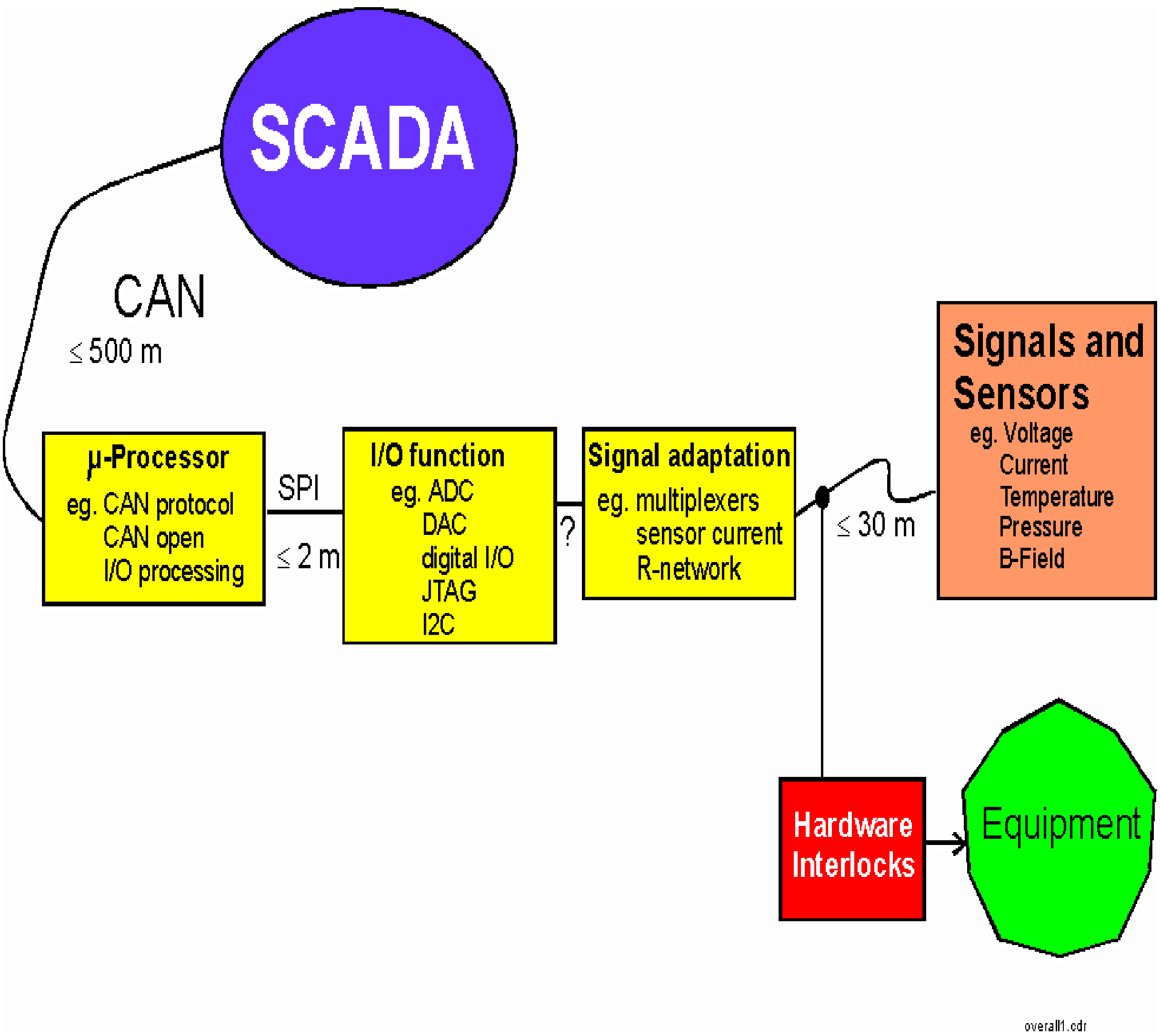
Pixel DCS Status and Issues 2/ 2001

G. D. Hallewell: RAL/CPPM

Contents

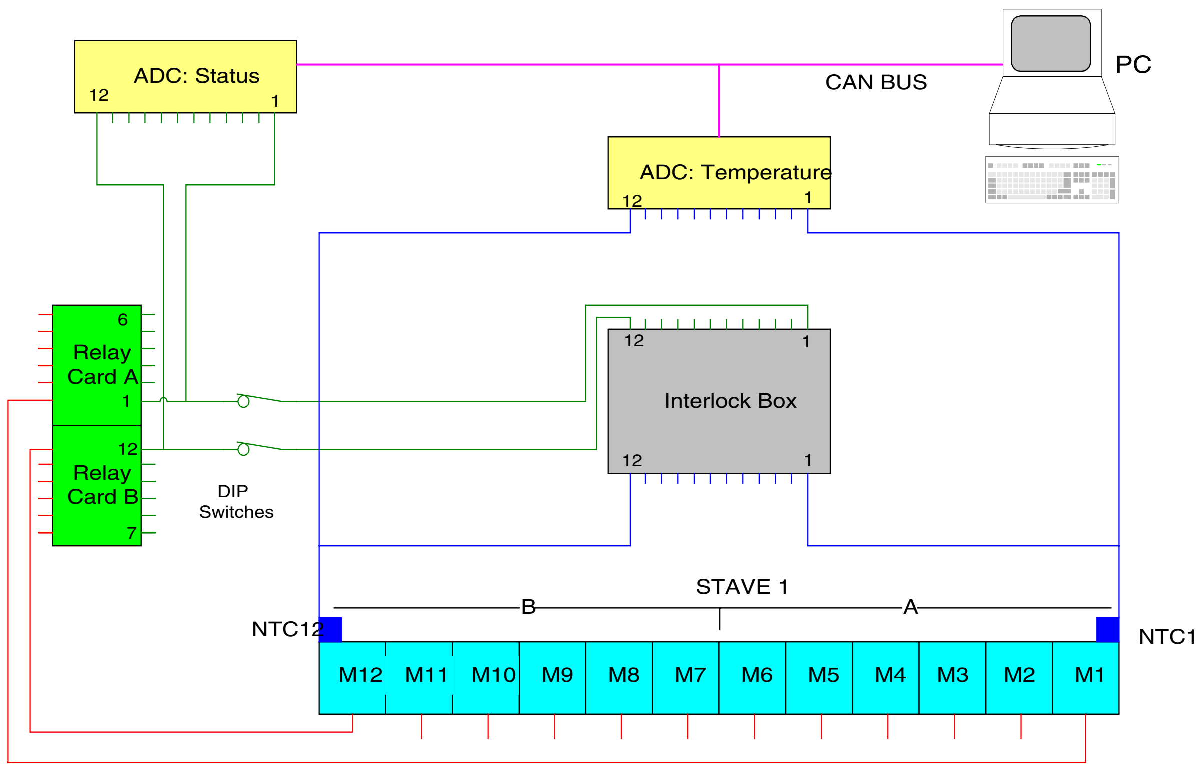
- **On-module NTC Temperature sensors & I-boxes (Interlock Boxes) to protect Pixel Modules**
- **Flow and Pressure Control in the Evaporative Cooling System and Analog Pneumatic Controls Development**
- **The “Embedded Local Monitor Box (E-LMB) as an acquisition node for slow monitoring.**
- **Possible Sharing of NTC information with LMBs for independent logging (connectivity issues)**
- **An Add-On DAC for the E-LMB (Draft Specification)**
- **Numbers of E-LMBs (and signal adapters) in final system for module temperature, PID flow control & PID tube bundle temperature control**
- **First Experience with PVSS2 (final SCADA) software.**
- **Highly Redundant LV UPS for I-Box, controls power**
- **Where from here/ how to divide the work**

Major Elements (Hard & Soft) of the Detector Control System



On-module NTC Temperature sensors & I-boxes (Interlock Boxes) to protect Pixel Modules

Interlock Box Control System



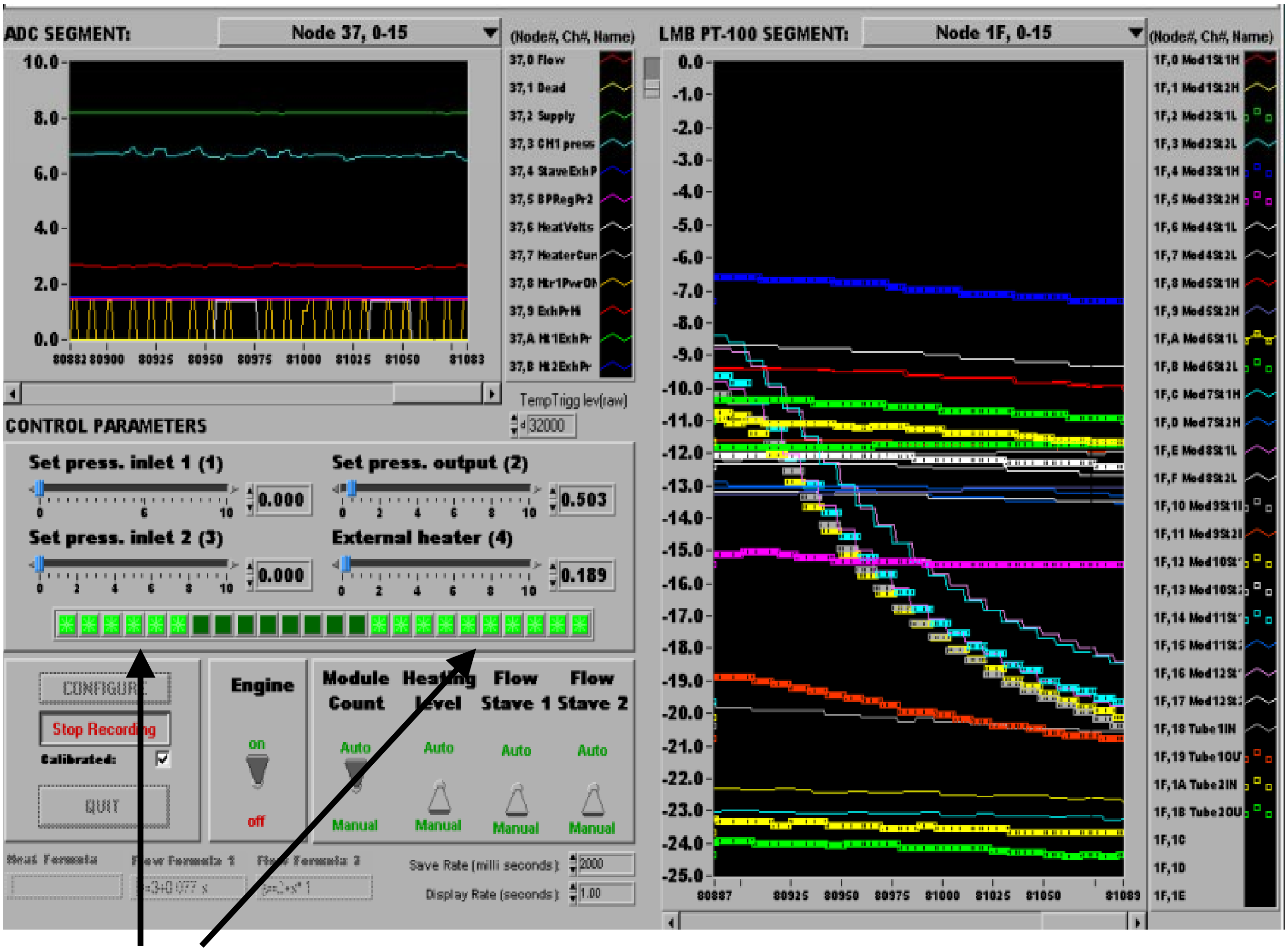
NTC Thermal Sensors glued on 22 Modules of Geneva Barrel SCT Full Length Prototype (Semitek AT series: 10kW @ 25 C)

NTC SMD resistors (Taiyo Yuden & Semitec) irradiated to 1.2×10^{15} p (25 GeV/c) /cm^2.
Dispersion pre&post irradiation ~ 0.3K, (< 0.5 K OK)

I-Box Hysteresis

In PIXELS, interlock set ("POWER DISABLE") @ 0.15ºC and reset ("POWER RE-ENABLE") @ – 0.79ºC.
Tested extensively with deliberate liquid runouts
Hard-wired T_{switch} of 2 comparators by fixed resistor network.

