LHC Rack Monitoring and Safety System

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1 Introduction

This document describes the functionality and implementation of that part of the rack monitoring and safety system which is physically located within the rack. Because of the limited amount of space available within the LHC racks the monitoring and safety system was designed to be placed entirely within the tangential turbine unit.

The rest of the system: field busses, power supplies, interfaces to PCs, etc., is not presented, but relevant details are discussed where necessary.

This document provides the information necessary for the effective use of the system. Sources of supplementary information, e.g. circuit diagrams etc., which may be useful during maintenance or installation are given in the references.

The system presented here is based upon the general approach agreed upon in July 2002 [1], the proposal made in November 2002 [2], and the updates of April [3] and July 2003 [4].

A substantial number of the LHC electronics racks will be in areas with low levels of radiation and high stray magnetic field strengths (referred to here as UX areas). We adopted the philosophy of designing one single system that would work equally well in the UX areas as in the US areas. To this end the system is designed around an ELMB, and uses the minimum of additional electronics in order to satisfy the system requirements.

In the following we describe the functionality, the implementation, and the interface to the DCS (i.e. relationship between the value passed to the DCS by the ELMB and physical quantity measured).

2 Functional specification

The purpose of the rack monitoring and safety system is threefold:

1. Provision of hard-wired, “last-resort” safety.
2. Monitoring of the rack environment.
3. Provision of user-definable analog inputs and digital I/O ports accessible via the DCS.

2.1 Safety

The safety system consists of a normally-closed thermo-switch (which opens above a specified temperature) and a smoke detector. These devices give the possibility to detect heat and smoke and to pass on this information to a higher level system in a robust manner. It is this higher level system which is ultimately responsible for assuring the safety of the equipment within the rack.

2.2 Monitoring

The monitoring function supplies the DCS with measurements of a set of parameters which characterize the environment within the rack. The monitored parameters are:

1. Air temperature inside the turbine unit (two sensors for redundancy).
2. Relative humidity of the air inside the turbine.
3. Air circulation status.
4. Tangential turbine currents (independently for the two turbines).
5. Status of the safety thermo-switch.
6. Status of rack door micro-switch (door open or closed).
7. Status indicating that the monitoring card is in situ within the turbine.
8. Air temperature in the rear of the rack (outside of the circulating air zone).
9. Provision for the addition of a resistance-based water leak detector.

2.3 User definable I/O

The system provides the DCS with the following I/O capability for general use:

1. 16 analog input channels readable by the DCS.
2. 8 digital output channels writable from the DCS.
3. 8 digital input/output channels read/writable via the DCS.

2.4 Constraints

1. For those racks in the UX zones, the rack monitoring system must be capable of withstanding the following radiation levels (over ten years):

Radiation	***Simulated dose***	***Test dose***
TID	1.2 [Gray]	84 [Gray]
NIEL	$5\ 10^{10}$ n/cm^2	$1\ 10^{12}$ n/cm^2

Table 1 Radiation levels assumed for the rack monitoring systems in the UX zones.

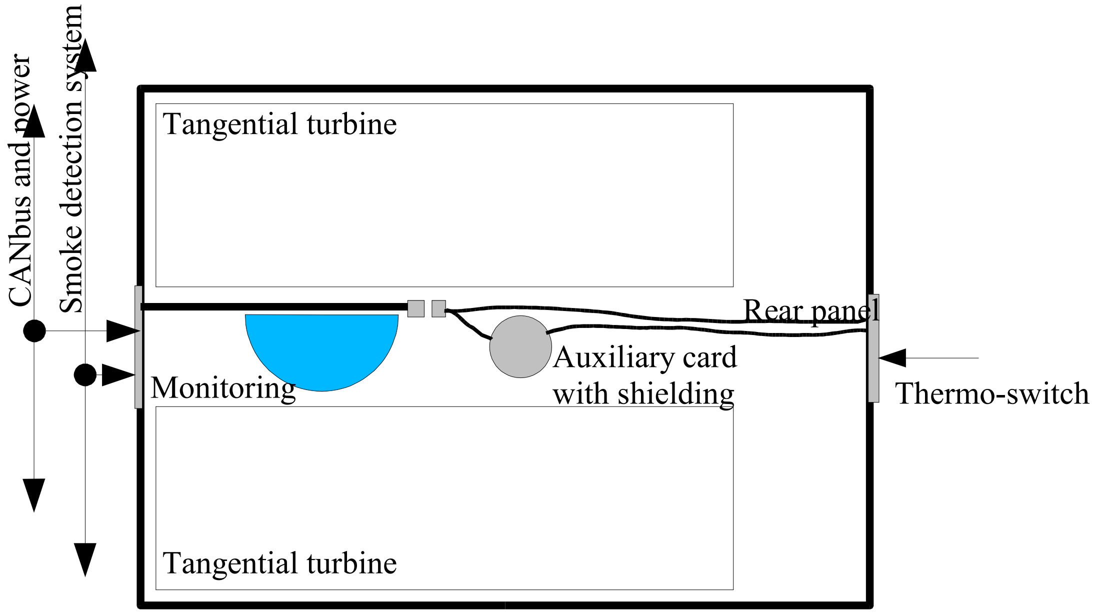
2. In case of a fault with the monitoring system, it must be possible to replace or repair the faulty component (or system) without interfering with the correct functioning of the equipment within the rack.

