SKA LFAA SPS Cabinet Specification Document

1 Document change log

Issue	Date	Change
1	4-05-2018	First Issue

2 Definitions, Acronyms and Abbreviations

ADC	Analog to Digital Converter
ADU	Analog Digital Unit
AAVS1	Aperture Array Verification System 1
CPF	Central Processing Facility
CPU	Central Processing Unit
CSP	Central Signal Processor
DDR3	Double Data Rate 3 (memory)
DDR4	Double Data Rate 4 (memory)
DN	Data Network
EMC	Electromagnetic Compatibility
FN	Field node (station)
FPGA	Field Programmable Gate Array
INAF	Istituto Nazionale di astrofisica
INAU	Infrastructure – Australia
INFRA	Infrastructure
IRA	Istituto di radioastronomia
iTPM	Italian Tile Processing Module
LFAA	Low Frequency Aperture Array
LFAA-DN	LFAA Data Network
MCCS	Monitor, Control and Calibration Sub-System
MCU	Micro Controller Unit
PCB	Printed Circuit Board
PPS	Pulse per second
PRE-ADU	Pre-Analog Digital Unit
PWM	Pulsed Wave Modulation
RF	Radio Frequency
RPF	Remote Processing Facility
SDP	Science and Data Processor
SKA	Square Kilometer Array
SNR	Signal Noise Ratio
SPS	Signal Processing Sub-System
TBD	To Be Defined
TBC	To Be Confirmed
TCP	Transmission Control Protocol
TPM	Tile Processing Module

UDP	User Datagram Protocol
VGA	Analog Gain Amplifier
WDM	Wavelength Division Multiplexing

3 Table of contents

1 Document change log 2
2 Definitions, Acronyms and Abbreviations 3
3 Table of contents 5
4 Scope 7
5 Applicable documents 8
6 Reference documents 8
7 Cabinet Subsystem Overview 9
7.1 General System Outline 9
7.2 Cabinet network 15
7.2.1 Station level network 15
7.2.2 Cabinet level network 18
7.3 Cabinet power management 21
7.4 Cabinet cooling 23
7.5 Cabinet layout 33
7.6 Cabinet management architecture 36
7.6.1 Rack management board 37
7.7 Cabinet synchronization 40
7.8 Cabinet mechanics 43
7.9 Cabinet assembly and maintenance 49
7.10 Cabinet cabling 52
7.11 Cabinet electrical power distribution 56
8 Cabinet detailed part list 61
8.1 TPM, sub-rack and management board 61
8.2 Cabinet mechanical 62

8.3 Cabinet electrical.....63

8.4 Cabinet cooling 66

8.5 Cabinet network & cabling.....68

9 Cabinet cost estimation.....70

4 Scope

This document defines the design specifications of the SKA LFAA Signal Processing Sub-System cabinets. In the document both cabinet and rack words are used as synonyms.
The baseline requirements acquired for the current cabinet design are based on the information present in AD1, AD2 and other SKA design documents.
The AD1 document contains the information related to the building that will contain the SKA LFAA rack, including the rack mechanical specification, room available space and organization, available power interface and cooling interfaces, clock and fiber routing to and from the cabinet, general building specification.
The AD2 document describes the synchronization signal specification delivered to each cabinet.
The RD1 document describes the current LFAA LOW internal structure. LFAA internal structure is summarized in Figure 1. The main elements are the Field Nodes (FN, or stations, the two terms are used as synonyms in this report), and the Digital System (DS). LFAA is composed of 512 Field Nodes, each one including 256 antennas. The DS is composed of three main elements: Monitor, Control and Calibration Sub-System (MCCS), Signal Processing Sub-System (SPS), LFAA Data Network (LFAA-DN).

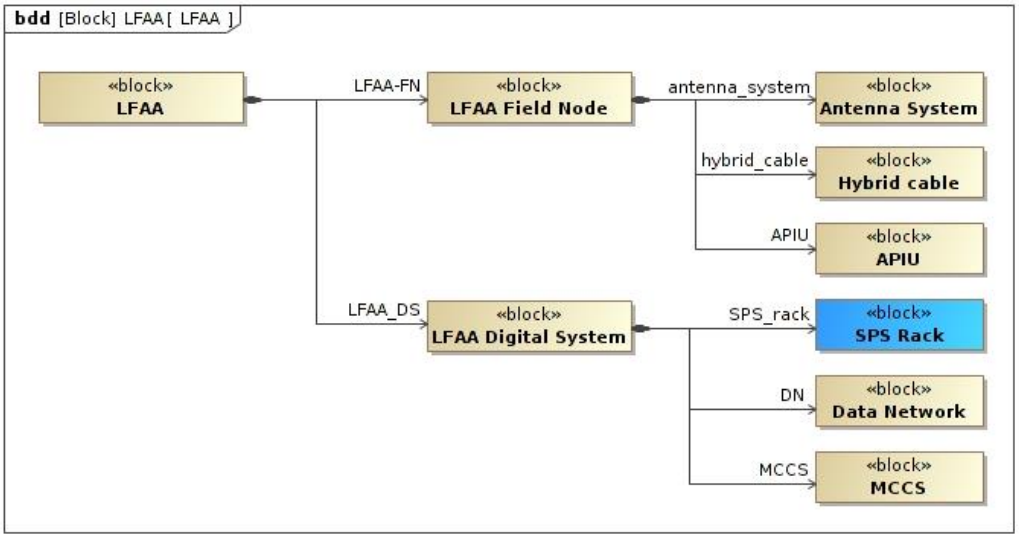


Figure 1 LFAA block definition diagram

5 Applicable documents

[AD1]	SADT TO LFAA INTERFACE CONTROL DOCUMENT - 100-000000-026-04
[AD2]	LFAA TO INFRA AUS INTERFACE CONTROL DOCUMENT - 100-000000-003-02
[AD3]	LFAA to CSP INTERFACE CONTROL DOCUMENT - 100-000000-004-03
[AD4]	LOW-SDP to LFAA INTERFACE CONTROL DOCUMENT - 100-000000-033-01

6 Reference documents

[RD1]	SKA-TEL-LFAA-0500034-SP-RSP-A-LFAA Digital System Requirements Specification.docx
[RD2]	SKA_Cabinet_Requirements_sheets.pdf
[RD3]	SKA_Subrack_Specification document.pdf
[RD4]	AAVID SKA liquid cooling system, P10155-53591-LCS-Schematics-r04.pdf
[RD5]	AAVID, HydroSink-Small-Size-Manual.pdf
[RD6]	AAVID, 415722-A-(HS-S-RADIATOR-1pass).pdf
[RD7]	AAVID, HYD-Pump-Datasheet-415614-r03-1.pdf

7 Cabinet Subsystem Overview

7.1 General System Outline

The SKA LFAA digital system is devoted to acquire the analog signals from all the on-the-field antennas, to perform the digital beam-forming and to provide the generated data to the central processor for further elaboration.
A STATION is a set of 16 TPM boards that manages 256 on-the-field antennas generating a single digital beam for further processing. Each antenna generates two analog signals that are transmitted by RFoF techniques over optical fiber directly to the TPM board to perform the analog to digital conversion and the beam-forming algorithm. All the TPM boards will be connected to the antennas by means of maximum 10-Km fiber.
The TPM acquisition function is performed together with several services that will be provided by a cabinet system; it provides the construction element of the LFAA acquisition system.

A specialized central building (with 296 core STATIONS) and 36 remote buildings (with 6 STATIONS each) will be available to contain the LFAA cabinets to provide the required acquisition functions respecting the maximum distance from the field antennas.

Each cabinet will provide the required interface to the other telescope elements to execute the TPM acquisition functions and will be compliant with the functional/performance and general requirements specified in the interface specification documents.

In this document the proposed cabinet design is composed by 32 iTPM boards organized in sub-racks as basic custom elements and a 1U cabinet management board that support rack level management functions. Since the iTPM sub-rack structure includes 8 iTPM boards and some services in a standard 19” 6U rack module, there are 4 Sub-Racks in each cabinet.

As general interface description, the diagram in Figure 2 (described in AD1), has been considered:

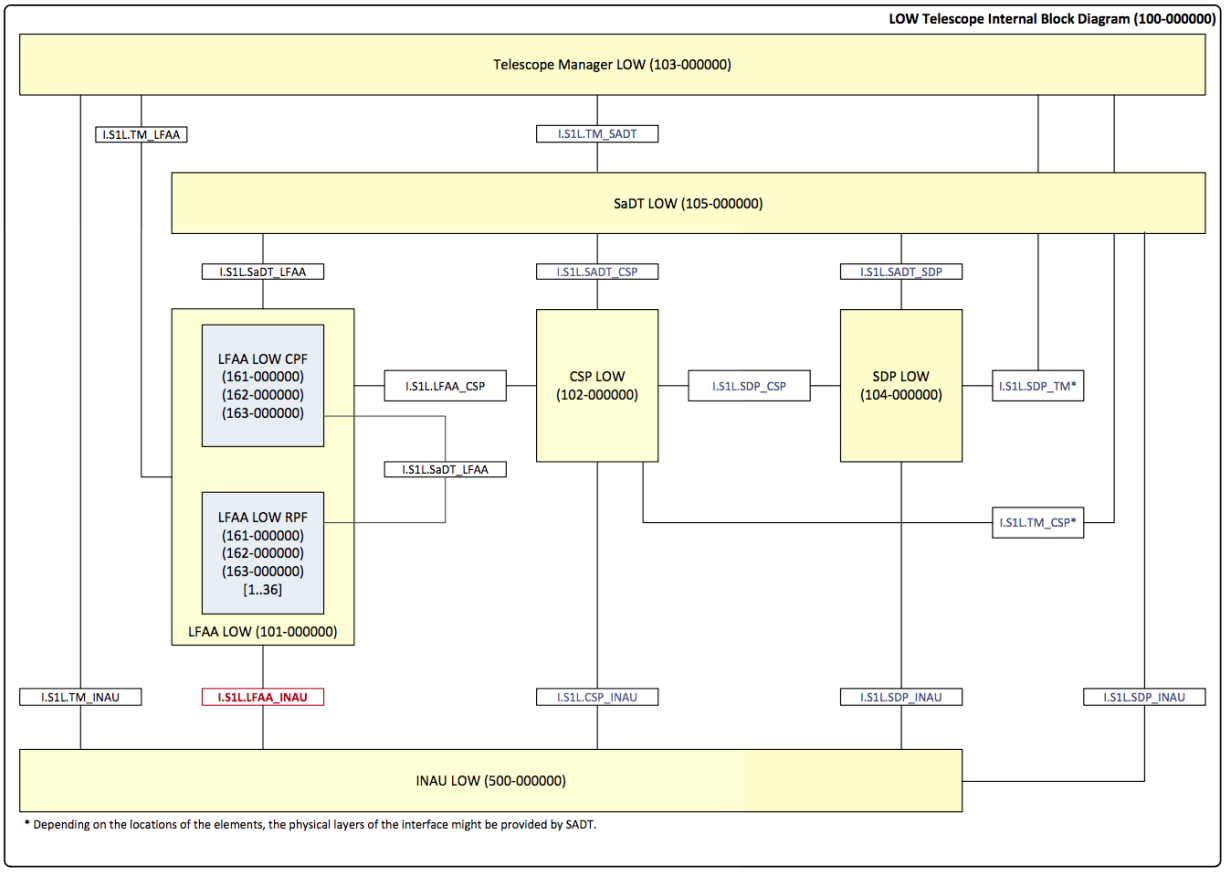


Figure 2 LOW Telescope Interface Diagram, [AD1]

The current LFAA Digital System internal structure includes three main elements, as shown in Figure 1:

- Monitor, Control and Calibration Sub-System (MCCS)
- Signal Processing Sub-System (SPS)
- LFAA Data Network (LFAA-DN)

Starting from Figure 2, the interfaces within LFAA digital system have been investigated more in detail and they are summarized in Figure 3.

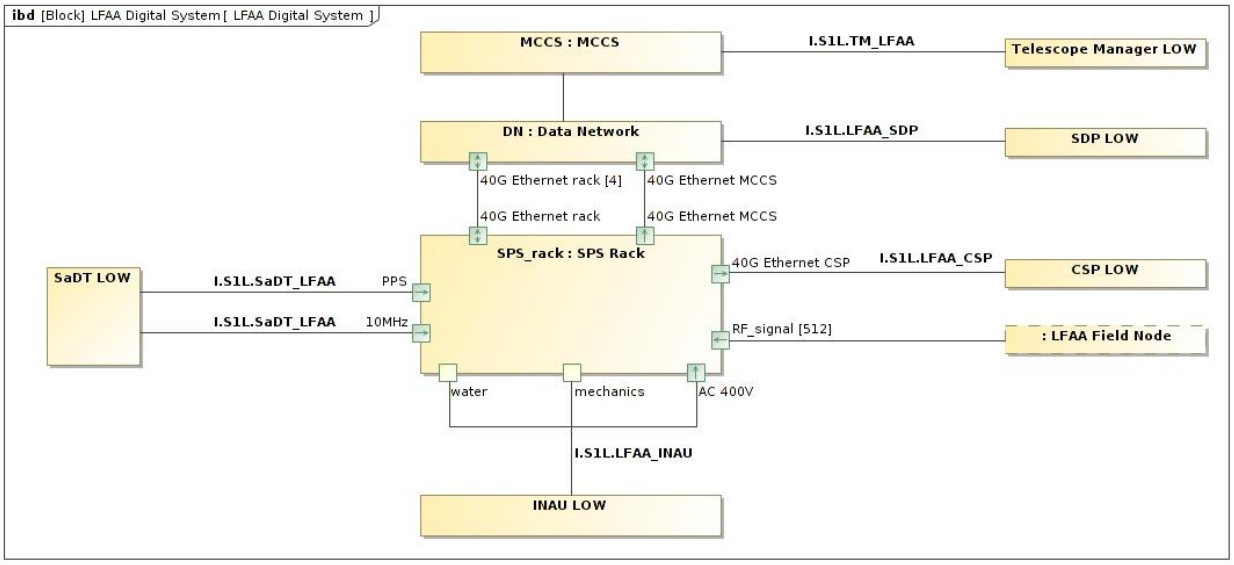


Figure 3 LFAA Digital System Interfaces

The MCCS is the unit that interfaces the telescope manager to control all the LFAA digital system.
The SPS is mainly implemented by the cabinets containing the TPMs, in the central and remote facilities.
The LFAA Data Network is the Ethernet network that transports the beam-forming data among TPMs, the station calculated beams and other information inside the LFAA structure and to/from the involved interfaces. The DN is physically composed of network switches, located inside the MCCS and SPS cabinets. Its portion pertaining to the SPS is thus also discussed here.

As resulting from the current available specifications each SKA LFAA cabinet shall perform the following main functions:

- receive the analog signal from 512 antennas to implement a 2 STATION interface with the TPM boards (32 TPM)
- provide the network connection between the TPM inside each STATION to calculate the station beam
- provide the network connection to transmit the calculated beams to other cabinet and to the CSP

- provide an input network connection from other racks or from a rack level network to allow multi-station beam-forming
- execute the calibration operations, managed by the MCCS
- distribute to the TPMs the reference clock and the synchronization signal
- distribute the power
- implement the cabinet level management
- provide the cabinet cooling

A solution in which each cabinet implements 3 STATION interfaces, integrating 48 TPM organized in six 6U sub-rack will be considered as an option.

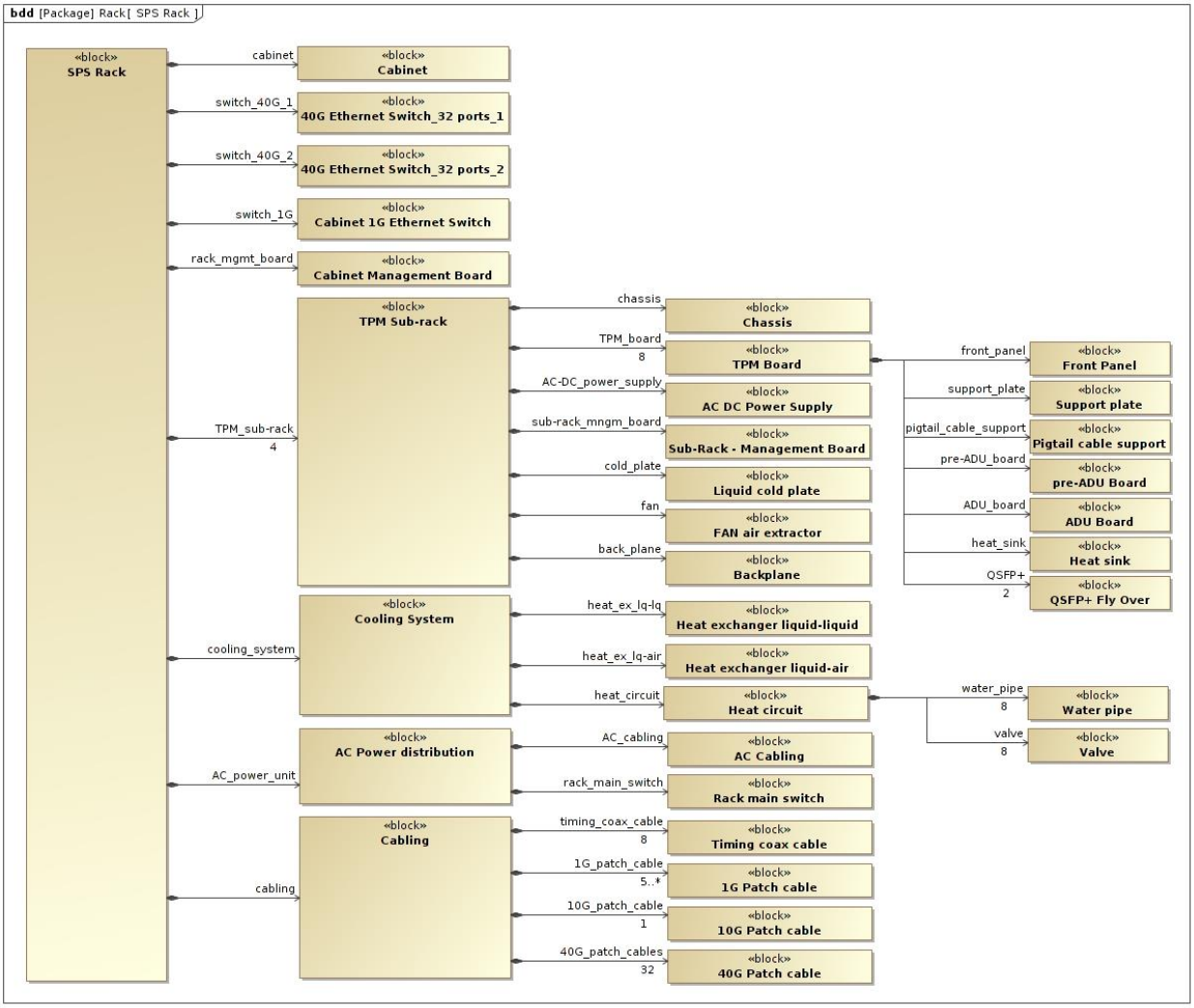


Figure 4 SPS Cabinet decomposition

Figure 4 and Figure 5 show the main elements included in the SPS rack and the connections between each element.

