REQUIREMENTS AND FUNCTIONAL SPECIFICATION

EVLA Correlator Room

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List of Abbreviations and Acronyms

ESD – Electrostatic Discharge

EVLA – Expanded Very Large Array near Socorro New Mexico

HEPA – High Efficiency Particulate Air Filter

MERV – Minimum Efficiency Rating Value

NRAO – National Radio Astronomy Observatory

PCB – Printed Circuit Board

Definitions

Revision History

Revision	Date	Changes/Notes	Author
DRAFT	Oct 18, 2005	Initial Release for NRAO feedback	R. Webber, B. Carlson
DRAFT2	Oct 21, 2005	Add summary table. Use NRAO-standard –48 VDC wiring colours.	R. Webber, B. Carlson
1.0	April 12, 2006	V1.0 release after VLA-site visit and review on April 5, 2006. Add holes to rack headprint for overhead cable tray mounting.	B. Carlson

1 Requirements Summary Table

Description	Parameters	Comments	Page
PHYSICAL			
Computer room floor	ESD dissipative, 10^8-10^{10} ohm, raised for cabling & cold air delivery	NRAO supplied and installed.	21, 34
Correlator room size	47'W x 48'D x 8.5'H (min) 9.5'(best)	Usable inside dimensions after raised floor install.	13
Correlator area footprint	20' x 18'	32-stat. Corr.	11
Correlator rack outside dimensions	30.0" W x 36" D x 89.5" H	Includes blower fans	18
Rack doors	RH swing; front smoked-glass; rear solid.		
Correlator rack weight	1000 lbs	Estimated	18
Correlator rack mounting	On NRAO-supplied pedestals		20
Correlator rack front/back clearance	2.5'		13
-48 VDC Power plant rack dimensions	24" W x 30" D x 84" H	Preliminary; 2 racks for 32-station corr.	24
-48 VDC Power plant rack weight	1500 lbs	Preliminary	24
-48 VDC Power plant rack front/back clearance	2.5'	Preliminary	24
-48 VDC Power plant battery string dimensions	4' x 3.2'	Preliminary; 2 strings for 32-station corr.	24
-48 VDC Power plant battery string weight (ea)	4170 lbs	Preliminary	24
-48 VDC Power plant batter string clearance (360^o)	3'	Preliminary; 2 strings can be in compact back-to-back config	
Screened room floor roughness	3" radius vertical, ½" radius horizontal	Applies to area underneath Correlator area footprint	22
Backend computer racks	Up to 6	Could be shelves for desk-top units	13
Control computer racks	Up to 2, 19" racks		13
Fiber racks	Up to 2, 19" racks	NRAO-defined/supplied	13
Number of Correlator racks	8 Stat/32; 10 Stat/40 16 Bas/32; 16 Bas/40		13

Description	Parameters	Comments	Page
ELECTRICAL, POWER, GROUNDING			
-48 VDC Power plant AC input	480 VAC, 3-phase delta; 211 kVA (**190 kW**) 32-stat; 280 kVA (252 kW) 40-stat;	Estimated. Assume 0.9 power factor; could be as high as 0.998 power factor.	22
110 VAC for auxiliary equipment, computers, outlets.	56 kVA (**50 kW**) 32-stat; 89 kVA (80 kW) 40-stat;	Requires battery backup; could be supplied as 480 VAC, with power x-former in room	22
AC for HVAC and lighting	Undefined	NRAO def.	23
-48 VDC total power requirement	167 kW 32-stat; 227 kW 40-stat	Estimated	23
-48 VDC power plant efficiency	90%	Preliminary	22
-48 VDC wiring power loss	2%		22, 27
-48 VDC power plant power losses	18.6 kW 32-stat; 25.2 kW 40-stat.	Based on 90% efficiency, estimated	
-48 VDC wiring power losses	3.4 kW 32-stat; 4.5 kW 40-stat	Based on 2% losses, estimated	
Station rack power requirements (ea)	7000 W, 146 A @ -48 VDC	Estimated.	23
Baseline rack power requirements (ea)	6700 W, 140 A @ -48 VDC; 9530 W, 200 A @ -48 VDC	Estimated. Numbers for 32-stat and 40-stat corr. respectively.	23
-48 VDC wire colour coding	-48 VDC hot—**VIOLET**; 48 VReturn—**BLACK**	Consistent with NRAO standard.	26
-48 VDC wiring	Wire thickness defined for 2% power and voltage loss.	#2 to #4/0 AWG	27
-48 VDC battery string capacity (ea)	5 min @ 2000 A		13
110 VAC wiring	Per NEC. Standard 3-prong sockets	Outlets as required by computers; aux in-floor outlets ~10' spacing.	28
-48 VDC system grounding	48 VReturn grounded at main distribution/breaker panel.	Well-defined DC current paths.	28

Description	Parameters	Comments	Page
ELECTRICAL, POWER, GROUNDING cont'd			
Grounding plan for EMC	Signal ground bonded to rack to screened-room floor; common-mode filter –48 VDC. 110 VAC 3rd-prong ground shortest distance.	Shunt common-mode noise between racks. Filter common-mode noise as feasible.	30
Radiated EMI levels from all room equipment.	Likely FCC Part 15 **Class A**	Requires testing to quantify	31
Conducted EMI levels on AC input.	FCC Part 15 **Class A**	Requires screened-room entry filters.	31
Safety	All COTS equipment certified to UL. Wiring per National Electrical Code. All under-floor cabling must be plenum rated.	Certified installers. Requires consultation with –48 VDC power plant mfg for installation to code.	24
Thermal overload protection	CPU-readable temperature sensors on each board; deadman thermostats on each board.	For correlator rack boards only. No direct sensing/protection for aux. COTS computers.	16
ENVIRONMENT			
Correlator rack cooling	Stat **1700 cfm**; Bas 1000 cfm 32-stat, 1700 cfm 40-stat	**T_{input} = 15 ^{o}C** max; air entry from floor, exhaust out the top	31
-48 VDC Power plant and battery cooling	18.6 kW or 25.2 kW load; self-cooled with front-to back fans. T_{amb_max} 40 ^{o}C	Preliminary. No air entry from floor required.	Mfg spec
Total room power dissipation	**240 kW** 32-stat; 332 kW 40-stat;	Estimated. Does not include: Lighting, HVAC, Fiber racks	22
Air quality	ISO Class 8	Additional MERV filtering recommended	33
ESD recommendations	Card-swipe interlock; ESD shoes; ESD coats.	Highly recommended for ESD protection.	34
Humidity	40-60% relative	Highly recommended for ESD protection.	34

Cosmic rays	No requirements	7000 ft altitude	35
Seismic	Zone 2B	NRAO responsibility for securing room equipment .	35

2 Introduction

This document describes requirements for the EVLA correlator room at the VLA Site Central Electronics Building. This includes requirements for physical layout of the correlator, mains power supplies and cable routing, safety and high frequency grounding, forced-air cooling, and particulate filtering.

The correlator will be inside a shielded room that is being constructed by NRAO. Requirements for the shielded room itself are beyond the scope of this document, and are NRAO's responsibility. However, the requirements defined in this document may impact the construction of the shielded room.

A synopsis of the general requirements for the correlator room is as follows:

- The correlator rack floor plan is to be as compact as possible. This is necessary to minimize inter-rack cable lengths which impacts high-speed signal integrity and cost. The correlator racks will occupy a space of approximately 20 ft x 18 ft, not including additional computer racks, fiber-optic racks, and the –48 VDC power plant. Refer to Figure 3-1 for more detailed information.

- Floor loading capacity to support the racks and associated equipment. Due to the weight of the racks, rack pedestals will be used and are to be built by NRAO. These pedestals mount on the screened-room sub-floor and so do not cause loading of the raised computer floor.

- The correlator runs off -48VDC in a similar manner and for similar reasons as a telephony central office. A central –48 VDC power plant and associated cabling is required to be installed to provide power for the correlator. The –48 VDC power plant must have batteries for 5 minute backup at full power. For a 32-station correlator, the –48 VDC power requirement is estimated at 167 kW. For a 40-station correlator, this increases to about 227 kW.

- Auxiliary computer systems will require battery-backed 110 VAC power. For a 32-station correlator, the 110 VAC power requirements are estimated at 50 kW or 56 kVA at 0.9 power factor.

- Total power dissipation of the room for a 32-station correlator is estimated at 235 kW, with the –48 VDC power plant operating at 90% efficiency. Thus, the HVAC system must be capable of handling this total power. For a 40-station correlator this increases to 302 kW.

- Required rack air entry temperature is maximum15 ^{o}C. The 8 Station racks require 1700 cfm (cubic feet per minute) of airflow each, and for a 32-station correlator, the 16 Baseline racks require 1000 cfm each. For a 40-station correlator there are a total of 26 racks and each requires 1700 cfm airflow. The air exit temperature rise is 10-14 ^{o}C. This airflow and inlet temperature has been calculated for the 7000 ft altitude of the VLA [1] [2].

- Air particulate contamination ISO class 8 with additional MERV filtering.

- A satisfactory ESD environment is necessary for the long-term reliability of the correlator. This document will make specific recommendations for ESD protection of the room's components.

3 Overview

The correlator room contains correlator racks, backend computers, fiber and switch racks, HVAC equipment, and the battery-backed -48VDC power plant. The racks have been located in a manner to keep high-speed cable lengths minimized between Station and Baseline racks to minimize cost and signal integrity degradation.

A simplified correlator room floor plan is shown in Figure 3-1.

