Central Signal Processor Requirements Specification

020.40.00.00.00-0001 REQ

Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
A	2019-12-31	A. Lear	All	Incorporated minor edits by M. McKinnon. Prepared PDF for approvals and release. Reference Design Release.
A.01	2021-08-09	O. Yeste Ojeda	All	Major revision based on 020.10.10.20.00-0005 "Subsystem Requirements Specification template" and 020.40.00.00.00-0001-REQ-A "Central Signal Processor: Preliminary Technical Requirements."
A.02	2021-08-25	O. Yeste Ojeda	All	Incorporated minor edits by R. Selina.
A.03	2021-09-30	O. Yeste Ojeda	All	Minor edits. Added CSP1030. Populated Section 9.
A.04	2022-02-04	O. Yeste Ojeda	All	Revision based on feedback from internal review.
B	2022-02-10	A. Lear	All	Formatting, copy-edits; prepared PDF for signatures and release.
B.01	2024-01-23	O. Yeste Ojeda	All	Revision towards CSP CDR. Requirements derived from limitations of the FSA have been withdrawn (such as primary/secondary subarrays verbiage). Requirements derived from DBE interfaces have been removed, as the DBE is now clearly separate from the CSP.
B.02	2024-02-21	O. Yeste Ojeda	All	Revision based on feedback from internal review. Adds Section 4 'Definitions'. Adds Section 7.5.5 'Cosmic Radiation' Adds Section 8.2.2.1 'Configuration Parameters' Modifies CSP0024, CSP0036-CSP0042, Modifies CSP3020 Adds CSP0065-CSP0067 Adds CSP1051-CSP1052 Adds CSP9006
C	2024-02-27	M. Archuleta	All	Minor formatting edits; prepared for release.

Version	Date	Author	Affected Section(s)	Reason
C.01	2024-	O. Yeste Ojeda	All	Revision based on feedback from CSP CDR. Definitions reviewed. Modifies CSP0008, CSP0009, CSP0018, CSP0032, CSP0042, CSP0053, CSP5010, CSP9001, CSP9002. Adds CSP0068. Withdraws CSP0064, CSP3010. Adds further clarifications. Minor adjustments
D	2024-08-07	P.Kotzé	All	Formatting for release.

Table of Contents

1 Introduction

1.1 Purpose

This document presents the complete set of Level 2 subsystem requirements that guide the design and development of the Central Signal Processor (CSP) subsystem. Requirements described in this document are derived from applicable ngVLA System Requirements and System-Level Specification documents as listed in the Applicable Documents table. The engineering process and requirements hierarchy that govern this specification are defined in [AD01] and [AD02] respectively.

The content of these requirements is at the subsystem level, conforming to the system architecture [AD06], but aims to be implementation agnostic within the subsystem boundaries. Some assumptions about the subsystem may be given, but only to the degree necessary to unambiguously define the subsystem requirements.

1.2 Scope

The scope of this document is to delineate the specifications for the Central Signal Processor (CSP) subsystem, specifically identified by configuration item number 020.40.00.00.00. Historically, the CSP functionally included the antenna Digital Back End (DBE), denoted by configuration number 020.30.25.00.00. However, due to a distinct functional partition between the DBE and CSP, the DBE is no longer considered within the CSP's functional domain. It is noteworthy that this set of requirements still incorporates functional aspects related to the DBE, which will be excluded in future versions, with clear identification of these requirements slated for removal. The document's scope encompasses:

- Assumptions on which the requirements are based.
- Definition of environmental conditions to be used in the definition of requirements.
- A complete set of requirements for the subsystem needed for the development, operation and maintenance of the subsystem, including interface requirements that are derived from the applicable list of ICDs.
- Numbering of all requirements and establishment of traceability to higher level requirements.
- Verification requirements and their traceability to the subsystem main requirements.
- Identification of Key Performance Parameters (KPPs) at the subsystem level.

The Level 2 Subsystem Requirements, along with detailed explanatory notes, are found in Section 8. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirement. In many cases, the notes contain an analysis of how the numeric values of requirements were derived to ensure correct interpretation of the requirements and to resolve ambiguity.

In cases where the requirements analysis is incomplete, such values are marked with TBD or TBC, which need to be resolved before the final specification is published.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents apply to this Requirements Specification to the extent specified. In the event of a conflict between the documents referenced herein and the content of this Requirements Specification, the content of the highest-level specification (in the requirements flow-down) shall be considered the superseding requirement for design elaboration and verification.

Ref. No.	Document Title	Rev./Doc. No.
AD01	ngVLA Systems Engineering Management Plan	020.10.00.00.00-0001 PLA
AD02	ngVLA Requirements Management Plan	020.10.15.00.00-0001 PLA
AD03	ngVLA System Requirements	020.10.15.10.00-0003 REQ
AD04	System Environmental Specification	020.10.15.10.00-0001 SPE
AD05	L1 System EMI/RFI Requirements	020.10.15.10.00-0002 REQ
AD06	System-Level Architecture Model	020.10.20.00.00-0002 DWG
AD07	L1 Safety Specification	020.80.00.00.00-0001 REQ
AD08	Security Plan and Requirements	020.80.00.00.00-0003 REQ
AD09	ngVLA System Electronics Specifications	020.10.15.10.00-0008 REQ
AD10	L1 System Technical Budgets	020.10.25.00.00-0002 DSN

2.2 Applicable ICDs

The following Interface Control Documents define the external boundary of this subsystem and are applicable to its specification:

Ref. No.	Document Title	Rev./Doc. No.
AD21	ngVLA Site Buildings Interface Specification	020.10.40.05.00-0095 ICD
AD22	CSP – Monitor & Control System Interface Specification	020.10.40.05.00-0105 ICD
AD23	CSP – Online Data Acquisition Interface Specification	020.10.40.05.00-0114 ICD
AD24	CSP – Central Fiber Infrastructure Interface Specification	020.10.40.05.00-0119 ICD
AD25	CSP – Technical Infrastructure Interface Specification	020.10.40.05.00-0151 ICD

Note that the ICDs listed above have not yet been developed as of the time of writing. Therefore, many of the associated requirements are preliminary or basic placeholders. Interfaces are within the scope of the Preliminary Design phase, and as such, they will be presented for review during the PDR.

2.3 Reference Documents

The following documents are referenced within this text or provide supporting context:

Ref. No.	Document Title	Rev./Doc. No.
RD01	Central Signal Processor Design Description	020.40.00.00.00-0006 DSN
RD02	Digital Back End and Central Signal Processor: Concept Options and Trade-Offs	020.40.10.25.00-0001 REP
RD03	ngVLA Time-Domain Correlator Considerations	P. Demorest, 01/05/18.
RD04	Interferometry and Synthesis in Radio Astronomy, 3rd Ed.	A. R. Thompson, J. M. Moran, G. W. Swenson Jr., 2017.
RD05	ALMA Memo No. 452, Passband Shape Deviation Limits	L. R. D'Addario, 04/09/03.
RD06	Timing Requirements & Considerations	ngVLA Elec. Memo no. 15
RD07	Subband Processor Requirements Specification	020.40.30.00.00-0001 REQ
RD08	Subband Processor Design Description	020.40.30.00.00-0002 DSN
RD09	Oscilloscope Mode Concept	ngVLA Computing Memo no. 10
RD10	ngVLA Project Lexicon and Acronyms	020.10.10.10.00-0005 LIS
RD11	ngVLA Antenna On-the-Fly Mapping Use Cases	ngVLA Antenna Memo no. 13
RD12	Updated RFI Impact Estimates & Influence on the System Design	ngVLA Memo no. 109
RD13	Headroom, Dynamic Range, and Quantization Considerations	ngVLA Elec. Memo no. 8

3 Definitions

The terms listed below have precise definitions and are consistently utilized throughout this document. These definitions are aligned with those provided in the ngVLA Lexicon [RD10], and any discrepancies between definitions shall defer to the definitions provided herein.

POLARIZATION PRODUCT: The correlation between the signals received by pairs of antennas with either the same (co-polarization products) or different antenna polarizations (cross-polarization products). Polarization products encompass various combinations such as XX, XY, YX, and YY for linearly polarized antennas, or RR, RL, LR, and LL for circularly polarized antennas.

SUBARRAY: A subarray is a set of antennas reserved for exclusive control that may be allocated one or more independent sets of processing resources in order to produce one or more data product streams. This definition has been harmonized at the system level and is uniformly applied across subsystems. One implication of this definition is that all CSP configuration parameters must be independently adjustable for different subarrays.

SUBBAND: In this document, the term 'subband' denotes one of the numerous digital signals received at the CSP input from the Digital Back End (DBE). The DBE partitions the digitizer output into frequency channels, known as subbands, which are subsequently chosen individually for additional processing and transmitted to the Central Electronics Building housing the CSP. Typically, a subband corresponds to the associated polarization pair, unless explicitly stated otherwise. Although bandwidth selection flexibility may impose constraints on the subband bandwidth, this bandwidth is ultimately a system design parameter determined by considering multiple trade-offs between the DBE and CSP designs. Therefore, this requirements specification does not specify the subband bandwidth.

4 Overview of Subsystem

4.1 Subsystem Boundary, Context, and External Interfaces

The Central Signal Processor (CSP) is the component of the ngVLA responsible for processing digital signals received from each antenna's Digital Back End (DBE) and generating raw data products[1] on a per-subarray basis. Depending on the subarray configuration, the CSP generates various data products, including visibilities, average pulse profiles, full-Stokes time-series data, and beamformed digital voltage for data recorders. The CSP receives digital signals from each antenna with a total bandwidth specified in CSP0008 (a minimum of 14 GHz), which is divided into multiple subbands. Each subband, received in the form of a time-stamped time series, represents a frequency channel generated and downselected by the DBE from the digitized spectrum. These subbands have a bandwidth of 218.75 MHz and are sampled at 250 MHz. They may cover non-contiguous portions of the frequency spectrum. Subbands are created by splitting the output of the digitizer into frequency subbands and then undergo preprocessing by the DBE for receiver calibration, addressing non-idealities such as I/Q imbalance compensation.

Figure 1 represents the product context of the CSP through its Systems Modelling Language (SysML) context diagram. All the CSP equipment is located at the Central Electronics Building (CEB) within the ngVLA Site Buildings subsystem (NSB, CI number 020.61.10.00.00). The NSB subsystem provides the CSP with power, HVAC room cooling, physical space, and RFI shielding [AD21].

The Central Fiber Optic (FIB) subsystem, identified by CI number 020.55.20.00.00, encompasses the optical fiber infrastructure. It plays a crucial role in facilitating the transmission of data from the DBE to

[1] By 'raw' data products, it is meant that calibrations performed offline will be carried out downstream by the Computing and Software System (CSS).

the CSP by providing the physical interface between the two components, as outlined in the corresponding Interface Control Document (ICD) [AD24].

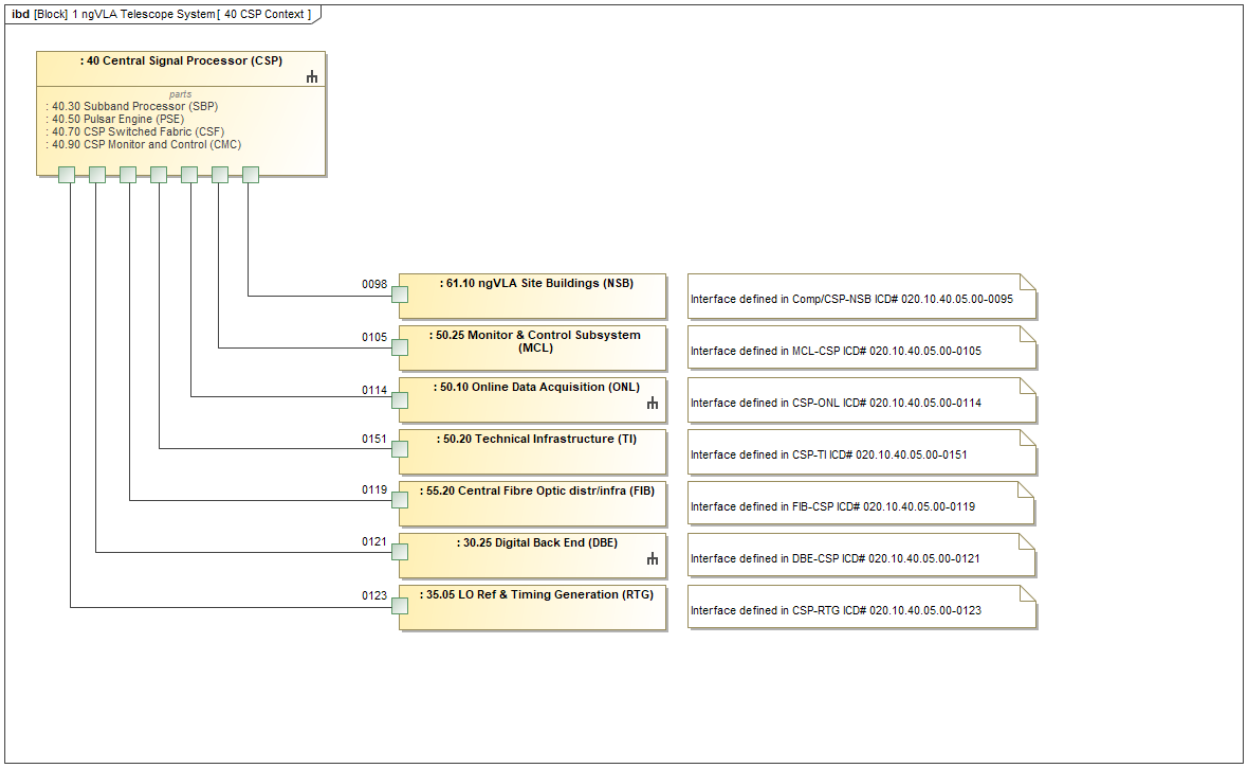

Figure 1 – Central Signal Processor product context.

In the context of the CSP, the LO Reference and Timing Generation subsystem (RTG, CI number 020.35.05.00.00) serves the function of providing the CSP with timing information synchronized to the central ngVLA time. This ensures precise timing coordination across the system. While the use of RTG is one approach to achieve this synchronization, alternative designs may opt to utilize Precision Time Protocol (PTP) servers for the same purpose.

Data products generated by the CSP are sent to the Computing and Software System (CSS, CI number 020.50.00.00.00), specifically its Online Data Acquisition sub-element (ONL, CI number 020.50.10.00.00) [AD23]. The Monitoring & Control subsystem (MCL, CI number 020.50.25.00.00) and the Technical Infrastructure (TI, CI number 020.50.20.00.00) of the CSS also interface with the CSP at various levels [AD22, AD25].

4.2 Subsystem Functional Overview

The functional overview of the CSP is better understood from the respective functional overviews of its component parts.

