	# IBL Type 1 Services Documentation

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IBL Type 1 Services Documentation

Abstract

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

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Distribution List

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History of Changes

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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	2013-04-22		Updated AXON drawing and minor changes.

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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 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 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.

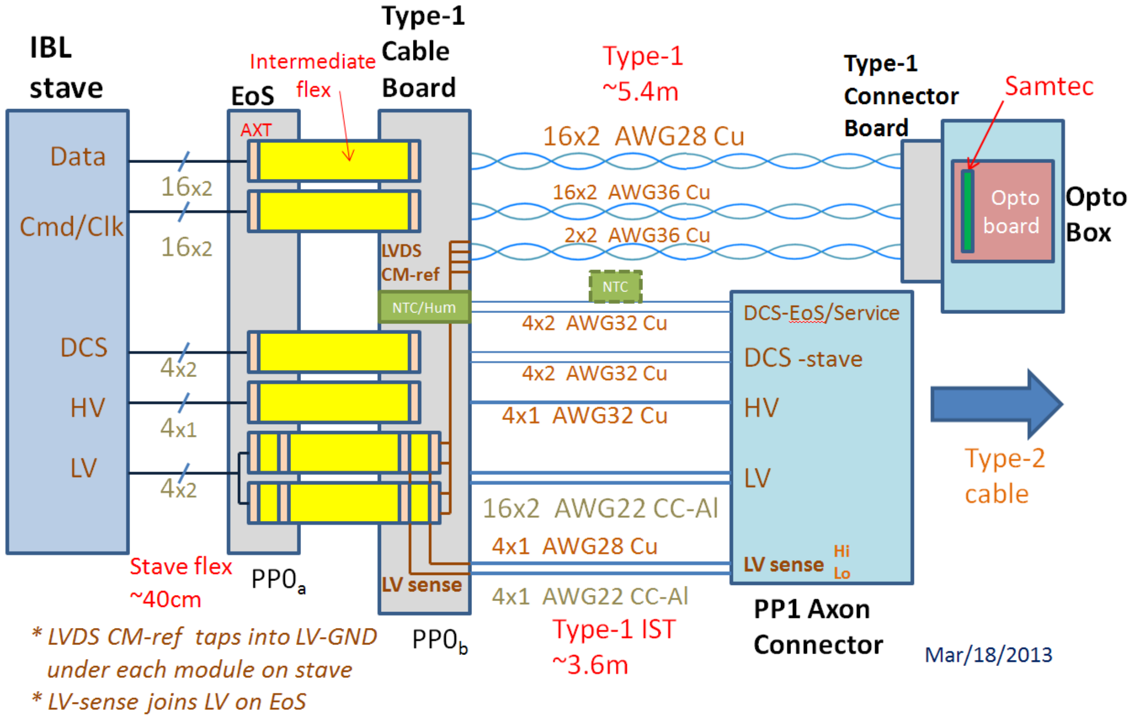


Figure 1-1 Block diagram of the Type-1 service scheme. There are some variations from stave to stave for DCS-EoS/Service with some staves having a humidity sensor on Cable Board and others having an NTC along bundle.

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, copper-clad aluminum wires are used to reduce this dominant contribution of material in radiation length. Copper wires would be more compact and mechanically robust, but it takes a factor of ~2 in material radiation length to accomplish the same resistance. 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. The resistance of the round trip path for the group is 0.138Ω, which corresponds to a voltage drop of 0.309V 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. The LV Hi-sense wire has lower current flow so that AWG28 Cu is used, while Lo-sense is using the AWG22 Cu-clad Al wire also. 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. The LV and sense wires all have radiation hard quad polyimide insulation. 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 AWG22 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.

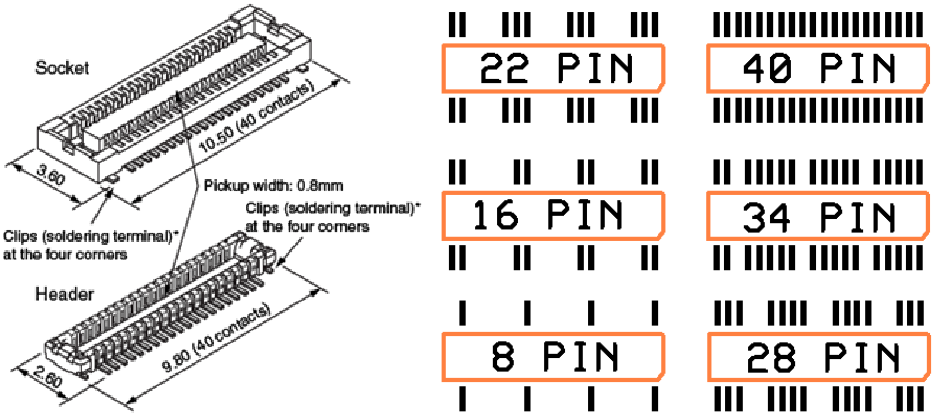


Figure 1-2 AXT 40 pin connector and the various pin grouping/removal patterns for HV tests.

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 so that we need to seek flexible connections at the EoS. The introduction of the intermediate flexes with corrugation for the EoS PP0 connection is aimed to provide this flexibility. This in term requires the Type-1 services to terminate on a sliding PP0 board for the connection to intermediate flexes.

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.
- The left most blank region is reserved for strain-relief tie down. With the mass dominated by the wires, the tie-down will be simply by lacing after deliberate introduction of slack

for the smaller wires. This non-permanent tie-down arrangement will also allow repairs by undo/redo lacing if necessary.

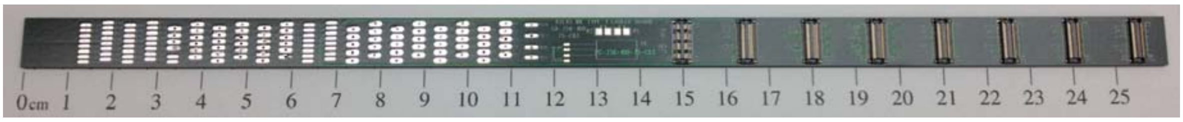


Figure 1-3: Picture of production PP0 cable board. Stave connection from intermediate flexes are coming from the right. Type-1 wire bundles are coming from the left. The board dimensions are 262mm in length and 11.5mm in width.

Supporting pads with slightly lower height than the connector mating height will be added between the AXT connectors to reduce the potential tilting of intermediate flex connectors. This will also allow applying epoxy between the intermediate flex and the pads at the final assembly as a connection hold-down in case of any concern on the AXT connection strength fatigue.

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 1-4, 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 AWG22 LV wires can only be packed into every other row in this connector due to the limited space between pins.

Figure 1-4 67pin μD AXON connector for LV/HV/DCS connection to Type-2 at PP1, with a diameter of 21mm.

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 1-5. 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. The plastic SLA shell with gold spray as used by nSQP was found to be somewhat fragile so that SLA Aluminum printing is used for IBL with more strength and more solid conductivity than metal sprays.

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 he 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.

