Monitor and Control Hardware Interface Layer: Preliminary Technical Requirements

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1 Introduction

1.1 Purpose

This document presents a set of technical requirements for the ngVLA Monitor and Control Hardware Interface Layer (M&C HIL). Many requirements flow down from the preliminary ngVLA System Requirements [AD02], which in turn flow down from the preliminary ngVLA Science Requirements [AD01]. This draft reflects a preliminary analysis of the science use cases and the operations concept, and the flow down recursively to the science, system, and subsystem requirements.

1.2 Scope

The scope of this document is the ngVLA M&C HIL. This consists of the Module Interface Board (MIB), similar to the EVLA Project MIB, and other related M&C HIL sub-boards and line-replaceable units (LRUs). This requirements document establishes the performance, functional, design, and test requirements applicable to the ngVLA M&C HIL.

Because the system touches upon or is part of all equipment in the antenna, sub-buildings, and the central electronics, there will be a high level of collaboration with all other Integrated Product Teams (IPTs) as their requirements will influence the Monitor and Control requirements and vice versa. This document includes interface requirements that need further decomposition in the conceptual design stage.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents are applicable to this technical specification to the extent specified. In the event of conflict between the documents referenced herein and the content of this technical specification, the content of this technical specification shall be considered a superseding requirement.

Ref. No.	Document Title	Rev/Doc. No.
AD01	Preliminary System Requirements	020.10.15.10.00-0003-REQ
AD02	System-Level Architecture Model	020.10.20.00.00-0002-DWG
AD03	System Reference Design	020.10.20.00.00-0001-REP
AD04	System Environmental Specification	020.10.15.10.00-0001-SPE
AD05	System EMC and RFI Mitigation Requirements	020.10.15.10.00-0002-REQ
AD06	L0 Safety Requirements	020.10.15.00.00-0004-REQ
AD07	Monitor & Control System: Reference Design Concept	020.50.25.00.00-0002-REQ

2.2 Reference Documents

The following references provide supporting context:

Ref. No.	Document Title	Rev/Doc. No.
RD01	Military Handbook, Reliability Prediction of Electronic Equipment	MIL-HDBK-217F
RD02	Non-electronic Parts Reliability Data	NPRD-95
RD03	Electromagnetic Compatibility	IEC 61000-3-5

3 Overview of the M&C HIL Technical Requirements

3.1 Document Outline

The technical requirements of the ngVLA M&C HIL determine the overall form and performance of the M&C HIL. The functional and performance specifications, along with detailed explanatory notes, are found in Section 4. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirements and should guide the verification procedures. In many cases, the notes explain or analyze how the numeric values of requirements were derived. Where numbers are not well substantiated, this is also documented in the notes. This makes the required analysis and trade-space available apparent to scientists and engineers who will guide the evolution of the ngVLA M&C HIL concepts. Documentation requirements can be found in Section 5.

Verification and Test requirements, from the conceptual design through to prototype, are described in Section 6. Section 7 (Appendix) contains relevant Monitor and Control maintenance information that informs the requirements of the M&C HIL.

3.2 General M&C HIL Description

The system will consist of an M&C Interface Board (MIB), similar to the EVLA Module Interface Board (MIB), which serves as the core hardware layer interface between the antenna M&C network and devices that need to be monitored and controlled. Additional boards proposed are analog and digital boards to provide flexibility and simplicity when added as part of the user device design. Finally, for M&C itself, antennas will be outfitted with six Line Replaceable Units (LRUs), currently called out as the M500 (Supervisor), M501 (Maintenance), M502 (Five Axis Antenna Control Unit), M503 (Antenna M&C Ethernet Switch), M504 (Weather Station), and M505 (Utility or Environmental). The first four and sixth LRUs are always present on the antennas, while the fifth is for selected remote antennas away from the array core at the VLA site.