After receiving the digitized data from the IRD modules, the DBE applies a calibration filter on the received signal in order to equalize the spectrum and further suppress the unwanted sideband from the down conversion process, effectively performing sideband separation digitally. Then, a frequency shifter coarsely tunes the digitized spectrum and removes any per-antenna LO-shift as needed. After that, the bandwidth is split into frequency subbands through a filter bank. Finally, the selected subband data streams undergo a requantization process and the resulting data packets are timestamped for its transmission to the SBP.

The SBP has the capability to perform 4 differentiated task which are independently configured for each subarray depending on the observation mode:

1. Delay and Phase Tracking
2. Fine Frequency Channelization
3. Beamforming (Linear Combination)
4. (Cross-)Correlation

For example, as the SBP follows the so-called FX architecture in interferometric modes, it performs tasks 1, 2 and 4, in that order. In beamforming modes, task 4 is not carried out. The following figures depict the functional diagram of all 4 tasks of the SBP, which are then briefly described. More details can be found in the SBP requirements and design documents [RD07,RD08].

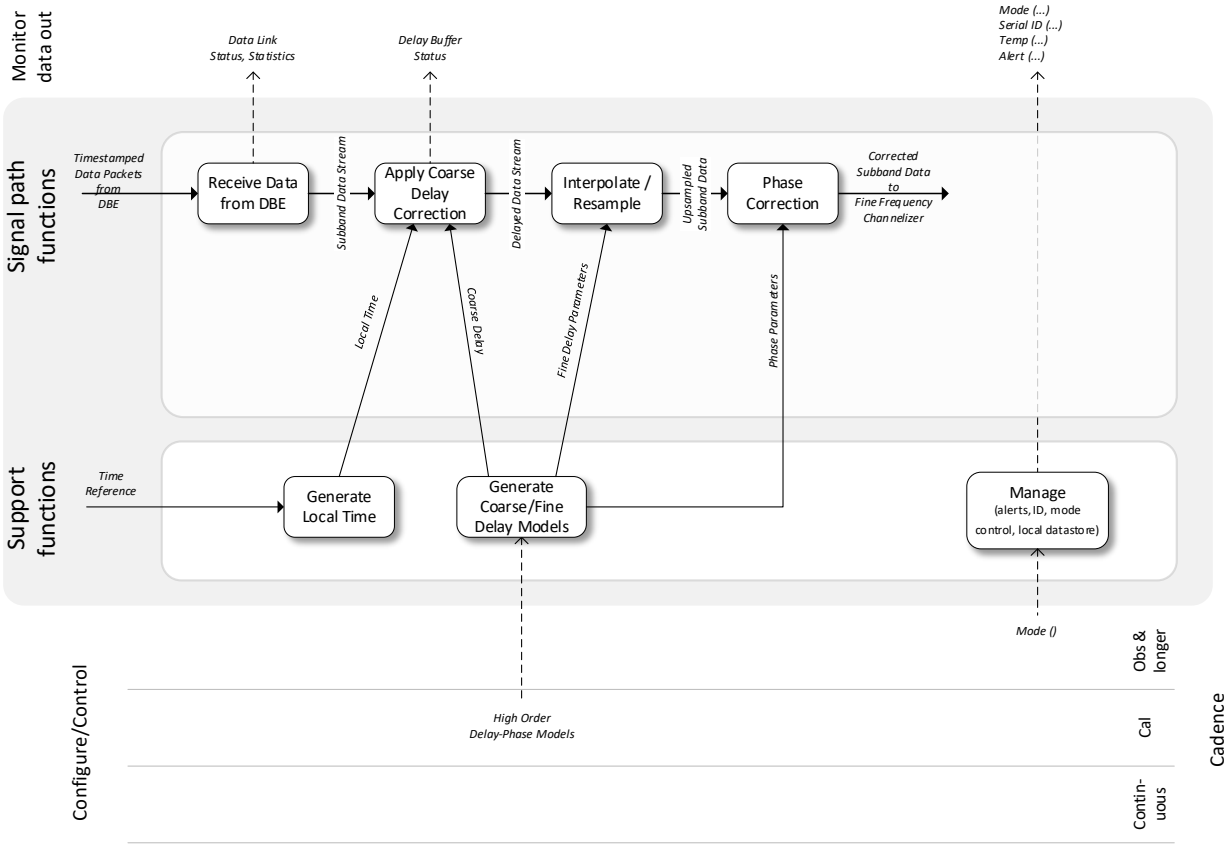

Figure 2 – Functional diagram of the delay and phase tracking task of the SBP.

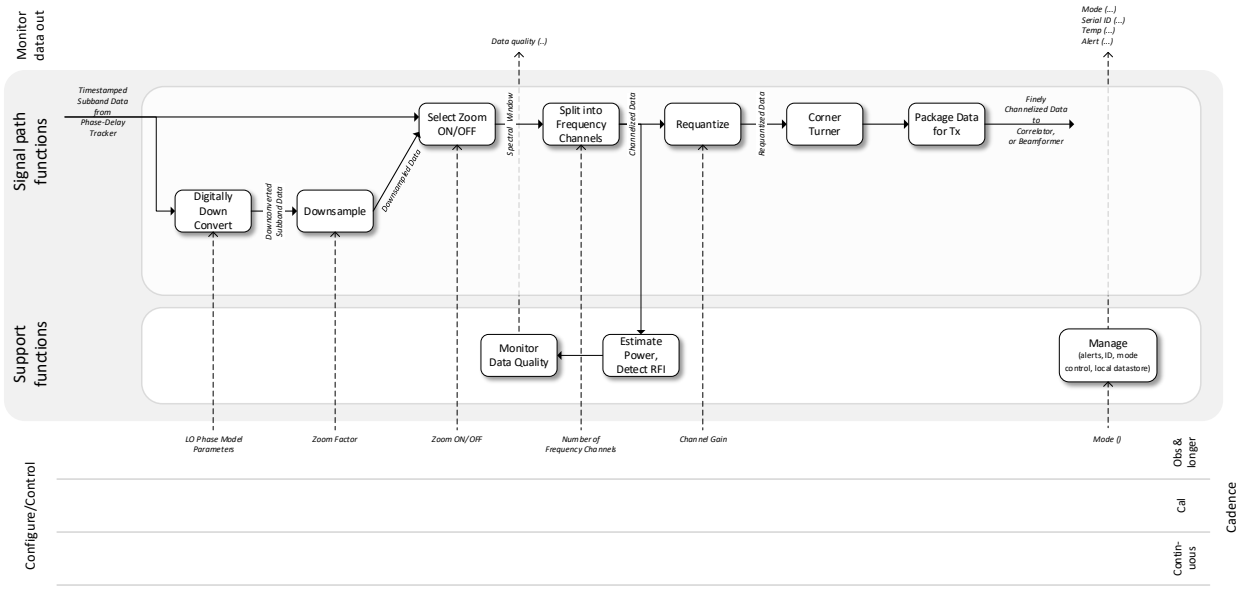

Figure 3 – Functional diagram of the fine frequency channelization task of the SBP.

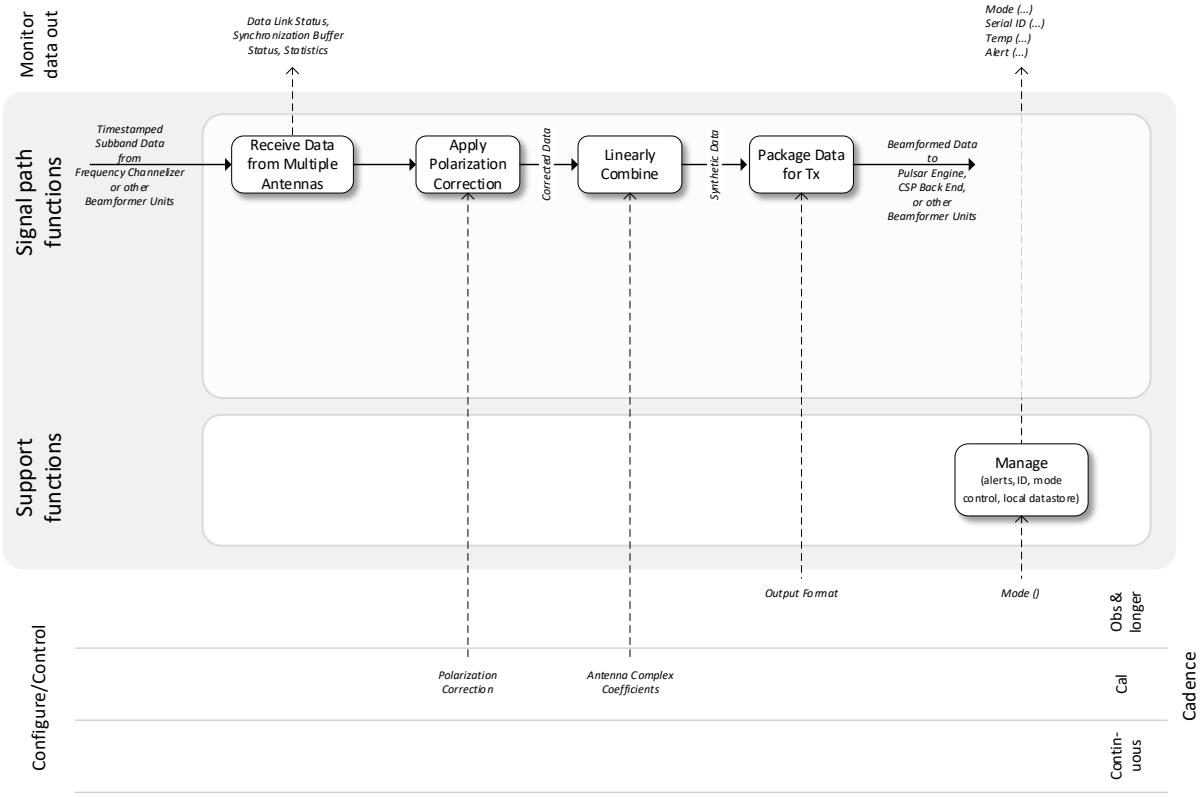

Figure 4 – Functional diagram of the beamforming task of the SBP.

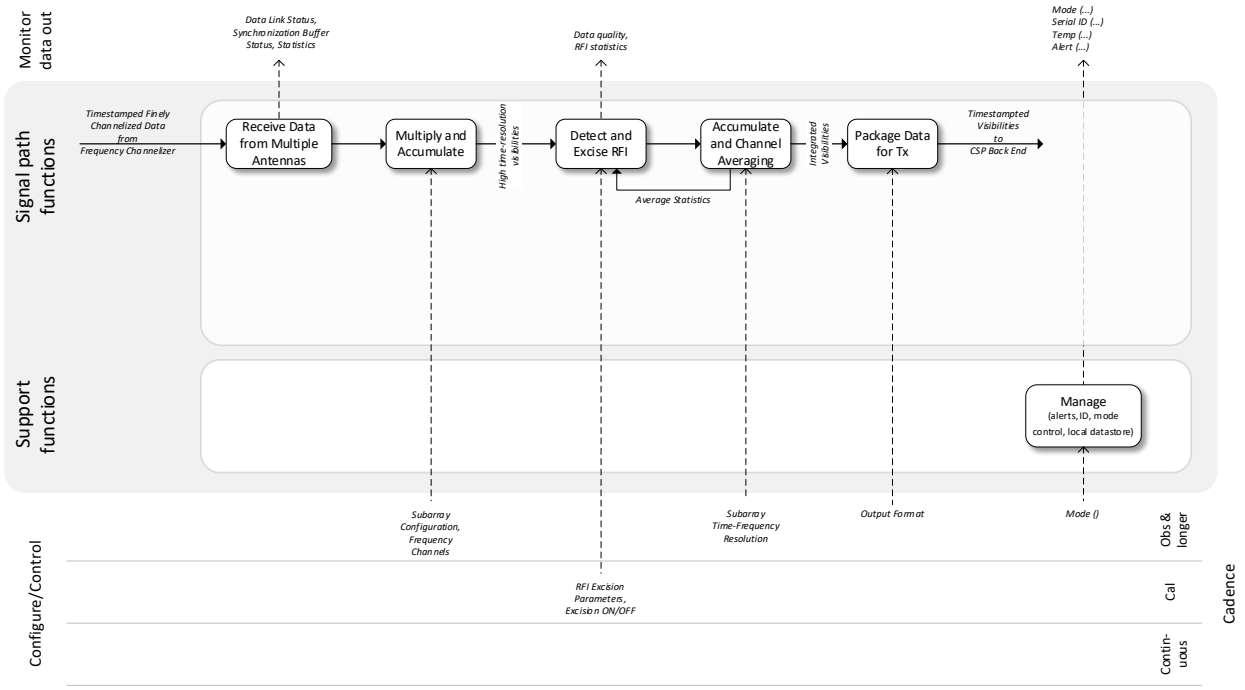

Figure 5 – Functional diagram of the correlation task of the SBP.

displays the SBP's delay and phase tracking function for each subband data stream from the DBE, involving reception, sorting, and storage of antenna data. The process corrects bulk delay, applies fine sub-sample delay through resampling, and introduces time-variable phase correction before transitioning to the fine frequency channelization function. While fine delay correction can be executed in the frequency domain, it may incur correlation loss depending on frequency resolution. However, the need to rectify sampling frequency offsets introduced at the antenna necessitates the use of a resampler. Thus, integrating fine delay corrections within the resampling process proves advantageous.

In , the SBP's fine frequency channelization is illustrated to split subband data into precise frequency channels for beamforming or correlator input. The function employs spectral zoom modes, allowing selective tuning and downsampling to achieve the finest frequency resolution. Data is then prepared for beamforming or correlation through requantization, data rearrangement, and packetization.

outlines the beamformer's functional diagram, showcasing multiple processing units for subarray signal combination. Starting with synchronization and polarization correction, signals are linearly combined based on defined coefficients. The resulting synthetic signal is requantized and prepared for transmission to the CSP Back End (CBE).

Finally, details the correlation function, collecting data from antennas via the fine frequency channelizer. A complex multiply-and-accumulate operation is executed, and short timescale visibilities are flagged for RFI. The produced data is then transmitted to the CBE for further processing and archiving.

4.3 Design Driving Requirements

The following table provides a summary of the major design-driving subsystem requirements. Should there be a conflict between the requirements listed here and the descriptions in Section 8, the latter shall take precedence. Refer to Section 8 for further details and a justification for these requirements.

