SKA RAM ALLOCATION

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LIST OF ABBREVIATIONS

Table 1: Abbreviations

Abbreviation	Description
A_i	Inherent Availability
A_o	Operational Availability
A_s	Science Availability
AOR	Annual Operating Requirement
Assy	Assembly
BITE	Built-In Test Equipment
BOM	Bill Of Material
C	Critical
CA	Criticality Analysis
CSP	Central Signal Processor
D-Level	Depot Level (Maintenance)
DMH/y	Direct Maintenance Hours per year (1st Line)
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FRACAS	Failure Reporting and Corrective Action System
Hr	Hours
I-Level	Intermediate Level
ILS	Integrated Logistic Support
ILSP	Integrated Logistic Support Plan
LFAA	Low Frequency Aperture Array
LOW	Low Frequency Telescope
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis
MID	Mid Frequency Telescope
MTBCF	Mean Time Between Critical Failures
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
OEM	Original Equipment Manufacturer
O-level	Organisation Level
PBS	Product Breakdown Structure
PSU	Power Supply Unit

R&R	Remove & Replace
RAM	Reliability, Availability and Maintainability
RF	Radio Frequency
RFI	Radio Frequency Interference
SaDT	Signal and Data Transport
SAT	Site Acceptance Test
SDP	Science Data Processor
SE	System Engineering (Group)
SEMP	Systems Engineering Management Plan
SKA	Square Kilometre Array
SKAO	Square Kilometre Array (SKA) Organisation
S-Level	Supplier Level
SRU	(Work)Shop Replaceable Unit
TEMP	Test and Evaluation Management Plan
TM	Telescope Manager

1 Introduction

1.1 Purpose of the Document

The availability requirements for the Telescopes will have a major impact on the design, capital and operational cost. The 'triangle' of design for reliability, maintenance planning and performance expectations must be well balanced.

The purpose of this document is to produce a definition of telescope availability that can be used in a practical way for design, option selection and maintenance planning. It is also very important that a high level of availability be achieved within the cost budget. The document also estimates the achievable overall uptime and allocates requirements to each of the major systems. The focus is on the availability and maintenance cost budgets for the telescopes.

Aperture synthesis telescopes are inherently robust. Their failure modes are not critical and a large fraction of the telescope can be unavailable, yet the telescope is still capable of performing valuable observations. Electronic systems generally don't require preventive maintenance other than inspection, cleaning and testing. The total science observation time can also be maximised by dynamic scheduling, switching between observation programs and taking maximum advantage of sub-array flexibility.

1.2 Scope of the document

The need for availability must be traded-off against the cost of un-availability. The scope of the document includes:

- Availability Definitions
- Telescope Availability State Definitions
- Telescope Reliability, Availability and Maintainability (RAM) Requirements
- System RAM Requirements
- Requirement Verification Matrix

1.3 Application

This document provides the current status of the RAM allocation and will be updated as more information becomes available. It currently provides information related and applicable to the Critical Design Review (CDR).

1.4 Definitions

Table 2: Definitions

Term	Definition
Configuration Management	As per the Configuration Management Plan document [RD5]
Corrective Maintenance	All maintenance activities that which are carried out to restore a faulty item to full functionality.
Critical Functions	A function that, if defective or unavailable, will result in the telescope not being available (i.e. Telescope not available, failed observation or a revised observation schedule).
Critical Failure	A failure which may cause injury, damage, or the telescope not being available. A critical failure in this context also includes failures which may result in loss of redundancy or degradation, and if not detected or repaired could result in the telescope not being available.
Direct Maintenance Hours (DMH)	The Direct Maintenance Hours (DMH) is limited to 1st line/on-equipment maintenance but includes all corrective, preventative, scheduled maintenance and inspections. It provides a measure of the amount of maintenance personnel hours required but excludes administrative, travelling, training and support delay times.
Facilities	All fixed and mobile installations, with accompanying services that are required for sustained support.
Fault Detection	The ability to detect malfunctions in real time, as soon and as surely as possible.
Fault Isolation	The ability to find the root cause of a fault, by isolating the LRUs whose operation mode is not nominal.
Inherent Availability A_i	The probability that the telescope is operationally capable at any point in time when used in an ideal support environment, i.e., one in which repair commences instantaneously upon failure.
Integrated Logistical Support (ILS)	A disciplined scientific approach to integrate, on an ongoing basis, by means of management and technical activities, all logistical elements, and combine them with the total system to ensure effective and economical support during the full life-cycle of the telescope. (please note elements are used in a logistical context)
Life Cycle Cost (LCC)	The cost of a system that entails all relevant direct marginal costs of the entire system, during its entire planned life including de-commissioning, removal and site restoration if planned. Where end of life is not planned, a fully amortised steady state end is assumed.
Logistic Support Analysis (LSA)	The selective application of scientific and engineering efforts during the system acquisition process, as part of the system engineering

Term	Definition
	and design engineering process, in order to comply with the supportability requirements and all other ILS objectives, by using an iterative process of definition, synthesis, trade-off, integration, testing and evaluation.
Maintainability	The measure of the ability of an item to be retained in or restored to a specified condition, when maintenance is performed by personnel having specified skill levels using prescribed procedures and resources at each level of maintenance and repair.
Maintenance	All actions necessary for retaining an item in or restoring it to a specified serviceable condition. It includes inspection, testing, classification in terms of serviceability, repair, modifications and recovery.
Operational Availability A_o	The probability that a system is operationally capable at any point in time when used in a realistic support environment, i.e., one in which repair cannot commence until sometime after the failure has occurred. It is thus a measure of not only reliability and maintainability, but also of the response time of the support system.
Operationally Capable	A telescope is operationally capable when it can perform astronomical observations. It is assumed that the telescope will be capable if more than 95% of its collecting area, signal processing and data reduction capabilities are available.
Preventive Maintenance	Maintenance activities to prevent the occurrence of critical failures or damage in conjunction with safety, economic or environmental aspects.
Product Breakdown Structure	A product-oriented family tree composed of hardware, software, and data which result from the engineering effort during the validation and integration development phases of a system, and which completely defines the project/program.
Reliability	The probability that an item can perform its intended function for a specified interval under stated conditions.
Scheduled Maintenance	Planned or scheduled maintenance is a list of predetermined maintenance actions carried out at regular time intervals that are aimed at the prevention of breakdowns.
Science Availability A_s	The probability that a system is operationally capable at any point in time when used in a realistic support environment including external weather and power conditions.
Software Updates	The update of major software components which will require frequent updates. It excludes low level and embedded software components which will not require frequent updates.

