	IBL Type 1 Services Documentation		
ATLAS Project Document No: **ATU-SYS-CD-0007**	*Institute Document No.*	*Created: 12/03/2012*	*Page:* **1 of** *26*
		Modified: 13/09/2014	*Rev. No.:* **6**

IBL Type 1 Services Documentation

Abstract

This document provides the documentation of IBL Type 1 Services from PP0 to PP1

Prepared by:

Rusty Boyd, Ludovic ERAUD, Tobias Flick, Stephane Debieux, Philippe Grenier, Sergei Kachiguin, Martin Kocian, Matt McCulloch, Nicolas Massol, David Nelson, Marco Oriunno, Ned Spencer, SU Dong, Steven Welch, Tamer Yildizkaya

Checked by:

Approved by:

Distribution List

Atlas IBL Collaboration for comments

History of Changes

Rev. No.	*Date*	*Pages*	*Description of changes*
1	2012-03-04	All	First partial draft
2	2012-11-13	All	Major expansion to full details for first complete draft.
3	2012-12-26	All	Many figures/tables updated and some details added.
4	2013-03-18	Many	HV/DCS wires replaced with no-twist AWG32. DCS channel assignments. PP1 potting details. Final cable board.
5	2013-09-01	Many	Many description and final component picture updates, especially on mechanical dimension and jacketing. Final AXON drawing. Connectivity tables reformatted and more complete.
6	2014-09-13	Many	Final as-built system description. Main updates: a) LV wires changed from AWG22 CC-Al to AWG24 Cu. b) Type-1 mounting scheme and integration spec updates. c) Several figures updated to final IBL package. d) More description on installation packaging.

Table of Contents

1 GENERAL INTRODUCTION

1.1 Scope

This document describes the specifications of the IBL inner Type-1 electrical services between the End of Stave (EoS) to the PP1 junction for powering, HV and DCS, or to the opto-box for data, clock/command signals. The design of Type-1 has to meet the significant challenge of limited space not only for the IBL inner volume constraint but just importantly to allow a viable installation. The embedding of the Type-1 services in the overall IBL service scheme can be found in (*Ref:Service-diagram*).

1.2 Cable Description, Purpose, and Requirements

The confinement for the internal services to a significant lower radius of <4cm compared to the existing pixel detector PP0 and service panel radius of ~16cm demands compact designs in general. For each end of an IBL stave, there is a corresponding Type-1 service bundle that is further divided into two subgroups:

The Data/Cmd/Clk sub-bundle:

- Event data from IBL modules at 160Mbit/s, one channel for each FE-I4.
- Control Command and Clock signals at 40 Mbit/s are shared between two FE-I4s with a 1->2 multi-drop.
- LVDS common mode voltage reference lines.

A different data transmission strategy with twisted pairs of wires is adopted for IBL due to the concern of radiation hardness of optical components at such a low radius. To avoid unnecessary signal quality degradation, this sub-bundle runs between EoS and the opto-box at large radius on the ID endplate as a continuous 5.4m long piece without intermediate connection at PP1.

The LV/HV/DCS sub-bundle:

- Low voltage supply and sensing lines are one group per Four-FE-I4 module, but the actual LV wires are further split into 4 thinner pairs per group to give better flexibility.
- HV supply is one group per Four-FE-I4 module, with return path shared with LV returns.
- DCS contains NTC temperature readings for each Four-FE-I4 module on stave, and further NTCs at EoS region and 1-2 channels per stave which can serve different sensors between the staves.

This 3.6m long sub-bundle starts at the EoS and transition to Type-2 cables (*Ref:Type2-EDMS*) at the PP1. Because the Type-1 cables and their connectors will need to be threaded through within the small aperture of the existing pixel B-layer for installation, the bulky LV cables need the intermediate break at PP1 and the connection to Type-2 is accomplished with a miniature custom AXON μD connector to fit within the installation profile.

The connections to the stave at EoS are accomplished with a set of high density connectors (Ref:Panasonic-AXT) located at the end of the Type-1 cable board, via a set of intermediate flexes (Ref:Intermediate-Flex) to the stave flex (Ref:Stave-Flex). The intermediate flexes are intended to provide the necessary thermal differential contraction stress relief for the ~+-4mm movement between the stave and Type-1 cable board during the extreme conditions of high temperature of beam pipe bake out and the cold regular operation. The difficulties in maintaining a controllable form for the Intermediate Flexes led to a late integration decision to use a wavy placement of the Type-1 services as the primary means to absorb this movement. The block diagram of the Type-1 services is shown in Figure 1-1. An important feature of the Type-1 services is that the bundle hardware are completely symmetric between the A and C side so that there is only 1 type of bundle (modulo some length differences and DCS channels usage) and a single form for each connector type. However, this is at the expense of an asymmetric Type-0 stave flexes between A and C sides so that the same service channel may serve different module locations along the stave between A and C sides.

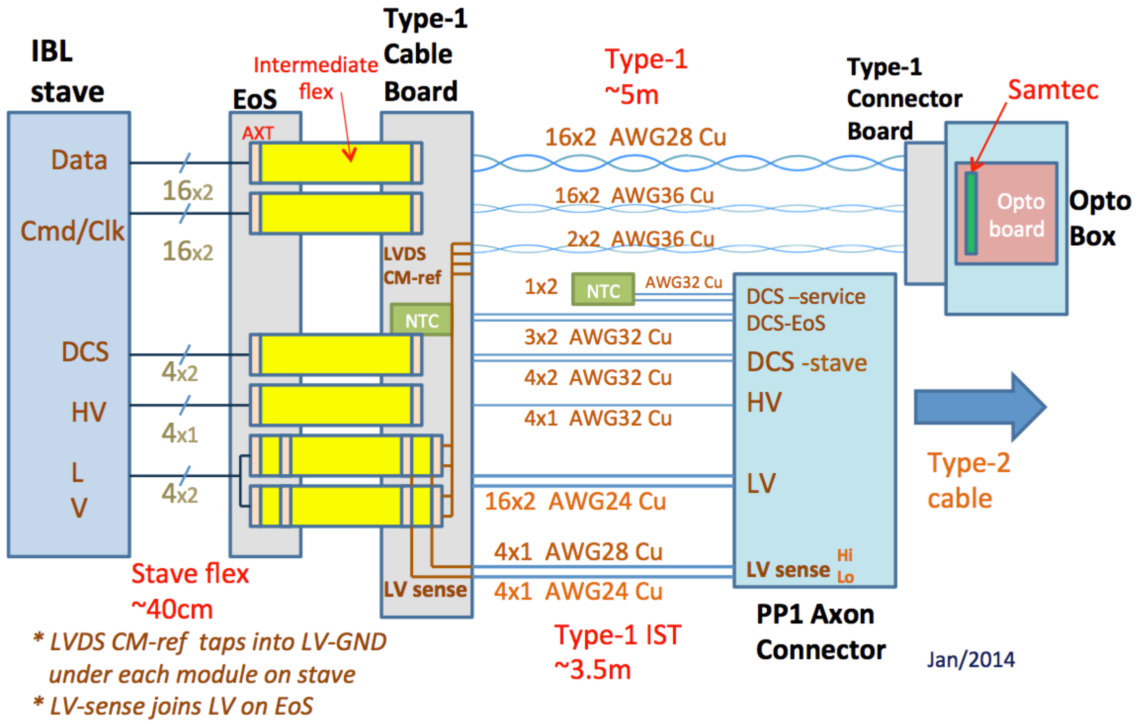


Figure 1-1 Block diagram of the Type-1 service scheme. There are some variations from stave to stave for DCS-EoS/Service with some staves having a humidity sensor on Cable Board and others having an NTC along bundle.

1.2.1 *Low Voltage Powering*

The inner service material is dominated by the low voltage (LV) supply wires which need to have a small enough resistance to avoid excessive voltage drop. The allowed voltage drop is defined by the minimum voltage required to operate FE-I4 maximum operating currents, and the maximum voltage the FE-I4 can potentially see in transient conditions of very low current. The very narrow voltage drop window allowed for direct powering already clearly ruled out the direct powering scheme from the cross section of the bulky Type-1 cables alone. The baseline IBL powering scheme is to utilize FE-I4 ShuLDO regulators with a minimal partial shunt current of 240mA (to prevent excessive transient over-voltage due to sudden current drop) to give the LV service chain a viable voltage drop budget.

For the Type-1 LV cables, the original intent was to use copper-clad aluminum wires in order to reduce this dominant contribution of material in radiation length. Out of concern of connect-ability and routing flexibility, the LV lines for each four-FE-I4 group are split into 4xAWG22 for each way of inlet and return. However, the difficulties of crimping Cu-clad Al wires on the very compact AXON μD connector eventually forced the design back to the more robust option of 4xAWG24 Cu wires instead, which has a resistance value very similar to the original 4xAWG22 Cu-clad Al option. The resistance of the round trip path for the group is 0.143Ω, which corresponds to a voltage drop of 0.321V when each FE-I4 is operating at the maximum current of 0.560mA. The discussion of the overall scheme of voltage drop shares at difference stages can be found in *(Ref:LV-budget*). Each half-stave also has an in+return pair of LV sensing wires. All wires used radiation hard polyimide insulation. The LV Hi-sense wire has lower current flow so that AWG28 Cu with QML (quad) insulation is used, while Lo-sense is using the AWG24 Cu wire like the LV lines, with HML (double) insulation. The LV sensing continues towards the stave through the intermediate flex and the EoS connector to terminate on the LV lines on the stave flex. This sensing scheme therefore taps into the LV without connectors in between the final sensing point and the FE-I4. Each LV+sense wire group of (4+4) takes up a 40 pin Panasonic AXT connector on the Cable Board, with the 0.56A nominal current on each AWG24 wire flowing into 4 pins on the AXT connector to be well within the current limit per pin of 0.3A. The Type-1 LV wire group will be a straight bundle without twist due to the lack of space and the rather rigid wires.

1.2.2 *Sensor Bias High Voltage*

The baseline HV supply requirement to accommodate the scenario of heavily irradiated planar sensors needing up to 1 KV of bias high voltage dictates much of the HV service considerations. The minimum spacing required for the HV connection points is the primary implementation issue. One measure to reduce the number of HV connection points is to not having separate HV return wires and just using the LV return as reference trough the stave and Type-1. Because the HV supply at PP2 is separate from the LV crate, the Type-2 cable LV return spider joint includes a separate branch of HV return for PP2. The Type-1 HV distribution is segmented to one AWG32 single copper wire per Four-FE-I4 module, at same modularity as the LV supply. The original design before Mar/2013 used AWG36 twisted pairs for HV and DCS. The use of twisted pairs was mainly for convenience of same type of wires as Cmd/Clk. Out of concern of their fragility when grouped together with other large wires, the wire gauge was increased to AWG32 and using readily available single wires. The connection of the 4 HV feeds per half stave at the EoS and the PP0 cable board are implemented in the same way, with the intermediate flex in between, on one 40 pin Panasonic AXT connector at each location and with pins removed to meet the HV clearance gap, in a similar way. A set of tests was performed for various configurations of pin grouping/removal patterns (see Figure 1-2) to check the breakdown points. The HV breakdown values and connection strengths for the various pin patterns are tabulated in Table 1-1.

