8.4 Internal Services and Support Structures

We describe in this section the internal electrical and cooling services for the pixel detector and the related support structures. Internal services (electrical, optical and cooling) are those elements within the volume of the Pixel Support Tube (see Figure 8.1.1 for an overview).

The elements of the electrical internal services are:

- Custom Type 0 cables attached to each pixel model on one end and with a miniature connector on the other;
- Patch Panel 0 (PP0) at the end of the active region of the pixel detector to which each Type 0 cable is connected via its miniature connector to a printed circuit board;
- Type 1 wire bundles that have individual wires in a bundle soldered on one end to the printed circuit boards at PP0 and feed-through printed circuit boards at Patch Panel 1 at the end of the Pixel Support Tube at the other; and
- A small number of Type 1 wires connected to temperature and other sensors

The elements of the optical internal services are:

- Custom optical transceiver boards (optoboards, described in section 4.4) that are connected to the PP0 printed circuit boards;
- Radiation-hard optical fiber ribbons that are connected to the optoboards and to a multi-connector assembly at the PP1 region; and
- A custom optical connector at PP1.

The elements of the cooling internal services are:

- Heat exchanger assemblies for each pixel cooling loop (88 loops) that consist of inlet(warm) and outlet(cold) aluminum tubes glued together to act as a heat exchanger for the entering and exiting C_3F_8 fluid;
- Small diameter capillary tubes connected on one end to the inlet of the heat exchange and on the other to the pixel detector cooling loop or optoboard cooling loop;
- Custom shaped exhaust tubes connected on the other end of the pixel detector or optoboard cooling loop and to the outlet of the heat exchanger.

The services are held by mechanical structures within the Pixel Support Tube. There are three principal structures:

- Service Quarter Panels (SQP). There are eight total SQPs, four on each end of the detector;
- Beam Pipe Support Structure (BPSS). There is a BPSS on each side of the active pixel detector region that holds the SQPs and supports the ATLAS beryllium beam pipe. The ability to adjust the horizontal and vertical position of the beam pipe is also built into the BPSS; and
- PP1 endplate elements and associated items.

We describe below each of the elements of the internal services and associated structures. First we described the support structures to also provide an overview, then the electrical services, then the mechanical/thermal aspects of the optoboards, optical fibers and custom connector (the electrical aspects of the optoboards have been described previously in section 4.4), next the cooling services and finally the integration of the Service Quarter Panels.

8.4.1 Services Support Structure

The services for the active region of the pixel detector are supported by the Beam Pipe Support Structure (BPSS) on each side of the active pixel detector region as shown in Figure 8.4.1. The BPSS also supports the LHC beryllium beam pipe within the ATLAS Inner Detector region. Mechanisms to allow adjustment of the beam pipe in the plane transverse to the beam are included in the BPSS and described briefly here.

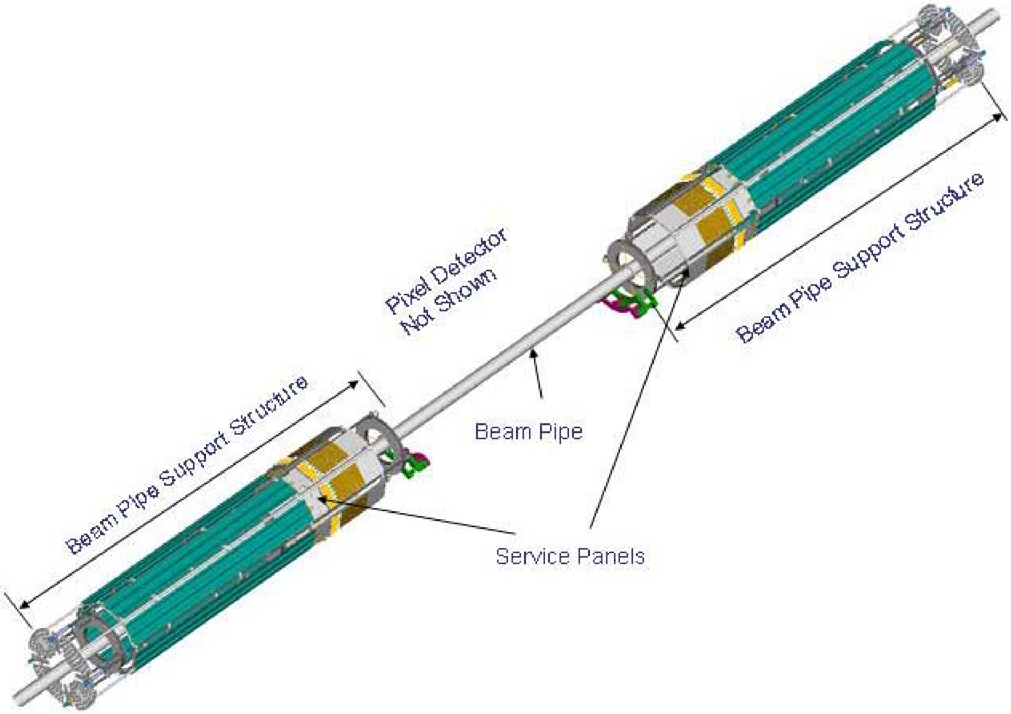

Figure 8.4.1. The relationship of the Beam Pipe Support Structure (BPSS) to the pixel detector and ATLAS beryllium beam pipe.

The BPSS is primarily constructed from carbon-fiber composite materials. The basic frame of the BPSS is illustrated in Figure 8.4.2 and consists of three, octagonal carbon-fiber-honeycomb structures with aluminum inserts that are adhesively bonded to carbon-fiber tubes to form the structure. Support points for the four service panels (see section 8.4.7) mounted on the BPSS are bonded into the octagonal structures. Supports for beam-condition monitors (Ref goes here) are also adhesively bonded to one of the octagonal structures.

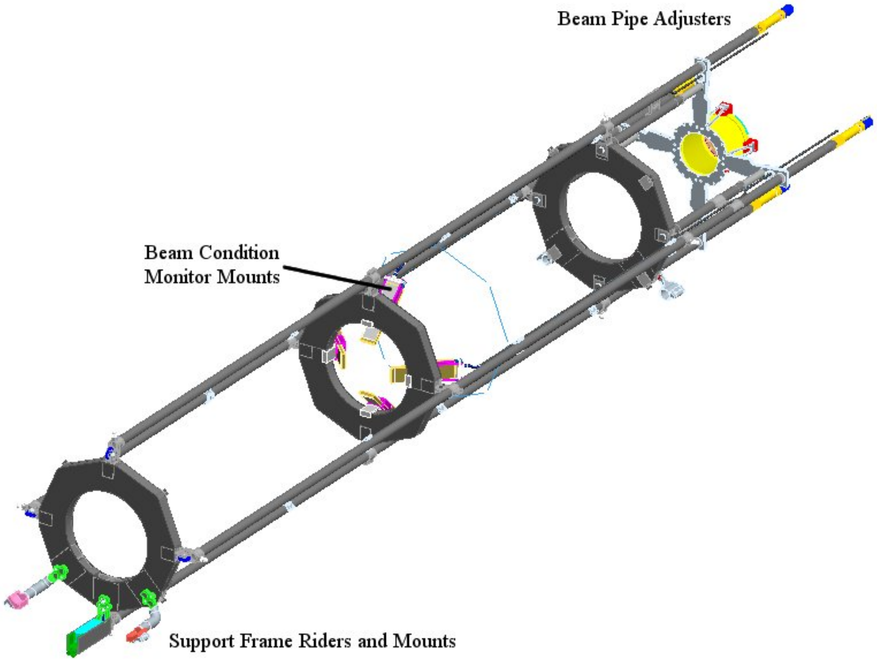

Figure 8.4.2. Illustration of the Beam Pipe Support Structure as described in the text.

Additional carbon-fiber/aluminum structures are connected to the BPSS (on an octagonal fiber/honeycomb plate) at the PP0 end to support the pixel detector support frame during insertion into the Pixel Support Tube – see Figure 8.4.3. Adjustable mount points on the pixel detector support frame ride on these structures during insertion. The precision pixel mounts bolted to an endplate on the pixel support frame engage mating mount points bonded into the PST. When this occurs, the pixel detector support frame lifts off the support structures on the BPSS by about 1mm and is fully supported by the PST mounts. In addition, an aluminum structure is also connected at the bottom of the octagonal carbon-fiber/honeycomb plate. A cable is attached to this structure and was used to pull the pixel detector package into the Pixel Support Tube.

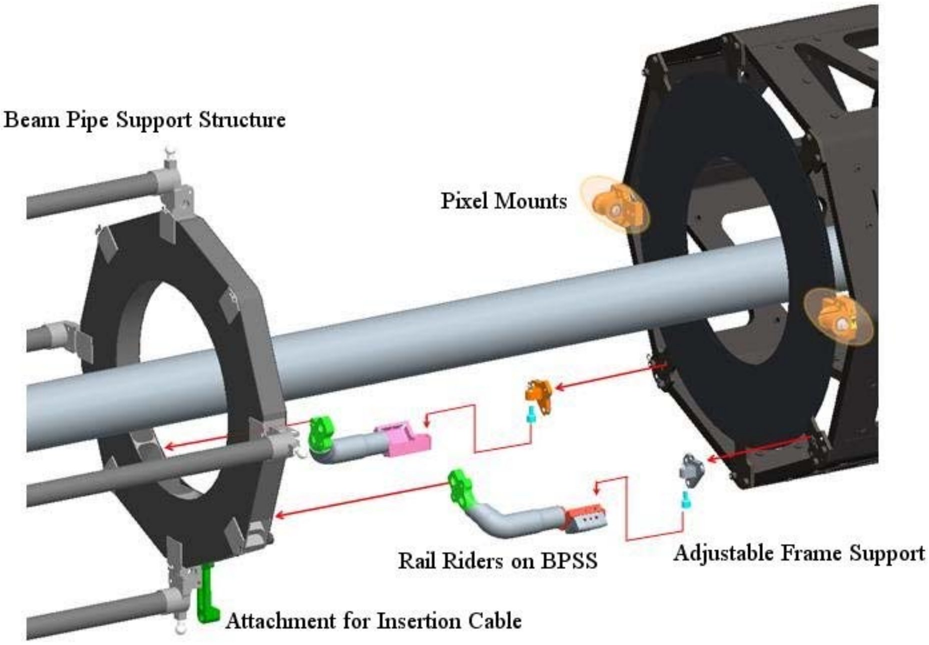

Figure 8.4.3 Expanded view of the structures on the BPPS that holdt the support frame during insertion as described in the text.