Term	Definition
System and Sub-system	A system/subsystem is a grouping of software and hardware. A system is a set of interacting or interdependent components forming an integrated whole.
Testability	The performance and functionality of Built-In-Test (BIT) capability of the LMC and TM which shall be assessed using FMECA analysis. This capability will be required for remote monitoring and fault isolation of equipment in-operation. The BIT of the TM/LMC will be characterised by: • A list of functions or sub-functions that are tested • A detection rate that gives the percentage of functions or items whose failure are detected • A localisation or isolation rate that gives the percentage of detected failures that are associated, without ambiguity, to the failure of an identified item or component

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 SKA1 Phase1 System Requirements Specification SKA-TEL-SKO-0000008
AD2 SKA1 Operational Concept Document SKA1-TEL-SKO-0000307

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 SKA Support Concept - SKA-TEL-SKO-0000103;
RD2 SKA Integrated Logistic Support Plan (ILSP) - SKA-TEL-SKO-0000104
RD3 SKA Configuration Management Plan SKA-TEL-SKO-0000126
RD4 SKA1 Interface Management Plan SKA-TEL-SKO-0000025

3 Operationally Capable Definition

A telescope is operationally capable when it can perform astronomical observations. For the purpose of defining availability: it is assumed that the SKA telescopes will be operationally capable, if more than 95% of its collecting area, signal processing and data reduction capabilities are available. ie:

- *For LOW: "2 out of 40 stations", or equivalent signal processing, correlation, or data reduction capabilities can be in a failed state and the telescope will still be operationally capable.*
- *For MID: "9 out of 197 dishes", or equivalent signal processing, correlation, or data reduction capabilities can be in a failed state and the telescope will still be operationally capable.*

A maintenance strategy will be developed to ensure that the Operational Availability goals can be achieved. The Availability requirements in this document are based on a "repair as soon as possible strategy" and that the redundancy calculations do not allow for deterioration.

Pulsar Search and Timing Processing

The Pulsar Search and Timing Processing Engines (PSS and PST) will perform important science observations. However, these capabilities is not critical and the operations the science program can be re-scheduled if these capabilities are not available. It is therefore assumed that the Telescope will still be "Operationally Capable" even if both these capabilities are not available.

4 Availability Definitions

The SKA Telescopes and support organisations must be developed to ensure maximum science data at the minimum cost. The cost of maintenance personnel will also be a major cost driver. Regular refresh programs will ensure the Telescopes are up-to-date with the latest technology developments. Reliable equipment is also extremely important to eliminate maintenance & repairs as far as possible.

Availability is defined: As the probability that a system is operating satisfactorily (or operationally capable) at any point in time under stated conditions. It is a measure of how often an item fails (reliability) and how quickly it can be restored to operation (maintainability).

Three (3) availabilities have been defined (also see figure below):

1. **Science Availability (A_s):** Science availability includes all the factors that can result in the telescope not being available for science. It includes telescope critical failures, replacements (of critical items), software updates, maintenance, logistic delays, weather and utility conditions.
2. **Operational Availability (A_o):** Operational availability includes only support, maintenance, software updates and operational related factors. (i.e. support delays, spare parts, personnel and design factors).
3. **Inherent Availability (A_i):** Inherent availability includes factors that can be affected by the design authority. It therefore includes only the design, architecture, topology, reliability and maintainability factors and excludes external factors such as weather and support environment.

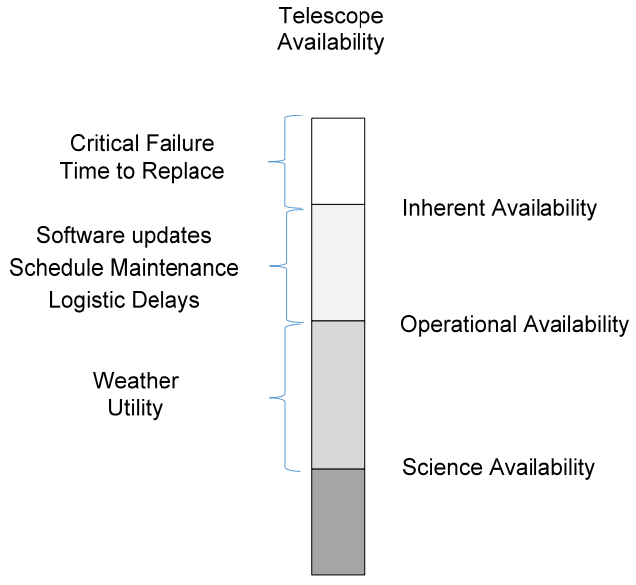


Figure 1: Science, Operational and Inherent Availability

5 Observatory, Telescope and System Demarcations

The Observatory Internal Block Diagram [RD4] shows the context of all the critical telescope systems. It also shows the critical interfaces and was used to develop the Product Breakdown Structure as below. Allocations were performed to these systems and the assumptions were noted.

The Hosting Agreements are being negotiated. It is assumed that the support elements will be outside the boundaries of the Observatory and will form part for the observatory support environment. The following elements are excluded from this report. It is expected that some of these they will be provided through the Hosting Agreements.

- Construction Camps
- Buildings
- Vehicles
- Cranes
- Support Base
- Roads
- Site Communication System
- Water and Waste Systems
- Accommodation System
- Landing Strips
- etc.

The following systems were outside the Telescope boundaries and therefore also excluded from this report.

