Roll-Out Plan for SKA1 MID

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Role	*Name*	*Designation*	*Affiliation*	*Signature*	*Date*
Author	R.T. Lord, et al.	AIV Senior Systems Engineer	SARAO	Richard Lord	2021-08-06
Author	D. Gammon	AIV Systems Engineer	SARAO	Donald Gammon	2021-08-06
Author	P. Hekman	MID AIV Lead Engineer	SARAO	P.Hekman	2021-08-09
Owner	P. Hekman	MID AIV Lead Engineer	SKAO	P.Hekman	2021-08-09
Approver	G. Swart	MID Telescope Engineer	SKAO	Gerhard Swart	2021-08-09
Released by	J. McMullin	Programme Director	SKAO	J P McMullin	2021-08-08

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GLOSSARY

[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" loosely refers to all products that are part of the TM, CSP and SDP Elements. It excludes all of the "front-end products", which loosely refers to all products that are part of the Dishes.

[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.

[Consortium] A group of organisations carrying out a work package during the Pre-Construction Phase of SKA1.

[Contractor] The entity carrying out a construction work package during the Construction Phase of SKA1.

[Element] A logical group of products, which forms part of the SKA1 Telescope System. This term should never be used to refer to an entity carrying out a work package.

[Front-End Products] The term "front-end products" loosely refers to all products that are part of the Dishes, including some Networks and SAT products. It excludes all of the "back-end products", which loosely refers to all products that are part of the TM, CSP and SDP Elements.

[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.

[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.

[Science Verification] All testing activities that are executed to verify the Telescope system against its Level-0 Requirements, i.e. to ensure that the Telescope system meets the needs of the science and operational users. Science verification will be implemented as a set of end-to-end tests of the system from proposal submission to data delivery. Each test verifies one or more observing modes.

[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

During the Pre-construction Phase the AIV Consortium established a high-level Roll-Out Plan for each SKA1 Telescope. For SKA1-Mid, this included the MeerKAT Precursor integration. The Mid Roll-Out Plan defines the sequence and timing of the installation, commissioning, and verification of the telescope various Products as part of the formal AIV process. This includes the integration done in the Integration Test Facility (ITF) and on the telescope sites. This document is the SKA1-Mid Roll-Out Plan - for the SKA1-Low Telescope Roll-Out Plan see [RD2].

The Roll-Out Plan, together with the Verification Strategy [RD40] provides an important input to the detailed MID Integration & Verification Plan, [RD5], and to each SKA1 Product's construction plan and schedule. This context is shown in Figure 1 below.

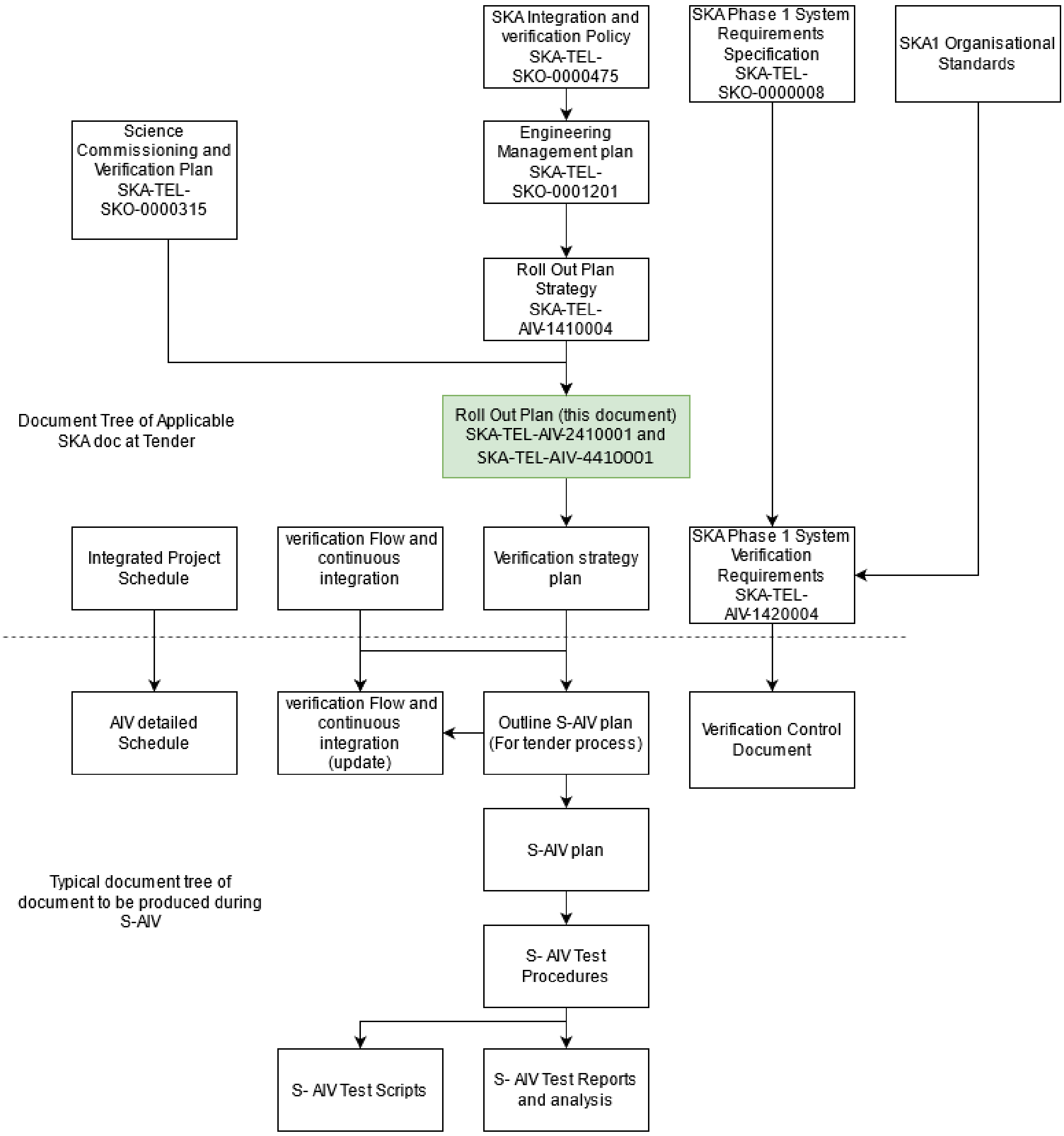

Figure 1: Key Documents Related to the MID Roll-out Plan.

1.2 Scope

SKA1-MID is located in South Africa and will consist of 133 SKA1-MID Dishes, plus another 64 MeerKAT Precursor Dishes. 16 of the 133 SKA1-MID Dishes will first be incorporated into the MeerKAT Array, as part of the MeerKAT Extension project (see Section 3.1), before being integrated into the SKA1-MID Array together with the 64 MeerKAT Precursor Dishes.

This document considers:

- **Sequencing of implemented functionality**, based on a prioritisation of requirements. The sequencing is based on risk mitigation and on Level-1 functionality required for integration and verification.
- **Scale**: How many dishes are deployed, over what timescale, and at which locations.

ECP-210012 *Staged Delivery* limits the initial spending of the SKA1 project to match the funding available at the Start of Construction. The ECP objective is not to change the telescope design or the ultimate plan, but to temporarily constrain the initial contracted delivery of Telescope systems and the System AIV effort to fit within the available funds, anticipating a return to the "full delivery" plan when funds are received. As a result, this document still defines the roll-out in accordance with the original "full delivery" and must be read in conjunction with [RD41] *Roll-out AIV MID with Staged Delivery*.

An ongoing assessment will be made to establish whether the path to "full delivery" can still be recovered. If not, then the "staged delivery" scenario will have to be optimised and fully incorporated into this and other AIV plans. In the interim, [RD41] should be used as guidance for contracting of Product scope and quantities and as a ceiling to AIV obligations.

1.3 Roll-Out Strategy

The underlying "rationale" or strategy of the Roll-Out Plan is described in [AD9]. ECP-210028 and ECP-210019 are incorporated into this document - impacting the quantities and timing of SKA, MeerKAT+ and MeerKAT dishes.

1.4 Construction Schedule

The following key dates are used as reference in the Roll-Out Plan:

- T0: Start of construction for the SKA1 project.
- C0: Start of Construction for each construction contract. Each contractor will have their own date.

The SKAO manages the construction schedule, [AD11], which also contains the dates associated with the high-level roll-out milestones that are described in this document. Any dates or durations that might be mentioned in this document need to be aligned with the construction schedule. In case of any discrepancies, the construction schedule shall take precedence.

1.5 Executive Summary

The Roll-Out Plan identifies six high-level stages:

1. Integration Test Facility
2. Array Assembly 0.5
3. Array Assembly 1
4. Array Assembly 2
5. Array Assembly 3
6. Array Assembly 4

Array Assemblies (abbreviated "AA") are defined in Section 3.4 as "required products installed", as input to the integration & verification process. An Array Assembly is characterised by the number of Dishes included in the array, and by its capability as an end-to-end Telescope System with pre-defined functionality.

The "staged delivery" (ECP-2100012) would result in a smaller array, reduced functionality, and an earlier end point for AIV work, designated AA*. Details are provided in [RD41], but by way of information, the stages for the staged delivery are listed below:

1. Integration Test Facility
2. Array Assembly 0.5
3. Array Assembly 1
4. Array Assembly 2 (which may be different to AA2 described in this document)
5. Array Assembly *, or AA*

This document describes the full baseline roll-out to AA4; the staged delivery and AA* [RD41] are not considered further in this document.

The details of the capabilities of each Array Assembly are provided later in this document. The size of each Array Assembly is shown in Table 1 below.

Table 1: Size of each Array Assembly.

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Total Number of Dishes	-	4	8	64	121 (1)	197
Number of MeerKAT Dishes (incl. MK+)	-	0	0	0 (2)	4	80 (3)

(1) 117 SKA1-MID Dishes (since 16 SKA1-MID Dishes are incorporated into MeerKAT Extension returned in AA4) plus 4 MeerKAT Dishes.
(2) The first MeerKAT Dish is handed-over to SKAO at the beginning of AA2 (see Section 10).
(3) 64 MeerKAT Precursor Dishes plus 16 MK+ Dishes.

1.6 Changes since the Previous Revision

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

- It incorporates ECP-210028 *Dish Structure change in drive and servo supplier*. This change also effectively reduces the number of SKA Dishes used and delivered by MK+ to 16 from 20 (i.e., matching the number of dishes provided by the MK+ project) and adds those 4 Dishes back to SKA to deliver.
- It incorporates ECP-210019 *MKI change in integration numbers*. This changes the release of the MK dishes to SKA from sets of 1, 7 and 56, to 1, 3 and 60.
- It incorporates ECP-200048 *Movement of MID CSP from site to the SPC.*
- Several minor clarifications.

It identifies the existence of ECP-210012 for *Staged Delivery* but this is not implemented in this document, rather the impact is summarised in [RD41].

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 Requirements Specification", SKA-TEL-SKO-0000008.
[AD2] "Design Baseline Document", SKA-TEL-SKO-0001075-01.
[AD3] "Engineering Management Plan", SKA-TEL-SKO-0001201-01.
[AD4] "SKA Configuration Management Plan", SKA-TEL-SKO-0000120.
[AD5] "SKA Integrated Logistic Support Plan (ILSP)", SKA-TEL-SKO-000104.
[AD6] "SKA Project Health, Safety and Environmental Management Plan", SKA-TEL-SKO-0000740.
[AD7] "Product Assurance Plan", SKA-TEL-SKO-0000739-02.
[AD8] "Agreement between The Republic of South Africa, represented by the Department of Science and Technology and The Square Kilometre Array Organisation concerning the Installation and Operation of the Square Kilometre Array", SKA Hosting Agreement RSA.
[AD9] "SKA1 Telescope Roll-Out Strategy", SKA-TEL-AIV-1410004.
[AD10] "SKA1_MID Physical Configuration Coordinates", SKA-TEL-INSA-0000537.
[AD11] "SKA1 Integrated Project Schedule", SKA-TEL-SKO-0001103-01.
[AD12] "SKA System Integration Test Facility Requirements Specification", SKA-TEL-AIV-1100004.
[AD13] "Science Commissioning and Verification Plan", SKA-TEL-SKO-0000315.
[AD14] "SKA1 Project Execution Plan", SKA-TEL-SKO-0001100.

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] R.T. Lord and D. Gammon, "Functional Allocation to Roll-Out Milestones for SKA1_MID", SKA-TEL-AIV-2410002.
[RD2] M.J. Hayes, A. MacLeod and Y. Chen, "Roll-Out Plan for SKA1_LOW", SKA-TEL-AIV-4410001.
[RD3] R.T. Lord and A. MacLeod, "Product Hand-Over Process", SKA-TEL-AIV-1450001.
[RD4] R.T. Lord, T. Cheetham, A. Schinckel and A. MacLeod, "SKA1 Integration Test Facility (ITF)", SKA-TEL-AIV-1100004.
[RD5] D. Gammon and R.T. Lord, "Integration and Verification Plan for SKA1_MID", SKA-TEL-AIV-2430001.
[RD6] D. Gammon and R.T. Lord, "Integration & Verification Plan for SKA1_MID – MS Project Schedule", SKA-TEL-AIV-2430002.
[RD7] R.T. Lord, D. Gammon and M. Hayes, "SKA Phase 1 System (Level 1) Verification Requirements", SKA-TEL-AIV-1420003.
[RD8] R.T. Lord, D. Gammon and M. Hayes, "SKA Phase 1 System (Level 1) Verification Requirements Spreadsheet", SKA-TEL-AIV-1420004.
[RD9] D. Gammon, "AIV Consortium Responsibilities regarding SKA Phase 1 System (Level 1) Requirement Verification", SKA-TEL-AIV-1420001.
[RD10] A. MacLeod, "AIV Risk Register", SKA-TEL-AIV-1210001.
[RD11] D. Gammon, "MeerKAT Integration Risk Register", SKA-TEL-AIV-2210001.
[RD12] R.T. Lord, "AIV Cost Model", SKA-TEL-AIV-1220001.

[RD13] N. Ebbendorf, "AIV Safety Management Plan", SKA-TEL-AIV-1470001.
[RD14] R.T. Lord and A. MacLeod, "EMC Control Plan for AIV", SKA-TEL-AIV-1480001.
[RD15] R.T. Lord and D. Gammon, "AIV Resource Plan for SKA1_MID", SKA-TEL-AIV-2240001.
[RD16] R.T. Lord and D. Gammon, "MeerKAT Precursor Integration Plan", SKA-TEL-AIV-2440001.
[RD17] D. Gammon, "Interface Control Document AIV to INFRA-SA", SKA-TEL-AIV-2310002.
[RD18] D. Gammon, "Interface Control Document MeerKAT to SKA1_MID SaDT", SKA-TEL-AIV-2310003.
[RD19] D. Gammon, "Interface Control Document MeerKAT to SKA1_MID TM", SKA-TEL-AIV-2310004.
[RD20] D. Gammon, "Interface Control Document MeerKAT to SKA1_MID DISH", SKA-TEL-AIV-2310005.
[RD21] T. Kusel, "SKA Dish Element Integration and Verification Plan", SKA-TEL-DSH-0000024.
[RD22] G. van der Merwe, "SKA1 Dish Qualification Model (SDQM) Integration and Verification Plan (I&VP)", 301-000000-007.
[RD23] D. Liebenberg, "SKA Logistic Engineering Management Plan", WP2-005.010.030-MP-002.
[RD24] C. Taljaard, "SKA Support Concept", SKA-TEL-SKO-0000103.
[RD25] S. Li, "Hazard Analysis Implementation Requirements", SKA-TEL-SKO-0000619.
[RD26] D.C.-J. Bock, *et al*, "Concept of Operations for the SKA Observatory", SKA-TEL-SKO-0000256.
[RD27] P. Ntuli, "SKA1-MID Power Budget Report", SKA-TEL-INSA-0005037.
[RD28] A. van Es and P. Hekman, "Early MeerKAT Integration Work Packages", SKA-TEL-SKAO-0000639.
[RD29] T. Kusel, et al, "SKA_MID Functional Architecture", 300-000000-001.
[RD30] Scaled Agile Framework (SAFe), http://www.scaledagileframework.com
[RD31] R. Hughes-Jones, T.Rayner, "SADT CSP-SDP requirements and Costs Following the Cost Control Project", SKA-TEL-SADT-0000625.
[RD32] "SaDT MID Construction Plan", SKA-TEL-SADT-0000639.
[RD33] J. Davis, H. Collingwood and D. Hindley, "SaDT Clocks MID Detailed Design Document", SKA-TEL-SADT-0000330-DDD.
[RD34] T. Cheetham, "MeerKAT Science / SKA1 Construction Interferences Management Plan", SKA-TEL-SKO-0000975.
[RD35] T. Cheetham, "MeerKAT_SKA1 Construction Interferences Risk Register", SKA-TEL-SKO-0000976.
[RD36] R. Brederode, "SKA1 TM Verification Plan", SKA-TEL-TM-0000008.
[RD37] T. Kusel, "MeerKAT Extension Project Management Plan", SSA4003-0007-001.
[RD38] J. McMullin and R. Laing, "Early Construction Opportunities (MeerKAT Extension + Early Production Arrays)", SKA-BD-28.09, 12-13 November 2018.
[RD39] R. Braun, et al, "Science and Operations Planning", SKA-TEL-SKO-00000822.
[RD40] P. Hekman, L. Stringhetti, G. Swart, "Integration and Verification Strategy", SKA-TEL-SKO-0001799.
[RD41] P. Hekman, G. Swart, "SKA1 Roll-out AIV MID with Staged Delivery", SKA-TEL-SKO-0001827
[RD42] R. Anthony, P. Hekman, MG Labate, G. Swart, "SKA1 Prototype System Integration (PSI) General Framework", SKA-TEL-SKA-0001756.

3 Roll-Out Considerations

3.1 MeerKAT Extension

The MeerKAT Extension project (abbreviated as MK+) is defined in [RD37] and is therefore not described in detail in this document. It does, however, have a significant impact on the roll-out of SKA1-MID.

The scope of the MK+ project includes:

- Expanding the MeerKAT Precursor Array with 16 SKA-compliant Dishes (see Figure 1), each with:
    - SKA Band 2 Feeds and MeerKAT L-Band Digitisers
    - S-Band Feeds and Digitisers
- MeerKAT back-end expansion to add 16 Dishes, i.e. expansion of the MeerKAT Correlator Beamformer (CBF)[1], MeerKAT Science Processor (SP) and MeerKAT Time & Frequency Reference (TFR).
- SKA ECP-210028 reduces the number of MK+ Dishes from 20 to 16. MeerKAT ECP, MKAT-ECP-256, will define which of the original 20 locations will be used, based on science requirements. This has not been confirmed yet.
- As part of the MK+ Infrastructure contract, SKA infrastructure (Dish foundations, platforms, roads, power, and fibre) will be delivered for 24 dish systems, including infrastructure for the first 4 AA0.5 SKA1-MID Dishes, as well as for the locations of the original 20 MK+ Dishes.

The biggest opportunity that the MK+ project provides is this infrastructure work which begins early, alleviating schedule pressure for SKA1-MID.

The participants of this project are Max Planck Gesellschaft (MPG), JLRAT, SARAO and SKAO.

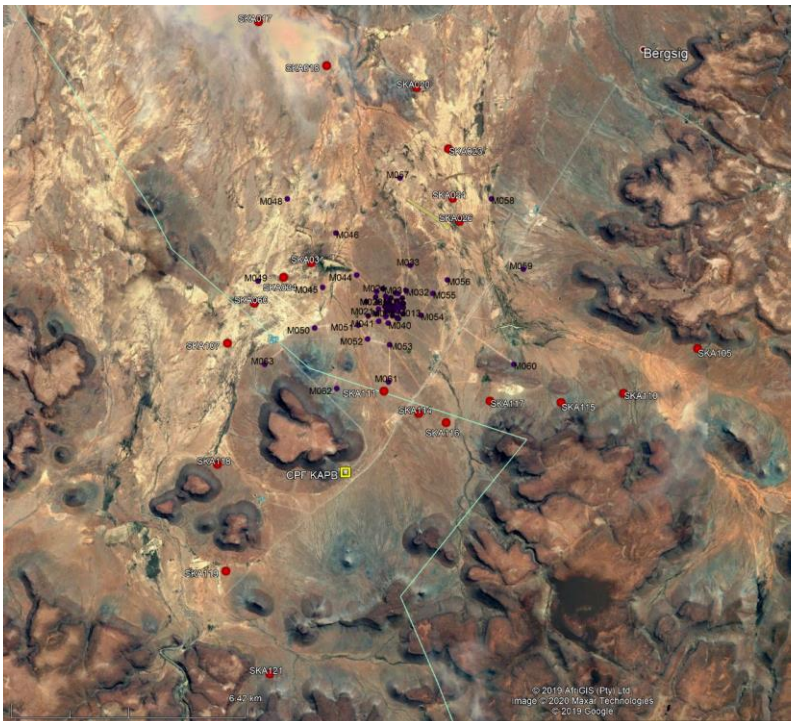

Figure 1: Google Earth view of MeerKAT Dishes (purple dots) and MeerKAT Extension Dishes (red dots).

[1] It is currently a goal to expand the MeerKAT Correlator to an 84-Dish Correlator.

The 16 MK+ Dishes will be on the SKA1-MID Dish locations with co-ordinates as given in [AD10] and as shown in Figure 1. Note that 16 of the 20 shown will be chosen based on MKAT-ECP-256. Section 9 identifies the array configuration roll-out, showing which Dishes will be rolled out within each Array Assembly, including MK+ Dishes.

The extended MeerKAT array will be integrated into SKA1-MID within AA4, towards the end of the construction period.

3.2 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 [RD42] for further information.

3.3 System Integration Test Facility (ITF)

The System ITF is planned ([AD12], [RD4]) for the end-to-end[2] integration of hardware, firmware, and software components in a convenient laboratory environment. It is desirable to only have pre-production (and later production) products in the System ITF, but the reality of construction delays might require the temporary use of some prototype products. It will contribute to the system-level design qualification and will verify most of the system-level interfaces, functionality and performance of the back-end products required for AA0.5 and AA1, such as:

- External product interfaces from the physical layer right up to higher layer interfaces such as data exchange formatting
- Basic control and monitoring via TM, LMC and NMGR
- Basic interferometry, such as obtaining fringes and demonstrating phase and amplitude closure (to the degree that it can be done in the ITF)
- Basic phase rotation and delay compensation models
- Correlator functionality
- Channelisation
- Bandpass calibration
- Time and frequency reference functionality
- Gain and Phase stability
- RFI detection

The level of testing in the System ITF needs to provide confidence that there will be minimal integration issues on-site. The line-up in the System ITF will be maintained, so that further releases of firmware and software (and hardware) may be tested in the System ITF, before being released on site.