3 System Implementation

3.1 Overview

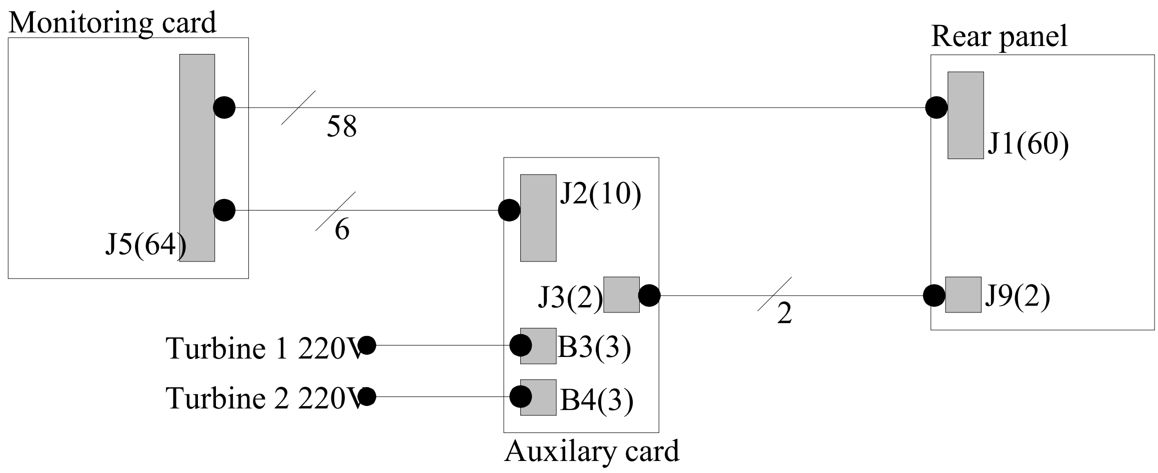
The rack monitoring and safety system is mounted entirely within the standard LHC turbine unit (shown in drawing 1). It consists of three components :

1. Monitoring card: A PCB housing the monitoring sensors, the ELMB, some additional circuitry, also serving as physical support for the smoke detector.
2. Auxiliary card: A small PCB supporting two small transformers used for measuring the currents of the tangential turbines. This PCB also holds the thermo-switch of the safety system.
3. Rear panel: A rear panel containing connectors for electrical connections to objects external to the turbine housing: door micro-switch, rear temperature sensor, and all of the user definable I/O.



Drawing 1 Plan view of the LHC tangential turbine unit showing the placement of the components of the rack monitoring and safety system.

The monitoring card is connected to the auxiliary card and rear panel by a split flat sixty-four conductor cable; the auxiliary card and rear panel has a two conductor connection for the thermo-switch (see Drawing 2).



Drawing 2 Interconnection between the rack monitoring and safety system components.

These components are described in more detail below.

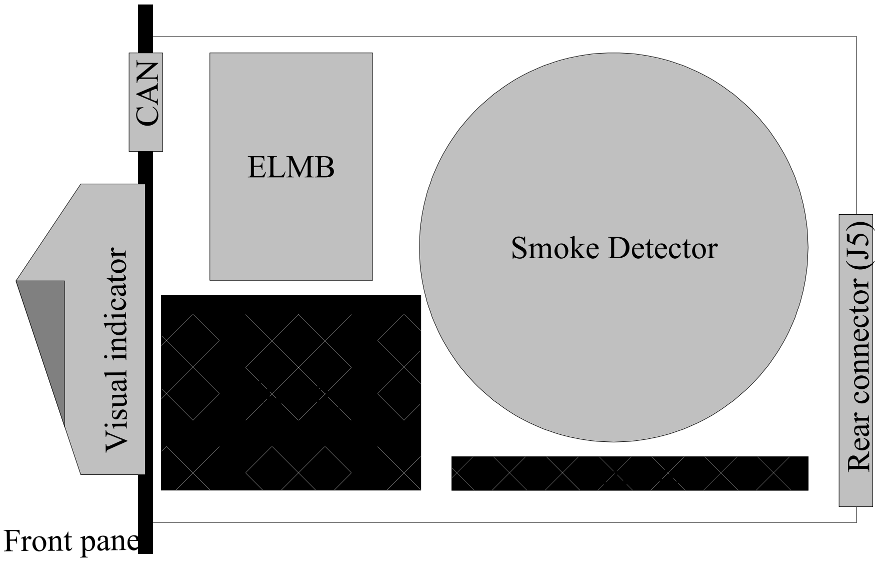
3.2 Monitoring card

The monitoring card houses the ELMB, all of the monitoring sensors, the smoke detector, and a front-panel indicator for the smoke detector. It is shown schematically in Drawing 3 and .

