Civil & Infrastructure Subsystems: Design Description

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1 Introduction

1.1 Purpose and Scope

The purpose of this document is to define the conceptual design of the ngVLA Civil & Infrastructure subsystems. The Civil & Infrastructure subsystems include the Array Infrastructure, the ngVLA Site Buildings, Operations Buildings, Science Data Center and Science Operations Building. The Visitor Center Building is managed separately and is not included.

The design description is a holistic definition of the design, including performance, functional, mechanical, environmental, safety, reliability, availability and maintainability characteristics. The design should also address compliance to external interfaces in cases where the interfaces have a direct impact on the design.

The designs are driven by the requirements stated in [AD01] and this design description aims to define a design that can meet all the requirements stated in [AD01]. While high-level requirements are presently documented, many detailed requirements will flow from documentation planned for the project PDR phase. Therefore, elaboration of the requirements in [AD01] is expected leading up to the PDR, and compliance of the design to the requirements will be documented at the PDR stage in an associated compliance matrix.

The Civil & Infrastructure subsystems are inherently at a lower level of maturity than the signal path components such as the Antenna, Antenna Electronics, and Central Signal Processor. Much of the array infrastructure design is interface-driven and therefore lags the development of these interfacing systems. The design of the buildings is informed by the Operations Concept [RD01] and Operations Plan [AD02], and the latter is still in development. Given these relationships, the overall maturity of these conceptual designs is low, but the level of detail captured in this report is intended to accurately scope the work, enable system-level costing, a risk assessment, and a technical readiness assessment.

1.2 Units

While the ngVLA project has standardized on metric units, civil and infrastructure systems will use imperial units given standard practices and material dimensions in the U.S. construction industry. This document is written in imperial units with metric units provided for context.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents may not be directly referenced herein, but provide necessary context or supporting material that informs these designs.

Ref. No.	Document Title	Rev/Doc. No.
AD01	Civil & Infrastructure Subsystem Requirements Specification	020.60.00.00.00-0003-REQ
AD02	Operations Plan	020.10.05.00.00-0003-PLA
AD03	Array Configuration Design Description	020.23.00.00.00-0002-DSN

2.2 Applicable ICDs

The following ICDs define the external boundaries of these subsystems and are applicable to this conceptual design. Note that not all ICDs are drafted as part of this conceptual design baseline, but have been identified for future development.

Ref. No.	Document Title	Rev./Doc. No.
AD20	Antenna to Array Infrastructure ICD	1021006-SPE-21-21100-001
AD21	Short Baseline Antenna to Array Infrastructure ICD	020.10.40.05.00-0038-ICD
AD22	Environmental Monitoring to Array Infrastructure ICD	020.10.40.05.00-0072-ICD
AD23	Array Infrastructure to Operations Buildings ICD	020.10.40.05.00-0082-ICD
AD24	Array Infrastructure to ngVLA Site Buildings ICD	020.10.40.05.00-0083-ICD
AD25	Array Infrastructure to Monitor & Control ICD	020.10.40.05.00-0084-ICD
AD26	Array Infrastructure to Central Fiber Optic ICD	020.10.40.05.00-0085-ICD
AD27	ngVLA Site Buildings Combined ICD	020.10.40.05.00-0095-ICD
AD28	ngVLA Operations Buildings Combined ICD	020.10.40.05.00-0086-ICD
AD29	ngVLA Data Center Combined ICD	020.10.40.05.00-0089-ICD

2.3 Reference Documents

The following additional documents are referenced within this text:

Ref. No.	Document Title	Rev/Doc. No.
RD01	Operations Concept	020.10.05.00.00-0002-PLA
RD02	Reference Study: ngVLA Buildings and Infrastructure	020.60.00.00.01-0002
RD03	Assessment for Very Large Array Facility – Including Site Infrastructure, Control Building, & Site Buildings	020.60.00.00.01-0002-REP
RD04	Assembly, Integration & Verification Concept	020.10.05.00.00-0005-PLA
RD05	Combined Antenna Power Budget Analysis	1021006-ANA-21-00000-005
RD06	Systems Engineering Management Plan	020.10.00.00.00-0001-PLA
RD07	H-9113-1 BLM Road Design Handbook	H-9113-1
RD08	Occupational Safety and Health Standards for General Industry	CFR 1910
RD09	Comparison of Radio Frequency Path Loss Models in Soil for Wireless Underground Sensor Networks	D. Abdorahimi and A. M. Sadeghioon. Journal of Sensors and Actuator Networks, 2019.
RD10	Remote Service Station Study	ngVLA Memo #69

3 Subsystem Context

The scope of this document is the conceptual design of multiple subsystems managed by the Civil & Infrastructure IPT, including the Array Infrastructure sub-system (CI 020.60.00.00.00) and the identified buildings required to support the facility and operations concept: the ngVLA Site Buildings (CI 020.61.10.00.00), Operations Buildings (CI 020.65.00.00.00), Science Data Center (CI 020.61.05.00.00) and Science Operations Center (CI 020.61.15.00.00).

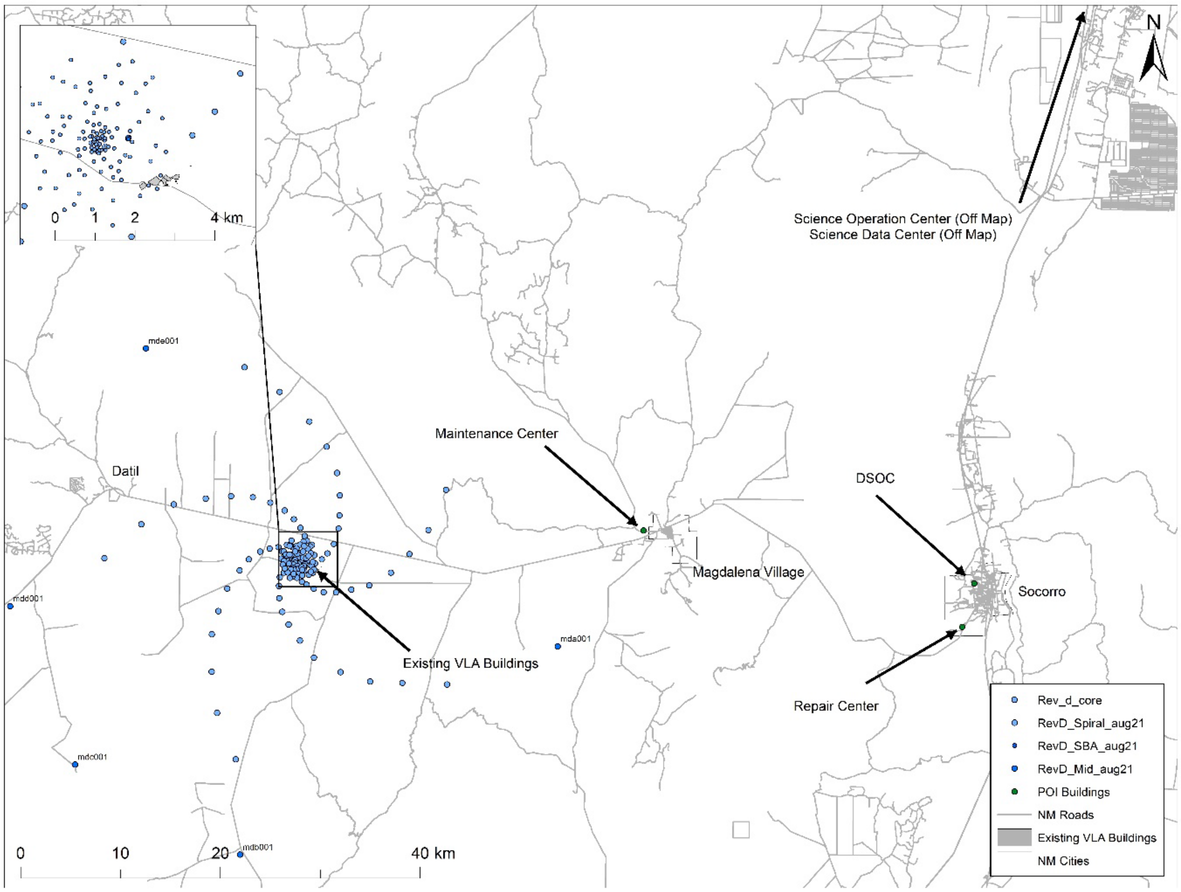

Figure 1: A site context diagram for infrastructure and buildings. The array infrastructure sub-system must connect all antenna sites to necessary services (power, fiber, roads). The sites of various buildings are also shown for context. The Maintenance Center, Repair Center and Array Operations Center (existing DSOC) are elements of the Operations Buildings package. The Science Operations Center and Science Data Center are off map.

The design of the array infrastructure, inclusive of the antenna foundations, service roads, and utility services, is largely driven by the design of the array configuration [AD03] and the interface requirements for the 18m antennas [AD20]. The conceptual design of the buildings is derived in support of the operations concept [RD01] and the assembly/integration/verification concept [RD04] of the project. We consider the impact of these high-level concepts first, as they significantly define and constrain the conceptual trade-space available.

3.1 Operations Infrastructure Concept

Key aspects of the operations infrastructure concept as described in the ngVLA Operations Concept [RD01] are summarized in this section. The material presented in the most recent version of [RD01] supersedes any material included here.

The operations concept requires specific support infrastructure. Workspace sizing estimates have been developed, though these are preliminary and will be revised and expanded as part of the overall Operations Plan [AD02]. To streamline operations and to minimize RFI, it is desirable to limit the number of staff and operating equipment located on-site, with maintenance and operations facilities spaced at distances that minimize travel time while maintaining a relatively quiet RFI environment in the vicinity of the array core.

Site maintenance activities will largely focus on diagnostics and replacement of line replaceable units (LRUs). A majority, if not all, of the line replaceable units (LRUs) and site maintenance equipment is expected to be located at the Maintenance Center and its warehouse, located near Magdalena, NM. The array site will have a limited number of occupied technical services buildings and garages compared to the present VLA infrastructure.

Items will be repaired offsite at a separate Repair Center, with tested and "green-tagged" assets shuttled to and stored at the Maintenance Center. The shuttling of personnel from the repair center to array will be minimized, and all material and personnel logistics are expected to be observatory-organized to minimize transport-related equipment failures.

Array operations will be coordinated from an Array Operations Center, located near the Repair Center. Most science operations, inclusive of scientific and user support, data reduction, and data quality assurance will be performed remotely at a Science Operations Center. Software maintenance and research and development of hardware and software will likewise be done remotely.

In the following table, a breakdown is given of the type of operations and maintenance work performed at various distances from the array core, and buildings and equipment needed to support the associated operations effort.

At Array (Core)	**Near Array (<25 mi. [40km])**	**Within NM (<150 mi. [241km])**	**Anywhere (>150 mi. [241km])**
Personnel • On-shift security • Working O&M staff: Field Techs/Engs, Equipment Operators	Personnel • Safety • Security • Field Techs/Engs • Infrastructure Techs/Engs	Personnel • Operators • Maintenance & Ops Coordinators • Administration • Repair Techs/Engs • Correlator Support • Computing Support • Safety	Personnel • Scientists • Sr. Administration • Data Analysis • User Support • Data Management • Software Dev. • Hardware Dev.
Buildings • Central Electronics • Garage • Depot/Warehouse • Security	Buildings • Maintenance Center (parts depot/warehouse, work space, garages)	Buildings • Repair Center • Array Operations Center	Buildings • Science Operations Center • Science Data Center
Equipment & Assets • Operating array assets	Equipment & Assets • Spare LRU/Hardware • Service vehicles	Equipment & Assets • Items under repair	Equipment & Assets • R&D equipment

At Array (Core)	Near Array (<25 mi. [40km])	Within NM (<150 mi. [241km])	Anywhere (>150 mi. [241km])
• Consumables (Warehouse) • Heavy equipment required at site at all time	• Equipment for testing, working on antennas, infrastructure, logistics	• Repair/test equipment & racks • Vehicles for shuttling assets and staff	• Data processing system & data archive

Table 1: Maintenance and Operations activities by location, consistent with the Operations Concept.

For long baseline array (LBA) antenna sites and some mid-baseline sites of the main array, Remote Support Stations (RSSs) may be located nearby. These support facilities fulfill many of the maintenance support functions allocated to the Maintenance Center. However, the RSS may be located in close proximity to the antennas (<0.6mi [1km]) in order to house time and frequency reference generation and distribution equipment.

3.2 *Integration and Testing Centers*

The buildings constructed in support of the operations phase must also support the assembly, integration, verification (AIV) and commissioning phases of the project. This construction phase is expected to span 10 years, requiring a long-term investment in appropriately outfitted space. It may be appropriate to lease dedicated spaces for AIV activities that are decommissioned at the end of the construction project, but we will incorporate these functions into the operations and maintenance facilities where this provides the best value.

