DSA-2000 Document No.

DSA-2000 System Design Description

Francois Kapp

Caltech

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Abstract

This document describes the high-level system design of the DSA-2000. It informs the lower-level design, incorporated in a series of subsystem designs, and elaborates the implementation of the system requirements, which in turn refines the science requirements.

# Introduction

The Deep Synoptic Array 2000, or DSA-2000, is a radio telescope array optimized for survey purposes. The array will consist of 2048 5m diameter dishes, which can instantaneously cover the 0.7 – 2 GHz frequency range and will span an area of 19 km × 15 km on a radio quiet site in a valley in Nevada. With near complete sampling of the uv-plane, it will be possible to use a real-time “radio camera” instead of a traditional digital correlator backend. During its five-year prime phase, the DSA-2000 will repeatedly image the entire viewable sky (~30,000 deg²) over sixteen epochs, detecting more than 1 billion radio sources. The data will be combined into a full-Stokes sky map with 500 nJy/beam RMS noise.

This document summarizes the top level (Level 1) design, with most of the design work occurring in the subsystems (Level 2), incorporated here by reference.

## Applicable Documents

The following documents are applicable to the extent stated in this document. In case of conflict between an applicable document and this document, the applicable document shall take precedence.

1. DSA-2000 Science Requirements, Version: PrePDR, D2k-00011-SYS-SPC
2. DSA-2000 System Requirements, Version: 1, D2k-00028-SYS-SPC
3. DSA-2000 Concept of Operations, Version 0.01, D2k-00003-PRJ-MGT
4. Survey Plan DSA-2000 Survey Implementation Plan (D2K-SIP), Version 2.8, D2k-00053-PRJ-OTH

## Reference Documents

The following documents are referenced in this document. In case of conflict between a reference document and this document, this document shall take precedence.

1. Hallinan, Gregg; Ravi, V.; et al. The DSA-2000 — A Radio Survey Camera
2. Selina, R.; Rao, U.; Bailes, M.; De Villiers, D. DSA-2000 Conceptual Design Review: Report from the Review Panel. Version 04: 05/12/2022
3. ArcGIS site for Spring Valley: <https://praxis.maps.arcgis.com/apps/instant/sidebar/index.html?appid=f686dbeef8414f1d97b26763143bd6af&locale=en>
4. Desert Research Institute Weather Station – North Spring Valley: <https://wrcc.dri.edu/weather/nnsv.html>
5. Uptime Institute Web Site: <https://uptimeinstitute.com/tiers>
6. Antenna Requirements: DSA-2000 Document No. 00031
7. Fabrication plan: DSA-2000 Document No. 00032
8. Design document for antenna mount: DSA-2000 Document No. 00036
9. Design document, solar power: DSA-2000 Document No. 00033
10. Conference presentation: Design of the DSA-2000 5m Diameter Antennas GASS2023 J04-4 AUG25.pdf
11. Memo: Specifying the wavefront errors for high accuracy widefield Mapping Antennas, DSA-2000 Document No. 00030
12. Memo: Dish FEA and Metrologyv2, DSA-2000 Document No. 00035
13. Analog Signal Path Design Document, DSA-2000 Document No. 00034
14. RCF Preliminary Design, DSA-2000 Document No. 00016
15. DAT Design, DSA-2000 Document No. 00012
16. RCP imaging pipeline design, DSA-2000 Document No. 00025
17. RCP computing hardware design, DSA-2000 Document No. 00051
18. PSR/FRB search subsystem design, DSA-2000 Document No. 00018
19. Monitoring and Control Design, DSA-2000 Document No. 00037
20. Observation Planner Design, DSA-2000 Document No. 00017
21. Timing and Synchronization: Preliminary Design, DSA-2000 Document No. 00045
22. DSA-2000 Fiber Infrastructure Preliminary Design, DSA-2000 Document No. 00057
23. Pulsar Timing Design, DSA-2000 Document No. 00026
24. Public Archive Requirements and Design, DSA-2000 Document No. 00013

## System Context

The context diagram for the DSA-2000 is shown in Figure 1. From the context, we identify external interfaces as well as work breakdown items. Important stakeholders, like the local community, do not interact with the system, but do interact with the site, and are therefore shown for completeness. Education and public outreach, ad site permitting are examples of activities that are designed to include the local community as much as possible from the early design of the system.