Parameter	Req. #	Value & design driver
Connected Antennas	CSP0006	The CSP shall support at least 263 dual-polarization antennas, full-bandwidth inputs, with a goal of fully scalable architecture. It drives the number of DBE Units and size of the SBP.
Per-Antenna Available Bandwidth	CSP0008	The CSP shall receive and process at least 14 GHz of nonredundant bandwidth from every antenna polarization, or the full instantaneous bandwidth of the band in use, whichever is less, with a goal of a fully scalable architecture supporting at least 20 GHz.
Interferometric Bandwidth	CSP0021	The CSP shall support processing all the available bandwidth consistent with CSP0008 in interferometric mode.
Beamformer Bandwidth per Beam	CSP0030	The CSP shall be able to generate each beam with at least 8 GHz or the full instantaneous bandwidth of the band in use, whichever is less, with a goal of generating the full available bandwidth specified by CSP0008. Together, they drive the number of SBP Units.
Pulsar Engine Bandwidth	CSP0038	The PSE shall support processing 8 GHz of bandwidth per beam, with a goal of all the receiver bandwidth in each band below 20 GHz.
Pulsar Engine Number of Beams	CSP0039	The PSE shall support processing 10 full-bandwidth beams without dedispersion and folding, or 5 full-bandwidth beams with dedispersion and folding, with a goal of processing all the beams available at the beamformer output. Together, they drive the size of the PSE.
Correlation Loss	CSP0009	The correlation loss attributable to the CSP shall be less than 0.6%. It drives the computational precision of the CSP. CSP size and power highly depends on that precision. An SNR loss budget within the CSP is included within the CSP Performance Budgets [RD01].
Commensal Signal Processors	CSP0014	The CSP switched fabric shall be scalable and allow flexible multicast for future commensal processing of visibilities and voltage data streams. It conditions the CSP architecture and network topology.

Parameter	Req. #	Value & design driver
Beamformer Aperture	CSP0028	The CSP shall support full beamforming capabilities for any subarray (including extended baselines) with an aperture equal or less than SYS1301 specification (700 km).
Beamformer Field of View	CSP0031	The CSP shall support generating beams pointed at any direction within the antenna primary beam. This includes beamforming the SBA (Small Baseline Array) as well. Together, they can drive the internal memory requirements. Network latency is not so important if accommodated via external memory.
Subarray Independence	CSP0019	The configuration of a subarray shall be completely independent of all other subarrays. Support of subarray independence has deep implications in the architecture, size and operation of the CSP.

5 Requirements Management

5.1 Requirements Definitions

Consistent with the Requirements Management Plan [AD02], the following definitions of requirement "levels" are used in the ngVLA program. The requirements in this document are at the L2 subsystem level.

Req. Level	Definition
L0	User requirements expressed in terms applicable to their needs or use cases (Science Requirements or Stakeholder Requirements)
L1	Requirements of the System, expressed in technical functional or performance terms (System Level Requirements)
L2	Requirements that define a specification for an element of the system, presuming a system architecture (Subsystem Requirements)

5.2 Requirements Flow Down

Figure 6 shows the relationships between the CSP subsystem (L2) requirements and the System (L1) Requirements from which they are derived. System Requirements include Security, Safety, and Environmental Specifications that apply to the CSP. They also include EMC and RFI Mitigation requirements. In an intermediate level between System and CSP requirements (L1.1), Electronics, Calibration and Technical Budgets requirements have been derived from the System Requirements and are applicable to the CSP subsystem as well.

Individual subsystem specifications (Level 2) flow from the Level 1 requirements and may not always be directly attributable to a single system requirement. For example, phase drift specifications at the system level may be apportioned to multiple subsystems, or a subsystem spec may be in support of multiple higher-level requirements. Completeness of the Level 2 requirements is assessed at the requirements review of each subsystem.

While this is a top-down design process, the process is still iterative rather than a "waterfall" or linear process. The feasibility and cost of requirements implementation lead to trade-offs that feedback to higher-level requirements. The end goal is to build the most generally capable system that will support the Key

Science Goals within the programmatic constraints of cost and schedule. Maintaining enumerated traceability between system requirements and subsystem requirements ensures that this trade-off process can be managed in a controlled way.

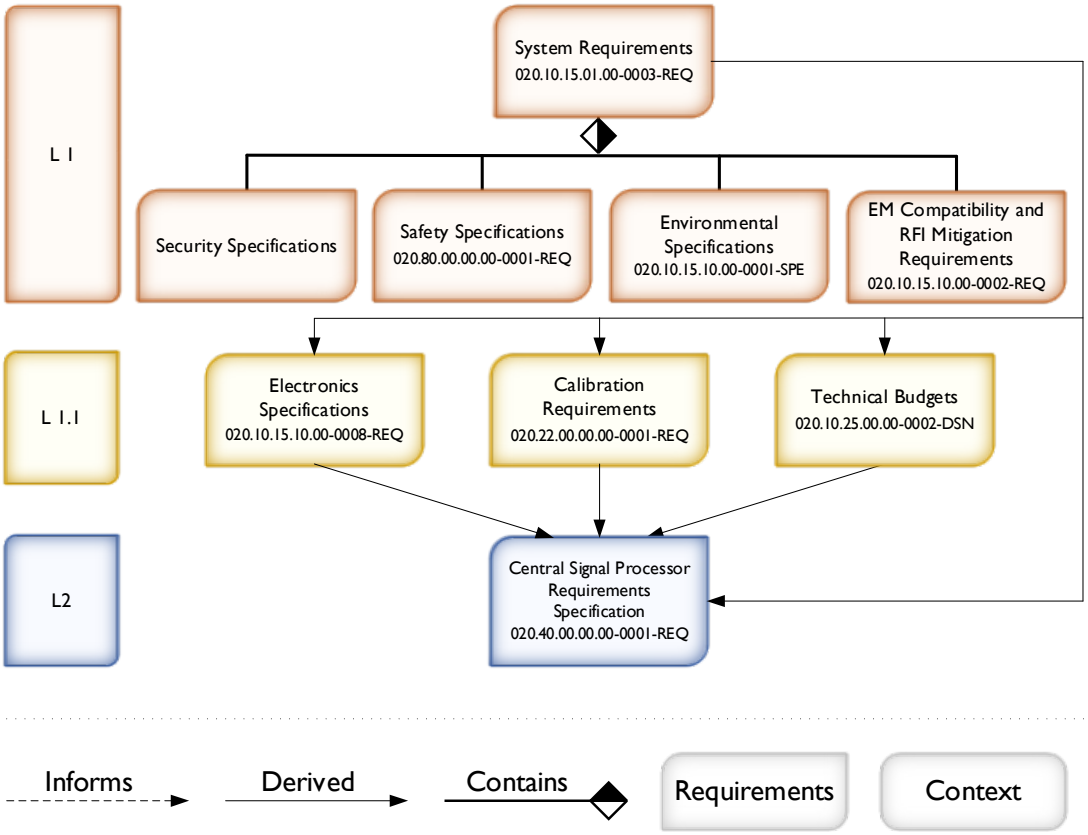

Figure 6 – Requirements flow-down to the Central Signal Processor Subsystem Requirements.

5.3 Verb Convention

This document uses "shall" to denote a requirement. The verbs "should" and "must" denote desired but not strictly required parameters. "Will" denotes a future happening. Desired but not required features are noted as "desirable" or "goals."

6 Assumptions

The following assumptions are made in the definition of these subsystem requirements:

1. Subsystem requirements apply to performance before any operational calibration corrections are applied unless explicitly stated otherwise.
2. Hardware requirements are applicable to a system functioning properly under normal operating environmental conditions, as defined in Section 7.1, unless explicitly stated otherwise.
3. Hardware requirements assume that all system parts that would normally be in place during observations are working within their respective specifications (e.g., HVAC, RTP system) unless explicitly stated otherwise.
4. Environmental requirements assume the antenna sites and ngVLA buildings are designed to host all corresponding CSP elements.

5. Functional requirements assume the CSP architecture represented in , where the subband bandwidth is fixed.
6. Functional requirements assume filter-bank based frequency channelizers in the down-selection of the processed bandwidth.
7. The system requirements specify a correlation loss of 5% for the overall digital system, which includes the antenna digitizer, Digital Back End (DBE), and Central Signal Processor (CSP). The distribution of this loss among these components is left to the system designer. In this requirements specification, the following allocation is assumed: 0.6% correlation loss for the CSP, 4% for the digitizer, and 0.4% for the DBE. This assumption is based on the headroom available at the digitizer [RD13], as well as the expected performance of the CSP and DBE designs.
8. The computation and application of the quantization correction are the responsibility of the Computing and Software System (CSS). However, the CSP will provide total power information as needed to compute these corrections.
9. Delay and phase model parameters are calculated by the Computing and Software System (CSS) subsystem and provided to the CSP. Thus, the CSS is responsible for compliance with System Requirements [AD03] in this regard, e.g., OTF mapping.
10. The delay and phase model parameters provided by the CSS include terms for the compensation of the drift of the antenna time standard with respect to the central time standard. The timestamping accuracy of the CSP is specified and validated assuming ideal (error-free) parameter inputs.
11. Beamforming coefficients are computed by the CSS. Hence, the ultimate responsibility for generating nulling directions and controlling side lobes resides in the CSS.
12. The support of per-baseline integration times does not include the CSP.
13. The CSP is not responsible for recording the failure of its items in a FRACAS (Failure Reporting, Analysis, and Corrective Action System).

7 Environmental Conditions

7.1 Normal Operating Conditions

All CSP equipment shall be installed in environmentally controlled facilities or racks. As such, the normal operating conditions are defined by the applicable ICD:

- [AD21] 020.10.40.05.00-0098 ngVLA Site Buildings–Central Signal Processor Interface Specification

This ICD leads to the corresponding CSP requirements, as defined by CSP subsystem interface requirements in Section 8.2.1.

The requirements in this section are derived directly from the system environmental specification [AD04] and, in some cases, necessitate specific verification methods. However, subjecting all CSP equipment to environmental testing could be costly and add minimal value. Therefore, these requirements may be relaxed in future releases for Commercial Off-The-Shelf (COTS) equipment.

7.2 Transportation Conditions

Parameter	Req. #	Value	Traceability
Packaging for Transportation	CSP9001	All CSP LRUs shall be transported using ESD, thermal, humidity, shock and vibration protective packaging in accordance with the System Environmental [AD04] and Electronics Specifications [AD09].	ETR0503 ENV0381 ENV0382 ENV0531

CSP9001 is a placeholder for future transportation conditions requirements.

Parameter	Req. #	Value	Traceability
Transportation Vibration Protection	CSP9007	All CSP LRUs packaged for transportation shall withstand persistent vibration with a power spectral density defined in Figure 1 of [AD04].	ENV0531

CSP9007 is a copy of the system environmental specification ENV0531. See [AD04] for additional details and rationale.

Parameter	Req. #	Value	Traceability
Mechanical Shocks	CSP9008	All CSP LRUs packaged for transportation shall survive mechanical shock levels from handling as defined in the MIL-STD-810H Method 516.8 Logistic Transit Drop Test, modified to use the drop heights specified in [AD04].	ENV0582

CSP9008 is a copy of the system environmental specification ENV0582. See [AD04] for additional details and rationale.

7.3 Storage Conditions

Parameter	Req. #	Value	Traceability
Packaging for Storage	CSP9002	All CSP LRUs shall be stored using ESD, thermal and humidity protective packaging in accordance with the System Environmental and Electronics Specifications.	ETR0503 ENV0372 ENV0373

CSP9002 is a placeholder for future storage conditions requirements.

7.4 Site Elevation

Parameter	Req. #	Value	Traceability
Altitude Range	CSP9003	All CSP elements shall be designed for operation and survival at altitudes ranging from sea level to 2500 m.	ENV0351

The CSP, located at the CEB, does not need to operate at higher altitudes.

7.5 Environmental Protection Requirements

7.5.1 Seismic

Parameter	Req. #	Value	Traceability
Seismic Protection	CSP9004	The CSP subsystem shall be designed to withstand a low-probability earthquake with up to 0.2g peak acceleration in either the vertical or horizontal axis.	ENV0521

The elements of the CSP shall not sustain residual damage under these conditions while in the installed and operational state. CSP9004 is a copy of system environmental specification ENV0521. See [AD04] for additional details and rationale.

7.5.2 Vibration

Parameter	Req. #	Value	Traceability
Vibration Protection	CSP9005	Not applicable.	ENV0531

CSP9005 is only applicable to the DBE, and hence does not apply to the CSP. CSP9005 is kept only for legacy purposes and will be removed in future releases. All DBE elements must meet ENV0531.

7.5.3 Mechanical Shock

No mechanical shock levels have been defined for the survival of the CSP LRUs when not packaged for transportation. See Section 7.2 for the shock levels defined for transportation conditions.

7.5.4 Lightning, Dust, Fauna, Solar Radiation, Rain/Water Infiltration, & Corrosion Protection

Protection against lightning, dust, fauna, solar radiation, rain/water infiltration and corrosion shall be provided by the environmentally controlled facilities in which the CSP elements are installed, as defined by the applicable ICD, [AD21]. No CSP element shall be installed outside these facilities.

7.5.5 Cosmic Radiation

Parameter	Req. #	Value	Traceability
SEU Detection and Mitigation	CSP9006	CSP devices shall implement industry best practices for detection and correction of SEU.	

CSP9006 is currently a placeholder for potential future requirements. It will be replaced by clearer, more verifiable requirements, as its current form lacks verifiability due to the undefined nature of 'best practices' associated with it. Note that SEUs affect FPGA devices much more severely than ASICs.

8 Subsystem Requirements

8.1 Functional and Performance Requirements

8.1.1 Operating Mode Requirements

Parameter	Req. #	Value	Traceability
Interferometric Capabilities	CSP0001	The CSP shall support an operating mode that generates auto and cross-correlation estimates, i.e., visibilities.	SYS0001 SYS0002 SYS0007 SYS0008 SYS0102 SYS0103
Beamforming Capabilities	CSP0002	The CSP shall support an operating mode that generates dual-polarization beamformed signals consistent with the polarization basis received at its inputs.	SYS0001 SYS0003 SYS0006 SYS0206

Parameter	Req. #	Value	Traceability
Transient Analysis Capabilities	CSP0003	Split into CSP0065 and CSP0066.	SYS0001 SYS0004 SYS0005 SYS0742
Pulsar Timing Capabilities	CSP0065	The CSP shall support an operating mode that generates full-Stokes pulse profiles through dedispersion and folding.	SYS0001 SYS0004 SYS0741
Search Capabilities	CSP0066	The CSP shall support an operating mode capable of generating full-Stokes profiles in scenarios where either the pulse period, dispersion measure, or both parameters are not available.	SYS0001 SYS0005 SYS0742

The above Operating Mode Requirements provide a simple overview of the different functionality required from the CSP, grouped by the nature of the data product. Different Operating Modes demand different functional and performance requirements. Such requirements are specified in the following sections. The CSP design can develop as many functional modes as needed to fully cover the functional and performance parameter space.

