# *Fibre routing for SCT Optical Links*

v. 0.5

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## SCOPE

The purpose of this document is to identify a solution to the routing of optical fibres from the SCT detector front-end to the RODs located in the counting room USA15. Solutions for the modularity of optical fibre grouping at all points along the route as well as the number and purpose of the foreseen break-points. Ideas and solutions in this document should be regarded as preliminary and under discussion.

***All technical drawings presented in this document are preliminary and are included for discussion only.***

## 1 INTRODUCTION

The SCT will be read-out and supplied with clock and control signals optically, with approximately 8000 data- and 4000 control links being required to achieve this requirement[1]. These numbers come from the fact that each silicon module will require one control and two readout links. It is imperative that the same optical link design be used in both the barrel and forward regions of the SCT to minimise the cost and development effort.

The modularity of the physical layout of barrel and forward is very different due to the inherently different geometries that must be employed to maximise the coverage of the detecting elements. The central region is instrumented with detectors in a 4-layered barrel structure, while the forward region is instrumented with detectors mounted onto disks. This leads to different sensor and readout geometries, and thus different module designs, for the barrel and forward regions of the SCT. The proposed layout of the Atlas Inner Detector is shown in Figure 1.

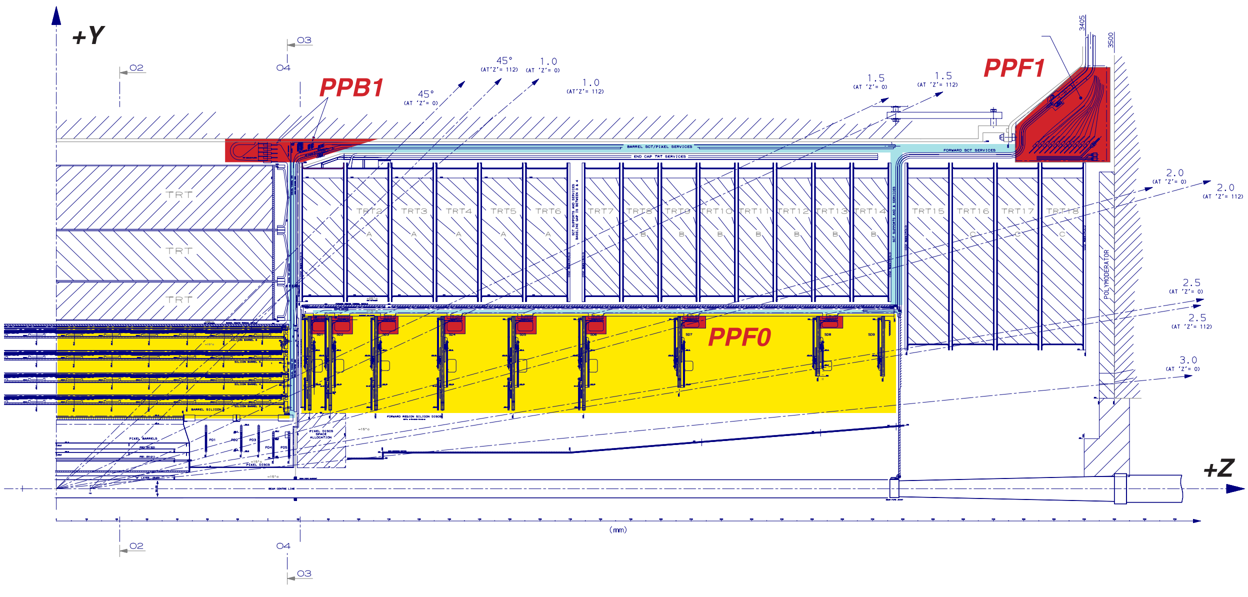


*Figure 1: Cross-section view of one quarter of the Atlas Inner Detector, showing the position of the SCT detector volume, cable paths and patch panels.*

The different module designs have an impact on the arrangement of the components making up the optical data transmission system. The differences are shown schematically in the context of the overall detector readout systems for the barrel and forward regions in Figure 2. The major difference is in the placement of the opto-packages (containing the optical transmitters and receiver) relative to the ASICs which drive them. In the case of the barrel SCT, shown in Figure 2(a.), the opto-package is mounted with its drive electronics separately from the front-end hybrid that is directly bonded to the silicon detector. In contrast, the forward front-end hybrid incorporates the opto-ASICs (VDC and DORIC) and the opto-package is mounted onto its own plugin-in PCB.

