Grounding and power distribution of the LHCb ST detectors
Version 1
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1. Introduction

This note describes the grounding and power supply distribution for the silicon strip detectors and electronics in the LHCb Silicon Tracker (ST). The different types of power supplies will be described together with the corresponding cabling. The grounding scheme, based on the LHCb recommendations [https://edms.cern.ch/document/584310/1] will then be outlined. The full ST readout electronics system is described in [http://cdsweb.cern.ch/record/836184]. The on-detector electronics relevant to this discussion are the readout hybrids (including the 'Beetle' front-end, [1]) and the Service Boxes, containing a Control Board (interface to TTC fiber and ECS network, [2]), Digitizer Boards (digitization and optical transmission of analog data from the detector) and its backplane(control/TTC signal distribution and power regulation).

The Silicon Tracker consists of two separated subdetectors. The Tracker Turicensis (TT), located between RICH1 and the dipole magnet and the Inner Tracker (IT) situated at the three tracking stations T1-T3 just around the beampipe downstream of the magnet. Although the mechanics is completely different, the electrical layout is largely the same. When not stated explicitly, the system described in this document is identical for both IT and TT.

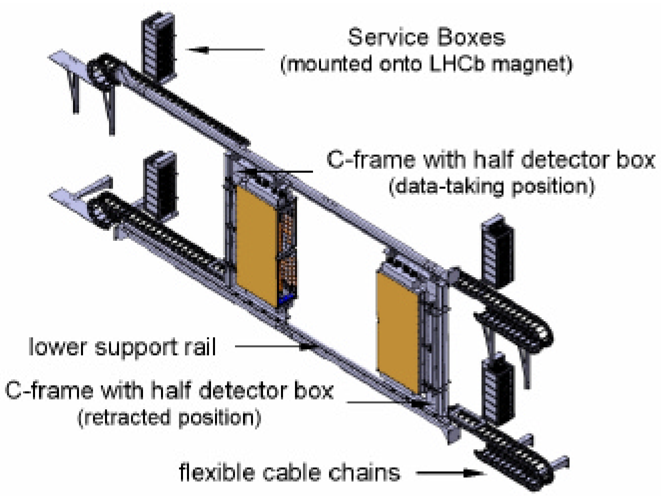

Fig. 1: View of the TT station, cryo side in service position

The TT station is located in a single enclosure containing 280 readout sectors. The readout sectors are distributed over the two halves of the TT station (access side and cryo side), according to their location. Furthermore, each half is split into an upper and a lower quadrant. This results in a partitioning of six Service Boxes per quadrant and a total of 24 boxes. Each half side of the TT detector can be moved away from the beampipe for maintenance and servicing.

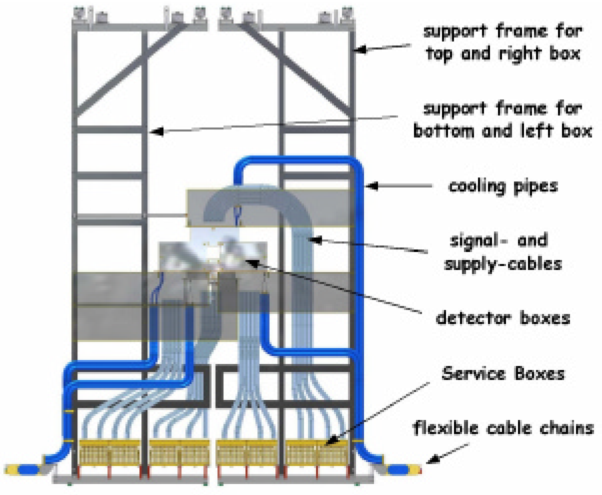

Fig. 2: View of one IT station.

The IT stations T1-T3 consist of four detector boxes per tracking station, each holding 28 readout sectors. The four detector boxes per tracking station are again distributed over the two sides (access and cryo side) of the LHCb detector, mounted on movable carbon fiber structures (‘curtains’) together with their associated Service Boxes.Contrary to the TT station, the IT Service Boxes are located on the curtains and move together with their respective detector boxes, when pulled away from the beampipe. For each curtain two detector boxes are read out with four Service Boxes, which results in a sum of 24 Service Boxes for the IT subdetector.