- Observation Management and Planning Systems
- Engineering Management Systems
- Regional Centres
- Power Generation Systems
- Grid Power System and Distribution Lines to the site
- SDP Power Systems
- SDP Cooling Systems

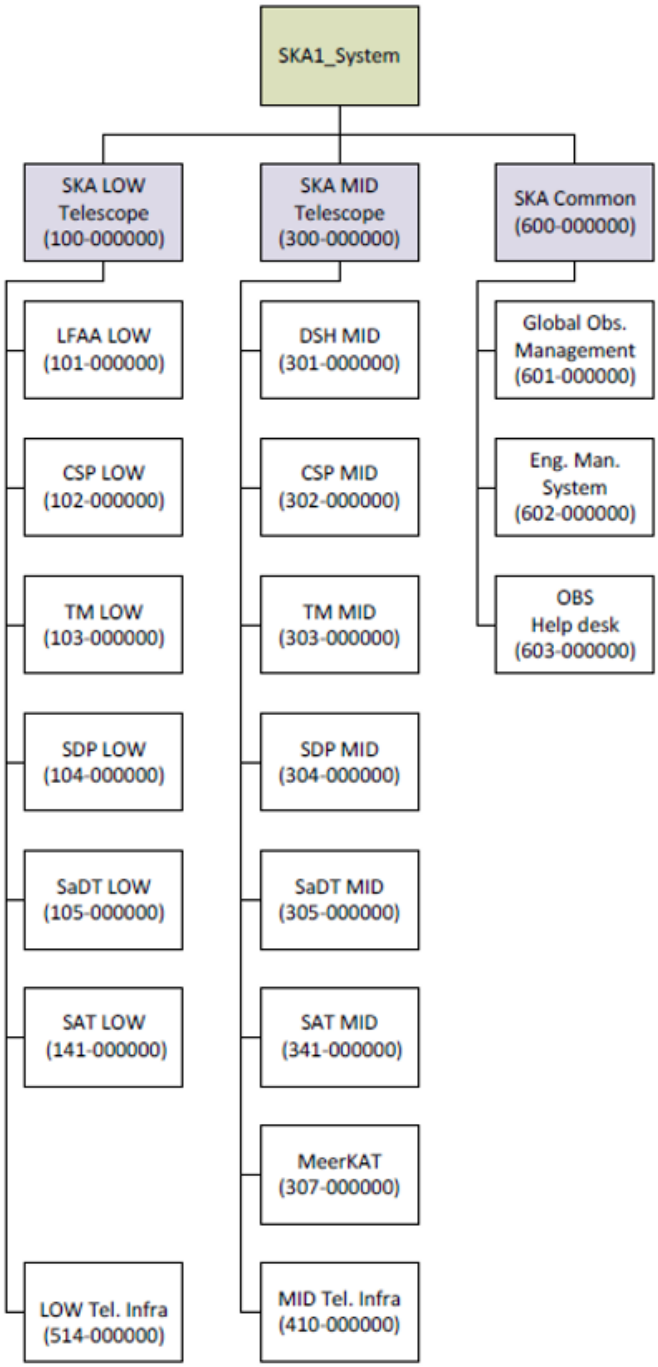


Figure 2: Product Breakdown Structure (PBS)

Table 3: MID Product Breakdown Structure

IND	REF NUMBER	MID SYSTEM / SUB-SYSTEMS
1	300-000000	SKA MID TELESCOPE
2	301-000000	MID DISH
2	307-000000	MeerKAT DISH
2	302-000000	CENTRAL SIGNAL PROCESSOR (CSP) MID
3	310-000000	CSP LOCAL MONITORING AND CONTROL (LMC) MID
3	311-000000	CSP CORRELATOR AND BEAMFORMER (CBF) MID
3	313-000000	CSP PULSAR SEARCH ENGINE (PSS) MID
3	314-000000	CSP PULSAR TIMING ENGINE (PST) MID
3	315-000000	CSP SUB ELEMENT INTEGRATION INFRASTRUCTURE MID
2	303-000000	TELESCOPE MANAGER (TM) MID
2	304-000000	SCIENCE DATA PROCESSING (SDP) MID
2	305-000000	SIGNAL AND DATA TRANSPORT (SADT) MID
2	341-000000	SYNCHRONISATION AND TIMING (SAT) MID
2	410-000000	SKA MID TELESCOPE INFRASTRUCTURE
3	401-010000	SITE MONITORING (ESSENTIAL TO TELESCOPE)
3	402-010000	POWER SYSTEM ZASI (ESSENTIAL TO TELESCOPE)
3	405-010000	OPERATIONS CONTROL CENTRE
3	405-020000	KAPB INFRASTRUCTURE (ESSENTIAL TO TELESCOPE)
3	413-000000	ARRAY INFRASTRUCTURE

Key: IND – Indenture Level of the PBS

REF NUMBER – Product Configuration Control Number

Table 4: LOW Product Breakdown Structure

IND	REF NUMBER	LOW SYSTEM / SUB-SYSTEMS
1	100-000000	SKA LOW TELESCOPE
2	101-000001	LOW FREQUENCY APERTURE ARRAY (LFAA) LOW
2	102-000000	CENTRAL SIGNAL PROCESSOR (CSP) LOW
3	110-000000	CSP LOCAL MONITORING AND CONTROL (LMC) LOW
3	111-000000	CSP CORRELATOR AND BEAMFORMER (CBF) LOW
3	113-000000	CSP PULSAR SEARCH ENGINE (PSS) LOW
3	114-000000	CSP PULSAR TIMING ENGINE (PST) LOW
3	115-000000	CSP SUB ELEMENT INTEGRATION INFRASTRUCTURE LOW
2	103-000000	TELESCOPE MANAGER (TM) LOW
2	104-000000	SCIENCE DATA PROCESSING (SDP) LOW
2	105-000000	SIGNAL AND DATA TRANSPORT (SADT) LOW
2	141-000000	SYNCHRONISATION AND TIMING (SAT) LOW
2	514-000000	SKA LOW TELESCOPE INFRASTRUCTURE

Key: IND – Indenture Level of the PBS

REF NUMBER – Product Configuration Control Number

6 Life Time Definition

The lifetime requirements for the Telescopes will have a major impact on the design, capital expenditure and operational cost. This section defines the lifetime parameters and should be used as inputs to the Level 1 requirements. It includes definitions of:

- Useful life, lifetime and expected life
- Wear-out and maintenance replacement
- Obsolescence, technology refresh, upgrades and retrofits.

The SKA Telescopes must be developed to operate within the expected lifetime requirements. The following lifetime related definitions are applicable:

Useful life, lifetime or expected life:

Wear-out is when an item or component failure rate increases, due to fatigue or depletion of material. The wear-out period of a system does not occur at one time for all components and the shortest-lived component will determine the wear-out period of the system. A system's *useful life* can be limited by its shortest-lived component unless it is replaced to extend the life of a system.