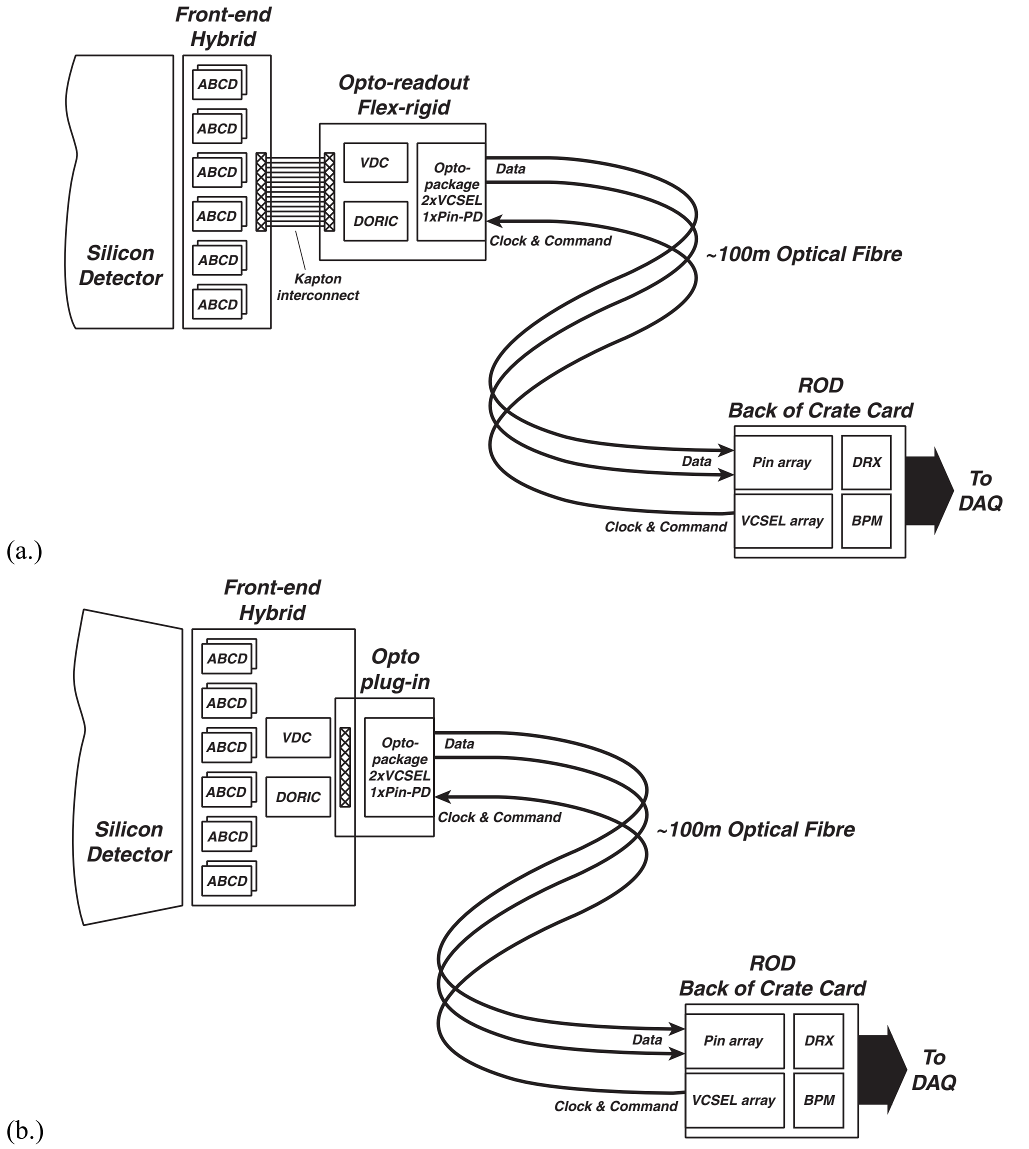


*Figure 2: Overview of SCT barrel (a.) and forward (b.) readout systems. Note different positions of custom opto-package, VDC and DORIC.*

# 2 GENERIC ISSUES

The main factors affecting optical fibre routing can be divided into four major types of constraint, which will be covered in detail below:

- System constraints (latency, power budget and handleability during installation)
- Layout constraints (feasibility of installation, available space and laser safety)
- Component constraints (connector-, ribbon- and cable modularity)
- Cost constraints (relative cost of components)

## 2.1 System constraints

Included in this category are issues which impact upon the proper functioning of a single link in its final configuration of components and their relative layout.

### 2.1.a Latency

Readout data are stored in pipeline buffers on the front-end ASICs until a level 1 trigger prompts the SCT to be read out. The depth of these buffers is fixed to be a finite value (3.3µs) and data are overwritten if they remain in the pipeline waiting to be read out longer than this time interval. It is therefore imperative that the level 1 trigger signal arrives at the front-end hybrids within the fixed time interval.

Several factors contribute to the length of time between the bunch crossing (BC) during which the event occurred and the trigger signal arriving at the front-end, as outlined the current SCT latency status document[2]. Two of these factors are related to the optical fibre routing: the fibre length between the ROD and the TTC crate where the signal is generated; and the length of fibre between the ROD and the detector front-end. In this document only the latter will be discussed in detail, although it should be noted that some trade-off between the two lengths is possible. The best estimate for the TTC-ROD distance results in a time delay of 5.4 BC in the worst case, based on the relative positions of TTC and ROD crates shown in Figure 3. This figure is based upon the rack allocation proposal most recently outlined by Philippe Farthouat and Mark Hatch.

