Services for the read-out of the ATLAS TRT cables types I and II, from detector to PP2

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Abstract

The read-out of the ATLAS TRT requires about 30000 digital links working at 40 Mbits/s. For cost reasons it was not possible to use fibre optics technology in the tracker volume of ATLAS. LVDS links using very thin twisted pair cables (36 AWG) have been implemented up to a point where a small number of optical Gbits links are used. Top of the art cables (small twisted pairs, low and high voltage cables) have been requested to selected companies, and accurately tested before being validated. Complex harnesses have been designed and are currently being fabricated. This paper will show how the cables were specified and validated. The production process and its status, the quality control and acceptance tests will then be presented.

I. Services from the TRT to the Patch Panels 2

The Patch Panels 2 (PP2) are intermediate points inside the ATLAS muons spectrometer where a break in the services allows the change of all cables types for longer distance transmission:

- Data signals coming from the front-end electronics over small twisted pair cables are serialized and transmitted through fibre optics to the back-end electronics;
- TTC and temperature lines coming/going from/to the front-end electronics over small twisted pair cables are and sent/ received through bundles of bigger twisted pair cables to/ from the back-end electronics;
- High-voltage coming through multi-conductors cable is transmitted to front-end via mini-coaxial cables;
- Bulk low voltage supply is feeding voltage regulators and several small lines are used to feed the front-end electronics.

This paper will focus on the cables going from PP2 to front-end, i.e. the Small Twisted Pair (STP) cables, the HV mini-coaxial and the twisted shielded pair or triple LV cables (LVt, LVp) and their connectors.

II. Cables selection

The harsh conditions around the TRT laid down severe criteria in choice of the cables/connectors: minimum volume, minimum radiation length, non-magnetic material, enclosed space, large amount of channels, long distance...

All this leads to a long term job for selecting the cables. The method has been to define roughly the needs, then to seek high quality companies, buy samples, test them and redefine more accurately the criterions taking into account technological possibilities. Close collaboration with the companies has proven to be always necessary in order to find the best compromises.

Then accurate technical specifications (TS) have been written down taking in account all the important parameters (cable construction, electrical performances, materials, marking, colours, safety, radiation, flexibility, minimum delivery length, packaging, drum size, quality control in the companies and at CERN, test reports, delivery schedule). Each TS was included in price inquiry or invitation to tender process in collaboration with the CERN purchasing service.

There are 3 categories of cables; those used for the Digital links, those used for High voltage supply and those used for the Low voltage supply.

A. Digital link

A cost comparison showed that a copper link was about 3 times cheaper than a fibre optic link. LVDS signals at 40 Mbits/ s where selected. Their transmission required miniature individually shielded twisted pair cables (STP).

1) STP cable construction

The conductors are very thin AWG36 cables. The shield and the jacket are an Aluminium/polyester foil wrapped clockwise (0.1mm) around the pair and 4 drain wires are wrapped counter clockwise in order to obtain a lower resistive path on the shield. Fig.1 gives a view of the construction and a summary of the main characteristics.

Pos	Description	Diametre	Remarks
1	Conductor of high strengh silver-plated copper alloy	0.16mm	1 x 0.16mm
2	Dielecticum of HFI 150	0.52mm	
3	Drain wire of silver plated copper		0.102 mm x 2
4	Wrap of Aluminium/polyester foil	0.75mm	
5	Jacket of HFI 150 natural	1.05mm 1.15mm max	Thickness 0.15mm

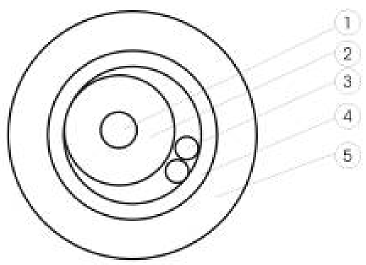

Figure 1:Shielded Twisted Pair characteristics

2) STP cable selection

To find out the crucial characteristics of the cable, a set of tests has been done on each sample:

- Visual inspection;
- On-line production tests (report from the company);
- Measurement of the electrical properties (cross-talk, attenuation; see Fig. 2) with a LAN tester (Wavetek LT8600);
- Checking of the signal quality by means of eye patterns done with scope on a random data transmission pattern;
- Data transmission measurements made with a home-designed bit error rate tester (BERT) which allows to scan the signal edges with respect to a strobing clock in steps of 2ns and the measurement of a working time window for all types of data transmissions (random data, all 0 or all 1);
- Compliance to the CERN IS23 (radiation resistance, halogen free components and behaviour in fire).

A lot of samples have been bought to various companies and tested to improve the cable's quality and define the best criteria.

In addition bundles of up to 15-m cables were used to perform the read-out of the TRT detector.

After a call for tender, the procurement of about 600 km of this STP has been launched.