Typical Screen from Bridgeview User Interface Taken in I-Box Hysteresis Studies



I-box channel status

Module Temperature Transients Provoked by Deliberate liquid run-out kept within acceptable limits (not exceeding +2 C) by I-Boxes

The I-Box and Thermal Runaway Prevention

- **Silicon Detectors must be kept near –7 C.**
- **I_{leak} and V_{dep} increase with irradiation over the lifetime of the detector. I_{leak} strongly temperature dependent and can cause a positive feedback runaway with T.**

Low mass Requirement on cooling system

➔➔ LOW THERMAL MASS ! !

At dissipation around 6 Watts/ detector tile,
heat-up rates > 5 C sec^{-1} on Si,
Evaporative OR Monophase liquid cooling!!!

➔ Need fast, HARD-WIRED interlocks (DIGITAL) between temperature sensors on individual Si detectors & their individual multi-rail power supply channels
(> 6000 in SCT & Pixel systems)

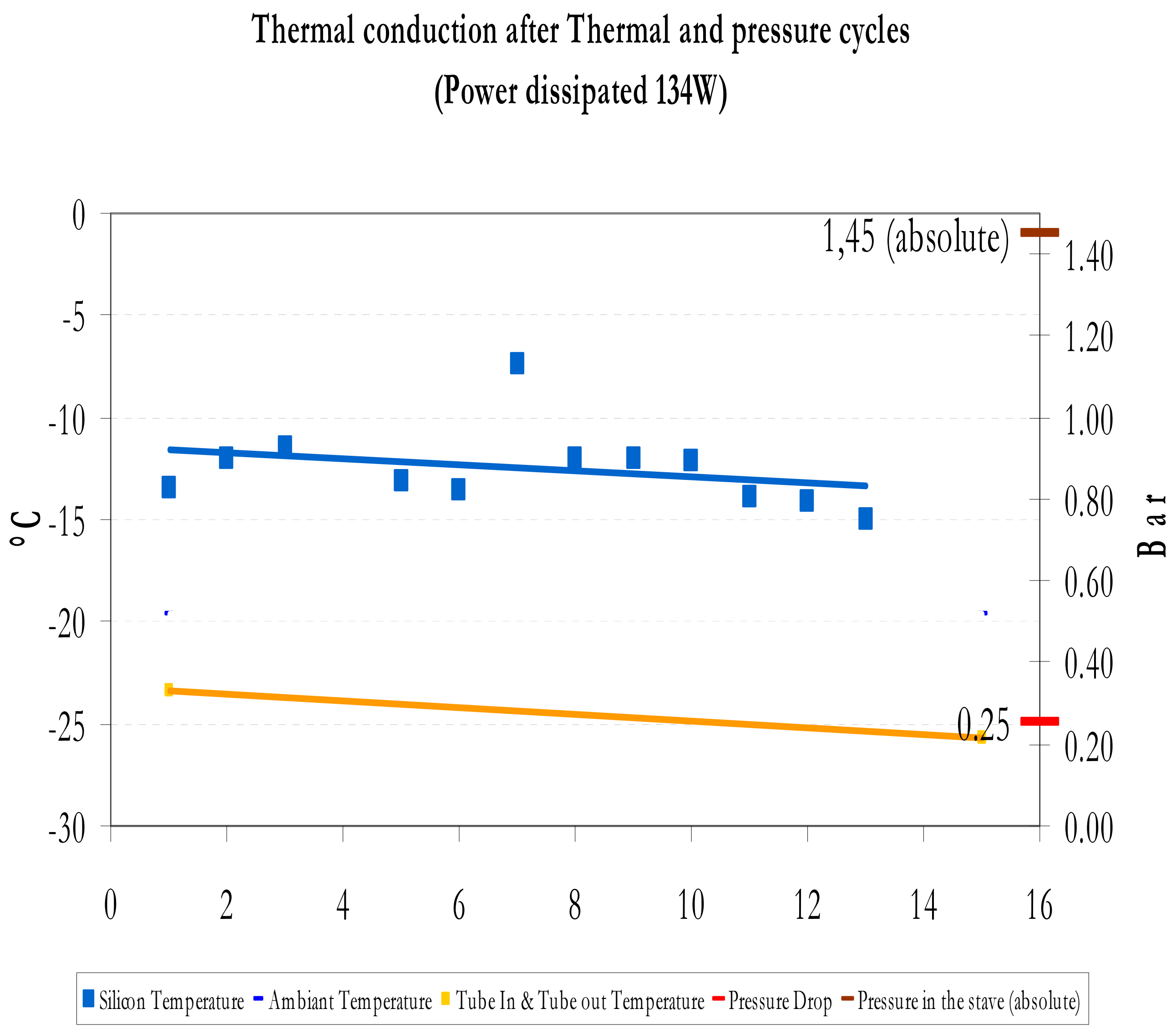
➔ Action MUST NOT depend on volatile SCADA software (PVSS2).
(FPGA OK if on redundant, cascaded UPS, together with T Sensors &Discriminators)

Pixel Stave Re-Baselining Qualification

Stave thermal conduction test
(November stave, After the Temperature cycles)

The Si temperature average is -12.96 °C on the tilted Si, and -7.34°C on the middle Si.

The Pressure drop along the stave is 0.2 Bar.



Flow and Pressure Control in the Evaporative Cooling System and Analog Pneumatic Controls Development

EVAPORATIVE SYSTEM OPERATION

- **Liquid refrigerant passes through injector / capillary at a mass low rate dependent on the liquid pressure upstream of the injector**
- **Liquid refrigerant evaporates in the on-detector cooling channels with attached silicon detectors**
- ***Pressure in channel ==> evaporating temperature***
  ==> silicon detector temperature

- **CONTROL PRINCIPLE**

(Comparison vs. Liquid):

- **Two Variable parameters**

(1) Mass Flow Rate:

- **pressure upstream of injector**
- **(via analog pneumatic-piloted regulator) ==>**

(vs. pressure at start of liquid circuit)

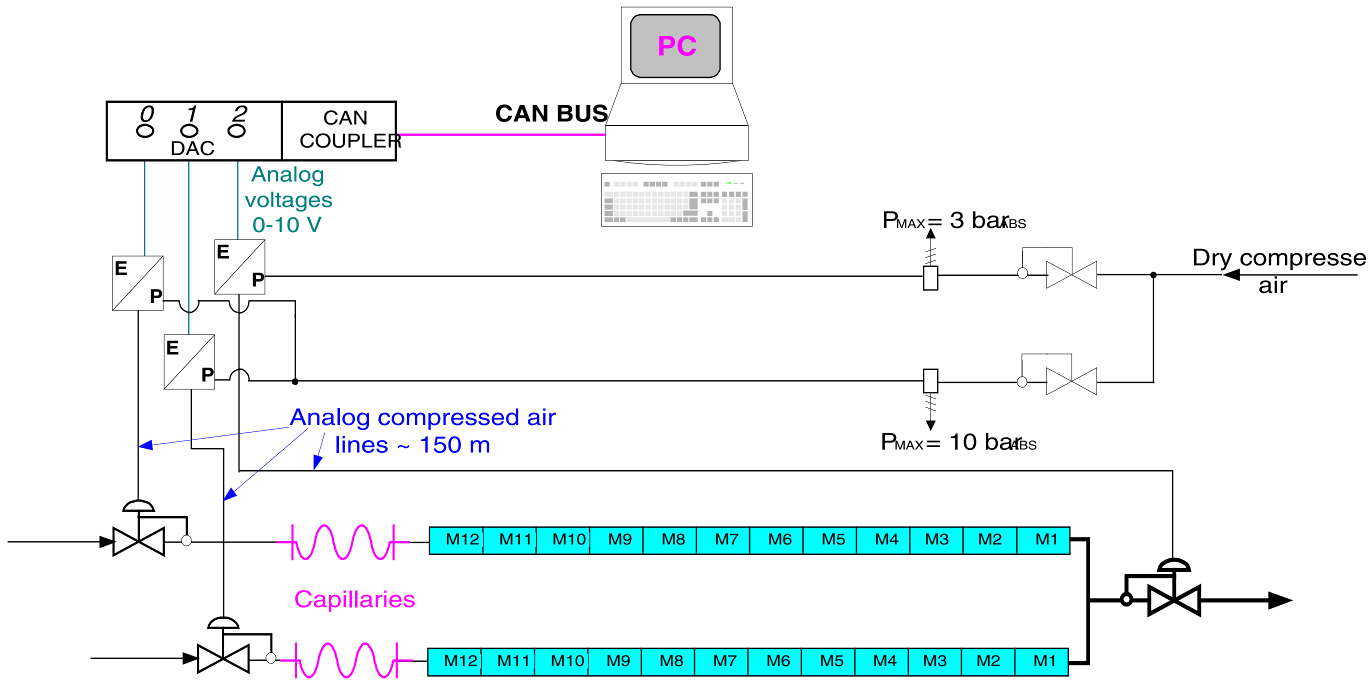
(2) Evaporating Temperature

- **pressure in on detector cooling channel**
- **(via analog pneumatic-piloted back-pressure regulator) ==>**