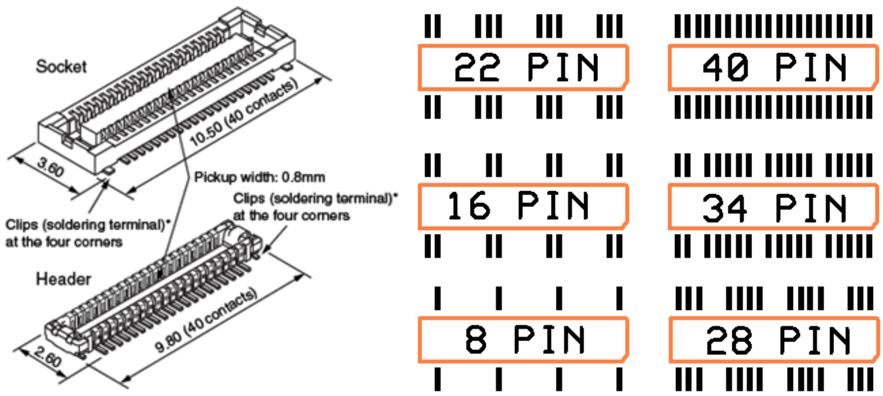


Figure 1-2 AXT 40 pin connector and the various pin grouping/removal patterns for HV tests.

Configuration	HV held (kV)	Assembly force (kg)
8 pin	3.0	0.30
16 pin	3.0	0.45
22 pin	2.5	0.75
28 pin	2.5	1.10
34 pin	1.75	1.20
40 pin	Not tested	1.50

Table 1-1 HV and connection strength tests for various AXT connector pin patterns.

The optimal choice of 28 pin option with 1.2mm gap between groups provides good clearance between HV groups and still a fairly strong snap of the connector force of 1.1kg. Note also that the same HV group spans both sides of the connector because the pins come very close between the two sides near the longitudinal middle axis of the connector.

1.2.3 *Control and Readout Data*

The control and readout signals lines have to route close to the beam pipe at low radius so that there is no viable means for optical transition until beyond PP1. The space limitation and radiation level concerns led to a position for the IBL opto-box at outer radius but inside the ID endplate. This requires a rather long 5.4m electrical transmission between the EoS and opto-box, which is a significant departure from the data transmission scheme of the present pixel system and at a higher data transmission rate of 160Mb/s. The data 8b/10b encoding from the FE-I4 is an important enabling element for this higher transmission rate.

The command and clock lines are one twisted pair of AWG36 copper wires each for a two-FE-I4 module with 1-to-2 multi-drop share between the two FE-I4s in the same module. These thin wires are adequate for the relatively slow 40MHz signals. There is no material savings for going to aluminum wires as they cannot be thinner than AWG30 due to brittleness. The data signal lines are one twisted pair of AWG28 copper wires per FE-I4. The larger wire size here is necessary to ensure the data transmission quality at 160 Mb/s. Out of material concerns, Cu-clad aluminum wires were initially targeted for the data wires. The data transmission tests with tightly sleeved bundles indicated some vulnerability of the Cu-clad Al twisted pairs due to its springiness resulting in difficulties to hold a tight twist so that the sleeve pressure can cause different pairs to mingle into each other, leading to poor spacing uniformity between the wires in a pair. Both control and readout twisted pairs have opted for double quad polyimide insulation to raise the impedance for better match with the stave flex and keeping a tight twist of 4-5 twists/inch for better transmission quality.

1.2.4 *LVDS Common Mode Reference*

Unlike the existing pixel detector with just ~1m long Type-0 cable between the modules and opto-board, the IBL electrical data transmission from EoS to opto-box over >5 meters with a lower LVDS voltage swing. This makes the control of the LVDS CM voltage a significantly more important issue than the present pixel system which let the CM level floating. Four separate CM reference lines from each half-stave, one for each four-FE-I4-module, tap into the LV return line immediately under the module on the stave. These four lines are carried through the Type-1 in the form of two twisted pairs of AWG36 Cu wires following the data/clk/cmd sub-bundle which terminate on the connector board into the opto-box, with the reference lines tied to the opto-board ground.

1.2.5 *DCS Monitoring*

There are total 8 pairs per half stave for DCS formed out of 16 single AWG32 Cu wires. 4 pairs are routed all the way to the NTCs on each Four-FE-I4 module for temperature monitoring. The PP0 cable board has 4 pairs of pads to terminate the remaining 4 DCS pairs for service monitoring:

a) One pair of pads on each PP0 cable board is used to solder an NTC at the end of 2cm long wires. The NTC will be glued onto the cooling pipe joint next to the cable board during the stave-Type1 integration.
b) One pair of pads on each PP0 cable board has NTC mounted on it for temperature of PP0 board itself.
c) Two pairs of pads on each PP0 cable board have difference usages for difference stave. For 2 staves at each end, the two pairs of pads will be used to connect a humidity sensor needing 3 pads. The NTC in b) is immediately next to the humidity sensor or the paired use with the humidity sensor. For staves where these two DCS pairs are not used for humidity sensors, the Type-1 wires will not be connected to the PP0 cable board but terminate near PP1 or in the middle of Type-1 bundle with NTCs to monitor the temperatures of the Type-1 bundle at various locations in the IST.

1.2.6 *PP0 Interface to Stave*

Due to the large temperature range the IBL inner services will be subject to from as low as -40C^{o} for coolants, to the +80 C^{o} when heated during beam pipe bake out. The thermal differential contraction of the Type-1 services within the IST is several mm for this large temperature variation. This can potentially cause dangerous forces on the staves. The Type-1 services need to be fixed to the IST at the PP1 for the volume seal. The introduction of the Intermediate Flexes (IF) with corrugation for the EoS PP0 connection was originally aimed to provide this flexibility at EoS end. This in term required the Type-1 services to terminate on a sliding PP0 board for the connection to intermediate flexes. The integration decision eventually led to a fixed cable board mounting at PP0 on IPT/IST while using relaxed Type-1 placement to absorb most of the thermal differential movements. This will be discussed further in section 1.2.11.

The PP0 cable board layout is shown in Figure 1-3. The stacked concept of the Intermediate Flexes means that the cable board connector order must be a reversed mirror image of the stave flex connector order. The connector orders and spacing are prioritized according to the various considerations:

- The Al LV layers at the bottom of the stave flex are more cleanly terminating at the farthest end of the stave flex without needing the vias to break through the busy signal layers. The LV connections also got the heaviest material to minimize the voltage drop with rather little margin so that placing the LV connectors closest to the gap between the stave and the cable board also helps to allow shorter and more flexible intermediate LV flexes. The cable board LV plane uses 2 oz (71µm) copper for a measured round trip resistance of 0.034Ω for the Four-FE-I4 module, including via effects.
- The Data/Cmd/Clk have sensitive data transmission quality concerns so that shorter intermediate flex lengths are also preferred to reduce the importance of impedance matching in the transition region. However, the soldering pads for this whole sub-bundle group is located at the outer-most end of PP1 cable board away from stave as this sub-bundle will be soldered to the cable board and tested first, while the LV/HV/DCS wires coming later (due to AXON connector production schedule constraint) will run above them to be soldered to the inner pads.

- The overall length is dictated by the beam pipe support wire position in z. This forced the rather tight spacing between AXT connectors of 15.0mm and the quite compact packing of the solder pads.
- The middle gap region is a required clearance to allow better access to the cooling pipe brazing joint in that region without interference with connectors and wire soldering points. This region is now populated with pads for NTCs and humidity sensors.

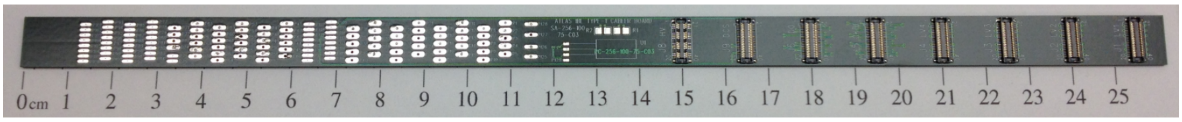


Figure 1-3: Picture of production PP0 cable board. Stave connection from intermediate flexes are coming from the right. Type-1 wire bundles are coming from the left. The board dimensions are 262mm in length and 11.5mm in width.

Due to the difficulty in holding the Intermediate Flex in controlled shape during thermal differential contraction and expansion, the PP0 region is eventually more rigidly constrained by potting the Type-1 cables into Z-stoppers mounted on carbon fiber rings on the IPT ~6 cm beyond the end of the cable board. This prevented the potential risk of cable board unseating from mounting clips due to the movement of heavy Type-1 cables and also allows simple tie-down of cable and flex with lacing cords and less concern on fatigue due of flex travel stressing the ATX connectors. The assembled cable boards after Intermediate Flex connection are shown in *Figure 1-4*.

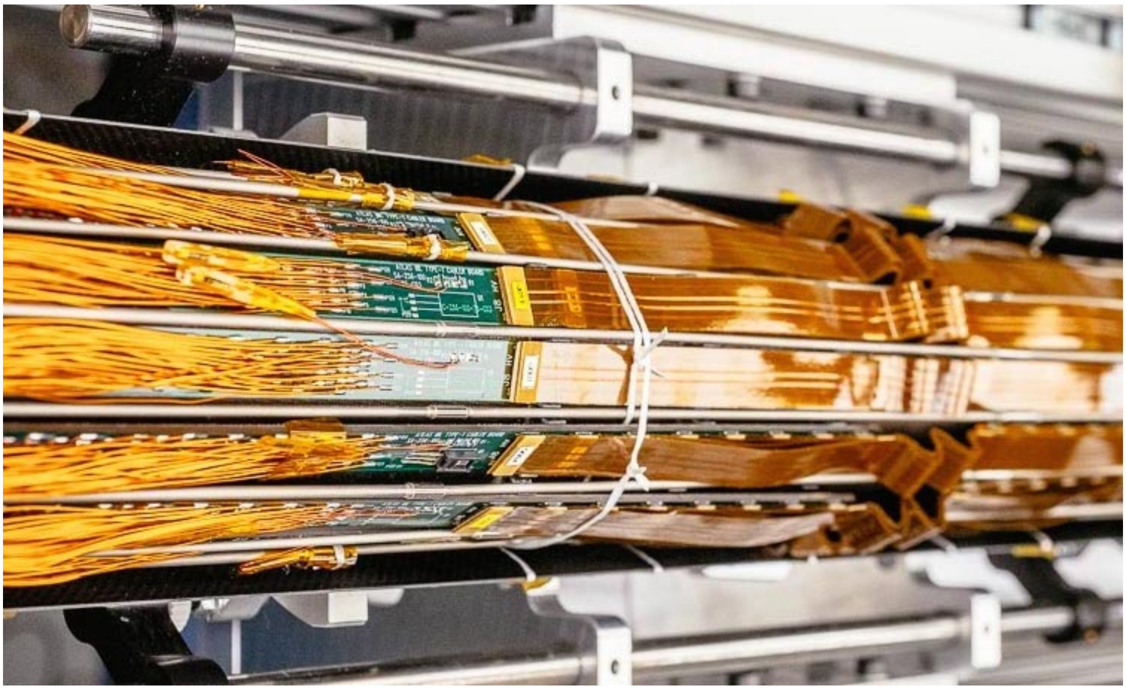


Figure 1-4 PP0 region with fully assembled cable boards and Intermediate Flex connected. The cooling pipe brazing joints at the cable board middle gaps are still visible for the three staves at the front, before NTCs are attached on them.