The PCB housing the ELMB is based on the standard ELMB motherboard [9] with some additional circuitry for the sensors. Thus there are two Bergtec 100 pin connectors (J1 and J2) onto which the ELMB is plugged.

Designing the monitoring system around the ELMB has saved much design work, and since the ELMB was designed for operation in the kind of radiation environment where the UX racks will be placed, it allows us to use one single implementation of the monitoring system everywhere. In keeping with this philosophy the rack monitoring system has the minimal amount of active electronics; only the monitoring of the tangential turbines' currents uses active components: a transistor and an operational amplifier. To save further on testing we selected devices which have been previously qualified for use in radiation by other groups (see details in appendix). The electronic circuit diagrams and layouts are available in EDMS [10].

Connection of the system to the experiment's DCS system is via a nine pin SubD connector on the front panel. The pin-out of this connector follows the standard set in the ELMB documentation [10] (see Table 2). Both the communication with the DCS (via CAN) and the power for the monitoring system pass via this connector. Power requirements are detailed in section 7.



Drawing 3 Placement of the principle components on the monitoring card.

One of the constraints of the system is that it may be repaired without powering off the rack. This constraint is largely satisfied as the monitoring card is supported within the turbine unit by two standard card guides, and is connected to the flat cable via a sixty-four pin rear connector (J5). Thus the entire card may be removed from the turbine unit. This allows a replacement of the ELMB if necessary (the most complex component), the test or replacement of the smoke detector, or the replacement of the complete card without interference with the functioning of the equipment in the rack. It is not however possible to make in situ repairs to the auxiliary card.

The ELMBs of the rack monitoring system run the standard software; as far as the DCS is concerned the rack monitoring system is a standard ELMB with analog inputs and digital I/O.

The Crystal ADC is set to work at 5V full scale, i.e. 1.2mV per LSB.

The monitoring card has two connectors: rear (64 pin – J5) and front (9 pin J3). The pin usage is shown in Table 2 and Table 3. The rear connector (J5) is connected to a 64 conductor flat cable. This cable is split: the first 58 conductors going to the rear panel and conductors 59-64 (shaded in the table) going to the auxiliary card.

The front panel of the turbine unit has a hole 100mm wide by 165mm high to provide passage for the smoke detector. This hole is covered by the front-panel of the monitoring card. In addition to the DCS connection (J3) the front panel also supports a connector (to be defined) for connection of the smoke detector to the main detection system, and a visual indicator which will light in the event of the smoke detector being triggered (see).

The pin out of the two connectors J3 nand J5 are given in Table 2 and Table 3.

SubD (J3)	***Usage***
1	Not connected
2	CAN_L
3	CAN_G
4	Power
5	Cable shielding
6	VCG
7	CAN_H
8	Power return
9	VCP

Table 2 Monitoring PCB front connector pin-out.

Be careful with the pinout of J5. This kind of connector has pins labeled a1, b1, a2, b2... It is connected via a flat cable to 3Com connectors on the rear panel and auxiliary PCB which have a numbering 1, 2, 3, 4, ... The correspondance between J5 of the monitoring card and J1 of the rear panel is is b1 – 1, a1 – 2, b2 – 3, ... The pin out of J5 was designed with the understanding that the correspondace was a1 – 1, b1 – 2, ...etc. resulting in a pair-wise reversal of the pins on the analog and digital connectors of the rear panel. Rather than modify the monitoring card the error was recuperated on the two smaller cards, leaving J5 untouched.

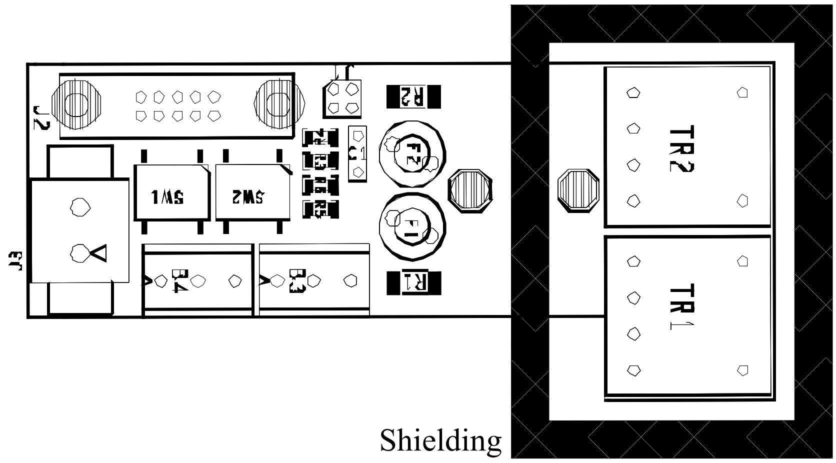
Usage	***Pin***		***Usage***
CH16+	a1	b1	CH16 -
CH17+	a2	b2	CH17 -
CH18+	a3	b3	CH18 -
CH19+	a4	b4	CH19 -
CH20+	a5	b5	CH20 -
CH21+	a6	b6	CH21 -
CH22+	a7	b7	CH22 -
CH23+	a8	b8	CH23 -
CH24+	a9	b9	CH24 -
CH25+	a10	b10	CH25 -
CH26+	a11	b11	CH26 -
CH27+	a12	b12	CH27 -
CH28+	a13	b13	CH28 -
CH29+	a14	b14	CH29 -
CH30+	a15	b15	CH30 -
CH31+	a16	b16	CH31 -
DGND	a17	b17	VREF
PA0	a18	b18	PA1
PA2	a19	b19	PA3
PA4	a20	b20	PA5
PA6	a21	b21	PA7
PC0	a22	b22	PC1
PC2	a23	b23	PC3
PC4	a24	b24	PC5
PC6	a25	b25	PC7
P3V3	a26	b26	Door Status
CH7+	a27	b27	CH7 -
CH8+	a28	b28	CH8 -
Ext Temp Probe	a29	b29	Ext Temp Probe
TS-Monitor -	a30	b30	TS-Monitor +
I-Monitor 1+	a31	b31	CardInSitu Status
I-Monitor 2+	a32	b32	DGND