Due to the different number of strips on a TT silicon sensor (512) compared to an IT sensor (384), the IT readout hybrid carries only three readout chips compared to a TT hybrid with four readout chips. For both TT and IT, a readout sector is connected to its dedicated readout hybrid and digitizer board. Hence, a TT Digitizer Board is transmitting data of four readout chips compared to an IT Digitizer Board with only three readout chips. As a TT Service Box is designed for 12 Digitizer Boards, the overall current consumption is approximately identical to an IT Service Box, which holds up to 16 Digitizer Boards. To summarize, the maximum number of readout chips per Service Box is limited to 48.

The silicon sensors itself are biased to a maximum of 500V. For cost saving reasons, 4 (IT) or 3 (TT) neighbouring readout sectors are grouped together via a dedicated patch panel in the counting house, which allows for disconnecting individual readout sectors. In addition, this design still leaves the future option of independent HV channels for each readout sector.

2. Power supplies

Service Boxes in the ST detector are completely independent, and use independent power supply channels. Each box requires two power supply channels:

1) a 4.5V channel, drawing a current of ca. 22A
2) a 7V channel, drawing a current of ca. 9A

The low voltage supplies are regulated and filtered locally on the Service Box backplane which then supplies the readout hybrid at the silicon detectors. Each hybrid is supplied by its own two (analogue and digital) low voltage regulators (LHC4913). This pair of two regulators can be switched on and off independently via ECS for each hybrid to isolate single readout sectors. Each regulator has a built-in current limit of 3A. An OCM-pin which signals an overcurrent condition, is constantly monitored via ECS as well.

The power supplies chosen are Wiener MARATON [3] with two sets of units: 7V, 44A and 15V, 23A per channel. Each Maraton DC/DC converter is carrying 6 units of each type.

The silicon sensor bias voltage is provided by a CAEN SY1527LC [4], which is equipped with A1511B modules. Each module has 12 channels and is delivering up to 500V at a maximum current of 10mA per channel. Each channel of the MARATON and CAEN A1511B is floating and isolated from the power supply chassis. The general grounding point is located at the detector as described in section 3. The silicon sensor bias is filtered on the readout hybrid with a 2^{nd} order lowpass of 2x 1000 ohms with 2x 100nF.

2.1. Global LV power supply system

The ST low-voltage power supply is based on the Wiener MARATON system. AC/DC converters with Power-Factor-Correction (PFC) are situated in the counting room. These generate a 380V DC supply that is delivered via 60m cables to DC/DC convertors close to the detector. These are radiation and magnetic-field tolerant, and each box contains 12 independent floating channels. Monitoring and control of the DC/DC convertors is carried out by modules located in the counting room.

As each MARATON DC/DC converter holds 12 channels and two channels are used per Service Box, the TT subdetector requires four MARATON systems (one per quadrant), which is the same for the IT subdetector.

2.2. Global Silicon Bias power supply system

The silicon-bias power supply system is using the CAEN SY-1527-LC mainframe with A-1511B modules. There is one mainframe for each of IT and TT, with the IT frame containing eight 12-channel modules and the TT frame containing 13 modules. These are all situated in the counting room. Twisted pair round shielded cables connect the module outputs to patch panels directly located under the HV power supplies (TT: D3E09, IT: D3D09). These patch panels are connecting the HV channels to the individual readout sectors and allow disconnecting of single sectors in case of failure. Both patch panels are secured against unintended manipulation with transparent polystyrol covers, which are key-locked (Fig. 3). Cables carry the voltage across 60m to a second patch panels located close to the detectors.

