Interface Control Document LMC to CSP Sub-elements

Document Number SKA-TEL-CSP-0000019
Context .... LMC_SE-ICD
CSP Document Number SKA-TEL.CSP.LMC-CSP-ICD-001
Revision: 3
CIDL ID SE-7b
Author .... Sonja Vrcic;Mike MacIntosh
Date 2015-12-11
Status .... Released
Classification .... Unrestricted

Prepared By	Name	Sonja Vrcic	Signature	Sonja Vrcic (Jan 14, 2016)
	Organisation	NRC		
Reviewed By	Name	Brent Carlson	Signature	Brent Carlson (Jan 14, 2016)
	Organisation	NRC		
	Name	Grant Hampson	Signature	Grant Hampson (Jan 25, 2016)
	Organisation	CSIRO		
	Name	Ben Stappers	Signature	Ben Stappers (Jan 29, 2016)
	Organisation	Manchester University		
	Name	Willem Van Straten	Signature	Willem van Straten (Jan 29, 2016)
	Organisation	Swinburne University		
Approved By	Name	David Loop	Signature	David Loop (Jan 22, 2016)
	Organisation	NRC		
Issued By	Name	Donna Morgan	Signature	
	Organisation	NRC		

DOCUMENT HISTORY

Issue	Date	ECN	Change Description
A	2014-01-30		First draft
B	2014-03-31		Updated figures in section 1.6
C	2014-04-11		Add ‘Interface Requirements’ section and renamed ‘Interface Specifications by class’ section as ‘Interface Implementation’. Updated Figure 1.2
D	2014-04-25		Updated by SV before TIM#2 to add requirements derived from TM requirements and ICD CSP to TM.
E	2014-07-02		Updated for CSP TIM#3. Added description of message content. Removed the list of detailed requirements.
F	2014-08-27		Updated after CSP TIM#3. Most notably, receptors and beams can be added/removed to/from a sub-array only at scan boundaries or to/from unused (idle) sub-array. Incorporated comments received from PSS and PST Sub-elements.
G	2014-10-27		75% version for PDR submission (as planned).
1	2015-03-02	CSP-PDR-OAR-097	Updated reference to date and time standard ISO 8601 Data elements and interchange formats – Information interchange – Representation of dates and time.
		CSP-PDR-OAR-098 CSP-PDR-OAR-099	Not applicable Survey Telescope has been delayed. (Added clarification regarding PAF beams and products (all the beams from the same antenna belong to the same sub-array. Capability baseline includes the products for all the beams).)
		CSP-PDR-OAR-101	Updated the document to consistently use number separators as follows: 1,000.00 (as in the Level 1 requirements).
		CSP-PDR-OAR-102 CSP-PDR-OAR-103	Not applicable sub-element Clock and Timing has been integrated in other sub-elements. (Updated Chapter to explain why 8-bit fields are used for parameters Packet ID and Number of Packets.)
		CSP-PDR-OAR-104	Updated section 1.7 to clarify division of responsibility for monitor and control functionality between LMC and other sub-elements.
		CSP-PDR-OAR-105	Updated section 1.8 to state that when the standards and protocols are selected, they will be listed in this document.
		CSP-PDR-OAR-106	Updated Section 6.3.5 to clarify CSP approach to modes and states definition (in this release).
		CSP-PDR-OAR-110	Updated Section 6.3 to refer to Section 1.8 for the list of standards.

		CSP-PDR-OAR-122	Updated Section 6.3.6.5 – added the list of events identified so far.
		CSP-PDR-OAR-130 CSP-PDR-OAR-131	Updated Chapters 10 and 0 to clarify why the interface definition for CSP_Low.CBF and CSP_Survey.COR is almost the same as for the external (CSP to TM) interface.
		CSP-PDR-OAR-506	Updated Sections 7.2.1, 7.3 and 7.4 to explicitly state that Observing Modes Pulsar Search and Pulsar Timing cannot be operated concurrently in the same sub-array. Pulsar Search and Pulsar Timing can be operated concurrently in different sub-arrays.
		n/a	Updated based on the comments received from Sharon Dousset (editorial) and Elisabetta Giani (pulsar search). In addition, some of the observations for the CSP to TM ICD were also propagated to this ICD. CSP_Mid.CBF delay models 2nd order polynomials, once per second (TBC).
2	2015-04-30	CSP-PDR-OAR-506	At TIM#4 it was concluded that CSP_Mid design will support concurrent operation of Pulsar Search and Pulsar Timing in the same sub-array. Sections: 7.5 and 7.6 have been updated accordingly. Note 1: this version of the document does not mention concurrency of the VLBI beam-forming with other Observing Modes (Imaging, Pulsar Search and Pulsar Timing) as it is not clear whether that is a requirement. Note 2: this version of the document does not include results of the re-baselining (consequently there is no support for Pulsar Search and Pulsar Timing in the CSP_Low).
		n/a	Updated CSP_Mid.PSS parameters based on the input from the PSS team (Section 8.3). Updated Chapters 8 and 9 to state that Pulsar Search and Pulsar Timing can be independently started, operated and stopped in up to 16 sub-arrays – that was implied, but not explicitly stated.
2A	2015-11-02		Updated as per SKA re-baselining. Removed references to CSP sub-element Clock and Timing Distribution. sysML diagrams provided by Mike MacIntosh. This version is a work in progress. Further updates are expected pending review by CSP_Low.CBF. Updated: PSS beam BW – up to 1200MHz, integration time for imaging.
2B	2015-11-23		Based on comments and discussion with Grant Hampson and Michael Rupen: Update description of interface with CSP_Low.CBF. Section 6.1 specifies which sub-element provides the network equipment (switch). Changed definition of the Observing Mode for Imaging, CSP defines a single Observing Mode for Imaging, which provides functionality required for Spectral-line Imaging, Continuum Imaging, zoom windows and pulsar phase binning (see description of Imaging Mode in Chapter

			7 and Chapter 10). - PST (parameters- table) - CBF.LOW(parameters for Imaging) - CBF.Mid (parameters for Imaging)
2C	2015-12-10		Ewan Barr provided the list of parameters for Pulsar Timing. Mike Pleasance provided the estimates for the Jones Matrices required by CSP_Mid.CBF. Thushara Gunaratne provided the estimates for the delay models for Mid.CBF. Brent Carlson provided the estimate for the number of Monitor Points in CSP_Mid.CBF.
3	2015-12-11		Delta PDR submission.

DOCUMENT SOFTWARE

Application		Version	Filename
Word processing	MS Word		SE-7b_SKA-TEL-CSP-0000019_3_ICD-LMC-to-CBF-PSS-PST_2015-12-11-v4.docx

ORGANISATION DETAILS

Designation	Name	Organisation
Primary Author for releases D and later.	Sonja Vrcic	NRC
Primary Author for releases A, B and C	Mike MacIntosh	STFC

TABLE OF CONTENTS

1 INTRODUCTION 16
1.1 Purpose of Document 16
1.2 Scope of Document 16
1.3 Intended Audience 16
1.4 Roles and responsibilities 17
1.5 Interface scope 18
1.6 Interface topology 18
1.7 Overview 21
1.8 Summary of standards 22
1.9 Guidelines for the ICD Development 22
1.10 Conventions 23
2 APPLICABLE AND REFERENCE DOCUMENTS 24
2.1 Applicable Documents 24
2.2 Reference Documents 24
3 SPECIFICATION CLASSES AND APPLICABLE STANDARDS 26
3.1 Interface Specifications - Electronic 26
3.2 Interface Specifications - Data exchange 26
4 TEST, DIAGNOSTIC OR MAINTENANCE FEATURES 27
5 SAFETY ASPECTS 28
6 INTERFACE IMPLEMENTATION – COMMON 29
6.1 Network Equipment 29
6.1.1 CSP_Low Network Equipment 29
6.1.2 CSP_Mid Network Equipment 29
6.2 Interface Implementation - Electronic 30
6.3 Interface Implementation - Data Exchange 30
6.3.1 Components and Capabilities 31
6.3.2 Error Handling 32
6.3.3 Extensibility and Future Compatibility 36
6.3.4 Naming Conventions 36
6.3.5 CSP Sub-element Modes and States 36
6.3.6 Operations 37
6.3.7 Protocol 41
7 INTERFACE IMPLEMENTATION – CSP_MID.CBF 43
7.1 CSP_Mid.CBF Capabilities 43
7.2 CSP_Mid.CBF Messages 45

7.3 CSP_Mid.CBF Scan Configuration 46
7.4 CSP_Mid.CBF Observing Mode Imaging 47
7.5 CSP_Mid.CBF Observing Mode Pulsar Search Beamforming 50
7.6 CSP_Mid.CBF Observing Mode Pulsar Timing Beamforming 52
7.7 CSP_Mid.CBF Observing Mode VLBI Beamforming 54
7.8 CSP_Mid.CBF Engineering Parameters 56
7.9 CSP_Mid.CBF Requirements for Data Persistence 56
7.10 CSP_Mid.CBF Alarms 57
7.11 CSP_Mid.CBF Events 57
7.12 CSP_Mid.CBF Monitor Points 57

8 INTERFACE IMPLEMENTATION – CSP_MID.PSS 58
8.1 CSP_Mid.PSS Capabilities 58
8.2 CSP_Mid.PSS Messages 59
8.3 CSP_Mid.PSS Observing Mode Parameters 60
8.4 CSP_Mid.PSS Engineering Parameters 63
8.5 CSP_Mid.PSS Requirements for Data Persistence 63
8.6 CSP_Mid.PSS Service from TM 64
8.7 CSP_Mid.PSS Alarms 64
8.8 CSP_Mid.PSS Events 65
8.9 CSP_Mid.PSS Monitor Points 65

9 INTERFACE IMPLEMENTATION – CSP_MID.PST 66
9.1 CSP_Mid.PST Capabilities 66
9.2 CSP_Mid.PST Messages 67
9.3 CSP_Mid.PST Observing Mode Parameters 67
9.4 CSP_Mid.PST Engineering Parameters 74
9.5 CSP_Mid.PST Requirements for Data Persistence 74
9.6 CSP_Mid.PST Alarms 75
9.7 CSP_Mid.PST Events 75
9.8 CSP_Mid.PST Monitor Points 75

10 INTERFACE IMPLEMENTATION – CSP_LOW.CBF 76
10.1 CSP_Low.CBF Capabilities 76
10.2 CSP_Low.CBF Messages 78
10.3 CSP_Low.CBF Scan Configuration 79
10.4 CSP_Low.CBF Observing Mode Imaging 80
10.5 CSP_Low.CBF Observing Mode Pulsar Search Beamforming 83
10.6 CSP_Low.CBF Observing Mode Pulsar Timing Beamforming 85
10.7 CSP_Low.CBF Engineering Parameters 87
10.8 CSP_Low.CBF Requirements for Data Persistence 87
10.9 CSP_Low.CBF Alarms 88

10.10 CSP_Low.CBF Events 88
10.11 CSP_Low.CBF Monitor Points 88

11 INTERFACE IMPLEMENTATION – CSP_LOW.PSS 89
11.1 CSP_Low.PSS Capabilities 89
11.2 CSP_Low.PSS Messages 90
11.3 CSP_Low.PSS Observing Mode Parameters 91
11.4 CSP_Low.PSS Engineering Parameters 94
11.5 CSP_Low.PSS Requirements for Data Persistence 94
11.6 CSP_Low.PSS Service Required from TM 94
11.7 CSP_Low.PSS Alarms 95
11.8 CSP_Low.PSS Events 95
11.9 CSP_Low.PSS Monitor Points 95

12 INTERFACE IMPLEMENTATION – CSP_LOW.PST 96
12.1 CSP_Low.PST Capabilities 96
12.2 CSP_Low.PST Messages 97
12.3 CSP_Low.PST Observing Mode Parameters 97
12.4 CSP_Low.PST Engineering Parameters 98
12.5 CSP_Low.PST Requirements for Data Persistence 98
12.6 CSP_Low.PST Alarms 98
12.7 CSP_Low.PST Events 98
12.8 CSP_Low.PST Monitor Points 99

13 INTERFACE VERIFICATION 100
13.1 Verification stages 100
13.2 Requirement Verification Methods 100

APPENDIX A. INTELLECTUAL PROPERTY DECLARATION 102

APPENDIX B. TO BE DEFINED 103

LIST OF TABLES

Table 1-1 Roles and responsibilities 17
Table 1-2 Interface class specifications 18
Table 2-1 Applicable Documents 24
Table 2-2 Reference Documents 24
Table 6-1 Messages transmitted over this interface 30
Table 7-1 CSP_Mid.CBF Capabilities 44
Table 7-2 CSP_Mid.CBF Scan Configuration 47
Table 7-3 CSP_Mid.CBF End Scan 47
Table 7-4 CSP_Mid.CBF Observing Mode Imaging – Configuration Parameters 48
Table 7-5 CSP_Mid.CBF Pulsar Search Beamforming Observing Mode Parameters 51
Table 7-6 CSP_Mid.CBF Parameters for Pulsar Timing Beamforming 53
Table 7-7 CSP_Mid.CBF Parameters for VLBI Beamforming 55
Table 8-1 CSP_Mid.PSS Capabilities 59
Table 8-2 CSP_Mid.PSS Observing Mode Parameters 61
Table 9-1 CSP_Mid.PST Capabilities 66
Table 9-2 Legend for Table 9-3 68
Table 9-3 CSP_Mid.PST - Observing Mode Parameters 68
Table 10-1 CSP_Low Capabilities 77
Table 10-2 CSP_Low.CBF Scan Configuration 80
Table 10-3 CSP_Low.CBF End Scan 80
Table 10-4 CSP_Low.CBF Observing Mode Imaging – Configuration Parameters 81
Table 10-5 CSP_Low.CBF Parameters for Pulsar Search Beamforming 84
Table 10-6 CSP_Low.CBF Parameters for Pulsar Timing Beamforming 86
Table 11-1 CSP_Low.PSS Capabilities 89
Table 11-2 CSP_Low.PSS Observing Mode Parameters 91
Table 12-1 CSP_Low.PST Capabilities 96
Table 13-1 Verification methods 101
Table 13-2 Summary of content to be defined 103

LIST OF FIGURES

Figure 1-1 CSP_Low sub-elements and interfaces 19
Figure 1-2 CSP_Mid sub-elements and interfaces 20

LIST OF ACRONYMS AND ABBREVIATIONS

ADD	Architecture Design Document
AIV	Assembly, Integration and Verification
AOR	Annual Operating Requirement
ARC	Architecture Work Package
ASCII	American Standard Code for Information Interchange, a character-encoding scheme.
ASIC	Application Specific Integrated Circuit
ASTRON	Netherlands Institute for Radio Astronomy
ATC	Astronomy Technology Centre
CA	Consortium Agreement
CAD	Computer Aided Design
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CI	Configuration Item
CIDL	Configuration Item Data List
CITA	Canadian Institute of Theoretical Astrophysics
CLI	Command Line Interface
CM	Configuration Management
COMP	Commissioning, Operation and Maintenance Plan
ConOps	Concept of Operations
COTS	Commercial Off-The-Shelf
CP	Construction Plan
CSCI	Computer Software Configuration Item
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Central Signal Processor
CUR	Curtin University
DDD	Detailed Design Document
DOC	Development and Operational Cost
DRD	Document Requirements Descriptions
DSH	Dish Element or Consortium
DSP	Digital Signal Processing

ECP	Engineering Change Proposal
EICD	External Interface Control Document
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interface
FAD	Feasibility Analysis Documentation
FFT	Fast Fourier Transformation
FMECA	Failure Modes, Effects and Criticality Analysis
FPGA	Field Programmable Gate Array
FTA	Fault Tree Analysis
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HDL	High Level Design Language
HSP	Health and Safety Plan
ICD	Interface Control Document
IICD	Internal Interface Control Document
ILS	Integrated Logistic Support
ILSP	Integrated Logic Support Plan
INAF	National Institute for Astrophysics
INFRA	Infrastructure Element or Consortium
I/O	Input/Output
IP	Intellectual Property
IR	SKA South Africa and Australia Infrastructure Requirements
KLAASA	Key Lab of Aperture Array and Space Application
LFAA	Low Frequency Aperture Array Element or Consortium
LSA	Logistical Support Analysis
MATLAB	MATLAB simulation language and application
M&C	Monitor and Control
MTTR	Mean Time To Repair
NCRA	National Centre for Radio Astrophysics
NIP	Non-Imaging Processor
NRC	National Research Council (Canada)
NZA	New Zealand Alliance
QA	Quality Assurance
OPS	Operations Work Package

OX	Oxford University
PA	Product Assurance
PDF	Portable Document Format
PDR	Preliminary Design Review
PHS&T	Packaging, Handling, Storage and Transportation
PIP	Physical Implementation Proposal
PMX	PowerMX
PSS	Pulsar Search
PST	Pulsar Timing
PTP	Prototyping Plan
QA	Quality Assurance
QAP	Quality Assurance Plan
QC	Quality Control
QP	Quality Plan
RAM	Reliability, Availability and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
RFI	Radio Frequency Interference
RMP	Risk Management Plan
RR	Risk Register
RRS	Reutech Radar Systems
RS	Requirement Specification
SAD	System Baseline Design
SADT	Signal and Data Transport Element and Consortium
SDP	Science Data Processing
SII	System Integration Infrastructure
SEMP	System Engineering Management Plan
SKA	Square Kilometre Array
SKAO	SKA Organisation
SKA-SA	SKA South Africa
SMART	Software Methods, Approaches, Research, and Technologies
SOW	Statement of Work
SPA	Software Product Assurance
SRR	System Requirements Review
STFC	Science and Technology Facilities Council

SWIN	Swinburne University of Technology
SW	Software
SYSML	System Engineering Simulation Language and application
TBC	To be confirmed
TBD	To be decided
TDT	Time Domain Team
TM	Telescope Manager Element and Consortium
UMAN	University of Manchester
UML	Unified Modelling Language
UTC	Coordinated Universal Time
VPL	Verification Planning Work Package
WBS	Work Breakdown Structure
WP	Work Package
WPEP	Work Package Execution Plan

LIST OF TERMS

Alarm – The term *Alarm* (with a capital A) refers to the CSP-generated message used to report errors and faults. This document describes only those Alarms generated by the CSP; Alarms generated by the TM are sent elsewhere (beyond the scope of the CSP/TM interface).

Active Alarm - An Alarm which has an alarm state that has been raised, but not cleared.

Alarm Detection Point - The entity that detected the alarm.

Component – The term *Component* (with a capital C) is used to refer to a CSP hardware or software Component that can be identified, controlled and monitored via this interface. The term Component is used to refer to the CSP sub-elements and their components, i.e. LRUs and software process. In many cases LRUs consist of many Components that can be identified, monitored and controlled independently. Each Component is assigned a unique identifier**.** For more information refer to Section 6.3.1.

Capability – The term *Capability* refers to a representation of a CSP functionality that can be identified, controlled and monitored via this interface. The CSP sub-elements provide a layer of abstraction to allow LMC to set, control and monitor signal processing without being aware of the sub-element implementation. This ICD identifies the set of Capabilities and their parameters. The most notable Capability is sub-array. For more information refer to Section 6.3.1.

Event – The term *Event* (with a capital E) refers to a message used to report an event. An Event is something that happens which may be of interest. Examples: a fault, a change of status, crossing a threshold, or an external input to the system.

Error - A deviation of a system from normal operation.

Fault - Lasting error or warning condition.

Log – A record generated and logged into a file in order to store (more-or-less permanently) information that can be of interest during testing and troubleshooting.

Perceived Severity - The severity of the Alarm as determined by the Alarm Detection Point using the information it has available. Severity is also assigned to Events (TBC).

Query – The term *Query* is used for LMC-generated messages that instruct the sub-element to report values for a set of parameters. In the technical literature Query is often referred to as a GET operation. A Query or GET can be issued for all read-only and read-write parameters.

Response – The term *Response* is used to describe a CSP-generated message that contains a response to a TM SET Parameters Request or Query/GET.

Scan - A scan is the atomic unit of observer command. Certain parameters can change only at scan boundaries, most notably the observing band and the composition of a Sub-Array. Note that, while the scan is a common concept used in most current interferometers and output data formats, it is still TBD whether “scan” will be so used by the SKA.

Sub-array – A collection of Capabilities used to perform an independent observing programme. CSP sub-array is an exclusive set of Capabilities. Exclusive in this context means that a Capability cannot belong to more than one sub-array at any given time.

1 INTRODUCTION

1.1 Purpose of Document

This document defines the interfaces between the CSP sub-element Local Monitor & Control (LMC) and other CSP sub-elements. In general, the interfaces are defined in accordance with the SKA Interface Management Plan [AD2].

1.2 Scope of Document

This document describes interfaces between the CSP_Low Local Monitor and Control (CSP_Low.LMC) sub-element and the following CSP_Low sub-elements:

1. CSP_Low Correlator and Beamformer (CSP_Low.CBF)
2. CSP_Low Pulsar Search Engine (CSP_Low.PSS)
3. CSP_Low Pulsar Timing Engine (CSP_Low.PST)

This document describes interfaces between the CSP_Mid Local Monitor and Control (CSP_Mid.LMC) sub-element and the following CSP_Mid sub-elements:

1. CSP_Mid Correlator and Beamformer (CSP_Mid.CBF)
2. CSP_Mid Pulsar Search Engine (CSP_Mid.PSS)
3. CSP_Mid Pulsar Timing Engine (CSP_Mid.PST)

1.3 Intended Audience

The intended audience of this document is the Systems Engineers and engineering teams of the leading and following parties of the interface.

1.4 Roles and responsibilities

Table 1-1 defines the roles and responsibilities for the relevant parties.

Table 1-1 Roles and responsibilities

Role	Sub-element	Point of contact	Responsibilities
Leading Party	LMC	LMC lead	Create and maintain this document.
Following Party	CSP_Low Correlator and Beamformer	LOW CBF lead	Contribute to, review and approve this document
Following Party	CSP_ Mid Correlator and Beamformer	MID CBF lead	Contribute to, review and approve this document
Following Party	CSP_Low Pulsar Search Engine	LOW Pulsar Search lead	Contribute to, review and approve this document
Following Party	CSP_Mid Pulsar Search Engine	MID Pulsar Search lead	Contribute to, review and approve this document
Following Party	CSP_Low Pulsar Timing Engine	LOW Pulsar Timing lead	Contribute to, review and approve this document
Following Party	CSP_Mid Pulsar Timing Engine	MID Pulsar Timing lead	Contribute to, review and approve this document
Reviewing Party	CSP_Low	CSP_Low Chief Scientist	Review and approve this document
Reviewing Party	CSP_Mid	CSP_Mid Chief Scientist	Review and approve this document

1.5 Interface scope

Table 1-2 lists the classes of interface specification which are included in this document.

