, Clipped data flagging, Dynamic range
Verify Channelisation performance	Channelisation Test	Filter banks (CSP-CBF)	• These tests verify the performance of the channelisers in the CBF Beamformer and the LFAA TPMs.

			● System parameters being verified include: ○ Channelisation transition band for adjacent frequency channels, channeliser maximum leakage for non-adjacent frequency channels, channeliser frequency, channel amplitude variation ● These tests may be a confirmation of a CSP L2-Requirement, and a verification of LFAA TPM channeliser functionality).
Correlator visibility products and functionality	Correlator Efficiency Correlator Signal to Noise Correlator Integration Rate	CSP-CBF	● This test verifies correlator function and correlator efficiency and also verifies the performance aspects of the correlator including Correlation Signal to Noise and the Correlation Integration Rate. These need to be operating correctly for correct visibilities to be produced. (These tests may also be a confirmation of CSP L2 Requirements). ● These tests require two test tones of known coherence and power and would require injecting correlated digitised noise - maybe using a simulator of the TPM interface.
Delay Tracking, Baseline delay and phase calibration	Baseline Delay Solution	Coarse Delay unit (CSP-CBF)	● The Coarse Delay unit removes the coarse time delays due to the geometric differences in signal path length. ● This test verifies the operation of the coarse time delay unit by injecting reference noise signals with a changing delay. ● This test may already be required by CSP to sign-off L2 Requirements (TBC).
Perform Bandpass Characterisation and Calibration (test channel with swept frequency tone - gain flatness over frequency)	Instantaneous BW Test	Front-to-back RF Chain.	● These tests verify the basic operation of the RF path from the TPM inputs to the output of the Correlator. The basic shape of the Bandpass is confirmed. ● System parameters being verified include:

			○ Spectral stability, Instantaneous bandwidth, Linearity, Clipping, Clipped data flagging, Dynamic range ○ Autocorrelation spectra, autocorrelation calibration ○ Fine frequency channel band edge, Spectral channels ○ Zoom windows, Zoom window centre frequency, Zoom window channels, Continuum with zoom windows, Zoom window noise leakage power ○ Overlapped window amplitude response, Correlation signal to noise, Correlator Integration rate.
Confirmation of system synchronisation	Demonstration	Front-to-back RF Chain	● Correct end-to-end data synchronisation is essential for proper operation of an Aperture Array. ● This test verifies the correct alignment of Data streams/packets and reveal delay aberrations like delay jumps occurring in the data streams that would otherwise corrupt visibility products. It also determines how sensitive is the system to the start-up sequence (TBC) and how easy the system is to "break".
Fringes	Fringes Test - ITF	Front-to-back RF chain, Data timing	● This test is a basic interferometry test looking for "fringe" variations in the visibilities from a simulated 2-station baseline. ● The test verifies the operation of the Front-to-back RF chain and the stability and coherence of the frequency/time references and correlator's cross-correlation function.

	Fringe Rotation & Stopping	Front-to-back RF chain Fine delay Tracking (CSP-CBF) Data timing	• This test verifies the operation of the Fine Time Delay and Coarse Delay units in the Correlator as well as overall stability in cross-correlation function and CSP-TM LMC interfaces. • It also demonstrates the ability of the ITF system to track a simulated celestial source.
	Baseline/ Frequency Mapping of Visibilities	Front-to-back RF chain, Correlator Interconnects	• This test verifies that the output visibility products correspond to the correct input baselines, polarisation product and frequency. • This is an essential test before attempting Phase Closure
Phase closure	Phase Closure - ITF Demonstration	Synchronisation, Front-to-back RF Chain, CSP-CBF	• Phase Closure is a front-to-back system test that verifies the phase stability of the telescope system by monitoring the closure phase of the baseline visibilities. • Phase Closure is a test that may be used often and progressively throughout the testing program • For testing phase closure at the ITF (without the sky), 3 correlated inputs are required.
Amplitude closure	Amplitude Closure - ITF Demonstration	CSP-CBF, LFAA/CSP Interfaces, End-to-end system test	• Amplitude closure is an end-to-end test verifying the stability of the AA1 RF chain and the stability of the Correlator. • System parameters being verified include: ○ Absolute flux density scale • For testing amplitude closure at the ITF (without the sky), 4 correlated inputs are required.

RFI detection (TBC - ITF to have EMC chamber?)	Test	LFAA Antenna and Field Node	● This test verifies that the level of RFI radiation from the LFAA Antenna/LNA system, PASD and power distribution systems, meet emissivity requirements. ● Other tests may include subsystems that are to be housed in the CPF. ● These products should be thoroughly tested at the product level and may be a construction requirement on LFAA - meeting emissivity requirements may be an LFAA L2 requirement (TBC).

3 Array Assemblies 0.5 and 1 (AA0.5 and AA1)

This section describes the characteristics, functions and capabilities of Array Assemblies 0.5 and 1.

- *Note that in terms of its configuration, as well as the set of tests that will be run, AA0.5 is a subset of AA1. The purpose of AA0.5 is to provide the earliest possible mitigation of technical risks, and demonstration of a working Telescope. These activities will provide input to the Production Readiness Reviews.AA0.5 may include early release or prototype products that will be accepted by the AIV Team, and later retrofitted. Unless specifically identified as AA0.5 roll out activity, all activities described in this section are applicable to both AA0.5 and AA1.*

The tables and diagrams below provide the following information:

- Block Diagram
- Product List
- Functionality
- Key engineering goals referenced to Integration, Risk Reduction and Verification strategies.

- *Note that the product list identifies components for AA0.5 which may be temporarily substituted by prototypes or products that are functionally equivalent for the purpose of early tests.*

The criteria for selecting location of stations and back-end equipment for Array Assemblies 0.5 and 1 is contained below within Section 13 and the proposed location of AA1 stations are shown in Section 13.2.

- *Note that AA0.5 will have 2 stations installed at each of the three AA1 clusters.*

3.1 AA0.5 and AA1 Block Diagram & Product List

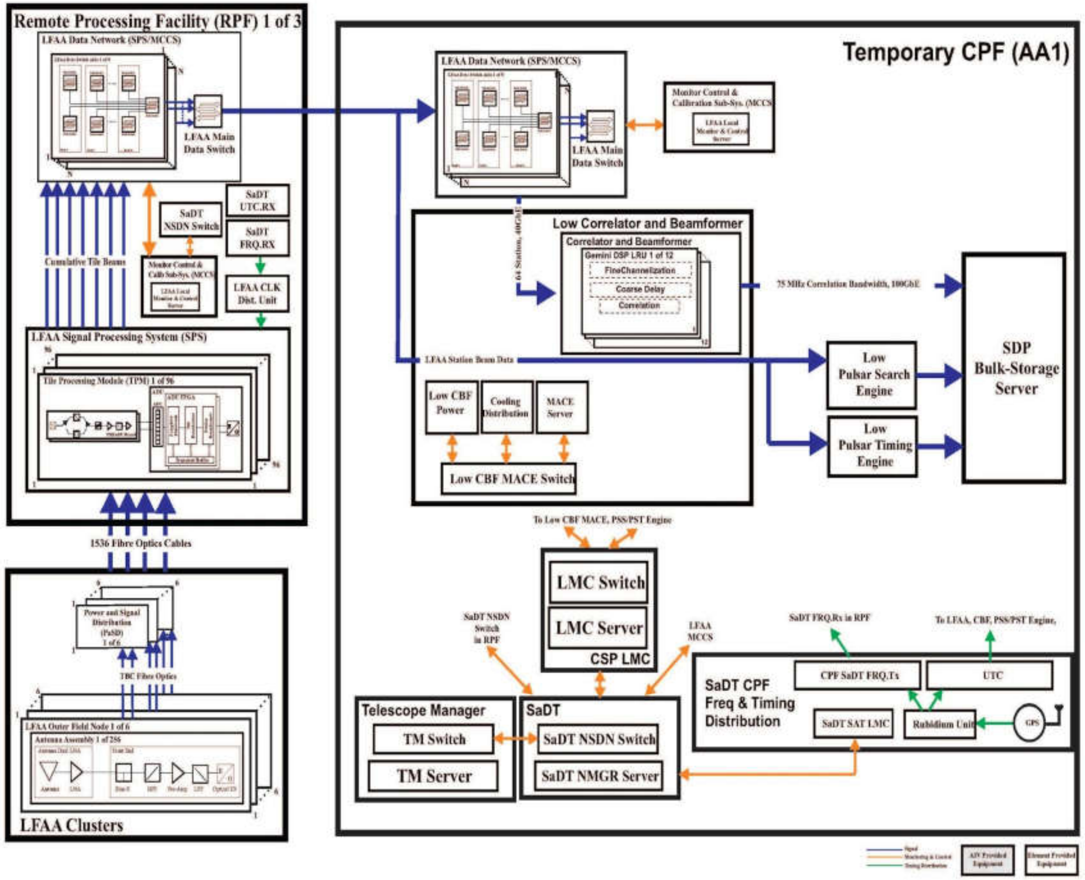


Figure 9: AA1 Block Diagram.

Table 7: AA0.5 and AA1 Product Lists.

CMN	Product name	Quantity (AA0.5)	Quantity (AA1)
101-000000	**LOW Frequency Aperture Array (LFAA) LOW**		
160-000000	Field Node	6	18
163-010000	Signal Processing System (SPS) Cabinets (populated)	3	9
164-010000	Monitor Control and Calibration Sub-system (MCCS) High Performance Computing Units	3	3
	LOW Frequency Aperture Array Data Network (LFAADN)	1	1
102-000000	**Central Signal Processor (CSP) LOW**		
110-000000	**Local Monitoring and Control (LMC)**		
110-020000	LMC Server	1	1
110-030000	LMC Switch	1	1
111-000000	**Correlator and Beamformer (CBF)**		
TBC	Alveo Cards	20	20
TBC	Alveo Server	1	1
TBC	P4 Switch	1	1
TBC	Monitoring and Control Environment (MACE) Server	1	1
TBC	Monitoring and Control Environment (MACE) Switch	1	1
113-000000	**Pulsar Search Engine (PSS)**		
113-010000	Compute Node	N/A	N/A
TBC	Control Network	N/A	N/A
TBC	Data Network	N/A	N/A
114-000000	**Pulsar Timing Engine (PST)**		
114-010000	Management Server (MSRV)	1	N/A
114-020000	Beam Server (BSRV) Active and spare	2	N/A
103-000000	**Telescope Manager (TM) LOW**		
103-000001	Sub-Array Coordinator LOW	N/A	1
103-000002	SDP Master Leaf Node LOW	1	1

103-000003	CSP Master Leaf Node LOW	1	1
103-000004	INFRA-AU Leaf Node	1	1
103-000005	LFAA Master Leaf Node	1	1
103-000006	SADT Leaf Node LOW	1	1
124-000000	Local Infrastructure for TM	10U Rack space	10U Rack space
TBC	External Information Manager	1	1
700-000004	Central Alarm Handler	1	1
700-000005	TM Alarm Handler	1	1
700-000006	Engineering Data Archive	1	1
700-000007	Central Coordinator	1	1
700-000010	Telescope Information Manager	1	1
700-000019	TM Monitor	1	1
700-000020	Logging Service	1	1
700-000021	Software System Monitor	1	1
700-000022	Life Cycle Manager	1	1
104-000000	**Science Data Processing (SDP) LOW**		
TBC	SDP Commissioning and AIV Support System	1	1
105-000000	**Networks LOW**		
140-000000	Local Infrastructure (LINFRA) LOW	3 Field Node Clusters and 2 RPFs (TBD)	3 Field Node Clusters and 3 RPFs
142-000000	Non-Science Data Network (NSDN)	1	1
143-000000	Network Manager	1	1
146-000000	CSP – SDP	N/A	N/A
141-000000	**Synchronisation and Timing (SAT)**		
141-011000	SAT.STFR.FRQ.THU	1	3
141-030000	SAT.STFR.UTC_SKA1-LOW	1	3
141-040000	SAT.Timescale.SKA1-LOW	N/A	N/A
141-060000	SAT.LMC.SKA1-LOW	1	1

TBC	GPS & Rubidium Unit	1	1
TBC	**Data Storage**		
500-000000	**Infrastructure Australia (INFRA-AU)**		
TBC	Remote Processing Facility (RPF)	1	3
TBC	Central Processing Facility (CPF)	1 Temporary RPF	1 Temporary RPF
TBC	Power for AA1 Verification (3 diesel generators)	3 generators (AIV)	3 generators (AIV)
TBC	"Worker's Hut" beside the Temporary CPF at the AA0.5/AA1 site. This hut would be air-conditioned and contain a computer terminal, basic electronics/equipment working area, tea and coffee facilities and a porta-loo"	1 (AIV)	1 (AIV)

3.2 Fibre Connectivity to ASKAP-Geraldton Fibre Link

Please refer to Figure 10 below. The figure shows the locations of:

1. The proposed location of AA0.5/AA1 and the Temporary CPF (**A**) (see Section 13.2 for AA1 site proposal),
2. The existing underground ASKAP-Geraldton fibre link (**E-D-F**).
3. The splice connection of the Trunk Long Haul Fibre into the ASKAP-Geraldton Fibre link (**D**).
4. The underground Trunk Long Haul Fibre (**D-C-B** thick purple line) from the splice point (**D**) to the fibre "spigot" at the site of the permanent CPF (**B**) beside the LOW Central Area.
5. The proposed AIV over ground fibre (**A-B** dotted line) from the AA1 Temporary CPF (**A**) to the fibre spigot at the site of the permanent CPF (**B**) – a distance of 3-4km.

There is planned an underground Trunk Long Haul fibre (**D-C-B**) that will be spliced into the existing Geraldton/ASKAP link (**F-E** thin purple line in Figure 10 below).

The Trunk Long Haul fibre will run to a pit/spigot at the site of the Permanent CPF (**B**). (The underground Long Haul fibre is the thick purple line.)

An over ground fibre from the AA1 Temporary CPF (**A**) to the Permanent CPF site (**B**) will be deployed, and connected into the Trunk Long Haul fibre at a fibre spigot at the Permanent CPF site (**B**) (The AIV over ground fibre is the black dotted line).

The connection between the AIV over ground fibre (**A-B**) and the underground Trunk Long Haul fibre (**B-C-D**), completes the fibre connection from the AA1 Temporary CPF to the ASKAP building and Geraldton.

It is essential that this Trunk Long Haul Fibre be installed and spliced into the existing ASKAP-Geraldton link before AA0.5 so AIV can have access to it. The fibre from the Temporary CPF to the Long-Haul Fibre spigot at the Permanent CPF site would only be 3-4 kms.

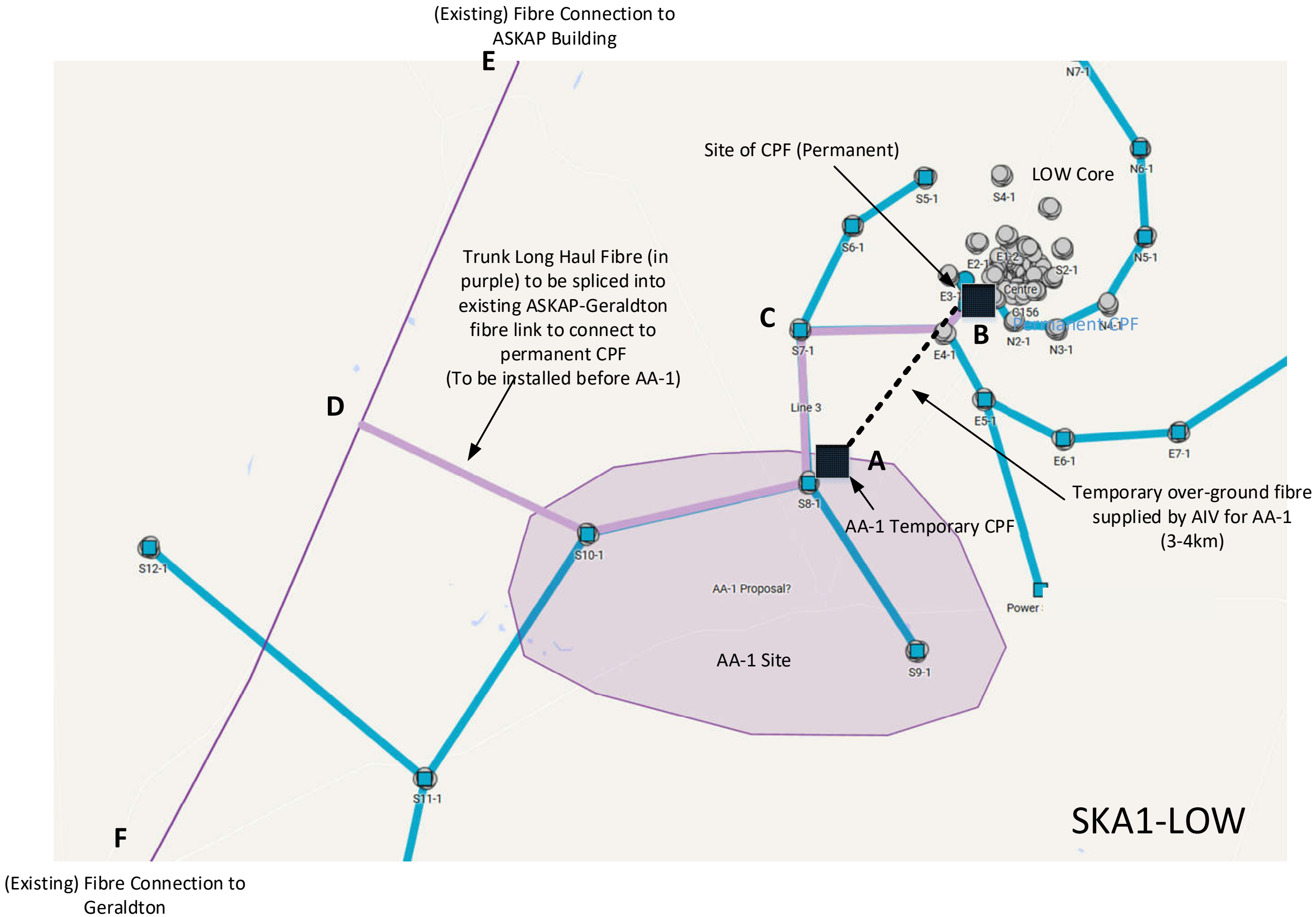


Figure 10: Fibre Connectivity to ASKAP-Geraldton Fibre link.

3.3 Rack Space Required in the Temporary CPF (RPF)

Infrastructure contractors will supply 4 racks in total in the Temporary CPF*. Each of the racks will be 2100mm from the base to the top of the rack i.e. 42U (4x42U = 168U rack space in total). There will be water cooling for the CSP.CBF equipment. The RPF will be air-conditioned and there will be enough shielded insertion points for optical fibre, etc. It is expected that the TM, SAT and Networks equipment could be placed in the same rack. The expected rack requirements from each Product Contractor are shown below:

Table 8: Rack Space required in Temporary CPF.

Product Contractor	**Rack Space Required**
MCCS	6
PSS	2
PST	12
CSP LMC (the estimate includes the LMC switch)	2
CBF (the estimate includes the following switches: P4, Low.CBF M&C and PTP)	21
TMC/OSO	12
SDP	21
Clocks	2
STFR (Calibration WR not needed anymore)	19
Networking	10
Data storage	21
Splice cabinet and patch panel	TBD
Test equipment	TBD
Cable management (2U per rack)	8
UPS	4
Total rack space needed (AA1)	**140**

Total rack space available (42U x 4)	168

*The Temporary CPF is a modified RPF. The modifications to this RPF would be minimal and the expectation is that this RPF would revert to a standard RPF after the integration of AA1.

3.4 AA0.5 and AA1 Functionality

This table details the required functionality for Array Assembly 1 (AA1). The function name, description and function number are derived from the SKA1_LOW Functional Architecture Document [RD10]. A more detailed breakdown of Sub-system functionality required for each AIV milestone and a complete list of the Level 1 SKA1_LOW functions derived from [RD10] is detailed in the Functional Allocation to Roll-Out Milestones for SKA1_LOW [RD1].

Note: TM is planning to have the Observation Execution Tool and Online Scheduling Tool available at AA2 onwards. The other observatory related tools (under TM PBS 601-000000) become available at AA*. At AA1, TM will be able to command the LOW Telescope manually via scripts and configure CSP, SDP and LFAA for observations and send pointing commands for LFAA.

Table 9: Description of Array Assembly 1 Functionality.

AA1 Array Functionality	Function Name	Function Description	Function No.	Function allocated to Sub-system	Comments
Operational Functionality	Control Station/substation Beams	Command the generation and control of the station beams required for the observation.	F.2.3.2.1, F.2.3.2.1.1, F.2.3.2.1.2	TM, LFAA	AA0.5 should support this, even if a manual process.

	Configure Visibilities	Configure the resources involved in the generation of visibilities. It generates high-level configuration commands and then breaks them into focussed commands to configure each processing node/resource.	F.2.3.3.2, F.2.3.3.2.1, F.2.3.3.2.2	TM, CSP	AA0.5 should support this, even if a manual process.
	Provide Time and Frequency reference	Provide the time and frequency reference necessary to ensure that all the data are properly time-stamped and can be synchronised.	F.6 F.6.1 F.6.2 F.6.3 F.6.4	SAT and Networks	Generate and distribute time and frequency reference. From AA0.5.
	Execute Observation	Execute the overall observation, from the reception of the electromagnetic signal to the generation of the data products and single channel holography	F.4, F.4.1, F.4.1.1, F.4.1.2, F.4.1.3, F.4.2, F.4.2.1, F.4.2.2 F.4.3.1, F.4.4, F.4.4.1	LFAA, CSP, SDP, TM	AA0.5 should support this, even if a manual process.
	Monitor Telescope	Monitor the health of the Telescope and the quality of	F.7, F.7.1, F.7.1.1, F.7.1.10, F.7.1.11, F.7.1.2, F.7.1.3, F.7.1.9, F.7.2.1, F.7.2.2	TM, LFAA, CSP, SDP, SAT and Networks	Monitor telescope resources and

		the data including RFI and weather			faults across the system from AA0.5.
	Manage Telescope Resources	Interpret and react to deviations in the required health of the telescope system	F.7.4	TM, LFAA, CSP, SDP, SAT and Networks	Response to faults and changes in system performance. Fail safe functionality should be available from AA0.5.
Imaging Functionality:	Form Station Beams	Generate a station beam from the signal from each antenna of the station.	F.4.2, F.4.2.1, F.4.2.2	TM, LFAA	Form station beams by applying calibration and beamforming weights during the beamforming. AA0.5 should support this, even if a manual process.
	Holography	Holography	Fxxx	CSP, LFAA	Single station holography for AA0.5 Interstation holography for AA1.
	Generate Visibilities	Produce visibility data and generate autocorrelation spectra.	F.4.3.1	CSP	Produce cross-correlation and

					auto-correlation data from AA0.5.
	Continuum and Spectral Line Imaging	Produce Continuum and Spectral Line Images	F.2.3.3.7, F.2.3.3.7.1, F.2.3.3.7.2, F.4.4.1	CSP, SDP	Configure imaging, produce images. AA0.5 should support this, even if a manual process

3.5 AA1 Key Engineering Goals, Integration and Risk Reduction

The table below details the Key Engineering Goals for the first Array Assembly (AA1) and the Risks being mitigated through specific Test Cases. Some of the system risks are to be partially retired at AA1, and completely retired by Array Assembly * (AA*). This table is to act as a guide for the Sub-system contractors on what tests and risk mitigation is to be performed at this AA1 milestone.

Note that test cases highlighted in green are earmarked for AA0.5.