In designing a system, the design engineer must ensure that the shortest-lived component lasts long enough or that it can be replaced when required. When a system consists of multiple components, maintenance replacements may be part of a preventive maintenance strategy.

The design engineer must also consider the maintenance replacement strategy to ensure that the system will be able to operate for the *expected life*.

Obsolescence and technology refresh or upgrades:

Obsolescence is when a component in a system is no longer produced or supported. If spare parts cannot be obtained or when it becomes too costly to support, obsolescence will limit the *useful life* of the system.

Technology refresh, refers to the adoption of newer technology to meet the changing needs or to mitigate the risk of obsolescence. A technology refresh may be introduced to extend the *useful life,* and the capabilities of a system.

When a system consists of multiple components, it may be cheaper to perform replacements and upgrades during a refit period. During this period the equipment will normally be out of commission and fitted with new components. To take full advantage of the new technology, refresh programs should also include retrofits.

Lifetime requirements:

The Observatory should be designed for a 50 year lifecycle (SKA1 Phase1 System Requirements Specification SKA-TEL-SKO-0000008 [AD1]). Maintenance replacements, refresh and retrofit programs must be identified to extend the life time of shortest-lived components. These programs will focus on obsolescence risk mitigation and the changing requirements within the astronomy community.

The following replacement programs needs to be identified:

- Infrastructure, Electrical Systems and Dish Structure: Additional to the preventive and condition monitoring activities low-level component replacements & renewal programs will be used to ensure that the observatory lifecycle requirements can be achieved.
- LFAA: Habitat, undergrowth management programs and antenna replacement programs must be identified.
- Computing and Data Processing Equipment: Technology refresh programs must be identified to ensure newer technology to meet the changing needs or to mitigate the risk of obsolescence.

7 Telescope Availability State Definitions

The Telescopes shall operate continuously on a 24hr, 7day per week basis. Preventive, scheduled and corrective maintenance will be performed while operating and a 5 day working week is envisaged.

The following Telescope Availability States Definitions are applicable and were used to calculate Telescope down time estimates. (Note: All transition times were assumed to be negligible for the purpose of this document).

Table 5: Telescope Availability States Definitions

State		Definition
Operational	Observing	At least one sub-array is in the Calibrating or Observing mode, for the purpose of science observations.
	Standby	The Telescope is functionally available for science observations, but is not used for observing. Sub-arrays could be in Standby or Configuring mode, or no sub-arrays are be configured or used for observations.
Non-Operational (Cannot be used)	Weather	Observing is not possible due to poor weather (e.g. wind and stow conditions).
	Utility	Observing is not possible due to utility problems (e.g. power or cooling water not available at the site or SDP operations centre).
	Engineering and Maintenance	The Telescope is not available for any science observations due to, scheduled maintenance, off-line calibration, software updates or testing. (functional capability testing)
	System Fault	Telescope is not available for any science observations, due to a critical system fault and is undergoing ***critical repair*** or awaiting for a ***critical support item*** (i.e. delay for personnel or spares)

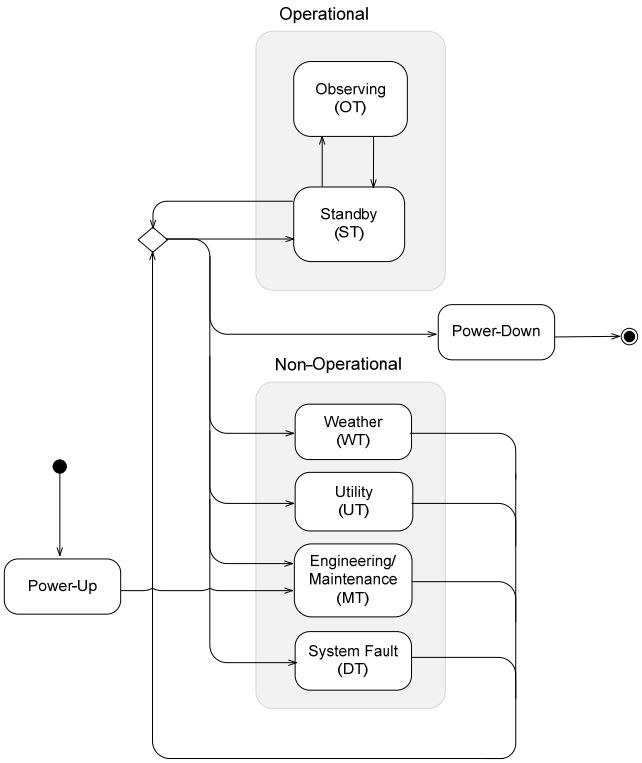


Figure 3: Telescope Availability State Diagram

The following formulae w.r.t the Telescope Availability State Definition are applicable:

Inherent Availability [1]

$$A_i = \frac{OT + ST}{OT + ST + CRT}$$

Operational Availability [2]

$$A_o = \frac{OT + ST}{OT + ST + MT + DT}$$

Science Availability [3]

$$A_s = \frac{OT + ST}{OT + ST + WT + UT + MT + DT}$$

Where:

OT *Observing Time: Sum of all the observing times.*

ST *Standby Time: Sum of all the standby times.*

WT *Weather: Sum of all the environmental down times*

UT *Utility: Sum of all the utility outages or too low/unavailable (power or cooling water)*

MT *Engineering and Preventative Maintenance: Sum of all maintenance down times (including software update and functional tests)*

DT *System Fault - Down Time (DT): Sum of all critical failure down time (critical repair time and critical support delay times)*

Note: The Telescope Downtime (System Fault) consist of critical repair and support delay times.

Critical Repair Time (CRT) is the time to replace an item that result in the Telescope not been available for observations.

Critical Support Delay (CSD) is the delay time to obtain a spare and to travel to site in order to repair or replace a critical item.

A Reliability, Availability and Maintainability (RAM) model is currently being developed and an Initial Availability Block Diagram can be seen in Annexure B. Best estimates were used to allocate time percentages to the Telescope Availability States. These percentages were then used to verify if the Availability requirements can be achieved.