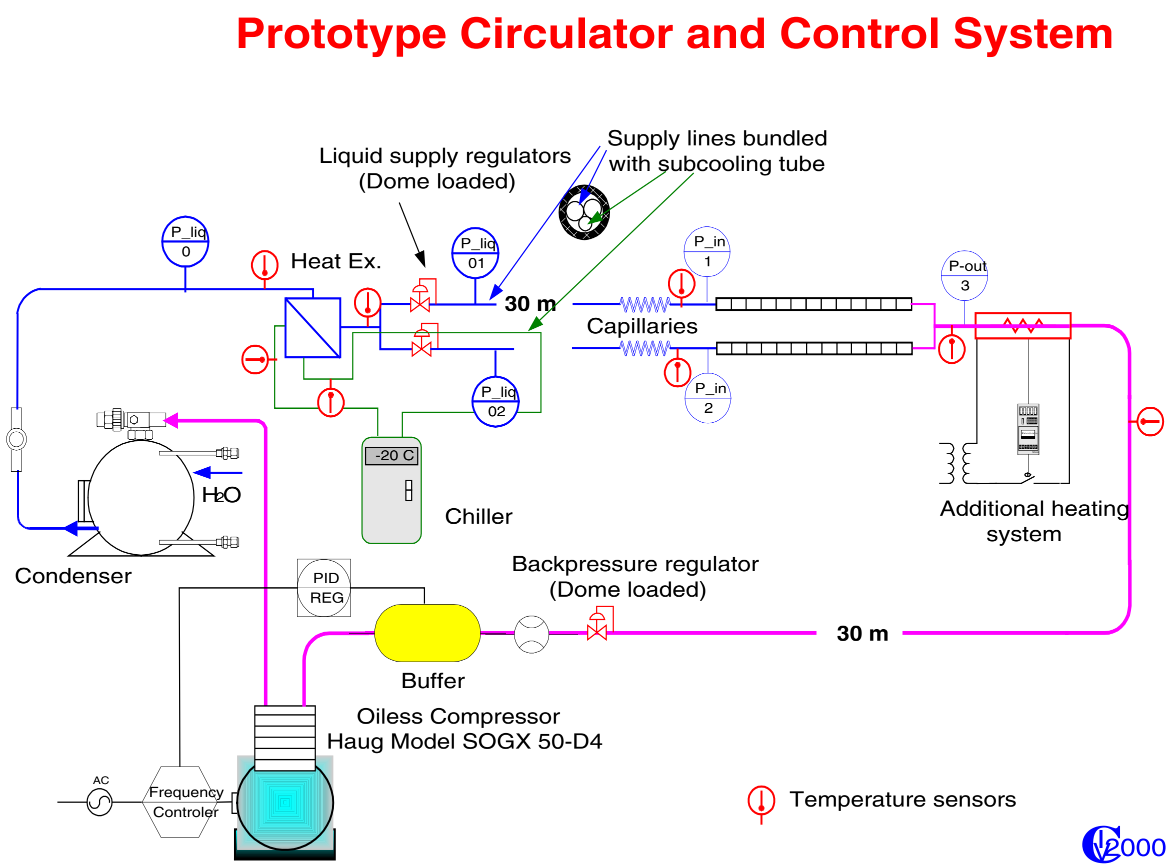
(vs. temperature of liquid delivery)

INDIVIDUAL CIRCUIT TEMPERATURES NOT POSSIBLE IN PARALLEL LIQUID SYSTEM WITH SINGLE SUPPLY TEMEPERATURE

Prototype Electro-Pneumatic Control Scheme



Schematic of Prototype C_3F_8 Evaporative Recirculator



FLOW VARIATION STUDIES

(1) FLOW VARIATION VIA INTERLOCK "ON" BIT COUNTING

DAC ➨ E2P ➨ Dome Loaded Regulator
Pressure Upstream of Capillary ➨ Flow

PROTOCOL

$$P_{CAPILLARY} = P_{SL(Tin)} + m * \#\text{ (powered modules)}$$

Where: $P_{SL(Tin)}$ **is the saturated liquid pressure at the C_3F_8 injection temperature (see cycle)**
m is incremental pressure (mbar) to remove heat of one Si module (~ 10 Watts)

PROTOCOL DEMONSTRATED TO WORK:
(Temperatures on remaining powered modules and exhaust stable with varying flow/load)

HOWEVER: need first to *accurately* find m via;

$$(P_{CAPILLARY(22\ Modules)} - P_{SL(Tin)})/22$$

ALSO, PROTOCOL sensitive to variable module power unless modified...

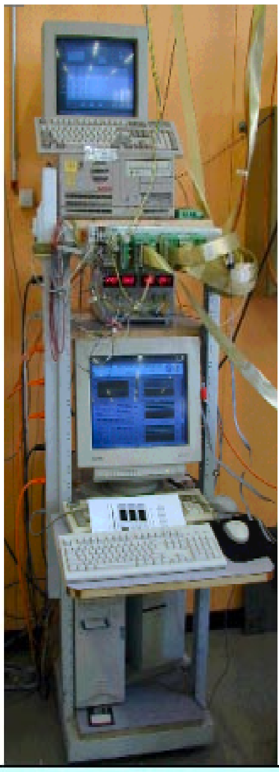
$$P_{CAPILLARY} = P_{SL(Tin)} + m' * \Sigma_i(\text{POWER}_{\ module(i)})$$

m is normalized pressure/power factor (mbar/W),

BUT...would need <u>continuous</u> V,I data for each module from DCS & Power Supplies: clumsy

Installed Test Structures and DAQ/Control System

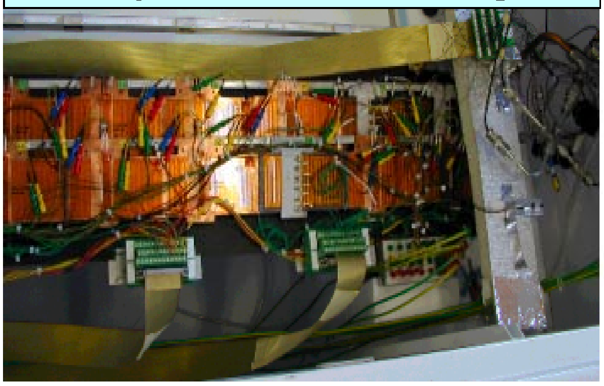
Present status of the installation in the lab – part two



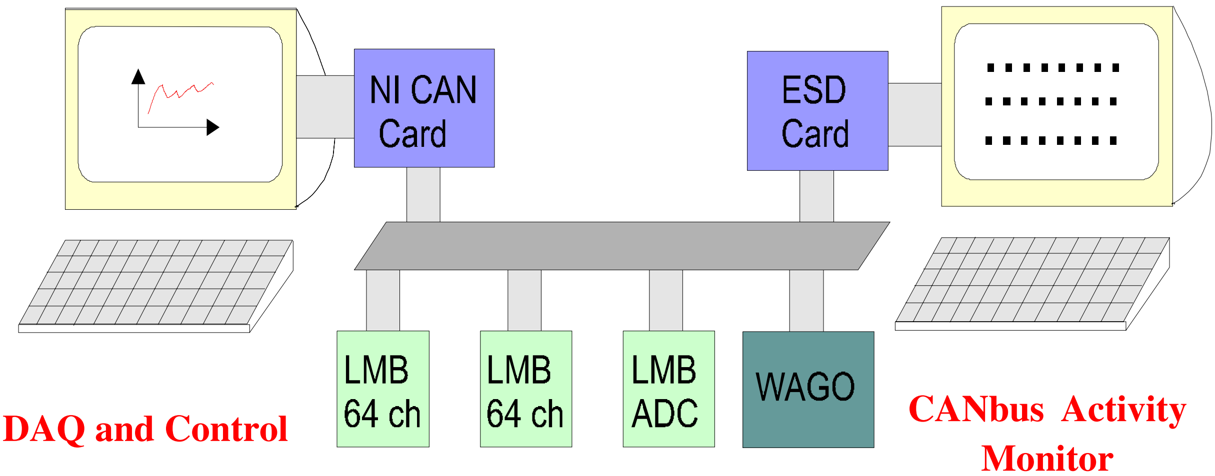
LMB and WAGO based
CanBus DAQ System
that enables monitoring of the
temperatures and basic control
parameters of the Cooling system

2 SCT thermal model staves and 2 "parallel ghost" SCT staves placed in the temperature controlled box

Detail of the manifolding into the staves, temperature sensors and heater wiring



CAN-bus & LMB based measurement system



CANbus Configuration

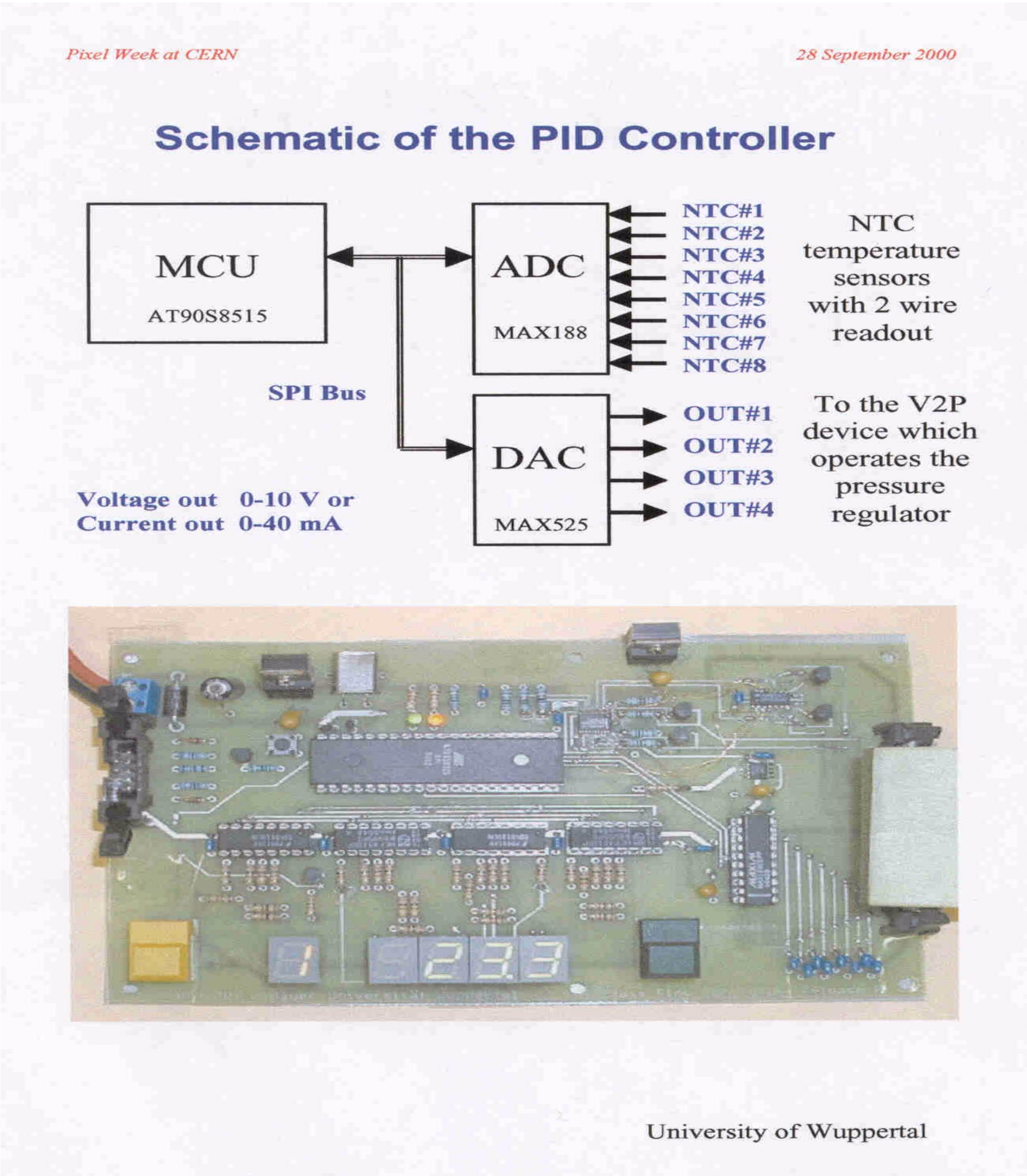
LMB PT100: (2 nodes)	LMB ADC: (4 nodes)	WAGO: (1 CAN coupler)
	Pressure (0-2.5V) (8 Sensors) Mass flow (0-2.5V) (1 Sensor)	Regulator Control (Via E/P driver) (DAC 0-10V) (3 Channels)
Temperature Pt-100, 4 wire (64 Sensors)	Temperature NTC (0-2.5V) (32 sensors)	Analyzer Heater Control (DAC 0-10V) (1 Channel)
	Module Interlock Status (0-5V) (32 sensors max)	

