Phase 2 Cryocooler System to Science Instrument (SI) ICD (CRYO_SI_02)

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–	4/4/2017	Initial baseline release per OCCB-CCR-1053 (SOF-4219)	OCCB (4/4/2017)

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1. SCOPE

The scope of this Interface Control Document (ICD) is to define, document and control the interface requirements between the Phase 2 Cryocooler System and SOFIA Science Instruments (SIs) that use Closed-Cycle Cryocoolers (CCCs) to achieve cryogenic temperatures for their focal plane array detectors while operating aboard the Boeing 747SP aircraft as part of the integrated SOFIA observatory. The Concept of Operations for the SOFIA Cryocooler Systems are described within APP-DA-PLA-PM17-2076, SOFIA Cryocooler System Concept of Operations (ConOps).

The Phase 1 Cryocooler System was a temporarily installed "pathfinder" Cryocooler System, initially designed and implemented to service the upGREAT Low Frequency Array (LFA) channel cryostat which was commissioned in May 2015 and the upGREAT High Frequency Array (HFA) channel cryostat which was commissioned in October 2016.

The Phase 2 Cryocooler System is a permanently installed system capable of servicing two (2) cold heads concurrently, to accommodate SIs that have multiple CCC-cooled cryostats (e.g., upGREAT HFA + 4GREAT), as well as next-gen SIs that may have 2 cold heads for increased cooling capacity.

The functionality and performance of the Phase 2 Cryocooler System is defined within SE01-2089, Phase 2 Cryocooler System Specification. The Phase 2 Cryocooler System-to-Aircraft System interfaces are defined and controlled by SE03-2067, Phase 2 Cryocooler System to Aircraft System ICD (CRYO_AS_02).

Figure 1-1 presents a context diagram, showing the Phase 2 Cryocooler System servicing the upGREAT HFA + 4GREAT configuration, identifying the relevant interfaces to other SOFIA subsystems, and identifying the applicable ICDs.

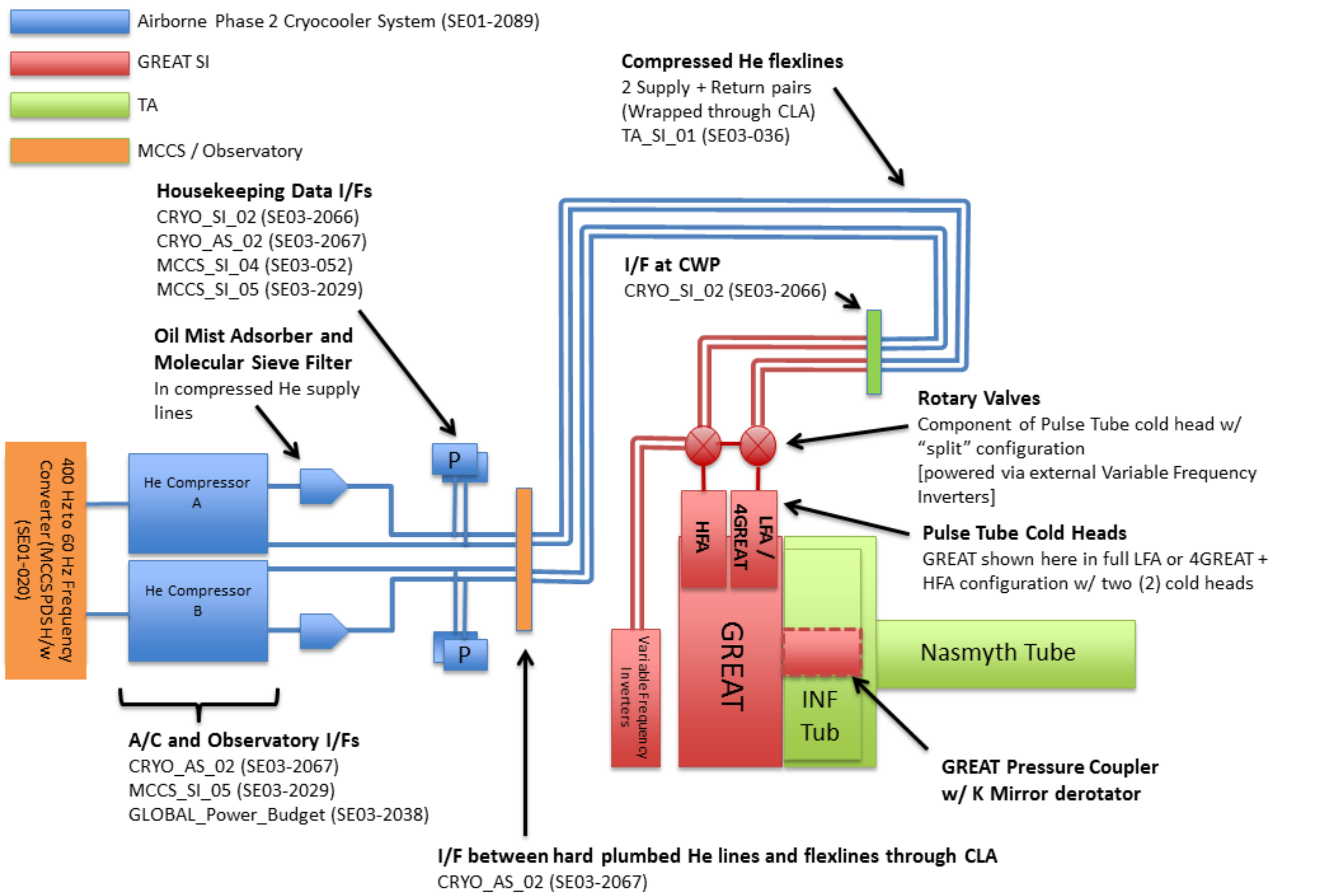


Figure 1-1 Context diagram of the Phase 2 Cryocooler System, identifying the relevant interfaces to other SOFIA subsystems, and identifying the applicable ICDs

Blue items indicate elements of the Cryocooler System, including compressed He lines wrapped through the CLA, while green items depict SOFIA Telescope Assembly (TA) elements, and red items depict (GREAT) SI elements, not within the scope of the Cryocooler System.

Not shown in the diagram above are the two (2) discrete signal lines between the Cryocooler control system and the PI Rack. Also, the 3-phase power interface from the SI variable frequency inverters to the Pulse Tube cold head rotary valves may optionally be routed via multiple #20 AWG Twisted Shielded Pair (TSP) interfaces within J75 and J76 through the Cable Load Alleviator (CLA) wrap from U400 to U403 via the L/H CLA Disconnect Panel U4.

2. PURPOSE

The purpose of this document is to define the electrical power, electronic signaling, and fluidic interfaces between the Phase 2 Cryocooler System and the Science Instruments (SIs) to ensure proper and safe operations of the integrated system aboard the SOFIA observatory.

3. REFERENCE DOCUMENTS

SOF-NASA-SPE-SE01-2089	Phase 2 Cryocooler System Specification
APP-DA-PLA-PM17-2076	SOFIA Cryocooler System Concept of Operations
SOF-AR-SPE-SE01-2028	SOFIA Science Instrument System Specification
SCI-AR-HBK-OP03-2000	SOFIA Science Instrument Developers’ Handbook
SOF-DA-ICD-SE03-036	Cable Load Alleviator Device / Science Instrument Cable Interface (TA_SI_01)
SOF-AR-ICD-SE03-2015	PI Equipment to PI Rack to Aircraft Interface ICD (SI_AS_01)
SOF-AR-ICD-SE03-2029	Principal Investigator Patch Panel to Principal Investigator Equipment Rack(s) Interface (MCCS_SI_05)
SOF-USRA-DWG-SE02-2596	Auxiliary PI Rack Arrangement
SOF-USRA-REP-SE07-2042	Auxiliary PI Rack Arrangement Design and Analysis
SOF-NASA-ICD-SE03-2067	Phase 2 Cryocooler System to Aircraft System ICD (CRYO_AS_02)
APP-DF-ICD-SE03-2038	Global Power Budget Interface Control Document
SOF-DA-ICD-SE03-002	Science Instrument Envelope (GLOBAL_09)
SOF-NASA-LIS-SE06-2017	Phase 2 Cryocooler Control System Cable Listing
SOF-NASA-DWG-SE02-4031	Phase 2 Cryocooler System, Drawing Index and General Notes
SOF-NASA-DWG-SE02-4032	Phase 2 Cryocooler System, Compressor System Installation
SOF-NASA-DWG-SE02-4033	Phase 2 Cryocooler System, Compressor System Interface Frame Assembly
SOF-NASA-DWG-SE02-4034	Phase 2 Cryocooler System, Compressor System, Base and Isolation
SOF-NASA-DWG-SE02-4035	Phase 2 Cryocooler System, Helium Gas Pallet, Assembly and Details
SOF-NASA-DWG-SE02-4036	Phase 2 Cryocooler System, Coolant Pallet, Assembly and Details
SOF-NASA-DWG-SE02-4050	Phase 2 Cryocooler System, Controller, Process and Instrumentation Diagram (P&ID)
SOF-NASA-DWG-SE02-4051	Phase 2 Cryocooler System, Controller, PLC 3 Control Panel Wiring Diagram
SOF-NASA-DWG-SE02-4052	Phase 2 Cryocooler System, Main Deck Control Panel Wiring Diagram
SOF-NASA-DWG-SE02-4053	Phase 2 Cryocooler System, Compressor Pallet Cables Wiring Diagram
SOF-NASA-DWG-SE02-4054	Phase 2 Cryocooler Systems, Aircraft Cables Wiring Diagram
SOF-NASA-DWG-SE02-4055	Phase 2 Cryocooler System, Field Wiring Cable Conveyance Diagram
SOF-NASA-DWG-SE02-3680	SOFIA Cryocooler Frequency Converter Rack Assembly & Detail
SOF-40611	SOFIA Electrical Wiring Diagram – Cryocooler Power Converters
SOF-40612	Cryocooler Frequency Converter Input Power Interface Box
SOF-40613	Cryocooler Frequency Converter Output Power Interface Box
A9747-9701-M1007	TA/CLA Hose Mounting Hardware
SOF-DWG-MG-4300.0.00 R05	Balancing Subassembly
SOF-NASA-REP-PA06-2032	Phase 2 Cryocooler System Failure Modes and Effects Analysis (FMEA)
APP-DF-ICD-SE03-2038	Global Power Budget Interface Control Document

SOF-DA-ICD-SE03-052	MCCS to Science Instrument Software Interface (Functional) ICD (MCCS_SI_04), Appendix B, Table B-2
APP-DA-PLA-PM17-2078	"24/7" Power and Network Connectivity between Flights Concept of Operations
SOF-NASA-REP-SE06-2014	Phase 2 Cryocooler System PLC 3 Input / Output (I/O) Listing
SOF-NASA-REP-SE06-2015	Phase 2 Cryocooler System Symbolic Logic Diagrams
SOF-NASA-PRO-SW04-2029	Phase 2 Cryocooler System HMI Screen Programming and Configuration Document
SOF-NASA-PRO-SW04-2030	Phase 2 Cryocooler System PLC 3 Programming and Configuration Document
SOF-NASA-CSCI-SW06-2251	Phase 2 Cryocooler System Software Version Description Document (VDD)
SOF-NASA-PRO-SV02-2470	Phase 2 Cryocooler System Software Load Procedure
SOF-NASA-PRO-SV02-2471	Phase 2 Cryocooler System Operational Procedures
IMC90	Cryomech CP2800 Series Cryogenic Refrigerator Installation and Operation Manual
NPD 8710.5	Policy for Pressure Vessels and Pressurized Systems (PVS)
NASA-STD-8719.17	NASA Technical Standard, Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)
DCP-S-065	Dryden Centerwide Procedure, Pressure Vessels & Pressurized Systems (PVS)
GH 2225 001	upGREAT Cryostat System Safety Assessment (SSA)
GI 2225 001	upGREAT Pulse Tube Pressure Test Plan
UGA-2200-004	upGREAT Closed-Cycle Coolers Feasibility Study
UGA-2200-006	upGREAT Closed-Cycle Coolers Specification

4. CRYOCOOLER SYSTEM TO SCIENCE INSTRUMENT (SI) INTERFACES

The Phase 2 Cryocooler System interfaces with the Science Instrument (SI) via compressed He (gas) lines, as well as electrical power and electronic signaling interconnections. Some of these interfaces may not be used in every SI configuration. These interfaces are defined within the following subsections.

4.1. Cryocooler System to SI Compressed He QD Fluidic Interfaces

The SOFIA Phase 2 Cryocooler System provides two (2) independently operated and controlled Cryomech CP2870 water-cooled He compressors, each capable of driving an SI-provided cold head. Typically, SI cold heads are Pulse Tube technology, which have very few moving parts, exhibit low characteristic vibration levels, and have a thermal performance that is reasonably insensitive to angular orientation.

The two (2) Cryocooler System compressors provide a source of very pure, pressurized He gas to the cold head(s) and cryostat(s) of a mated SI via two (2) Supply / Return pairs of self-sealing Quick Disconnect (QD) fittings. When the compressors are operating, each independently generates a steady-state pressure differential between the associated High Pressure Supply QD and the Low Pressure Return QD.

The specific operating Supply and Return He pressures are dependent on the static He charge pressure of the non-operating system, and within the operating constraints of the compressor this may be adjusted somewhat to meet SI-specific requirements, which are generally driven by the SI cold head and SI thermal performance requirements.

A typical static He charge for the Cryomech CP2870 compressor is 230 ± 5 psig (15.8 ± .34 bar), with associated typical operating steady-state pressure differential of approximately 220 to 250 psid (15.2 to 17.2 bar). For more information regarding the nominal operating pressure ranges, as well as the high and low pressure setpoints that will trip and clear the associated warnings, alarms and error messages, consult Section 4.2.3.

Additional detail is provided within the IMC90 Cryomech CP2800 Series Cryogenic Refrigerator Installation and Operation Manual, and SI developers should consult the SOFIA Program for technical guidance re: operating conditions that may approach or exceed the specified nominal parameter ranges.

The Cryocooler-to-SI compressed He QD interface demark is located at the U404 patch panel, which is mounted just aft of the Counterweight Plate (CWP), adjacent and orthogonal to the U402 and U402A TA Patch Panels (electrical power and grounding interfaces).

The U404 patch panel design is per drawing A9747-9701-M1007, TA/CLA Hose Mounting Hardware.

The routing of compressed He flex lines from the compressors to the Cryocooler-to-SI QD interface is documented within SE03-2067 (CRYO_AS_02) and SE03-036 (TA_SI_01).

Figure 4.1-1 presents an aft-facing view of the TA, showing the location of the U404 interface demark, relative to the SI and several other patch panels.

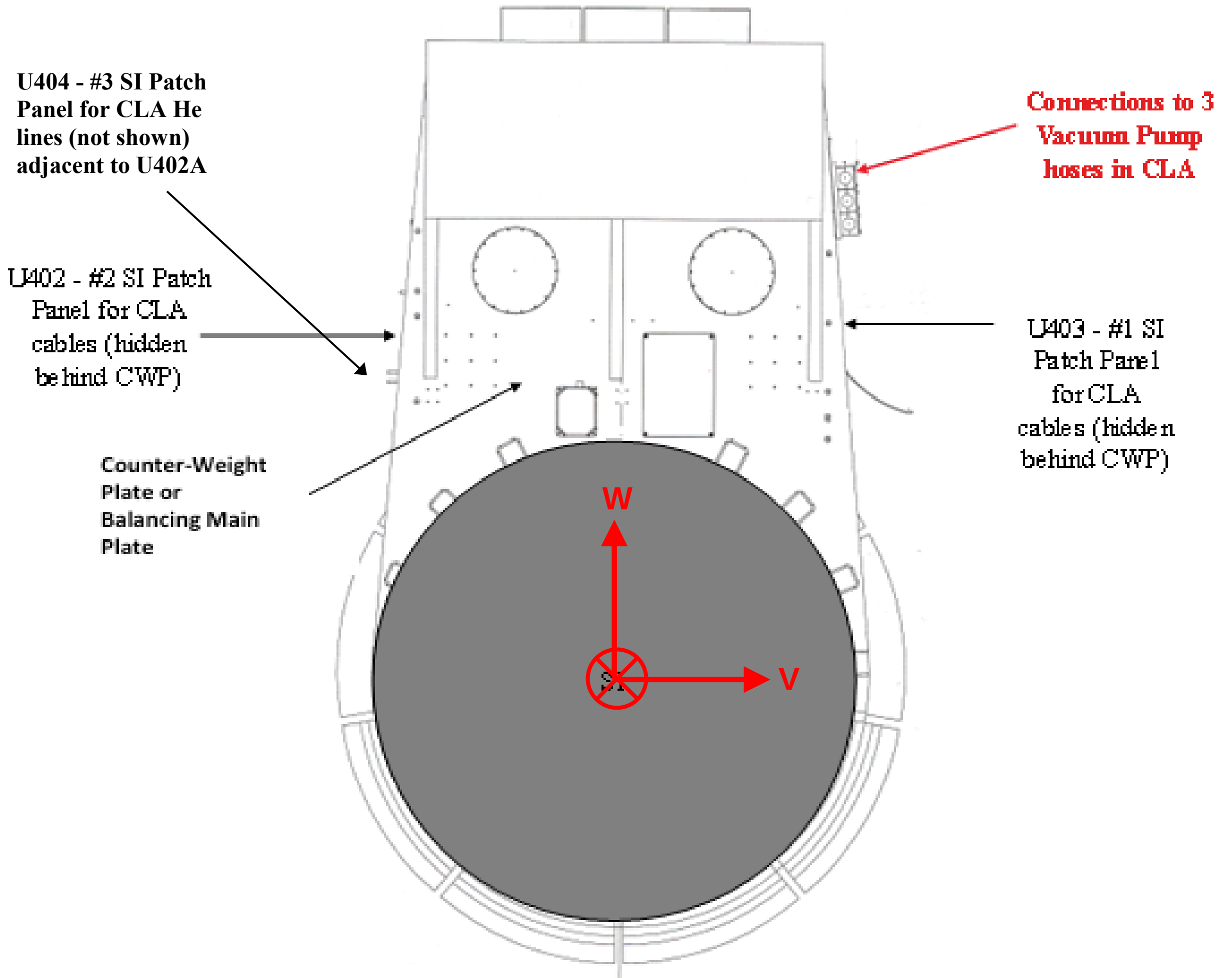


Figure 4.1-1. Front-view of SI mounting location on the TA

Ref: SOF-DWG-MG-4300.0.00 R05 "Balancing Subassembly"
Ref: Figure 4-1 ENLARGED – Appendix "SOF-DA-ICD-SE03-037 (TA_SI_02)

In this figure, ⊗ represents the geometric center of the TA Instrument Mounting Flange (IMF), which is coincident with the IR beam center.