Table 6: Availability State Percentages (Down Time Estimations)

	MID-Telescope-Time %	LOW-Telescope Time %
Observing (OT)	88%	90%
Standby (ST)	0%	0%
Weather (WT)	3%	1%
Utility (UT) (Power and cooling water)	4%	4%
Engineering / Maintenance (MT) (scheduled maintenance, off-line calibration, software updates or testing)	3%	3%
System Fault (DT)	2%	2%
Critical Repair Time (CRT)	1%	1%
Critical Support Delay (CSD)	1%	1%
	100%	100%

8 RAM Estimations

Science, Operational and Inherent Availability predictions were subsequently calculated using the formulae and time allocations. These calculations show the current predictions and will continually be monitored and improved as more information become available.

Science Availability, Operational Time and Standby Time are not design requirements, but will be used during operations as Key Performance Indicators (KPIs).

Table 7: Science, Operational and Inherent Availability Summary

Availability	MID Telescope	LOW Telescope
Inherent - A_i	99%	99%
Operational - A_o	95%	95%
Science - A_s	89%	91%

8.1 Telescope Operational Availability

Operational Availability is defined as the percentage of time the telescope is Operationally Capable to perform observations. It excludes the weather conditions and includes the support environment. A maintenance and support system shall be required to restore failures as quickly as possible and to ensure the availability of spare parts and skilled personnel.

Available entities will be allocated to a ***Resource Pool*** and managed by the Telescope Manager (TM). The required resources will be selected by TM from this pool and allocated to sub-arrays for various observations. The following array definitions are applicable:

A ***Sub-Array*** is an array selected by the operator (or script) for observations. Entities which require maintenance will be allocated to a ***Maintenance Sub-Array*** for maintenance and a maximum of 16 sub-arrays will be available.

An ***Engineering Array*** will be an *array* and will be used during integration and testing. Equipment or entities that are partially integrated, not verified and not accepted, will be part of the *Engineering Array*. Entities in the *Engineering Array* will not be available for observations and will be controlled by the integration team. Entities in the *Engineering Array* will be selected by the operator as *"Fitted" (to form part of the Resource Pool* before it can be used as part of a sub-array).

Maintenance will be performed in one or more ***Maintenance Sub-Arrays***. In general it is envisaged that only one maintenance array will be required and entities which require maintenance will be allocated to this Sub-Array. However, more than one (1) maintenance sub-array could be selected if required to test different scenarios. The operator will be able to hand over the control of an array to the maintainer for maintenance. Entities in the Maintenance sub-array will not be available for observations and will be in control of the maintenance authority.

Equipment or entities that are partially fitted or temporarily disabled for rebuild (i.e., deep-maintenance) will be removed from the resource pool and allocated to the ***Engineering Array***. Entities in the *Resource Pool* will be selected by the operator as *"not-Fitted" to form part of the* Engineering *Array.*

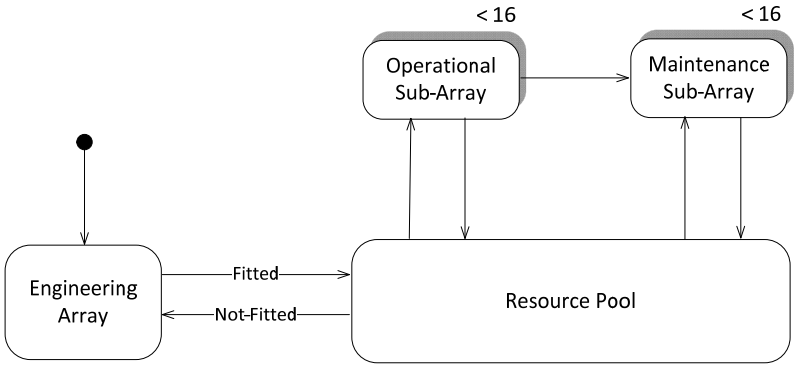


Figure 4: Engineering and Mantenance Array Definition

The following Operational Availability requirements are applicable at telescope level:

MID: The MID Telescope shall have an Operational Availability (A_o) of at least 95%.

LOW: The LOW Telescope shall have an Operational Availability (A_o) of at least 95%.

8.2 Inherent Availability

As previously discussed, Inherent Availability is related to the inherent reliability and maintainability design characteristics of the telescope. It is defined as the percentage of uptime related to the operational time and excluding weather conditions and the support environment. It assumes that maintenance personnel and spare parts are available in an ideal support environment. It includes the downtime required to perform corrective maintenance for critical items but excludes the time required to perform preventive maintenance and software updates and regular off-line functional test & calibration activities.

A series configuration was used and Availability Block Diagrams (ABD) have been developed (Annexure B). These diagrams are based on the Telescope definition and include all the critical telescope functionalities. (A critical function is defined in Table 2). The ABD estimates the Reliability and Maintainability parameters and assumes redundancies to determine an achievable allocated requirement for the Systems. It also identifies potential single point failures which should be reviewed and mitigated if possible.

The Inherent Availability budgets can be seen in Table 8.

Testability Requirements: Failure identification is critical to ensure the minimum down time. A list of functions or sub-functions will be developed and a detection rate, localization rate and false alarm rate will be determined using the Logistic Support Analysis [RD2] process.

There will be one or more Telescope Operators for each telescope at all times. During operation, a Telescope Operator will monitor the progress of the observations and data quality to ensure that the observations are successful.

In the event of a fault, the Telescope Operator will:

- Be informed by the Telescope Manager that a fault has occurred and of any action taken automatically;
- Identify that a fault has occurred;
- Identify the impact of the fault on on-going operations;
- Isolate the faulty system from the rest of the telescope if not done automatically;
- Authorise the continuation of observing if possible;
- Attempt high level trouble-shooting, depending on the nature of the fault;
- Add freeform comments to a log of the fault, such as its symptoms and effects, any additional manual corrective action taken and any impacts on existing observations; and
- Notify appropriate personnel.

The Telescope health and status trends will be monitored by the maintenance authority. The maintainers will also be responsible for maintenance, replacement and trouble-shooting down to LRU level. The Maintainer will:

- Monitor the Health of the Telescope;
- Perform Telescope-level failure identification and Telescope functional tests;
- Operate and perform maintenance on the equipment in the Maintenance Array;
- Perform analysis and determine trends on failure and health data;
- Upload software and perform software tests;
- Perform failure isolation and functional tests, using specialised test and control equipment;
- Identify the nature and location of the fault;
- Perform trouble-shooting activities;
- Obtain the correct spare parts and consumables required from the store; and
- Log the repair actions such as the failure mode and the tasks performed.