Consistent with the AIV Concept [RD04], electronics and other components will be directed to one of several integration and test centers, where they will be assembled into LRUs and tested in-house prior to being shipped to the warehouse for inventory and storage. These LRUs will be checked out of the central warehouse by antenna integration teams for antenna assembly, integration, and tests. We focus on the AIV needs for antenna integration, as the antennas make up the majority of the system parts count, but consideration must be given to the production of the central signal processor and other systems in future stages of the design.

We note that the AIV concept starts from the premise that the project is NRAO-led and executed. As partners eventually join the project in formal capacities, some assembly, integration and test functions are expected to move to partner facilities, and the associated AIV requirements upon the ngVLA buildings are reduced. These considerations will be reflected in the preliminary and final design technical baselines as partner contributions are formalized.

3.2.1 Assembly Centers

Table 2 lists six integration and test lines, along with the basic building requirements. Some of these production lines could be housed in the same structure. Of the six integration lines, the Integrated Receivers, Front End Enclosure, and Power Supply lines are best understood. An additional facility or facilities for the remaining lines must be identified. It is possible one or more of these lines could be located in a leased structure, and possibly near a metropolitan center. This discussion will continue as the ngVLA construction and integration plan matures.

Integration Line	Location	Total Size (sf)	Occup.	Loading Docks	Clean Room (sf)	RFI Chamber (sf)	Stock Room (sf)	Offices
Integrated Receivers SA501/502	CDL	5000	6	1	2000	150	1000	3
Front End	Repair Center	16000	15	2	2000	150 (x2)	1000	5
Power Supplies & HIL	DSOC	5000	3	1	-	-	1500	1
DBE	NAO (TBC)	5000	6	1	1000	-	1000	3
WVR & Wx Stations	TBD	3000	2	1	1000	-	100	1
LO, Reference & Timing	TBD	5000	4	1	3000	150	500	2

Table 2: ngVLA assembly centers and building requirements. Note that room sizes are given in square feet.

3.2.1.1 Line 1: Integrated Receiver Package

The Integrated Receiver Digitizer assemblies are being designed and developed at the NRAO Central Development Laboratory (CDL) in Charlottesville, Virginia. It is expected that these assemblies will be manufactured and tested out of house and delivered to the CDL for integration into the SA501/502 IRD LRUs. Tested LRUs will then be shipped to the Front End integration center, which is expected to be near Socorro, NM.

3.2.1.2 Line 2: Front End Enclosure

The Front End Enclosure includes two dewars, six cryogenic receivers, the integrated receiver downconverters and digitizers, and other support electronics. The assembly and testing of the Front End subsystem requires a center of considerable size and sophistication, with 16,000 sq. ft. [1486 m^2] of total floor space, 2,000 sq. ft. [186 m^2] of clean room, and a stock room sufficient to collect and store the various components awaiting integration. The Front End integration center is a prime candidate for re-purposing into the Repair Center when complete, as many of the integration and test functions are common between the this AIV line and the operations phase. This building may be built as AUI/NRAO property, or it may be constructed by a local entity (New Mexico Tech or the City of Socorro) and leased to NRAO. A possible existing commercial building has also been identified. Completed and tested assemblies from this center will be transported by NRAO staff to the ngVLA Warehouse, where they will reside until antenna integration.

3.2.1.3 Line 3: Power Supplies & HIL

The -48VDC supplies are expected to be fabricated and tested by a vendor, and may be a COTS device. The lower voltage power supplies will be an NRAO design, fabricated on contract, then integrated with the monitor and control hardware interface layer (HIL) electronics into their respective LRUs. The LRUs are common/shared by both systems, and integration is required before LRU-level acceptance testing. Upon acceptance, these will be transported to the ngVLA Warehouse for future integration into the antennas.

3.2.1.4 Line 4: DBE

The Digital Back-End (DBE) electronics are expected to be manufactured and tested on contract at the PCB level. Integration of printed circuit boards and other standalone components into LRUs may take place in Line 4, or at an off-site manufacturing house. Each unit will undergo acceptance testing prior to becoming part of the warehouse inventory.

3.2.1.5 Line 5: WVR, Weather Stations

Water Vapor Radiometers (WVR) for each antenna consist of a number of LRUs that must be integrated and tested. As with other systems, primary production is expected to be performed on contract, with NRAO integrating and testing at the LRU level. The approximately 65 weather stations required will also need to be integrated into their respective LRUs, and these two production lines can likely be combined.

3.2.1.6 Line 6: LO Reference & Timing

The antenna local oscillator and timing system components will be manufactured on contract. Integration of connectorized components and printed circuit boards will take place in this assembly line, followed by acceptance testing before entering warehouse inventory. The antenna local oscillator system may be integrated into the IRD LRUs, but reference distribution and recovery modules are expected to be a separate production line. The time and frequency reference modules are some of the most sensitive opto-electronic RF modules in the array and may require clean rooms for the component-level assembly.

3.2.2 Warehouse

Though not an integration center, the project warehouse is listed here for completeness. A warehouse sufficient to house components and LRUs during array construction, and spares and consumables during operations, is recommended to be built as part of the Maintenance Center. Sizing of the facility will need to account for the expected cadence of construction, with parts likely stored for a period of months before being distributed for integration into the array. A portion of the warehouse must be climate controlled, as several of the electronic assemblies are susceptible to extreme temperatures, and ESD risk is reduced through humidity control. The existing VLA site warehouse can also be used for cold storage of consumables and short-term storage of parts prior to integration into the array.

4 Array Infrastructure Design

4.1 Product Structure

The Array Infrastructure subsystem (INF) will support array operations, array maintenance and engineering, and array development. Five primary components have been identified as elements of the Array Infrastructure:

1. **Antenna Foundations** serve as physical anchors to support the stability requirements for the antennas. This category also includes the foundations necessary to support other system elements located near the antennas such as the glycol chiller, transformer pads, and weather station pads.
2. **Operations Roads** provide unrestricted access to operational facilities, antennas, and other array infrastructure to support maintenance and operational activities.
3. **Utility Trenches** house electrical and fiber optic cabling between the array facilities and antennas, with specific focus to the Plains of San Agustin. Interfacing with existing power and fiber infrastructure will likely be necessary outside of Plains, and mid-baseline utility infrastructure may be pole-strung (including fiber optic cables).
4. **Fiber Utility** identifies the components required to support fiber optic installation and maintenance. Interfacing with existing fiber networks and leveraging existing easements will be necessary outside of the Plains. The Central Fiber Infrastructure (FIB) work package will inform the high-level design of fiber infrastructure, but INF will be responsible for the construction of underground and pole-strung fiber as part of broader civil construction contracts.
5. **Electrical Utility** identifies the elements required to support electrical service installation, support, and maintenance, as well as provide central generator back up capabilities and associated switchgear.

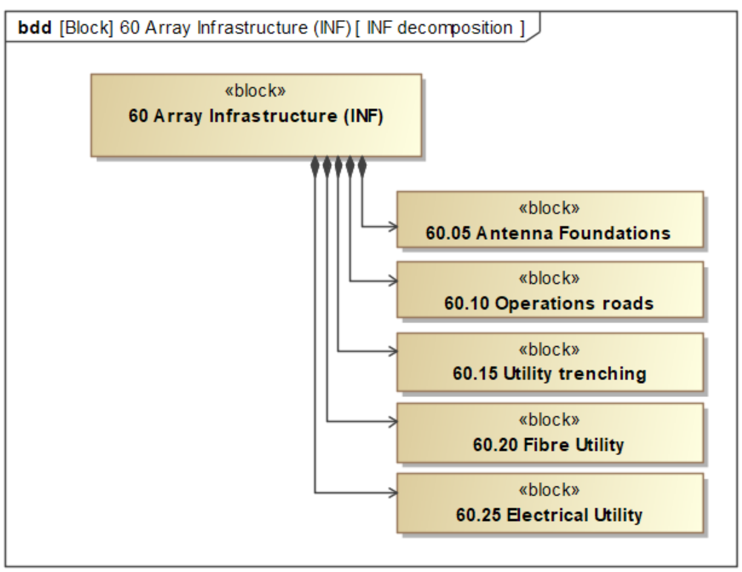

Figure 2: Array Infrastructure Subsystem Decomposition

The Array Infrastructure scope may also include ancillary utility systems necessary to support the ngVLA site buildings such as the domestic and fire water supply. Array Infrastructure interfaces to other subsystems, and associated ICD information, are shown in the context diagram in Figure 3 (on the next page).

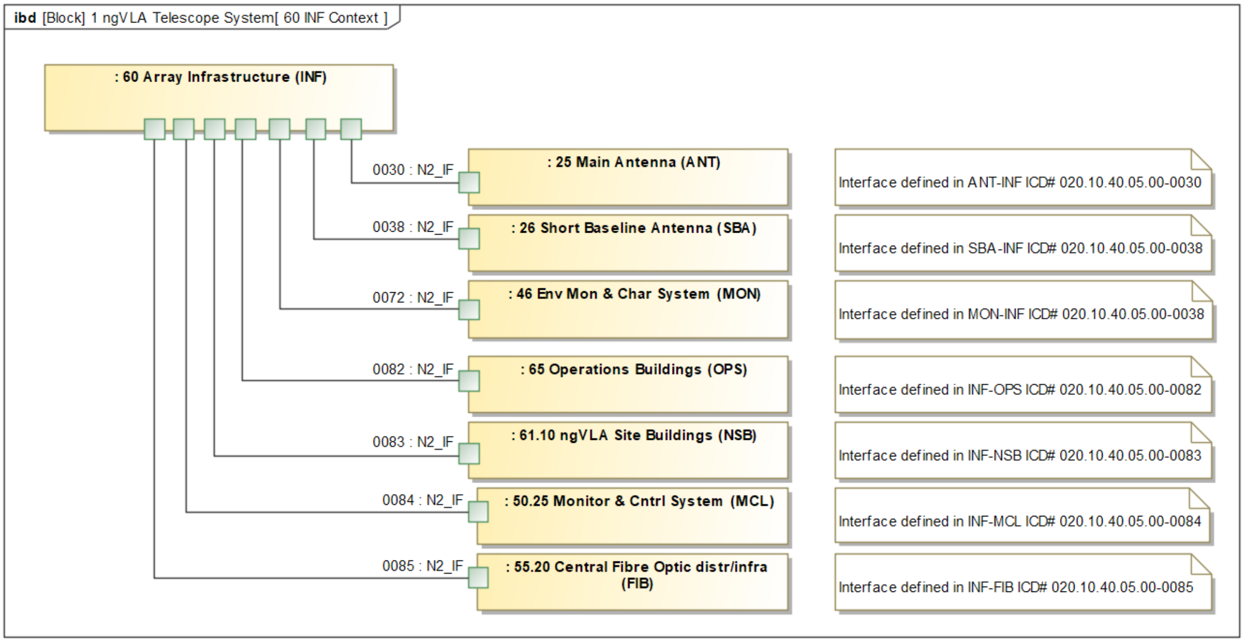

Figure 3: Array Infrastructure Context Diagram.

4.2 *Product Design*

4.2.1 Antenna Foundations

4.2.1.1 18m Antenna foundations

The 18-meter antennas will require a substantial foundation to meet the pointing stability requirements and to withstand the survival conditions. The antenna foundation specification performance requirements are largely established by mtex in the associated ICD [AD20].

Mtex has prescribed the required stiffness to support the pointing performance, the survival loads under various operational scenarios including seismic events and survival wind stow, the interface bolt pattern specification, and other key parameters that significantly define the antenna foundation concept.

The maximum survival loads at wind stow are shown in Table 3. The survival wind loads exceed the survival seismic load cases and therefore present the limiting design loads for the foundation. The minimum stiffness required to meet the pointing and dynamic performance requirements (e.g., slew and settle time) are shown in Table 4.

A supporting conceptual design for the antenna foundation is shown in Figure 4 and Figure 5. Details of the top hexagonal slab are prescribed in the ICD and associated antenna design documentation. The bond beams and piers are diagrammatic of a typical foundation, but the design of the piers, bond-beams and any over excavation of soils will be based on the prescribed foundation stiffness and the results of site-specific geotechnical analysis. These foundations will be placed at the approximate location coordinates (±66' [±20m]) set in the Array Configuration [AD03], adjusted for local site conditions determined in a final site survey. Note that this 66' tolerance is distinct from the separate site development assessment that may lead to antenna sites moving by kilometers or more to accommodate stakeholder and regulatory input.

Survival, Wind Velocity = 111.85 MPH [50 m/s]			Forces (Kips, 1000 lbf)				Moments (Kip*Ft)			
Condition / Description	**Elev. Angle**	**Wind Approach**	**F_X**	**F_Y**	**F_R**	**F_Z**	**M_X**	**M_Y**	**M_R**	**M_Z**
Maximum Shear Forces (F_X & F_R) Concurrent w/ Max Downward Thrust ($-F_Z$)	88 (Stow)	0	89.9	0.2	89.9	-113.8	-22.9	2967.2	2967.3	-28.8
Max Over Turning Moment (M_Y & M_R) Concurrent with Max Uplift ($+F_Z$)	88 (Stow)	135	-60.0	27.2	65.9	61.6	-1538.6	-2825.6	3217.3	-431.5
Maximum Twisting Moment (M_Z)	88 (Stow)	90	-5.8	37.8	38.2	11.2	-2190.6	-108.4	2193.2	652.0

Table 3: Survival forces (wind only) and moments for the 18-meter ngVLA antenna foundations.

