13.5 Detector Control System

The ATLAS Inner Detector (ID) incorporates three sub-detectors which have to be operated in a high radiation environment inaccessible for servicing during long periods. All are optimized for low mass, but have to maintain good performance and mechanical stability over a large surface area for a long period. The detectors require a Detector Control System (DCS) that can track both fast and very slow variations in important detector parameters, and which can take appropriate corrective action to maintain the required high level of detector stability.

Even though all the ID sub-detectors operate in a similar environment, the detectors themselves are very different. The pixel detector has a very high power density across the active area which needs a sophisticated fast interlock system between power supplies and the cooling system. The Semi-Conductor Tracker (SCT) covers a large area with silicon detectors which have to be very stable and well aligned. The Transition Radiation Tracker (TRT) is a gaseous detector with the controls of the gas system closely coupled to the high voltage system.

All the sub-detectors in the ID will have their own DCS, with a minimum of one Local Control Station (LCS) per sub-detector. It is our understanding that most of the high level system, including the high level software and LCS interface boards for connection with a field-bus, will be defined by the central ATLAS DCS group and will be easily adaptable to individual detectors. Most boards in the LCS will probably be common for all ATLAS sub-detectors. The DCS of the ID sub-detectors will fully conform to the requirements set out in the ATLAS DCS User Requirements Document [13-5].

Generally the DCS of the ID sub-detectors controls, monitors and supervises operation of the sub-detectors and the related apparatus. Its main aims are;

- parameter monitoring, loading, logging and setting
- issuing commands for certain actions - mostly operational
- correlating parameters from different parts of the detector
- collaborating with the DAQ system via the '`Run_control`' layer
- supervising the safety of the detector in collaboration with Central Safety System
- setting alarms, emergency procedures etc

The status of all components should - whenever necessary - be available and user intervention should be possible where allowed. As the DCS of the ID sub-detectors is part of the overall ATLAS DCS, it will accept general ATLAS commands and return the summary status of the ID subsystem. Additionally, the DCS shall supply a user interface to allow autonomous operation during the construction, testing, commissioning and calibration of the ID sub-detectors.

The lowest level DCS elements (the "front-end" monitors within the ID volume) must be engineered into the design of each sub-detector with the addition of the minimum amount of extra mass. Signals from the monitoring of some common parameters, listed below, can be distributed among the DCSs of all the ID sub-detectors:

- radiation levels;
- B field;
- humidity;
- nitrogen atmosphere;

- flammable gas / flammable liquid detection;
- smoke detection;
- low oxygen level detection;
- alignment (SCT & pixels).

In addition, all sub-detectors will monitor their own detector temperatures and power supply voltages and currents. A common technical solution for these measurements would need a far reaching cooperation between groups. It is however not clear if a common solution in these areas would simplify the design or operation of the detectors. Since the interlock connection between the temperature measurements in the cooling system and the detector power supplies is very sub-detector specific, this might prevent the sub-detectors finding a common solution.

The ATLAS DCS group plans to equip VME readout crates/fan units with field-bus interfaces. It will be possible using standard ATLAS DCS protocols to monitor all crate voltage rails, current consumptions and temperatures and to remotely turn crate supplies on and off. Protocols for crate control are under study in the ATLAS DCS community.

In the following sections the DCS for the sub-detectors of the ATLAS ID will be described.

13.5.1 Pixel Detector Control System

13.5.1.1 Overview

From the control point of view, the main components of the pixel detector are the cooling system and the power supplies. As an increase in temperature can cause irreparable damage to the detector, a sophisticated interlock system must interact between these two components. Besides the general requirements, the main effort of the detector specific control system is a proper handling of these safety strategies. Figure 13-12 is an overview of the DCS.

The detector is subdivided into 8 disks and 3 barrel cylinders. Disks consist of 10 sectors of 14 or 8 modules, while the cylinders contain around 130 staves of 13 modules. In total there are about 2500 modules on about 200 staves/disk-sectors. For power supply, a module is the smallest unit the DCS can act on, while for cooling it is the disk sector or barrel stave. Each module requires a set of low and high voltages to operate the pixel readout ICs and controller IC, and to deplete the active silicon substrate. The modularity of the pixel power supplies is based on the mechanical design of the detector. Several further aspects determine the choice of modularity:

- The depletion voltage and current of the sensors depend strongly on the overall radiation dose the individual detector is exposed to. This dose is expected, for example, to differ by more than a factor of two over the length of a given barrel layer. Consequently, modules on the same detector element will require substantially different voltage and current settings as their exposure increases;
- Degradation of the heat sinking of pixel modules to the stave cooling tubes (for example due to delamination of a thermal epoxy connection) can accelerate substrate ageing in single modules;
- As an access to the detector is probably only possible once per year, a high modularity minimizes the amount of the detector out of service for long periods.

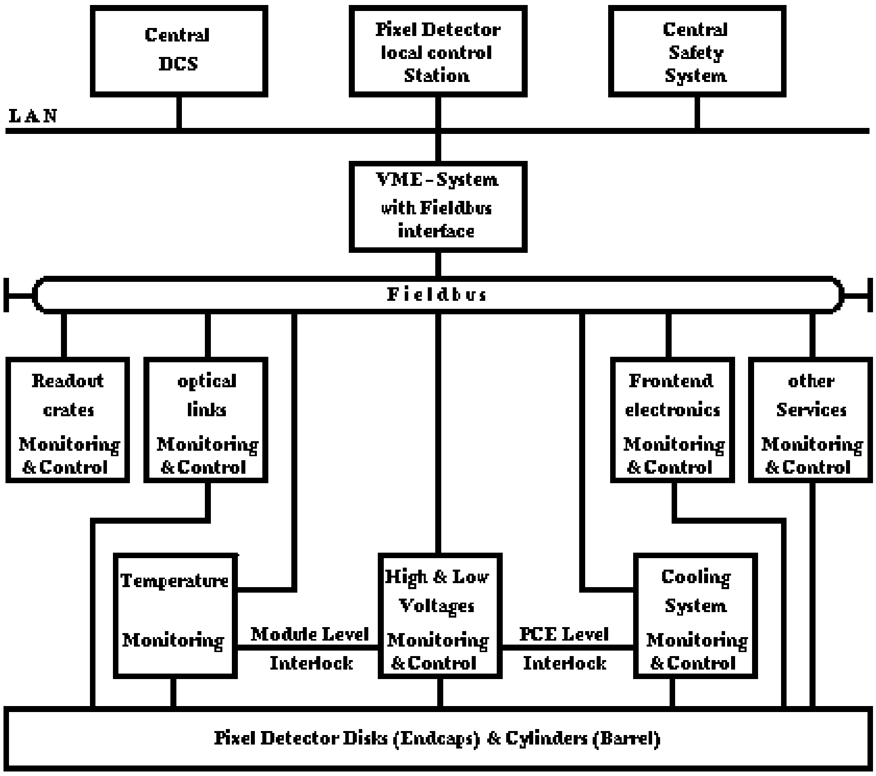

Figure 13-12 Pixel DCS, showing the position of the cooling/power interlocks in the overall DCS hierarchy

For these reasons each pixel module should have its own power supply.