1.2.7 *Interface to External Services*

Unlike the current pixel detector service quarter panels with packed connections at PP1 transitioning to Type-2 cables, the IBL Type-1 services will not have the necessary space to make the Type-2 transition all within the IBL radius. The PP1 end of the Type-1 services therefore has to first turn onto the ID endplate to route toward larger radii until appropriate locations with opening for Type-2 transitions are available.

For the LV/HV/DCS, there is strong incentive to make the transition to Type-2 cables soon after the exit of PP1 to keep this bulky part of the Type-1 cable short to reduce the burden of packing them for installation with the IBL. The LV/HV/DCS sub-bundle therefore terminates just outside of PP1 for a total length of ~3.6m. Because the Type-1 bundle on one side of the IBL needs to be installed with IBL through the current pixel detector, there must be a packing solution to keep all PP1 connectors within the IST tube for installation. This demands a very densely packed connector (diameter<25mm) with >60 pins. This is unfortunately a packing requirement denser than the most compact on-shelf connectors from e.g. LEMO. The custom AXON 67pin μD connector, as shown in Figure 1-5, with a diameter of 21mm was therefore taken as a baseline, although it was recognized that the choice of custom connectors can been extra cost and long lead time. The thick LV wires can only be packed into every other row in this connector due to the limited space between pins. Due to the lack of space, only very simple form of keying for connector mating is kept which requires significant care and training in the mating procedure to avoid bending pins. The tolerance of the male pin angular position precision was tightened to 1^{o} after the first round prototype to reduce the mating risk. Given that the result of mating incidents are always bent female socket pins, the design would have been less risking if Type-1 end used male type while Type-2 end used the female type since the Type-1 side becomes impossible to replace after installation, before the final mating. Fortunately, there were no mating incidents in final mating to Type-2 after installation.

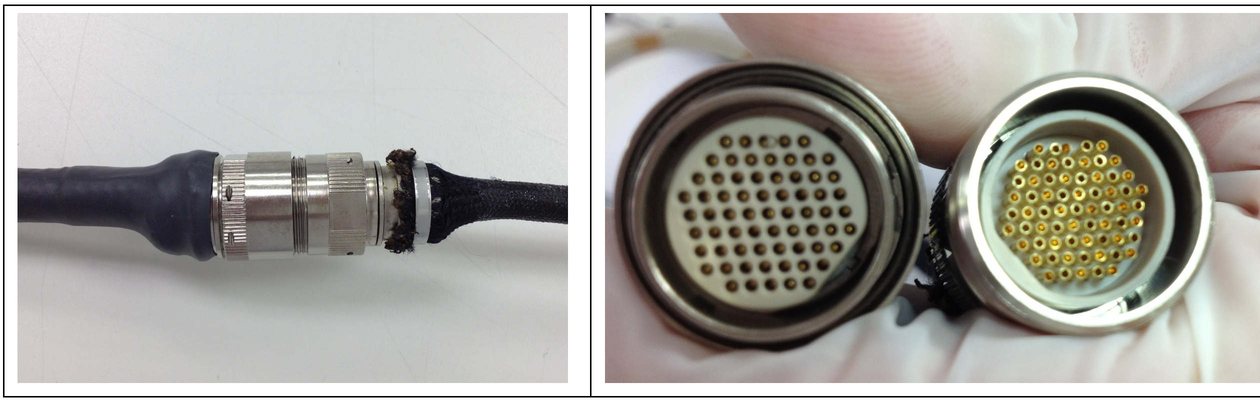


Figure 1-5 67pin μD AXON connector for LV/HV/DCS connection to Type-2 at PP1, with a diameter of 21mm. The left hand photo shows the connected assembly with the Type-1 cable coming from the right. In the right hand photo, the female Type-1 connector is on the right, while the male Type-2 connector with Peek mold is on the left.

The data/cmd/clk signal cable is a single piece from PP0 cable board to the opto-connector board without an intermediate connector given the concern on data transmission quality reduction over connectors and the difficulties in finding satisfactory cost effective connector solutions to meet the tight space requirement. The opto-box is located at the outer radius of ID endplate volume to result in a 5.4m long Type-1 services for the data/cmd/clk sub-bundle. Even though the smaller wires gauges and the closer end point of the data/cmd/clk sub-bundle allows the single piece solution, the opto-end connector still needs to be small for packing within the IST for installation. The Type-1 bundle wires will be soldered to the connector board and protected by a custom SLA connector shell. The high density connector SamTec 100pin connector is used for the connection to the opto-board. The layout of the connector board (*Ref:Connector-Board-PCB*) and the model of the shell are shown in Figure 1-6. The asymmetric shape of the connector board shell is aimed to allow cables to come in from a convenient angle to ease the packing for installation.

1.2.8 *Grounding and Shielding*

The grounding for LV/HV are via the return lines isolated for each four-FE-I4-module group separately all the way to PP2 supply. The Type-1 bundles within the IST volume only have lacing cord to hold the bundle together without braid shielding. The bundle sections outside the PP1 sealing ring are wrapped with thin polyimide film followed by copper braid, and a sleeve on the outside, to better protect the bundle in the more hostile environment of the ID endplate region both electrically and mechanically. For the LV/HV/DCS sub-bundle, a drain wire is implemented through the AXON connector central pin then brought to the bundle other surface to be immediately under the braid. The braid and drain wire of the bundles will terminate at the PP1 sealing ring and clamped together electrically to the common pixel Faraday cage. The DC bonding of the cable shields is preferred choice for IBL which is an added component within the pixel system. The final cable connector shells are also gold plated from inside as part of the EM shielding connected to the cable braid through the contact at the connector neck.

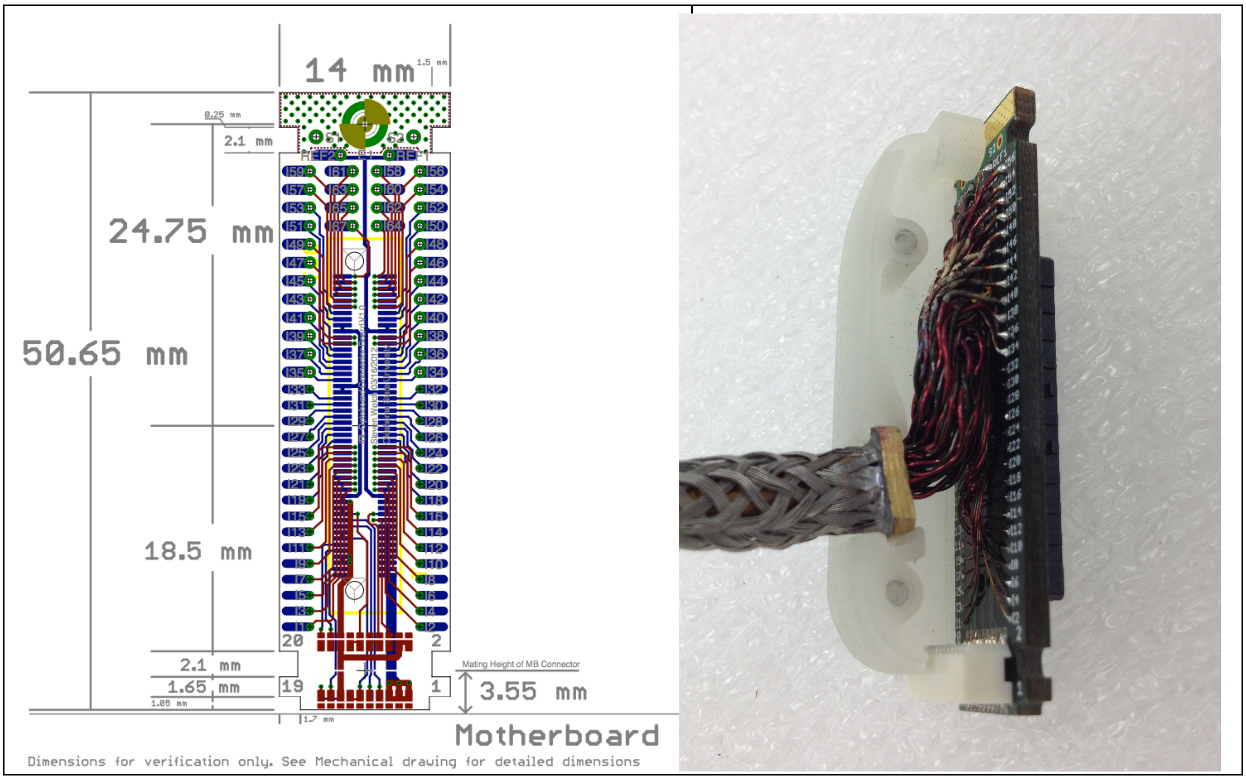


Figure 1-6 Opto-box connector board PCB layout and a connector assembly with shell. Notice the ferrule and nut soldered to the cable braid at the connector neck provide the strain-relief (a la nSQP) for the wires. The wires are also deliberately relaxed into partial loops to avoid direct tension.

1.2.9 *PP1 Sealing*

The Type-1 service path through the PP1 at Z=+-3m ID end plate area need to be sealed to keep the IBL volume inside IST isolated and dry. This is achieved by potting the Type-1 bundles with soft glue (Hysol EA9396 with radiation hardness >1 Grad) injected into a mould to form a smooth and elastic cylinder at PP1 to slot into the soft PP1 sealing rings *(Ref:PP1-sealing-ring)*. The potting is contained within a carbon fiber outer ferrule to both provide a smoother and stronger surface and prevent individual wires splitting off the potting. The CF ferrule is threaded over the bare bundle first and the potting process injects glue into the ferrule. The potting ferrule extends outside the sealing ring to provide a solid support to bond the Type-1 braid of the outer section with conductive epoxy (Epoxies 40-3905). There is an EMI shield clamp ring immediately outside the PP1 sealing ring where the shielding braid of the cable terminate and exposed to a soft conductive ring clamping onto the braid around the potted section of Type-1 bundle for a firm clamp to complete the electrical shield connection. The potting section is 3.9mm long to be safely beyond the combined thickness of PP1 sealing ring and EMI clamp of 3.6mm. The cable braid will wrap onto the potting section under the EMI clamp and bonded to the potting section with conductive epoxy to ensure the firm electrical clamp. The potting scheme is described in *(Ref:PP1-potting)*.