Figure 4.1-2 presents a photograph showing the location of the Cryocooler-to-SI compressed He QD interface U404 Patch Panel installation (note that at the time that this photograph was taken, only 1 Supply / Return pair of flex lines and QDs had been installed).

Also shown in Figure 4.1-2 are the U402 Patch Panel with a variety of power and grounding interfaces for use by SIs, as well as the U402A Patch Panel, presently populated only with the recently added J132 power interface.

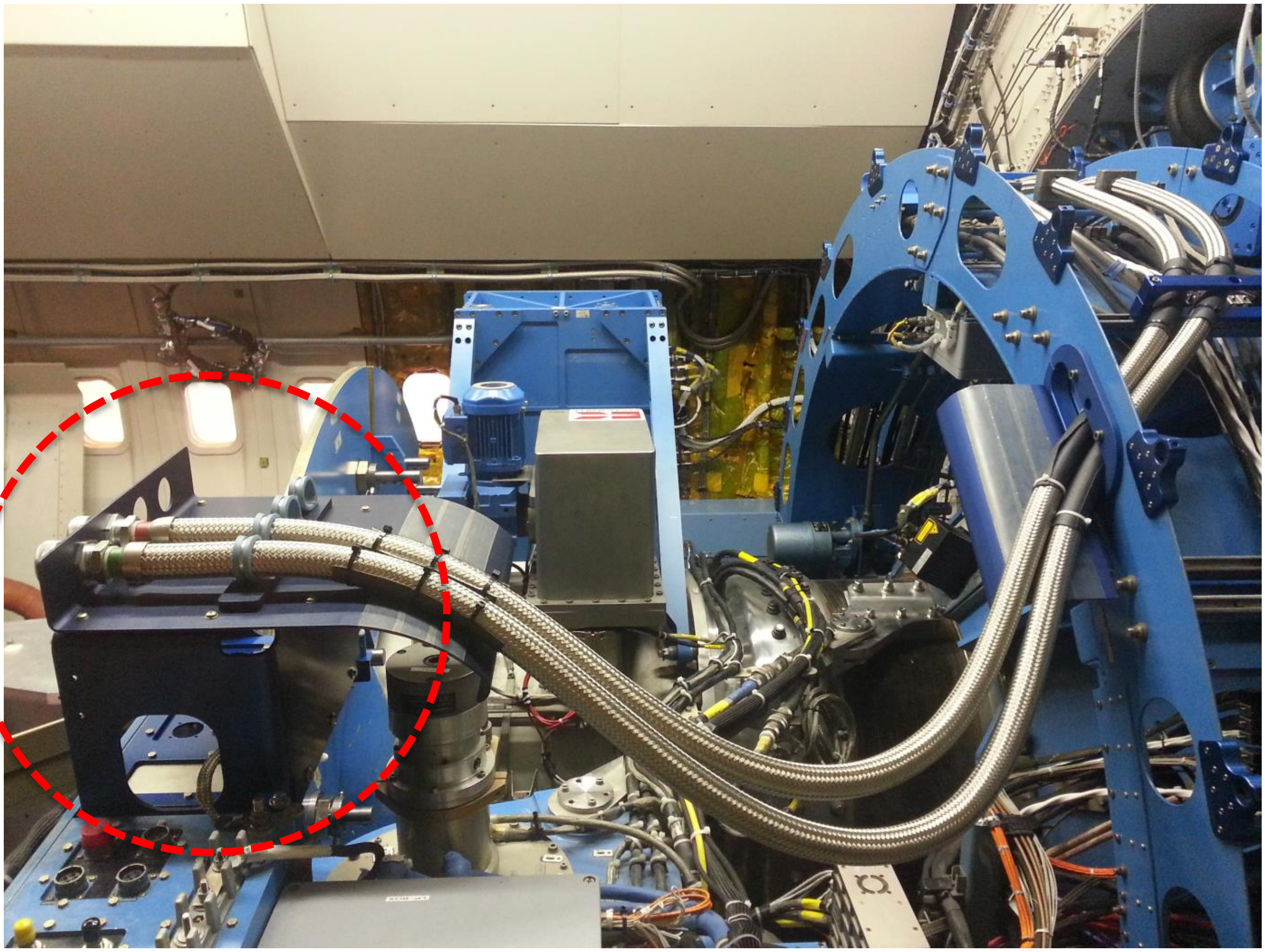


Figure 4.1-2. Photograph showing the location of the U404 compressed He QD patch panel

Figure 4.1-3 positions the center of the QD pattern on the U404 compressed He patch panel in the TA coordinate system. The geometric center of this pattern, marked with a ⊗ is located at the U,V,W coordinates presented in Table 4.1-1, below.

The U,V,W coordinates of the U404 He patch panel I/F (the center of the 2 pairs of QDs, defined here in the TA coordinate system) are:

Table 4.1-1: U,V,W coordinates of the geometric center of the U404 He QD Patch Panel

	Center of compressed He QD pattern on U404 patch panel		Center of IMF SI I/F (IR Beam Center) [Ref.]	
U	85.19 inches	2163.8 mm	89.96 inches	2285.0 mm
V	-35.13 inches	-892.2 mm	0.00 inches	0.0 mm
W	42.30 inches	1074.3 mm	3.31 inches	84.0 mm

The 4 QDs, arranged as two Supply / Return pairs, have centerlines evenly spaced at 3.00 inches (76.2 mm).

The SOFIA Observatory Systems and Systems Engineering and Integration (SE&I) groups have a 3D solid model of this Cryocooler-to-SI compressed He patch panel interface, and will make this available to SI developers in standard exchange formats such as STEP (.stp) and IGES to facilitate specification and detailed designs of the SI flex line lengths, routing and restraints.

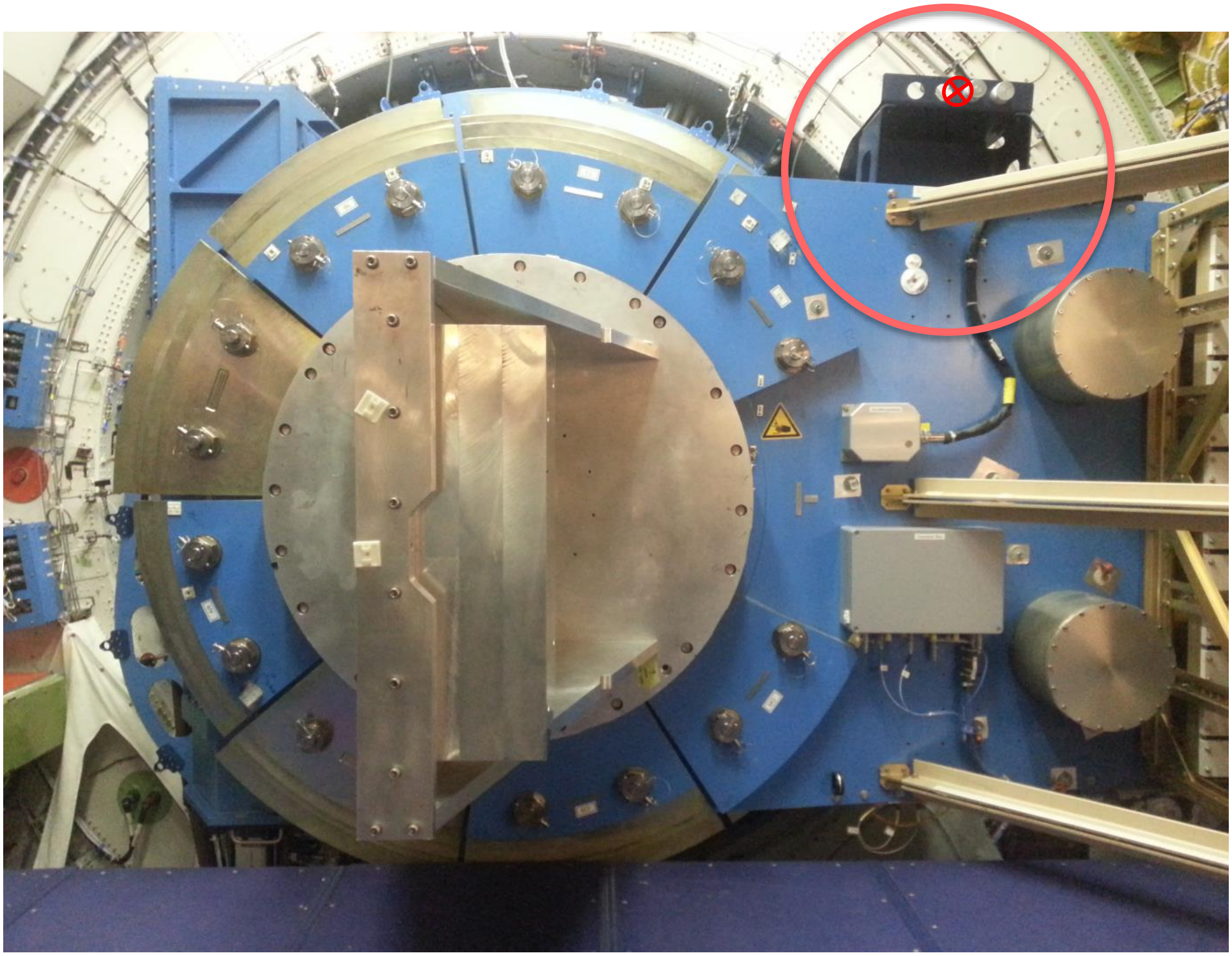


Figure 4.1-3. Photograph depicting geometric center ⊗ of He QD pattern on U404 He patch panel

The QDs used at the Cryocooler-to-SI compressed He interface are ¾ inch size Eaton / Aeroquip 5400 Series Low Air Inclusion Refrigerant QDs. The bulkhead-mounted patch panel QDs are male.

Figure 4.1-4 provides a product line summary of these Aeroquip 5400 Series QD fittings; please refer to Appendix B, Figure B-1 for further details.

Note that the Cryocooler-to-SI compressed He interface couplings (and many other QD fluid interfaces within the Cryocooler system) are ¾ inch (-12) size couplings, though the Commercial Off The Shelf (COTS) Cryocooler compressors, adsorber cartridges, and cold heads have largely standardized on the use of ½ inch (-8) size couplings.

5400 Series
Low Air Inclusion Refrigerant

Eaton's 5400 Series low air inclusion product line is designed for air conditioning, refrigerant, gaseous and fluid transfer applications.

Product Features

- Brazed or threaded end connections for versatility of installation on tubing or hose
- Tubular valve construction for low fluid loss and air inclusion
- Thread together design allows connection and disconnection against pressure
- Lock washer and jam nut standard for optional bulkhead mounting
- Standard seal material: Neoprene
- Guardian Seal™ plating for excellent corrosion resistance

Figure 4.1-4. Summary description of Aeroquip 5400 Series QD interface couplings

SI developers are responsible for providing, routing and restraining the flex lines between the He QD interface defined herein and the cold head servicing their cryostat.

a) SI-provided flex lines shall be terminated with ¾ inch (-12 size) 5400 series female QD coupling halves. Specification of -146 Buna-N elastomeric seals is recommended (note that Buna-N is not the standard Neoprene elastomer seal material for this QD series). Other common designations for Buna-N are Nitrile Butadiene Rubber (NBR), Nitril-Kautschuk Perbunan, Nitril-Butadien-Kautschuk, and other variants. The exact Eaton / Aeroquip QD P/N will be dependent on the style and size of the end fitting and hose adapters selected by the SI developer for the Supply and Return connections to their cold head.

Dust Caps and Dust Plugs should be provided and used at all times when these QD interfaces are unmated, to protect the QD sealing surfaces.

The Cryocooler System carries a Pressure Vessel & Pressurized Systems (PVS) certification for a Maximum Operating Pressure (MOP) of 400 psi (27.6 bar). To assure integrated system compliance with DCP-S-065, all SI-provided flex lines must be qualified by the manufacturer / vendor to 4 x MOP = 1600 psi (110.3 bar), and with the guidance and concurrence of SOFIA S&MA and AFRC Pressure Systems Manager, must each be individually "proof" tested to an acceptance level of 2 x MOP = 800 psi (55.2 bar).

In order to assure the integrity of the integrated He loop, it is recommended that the SI developer leak check their lines, fittings, cold head and any associated Pressure Relief Devices (PRDs) at 1 x MOP.

b) For compliance with NPD 8710.5, *Policy for Pressure Vessels and Pressurized Systems (PVS)*, NASA-STD-8719.17 and DCP-S-065, all pressurized flexible lines shall be properly restrained at both ends and at intermediate intervals as necessary to mitigate hazards from whipping hoses.

SI developers are further advised that pressurized flexible hoses must be retested at 1 x MOP no less frequently than every 5 years, and labeled to reflect these recertification intervals.

To avoid misconnections, Supply and Return lines should be clearly marked at both ends.

For reference, the SOFIA Cryocooler System uses an annularly corrugated stainless steel flexible line with a stainless steel wire overbraid with a 1 inch ID, manufactured by Witzenmann GmbH, P/N HYDRA RS331. A data sheet for this flexible line is provided in Appendix B as Figure B-2.

When the SI cryostat and cold head are integrated with the SOFIA Cryocooler System, the SI cold head and associated rotary valve and flex lines are protected by various Cryocooler System Pressure Relief Valves (PRVs) and Rupture Disks. However, when the SI is disconnected from the Cryocooler System (i.e., at the end of a flight series), the SI System Safety Assessment (SSA), Qualification and Acceptance pressure test plans, and Airworthiness Data Package must show that the SI safely accommodates or vents the pressure that could build up in this now isolated volume.

The SOFIA Phase 2 Cryocooler System does support the capability of pumping out and backfilling the He loops via ¼ inch service access Aeroquip 5400 series QDs on each of the Helium compressors. SI developers will likely wish to procure or develop their own GSE pump-out and flush or backfill manifolds to facilitate and expedite He loop servicing of the SI-provided cold head and associated components, if so desired. Any such pressurized GSE will need to comply with the aforementioned PVS safety policies and procedures.

A photograph of a representative SI (upGREAT LFA) connected to the U404 He QD patch panel is provided as Figure 4.1-5. Note the use of "butterflied" Adel clamps to co-restrain the pair of compressed He flex lines.

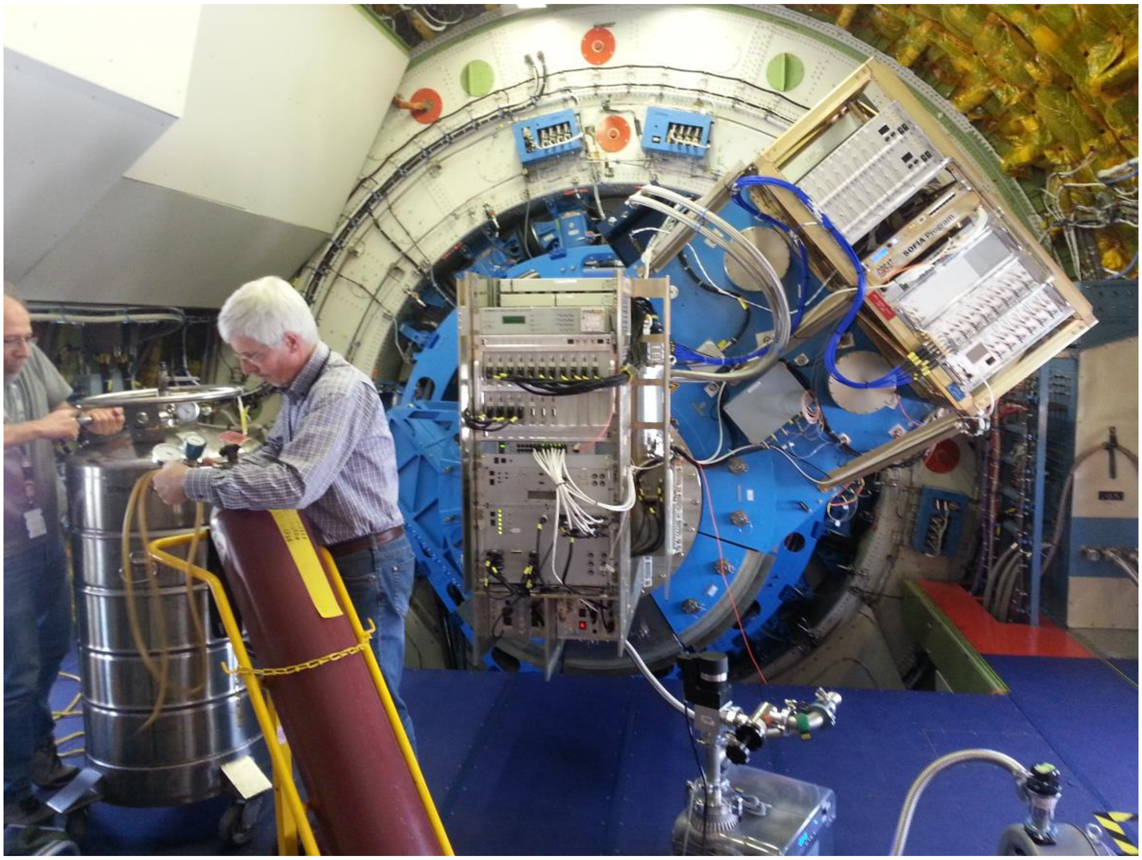


Figure 4.1-5. Photograph showing upGREAT LFA interfaced to the U404 compressed He QD patch panel via a pair of co-restrained flex lines

4.2. Cryocooler Control System & Electrical / Electronic Interfaces

The Cryocooler System includes a control system which provides user interface Command and Monitoring functionality both local to the compressors in the aft upper deck, and remotely on the main deck to provide situational awareness to the Mission Director (MD) and the SI / PI team. The control system monitors a number of system performance and housekeeping parameters, performs system safing functions, and annunciates warnings and alarms.