The testability requirements have been developed for each system and can be seen in Annexure C and D.

8.3 Maintenance Budgets

Direct Maintenance Hours (DMH) provides a measure of the maintenance personnel hours required on-site. The DMH and Mean Time To Repair (MTTR) budget estimates have been developed for each system and can be seen in Table 8. It is limited to on-equipment maintenance and *includes* all:

- Corrective maintenance
- Preventive maintenance
- Scheduled maintenance
- Inspections
- Test time and
- Software uploads and setup time.

It *excludes*:

- Management and supervision hours
- Maintenance administrative time
- Travelling to site
- Maintenance training
- Support delay times (waiting for spares or support equipment)
- Inactive time (personnel vacation and training hours)

8.4 System Requirements Table

The tables below provides a summary of all the system budget parameters. A textual description of these budgets can also be seen in Annexure D. These estimates are based on the current design and cost estimations and will be refined as more information becomes available.

Table 8: System Availability Requirements

Ref #	SYSTEM / SUB-SYSTEM	A_i	MTTR (crit) (hours)
1	LFAA	0.999	-
2	MID DISH (Dish only)	0.950 *	4
	MID DISH (Array)	0.999	-
3	CSP LOCAL MONITORING AND CONTROL (LMC)	0.999	1
4	CSP CORRELATOR AND BEAMFORMER (CBF)	0.999	1
5	CSP PULSAR SEARCH ENGINE (PSS)	0.950 **	2
6	CSP PULSAR TIMING ENGINE (PST)	0.950 **	2
7	TELESCOPE MANAGER	0.999	2
8	SCIENCE DATA PROCESSING	0.999	2
9	SIGNAL AND DATA TRANSPORT	0.999	4
10	SYNCHRONISATION AND TIMING	0.999	16
11	TELESCOPE INFRASTRUCTURE	See annex	-
	Telescope $A_{i\ (LOW)}$	99%	
	Telescope $A_{i\ (MID)}$	99%	

Key: Ref - Reference number used in Annexure D

MTTR (crit) the Mean Time To Repair for critical failures (telescope cannot perform observations)

* The “k out-of n” redundancy in the array configuration provides a high level of Inherent Availability. The array, MID and LOW are for all practical purposes 100% available.

** Valuable observations can still be performed without the Pulsar Search and Timing processing engines. A failure of these capabilities are therefore not critical and are excluded from the availability calculations.

Table 9: System Maintenance Down Time Estimates

Ref #	SYSTEM / SUB-SYSTEM	MDT (for hardware)	MDT (for software)
1	LFAA	-	1
2	MID DISH (Dish)	16	1
	MID DISH (Array)	-	-
3	CSP LOCAL MONITORING AND CONTROL (LMC)	-	1
4	CSP CORRELATOR AND BEAMFORMER (CBF)	-	2
5	CSP PULSAR SEARCH ENGINE (PSS)	-	-
6	CSP PULSAR TIMING ENGINE (PST)	-	-
7	TELESCOPE MANAGER	-	2
8	SCIENCE DATA PROCESSING	-	2
9	SIGNAL AND DATA TRANSPORT	-	1
10	SYNCHRONISATION AND TIMING	-	1
11	TELESCOPE INFRASTRUCTURE	1	-
	Sub Total	17	11.0
	Total		28.0

Key: Ref - Reference number used in Annexure D
MDT - Maintenance Down Time Per Year

Table 10: System Personnel Estimates

Ref #	SYSTEM / SUB-SYSTEM	MID			LOW		
		DMH (OLM)	DMH (ILM)	FTE	DMH (OLM)	DMH (ILM)	FTE
1	LFAA	-	-	-	3,500.00	xxx	2.56
2	MID DISH (40hous x 197 x 2)	14,608.00	7,216.00	12.40	-	-	-
3	CSP LOCAL MONITORING AND CONTROL (LMC)	6	8	0.008	6	8	0.008
4	CORRELATOR AND BEAMFORMER (CBF) (MID& LOW)	755		0.429	440		0.250
5	PULSAR SEARCH ENGINE (PSS)	186		0.106	143		0.081
6	PULSAR TIMING ENGINE (PST)	34		0.019	50		0.028
7	TELESCOPE MANAGER	60		3	60		3
8	SCIENCE DATA PROCESSING			xxx			xxx
9	SIGNAL AND DATA TRANSPORT			xxx			xxx
10	SYNCHRONISATION AND TIMING			xxx			xxx
11	TELESCOPE INFRASTRUCTURE			xxx			xxx
12	SUPPORT INFRASTRUCTURE MID			Xxx *			
13	SUPPORT INFRASTRUCTURE LOW						Xxx *
			Total	16.0		Total	5.9

Key: FTE = (team-qty-size x DMH) / 1760

The MID and LOW Support Infrastructure are not part of the Telescopes.

9 Requirement Verification

A requirement verification matrix has been developed and can be seen below. It shows the requirements as well as the verification method to be used. The following verification methods are applicable:

- **A Logistic Support Analysis (LSA)** will be performed to verify the spare part and maintenance personnel requirements.
- **RAM Measurements (RAM)** will be performed using Job Card data (failure data) to determine the Reliability, Availability and Maintainability parameters. It will also be used to analyse the spare parts and personnel requirements.
- **Reliability Analysis and HALT & HASS Tests (H&H)** will be performed, where possible, to ensure that the equipment is reliable. It will also be used as an input to estimate spare part quantity and maintenance requirements.
- **FMECA** will be performed to determine the failure criticality and maintenance and failure detection requirements.
- **Maintainability Analysis (MA)** will be performed to determine if the equipment is repairable, accessible and maintainable within the maintenance and support concept.
- **Evaluation (EV)** The design and equipment will be evaluated to determine if the system comply with the requirement.