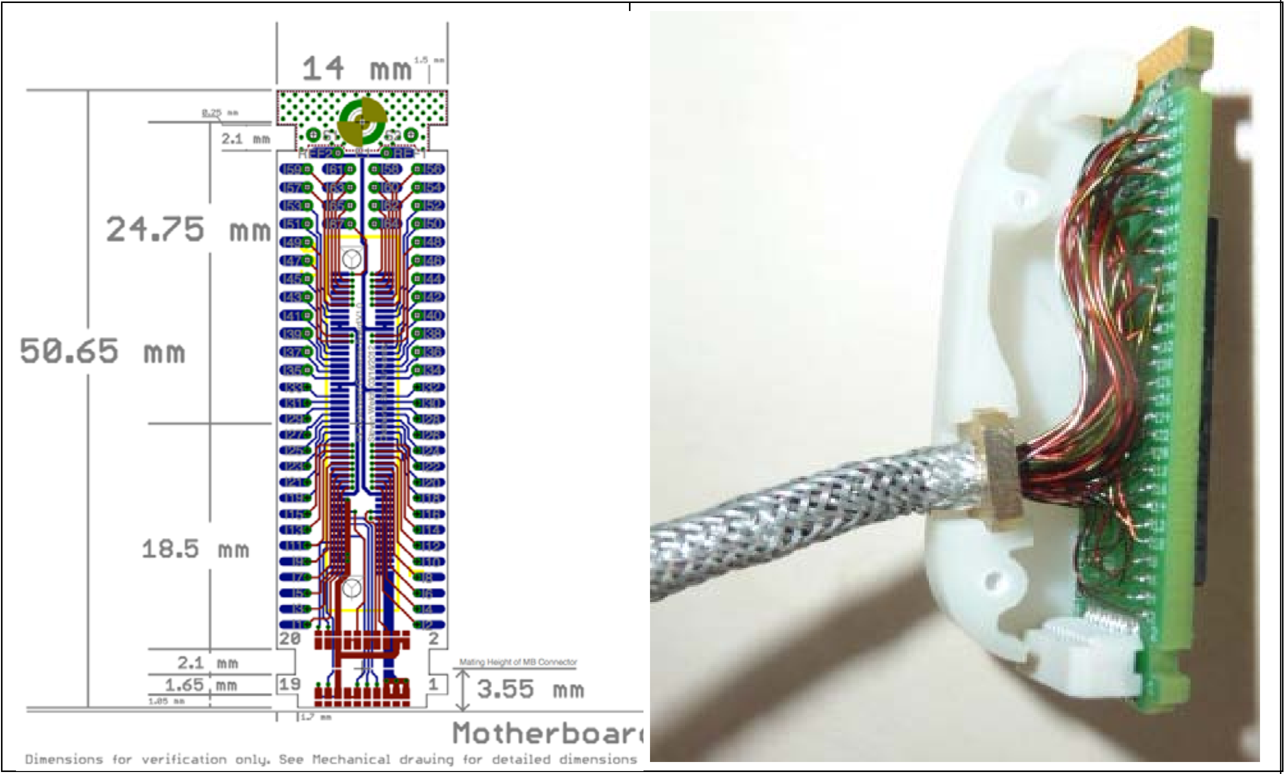


Figure 1-5 Opto-box connector board PCB layout and a prototype connector assembly with shell (the prototype plastic shell will be replaced by Al for production). Notice the ferrule and square nut soldered to

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 tube to both provide a smoother and stronger surface and prevent individual wires splitting off the potting. The CF tube will be threaded over the bare bundle first and the potting process injects glue into the tube. 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)*.

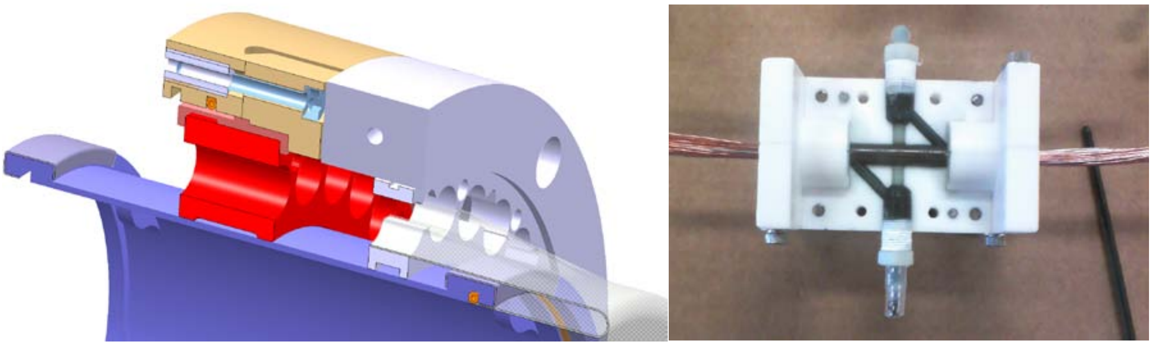
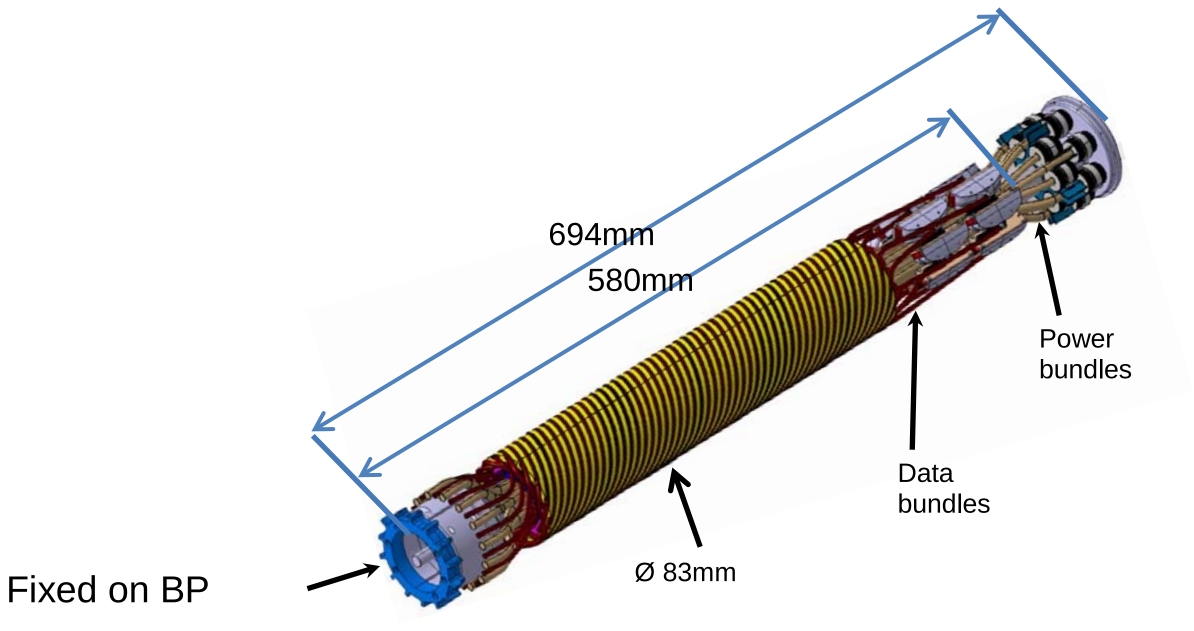


Figure 1-6 Left: PP1 sealing concept with potted Type-1 bundles expected to slot into the (red) sealing rings and cable braid outside PP1 to terminate and be clamped under the EMI shielding ring (grey). Right: Prototype Type-1 cable potting mould setup.

