HCAL Read-out Box Low Voltage System

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Requirements

The front-end electronics for the barrel and end-cap calorimeters are contained in individual readout boxes (RBX) located on the outer surface of the absorber. Local power supplies or DC-to-DC converters cannot be used as the magnetic field strength is 4 Tesla (40Kgauss) at that location. Also, any component placed at the readout boxes must meet a difficult reliability requirement.

Each readout box requires +6.5V and +4.5V as primary voltages. Specifications for ripple and EMI/EMC will be very tight because of the low noise requirement on the electronics. Components of the low voltage system inside the readout box should introduce minimum additional heat load.

Radiation condition at the location of the readout boxes is estimated in 3.1×10^{11} neutrons/cm^2 for 10 years of LHC operation. Charged particle doses are negligible. Components for this location must be shown to withstand this level of radiation.

Low voltage system

The proposed topology for the DC low voltage power distribution is depicted in figure 1. It consists of AC/DC converters located in the control room, that rectify the three phase mains and generate a primary DC voltage about 200-300V. This high voltage is distributed from the control room to the detector. Each rectifier supplies several DC-DC converters located in the periphery of the detector near the front-end electronics. The switching regulators convert the high voltage into appropriated low voltages that are locally distributed to the detector read-outs. Local regulation is performed in the front-end electronics at the board level using special low-dropout linear voltage regulators developed by CERN RD-49 collaboration [a]. The main advantage of this topology is the reduction in volume of the distribution cable due to the relatively low primary currents. Locating the DC-DC converters in the hostile environment of the detector cavern is a disadvantage due to the presence of magnetic field and radiation.

The HCAL front-end electronics requires four different voltages; +5.5V analog voltage and +5.5V, +3.3V and +2.5V digital voltages. Each board accommodates 6 read-out channels and the total power estimated per board including the LV regulators is about 9 W. As it was pointed above, special designed regulators are used at each board to regulate the bias voltage. Performance tests over those regulators have proved they can resist without problem the radiation level around the readout boxes and also reject line differential perturbations at relatively high frequency. The linear regulators can operate with input voltages up to 12 V and a minimum input to output voltage drop of 0.5V per 1A load. Distribution buses inside the readout boxes power-up each board. Figure 2 illustrates the front-end module.

There are three different types of readout boxes. It is due to mechanical constraints, number of channels per box, location of the box, etc. Table 1 resumes the current consumption of each one. The indicated values are the nominal current and between parenthesis the design current.

	# RBXs	# Channels / RBX	Current (6.5V)	Current (4.5V)
HB Barrel	36	138	18.12A (22.65A)	26A (32.5A)
HE End-Cap	36	102	13.88A (17.35A)	21A (26.25A)
HO Wheel 0	6	108	14.3A (17.88A)	21.4A (26.75A)
HO Wheels 1 / -1	6 / 6	72	9.65A (12.1A)	16A (20A)
HO Wheels 2 / -2	6 / 6	72	9.65A (12.1A)	16A (20A)

Table 1

DC-DC converters will be located on the periphery of the detector. In particular, for HB converters will be located on the surface of wheel 0 and for HE on the surface of disk 1. For HO, converters will be located on wheels –2, -1, 0, 1, 2, respectively. Converters have to operate in an environment with magnetic field and high-energy neutrons. The stray magnetic field level on those areas can reach a maximum strength of 0.32 Tesla (3200 Gauss). The fluence predicted for 10 years of LHC operation will be between 1.5 / 3 x 10^{10} neutrons/cm^2. Because of the well-know lack of radiation tolerance for some power supply components, validation is required for those systems.

The cables between the converters and the RBX are designed to avoid large voltage drop across them, which means the cross-section is over designed for such a current. These lines do not need current protection supplemental to that built-in into the switching power supplies. Under any plausible fault condition, the maximum current that the power supply delivers is lower than the rated current capability of the wires. The voltage drop estimated for those conductors is about 0.8 / 1V.