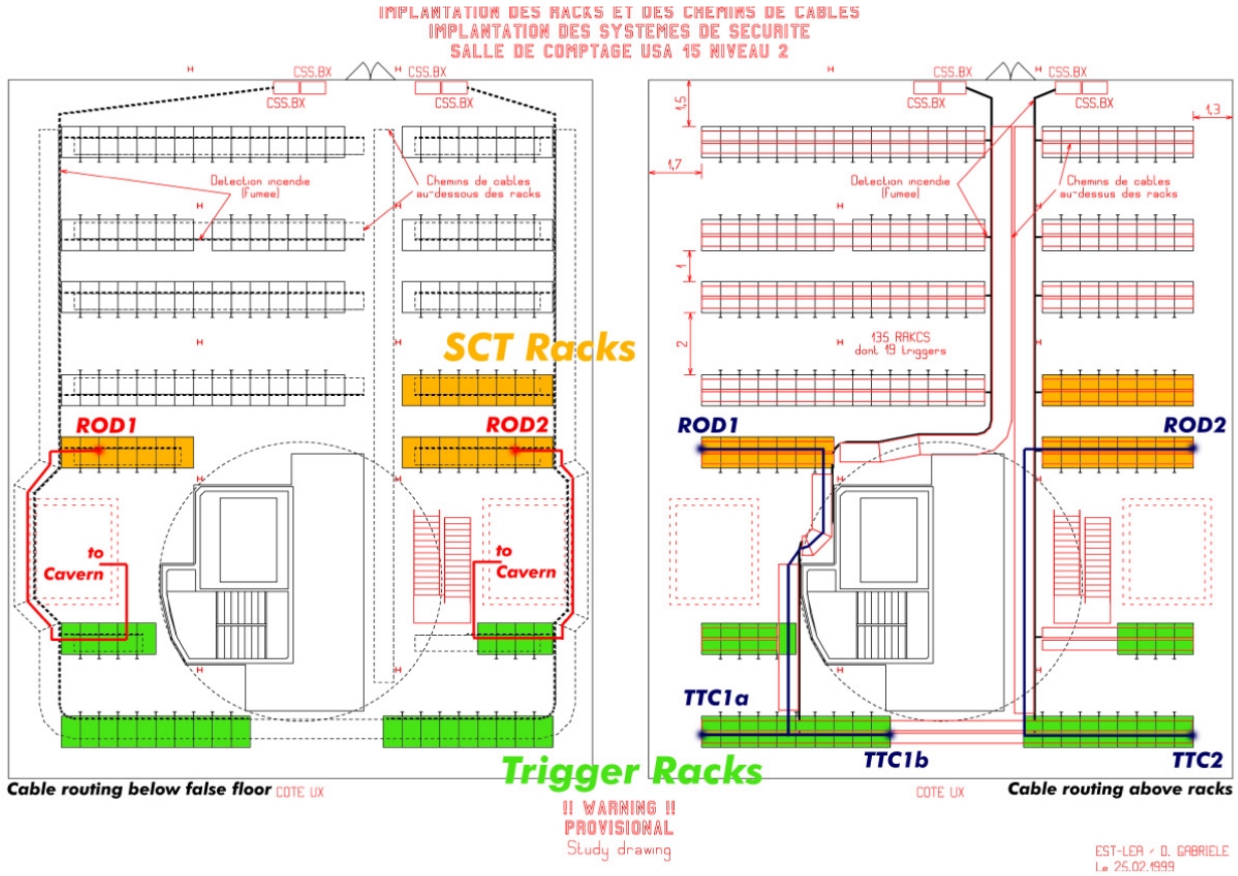


*Figure 3: Relative positions of TTC and SCT racks in the counting room (USA15), with proposed cable routes shown for information.*

The current latency survey[2] gives a total latency of 132.0 BC, including the current SCT-wide contingency of 6.5 BC. The current survey allows 6.4 BC for TTC-ROD distance and 19.4 BC for a 97m optical fibre length from ROD to DORIC.

### 2.1.b Power budget

The minimum light level arriving at DORIC for in-spec decoding of clock and control information must be 200µW. The comparable specification at the ROD is as yet undefined, although the level may be slightly lower.

### 2.1.c Installation – handleability

In order to handle the large number of individual fibres while minimising the risk of fibre breakages it is prudent to group the fibres as early as possible. In practice this means using fibre ribbon wherever possible and only breaking this out into individual fibres close to the actual opto-packages. Ribbons will be protected inside a loose tube cable for the final run to the counting room. For increased protection a solution to over-sleeve several ribbons in situ is currently under investigation with a cable manufacturer.

## 2.2 Layout constraints

### 2.2.a Installation – feasibility

It is likely that fibre ribbon will be purchased pre-terminated with MT connectors, as it is too difficult to terminate optical fibre in situ during installation. During installation account must therefore be taken of the fact that it will not be possible to feed the optical fibre ribbon through apertures which are only the size of the ribbon itself as MT connectors are considerably larger (~ 7mm x 8mm x 3mm) than bare ribbon. Because the fibre ribbon cannot be terminated to fit exactly during installation allowance must be made for slack fibre management at the foreseen breakpoints. It is currently estimated that the additional length which should be allowed for is of the order of several centimetres due in part to uncertainties in calculating the *exact* route a particular ribbon will take once finally installed in the experiment.