The adjustment of the beam pipe inside the Pixel Support Tube is implemented by attaching four stainless steel wires in an to aluminum collar in turn attached to the beam pipe at the PP0 region. The adjustment mechanism for these wires is built into the BPSS and is accessible from the end of the Pixel Support Tube after the pixel system is inserted into the PST. The adjustment range in the vertical and horizontal directions is +/-10mm.

8.4.2 Type 0 Cables

Each module is electrically connected via a single custom, miniature, round so-called Type 0 cable. This cable consists of discrete wires terminated to a printed circuit board (PCB) housing a 36 pin, dual row, surface mount, 0.5mm pitch connector. Type 0 cables for the barrel modules have such a connector on both ends and are connected to modules at the bi-stave integration step (section 8.2), whereas for disk cables one end was permanently soldered to the module flexible hybrid during module assembly. Each barrel module has a flexible "pigtail" that reaches the back side of the stave, where the Type 0 cable can be plugged in. All disk 1 and 3 cables are 82cm long, while disk 2 cables are 57cm long, making permanent (solder) cable-to-module integration possible. However, 40 different type 0 cable lengths are required in the barrel and the length for each module is not determined before assignment of a stave to a specific position within a layer.

The barrel and disk type 0 cables are electrically similar, but the mechanical construction is different. Table 8.4.1 lists the conductors that make up each cable. All conductors have polyurethane "magnet wire" insulation with the exception of the disk bias voltage, which has polyimide. The thickness of insulation used varies from 6 microns up to 25 microns, depending on requirements including controlled impedance of twisted pairs and high voltage hold-off for the bias voltage. All barrel conductors are pure aluminum and the termination is done by heavy-gauge wire bonding. All disk conductors have a copper exterior and are terminated by soldering. The disk current-carrying conductors are copper-clad aluminum to reduce material, and have a 90% by volume aluminum core. The material penalty from soldering and copper used in disk cables is compensated by having only one connector. The largest diameter conductor used in barrel cables is 300μm because wire bonding was not reliable for heavier gauges, thus multiple wires are used for power.

	Disk			Barrel	
Purpose	Cond. Dia. (μm)	Format	Metal	Cond. Dia. (μm)	Format
Analog power	400	Twisted pair	Cu-clad Al	300	6x single wire
Digital power	400	Twisted pair	Cu-clad Al	300	4x single wire
High side sense	62	Single wire	Cu	100	Single wire
Return sense	250	Single wire	Cu-clad Al	300	Single wire
Clock, data, and temp. sense	62	Twisted pair	Cu	100	Twisted pair
Bias voltage	150	Twisted pair	Cu	100	Twisted pair

Table 8.4.1 Characteristics of conductors in Barrel and Disk Type 0 cables.

The manufacture of the cables was very labor-intensive. For the disk cables, the conductors were cut to length first and then bundled manually into a silicone sleeve (surgical tubing) for protection. The individual wires were then soldered to the connector PCB and the module flex hybrid one-by-one. Figure 8.4.4a shows a section through a disk cable.

For the barrel, the bundling was automated. Spools of pre-bundled wires tied with silk thread were cut to length, processed to strip the insulation, and manually wire-bonded to the connector PCBs one-by-one. Figure 8.4.4b shows a detail of the ends of a barrel cable. The insulation stripping for the barrel cables was a high temperature chemical process and this caused some problems. The geometrical arrangement of the wires during the stripping operation could result in built-in stresses that led to mechanical failure of the conductor later on. This was not discovered until a full quantity of cables for the detector had been produced. For Layers 0 and 1, new cables were manufactured with geometrical control during stripping and improved quality control. For Layer 2 enough cables were accepted from the initial production following stricter quality control, including visual inspection of the individual wires before and after mechanical stress testing.

Figure 8.4.4. (a) Section through a disk T0 cable and (b) detail of a barrel T0 cable.

The voltage drops in the power conductors of the Type 0 cables are significant - approximately 10% of the total services voltage drop for just 1% of the distance. This was a conscious choice to minimize material in the detector active volume. Because of this, the resistance of each cable was carefully controlled. Figure 8.4.5 shows the measured voltage drops on the barrel Type 0 cables (this does not include the pigtail of each module which adds approximately 80mV). Figure 8.4.6 shows the distribution of voltage drops in disk cables after soldering to the module hybrid.

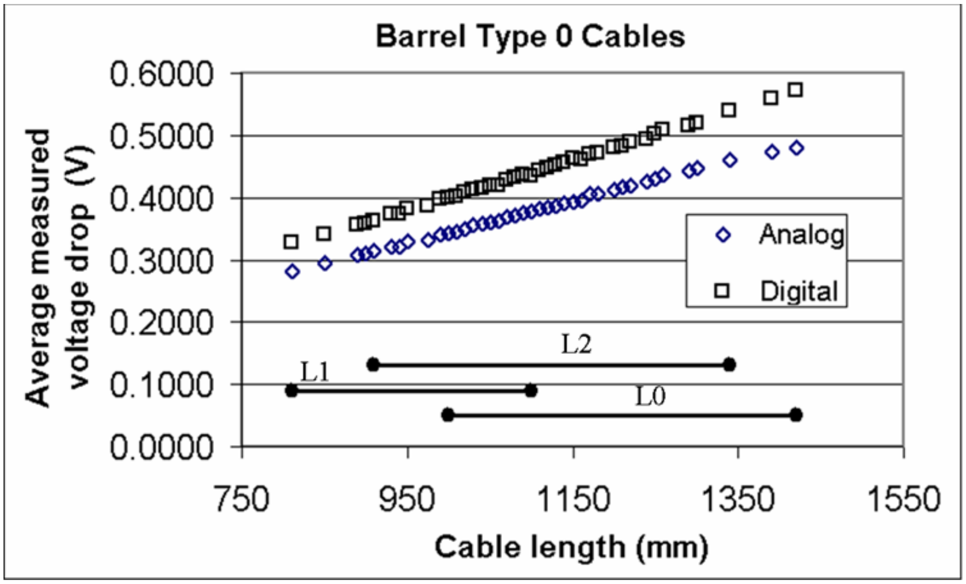

Figure 8.4.5 Average of measured voltage drops in barrel Type 0 cables vs. cable length, atthe highest operating current. Values are round trip. The horizontal lines show the length range spanned by each layer. The 300 micron wire resistance derived from these measurements is 0.4 Ω/m.

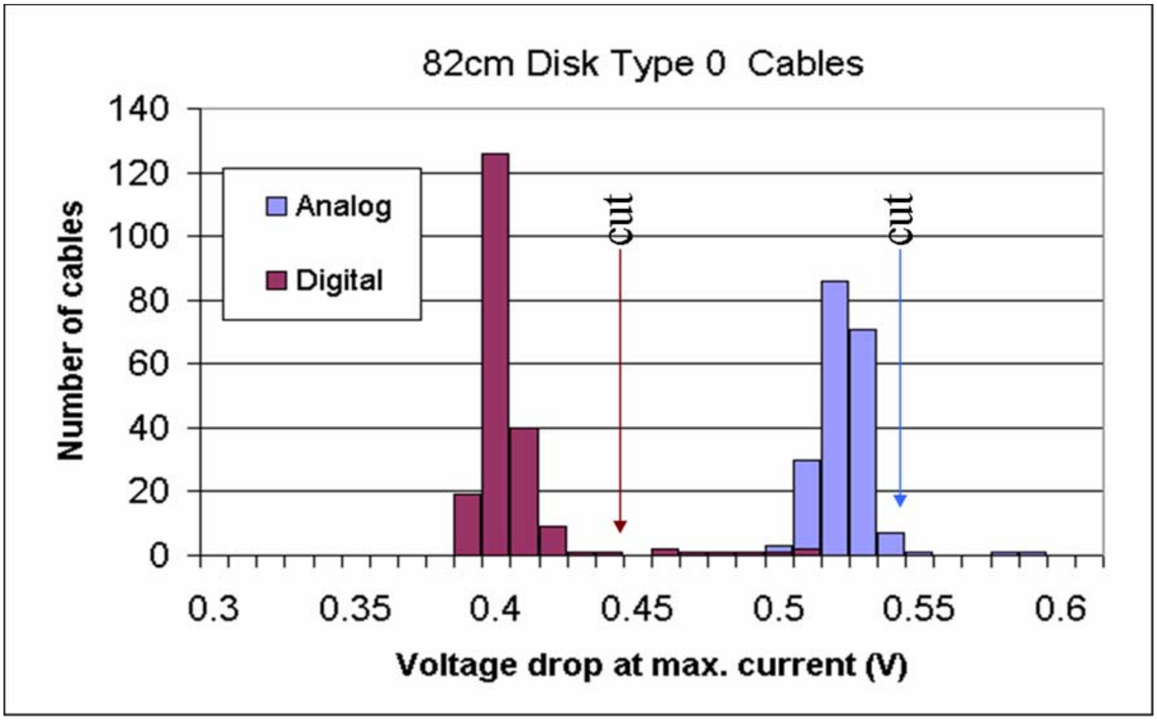

Figure 8.4.6. *Measured voltage drop distributions for disk 1 and 3 type 0 cables, round-trip at highest operating current. The quality control acceptance cuts are indicated. The 400 micron copper-clad aluminum wire resistance derived from these measurements is 0.25 Ω/m.*

8.4.3 PP0

The Patch Panel 0 (PP0) is the first point at which the active elements of the detector are connected to the service plant. The Type-0 micro-cables with all control power and data end in one 30-pin surface mount connector at PP0. The electrical/optical conversion is made by the opto-boards that are also connected at PP0. The electrical PP0 connections are arranged on printed circuit boards. Each service panel (one panel is one octant) has one rigid printed circuit “mother board” housing up to 42 module connectors and 6 opto-board connectors. The core of the rigid boards is glass-filled polyimide for radiation hardness. Additionally, each outer service panel has six flexible printed circuit extensions for an additional 36 modules and six opto connectors. The flexible circuits are wrapped around the end of the panel so that these six opto boards are on the bottom of the service panel. An illustration of the PP0 region, showing elements of these printed circuit boards and other details, shown in Figure 8.4.7