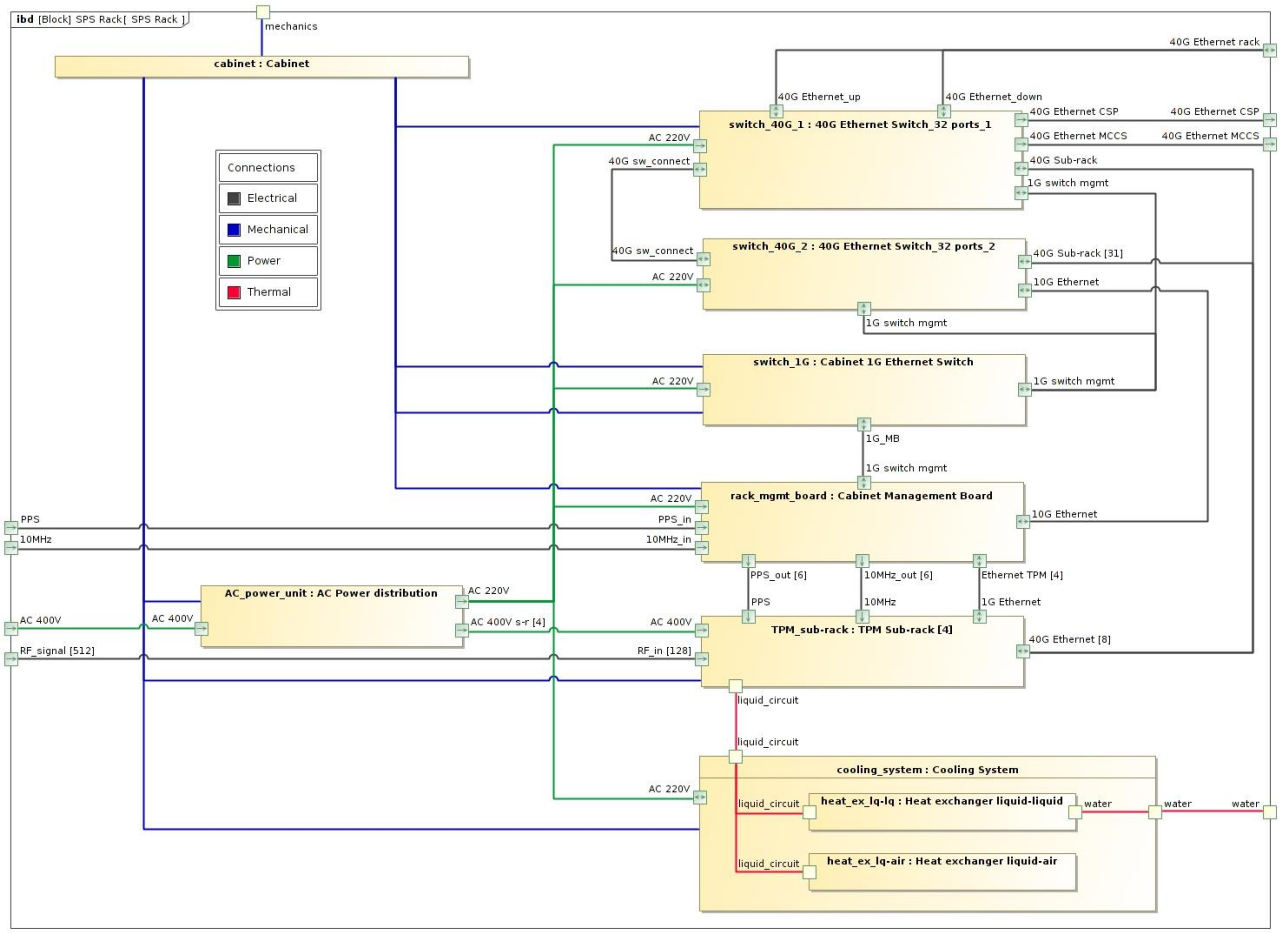


Figure 5 SPS Cabinet internal connections

7.2 Cabinet network

Cabinet network shall provide several communication capabilities, running at different speeds to support all the cabinet functions. It provides the connections to communicate with the CSP and the Telescope Manager, through the internal MCCS system.
The main data rate will transit on a 40G Ethernet network, with optional 100G Ethernet uplink for the connection to or from the cabinet to the outer cabinets.
The lower speed data will be transmitted on a 1G data network inside the rack and joined to the 40/100 Gbit network to communicate with the MCCS and the Telescope Manager application.
The network is organized at station level and then at cabinet level.

7.2.1 Station level network

The station level network shall provide the capabilities summarized in the diagram and in the table below. For each communication data the expected bit rate, the used network, the calculated channel occupancy, the packets per second, the required number of connections and the required number of the cable interface are listed. Transient buffer figures are TBC, and assume that the buffer will be implemented in the TPM memory.

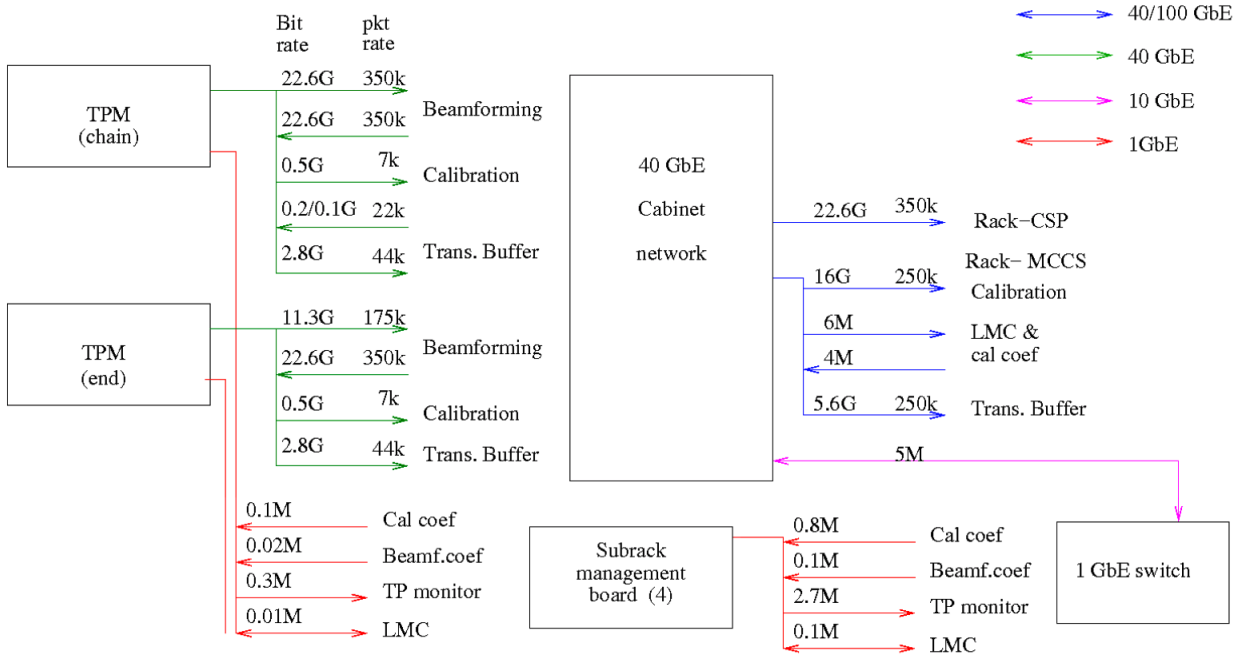


Figure 6 station level network specification

Beamforming	Bit rate	Network	Occupancy	Pkt/sec	n° conn	Cable
TPM ->TPM beamforming 16 bit IN, 8 KB	2,26E+10	40G	56,5%	3,60E+05	15	16 QSFP
TPM ->TPM beamforming 16 bit OUT	2,26E+10	40G	56,5%	3,60E+05	15	
TPM-> 40G SW beamforming 8 bit OUT	1,13E+10	40G	28,3%	1,80E+05	1	
Calibration Spigots						
TPM -> MCCS, calib spigots, 8KB	5,00E+08	40G	1,3%	7,96E+03	16	
Sub-rack management						
MCCS -> sub rack management	1,00E+06	1G	0,1%	1,59E+01	2	2 RJ45
sub rack management -> MCCS	3,00E+06	1G	0,3%	4,78E+01	2	
subrack man -> TPM, raw coeff	1,00E+05	1G	0,0%	1,59E+00	16	
sub rack management <-> TPM	5,00E+05	1G	0,1%	7,96E+00	16	
Transient buffer, MCCS						
Option 1 trans buff out of Cabinet						
TPM -> MCCS trans buffer	3,50E+08	40G	0,9%	5,57E+03	1	0

Table 1: Station level network

For each station a 40G Ethernet data network and a 1G Ethernet management network are defined, joined together at cabinet level.

In the beam-forming the TPMs inside each station shall be connected with a cabinet 40G data network to share the partial beam data with 16-bit resolution at 22 Gbit/s of data rate.

The TPMs are connected logically in a serial chain: the first TPM generates the first internal beam-form data to the second one that adds the contribute coming from the corresponding antennas and propagates it. The last station TPM generates a half resolution beam-form data that shall be transmitted as station output.

Each TPM provides one 40G Ethernet port on a QSFP interface, while the second one QSFP available on the board shall be left unconnected or removed if no upgrade capabilities will be requested (TBC).

Each TPM generates also continuously calibration data that shall be received by the MCCS computer in the LFAA network, outside the cabinet. The MCCS computer sends back raw calibration data to the Subrack management board that elaborate and distribute to each TPM on the same network.

Each station generates also a Transient Buffer data that shall be either delivered continuously to the MCCS on the 40G Ethernet network, or stored locally in TPM DDR memory and uploaded to the SDP on request. In this latter case the upload will involve at most 2-4 TPM at any given time, in turn.

The beam-forming, the calibration and the transient buffer data are shared with 8KB UDP packets, without flow control and retransmission capabilities.

It is also requested that communication packet ordering transmitted with the UDP is respected in order to allow raw data reconstruction. Corrupted or out-of-order packets in the beam-forming data will be discharged. The maximum bit and packet error rate shall be defined to guarantee that the total number of corrupted or missed packets to CSP will not exceed a TBD fraction, in order not to degrade the final SNR. Corrupted packet in the calibration data and management data shall be recovered by TCP protocol that manages consistency check and retransmission.

The management 1G Ethernet network connects the 8 sub-rack TPMs to the sub-rack management board with direct UDP access through the backplane and the local switch (integrated in the management board itself). The sub-rack management board then can communicate through TCP or UDP with the cabinet level management network by means of one or two copper gigabit cables with RJ45 interface.

7.2.2 Cabinet level network

The cabinet level network shall connect the internal stations and shall provide the connection to the CSP, the MCCS and the surrounding cabinets.
The proposed implementation is detailed in the figure below.

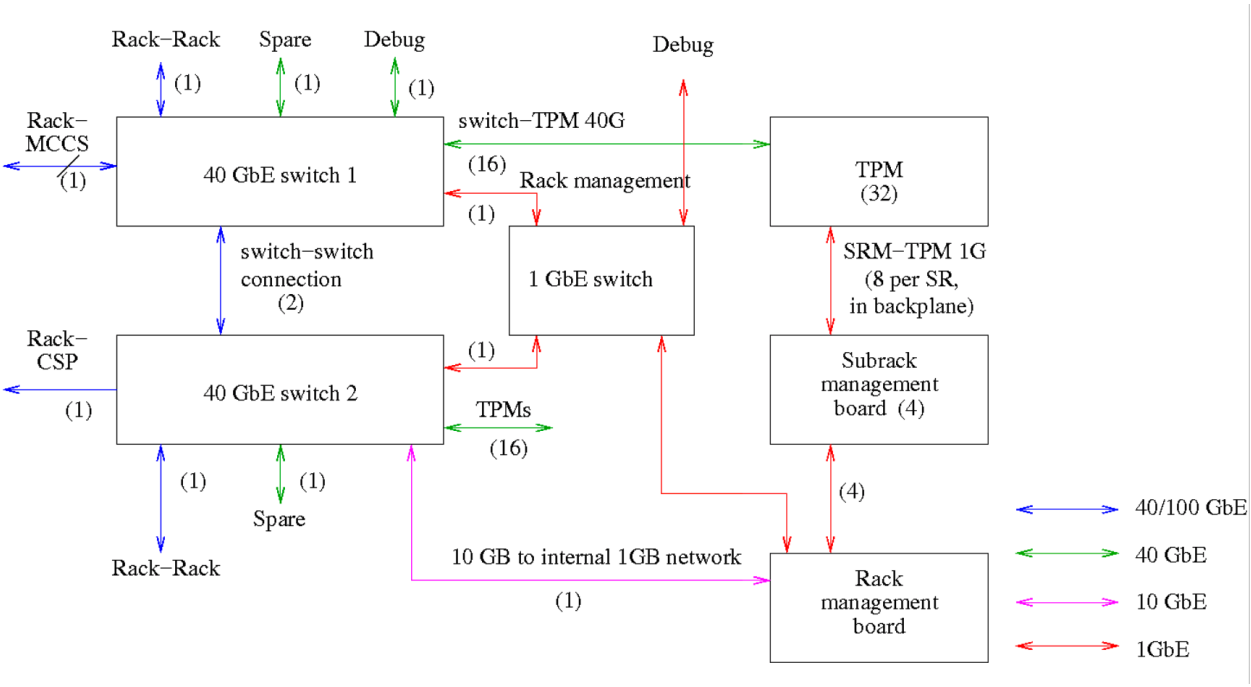


Figure 7 Cabinet level network

If a 100G uplink can be available to the CSP, the cabinet shall be locally joined together to reduce the number of connection from the LFAA data network to the CSP data network.

The 1G cabinet management network shall be connected to the 40K LFAA data network by the external side and to the STATION management network to the internal side. On this network also the other cabinet elements shall be connected: power distributor, heat exchanger and so on.
Cabinet level network can be conditioned by the commercial network switches available from the market. Probably at least two switches are needed to implement the 40G cabinet network and also the connection between the switches should be considered.

Connections required at cabinet level are listed in the table below, together with related characteristics and aggregated traffic.

Management 1G Network	TX	Occupancy	RX	Occupancy	Network	Pkt/sec	n° conn	# QSFP Ports
40G Uplink	3,00E+06	0,0%	7,00E+06	0,0%	40G	1,09E+02	1	1
Rack management board	1,00E+06	0,0%	1,00E+06	0,0%	1G	1,56E+01	1	
Station 0 management	1,00E+06	0,0%	3,00E+06	0,0%	1G	4,69E+01	2	
Station 1 management	1,00E+06	0,0%	3,00E+06	0,0%	1G	4,69E+01	2	
Management spare					1G		0	
Cabinet maintenance					1G		1	
Stations data 40G Network	TX	Occupancy	RX	Occupancy	Network	Pkt/sec		
Station 0 beamforming 16 bit, TPM <-> TPM	3,39E+11	56,5%	3,39E+11	56,5%	40G	1,08E+07	15	16
Station 0 beamforming, 8 bit, TPM -> 40G	1,13E+10	28,3%			40G	1,80E+05	1	
Station 0 calibration, TPM <-> TPM	8,00E+09	1,3%	1,60E+06	0,0%	40G		15	
Station 1 beamforming 16 bit, TPM <-> TPM	3,39E+11	56,5%	3,39E+11	56,5%	40G	1,08E+07	15	16
Station 1 beamforming, 8 bit, TPM -> 40G	1,13E+10	28,3%			40G	1,80E+05	1	
Station 1 calibration	8,00E+09	1,3%	1,60E+06	0,0%	40G			
Switch <-> Switch	TBD		TBD		40G	TBD	2	2
Station 0 spare						0	0	1
Station 1 spare							0	1
External Interfaces	TX	Occupancy	RX	Occupancy	Network	Pkt/sec		
Rack, (2 Station) -> CSP, beamforming	2,26E+10	56,5%	0	0,0%	40G	3,60E+05	1	1
Station -> CSP spare					40G	0,00E+00	0	1
Rack, (2 Station) -> MCCS, spigots	1,60E+10	40,0%	0	0,0%	40G	2,55E+05	1	1

MCCS -> Rack (2 stations)	0,00E+00		3,20E+06	0,0%	40G	5,10E+01	1	0
MCCS -> Rack, Spare					40G	0,00E+00	0	1
Rack <-> Rack , Option, IN	2,26E+10	56,5%			40G	3,60E+05	1	1
Rack <-> Rack , Option, OUT			2,26E+10	56,5%	40G	3,60E+05	1	1
Rack <-> Rack , Spare					40G	0	0	1

Table 2: 32-TPM cabinet network

For the 40G data network it is assumed that the station network will be integrated with the Cabinet network as a single element, sharing the switches.

The connection to the CSP shall be able to transmit the station beam-forming data outputs on a single aggregated connection. Direct connection to the CSP is expected.

Similarly the station connection to the MCCS shall aggregate the calibration data and also the management data. A connection to the MCCS internal network is expected (TBC).

Optionally, each cabinet shall allow a connection to other two cabinets for possible station level aggregated beam-forming (TBD).

Switch level spare ports shall be provided, in order to allow at least one free port for each used interface.

As mentioned in the station network level, the maximum bit error rate, the number of packet for second allowed, the packet ordering shall be considered in the final design.

Let us consider the packet ordering of the station output beam-forming: assuming that the generated packets are equally distributed, the expected packet-to-packet latency is about 5.8 us (1.6 us is the time requested for a 8 Kbyte packet on the 40G network and 4.22 us is the expected time between successive packets). If the involved switches can assure a maximum propagation latency below that, it can be assumed that the transmission ordering will be preserved on the network.

7.3 Cabinet power management

Cabinet power shall be developed accordingly to AD1 and general functional and safety requirements.
A single three-phase supply input is available from infrastructure, coming from the floating floor below the cabinet. The cabinet shall provide the supply for the TPM sub-racks, the rack management unit, the network switches, and the heat exchanger.