Modularity of DC-DC converters is the primary requirement. It will facilitate replacement of fault units during short-period scheduled access to the cavern providing a reduction in the time that a part of the sub-detector is down. Thus, each modular unit will include two basic power converters to attain the required output low-voltages but also protection, filtering, monitoring system and interface for remote operation. The heat is removed from those units using a water cooling system.

The tendency, in this design, is to use commercial units (COTS), but it is difficult to satisfy all the requirements with such units. Instead, 'semi-custom' design has been used based on COTS with the collaboration of manufactures. Test and analysis have to be performed to validate the operation of those units under radiation and magnetic field. Tests performed using low-energy neutron have demonstrated that DC-DC converters are only sensitive to displacement damage for the fluence level estimated if the feedback loop includes a standard opto-coupler. The replacement of this critical device by one manufactured by HP has proved to be an effective solution. Due to the total dose is very low in the periphery of the detector, a test that is very important to validate the operation of converters in neutron radiation environments is the tolerance to single event effects (SEE). The neutron fluence in periphery of the detector is relatively high in the range of energy between 60MeVand 200MeV. The idea is to test single event burn-out (SEB), single event gate rupture (SEGR) on power devices and induced 'glitches' or single event upset (SEU) in the control circuit that can produce a permanent failure in power devices. SEB tests performed have shown that commercial designs have to be de-rated for safe operation. In particular, for step-down converters, the critical device is the switching transistor and its output voltage has to be de-rated by a factor 2 or 3 for reliable operation. It implies the DC-DC converters have to operate under de-rated conditions or this critical component has to be replaced by either a SEB tolerant device or a transistor with higher blocking voltage capabilities.

Due to the magnetic field, a magnetic shield has to be designed to reduce the magnitude of the field near the power converter, avoiding saturation of the magnetic materials. The shield will be designed combining soft iron and mu-metal.

Switching converters are noisier than linear power supplies. Additional input and output filters are necessary to reduce the noise to acceptable levels. These units have to have a combination of differential-mode and common-mode filters to attenuate the conductive noise and the noise radiated by the input and output cables. Appropriated shielding will be necessary to reduce the interference radiated by the converter.

A high voltage distribution is used as primary voltage for the DC-DC converters. Several converters, around 6 to 9 units, are connected in parallel and powered-up by individual AC/DC converters located in the control room. The total number of AC/DC converter units is 13. They are standard three phase bridge rectifiers with transformer. They will be housed into racks and water cooled.

Remote turn on/off and measure of the principal variables of the converters is performed by the monitoring system. This circuit consists of two parts, the data acquisition system resident in the control room and conditioning circuits included into each DC-DC converter and AC-DC converter units. The data acquisition unit is based on differential amplifiers with high common mode impedance and differential input matched to the characteristic impedance of the sensor cable. The input analog signals received are processed and sent to the SCADA based control for displaying. The system also has the possibility of sending a digital signal to the DC-DC converter units for remote turn on/off. The conditioning circuits sense the output voltages and currents of the DC-DC converter units and the temperature of the converters. The signal level is boosted and transmitted to the control room via operational amplifiers. Each converter power-up individually its own conditioning circuit. Figure 3 depicts the conditioning circuit.

Grounding and Protections

RBX can be considered as an optical input / optical output processor. The only galvanic connection with the exterior is through the input power cables and high voltage cables. Services connections are isolated with plastic devices and the CANopen monitor link is isolated using opto-couplers. The RBX have a defined common ground point that is the connection of the negative input power cable. That point will be connected to the metallic structure of the detector via a cooper strap. Figure 4 depicts the grounding scheme for the low voltage system. Twisted and shielded cables will connect the DC-DC converters with the RBX. It will help to reduce EMI from the cables as well as reduce the EM susceptibility of the RBX. Due to the high magnetic field around the RBX, it is not possible to include any effective common-mode filter at the RBX power input.