Table 1-2 Interface class specifications

Interface class	Included in document?
Mechanical	N
Fluid	N
Thermal	N
Electromagnetic	N
Optical	N
Electrical	N
Electronic	Y
Electro-optical	N
Data exchange specifications	Y
Human-Machine Interface	N

1.6 Interface topology

An instantiation of LMC sub-element exists both in CSP_Low and CSP_Mid.

Figure 1-1 shows CSP_Low sub-elements and interfaces they implement. As shown in Figure 1-1 CSP_Low.LMC implements interfaces with the following CSP_Low sub-elements:

1. CSP_Low Correlator and Beamformer (CSP_Low.CBF)
2. CSP_Low Pulsar Search Engine (CSP_Low.PSS)
3. CSP_Low Pulsar Timing Engine (CSP_Low.PST)

Figure 1-2 shows CSP_Mid sub-elements and interfaces they implement. As shown in Figure 1-2 CSP_Mid.LMC implements interfaces with the following CSP_Mid sub-elements:

1. CSP_Mid Correlator and Beamformer (CSP_Mid.CBF)
2. CSP_Mid Pulsar Search Engine (CSP_Mid.PSS)
3. CSP_Mid Pulsar Timing Engine (CSP_Mid.PST)

All above listed interfaces are data exchange interfaces which use electronic interfaces for physical connection.

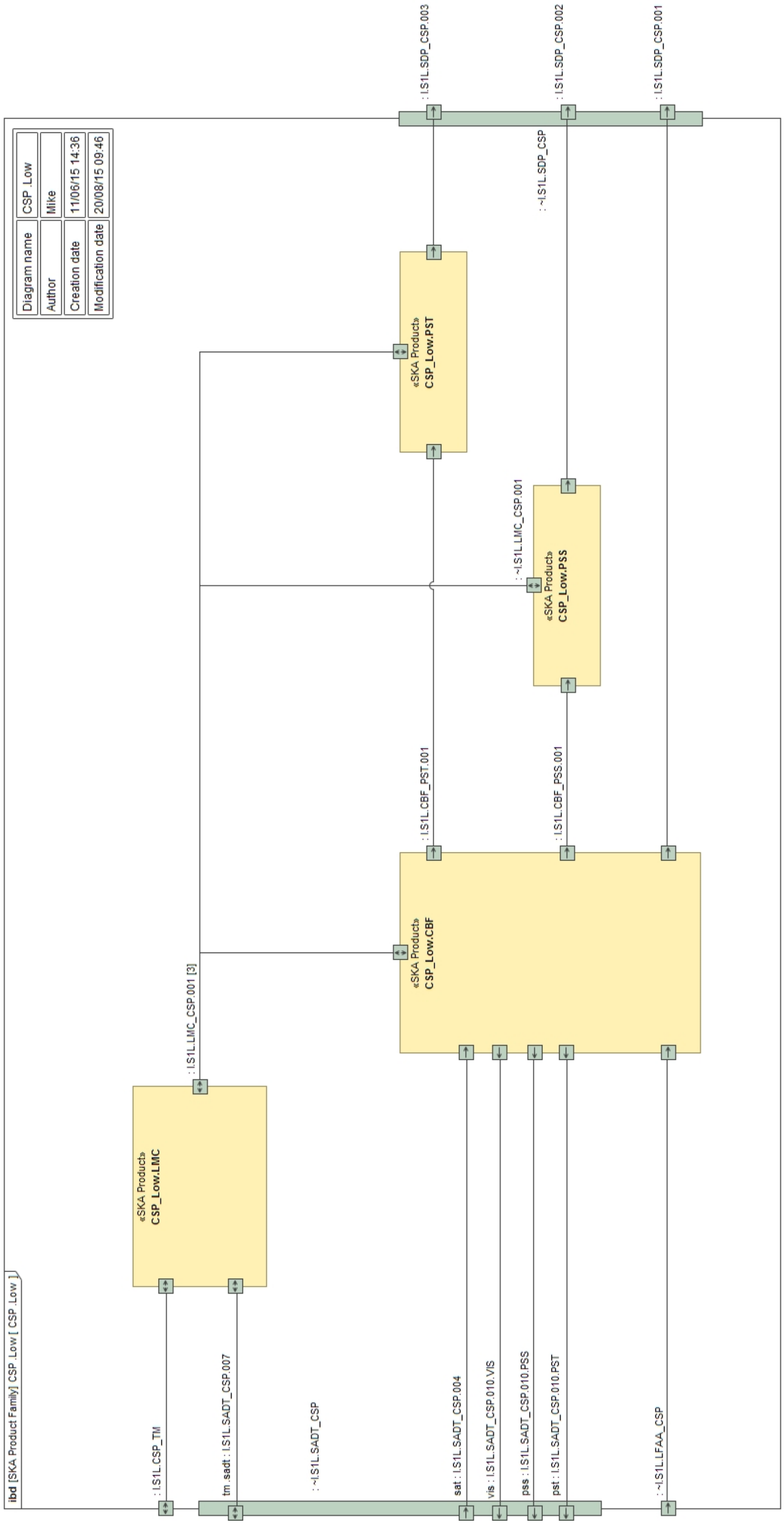


Figure 1-1 CSP_Low sub-elements and interfaces

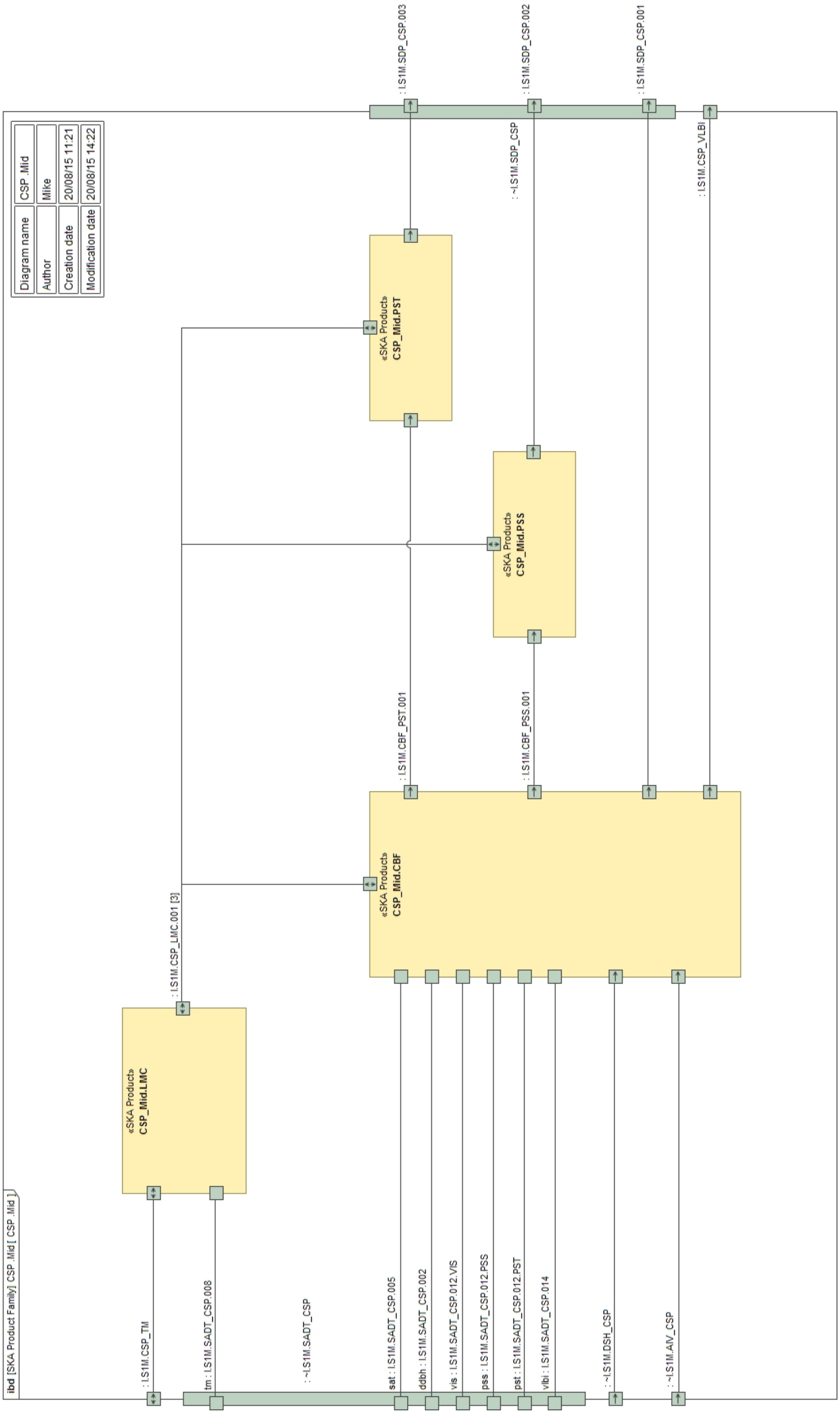


Figure 1-2 CSP_Mid sub-elements and interfaces

1.7 Overview

In each telescope, CSP LMC makes provision for TM to monitor and control CSP as a single entity. CSP LMC translates commands and queries received from TM in the commands and queries for individual CSP sub-elements, collates responses received from other sub-elements, as appropriate, and reports to TM. In addition, LMC makes provision for TM to obtain the list of CSP sub-elements and their components, to query status of individual sub-elements and set configurable parameters. In other words, LMC makes provision for TM to monitor and control CSP as a single entity and to monitor and control individual CSP sub-elements and their components, when needed.

Each of the CSP sub-elements LMC interfaces with, implements a single interface with LMC. Consequently, each sub-element is responsible for internal monitoring and control of its components. CSP sub-elements derive and report overall sub-element status and implement parameters that apply to a sub-element as a whole. The sub-elements make provision for LMC to issue commands at the sub-element level and translate those commands in the commands for individual components. The sub-elements make provision for LMC to obtain the list of components that a particular sub-element comprises, and the status and setup for the individual components. In other words, LMC can issue commands and queries both at the sub-element level and for the individual components.

SKA1_Low and SKA1_Mid telescopes support sub-arraying, i.e. allow user/operator to sub-divide collecting area (receptors) in up to 16 independently configurable sub-arrays. The term ‘independently’ in this context means that apart from the limitations imposed due to finite hardware and computing resources, sub-array creation, Observing Mode changes and destruction can be performed independently for each sub-array. LMC makes provision for TM to create and destroy sub-arrays, set Observing Mode and other parameters for each sub-array, specify when to start/stop signal processing and/or generation of output products for each sub-array, etc.

LMC provides a layer of abstraction that allows TM to monitor and control observations (i.e. signal processing) without being aware of the CSP implementation details. In the same manner, all CSP sub-elements provide a layer of abstraction that allows LMC to monitor and control observations without being aware of the sub-element implementation details. For this purpose a concept of ‘Capability’ has been introduced which allows LMC to monitor and control functionality implemented by other sub-elements without being aware of the hardware and software components that implement particular functionality. For example, LMC can instruct a sub-element (e.g. CSP_Low.CBF) to create a sub-array, specify which stations belong to the sub-array, how to process input data received from the stations that belong to the sub-array (by setting Observing Mode) and when to start processing (by specifying the Activation Time when setting the Observing Mode). For further discussion and definition of the Capability refer to Section 6.3.1.

Note that the system-level SKA documents often use the term LMC (Local Monitor and Control) to refer to the monitor and control functionality implemented by each SKA Element, as opposed to Telescope Manager, which is responsible for the overall telescope monitoring and control. In the SKA system-level documentation, the term LMC (Local Monitor and Control) is used to refer to monitor and control functionality local to each SKA Element, including CSP. However, only a part of the monitor and control functionality local to the CSP is implemented by the sub-element CSP LMC. All CSP sub-elements implement monitor and control functionality local and specific to the sub-element.

This document defines interfaces between the sub-element LMC and other CSP sub-elements in the CSP_Low and CSP_Mid.

1.8 Summary of standards

As requested in the SKA Interface Management Plan (AD2) this document uses an OSI Model (RD3) to describe the interface.

Protocols and standards used to implement this interface are TBD.

When the standards and protocols are selected, this document will be updated accordingly.

Note: *Standards and protocols to be used for interfaces between SKA Element Telescope Manager and other SKA Elements is TBD. Wherever possible this interface will use the same protocols and standards.*

1.9 Guidelines for the ICD Development

For each CSP sub-element that implements interface with LMC sub-element the ICD will specify:

1. Operational and observing modes, and for each mode information and parameters to be provided by CSP LMC (in most cases the parameters originate from Telescope Manager via CSP LMC).
2. States, state transitions and state machine.
3. Implemented commands.
4. List of configuration parameters indicating valid range, default setting, significance, use modes (use cases), etc.
5. Definition (format and content) of the messages.
6. Valid message sequences.
7. Naming conventions.
8. List of implemented alarms and events.
9. List of monitor points (indicate default setup for each monitor point or type).
10. Health status reports, error and failure detection and reporting.
11. Results of FMECA and/or suggestions for implementation of the results of FMECA by CSP LMC and/or TM.
12. Support for logging, remote logging, and remote diagnostic.
13. Instructions related to hardware, firmware and software upgrades.
14. Detailed list of all information that shall be stored by TM (as a part of the Telescope Model or elsewhere).
15. List of information to be provided to the sub-element by:
    a) LMC sub-element
    b) TM via LMC
    c) other SKA1 Elements via TM and LMC

d) other CSP sub-elements via LMC

1.10 Conventions

This document uses the present tense when describing the interface and the future tense when discussing the work that has to be performed in order to complete this ICD.

2 APPLICABLE AND REFERENCE DOCUMENTS

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.

Table 2-1 Applicable Documents

Ref No	Document/Drawing Number	Document Title	Version
AD1	SKA-TEL-CSP-0000159	SKA Statement of Work for Central Signal Processor	-
AD2	SKA-TEL.SE.INTERF-SKO-MP-001	SKA Interface Management Plan	A
AD3	SKA-TEL-CSP-0000010	SKA CSP Element Requirement Specification (SE-2)	Rev 1
AD4	SKA-TEL-CSP-0000014	SKA CSP Element Architecture Design Document (SE-5)	-

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.

Table 2-2 Reference Documents

Ref No	Document/Drawing Number	Document Title	Version
RD1	SKA-TEL-TM-0000031	SKA TM to Element LMC Interface Guidelines	-
RD3	N/A	International ISO/IEC Standard 7498-1. Second edition 1994-11-15. Corrected and reprinted 1996-06-15, Information technology – Open Systems Interconnection – Basic reference Model: The Basic Model.	Second edition 1994-11-15
RD5	ISO 8601	ISO 8601:2004(E), Data elements and interchange formats – Information interchange – Representation of dates and times	2004-12-01
RD7	SKA-TEL-CSP-0000155	SKA1-LOW Interface Control Document CSP to TM	-
RD8	SKA-TEL-CSP-0000156	SKA1-MID Interface Control Document CSP to TM	-

Ref No	Document/Drawing Number	Document Title	Version
RD9	SKA-TEL-CSP-0000066	SKA CSP_Mid Correlator & Beamformer Sub-element Detailed Design Document (EB-4a)	-
RD10	SKA-TEL-CSP-0000055	SKA CSP_Low Correlator & Beamformer Sub-element Detailed Design Document (EA-4a)	-
RD11	SKA-TEL-CSP-0000082	SKA CSP Pulsar Search Sub-element Detailed Design Document (ED-4a)	-
RD12	SKA-TEL-CSP-0000090	SKA CSP Pulsar Timing Sub-element Detailed Design Document (EE-4a)	-
RD13	SKA-TEL-CSP-0000102	SKA CSP Local Monitor and Control Sub-element Detailed Design Document (EG-2a)	-
RD14	N/A	PSRCHIVE and PSRFITS An Open Approach to Radio Pulsar Data Storage and Analysis, A. W. Hotan, W. van Starten, R. N. Manchester, Swinburne Centre for Astrophysics and Supercomputing, Australia Telescope national Facility, Netherlands Foundation for Research in Astronomy, 2004	
RD15	N/A	PSRCHIVE and PSRFITS Definition of the Stokes parameters and Instrumental Basis Convention, W. van Straten, R. Manchester, S. Johnston, J. Raynolds, Swinburne Centre for Astrophysics and Supercomputing, CSIRO Astronomy and Space Science,	
RD16	SKA-TEL-CSP-0000050	SKA1 CSP_Low Correlator & Beamformer Sub-element Requirement Specifications (EA-1)	
RD17	SKA-TEL-CSP-0000062	SKA1 CSP_Mid Correlator & Beamformer Sub-element Requirement Specifications (EB-1)	
RD18	SKA-TEL-CSP-0000078	SKA1 CSP Pulsar Search Engine Sub-element Requirement Specifications (ED-1)	
RD19	SKA-TEL-CSP-0000086	SKA1 CSP Pulsar Timing Sub-element Requirement Specifications (EE-1)	
RD20	SKA-TEL-CSP-0000100	SKA1 CSP Local Monitor and Control Sub-element Requirement Specifications (EG-1)	

3 SPECIFICATION CLASSES AND APPLICABLE STANDARDS

Wherever possible, LMC to CSP sub-element interface will use the same protocols, standards and conventions as the CSP to TM interface [RD7] [RD8]. Reuse minimizes the need to translate between the states, names and messages used at the telescope level (i.e. by the Telescope Manager) and the states, names and messages used by the CSP sub-elements (and vice versa).

General requirements for interfaces between TM and other SKA Elements will be defined in the document SKA1 LMC Interface Guidelines [RD1]. The LMC Interface Guidelines [RD1] will define communication infrastructure (protocol stack), format and content of the messages, types of messages, state machine, naming conventions, etc. Based on that, standards and conventions for the CSP to TM interface will be defined in the CSP to TM ICD [RD7] [RD8]. The protocol stack, standards and conventions for this interface will be defined based on CSP to TM ICD [RD7] [RD8].

3.1 Interface Specifications - Electronic

The OSI/ISO physical layer is TBD.

3.2 Interface Specifications - Data exchange

Using a model of process interactions, such as the Open Systems Interconnection standard, the data exchange between interfacing entities shall be fully described in this section.

As stated above, the protocol to be used for data exchange has not been identified. Format of messages and message types have not been defined. When identified and defined both will be added here.

4 TEST, DIAGNOSTIC OR MAINTENANCE FEATURES

The following design features are provided at the interface between LMC and other CSP sub-elements exclusively for testing, diagnosis or maintenance procedures, for the interface itself:

1) Both LMC and CSP sub-elements shall provide for optional logging of the messages received and transmitted via this interface.
2) CSP sub-elements shall make provision for LMC to activate/deactivate logging of the messages received and transmitted on this interface.
3) Both LMC and other sub-elements shall detect and report errors on this interface, such as time outs, CRC errors, checksum errors, dropped packets, etc.
4) LMC shall maintain connectivity with CSP sub-elements at all times. Each CSP sub-element shall maintain connectivity with LMC at all times. Both sides of each interface shall monitor the activity and transmit keep-alive messages in the absence of other activity. Frequency of keep-alive messages is TBD.
5) All CSP sub-elements shall provide engineering interfaces (GUI and/or CLI) based on the SKA standards (TBD) for the look-and-feel of human-machine interfaces.

5 SAFETY ASPECTS

CSP sub-elements consist mainly of computers and digital hardware; safety concerns are overheating and power surges. CSP sub-elements implement sensors that detect temperature and power surges. Temperature and voltage measurements are monitored on the regular basis (periodically). Measurements are reported periodically and when the value crosses one of the pre-configured thresholds.

In addition, Printed Circuit Boards are equipped with 'dead-man' protection mechanism able to autonomously switch-off supply of power when a hazardous situation (overheating, power surge) is detected.

In the case of loss of communication with LMC for longer than TBD period of time, CSP sub-elements stop the on-going signal processing and transmission of output data and set the equipment to the low-power mode.

6 INTERFACE IMPLEMENTATION – COMMON

This chapter describes all aspects of the LMC to CSP sub-element interfaces common to the following interfaces:

1. CSP_Low.LMC to CSP_Low.CBF
2. CSP_Low.LMC to CSP_Low.PSS
3. CSP_Low.LMC to CSP_Low.PST
4. CSP_Mid.LMC to CSP_Mid.CBF
5. CSP_Mid.LMC to CSP_Mid.PSS
6. CSP_Mid.LMC to CSP_Mid.PST

All above listed interfaces (1 to 6) use the same set of standards, protocols, message types, message format, naming conventions and, in general, implement the same functionality.

Messages, parameters, message sequences, and other features *specific to each individual interface* are described in chapters 7 to 13.

As stated in Chapter 3, protocol stack, message encoding, naming conventions, etc. are still to be defined (TBD).

6.1 Network Equipment

6.1.1 CSP_Low Network Equipment

CSP_Low.LMC provides network equipment (switch) for the following interfaces:

1. CSP_Low.LMC to CSP_Low.CBF
2. CSP_Low.LMC to CSP_Low.PSS
3. CSP_Low.LMC to CSP_Low.PST

More precisely, CSP_Low.CBF, CSP_Low.PSS and CSP_Low.PST connect to the switch provided by CSP_Low.LMC.

6.1.2 CSP_Mid Network Equipment

CSP_Mid.CBF provides network equipment (switch) for the following interfaces:

1. CSP_Mid.LMC to CSP_Mid.CBF
2. CSP_Mid.LMC to CSP_Mid.PSS
3. CSP_Mid.LMC to CSP_Mid.PST

More precisely, CSP_Mid.LMC, CSP_Mid.PSS and CSP_Mid.PST connect to the switch provided by CSP_Mid.CBF.

6.2 Interface Implementation - Electronic

TBD (see Chapter 3).

6.3 Interface Implementation - Data Exchange

This section contains data exchange specifications for the LMC to CSP sub-element interfaces including:

- Definition (format and content) of the messages and
- Definition of the time sequenced behaviour of these messages.