The M502 Five Axis controller will likely be provided as part of the antenna contract, but a provision has been left in place for an NRAO-produced unit. Also, the antenna contract may specify use of a NRAO MIB.

The M&C system is an Ethernet fiber-based system that provides a great deal of RFI immunity versus copper connections. Other systems will be utilizing fiber as well throughout the antenna, so the fiber infrastructure will manage the M&C fiber infrastructure as well. Commercial products such as the fiber Ethernet switch are considered a gray area for LRUs. If the switch is easily replaceable by exchanging labeled cables, etc., then it could be considered a LRU. However, if it goes into programming in the field or insertion into a RFI shielded enclosure, it would not be considered a LRU since this would require additional labor at the antenna and a higher-level Tier I support team.

4 M&C HIL Functional and Performance Requirements

These requirements apply to a properly functioning system under operating environmental conditions unless otherwise stated.

4.1 Functional Requirements

Parameter	Req. #	Value	Traceability
Ethernet Interface	MCH0100	The MIB shall provide a high-level Ethernet interface to the M&C system; 1000Base-SX; SFP.	SYS3101
Serial Interface	MCH0101	Device (LRU) driven; CAN, SPI, USB, RS232, RS485, I^2C.	SYS3101
Parallel Interface	MCH0102	Device (LRU) driven; PC104, GPIO.	SYS3101
Device Identification	MCH0103	The MIB shall provide the protocol interfaces to support device identification.	SYS2406, SYS2407, SYS2408, SYS3102, SYS3103
Low-Speed Sampling-Analog	MCH0104	The M&C HIL shall provide analog data to system (screens, archive, etc.); ±10V span; ≥12 bits; <200 kHz.	SYS3101
High-Speed Sampling-Analog	MCH0105	The M&C HIL shall provide the capability of analog data recording, with a high-speed oscilloscope function for remote diagnostics; ±2V span; ≥8 bits; ≥100 MHz.	SYS3105
Digital to Analog Capability	MCH0116	The M&C HIL shall provide a function generator feature for remote and long-term maintenance.	SYS3105
Cross Point Switch-Analog and Digital	MCH0108	The M&C HIL shall provide logic analyzer capabilities for remote & long-term maintenance; inputs/multiple digital paths.	SYS3105
Weather Monitoring: Wind Speed	MCH0109	The M&C HIL shall provide wind speed measurements at each antenna site: W 33 m/s average over 10 min, W ≤40 m/s gust.	SYS2501
Weather Monitoring: Temperture	MCH0110	The M&C HIL shall provide temperature measurements at each antenna site: –20 C ≤T ≤45 C.	SYS2501
Weather Monitoring: Humidity	MCH0111	The M&C HIL shall provide humidity measurements at each antenna site: 0% to 100% RH	SYS2501
Weather Monitoring: Barometric Pressure	MCH0112	The M&C HIL shall provide barometric pressure measurements at each antenna site: 50 to 1100 hPa, ±0.10 hPa.	SYS2501
Weather Monitoring: Precipitation	MCH0113	The M&C HIL shall provide precipitation measurements at each antenna site: 5 cm/hr. over 10 min.	SYSTBD

Parameter	**Req. #**	**Value**	**Traceability**
Safety Weather Monitoring	MCH0114	The M&C HIL shall be designed to have redundant measurements for wind and temperature at each antenna site; ≤1minute periods	SYS2502
Weather Archive	MCH0115	The M&C HIL shall collect and forward, to the archive, weather data from all weather stations at no less than 1-minute periods.	SYS2503