Table 3 Detailed Pinout of J5

3.3 Auxiliary card

In order to monitor the currents of the tangential turbines we use a pair of transformers (this isolates the PCB from the 230V mains power used by the turbines). Since the transformers must be magnetically shielded when used in the UX areas they are mounted on a separate auxiliary card. This card is shaped and laid out so that the two transformers may be contained within a cylindrical iron shielding, while the connectors to the rear panel and monitoring card are accessible.

Drawing 4 Shows the layout of the auxiliary PCB indicating the location of the shielding. Detailed drawings of the shielding may be found in reference [11].

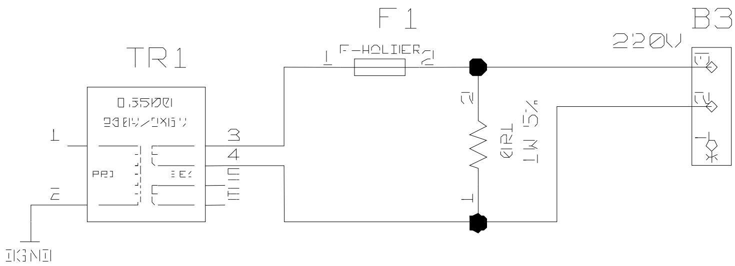


Drawing 4 Layout of the auxiliary PCB.

If the shielding is present (i.e. In the UX areas) it is screwed onto a profiled bar which forms part of the turbine unit, otherwise the PCB itself is screwed onto the bar. This card is not accessible while the turbine is in situ in the rack.

The tangential turbines are powered directly by the 230 V mains supply. To measure the current used we have a shunt on the auxiliary card. The bulk of the nominal 1.5A current passes through a 0.1Ω resistor on the PCB. The rest is used to give a sinusoidal signal to the monitoring card via a transformer.

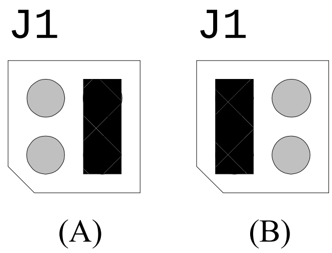
The transformers are not capable of sustaining the full current of the turbines. Thus in order to avoid catastrophic failure in the event of a fault causing the entire turbine current to pass through one of the transformers we have added fuses in series with the primary coils.



Drawing 5 Shunt and transformer used for the measurement of the turbine current.

We have also chosen to place the thermo-switch of the safety system on this card, specifically to avoid the possibility that this safety device can be removed from the rack.

There are in fact two thermo-switches (40ºC or 60ºC) mounted on the PCB. At installation one or the other is selected via a jumper (J1). This covers the two cases where there is or is not a heat exchanger mounted directly below the turbine unit. Position the jumper as in Drawing 6 (A) to select SW1 (40°C) or as in Drawing 6 (B) to select SW2 (60°C).



Drawing 6 Selection of temperature on the auxiliary circuit board.

Pins (J2)	***Usage***
1	Thermo-switch status (-)
2	Thermo-switch status (+)
3	Monitoring card in situ
4	Turbine 1 current monitor signal
5	DGND
6	Turbine 2 current monitor signal
7 – 10	Not connected

Table 4 Pin out of the J2 connector which takes the last six conductors of the flat cable coming from the monitoring card.

3.4 Rear-panel PCB

In order to facilitate the break-out of the many signals passing between the monitoring card and the rear panel a small PCB is mounted on the rear panel of the turbine housing. The first fifty-eight conductors of the flat cable coming from the monitoring card arrive on a 60 connector (J1) on this board, and these connections are then distributed to a number of connectors accessible from the rear exterior of the turbine unit (see Table 5).