A preliminary powering scheme is in the following figure

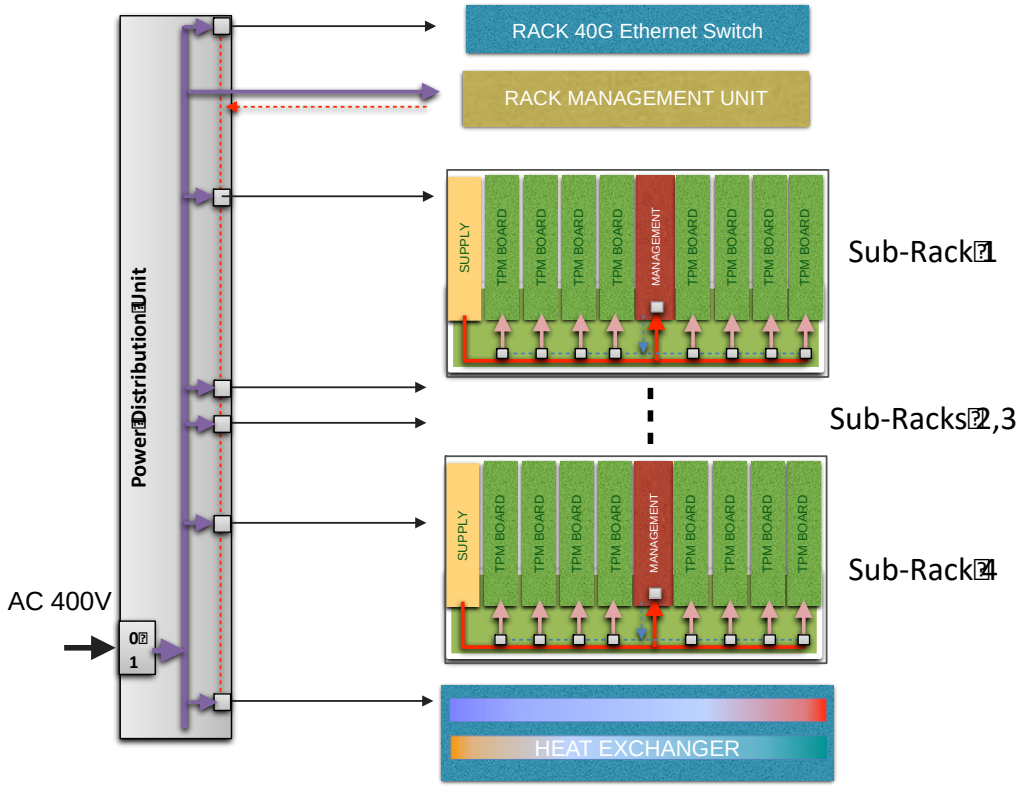


Figure 8 LFAA Cabinet supply scheme

The cabinet power distribution unit shall be designed with the following functions:

- input switch with required safety functions
- rack management unit supply always available
- rack switches supply on/off function, expected about 200W
- heat exchanger on/off function, expected about 200W
- TPM sub-racks on/off function, expected about 1000W each

Each element shall guarantee safety functions in relation to the implemented functions.
Safety functions are distributed over three levels:

- Cabinet general, directly implemented in the PDU
- Cabinet elements, managed by the monitoring and active functions executed by the rack management board
- Single elements, means sub-rack, switches and heat exchanger

The sub-racks are managed and can monitor all the absorbed power of each TPM and implement secure power-off procedure with programmable power thresholds.

7.4 Cabinet cooling

The cabinet shall be a close system also w.r.t. the cooling. The LFAA buildings (central and remotes) will provide a liquid circuit to each rack from the floor, dimensioned to meet the total cabinet absorbed power.

The current cabinet power budget is summarized in the following table (all values are Watt).

CABINET ELEMENT, WORST	Absorbed Power	N°	TOT	To Liquid	To AIR
TPM Sub-rack	1.144	4	4576	3889,6	686
40GETH Switches	500	2	1000	0	1000
Rack Management	33	1	33	0	33
Cabinet Fans	300	1	300	0	300
Pumps	320	1	320	0	320
Auxiliary 24V	200	1	200	0	200
TOTAL ABSORBED POWER			6429	3890	2539
CABINET ELEMENT, TYPICAL	**Absorbed Power**	**N°**	**TOT**	**To Liquid**	**To AIR**
TPM Sub-rack	988	4	3952	3359	593
40GETH Switches	200	2	400	0	400
Rack Management	22	1	22	0	22
Cabinet Fans	200	1	200	0	200
Pumps	234	1	234	0	234
Auxiliary 24V	100	1	100	0	100
TOTAL ABSORBED POWER			4908	3359	1549

Table 3 Cabinet power budget and cooling strategy, colored cells are tentative values

The Worst case scenario has been defined assuming the maximum power allocation to each single cabinet elements that shall be respected in each functional condition as design specification.
The Typical is the target operative condition that has been estimated upon the current test done on the AAVS1 site and from cabinet design analysis.

Sub-rack power estimation comes from the [RD3] feasibility study; the 40G Ethernet power estimation comes from the declared absorbed power of several commercial products that can vary from 150W up to 400W, depending on configuration and traffic.
The other range cell values will be defined with the cabinet final design, but the overall impact on the total absorbed power is minor.
The sub-rack absorbed power is expected to be transferred mainly directly to the liquid through the iTPM heat sink and the backplane liquid cold plate air radiator; it is expected that only about 15% of the generated power will be transferred to the cabinet internal air.
All the other cabinet elements will be directly cooled by air, due to the expected limited absorbed power.
The total typical (worst) power directly transferred to the liquid will be about 3.360 (3.890) Watt and the remaining 1.550 (2.540) Watt will be transferred to the air. This estimation is function of the final temperature working point that will be chosen for the various elements present in the cabinet, mainly iTPM FPGA temperature, sub-rack cold plate temperature, sub-rack internal liquid flow speed and cabinet internal air temperature. A characterization and the working set-point shall be done on the final design with the field application loaded on the TPM FPGAs.

To manage the expected cabinet power dissipation scenario, based on the iTPM sub-rack design, a mixed liquid-to-liquid and air-to-liquid cooling system shall be provided.

The cabinet liquid circuit specification is summarized in the Figure 9.

The infrastructure cooling liquid is interfaced with a cabinet liquid-to-liquid heat exchanger with two valves for possible isolation. The liquid-to-liquid cabinet exchanger allows the required isolation between the cabinet internal liquid circuit and the external one. The internal circuit shall be managed with a dedicated circulator in order to fix the flow speed of the liquid. The liquid–to-liquid heat exchanger shall be able to transfer all the expected cabinet power dissipation, with a (140 %) margin with a maximum temperature difference of 5-8 °C in the typical expected load configuration (7 KW liquid to liquid heat exchanger has been proposed).

The cabinet internal liquid shall be pure water. The sub-rack cold plates are alloy based and due to this fact possible galvanic current shall be evaluated in order to avoid metal corrosion inside the cooling circuit. The other materials allowed in contact with the cooling water are stainless steel and plastics.

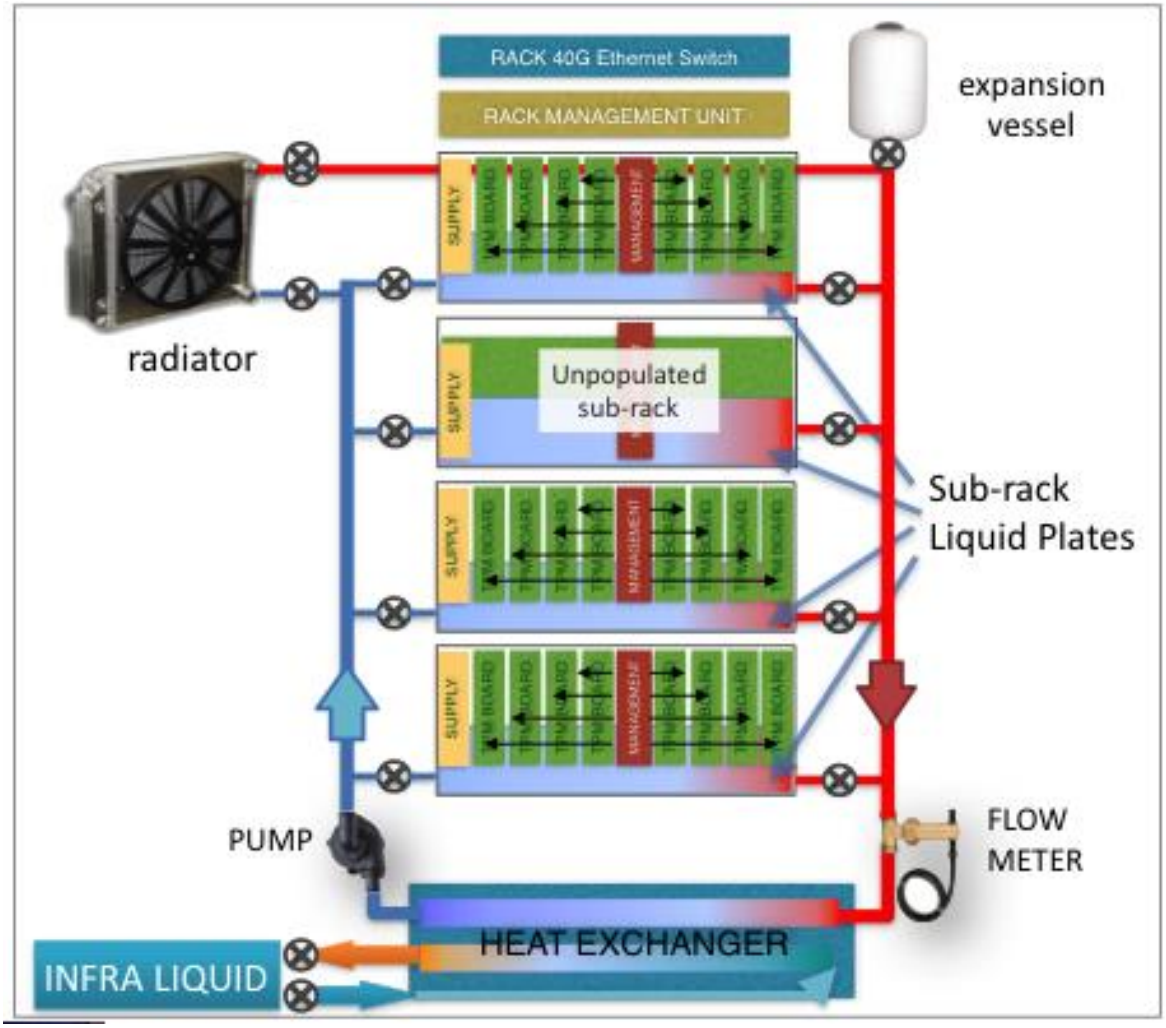


Figure 9 LFAA Cabinet liquid cooling circuit, main elements

The main elements required for the cooling liquid circuits are the following:

- liquid-to-liquid heat exchanger
- internal circulating pumps
- internal flow meters, pressure and temperature meters
- valves to isolate the single elements for maintenance
- liquid to air radiator
- expansion vessel to maintain the selected internal circuit water pressure
- sub-racks liquid cold plates
- internal pipes

Pumps type selection is critical with respect to requested maintenance intervals: low working pressure allows magnetic pumps with very long life; higher pressure requires mechanical pumps. In the magnetic pumps the rotating elements have reduced contact with fixed elements allowing very poor consumption and long lifetime.

The overall pressure drop is mainly defined by the elements in the circuits: the liquid cold-plate (with inside elements that on one side increase the transfer surface from liquid to alloy, on the other increase pressure drop), the valves and the radiator (pipes drop is not considered at this design level, assuming correct dimensioning).

The liquid cold-plate pressure drop is defined by sub-rack design parameter, and reported in Table 4.

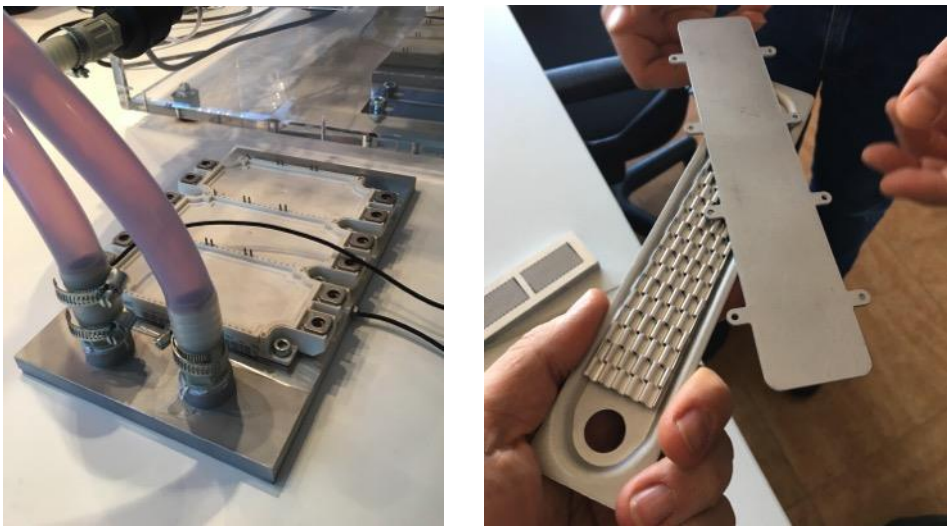


Figure 10 Liquid cold-plate, external and internal examples, with liquid to allow increased surface elements

The valves pressure drop depends on the selected type: automatic stop or ball valves.

The ball valves have very low pressure drop but requires manual operation for rotation, and two elements are needed to isolate both the sides of the circuit, where needed.

The automatic valves typically isolate both the sides of the connected elements, require just a pressure of one element to separate the two sides but imply a high water pressure drop due to internal construction.

If the total pressure can be maintained around 1 bar, the better magnetic pumps can be selected.



Figure 11 Internal liquid valve examples, on the left ball valves, on the right quick stop valves

The following circuit pressure drop table shall be considered:

Element	expected drop (bar)	Flow rate l/min	series/parallel
Liquid to liquid exchanger	0,135	-	serial
Flow meter	low	-	serial
subrack cold plate	0,45	10	parallel, x4
ball valves	low	-	parallel, x4
air radiator	medium	-	parallel x1
Pipes, constant	na	-	serial

Table 4 Liquid cooling pressure drops

To manage the cabinet internal temperatures, the internal liquid circuit shall be structured with two internal circulations, the Subrack cold plate and the air radiator with separate pumps in order to select different flow rates, Figure 14.

An example of stainless steel liquid exchanger is shown in Figure 12 . This type of liquid exchanger is proposed as reference, based on its construction characteristic: robustness, no maintenance and low pressure drop.

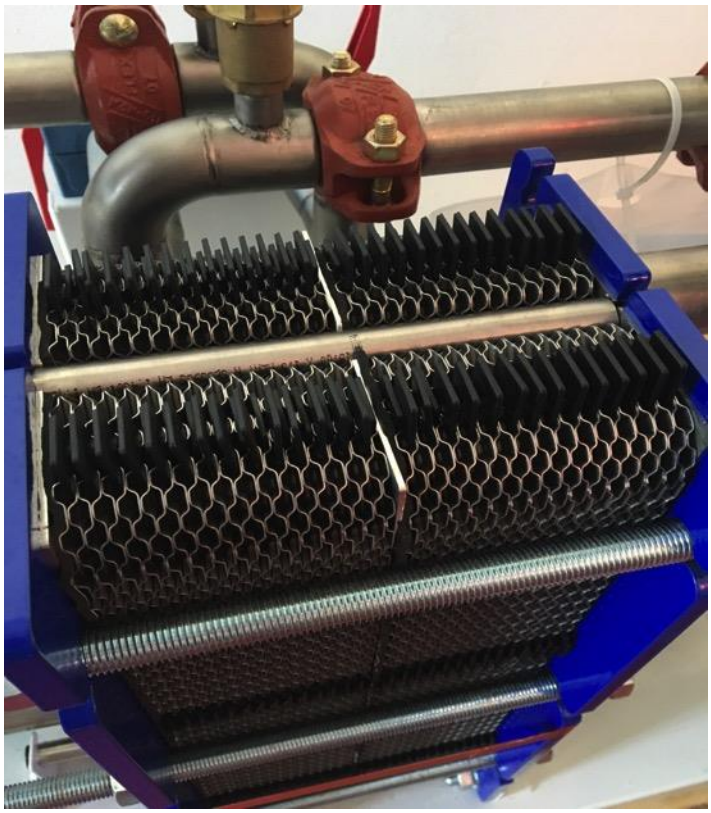


Figure 12 Stainless steel liquid exchanger, courtesy of AAVID Thermalloy

The cabinet internal power that cannot be cooled directly by the liquid shall be dissipated by cold air.

The planned air cooling strategy is described, for the sub-rack elements, in the following scheme, Figure 13.
Two systems will integrate to manage the air cooling: the sub-rack air cooling system and the cabinet radiator.
The sub-rack air cooling provides up to four small fans that move air to or from the TPM array and the cold plate radiator to manage a local air to liquid heat transfer. Fan speed can be managed locally to adjust the TPM internal flow speed and temperature if the air direction will be chosen from the BACK to the FRONT of the sub-rack. If the air direction will be chosen from the FRONT to the BACK only the air speed inside the sub-rack can be managed.
The cabinet air cooling is completed by a liquid-to-air radiator, inserted in the same internal liquid circuit.

This radiator will be completed with a dedicated fan (one or more) to contribute for the cabinet level air flow. The cabinet front panel shall be close to the air flow, with exception of the holes in the TPM sub-rack panels and the cabinet radiator site. This allows a defined air flow inside the cabinet.

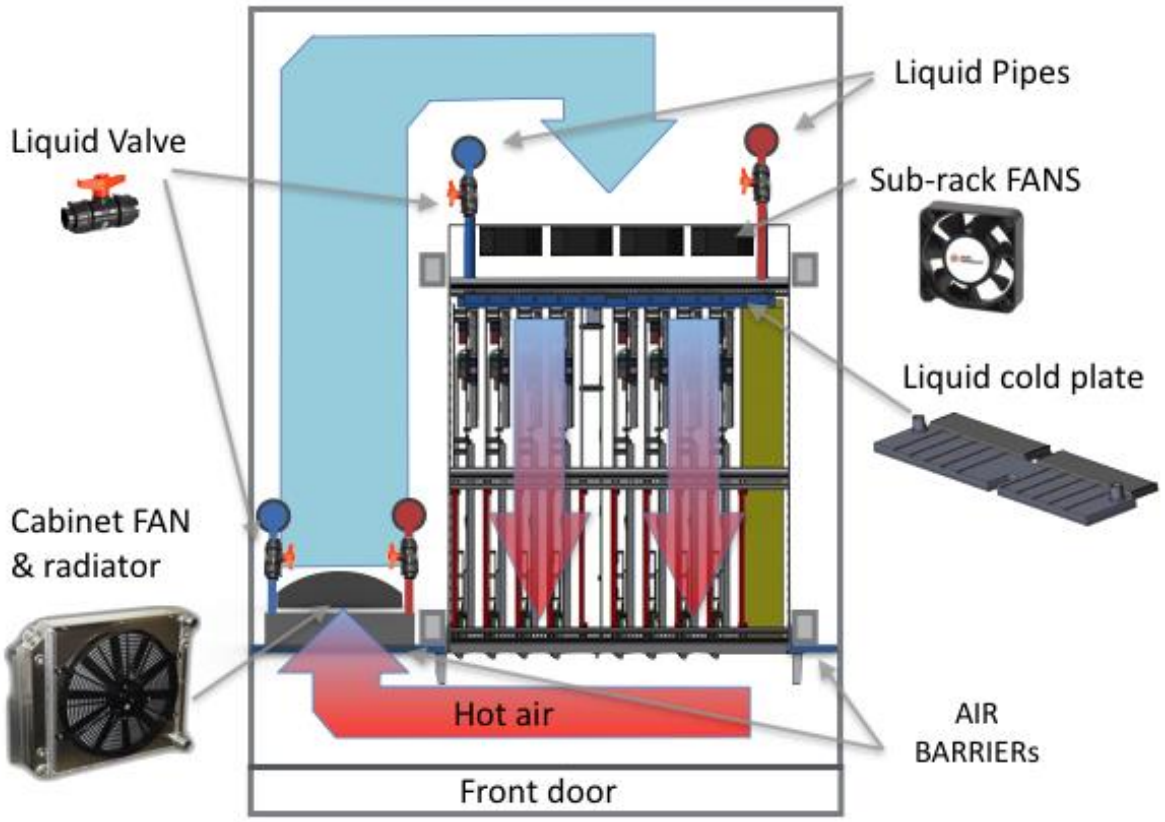


Figure 13 Cabinet air cooling, sub-rack detail, clockwise direction (top view)

The cabinet radiator shall be dimensioned to collect the power coming from the cabinet elements not connected to the liquid circuit, like the Ethernet switches, the rack management board and the residual power coming from the TPM sub-racks.
This element helps to fix the internal cabinet temperature working point.
The system can work with both air direction but some differences in the selection are expected.
The clockwise direction (assuming that the cabinet 19" TPM column is on the left) allows the local interaction of the sub-rack cold-plate with the managed small fan speed to obtain a uniform TPM temperature, with cold air directly driven to the hottest part of the TPM board.