Figure 4.2-1 is a CAD graphic depiction of the Cryocooler System compressor installation, showing the Control System enclosure and HMI touchscreen display mounted on top of the Water Vapor Monitor (WVM) electronics rack in the SOFIA aft upper deck.

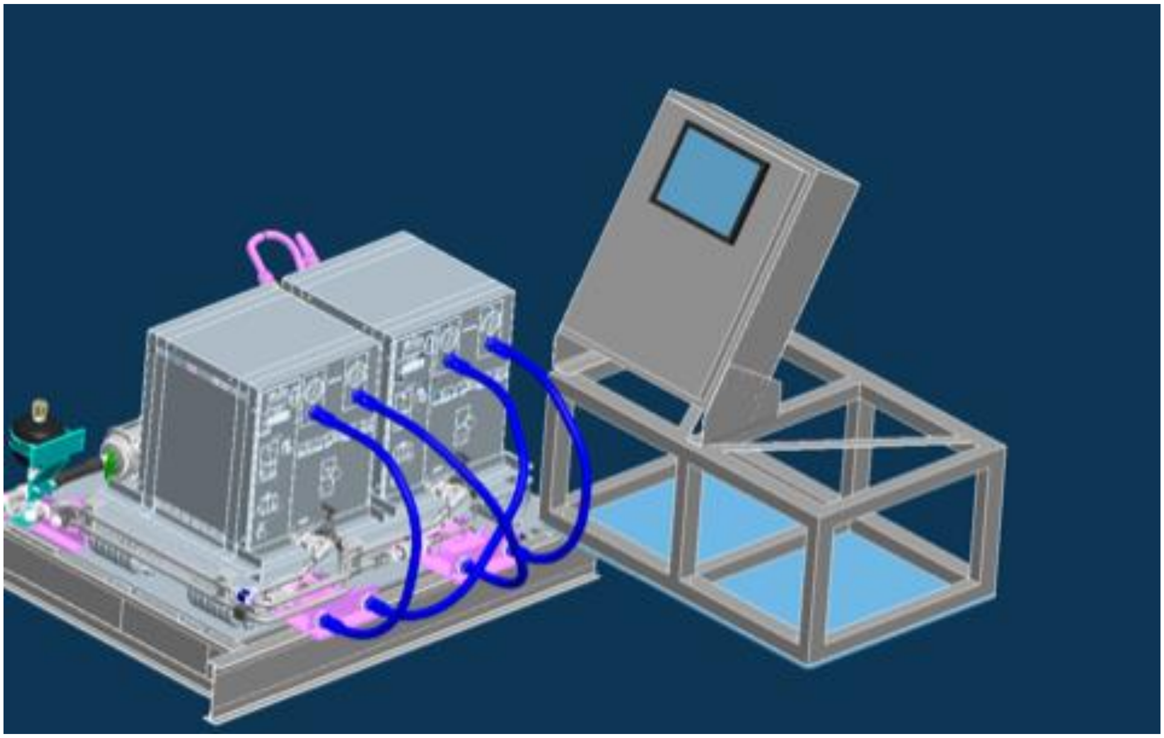


Figure 4.2-1 Cryocooler compressor installation showing notional Control System enclosure

The control system will have the following interfaces for operation:

- Compressors (with added instrumentation)
  - Compressor intrinsic I/O (from each compressor)
  - Added instrumentation and sensors for safety interlocks and display data
    - Accel (2-axis)
    - Tilt (2-axis)
    - Pressure (transducers on He Supply and Return lines of each compressor)
- Ambient Smoke detection (local to compressor installation)
- Coolant Pallet and Cooling System
  - Inlet coolant temperature
  - Outlet coolant temperatures for each compressor
  - Coolant flowrate for each compressor
  - Coolant Pump Inlet and Supply Pressures (high pressure cut-off and low-pressure detection of coolant loss)
  - Upper Deck HX Air Inlet temperature
  - Upper Deck HX Coolant Inlet temperature
  - TA Pit HX Air Inlet temperature
- 200 VAC, 60 Hz, 3-Phase Input Power
  - From Unitron Frequency Converters (FCs) within scope of MCCS PDS
  - 28 VDC Control Power to be generated internally via DC power supply
- 200 VAC, 400 Hz, 3-Phase Input Power
  - From Observatory Bus 4 for Upper Deck and TA Pit HX Fan power

- 200 VAC, 60 Hz, 3-Phase Output Power
  - To Compressors
  - To Coolant Pump
- 200 VAC, 400 Hz, 3-Phase Output Power
  - To Upper Deck and TA Pit HX Fans
- MCCS
  - Transmit Cryocooler System housekeeping (HK) data to MCCS (DAS) and Archiver via Modbus TCP / Ethernet interface for recording and archival
- Science Instrument (SI) I/O
  - Compressor operational status discrete signal to SI from each compressor to support synchronization of SI cold heads with compressor operation
  - Transmit Cryocooler System housekeeping (HK) data to SI via Modbus TCP / Ethernet interface for PI team monitoring, recording and archival
- Local (Upper Deck) Control Panel Front panel I/O
  - Operator interface when in LOCAL control mode
  - HMI touchscreen displays w/ GUI screens
    - Temperature and pressure displays on the control panel will remain active even when system is in REMOTE control mode
  - AC Power ON / OFF (manual switch)
  - UPPER DECK / MAIN DECK compressor operate select (manual switch)
  - Compressor Power Lockout (manual switch for each compressor)
  - Circuit Breakers (each compressor, Control Power, Coolant Pump, Upper Deck Cooling Fan, TA Pit Cooling Fan)
  - Indicator lights (AC Power On, Compressor Operator Select MAIN DECK / UPPER DECK)
  - RJ-45 PROFINET Ethernet port to support connection of laptop with a browser interface for accessing / downloading Cryocooler System HK data recorded by internal datalogger
- Remote (Main Deck) Control Panel Front panel I/O
  - Operator interface when in REMOTE control mode
  - HMI touchscreen displays w/ GUI screens
    - Temperature and pressure displays on the control panel will remain active even when system is in LOCAL control mode
  - FLIGHT / GROUND / OFF mode selector (manual switch)
  - Indicator lights (Compressor Operate Select MAIN DECK / UPPER DECK, Fire Alarm, System Alarm, System Fault, Compressor A On, Compressor B On, Cooling Pump On, Upper Deck HX Fan On, TA Pit HX Fan On, Upper Deck HX Cold Air Valve Open)
  - RJ-45 PROFINET Ethernet port to support connection of laptop with a browser interface for accessing / downloading Cryocooler System HK data recorded by internal datalogger
- MD Console Status Display “Dashboard”
  - Compressor A On
  - Compressor B On
  - Cryocooler System Alarm annunciator
- Smoke Alarm Status

Figure 4.2-2 shows the control system interface block diagram and its various interfaces to the Compressors, Control Panels, Coolant Pallet, SI, and the MCCS (PDS, DAS, and Archiver). The portion of Figure 4.2-2 control block diagram that includes the SI interface, the Main Deck Control Panel (in the AUX PI Rack) and the MCCS DAS interface, is enclosed in a red dashed line.

Note that this section includes certain subsections and figures which include interfaces that are outside the scope of this ICD, but are presented to provide context for the nature of the Cryocooler Control System and the Cryocooler System to SI interfaces that are the subject of this document.

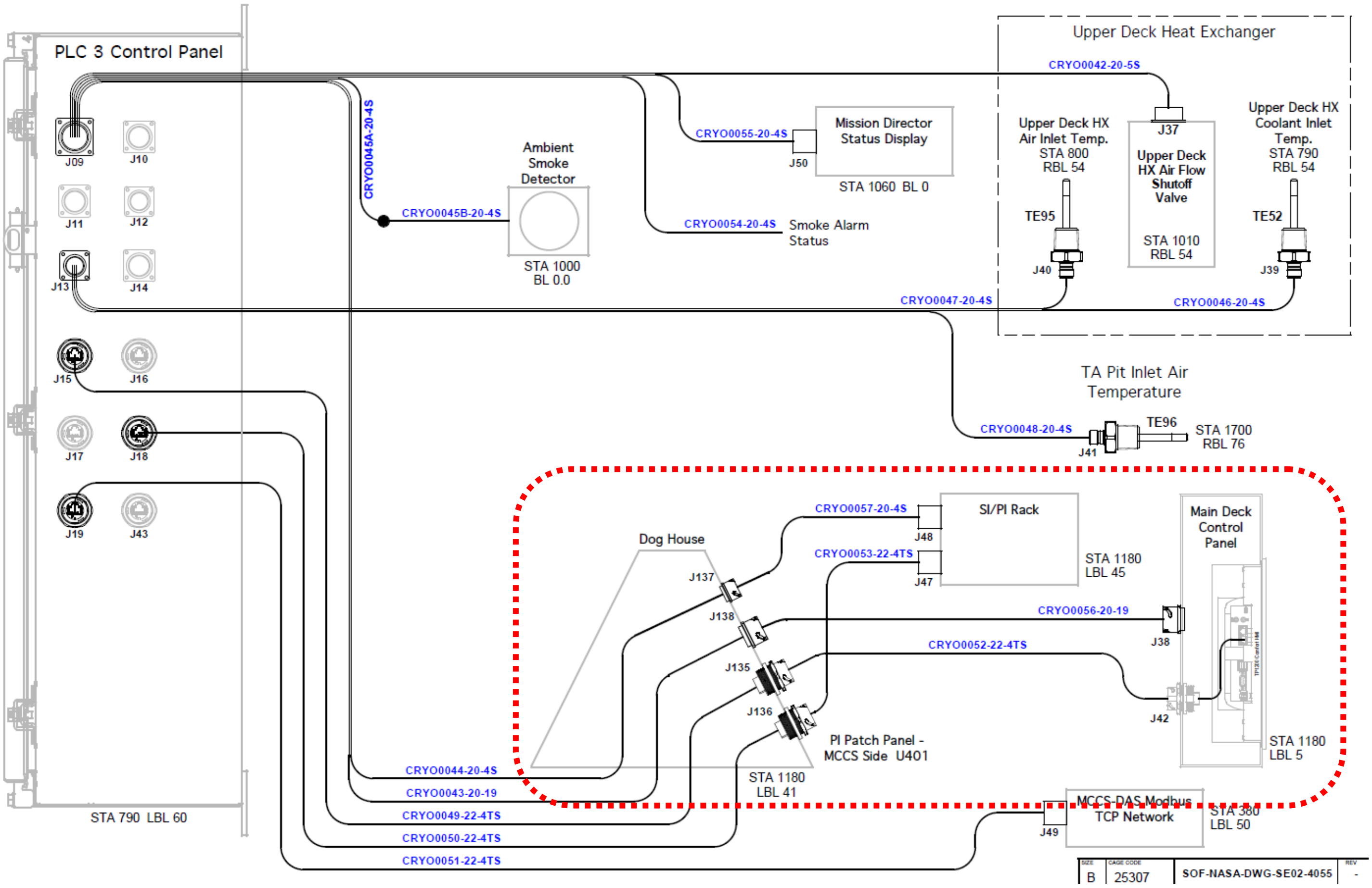


Figure 4.2-2 Cryocooler control system block diagram excerpt showing SI / PI Rack and AUX PI Rack interfaces (ref.: SOF-NASA-DWG-SE02-4055 Sheet 4 of 4)

4.2.1. Control System-to-Compressor Interface

The control system interfaces to the compressors through a DB15 Connector on each compressor. It should be noted that while the compressors do provide various signaling interfaces for control and monitoring purposes, there is no direct interface between the Cryocooler System compressors and the SI; all SI interfaces are provided by the Cryocooler control system.

Table 4.2.1-1 shows the compressor DB15 connector pin configuration.

Table 4.2.1-1: Compressor DB15 System I/O Connector Configuration

PIN #s	ITEM	Signal Level
1, 2	Compressor Running Signal	Contact CLOSED / 24 VDC when running
3, 4	HIGH He pressure	Contact CLOSED / 24 VDC when pressure exceeds limit
5, 6	HIGH He temperature	Contact CLOSED / 24 VDC when temperature exceeds limit
7, 8	Compressor Unit GOOD	Contact CLOSED / 24 VDC when no ERRORS or WARNINGS are present
9	Input Reference	
10	+24 VDC Return	
11	Isolated +24 VDC	40 mA max
12	LOCAL / REMOTE Toggle	LOCAL when FALSE / REMOTE when TRUE
13	Remote Interlock	INHIBITS Compressor operation when TRUE
14	Local STOP	Compressor STOP command on TRUE event when in LOCAL mode Inactive in REMOTE mode
15	Local START Compressor Status	Compressor START command on TRUE event when in LOCAL mode REMOTE mode Compressor ON when TRUE / Compressor OFF when FALSE

Generally, during nominal operations the compressors will be operated in REMOTE mode via the Phase 2 Cryocooler control system. The Main Circuit Breaker and the Power Circuit Breaker will be left CLOSED.

In addition to the I/O connector defined above, the control system will interface with each compressor via a Modbus TCP Ethernet RJ-45 communications port, which supports enhanced Control & Monitoring and troubleshooting of the compressor systems with a comprehensive set of parameters, as well as access to data stored within the compressor systems.

4.2.2. Control System and Control Panels

To support Control & Monitoring and to provide situational awareness, the Phase 2 Cryocooler System provides two (2) Control Panels: A Local Control Panel located in the aft Upper Deck in proximity to the compressors and coolant pallet; and a Remote Control Panel located on the Main Deck.

Both of these Control Panels provide Control & Monitoring functionality, but while both Control Panels will simultaneously support monitoring, only one Control Panel will be enabled for control functionality at any given time, selectable by a COMPRESSOR OPERATE SELECT toggle switch on the Local (Upper Deck) Control Panel. MAIN DECK and UPPER DECK indicator lamps indicate which of the control panels is enabled for control functionality.

The Local Control Panel includes an AC POWER toggle switch, which provides the primary local ON / OFF control for the Phase 2 Cryocooler System, and a POWER ON indicator lamp, as well as AC Power CBs for each of the two (2) compressors, the Coolant Pump, and each of the two (2) Cooling Fans, i.e., one for the Upper Deck HX fan, and one for the TA Pit HX fan.

The Control System design is based on a Programmable Logic Controller (PLC) powered by DC Power generated internally within the Local Control Panel, which has a dedicated DC CONTROL POWER Circuit Breaker (CB). If the CONTROL POWER CB is OPEN, the control system is inactive and the compressors cannot run, unless they are manually switched to LOCAL mode (not to be confused with use of the Local Control Panel when the Compressor Operate Select switch is set to UPPER DECK).

The Local Control Panel also includes a COMPRESSOR POWER LOCKOUT toggle switch for each compressor, as well as a Human Machine Interface (HMI) display, which provides a touch screen Graphical User Interface (GUI), as well as 10 programmable "soft" buttons, which will support the Control and Monitoring functionality described in the following subsections.

The Remote (Main Deck) Control Panel is a 7 PU (12.25 inch nominal front panel height) chassis that lacks CBs and power control toggle switches, but does provide a second fully functional HMI touch screen display, a toggle switch which selects whether the Phase 2 Cryocooler System is operating in GROUND or FLIGHT mode (programmable modes which primarily control which HX fan is active, and therefore where the majority of the system waste heat from the compressor(s) is being rejected), as well as a number of color-coded indicator lamps that display coolant pump operation, which compressor(s) and HX fan(s) is (are) operating, and annunciate system alarms, faults and fire alarm.

The main deck control panel will be connected to the upper deck controller enclosure via a Profinet Ethernet interface with a CAT-5 cable with RJ-45 connectors, as well as a multi-conductor cable with 19 contact circular connectors that will drive the indicator lamps and provide a source of +24 VDC to power the HMI display. No external power source (e.g., from the U401 PI Patch Panel via the AUX PI Rack) is needed to power the main deck control panel.

Both control panels also include a ruggedized industrial RJ-45 PROFINET connector, which may be used to interface a GSE computer with the PLC for programming, troubleshooting, or to access and download HK data that is stored within the internal datalogger.

Graphics showing a preliminary layouts of the CBs, switches, buttons, indicators and the touchscreen HMI displays on the Phase 2 Cryocooler System Local and Remote Control Panels, as well as the proposed / notional mounting locations, are presented below as Figures 4.2.2-1 and 4.2.2-2.