Power supplies

The power supply for a pixel modules consists of the required set of different voltages (Vdd, Vcc and Vdep), in a 'multivoltage' channel, and has its own interlock connection (such a scheme is also under development for BaBar). This interlock is connected to the temperature monitors of the cooling system (Section 13.5.1.2), and switches off the individual module power in case of local overheat or any other cooling system problem which might damage it.

The nominal voltages and power supply functionality, parameter setting, and monitoring requirements are discussed in Section 10.4.11 together also with the power supply requirements for the control of optical links. The power supplies are arranged in crates requiring an interface for remote control (CAN-Bus or another field-bus). As the detector safety-related operations will be done at a very low level inside the DCS hierarchy, the main tasks of the higher level DCS will be histogramming, transferring of commands and reading back status information. Depending on the number of nodes which can be handled by one field-bus interface, only 1 or 2 interfaces may be necessary to handle all power supplies.

Working point of the readout

The front-end pixel readout ICs are controlled through locally-generated currents and voltages, which determine the working point of the readout. As it is foreseen to preload the settings of these parameters for each pixel module through single serial links, the DCS-hardware will provide the transmitters for these channels, and the DCS-software will synthesize the data format out of the database information. The pixel DCS will give a read-back of the settings through the physics data path, for verification. The requirements for online monitoring of the control sources are under investigation.

We prefer to locate power supply racks in an area completly accessible to personnel during the running of the experiment. The USA15 service cavern is suitable in this regard. If radiation and magnetic field levels permit, the supplies could be mounted closer to the detector. However, low level monitoring hardware such as signal conditioning electronics for critical temperature sensors, coolant flows, and related digital interlock circuitry - on which the safety of the detector critically depends - must be located, together with the necessary Uninterruptable Power Supplies (UPSs), in USA15. The types of electronics modules required for this are discussed in Section 13.5.1.2.

13.5.1.2 Cooling system monitor and control, and coolant-power interlocking

The cooling system can be subdivided into:

1. 100 PCEs (parallel cooling elements) each serving two staves/disk sectors (or single staves in the vertexing layer)
2. the recirculating cooling plant itself. (As binary ice cooling is still under evaluation, details concerning monitoring and control of the binary ice generator are not discussed here.)

A system of interlocking pixel detector power (D.C. low voltage for the detector front end electronics and depletion voltages for the detector substrates) is considered vital to prevent the very rapid heating up of detectors in the event of a coolant failure. An interlock scheme is being developed that is transparent to the final choice of cooling scheme (Binary Ice, Fluorocarbon total evaporation or mono-phase coolant). The interlock scheme will operate at two levels:

1. disabling of power delivery to all the pixel detector modules on a PCE in the event that low or no coolant flow is detected in the coolant return line from that element (indicating a leak or blockage), or in the event that an over-temperature condition is detected among a majority of temperature sensors located on the cooling tube of the particular element.
2. disabling of power delivery to a single pixel detector module in the event that an over-temperature condition is detected in that module alone. This could be due to a problem in the thermal coupling of the module to the coolant tube, and may arise even if coolant is flowing normally through the tube.

Parallel cooling element level interlock
For each PCE, several parameters need to be monitored, and some of these must be used as entries to a finite state machine (FSM) which sets the '**PCE level interlock**'. This interlock acts on the PCE itself (shutting valves if a leak is detected), and on the power supplies of all related detector modules. In order be sure of the proper operation with binary ice (and to detect leaks reliably), flow rate and ice concentration in the supply and return tubing must be monitored as well as the temperature along the PCE itself. This information will be combined with the temperature measurements from the single module monitoring.

The possible monitoring requirement per PCE is summarised below:

- analog voltages derived from ~ 6 temperature sensors (on structure/tubing), requiring discrimination where used for hard-wired control functions

- analog voltages from 4 differential pressure measurements, for volumetric flow and input and output ice concentration, requiring discrimination where used for hard-wired control functions
- 1 or 2 TTL output register bits (for driving PCE input and output valves: the number of bits required depends on a finite state algorithm for the closure and opening sequence)
- 2 TTL input register bits (readback of valve status)

These give, for the PCE level interlock, a total of about 2000 analog voltages, 400 digital output and 400 digital input bits.

Low coolant return flow in a PCE may be detected most easily by a differential pressure transducer measuring the pressure drop along a known length of coolant return tube. The Honeywell 26B1, -C1 & -D1 sensors are examples of a class of inexpensive pressure transducers that would allow monitoring at the individual PCE level. The DC voltage from the pressure sensor can be compared with a threshold voltage representing the known minimum volumetric flow necessary to adequately cool the element. In the case of uniphase liquid coolant or total evaporation of a fluorocarbon liquid, the problem is relatively simple. In the case of binary ice, there is an ambiguity since the cooling capacity depends on the overall volumetric flow and ice concentration: identical pressure drops can be generated for many combinations of flow rate and ice concentration. Knowledge of the ice concentration at the input of the detector cooling element is therefore required from a second measurement. One advantage of the use of coolant flow sensors is that they may be installed, (together with their signal and power wiring) outside the ID volume, provided the placement is in a zone with acceptably low radiation levels.

It is also possible to equip the PCE cooling tube with several radiation-resistant temperature sensors; for example platinum resistance thermometers (RTDs) running 3 wire readout. In this way, the power could be disabled if a majority of the temperature sensors register an overtemperature condition.

Most of the analog voltages listed above will be split between monitoring (scanning ADC) and interlock operations requiring discrimination before entry into the FSMs which handle the PCE level interlocks. These signals would need to be read independently of the main detector data acquisition scheme using the simplest possible hardwired techniques, avoiding dependence on system software. The control system electronics would be backed up with automatic change-over to UPS in the event of a failure of the commercial electricity supply, to which the detector LV and HV power supplies would be connected.

We have begun discussions with companies to determine how these different measurements could be combined on dedicated control boards (carrying FSMs implemented in Field Progammable Gate Arrays [FPGAs]), or maybe with commercial PLDs.

The interlock scheme would also be required to take further intelligent action in the event of an overtemperature condition on a pixel stave or disk sector. Since the cause could be a coolant leak, it will be necessary to shut isolation valves to the cooling element to prevent the ingress of air into the main coolant recirculation system, which would reduce its efficiency. Isolation valves would be situated outside the inner detector volume, in the vicinity of coolant supply and return manifolds, but would probably be in the fringe field of the ATLAS toroid.