K-Shear (Horizontal Axis X & Y)	K-Shear (Vertical Axis - Z)	K-Rotation (Horizontal Axis X & Y)	K-Rotation (Vertical Axis - Z)
[Kips/in]	[Kips/in]	[Kips-in/arcsec]	[Kips-in/arcsec]
1550	34650	127500	99300

Table 4: Minimum foundation stiffness required to support the antenna performance specifications.

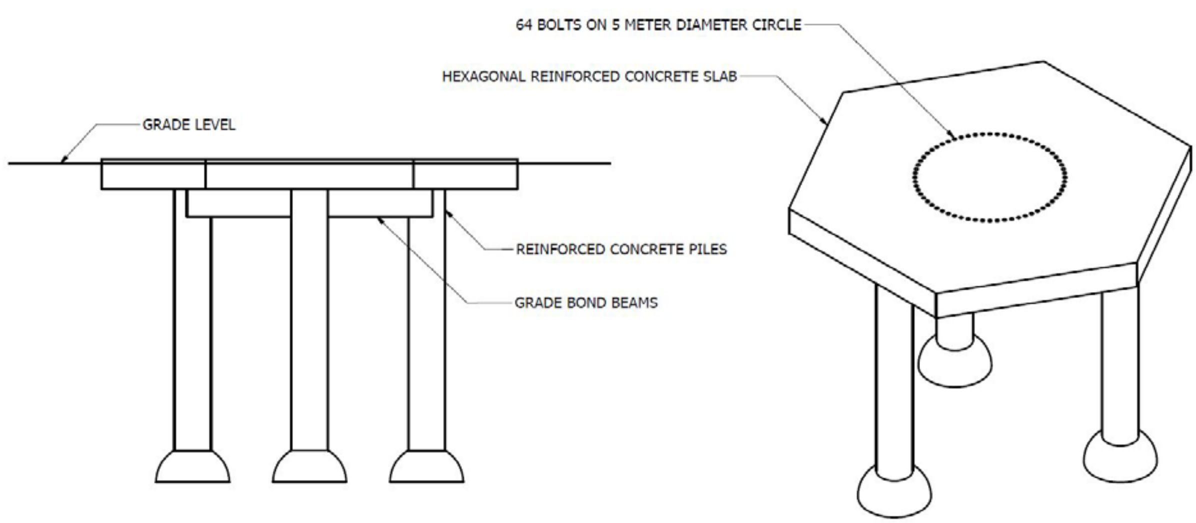

Figure 4: Antenna foundation supports. Note that site grade is approximately level with the pad, and the piles extend below grade. The 64 1.75" diameter bolts on a 16.896' [5150mm] circle form the primary interface to the antenna pedestal.

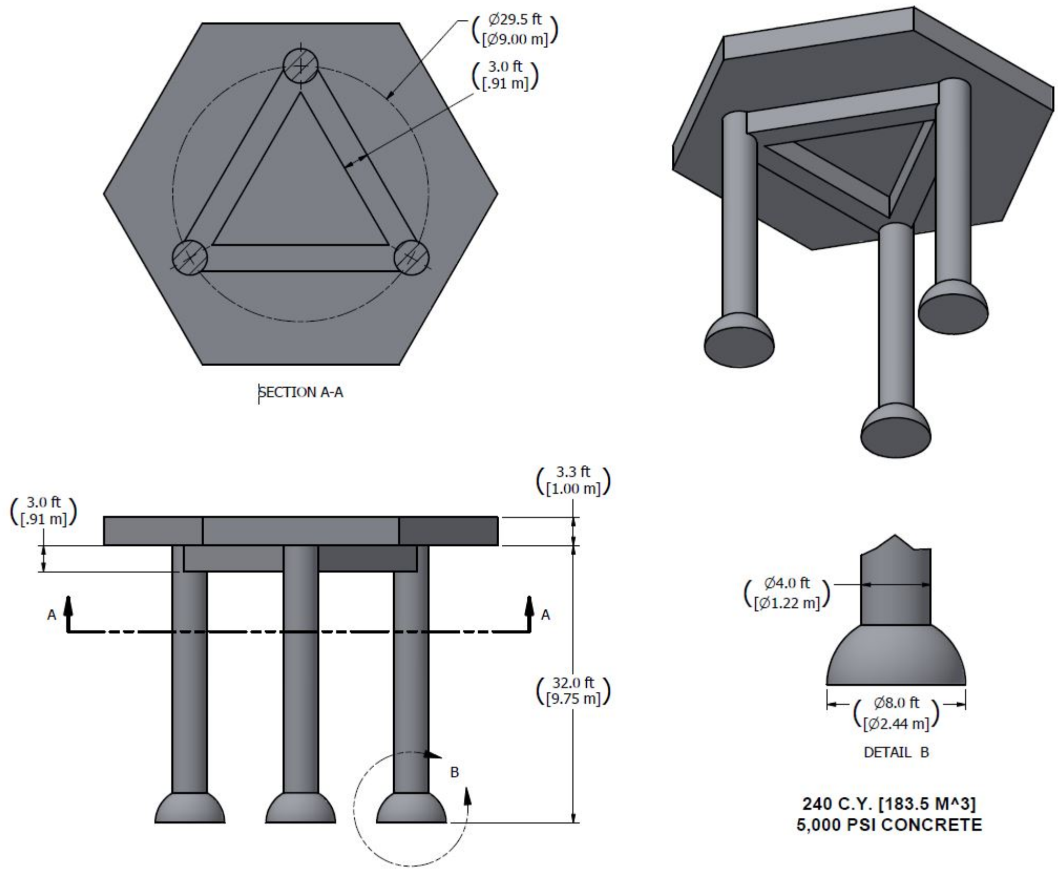

Figure 5: Antenna foundation specifications. The size of the hexagonal pad is specified in the ICD [AD20] along with a required stiffness. The bond beams and piers shown are notional, and the details of the sub-grade design will vary with local soil conditions.

The conceptual design for the antenna foundation consists of a 39.4' [12m] flat-to-flat hexagonal base pad, 3.3' [1m] deep, constructed of reinforced concrete. The base pad will have three 4' [1.2m] diameter piles extending down ~30' [9.1m] into the earth. A 3' x 3' [0.9m x 0.9m] grade beam will tie the antenna foundation to the piers and strengthen the foundation overall. The base pad design will be common to all 18m antennas, with the piers and bond beam tailored to the local soil conditions. The shown design uses approximately 240 cubic yards [184 m^3] of reinforced concrete.

The hexagonal base pad will be crowned for drainage and is expected to protrude 4" [10cm] above local grade. The antenna anchor bolts are provided by the antenna vendor along with an anchor bolt template/cage to ensure alignment of the foundation bolts to the antenna pedestal. The concrete contractor needs to ensure that the template/cage is installed centered and level, with no significant voids during pour, but the relative position of each bolt is assured by the template.

The foundation will include embedded conduits and pipes for electrical utilities, data services and cooling fluids to enter the antenna pedestal through the foundation, as well as bonding points for the ground electrode. The designs of these interfacing systems are still TBD and will be added to future versions of the antenna ICD [AD20].

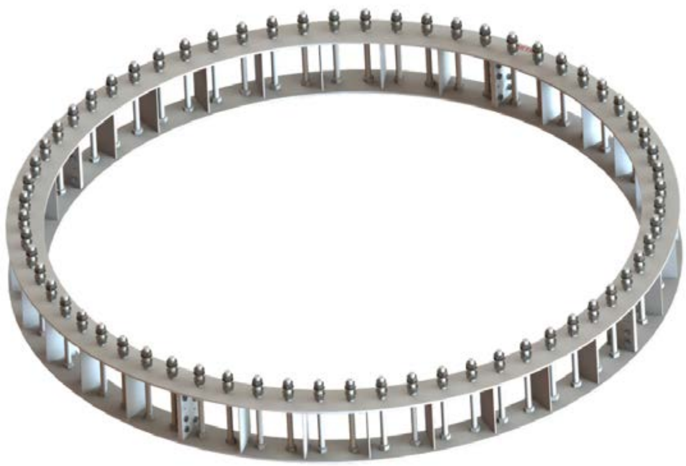

Figure 6: Antenna anchor bolts with template ring/cage. The ring is embedded in the concrete foundation during the pour, with the top ring level with the top of the slab. The ring is 5150mm in diameter.

4.2.1.2 Ancillary Foundations

In addition to the antenna pad, monolithic slab foundations are expected for the electrical service transformer and glycol chiller. These designs and their placement relative to the antenna foundations are TBD.

4.2.1.3 Antenna Security Fences

ngVLA antennas may be located on lands with multiple uses such as livestock grazing. It is important on multi-use land not to impede cattle and large game herds. However, the antenna feed arm also approaches ground level 1.6' [0.5m] off the foundation slab at the lowest elevation, which necessitates a degree of protection for the antennas, wildlife, and site staff and visitors. The center of the core, where the antenna positions are most compact, will be protected by a 0.6 mi x 0.6 mi [1km x 1 km] barbwire fence. For all remaining antennas on the Plains of San Agustin, a barbwire perimeter fence will be installed in the immediate surroundings of each antenna only. A nominal size of the fenced area around each antenna will be 60' x 60' [15.2m x 15.2m], forming a tight perimeter around each antenna and ancillary equipment (chiller & transformer).

A preliminary specification for this fence would implement considerations for wildlife: A top wire or rail preferably no more than 40" [1.02m] above the ground, and absolutely no more than 42" [1.07m]; At least 12" [0.3m] between the top two wires; At least 18" [0.46m] between the bottom wire or rail and the ground; Smooth wire or rail for the top, smooth wire on bottom. No vertical stays; Posts at 16.5' [5m] intervals.

Fencing at the mid-baseline and long-baseline stations is typically around the one to three antennas at each site, and would enclose 1-2 acres [0.4 to 0.8 hectares] of land. Chain link fences will be installed encompassing the antennas and ancillary buildings at these sites.

4.2.1.4 Weather Station Infrastructure

Weather stations are required at each of the 46 remote mid-baseline and ten long-baseline locations, with another seven situated around the core and spiral arms sites. The expected infrastructure at each site includes a center foundation pile (3' diameter, 6' deep [0.9 x 1.8m]). We assume a 35' [10.7m] self-supported tower in this design since self-supported towers are preferable for both maintenance and to minimize the impact on migratory birds. Guy wire anchor blocks may be added if necessary to meet the survival environmental conditions. Power and data communications would be provided by conduits from the nearest antenna, or dedicated transformers and pull boxes if sufficiently remote (TBD depending on selected weather station placement.) A perimeter fence of the same design as described in 4.2.1.3 will also be provided around each tower. We will assume that the tower is of a type that can be lowered for maintenance, so the fence access gate will be sized and oriented to allow the tower to be lowered and raised with the gate in the open position.

4.2.1.5 6m Antenna Foundations

The design of the 6m Short Baseline Array (SBA) antenna foundations will be developed at a later stage of the project, once a conceptual design of the 6m short baseline array antenna is approved. For costing purposes, the 18m antenna design will be scaled by the ratio of the aperture area.

4.2.2 Roads & Utility Trenches

4.2.2.1 Plains of San Agustin

The central core and five spiral arms will require the use of public and administrative use only roads for assembly and integration during the construction phase and for antenna maintenance during operations. Utility trenches are also required to provide underground utility services (electrical and fiber optic communications) to each antenna. The concept of a shared right-of-way for all roads and trenches is adopted in this design. The trench will be constructed first and the roadbed will be constructed above the trench. The roadbed and trench will deviate at any pull boxes or junction boxes only, minimizing the total disturbance of the construction project. Shared drainage structures will protect both the underground utility services and the roadway.

Roads will connect all the antennas in the central core to the support buildings and allow for access from one antenna to another for maintenance. Figure 7 details the road concept for the central core. The selected configuration aims to minimize total disturbance and to reuse existing county and VLA access roads where they exist. Portions of the VLA north and west arm access road/track are used, as well as the previous alignment of Hwy 60 (south of the core in Figure 7). The road configuration will require approximately 28.3 miles [45.5 km] of access road for the central core, of which 3.7 miles [6.0 km] use existing routes.