The end-to-end line-up of products in the MID System ITF would include:

- Noise sources and signal generators to provide RF signals to test the signal path
- Four Dish SPFRx Digitisers (Digitiser and Pedestal Unit)

[2] Excluding the actual Dish Structures and Feeds, but including the SPF Receivers (or Digitisers).

- Pre-production correlator/beamformer, supporting four data streams with one boresight PST beam
- Early release software from TM for telescope management
- Early release software from SDP for visibility data capture
- SDP to provide data in MS format and intention to use CASA for post processing (spectra, gain solutions, closure quantities, bandpass solutions, etc). Optionally, the provision of initial versions of pipelines for further processing.
- Early versions of SDP real-time pipelines (complex gain solutions for beamforming, pointing data acquisition)
- Reference frequency and time distribution systems, i.e. SAT.FRQ, SAT.UTC and SAT.LMC
    - A Rubidium clock would provide a sufficiently accurate time and frequency reference source, i.e. it is not necessary to have SAT.CLKS at the System ITF
- Non-science data networks, i.e. NSDN and NMGR
- System LMCs

The functionality and performance of the long-range fibre link from site Central Processing Facility (CPF) to Science Processing Centre (SPC) in Cape Town and the long-range DDBH links will probably not be verified at the System ITF. These links use COTS equipment with standard interfaces and technology.

The functionality of management interfaces should be verified, e.g. the interfaces between the network equipment management system and NMGR and the interfaces between NMGR and TM. These interfaces are likely to be verified at the contractor's integration facility.

Also, the full performance of SAT.FRQ and SAT.UTC will not be fully verified at the System ITF, as the performance of these sub-elements can only be undertaken on the on-site system. The on-site system will be used to verify the performance of SAT.FRQ, SAT.UTC and DDBH, and the performance of the CPF to SPC- link. This end-to-end line-up will evolve over time.

3.4 Array Assemblies

Five Array Assemblies are planned, as outlined in Table 1. Each Array Assembly has the following attributes:

- Number of Dishes
- Array capability (functionality provided by the integrated system, including the functionality of CSP, TM, SDP, etc.), which limits the amount of engineering verification work and on-sky observations that can be performed with the array.
- A date, as defined by [AD11], before which all required products have been *installed* and stand-alone tested, i.e. not necessarily *integrated*. The system-level integration and verification activities commence after this date.

The Array Assembly concept is further illustrated in Figure 2, which shows:

- The MeerKAT Extension project will add a further 16 Dishes to the MeerKAT Precursor, see Section 3.1.
- The integration of the MeerKAT Precursor Dishes is planned within AA4, towards the end of the Construction Period.
- The number of verified SKA Dishes (i.e. excluding MeerKAT and MK+ Dishes) that have been handed-over by the Dish contractor ramps up linearly over time.

- The capability of an Array Assembly determines the functionality that is required from TM, CSP, SAT, Networks and SDP products.
- 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. The main 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 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 planned that both teams will work closely together during the Construction Phase. Refer to the Science Commissioning and Verification Plan [AD13] for further detail.

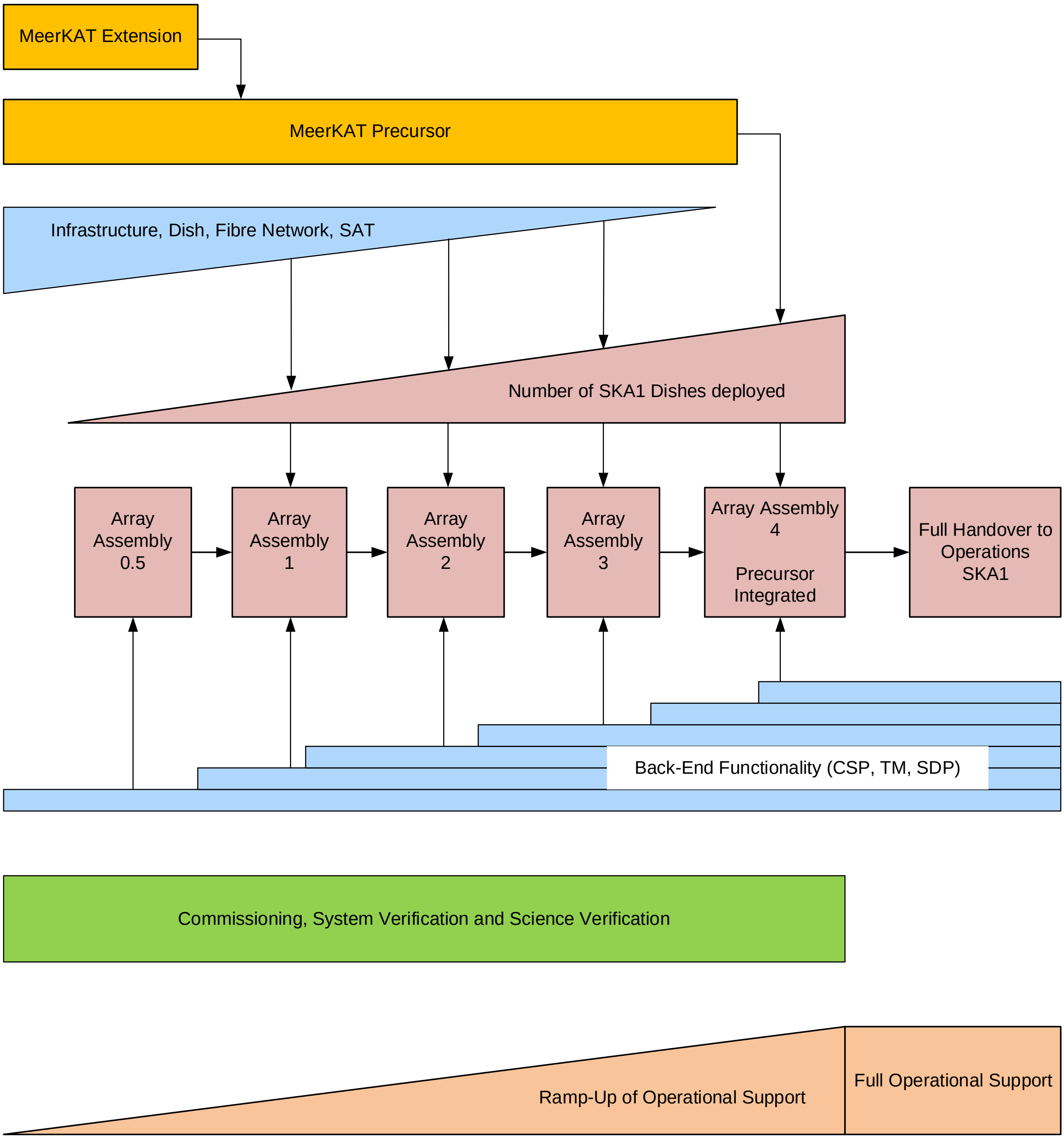

Figure 2: The Array Assembly concept of the Roll-Out Plan.

3.5 Array Assembly 0.5

Historically, AA1 (with 8 Dishes) has been regarded as the earliest end-to-end Telescope system that could be installed and commissioned on-site.

During the SKA Board meeting in November 2018, [RD38], the SKA Board was presented with the MeerKAT Extension project and the concept of AA0.5. The following text has been copied from [RD38]:

"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 MID Dishes, but similar arguments apply to individual scalable sub-systems such as the Correlator/Beam Formers. The evaluation phase would normally 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 MID and LOW AA0.5 systems.*
  - *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."*

The term AA0.5 encapsulates that it is:

a) smaller than AA1, a
b) rolled out earlier than AA1, and
c) it is on the journey to AA1.

Importantly, the work involved for AA0.5 must be the original work which was planned but is being performed earlier, i.e. the work must be line with the design baseline, should not be abortive in nature.

AA0.5 will be used to qualify the system design, to the extent that this is possible with such a small array with limited functionality. The objective is still to allow only pre-production or production products on site, and only after a sufficient level of integration testing has occurred in the System ITF. The go-ahead for the manufacture of production items, such as the Correlator and Digitiser/Packetiser, depends on the successful verification testing with AA0.5.

3.6 On-Site and Off-Site Activities

As illustrated in Figure 3, system-level activities will take place both on-site, as well as off-site at the System ITF. The AA0.5 gate in the ITF may have to be more flexible than the later ones to accommodate the actual status of the systems at that time.

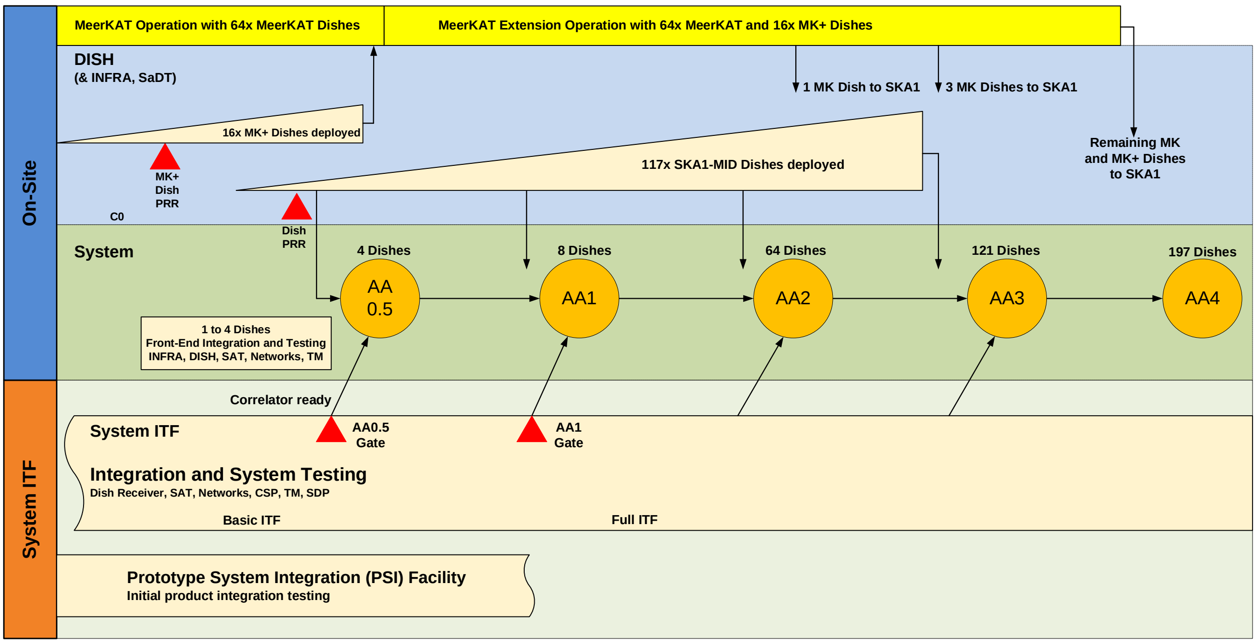

Figure 3: Overview of SKA1-MID Roll-Out.

3.6.1 On-Site Activities

The MK+ infrastructure contractor will be the first to work on-site, starting in or near the core. SARAO plans that this infrastructure contractor will complete its entire scope of work to service 24 Dish locations as early as possible, in order not to be a bottleneck for the Dish Contractor.

The MK+ scope of infrastructure work includes the provision of roads, 24 Dish foundations and platforms, associated power and fibre reticulation to 24 dishes, establishment of the Visserskloof contractor camp and security guard huts for the NRF land. This work needs to be fully compliant with regard to the SKA1 requirements.

The following SKA1-MID infrastructure contract scope of work includes the provision of roads, the remaining Dish foundations and platforms and all associated power and fibre reticulation, repeater shelters on the spiral arms, the Eskom power upgrade, local standalone PV power systems[3] to serve individual Dishes on the spiral arms, the upgrade to the Power Facility and CPF, site monitoring and security (fencing of base stations in spiral arms).

When the Dish Contractor hands-over the first acceptance-tested Dish, it imposes requirements on the timing contractor(s) to supply time and frequency reference signals, as well as the required DDBH (for Dishes further than 10 km from the MID-CPF, i.e. not directly applicable to AA0.5 and AA1) and NSDN networking equipment at the Dish.

A Production Readiness Review (PRR) is conducted after the construction and testing of the first four Dishes. This milestone is a quality gate for the Dish Contractor, after which full-scale production of the Dishes will commence. There should be a pause in Dish production (but not infrastructure production) until the PRR milestone is passed.

There is a significant amount of Dish-level AIV activity, to integrate and acceptance-test individual Dishes. The system-level AIV Team will, however, also have a presence on site, in order to observe the Dish-level AIV activities, to assist the SKAO with the hand-over process, and to perform the integration work related with integrating a Dish with timing equipment, Network equipment and with infrastructure.

3.6.2 Off-Site (PSI and System ITF) Activities

Once early prototype and pre-production hardware/firmware/software has been installed in the PSI and/or System ITF, a number of Integration Events will occur, in order to verify external interfaces between products (see [RD5]). All major products of the signal chain shall be tested within the System ITF prior to final installation on-site.

Further testing might be conducted in the System ITF, in order to evaluate the readiness of products being released for AA2, AA3 and AA4.

The System ITF will be maintained during the entire construction period with updated hardware, firmware and software.

[3] There will also be a prototype PV plant built to test and verify EMC/EMI compliance before rolling out the remaining PV plants in the spiral arms.

3.7 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 [RD23]). This is now incorporated in the SKA Integrated Logistics Support Plan (see [AD5]). It provides guidance regarding Logistic Support and Resources, such as:

- Manpower 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

The Logistic Support Roll-Out should be supported by all contractors. The reader is also referred to the Logistic Support documents, [AD5] and [RD24].

3.8 Roles and Responsibilities

During the Construction Phase, many groups of people will be accessing various resources on site and working on various overlapping jobs. The roles and responsibilities for AIV work during construction are described in the SKA1 Engineering Management Plan [AD3], the SKA1 Project Execution Plan [AD14], the SKA1-MID I&V Plan [RD5], and the SKA1-MID AIV Resource Plan [RD15].

All contractors and individuals directly or indirectly involved with the production, construction or maintenance activities for SKA1 will be responsible for cultivating a working attitude that supports Health & Safety. Everybody needs to be compliant with the Health & Safety regulations, see [RD13], and the SKA Health, Safety and Environmental Management Plan[AD6].

4 Software Roll-Out

4.1 Introduction

The SKA1 project has adopted the Scaled Agile Framework (SAFe®)[4] approach for rolling out software in a lean-agile manner during construction (see [AD3] and [RD30]).

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 an entire Telescope.

4.2 Large Solution SAFe®

Various configurations of SAFe® exist (see [RD30]). The configuration adopted by SKA1 is called “Large Solution SAFe®”, see Figure 4. It coordinates Agile Release Trains (ARTs) with a Solution Train with the aim 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

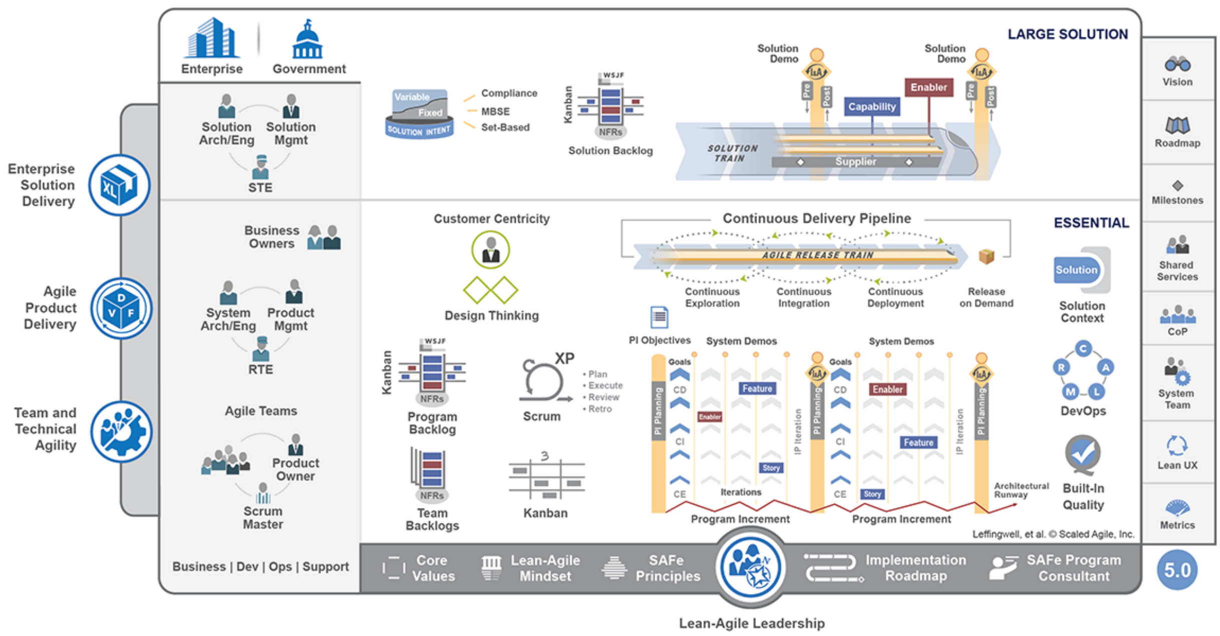

Figure 4: Large Solution SAFe® (see [RD30]).

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

4.3 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 lower-level product definitions
- Fixed lower-level 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

4.4 Release on Demand, Develop on Cadence

Software development is planned on a 3-month “cadence” called a Program Increment (PI). At each Program Increment 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.

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. The release of software needs to consider what will be released, when will the release happen, who will be affected by the release, and is the engineering support for this release available. In reality, controlled releases of parts of the system will happen frequently, otherwise development flow will stall and schedules will slip.

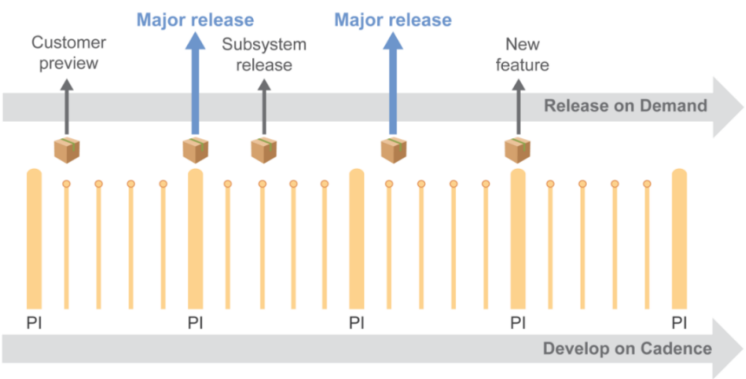

Figure 5: Release on Demand, Develop on Cadence.

4.5 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 concept of Continuous Integration is also starting to be applied at system-level, in the sense that continuous developmental integration will be happening at the PSI and at the System ITF, instead of isolated qualification gates.

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[5]. 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.

4.6 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 PSI or System ITF, where real prototype or pre-production hardware is available for integration testing
3. The on-site Telescope system

The Software Teams will perform integration and extensive testing of their software within the Software Solution Test Environment, prior to deploying the software to a PSI or the System ITF or On-Site. Integration, testing and deployment of software occurs continuously, but new features are not activated or available until they are released (using feature toggles). Release of software (by activating features) occurs on-demand as needed by the AIV Team (see Figure 6), and makes releasing a quick and low-risk exercise.

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.

[5] In the experience of ASKAP, software was deployed every 2-4 weeks. A similar deployment frequency is expected for SKA1.

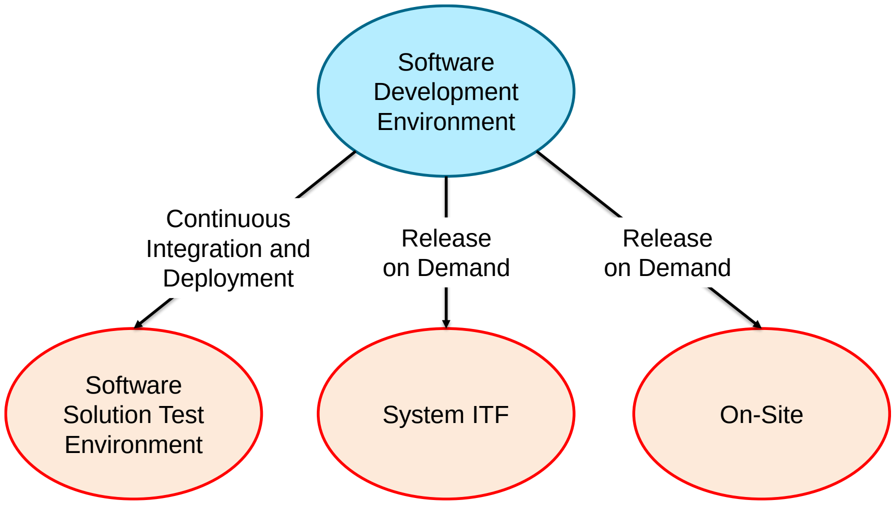

Figure 6: Software being released to the three primary software platforms.

4.7 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 system. This makes it possible to verify new software in a laboratory environment, but with an intermediate level of system complexity, representative of the full system.

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 System ITF, particularly as the System ITF will not support hardware at anything like full scale.

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 or ITF environment, in order to encourage the early release of software for early integration. However, formal verification testing will require 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[6].
- The intention is to release software on a regular basis to site leading up to AA0.5 as the assembly, integration and verification process proceeds.
- Software is released often into the PSI and ITF environment, 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

[6] Note that software will always be under source code configuration control in the sense that it is developed using a system such as Github. 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.

functionality comes on-line. This can be done with the use of Virtual Machines (VMs). A new VM 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/).