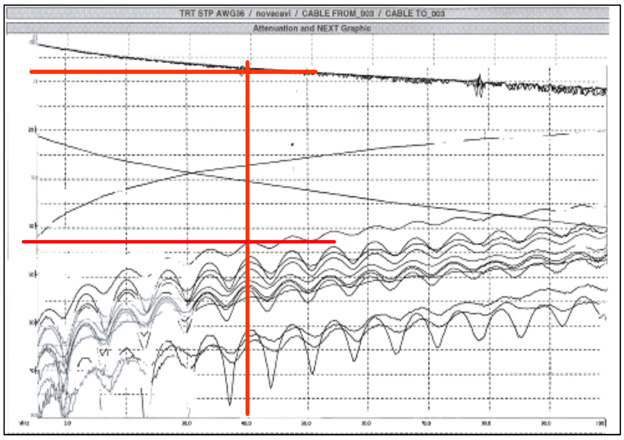

Figure 2:STP cable attenuation-to-cross-talk ratio graphic (ACR) better than 8dB for 15m, 40MHz

B. HV cable

3) HV cable construction

The thinnest coaxial cable withstanding 2kVDC has been obtained by optimization of the ratio between the HV core and the sheath radii. The outer diameter is as small as 1.05mm.

The cable construction has been driven by the fact that eliminating air gaps should improve its life-time by reducing corona effects.Extrusion of the dielectric around a single core HV wire conductor minimises voids at the conductor surface and better than with a stranded wire are obtained.

An Aluminium/polyester foil wrapped clockwise around the dielectric also minimises voids and is therefore much better than a braid. Two drain wires wrapped counter clockwise reduces the linear resistance of the return path and simplifies the assembly process.

As life-time is a serious criterion, the HV cable has been tested against partial discharges following an international standard (IEC 60502-2, IEC 270).

4) HV partial discharge test

A partial discharge (PD) is an electric discharge that bridges insulation between conductors because of air trapped between materials or inside dielectric, or because of other imperfections in the insulation or construction. Although they involve only small amounts of energy, they can cause progressive deterioration and failure of dielectrics. The sensitivity of the measurement of partial discharges (corona) was better than 5 pC.

The cable was tested with a 50-Hz AC sinusoidal voltage (AC voltages are more damaging than DC voltages). Two measured values are of importance:

- The inception voltage: the voltage at which PD are observed when voltage increases;
- The extinction voltage: the voltage at which PD are observed when voltage decreases.

For the selected cable, the DC inception voltage is 2121 V for a rating voltage in TRT of 1.6kVDC giving a minimum safety margin.

C. LV cable

The cables providing the analog and digital supplies to the front-end electronics are routed together from PP2 to the detector, and they feed sensitive electronics. Therefore some care must be taken. Twisted pair (Vdd and return) shielded cables where used for digital supply and twisted triple (Vcc, Vee and Return) shielded cables were used for the analog supply.

The copper cross section had to be optinmised in order to minimize the voltage drop along the line (can be up to 15-m long) but also to stay within the allocated volume envelope. This leaded to choose 5 types of cables with a copper cross-section in the range $0.6mm^2$ to $1.5mm^2$.

The overall outer diameter has been reduced, in minimizing the sheath thickness, the diameter of braid strand wires (0 .1mm) and in choosing the thinnest jacket (a wrapped adhesive polyemide foil).

A good flexibility was obtained in increasing the number of strand wires of each conductor and choosing a good insulating material.

III. Connectors

The selection of connectors was driven by tight requirements at different levels.

Independence from a specific vendor, possibility of in-house repairing, smallest possible size, vertical plug, mixed thin (AWG36) and big (AWG16) cables, shield connection, locking mechanism, radiation resistance, reliability, cost, … All this lead to some custom developments.

The best choice for the STP cables was to solder them on printed circuit boards. This technique is used in the industry for thin cables although most of them are hidden in back potting.

Hereafter are some examples of connectors used for the ATLAS TRT:

- Souriau 26 and 43 positions or Molex 6 positions for low voltage power supplies;
- Omnetics 5 positions with a locking mechanism for connecting the temperature sensors;
- Customs and/or hybrids connectors (called roofs or paddle's cards) at the level of the front-end boards or of the extra patch panel (PPF1) used in the end-cap;
- High voltage multi-contacts connectors (51 pos. or 3 pos.) specially developed with LEMO and Radiall.

IV. Mock-up for cables

In all stages of the design and of components selection, the choices were guided by CAD drawings. But a lot of learning came out from real size mock-ups. A 5/32 mock-up of the LArg cryostat has been equipped with TRT barrel and End-Cap cables; mock-ups of some detector local areas and cable trays helped to optimize parts of assembly and path of the cables and allowed to properly define a packing factor for the bundles. A formula defining the size of the cable trays came from this practical experience: $S = n \times 1.57 \times D^2$, where S is the cable tray cross-section, D is the cable diameter and n is the number of cables.