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 and the fast unwind process with dedicated tooling are beneficial for minimizing the radiation exposure of installation personnel. The current baseline installation scheme *(Ref:Type-1-wrapping)* is illustrated in *Figure 1-7*. 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. The longer Data/Clk/Cmd cables are wound onto grooved shells wrapped around the installation spool in 3 layers, with the help of a large winding wheel. The same tooling will be used for the unwinding after installation. 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.



1.2.11 ***Figure 1-7 Type-1 service wrapping and packing scheme for installation.Material radiation hardness***

The radiation level at the inner Type-1 service region is similar to what the IBL detector will experience so that the Type-1 material also need to be able to survive ~250Mrad.The connector board at near the opto-box is at a much larger radius so *that radiation hardness is* less important.The production cable board, bundle prototypes and potting sections were brought to Sandia for irradiation in Feb/ 2013 with Cobolt-60 source integraed ~250Mrad. No significant radiation damage effect were observed on all the pieces tested. The only noticed effect was the conductive epoxy used for the bonding of potting tube and braid has changed color. However, the conductivity measured showed no effect.

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) / Ludovic Eraud (LPSC)

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.

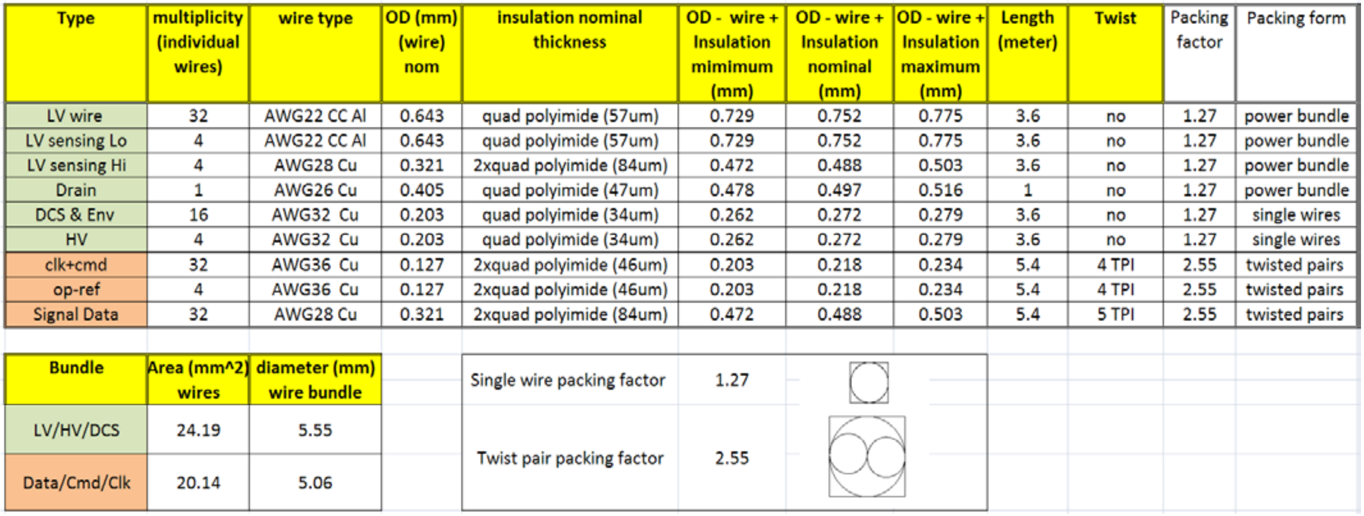
2) Pre-production: 12 complete bundles will be produced with the final lengths and all production components, including the AXON connectors, to aim for essentially production quality. The data/clk/cmd sub-bundle will be subject to extensive tests while waiting for the AXON connector delivery. The full 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	AWG22 CC Al	0.643	quad polyimide (57um)	0.729	0.752	0.775	3.6	no	1.27	power bundle
LV sensing Lo	4	AWG22 CC Al	0.643	quad polyimide (57um)	0.729	0.752	0.775	3.6	no	1.27	power bundle
LV sensing Hi	4	AWG28 Cu	0.321	2xquad polyimide (84um)	0.472	0.488	0.503	3.6	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	3.6	no	1.27	single wires
HV	4	AWG32 Cu	0.203	quad polyimide (34um)	0.262	0.272	0.279	3.6	no	1.27	single wires
clk+cmd	32	AWG36 Cu	0.127	2xquad polyimide (46um)	0.203	0.218	0.234	5.4	4 TPI	2.55	twisted pairs
op-ref	4	AWG36 Cu	0.127	2xquad polyimide (46um)	0.203	0.218	0.234	5.4	4 TPI	2.55	twisted pairs
Signal Data	32	AWG28 Cu	0.321	2xquad polyimide (84um)	0.472	0.488	0.503	5.4	5 TPI	2.55	twisted pairs

Bundle	Area (mm^2) wires	diameter (mm) wire bundle
LV/HV/DCS	24.19	5.55
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 long 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), Axotress copper braid (with 160µm 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 NOMAX lacing tape A-A-52084.

The detailed wire list and connector pin assignments are tabulated in Table 2-2 and Table 2-3. 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 as in Figure 2-1 indicate that the cable board inner edge Z coordinate is Z=573mm and the PP1 center line at the outer face of the searing ring and inner edge of the EMI clamping ring is Z=3328mm. To allow slight non-straightness of the cable routing within IST, this section of the bundle should aim for 3328-573+20=2775mm with 20mm extra length. The outer sections from PP1 center line to connector board (Axon connector) of

2600mm (1002mm) includes 150mm (20mm) routing contingency. The longest LV wires are ~3635mm. The LV/HV/DCS sub-bundles will have different bundle lengths to stagger them by ~10cm in Z as all AXON connector packed at the same Z location will exceed the IBL radial envelope for installation. The longest Data/Cmd/Clk wires are ~5170mm.

For the variations of bundles types due the 2 different lengths (to be updated by Raphael/Tamer) 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.