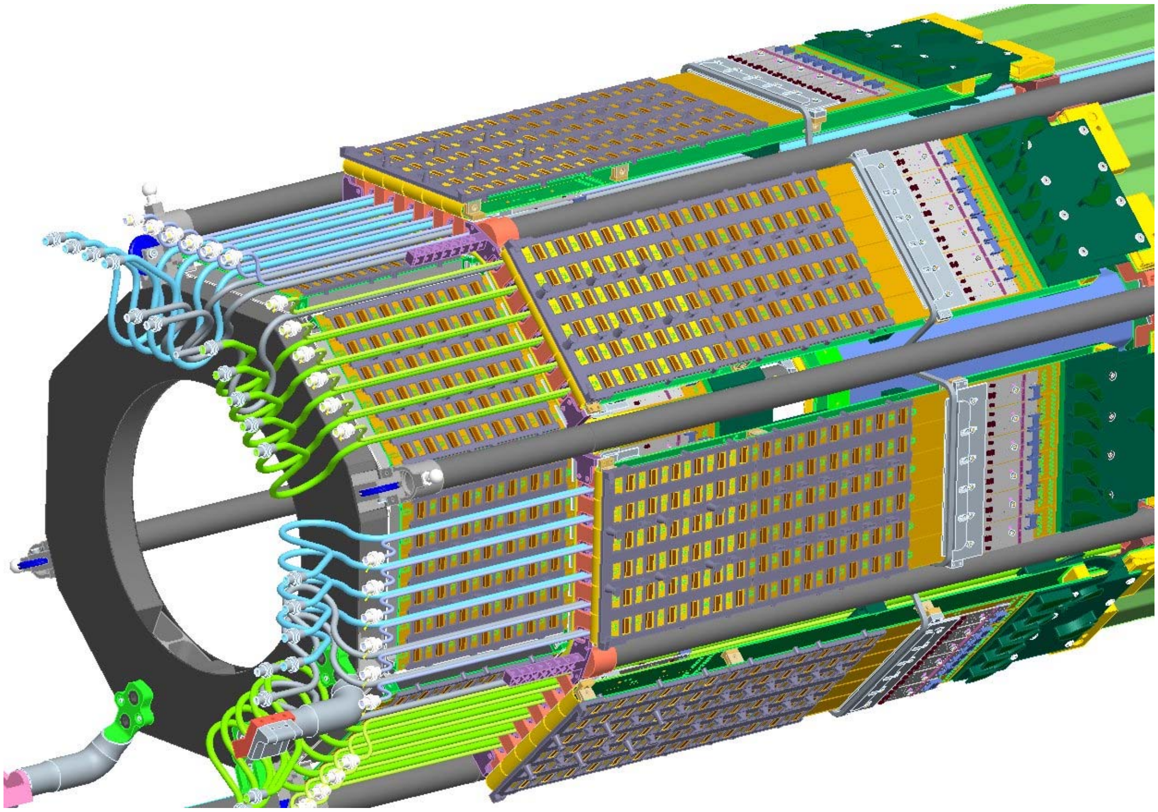

*Figure 8.4.7 Illustration of the PP0 region. ***Need to add annotation of this****

Flexible circuit boards are only used on the outer service panels. For a rigid board the opto-board is always on top (i.e. facing away from the beam pipe), whereas the flexible boards are wrapped around the end of the service panel so that their opto-boards are always on the bottom of the panel (i.e. towards the beam pipe).

The layout of the PP0 rigid circuit boards consists of repetitions of two basic cells, denominated PP0-A and PP0-B, which are mixed and matched at the layout level as needed. In total there are five unique rigid board layouts to accommodate all the variations.

Only differential signals, temperature sense lines and ground reference are routed a significant distance on the circuit boards. Power and high voltage are delivered by discrete wires (Type 1 services – section 8.4.4) terminated in solder holes or pads next to each connector. Signals are routed on broad-side coupled 100~μm wide traces with 75~μm core thickness for impedance control. Nominal impedance is 70~Ω. The rigid boards have three metal layers, with the buried layer 75~μm under the top layer, and a 1.6mm total thickness.

8.4.4 Type 1 Electrical Service Assemblies

The Type 1 electrical service assemblies include all low-voltage power lines for the pixel modules and optical readout, high-voltage lines for the pixel modules, lines for temperature monitoring of the pixel modules and opto-boards and lines for environmental(temperature and humidity) monitoring within the Pixel Support Tube.

At one end, twisted pair electrical lines are soldered to the PP0 printed circuit board or soldered or crimped to connectors for environmental sensors. The twisted pair wires are soldered at the PP1 end to thin, printed circuit boards. The area available at the end of the Pixel Support Tube is insufficient to allow for penetration of the twisted pair wires. Thus there is a transition made in this region from twisted pair to thin printed circuit boards. These PP1 printed circuit boards are laminated together (section 8.4.7) thereby substantially reducing the cross-sectional area for the services in the very crowded region at the end of the Pixel Support Tube. Short twist-pair wires are soldered to the other end of each printed circuit board and connected to a multi-pin connector(Ref. LEMO...).

The components of the Type I assemblies – internal twisted-pair wires of different gauges, PP1 printed circuit boards, external twisted-pair wires and multi-pin connectors – were assembled in pairs(Ref LEMO USA) to form single 5m long assemblies of three types – low-voltage power, high-voltage and optical power/environmental. The wire types and gauges for the different assemblies are summarized in Table 8.4.4.1. Copper-clad aluminum magnet wire is a standard industrial product containing 10% copper by volume outside an aluminum core.

	Number of Twisted Pairs	Wire Type	Conductor diameter	Insulation
Low Voltage Power			(μm)	
Internal	14	Solid copper-clad aluminum	813	Polyurethane
	14	Solid copper-clad aluminum	643	Polyurethane
	28	Solid copper-clad aluminum	404	Polyurethane
External	28	Stranded-tin-plated copper	7x150	Polyimide
	28	Stranded-tin-plated copper	7x120	Polyimide
Optical control and Environmental				
Internal	44	Solid copper	127	Polyurethane
External	44	Stranded-tin-plated copper	7x120	Polyimide
High Voltage				
Internal	26	Solid copper	127	Polyimide
External	26	Stranded-tin-plated copper	7x120	Polyimide

Table 8.4.2 Components of the Type I electrical services assemblies described in the text.

All soldering was done by hand. The connectivity and resistance of each circuit was measured using commercially available, computer-controlled cable checkers (Ref...) during the assembly process and after completion of the assemblies. Resistances were compared to nominal values and deviations outside acceptance windows triggered repair procedures. All completed assemblies were required to have 100% connectivity and to have acceptable resistance values. There are about 320,000 solder joints in all assemblies.

The completed assemblies were cut in the middle and each twisted pair soldered to the appropriate location on the PP0 printed-circuit board assemblies or crimped/soldered to small connectors for the environmental sensors. Extensive quality control procedures were used to verify the correct connectivity and again to measure the resistance of each circuit after making the PP0 printed circuit board connection. Repair procedures were completed (on approximately 0.1% of the circuits) and 100% connectivity and acceptable resistance were required for the Type I – PP0 assemblies.

8.4.5 Optical Components

Some elements of the optical system are described here and the remainder in section 8.5. The optical boards containing electronics, VCSELs and PIN diodes have already been described in Section 4.

Fiber ribbons are connected to the opto-boards on one end and to a custom connector at PP1. Each of the opto-boards is connected at PP0 by a bare ferrule of an MT8-connector without a connector housing to an 8-way radiation hard SIMM optical fibre ribbon. Two 8-way ribbons coming from PP0 go into an MF16 (MF-A1/MT16) connector which fits into the custom made PP1 connector(described below). There are 494 “long” (251.0 cm) and 246 “short” (226.0 cm) bare (no protective coating) ribbons. The eight PP1 connectors (1 per quadrant of side A and C) incorporate the MF16 connectors of the 320 double ribbons. The machined, aluminum PP1-connector (Ref manufacturer) is shown in Figure 8.4.8.

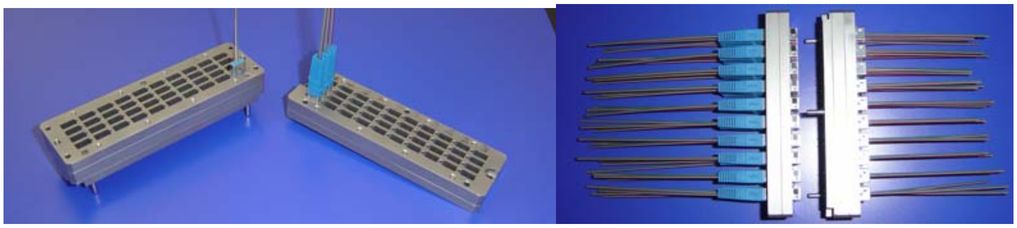

Figure 8.4.8 Custom connector at PP1 for connection of the optical ribbons. There is one such connector per quadrant at PP1.

Three steps were taken in the testing of the optical ribbons during the assembly of the Service Quarter Panels.

Pre-assembly

Each optical fibre was subject to a visual inspection to make sure it was not damaged during handling or labelling. Then, after a calibration procedure, they were tested to ensure that the attenuation was within expectation (< 20% excluding losses from additional test fibres). Any ribbon failing this test, was retested at the end of our test cycle to verify whether it needed to go back to the manufacturer or if the results were biased due to operator error or some dust on the connector-mating surface.

Post Installation (no optoboard connected)

The same pre-installation test was run after the fibres were installed in the Service Quarter Panels. This test ensured that there were no breaks during the installation.

Optoboard connected

Here the complete opto-link (including the fibers) was tested (see Section 4 for more details and definitions). After the opto-boards were installed, the best VISET and DAC settings for DRX were obtained. Then, a pseudo-random signal was sent from the BOC in a test configuration. This signal was fed back from the PP0 connectors to the opto-boards and was compared with the original signal. If there were no changed bits during this test, it meant that both opto-board and the connecting fibers worked as expected. If a link failed this test, both opto-board and the fibres were retested, and in some cases replaced.

8.4.6 Cooling System Components

A schematic view of the cooling system components within the region of the Pixel Support Tube is shown in Figure 8.4.9. We provide a brief description of these components here. The overall ATLAS evaporative cooling system is described in Ref. ???.

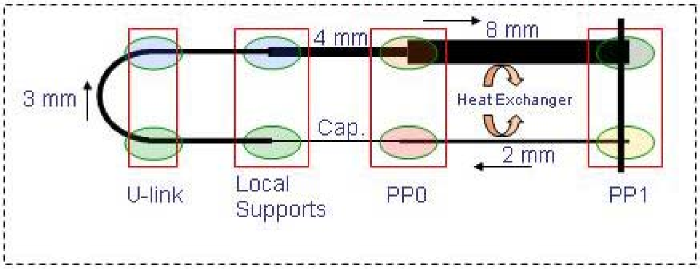

Figure 8.4.9 A schematic representation of the components of the pixel evaporative cooling system within the region of the Pixel Support Tube (indicated by the dashed line). The approximate inner diameters of the various tubes are shown apart from the capillary tubing(Cap. In the Figure).