4.2 System Monitoring Requirements

Parameter	Req. #	Value	Traceability
LRU Monitoring	MCH0150	Each LRU shall provide on-board monitoring and diagnostics to determine the health and status of the unit.	SYS3101
LRU Alerts	MCH0151	When an LRU is out of specification, it shall generate a prioritized alert for processing by the operator and maintenance scheduler.	SYS3102
Monitor Archive	MCH0152	Monitor data and alerts shall be archived at variable rates, depending on criticality, for the full life of the instrument. (SYS2801)	SYS3103
Subsystem Monitoring Screens	MCH0153	Engineering consoles shall be provided for all major subsystems.	SYS3104
Fast Read-Out Modes	MCH0154	Fast-read out modes shall be available for remote engineering diagnostics of all LRUs (i.e. an on-board oscilloscope function).	SYS3105

4.3 Environmental Requirements

Parameter	Req. #	Value	Traceability
Temperature-Normal Operating Conditions	MCH0203	The M&C HIL, with environmental conditioning from the Antenna Electronics Environmental Control System, shall have normal operations in the temperature range of: controlled environment (0°C to 60°C) when the system is exposed to the outside environment (–15°C ≤T ≤35°C)	ENV0323
Temperature Rate of Change-Normal Operating Conditions	MCH0204	The M&C HIL, with environmental conditioning from the Antenna Electronics Environmental Control System, shall have normal operations in the temperature rate of change when the system is exposed to the outside environment: 3.6°C/Hr.	ENV0324
Humidity-Normal Operating Conditions	MCH0205	The M&C HIL weather station components that are exposed to the environmental conditions shall be operate in a humidity range of 0% to 100% (non-condensing)	SYSTBD

Parameter	Req. #	Value	Traceability
Altitude-Normal Operating Conditions	MCH0206	The M&C HIL shall be designed to operate at altitudes ranging from sea level to 2500m	ENV0351
Temp-Survivability	MCH0207	The M&C HIL shall survive at a temperature range of –30°C ≤T ≤50°C, non-energized state	ENV0342

4.4 Maintenance, Availability, and Reliability Requirements

Parameter	**Req. #**	**Value**	**Traceability**
Mean Time To Failure	MCH0250	The M&C HIL shall have a MTBF of ≥131,400 Hours	SYS2402
Modulation	MCH0251	The M&C HIL and its subassemblies shall be modularized into Line Replaceable Units (LRUs)	SYS2403
Predictive and Self-Diagnostic Function	MCH0252	The M&C HIL shall provide the required communication interface for antenna system/subsystem to route predictive maintenance and self-diagnosis data.	SYS2405
Configuration Monitoring	MCH0253	The M&C HIL shall provide the required communication interface for antenna system/subsystem to route monitoring and tracking information.	SYS2406
Engineering Console	MCH0254	The M&C HIL shall provide the required communication interface for antenna system/subsystem to route needed information for system status and to assist in real-time diagnosis.	SYS2407
Engineering Database	MCH0255	The M&C HIL shall record monitor data at variable rates for automated use by predictive maintenance programs and for direct inspection by engineers and technicians.	SYS2408
Reliability, Availability, and Maintainability	MCH0400	The M&C HIL shall undergo reliability, availability, and maintainability analysis per MIL-HDBK-217F.	SYS2402

The maintenance and reliability requirements support high-level requirements that limit total array operating cost. Monitor points/sensors should be included in the MTBF/MTTR analysis, but sensors and other components that can be reasonably deemed ancillary to operation may be removed from the determination of compliance with the MTBF requirement. A software failure for which the system can automatically recover is also excluded. "Failure" is defined as a condition that places the system outside of its performance specifications or into an unsafe state, requiring repair. For the M&C HIL, the MTBF must be high as this subsystem is the link between LRUs and the online control system.