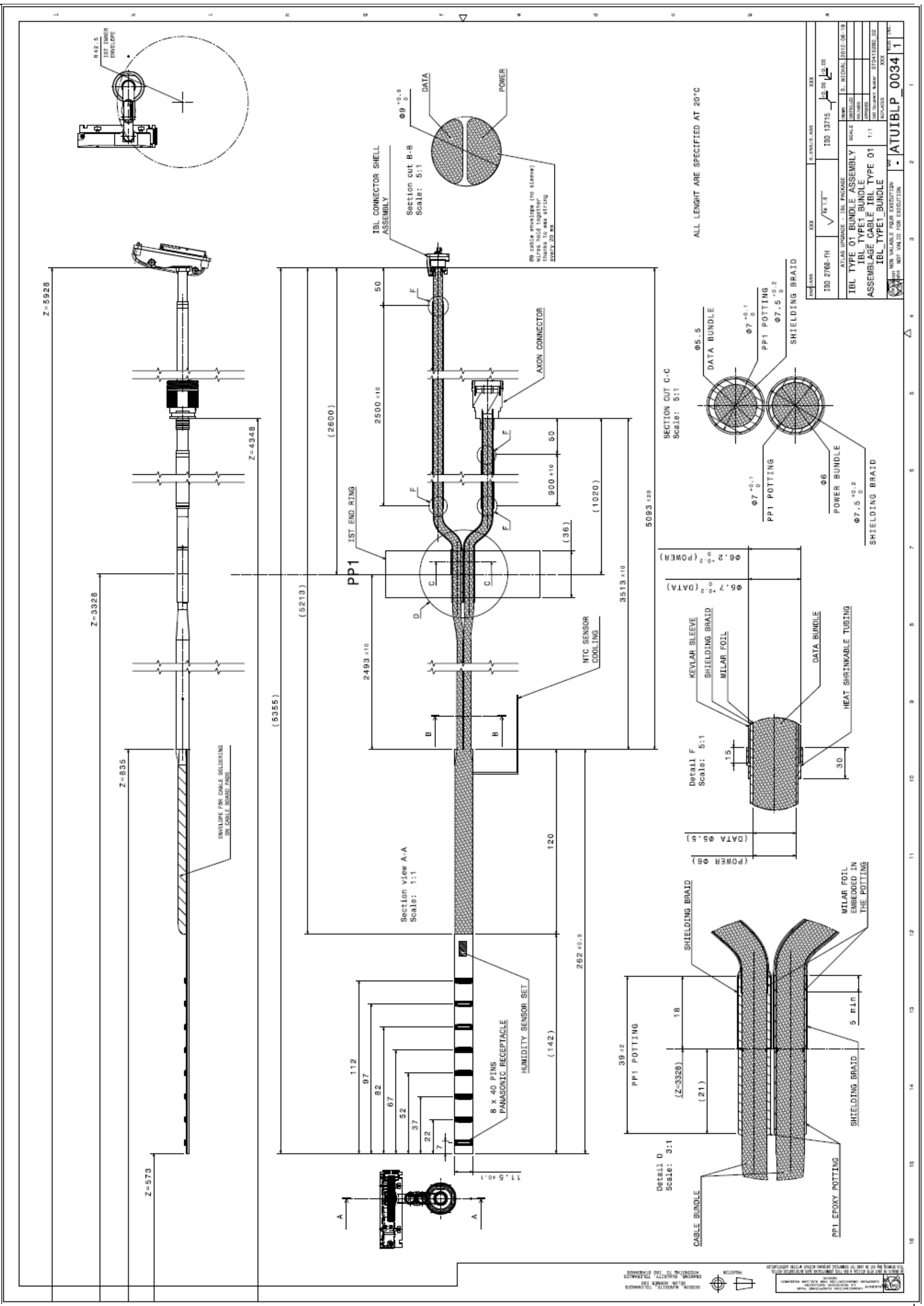
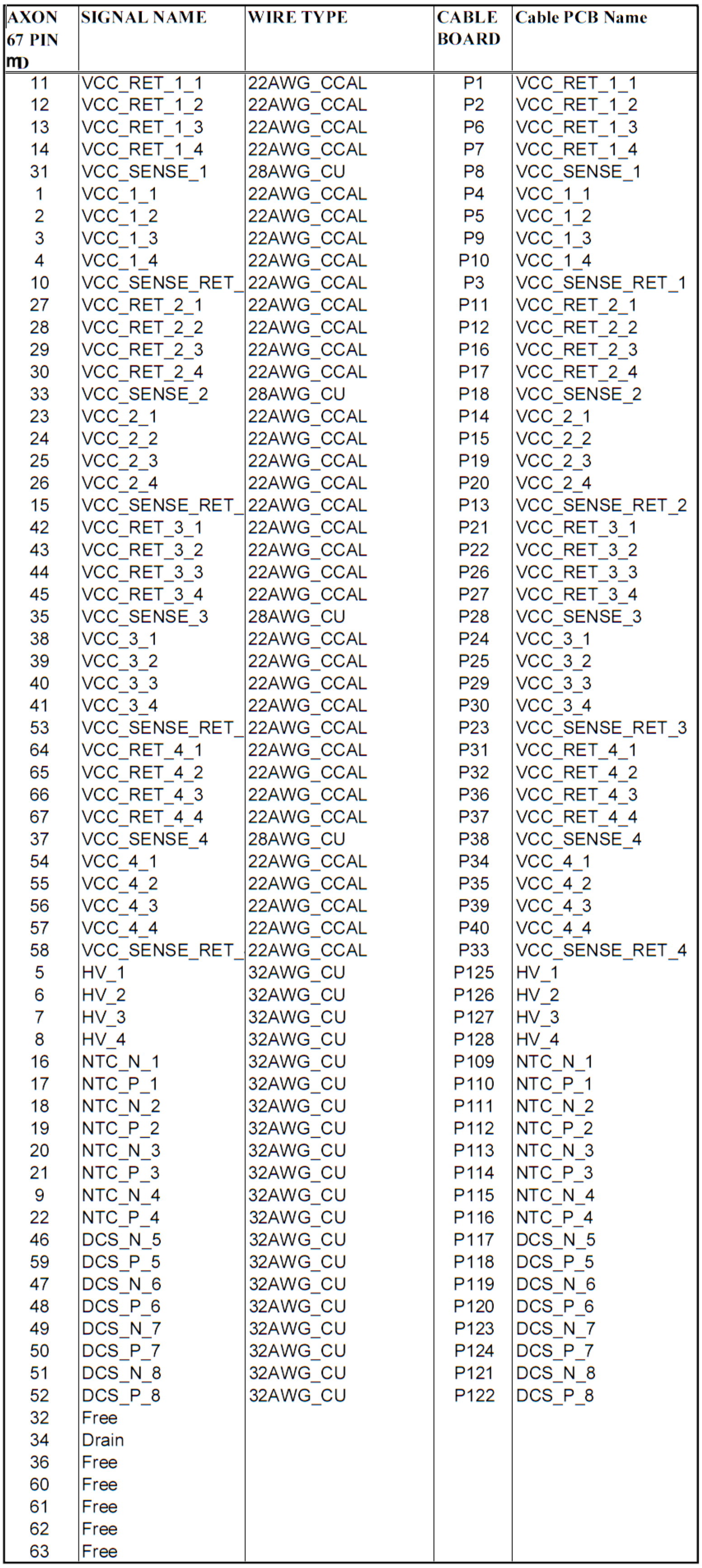
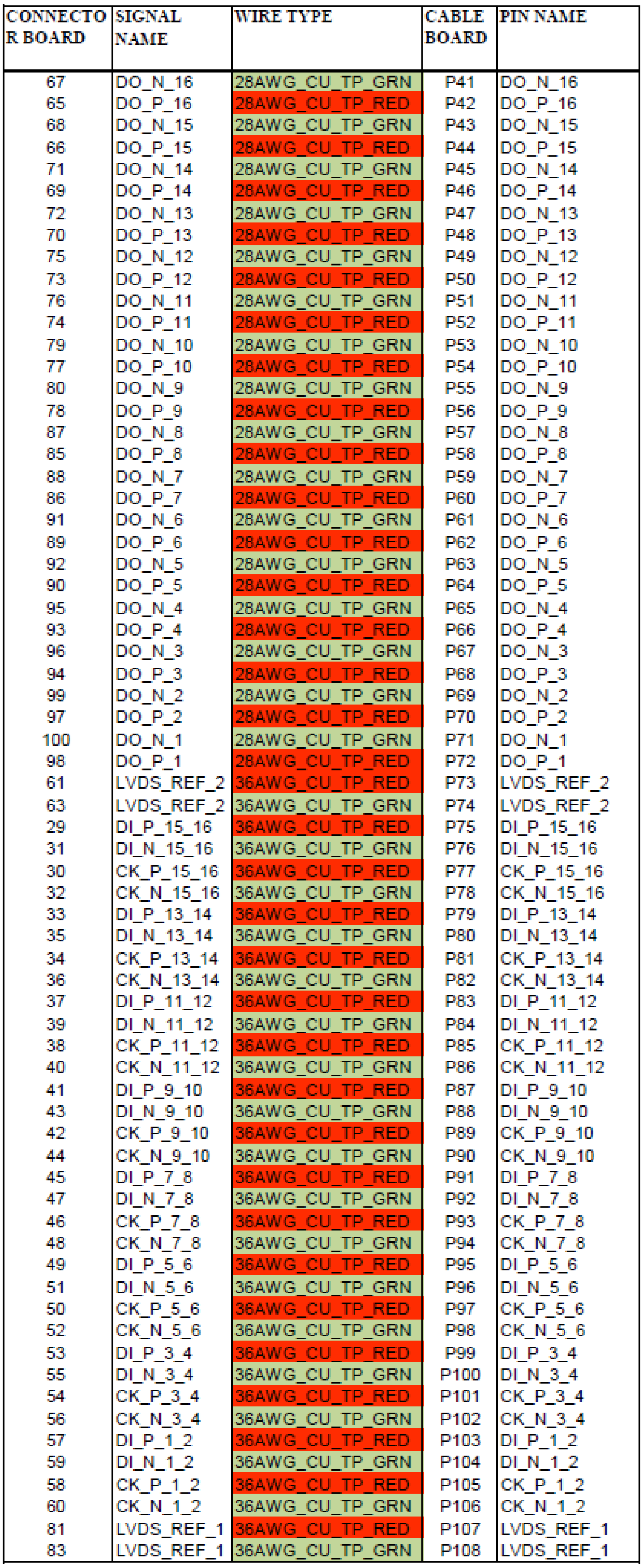