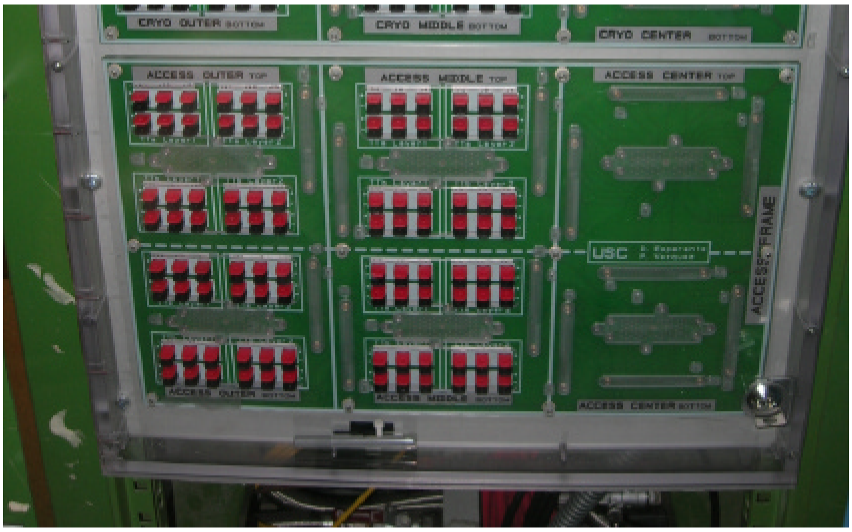

Figure 3: Part of the TT counting house HV patch panel.

In case of the IT, these patch panels are located in T0A13 and T0A03 in the bunker under the tracking stations itself. From here, the HV is routed through moving cable chains to the respective detector box where a PCB feedthrough provides the entry into the detector box and the internal connection to the readout hybrid.

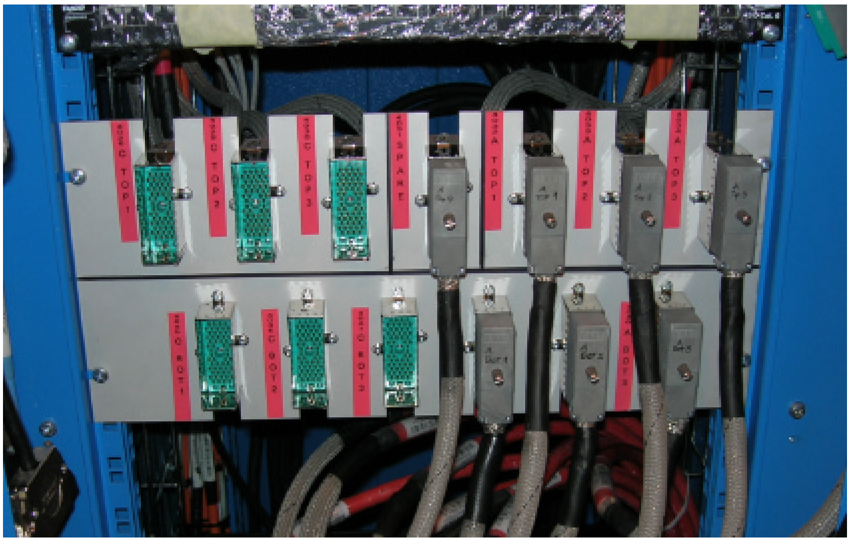

Figure 4: TT HV patch panel at P1A03

The second patch panel for TT is located in P1A03 on the platform (Fig. 4). The HV is then connected to a third set of patch panels, which are located on top of each Service Box frames in each quadrant. From here the cables go via the moving cable chains to a fourth set of patch panels, mounted directly on top and underneath the TT detector box. Here, the HV supply is connected to the polyimide cables, which pass the box feedthroughs towards the readout hybrids. At every patch panel, all shield connections of the HV bias cables are connected to the local metallic structure, which in turn is connected to the safety ground.

3. Grounding and Cabling

For both subdetectors, the main grounding star point has been defined as the cooling plate (TT) or rod (IT) inside the detector box, to which the readout hybrids are mechanically and electrically attached to. To pass the signals and power lines through the thermal isolation, for TT a polyimide cable is being used while the IT subdetector uses a printed circuit board, embedded into the box cover. Outside of the thermal isolation, each readout hybrid is connected to its own 68-wire data cable. The cable is a custom made halogen-free type which was optimized for low material budget, since the cable is routed through the detector acceptance in case of the IT subdetector.
The cable consists of 34 pairs of 30 AWG wire (equivalent to 0.056 mm2), out of which 10 (TT) or 18 (IT) wires are dedicated to the ground connection. The shield is designed as a 25 um aluminum metal layer on a polyester foil, which is connected to both sides to the connector shield. No copper braid was used due to its large impact on the material budget. On the detector side, the connector shield is connected via the mounting screws of the connector panel itself to the outer detector box shield. On the Service Box side, each data cable plugs into its digitizer board. As the shield connection is separate from the electrical ground connection, the shield is individually connected via a dedicated wire to the aluminum frame of the Service Box itself.