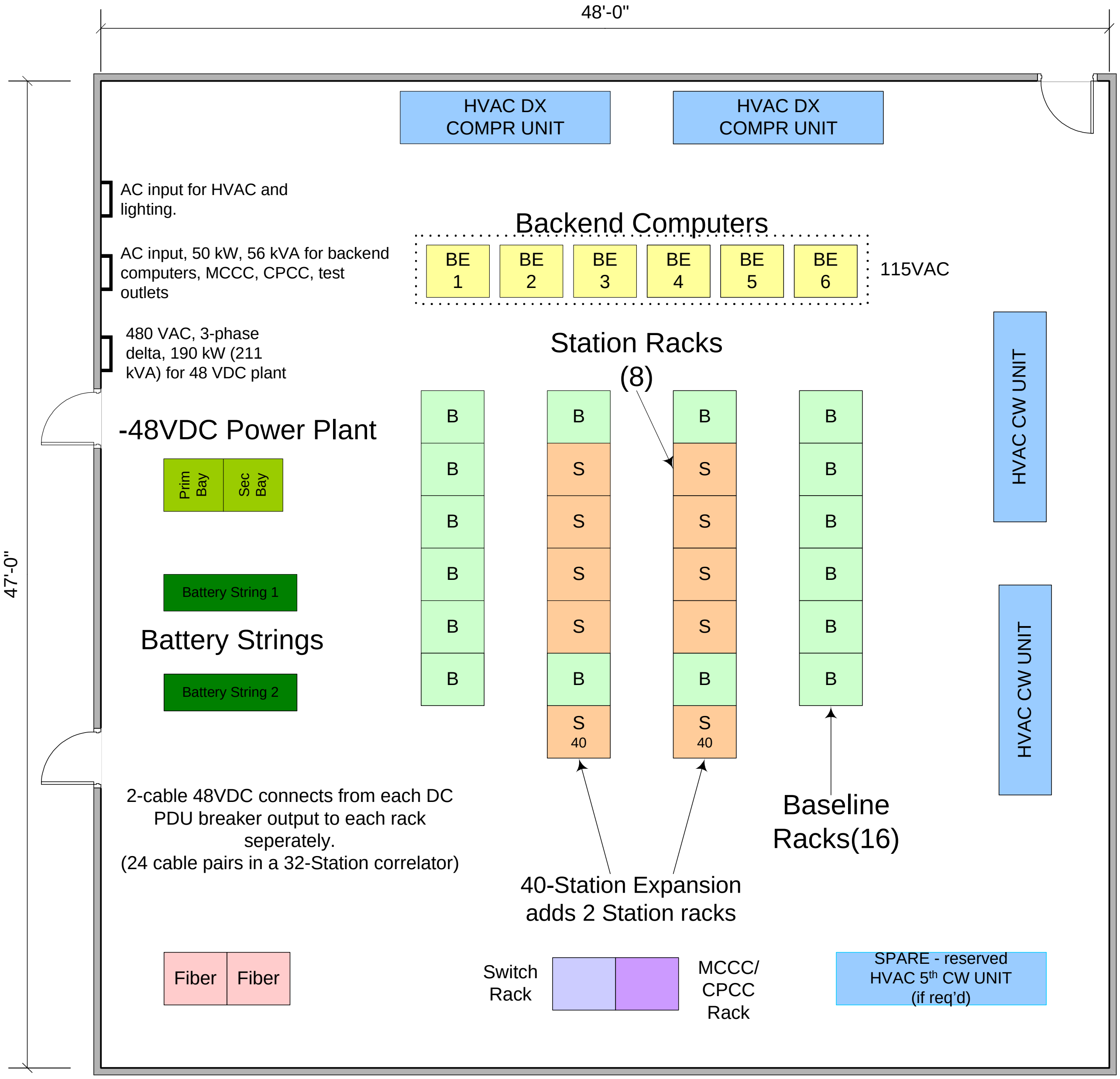


Figure 3-1 Correlator room floor plan

An overview description of the correlator room and its components is as follows:

- **Room size –** Correlator room usable inside dimensions (i.e. with the raised computer floor installed), are 47'W x 48'D x 8.5'H. The 8.5' height is a minimum requirement—for more headroom for overhead cable trays etc. this should be at least 9.5'.

- **Correlator racks –** The total rack height is 89.5" (7' 5.5") and a *minimum* of 1 ft of additional overhead clearance is required for air exhaust. Both Station and Baseline racks will be the identical size and contain 2-12U sub-racks, 1-6U sub-rack, 1 air duct and a fan tray assembly. The nominal rack footprint is 2.5' wide x 3' deep, and there is 2.5' of front to back clearance between each row of racks. Racks within each row stand side-by-side, and there is no space requirement between these racks. The baseline plan is to install the racks and cables in the correlator room in advance of the arrival of limited production and full production boards. The racks will be installed on pedestals, and the bottom of the rack will be flush with the raised computer floor.

- **-48 VDC power plant –** This is a COTS (Commercial Off-the-Shelf) standalone power plant. This system will require two 19" racks (bays) to supply power for a 32-station correlator. Each rack contains one or more AC-DC converters (PCUs—Power Converter Units) and control electronics. One or more racks may be added later for additional power for a total maximum capacity of 10,000 A (480 kW). This system is fed with 480 VAC 3-phase power.

- **Battery strings –** These are sets of 48 VDC batteries that are needed to provide the 5 minute power backup for the correlator. These batteries represent a significant floor load in themselves, and may require the construction of separate pedestals so they don't directly load the raised floor. Each battery string provides 2000 A for 5 minutes, is 4' x 3.2' x 6' high, weighs approximately 4170 lbs, and has a 360^{o} 3 ft clearance requirement. There are no personnel safety concerns for these units as they are intended for an office environment. For a 32-station correlator at 167 kW load, 2 strings are required. For a 40-station correlator at 227 kW, 3 strings are required.

- **Backend computers –** These are the post-processing "backend" computers for the correlator. They are COTS PCs powered by 110 VAC. The exact number of racks and computers, and the configuration of the computers (i.e. rack-mount or desk-top) has not yet been determined, however a minimum cost/maximum performance approach will be taken (e.g. they could be rack-mount computers, or desk-top computers mounted in rack shelves). It is likely that there are on the order of 50 or so backend computers.

- **MCCC/CPCCC and Switch rack(s) –** These are one or two 19" racks containing the correlator MCCC (Master Correlator Control Computer), CPCC (Correlator Power Control Computer), Ethernet switches, and possibly the few required Phasing Boards (fed with –48 VDC). These computers will likely be fed off of their own secondary 110 VAC backup power supplies. The exact configuration of these computers has not yet been determined, although it is likely that the CPCC computer will be a rack-mount, high-availability Compact-PCI system. It is not yet clear whether the "Switch rack" is a separate entity, or whether everything can be contained in one rack. Ethernet switches required between the correlator and the backend computers will likely reside in the same racks as the backend computers.

- **HVAC systems –** These are systems installed by, and under the responsibility of NRAO and are shown in their approximate location. These systems filter the air as per the requirements defined in this document and provide air at the required volume flow rate for all of the racks via the space underneath the raised computer floor. The racks are cooled with 15 ^{o}C cold air flow of 1700 cfm each. The room HVAC system must be capable of supplying enough cold air for all of the racks. For a 32-station correlator, the HVAC system must have enough cooling capacity for ~235 kW and for a 40-station correlator this increases to ~302 kW.

- **Air particulate contamination –** The requirement is ISO Class 8. Additional HEPA air filtering at the HVAC system or at the racks to filter 0.3 micron particulates may be required to improve air quality.

- **Rack loading –** Each large correlator board will have a ~10lb extruded aluminum heat sink attached to it. The combined weight of each board with heat sink will be approximately 15 lbs, and there are up to 16 boards in each rack. Along with other things, the total rack weight is likely to be about 1000 lbs. The rack is mounted on a pedestal that is attached to the screened-room sub-floor. Thus, the raised floor does not have to bear the load of correlator racks, however the pedestal, the screened-room sub-floor, and the supporting sub-structure must be capable of supporting rack point and combined loads.

- **Station rack to Baseline rack high-speed cabling** – All high-speed interconnect cabling will be routed through the rear of each rack and down to the screened-room sub-floor (refer to Figure 7-1). There are about 500 cables that connect Station and Baseline racks, routed in a star configuration. The screened-room sub-floor must be free of sharp protrusions. Since there a large number of cable crossings, additional hardware may be required to eliminate potentially damaging cable crush, although this can be installed when the cable is installed and does not form part of the room requirements. These cables must be "plenum rated" since they are contained within the air delivery path.

- **-48 VDC power cabling** – A pair of high current capacity power cables will run from the –48 VDC distribution/breaker panel to each rack. This cable is routed in overhead cable trays. These trays generally are located in the region near the back of the racks. Cable entry cutouts at the top-rear of each rack allow the power cable to be fed downward to a breaker panel mounted at the top rear of each rack. Each large board in a rack has its own breaker in this panel, and a wire pair from each breaker feeds each board. In addition, there is a manually operated power switch (red panic button) inside the back of each rack, to allow the power to be cut to the rack at that point. It is important to note that the –48 VDC return cable is isolated and does not connect to chassis ground in the rack. The –48 VDC return cable is connected to earth/chassis ground at the –48 VDC distribution panel, located near the power plant.

- **Fiber, Ethernet and M&C cabling** – A separate overhead cable tray running along the front of each rack contains all additional cable routing including fiber from the antennas from the fiber racks, the Monitor and Control (M&C) Ethernet network cables, the correlator-to-backend 1 Gbps Ethernet cables, and the rack fan and power supply monitor and control cables.

- **Rack fan power monitor and control –** Each board in each rack has one power supply monitor and one power supply control line. These TTL-level I/O lines are referenced to earth/rack chassis ground, and all get fed via terminal blocks and cables to digital I/O control cards in the CPCC. Similar fan speed monitor and control lines exist for the rack fans, also routed to the CPCC. Thus, it is possible to monitor and control power (on/off) to each board in the system as well as monitor and control fan speed. These lines, along with thermal sensors on each board accessed by the M&C network, will be used to intelligently control power and rack cooling in the system.

- **Thermal overload protection –** Each board with an embedded processor (Station Board, Baseline Board, Phasing Board, Timecode Board) has temperature sensors on the board that can be read to determine board operating temperature. If temperature starts increasing and reaches a certain trip point, the CPCC can be signaled to shut power off on the board. Additionally, each board has a deadman mechanical thermostat that will trip and shut the power supplies off on the board if the preset trip temperature is reached (the preset trip temperature is TBD, but is likely 75-80 ^{o}C). This ensures that even if network communications is lost and CPUs go down, the boards will protect themselves from thermal overload.

The same diagram as Figure 3-1, but with the nominal location of power and signal cable trays is shown in Figure 3-2.