Table 10: Description of AA1 Key Engineering Goals

AA1 Key Engineering Goals	Test Cases		Demonstrating/Mitigating Risk

	(Type)	System/Subsystem Function Check	
Correct operation of POST (Power On Start-up Test), BIT (Built In Test) and alarm handling	Power Cycle Test	System	● This test shall mitigate the risk of the AA1 system returning to a non-defined state after a shutdown cycle and also mitigate the risk of "infant mortality" in subsystem components. ● AA1 system will be powered up and powered down a number of times to check correct initialisation and recovery of the system. ● For a successful test, the system shall successfully return to an idle state after powering up after a shutdown cycle. ● Note: At present there is no L1 requirement to meet a power cycle test (Included in Sub-system L2 Requirements? (TBC)). ● This test may require a UPS for all subsystems to stop the transients killing power supplies.
	Steady State Soak Test	Subsystems/ components	● This test would mitigate the risk of "infant mortality" in components and subsystems and also the risk of overheating due to incorrect or inefficient cooling systems. ● Compared to the test in the ITF, the risk is further reduced as the test is being conducted in the actual MRO environment (representative temp fluctuations, humidity & rain, wind, lightning and wild animals)
	System Failures Test	System	● This test introduces planned "Faults" into the AA1 system including signal loss, data packet loss and thermal/cooling issues. ● This test mitigates the risk of missing monitor points in the monitoring system and alarms that may be missed due to incorrect mapping of monitoring points by User Interfaces. ● This test would also simulate System failures - blackout, brownouts and would demonstrate what state the system returns to.

			• This test would mitigate the risk of unknown/undefined states and modes the system may enter into during fault conditions. • It also demonstrates what alarms are generated and how the alarms are handled. • This test also tests "failsafe" functions which have been designed into the system - e.g. that the TM will shut down a piece of equipment before actual serious damage is caused. • The Line Replaceable units (LRUs) of all products need to be “fail safe” with each rack being “fail safe” - this is independent of TM. These also need to be tested.
	Power Consumption Test	System and Sub-system	• This test mitigates the risk of overconsumption of power by the AA1 system/subsystem due to either faults or design errors - i.e. outside the specifications of the system.
Basic operational Interface (TM)	Demonstration	TM LMC interfaces to other products	• Mitigates the risk of data/communications problems between TM LMC and the other Sub-system LMCs in the AA1 system. • This demonstration also verifies the operation of the Networks NMGR. The NMGR is essentially the LMC for the NSDN and CSP-SDP data pipeline. As all TM/LMC traffic uses NSDN, then the NSDN functionality is also tested/verified. • Correct data communications are essential for setting fringe rates, delay corrections and zoom functions in the correlator as well as setting correct beamformer weights and ACM retrieval in the LFAA TPMs. • May also serve as a stress test of the various digital interfaces within the system (bandwidth and utilisation) to ensure that data isn't lost and that the system can keep up with data demand.

Band pass characterisation and calibration (gain flatness over frequency)	Instantaneous BW Test	Front-to-back RF Chain.	• These tests confirm the basic operation of the RF path from the TPM inputs to the output of the Correlator. The basic shape of the Bandpass is confirmed. • Risks that are mitigated include possible problems with sampling of the ADC in the TPMs, beam weights in the TPM beamformer, filter banks in the CBF, and the autocorrelation function in the Correlator. • Also a very useful initial end-to-end test of the RF path from the ADC inputs to the TPMs to the output of the Correlator. • Note: This is an early sky test without confirmation of station beam shape and pointing, with likely a number of sources in the observing field. Accurate bandpass shapes / ripples should not be inferred from this test (these parameters are more likely to be verified in the controlled ITF tests). It would however provide a basic initial test of Front-to-back RF chain operation.
Manual calibration and beam steering	Basic Pointing Test	TM LMC to LFAA interface	• Basic pointing tests will be conducted on the station beam to check basic pointing function. • Beam shape will be required for accurate beam location (see Raster Scan, below). • The station beam shall be pointed on and off the galactic centre and the Sun. Drift scans of the Galactic Centre may also be employed. Output signal power is to be monitored - obtained from both LFAA ACM and CSP.CBF (autocorrelation). • This test will mitigate risk of incorrect programming and operation of the LFAA TPM beamformer (including ACMs) and also in the TM LMC interface with the LFAA Monitor, Control and Calibration Servers (MCCS). • This test can also check the ability to calibrate and derive beam weights in an effective way e.g. show that the "Hexacopter" test method is suitable (TBC) • It is also a very useful Front-to-end test for checking RF and Correlator function.

Ability to reliably conduct long observing runs (beam shape, beam stability over seconds, minutes and hours including operational interface stability (SW))	24 Hour Drift Scan Test	Full system, SAT and STFR	● Drift scans are simple and effective diagnostics of overall antenna and receiver performance (Gain, Tsys) and confirm the telescope systems ability to reliably conduct long observing runs. ● In a drift scan, the auto-correlated power of an antenna-receiver path is measured as a function of frequency and time and then compared to a prediction based on the antenna primary beam pattern, receiver properties, and a model of the sky noise (e.g. zenith transit of the Galactic Plane). ● Risks to be mitigated by this test include: ○ Long term instability of the RF Chain and the data throughput, ○ Instability in the SAT STFR systems, ○ Incorrect programming of the LFAA TPMs with beam weights and beam steering information ● Instability in Correlator function and operational interface.
Basic test of beam shape and beam stability (Raster or drift scan)	Raster Scan Test	LFAA TPM and MCCS systems, TM LMC and LFAA interfaces	● Raster scan shall be conducted to confirm correct beamforming over a wide pointing range. ● A Station beam is formed and scanned backwards and forwards orthogonally across the Galactic plane (or calibration source) for 24 hours. ● Raster scans will test for the following parameters: Beamforming and beam control properties, Beam stability, Pointing accuracy and will prove the ability of the stations to form beams. They will help determine whether the beam shape is stable. ● Raster scans will mitigate risks in the programming and timing of the LFAA TPM and MCCS systems and their interfaces with the TM Emulator. ● Drift scans and Step scans may be employed as a suitable backup to the Raster scan.

Fringes	Fringes Test - AA1	Front-to-back RF chain, Data timing	● This test is a basic interferometry test looking for "fringe" variations in the visibilities from a 2-station baseline. ● One of the significant risks to be mitigated in AA1 is that the time and frequency signals distributed from the SAT STFR system (to the LFAA TPM ADC and the CSP Correlator) are not coherent, or does not have the required accuracy. ● Other risks include interfacing and timing issues between LFAA and CSP data products. ● This test observation obtains interferometric "fringes" from a strong astronomical source like the Galactic Centre or the Sun. ● Note: Approximate positions of stations and lengths of cables will need to be known to prevent very fast wrapping of visibility phases on long baselines. In practice, this will be known more accurately with the Fringe/Rotation stopping test.
Interferometry pointing	Baseline (Delay) Solution Test	Full system, CSP Coarse Time Delay	● The Baseline (Delay) Solution using Phase closure is used to accurately determine the delays between the stations, determining accurately the distances between stations and their phase centre locations on the earth's surface. ● This test mitigates the risk of Front-to-end timing and RF instabilities as well as risks associated with SAT STFR distribution. ● It also confirms the correct calculation and extraction of delay information from the CSP Correlator and implementation of delays by the CSP-TM interface. ● Note: This test will require a number of observations at different hour angles. Suitable software to perform the Delay Solution fitting will also be required.
Fringe rotation and delay compensation models.	Fringe Rotation & Stopping Demonstration	Front-to-back RF chain, Fine delay Tracking	● For this test, a bright source is tracked for a long period of time and the phases of the visibilities are monitored for their stability.

		(Correlator), Data timing	• The Fine Time Delay units in the Correlator are essential to the proper alignment of time domain input signals prior to correlation. • This demonstration mitigates the risk of unexpected delay/phase jumps in the Fine Delay control system. • It also confirms the operation of the Coarse Delay unit as well as overall stability in correlator function and CSP-TM LMC interfaces. • It also demonstrates the ability of the AA1 system to track a celestial source.
Phase closure	Phase Closure - AA1 Demonstration	Synchronisation, Front-to-back RF Chain, Correlator	• Phase Closure is a test that will be used often and progressively throughout the testing program. • It is a system test that mitigates risk with Front-to-end timing and data interface problems as well as mitigating risk with fine delay units and Correlator function. • It is an excellent measure of the stability of phase coherence through the system. • In this observation test, a celestial source is tracked and "closure phase" monitored as a function of time.
Amplitude closure	Amplitude Closure - AA1 Demonstration	Correlator, LFAA/CSP Interfaces, End-to-end system test	• Amplitude closure is an end-to-end test checking for stability of the AA1 RF chain and the stability of the Correlator. • This is a test that will also be used often and progressively throughout the testing program. • This test mitigates the risks of instability in inter-Sub-system interfaces (primarily LFAA to CSP) and also any temporal/delay/coherence instability in the production of cross-correlation visibilities by the Correlator.

Absolute & relative timing models (1PPS and synchronisation tone)	Test	SAT and STFR systems	- Observing an unresolved source with the AA1 array will allow long term stability measurements of the timing system. - Observations of 24 hours will help mitigate risk of instability in the SAT clock and STFR distribution system. - Any jumps in the 1PPS and synchronisation tone will appear as time delay jumps in the correlated visibilities.
Telescope Model	Demonstration	LFAA, TM, SDP	- These tests mitigate risks in the computation, recording and implementation of the dynamic computational models of the Telescope including configuration information, numerical models, geodetic and geometric models. - Risk is also mitigated by testing (through observation) the AA element and station beam model, which is a model for each element and station beams as a function of azimuth and zenith angle, frequency and polarisation.
Basic continuum image	First Images - Sky Brightness Distribution Test	Full system, CSP products with SDP	- Sky Brightness Distribution (for AA1): - Observe celestial sources with a minimum of 3 stations (up to 24 stations for AA1 - distributed among three 6-station clusters for AA1). - Produce an image of sky brightness distribution by doing an FFT of measured sky visibilities. - Demonstrate basic imaging performance with available AA1 correlator BW (75MHz). - Produce first image (snapshot) of a single or small group of bright sources. - Determine AA1 array point spread function (PSF) from image of single bright compact source.

			● CSP to only provide part (75MHz) of the full 300MHz bandwidth for correlation. Multiple observations at different centre frequencies may be performed (or use a selection of LFAA channels for processing). ● Mitigates the risk of interfacing CSP to SDP data products when using real sky data and demonstrates end-to-end functionality of the SKA1_LOW system. ● This is the key end to end system test. To successfully complete this test, almost all system products need to be working correctly - except perhaps high quality station beamforming.
Basic spectral line Image	First Images - Sky Brightness Distribution Test	Full system, CSP products with SDP	● Sky Brightness Distribution (for AA1): ○ Observe celestial sources with 24 stations (distributed among three 6-station clusters for AA1). ○ Produce an image of sky brightness distribution by doing an FFT of measured sky visibilities. ○ Demonstrate basic imaging performance at 3 different frequencies (lower edge, mid-band and upper edge of receiver bandwidth) at a 75MHz bandwidth with channel BWs of 4kHz. ○ Produce the first image (snapshot) of a single or small group of bright sources. ○ Determine AA1 array point spread function (PSF) from image of single bright compact source. ● CSP to only provide part (75MHz) of the full 300MHz bandwidth for correlation. Multiple observations at different centre frequencies may be performed (or use a selection of LFAA channels for processing).

			• As in the Basic Continuum Image Test, this test mitigates the risk of interfacing CSP to SDP data products when using real sky data and demonstrates end-to-end functionality of the SKA1_LOW system. • Holography??
Frequency agility (how quickly we can change observing frequency on LOW?)	Test	LFAA, CSP and TM	• This test mitigates the risk of slow set/transition times for system parameters. • It will specifically check the operation of the LFAA, CSP systems and TM Emulator systems.
Development of methods for managing beam shapes, pointing models, beam rotation	Analysis/Task	LFAA, CSP and TM	• This development task improves the efficiency of the beam shape modelling with real sky data. • This test mitigates the risk of incorrect beam weight models for the TPM beamformers.
Confirmation of system synchronisation	Demonstration	Front-to-back RF Chain	• Correct end-to-end data synchronisation is essential for proper operation of an Aperture Array. • Data streams/packets need to be aligned in time for correct operation. • Correct delay alignment is essential for accurate correlation. • This test mitigates the risk of delay aberrations like delay jumps occurring in the data streams that would otherwise corrupt visibility products.
Early performance comparisons against simulations	Analysis	LFAA TPM Beamformer systems	• This analysis would most likely be conducted by the commissioning scientists within the Science Commissioning & Verification Team, feeding information back to the LFAA contractors about the beam weights models used in the TPMs. • This analysis would mitigate risk in the methods used to form beams and correct beam weights and check the overall conformance of the AA1 system to SVT expectations.

Do comparison observations with MWA.	Demonstration	AA1 System, LFAA TPM/MCCS calibration and beam weights, CSP Cross-correlation efficiency	● As the MWA observes the same sky as AA1, simultaneous observations may be conducted to prove the overall ability of the AA1 to measure astronomical source strengths and produce preliminary images. ● Observing common astronomical sources (including the Galactic Centre and the Sun) will be very useful data in assessing the ability of the AA1 system to effectively measure the Flux density of these sources. ● A side-by-side test with the MWA would mitigate risk in incorrect beam weights and calibration parameters in the LFAA TPMs and the efficiency of the CSP cross correlation function and would be a very important test for gauging the overall operation of the AA1 system.

3.6 AA1 Verification Outcomes

The table below details the Key Engineering Goals for tests performed throughout Array Assemblies 0.5 and 1.

Some L1 requirements are partially verified during these activities. This table is not for requirements verification traceability, but to act as a guide for the product contractors on what verification is to be performed at this AA1 milestone.

Table 11: Description of Array Assembly 1 Verification Outcomes.

Key Engineering Goals	Test Cases (Type)	System/Subsystem Function Check	Verification Outcomes
Correct operation of POST (Power On Start-up Test), BIT (Built In Test) and alarm handling	Power Cycle Test	System	● Verifies the correct initialisation and recovery of the system from a power cycle.
	Steady State Soak Test	Subsystems/ components	● Verify and measure the steady state operation of the AA1 system in the actual MRO environment (representative temp fluctuations, humidity & rain, wind, lightning and wild animals)
	System Failures Test	System	● Verifies what alarms are generated and how the alarms are handled. ● Verifies "failsafe" functions which have been designed into the system - e.g. that the TM will shut down a piece of equipment before actual serious damage is caused.

	Power Consumption Test	System and Sub-system	• Verifies the steady state and power-on power consumption (L2 Requirements?) • Verifies correct power-on/power-off sequencing
Basic operational Interface (TM)	Demonstration	TM LMC interfaces to other products	• Verifies correct data communications for setting fringe rates, delay corrections and zoom functions in the correlator as well as setting correct beamformer weights and ACM retrieval in the LFAA TPMs. • This demonstration also verifies the operation of the Networks NMGR. The NMGR is essentially the LMC for the NSDN and CSP-SDP data pipeline. As all TM/LMC traffic uses NSDN, then the NSDN functionality is also tested/verified. • Verifies the robustness of various digital interfaces within the system (bandwidth and utilisation) to ensure that data isn't lost and that the system can keep up with data demand.
Band pass characterisation and calibration (gain flatness over frequency)	Instantaneous BW Test	Front-to-back RF Chain.	• These tests verify the basic operation of the RF path from the TPM inputs to the output of the Correlator. The basic shape of the Bandpass is confirmed. • System parameters being verified include: ○ Spectral stability, Instantaneous bandwidth, Linearity, Clipping, Clipped data flagging, Dynamic range ○ Autocorrelation spectra, autocorrelation calibration, channelisation transition band for adjacent frequency channels, channeliser maximum leakage for non-adjacent frequency channels, channeliser frequency, channel amplitude variation ○ Fine frequency channel band edge, Spectral channels ○ Zoom windows, Zoom window centre frequency, Zoom window channels, Continuum with zoom windows, Zoom window noise leakage power

			○ Overlapped window amplitude response, Correlation signal to noise, Correlator Integration rate.
Manual calibration and beam steering	Basic Pointing Test	TM LMC to LFAA interface	● Will verify basic pointing function on the station beams ● Will also verify the ability to calibrate and derive beam weights in an effective way e.g. show that the "Hexacopter" and measured EEPs can be used to calibrate station beams. ● Will verify the Front-to-end RF and Correlator autocorrelation function. ● System parameters being verified include: ○ Control of station beam properties ○ Multiple beam capability ○ Beam steering ○ Multiple beam bandwidths
Basic test of beam shape and beam stability (Raster or drift scan)	Raster Scan Test	LFAA TPM and MCCS systems, TM LMC and LFAA interfaces	● Raster scan shall verify the ability of the stations to form beams correctly over a wide pointing range and will verify the following parameters: ○ Station beam stability, Beamforming and beam control properties, Beam stability, Pointing accuracy.
Ability to reliably conduct long observing runs (beam shape, beam stability over seconds, minutes and hours including operational interface stability)	24 Hour Drift Scan Test	Full system, SAT and STFR	● Drift scans verify overall antenna and receiver performance (Gain, Tsys). ● System parameters being verified include: ○ Calibration update period ○ Real time calibration

Fringes	Fringes Test - AA1	Front-to-back RF chain, Data timing	● This test is a basic interferometry test looking for "fringe" variations in the visibilities from a 2-station baseline. ● The test verifies the operation of the Front-to-back RF chain and the stability and coherence of the frequency/time references and correlator's cross-correlation function.
Interferometry pointing	Baseline (Delay) Solution Test	Full system, CSP Coarse Time Delay	● The Baseline (Delay) Solution using Phase closure is used to accurately determine the delays between the stations, effectively determining accurately the distances between stations and their phase centre locations on the earth's surface. ● The test verifies the correct calculation and extraction of delay information from the CSP Correlator and implementation of delays by the CSP-TM interface.
Fringe rotation and delay compensation models.	Fringe Rotation & Stopping Demonstration	Front-to-back RF chain, Fine delay Tracking (Correlator), Data timing	● For this test, a bright source is tracked for a long period of time and the stability of the phases of the visibilities are monitored. ● This test verifies the operation of the Fine Time Delay and Coarse Delay units in the Correlator as well as overall stability in cross-correlation function and CSP-TM LMC interfaces. ● It also demonstrates the ability of the AA1 system to track a celestial source.
Phase closure	Phase Closure - AA1 Demonstration	Synchronisation, Front-to-back RF Chain, Correlator	● Phase Closure is a front-to-back system test that verifies the phase stability of the telescope system by monitoring the closure phase of the baseline visibilities.
Amplitude closure	Amplitude Closure - AA1 Demonstration	Correlator, LFAA/CSP Interfaces, End-to-end system test	● Amplitude closure is an end-to-end test verifying the stability of the AA1 RF chain and the stability of the Correlator. ● System parameters being verified include:

			○ Absolute flux density scale
Absolute & relative timing models (1PPS and synchronisation tone)	Test	SAT and Networks	● Observing an unresolved source with the AA1 array will verify the long term stability of the timing system. ● System parameters being verified include: ○ SKA1_LOW coherence losses 1s ○ SKA1_LOW Frequency reference phase drift ○ SKA1_LOW Pulse per second precision ○ SKA1_LOW Pulse per second synchronisation
Telescope Model	Demonstration	LFAA, TM, SDP	These tests verify the dynamic computational model of the Telescope including configuration information, numerical models, geodetic and geometric models. The AA element and station beam model is a model for each element and station beams as a function of azimuth and zenith angle, frequency and polarisation. Telescope Model verification includes: ● Telescope Model ● Single geodetic model (Telescopes). ● Single geometric model. ● AA element and station beam model.
Basic continuum image	First Images - Sky Brightness	Full system, CSP products with SDP	● This is the key end to end system verification test. To complete this test, almost all system products need to be working successfully.

	Distribution Test		● System Parameters being verified include: ○ Continuum Imaging. ○ Polarisation dynamic range: imaging ○ Holography??
Basic spectral line Image	First Images - Sky Brightness Distribution Test	Full system, CSP products with SDP	● Similar to the Basic Continuum Image goal, this is another key end to end system verification test.
Frequency agility (how quickly we can change observing frequency on LOW?)	Test	LFAA, CSP and TM	● This test verifies the set/transition times for telescope system parameters. ● It will specifically check the operation of the LFAA, CSP systems and TM Emulator systems.
Development of methods for managing beam shapes, pointing models, beam rotation	Analysis/Task	LFAA, CSP and TM	● This development task verifies the efficiency of the beam shape modelling with real sky data.
Early performance comparisons against simulations	Analysis	LFAA TPM Beamformer systems	● This analysis would most likely be conducted by the commissioning scientists within the Science Commissioning & Verification Team, feeding information back to the LFAA contractors about the beam weights models used in the TPMs. ● This analysis would verify the methods used to form beams and correct beam weights and check the overall conformance of the AA1 system to SVT expectations.
Do comparison observations with MWA.	Demonstration	AA1 System, LFAA TPM/MCCS calibration and	● A side-by-side test with the MWA verifying the correct beam weights and calibration parameters used in the LFAA TPMs and the efficiency of the CSP cross correlation function and would be a very important test for verifying the overall operation of the AA1 system.

		beam weights, CSP Cross-correlation efficiency	● System parameters being verified include: ○ Absolute flux density scale

4 Array Assembly 2 (AA2)

This section describes the characteristics and capabilities of Array Assembly 2.

The tables and diagrams below provide the following information for Array Assembly 2:

- Block Diagram
- Product List
- AA2 Array Assembly Functionality
- Key engineering goals for the AA2 Array Assembly, referenced to L1 requirement Verification.

A proposed configuration for AA2 is shown in Section 13.3 and follows a number of assumptions:

- AA2 should be a superset of AA1.
- The AA2 configuration should incorporate a mixture of short and long fibre runs for testing the SAT STFR system.
- The AA2 configuration should incorporate a mixture of short and long baselines for testing proper operation of Fringe Rotation and Delay Tracking.
- There should be a sizeable portion of the stations located in the Low Central Area to support suitable UV coverage and Point Spread Function.
- The configuration should be confirmed as early as possible and should take into account the constraints of construction contractors and the potential needs of Science Commissioning and Verification.

AA2 is expected to use a Maser as the preferred time clock. The AIV-provided Rubidium and GPS (provided at AA1) may be used as a temporary time reference if the Maser is not available.

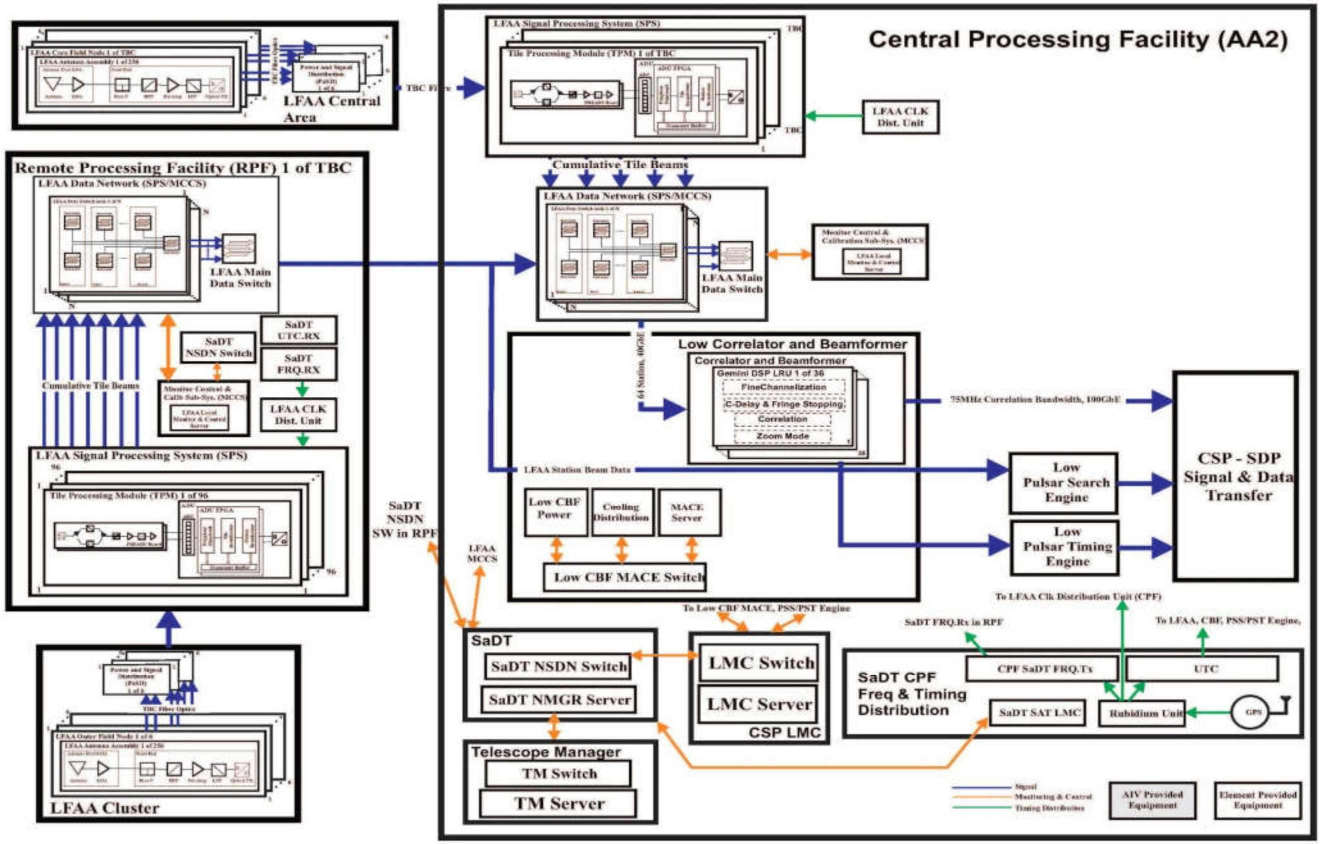


Figure 11: AA2 Block Diagram.