THE SOLUTION…

C_3F_8 proportional flow regulation to maintain Temperature

(NTC sensor) at exhaust above T_{evap} for varying (analog) load
(Independent of module power variations)

Single Chip PID For Coolant Flow Control (On ATMEL RISC μController [C→Gnu])



Functional description of the PID controller

- There can be up to 4 independent PID controllers in our prototype hardware.
- Each PID uses 2 temperature sensors: 1 main sensor [outlet tube, usually after the heater] and 1 security sensor [end of stave tubing].

Sample rate 4 Hz

$$Out_P = P * (Temp - Setpoint)$$
$$Out_I = I * Accumulated\_Error$$
$$Out_D = D * (Error - Last\_Error)$$

$$Out = Out_P + Out_I + Out_D$$

The temperature of the security sensor is monitored and if its value is above a defined critical temperature

$$Temp_{crit} = Temp_{evap} + \Delta Temp, \Delta Temp \in (2\text{-}3\ K)$$

the PID mode is disabled. In this case a constant mass flow, capable of cooling the full staves power is used.

University of Wuppertal

All Hardware Elements of Cooling Control System Satisfactorily Demonstrated

- Hard-wired Power Interlock & NTC sensors
- PID algorithm in ATMEL RISC μ
  → DAC
  →V2P
  → Analog Air-loaded regulator
  for coolant flow control
- Powered modules and exhaust stable (in spec. ranges) during (1-22 module switching) transients and exhaust tube temperature maintained several degrees above evaporation temperature, indicating liquid run out maintained just beyond end of structure.

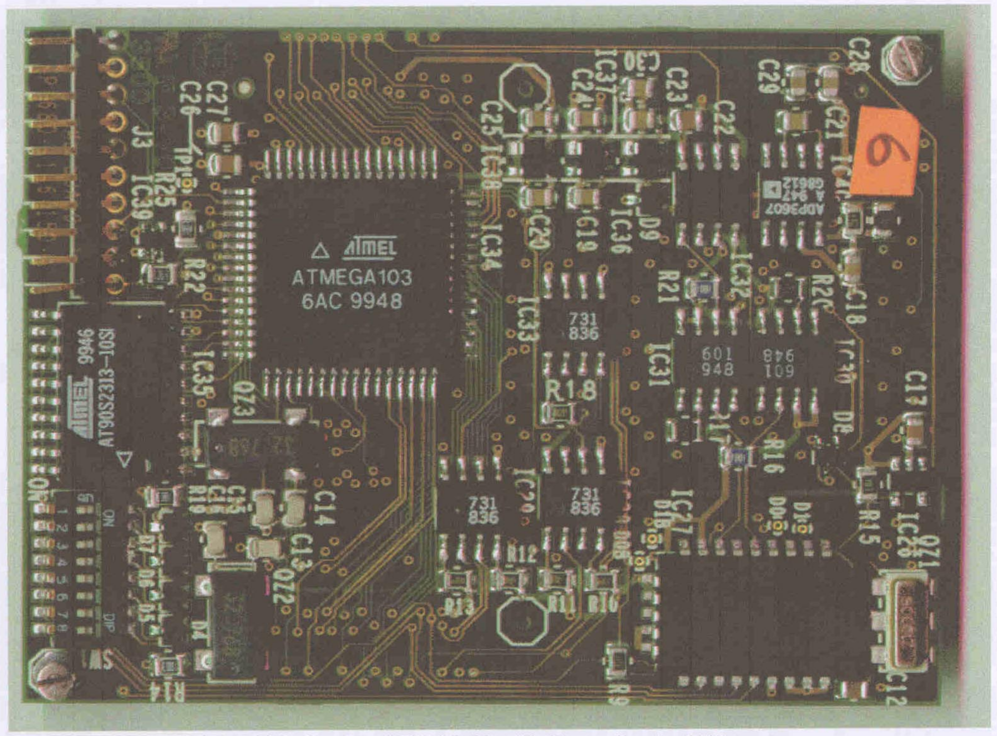
† Implications for Services

- With Flow regulation,
  unnecessary to directly heat individual exhaust tubes;
- With precooling of entry C_3F_8 liquid, very low power required (ONLY!) on active insulation per circuit exhaust
  (~ 40W on 2 meters length, 5 mm Armaflex)
- Input Liquid Tubing Probably may not require active insulation with $T_{precool}$ ~ -15 °C(to test).

FUTURE STUDIES

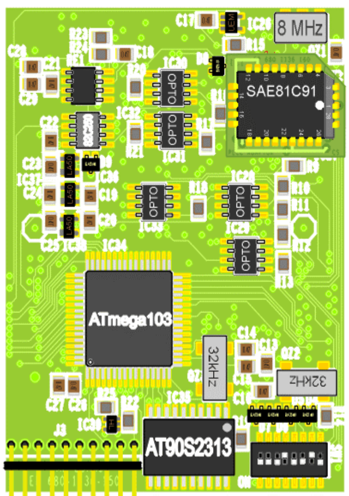
Integrate the PID algorithm on new E-LMB, with new Development of Add-on DAC

Same ATMEL Family µController in ATLAS DCS (E-Local Monitor Board)



Front side of Embedded Local Monitor Board ELMB Size 50x66 mm October 2000 version