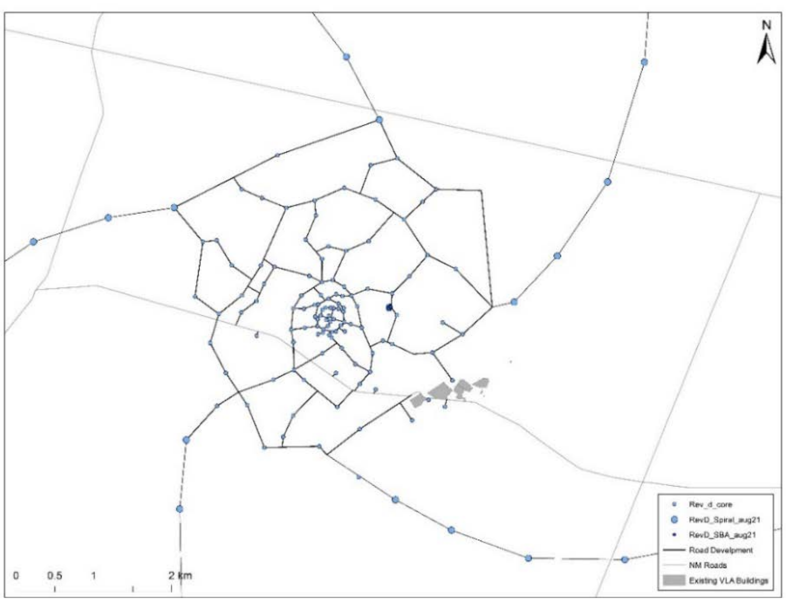

Figure 7 - Road configuration for ngVLA central core and spiral arm antennas.

An access road will follow the five spiral arms and connect all antennas to the central site. Approximately 15 miles [24.1 km] of access road will be needed for each of the five arms (Table 5, on the next page). Existing roadways provide adequate alternative routes to the outlying stations so no new roads are expected to connect between the arms. The proposed alignment of these roads is shown in Figure 8. An existing BLM road is used to access the ngVLA antenna sites at the end of the NE arm (arm 'c') reducing 1m [1.8 km] of disturbance to the grasslands.

To assure long life and the ability to facilitate the antenna assembly and maintenance, a 6" deep, ¾" crushed stone base is adopted as the conceptual design of all new service roads. A standard single lane 12' [3.7m] width is specified, with turnouts at 1000' [305m] intervals consistent with BLM road standards [RD07]. A storm water analysis will be required to define any new drainage structures to prevent washout, erosion or other negative impacts to the surrounding ecosystem.

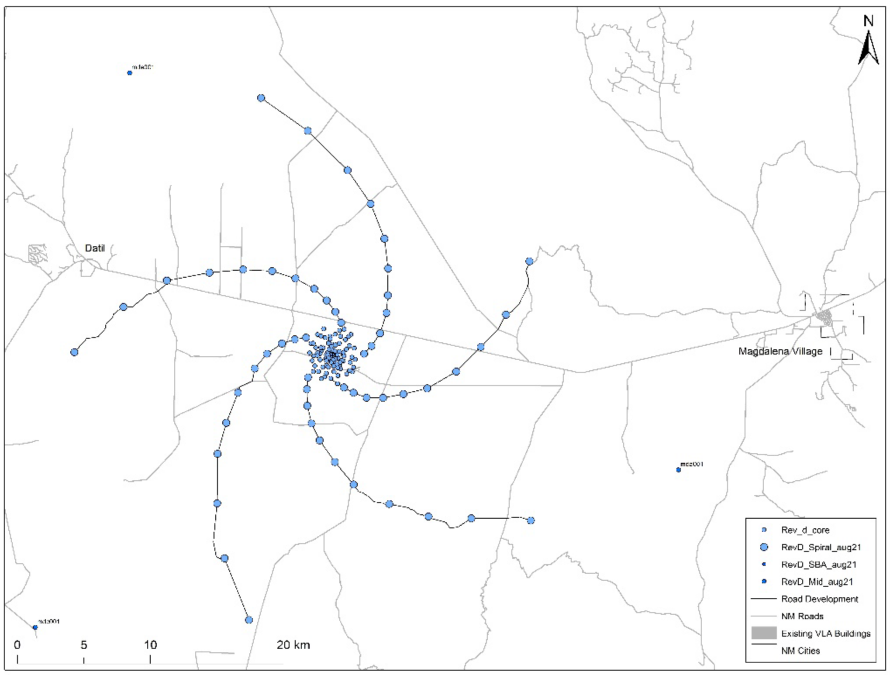

Figure 8: Road and utility trench configuration for the spiral arms on the Plains of San Agustin. Existing road alignments are reused where feasible to reduce the total site disturbance.

Road Section	Length (ft)	Length (km)	Length (mi)	Area (acres)
Core	149168	45.5	28.3	41.1
Spiral - a	79031	24.1	15.0	6.6
Spiral - b	78186	23.8	14.8	6.6
Spiral - c	67329	20.5	12.8	5.7
Spiral - d	63153	19.2	12.0	5.3
Spiral - e	83284	25.4	15.8	7.0
Total	**520152**	**158.5**	**98.5**	**43.7**

Table 5: Road construction on the Plains of San Agustin. Note that this includes reused and improved existing sections of roadway.

4.2.2.2 Mid-Baseline & Long Baseline Stations

Roads for the mid-baseline and long baseline antenna sites will consist of single lane gravel access roads, constructing 'last mile' connections to the nearest county or state road. Pullouts would not be installed unless the road exceeds 0.3 miles [0.5 km] in length. Sub-grade specifications and cross sections will match the spiral arm roads, unless site conditions warrant tailoring. Utilities may be pole strung, but would be trenched for the last 0.5 mile [0.8 km] when feasible to reduce site EMI risks.

4.2.3 Site Electrical Infrastructure

4.2.3.1 Assumptions

The ngVLA will use the existing medium voltage (12.470kV) utility feed from Socorro Electric Cooperative as the primary source of power at the VLA site. The service may be upgraded to account for the increased site load. If the project wishes to procure renewable energy, this would be accomplished with a grid service contract with a remote supplier (i.e., the renewable power would be grid connected and remote from the ngVLA site). This decision is primarily driven by RFI concerns, as a photovoltaic installation (either centralized or distributed) at the ngVLA site presents an RFI risk. The grid service contract will be considered as part of the preliminary design activities in consultation with the Operations IPT.

The present antenna power budget [RD05] is highly conservative, with a peak demand of 128kVA, a short-term average load of 53kW, and a long-term average load of 27kW per antenna. These values are well in excess of the VLA and ALMA antennas, which operate on 75kVA services (sized for peak demand). The ngVLA antenna design should be inherently more efficient given the size, slew rates, and cryogenic design. We will assume that these projected loads will drop by a factor of two (i.e., be marginally more efficient than the VLA antennas) as the power demands are better understood. The progression of the antenna power budget will be monitored in the preliminary design phase and final service sizes adjusted accordingly.

We will also assume that system startup and slews can be staggered, enabling the electrical distribution system to be designed to the short-term average (rather than the peak demand) of each antenna. This is true for the VLA electrical distribution system today. Should this assumption prove invalid, the overall electrical distribution concept remains the same, but most component sizes increase by 140% beyond those specified in this document.

4.2.3.2 Design Drivers

The primary design goals include minimizing system downtime for preventive maintenance, eliminating all single-point failures during regular operations, and minimizing single-point failures during preventative maintenance. This is necessary to meet the system availability requirements established in the technical specification.

4.2.3.3 Plains of San Agustin

The electrical grid proposed by this document follows a circular distribution model (see Figure 9, on the next page). To this end, the backbone consists of multiple switchgear enclosures, each with at least two power sources. This level of redundancy allows for individual components of the grid to be removed for maintenance with minimal impact to site performance. The specific level of impact varies depending on the placement and function of each switchgear cabinet, and will be discussed further on.

As a point of comparison, the existing VLA uses a centralized distribution model. At the present site, all loads can be traced back to a single distribution switchgear, and any maintenance to this central piece of switchgear requires that the array go dark.

The ngVLA grid will be supported by three generators. Two will be rated as prime sources, and one rated for emergency backup. While all three generators are expected to be utilized in a backup capacity, generators rated as prime sources meet more stringent environmental regulations and are capable of prolonged operation. The two prime sources will each support one of the main branches, the CW (clockwise) and CCW (counter clockwise) busses.

The third generator will be connected to both of the main branches via interlocked disconnects. As configured, it may be connected in the place of either prime source while one is down for maintenance or testing. The prime source rated generators will be sized to approach a rating of two-thirds the total site load, accounting for any site elevation or environmental de-rating.

This conceptual design includes seven (TBC) switchgear cabinets to supply major site loads. Five (TBC) of these switchgear cabinets will supply antennas in chains of approximately thirty, serving an arm and a fraction of the core. The fifth and sixth cabinets will provide power to the new Central Electronics Building and various ancillary ngVLA Site Buildings.

Figure 9 illustrates the main electrical grid components for the ngVLA central site.

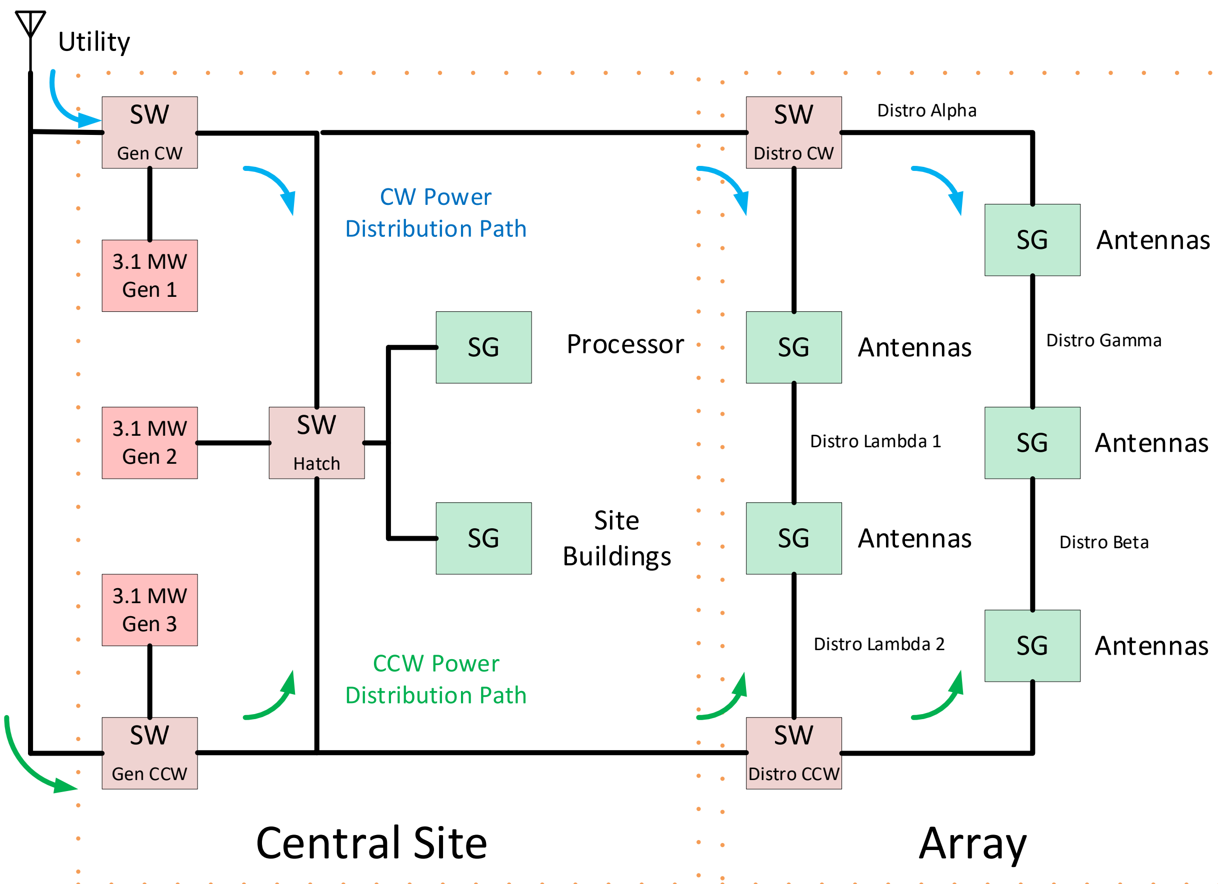

Figure 9: ngVLA central site electrical grid components. Generator sizes are approximate and will be refined as the antenna electrical load is better understood.

4.2.3.4 Mid-Baseline & Long Baseline Stations

Remote ngVLA antenna sites are a mix of 'greenfield' sites and existing observatory sites (e.g., VLBA sites). Existing remote antenna sites are anticipated to reuse or interface to existing VLBA infrastructure or its equivalent, whereas new remote antenna sites will be constructed from the ground up. In either case, these sites will be supplied with a single switchgear enclosure, a transformer per antenna, and a generator connection point.

The current remote locations of the VLBA are supported by backup power generators. The presence of local time and frequency references (e.g., Hydrogen masers) at most mid-baseline and long baseline sites creates a similar need for reliable site power, so each site will be provided with a 75kVA backup power source. The implementation of this backup power source is TBD. The baseline choice would be diesel backup generators, but these are not ideal given their scheduled preventive maintenance needs, scheduled weekly test runs, and environmental impact. The project will monitor developments in microgrid lithium battery and inverter packages (e.g., Tesla powerpack) and perform a trade study of the two alternatives, inclusive of lifecycle cost analysis and sustainability, prior to the PDR.