Table 12: AA2 Product List.

CMN	Product name	Quantity Required (AA2)
101-000000	**LOW Frequency Aperture Array (LFAA) LOW**	
160-000000	Field Node	128
163-010000	Signal Processing System (SPS) Cabinets (populated)	32
164-010000	Monitor Control and Calibration Sub-system (MCCS) High Performance Computing Units	8 to 10
	LOW Frequency Aperture Array Data Network (LFAADN)	1
102-000000	**Central Signal Processor (CSP) LOW**	
110-000000	**Local Monitoring and Control (LMC)**	
110-020000	LMC Server	1
110-030000	LMC Switch	TBC
111-000000	**Correlator and Beamformer (CBF)**	
TBC	Alveo Cards	20
TBC	Alveo Server	1
TBC	P4 Switch	1
TBC	Monitoring and Control Environment (MACE) Server	1
TBC	Monitoring and Control Environment (MACE) Switch	1
113-000000	**Pulsar Search Engine (PSS)**	
113-010000	Compute Node	N/A
TBC	Control Network	N/A
TBC	Data Network	N/A
114-000000	**Pulsar Timing Engine (PST)**	
114-010000	Management Server	1
114-020000	Beam Server	4
103-000000	**Telescope Manager (TM) LOW**	
103-000001	Sub-Array Coordinator LOW	1
103-000002	SDP Master Leaf Node LOW	1
103-000003	CSP Master Leaf Node LOW	1
103-000004	INFRA-AU Leaf Node	1

103-000005	LFAA Master Leaf Node	1
103-000006	SADT Leaf Node LOW	1
124-000000	Local Infrastructure for TM	10U Rack space
TBC	External Information Manager	1
700-000001	Observation Execution Tool	1
700-000002	Online Scheduling Tool	1
700-000004	Central Alarm Handler	1
700-000005	TM Alarm Handler	1
700-000006	Engineering Data Archive	1
700-000007	Central Coordinator	1
700-000010	Telescope Information Manager	1
700-000015	TM UI Backend	1
700-000016	Telescope GUI	1
700-000019	TM Monitor	1
700-000020	Logging Service	1
700-000021	Software System Monitor	1
700-000022	Life Cycle Manager	1
600-000005	Observation data Archive	1
104-000000	**Science Data Processing (SDP) LOW**	
TBC	SDP Commissioning and AIV Support System	1
105-000000	**Networks LOW**	
140-000000	Local Infrastructure (LINFRA) LOW	At least 4 RPFs (including AA1) and Field Node reticulation
142-000000	Non-Science Data Network (NSDN)	1
143-000000	Network Manager	1
146-000000	CSP – SDP	1
141-000000	**Synchronisation and Timing (SAT)**	
141-011000	SAT.STFR.FRQ.THU	4
141-030000	SAT.STFR.UTC_SKA1-LOW	4

141-040000	SAT.Timescale.SKA1-LOW	1 (Dependent upon Availability)
141-060000	SAT.LMC.SKA1-LOW	1
TBC	GPS & Rubidium Unit	1 (Required if SAT.Timescale not available)
500-000000	**Infrastructure Australia (INFRA-AU)**	
TBC	Remote Processing Facility (RPF)	4 (Including AA1)
TBC	Central Processing Facility (CPF)	1

4.1 AA2 Hardware to be supplied by AIV

AIV will not be supplying any additional hardware for AA2.

4.2 AA2 Migration from AA1 Temporary CPF to permanent CPF at AA2

The permanent Central Processing Facility (CPF) will not be available at the time of AA1 verification and the backend products of AA1 will be housed in the "Temporary CPF". At the end of the AA1 verification, there will be a migration of equipment from the Temporary CPF into the permanent CPF for AA2. There are planned downtime allowances and regression testing of the AA2 system after reinstallation in the CPF. This testing regime is covered in the AIV LOW I&V Schedule [RD6], [RD7].

Some installation and testing may be commenced for AA2 without the AA1 backend. The installation and L2 testing of the additional 48 LFAA stations for AA2 can proceed before the migration of the AA1 backend. The next step is to migrate the CSP.CBF from AA1 to AA2 and conduct the associated regression testing. The AA1/AA2 CBF is only likely to be a couple of racks of equipment so the migration should not be a complex task. The reconnection of the GPS/Rubidium may then proceed and the verification tests for AA2 will be redone as for AA1. The NSDN system will need to be reconfigured with IP addresses etc, along with the reinstallation of the TM server/switches and SDP equipment. When the migration of the required components of AA1 is complete and the necessary integration with the additional AA2 products is done, the verification testing for AA2 may begin.

4.3 AA2 Functionality

This table details the required functionality for Array Assembly 2 (AA2). The function name, description and function number are derived from the SKA1_LOW Functional Architecture Document [RD10]. A more detailed breakdown of Functionalities required for each AIV milestone and a complete list of the SKA1_LOW functions derived from [RD10] is detailed in the Functional Allocation to Roll-Out Milestones for SKA1_LOW [RD1].

Table 13: Description of Array Assembly 2 Functionality

AA2 Array Functionality	Function Name	Function Description	Function No.	Function allocated to Sub-system	Comments
Operational Functionality	Manage observation	Manage and control the life cycle of an observation, including design/sequence observation and design project	F.2, F.2.1.3, F.2.2.3, F.2.3.2, F.2.3.2.1, F.2.3.2.1.1, F.2.3.2.1.2, F.2.3.3, F.2.3.3.1, F.2.3.3.1.1, F.2.3.3.1.2 F.2.3.3.2, F.2.3.3.2.1, F.2.3.3.2.2, F.2.3.4	TM, CSP, LFAA, SDP	Configure and Control station beams, configure and select visibilities, sub-arrays
	Calibrate Sub-Arrays	Calculate the calibration coefficients to be applied at different levels for the overall calibration of the Telescope.	F.3 F.3.1 F.3.2	LFAA, SDP, CSP	Calibrate Sub-Arrays, station beams, visibilities, tied array beams

			F.3.3 F.3.4		and imaging data products
	Provide Time and Frequency reference	Provide the time and frequency reference necessary to ensure that all the data are properly time-stamped and can be synchronised.	F.6 F.6.1 F.6.2 F.6.3 F.6.4	SAT and Networks	
	Execute Observation	Execute the overall observation, from the reception of the electromagnetic signal to the generation of the data products	F.4, F.4.1, F.4.1.1, F.4.1.2, F.4.1.3, F.4.2, F.4.2.1, F.4.2.2 F.4.3, F.4.3.1, F.4.3.3, F.4.4, F.4.4.1, F.4.4.2, F.4.4.3	LFAA, CSP, SDP	Front to back process incorporating all parts of the AA1 system, process sub-array beams
	Monitor Telescope	Monitor the health of the Telescope and the quality of the data.	F.7, F.7.1, F.7.1.1, F.7.1.10, F.7.1.11, F.7.1.13, F.7.1.2, F.7.1.3, F.7.1.5, F.7.1.8, F.7.1.9, F.7.2, F.7.2.1, F.7.2.2, F.7.2.3, F.7.3	TM, LFAA, CSP, SDP, SAT and Networks	Monitor telescope resources and faults across the system as well as environment and RFI. Examine Data Quality
	Manage Telescope Resources	Interpret and react to deviations in the required health of the telescope system	F.7.4	TM, LFAA, CSP, SDP, SAT and Networks	Response to faults and changes in system performance

Imaging Functionality:	Form Station Beams	Generate a station beam from the signal from each antenna of the station.	F.4.2, F.4.2.2	TM, LFAA	Form station beams by apply calibration and beamforming weights during the beamforming
	Holography	Holography	Fxxx	CSP, LFAA	Interstation holography
	Generate Visibilities	Produce visibility data and generate autocorrelation spectra.	F.4.3.1	CSP	Produce cross-correlation and auto-correlation data
	Continuum and Spectral Line Imaging	Produce Continuum and Spectral Line Images	F.2.3.3.7, F.2.3.3.7.1, F.2.3.3.7.2, F.4.4.1	CSP, SDP	Configure imaging, produce images
Non-Imaging Functionality	Pulsar Timing	Configuration and processing of PST data (4 beams)	F.2.3.2.3, F.2.3.2.3.1, F.2.3.2.3.2, F.2.3.2.4, F.F.2.3.2.4.1, F.2.3.2.4.2, F.2.3.2.9, F.2.3.3.4, F.2.3.3.4.1, F.2.3.3.4.2, F.2.3.3.6, F.2.3.3.6.1 F.2.3.3.6.2, F.2.3.3.9.1 F.2.3.3.9.2, F.4.3, F.4.3.3, F.4.3.5, F.4.4.3	TM, CSP	Configure and select PST analysis resources and configuration, process Pulsar Timing data, Pulsar Timing

	Control Dynamic Spectrum Production	Produce Dynamic Spectra	F.2.3.2.8, F.2.3.3.10, F.2.3.3.10.1, F.2.3.3.10.2	TM, CSP	Configure and control Dynamic Spectrum analysis of non-imaging data

4.4 AA2 Key Engineering Goals, Integration and Risk Reduction

The table below details the Key Engineering Goals for Array Assembly 2 (AA2) and the Risks being mitigated through specific Test Cases. This table is to act as a guide for the Sub-system contractors on what test and risk mitigation is to be performed at this AA2 milestone.

Table 14: Description of Array Assembly 2 Key Engineering Goals

AA2 Key Engineering Goals	Test Cases (Type)	System/Subsystem Function Check	Demonstrating/Mitigating Risk
Bandpass Calibration and Stability	Test	CSP, LFAA, SDP	• These tests confirm the basic operation of the RF path from the TPM inputs to the output of the Correlator. The basic shape of the Bandpass is confirmed. • Risks that are mitigated include possible problems with sampling of the ADC in the TPMs, beam weights in the TPM beamformer, filter banks in the CBF, and the autocorrelation function in the Correlator. • These tests will verify the calibration and stability of the bandpass spectrum and station beams including Spectral Stability, Instantaneous Bandwidth, Clipped data flagging, Station beam stability, Absolute flux density scale
Polarisation Characterisation	Analysis Test	CSP, LFAA, SDP, TM	• Polarisation purity is essential for high polarisation dynamic range. • Measure the polarisation leakage and test calibration methods. • Measure polarisation dynamic range for imaging and non-imaging (e.g. pulsar timing) observations.
Multiple Beams	Test	CSP, SDP, LFAA, TM	• These tests mitigate the risks of incorrect beamforming function in the LFAA.TPMs and CSP.CBF, and correlator function within the CSP.CBF when the array is requested to form

			independent Multiple Beams within a sub-array. Multiple beams are required for conducting parallel observations and experiments.
Fine Channel (correlator) bandpass characterisation	Test Demonstration	LFAA, CSP, SDP	● These tests mitigate the risks of channel to channel leakage and passband flatness irregularity in the spectral channels of the LFAA TPMs and CSP.CBF fine channelization system.
Zoom Windows	Test	CSP, SDP	● These tests mitigate the risks of spectral irregularities in the CSP Zoom Windows function. Accurate spectral zooming is required for the spectral integrity of the expanded spectrum.
Correlator Function	Test	CSP	● These tests are a performance indicator on the quality of operation of the correlator. These tests mitigate the risks of correlator instability and data loss.
Dynamic Spectrum	Test	SDP, CSP, TM, SAT and Networks	● This test mitigates risk in the creation of high time resolution dynamic spectrum data products showing time, frequency and polarisation data. Dynamic spectrum and Dynamic spectrum sub-array support are verified.
Time and Frequency reference	Test	SAT and Networks	● These tests mitigate the risk of instability due to coherence loss and phase drift in the Timing and frequency reference system by observing an unresolved source with the AA2 array over a long period of time. ● This test will verify the long term stability of the timing system including coherence losses, reference frequency phase drift and Pulse Per Second precision and synchronisation.
CSP-SDP Link	Demonstration	CSP, SAT and Networks, SDP, TM	● This test verifies the operation and the data transport capacity for the CSP-SDP data pipeline between the MRO site and the Pawsey Centre in Perth.
Observing	Test	LFAA, SAT and Networks, CSP, SDP, TM	● This test mitigates the risks of slow or unstable switching between observing modes.

Sub-arrays	Demonstration and Test	CSP, SDP, TM	• These tests mitigate the risks of incorrect setup, creation and operation of Sub-arrays, including risks associated with set up time, granularity, independence and configuration. • Pointing tests are conducted to confirm proper beamforming and independent steering of sub-arrays. • Risk associated with setting incorrect bandwidth and frequency resolution are also mitigated. Risks associated with Sub-array scheduling blocks are also addressed.
Pulsar Timing	Test and Demonstration	CSP, TM	• System synchronisation, Time and Frequency reference system stability, accurate timing and Time stamping are critical for the correct operation of the Pulsar Timing System. • These tests mitigate risks associated with Timing Beam formation, Time stamping of data and Beamforming S/N ratio. Risks are also mitigated in the timing system including bandwidth, Timing Resolution and dispersion measure removal.
RFI and EMC	Test, Demonstration and Inspection	LFAA, SAT and Networks, CSP, SDP, TM, INFRA-AU	• AA2 RFI risk mitigation includes testing for Electromagnetic radiation from components of SKA1_LOW and Self-induced RFI; testing the basic operation of the RFI Flagging, Excision and Masking systems including Fixed Flagging from TM. Risk due to RF leakage problems with the Central Processing Facility RFI shielding and penetrations are also mitigated.
Telescope Management – Assessment of Operational Interface	Test	TM, SDP, CSP, LFAA	• Mitigates the risk of data/communications problems between TM LMC and the other Sub-system LMCs in the AA2 system. • This demonstration also verifies the operation of the Networks NMGR. The NMGR is essentially the LMC for the NSDN and CSP-SDP data pipeline. As all TM/LMC traffic uses NSDN, then the NSDN functionality is also tested/verified. • Confirms the correct function of Telescope Management scaled to the AA2 array.

			• May also serve as a stress test of the various digital interfaces within the system (bandwidth and utilisation) to ensure that data isn't lost and that the system can keep up with data demand. • These tests also mitigate risks in the setup and operation of scheduled maintenance and system error logs and observing logs, active alarms/alarm filtering and latency functions. • The operator control test confirms the ability for authorised personnel to take manual control of the telescope, its subarrays and instrumentation. • Access to various data bases including weather, RFI satellite and aircraft activity and ionospheric activity is also provided.
Science Data Processing Pipeline	Demonstration	SDP	• A Global Sky Model is used for calibration and continuum subtraction for the LOW telescope. A frequency dependent image model is used in all imaging. Basic Global Sky Model functionality will be available for AA2 using existing 3rd party tools. This will support station calibration and basic imaging (using 3rd party tools). • A successful demonstration reduces the risk of the incorrect use of the Global Sky Model for calibration and continuum subtraction.
Telescope Model	Demonstration	LFAA, TM, SDP	• These tests mitigate risks in the computation, recording and implementation of the dynamic computational models of the Telescope including configuration information, numerical models, geodetic and geometric models. • Risk is also mitigated by testing (through observation) the AA element and station beam model, which is a model for each element and station beams as a function of azimuth and zenith angle, frequency and polarisation.

Monitoring	Inspection	INFRA-AU, TM, SAT and Networks	● Monitoring is an Infrastructure activity. These inspections mitigate the risk of critical blind spots in the visual monitoring system and RFI leakage/generation in the telescope array system or support infrastructure.
Regression Testing	Test	All Products	For SKA1-LOW, the key points during construction where regression testing needs will be reviewed: ● The system hardware is expanded at each of the AIV LOW Milestones ● Software or Firmware upgrades are made to any of the Sub-system products ● The AA1 backend system is migrated to the CPF at AA2 ● Any hardware configuration change ● Any technology refresh ● Any major production batch changes ● Regression testing may be either a full system test with complex tests like fringes, basic imaging or drift scans or more simple tests like sanity checks, reconfirmation of Sub-system interfaces and data flow protocols. E.g. fix for a simple, low level bug that corrupts metadata.
Verification of Hardware and Software Interfaces	Test	All Products	● The verification of hardware and software interfaces between products is an essential part of the LOW System Integration process.

4.5 AA2 Verification Outcomes

The table below details the Key Engineering Goals for AA2 and the verification outcomes at this Roll-Out Milestone (including some L1 Requirements). This table is to act as a guide for the Sub-system contractors on what verification is to be performed at this AA2 milestone.

Table 15: Description of Array Assembly 2 Verification Outcomes

AA2 Key Engineering Goals	Test Cases (Type)	Sub-system	Verification Outcomes
Bandpass Calibration and Stability	Test	CSP, LFAA, SDP	These tests verify the calibration and stability of the bandpass spectrum and station beam. Verification includes: ● Spectral Stability ● Instantaneous Bandwidth ● Clipped data flagging ● Station beam stability ● Absolute flux density scale
Polarisation Characterisation	Analysis Test	CSP, LFAA, SDP, TM	These tests verify the polarisation dynamic range for imaging and non-imaging observations. Verification includes:

			• SKA1_LOW Polarisation dynamic range: imaging • SKA1_LOW Polarisation dynamic range: Pulsar Search • SKA1_LOW Polarisation dynamic range: Pulsar Timing
Multiple Beams	Test	CSP, SDP, LFAA, TM	These tests verify the capability of the array to form independent beams from each station within a sub-array. Verification includes: • SKA1_LOW Multiple beam capability • SKA1_LOW beam steering • SKA1_LOW multiple beam bandwidths
Fine Channel (correlator) bandpass characterisation	Test Demonstration	LFAA, CSP, SDP	These tests verify the performance of the LFAA TPM, CSP CBF's fine channelization system. Verification includes: • SKA1_LOW autocorrelation calibration • SKA1_LOW Continuum Imaging. • SKA1_LOW channelisation transition band for adjacent frequency channels. • SKA1_LOW channeliser maximum leakage for non-adjacent frequency channels • SKA1_LOW channeliser frequency channel amplitude variation • SKA1_LOW fine frequency channel band edge • SKA1_LOW spectral channels

Zoom Windows	Test	CSP, SDP	These tests verify the Zoom windows function of the CSP CBF. Verification includes: ● SKA1_LOW zoom windows. ● SKA1_LOW zoom window centre frequency ● SKA1_LOW zoom window channels. ● SKA1_LOW continuum with zoom windows. ● SKA1_LOW zoom window noise leakage power ● SKA1_LOW Overlapped window amplitude response
Correlator Function	Test	CSP	Verification includes: ● SKA1_LOW correlation signal to noise ● SKA1_LOW correlator Integration rate.
Dynamic Spectrum	Test	SDP, CSP, TM, SAT and Networks	This test verifies the creation of high time resolution dynamic spectrum data products showing time, frequency and polarisation data. Requirements verification includes: ● SKA1_LOW Dynamic spectrum. ● SKA1_LOW Dynamic spectrum sub-array support.
Time and Frequency reference	Test	SAT and Networks	Observing an unresolved source with the AA2 array will verify the long term stability of the timing system. Verification includes:

			• SKA1_LOW coherence losses 1s • SKA1_LOW Frequency reference phase drift • SKA1_LOW Pulse per second precision • SKA1_LOW Pulse per Second synchronisation • UTC accuracy. • Central frequency reference
Monitoring	Inspection	INFRA-AU, TM, SAT and Networks	Monitoring is an Infrastructure activity. Monitoring performed during the AA2 Array Assembly include: • Visual monitoring. • RFI Monitoring
Observing	Test	LFAA, SAT and Networks, CSP, SDP, TM	This test verifies the switching time between observing modes. Verification includes: • Mode transition
Sub-arrays	Demonstration and Test	CSP, SDP, TM	These tests verify the setup, creation and operation of Sub-arrays. Verification includes: • SKA1_LOW subarray support • SKA1_LOW subarray set up time • SKA1_LOW subarray membership • SKA1_LOW subarray granularity

			• SKA1_LOW subarray independence • SKA1_LOW subarray configuration • SKA1_LOW subarray tied-array beam station exclusion • SKA1_LOW subarray station allocation • SKA1_LOW subarray station failure flagging • SKA1_LOW Maintenance subarray • SKA1_LOW subarray pointings • SKA1_LOW subarray frequency resolution • SKA1_LOW subarray bandwidth • SKA1_LOW subarray visibility time resolution • SKA1_LOW subarray logical control and monitoring • SKA1_LOW subarray logical data flows • SKA1_LOW subarray scheduling block set-up time • SKA1_LOW simultaneous scheduling blocks • SKA1_LOW subarray scheduling block allocation • SKA1_LOW subarray independence of scheduling block
Pulsar Timing	Test and Demonstration	CSP, TM	These tests verify the setup and operation of the telescope Pulsar Timing system. Most of the basic Pulsar Timing requirements are verified at AA2. Verification includes:

			• SKA1_LOW Pulsar timing array diameter • SKA1_LOW Pulsar timing observing band • SKA1_LOW Pulsar timing bandwidth • SKA1_LOW Beamforming S/N ratio: Pulsar timing. • SKA1_LOW Time stamping • SKA1_LOW Timing Beams • SKA1_LOW Pulsar timing Dispersion Measure. • SKA1_LOW Pulsar Timing Resolution
RFI and EMC	Test, Demonstration and Inspection	LFAA, SAT and Networks, CSP, SDP, TM, INFRA-AU	RFI and EMC requirements are partially verified at AA2. AA2 verification includes: • Electromagnetic radiation • Self-induced RFI • RFI Flagging including Fixed Flagging from TM • RFI Masking • Central Processing Facility RFI shielding. • Central Processing Facility RFI penetrations.
Telescope Management – Assessment of Basic Operational Interface	Test	TM, SDP, CSP, LFAA	These tests verify the basic operation of the Telescope scaled to AA2. Verification includes: • Scheduled maintenance logs.

			• System error logs. • System status. • Latency of TOO scheduling block initiation. • Time accounting categories • Sky mapping • SKA1 user accounts • Resolving names to astronomical co-ordinates • Provision of known sources • Proposal verification • SDP pipeline list • Simulated execution of scheduling blocks. • Operator control • Observing log • Appending log entries • Observing mode latency • Rules for issuing VOEvents • Latency of initiating a response. • VOEvent issue latency.

			- Active alarms. - Alarm filtering. - Alarm latency. - Access to historical data. - Total electron content. - Ionospheric activity. - Weather station database - Satellites. - Commercial flights. - RFI database
Telescope Model	Demonstration	LFAA, TM, SDP	These tests verify the dynamic computational model of the Telescope including configuration information, numerical models, geodetic and geometric models. The AA element and station beam model is a model for each element and station beams as a function of azimuth and zenith angle, frequency and polarisation. Telescope Model verification includes: - Telescope Model - Single geodetic model (Telescopes). - Single geometric model. - AA element and station beam model.