Figure 2-1 Type-1 harness general mechanical specifications (ATUIBLP_0034). Details to be updated, in particular the LV/HV/DCS bundle length will have two types and the final bundle diameters pending packing tests at AXON.



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



CONNECTOR BOARD	SIGNAL NAME	WIRE TYPE	CABLE BOARD	PIN NAME
67	DO_N_16	28AWG_CU_TP_GRN	P41	DO_N_16
65	DO_P_16	28AWG_CU_TP_RED	P42	DO_P_16
68	DO_N_15	28AWG_CU_TP_GRN	P43	DO_N_15
66	DO_P_15	28AWG_CU_TP_RED	P44	DO_P_15
71	DO_N_14	28AWG_CU_TP_GRN	P45	DO_N_14
69	DO_P_14	28AWG_CU_TP_RED	P46	DO_P_14
72	DO_N_13	28AWG_CU_TP_GRN	P47	DO_N_13
70	DO_P_13	28AWG_CU_TP_RED	P48	DO_P_13
75	DO_N_12	28AWG_CU_TP_GRN	P49	DO_N_12
73	DO_P_12	28AWG_CU_TP_RED	P50	DO_P_12
76	DO_N_11	28AWG_CU_TP_GRN	P51	DO_N_11
74	DO_P_11	28AWG_CU_TP_RED	P52	DO_P_11
79	DO_N_10	28AWG_CU_TP_GRN	P53	DO_N_10
77	DO_P_10	28AWG_CU_TP_RED	P54	DO_P_10
80	DO_N_9	28AWG_CU_TP_GRN	P55	DO_N_9
78	DO_P_9	28AWG_CU_TP_RED	P56	DO_P_9
87	DO_N_8	28AWG_CU_TP_GRN	P57	DO_N_8
85	DO_P_8	28AWG_CU_TP_RED	P58	DO_P_8
88	DO_N_7	28AWG_CU_TP_GRN	P59	DO_N_7
86	DO_P_7	28AWG_CU_TP_RED	P60	DO_P_7
91	DO_N_6	28AWG_CU_TP_GRN	P61	DO_N_6
89	DO_P_6	28AWG_CU_TP_RED	P62	DO_P_6
92	DO_N_5	28AWG_CU_TP_GRN	P63	DO_N_5
90	DO_P_5	28AWG_CU_TP_RED	P64	DO_P_5
95	DO_N_4	28AWG_CU_TP_GRN	P65	DO_N_4
93	DO_P_4	28AWG_CU_TP_RED	P66	DO_P_4
96	DO_N_3	28AWG_CU_TP_GRN	P67	DO_N_3
94	DO_P_3	28AWG_CU_TP_RED	P68	DO_P_3
99	DO_N_2	28AWG_CU_TP_GRN	P69	DO_N_2
97	DO_P_2	28AWG_CU_TP_RED	P70	DO_P_2
100	DO_N_1	28AWG_CU_TP_GRN	P71	DO_N_1
98	DO_P_1	28AWG_CU_TP_RED	P72	DO_P_1
61	LVDS_REF_2	36AWG_CU_TP_RED	P73	LVDS_REF_2
63	LVDS_REF_2	36AWG_CU_TP_GRN	P74	LVDS_REF_2
29	DI_P_15_16	36AWG_CU_TP_RED	P75	DI_P_15_16
31	DI_N_15_16	36AWG_CU_TP_GRN	P76	DI_N_15_16
30	CK_P_15_16	36AWG_CU_TP_RED	P77	CK_P_15_16
32	CK_N_15_16	36AWG_CU_TP_GRN	P78	CK_N_15_16
33	DI_P_13_14	36AWG_CU_TP_RED	P79	DI_P_13_14
35	DI_N_13_14	36AWG_CU_TP_GRN	P80	DI_N_13_14
34	CK_P_13_14	36AWG_CU_TP_RED	P81	CK_P_13_14
36	CK_N_13_14	36AWG_CU_TP_GRN	P82	CK_N_13_14
37	DI_P_11_12	36AWG_CU_TP_RED	P83	DI_P_11_12
39	DI_N_11_12	36AWG_CU_TP_GRN	P84	DI_N_11_12
38	CK_P_11_12	36AWG_CU_TP_RED	P85	CK_P_11_12
40	CK_N_11_12	36AWG_CU_TP_GRN	P86	CK_N_11_12
41	DI_P_9_10	36AWG_CU_TP_RED	P87	DI_P_9_10
43	DI_N_9_10	36AWG_CU_TP_GRN	P88	DI_N_9_10
42	CK_P_9_10	36AWG_CU_TP_RED	P89	CK_P_9_10
44	CK_N_9_10	36AWG_CU_TP_GRN	P90	CK_N_9_10
45	DI_P_7_8	36AWG_CU_TP_RED	P91	DI_P_7_8
47	DI_N_7_8	36AWG_CU_TP_GRN	P92	DI_N_7_8
46	CK_P_7_8	36AWG_CU_TP_RED	P93	CK_P_7_8
48	CK_N_7_8	36AWG_CU_TP_GRN	P94	CK_N_7_8
49	DI_P_5_6	36AWG_CU_TP_RED	P95	DI_P_5_6
51	DI_N_5_6	36AWG_CU_TP_GRN	P96	DI_N_5_6
50	CK_P_5_6	36AWG_CU_TP_RED	P97	CK_P_5_6
52	CK_N_5_6	36AWG_CU_TP_GRN	P98	CK_N_5_6
53	DI_P_3_4	36AWG_CU_TP_RED	P99	DI_P_3_4
55	DI_N_3_4	36AWG_CU_TP_GRN	P100	DI_N_3_4
54	CK_P_3_4	36AWG_CU_TP_RED	P101	CK_P_3_4
56	CK_N_3_4	36AWG_CU_TP_GRN	P102	CK_N_3_4
57	DI_P_1_2	36AWG_CU_TP_RED	P103	DI_P_1_2
59	DI_N_1_2	36AWG_CU_TP_GRN	P104	DI_N_1_2
58	CK_P_1_2	36AWG_CU_TP_RED	P105	CK_P_1_2
60	CK_N_1_2	36AWG_CU_TP_GRN	P106	CK_N_1_2
81	LVDS_REF_1	36AWG_CU_TP_RED	P107	LVDS_REF_1
83	LVDS_REF_1	36AWG_CU_TP_GRN	P108	LVDS_REF_1