DC-DC converter units will be housed into shielded boxes to avoid EM radiations. Boxes will be attached to the metallic structure. Due the input high voltage cable is floating, for safety reasons it can be referenced to ground either at the control room or locally at the DC-DC converter unit. Also the cable can be floating but in that case a protection circuit have to be included to avoid dangerous potential between it and ground. In picture 4 it is shown the input cable floating without any specific protection and also it depicts a distribution based on individual cables per DC-DC converter units. At this moment there is not a clear solution about the topology of this distribution, it can be based on individual cables or a single cable per group of DC-DC converter units. For the final topology, an appropriated grounding scheme will be chosen from the three possibilities enumerated above.

AC-DC converters will include a transformer with shielding and the input circuit ground will be connected to the control room. The rack housing those units will be connected to the same ground point. The additional requirement for those units is to include snubber circuits in the rectifier to limit the voltage recovery rate of diodes and reduce the EMI.

Each line is protected against transient over-voltages by transient-absorber circuits. The cables between the DC-DC converters and the RBX are normally over-designed for the maximum current that they carry because a relatively low voltage drop is accepted. The maximum current that the converter can deliver is always lower than the maximum current rating of those cables. Table 2 shows their cross-section. These cables are damped selecting an appropriated value of the capacitor located at the RBX's input power. This prevents over-voltage at the input power when the front-end electronics suddenly changes the current consumption. The input cables will be protected by fuses located at the output of the AC/DC converters. Standard over-voltage and current protection is required for the AC/DC converters. The input cables of the monitor system are protected in the conditioning circuit by the matching resistors and the limited output current the operational amplifiers can deliver.

System	Length	Dgn curr. 7.5V	Cross-sec.	Commercial Cross-sec.	Dgn curr. 5.5V	Cross-sec.	Commercial Cross-sec.
HB	15mts	22.65A	15.9 mm^2	16 mm^2	32.5A	22.65 mm^2	24 mm^2
HE	8mts	17.35A	7.09 mm^2	8 mm^2	26.25A	10.76 mm^2	12 mm^2
HO (0)	5mts	17.88A	6.24 mm^2	8 mm^2	26.75A	9.36 mm^2	12 mm^2
HO (1/2)	5mts	12.1A	4.22 mm^2	8 mm^2	20A	7 mm^2	12 mm^2

Table 2

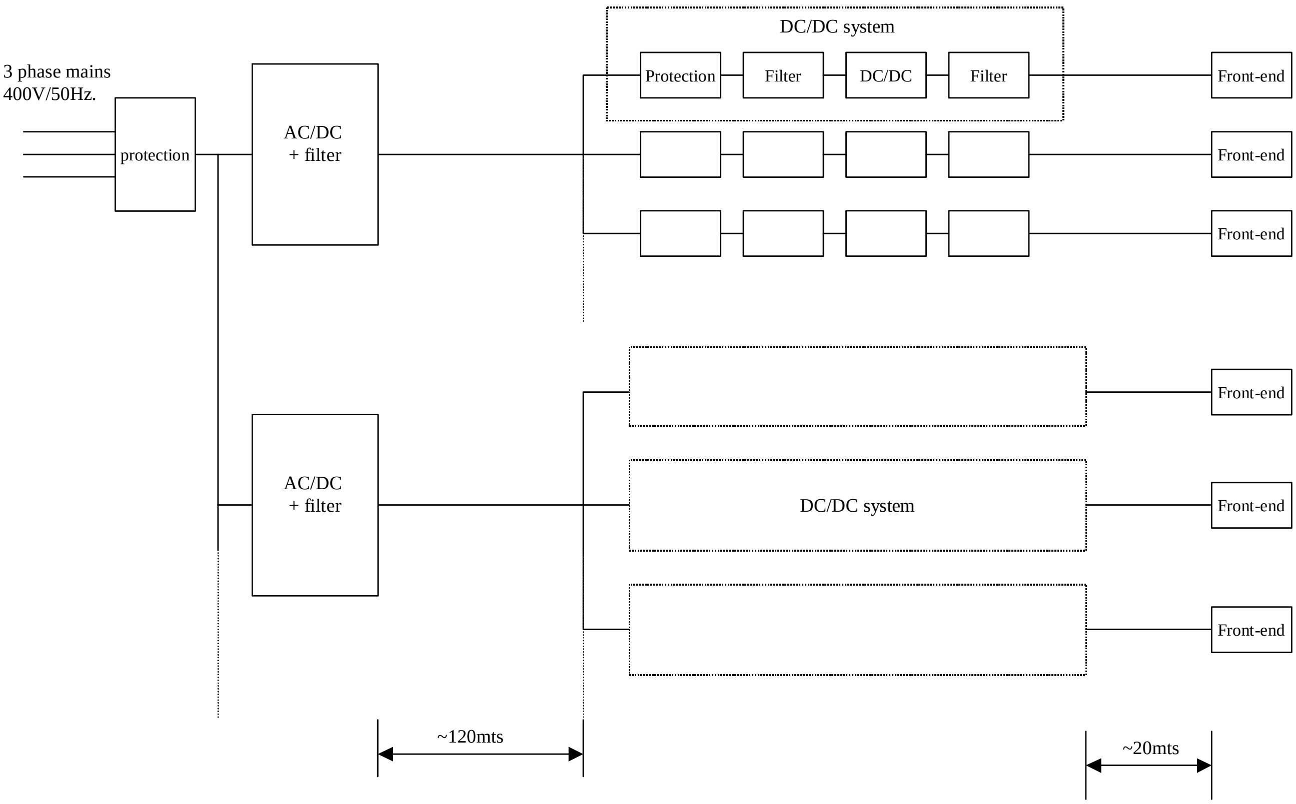
Procurement and actual status of the different sub-systems