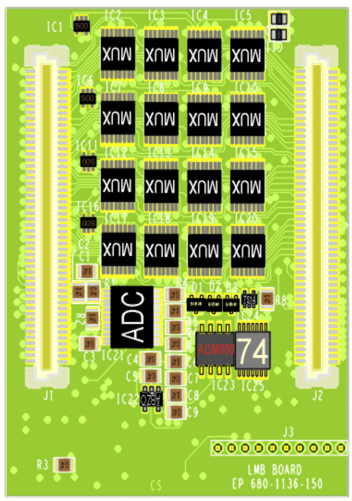
Top side



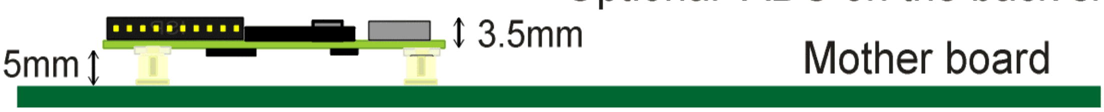
50x66mm

Bottom side

PCB bottom side



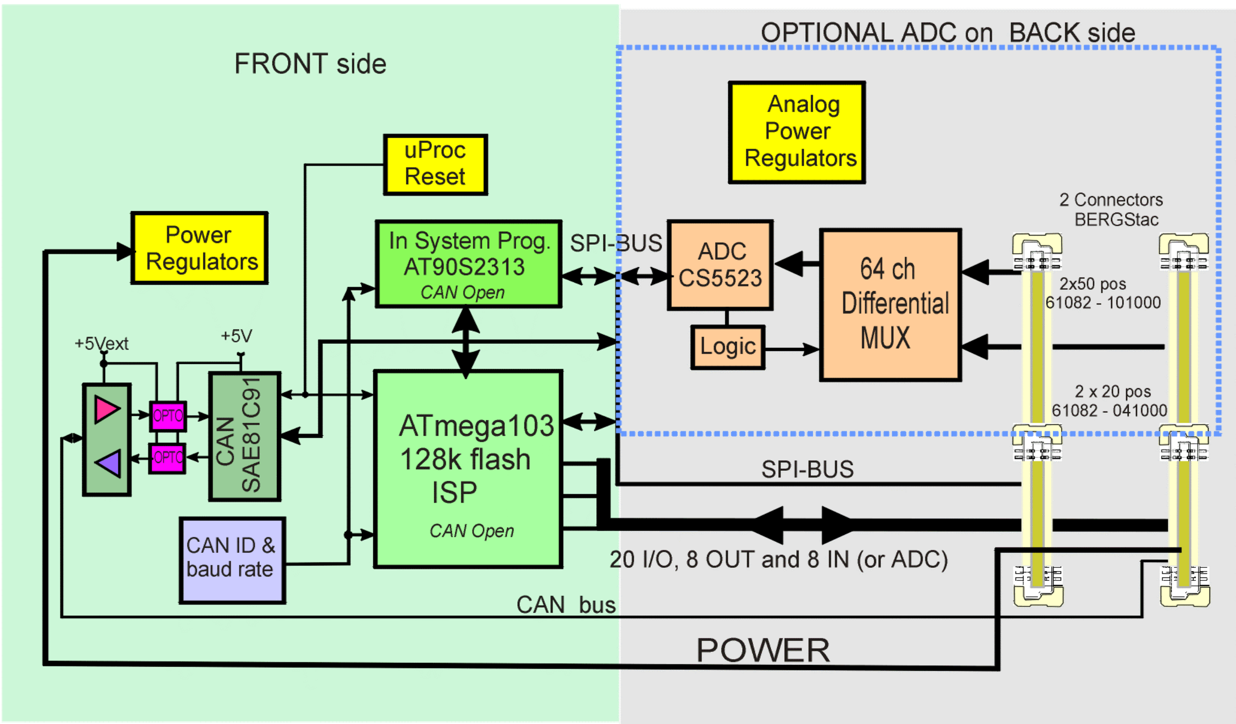
Optional ADC on the back side

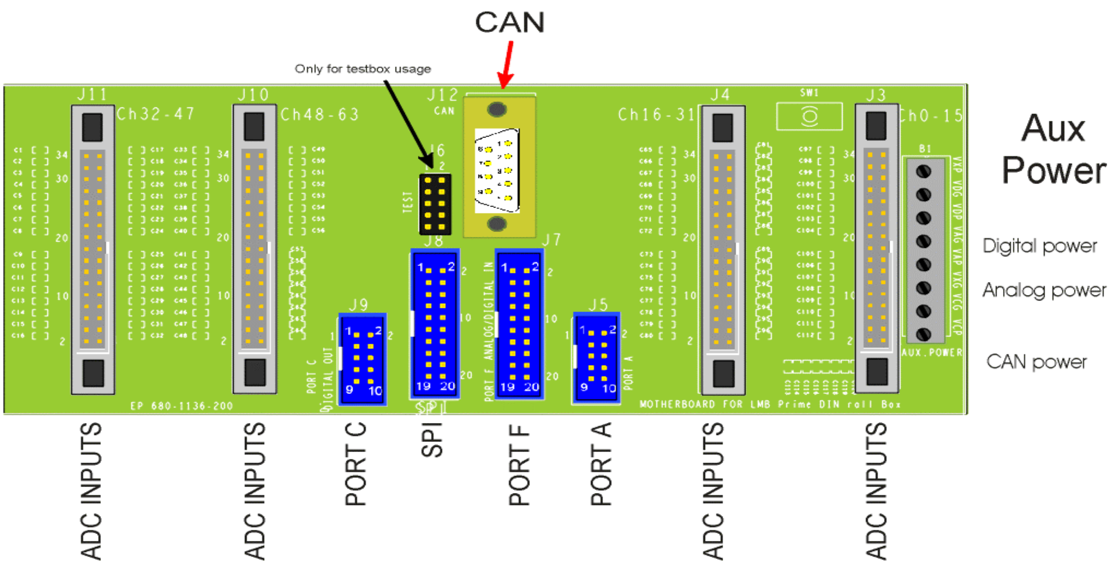


ATLAS E-LMB Block Diagram,

Shows ATMEL 128K RISC µController, SPI ports for connection to external DAC cards (NIKHEF)

(µcontroller allows flow control implementation using either smart (PID) algorithm, or else transparent (DAC only))





Draft Specification for External E-LMB DAC

(1) Number of DACs per SPI port: 4

(2) DAC Bits Precision : 10*

* This precision sufficient for the pixel & SCT cooling controls (analog flow & evaporation pressure setting), but may be insufficient for other (as yet undefined) uses/users.

(3) E-LMB Connection Path: SPI-PORT of E-LMB motherboard

(4) DAC Analog Output type: 4-20 mA

(5) DAC Output connector: 8-pin DIL ribbon (unshielded)

(6) Power Supply Rails: As E-LMB/ motherboard

Preference Compatibility with SPI-PORT (J8) on E-LMB motherboard viz: + 5V analog, -5V analog, analog ground
+ 5V digital, digital ground

(7) Power Supply Connects:

Preferred via J8 (E-LMB motherboard SPI-PORT)

(8) Local Memory: For 4 digital words (10 bit eqv.): one / DAC channel

(9) Time between local memory refresh: 0.1 seconds minimum

Baseline Evaporative Circulator System

In Personnel Accessible Area (USA 15)

- Remote, Hermetic, Oil-less compressors
- Local PID controllers regulating:
  aspiration pressure (compressor speed control)
  condenser pressure (chilled water flow rate)

- **Six such compressor sets:**

  Advantage of compressor parallelism:
  allows prior use in assembly sites.

In Personnel Inaccessible area UX15

(high B, radiation fields)

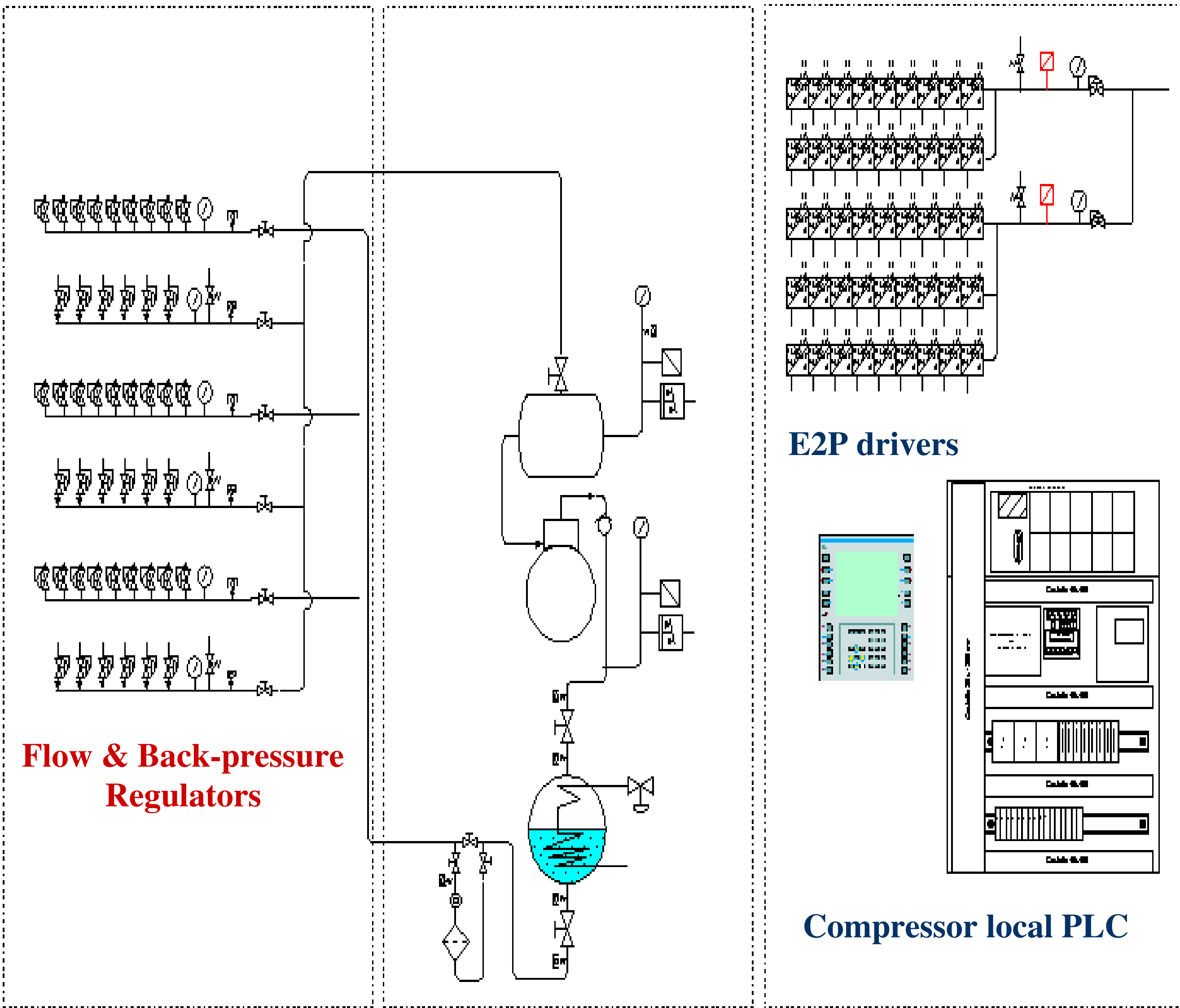
Dome Loaded Pressure Regulators for:

Delivery of Sub-Cooled Liquid to each circuit
(Linear Flow regulation between Condenser
Pressure and Saturated Liquid Line)

Operating temperature on each circuit,
control of boiling pressure
(variable to accommodate Si radiation damage).

**Active Insulation on Critical Parts of
Coolant Delivery and Exhaust Tubing**

Placement of Recirculator Control Components in Final ATLAS Installation



Regulators on ATLAS Service Platforms

Compressor, Condenser , Compressor local PLC & E2P drivers in USA15 Technical Cavern

LMB (and I-Box) Channel Count for Pixel Modules

(1) B-Layer

NTCs for Module Count: 12*13*2 = 312:
CORRESPONDING 64 Chan LMBs = 4.875
I-Box Channel Count: 12*13*2 = 312:
Analog In Channel Count: 12*13*2 = 312 (I-Bit Status)
CORRESPONDING 64 Chan LMBs = 4.875

(2) Layer 1,2

NTCs for Module Count: 48*13*2 = 1248:
CORRESPONDING 64 Chan LMBs = 19.5
I-Box Channel Count: 48*13*2 = 1248:
Analog In Channel Count: 48*13*2 = 1248 (I-Bit Status)
CORRESPONDING 64 Chan LMBs = 19.5

(3) Disks (Guess)

NTCs for Module Count: 26*6*4 = 624:
CORRESPONDING 64 Chan LMBs = 9.75
I-Box Channel Count: 26*6*4 = 624:
Analog In Channel Count: 26*6*4 = 624 (I-Bit Status)
CORRESPONDING 64 Chan LMBs = 9.75

64 Chan LMBs (Modules Only) = 34.125
Additional 64 Chan LMBs (I-bits) = 34.125

THEREFORE COUNT I-BITS FOR FREE IN P/S?