Utility power will be supplied to new remote antenna sites via a single low-voltage switchgear cabinet. These enclosures will contain three breakers and a multi-function relay. In addition to these basic components, remote ngVLA switchgear units will tie into the monitor and control (M&C) system for the entire array.

Qualified personnel will have access to view data pertaining to current power quality and status. Qualified personnel will also have the ability to operate the breaker, remotely via the M&C network, in order to remove and apply utility power to the antenna[1].

4.2.4 Fiber Optic Infrastructure

The fiber optic infrastructure on the Plains of San Agustin will rely on point-to-point connections from each antenna to the Central Electronics Building (CEB), providing a star topology to the network. Direct burial single mode fiber will be used and may be spliced and bundled into common jackets as it runs down each spiral arm towards the array core. The maximum link distance is approximately 15 miles [24 km] and we assume that this distance will be spanned without active repeaters (only Erbium Doped Fiber Amplifiers, EDFAs) on 100 gbps channels using dense wavelength-division multiplexing (DWDM) for the astronomical data transmission system (DTS). Developments in link technology and fiber specification will need to be monitored throughout the design phase and a technology standard/generation targeted for the start of the construction phase.

The total anticipated fiber count for these direct point-to-point fiber optic services, per antenna, is summarized in Table 6. As the incremental cost of fiber strands in a run is relatively small, we have favored splitting out various services and distributing them on dedicated fibers for simplicity in design. Significant additional dark fiber (equivalent to lit capacity) will also be installed for redundancy and future expansion.

The decision to use DWDM on the plains should be considered preliminary and will be finalized in the preliminary design phase based on best-value analysis. If less costly at the system level, the DTS system could be implemented as 8 independent links with dedicated fibers (16 fibers for DTS, per antenna). This is a fairly simple trade between the cost and complexity of DWDM transmitters and optical combiners vs more installed fiber strands. In this monochromatic alternative, spare fiber capacity would increase proportionately to still have dark fiber equivalent to lit capacity (20 lit fiber strands, total installed capacity of 40 strands)

Function	Bandwidth	Fiber strand count
Data Transmission System	800 gbps (100 x 8 DWDM)	2-16 (DWDM vs Monochromatic)
Monitor & Control	1-10 gbps	2
LO Reference Distribution	N/A	1
Time Distribution	N/A	1

[1] An analysis of the backup power requirements to maintain communication over the M&C network for extended outages in support of this remote maintenance feature will be necessary and advanced in the PDR phase.

Function	Bandwidth	Fiber strand count
Minimum Fiber Strands		**6-20**
Redundancy / Expansion		6-20
Installed Capacity		**12-40** (DWDM vs Monochromatic)

Table 6: Fiber Infrastructure for Antennas on the Plains of San Agustin.

Off the Plains, the mid-baseline stations need to make more economical use of fiber over the ~186 mile [~300km] maximum link distance where coherent frequency references will be distributed to the antenna[2]. For these antennas DWDM is required for the data transmission and monitor and control networks, which share a pair of fibers. The centrally distributed local oscillator frequency reference and timing reference share a dedicated fiber. A total of three strands service each antenna with one spare fiber provided for serviceability. The fiber infrastructure for these mid-baseline antennas is summarized in Table 7

Function	Bandwidth	Fiber strand count
Data Transmission System	800 gbps (100 x 8 DWDM)	2
Monitor & Control	1-10 gbps (DWDM)	0 (included in DTS)
LO Reference Distribution	N/A	0.5 (shared with timing)
Time Distribution	N/A	0.5 (shared with LO)
Minimum Fiber Strands		**3**
Redundancy / Expansion		1
Installed Capacity		**4**

Table 7: Fiber Infrastructure for Mid-Baseline Antennas.

At mid-baseline antennas further than ~186 miles [~300km] from the core, and all long baseline antennas, the data transmission system relies on packet switched network connections to a local ISP. In this scenario, only two fibers are lit to each antenna for combined data transmission and monitor and control traffic. Frequency and time references are located at the site, housed in a site building or other nearby structure (e.g., prefabricated telecom building), with time and frequency signals distributed on local fiber within the site. The fiber optic infrastructure for these long baseline antennas is summarized in Table 8. For a typical three antenna LBA site, a total of 12 fibers would be strung from the ISP to the LBA site, terminating at the site building. A minimum of six fibers would then fan to each antenna: two to support the data transmission links, two for the local distribution of time and frequency references from the site building, and two dark spares for redundancy.

Function	Bandwidth	Fiber strand count
Data Transmission System	800 gbps (100 x 8 DWDM)	2
Monitor & Control	1-10 gbps (DWDM)	0 (included in DTS)
LO Reference Distribution	N/A	0 (+1 local fiber)
Time Distribution	N/A	0 (+1 local fiber)
Minimum Fiber Strands		**2**
Redundancy / Expansion		2
Installed Capacity		**4 (+2 local fibers)**

Table 8: Fiber Infrastructure, per antenna, servicing Long Baseline Array sites.

[2] Coherent LO references will be distributed out to at least 300km, with a goal of 1000km if technically feasible and economically viable. Infrastructure to these mid-baseline sites may change accordingly in the PDR phase.

4.3 Environmental Protection Considerations

Environmental protection is considered as follows in this conceptual design:

- Foundations: all foundations will be sized for the survival environmental conditions. They will be sloped for drainage, will be sited above grade, and the site drainage design will consider storm water runoff for 50-yr events.
- Electrical: all plains infrastructure is below ground for protection. All above ground equipment will be in enclosures rated a minimum of NEMA 3, with NEMA 4 preferred. The only planned exception will be the generator housings which will be standard outdoor enclosures rated for the site environmental survival conditions.
- Fiber Optics: all plains infrastructure is below ground (no overhead pole strung installations) for thermal stability and environmental protection. Armored direct burial cable is preferred. However, any splice enclosures and delivery point/termination enclosures will be above grade and rated NEMA 4 or higher. Any active equipment (e.g. switches, EDFAs) will be mounted in climate-controlled spaces (Antennas, planned site buildings, or dedicated prefabricated buildings) only.

4.4 RFI, EMC and Lightning Protection Considerations

RFI and EMC compliance will need to be considered in the electrical and fiber optic system designs, with lighting protection most relevant to the electrical and foundation designs.

The system-level requirements for RFI detrimental emission thresholds and EMC compliance apply to all ancillary electronics equipment installed as part of the array infrastructure. This will be especially important for controllers associated with the generator sets and switchgear. Associated systems may need to mounted in RFI shielding enclosures, while retaining appropriate certifications for the equipment in question.

The medium voltage step down transformers (12.470kV to 480kV) are expected to be delta-delta transformers. Transformers inherently provide a degree of isolation for transient events and lightning strikes, but the use of a delta-delta (vs delta-wye) implementation eliminates a ground point on the service and associated ground loops, improving overall EMC performance.

Each above ground electrical primary cabinet and transformer will have a local ground electrode designed in accordance with NEC and IEC 62305. The antenna foundations will have their reinforcing rebar bonded to the ground electrode. The design of the ground electrode is TBD pending specifications from the antenna vendor, but is expected to be a ground ring in clean native fill encircling the foundation. Exothermic welds would be used for long-term reliability at all ground bond points. The details of this design will be elaborated as part of the preliminary design activities and captured in the associated antenna to array infrastructure ICD [AD20].

4.5 Reliability, Availability and Maintainability

The system availability budget places a high standard on support system availability, including the array infrastructure system. This is most relevant to the electrical system, which needs to be designed to avoid single points of failure and service interruptions for routine maintenance. The proposed ring topology aims to maintain array availability as describe in the following subsections.

4.5.1 Electrical System Behaviors

4.5.1.1 Normal Operation

Referring to Figure 9, during normal operations the site will be supplied by utility power through both the clockwise (CW) and counter clockwise (CCW) generator buses. Loads will be shared in approximately equal division between the CW and CCW buses. Generators 1 and 3 will be on standby ready to transition power.

4.5.1.2 System Fault Response

In the event of a system fault, trained array staff will be able to reroute power through the local grid to remove the impacted components. Where possible, these transitions will be automated to minimize impact to array observations. When automatic transitions are not possible, or the automated response leaves the array in an impacted state, trained NRAO electrical staff will be relied upon to manually transition the array to the best available configuration.

All array antennas will rely upon local UPS systems to maintain power during electrical grid configuration changes. Devices that run directly on the 480-volt system (e.g., antenna drives) will shutdown, but the antenna electronics will run for a period of minutes to enable the site power to be restored and resume operation. As the batteries approach 10% of their charge, the system will begin an orderly shutdown. The impact to the array's performance due to faults in other busses varies throughout the system.

The utility connection to the CEB has received special attention, with redundant step-down transformers supplying this building (in addition to the redundant generator services and transfer switches incorporated into the ring topology at the site). All transfer switches would be automatic with manual overrides for authorized service personnel. Critical systems within the facility would be further protected with a local UPS system.

Table 9 (next pages) identifies the effects of faults throughout the ngVLA electrical distribution system. Events in the first protective action and second protective action columns are automatic system responses. The array impact column identifies the worst-case loss of function following the automated response. Short-term and long-term corrective actions identify actions taken by site personnel to mitigate and eventually correct the system impact.

Fault Location	1st Protective Action	2nd Protective Action	Array Impact	Short Term Corrective Action	Long Term Corrective Action	After Hours Call-Out Required?
CEB Load	Upstream Breaker Trips		Drop CEB Load	Remove faulted load	Replace faulted load	Consider
CEB Transformer	Upstream Breaker Trips	Re-route power through redundant service	None	Remove faulted load	Develop corrective maintenance plan	No
CEB Switchgear	Upstream Breaker Trips		Drop CEB	If breaker, replace	Develop corrective maintenance plan	Yes
Ancillary Buildings Switchgear Load	Upstream Breaker Trips		Drop non-essential load	Remove faulted load	Replace faulted load	No

Fault Location	1st Protective Action	2nd Protective Action	Array Impact	Short Term Corrective Action	Long Term Corrective Action	After Hours Call-Out Required?
Ancillary Buildings Switchgear	Upstream Breaker Trips		Drop all non-essential site building load	If breaker, replace	Develop corrective maintenance plan	Consider
Hatch	Upstream Breaker Trips		Drop processor and all non-essential load	If breaker, replace	Develop corrective maintenance plan	Yes
Distro CW	Upstream Breaker Trips	Re-route power through Distro CCW and Distro Gamma	None	If breaker, replace	Develop corrective maintenance plan	No
Distro CCW	Upstream Breaker Trips	Re-route power through Distro CW and Distro Gamma	None	If breaker, replace	Develop corrective maintenance plan	No
Distro Alpha	Upstream Breaker Trips	Re-route power through Distro Beta as necessary	Drop 30 Antennas on spiral arm 'a' and core.	If breaker, replace	Develop corrective maintenance plan	Yes
Distro Beta	Upstream Breaker Trips	Re-route power through Distro Alpha as necessary	Drop 30 Antennas on spiral arm 'b' and core.	If breaker, replace	Develop corrective maintenance plan	Yes
Distro Gamma	Upstream Breaker Trips		Drop 30 Antennas on spiral arm 'c' and core.	If breaker, replace	Develop corrective maintenance plan	Yes
Distro Lambda 1	Upstream Breaker Trips		Drop 30 Antennas on spiral arm 'd' and core.	If breaker, replace	Develop corrective maintenance plan	Yes
Distro Lambda 2	Upstream Breaker Trips		Drop 30 Antennas on spiral arm 'e' and core.	If breaker, replace	Develop corrective maintenance plan	Yes

Fault Location	1st Protective Action	2nd Protective Action	Array Impact	Short Term Corrective Action	Long Term Corrective Action	After Hours Call-Out Required?
Generator Gear CW	Upstream Breaker Trips	Re-route power through Generator Gear CCW	None	If breaker, replace	Develop corrective maintenance plan	No
Generator Gear CCW	Upstream Breaker Trips	Re-route power through Generator Gear CW	None	If breaker, replace	Develop corrective maintenance plan	No
480 VAC Antenna Load	Upstream Breaker Trips		Drop single antenna	Remove faulted load	Replace faulted load	No
Generator1	Generator Breaker trips	Generator 2 starts and routes power through Hatch	None	None	Develop corrective maintenance plan	No
Generator3	Generator Breaker trips	Generator 2 starts and routes power through Hatch	None	None	Develop corrective maintenance plan	No

Table 9: Impact of single-system faults.

4.5.2 Maintainability/Lifecycle Support

The vast majority of maintenance, both preventative and corrective, performed on the proposed ngVLA will have minimal impact on array availability. The number of antennas reduces the impact of dropping a single antenna to less than 1%. Table 10 offers a comparison of impacts related to performing maintenance on various regions of the array compared to the VLA as a baseline.