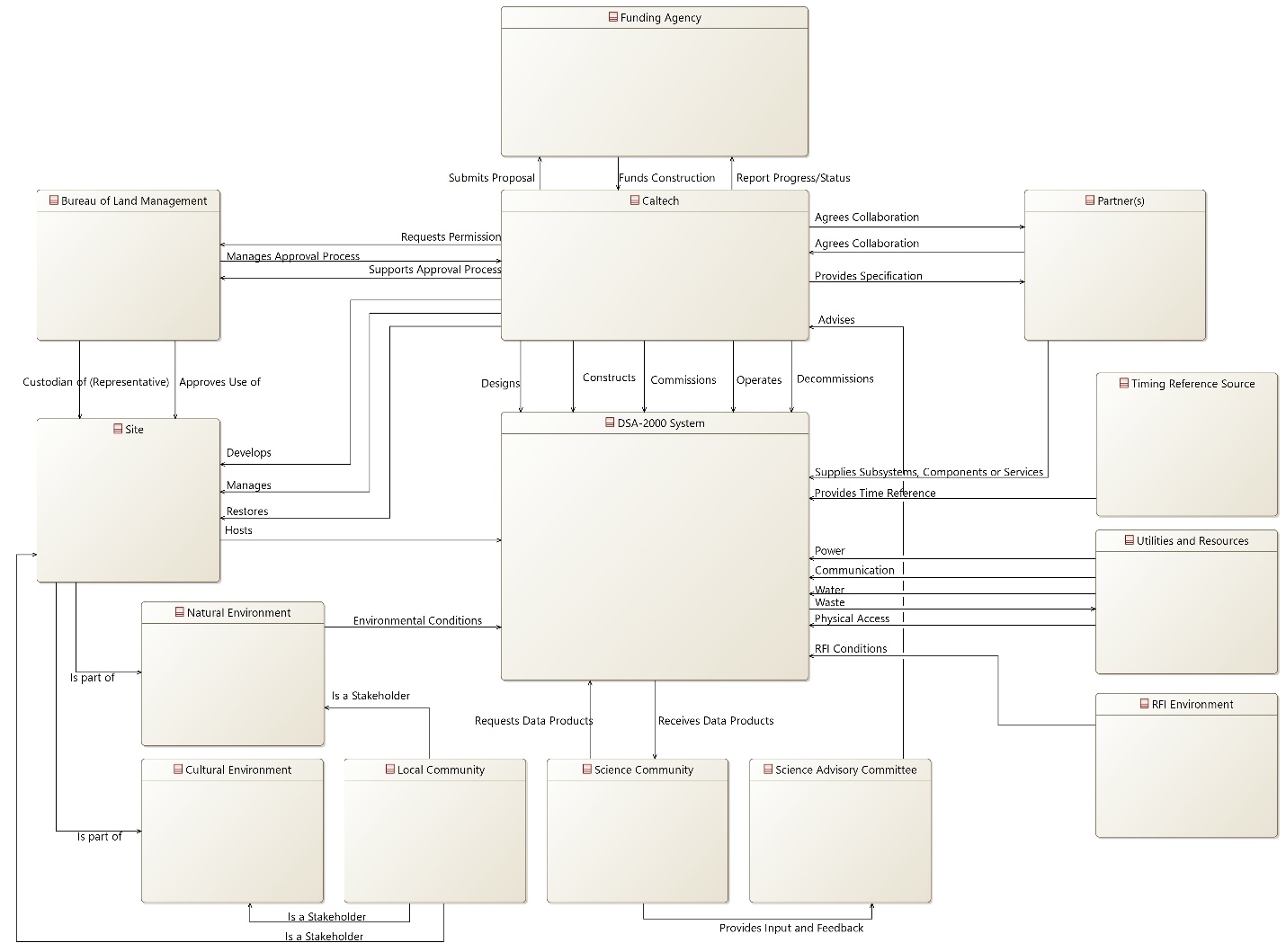


Figure : DSA-2000 Context diagram

## DSA-2000 Design Approach

The DSA-2000 is being designed using a risk-based approach. Technologies and subsystems that were novel and therefore riskier, were advanced prior to the formal top-down system engineering. In this way, the viability of key enabling technologies could be proven before committing large funding to the project. The team has the benefit of access to many experienced scientists and engineers with a broad understanding of the requirements for an instrument of this type. This means that there is a high level of system understanding, even at the subsystem level. Because of this, the design of the key enabling technologies were done so that they would be easy to integrate into an actual system. The project is now connecting the bottom-up and top-down work, to ensure that the integration of all subsystems can be managed within the budget and schedule. This process will continue into the Final Design Phase to ensure all requirements are met as the subsystem detail designs mature.

## DSA-2000 Lifecycle

The lifecycle phases of the DSA-2000 System are as follows:

1. Concept Design Phase (Completed with the conclusion of the Concept Design Review)
2. Technology Maturation Phase
3. Preliminary Design Phase (Concludes in a Preliminary Design Review)
4. Final Design Phase (Concludes in a Final Design Review)
5. Implementation Phase (Includes construction, engineering verification and commissioning)
6. Operational Phase
7. Decommissioning and Site Restoration Phase

Phases may overlap and boundaries between phases can be crossed. For example, activities in the Technology Maturation Phase will result in artifacts that are used in the Concept and Final Design Phases. Each of the phases are briefly elaborated below.

### Concept Design Phase

The Concept Design Phase commenced with the conceptualization of the instrument, documented in the Astro2020 APC White Paper (Hallinan, et al., 2019); and concluded with the Concept Design Review, which was documented in the panel report (Selina, Bailes, Rao, & De Villiers, 2022).

### Technology Maturation Phase

The Technology Maturation Phase is a project critical phase that overlaps with the both the Concept and Preliminary Design Phases. The intention behind this phase is to mature key enabling technologies – identified as Technology Drivers in (Hallinan, et al., 2019) – to the point where the major project risks related to these technologies are retired. The key technologies that are developed during this phase include:

1. The robust, low-cost azimuth/elevation antenna subsystem, including:
   1. The manufacturing system for the prime reflector
   2. The design of the complete antenna subsystem
2. The signal path, including:
   1. The wideband Low Noise Amplifier (LNA)
   2. The wideband feed covering the 0.7 – 2 GHz band
   3. The fiber transmitter and fiber receiver
3. The Radio Camera

The artefacts of this phase are typically captured in internal reports, papers, or memo’s, which are subsequently captured in the formal project documentation.

To support verification of these technologies, the Technology Maturation Phase includes two dedicated verification events:

* 1. The construction of a small-scale test array, called the DSA-2000 Test Array. The requirements for the test array will be a minimal subset of the requirements for the full array and explicitly capture ultimate design requirements as goals, with requirements set to match the development stage appropriate at the time of execution. The test array additionally serves as a development and evaluation platform and may be retrofitted repeatedly during development. Once the project proceeds to the implementation phase, the test array will be brought to production standard and used as a staging platform to test software systems, prior to production release. The test array therefore exists beyond the Technology Maturation Phase.
  2. The single node Radio Camera Processor prototype. This is a single node of the integrated Radio Camera Processor, running with simulated inputs.

The Technology Maturation Phase results in varying levels of product maturity across the system. The maturation of the technology requires a corresponding maturation of the products. An artefact of this, is that there are subsystems and components that are more developed than others. It is expected that this would be aligned with the perceived technology risk at the start of the project – higher risk elements were prioritized.

### Preliminary Design Phase

The Preliminary Design Phase formally starts at the conclusion of the Concept Design Phase and concludes in a Preliminary Design Review (PDR). Key project milestones that occur during this phase, are the submission of the MSRI-2 preliminary proposal, and the commencement of the environmental approval process.

During the Preliminary Design Phase, all products are defined and requirements for the system and subsystems are formalized, released, and controlled for the remainder of the project. A project execution plan, with associated work breakdown structure, project, schedule, budget, and risk register is developed and maintained for the remainder of the project.

### Final Design Phase

The Final Design Phase commences with the closeout of the Preliminary Design Review and concludes in a Final Design Review (FDR). Key project milestones during this phase are the environmental approval for construction and final funding proposal submissions.

By the conclusion of this phase, all design documentation for the system will be released and controlled.

### Implementation Phase

The start of the Implementation Phase is predicated on three key milestones:

1. The environmental approval to proceed

2. The funding approval/s to proceed

3. The closeout of the Final Design Review

While the actual implementation tasks can only be started during this phase, the Final Design Phase will provide the baseline for the Implementation Phase, which will be maintained and ultimately lead to an Operational Support Baseline (OSBL) – the formal start of the Operational Phase. The OSBL requires all as-built documentation, as well as the support systems and information needed to operate the system during the remainder of its lifecycle.

Prior to production, the system and any products that enter serial production will be subject to a Production Readiness Review (PRR). This review augments the FDR output with a review of the appropriate production plans.

### Operational Phase

The Operational Phase includes the actual operation of the instrument produced by the project, which will initially be guided by the Concept of Operations document and develop further. This phase also implements the Logistics Support Plan, which is produced during the Final Design Phase, released for review during the Final Design Review, and subsequently maintained and updated during the Implementation Phase to reflect the as built status accurately.

Routine and corrective maintenance commences when the first antennas are constructed and reaches full scale during the operational phase. This means that the Operational Phase overlaps with the Implementation Phase since the deployment of the array will take time. The maintenance done prior to the release of the OSBL will be useful to develop the maintenance plans to maturity.

### Decommissioning and Site Restoration Phase

At the end of the instrument life, it must be decommissioned, and the site restored to a natural state. Preparation and planning for this phase must be reviewed at all stage gates to ensure the design is compatible with the decommissioning and restoration plans that will be required by the Bureau of Land Management.

# System Requirements

The Requirements for the DSA-2000 are captured in D2k-00028-SYS-SPC-DSA-2000 System Requirements. That document also provides traceability to the science requirements.

# System design

## System Observations

The DSA-2000 will perform a diverse set of observations, as described in the science and system requirements. These are listed here – for definitions refer to the System Requirements:

1. Continuum Imaging
2. Zoom Band A Imaging
3. Zoom Band B Imaging
4. Pulsar Timing
5. Fast Time Domain - FRB Search
6. Fast Time Domain - Pulsar Search
7. Target of Opportunity

These observations will all run concurrently, with only Target of Opportunity and Directors Time as exceptions, since the pointings will be specific to the opportunity.

## Data Products

To capture the results of the observations above, the following data products will be produced and made available through a public archive:

1. Continuum Imaging Data Product
2. Continuum Polarization Imaging Data Product
3. HI Low resolution Data Product
4. Zoom band A (Extragalactic) Imaging Data Product
5. Band B (Galactic) Imaging Data Product
6. Extracted source catalogues
7. Pulsar Timing Data Product
8. Fast Transient Search Data Product
9. Fast Periodic Search Data Product

Definitions of the Data Products are captured in the System Requirements.