A Reliability, Availability, Maintainability analysis shall be performed in order to locate weak design points and to determine whether the design meets the Maintenance and Reliability requirements. The project recommends applying the Parts Count Method for predicting system reliability as described in the MIL-HDBK-217F, but the designer may propose to use other methods. For non-electronic parts, the values of NPRD-95 [AD22] or data from manufacturers or other databases may be used. Another, more time consuming (and considered more accurate) method, the Parts Stress Analysis Prediction, is also described in MIL-HDBK-217F. This may be used if the result of the Parts Count Method does not comply with the Maintenance and Reliability requirements.

ngVLA equipment will typically operate at an elevation of 2200 m above sea level, where temperature and pressure might decrease the MTBF relative to that at low elevations. These conditions shall be taken into specific account in the reliability prediction by using the environmental factor given in MIL-HDBK-217F. The analysis shall result in estimates of the Mean Time to Failures (MTTF) and Mean Time to Repair (MTTR), assuming that any scheduled preventive maintenance is performed.

4.5 Lifecycle Requirements

Parameter	Req. #	Value	Traceability
Design Life	MCH0300	The M&C HIL shall be designed to be operated and supported for a period of 20 years.	SYS2801
Life Cycle Optimization	MCH0301	The M&C HIL design shall minimize its lifecycle cost for 20 years of operation.	SYS2802

4.6 Safety Design Requirements

Parameter	Req. #	Value	Traceability
Controls for Safe Operations	MCH0350	The M&C HIL shall be designed to allow manual shutoff commands to part of the antenna that are identified as a potential hazard during an emergency and when energized.	SAF0040; SYS2701
Safety Design	MCH0351	The design of the M&C HIL shall incorporate all means necessary to preclude or limit hazards to personnel and equipment during assembly, disassembly, test, and operation.	SAF0042
Subsystem Self-Monitoring	MCH0352	The M&C HIL shall provide the communication interface between the antenna electronic subassemblies and the control center for the purpose system state-of-health monitoring.	SYS2701
IT Security	MCH0353	The M&C HIL shall be designed and operated in accordance with current IT Security best practices as defined by NSF-funded Center for Trustworthy Scientific Infrastructure (https://trustedci.org) and the AUI Cyber Security Policy.	SYS2702

4.7 Electromagnetic Compatibility Requirements

Parameter	Req. #	Value	Traceability
Shielding & Emission Limits	MCH0400	The M&C HIL element shall exhibit complete electromagnetic compatibility (EMC) among components (intra-system electromagnetic compatibility).	SYS2106

5 Documentation Generation and Storage Goals

5.1 Technical Documentation

All documentation related to the M&C HIL shall meet the following requirements:

- The language used for written documentation shall be English.
- Drawings shall be generated according to ISO standards and use metric units.
- Layouts of electronic circuits and printed circuit boards shall also be provided in electronically readable form. The ngVLA preferred formats are Altium Designer files for electronic circuit diagrams and printed circuit board layouts.
- The electronic document formats are Microsoft Word and Adobe PDF.
- The preferred CAD system used is AutoDesk Inventor and/or AutoCAD.

Any deviation from the above shall be agreed to by ngVLA.

5.2 Software and Software Documentation

The M&C HIL software and any other specially developed software are deliverables. The software shall be delivered in source and object form, together with all procedures and tests necessary for compilation, installation, testing, upgrades, and maintenance.

Software must be tagged with suitable version numbers that allow identification (also online remotely) of a release. Software user manuals developed under this specification and for any other commercial software used (controller embedded software, special tools, etc.) shall be provided, along with software maintenance and installation upgrade documentation. Full Test and Acceptance procedures shall be documented.

6 Verification and Quality Assurance

The design may be verified to meet the requirements by design (D), analysis (A), inspection (I), a factory acceptance test (FAT), or a site acceptance test (SAT). The definitions of each are given below.

Verification by Design: The performance shall be demonstrated by a proper design, which may be checked by the ngVLA project office during the design phase by review of the design documentation.

Verification by Analysis: The fulfillment of the specified performance shall be demonstrated by appropriate analysis (hand calculations, finite element analysis, thermal modeling, etc.), which will be checked by the ngVLA project office during the design phase.

Verification by Inspection: The compliance of the developed item is determined by a simple inspection or measurement.