System's Interferometric, Total Power, and On-The-Fly Mapping Modes govern the interferometric capabilities of the CSP; System's Phased Array and VLBI Modes define the beamforming capabilities of the CSP; and System's Pulsar Timing and Pulsar and Transient Search Modes are supported by the Pulsar Timing and Search capabilities of the CSP, respectively.

Parameter	Req. #	Value	Traceability
Reconfiguration Time	CSP0004	The CSP shall be able to change the full configuration (including functional mode) of a subarray within 10 seconds or less from the time such a reconfiguration command is received.	SYS0009 SYS0908 SYS3005

CSP0004 is currently a placeholder for future, more specific requirements. The 10-second allocation is for the entire ngVLA system, and it is not yet clear what the CSP's allocation will be in the reconfiguration time budget. Additionally, CSP0004 will likely be developed into different use cases, each with varying time allocations depending on the specific system requirements.

Parameter	Req. #	Value	Traceability
Standby Mode	CSP0005	The CSP shall include a Standby functional mode where the status and health can be monitored with the goal of minimizing power consumption in this mode. This shall be the default mode.	SYS0010 SYS0011 SYS9990

CSP0005 defines Standby Mode as the default mode. This default mode is the functional mode to which the CSP must revert in the absence of a proper functional mode command. The intended granularity of the standby mode is on a per-Line Replaceable Unit (LRU) basis, meaning that LRU resources not actively participating or allocated to any specific subarray are in 'standby' mode or a similar state, thereby minimizing power consumption.

8.1.2 General Functional and Performance Requirements

Parameter	Req. #	Value	Traceability
Connected Antennas	CSP0006	The CSP shall support at least 263 dual-polarization antennas, full-bandwidth inputs, with a goal of fully scalable architecture.	SYS1021 SYS1001 SYS1309
Polarization	CSP0007	The CSP shall allow processing both polarizations in all its Operating Modes.	SYS1900 SYS0102 SYS0207 SYS0305 SYS6104
Longest Baseline	CSP0010	The CSP shall support extended baselines (VLB) out to 8800 km.	SYS1301

The computational requirements of the CSP are determined by the number of antennas and the processed instantaneous bandwidth. To ensure long-term value, it is preferred that the CSP architecture is inherently scalable to accommodate any number of antenna inputs or receiver bandwidth. This not only mitigates the risk of future hardware upgrades lacking sufficient value to justify the replacement of old hardware but also supports the gradual deployment of the CSP in multiple phases and allows for graceful degradation of the system in the event of malfunction.

CSP0006 and CSP0010 emanate from the current array configuration. This configuration concept defines a 263-antenna ngVLA, arranged as 214 antennas for the main array, 19 antennas for the SBA (Short Baseline Array), and 30 antennas for the LBA (Long Baseline Array). The preferred design will be scalable to any given number of antennas, as opposed to a constrained architecture.

Finally, CSP0006 currently does not incorporate provisions for 'spare' or additional antenna inputs. Firstly, antenna inputs are not hardwired to CSP computational resources, allowing for the possibility of connecting new antennas simply to the CSP input switched fabric. Secondly, while scalability is not an official requirement, it is a characteristic shared by all designs considered for the CSP. Lastly, the exact allocation of spare inputs remains undetermined. Nonetheless, supporting at least a 5% increase (equivalent to 13 additional antennas) is considered sufficient.

Parameter	Req. #	Value	Traceability
Frequency Coverage	CSP0063	The CSP shall support observations within the system RF coverage, i.e., from 1.2 to 50 GHz and from 70 GHz to 116 GHz.	SYS0801 SYS0803 SYS0804 SYS0805

While not directly influencing the CSP architecture, this requirement serves as the basis for deriving additional CSP specifications by defining the system's minimum and maximum radio frequencies.

Parameter	Req. #	Value	Traceability
Per-Antenna Available Bandwidth	CSP0008	The CSP shall receive and process at least 14 GHz of nonredundant bandwidth from every antenna polarization, or the full instantaneous bandwidth of the band in use, whichever is less, with a goal of a fully scalable architecture supporting at least 20 GHz.	SYS0903

The maximum bandwidth processed in each Operating Mode is determined by the non-redundant bandwidth transmitted from every antenna (CSP0008). Within the ngVLA system, the CSP processes several DBE subbands, collectively constituting the processed bandwidth. The DBE, situated at the antenna, downselects a subset of subbands, which may or may not align with the subbands of a sideband. Consequently, CSP0008 does not specify the bandwidth per sideband.

However, it is important to note that the CSP is not required to process all available bandwidth in every Operating Mode. Additional constraints, such as simultaneous subarray operation or specific Operating Modes, may limit the amount of bandwidth processed, as detailed in subsequent sections. Nonetheless, there is potential for processing up to 20 GHz of bandwidth in any Operating Mode in the future [RD03], underscoring the rationale behind striving for a scalable design.

Parameter	Req. #	Value	Traceability
Correlation Loss	CSP0009	The correlation loss attributable to the CSP shall be less than 0.6%.	SYS1033

Correlation loss will be measured using a predefined set of use cases, as specified in Section 10.2. One such case involves a white (flat spectrum) Gaussian signal and noise with moderate SNR, measured over the bandwidth of a subband.

System requirement SYS1033 sets an overall correlation loss of 5% for the 'digital system.' This digital system encompasses 3 distinct components, the digitizer and the Digital Back End at the antenna, as well as the CSP in the Central Electronics Building. In CSP0009, the CSP correlation loss assumes a digitizer correlation loss of 4% and 0.4% for the DBE, aligning with the current system technical budget for digital correlation loss [AD10]. Digital correlation losses typically occur when data are approximated by their finite precision representation, which can include various parameters such as signals, delays, phases, (filter) coefficients, or correlation estimates.

While this requirement formally applies only in interferometric mode, it might impact the common per-antenna processing chain of all operating modes and is therefore included with general requirements.

CSP0009 applies to all frequencies within the system frequency span defined by SYS0803, SYS0804, and SYS0805. The CSP frequency channelization strategy must ensure this requirement can be fulfilled without gaps in frequency coverage. For instance, adequate spectral overlap across subbands must be allocated so that frequency channels at the subband edges failing to meet CSP0009 criteria are discarded, while adjacent subbands meet CSP0009 for the corresponding RF band.

A correlation loss budget for the CSP will be included within the CSP Design Description document [RD01].

Parameter	Req. #	Value	Traceability
Timing Accuracy	CSP0012	The timing error introduced by the CSP shall be consistent with the timing error budget of the system.	SYS2002 SYS2003

While data processing within the CSP is discrete-time, subsample delay correction may introduce additional frequency-dependent uncertainty in signal timing. This error must align with the System Technical Budgets [AD10]. Currently, the maximum overall system error, as per SYS2002, is 10 ns, with a target of 1 ns. It is anticipated that any random timing errors introduced by the CSP will be negligible compared to this, and any systematic timing error can be corrected in post-processing.

Parameter	Req. #	Value	Traceability
Polarization Dynamic Range	CSP0013	Any polarization transformation within the CSP shall support the polarization dynamic range established in SYS6104 (35 dB at < 8 GHz).	SYS1902 SYS6104

CSP0013 serves as a placeholder requirement. Future specifications will establish the maximum quantization error during the application of polarization corrections or transformations.

Parameter	Req. #	Value	Traceability
Commensal Signal Processors	CSP0014	The CSP switched fabric shall be scalable and allow flexible multicast for future commensal processing of visibilities and voltage data streams.	SYS0502 SYS5600 SYS5601 SYS5602 SYS5603

Commensal Signal Processors defined in CSP0014 are inherently supported by the assumed CSP architecture, but it must be enabled by supporting multicast capabilities.

Parameter	Req. #	Value	Traceability
Self-Generated Spurious Signal Power Level	CSP0015	The CSP shall not generate spurious signals above –43 dB relative to the system noise level on cold sky over a 1 MHz bandwidth.	SYS2104

This applies to spurious signals other quantization noise. It does not account for ill-posed cases, such as the system noise level well below one quantization step.

8.1.2.1 Overall amplitude gain accountability

Parameter	Req. #	Value	Traceability
Amplitude and Delay/Phase Variations Accountability	CSP0061	The amplitude and delay/phase variations introduced by the CSP at any given time shall be known with an accuracy better than TBD (<0.035dB).	SYS1501 SYS4601 SYS1601

Ideally, any amplitude and delay/phase variations introduced by the CSP should be perfectly known. However, some time-varying processes such as delay or phase tracking may introduce small amplitude or delay/phase variations that change with time scales much smaller than the correlator accumulation period. Under those circumstances, tracking and compensating for such fast-paced variation becomes unwieldy. The main purpose of CSP0061 is to limit the contribution of the CSP to the system's gain stability budget. The upper limit on the accuracy, 0.035dB, is derived from SYS4601, which calls for an antenna gain stability dG/G < 0.004.

An additional goal of CSP0061 aims at enforcing time-controlled configurations of the system. Any configuration change in the gain of the CSP must occur at known instants, as commanded by the Monitor & Control subsystem. More requirements may be added to this section in the future as needed.

8.1.2.2 Timing requirements

Parameter	Req. #	Value	Traceability
Timestamped Data Products	CSP0059	CSP data products shall be timestamped using an external time reference.	SYS2002 SYS2003

System requirements SYS2002 and SYS2003 call for ngVLA data products that can be retroactively time referenced to a global time standard such as GPS, TAI or UTC. This is attained by referencing data products with respect to a locally generated central time reference. The resulting timestamps are retroactively corrected offline using the time difference between the central time standard and the global one.

The DBE is responsible for generating timestamped data referenced to the locally generated antenna time reference. Upon reaching the CSP, these timestamps undergo regeneration based on an externally provided delay model. This process ensures that subband data streams are referenced to the central time standard and aligned in time before undergoing beamforming or cross-correlation. The SBP achieves this through the application of phase-delay models provided by the CSS (refer to Assumption 10). All data products produced by the CSP must be timestamped using the central time standard.

Parameter	Req. #	Value	Traceability
Timestamp Accuracy	CSP0060	In converting from antenna to central time, the error of the generated CSP timestamps shall be less than 10 ps with respect to the timestamps that an ideal system would generate from the same inputs.	SYS2002 SYS2003 [AD10]

Since the timestamping process on the CSP depends on external sources (antenna time reference input, phase-delay models, etc.) the intent of CSP0060 is to specify the maximum error contribution from the CSP to the system timing error referred to by SYS2002 and SYS2003.

The value of 10 ps is based on the timing error budget for the ngVLA system specified by [AD10]. When determining this value, the DBE was considered as the principal source of error, and the contribution of other CSP systems negligible in comparison. 10 ps equals 1% of the overall system timing precision goal, 1 ns.

CSP0060 requires that the CSP internally corrects significant enough systematic errors as part of its timestamping process. However, a different approach in which systematic errors are corrected by the CSS could be considered in the future if deemed beneficial.

8.1.3 Subarray Operation Requirements

The CSP is required to fully support the operation of the ngVLA as separate subarrays, as defined in Section 3, treating each subarray akin to a distinct telescope in its functionality.

Parameter	Req. #	Value	Traceability
Subarray Operation	CSP0016	The CSP shall support the operation of multiple subarrays at the same time, where each subarray employs an arbitrary subset of antennas.	SYS0601 SYS0603

Any antenna can be assigned to any subarray to prevent the formation of clusters of antennas assigned together.

Parameter	Req. #	Value	Traceability
Number of Subarrays	CSP0017	The CSP shall support simultaneous operation of at least 10 subarrays.	SYS0601

The analysis of current system requirements does not anticipate the need to operate more than 10 subarrays at any given time.

Parameter	Req. #	Value	Traceability
Subarray Independence	CSP0019	The configuration of a subarray shall be completely independent of all other subarrays.	SYS0606 SYS0608

The configuration of any subarray should be independent and not influenced by the operation or configuration of any other subarray. As defined, a subarray is expected to have its own dedicated set of processing resources, ensuring the requested independence. Additionally, subarrays must be allocated mutually exclusive subsets of antennas, meaning there should be no overlap in antenna usage between subarrays.

The preceding set of requirements delineates the minimum specifications for subarray operation, providing foundational guidance for the design of the CSP. The subsequent requirements aim to explicate particular facets of the minimum essential capabilities required for the seamless operation of the CSP.

Parameter	Req. #	Value	Traceability
Subarray Reconfiguration	CSP0020	The CSP shall support adding and subtracting elements from a subarray without interrupting an observation.	SYS0602 SYS0607

CSP0020 is direct consequence from System Requirements [AD03]. In this regard, System Requirements clarify that "[…] the addition or subtraction of array elements from a subarray needn't be immediate, and can occur at a natural boundary point such as a scan boundary."

The primary purpose of this requirement is to allow for maintenance of certain antennas without interrupting ongoing observations. However, the current formulation of CSP0020 does not accurately capture this intent; it is excessively strict and may not be feasible in all scenarios. Consequently, a system-level revision of this requirement is currently underway.

Parameter	Req. #	Value	Traceability
Secondary Subarray Capabilities	CSP0058	Withdrawn.	SYS0606 SYS0608

CSP0058 originated from implementation-related limitations, introducing an artificial distinction between 'primary' and 'secondary' subarrays, with the latter having certain configuration restrictions imposed by the former. This requirement has been withdrawn and may be formally retired in future releases.

Parameter	Req. #	Value	Traceability
Simultaneous Subarray Capabilities	CSP0018	The CSP shall support subarray operation with combinations and capabilities equal to or greater than the functionality described in Table 1.	SYS0604 SYS0605

Table 1 – Required sub-array commensality (taken from System Requirements [AD03]). The primary or full-featured mode is the Y-axis, with the impact on the secondary mode denoted in each column

System Functional Mode*	Interfer.	Phased Array	PA Timing	PA Search	VLBI	TP	OTF
Interferometric	Full[1]	Limited[2]	Limited[2]	Limited[2]	Limited[2]	Full[1]	Full[1]
Phased Array	Limited[3]	Full[1]	Full[1]	Full[1]	Full[1]	Full[4]	Limited[3]
PA Timing	Limited[3]	Full[1]	Full[1]	Full[1]	Full[1]	Full[4]	Limited[3]
PA Search	Limited[3]	Full[1]	Full[1]	Full[1]	Full[1]	Limited[3]	Limited[3]
VLBI	Limited[3]	Full[1]	Full[1]	Full[1]	Full[1]	Full[4]	Limited[3]
Total Power	Full[1]	Full[4]	Full[4]	Limited[2]	Full[4]	Full[1]	Full[1]
On-The-Fly	Full[1]	Limited[2]	Limited[2]	Limited[2]	Full[1]	Full[1]	Full[1]

Table 1 Notes:

* 'Functional mode' refers to its system-level definition. Mapping of 'system functional modes' to 'CSP functional modes' is design-dependent, and therefore no specifications in this regard are provided in this document.