The C_3F_8 fluid enters the pixel volume at PP1 at a temperature of +20-35^{o}C and a pressure of 11-15 bar absolute. The fluid passes through the inlet side of a heat exchanger and is pre-cooled before reaching a capillary tube? at PP0. The length and diameter of the capillary tube is selected to provide a substantial pressure drop, typically up to about 10-12 bar absolute for most circuits. The pressure in the local support or other circuit (for the opto-boards) is controlled by an external regulator (back pressure regulator) in the exhaust line well outside the pixel detector volume(Ref. evap cooling paper again). The fluid enters the local support and evaporation occurs from the heat of the pixel detector modules and associated services. The normal evaporation pressure in the barrel and disk regions is nominally < 3 bar absolute, leading to an evaporation temperature as low as -25^{o}C. The opto-board cooling circuits are normally operated at a higher pressure, up to about 5.5 bar absolute. In the barrel region, two local supports – staves – are connected by a custom-fabricated U-link and similarly in the disk region two sectors are connected by a U-tube. The fluid exits from a local support through custom-bent tubes and then passes to the exhaust side of the heat exchanger, thereby cooling the entering fluid. Custom, low-mass connectors of a single-design concept(but with varying dimensions) are used at each connection within the pixel volume: at PP1 to connect external pipes to the inlet or outlet of the heat exchanger; at PP0 to connect either capillaries or exhausts from the local supports; at the local supports and at U-links (U-shaped pipes) connecting two local supports. We describe briefly each of these components below. A summary of the number of circuits and basic operating parameters is given in Table 8.4.3 and a summary of tubing sizes and types, not including the local supports (already described in previous sections), is given in Table 8.4.4.

	Number of Cooling Circuits	Nominal Flow Rate (g/s)
Barrel Region	56	4.2 – 4.6
Disk Regions	24	2.3
Optical Readout	8	4.3
Total	88	

Table 8.4.3. Pixel detector cooling circuits and basic operating parameters.

Item	Material	Number	ID(mm)	OD(mm)
Heat exchanger – inlet	Aluminum	88	2.07	2.78
Heat exchanger – outlet Type 0	Aluminum	88	4.05	4.76
Heat exchanger – outlet Type 1	Aluminum	88	8.92	8.73
Barrel capillary	Copper-Nickel	56	0.8	0.98
Disk Capillary	Copper-Nickel	32	0.55	0.98
Opto Capillary	Copper-Nickel	8	0.8	0.98
Barrel Exhaust	Aluminum	56	4	4.71
Disk Exhaust	Aluminum	24	4.05	4.76

Table 8.4.4. Tube types and sizes for components of the internal cooling circuits.

Heat Exchangers

A schematic view of a heat exchanger is shown in Figure 8.4.10. All heat exchangers are functionally identical and consist of two aluminum pipes bonded along their length with a thermally conducting epoxy (Ref goes here) The length over which the tubes are glued is 1.92-2.02m.

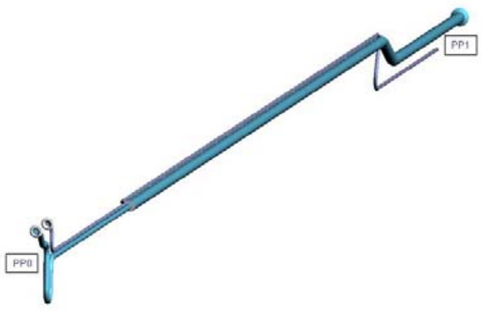

Figure 8.4.10. Schematic view of a typical heat exchanger as described in the text.

The inlet-side of the heat exchanger is a single tube running from the PP1 region to the PP0 region. The exhaust side of the heat exchanger consists of a larger-diameter tube (Type 1 region in Table 8.4.4) coupled through a welded transition piece to a smaller-diameter tube (Type 0 region in Table 8.4.4). The smaller diameter is required to fit the tube between connectors on the PP0 printed circuit board(see Figure 8.4.7). The tubes were bent at the PP1 end to match the appropriate hole pattern in the PP1 endplates (described in section 8.4.7). The tubes were bent at the PP0 region to match the inlet and exhaust tubing from the active detector region – see Figure 8.4.11. A U-bend was made in each exhaust section to facilitate small motions of the tubes installation of the pixel detector, to allow easier mating of the connectors and to allow for small changes from thermal contraction.

Figure 8.4.11 Photographs of heat exchangers at the PP0 end as described in the text. The black objects are temporary protection for the ends of the tubes.

All heat exchanger assemblies were tested. The inlet or exhaust side of the heat exchanger was connected to a helium leak checker on one end and the other end plugged. Leak checks were completed after assembly and after pressure cycling the inlet (outlet) to about 20(16) bar absolute, respectively, 50 times.

Capillary Assemblies

Capillary assemblies consist of small-diameter, copper-nickel (Cu-Ni) tubing adhesively bonded to fittings (described below) on each end. The Cu-Ni tubing was produced by a custom extrusion (Ref or footnote goes here). The interior dimensions were different for the barrel/optical and disk capillaries. The inner and outer diameters are summarized in Table 8.4.6.2. The length of each capillary was adjusted by making a comparison of a precise measurement of the pressure drop of nitrogen gas at a fixed flow rate across each capillary to the same measurement using a reference capillary (separate reference capillary for barrel and disk). Capillaries for barrel Layer 2 were approximately 110 cm long and capillaries for barrel layers 0 and 1 were about 120 cm long. Disk capillaries were also about 120 cm.

The ends of the capillaries were adhesively bonded (footnote Hysol 9394) to aluminum fittings (described in more detailed below). A picture of a capillary bonded to a fitting is shown in Figure 8.4.6.3a and Figure 8.4.6.3b.

Figure 8.4.12 Capillary bonded to aluminum fitting. (a) View from the back of the fitting and (b) view from the front of the fitting.

Each capillary was tested by connection to a helium leak checker after assembly, after thermal cycling 50 times from about 20^{o}C to about -25^{o}C and after pressure cycling to 20 bar absolute also 50 times.

U-links and U-tubes

Connections between two staves in the barrel region and two sectors in the disk region were made by U-links and U-tubes, respectively. A U-link is shown in Figure 8.4.13a. The design of the U-link is driven by tight space constraints at the ends of the staves. The U-link is a machined and bent small aluminum structure made with multiple e-beam and laser welds. A U-tube is a simple round tube bent into a U-shape to which the appropriate fittings are attached by laser welding (see Figure 8.4.13b).

Figure 8.4.13 (a) U-link structure used to connect to staves to form a bi-stave unit and (b) U-tube for connecting disk sectors, during assembly of a disk.

Local Support Exhaust Tubes

Local support exhaust tubes are attached at the exhaust-end of a bi-stave or bi-sector cooling circuit to route the fluid to the heat exchangers. The tube diameters are given in Table 8.4.6.2. The local support exhaust tubes are custom-bent aluminum tubes. In the barrel region, 56 different tube types – each tube was a unique shape - were bent by a commercial three-dimensional bending process (Ref vendor). In the disk region, there were three types of tubes corresponding to the three disk positions and were bent by hand using forms. Custom fittings were attached by laser welding, as described below.

Custom Fittings

Custom fittings were used throughout the region inside the Pixel Support Tube and at Patch Panel 1 to connect the cooling pipes and capillaries. Custom fittings were chosen to minimize material (radiation lengths) compared to commercially available fittings and to provide functionality (electrical isolation) not found by commercially available fittings.

Tapered, aluminum metal-to-metal fittings were used within the pixel detector volume except at the PP1 region. The concept of the tapered fitting is shown in Figure 8.4.14(a). The appropriate aluminum pipe (Table 8.4.6.2) was welded (Ref EB Industries) to these fittings, as shown in Figure 8.4.14(b). Fittings were also glued to capillaries, as already described above.

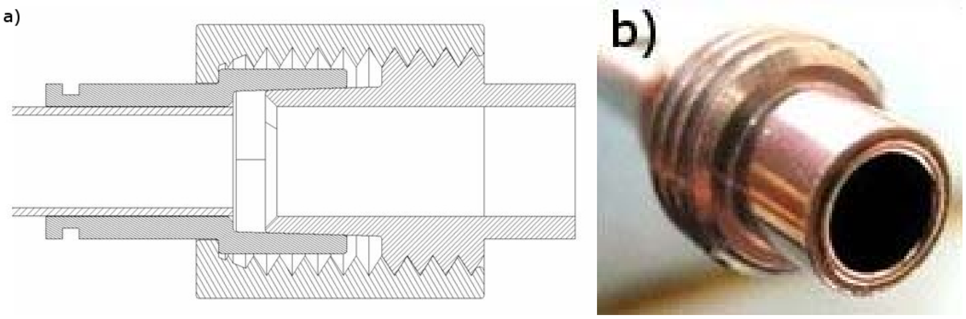

Figure 8.4.14 (a) Concept for tapered aluminum, metal-to-metal fitting; (b) fitting with welded aluminum pipe.

This type of fitting was used to for all cooling connections within the Pixel Support Tube except for the end of the heat exchangers at the PP1 region. An electrical break at PP1 for both inlet and exhaust lines of the heat exchanger was implemented as shown in Figure 8.4.15 for an inlet line. The glass-filled PEEK ferrule is a glued assembly that also contains a filter screen with pore diameter of 380 microns. The inlet or outlet tubing is flared and makes contact with the ferrule held by a nut and threads to provide a leak tight seal.

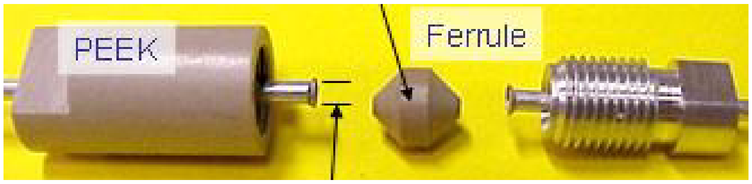

*Figure 8.4.15 Example of an inlet fitting at PP1 that provides also electrical isolation between the two sides of the circuit. **Will improve***

8.4.7 Service Quarter Panels

The electrical, optical and cooling components described above were integrated into eight Service Quarter Panels (SQP), four on each side of the detector. We first provide a brief overview of the SQP structure and then describe the assembly and testing of an SQP, including a few components not already described above.

An overview of an SQP is illustrated in Figure 8.4.16. The Type 1 electrical services are not shown in this illustration.