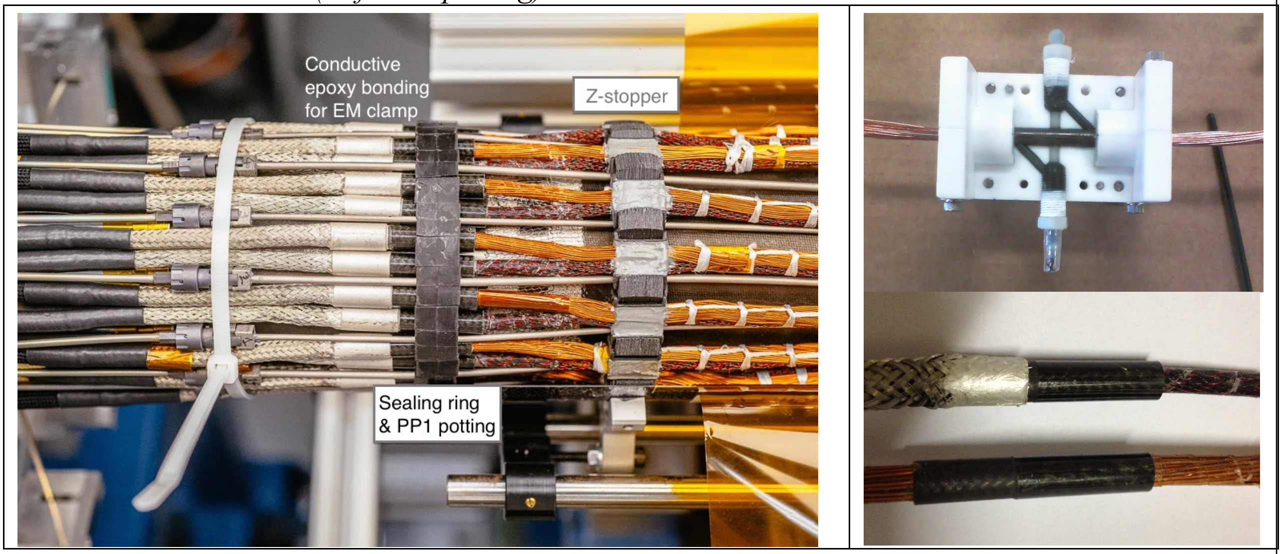


Figure 1-7 Left: PP1 sealing and EM clamp region with potted Type-1 bundles slotted into the sealing rings and cable braid outside PP1terminated with conductive epoxy onto the potting ferrule for the EMI shielding ring to clamp on. Right top: Prototype Type-1 cable potting mould setup. Right bottom: Finished potting before and after the final braid bonding with conductive epoxy.

The bundle diameters turned out to be a very tightly constrained problem. The PP1 sealing ring holes are bound within a 10mm radial gap and at least 1mm of space needs to be left between the holes to allow the braids to wrap onto the potting at the EMI clamp. This space constraint caused a revisit of the wire selection and packing strategy that changed the very thin AWG36 twisted pairs for the LV/HV/DCS bundle into larger AWG32. The original design required these AWG36 wires to be wrapped around the larger wires to avoid breaking under stress. This wrapping turned out to be very costly in the bundle cross section. Going to larger AWG32 wires provides a more straight forward wire strength improvement and allow the wires to be laid straight without wrapping so that the AWG32 wires have a negligible impact on the overall bundle size. The bare wire bundle diameters for the LV/HV/DCS and data/Cmd/Clk bundles are specified as <5.7mm and <4.7mm respectively. The PP1 potting is given 7.0mm outer diameter for the potting tube and injecting glue for seal.

1.2.10 *Installation packaging*

A key challenge of the inner services for IBL is to fit in the smaller envelope of the IST tube not only in the final configuration but also allow a packing scheme to thread all Type-1 services including the connectors from one side through the existing pixel B-layer. This led to the choice of the small custom AXON 67pin μD for LV/HV/DCS and finely tuned connector board shell shape and orientation to allow compact packing. In the scenario of in-situ installation in the cavern, the well packed initial configuration is constrained by the overall IBL package length for lowering into the cavern and turning space bound by the Toroid. This defines and packing volume of 8.3cm diameter and ~60cm long between the beampipe support wire frame and the outer installation spool plate. The installation packaging scheme *(Ref:Type-1-wrapping)* is shown in *Figure 1-8*.

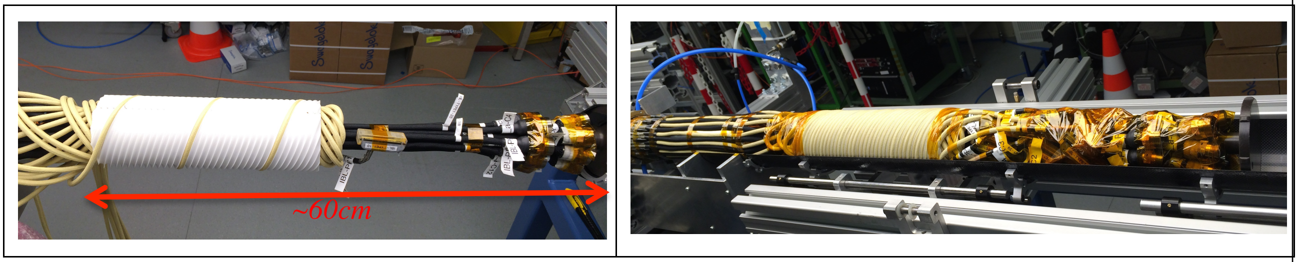


Figure 1-8 Type-1 service wrapping and packing scheme for installation. Left: The data cable winding process at the starting on the first cable of the 3rd winding layer. Right: End of winding and connector packing ready for installation.

The short section of the LV/HV/DCS sub-bundles with AXON connectors are laid straight to the installation mounting end plate. The LV/HV/DCS sub-bundles actually have slightly different lengths between odd and even staves so that the AXON connectors stagger in Z to allow them to fit onto two separate installation plates since they would not fit into a single plate at the same Z location without violating the IBL radial envelope for installation. Due to the tight distance between the two rows, only the short power bundle use the AXON shrink-wrap backside (see *Figure 1-5*) like Type-2 cables while the long power bundles use simple straps for the backside of AXON connector with slightly shorter length. The longer Data/Clk/Cmd cables are wound onto grooved shells wrapped around the installation spool in 3 layers. The need to pack all bundles within the IBL envelope also demands strict control of the bundle diameters in the region just outside PP1. Besides the bare bundle wire selection and packing strategy, the wrapping film/braid/sleeve also need to be made as thin as possible for tightly wrapped bundles. The radial space conflict with the cooling pipe brazing joint and support is one of the main drivers on the bundle size. The data/cmd/clk bundle wrapping groove also requires the fully sleeved bundle diameter to be <6mm with tight and uniform jacketing control.

1.2.11 *Type-1 integration on IPT/IST*

The prototype testing unfortunately revealed that it was very difficult to hold the IF to desired shape and the somewhat stiff LV IF was also a concern for the forces on the delicate AXT connectors during repeated movements while there is no space to implement additional clamp on the AXT connectors. There was a further concern that transverse forces on the Type-1 during the movements can unseat the Type-1 cable board from its mounting clip. This led to the eventual integration decision to fix the Type-1 cable to IPT/IST near the cable board with one of the Z-stoppers, while using relaxed Type-1 placement to absorb most of the thermal differential movements. This introduced a further complication in the Type-1 assembly for the inner section lacing to make sure the region corresponding the to Z-stoppers should have a long straight through lace without round knot.

1.3 Responsibilities and Contacts

Item	Description	Name (Institution)
Type-1 wires	All wires used in Type-1 cables	David Nelson (SLAC/UCSC)
PP0 cable board	PP0 PCB with AXT connecters for intermediate flex and soldering pads for Type-1 wires	David Nelson (SLAC/UCSC)
PP1 AXON connector	PP1 67pin μD AXON connector for LV/HV/DCS	David Nelson (SLAC/UCSC)
Opto-box connector board	PCB to terminate data/cmd cables at opto-box	Steven Welch (Oklahoma State)
Opto-box connector shell	Shell for opto-box connector	Tamer Yildizkaya (LAPP)
Grounding and shielding		Ned Spencer (UCSC)
PP1 cable Potting	Type-1 cable potting at PP1 for sealing	Marco Oriunno (SLAC)
Cable length		Raphael Vuillermet (CERN)
Cable routing	Cable routing from PP1 to Opto-box and PP1 connections with Type-2	Nicolas Massol (LAPP)
Installation wrapping	Cable wrapping or installation	Tamer Yildizkaya (LAPP)
Q/A procedures	Q/A procedures and testing	Philippe Grenier (SLAC)
Commissioning	Commissioning after installation	Martin Kocian (SLAC)
Documentations		Dong Su (SLAC)

1.4 Deliverables

1) Temporary prototypes: 2 prototype bundles of with approximate final lengths and all final components except the AXON connectors (due to the long lead time) for LV/HV/DCS using substitute LEMO connectors to enable system integration tests at SR1 and obtain operational feedback for the final assembly, packaging and testing procedures.

2) Pre-production: 12 complete bundles will be produced with the final lengths and all production components, including the AXON connectors, to aim for essentially production quality. The data/clk/cmd sub-bundle will be subject to extensive tests while waiting for the AXON connector delivery. The full prototypes with LV/HV/DCS sub-bundle after the AXON connector delivery will be only subject to established standard Q/A tests with fast turn around to qualify the AXON connector assembly and trigger the remaining AXON production.

3) Production: 28 production bundles, including PP1 potting, for the full system.

2 Cable Construction

2.1 Overall Bundle Specifications

The overall bundle mechanical layout (Ref:Type1-bundle-spec) is summarized in Figure 2-1. The characteristics of the wires use in the Type-1 bundles are summarized in Table 2-1. Most wires are custom made by MWS Wire Industries due to special polyimide insulation required for radiation hardness and required well-controlled twist for the twisted pairs to maintain uniform impedance. The choice of double quad insulation thickness for some of the wires is primarily to tune the impedance of the twisted pairs to match stave flex signals.