Table 11: Requirements Verification Matrix

No	Requirement	LSA	RAM	H&H	FMECA	MA	EV
1	Availability	x	x				
1a	Reliability		x	x			
2a	Maintenance Personnel		x			x	
2b	MTTR					x	
3	Software Update						x
4	Testability				x		x

Annexure A: RAM Formulae

The following formulae were used and are applicable:

Science Availability: [4]

$$A_s = \frac{Science\ Available\ Time}{Total\ Calendar\ Time}$$

or

$$A_s = \frac{OT + ST}{OT + ST + WT + UT + MT + CMT}$$

Operational Availability: [5]

$$A_o \approx \frac{MTBM}{MTBM + MMT + MLD}$$

where:

MTBM: Mean Time Between Maintenance (preventative, corrective and software)
MMT: Mean Maintenance Time (preventative, corrective and software)
MLD: Mean Logistic Delay Time (personnel and spares)

or

$$A_o = \frac{OT + ST}{OT + ST + MT + CMT}$$

Inherent Availability: [6]

$$A_i = \frac{MTBcF}{MTBcF + MTTR}$$

where:

MTBcF: Mean Time Between Failures
MTTR: Mean Time To Repair (corrective only)

or

$$A_i = \frac{OT + ST}{OT + ST + CMT}$$

Availability with k out of n redundancy

$$A_{tot} = \sum_{k=0}^{N-M} C_k^N \, {A_0}^{N-k} (1 - A_0)^k \quad [7]$$

Unavailability

$$U_{tot} = 1 - A_{tot} \quad [8]$$

Availability in series configuration

$$A_{tot} = \prod_{i=1}^{M} A_i \quad [9]$$

Availability in parallel configuration

$$A_{tot} = 1 - \prod_{1}^{n} (1 - A_n) \quad [10]$$

MID -Telescope Availability

$$A_{mid} = A_m^9 \times A_s^7 \quad \text{..or} \quad [11]$$

$$A_{mid} = A_{groups}^{16}$$

LOW -Telescope Availability

$$A_{low} = A_m^9 \times A_s^7 \quad \text{..or} \quad [12]$$

$$A_{low} = A_m^9 \times A_s^7$$

Total MTBF [13]

$$MTBF_T = \frac{1}{(Qty \times (\frac{1}{MTBF_i})}$$

where:

$MTBF_T$:	*Mean Time Between Failure Total*
Qty	*Quantity (of items)*
$MTBF_i$	*Mean Time Between Failure (for the item)*

Annexure B: Initial Telescope Availability Block Diagram

Note: The Availability Block Diagram is an initial diagram and will be refined as more information becomes available.

LOW Telescope Availability Block Diagram
LFAA L01
NSDN (LFAA - CSP) L0301
DDBH (LFAA - CSP) L0302
Network Management L0305
SAT L04
TM L04
CBF L0602
CSP-SDP data and NSDN Network L0303 & L0304
Rack Power L0701
Power Distribution L0703
Rack Cooling L0702
SDP L08
SDP Infra L0501
SDP Infra L0502
1 Antenna
2 Antenna Pair Interface
3 Tile Beamformer
4 MCCS - TPM & LFAA/DN
1 Switch and Routers (Node)
2 Switch and Routers (TM)
3 NSDN Servers
1 Transmission Side
2 EMS Server etc.
1 Network LMC
2 Network Manager
1 Maser Clock
2 Transmitter
3 Receivers etc.
1 TM Servers
1 LMC
2 Master Server Units
3 Correlator Units
4 Beamformer Units
1 DVDM CSP Side
2 Repeater Stations + PWR
3 DVDM SDP Side
1 CBF Power System
1 Transformers
2 Mini Sub-station
1 HVAC Systems
1 LMC
2 Master
3 Processing
1 SDP Power System
1 SDP Cooling System
Ai = Ai(NSDN) x Ai(DDBH) x Ai(SAT) x Ai(TM) x Ai(CBF) x Ai(CSP-SDP Network) x Ai(Rack Power) x Ai(Pwr Dist) x Ai(Rack Cooling) x Ai(SDP) x Ai(SDP Rack Power) x Ai(Rack Cooling)
MID Telescope Availability Block Diagram
MID Array
MeerKat Array
NSDN (Dish - CSP) M0301
DDBH (Dish - CSP) M0302
Network Management M0305
SAT M04
TM M04
CBF M0602
CSP-SDP data and NSDN Network M0303 & M0304
Rack Power M0701
Power Distribution M0703
Rack Cooling M0702
SDP M08
SDP Infra M0501
SDP Infra M0502
1 Interface Rack
1 Switch and Routers (Node)
2 Switch and Routers (TM)
3 NSDN Servers
1 Transmission Side
2 EMS Server etc.
1 Network LMC
2 Network Manager
1 Maser Clock
2 Transmitter
3 Receivers etc.
1 TM Servers
1 LMC
2 Master Server Units
3 Correlator Units
4 Beamformer Units
1 DVDM CSP Side
2 Repeater Stations + PWR
3 DVDM SDP Side
1 KAPB Power System
1 Transformers
2 Mini Sub-station
1 HVAC Systems
1 LMC
2 Master
3 Processing
1 SDP Power System
1 SDP Cooling System
Ai = Ai(NSDN) x Ai(DDBH) x Ai(SAT) x Ai(TM) x Ai(CBF) x Ai(CSP-SDP Network) x Ai(Rack Power) x Ai(Pwr Dist) x Ai(Rack Cooling) x Ai(SDP) x Ai(SDP Rack Power) x Ai(Rack Cooling)

Annexure C: Telescope RAM Requirements

M	MID Telescope, 300-000000

Assumptions

- The “k out-of n” redundancy in the array configuration provides a high level of Inherent Availability. The array availability is assumed to be 100% available.
- Power provided to the site is external the Telescope
- Power is provided to the SDP centre and is external to the Telescope

Availability

1	The MID-Telescope shall have an Inherent Availability of more than 99%

Maintenance Personnel

2	The MID-Telescope shall require less than xxx FTEs per year. (O-Level and I-Level maintenance)

Software Update

3	SKA1_Mid Telescope shall facilitate updates of major software components within the Telescope down time allocations.

Testability Requirement

4	SKA1_Mid shall each test, detect, isolate and report failures to the operational and maintenance personnel
4a	SKA1_Mid shall detect more than 99% of all Critical Failures.
4b	SKA1_Mid shall isolate and log more than 95% of all failures down to a LRU level.