The clockwise air direction, in case of opened cabinet door, maintains the complete operation for the system, also for long operation. On the other hand, in case of rear operation the situation is reverse.
In the counterclockwise air direction the main difference is that the refreshed air passes through the iTPM optical receiver before reaching the digital part of the board, where more power density to be released to the air is expected. Some less efficiency is expected in this case, to be evaluated on the final prototypes.

A cooling circuit design has been proposed by AAVID Thermalloy [RD4], as possible supplier, and is detailed in the following Figure 14.

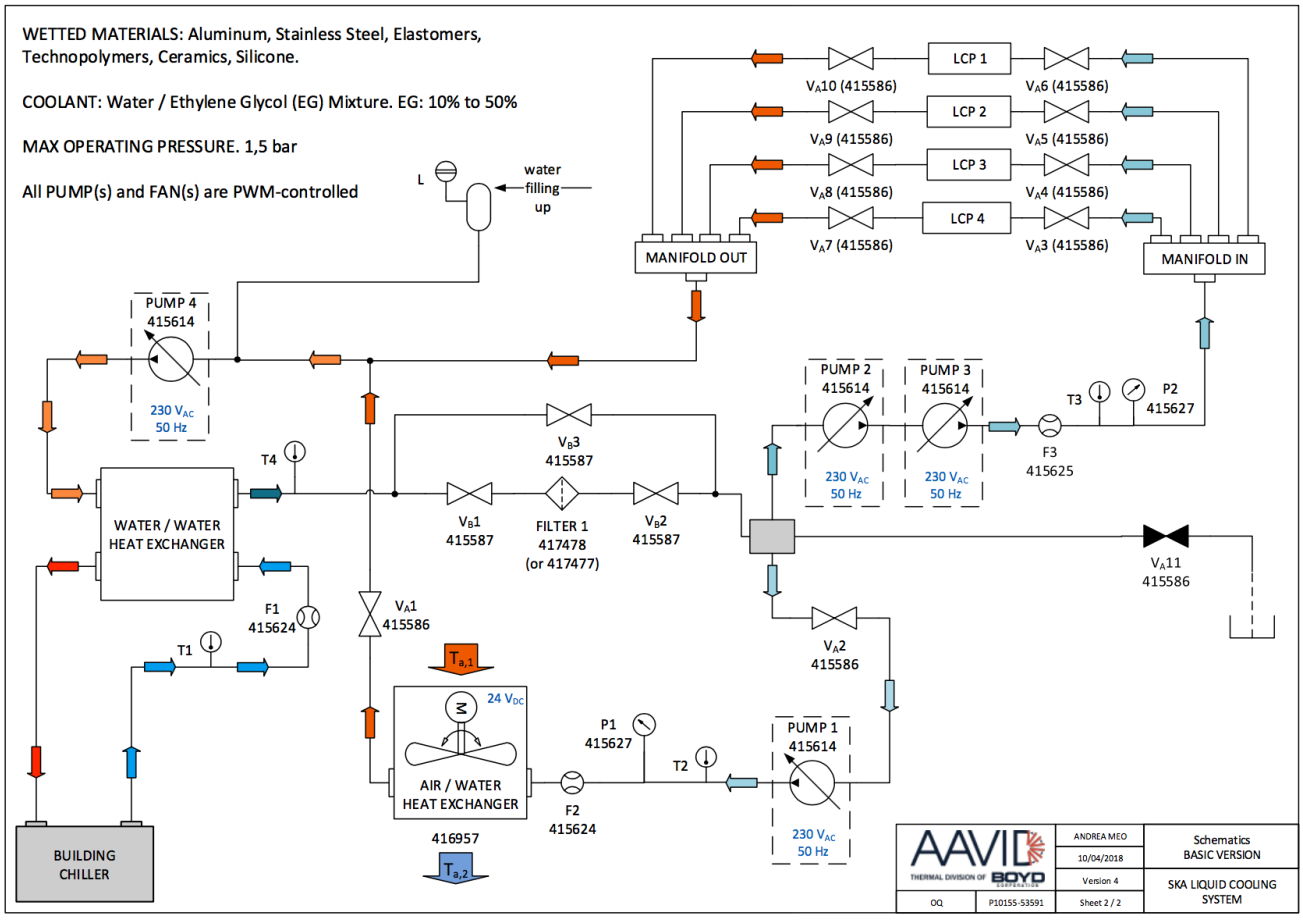


Figure 14 SKA cabinet liquid cooling system, basic version [RD4]

Three main circuits are defined: the building circuit, the cold plate circuit and the air/water circuit.
The building circuit comes from the floor to the cabinet water/water heat exchanger and come back directly to the building. Inlet water temperature and flow are monitored before the water/water heat exchanger on the external liquid interface. The water-water heat exchanger has two separate circuits, the outer and the inner and provides the capability to transfer the heat from each other without liquid direct contact. This element is required to create a cabinet separated circuit for overall system availability, maintenance and independent internal flow speed control (internal liquid circuit issues has no effect on the external one).
On the internal side of the water-water heat exchanger the liquid temperature of the cooled water is monitored before the distribution circuit.
As first element of the internal liquid circuit a by-passable filter is inserted as option for maintenance and bypassed in the normal operative mode in order to minimize the circuit pressure drop and the power requested to the pumps.
After the optional filter the circuit is split up to the sub-racks cold plates circuit and the AIR/WATER heat exchanger circuit. A maintenance valve is present here for circuit filling/emptying.

On the sub-racks branch two pumps [RD7] are placed serially to provide the requested pressure and flow to the circuit, to compensate the cold plate pressure drop. After the pumps all the variables related to the fluids are monitored (pressure, flow and temperature) before the connection to the manifold element, that uniformly distribute the liquids to the sub-rack cold plates.
Before and after each sub-rack cold plate a manual valve is present to allow the isolation of each cold plate from the circuit in order the allow the replacement of the unit.
After the sub-rack liquid cold plate the manifold collects back the liquid to a single pipe that joins the liquid coming back from the water/air heat exchanger to the last pumps.
This pump works on both the internal circuits in order to allow a two level flow control and a minimal circulation in case of single failure of the other pumps.
Before the last pumps [RD7] the connection to the expansion vessel is provided, in order to maintain the selected circuit pressure stable with cabinet internal temperatures.

On the water-air branch a similar circuit is present with only one pumps [RD7] and a connection to the heat water-air exchanger elements. Optionally on this circuit a second heat exchanger elements can be added to increase the air-to-liquid heat transfer capability (it is expected to be

below 2 KW up to 6 KWh, [RD6]) removing the sub-rack liquid exchanger branch for other possible cabinet designs.
The air-liquid heat exchanger [RD6] has two fans, PWM controlled, to integrate the action of the sub-rack fans and to control also the cabinet internal air temperature.

In the cabinet mechanics, the transfer of the air between the front side and the rear side will be forced through the air-liquid heat exchanger in order to sum the pressure gap coming from this fans to the ones present the sub-racks.

That circuit has been dimensioned with the inlet liquid specification reported in [AD2], with an internal maximum liquid temperature of 25°C as output for the sub-rack liquid cold plates and with a maximum pressure of 1.5 BAR.

The liquid is mainly pure water added with some Glycol in order to avoid the growth of undesired particles in the liquid.

The cabinet management board shall collect all the temperature information of the system elements, including sub-racks elements, and set the pumps speeds and fan speeds accordingly to optimize the working temperature set-point and the power required for the cooling process.

From similar previously developed system from AAVID, based on their HydroSync product [RD5], the pumps 2,3,4 are configured to work with 60-70% of their maximum power, the pump 1 to the 50% fo the maximum power. This design can assure that a single failure on the pumps 2,3,4 can be totally recovered by increasing the speed of the others and also a failure of the pump1 can be partially compensated increasing the speed of the pump 4 that for the circulation from all the system back to the liquid-to-liquid heat exchanger.
The flow, temperature and pressure sensors placed on the circuit will provide to the management software the information needed to manage these situations.

7.5 Cabinet layout

Cabinet elements are summarized in the following table, Table 5.

Description	n°	Rack Unit	Positioning
Processing			
iTPM sub-rack	4	6	19" column
40G Eth switch	2	1	19" column
1G Eth switch	1	1	19" column
Rack Management	1	1	19" column
Cooling			
AIR to liquid exchanger	1	0	Side
Liquid to liquid exchanger	1	na	19" column
Pumps	4	0	Below
Expansion vessel	1	0	Below
Powering			
General power, manual	1	1	Side/19" column
Power distributions, actives	-	-	Side/19" column
Mechanics			
External chassis	-	-	-
Internal supports	-	-	-
Cabling elements	-	-	-

Table 5: iTPM-sub-rack-based cabinet elements

Current proposed design is compatible with the specified Varistar LHX/20 cabinet that includes the liquid–to-air radiator with fan and with a standard chassis available on the market (eg, ABB customized by RGM mechanical company).
Both the mechanics are not shielded at chassis level, assuming that all the internal elements are properly certified for EMC. This policy confirms the one followed by AAVS1, where the iTPM board has been certified with good results by the Australian laboratory.

The presence in the Varistar LHX 20 option of the heat exchanger column on the side has a partial impact on the overall layout. The preliminary schematic layouts are shown in Figure 15.

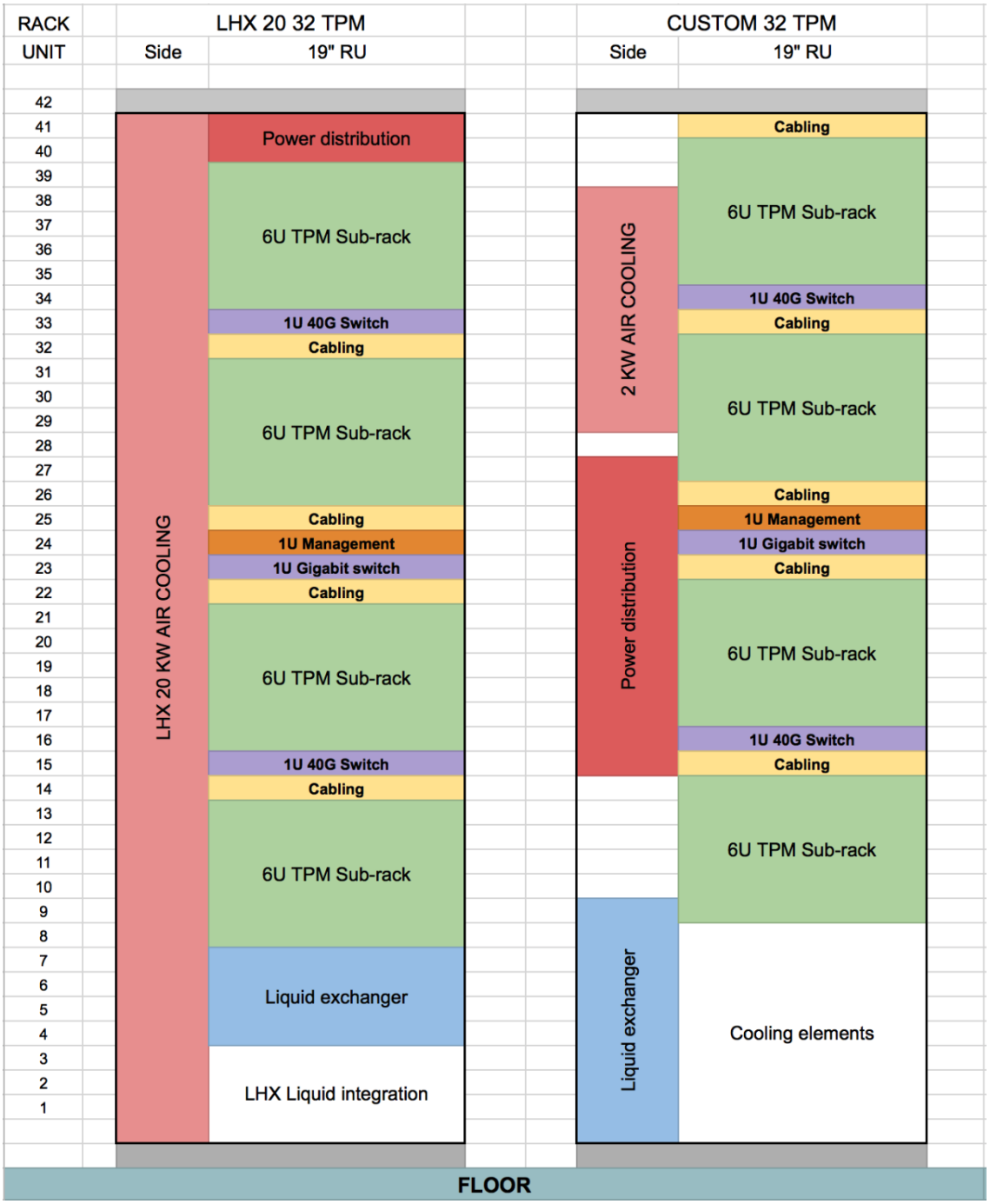


Figure 15 Cabinet preliminary layout, Varistar & standard, front view

The Power distributor element shall implement the general on/off switch, with manual activation and the required safety passive protections. As reported in Figure 8 LFAA Cabinet supply scheme, the power distribution unit shall manage all the controlled switches that can power all the other cabinet elements, with exception of the management board that shall be always powered.

The TPM sub-rack shall be possibly coupled with the 40G Ethernet switch placed in the middle to implement a complete station module. With this approach the 40G QSFP connection are short and local and all the TPM of a single station are connected to the same switch to assure communication efficiency.

In the Figure 15 the yellow cabling units are empty space for fibers and general cabling to allow maintenance capability and the possibility to extract a single TPM without other cable removal.

The cabinet management and the 1Gbit management switch (optional) can be placed in the middle or everywhere in the 19” column. The middle position can be optimal for clock cabling and network connections to each sub-rack.

The liquid cooling circuit shall be placed on the bottom, with the liquid exchanger connected with the infrastructure liquid circuit by one side and to the cabinet internal circuit on the other. Also pumps and other liquid elements shall be placed on the bottom of the rack, with exception of the expansion vessel that shall be placed above the liquid circuit, to allow air removal and maintain the selected secondary pressure.

7.6 Cabinet management architecture

The Cabinet management is structured over three levels: cabinet level, sub-rack level and iTPM level.

The management functions related to a specific level shall be allocated to a corresponding element to allow proper functional separation and maintainability.

Cabinet level functions shall include power distribution, cooling and other electromechanical interfaces.

Sub-rack level functions shall include: sub-rack level power distribution (to TPMs), iTPM configuration, iTPM startup sequence, synchronization distribution, cooling and status monitoring.

iTPM level ones execute the power management and configuration commands and support the TPM system monitoring for internal voltages and temperatures.

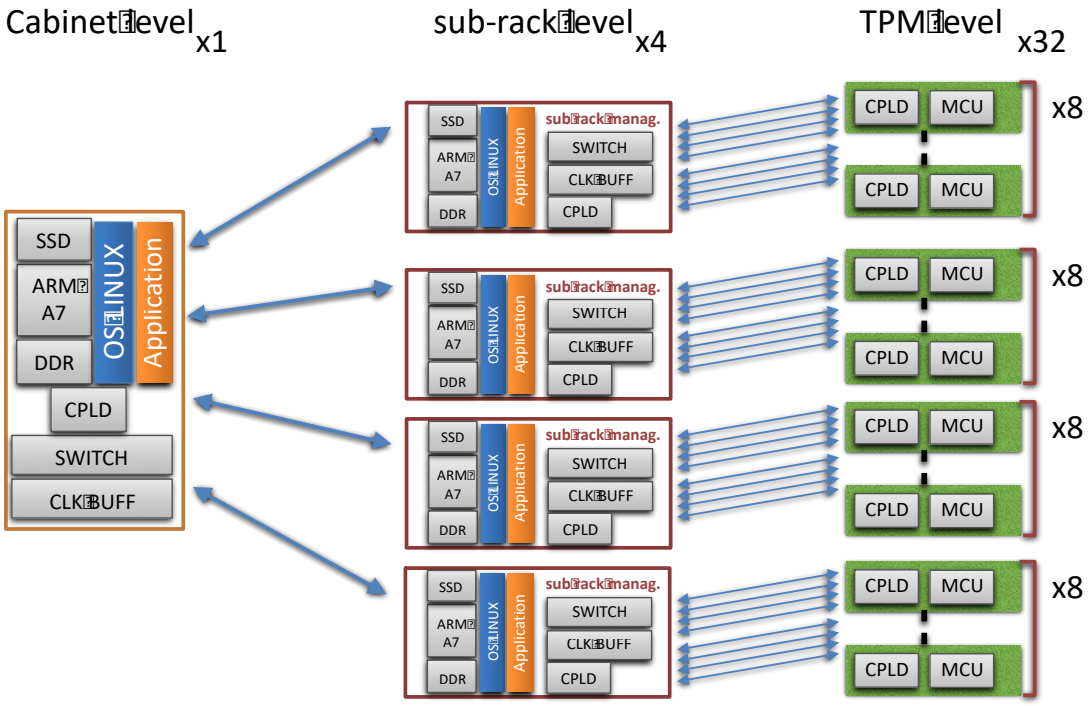


Figure 16 Cabinet management processing architecture

Each level communicates with a dedicated Ethernet gigabit connection with UDP based protocol for direct memory access and TCP protocol (or similar) for high level operations.

At cabinet and sub-rack levels a complex CPU, with Linux OS shall be present to manage secure TCP based communication with the Telescope Manager and the MCCS applications. The CPUs shall be directly connected on the gigabit network and each board shall also provide a CPLD with a hardwired gigabit UDP interface to allow the low level hardware direct interface and safety critical functions in order to avoid the need of a real time OS on the CPU.

On the iTPM a simple MCU integrate the CPLD functions to execute sequential operations and complex commands received from the management software.

