Grounding and Shielding of the ATLAS TRT - an overall strategy

Zbigniew Hajduk

Institute of Nuclear Physics – 31- 342 Kraków ul.Radzikowskiego 152; Poland
Zbigniew.Hajduk@ifj.edu.pl,

Martin Mandl

CERN/EP-ATE – 1211 Geneva 23; Switzerland
Martin.Mandl@cern.ch

for the TRT collaboration

Abstract

This paper addresses practical considerations for the engineering of the grounding and shielding system of the ATLAS TRT - **T**ransition **R**adiation **T**racker. It summarises ideas and decisions taken up to now and points out items not fixed yet.

I. INTRODUCTION

A ground system should ensure personnel and equipment safety and help the electrical-noise reduction. Defining the potential of each conductive material to be at certain value achieves safety. A proper signal referencing together with shielding of both sensitive and noisy parts provide noise reduction. Improper solutions for grounding can introduce additional noise to the system.

A way to define the potential of the conductive structures and signal-reference system can be chosen within two philosophies. Either massively connecting everything together which translates into lowest impedance between any two points; simultaneously allowing loops and shield currents to flow everywhere or trying to control the currents which flow in the system; what allows to break these loops and to ban shield currents from intruding the system.

Baseline of the TRT design is to follow *"The ATLAS Policy on Grounding and Power Distribution"* [1] which gives the following guidelines:

- *[...]electrical isolation of all systems, [...]*
- *[...] floating low-voltage power supplies, [...]*
- *[...] floating high-voltage power supplies, [...]*
- *[...] data transmission, clock and trigger distribution through optical links or shielded twisted-paid cables, [...]*
- *[...] detector located inside a faraday cage. [...]*

Strict application of these rules negates the first philosophy at an intersystem level, but still allows it inside the sub-detector. Implementing provisions for both philosophies allows to postpone the choice until more experience has been acquired with real system. However only the final system will show all systematic effects which could not have been predicted at design level and small prototype.

The following text will show how to realise both approaches.

II. ANALYSIS OF THE STRUCTURE OF THE TRT

A. *Front-end Electronics*

The front-end of the TRT detector - Figure 1 - consists of a detecting element – the straw, an amplifier, shaper, and baseline restorer – the ASDBLR ASIC chip - and a digital CMOS readout chip –the DTMROC. Each DTMROC is able to serve two ASDBLRs and thus 16 straws. The configuration of the electronics on the PCB boards carrying the chips depends on the sub-detector and differs for end-cap and barrel.

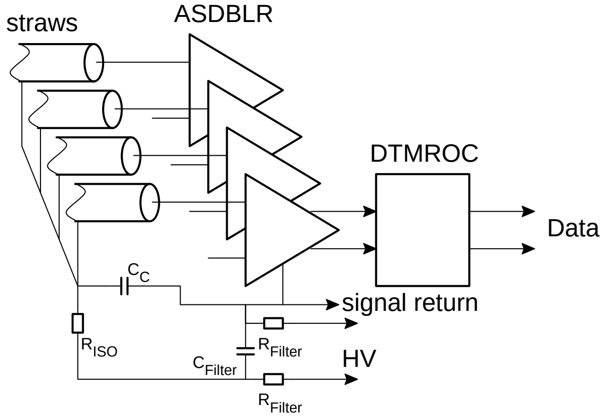

Figure 1: Schematic diagram of the TRT front end electronics

B. *TRT End Cap*

The end-caps are subdivided into units called wheels. There are three types of wheels (A,B and C) each containing different number of active elements. The smallest subdivision of the wheel from LV-power distribution point of view is 1/32 part of 16-plane wheel (in azimuthal direction. The smallest granularity in z-direction (along beam) is a sub-wheel of 8 planes. Figure 2 shows the physical structure of a 8-plane wheel. Three carbon fibre rings together with the printed circuit boards (the active and the passive 'webs') and the straws form a self carrying structure, which is mounted inside the external support so called 'squirrel cage'. The trays carrying cables and services are mounted outside the squirrel cage.

The active web extends over 1/32 of a wheel and provides HV and signal connections to the straws.

The 'inner seal' is made out of the copper-plated kapton - which also serves as a part of the signal paths. The rings 1 and 2 are at the sides connected by copper-plated kapton strips.