## System Modes and States

The DSA-2000 is designed for survey, and operation is highly automated. This allows a very simple implementation of system modes and states, as shown in Figure 2. When the system is in SURVEY Mode, where it is intended to be most of the time, all observations run commensally. SAFE Mode is used to deal with adverse environmental conditions – primarily strong wind, but also prolonged periods of low solar irradiation. MANUAL Mode is used for human Operators to control the system and is useful in Commissioning and Test. A DEGRADED State is defined when the telescope status does not meet the requirements to be available. A description of the modes and states and transitions is captured in

Table 1. In SURVEY and MANUAL Modes or in the DEGRADED state, it is possible to partition the array into up to 4 subarrays for engineering, maintenance, and test purposes. Modes and Commands are managed by the Monitoring and Control subsystem and must be adhered to by all on-site subsystems.

A diagram of a survey manual

Description automatically generated

Figure : The Modes and States of the DSA-2000

Table : DSA-2000 Modes and States Description

| State/Mode | Description | Entry Conditions | Exit Conditions |
| --- | --- | --- | --- |
| OFF State | In this state, power is unavailable from the grid, due to maintenance or a fault condition - internal or external to the system. The state can be commanded by an Operator, or automatically by the MNC, following detection of a power outage. Each subsystem will initiate shutdown prior to entering this state. Backup power from FAC will provide sufficient power for an orderly shutdown. Individual antennas may still be powered from their solar power stations and will enter a SAFE state after a timeout for communications. The system, prior to entering the OFF state will issue a notice to Operators and the Support Team. | 1. Power failure from any system condition detected by MNC, followed by a Shutdown Command issued to all system elements. 2. Shutdown Command issued by an Operator prior to a maintenance or other task that requires the OFF State, or for reasons of safety. 3. System failure leading to loss of power, from any mode. | 1. Operator Intervention to restore power. System will enter SAFE Mode. |
| SAFE Mode | The SAFE Mode is entered upon power-up, whenever environmental conditions trigger MNC to issue a SAFE Command (expected to be predominantly based on wind speed exceeding the antenna limit), or by command from an Operator. In this state, the antennas will all enter STOW, and processing by RCF and RCP will complete the current task and then become idle. DAT and ARC continue operating for as long as tasks are available. All subsystems will initiate self-test and report results to MNC. If the condition for entering SAFE Mode is cleared, MNC will return the system to the previous operational mode.  Any system updates will be performed with the telescope in SAFE Mode, after an Operator ensures that the system is in a suitable state for the update to be performed. | 1. Automatically when power is restored. 2. Automatically from any Mode or State if MNC detects environmental conditions outside the operating specification. 3. Manually from any powered Mode or State by an Operator issuing a SAFE Command. | 1. Automatically to the prior mode after the entry condition is cleared. 2. Manually to any mode or state by an Operator command, provided the system status is not degraded and the environmental conditions are favorable for the target mode. 3. Following power-up, automatically to SURVEY Mode, unless interrupted by an Operator, provided the self-test results and environmental conditions are available and favorable. |
| MANUAL Mode | In MANUAL Mode, the telescope can be operated by an Operator (on-site or remotely).  Manual Mode can only be entered by Operator Command, from SAFE, SURVEY or DEGRADED Modes/States. In this mode the telescope is entirely under manual control, although that includes scripted operation. This mode is anticipated to be used mostly for test, commissioning, debug, and potentially, customized observations. | 1. Manually from any powered Mode or State by an Operator issuing a MANUAL Command, provided the environmental conditions are favorable. The Operator Command will override self-test failures to allow debug of system problems. 2. Automatically from SAFE Mode after the entry condition is cleared, by command from MNC. (Only if the system was in MANUAL Mode prior to automated transition to SAFE Mode) | 1. Manually to any mode or state by an Operator command, provided the system status in not degraded and the environmental conditions are favorable for the target mode. |
| SURVEY Mode | SURVEY Mode is where the system is intended to spend the bulk of its operational life, with an automated series of surveys, managed by the OPL. In this mode, all functions operate under automated control and no human intervention is required, unless the system fails in a way that invalidates AVAILABLE status. | 1. Manually from any mode or state by an Operator command, provided the system status is not degraded and the environmental conditions are favorable. 2. Automatically from SAFE Mode after the entry condition is cleared, by command from MNC. (Only if the system was in SURVEY Mode prior to automated transition to SAFE Mode) 3. Following restoration of power, automatically from SAFE Mode, provided the system status is not degraded and the environmental conditions are favorable. | 1. Manually to any mode or state by an Operator command, provided the system status in not degraded and the environmental conditions are favorable for the target mode. 2. Automatically to SAFE Mode, if MNC detects environmental conditions outside the operating specification. 3. Automatically to DEGRADED Mode, by command from MNC, when the reported errors cross a defined threshold to be below the AVAILABLE limits as defined in the system requirements. |
| DEGRADED State | DEGRADED State is entered when the telescope has failures that mean it is not AVAILABLE as per the definition in the system requirements. It may be possible to perform a subset of observations, but the full commensal survey cannot continue. The OPL will determine if any observations are possible and continue with these, while flagging any data for observations that cannot continue. Entry into DEGRADED State will trigger notification of the maintenance team for intervention. | 1. Manually from any powered mode or state by an Operator command, provided the environmental conditions are favorable. 2. Automatically from any powered mode, by command from MNC, when the reported errors cross a defined threshold to be below the AVAILABLE limits as defined in the system requirements. | 1. Automatically to the prior mode if the system recovers from the error conditions sufficiently to meet the AVAILABLE limits. 2. Automatically to SAFE Mode, if MNC detects environmental conditions outside the operating specification. 3. Manually to MANUAL Mode, by Operator Command, to facilitate system test and debug. |

## Subsystem Definitions

The DSA-2000 system is decomposed into 14 subsystems, each with a person (Subsystem Lead) leading the development of the subsystem. The defined subsystems of the DSA-2000 are shown in Figure 3 and further elaborated in Table 2, as well as the remainder of this section of the document.

The system decomposition was driven by a combination of factors, including the functional breakdown, performance considerations, risk, procurement, implementation plans, expected cost and availability of personnel. Where no suitable person was available within Caltech to take on the role of Subsystem Lead, partnerships or contracts were entered into to ensure the right skills for the position. Given the skills and experience available in the subsystem lead group, a combined bottom-up/top-down approach is followed to mature the design expeditiously.