A prototype coolant interlock system has been developed and implemented on an array of four thermal prototype pixel barrel staves. Pneumatically-actuated shut-off valves[1] are piloted with compressed air using miniature solenoid valves[2]. Such an electro-pneumatic control chain for

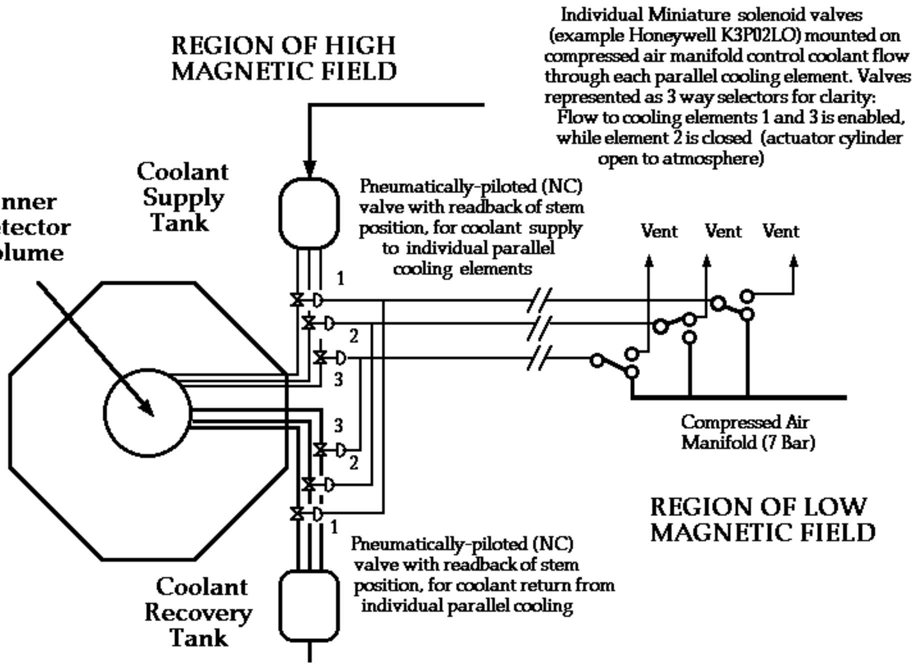

Figure 13-13 A possible implementation of part of the interlock system, showing the positions of shut-off valves near the coolant supply and collector reservoirs on the ATLAS service platforms.

operation and readback of the positions of coolant shut-off valves would be suitable for operation in the ATLAS toroid fringe field . Figure 13-13 shows a possible implementation of the interlock system with isolation valves located on manifolds close to coolant supply and return reservoirs on the ATLAS service platforms. The solenoid valves with their compressed air manifold would be located in a region distant from the magnetic field, and would communicate with the coolant isolation valves through miniature hoses.

Figure 13-14 shows a schematic of a prototype first stage power interlock circuit allowing power application to a pixel module only if:

- the coolant supply and return isolation valves of the PCE open, when commanded open, (i.e. there is no fault condition), and
- there is an acceptable coolant flow, and
- "POWER ON" has been requested by the operator

The circuit of Figure 13-14 (up to "J5") is presently used to drive single staves in thermal studies. In the full interlock sequencer under design, failure of the valves to open correctly when commanded, or of the coolant flow to reach the required level will disable the power to the PCE. The valves will be returned to the closed state in a sequence which allows time for evacuation of any remaining coolant in a possibly damaged “underpressure” section of tube to be evacuated by the circulation pumps. This sequencing (probably necessary with a water-based binary ice coolant) will be overseen in FPGA-based FSMs or commercial PLDs. The electronics for the measurement of critical temperatures, flows and control of coolant valves and power relays will be part of the pixel-specific area of the DCS. It is anticipated that multi-channel valve driver

1. Whitey model 92S6MM-C-L2, 6 mm with stem position switch
2. Honeywell model K3P02LO, 5 Volt, 100mA, directly interfacable to TTL logic

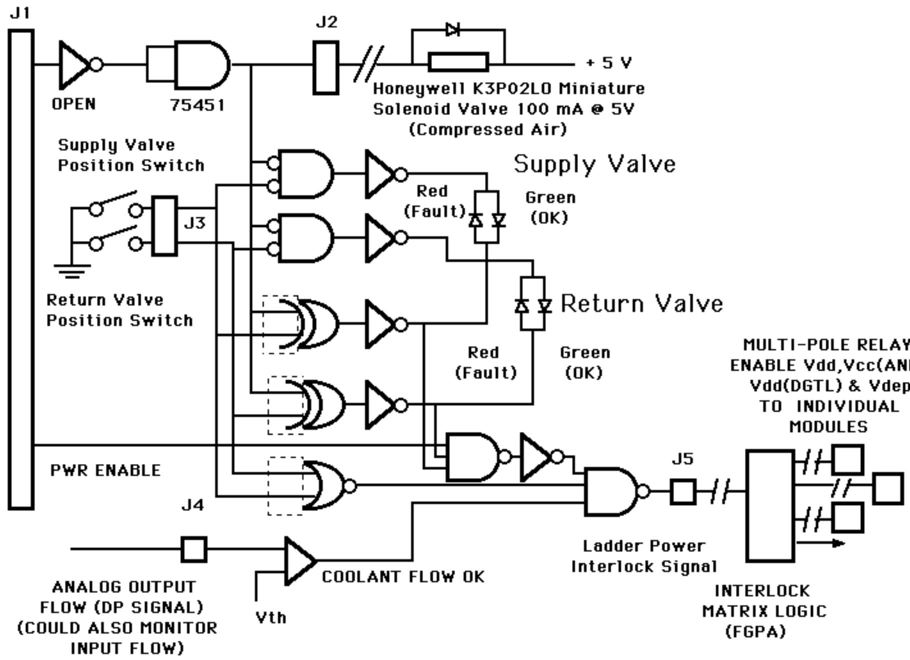

Figure 13-14 Interlock circuit allowing power application through the FPGA interlock matrix only when the coolant flow valves are open and there is sufficient coolant flow. A second level of interlock (not shown) disables power to individual modules if their temperature becomes too high.

cards and RTD - reading cards will be developed, and that the power supply interlock matrix will be stored in a series of routing FPGAs, which will pass forward the responses of the temperature/coolant flow FSMs to detected fault conditions.

The critical elements of the control system will operate on an UPS system as illustrated in Figure 13-15. In the scheme foreseen, power is derived from a 24 volt power supply running on the normal AC supply. In the event of AC failure, this supply will go off line, if even only for a short time until a diesel back-up generator starts, and power will be derived from a 24 Volt battery pack, normally kept charged. Power for various analog and digital functions is derived from redundant DC-DC converters, with automatic diode change-over. Not shown in Figure 13-15 is a further layer of diode changeover at the +/- 15 V and 5 V loads, should the in-service DC-DC converter drop off line.

Module level cooling interlock

Each pixel detector module will carry an on-board temperature sensor, read out independently of the data acquisition scheme, using simple hard-wiring. The sensor readout might share the same cable as the module power supply, and might be read directly into the power supply to cut power in an over-temperature condition.