Table 6-1 below contains the preliminary list of messages exchanged over this interface; the exact list of messages and their content will be defined when the underlying protocols, message encoding and model of interaction with TM are defined (TBD). For more information refer to the CSP to TM ICD [RD7] [RD8].

Standards and protocols used on this interface are defined in Section 1.8.

Note: LMC is a CSP sub-element and implements internal monitor and control functionality in the same fashion as other sub-elements; however events, alarms, monitor point reports, and other messages generated by LMC are not transmitted via this interface.

Table 6-1 Messages transmitted over this interface

Message	Generated by	Description
SET Parameters	LMC	Set value of the sub-element parameters. Also used to request mode and state transitions. Requires write access to sub-element parameters. Note: In the absence of the protocol definition, for simplicity, this version of the ICD assumes that LMC will use a single command 'SET Parameters' to request configuration changes and state transitions.
GET Parameters (query)	LMC	Get values (status) of the sub-element parameters. In the absence of the protocol definition, for simplicity, this version of the ICD assumes that all Queries will use the same format.
Response	CBF, PSS, PST	Generated by the sub-elements in response to the LMC commands and queries ('SET Parameters' or 'GET Parameters').
Alarm	CBF, PSS, PST	Generated by the sub-elements to report errors and faults.

Message	Generated by	Description
Event	CBF, PSS, PST	Generated by the sub-element to report events that may be of interest to LMC/TM. Events to be reported will be agreed upon in advance and documented in this ICD.
Monitor Point Reports	CBF, PSS, PST	Generated by the sub-elements to report status for a selected subset of parameters (so called Monitor Points). The set of Monitor Points will be determined based on the analysis of the design. Additional Monitoring Points may be implemented based on FMECA. Sub-elements make provision for LMC to set frequency, status (enabled/disabled) and other MP parameters (using SET Parameters).

6.3.1 Components and Capabilities

Objects that can be managed (identified, monitored and controlled) via this interface can be classified in two groups:

1. **Hardware and software Components**, including CSP sub-element and its Components (LRUs and software process). Some LRU make provision for the individual sub-components to be monitored and controlled via this interface. Types of Components that can be identified, controlled and monitored via this interface are implementation-dependent and will be defined and documented in future releases of this ICD (when the CSP design is defined to a sufficient detail). Each Component is assigned a unique identifier based on its physical location and role. A Component may comprise several other Components, in which case it owns and controls those Components; such Components may be referred to as sub-Components or subordinate Components. Terms sub-Component and subordinate Component are used only in relative terms, e.g. Component B is a sub-Component of Component A and Component C is a sub-Component of Component B.
2. **CSP Capabilities**. Capability is a representation of functionality that can be identified, controlled and monitored via this interface. Capabilities provide a layer of abstraction to allow LMC to set, control and monitor signal processing, and other CSP functions, without being aware of the details of the sub-element implementation. The most notable Capability is sub-array. For each Capability, a sub-element can report a set of associated parameters (including status and health indicators) and the list of Components and Capabilities owned and/or used by a Capability. In some cases a Capability has exclusive use and control of a Component; while in others two or more Capabilities use the same Component. For this reason, state and mode transitions at the Capability level do not necessarily translate into state and mode transitions for the Components used by the Capability. Allocation of hardware and software Components to Capabilities is implementation-dependent and is not described in this ICD. A Capability can own and control other Capabilities (e.g. a sub-array can own a PSS beam).

CSP sub-elements implement a self-describing interface that allows TM, via LMC, to 'discover' Components and Capabilities via interrogation. For each sub-element, Components and Capabilities are organized in a hierarchical order, as a tree. For each sub-element, the top level of the hierarchy (i.e. the root of the tree) is the sub-element instantiation. Via this interface, LMC can request the list of parameters and their values, and the list of subordinate Components and Capabilities for each object in the hierarchy (each Component and Capability).

Status of the sub-element is a rolled-up status of its Components and Capabilities.

Sub-elements make provision for LMC to query:

- Rolled-up status for a sub-element (and other parameters of the sub-element instantiation).
- Status and parameters for an individual Component (or for a group of Components).
- Status and parameters for a particular Component and all its sub-components.
- Status and parameters for a Capability (or a group of Capabilities), this includes availability, i.e. how many Capabilities of a particular type are available, how many are available for use, i.e. not already used for on-going observations or not assigned to existing sub-arrays.

Sub-elements make provision for LMC to query:

- List of Capabilities that use a particular Component.
- List of Components used by a particular Capability.
- List of Components and Capabilities in use.
- List of Components and Capabilities not in use.

6.3.2 Error Handling

This section defines how LMC and sub-elements handle errors and failures related to this interface.

More information will be added when the protocol stack is defined.

6.3.2.1 Loss of Connectivity

When LMC detects loss of connectivity[1] with a sub-element, LMC generates an Alarm to notify TM (operators via TM) and keeps trying to establish communication with the sub-element. Operational status of the sub-element is reported as unknown.

In the case when a sub-element detects loss of connectivity with LMC:

1. The sub-element generates and logs an Alarm (Note: An attempt to transmit the Alarm message is likely to fail, due to the loss of connectivity).

[1] What exactly 'loss of connectivity' means on this interface, and how it is detected, will be defined when the protocol stack is selected (TBD).

2. When the valid interval for the delay models and other parameters that require real-time updates expires, the sub-element either flags output data or stops generation of output products (TBD for each Observing Mode individually).
3. Auxiliary data collected by the sub-element (e.g. input counts) cannot be delivered to LMC (and TM).
4. To be confirmed (TBC): If communication is not established after TBD period of time, the sub-element assumes that it is no longer useful to keep generating output data and sets all sub-arrays to idle mode.
5. To be confirmed (TBC): If communication is not established after an additional TBD period of time, the sub-element sets equipment to low-power state. Note: the low-power state is not supported for all Components; state transition to be performed in this case is implementation-specific and will be defined for each sub-element and each Component when the CSP design is defined in more detail.

6.3.2.2 Unexpected, Malformed or Invalid Message

Both the LMC and sub-elements perform syntactic and semantic checks for received messages.

TBD: *LMC and other sub-elements implement bad message counters and use those counters to throttle logging and alarm reporting. The bad message counters are reset periodically*[2]*; at any time each counter indicates the number of bad messages received during the most recent period. LMC and other sub-elements could use the bad message counters to temporarily disable the interface when an excessive number of bad messages is received over a short period of time – the exact functionality requires more consideration; analysis will be performed during Stage 2* (pending the selection of the protocol stack).

When connectivity with LMC is lost, sub-element is isolated and therefore unable to report alarms; during such periods, errors and alarms are logged locally, so that they can be analysed later, when connectivity is established.

When LMC receives an unexpected, malformed or invalid message, it performs the following actions:

- Updates the bad message counter (if implemented on this interface).
- Generates an Alarm to notify TM and operator. Bad message counters can be used to implement alarm suppression and avoid generation of Alarm foods in the case that one of the sub-elements repeatedly generates invalid, unexpected or malformed messages.
- Logs an event.
- Discards the message[3].

[2] Before the reset, the content is logged in the local log file and optionally sent to LMC/TM, either in the form of alarm or as monitor data (TBD).

[3] To discard a message means to stop further processing and remove the message from the sub-element Input Queue (and any other queue maintained by the sub-element); a discarded message cannot be displayed, revoked or deleted.

When a sub-element (other than LMC) receives an unexpected, malformed or invalid message, the sub-element performs the following actions:

- Increments the bad message counter (if implemented for this interface).
- Generates an Alarm to report the event. Depending on the protocol and point where the error was detected, an unexpected, malformed or invalid message can be reported both using an Alarm and in the Response message generated as a direct response to the received message. The bad message counters may be used to implement alarm suppression and avoid Alarm floods in the case when LMC repeatedly generates unexpected, malformed or invalid messages.
- Logs an event.
- Discards the message[4].

6.3.2.3 Message Time-out

Both LMC and sub-elements expect the other side of the interface to confirm receipt of messages within a pre-defined time period. Detection, handling and reporting of message time-outs, will be defined in more detail when the protocols stack is defined.

Both LMC and sub-elements:

1. report time-out using Alarm messages
2. re-transmit the messages that were not confirmed in the expected time frame,
3. maintain re-transmission counter, and
4. use the re-transmission counter to throttle Alarm generation (in the case of repeated re-transmissions).

6.3.2.4 Extremely High Message Rate

TBD: A possibility of (intentional or unintentional) starvation of sub-element resources (including LMC sub-element) due to an extremely high message rate will be analysed when the protocol and underlying communication infrastructure is defined. All sub-elements should implement techniques to prevent starvation of resources.

6.3.2.5 Invalid Configuration and State Transition Requests

When a sub-element receives a SET Parameters message (i.e. a request to re-configure parameters or to perform state transition), the sub-element checks whether the request can be executed at the specified Activation Time. If the SET Parameters cannot be executed at the specified time, the sub-

[4] To discard a message means to stop further processing and remove the message from the sub-element Input Queue (and any other queue maintained by the sub-element); a discarded message cannot be displayed, revoked or deleted.

element discards[5] the received message and generates Response and/or Alarm message (or both) to inform LMC that the request has been rejected.

Note: It is TBD whether TM wants CSP to generate both Reject and Alarm message. Design decisions for the CSP to TM interface will affect design of this interface.

Examples:

- Sub-element rejects "create sub-array" request if a sub-array with the same sub-array ID already exists.[6]
- Sub-element rejects a request to add receptors and/or tied-array beams to a sub-array if those receptors and/or tied-array beams are already assigned to another sub-array. Resources (receptors and tied-array beams) must be explicitly removed from one sub-array before they can be added to another sub-array.[6]
- Sub-element rejects a request to transition to the low-power state if the specified Component does not implement low-power state.

Note: When possible, TM sends SET Parameters messages to LMC in advance of the specified Activation Time. In the same manner, when possible, LMC sends the SET Parameters messages to sub-elements in advance of the Activation Time. The sub-element verifies that the received SET Parameters message can be executed at the specified Activation Time, taking in consideration previously received requests that are waiting to be activated. For more information refer to Section 6.3.6.1.

6.3.2.6 Failed Re-configuration and State Transition

If a SET Parameters message fails at Activation Time, CSP generates an Alarm message to notify TM.

In the case when a re-configuration affects two or more CSP Components, if one Component fails to re-configure, CSP continues with the re-configuration of other Components.

Examples:

- If, during shut-down of the CSP equipment, one Component does not complete shut-down procedure as expected, CSP reports the problem (generates Alarm) and continues with the shut-down procedure.
- If during re-configuration of a sub-array that uses several LRUs, one LRU fails (e.g. becomes unresponsive or does not activate new configuration as expected), sub-element generates an Alarm, and continues with the re-configuration of other LRUs.

If one or more Components affected by the configuration change fail in advance of the Activation Time, the sub-element still re-configures other Components at the Activation Time.

TBD: Sub-elements generate an Alarm message for each failed re-configuration attempt. In addition, the sub-elements could generate a report to report status for all Components and

[5] To discard a message means to stop further processing and remove the message from the sub-element Input Queue (and any other queue maintained by the sub-element); a discarded message cannot be displayed, revoked or deleted.
[6] These rules have been introduced to avoid accidental overwrite of the previously transmitted configuration (they could be removed if deemed unnecessary or undesirable).

Capabilities affected by the configuration change. It is TBD (by TM Consortium) whether TM wants to receive such report (TM may prefer to query status). The decision to be made for the CSP to TM interface will affect implementation of this interface.

6.3.3 Extensibility and Future Compatibility

All CSP sub-elements implement self-describing interface which allows LMC to obtain the list of Components and Capabilities, and the list of parameters for each Component and Capability. This allows LMC to 'discover' newly added parameters, Components and Capabilities.

Upon request (query) the sub-elements report the version of the protocol they support (for this interface).

Messages generated by the LMC and other sub-elements include the version of the protocol. There is a single instance of the LMC to sub-element interface for each sub-element in each telescope. It is up to LMC to allow for software and interface upgrades; other CSP sub-elements implement only one version of the protocol at any given time and expect LMC to handle that version.

When a new version of the sub-element hardware and/or software, which includes a new version of the LMC to sub-element interface, is deployed, LMC instructs the sub-element to start using the new version - this may include a request to power-cycle or reboot a particular piece of equipment (e.g. the server running the sub-element master control software) or to restart a software process. The exact sequence of commands will be defined by each sub-element and documented in this ICD.

6.3.4 Naming Conventions

External CSP naming conventions are still to be defined (TBD) in the CSP to TM ICD [RD7] [RD8].

Wherever possible, the same naming conventions will be used on this interface. Any discrepancy will be documented here.

6.3.5 CSP Sub-element Modes and States

CSP sub-elements will implement modes and states as described in the CSP to TM ICD [RD7] [RD8].

Note: To avoid repetition, modes and states are, at this time, defined in the CSP to TM ICD [RD7] [RD8] only. This allows CSP Consortium to make available the description of the proposed CSP modes and states to a wider SKA community. SKA Organization and TM Consortium will define the SKA Control Model, i.e. modes, states, commands, and other aspects of the monitor and control functionality, to be implemented by all Elements. The SKA Control Model has not been defined yet; the modes and states presented in CSP to TM ICD [RD7] [RD8] are a proposal. When the SKA Control Model is defined, CSP will identify which modes and states (and other aspects of the SCM) apply for CSP, and will modify this ICD accordingly.

Each CSP sub-element will indicate, in this document, the modes and states it implements, or more precisely, will indicate if there are any discrepancies (limitations, additions) with respect to the SKA

Control Model. (It is possible that some modes, states or state transitions will not apply for some sub-elements).

6.3.6 Operations

This section describes operational concepts, i.e. how this interface is used.

Details of the protocol are defined in the section 6.3.7.

6.3.6.1 Set Sub-element Parameters

Each CSP sub-element make provision for LMC to control the sub-element (and its Components and Capabilities) by setting (changing the values) of its parameters.

The operational concepts and use of the SET Parameters messages is the same as described in CSP to TM ICD [RD7] [RD8].

Most notably, the sub-elements are able to receive SET Parameters message in advance of the Activation Time specified in the message, and to execute the request, i.e. set parameters as requested in the message, at the specified Activation Time. Reconfiguration of the sub-element (i.e. its Components and Capabilities) begins at the specified Activation Time.

When a sub-element receives a SET Parameters message that does not specify Activation Time it should start re-configuration as soon as possible.

All CSP sub-elements support independent operation of up to 16 sub-arrays, which implies ability to receive multiple SET Parameters messages in advance (of the Activation Time), not necessarily in the order in which they should be executed. In other words, CSP sub-elements are required to implement and maintain the 'Activation Queue'. Most of the functionality related to the Activation Queue described in CSP to TM ICD [RD7] [RD8] is applicable to LMC and all other CSP sub-elements.

6.3.6.2 Get Sub-element Parameters (Query)

LMC uses a Query (GET Parameters message) to obtain status, parameters and the list of the subordinate Components and Capabilities of the CSP sub-elements.

Upon receipt of a Query message, sub-element generates a Response message that contains the list of parameters and their values, and sends Response to the originator of the LMC.

For more details refer to CSP to TM ICD [RD7] [RD8].

6.3.6.3 Monitor Points

Monitor points are parameters (attributes) that are periodically monitored.

Information related to monitor points provided in CSP to TM ICD [RD7] [RD8] also applies to this interface.

Each CSP sub-element autonomously monitors and reports status of its Monitor Points; i.e. each sub-element monitors parameters identified as Monitored Points, generates Monitor Point Reports according to pre-configured parameters (frequency and/or thresholds) and sends the Monitor Point Reports to the pre-configured destination address. LMC intervention is not required.

The destination address for the Monitor Point Reports is a configurable parameter of each CSP sub-element.

Destination address persists over power-down and restart of the sub-elements, so that monitor point reporting can resume after initialization.

6.3.6.4 Alarms

CSP sub-elements generate *Alarm* messages to report errors and faults.

Information related to Alarms, provided in CSP to TM ICD [RD7] [RD8] also applies to this interface.

Each CSP sub-element generates alarms autonomously, i.e. a sub-element that detects error or fault generates Alarm message and sends it to the pre-configured destination. LMC intervention is not required.

The destination address for the Alarm messages is a configurable parameter of each CSP sub-element.

Destination address persists over power-down and restart of the sub-elements, so that Alarm reporting can resume immediately after initialization (more precisely as soon as possible, since alarms can be generated during initialization).

6.3.6.5 Events

CSP sub-elements use Event messages to report detected events that may be of interest to LMC and TM.

Event messages may be used to report progress. For example, upon successful reconfiguration, sub-element could use an Event message to report that it is ready to start processing observed data.

Event related information provided in CSP to TM ICD [RD7] [RD8] also applies to this interface.

When a sub-element detects an event of interest, it generates an Event message and sends that message to LMC.

For each type of event, LMC and sub-element that generates event will perform analysis to determine whether a strategy to prevent generation of an excessive number of messages should be implemented. Message volume suppression might be required for events used to report status changes that can oscillate between two or more states and therefore result in generation of the excessive number of events. So far such event messages have not been identified.

At this time the following events to be reported to LMC have been identified:

a) Pulsar timing completed for a particular pulsar (generated once for each pulsar, volume suppression not required).

b) Indication that pulsar timing has been completed and that CSP_Mid.PST / CSP_Low.PST is ready to start next Pulsar Timing operation (generated once for each pulsar, volume suppression not required).

6.3.6.6 Logging

Each CSP sub-element and Component that has a capacity, maintains its own log file. Log records are added to the Component log file in the order in which they are generated. When the log file capacity is reached, a new log record overwrites the oldest.

Content and format of the log records are defined in CSP to TM ICD [RD7] [RD8].

CSP implements logging levels as defined in CSP to TM ICD [RD7] [RD8].

On request, sub-elements report the location of the log file and allow TM, via LMC, to obtain a copy of the log file.

Note: Depending on the choice of protocol, different data streams may be used for exchange of messages (Get/Set/Response/Alarms/Event) and for file transmission (TBD).

Implementation details TBD.

6.3.6.7 Software/Firmware Upgrade

CSP sub-elements make provision for TM, via LMC, to deploy new versions of software and firmware, and to trigger restart so that a Component initializes using a newly deployed version.

On request, sub-element is able to report the currently used version of software and firmware of its Components, and the date and time at which the currently used software and firmware were installed.

Software/firmware upgrade may be requested for an individual Component or for all Components that use software or firmware package (file) in question.

Depending on the choice of protocol, different data streams may be used for exchange of messages (Get/Set/Response/Alarms/Event) and for file transmission (TBD).

Implementation details TBD in the future releases of this document.

6.3.6.8 Reset/Restart/Reboot

Each CSP sub-element makes provision for LMC to request reset, restart and/or reboot for Components where such functionality is supported. Details are implementation-dependent and will be specified for each sub-element individually (and documented in this ICD).

6.3.6.9 Low-power State

Where possible, CSP sub-elements shall make provision for TM, via LMC, to request transition of the sub-element or its individual Components to a low-power “sleep” state.

When placed in the low-power state a sub-element (or individual Component) remains in the low-power state until a request to transition to the normal operating state (ok) is received from the LMC. The LMC can also request power-down, reset or reboot for the sub-element (or individual Component) in the low-power state.

A sub-element may be placed in the low-power state during prolonged periods of inactivity, and when CSP equipment is powered by batteries (due to loss of the main power source).

In most cases the low-power state is not the same as Idle Mode. For example, for the FPGA-based solutions, a transition to the low-power state causes de-programming of FPGAs, while Idle Mode simply stops data processing.

It is TBD whether all CSP sub-elements and Components implement the low-power state.

6.3.6.10 Power-down

All CSP sub-elements make provision for TM, via LMC, to request:

1. Staged power-down of the sub-element. Staged power-down is required in order to prevent power surges.
2. Delayed power-down of the sub-element. TM, via LMC, can specify when the shut-down should start.
3. Where possible, power-down for individual Components (e.g. LRUs, Servers).

6.3.6.11 Power-up

All CSP sub-elements make provision for TM, via LMC, to request:

1. Staged power-up of the sub-element. Staged power-up is required in order to prevent power surges.
2. Delayed power-up of the sub-element. TM, via LMC, can specify when the power-up should start.
3. Where possible, power-up for individual Components (e.g. LRUs, Servers).

6.3.6.12 Sub-Array

All CSP sub-elements make provision for TM, via LMC, to assign a sub-set of sub-element resources to a particular sub-array. A sub-set in this context may include the entire sub-element -- i.e. all Components and Capabilities of a particular CSP sub-element can belong to the same sub-array.

For a detailed discussion of sub-arrays, refer to CSP to TM ICD [RD7] [RD8].

6.3.6.13 Redundancy

Requirements for redundancy will be determined based on the RAMS (reliability, availability, main tenability and safety) analysis during the Detailed Design Phase. At this time it is assumed that redundancy will be provided for Components that implement interfaces with LMC, and for LMC itself. The exact mechanism for failure detection and switchover to a standby component is still to be determined (TBD) for each sub-element.

6.3.7 Protocol

6.3.7.1 Conventions

This section defines conventions used in this protocol specification and in the messages.

6.3.7.1.1 Date and Time

Date and time in the messages is specified using the following format:

- UTC (Coordinated Universal Time) displayed as ISO 8601.

Requirements for time precision in messages exchanged over this interface have not been identified (TBD).

For the FPGA/ASIC based solutions, re-configuration occurs on system tick TBD, therefore the start of a scan or other re-configuration requests could be specified with TBD precision. Better precision could be achieved if required, as FPGAs could be programmed to start product generation at an exact time.

However, note that the Activation Time is the time when re-configuration of the CSP equipment should start. Depending on the design, more than 20 seconds may be needed to re-configure CSP when switching Observing Modes, in particular in CSP_Mid.CBF when switching bands (exact duration is implementation dependant and still TBD). Therefore, the beginning of a scan and other massive configuration changes need not be specified with high precision.

Higher precision is required when specifying the epoch – exact requirements TBD.

6.3.7.2 Parameters Common to all Sub-elements

The list of parameters to be implemented by all sub-elements is provided in the CSP to TM ICD [RD7] [RD8].

6.3.7.3 Parameters Common to all LRUs

The list of parameters to be implemented for LRUs is provided in the CSP to TM ICD [RD7] [RD8].