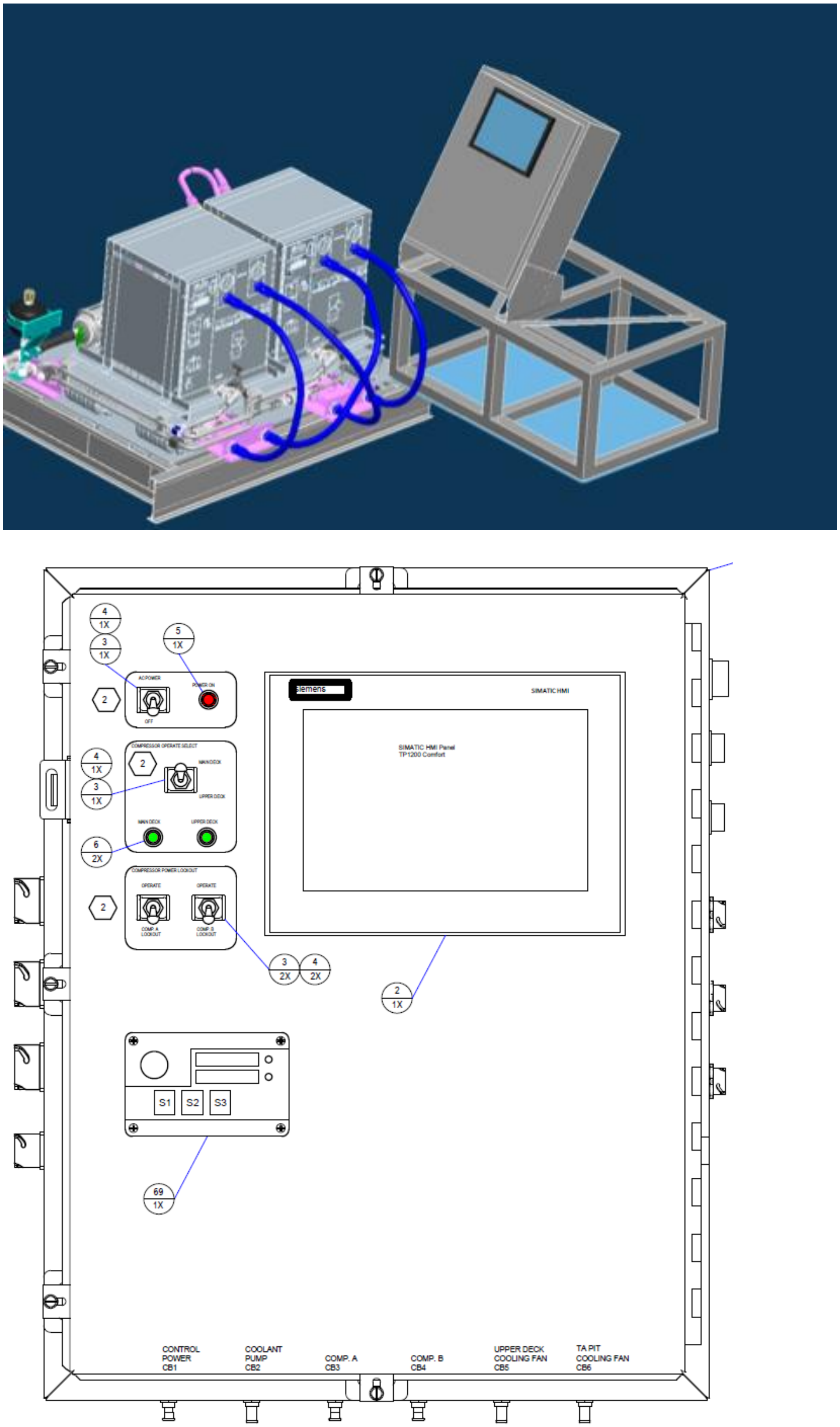


Figure 4.2.2-1 Preliminary mounting location and layout of Phase 2 Cryocooler System Upper Deck (Local) Control Panel

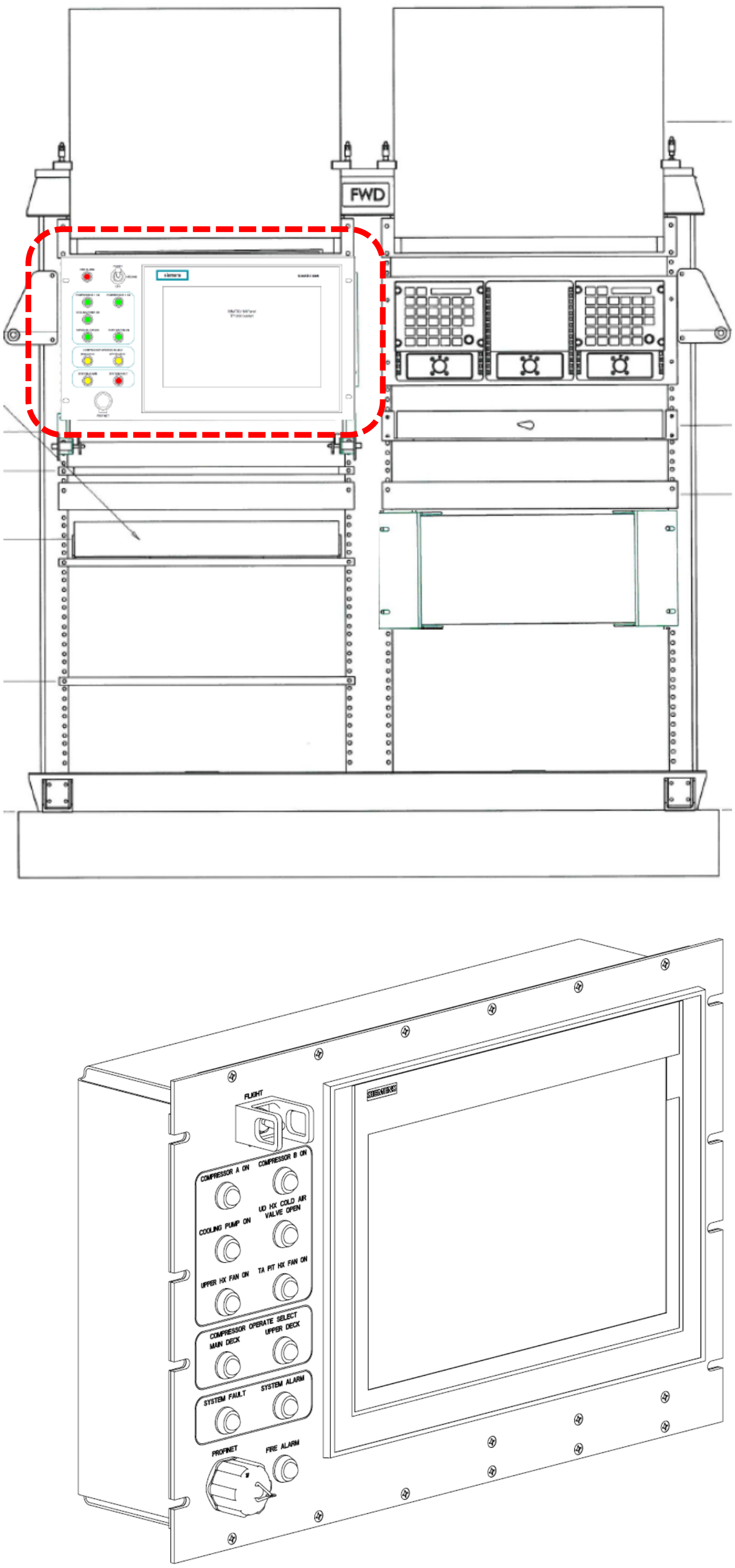


Figure 4.2.2-2 Preliminary location and layout of 7 PU Phase 2 Cryocooler System Main Deck (Remote) Control Panel (shown here in upper portion of AUX PI Rack)

4.2.3. Control System Signal Conditioning, Warnings & Alarms

The Cryomech CP2870 He compressors of the Phase 2 Cryocooler System each have a set of internal temperature and pressure sensors, and are preset with high and low threshold values for Warning and Alarm conditions. The factory preset threshold values are defined in Table 4.2.3-1:

Table 4.2.3-1: Cryomech CP2870 preset Compressor Temperature and Pressure Sensor Warning & Alarm limits

Temperature Values (°F)

	Helium	Oil	Coolant In	Coolant Out
Over Alarm	190	125	110	125
Over Warning	170	110	85	110
Over Recovery	120	110	80	110
Under Recovery	50	50	50	50
Under Warning	45	45	45	45
Under Alarm	40	40	40	40

Pressure Values (psi)

	Supply Active	Return Active	Differential	Static
Over Alarm	400	250	400	300
Over Warning	375	240	275	280
Over Recovery	375	240	275	280
Under Recovery	170	50	75	170
Under Warning	170	50	75	170
Under Alarm	150	40	50	100

Temperature Values (°C)

	Helium	Oil	Coolant In	Coolant Out
Over Alarm	88	52	43	52
Over Warning	77	43	29	43
Over Recovery	49	43	27	43
Under Recovery	10	10	10	10
Under Warning	7	7	7	7
Under Alarm	4	4	4	4

Pressure Values (bar)

	Supply Active	Return Active	Differential	Static
Over Alarm	27.6	17.2	27.6	20.7
Over Warning	25.9	16.5	19.0	19.3
Over Recovery	25.9	16.5	19.0	19.3
Under Recovery	11.7	3.4	5.2	11.7
Under Warning	11.7	3.4	5.2	11.7
Under Alarm	10.3	2.8	3.4	6.9

Alarm conditions, highlighted in red in Table 4.2.3-1, are lock-out contributors. Signal conditioners will be utilized for GFE sensors installed on, within or in proximity to the compressors. These sensors support the following functionality:

- Cryocooler System HK data recorded internally, and provided to SI and MCCS
- Yellow Warning annunciators
- Red Alarm annunciators and compressor shutdown interlocks
    - Latched Alarm annunciators can only be cleared if the alarm condition has been resolved and by pressing a momentary ALARM RESET button on the GUI
        - Each alarm has its own latching circuit
        - If multiple alarm conditions exist, resetting one alarm will not reset other alarms if the associated alarm condition is still active

    - A successful alarm reset does not result in a compressor re-start, a normal START procedure must be followed
- Alarm will also result in an Audible Alarm Buzzer going ON
    - Buzzer will have a momentary Acknowledge button to silence the buzzer
    - Any new or recurring alarm will cause Buzzer to go ON again
    - ALARM RESET also acts as Alarm Acknowledge

The initially recommended preset limits for the additional GFE temperature, pressure, inclinometer (tilt) and lateral acceleration (turbulence) sensors for the compressors are presented in Table 4.2.3-2 (note that these limits are notional and easily reconfigurable via the PLC):

Table 4.2.3-2: Compressor Temperature, Pressure and Dynamics Sensors Warning & Alarm limits (notional)

Parameter Limits	Warning	Alarm
Motor Capsule temperature (˚C)	87	92
Compressor Outlet (˚C)	105	110
Heat Exchanger Outlet (˚C)	54	59
Internal Ambient temp (˚C)	52	55
Supply High Pressure (psi)	>365	>369
Return Low Pressure (psi)	<22	<16
Compressor tilt (° pitch or roll)	N/A	±15
Compressor lateral acceleration (g)	N/A	0.5

4.2.4. Cryocooler System to SI Electrical Power Interfaces

Generally speaking, SI cryostat cold heads require a source of power, in addition to the pressure differential provided by the compressor, in order to operate. In a typical industrial cryocooler configuration, the cold head power is provided by the compressor with which it is paired.

SOFIA SIs (e.g., upGREAT, HiRMES) generally use external 3rd party power supplies, with variable frequency drive units, to power the rotary valves of their Pulse Tube cold heads (this provides the capability of adjusting the frequency of the pressure pulses to optimize cooling performance).

If the SI places the cold head power supplies in a PI Rack (as w/ upGREAT), it is necessary to route this power to the SI via the Cable Load Alleviator (CLA).

For adequately low power applications (e.g., 230 VAC 3-phase @ < 300 mA / phase), it is possible for the SI to use existing patch panel interfaces and cables routed under the SOFIA main deck floor panels and through the CLA. For example, U400 / U403 J75 through J79 each have ten #20 AWG Twisted Shielded Pairs (TSPs) which can be allocated for this low-power application.

No direct Cryocooler System-to-SI electrical power interfaces are provided.

If an SI chooses to place their cold head power supply on the TA side of the CLA cable interface (e.g., in the CWR), a discrete signaling interface will need to be routed to the CWR to allow the powered cold head operation to be synchronized with the compressor operation.

The Cryocooler System does provide such an interface to the SI PI Rack (ref. Section 4.2.5, Table 4.2.5-1, and Figure 4.2.5.1-1, below), however any routing or extension of this signal from the PI Rack to the SI assembly or CWR through the CLA (e.g., using U400 / U403 J75 ~ J79) would represent an intra-SI interface, and therefore outside the scope of this document. Further details re: these U400 and U403 patch panels may be found within the SE03-2029 (MCCS_SI_05) and SE03-036 (TA_SI_01) ICDs.

4.2.5. Cryocooler System to SI Electronic Signal Interfaces

The Phase 2 Cryocooler System supports the operation of up to two (2) He compressors driving Pulse Tube cold heads. To support synchronization of the SI cold heads with their associated compressor operations, the Cryocooler System controller provides two (2) Compressor Run Status direct discrete signaling interfaces to the SI PI Rack via a connector on the PI Patch Panel “doghouse” which is located just aft of the Primary or Aux PI Rack positions, as defined in SE03-2015, *PI Equipment to PI Rack To Aircraft Interface ICD* (SI_AS_01).

These two (2) Compressor Run Status discrete signals from the Cryocooler System are 0 VDC Sink / 24 VDC Source status outputs transmitted via a 20 AWG multi-conductor cable.

Because each compressor provides a steady pressure differential between the Supply and Return connections, and any modulation or chopping of this pressure (e.g., for a Pulse Tube cold head) is controlled by the SI, any synchronization between the two cold heads is the responsibility of the SI; the Cryocooler System merely signals to the SI the operating status of each compressor.

All other HK data provided by the Cryocooler System to the SI are transmitted via a Modbus TCP interface, transmitted to the SI PI Rack via the U401 J136 RJ-45 receptacle, also located on the PI Patch Panel. Modbus TCP is an open industrial standard network protocol that communicates over Ethernet TCP/IP. The Modbus protocol defines a message structure with a common format for the layout and content of message fields. The SI will identify messages addressed to it, check for data errors, extract and parse the data contained in the message, and store data as specified within this document.

Similarly, the Cryocooler System will transmit the same HK data to the MCCS using this same Modbus TCP protocol, as defined within SE03-2067 (CRYO_AS_02).

For further details of the Cryocooler System-to-SI signal interfaces, please refer to Tables 4.2.5-1 and 4.2.5-2 below, as well as subsections 4.2.5.1 and 4.2.5.2. Note that the J135 and J138 connections support the Phase 2 Cryocooler System Main Deck Control Panel in the AUX PI Rack, but do not represent Cryocooler System-to-SI interfaces, *per se*.

Table 4.2.5-1 Cryocooler System to SI Discrete and Modbus TCP Housekeeping Signal I/F Connectors

U401 Ref. Des.	Application	AWG	#Contacts Defined	U401 Patch Panel Receptacle P/N	Cable end Mating Plug P/N
J136	Modbus HK data to SI	22	4	TE Connectivity 2008615-2	TE Connectivity 1954656-1
J137	Compressor Run Status Discretes (2) to SI	20	4	MS3470W10-6S (6 sockets) w/ MS3181-10CA dust cap	MS3476W10-6P (6 pins) w/ M85049/52S10 clamp, backshell
J135	Profinet to Main Deck OP	22	4	TE Connectivity 2008615-2	TE Connectivity 1954656-1
J138	Main Deck OP Signals / Power	20	19	MS3470W14-19S (19 sockets) w/ MS3181-14CA dust cap	MS3476W14-19P (19 pins) w/ M85049/52S14 clamp, backshell

Please refer to drawing SE02-4054, *SOFIA Phase 2 Cryocooler System, Aircraft Cables Wiring Diagram,* for cable design and fabrication details. Excerpts of this drawing are presented below as Figures 4.2.5.1-1 and 4.2.5.2-1.

While an SIs use of these signal interfaces may be somewhat SI-specific, given the Cryocooler System and “24 / 7” powered Concept of Operations (ConOps), use of these HK signals by the integrated SI will allow both local and remote users the maximum situational awareness and insight into system performance with a simple, but robust and rich user interface feature set.

To the extent that this is supported by the SI data acquisition, networking and infosec considerations, the Cryocooler System HK data outputs may be monitored, recorded and archived by the SI, and the remote monitoring function may be extended over computer networks to users at offsite locations, potentially including offices at AFRC Bldg. 703, nearby hotel rooms, or even the SI / PI team’s home institutions.

The infosec configurations and protocols necessary to support such remote connectivity are not within the scope of this ICD, however the user is advised that they should initiate discussions with USRA Mission Operations (MOPS) IT support staff re: such requirements as early as possible, as coordination, approval and implementation of the necessary firewall configurations with AFRC can take as long as 2+ weeks.

Because the Phase 2 Cryocooler System also provides HK data directly to the MCCS, it is not necessary for SIs that use the SOFIA Cryocooler System include Cryocooler System HK parameters within the SI HK data that is provided to the MCCS, as controlled and defined within the applicable SI to MCCS software / functional ICD.