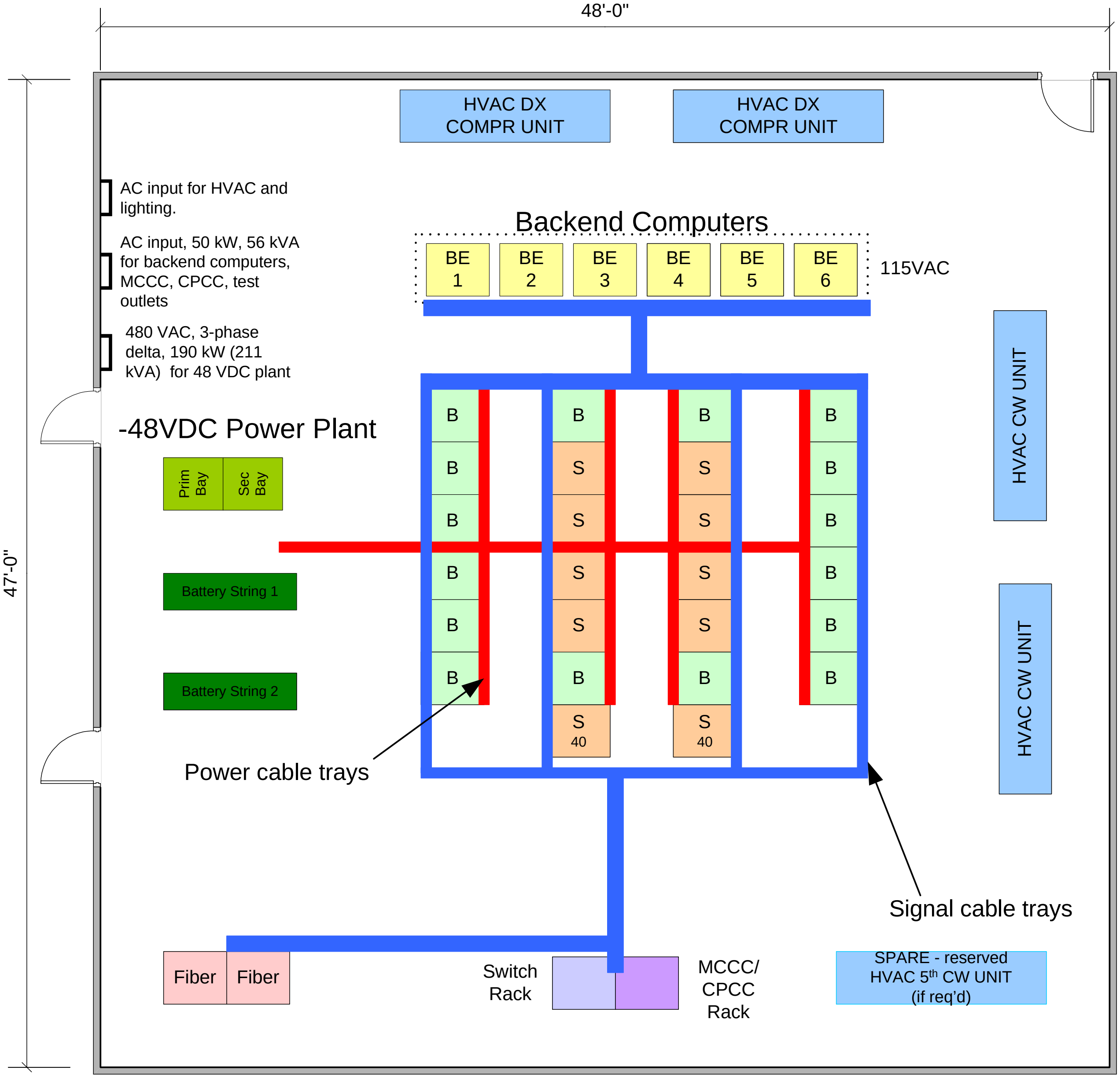


Figure 3-2 Rack layout with locations of overhead cable routing trays shown in red and blue.

4 Physical Requirements

4.1 Correlator Rack Parameters

This section defines rack physical specifications such as outside dimensions, footprints, and weights. The Station and Baseline racks are virtually identical in design, however the Station racks will likely be lighter than that specified in this section.

4.1.1 Rack Dimensions

Outside rack dimensions:

- Height 89.5” including the top-mount fan-tray assembly.
- Width 30”.
- Depth 36”.

4.1.2 Rack Weight

The table below lists correlator rack component weights and total weight estimates.

Quantity	Description	Unit Weight (lbs)	Total Weight (lbs)
1	Unpopulated rack	400	400
2	12U sub-rack (populated)	20	40
16	Baseline or Station board	15	240
1	6U sub-rack (populated)	10	10
1	3U Fan Tray (with 4-8”fans)	30	30
1	9U Air Duct	30	30
1	Ethernet switches, 48 VDC breaker panel, feed-thru backplanes	100	100
1	HM high-speed cable, 48VDC cable, various cable, miscl items.	150	150
		Total Rack Weight	**1000**

Table 4-1 Correlator rack component and total weight.

4.1.3 Rack Footprint

The correlator rack footprint has a 30” x 24” opening that is used to allow cool air from the HVAC system to enter into the rack in a bottom-to-top flow. The four corners of the floor panel have mounting holes that allow connection to the rack pedestal. The rack pedestal must be designed to mate with these hole locations, and to not block airflow in the 24” x 30” opening.

The rack footprint is shown below—refer to drawing D25015M0001.

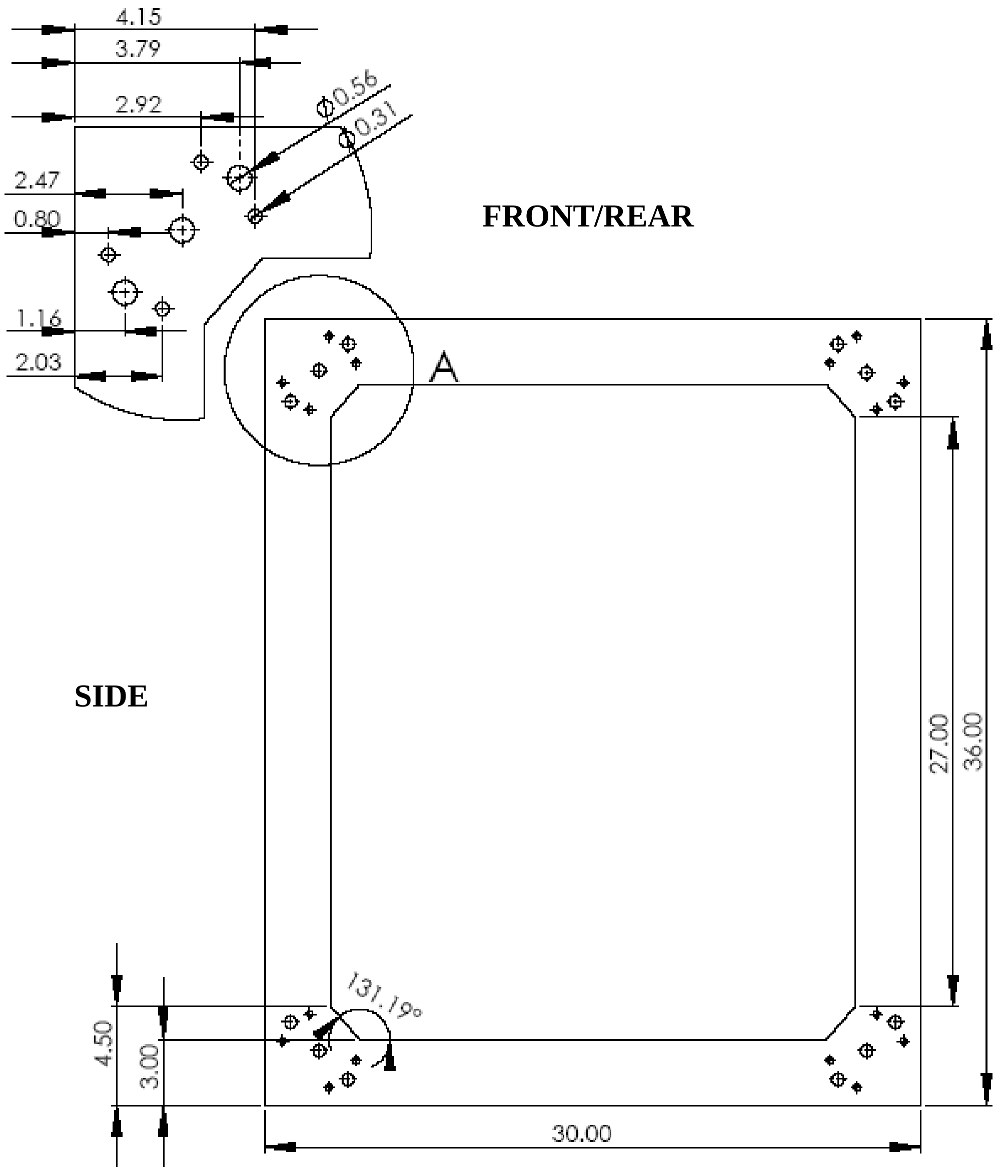


Figure 4-1 EVLA rack floor panel

4.1.4 Rack Head Print

The rack roof panel will provide a 24" x 22.75" opening for mounting of the fan tray assembly. Four 3.5" holes in each corner of the rack roof panel are used as access for –48VDC power, Ethernet, fiber and monitor & control cabling entering into the rack.

A fan tray assembly mounts directly onto the rack roof panel and blocks about ½ the openings of the 4 corner cable inlet openings. The function of the fan tray assembly is to draw air upward through the vertical cavity of the rack and exhaust it out the top of the rack. Each of the fans can be individually and easily removed and replaced without cutting power to the rack. Removal and installation is via the front and back of the racks.

The rack headprint is shown below. The front (fiber and control) and rear (-48 VDC power) overhead cable trays should be located in approximately the locations shown, at least 1 ft above the top of the rack's fan tray assembly. Four ½" corner holes are included in the rack roof for the purposes of attaching the cable trays. Maximum load per hole is 100 lbs. Note that the fan tray assembly partially blocks the cable entry holes. Refer to drawing D25015M0002.

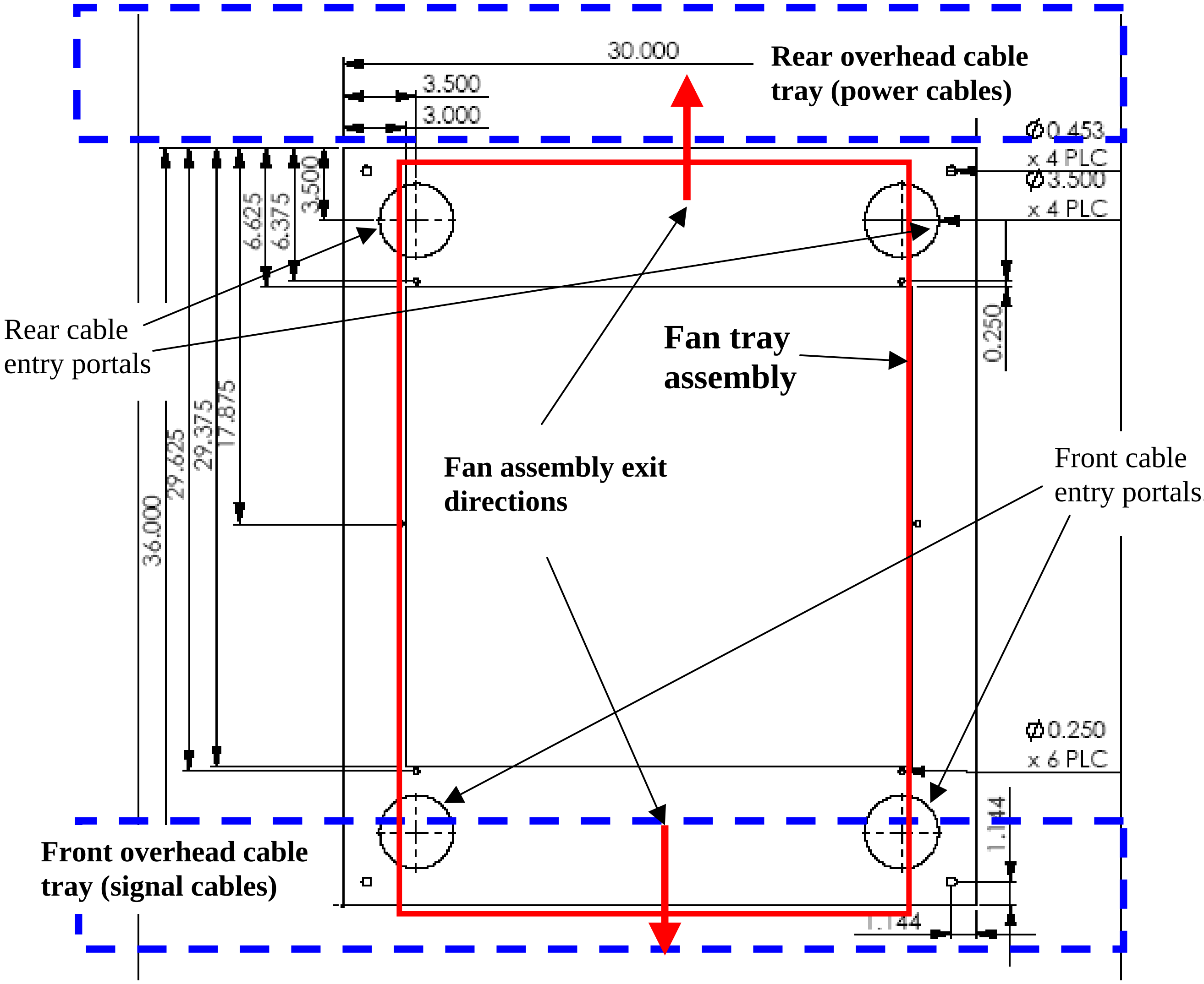


Figure 4-2 EVLA rack head print

4.2 Rack Pedestal Requirements

The correlator rack pedestal will be designed and built by NRAO. The pedestal must mate with the rack and the hole locations as defined by Figure 4-1. Since correlator racks will be arranged in rows, it is acceptable if a monolithic pedestal is built to contain an entire row of racks as shown in Figure 3-1, with 30.00” allowed for each rack. In this case, the side panels in adjoining racks are not installed. The pedestal must be designed to minimize airflow blockage to easily allow for the 1700 cfm airflow required by each rack and delivered through the opening to each rack shown in Figure 4-1.