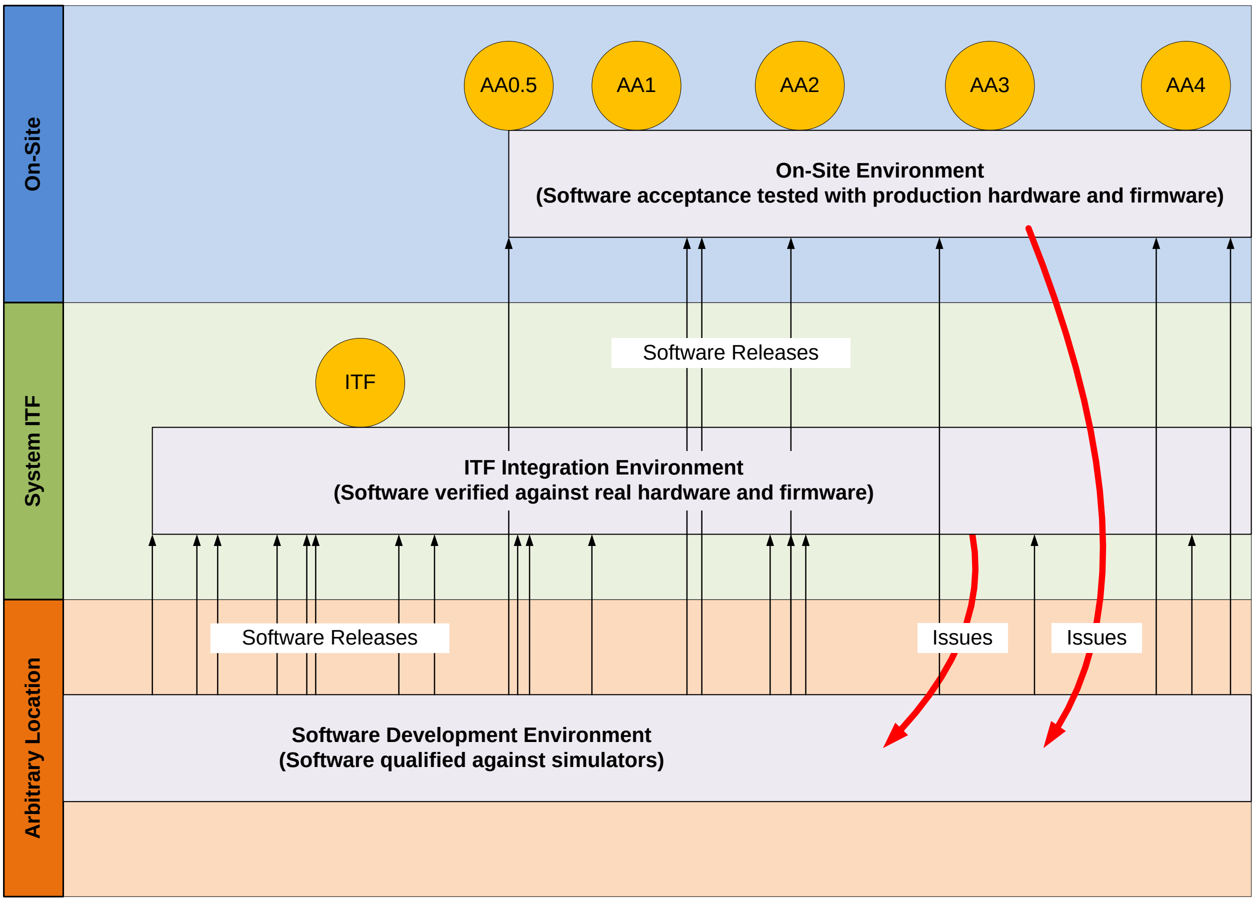

Figure 7: Software release management process.

4.8 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, [AD4], 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.

4.9 Interaction between SAFe and AIV

As stated in the I&V Strategy document, [RD40], 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 them 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 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[7] 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

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 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

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

automated continuous integration and deployment is achieved, the software system may need to be restarted to release certain functionality, but system downtime should be very minimal.

As described in [RD36] (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.

5 Infrastructure and Dish Roll-Out

The roll-out of infrastructure could be a major constraint for all other roll-out activities. Fortunately, SKAO has planned a "big bang" approach[8] to rolling-out all SKA1-MID infrastructure, including the fibre infrastructure, early during the Construction Phase, remaining well ahead of the demands of other on-site contractors, such as the Dish and timing contractors. This planning is based on experience with rolling-out MeerKAT Precursor infrastructure. The MK+ project furthermore necessitates that some infrastructure work will be rolled out even earlier. Given the availability of required infrastructure, the Dish Contractor is urged to roll-out Dishes as quickly as possible.

Figure 8 shows a summary of the SKA1-MID Dish roll-out, relative to T0.

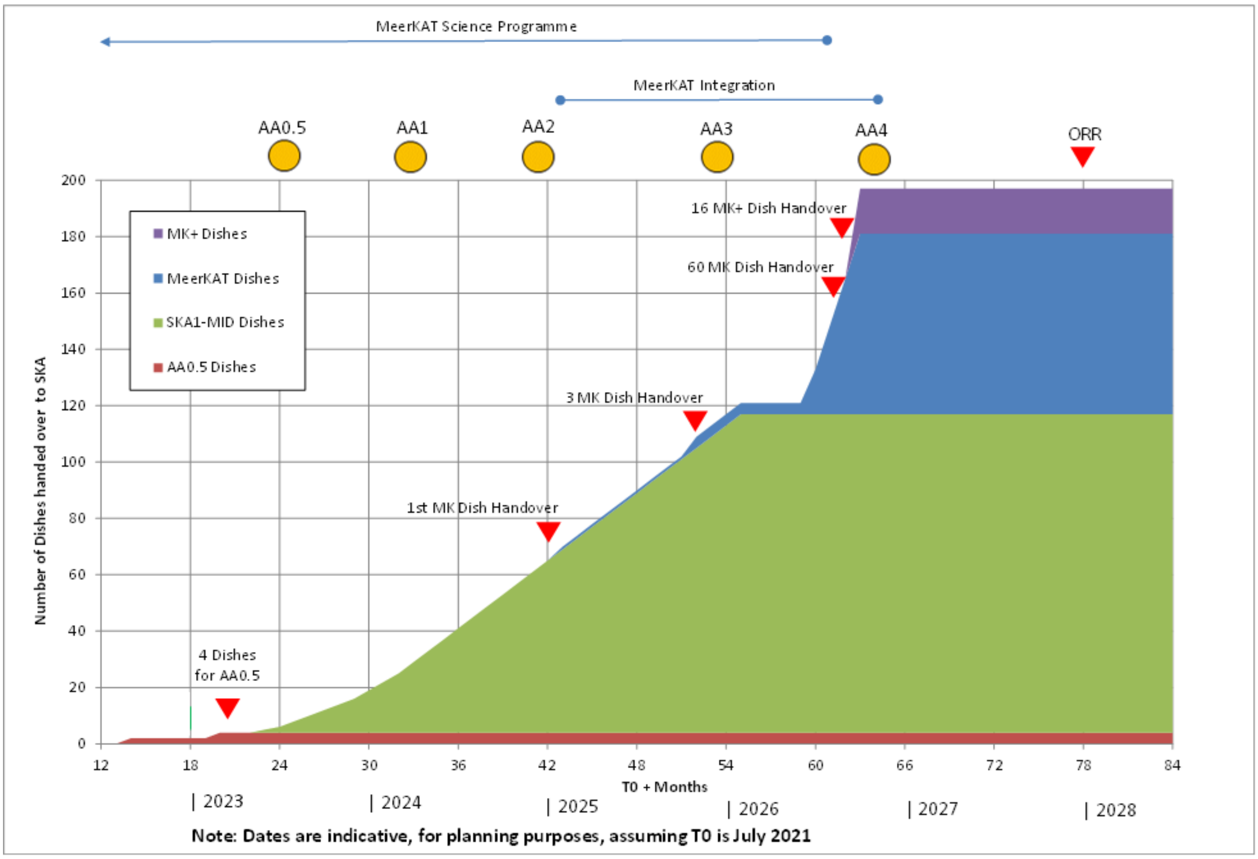

Figure 8: Overview of SKA1-MID Dish Roll-Out with MeerKAT integration.

Refer to the project schedule [AD11] for the latest information regarding dates and timelines. The maximum rate of Dish production is assumed to be 4 Dishes per month, based on information provided by the Dish Consortium. Refer to Section 9 on the array configuration roll-out for which Dishes are to be included in stages for each Array Assembly. The figure also shows:

- Four Dishes are provided early for AA0.5.
- The integration of the 64 MeerKAT Dishes towards the end of the construction period, in a phased manner. Refer to Section 10 on MeerKAT integration.
- The inclusion of the 16 Dishes used in MeerKAT Extension within AA4, at the end of the construction period. Refer to Section 3.1 on MeerKAT Extension.

[8] The "big bang" approach is dependent on servitude agreements being in place in the 3 spiral arms.

6 Array Assembly Capabilities

6.1 Introduction

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

1. Integration Test Facility
2. Array Assembly 0.5
3. Array Assembly 1
4. Array Assembly 2
5. Array Assembly 3
6. Array Assembly 4

These high-level milestones form the basis for design consortia to plan their product-level construction roll-out and associated costs.

The dates for these high-level milestones are contained in [AD11]. The dates relevant to AIV are those at which all products that are required for that milestone are successfully *installed*, i.e. not necessarily *integrated*. The system-level integration and verification activities that are planned to be conducted with an Array Assembly will commence *after* this date. Some of these activities may have been started or partially completed with previous Array Assemblies.

This chapter describes the capabilities of each Array Assembly, including the capability of the Qualification System in the ITF, so that the required functionality from all other Elements can be derived. This derivation will be done in the next chapter.

The capabilities of each Array Assembly are derived from the functionality required for integration and verification, based on risk mitigation. The Verification Requirements document [RD7] identifies the verification tests that are associated with each Array Assembly.

6.2 Capability of the System ITF

The System Integration Test Facility (ITF) will be used by contractors for interface testing between products and for product verification. The interfacing tests will be conducted at Integration Events throughout the Construction Phase, to be co-ordinated by the AIV Team (see [RD5]). On-going periodic test events will be performed to verify function and performance of a line-up of products that represent the on-site system. The products integrated in the System ITF will include four Band 2 Receivers, SAT, Networks[9], CSP, TM and SDP products (see Figure 9). One or more noise sources and signal generators will be used to generate test signals and simulate sky signals to the Receivers.

The capability of the initial System ITF is, ideally, very similar to the capability of Array Assembly 0.5. However, certain restrictions do apply. For example, the System ITF line-up of products does not include any real Dishes, hydrogen masers, long range DDBH or the long-range fibre link between CSP and SDP. Note that DDBH does not exist for links <10 km. There is a goal to have Pulsar Timing (PST) incorporated into the ITF so support its deployment in AA1 or even AA0.5.

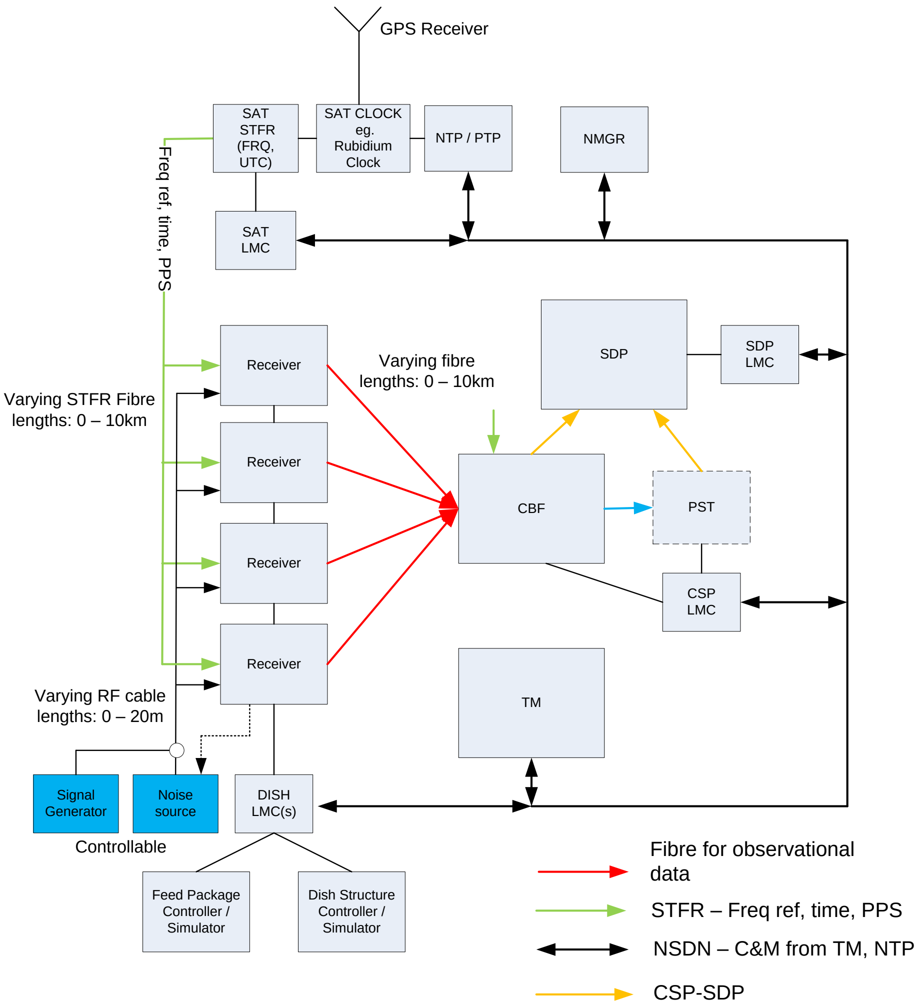

Figure 9: Typical configuration of products in the System ITF.

[9] SAT includes SAT.UTC, SAT.FRQ and SAT.CLOCKS. Networks includes DDBH (for MID), NSDN and CPF-SPC. Both need their respective network management hardware and software, SAT.LMC and NMGR.

Table 2: Capability of the System ITF.

	Capability of the System ITF
Date	Refer to [AD11]
Number of Dishes	Not applicable
Baselines	Baselines equivalent to those of Array Assembly 0.5 can be achieved by delaying the RF signal using co-axial cable and/or fibre cable.
Receiver Bands	Four Band 2 Receivers are required for the ITF, but without their corresponding Feeds. The RF signals will be obtained from noise sources.
Clock, Frequency and Time distribution	Perhaps Rubidium Clock. Basic 1 PPS time and frequency distribution, possibly using the clock and a signal generator. (Precision frequency and timing and distribution not necessary)
Correlator Size	4 Dish Correlator
Channelization	16k channels per frequency slice, no channel averaging
Correlated Bandwidth	400MHz *with a goal of 800 MHz*
Pulsar Timing Beams (CBF)	A single beam, as goal.
Pulsar Timing Processing (PST)	A single PST beam, as goal.
Pulsar Search Beams (CBF)	No
Pulsar Search Processing (PSS)	No
Zoom Mode	No

	Capability of the System ITF
Sub-Arraying	No
Transient Buffer	No
VLBI	No
Operational Functionality	• Basic operator control • Basic health monitoring

The primary objective of the System ITF is to help with qualifying the system-level design, and to verify the Array Assembly 0.5 functionality of all hardware/firmware/software products that will be deployed on-site. It is expected that the following functional and performance verification tests will be executed:

- Verify hardware and software product interfaces
- Verify basic operator interface to control the system and to monitor system health
- Verify the available functionality provided by NMGR, NSDN and SAT.LMC
- Verify data link between DSH and CSP
- Verify channelisation performance, including cross-talk between channels
- Check for spurious signals
- Verify correlator visibility products, e.g. packet content, data product labelling
- Perform basic baseline delay and phase calibration (to the degree that it can be done in the ITF [(1)])
- Obtaining fringes, phase closure and amplitude closure, delay tracking (to the degree that it can be done in the ITF [(1)])
- Verify time and frequency reference functionality
- Verify gain and phase stability (to the degree that it can be done in the ITF [(1)])
- Verify gain flatness with frequency
- Perform bandpass calibration (to the degree that it can be done in the ITF - normally this is done on the sky with strong continuum point source calibrators)
- Verify correlator efficiency (to the degree that it can be done in the ITF)
- Verify simple beamforming
- Verify EMI requirements
- Exercise in advance the test procedures and testing scripts that will be used during AA tests

(1) Verification of delay tracking and delay and phase calibration will require suitable simulated input signals, and the generation of these input signals needs to be carefully planned.

The System ITF will also be used to integrate/test systems in preparation for AA2, AA3 and AA4, but the detailed configurations and requirements will be established during construction, in the AIV Planning process.

6.3 Capability of Array Assembly 0.5 and Array Assembly 1

Array Assembly 0.5 and Array Assembly 1 share many of the same characteristics and functionality and are therefore addressed at the same time in this document. The differences between the two are highlighted where necessary.

Array Assembly 0.5 is the first time that representative hardware/firmware/software is installed and integrated on-site to form an end-to-end functional radio telescope. It will be used to verify some engineering (Level-1) requirements, to the degree possible, even though the expected performance needs to be scaled appropriately.

For AA0.5 and AA1, SDP and CSP is installed in the existing MID-CPF (KAPB) and therefore no high capacity CPF to SPC link is required, however this link needs to be established during this time.

Table 3: Capability of Array Assembly 0.5 and Array Assembly 1.

	Capability of Array Assembly 0.5 and Array Assembly 1
Date	Refer to [AD11]
Number of Dishes	AA0.5: 4 AA1: 8
Baselines	All Dishes are located near the core within a 1 km radius (see Section 9)
Receiver Bands	AA0.5: • Band 1 and 2 on all SKA1-MID Dishes • *Goal to have Band 5 on all four Dishes using downconverters[10]*. AA1: • Band 1 and 2 on all SKA1-MID Dishes • Band 5 on all SKA1-MID Dishes using downconverters[10], *with a goal to have the SKA digitisers installed.*
Clock, Frequency and Time distribution	MeerKAT Maser. Frequency and time distribution. (Although a precision clock is not necessary for AA0.5 and AA 1 and a Rubidium clock could be used)

[10] The ability to observe in the higher frequency bands using a cooled receiver is highly desirable (for holography using geostationary satellites and accurate pointing/surface measurements on astronomical sources, respectively). At time of writing this was an ECP under consideration - ECP-210030 - Mitigations to Allow Band 5 Functionality at Early Array Releases (AA0.5 and AA1)

	Capability of Array Assembly 0.5 and Array Assembly 1
Correlator Size	AA0.5: 4 Dish Correlator AA1: 8 Dish Correlator
Channelization	16k channels per frequency slice, no channel averaging
Correlated Bandwidth	800 MHz
Pulsar Timing Beams (CBF)	AA0.5: • Single beam, as a goal. AA1: • 1 Beam (Boresight) • PST channelization • Bandwidth up to 800 MHz, commensally with Correlation • SDP will have basic real-time calibration available for AA1 which can provide calibration solutions for the Pulsar Timing Beams. However, meaningful tests can be conducted even if no calibration solutions are available. For example, a bright pulsar like Vela can be observed with a single Dish and used to test the channelizer used in the beam former and the pulsar timing engine.
Pulsar Timing Processing (PST)	AA0.5: • Single beam PST as a goal AA1: • Basic for 1 Beam • Bandwidth up to 200 MHz
Pulsar Search Beams (CBF)	No
Pulsar Search Processing (PSS)	No
Zoom Mode	No
Sub-Arraying	Yes. It is desirable to have sub-arraying functionality as early as possible.

	Capability of Array Assembly 0.5 and Array Assembly 1
Transient Buffer	No
VLBI	No
Operational Functionality	• Basic monitor and control for interferometric imaging and single tied-array beam • Basic health/alarm displays • Interfaces to Dish, CSP, Infrastructure, SDP, SAT, Networks (minimal functionality) • Pointing and delay models • Beam-forming (one beam; optional) • Simple scripting layer to allow sequencing of tests • Need ability to make and execute SB's, but not scheduler.

Commissioning signal displays need to be available. SDP will provide data for the required signal displays for AA0.5 and AA1 and TM (also located within the MID-CPF) will need to log and display sensor, control, and monitoring data.

The tests envisaged for AA0.5 are very similar to those planned for AA1 and documented in the Verification Plan for MID [RD5] and associated Test Procedures. For AA0.5, however, there is more of an emphasis on integration and testing than formal verification.

- Correlator products
    - Validate cross and autocorrelations
    - Start RFI characterisation and development of flagging heuristics
    - Search for spurious signals
- Basic interferometry
    - First fringes
    - Validate delay models
    - Check time and frequency reference stability
- Dish tests
    - Interferometric pointing
    - Holography (surface accuracy; beams and voltage patterns) in all available bands
    - Comparison with EM models
- Array calibrations
    - Antenna locations and cable delays
- Complex gain stability
    - Long tracks
    - Phase transfer between calibrators
    - Self-calibration and image dynamic range for simple target fields
    - Noise diode calibration
    - Flux density scale

    - Form boresight tied-array beam
- Other calibrations
    - Bandpass (ripple, stability)
    - Polarization leakage (on-axis Jones matrices)
- System sensitivity
    - Noise level on “blank” sky
- Preliminary imaging
    - Limited by the number of antennas available to “simple” fields
- Types of test observation
    - Basic execution of an observation (either through an SB or an observing script)
    - Pointed observations of bright, mostly unresolved calibrators
    - “Blank” sky
    - Scan patterns: star or raster for holography; cross or 5-point for pointing
- Verification testing
    - Verify hardware and software product interfaces
    - Verify reliability requirements by starting to perform stress tests of the system such as long acquisition runs, long schedule executions, long schedules with many different pointings, etc.
    - Verify safety procedures such as power-off, power-recovery, slew to stow position because of strong wind, etc.
    - Verify basic operator interface to control the system and to monitor system health
    - Verify the available functionality provided by NMGR, NSDN and SAT.LMC
    - Verify the available SAT.FRQ, SAT.UTC and SAT.CLOCKS management functionality provided by SAT.LMC via TM
    - Verify science data link performance between DSH and CSP over direct connection between DSH and CSP
    - Verify non-science data link performance between pedestal-located NSDN and MID-CPF-located NSDN
    - Verify non-science data connectivity between NSDN and all NSDN-connected equipment at all locations including pedestal, MID-CPF and the Operations Control Centre
    - Verify all NSDN carried services e.g. voice, desk-top data and BMS, at all locations
    - Verify time and frequency reference accuracy and stability using interim CLOCKS solution[11]
    - Verify channelisation performance
    - Verify frequency agility
    - Verify correlator efficiency
    - Verify EMI requirements
    - Verify configuration of the available components by the telescope/system

All of these tests are possible with AA0.5, and tied-array beamforming is a goal.

The Dish design should be qualified using cooled high-frequency receivers to reduce the risk in manufacture. Especially the very demanding pointing specification (particularly offset) would need to be qualified as early as possible, preferably with AA0.5.

[11] Although some of the PST timing performance accuracy can be verified with Array Assembly 1, the 10 ns accuracy to an absolute timing reference can only be verified with Array Assembly 2, when the CLOCKS hydrogen maser becomes available.

6.4 Capability of Array Assembly 2

The verification of engineering (Level-1) requirements reaches a new level with Array Assembly 2, since major new functionality becomes available. The operational interface is more advanced, and the maintenance support system should be deployed and functional.