Label	***Type(#pins)***	***usage***
J1	3M(60)	Flat cable connection to monitoring card
J2	3M(34)	Analog input connector
J3	3M(10)	ELMB PORTA
J4	3M(10)	ELMB PORTC
J5	AMP(2)	Door micro-switch
J6	AMP(4)	Reserved for leak detector
J7	AMP(2)	Temperature sensor in rear of rack
J8	AMP(2)	External safety (thermo-switch) connection
J9	AMP(2)	To thermo-switch on auxiliary PCB

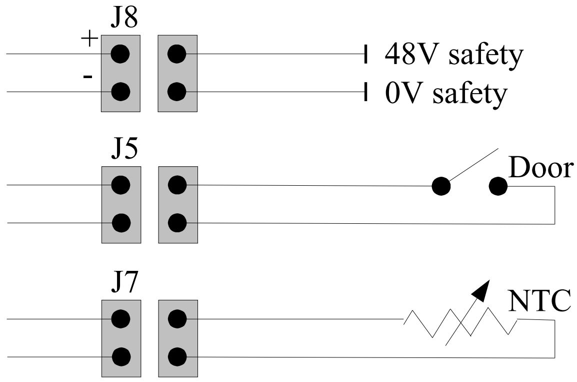
Table 5 Connectors on the rear panel. J1 and J9 are inward facing (i.e. towards the interior of the turbine unit) the rest are outward facing.

Connectors J1 and J9 are mounted facing towards the inside of the turbine; J1 connects to the monitoring card, and J9 connects to the auxiliary card (see Drawing 2). The pin out of J1 is identical to that of J5 of the monitoring card, except that pins 59 and 60 are not connected.

J8 provides the external connection to the thermo-switch of the safety system. This connector is polarized; when connecting to the 48V supply care must be taken to apply the voltage in the correct sense. An incorrect connection will not affect the functioning of the safety system, but it will mean that the ELMB will not be able to correctly monitor it.

The door micro-switch connector connects to J5; there is no polarity. J7 gives the possibility to mount an 22kΩ NTC in the rear of the rack for temperature measurements.

The pin outs of J2, J3, and J4 are exactly the same as for the standard ELMB motherboard [9]; The digital connectors (J3 and J4) provide the PORT I/O, 3.3V and DGND; the analog connector (J2) supplies VREF, DGND (there is only one ground on the board), and connections to the ADC inputs.



Drawing 7 Connection of J5, J7 and J8.

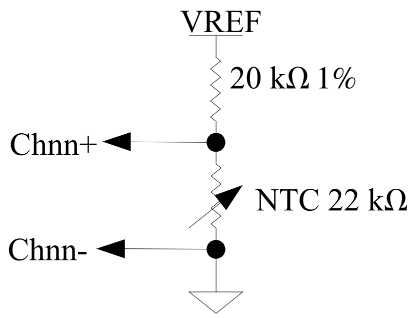
J6 is provided for a leak connector if deemed necessary.

The user I/O connectors are polarized 3M flat cable connectors with locking lugs [REF], and the rest are AMP two or four pin connectors [REF].

3.5 Sensors

The following details the sensors built onto the monitoring card and the implementation of the electronics used to read them out. The ELMB channel where the data may be accessed is also given.

1. <u>Temperature:</u> We use Negative Temperature Coefficient (NTC) thermistors [REF] for measuring the temperature. The NTC is put in a voltage divider circuit with a standard resistor and as the temperature changes, the voltage across the NTC varies. This voltage is measured by the ELMB.



Drawing 8 Voltage divider circuit for measuring temperature.

   There are two such circuits on the monitoring card so as to provide redundancy.

   - Input to ADC0, ADC1.

2. <u>Relative humidity:</u> The relative humidity is measured with a HIH-3610 sensor from Honeywell [REF]. This is a three terminal device: 5V, 0V and V_{out}. It is a low power device consuming approximately 200 µA. V_{out} is

proportional to the relative humidity of the surrounding air. This device is present for the detection of conditions liable to lead to condensation within the rack. The 5V supply of the device is provided by the ELMB.

- Input to ADC2

3. Air-flow: The sensor is implemented with a self-heating 330Ω NTC [REF], in a voltage divider circuit similar to that used for measuring the temperatures but with a 47Ω standard resistor. Measurements have shown this sensor to be sensitive to the difference between no forced air flow and forced air flow, whether due to the sub-rack fan-trays, the turbines, or both. It is not sensitive to the difference between fan-trays plus turbines, and turbines alone. Use of this sensor is optional (via placement of a jumper) because it uses ~10mA in moving air and ~20mA in still air. The difference in current is measured via a voltage level input to the ELMB.