The most critical component in this system is the DC-DC converter unit. They have to operate in a difficult environment with magnetic field and radiation. Analysis and tests have been performed on different product to test the capability of them to operate safely in radioactive areas. As it was described above, usually the critical device is the high voltage-switching transistor. The solution is to de-rate the converter or replace the transistor by a SEB tolerant device or a device with higher blocking-voltage capabilities. At the moment there is not a final decision about what converter to use. There are two possibilities; one is to use de-rated converters where is not possible to change any component. The other is to use a commercial converter where it is possible to replace critical devices. In case of a final solution based on the first option, after the converter passed 'screening tests', several units will be purchased under agreement with the manufacture the critical device belong to the same batch. The units will be radiated and the results will be used to estimate the life-time of those converters operating under neutron radiation. Under favorable results, the total number of units will be purchased. These units have to include the critical devices from the lot already tested. In case of the other option, the manufacture agrees to help in the selection of a replacement of the critical component, but it is our responsibility is to test and purchase the critical devices. The manufacture will include them into the converters manufactured for this system.

In both cases, the complete unit has to include additional components as filters, magnetic and EM screening, monitoring conditioning circuits, cooling system, etc. The assembly of those parts and the complete unit as well as the testing is still under consideration if it is performed in the Laboratory or sent out with a manufacture.

Cables is general will be purchased via CERN. If it possible, the complete manufacture of the cable assembly will be required. At the moment two vendors sent quotations for them. AC/DC converters will be specified. A few prototypes from the selected vendor will be purchased and tested before the purchase of the final lot.

Figure 1



3 phase mains
400V/50Hz.
protection
AC/DC
+ filter
AC/DC
+ filter
DC/DC system
Protection
Filter
DC/DC
Filter
Front-end
Front-end
Front-end
Front-end
DC/DC system
Front-end
Front-end
~120mts
~20mts