As a consequence of ECP-200048 to move CSP equipment from the CPF (KAPB) to the SPC, from AA2, CSP and SDP equipment is located at the SPC location in Cape Town at AA2 and the high capacity CPF-SPC link is required.

Table 4: Capability of Array Assembly 2.

	Capability of Array Assembly 2
Date	Refer to [AD11]
Number of Dishes	64
Baselines	Most Dishes are located in the inner core, but some are located along a spiral arm, including the tip of the spiral arm, in order to provide a few long baselines (see Section 9).
Receiver Bands	• Band 1 and 2 on all SKA1-MID Dishes • Band 5 on 32 SKA1-MID Dishes
Clock, Frequency and Time distribution	Hydrogen Maser and precision frequency and timing distribution system The MeerKAT masers will be incorporated into the clock ensemble, provided by the SAT Contractor. It has been confirmed that the MeerKAT masers can be used without interrupting the MeerKAT Science Programme.
Correlator Size	64 Dish Correlator
Channelization	16k channels per frequency slice, no channel averaging
Correlated Bandwidth	4 x 200 MHz

	Capability of Array Assembly 2
Pulsar Timing Beams (CBF)	6 Beams (Steerable) Simple PST Jones Matrix boresight correction PST channelization Bandwidth up to 800 MHz, variable simultaneity with PSS-BF and Correlation
Pulsar Timing Processing (PST)	6 Beams Bandwidth up to 800 MHz
Pulsar Search Beams (CBF)	Up to 400 Beams (Steerable) PST-BF commensally with Correlation Full bandwidth per beam, Bands 1&2 only
Pulsar Search Processing (PSS)	16 Beams Not fully pipelined software, some TBD modules not yet operating in real time Full bandwidth per beam
Zoom Mode	Maybe
Sub-Arraying	Yes The sub-arraying functionality implies concurrent operation for both the imaging mode (Continuum and Spectral Line) and the non-imaging mode (Pulsar Timing and Pulsar Search beams). The sub-arraying functionality allows different modes across different sub-arrays, independent of commensal operation of modes in the same sub-array
Transient Buffer	No
VLBI	No

	Capability of Array Assembly 2
Operational Functionality	• Basic Operator Interface • Basic scheduling of observations • Sub-Arraying, i.e. the support of concurrent operations of subsets of the available array • Data Quality Assurance • Basic Maintainer Interface • High capacity CPF to SPC network link required

The engineering verification effort will focus on the verification of:

- **Imaging Functionality**(*)
    - Continuum Imaging
    - Spectral Line Imaging
- **Non-Imaging Functionality**
    - Pulsar Timing (6 Beams)
    - Pulsar Search (16 Beams)
    - IQUV imaging over the full primary beam
    - RFI detection/flagging/excision

Verification tests would include the verification of:

- Continuum sensitivity
- Spectral line sensitivity
- Imaging dynamic range
- Real-time calibration pipeline processing
- Quality assessment pipeline
- Channelization, possibly with zoom mode performance
- Verify time and frequency reference accuracy and stability using final CLOCKS solution
- Pulsar Timing performance
- Pulsar Search performance
- Time and Frequency accuracy for Pulsar Timing
- Absolute Timing relative to UTC
- EMI requirements
- Polarisation calibration
- Imaging and non-imaging calibration
- Regression tests
- Verify hardware and software product interfaces
- As per AA0.5 and AA1, stress tests and safety procedures will be exercised continuously
- CPF to SPC data link between the MID-CPF and the Science Processing Centre located in Cape Town

(*) The SDP Operational System's imaging functionality might not be verified using AA2. (Note: The current development of the Data Processing Agile Release Train is moving in the direction of having a basic pipeline available earlier.) However, the SDP Commissioning and AIV Support System will allow verification of imaging functionality of the rest of the telescope. Data captured using AA2 could potentially be used in the Software Solution Test Environment to verify the SDP Operational System's imaging functionality, but this activity would be independent of the AA2 activities described here.

6.5 Capability of Array Assembly 3

The key engineering verification objectives are largely the same as for Array Assembly 2, but also incorporate the increased number (and size) of baselines, the increased number of Pulsar Search beams, and additional major new functionality.

Array Assembly 3 is also the first time that MeerKAT Precursor Dishes are integrated into the SKA1-MID array. The engineering verification effort therefore also focuses on the verification of the functionality and performance of these MeerKAT Precursor Dishes.

SDP and CSP is installed in the new MID SPC in Cape Town (ECP-200048), and the high capacity CPF to SPC network link is required.

Table 5: Capability of Array Assembly 3.

	Capability of Array Assembly 3
Date	Refer to [AD11]
Number of Dishes	121, of which 4 are MeerKAT Dishes
Baselines	Dishes are located in all three spiral arms (see Section 9)
Receiver Bands	• Band 1 and 2 on all SKA1-MID Dishes • Band 5 on 64 SKA1-MID Dishes • Band 1 and 2 on 8 MeerKAT Dishes
Clock, Frequency and Time distribution	Hydrogen Maser and precision frequency and timing distribution system
Correlator Size	128 Dish Correlator
Channelization	Standard channelization (~64k channels)
Correlated Bandwidth	Full bandwidth for all Bands 1, 2 and 5

	Capability of Array Assembly 3
Pulsar Timing Beams (CBF)	16 Beams (Steerable) Simple PST Jones Matrix boresight correction PST channelization Up to full bandwidth, variable simultaneity with PSS-BF and Correlation
Pulsar Timing Processing (PST)	16 Beams Full bandwidth for all Bands
Pulsar Search Beams (CBF)	Up to 1500 Beams (Steerable) Variable simultaneity with PST-BF and Correlation Full bandwidth per beam All Bands
Pulsar Search Processing (PSS)	128 Beams Not fully pipelined software, some TBD modules not yet operating in real time Full Bandwidth per Beam
Zoom Mode	Bands 1, 2 and 5
Sub-Arraying	Yes
Transient Buffer	No
VLBI	No
Operational Functionality	• Full Operator Interface • Full Maintainer Interface • SDP (located in the MID SPC) functionality to perform real-time calibration and basic imaging workloads, scaled to array size • High capacity CPF to SPC network link

In addition to the verification effort described for Array Assembly 2, the engineering verification effort will focus on the verification of:

- Basic imaging functionality of the SDP Operational System
- Non-Imaging Functionality
    - Pulsar Search (128 Beams)
- MeerKAT integration activities
- CPF to SPC data link between the MID-CPF and the Science Processing Centre located in Cape Town

6.6 Capability of Array Assembly 4

Array Assembly 4 is the final Array Assembly. All functionality from all products is included with this Array Assembly, as well as the incorporation of all MeerKAT Precursor Dishes. This Array Assembly therefore marks the final verification (to the degree possible) of all Level-1 Requirements and the commissioning of the full array for all science areas.

Table 6: Capability of Array Assembly 4.

	Capability of Array Assembly 4
Date	Refer to [AD11]
Number of Dishes	197 of which 64 are MeerKAT Dishes and 16 are MK+ Dishes
Baselines	The entire SKA1-MID Dish configuration is populated with Dishes, including all of the MeerKAT Dishes
Receiver Bands	• Band 1, 2 and 5 on all SKA1-MID Dishes • Band 1 and 2 on 64 MeerKAT Dishes
Clock, Frequency and Time distribution	Hydrogen Maser and precision frequency and timing distribution system
Correlator Size	197 Dish Correlator
Channelization	Standard channelization (~64k channels)
Correlated Bandwidth	Full bandwidth for all Bands
Pulsar Timing Beams (CBF)	16 Beams (Steerable) Per-antenna and per-beam PST Jones Matrix correction PST channelization Up to full bandwidth, variable simultaneity with PSS-BF and Correlation

	Capability of Array Assembly 4
Pulsar Timing Processing (PST)	16 Beams Full bandwidth for all Bands
Pulsar Search Beams (CBF)	Up to 1500 Beams (Steerable) Variable simultaneity with PST-BF and Correlation Full bandwidth per beam Bands 1&2 only
Pulsar Search Processing (PSS)	1500 Beams Fully pipelined software, real-time operation Full bandwidth per Beam
Zoom Mode	Band 1, 2 and 5
Sub-Arraying	Yes
Transient Buffer	Yes
VLBI	Yes (4 Beams)
Operational Functionality	• Full Operator Interface • Full Maintainer Interface • Full SDP functionality

In addition to the verification effort described for Array Assembly 3, the engineering verification effort will focus on the verification of:

- **Non-Imaging Functionality**
    - Pulsar Search (1500 Beams)
    - Transient buffer
    - VLBI (4 Beams)

7 SKA1-MID Observing Modes

Level-1 Requirement SKA1-SYS_REQ-3547 (see [AD1]) states that the SKA1-MID Telescope, when commanded, shall operate simultaneously with any combination of the following observing modes:

- Imaging
- Pulsar Search
- Pulsar Timing
- Dynamic Spectrum
- Transient Search
- VLBI

Simultaneous observation across the telescope is achieved through the use of subarrays.

The availability and functionality of these observing modes will ramp-up during construction, as described in Section 6. For every Array Assembly, the purpose of the integration & verification activities (see [RD5]) is to arrive at an integrated end-to-end Telescope System whose key engineering objectives have been achieved. At the highest level, these engineering objectives are the availability of telescope observing modes, which are summarised in Table 7.

Table 7: SKA1-MID Observing Modes.

	# Dishes	Frequency Bands	Imaging	Pulsar Timing	Dynamic Spectrum	Pulsar Search	Transient Capture	VLBI
AA0.5	4	Band 1 Band 2 Band 5: goal on 4 Dishes, but may not be supported by correlator	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth	? • Goal, single beam				
AA1	8	Band 1 Band 2 Band 5: on 2 Dishes, goal on 4	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth	✓ • Basic • 1 boresight non-steerable beam • 400 MHz bandwidth				
AA2	64	Band 1 Band 2 Band 5: on 32 Dishes	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth	✓ • 6 steerable beams • With de-dispersion • 800 MHz bandwidth		✓ • 16 steerable beams • Not fully pipelined • Non-real time operation • Full bandwidth		
AA3	121 Includes 8 MeerKAT Dishes	Band 1 Band 2 Band 5: on 64 Dishes	✓ • Continuum and Spectral Line imaging pipelines • 64k channels • Zoom mode • 5200 MHz bandwidth	✔ • 16 steerable beams • With de-dispersion • Full bandwidth	? • Maybe	✓ • 128 steerable beams • Not fully pipelined • Non-real time operation • Full bandwidth	? • Maybe	

✓ Functionality is partially implemented

✔ Functionality is fully implemented

? Not sure if functionality will be implemented

AA4	197 Includes all MeerKAT Dishes	Band 1 Band 2 Band 5	✓ • Full Continuum and Spectral Line imaging pipelines • 64k channels • Zoom mode • Full bandwidth	✓ • 16 steerable beams • With de-dispersion • Full bandwidth	✓ • Supported by PST	✓ • 1500 steerable beams • Fully pipelined • Real time operation • Full bandwidth	✓	✓ • 4 beams

8 Required Roll-Out of Element Functionality

8.1 Introduction

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

1. Integration Test Facility
2. Array Assembly 0.5
3. Array Assembly 1
4. Array Assembly 2
5. Array Assembly 3
6. Array Assembly 4

These high-level milestones form the basis for Design Consortia to plan their product-level construction roll-out and associated costs. Element and sub-Element construction plans should align with this roll-out plan and the SKAO master construction schedule. The dates for these high-level milestones are contained in [AD11].

This chapter describes the required roll-out of Element functionality to support these high-level milestones. This functionality is linked to the Array Assembly capabilities (including the capability of the System ITF) described in the previous chapter.

To further describe the required functionality of each Element at each roll-out milestone; the system-level functions for SKA1-MID have been mapped to these high-level milestones in [RD1]. All Design Consortia therefore have a much clearer description of the functionality that their respective products need to provide at each roll-out milestone.

8.2 MID Infrastructure required functionality for major Roll-Out Milestones

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

SKAO needs to stay abreast of the planned roll-out of Dishes, which is summarised in Section 5. The sequence in which the Dishes will be rolled out is described in Section 9.

There is currently an open ECP to incorporate a centralised PV Plant on site. If approved, the delivery of this centralised PV Plant needs to be coordinated with the establishment of the Array Assemblies.

Table 8: MID Infrastructure required functionality for major Roll-Out Milestones.

	Required Functionality for MID Infrastructure
System ITF	No input required
AA 0.5 and AA 1	Each Dish requires the following infrastructure: • A foundation to support each Dish under the precision, degraded and survival load conditions • Sufficient power • Access road and platform to each Dish location to handle and accommodate all the vehicles In addition to the infrastructure required for each Dish, the following requirements apply: • Sufficient racks, power and cooling for equipment available in MID-CPF • Fully functional communication and emergency communication systems • Construction camp to accommodate the required number of people • Functional water and sanitation infrastructure • One weather station working, close to the centre of the array • RFI Monitoring station
AA 2	In addition to the infrastructure required for each Dish, the following requirements apply: • Weather Stations, STI System, RFI Monitor and BMS to be fully functional • Buildings to be fully functional • All the security features to be fully functional • The power and cooling infrastructure and the local PV power systems for AA2 Dishes on the spiral arms to be fully functional

	Required Functionality for MID Infrastructure
AA 3	In addition to the infrastructure required for each Dish, the following requirements apply: • Full site monitoring in place • Full security in place • Full racks, power and cooling for equipment available in MID-CPF • The power infrastructure and the local PV power systems for AA3 and AA4 Dishes on the spiral arms to be fully functional
AA 4	All infrastructure work is already completed

8.3 DISH required functionality for major Roll-Out Milestones

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

The roll-out of SKA1-MID Dishes has already been shown in Figure 8 on page 33. The required roll-out of Receiver Bands is shown in Table 9.

Table 9: DISH Roll-Out of Receiver Bands.

	Band 1	Band 2	Band 5
System ITF	-	4 x SPFRx including Sampler (Digitiser) and Pedestal Unit (Packetiser)	-
1st Dish	-	Yes	-
AA 0.5	Yes	Yes	*Goal of 4 Dishes with downconverters*
AA 1	Yes	Yes	8 Dishes with downconverters, *and goal of SKA digitisers.*
AA 2	Yes	Yes	On 32 Dishes
AA 3	Yes	Yes	On 64 Dishes
AA 4	Yes	Yes	Yes

Note that four Band 2 SPFRx (Digitiser and Packetiser) are required for delivery to the System ITF. Four Dish LMC, Dish Structure Controller/Simulators and Feed Package Controller/Simulators are also required for the System ITF, in order to test the interface to TM and pointing commands from TM.

In addition, equipment delivered for the first time to later AA's (such as the Band 5 SPFRx) should also first be delivered to the ITF for testing before being integrated on site.

8.4 Networks required functionality for major Roll-Out Milestones

The SADT Construction Plan, [RD32], contains more detail with regard to the roll-out of the network functionality and should be aligned with this high-level Telescope Roll-Out Plan.

The functional allocation to roll-out milestones for the fibre network is provided in [RD1]. The support required from the fibre (infrastructure) network for the System ITF is described in Section 6.2 and in Figure 9. The roll-out of all Dish-related fibre network products is driven by the planned roll-out of Dishes, which is summarised in Figure 8 on page 33, and the sequence in which the Dishes are rolled out is described in Section 9.

The functional requirements for the networks depend on the following construction activities:

- **Infrastructure:**
    - Fibre laid to each Dish foundation from the KAPB building. The interface is with DISH for the fibre connection and Mid Infrastructure for threading the fibre though the foundation in a duct. (Interface to MID Infrastructure and interface between fibre network and DISH.)
- **At each Dish pedestal:**
    - DDBH transceivers/network equipment installed, for fibre distances > 10km (interface to DISH, fibre infrastructure, NSDN)
    - NSDN equipment installed (interface to Dish (M&C), Infrastructure, SAT, DDBH, CCTV & Weather stations)
- **At the KAPB building:**
    - DDBH transceivers/network equipment installed (interface to CSP Infrastructure, NSDN)
    - NSDN equipment installed (TM, Infrastructure, SAT, CSP)
    - NMGR equipment and software installed (interfaced to TM, Infrastructure, NSDN, DDBH, CPF -SPC)
    - CPF-SPC link equipment (interfaced to Infrastructure)
- **At the SPC building:**
    - NSDN equipment installed (CSP and SDP)
    - CPF-SPC link equipment (interfaced to Infrastructure)
- **Local PV Systems:**
    - NSDN equipment installed (interfaced to Infrastructure, BMS devices)
- **Repeater Shelters:**
    - DDBH Equipment Installed (interfaced to infrastructure, NSDN)
    - NSDN equipment installed (interfaced to Infrastructure, SAT, DDBH, CCTV & Weather Stations BMS devices)

Before the commencement of Array Assembly 0.5 the following should be noted:

- There is no TM on site, which means the NSDN network, or anything connected to it cannot interface to any TM products.

Prior to AA2 CSP and SDP equipment will be located in the MID-CPF (KAPB).As a consequence of ECP-200048 to move CSP equipment from the CPF (KAPB) to the SPC, CSP and SDP equipment will be located in the SPC from AA2. The CPF to SPC link will require increasing capacity as shown in Table 10.

Table 10 summarises the “step-change” functionality that is required for each of the major roll-out milestones.

Table 10: Fibre Network required functionality for major Roll-Out Milestones.

	Required Functionality for Networks
System ITF	• NSDN connecting all equipment to TM and LMCs for DISH, CSP, SAT and SDP • Network management (NMGR) for NSDN equipment installed (TBC) • Remote access: Operator control and monitoring to TM, access to displays, access to SDP stored data, internet connection. Since DDBH and CPF-SPC network equipment is not required at the System ITF, the consequence is that not all of NMGR functionality will be tested.
AA 0.5	Same as for AA1 in the row below, except that the requirement is for only four Dishes. Furthermore, the SKA NSDN network and NMGR server might not be completely installed, i.e. the MeerKAT network might be the only network in place. So there might need to be a shared or hybrid model in place, also for the purpose of safety and health monitoring, whereby the MeerKAT network is used temporarily.
AA 1	All SDP and CSP hardware will be installed inside the KAPB building for AA1. **At the KAPB building:** • NSDN equipment connecting all equipment to TM, NMGR and LMCs for 8 x DISH, CSP, SAT and SDP • Network management (NMGR) server and software for NSDN equipment installed • Temporary on-site CSP-SDP connection installed, 0.024Tb/s TBC (interface to SDP in MID-CPF) **Remote access to Site (from Cape Town and beyond):** • Establish the CSP-SPC link. (Note that the CSP and SDP equipment for AA1 is within the MID-CPF building) Operator control and monitoring to TM from Operations Control Centre in Cape Town. (Since the SOC will not be ready, the MeerKAT Operations Control Centre might be used, but this has not been confirmed.) • Access to displays • Access to SDP data products • Internet connection
AA 2	**Continue roll-out as for AA1, and in addition:** • DDBH equipment for links > 10km • DDBH to one or more Dishes at spiral arm extremities • Repeater shelters (Inner and Outer) built and operational, to amplify, regenerate, distribute and aggregate DDBH/NSDN signals to the spiral arm Dishes. But only to the extent needed for AA2 Dishes. • Network management (NMGR) for NSDN and DDBH equipment installed

	Required Functionality for Networks
	At least one long baseline is required along one spiral arm (see Section 9). As a consequence of ECP-200048 to move CSP equipment from the CPF (KAPB) to the SPC, from AA2, CSP and SDP equipment is located at the SPC location in Cape Town at AA2 and the high capacity CPF-SPC link is required. **CPF-SPC Link (Site to Cape Town)** CPF-SPC data transport requirements: 2 Tb/s (TBC).
AA 3	**Continue roll-out and in addition:** **Infrastructure:** • Fibre link to SDP procured • SDP is in the MID Science Processing Centre **CPF-SPC Link (Site to Cape Town)** • Since all SDP hardware and CSP hardware (ECP-200048) for AA3 will be installed in the Science Processing Centre (SPC) in Cape Town, the high capacity CPF-SPC link is required. • CPF-SPC data transport requirements: 7 Tb/s, TBC • Network management (NMGR) for CPF-SPC equipment installed
AA 4	All network work is completed. CPF-SPC data transport requirements: 10 Tb/s (TBC). Refer to [RD31].

8.5 SAT required functionality for major Roll-Out Milestones

The SADT Construction Plan, [RD32], contains more detail with regard to the roll-out of the SAT functionality and should be aligned with this high-level Telescope Roll-Out Plan.

The functional allocation to roll-out milestones for SAT is provided in [RD1]. The support required from SAT for the System ITF is described in Section 6.2 and in Figure 9. The roll-out of all Dish-related SAT products is driven by the planned roll-out of Dishes, which is summarised in Figure 8 on page 33, and the sequence in which the Dishes are rolled out is described in Section 9.

The functional requirements for SAT depend on the following construction activities:

- **At each Dish:**
    - SAT.STFR FRQ and UTC equipment installed (interface to DISH SPFRx)
- **At the KAPB building:**
    - SAT.STFR.UTC and SAT.STFR.FRQ equipment installed
    - SAT.LMC equipment and software installed.
    - Clock equipment installed and connected to SAT.STFR.FRQ Distribution and SAT.STFR.UTC Distribution
    - Clock software installed
- **Repeater Shelters:**
    - SAT.STFR.UTC and SAT.STFR.FRQ equipment installed (TBD)

Before the commencement of Array Assembly 0.5 the following should be noted:

- The Dish Contractor will verify Dishes with the Dish Verification System. Time and frequency will be obtained from the MeerKAT array. There is no need for SAT to provide any products on-site until AA0.5.

Table 11: SAT required functionality for major Roll-Out Milestones.

	Required Functionality for SAT
System ITF	• SAT.CLOCKS: non-precision time and frequency reference connected to GPS, for example GPS Rubidium clock • SAT.STFR.FRQ distribution and SAT.STFR.UTC distribution to 4 SPF Receivers The full functionality of SAT.LMC and CLOCKS will not be tested.
AA 0.5	Same as for AA1 in the row below, except that the requirement is for only four Dishes.
AA 1	**At the KAPB building:** • Temporary SAT.CLOCK installed and connected to SAT.STFR. There is no necessity for a high-accuracy clock at this stage, but the distributed clock signal must be coherent. The intention is to use the MeerKAT Masers for providing the clock signal. A temporary Rubidium clock could also be used.