A diagram of a diagram

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Figure : DSA-2000 System first level decomposition into Subsystems

Table : DSA-2000 System Decomposition

|  |  |  |  |
| --- | --- | --- | --- |
| WBS Reference | Subsystem Acronym | Subsystem Name | Brief Description |
| 1.01 | AST | Antenna Stations | Each of 2048 Antenna Stations consists of an individual antenna with associated solar power system. The solar power system is optimized to support the availability of the antenna. Local Monitoring and Control at each AST is by an antenna controller – a single board computer that is connected to the MNC by the CNW.  The antenna also hosts electronics from the ASP, including the dual polarization feed, 2 Low Noise Amplifiers (LNA) and the drivers for the RF over Fiber links (in the Front-End Module). |
| 1.02 | ASP | Analog Signal Path | The Analog Signal Path includes the dual polarization feed, 2 LNAs and dual RF over Fiber links, which consist of a Front-End Module at the antenna, fiber patch cables and a Back-End Module in the Control Building. The Front-End Module contains filters to manage problematic RFI. The fiber between the antenna and the Control Building is part of Facilities. The ASP interfaces to the antenna and the Radio Camera Frontend. |
| 1.03 | RCF | Radio Camera Frontend | The Radio Camera Frontend receives the analog signals for both polarizations from all antennas via the ASP, converts it to digital, and then produces channelized output data products. This includes the channelized data for the Radio Camera Processor, as well as beam formed data for the Pulsar Timing. The output of the RCF is passed to the Radio Camera Processor and Pulsar Timing subsystems via the Signal Network. This processing is FPGA based, allowing for an efficient interface between the Analog to Digital Converters and the processing in the FPGAs. |
| 1.05 | RCP | Radio Camera Processor | The RCP is at the heart of the design of the DSA-2000. It is the deterministic imaging pipeline that accepts a set of channelized signal inputs from the RCF and processes this further to produce images. In contrast to more traditional radio telescope architectures, the RCP includes cross-correlation, flagging, calibration, gridding, and imaging. |
| 1.04 | DAT | Data Management | The data subsystem (DAT) is responsible for data management, data quality assurance, further processing of images and mosaics, and preparing data products for the Public Archive. Since the processing in the RCP is highly deterministic, and that of the DAT less so, DAT includes a data buffer to store data until it is science ready. |
| 1.06 | SNW | Signal Network | The high-speed Ethernet network that transports the digital signals through the telescope. The interfaces between RCF and RCP; RCF and PT, as well as RCP and DAT, are all carried through the SNW. |
| 1.07 | MNC (also MC) | Monitoring and Control | Central Monitoring and Control. Provides the means to control all control points and monitor and log all monitoring points as will be defined for each subsystem. MNC creates a framework that allows subsystems to expose monitor and control points, as well as log data. It is also capable of hosting microservices that automate low level operational aspects of the system. MNC interfaces with most on-site subsystems, including FAC for building management, weather station and RFI monitoring. MNC does not have a direct interface to ARC or SEQ. MNC controls the telescope modes. |
| 1.08 | OPL | Observation Planner | Fully automated observation planning, scheduling, and execution of the surveys. Interfaces to all relevant information to determine the best observations for an optimum survey. |
| 1.09 | CNW | Control Network | Low-speed Ethernet monitor and control network. |
| 1.10 | TS | Timing and Synchronization | Establish the time and frequency references for the telescope and provide the means to trace time back to a suitable standard. Distribute time for all time critical functions, including to the RCF, where data is timestamped for the first time. |
| 1.11 | SEQ | Support Equipment | All COTS or custom equipment directly required to operate and maintain the telescope on site. |
| 1.12 | FAC | Facilities | The infrastructure and buildings to host the telescope and connect it to all the required utilities. Also includes communication (backhaul fiber) and the on-site fiber network. |
| 1.20 | PT | Pulsar Timing | The hardware and software required to produce pulsar timing data products from the channelized, beam formed signals, received from the RCF. |
| 1.21 | ARC | Public Archive | The public facing interface to the telescope. Hosting of data products for access by the science community. Software, computing, and storage systems to serve science-ready data to science users, including the public. The archive is to be developed and managed by Caltech/IPAC; and will be hosted off-site. |

## Interface Identification

From the system context and breakdown described above, several external and subsystem interfaces are implied. A block diagram to support identification of subsystem interfaces is shown in Figure 4.

The sky signals, after being received and amplified, are transmitted to the Control Building via analog fiber links. Each antenna has two signal paths, for a total of 4096 analog signals. The full sky band (700 MHz to 2 GHz) is then sampled, phase aligned and channelized in the RCF, before being transmitted to the RCP via high-speed Ethernet network. For Pulsar Timing, the signals are also formed into 4 steerable beams before being transmitted to the PT subsystem to perform the timing processing. The RCP performs the calculations of visibilities, flagging, calibration, gridding, and imaging in a deterministic pipeline. The outputs of the RCP – single images – are then further processed by the DAT to create mosaics and perform quality checks before the science data products are sent to the off-site ARC. Monitor and control signals are carried on a separate network that interfaces to the endpoints with 1 Gigabit Ethernet – by copper (RJ45) connection when in the same rack, or SFP fiber modules appropriate for the distance of the connection. The distribution of MNC signals in the Array Area is done by Passive Optical Network (PON). This reduces the fiber count. Optical splitters are located in Nodes, distributed through the Array Area, and on average 12 antennas are served via a single fiber. The maximum distance of fiber from the Control Building to the furthest antenna is less than 20 km.

In the Control Building, the Data Center area hosts racks of computing equipment for all the on-site processing, using hot/cold aisle air management and front to back cooling. Power Management and Cooling (not shown in the diagram) are provided by the FAC subsystem. Power is backed up by UPS to allow graceful shutdown. The current estimates indicate that extended backup power would not be necessary to meet the availability requirement. Small backup generators will serve the Accommodation building and provide emergency power in case of an extended power outage.

Backhaul fiber will connect the Control Building to the outside world. The fiber will connect to the closest fiber route and from there a service provider will be selected to provide connectivity to the outside world.