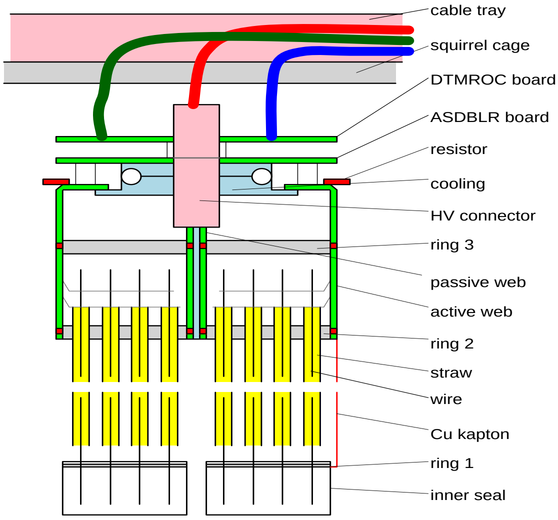

Figure 3: Axial view (rz-plane) of an eight-plane wheel

C. *TRT Barrel*

The front-end electronics of the barrel TRT is the same as that of the end cap, however, the granularity is different defined by DTMROC granularity (16 channels; straws).

Figure 3 shows the physical structure of a barrel module: a carbon-fibre shell surrounds each module and guarantees the mechanical stability; the straws are plugged into the 'HV plate' which is connected to a fuse box and than HV cables; the signal wires connect over the tension plate to the electronics; the cooling plate is situated on top of the tension plate; and finally the roof board collects all data into cables.

III. INTERFACES TO THE ENVIRONMENT

Figure 4 shows the environment of the TRT with the LAr calorimeter outside the TRT, the SCT and PIXEL detectors and the beam pipe inside the TRT, where the services penetrate the whole system.

The services of the TRT barrel run from its electronics at its front face over a patch panel at PPB1 along the inner wall of the calorimeter to the active patch panel at PPB/F2 (close to the front-end electronics of the LAr). The services from the TRT end cap run from its electronics at its circumference along the calorimeter wall over patch panel at PPF1 to the patch panel at PPB/F2. The SCT and PIXEL services penetrate the TRT between the barrel and the end cap and between the section B and C.

The possible EMC problems concentrate in five zones:

- between the TRT end cap and the SCT- forward - the straws can be influenced by the electronics and services of the SCT;

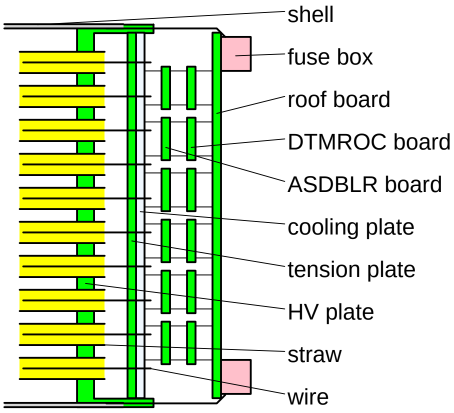

Figure 4: Axial view of the physical structure of an end of the barrel module

- between the TRT barrel and the TRT end cap - the barrel electronics and services as well as the services of the silicon detectors face the sensitive straws of the first wheel of the end cap;
- between the last wheel B and the first wheel C of the end cap - the services of the SCT are parallel to the straws;
- at the inner wall of the calorimeter - the electronics of the TRT faces its own services, the services of the TRT barrel and silicon detectors;
- outside the Inner Detector - all services run in parallel up to active patch panels (PPB/F2) next to the electronics of calorimeter.

A quantitative estimation of interferences at the system level is not possible. ATLAS is still in evolving design phase where some solutions are not yet identified. The LAr calorimeter is the most likely victim of the noise generated by the TRT detector .The noise level of the TRT must stay below the threshold of the LAr detector to avoid a degradation of its performance. Additional crosstalk could appear at PPB/F2 where the active patch panels are located and all services have to pass close to the LAr front-end electronics.

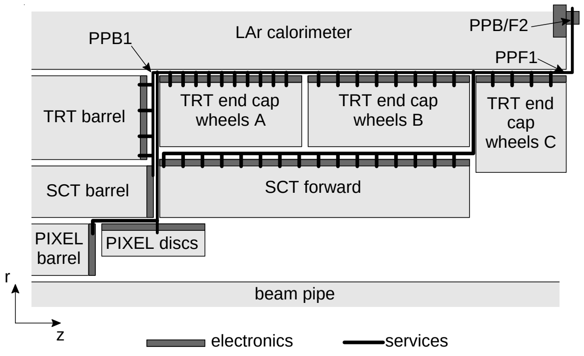

Figure 2: Axial view of the environment of the TRT.

The electronics of the SCT is located close to the open end of the TRT end-cap straws where the anode wire is not protected by the straw cathode.