Regression Testing	Test	All Products	For SKA1-LOW, the key points during construction where regression testing needs will be reviewed: ● The system hardware is expanded at each of the AIV LOW Milestones ● Software or Firmware upgrades are made to any of the Sub-system products ● The AA1 backend system is migrated to the CPF at AA2 ● Any hardware configuration change ● Any technology refresh ● Any major production batch changes Regression testing may be either a full system test with complex tests like fringes, basic imaging or drift scans or more simple tests like sanity checks, reconfirmation of Sub-system interfaces and data flow protocols. E.g. fix for a simple, low level bug that corrupts metadata.
Verification of Hardware and Software Interfaces	Test	All Products	The verification of hardware and software interfaces between products is an essential part of the LOW System Integration process.

5 Array Assembly * (AA*)

As per ECP200012 AA* has been designed as a breakpoint in the rollout of SKA LOW. A decision will be made at a defined point in time if AA* will be the final step in the roll out of SKA 1 LOW, or if work will continue on to AA4 (refer Appendix B).

This section describes the characteristics and capabilities of Array Assembly * with it following directly after AA2.

The tables and diagrams below provide the following information for Array Assembly *:

- Block Diagram
- Product List
- AA* Array Assembly Functionality
- Key engineering goals for the AA* Array Assembly, referenced to L1 requirement Verification.

A proposed configuration for AA* is shown in Section **Errore. L'origine riferimento non è stata trovata.** and follows a number of assumptions:

- AA* should be a superset of AA2.
- The AA* configuration should incorporate a mixture of short and long fibre runs, preferably out to the available ends of the spiral arms for testing the SAT STFR system.
- The AA* configuration should incorporate a mixture of short and long baselines for testing proper operation of Fringe Rotation and Delay Tracking
- There should be a sizeable portion of the stations located in the LOW Central Area to support suitable UV coverage and Point Spread Function.
- The configuration should be confirmed as early as possible, and should take into account the constraints of construction contractors and the potential needs of early science.

Note that there will be a concerted effort by the AIV Team to prove the scalability of the SKA LOW system to 307 stations as early as possible.

The AIV Team will continue to add stations into the array in an opportunistic fashion during the work on AA*. The array will incorporate 64 stations (AA2) at the start of AA* testing and will grow to 307 stations by the end of AA* testing. For efficiency, the AIV Team will add stations in batches. The batch size will be determined by:

- The availability of stations that are ready to add,
- The absence of scalability issues within the system,
- The risk to overall system stability (and the ability to roll-back if needed),
- The ability to add stations in a way that doesn't impact planned integration and verification.

This can be assessed on a case by case basis.

Depending on available stations and functionality, there may also be a reassessment of test sequencing during construction. The decision to bring forward some of the test cases planned for AA4 will be made opportunistically. Again, this can be weighed and managed on a case-by-case basis at the time.

5.1 AA* Block Diagram and Product List

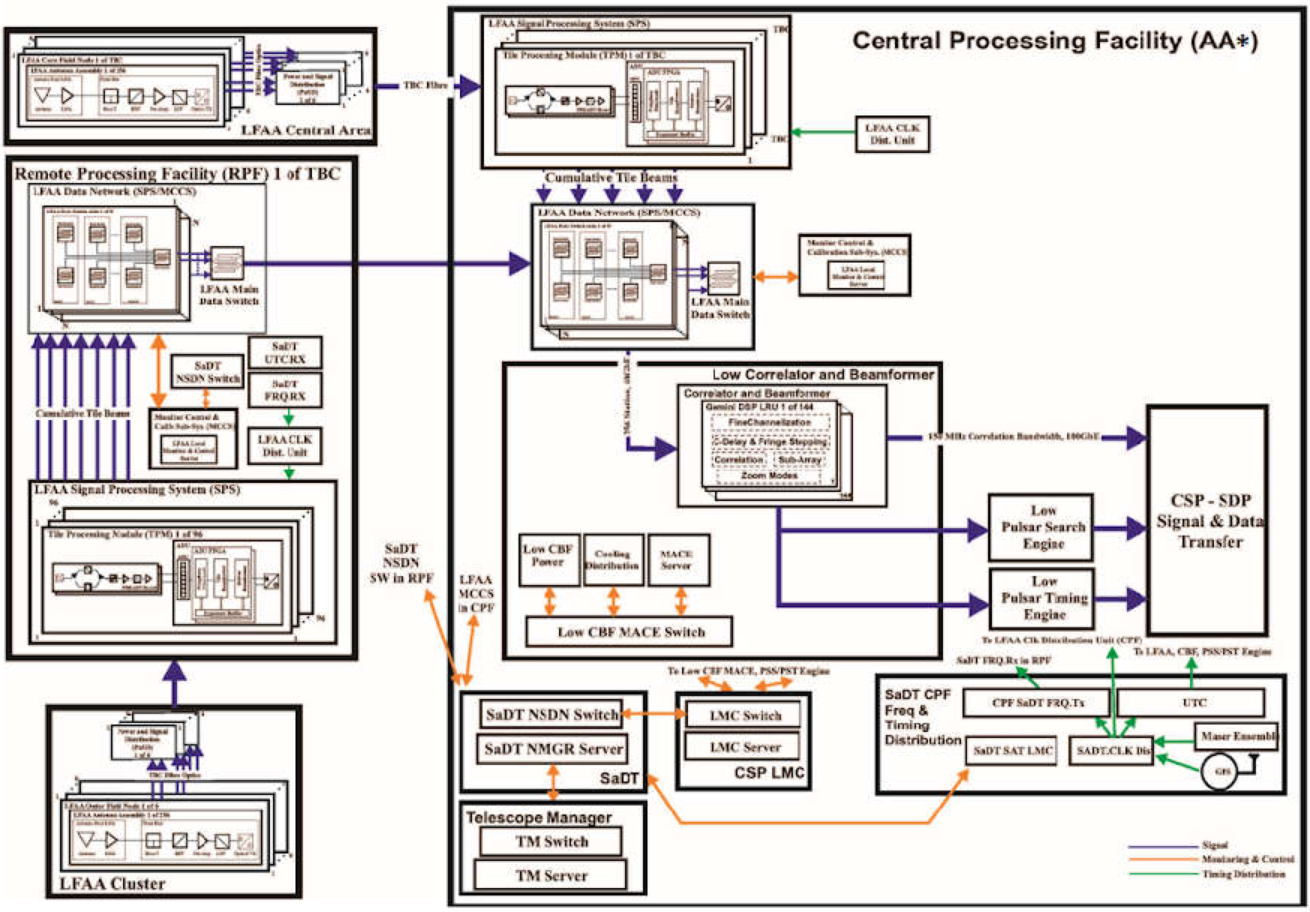


Figure 12: AA* Block Diagram.

Table 16: AA* Product List.

CMN	Product name	Quantity Required (AA*) *Pro rata'd based on 307 FN*
101-000000	**LOW Frequency Aperture Array (LFAA) LOW**	
160-000000	Field Node	307
163-010000	Signal Processing System (SPS) Cabinets (populated)	150 TBC
164-010000	Monitor Control and Calibration Sub-system (MCCS) High Performance Computing Units	38 TBC
	LOW Frequency Aperture Array Data Network (LFAADN)	1

102-000000	**Central Signal Processor (CSP) LOW**	
110-000000	**Local Monitoring and Control (LMC)**	
110-020000	LMC Server	1
110-030000	LMC Switch	TBC
111-000000	**Correlator and Beamformer (CBF)**	
TBC	Alveo Cards	180 TBC
TBC	Alveo Server	~~9~~
TBC	P4 Switch	8
TBC	Monitoring and Control Environment (MACE) Server	1
TBC	Monitoring and Control Environment (MACE) Switch	1
113-000000	**Pulsar Search Engine (PSS)**	
113-010000	Compute Node	TBC
TBC	Control Network	1
TBC	Data Network	1
114-000000	**Pulsar Timing Engine (PST)**	
114-010000	Management Server	1
114-020000	Beam Server	10 TBC
103-000000	**Telescope Manager (TM) LOW**	
103-000001	Sub-Array Coordinator LOW	1
103-000002	SDP Master Leaf Node LOW	1
103-000003	CSP Master Leaf Node LOW	1
103-000004	INFRA-AU Leaf Node	1
103-000005	LFAA Master Leaf Node	1
103-000006	SADT Leaf Node LOW	1
124-000000	Local Infrastructure for TM	1
TBC	External Information Manager	1
700-000001	Observation Execution Tool	1
700-000002	Online Scheduling Tool	1
700-000004	Central Alarm Handler	1
700-000005	TM Alarm Handler	1

700-000006	Engineering Data Archive	1
700-000007	Central Coordinator	1
700-000010	Telescope Information Manager	1
700-000015	TM UI Backend	1
700-000016	Telescope GUI	1
700-000019	TM Monitor	1
700-000020	Logging Service	1
700-000021	Software System Monitor	1
700-000022	Life Cycle Manager	1
600-000001	Observation Design Tool	1
600-000002	Observation Planning Tool	1
600-000003	Project Planning Tool	1
600-000005	Observation Data Archive	1
104-000000	**Science Data Processing (SDP) LOW**	
104-000001	SDP Compute Hardware	1
104-000002	SDP Preservation Hardware	1
701-000000	SDP Software	1
105-000000	**Networks LOW**	
140-000000	Local Infrastructure (LINFRA) LOW	Quantity dependent upon 14 RPFs and no. of LFAA Field Nodes TBC
142-000000	Non-Science Data Network (NSDN)	1
143-000000	Network Manager	1
144-000000	To External	1
146-000000	CSP – SDP	1
147-000000	SDP Network	1
141-000000	**Synchronisation and Timing (SAT)**	
141-011000	SAT.STFR.FRQ.THU	14
141-030000	SAT.STFR.UTC_SKA1-LOW	12 TBC

141-040000	SAT.Timescale.SKA1-LOW	1
141-060000	SAT.LMC.SKA1-LOW	1
TBC	GPS & Rubidium Unit	N/A
500-000000	**Infrastructure Australia (INFRA-AU)**	
TBC	Remote Processing Facility (RPF)	14 TBC
TBC	Central Processing Facility (CPF)	1

5.2 AA* Functionality

This table details the required functionality for Array Assembly * (AA*). The function name, description and function number are derived from the SKA1_LOW Functional Architecture Document [RD10], and are based on AA3 functionalities. A more detailed breakdown of Functionalities required for each AIV milestone and a complete list of the SKA1_LOW functions derived from [RD10] is detailed in the Functional Allocation to Roll-Out Milestones for SKA1_LOW [RD1].

Table 17: Description of Array Assembly * Functionality

AA* Array Functionality	Function Name	Function Description	Function No.	Function allocated to Sub-system	Comments
Operational Functionality	Manage observation	Manage and control the life cycle of an observation, including design/sequence observation and design project and track project progress	F.2, F.2.1, F.2.1.1, F.2.1.2, F.2.1.3, F.2.2, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3, F.2.3.1, F.2.3.2, F.2.3.2.1, F.2.3.2.1.1, F.2.3.2.1.2, F.2.3.3, F.2.3.3.1, F.2.3.3.1.1, F.2.3.3.1.2 F.2.3.3.2, F.2.3.3.2.1, F.2.3.3.2.2, F.2.3.3.4 F.2.3.4, F.2.4, F.2.4.1, F.2.4.2, F.2.4.3	TM, CSP, LFAA, SDP	Configure and Control station beams, configure and select visibilities, sub-arrays
	Calibrate Sub-Arrays	Calculate the calibration coefficients to be applied at	F.3 F.3.1	LFAA, SDP, CSP	Calibrate Sub-Arrays, station beams,

		different levels for the overall calibration of the Telescope.	F.3.2 F.3.3 F.3.4		visibilities, tied array beams and imaging data products
	Dynamic Spectrum		F.2.3.2.8 F.2.3.3.10 F.2.3.3.10.1 F.2.3.3.10.2	CSP, TM	
	Provide Time and Frequency reference	Provide the time and frequency reference necessary to ensure that all the data are properly time-stamped and can be synchronised.	F.6 F.6.1 F.6.2 F.6.3 F.6.4	SAT	Maser Ensemble in CPF
	Execute Observation	Execute the overall observation, from the reception of the electromagnetic signal to the generation of the data products	F.4, F.4.1, F.4.1.1, F.4.1.2, F.4.1.3, F.4.2, F.4.2.1, F.4.2.2, F.2.4.3, F.4.3, F.4.3.1, F.4.3.2, F.4.3.3, F.4.3.4, F.4.4, F.4.4.1, F.4.4.2, F.4.4.3	LFAA, CSP, SDP	Front to back process incorporating all parts of the AA3 system, process sub-array beams
	Transients	Configure and Control transient Capture and Transient detection Alerts (TOO)	F.4.4.4, F.2.3.2.7, F.2.3.2.7.1, F.2.3.2.7.2	SDP, TM, LFAA	
	Manage Non-Science Observation Data	Manage (including storing and updating) data (models, catalogues, etc.) that are necessary to support the Observation but are not science data.	F.5 F.5.1 F.5.2 F.5.3	TM	
	Monitor Telescope	Monitor the health of the Telescope, the quality of the data and imaging and non-imaging resources.	F.7, F.7.1, F.7.1.2, F.7.1.3, F.7.1.4, F.7.1.5, F.7.1.6 F.7.1.7, F.7.1.8, F.7.1.9, F.7.1.12, F.7.1.13, F.7.2, F.7.2.1, F.7.2.2, F.7.2.3, F.7.3	TM, LFAA, CSP, SDP, SAT, Networks	Monitor telescope resources and faults across the system as well as environment and RFI. Examine Data Quality

	Manage Telescope Resources	Interpret and react to deviations in the required health of the telescope system	F.7.4	TM, LFAA, CSP, SDP, SAT, Networks	Response to faults and changes in system performance
Imaging Functionality:	Form Station Beams	Generate a station beam from the signal from each antenna of the station.	F.4.2, F.4.2.2	TM, LFAA	Form station beams by apply calibration and beamforming weights during the beamforming
	Form Visibilities	Produce visibility data and generate autocorrelation spectra.	F.4.3.1	CSP	Produce cross-correlation and auto-correlation data
	Continuum and Spectral Line Imaging	Produce Continuum and Spectral Line Images	F.2.3.3.7, F.2.3.3.7.1, F.2.3.3.7.2, F.4.4.1	CSP, SDP	Configure imaging, produce images
Non-Imaging Functionality:	Pulsar Search	Configuration and processing of PSS data (125 beams)	F.2.3.2.2, F.2.3.2.2.1, F.2.3.2.2.2, F.2.3.3.3, F.2.3.3.3.1, F.2.3.3.3.2, F.2.3.3.5, F.2.3.3.5.1 F.2.3.3.5.2, F.2.3.3.8, F.2.3.3.8.1, F.2.3.3.8.2, F.4.3.4, F.4.4.2	TM, CSP	Configure and select PSS analysis resources and configuration, search for pulsar, process pulsar candidates
	Pulsar Timing	Configuration and post-processing of PST data (8 beams)	F.2.3.2.3, F.2.3.2.3.1, F.2.3.2.3.2, F.2.3.3.4, F.2.3.3.4.1, F.2.3.3.4.2, F.2.3.3.6, F.2.3.3.6.1 F.2.3.3.6.2, F.2.3.3.9, F.2.3.3.9.1 F.2.3.3.9.2, F.4.3.3, F.4.4.3	TM, CSP	Configure and select PST analysis resources and configuration, process Pulsar Timing data, Pulsar Timing

5.3 AA* Key Engineering Goals, Integration and Risk Reduction

The table below details the Key Engineering Goals for Array Assembly * (AA*) and the Risks being mitigated through specific Test Cases. This table is to act as a guide for the Sub-system contractors on what testing and risk mitigation is to be performed at this AA*milestone.

Table 18: Description of Array Assembly * Key Engineering Goals

AA* Key Engineering Goals What is different to AA3??	Test Cases (Type)	Sub-system	Demonstrating/Mitigating Risk
Bandpass Calibration and Stability	Test	CSP, LFAA, SDP	• These tests mitigate the risks associated with scale for the Bandpass Calibration and Stability. These are essentially repeats of the tests conducted at AA2 scaled up to the 307 station array of AA*.
Imaging Dynamic range	Test and Analysis	CSP, SDP, TM, LFAA	• These tests mitigate the risks associated with Imaging Dynamic Range. AA* verification includes Polarisation Dynamic range for imaging, Pulsar Search and Pulsar Timing
Sub-arraying Functionality and Performance	Demonstration and Test	CSP, SDP, TM	• These tests mitigate the risks of incorrect setup, creation and operation of Sub-arrays, including risks associated with set up time, granularity, independence and configuration. • Pointing tests are conducted to confirm proper beamforming and independent steering of sub-arrays. • Risk associated with setting incorrect bandwidth and frequency resolution are also mitigated. Risks associated with Sub-array scheduling blocks are also addressed. • These are essentially repeats of the tests conducted at AA3 scaled up to the 307 station array of AA*.
Pulsar Search	Test and Demonstration	CSP, TM	• These tests mitigate risk in the setup and implementation of the Pulsar Search system including the setup of the number of beams, the Signal to Noise, number of channels and the search sampling interval. These tests also confirm the configurability of the system and the evaluation of Pulsar candidates.

Pulsar Timing	Test and Demonstration	CSP, TM	● System synchronisation, Time and Frequency reference system stability, accurate timing and Time stamping are critical for the correct operation of the Pulsar Timing System. ● These tests mitigate risks associated with Timing Beam formation, Time stamping of data and Beamforming S/N ratio. Risks are also mitigated in the timing system including bandwidth, Timing Resolution and dispersion measure. ● These tests verify the setup and operation of the telescope Pulsar Timing system. Most Pulsar Timing requirements are partially verified at AA2. These are essentially repeats of the tests conducted at AA2 scaled up to the 307 station array of AA*.
Dynamic Spectrum	Test	SDP, CSP, TM, SAT, Networks	● This test mitigates risk in the creation of high time resolution dynamic spectrum data products showing time, frequency and polarisation data. These tests verify the setup and operation of the telescope Dynamic Spectrum system. The Dynamic Spectrum system is partially verified at AA2. AA* continues the Dynamic Spectrum verification scaled up to the 307 station array for AA*.
Transients	Demonstration	SDP, TM, LFAA, CSP	● This test mitigates risk in the transient detection system where the LFAA and CSP systems combine to create a "signal detection event", and also in the transient imaging pipeline (CSP, SDP) which activates the capture of images local to the transient's location by an external trigger. ● This test confirms the correct operation of the Transient Search function as well as Transient buffer and the transient capture latency. ● These tests verify the setup and operation of the LOW telescope Transients Detection system. The operation of the Transient detection system requires further functionality from PSS. PSS functionality becomes available at AA* with an array large enough (307 stations) and sensitive enough for transient detection.
Telescope Model	Demonstration	TM, SDP	● These tests mitigate risks in the computation, recording and implementation of the dynamic computational models of the Telescope including

			configuration information, numerical models, geodetic and geometric models. ● Risk is also mitigated by testing (through observation) the AA element and station beam model, which is a model for each element and station beams as a function of azimuth and zenith angle, frequency and polarisation. ● Many Requirements for the Telescope Model are partially verified at AA3. AA* continues the verification scaled to the sensitivity of the 307 station AA* array
Calibration Modelling and Real Time, on-sky, auto calibration	Demonstration	LFAA, SDP, TM	● These tests mitigate risk in the operation of Real time calibration, Closed-loop calibration and the generation and use of the Global sky model.
Science Data Processing Pipeline (Demonstrated data throughput handling)	Demonstration	SDP	● The risks mitigated in these tests are primarily of the scale of SDP data throughput. These tests completely verify the SDP Pipeline at AA*, unless the optional AA4 stage is confirmed, in which case the verification at AA* will be only partial. ● Risks are to be mitigated in the handling of Standard pipeline, Calibration pipeline and Continuum imaging pipeline products as well as Spectral line emission, Spectral Line Absorption and Slow Transient pipeline and products. ● There is also an Image Pipeline Quality Assessment performed to assess Astrometry, Photometric, Radiometric, Polarimetric and Spectrometric performance metric, storage and displays
Glass box Calibration	Test and Demonstration	SDP, LFAA, CSP, SAT, Networks, TM	● These tests mitigate risk in the setup and operation of the Glass box Calibration system. Verification is started at AA* and may be optionally completed at AA4. AA* verifications include Glass Box Calibration parameter application and storage.
Observing Modes	Demonstration and Test	TM, SDP	Many of the Observing modes are implemented in AA* and may be optionally completed in AA4. AA* verification includes: ● Sky mapping. ● Continuum and spectral line imaging mode. ● Commensal Observing Modes.

			- Commensal time domain and continuum observations. - Specific epoch observations. - Tied array beam independence. - Scale sensitive deconvolution. - Peeling. - Direction dependent effects (aperture array and faraday rotation). - Continuum source finding. - Spectral line source finding. - Stacking.
Science Data Archives	Test and Demonstration	SDP, SAT, Networks, TM	- AA* is a continuation of the verification of the Science Data Archives system. - AA* risk mitigation includes mitigating problems with the establishment and operation of the Science data archives and science processing centres, the use of Mirror sites and the Web and Virtual Observatory interfaces; Operation of the Archive API; QA annotation and the Distribution of data products; the establishment of Levels of access to the archive as well as Processing capability.
Monitoring	Inspection	INFRA-AU, TM, SAT, Networks	- Monitoring is an Infrastructure activity and is continued during the AA* Array Assembly. - These inspections continue to mitigate the risk of critical blind spots in the visual monitoring system and RFI leakage/generation in the telescope array system or support infrastructure.
Power Supply Functionality and Performance	Test and Demonstration	INFRA-AU, LFAA, SDP, CSP, TM, SAT, Networks	- The Power Supply system is incrementally tested during the construction and commissioning phase as the size of the array is added to. - Risks being mitigated at AA* include problems with the implementation and operation of Low Power Mode, Uninterrupted power system, Power overload system, Power interruption survivability and maintenance of the SKA1 Mid and SKA1_LOW Power quality standard

RFI and EMC	Test, Demonstration and Inspection	LFAA, SAT, Networks, CSP, SDP, TM, INFRA-AU	• AA* continues the verification of the RFI and EMC testing for the telescope, the RFI and EMC requirements were partially verified at AA3. • AA* risk mitigation includes Electromagnetic radiation from components of SKA1-LOW and Self-induced RFI, the basic operation of the RFI Flagging, Excision and Masking systems including Simple Power Threshold Flagging. Risk due to RF leakage problems with the Central Processing Facility RFI shielding and penetrations are also mitigated.
Availability, Reliability and Maintainability	Analysis and Demonstration	LFAA, CSP, SDP, SAT, Networks, TM	• AA* is a continuation of the analysis and demonstration of the Fail Safe system as shown at AA3. Risks such as incomplete Failsafe provisions, warnings and recovery sequences are mitigated for the AA* array. Verification can should be completed in AA*, unless the optional AA4 stage is confirmed.
Quality Factors Requirements	Demonstration and Test	INFRA-AU, LFAA, CSP, SDP, TM	• AA* continues the verification of the Quality Factors Requirements for the telescope. • Risks mitigated include the incorrect setup and operation of Logging of operational state, Reporting of alarms, Fault database, Testability, Remote diagnostic capability
Telescope Management – Assessment of Complete Operational Interface	Test	TM, SDP, CSP, LFAA	Many of the Telescope Management tests and demonstrations were started at AA2 and continue to be expanded through AA* and, optionally, to AA4. AA* further verification includes: • Elapsed time tracking. • Observation report. • SKA1 user account. • Resolving names to astronomical coordinates. • Provision of known sources. • Proposal verification. • Ranked list of proposals. • SDP pipeline list.
Regression Testing	Test	All Products	For SKA1-LOW, the key points during construction where regression testing needs will be reviewed:

			• The system hardware is expanded at each of the AIV LOW Milestones. • Software or Firmware upgrades are made to any of the Sub-system products. • Any hardware configuration change. • Any technology refresh. • Any major production batch changes. Regression testing may be either a full system test with complex tests like fringes, basic imaging or drift scans or more simple tests like sanity checks, reconfirmation of Sub-system interfaces and data flow protocols. E.g. fix for a simple, low level bug that corrupts metadata.
Verification of Hardware and Software Interfaces	Test	All Products	The verification of hardware and software interfaces between products is an essential part of the LOW System Integration process.