The low voltage connection of the Service Boxes is done with shielded two-wire cables. The cross section was chosen to limit the maximum voltage drop along the cable to about 0.5V. As a result, for the 4.5V/22A supply, cables of $25mm^2$ were chosen (SCEM 04.08.82.250.2) and for the 7V/9A supply, a $16mm^2$ cable (SCEM 04.08.82.160.2) was used. Both of these cables have a common copper shield for both wires. At the Service Box side, both these shields are connected via an M6 screw to the Service Box frame (Fig. 5). At the MARATON DC/DC power supply end, all cables were clamped onto a ground bar at the back side of the crate, which itself has been connected via a copper braid to the electronics rack (Fig. 6).

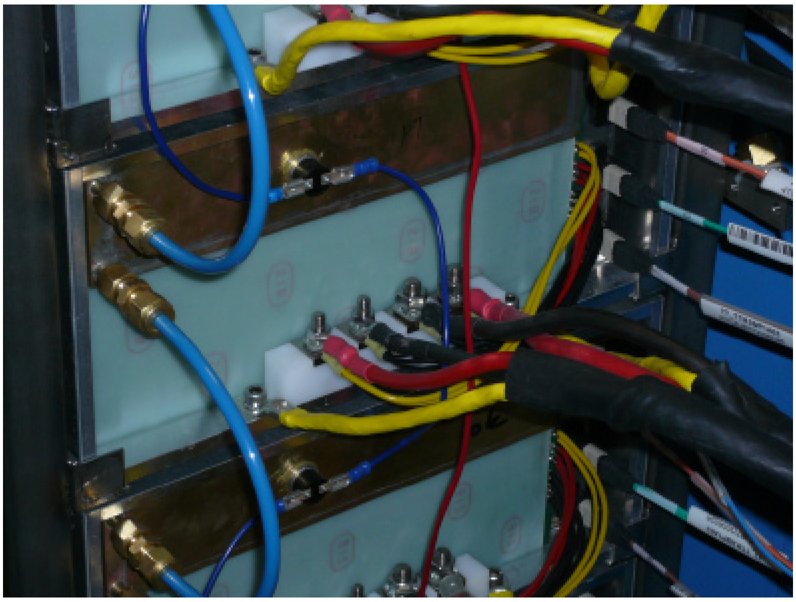

Figure 5: LV connection of a Service Box.

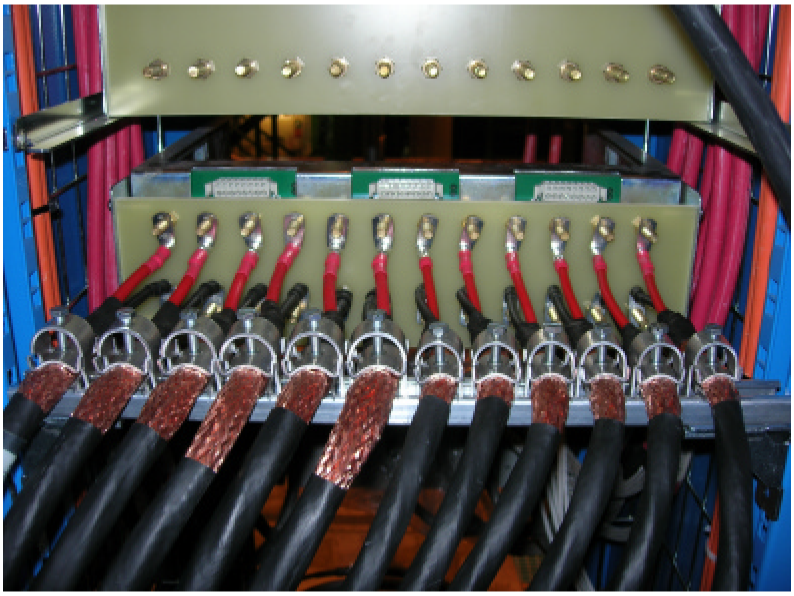

Figure 6: Photo of MARATON LV connections with shield clamps during installation.