### 2.2.b Available space

The finite free volume within ATLAS will have particular impact on the design of patch panels, which are required allow installation and to make the transition from ribbon to cable.

Cable routing in the z-direction is only possible at specific locations in ϕ, which impacts upon the route that can be chosen for the readout fibres.

### 2.2.c Laser safety

A detailed discussion of all aspects of laser safety as it pertains to the ATLAS SCT optical readout and alignment systems is outside the scope of this document and can be found elsewhere[3]. All fibre ribbons and cables, if inadvertently broken at a point along their length, represent a $k\times3$A hazard level and thus require mechanical protection and adequate labelling. The fibre cable will therefore be enclosed in cable trunking which will require a special tool to gain access to the cable. The hazard level at connector breaks will be 3B due to the polished end-faces and patch panels will therefore have to be encased with interlocks fitted so that lasers are disabled when the patch panels are open. As the total number of patch panels is small the interlock system will not represent a large cabling overhead.

## 2.3 Component constraints

### 2.3.a Connector modularity

The most widely commercially available multi-fibre connector (the MT family) can be purchased in modularities of 4- 8- and 12-way interconnects, all of which share the same ferrule outline. It is foreseen to use 8- and 12-way MT connectors as these most closely match the proposed fibre modularities.

### 2.3.b Ribbon modularity

6- and 12-way optical fibre ribbon has been purchased for use in the ATLAS optical readout and control system. The 6-way ribbon is foreseen for the clock and control data paths while the 12-way ribbon is destined for the readout data path.

### 2.3.c Cable modularity

The current prototype optical fibre cable is a custom development by Ericsson Cables in collaboration with the ATLAS Liquid Argon Calorimeter and the CMS Tracker. The chosen modularity of 96 fibres (8 12-way ribbons) matches all of the applications and is unlikely be changed. Development of another custom optical fibre cable within the current cost constraints would not be possible as the quantity required for the ATLAS SCT is relatively small in a commercial sense.

## 2.4 Cost constraints

The ATLAS SCT optical readout and control system is cost limited, with current budgetary calculations allowing for a small amount of contingency. It is clear that all proposed routing schemes must be valued at less than the amount of capital available. The current cost model approximately breaks down as follows:

- Fibre 17%
- Opto-package 43%
- Dog-leg 7%
- Connectors 9%
- On-detector ASICs 2%
- Off-detector ASICs 8%

This leaves 4% contingency after allowing for the 10% contribution to Module 0 production. There are three connector breaks foreseen in the current cost breakdown.

## 2.5 Generic routing scheme

The above constraints lead to the generic routing picture shown in Figure 4, which contains three connector-break points between detector and ROD. The details of each individual cable section and the arguments for choosing the particular layout follow.