The services of the SCT and the PIXEL detector are running either close to the open end of the TRT end-cap straws, in parallel to the straws, or in parallel to the services of the TRT. Although the data is transmitted over optical fibres, the power lines and cooling pipes are potential aggressors. Due to the confined space, SCT and PIXEL use a special tape cables [3] to deliver their power. Its high capacitance allows an effective filtering of the noise produced by the digital front-end electronics, but produces high surrounding electric field which couples to the TRT. Preliminary measurements [4] showed uncomfortable crosstalk from the SCT power tapes to the TRT.

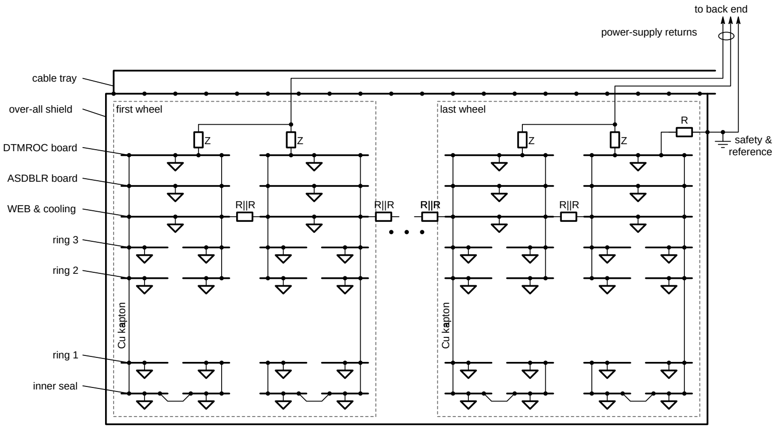

Figure 5: Grounding scheme of the TRT end cap - the controlled-currents method

The beam pipe which carries the particles beam is also a possible noise source if not properly grounded [5].

Only close field coupling is possible inside ATLAS due to the short distances among the sub-detectors. The conductive coupling is eliminated by definition. The [1] enforces the electrical isolation of all subsystems.

IV. GROUNDING & INTERCONNECTING

A. *TRT End Cap*

The interconnections among the different conductive parts and "grounds" inside the detector have to be system related for the controlled-currents grounding approach. The connections have to be designed to allow the currents of the different subsystems to flow where they belong without interfering with other subsystems. The main aim is to break all current loops for low frequencies and to provide paths of proper impedance for high frequencies.

Figure 5 shows the grounding scheme for the TRT end cap. The FE boards have multiple signal connections between each other. Thus their grounds are full planes which are connected tightly over multiple ground pins on their interface connectors. Having common supply lines, the two halves have to be decoupled by the impedance Z of the power-supply filter.

The front-end electronics plugs onto the active webs. The cooling (metallic) structure connects the two active webs and the two passive webs and provides a substantial ground plane. A copper-plated kapton sheet connects the inner seal, ring 1 (capacitively coupled to the wires of the straws) to the ground plane of the active web. Because this connection is seen as a part of the signal return path, the "left" and "right" side are connected and force the return current of the "right" side to flow over the left "side". This is undesirable, whereas breaking this connection and adding a return path for both sides would be a more uniform approach.

Ring 2 and 3, which are strongly coupled to the outputs of the straws, are also connected in this way.

A segmentation of the system into ground subsystems in the azimuthal direction is impossible because of the continuous carbon fibre rings and the cooling and gas pipes. So the different parts of the ground system have to be connected together to provide the lowest impedance. However, in the axial direction a segmentation, which makes it possible to control the system currents, is possible. Though there is a high capacitive coupling among the wheels - especially between two copper-plated kapton sheets between two wheels - a separation can decrease crosstalk.

A global reference point is necessary to stay within the common mode range of the differential receivers for data and control signals. The squirrel cage would provide a good conductive structure for this purpose. As the squirrel cage is intended to be part of a shielding structure, shield currents may introduce potential differences. In addition, the squirrel cage is not present at the level of the wheels C. The reference point should be chosen as to provide the same potential for the front-end electronics and the structures which surround the sensitive part of the detector. In the case of TRT this would be the ASDBLR-board ground. The ground planes of the interconnected ASDBLR boards would build the reference ground plane for the system. For feasibility reasons, the level of the web and the cooling structure was chosen instead, as reference plane. Additional ground connections between an ASDBLR board and the active web strongly bind the board-ground to this reference. Connecting the active webs to its neighbours of the next wheel with a big number of small value resistors - three per 1/96 of a wheel - and additional ones in the azimuthal direction among the flexible parts of the webs provide a good global reference plane and allow local filtering of voltage differences [6].