6.3.7.4 Parameters Common to all Capabilities

The list of parameters to be implemented for all Capabilities is provided in the CSP to TM ICD [RD7] [RD8].

6.3.7.5 Messages

This interface uses the same messages as CSP to TM interface.

Refer to CSP to TM ICD [RD7] [RD8] for the list of messages and their content.

7 INTERFACE IMPLEMENTATION – CSP_MID.CBF

Interface CSP_Mid.LMC to CSP_Mid.CBF is described as follows:

- Aspects of the CSP_Mid.LMC to CSP_Mid.CBF interface that are common to all CSP sub-elements are described in Chapter 6.
- This chapter describes all aspects of the CSP_Mid.LMC to CSP_Mid.CBF interface that are *specific* to this interface.

The content to be provided in this chapter is described in Section 1.9.

7.1 CSP_Mid.CBF Capabilities

Table 7-1 lists the Capabilities implemented by CSP_Mid.CBF sub-element.

Sub-arrays are created and destroyed dynamically, as requested by CSP_Mid.LMC.

Capabilities antenna-input, PSS-beam, PST-beam and VLBI-beam are created during initialization or when new equipment is installed and powered-up.

At creation, CSP_Mid.CBF assigns:

- Set of hardware and software Components used by a Capability. In some cases a Capability is in full control of hardware or software Component; in others it uses a part of the functionality implemented by the Component.
- Unique identifier used in the LMC and CBF generated messages to refer to a particular CBF Capability. Capability ID is assigned by CSP_Mid.CBF and reported to LMC as a part of CSP_Mid.CBF self-description.

Antennas, PSS, PST and VLBI beams can be moved in and out of a sub-array only when the sub-array Observing Mode is IDLE and at scan boundaries i.e. after one scan ends and before the next scan begins.

Capability baseline exists only in the context of a sub-array and has been defined to allow TM, via LMC, to query status of the output products for a particular baseline or group of baselines. (It is TBC whether such functionality is useful and required).

Table 7-1 CSP_Mid.CBF Capabilities

CSP_Mid.CBF Capability	Max. Number of Instances	M&C Functionality Supported (and Comments)
sub-array	16	List availability Create Delete Add/remove antennas Set input Band (1, 2, 3, 4 or 5) Add/remove PSS beams Add/remove PST beams Add/remove VLBI beams Set Observing Mode and parameters (Table 7-2) Stop signal processing and generation of output products – implemented as set Observing Mode IDLE (Table 7-3) Real-time updates for Observing Mode parameters (delay models and similar) Query parameters & status
antenna-input	197	Antenna (receptor) is not part of CSP; this Capability has been defined to allow TM, via CSP_Mid.LMC, to disable/enable use of a particular antenna and to query status of input signal and overall status of the CSP Components that process input from a particular antenna. (Mapping between the Antenna ID and Capability ID is TBD.) List availability Disable (set receptor not available for use) Enable (set receptor is available for use) Query parameters & status
CBF-PSS-beam	1,500	List availability Disable / Enable Set parameters (including destination MAC and IP addresses for CSP_Mid.CBF output data) Query parameters & status
CBF-PST-beam	16	List availability Disable / Enable Set parameters (including destination MAC and IP addresses for CSP_Mid.CBF output data) Query parameters & status

CSP_Mid.CBF Capability	Max. Number of Instances	M&C Functionality Supported (and Comments)
CBF-VLBI-beam	4	List availability Disable / Enable Set parameters (including destination MAC and IP addresses for CSP_Mid.CBF output data) Query status and parameters
baseline	19,503 n*(n-1))/2 + n n is the number of receptors (197)	Query parameters & status Disable/enable generation and/or transmission of the output products. (It is TBC whether disable/enable function for individual baselines is required). Auto-correlations (correlations of receptors with themselves) are also represented as baselines.

7.2 CSP_Mid.CBF Messages

This section describes CSP_Mid.CBF-specific messages.

CSP_Mid.LMC can use SET Parameters messages to:

1. Create / delete sub-array.
2. Add / remove antennas to/from a sub-array.
3. Add / remove PSS beams, PST beams or VLBI beams to/from a sub-array.
4. Select Band (1, 2, 3, 4 or 5). For CSP_Mid.CBF Band is specified per sub-array. Band is property of an antenna; all antennas in a sub-array must use the same Band. Other parameters, such as centre frequency and frequency reference may be required.
5. Set Observing Mode for a sub-array and start scan. See Table 7-2.
6. Stop scan (stop signal processing and generation of output products, implemented as set Observing Mode=idle). See Table 7-3.

   TBD: *It is still to be defined what it means to set a sub-array in IDLE MODE. CSP_Mid.CBF could a) define a default configuration which is set when a sub-array is IDLE, or b) keep the configuration as-is but stop generating output products (visibilities and beam data), or c) keep operating as for the previously set non-IDLE mode, but do not expect (and apply) real-time updates for the delay models, Jones Matrices, and similar. Definition of IDLE mode is implementation dependent and will be described in this ICD if it has implications for the interface with LMC.*

7. Set time-dependent parameters as applicable for the particular Observing Mode. These updates are provided for each on-going observation (i.e. each non-IDLE sub-array) as specified for each Observing Mode (in the following sections).

8. Delete sub-array. Delete sub-array releases, all antenna-inputs and other Capabilities that were assigned to the sub-array. TBD: Depending on the definition of the IDLE mode, the components that were used by the sub-array may be set in IDLE mode.
9. Set 'engineering' parameters of the CSP_Mid.CBF sub-element and its Components and Capabilities. Some of the parameters can be set only when not used (i.e. when Observing Mode is IDLE). List of engineering parameters, access-rights and other constrains is TBD.

CSP_Mid.LMC can specify in each SET Parameters message date & time when CSP_Mid.CBF should start re-configuration. As indicated in Section 6.3.6.1, when CSP_Mid.CBF receives a SET Parameters message that does not specify Activation Time, it shall start re-configuration as soon as possible.

CSP_Mid.LMC can use GET Parameters message to query parameters and status of the CSP_Mid.CBF sub-element and its Components and Capabilities.

As described in section 6.3.6, CSP_Mid.CBF generates:

- Response for each received SET Parameters and get Parameters messages
- Alarms
- Events
- Monitor Point reports.

7.3 CSP_Mid.CBF Scan Configuration

Table 7-2 lists the parameters to be specified by CSP_Mid.LMC to set Observing Mode and start scan. The date & time when to start re-configuration of the sub-array is indicated in the message. If the message does not specify date & time when to start re-configuration of the sub-array, CSP_Mid.CBF shall start re-configuration of the sub-array as soon as possible.

CSP_Mid.CBF starts generated output as soon as re-configuration is completed.

Note: In general, a sub-array will use more than one, and in most cases many, output spigots to transmit generated output products; not all components begin generating output data at the same time; CSP_Mid.CBF may generate incomplete data sets at the beginning of a scan; the recipient of the CSP_Mid.CBF output must be able to handle incomplete data sets.

Once configured, CSP_Mid.CBF keeps the sub-array configuration until one of the following happens:

- CSP_Mid.CBF receives a command to re-configure the sub-array (as specified in Table 7-2 and Table 7-3).
- CSP_Mid.CBF receives a command to delete the sub-array.
- CSP_Mid.CBF receives a command to transit in low-power mode.
- CSP_Mid.CBF receives a command to shut-down.
- CSP_Mid.CBF monitor and control function fails so that the configuration is lost.

Table 7-2 CSP_Mid.CBF Scan Configuration

CSP_Mid.CBF Scan Configuration	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set sub-array parameters.
Activation Time	Date & time	UTC	Date and time when to start re-configuration of the sub-array.
Scan ID	Integer	64-bit	Scan ID to be inserted in CBF output products.
Any combination of the following Observing Modes can be specified (in the same message):			
Observing Mode Imaging	Enumeration	IMAGING	Observing Mode parameters as specified in Table 7-4 on page 48.
Observing Mode Pulsar Search	Enumeration	PULSAR SEARCH BEAMFORMING	Observing Mode parameters as specified in Table 7-5 on page 51.
Observing Mode Pulsar Timing	Enumeration	PULSAR TIMING BEAMFORMING	Observing Mode parameters as specified in Table 7-6 on page 53.

Table 7-3 CSP_Mid.CBF End Scan

CSP_Mid.CBF End Scan	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set sub-array parameters.
Activation Time	Date & time	UTC	Date and time when to start re-configuration of the sub-array.
Observing Mode	Enumeration	IDLE	Use to set sub-array in IDLE mode (the setup of the CSP_Mid.CBF in this mode is TBD).

7.4 CSP_Mid.CBF Observing Mode Imaging

CSP_Mid.CBF configuration and output products are the same for Spectral-line Imaging and Continuum Imaging; CSP_Mid.CBF implements a single Observing Mode Imaging.

Observing Mode Imaging can be started, operated and stopped independently and concurrently in up to 16 sub-arrays.

For each sub-array in Imaging mode, CSP_Mid.CBF makes provision for TM, via LMC, to configure up to four zoom windows, each with bandwidth selected independently from values within 10% of 4 MHz, 8 MHz, 16 MHz, 32 MHz, 64 MHz, 128 MHz, and 256 MHz; each independently tuned, with frequency granularity better than 1.1 MHz, such that the entire zoom window lies anywhere within the subarray's digitized observing band. CSP_Mid.CBF is able to produce output products (correlated visibilities and autocorrelations for all polarization products) concurrently for four zoom windows and over the entire digitized band, not covered by the zoom window(s), with an evenly spaced frequency resolution of 1 MHz +/- 10%.

CSP_Mid.CBF can perform Imaging concurrently in the same sub-array with the following Observing Modes:

1. Pulsar Search Beamforming
2. Pulsar Timing Beamforming

Note: CSP_Mid.CBF is the only CSP sub-element used for Observing Mode Imaging; other CSP_Mid sub-elements are not used for this mode.

Observing Mode Spectral-line Imaging can be started, operated and stopped independently and concurrently in up to 16 sub-arrays.

Table 7-4 CSP_Mid.CBF Observing Mode Imaging – Configuration Parameters

CSP_Mid.CBF Imaging Mode Parameter	Type	Range	Description
Observing Mode	Enumeration	IMAGING	Observing Mode
Number of channels	TBD	TBD	TBD: Is number of channels a configurable parameter? SKA1-CSP_REQ-2195-00 [AD3]: For each subarray in continuum or spectral line imaging mode, CSP_Mid shall deliver up to 65,536 +/- 20% linearly spaced channels across the bandwidth delivered to SDP. SKA1-CSP_REQ-2971-00 [AD3]: For each SKA1_Mid subarray in zoom mode, CSP_Mid shall produce correlated visibilities and autocorrelations for all polarization products, over the entire digitized band(s) not covered by the zoom window(s), with an evenly spaced frequency resolution of 1 MHz +/- 10%.
Integration time	Integer	TBD	Integration time for correlation products, specified in milliseconds. SKA1-CSP_REQ-2197-00 [AD3]: For each subarray, CSP_Mid shall have independently configurable visibility integration periods which are within 2% of 0.14s, and within 10% of (2, 3, 5, 10) times 0.14s.
Number of phase bins	Enumeration	1..256 (TBC)	By default, the number of phase bins = 1, i.e. no binning. Number of phase bins * number of channels * 4 <= 262,144. Number of phase bins will be defined as enumeration, i.e. only a limited choice will be available.
Pulsar ephemeris	TBD	TBD	Parameters required for pulsar phase binning, i.e. required when the number of phase bins > 1.
The physical location of the centre of the sub-array	TBD	TBD	

CSP_Mid.CBF Imaging Mode Parameter	Type	Range	Description
RFI mask	TBD	TBD	Mask for RFI excision. Specified per station. See SKA1-CSP_REQ-2474-00 [AD3].
RFI excision level	TBD	TBD	When to start RFI excision and for how long to perform excision. Other RFI mitigation parameters can be defined (TBD). See SKA1-CSP_REQ-2473-00 [AD3]. CSP_Mid.CBF may implement additional parameters for dynamic control of RFI excision, for example, a choice of RFI excision algorithms.
RFI excision period	TBD	TBD	
Optionally, TM, via LMC, may specify up to 4 zoom windows. The parameters specified below are specified for each zoom window independently.			
Zoom window ID	Integer	1..4	Identifier used to refer to the zoom window in further commands, queries and reports (including alarms). Must be unique within a sub-array.
Zoom window bandwidth	Enumeration	TBD	SKA1-CSP_REQ-2968-00 [AD3]: CSP_Mid, for each subarray in zoom mode, shall produce correlated visibilities and autocorrelations for all polarization products, for up to four zoom windows, each with bandwidth selected independently from values within 10% of 4 MHz, 8 MHz, 16 MHz, 32 MHz, 64 MHz, 128 MHz, and 256 MHz.
Position of the zoom window within the input band	TBD	TBD	SKA1-CSP_REQ-2969-00 [AD3]: The centre frequency of each CSP_Mid zoom window shall be independently selectable by TM, with a step size within 10% of 1MHz, such that the full zoom window is contained within the available digitized band.
Number of spectral channels for output products for a zoom window.	Integer	TBD	SKA1-CSP_REQ-2970-00 [AD3]: For each subarray in zoom mode, CSP_Mid shall produce 16384 equally spaced frequency channels across each of that subarray's zoom windows.

Before CSP_Mid.CBF can begin to generate output products, the CSP_Mid.CBF and SDP shall exchange the following information via LMC and TM:

1. After allocating resources to be used for the specified sub-array and Observing Mode, CSP_Mid.CBF shall notify SDP via LMC/TM regarding the number of output streams (spigots) to be used to transmit CSP_Mid.CBF products (visibilities) to SDP. Distribution of baselines/products per stream shall be also indicated.
2. SDP shall send to CSP_Mid.CBF, via TM/LMC, destination addresses (MAC and IP addresses) for the CSP_Mid.CBF products.

In addition to the parameters specified in Table 7-4 above, for each sub-array in Imaging mode, CSP_Mid.CBF requires TM/LMC to provide delay tracking and calibration information in advance of the specified configuration Activation Time, and at regular intervals during the scan.

For each sub-array in Imaging Observing Mode, TM, via CSP_Mid.LMC, shall provide:

1. Delay models for each antenna that belongs to the sub-array.

2. On-sky calibration residuals sourcing from the SDP (i.e. antenna-based delay corrections).

For each sub-array in Imaging Mode, TM, via CSP_Mid.LMC, provides delay models for each antenna and each polarization (two models per antenna for up to 197 antennas).

For Band 5, two 2.5 GHz bands are derived, using digital filters, from a single wide band coming from a single sampler; the same delay model applies for both 2.5GHz bands (TBC).

TM shall provide the second order polynomial, with 64-bit coefficients, per antenna per polarization every 10 seconds.

For 197 antennas the estimate is 197*2*3 * 64-bits / 10 seconds = 7564.8 bps

TM shall provide delay models in advance of the specified configuration Activation Time and at regular intervals during the scan. For each delay model TM indicates the time when the model becomes valid (i.e. when CSP_Mid.CBF should start using the model).

TBD: It is to be defined how much in advance a delay model has to be delivered to CSP_Mid.CBF in order to be applied at the time specified in the message.

7.5 CSP_Mid.CBF Observing Mode Pulsar Search Beamforming

Overview:

1. CSP_Mid.CBF can form up to 1,500 Pulsar Search beams.
2. Any number of pulsar search beams can be assigned to any sub-array.
3. Pulsar Search beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. PSS beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

For the Observing Mode Pulsar Search to be accepted, the sub-array must contain at least one receptor and at least one CBF-PSS-beam. In other words, receptors and CBF-PSS-beams must be assigned to a sub-array in advance of Observing Mode configuration. Re-configuration may be scheduled to start at the same time for ‘add receptor’, ‘add CBF-PSS-beam’ and ‘set Observing Mode’ requests.

Capabilities CBF-PSS-Beam are created at CSP_Mid.CBF initialization. At that time CSP_Mid.CBF assigns ID to each CBF-PSS-beam and selects hardware to be used for each CBF-PSS-beam.

Destination addresses for CBF-PSS-beam output data are provided by the CSP_Mid.PSS, via LMC, for each scan, before the scan Activation Time.

If some of the destination addresses change during a scan, due to CSP_Mid.PSS failure or other event, CSP_Mid.CBF accepts the destination addresses as provided by LMC and starts using them as soon as possible.

CSP_Mid.CBF can form Pulsar Search beams concurrently in the same sub-array with the following Observing Modes:

1. Imaging
2. Pulsar Timing Beamforming

Note: For every sub-array in Pulsar Search Beamforming Mode, CSP_Mid.CBF concurrently generates visibilities. It is still to be defined (TBD) whether the CSP_Mid.CBF will define a default set of imaging parameters to be used by CBF in a sub-array in Pulsar Search Beamforming mode where Imaging is not explicitly configured.

Table 7-5 CSP_Mid.CBF Pulsar Search Beamforming Observing Mode Parameters

CSP_Mid.CBF Pulsar Search Parameter	Type	Range	Description
Observing Mode	ASCII String	Pulsar Search	Observing Mode
Scan ID	Integer	64-bit	Scan ID to be inserted in the CBF output data flowing to PSS.
Phase centre of the sub-array	TBD	TBD	
Number of channels per beam	Integer	4096	TBD: Is this a configurable parameter?
Number of bits per sample	Integer	TBD	Number of bits per sample in the beamformer output (for the data passed to CSP_Mid.PSS).
Parameters specified for each PSS beam (for up to 1500 PSS-beams):			
PSS Beam ID	Integer	TBD	PSS Beam ID as specified by TM/LMC. Note: Beam ID specified by TM/LMC is not the same as CBF PSS-beam Capability ID. Internally CBF must perform mapping of TM/LMC assigned IDs into CBF IDs.
PSS Beam BW	Integer	TBD	Up to 2100MHz per beam in ~300MHz chunks. Note: TM and CSP could make provision for user to choose PSS beam configuration/packing from one of the pre-defined beam configurations or to specify parameters for each PSS beam independently.
PSS Beam centre frequency	Integer	TBD	
PSS Beam Delay Centre	TBD	TBD	
Antennas to be used in beamforming	List of antenna IDs	SKA1 and MeerKAT antennas	Optionally, users may specify a subset of antennas that belong to the sub-array to be used in beamforming. If not specified, CSP_Mid.CBF uses all antennas that belong to the sub-array.
PSS Beam Destination Address(es)	TBD	TBD	Destination addresses (MAC, IP, port) must be provided by CSP_Mid.PSS, via LMC, before CBF starts generating output products (beam data).

In addition to the parameters specified in Table 7-5, TM, via LMC, provides the following parameters:

1. Per-antenna, per-beam delay+cal models relative to the primary delay centre. Total of up to 197*1,500 models. However, these models are relative to the delay centre and should have a low update rate.
2. Weights to be used in beamforming (per antenna per PSS-beam).
3. Jones Matrix consisting of 9+9bits x 4 coefficients per antenna per channel (197x4096); update should be provided every 100 seconds.
   Estimate for the volume of data: 18bits*4*200*4096/100 seconds = ~590Kbps
4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift).

As discussed in CSP to TM ICD [RD8] delay tracking, calibration and beamforming related parameters are provided by TM, via CSP_Mid.LMC, in advance of the scan Activation Time and at regular intervals during the scan.

Messages that contain delay tracking, calibration and beamforming parameters indicate the time when CSP_Mid.CBF should start using new values.

TBD: Cadence for the updates.

TBD: How much in advance a message must be delivered to CSP_Mid.CBF in order to be applied at the time specified in the message.

7.6 CSP_Mid.CBF Observing Mode Pulsar Timing Beamforming

Overview:

1. CSP_Low.CBF can form up to 16 Pulsar Timing beams.
2. Any number of pulsar timing beams can be assigned to any sub-array.
3. Pulsar Timing beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. CBF-PST-beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

CSP_Mid.CBF can form Pulsar Timing beams concurrently in the same sub-array with the following Observing Modes:

1. Imaging
2. Pulsar Search Beamforming

Note: For every sub-array in Pulsar Timing Beamforming Mode, CSP_Mid.CBF concurrently generates visibilities. It is still to be defined (TBD) weather the CSP_Mid.CBF will define a default set of imaging parameters to be used by CBF in a sub-array in Pulsar Timing Beamforming mode where Imaging is not explicitly configured.

Table 7-6 CSP_Mid.CBF Parameters for Pulsar Timing Beamforming

CSP_Mid.CBF Pulsar Timing Parameter	Type	Range	Description
Observing Mode	Enumeration	Pulsar Timing	Observing Mode
Scan ID	Integer	64-bit	Scan ID to be inserted in the CBF output data flowing to PST.
The following parameters are specified for each of up to 16 PST beams:			
PST Beam ID	Integer	1..16	PST Beam ID as specified by TM/LMC. Note: Beam ID specified by TM/LMC is not the same as CBF-PST-Beam Capability ID. Internally CBF must perform mapping of TM/LMC assigned IDs into CBF-PST-Beam IDs.
Antennas to be used in beamforming	List of antenna IDs	TBD	Optionally user may specify a subset of the antennas that belong to the sub-array to be used in beamforming. If the list of stations is not specified, CSP_Mid.CBF uses all the antennas that belong to the sub-array.
PST Beam BW	Integer	Up to full bandwidth	For Band 5 maximum of 2.5GHz can be specified.
PST Beam centre frequency	Integer	TBD	For Band 5, each beam must be placed within one of the two 2.5GHz bands.
PST Beam Delay Centre	TBD	TBD	
Number of bits per sample	Integer	TBD	Number of bits per sample in the CSP_Mid.CBF output (for the data passed to CSP_Mid.PST). TBD: Is the number of bits per sample configurable parameter?
Destination Address(es)	TBD	TBD	Destination addresses (MAC, IP, port) provided by CSP_Mid.PST, via LMC, before CSP_Mid.CBF can start generating output products (beam data). Destination addresses may be received in a separate message.

In the case that some of the CSP_Mid.PST equipment fails during an observation (scan), CSP_Mid.CBF may receive destination address change notification during the scan. CSP_Mid.CBF should begin to use the new destination addresses as soon as possible. Time required to propagate the change is TBD.