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.

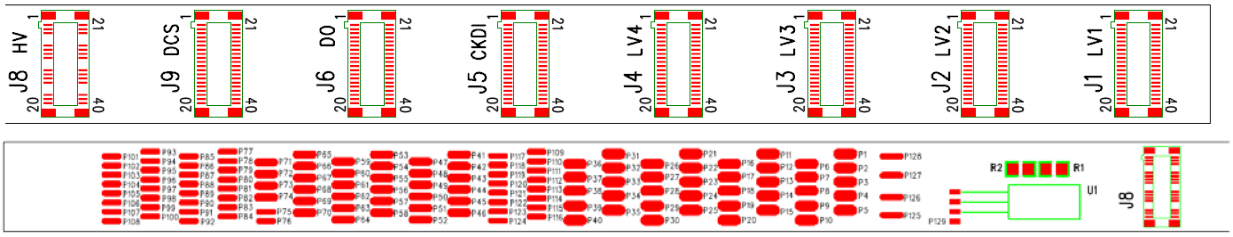


Figure 2-2 Cable Board connector and pad section layout and pad number assignments.

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 AWG22/AWG28 sizes are assigned to alternating rows to make the connection density manageable. The LV/HV/DCS wires are single AWG32 Cu without twist.

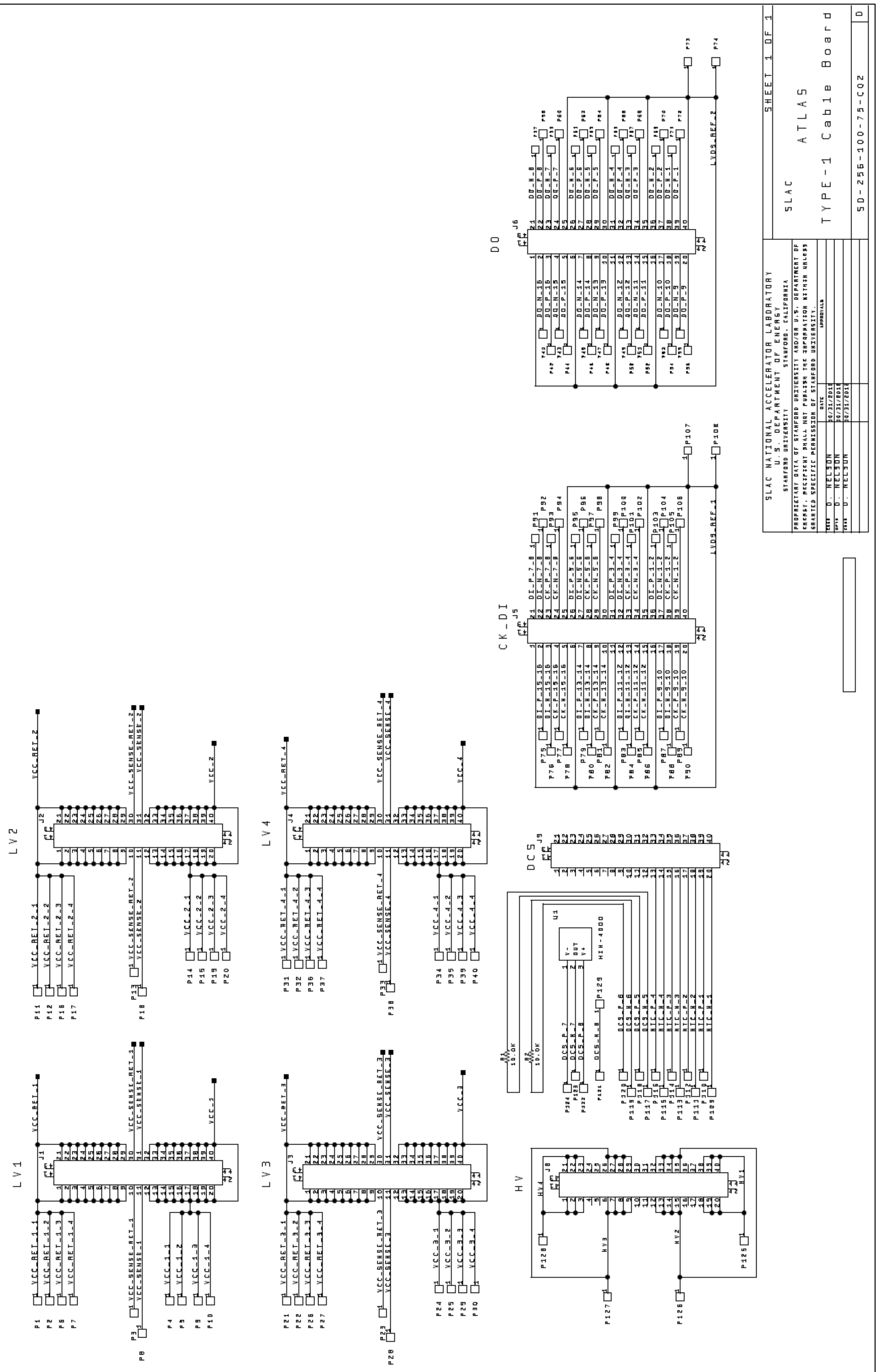


Figure 2-3 PP0 cable board schematics.