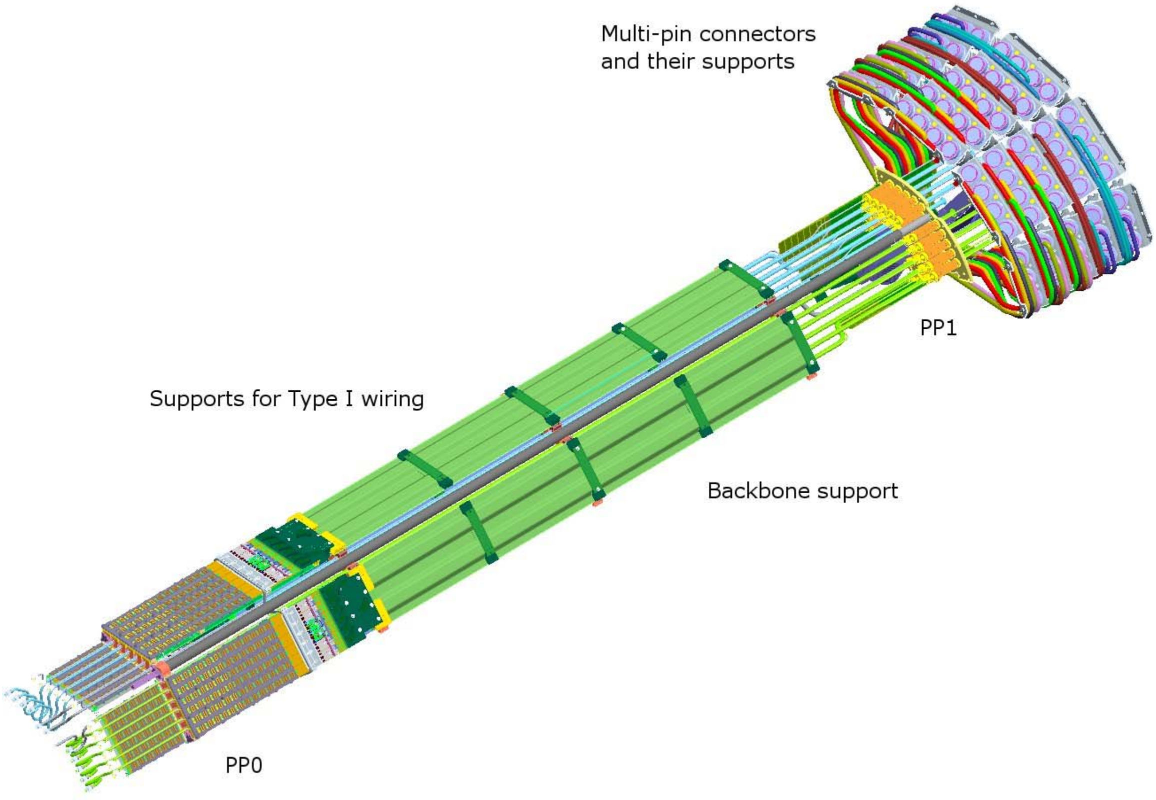

*Figure 8.4.16 Illustration of a SQP. The internal Type 1 electrical services are not shown for clarity. Annotation needs to be fixed*****

A SQP consists of the following principal substructures (described in more detail below):

- A “backbone” structure that supports the heat exchangers, a PP1 aluminum endplate and structures for optical ribbon support and routing;
- Two inner and two outer service panels that each contain the Type 1 electrical services attached to the PP0 printed circuit boards (as described previously) and
- A cooling circuit for the opto-boards finally mounted on the PP0 printed circuit boards

Photographs of the backbone structure are shown in Figure 8.4.17a (overview) and Figure 8.4.17b(detail PP1 region). This structure consists of a carbon-fiber tube (custom manufactured) to which support arms are attached. The support arms are either machined aluminum pieces(at the PP0 end only) or plastic pieces fabricated by a stereo lithography process to provide a complex shape(Reference here). Additional plastic pieces (also manufactured by stereo lithography) for routing fibre ribbons are adhesively bonded to the carbon fiber tube as shown in Figure 8.4.17b.

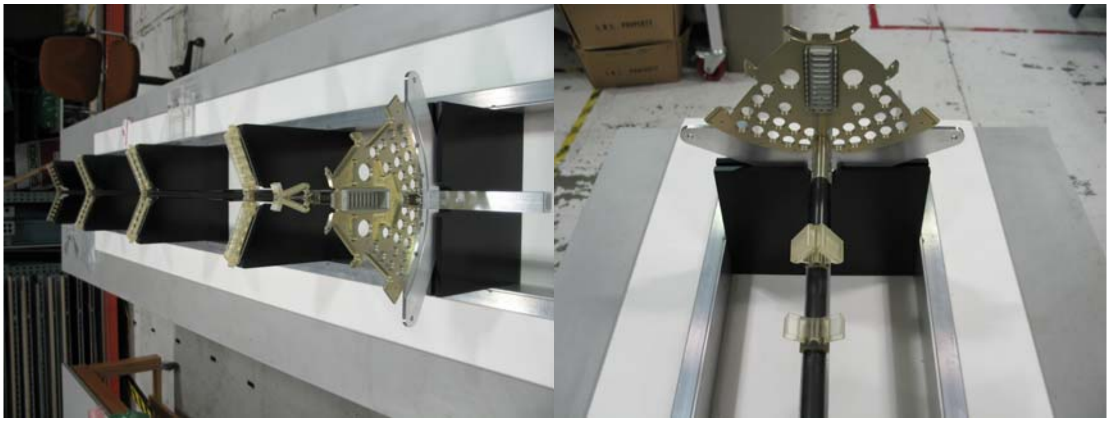

Figure 8.4.17 (a) Overview of Service Quarter Panel backbone and (b) expanded view at the PP1 region, as described in the text.

The backbone is attached to a machined aluminum plate at the PP1 end – the PP1 quarter plate – that has penetrations for the heat exchanger tubes, the Type 1 electrical services (laminated printed circuit boards), the connection of nitrogen gas to provide a dry atmosphere inside the Pixel Support Tube and a penetration for the routing of optical fibers to the PP1 optical connector plate. An illustration of the PP1 region is shown in Figure 8.4.18.

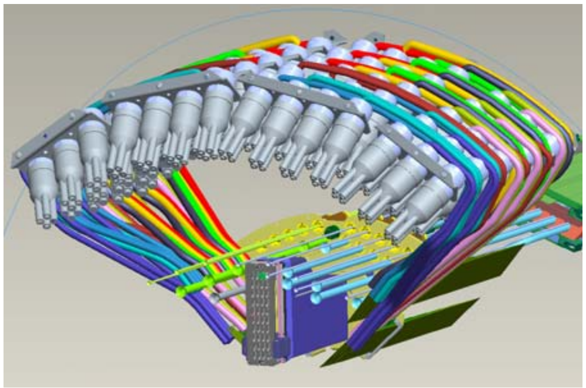

Figure 8.4.18 Illustration of the PP1region with the components described in the text.

The heat exchangers are placed into the support arms of the backbone structure and the inlet and exhaust pipes penetrate through the PP1 quarter plate as shown in Figure 8.4.18. Bellows-assemblies are attached to each heat exchanger and to the PP1 quarter plates. These assemblies provide a gas seal by using a thin-wall, but tight-fitting PEEK sleeve around each heat exchanger tube and threaded PEEK insert that connects to the PP1 quarter plate. The copper bellows, glued to the PEEK parts, are necessary to allow for contraction of the heat exchangers during cold operation by 2-3mm. The region of the bellows is shown in Figure 8.4.19.

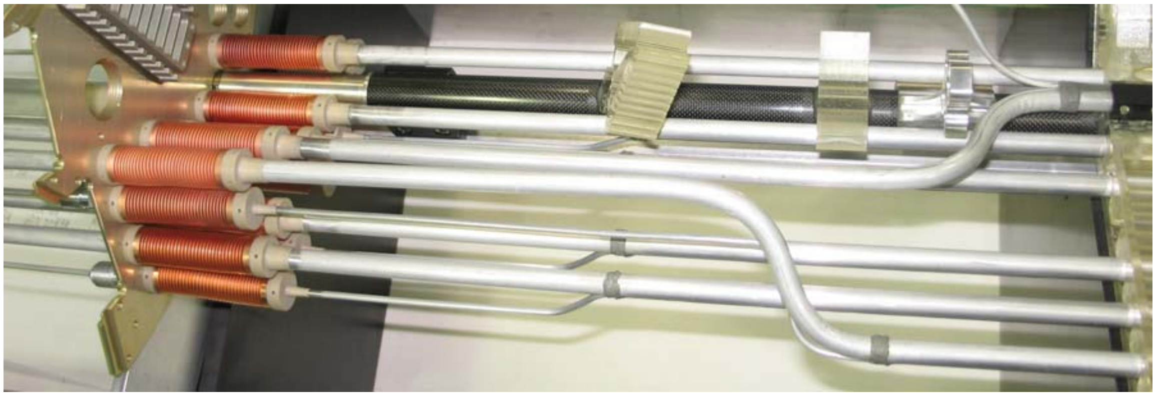

Figure 8.4.19 Heat exchangers loaded into a backbone in the region of the PP1 quarter plate showing the bellows-assembly seal described in the text.

A service panel assembly consists of a PP0 printed circuit board unit connected to a corrugated carbon-fiber support that holds and guides the Type-1 electrical services that are soldered to the PP0 unit. Plastic structures (manufactured by stereo lithography) and mounting tabs are mounted to a service panel. An inner service panel mounts to the backbone structure on the side closer to the beamline of ATLAS (inside). An outer service panel mounts to the outer side of the backbone structure.

The services panels are connected with small aluminum screws to the support arms of the backbone structure. The laminated printed circuit boards from each Type-1 electrical services bundle are captured by an aluminum flange that bolts to the PP1 quarter plate. A photograph of the region near the PP1 quarter plate is shown in Figure 8.4.20. The complexity of the connections and the tight clearances are evident from this photograph.