For each sub-array in Pulsar Timing Beamforming mode, CSP_Mid.CBF requires TM/LMC to provide the following in advance of the specified scan Activation Time and at regular intervals during the scan:

1. Per antenna, per PST-beam delay+cal models relative to the primary delay canter (a model for each of up to 197 antennas for up to 16 PST beams; that is 3152 models). These models are relative to the delay canter and should have a low update rate.
2. Weights to be used in the tied-array beamforming (for each antenna per PST beam).

3. Jones Matrix, as follows:

   40 taps in the filter

   (16+16b)*4 matrix coefficients per tap

   Jones Matrix per antenna / per channel / per beam (200/250/16)

   Update every 100 seconds (the update rate is mostly driven by how far from the boresight the PST beams are allowed to point).

   Estimate for the data volume: 40*32*4*200*250*16/100 = 40.96Mbps

4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift). (TBC)

TBD: The exact requirements (the number of bytes and cadence) for the above listed parameters are still to be defined.

Messages with updates for the above listed parameters indicate the time when CSP_Mid.CBF should start using new values.

TBD: It is to be defined how much in advance a message must be delivered to CSP_Mid.CBF in order to be applied at the time specified in the message.

7.7 CSP_Mid.CBF Observing Mode VLBI Beamforming

Overview:

1. CSP_Mid.CBF can form up to 4 VLBI beams.
1. Any number of VLBI beams can be assigned to any sub-array.
2. VLBI beamforming can be started, operated and stopped independently in up to four sub-arrays.
3. VLBI beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

Concurrency with other Observing Modes is not supported within the same sub-array. Other Observing Modes can be performed in other sub-arrays concurrently with VLBI beamforming.

Note: CSP_Mid.CBF generates visibilities for every sub-array in the VLBI Beamforming mode. It is still to be defined (TBD) weather the CSP_Mid.CBF will define the default configuration for the imaging related parameters to be used for the sub-array in VLBI Beamforming mode.

Table 7-7 CSP_Mid.CBF Parameters for VLBI Beamforming

CSP_Mid.CBF VLBI BF Parameter	Type	Range	Description
Observing Mode	Enumeration	VLBI BAMFROMING	Observing Mode
Scan ID	Integer	64-bit	Scan ID to be inserted in the CBF output data flowing to PST.
Channelization parameters	TBD	TBD	
RFI mask	TBD	TBD	Mask for RFI excision. Specified per station. See SKA1-CSP_REQ-2474-00 [AD3].
RFI excision level	TBD	TBD	When to start RFI excision and for how long to perform excision. Other RFI mitigation parameters can be defined (TBD). See SKA1-CSP_REQ-2473-00 [AD3]. CSP_Mid.CBF may implement additional parameters for dynamic control of RFI excision, for example, a choice of RFI excision algorithms.
RFI excision period	TBD	TBD	
Gain setting	TBD	TBD	Dynamic behaviour parameters such as digital gain measurement settings schedule or similar.
The following parameters are specified for each of up to 4 VLBI beams:			
VLBI Beam ID	Integer	1..4	PST Beam ID assigned by TM/LMC. Note: Beam ID specified by TM/LMC is not the same as CBF-VLBI-Beam Capability ID. Internally CBF must perform mapping of TM/LMC assigned IDs into CBF-VLBI-Beam IDs.
Antennas to be used in beamforming	List of antenna IDs	TBD	Optionally user may specify a subset of the antennas that belong to the sub-array to be used in beamforming. If the list of stations is not specified, CSP_Mid.CBF uses all the antennas that belong to the sub-array.
VLBI Beam BW	Enumeration	512MHz, 256MHz, 128MHz, 64MHz, 32MHz, 16MHz, 4MHz or 1MHz.	VLBI standard bandwidths of 512 MHz, 256 MHz, 128 MHz etc. The number of beams (on the same sky delay centre) increases with the decreasing bandwidth (i.e. 1x512 MHz, 2x256 MHz etc.). Details TBD.
VLBI Beam centre frequency	Integer	TBD	Centre frequency can be anywhere within the band range. For Band 5, each beam must be placed within one of the two 2.5GHz bands.
Number of bits per sample	Integer	TBD	Number of bits per sample in the CSP_Mid.CBF output.
Destination Addresses	TBD	TBD	Destination addresses (MAC, IP, port) for the CSP_Mid.CBF output.

For each sub-array in VLBI Beamforming mode, CSP_Mid.CBF requires TM/LMC to provide the following in advance of the specified scan Activation Time and at regular intervals during the scan:

1. Per beam, per antenna, delay models (as described in Section 7.4). For each of up to 4 VLBI beams, TM shall provide a delay model for each antenna used in beamforming.
2. On-sky calibration residuals sourcing from the SDP (i.e. antenna-based delay corrections).
3. Weights to be used in creating the tied-array beams (per antenna per VLBI beam).

As discussed in CSP to TM ICD [RD8] delay tracking, calibration and beamforming related parameters are provided by TM, via CSP_Mid.LMC, in advance of the scan Activation Time and at regular intervals during the scan.

TBD: The exact requirements (the number of coefficients, number of bits per coefficient and cadence) for the above listed parameters are still to be defined.

Messages that contain delay tracking, calibration and beamforming parameters indicate the time when CSP_Mid.CBF should start using new values.

TBD: It is to be defined how much in advance a message must be delivered to CSP_Mid.CBF in order to be applied at the time specified in the message.

7.8 CSP_Mid.CBF Engineering Parameters

CSP_Mid.CBF implements parameters that are common to all CSP_Mid sub-elements, LRUs, sub-arrays, Capabilities, Alarms, Events and Monitor Points, as specified in Chapter 6.

This section will specify parameters specific to CSP_Mid.CBF.

7.9 CSP_Mid.CBF Requirements for Data Persistence

This section will list data generated by CSP_Mid.CBF that should be stored by the Telescope Manager.

Preliminary list includes:

1. Configuration data:
    - Versions of hardware, firmware and software for all Components
    - LRU serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

The list of auxiliary data generated by CSP_Mid.CBF is TBD.

For each type of the auxiliary data this section will define:

- Content
- Format

- Where the data is stored.

Detailed list TBD in the future releases of this ICD.

7.10 CSP_Mid.CBF Alarms

List of Alarms generated by CSP_Mid.CBF.

7.11 CSP_Mid.CBF Events

List of Events generated by CSP_Mid.CBF.

7.12 CSP_Mid.CBF Monitor Points

List of Monitor Points for CSP_Mid.CBF is TBD.

The current estimate is that CSP_Mid.CBF will consist of ~300 'pizza boxes' housing PowerMX Heron motherboard and associated hardware. Depending on the granularity of reporting, there can be between 2,000 and 10,000 monitor points per box. In total, CSP_Mid.CBF may have to monitor and report up to 3,000,000 Monitor Points.

Overall monitoring and reporting strategy requires more analysis; some data reduction will be considered, however, even if status for all MPs is reported to TM, CSP_Mid.CBF will report to TM only when change is significant. For example, CSP_Mid.CBF may record minor fluctuations locally and report to TM trends and values that cross pre-defined thresholds.

Examples of the CSP_Mid.CBF monitor points: temperature and voltage monitor points on the PowerMX Heron modules, FPGAs internal temperature monitoring, FPGA internal signal eye monitor capability (up to ~100 MPs per FPGA), I^2C connections to peripherals (10-100 MPs per board), communication status of all SERDES receivers, etc.

8 INTERFACE IMPLEMENTATION – CSP_MID.PSS

Interface CSP_Mid.LMC to CSP_Mid.PSS is described as follows:

- Aspects of the CSP_Mid.LMC to CSP_Mid.PSS interface that are common to all CSP sub-elements are described in Chapter 6.
- This chapter describes all aspects of the CSP_Mid.LMC to CSP_Mid.PSS interface that are *specific* to this interface.

The content to be provided in this chapter is described in Section 1.9.

8.1 CSP_Mid.PSS Capabilities

Table 8-1 lists the Capabilities implemented by the sub-element CSP_Mid.PSS.

Sub-arrays are created and destroyed dynamically, as requested by CSP_Mid.LMC.

Capabilities CSP-PSS-beam are created during initialization or when new equipment is installed and powered-up. At creation, CSP_Mid.PSS assigns:

- Set of hardware and software Components used by a Capability.
- Unique identifier used in the LMC and PSS generated messages to refer to a particular CSP-PSS-Beam. Capability ID is assigned by CSP_Mid.PSS and reported to LMC as a part of CSP_Mid.PSS self-description.

CSP-PSS-Beams can be moved in and out of a sub-array only when the sub-array Observing Mode is IDLE and at scan boundaries i.e. after one scan ends and before the next scan begins.

Table 8-1 CSP_Mid.PSS Capabilities

CSP_Mid.PSS Capability	Max. Number of Instances	M&C Functionality Supported
sub-array	16	List availability Create Delete Add/remove antennas (antennas must be added to the sub-array in advance of scan configuration). Select Band (1, 2, 3, 4 or 5). Add/remove CSP-PSS-Beams to/from the sub-array Set Observing Mode parameters (see Table 8-2). Stop signal processing and generation of output products (implemented as set Observing Mode IDLE, see Table 7-3). Real-time updates for Observing Mode parameters (delay models and similar, see Section 8.3) Query parameters and status
CSP-PSS-beam	1,500	List availability Disable / Enable Set parameters Query parameters & status

8.2 CSP_Mid.PSS Messages

CSP_Mid.LMC can use SET Parameters messages to:

1. Create / delete sub-array.
2. Add / remove antennas to/from a sub-array.
3. Add / remove CSP-PSS-Beams to/from a sub-array.
4. Select Band (1, 2, 3, 4 or 5). Band is specified per sub-array. All antennas in a sub-array must use the same Band. Other parameters, such as centre frequency and frequency reference may be required.
5. Set Observing Mode parameters for a sub-array, including date & time when to begin re-configuration, see Table 8-2.
6. Stop scan, i.e. stop signal processing and generation of output products, implemented as set Observing Mode IDLE, see Table 7-3.

7. Set time-dependent parameters required for Pulsar Search. TM, via LMC, provides regular updates for each on-going observation (i.e. each non-IDLE sub-array), as specified in Section 8.3.
8. Delete sub-array.
9. Update BRDZ list and other RFI related parameters.
10. Set ‘engineering’ parameters of the CSP_Mid.PSS sub-element and its Components and Capabilities. Some of the parameters can be set only when the sub-element, Capability and/or Component is not used (i.e. when Observing Mode is IDLE). List of engineering parameters, access-rights and other constrains is TBD.

CSP_Mid.LMC can use GET Parameters message to query parameters and status of the CSP_Mid.PSS sub-element and its Components and Capabilities.

CSP_Mid.PSS generates:

- Responses for received SET Parameters and GET Parameters message (as described in section 6.3.6).
- Alarms
- Events
- Monitor Points Reports

Future releases of this ICD will provide the exact list of messages and parameters.

8.3 CSP_Mid.PSS Observing Mode Parameters

Overview:

1. CSP_Mid.CBF can form up to 1,500 Pulsar Search beams.
2. Any number of pulsar search beams can be assigned to any sub-array.
3. Pulsar Search beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. PSS beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

For the Observing Mode Pulsar Search to be accepted, the sub-array must contain at least one receptor and at least one CSP-PSS-Beam. In other words, receptors and CSP-PSS-Beams must be assigned to a sub-array in advance of Observing Mode configuration; although the re-configuration may be scheduled to start at the same time for ‘add receptor’, ‘add CSP-PSS-beam’ and ‘set Observing Mode’ requests.

Capabilities CSP-PSS-Beam are created at CSP_Mid.PSS initialization and when new hardware is detected. When a new CSP-PSS-Beam has been initialized and becomes available, CSP_Mid.PSS notifies LMC using an Event message.

Table 8-2 lists the parameters to be specified in the LMC-generated message ‘Set Sub-array Observation Mode Pulsar Search’.

CSP_Mid.PSS selects which Capability to use for which beam specified in the message and provides mapping between the IDs as specified in the message and internal IDs.

After allocating resources to be used for the specified sub-array and Observing Mode, CSP_Mid.PSS shall notify CSP_Mid.CBF, via LMC, which destination addresses to use for which PSS-Beam.

Table 8-2 CSP_Mid.PSS Observing Mode Parameters

CSP_Mid.PSS Observing Mode Parameter	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set parameters.
Parameters specified per sub-array			
Activation Time	Date & time	UTC	Date and time when to begin re-configuration of the sub-array.
Scan ID	Integer	64-bit	Scan ID to be inserted in the CSP generated output products.
Pointing Name	TBD	TBD	Antenna pointing symbolic name and coordinates (same as observed source name and co-ordinates in the CBF configuration).
Pointing coordinates	TBD	TBD	
Pointing switching schedule	TBD	TBD	Schedule for switching between observed sources - if CSP is required to handle source switching autonomously (requirements TBD).
Beam BW	Integer or enumeration	300MHz	
Number of bits per sample	Integer	TBD	Number of bits per sample in the CSP_Mid.PSS input data (CSP_Mid.CBF output data).
Acceleration Search	Boolean	Enable Disable	Observing Mode: Acceleration Search (a.k.a. Pulsar Search) and Single Pulse Search (a.k.a. Transient Search) can be performed concurrently.
Single Pulse Search	Boolean	Enable Disable	
Integration time	Integer	Up to 1,800 seconds	The maximum length of a data chunk on which search can be performed.
Acceleration Range	Integer	0-350 m/s^2 Default=0	Range in source acceleration to be searched. Specified as integer number of milliseconds.
Number of Trials	Integer	TBD	Number of trials to be performed.
Time Resolution	Integer	50-800 µs (2n * 50 µs)	Time resolution of input data. Values in increments (2n * 50 µs).
Dispersion Measure	Integer	0-3000 pc cm-3	Dispersion correction. TBD: Do we need a separate DM search range for single-pulsar sources (transients)?
Number of Frequency Channels	Integer	1,000-4,096	Multiple of 1,000 or of 1,024 (NIP.PSS.009) - TBD

CSP_Mid.PSS Observing Mode Parameter	Type	Range	Description
Time Sample per Block	Integer	Up to (integration time) / (time resolution)	Number of time samples in each block of data.
Sub-bands	Integer	Up to 64	Number of frequency band groups summed up during folding.
Input Buffer Size	Integer	2^18-2^24	Size of the buffer receiving raw data.
Harmonic summing control parameter	Integer	1-32	Number of the “harmonic folds” on the initial Fourier power-spectrum summed up.
Complex FFT Control Parameters	TBD	TBD	CXFT control parameters.
Candidate Sifting Parameters	TBD	TBD	Constraints on matches between candidates.
Candidates Output Parameters	TBD	TBD	Define data sinks and subscriber to be notified (TBC).
Single Pulse Threshold	Integer	TBD	Threshold for a single pulse trigger.
Single Pulse Optimization Parameters	TBD	TBD	Single pulse optimization parameters.
RFI Mask list	TBD	TBD	Interference Mask to be used and updated by CSP_Mid.PSS.
DREAD Beam Statistics	Table of floats	TBD	DREAD: statistics of spectra to derive the normalization factors.
CDOS Control Parameters	TBD	TBD	CDOS: control parameters and related statistical data. Exact list of parameters TBD.
RFIM Control Parameters	TBD	TBD	RFIM: control parameters. Exact list of parameters TBD.
Parameters to be specified for each PSS beam (for up to 1500 beams):			
PSS Beam ID	Integer	TBD	Beam ID as specified by TM/LMC (corresponds to Beam ID obtained from the CSP_Mid.CBF output data). CSP_Mid.PSS performs mapping between the PSS beam configuration specified in the TM/LMC message and the PSS Capabilities; more precisely, CSP_Mid.PSS decides which Capability CSP-PSS-Beam to use for which PSS Beam ID and informs CSP_Mid.CBF, via LMC, where to send data for each PSS Beam ID.
PSS Beam pointing co-ordinates	TBD	TBD	Pointing co-ordinates of the beam.
PSS Beam centre frequency	Integer	TBD	Beam center frequency and beam delay center,

CSP_Mid.PSS Observing Mode Parameter	Type	Range	Description
PSS Beam delay centre	TBD	TBD	relative to the array delay center. TBD: beam center frequency and delay center are required by CSP_Mid.CBF but may not be needed by CSP_Mid.PSS. TBD: TM and CSP could make provision for the user to choose one of the pre-defined PSS beam configurations or to specify parameters for each PSS beam independently.
Destination address	TBD	TBD	Per beam destination address, for CSP_Mid.PSS output.

In addition to the parameters provided in advance of the scan Activation Time (listed in Table 8-2), TM, via CSP_Mid.LMC, provides updates for the following parameters for on-going observations, as applicable:

1. On-sky calibration residuals sourcing from the SDP via TM and LMC for beamforming (i.e. antenna-based delay corrections), as applicable.
2. Pulsar ephemeris models (polynomials) sourcing from TM, via LMC, at a regular rate.
3. Weights used in beamforming (for each beam).

TBC:

4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift).

As discussed in CSP to TM ICD [RD8] these parameters are provided by TM, via CSP_Mid.LMC, in advance of the scan Activation Time, and at regular intervals during the scan.

TBD: The exact requirements (content and cadence) for the above listed parameters are still to be defined.

Messages that contain delay tracking, calibration and beamforming parameters indicate the time when CSP_Mid.PSS should start using new values.

TBD: It is to be defined how much in advance a message must be delivered to CSP_Mid.PSS in order to be applied at the time specified in the message.

8.4 CSP_Mid.PSS Engineering Parameters

CSP_Mid.PSS implements a common set of parameters for sub-element, LRUs, Capabilities, Alarms Events and Monitor Points as specified in Chapter 6. This section will list only parameters specific to CSP_Mid.PSS.

8.5 CSP_Mid.PSS Requirements for Data Persistence

This section should list data generated by CSP that should be stored by the Telescope Manager:

1. Configuration data:

    - Version of hardware, firmware and software for all Components
    - Serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

In addition CSP_Mid.PSS generates the following:

1. Updates for the RFI Mask
2. Updates for the BRDZ List
3. Spectral statistics for on-going Pulsar Search Observations
4. Ancillary data for on-going Pulsar Search Observations (Data Chunk IDs, description and quality)

The complete list of auxiliary data generated by CSP_Mid.PSS is TBD.

For each type of the auxiliary data this section will define:

- Content
- Format
- Where the data is stored.

Detailed list TBD in the future releases of this ICD.

8.6 CSP_Mid.PSS Service from TM

TM, via LMC should provide access to the following information:

1. BRDZ list
2. Known pulsars
3. Long term RFI
4. Short term RFI
5. Satellite positions

TBD: It is to be defined how and when this information is delivered to CSP_Mid.PSS. TM, via LMC, might monitor some of these and notify PSS when updates are available, or inform operations to schedule maintenance in order to download updates.

8.7 CSP_Mid.PSS Alarms

Refer to the CSP to TM ICD [RD8] for the preliminary list of CSP_Mid.PSS alarms.

8.8 CSP_Mid.PSS Events

CSP_Mid.PSS generates the following events:

1. Pulsar search completed (for a particular sub-array). Rational: CSP_Mid.PSS requires an entire observation to be completed before it can begin the required acceleration processing; there is a lag between the end of an observation and the end of processing. This places constraints on scheduling of observations, as the next Pulsar Search observation should not start before the processing for the previous observation has been completed. CSP_Mid.PSS generates an Event message to inform to LMC/TM when the processing has been completed.

8.9 CSP_Mid.PSS Monitor Points

Estimate for the number of monitor points:

For each of 750 servers: ~10 monitor points (status, >3xtemperatures, running time, data chunk processed).

For each of   75 racks : ~ 10 monitor points (status, number of servers running, power, >2 temperatures)

For each of 1,500 beams: ~16 indicators.

Total: ~ 32,000 monitor points.

Auxiliary data (observation monitoring): 20 * 1500 = 30,000.

9 INTERFACE IMPLEMENTATION – CSP_MID.PST

Interface CSP_Mid.LMC to CSP_Mid.PST is described as follows:

- Aspects of the CSP_Mid.LMC to CSP_Mid.PST interface common to all CSP sub-elements are described in Chapter 6.
- This chapter describes all aspects of the CSP_Mid.LMC to CSP_Mid.PST interface *specific* to this interface.

Overview of the CSP_Mid.PST functionality (relevant to this interface):

- CSP_Mid.PST makes provision for TM, via CSP_Mid.LMC, to configure simultaneous Pulsar Timing in up to 16 beams.
- Pulsar Timing can be started, operated and stopped independently and concurrently in up to 16 Pulsar Timing beams.
- CSP_Mid.PST implements PST-beam as a Capability and is able to receive commands and queries for individual PST-beams (abstraction of functionality). CSP_Mid.PST performs mapping of the Capability PST-Beam to CSP_Mid.PST hardware and software components.

9.1 CSP_Mid.PST Capabilities

CSP_Mid.PST does not implement sub-array as a Capability; consequently, CSP_Mid.PST is not able to report status per sub-array. Instead, CSP_Mid.PST makes provision for CSP_Mid.LMC to control and monitor CSP_Mid.PST functionality and status for individual PST-Beams.

During initialization and when new equipment is turned on and detected, CSP_Mid.PST assigns hardware (compute nodes, servers and/or other resources) to Capabilities. CSP_Mid.PST reports to CSP_Mid.LMC how many CSP-PST-Beams are available and what is their status, including Observing Parameters.

Table 9-1 CSP_Mid.PST Capabilities

CSP_Mid Capability	Max. Number of Instances	M&C Functionality Supported
CSP-PST-beam	16	List availability. Set Observing Mode and start processing input data received from CBF (see Table 9-3) Stop Pulsar Timing (or other processing), implemented as “Set Observing Mode = IDLE” (see Table 7-3) Real-time updates for Pulsar Timing observations Disable / Enable (TBC) Set engineering parameters, for example: logging level, alarm thresholds, monitor point reporting, etc. Query parameters & status

9.2 CSP_Mid.PST Messages

This section describes CSP_Mid.PST specific messages.

CSP_Mid.LMC generated messages:

1. Query availability and status of CSP_Mid.PST equipment and CSP-PST-Beams
2. Set Observing Mode for a CSP-PST-Beam (see Table 9-3)
3. Stop Observing Mode for a CSP-PST-Beam (implemented as "set Observing Mode = IDLE", see Table 7-3)
4. Time-dependent updates (implemented as set parameters)
5. Set CSP_Mid.PST engineering parameters
6. Query CSP_Mid.PST parameters and status, including status and setup of CSP_Mid.PST, its Components and CSP-PST-Beams.