7.6.1 Rack management board

The rack management board shall collect all the cabinet level functions not directly implemented at sub-rack level and fit on a single rack unit to minimize volume occupancy.
The board shall provide the following interfaces:

- 40G Ethernet network by two 10G separate link connected on a single front panel QSFP cage
- 1G Ethernet interface by 8 RJ45 front panel interface and 2 side RJ45 interface
- 10 MHz clock input and 10 MHz clock outputs (x6)
- PPS input and 6 PPS outputs
- GPIO with various standard to manage cabinet power distribution, cabinet elements (e.g. switch status for the cabinet open door, internal temperatures) and the cooling elements (PWM for pumps and fans, liquid temperature sensor, pressure sensors and so on)

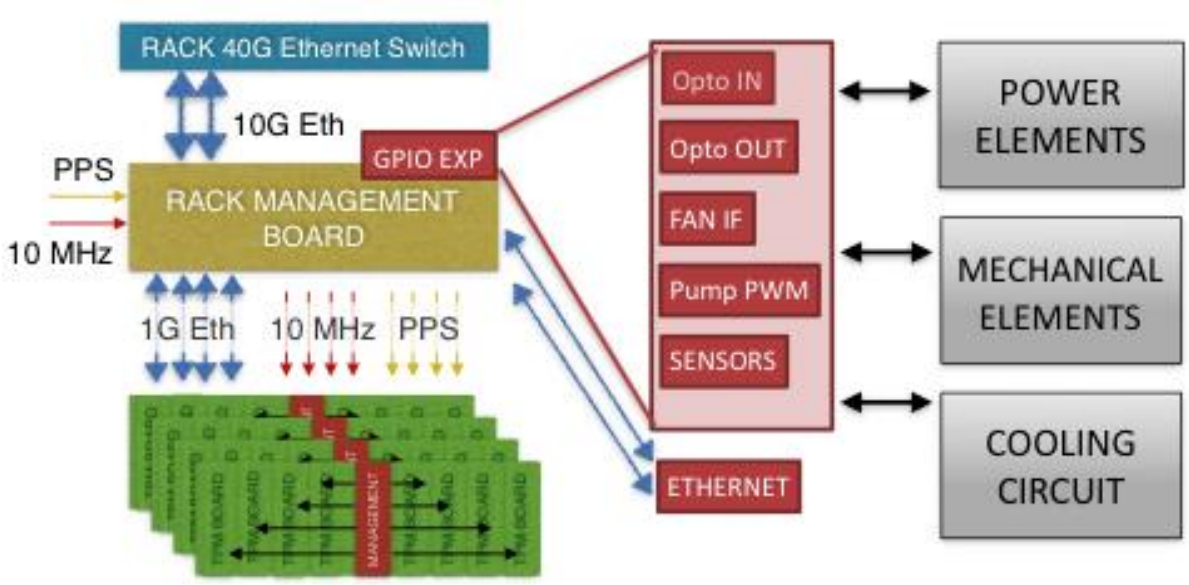


Figure 17 Rack management board interfaces

The rack management board shall be placed in a 1U unit with panel direct connector access for the QSFP, all the clock and PPS interfaces and the 8 RJ45 interfaces; some status LED shall also be visible from the front panel to indicate the board status. On the opposite side of the unit, on the rear side, a removable connector with all the other specialize I/O, the two remaining Ethernet ports and the power supply input shall be present.
The requested power shall be less than 40W on the AD 220V directly distributed from the cabinet power distribution unit.
The unit shall be possibly fan-less to be integrated in the cabinet air cooling system, no liquid interface is available for that element. The cooling air direction shall be selectable, from front to rear and vice-versa to allow a functional verification on the final prototype.

The management board shall provide the following resources:

- 14 port Ethernet L2 switch with x2 10G ports, x10 1G ports over copper cable, x2 1G ports over GMII or similar for internal connection to the CPU and the CPLD
- ARM based processor with Linux OS, connected on the gigabit management network
- 512 MByte volatile ram and 4 GByte of non volatile memory for OS and application data
- SATA II disk interface for optional storage
- PCI Express interface for growth capability
- CPLD to manage hardware low level function

- System monitor MCU
- Low noise differential clock buffer for 10 MHz reference, with 6 outputs (low RMS added jitter, <100 fs broadband), SMA or similar cable interfaces
- Low noise single ended clock buffer for PPS distribution with 6 outputs, SMA or similar cable interfaces
- Processor trace port, for debug
- User accessible GPIOs to design the requested cabinet sensor and actuator interfaces.

Possible interference between the synchronization signals and the TPM fiber receiver circuit shall be considered, as feedback from AAVS1 prototypes. It can be evaluated an alternative optical distribution circuit inside the cabinet to remove this possible issue.

7.7 Cabinet synchronization

The SKA LFAA cabinet shall assure a high performance synchronization distribution network, fundamental element for the overall telescope performances.
The synchronization signals are the 10 MHz reference and the PPS that come to each cabinet from SaDT LOW and shall be distributed accurately to each TPM and to each ADC input, with low performance degradation and without measurable difference between the several paths.
To meet these needs, all the possible strategy to minimize path differences shall be adopted as priority in the cabinet design and an accurate electronic design shall be done.
The proposed cabinet synchronization distribution network is detailed in Figure 18.

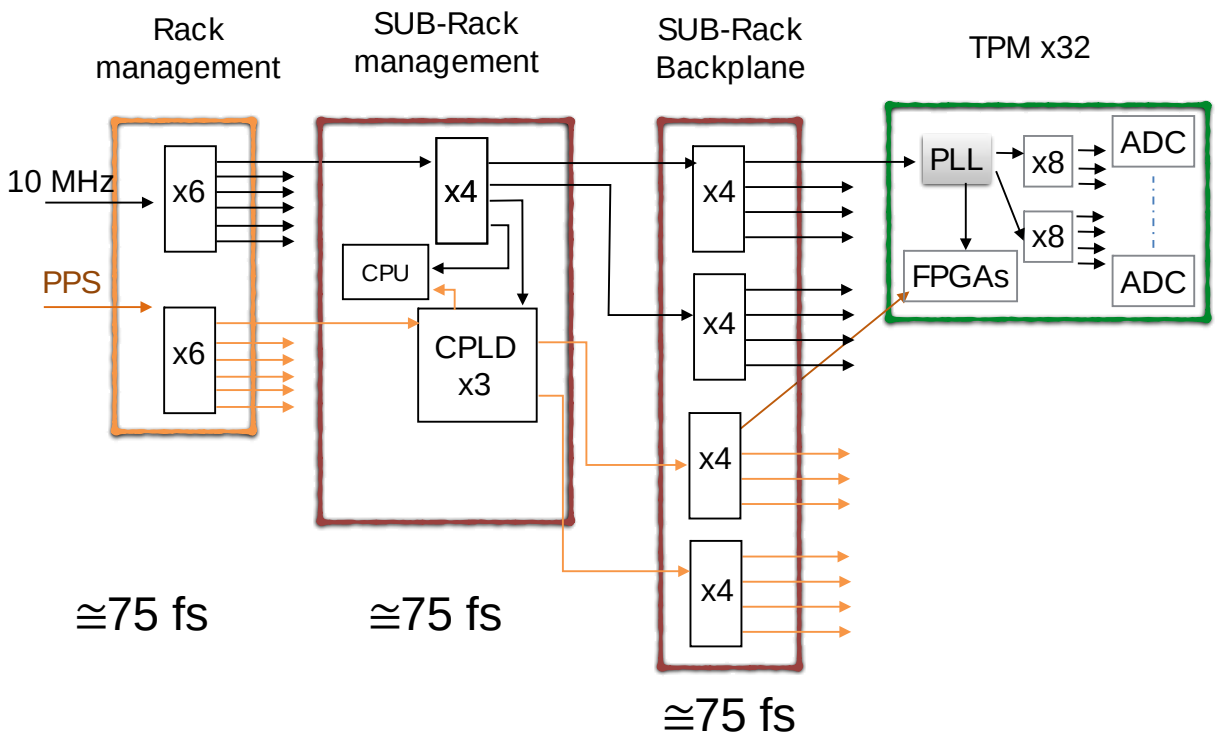


Figure 18 SKA LFAA cabinet clock distribution network

The 10 MHz and PPS signals coming from the infrastructure shall be connected to a first level of clock distribution, integrated in the rack management board.
The 10 MHz signal shall be treated as high performance RF signal, with related shielded cables, connection and full differential paths on the electronic circuits. On the electronics board, isolation and filtering criteria shall be adopted in order to minimize interference.

The PPS signal shall be treated as high speed single ended digital signal with less stringent design isolation criteria.
For each channel a deterministic and equalized path shall be guaranteed between the source and the outputs, and the difference in latency shall be minimized and verified. Because of the technology difference of the two signals, i.e. single ended for PPS and differential for the 10 MHz reference, different circuits are needed to implement the distribution path and as consequence the propagation delay will result different. A characterization shall be done and a specific SaDT LOW system requirement shall be defined in order to assure the overall synchronization function.

Note: currently a lack of specification related to the phase relation between the PPS and the 10 MHz reference has been notified, but it is still pending (open issues to be noted). At the current design status the two input signals are not phase-aligned and they are propagated each with a separate path to the TPM FPGA inputs. The FPGA receives a multiplied 10 MHz phase-aligned clock for internal operation: this clock is used to sample the PPS signal. In order to respect the FPGA I/O timing specs (setup time, hold time) the PPS signal shall be guaranteed stable for all the devices at the sampling time. If the PPS does not respect this specification, different behaviors are expected, with lack of synchronization between the different FPGAs.

The buffered output signals from the rack management board shall be connected by means of RF cable to each sub rack management board for the second level of distribution.
To minimize possible interference and cable signal degradation, the rack management board shall be placed in the middle of the cabinet layout with equal length cable used for the connection to all the sub racks.
Cable loss can have negative effect on the final performance of the distribution network, in terms of added jitter due to the relation of the active buffer with the input signal slope (V/ns).
The added noise of the differential clock buffer currently adopted for the iTPM, expressed in terms of added RMS jitter is reported in the following Figure 19.

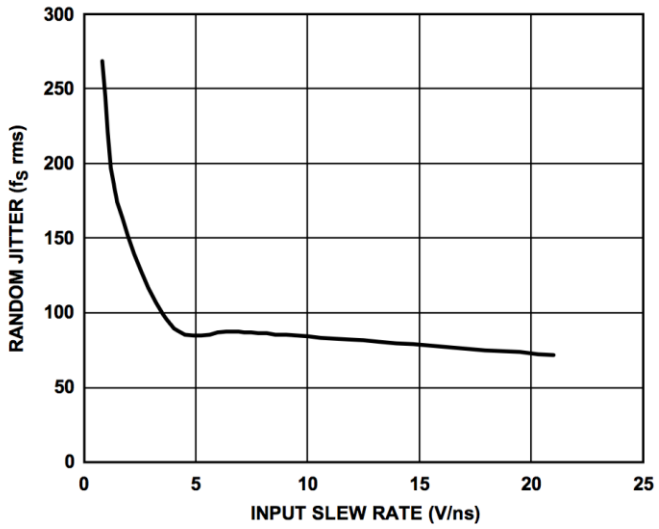


Figure 19 ADCLK948 clock buffer added jitter as function of input slope signal

Optical transmission inside the cabinet between the rack management board and the sub-racks can also be considered, in order to exclude the cable loss and possible interference with the optical receiver circuits of the TPMs.
Each element of the distribution chain will introduce white noise to be added “in quadrature” to the one present in the input signal, in absence of deterministic undesired contributions.
A total amount of added jitter shall be guaranteed from the cabinet source to each TPM to maintain the final SNR system performances. The presence of active PLL with jitter cleaning in the distribution path shall require a system characterization with prototypes in order to define the jitter budget to the single elements.

The sub-rack management board will distribute the 10 MHz reference to the backplane with two signals with dedicated RF paths and the PPS in similar way but using digital high speed connectors. In the sub-rack management board the two synchronization signals are also distributed to the CPLD to allow possible software managed synchronized operations.

In the sub-rack backplane the last clock distribution elements are present to route the signals to each TPM. Also the backplane shall guarantee the minimal signal loss, degradation and interference with external noise source.
The same propagation delay shall be assured in the sub-rack from the signal source on the management to each TPM, with expected difference between the 10 MHz reference and the PPS signals.

7.8 Cabinet mechanics

The cabinet mechanics shall respect all the infrastructure specifications [AD2] in terms of occupied volume, maximum weight, available maintenance space, air and liquid floor interface, optical fiber interface from the top.
A possible cabinet complete design is presented in the following sections. All the cabinet elements have been integrated with standard elements, where available, considering installation and maintenance processes.

The objective of this design activity is the requirement validation and a first cabinet constructive design to implement a first prototype required to test all the selected solutions.

On the basis of this first complete design it is also compiled the bill of material and evaluated the cost of the single elements, with the available granularity.

In the proposed design, two standard 80 x 60 cm^2 rack structure have been paired to obtain the requested 80x120 cm^2 external volume of the cabinet. This solution allows standard catalog component selection and a robust structure, with IP55 feature, see Figure 17, Figure 21.

Cabinet internal layout has been organized with two internal main volumes, the 19” rack column on the right and a 20 cm side on the left.

On the cabinet front side a single port has been selected, opening on the right, with a transparent glass to allow the vision of the status lights of the present elements by an operator.

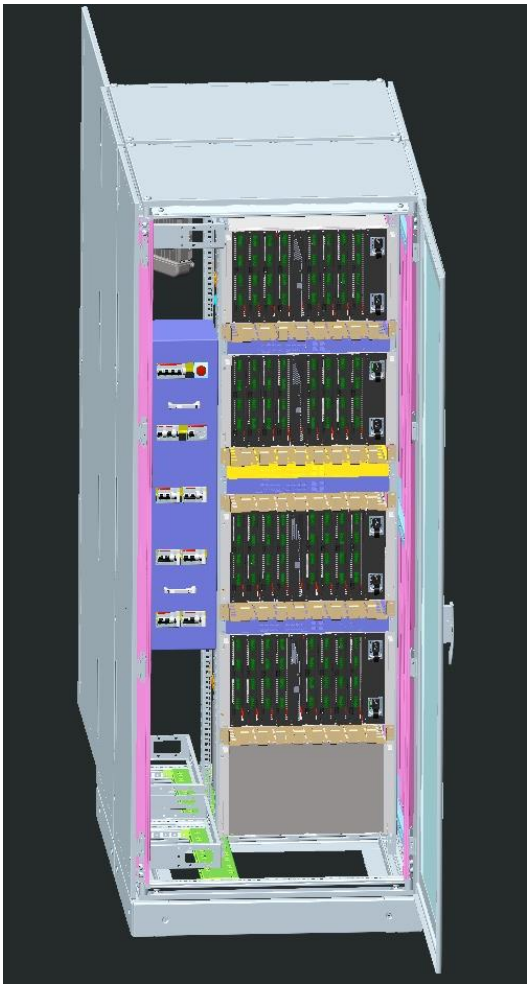


Figure 20 SKA LFAA iTPM cabinet main elements

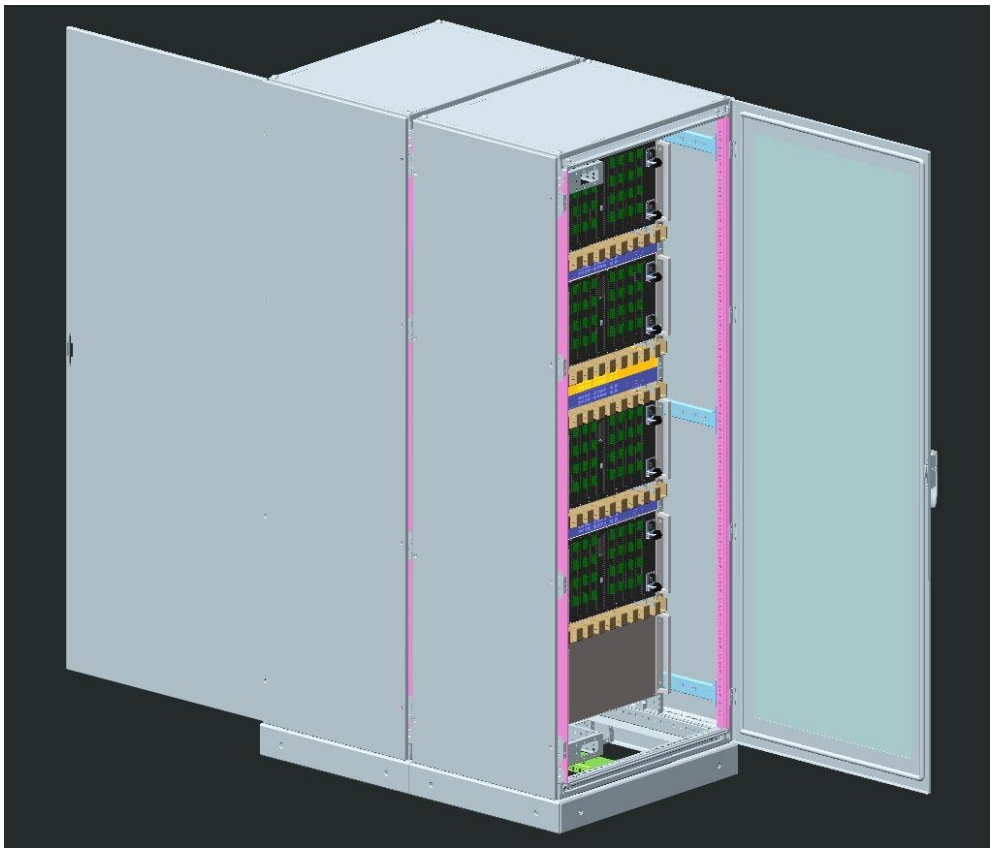


Figure 21 Cabinet double doors with glass on the front side

On the cabinet back side, a metal door has been chosen to allow practical maintenance access to the cooling circuit and to the connection elements from the infrastructure.
A standard footer, a top and side metal enclosures will complete the external body of the cabinet, ensuring the requested inner volume separation from the building.

The Infrastructure specification document guarantees 90 cm of free space in front and on the back side of each cabinet, allowing the complete opening of the doors providing a simple access to the internal elements.

The 19” rack column will house the iTPM sub-racks, the Ethernet switches and the cabinet management board with the layout defined in the chapter 7.5. This column has more than 20 cm of space in the front before the door to allow practical cabling for the front panels and also a

small space, about 4 cm on the left, for fiber and power routing from the top to the iTPM front panel.

The internal structure is built with a combination of standard elements and custom parts.

The 19" rack elements are standard elements but for the insertion of the sub-rack custom guides have been designed (orange in the picture of Figure 22), integrated with the cabling unit to provide the required support for sub-rack insertion and extraction.

The metallic guides for the sub-rack are placed in the volume of the 1U cabling space, in order to maintain the standard vertical step.
Each sub-rack and the cabinet management board have below a cabling unit to allow the routing of the required cables with minimal usage of the elements front panel, mainly to simplify the cabling and the element removal.

On the bottom of the 19" rack column, a closed volume will house cooling liquid circuit elements (shown open and empty in the Figure 21), to minimize interaction with the electronics circuits and to interface with the infrastructure incoming cooling liquid interface from the floor.