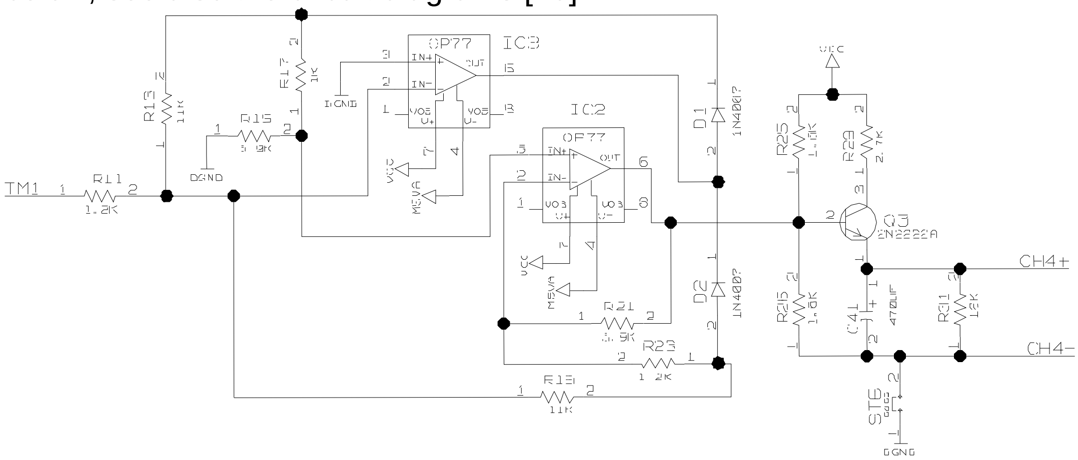
- Input to ADC6

4. Input power voltage: The voltage between pins four and eight of the front panel connector (J3) is measured. These two pins provide the power for the monitoring system via the same cable as the CAN communication. A voltage divider takes ¼ of the voltage difference and passes it to the ELMB, since the power lines should carry around 8V – 12V [9] and the ADC full scale is 5V.

- Input to ADC3

5. Tangential turbine currents: The currents drawn by the two tangential turbines are measured independently. A sinusoidal signal proportional to the turbine current is provided by the auxiliary card.

   This signal is rectified and smoothed on the monitoring card giving a voltage level which is measured by the ELMB. The circuit uses OP27E operational amplifiers (powered by +/- 5V supplied by the ELMB) and a 2N2222A transistor. Both of these components have been qualified for use in radiation (see section 8). The circuit for monitoring on current is shown below, see also the circuit diagrams [10].



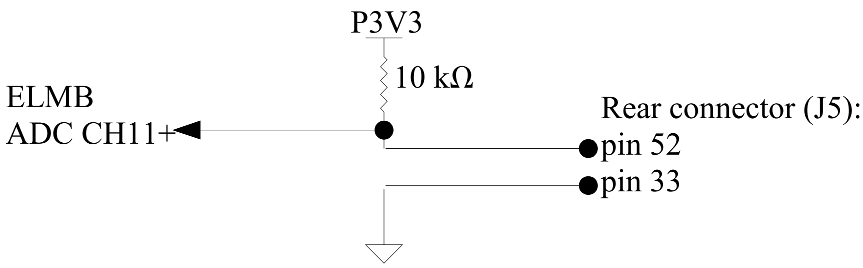
Drawing 9 The rectification, amplification and smoothing circuit for measuring the current in the tangential turbines.

- Input to ADC4 for turbine 1
- Input to ADC5 for turbine 2

6. Leak detector circuit: There is no circuit on the monitoring card as the foreseen leak detector does not seem to be very useful. however an adapter socket is reserved for use if a leak detector is added. These devices typically use a change in resistance to detect a leak and two ADC input channels are thus also reserved.

- Reserve ADC7, ADC8

7. Door status: The new LHC racks are fitted with a contact which is open when the rear rack door is closed [CHECK]. There is a simple pull-up resistor circuit on the monitoring card to monitor whether the door is open or closed. When the door is closed the two pins are shorted together. We monitor the status with an analog rather than digital value, to allow the ELMB to operate with the digital I/O disabled.



Drawing 10 Circuit for monitoring the state of the door.

- Input to ADC11

8. Monitoring card in situ:

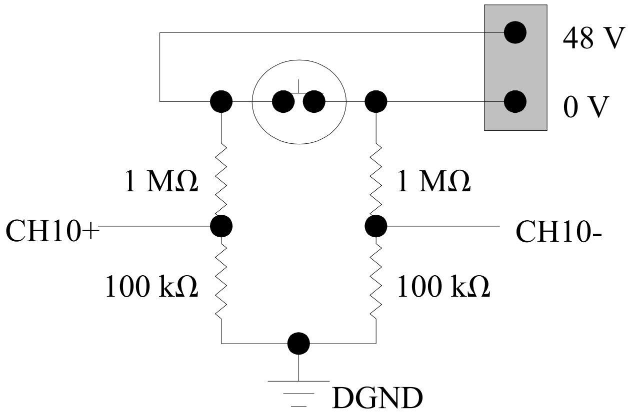
Since the monitoring card is powered and communicates via the front panel connector, it will continue to function partially even if not plugged into the turbine. In order to ascertain whether the card is actually plugged correctly in position a circuit identical to Drawing 10 is used. The short between the two pins in this case is implemented on the auxiliary card.

- Input to ADC12

9. Temperature in the back of the rack: The temperature in the rear of the rack is measured in the same way as the temperature in the front. A two pin connector is provided on the rear panel for the connection of a 22kΩ NTC.

- Input to ADC9

10. Thermo-switch status: A direct measurement of the status of the thermo-switch (open or closed). For simplicity of implementation this is input to the ELMB in analogue form.



Drawing 11 Monitoring of the thermo-switch. The ADC sees either 0V or 4.8V from the voltage dividers.