Type	multiplicity (individual wires)	wire type	OD (mm) (wire) nom	insulation nominal thickness	OD - wire + Insulation mimimum (mm)	OD - wire + Insulation nominal (mm)	OD - wire + Insulation maximum (mm)	Length (meter)	Twist	Packing factor	Packing form
LV wire	32	AWG24 Cu	0.511	HML polyimide (28um)	0.554	0.566	0.577	3.5	no	1.27	power bundle
LV sensing Lo	4	AWG24 Cu	0.511	HML polyimide (28um)	0.554	0.566	0.577	3.5	no	1.27	power bundle
LV sensing Hi	4	AWG28 Cu	0.321	2xquad polyimide (84um)	0.472	0.488	0.503	3.5	no	1.27	power bundle
Drain	1	AWG26 Cu	0.405	quad polyimide (47um)	0.478	0.497	0.516	1	no	1.27	power bundle
DCS & Env	16	AWG32 Cu	0.203	quad polyimide (34um)	0.262	0.272	0.279	3.5	no	1.27	single wires
HV	4	AWG32 Cu	0.203	quad polyimide (34um)	0.262	0.272	0.279	3.5	no	1.27	single wires
clk+cmd	32	AWG36 Cu	0.127	2xquad polyimide (46um)	0.203	0.218	0.234	5	4 TPI	2.55	twisted pairs
op-ref	4	AWG36 Cu	0.127	2xquad polyimide (46um)	0.203	0.218	0.234	5	4 TPI	2.55	twisted pairs
Signal Data	32	AWG28 Cu	0.321	2xquad polyimide (84um)	0.472	0.488	0.503	5	5 TPI	2.55	twisted pairs

Bundle	Area (mm^2) wires	diameter (mm) wire bundle
LV/HV/DCS	14.55	4.30
Data/Cmd/Clk	20.14	5.06

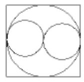
Single wire packing factor	1.27	
Twist pair packing factor	2.55	

Table 2-1 Summary of the characteristics of the wires used in the Type-1 bundles. The bundle cross section area/diameter estimate is for wires only before any wrapping sleeves. Wire lengths are approximate in the table (detailed dimensions are in Figure 2-1).

The drain wire is only laid along the short section of the LV/HV/DCS sub-bundle outside the PP1 sealing point.The section of the LV/HV/DCS sub-bundle outside the PP1 sealing region are wrapped with a 12μm polyimide foil followed by the Axotress tin-plated Cu braid for shielding and an outer-most Nomex braided sleeve. The section of the Data/Cmd/Clk sub-bundle outside PP1 has a similar packaging, with a 12μm thick kapton film (CAPLIN PIT0.5N/25.4) inner wrapping (this differs from nSQP where mylar films were used and we found the radiation hardness of mylar is questionable for the IBL radius), copper braid (Alpha Wire #2140, with 160 μm diameter wires and 6mm diameter tube size) and a Kevlar (K-flex KEV0.25, 265μm thickness) outer sleeve. The Kevlar sleeve has less splinter for a smoother surface to slide easily for the complex ID-endplate routing. These wrapping material choice are all aiming at thinnest options as the fully jacketed bundle sizes have very tight constraints to fit into the installation space outside PP1. The inner section lacing will be done with lacing cord TECHLACE NOMEX lacing tape A-A-52084.

The detailed wire list and connector pin assignments are tabulated in **Table 2-4** and Table 2-5. Note that the unified service names apply throughout the service chain from the stave to PP2 and symmetric between A and C side. However, the service channels names map to different module locations between the A and C side (see stave flex documentation (*Ref:Stave-Flex*) for details).

The dimensions of the Type-1 bundles are shown in Figure 2-1. The mechanical tolerance specifications were settled at a rather late stage of design largely driven by the realization that the Intermediate Flex connecting the stave and cable board is too difficult to realize with the desired flexibility. With the support system for the stave, cables and PP1 all mounted on the Inner Pixel Tube (IPT) made of carbon fiber, the differential thermal expansion/contraction between the

Type-1 cables and the IPT support can build up to ±4mm for the expected temperature excursion of ±60°C from room temperature during beam pipe bake out and normal cold operation. A longitudinal slack of a few mm unfortunately translates to several cm of transverse deflection which must be carefully managed within the narrow IBL volume. A set of 5 Z-stoppers located at the support rings will be potted on the inner section of Type-1 at high precision to give each section between the Z-stoppers ~1mm slack which translates to an initial transverse wave amplitude of ~18mm at room temperature. This sets a challenging length tolerance spec of ±5mm for the ~2.5m inner section between the cable board and the PP1 sealing section. The potting ferrule has a ±5mm longitudinal adjustment wrt the sealing ring to absorb this tolerance. There was also some initial concerns in lacing together the entire bundle with a mixture of aluminium and copper wires for CTE stress on thinner wires. A thermal mock test showed bundle movement during temperature change but no wire breakage due to lacing constraint. The LV/HV/DCS sub-bundles will have different bundle lengths to stagger them by 4cm in Z as all AXON connector packed at the same Z location will exceed the IBL radial envelope for installation. The length tolerance on the outer section of 920/960mm for the LV/HV/DCS sub-bundle from PP1 to the AXON connector neck is also ±5mm to ensure the packing form for installation. The outer section of ~2.45m for the data sub-bundle between PP1 and the opto-connector has a tolerance of ±20mm. The installation winding spool (Figure 1-8) has a turning junction between two winding layers which can take up this tolerance.

For the variations of bundles types due the 2 different lengths of LV/HV/DCS sub-bundle for installation packing, and the different usage of the last two DCS channels for different bundles, the specification differences are summarize in Table 2-1:

Type	LV/HV/DCS Bundle Length	Sensor type / location	Staves
1	short	Humidity	2,12
2	long	Humidity	5,9
3	short	NTC at Z=100cm	4,6,8,10,14
4	long	NTC at Z=250cm	1,3,7,11,13

Table 2-2 Type-1 bundle types depending on the bundle length and DCS measurement types. The variations follow the stave numbers for both A and C sides in the same way.

The variations of DCH channel assignments and the sensor details are summarized in Table 2-3.

Channel	Bundle Type	Sensor	Sensor spec
DCS_5	All	NTC (Cable Board)	Panasonic ERT-JOEG103FA (0402 package)
DCS_6	All	NTC (Cooling pipe)	Semitec 103-JT-025
DCS_7,8	1-2	Humidity	Honeywell HIH4000
DCS_8	3-4	NTC (Bundle)	Semitec 103-AT-2

Table 2-3 DCS channels assignments and sensor specs.

Note that the NTCs selected are of different types because of the different mounting requirements. The cable board NTC is a surface mount while the others are to be soldered to the end of wires. The cooling pipe NTC needs to be very thin and small in size to fit onto the surface of the cooling pipe, while the NTC for the mid-bundle positions need to be more robust.

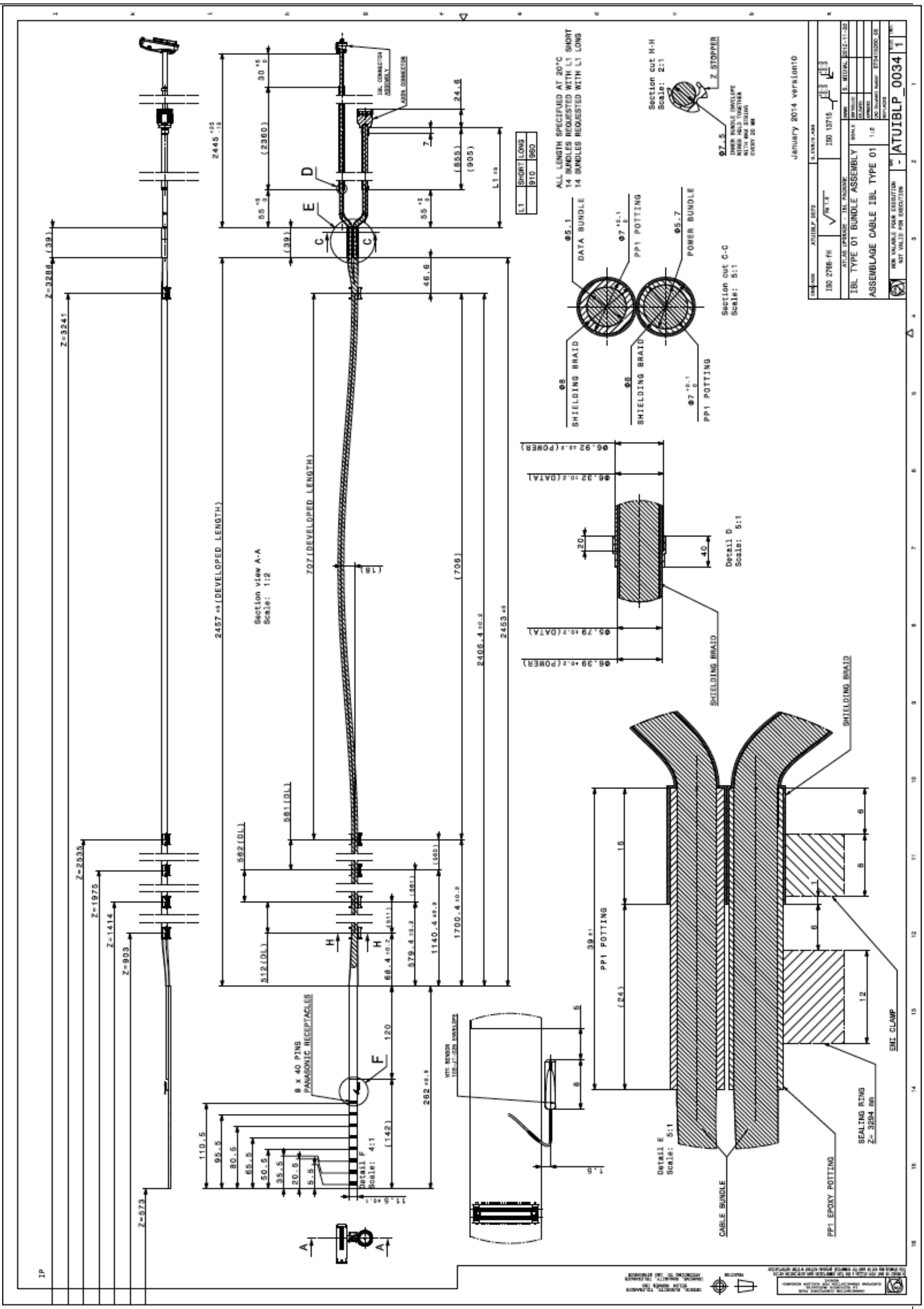


Figure 2-1 Type-1 harness general mechanical specifications (ATUIBLP_0034).