	Required Functionality for SAT
	• STFR.FRQ and STFR.UTC equipment • SAT.LMC server and software
AA 2	**Continue roll-out as for AA1, and in addition:** • SAT.STFR.FRQ and SAT.STFR.UTC to one or more Dishes at spiral arm extremities • Install clock ensemble (H Masers) and connect to SAT.STFR.FRQ and SAT.STFR.UTC system (implied by requirement for Pulsar Timing) • Repeater shelters (Inner and Outer) built and operational, to amplify, regenerate, distribute and aggregate UTC/FRQ signals to the spiral arm Dishes. But only to the extent needed for AA2 Dishes.
AA 3	**Continue roll-out and in addition:** • Incorporation of MeerKAT Masers (TBC), monitor & control network.
AA 4	All SAT work is completed.

8.6 CSP required functionality for major Roll-Out Milestones

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

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

The roll-out of major CSP functionality needs to be aligned with the FPGA development effort that is required to achieve such functionality. After providing the basic imaging and beamformer functionality, the main development areas are:

- Band 5
- PST
- PSS
- Zoom Mode
- Transient Buffer
- VLBI

The first correlator deployed at the System ITF will be equal to the correlator for AA0.5. Prior to AA2, the correlator at the System ITF will need to be updated from the TDC architecture (AA0.5 and AA1) to the full Mid.CBF architecture, in order to verify FW and SW for AA2, AA3 and AA4 prior to it being deployed on-site. This will be a substantially larger system than the TDC systems, since a full Frequency Slice Processor is required to run the representative firmware and software.

ECP-200048 moves CSP equipment, including CBF, PST and PSS from the CPF (KAPB) to the SPC, from AA2. AA0.5 and AA1 CSP equipment will be located in the KAPB CPF.

Table 12: CSP required functionality for major Roll-Out Milestones.

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Number of CBF Racks	1 (specialised-A) (1)	1 (specialised-A) (1)	1 (specialised-B) (1)	7 + 1 M&C	26 + 1 M&C	27 + 1 M&C
CBF Size (Number of Dishes)	4 Dish	4 Dish	8 Dish	64 Dish (required) 70 Dish (provided)	128 Dish (required) 130 Dish (provided)	197 Dish
Inclusion of MeerKAT Dishes	Agnostic (2)	Agnostic (2)	Agnostic (2)	Agnostic (2)	Agnostic (2)	Agnostic (2)
Release Maturity	Pre-Production	Pre-Production	Pre-Production	Production (3)	Production	Production
Band 1 and 2	Yes	Yes	Yes	Yes	Yes	Yes
Band 5	No	No Goal to support four Band 5 Receivers	Partially (4) Band 5 data re-sampled to B1/B2 by the Band 5 Digitiser before it enters CSP, and then processed as B1/B2 data	Yes	Yes	Yes

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Channelization	16k channels per frequency slice no channel averaging	16k channels per frequency slice no channel averaging	16k channels per frequency slice no channel averaging	16k channels per frequency slice no channel averaging	Standard channelization ~64k channels	Standard channelization ~64k channels
Correlated Bandwidth	800 MHz (No distinct FSPs) (5)	800 MHz (No distinct FSPs) (5)	800 MHz (No distinct FSPs) (5)	4 x 200 MHz (4 FSPs total; rack space for 7)	26 x 200 MHz (26 FSPs total)	Full capability (26+1 FSPs total)
Pulsar Timing Beams (CBF)	No (Goal to have AA1 PST beamforming)	No (Goal to have AA1 PST beamforming)	1 Beam (Boresight) PST channelization Bandwidth up to 800 MHz, fully commensal with Correlation (No distinct FSPs) (5)	6 Beams (Steerable) Simple PST Jones Matrix boresight correction PST channelization Bandwidth up to 800 MHz, variable simultaneity with PSS-BF and Correlation (4 FSPs total)	16 Beams (Steerable) Simple PST Jones Matrix boresight correction PST channelization Up to full bandwidth, variable simultaneity with PSS-BF and Correlation (13 FSPs total)	16 Beams (Steerable) Per-antenna and per-beam PST Jones Matrix correction PST channelization Up to full bandwidth, variable simultaneity with PSS-BF and Correlation (26+1 FSPs total)

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Number of PST Racks (TBC)	0	0	1	2	2	2
Pulsar Timing Processing (PST)	No	No (Goal to have AA1 PST beamforming)	Basic for 1 Beam Bandwidth up to 400 MHz	6 Beams Bandwidth up to 800 MHz De-dispersion processing	16 Beams Full bandwidth for all Bands	16 Beams Full bandwidth for all Bands
Pulsar Search Beams (CBF)	No	No	No	Up to 384 steerable Beams; variable simultaneity with PST-BF and Correlation Full bandwidth per beam Bands 1&2 only	Up to 1500 steerable Beams; variable simultaneity with PST-BF and Correlation Full bandwidth per beam All Bands	Up to 1500 steerable Beams; variable simultaneity with PST-BF and Correlation Full bandwidth per beam All Bands
Number of PSS Racks (TBC)	0	0	0	1	3	33

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Pulsar Search Processing (PSS)	No	No	No	16 Beams Not fully pipelined software, some TBD modules not yet operating in real time Full bandwidth per beam	128 Beams Not fully pipelined software, some TBD modules not yet operating in real time Full Bandwidth per beam	1500 Beams Fully pipelined software, real-time operation Full bandwidth per beam
Zoom Mode	No	No	No	Maybe	Yes	Yes
RFI detection	No	No	No	Simple power threshold flagging	Simple power threshold flagging	More sophisticated RFI mitigation
Sub-Arraying	Yes (6)	Yes (6)	Yes (6)	Yes (6)	Yes (6)	Yes (6)
Transient Buffer	No	No	No	No	Maybe (Yes, if necessary)	Yes
VLBI	No	No	No	No	No	Yes

	System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Control and monitoring interface	Basic operator control, basic health monitoring	Basic operator control, basic health monitoring	Basic operator control, basic health monitoring	Basic operator control, basic health monitoring	Full operator and maintainer interface	Full operator and maintainer interface

(1) Special rack, not part of the final system. This rack is not disturbed during AA2 installation. The rack for AA1 is the same as the rack for the ITF, but it includes VCCs (Very Coarse Channelizers) for 8-Dish capability.

(2) After MeerKAT has been integrated into SKA1-MID, i.e. after SKA1-MID Digitisers have been installed on the MeerKAT Dishes, the data coming from MeerKAT Dishes is indistinguishable from data coming from SKA1-MID Dishes.

(3) There might not be enough time between AA1 and AA2 to verify on-the-sky before triggering full production buy. This means that there is a risk that there could be an issue found on the sky that cannot be solved within the production hardware. Primarily this risk is "does the purchased FPGA have enough logic to solve some low-level issue that is showing an unacceptable systematic bias found on the sky". However, this risk is largely mitigated by getting on the sky earlier with AA0.5 and the progress made on the TALON hardware during bridging.

(4) The assumption is that digitizer firmware can be modified to provide data from the Band 5 ADCs into the Band 1/2 data stream to Mid.CBF so that Mid.CBF Band 5 specific processing firmware is not required. It is also assumed that the Dishes are adequately qualified with cooled high-frequency receivers at an earlier stage. The very demanding pointing specification (particularly offset) needs to be qualified with cooled high-frequency receivers as early as possible.

(5) The TDC architecture used for AA0.5 and AA1 does not have specific hardware allocated to re-configurable Frequency Slice Processors. Instead, there is a single FPGA design that performs VCC processing for one receptor plus correlation and PST beamforming for a portion of the bandwidth.

(6) The sub-arraying functionality implies concurrent operation for both the imaging mode (Continuum and Spectral Line) and the non-imaging mode (Pulsar Timing and Pulsar Search beams), to within the expected limitations of FSP resources.

Definition of terms:

- VCC (Very Coarse Channelizer) is generally the part of the Frequency Slice Architecture that does Dish-based, Band-dependent processing, but also includes Pulsar Search Window selection and channelization.
- FSP (Frequency Slice Processor). Each FSP performs one of (imaging) Correlation, PST beamforming, PSS beamforming, or VLBI. For Correlation, PST and VLBI, operates on a ~200 MHz slice of bandwidth, from any Band. See ECP-170017 support document T1-SUP-0045 for more information.

8.7 OMC required functionality for major Roll-Out Milestones

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

OMC 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.

The functional allocation to roll-out milestones needs to be consistent with the expected Array Assembly Capabilities, as described in Section 0.

Table 13: OMC required functionality for major Roll-Out Milestones.

	Required Functionality for OMC
System ITF	**LOW (provided for completeness)** • Configure LFAA for Observation • Calculate Local Pointing (coordinate conversion) • Send Pointing Commands (LFAA) **MID** • Configure Dish • Calculate Local Pointing (coordinate conversion, azimuth wrap) • Send Pointing Commands (DSH) • Stow DSH (manual, wind) **COMMON** • Configure CSP for observations (limited modes) • Configure SDP for observations (limited modes) • Monitor Element Characteristics (attributes, alarm triggers) • Control Element Lifecycle (Start-up or Shutdown state, Operational State) • Synchronise with Telescope Network Time • Calculate Delays • Report OMC 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 OMC control) • Command Telescope (Manually, via Scripts) • Prepare and execute simple scheduling blocks • Manage Calibration 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 0.5	Essentially, the same functionality as for AA1 below. Except for: • Execute raster scan for holography • Execute pointing cross-scan • Reference pointing, including band-dependent offsets.
AA 1	**LOW (provided for completeness)** • Configure LFAA for Observation • Calculate Local Pointing (coordinate conversion) • Send Pointing Commands (LFAA) **MID** • Configure Dish • Calculate Local Pointing (coordinate conversion, azimuth wrap) • Send Pointing Commands (DSH) • Control Tied Array Beam Pointing (restricted to boresight) • Stow DSH (manual, wind) **COMMON** • Configure CSP for observations (limited modes) • Configure SDP for observations (limited modes) • Monitor Element Characteristics (attributes, alarm triggers) • Control Element Lifecycle (Start-up or Shutdown state, Operational State) • Synchronise with Telescope Network Time • Calculate Delays • Report OMC 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 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	**MID – Integration of a single MeerKAT Dish into SKA1-MID** • Receive data from MeerKAT LMC • Configure MeerKAT Dish • Send MeerKAT Pointing Commands • Manual and Wind Stow MeerKAT Dish **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 o Definition, o Configuration, o Failure Handling, o Status Monitoring, o Control Authority, o Management with CSP, o Concurrent processing on Sub-Array (Limited Modes) • Interpret Instructions from SB Script into Telescope Commands • Execute Scheduling Blocks • Run Observation Schedules o Create a Schedule of SBs, o Maintain Schedule, o Manage Concurrent Execution of SBs • Persist TMO Data (Initial) • Simulate Scheduling Block Execution • Control Element Lifecycle (Switch on, Shutdown Signal Events) • Receive and Persist Ionospheric Activity • Pointing Corrections (Refraction) • GUI Display o Environmental Information, o Schedule, o QA Metrics, o Sub-Arrays, o Alarms, o Health, o 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	**MID – Integration of remaining MeerKAT Dishes into SKA1-MID** • Receive data from MeerKAT LMC • Configure MeerKAT Dish • Send MeerKAT Pointing Commands • Manual and Wind Stow MeerKAT Dishes **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	**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

8.8 SDH&P required functionality for major Roll-Out Milestones

The functional allocation to roll-out milestones for SDH&P is provided in [RD1].

SDH&P 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 SDH&P's processing performance can only occur in the Software Test Environment, since full-scale SDH&P hardware is only available for AA4, by which time the verification of processing performance needs to be complete.

In order to deliver maximum value as early as possible using the SAFe framework, maximum agility is required during the construction of SDH&P software. To achieve maximum agility, only critical functionality required by other products need to be specified for SDH&P.

Table 14: SDH&P required functionality for major Roll-Out Milestones.

	Required Functionality for SDH&P
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 0.5, so that the interfaces between back-end products that are required for Array Assembly 0.5 can be fully verified in the ITF. Certain external interfaces: • Basic TM monitoring & control interface (Tango) • CSP visibility interface (SPEAD) Functionality supported at AA0.5 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 existing (3rd party) tools(*) • 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 (e.g. CASA) allows the use of a wide range of qualified (on other telescopes) functionality during integration and commissioning.

	Required Functionality for SDH&P
	Milli-SDP hardware deployment at ITF. The required functionality is provided by the SDP Commissioning and AIV Support software[12].
AA 0.5	The functionality is essentially the same as for AA1, except for: • Using data from bright point source observations to determine antenna complex gain corrections for pulsar beam forming, is a goal • Basic real-time calibration is a goal • basic time series analysis

AA 1	SDH&P provides complete commissioning and ITF/AIV support functionality including functionality required to support AA2.
	
	Certain external interfaces:
	• Basic TM monitoring & control interface (Tango)
	• CSP visibility interface (SPEAD)
	
	Functionality supported at AA1 and AA2 scale:
	• Visibility Data Ingest (receive & pre-processing)
	• Generate Ingest QA metric data
	• Basic automated or semi-automated procedures for:
	  ○ Using data from a 5-point scan to determine antenna pointing corrections.
	  ○ Using data from bright point source observations to determine antenna complex gain corrections for pulsar beam forming.
	• Basic real-time calibration
	• Store data on disk in suitable format (i.e. MS) for processing with existing (3rd party) tools[(*)]
	• Process data with existing (3rd party) tools for:
	  ○ commissioning signal displays
	  ○ basic imaging
	  ○ basic time series analysis
	• Additional SDP pipeline capability for calibration, imaging and pulsar data processing will be developed and tested in the SAFe framework at AA1.
	
	[(*)] Note: The ability to process visibility data with existing 3rd party tools (e.g. CASA) allows the use of a wide range of qualified (on other telescopes) functionality during integration and commissioning.
	
	Milli-SDP hardware deployment in CPF (KAPB). The required functionality is provided by the SDP Commissioning and AIV Support software.

[12] The architecture of the SDH&P has been developed so that variants of the SDH&P system, or new systems using SDH&P components, can be constructed. The Commissioning and AIV Support software is a product variant of SDH&P software built with a combination of SDH&P 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.

	Required Functionality for SDH&P
AA 2	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. As a consequence of ECP-200048 to move CSP equipment from the CPF (KAPB) to the SPC, from AA2, CSP and SDP equipment is located at the SPC location in Cape Town at AA2. The SDP Commissioning and AIV Support software and Milli-SDP hardware will remain on site for AA2, AA3 and AA4 to continue to provide integration and commissioning support for the telescope hardware. Support the integration of the 1st MeerKAT Dish into SKA1-MID, by supporting the data processing of a heterogeneous array, for example the processing of heterogeneous beams.
AA 3	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 AA3 scale. This functionality is provided by the SDP Operational System and will be deployed (hardware and software) at the Science Processing Centre in Cape Town. Support the integration of the remaining MeerKAT Dishes into SKA1-MID.
AA 4	The first operational deployment of the SDP Operational System. This deployment will provide full SDH&P hardware and software functionality and performance. The SDP Operational System will be deployed at the Science Processing Centre in Cape Town.

8.9 AIV required functionality for major Roll-Out Milestones

Table 15: AIV required functionality for major Roll-Out Releases.

	Required Functionality for AIV
System ITF	Scripts for running basic interferometry tests and analysing data from the ITF Qualification System.
AA 0.5 and AA 1	Specific scripts required for running the basic interferometry and other planned tests, and analysing data.
AA 2	Scripts for running tests and analysing data from AA 2.
AA 3	Scripts for running tests and analysing data from AA 3. All MeerKAT Precursor LMCs that interface to TM are written and tested. All MeerKAT Precursor interfaces to SaDT are tested. All MeerKAT Precursor interfaces to DISH are tested. All MeerKAT Precursor interfaces to MID Infrastructure are tested.
AA 4	Scripts for running tests and analysing data from AA 4. MeerKAT Precursor integration procedure finalised.

9 Array Configuration Roll-Out

9.1 Introduction

The array configuration and Dish numbering for the entire SKA1-MID Telescope is given in the following document: SKA1_MID Physical Configuration Coordinates, [AD10].

The strategy for deciding on the sequence in which Dishes will be constructed is based on the following considerations:

- Verification and commissioning requirements
- Minimisation of costs
- Infrastructure constraints, including the roll-out of PV stations
- MeerKAT Extension

Based on these considerations, the roll-out of SKA1-MID Dishes should effectively occur in seven batches. These batches are summarised in Table 16 and described in more detail in the subsections that follow. The Dish roll-out and exact Dishes which form part of a batch are listed in Table 16 and Table 17.

Figure 10: An overview of the MeerKAT radio telescope currently operating in the Karoo in the Northern Cape, South Africa (http://www.ska.ac.za).

Table 16: Roll-out of Dishes.

		System ITF	AA 0.5	AA 1	AA 2	AA 3	AA 4
Full Delivery	Number of SKA1 Dishes	-	4	8	64	117	117
	Number of MK+ dishes		0	0	0	0	16
	Number of MK Dishes	-	0	0	0(2)	4(2)	64
	Total number of Dishes		**4**	**8**	**64**	**121**(1)	**197**

(1) 117 SKA1-MID Dishes (since 16 SKA1-MID Dishes are incorporated into MeerKAT Extension) plus 4 MeerKAT Precursor Dishes. It was 8 but has been changed to 4 by ECP-210019.

(2) The first MeerKAT Dish is handed-over to SKAO at the beginning of AA2. The second set of 3 are added in AA3 and the remainder in AA4.

Table 17: SKA1-MID Array Configuration Roll-Out.

Batch #	Number of Dishes	Rationale
1	4	• AA0.5 • Subset of AA1

2	+4
	Total of 8
		• AA1
		• Short baselines (< 1km) for ease of verification and commissioning
		  ○ Reduced need for fringe rotation
		  ○ Ability to detect Dish-to-Dish interference
		• Close to the array core and near the MID-CPF (KAPB) for ease of access and for minimising cost
		• Close to the array core to ensure that all required infrastructure is in place
		• Configuration optimised for good uv-coverage, although this takes secondary importance

3	+4 Total of 12	• 4 more Dishes with increasingly longer distance from the MID-CPF (KAPB) to allow testing of long fibre runs and

		the performance of the Time & Frequency distribution system • Allow testing of the full delay model • One of the Dishes at the tip of a spiral arm • One of the Dishes near a repeater hut (5th-last Dish from the tip of the spiral arm) • Includes two PV stations: one located at the tip of the spiral arm, one located at the repeater hut • Early construction of two PV plants to provide sufficient time for PV plant qualification (e.g. RFI qualification)
4	+52 Total of 64	• AA2 • Population of the inner core and a few longer baselines • Partially optimised uv-coverage (within other constraints) for performing demonstration science
5	+34 Total of 98	• All remaining Dishes, except the remaining 19 Dishes that require PV stations on spiral arms
6	+19 Total of 117	• AA3 (excluding 4 MeerKAT Dishes) • Last 19 Dishes, all at the ends of the spiral arms, all requiring PV plants • PV plants to be built as late as possible to minimise costs
7	+16 Total of 133	• AA4 (excluding 64 MeerKAT Dishes) • 16 SKA1-MID Dishes that were part of MK+, being integrated back into the SKA1-MID Array

Table 18: Identification of Dishes that form part of a batch.

Batch #	Dish Name	Comment
1	SKA 001 SKA 036 SKA 063 SKA 100	Sequence of construction decided by Dish Contractor (with SKAO approval)
2	SKA 046 SKA 048 SKA 077 SKA 081	Sequence of construction decided by Dish Contractor (with SKAO approval)
3	SKA 015 (1st) SKA 025 (2nd) SKA 009 (3rd) (with PV) SKA 008 (4th) (with PV)	To be constructed in the specified sequence, with increasingly longer distance from the MID-CPF

4	SKA 013 SKA 014 SKA 016 SKA 019 SKA 027 SKA 028 SKA 030 SKA 032 SKA 033 SKA 035 SKA 038 SKA 039 SKA 040 SKA 041 SKA 042 SKA 043 SKA 044 SKA 045 SKA 049 SKA 050 SKA 051 SKA 052 SKA 054 SKA 055 SKA 061 SKA 067 SKA 068 SKA 070 SKA 075 SKA 079 SKA 082 SKA 083 SKA 089 SKA 091 SKA 092 SKA 093 SKA 095 SKA 096 SKA 097 SKA 098 SKA 099 SKA 101 SKA 102 SKA 103 SKA 104 SKA 106 SKA 108 SKA 109 SKA 113 SKA 123 SKA 125 SKA 126	Sequence of construction decided by Dish Contractor (with SKAO approval)

5	SKA 002 SKA 003 SKA 020 TBC* SKA 022 SKA 026 TBC* SKA 029 SKA 037 SKA 047 SKA 053 SKA 056 SKA 057 SKA 058 SKA 059 SKA 062 SKA 064 SKA 065 SKA 066 SKA 069 SKA 071 SKA 072 SKA 073 SKA 074 SKA 076 SKA 078 SKA 080 SKA 084 SKA 085 SKA 086 SKA 087 SKA 088 SKA 090 SKA 094 SKA 111 TBC* SKA 114 TBC*	Sequence of construction decided by Dish Contractor (with SKAO approval). SKA 022 is delayed to AA3 to avoid RFI close to the Visserskloof construction camp (see ECP-190023).
6	SKA 004 SKA 005 SKA 006 SKA 007 SKA 010 SKA 011 SKA 012 SKA 021 SKA 112 SKA 120 SKA 122 SKA 124 SKA 127 SKA 128 SKA 129 SKA 130 SKA 131 SKA 132 SKA 133	All of these Dishes on the spiral arms require PV plants, Sequence of construction decided by Dish Contractor (with SKAO approval).

7	SKA 017 SKA 018 ~~SKA 020 TBC*~~ SKA 023 SKA 024 ~~SKA 026 TBC*~~ SKA 031 SKA 034 SKA 060 SKA 105 SKA 107 SKA 110 ~~SKA 111 TBC*~~ ~~SKA 114 TBC*~~ SKA 115 SKA 116 SKA 117 SKA 118 SKA 119 SKA 121	MK+ Dish Integration

*Note that only 16 Dishes are used for MK+ out of the originally planned 20, hence the extra 4 are incorporated into batch 5 (AA3), but this still needs to be confirmed under MKAT-ECP-256.

9.2 Batch #1

The first four Dishes are provided early). They are a subset of the Dishes identified for AA1 (see Batch #2).