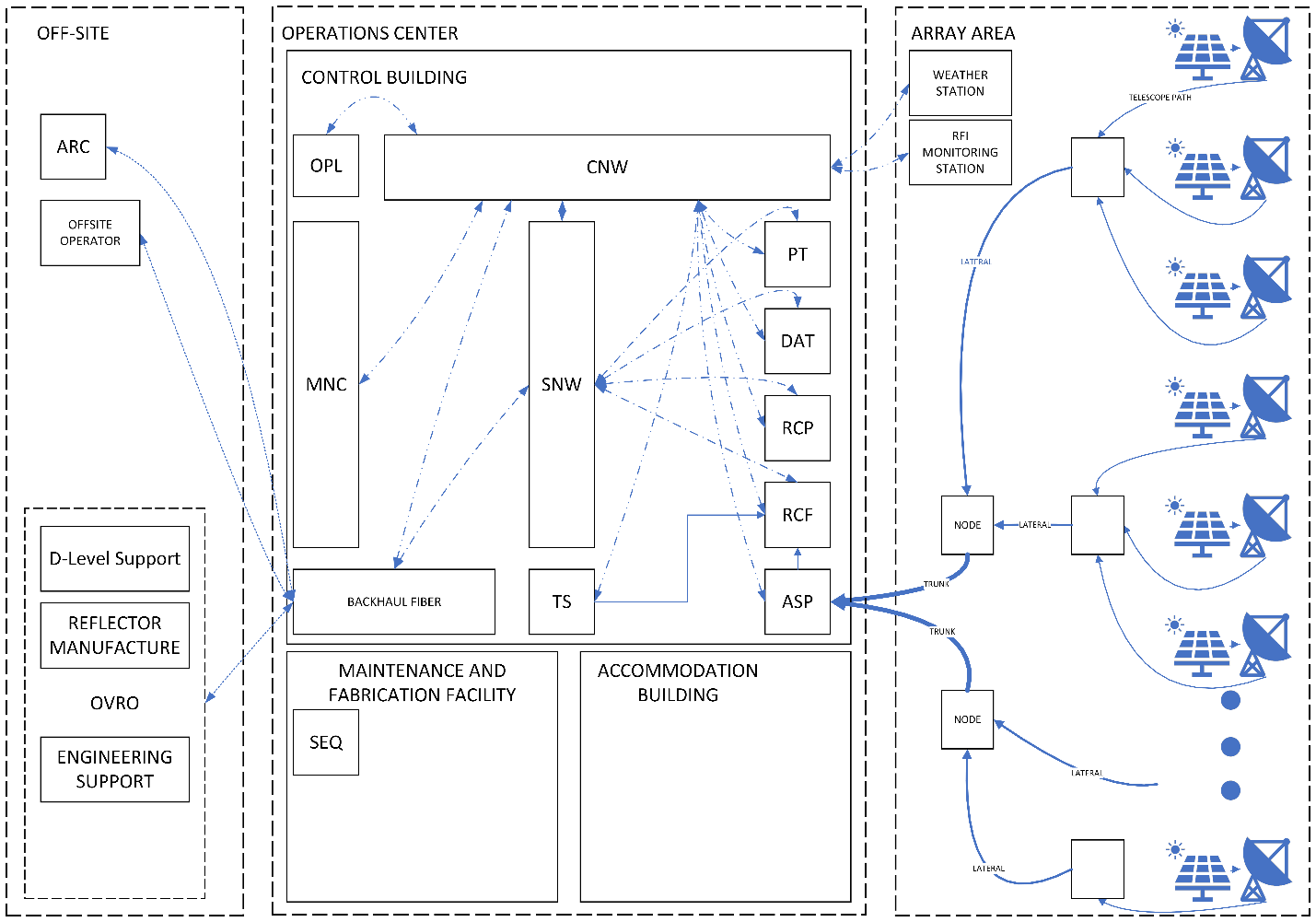


Figure : Identification of DSA-2000 interfaces

At the conclusion of the preliminary design phase, not all interfaces are fully defined. Key interfaces have preliminary interface control documents. A list of system interfaces is provided in Table 4 together with the status of documentation. Lead and Follow subsystems are defined by which takes the lead in developing the ICD, rather than any technical aspect of the interface itself.

Table : DSA-2000 External Interfaces Summary

| Document | Lead Subsystem | External Party | Description |
| --- | --- | --- | --- |
| D2k-00087-FAC-EXT-ICD | FAC | Site (Utilities and Resources) | This interface includes the connection to and supply of electricity, communications, water, physical access, and provision for the supply of Liquid Petroleum Gas (for heating and backup power); as well as the removal of waste (sewerage and garbage). |
| D2k-00088-TS-EXT-ICD | TS | Time Reference | This document describes how the system will interface to external providers of time referencing. This is now planned to be done using GNSS. |
| D2k-00089-MNC-EXT-ICD | MNC | Operators | This document describes how an operator would interface to the system. |
| D2k-00090-ARC-EXT-ICD | ARC | Science Community via the Public Archive | This document describes how a user would access the science data. |

Table : DSA-2000 Internal Interfaces Summary

| Document | Lead Subsystem | Follow Subsystem | Description |
| --- | --- | --- | --- |
| D2k-00060-AST-ICD | AST | ASP | The interface between the AST and the ASP, consists of a mechanical and power interface for the elements of the ASP that is hosted at the antenna, as well as relaying Monitoring and Control Data, which is transferred via Ethernet between the Antenna Controller and the MNC subsystem. The Antenna Controller will be selected to provide all the required low-level interfaces to connect to the elements of the ASP. |
| D2k-00061-AST-ICD | AST | FAC | AST interfaces to the site via the pedestal, and the rest of the system via the fiber network. Both the installation of the pedestal and the termination of the fiber network will be specified by the AST subsystem, with the work carried out under FAC.. |
| D2k-00065-ASP-FAC-ICD | ASP | FAC | ASP specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. Also includes the fiber penetration to the Control Building. |
| D2k-00066-RCF-FAC-ICD | RCF | FAC | RCF specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00067-RCP-FAC-ICD | RCP | FAC | RCP specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00068-DAT-FAC-ICD | DAT | FAC | DAT specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00069-TS-FAC-ICD | TS | FAC | TS specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00070-PT-FAC-ICD | PT | FAC | PT specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00071-SNW-FAC-ICD | SNW | FAC | SNW specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00072-CNW-FAC-ICD | CNW | FAC | CNW specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00073-OPL-FAC-ICD | OPL | FAC | OPL specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00074-MNC-FAC-ICD | MNC | FAC | MNC specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. In addition, this interface deals with the monitor and control of the buildings, including power, cooling and any other facilities that require automated monitoring or control. |
| D2k-00075-SNW-FAC-ICD | SNW | FAC | SNW specific power, mechanical, interconnect and cooling interface requirements with the standard racks provided by FAC. |
| D2k-00076-FAC-ICD | FAC | General | Generic Data Center power, mechanical, interconnect and cooling interfaces and standards. |
|  | MNC | All on-site | The MNC interfaces to all on-site subsystems and the outside world for remote monitoring and control. To enable this, a set of generic Interface Control Documents were created, which describe the basic mechanisms common to all subsystems. Each subsystem must then augment the generic document with the details of control and monitoring points, logging requirements and any additional interface details as required. The generic interfaces are listed below: |
| MNC ICD Authorization Database to Authorization Interface: DSA2k-00038-MNC-ICD |  |  | The interface to the Authorization Database, used to authorize users or services. |
|  |  |  |  |
| MNC ICD: Distributed Key Value Store (EtcdI) to DSA-2000 Distributed Key Value Store Instance: DSA2k-00039-MNC-ICD |  |  | The interface between the Open Source Distributed Key Value Store 'etcd' and the DSA-2000 Distributed Key Value Store Instance (DKVSI). The interface is used to protect higher level code from implementation changes by providing a guaranteed interface. |
| MNC ICD: DKVSI and the Distributed Key Value Store Horizontal Scaler Interface (DKVSHSI): DSA2k-00040-MNC-ICD |  |  | The interface between DKVSI and the Distributed Key Value Store Horizontal Scaler, which provides horizontal scaling to achieve the reach for all system elements connected to MNC. |
| Generic minimal interface between any subsystem and DKVS Horizontal Scaler Interface (DKVSHSI) interface: DSA2k-00041-MNC-ICD |  |  | The minimal interface between any subsystem and the DKVS Horizontal Scaler. It is used to pass the minimally required set of monitor data into the MNC subsystem and provides the minimal set of commands each subsystem is required to handle. |
| MNC ICD Logging to Subsystem Interface: DSA2k-00042-MNC-ICD |  |  | The logging interface for all subsystems. The interface is used to allow logs to be aggregated onto a central server and to allow changing log verbosity via commands through MNC. |
| D2k-00076-AST-MNC-ICD | AST | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00077-ASP-MNC-ICD | ASP | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00078-RCF-MNC-ICD | RCF | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00079-RCP-MNC-ICD | RCP | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00080-DAT-MNC-ICD | DAT | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00081-TS-MNC-ICD | TS | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00082-PT-MNC-ICD | PT | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00083-SNW-MNC-ICD | SNW | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00084-CNW-MNC-ICD | CNW | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00085-OPL-MNC-ICD | OPL | MNC | The subsystem specific part of the interface to the MNC. Physical connectivity is by CNW on 1 Gigabit Ethernet. |
| D2k-00062-ASP-ICD | ASP | RCF | The 2x2048 analog signals, after conversion from optical to electrical, will be carried from the ASP to the RCF. It is assumed that blind mate connectors can be used for this interface to eliminate cabling. |
| D2k-00019-RCF-ICD-RCF\_RCP | RCF | RCP | The interface between the RCF and RCP subsystems. Used to transfer high data rate (∼ 1013 bits/s) digital, channelized voltages from all antennas in the DSA array to the RCP processing nodes. Physical connectivity is provided by the SNW - a large (∼ 1000-port) 100 Gb/s Ethernet network. As such, using the terminology of the OSI (open systems interconnection) model, this ICD concerns itself with communication layers 4 and higher. |
| D2k-00063-RCF-ICD | RCF | TS | The interface between the TS and RCF to provide timing and synchronization. |
| D2k-00064-RCF-ICD | RCF | PT | The interface between the RCF and PT subsystems. Used to transfer high data rate digital, channelized, beam-formed voltages from RCF to the PT processing nodes. Physical connectivity is provided by the SNW - a 100 Gb/s Ethernet network. As such, using the terminology of the OSI (open systems interconnection) model, this ICD concerns itself with communication layers 4 and higher. |
| D2k-00023-DAT-ICD | DAT | RCP | The interface from the RCP DAT. High-speed, with sustained data rates and latency requirements. This interface is carried on the high-speed Ethernet network provided by SNW. |
| D2k-00022-DAT-ICD | DAT | ARC | The mechanism for moving data from the on-site post-processing system to the off-site public archive. The interface centers on the concept of a “suitcase” of data, which may be transferred via fiber or shipped disks. |
| Note 1 | ASP | ASP | The series of interfaces between the antennas and subsequent processing is all contained within the ASP subsystem. For this reason, there is no system level ICD for it. The technique and performance of the transfer of signals is a subject for the subsystem design. These interfaces are critical to the performance of the telescope, and therefore listed here, but addressed within the subsystem. |