Two jigs have been used to define the routing, the length and assembly sequence of the End-cap to PP1 (EC-PP1) harnesses before production. Jigs are real size mock-ups of the regions of the TRT where are routed the EC-PP1 harnesses, including Patch panel 1 (PP1). They are of 2 types of them, one left and one right hand. Inside the jig, the cables have some slacks to allow a tolerance on the connector's positions. It has been shown that a margin on the length of +/- 15mm was the maximum acceptable. They also allowed to discover that two types of connectors (roof boards) had to be used because of the mechanical rings holding the end-cap TRT wheels, and that special loops of cables are required in some places. It also shown that twisting the loops on a small length near the roof boards and PP1, solves the problem of having shorter/longer STP wires in the bending of the cables. The exact length of cables for each wheel has been measured on the jigs.

They now serve to check and validate the harnesses at reception.

To summarize, the scale 1:1 mock-ups are very useful to define the cable's length, routing, the assembly sequences and the assembly easiness but also to find and solve unexpected problems and validate all solutions before mass production.

V. Harnesses

There are several TRT harnesses to go from the barrel TRT to PP2, from the end-cap wheels to PP1 and from PP1 to PP2. In a nut-shell they are:

- 736 complex harnesses (multi-cables, multi-connectors, multi-lengths);
- 2'800 point-to-point bundles;
- 360'000 soldering point to be manually done.

The harnesses have been (and are still being) produced in three assembly workshops:

- One in Cracow (Poland) with 3 people;
- One in Dubna (Russia) with 8 to 16 people;
- One in CERN (Switzerland) with 2 to 5 people.

The harnesses are used to feed the detector with high voltage, the front-end electronics with low voltage, to read-out the front-end electronics (data and TTC signals) and to monitor the temperature of the detector and its read-out electronics.

The assembly represents a substantial amount of work, mainly done by hand (soldering of the small twisted pairs on PCBs), with a tight schedule, in distant sites. A good organization was required to avoid a waste of time in goods delivery, assembly work and return of harnesses. An accurate schedule for the assembly process has been established with the target to receive all the harnesses on time for installation. It has been updated several times depending on production/staff variations.

A lot of time has been taken before starting to find the more efficient way of production. Different strategies have been tested to minimize the assembly time and to simplify the process so that an operator can easily remember it. For example the harnesses have been simplified to follow the physical segmentation of the detector but also to split them into small identical (except the length) sub-harnesses; this lead to time saving, made the tests and repair easier and allowed parallel work. Special tools have been designed for some parts (e.g. to crimp ferrules over the shield, to tag the wires), very low temperature soldering has been used in order to reduce the risk of short circuits and operators have been trained.

A constant anticipation of production rate allowed to adjust delivery priorities. The management of people, tasks, tooling, and shipments was essential to reach the target.

As already mentioned, three groups of harnesses have to be produced:

- End-cap to PP1 (EC-PP1);
- PP1 to PP2 (PP1-PP2);
- Barrel harnesses.

5) EC-PP1:

One harness contains the low voltage power supplies cables and the STP cables. These harnesses are the most complex. There are 64 harnesses. Each harness is a compound of 5 basic STP harnesses and 1 LV harness. The basic STP harness is made of 4 roof connectors linked by 68 STP cables to 2 PP1data and 1 TTC-Temp connectors (3 to 20 temperature lines depending on the sectors) with 2 STP each. The position of the connectors is different for each harness.

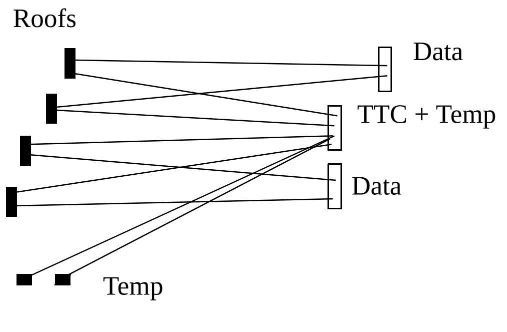

Figure 3:basic STP harness EC-PP1

The assembly of the basic STP harnesses has started in Dubna. It has been decided to start the assembly from the roof side and leave pigtails of cable of the max length toward PP1. The pigtails are fixed and tagged by tools. The roofs boards are twisted and fastened on a wooden plate, the tools are put in place and then a smooth tension is applied on the cables to find their nominal length. Then the cables are trimmed and assembly of PP1 connector made.

In the mean time, the work on temperature lines was made. The cables were cut and stripped in CERN, sent to Cracow for assembly and moulding (back-potting with polyurethane resin). The operator trained at CERN was provided with all the material to do the job there. Then the all was sent to Dubna.