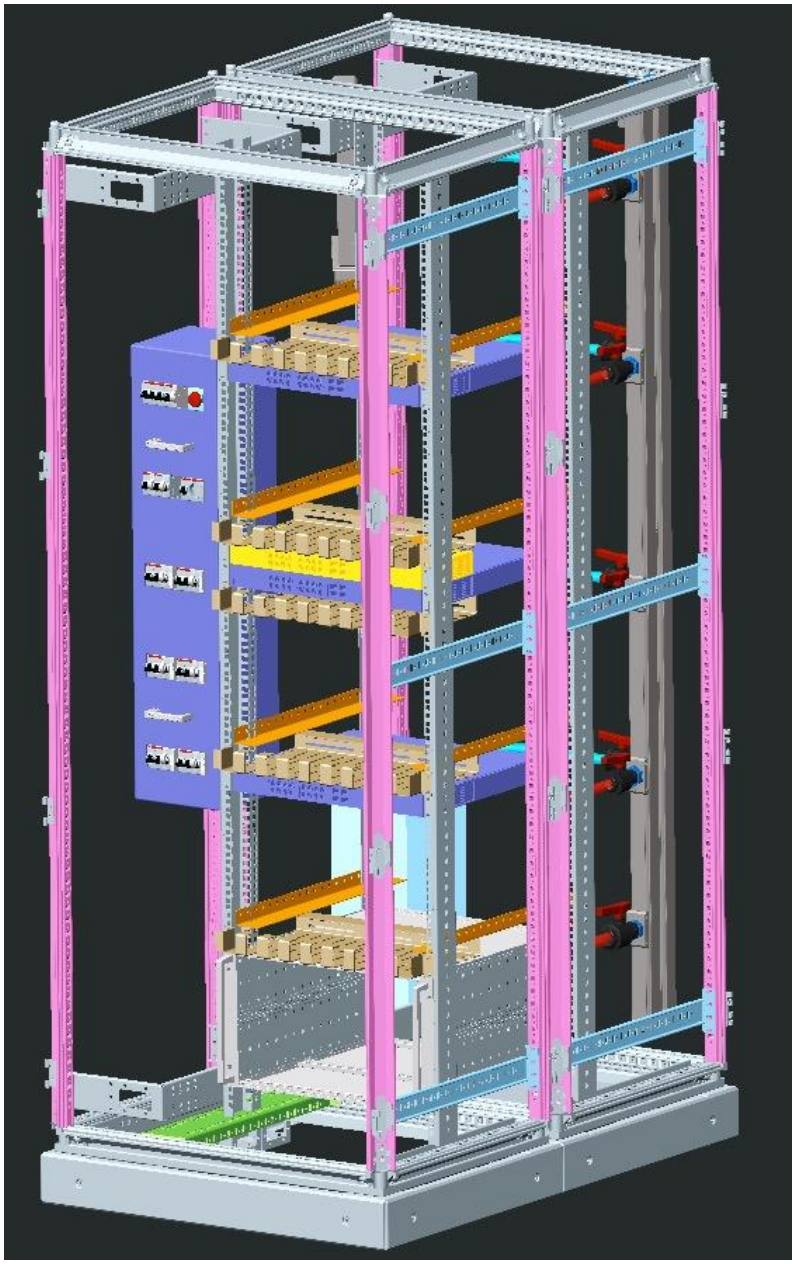


Figure 22 SKA LFAA cabinet layout, main concept & metallic structure

The small size elements of the cooling circuit described in the previous paragraph 0 will be pre-assembled in this element with the interface valves accessible from the rear side of the column (Figure 23 and Figure 24).

With current 19" rack elements, the maximum depth is below 50 cm, resulting large free space behind the column element to the back of the cabinet. In this volume all the remaining elements of the cooling circuit will be placed: the pipes, the liquid to liquid heat exchanger, the manifold, the liquid to air heat exchanger and the expansion vessel.

The infrastructure cooling pipes that come from the floor are connected, by two valves, to the liquid to liquid heat exchanger placed on the right, close to the floor (within the pictures). The pipe of the internal circuit coming from the exchanger are connected to the volume containing the pumps and the other small cooling elements from witch they come back to the manifold (on the right) and to liquid to air heat exchanger on the left.

The manifold is a vertical, metallic structure that takes the output from the pumps placed on the bottom and distributes almost uniformly the liquid to the several drains present in the circuit, the sub-rack liquid cold plates and the liquid to air exchanger. The same element collects the heated liquid back to the bottom to close the circuit (light blue pipes for the cold liquid, red pipe for the hot liquid in the pictures).

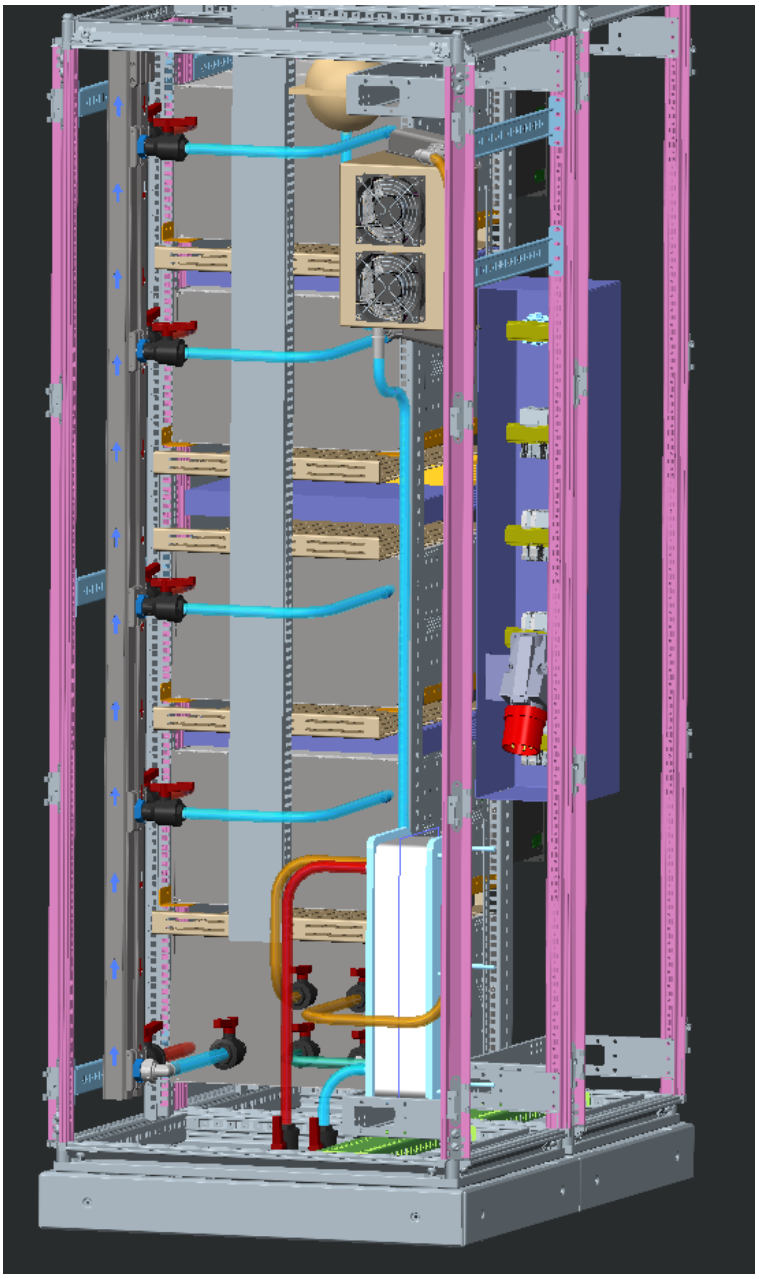


Figure 23 Cabinet back access, backdoor hidden, cooling circuit and power input

Each units collected to the manifold can be separated by a valve for maintenance removal with a small liquid dispersion. The pipe and valve distribution routing will exclude the natural contact between liquid and electric power distributing elements.

With this approach the liquid-to-air exchanger is placed on the backside of the cabinet, on the top-right above the electric power distribution reserved volume.
Two fans that force the air through the radiator element complete the air to liquid radiator. The related air direction shall be chosen conforming to the choice done for the fans present in iTPM the sub rack elements [RD3].
The internal position of all the cabinet elements shall be optimized in order to allow the flow of the internal air between the front side and the rear side.

The expansion vessel is placed over the liquid to air heat exchanger in the upper part of the cabinet to collect possible air present in the circuit and stabilize the pressure due to possible temperature variations.

Some valves required for the filter insertion and the filling of the circuit are not shown in the current drawings.

Thanks to the low pressure and low temperature of the circuit, high quality silicon flexible pipes have been proposed for all the internal circuit connections, simplifying the

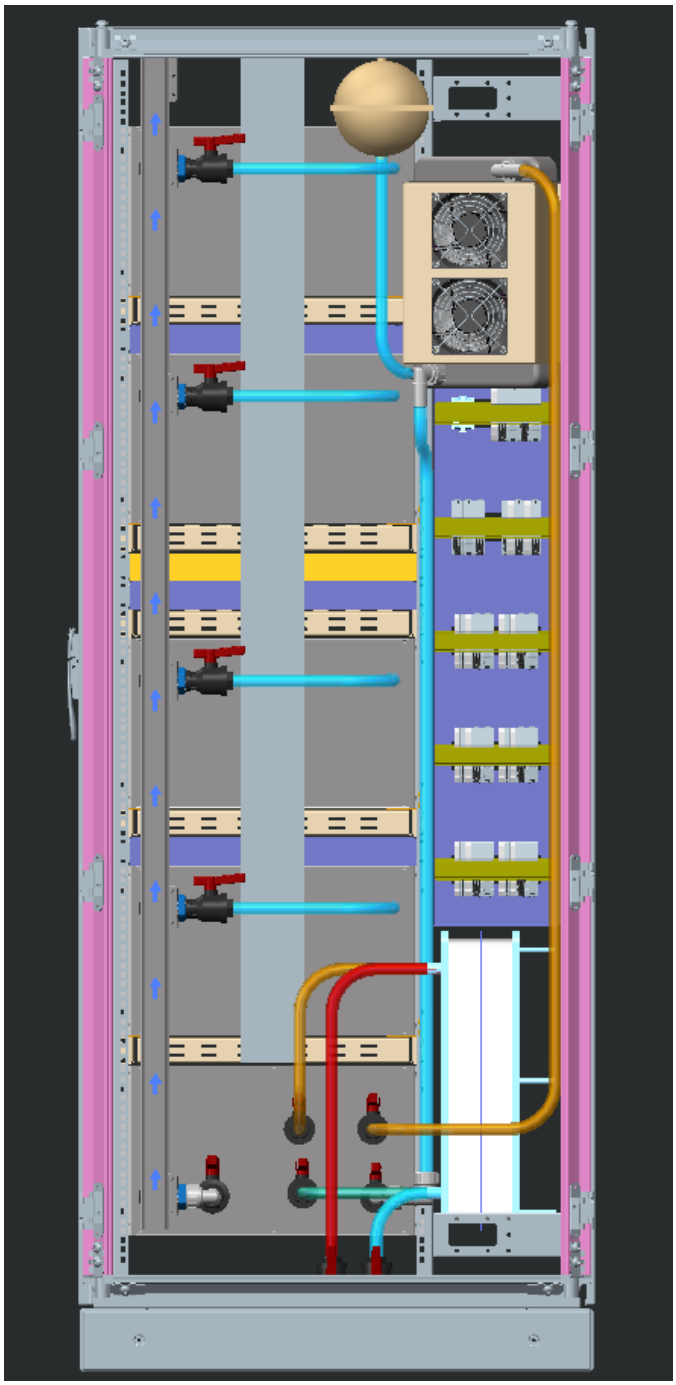


Figure 24 Cabinet rear side

construction and the maintenance.

The electrical components, related to the power distribution and the required protections are inserted in the left space of the cabinet, inside a metallic box.
All the main function and protection circuits are directly accessible from the cabinet front panel and the connection to the rack element can be done with directly cabling from the rear or from the side.
The metallic box will provide a standard DIN guide to allow the usage of standard elements to implement the electrical circuit described in the previous section.

Some status lights and emergency buttons will be placed here for quick access to the maintenance operators.

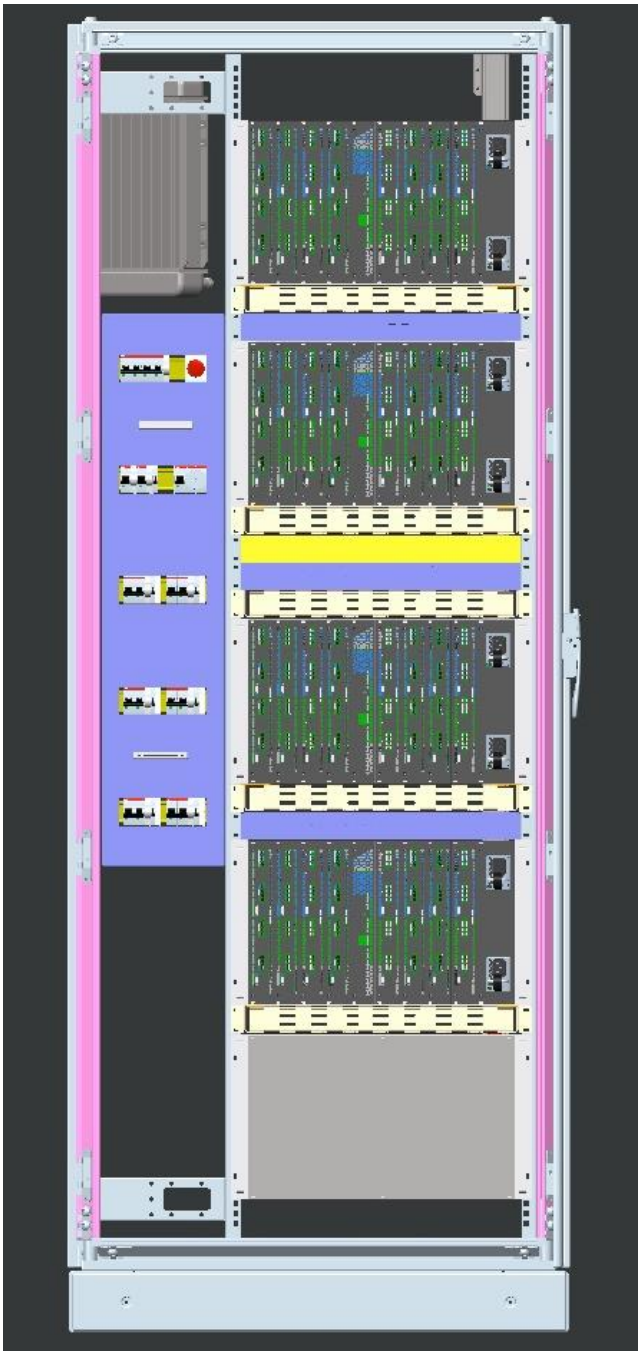


Figure 25 Cabinet layout front view

7.9 Cabinet assembly and maintenance

Cabinet design has been guided to allow modular assembly and pre-defined and simplified maintenance.
The following main modules shall be defined:

- cabinet mechanics, including external and internal structural elements and cabling guides
- iTPM sub-racks
- cabinet 19” 1U modules, cabinet management board and Ethernet switches
- cabinet power module
- cabinet cooling box (containing pumps and sensors)
- cooling kit, including liquid to liquid, air to liquid heat exchangers, manifold and expansion vessel

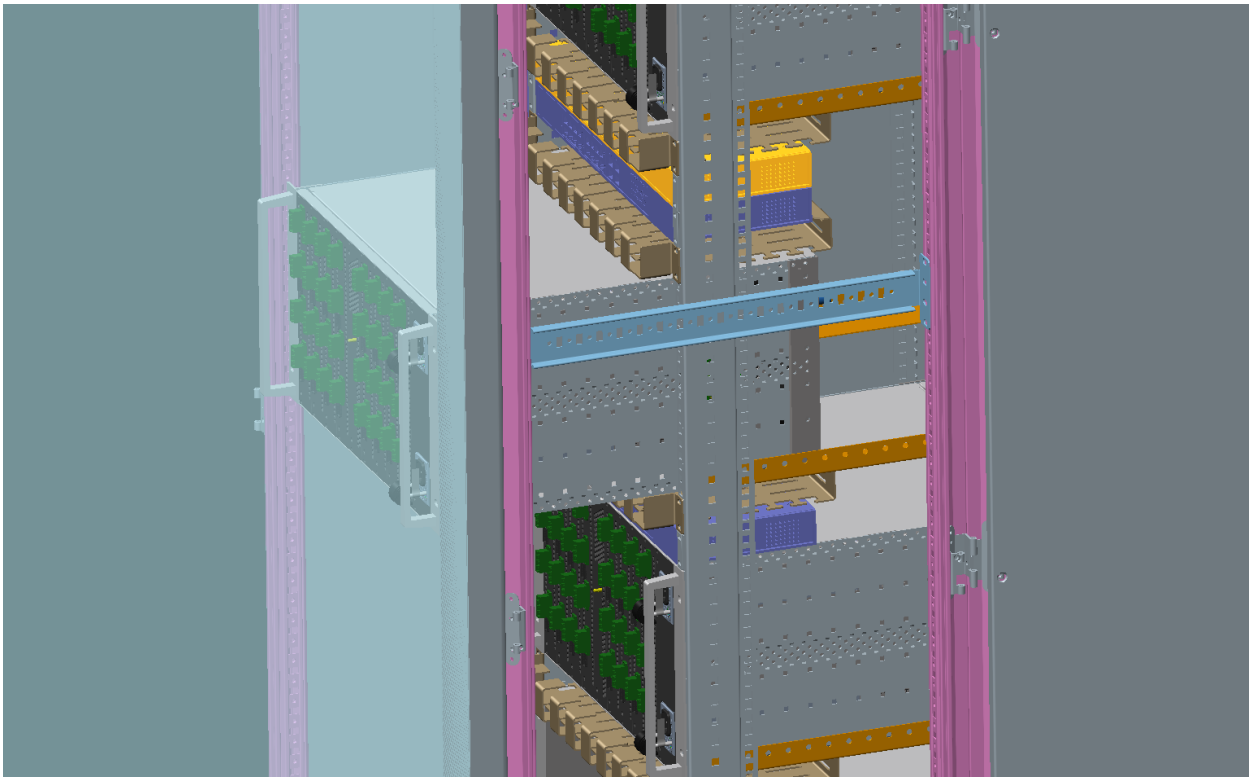


Figure 26 Sub rack insertion/extraction

The cabinet cooling kit shall be assembled to the mechanics before system installation.
All the other elements can be inserted in the structure from the front side of the cabinet and connected to the power supply and the cooling system on the back side. All the data and signal cables will be accessible directly from the front panel.
The connections from the infrastructure floor sources, power and cooling, shall be done by the cabinet back side (Figure 23, Figure 24).
It is expected that the iTPM sub-rack is inserted either as complete module, 30 Kg of weight or partially populated module, without iTPM, resulting is a really lighter module. In any case dedicated metallic guides have been prepared to simplify the insertion/removal of all the sub-rack and to sustain the full weight of the units.
For sub-rack installation and maintenance both iTPM and the power supply units can be any hot-swap removable.
The iTPM shall be placed in stand-by mode by management command before removal.
A single supply unit can be replaced with the system running, if the redundant module is present, without affecting the main functions.