AXON 67 PIN µD FEMAL	SIGNAL NAME	WIRE TYPE	CABLE BOARD
11	VCC_RET_1_1	24AWG_CU	P1
12	VCC_RET_1_2	24AWG_CU	P2
13	VCC_RET_1_3	24AWG_CU	P6
14	VCC_RET_1_4	24AWG_CU	P7
31	VCC_SENSE_1	28AWG_CU	P8
1	VCC_1_1	24AWG_CU	P4
2	VCC_1_2	24AWG_CU	P5
3	VCC_1_3	24AWG_CU	P9
4	VCC_1_4	24AWG_CU	P10
10	VCC_SENSE_RET_1	24AWG_CU	P3
27	VCC_RET_2_1	24AWG_CU	P11
28	VCC_RET_2_2	24AWG_CU	P12
29	VCC_RET_2_3	24AWG_CU	P16
30	VCC_RET_2_4	24AWG_CU	P17
33	VCC_SENSE_2	28AWG_CU	P18
23	VCC_2_1	24AWG_CU	P14
24	VCC_2_2	24AWG_CU	P15
25	VCC_2_3	24AWG_CU	P19
26	VCC_2_4	24AWG_CU	P20
15	VCC_SENSE_RET_2	24AWG_CU	P13
42	VCC_RET_3_1	24AWG_CU	P21
43	VCC_RET_3_2	24AWG_CU	P22
44	VCC_RET_3_3	24AWG_CU	P26
45	VCC_RET_3_4	24AWG_CU	P27
35	VCC_SENSE_3	28AWG_CU	P28
38	VCC_3_1	24AWG_CU	P24
39	VCC_3_2	24AWG_CU	P25
40	VCC_3_3	24AWG_CU	P29
41	VCC_3_4	24AWG_CU	P30
53	VCC_SENSE_RET_3	24AWG_CU	P23
64	VCC_RET_4_1	24AWG_CU	P31
65	VCC_RET_4_2	24AWG_CU	P32
66	VCC_RET_4_3	24AWG_CU	P36
67	VCC_RET_4_4	24AWG_CU	P37
37	VCC_SENSE_4	28AWG_CU	P38
54	VCC_4_1	24AWG_CU	P34
55	VCC_4_2	24AWG_CU	P35
56	VCC_4_3	24AWG_CU	P39
57	VCC_4_4	24AWG_CU	P40
58	VCC_SENSE_RET_4	24AWG_CU	P33
5	HV_1	32AWG_CU	P125
6	HV_2	32AWG_CU	P126
7	HV_3	32AWG_CU	P127
8	HV_4	32AWG_CU	P128
16	NTC_N_1	32AWG_CU	P109
17	NTC_P_1	32AWG_CU	P110
18	NTC_N_2	32AWG_CU	P111
19	NTC_P_2	32AWG_CU	P112
20	NTC_N_3	32AWG_CU	P113
21	NTC_P_3	32AWG_CU	P114
9	NTC_N_4	32AWG_CU	P115
22	NTC_P_4	32AWG_CU	P116
46	DCS_N_5	32AWG_CU	P117
59	DCS_P_5	32AWG_CU	P118
47	DCS_N_6	32AWG_CU	P119
48	DCS_P_6	32AWG_CU	P120
49	DCS_N_7	32AWG_CU	P123
50	DCS_P_7	32AWG_CU	P124
51	DCS_N_8	32AWG_CU	P121
52	DCS_P_8	32AWG_CU	P122
32	Free		
34	Drain		
36	Free		
60	Free		
61	Free		
62	Free		
63	Free		

Table 2-4 Type-1 cable wires and connector pin assignments for LV/HV/DCS sub-bundle.

SIGNAL NAME	OPTO-BOARD SAMTEC	CONNECTOR BOARD PADS	CABLE BOARD PADS	WIRE TYPE
DO_N_16	67	I36	P41	28AWG_CU_TP_GRN
DO_P_16	65	I34	P42	28AWG_CU_TP_RED
DO_N_15	68	I37	P43	28AWG_CU_TP_GRN
DO_P_15	66	I35	P44	28AWG_CU_TP_RED
DO_N_14	71	I40	P45	28AWG_CU_TP_GRN
DO_P_14	69	I38	P46	28AWG_CU_TP_RED
DO_N_13	72	I41	P47	28AWG_CU_TP_GRN
DO_P_13	70	I39	P48	28AWG_CU_TP_RED
DO_N_12	75	I44	P49	28AWG_CU_TP_GRN
DO_P_12	73	I42	P50	28AWG_CU_TP_RED
DO_N_11	76	I45	P51	28AWG_CU_TP_GRN
DO_P_11	74	I43	P52	28AWG_CU_TP_RED
DO_N_10	79	I48	P53	28AWG_CU_TP_GRN
DO_P_10	77	I46	P54	28AWG_CU_TP_RED
DO_N_9	80	I49	P55	28AWG_CU_TP_GRN
DO_P_9	78	I47	P56	28AWG_CU_TP_RED
DO_N_8	87	I52	P57	28AWG_CU_TP_GRN
DO_P_8	85	I50	P58	28AWG_CU_TP_RED
DO_N_7	88	I53	P59	28AWG_CU_TP_GRN
DO_P_7	86	I51	P60	28AWG_CU_TP_RED
DO_N_6	91	I56	P61	28AWG_CU_TP_GRN
DO_P_6	89	I54	P62	28AWG_CU_TP_RED
DO_N_5	92	I59	P63	28AWG_CU_TP_GRN
DO_P_5	90	I57	P64	28AWG_CU_TP_RED
DO_N_4	95	I60	P65	28AWG_CU_TP_GRN
DO_P_4	93	I58	P66	28AWG_CU_TP_RED
DO_N_3	96	I63	P67	28AWG_CU_TP_GRN
DO_P_3	94	I61	P68	28AWG_CU_TP_RED
DO_N_2	99	I64	P69	28AWG_CU_TP_GRN
DO_P_2	97	I62	P70	28AWG_CU_TP_RED
DO_N_1	100	I67	P71	28AWG_CU_TP_GRN
DO_P_1	98	I65	P72	28AWG_CU_TP_RED
LVDS_REF_2	61		P73	36AWG_CU_TP_RED
LVDS_REF_2	63		P74	36AWG_CU_TP_GRN
DI_P_15_16	29	I2	P75	36AWG_CU_TP_RED
DI_N_15_16	31	I4	P76	36AWG_CU_TP_GRN
CK_P_15_16	30	I1	P77	36AWG_CU_TP_RED
CK_N_15_16	32	I3	P78	36AWG_CU_TP_GRN
DI_P_13_14	33	I6	P79	36AWG_CU_TP_RED
DI_N_13_14	35	I8	P80	36AWG_CU_TP_GRN
CK_P_13_14	34	I5	P81	36AWG_CU_TP_RED
CK_N_13_14	36	I7	P82	36AWG_CU_TP_GRN
DI_P_11_12	37	I10	P83	36AWG_CU_TP_RED
DI_N_11_12	39	I12	P84	36AWG_CU_TP_GRN
CK_P_11_12	38	I9	P85	36AWG_CU_TP_RED
CK_N_11_12	40	I11	P86	36AWG_CU_TP_GRN
DI_P_9_10	41	I14	P87	36AWG_CU_TP_RED
DI_N_9_10	43	I16	P88	36AWG_CU_TP_GRN
CK_P_9_10	42	I13	P89	36AWG_CU_TP_RED
CK_N_9_10	44	I15	P90	36AWG_CU_TP_GRN
DI_P_7_8	45	I18	P91	36AWG_CU_TP_RED
DI_N_7_8	47	I20	P92	36AWG_CU_TP_GRN
CK_P_7_8	46	I19	P93	36AWG_CU_TP_RED
CK_N_7_8	48	I21	P94	36AWG_CU_TP_GRN
DI_P_5_6	49	I22	P95	36AWG_CU_TP_RED
DI_N_5_6	51	I24	P96	36AWG_CU_TP_GRN
CK_P_5_6	50	I23	P97	36AWG_CU_TP_RED
CK_N_5_6	52	I25	P98	36AWG_CU_TP_GRN
DI_P_3_4	53	I26	P99	36AWG_CU_TP_RED
DI_N_3_4	55	I28	P100	36AWG_CU_TP_GRN
CK_P_3_4	54	I27	P101	36AWG_CU_TP_RED
CK_N_3_4	56	I29	P102	36AWG_CU_TP_GRN
DI_P_1_2	57	I30	P103	36AWG_CU_TP_RED
DI_N_1_2	59	I32	P104	36AWG_CU_TP_GRN
CK_P_1_2	58	I31	P105	36AWG_CU_TP_RED
CK_N_1_2	60	I33	P106	36AWG_CU_TP_GRN
LVDS_REF_1	81		P107	36AWG_CU_TP_RED
LVDS_REF_1	83		P108	36AWG_CU_TP_GRN

Table 2-5 Type-1 cable wires and connector pin assignments for Data/Cmd/Clk sub-bundle.

2.2 Connectors

2.2.1 *PP0 Cable Board*

The PP0 cable board schematic is shown in Figure 2-3. The Panasonic ATX connectors used on the cable board are 40pin AXT540124 with 0.4mm pitch. The connector mould is made of radiation hard Liquid Crystal Polymer resin. The cable board PCB material is polyimide with polyimide ISOLA P96 epoxy and AKAFLEX KDF 0/25/25 HT bottom coverlay. LV connector pins are ganged to ensure the current through each pin is well under the spec of 0.3A/pin. HV connector with unused pins pulled out was tested to be able to hold 2.5V. The cable board PCB is fabricated by Vector Fabrication Inc. The Cable Board pad assignments are sown in the layout of the pad section in Figure 2-2.

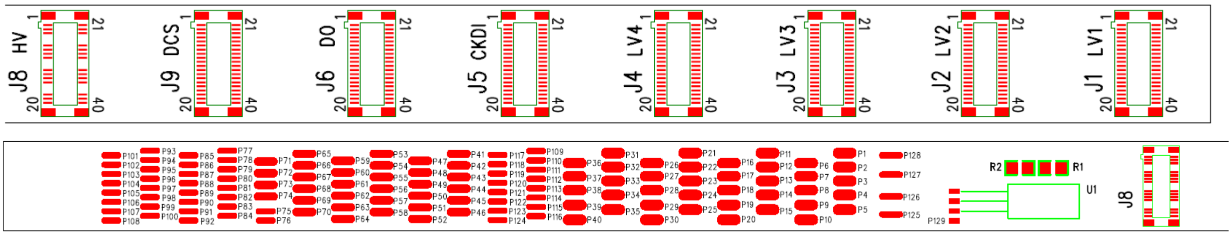


Figure 2-2 Cable Board connector and pad section layout and pad number assignments.

2.2.2 *Opto-box Connector Board*

The schematics (*Ref:Connector-board-schematics*) of the connector board is shown in Figure 2-4. The PCB fabrication is at the CERN PCB shop. The high density SamTec 100pin LSHM-150 connector is used for the connection to the opto-board. The LVDS common mode reference lines with two twisted pairs will be connected to the REF1 and REF2 points respectively with two wires from the same pair merged into one point. The connector shell is special custom SLA design to give a profile and orientation that can ease the packing for installation, and provide strain relief. The connector shells will also have a gold spray coating as EMI shield.