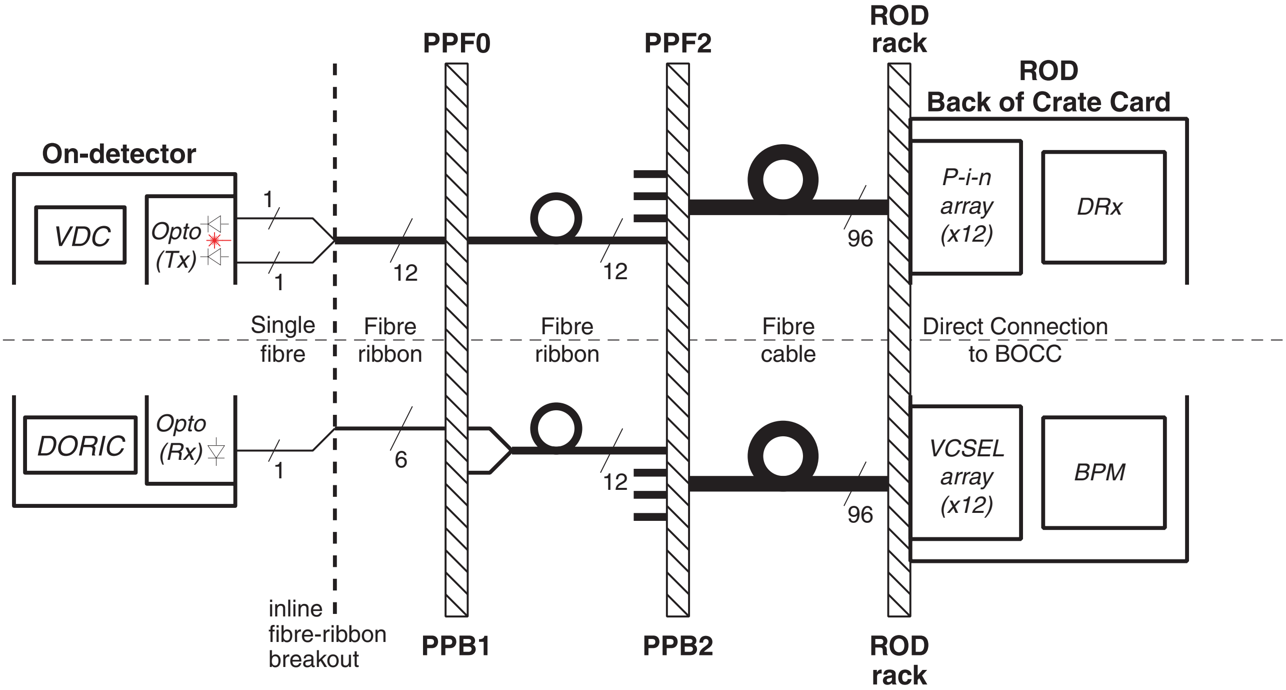


*Figure 4: System-level diagram of the SCT optical links. Readout data flow along the upper channel from detector (left) to ROD (right) while clock and command data flow from ROD to detector in the lower channel.*

# 3 HYBRIDS TO PPB1/PPF0

## 3.1 SCT Barrel routing

The SCT barrel structure consists of four barrels supporting 32,40,48,52 staves of 12 modules each, the numbers increasing at larger radii. Each stave is cabled in two halves, the smallest cabling assembly thus serving six modules. This matches the fibres modularity as each cabling assembly (*harness*) requires 12 data readout fibres and 6 control fibres terminated in one MT12 and one MT8 (since there is no MT6). Fibre ribbon will run from the end of the barrel to PPB1 where the first patch panel is located. On the barrel surface fibres will be broken out of the ribbon to feed successive modules away from the barrel end-flange.

Since the detector modularity matches that of the fibre ribbon there is no wasted (*dark*) fibre up to PPB1 for the barrel cabling. This statement holds whatever the number of fibre exits per end-flange. Visualisation of cable exits using both computer generated and physical models has led to the conclusion that there will have to be eight exits per end of the SCT barrel. There is then sufficient space to accomodate all of the power tapes and optical fibre ribbons.

The exact nature of the patch panel at PPB1 is still under investigation, the current baseline for making the MT connection being the CERN-designed FibreClip[4].

## 3.2 SCT Forward routing

The forward disks do not match the 6-off module modularity of the barrel. This leads to less efficient use of optical fibre ribbon and connectors, as shown by the mapping of fibres into connectors illustrated in Figure 5. It is proposed to use four exit points per disc to bring the optical fibre ribbons onto the surface of the forward support cage. These will allow sufficient space to bring all fibres out at patch panels on the edge of the disc (see below).

The Disc 2 (b) configuration makes less efficient use of connectors because of the added difficulty in installing fibre harnesses onto a disc that must cover modules on both sides. This situation is undesirable from a handling point of view during installation as it is incompatible with current ideas for the scenario used to install services onto the disc surface.

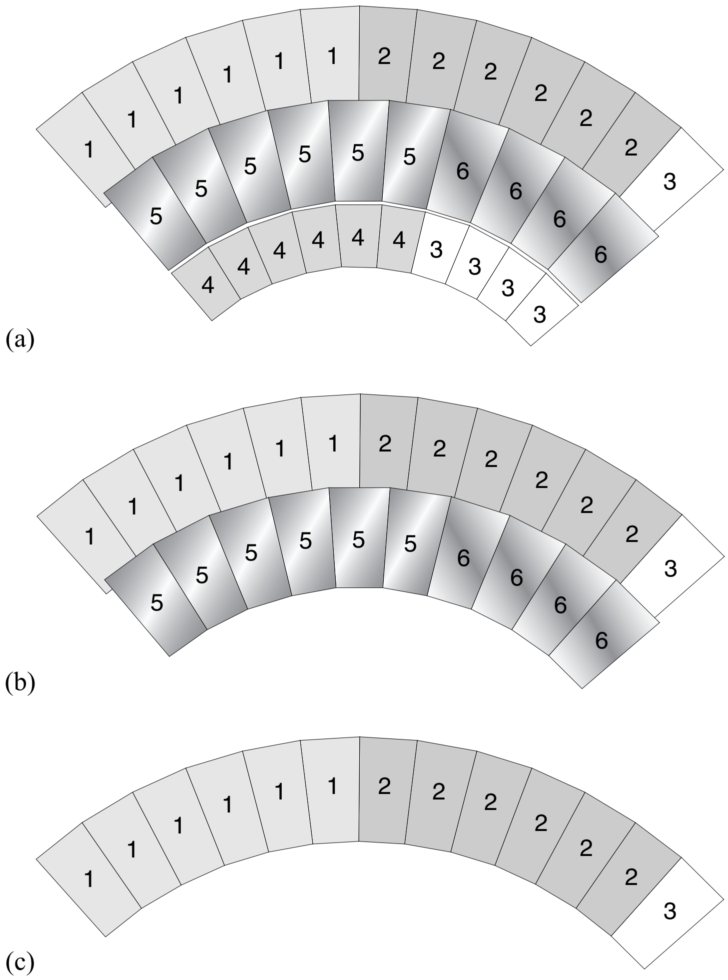


*Figure 5: Connector configuration for the three types of disc layout. Connectors 1-4 cover modules facing the IP, while connectors 5&6 face away from the IP.*

It is highly desirable from the point of view of installation of the readout and control optical system to have a connector break actually on the edge of the disks in the same manner as the power connection. This break-point is referred to as PPF0 in this document.