# Subsystem Designs

## Antenna Stations

The Antenna Stations design is described in the following documents and artefacts:

1. Requirements: D2k-00031-AST-REQ Antenna Requirements [6]
2. Fabrication plan: D2k-00032-AST-OTH Antenna Fab [7]
3. Design document for the mount: D2k-00036-AST-DES Antenna Turnhead and Mount Design [8]
4. Design document, solar power: D2k-00033-AST-DES Antenna Solar Power Module V2 [9]
5. Conference presentation: Design of the DSA-2000 5m Diameter Antennas GASS2023 J04-4 AUG25.pdf [10]
6. Memo: D2k-00030-AST-DES Specifying the wavefront errors for high accuracy widefield Mapping Antennas.pdf [11]
7. Memo: D2k-00035-AST-PRG Dish FEA and Metrologyv2.pdf [12]

## Analog Signal Path

Refer to the Analog Signal Path Design Document, document D2k-00034-ASP-DES [13].

## Radio Camera Frontend

Refer to the RCF Preliminary Design, document D2k-00016-RCF-DES [14].

## Data Management

Refer to the DAT Design, document D2k-00012-DAT-DES [15].

## Radio Camera Processor

Refer to the RCP imaging pipeline design, document D2k-00025-RCP-DES [16], RCP computing hardware design, document D2k-00051-RCP-DES [17], and the PSR/FRB search subsystem design, document number D2k-00018-RCP-DES [18].

## Signal Network (SNW)

The Signal Network is based on commodity Ethernet communications equipment and is envisaged to be mostly a procurement exercise. The subsystem will be specified in terms of number and distribution of ports, link ranges, supported protocols, data rates, latencies, subsystem availability, form factor, power constraints, cooling, and interfaces in a procurement specification during the Final Design Phase.

Since the Signal Network is constrained to the Data Room in the Control Building, no long-range links are required, but the Data Room will contain space for 140 racks of equipment in a 400m2 space, therefore short-range fiber interconnect will be needed.

## Monitoring and Control (MNC)

Refer to the Monitoring and Control Design, document D2k-00037-MNC-DES [19].

## Observation Planner (OPL)

Refer to the Observation Planner Design, document D2k-00017-OPL-DES [20].

## Control Network (CNW)

The Control Network is based on commodity Ethernet communications equipment and is envisaged to be mostly a procurement exercise. The subsystem will be specified in terms of number and distribution of ports, link ranges, supported protocols, data rates, latencies, subsystem availability, form factor, power constraints, cooling, and interfaces in a procurement specification during the Final Design Phase. The CNW extends from the Control Building to all antennas and forms a part of the interface of all subsystems with then MNC. The connection to the ASTs and other elements in the Array Area is via Passive Optical Network (PON). The PON reduces the fiber and port count. Up to 16 AST’s could be connected to a single fiber through a splitter. In practice, the fiber design achieves an average reduction ratio of 12 and we will make provision for 200 ports on the CNW facing the Array Area.

The CNW will be distributed as top-of-rack switches in all the subsystems that require multiple ports per rack. Within each rack, 24 1 GbE ports are provided (24 port switches are currently the most economical option that will meet all requirements). The top-of-rack switches aggregate links onto 10GbE for connection to switches mounted in the MNC racks. The 10GbE links are provided on SFP ports, which allow low-cost, intermediate range optical transceivers to be used for interconnect.

A breakdown of the switch and port count is shown in Table 5.

The uplink ports are aggregated in 5 24 port 10GbE switches and one 20 port 40GbE switch. MNC will interface to the 40GbE switch.

Table : Control Network Port/Switch Count

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Subsystem | Required 1 GbE Ports | 10 GbE Uplink Ports | Number of Switches | Available 1 GbE Ports |
| AST | 200 | 10 | 10 | 240 |
| ASP – none, included with AST and RCF |  |  |  |  |
| RCF | 211 | 27 | 27 | 648 |
| RCP | 530 | 67 | 67 | 1608 |
| DAT | 27 | 13 | 13 | 312 |
| MNC | See Text |  |  |  |
| OPL | 3 | 1 | 1 | 24 |
| TS | 2 | 1 | 1 | 24 |
| FAC | 6 | 1 | 1 | 24 |
| External | 1 | 0 | 0 | 1 |
| **Total** | **980** | **120** | **120** | **2881** |

Since it is based on commodity hardware and industry standards, the interfaces can assume these standards for the lower levels and specify the higher layers only. During the Final Design Phase, dedicated reference design and procurement specification documents for the CNW will be produced.

## Timing and Synchronization

Refer to Timing and Synchronization: Preliminary Design, DSA-2000 Document No. 00045 [21], as well as referenced memos.

## Support Equipment

The support equipment is currently specified as follows:

1. Staff Tools (the tools required by on-site staff to perform their daily duties)
   1. Computers (one per staff member, replaced on a three-year cycle)
   2. Mechanical Tool Kits (one per technician, individual tools maintained)
   3. Electrical Tool Kits and handheld test equipment (one toolkit and multimeter per technician). Portable OTDR, Oscilloscope, Spectrum Analyzer and Network Analyzer per team.
2. Special Tools – currently a budgetary placeholder to accommodate any special jigs identified during final design and required for maintenance of antenna stations or other distributed system elements.
3. Vehicles
   1. 2 x Antenna Assembly Vehicles – off-road capable to access the entire site during implementation. One to be retained in case an antenna needs to be removed from its mount for maintenance.
   2. 4 x ATV’s – off-road capable to access the entire site routinely.
   3. 4 x Site Trucks – off-road capable to access the entire site if required.
4. A transportable antenna test bench that can be used to verify basic antenna operation and performance following major maintenance.

## Facilities

### Fiber network

Each antenna will transmit the analog signals for two polarizations back to a Control Building via Radio Frequency over Fiber (RFoF) links. Each antenna will also be connected to the Control Network via a fiber connection. In total, each antenna requires three fibers. The control network to the antennas is multiplexed – optionally in the time or frequency domain – which reduces the total fiber count and resulting cost. The fiber network design is advanced and documented in the Fiber Infrastructure Preliminary Design, DSA-2000 Document number 00057 [22]. The fiber design, site location and layout are also captured in an ArcGIS database (see reference [3]).