The most elegant system of power supplies (allowing the least error-prone interlock scheme) would combine all the required voltages for a detector module into a multi-voltage channel to which a single interlock or temperature sensor input would disable all the voltage rails simultaneously. If it does not prove possible for financial reasons to equip each of the approximately 2500 pixel detector modules with an individual multivoltage supply, distributor/dividers could be used to supply modules from common low and high voltage supplies. The interlock scheme

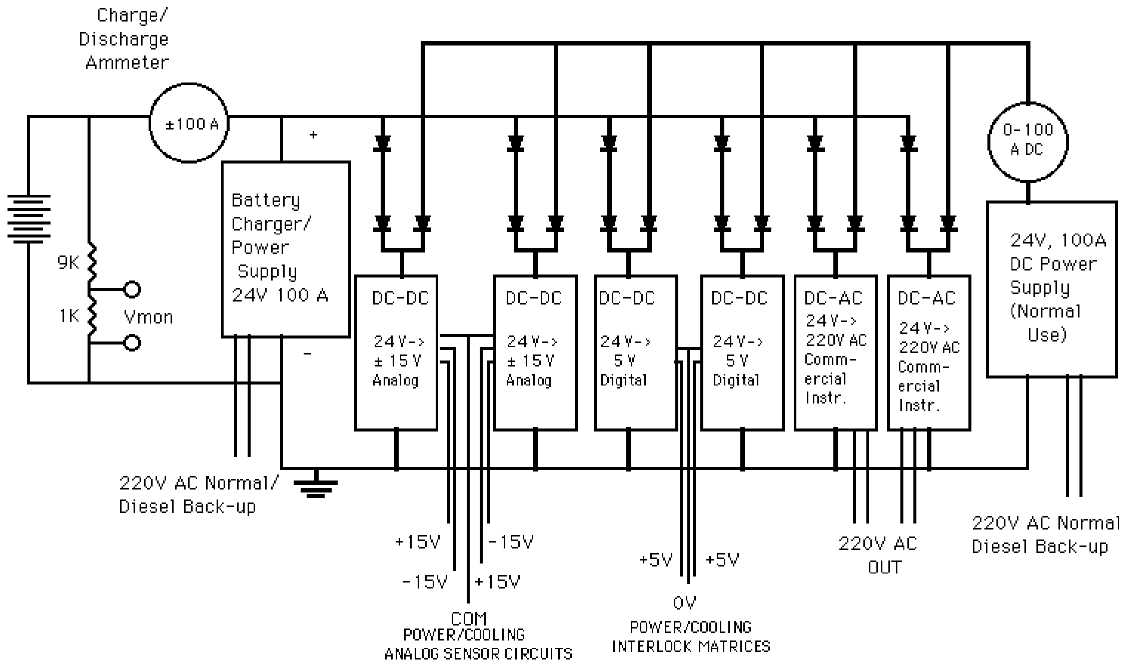

Figure 13-15 Possible implementation of an uninterruptable power supply scheme with battery back-up for pixel power/coolant/ temperature interlock electronics.

would need more care to ensure that the correct combinations of Vdd, Vcc and Vdep were shut down for a particular pixel module.

The signal from each of the 2500 module RTD/PT100s is split between

a discriminator whose output connects to the interlock input of its related multivoltage channel (this discriminator could be part of the multivoltage module itself). This will be the fast **'module level interlock'**

an analog multiplexer input to a scanning ADC. Its information is used for the analysis of the behaviour of the cooling system to avoid failures in advance.

The electronics needed to energise, signal condition, and discriminate the temperature signals from the on-module sensors will be powered either directly from the power supplies themselves, or via the same type of electronics foreseen for the signals for the PCE-level interlocks supplied through the scheme of Figure 13-15. Split analog signals will be read out through the pixel DCS (Figure 13-12).

13.5.2 SCT Detector Control System

The structure of the SCT DCS is shown in Figure 13-16. On the top level is the Local Control Station (LCS) which is the interface to the global DCS in ATLAS. The LCS is connected to nodes which perform signal processing functions such as data normalization, temporary storing and comparison with the status tables. The nodes contain microprocessors and may have a local user interface, or Satellite Control Station, which can operate the node when the unit is not connected to the LCS. This feature is especially important during system tests in the installation

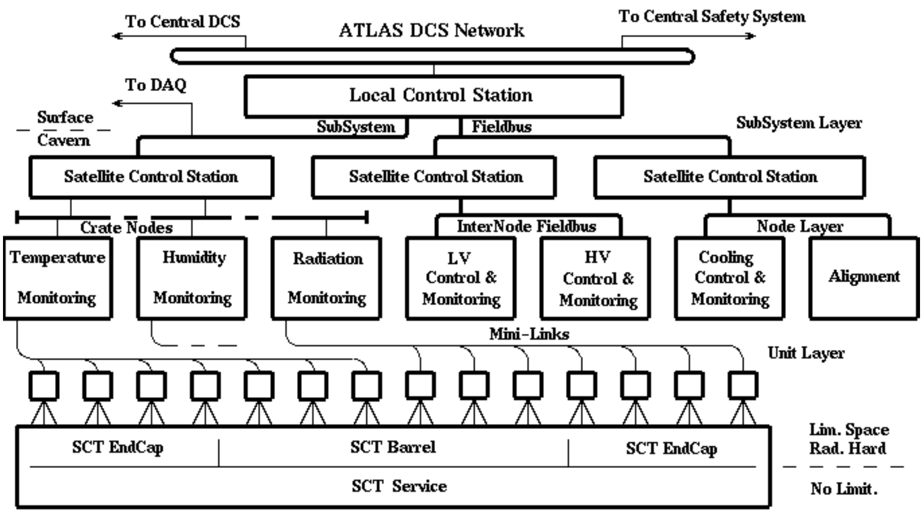

Figure 13-16 The General Structure of the SCT-DCS.

phase. The SCT has grouped the nodes of the DCS in conformity with the types of functions they perform. The SCT has the following nodes:

- monitoring of subdetector conditions, temperature, humidity etc.
- control and monitoring of low voltage
- control and monitoring of high voltage
- control and monitoring of detector cooling
- supervision of the detector alignment system

In the SCT, smallest units which concern the DCS are the 4088 detector modules. Each contains a set of the sensors and actuators serving or operated by the nodes of the DCS. Some of the nodes of the SCT DCS nodes are described elsewhere in this document. The alignment system is described in section 9.3.3. The high voltage and low voltage supplies are described in section 11.4.8. The design of the cooling system is described in section 11.7. The DCS part of the cooling system, the monitoring system for the operational parameters and the interlock system are discussed below. Detailed requirements for the SCT DCS can be found in ref. [13-6].

13.5.2.1 Cooling system interface to DCS and slow control

For the purposes of interfacing the individual components into the overall ATLAS DCS system, the cooling system has been divided into subsystems which can run on a stand-alone basis. These comprise the following items.

- The Binary-ice machines and their associated pipes, pumps, sensors and valves.
- The leakless loops and their valves, pumps and reservoirs.
- The cooling for the environmental shield. As stated earlier, this is probably an individual Binary-Ice machine although it is possible that it might reside within the main Binary-Ice plant and operate as a separate loop. In this case, it would utilize common components, for example, compressors and PLCs/PLDs (Programmable Logic Controllers / Programmable Logic Devices).