5.4 AA* Verification Outcomes

The table below details the Key Engineering Goals for Array Assembly * and the L1 requirements to be verified at this Roll-Out Milestone. This table is to act as a guide for the Sub-system contractors on what verification is to be performed at this AA* milestone.

Table 19: Description of Array Assembly * Verification Outcomes

AA* Key Engineering Goals	Test Cases (Type)	Sub-system	Verification Outcomes
Bandpass Calibration and Stability	Test	CSP, LFAA, SDP	These tests verify the calibration and stability of the bandpass spectrum and station beam. AA* verification continues with: • Spectral Stability. • Instantaneous Bandwidth. • Clipped data flagging.

			• Station beam stability. • Absolute flux density scale.
Imaging Dynamic range	Test and Analysis	CSP, SDP, TM, LFAA	AA* verification continues with: • Polarisation Dynamic range for imaging, Pulsar Search and Pulsar Timing
Sub-arraying Functionality and Performance	Demonstration and Test	CSP, SDP, TM	These tests continue to verify the setup, creation and operation of Sub-arrays. Verification includes: • Sub arraying. • SKA1_LOW subarray support • SKA1_LOW subarray set up time • SKA1_LOW subarray membership • SKA1_LOW subarray granularity • SKA1_LOW subarray independence • SKA1_LOW subarray configuration • SKA1_LOW subarray tied-array beam station exclusion • SKA1_LOW subarray station allocation • SKA1_LOW subarray station failure flagging • SKA1_LOW Maintenance subarray • SKA1_LOW subarray pointings • SKA1_LOW subarray frequency resolution • SKA1_LOW subarray bandwidth • SKA1_LOW subarray visibility time resolution • SKA1_LOW subarray logical control and monitoring • SKA1_LOW subarray logical data flows • SKA1_LOW subarray scheduling block set-up time • SKA1_LOW simultaneous scheduling blocks • SKA1_LOW subarray scheduling block allocation • SKA1_LOW subarray independence of scheduling block

Pulsar Search	Test and Demonstration	CSP, TM	These tests verify the setup and operation of the telescope Pulsar Search system. Pulsar Search requirements are completely verified at AA*, unless optional stage AA4 is confirmed. AA* Verification includes: ● SKA1_LOW Pulsar search array diameter ● Number of beams: SKA1_LOW Pulsar Search ● SKA1_LOW Beamformer S/N Pulsar Search ● SKA1_LOW Pulsar Search Candidates ● SKA1_LOW Pulsar Search number of channels ● SKA1_LOW Pulsar search sampling interval ● SKA1_LOW Pulsar Search Configurability
Pulsar Timing	Test and Demonstration	CSP, TM	These tests verify the setup and operation of the telescope Pulsar Timing system. Most Pulsar Timing requirements are partially verified at AA2 but continues in AA* with the Pulsar Timing verification. AA* Verification includes: ● SKA1_LOW Pulsar timing array diameter ● SKA1_LOW Pulsar timing observing band ● SKA1_LOW Time stamping ● SKA1_LOW Timing Beams ● SKA1_LOW Pulsar timing Dispersion Measure ● SKA1_LOW Pulsar Timing Resolution
Dynamic Spectrum	Test	SDP, CSP, TM, SAT, Networks	These tests verify the setup and operation of the telescope Dynamic Spectrum system. Most Pulsar Timing requirements are verified at AA1 and AA2. AA* continues the Dynamic Spectrum verification and includes: ● SKA1_LOW Dynamic spectrum. ● SKA1_LOW Dynamic spectrum sub-array support.
Transients	Demonstration	SDP, TM, LFAA, CSP	These tests verify the setup and operation of the LOW telescope Transients Detection system. More of the Transient Detection requirements are verified at AA* with PSS supplying the required functionality and the AA* array being large enough (307 elements) and sensitive enough for transient detection. AA* verification includes: ● Transient search ● SKA1_LOW transient capture latency

Telescope Model	Demonstration	TM, SDP	Many Requirements for the Telescope Model are partially verified at AA2. The AA* (further) verification includes: ● Telescope Model ● Single geodetic model (Telescopes). ● Single geometric model.
Calibration Modelling and Real Time, on-sky, auto calibration	Demonstration	LFAA, SDP, TM	AA* Calibration verification includes: ● Real time calibration ● Calibration and Imaging formalism ● Closed loop calibration. ● Global sky model.
Science Data Processing Pipeline (Demonstrated data throughput handling)	Demonstration	SDP	Many Requirements for the SDP Pipeline are further verified at AA*. The AA* verification includes: ● Standard pipeline products. ● Calibration pipeline. ● Continuum imaging pipeline. ● Spectral line emission pipeline. ● Spectral line emission data products. ● Spectral line absorption pipeline. ● Spectral line absorption data products. ● Slow transient pipeline. ● Slow transient data products.
Image Pipeline Quality Assessment	Test and Demonstration	SDP, TM	Image Pipeline Quality Assessment further verification at AA* includes: ● Performance assessment ● Performance goals ● Quality assessment ● Automated Quality Assessment. ● Astrometry, Photometric, Radiometric, Polarimetric and Spectrometric performance metric, storage and display ● Pipeline quality assurance

Glass box Calibration	Test and Demonstration	SDP, LFAA, CSP, SAT, Networks, TM	The Glass box Calibration verification is continued in AA* with potential to further advance at AA4, in case the AA4 stage is confirmed. AA* verifications includes: ● SKA1_LOW Glass Box Calibration ● SKA1_LOW Glass Box Calibration: parameter application ● SKA1_LOW Glass Box Calibration: parameter storage
Observing Modes	Demonstration and Test	TM, SDP	More Observing modes are implemented in AA* and optionally completed in AA4. AA* verification includes: ● Sky mapping ● Continuum and spectral line imaging mode. ● Commensal Observing Modes ● Commensal time domain and continuum observations. ● Specific epoch observations ● Tied array beam independence ● Scale sensitive deconvolution ● Solution for pointing errors. ● Peeling. ● Direction dependent effects. ● Aperture Array DDE ● Faraday Rotation DDE ● Continuum source finding. ● Spectral line source finding. ● Stacking
Science Data Archives	Test and Demonstration	SDP, SAT, Networks, TM	AA* is the continuing verification of the Science Data Archives system. AA* verification includes: ● Science data archives ● Role of science processing centres. ● Mirror sites. ● Web interface.

			- Virtual Observatory interface. - Archive API. - QA annotation. - Distribution of data products. - Levels of access to the archive Processing capability
Monitoring	Inspection	INFRA-AU, TM, SAT, Networks	Monitoring is an Infrastructure activity. Monitoring is continued during the AA* Array Assembly. Verification includes: - Visual monitoring. - RFI Monitoring
Power Supply Functionality and Performance	Test and Demonstration	INFRA-AU, LFAA, SDP, CSP, TM, SAT, Networks	The Power Supply system is incrementally tested during the construction and commissioning phase as the size of the array is added to. Verification testing completed at AA* includes: - SKA1_LOW RFI power delivery. - Low Power Mode - Uninterrupted power - Power overload - Power interruption survivability - SKA1 Mid and SKA1_LOW Power quality standard
RFI and EMC	Test, Demonstration and Inspection	LFAA, SAT, Networks, CSP, SDP, TM, INFRA-AU	AA* continues the verification of the RFI and EMC testing for the telescope. Many of the RFI and EMC requirements were partially verified at AA2. AA* verification includes: - Electromagnetic radiation - Self-induced RFI - RFI Flagging - RFI Excision - RFI Masking - Central Processing Facility RFI shielding. - Central Processing Facility RFI penetrations.

Availability, Reliability and Maintainability	Analysis and Demonstration	LFAA, CSP, SDP, SAT, Networks, TM	AA* Verification includes: ● Fail safe provisions. ● Fail safe state ● Fail safe warnings ● Fail safe recovery ● Software updates
Quality Factors Requirements	Demonstration and Test	INFRA-AU, LFAA, CSP, SDP, TM	AA* continues the verification of the Quality Factors Requirements for the telescope. Many of the Quality Factors were partially verified at AA1 and AA2. AA* Verification includes: ● Logging of operational state ● Reporting of alarms ● Fault database ● Testability ● Remote diagnostic capability
Telescope Management – Assessment of Complete Operational Interface	Test	TM, SDP, CSP, LFAA	Many of the Telescope Management tests and demonstrations are started at AA2 , continued in AA*, and optionally expanded through AA4. AA* verification includes: ● Elapsed time tracking ● Observation report ● SKA1 user account ● Resolving names to astronomical co-ordinates ● Provision of known sources ● Proposal verification ● Ranked list of proposals ● SDP pipeline list
Regression Testing	Test	All Products	For SKA1-LOW, the key points during construction where regression testing needs will be reviewed: ● The system hardware is expanded at each of the AIV LOW Milestones ● Software or Firmware upgrades are made to any of the Sub-system products

			• Any hardware configuration change • Any technology refresh • Any major production batch changes Regression testing may be either a full system test with complex tests like fringes, basic imaging or drift scans or more simple tests like sanity checks, reconfirmation of Sub-system interfaces and data flow protocols. E.g. fix for a simple, low level bug that corrupts metadata.
Verification of Hardware and Software Interfaces	Test	All Products	The verification of hardware and software interfaces between products is an essential part of the LOW System Integration process.

6 Array Assembly 4 (AA4)

Refer to Appendix B

7 Required Functionality for each Array Assembly

7.1 Introduction

The Roll-Out Plan identifies five high-level milestones:

1. Integration Test Facility Qualification Event (ITF-QE)
2. Array Assemblies 0.5 and 1
3. Array Assembly 2
4. Array Assembly *
5. (Optional) Array Assembly 4

These high-level milestones form the basis for design authorities to plan their Sub-system -level construction roll-out and associated costs. The dates for these high-level milestones are contained in the SKA Integrated Project Schedule [AD3].

This chapter describes the required roll-out of functionalities to support these high-level milestones. This functionality is linked to the Array Assembly capabilities (including the capability of the ITF Qualification System) described in the previous chapters. The sections in this chapter are intended to be a high level description of more detailed Functionality for each AIV milestone described in tables in [RD1]. A complete list of all of the SKA1_LOW functions derived from the SKA1_LOW Functional Architecture [RD10] is also detailed in [RD1].

7.2 INFRA-AU required functionality for major Roll-Out Releases

Table 20: Roll-Out of INFRA-AU.

	Required Functionality
System ITF	No input Required
AA0.5 and AA1	• Ground prepared & roads ready for AA1 (18 stations - three clusters of six stations each) along southern spiral arm (cluster locations S8, S9, S10) • Fit out of three Remote Processing Facilities (RPF) at station clusters S8, S9, S10 (including rack space, power and cooling) for back-end electronics, computers, timing and network equipment. • Supply of extra temporary RPF (“AA1 Temporary CPF”) to act as shielded room for AA1 correlator and back-end electronics. This temporary RPF to be mounted next to RPF at S8 station cluster. • Communication and emergency communication to be fully functional. • Weather Stations, Visual Monitoring, RFI monitoring. • A “Worker’s Hut” will be available beside the Temporary CPF at the AA0.5/AA1 site. This hut would be air-conditioned and contain a computer terminal, basic electronics/equipment working area, tea and coffee facilities and a porta-loo.

AA2	• Ground prepared & roads ready for AA2 (64 stations) located in LOW Central Area and out along the southern spiral arm. • Power for AA2 stations. • Central Processing Facility (CPF) completed (including rack space, power and cooling) for back-end electronics, computers, timing and network equipment. • Pawsey Facility (including rack space, power and cooling) for back-end electronics, computers, timing and network equipment suitable for AA2. • Weather Stations, Visual Monitoring, RFI monitoring, STI system and BMS to be fully functional.
AA*	• Ground prepared & roads ready for AA* (307 stations) located in LOW Central Area and out along three spiral arms. • Power for AA* stations. • All support facilities at Central Processing Facility (CPF) and Pawsey Centre (including rack space, power and cooling) for back-end electronics, computers, timing and network equipment. • Full site monitoring in place.
AA4 **(optional)**	• Ground preparation & roads, power generation and reticulation complete for AA4 (512 stations). • Power for AA4 stations. • All support facilities at Central Processing Facility (CPF) and Pawsey Centre (including rack space, power and cooling) for back-end electronics, computers, timing and network equipment. • Full Site monitoring in place.

7.3 LFAA required functionality for major Roll-Out Releases

The roll-out of SKA1_LOW stations has already been listed in Table 29 and the required functionality for LFAA is shown in Table 21. The detailed functional allocation to roll-out milestones for LFAA is provided in [RD1].

Table 21: Roll-Out of LFAA Stations and required Functionality.

	Required Functionality
System ITF	>= 4 station front ends including TPMs, MCCS and SPS.
AA0.5 and AA1	● 18 stations (three clusters of 6 stations) located at Station clusters S8, S9, S10 along the southern spiral arm handed over to AIV. ● Includes MCCS and SPS housed in RPFs at each station cluster. ● LMC to support the final beam pointing model and auto calibration.
AA2	● First 64 stations (including Field Nodes, MCCS and SPS) are handed over to AIV. ● LMC to support the final beam pointing model and auto calibration. ● Note that this assembly shall include AA1 stations and RPFs ● One 6-station cluster located at the end of the southern spiral arm. ● Remainder of stations located in LOW Central Area with electronics housed in the Central Processing Facility (CPF).
AA*	● First 307 LFAA stations (including Field Nodes, MCCS and SPS) handed over to AIV. ● Stations located in LOW Central Area and some along all three spiral arms (see Section 10.4).
AA4 (optional)	● Complete delivery of 512 stations (including Field Nodes, MCCS and SPS), handed over to AIV.

7.4 SAT and Networks required functionality for major Roll-Out Releases

The detailed functional allocation to roll-out milestones is provided in [RD1].

Table 22: SAT and Networks required functionality for major Roll-Out Releases.

	Required Functionality
System ITF	• SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution adequate to simulate connection to 1 station cluster RPF including SAT.LMC • GPS/Rubidium non-precision time and frequency reference required – to be supplied by AIV) • NSDN required to support non-science data including TM data and LMC requirements. • NSDN required to support CSP.LMC • NMGR to provide monitoring and control for NSDN • CSP-SDP network link not required. (SDP in ITF)
AA0.5 and AA1	• SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for connection between 3 station cluster RPFs (S8, S9, S10) and AA1 Temporary CPF located at Cluster location S8 including SAT.LMC. • GPS/Rubidium non-precision time and frequency reference – to be supplied by SAT) • NSDN required for connection of 3 station cluster RPFs (S8, S9, S10) to AA1 Temporary CPF located at station cluster S8 and between any equipment in the RPFs and AA1 Temporary CPF. • NSDN link offsite required to allow remote access (10Gbs link). • NSDN for phones, security and alarms etc. • NMGR to provide monitoring and control for NSDN • CSP-SDP network link not required (SDP server in AA1 Temporary CPF).
AA2	• Digital Fibre installed to the required outer southern spiral RPF connecting RPFs to CPF. • SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections between outer spiral RPFs and CPF.

	• SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections within CPF. • SAT.LMC in CPF • CLOCKS: precision time and frequency reference (Maser (TBC) - otherwise GPS/Rubidium - supplied by SAT) • NSDN between LFAA, CSP and TM between RPFs and CPF • NSDN between LFAA, CSP and TM within the CPF • NSDN for phones, security and alarms etc. • Provision of NMGR • CSP-SDP data pipeline between MRO and Pawsey is required.
AA*	• Digital Fibre installed to the required outer spiral RPFs. • SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections between outer spiral RPFs and CPF. • SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections within CPF. • SAT.LMC in CPF • Completion of full timing and clocks (Maser ensemble) • SAT.LMC completed and commissioned • NSDN between LFAA, CSP and TM between RPFs and CPF • NSDN between LFAA, CSP and TM within the CPF • NSDN for phones, security and alarms etc. • Completion of NSDN between MRO site, Pawsey Centre and Science Operations Centre in Perth for SDP • Completion of NMGR. Need to integrate NMGR with AARNET network management system and TM • CSP-SDP and NSDN for EOC Completed • CSP-SDP data pipeline between MRO and Pawsey completed.
AA4 (optional)	All SAT and Networks work is completed: • All Digital Fibre installed to the outer spiral RPFs.

	• Completion of SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections between outer spiral RPFs and CPF. • Completion of SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution for LFAA, CSP - connections within CPF.

7.5 CSP required functionality for major Roll-Out Releases

The detailed functional allocation to roll-out milestones for CSP-LOW is provided in [RD1].

PSS, PST and CBF functionality will be developed, tested and verified incrementally according to the SAFe methodology.

Table 23: CSP required functionality for major Roll-Out Releases.

	ITF-QE	Array Assembly 0.5	Array Assembly 1	Array Assembly 2	Array Assembly *	Array Assembly 4
Standard Correlator Size	>=4 Station	Up to 6 Station	Up to 18 Station	64 Station	307 Station	512 Station
Station Beams	1	1	384x1-channel or 48x8-channel	384x1-channel or 48x8-channel	384x1-channel or 48x8-channel	384x1-channel or 48x8-channel
Delay, Fringe Stopping & Doppler	All	All	All	All	All	All
Timing Epoch & Integration Percent	Integration Percent	Integration Percent	Integration Percent	Integration Percent	Integration Percent	Both

Assembly Maturity	Pre-Production	Pre-Production	Pre-Production	Production	Production	Production
Channelization	Standard fine channelization (5.4 kHz)	Standard fine channelization (5.4 kHz)	Standard fine channelization (5.4 kHz)	Standard fine channelization (5.4 kHz)	Standard fine channelizatio n (5.4 kHz)	Standard fine channelization (5.4 kHz)
Correlated Bandwidth	75 MHz	75 MHz	75 MHz	150 MHz	Full BW (300MHz)	Full BW (300 MHz)
Zoom Mode	No	No	No	Yes (0.2, 0.45, 0.9, 1.8kHz)	Yes (0.014, 0.028, 0.056, 0.113, 0.2, 0.45, 0.9, 1.8kHz)	Yes (All)
Zoom Bands	0	0	0	16	32	64

Beamforming for Pulsar Search (CBF)	9 beams	9 beams	30 beams	30 beams	250 beams	500 beams
Pulsar Search (PSS)					125 beams	500 beams Pulsar de-dispersion and acceleration processing
Beamforming for Pulsar Timing (CBF)	4 beams	4 beams	4 beams	4 beams	80 beams	16 beams
Jones Matrix Correction (CBF)	No	No	No	No	Partial	Yes
Pulsar Timing (PST)				4 beams	8 beams	16 beams
RFI	No	No	No	Fixed flagging from TM	Further developed Signal detection and mitigation scheme	Final signal detection and mitigation scheme

Sub-Arraying	2 subarrays	4 subarrays Includes Engineering subarray	8 subarrays	8 subarrays	16 subarrays	16 subarrays
Substations			512 substations	720 substations	1440 substations	2880 substations

7.6 TM required functionality for major Roll-Out Releases

The TM functionality table below includes a category for Operations (OPS). This is a list of functionality that is deferred to post-construction phase by agreement with the SKAO.

The detailed functional allocation to roll-out milestones for TM is provided in [RD1].

TM functionality will be developed, tested and verified incrementally at the SAFe sprint (2 weeks) and Program Increment (3 months) cadence. Most of this functionality will be verified in the Software Test Environment as far as possible, in order to minimise the impact (of frequent software releases) on the verification of the hardware components of the telescope.

Table 24: TM required functionality for major Roll-Out Releases.

	Required Functionality for TM
System ITF	**LOW** ● Configure LFAA for Observation ● Calculate Local Pointing (coordinate conversion) ● Send Pointing Commands (LFAA) **COMMON** ● Configure CSP for observations (limited modes) ● Configure SDP for observations (limited modes) ● Monitor Sub-system Characteristics (attributes, alarm triggers) ● Control Sub-system Lifecycle (Start-up or Shutdown state, Operational State) ● Synchronise with Telescope Network Time ● Calculate Delays ● Report TM Software Versions ● Report External Item Software and Firmware Versions ● Receive and Persist Earth Orientation Parameters ● Pointing Corrections (Earth Orientation, Gravitational Effects)

	• Aggregate and Report Internal Status
	• Continuum and Spectral Line Imaging Mode (no distinction in SDP control)
	• Command Telescope (Manually, via Scripts)
	• Manage Calibration and Telescope Model Data
	• Manage Instrumental Configuration Data
	• Manage Logging Messages (Access, Control, Report Logging)
	• Manage Telescope Alarms
	• Persist Data for Retrieval (Limited Capacity)
	• Basic Display
	    ○ Health
	    ○ Alarms
	    ○ Attributes
	    ○ QA Metrics
	• Telescope to Low Power Mode (manual, automatic)
	• Access Remote Debugging Interfaces

AA0.5 and AA1	**LOW** • Configure LFAA for Observation • Calculate Local Pointing (coordinate conversion) • Send Pointing Commands (LFAA) **COMMON** • Configure CSP for observations (limited modes) • Configure SDP for observations (limited modes) • Monitor Sub-system Characteristics (attributes, alarm triggers) • Control Sub-system Lifecycle (Start-up or Shutdown state, Operational State) • Synchronise with Telescope Network Time • Calculate Delays • Report TM Software Versions

	• Report External Item Software and Firmware Versions
	• Receive and Persist Weather Data, Earth Orientation Parameters
	• Pointing Corrections (Earth Orientation, Gravitational Effects)
	• Aggregate and Report Internal Status
	• Continuum and Spectral Line Imaging Mode (no distinction in SDP control)
	• Command Telescope (Manually, via Scripts)
	• Manage Calibration and Telescope Model Data
	• Manage Instrumental Configuration Data
	• Manage Logging Messages (Access, Control, Report Logging)
	• Manage Telescope Alarms
	• Persist Data for Retrieval (Limited Capacity)
	• Basic Display
	  ○ Health,
	  ○ Alarms,
	  ○ Attributes,
	  ○ QA Metrics
	• Telescope to Low Power Mode (manual, automatic)
	• Access Remote Debugging Interfaces

AA 2	**COMMON**
	• Receive and Persist Flight and Satellite Information, Weather Forecast, Astronomical Catalogues, Total Electron Content (TEC)
	• Identify RFI Threats, Manually Generate RFI Flags
	• Sub-Arrays
	  ○ Definition,
	  ○ Configuration,
	  ○ Failure Handling,
	  ○ Status Monitoring,

	○ Control Authority, ○ Management with CSP, ○ Concurrent processing on Sub-Array (Limited Modes) ● Interpret Instructions from SB Script into Telescope Commands ● Execute Scheduling Blocks ● Run Observation Schedules ○ Create a Schedule of SBs, ○ Maintain Schedule, ○ Manage Concurrent Execution of SBs ● Persist TMO Data (Initial) ● Simulate Scheduling Block Execution ● Control Sub-system Lifecycle (Switch on, Shutdown Signal Events) ● Receive and Persist Ionospheric Activity ● Pointing Corrections (Refraction) ● GUI Display ○ Environmental Information, ○ Schedule, ○ QA Metrics, ○ Sub-Arrays, ○ Alarms, ○ Health, ○ Weather Alerts, Forecasts ● Pulsar Timing Observation Mode ● Pulsar Search Observation Mode ● Zoom Windows ● Dynamic Spectrum Observing Mode ● Manage Telescope Alarms (Add, Remove, Change Attributes)

	● Support Software and Firmware upgrades ● Authorise User Requests ● Capture Operator Scheduling Block Logs ● Persist Applied Phase Compensation ● QA Alerts and Annotations
AA 3*	**COMMON** ● Receive VO events ● Control Power Consumption ● Maintain Power Load Configuration ● Report Power Availability and Consumption ● Evolved GUI Display ● TOO Triggers **TM Observatory** ● Register Users, Authorise User Requests ● Receive Satellite Information, Catalogues, Weather Forecasts ● Create Observations (SBs, API, Commensal Observations on Same Sub Array, Restrictions) ● Create Projects without Proposals ● Assist Observation Planning ● Manage Calibrator Catalogue ● Synchronise with Telescope Network Time ● Plan Commensal Use of the Telescope (limited) ● Persist TMO Data
AA 4 (Optional)	**COMMON** ● Receive Internal Transient Events

	• Execute VLBI observations • Persist Data for Retrieval (Full Capacity) • Assist Evaluation of Telescope Effectiveness • Assist with Performance Measuring • Mobile Device Platform for Reporting Telescope Behaviour • Imaging Transient Search Observing Mode • Performance of TM (latency, accuracy, availability, MTTR, MTBF) • Concurrent processing on Sub-Array • Evolved GUI Display • Automatic Execution Mode **TM Observatory** • Assist Proposal Creation, Submission, Review, Withdrawal • Control Proposal Submission • Create Project from Proposal • Report Telescope Usage per Project • Provide Sensitivity Calculator Interface

7.7 SDP required functionality for major Roll-Out Releases

The detailed functional allocation to roll-out milestones for SDP is provided in [RD1].