2.2.3 *AXON connector*

The AXON 67 pin μD connector is a custom made solution for the LV/HV/DCS connections near PP1 with the installation constraint demanding a connector of minimal size. The AXON connector assembly drawing is shown in Figure 2-5. The connector and wire connections to it will be a packaged delivery from AXON with an internal Q/A. A pigtail representing the Type-2 side of the connection will be part of the order to allow our own tests. The pin assignments and signal mapping is shown in Figure 2-6. Note the large wires with AWG24/AWG28 sizes are assigned to alternating rows to make the connection density manageable. The LV/HV/DCS wires are single AWG32 Cu without twist.

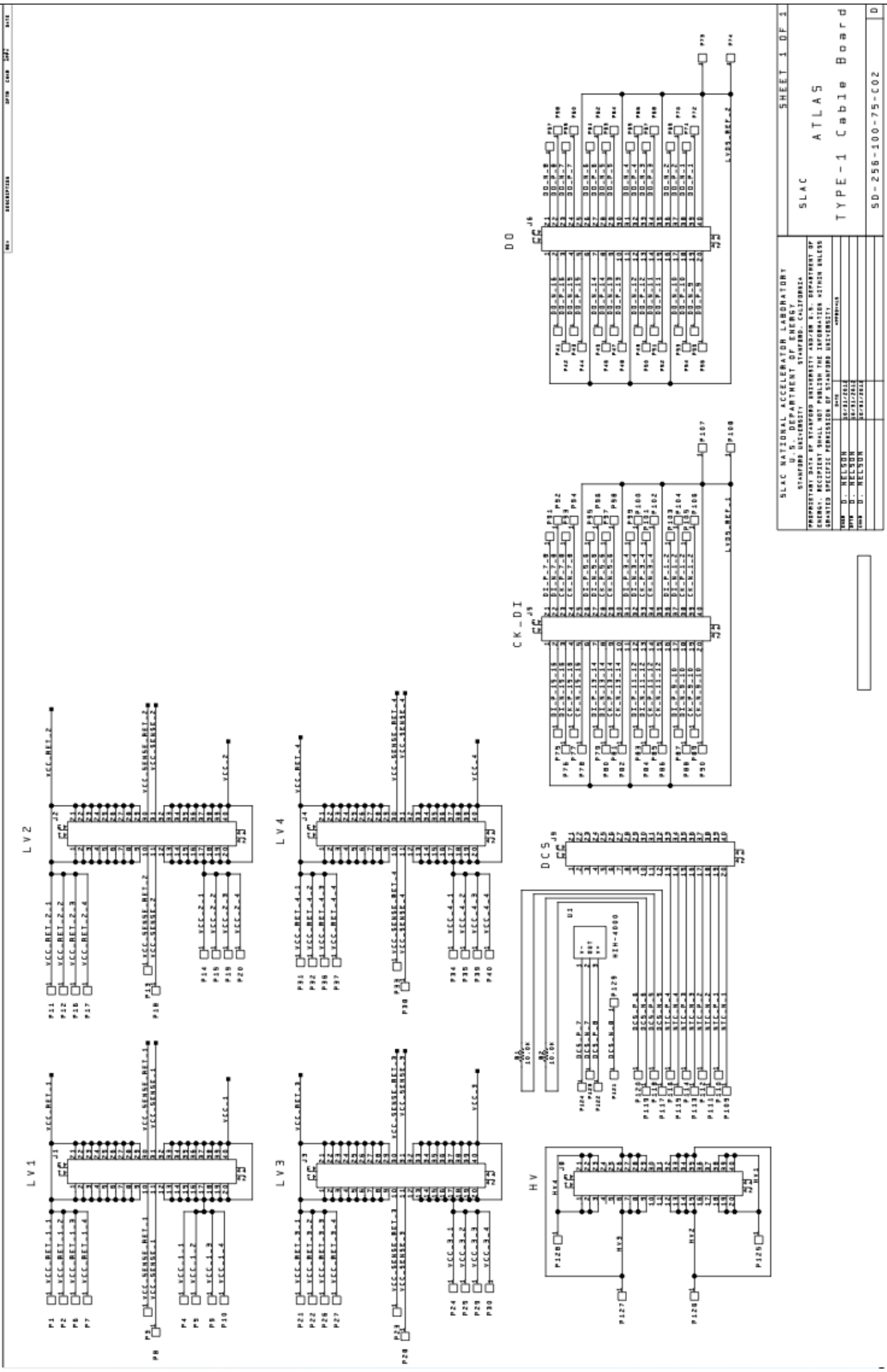


Figure 2-3 PP0 cable board schematics.

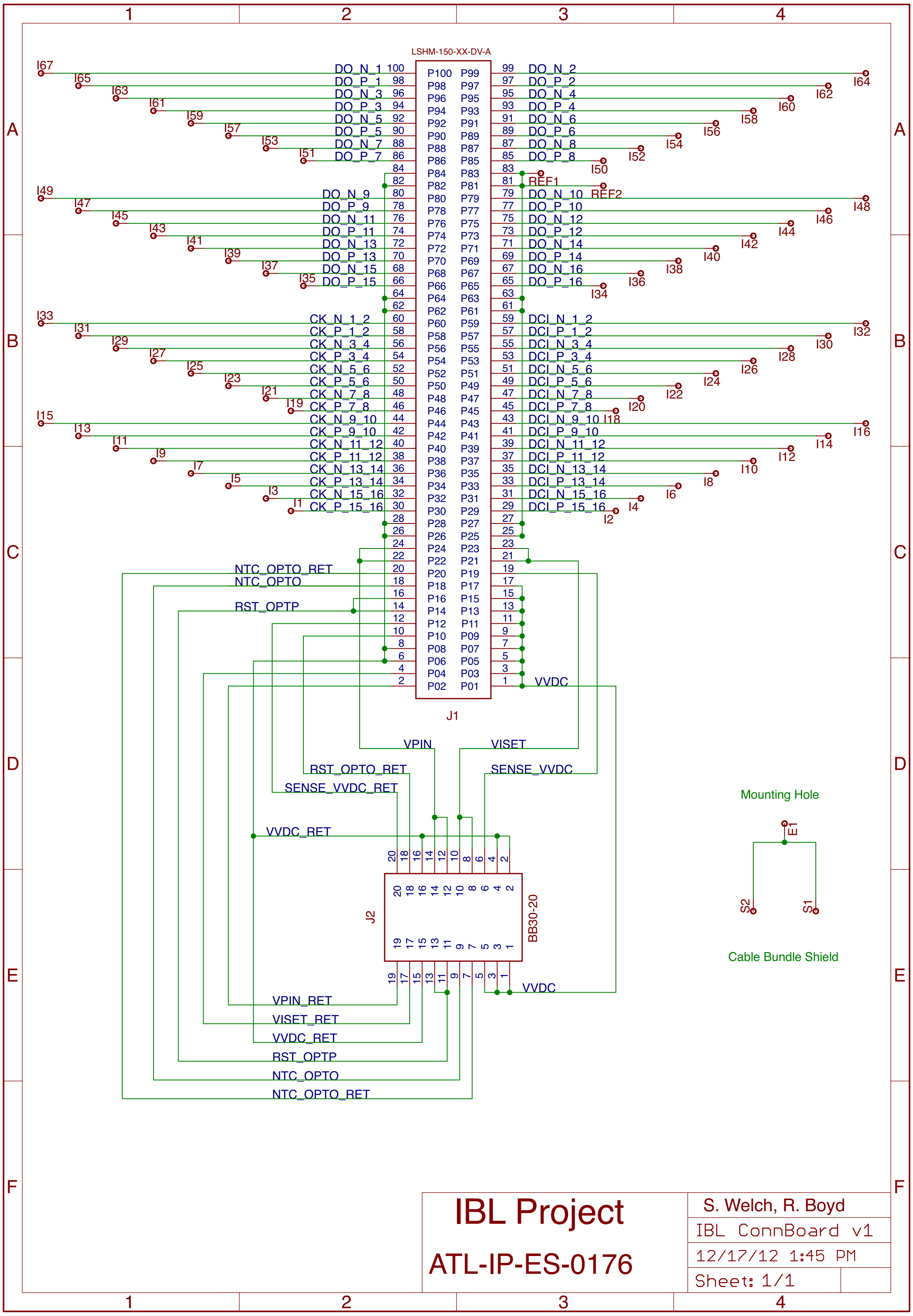


Figure 2-4 Opto-box connector board schematics.

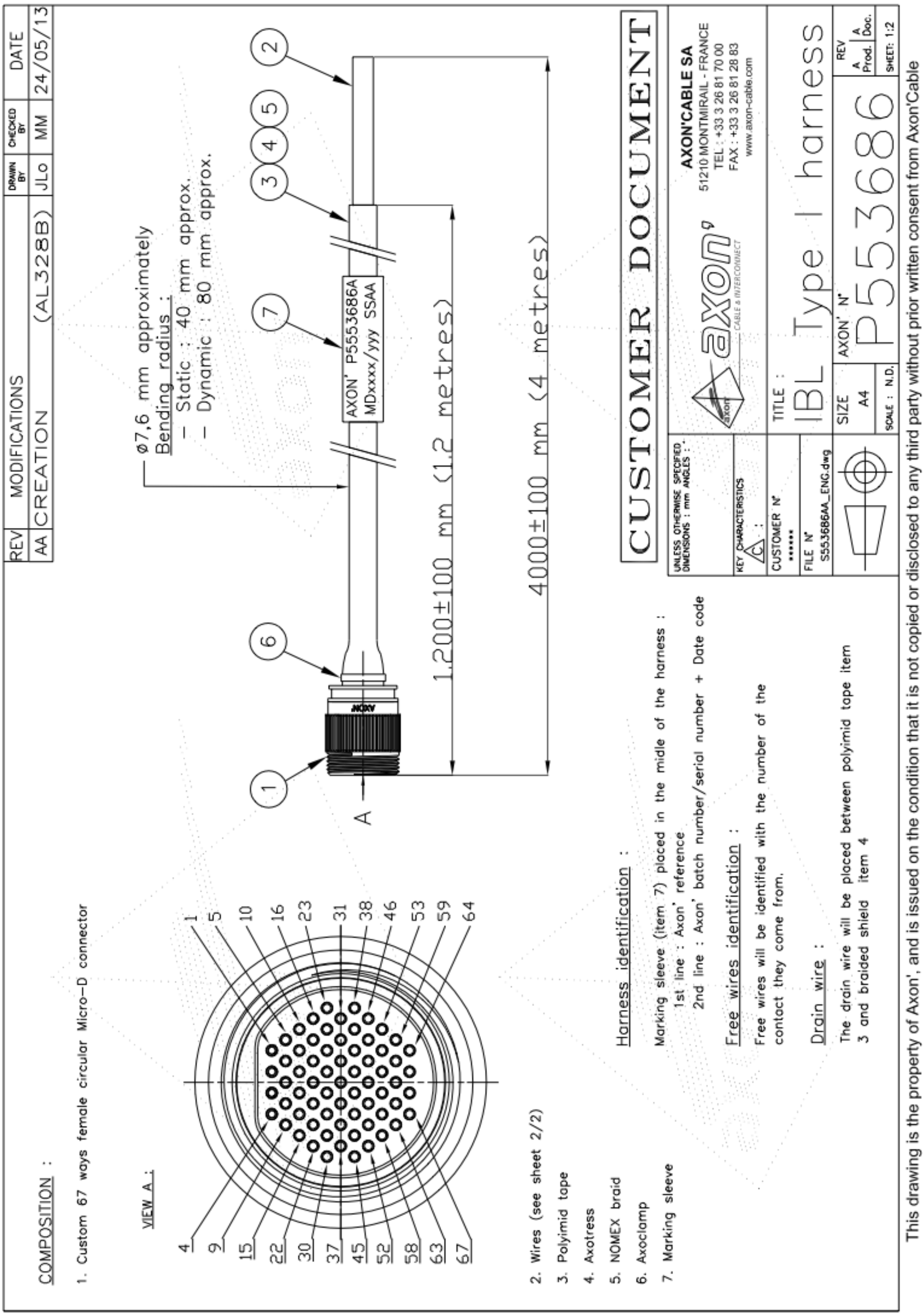


Figure 2-5 AXON connector and cable hardness description.