4.2.5.1. Cryocooler System to SI Compressor Run Status Discrete Signal Interfaces

The two (2) Cryocooler System Compressor Run Status output discretes to the SI PI Rack are asserted, indicating that the condition is TRUE / ON, when the Cryocooler System controller sources a 24 VDC @ 50 mA (max) signal between the associated pair of pins, and the condition is FALSE / OFF when the Cryocooler System control system sinks 0 VDC across these pins.

a) The Cryocooler System-to-SI Compressor Run Status discrete signal interface is defined at the PI Patch Panel U401 J137 receptacle, per Table 4.2.5-1. The contact assignments for these signals are depicted in Figure 4.2.5.1-1, below. SI-provided cables that interface with the U401 J137 receptacle shall be equipped with a MS3476W10-6P plug (P137) with an M85049/52S10 clamp and backshell.

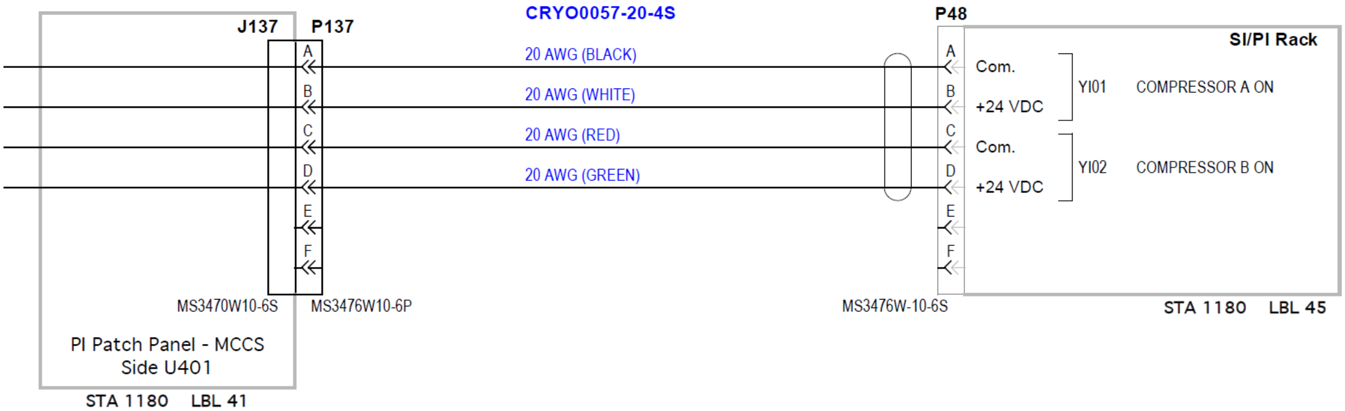


Figure 4.2.5.1-1 Compressor Run Status Discrete Interfaces (ref. NASA-SOF-DWG-SE02-4054)

Though the interface is formally defined at the U401 J137 connector, SIs that provide a MS3470W10-6P bulkhead receptacle on their PI Rack chassis for this interface may be able to make use of the Cryocooler-provided cable CRYO0057-20-4S, as shown above in Figure 4.2.5.1-1. It will have a length adequate to position the MS3476W-10-6S plug (P48) in most portions of the PI Rack.

b) SI inputs for these signals shall have an input impedance of at least 500 Ω to ensure that each will draw no more than 50 mA signal current at 24 VDC.

c) In addition, the SI signal and signal return contacts shall be isolated from SI power and ground by at least 1 MΩ.

4.2.5.2. Cryocooler System to SI Health & Status Housekeeping (HK) Signal Interface

The Phase 2 Cryocooler System will transmit HK data to the SI via a Modbus TCP protocol over a single Ethernet TCP/IP connection between the Cryocooler System controller Programmable Logic Controller (PLC) to one Ethernet port on the SI. The connection will be over a single CAT5 cable and connected to the Scalance XB005 unmanaged Ethernet switch in the Cryocooler System controller.

a) The SI shall provide an Ethernet TCP/IP connection via an RJ-45 connection to a switch or router.

The Cryocooler System-to-SI housekeeping (HK) data interface is defined at the PI Patch Panel U401 J136 receptacle, per Table 4.2.5-1. The contact assignments for this Modbus TCP Ethernet signal are depicted in Figure 4.2.5.2-1, below.

b) SI-provided cables that interface with the U401 J136 RJ-45 receptacle shall be equipped with a TE Connectivity 1954656-1 RJ-45 plug (P136).

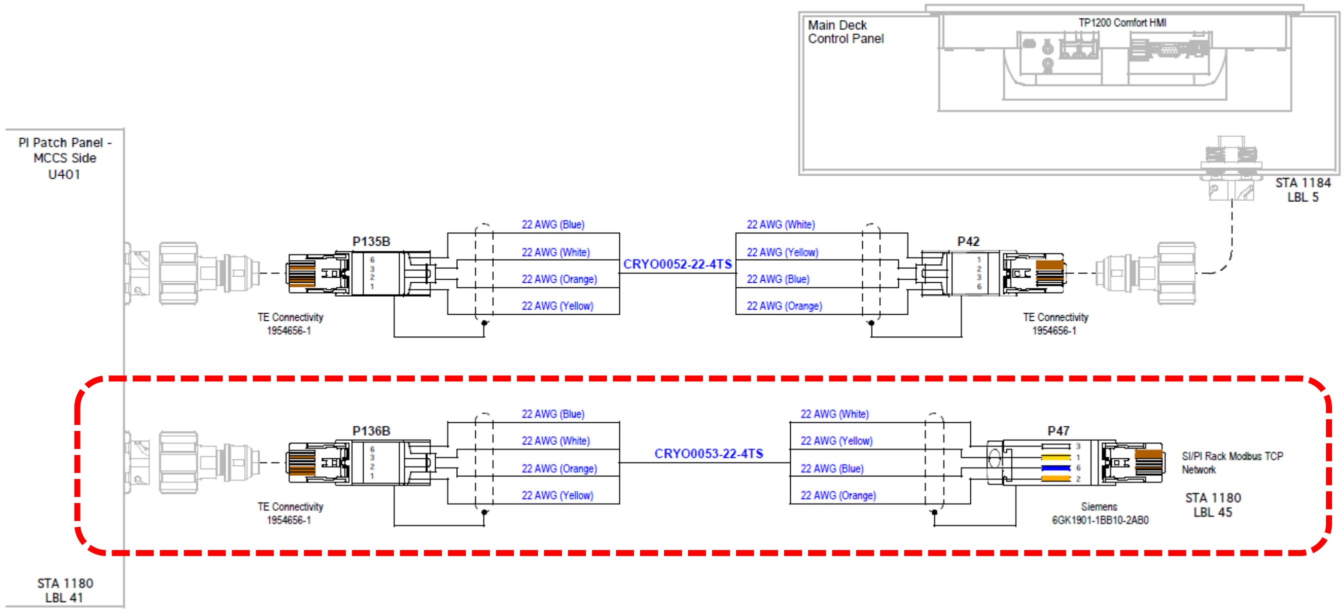


Figure 4.2.5.2-1 Cryocooler System Housekeeping (HK) Data Signal Interface (ref. NASA-SOF-DWG-SE02-4054)

Though the interface is formally defined at the U401 J136 connector, SIs may be able to make use of the Cryocooler-provided cable CRYO0053-22-4TS as shown above in Figure 4.2.5.1-1. This SI/PI Rack Modbus TCP Network cable is a Siemens 6XV1841-2A network cable, a rugged, industrial CAT 5, 2 x 22 AWG Twisted Pair cable with overall shield, terminated at the SI end with a Siemens 6GK1901-1BB10-2AB0 RJ-45 plug (P47). It will have a length adequate to position the P47 plug in most portions of the PI Rack.

Modbus TCP is an open standard network protocol developed for industrial automation systems. The Modbus protocol defines a message structure with a common format for the layout and content of message fields for communications and control between controllers and networked computers. Modbus “devices” communicate using a master-slave (client-server) technique.

The master/client (SI) initiates a transaction (query). The slave/server (Cryocooler System PLC) responds by supplying the required data to the client. The SI will identify messages addressed to it, check for data errors, extract and parse data contained in the message, and store data as needed.

The Modbus Application Data Unit (ADU) contains a Modbus Application Protocol Header (MBAP) of 7 bytes, a Function Code of 1 byte and the data. For transmission this ADU is encapsulated into the TCP/IP data container without being modified. See Modbus Protocol Reference Guide at http://modbus.org/docs/PI_MBUS_300.pdf .

The Cryocooler System controller PLC will provide the server responses to the SI client queries. Each transmission will contain all data for one update cycle. The PLC operates in sub-millisecond scan cycles so responses will be deterministic and real-time. The SI will control update rates and provide time stamps for each update. If the SI Ethernet is shared by multiple systems, an SI Ethernet switch may be required to eliminate collisions and queries delays.

The Cryocooler System controller client response to each SI query will contain an array of 16 bit words. Some words will represent discrete or Boolean states and the remaining words will represent parameter values. Parameters such as temperature and pressure will be represented by two consecutive 16 bit registers that will be combined to provide a 32 bit floating point number.

Modbus Server Parameters:

- Connection Type: 11
- Client IP Address: 129.168.0.[xxx]
- Server IP Address: 129.168.0.[xxx]
- Remote Port: 0
- Local Port: 502

Table 4.2.5.2-1 provides a list of parameters and associated Modbus register values.

Table 4.2.5.2-1 Cryocooler System Modbus TCP Housekeeping (HK) Signal Parameters and Associated Modbus Register Values

Modbus Register	Data Type	Tag No	Description
30001[0]	Bool	TSA91	Temperature Switch Alarm - Compressor area smoke detection Fault
30001[1]	Bool	XA301	System Alarm – Environmental Monitor Fault – acceleration, inclination, smoke detector
30002[0]	Bool	YC54	Event Control – Cooling pump start
30002[1]	Bool	YC57	Event Control – Upper Deck HX fan start
30002[2]	Bool	YC59	Event Control – TA Pit HX fan start
30002[3]	Bool	ZSO58A	Position Switch Open – Upper Deck HX valve open
30002[4]	Bool	XA331	System Alarm – Cooling system Alarm
30002[5]	Bool	XA332	System Alarm – Compressor A cooling system Fault
30002[6]	Bool	XA333	System Alarm – Compressor B cooling system Fault
30002[7]	Bool	XA334	System Alarm – Cooling system common Fault
30003[0]	Bool	YC81	Event Control – Compressor A power contactor closed
30003[1]	Bool	YY26	Event Relay – Compressor A on
30003[2]	Bool	XA311	System Alarm – Compressor A Alarm
30003[3]	Bool	XA312	System Alarm – Compressor A Fault
30003[4]	Bool	XA313	System Alarm – Cryomech Compressor A Alarm
30003[5]	Bool	XA314	System Alarm – Cryomech Compressor A Fault
30004[0]	Bool	YC82	Event Control – Compressor B power contactor closed
30004[1]	Bool	YY46	Event Relay – Compressor B on
30004[2]	Bool	XA321	System Alarm – Compressor B Alarm
30004[3]	Bool	XA322	System Alarm – Compressor B Fault
30004[4]	Bool	XA323	System Alarm – Cryomech Compressor B Alarm
30004[5]	Bool	XA324	System Alarm – Cryomech Compressor B Fault
30005 30006	32 Bit Float	GT97	Acceleration Transmitter – Lateral axis acceleration
30007 30008	32 Bit Float	GT98	Acceleration Transmitter – Vertical axis acceleration
30009 30010	32 Bit Float	ZT93A	Position Transmitter – Compressor pitch axis tilt position
30011 30012	32 Bit Float	ZT93B	Position Transmitter – Compressor roll axis tilt position
30013 30014	32 Bit Float	TE50	Temperature Element – Compressor A coolant return temperature
30015 30016	32 Bit Float	TE51	Temperature Element – Compressor B coolant return temperature
30017 30018	32 Bit Float	TE52	Temperature Element – TA Pit HX coolant inlet temperature
30019 30020	32 Bit Float	TE54	Temperature Element – Compressor coolant supply temperature
30021 30022	32 Bit Float	TE95	Temperature Element – Upper Deck HX inlet air temperature
30023 30024	32 Bit Float	TE96	Temperature Element – TA Pit HX inlet air temperature

Modbus Register	Data Type	Tag No	Description
30025 30026	32 Bit Float	FT55	Flow Transmitter – Cryomech Compressor A coolant flowrate
30027 30028	32 Bit Float	FT56	Flow Transmitter – Cryomech Compressor B coolant flowrate
30029 30030	32 Bit Float	PT53	Pressure Transmitter – Coolant system accumulator gas pressure
30031 30032	32 Bit Float	PT54	Pressure Transmitter – Compressor coolant supply pressure
30033 30034	32 Bit Float	IT54	Current Transmitter – Cooling pump current
30035 30036	32 Bit Float	IT57	Current Transmitter – Upper Deck HX fan current
30037 30038	32 Bit Float	IT59	Current Transmitter – TA Pit HX fan current
30039 30040	32 Bit Float	TE13B	Temperature Element – Cryomech Compressor A compressor module He outlet temperature
30041 30042	32 Bit Float	TE17B	Temperature Element – Cryomech Compressor A HX outlet oil temperature
30043 30044	32 Bit Float	PT61	Pressure Transmitter – Compressor A He return pressure
30045 30046	32 Bit Float	PT62	Pressure Transmitter – Cryomech Compressor A He supply pressure
30047 30048	32 Bit Float	IT81	Current Transmitter – Cryomech Compressor A supply power current
30049 30050	32 Bit Float	TE33B	Temperature Element – Cryomech Compressor B compressor module He outlet temperature
30051 30052	32 Bit Float	TE37B	Temperature Element – Cryomech Compressor B HX outlet oil temperature
30053 30054	32 Bit Float	PT65	Pressure Transmitter – Compressor B He return pressure
30055 30056	32 Bit Float	PT66	Pressure Transmitter – Cryomech Compressor B He supply pressure
30057 30058	32 Bit Float	IT82	Current Transmitter – Cryomech Compressor B supply power current

4.2.6. Cryocooler System Housekeeping Datalogger to GSE Computer Interface

The Phase 2 Cryocooler System controller provides an internal datalogger capability that supports continuous date and time-stamped recording of all HK parameters at a rate of 1 Hz in a circular log for up to 1000 hours (41+ days) of continuous Cryocooler System operations. An Alarm fault event triggers a second, distinct log file, which captures the HK parameters at a rate of 1 Hz for the 55 minutes leading up to the Fault, and for 5 minutes following the Fault Alarm event.

Each log comprises two files, one for the analog input HK parameters, and another for discrete parameters.

This is primarily to provide datalogging capability and troubleshooting activities during extended periods in which the majority of the MCCS subsystems (including the DAS, PIS, Archiver, etc.) and many SI subsystems may be offline (e.g., between flights, over weekends, etc.).

The procedure for accessing this internally logged HK data via use of a GSE computer using a CAT5 Ethernet cable connected to a PROFINET RJ-45 port on one of the Phase 2 Cryocooler System control panels is defined in SOF-NASA-PRO-SV02-2471, Phase 2 Cryocooler System Operational Procedures.

5. SAFETY HAZARDS

Phase 2 Cryocooler System Preliminary Failure Modes & Effects Analysis (FMEA) document APP-DF-REP-PA06-2032 has been developed to address the hazards identified for the installation and operation of the Phase 2 Cryocooler System, and associated hazard mitigations.

Developers of SIs that will interface with the SOFIA Cryocooler System are encouraged to read and become familiar with SOFIA Generic Hazard Report (HR) SOFIA SI Cryocooler-Cooled Cryostat Overpressure and Habitable Atmosphere Hazards, which identifies overpressure hazards and associated mitigations, including the use of code-stamped Pressure Relief Valves and Burst Discs with specific cracking pressures that support the established MOP of the integrated SI / Cryocooler System. This generic SI HR will be published within SCI-AR-HBK-OP03-2000, SOFIA SI Developers' Handbook, Appendix G.

6. CRYOCOOLER CONOPS AND RELATED INSTALLATION TIMELINE AND ORDER OF OPERATIONS CONSIDERATIONS

In a typical SI installation operation, it is customary for the transportation and mechanical installation of the SI (including the PI rack and CWR installations) to be completed before executing the SI cable installation procedure. However, in the case of SIs which have cryostats cooled by CCC systems, there are scenarios in which this may not be practical.

As discussed within APP-DA-PLA-PM17-2076, *SOFIA Cryocooler System Concept of Operations*, it is often important to minimize any lapse in active cooling between the time that the SI is disconnected from the GSE cryocooler compressor(s) in the lab and when it is integrated with the Cryocooler System aboard SOFIA and active cooling is re-initiated.

Though the time constraints associated with this are SI-specific, lapses in cooling longer than an established threshold can result in a loss of cryopumping within the vacuum space within the cryostat, which can in turn cause the high vacuum to go “soft” and potentially lead to contamination. In some cases, contingency operations such as pumping down the vacuum space with a GSE turbo-molecular vacuum pump may be necessary, and critical line-op or flight timelines can be impacted.

For this reason, SI developers, in conjunction with USRA MOPS staff, should consider developing dovetailed SI installation and SI cable installation procedures and timelines such that the installation and connection of the He flex lines from U404 to the SI cold head(s), as well as any power and signal cables necessary to support active cooling aboard SOFIA, are completed prior to – or in parallel with – other less time-critical aspects of the SI mechanical installation, to minimize any lapse in active cooling. Ideally, active cooling can commence within minutes of getting the SI aligned with the SOFIA TA IMF dowel pins with perhaps 1 or 2 mounting bolts installed. This consideration may also drive requirements and design features of the SI installation cart.