Component Level	% of VLA Array Impacted	% of ngVLA Array Impacted
Antenna	3.7%	0.4%
Antenna Chain	33%	12.3%
Switchgear	100%	0%–12.3%
Correlator/Processor Switchgear	100%	100%
Single Generator	100%	0%

Table 10: Comparison of maintenance impact on array regions.

Preventive maintenance, in the form of testing and inspections, will be conducted on a rolling basis throughout the array. It is intended that every component of the electrical grid, within the plains array, will be inspected either every six to twelve months. Components requiring regular exercising will be operated on a similar schedule. All remote antennas will be inspected and maintained on an annual basis.

4.6 Manufacturability Considerations

All array infrastructure products used for the fiber optic and electrical system construction are expected to be COTS devices. The foundations would be constructed in-place using conventional materials – the expected concrete strength, steel reinforcement and sub-grade soil preparation are not esoteric and multiple qualified contractors are expected for any site.

Site integration activities will be considered in the detailed site design. E.g., an assembly area for the main reflectors may need to be prepared adjacent to the antenna foundations, when a neighboring antenna foundation cannot be used for assembly.

4.7 Safety Analysis

Roads will be constructed in accordance with the BLM Road Design Handbook [RD07] or other regulations applicable to the site, whichever is most stringent.

All electrical infrastructure will be constructed in accordance with the NEC and adhere to federal safety standards. A safety hazard analysis will be conducted as part of the preliminary design phase to ensure that all maintenance operations can be conducted in a manner consistent with OSHA CFR1910 [RD08] and AUI/NRAO safety policies.

4.8 Technology Readiness Assessment

Consistent with the standards of the ngVLA SEMP [RD06] the array infrastructure design is assessed to presently be at TRL 3. This is largely due to uncertainty in the interfacing requirements today and overall (low) design maturity. However, the functional requirements do not appear to drive the design into esoteric parameter space and comparable systems are in operation today. The preliminary design should be realizable with COTS devices (i.e., devices with TRL5 or higher).

5 Buildings Design

5.1 Product Structure

Various buildings are needed to support operations across the system as shown in Figure 10 below. These include buildings to support the hosting of telescope equipment, maintenance operations, science operations, and outreach activities. Locations for each building are given consistent with Table 1.

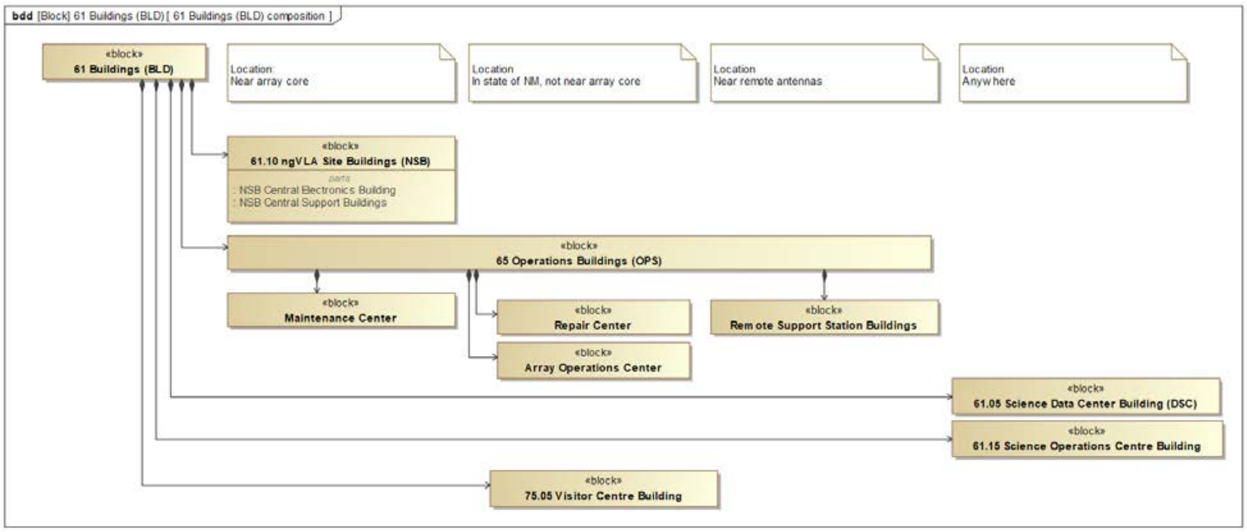

Figure 10: Buildings decomposition and location.

5.1.1 ngVLA Site Buildings (NSB)

The major facility for NSB is the Central Electronics Building that will house the central signal processor, central IT infrastructure, and time and frequency generation and distribution equipment.

The ngVLA Site Buildings also include non-essential central support buildings to support maintenance operations on site, such as heavy equipment storage, equipment garages, and security facilities.

NSB interfaces to other subsystems, and associated ICD information, are shown in the context diagram in Figure 11. These interfaces pertain mainly to the interfaces to the Central Electronics Building:

1. Interfaces between array infrastructure and the Central Electronics Building, including power supply interfaces and fiber utilities.
2. Central Electronics Building interfaces to hosted equipment for the supply of space, power, cooling, etc.

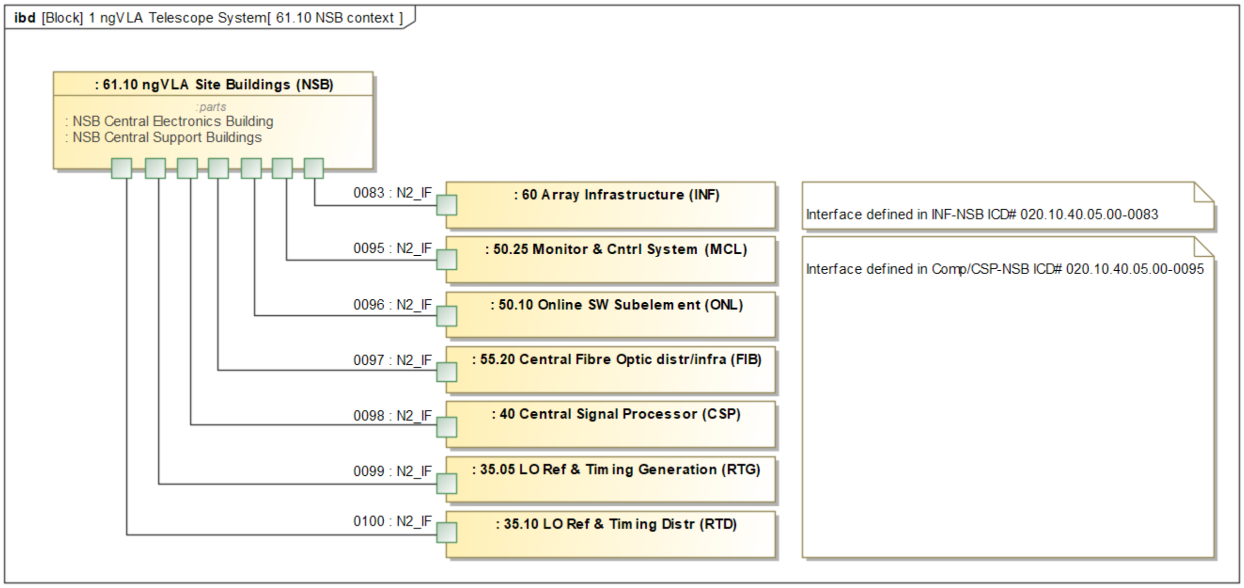

Figure 11: ngVLA Site Buildings Context Diagram.

5.1.2 Operations Buildings (OPS)

Operations buildings encompass a wide range of buildings to support array operations and maintenance across the full physical extent of the array. These include

- Near the array core:
  - Maintenance Center
- Within the State of New Mexico:
  - Array Operations Center
  - Repair Center
- At LBA stations and remote mid-baseline antenna sites:
  - Remote Support Station Buildings

The **Maintenance Center** will serve as a central duty station for safety, security, and maintenance personnel, as well as maintenance activities and ready spare storage. The Maintenance Center will include garages for service vehicles and a Warehouse for controlled logistics.

The **Array Operations Center** provides office and laboratory space, as well as storage and transfer capabilities, and computing infrastructure operations staff.

The **Repair Center** is collocated with or near the Array Operations Center. It will serve as the location for diagnostic, repair, and test activities for electronic LRUs and other equipment. Parts that fail will be sent to the Repair Center for repair, and then will be returned to the Maintenance Center as ready spares.

The **Remote Support Stations** will include all the operations buildings that are required for the long baseline antennas and for antennas in remote locations that cannot be serviced from the Maintenance Center.

OPS interfaces to other subsystems, and associated ICD information, are shown in the context diagram in Figure 12 (on the next page).

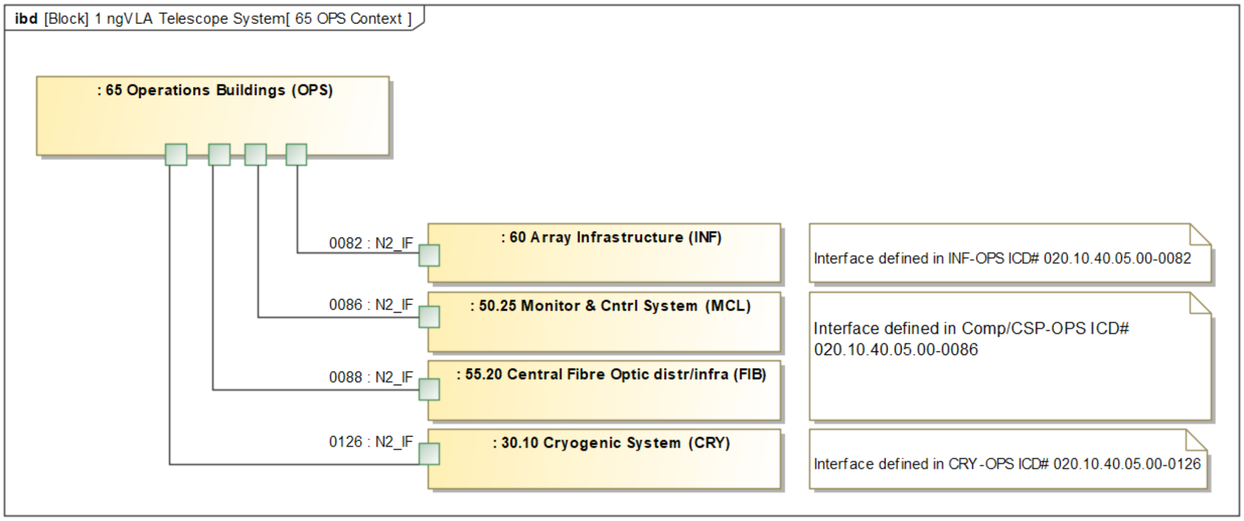

Figure 12: Operations Building Context Diagram.

5.1.3 Science Operations Center (SOC) and Science Data Center (DSC)

The **Science Operations Center** and **Science Data Center** buildings will likely be located in a large metropolitan area. They host mainly two activities:

a) ngVLA Science Operations Center: This facility supports research, development, and software operations staff and will primarily consist of office space. It will host staff that do not need regular access to the antenna sites, such as sr. management, staff scientists, data analysts, and firmware and software engineers.
b) Science Data Center: This facility will house high performance computing equipment for the offline processing system that is responsible for post-processing data products. It will also include the storage equipment required for data archiving. Office space will be included for staff responsible for the maintenance of the data center.

DSC interfaces to other subsystems are shown in the context diagram in Figure 13. The managed interfaces are mainly related to the hosting requirements of the computing equipment including space, power and cooling interfaces.