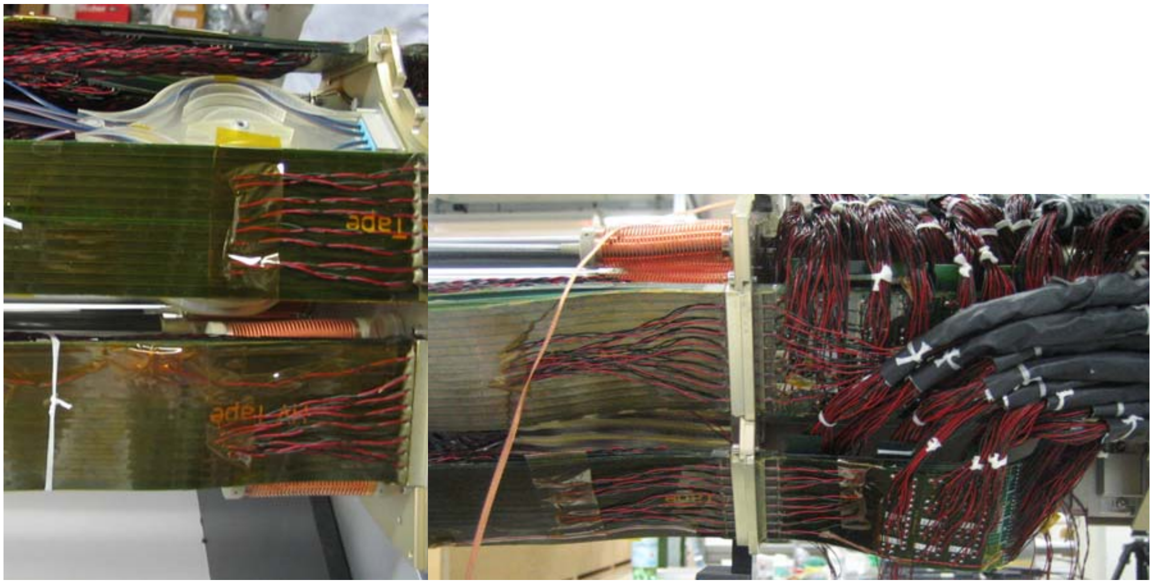

*Figure 8.4.20 Region near a PP1 quarter plate after the attachment of inner and outer service panels. ***Needs work!!!*

Opto-boards are mounted to the PP0 printed circuit boards (by their respective connectors). The optical fiber ribbons are attached to the opto-boards and routed along a service panel to a plastic structure attached to the PP1 quarter plate that captures the ribbon but that can take up slack in the ribbon needed for attachment to the PP1 optical connector. One of these plastic structures may be seen in Figure 8.4.20a and these were also made by stereo lithography. The fibers are routed through the PP1 quarter plate and into a box structure (not yet in place in Figure 8.4.20a) to which the PP1 connector plate is attached. The box structure is needed to position the connector plate away form the PP1 endplate to allow access.

Temperature control of the opto-boards is accomplished by a cooling circuit that routes coolant to aluminum structures and fingers brought into contact with the opto-boards through a thermal-grease interface(Reference goes here). A photograph of the thermal fingers and structures in contact with the opto-boards are shown in Figure 8.4.21.

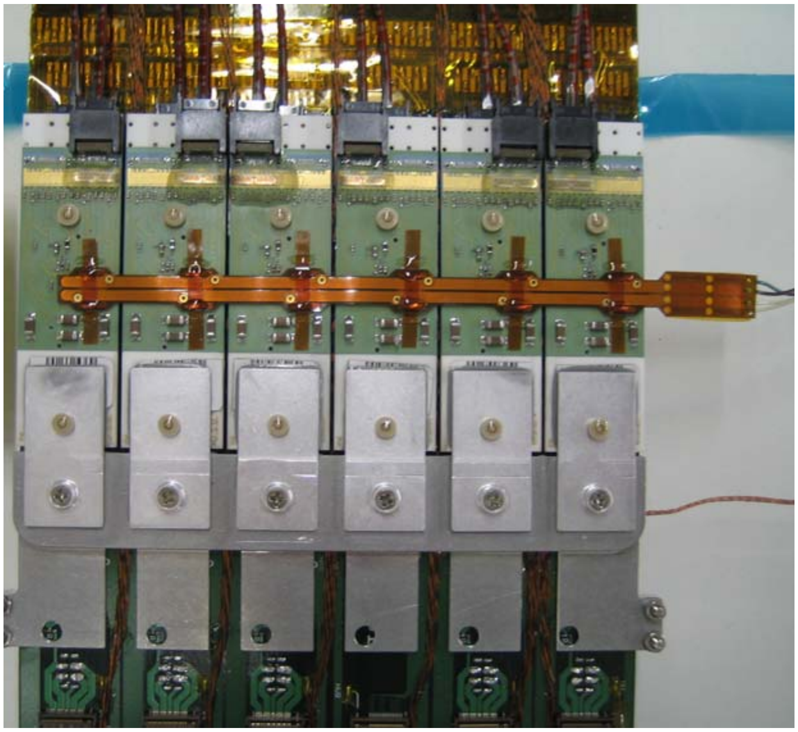

Figure 8.4.21 Photograph of the cooling connection made to the opto-boards, as described in the text.

During the initial testing of opto-boards on a prototype Service Quarter Panel, it was realized that additional thermal control of the opto-board temperature was required, in particular to prevent the opto-board temperature from being too cold. The additional thermal control was instituted largely after the fabrication of the service panels had been completed. The additional elements consist of copper-on-kapton heaters attached (glued as seen at the top in Figure 8.4.21) to the opto-boards and a thermal “blanket” shaped from a kapton-copper laminate that was placed over the opto-boards such that self-heating would also increase their temperature. These heaters were connected to small, multi-wire cables passing through a spare hole in the PP1 quarter plate and connected externally to controllable power supplies to regulate the temperature.

We very briefly describe the assembly and testing of the Service Quarter Panels here. All of the mechanical, cooling and electrical services components of the Service Quarter Panels were made or integrated at a single production site in the United States. The assembly of service panels and integration of heat exchangers with the backbone supports and PP1 quarter plates occurred at this site. Extensive quality control procedures were implemented for the Type 1 electrical services to verify connectivity and measure resistances at each major step of the assembly of the service panels. Outer service panels were attached to the loaded backbone structure for each of the eight SQP. These substructures were shipped from the United States to CERN. The inner service panels were shipped separately. [1]

The final integration of the SQPs occurred at CERN. Opto-boards were attached to the service panels and fibre ribbons connected. The pixel detector has 272 opto-boards with 316 VCSEL and 272 PiN packages on-detector. Extensive qualification testing was done for the optical system. Three steps were taken in the testing of the optical ribbons. Each optical fibre was subject to a visual inspection to make sure it was not damaged during handling/labeling. Then, after a calibration procedure, they were tested to ensure that the attenuation was within expectation (< 20% excluding losses from additional test fibres). The same test was run after the fibres were installed in the SQPs. This test ensured that there were no breaks during the installation. Once the opto-board was attached, the complete optolink (including the fibers) was tested. The best VISET and DAC settings for DRX were obtained. A pseudo-random signal was sent from the BOC card at the test setup. This signal was returned from the PP0 connectors to the opto - boards and compared with the original signal at the test setup to find the number of bits that changed. If a link failed this test, both opto-board and the fibers were retested separately. Parts that failed were replaced such that the final yield for a SQP was 100% at this stage of assembly.

Inner service panels were attached at CERN. This included also complex routing of temperature and environmental connections.

The final step in the completion of the Service Quarter Panels was to prepare the external Type 1 services and heat exchangers to allow for insertion of the assembled pixel package into the Pixel Support Tube (see section 8.8 and 8.9). The clearance between the inner diameter of the Pixel Support Tube and the outer radius of the quarter plate was only a few millimeters. Thus it was required to bend and compact temporarily the external Type 1 electrical services to allow them (on one side) to pass through Pixel Support Tube. In order to do this, a protective aluminum structure was made to fit over the heat exchanger tubes exiting from the PP1 quarter plate.

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[1] One SQP was shipped with both inner and outer service panels attached to the integrated backbone structure.

The external Type 1 electrical services were bent and compressed and held to the protective structure as shown in Figure 8.4.22. Temporary extensions of the heat exchanger pipes were added before this stage such that vacuum leak checking could be done during the final integration of the SQP with the cooling circuits of the pixel detector (see section 8.8). These extensions are partially visible in Figure 8.4.22.

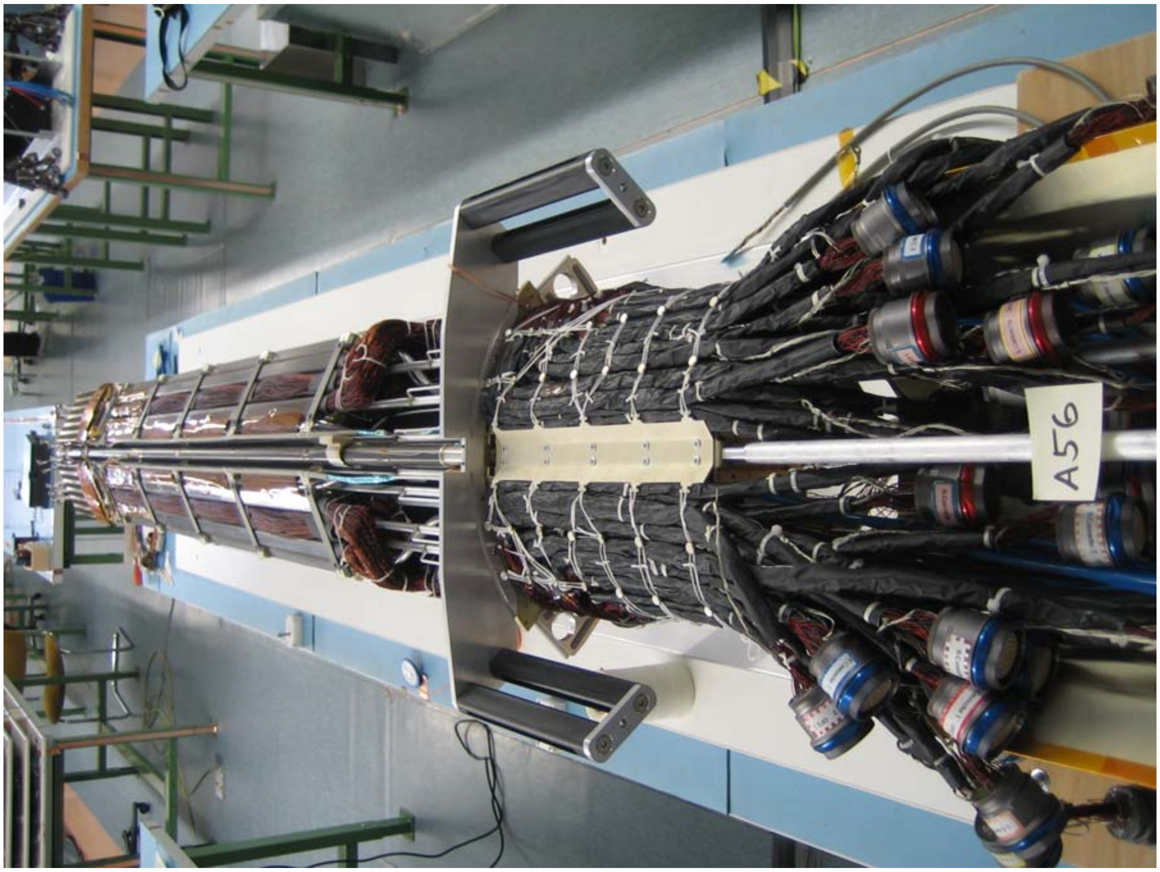

Figure 8.4.22 Photograph of the external Type 1 electrical services compacted as described in the text.

A completed SQP was transported to the integration site of the pixel detector package, described in Section 8.8.