Figure 2

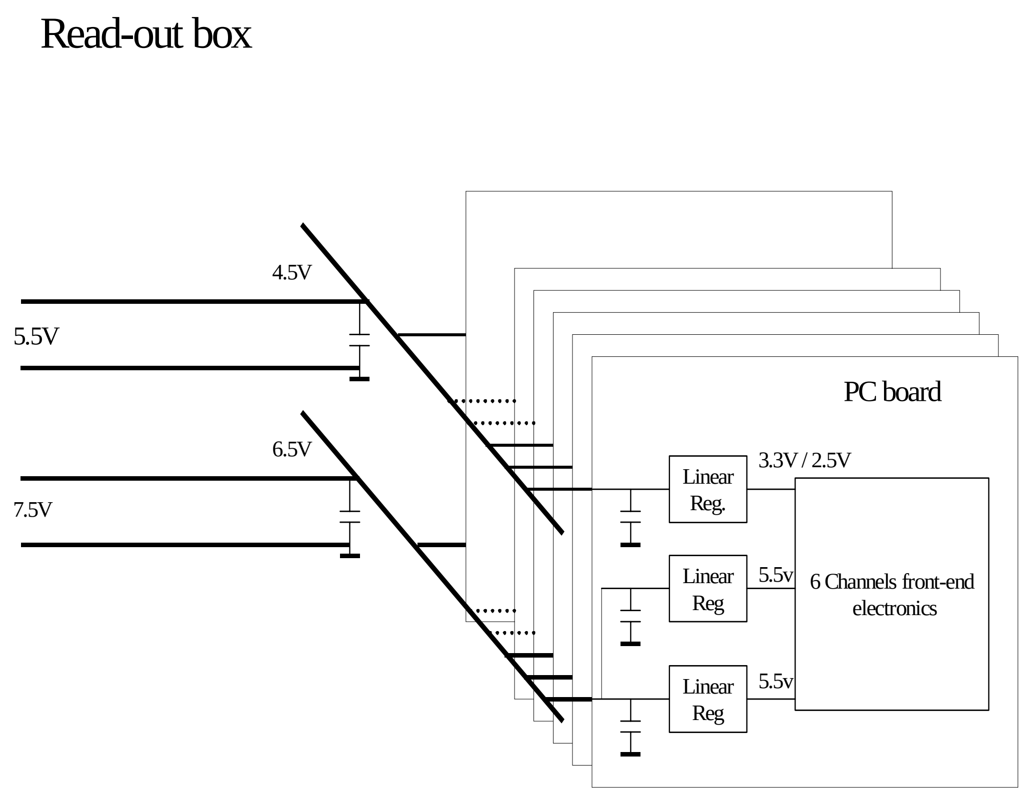

Read-out box
4.5V
5.5V
6.5V
7.5V
PC board
Linear Reg.
3.3V / 2.5V
Linear Reg
5.5v
6 Channels front-end electronics
Linear Reg
5.5v