This scheme provides a connected shield on all ends of any shielded cable, which the shields connected to a local metallic structure. None of these shields is used for power or data transmission and under normal operation, this is be completely free of current.
The high voltage silicon sensor bias is sharing the common ground star point at the detector. The bias voltage itself is also passing the thermal isolation through the polyimide cables (TT) or the printed circuit board feedthrough (IT).

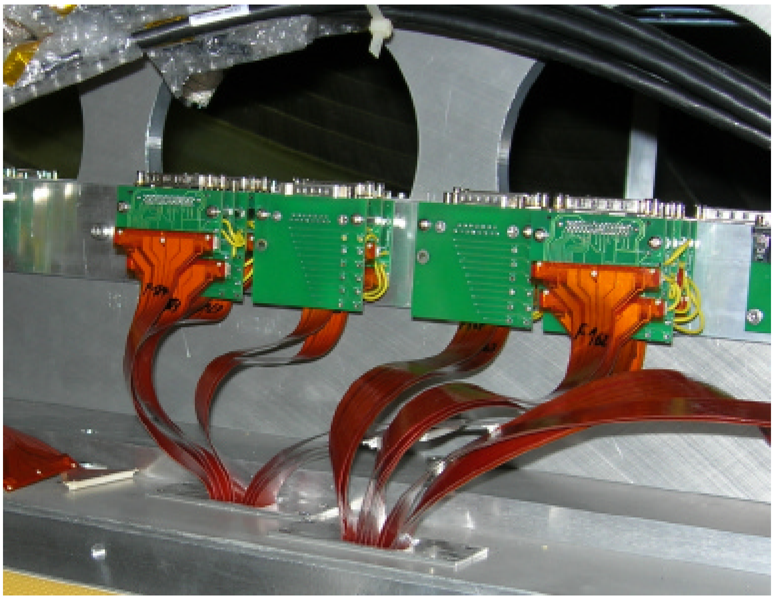

Figure 7: polyimide feedthrough for the TT subdetector

Both types of feedthroughs have been tested to bias voltages of up to 1500V without problems. At the outside of the TT detector, a 15 pin Sub-D connector (Amphenol 17TT, rated up to 500V AC, [5]) is used to connect to a round twisted pair cable (SABIX D 345 FRNC TP, halogen free, 500V max., [6]) with a composition of 6x2x0.25mm^2 (Fig. 7). This cable is connected to the high voltage patch panel on top of each Service Box tower. Again, the cable shield is connected on both side to the metallic structure and does not transport any current. At the Service Box patch panels, the bias voltages are connected to the main HV bias cables (SCEM 04.31.52.100.5), which are connected with 56 pin EDAC connectors [7]. These main HV bias supply cables are split once more at the platform rack (P1A03) for easier maintenance and testing before connecting to the HV patch panel in the counting house (D3E09). For the IT subdetector, four 15 pin Sub-D connectors are directly mated in a fan-out fashion to their respective main HV bias cables, which connect to patch panels in the bunker underneath the tracking stations T1-T3 (T0A13 and T0A03). From here, the cables are extended into the counting house (D3D09), where they connect to the IT HV patchpanel.

For all operational cables, spare cables have been installed in the cable trays as well. The spare low voltage cables which are terminated with cable lugs have been screwed on both ends to their respective cable trays to prevent them from being accidentially connected. As this is not possible for the 56-pin EDAC connector, these have been wrapped in protective covers and mechanically fixed.