8.5 External Services

External services include electrical cables, optical fibers and cooling pipes that connect to the pixel detector at the PP1 region – see Figure 8.5.1 for reference to cable types and patch panel logical locations.

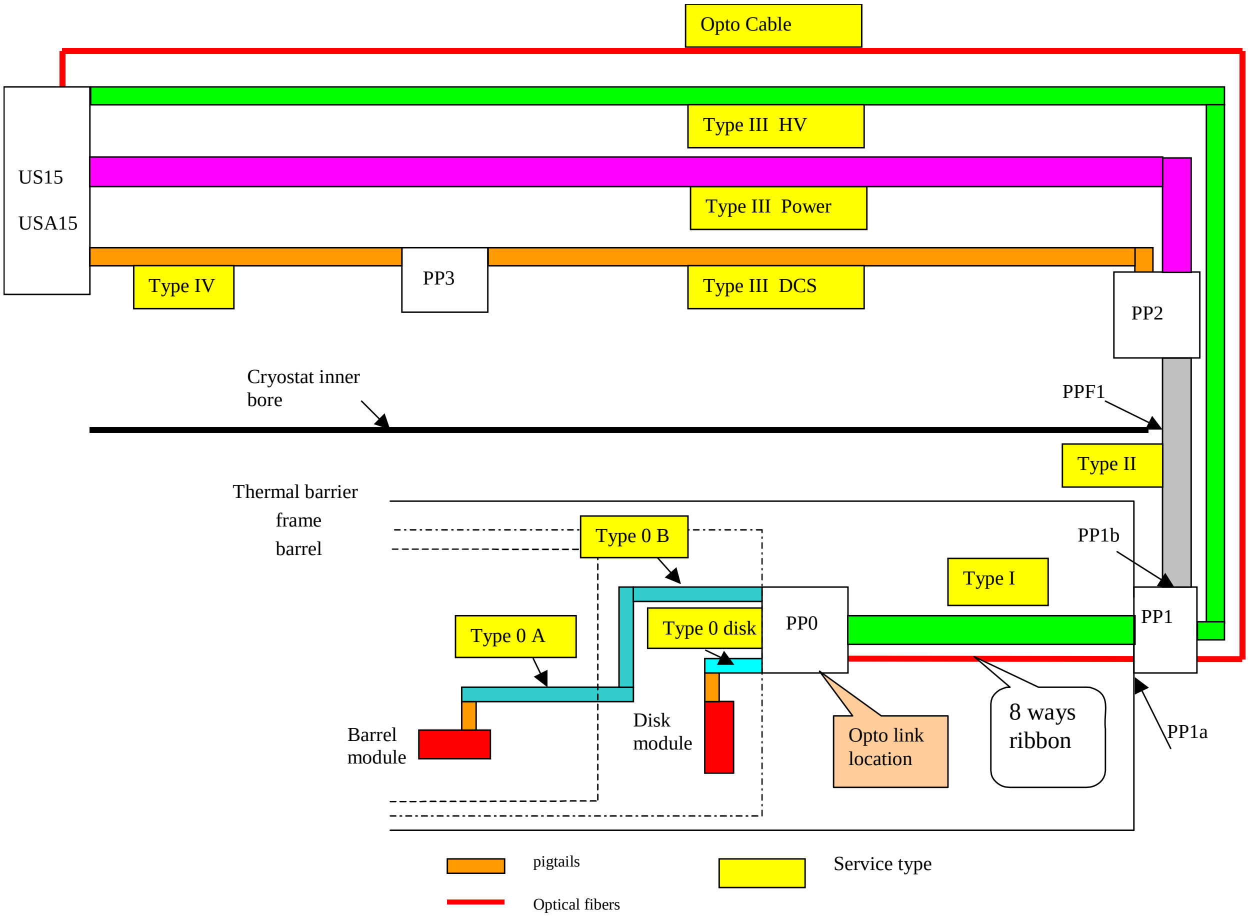

*Figure 8.5.1 Overview of the pixel internal and external services and patch panels. ***Placeholder*****

Patch panels and active elements – voltage regulators – are also part of the external pixel services. An overview of the Data Control System and its components has already been given in Section 4.6. We describe here additional elements of the external services and related systems.

All the services have to be disconnected at PP1 to allow for removal/installation of the pixel system. While at PP0 and PP1 all the cables and cooling connections are located close together in the same area, cables, fibres and cooling tubes at the other patch panels are placed in different locations because they are subject to different requirements. In general the component used between PP1 and PP2 have to be radiation resistant (up to 5 x 10^5 Gy), while the more external components use standard material.

The PP2 locations for the cables are placed in specifically designed platforms after the first layer of the muon spectrometer system. The PP3 locations are outside the ATLAS active detector volume. The PP4 locations are in the counting rooms, close to the power supply units.

Each PP2 platform hosts a different combination of active regulation stations (described in 8.5.4) and passive patch panels for the temperature and environmental monitoring signals. Space constraints, the high number of connections per platform and the position inside the toroidal magnetic field has required a careful design to allow maintenance during operation.

PP3 is mainly the place where the front end components of the DCS are located:BBIM, BBM and optical services. All the temperature and environmental monitoring signals and opto services go through PP3. For the opto-services cables, PP3 is only a break point, while for all the other signals monitoring function also create the logical signals for the interlock system.

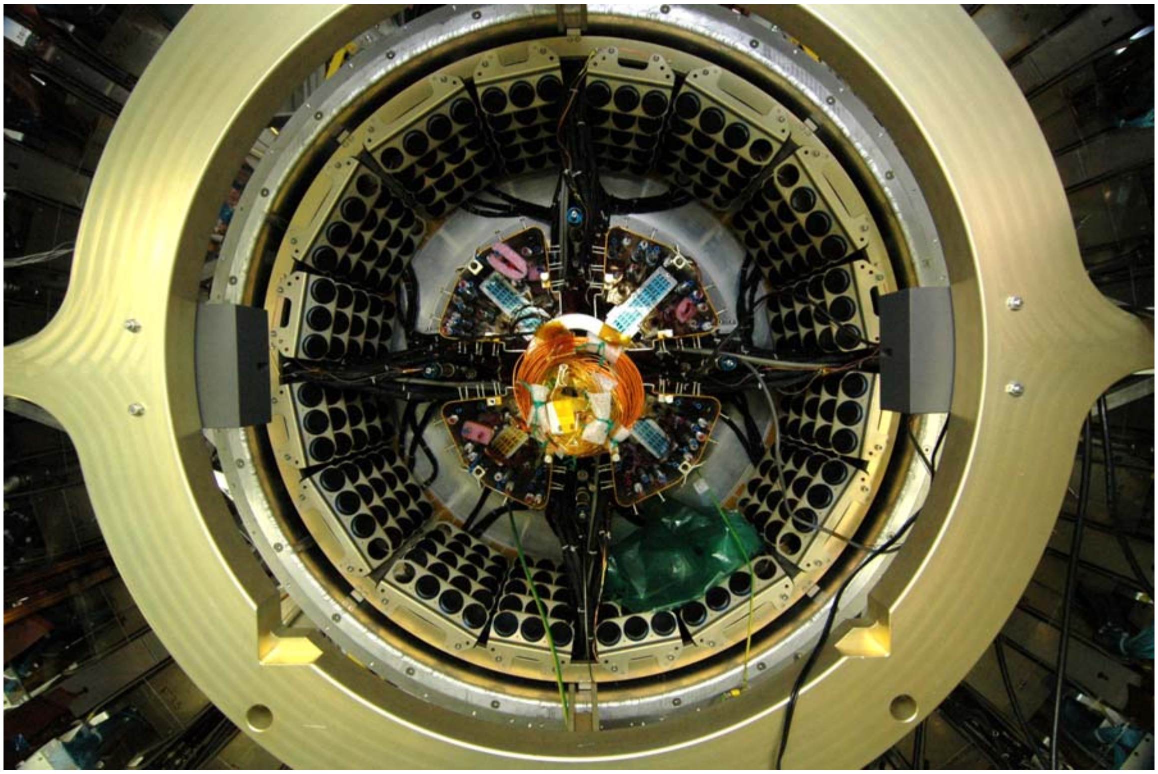

Figure 8.5.2 Photograph of the PP1 region at the end of the Pixel Support Tube before connection of external services.

8.5.1 Cooling Pipes

Connections to the ATLAS evaporative cooling system are made at PP1. A photograph of the PP1 region, before connections were made to the external services, is shown in Figure 8.5.2. Custom bent aluminum exhaust and inlet pipes are used to connect the corresponding pipes from the heat exchangers (described in 8.4.6) to external stainless steel blocks located about 40 cm from the beamline to which copper pipes have been brazed. Photographs of these custom pipes are shown in Figure 8.5.3a and Figure 8.5.3b. There are 53 different geometries made by custom pipe bending. A fitting is attached by laser welding to one end and this end bolts into the stainless steel block. The remainder of the evaporative cooling system is described in Ref. ###.

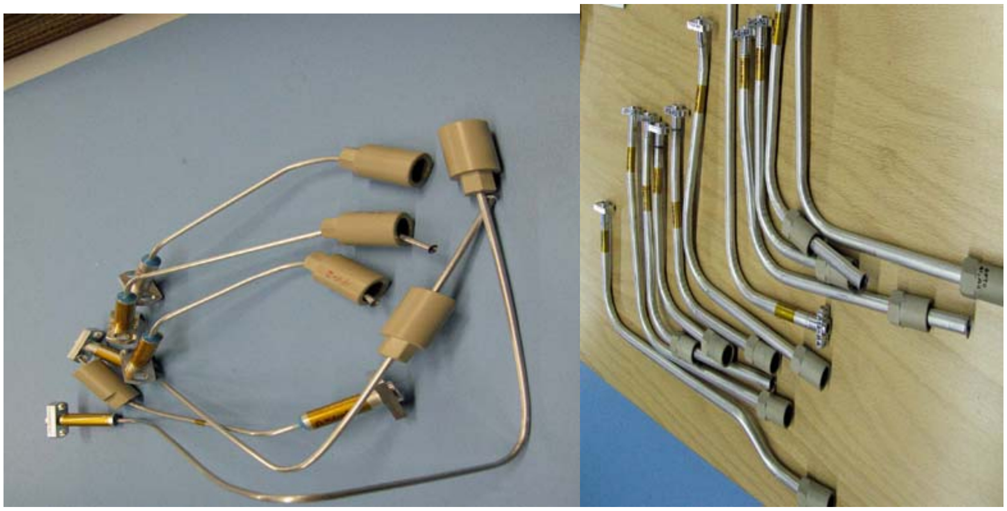

Figure 8.5.3 Photograph of the custom pipes connectng PP1 to the ATLAS evaporative cooling system.