LMB Channel Count for Pixel Coolant Monitor & Control

(1) B-Layer (Example Breakdown)

12 circuits of 2 staves in series: 12 inputs, 12 outputs

NTCS on/near on-detector structure per circuit (1/E-LMB analog input)

(1)	Input, stave tube 1
(2)	Output, stave tube 1 or Input, stave tube 2
(3)	Output, stave tube 2 exhaust (control function)
(4)	Output, stave tube 2 exhaust (reserve sensor for control function)
(5)	Exhaust Remote (control function)
(6)	Exhaust Remote (reserve sensor for control function)
(7)	Pressure measurement (upstream of capillary)
(8)	Pressure measurement (exhaust)
	SUBTOTAL: 72 NTC sensors/ Analog Inputs

PID DACs in LMB μcontrollers for flow control:
(1/E-LMB analog output channel): 12
DACs in LMB μcontrollers for boiling pressure control:
(1/E-LMB analog output channel): 12

LMBs 1.125 (Analog Input Channels Only): 1.125
LMBs for DAC (@4 DAC/E-LMB): 6

LMB Channel Count for Pixel Coolant Monitor & Control

(2) Layers 1,2 (Example Breakdown)

48 circuits of 2 staves in series: 48 inputs, 48 outputs

NTCS on/near on-detector structure per circuit (1/E-LMB analog input)

- (1) Input, stave tube 1
- (2) Output, stave tube 1 or Input, stave tube 2
- (3) Output, stave tube 2 exhaust (control function)
- (4) Output, stave tube 2 exhaust (reserve sensor for control function)
- (5) Exhaust Remote (control function)
- (6) Exhaust Remote (reserve sensor for control function)
- (7) Pressure measurement (upstream of capillary)
- (8) Pressure measurement (exhaust)

SUBTOTAL: 368 NTC sensors/ Analog Inputs

PID DACs in LMB µcontrollers for flow control:
(1/E-LMB analog output channel): 48
DACs in LMB µcontrollers for boiling pressure control:
(1/E-LMB analog output channel): 48

LMBs 1.125 (Analog Input Channels Only): 5.75
LMBs for DAC (@4 DAC/E-LMB): 24

LMB Channel Count for Pixel Coolant Monitor & Control

(3) Disks (Example Breakdown)

26 circuits of multisectors in series: 26 inputs, 26 outputs

NTCS on/near on-detector structure per circuit (1/E-LMB analog input)

(1) Input, stave tube 1
(2) Output, stave tube 1 or Input, stave tube 2
(3) Output, stave tube 2 exhaust (control function)
(4) Output, stave tube 2 exhaust (reserve sensor for control function)
(5) Exhaust Remote (control function)
(6) Exhaust Remote (reserve sensor for control function)
(7) Pressure measurement (upstream of capillary)
(8) Pressure measurement (exhaust)

SUBTOTAL: 208 NTC sensors/ Analog Inputs

PID DACs in LMB μcontrollers for flow control:
(1/E-LMB analog output channel): 26
DACs in LMB μcontrollers for boiling pressure control:
(1/E-LMB analog output channel): 26

LMBs 1.125 (Analog Input Channels Only): 3.25
LMBs for DAC (@4 DAC/E-LMB): 13

LMB Channel Count for Pixel Tube Bundle External Temperature Control

Assumption:

Each bundle has active insulation over ~30 m between PPB3 & PPB1, which is divided into 3 zones as follows :

(1) PPB1 to end of ID volume
(2) End of ID volume to PPB2
(3) PPB2 to PPB3

Each zone of each bundle has 4 temperature sensors :
2 for monitoring and 2 for control:
Two require PID activity to control the active insulation heaters.

Surface	Input Bundles / End	Output Bundles /End	Totals (Both Ends)
B layer	4(3 tubes)	4(3 tubes)	8 (3 tubes)
1,2	4(6 tubes)	8(3 tubes)	24
Disks	1(6 tubes)	3(3 tubes)	
	1(7 tubes)	1(4 tubes)	12

Total No bundles (Both ends):	44
No Zones (44*3) :	132
No Sensors (44*3*4) :	528
E-LMBs for these Sensors :	8.25
No PID controllers (44*3) :	132
E-LMBs for PID controllers:	33

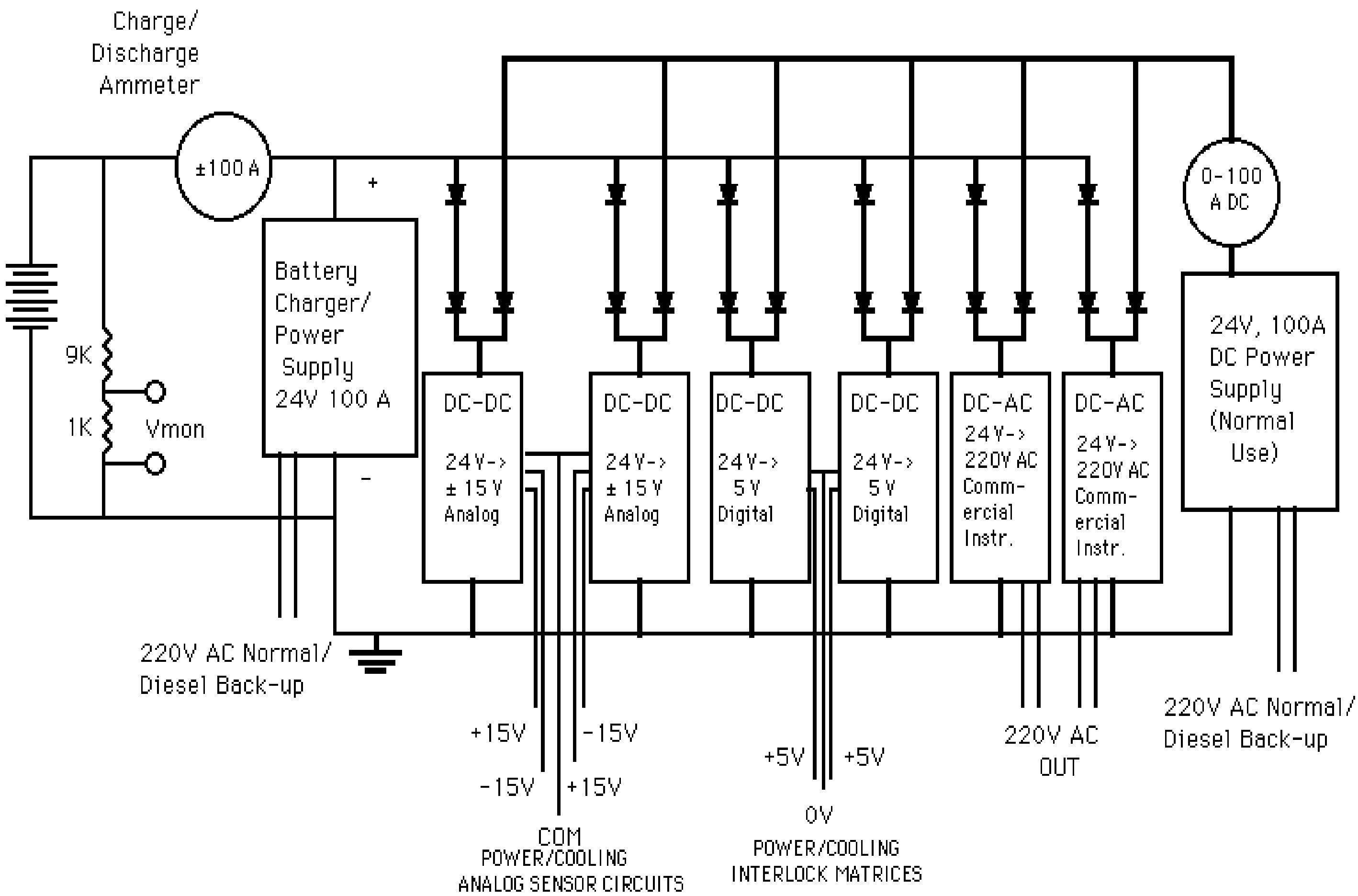
TOTAL E-LMB REQUIREMENT (SET& SUBSET):
(MODULES+CIRCUIT CONTROL+TUBE BUNDLES)
52.5 (INPUTS, NOT INCLUDING I-Bits, 76 for DAC/PID DAC)

CONCLUDE:

NEED 8 PID DACs PER E-LMB, OR REDUCE # BUNDLE ZONES)

Highly Redundant UPS for I-Box Power

- **Most Commercial UPS gives 120/220V, generated by DC-AC conversion, OK for servers etc…**
  - **Protects against primary AC failure and lightning etc but does not protect against downstream AC-DC supply failure.**
- **It is preferable to have the redundancy as close as possible to the protected load: i.e. at the LVDC level**

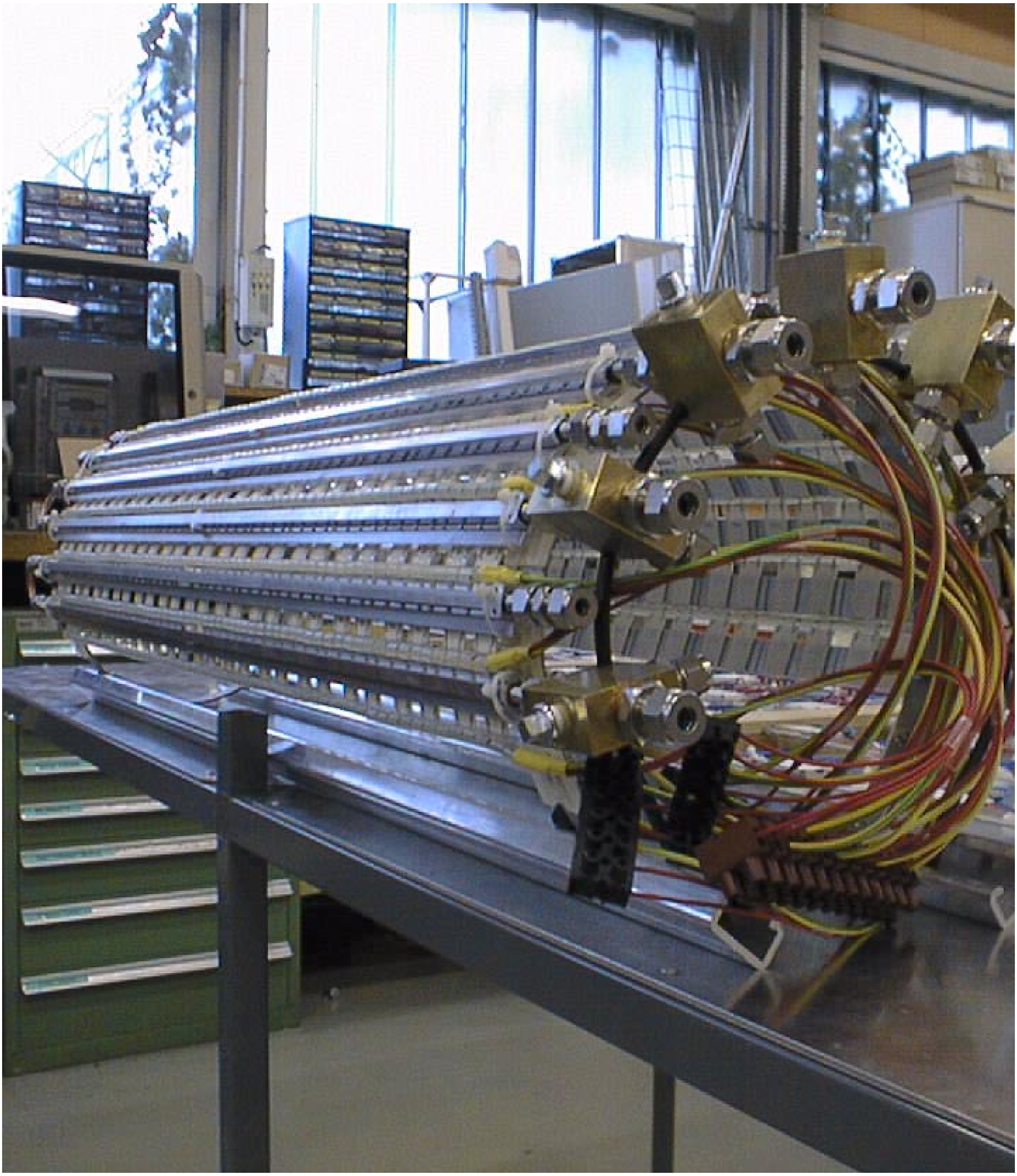


We need now to start development:
Candidate DC-DC converters include Kepco ERD series.