SI developers and PI teams should also be aware that per PM17-2076, there are additional lapses in active cryocooling of various durations during day of flight and pre-flight operations that should be anticipated and planned for accordingly.

A lapse of approximately 30 to 45 minutes is typical whenever SOFIA is towed between the hangar and the flight line. Generally speaking, SOFIA remains unpowered from the time it is disconnected from the hangar shore power interface until it is connected to GSE ground power carts out on the flight line. SIs that are particularly sensitive to such lapses may be able to request an APU start-up and power transfer soon after SOFIA has cleared the hangar. Such requests should be addressed to AFRC-OE.

Finally, the power transfers from APU or GSE ground power cart to aircraft engine generator power, and vice-versa, though much shorter than the power lapse during towing operations, is not “bumpless” and sometimes results in a sudden dropout in the 60 Hz, 3-phase power feed from Observatory Bus 4, and a less-than-orderly shutdown of the compressors, controller PLCs, I/O modules and power relays.

Because of this, the nominal operating procedure for the Cryocooler System (and the synchronized Pulse Tube cold head rotary valve) generally include sequences to manually shut-down and restart portions of the Cryocooler System, and all Mission and Flight crew, and the ground support teams, are all routinely briefed during the preflight briefs that all power transfers must be closely coordinated with the MD and the SI / PI team.

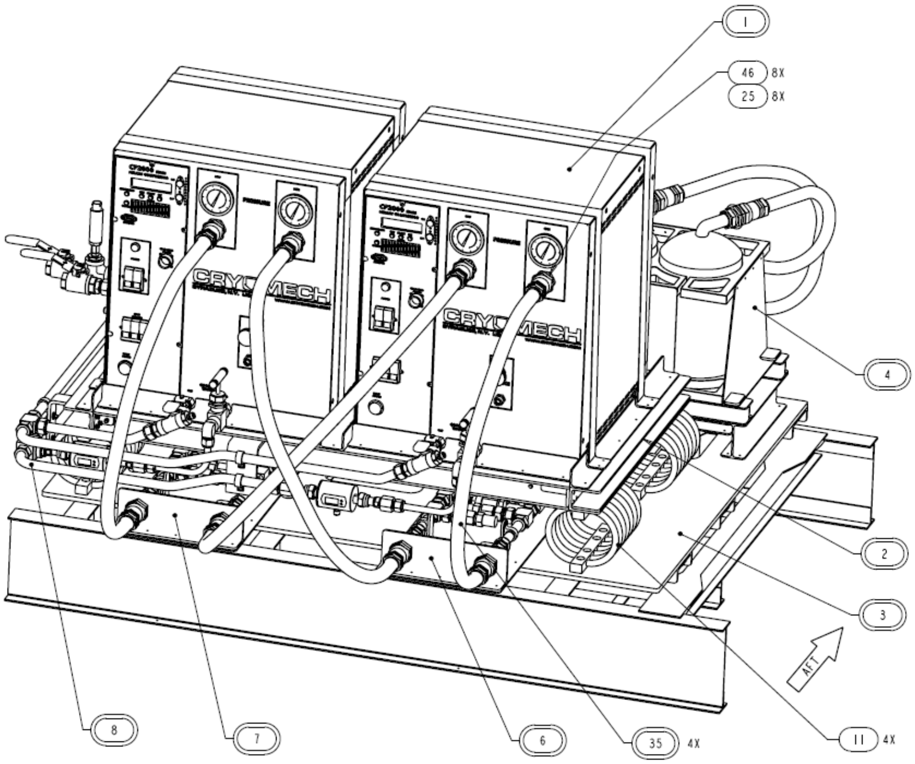


Figure 6-1: Cryocooler Compressor Package Location, isometric view

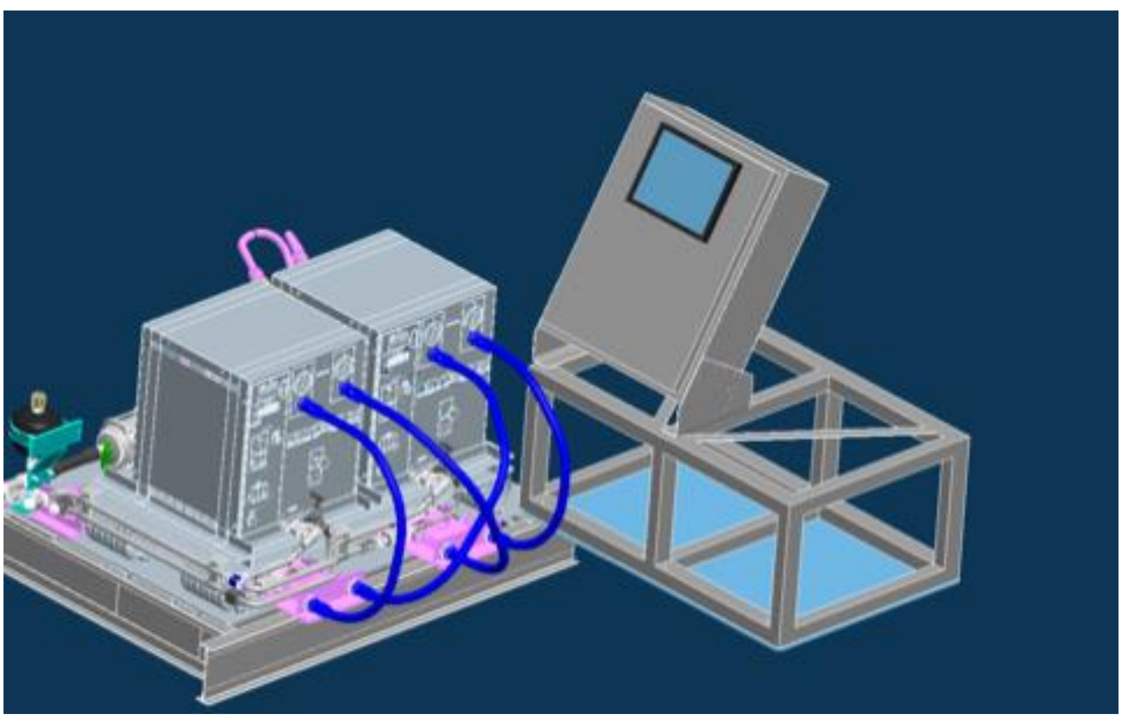


Figure 6-2: Cryocooler Compressor Package Location, 3D rendering showing WVM electronics rack and notional Upper Deck (Main) Control Panel mounting

APPENDIX A. ACRONYMS AND ABBREVIATIONS

A/C	Aircraft
A/D	Analog to Digital
BL	Butt Line
CB	Circuit Breaker
CCC	Closed-Cycle Cryocooler
CG	Center of Gravity
CLA	Cable Load Alleviator
COTS	Commercial Off The Shelf
CWP	Counterweight Plate (of TA Balancer Subassembly)
CWR	Counterweight Rack
D/A	Digital to Analog
DAS	Data Acquisition System (MCCS subsystem)
DESO	Double End Shut-Off (fluidic QD coupling)
EU	Engineering Unit
FC	Frequency Converter
FMEA	Failure Modes & Effects Analysis
FS	Fuselage Station
GREAT	German REceiver for Astronomy at Terahertz frequencies
GSE	Ground Support Equipment
HFA	High Frequency Array (upGREAT channel / cryostat)
HK	Housekeeping (data)
HMI	Human Machine Interface
HR	Hazard Report
HX	Heat eXchanger
Hz	Hertz (cycles per second)
ICD	Interface Control Document
I/F	Interface
IMF	Instrument Mounting Flange
I/O	Input / Output
kVA	kilo Volt Amperes
LFA	Low Frequency Array (upGREAT channel / cryostat)
LHe	Liquid Helium
mA	milli-Amperes
MCCS	Mission Control Communication System
MOPS	Mission Operations
MPa	Mega-Pascals
MPIfR	Max Planck Institute für Radioastronomie
N/A	Not Applicable
NC	No Connection (unused contact location)
NC	Normally Closed (switch or relay contact)
NO	Normally Open (switch or relay contact)
OPP	Observatory Power Panel
Pa	Pascal (Newtons per square meter)

PDS	Power Distribution System (MCCS subsystem)
PI	Principal Investigator
PLC	Programmable Logic Controller
PRD	Pressure Relief Device
PRV	Pressure Relief Valve
psi	pounds per square inch
QD	Quick Disconnect (fluidic coupling)
RDW	Request for Deviation or Waiver
RET	Return
RTB	Return To Base
SI	Science Instrument
SOFIA	Stratospheric Observatory For Infrared Astronomy
TA	Telescope Assembly
TP	Twisted Pair
TSP	Twisted Shielded Pair
USRA	Universities Space Research Association
VAC	Volts Alternating Current
VDC	Volts Direct Current

APPENDIX B. INTERFACE HARDWARE DATA SHEETS

5400 Series
Low Air Inclusion Refrigerant

Eaton's 5400 Series low air inclusion product line is designed for air conditioning, refrigerant, gaseous and fluid transfer applications.

Product Features

- Brazed or threaded end connections for versatility of installation on tubing or hose
- Tubular valve construction for low fluid loss and air inclusion
- Thread together design allows connection and disconnection against pressure
- Lock washer and jam nut standard for optional bulkhead mounting
- Standard seal material: Neoprene
- Guardian Seal™ plating for excellent corrosion resistance

Physical Characteristics

Coupling Size	Max. Operating Pressure Connected		Min. Burst Pressure Connected		Max. Operating Pressure Disconnected Male Half		Female Half		Vacuum Connected Only	Rated Flow		Air Inclusion	Fluid Loss
(in)	(bar)	(psi)	(bar)	(psi)	(bar)	(psi)	(bar)	(psi)	(in./Hg)	(lpm)	(gpm)	cc. max.	cc.max.
1/4	207	3,000	621	9,000	172	2,500	34	500	28	8	2	.10	.05
1/2	121	1,750	359	5,200	121	1,750	28	400	28	53	14	.10	.10
3/4	48	700	145	2,100	55	800	28	400	28	132	35	.30	.10
1	48	700	145	2,100	48	700	21	300	28	284	75	.50	.20

Applications & Markets

- Mobile air conditioning and refrigerant

Flow Data

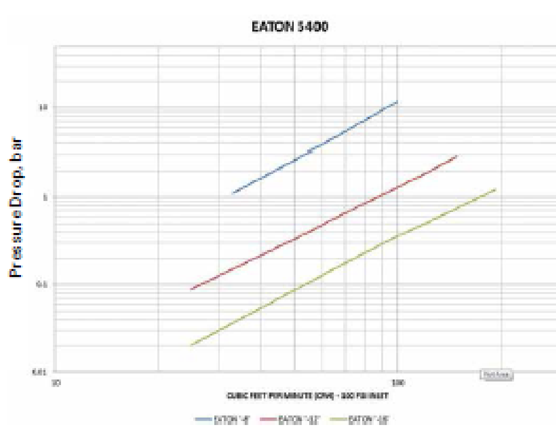


Figure B-1.1 Data Sheet for Eaton / Aeroquip 5400 Series Quick Disconnect (QD) couplings (Sh. 1 of 5)

5400 Series
Low Air Inclusion Refrigerant

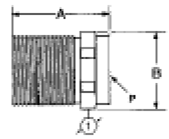


Figure 1

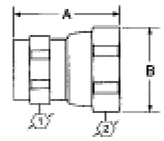


Figure 2

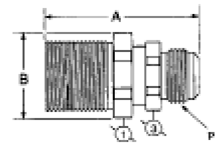


Figure 3

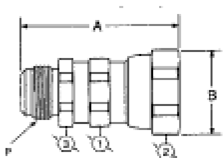


Figure 4

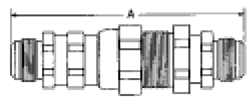


Figure 5

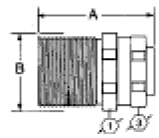


Figure 6

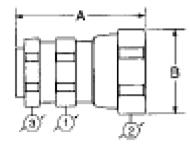


Figure 7

Dimensions – No Adapter

Part Number Neoprene	Coupling Type	Body Size	Type	Fig.	Dimensions A		B		Hex ①		Hex ②		Hex ③	
					mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
5400-S2-4	Male	1/4	No Adapter	1	27.4	(1.08)	21.1	(.83)	19.1	(.75)	-	-	-	-
5400-S5-4	Female	1/4	No Adapter	2	33.3	(1.31)	21.1	(.83)	16.0	(.63)	19.1	(.75)	-	-
5400-S2-8	Male	1/2	No Adapter	1	34.8	(1.37)	32.0	(1.26)	29.0	(1.14)	-	-	-	-
5400-S5-8	Female	1/2	No Adapter	2	40.6	(1.60)	33.0	(1.30)	26.0	(1.02)	30.0	(1.18)	-	-
5400-S2-12	Male	3/4	No Adapter	1	44.2	(1.74)	46.4	(1.83)	41.0	(1.64)	-	-	-	-
5400-S5-12	Female	3/4	No Adapter	2	55.1	(2.17)	45.0	(1.77)	35.0	(1.38)	41.0	(1.61)	-	-
5400-S2-16	Male	1	No Adapter	1	46.5	(1.83)	53.0	(2.09)	48.0	(1.89)	-	-	-	-
5400-S5-16	Female	1	No Adapter	2	61.1	(2.41)	56.0	(2.20)	45.0	(1.77)	50.0	(1.97)	-	-

Dimensions – SAE 37° (JIC)

Part Number Buna-N	Coupling Type	Body Size	Port Size	Thread	Type	Fig.	Dimensions A		B		Hex ①		Hex ②		Hex ③	
*Couplings must be ordered by components as shown on page 150.							mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
5410-S17-4-4*	Male	1/4	7/16	7/16-20	SAE 37° (JIC)	3	47.8	(1.88)	21.1	(.83)	19.1	(.75)	-	-	16.0	(.63)
5410-S14-4-4*	Female	1/4	7/16	7/16-20	SAE 37° (JIC)	4	49.0	(1.93)	21.1	(.83)	16.0	(.63)	19.1	(.75)	15.7	(.62)
5410-4-4*	Complete	1/4	7/16	7/16-20	SAE 37° (JIC)	5	89.9	(3.54)	-	-	-	-	-	-	-	-
5410-S17-6-4*	Male	1/4	9/16	9/16-18	SAE 37° (JIC)	3	48.0	(1.89)	21.1	(.83)	19.1	(.75)	-	-	16.0	(.63)
5410-S14-6-4*	Female	1/4	9/16	9/16-18	SAE 37° (JIC)	4	49.3	(1.94)	21.1	(.83)	16.0	(.63)	19.1	(.75)	15.7	(.62)
5410-6-4*	Complete	1/4	9/16	9/16-18	SAE 37° (JIC)	5	90.4	(3.56)	-	-	-	-	-	-	-	-
5410-S17-6-8*	Male	1/2	9/16	9/16-18	SAE 37° (JIC)	3	55.4	(2.18)	31.8	(1.25)	28.7	(1.13)	-	-	25.4	(1.00)
5410-S14-6-8*	Female	1/2	9/16	9/16-18	SAE 37° (JIC)	4	61.7	(2.43)	33.3	(1.31)	25.4	(1.00)	30.2	(1.19)	25.4	(1.00)
5410-6-8*	Complete	1/2	9/16	9/16-18	SAE 37° (JIC)	5	107.4	(4.23)	-	-	-	-	-	-	-	-
5410-S17-8-8*	Male	1/2	3/4	3/4-16	SAE 37° (JIC)	3	57.9	(2.28)	31.8	(1.25)	28.7	(1.13)	-	-	25.4	(1.00)
5410-S14-8-8*	Female	1/2	3/4	3/4-16	SAE 37° (JIC)	4	64.3	(2.53)	33.3	(1.31)	25.4	(1.00)	30.2	(1.19)	25.4	(1.00)
5410-8-8*	Complete	1/2	3/4	3/4-16	SAE 37° (JIC)	5	112.8	(4.44)	-	-	-	-	-	-	-	-
5410-S17-10-12*	Male	3/4	7/8	7/8-14	SAE 37° (JIC)	3	69.9	(2.75)	46.5	(1.83)	41.4	(1.63)	-	-	35.1	(1.38)
5410-S14-10-12*	Female	3/4	7/8	7/8-14	SAE 37° (JIC)	4	80.3	(3.16)	45.7	(1.80)	35.1	(1.38)	41.1	(1.62)	35.1	(1.38)
5410-10-12*	Complete	3/4	7/8	7/8-14	SAE 37° (JIC)	5	135.4	(5.33)	-	-	-	-	-	-	-	-
5410-S17-12-12*	Male	3/4	1 1/16	1 1/16-12	SAE 37° (JIC)	3	72.6	(2.86)	46.5	(1.83)	41.4	(1.63)	-	-	35.1	(1.38)
5410-S14-12-12*	Female	3/4	1 1/16	1 1/16-12	SAE 37° (JIC)	4	83.1	(3.27)	45.7	(1.80)	35.1	(1.38)	41.1	(1.62)	35.1	(1.38)
5410-12-12*	Complete	3/4	1 1/16	1 1/16-12	SAE 37° (JIC)	5	140.7	(5.54)	-	-	-	-	-	-	-	-
5410-S17-16-16*	Male	1	1 5/16	1 5/16-12	SAE 37° (JIC)	3	75.9	(2.99)	53.3	(2.10)	47.8	(1.88)	-	-	44.5	(1.75)
5410-S14-16-16*	Female	1	1 5/16	1 5/16-12	SAE 37° (JIC)	4	89.7	(3.53)	56.9	(2.24)	44.5	(1.75)	50.8	(2.00)	44.5	(1.75)
5410-16-16*	Complete	1	1 5/16	1 5/16-12	SAE 37° (JIC)	5	149.6	(5.89)	-	-	-	-	-	-	-	-