1. Full capabilities in all functional modes must be maintained within the constraints of the maximum data input to the correlator back-end.
2. Minimum functionality must include full-bandwidth correlation in one subarray, concurrent with phased array operations in another subarray. Phased array timing, search, and VLBI mode capabilities may have a restricted number of beams or bandwidth to comply with the maximum data input constraint to the correlator back-end.
3. Full capabilities in the phased array timing, search, and VLBI modes must be ensured, with interferometric, total power, or on-the-fly mode capabilities (processed bandwidth, time, and/or spectral resolution) constrained by the maximum data input to the correlator back-end.
4. Data rates for these functional modes are expected to be sufficiently small to support full capabilities in all functional modes.

CSP0018 serves as the primary requirement guiding the availability of CSP resources for additional simultaneous subarrays necessary to initiate an observation. In CSP designs that allocate resources on a per-subarray basis, the overall size of the CSP is likely dictated by the worst-case scenario of the full-bandwidth whole array. However, CSP designs that allocate resources to subarrays without considering their size must ensure that the minimum capabilities described by CSP0018 are satisfied.

8.1.4 Interferometric Requirements

The following requirements aim at defining the required performance of the CSP for subarrays observing in interferometric mode.

Parameter	Req. #	Value	Traceability
Interferometric Bandwidth	CSP0021	The CSP shall support processing all the available bandwidth consistent with CSP0008 in interferometric mode.	CSP0008

Processing all the available bandwidth shall be allowed in interferometric mode.

Parameter	Req. #	Value	Traceability
Number of frequency channels	CSP0011	The CSP shall support at least 240,000 frequency channels (per polarization) in interferometric modes, with a goal of 2,000,000 channels.	SYS1402

CSP0011 allows the CSP to operate in coarser frequency resolutions as a function of the overall bandwidth so that the resulting number of channels does not exceed the specified value. The highest spectral resolution is specified below depending on the Operating Mode.

It is worth noting that CSP0011 does not apply to beamforming modes. This is because the number of frequency channels in a beamformer is determined solely by bandwidth and frequency resolution. On the other hand, adhering to the finest frequency resolution specified in interferometric mode by CSP0022 would lead to an excessively large number of frequency channels spanning the entire bandwidth. CSP0011 provides CSP designers with the opportunity to evaluate scenarios where sacrificing processed bandwidth in favor of finer spectral resolution, such as employing spectral zoom techniques, could offer significant benefits.

Parameter	Req. #	Value	Traceability
Interferometric Flexible Frequency Resolution	CSP0023	The CSP shall support independent frequency resolution settings per subband in interferometric observations.	SYS1403

The frequency resolution in interferometric mode must be configurable. Otherwise, at least 14 million frequency channels must be supported to meet the required interferometric bandwidth of 14 GHz specified in CSP0021, and the highest frequency resolution of 1 kHz specified in CSP0024.

Note that the subarray independence requirement CSP0019 implies that frequency resolution can be configured independently for each subarray.

The call for independent subband frequency resolution originates from the need for accommodating spectral line and continuum observations in a single setting, as described in System Requirements [AD03].

Parameter	Req. #	Value	Traceability
Interferometric Frequency Resolution Spacing	CSP0062	The CSP shall ensure that the spacing between adjacent frequency resolution values available for selection in interferometric observations is no more than one octave (TBC).	SYS1405

CSP0062 serves as the initial effort to guide CSP designers regarding the flexibility in establishing the required frequency resolution. Higher-level requirements do not explicitly provide any indication in this

regard. Nevertheless, it is evident that the standard operation mode does not involve the highest frequency resolution, as it leads to an impractical number of frequency channels. Additionally, not every value can be employed as a valid frequency resolution configuration. A minimum requirement of one octave has been considered reasonable, although further confirmation is needed to validate such granularity.

Parameter	Req. #	Value	Traceability
Interferometric Frequency Resolution	CSP0022	The finest frequency resolution in interferometric observations shall be at least 1 kHz, with a goal of 400 Hz.	SYS1401

It is expected that the finest frequency resolutions can only be achieved if at least one other parameter affecting the CSP output data rate is constrained to keep the output data rate within the limits specified by CSP1036. This means that either the number of antennas in the subarray, the bandwidth, or the time resolution must be constrained with respect to the maximum CSP capabilities to control the CSP output data rate.

Parameter	Req. #	Value	Traceability
Interferometric Time Resolution	CSP0024	The CSP shall support correlation integration times ranging from 10 ms to 5 s, with the goal of reaching a minimum integration time of 1 ms.	SYS0106 SYS2001

The goal of reaching integration times of 1ms in CSP0024 refers to the minimum time resolution, not the quantization step of the configurable time resolutions. Using a logarithmic set of values as the configurable time resolutions may be acceptable, e.g., [100ms, 200ms, 400ms, …]. There is no clear indication in higher-level requirements what set of values would be acceptable. OTF modes have been included within the supported range, as the scan mode makes no qualitative difference in the CSP operation. The data rate at the CBE input may impose limitations on the total bandwidth observable at the shortest integration times. Configurations requiring per-baseline integration times will be accommodated by the CSS. Additionally, it is important to note that the coarsest time resolution specified in SYS2001, 5 seconds, pertains to the final data product rather than the CSP output. There is a possibility that this value could be decreased in the future through long-term visibility integration at the CSS.

Parameter	Req. #	Value	Traceability
Interferometric Channel Flatness	CSP0025	The in-band frequency response of any CSP frequency channel (e.g., channel passband ripple) shall be consistent with CSP correlation loss requirements.	CSP0009 SYS1701 SYS1702 SYS1703

Channel passband flatness will be determined by correlation loss requirements. The specific requirement will be developed at the SBP level, where the fine frequency channelizer resides.

The frequency response of the CSP within the band of a frequency channel produces a correlation or SNR loss with respect to an ideal rectangular function. The effect of slope, ripple, etc., can be computed according to formulas described [RD04, RD05]. For example, for a correlation loss of 0.05%, the maximum sinusoidal peak-to-peak ripple in an otherwise perfectly rectangular channel should be less than 0.39 dB.

Parameter	Req. #	Value	Traceability
Interferometric Frequency Selectivity	CSP0026	The channel frequency response of the CSP in interferometric mode shall be, relative to the channel center, -3.01±0.01 dB at the channel edge, -60 dB or better at the center of the adjacent channel, and -80 dB or better beyond the adjacent channel edge, with a goal of reaching -80 dB at the center of the adjacent channel and beyond.	SYS6105 SYS6106

The frequency selectivity specified in interferometric mode satisfies the System emissive dynamic range requirement SYS6106. It also satisfies the absorptive dynamic range SYS6105 assuming a certain decreasing trend of the sidelobe level. Quantization of the window coefficients must also be considered as it could limit the sidelobe decay.

CSP0026 is likely more than what is necessary to fulfill SYS6105 or SYS6106 (spectral dynamic range requirements). Instead, it has been deemed a reasonable assumption of CSP capabilities.

Parameter	Req. #	Value	Traceability
Interferometric Polarization Products	CSP0027	The CSP shall allow generating any combination of the four parallel-pol and cross-pol correlations within a subarray.	SYS0102 SYS0105

In practice, the CSP may compute all four polarization correlation products, but must be able to select which ones are output for better control of the output data rate.

Parameter	Req. #	Value	Traceability
Power Spectral Density Scale	CSP0067	The CSP shall generate same-antenna correlation products at a period synchronized to twice the switched power reference trigger signal, with separate accumulated cal ON and cal OFF data and metadata to distinguish them.	SYS4401

CSP0067 currently serves as a placeholder for future requirements pending coordination of the synchronization method at a system level. Given that data at the correlator input has been referenced to central time, it is conceivable that the CSP may need to synchronize integration intervals of the auto-correlation products with externally provided parameters to fulfill the requirements of CSP0067.

8.1.5 Beamforming Requirements

The following requirements define functional and performance capabilities of the beamforming operating mode.

Parameter	Req. #	Value	Traceability
Beamformer Aperture	CSP0028	The CSP shall support full beamforming capabilities for any subarray (including extended baselines) with an aperture equal or less than SYS1301 specification (700 km).	SYS0201 SYS1301

CSP0028 is specified for the minimum aperture of the Main Array as defined in SYS1301. It is understood that the intent is to support beamforming capabilities for the true final configuration of the Main Array, which likely will increase the aperture.

When provided with the proper beamforming and polarization calibration coefficients, the beamformed radiation pattern can meet polarization dynamic range requirements, include nulling directions, and control its side-lobe level, as per System Requirements [AD03]. Therefore, the responsibility of such capabilities lies in the subsystem generating those coefficients.

As per System Requirements [AD03]: "The need for phased array capability over the full main array is due to the expected sub-array allocations. […] The use of the main array aperture size in this definition is not intended to preclude using the extended baselines […] so long as the phased sub-array does not exceed 700 km in extent."

Parameter	Req. #	Value	Traceability
Number of Beams	CSP0029	The CSP shall support producing a minimum of 10 beams, with a goal of 50 beams, distributed over the active subarrays.	SYS0203 SYS0301 SYS0401 SYS0501

The number of beams is for the whole array. Hence, it might be distributed over subarrays in this operating mode. CSP0029 accounts for the most demanding use case, currently specified by SYS0203 (Phased Array Operating Mode requirements). SYS0301 (Pulsar Timing Operating Mode requirements), SYS0401 (Transient and Pulsar Search Operating Mode requirements), and SYS0501 (VLBI Operating Mode requirements) demand less or equal capabilities.

In practice, the CSP designs under consideration can exchange bandwidth for the number of beams. CSP0029 specifies the minimum number of beams for the full bandwidth specified in CSP0030.

Parameter	Req. #	Value	Traceability
Beamformer Bandwidth per Beam	CSP0030	The CSP shall be able to generate each beam with at least 8 GHz or the full instantaneous bandwidth of the band in use, whichever is less, with a goal of generating the full available bandwidth specified by CSP0008.	SYS0302 SYS0402 SYS0505

The minimum bandwidth of the beamformer has been determined as the best value solution to inform the designer about minimum requirements that must be satisfied for subarray operations (in which some other subarrays may be simultaneously observing using different functional modes) along with other requirements, particularly the number of beams in CSP0029. A particular CSP design might support increased bandwidth for the beamformer if deemed advantageous or achieved at a relatively low cost. Similarly, some CSP designs might allow different trade-offs to increase the per-beam bandwidth, such as allocating more bandwidth for fewer beams.

Parameter	Req. #	Value	Traceability
Beamformer Field of View	CSP0031	The CSP shall support generating beams pointed at any direction within the antenna primary beam. This includes beamforming the SBA (Small Baseline Array) as well.	SYS0205

While the SBA employs smaller antennas, resulting in a wider field of view, the much larger aperture size when beamforming the main array means that the requirements are more stringent. Nonetheless, explicitly mentioning the SBA aims to clarify that there are no restrictions on the beamformer's field of view for the SBA.

Parameter	Req. #	Value	Traceability
Beamforming SNR Loss	CSP0032	The CSP shall generate a beamformer output with an SNR at least 95% of what an ideal beamformer would produce for the same inputs, including beamforming weights as part of the input parameters.	SYS0208

The beamformer's field of view, aperture, and correlation loss requirements could guide the designer in selecting the most advantageous beamforming technique, such as True Time Delay beamforming or a narrowband approximation based on Phase-Shift beamforming.

Parameter	Req. #	Value	Traceability
Beamformer Polarization Correction	CSP0033	The CSP shall support per-antenna polarization calibration in beamforming mode.	SYS0207 CSP0032

Polarization correction is expected to happen at the same time as the application of beamforming complex coefficients.

Parameter	Req. #	Value	Traceability
Concurrent Interferometric Mode	CSP0034	The CSP shall generate cross-correlation products for one of the phase centers while operating in beamforming mode. The bandwidth processed, as well as the time and frequency resolutions of these cross-correlation products might satisfy lower specifications than the interferometric requirements in Section 8.1.4. (TBD)	SYS0202 SYS0209 SYS1061 SYS4310 SYS4311

Concurrent visibilities required by CSP0034 are required for calibration purposes. It is expected that the synthetic beam for which visibilities are measured is pointed toward a calibrator within the primary beam of the antenna.

The CSP is required to adhere to CSP0034 while ensuring the fulfillment of simultaneous subarray capabilities as specified in CSP0018. In other words, if additional CSP resources are allocated to meet the requirements of CSP0034, it should not affect the resources available for concurrent observing subarrays.

Parameter	Req. #	Value	Traceability
VLBI Support	CSP0035	The CSP shall be able to select the bandwidth and format the output of the beamformer in compliance with bandwidth and quantization specifications in support of VLBI Observing Mode.	SYS0503 SYS0504 SYS0745 SYS0746

Compatibility with a standard VLBI format, such as VDIF, is anticipated. This requirement is driven by the expectation of utilizing existing VLBI recording hardware for a potential future scenario where a VLBA recorder could be connected to the CSP as a custom back end.

8.1.6 Pulsar Timing and Search Requirements

The following requirements define the performance and functional requirements of the Pulsar Timing and the Search operating modes of the CSP. The associated functions are performed at the PSE, which will usually operate on the beamformed outputs of the SBP.

Parameter	Req. #	Value	Traceability
Stokes Parameters	CSP0036	The CSP shall produce all Stokes parameters when operating in pulsar timing and search modes.	SYS0305 SYS0405
Dedispersion and Folding Capabilities	CSP0037	The CSP shall support dedispersion and folding functions to facilitate the generation of pulse profiles.	SYS0741 SYS0407

The above requirements specify general processing capabilities in Pulsar Timing and Search observing modes.

Parameter	Req. #	Value	Traceability
Pulsar Engine Bandwidth	CSP0038	The PSE shall support processing 8 GHz of bandwidth per beam, with a goal of all the receiver bandwidth in each band below 20 GHz.	SYS0302

The objective is for the PSE to be capable of processing the complete output from the beamformer. It is important to note that the current design permits the adjustment of the trade-off between the number of beams and the bandwidth allocated per beam. This means that fewer beams can be produced with an increased bandwidth per beam.

Parameter	Req. #	Value	Traceability
Pulsar Engine Number of Beams	CSP0039	The PSE shall support processing 10 full-bandwidth beams without dedispersion and folding, or 5 full-bandwidth beams with dedispersion and folding, with a goal of processing all the beams available at the beamformer output.	SYS0301 SYS0401

Note that CSP0039 permits halving the processed beam-bandwidth product when the functional mode involves dedispersion and folding. In essence, the PSE design should be scalable, allowing for the upgrading of processing capabilities in the future without necessitating the retirement of existing hardware.