Verification by Factory Acceptance Test: The compliance of the developed item / assembly / unit with the specified performance shall be demonstrated by tests. A FAT is performed without integration with interfacing systems.

Verification by Site Acceptance Test: The compliance of the developed item / assembly / unit with the specified performance shall be demonstrated by tests. SAT is performed on-site with the equipment as installed.

Multiple verification methods are allowed.

The following table summarizes the expected verification method for each requirement.

Req. #	Parameter/Requirement	D	A	I	FAT	SAT
MCH0100	Ethernet Interface	*				
MCH0101	Serial Interface	*				
MCH0102	Parallel Interface	*				
MCH0103	Device Identification					*
MCH0104	Low-Speed Sampling-Analog				*	
MCH0105	High-Speed Sampling-Analog				*	
MCH0106	Digital to Analog Capability				*	
MCH0107	Programmable I/O Bits-Digital				*	
MCH0108	Cross Point Switch-Analog and Digital				*	
MCH0109	Weather Monitoring-Wind Speed				*	
MCH0110	Weather Monitoring-Temp				*	
MCH0111	Weather Monitoring-Humidity				*	
MCH0112	Weather Monitoring-Barometric Pressure				*	
MCH0113	Weather Monitoring-Precipitation				*	
MCH0114	Safety Weather Monitoring				*	
MCH0115	Weather Archive				*	
MCH0150	LRU Monitoring					*
MCH0151	LRU Alerts					*
MCH0152	Monitor Archive					*
MCH0153	Subsystem Monitoring Screens				*	
MCH0154	Fast Read-Out Modes					*

Req. #	Parameter/Requirement	D	A	I	FAT	SAT
MCH0202	Humidity-Precision Operating Conditions				*	
MCH0203	Temperature-Normal Operating Conditions				*	
MCH0204	Temperature Rate of Change-Normal Operating Conditions				*	
MCH0205	Humidity-Normal Operating Conditions				*	
MCH0206	Altitude-Normal Operating Conditions				*	
MCH0207	Temp-Survivability				*	
MCH0250	Mean Time To Failure		*			
MCH0251	Modulation			*		
MCH0252	Predictive and Self-Diagnostic Function					*
MCH0253	Configuration Monitoring					*
MCH0254	Engineering Console					*
MCH0255	Engineering Database					*
MCH0400	Reliability, Availability, and Maintainability		*			
MCH0300	Design Life		*			
MCH0301	Life Cycle Optimization		*			
MCH0350	Controls for Safe Operations					*
MCH0351	Safety Design		*			
MCH0352	Subsystem Self-Monitoring					*
MCH0353	IT Security		*			
MCH0400	Shielding & Emission Limits				*	

Table 1 - Expected requirements verification method.

7 Appendix

7.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
CDR	Critical Design Review
CoDR	Conceptual Design Review
CW	Continuous Wave (Sine wave of fixed frequency and amplitude)
EIRP	Equivalent Isotropic Radiated Power
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMP	Electromagnetic Pulse
FDR	Final Design Review
FEA	Finite Element Analysis
FOV	Field of View
FWHM	Full Width Half Max (of Primary Beam Power)
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IF	Intermediate Frequency
KPP	Key Performance Parameters
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LO	Local Oscillator
LRU	Line Replaceable Unit
MTBF	Mean Time Between Failure
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
ngVLA	Next Generation VLA
PDR	Preliminary Design Review
RD	Reference Document
RFI	Radio Frequency Interference
RMS	Root Mean Square
RSS	Root of Sum of Squares
RTOS	Real-Time Operating System
RTP	Round Trip Phase
SAC	Science Advisory Council
SNR	Signal to Noise Ratio
SRSS	Square Root Sum of the Square
SWG	Science Working Group
TAC	Technical Advisory Council
TBD	To Be Determined
VLA	Jansky Very Large Array

7.2 Maintenance Definitions

7.2.1 Maintenance Approach

Required maintenance tasks shall be minimized. Maintenance shall be mainly performed at assembly and subassembly level by exchange of Line Replaceable Units (LRUs). LRUs are defined as units that can be easily exchanged (without extensive calibration, of sufficient low mass and dimension for ease of handling, etc.) by technician-level maintenance staff. LRU exchange shall be possible by two trained people within four working hours. It is desirable that LRU replacement be possible using only standard tools identified in a maintenance manual for the M&C HIL. A step-by-step procedure for safe exchange of every LRU shall be provided in the Maintenance Manual.