Figure B-1.2 Data Sheet for Eaton / Aeroquip 5400 Series Quick Disconnect (QD) couplings (Sh. 2 of 5)

5400 Series
Low Air Inclusion Refrigerant

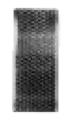
Dimensions – Braze Tubing Adapter

Part Number Neoprene	Coupling Type	Body Size	Tube O.D. Size	Type	Fig.	Dimensions A mm	A (in)	B mm	B (in)	Hex ① mm	Hex ① (in)	Hex ② mm	Hex ② (in)	Hex ③ mm	Hex ③ (in)
*Couplings must be ordered by components as shown on page 150.						mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
5401-S17-4-4*	Male	1/4	1/4	Braze Tubing Adapter	6	38.6	(1.52)	21.1	(.83)	19.1	(.75)	-	-	16.0	(.63)
5401-S14-4-4*	Female	1/4	1/4	Braze Tubing Adapter	7	39.9	(1.57)	21.1	(.83)	16.0	(.63)	19.1	(.75)	16.0	(.63)
5401-S17-6-4*	Male	1/4	3/8	Braze Tubing Adapter	6	38.6	(1.52)	21.1	(.83)	19.1	(.75)	-	-	16.0	(.63)
5401-S14-6-4*	Female	1/4	3/8	Braze Tubing Adapter	7	39.9	(1.57)	21.1	(.83)	16.0	(.63)	19.1	(.75)	16.0	(.63)
5410-S17-6-8*	Male	1/2	3/8	Braze Tubing Adapter	6	44.5	(1.75)	33.3	(1.31)	28.7	(1.13)	-	-	25.4	(1.00)
5401-S14-6-8*	Female	1/2	3/8	Braze Tubing Adapter	7	50.8	(2.00)	33.3	(1.31)	25.4	(1.00)	30.2	(1.19)	25.4	(1.00)
5401-S17-8-8*	Male	1/2	1/2	Braze Tubing Adapter	6	44.5	(1.75)	33.3	(1.31)	28.7	(1.13)	-	-	25.4	(1.00)
5401-S14-8-8*	Female	1/2	1/2	Braze Tubing Adapter	7	50.8	(2.00)	33.3	(1.31)	25.4	(1.00)	30.2	(1.19)	25.4	(1.00)
5401-S17-10-12*	Male	3/4	5/8	Braze Tubing Adapter	6	62.7	(2.47)	45.7	(1.80)	41.4	(1.63)	-	-	35.1	(1.38)
5401-S14-10-12*	Female	3/4	5/8	Braze Tubing Adapter	7	73.2	(2.88)	45.7	(1.80)	35.1	(1.38)	41.4	(1.63)	35.1	(1.38)
5401-S17-12-12*	Male	3/4	3/4	Braze Tubing Adapter	6	62.7	(2.47)	45.7	(1.80)	41.4	(1.63)	-	-	35.1	(1.38)
5401-S14-12-12*	Female	3/4	3/4	Braze Tubing Adapter	7	73.2	(2.88)	45.7	(1.80)	35.1	(1.38)	41.4	(1.63)	35.1	(1.38)
5401-S17-16-16*	Male	1	1	Braze Tubing Adapter	6	71.1	(2.80)	56.9	(2.24)	47.8	(1.88)	-	-	44.5	(1.75)
5401-S14-16-16*	Female	1	1	Braze Tubing Adapter	7	84.8	(3.34)	56.9	(2.24)	44.5	(1.75)	50.8	(2.00)	44.5	(1.75)

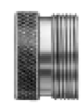
Dust Caps and Dust Plugs

Dust Cap with Gasket	Dust Plug with Gasket	Body Size
5400-S6-4	5400-S8-4	1/4
5400-S6-8	5400-S8-8	-1/2
5400-S6-12	5400-S8-12	3/4
5400-S6-16	5400-S8-16	1

Dust Cap



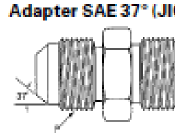
Dust Plug



Adapter SAE 37° (JIC)

O-Ring	Brass	Steel	Body Size	Thread	Tube O.D. Size
22546-12	202220-4-4B	202220-4-4S	1/4	7/16-20	1/4
22546-12	202220-6-4B	202220-6-4S	1/4	9/16-18	3/8
22546-17	-	202220-6-8S	1/2	9/16-18	3/8
22546-17	202220-8-8B	202220-8-8S	1/2	3/4-16	1/2
22546-23	-	202220-10-12S	3/4	7/8-14	5/8
22546-23	-	202220-12-12S	3/4	1 1/16-12	3/4
22546-28	-	202220-16-16S	3/4	1 3/16-12	1

Adapter SAE 37° (JIC)



Adapter – Braze

O-Ring	Brass	Steel	Body Size	Thread	Tube O.D. Size
22546-12	202208-4-4B	-	1/4	1/2-20	1/4
22546-17	202208-4-8B	-	1/2	7/8-20	1/2
22546-12	202208-6-4B	-	1/4	1/2-20	3/8
22546-17	202208-6-8B	-	1/2	7/8-20	3/8
22546-17	202208-8-8B	-	1/2	7/8-20	1/2
2254617	202208-10-8B	202208-10-8S	1/2	7/8-20	5/8
22546-23	202208-10-12B	202208-10-12S	3/4	1 1/4-18	5/8
22546-23	202208-12-12B	-	3/4	1 1/4-18	3/4
22546-23	202208-14-12B	-	1	1 1/4-18	7/8
22546-28	202208-14-16B	-	1	1 19/32-20	7/8
22546-28	202208-16-16B	-	1	1 19/32-20	1
22546-28	202208-18-16B	-	1	1 19/32-20	1 1/8
22546-28	202208-20-16B	-	1	1 19/32-20	1 3/16
22546-28	202208-22-16B	-	1	1 19/32-20	1 1/4

Adapter – Braze
(O-Ring Required)

Hose Fitting SAE 100R5†

O-Ring	Fitting Assembly	Body Size	Hose Size	Thread	Dimensions D mm	D (in)
					mm	(in)
22546-12	487-4-4S	1/4	-4	1/2-20	23.4	(.92)
22546-12	487-4-6S	1/4	-6	1/2-20	24.4	(.96)
22546-17	487-8-6S	1/2	-6	7/8-20	24.4	(.96)
22546-17	487-8-8S	1/2	-8	7/8-20	26.9	(1.06)
22546-23	487-12-10S	3/4	-10	1 1/4-18	27.2	(1.07)
22546-23	487-12-12S	3/4	-12	1 1/4-18	27.2	(1.07)
22546-28	487-16-16S	1	-16	1 19/32-20	25.7	(1.01)

†Additional dash styles available.

Hose Fitting SAE 100R5
(O-Ring Required)

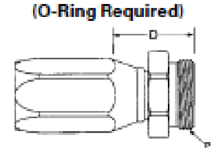


Figure B-1.3 Data Sheet for Eaton / Aeroquip 5400 Series Quick Disconnect (QD) couplings (Sh. 3 of 5)

5400 Series
Low Air Inclusion Refrigerant

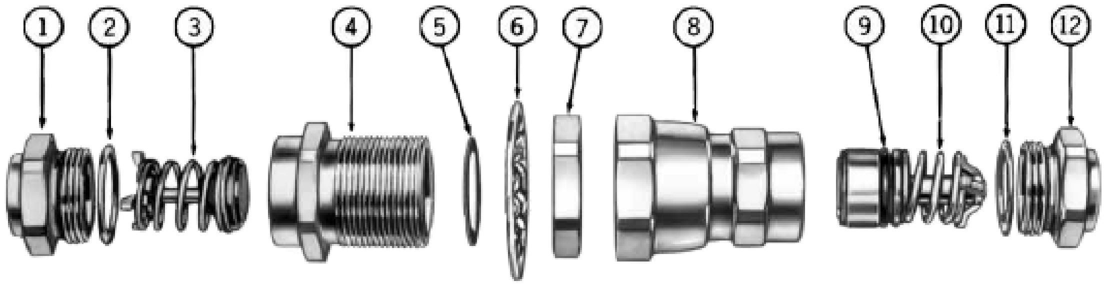
For assemblies, order by components as shown by base number and dash (-) size below. Example, if a 5401-S14-10-12 is required, order as components, (1) 5400-S5-12, (1) 202208-10-12B Adapter and (1) 22546-23 O-Ring.

Assembly Part Number	5400-S2 Female Half	Quantity	5400-S5 Male Half	Quantity	202208-Brass Braze-On Adapter	Quantity	202220-Steel 37° SAE Adapter	Quantity	22546 O-Ring	Quantity
5401-S14-10-12			-12	1	-10-12B	1			-23	1
5401-S14-10-8			-8	1	-10-8B				-17	1
5401-S14-12-12			-12	1	-12-12B	1			-23	1
5401-S14-16-16			-16	1	-16-16B	1			-28	1
5401-S14-4-4			-4	1	-4-4B	1			-12	1
5401-S14-6-4			-4	1	-6-4B	1			-12	1
5401-S14-6-8			-8	1	-6-8B	1			-17	1
5401-S14-8-8			-8	1	-8-8B	1			-17	1
5401-S17-10-12	-12	1			-10-12B	1			-23	1
5401-S17-10-8	-8	1			-10-8B	1			-17	1
5401-S17-12-12	-12	1			-12-12	1			-23	1
5401-S17-14-16	-16	1			-16-16	1			-28	1
5401-S17-4-4	-4	1			-4-4B	1			-17	1
5401-S17-6-4	-4	1			-6-4B	1			-12	1
5401-S17-6-8	-8	1			-6-8B	1			-17	1
5401-S17-8-8	-8	1			-8-8B	1			-17	1
5410-12-12	-12	1	-12	1			-12-12S	2	-23	2
5410-16-16	-16	1	-16	1			-16-16S	2	-28	2
5410-4-4	-4	1	-4	1			-4-4S	2	-12	2
5410-6-8	-8	1	-8	1			-6-8S	2	-17	2
5410-8-8	-8	1	-8	1			-8-8S	2	-17	2
5410-S14-10-12			-12	1			-10-12S	1	-23	1
5410-S14-12-12			-12	1			-12-12S	1	-23	1
5410-S14-16-16			-16	1			-16-16S	1	-28	1
5410-S14-4-4			-4	1			-4-4S	1	-12	1
5410-S14-6-4			-4	1			-6-4S	1	-12	1
5410-S14-6-8			-8	1			-6-8S	1	-17	1
5410-S14-8-8			-8	1			-8-8S	1	-17	1
5410-S17-10-12	-12	1					-10-12S	1	-23	1
5410-S17-12-12	-12	1					-12-12S	1	-23	1
5410-S17-16-16	-16	1					-16-16S	1	-28	1
5410-S17-4-4	-4	1					-4-4S	1	-12	1
5410-S17-6-4	-4	1					-6-4S	1	-12	1
5410-S17-6-8	-8	1					-6-8S	1	-17	1
5410-S17-8-8	-8	1					-8-8S	1	-17	1

Figure B-1.4 Data Sheet for Eaton / Aeroquip 5400 Series Quick Disconnect (QD) couplings (Sh. 4 of 5)

5400 Series
Low Air Inclusion Refrigerant

Assembly Instructions/Component Part Numbers



Typical Male Coupling Half (S2)

Assembly Instructions

Steps:

1. After tubing or hose has been connected to adapters ① and ⑫, install O-Rings ② and ⑪* on adapters. Be sure O-Rings are not twisted.
2. Oil O-Rings ② and ⑪ liberally with system fluid to prevent them from scuffing and tearing when coupling body is threaded on adapter.
3. S2 Half—Lubricate poppet face with system fluid. Insert poppet valve assembly ③ into body ④. Tighten body ④ on adapter ①. After body and adapter make metal-to-metal contact, tighten by rotating body ④ 1/8" with respect to adapter ① or torque per table value.

   S5 Half—Oil O-Ring ⑨* liberally with system fluid. Insert valve and sleeve assembly 10 into body ⑧. Tighten body ⑧ on adapter ⑫. After body and adapter make metal-to-metal contact, tighten by rotating body ⑧ 1/8" with respect to adapter ⑫ or torque per table value.
4. Coupling Connection—Lubricate gasket seal ⑤ on 5400-S2 half with system fluid. Thread union nut ⑧ on 5400-S2 half. Tighten union nut to torque values shown in table. Be sure S2 and S5 bodies do not rotate during connection.

Typical Female Coupling Half (S5)

Bulkhead Mounting—S2 Half

Install lock washer ⑥ on S2 half. Insert S2 half through bulkhead, and tighten jam nut ⑦ so that lock washer teeth are fully compressed.

NOTE: Lock washer 6 must be between hex of S2 half and bulkhead.

Maximum Bulkhead Thickness

Body Size	Lock Washer Installed	Lock Washer Not Used
1/4	.206	.256
1/2	.136	.203
3/4	.232	.292
1	.101	.161

Torque Values

Recommended torque values in ft. lbs., are listed below.

Dash Size	Adapter to Body: Braze Type or Aluminum	Adapter to Body: Non-braze Type Steel or Brass	S2 Half to S5 Half
–4	6–8	12–15	10–12
–8	15–20	35–45	35–37
–12	35–40	45–55	45–47
–16	50–60	55–65	65–67

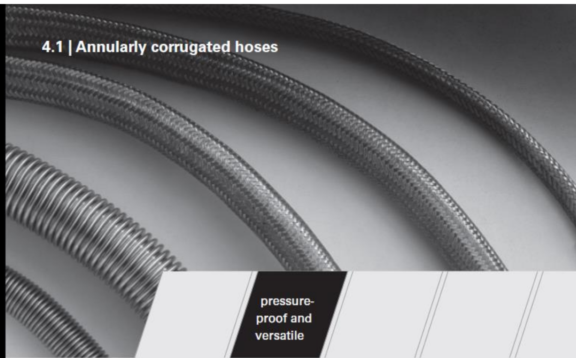
*IMPORTANT: Generous lubrication is required for all gaskets and O-Rings. Use refrigeration oil only when used in refrigerant system.

Component Part Numbers

Item Number	Dash Size→ O.D. Tube Size→	–4 1/4"–3/8"	–8 1/4"–5/8"	–12 5/8"–7/8"	–16 7/8"–13/8"	Line Ref.
	Typical Male Half					1
1	Tubing Adapter	202208–*–4	202208–*–8	202208–*–12	202208–*–16	2
2	O-Ring	22546–12	22546–17	22546–23	22546–28	3
3	Poppet Valve Assembly	5400–S20–4	5400–S20–8	5400–S20–12	5400–S20–16	4
4	Body	5400–17–4	5400–17–8	5400–17–12	5400–17–16	5
5	Gasket Seal	22008–4	22008–8	22008–12	22008–16	6
6	Lock Washer	5400–54–4S	5400–54–8S	5400–54–12S	5400–54–16S	7
7	Jam Nut	5400–53–4S	5400–53–8S	5400–53–12S	5400–53–16S	8
	Typical Female Half					9
8	Union Nut and Body Assembly	5400–S16–4	5400–S16–8	5400–S16–12	5400–S16–16	10
9	O-Ring	22546–10	22546–112	22546–116	22546–214	11
10	Valve and Sleeve Assembly	5400–S19–4	5400–S19–8	5400–S19–12	5400–S19–16	12
11	O-Ring	22546–12	22546–17	22546–23	22546–28	13
12	Tubing Adapter	202208–*–4	202208–*–8	202208–*–12	202208–*–16	14

*Specify O.D. Tubing size of adapter required in 16th of an inch. Example: –4 coupling with 3/8" O.D. tubing is 6/16 or –6. Part number is then 202208–6–4.

Figure B-1.5 Data Sheet for Eaton / Aeroquip 5400 Series Quick Disconnect (QD) couplings (Sh. 5 of 5)



The following section contains descriptions of the most common types of hose. The two features that characterise the hoses are the version and the corrugation:

	Geometric dimension	Designation
Version:	Wall thickness	medium / heavy
Corrugation:	Length of corrugation	narrow / medium / wide

Note that pressure resistance increases both with wall thickness and corrugation length. Flexibility, on the other hand, falls with both increasing corrugation length and wall thickness.

The technical detail tables are preceded by a description of the hose type. If you cannot find "your" hose, please contact us. Witzenmann produces a multitude of hose types. The hose for your application will certainly be among them.

Operating pressure

The operating pressures in the following tables that are applicable to stainless steel contain two pressure values:

1) Permissible operating pressure Pzul at 20 °C for static loading without movement with a bursting safety factor of 3 (**SF 3**).

2) Nominal pressure level as defined in DIN EN ISO 10380: maximum permissible pressure as defined in DIN EN ISO 10380 rounded to the associated pressure level. The maximum permissible pressure includes a bursting safety factor of 4 (**SF 4**) and an average flexibility of 10,000 load cycles in the U-bend (see Section 3).

At higher operating temperatures, the reduction factor given on page 245 applies to the two pressure values.

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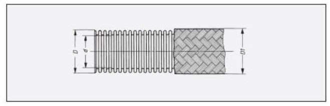
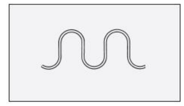
4.1 | Annularly corrugated hoses, stainless steel

HYDRA

Type RS 331 (up to DN 100), Type RS 330 (from DN 125)

medium version, normal corrugation





Construction:
Annularly corrugated all-metal hose made of butt-welded tube with or without braiding.

Versions:
- RS ...**S00** without braiding
- RS ...**S12** with single stainless steel wire braiding

Type tests:
The hose type is tested in accordance with DIN EN ISO 10380.