Parameter	Req. #	Value	Traceability
Pulsar Engine Time Resolution	CSP0040	The PSE shall allow adjusting the time resolution, with the highest resolution equal or better than 488 ns.	SYS0304 SYS0306 SYS0404

The minimum time resolution has been determined by the requirement to produce 2048 "bins" assuming a 1-ms pulse profile, surpassing the necessary resolution for transient and pulsar searches. To handle the

data rate effectively, it is recommended to adjust and potentially increase the time resolution. For example, a time resolution of 14 ms aligns with generating 2048 bins within a 30-second pulse. Refer to CSP0055 for an additional requirement concerning the number of bins.

Parameter	Req. #	Value	Traceability
Pulsar Engine Frequency Resolution	CSP0041	The PSE shall support a frequency resolution of at least 1 MHz, with a goal of 50 kHz.	SYS0303 SYS0403

The relationship between time and frequency resolutions is interdependent. Data that is finely frequency-channelized will naturally result in poorer time resolution. The product of both resolutions will consistently exceed a value greater than one, meaning that the PSE will not support oversampling.

Parameter	Req. #	Value	Traceability
Pulsar Timing SNR Loss	CSP0042	The SNR loss of the CSP pulsar timing subsystem, relative to an ideal processor, shall be less than 5%	SYS0309
Search Mode SNR Loss	CSP0068	The SNR loss of the CSP search subsystem, relative to an ideal processor, shall be less than 5%	SYS0406

The SNR loss specified above is distinct and supplementary to other SNR losses outlined, particularly the beamforming SNR loss (CSP0032). In both the Pulsar Timing and Search Modes, the CSP initially synthesizes a signal through beamforming, followed by specific processing tailored to the operating mode. CSP0042 and CSP0068 pertain solely to this specialized processing.

8.1.7 RFI Mitigation Requirements

Parameter	Req. #	Value	Traceability
RFI Mitigation	CSP0049	It is a goal that the CSP implement RFI mitigation algorithms that can be deactivated.	SYS2604 SYS4100 SYS4101 SYS4102

CSP0049 is a placeholder of proper future RFI detection and excision requirements specifying minimum performance requirements.[2] The most recent assessment of the needs of the ngVLA in terms of RFI handling can be found in [RD12]. The analysis therein points out that the necessity for RFI mitigation algorithms within the CSP must be determined through an evaluation of their effectiveness and a comprehensive characterization of the ngVLA radio environment.

8.1.8 Delay and Phase Tracking Requirements

The requirements in this section apply to both interferometric and beamforming modes. The update rate is determined by interferometric mode requirements.

[2] RFI mitigation requirements shall be fully developed by PDR.

Parameter	Req. #	Value	Traceability
Geometric Delay	CSP0050	The CSP shall compensate for geometric and atmospheric delays in accordance with CSP0010 (baselines up to 8800 km long) and for any observing elevation angle.	CSP0010 SYS0108 SYS0602 SYS1102

For context, the maximum geometric delay in 10,000-km baselines is 3.3 ms, which is small compared to the expected network latency (more details in the specific interface requirements below). However, the geometric delay compensation requirement applies to the main phase center position. Multiple phase centers will require differential delay corrections and are fully supported (i.e., anywhere within the same antenna lobe) only for the beamforming-specific aperture limit; see CSP0028.

It is assumed that the phase and delay correction model parameters are computed by the CSS. Therefore, requirements such as SYS0602 (array phase center preservation) or the location of the array phase center have no impact on CSP requirements.

Parameter	Req. #	Value	Traceability
Delay and Phase Tracking Update Rate	CSP0051	The system shall be able to update the delay and phase corrections at a rate of at least 10 Hz, with a goal of 20 Hz. (TBC)	SYS5700 SYS5701 SYS5702 SYS0204 SYS0205

The delay and phase tracking update rate specified in CSP0051 does not refer to the rate at which the CSP receives new delay and phase models from the CSS, as this can be much slower. Additionally, it does not refer to the rate at which fine delay corrections are internally updated within the CSP, which needs to be much faster. Instead, the intent of CSP0051 is to specify the update rate required for the delay model during On-The-Fly (OTF) mapping, ensuring that the phase center accurately follows the antenna's movement across the sky. This requirement is still under development, pending the finalization of the CSS and CSP interface, as well as the delay model management strategy.

Parameter	Req. #	Value	Traceability
Sampler Clock Offset Support	CSP0052	It is a goal that the CSP delay and phase tracking process supports compensating for a digitizer clock offset.	SYS2105

The current design includes support for Sampler Clock Offset compensation. The adoption of this technique is driven by the desire to enhance the mitigation of self-generated RFI at the digitizer, as well as to address spectral components that may be aliased during the digitization process.

Parameter	Req. #	Value	Traceability
Delay and Phase Tracking SNR Loss	CSP0053	The SNR loss incurred by the CSP with respect to an ideal delay and phase tracker with the same inputs shall not exceed its maximum allowance CSP0009.	CSP0009

CSP0053 is somewhat redundant with CSP0009 and is included here only to emphasize that the SNR loss of the tracking algorithm must be accounted for in the overall CSP budget. It is up to the designer to

determine the distribution of the overall CSP allocation across different DSP stages, including delay and phase tracking.

Parameter	Req. #	Value	Traceability
OTF Mapping Rate	CSP0064	Withdrawn.	

It has been determined that OTF mapping requirements do not impose any additional demands on the CSP, other than the delay model update rate requirements specified in CSP0051.

8.1.9 Dedispersion Requirements

Parameter	Req. #	Value	Traceability
Dispersion Measure Range	CSP0054	The CSP shall be able to compensate for dispersion measures up to 3000 pc/cm^3.	SYS0308

This value is intended for dedispersing pulses originating from hypothetical observations of pulsars near the center of the Milky Way.

8.1.10 Folding Requirements

Parameter	Req. #	Value	Traceability
Pulse Profile Bins	CSP0055	The CSP shall generate a minimum of 2048 pulse profile bins.	SYS0304
Pulse Period	CSP0056	The CSP shall be capable of folding for pulse periods spanning from 1 msec to 30 sec.	SYS0306

The above set of requirements were extracted from [RD03].

8.1.11 Legacy DBE Requirements

The following set of legacy requirements was included at a time when the functional partition of the DBE and the CSP was unclear. These requirements specifically apply to the DBE and are retained here solely for traceability purposes; however, they may be removed in future releases.

8.1.11.1 Sideband Separation Requirements

Parameter	Req. #	Value	Traceability
Sideband Separation	CSP0043	The DBE shall apply sideband separation and equalization filters to the receiver digitized signal.	SYS1704
Sideband Separation Level	CSP0057	When provided with ideal (error-free) sideband separation calibration coefficient, the DBE shall achieve an unwanted sideband rejection greater than 30 dB, goal of 40 dB, within the usable bandwidth.	SYS1704

8.1.11.2 Subband Generation Requirements

Parameter	Req. #	Value	Traceability
Subband Generation	CSP0044	The DBE shall split the receiver's output signal into frequency subbands.	SYS0905

Parameter	Req. #	Value	Traceability
Subband Selection	CSP0045	It shall be possible to select any arbitrary subset of subbands within the frequency band in use that does not exceed the bandwidth limit specified by CSP0008.	SYS0905
Subband Bandwidth	CSP0046	The subband bandwidth shall be 250 MHz or smaller.	SYS0907
LO Offset Support	CSP0048	The DBE subband generation process shall compensate for LO offsets at the antenna level as necessary.	SYS2105

8.2 Interface Requirements

In this section, requirements are derived from the applicable ICDs as listed in Section 2.2. As stated in the SEMP [AD01], ICDs define the interface, but do not contain any requirements. All interface requirements that drive the design and verification of the subsystem shall be listed in this section.

Currently, most of the interface requirements are simple placeholders that will be fully developed during the PDR phase of the project.

All requirements related to DBE interfaces have been withdrawn but are still shown herein for documentation purposes.

8.2.1 020.10.40.05.00-0095 ngVLA Site Buildings Interface Requirements

The ngVLA Site Buildings subsystem (NSB, CI number 020.61.10.00.00) hosts all CSP elements in a central facility, the Central Electronics Building (CBE), that provides an environmentally controlled space, power, and RFI shielding. This interface defines the CSP dimensions, thermal load, EMI emissions, and fixing.

Parameter	Req. #	Value	Traceability
CSP Shielding	CSP1024	Superseded by CSP1028.	
CSP Safety Monitoring	CSP1025	Parameters that affect the health/safety of the CSP (e.g., temperature) shall be monitored by both the CSP and the NSB subsystems.	[AD21] SYS2502
CSP Dimensions	CSP1026	The CSP dimensions shall be compliant with specifications in [AD21].	[AD21]
CSP Thermal Load	CSP1027	The CSP thermal load shall be compliant with specifications in [AD21].	[AD21]
CSP RFI Emissions	CSP1028	The CSP RFI emissions shall be compliant with specifications in [AD21].	[AD21] ETR0601 EMC0310
CSP Fastening	CSP1029	The CSP shall use the fastening device defined in [AD21].	[AD21]
Backup Power Operation	CSP1030	The NSB shall still be compliant with specifications in [AD21] in the event of an interruption of the main power system and while the CSP operates on a backup power system, e.g., environmental specifications.	[AD21]
CSP Immunity	CSP1045	The CSP shall comply with [AD21] immunity specifications.	[AD25]

Parameter	Req. #	Value	Traceability
CSP Normal Operation Temperature	CSP1046	The CSP shall satisfy subsystem requirements for an ambient temperature within the range 0 C ≤ T ≤ 30 C (TBC).	[AD21] ETR0903
CSP Normal Operation Relative Humidity	CSP1047	The CSP shall satisfy subsystem requirements for an ambient relative humidity (non-condensing) within the range 30% ≤ RH ≤ 70% (TBC).	[AD21] ETR0903
CSP Maximum Power Consumption	CSP1050	The overall power consumption of the CSP shall not exceed 2MW (TBC).	[AD21]

These ranges are generally supported by commercial electronic components. Subsystem requirements are defined in Section 8.

CSP1028 is a placeholder for a future requirement. The current assumption is that the CSP equipment complies with applicable commercial regulations, while the RFI shielding provided by NSB guarantees no significant degradation of the system sensitivity. This requirement will be determined from the ICD specification.

CSP1050 includes all equipment comprising the CSP. For example, it would include the coolant distribution units of a liquid cooling system used by the CSP, but not the HVAC equipment used for room temperature control. The current value of 2MW was derived from the reference design and has been significantly reduced in the current design concept [RD01].

8.2.2 020.10.40.05.00-0105 CSP–MCL System Interface Requirements

This interface aims to support the M&C data interface between the CSP at the central facility and the M&C subsystem (MCL, CI number 020.50.25.00.00). It defines the extent and cadence of monitor data, as well as configuration parameters and operational commands. It also specifies the communication protocols and the physical and mechanical interface between the CSP and MCL.

Parameter	Req. #	Value	Traceability
CSP M&C Physical Interface	CSP1031	The CSP physical interface with MCL shall follow the specifications in [AD22].	[AD22]
CSP Configuration Data Rate	CSP1032	The CSP interface with MCL shall provide enough throughput to effectively command and communicate configuration and applicable calibration parameters to the CSP, as specified in [AD22].	[AD22]
CSP Monitor Parameters	CSP1033	The CSP shall monitor and send via the M&C interface the set of parameters defined in [AD22].	[AD22]
CSP Configuration Protocol	CSP1034	The CSP shall support the configuration protocol and command set defined in [AD22].	[AD22]

8.2.2.1 Configuration Parameters

The CSP receives its observation configuration parameters via the MCL-CSP interface. These parameters are then processed by the CMC, which converts them into low-level commands as necessary to control the hardware.

A number of these configuration parameters are initially received at the beginning of a scan and persist unchanged throughout its duration, necessitating no updates during this period. Nonetheless, there exist specific configuration parameters that mandate periodic updates throughout the scan. The subsequent set of requirements is established to outline the essential minimum capabilities of the CSP to effectively process and implement the streamed parameter updates.

Parameter	Req. #	Value	Traceability
Configuration Parameters	CSP1051	The CSP shall receive, process, and prepare to apply the configuration parameters outlined in Table 2 within the specified processing time.	[AD22]

The following is a preliminary description of the parameters that the CSP needs to process. The processing time indicates the duration required for the CSP to process and implement the received configuration. Configuration parameters received with an anticipation shorter than the processing time will be applied as soon as possible, which may occur after their designated applicability time. The CSP is responsible for communicating such an event and flagging any data products that may be affected. Specific procedures to address this potential issue will be developed in [AD22].

Table 2 – Configuration parameters of the CSP received from the MCL subsystem.

Parameter	Description	Cadence	Processing Time	Multiplicity
High-Order Delay Model	A polynomial function of time designed to transform data from antenna time to a standardized central time. It accounts for corrections related to geometric and instrumental delays, along with any further adjustments resulting from calibration procedures.	< 1 Hz [3]	2 s	Per antenna, per subband, per phase reference position
High-Order Phase Model	A polynomial function of time that defines the instantaneous phase correction to be applied to a delay-corrected subband signal.	< 1 Hz [3]	2 s	Per antenna, per subband, per phase reference position
Polarization Correction	A Jones matrix operator applied prior to beamforming. (May be combined with Beamforming Coefficients).	TBD	TBD	Per antenna, per subband/frequency channel, per phase reference position (TBC)

[3] The system assumes continuous updating of the phase reference position during on-the-fly (OTF) observing modes. System Requirements [AD03] mandate a minimum update frequency of 10 Hz for the phase reference position, with a target of achieving 20 Hz.

Parameter	Description	Cadence	Processing Time	Multiplicity
Beamforming Coefficients	Complex weights assigned to each antenna within a subarray. They are utilized in the linear combination process, resulting in the creation of the synthetic 'beam' signal.	TBD	TBD	Per antenna, per frequency channel, per phase reference position

Parameter	Req. #	Value	Traceability
Continuous Parameter Application	CSP1052	The CSP shall continue to apply the last received configuration parameters until a new update is received.	[AD22]

The CSP must not assume that updates will be received at any specific cadence, including the indicated cadence or any other. The above requirement assigns full responsibility to the MCL system for ensuring the proper update of configuration parameters.

8.2.3 020.10.40.05.00-0114 CSP– Online Data Acquisition Interface Requirements

This interface supports the transmission of data and metadata generated by the CSP to the Computing and Software System (CSS, CI number 020.50.00.00.00), particularly the Online Data Acquisition subsystem (ONL, CI number 020.50.10.00.00) [AD23]. The CSS is responsible for further processing the data as needed for calibration and archiving. This interface describes both the physical and logical specifications.