SDP functionality will be developed, tested and verified incrementally at the SAFe sprint (2 weeks) and Program Increment (3 months) cadence. Most of this functionality will be verified in the Software Test Environment as far as possible in order to minimise the impact (of frequent software releases) on the verification of the hardware components of the telescope. Verification of SDP's processing performance can only occur in the software test environment since full scale SDP hardware is only available for AA* (by which time the verification of processing performance needs to be complete, unless the optional stage AA4 is confirmed).

In order to deliver maximum value as early as possible using the SAFe framework, maximum agility is required during the construction of SDP software. To achieve maximum agility only critical functionality required by other products need to be specified for SDP. During the SDP CDR, SDP has agreed with SKAO to pull forward the AA3 hardware deployment (Centi-SDP HW ready) milestone in order to provide AA3's compute resource earlier to avoid science commissioning bottlenecks. SDP expects that with the presence of the Pawsey Centre for LOW, and as the first hardware deployment into the SPC is small, the SDP AA3 hardware deployment (Centi-SDP HW) could go into the SPC at any point given that the fibre links between the SPC and site are available (this fibre link will be commissioned at AA2). Given that AA* is 51 stations more than AA3 all of this should also be achievable for AA*.

SDP has confirmed that the functionality that specifically relates to Long Term Preservation and the SPC can't be formally verified until the SPC (with the interface to site) and the Long-Term Preservation hardware is available and the interface to SRCs for which there is currently no date for. Other functionality could be verified earlier. If certain functionality is required for science commissioning purposes, then this can be provided, but formal verification may have to wait until the target hardware is available. Further information may be found in the SDP Construction and Verification Plan [RD13].

Table 25: SDP required functionality for major Roll-Out Releases.

	Required Functionality
System ITF	The functionality required for the System ITF is minimalistic. The main requirement in the System ITF is to have an end-to-end line-up of products in a laboratory environment, and to be able to record and process data from the correlator. Ideally, the functionality provided for the System ITF is similar to the functionality provided for Array Assembly 1, so that the interfaces between back-end products that are required for Array Assembly 1 can be fully verified in the ITF.

	Certain external interfaces: - Basic TM M&C interface (Tango) - CSP visibility interface (SPEAD) Functionality supported at AA1 scale: - Visibility data Ingest (receive & pre-processing) - Generate Ingest QA metric data - Store data on disk in suitable format (i.e. MS) for processing with suitable existing (3rd party) reduction package* - Process data with existing (3rd party) tools for ITF signal displays (subset of commissioning displays). * Note: The ability to process visibility data with existing 3rd party tools allows the use of a wide range of qualified (on other telescopes) functionality during integration and commissioning. Recommendation: require that data can be written in a format that can be transferred to a suitable, existing Low frequency reduction package, as CASA will not be suitable for Low frequency. CASA can do basic processing but does not have any capability for dealing with DDE's. Should be adequate for basic AA0.5/1 tests. Milli-SDP hardware deployment at ITF This required functionality is provided by the SDP Commissioning and AIV Support software[6].

[6] The architecture of the SDP has been developed so that variants of the SDP system, or new systems using SDP components can be constructed. The Commissioning and AIV support software is a product variant of SDP software built with a combination of SDP components and other software including, but not limited to, CASA. This product variant will be used for example to perform acceptance tests on various components and implement specific tools needed by the commissioning science teams.

AA0.5 and AA1	SDP Provides complete commissioning and ITF/AIV support functionality including functionality required to support AA2.
	
	Certain external interfaces:
	- Basic TM M&C interface (Tango)
	- CSP visibility interface (SPEAD)
	
	Functionality supported at AA1 & AA2 scale:
	- Visibility data Ingest (receive & pre-processing)
	- Generate Ingest QA metric data
	- Basic real-time calibration
	- Store data on disk in suitable format (i.e. MS) for processing with suitable existing (3rd party) reduction package*
	- Process data with existing (3rd party) tools for:
	  - commissioning signal displays
	  - basic imaging
	  - basic time series analysis
	
	* Note: The ability to process visibility data with existing 3rd party tools allows the use of a wide range of qualified (on other telescopes) functionality during integration and commissioning. Recommendation: require that data can be written in a format that can be transferred to a suitable, existing Low frequency reduction package, as CASA will not be suitable for Low frequency.
	
	Milli-SDP hardware deployment in the temporary CPF (RPF).
	
	This required functionality is provided by the SDP Commissioning and AIV Support software.

AA2	The SDP Commissioning and AIV Support software (and Milli-SDP hardware) deployed for AA1 provides all the required functionality to support AA2 and therefore no additional deployment is required. The SDP hardware will be relocated to the CPF once available. The SDP Commissioning and AIV Support software (and Milli-SDP hardware) could remain on site (in the CPF) for AA3 & AA4 to continue to provide integration and commissioning support for the telescope hardware.
AA*	Sufficient functionality to perform real-time calibration and basic imaging workloads in the context of a system controlled by TM with appropriate control, monitoring and reporting. Minimal set of functionality for the AA3 release of the SDP Operational System to work at AA* scale. This functionality is provided by the SDP Operational System and will be deployed (hardware and software) at the Science Processing Centre in Perth (Pawsey).
AA4 (Optional)	The first operational deployment of the SDP Operational System. This will provide full SDP hardware and software functionality and performance. The SDP Operational System will be deployed at the Science Processing Centre in Perth (Pawsey).

7.8 AIV required functionality for major Roll-Out Releases

Table 26: AIV required functionality for major Roll-Out Releases.

	Required Functionality
System ITF	● Observing Integration and Qualification testing by contractors in off-site Integration Test Facility. ● Scripts for running basic interferometry tests and analysing data from the ITF Qualification System. ● Provision of GPS-disciplined Rubidium.
AA0.5 and AA1	● Scripts, harnesses and equipment for running basic interferometry tests and analysing data from AA1. ● AIV will supply over-ground fibre from the AA1 Temporary CPF to the Trunk fibre spigot located at the CPF site (a distance of 3-4 kms). Splicing into this Trunk fibre will allow data connectivity between the AA1 Temporary CPF and the MRO ASKAP building and then on to Geraldton. ● Temporary fibre and splicing for connection between RPFs at station clusters S8, S9 and S10 and AA1 Temporary CPF at S8. ● Diesel generators required for AIV verification activities at Station clusters S8, S9, S10 and AA1 Temporary CPF. ● A "Worker's Hut" will be available beside the AA1 Temporary CPF at the AA1 site. This would be air-conditioned and contain a computer terminal, basic electronics/equipment working area, tea and coffee facilities and a porta-loo.
AA2	Scripts, harnesses and equipment for running tests and analysing data from AA2.
AA*	Scripts, harnesses and equipment for running tests and analysing data from AA*.
AA4 (Optional)	Scripts, harnesses and equipment for running tests and analysing data from AA4.

8 Risks and Assumptions

8.1 Risks

Risks and risk mitigations with respect to SKA1_LOW rollout were developed during pre construction and summarized in the AIV Risk Register [RD1]. Subsequently the risks were migrated to the Jira project, SKA Risk Register, and below are shown the main risks associated with SKA LOW Telescope as of August 29th 2021.

The indicated Risk Score is an assessment based on both impact and likelihood, with High Level Risks shown in red (Score > 10), and Medium Level Risks in yellow (Score >5 and <=10).

Table 27: Main Roll-Out Risks for SKA LOW.

T	Key	Summary	Updated	Risk Score ↓
!	RM-13011	LOW: Restart of economy after C19 will increase price of electronic components	27/Aug/21	(((20)))
!	RM-12469	Inadequate Progression of TRL for Frequency Distribution	11/Aug/21	(((16)))
!	RM-12497	No framework contract for FPGA prices causing uncertainty in budget.	27/Aug/21	(((15)))
!	RM-12336	CPF Delayed	27/Aug/21	(((12)))
!	RM-12266	Land Access Delayed	11/Aug/21	(((12)))
!	RM-12408	Pre-cursor Project Operations and SKA Construction Clash	11/Aug/21	(((12)))
!	RM-12295	COTS Hardware Performance	27/Aug/21	((9))
!	RM-12269	More Rock Encountered than estimated	23/Jul/21	((9))
!	RM-12299	Adverse Weather	11/Aug/21	((8))
!	RM-12465	Construction Camp Incorrectly Sized	26/Aug/21	((8))
!	RM-12511	Disparate power savings not realised ECP200010	26/Aug/21	((8))
!	RM-12472	Field Node Deployment Effectiveness	26/Aug/21	((8))
!	RM-12406	Roll Out Sequence of Digital and Test Elements is not Optimised for LOW Front End	27/Aug/21	((6))

8.2 Assumptions

This AIV LOW Roll out Plan is based on the following assumptions. (These assumptions currently translate to managed risks and contingency).

Table 28: Assumptions for SKA1_LOW AIV.

Assumption Number	***Description***
1	The SKAO will contractually bind each contractor with regard to the repair and replacement of faulty components. i.e. components which fail for any reason during the construction phase.
2	The SKAO will manage all contractual issues relating to entities delivering products. The production contracts will clearly specify contractor responsibilities and response times to ensure a quick turn-around time when products fail. The contractors will honour the contractual agreements with regard to the repair and replacement of faulty components. This includes responding in a timely manner to any issues raised by the AIV Team relating to the physical configuration, functional configuration or performance. The AIV Team does not carry the risk, should a product have any issues after a successful hand-over, or should the SKA1 Telescope System not meet its Level-1 Requirements.
3	It is assumed that there are off-site Integration Test Facilities (ITFs) for MID and LOW, which support some system level integration in a convenient and collaborative environment.
4	The contractors will plan and perform their roll-out, assembly, integration and verification at product-level, prior to handing over an acceptance-tested product. The contractors will participate and abide by the hand-over process when handing a product over to the SKAO. Products delivered to the System ITF will have Technology Readiness Level 6 or higher. From AA1 onwards products delivered to site will have Technology Readiness Level 7 or higher. Statement adjustment to reflect station integrator instead of prime contractor for LFAA
5	Product contractors are responsible for Product shipment and installation on site, and for performing acceptance testing after installation.
6	The contractors will provide integration support and training after handing over a product to the SKAO.
7	The systems used by contractors for quality assurance, configuration management, issue tracking and asset tracking will be compatible with the systems of the SKAO.
8	The contractors will comply with relevant site constraints, including the need for personnel to have had Health and Safety, as well as Heritage inductions.
9	The infrastructure contractor will provide the following items which may be used by the AIV Team: • On-site power, water and sewage provisions • On-site accommodation • On-site offices, workshops and storage • On-site security provisions • On-site provision of communication systems • On-site provision of access equipment, such as cherry pickers and scissor lifts.

10	The AIV cost model is based on the assumption that the Construction Phase will last for five years after placement of the AIV contract.
11	The AIV Team will not be responsible for the Logistic roll-out, which entails the following: - Early Operations (supporting telescope operation, maintenance and configuration management) will be available as soon as the first Dish and first Station have been handed over to the SKAO. - The Early Operations team will ensure adequate maintenance of delivered and installed products.
12	All products will be handed-over to the SKA Organisation and not to the AIV Team. The AIV Team will be called upon by the SKA Office to assist with the hand-over process and to make a recommendation regarding the product to be handed-over.

9 Roll-Out Considerations

Table 29 provides an overview of a possible roll-out scenario for the SKA LOW stations. It shows the number of stations AIV requires to perform the Integration and Verification Testing of Array Assemblies AA1 to AA4.

Table 29: Roll-Out of new SKA1_LOW Stations to be updated to align with latest IPS.

Year	AIV/LFAA Milestone	Time since C0 [months]	Elapsed Period [months]	Total LOW Stations Required [minimum]	Monthly Station Construction Output
1		-			
2	AA0.5	18	18	6	0.3
3	AA1	36	18	18	0.6
4	AA2	48	12	64	3,8
5	AA*	59	11	307	22
6	AA4	71	12	512	17

The maximum roll out rate assumes that deployment of the bulk of the stations in the Central Area will occur after the INFRA-AU Contractor has completed Central Area site construction and construction of the CPF (refer to [AD3]). To achieve the minimum number of stations required for AIV Verification testing at AA* and AA4, the table also assumes a maximum station roll out rate of 17 stations per month in Year 6.

The LFAA will include a Production Readiness Review (PRR) at ITF stage, before the complete roll out of the rest of the stations. The PRR will be an opportunity for the AIV Team to feed-back system validation information before mass production. This PRR is an essential part of the successful commissioning and verification of the SKA LOW Telescope, and will be defined and conducted by SKAO, with support from the AIV Team.

Note: C0 in Table 29 above is the commencement of construction with the expected start of the INFRA-AU site work.

10 Array Assembly Configuration

The array configuration for the entire SKA LOW Telescope is given in [RD9] and [RD12].

The array configuration roll out, i.e. the order in which new SKA LOW Stations are constructed and set to work, will be developed prior to the construction phase of the project. AIV have the following needs regarding the Array Configuration Roll Out:

- Array Assemblies 0.5 and 1 – The array will be designed to achieve maximum test coverage for risk reduction and verification. This includes the aims of hardware abstraction, control and monitoring, performance testing and basic imaging. The minimum long baselines required for AA1 need to be in the order of 1-2 km. One possibility is to locate AA1 along the southern spiral arm at station cluster locations S8, S9, S10 positioned in a triangle with locations separated by 3-5 km baselines. The current LOW correlator design would allow AA1 to connect up to 18 stations. This would provide great flexibility in the connection of "portions" of the 3 clusters, allowing an incremental increase in AA1 complexity. The natural progression of complexity would be from one cluster (for basic beamforming and pointing) to portions of two clusters (for fringes) to portions of three clusters (for Phase and Amplitude closure and imaging).

- Array Assemblies AA2 to AA* and, optionally, AA4 – Later Array Assemblies, AA2, AA* and optionally AA4, would need to have stations located in the Central Area with backend products housed in the Central Processing facility (CPF). At least one long baseline should be included from AA2 onwards to allow testing of long fibre runs, the full delay model and full fringe implementation. It is assumed that stations populated in early array assemblies become subsets of the stations used in later array assemblies.

- Configuration of AA2 and AA* has been proposed in the previous sections. These arrays will have improved sensitivity and functionality that will allow for more complex AIV tests and early commissioning, and their configuration should be determined in conjunction with the SKA1_LOW Science Team.

10.1 Selection Criteria for Location of Array Assembly 1

Below is the list of criteria considered in the selection of the location for AA1. Also listed are five location options that were considered. LOW Station locations and distances are derived from the SKA1_LOW_NWA_working_model (link below):

https://www.google.com/maps/d/edit?mid=1lrf08LHy5WxbY08SQV1x0F33N2U

The table below outlines the selection parameters met (or not met) by each option.

A map and Google Earth Image of Option 1 are shown below in Figure 13 for reference.

AA1 Location Selection Criteria

1. Away from the LOW Central Area. This is to allow INFRA-AU and LFAA to layout the infrastructure and stations for the Central Area unimpeded by AIV AA1 activity (very high priority).

2. At least 4 stations in order to allow for timing synchronisation, amplitude and phase closure tests (critical) but initially not many more than that, so that fault isolation and debugging is straightforward. Scalability to between 12 and 18 stations to demonstrate scalability and uncover systematic issues with improved sensitivity (critical). Suitable baselines for basic imaging. A group of three clusters in a roughly triangular configuration with baselines in the order of 3-4 kms (very high priority).

3. Clusters on the same spiral arm to maximise use of permanently installed fibre runs, and minimise need for temporary fibre (critical).

4. Fibre connectivity to ASKAP and Perth via Trunk Long Haul Fibre (high priority).

5. Close access to roads, and sufficiently close to the main construction area to allow potential sharing of resources (desirable).

6. Reasonably close to the Central Area for AA1 to make up baselines of 6-7 kms when AA1 incorporated into AA2 (desirable).

7. Use final, or representative, configuration products for INFRA-AU, LFAA, SAT and Networks as much as possible. AIV to try and dovetail AA1 configuration into final LOW product configurations such as RPF locations, SAT fibre runs and RPF electronics. i.e. try to use final version products as much as possible without using one-off “specials”. This will ensure that test results are representative (very high priority) and minimise the cost of expensive test setups (very high priority).

8. Integration of any power infrastructure available (desirable) to help make test results representative and to keep costs down.

9. LOW RFI environment (desirable).

10. Earliest possible availability (very high priority).

11. Does not make large assumptions about the contents of the hosting agreement (high priority).

Possible AA1 Location Options (as per Station Cluster)

Option 1: Station Clusters S8, S9 and S10

Option 2: Station Clusters S7, S8, S10

Option 3: Station Clusters N13, N14, N15

Option 4: Station Clusters E4, N2, E5

Option 5: Station Clusters N8, N9, N10

Table 30: AA1 Location Option Assessment Table.

Criteria	Option 1	Option 2	Option 3	Option 4	Option 5
Station Clusters	S8, S9, S10	S7, S8, S10	N13, N14, N15	E4, N2, E5	N8, N9, N10
Away from the LOW Central Area?	Yes S8 is 4.9km away from Central Area	Yes S7 is 3.5km away from Central Area	Yes N13 is 17.5km away from Central Area	No, N2 is less than 1km away from the Central Area. E4 is 500m away from CPF	Yes N8 is 4.9km away from Central Area
Suitable Baselines for Basic Imaging?	Yes, 3.5-4- 5.5km	Yes, 2.5-3.5-4.25km	No, baselines are too long for basic imaging(TBC) 6-9.3-13.6km	Yes, 1-1.4-1.4km	Yes, 3.5-4- 5.5km
On the same spiral arm?	Yes	Yes	Yes	No, may present fibre connectivity issues (TBC).	Yes
RPFs at Each Cluster?	Yes	Yes	Yes	No, E4 and N2 clusters do not have RPFs.	Yes
Fibre Connectivity?	Yes 3km over ground connection from S8 to CPF fibre spigot	Yes 1.75km over ground connection from S7 to CPF fibre spigot	Yes 4.1km from N14 over ground to ASKAP building	Yes, E4 is 500m from CPF fibre spigot	No, CPF is 5.6km away from N8. MRO is 15km away from N8.
Road access?	Yes, Boolardy-Kalli Rd passes 2.5 km south of S8 and 600m north of S9. Unmarked access roads 500m and 1.1km either side of S8.	Yes, an unmarked access road 1.75km to the west of S7 and 500m west of S8.	Yes, MRO is 4.1km south-east of N14	Not as yet, Boolardy-Kalli Rd 4.5 km to South. Unmarked access road 600m to east of E4.	Not as yet, Beringarra-Pindar Rd is 3.5km to the west of N9. Unmarked access road 2.8km to the east of N8.

Proximity to Central Area for AA2 integration?	Yes, S8 is 4.9km away from Central Area. Max baseline is 8.2km (Central Area-S10)	Yes, S7 is 3.5km from Central Area. Max baseline is 8.2km (Central Area-S10)	No, N13 is 17.5km away from the Central Area. Max baseline is 23km (Central Area-N14)	Yes. N2 is less than 1km from Central Area. Max baseline is 2.1km (Central Area-E5)	Yes, N8 is 4.9km away from Central Area. Max baseline is 8.2km (Central Area-N10)
Use Final products	Yes	Yes	Yes	Yes	Yes
Power options?	Diesel Gensets at each RPF.	Diesel Gensets at each RPF.	Could use Diesel Gensets at each RPF	Diesel Gensets at each RPF	Diesel Gensets at each RPF
	The LOW Power Station is 2.2km NE of S9 – possible power cable connection?		Power from ASKAP? Cable run of 4.1km from N14 to ASKAP building. Unsure of power availability from ASKAP.		
RFI	Some RFI from Diesel Gensets and equipment huts.	Some RFI from Diesel Gensets and equipment huts.	Some RFI from Diesel Gensets and equipment huts.	Some RFI from Diesel Gensets and equipment huts	Some RFI from Diesel Gensets and equipment huts
	No Genset RFI if connected sourced from Power station		No Genset RFI if power sourced from ASKAP		
Pass/Fail	Pass, No major issues	Pass, dependent on clearance distances from CPF and Central Area	Fail, baselines too long for imaging (TBC) (6-9.3-13.6km)	Fail, clusters too close to Central Area and CPF, would interfere with INFRA-AU and LFAA	Fail, clusters too far from CPF or MRO for fibre connectivity

		preferred by INFRA-AU, LFAA and Networks during construction		installation. Also, E4 and N2 clusters do not have RPFs	

A map and Google Earth Image of Option 1 is shown below in Figure 13 for reference.

10.2 Station Configuration and Locations for AA1

A proposed configuration for AA1 is Option 1 in Table 30 above and is shown below in Figure 13. This selection follows a number of assumptions:

- The AA1 configuration should be located away from the LOW Central Area (to allow INFRA-AU and LFAA roll-out to proceed) but within reasonable proximity so as to be incorporated into AA2.
- The AA1 configuration should incorporate reasonable baseline lengths to properly test fringe rotation and delay correction.
- AA1 should be at least 4 stations.
- AA1 should have close proximity to roads and be on the same spiral arm.
- AA1 should have fibre connectivity to the MRO ASKAP building, Geraldton and the Pawsey Centre at Perth.
- AA1 should dovetail into the final SKA1_LOW configuration.

The proposed Stations for the AA1 Array Assembly includes stations in the Southern Spiral arm: S8, S9, S10. The 18 stations for AA1 are listed below in Table 31:

Table 31: Station Configuration and locations for AA1.