In addition, since many high-speed plenum-rated cables will be routed from the rack to the screened room floor through the pedestal, and since the cables cannot withstand sharp edges and too much cable crush, a minimum 3” radius in the vertical direction, and a minimum ½” radius in the horizontal direction is required. This requirement can likely be met if there is no horizontal member running along the base of the pedestal as shown in Figure 4-3.

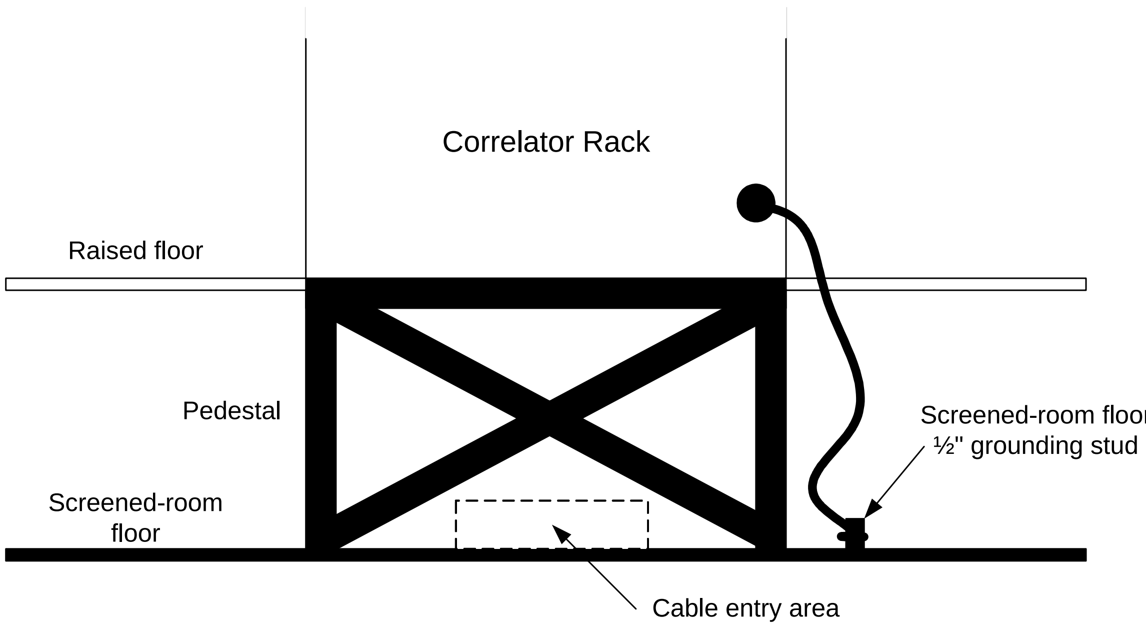


Figure 4-3 Rack pedestal simplified design to eliminate cable crush.

4.3 Floor Loading

A 20” high raised computer floor system provides a convenient way to duct cooling air from the HVAC systems to the racks and to route high-speed inter-rack cabling. The correlator room floor must be able to support the weight of all of the racks shown in Figure 3-1, except for the correlator racks themselves that will be on pedestals and do not load the floor. Raised floor load bearing capability is a function of the manufacturer’s specification and the positioning of the equipment relative to the raised floor grid.

Each correlator rack will be mounted onto a pedestal attached to the screened room sub-floor. There will be an airtight cutout in the floor for each pedestal to be placed; the top of the pedestal/bottom of the rack will be flush to the room’s floor. The correlator racks will give the appearance of being mounted to the room’s floor.

Probably the heaviest component in the correlator room will be the –48 VDC battery strings that weigh about 4170 lbs each. It is possible that pedestals for these battery strings will be required so that the raised floor does not have to bear this load. The –48 VDC power plant bays weigh about 1500 lbs each, and these could require pedestals or additional under-floor supports.

4.4 Screened Room Physical Requirements

The primary physical requirement, other than floor loading as defined in other sections of this document, is that the screened room sub-floor underneath the raised floor in the area bounded by the correlator (Station and Baseline) racks must be free of sharp protrusions that can damage or crush the 500 or so high-speed plenum-rated cables that route from the Station racks in a star pattern to the Baseline racks. To prevent cable damage, the following requirements are placed on the screened-room sub-floor:

1. The minimum radius for all protrusions in the vertical direction is specified as 3”.

2. The minimum radius for all protrusions in the horizontal direction is specified as ½”.

To meet the above requirements it is likely necessary that rubber or plastic bumpers be installed over all screened-room floor protrusions, and in the horizontal direction over all orthogonal protrusions up to a height of 4” above the floor.

5 Power System Requirements

5.1 AC Input Requirements

There are three requirements for AC input to the correlator room. The first requirement is for the AC supply for the –48 VDC power plant. The second requirement is for the AC supply for the equipment in the room that will run off 110 VAC, and for auxiliary output 110 VAC for test equipment. The third requirement is AC for the HVAC systems and for lighting etc. These requirements are as follows:

1. For the –48 VDC power plant, 3-phase 480 VAC delta is required. For a 32-station correlator, the total estimated power is 211 kVA (190 kW). This is based on a 90% power plant efficiency and a 2% power cable loss. The power supply’s power factor is nominally 0.9 and could be as high as 0.998. This supply does not require battery backup, however surge suppressors on this line, according to the power plant manufacturer’s recommendations are required. If a 40-station correlator is to be supported, then the total estimated power is 280 kVA (252 kW).

2. The 110 VAC for auxiliary equipment and computers for a 32-station correlator has a total estimated power requirement of approximately 50 kW, at 0.9 power factor (56 kVA). This power requirement is highly dependent on how many backend computers are installed, the power dissipation per computer, the number of Ethernet switches required and the power per switch. This power requirement

is roughly a factor of 1.5X over the minimum requirement. For a 40-station correlator, up to 80 kW could be required. This 110 VAC supply must be battery-backed and surge protected. Battery back-up time should be a minimum of 5 minutes.

Note that it is likely convenient for this AC supply to enter the room as 480 VAC 3-phase battery-backed, and use an in-room power transformer to produce 3 phases of 110 VAC to standard 110 VAC 3-prong outlets. The relative phase of 110 VAC from outlet-to-outlet is not important. If battery-backed input is not possible, then a UPS system (not shown in Figure 3-1) will have to be installed in the room.

3. The AC input for the HVAC and lighting systems is NRAO's responsibility and is beyond the scope of this document.

5.2 –48VDC Power Requirements

This section defines the –48 VDC supply requirements for each rack for a 32-station correlator. In a 32-station correlator there are 16 Station Boards, 10 Baseline Boards, and additional auxiliary boards and fans per rack. **Note that these requirements are preliminary and are based on power estimates, not on actual power measurements**.

1. Station rack –48 VDC power requirement: 7000 W (146 A @ -48 VDC). This includes 150 W for a –48 VDC Ethernet switch, and 400 W for the fans.

2. Baseline rack –48 VDC power requirement: 6700 W (140 A @ -48 VDC) (also includes 350 W for 1 Phasing Board, although the final location of Phasing Boards has not yet been determined). (For a 40-station correlator, there are 15 Baseline Boards per rack for total estimate power dissipation of 9530 W)

Note that it is likely prudent to use wire for each rack for 10 kW power dissipation (208 A @ -48 VDC).

3. For cost reasons the MCCC will likely be powered off 110 VAC, with its own secondary backup.

4. For reliability and cost reasons, the CPCC will likely be powered off 110 VAC, with its own secondary battery backup.

5. For cost reasons the backend computers will be powered off 110 VAC.

As there are 8 Station racks and 16 Baseline racks in the system, the total –48 VDC power requirement is **167 kW for a 32-station correlator** (3500 A @ -48 VDC, with 2% cable loss). For **a 40-station correlator, this increases to 227 kW** (4730 A @ -48 VDC, with 2% cable loss).

5.3 –48 VDC Power Plant

The –48 VDC power plant is a COTS system designed for a telephony central office system. One such system is the Emmerson Network Power/Marconi SAG582140000 Model LPS48E1 plant and has the following basic specifications:

1. 19" rack-mount system. A complete system consists of multiple "bays" (a bay is one 19" rack), and each bay contains multiple 480 VAC to –48 VDC 200 A converter modules (LPS200E50 PCU). Each bay can produce up to 2000 A and the maximum number of bays that can be wired together is 5 for a total capacity of 10,000 A. PCUs can be operated in an N+1 redundant configuration and can be hot-replaced. It is a requirement of the correlator system that the power plant is N+1 redundant with hot-swap/replacement capability.

2. For a 32-station correlator requiring an estimated 3500 A, two bays will be required, and for N+1 redundant operation a total of 20 PCUs will be required. For a 40-station correlator, 3 bays are required. It is likely possible to add the 3rd bay after the initial installation if required. Each bay occupies a floor area of 30" x 24", and each one weighs approximately 1500 lbs. Minimum clearance around the bays is 2.5 ft, although bays can be adjacent to each other as shown in Figure 3-1.

3. The output of the plant is wired to 2 battery strings (3 for a 40-station correlator) to provide the 5 minutes of backup at full power. These battery strings will occupy a floor area of 4' x 3.2' and weigh 4170 lbs each.

4. The system meets UL safety standards for a Custom Built Power Distribution Center for Communications Equipment.

A drawing of the Emmerson Network Power 431829 battery string is shown in Figure 5-1.