With the first optical connection at PPF0 it is undesirable to have an optical connection at PPF1. The most compelling argument against a break at PPF1 is one of cost. Re-evaluation of the number of connections required in the light of the number of dark interconnects due to the mismatch in detector and fibre modularity already reduces the budget contingency by 50%. Addition of another connector break would take the optical data transmission system over budget.

Table 1 gives the relevant numbers for the exit configuration we wish to use.

| | **Four exits per side of the SCT** | | | | | |
|---|---|---|---|---|---|---|
| | **Discs 1,3,4,5,6** | **Type total** | **Discs 2,7,8** | **Type total** | **Disc 9** | **Fwd total** |
| **Number per type** | 5 | | 3 | | 1 | |
| **Number of Modules** | 33 | 165 | 23 | 69 | 13 | 247 |
| **Number of Data Fibres** | 66 | 330 | 46 | 138 | 26 | 494 |
| **Number of C&C Fibres** | 33 | 165 | 23 | 69 | 13 | 247 |
| **PPF0 – MT12 required** | 5.5 | 27.5 | 3.8 | 11.5 | 2.2 | 41.2 |
| **PPF0 – MT12 actual** | 6 | 30 | 5 | 15 | 3 | 48 |
| **PPF0 – MT8 required** | 5.5 | 27.5 | 3.8 | 11.5 | 2.2 | 41.2 |
| **PPF0 – MT8 actual** | 6 | 30 | 5 | 15 | 3 | 48 |

*Table 1: Overview table of the fibre usage for the single exit per quadrant configuration.*

## 4 PPB1/PPF0 TO PPB(F)2

The second patch panel allows for the change from bare ribbon to ribbon cable. It is essential, in order to maximise the use of ribbon cable, that one is able to mix barrel and forward ribbons in the same cable. This fact requires the forward and barrel optical services paths to be in the same position in ϕ so that the patch panels can be in the same place. For ease of nomenclature the second patch panel will be generically known at Patch Panel 2 (PP2) for the rest of this document.

Figure 6 shows the proposed exit chimneys for use by the optical fibres. It is possible that the fibre patch panel may be located on the outside wall of the cryostat rather than in one of the chimneys. This would allow the mixing of barrel and forward ribbons to occur even if they arrived at PP2 in two separate chimneys. This will be important to reduce the amount of fibre wasted in the cable as this represents the longest length of optical fibre that is required and dark fibre in this run yields a large budgetary overhead.