LRUs shall be defined by the M&C HIL designer, depending on the design. The LRUs will be maintained by the ngVLA project (with or without industrial support).

7.3 Monitor and Control Maintenance Considerations

7.3.1 Introduction

Maintenance for 263 or more ngVLA antennas will be complex especially given the proposed requirement of only a one visit/year for antennas. The maintenance approach to the antenna may impose monitoring and control requirements on the M&C HIL. These broader maintenance considerations are explored in this section.

7.3.2 Documentation

General documentation will be stored at each antenna for network loss. Specific documentation will be stored at each antenna or device for network loss. When a MIB or device is exchanged, all specific information will be either pre-loaded or loaded automatically into the antenna or device. Specifically, this includes any module firmware such as FPGAs updates, and MIB software updates.

7.3.3 Antenna Recovery

Automatic recovery is preferable to restore operation after failure due to external events. Full recovery (cold startup) usually follows a major power event. The antenna is placed into a safe position (stowed). Once communications are reestablished with the operational center, critical observational devices (HVAC, Dewar vacuum, cryogenics, etc.) are powered up based upon last antenna status, then non-critical devices are powered up.

The antenna must next establish timing synchronization to the array. The antenna self-tests at the antenna/device level, and self-testing continues until last antenna statuses match and receivers are operational. Operations staff conduct external/internal visual/aural inspection during self-testing. The antenna joins the calibration array automatically (preferred) or via Operations, and once calibrated it transfers to the observational array automatically (preferred) or via Operations.

Recovery (warm startup) usually follows an antenna temporary protective event such as high winds, extreme cold, etc. The antenna self-tests at the antenna/device level during the event, and after the event Operations staff conduct external/internal visual/aural inspection by operations. The antenna joins the calibration array automatically (preferred) or via Operations, and once antenna calibrated it transfers to the observational array automatically (preferred) or via Operations.

Complex maintenance (yearly checkup) would be full recovery (most likely) or recovery once personnel clears. Simple maintenance (repair) would be recovery (most likely) or full recovery (for critical observation devices) once personnel clears.

7.3.4 Resets: MIB, FPGA, Device Reset and Programming, and Device Power

Each MIB shall be individually resettable and remotely programmable. Device and FPGA program reset shall occur via MIB and/or via MIB reset, if applicable. FPGA and FPGA support memory shall be programmable via MIB. Devices should be capable of being individually remotely powered up or down.

7.3.5 Remote Maintenance Monitoring Instrumentation

- Oscilloscope ≥100 MHz sampling
- Logic analyzer/logic stimulator ≥100 MHz sampling; number of logic probes: TBD.
- Spectrum analyzer: requirements TBD.
- Signal generator: requirements TBD.

7.3.6 Reliability Centered Maintenance (Predictive & Preventive Maintenance)

Reliability centered maintenance (RCM) includes predictive maintenance (AKA condition monitoring) and preventive maintenance. This technique mainly relies upon conditional monitoring that would achieve just-on-time array-wide observing for ngVLA.

7.3.7 Predictive Maintenance

To evaluate equipment condition, predictive maintenance utilizes non-destructive measurement technologies such as infrared, acoustic including ultrasonic and sound level, visual, vibration, and other specific online testing. When the instrumentation feature is not being used by maintenance personnel, it would be processing conditions at the antenna for each device. Coupling these equipment measurements with measurements of observational performance would link antenna astronomical performance to equipment maintenance.