Material of hose:
stainless austenitic steel to DIN EN ISO 10088-2, bright
- standard: material no. 1.4404 comparable with AISI 316 L
- standard: material no. 1.4541 comparable with AISI 321
- other materials: e.g. material no. 1.4571 comparable with AISI 316Ti on request

Material of braiding:
stainless austenitic steel
- material no. 1.4301 comparable with AISI 304
- material no. 1.4571 comparable with AISI 316Ti on request

Temperature range:
-270 °C up to max. 600 °C (only for the hose)

Operating pressure:
The following tables with technical data of metal hoses contain two pressure values. Please refer to the general information on page 50.
SF = Bursting Safety Factor (3 or 4)

Connection fittings:
- flanges
- threaded connections
- welding ends
- customized connections on request

Approvals:
see page 16 – 17

Production lengths:
- DN 4 5 – 30 m
- DN 6-50 10 – 100 m
- DN 65-100 20 m
- DN 125-150 10 m

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4.1 | Annularly corrugated hoses, stainless steel

HYDRA

Type RS 331

medium version, normal corrugation

DN	Type	Inside diameter	Outside diameter	Permissible deviation	Minimum bending radius* one bending process	Nominal bending radius** frequent bending	Perm. static operating pressure at 20 °C SF 3	Nominal pressure DIN EN ISO 10380 SF 4	Weight. approx.
–	–	d	D, D1	d, D, D1	r_{min}	r_n	P_{zul}	–	–
–	–	mm	mm	mm	mm	mm	bar	PN	kg/m
4	RS331S00	4.2	7.1	±0.1	15	80	40	40	0.06
	RS331S12		8.2		25		135	100	0.11
6	RS331S00	6.2	9.7	±0.2	15	80	25	25	0.08
	RS331S12		10.8		25		200	150	0.14
8	RS331S00	8.3	12.3		16	120	20	20	0.10
	RS331S12		13.7		32		180	100	0.21
10	RS331S00	10.2	14.3		18	130	16	16	0.11
	RS331S12		15.7		38		140	100	0.23
12	RS331S00	12.2	16.8		20	140	12	10	0.12
	RS331S12		18.2		45		85	65	0.25
16	RS331S00	16.2	21.7		28	160	8	6	0.19
	RS331S12		23.3		58		90	65	0.40
20	RS331S00	20.2	26.7	±0.3	32	170	5	4	0.27
	RS331S12		28.3		70		55	40	0.49
25	RS331S00	25.5	32.2		40	190	4	4	0.38
	RS331S12		34.2		85		65	50	0.79
32	RS331S00	34.2	41.0		50	260	3	2.5	0.49
	RS331S12		43.0		105		35	25	0.96
40	RS331S00	40.1	49.7		60	300	2.5	2.5	0.77
	RS331S12		52.0		130		60	40	1.46
50	RS331S00	50.4	60.3	±0.4	70	320	1.5	0.5	0.91
	RS331S12		62.6		160		35	25	1.67
65	RS331S00	65.3	78.0		115	460	1	0.5	1.51
	RS331S12		81.2		200		40	25	2.88

** Minimum bending radius ≤ DIN EN ISO 10380 Type 1/2*

*** Nominal bending radius ≤ DIN EN ISO 10380 Type 1*

Please quote when ordering:

1. Type of hose, material, nominal diameter (DN), nominal length (NL)

2. Type of connection fitting, material

3. Operating conditions, refer to Inquiry Specification, page 47

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4.1 | Annularly corrugated hoses, stainless steel

HYDRA

Type RS 331 (up to DN 100), Type RS 330 (from DN 125)

medium version, normal corrugation

DN	Type	Inside diameter	Outside diameter	Permissible deviation	Minimum bending radius one bending process	Nominal bending radius frequent bending	Perm. static operating pressure at 20 °C SF 3	Nominal pressure DIN EN ISO 10380 SF 4	Weight. approx.
–	–	d	D, D1	d, D, D1	r_{min}	r_n	P_{zul}	–	–
–	–	mm	mm	mm	mm	mm	bar	PN	kg/m
80	RS331S00	80.2	94.8	±0.5	130	660	2	0.5	2.28
	RS331S12		98.0		240		35	16	4.08
100	RS331S00	100.0	116.2		160	750	1.5	0.5	2.53
	RS331S12		119.4		290		25	10	4.54
125	RS330S00	126.2	145.0	± 0.6	350	1000	0.8	0.5	2.68
	RS330S12		148.2				15	6	5.25
150	RS330S00	151.6	171.0	± 1.4	400	1250	0.5	0.5	3.41
	RS330S12		174.2				10	6	6.48

Please quote when ordering:

1. Type of hose, material, nominal diameter (DN), nominal length (NL)

2. Type of connection fitting, material

3. Operating conditions, refer to Inquiry Specification, page 47

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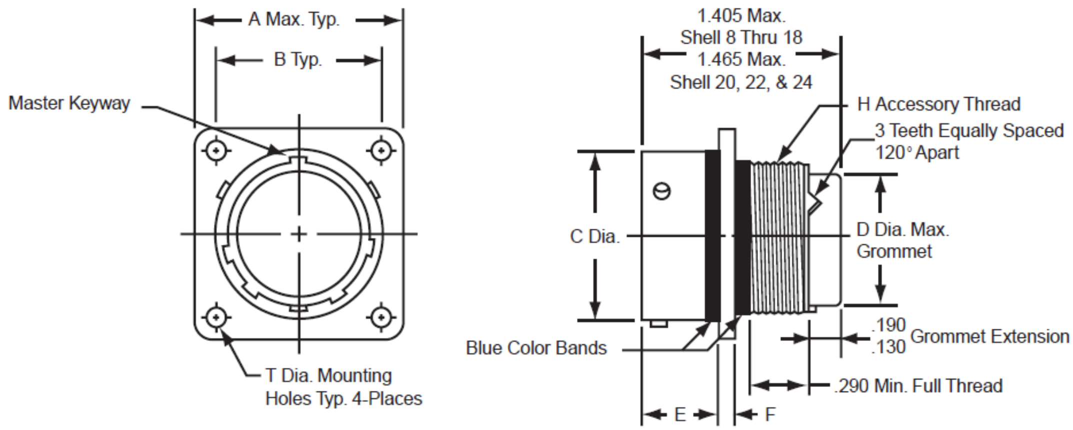
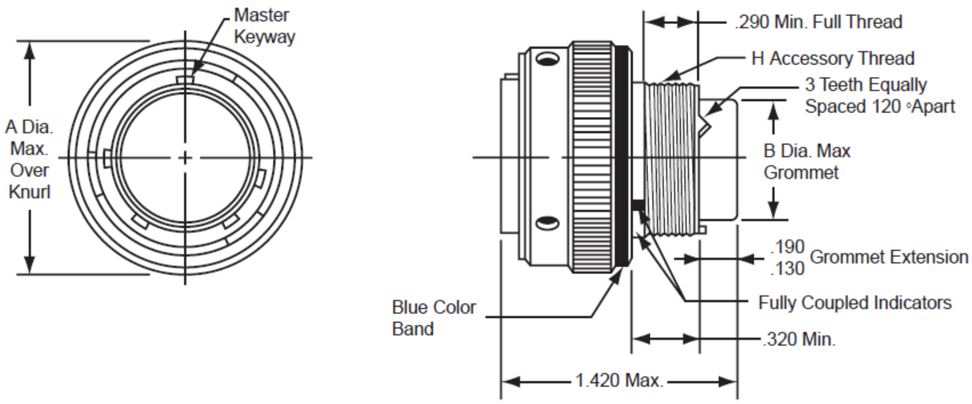
Figure B-2 Data Sheet for Witzenmann GmbH HYDRA RS331 Flexible He lines



To complete order number see how to order, page 14.

Shell Size	A Max.	B ±.005	C Dia. ±.003	D Dia. Max.	E	F ±.016	H Accessory Thread Class 2A	T ±.005
8	.828	.594	.471	.305	.462/.431	.062	.5000-20 UNF	.120
10	.954	.719	.588	.405	.462/.431	.062	.6250-24 UNEF	.120
12	1.047	.812	.748	.531	.462/.431	.062	.7500-20 UNEF	.120
14	1.141	.906	.873	.665	.462/.431	.062	.8750-20 UNEF	.120
16	1.234	.969	.998	.790	.462/.431	.062	1.0000-20 UNEF	.120
18	1.328	1.062	1.123	.869	.462/.431	.062	1.0625-18 UNEF	.120
20	1.453	1.156	1.248	.994	.587/.556	.094	1.1875-18 UNEF	.120
22	1.578	1.250	1.373	1.119	.587/.556	.094	1.3125-18 UNEF	.120
24	1.703	1.375	1.498	1.244	.620/.589	.094	1.4375-18 UNEF	.147

Figure B-3 Data Sheet for U401 J137 MS3470W10-6S bulkhead receptacle for SI interface with Cryocooler COMPRESSOR RUN STATUS discrete signals



Plug Shell,
Bayonet Coupling

Military No. MS3476
Amphenol/Matrix No. MB16

Shell Size	A Dia. Max.	B Dia. Max.	H Accessory Thread Class 2A
8	.782	.305	.5000-20 UNF
10	.926	.405	.6250-24 UNEF
12	1.043	.531	.7500-20 UNEF
14	1.183	.665	.8750-20 UNEF
16	1.305	.790	1.0000-20 UNEF
18	1.391	.869	1.0625-18 UNEF
20	1.531	.994	1.1875-18 UNEF
22	1.656	1.119	1.3125-18 UNEF
24	1.777	1.244	1.4375-18 UNEF

Figure B-4 Data Sheet for P137 MS3476W10-6P plug for SI interface with Cryocooler COMPRESSOR RUN STATUS discrete signals

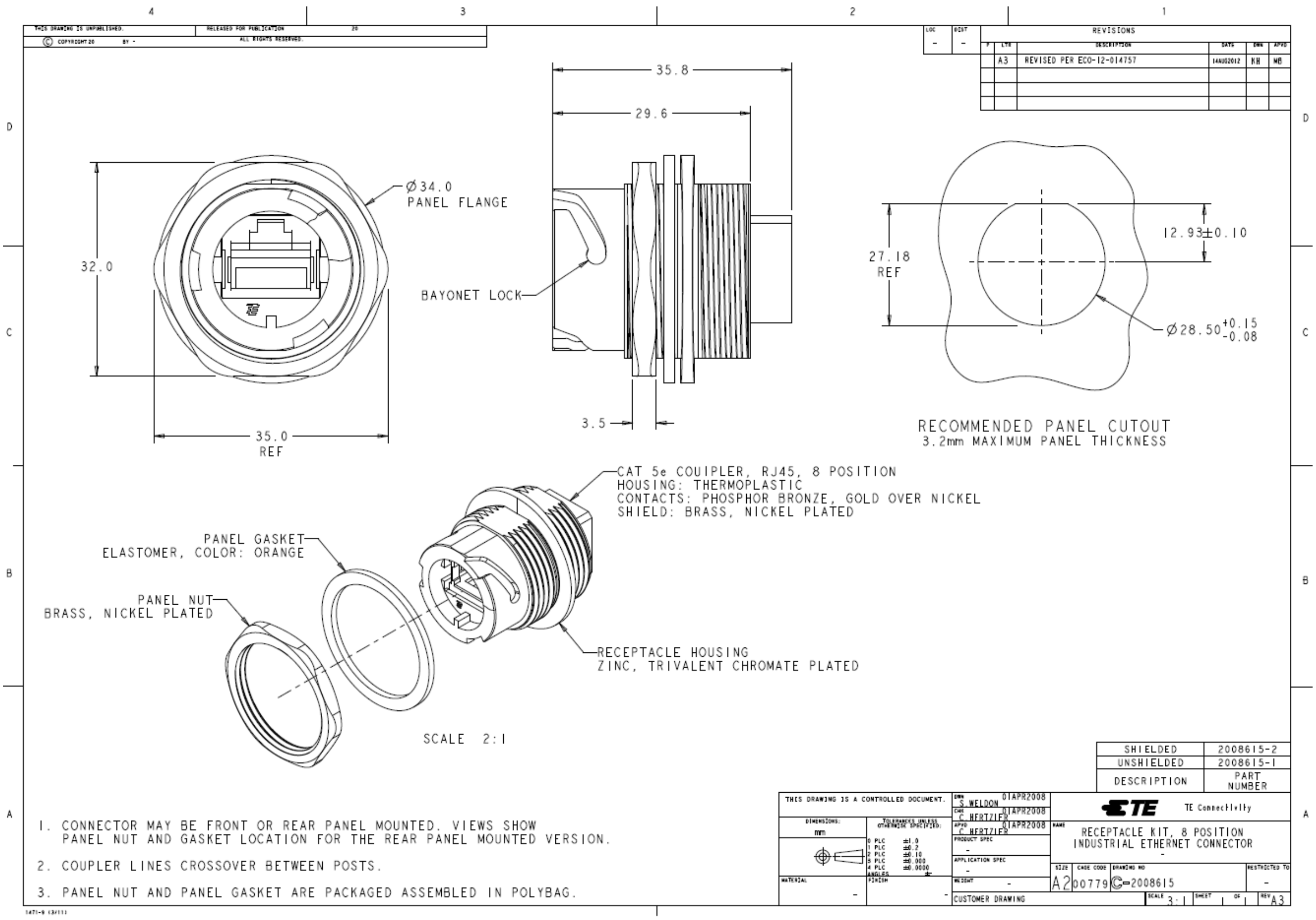


Figure B-5 Data Sheet for U401 J136 TE Connectivity AMP 2008615-2 bulkhead receptacle for SI interface with Cryocooler HK Modbus TCP / Ethernet signal

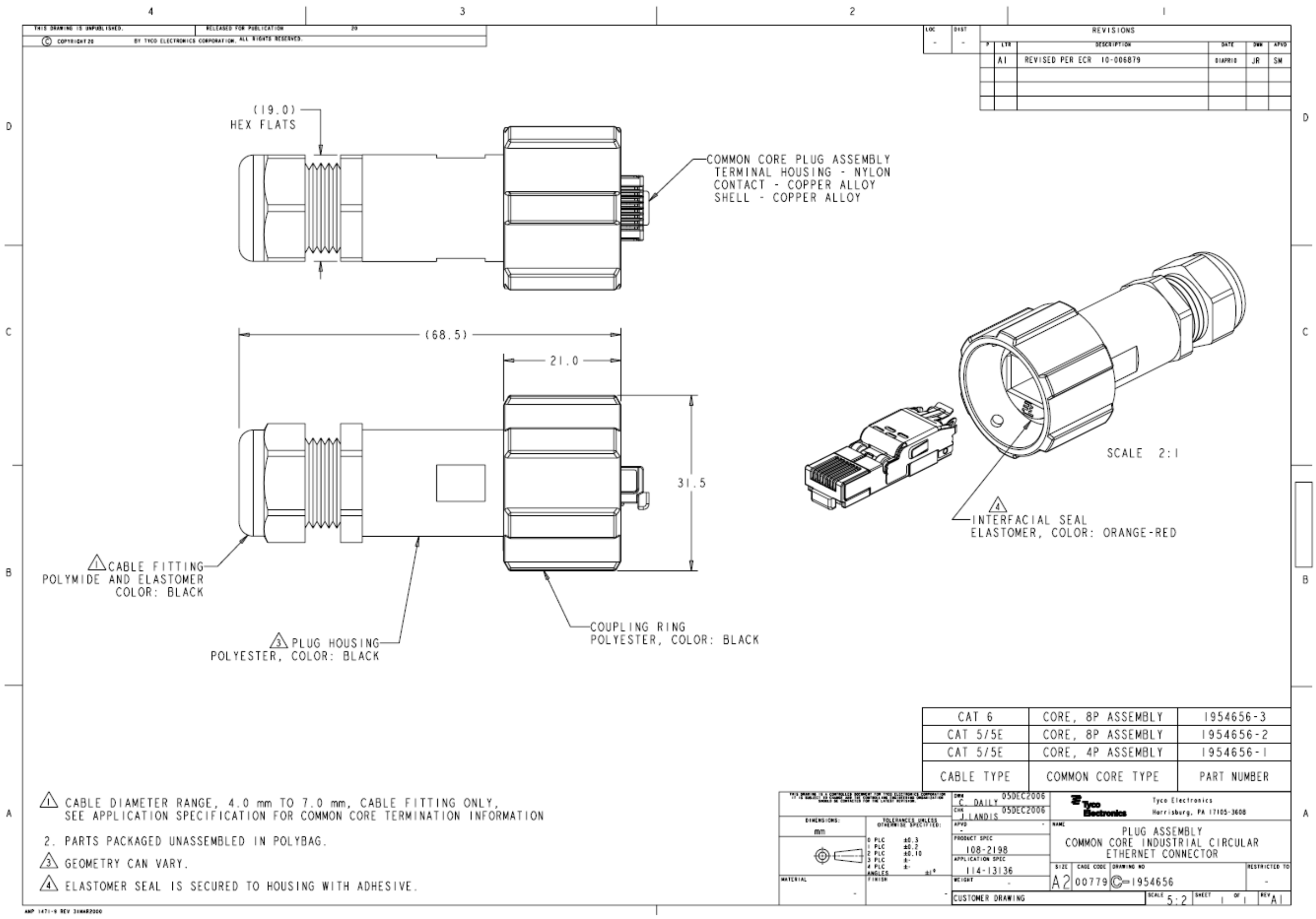


Figure B-6 Data Sheet for P136 TE Connectivity AMP 1954656-1 cable plug for SI interface with Cryocooler HK Modbus TCP / Ethernet signal