L	LOW Telescope, 100-000000

Assumptions

- The “k out-of n” redundancy in the array configuration provides a high level of Inherent Availability. The array availability is assumed to be 100% available.
- Power provided to the site is external the Telescope
- Power is provided to the SDP centre and is external to the Telescope

Availability

1	The LOW-Telescope shall have an Inherent Availability of more than 99%

Maintenance Personnel

2	The LOW-Telescope shall require less than xxx FTEs per year. (O-Level and I-Level maintenance).

Software Update

3	SKA1_LOW Telescope shall facilitate updates of major software components within the Telescope down time allocations.

Testability Requirement

4	SKA1_LOW shall each test, detect, isolate and report failures to the operational and maintenance personnel
4a	SKA1_LOW shall detect more than 99% of all Critical Failures.
4b	SKA1_LOW shall isolate and log more than 95% of all failures down to a LRU level.

Annexure D: System RAM Requirements

1	**LFAA, 101-000001**
Assumptions	
All 64 Control and monitor servers are critical to the operation of the LOW telescope Only one person per maintenance activity is assumed.	
Availability	
1	The LFAA shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	A LFAA shall require less than 2.6 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The LFAA shall have a MTTR for critical failures, of less than 1 hour
Software Update and Maintenance Down Time	
3	The LFAA shall be designed not to require software and hardware maintenance down time, in excess of 1 hour per year. (during steady state operations)
Testability Requirement	
4	The Monitor and Calibration Servers shall identify all failures and report the health status of the following LRUs to the Telescope Manager (TM): Pyramid Antenna Power Interface Unit Antenna Power Supply Module Tile Processing Module 39-Port 40GBE Data switch PPS/10Mhz Clock Distribution Unit Rack Power Supply Unit Rack Cooling System Data Switch Rack Interconnect MCCS Rack Assembly Data Switch MCCS Servers MCCS Rack Cooling System

2	**MID DISH / MeerKAT RECEPTORS, 301-000000, 307-000000**
Assumptions	
Three (3) cryocooler systems per dish will require maintenance every 1.3 years each The MeerKAT dish will be retrofitted with MID receivers. The availability of a single dish is not critical to the operation. (95% of the dishes can be in a failed state). A failure of a single dish is not critical and a large fraction (ie 5%) of the dish array can be unavailable, yet the telescope is still capable of performing valuable observations. It is assumed the number of dishes available will not degrade below 95% and any failures will be restored as soon as possible. (Spares will be available and personnel will work 5days per week). **Availability**	
1	The Dish shall have an Inherent Availability of more than 95.0%
Maintenance Personnel	
2a	A Dish shall require less than 12.4 FET.
2b	The Dish shall have a MTTR of less than 4 hours.
Software Update and Maintenance Down Time	
3	The Dish shall be designed not to require software and hardware maintenance down time, in excess of 17 hours per year.
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD …

3	LOCAL MONITORING AND CONTROL (CSP), 310-000000, 110-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than .008 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 1 hours.
Software Update and Maintenance, Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 1 hour per year. (during steady state operations)
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

4a	CORRELATOR AND BEAMFORMER (MID), 311-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than 0.43 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 1 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 2 hours per year. (during steady state operations)
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

4b	CORRELATOR AND BEAMFORMER (LOW), 111-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than 0.25 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 1 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 2 hours per year. (during steady state operations)
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

5a	PULSAR SEARCH ENGINE (PSS) MID, 313-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 95%
Maintenance Personnel	
2a	The System shall require less than 0.106 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	Not applicable
Software Update and Maintenance Down Time	
3	Not applicable
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

5b	PULSAR SEARCH ENGINE (PSS) LOW, 113-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 95%
Maintenance Personnel	
2a	The System shall require less than 0.081 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	Not applicable
Software Update and Maintenance Down Time	
3	Not applicable
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

6a	PULSAR TIMING ENGINE (PST) MID, 314-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 95%
Maintenance Personnel	
2a	The System shall require less than 0.019 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	Not applicable
Software Update and Maintenance Down Time	
3	Not applicable
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

6b	PULSAR TIMING ENGINE (PST) LOW, 114-000000
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 95%
Maintenance Personnel	
2a	The System shall require less than 0.028 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	Not applicable
Software Update and Maintenance Down Time	
3	Not applicable
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

7	TELESCOPE MANAGER, **303-000000, 103-000000**
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than 3 FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 2 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 2 hours per year. (during steady state operations).
Testability Requirement	
4	The LMC shall report its health status of the following LRUs: TBD TBD

8	SCIENCE DATA PROCESSING
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than xxx FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 2 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 2 hours per year. (during steady state operations)
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

9	SaDT, **305-000000, 105-000000**
Assumptions	
Availability	
1a	The NSDN shall have an Inherent Availability of more than 99.9% (critical failure) The DDBH shall have an Inherent Availability of more than 99.9% (critical failure) The CSP-SDP shall have an Inherent Availability of more than 99.9% (critical failure)
Maintenance Personnel	
2a	The System shall require less than xxx FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 4 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 1 hours per year. (during steady state operations)
Testability Requirement	
4	The LMC shall report its health status of the following LRUs to the Telescope Manager (TM): TBD TBD

10	SYNCHRONISATION AND TIMING **341-000000, 141-000000**
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than xxx FETs for corrective and preventative maintenance. (O-Level and I-Level)
2b	The System shall have a MTTR (for critical failures) of less than 16 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 1 hours per year. (during steady state operations).
Testability Requirement	
4	The LMC shall report its health status of the following LRUs: TBD TBD

11a	MID Telescope Infrastructure **410-000000**
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than 3 FETs for corrective and preventative maintenance. (O-Level and I-Level)
	The System shall have a MTTR (for critical failures) of less than 2 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 2 hours per year. (during steady state operations).
Testability Requirement	
4	The LMC shall report its health status of the following LRUs: TBD TBD

11a	LOW Telescope Infrastructure **514-000000**
Assumptions	
Availability	
1	The System shall have an Inherent Availability of more than 99.9%
Maintenance Personnel	
2a	The System shall require less than xxx FETs for corrective and preventative maintenance. (O-Level and I-Level)
	The System shall have a MTTR (for critical failures) of less than 2 hours.
Software Update and Maintenance Down Time	
3	The System shall be designed not to require software and hardware maintenance down time, in excess of 1 hours per year. (during steady state operations).
Testability Requirement	
4	The LMC shall report its health status of the following LRUs: TBD TBD