CSP_Mid.PST generates responses to TM messages, monitoring data, events and alarms.

Future releases of this ICD will contain the complete list of messages and set of parameters for each message.

9.3 CSP_Mid.PST Observing Mode Parameters

Table 9-3 lists the Observing Mode parameters to be provided by CSP_Mid.LMC.

CSP_Mid.LMC provides Observing Mode configuration for each CSP-PST-Beam individually, as shown in Table 9-3. It is to be defined (TBD) whether a single message may contain configuration for more than one CSP-PST-Beam.

CSP_Mid.LMC performs mapping between PST-beam IDs assigned by TM and CSP_Mid.PST Capabilities CSP-PST-Beam. More precisely CSP_Mid.LMC decides which CSP_Mid.PST Capability to use for which PST-Beam ID. CSP_Mid.LMC then forwards TM specified PST-Beam configuration to CSP_Mid.PST, as specified in Table 9-3.

CSP_Mid.LMC obtains the destination addresses for the CSP_Mid.CBF output for each PST-Beam, and sends that information to CSP_Mid.CBF.

CSP_Mid.LMC provides a mechanism for CSP_Mid.PST to send to TM recommendation (notification) to stop on-going pulsar timing observation and to indicate the reason. This can be implemented as an Event message (TBC).

Table 9-2 Legend for Table 9-3

Mode	
All	All
PT	Pulsar Timing
DS	Dynamic Spectrum (proposed - TBC)
FT	Flow Through (proposed - TBC)
When is the parameter required (When):	
SCfg	Scan Configuration - to be received in advance of the 'activation time' specified in the message.
SStart	At the beginning of the scan.
Intg	To be received after each N-second integration.
MC	May change, i.e. may be updated during an observation (scan).
Implementation (support) Priority (P) :	
H	High
M	Medium
L	Low
C	Not known if required until calibration model of the telescope is defined.
D	To be defined (TBD)

Table 9-3 CSP_Mid.PST - Observing Mode Parameters

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
Activation Time	String	UTC	All	SCfg	Date & Time when to start PST re-configuration	H
PST Beam ID	TBD	TBD	All	SCfg	Identifier assigned by CSP_Mid.LMC (or TM) used to identify beam configuration. CSP_Mid.PST selects which PST server (node) to use for this this scan and PST-Beam ID, and provides 'mapping' from the PST Beam ID provided by TM to PST Node ID (Capability ID).	H
CSP-PST-Beam ID	TBD	TBD	All	SCfg	Identifier of the Capability CSP-PST-Beam to be used for this configuration. Note: It is better to use an abstract Capability ID than the identifier of the PST node (or server) used by the Capability. In the future, a single server may be able to process data from more than one beam.	H
Scan ID	64 bits	TBD	All	SCfg	64-bit Scan ID inserted in the CBF output data.	H

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
Type of observation to be performed (OBSMODE)	string	PULSAR_TIMING	All	SCfg	The observing mode that the given PST server should operate in. In the future, two more Observing Modes may be added (an ECP has been proposed to add Observing Modes): Dynamic Spectrum and Flow Through.	H
Observer ID (OBSERVER)	string		All	SCfg	Observer in charge of observations.	L
Project ID (PROJID)	string		All	SCfg	Project that the observations are for.	L
Pointing ID (PNT_ID)	string		All	SCfg	ID for sub-array pointing.	H
Sub-array ID (SUBARRAY_ID)	string		All	SCfg		H
Source (SRC_NAME)	string		All	SCfg	Name or ID of source	H
ITRF (ITRF)	double[3]	[m,m,m]	All	SCfg	ITRF coordinates of the telescope delay centre.	H
Receiver ID (FRONTEND)	string		All	SCfg	Receiver name or ID (instrument).	H
Number of polarization channels (NRCVR)	int	[1, 2]	All	SCfg		H
Native polarization of feed (FD_POLN)	string	[LIN, CIRC]	All	SCfg		H
Feed handedness (FD_HAND)	int	[-1,+1]	All	SCfg	Code for sense of feed. FD_HAND = +1 for XYZ forming RH set with Z in the direction of propagation. Looking up into the feed of a prime-focus receiver (or at the sky), for FD_HAND = +1, the rotation from A (or X) to B (or Y) is counter clockwise or in the direction of increasing Feed Angle (FA) or Position Angle (PA). For circular feeds, FD_HAND = +1 for IEEE LCP on the A (or X) probe. See van Straten et al. (2010), PASA, 27, 104 for a full description of the polarisation conventions adopted for PSRFITS and PSRCHIVE RD14 AND RD15.	H
Feed angle (FD_SANG)	double	Degrees [-180,180]	All	SCfg	Feed angle of the E-vector for an equal in-phase response from the A(X) and B(Y) probes, measured in the direction of increasing FA or PA (clockwise when looking down on a prime focus receiver) and in the range +/- 180 deg.	H

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
Feed tracking mode (FD_MODE)	string	[FA, CPA, SPA, TPA]	All	SCfg	During an observation: 'FA' means constant FA, i.e., that the feed stays fixed with respect to the telescope reference frame; 'CPA' means that the feed rotates to maintain a constant PA, i.e., it tracks the variation of parallactic angle. Note that for COORD_MD = 'GALACTIC' PA is with respect to Galactic north and similarly, for COORD_MD = "ECLIPTIC' PA is with respect to Ecliptic north. For 'SPA' the FA is held fixed at an angle such that the requested PA is obtained at the mid-point of the observation; 'TPA' is relevant only for scan observations - the feed is rotated to maintain a constant angle with respect to the scan direction.	H
Feed position angle (FA_REQ)	double	Deg. [-180,180]	All	SCfg	The requested angle of the feed reference, for FD_MODE = 'FA', with respect to the telescope reference frame (FA = 0), and for FD_MODE = 'CPA', with respect to celestial north (PA = 0) or with respect to Galactic north for COORD_MD = 'GALACTIC'.	H
Centre frequency (OBSFREQ)	double	MHz	All	SCfg	Centre frequency of observation	H
Total (critical) bandwidth (OBSBW)	double	MHz	All	SCfg	Total (critical) bandwidth of observation.	H
Number of frequency channels (OBSNCHAN)	double		All	SCfg		H
Oversampling ratio (OVRSAMP)	int[2]		All	SCfg	Numerator and denominator for the oversampling ratio.	H
Beam major axis (BMAJ)	double	Deg.	All	SCfg		L
Beam minor axis (BMIN)	double	Deg.	All	SCfg		L
Beam position angle (BPA)	double	Deg.	All	SCfg		L
Frame of coordinates (COOR_MD)	string	[GALACTIC, EQUATORIAL, ECLIPTIC]	All	SCfg	Frame of coordinates.	H
Coordinate epoch (EQUINOX)	double	JD or MJD	All	SCfg		H
STT_CTD1	string	hh:mm:ss.sss or ddd.ddd	All	SStart	X component of starting coordinates in COORD_MD frame.	H
STT_CRD2	string	hh:mm:ss.sss or ddd.ddd	All	SStart	Y component of starting coordinates in COORD_MD frame.	H

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
Track mode (TRK_MODE)	string	TRACK, SCANGC, SCANLA	All	SCfg	For 'TRACK' the beam axis tracks a fixed point on the sky; for 'SCANGC' the beam axis tracks at a uniform rate along a great circle on the sky; for 'SCANLAT' the beam axis tracks at a uniform rate along a line of constant latitude or declination (depending on COORD_MD).	H
STP_CRD1	string	hh:mm:ss.sss or ddd.ddd	All	Intg	X component of the final coordinates in COORD_MD frame. Required at the end of each sub-integration (not the end of each observation). Required for non-tracking observations only. This could be every 1 second to every hour, but would only be needed in the case of non-tracked scans. Currently there is no use case for non-tracked scans with the PST, so this is unlikely to be used.	H
STP_CRD2	string	hh:mm:ss.sss or ddd.ddd	All	Intg	Y component of the final coordinates in COORD_MD frame. Required at the end of each sub-integration (not the end of each observation). See STP_CRD1 for more comments.	H
De-dispersion measure (DM)	double	pc cm^-3 [0:10,000]	PT, DS	SCfg	De-dispersion measure for coherent/incoherent de-dispersion.	H
Rotation measure (RM)	double	rads m^-2 [-?:+?]		SCfg	Rotation measure for coherent de-faraday rotation. To de-faraday rotate low frequency signals while maintaining high time resolution may imply that we need to perform coherent rotation measure correction. This is not a requirement at the moment but may be implicitly derived from existing requirements - To Be Defined (TBD).	D
Maximum length of observation (SCANLEN_MAX)	float	Seconds [30:43200]	All	SCfg	Maximum length of observation.	H
Pulsar ephemeris (EPHEMERIS)	ASCII text		PT	SCfg	Pulsar ephemeris for pulsar being observed. The ephemeris files should be of the order a few kilobytes.	H
Pulsar phase predictor (PREDICTOR)	ASCII text		PT	SCfg	Pulsar phase predictor generated from ephemeris (T2 format). The predictor received from the SDP must have enough coefficients to represent the phase of the pulsar to better than 1 ns RMS over the full bandwidth of the scan and up to SCANLEN_MAX. More information related to predictors is provided below this table.	H
Output frequency channels (OUTNCHAN)	int	[1:2250]	PT, DS	SCfg	The number of output frequency channels.	H
Output phase bins (OUTNBIN)	int	[64:2048]	PT	SCfg	The number of phase bins in output.	H
The integration time for each output bin (OUTTBIN)	double	Seconds [0.00032:60]	DS	SCfg	The integration time for each output bin.	H

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
The duration of each output sub-integration (OUTSUBMINT)	double	Seconds [1:60]	All	SCfg	The size of each output sub-integration.	H
Stokes parameters (OUTSTOKES)	string	combination of I,Q,U,V	DS	SCfg	The Stokes parameters to output when in Dynamic Spectrum mode.	H
The number of bits per output sample (OUTNBIT)	int	[1,2,4,8,16,32]	DS, FT	SCfg	The number of bits per output sample.	H
The number of samples integrated in SK statistics (SK_INT)	int	[?:?]	PT, DS	SCfg	The number of samples integrated in SK statistics.	H
SK Excision limits (SK_EXCIS)	double	Standard deviation [?:?]	PT, DS	SCfg	SK Excision limits (RFI threshold).	H
The number of channels in FT output (OUTNCHAN_FT)	int	<=OBSNCHAN	FT	SCfg	Number of channels to propagate to SDP in Flow Through mode.	H
Channels to be passed to SDP (OUTCHAN_FT)	Int	[OUTNCHAN_FT]	FT	SCfg	List of channel numbers to be passed to SDP in Flow Through mode (of length OUTNCHAN_FT).	H
Number of antennas (NANTS)	int	[1..197]	All	SCfg, Intg	The number of antennas in the sub-array. Required at the end of each N-second sub-integration (average weights for previous N seconds)	M
List of antennas (ANTENNAS)	int	Antenna IDs	All	SCfg, Intg	The IDs of the antennas included in the sub-array. Required at the end of each N-second sub-integration.	M
Antenna weights (ANT_WEIGHTS)	double	TBD	All	SCfg, Intg	The average weight for each antenna over the course of a sub-integration. These are the same weights that are delivered to the CBF. Required at the end of each N-second sub-integration (average weights for previous N seconds).	M

CSP_Mid.PST Parameter (Keyword)	Type	Units, valid values or range (all TBD)	Mode	When	Description	P
RFI frequencies (FREQ_MASK)	ASCII text	TBD	All	SCfg	A text file containing a list of known RFI frequencies to excise from the data - the PST has the capability to identify very narrow band signals. This would be an ASCII text file containing a list of frequencies and bandwidths for known RFI not excised by the CBF. Might change during course of an observation, but does not change over the course of a sub-integration. Suggestion would be that RFI channel lists would be updated on intervals of 10 seconds or more (most likely more). There is no specification on this at the moment, but it seems like a reasonable precaution to ensure data quality. RFI update should be delivered from LMC to PST every 10 or more seconds. The exact format is TBD, probably a text file, 2-column, tab-delimited. Size of the RFI files should be of the order 10s of kilobytes.	M
Cal mode (CAL_MODE)	string	OFF, SYNC, EXT1, EXT2	TBD	SCfg	Operation mode for the injected calibration: for 'OFF' there is no injected calibration; for 'SYNC' the calibration is pulsed synchronously with the folding frequency; 'EXT1' and 'EXT2' indicate that the calibration is driven by one of two possible user-defined external signals.	C
Calibration modulation frequency (E) (CAL_FREQ)	double	HZ	TBD	SCfg	Modulation frequency for the injected calibration signal.	C
Cal duty cycle (E) (CAL_DCYC)	double		TBD	SCfg	Duty cycle for the injected calibration signal.	C
Cal phase (E) (CAL_PHS)	double		TBD	SCfg	Cal phase (wrt start time). Phase of the leading edge of the injected calibration signal in SYNC mode.	C
Number of states in cal pulse (I) (CAL_NPHS)	double		TBD	SCfg	Number of pulses across one period of calibration phase.	C
Destination address(es)	MAC, IP, port	TBD	All	SCfg	Destination addresses for the CSP_Mid.PST output data. To be provided by SDP, via TM and LMC, before the start of the scan. TBD: Destination addresses may be provided in the same message with other configuration parameters or (more likely) after the SDP configuration and preparation for the scan has been completed (but shall be received before the scan Activation Time).	H

The SDP should provide, via TM and LMC, pulsar phase/longitude predictors as generated from the pulsar ephemerides (either managed by SDP or TM). Alternatively, the SDP could provide and manage the software stack for predictor generation which is used by CSP_Mid.PST to generate pulsar phase/longitude predictors with ephemerides provided by TM (via updates from SDP).

The size of predictor files scales with the number of frequency and time coefficients and the length of the validity period. For a 12 time, 12 frequency coefficient predictors that lasts 3 hours, the file size is 15 kB. Increasing the validity period by a factor of two increases the file size by a factor of 2 and vice versa. The largest predictor file that may be considered for SKA1 would be of the order 60 kB. Polyco files with the same number of coefficients are smaller than this; only predictor file sizes need to be considered when calculating maximum data rates.

TBD: CSP PST group anticipates that the human telescope operators will need to see various forms of diagnostic information during the observation. Content and format for plots will be specified in this ICD. TM Consortium will select the format for diagnostic plots. PST will not be capable of a vast array of diagnostics such as those that provide information on timing precision. These higher level diagnostics should be provided by the SDP.

TBD: at the implementation detail level: CSP_Mid.PST could send images to TM (e.g. PNG or JIF) or, if the TM expects to be able to query the data in multiple ways, CSP_Mid.PST might send TM a copy (possibly reduced in dimension) of the information that is sent to the SDP.

9.4 CSP_Mid.PST Engineering Parameters

CSP_Mid.PST implements a common set of parameters for the sub-element, LRUs, Capabilities, Alarms Events and Monitor Points as specified in Chapter 6. This section lists only parameters specific to CSP_Mid.PST.

9.5 CSP_Mid.PST Requirements for Data Persistence

This section should list data generated by CSP that should be stored by Telescope Manager.

1. Configuration data:
    - Version of hardware, firmware and software for all Components
    - Serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

The list of auxiliary data generated by CSP_Mid.PST is TBD.

For each type of the auxiliary data this section will define:

- Content
- Format
- Where the data is stored.

Detailed list TBD in the future releases of this ICD.

9.6 CSP_Mid.PST Alarms

List of Alarms generated by CSP_Mid.PST is to be defined (TBD).

9.7 CSP_Mid.PST Events

Events generated by CSP_Mid.PST:

- Recommendation to stop on-going pulsar timing for a particular pulsar (includes reason).

9.8 CSP_Mid.PST Monitor Points

Estimate for the number of monitor points: ~ 300 Monitor Points.

Estimate is based on the proposed physical implementation.

10 INTERFACE IMPLEMENTATION – CSP_LOW.CBF

Interface CSP_Low.LMC to CSP_Low.CBF is described as follows:

- Aspects of the CSP_Low.LMC to CSP_Low.CBF interface that are common to all CSP sub-elements are described in Chapter 6.
- This chapter describes aspects of the CSP_Low.LMC to CSP_Low.CBF interface that are *specific* to this interface.

Content to be provided in this chapter is described in the Section 1.9 on page 22.

10.1 CSP_Low.CBF Capabilities

Table 10-1 lists Capabilities implemented by CSP_Low.CBF.

Sub-arrays are created and destroyed dynamically, as requested by CSP_Low.LMC.

Capabilities station-input, CBF-PSS-beam and CBF-PST-beam are created during initialization or when new equipment is installed and powered-up. At creation, CSP_Mid.CBF assigns:

- ➢ Set of hardware and software Components used by a Capability. In some cases a Capability is in full control of the hardware or software Component; in others it uses a part of the functionality implemented by the Component.
- ➢ Unique identifier (integer) which is used in the LMC and CBF generated messages to refer to a particular CBF Capability. Capability ID is assigned by CSP_Mid.CBF and reported to LMC as a part of CSP_Mid.CBF self-description.

Stations can be added and removed to/from a sub-array on TM/LMC request only when the sub-array Observing Mode is IDLE or at scan boundaries, i.e. when one scan ends and the next scan starts.

A station can belong to a single sub-array at a time, in other words, all input data from the same station is processed within the same sub-array.

Depending on the station configuration, input data from each station can consist of up to 16 beams.

The following aspects of the interface are still to be defined (TBD):

1. Is the number of beams per station configurable?
2. Input from each station consists of 384 coarse channels. Is allocation of coarse channels to station-beams configurable, i.e. can it be different for different observations or is it fixed?
3. Beam configuration should be the same for all the stations that belong to the same sub-array. If station-beam configuration is configurable, does TM, via LMC, specify the beam configuration per sub-array?
4. Is it useful to define a CSP_Low.CBF Capability station-beam, so that TM/LMC can query the status of individual station-beams and set beam parameters (if any are implemented)?
5. Should TM/LMC be able to query the status of individual coarse channels and/or set parameters of coarse channels (if any are implemented)?

6. Is there a need to specify Observing Mode configuration for each station-beam individually or is the Observing Mode configuration specified once and applies for all the station-beams in a sub-array?

In the same manner as stations, CBF-PSS-beams and CBF-PST-beams can be added / removed to/from a sub-array only at scan boundaries or when the sub-array is in IDLE mode.

Capability baseline exists only in the context of a sub-array and has been defined to allow TM, via LMC, to query status of the output products for a particular baseline or group of baselines. (It is TBC whether such functionality is useful and required).

Table 10-1 CSP_Low Capabilities

CSP_Low Capability	Max. Number of Instances	M&C Functionality Supported
sub-array	16	List availability Create Delete Add/remove stations TBC: Set station-beam configuration. Add/remove CBF-PSS-beams and/or CBF-PST-beams Set Observing Mode and related parameters including the date & time when to start re-configuration (Table 10-2). Stop signal processing and generation of output products - set Observing Mode IDLE (Table 10-3). Real-time updates for Observing Mode parameters (delay models and similar), as described in Sections 10.4, 10.5 and 10.6. Query parameters & status
station-input	512	Station is not part of CSP; Capability station-input has been defined to allow TM to query status of input signal and status of the CSP Components that process input from a station. Input from each station consists of 384 coarse channels. Disable (set 'not available for use') Enable (set 'available for use') Query parameters & status.
CBF-PSS-beam	500 User will be able to trade beams for bandwidth - details TBD.	List availability Disable / Enable Set parameters Set list of stations used in beamforming. Get parameters & status

CSP_Low Capability	Max. Number of Instances	M&C Functionality Supported
CBF-PST-beam	16	List availability Disable / Enable Set parameters Set list of stations used in beamforming. Get parameters & status
baseline	131,328 n*(n-1))/2 + n n=512 number of stations	Get status Disable/enable transmission of the output products. Note: Auto-correlations (correlation of a station with itself) are also represented as baselines.

10.2 CSP_Low.CBF Messages

CSP_Mid.LMC can use SET Parameters messages to:

1. Create / delete sub-array.
2. Add / remove stations to/from a sub-array.
3. TBD: Configure station–beams.
4. Add / remove CBF-PSS-beams and/or CBF-PST-beams to/from a sub-array.
5. Specify centre frequency and frequency reference (TBC).
6. Set Observing Mode for a sub-array. Message content as specified in Table 10-2 and Sections 10.4, 10.5, and 10.6.
7. Stop scan (stop signal processing and generation of output products, implemented as set Observing Mode=IDLE). See Table 10-3.
8. Set time-dependent parameters as applicable for the particular Observing Mode. All CSP_Low.CBF no-IDLE modes require updates for each on-going observation as specified in Sections 10.4, 10.5, and 10.6.
9. Delete sub-array.
10. Set ‘engineering’ parameters of the CSP_Low.CBF sub-element and its Components and Capabilities. Some of the engineering parameters can be set (modified) only when a component or Capability is not used (i.e. when Observing Mode is IDLE). List of engineering parameters, access-rights and other constrains is TBD.

CSP_Low.LMC can use message GET Parameters to query parameters and status of the CSP_Low.CBF sub-element and its Components and Capabilities.

As described in section 6.3.6, CSP_Low.CBF generates:

- Response for each received SET Parameters and GET Parameters message
- Alarms
- Events
- Monitor Points Reports.

10.3 CSP_Low.CBF Scan Configuration

Table 7-2 lists the parameters to be specified by CSP_Low.LMC to set Observing Mode and start scan. The date & time when to start re-configuration of the sub-array is indicated in the message. If the message does not specify date & time when to start re-configuration of the sub-array, CSP_Low.CBF starts re-configuration of the sub-array as soon as possible (as specified in Section 6.3.6.1).

CSP_Low.CBF starts generated output as soon as re-configuration is completed.

Note: In general, a sub-array uses more than one, and in most cases many, output spigots to transmit generated output products; not all components begin generating output data at the same time; this means that CSP_Low.CBF may generate incomplete data sets at the beginning of a scan; the recipient of the CSP_Low.CBF output must be able to handle incomplete data sets.