### Site Buildings

A conceptual layout of the buildings in the preferred location is shown in Figure 5. In this sketch, the camera is positioned to the northeast of the buildings, with the array extending to the east. The arrow in the sketch points to the north. The buildings are planned in an old disused quarry site, to reduce new ground disturbance. An existing 24kV power line runs along a road that passes close to the location. There are three site buildings planned: a Control Building (shown with a light-colored roof), a Fabrication and Maintenance Building (shown with a red roof), and an Accommodation Building (shown with a brown roof). An area around the buildings will be paved to reduce dust. Parking for 19 vehicles and a laydown yard is also planned. A plan view of the site layout is shown in Figure 6.

Two aspects that are designed to reduce the risk of RFI is that the data center is located in the basement of the Control Building, and a berm is to be created between the site building and the array to provide additional RFI shielding.

A building with a parking lot

Description automatically generated

Figure : Site Building Conceptual Layout

A blueprint of a building

Description automatically generated

Figure : Plan view of site building layout

#### Control Building

The Control Building will host, and the design is dominated by, the processing facility in a data center designed according to Tier 1 as defined by the Uptime Institute. The Uptime Institute [5] defines Tier I as follows:

*“A Tier I data center is the basic capacity level with infrastructure to support information technology for an office setting and beyond. The requirements for a Tier I facility include:*

*An uninterruptible power supply (UPS) for power sags, outages, and spikes.*

*An area for IT systems.*

*Dedicated cooling equipment that runs outside office hours.*

*An engine generator for power outages.*

*Tier I protects against disruptions from human error, but not unexpected failure or outage. Redundant equipment includes chillers, pumps, UPS modules, and engine generators. The facility will have to shut down completely for preventive maintenance and repairs, and failure to do so increases the risk of unplanned disruptions and severe consequences from system failure.”*

While the use of the Uptime Institute definition is useful, certification of the data center is not required. A Tier 1 data center is expected to be available 99.671% of time. For the DSA-2000 we apply this requirement to the data center infrastructure only, and allocate different availabilities to the individual subsystems as described in section 5.

The rack space calculation is based on standard 42u high racks, 600mm wide by 1200mm deep. The rack count is based on current subsystem estimates as follows:

1. RCF, PT and TS: 27 racks total (See RCF Design Document for detail)
2. RCP:
   1. Imaging: 380 x 4u servers, 8 per rack = 48 racks
   2. Fast Time Domain: 150 x 4u servers, 8 per rack = 19 racks
3. DAT:
   1. Compute: 15 x 2 u servers, 1 rack
   2. Storage: 12 racks
4. OPL: Dual redundant servers, 1 rack allocated
5. MNC: 2 racks
6. SNW: Distributed
7. CNW: Distributed + 1 rack for Array Area facing ports
8. Backhaul Fiber/Communications: 1 rack
9. Facilities/Building Management: 1 rack

Total rack count: 113

The primary constraint on the rack layout is the need to limit cabling from the antennas to the RCF and MNC. All these signals are on fiber. A secondary consideration is to limit the intra-rack cabling. Based on these priorities, the RCF racks were placed on one side of the Data Center, arranged in rows of 14 racks. This allows all the RCF racks to be placed in two rows. To fit in 113 racks would then require a total of 9 rows, but to keep room for expansion, and to allow for an even number of rows to simplify the hot/cold aisle containment, the design is for 10 rows, which would allow up to 140 racks to be installed. A sketch of this layout is shown in Figure 7. Note the hot aisle containment between rows of racks. Cooling units will be installed against the walls on the margin (2.4m), allowing ample space. The UPS system will be installed in an adjacent room. The Data Center, including the UPS room and the cooling system will be contained in an EMC shielded area to prevent RFI.

A row of black rectangular objects

Description automatically generated

Figure : Data Center Rack Layout

The worst-case power consumption is for the imaging servers, each with a power envelope of 2.7kW. Actual power consumption will be lower than that, but with 8 servers in a rack, the per rack power consumption will still reach close to 20kW, which is challenging for pure air cooling. We are planning a hybrid water/air cooling system to address this. The rack power envelope for pure air cooling design is 10kW per rack, which is appropriate for the RCF racks. The total power envelope is 2 MW, with 200 kW of that budget allocated to the solar powered antenna stations. While the power budget is still expected to mature during the final design phase, estimating the power and cooling requirements based on 2 MW is a conservative approach at the conclusion of the preliminary design phase. This would also allow ample cooling capacity to deal with other heat sources, like the UPS, lighting, and people.

Adding a 2 MW UPS with batteries in a separate room, with space allowed for fire suppression, and a 2 MW hybrid cooling system distributed along the one side of the facility, completes the layout for the Data Center as shown in Figure 8. Not shown in the image, are the underfloor cooling air and water distribution (600 mm space) and the electrical and fiber cable management systems above the racks. Since the connections to the Array Area are all fiber, with no electrical penetrations, the filtering is limited to the incoming power on the side of the UPS, which will also face away from the Array Area. The resulting floor area is 520 m2. This is assumed to be the basement floor of the Control Building. The control room, labs, meeting rooms and supporting spaces will make up the top floor.

In the preferred location, we have identified a quarry, which would be an ideal place to locate the buildings. The ground is already disturbed, leading to minimal environmental or cultural concern. The depression will allow the building to take advantage of additional RFI attenuation from the terrain.

A diagram of a computer chip

Description automatically generated

Figure : Data Center Layout

#### Fabrication and Maintenance Building

The Fabrication and Maintenance Building will be the facility where antenna integration happens in the Implementation Phase, then become the workshops and stores during Operations. The building will be sized to accommodate sufficient antenna components to provide a buffer in times of bad weather, when the Array Area may not be accessible. We estimate a building of 900 m2 would be conservative. The building will be located adjacent the Control Building, but away from the Array Area, as it will not be fully shielded, and it is likely that welding and other noise generating activities will be carried out here occasionally.

#### Accommodation Building

The Accommodation Building will provide overnight facilities. During Construction and Commissioning, this will be used by the engineering team members for short stays. Security staff will also use this while working shifts. During Operations, it is intended that the building will provide kitchen facilities, with on-site accommodation becoming less frequent. The facility will be maintained to serve as emergency accommodation and for times when night work is required, as well as for on-going security use. The total capacity of the Accommodation Building would be for 15 people to sleep there in a combination of single and shared rooms.

### Weather Station

A weather station will be deployed to control the measure the environmental conditions – particularly wind strength. The location of the weather station is still to be determined, but since there is a publicly accessible weather station operated by the Desert Research Institute [4] in the preferred location, towards the western side of the valley, it would likely be more useful to place the DSA-2000 weather station closer to the center of the array. The weather station will access fiber through the same mechanism as the antennas and will operate on solar power too. Commercially available weather stations will be evaluated for RFI prior to making a build vs buy decision.

### RFI Monitoring Station

An RFI Monitoring Station will be deployed to perform continuous long-term monitoring of the local RFI environment. If problematic in-band interferers are detected, it would also be possible to use a subset of the array to localize the source.

## Pulsar Timing

Refer to the Pulsar Timing Design, document D2k-00026-PT-DES [23].

## Public Archive

Refer to the Public Archive Requirements and Design, document D2k-00013-ARC-DES [24].