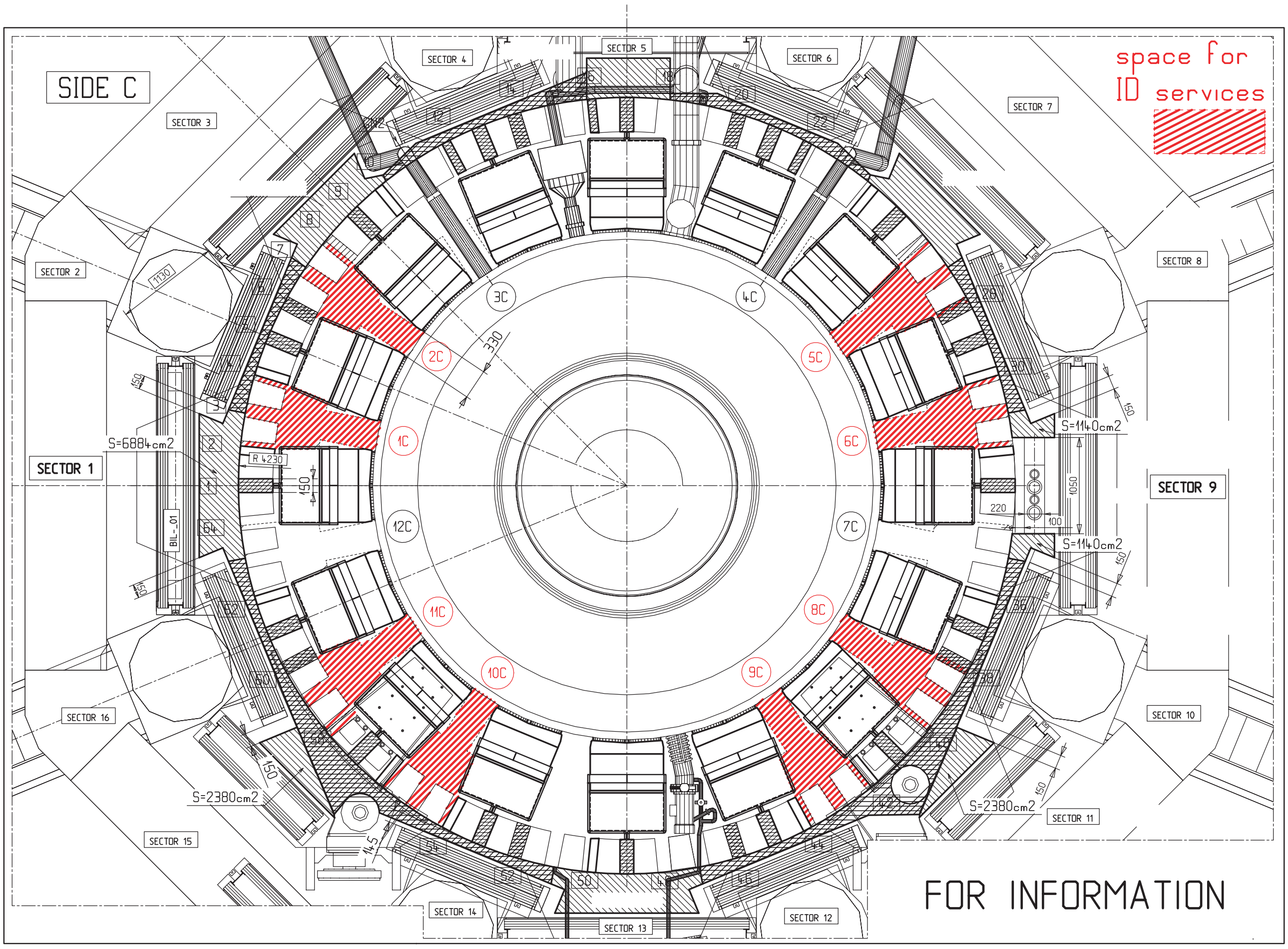


*Figure 6: End-view of the inner part of the ATLAS detector*[†]*, showing proposed exit chimneys for optical fibre routing*[‡]*. These exits are 1C, 2C, 5C, 6C, 8C, 9C, 10C & 11C.*

A routing factor common to both parts of the system is that the 6-way control fibre ribbons should be joined into 12-way ribbons along their paths to PP2. The method for achieving this should be similar to the break-out foreseen close to the detector modules, although the exact configuration is still to be defined.

## 4.1 SCT Barrel routing

Ribbons will run along the inner cryostat wall and up the end of the cryostat to PP2. They may be protected by a kind of Kevlar oversleaving which is currently under investigation with Ericsson Cables. The oversleaving would offer some mechanical protection and reduce the number of units to make handling and routing easier.

## 4.2 SCT Forward routing

Ribbons from the forward SCT detectors will follow the route to PPF1 shown in Figure 1. At that point they should join the barrel SCT ribbons in the same ϕ position. Oversleaving would be employed if it proves possible for the same reasons as given above for the barrel ribbons. Due to the mismatch in detector and ribbon modularity dark fibre cannot be avoided between PPF0 and PP2. The amount of dark fibre is given in Table 2.

| **Four exits per side of the SCT** |
| --- |

[†] *Taken from Drawing number AT722221PL*
[‡] *Ref. A.Nicholls, RAL*

| | "Wheel 1" | Type total | "Wheel 2" | Type total | "Wheel 9" | Fwd total |
|---|---|---|---|---|---|---|
| **PPF0 – PP2 12 fibre ribbon** | 6 | 30 | 5 | 15 | 3 | 48 |
| **Dark 12way ribbon** | 8.3% | | 23.3% | | 27.8% | 14.2% |
| **PPF0 – PP2 6to12 ribbon fan-in** | 3 | 15 | 3 | 9 | 2 | 26 |
| **Dark 6to12 ribbon fan-in** | 8.3% | | 36.1% | | 45.8% | 20.8% |
| **PP2 – MT12 quantity** | 9 | 45 | 6 | 18 | 5 | 74 |

*Table 2: Ribbon fibre wastage for a single exit/quadrant configuration of the forward SCT.*

# 5 PP2 TO ROD RACK

With the fibre ribbons from forward and barrel SCT available at the same patch panel it is possible to reduce the amount of dark fibre in the 96-way ribbon cable. In the single exit/quadrant configuration the amount of dark fibre will be 11.3% when the fibres are mixed, as compared to 16% dark fibre if they remain separate. This represents a substantial saving and should provide the baseline solution.

The distance from PP2 to ROD rack represents the longest part of the data path and is therefore the most important when considering the latency implications of a particular route. Since the counting room (USA15) is situated on one side of the experimental cavern (UX15) the cable lengths will differ depending upon which part of the detector they come from. The implications of cable length calculations made ATLAS integration group are shown in Table 3. Routing via the outside of the detector from sector 1 carries a length penalty which cannot be accommodated in the current latency budget. For this reason it is proposed to make use of the route via the voussoir which allows all sectors to be accommodated in the latency budget.