The LV harnesses are made with twisted triple and pair cables which start from 3 LV PP1 connectors and are distributed to each roof. The LV assembly was done in parallel in Dubna by cutting cable's length, mounting PP1 connectors and preparing roof's end.

The final harness is obtained in adding the temperature pigtails in the STP harnesses and then adding the LV lines.

All the EC-PP1 harnesses for one end-cap side (160 harnesses) has been completed by the end of August 2005.

The harnesses for the second end-cap side should be completed in the beginning of 2006.

The HV line are gathered in special harnesses and there are 24 HV harnesses in total. Each one is a set of 2 harnesses; one for the wheels of type A, and one for the wheels of type B. Type A is made with 12 connectors of 3 HV lines each. Each line is filtered by an RC cell, and groups of 3 RC cells are drowned in an araldite resin type D to form a filter box. The cables are soldered to HV3 front-end connectors then held by a back-potting. The resin also makes the insulation. Type B is similar but made with 8 connectors and 8 filters boxes.

Each length from PP1 to front-end connector is different and has been defined on a jig.

A long development period and a lot of serious problems appeared when starting the HV harnesses production leading to a low and disappointing yield. A review of all the stages of production was done to understand and solve the problems. Cleaner working areas, better cleaning of components, more care taken in assembly process, modification of moulds, improvements in the preparation of the resin mixture, insertion of some electrical tests at different steps of the process, were necessary to resume the production with a good yield.

6) PP1-PP2:

48 HV harnesses of different lengths are done at CERN. Each one consists of a bundle of HV, return and interlock cables ended by 51 contacts connectors.

960 STP harnesses of different lengths are built in Dubna. Each one consists of a bundle of 28 STP cables + 2 spares, identical for data and TTC-temp. ended by 2 circuits with connector where the STP are soldered.

64 LV harnesses of different lengths are done in Dubna. Each one consist of a bundle of LV cables of various size ended by 2 cable-to-pcb connectors at PP2, and 3 cables-to-cables connectors at PP1. On each end the polyemide foil is stripped over 2 cm to allow the connection of the shield.

7) BARREL:

32 HV harnesses are done at CERN. These harnesses are identical to the HV PP1-PP2 harnesses (at the exception of the connector pin-out).

192 STP harnesses of different lengths are made in Dubna. Each one consists of a bundle of STP cables + 2 spares, linking from 2 to 4 paddle cards to 2 to 3 PP1 connectors. There are 3 different harnesses per sector, and 2 types of sectors: left and right. The lengths range from 7 to 15m.

64 LV harnesses are done in Dubna. Each one consists of a bundle of LV cables of various size ended by 1 cable-to-pcb connector at PP2, and 8 connectors at front-end. The connection of the shield is done as for the LV PP1-PP2 harnesses.

VI. Harnesses Integration

All the harnesses are tested at the end of the assembly process.

At reception at CERN, all harnesses are checked again (lengths on the jig, electrical DC and AC tests, HV).

EC-PP1 harnesses are laid down in the appropriated cable's tray and labelled. Once completed the cable trays are moved to ATLAS inner detector integration building (SR1) and mounted on the detector.

The barrel and PP1-PP2 cables will be shipped to the ATLAS installation team for being routed on the calorimeter cryostat at the beginning of 2006.

Dedicated test benches have been set up, including especially designed electronics boards, adaptors and bundles of cables. One operator does all the tests, and fills a personal report sheet for each harness.

Another check-up is foreseen after installation to insure that no link has been broken before all the access points are closed.

Figure 4:Cable trays inserted into squirrel cage, which goes over the TRT End-Cap wheels.

VII. Status

After 2 periods of 2 weeks of learning at CERN, the head of the workshop started the assembly in Dubna. The production rate is good and the main objectives (i.e. to get a quantity or some type of harnesses at a given date) have been reached so far. The actual status by the end of September 2005 is:

EC-PP1:

- STP-LV: 32/64 received. First end-cap side completed;
- HV: 34/48 received, but production almost completed.

EC PP1-PP2:

- HV: 48/48 received;
- STP: 405/960 received;
- LV: 56/64 received, 8 last done in Dubna.

BARREL:

- HV: 22/32 done;
- STP: 21/192 received;
- LV: 4/ 64 received.

VIII. Conclusion

The TRT harnesses assembly is a very complex process happening in very remote places (CERN, Cracow and Dubna). A lot of time has been spent to qualify and procure the different components. Full size mock-ups of all critical areas have been done and such a step is absolutely necessary. The assembly process has been carefully studied with the team in charge of the construction in Dubna and some optimisation of the design has been done in order to facilitate and speed up the work. Several technical problems occurred during the ramping up of the production (mainly with the HV part) but are now solved.

Acceptance tests at different steps of the process are essential.