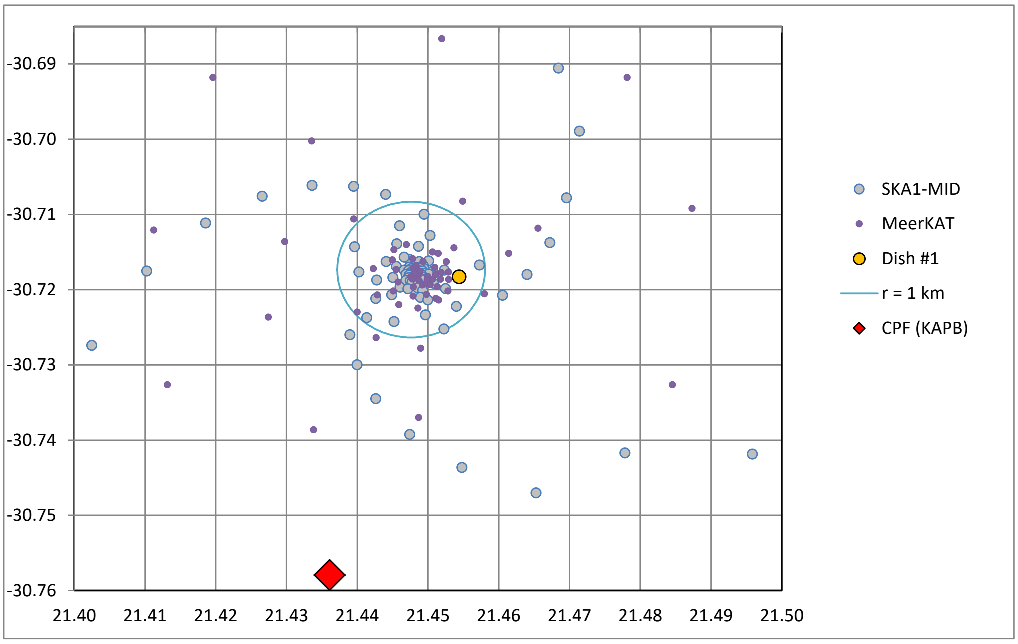

Figure 11: Dish #1 (yellow dot) in relation to the MID-CPF (KAPB) and MeerKAT Dishes.

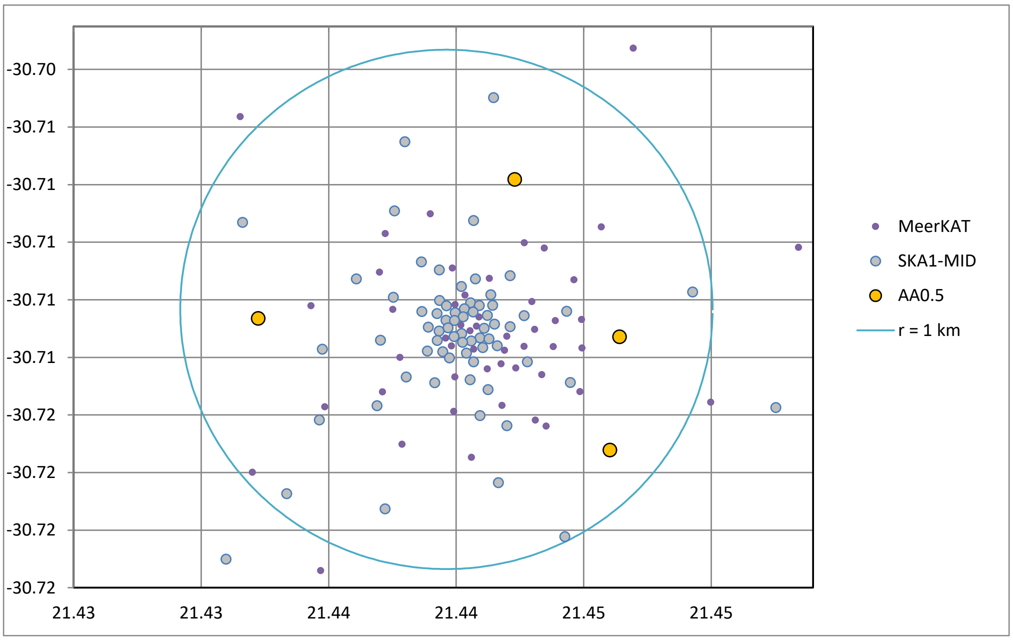

Figure 12: The four Dishes (yellow dots) constituting AA0.5.

9.3 Batch #2

The centre of the core is densely populated with MeerKAT Dishes, and it is therefore advisable not to construct the first few SKA1-MID Dishes near the very centre. The Dish Contractor will need space for large containers and will be using large heavy-duty machinery, and therefore a large and safe operating area is needed.

Construction activity will also generate RFI, which is undesirable for MeerKAT, since it is fully operational at the time. The RFI problem is slightly reduced by starting construction just outside of the centre of the core. Refer to MeerKAT Science / SKA1 Construction Interferences documents, [RD34] and [RD35].

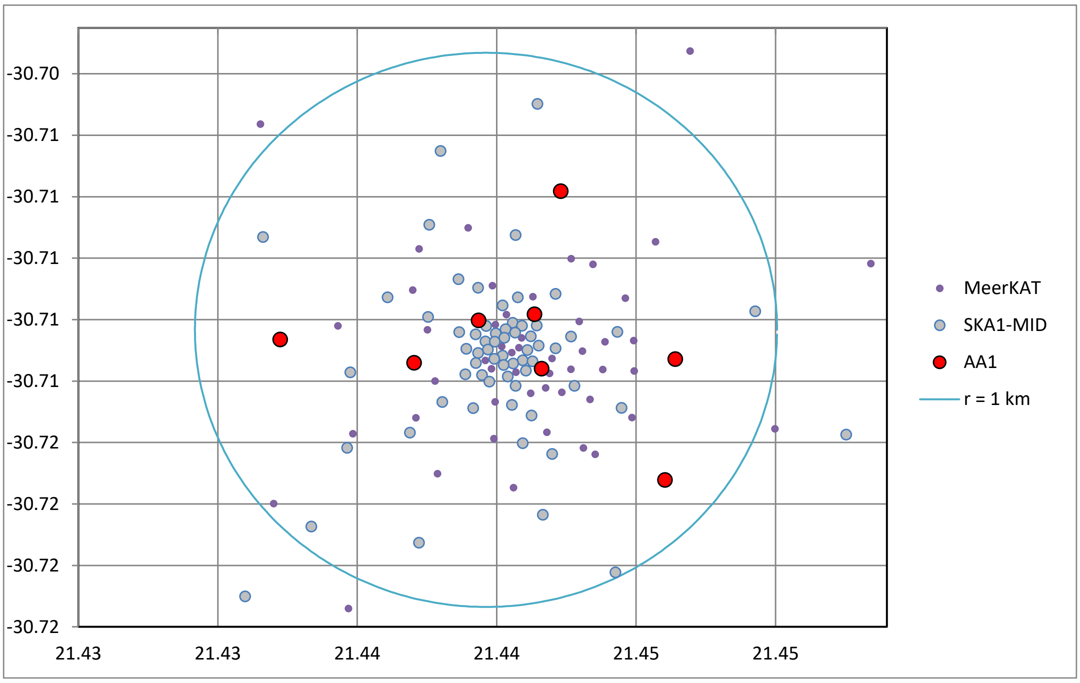

Figure 13: AA1 consisting of eight Dishes, all within a 1 km radius of the inner core.

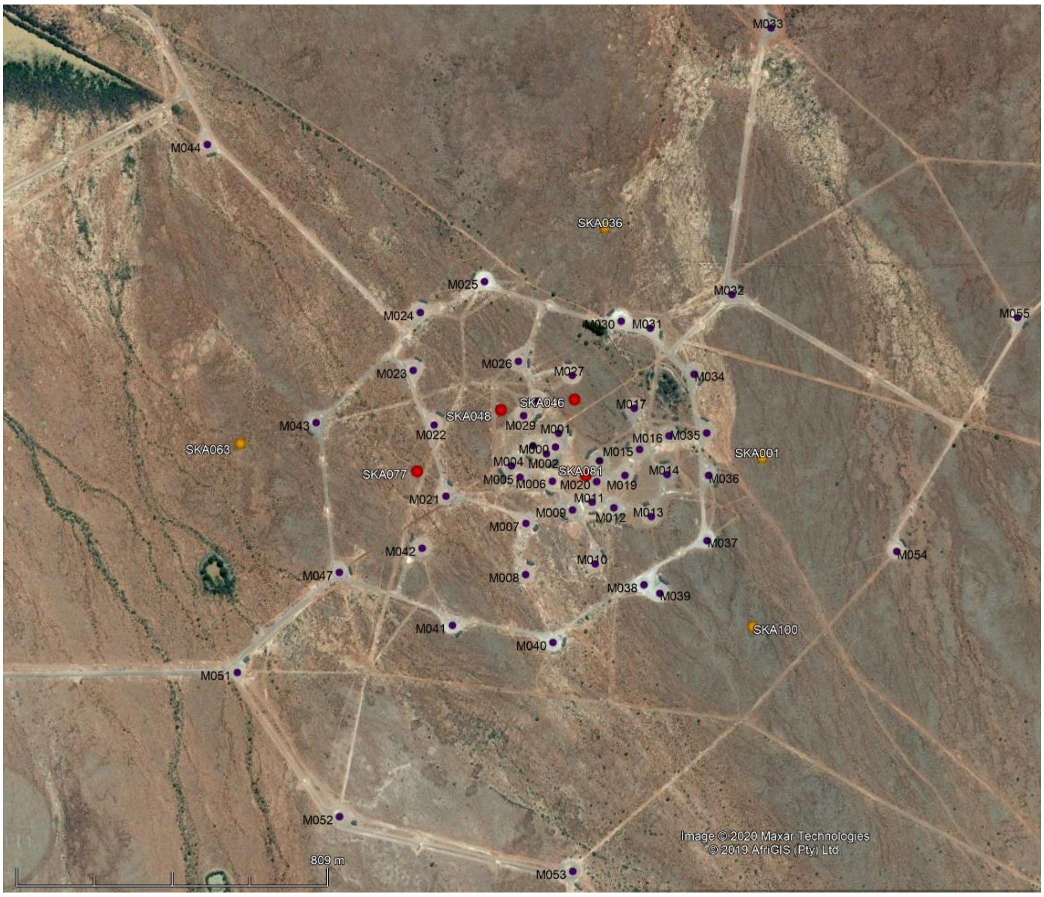

Figure 14: Google Earth view showing AA0.5 (orange dots), AA1 and MeerKAT (black dots).

9.4 Batch #3

For various reasons, it is desirable to construct Dishes at longer baselines as soon as possible after AA1:

- To test the long fibre runs and the performance of the Time & Frequency distribution system.
- To allow testing of the full delay model.
- To construct at least one PV plant early to provide sufficient time for PV plant qualification (e.g. RFI qualification).

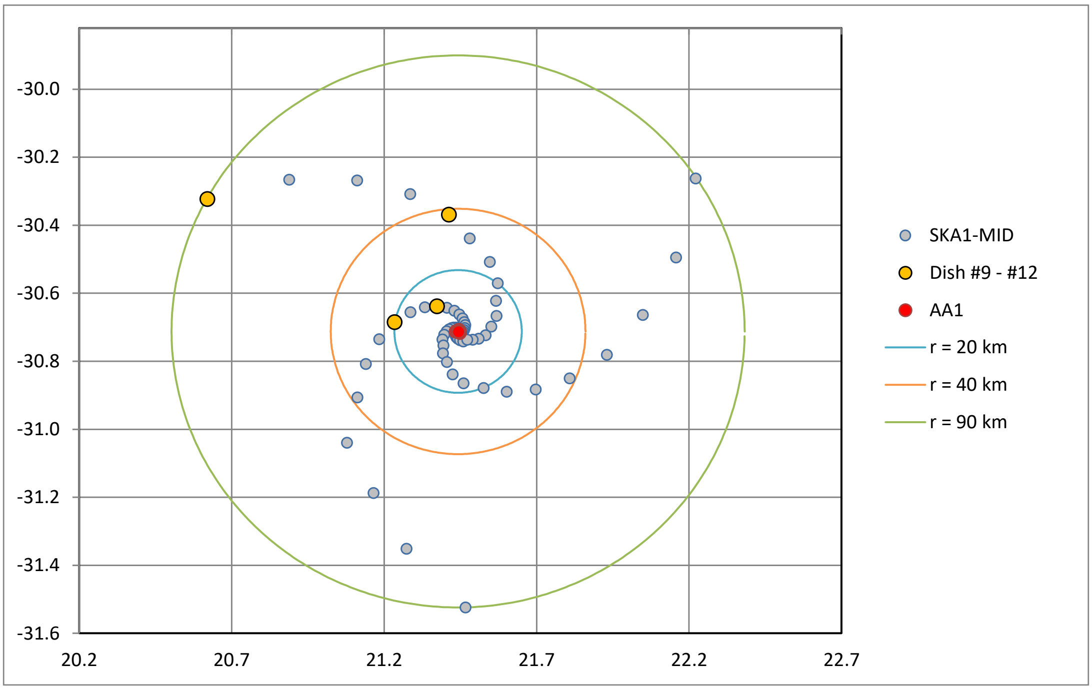

Figure 15: Dishes comprising Batch #3 (yellow dots) in ever-increasing distance from the MID-CPF.

9.5 Batch #4

Batch #4 includes the roll-out of another 52 Dishes, bringing the total to 64 Dishes which comprise AA2.

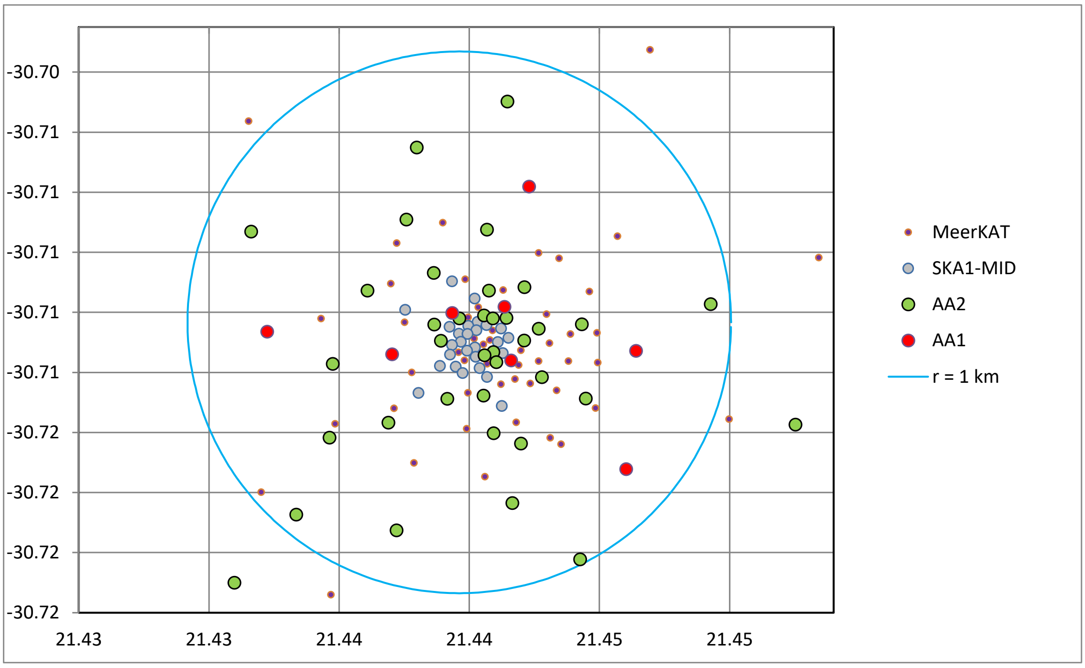

Figure 16: Many of the AA2 Dishes (green dots) are located in the inner core within a 1 km radius.

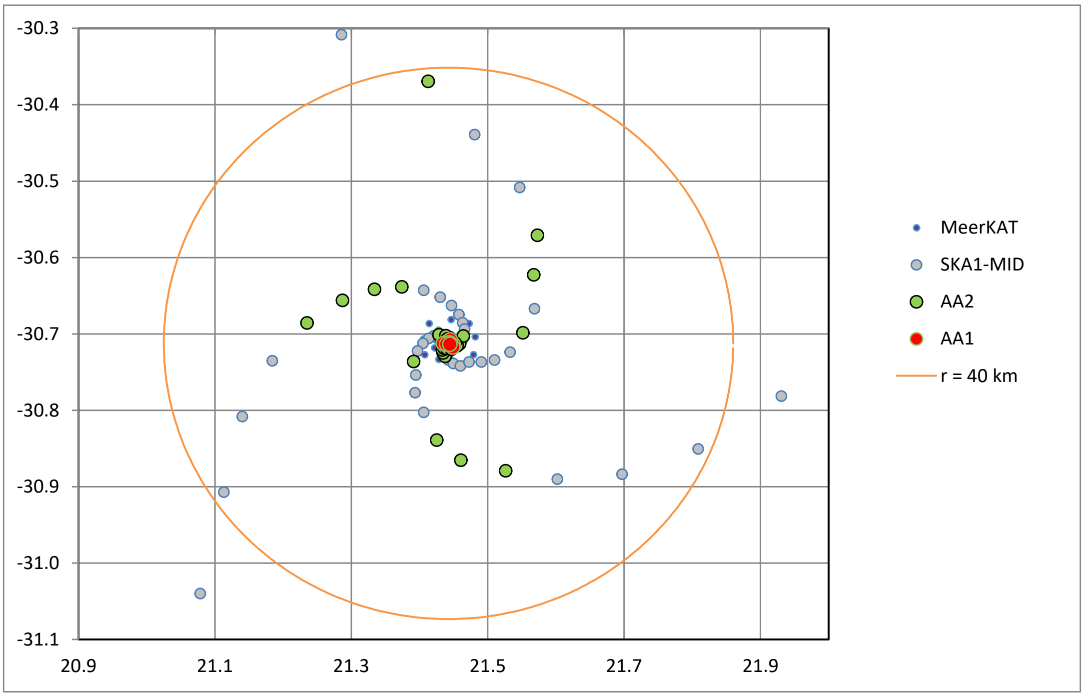

Figure 17: Dishes comprising AA2 (green dots) and AA1 (red dots), excluding Dish 008 on spiral tip.

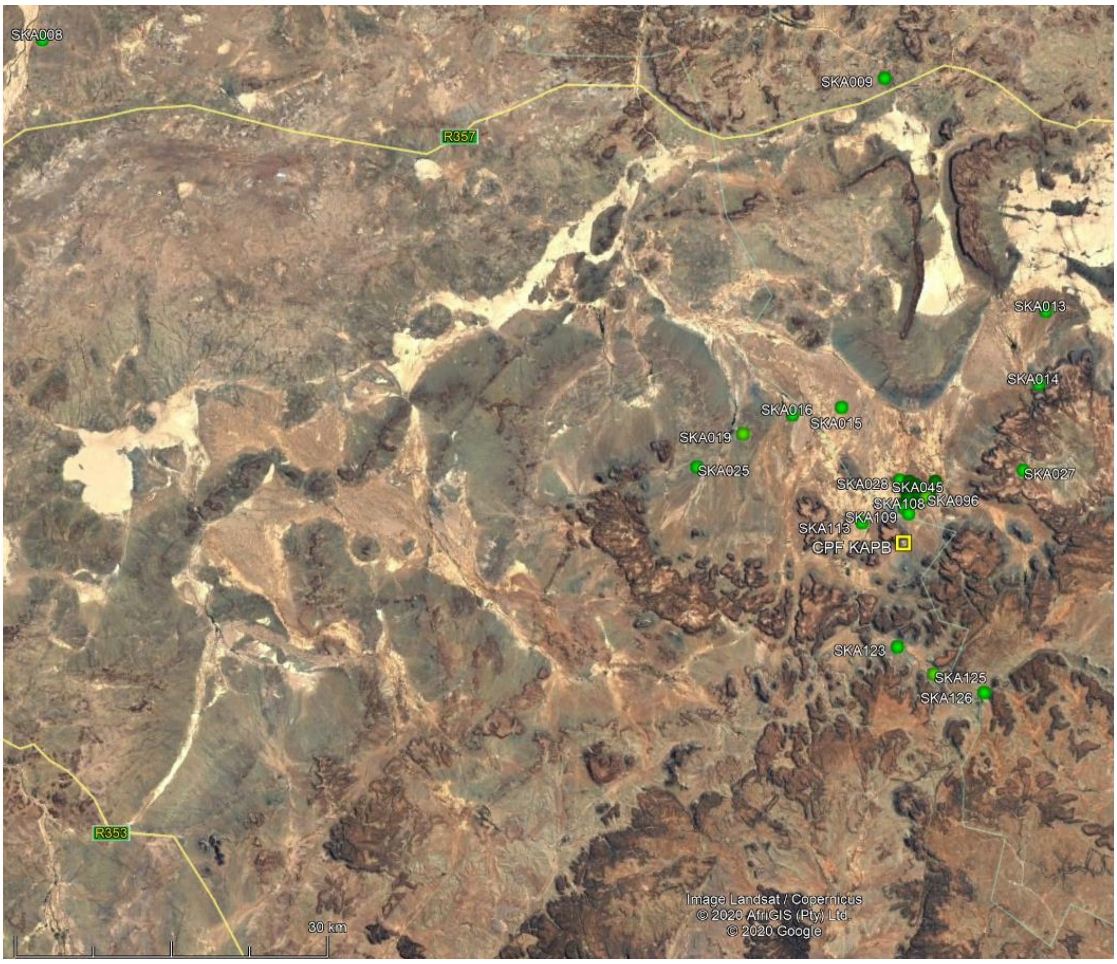

Figure 18: Google Earth view showing AA2.

9.6 Batch #5

Batch #5 is the roll-out of the remaining Dishes, except for the last 19. The last 19 Dishes all require PV plants, and their construction is delayed as much as possible.