It has been proposed that all cables should break at a third patch panel at the edge of the detector. For the fibre systems this would require a break in the ribbon cable. The over-riding argument against making a break in the optical fibres at this point is cost, as with the break at PPF1. The link budget is not sufficient to allow a further break point due to the attendant connector cost. A break in the ribbon cable would also introduce extra slack length as it is unlikely to be possible to specify the cable length with great precision. This would negate the length gains made by preferring the voussoir route to the counting room and jeopardise the latency budget.

| | Best (shortest) | Worst (longest) | Voussoir (worst) |
|---|---|---|---|
| **TTCvi – ROD** | 24m | 27m | |
| **Timing (5m/B.C.)** | 4.8 B.C. | 5.4 B.C. | |
| **ROD – PPB1** | 74m (sector 9) | 107m (sector 1) | 89m (sector 1) |
| **PPB1 – DORIC** | 1m | 2m | 2m |
| **Patch Panels** | 2m | 2m | 2m |
| **Cavern Cable length uncertainty** | 5m | 5m | 5m |
| **Total ROD – DORIC** | 82m | 116m | 98m |
| **Timing (5m/B.C.)** | 16.4 B.C. | 23.2 B.C. | 19.6 B.C. |
| **Total time for fibre paths**<br>**(cf. John Lane 25.8 B.C.)** | 21.2/21.8<br>(-4.6/-4.0) | 28.0/28.6<br>(+2.2/+2.8) | 24.4/25.0<br>(-1.4/-0.8) |

*Table 3: Current estimates of latency-related fibre lengths.*

# 6 SUMMARY AND CONCLUSIONS

The SCT Barrel layout requires that the services exit at eight points per end due to space constraints for the cabling. Matching this number of exits in the forward SCT would lead to an unnecessarily large overhead in dark fibre, leading to the conclusion that one cable exit per quarter disc should be used for the optical fibres. The implications of these statements in terms of the required number of fibres and the proportion of dark fibre are given in Table 4. The assumption made for the forward is that clock & command channels only get combined with other channels from the same disc. Given the exit configuration just described, the number of connector ferrules required for this solution is shown in Table 5.

The number of connector break-points must remain at three, the minimum number to ensure installation is possible, since a greater number of connectors would put this part of the SCT project over budget. It is therefore foreseen to only make the breaks shown in Figure 4.

The latency arguments presented lead to a strong case for making use of the voussoir route for ribbon cables coming from sectors on the other side of the detector from USA15. If this route were not available it could have serious implications for the successful readout of the SCT.

| | Barrel Octant 1 | Barrel Octant 2 | Forward Quadrant |
|---|---|---|---|
| Number of Modules | 132 | 132 | 247 |
| Number of Data Fibres | 264 | 264 | 494 |
| Number of C&C Fibres | 132 | 132 | 247 |
| PPB1/F0 – MT12 quantity | 22 | 22 | 41.2 |
| PPB1/F0 – MT8 quantity | 22 | 22 | 41.2 |
| PPB1/F0 – PP2 12-way ribbon | 22 | 22 | 48 |
| Dark 12-way ribbon | 0.0% | 0.0% | 14.2% |
| PPB1/F0 – PP2 6to12 ribbon fan-in | 11 | 11 | 26 |
| Dark 6to12 ribbon fan-in | 0.0% | 0.0% | 20.8% |
| PP2 – MT12 quantity | 33 | 33 | 74 |
| PP2 – ROD 12-way ribbon | 33 | 33 | 74 |
| PP2 – ROD 8×12-way fibre cable | 4.125 | 4.125 | 9.25 |
| Dark fibre in cable | 17.5% | 17.5% | 22.8% |
| Combined cable | 17.5 | | |
| Dark fibre in combined cable | 11.3% | | |

*Table 4: Overview table of the fibre usage in the proposed exit configuration.*

| | MT12 | MT8 |
|---|---|---|
| **PPB1** | 704 | 704 |
| **PPF0** | 768 | 768 |
| **PP2 (required)** | 2208 | |
| **PP2 (all connectorised)** | 2304 | |
| **ROD (required)** | 1104 | |
| **ROD (all connectorised)** | 1152 | |
| **Total (required)** | 4784 | 1472 |
| **Total (all connectorised)** | 4928 | |

*Table 5: Overview table of the ferrule requirements for the proposed exit configuration. N.B. two ferrules required for each connector break apart from at ROD end due to use of receptacle array devices.*

# 7 REFERENCES


1 "Atlas Inner Detector Technical Design Report vol.2", CERN/LHCC/97-17, ATLAS TDT 5, 30 April 1997

2 John Lane, "Survey of SCT latency budgets", version: 8 Jun 99, available from: <http://www.hep.ucl.ac.uk/~jbl/SCT/SCT_latency.txt>

3 Document in preparation, see: <http:// www.cern.ch/Atlas/GROUPS/FRONTEND/links/install/laser_safety/>

4 see < http://nicewww.cern.ch/~mclaren/atlas/install/FibreClip/Welcome.html>