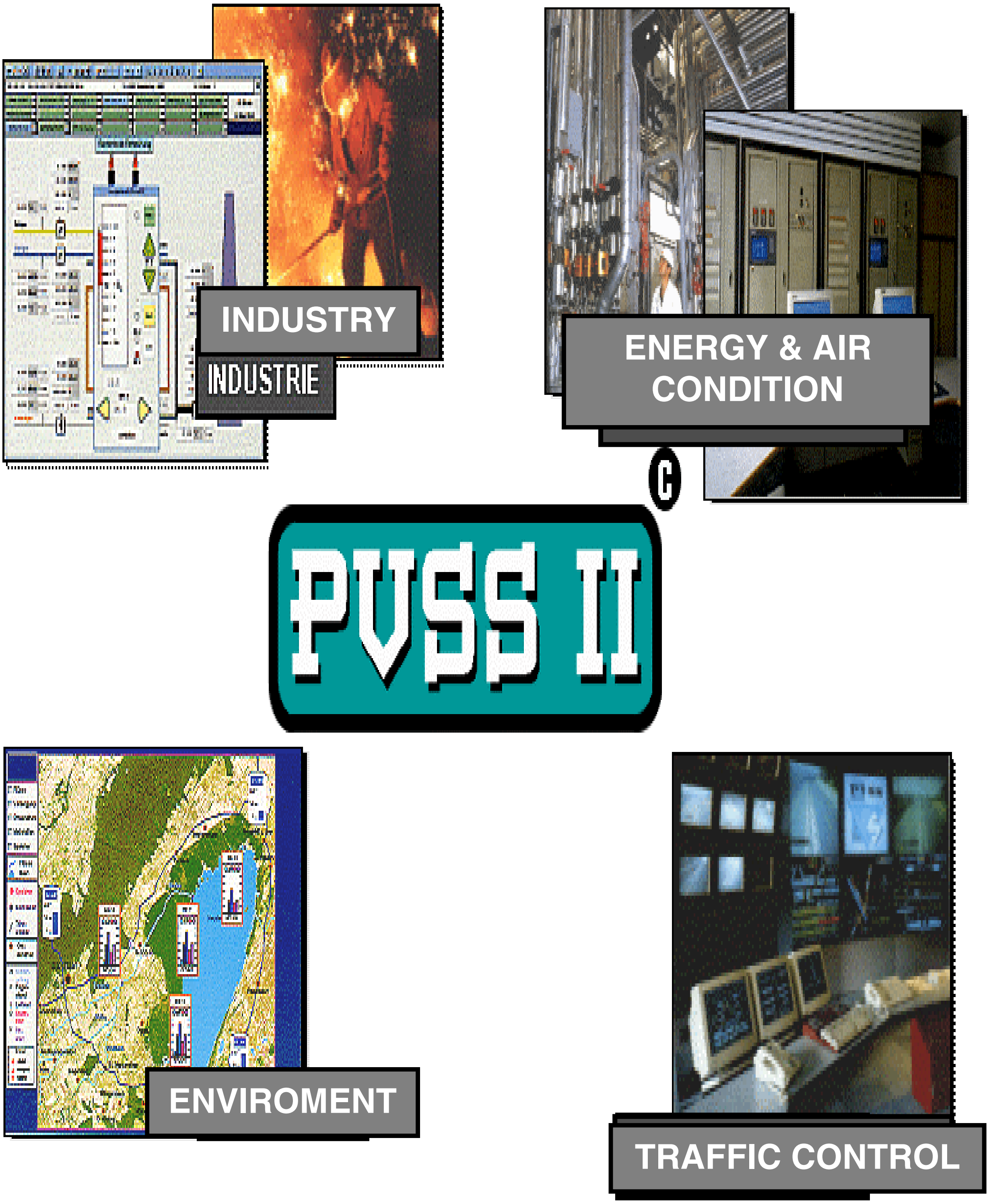
Modularity of Circuits and Analog Flow Elements in ATLAS SCT & Pixel Evaporative Cooling Demonstrator.

Layer	Circuits	Supply Capillaries / Circuit	Power/ (Output) circuit (W)	Flow regs	Boiling Pr. Regs
SCT 4	2	2	480	4	2
SCT 3	2	2	480	4	2
SCT 2	2	1	480	2	1
SCT 1	2	1	480	2	1
Pixel 2	3	1	208	3	3
Pixel 1	2	1	208	2	2
B layer	1	1	288	1	1
SCT disk/4	1	3	330	3	1
Pixel disk/6	1	1	96	1	1
TOTALS			4218	22	14
TOTAL FOR SCT 4			6720	28	14

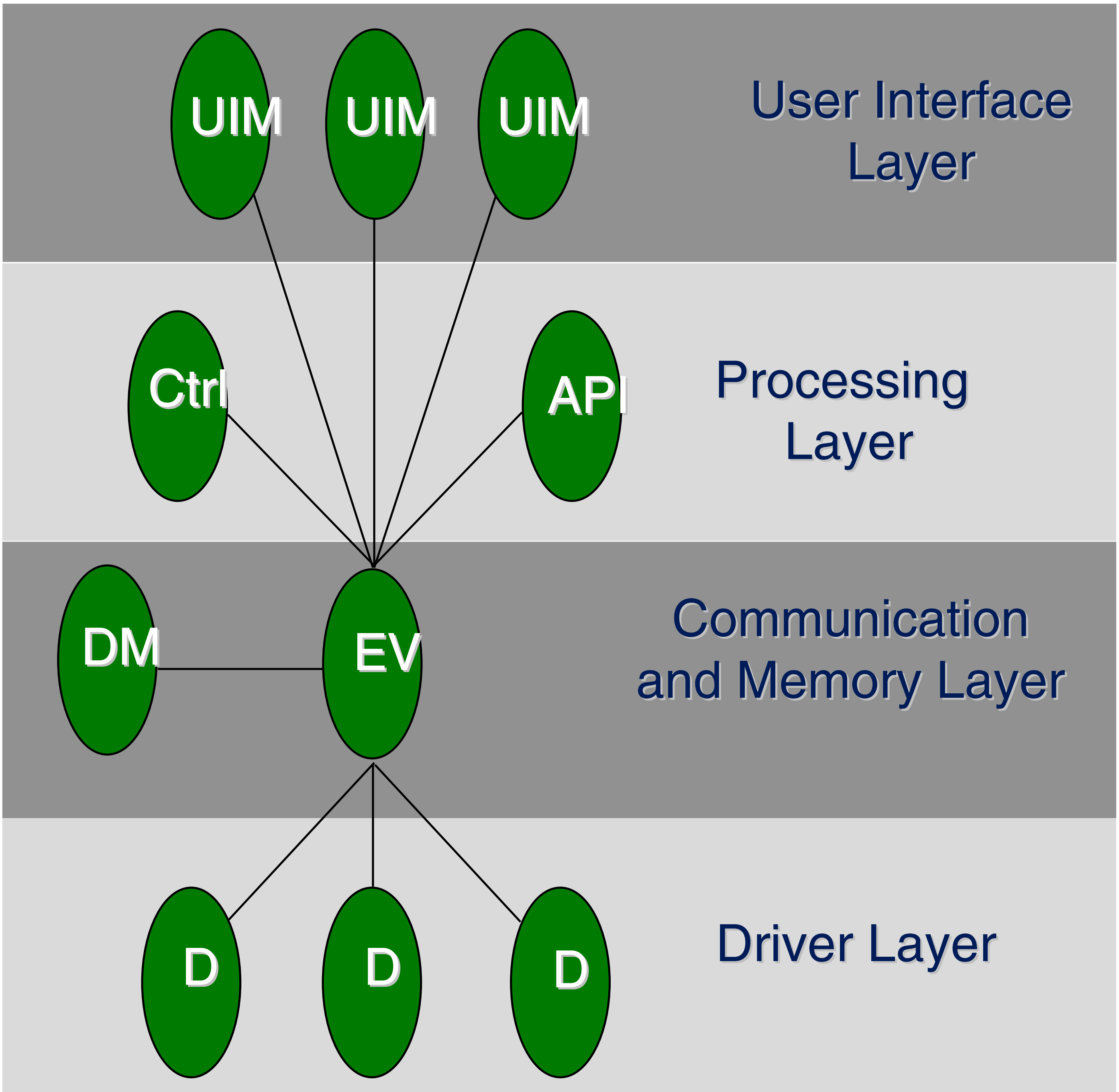
Dummy Pixel Staves for Cooling Demonstrator



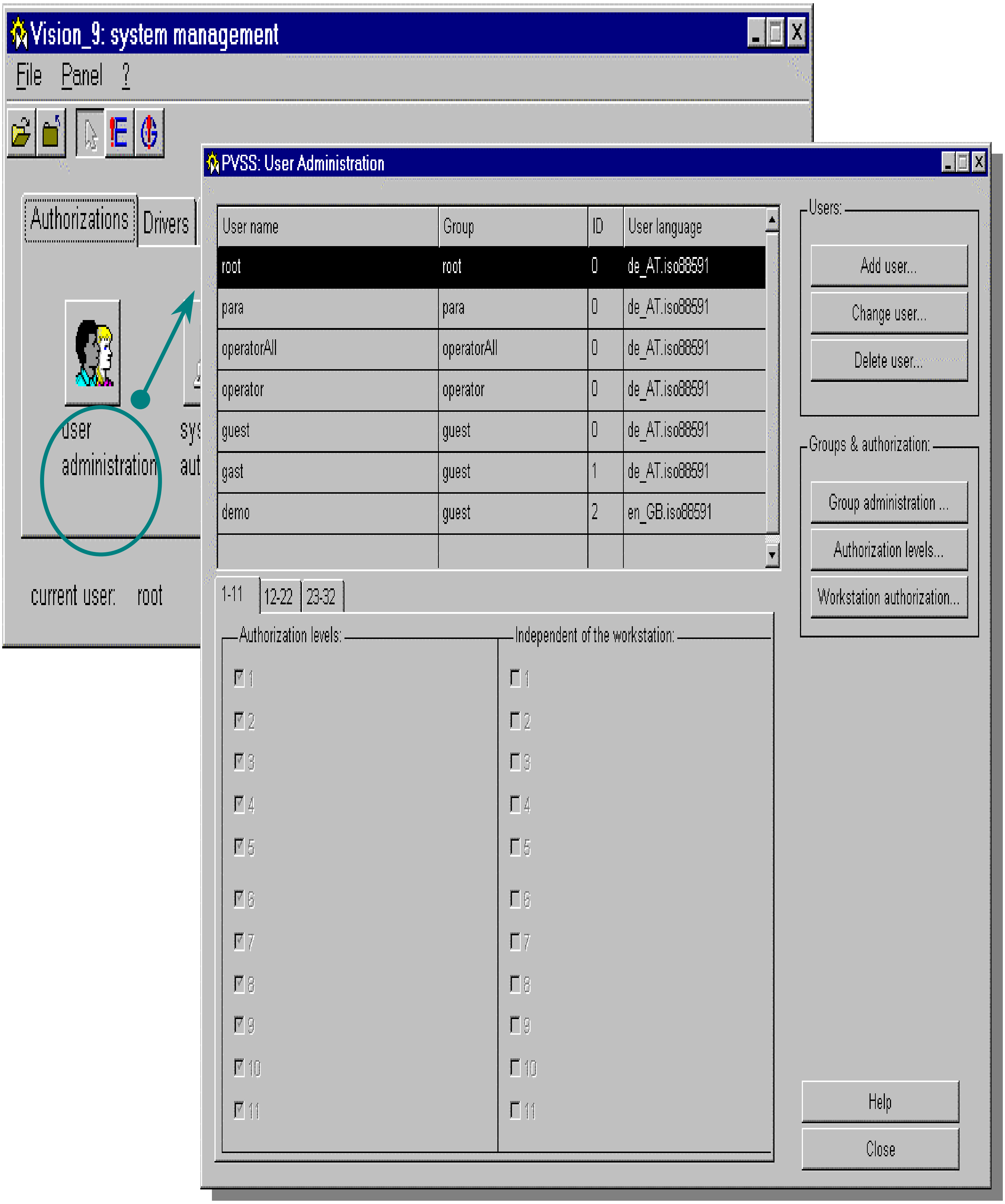
ATLAS SCADA: PVSS2. Chosen 9/2000 Until 6/2001 for Evaluation/Final Decision: Range of Application