The wheels connected in this way to form one module with a common shield have only one single connection to this surrounding shield. The safety and reference-ground cable connects at the same point from the outside. This provides the reference and safety potential and avoids shield currents flowing into the system. An impedance can decouple the reference plane for high frequency as no current should flow over this connection.

The design of the grounding scheme allows optional change to the second grounding approach - low impedance one.

B. TRT Barrel

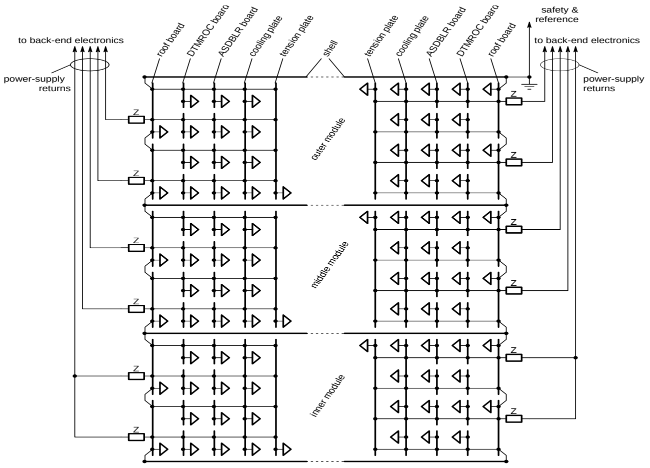

Figure 6: Grounding of the TRT barrel - method of lowest impedance.

The design of the barrel does not allow to implement the controlled-current approach. It was decided to apply only the low-impedance approach.

Figure 6 shows the grounding scheme for the TRT barrel. The straws of each module (96) are housed in separate carbon-fibre shells. The front-end electronics covers both ends of the shells. A copper layer at the outer wall of the outermost module and one at the inner wall of the innermost module form, together with shield layer at the roof boards, an over-all shield.

The roof boards will create the reference plane, to which the reference/safety line connects. All of the electronics inside the shield tie tightly to the reference plane. The ground plane of the tension plate connects through the cooling plate and the FE boards to the reference at the roof board. The incoming services are decoupled over the filter impedances. This grounding scheme foresees to have the lowest possible impedance between any two points of the system. This will allow currents to flow over multiple parallel paths.

V. SHIELDING

C. TRT End Cap

The squirrel cage would be an ideal candidate for an over-all shield for the TRT end cap. Its 6 mm thickness would provide even adequate absorption loss. However, it is punctured by some many openings for services and cables that 50-µm-copper foil will have to cover the complete end-cap or subsets of the wheels.

The number and the size of the shield openings and the way how the services penetrate the shield will influence its effectiveness. A conductive cable tray -strongly connected to the shield - acts as a feed-through capacitor or wave-guide below cut-off for the services.

The services enter the shield from a common point and cable tray having a high capacitive coupling to the cable shields provides additional filtering.

D. TRT barrel

The design of the TRT barrel includes only an over-all faraday shield. However, the cooling plate provides, together with the ground plane of the tension plate, a shield (fig.3) between the straws and the front-end electronics. For the over-all shield, it is intended to cover the outer wall of the shell of the outermost module and the inner wall of the shell of the innermost module with a 50-µm-copper film. A special ground plane on the roof board should close the front-faces of the shield.

The technical details of this design are not entirely defined - it will be rather difficult to interconnect the single roof boards such as to provide a seamless connection. It is recommended to add an additional copper foil on the top, as in the end cap, to achieve the same results.

VI. CABLES & SERVICES

The shield currents are not allowed to enter into regions with sensitive electronics. Therefore the services and especially their exits have to be treated carefully. The main concern is to avoid DC ground loops. The effects of unavoidable ground loops for high frequencies can be reduced by limiting the loop area. Thus it is essential to route services which belong to the same unit within a common cable tray.

A. Data & Control Signals

Following explains how it is planned to connect the data and the control cables to the grounding system (Figure 7). The individually-shielded twisted pair shield (STP) is connected directly to the DTMROC (or roof respectively) ground and over a capacitor to the local ground of the active patch panel at PPB/F2 to break the ground loop for low frequencies but to allow to short-circuit high-frequency noise currents. The common shield of the twisted-pair bundles (which are used after patch panel) is connected directly to the patch-panel ground and over a capacitor to the ground of the back-end electronics. Separate cables or braids respectively provide the reference point and safety.