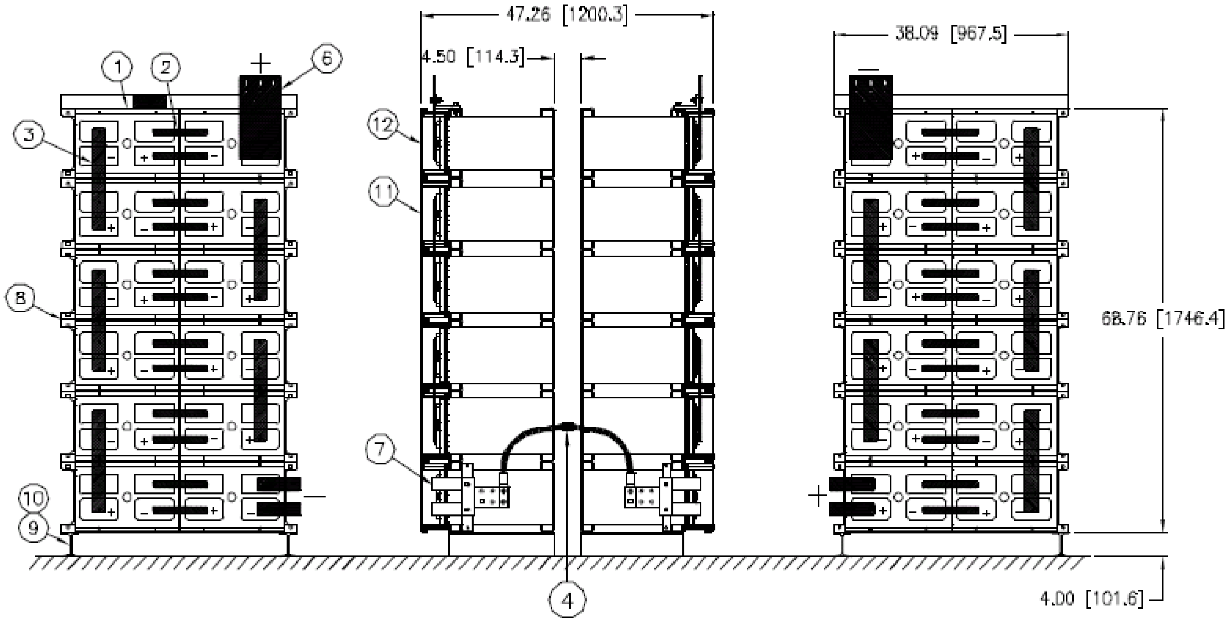


Figure 5-1 Emmerson Network 431829 2000 A battery string.

For a complete list of specifications for the power plant, refer to [3] (the first few pages of which are attached to the appendix of this document). The exact specifications and requirements for the room cannot be determined until the final power plant selection has been made through a competitive bidding process. Thus, **these specifications are preliminary in nature only**, although they will likely be used to develop the specifications for the system.

A simplified wiring diagram of the power plant and the correlator racks is shown in Figure 5-2. “Remote Control” is TBD but is likely two contacts that, when short-circuited, interrupt power to the correlator using the “Power interrupt switch”. A red “panic button” emergency shutdown switch will also break power to the entire correlator using the same mechanism. The power plant itself can also be monitored remotely via Ethernet to detect and diagnose system problems.

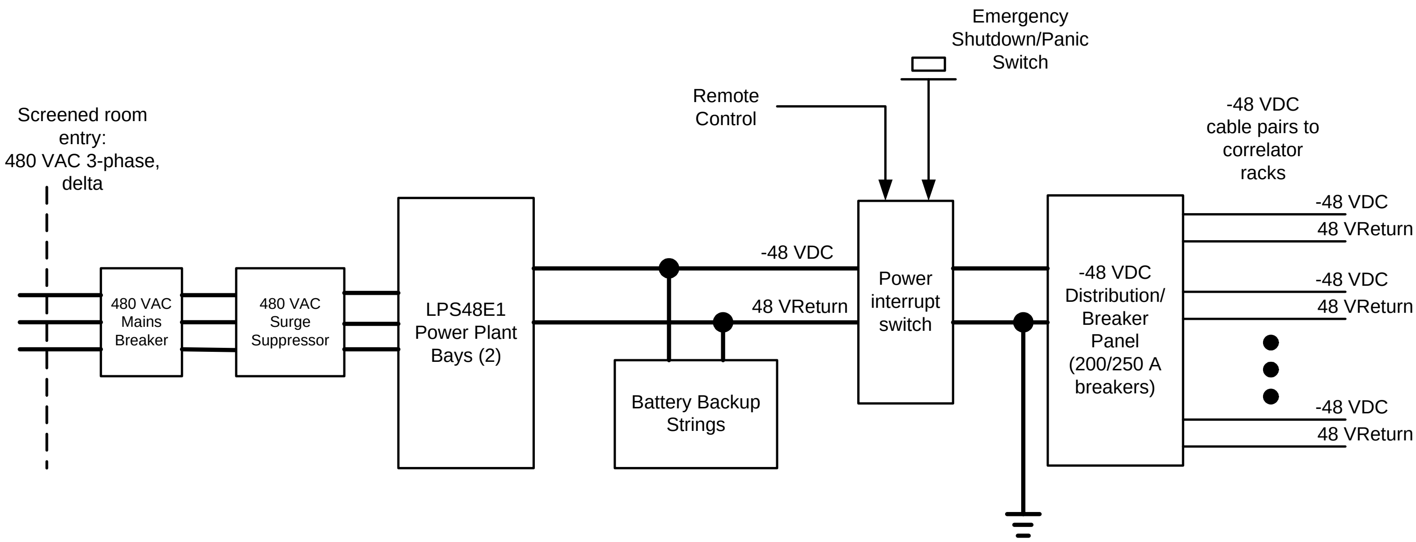


Figure 5-2 Simplified –48 VDC system wiring diagram

5.4 –48 VDC Wiring

The –48 VDC power supply is a two-wire system. The hot wire is the –48 VDC line, and the return or "neutral" wire is the "48 VReturn". The 48 VReturn is connected to earth/room ground at the –48 VDC distribution panel. There is no colour code standard for 48 VDC wiring and so the following standard color scheme will be used:

- The **–48 VDC hot line is VIOLET.**
- The **48 VReturn line is BLACK**[1].

If the entire cable jacket is not available in these colours, then the cable will be marked at each end with the correct colour. Appropriately sized termination lugs are to be used at each end and are TBD.

Both the –48 VDC hot, and the 48 VReturn are routed to each rack, via the overhead cable routing trays, from the distribution panel with a pair of wires. Each pair of wires connects to the output of a 200 A breaker (for Station racks) or 250 A breaker (for Baseline racks—40 station configuration) in the main distribution panel.

Within each rack, the pair of 48 V wires is routed to a rack breaker panel and rack shutdown/panic switch located at the rear of the rack, inside the back door[2]. Each large board (Station Board, Baseline Board), and group of small boards (Fanout Boards) and fans is fed by an appropriately sized pair of colour coded wires[3] from its own

[1] There is no standard for 48 VDC wire colours. This is defined in consultation with NRAO so that 48 VDC wiring colours within the entire EVLA are consistent.
[2] It may be desirable for the red panic switch to protrude out the back door/panel of the rack so the rack can be powered off before the door is opened. Although, this could result in inadvertent shutdown.
[3] Same colour code as defined for the –48 VDC to rack wiring.

appropriately sized breaker (estimated as 20 A for each Baseline Board, 15 A for each Station Board, 15 A for Fanout Boards, and 12-15 A for fans) breaker from the breaker panel.

The **48 VReturn is not connected to rack chassis** at this breaker panel, nor at any point within the rack. This guarantees that the 48 V return current flows to the power plant via the 48 VReturn only.

A simplified diagram of the rack power distribution requirement is shown in Figure 5-3.

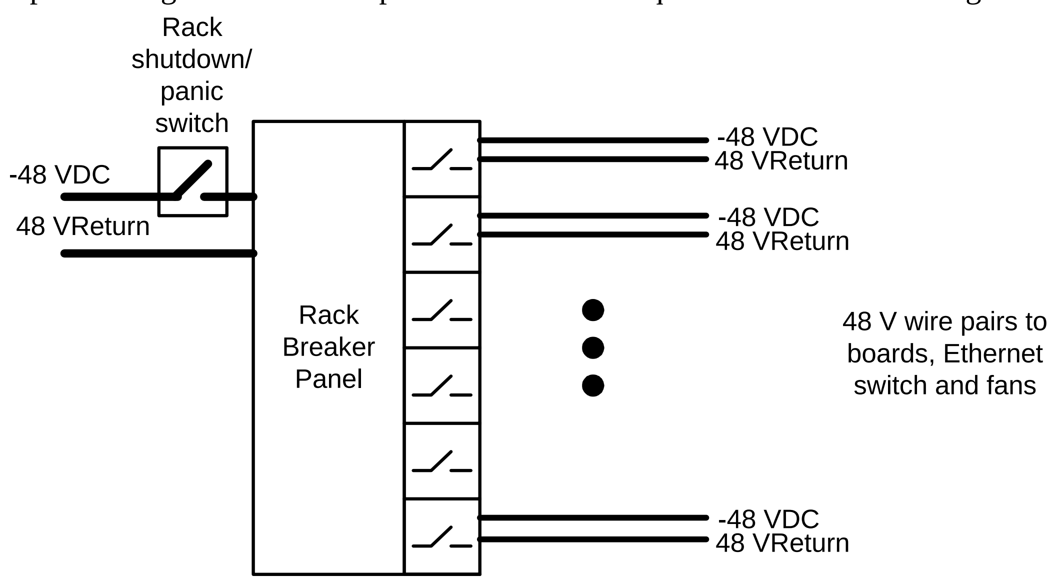


Figure 5-3 Simplified rack wiring diagram

For maximum 2% voltage drop at 200 A for two conductor wire, each wire in the 48 V cable pair from the main distribution panel to each rack should be the correct gauge according to Table 5-1:

Distance (ft)	Gauge	~Weight (lbs/1000 ft)	~Weight (lbs @ max D)
D <14.4	#2	260	3.74
14.4< D <23.2	#1/0	410	9.51
23.2< D <29.2	#2/0	495	14.5
29.2< D <44	#4/0	795	35

Table 5-1 Wire pair distance versus wire gauge for a 2% voltage drop @ 200 A

A 2% voltage drop at 200 A and 48 VDC is a voltage drop of 1 V and corresponds to a power loss in each cable pair of 192 W. This is the power loss **in this cable only**, not including breaker losses, and rack breaker-to-module wiring losses. The wire gauges shown in Table 5-1 should be considered the minimum requirement. According to estimations from Figure 3-2, that the maximum 48 VDC cable length is ~44 ft, depending on the location of the –48 VDC distribution panel.

Within a rack for 2% voltage loss, and assuming a maximum 6 ft of wire at 20 A, the breaker panel-to-board wire gauge should be #14.

5.5 110 VAC Wiring

The AC required for operation of all auxiliary computer systems in the room is 110 VAC single phase with normal 110 VAC polarized 15 A 3-prong outlets. Battery backup for 5 minutes of operation is required. There is no requirement for an "isolated ground", whereby the grounding plug on each outlet has its own ground wire tied to a single point ground at or near the distribution panel. In fact, this kind of grounding scheme can be problematic for conducted EMI as it results in large ground loops between equipment. From an EMI perspective, it is preferable if the grounding plug on each outlet is tied to the screened-room ground at the closest, most convenient point.