AA1 Station Location	Station No.	No. of Stations
Southern Spiral Arm	S8, S9, S10	18
LOW Central Area		0
Total		**18**

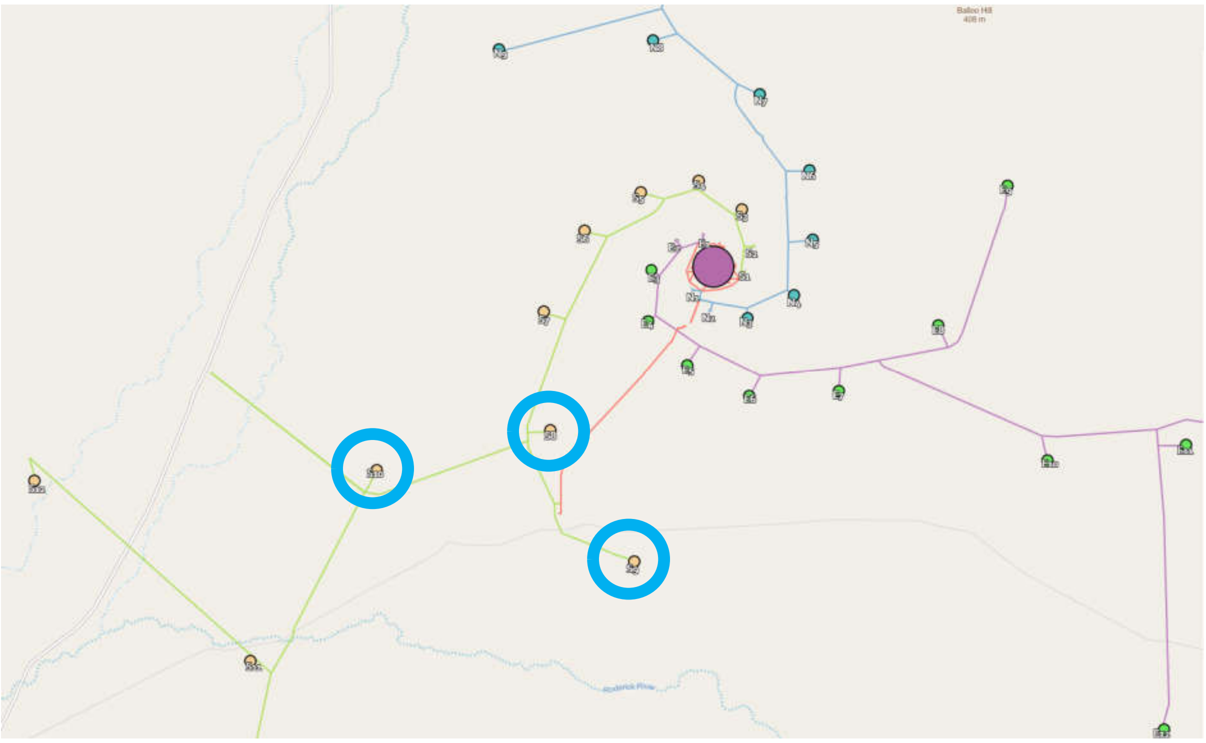


Figure 13: Proposed Field Node Locations for AA1 (Option 1) on Southern Spiral Arm

10.3 Station Configuration and Locations for AA2

A proposed configuration for AA2 is shown below in Figure 14 and Table 32 and follows a number of assumptions:

- AA2 should be a superset of AA1.
- The AA2 configuration should incorporate a mixture of short and long fibre runs for testing the STFR system.
- The AA2 configuration should incorporate a mixture of short and long baselines for testing proper operation of Fringe Rotation and Delay Tracking.
- There should be a sizeable portion of the stations located in the LOW Central Area to support suitable UV coverage and Point Spread Function.
- The configuration should be confirmed as early as possible and should take into account the constraints of construction contractors and the potential needs of early science.

The proposed Stations for the AA2 Array Assembly includes stations contained within AA1 (S8, S9, S10) and a station at the end of the Southern Spiral Arm (S16), assuming the Design Baseline is used.

The remainder of the stations are contained within the Central Area. The 64 stations for AA2 are listed below.

Table 32: Station Configuration and Locations for AA2.

AA2 Station Location	Station No.								No. of Stations
Southern Spiral Arm	S8, S9, S10, S16								24
LOW Central Area	66	111 23 56 90 31 144	22 36 146 73 33 72	69 108 70 183 89 4	80 52 200 176 59 167	30 193 57 17 165	78 16 132 88 8	91 98 62 32 158	40
Total									**64**

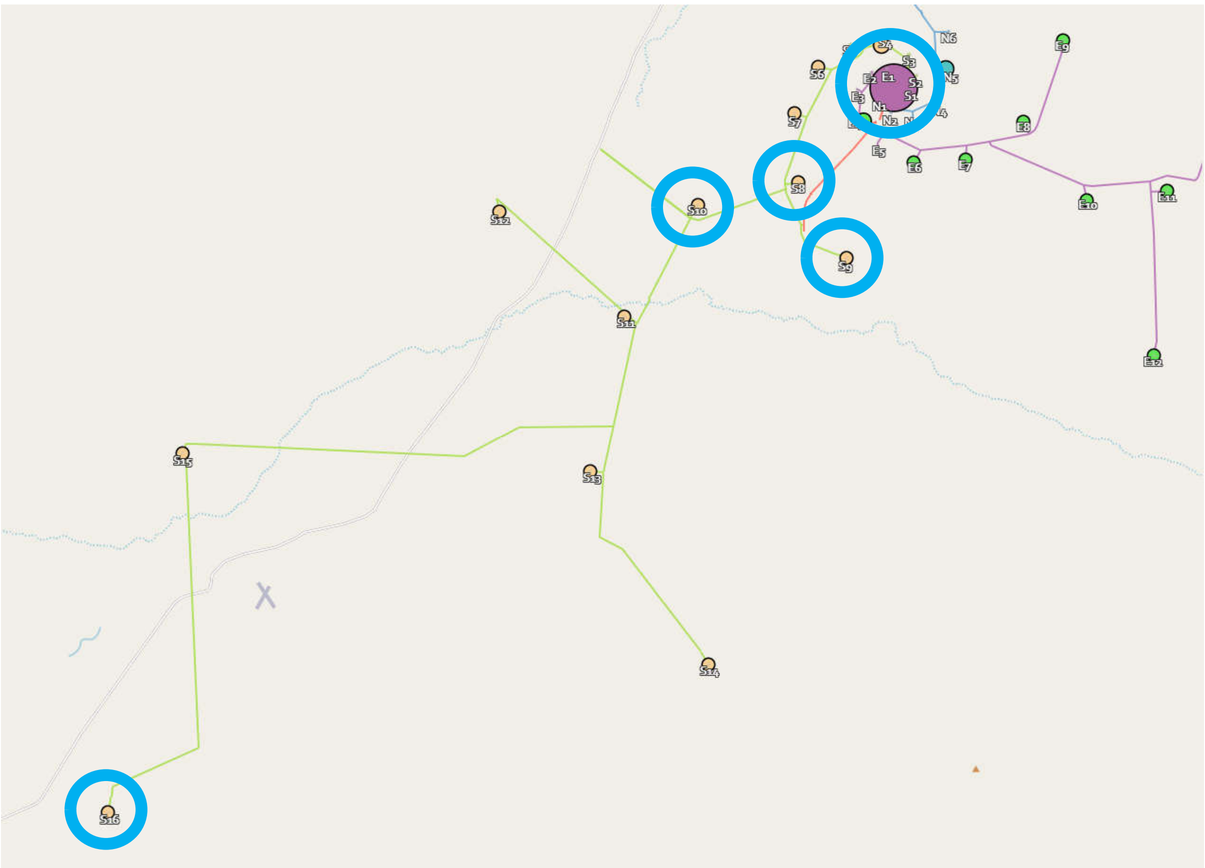


Figure 14: Proposed Field Node Locations for AA2 on Southern Spiral Arm

10.4 Station Configurations and Locations for AA*

A proposed configuration for AA* is shown below in Figure 15 **Errore. L'origine riferimento non è stata trovata.** and Table 33**Errore. L'origine riferimento non è stata trovata.** and follows a number of assumptions:

- AA* should be a superset of AA2.
- The AA* configuration should incorporate a mixture of short and long fibre runs, preferably out to the available ends of the spiral arms for testing the STFR system.
- The AA* configuration should incorporate a mixture of short and long baselines for testing proper operation of Fringe Rotation and Delay Tracking
- There should be a sizeable portion of the stations located in the LOW Central Area to support suitable UV coverage and Point Spread Function.
- The configuration should be confirmed as early as possible, and should take into account the constraints of construction contractors and the potential needs of early science.

The proposed Stations for the AA* Array Assembly includes stations contained within AA1, and AA2 and stations E8, E9, E10, E12., E14, N8, N9, N10 N11, N14, S8, S9, S10, S12, S14 and a station at the end of each of the Spiral Arms (S16, N16, E16) where S16, N16, E16 are the outermost stations on the three Spiral arms assuming the Design Baseline is used. The remainder of the stations are contained within the Central Area. The proposed 307 stations for AA* are listed below.

Table 33: Station Configuration and Locations for AA*.AA* Station Location	**Station No.**										**No. of Stations**
Spiral Arms	S8, S9, S10, S16, N8, N9, N10, N16, E8, E9, E10, E16 E12, E14, N11, N14, S12, S14										72 + 36 = 108
LOW Central Area	66	111	22	69	80	30	78	91	23	36	184 + 15 = 199
		108	52	193	16	98	56	146	70	200	
		57	132	62	90	73	183	176	17	88	
		32	31	33	89	59	165	8	158	144	
		72	4	167	14	185	142	19	224	7	
		160	74	42	171	79	96	27	75	85	
		212	15	63	205	24	29	25	112	187	

	84	1	120	175	44	38	67	54	155	
	49	170	87	216	105	35	156	121	86	
	58	150	60	143	68	151	18	45	100	
	76	195	107	34	172	20	64	191	115	
	2	125	48	71	61	130	55	202	223	
	140	37	41	46	139	213	104	9	99	
	13	192	114	204	21	12	147	82	103	
	138	106	11	119	6	194	5	93	168	
	28	197	154	26	92	110	77	50	10	
	53	95	166	40	128	162	113	222	129	
	214	102	65	109	97	123	141	39	83	
	148	198	81	3	135	51	145	207	149	
	137	43	163	101	181	180	117	206	126	
	177	124	133							
	208, 190, 153, 164, 173, 219, 201, 184, 217, 203, 186, 199, 161, 179									
Total										**307**

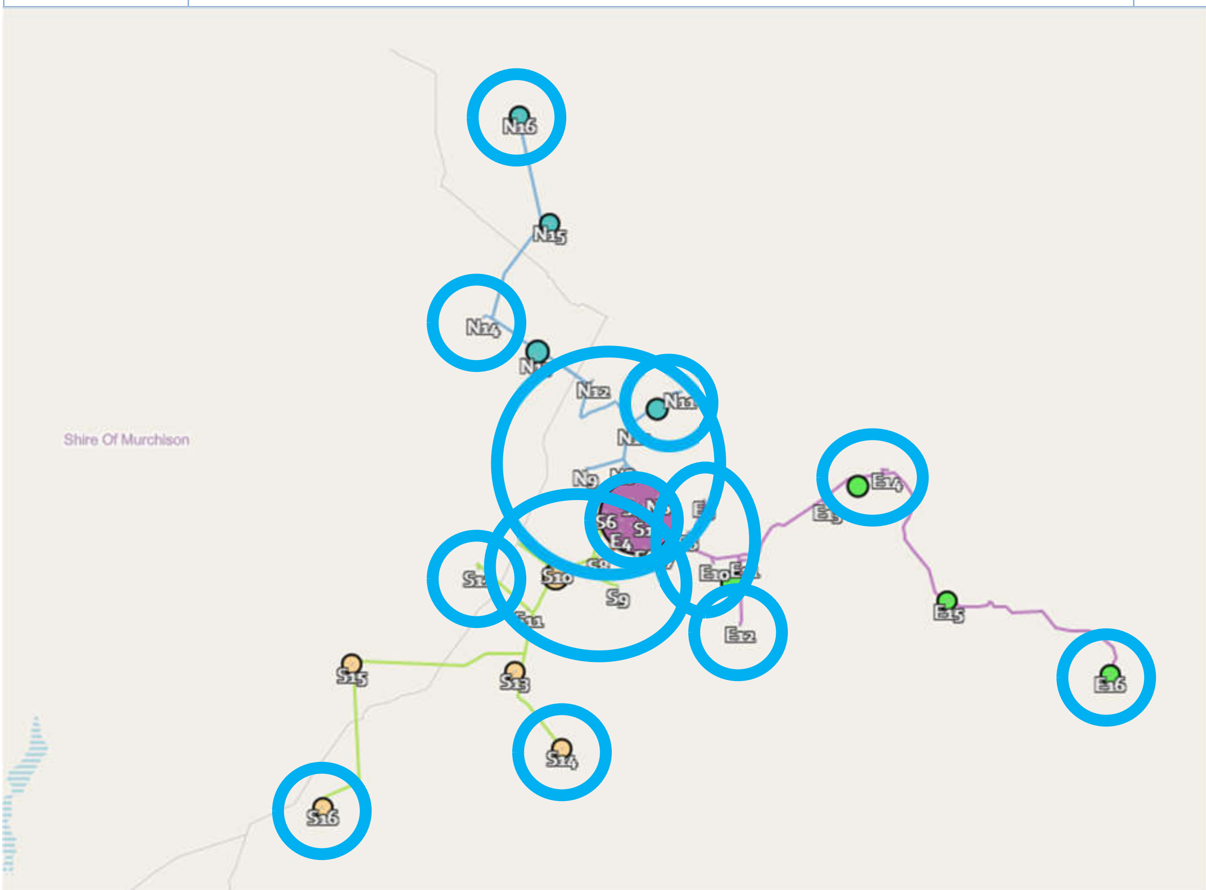


Figure 15: Proposed Field Node Locations for AA* on three Spiral Arms

10.5 Station Configurations and Locations for AA4

Refer to Appendix B

Appendix A: **TBCs and TBDs**

This appendix covers the TBCs and TBDs for the LOW Roll-Out Plan. These are included below in Table 34:

Table 34: TBCs and TBDs for SKA1_LOW Roll Out Plan Needs to be reviewed for the latest information

Section	Title	Description	Responsibility
Table 3	ITF Product List	PBS numbers for: CSP.CBF, CSP.LMC components; TM External Information Manager; SDP Commissioning and AIV Support System; ITF GPS & Rubidium Unit.	To be confirmed with Product Contractors and CM manager.
Table 5	ITF-QE Key Engineering Goals	Peak Load Requirement for the Power Cycle Test	L2 power consumption specs of Products to be confirmed with Product Contractors after hardware development and prototypes constructed
Table 5	ITF-QE Key Engineering Goals	Scaled AA1 System for Steady State Soak Test	L2 power consumption specs of Products to be confirmed with Product Contractors after hardware development and prototypes constructed
Table 7	AA1 Product List	PBS numbers for: CSP.CBF, CSP.LMC components; TM External Information Manager; SDP Commissioning and AIV Support System; ITF GPS &	To be confirmed with Product Contractor CM managers.

		Rubidium Unit; INFRA.RPF, INFRA.CPF buildings; Power for AA1 Verification (3 diesel generators)	
Table 10	AA1 Key Engineering Goals	L2 requirements available for Power Cycle Test of AA1 products?	
Table 11	AA1 Verification Outcomes	Is the Hexacopter test method useful for measuring beam shape?	Will be confirmed during AAVS1.5 and AA0.5 field testing.
Table 12	AA2 Product List	PBS numbers for: CSP.CBF, CSP.LMC components; TM External Information Manager; SDP Commissioning and AIV Support System; ITF GPS & Rubidium Unit; INFRA.RPF, INFRA.CPF buildings. Quantity for: CSP.LMC switches.	To be confirmed with Product Contractor CM managers.
Table xx	AA* Product List	PBS numbers for: CSP.CBF, CSP.PSS, CSP.LMC components; TM External Information Manager; INFRA.RPF, INFRA.CPF buildings. Quantities for: CSP.LMC switches, CSP.PSS Compute nodes.	To be confirmed with Product Contractor CM managers.
Table 20	AA4 Product List	PBS numbers for: CSP.CBF, CSP.PSS, CSP.LMC components; TM External Information Manager; INFRA.RPF, INFRA.CPF buildings. Quantity for: CSP.LMC switches.	To be confirmed with Product Contractor CM managers.
10.4	SAT and Networks Required Functionality	Maser supplied at AA2?	To be confirmed by SAT and Networks

Table 33	AA1 Location Option Assessment Table	Option 3 - baselines too long for basic imaging	To be confirmed with Science Commissioning and Verification Team
Table 33	AA1 Location Option Assessment Table	Option 4 - may present fibre connectivity issues	To be confirmed with Science Commissioning and Verification Team
Table xx	AA* Science verification Functional Description Station Listings	All TBC	

Appendix B: **Array Assembly 4 (AA4)**

This section covers the characteristics and capabilities of Array Assembly 4 and would be the final array assembly if the decision is made to proceed.

The tables and diagrams below provide the following information for Array Assembly 4:

- Block Diagram
- Product List
- AA4 Array Assembly Functionality
- Key engineering goals for the AA4 Array Assembly, referenced to L1 requirement Verification.

At this AA4 stage, all required products have been installed at site, the full array and complement of LFAA, SAT, Networks, CSP, SDP and TM hardware has been installed, and the telescope is undergoing final stages of verification against L1 requirements.

AA4 Block Diagram Product List

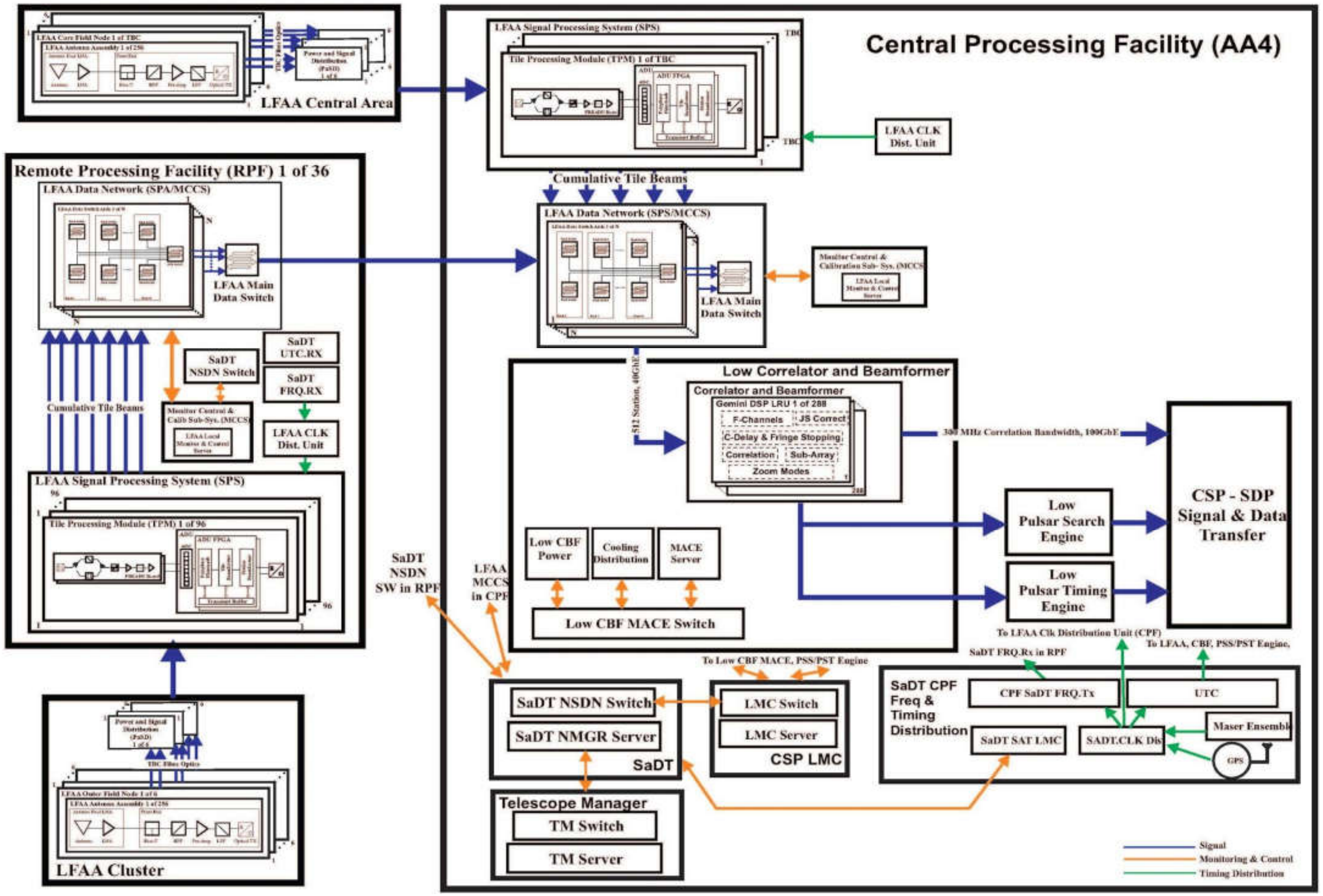


Figure 16: AA4 Block Diagram.

Table 35: AA4 Product List.

CMN	Product name	Quantity Required (AA4)
101-000000	**LOW Frequency Aperture Array (LFAA) LOW**	
160-000000	Field Node	512
163-010000	Signal Processing System (SPS) Cabinets (populated)	256
164-010000	Monitor Control and Calibration Sub-system (MCCS) High Performance Computing Units	64
	LOW Frequency Aperture Array Data Network (LFAADN)	1
102-000000	**Central Signal Processor (CSP) LOW**	
110-000000	**Local Monitoring and Control (LMC)**	
110-020000	LMC Server	1
110-030000	LMC Switch	TBC
111-000000	**Correlator and Beamformer (CBF)**	
TBC	Alveo Cards	420
TBC	Alveo Servers	21
TBC	P4 Switches	20
TBC	Monitoring and Control Environment (MACE) Server	1
TBC	Monitoring and Control Environment (MACE) Switch	3
113-000000	**Pulsar Search Engine (PSS)**	
113-010000	Compute Node	167
TBC	Control Network	1
TBC	Data Network	1
114-000000	**Pulsar Timing Engine (PST)**	
114-010000	Management Server	1
114-020000	Beam Server	16
103-000000	**Telescope Manager (TM) LOW**	
103-000001	Sub-Array Coordinator LOW	1
103-000002	SDP Master Leaf Node LOW	1
103-000003	CSP Master Leaf Node LOW	1
103-000004	INFRA-AU Leaf Node	1

103-000005	LFAA Master Leaf Node	1
103-000006	SADT Leaf Node LOW	1
124-000000	Local Infrastructure for TM	1
TBC	External Information Manager	1
700-000001	Observation Execution Tool	1
700-000002	Online Scheduling Tool	1
700-000004	Central Alarm Handler	1
700-000005	TM Alarm Handler	1
700-000006	Engineering Data Archive	1
700-000007	Central Coordinator	1
700-000010	Telescope Information Manager	1
700-000015	TM UI Backend	1
700-000016	Telescope GUI	1
700-000019	TM Monitor	1
700-000020	Logging Service	1
700-000021	Software System Monitor	1
700-000022	Life Cycle Manager	1
600-000001	Observation Design Tool	1
600-000002	Observation Planning Tool	1
600-000003	Project Planning Tool	1
600-000004	Proposal Handling System	1
600-000005	Observation Data Archive	1
104-000000	**Science Data Processing (SDP) LOW**	
104-000001	SDP Compute Hardware	1
104-000002	SDP Preservation Hardware	1
701-000000	SDP Software	1
105-000000	**Networks LOW**	
140-000000	Local Infrastructure (LINFRA) LOW	To complete 36 Outer Field Node clusters and all Central Area Field Nodes

142-000000	Non-Science Data Network (NSDN)	1
143-000000	Network Manager	1
144-000000	To External	1
146-000000	CSP – SDP	1
147-000000	SDP Network	1
141-000000	**Synchronisation and Timing (SAT)**	
141-011000	SAT.STFR.FRQ.THU	36
141-030000	SAT.STFR.UTC_SKA1-LOW	36
141-040000	SAT.Timescale.SKA1-LOW	1
141-060000	SAT.LMC.SKA1-LOW	1
TBC	GPS & Rubidium Unit	N/A
500-000000	**Infrastructure Australia (INFRA-AU)**	
TBC	Remote Processing Facility (RPF)	36
TBC	Central Processing Facility (CPF)	1

AA4 Functionality

This table details the required functionality for Array Assembly 4 (AA4). The function name, description and function number are derived from the SKA1_LOW Functional Architecture Document [RD10]. A more detailed breakdown of Functionalities required for each AIV milestone and a complete list of the SKA1_LOW functions derived from [RD10] is detailed in the Functional Allocation to Roll-Out Milestones for SKA1_LOW [RD1].

Table 36: Description of Array Assembly 4 Functionality.