All electrically conducting surfaces have to be grounded for safety reasons. Both the TT and the IT are running on horizontal rails to enable easy servicing. Although the moving structures are in direct metallic contact with these rails, additional grounding cables were used to enhance the cross section of the safety ground.For the TT station, 2x 50 mm^2 copper braids were included in each cable chain of the four quadrants adding up to a total grounding cross section of 200 mm^2 per moving half station. At the moving side, the

braids are firmly connected via crimped lugs and screws to the aluminum frame of the detector box. At the fixed end, the braids are screwed to the frame holding the Service Boxes in each quadrant. Each Service Box frame itself is then connected directly to safety ground.
For the IT half stations, one 35 mm2 copper cable (yellow-green, SCEM 04.08.61.376.7) per half station was used. As the Service Boxes are moving with the stations, the moving end is connected to the Service Box mounts while the fixed end is connected to the local metallic structure at the fixed end of the cable chain.
None of the cables have to be disconnected when moving any part of the detector from the operational position into the maintenance position or vice versa.

4. Cooling

Both subdetector detector boxes are cooled with C_6F_{14} which is electrically not conductive. As the main purpose of the cooling is to keep the silicon sensors cold to avoid radiation damages, a coolant temperature of -15 deg C has been chosen.

Due to its mechanical design, the TT detector contains per quadrant one horizontal cooling plate, where the readout hybrids and silicon sensors are attached to. To further enhance the cooling power, an additional vertical radiator is placed in each quadrant. The IT detector boxes are cooled by a cooling rod, to which all sensors are attached to via their respective readout hybrids.

At the Service Boxes, the linear regulators for the box electronics itself and the readout hybrid in the detector are the major heat generating units. A brass cooling plate, which is connected to the mixed water cooling system is therefore mounted directly on top of these regulators at the back side of every Service Box. A separate linear regulator on each Control Board in a Service Box is also water-cooled with a dedicated brass heatsink. The main heatsink on the backplane is supervised by a overtemperature switch which is connected to the LHCb Detector Safety System (DSS) and opens at 60 deg C. In case of a water leak, sensors in collection basins underneath the Service Boxes are used to signal an alarm to the DSS, which then closes the water supply valves.

5. Operation

In this section, general guidelines for safe detector operation are described.

5.1 Low voltage operation

All on-detector readout electronics are powered via Service Boxes. Each Service Box has to be supplied with two voltages, which have to be switched simultaneously by the MARATON power supply . This is commanded via the Experiment Control System (ECS). While the TT Service Boxes are equipped with a smaller number of Digitizer Boards compared to IT Service Boxes (12 compared to 16), the total current load is comoparable for both types of subdetectors. At full operation, the 7V channel is drawing about 9A, while the 4.5V channel has to deliver up to 22A. An exception are the IT Service Boxes, which are only loaded with

12 instead of 16 Digitizer Boards, which only draw 16A (4.5V channel) and 7A (7V channel).
For safety reasons, three current limiting systems are working at the MARATON level. The first and tightest level is located in the ECS software, which is set to 110 % of the nominal current. The second level is supervised in the firmware of the Remote Control Module (RCM) of each MARATON power supply system. It is located in the counting house and set to a trip level of 120 % of the nominal current. A third and final limit is located in the DC/DC converter at the detector, where the trip level is set to 125 %. This approach should provide us maximum security against excessive currents delivered by the LV power supply system

5.2 High voltage operation

The sensor high voltage is needed for reverse biasing of the semiconductor junction inside a silicon detector. The exact voltage required is determined by the need of exceeding the voltage for full depletion for reduced charge collection time. Furthermore, the depletion voltage is influenced by the accumulated particle fluence on each sensor [8]. For the particle fluences expected at LHCb, we expect a decrease of the depletion voltage without reaching the point of semiconductor type inversion.
For the start of LHCb, we decided to start at a common biasing voltage of 400V. For non-irradiated sensors, the resulting currents are in the order of 1uA or less. Measurements during installation and commissioning have showed, that due to the grouping of sensors into one readout sector and connecting several readout sectors to one HV channel currents up to 10uA per channel are fine. For the large TT readout sectors, even up to 200uA after long storage periods is acceptable as these currents decrease with time (few days) to normal levels. However, leakage currents will increase linearly with received fluence and can reach up to few mA per individual sensor. As a result, the programmed current limits in the HV supply system have to be adjusted over time.
For normal switching of the HV channels, we set the ramp slope to 10V per second to limit the charging currents.

References:

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