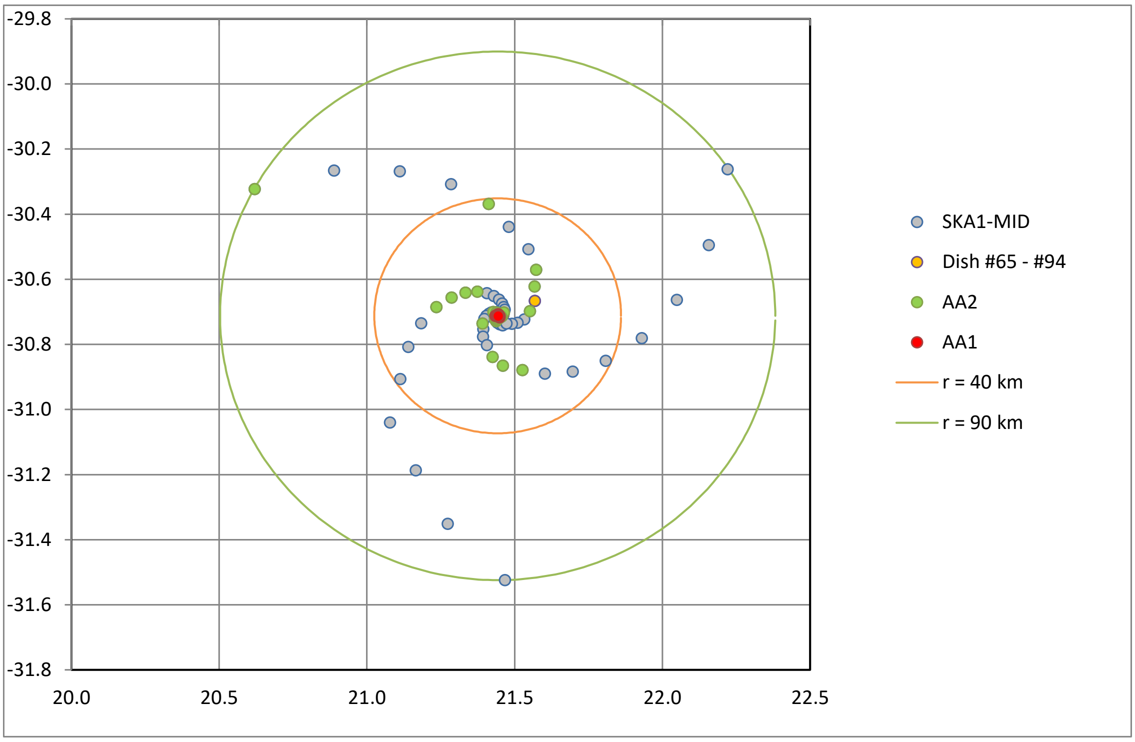

Figure 19: Only one Batch #5 Dish (yellow dot) on a spiral arm.

Note that the 16 Dishes used for MK+ out of the original 20 and hence the 4 to be incorporated in batch 5 (AA3) still need to be confirmed under MKAT-ECP-256.

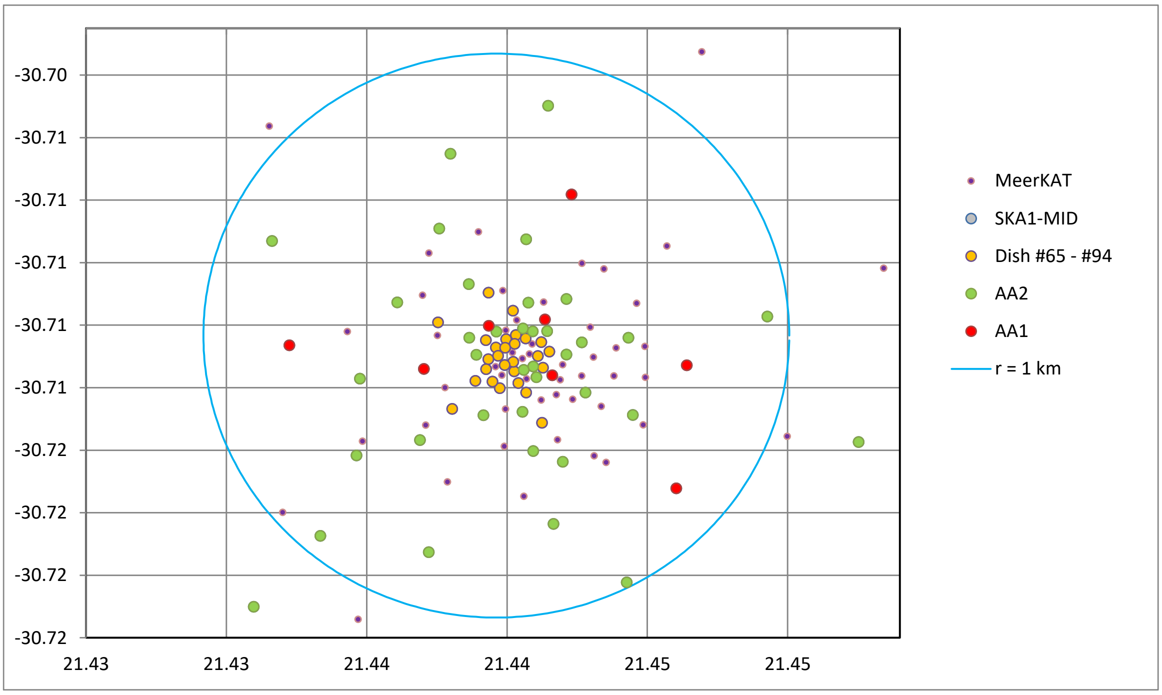

Figure 20: Most of the Batch #5 Dishes (yellow dots) are in the inner core within a 1 km radius.

9.7 Batch #6

This batch is the roll-out of the last 19 Dishes on the spiral arms, all of which require PV plants.

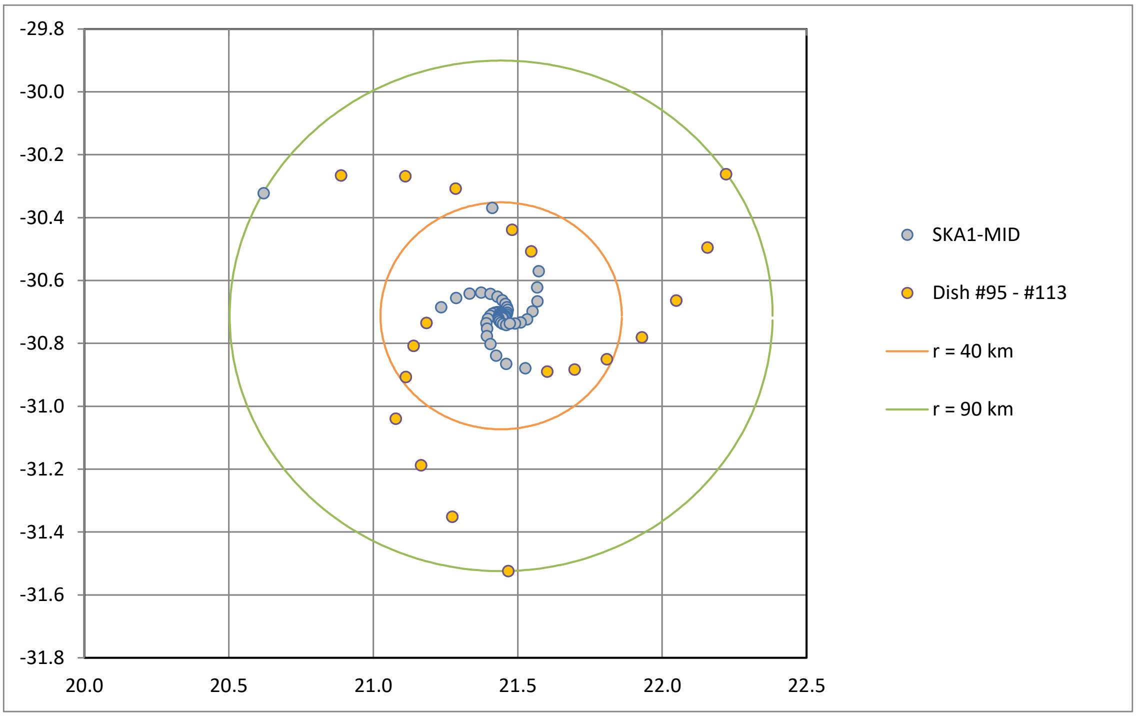

Figure 21: The last 19 Dishes on spiral arms which require PV plants.

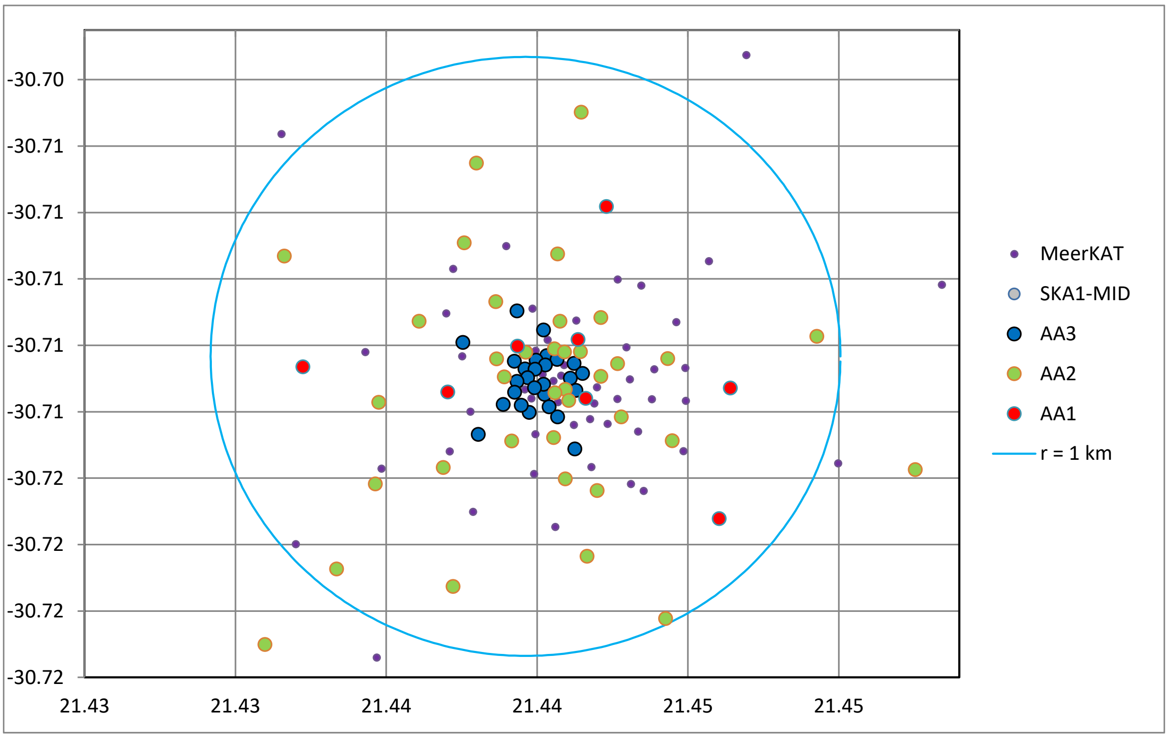

Figure 22: Many of the AA3 Dishes (blue dots) are located in the inner core within a 1 km radius.

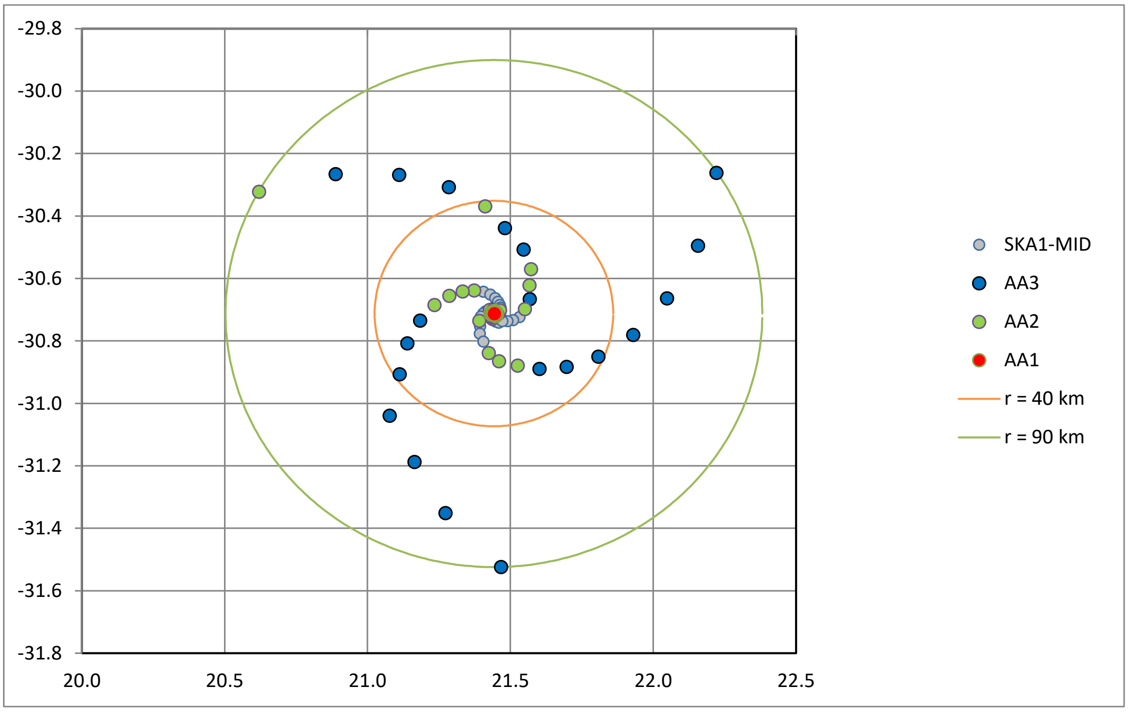

Figure 23: AA3 Dishes (blue dots), AA2 Dishes (green dots) and AA1 Dishes (red dots).

Note that the 16 Dishes used for MK+ out of the original 20 and hence the 4 to be incorporated in batch 5 (AA3) still need to be confirmed under MKAT-ECP-256.

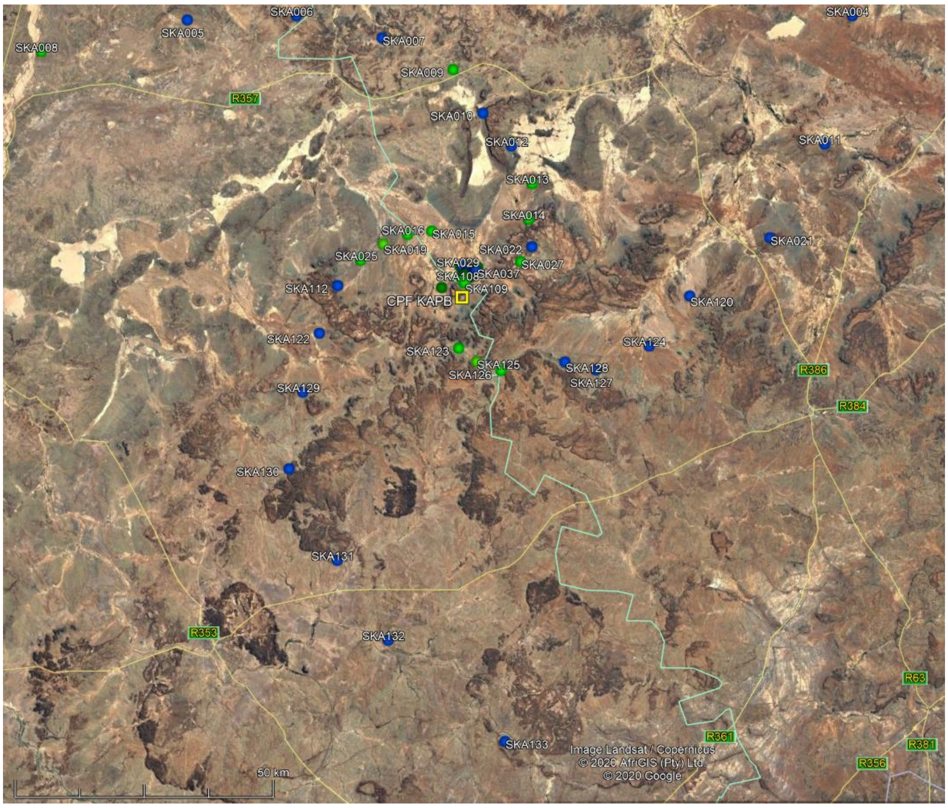

Figure 24: Google Earth view showing AA3 (blue dots) and AA2 (green dots).

9.8 Batch #7

This batch comprises the 16 SKA Dishes that were part of the MK+ project.

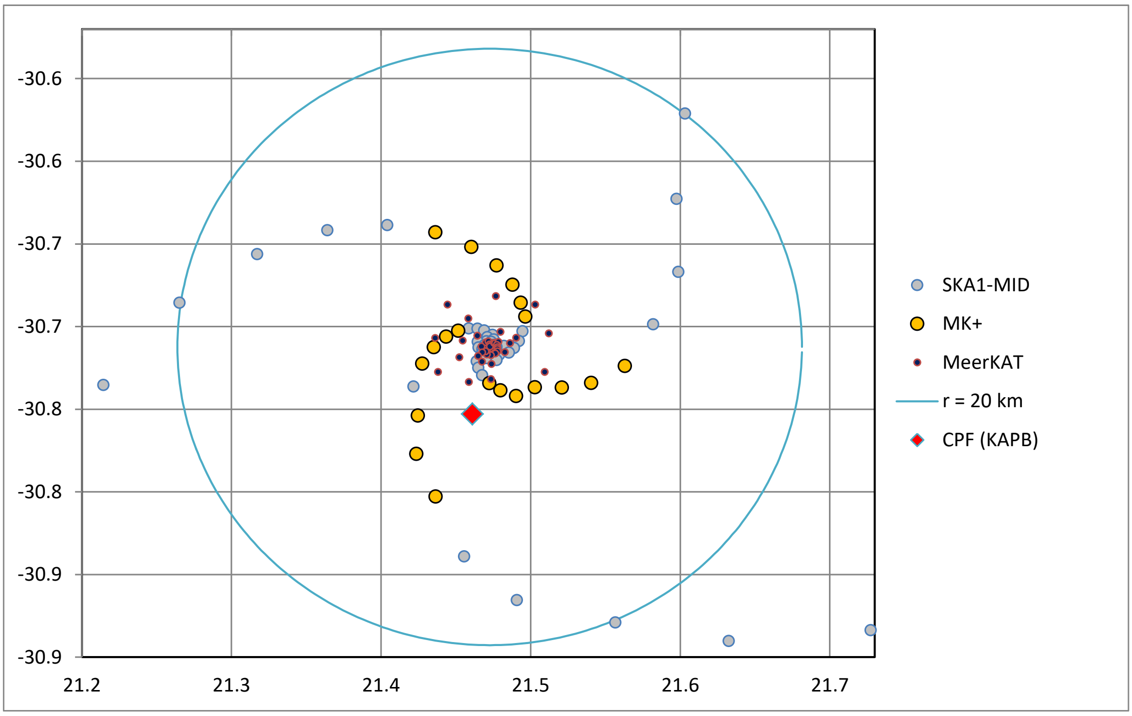

Figure 25: The 16 MK+ Dishes (yellow dots) are within a 20 km radius.

Note that the 16 Dishes used for MK+ out of the original 20 still need to be confirmed under MKAT-ECP-256.

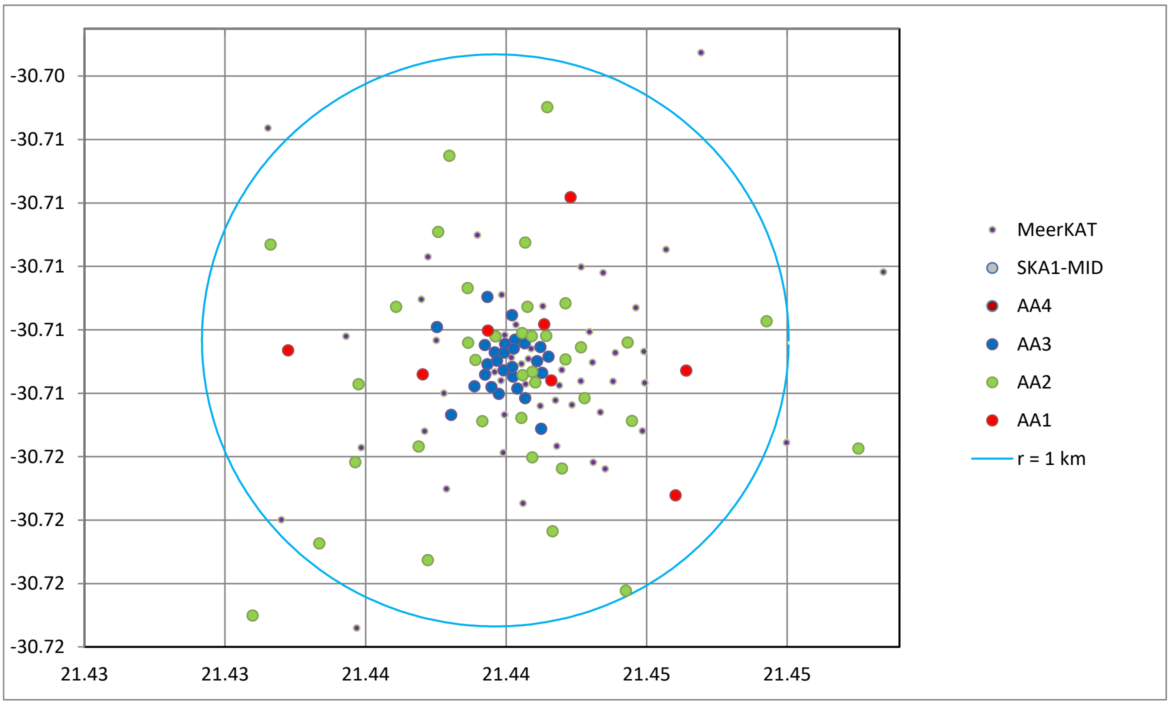

Figure 26: The fully populated inner core.

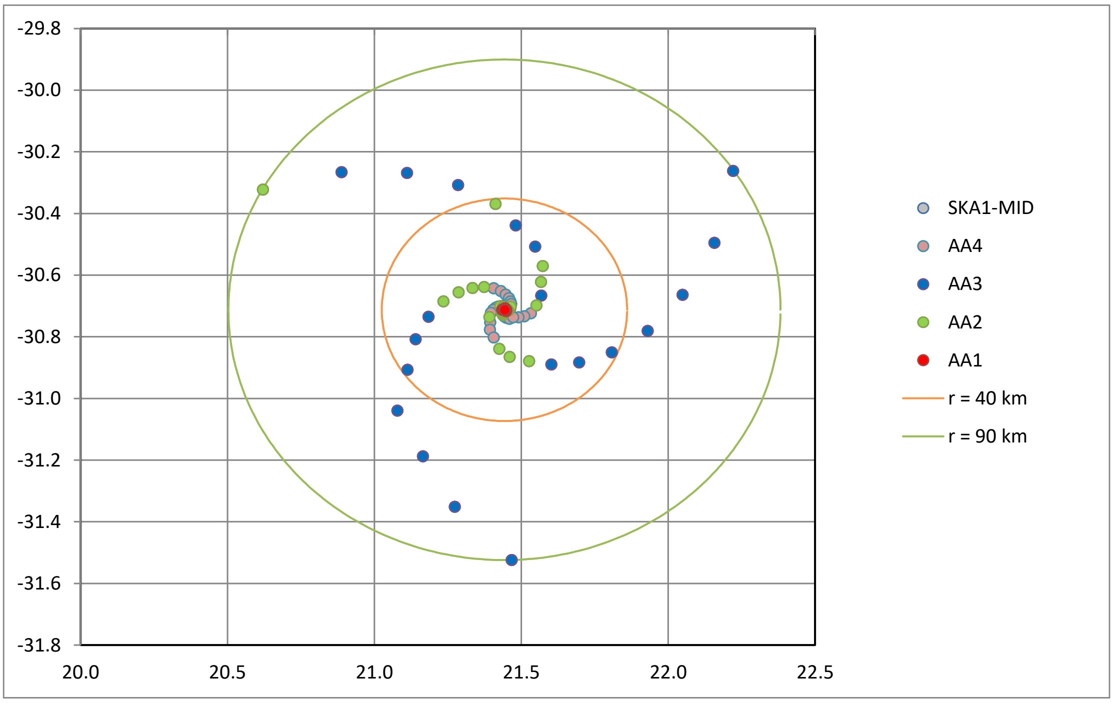

Figure 27: The entire SKA1-MID Array, showing AA1, AA2, AA3 and AA4.