When the thermo-switch is closed (normal) the voltage measured will be ~0, when opened (alarm) the voltage will be in excess of 4V. The measurement circuitry is shown below.

- Input to ADC10

11. User analog inputs: Sixteen channels are available to the user via the rear panel. See section 3.4.
    - Inputs ADC16-ADC31
12. User digital I/O: ELMB Ports A and C are available to the uses. See section 3.4.
    - PORTA (bi-directional)
    - PORTC (output only)

3.6 Power consumption

The ELMB is an intrinsically low power device, and the monitoring system has very little in the way of active electronics to power. We have measured the current used by the system when powered by 10V (VDP and VAP):

Configuration	***Current [mA]***
No air flow sensor (Jumper removed)	48
With air flow sensor (plus air flow)	58
With air flow sensor (no air flow)	60

Table 6 Current consumption of the monitoring card when powered at 10V.

3.7 ELMB encodings

The ELMB runs the standard software and should be configured as follows:

- Node Id – as required
- ADC conversion rate – 60 or 80Hz
- ADC Range – 5V
- Number of ADC Channels – 16 (or 32 if user inputs are used)
- ADC mode – Unipolar

The digital I/O channels are not used by the rack monitoring system and may be disabled.

The relationship between the value measured by the ELMB ADC (A is ADC counts not microvolts) and the physical quantity measured is shown in Table 7.

Parameter[Unit]	***ADC Channel***	***Formula***
Temperature [°C]	0,1,9	$\frac{3740}{(12.646+\ln(\frac{32768}{A}-1))}-273$
Relative humidity [%]	2	$161(\frac{A}{65536}-0.16)$
Supply voltage [V]	3	$20(\frac{A}{65536})$
Turbine current [A]	4,5	$\frac{A+6810}{16730}$
Air-flow [Binary] (threshold to be defined)	6	$A>threshold$ Airflow $A<threshold$ No airflow
Leak detector	7,8	
Thermo-switch status [Binary]	10	$A<50$ Thermo-switch closed $A>40000$ Thermo-switch open
Door status [Binary]	11	$A<50$ Door closed $A>40000$ Door open
Card in situ [Binary]	12	$A<50$ Card in situ $A>40000$ Card not in situ

Table 7 Correspondence between ADC value (A) and physical quantities.

Notes:

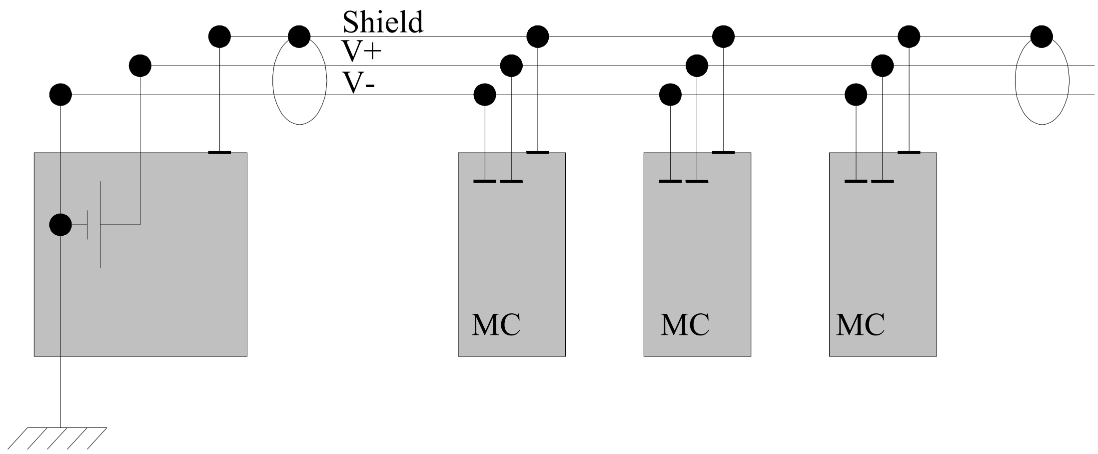
1. The turbine current is a linear fit to the prototype card, it may be necessary to calibrate individual systems.
2. The threshold for the air-flow sensor is to be determined.
3. The leak detector is as yet undefined.
4. The status of the door may be inverted, we will only know when we receive an LHC rack.

4 Integration with higher level systems

4.1 Powering, communication and "grounding"

A system to provide monitored and powered CAN buses suitable for use by the rack monitoring system is under development by ATLAS. In addition to providing power and the communications medium the system will monitor the current drawn by the devices on the bus and can reset the ELMBs by cycling the power in the event of a problem.