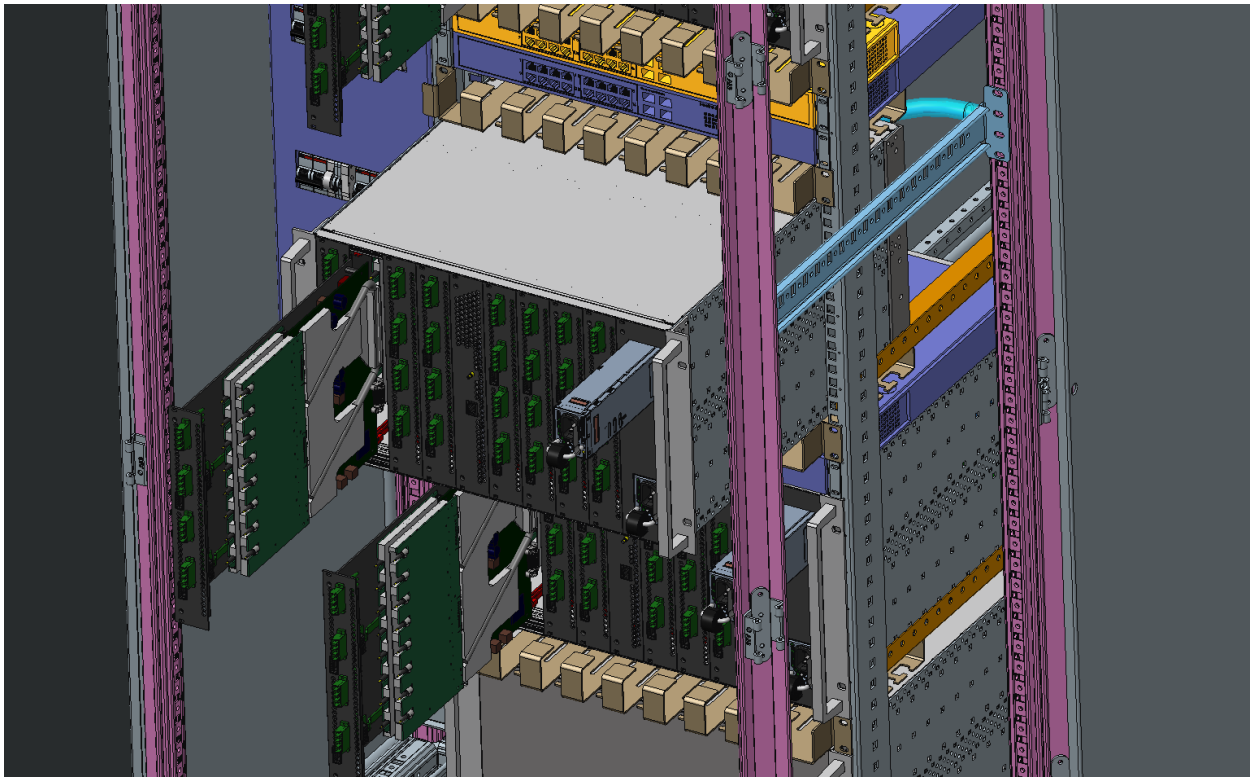


Figure 27 iTPM and supply unit replacement

The other elements of the sub-rack cannot be replaced with the same direct operation.
To substitute the sub-rack management board, the backplane or other internal elements, the sub-rack shall be powered off and removed from the cabinet.

The maintenance operation for the liquid cooling circuit are described as reference in the Hydro Sink user Manual [RD5] and shall be updated for the final cabinet design.

No maintenance is expected for the power distribution circuit where the involved current values and the self-protection circuit used, assure a safe functionality. Each single element is a standard component that can be substituted by a qualified operator directly on the site.

7.10 Cabinet cabling

The cabinet cabling design mainly copes with the RF fiber cabling and the high speed 40G Ethernet cabling as more complex and critical elements.
Cabinet cabling shall take into account the routability and maintainability of the cable themselves and the related connected elements.

The main cabinet cabling design elements are the front space between the 19” rack front panel and the front door, the 1U spacers inside the 19” element and the cable duct behind the same elements. Beside the 19” rack column a volume is also available for vertical cable routing.

The iTPM sub-rack design has been driven to minimize cable interface with all the connectors available on the front panel. Each iTPM sub-rack shall be connected with sixteen fiber connector, LC type and one 40G Ethernet QSFP cable. In the center of the iTPM Subrack the synchronization signals and the management ethernet shall be connected too and on one side the AC power supply.

The fiber cable coming from the antennas is expected to be similar to the AAVS1 one, that is a twelve fiber cable assembly directly coming from the infrastructure to the top of the cabinet and connected with a breakout to the TPM inputs. Each cable is ended with twelve LC connections: eight of them are used and four are spare. Each TPM requires two fiber cables, sixteen for each sub-rack.
The sub-rack fiber cable comes to the cabinet from an opening on the top side of the cabinet and slides down in the vertical duct behind the 19” rack column. On the top of the cabinet a flap corresponding to the cable duct is present in order to isolate the inner volume in the cable entrance area, Figure 28.

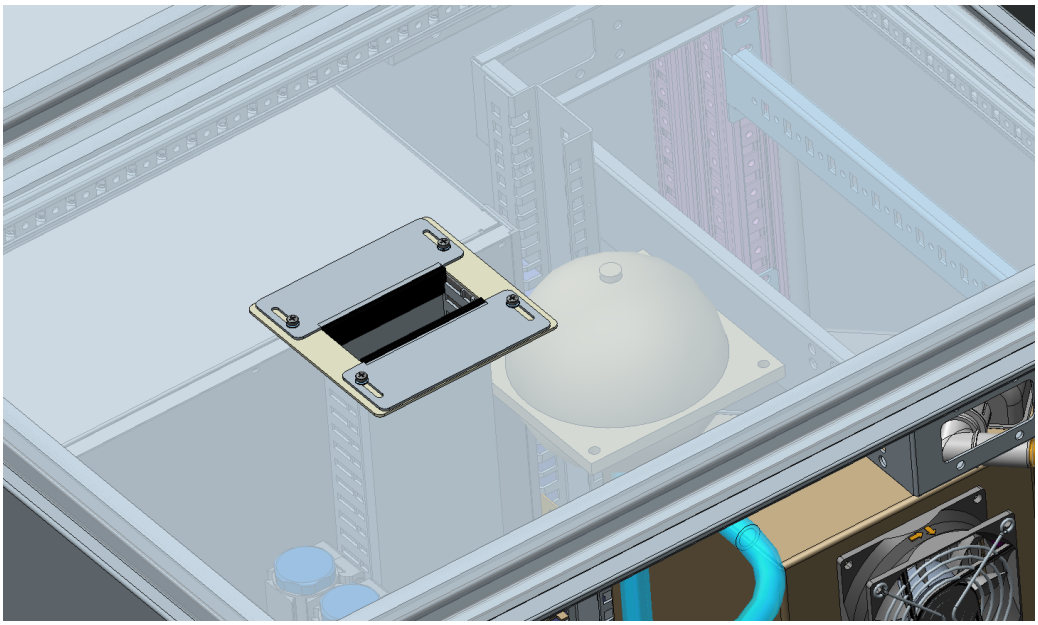


Figure 28 Opening on the top side of the cabinet

Under each sub-rack a 1U spacer is reserved for cabling. The fibers coming from the vertical duct behind pass through the cable spacer and can be connected vertically to each iTPM. The available spacer can also be used to match the fiber length or for maintenance operations. The positioning of this spacer below the Subrack is due because of the volume required for the Subrack mechanical guides.

Also the 40G Ethernet cabling has been optimized at cabinet level by the 19” rack column layout, taking into account the functional network specification and the layout optimization.

Coming from the cabinet network specification, at least a 36 QSFP port switch plus spare is needed for the cabinet 40G Ethernet network, to connect the TPMs inside and the outer elements.
Available from the market (early 2018) only up to 32 port switches with QSFP interfaces are available; as consequence a two switch solution is proposed, interconnected to each other.

Each switch shall be connected to the 16 TPMs requested for each station; these TPM shall be placed in two adjacent Subrack and the related switch shall be placed in the middle.
This approach optimizes the cabling because all the station data is routed on the same node and only the produced station beamforming shall be transmitted or received.

The positioning of a station switch in the middle of the two Subrack provide also shorter cable and a almost vertical routing to the TPM with several advantages.

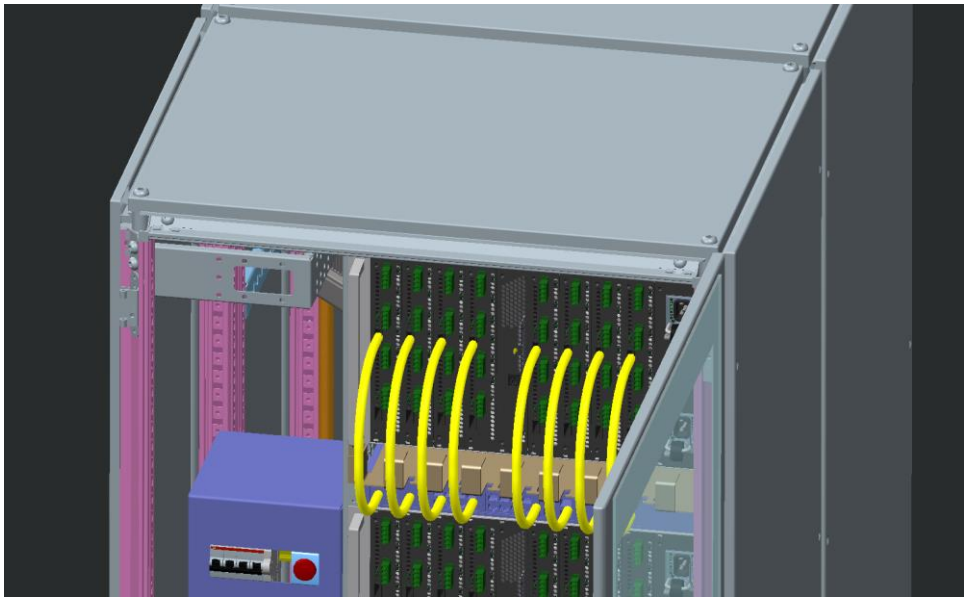


Figure 29 Example of 40G QSFP cable connections

All the TPMs are connected with the same length cable, as short as possible, reducing cable cost and simplifying the maintenance
The cost is reduced because the reduced length allows passive copper cables (cheaper and no absorbed power for optical interfaces) and the length uniformity increase single item volume.

The maintenance is simplified both for the routing, that allow a single cable removal to replace a TPM and for the spare part, because a single code shall be considered for all TPMs.

The two switches will be connected one to each other with two QSFP cables (copper or optical, TBD) considering one for data and one spare, and connected to the infrastructure (expected with optical cables to cover lengths greater than 3 meters).

The QSFP copper cables, used for internal TPM routing, are quite rigid and require considerable space in the front for correct routing. At least 20 cm of space between the front panel and the cabinet door shall be provided for routing and maintenance.

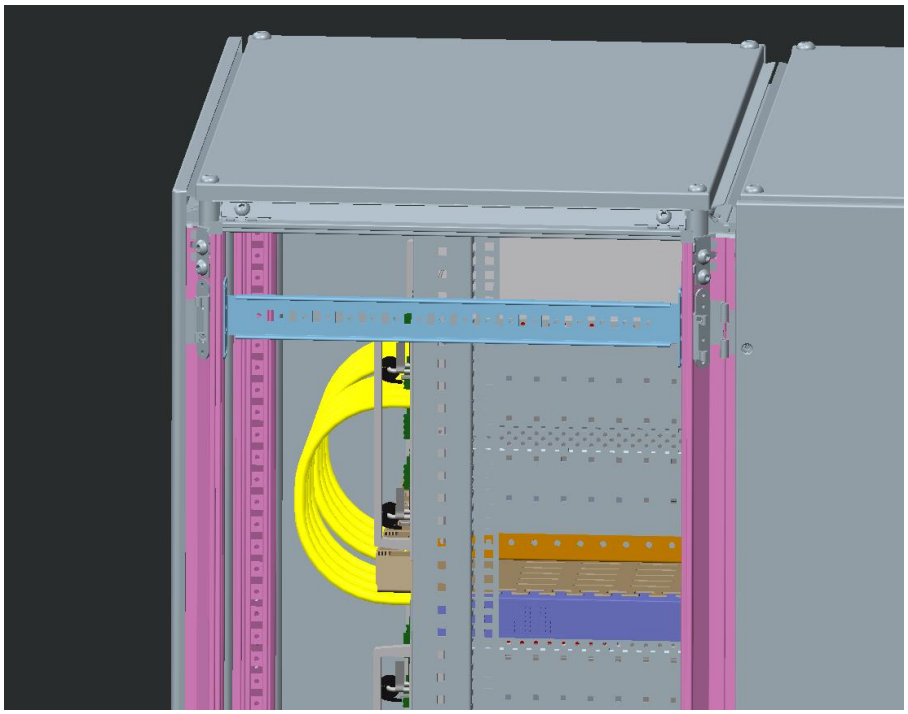


Figure 30 Front panel QSFP cable routing, TPM to switch example, side view

Relating the remaining cable, assuming the previous cabling cabinet elements, no critical issues are expected.
The synchronization incoming signal can share the RF fiber path from the ceil to the center of the cabinet to reach the management board. From there eight cable, optical or RF shielded, shall be connected to each Subrack management board.

The gigabit management board is similar, with more flexible cables that shall connect the cabinet management board to each Subrack.

The power supply distribution, done internally with standard 220V-AC cables, shall start from the bottom side of the 19” column and reach directly the rear supply inputs (the switches, the cabinet management elements) or reach the front panel by the available space on the side to match the Subrack supply units.

7.11 Cabinet electrical power distribution

The cabinet electrical supply interface is a single connector (400VAC, 16A), coming from the floor aperture below the cabinet (SPEC REF).
This general supply shall be distributed to the cabinet components providing manual and automatic switch functions and balancing the load on the three phases in compliance with the requested normative for certification and safety.

The simplified power supply scheme is described in the Figure 31

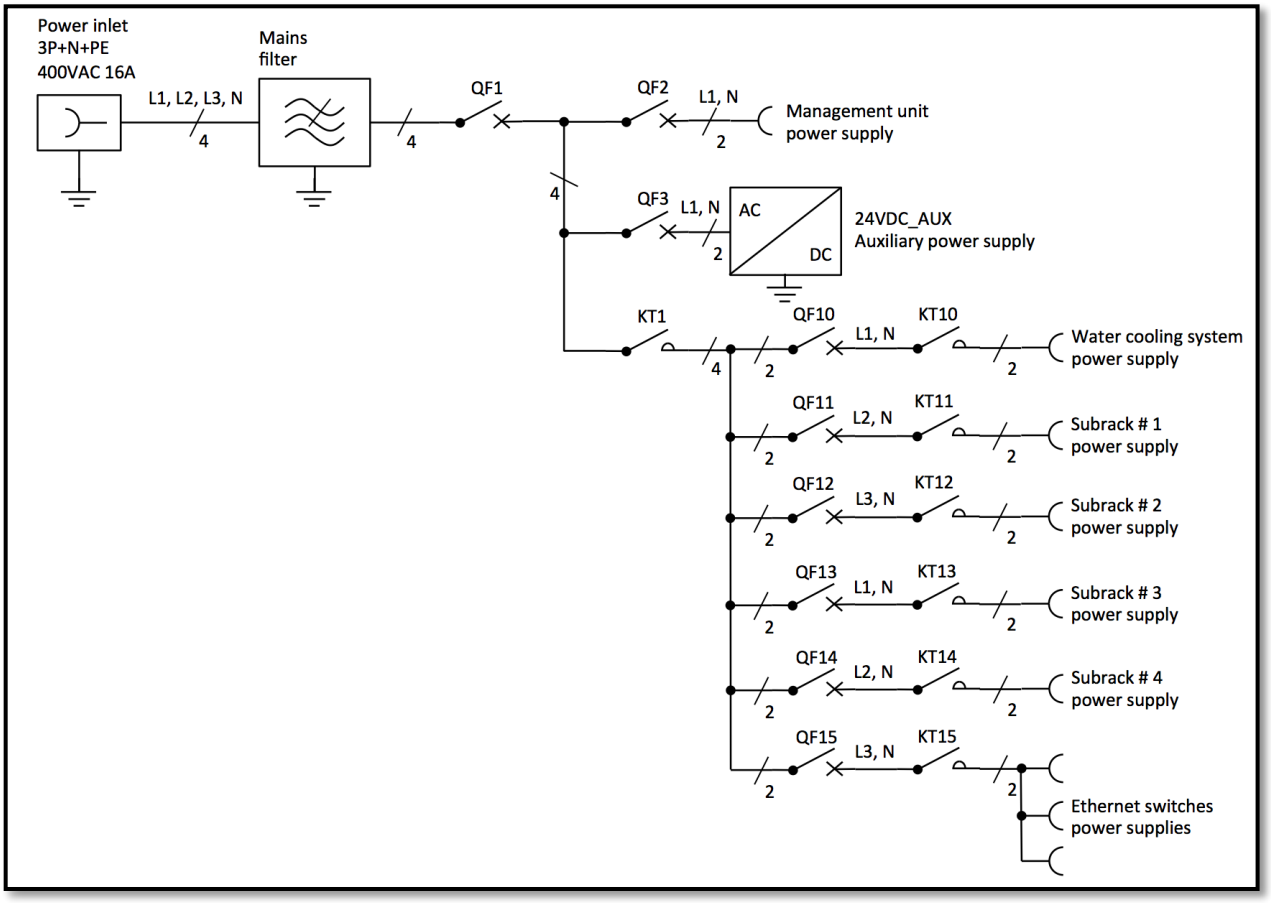


Figure 31 Simplified cabinet power supply scheme

The general cabinet power ON/OFF operation shall be done manually, because no auxiliary supply has been defined in the INAF specifications. At the power ON the cabinet shall activate only the management function with a low absorption condition (some status check and network

up) and move to a stand-by state, ready to receive the start up procedure commands from the MCCS or the TM applications.
The power to the rack is provided by means of a three-phase power inlet equipped with neutral input and earth connection (IEC standard, 3P+N+PE, 16A, 400VAC, red). Suitable part numbers are:

- Gewiss GW66508, interlocked
- Gewiss GW60408, non-interlocked



Figure 32: Gewiss power inlets

The main filter allows reducing the conducted emissions of the whole rack. A possible part number is EPCOS B84131M0003A116, 4 lines filter, 16A



Figure 33 EPCOSS filter

From the main filter the power is distributed to various equipments fitted into the rack (management unit, sub-racks, water cooling system, Ethernet switches); the loads shall be

distributed among the three phases to allow a correct balancing of the currents drawn from the grid.
Two kinds of switches are foreseen: circuit breakers (QFx) and contactors (KTx). Circuit breakers are only intended for magneto-thermal protection of the secondary circuits and can be operated only manually; contactors are normally placed in series to the circuit breakers and can be operated by software by means of I/O modules connected to the management unit via Ethernet link. With this approach it is possible, for the management unit, to power-on and power-off each sub-unit into the rack.