The CPCC and MCCC computers, essential for overall correlator monitor and control, will be equipped with their own secondary battery backup systems so that they can withstand prolonged power failures. The battery backup time for these computers is TBD, but should be for the longest duration of time that power is likely to be off. The failure mode of the CPCC will be designed such that if it loses power, all correlator board power supplies it is controlling will automatically shut down. This is accomplished via a TTL control signal to each board power supply, that if it is lost, results in the power supply shutdown.

The backend processing computers are likely inexpensive COTS rack-mount or desk-top computers, running off the 5 minute battery-backed 110 VAC, with standard 110 VAC 15 A 3-prong outlets.

Additional in-floor (i.e. between correlator rack rows and near backend computers) and wall-mount 110 VAC 3-prong outlets should be available in the room, spaced apart approximately every 10 ft. These will be used for test equipment and task lighting on an ad-hoc basis.

The HVAC and lighting system AC requirements are not defined in this document and are the responsibility of NRAO.

6 System Grounding Requirements

The correlator requires a system grounding scheme that meets National Electrical Code safety requirements and that is satisfactory for Electro-Magnetic Compatibility (EMC) of system components for reliable operation.

On the safety side, the AC systems use standard electrical practice whereby if a neutral exists, it is grounded to earth/screened-room ground at the breaker/distribution panel. It is assumed that the screened room will be grounded to earth ground using standard acceptable wire gauge and practice (e.g. metal water pipe into the earth for sufficient depth and distance), and that the screened room metal represents an acceptable ground for any purpose (although for neutral and 48 VReturn safety grounding, well-established safety grounding points must be defined).

On the signal and EMI/EMC side, the basic scheme is to shunt common-mode noise that wants to travel between racks via metal-to-metal connections, and filter sources of common-mode noise within racks to prevent it from traveling on rack-to-rack signal lines. There is currently no plan to put common-mode cable chokes on all rack-to-rack signal cabling, unless reliable operation of the system requires it.

Shunting common-mode noise between racks is accomplished by solidly connecting signal grounds on circuit boards to rack chassis (as supported in the existing design), and connecting rack chassis to the screened room ground (floor). There is a requirement to have a ½" stud/bolt on the screened-room floor below each rack for the purposes of establishing a solid rack-to-screened room floor connection (Figure 4-3), although normally the best RF ground is established with sub-rack/rack/pedestal/floor metal-to-metal connections and so every effort should be made to ensure good metal-to-metal connections at all rack bolting points.

One of the major sources of common-mode noise within the racks is the –48 VDC-to-DC power supplies on the boards. Thus, all –48 VDC-DC power supplies on all boards will contain common-mode filters to minimize conducted EMI that can couple into rack-to-rack signal cable. These filters are designed to meet FCC Part 15 Class B conducted EMI requirements.

Additional high-speed inter-rack signals such as Ethernet are transformer coupled and so do not present paths for common-mode ground loops. The power monitor and control lines from the CPCC to all of the boards/racks in the system are direct connect lines, referenced to earth ground, and could present paths for common-mode ground loops. Since these are very low-frequency on/off control lines, they will be heavily filtered with ferrites to minimize common-mode conduction. A simplified diagram of the correlator system grounding scheme is shown in Figure 6-1.

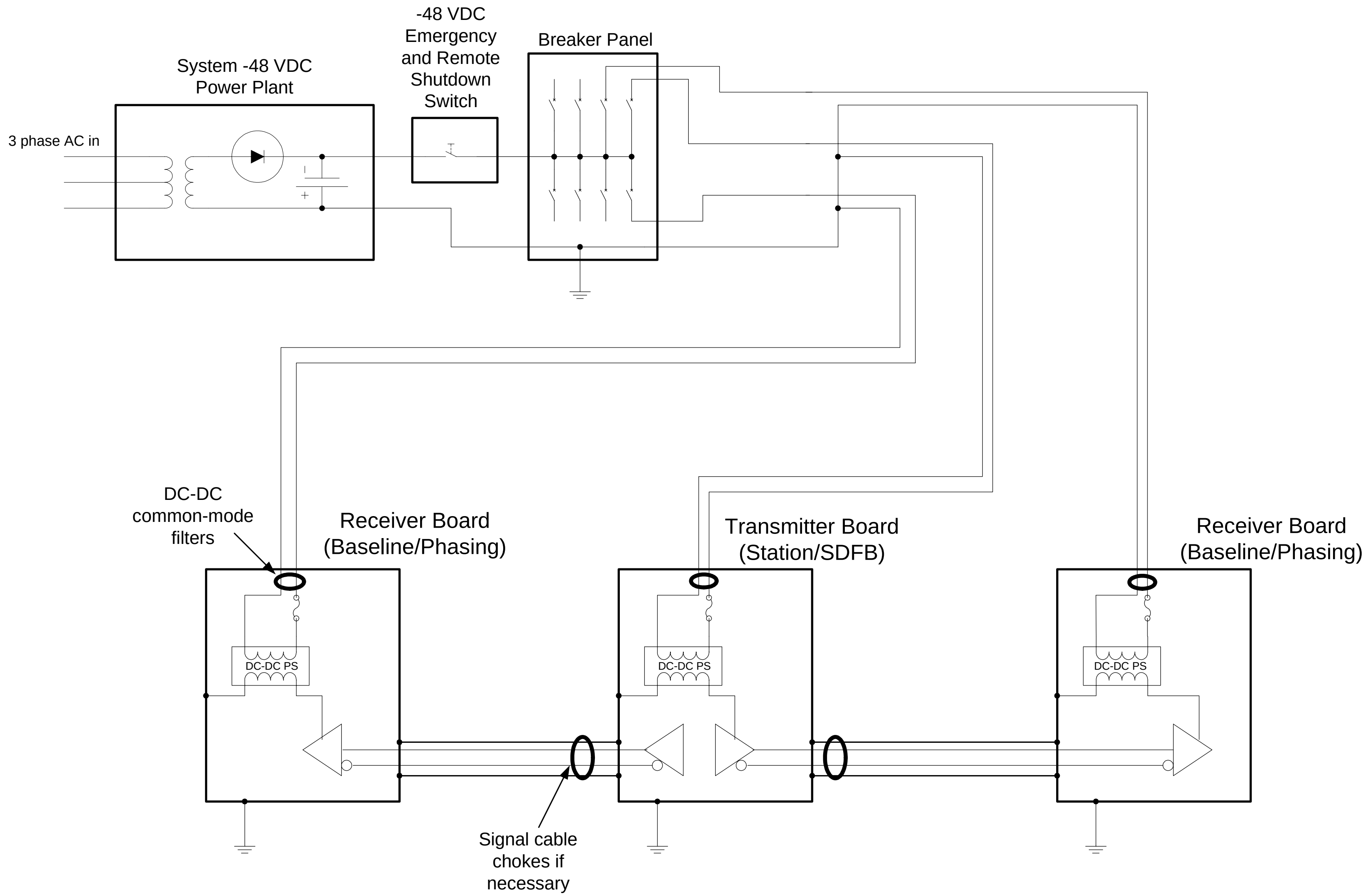


Figure 6-1 Simplified correlator system grounding scheme.

7 Environmental Requirements

7.1 Screened Room

7.1.1 Electro-Magnetic Interference (EMI)

The EMI shielding requirements for the correlator screened room are not defined by this document. The correlator racks are not EMI tight and thus there will be substantial leakage of EMI from the racks to the surrounding room. The level of EMI that will radiate from the racks is not known. However, as a baseline, it is anticipated that radiated EMI will be in the region of FCC Part 15, Class A[4] levels. High-speed design techniques that naturally lend themselves to low RFI emissions are used in the design of the correlator, and past experience indicates that this is at least good enough to meet Class A levels, without EMI-tight enclosures. Further testing of correlator prototype hardware is required to gauge whether Class A levels can be met or not.

The –48 VDC power plant and COTS computers and switches are the primary generators of conducted EMI. The –48 VDC power plant is specified to meet Class A levels for conducted EMI. COTS computers, especially desktop computers are normally certified for Class B. Network switches will at least meet Class A levels, and may meet Class B. Nevertheless, the correlator room AC supplies must use appropriate filtering on entry to the screened room to ensure that damaging conducted EMI remains in the screened room.

7.2 Rack Cooling and Airflow

Each rack requires 1700 cfm[5] of air at maximum 15 ^{o}C for cooling to ensure long-term reliable operation [4]. This air is delivered to the each rack from below via the rack pedestal, and exhausted out the top. Each rack contains 4 blower fans, mounted at the top of each rack to assist with airflow through the rack. The “rack as a duct” approach to cooling has been taken after considerable testing and investigation [2]. A simplified cross-section of the Baseline rack, showing airflow is shown in Figure 7-1.

[4] Class A levels are for “industrial” installations, and Class B levels are for “commercial” installations. Class A is 40-50 dB uV/m, and Class B is 10 dB lower.
[5] As previously noted, the Baseline racks for a 32-station correlator require only 1000 cfm.

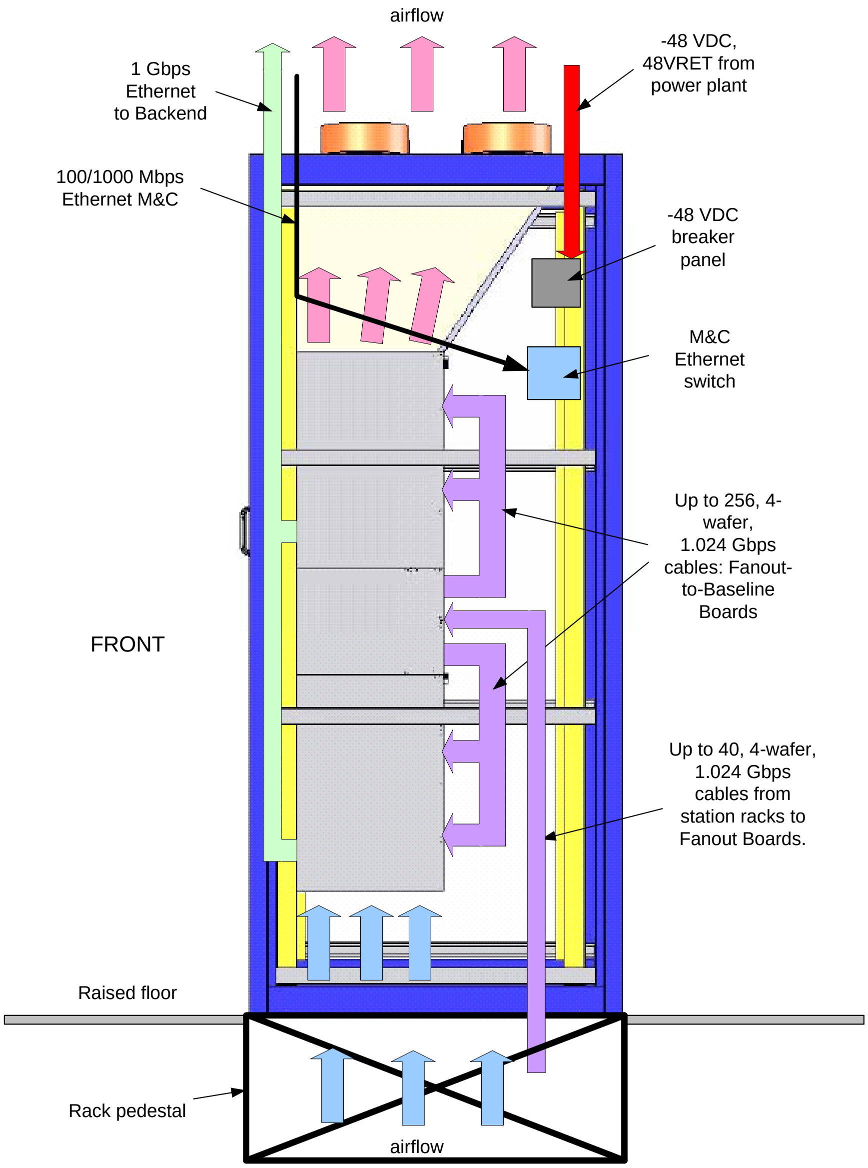


Figure 7-1 Cross-section of Baseline rack showing airflow and cable routing.