AA4 Array Functionality	Function Name	Function Description	Function No.	Function allocated to Sub-system	Comments
Operational Functionality	Manage Proposals	Provide tools to manage and allow the generation, generation, review and assessment of proposals.	F.1, F.1.1, F.1.2, F.1.2.1, F.1.2.2, F.1.2.3, F.1.3, F.1.3.1, F.1.3.2, F.1.3.3, F.1.3.4, F.1.4, F.1.4.1, F.1.4.2, F.1.4.3, F.1.5	TM	
	Manage observation	Manage and control the life cycle of an observation, including design/sequence observation and design project and track project progress	F.2, F.2.1, F.2.1.1, F.2.1.2, F.2.1.3, F.2.2, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3, F.2.3.1, F.2.3.2, F.2.3.2.6, F.2.3.3, F.2.3.3.1, F.2.3.3.1.1, F.2.3.3.1.2 F.2.3.4, F.2.4, F.2.4.1, F.2.4.2, F.2.4.3	TM, CSP, LFAA, SDP	Configure and Control station beams, configure and select visibilities, sub-arrays

	Calibrate Sub-Arrays	Calculate the calibration coefficients to be applied at different levels for the overall calibration of the Telescope.	F.3 F.3.1 F.3.2 F.3.3 F.3.4	LFAA, SDP, CSP	Calibrate Sub-Arrays, station beams, visibilities, tied array beams and imaging data products
	Dynamic Spectrum		F.2.3.2.8 F.2.3.3.10 F.2.3.3.10.1 F.2.3.3.10.2 F.4.3.6	CSP, TM	
	Execute Observation	Execute the overall observation, from the reception of the electromagnetic signal to the generation of the data products	F.4, F.4.1, F.4.1.1, F.4.1.2, F.4.1.3, F.4.2, F.4.2.1, F.4.2.2 F.4.3, F.4.3.1, F.4.3.2, F.4.3.3, F.4.3.4, F.4.4, F.4.4.1, F.4.4.2, F.4.4.3	LFAA, CSP, SDP	Front to back process incorporating all parts of the telescope system, process sub-array beams
	Transients		F.4.2.3 F.2.3.2.7 F.2.3.2.7.1 F.2.3.2.7.2	CSP, TM, LFAA	

	Manage Non-Science Observation Data	Manage (including storing and updating) data (models, catalogues, etc.) that are necessary to support the Observation but are not science data.	F.5 F.5.1 F.5.2 F.5.3	TM	
	Monitor Telescope	Monitor the health of the Telescope, the quality of the data and imaging and non-imaging resources.	F.7, F.7.1, F.7.1.1, F.7.1.2, F.7.1.3, F.7.1.4, F.7.1.5, F.7.1.6 F.7.1.7, F.7.1.8, F.7.1.9, F.7.1.10, F.7.1.11, F.7.1.12, F.7.1.13, F.7.2, F.7.2.1, F.7.2.2, F.7.2.3, F.7.3	TM, LFAA, CSP, SDP, SAT, Networks	Monitor telescope resources and faults across the system as well as environment and RFI. Examine Data Quality
	Manage Telescope Resources	Interpret and react to deviations in the required health of the telescope system	F.7.4	TM, LFAA, CSP, SDP, SAT, Networks	Response to faults and changes in system performance
	Deliver Science Ready Data	Archive the data ready to be processed by the scientific community and allow access to these data.	F.8 F.8.1 F.8.2	SDP	
Imaging Functionality:	Form Station Beams	Generate a station beam from the signal from each antenna of the station.	F.4.2, F.4.2.2	TM, LFAA	Form station beams by apply calibration and beamforming weights during the beamforming

	Form Visibilities	Produce visibility data and generate autocorrelation spectra.	F.4.3.1	CSP	Produce cross-correlation and auto-correlation data
	Continuum and Spectral Line Imaging	Produce Continuum and Spectral Line Images	F.2.3.3.7, F.2.3.3.7.1, F.2.3.3.7.2, F.4.4.1	CSP, SDP	Configure imaging, produce images
Non-Imaging Functionality:	Pulsar Search	Configuration and processing of PSS data (500 beam)	F.2.3.2.2, F.2.3.2.2.1, F.2.3.2.2.2, F.2.3.3.3, F.2.3.3.3.1, F.2.3.3.3.2, F.2.3.3.5, F.2.3.3.5.1 F.2.3.3.5.2, F.2.3.3.8, F.2.3.3.8.1, F.2.3.3.8.2, F.4.3.2, F.4.4.2	TM, CSP	Configure and select PSS analysis resources and configuration, search for pulsar, process pulsar candidates
	Pulsar Timing	Configuration and post-processing of PST data (16 beam)	F.2.3.2.3, F.2.3.2.3.1, F.2.3.2.3.2, F.2.3.2.4, F.2.3.2.4.1, F.2.3.2.4.2, F.2.3.3.4, F.2.3.3.4.1, F.2.3.3.4.2, F.2.3.3.6, F.2.3.3.6.1 F.2.3.3.6.2, F.2.3.3.9, F.2.3.3.9.1 F.2.3.3.9.2, F.4.3.3, F.4.3.5, F.4.4.3	TM, CSP	Configure and select PST analysis resources and configuration, process Pulsar Timing data, Pulsar Timing

AA4 Key Engineering Goals, Integration and Risk Reduction

AA4 will be the first time the full CSP-SDP data transmission capacity will be tested, transmitting at 9.2Tbps on the CSP-SDP link.

The other main risks at AA4 are likely to be software issues in TM and SDP.

It is likely that the majority of fixes at this stage of the project will be limited to software patches and fixes.

AA4 Verification Outcomes

The table below details the Key Engineering Goals for Array Assembly 4 and the L1 requirements to be verified at this Roll-Out Milestone. At this stage the focus of AIV activities moves entirely towards formal verification and sign-off against L1 requirements. This table is to act as a guide for the Sub-system contractors on what verification is to be performed at this AA4 milestone.

Table 37: Description of Array Assembly 4 Verification Outcomes.

AA4 Key Engineering Goals	Test Cases (Type)	Sub-system	Verification Outcomes
Completion of SKA1_LOW Assembly	Inspection	LFAA, CSP, SDP, SAT, Networks, TM	Verification will include: ● No of stations ● SKA1_LOW antennas per station. ● SKA1_LOW station diameter. ● LOW Configuration ● Maximum Baseline length
Bandpass Calibration and Stability	Test	CSP, LFAA, SDP	These tests verify the calibration and stability of the bandpass spectrum and station beam. Verification includes: ● Spectral Stability ● Instantaneous Bandwidth ● Clipped data flagging ● Station beam stability ● Absolute flux density scale

Imaging Dynamic range	Test and Analysis	CSP, SDP, TM, LFAA	Verification includes: ● Polarisation Dynamic range for imaging, Pulsar Search and Pulsar Timing
CSP-SDP Data Pipeline	Test	CSP, SAT, Networks, SDP, TM	Verification includes: ● Data pipeline capacity of 9.2Tbps on the CSP-SDP link.
Sub-arraying Functionality and Performance	Demonstration and Test	CSP, SDP, TM	These tests verify the setup, creation and operation of Sub-arrays. Verification includes: ● Sub arraying. ● SKA1_LOW subarray support ● SKA1_LOW subarray set up time ● SKA1_LOW subarray membership ● SKA1_LOW subarray granularity ● SKA1_LOW subarray independence ● SKA1_LOW subarray configuration ● SKA1_LOW subarray tied-array beam station exclusion ● SKA1_LOW subarray station allocation ● SKA1_LOW subarray station failure flagging ● SKA1_LOW Maintenance subarray

			• SKA1_LOW subarray pointings • SKA1_LOW subarray frequency resolution • SKA1_LOW subarray bandwidth • SKA1_LOW subarray visibility time resolution • SKA1_LOW subarray logical control and monitoring • SKA1_LOW subarray logical data flows • SKA1_LOW subarray scheduling block set-up time • SKA1_LOW simultaneous scheduling blocks • SKA1_LOW subarray scheduling block allocation • SKA1_LOW subarray independence of scheduling block
Pulsar Search	Test and Demonstration	CSP, TM	These tests verify the setup and operation of the telescope Pulsar Search system. Most Pulsar Search requirements are partially verified at AA3. AA4 completes the Pulsar search verification. AA4 Verification includes: • SKA1_LOW Pulsar search array diameter • Number of beams: SKA1_LOW Pulsar Search • SKA1_LOW Beamformer S/N Pulsar Search • SKA1_LOW Pulsar Search Candidates • SKA1_LOW Pulsar Search number of channels

Pulsar Timing	Test and Demonstration	CSP, TM	These tests verify the setup and operation of the telescope Pulsar Timing system. Most Pulsar Timing requirements are partially verified at AA2. AA4 completes the Pulsar Timing verification. AA4 Verification includes: ● SKA1_LOW Pulsar timing array diameter ● SKA1_LOW Pulsar timing observing band ● SKA1_LOW Pulsar timing subarray support ● SKA1_LOW Pulsar timing observation time ● SKA1_LOW Time stamping ● SKA1_LOW Timing Beams ● SKA1_LOW Pulsar timing Dispersion Measure ● SKA1_LOW Pulsar Timing Resolution
Dynamic Spectrum	Test	SDP, CSP, TM, SAT and Networks	These tests verify the setup and operation of the telescope Dynamic Spectrum system. Most Pulsar Timing requirements are verified at AA1 and AA2. AA4 completes the Dynamic Spectrum verification. AA4 Verification includes: ● SKA1_LOW Dynamic spectrum. ● SKA1_LOW Dynamic spectrum sub-array support. ● SKA1_LOW Dynamic spectrum and Pulsar timing total beams.

Transients	Demonstration	SDP, TM, LFAA, CSP	These tests verify the setup and operation of the LOW telescope Transients Detection system. Some of the Transient Detection requirements are partially verified at AA3. AA4 completes the verification. AA4 verification includes: ● Transient search ● SKA1_LOW transient capture latency ● SKA1_LOW transient archiving
Telescope Model	Demonstration	TM, SDP	Many Requirements for the Telescope Model are partially verified at AA2 and AA3. The AA4 verification includes: ● Telescope Model ● Single geodetic model (Telescopes). ● Single geometric model.
Science Data Processing Pipeline (Demonstrated data throughput handling)	Demonstration	SDP	Many Requirements for the SDP Pipeline are verified at AA3. The AA4 verification includes: ● Performance assessment ● Performance goals ● Quality assessment
Glass box Calibration	Test and Demonstration	SDP, LFAA, CSP, SAT, Networks, TM	The Glass box Calibration verification is partially completed at AA3. AA4 verifications includes: ● SKA1_LOW Glass Box Calibration ● SKA1_LOW Glass Box Calibration: parameter application

			• SKA1_LOW Glass Box Calibration: parameter storage
Observing	Demonstration	TM	• Sky mapping
Monitoring	Inspection	INFRA-AU, TM, SAT, Networks	Monitoring is an Infrastructure activity. Monitoring completed during the AA4 Array Assembly include: • Visual monitoring. • RFI Monitoring
Power Supply Functionality and Performance	Test and Demonstration	INFRA-AU, LFAA, SDP, CSP, TM, SAT, Networks	The Power Supply system is incrementally tested during the construction and commissioning phase as the size of the array is added to. Verification testing completed at AA4 includes: • SKA1_LOW RFI power delivery. • Low Power Mode • Uninterrupted power • Power overload • Power interruption survivability • SKA1 Mid and SKA1_LOW Power quality standard
RFI and EMC	Test, Demonstration and Inspection	LFAA, SAT, Networks, CSP, SDP, TM, INFRA-AU	AA4 completes the verification of the RFI and EMC testing for the telescope. Many of the RFI and EMC requirements were partially verified at AA2 and AA3. AA4 verification includes: • Electromagnetic radiation • Self-induced RFI

			• RFI Flagging • RFI Excision • RFI Masking • Central Processing Facility RFI shielding. • Central Processing Facility RFI penetrations.
Availability, Reliability and Maintainability	Analysis and Demonstration	LFAA, CSP, SDP, SAT, Networks, TM	AA4 Verification includes: • Operational availability • Fail safe provisions. • Fail safe state • Fail safe warnings • Fail safe recovery • SKA1_LOW maintenance hours • Software updates
Quality Factors Requirements	Demonstration and Test	INFRA-AU, LFAA, CSP, SDP, TM	AA4 completes the verification of the Quality Factors Requirements for the telescope. Many of the Quality Factors were partially verified at AA1 through to AA3. AA4 Verification includes: • Logging of operational state • Reporting of alarms

			- Fault database - Testability - Remote diagnostic capability
Telescope Management – Assessment of Complete Operational Interface	Test	TM, SDP, CSP, LFAA	Many of the Telescope Management tests and demonstrations were performed at AA2 and AA3. AA4 verification includes: - Elapsed time tracking - Lifetime of SKA1 logs - Observation report - Central location for databases. - SKA1 user accounts - Tool for proposal submission - PI editing rights - Central database for proposals - Library of template configurations - Sensitivity calculator - Resolving names to astronomical coordinates - Provision of known sources

			• Scientific justification submissions • SKA1_LOW and SKA1_Mid in single proposal • Proposal verification • Observation comparison to Key Science Projects • Proposal management system availability • Assignment of assessor and referee • Proposal grading • Proposal feasibility report • Ranked list of proposals • Proposal grading feedback • Design and adjustment of approved projects • Extraction of technical information from proposals • Verification of technical configuration parameters • SDP pipeline list • Resource for Scheduling Block execution • Short-term plan adaptability • Scheduling Block status

			• Scheduling Block status changes • Commensal Scheduling Block identification • Commensal Project packaging • Commensal Scheduling Block ranking • Help desk • Semester queue. Operations construction of scheduling blocks • Testing the schedule • API for construction of schedule
Regression Testing	Test	All Products	For SKA1-LOW, the key points during construction where regression testing needs will be reviewed: • The system hardware is expanded at each of the AIV LOW Milestones • Software or Firmware upgrades are made to any of the Sub-system products • Any hardware configuration change • Any technology refresh • Any major production batch changes Regression testing may be either a full system test with complex tests like fringes, basic imaging or drift scans or more simple tests like sanity checks, reconfirmation of Sub-system interfaces and data flow protocols. E.g. fix for a simple, low level bug that corrupts metadata.

Verification of Hardware and Software Interfaces	Test	All Products	The verification of hardware and software interfaces between products is an essential part of the LOW System Integration process.
Final verification of all L1 Requirements and Commissioning of Full Array for all Science Areas.			AA4 will complete the final verification of all L1 Requirements for the LOW telescope. At the completion of successful verification, the telescope will theoretically behanded over to Science Operations. In practice the telescope is likely to be handed over gradually, initially with high-priority observing modes.

Station Configurations and Locations for AA4

AA4 comprises the full array of 512 Stations with the LOW Central Area fully populated and the station clusters along all three spiral arms in place. The Figure below shows the locations of the Field nodes along the three spiral arms at the LOW Central Area.

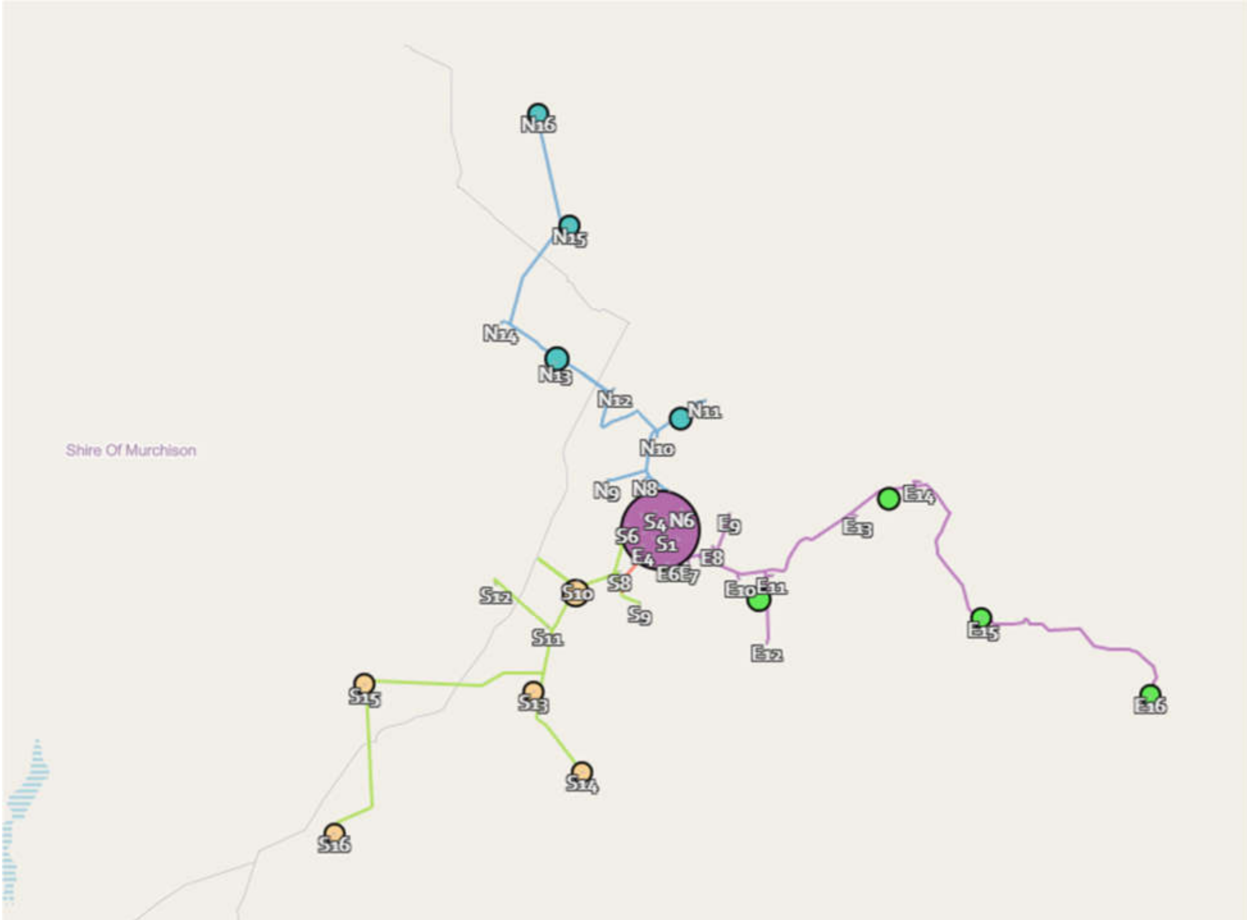


Figure 17: Field Node Locations of Full SKA LOW Telescope

LIST OF ABBREVIATIONS

AA	Array Assembly
AD	Applicable Document
AIV	Assembly, Integration and Verification
ASKAP	Australian SKA Pathfinder
CASA	Common Astronomy Software Applications package
CBF	Correlator Beamformer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CPF	Central Processing Facility
CSP	Central Signal Processor
EMC	Electromagnetic Compatibility
FN	Field Node
FPGA	Field-Programmable Gate Array
FTE	Full-Time Equivalent
GUI	Graphical User Interface
HI	Neutral Hydrogen 21cm Line
IGO	Inter-Governmental Organisation
INFRA-AU	Infrastructure Australia
IPS	Integrated Project Schedule
IRR	Integration Readiness Review
ITF	Integration Test Facility

ITF-QE	ITF Qualification Event
KO	Kick-Off
LEMP	Logistic Engineering Management Plan
LFAA	LOW Frequency Aperture Array
LFAADN	LOW Frequency Aperture Array - Data Network
LMC	Local Monitoring and Control
LSA	Logistic Support Analysis
MCCS	Monitor, Control and Calibration Subsystem
MRO	Murchison Radio Observatory (in Western Australia)
MS	Measurement Set
NSDN	Non-Science Data Network
OBSMGT	Observation Management
OEM	Original Equipment Manufacturer
PCA	Physical Configuration Audit
PHS&T	Packaging, Handling, Storage and Transportation
PRR	Production Readiness Review
PSI	Prototype System Integration
PSS	Product Supplier Support
QA	Quality Assurance
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference

RPF	Remote Processing Facility
SaDT	Signal and Data Transport
SAFe	Scaled Agile Framework
SAT	Synchronisation and Timing
SB	Scheduling Block
SDP	Science Data Processor
SKA	Square Kilometre Array
SKAO	SKA Project Office
SKA1	Square Kilometre Array Phase 1
SPS	Signal Processing Subsystem
STFR	System for the Time and Frequency Reference signals
T0	Start of Construction period
TBC	To Be Confirmed
TBD	To Be Determined
TELMGT	Telescope Management
TM	Telescope Manager
TPM	Tile Processing Module
TRL	Technology Readiness Level
UTC	Coordinated Universal Time
UV	Array Coordinates
VO	Virtual Observatory

DOCUMENT HISTORY

Revision	Date of Issue	Engineering Change Number	Comments
A	2014-07-30	-	First draft released for internal review.
B	2014-08-14	-	Updated draft incorporating responses to internal review comments.
C	2014-10-20	-	Added Logistics Support section. Addressed all OAR comments for Rev B to Rev C, and feedback received during the SKA Engineering Meeting.
01	2014-11-27	-	Incorporated comments received from another round of review of the SKA Office.
02	2015-3-10	-	Addresses some COARs from the PDR.
03	2015-11-30	CN-AIV-150004	Major new release, incorporating input from all Consortia and the SKA Office, as well as meetings held at the 2015 SKA Engineering Meeting.
04	2016-02-29	CN-AIV-160003	Removal of dates and durations, and alignment with Roll-Out Strategy document. Addition of AA1 configuration options. Reviewed by all Consortia Leads, and inclusion of resultant OAR comments.
05	2016-11-14	CN-AIV-160008	For each Array Assembly: Expanded detail, and provided references to the PBS, the L1 Requirements and the Functional Analysis. Provided details of technical risks mitigated at each Array Release. Updated list of Assumptions and Risks. Moved supplementary information to Appendices. Functional Allocation to Milestone tables included in appendices.
05A	2017-10-31	CN-AIV-170009	Update to Block diagrams to meet SaDT requirements, refresh of Product Functional tables in Appendices and Required Functionality tables for TM and SDP. Inclusion of SAFe section in SW Management. Update of LFAA product names in line with PBS. Inclusion of proposed AA2 and AA3 Station Configurations. Mention of the LOW Deployment Array vs LOW Design Array in line with outcomes of CCP. Inclusion of hardware to be provided by AIV for ITF, AA1 and AA2. Rack space requirements for AA1 Temporary CPF.
06	2017-12-15	ECP-170050 ECP-170028 ECP-170031	Major new release, incorporating comments from System Pre-CDR.
07	2018-11-19	CN-AIV-180004	Remove "Functional Allocation to Roll-Out Milestones" Appendix to new document SKA-TEL-AIV-4410002. Minor adjustments to the TM roll-out as per observation TMCDR-480. Minor updates for CDR release. Changes affect the naming used for some products in the block diagrams, in accordance with comments raised by Maria Grazia-Labate. SKA1-LOW Observing Modes summary table included in Section 3.
08	2019-05-06	CN-AIV-190001	Incorporates actions from AIV CDR.
08a	2020-04-04	NA	New major section on AA0.5 added Description of Science Commissioning added Description of station acceptance and integration expanded
08b	2020-05-26	NA	Review comments from OAR addressed (AVS, DH, NPR, RA) plus review comments from JO addressed. Review comments from RL not yet addressed.

08c	2020-05-29	NA	Review comments from RL addressed. One major outstanding comment is to describe the relationship between ITF and AA0.5 activities.
09	2020-06-19	ECP-200011	Issued
10	2022-01-12	ECP-210012 ECP-200027, ECP200074 ECP-200039 ECP-190004 ECP-210037 ECP-200044 ECP-200026 ECP-200036 ECP-210066	Updated many sections as a result of the listed ECPs; ECP-210012: addition of AA* as an alternative step to AA3 ECP-200027, ECP200074: adjustment of station locations ECP-200039: CoTs solution for the implementation of Low CBF ECP-190004: Enabling Holography for LOW telescope ECP210037: Update of new functionality for SKA-Low in AA0.5 and AA1 Reflection of the change from LFAA prime contractor to LFAA station integrator ECP-200044: Common interface CBF-Pulsar processing ECP-200026: Updating constraints on beams, sub-stations, bandwidth ECP-200036 - Perform Low.CBF VLBI beam generation on Low.PST servers ECP-210066: Temporary Items: Transfer from LOW AIV and FN Scopes and addition of new S-AIV HW to Infrastructure Contract 1/3 Scopes

DOCUMENT SOFTWARE

	Package	Version	Filename
Word Processor	MS Word	Word 2010	SKA-TEL-AIV-4410001-SE-RP-MPL-Roll-Out Plan for SKA1_LOW.docx
Block Diagrams	MS Visio	Visio 2013	SKA1_LOW Roll-Out Plan.vsd
Other			

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