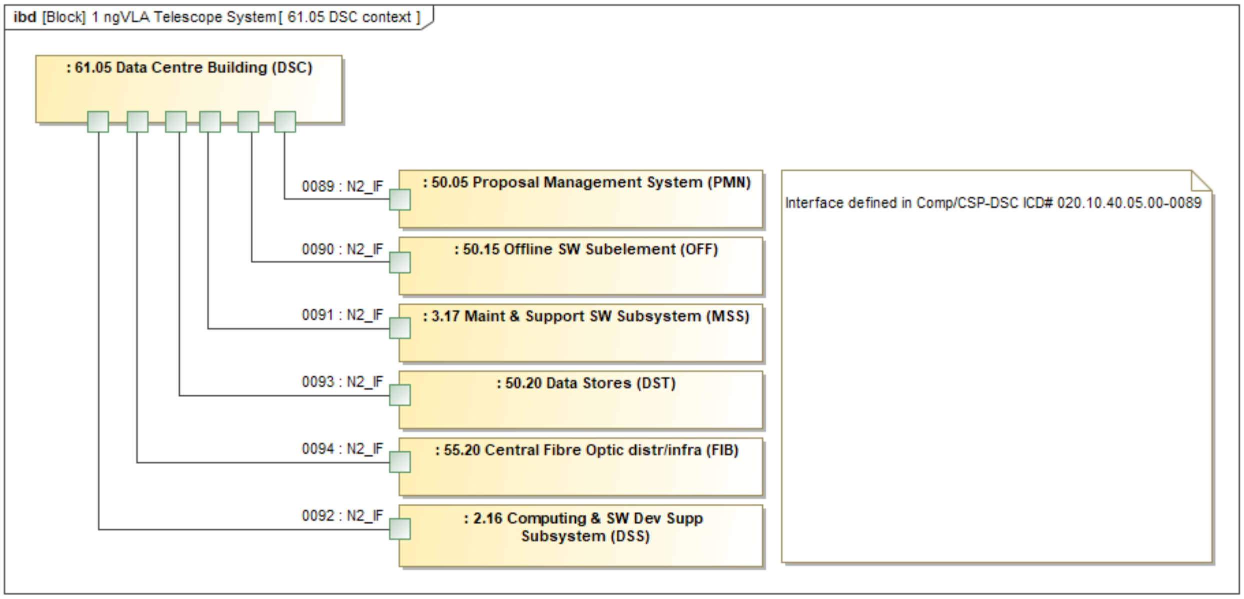

Figure 13. Data Science Center Building Context Diagram

5.1.4 Visitor Center

The visitor center supports public outreach and engagement with the ngVLA facility and radio astronomy more broadly. The Visitor Center will be located on the plains of San Agustin, accessible from Highway 60. The requirements for the Visitor Center will be documented and managed separately from this Requirements Specification.

5.2 Product Design

5.2.1 ngVLA Site Buildings

In the effort to have a minimum of full-time staff located at the site, only security guards and possibly ES&S representatives will be a constant presence at the ngVLA site. Transient staff including the maintenance technicians, equipment operators and equipment mechanics would only be at the site as required. The main building at the site would be the Central Electronics Building (CEB), which would house the central signal processor, time and frequency generation and distribution equipment, and all required on-site computing. This building would be constructed mostly as an RFI-tight building, possibly partially underground with an earth berm. It would house a few offices and a conference area to facilitate on-site meetings and support for AIV and CSV teams during the construction period.

Generators for site backup power and associated switchgear will be at the central site near the CEB. A heavy equipment shop would need to be on site to facilitate maintenance and repairs to the site equipment, such as personnel lifts, cranes, a road grader, and water truck. A vehicle depot housing dedicated site maintenance vehicles and heavy equipment would also be located at the central site. As with the current VLA, an RFI testing chamber will be located at the central site, though one will also be required at the Repair Center in Socorro.

Moving the majority of operations off site does not necessarily mean the existing buildings will be demolished. An assessment of the existing site infrastructure would retain the majority of these buildings for site support and cold storage.

The warehouse and RFI chamber will remain, with minor improvements to the reverberation chamber and associated electronics. While LRUs will be stored at the Maintenance Center, ready spares can be kept on site in the site warehouse.

The antenna barn and transporter barns may be repurposed as the heavy equipment shop and depot. The track shop would also function well as an extension to the depot. A number of the other existing metal buildings, including tech services and the auto shop/servo building, can be used for cold storage to aid in construction of the ngVLA.

The existing fire water system, domestic water system, and sanitary sewer system are presently all in serviceable condition and will be retained with necessary updates to support the design life of the ngVLA. This decision is dependent on final site occupancy as established in the Operations Plan. Should site occupancy exceed the present VLA staffing level, these services may need to be significantly expanded and replacement may become a more affordable alternative.

Trash services at the VLA presently rely on a local landfill. Changes in regulations preclude extending the existing landfill, so a mobile transfer station is preferred for ngVLA. A garbage truck with compactor will be stationed at the site and would periodically be driven to the Socorro landfill. Hazardous waste would continue to be stored and disposed of in a separate program, with temporary on-site inventory and storage before transport for disposal.

Buildings and structures that cannot be reused or repurposed would ultimately have to be demolished as part of any planned VLA decommissioning effort. The general intent is that site maintenance and operations functions will be conducted from existing VLA structures, updated to current code and retrofitted as required. The only new facility to be constructed at the VLA site will be the Central Electronics Building.

Additional information on the existing facilities that informs their reuse, upgrade, or decommissioning can be found in the Appendix.

5.2.1.1 Central Electronics Building

The Central Electronics Building (CEB) would house the central signal processor, time and frequency generation and distribution equipment, and all required on-site IT infrastructure and computing. An assessment was performed for possibly housing this equipment in the VLA Control Building, but this option is not preferred since:

1. The existing RFI-shielded correlator room and associated HVAC and electrical services are significantly undersized to house the ngVLA correlator design.
2. The retrofit and expansion costs on this facility to support the redundant services necessary for system availability would likely exceed the cost of new construction. (See RD03 for an assessment)
3. The VLA and ngVLA could not coexist in a transition phase, requiring that the VLA be turned off years before ngVLA has comparable capabilities.

For these reasons, new construction is preferred for the CEB. A summary of the occupied areas of the building is shown in Table 11 (on the next page). Note that this area only encompasses the spaces that are required to support the array. Additional mechanical rooms for HVAC, UPS and other building services are expected, likely increasing total building area by 25%.

Since most of the facility requires RFI shielding, environmental control, ESD safe flooring and UPS backup, it is likely most practical to build the entire facility to this standard and incorporate the RFI shielding in to the outer shell of the structure. Achieving the requisite 100dB of shielding may be most practical using a combination of a standard faraday cage techniques along with attenuation from earthen fill. If the building is constructed with an earth berm surrounding the structure, each 1.6' [0.5m] of berm depth can offer 5-

25 dB of attenuation, even at <1 GHz frequencies, depending on the composition of the soil [RD09]. High clay content offers the most attenuation. These same high-clay soils are considered low-quality fill below foundations, and are frequently over excavated and replaced with soils suitable for high compaction. Given the extent of construction at the site, a building berm may prove an economical way to reuse this excess material from antenna foundation construction and reduce the total cost of facility construction by permitting a lower level of shielding in the building envelope.

CEB Areas	Area (sq. ft)	Functional Requirements
Central Signal Processor	4000	RFI Shielded, Humidity Controlled, ESD, UPS
CSP Technician Laboratory	250	RFI Shielded, Humidity Controlled, ESD
Fiber Point of Entry / Patch Room	250	HEPA Filtered
IT/Computing Infrastructure	2000	RFI Shielded, Humidity Controlled, ESD, UPS
Reference Generation & Distribution	2000	RFI Shielded, Humidity Controlled, ESD, UPS
Reference Distribution Technician Laboratory	250	RFI Shielded, Humidity Controlled, ESD
Offices (4)	600	
Conference Room	300	
Local Operator Room	300	RFI Shielded
Logistics Area	250	
Occupied Area	**10,200**	

Table 11: CEB Floor Areas & Functional Requirements. Space sizes TBC in the associated ICDs.

5.2.2 Operations Buidings

The operations buildings are located at multiples sites given the extent of the array and the tiered maintenance structure adopted in the Operations Concept. A context diagram showing the locations of the Maintenance Center, Array Operations Center and Repair Center can be seen in Figure 1.

5.2.2.1 Maintenance Center

To minimize staff at the ngVLA site, the Operations Concept proposed to construct an offsite campus close enough to house specific technical services for the array, but far enough away so that RFI from these activities is not be a concern. Magdalena, NM is an ideal location for the second campus. It is located 24 miles [38.6km] from the ngVLA site and 27 miles [43.5km] from the Array Operations Center and Repair Center in Socorro. We propose a notional site (TBC) in the vicinity of the Magdalena Airport on the west side of town, with easy access to Hwy 60 and CR107.

Technical services including the Cryogenics, Machine Shop, Auto Shop, Servo, HVAC, Electricians, ES&S, Antenna Technicians, and the main Warehouse would be located in the Magdalena area. The technical staff would be stationed at the Magdalena campus and would perform maintenance and repairs on the antenna components on site. For maintenance or repair that requires an antenna visit, the technicians stationed in Magdalena would travel directly to the affected antenna, without necessarily needing to travel to the central site.

The Maintenance Center, given the new location, would be new construction. Typical commercial/industrial metal building standards are expected, with integrated logistics for shipping and receiving. The size of the technical services facilities would be based on VLA experience, scaled to the ngVLA operational load. Approximate facility areas by function are summarized in Table 12 below. Note that these are approximate sizes of the areas allocated to the intended purpose, and additional space is required for electrical and mechanical rooms and other ancillary spaces. Nominal building sizes are likely 25% larger.

Maintenance Center Areas	**Area (sq. ft)**	**Functional Requirements**
Cryogenics	3000	Clean Room, ESD
Machine Shop	3000	Fume Hoods, ventilation, hazardous material storage.
Servo	3000	ESD, Humidity controlled.
Antenna Mechanics	1500	Hazardous material storage.
Electricians	1500	ESD, Humidity controlled.
HVAC	1500	ESD, Humidity controlled.
Warehouse & Logistics	6000	Humidity controlled.
Auto Shop	5000	Hazardous material storage.
Offices - Admin & Mgt.	2000	
Security	1000	
Occupied Area	**27,500**	

Table 12: Maintenance Center Areas (TBC).

Lavatories with emergency showers are expected to be distributed amongst all facilities. All facilities would be outfitted with HVAC. The present concept is for a 'campus' organization with multiple smaller facilities dedicated to each purpose. This permits a sense of ownership by each functional group of their respective spaces and avoids functional use conflicts, but is inherently less flexible than a more integrated space.

Depending on the on-shift presence at the Maintenance Center Campus, some additional common-use spaces may be prudent such as a cafeteria. A large parking lot will be required for both staff vehicles and the maintenance vehicle depot. The later should be behind a security fence for overnight storage.

The layout of the maintenance center will be developed as part of the preliminary design activities.

5.2.2.2 Array Operations Center

The ngVLA array operations center houses array operations staff, computing support, correlator support, system diagnostics support, and administrative and management staff.

The Domenici Science Operations Center (DSOC), located on the campus of New Mexico Tech (NMT) in Socorro, NM, is home to the offices, labs and computing rooms that support VLA and VLBA operations. Scientific, Computing, Engineering, Fiscal, and Human Resources staff are all co-located in this building. The facility has a total of 66,950 sq. ft. [6220 m^2] and a typical occupancy of 200 staff. NRAO has a 99-year lease on the building at low cost, and pays NMT a market-rate service contract for facility maintenance services.

ngVLA staffing levels on these functions are expected to be comparable to VLA and VLBA. The DSOC is a well-maintained facility and has been assessed as still suitable for this purpose for ngVLA given the projected staffing levels and design life. Continuity of use for these functions remains the most cost-effective solution, so this conceptual design retains the existing Domenici Science Operations Center (DSOC) to fulfill this need for the ngVLA. No significant retrofit work is expected or included in this concept.

Importantly, the DSOC presently also functions as a repair center for the VLA. As it is currently configured, the facility will not support the larger repair staff and functions needed for ngVLA. A number of ngVLA LRUs are appreciably larger than their EVLA equivalents that are more modular. The building does not have a proper loading dock to receive and ship these larger assemblies, or to allow for reasonable service of the larger LRUs. The basement is suitable for some of the smaller AIV production lines, and is presently targeted for the power supplies and monitor and control hardware modules. These modules are relatively small with less stringent integration and test requirements that can likely be accommodated in the existing space with minimal retrofits. However, if supporting an ngVLA AIV production line is feasible while concurrently supporting VLA and VLBA operations is TBC.

For these reasons, the DSOC is expected to remain as the Array Operations Center, but not to serve as the Repair Center for ngVLA. No significant retrofit or expansion of the building is necessary for this narrowed purpose. After the AIV phase is complete, the 1st floor will remain used for engineering support, but tailored to R&D and system-level diagnostics. LRU repairs will be relocated to the nearby Repair Center. Engineering staff will be split between both facilities, with technicians primarily based at the Repair Center.

5.2.2.3 Repair Center

The Repair Center will house the off-site technicians and engineering staff responsible for the diagnostic and repair of the line replaceable units swapped from the antennas by the Maintenance Center staff. The facility is expected to be a large laboratory/warehouse space, approximately 25,000 sq. ft., [2323 m^2] with assembly lines dedicated to each LRU. Each line enables diagnostics, disassembly, repair and retest before a logistics group transfers the repaired and qualified LRUs to the warehouse at the maintenance center for future dispatch into the array.

The repair center is envisioned as a single large facility to enable reconfiguration of the space over the design life, based on actual failure rates and required test and repair instrumentation. ESD flooring is required in all laboratory spaces in addition to HVAC with HEPA filters and humidity control.

A few dedicated spaces in the repair center include:

- An anechoic RFI chamber for diagnostics and qualification of emission sensitive devices.
- A separate foundation and enclosed space for environmental testing characterization.
- Limited office space adjacent to the laboratory.
- A shipping and receiving dock with an enclosed storage area (to provide an environmental seal to the laboratory spaces).

The Repair Center may be new construction or a retrofit to an existing facility available in Socorro. A candidate location for the facility would be the city industrial park on Enterprise Road, on the southwest side of Socorro.