- The cold gas supply for the SCT detector environmental shield.
- The interlock i/o bus which, for example, interlocks the power supplies and the Binary-ice cooling. The power supplies receive information on the thermal status of the temperature sensors mounted on the individual modules.

Each subsystem has a dedicated PLC which runs its subsystem as an autonomous unit. Figure 13-17 shows a possible layout of the system. Some of the PLC's digital i/o channels are used to hardwire the DCS interlocks. In this way, the failure of any sub-system component can be communicated to any other devices that require that information, without reliance on any form of active bus or network.

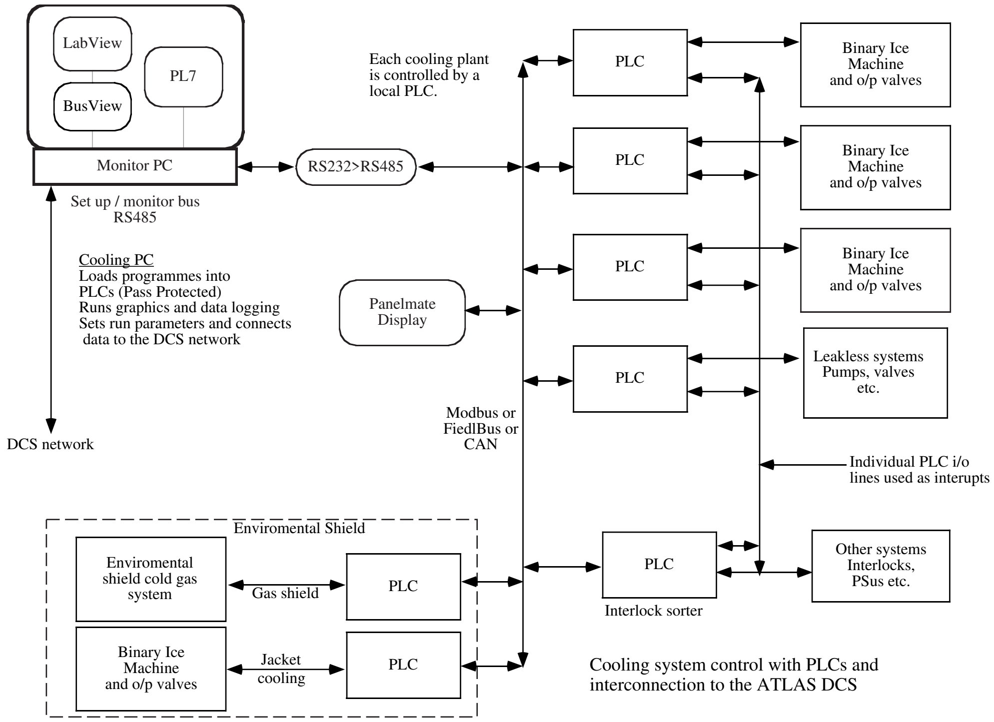

Figure 13-17 A possible layout of the subsystem PLCs and their interconnections.

A PC will be used as the Local DCS Terminal to a) program the PLCs and b) monitor the system statuses via the PLCs, and pass this data to the main ATLAS DCS network. The PC will also run local system software.

The PLCs will be linked to each other and a PC by a communications bus which might comprise one industrial field-bus standard such as CAN or MODBUS. LCD panels (for example 'Panelmate') would be mounted in the DCS Cooling racks for local display of system parameters. These units allow the signals from almost every type of sensor to displayed without the need for separate signal conditioning amplifiers.

A diagram of the layout of the principal elements of the cooling system, their connections to each other, their PLCs and the DCS system is shown in Figure 13-17.

Some possible failure modes are discussed below along with the restorative action that would be taken.

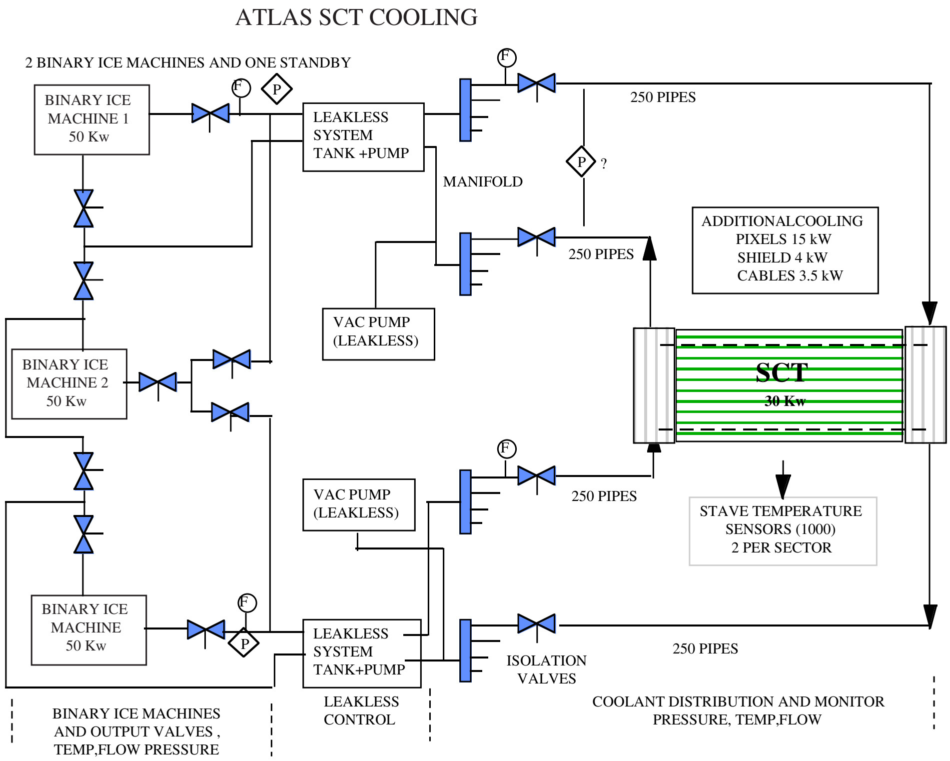

Figure 13-18 Principle Elements of the cooling system.

In the event of a single detector module's temperature deviating from its nominal value, the cooling system will be unable to take any action. The module's power supply may decide to reduce or remove the applied voltages to overcome the problem. In such an event, the power supply DCS sub-system will inform the cooling sub-system. If an entire local support of modules undergoes a thermal excursion, this event should be noted by both the relevant DCS sub-systems. A signal will be sent to the appropriate supplies to lower the voltages and to the cooling system. A local alarm will then be activated to prompt investigation of the problem. In the event of failure of a part of the cooling plant, all module supplies would be turned off, via DCS and the reserve cooling plant would be brought on-line. Once the cooling had restarted and after operator validation, the power supplies could be turned on to recommence data taking. In the event of an even more catastrophic failure, perhaps a total power loss, the PLCs of the cooling plant will continue on interruptible supplies. The degree of cooling capacity that would be available on permanent supplies is still under discussion. It is anticipated that, as a minimum, the environmental cooling would continue unchanged.