# Logistics

The logistics support of a system the scale of DSA-2000 becomes an important part of the design. Here we briefly describe the process to date and what will follow during the Final Design Phase. During the Final Design Phase, these concepts will be developed into a standalone Logistics Support Plan.

## Availability Analysis

The overall availability of the telescope is specified in terms of sensitivity and bandwidth in the following requirements:

* SysR-0033 Availability The DSA-2000 shall be available for observation and/or calibration > 80% of time during its operational life. Lost time includes scheduled and unscheduled maintenance, loss of performance due to RFI, power loss, weather stow and any other cause of system unavailability.
* SysR-0034 Usable Bandwidth The DSA-2000, when available, shall have a usable bandwidth of > 65%. Usable bandwidth is defined to be the fraction of channels over the Frequency Range where the noise is < 1.5 times the thermal noise.
* SysR-0035 Usable collecting area The DSA-2000, when available, shall have > 97% of the total array collecting area available and fully operational throughout the processing pipeline.
* SysR-0036 System Lifetime The DSA-2000 shall be designed for an operational lifetime of 20 years (TBC), with a goal for all non-wear mechanical components of 40 years.

These requirements were used to perform a preliminary availability analysis, which in turn was used to allocate availability per subsystem. The results are shown in Table 6.

Radio Frequency Interference (RFI) impacts the availability of the system as well. The impact of RFI is summarized in Table 7.

Table : Availability Allocation to Subsystems

|  |  |  |  |
| --- | --- | --- | --- |
| Reference | Subsystem Acronym | Allocated Availability | Rationale |
| 1.01 | AST | 90% | Limited by solar power, maintenance, and large number of antennas |
| 1.02 | ASP | 98.4% | Even distribution among subsystems for preliminary design |
| 1.03 | RCF | 98.4% | Even distribution among subsystems for preliminary design |
| 1.04 | DAT | 98.4% | Even distribution among subsystems for preliminary design |
| 1.05 | RCP | 98.4% | Even distribution among subsystems for preliminary design |
| 1.06 | SNW | 99.99% | Specified to supplier |
| 1.07 | MNC | 98.4% | Even distribution among subsystems for preliminary design |
| 1.08 | OPL | 100% | Human Backup |
| 1.09 | CNW | 99.99% | Specified to supplier |
| 1.10 | TS | 98.4% | Even distribution among subsystems for preliminary design |
| 1.11 | SEQ | N/A | Support Equipment has only a secondary effect on availability |
| 1.12 | FAC | 99.671% | Tier 1 (lowest) data center availability |
| 1.20 | PT |  | Even distribution among subsystems for preliminary design |
| 1.21 | ARC | N/A | The system can absorb downtime from the Archive without impact to the observing schedule, provided the on-site buffers do not get full. |
| SYS | System | 80.1% | This will be refined as the subsystem numbers mature. It is expected that some subsystems will easily exceed their allocations, which will then be moved to the subsystems where it is more challenging. |

Table : RFI Levels, Definition, Impact and Probability

|  |  |  |  |
| --- | --- | --- | --- |
| RFI Level | Definition | Impact | Expected % of time |
| 4 | Extreme RFI Levels (above damage level) | System Damage. The most likely component to be damaged due to high RFI levels is the Low Noise Amplifier in the ASP. Measured results indicate a damage level of XX dBm at the input to the LNA. | Extremely unlikely to occur during the operational life of the DSA-2000 |
| 3 | Very High RFI Levels. | Periods of activity where transmissions cause non-linearity in the signal chain (e.g. ADC saturation) with a high duty cycle that cannot be excised in real-time from the data. Result is total data loss. | The system will be designed to limit total signal loss to << 1% of time. Current RFI measurements indicate that this should be achievable without compromise in the preferred location. |
| 2 | High RFI Levels. | Periods of activity where transmissions cause non-linearity in the signal chain (e.g. ADC saturation) with a low duty cycle (e.g. certain types of pulsed radar) that can be excised in real-time from the data. Observations continue with medium impact. Result is partial and tolerable data loss for short times of the total band at low duty cycle. | The system will be designed to limit partial signal loss to < 1% of time. Current RFI measurements indicate that this should be achievable without compromise in the preferred location. |
| 1 | Medium RFI Levels | Periods of activity where observing can proceed. Transmissions occupy a small fraction of our band (< a few hundred MHz) and do not cause non-linearity in our signal chain. We can still do astronomical observations without too much impact. Result is partial and tolerable data loss of a small portion of the total band. | In our preferred location, the current estimate is that 5% of the band will be subject to interference very frequently – in practice, all the time. The level varies across the array. The levels will be monitored during the Final Design Phase, but it is not expected to be a limiting factor in telescope availability, since the requirements are stated for 65% of the band available. |

As the subsystem designs mature, the availability analysis based on the designs, will be updated. To ensure the system design remains on track, this will be done approximately halfway through the Final Design Phase, and again just prior to the Final Design Review, with fully matured designs. This enables a system-wide assessment of impacts and a re-allocation of availability targets.

Reliability analysis can be difficult to perform accurately. Use of manufacturer supplied Mean Time To/Between Failure specifications can be misleading and unreliable. Several techniques are available to subsystems or components to augment the analysis and improve availability. These include:

1. Increase Mean Time To Failure (MTTF):
   1. ​Perform Highly Accelerated Lifecycle Testing (HALT) during the Final Design Phase. While this does not necessarily improve the quality of the analysis, it is an effective way of eliminating the main failure modes by design. This is performed on early prototypes, and failures are subjected to Root Cause Analysis (RCA) and then the design is modified to eliminate the root cause of the most frequent failures. This is more practical on a module scale, for example for the Antenna Controller, rather than at subsystem scale.
   2. Perform Highly Accelerated Stress Screening (HASS) during production. HASS limits are lower than HALT limits and aim to weed out parts that have latent defects prior to integration into the system.
   3. Robust testing for software​. Extensive testing of software in representative environments can improve the availability of the software, which for several subsystems is expected to be the dominant factor in overall system availability.
2. Reduce Mean Time To Repair (MTTR):​
   1. Definition of Line Replaceable Units (LRU’s) that can be rapidly exchanged to return the system to operation​ quickly. This is particularly important for any elements deployed in the Array Area. Access to the array will be slow and limited by daylight and weather. Modular designs that can be replaced quickly will reduce the amount of time it takes to return the subsystem to operational status.
   2. Determination of adequate Hot and/or Cold spares based on the availability analysis.
   3. Automatic, rapid detection of failures by ample use of monitoring of all key parameters. It is possible to use Machine Learning techniques to do predictive maintenance as well, provided the monitoring data covers the key indicators of imminent failure.
   4. Automatic localization of failures to a single LRU or piece of operational software​ will ensure that the correct repair is undertaken first time, reducing the MTTR.
   5. If transient failures occur, the system will automatically return to operation if these failures are cleared by an automated restart.
   6. Since the Array Area will be inaccessible during darkness, as well as during periods of bad weather, technicians will work in shifts during summer and over weekends to maximize the use of daytime for field work​.
   7. The system will have 24/7 support for the equipment hosted in the Data Center of the Control Building.​
   8. The system will include stores to keep and manage spares​. For larger parts, the stores will be hosted in the Maintenance and Fabrication Building, while smaller parts will be hosted in the Control Building, where humidity and electrostatic discharge will be controlled.
   9. D-level maintenance (performed at OVRO) will be planned during the Final Design Phase, and then adjusted during Operations, to keep up with the replacement rate of spares on site.