Each of the 4 blower fans at the top of the rack is hot-swappable using a custom-design fan tray assembly. Failure of a blower fan does not require rack shutdown, but could increase the temperature in the rack by up to 5 ^{o}C, if the remaining working fans are increased in speed to compensate. Thus, when a fan fails, it should be replaced as soon as reasonably possible thereafter (e.g. the next morning when maintenance people are on site).

The speed of each fan can be monitored remotely by the CPCC computer to detect failures and operating speed. To maintain approximately uniform cooling across the system a single fan-speed voltage control line (0-10 VDC) to each rack will be controlled by the CPCC. This also serves as fan-speed control during “sleep-mode” when the mains

AC power fails and the correlator boards are put into low power mode to maintain a constant temperature inside each rack to minimize system thermal cycling.

The temperature rise of the exhaust air is approximately 10-14 ^{o}C, at a 10 kW total rack power load.

7.3 Air Quality

The main concern with air quality is elimination of dust buildup that can reduce correlator component cooling, and the elimination of any metal particles that, if free to roam, could result in short-circuiting of high-density circuitry on correlator circuit boards. The recommendations in this section are derived from [5] [6] [7].

The recommended air quality for the room, and in particular the air fed to the racks is ISO 14644-1 class 8. An additional MERV 13 filter, that removes ~75% of the 0.3-1 micron particles is also recommended. The following table defines the ISO air quality standards

ISO Classification Number	Maximum concentration limits (Particles/m3 of air) for particles equal to and larger than the considered sizes shown below					
	>= 0.1µm	>= 0.2m	>= 0.3µm	>= 0.5µm	>= 1µm	>= 5.0µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1000	237	102	35	8	
ISO Class 4	10000	2370	1020	352	83	
ISO Class 5	100000	23700	10200	3520	832	29
ISO Class 6	1000000	237000	102000	35200	8320	293
ISO Class 7				352000	83200	2930
ISO Class 8				3520000	832000	29300
ISO Class 9				35200000	8320000	293000

Table 7-1 ISO air quality standards.

There is no plan or requirement for filtering the air into each rack, however NRAO may wish to integrate a filter into the rack pedestal design, if so desired.

Any ductwork or metal work within the correlator room, including the screened room construction must use a method that **does not result in tin whisker growth**. This can be accomplished by using hot-dipped galvanized metal only for any tin-plated surfaces.

Any room tiles or components should not be made of dust-trapping or dust-producing/shedding material.

Once the correlator room is constructed and the racks, pedestals, and raised floor are in place, the room must be thoroughly cleaned to eliminate construction dust particles.

7.4 Electro-Static Discharge (ESD)

When the correlator is fully operational and all of the racks are closed, there is no particular ESD requirement for the room. However, the following recommendations should be followed to ensure that when boards have to be replaced or removed for repair, no inadvertent damage or degradation in reliability occurs. These are procedures followed by the correlator board manufacturer and at the NRC laboratory in Penticton where boards are tested. Failure to adhere to these recommendations could result in decreased system reliability and availability, and outright failure of system components.

1. The room should be maintained at 40-60% relative humidity to reduce the ESD effects of any secondary items such as board paper tags, paper documents, static-charge generating/build-up susceptible clothing etc. This level of humidity is also important to ensure adequate “wetting” of the human body to ESD protection devices (as described below). Simply put, a dry environment is not conducive to dissipation of static charge build-up between items and between items and the human body.

2. The raised floor should be an ESD static dissipative floor specifically designed for the purposes of an ESD controlled area. Floor installation must follow manufacturer’s recommendations to ensure that every location on the floor has a static dissipation path to ground.

3. Each of the room’s entrances should be equipped with a card-swipe/lock mechanism so that only qualified personnel can enter the room. All personnel with card-swipe access must agree to adhere to all ESD rules.

4. Any person entering the room must wear an ESD lab coat and ESD dissipative shoes. Such items can be purchased for a nominal cost from several suppliers. ESD dissipative shoes can be purchased in many styles to suit almost everyone’s liking and it is simply a matter of operations personnel putting on the shoes and coat in the morning when they start work.

5. To facilitate non-regular users of the room, an assortment of ESD lab coats and ESD heal straps should be kept external to the room at each entrance.

6. At each entrance, external to the room, a commercially available testing station should be set up. This testing station consists of a metal floor pad, a push-button switch, and a RED/GREEN LED indicator. Every person entering the room must stand on the metal floor pad and obtain a GREEN LED indication before entering the room.

7. The room must be purged of all non-ESD safe items, in particular work surfaces and chairs. Only ESD-dissipative work surfaces, properly connected to ground, and ESD-dissipative chairs should be in the correlator room.

Once this environment and procedures are in place, people can move freely around the room and handle correlator boards and components without any additional ESD precautions such as wrist straps. When boards are to be removed from the room, they must be placed in ESD-safe bags and only opened at a site where similar ESD precautions and procedures have been set up.

7.5 Cosmic Rays

It is not believed that any additional construction or environmental specifications are required to mitigate the effects of cosmic rays at the 7000 ft altitude of the VLA. Extensive on-line and off-line error checking is performed in the correlator, and all programmable chips (FPGAs) are in-system programmable so the system can recover "gracefully" from any upset events. In addition, all boards can be remotely booted and/or power-cycled in case an unrecoverable event occurs. At the most, to mitigate the effects of cosmic rays in changing FPGA "personalities", it may be necessary to reload FPGA personalities every time there is a configuration change, as is planned for the ALMA correlator.

Oxygen enrichment could be performed in the correlator room, although this is likely not necessary.

7.6 Seismic

The VLA site is located in seismic zone 2B. Specific room construction and rack installation instruction is beyond the scope of this document, and NRAO should take the lead on defining what is required to meet seismic zone 2B requirements.

Anchoring the rack pedestal at all four corners, and or, anchoring all racks together with cross-members may be necessary to meet seismic zone 2b requirements.

8 References

[1] Halman, M., EVLA Correlator Rack Thermal Performance, NRC-EVLA Memo# 025, *In Prep*.

[2] Webber, R., Halman, M., TEST AND VERIFICATION RESULTS: EVLA Correlator Rack: Thermal Mock-up Tests, TVR Document A25031N0003, Revision 1.0, April 29, 2005.

[3] SAG582140000, System Application Guide, Spec. No. 582140000 (Model LPS48E1) Issue AA, January 14, 2004.

[4] Carlson, B., TEST AND VERIFICATION REPORT: EVLA Correlator Reliability Report #1, TVR Document: A25010N0003, Revision Report #1, June 6, 2005.

[5] Sun Microsystems Data Center Site Planning Guide, 805-5863-13, Sun Microsystems, Inc., 2002

[6] ISA-S71.04-1985, Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants. Instrument society of America, North Carolina, 1985. (www.isa.org)

[7] Site Preparation Guide, HP Integrity rx7620-16 Server, Third Edition, A7027-96015 May 2004

9 Index

LPS INTRODUCTION

LPS is Marconi's next generation power platform. Its high-degree of integration and revolutionary design pack unparalleled capacity and features into a small footprint. Key features and benefits include:

- A patented internal bus work that improves AC and DC cable routing options.
- A modular distribution design that includes built-in monitoring for both fuses and breakers.
- An integrated DC bus that eliminates costly overhead busses and eases plant expansion.
- An integrated **LMS**[1] design that simplifies monitoring of external equipment.
- A controller with a backplane that accepts plug-in alarm cards and LMS I/O cards.

LPS48E1 OVERVIEW

LPS48E1 is a –48VDC digital power plant that operates with 200 Amp Power Conversion Units (PCUs) powered from 480V AC.

Each bay provides power conversion and distribution – up to ten PCUs (2000A total) along with 2400A of distribution. Larger plants up to 10,000A are created by adding secondary bays.

The heart of this system is the **LPS200E50** PCU. A true three-phase three-wire rectifier, the unit operates at 0.998 power factor and with less than 5% THD. It can deliver 110% of rated current up to 40°C, and a reduced amount up to 80°C by virtue of its thermal current limit feature. Designed for positive ground applications, the normal output voltage ranges from 47 to 58 volts, with a test voltage adjustable down to 45 volts.

AC service is wired individually to each PCU. A horizontal terminal strip is located on the left top of the bay. An optional Power Distribution Service Cabinet (**PDSC**) bolted to the left side of the bay facilitates wiring in one or two AC branch circuit applications.

Distribution is divided into two rows, top and bottom. Each row has a flexible design that accommodates breakers and fuses, up to a 1200 amps maximum. There can be up to 24 (3-100A) breakers/fuses or up to 12 (100-800A) devices, or a combination. Elements of 100A and greater include a shunt for monitoring by the meter, control and alarm (**MCA**) panel.

The MCA consists of a multi-line vacuum fluorescent display, plus a removable CPU and alarm cards located in a shelf below the distribution. The shelf is dual-purpose and accepts an LMS CPU for modem and Ethernet access, plus LMS I/O cards for other monitoring points.

As a system, the MCA controls the steady state output voltage to within 0.05% of any setting, from no load to full load. The MCA also uses a patented algorithm to balance the PCU output currents to within 1% of their rated current.

[1] LMS is Marconi's newest monitor featuring a distributed I/O architecture, an Ethernet port and Web pages.