13.5.2.2 Monitoring of operating parameters

The monitoring of the SCT detector is split among several nodes of the DCS. Most monitoring can be done in a rather friendly environment outside the SCT detector where the services are generated. For monitoring in the high radiation environment inside the SCT thermal insulation, the aim is to have as few complex active elements as possible but the choice of technique also has to take into account the amount of material which will be introduced into the tracker. The sampling frequency of the monitoring is not foreseen to exceed 1 Hz for a full set of parameters. In the event of a power failure, the monitoring will continue to run on UPS. The following parameters will be monitored by the SCT DCS:

- the low voltage and current,
- the high voltage and current,
- the temperature of the modules,
- the SCT environment and cable bundles passing the TRT,
- the humidity inside SCT,
- the barometric pressure inside the SCT,
- the radiation inside the SCT,
- the status of the cooling system, and
- the status of the interlock system.

The monitoring of voltages and currents is done at the power supplies. It is believed that the voltages at the module can be known to a precision better than 2.5% of nominal value even without remote sensing. The monitoring of the power supplies is connected to the LCS through an industrial standard interface such as CAN bus.

Temperature monitoring is done within the high radiation environment. Platinum thermal resistor sensors PT100/PT1000 will be used giving a relative precision better than 0.2 ˚C and the corresponding absolute precision will be better than 0.5 ˚C. The power cables have leads for bringing the signals of the probes to readout boards outside the high radiation environment. A temperature monitoring crate has 10 readout boards with 32 input channels each giving 320 channels/crate. In total about 4000 temperature monitoring channels will be needed or 125 readout boards. The crates are connected to the LCS through an industrial standard interface. The monitoring crate will be placed close to the power supply crates and the patch panel.

Methods of reducing the number of sensor wires are under investigation. One possible reduction can be achieved by converting the parallel readout to serial form before transferring the data outside the tracker with an analogue radiation hard multiplexer or alternatively by using a comparator chain with a common ramp. In such architecture one unit per local support in the barrel or a similar segmentation in the forward direction is needed.

It may be necessary to monitor barometric pressure and humidity inside the thermal shield of the SCT. This data is needed for the alignment system. The necessary precision of the measurement of the barometric pressure is 1mbar. The SCT will be flushed with dry air or nitrogen inside the thermal shield. Ideally there is negligible humidity, but in the event of leaks there may be humidity, and the refractive index of the atmosphere will change. The monitoring system must sense small amounts of water vapour. Only a few monitoring points are needed both for humidity and barometric pressure.

Commercially available monolithic pressure sensors are being irradiated in order to test they fulfil the radiation tolerance needed in the SCT. A method of monitoring the humidity without active elements inside the high radiation environment is under investigation. The method is based on the absorption of light in water vapour.

13.5.2.3 Interlocks

The SCT interlock system will be a combination of hardwired and software driven units. The system should be immune against single point failure. The operational state of the interlock system will be monitored by the DCS. In a minimum configuration the interlock system will have the following inputs.

- general safety system (GSS)
- cooling interlock
- monitoring interlock

The temperature interlock from the cooling system is the primary protection system and has to be fast. This interlock is hardwired between the cooling system and the power supplies. The hardwired interlock is backed up by a software interlock generated by the monitoring system. In addition to the temperature data from the cooling system the monitoring system has access to the temperature data of the modules. By following the trends of the temperature data corrective actions can be taken before a interlock is generated. The interlock system will be connected to a UPS.

13.5.3 TRT Detector Control System

The TRT detector, while a part of the inner detector, has its own very specific features:

- it is a gaseous tracking detector with very short drift time
- it is a proportional detector measuring energy deposits from charged tracks and X-ray photons

The `L(ocal)DCS` - a sublayer of the *G(lobal) DCS* - should oversee the stability of parameters that affect the detector performance. In the following subsections we describe the proposed configuration of the TRT DCS, concentrating on the issues which are TRT - specific.

13.5.3.1 Functionality

The detector hardware controlled by the DCS is scattered over quite a large surface (and volume). As shown in Section 12.9.4.2, the gas system is going to be placed both on the surface and underground. Different parts of the electronics will be positioned in the experimental cavern, in the service cavern and in the surface counting room. The LDCS will be split according to the ‘geographic’ positions of the parts of detector to be controlled: we plan to use two L(ocal) C(ontrol) C(rates)- one on the surface, the other in the service cavern - USA15.

The detailed functionality of the TRT subsystems served by DCS is described in the TRT services subchapters. Here we describe only the DCS role for the subsystems, listed below;

1. Temperature measurement system
2. Gas system
    a. Gas distribution
    b. Gas mixing
    c. Gas purification

   d. Gain stabilising system
   e. High Voltage power supply system
3. Low Voltage power supply system
4. Cooling system
   a. Gas cooling
   b. Water cooling
5. Electronic racks control system
6. Interlock system

In addition, the DCS system has connections to centrally provided services: the Global DCS, the Central Safety System, the Environmental Control System and the LHC machine control system. In principle, these connections are redundant, since sole connection to the GDCS should suffice. However in our understanding they are necessary to guarantee safe stand-alone operation of the detector.

To perform this function we envisage the DCS hardware structure illustrated in Figure 13-19 in and discussed in the following paragraphs.

13.5.3.2 Hardware

Local control station crates

Two Local Control Station Crates handle the entire system. They contain interfaces to the controllers of the TRT subsystem electronics, input-output registers for less complicated tasks and the CPU which holds the operating system and runs the monitor and control software. The interfaces might be proprietary, custom built or standard depending on the choice in the subsystem. We would strongly support the standardization of the communication media to allow simplification of the software, protocols, maintenance etc.

The LCSs are connected together via a LAN on which Global DCS communications also take place. The `TRT user` (identified through several layers of verification) can communicate with DCS either at the level of `Terminals` or via LAN from `Local Workstation` or remotely from any authorised computer.

Temperature measurements

The detector cabling structure (see chapter 12) provides a set of cables over which the controlling functions can be executed within the detector. At present we only plan to use these for temperature measurements. The number of lines in the cables is limited to 2688 (Table 12-25). We will use any standard temperature sensor adopted by ATLAS, but at the moment we prefer resistive sensors (PT-100; PT-1000) with two-wire readout (due to the limited number of lines). The current sources, multiplexers and ADCs will be located in dedicated crates with a simple controller communicating with the LCS (over any adopted standard field-bus or even an RS-232 connection). The positioning of the temperature sensors within the detector volume must be carefully optimized from the point of view of detector safety, stability of operation and the control of important regions. Some temperature sensors will supervise the cooling system inside the detector. Others will help control services outside the ATLAS volume, including electronics racks, power supplies, the cooling system and gas systems. These temperature measurements will use the standard hardware of the given subsystem but information will be collected by a central (at the TRT level) temperature display. From the technical point of vie, the design of the