The management unit itself and the auxiliary voltage supply cannot be switched on and off automatically: only manual operation is foreseen.

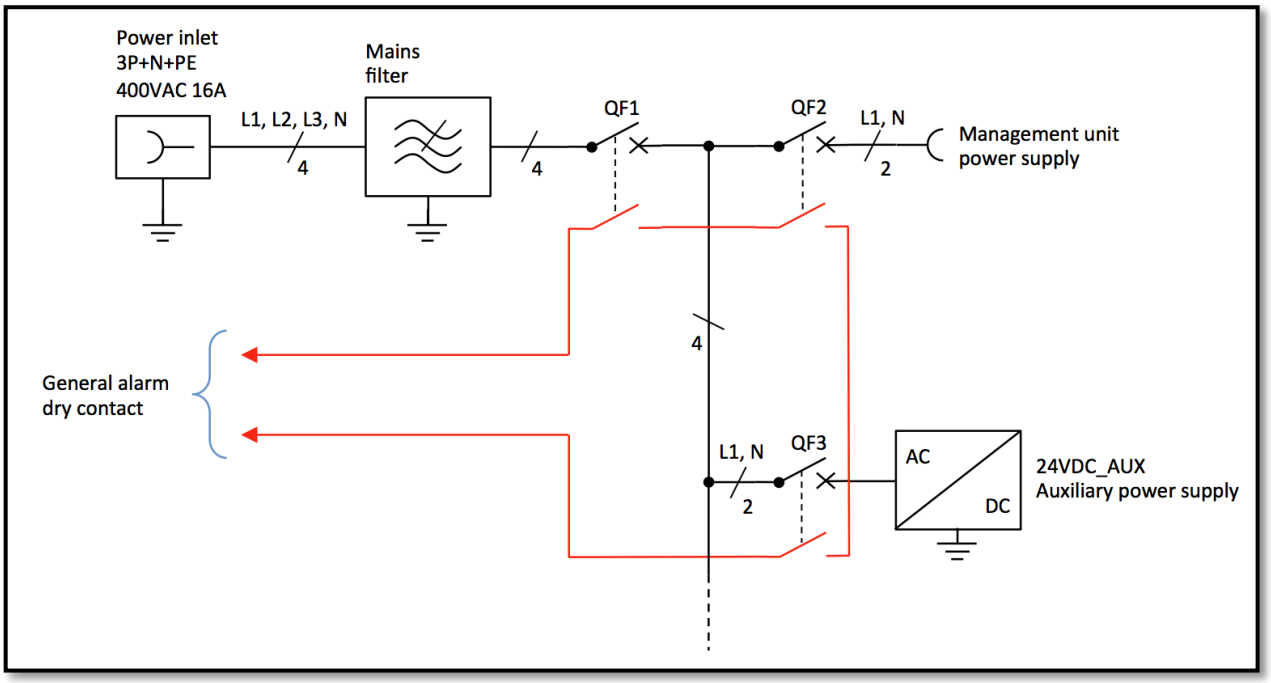


Figure 34 24V cabinet auxiliary circuit

Each circuit breaker or contactor is equipped with isolated auxiliary contacts: these are used to read the status of each switch by means of the I/O modules; the switch status contacts that are not read back by the management unit are used to generate an output alarm that can be read from the infrastructure monitoring equipments. The switches that generate such alarm are those that, when open, prevent the management unit to work correctly: QF1, QF2 and QF3; the

auxiliary normally open contacts of these elements are placed in series and output as a dry contact.

Each secondary power supply line can be switched on and off by means of an I/O module, with the possibility to read back the status of any switch. The following diagram shows the connections of the I/Os and the related auxiliary contacts.

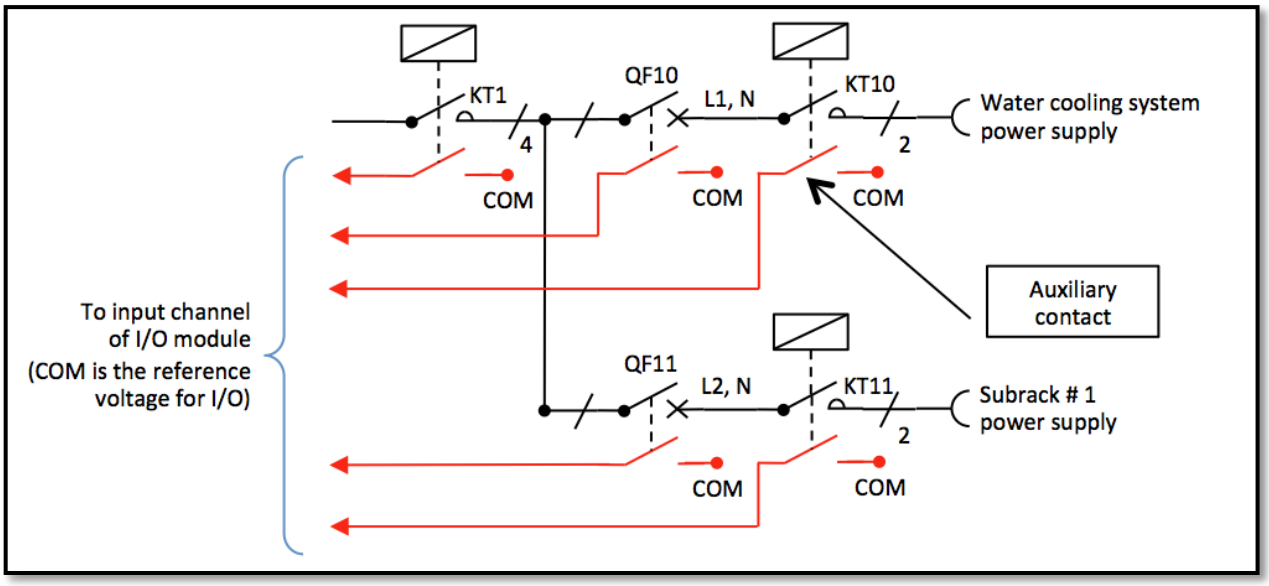


Figure 35 Switch circuit management I/O

Each contactor can be operated by software or can be manually switched-on bypassing the software setup (normally for debug purpose or maintenance). The manual switches are placed on the front panel of the rack, adjacent to the circuit breaker of same power supply line.

The following diagram shows the circuitry used to drive the contactors.

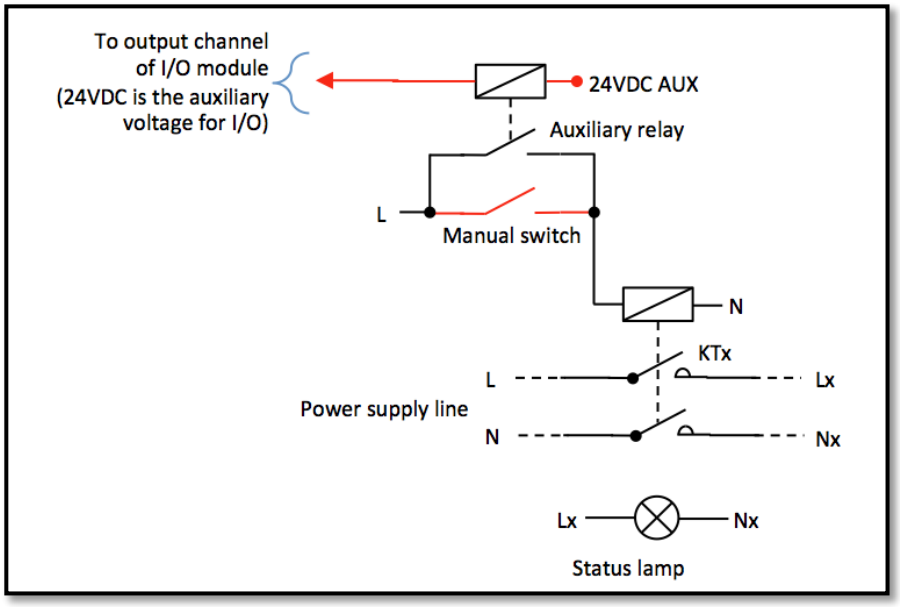


Figure 36 Contactor drive circuit

A possible approach to implement the management interface to the power distribution elements and also to some of the cooling elements can be based on industrial standard I/O modules.

For example the ones manufactured by MOXA, with the following part numbers:

- MOXA E1210 with 16 digital inputs;
- MOXA E1212 with 8 digital inputs and 8 digital outputs.

This can be connected to the management with the cabinet management Ethernet network with the Modbus over TCP/IP protocol.

They can be interfaced also for PWM and functional sensor monitoring for the cooling circuits and can extend the interface directly available on the cabinet management board.



Figure 37 Modbus I/O module

8 Cabinet detailed part list

Cabinet part list has been organized in subsection, organized mainly in relation to the production or procurement branches.
The following section has been identified:

1. TPM, Subrack and management board, custom electronic and mechanical board design
2. Cabinet mechanical
3. Cabinet electrical
4. Cabinet cooling
5. Cabinet network & cabling

8.1 TPM, sub-rack and management board

Description	Manufacturer	Part Number	Quantity
TPM	INAF + various	iTPM 1.5	32
TPM sub-rack	INAF + various	na	4
Rack management	Sanitas EG srl	Rack_man_1.0	1

The TPM means the TPM-ADU and the TPM pre-ADU, heat sink and mechanical items that complete the TPM assembly.
The TPM sub-rack means the backplane, the management board, the power supply units, the liquid cold plate and the 6U 19” mechanical items that complete the TPM assembly.
The rack management means the management board configured for cabinet function and the relate 1U mechanical items required for the 19” rack installations
These elements are custom design elements, based on the proposed design presented in [RD3].

8.2 Cabinet mechanical

Cabinet mechanical component list is based on the custom design presented in the current document.
Two main sections are present: the commercial material list, mainly related to the standard external and internal structural cabinet elements components and the custom elements.
The design of the standard elements has been done based on ABB components, selected for the price/quality parameter.

Rack components

Reference	Description	Manufacturer	Part Number	Quantity
na	Base, Top, Plinth 800x600x2100 mm	ABB	EK8060KN	2
na	Uprights for structure	ABB	EM2000	2
na	Front door, glazed	ABB	ET2080K	1
na	Rear door, blind	ABB	EC2080K	1
na	Plinth flanges front and rear	ABB	ZN8000	1
na	Plinth flanges side	ABB	ZN6000	2
na	Side covers	ABB	EL2080K	2
na	Rack 19" frame	ABB	EG2005	1

Internal carpentry

Reference	Description	Manufacturer	Part Number	Quantity
na	Internal mechanical & cabling cabinet elements	RGM	various	1

8.3 Cabinet electrical

The components related to the electrical circuit described in the related section in this document are listed below, grouped for functionalities.

Power distribution

Reference	Description	Manufacturer	Part Number	Quantity
na	Power inlet 3P+N+PE IEC 16A Red	Gewiss	GW66508	1
na	Mains filter 4 lines, 16A	Epcos	B84131M0003A116	1
QF1	Circuit breaker, 4 poles, 16A, C curve, 10kA breaking capacity	ABB	S204M-C16	1
QF2	Circuit breaker, 2 poles (1P+N), 2A, C curve, 10kA breaking capacity	ABB	SN201M-C2	1
QF3	Circuit breaker, 2 poles (1P+N), 2A, C curve, 10kA breaking capacity	ABB	SN201M-C2	1
QF10	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QF11	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QF12	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QF13	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QF14	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QF15	Circuit breaker, 2 poles (1P+N), 6A, C curve, 10kA breaking capacity	ABB	SN201M-C6	1
QFx-AUC	Auxiliary contact for circuit breakers	ABB	S2C-H6R	9
KT1	Contactor, 4 poles, 30A, 250VAC coil	ABB	AF16-40-00-13	1
KT1-AUX	Auxiliary contact for power contactor AF16	ABB	CAL4-11	1
KT10	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1

KT11	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1
KT12	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1
KT13	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1
KT14	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1
KT15	Contactor, 2 poles, 25A, 230VAC coil with manual auto-on-off	Finder	22.32.0.230.4340	1
KT1x-AUX	Auxiliary contact for contactor 22.32.0.xxx	Finder	22.33	6

Alarm indication

Reference	Description	Manufacturer	Part Number	Quantity
na	Led indicator, 22 mm diameter, green	ABB	ML1-100G	1
na	Led block, green, 230VAC	ABB	MLBL-07G	1
na	Dummy block	ABB	MDB-2	2
na	Indicator housing for DIN rail	ABB	MA1-8001	1

Auxiliary power supply

Reference	Description	Manufacturer	Part Number	Quantity
AC-DC	Power supply AC/DC, 230VAC in, 24VDC out, 10A out, active PFC	Meanwell	DRP-240-24	1

Power distribution automation

Reference	Description	Manufacturer	Part Number	Quantity
na	Auxiliary relay, DIN rail mounting	Finder	38.51.0.024.0050	8
na	Auxiliary switch for AUTO/MAN function	ABB	E211-16-10	7
na	Led indicator, red, 250VAC	ABB	E219-C	8

na	Dummy module, 17.5 mm, DIN rail mounting	ABB	EB 176 5 + EB 183 1	5
na	I/O module, Modbus over TCP/IP, 16 digital inputs	MOXA	E1210	1
na	I/O module, Modbus over TCP/IP, 8 digital inputs + 8 digital outputs	MOXA	E1212	1

Service outlet

Reference	Description	Manufacturer	Part Number	Quantity
na	Auxiliary power outlet, 230VAC, Australian standard	ABB	M1176-L10	1
na	Auxiliary power outlet, 230VAC, European standard	ABB	M1170	2
na	Circuit breaker, 2 poles (1P+N), 2A, C curve, 10kA breaking capacity	ABB	SN201M-C2	1

Accessories

Reference	Description	Manufacturer	Part Number	Quantity
na	Door open switch	ABB	EV1140	2
na	Service lamp	ABB	EV1048	2

8.4 Cabinet cooling

The components related to the cooling circuit described in the related section of this document are listed below, provided directly by AAVID Thermalloy design group.

AAVID P/N	Description	Basic Version Quantity
415614	HYD PUMP 02-80W-55LPM-0,6bar	4
TBD	Aluminium PIPE for Pressure and Temperature sensor	2
415574	HYD PIPE: Silicone pipe 18x24	10
415626	HYD PIPE: Silicone pipe 14x20	5
TBD	Aluminium PIPE for Temperature sensor	2
TBD	PT100 M4x10 Length TBD	4
415624	HYD FLOW SENSOR DN10 G1/2mm	2
415625	HYD FLOW SENSOR DN15 G3/4mm	1
415627	HYD LIQUID PRESSURE SENSOR 4bar	2
417783	HYD W/W-HEX 7kW	1
415657	HS TANK (LEVEL SENSOR INCLUDED) - S.A. 2027CS	1
415658	HS TANK CAP - S.A. 2304 FOR TANK S.A. 2027CS	1
416541	HS LEVEL SENSOR WIRE - H03VVH2-F 2X0.5 WHITE L2000	1
TBD	Manifold	2
415587	HYD Valve PPH G3/4 F/F S7	3
415586	HYD Valve PPH G1/2 F/F S7	11
415576	HS-M Hose Nozzle 3/4Fx20mm	~40
415955	HYD CLAMP CAW 28.6/C W4	~40
415578	HS-M Nipple 3/4M	~40
415577	HS-S Nipple 1/2M	~15

415575	HS-S Hose Nozzle 1/2Fx16mm	~15
415954	HYD CLAMP CAW 23.5/C W4	~15
416857	HYD 90° Tee 3/4F - 0700240.070505	~4

8.5 Cabinet network & cabling

The cabinet network elements are detailed for the two Ethernet switches, the related QSFP cabling and the RF cables, required for distributing clock and PPS.

For the switch, from the market survey some unexpected situation comes up:

- the optimal combination of the 40G Ethernet and 100G Ethernet configuration has been founded only from a company that sells these devices on the web, without offering the support and the lifetime required.
- the companies specialized for this devices offers only upgraded of the requested transmission speed, with at least 32 QSFP ports with 100GEthernet capabilities or more.

Based on this considerations the following alternative switches has been identified:

40G Ethernet switch

Description	Manufacturer	Part Number	Quantity
32 QSFP port 100G Ethernet switch, managed	ARISTA	7050CX3-32S	2
TBD	MELLANOX	TBD	alt

Internal cables, Ethernet

Description	Length, cm	Number	Function
40G QSFP - QSFP copper	50,TBC	32	TPM to 40GE switch connection
40G QSFP - QSFP copper	150, TBC	2	40GE switch to switch connection
1G RJ45 shielded	100, TBC	2	Management to subrack
1G RJ45 shielded	150, TBC	2	Management to subrack

Internal cables, clock distribution

Description	Length, cm	Number	Function
RF SMB to SMB	150, TBC	4	10 MHz reference from management to subracks
RF SMB to SMB	150, TBC	4	PPS reference from management to subracks

The availability survey of the switch shall be updated before the final part list definition.

9 Cabinet cost estimation

The cost corresponding to the identified part list is summarized below, including also a quote for the labor cost required to assemble and test the complete cabinet.
The cost meaning is different by the Yellow and Green/Blue cell:

- the Yellow cost include the production cost and the labor cost of the custom design defined in collaboration with the SKA working group, NO GROSS MARGIN is included.
- the Green cells are final quote of components to the SKA organization coming from companies delivered with the required guarantees FOB, including the respective gross margin.
- the Blue cells are final quote for the labor cost to the SKA organization coming from companies, including the respective gross margin.

Official quotes has been assigned to the SKA organization for the main items, based on the proposed design, covering almost the total budget.

Description	Quantity	Unit cost	Cab. cost	Reference
iTPM Subrack	4	€ 2.323	€ 9.292	INAF
TPM	32	€ 2.589	€ 82.848	INAF
rack management	1	€ 726	€ 726	SANITAS
External cabinet chassis	1	€ 1.326,00	€ 1.326,00	RGM
Cabinet internal carpentry	1	€ 1.810,00	€ 1.810,00	RGM
Cabinet electrical distribution	1	€ 1.720,00	€ 1.720,00	RGM
40G Switch	2	€ 8.748,54	€ 17.497,08	Mellanox/Arista
Cooling circuit	1	€ 3.242,00	€ 3.242,00	AAVID
Data cabling	1	€ 1.488,72	€ 1.488,72	ARISTA/SAMTEC
Cabinet assembling, electrical and mechanical, labour cost	1	€ 1.800,00	€ 1.800,00	RGM
Cabinet assembling, cooling circuit	1	€ 600,00	€ 600,00	RGM
Final TESTING	1	€ 600,00	€ 600,00	RGM