8.5.2 Optical Fibers

The internal optical fiber ribbons and the connector at PP1 have been described in the previous section. The connection outside the pixel detector between PP1 and USA15 is done by optical unitube fiber cables that contain eight 8-way ribbons each. Though there are eight single fibers in a ribbon, only 6 or 7 fibers are actually used for transmitting data from the modules or receiving TTC information for the modules.

The total number of single fibers for the pixel detector is 3774. The inside of the ATLAS detector is a zone of high radiation limiting the lifetime and the light transmission of optical fibers. Outside the ATLAS detector the radiation levels will be considerably lower than the ones inside. Therefore radiation hard SIMM50[2] multi-mode fibers are used inside the ATLAS detector(the fiber ribbons described previously) and radiation tolerant GRIN50[3] fibers for timing and GRIN62.5 fibers for data transfer outside of the detector.

Eighty optical unitube fiber cables transfer the data and timing information between PP1 and the counting room in USA15. The unitube cable has a protective sheath of halogen free flame retardant polyethylene (HFFR-PE). In addition, there are two spare fiber cables per side. The 84 fibre cables consist each of 8 about 8.1 m long radiation hard SIMM50 ribbons which are fusion-spliced to 8 about 71.1 m long radiation tolerant GRIN50/62.5 ribbons. The total length of the stainless steel tube that protects the spliced joint is about 60 cm and over this length the cable diameter grows from 0.95 cm to 1.4 cm. This technique of splicing avoids having any additional patch panel and there is the advantage that splicing is cheaper and more reliable than connectors.

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[2] SIMM - Step Index Multimode fibre from Fujikura***need full name here***

[3] GRIN – Graded Index fibre from Draka ***need full name here***

All internal ribbons and all 84 optical fiber cables were tested at the factory in a configuration similar to the installation configuration in the ATLAS detector. Light was injected at the PP0 end of the ribbon and detected at the USA15 end of the fiber cable. This method measures the total light loss. The attenuation of the light signal was smaller than 2.5 dB for the data transfer lines, and smaller than 3.5 dB for the TTC lines.

After installation of the optical fiber cables in the ATLAS cavern, all 84 cables with their 672 ribbons were tested with an optical time domain reflectometer (OTDR) in order to guarantee that no fibers were damaged during cable instalation and fixation in the electronics racks.

8.5.3 Electrical Cables and Patch Panels

The functional location of the Patch Panels(PP2, PP3, etc) is defined in Figure 8.5.1. We summarize here the principal parameters of the electrical cables (see Table 8.5.1).

Cable Type	Function	Wire Size/Gauge	Wire	Total Number	Insulation Type
Low voltage Type II				276	
	VDD	2 x AWG20 1 x AWG22 1 AWG28	7 twisted quad		SILTEM
	VDDA	2 x AWG20 1 x AWG22 1 AWG28	7 twisted quad		SILTEM
	VVDC	3 x AWG22	1 twisted quad		SILTEM
Low-voltage Type III				276	
	VDD	AWG16	7 twisted pair		
	VDDA	AWG14	7 twisted pair		
	VVDC	AWG18			
High voltage				336	
	High voltage	AWG26	4 x 7 twisted pair		SILTEM

Table 8.5.1 Characteristics of low-voltage and high-voltage cables connecting the pixel detector at PP1 to external power supplies, voltage regulators and monitoring stations.

Type II Low-Voltage Cables

A low-voltage Type II cable is a bundle of three sub-cables. Two cables (VDD,VDDA) have seven twisted conductors (2xAWG20, 1 xAWG22, 1 AWG28). The third cable, VVDC, has one twisted quad-set of conductors of (3 xAWG22, 1 AWG28). These sub-cables are insulated with SILTEM(Footnote SILTEM is a flexile siloxane-polyetherimide polymer , non –halogenated, that is used for cable coating and has been qualified as radiation resistant at a level higher than the 5 x 10^5 Gy) and electrically shielded. The bundle is DC-grounded at PP1 and AC-grounded at PP2. The cable bundle is terminated at PP1 with a 64 pin connector (Footonote LEMO Series 5F (FGW.5F.364.XLC) and at PP2 with a 66 pin connector (Footnote Positronics GMCT66M00P0Z0). A total 276 are installed.

Type III Low-voltage Cables

Low-voltage Type III cables are individual cables with standard insulation. A VDD (VDDA) cable has seven twisted pairs of AWG16 (AWG14) wire, while a VVDC cable has one twisted pair of AWG18 wire. A VDD or VDDA cable is terminated at both ends with a 34 pin connector (Footnote Positronic GMCT34M0TLR00). VVDC cables are terminated at both ends on a 9pin Sub-D connector.

High Voltage Cables

The high voltage cables run from PP1 to PP4. A HV cable is also a bundle of four ssub-cables. Each sub-cable is made of seven twisted pairs of AWG26 conductors, SILTEM insulated and rated for use at 700V. The high voltage cable bundle is terminated at PP1 with a 64 pin connector (FootnoteLEMO Series 5F (FGW.5F.364.XLC)) and at PP4 with a 22 pin connector (Footnote LEMO/REDEL Rectangular High Voltage Connector standard at CERN (SCEM 09.41.34.110.8 22 pins). In total 336 cables are installed.

Patch Panel 2

The voltage regulation system at PP2 is described below in 8.5.4. *****Other functions briefly here*****

Patch Panel 3

Patch Panel 4

The connection between low-voltage and high-voltage cables and their respective power supplies is made at Patch Panel 4(PP4). Additional monitoring hardware is also provided at PP4. Connectivity and current monitoring between the low voltage power supplies (VDD and VDDA for each module) and the local regulators at PP2 is implemented. In order to conserve resources, one low voltage supply channel supplies 6 or 7 circuits, corresponding to a half stave or a sector. Ground is common within a group of 6 or 7 circuits but isolated between them. A current measurement is made through a low value, high precision resistor in each of the 6 or 7 circuits. The measurement is then digitized and read out over an Embedded Local Monitoring Board (ELMB) via a CAN bus. The measurements are monitored through the pixel DCS software.

High voltage monitoring functions in a similar manner but at higher voltage and lower current. Monitoring boards housed in 16 crates at PP4 will monitor up to 117 detector module currents per crate, in the range 0.4 – 4 mA. In addition, the hardware allows the connectivity to change from 6 or 7 circuits per supply channel (current configuration) to only 1 or 3 circuits per supply channel (future configuration), once radiation damage of the pixel sensors causes the high voltage current requirements to exceed the capacity of a single power supply channel. The change can be accomplished by removal of circuit jumpers on VME-form-factor cards at PP4 at the appropriate time. Grounding is common within pairs of circuits and isolated between pairs. Individual circuit current measurement capability, corresponding to a single module, is included in the design and a bad circuit can be disconnected. The measurement is digitized and read out over an ELMB via CAN bus and monitored through the pixel DCS software.

8.5.4 PP2 Voltage Regulators

The low voltages necessary for the pixel integrated circuits and the inherent resistance of the power supply cables, require voltage regulation to be implemented as close as possible to the pixel detector. Voltage-regulation is provided by custom-designed and custom-built, remotely-programmable regulator stations located at PP2(Refs go here). These stations provide individual power outputs with low ripple and protect the integrated circuit electronics against transients up to 4 volts, the nominal maximum rating of the 0.25 micron integrated circuit electronics. One regulation station powers up to 84 detector modules and also provides power to the opto-boards.

A regulation station consists of 12 printed circuit boards(Regulator Boards) and a Controller Board housed in a custom crate. The unregulated input voltages enter the crate via an input board and are distributed to the Regulator Boards by a custom backplane. The regulated voltages are in-turn provided under computer control by the Regulator Boards and distributed via the backplane to the Type II cables and thereby to the pixel front-end electronics.

A Regulator Board is built on a highly dissipative substrate (approx 20W/board). Each board provides 15 independent voltage channels, 14 for the pixel module electronics and one redundant line for the opto-board. Each board houses 16 rad-hard voltage regulators(Footnote manufactured by ST Microelectronics - LHC4913 positive voltage regulators). Output voltages are programmable in the range 1.4-2.6V, at the load, with a 10mV regulation step. The board has the capability to digitally adjust the output voltage and to monitor voltages and currents of each output channel as well as the temperature of the board. Current compensation is implemented for each voltage and the maximum current per channel is 3A for the module channels and 1A for the opto-board channel.

A Controller Board supervises all operations and communicates with the Regulator Boards and with the pixel data control system. The implementation of the Controller Board is based on an FPGA (Footnote, ACTEL PRO ASIC PLUS APA075). The FPGA can be reprogrammed via the CAN bus to allow for adjustments of the voltages and currents provided to the front end electronics during the lifetime of the experiment.

The regulation station will operate in a moderate radiation environment and is required to operate with no degradation up to a total dose of about 140 Gy and a maximum neutron fluence of about 1.3 10^{12} 1 MeV n_{eq}/cm^2. The location of the regulation station (PP2) allows a limited possibility of access for repairs. Prototypes of the regulator and controller boards have been extensively tested under radiation. The tests have shown that the performance of the boards is substantially unchanged after radiation. These results have been achieved by proper selection of the components and design.

The mechanical structure of the regulation station is completely enclosed in mechanical panels to ensure proper electrical shielding. The boards are cooled with a dedicated C_6F_{14} circuit similar to that used for other elements of the ATLAS inner detector. The 28 regulation stations are distributed in 12 different locations near the first layer of muon chambers in the ATLAS detectors, and are mounted in groups of two or three crates.

8.5.5 Electrical Services Testing

Testing of the electrical services took place during various stages of the installation and during a final test of the full chain, from the counting room at PP4 to PP1 and back. A hardware and software package was designed for this purpose, to ensure that safe connections could be made at PP1 to the internal pixel services and modules. All elements of the electrical chain were tested, including low voltage power supplies, opto-link power supplies, active low voltage fan-outs at PP4, regulator boards at PP2, high-voltage power supplies, passive HV fan-outs at PP4, as well as the complete interlock system. Service tests included basic continuity checks, PP4/PP1 measurement cross-checks, interlock functionality tests and calibration of the voltage regulators at PP2.

Measurements were made at PP1 using hardware with the GPIB (General Purpose Interface Bus) interface, including a set of digital multimeters, switching matrices and a programmable load generator. This hardware was connected to the PP1-end of each of the Type-II cables. The software was responsible for controlling the DCS (Detector Control System) and GPIB hardware to switch through all channels in a cable, supply the proper termination loads and test all channels. The design of the software simultaneously checked the connectivity mapping of the detector, as used in DCS. The full documentation for the service tests summarized above can be found in ATL-IP-QA-0026. Any services responsible for transferring the data to the external read-out system were tested separately during DAQ sign-off (see Section XX).