Note that the 16 Dishes used for MK+ out of the original 20 and hence the 4 to be incorporated in batch 5 (AA3) still need to be confirmed under MKAT-ECP-256.

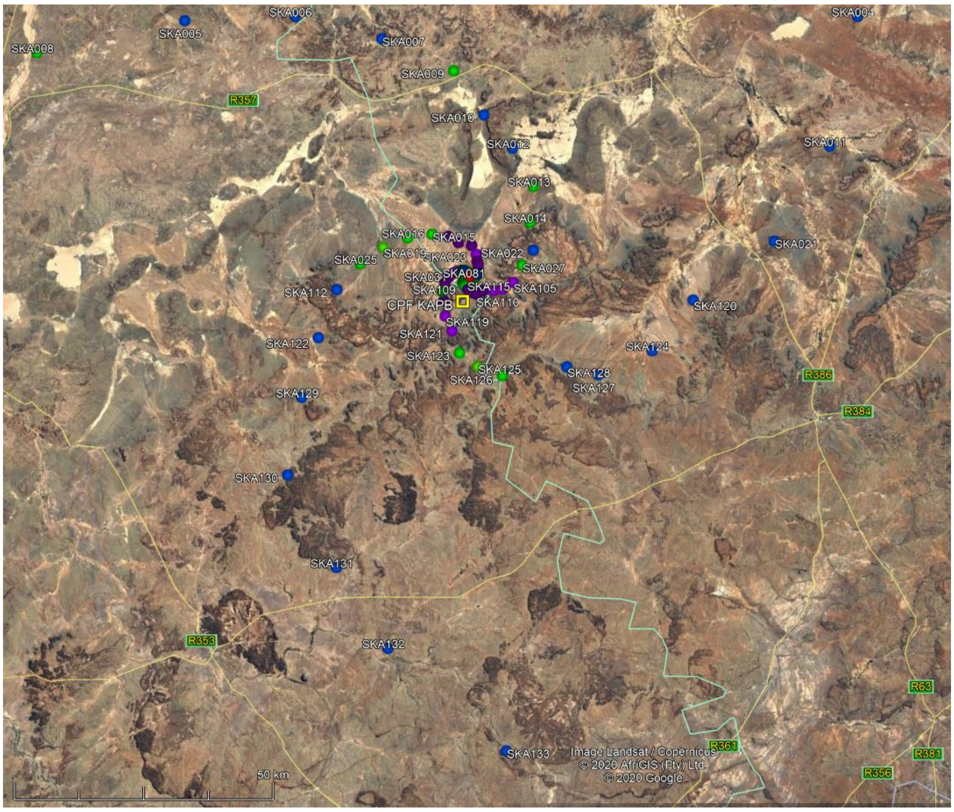

Figure 28: Google Earth view of the entire SKA1-MID Array (AA3 blue dots, AA2 green dots, MK+ Dishes for AA4 purple dots).

10 MeerKAT Precursor Integration

The MeerKAT Precursor integration plan is described in more detail in [RD16]. This section merely summarises the key issues that pertain to the Roll-Out Plan of SKA1-MID.

Note that once a MeerKAT Dish has been handed-over to the SKAO for integration into SKA1-MID, that Dish needs to be maintained by SKA Operations.

10.1 Date of Integration

At a high level, the integration of MeerKAT into SKA1-MID occurs in four stages:

- Early preliminary testing is planned without any MeerKAT Dishes being removed from the MeerKAT array.
- A single MeerKAT Dish is used for integration testing during AA2.
- The single MeerKAT Dish plus a further three MeerKAT Dishes are integrated into AA3.
- The remaining 60 MeerKAT Dishes and 16 MK+ Dishes are integrated into AA4.

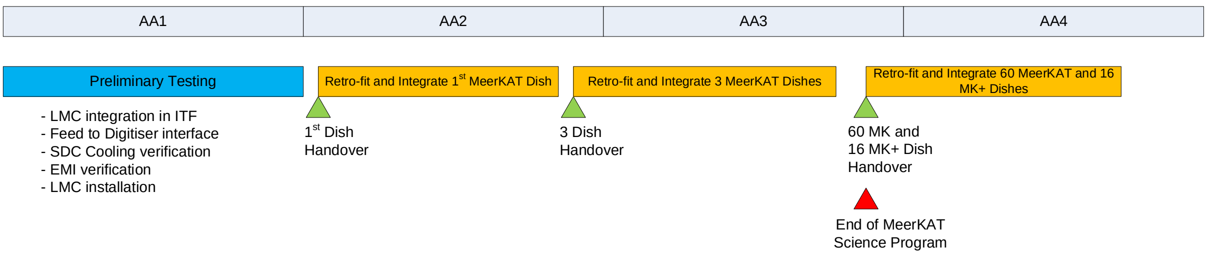

Figure 29: MeerKAT Integration timeline.

This high-level schedule is illustrated in Figure 29 and in Figure 8 on page 33.

A key date in the MeerKAT Integration Schedule is the date at which 60 MeerKAT Dishes plus 16 SKA Dishes used for MK+ are handed-over to the SKAO. This date marks the end of the MeerKAT Science Programme (it is assumed that some MeerKAT Science can continue with 76 MeerKAT Dishes until that date), and has been deliberately moved as late as possible in the construction phase. The (short) period between the end of the integration process and the end of Array Assembly 4 is needed by the System AIV Team to wrap-up the remaining system-level verification work of the entire integrated SKA1-MID array.

10.2 Integration Process

The "preliminary testing" phase can start as soon as the contract for MeerKAT Integration has been awarded, ideally at the beginning of the construction phase. During this phase the bulk of the development work for the MeerKAT Dish LMC is done. This phase is also used to perform all the work that can be done without needing an actual MeerKAT Dish.

The first MeerKAT Dish needs to be handed-over to the SKAO at the beginning of AA2. The duration for retro-fitting the first MeerKAT Dish is expected to take about 8 months and will provide a huge amount of information with regard to costing, duration, LMC integration and performance, rack layout and connections, indexer connection, fibre connection diagrams, processes, verification scripts, integrated performance, etc.

The entire retro-fitting process will be “industrialised” with the next three MeerKAT Dishes, which need to be handed-over to the SKAO towards the beginning of AA3. This phase is expected to take about 8 months. Exactly which four Dishes will be the first to be integrated has not yet been decided, but they will be selected so as to minimise the impact on the MeerKAT Science Programme.

Once the retro-fitting work has been streamlined, it is expected that it will take no more than 12 months to integrate the remaining 60 MeerKAT Dishes and 16 MK+ Dishes. This work is highly “parallelisable”, which means that it can be completed faster if multiple teams work in parallel.

The end of the MeerKAT Science Programme also marks the end of the MeerKAT Timescale. The SaDT Consortium has planned the integration of the MeerKAT Maser into the SKA1-MID clock ensemble, and the establishment of the SKA1 Timescale (see [RD33]).

10.3 Space Requirements inside the KAPB

The amount of rack space inside the MID-CPF (KAPB) is limited and therefore requires careful planning. While MeerKAT (including the 16 MK+ Dishes) is operational, both MeerKAT and SKA1-MID will require rack space. Once MeerKAT has been integrated into SKA1-MID, more rack space will become available, since many MeerKAT racks will become obsolete.

ECP-200048 moves CSP equipment, including CBF, PST and PSS from the CPF (KAPB) to the SPC, from AA2. This significantly reduces the space constraints in the CPF. It makes sense to only install the full PSS beam processing hardware at the end of the Construction Phase, when the cost of hardware is lower and the existing beamformer has been fully commissioned. The upgrading of the number of pulsar search beam processing can thus be scheduled to occur after MeerKAT has been integrated.

MID Infrastructure is managing the space (and power) budget inside the MID-CPF, see [RD27]. The MeerKAT Precursor Integration Plan, [RD16], also discusses the rack space issue in more detail.

11 Science Commissioning and Verification

The purpose of Science Verification (SV) is to demonstrate the scientific performance of the SKA Telescope to the astronomical community, and hence to verify the Telescope against the majority of the Level 0 (Science) Requirements. The Science Commissioning and Verification Plan is given in [AD13], and only the high-level milestones relevant to the roll-out of SKA1-MID and the handover to Operations are summarised here. The information presented here is consistent with the Science Commissioning and Verification Plan [AD13], but supersedes Rev 2 of the Science Planning document [RD39], which will be updated.

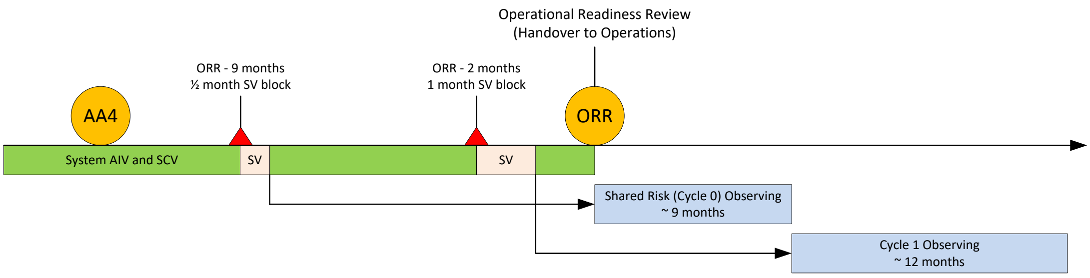

Figure 30: Science Verification preparation for Cycle 0 and Cycle 1 observing.

The first cycle (Cycle 0) of open science observing is expected to be "shared risk" science, defined to imply that should a scheduled observation be unsuccessful for any reason, there would be no guarantee that the proposal would be rescheduled. This cycle is anticipated to start immediately after the end of construction and roughly coincident with the Operations Readiness Review (ORR).

The timetable leading up to Cycle 0 Observing is:

- Dedicated SV block — Start date: ORR - 9 months
- Observing Modes Review — Start date: ORR - 7 months
- Proposal Call — Start date: ORR - 6 months
- Proposal Review — Start date: ORR - 4 months
- Proposal Allocation — Start date: ORR - 1 month
- Cycle 0 Observing — Start date: ORR

The Operations Readiness Review (ORR) will take place at the end of AA4 and is informed by a second extended block of SV observations. At this point, System AIV should be complete for the whole system and all of the high-priority modes should have been through the commissioning process (in many cases also preliminary science verification). Handover of the commissioned and verified system to Operations for scheduled observing is, however, a gradual one. It is expected that specific modes will be released in sequence, starting with basic (and commonly used) modes and leaving difficult and esoteric ones for later.

The timetable leading up to the second cycle (Cycle 1) of open science observing is:

- Dedicated SV block — Start date: ORR - 2 months
- Operations Readiness Review — Start date: ORR + 1 month
- Proposal Call — Start date: ORR + 3 months
- Proposal Review — Start date: ORR + 5 months
- Proposal Allocation — Start date: ORR + 8 month
- Cycle 1 Observing — Start date: ORR + 9 months

12 Assumptions and Risks

Many of the assumptions made by the AIV Consortium with regard to the roll-out process are listed in other documents, such as the Product Hand-Over Process, [RD3], the MeerKAT Precursor Integration Plan, [RD16], the Cost Model, [RD12], and the Risk Register, [RD10].

The following is a list of some of the important assumptions that are being made:

- Contractors deliver products to the System ITF with Technology Readiness Level 6 (TBC) or higher.
- Contractors install products on-site for the various Array Assemblies with Technology Readiness Level 7 or higher.
- Production contracts clearly specify contractor responsibilities and response times, to ensure a quick turn-around time when components fail.
- Product Contractors provide integration support to the AIV Team, after installation and hand-over to the SKA Observatory. During integration, many issues may arise, and the domain knowledge of the Product Contractors will be needed to troubleshoot these issues.
- Contractors comply with site constraints, including the need for personnel to have had Health and Safety inductions.
- The AIV Team is not responsible for repairing or replacing faulty components, and does not have any resources for repairs and warranties. It is assumed that the SKAO will put contractual agreements in place, as part of the Procurement Model, whereby contractors will repair and/or replace faulty components during the Construction Phase.

Whilst there are numerous technical and project benefits for AA0.5, there are also challenges and concerns that have been identified:

- Schedule
  a. The manufacture of some products may take longer than anticipated, with the result that such products may not be available on AA0.5 timescales.
  b. Task durations require further detail to estimate critical path and float areas to understand the program risk.
- Quality
  a. Work/design on Elements, ICDs, Bridging Tasks or the System may be incomplete, but may be forced to pass through gates in order to achieve AA0.5 progress, leading to reduced quality. AA0.5 may therefore be rolled out with products that are not fully validated.
  b. The System ITF verification process may not be fully developed.
  c. Interfaces not mature/coordinated could lead to divergent/abortive work.
  d. Product Assurance requirements, systems and resources would need to be mobilized: increased resources and costs.
- Resources
  a. SKAO would need to ramp up staff sustainably to match construction organogram as the construction phase will start sooner.
  b. Additional resources required for longer period than originally planned, leads to an increased cost cap (assuming a constant marching army).
- Costs
  a. The integration of AA0.5 leads to a significant reduction in risk and anticipated cost for delivery but has additional determined costs due to the earlier ramp up of staff and retrofits of pre-production components.

Table 18 lists the major risks that are currently identified with regard to a successful Roll-Out of SKA1-MID (also refer to the AIV Risk Register [RD10]).

Mitigation proposals include:

- Availability and project-wide support of a System-Level Integration Test Facility.
- A pool of resources with in-depth knowledge of performing Telescope AIV work, which transitions from the Construction Phase into Operations.

Table 19: Major Roll-Out Risks for SKA1-MID.

Risk Title	***Risk Description***
Late release of software/firmware functionality during Construction Phase	The software and firmware dominated Contractors (CSP, SDP(*) and TM) may find it extremely difficult to deliver functional products soon after award of the tender. (*) The SDP Commissioning and AIV Support product mitigates this risk for SDP, as SDP can provide nearly full functionality using 3rd party tools. This is largely due to using SAFe.
Participating organisations not delivering on their contributions on time, or to an acceptable level of quality	The AIV Team has little leverage at its disposal (since it does not control the financial or manpower resources) for enforcing participating organisations to deliver on their contributions on time and to an acceptable level of quality. For software elements this risk is (partially) mitigated using SAFe.
Late delivery of products by the contractors during construction.	Poor project management at Product-level. Lack of resources at Product-level. Unforeseen technical issues. Unforeseen environmental/external issues. Supply chain delays. Staff availability. The shipment of components to site, and the shipment of faulty components back to the OEM, might cause longer than expected delays. Unavailable, late or inaccurate delivery plan schedules have a range of side effects on AIV planning and activities.
Slower than anticipated roll-out of infrastructure work	The "big bang" approach planned by Infrastructure might be compromised if servitude agreements with land owners are not concluded in time.

Risk Title	*Risk Description*
Incomplete maintenance and logistics planning	Incomplete maintenance and logistics planning, resulting in wasted expenditure and delays in getting the instrument operational / fixed when problems occur. Lack of a detailed maintenance plan creates a risk that the equipment is not being designed with maintenance requirements considered. This has the potential to result in equipment that is delivered which is difficult to diagnose, difficult to perform physical maintenance tests on, and difficult to re-commission after repair. There is also a time implication from knowing and planning for the support requirements and having the support capabilities physically commissioned (e.g. support equipment, spares, technical data, training, etc).
Resources not established early enough	The establishment of resources will take some time, and if this is only started at the beginning of the Construction Phase, this may delay AIV activities from getting started.
Missing or inadequate Level-1 Requirements	Missing or inadequate Level-1 Requirements will become evident during the Integration & Verification stage. The AIV Team will inherit the problems that this might cause.
MeerKAT integration running late	There is a risk that the MeerKAT construction schedule is late, and / or that the MeerKAT Science Programme takes longer than anticipated. This will cause the integration effort to take longer than anticipated. Some form of curtailment or deferring of the Science Programme might be a mitigation option.

LIST OF ABBREVIATIONS

AA.................................Array Assembly

AA* ....Final Array Assembly included in "Staged Delivery"

AD.................................Applicable Document

AIV ....Assembly, Integration and Verification

ALMA............................Atacama Large Millimeter/submillimeter Array

ART ....Agile Release Train

ATCA.............................Australia Telescope Compact Array

CASA ....Common Astronomy Software Applications package

CSIRO............................Commonwealth Scientific and Industrial Research Organisation

CSP ....Central Signal Processor

DDBH............................Digital Data Back Haul

DSH...............................Dish

EMC ....Electromagnetic Compatibility

FSA ....Frequency Slice Architecture

FSP................................Frequency Slice Processor

FTE................................Full-Time Equivalent

FPGA.............................Field-Programmable Gate Array

GUI ....Graphical User Interface

HI ....Neutral Hydrogen 21cm Line

IGO ....Inter-Governmental Organisation

INFRA-SA ....Infrastructure South Africa Consortium

ITF.................................Integration Test Facility

JIT ....Just-in-Time

JVLA..............................Karl G. Jansky Very Large Array

KAPB.............................Karoo Array Processor Building

KAT-7............................7-dish Karoo Array Telescope

KO.................................Kick-Off

LEMP ....Logistic Engineering Management Plan

LFAA ....Low Frequency Aperture Array Consortium

LMC ....Local Monitoring and Control

LSA................................Logistic Support Analysis

MeerKAT ....64-dish Karoo Array Telescope

MK+ ....MeerKAT Extension project

MS ....Measurement Set (visibility data stored in a CASA table)

NMGR...........................Network Manager

NRF ....National Research Foundation (in South Africa)

NSDN ....Non Science Data Network

OEM ....Original Equipment Manufacturer

OMC ....Observation Management & Control

PCA ....Physical Configuration Audit

PHS&T ....Packaging, Handling, Storage and Transportation

PI ....Program Increment

PRR ....Production Readiness Review

PSI................................Prototype System Integration

PSS...............................Pulsar Search component of CSP.MID

PST...............................Pulsar Timing component of CSP.MID

QA ....Quality Assurance

RD................................Reference Document

RF ....Radio Frequency

RFI ....Radio Frequency Interference

SaDT ....Signal and Data Transport

SAFe ....Scaled Agile Framework

SARAO ....South African Radio Astronomy Observatory (previously called SKA SA)

SAT ....Synchronisation and Timing

SDH&P..........................Science Data Handling & Processing

SDP ....Science Data Processor

SKA ....Square Kilometre Array

SKAO............................SKA Project Office

SKA1 ....Square Kilometre Array Phase 1

SKA SA ....SKA South Africa (now called SARAO)

SPC ....Science Processing Centre

STFR.............................System for the Time and Frequency Reference signals

STI................................Site Test Interferometer

TBC ....To Be Confirmed

TBD ....To Be Determined

TM ....Telescope Manager

UTC................................Coordinated Universal Time

UV..................................Array Coordinates

VCC................................Very Coarse Channelizer

VLBI ....Very Long Baseline Interferometry

VM.................................Virtual Machine

VO..................................Virtual Observatory

DOCUMENT HISTORY

Revision	Date Of Issue	Engineering Change Number	Comments
A	2014-06-30	-	First draft released for internal review.
B	2014-08-20	-	Second draft released for internal review, and meeting AIV's Milestone #4.
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	2014-11-26	-	Incorporated comments received from another round of review of the SKA Office.
02	2015-04-14	-	Incorporate items identified at PDR.
03	2015-11-30	CN-AIV-150003	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-160002	Removal of dates and durations, and alignment with Roll-Out Strategy document. Reviewed by all Consortia Leads, and inclusion of resultant OAR comments.
05	2016-10-26	CN-AIV-160007	Major new release, incorporating the functional allocation to roll-out milestones. Feedback incorporated from the SKA Office and from Design Consortia.
05A	2017-10-30	CN-AIV-170008	Draft release for System Pre-CDR. See Section 1.6 for a list of changes since the previous revision.
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-2410002. Minor adjustments to the TM roll-out as per observation TMCDR-480. Added section on Observing Modes.
08	2019-05-02	CN-AIV-190001	Incorporates actions from AIV CDR.
08A	2020-01-27	-	First internal review of incorporation of MeerKAT Extension, AA0.5 and latest developments since the System CDR.
08B	2020-03-04	-	Incorporation of MeerKAT Extension, AA0.5 and latest developments since the System CDR. The Deployment Baseline concept has been removed.
08C	2020-03-27	-	Inclusion of Band 1 for AA0.5, correlator support for Band 5 for AA1, and minor clarifications. Separation of SaDT into SAT and Networks.
08D	2020-04-24	-	Inclusion of minor updates following review from NRC and SKAO.

8E	2020-04-27	-	Inclusion of further OAR comments.
09	2020-05-19	ECP-190023 ECP-200007 ECP-200013 ECP-200014	Major release after the approval of the listed ECPs, which include the AA0.5 ECP and the MK+ ECP.
10	2021-04-23	ECP 210012 ECP-210028 ECP-210019 ECP-200048	References made to AA*. Implementing "change in Dish drive and servo supplier" which reduces the no of MK+ dishes to 16. Also implementing the "MKI change in integration numbers" which allows 4 MK dishes to be handed over later for integration into SKA.

DOCUMENT SOFTWARE

	Package	Version	Filename
Word Processor	MS Word	Word 2010	SKA-TEL-AIV-2410001-10_RollOutPlanForSKA1_MID.docx
Block Diagrams	MS Visio	Visio 2013	SKA1_Mid Roll-Out Plan.vsd
Other			

ORGANISATION DETAILS

Name	SKA Observatory
Registered Address	Jodrell Bank Lower Withington Macclesfield Cheshire, SK11 9FT, UK
Website	www.skao.int