Figure 3

Conditioning Circuit

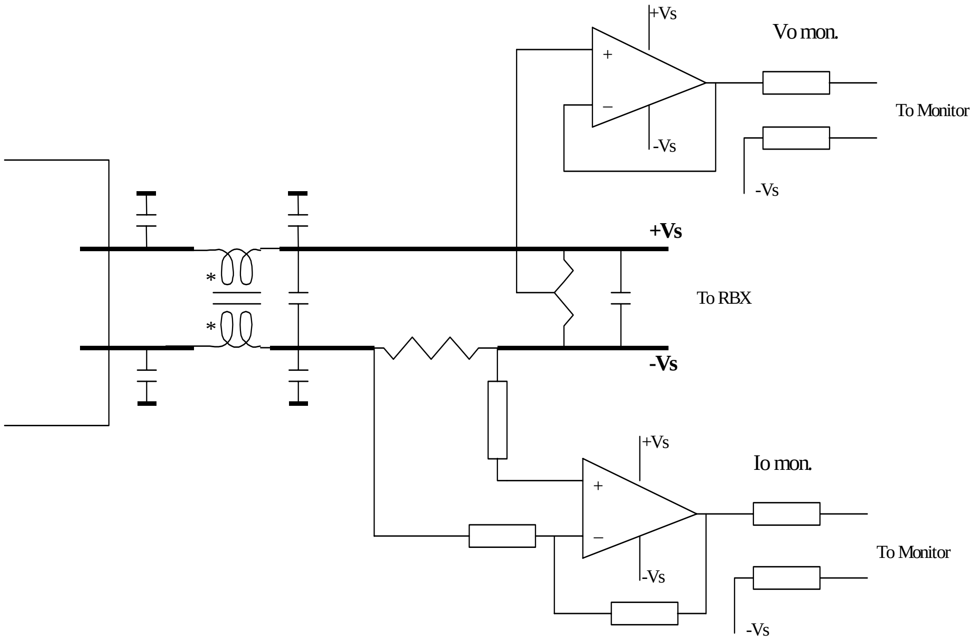
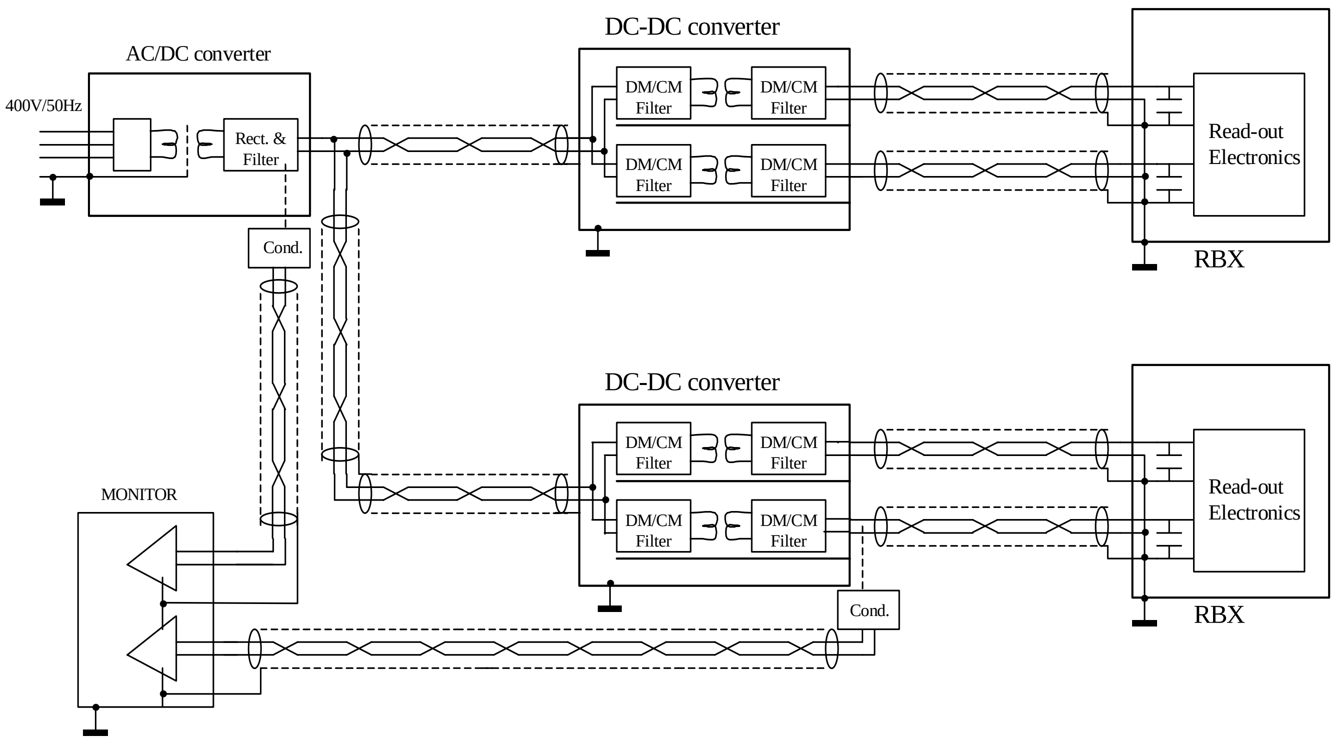


Figure 4



AC/DC converter
400V/50Hz
Rect. &
Filter
Cond.
DC-DC converter
DM/CM
Filter
DM/CM
Filter
DM/CM
Filter
DM/CM
Filter
Read-out
Electronics
RBX
DC-DC converter
DM/CM
Filter
DM/CM
Filter
DM/CM
Filter
DM/CM
Filter
Read-out
Electronics
RBX
MONITOR
Cond.