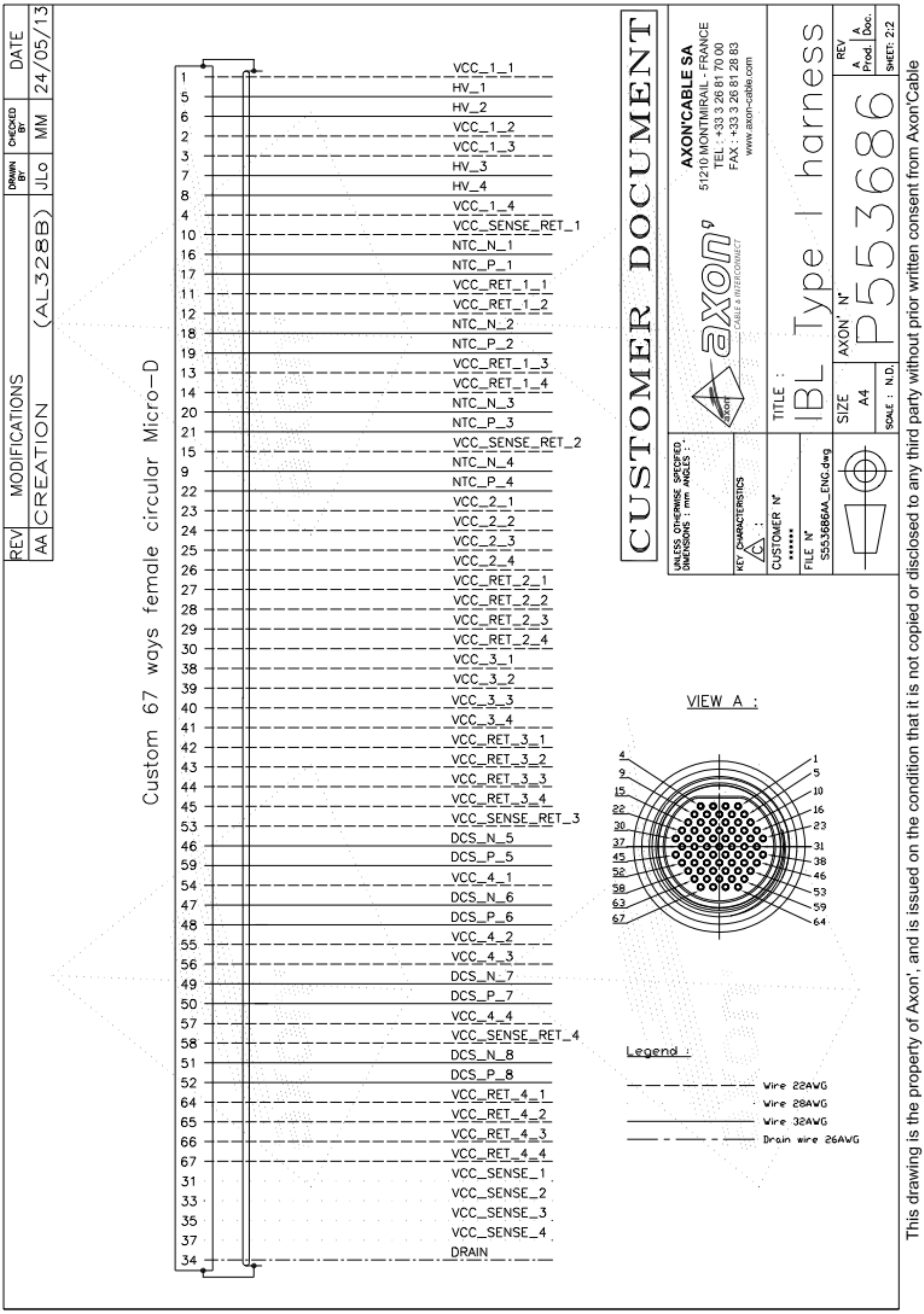


Figure 2-6 AXON connector pin assignments and wire subgroups.

3 Assembly Procedure

Due to the two sub-bundle structure and connectors from different sources at different times, the bundle assembly needs to follow a topologically viable sequence and still enable as much as parallel operations as possible. The major steps (many minor preparation steps are omitted for this document but their sequence are crucial) of the envisaged sequence (all steps at SLAC assembly site except step 1):

1. AXON assembly of LV/HV/DCS bundle PP1 end, including braid and Nomex sleeve. Internal Q/A. Apply kapton film wrapping, braid and Kevlar sleeve to the outer section of the data/cmd/clk sub-bundle.
2. Wind data sub-bundle wire loops on template poles to make initial bundle to length.
3. Apply 3-layer jacketing of kapton/braid/kevlar with uniform/tight dimension control.
4. Solder connector boards on data/cmd/clk sub-bundle wires and assemble connector shells.
5. Solder data/cmd/clk sub-bundle wires to the cable board at PP0 end.
6. Conduct electrical data transmission Q/A to the assembled data/cmd/clk sub-bundle.
7. Reception test of AXON LV/HV/DCS sub-bundles and redressing preparation.
8. Full bundle integration starts with firstly selecting bundle type (LV/DCS variations).
9. Solder the PP0 end of the LV/HV/DCS sub-bundle (with the PP1 end already assembled at AXON) to the cable board.
10. Q/A on the LV/HV/DCS section of assembled full bundle.
11. Apply lacing cord to inner section from Eos-PP1of the full bundle.
12. Perform PP1 feed-through epoxy potting and attach braid with conductive epoxy fro both sub-bundles together.
13. Thermal cycle the fully assembled bundle.
14. Final full Q/A process.

Steps 2-6 are independent of the AXON connector and LV/HV/DCS sub-bundle so that they will in fact be executed in parallel to the AXON connector production and being ready for full bundle integration before the AXON connecters are delivered to minimize the assembly and tests needed after the long AXON connector delivery with a long lead time. A more detailed assembly procedure is separately documented at (*Ref:Type1-assembly*).

4 Quality Assurance Procedures

All bundles will have automated connectivity and resistivity tests. Additional precision resistivity tests are done for the LV wires and connections. The main Q/A procedure for the data/cmd/clk sub-bundle will include channel-by-channel transmission eye-diagram scope checks. A full blown Bit Error Test (BER) test setup is already established which will be run on each channel for 10^{-10} level error checks with other channels in the same bundle producing asynchronous cross talk noise. Q/A also includes a final length check. The Q/A procedures will be documented in a separate note (*Ref:Type1-QA*).

5 References (Ref:Connector-Board-PCB)

- *Ref:Connector-Board-PCB*, IBL connector board PCB layout (ATL-IP-ES-0177). <https://edms.cern.ch/document/1159015/>.
- *Ref:Connector-board-schematics*, IBL connector board schematics (ATU-IP-ES-0176). <https://edms.cern.ch/document/1159014>.
- *Ref:Intermediate-Flex*, IBL Intermediate Flex (Schematic:ATU-SYS-ED-0034, PCB:ATU-SYS-ES-0012). <https://edms.cern.ch/document/1169179, https://edms.cern.ch/document/1177768>.

- *Ref:LV-budget*, Low Voltage budget specification (IBL sharePoint). <https://espace.cern.ch/atlas-ibl/OffDecWG/Shared%20Documents/Forms/AllItems.aspx?RootFolder=%2Fatlas%2Dibl%2FOffDecWG%2FShared%20Documents%2FServices>.
- *Ref:Panasonic-AXT*, Panasonic F4S series AXT connector. <http://www.panasonic-electric-works.es/catalogues/downloads/connectors/ds_65312_en_f4s.pdf>.
- *Ref:PP1-potting*, Description of Type-1 PP1 cable potting (IBLCM Type1-signoff talk). <https://indico.cern.ch/materialDisplay.py?contribId=3&materialId=slides&confId=222273>.
- *Ref:PP1-sealing-ring*, PP1 sealing ring and EMI clamp. (IBLGM talk). <https://indico.cern.ch/materialDisplay.py?contribId=28&sessionId=3&materialId=slides&confId=176693 >.
- *Ref:Service-diagram*, IBL overall service block diagram. <https://login.cern.ch/adfs/ls/?wa=wsignin1.0&wtrealm=https%3a%2f%2fespace.cern.ch%2f_trust%2f&wctx=https%3a%2f%2fespace.cern.ch%2fatlas-ibl%2fOffDecWG%2f_layouts%2fAuthenticate.aspx%3fSource%3d%252Fatlas%252Dibl%252FOffDecWG%252FShared%2520Documents%252FServices%252FIBL%255FBlockdiagram%252Epdf>.
- *Ref:Stave-Flex*, IBL Stave Flex, Type-0 services (ATU-SYS-EN-0005). <https://edms.cern.ch/document/1229722/>.
- *Ref:Type1-assembly*, Type-1 bundle assembly procedure (to be drafted).
- *Ref:Type1-bundle-spec*, Type-1 bundle overall mechanical specification (ATUIBLP_0034). <https://edms.cern.ch/document/1211809>.
- *Ref:Type1-QA*, Type-1 production Q/A pocedure (ATU-SYS-QA-0001).
- *Ref:Type-1-wrapping*, Type-1 cable wrapping for installation (IBLGM talk). <https://indico.cern.ch/getFile.py/access?contribId=33&sessionId=3&resId=1&materialId=slides&confId=176693>.
- *Ref:Type2-EDMS*, Type-2 services (ATU-SYS-CD-007). <https://edms.cern.ch/document/1203554/>.