Once configured, CSP_Low.CBF keeps the sub-array configuration until one of the following occurs:

- CSP_Low.CBF receives a command to re-configure the sub-array (as specified in Table 7-2 and Table 7-3).
- CSP_Low.CBF receives a command to delete the sub-array.
- CSP_Low.CBF receives a command to transit in low-power mode.
- CSP_Low.CBF receives a command to shut-down.
- CSP_Low.CBF monitor and control function fails so that the configuration is lost.

Table 10-2 CSP_Low.CBF Scan Configuration

CSP_Low.CBF Scan Configuration	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set sub-array parameters.
Activation Time	Date & time	UTC	Date and time when to start re-configuration of the sub-array.
Duration	Integer	TBD	Optionally, TM/LMC can specify scan duration (TBC).
Scan ID	Integer	64-bit	Scan ID to be inserted in CBF output products.
Any combination of the following Observing Modes can be specified (the same message):			
Observing Mode Imaging	Enumeration	IMAGING	Observing Mode parameters as specified in **Table** 10-4 on page 81.
Observing Mode Pulsar Search	Enumeration	PULSAR SEARCH BEAMFORMING	Observing Mode parameters as specified in Table 10-5 on page 84.
Observing Mode Pulsar Timing	Enumeration	PULSAR TIMING BEAMFORMING	Observing Mode parameters as specified in Table 10-6 on page 86.

Table 10-3 CSP_Low.CBF End Scan

CSP_Low.CBF End Scan	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set sub-array parameters.
Activation Time	Date & time	UTC	Date and time when to start re-configuration of the sub-array.
Observing Mode	Enumeration	IDLE	Use to set sub-array in IDLE mode (the setup of the CSP_Low.CBF in this mode is TBD).

10.4 CSP_Low.CBF Observing Mode Imaging

CSP_Low.CBF configuration and output products are the same for Spectral-line Imaging and Continuum Imaging; CSP_Low.CBF implements a single Observing Mode Imaging.

Observing Mode Imaging can be started, operated and stopped independently and concurrently in up to 16 sub-arrays.

Input from each station may consist of up to 16 beams. It is to be defined (TBD) whether the station-beam setup is configurable, and should it be specified as a part of a scan configuration.

For each sub-array in Imaging mode, CSP_Low.CBF makes provision for TM, via LMC, to configure up to four zoom windows, each with bandwidth selected independently from values within 10% of 4 MHz, 8 MHz, 16 MHz, and 32 MHz; each independently tuned, with frequency granularity better than 1.1 MHz, such that the entire zoom window lies anywhere within the subarray's digitized observing band. CSP_Low.CBF is able to produce output products (correlated visibilities and autocorrelations for all polarization products) concurrently for four zoom windows and over the entire digitized band (300MHz, 384 coarse channels), with an evenly spaced frequency resolution of 1 MHz +/- 10%.

TBD: Are zoom windows defined per beam? Does CSP_Low.CBF allow for total of up to 4 zoom windows per sub-array, or up to 4 zoom windows per beam per sub-array?

TBD: Is the frequency resolution, integration time, number of phase bins and zoom windows configuration the same for all the beams in the sub-array? Are some, or all, of these parameters specified for each beam independently?

CSP_Low.CBF can perform Imaging concurrently in the same sub-array with the following Observing Modes:

1. Pulsar Search Beamforming
2. Pulsar Timing Beamforming

Note: CSP_Low.CBF is the only CSP sub-element used for Observing Mode Imaging; other CSP_Low sub-elements are not used for this mode.

Table 10-4 CSP_Low.CBF Observing Mode Imaging – Configuration Parameters

CSP_Low.CBF Imaging Mode Parameter	Type	Range	Description
Observing Mode	Enumeration	IMAGING	Observing Mode
Frequency resolution	TBD	TBD	
Integration time	Integer	TBD	Integration time for correlation products, specified in milliseconds. SKA1-CSP_REQ-2150-0 [AD3]: For each subarray, CSP_Low shall have independently configurable visibility integration periods which are within 2% of 0.9s, and within 10% of (2, 3, 5, 10) times 0.9s.
Number of phase bins	Integer	1..256 (TBC)	By default, the number of phase bins = 1, i.e. no binning. Number of phase bins * number of channels * 4 <= 262,144. Number of phase bins may be defined as enumeration, i.e. only a limited choice may be available (TBD).
Pulsar ephemeris	TBD	TBD	Parameters required for pulsar phase binning, i.e. required when the number of phase bins > 1.
The physical location of the centre of the sub-array	TBD	TBD	
RFI mask	TBD	TBD	Mask for RFI excision. Specified per station. See SKA1-CSP_REQ-2474-00 [AD3].
RFI excision level	TBD	TBD	When to start RFI excision and for how long to perform

CSP_Low.CBF Imaging Mode Parameter	Type	Range	Description
RFI excision period	TBD	TBD	excision. Other RFI mitigation parameters can be defined (TBD). See SKA1-CSP_REQ-2473-00 [AD3]. CSP_Low.CBF may implement additional parameters for dynamic control of RFI excision, for example, a choice of RFI excision algorithms.
Optionally, TM, via LMC, may specify up to 4 zoom windows. TBC: The parameters specified below are specified for each zoom window independently.			
Zoom window ID	Integer	1..4	Identifier used to refer to the zoom window in commands, queries and reports (including alarms). Must be unique within a sub-array.
Bandwidth	Enumeration	TBD	Currently defined L2 Rev1 as: 4 MHz, 8 MHz, 16 MHz, and 32 MHz (±10%). TBD: is the zoom window bandwidth specified as a multiple of the coarse channel bandwidth?
Position of the zoom window within the input band	TBD	TBD	Zoom window may be placed anywhere within the digitized input band (300MHz), but quantized to the coarse channel frequencies. TBD: Is a zoom window defined by the list of coarse channels or by the central frequency?
Number of spectral channels	Enumeration	TBD	Most likely a user (via TM/LMC) will be able to choose the number of channels from the pre-defined list of values.

Before CSP_Low.CBF can begin to generate output products, the CSP_Low.CBF and SDP shall exchange the following information via LMC and TM:

1. After allocating resources to be used for the specified sub-array and Observing Mode, CSP_Low.CBF shall notify SDP via LMC/TM regarding the number of output streams (spigots) to be used to transmit CSP_Low.CBF products (visibilities) to SDP. Distribution of baselines/products per stream shall be also indicated.
2. SDP shall send to CSP_Low.CBF via TM/LMC destination addresses (MAC and IP addresses) for the CSP_Low.CBF products.

For each sub-array in Imaging mode, CSP_Low.CBF requires TM/LMC to provide delay tracking and calibration in advance of the specified configuration Activation Time, and at regular intervals during the scan.

For each sub-array in Imaging Observing Mode, TM, via LMC, shall provide:

1. Delay models per beam per station. (There can be up to 16 beams per station.)
2. On-sky calibration residuals sourcing from the SDP (i.e. station-based delay corrections).

The delay correction derived from calibration (and provided by SDP) shall be rolled-up (by TM) with the geometric delay and delivered as a single delay model.

For each delay model TM/LMC shall specify the time when the model becomes valid (i.e. when CSP_Low.CBF should start using the model).

TBD: It is to be defined how much in advance a delay model has to be delivered to CSP_Low.CBF in order to be applied at the time specified in the message.

Note: There can be up to 16 concurrent sub-arrays with up to 16 beams each; CSP_Low.CBF may require regular updates up to 256 delay polynomials. The polynomial returns delay in units of time or distance.

Cadence and number of coefficients for the delay models are TBD.

10.5 CSP_Low.CBF Observing Mode Pulsar Search Beamforming

Overview:

1. CSP_Low.CBF can form up to 500 Pulsar Search beams.
2. Any number of PSS beams can be assigned to any sub-array.
3. Pulsar Search beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. PSS beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

For the Observing Mode Pulsar Search to be accepted, the sub-array must contain at least one receptor and at least one CBF-PSS-beam. In other words, receptors and CBF-PSS-beams must be assigned to a sub-array in advance of the Observing Mode configuration. Note however, that re-configuration may be scheduled to start at the same time for the commands ‘add receptor’, ‘add CBF-PSS-beam’ and ‘set Observing Mode’ requests.

TBD: Number of PSS-beams can be traded for bandwidth. Details to be defined.

CSP_Low.CBF can form Pulsar Search beams concurrently in the same sub-array with the following Observing Modes:

1. Imaging
2. Pulsar Timing Beamforming

Table 10-5 CSP_Low.CBF Parameters for Pulsar Search Beamforming

CSP_Low.CBF Pulsar Search Parameter	Type	Range	Description
Observing Mode	Enumeration	Pulsar Search	Observing Mode
Scan ID	Integer	64-bit	Scan ID to be inserted in the CBF output data flowing to PSS.
Phase centre of the sub-array	TBD	TBD	
Stations to be used in beamforming	List of station IDs	1..512	Optionally user may specify a subset of stations that belong to the sub-array to be used in tied-array beamforming. If not specified, CSP_Low.CBF uses all the stations that belong to the sub-array. TBD: Should user, via TM and LMC, be able to specify the list of stations for each PSS beam individually?
Station-beam to be used in beamforming	List	1..16	Input from each station may consist of up to 16 beams. This parameter identifies the station-beam to be used in PSS-beamforming. TBD: Should user, via TM and LMC, be able to select the station-beam to be used in beam-forming for each PSS beam individually?
Number of bits per sample	Integer	TBD	Number of bits per sample in the beamformer output (for the data passed to CSP_Low.PSS).
The following parameters are specified for each of up to 500 PSS beams:			
PSS Beam ID	Integer	TBD	PSS Beam ID as specified by TM/LMC. Note: Beam ID specified by TM/LMC is not the same as CBF-PSS-beam Capability ID. CSP_Mid.CBF performs mapping from the TM/LMC specified PSS Beam ID into CBF-PSS-beam and decides which Capability CBF-PSS-beam to use for each PSS Beam.
PSS Beam BW	Integer	TBD	TBD: Is PSS-beam bandwidth specified as a multiple of the coarse channel bandwidth? TBD: User (via TM/LMC) can trade the number of PSS beams for bandwidth – details TBD. TBD: CSP could make provision for user to choose PSS beam configuration/packing from one of the pre-defined beam configurations or to specify parameters for each PSS beam independently.
PSS Beam centre frequency	Integer	TBD	
PSS Beam Delay Centre	TBD	TBD	
PSS Beam Destination Address(es)	TBD	TBD	Destination addresses (MAC, IP, port) must be provided by CSP_Low.PSS, via LMC, before CSP_Low.CBF starts generating output products (beam data).

In the case that some of the CSP_Low.PSS equipment fails during an observation (scan), CSP_Low.CBF may receive address change notification during a scan. In such case, CSP_Low.CBF should begin to use the new destination addresses as soon as possible. Time required to apply the address change is TBD.

For each sub-array in Pulsar Search beamforming mode, CSP_Low.CBF requires TM/LMC to provide the following in advance of the specified Activation Time and at regular intervals during the scan:

1. Per-station, per PSS beam delay+cal models relative to the primary delay canter. A model is required per station per PSS beam (that's a model for each of up to 512 stations for up to 500 PSS beams - up to 256,000 models). However, these models are relative to the delay canter and should have a low update rate.
2. Weights to be used in the tied-array beamforming (for each PSS beam).
3. Jones Matrix per coarse channel (1MHz channel) per PSS beam, that's up to 384x500=192,000 Jones Matrices.
4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift). (TBC)

Messages with updates for the above listed parameters indicate the time when CSP_Low.CBF should start using new values.

TBD: It is to be defined how much in advance configuration parameters and updates have to be delivered to CSP_Low.CBF in order to be applied at the time specified in the message.

10.6 CSP_Low.CBF Observing Mode Pulsar Timing Beamforming

Overview:

1. CSP_Low.CBF can form up to 16 Pulsar Timing beams.
2. Any number of CBF-PST-beams (Capabilities) can be assigned to any sub-array.
3. Pulsar Timing beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. CBF-PST-beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

CSP_Low.CBF can form Pulsar Timing beams concurrently in the same sub-array with the following Observing Modes:

3. Imaging
4. Pulsar Search Beamforming

Table 10-6 CSP_Low.CBF Parameters for Pulsar Timing Beamforming

CSP_Low.CBF Pulsar Timing Beamforming Parameter	Type	Range	Description
Observing Mode	Enumeration	Pulsar Timing Beamforming	Observing Mode
Scan ID	Integer	64-bit	Scan ID to be inserted in the CBF output data flowing to PST.
Phase centre of the sub-array	TBD	TBD	
The following parameters are specified for each of up to 16 PST beams:			
PST Beam ID	Integer	1..16	PST Beam ID as specified by TM/LMC. Note: Beam ID specified by TM/LMC is not the same as CBF PST-beam Capability ID. Internally CBF must perform mapping of TM/LMC assigned IDs into CBF IDs.
PST Beam BW	Integer	Up to 300MHz	TBD: Is PST-beam bandwidth specified as a multiple of coarse channel bandwidth?
PST Beam centre frequency	Integer	TBD	
PST Beam Delay Centre	TBD	TBD	
Stations to be used in beamforming	List of station IDs	1..512	Optionally user may specify a subset of the stations that belong to the sub-array to be used in PST beamforming. If the list of stations is not specified, CSP_Low.CBF uses all the stations that belong to the sub-array.
Station-beam to be used in beamforming	Integer	1..16	Input from each station may consist of up to 16 beams. This parameter identifies the station-beam to be used in PST beamforming.
Number of bits per sample	Integer	TBD	Number of bits per sample in the CBF output (for the data passed to CSP_Low.PST).
Destination Address(es)	TBD	TBD	Destination addresses (MAC, IP, port) for the PST beam data, must be provided by LMC before CBF can start generating output products (beam data).

In the case that some of the CSP_Low.PST equipment fails during an observation (scan), CSP_Low.CBF may receive address change notification during the scan. CSP_Low.CBF should begin to use the new destination addresses as soon as possible. Time required to propagate the change is TBD.

For each sub-array in Pulsar Timing beamforming mode, CSP_Low.CBF requires TM/LMC to provide the following in advance of the specified configuration Activation Time and at regular intervals during the scan:

1. Per-station, per PST-beam delay+cal models relative to the primary delay canter. A model is required per station per PST beam (a model for each of up to 512 stations for up to 16 PST

beams; that is 8192 models). These models are relative to the delay canter and should have a low update rate.

2. Weights to be used in the tied-array beamforming (per station per PST beam).
3. Jones Matrix per coarse channel (1MHz channel) per station per PST beam. That's up to 384 x 512 x 16 = 3,145,728 Jones Matrices. To be confirmed by PST group (TBC).
4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift). (TBC)

TBD: The exact requirements (the number of bytes and cadence) for above listed parameters are still to be defined.

Messages with updates for the above listed information indicate the time when CSP_Low.CBF should start using new values.

TBD: It is to be defined how much in advance this information has to be delivered to CSP_Low.CBF in order to be applied at the time specified in the message.

TBD: When Pulsar Timing has been completed for a particular pulsar, TM, via LMC, may instruct CSP_Low to start timing for the next pulsar in the list – it is TBD whether that will require re-configuration of the CSP_Low.CBF.

10.7 CSP_Low.CBF Engineering Parameters

CSP_Low.CBF implements parameters that are common to all CSP_Low sub-elements, LRUs, sub-arrays, Capabilities, Alarms, Events and Monitor Points, as specified in Chapter 6.

This section will specify parameters specific to CSP_Low.CBF.

10.8 CSP_Low.CBF Requirements for Data Persistence

This section will list data generated by CSP_Low.CBF that should be stored by Telescope Manager.

The preliminary list includes:

1. Configuration data:
    - Versions of hardware, firmware and software for all Components
    - LRU serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

The list of auxiliary data generated by CSP_Low.CBF is TBD.

For each type of the auxiliary data this section will define:

- ➢ Content

- Format
- Where the data is stored.

Detailed list TBD in the future releases of this ICD.

10.9 CSP_Low.CBF Alarms

List of Alarms generated by CSP_Low.CBF TBD.

10.10 CSP_Low.CBF Events

List of Events generated by CSP_Low.CBF TBD.

10.11 CSP_Low.CBF Monitor Points

List of Monitor Points for CSP_Low.CBF is TBD.

11 INTERFACE IMPLEMENTATION – CSP_LOW.PSS

Interface CSP_Low.LMC to CSP_Low.PSS is described as follows:

- Aspects of the CSP_Low.LMC to CSP_Low.PSS interface that are common to all CSP sub-elements are described in Chapter 6.
- This chapter describes all aspects of the CSP_Low.LMC to CSP_Low.PSS interface that are *specific* to this interface.

The content to be provided in this chapter is described in Section 1.9.

11.1 CSP_Low.PSS Capabilities

Table 11-1 CSP_Low.PSS Capabilities

CSP_Low.PSS Capability	Max. Number of Instances	M&C Functionality Supported
sub-array	16	List availability Create Delete Add/remove stations Center frequency and frequency reference, if required. Add/remove CSP-PSS-Beams Set Observing Mode parameters Stop signal processing and generation of output products - set Observing Mode IDLE. See Table 10-3. Real-time updates for Observing Mode parameters (delay models and similar) Query parameters and status
CSP-PSS-beam	500	List availability Disable / Enable Set parameters Query parameters & status (including Beam ID received in the CBF data and input addresses – i.e. destination for CBF products).

Capabilities CSP-PSS-beam are created during initialization or when new equipment is installed and powered-up. At creation, CSP_Low.PSS assigns:

- Set of hardware and software Components used by a Capability. In some cases a Capability is in full control of hardware or software Component; in others it uses a part of the functionality implemented by the Component.

- Unique identifier used in the LMC and PSS generated messages to refer to a particular CSP-PSS-Beam. Capability ID is assigned by CSP_Low.PSS and reported to LMC as a part of CSP_Low.PSS self-description.

CSP-PSS-Beams can be moved in and out of a sub-array only when the sub-array Observing Mode is IDLE and at scan boundaries i.e. after one scan ends and before the next scan begins.

11.2 CSP_Low.PSS Messages

CSP_Low.LMC can use SET Parameters messages to:

1. Create / delete sub-array.
2. Add / remove stations to/from a sub-array. TBD: Does CSP_Low.PSS need the list of stations that belong to the sub-array? Does CSP_Low.PSS need the list of stations and station-beams used in beamforming?
3. Add / remove CSP-PSS-beams to/from a sub-array.
4. Set centre frequency and frequency reference (TBC).
5. Set Observing Mode parameters for a sub-array (including date & time when to begin re-configuration), as specified in Section 11.3.
6. Stop scan, i.e. stop signal processing and generation of output products, implemented as set Observing Mode IDLE (content as defined in Table 10-3 on page 80).
7. Set time-dependent parameters required for Pulsar Search. Regular updates are provided for each on-going observation (i.e. each non-IDLE sub-array), as specified in Section 11.3.
8. Delete sub-array.
9. Update BRDZ list and other RFI related parameters.
10. Set 'engineering' parameters of the CSP_Low.PSS sub-element and its Components and Capabilities. Some of the parameters can be set only when sub-element, Capability and/or Component is not used (i.e. when Observing Mode is IDLE). List of engineering parameters, access-rights and other constrains is TBD.

CSP_Low.LMC can use GET Parameters message to query parameters and status of the CSP_Low.PSS sub-element and its Components and Capabilities.

CSP_Low.PSS generates:

- Responses for received SET Parameters and GET Parameters message (as described in section 6.3.6).
- Alarms
- Events
- Monitor Points Reports

Future releases of this ICD will provide the exact list of messages and parameters.

11.3 CSP_Low.PSS Observing Mode Parameters

Overview:

1. CSP_Low.CBF can form up to 500 Pulsar Search beams.
2. Any number of CSP-PSS-beams can be assigned to any sub-array.
3. Pulsar Search beamforming can be started, operated and stopped independently in up to 16 sub-arrays.
4. CSP-PSS-beams (Capabilities) must be assigned to a sub-array in advance of the Observing Mode configuration.

Table 11-2 lists the parameters to be specified in the CSP_Low.LMC-generated message 'Set Sub-array Observation Mode Pulsar Search'.

Note: CSP_Low.PSS implements two sub-modes: acceleration search (a.k.a. Pulsar Search) and single pulse search (a.k.a. Transient Search). Both modes can be enabled concurrently, during the same scan. A single message is used to configure both searches.

Configuration for the Observing Mode Pulsar Search can be accepted only when the sub-array contains at least one receptor and at least one CSP-PSS-Beam. In other words, receptors and CSP-PSS-Beams must be assigned to a sub-array in advance of Observing Mode configuration.

Note however that the re-configuration may be scheduled to start at the same time for all three commands: 'add receptor', 'add CSP-PSS-beam' and 'set Observing Mode'.

CSP_Low.PSS selects which Capability to use for which PSS beam specified in the message and provides mapping between the PSS Beam IDs specified in the message and Capability IDs.

After allocating resources to be used for the specified sub-array and Observing Mode, CSP_Low.PSS shall notify CSP_Low.CBF, via LMC, which destination addresses to use for which PSS Beam.

Table 11-2 CSP_Low.PSS Observing Mode Parameters

CSP_Low.PSS Observing Mode Parameter	Type	Range	Description
Sub-array ID	ASCII String	-	Sub-array ID unique per telescope.
Action	ASCII String	Set	Set parameters.
Parameters that apply for all the PSS beams in the sub-array:			
Activation Time	Date & time	UTC	Date and time when to begin re-configuration of the sub-array.
Scan ID	Integer	64-bit	Scan ID to be inserted in the CSP generated output products.
Pointing Name	TBD	TBD	Station-beam pointing symbolic name and coordinates (observed source name and co-ordinates).
Pointing Coordinates	TBD	TBD	

CSP_Low.PSS Observing Mode Parameter	Type	Range	Description
Pointing Switching Schedule	TBD	TBD	Schedule for switching between observed sources - if CSP is required to handle source switching autonomously (requirements TBD).
PSS Beam BW	Integer or enumeration	TBD	
Number of bits per sample	Integer	TBD	Number of bits per sample in the data received from CSP_Low.CBF.
Acceleration Search	Boolean	Enable Disable	Acceleration Search (a.k.a. Pulsar Search) and Single Pulse Search (a.k.a. Transient Search) can be performed concurrently – both can be enabled.
Single Pulse Search	Boolean	Enable Disable	
Integration time	Integer	Up to 1,800 seconds	The maximum length of a data chunk on which search can be performed.
Acceleration Range	Integer	0-350 m/s^2 Default=0	Range in source acceleration to be searched. Specified as integer number of milliseconds.
Number of Trials	Integer	TBD	Number of trials to be performed.
Time Resolution	Integer	50-800 µs (2n * 50 µs)	Time resolution of input data. Values in increments (2n * 50 µs).
Dispersion Measure	Integer	0-3000 pc cm-3	Dispersion correction. TBD: Do we need a separate DM search range for single-pulsar sources (transients)?
Number of Frequency Channels	Integer	1,000-4,096	Multiple of 1,000 or of 1,024 - TBD
Time Sample per Block	Integer	Up to (integration time) / (time resolution)	Number of time samples in each block of data.
Sub-bands	Integer	Up to 64	Number of frequency band groups summed up during folding.
Input Buffer Size	Integer	2^18-2^24	Size of the buffer receiving raw data.
Harmonic summing control parameter	Integer	1-32	Number of the “harmonic folds” on the initial Fourier power-spectrum summed up.
Complex FFT Control Parameters	TBD	TBD	CXFT control parameters.
Candidate Sifting Parameters	TBD	TBD	Constraints on matches between candidates.
Candidates Output Parameters	TBD	TBD	Define data sinks and subscriber to be notified (TBC).
Single Pulse Threshold	Integer	TBD	Threshold for a single pulse trigger.