Parameter	Req. #	Value	Traceability
CSP Data Physical Interface	CSP1035	The CSP physical interface with ONL shall follow the specifications in [AD23].	[AD23]
CSP Output Data Rate	CSP1036	The CSP average and maximum output data rate shall not exceed the limits in [AD23].	CON104 CON105 [AD23]
CSP Output Data Format	CSP1037	The CSP data output shall use the communications protocol and data format specified in [AD23].	[AD23]

8.2.4 020.10.40.05.00-0119 CSP–Central Fiber Infrastructure Interface Requirements

The elements of the CSP at a central facility receive data from the antennas via the Central Fiber Optic Distribution subsystem (FIB, CI number 020.55.20.00.00). This interface is expected to use industry standards allowing high data rate (>100 Gb/s per link), long distance (~100 km) communications. The CSP must account for common operational capabilities of such systems. This interface aims at defining the physical specifications, but the logical specification belongs to a separate interface between the DBE and the SBP. Note that this interface must also cover the physical specification between the FIB subsystem and the DBE in cases where the latter is located at the central facility (could be the case for the SBA).

Parameter	Req. #	Value	Traceability
Network Latency	CSP1038	The CSP shall support data transport delays of up to 250 ms with no additional correlation loss.	[AD24] SYS0502

Parameter	Req. #	Value	Traceability
Packet-Loss Tolerance	CSP1039	The CSP shall be tolerant of packet loss in communication of data from the antennas.	[AD24]
CSP Input Data Physical Interface	CSP1040	The CSP physical interface with FIB shall follow the specifications in [AD24].	[AD24]

The System Requirements' goal of connecting to other flagship capabilities states, "A minimum capability would provide the requisite delay buffers to accommodate the projected network delays to the GBT. A more capable implementation would have delay buffers to interface with Effelsberg and phased ALMA." Specific network latency required is still under assessment.

It is anticipated that the communication links from the antennas may incur data loss, particularly in long-distance links using third-party infrastructure. The CSP shall be tolerant of this data loss, meaning that it must be integrated into operation, by monitoring and reporting such events as will be determined in the future. CSP performance, however, will be impacted by data loss.

Note that the current parameter of 250 ms has been determined as a trade-off value between memory resources required at the CSP and the expected network latency when transmitting several hundred gigabits per second through commercial fiber from the outermost antennas. The uncertainty surrounding this requirement at the time of writing is significant, and this value may change in the future.

8.2.5 Legacy CSP–LO Reference & Timing Generation Interface Requirements

Many interface requirements are specific to a particular design. In the current CSP design concept, the CSP operates asynchronously with respect to ngVLA central time, eliminating the need for a frequency reference. Additionally, CSP time is solely utilized to determine when computations are performed or, equivalently, when data flows through the system. Therefore, only a coarse notion of central time within millisecond precision is necessary for the CSP, and this can be more cost-effectively achieved by leveraging an existing interface (CSP-MCL), rather than implementing an additional interface for time distribution. This may be based, for example, on the Precision Time Protocol. Consequently, there is currently no interface between the CSP and the RTG subsystem, and the related set of requirements has been withdrawn.

This set of requirements is kept herein for legacy purposes only and may be removed in future releases.

Parameter	Req. #	Value	Traceability
CSP Timing Interface	CSP1043	Withdrawn.	
CSP External Frequency Interface	CSP1044	Withdrawn.	

8.2.6 Legacy DBE Interface Requirements

The following requirements have been withdrawn as they are related to interfaces of the DBE other than the DBE-CSP interface. Traceability of related DBE retirements point now to the proper ICD.

Parameter	Req. #	Value	Traceability
Deterministic Input Data Buffer Latency	CSP1001	Withdrawn.	
IRD Data BER	CSP1002	Withdrawn.	

Parameter	Req. #	Value	Traceability
IRD Data Integrity	CSP1003	Withdrawn.	
IRD Data Clock Recovery	CSP1004	Withdrawn.	
IRD Data Modulation	CSP1005	Withdrawn.	
IRD Data FEC Encoding	CSP1006	Withdrawn.	
IRD Data Deserialization	CSP1007	Withdrawn.	
IRD Data Format	CSP1008	Withdrawn.	
DBE Power Interface	CSP1009	Withdrawn.	
DBE Shielding	CSP1010	Withdrawn.	
DBE Safety Monitoring	CSP1011	Withdrawn.	
DBE Dimensions	CSP1012	Withdrawn.	
DBE Thermal Load	CSP1013	Withdrawn.	
DBE RFI Emissions	CSP1014	Withdrawn.	
DBE Fastening	CSP1015	Withdrawn.	
DBE M&C Physical Interface	CSP1016	Withdrawn.	
DBE Monitor Data Rate	CSP1017	Withdrawn.	
DBE Configuration Data Rate	CSP1018	Withdrawn.	
DBE Monitor Parameters	CSP1019	Withdrawn.	
DBE Configuration Protocol	CSP1020	Withdrawn.	
DBE Fiber Interface	CSP1021	Withdrawn.	
DBE Input Data Rate	CSP1022	Withdrawn.	
DBE Output Data Rate	CSP1023	Withdrawn.	
DBE Timing Interface	CSP1041	Withdrawn.	
DBE External Frequency Interface	CSP1042	Withdrawn.	

Parameter	Req. #	Value	Traceability
DBE Normal Operation Temperature	CSP1048	Withdrawn.	
DBE Normal Operation Relative Humidity	CSP1049	Withdrawn.	

8.3 Safety and Security Requirements

This section defines all design requirements necessary to support the Level-1 Safety, Security and Cybersecurity requirements derived from [AD03], [AD07], and [AD08].

Parameter	Req. #	Value	Traceability
Safety Specification	CSP2001	The CSP shall comply with Safety Specifications [AD07].	[AD07] SYS2700
Security Specification	CSP2002	The CSP shall comply with Security Plan and Requirements [AD08].	[AD08] SYS2703
Cybersecurity Specification	CSP2003	The CSP shall be engineered and deployed in accordance with current best practices in IT Security, as defined by the NSF-funded Center for Trustworthy Scientific Infrastructure and the AUI Cyber Security Policy.	SYS2702

The above set of requirements serve as placeholders and will be developed in the future.

8.4 Reliability, Availability, and Maintainability Requirements

This section defines all RAM requirements and Logistic Support requirements derived from [AD03].

Parameter	Req. #	Value	Traceability
Safe Restart	CSP3001	All CSP sub-elements shall restore the Standby (Default) Mode in the event of network or power outages, or after a full power cycle, without human intervention.	SYS2304 SYS3114
Modularization	CSP3002	The CSP shall be modularized into Line Replaceable Units (LRUs) to facilitate site maintenance.	SYS2403
Self-Diagnostic Function	CSP3003	All CSP sub-elements shall incorporate self-diagnosis functions to identify faults based on recorded monitor data.	SYS2405
Configuration Monitoring	CSP3004	The CSP shall include monitoring and tracking of its configuration to the LRU level.	SYS2406
Engineering Console	CSP3005	The CSP shall include an engineering console to communicate system status and assist in real-time diagnosis at the LRU level.	SYS2407
Monitor Variable Data Rate	CSP3006	The CSP shall stream monitor data at variable rates (0.1 sec to 10 min) for automated use by predictive maintenance programs and for direct inspection by engineers and technicians.	SYS2408 SYS2409

Parameter	Req. #	Value	Traceability
Spares Planning	CSP3007	Failure analysis shall be used in the planning of spares inventory. Factors considered shall include the projected availability for spares, the time required to repair the failure, and the viability of critical vendors.	SYS3204
Operations and Maintenance: Transfer of Deliverables	CSP3008	All procedures, test equipment, and test software shall be delivered to the Operations and Maintenance staff prior to full operations.	SYS3211
Remote Updates	CSP3009	The CSP shall permit the update of individual LRU firmware and software to be performed remotely via a network connection.	SYS3223
Local Control	CSP3010	Withdrawn (applies only to DBE)	SYS3224
LRU Monitoring	CSP3011	All CSP LRUs shall provide on-board monitoring and diagnostics to determine the health and status of the unit.	SYS2701 SYS3101
Automated Failure Reporting	CSP3012	The Self-Diagnostic Function shall automatically log issues to the issue tracking database via the M&C system.	SYS3102 SYS3225 SYS3235 SYS3238
LRU Interchangeability	CSP3013	LRUs should be interchangeable with no on-site calibration, tuning, or alignment.	SYS3232
Electronic Identification	CSP3014	All LRUs shall have electronically identifiable (Bar Code, RFID tag or similar) Part Marking as defined in the Configuration Management Plan.	SYS3233
Identify Failures Physically	CSP3015	All LRUs shall identify a failed state via physical display (e.g., LED).	SYS3234
Report Predicted Failures	CSP3016	All LRUs, where possible, shall report fault prediction sensor data via the M&C system.	SYS3236
Failure Information Source	CSP3017	All LRUs shall report failure information in line with failure isolation as identified in a FMECA analysis.	SYS3237
Fast Read-Out Modes	CSP3018	Fast read-out modes shall be available for remote engineering diagnostics of all LRUs (i.e., an on-board oscilloscope function).	SYS3105
Hot Swaps of LRUs	CSP3019	The CSP shall be designed to accommodate and recover from hot swaps with minimal human interaction.	SYS3111
Preventive Maintenance	CSP3021	The CSP shall not require down time due to preventive maintenance. All preventive maintenance of the CSP shall be done while the CSP is operational, without interrupting observations.	SYS2603
EMI/RFI Compliance	CSP3022	Superseded by Section 8.2.1.	
DBE Mean Time Between Maintenance	CSP3023	Withdrawn.	SYS2610

CSP3018 is not aimed at scientific data but fast read out of monitor points. See [RD09] for further context.

The intent of CSP3021 is to require that preventive maintenance be done on a reduced number of LRUs, which can be taken out of operation during maintenance, while the rest of the CSP equipment remains operational. Additional sub-elements (e.g., SBP Units) may be installed as needed to guarantee minimum operational capabilities during maintenance.

CSP3023 applied only to the DBE and has been withdrawn from the set of CSP requirements.

Parameter	Req. #	Value	Traceability
CSP Availability and Reliability	CSP3020	The CSP MTBF shall exceed 4100 hours (11000 goal); with an MTTR of less than 12 hours. (TBC)	SYS2601 SYS2602 SYS2605 [AD10]

CSP3020 pertains to critical failures that render the CSP inoperable. However, individual node failures affecting antennas or bandwidth, which lead to a graceful degradation of CSP processing capabilities, will necessitate distinct considerations.

8.5 Configuration and Document Management Requirements

This section defines Configuration Management requirements and Documentation requirements, derived from [AD03].

Parameter	Req. #	Value	Traceability
Serial Numbers	CSP4001	All configuration items (e.g., LRUs) shall be uniquely identifiable to facilitate status and location tracking across the Observatory. Identification for LRUs shall be both visible and electronic.	SYS3600
Version Control	CSP4002	All custom software and firmware delivered as part of the system shall be version controlled via a configuration management process.	SYS3602
Configuration Retrieval	CSP4003	All configurable LRUs shall retrieve their software, firmware, and hardware parameter configuration automatically after installation.	SYS3603
As-Built Drawings	CSP4004	As-built drawings shall be provided for all custom hardware and facilities delivered as part of the system.	SYS6001
Operations and Maintenance Manuals	CSP4005	Operations and Maintenance Manuals shall be provided for each LRU in the system.	SYS6002
Units	CSP4006	Design materials and documentation shall use SI (metric) units.	SYS6003
Language	CSP4007	The language used for written documentation shall be English.	SYS6004
Electronic Document Format	CSP4008	Native, editable file formats of all documents and drawings of record shall be delivered, along with their PDF versions.	SYS6005

8.6 Life Cycle Requirements

This section defines the System Life Cycle requirements, including design and development, AIV, and CSV as derived from [AD03].

Parameter	Req. #	Value	Traceability
Design Life	CSP5001	The CSP shall be designed for an expected operational life of no less than 30 years.	SYS2801
Cost Optimization	CSP5002	The CSP shall be designed to minimize total life-cycle costs over the projected design life, extending through system decommissioning/disposal.	SYS2802
Sustainability	CSP5003	Sustainability and long-term environmental impact shall be considered in any material or design trade-study.	SYS2803
Part Selection for Maintainability	CSP5004	Individual component selection criteria shall include the projected continuity of support for the component or interchangeable equivalents over the system design life.	SYS2805
Critical Spares	CSP5005	CSP critical spares shall be identified and provided with sufficient inventory to support the facility for its operational life (CSP5001).	SYS2812
Packaging Supply	CSP5006	When applicable, shipping cases and packaging for transportation and storage of CSP elements in compliance with CSP9001 and CSP9002 shall be provided.	SYS3904 SYS3905 SYS3912
Quality Control of Deliverables	CSP5007	Stand-alone acceptance testing of software and hardware deliverables shall occur before delivery and installation on the array.	SYS3702
Test Fixtures	CSP5008	Test fixtures and procedures shall be provided for CSP level verification.	SYS2811
Testing of Software and Firmware	CSP5009	All software and firmware shall be delivered with automated unit, integration, and regression testing suites.	SYS2814
ICD LRUs	CSP5012	ICDs shall be delivered for each CSP LRU.	SYS2818
Incremental Delivery to Operations	CSP5013	Operational capabilities and modes shall be made available in stages during the transition from construction to full operations.	SYS2830

In System Requirements [AD03], operational life is defined to start at the full operations milestone and close-out of the construction project, and SYS2801 sets a duration of 20 years. However, the operational life of the CSP is defined to start with construction and commissioning activities, 10 years ahead of full operations.

Critical spares are defined as parts that are likely to be obsoleted over the operating life, are unlikely to have market substitutes, and cannot be produced/ordered in small volumes.

Parameter	Req. #	Value	Traceability
AIV Software Tools	CSP5010	Development tools, compilers, source code, and the build system shall be delivered in the form of preinstalled virtual machines, with all necessary licenses included for the lifespan of the telescope. These virtual machine disk images shall be archived with all documentation as Controlled Items.	SYS2815

The motivation to call for a virtual machine is to ensure compatibility and usability of the compilation chain over the life of the facility.

Parameter	Req. #	Value	Traceability
Electronics Specifications	CSP5011	All electronic components of the CSP shall be designed, manufactured, assembled, manipulated, shipped, installed, and maintained in compliance with System Electronics Specifications [AD09].	[AD09]

CSP5011 functions as a provisional framework for anticipated future needs. The goal is to implement consistent design standards and practices throughout the telescope. However, given the extensive use of Commercial Off-The-Shelf (COTS) systems and outsourcing by the CSP, strict adherence to these standards may result in an unjustified rise in costs. Consequently, CSP5011 and its associated requirements are subject to revision as a goal, rather than requirement.