Family:	LPS
Spec. No.:	582140000
Model:	LPS48E1
Output Voltage:	-48 Volts DC
Output Capacity:	
per System (five Power/Distribution Bays):	10,000 Amperes, maximum
per Power/Distribution Bay	2400 Amperes, maximum
per Distribution Row (two Distribution Rows per Power/Distribution Bay):	1200 Amperes
per PCU:	200A / -48V
Agency Approval:	Listed UL 1801
Framework Type:	Seismic Rated (Zone 4) Box Framework (Seismic rated through design verification and analysis only. Test results pending.)
Mounting Width:	24 Inches, plus 10 inches if PDSC used
Mounting Depth:	30 Inches
Mounting Height:	84 Inches
Access:	Single Bay Plants: Front Access for Installation, Maintenance, and Operation. Multi-Bay Plants: Front and Rear Access for Installation and Maintenance, Front for Operation.
Secondary Bay(s) Available:	Nine
Control:	Microprocessor
Color:	Silver (Lorain Spec. M500-142)
Options:	Primary Bay (cannot be used with bolt-on PDSC [AC Input 'Power Distribution Service Cabinet']), Primary Bay (must be used with bolt-on PDSC [AC Input 'Power Distribution Service Cabinet']), Secondary Bay (cannot be used with bolt-on PDSC [AC Input 'Power Distribution Service Cabinet']), Secondary Bay (must be used with bolt-on PDSC [AC Input 'Power Distribution Service Cabinet']), PCU, Bolt-On PDSC (AC Input 'Power Distribution Service Cabinet') (22kA interrupting capacity), Bolt-On PDSC (AC Input 'Power Distribution Service Cabinet') (65kA interrupting capacity), Optional LMS Monitor (Refer to SAG586505000 for additional LMS options.), MCA Customer Alarm Relay Card
Accessories:	Distribution Devices, Internal Ground Busbar Assembly, External Top-Mount Battery Input Busbar Assembly, External Top-Mount Ground (Load Return) Busbar Assemblies, Load Return Lug Extension Busbar Assembly, Battery Charge Temperature Compensation Probe, Replacement MCA Network Cable, Replacement LMS Network Cable, Replacement Circuit Cards
Environment:	0°C to +40°C (+32°F to +104°F)

582140000 Primary Power/Distribution Bay

List 30: Optional Bolt-On PDSC (22kAIC)

List 31: Optional Bolt-On PDSC (65kAIC)

See *ACCESSORY INFORMATION* Section for…

Internal Ground Busbar Assembly

External Top-Mount Battery Input Busbar Assembly

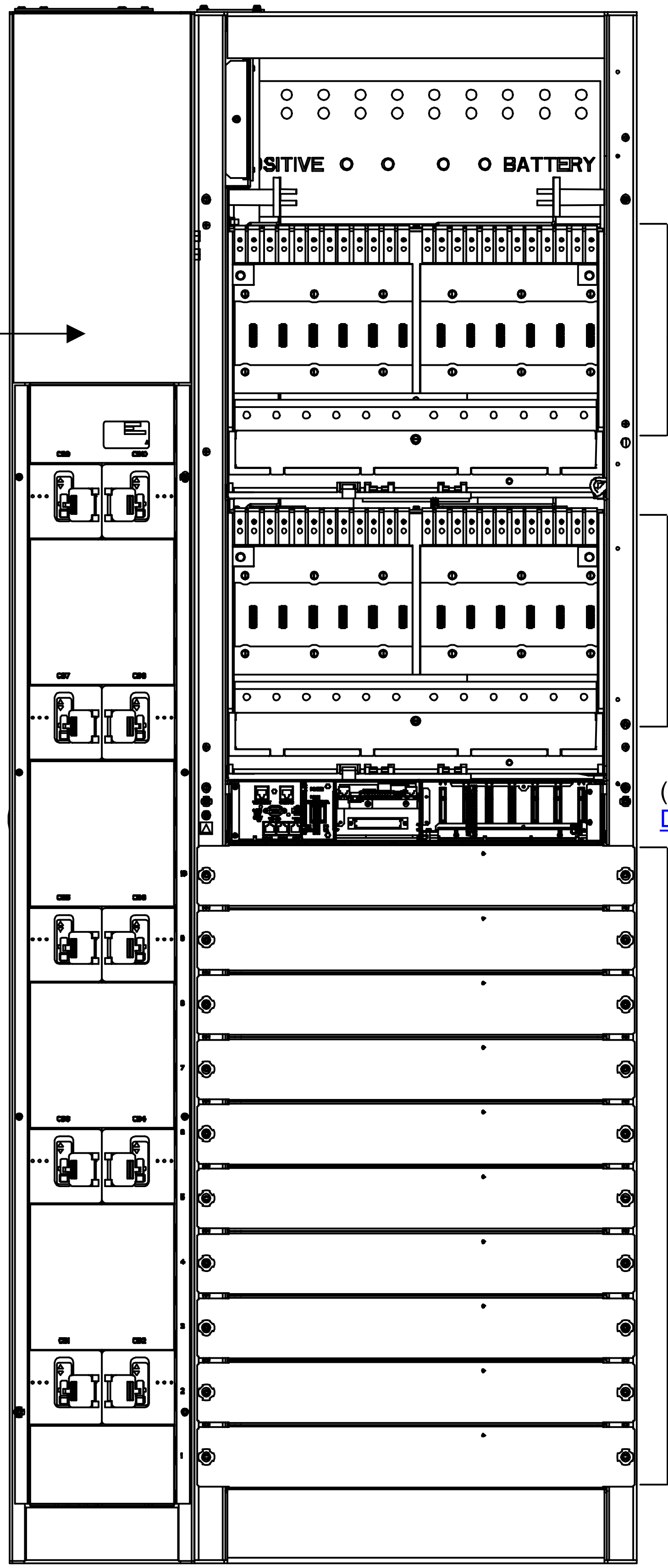
External Top-Mount Ground (Load Return) Busbar Assemblies

Load Return Lug Extension Busbar Assembly

Battery Charge Temperature Compensation Probe

List 1: Primary Power/Distribution Bay (e/w Individual PCU Feed AC Input Termination Panel)

List 2: Primary Power/Distribution Bay (for use with optional bolt-on PDSC)



Distribution Row (see Distribution Devices in *ACCESSORY INFORMATION* Section for distribution options)

Distribution Row (see Distribution Devices in *ACCESSORY INFORMATION* Section for distribution options)

(see Monitor/Control Diagram)

List 20: PCU

582140000 Secondary Power/Distribution Bay

List 30: Optional Bolt-On PDSC (22kAIC)

List 31: Optional Bolt-On PDSC (65kAIC)

See *ACCESSORY INFORMATION* Section for…

Internal Ground Busbar Assembly

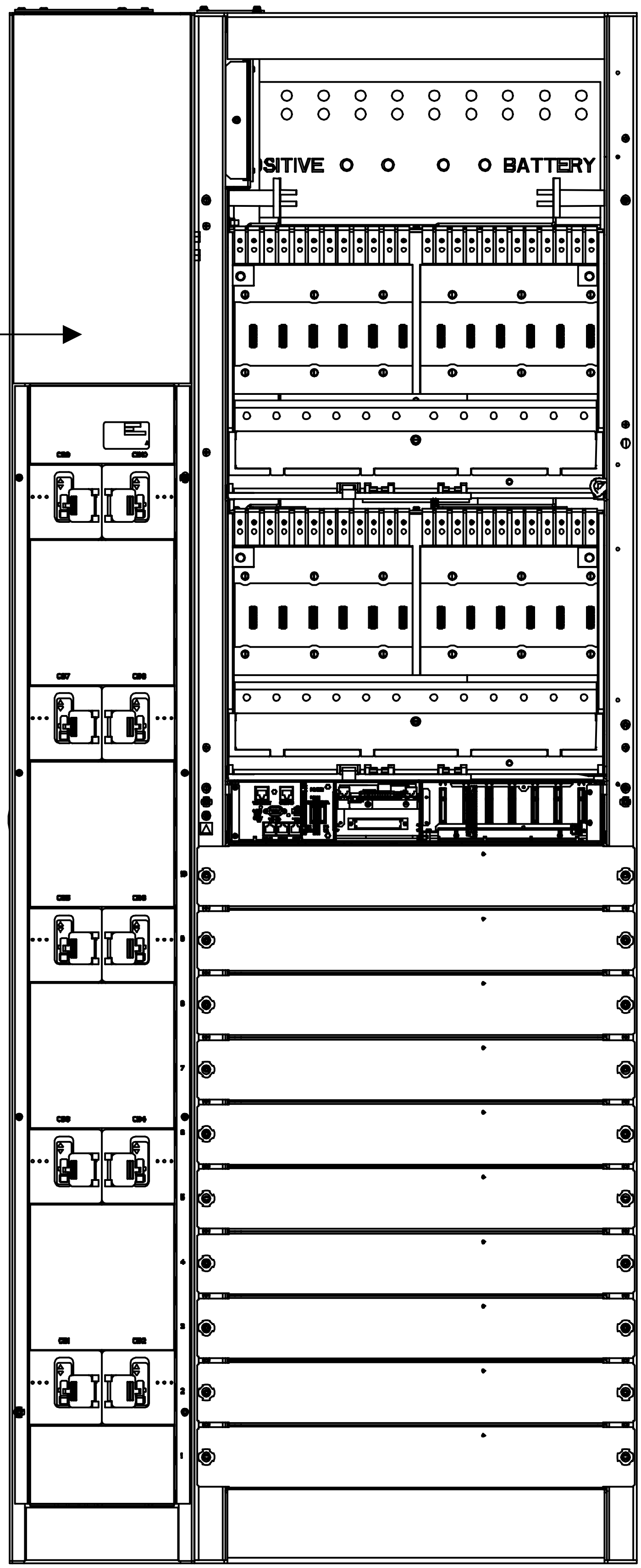
External Top-Mount Battery Input Busbar Assembly

External Top-Mount Ground (Load Return) Busbar Assemblies

Load Return Lug Extension Busbar Assembly

List 11: Secondary Power/Distribution Bay (e/w Individual PCU Feed AC Input Termination Panel)

List 12: Secondary Power/Distribution Bay (for use with optional bolt-on PDSC)



Distribution Row (see *Distribution Devices* in *ACCESSORY INFORMATION* Section for distribution options)

Distribution Row (see *Distribution Devices* in *ACCESSORY INFORMATION* Section for distribution options)

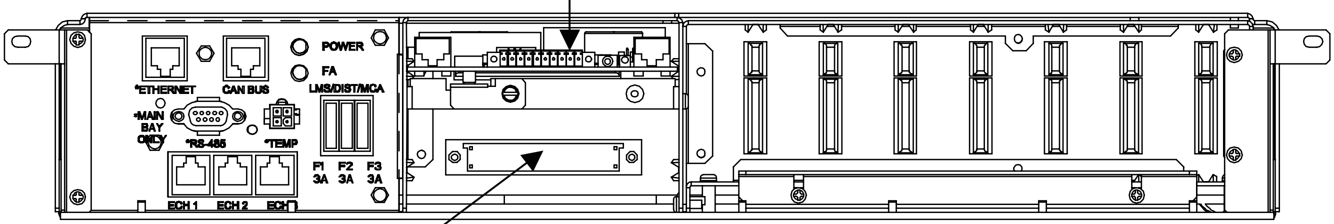
(see Monitor/Control Diagram)

List 20: PCU

582140000
Monitor/Control Diagram

P/O List 1 and 2: MCA Circuit Card (Primary Bay)

P/O List 11 and 12: ROUTER Circuit Card (Secondary Bay)



List 50: Optional LMS Monitor

Refer to SAG586505000 for additional LMS options.

Available MCA Input/Output (I/O) Circuit Cards

List 70: MCA Customer Alarm Relay Circuit Card (Six [6] Form-C Contacts)

SEE ALSO

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