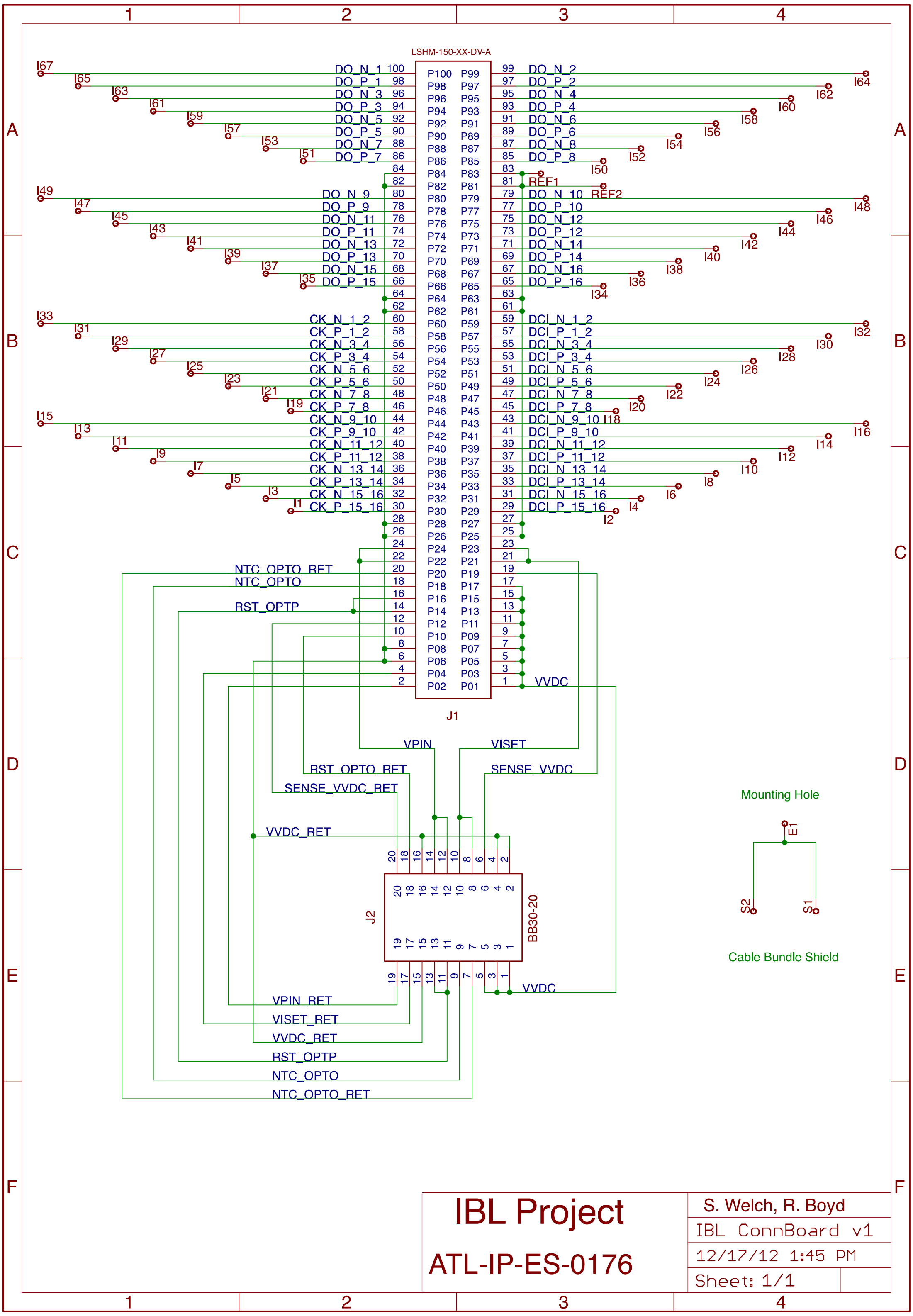
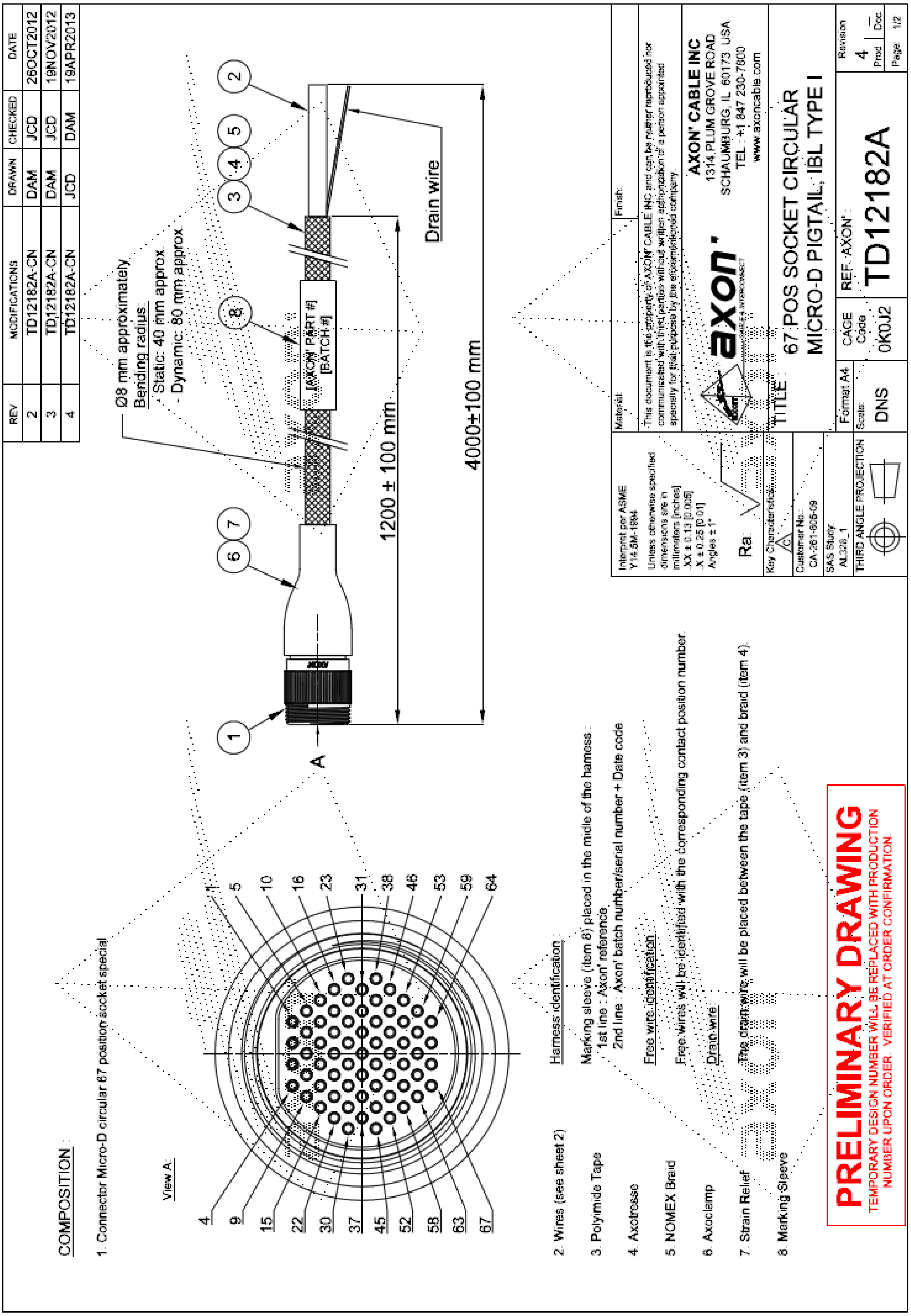


Figure 2-4 Opto-box connector board schematics.