7.3.7.1 Predictive Maintenance Methods

Remote visual inspection provides a cost-efficient primary assessment. Essential information and defaults can be deduced from the external and endoscopic examinations. Good lighting is essential.

Vibration analysis is most productive on high-speed rotating equipment and can be the most expensive and difficult component to analyze. Vibration analysis, when properly done, allows the user to evaluate the condition of equipment to avoid failures.

Acoustical analysis can be done on a sonic or ultrasonic level. Ultrasonic techniques for condition monitoring make it possible to hear friction and stress in rotating machinery, as they produce distinctive sounds in the upper ultrasonic range that can predict deterioration faster than conventional techniques.

Sonic level monitoring is less expensive, but it also has fewer uses than ultrasonic technologies. Sonic technology is useful only on mechanical equipment, while ultrasonic equipment can detect electrical problems and is more flexible and reliable in detecting mechanical problems.

Infrared monitoring and analysis has the widest range of application (from high-speed to low-speed equipment), and is effective for spotting both mechanical and electrical failures and is considered to be a cost-effective technology. Model based condition monitoring for motors involves spectral analysis on the motor's current and voltage signals and then compares the measured parameters to a known and learned model of the motor to diagnose various electrical and mechanical anomalies.

7.3.8 Preventive Maintenance

Preventive maintenance uses average or expected life statistics to predict when maintenance will be required. Any planned preventive maintenance shall be documented in the Maintenance Manual.

7.3.8.1 Preventive Maintenance Methods

Oil analysis occurs offline and may require years to become effective. Basically, it can be thought of as used oil analysis and wear particle analysis. Used oil analysis determines the condition of the lubricant itself for both quality and suitability. Wear particle analysis determines the mechanical condition of machine components that are lubricated. Wear particle analysis allows identification of the composition of the solid material present and evaluation of particle type, size, concentration, distribution, and morphology.

Periodic calibration and maintenance would occur annually. An example for periodic calibration is COTS instrumentation such as weather instrumentation that requires yearly calibration to maintain performance specifications. An example for periodic maintenance is yearly lubricant replacement such as oil or grease, which would include sampling for later analysis.

7.4 Maintenance Database

While predictive and preventive maintenance begins with a robust M&C system to provide the best possible information, it ends at a Computerized Maintenance Management System (CMMS). This system would evaluate the status of a particular antenna to the device or object level, then write up a maintenance form for an issue that needs attention as soon as possible or create a punch-list item for the next antenna maintenance visit. The form would include information such as the azimuth, elevation, observation being run, temperatures, visual, aural, the device or object in question, and the detected issue. For the punch-list situation, gathering further information can help correlate the issue with other influencing factors such as antenna position or temperature to point personnel to the probable cause at the antenna or when the device is in for repair.

The importance of the CMMS can be viewed from an extreme thought experiment case: All 263 antennas have 10 random fault conditions at the same time. The CMMS would prioritize each antenna's condition for observational impacts, then provide that information to the operations staff, instead of having 2,630 faults vying for operations staff attention to sort priorities and observational impacts.

7.5 Monitor and Control Redundancy

Redundancy for the ngVLA within the M&C is limited, as having two MIBs in every device is not practical. However, an exception may be the M500 M&C Supervisor module, which can be viewed as equivalent to the VLBA Control Computer. Having two high-level MIBs able to operate the antenna reduces single-point failure. Also, when both MIBs are operational, the operational tasks can be subdivided between them for efficiency. Only when one fails does the other take up the full task load at a lessened efficiency level. This loss of efficiency will not compromise the observation.

7.6 Redundancy Outside of Monitor and Control

The current block diagram does not indicate devices that require redundancy. Therefore, each IPT group designer will have to determine if redundancy is required for their devices and how it can be provided.