9 Key Performance Parameters (KPPs)

Key Performance Parameters (KPPs) identify critical subsystem capabilities or characteristics that may either have a detrimental impact on the effectiveness of efficiency of the system if not met, or could have a very large positive impact if the specification is exceeded. Subsystem KPPs typically support System KPPs and there should be traceability between them. Each KPP must have a threshold range and objective value. The responsible engineer designs the subsystem to meet the objective value, but performance within the threshold range is considered acceptable. During the design phase, there should be a concerted effort to optimize the KPPs. If the responsible engineer finds that the minimum threshold level of a KPP cannot be achieved the project office shall be notified immediately.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Subarray Independence Objective value: Full independence Threshold range: Any dependency across subarrays	CSP0019	SYS0606 SYS0608

Full subarray independence is critical for ngVLA operations.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Per-Antenna Available Bandwidth Objective value: 20 GHz Threshold range: >14 GHz	CSP0008	SYS0903

Any limitation to the processed bandwidth should be informed to upper management.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Correlation Loss Objective value: 0.0% Threshold range: <0.6%	CSP0009	SYS1033 SYS1034 SYS1035

The current design concept allocates 0.6% correlation to the CSP, while the remaining 0.4% is assigned to the DBE. CSP0009 specifies the joint loss, so this KPP must be jointly monitored.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Beamforming SNR Loss Objective value: 0% Threshold range: <5%	CSP0032	SYS0208

This KPP has a direct impact on the system's sensitivity in Phased Array Operating Mode.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Pulsar Timing and Search SNR Loss Objective value: 0% Threshold range: <5%	CSP0042 CSP0068	SYS0309 SYS0406

This KPP has a direct impact on the system's sensitivity in Pulsar Timing and Search Operating Modes.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Timestamp Accuracy Objective value: 0 ps Threshold range: <10 ps	CSP0060	SYS2002 SYS2003 [AD10]

The timestamping accuracy of the CSP is deemed negligible when compared to the timing error budget of the ngVLA system. Any deviation from this assumption may impact the system's ability to meet dynamic range requirements, among other potential adverse effects.

Many CSP requirements are critical in the sense that the System relies solely on the CSP to satisfy a requirement. Therefore, if not met, they would have a significant impact on the system's effectiveness. Nevertheless, they have not been included as KPP as their satisfaction is not deemed at risk, and they do not support any system KPP. Future revisions may include additional KPPs based on updated risk assessment.

10 Verification

The design will be verified to meet the requirements by analysis (A), inspection (I), demonstration (D), or test (T), each defined below.

Verification by Analysis: The compliance of the subsystem to the requirement is demonstrated by appropriate analysis (hand calculations, finite element analysis, modeling and simulation, etc.).

Verification by Inspection: The compliance of the subsystem to the requirement is determined by a simple inspection of the subsystem or of its design documentation.

Verification by Demonstration: The compliance of the subsystem to the requirement is determined by a demonstration.

Verification by Test: The compliance of the subsystem to the requirement is determined by means of a test with and associated analysis of test data.

Multiple verification methods are allowed over the course of the design phase. The primary (final) verification method to be used for the product during the qualification phase prior to its Critical Design Review is identified below.

10.1 Verification Methods

10.1.1 Functional and Performance Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP0001	Interferometric Capabilities		*		
CSP0002	Beamforming Capabilities		*		
CSP0004	Reconfiguration Time	*			*
CSP0005	Standby Mode		*		
CSP0006	Connected Antennas		*		
CSP0007	Polarization		*		
CSP0008	Per-Antenna Available Bandwidth		*		
CSP0009	Correlation Loss	*			*
CSP0010	Longest Baseline		*		
CSP0011	Number of frequency channels		*		
CSP0012	Timing Accuracy		*		
CSP0013	Polarization Dynamic Range		*		
CSP0014	Commensal Signal Processors		*		
CSP0015	Self-Generated Spurious Signal Power Level	*		*	
CSP0016	Subarray Operation		*		
CSP0017	Number of Subarrays		*		
CSP0018	Simultaneous Subarray Capabilities		*		
CSP0019	Subarray Independence		*	*	
CSP0020	Subarray Reconfiguration		*	*	
CSP0021	Interferometric Bandwidth		*		
CSP0022	Interferometric Frequency Resolution		*		
CSP0023	Interferometric Variable Frequency Resolution		*		
CSP0024	Interferometric Time Resolution		*		
CSP0025	Interferometric Channel Flatness		*		
CSP0026	Interferometric Frequency Selectivity	*			
CSP0027	Interferometric Polarization Products		*		
CSP0028	Beamformer Aperture		*		
CSP0029	Number of Beams		*		
CSP0030	Beamformer Bandwidth per Beam		*		
CSP0031	Beamformer Field of View		*		

Req. #	Parameter/Requirement	A	I	D	T
CSP0032	Beamforming SNR Loss	*			*
CSP0033	Beamformer Polarization Correction		*		
CSP0034	Concurrent Interferometric Mode		*		
CSP0035	VLBI Support		*		
CSP0036	Stokes Parameters		*		
CSP0037	Dedispersion and Folding Capabilities		*		
CSP0038	Pulsar Engine Bandwidth		*		
CSP0039	Pulsar Engine Number of Beams		*		
CSP0040	Pulsar Engine Time Resolution		*		
CSP0041	Pulsar Engine Frequency Resolution		*		
CSP0042	Pulsar Timing SNR Loss	*			
CSP0049	RFI Mitigation		*		
CSP0050	Geometric Delay		*		
CSP0051	Delay and Phase Tracking Update Rate		*		
CSP0052	Sampler Clock Offset Support		*		
CSP0053	Delay and Phase Tracking SNR Loss	*			
CSP0054	Dispersion Measure Range		*		
CSP0055	Pulse Profile Bins		*		
CSP0056	Pulse Period		*		
CSP0059	Timestamped Data Products		*		
CSP0060	Timestamp Accuracy	*		*	
CSP0061	Amplitude and Delay/Phase Variations Accountability		*	*	
CSP0062	Interferometric Spectral Resolution Spacing		*	*	
CSP0063	Frequency Coverage	*			
CSP0065	Pulsar Timing Capabilities		*		
CSP0066	Search Capabilities		*		
CSP0067	Power Spectral Density Scale	*			
CSP0068	Search Mode SNR Loss	*			

10.1.2 Interface Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP1025	CSP Safety Monitoring				*
CSP1026	CSP Dimensions		*		
CSP1027	CSP Thermal Load				*
CSP1028	CSP RFI Emissions				*
CSP1029	CSP Fastening		*		
CSP1030	Backup Power Operation			*	
CSP1031	CSP M&C Physical Interface		*		
CSP1032	CSP Configuration Data Rate				*
CSP1033	CSP Monitor Parameters			*	
CSP1034	CSP Configuration Protocol			*	
CSP1035	CSP Data Physical Interface		*		
CSP1036	CSP Output Data Rate				*
CSP1037	CSP Output Data Format			*	
CSP1038	Network Latency			*	
CSP1039	Packet-Loss Tolerance			*	

Req. #	Parameter/Requirement	A	I	D	T
CSP1040	CSP Input Data Physical Interface		*		
CSP1045	CSP Immunity				*
CSP1046	CSP Normal Operation Temperature				*
CSP1047	CSP Normal Operation Relative Humidity				*
CSP1050	CSP Maximum Power Consumption				*
CSP1051	Configuration Parameters			*	
CSP1052	Continuous Parameter Application			*	

10.1.3 Safety and Security Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP2001	Safety Specification			*	
CSP2002	Security Specification			*	
CSP2003	Cybersecurity Specification			*	

10.1.4 Reliability, Availability, and Maintainability Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP3001	Safe Restart			*	
CSP3002	Modularization		*		
CSP3003	Self-Diagnostic Function			*	
CSP3004	Configuration Monitoring			*	
CSP3005	Engineering Console			*	
CSP3006	Monitor Variable Data Rate			*	
CSP3007	Spares Planning	*			
CSP3008	Operations and Maintenance: Transfer of Deliverables	*			
CSP3009	Remote Updates			*	
CSP3011	LRU Monitoring			*	
CSP3012	Automated Failure Reporting			*	
CSP3013	LRU Interchangeability			*	
CSP3014	Electronic Identification		*		
CSP3015	Identify Failures Physically			*	
CSP3016	Report Predicted Failures	*			
CSP3017	Failure Information Source			*	
CSP3018	Fast Read-Out Modes			*	
CSP3019	Hot Swaps of LRUs			*	
CSP3020	CSP Availability and Reliability	*			
CSP3021	Preventive Maintenance			*	

10.1.5 Configuration and Document Management Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP4001	Serial Numbers		*		
CSP4002	Version Control		*		
CSP4003	Configuration Retrieval		*		
CSP4004	As-Built Drawings		*		
CSP4005	Operations and Maintenance Manuals		*		
CSP4006	Units		*		

CSP4007	Language		*		
CSP4008	Electronic Document Format		*		

10.1.6 Life Cycle Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP5001	Design Life	*			
CSP5002	Cost Optimization	*			
CSP5003	Sustainability	*			
CSP5004	Part Selection for Maintainability		*		
CSP5005	Critical Spares		*		
CSP5006	Packaging Supply		*		
CSP5007	Quality Control of Deliverables		*		
CSP5008	Test Fixtures		*		
CSP5009	Testing of Software and Firmware		*		
CSP5010	AIV Software Tools		*		
CSP5011	Electronics Specifications		*		
CSP5012	ICD LRUs		*		
CSP5013	Incremental Delivery to Operations		*		

10.1.7 Environmental Requirements

Req. #	Parameter/Requirement	A	I	D	T
CSP9001	Packaging for Transportation		*		
CSP9002	Packaging for Storage		*		
CSP9003	Altitude Range			*	
CSP9004	Seismic Protection				*
CSP9005	Vibration protection				*
CSP9007	General Vibration				*
CSP9008	Mechanical Shocks				*

10.2 Verification Requirements

Req. #	Parameter/ Requirement	Verification Requirement
CSP0004	Reconfiguration Time (Analysis)	A reconfiguration flowchart and timing diagram showing compliance shall be provided.
CSP0004	Reconfiguration Time (Test)	The reconfiguration time for a predefined set of use cases shall be measured after CSP subsystem integration.
CSP0009	Correlation Loss (Analysis)	CSP Performance Analysis shall include a calculation of the correlation loss for the set of use cases specified in Table 3.
CSP0009	Correlation Loss (Test)	The correlation loss of the CSP for the set of use cases specified in Table 3 shall be measured after CSP subsystem integration.
CSP0015	Self-Generated Spurious Signal Power Level (Analysis)	CSP Performance Analysis shall include a calculation of the self-generated spurious signal power level.

Req. #	Parameter/ Requirement	Verification Requirement
CSP0015	Self-Generated Spurious Signal Power Level (Test)	The self-generated spurious signal power level of the CSP for a predefined set of use cases shall be determined by simulation.
CSP0026	Interferometric Frequency Selectivity	CSP Performance Analysis shall include a calculation of the interferometric frequency selectivity.
CSP0032	Beamforming SNR Loss (Analysis)	CSP Performance Analysis shall include a calculation of the beamforming SNR loss.
CSP0032	Beamforming SNR Loss (Test)	The beamforming SNR loss of the CSP for a predefined set of use cases shall be measured after CSP subsystem integration.
CSP0042	Pulsar Timing SNR Loss	CSP Performance Analysis shall include a calculation of the SNR loss incurred in Pulsar Timing operating mode.
CSP0060	Timestamping Accuracy (Analysis)	An analysis of the timing error sources, magnitude, and nature (systematic vs random).
CSP0068	Search Mode SNR Loss	CSP Performance Analysis shall include a calculation of the SNR loss incurred in Search Mode operating mode.
CSP1028	CSP RFI Emissions (Test)	Test as per [AD05].
CSP1050	CSP Maximum Power Consumption (Test)	Power consumption characterization in normal operation conditions
CSP9004	Seismic Protection (Test)	All LRUs must operate as per specifications after being subjected to the specified peak acceleration
CSP9005	Vibration Protection (Test)	All three axes as defined in the MIL-STD-810H Method 514.8 Procedure I for General Vibration, for a period of 60 minutes
CSP9007	Transportation Vibration Protection (Test)	All three axes as defined in the MIL-STD-810H Method 514.8 Procedure I for General Vibration, for a period of 60 minutes
CSP9008	Mechanical Shocks (Test)	MIL-STD-810H Method 516.8 Logistic Transit Drop Test

Table 3 – Set of use cases used for verification of Correlation Loss requirement CSP0009. More use cases may be added in future releases of this document.

Use Case #	Parameter/ Requirement
Case 1	White (flat spectrum) Gaussian signal and noise with moderate SNR (TBD), measured over the bandwidth of a subband.

11 Appendix

11.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
AIV	Acceptance, Integration, and Verification
ARCS	Advanced RF Containment System
ATF	Antenna Time and Frequency
BER	Bit Error Rate
BMR	Bins, Modules and Racks
CEB	Central Electronics Building
CI	Configuration Item
COTS	Commercial Off-The-Shelf
CSP	Central Signal Processor
CSS	Computing and Software System
DBE	Digital Back End
EIRP	Effective Isotropic Radiated Power
EMI	Electromagnetic Interference
FEC	Forward Error Correction
FIB	Central Fiber Optic Distribution / Infrastructure
FMECA	Failure Mode, Effects & Criticality Analysis
FRACAS	Failure Reporting, Analysis, and Corrective Action System
GPS	Global Positioning System
HVAC	Heating, Ventilation and Air Conditioning
ICD	Interface Control Document
I/Q	In-phase (I) and quadrature (Q)
IRD	Integrated Receivers and Digitizers
KPP	Key Performance Parameter
LBA	Long Baseline Array
LO	Local Oscillator
LRU	Line Replaceable Unit
M&C	Monitor & Control
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
MTTR	Mean Time to Repair or Replace
ngVLA	Next Generation Very Large Array
NSB	ngVLA Site Buildings
NRAO	National Radio Astronomy Observatory
ONL	Online Data Acquisition
OTF	On the Fly
PDR	Preliminary Design Review
PSE	Pulsar Engine
PTP	Precision Time Protocol
RD	Reference Document
RF	Radio Frequency
RFI	RF Interference

Acronym	Description
RTD	LO Reference and Timing Distribution
RTG	LO Reference and Timing Generation
SBA	Small Baseline Array
SBP	Subband Processor
SEU	Single Event Upset
SNR	Signal-to-Noise Ratio
SysML	Systems Modelling Language
TAI	International Atomic Time
TBC	To Be Confirmed
TBD	To Be Determined
UTC	Coordinated Universal Time
VDIF	VLBI Data Interchange Format
VLB	Very Long Baseline
VLBI	VLB Interferometry
XE	Crosscorrelation Engine

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