REV	MODIFICATIONS	DRAWN	CHECKED	DATE
2	TD12182A-CN	DAM	JCD	26OCT2012
3	TD12182A-CN	JCD	JCD	19NOV2012
4	TD12182A-CN	JCD	DAM	19APR2013

COMPOSITION :

1. Connector Micro-D circular 67 position socket special
2. Wires (see sheet 2)
3. Polyimide Tape
4. Axotresse
5. NOMEX Braid
6. Axoclamp
7. Strain Relief
8. Marking Sleeve

Harness identification :

Marking sleeve (item 8) placed in the midle of the harness :
1st line : Axon' reference
2nd line : Axon' batch number/serial number + Date code

Free wire identification :

Free wires will be identified with the corresponding contact position number.

Drain wire :

The drain wire will be placed between the tape (item 3) and braid (item 4).

Ø8 mm approximately

Bending radius :
- Static: 40 mm approx
- Dynamic: 80 mm approx

Interpret per ASME Y14.5M-1994

Unless otherwise specified dimensions are in millimeters [inches]
.XX ± 0.13 [0.005]
.X ± 0.25 [0.01]
Angles ± 1°

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TITLE : 67 POS SOCKET CIRCULAR MICRO-D PIGTAIL, IBL TYPE I

Customer No.: CA-261-805-09

SAS Study: AL328_1

Format A4 | Scale: DNS | CAGE Code 0K0J2 | REF. AXON' : TD12182A | Revision 4 | Prod – | Doc | Page 1/2

PRELIMINARY DRAWING

TEMPORARY DESIGN NUMBER WILL BE REPLACED WITH PRODUCTION NUMBER UPON ORDER. VERIFIED AT ORDER CONFIRMATION.

Figure 2-5 AXON connector and cable hardness description.

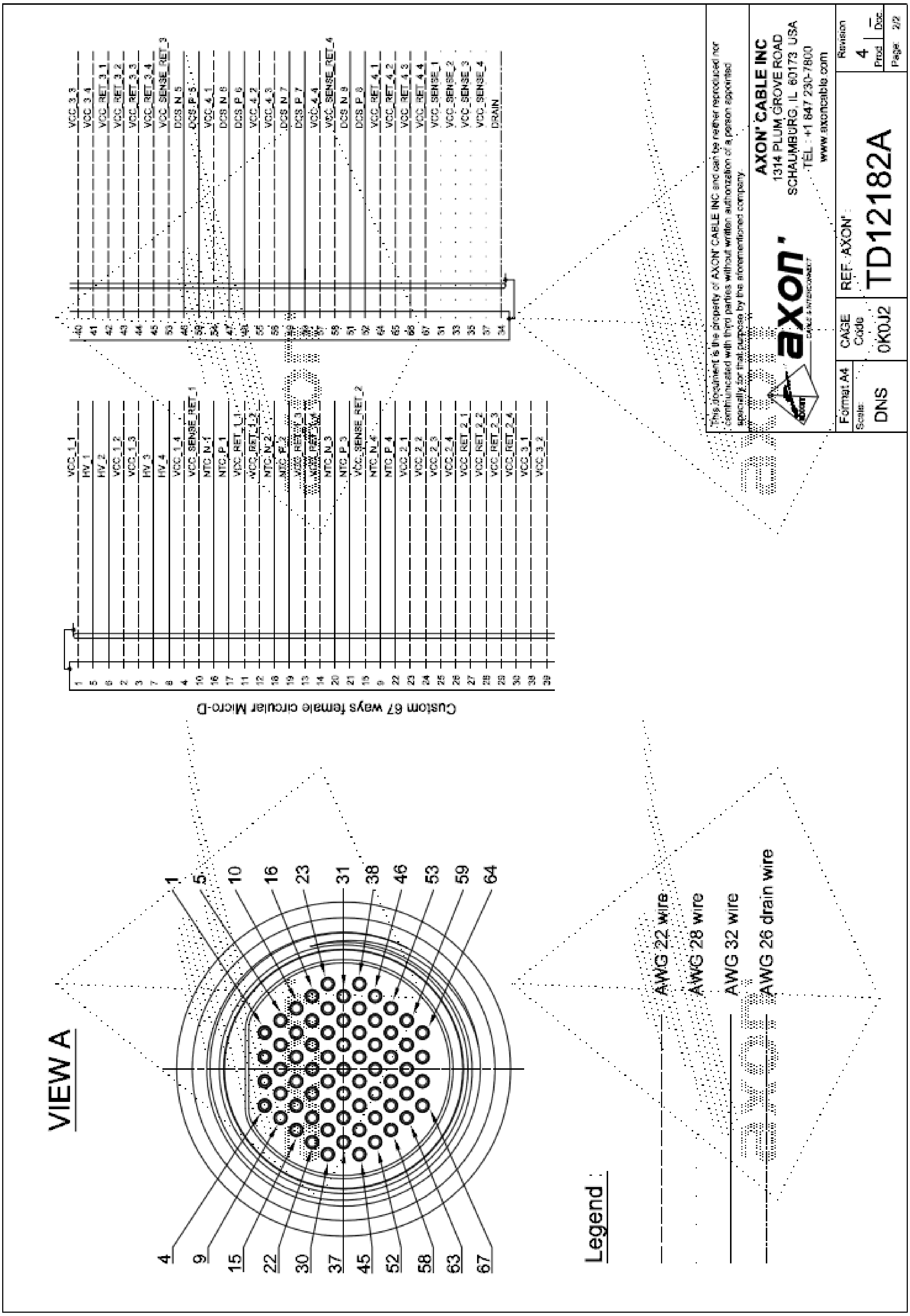

Figure 2-6 AXON connector pin assignments and wire subgroups.

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 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.
2. Apply kapton film wrapping, braid and Kevlar sleeve to the outer section of the data/cmd/clk sub-bundle.
3. Solder connector boards on data/cmd/clk sub-bundle wires and assemble connector shells.
4. Solder data/cmd/clk sub-bundle wires to the cable board at PP0 end.
5. Conduct electrical data transmission Q/A to the assembled data/cmd/clk sub-bundle.
6. Perform epoxy potting of the PP1 sealing on Data/Cmd/Clk sub-bundle and attach braid to potting section with conductive epoxy.
7. Solder the PP0 end of the LV/HV/DCS sub-bundle (after receiving the sub-bundle from AXON with the PP1 end already assembled at AXON) to the cable board.
8. Q/A on the LV/HV/DCS section of assembled full bundle.
9. Trim braid/sleeve on LV/HV/DCS sub-bundle from AXON to right length then perform PP1 feed-through epoxy potting and attach braid with conductive epoxy.
10. Apply lacing cord to inner section from Eos-PP1of the full bundle.
11. Thermal cycle the fully assembled bundle.
12. 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. 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. Further tests will be performed for HV/LV/DCS Q/A. 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/>.
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