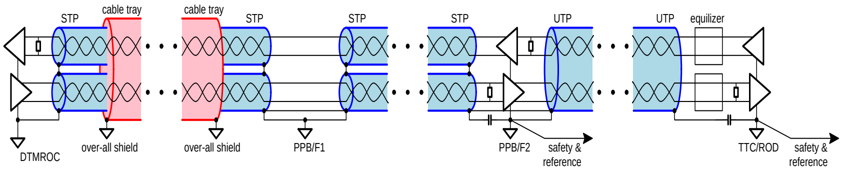

Figure 7: Grounding of the data/control cables

The cable trays connected to the over-all shield act as feed-through capacitors and extra shield for the cables. In addition they cancel coupling area of potential loops between two cables.

B. *Low-Voltage Supply*

The low-voltage power supply cables for analogue and digital sections will have separate ground returns and shields. The shields are connected directly to the DTMROC ground plane and over a capacitor to the low-voltage patch panel at PPB/F2. This measure cuts flow of the low frequency currents in shields. High-frequency currents are short circuited over the capacitance to the cable tray. The lower static magnetic field and more available space allow one to use efficient filters at PPB/F2. Thus it is possible to switch to cheaper multi-core cables with a common shield which has to be connected to the safety line at the floating power supplies.

C. *High-Voltage Supply*

Miniature coaxial cables are used inside the Inner Detector for the high-voltage distribution. The shields of these cables carry the return currents. Outside the Inner Detector, the transmission is implemented by multi-core coaxial cables. Separate lines are reserved for the currents return (common for all units within the same cable). Thus the shield does not have to carry any return current.

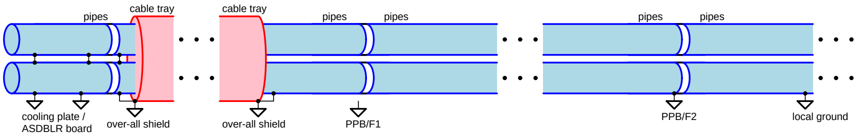

Figure 8: Grounding of the services piping

D. *Gas & Cooling Pipes*

The sectioning of the gas and cooling pipes inside the TRT is not feasible. Thus they were chosen to build together with the cooling structure and the active and passive web the reference plane. Non-conductive inserts electrically break the pipes where they enter the TRT volume (Figure 8). Inside the detector, the pipes are heavily connected to the cooling structures. Outside the detector they are bonded to the over-all shield. Further insulation pieces at several detector interfaces can allow one to define the separate parts of the pipes as "electrical" parts of other sub systems. In these cases, the pipes are to be tied to the local grounds.

VII. PCBS

The layers of full ground and power planes provide additional decoupling capacitances of about 20 pF/cm^2 with very low inductance. The effectiveness and advantage of split ground planes over continuous planes, depend very much on the layout and the circuit design. The split planes work effectively when the different planes are completely decoupled and no signal trace crosses the gap in between. Split ground planes which overlap each other and have thus high capacitive coupling, tend to provoke system oscillations. When a signal line crosses the split, the return current can not flow back directly under the trace and has to take the longer path. This enlarges the surface of the loop which is formed by the trace and the return path and causes an increased crosstalk with other signal traces and environment.

The ideally balanced signals would not need a local return path, but in practice the balance always degrades at some frequency, and so a nearby return path is needed for reduction of the resulting common-mode leakage. The planes close to differential traces are a part of the transmission line. A break in such a line means an inhomogeneity and causes reflections.

As the TRT-front-end electronics has a lot of interfaces between the analogue and the digital part and complete decoupling of split planes would be difficult, it is recommended to use a single solid ground plane.

VIII. GROUND CONNECTIONS

To have "as good as possible" ground connections, seamless joints would be the optimum. However, this is not feasible in the TRT. To define the DC potential of a conductive structure a single point connection is enough. In case of high frequencies the connections additionally have to grant a low impedance. Point-like connections have an inductance depending on their length and cross section thus theirs impedance rises with the frequency. A systematic approach can help identify where to the connections belong, in order to allow return currents to flow back to the source without detour. An impedance approach requires provisions of smallest possible resistance and reactance in the system. This means that one must put multiple connections in parallel to decrease the impedance.

In terms of frequency, it is a rule of thumb to make the connections each 1/20 to 1/10 of the wavelength of the highest frequency produced or introduced into the system in order to minimise standing waves. According to this, the connections between any parts in TRT should be placed every 5 to 7 cm. Interconnection wires (possibly braids) should be as short and as broad as possible for lowest possible inductance.

IX. REFERENCES

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