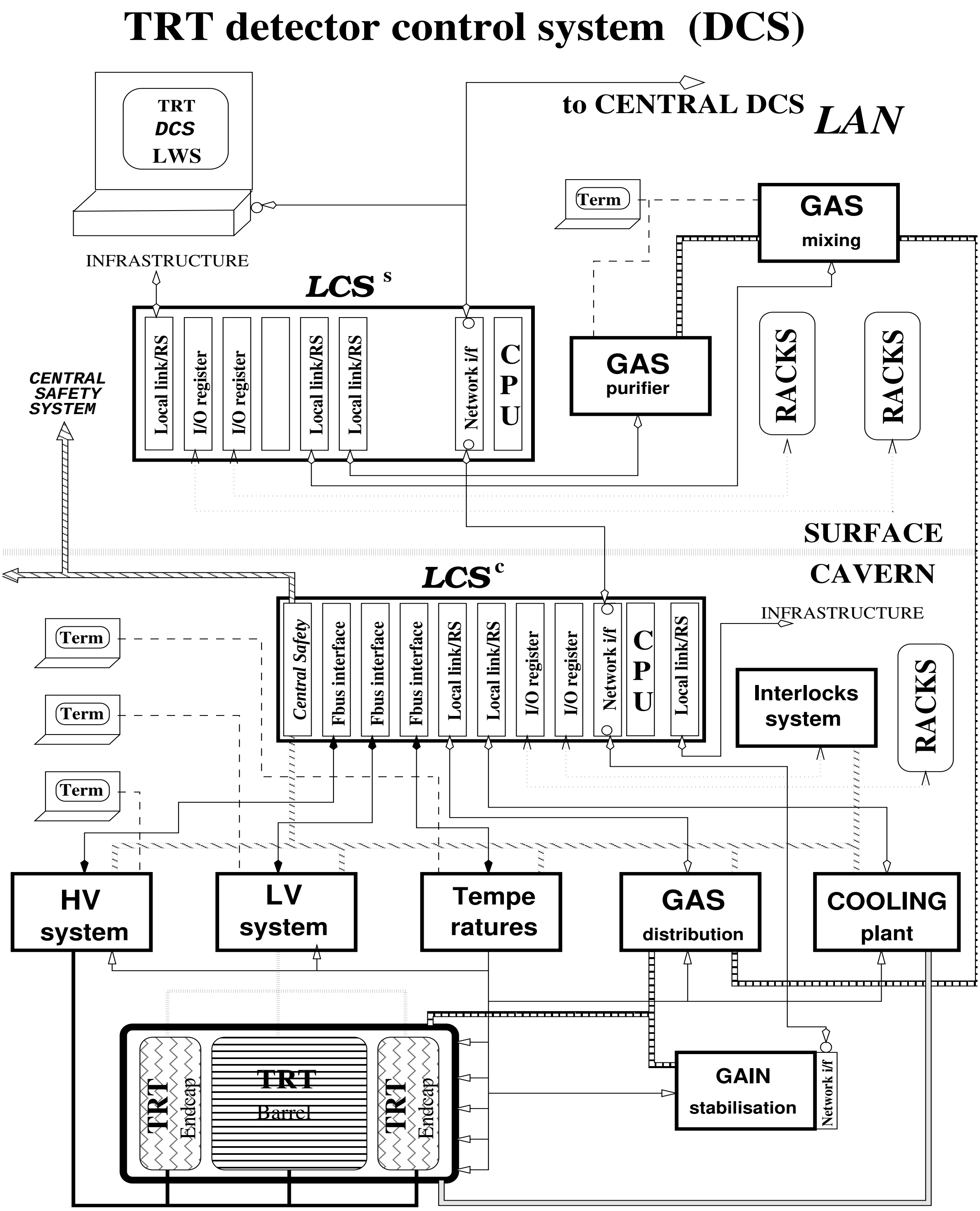

Figure 13-19 Functional diagram of TRT DCS hardware

system itself does not pose too high a technological challenge; however the choice of appropriate sensors - *radiation hard* - directs us toward resistive, rather than semiconductor, devices.

Gas system

The functionality and role of the gas system have been described in earlier chapters (Section 12.9.4). Each of the building blocks of this system will be operated by gas system controller(s). The importance of the gas system for the correct performance of the detector necessitates its fully stand-alone operability. The role of the TRT DCS is to serve both, as a supervisor and as a platform where information is collected and correlations are performed. The system will monitor and control the following parameters;

- Steering of the execution of functional states: running, purging, filling, stand-by etc;
- Quality of the gas mixture i.e Xe/CO_2/CF4 concentrations, contamination levels of H_2O and O_2 and other pollutants;
- Pressures and flows in different parts of the system;
- Gas supplies status (pressure), reserve etc.;
- Purifier system - purifying quality, status of purifying media (for maintenance purposes);
- Gain stabilizing system - monitoring of the position of Fe-55 peak;
- Status of the system hardware - setting of the valves, compressors, pumps etc;

The status of the gas system should be tied to the detector safety interlock, which, in case of unpredictable behaviour, uncontrollable parameter drift or any predefined emergency condition would activate detector shutdown (high voltage, low voltage etc).

High voltage system

The controls of the high voltage system are defined in the introduction and ATLAS UR document. We hope that due to the functional and operational similarities of all power systems, the elements communicating with the operators will be standardized. Here we illustrate the TRT specific aspects of the DCS.

The gas system controls are closely coupled via software control to the high voltage system where the gas gain stabilising function takes place. Based on the drift in peak position from Fe-55 sources, the system tunes the values of the high voltage applied to the straws to maintain constant gas amplification in a changing environment. The granularity of the controls and number of separate stabilising circuits will be defined at later stage, following tests on large scale prototypes. All other functions of the system are described in more detail in (Section 12.9.2). The HV has to be interlocked with the gas system to ensure safety of the detector. Limited access to the system controls has to be maintained even in case of the network or field bus going down. Most likely this has to be ensured by hardwired means to allow the detector to be safely shut down.

Low voltage system

The controls of the Low Voltage power supply system for the TRT will conform to the general standards and functionalities as defined in the ATLAS UR document. The parameters to be controlled are discussed in Section 12.9.3**.** Below we emphasize the importance of the interlocks to crucial points of other systems. Communications media between the LCS and the monitoring and controlling software should be standardized at least within the Inner Detector community.

Cooling system

The cooling system uses two cooling fluids; gaseous CO_2 for cooling and ventilation of the TRT endcap detectors (Section 12.9.5), and water which removes heat from the gas and cools both front-end electronics and barrel detectors (Section 12.9.6). The interlock system must, for example, turn off the power supplies in the event of a cooling failure.

Interlock system

The interlock system plays a very important role in safety of detector operations. Many different failure modes require urgent intervention. Normal control paths over links, networks, operating systems and supervising software could be much to slow and moreover not reliable enough. Hardwired protections have to be implemented. We plan to use the following interlocks in the TRT DCS.

1. general safety system (GSS) interlock to LV_PS, HV_PS, gas system
2. HV power supply system to Gas System and Detector Cooling systems
3. LV power supply system to Electronics Cooling system
4. LV power supply system to Temperature Measuring system (might be executed in software only)
5. HV power supply system to Temperature measuring system (might be executed in software only)

The status of implemented interlocks has to be monitored carefully. Access to this data has to be ensured even in the case of power failure. Thus we believe that most of the interlock system has to be put onto UPS.