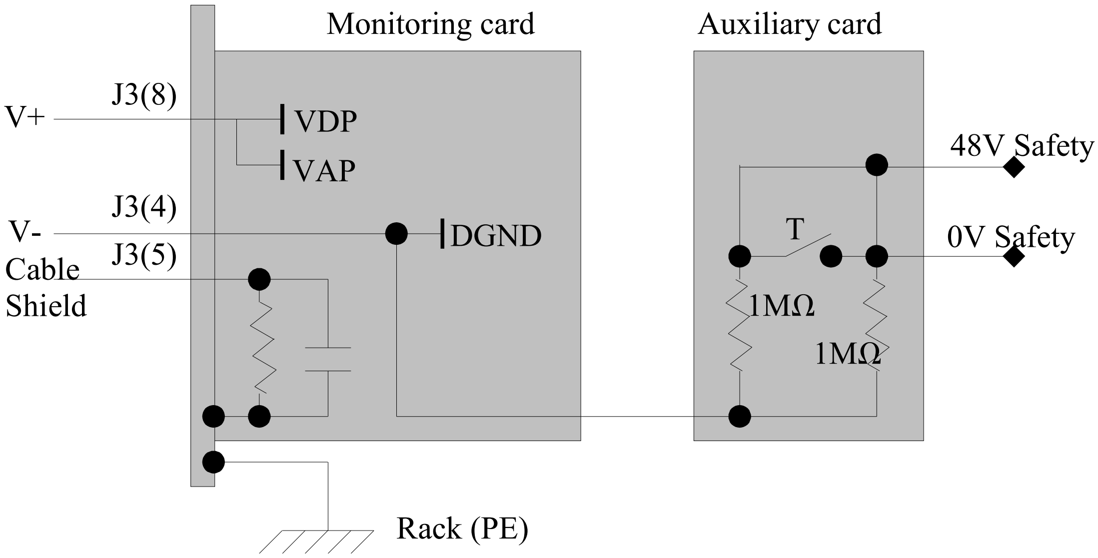
The powering scheme will be as shown in Drawing 12. A rack mounted unit will house the power and monitoring systems. The number of systems that may be placed on a bus will be limited by the voltage drops in the cable and this will depend upon the physical layout of the racks and the type of cable used.



Drawing 12 Powering of the rack monitoring system.

The electronics on the monitoring card is floating with respect to the rack since it is powered via the front connector and the current monitoring circuit is isolated from the mains power of the turbines by the transformers. Drawing 13 shows the power connections on the monitoring card, as well as the connection between the cable shield and the front panel.

In Cadence the metalized mounting holes for the front panel are tied to GND, since our system is floating with respect to the rack (and thus the front-panel) we refer to our 0V as DGND. Note, however, that we use the DGND for both digital and analog grounds.



Drawing 13 Schematic of the power and safety connections in the rack monitoring system.

4.2 Safety systems

In the baseline use of the rack monitoring and safety system the electrical distribution systems of the LHC experiments will use the thermo-switch to cut power to the rack in the event of excessive heating.

In the case of the CANALIS system of ATLAS and CMS, at least in the US zones, the thermo-switch will be connected directly to a microPLC situated just above each rack. In the case of the experiments using the Hazemeyer units the thermo-switch provides a 48V potential free normally closed contact.

As discussed above, the opening temperature of the thermo-switch is selectable as either 40ºC or 60ºC.

The smoke detector is a Securiton SSD 530 device [12]. It has no electrical connection with the rest of the monitoring and safety system presented here; an industry standard detection system will monitor the detectors either via a bus or 4-20mA current loops. This system is PLC based, readable by the DCS, and the actions to be taken on receipt of an alarm are configurable.

It has been demonstrated that the smoke detector is able to effectively detect smoke within the rack [5] when placed inside the turbine.

4.3 Use of the user I/O functionality

When using the general purpose I/O connections a number of considerations should be borne in mind (refer to ELMB documentation [9]):

1. The I/O channels are referenced to DGND of the monitoring card (provided

on J2, J3, and J4 of the rear panel) not to the rack (protected earth).

2. Current sourced or sunk through the I/O channels should be kept to a strict minimum, as it is supplied directly by the ELMB.
3. The common mode input of the ADC is limited to -2V to +5V, see [9].

Given the above, opto-isolators should be used for digital control.

5 Radiation qualified components

1. Operation amplifier OP27: see ESA database: https://escies.org/public/radiation/esa/database.html
2. Transistor 2N2222A: see ESA database: https://escies.org/public/radiation/esa/database.html
3. Humidity sensor: test done by EP/ESS at CERN, see:

6 References

Documents related directly to the rack project can be found at:

http://ess.web.cern.ch/ESS/rackControlProject/index.htm

1. Strategy document 2002.
2. Presentation November 2002.
3. Presentation April 2003.
4. Presentation June 2003.
5. Memo: Smoke detection tests 1.
6. Memo: Smoke detection tests 2.
7. Effect of magnetic field on AIRPAX 66L040 thermo-switch.
8. Test of shielding performance in magnetic field.

Documents related to the ELMB are at:

http://atlas.web.cern.ch/Atlas/GROUPS/DAQTRIG/DCS/ELMB/ELMBhome.html

9. ELMB documentation.

All engineering drawings, circuit diagrams, etc. will be put in EDMS:

10. Rack monitoring circuit diagrams.
11. Mechanical drawings of auxiliary PCB shielding.

Other documentation:

12. Securiton smoke detection.

7 Contributors

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