In addition to the long-term operations function, the Repair Center would be an ideal area for assembly and integration support of the front end enclosures during the construction phase of the project. Procurement or construction of this space is therefore recommended in the first year of the construction effort.

5.2.2.4 Remote Support Stations

The mid-baseline and long baseline antennas will be far away enough that maintenance from the central site would require constant travel and lodging for the service technicians. In some cases, this could be problematic in that long travel distances could be required, and overnight lodging could be difficult to locate.

The Remote Support Stations (RSSs) act as secondary depots for the maintenance of antennas in the mid-baseline array and long baseline array. The quantity and distribution of the RSSs is dependent on the final array configuration and is still TBD. An earlier analysis [RD10] was performed for the Rev C configuration and concluded that two RSSs could serve the most remote mid-baseline sites. An RSS would also be included at each LBA site, for a total of 12 structures. This analysis will be repeated for the configuration rev D (the conceptual design baseline) and is expected to show similar but slightly higher results given the more extended nature of the mid-baselines in the Rev D configuration.

The concept for the RSS is:

1. A duty station for remote technicians that do not travel from the Maintenance Center.
2. A local depot for ready LRU spares and consumables.
3. A work area for diagnostics, equivalent to functions (Cryo, HVAC, etc.) performed at the Maintenance Center.
4. A housing for time and frequency distribution equipment and possibly networking equipment to service the remote sites (analogous to the CEB at the VLA site in these respects).

a) Possibly short-term housing for centrally dispatched technicians (TBC).

Each RSS is expected to be approximately 2000 sq. ft. [186 m^2] The buildings would be shielded if located within 10 km of an antenna, which is expected at each of the LBA sites. The mid-baseline RSSs may be located separately from the antennas to defray this cost, but the trade will be performed as part of the preliminary design phase.

The site technicians at each RSS would be responsible for coordinating with the warehouse for replacement LRUs, and maintaining and servicing the remote antennas in their assigned region.

5.2.3 Science Operations Center

The Science Operations Center is intended to house science operations functions, R&D and management/administration that do not need to be collocated or near the array. This is analogous in function to the North American ALMA Science Center, located in Charlottesville, and diverges from the VLA model, where scientific operations and user support functions are co-located with array operations, engineering and maintenance at the DSOC in Socorro, NM.

Conceptually, this choice is driven by the opportunity for easier employee recruitment and retention. The site and concept for the SOC is still TBD at this stage of the project. The facility is expected to be located in a major metropolitan area (Albuquerque, Denver, Austin, etc., are options). The building is expected to be a typical academic office building, and colocation on a university partner campus is likely. The building has no unique requirements so this can likely be a leased structure that is outfitted by NRAO and maintained on lease, similar to the DSOC today.

The preliminary occupancy figures listed in the technical requirements [AD01] for 138 people, with additional space for visiting scientists and associated programs. Assuming a total occupancy of 175, an approximate office building size of 45,000 sq. ft. [4181 m^2] should provide a point of reference for costing.

5.2.4 Science Data Center

The science data center is expected to be configured as a commercial data center – large open space, suspended ESD-safe floor for under floor HVAC and electrical ducting, central UPS and generator backup, etc.

An open trade concerns the operation of an NRAO-owned data center vs a leased space vs leased computing power. Present trends in costs and the expected steady-state computing load suggests an owned solution will be preferred to a cloud-based solution, but this remains to be documented closer to the system PDR.

Preliminary system sizing is for 200 racks. We will use a rule of thumb of 42 sq. ft [3.9 m^2] per rack for a total of 8400 sq. ft [780 m^2] of building space. This includes aisles, power and cooling system space allocations. In addition, this building should have on-site office space sufficient for 25 persons who are responsible for the administration and maintenance of the data center. An approximate building size of

12,000 sq. ft. [1115 m^2] will be used for costing purposes. This facility could be combined with the Science Operations Center if new construction proves economical for both.

5.3 Environmental Protection & Sustainability Considerations

All new structures within the state of NM will be built consistent with the New Mexico Commercial Building Code. Wind, snow and seismic standards will conform to the code and the project survival environment requirements, designed to whichever is the most stringent.

All new structures will be built to a Leadership in Energy and Environmental Design (LEED) Gold-level certification or higher, as applicable to new construction as defined in LEED v4.1.

5.4 RFI, EMC and lightning protection

The Central Electronics building and the RSS stations will be built with 100 dB of shielding to permit the installation of COTS electronics and computing equipment within the building. This shielding level may be attained by a combination of a faraday cage and attenuation from earthen fill in the case of the CEB, which may be an earth-bermed or partially underground facility.

All new buildings will be protected from both direct and nearby lightning strikes, achieving Protection Level I as defined in IEC 62305-1/3. The buildings will also be protected against Lightning Electromagnetic Impulse (LEMP) in accordance with IEC 62305-4.

5.5 Reliability, Availability, Maintainability

A detailed analysis of the building systems impact on system reliability and availability (FMECA analysis) will be performed as part of the preliminary design activities. The intent is to identify all points of failure in the building services that can impact array reliability. E.g., UPS systems will need ready spares and bypass circuitry to ensure they can be serviced and repaired without interrupting power to connected devices. Fire alarm panels frequently include electrical service disconnects for safety, and therefore these must be serviced regularly with ready spares on site. These are just examples, and a full list of critical parts will be developed based on the FMECA analysis in support of the facility availability and maintainability requirements.

5.6 Safety Analysis

A Safety Hazard Analysis will be performed as part of the facility layout and design for each building and campus described in this document. The intent is to ensure that any building features necessary for the safety of personnel and equipment are in reflected in the design (e.g. adequate clearances for service, remote disconnects and lockouts, etc.)

5.7 Technology Readiness Assessment

Consistent with the standards of the ngVLA SEMP [RD06] the building designs are assessed to presently be at TRL 3. This is largely due to uncertainty in the requirements today and low overall design maturity. However, the functional requirements do not appear to drive the designs into esoteric parameter space, and comparable facilities exist today. The preliminary design should be realizable with COTS devices (i.e., devices with TRL5 or higher) and conventional well-proven construction techniques.

6 Appendix A: Assessment of Current Facilities for Reuse

A key trade for the ngVLA site buildings, operations buildings, science operations center and science data center is the possible reuse of existing VLA infrastructure. Context on the selected facilities for reuse vs new construction is summarized here.

An equivalent trade is not considered for the array infrastructure, as the needs of the ngVLA are appreciably different that significant reuse is not feasible. Small sections of infrastructure, such portions of the site access roads, electrical and fiber distribution, and generator backup services (updated since 2015) are considered and incorporated on a case by case basis into the design, but do not present a significant trade study for evaluation.

6.1 VLA Buildings and Utility Infrastructure

The existing buildings and infrastructure at the central VLA site have been serving the observatory for over 40 years, and though well maintained, they have exceeded their design life. To better determine if these structures are candidates for renovation and upgrading, NRAO contracted the engineering firm Bohannan Huston to perform a high-level site building and infrastructure assessment. The purpose of this study was to evaluate the suitability of the current facilities and infrastructure for ngVLA use. A brief summary is provided in the sections below. The full report is provided as [RD03], Bohannan Huston VLA Site Assessment.

The site buildings evaluated for this study include the two-story brick Control Building and the pre-fabricated metal Warehouse, Technical Services, Track, Generator, Carpentry, Auto/Electrical Shop, and Antenna Barn buildings.

The Control Building, erected in 1975, was determined to be in overall good condition. However, if major renovation to the building were to occur, the standards to which the building were originally constructed would no longer be applicable. Several improvements would be required to bring the building into compliance with current American with Disabilities Act (ADA) standards. Structurally, the Control Building is sound, though extensive structural efforts would be required to modify the elevator core and the access areas. The mechanical and electrical systems in the building are in good condition and have undergone consistent and routine maintenance, but all are original and would be likely targets for replacement, with the exception of the newly installed main electrical panel. Plumbing fixtures are older and in fair condition. Finally, it was noted that most of the Cat 5 technology wiring in the building is unshielded and provides a source for EMI emissions.

Based on the Bohannan Huston observations of the existing control building, it is our opinion that the current building will not adequately serve the needs of the proposed expansion due to substantial reconfiguration of the current floor plans needed to meet current Building Code and Accessibility requirements as well as upgrades and replacements of the mechanical and electrical systems to support ngVLA electronics.

The site's pre-fabricated metal buildings appear structurally sound. At present, an initiative is underway to replace the exterior windows and doors. Should the buildings be called into future service, new exterior skins should be considered. The electrical systems are a combination of original and upgraded sections. Most of the HVAC systems have been upgraded over the past decade.

Potable water is available at all facilities at the VLA via an onsite closed-loop system. The facilities are supplied by a groundwater well that pumps into a 30,000-gallon [113,562 liter] above-ground steel storage tank. The distribution system piping varies in size and material type depending on its location. Piping has been reliable with minimal leaks and repairs. The fire pump is rated for 1,000 gal/min [3,785 liter/min] and has been recently upgraded with a new controller unit. Although adequate for their current use, upgrades to the domestic water system will be needed to support the 30-year design life of the ngVLA.

The onsite sanitary sewer system consists of a gravity collections system that serves the control building, visitor center, and most of the other site buildings. This collection system drains to a lift station that then transports waste water to a two-cell facultative lagoon system for processing and disposal. The lagoons are in good condition and are adequate to provide service for the future facility, though they may have to be modified to a more appropriate size depending on the expected site occupancy. The sewage lift station is in good condition, but it has been identified as needing to be replaced to meet code requirements and provide better efficiency. The existing collection system is in good condition. Without additional lift stations, the extent of service that can be provided to the site buildings is limited by the site topography. The ability to connect new buildings that may be a part of the proposed expansion to the current gravity system will be location-dependent.

6.2 Domenici Science Operations Center

The Domenici Science Operations Center (DSOC), located on the campus of New Mexico Tech (NMT) in Socorro, NM, is home to the offices, labs and computing rooms that support VLA and VLBA operations. Scientific, Computing, Engineering, Fiscal, and Human Resources staff are all co-located in this building. NRAO has a 99-year lease on the building at low cost, but pays NMT a market-rate service contract for facility maintenance services.

While the DSOC is in good condition, as it is currently configured will not support the electronics division staff needed for ngVLA. The basement is not suited for any of the large-scale production lines that will be needed for building and testing ngVLA assemblies during the AIV phase. The building does not have a proper loading dock to receive and ship components and assemblies, or to allow for reasonable transportation of the larger LRUs. These limitations also apply to the operations phase.

For these reasons, the DSOC is expected to remain as the Array Operations Center, but not to serve as the Repair Center for ngVLA. The DSOC remains well suited to house Operations, Administration, Correlator Support, Computing Support, Safety, and some system-level engineering support.

7 Appendix B: Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
ADA	Americans with Disabilities Act
AIV	Antenna Integration and Verification
AOC	Array Operations Center
AUI	Associated Universities Incorporated
CCW	Counter Clockwise
CDL	Central Development Laboratory
CEB	Central Electronics Building
CI	Configuration Item
CNC	Computer Numerical Control
COTS	Commercial Off The Shelf
CSV	Commissioning and Science Validation
CW	Clockwise
DBE	Digital Back End
DSC	Science Data Center
DSOC	Domenici Science Operations Building
DTS	Data Transmission System
DWDM	Dense Wavelength-Division Multiplexing
EDFA	Erbium Doped Fiber Amplifiers
EIU	Electrical Infrastructure Upgrade
EMC	Electromagnetic Compatibility
EMS	Emergency Medical Services
ESD	Electro-static Discharge
ES&S	Environment, Safety, and Security
FMECA	Failure Mode Effect and Criticality Analysis
HEPA	High Efficiency Particulate Air
HIL	Hardware Interface Layer
HVAC	Heating, Ventilation, and Air Conditioning
ICD	Interface Control Document
INF	Array Infrastructure Subsystem
kVA	kilo-Volt-Ampere
LBA	Long Baseline Array
LEED	Leadership in Energy and Environmental Design
LO	Local Oscillator
LRU	Line Replaceable Unit
LV	Low Voltage
M&C	Monitor and Control
MV	Medium Voltage
MVA	Medium-Volt-Ampere
NEC	National Electric Code
NMT	New Mexico Tech (New Mexico Institute of Mining & Technology)
ngVLA	Next Generation VLA
NRAO	National Radio Astronomy Observatory
NSB	ngVLA Site Buildings

Acronym	Description
OPS	Operations Buildings
PDR	Preliminary Design Review
RD	Reference Document
RFI	Radio Frequency Interference
RSS	Remote Support Station
SCADA	Supervisory Control and Data Acquisition
SEMP	Systems Engineering Management Plan
SOC	Science Operations Center
TBC	To Be Confirmed
TBD	To Be Determined
TRL	Technical Readiness Level
UPS	Uninterruptible Power Supply
VLA	Jansky Very Large Array
VLBA	Very Large Baseline Array
WVR	Water Vapor Radiometer

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