Readout crates / electronics racks

The controls of this system should be standard for whole of ATLAS. At the moment TRT has no special requirements for control of this equipment.

Uninterruptable power supplies

Certain parts of the equipment should be supplied from UPS. The TRT DCS should have access to the status of the UPS in use. Following a power failure - the remaining power autonomy on UPS should be known. Very important pieces of hardware should be also put on ‘generator’ back-up power. One example is the gas control system, where failure to deliver fresh gas can result in unstable periods of many hours before the gas composition returns to nominal specifications.

Environmental parameters

Environmental parameters including humidity and atmospheric pressure in the cavern and at surface, the purity of the air in cavern (dust levels etc.) should be monitored by GDCS and made available to the detectors. The TRT might need the humidity measurements inside the detector due to widespread use of composite materials which can exhibit high dimensional sensitivity to moisture. The method of measurement is presently not clear and the number of available lines/pipes etc to the volume of detector is very limited.

The LDCS should also have access to the control and status of infrastructure including AC mains, air conditioning etc. However this area again should be standard across the ATLAS experiment.

13.5.3.3 Software

Figure 13-20 shows the possible software configuration at the level of the sub-detector controls which might accomplish the control tasks discussed in the introduction.

Individual hardware subsystems (Units on the figure) are accessed through user - specific interfaces (IF) connected to the Control Processes - one process for each of the subsystems. A Control Process is a piece of software which performs all the communication between the controlled hardware and all the other components of the system. The system components are treated as objects which can be in different states as the result of actions or spontaneous changes of state. The software could be specified as follows:

- STATE MANAGER - a software component which performs necessary logic as a reaction to the commands, change of object states, errors and emergencies. This is a port to the upper level of the DCS.
- USER INTERFACE - connects the Local Work Station to the system. This a allows the user to issue commands, display monitored parameter values, set values of the parameters and monitor the behaviour of the controlled system
- ERROR MESSAGE SERVER - connects to the Control Processes and provides the error handling. Logs the errors into log-files, warns the operator if deviations pass pre-set limits, Provides the necessary mechanism for an error priority system. Communicates with EMS of higher level.
- DATA BASE SERVER - collects the values of the parameters from the Control Processes, updates and writes them to the Data Base. During the detector initialization phase, it reads the parameter values and passes them to the CPs.

The organization of the Data Base is a very important issue. The size of the experiment and the amount of data to be stored puts a severe restriction on the frequency of updates. A reasonable solution seems to be ‘windowing’ - parameter values are updated in the Data Base only when deviation from existing record is bigger than a ‘half-window’. A new value then becomes the reference to which new measurements are compared. A mechanism to prevent unwanted drift of parameters should be built-in.

The proposed organization of the software puts a requirement onto the central DCS group. Most of the software should be standard i.e. provided by the ATALS DCS group. Only hardware specific packages might be written by detector groups. However if the detector uses ATLAS standardized hardware (eg. field-bus), the relevant software and its maintenance should be centrally supplied.

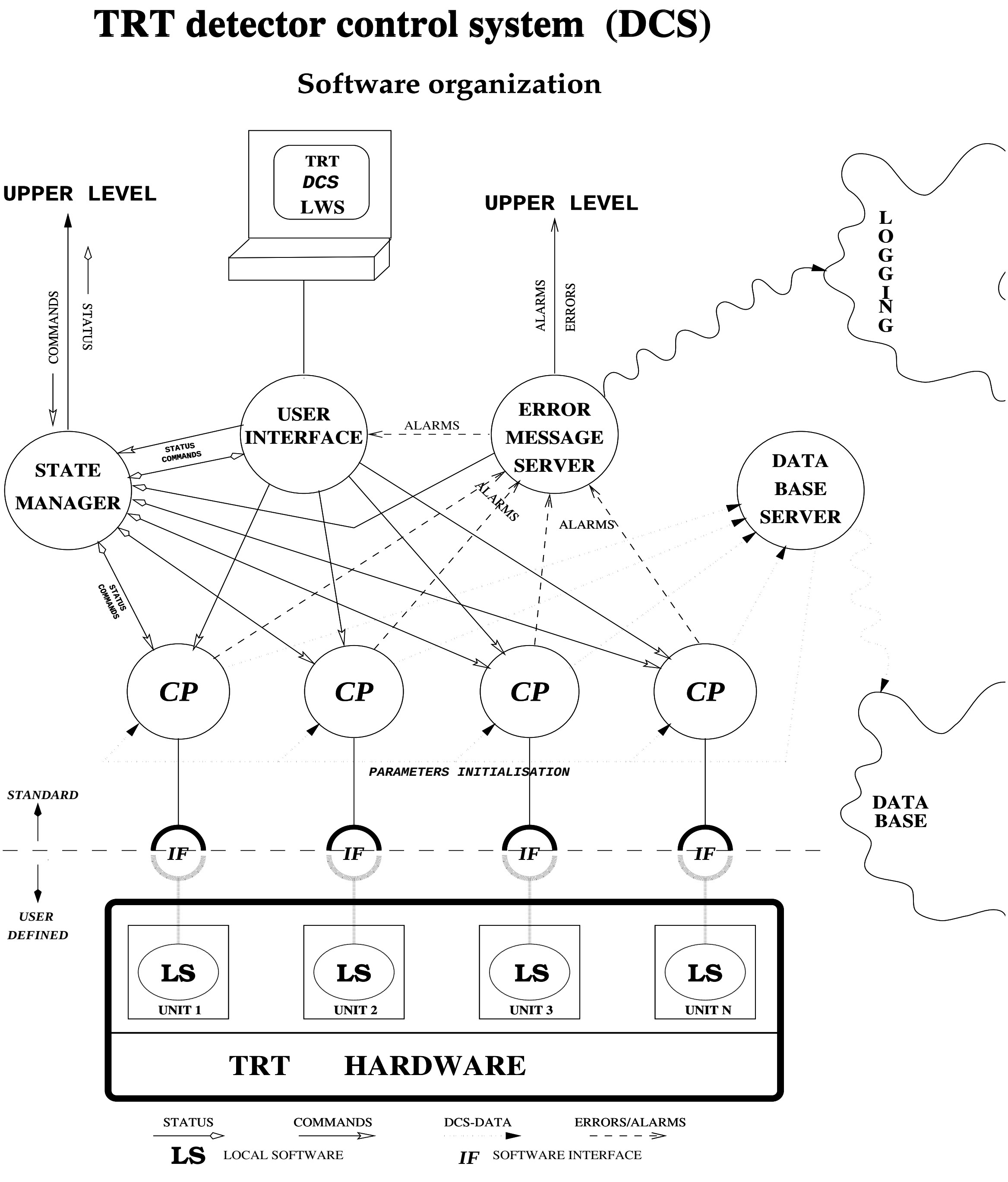

Figure 13-20 Schematic diagram of possible solution for TRT Detector Control System software

13.6 References

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