CSP_Low.PSS Observing Mode Parameter	Type	Range	Description
Single Pulse Optimization Parameters	TBD	TBD	Single pulse optimization parameters.
RFI Mask list	TBD	TBD	Interference Mask to be used and updated by CSP_Low.PSS.
DREAD Beam Statistics	Table of floats	TBD	DREAD: statistics of spectra to derive the normalization factors.
CDOS Control Parameters	TBD	TBD	CDOS: control parameters and related statistical data. Exact list of parameters TBD.
RFIM Control Parameters	TBD	TBD	RFIM: control parameters. Exact list of parameters TBD.
Parameters to be specified for each PSS beam Individually:			
PSS Beam ID	Integer	TBD	Beam ID (as specified by TM/LMC).
Destination address	TBD	TBD	Destination address for CSP_Low.PSS output.
Beam co-ordinates	TBD	TBD	Pointing co-ordinates of the PSS beam.
Beam centre frequency	Integer	TBD	Beam center frequency and beam delay center, center relative to the array delay center. TBD: beam center frequency and delay center are required by CSP_Low.CBF but may not be needed by CSP_Low.PSS. TBD: TM and CSP could make provision for the user to choose one of the pre-defined PSS beam configurations or to specify parameters for each PSS beam independently.
Beam delay centre	TBD	TBD	

In addition to the parameters provided in advance of the scan Activation Time (listed in Table 11-2), TM via CSP_Low.LMC provides updates for the following parameters for on-going observations, as applicable:

1. On-sky calibration residuals sourcing from the SDP via TM and LMC for beamforming (i.e. antenna-based delay corrections), as applicable.
2. Pulsar ephemeris models (polynomials) sourcing from TM, via LMC, at a regular rate.
3. Weights used in beamforming (for each PSS beam).
4. Diurnal variations of ionospheric parameters (that affect Doppler Frequency Shift) – this requirements is to be confirmed (TBC).

As discussed in CSP to TM ICD [RD7] these parameters are provided by TM, via CSP_Low.LMC, in advance of the scan Activation Time, and at regular intervals during the scan.

TBD: The exact requirements (the number of bytes and cadence) for the above listed parameters are still to be defined.

Messages that contain delay tracking, calibration and beamforming parameters indicate the time when CSP_Low.PSS should start using new values.

TBD: It is to be defined how much in advance a message must be delivered to CSP_Low.PSS in order to be applied at the time specified in the message.

11.4 CSP_Low.PSS Engineering Parameters

CSP_Low.PSS implements common set of parameters for sub-element, LRUs, Capabilities, Alarms Events and Monitor Points as specified in Chapter 6. This section will list only parameters specific to CSP_Low.PSS.

11.5 CSP_Low.PSS Requirements for Data Persistence

This section should list data generated by CSP that should be stored by Telescope Manager:

1. Configuration data:
    - Version of hardware, firmware and software for all Components
    - Serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

In addition CSP_Low.PSS generates the following:

1. Updates for the RFI Mask
2. Updates for the BRDZ List
3. Spectral statistics for on-going Pulsar Search Observations
4. Ancillary data for on-going Pulsar Search Observations (Data Chunk IDs, description and quality)

The complete list of auxiliary data generated by CSP_Low.PSS is TBD.

For each type of the auxiliary data this section will define:

- Content
- Format
- Where the data is stored.

Detailed list TBD in the future releases of this ICD.

11.6 CSP_Low.PSS Service Required from TM

TM should provide access to the following information:

1. BRDZ list
2. Known pulsars
3. Long term RFI
4. Short term RFI
5. Satellite positions

11.7 CSP_Low.PSS Alarms

Refer to the CSP to TM ICD [RD7] for the preliminary list of CSP_Low.PSS alarms.

11.8 CSP_Low.PSS Events

CSP_Low.PSS generates the following events:

1. Pulsar search completed (for a particular sub-array). Rational: CSP_Low.PSS requires an entire observation to be completed before it can begin the required acceleration processing; there is a lag between the end of an observation and the end of processing. This places constraints on scheduling of observations, as the next Pulsar Search observation should not start before the processing for the previous observation has been completed. CSP_Low.PSS generates an Event message to inform CSP_Low.LMC (and TM) when the processing has been completed.

11.9 CSP_Low.PSS Monitor Points

Estimate for the number of monitor points:

For each of 250 servers: ~10 monitor points (status, >3xtemperatures, running time, data chunk processed).

For each of 25 racks: ~ 10 monitor points (status, number of servers running, power, >2 temperatures)

For each of 500 beams: ~16 indicators.

Total: ~ 10,750 monitor points.

Auxiliary data (observation monitoring): 20 * 500 = 10,000.

12 INTERFACE IMPLEMENTATION – CSP_LOW.PST

Interface CSP_Low.LMC to CSP_Low.PST is described as follows:

- Aspects of the CSP_Low.LMC to CSP_Low.PST interface common to all CSP sub-elements are described in Chapter 6.
- This chapter describes all aspects of the CSP_Low.LMC to CSP_Low.PST interface *specific* to this interface.

Overview of the CSP_Low.PST functionality (relevant to this interface):

- CSP_Low.PST makes provision for TM, via CSP_Low.LMC, to configure simultaneous Pulsar Timing in up to 16 beams.
- Pulsar Timing can be started, operated and stopped independently and concurrently in up to 16 Pulsar Timing beams.
- CSP_Low.PST implements CSP-PST-beam as a Capability and is able to receive commands and queries for individual CSP-PST-beams (abstraction of functionality). CSP_Low.PST performs mapping of the Capability CSP-PST-Beam to CSP_Low.PST hardware and software components.

12.1 CSP_Low.PST Capabilities

CSP_Low.PST does not implement sub-array as a Capability, consequently CSP_Low.PST is not able to report status per sub-array. Instead, CSP_Low.PST makes provision for CSP_Low.LMC to control and monitor CSP_Low.PST functionality and status for individual CSP-PST-Beams.

During initialization and when new equipment is turned on and detected, CSP_Low.PST assigns hardware (compute nodes, servers and/or other resources) to Capabilities. CSP_Low.PST reports to CSP_Low.LMC how many CSP-PST-Beams are available and what is their status, including Observing Parameters.

Table 12-1 CSP_Low.PST Capabilities

CSP_Low Capability	Max. Number of Instances	M&C Functionality Supported
CSP-PST-beam	16	List availability. Set Observing Mode and start processing input data received from CBF (see Table 9-3) Stop Pulsar Timing (or other processing), implemented as “Set Observing Mode = IDLE” (see Table 10-3) Real-time updates for Pulsar Timing observations Disable / Enable (TBC) Set engineering parameters, for example: logging level, alarm thresholds, monitor point reporting, etc. Query parameters & status

12.2 CSP_Low.PST Messages

This section describes CSP_Low.PST specific messages.

CSP_Low.LMC generated messages:

1. Query availability and status of CSP_Low.PST equipment and CSP-PST-Beams.
2. Set Observing Mode for a CSP-PST-Beam (see Table 9-3)
3. Stop Observing Mode for a CSP-PST-Beam (implemented as “set Observing Mode = IDLE”, see Table 10-3)
4. Time-dependent updates (implemented as set parameters)
5. Set CSP_Low.PST engineering parameters
6. Query CSP_Low.PST parameters and status, including status and setup of CSP_Low.PST, its Components and CSP-PST-Beams.

CSP_Low.PST generates responses to TM messages, monitoring data, events and alarms.

Future releases of this ICD will contain the complete list of messages and set of parameters for each message.

12.3 CSP_Low.PST Observing Mode Parameters

Observing Mode parameters for the CSP_Low.PST are virtually the same as defined in Table 9-3 on page 68 for CSP_Mid.PST. The only difference is that CSP_Low receives input from up to 512 LFAA stations. Input from each station may consist of up to 16 beams; when specifying the input data used to form PST beams, CSP_Low.LMC has to identify station-beam used in beamforming; all other parameters are as specified in Table 9-3.

CSP_Low.LMC provides Observing Mode configuration for each CSP-PST-Beam individually, as shown in Table 9-3. It is to be defined (TBD) whether a single message may contain configuration for more than one CSP-PST-Beam.

CSP_Low.LMC performs mapping between PST Beam IDs assigned by TM/LMC and CSP_Low.PST Capabilities (CSP-PST-Beam). More precisely:

1. CSP_Low.LMC decides which CSP_Low.PST Capability to use for which PST Beam ID.
2. CSP_Low.LMC then forwards TM specified PST Beam configuration to CSP_Low.PST, as specified in Table 9-3.
3. CSP_Low.LMC obtains the destination addresses for the CSP_Low.CBF output, and sends that information to CSP_Low.CBF.

CSP_Low.LMC provides a mechanism for CSP_Low.PST to send to TM recommendation (notification) to stop on-going pulsar timing in a particular CSP-PST-Beam and to indicate the reason. This can be implemented as an Event message (TBC).

TBD: CSP PST group anticipates that the human telescope operators will need to see various forms of diagnostic information during the observation. Content and format for plots will be specified here in this ICD. TM Consortium will select the format for diagnostic plots. PST will not be capable of a vast array of diagnostics such as those that provide information on timing precision. These higher level diagnostics should be provided by the SDP.

TBD: at the implementation detail level: CSP_Low.PST could send images to TM (e.g. PNG or JIF) or, if the TM expects to be able to query the data in multiple ways, CSP_Low.PST might send TM a copy (possibly reduced in dimension) of the information that is sent to the SDP.

12.4 CSP_Low.PST Engineering Parameters

CSP_Low.PST implements a common set of parameters for the sub-element, LRUs, Capabilities, Alarms Events and Monitor Points as specified in Chapter 6. This section lists only parameters specific to CSP_Low.PST.

12.5 CSP_Low.PST Requirements for Data Persistence

This section should list data generated by CSP that should be stored by the Telescope Manager.

1. Configuration data:
    - Version of hardware, firmware and software for all Components
    - Serial numbers (where available)
2. Setup (configuration parameters)
3. Status reports
4. Alarms
5. Monitor data

The list of auxiliary data generated by CSP_Low.PST is TBD.

For each type of the auxiliary data this section will define:

- ➢ Content
- ➢ Format
- ➢ Where the data is stored.

Detailed list TBD in the future releases of this ICD.

12.6 CSP_Low.PST Alarms

List of Alarms generated by CSP_Low.PST.

12.7 CSP_Low.PST Events

Events generated by CSP_Low.PST:

- ➢ Recommendation to stop on-going pulsar timing for a particular pulsar (includes reason).

12.8 CSP_Low.PST Monitor Points

Estimate for the number of monitor points: ~ 300 Monitor Points.

Estimate is based on the proposed physical implementation.

13 INTERFACE VERIFICATION

Interface verification occurs at many stages in the integration of the sub-elements. It is carried out to demonstrate that the design and implementation conform to the ICD, and it will be described in formal procedures. A key distinction is made between verification tests which require the interfacing sub-element and those that do not (using a simulator or standard test equipment). The ICD shall contain a section on the verification methods to be used to:

1. Verify the design and implementation of interfacing hardware and software without the interface being made
2. Verify the interface for integration and acceptance purposes (involving the interface being made)

The execution of the first case (interface not made) is the responsibility of the respective interfacing parties.

The leading interfacing party (CSP.LMC) is responsible for specifying verification methods and procedures, and for executing them, in the second case above (interface made).

For each interface specification, the verification method and the level at which the verification will occur must be specified.

13.1 Verification stages

The Interface validation and verification process occurs in at least three stages:

a) Validation and verification of the interface control document through formal reviews during the design phase. This stage is the responsibility of the leading party, using models and analysis methods which themselves have been validated and verified.

b) Verification of the interface implementation by individual sub-elements during their design qualification phase by means of exercising the interface with the use of test equipment and/or simulators. This verification is the responsibility of the individual sub-elements, under the supervision of the Element System Engineering team.

c) Verification of the interface during integration of the sub-elements, as part of system integration testing. This verification is the joint responsibility of the Element System Engineering team and the leading party. This stage has two phases – a formal Acceptance verification made at Element level and in isolation, followed by a carefully controlled sequence of making and verifying made interfaces as part of integration.

13.2 Requirement Verification Methods

The interface verification methods are defined in Table 13-1.

Table 13-1 Verification methods

Method	Description
Analysis	A form of verification that uses established technical or mathematical models or simulations, algorithms, charts, graphs, circuit diagrams, or other scientific principles and procedures to provide evidence that stated requirements are met.
Demonstration	A form of verification that involves the actual operation of an item to provide evidence that the required functions are accomplished under specific scenarios. The items may be instrumented and performance monitored.
Inspection	A form of verification that is generally non-destructive and typically includes the use of sight, hearing, smell, touch, and taste; simple physical manipulation; and mechanical and electrical gauging and measurement.
Test	A form of verification in which physical experimental principles and procedures are applied to determine the properties or functional capabilities of an item.

Appendix A. Intellectual Property Declaration

There is no IP to declare in this document.

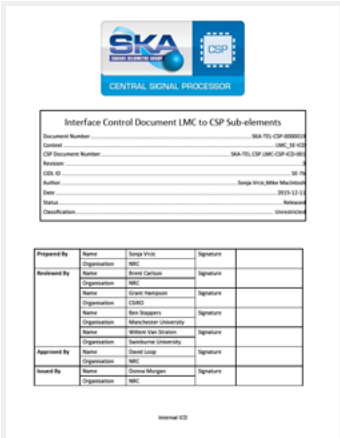
Appendix B. To Be Defined

Summary of the content marked as 'to be defined' in this version of the document

Table 13-2 Summary of content to be defined

To be defined	Depends on
Protocols and standards to be used to implement this interface.	[RD1], [RD7], [RD8]
Format and content of messages.	[RD7], [RD8], CSP Design
Naming conventions for Components, Capabilities, Alarms, Events, Monitor Points, Messages, Parameters, etc.	[RD1], [RD7], [RD8], CSP Design
Modes and States.	[RD1], [RD7], [RD8], CSP Design
List of commands for each sub-element, for instance, support for reboot, restart, power-down, etc.	CSP sub-element design
Alarms, Events, Monitor Points implemented by CSP sub-elements.	CSP sub-element design
CSP generated auxiliary data for each sub-element and each telescope.	CSP sub-element design, requirements defined by SDP
Further work on refinement of Observing Modes and their parameters is required.	CSP design, System-level requirements, Concept of Operations
Component and Capability Health Reporting guidelines.	SKA standards,[RD7], [RD8]
Guidelines for implementation of logging.	SKA standards, [RD7], [RD8]
Guidelines for implementation of alarms and events. Alarm severity levels.	SKA standards, [RD7], [RD8]
Messages generated by sub-elements to acknowledge/accept/report receipt and activation of SET Parameters message (and other commands).	SKA standards, [RD7], [RD8]

To be defined	Depends on
Requirements for precision when specifying time for activation of commands, in particular scan start, scan end (or duration), epoch for parameters related to delay tracking, calibration and beamforming, epoch for pulsars, etc.	SKA Concept of Operations and CSP sub-elements
Depending on the choice of the protocol, different data streams may be used for exchange of messages (Get/Set/Response/Alarms/Event) and for file transmission.	[RD7], [RD8], choice of protocols/framework
Framework and guidelines for engineering interfaces (Chapter 3).	TM Guidelines, CSP Design
TBD: What should LMC do in the case of loss of communication with TM? What should LMC do (other than report alarm) in the case of loss of communication with sub-element?	Concept of Operations, CSP requirements
SKA system requirements allocate 30 seconds for the telescope Observing Mode change. Allocation (budget) for the CSP Observing Mode changes is still to be defined.	SKA Design, CSP design
Does SDP provide pulsar phase/longitude predictors for Pulsar Timing?	SDP Design


CENTRAL SIGNAL PROCESSOR

Interface Control Document LMC to CSP Sub-elements

SE-7b_SKA-TEL-CSP-0000019_3_ICD-LMC-to-CBF-PSS-PST_2015-12-11-v4

Adobe Document Cloud Document History 1/29/16

Created:	1/14/16
By:	Donna Morgan (donna.morgan@nrc-cnrc.gc.ca)
Status:	SIGNED
Transaction ID:	CBJCHBCAABAAFM6h4BSlC9IZXnZ5tK16fuLaQ62UneUN

"SE-7b_SKA-TEL-CSP-0000019_3_ICD-LMC-to-CBF-PSS-PST_2015-12-11-v4" History

Document created by Donna Morgan (donna.morgan@nrc-cnrc.gc.ca)
1/14/16 - 4:12:06 PST - IP address: 132.246.199.39

Document emailed to Sonja Vrcic (sonja.vrcic@nrc-cnrc.gc.ca) for signature
1/14/16 - 4:14:59 PST

Document viewed by Sonja Vrcic (sonja.vrcic@nrc-cnrc.gc.ca)
1/14/16 - 4:15:22 PST - IP address: 132.246.199.107

Document e-signed by Sonja Vrcic (sonja.vrcic@nrc-cnrc.gc.ca)
Signature Date: 1/14/16 - 4:16:03 PST - Time Source: server - IP address: 132.246.199.107

Document emailed to Brent Carlson (brent.carlson@nrc-cnrc.gc.ca) for signature
1/14/16 - 4:16:05 PST

Document viewed by Brent Carlson (brent.carlson@nrc-cnrc.gc.ca)
1/14/16 - 5:12:30 PST - IP address: 132.246.199.113

Document e-signed by Brent Carlson (brent.carlson@nrc-cnrc.gc.ca)
Signature Date: 1/14/16 - 5:12:55 PST - Time Source: server - IP address: 132.246.199.113

Document emailed to David Loop (david.loop@nrc-cnrc.gc.ca) for signature
1/14/16 - 5:12:57 PST

Document viewed by David Loop (david.loop@nrc-cnrc.gc.ca)
1/14/16 - 10:41:41 PST - IP address: 62.202.39.93

Document viewed by David Loop (david.loop@nrc-cnrc.gc.ca)
1/18/16 - 1:21:09 PST - IP address: 132.246.192.112

Document viewed by David Loop (david.loop@nrc-cnrc.gc.ca)
1/22/16 - 1:59:20 PST - IP address: 96.54.1.26

Document e-signed by David Loop (david.loop@nrc-cnrc.gc.ca)
Signature Date: 1/22/16 - 1:59:59 PST - Time Source: server - IP address: 96.54.1.26

Document emailed to Grant Hampson (grant.hampson@csiro.au) for signature
1/22/16 - 2:00:02 PST

Document viewed by Grant Hampson (grant.hampson@csiro.au)
1/22/16 - 5:11:59 PST - IP address: 1.129.97.21

Document e-signed by Grant Hampson (grant.hampson@csiro.au)
Signature Date: 1/24/16 - 2:28:43 PST - Time Source: server - IP address: 152.83.36.209

Document emailed to wvanstraten@swin.edu.au for signature
1/24/16 - 2:28:45 PST

Donna Morgan (donna.morgan@nrc-cnrc.gc.ca) replaced signer wvanstraten@swin.edu.au with Willem van Straten (vanstraten.willem@gmail.com)
1/28/16 - 12:40:56 PST - IP address: 132.246.199.39

Document emailed to Willem van Straten (vanstraten.willem@gmail.com) for signature
1/28/16 - 12:40:57 PST

Document viewed by Willem van Straten (vanstraten.willem@gmail.com)
1/28/16 - 2:24:32 PST - IP address: 66.249.82.134

Document e-signed by Willem van Straten (vanstraten.willem@gmail.com)
Signature Date: 1/28/16 - 2:45:09 PST - Time Source: server - IP address: 136.186.248.14

Document emailed to Ben Stappers (ben.stappers@manchester.ac.uk) for signature
1/28/16 - 2:45:11 PST

Document viewed by Ben Stappers (ben.stappers@manchester.ac.uk)
1/28/16 - 10:34:04 PST - IP address: 84.13.180.148

Document e-signed by Ben Stappers (ben.stappers@manchester.ac.uk)
Signature Date: 1/28/16 - 10:37:41 PST - Time Source: server - IP address: 84.13.180.148

Document emailed to Donna Morgan (donna.morgan@nrc-cnrc.gc.ca) for signature
1/28/16 - 10:37:42 PST

Document viewed by Donna Morgan (donna.morgan@nrc-cnrc.gc.ca)
1/29/16 - 8:53:40 PST - IP address: 132.246.199.39

Document e-signed by Donna Morgan (donna.morgan@nrc-cnrc.gc.ca)

Signature Date: 1/29/16 - 8:54:33 PST - Time Source: server - IP address: 132.246.199.39

Signed document emailed to Willem van Straten (vanstraten.willem@gmail.com), wvanstraten@swin.edu.au, David Loop (david.loop@nrc-cnrc.gc.ca), Donna Morgan (donna.morgan@nrc-cnrc.gc.ca), Grant Hampson (grant.hampson@csiro.au), Brent Carlson (brent.carlson@nrc-cnrc.gc.ca), Ben Stappers (ben.stappers@manchester.ac.uk) and Sonja Vrcic (sonja.vrcic@nrc-cnrc.gc.ca)

1/29/16 - 8:54:33 PST