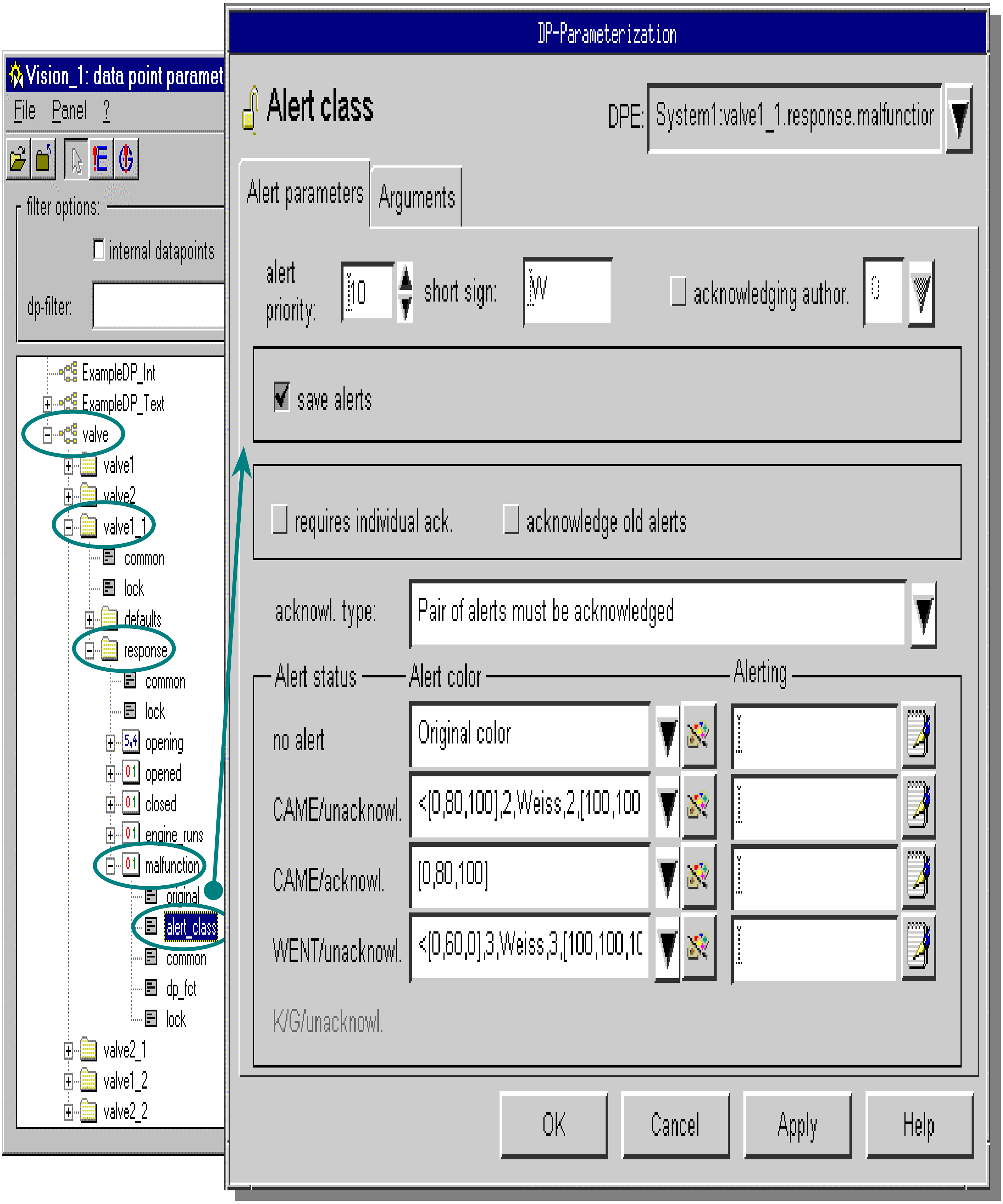
PVSS II Manager Overview



System management / user admin.



Alert class



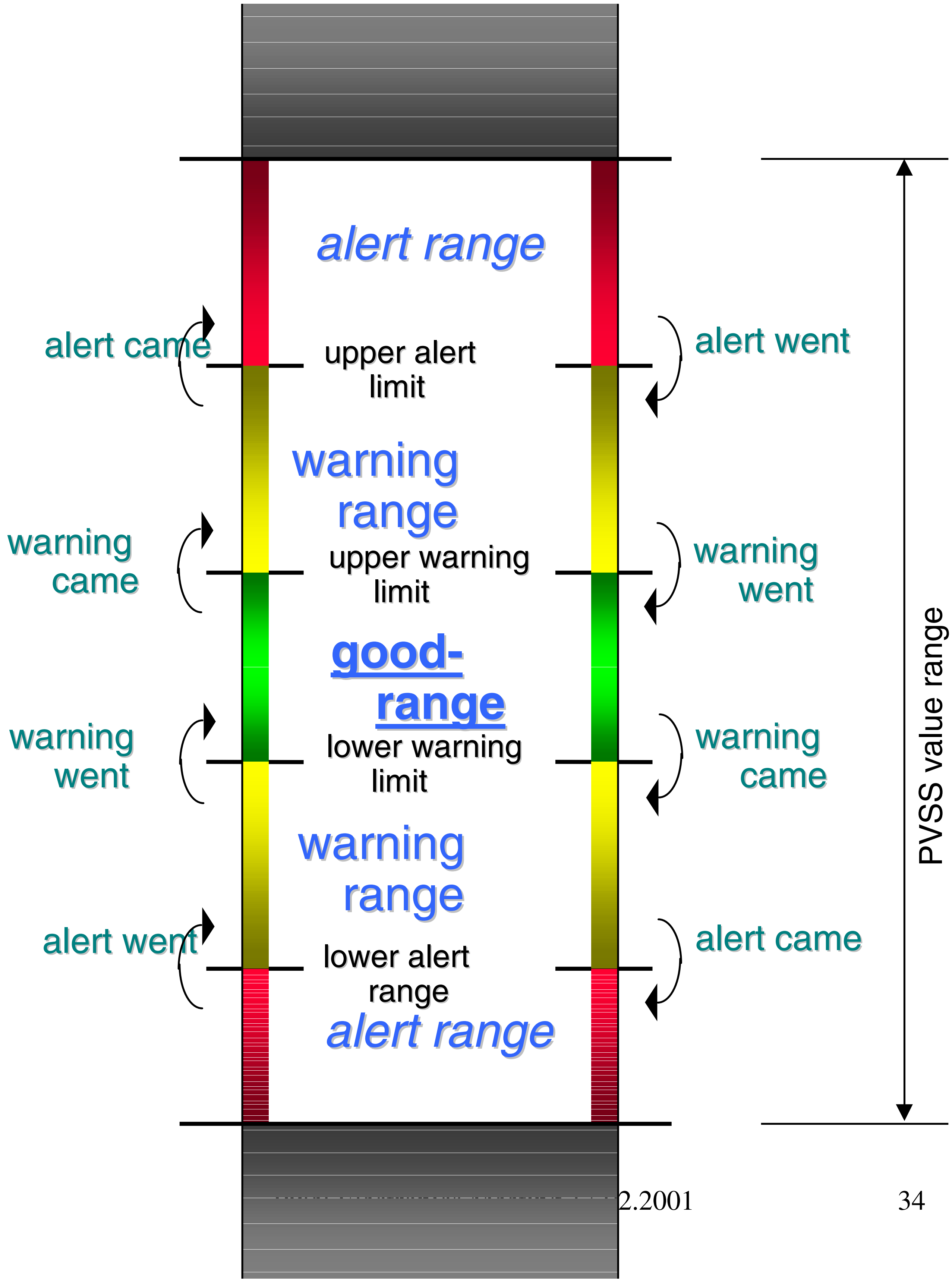
Vision_1: data point paramet
File Panel ?
filter options:
internal datapoints
dp-filter:
ExampleDP_Int
ExampleDP_Text
valve
valve1
valve2
valve1_1
common
lock
defaults
response
common
lock
opening
opened
closed
engine_runs
malfunction
original
alert_class
common
dp_fct
lock
valve2_1
valve1_2
valve2_2
DP-Parameterization
Alert class
DPE: System1:valve1_1.response.malfunctior
Alert parameters
Arguments
alert priority:
10
short sign:
W
acknowledging author.
save alerts
requires individual ack.
acknowledge old alerts
acknowl. type:
Pair of alerts must be acknowledged
Alert status
Alert color
Alerting
no alert
Original color
CAME/unacknowl.
<[0,80,100],2,Weiss,2,[100,100
CAME/acknowl.
[0,80,100]
WENT/unacknowl.
<[0,60,0],3,Weiss,3,[100,100,1(
K/G/unacknowl.
OK
Cancel
Apply
Help

PVSS II Uses C-like Scripts to Link DataPoints (eg analog inputs like T, P) to communicate with DB, reactions: Example for a Ctrl-Function

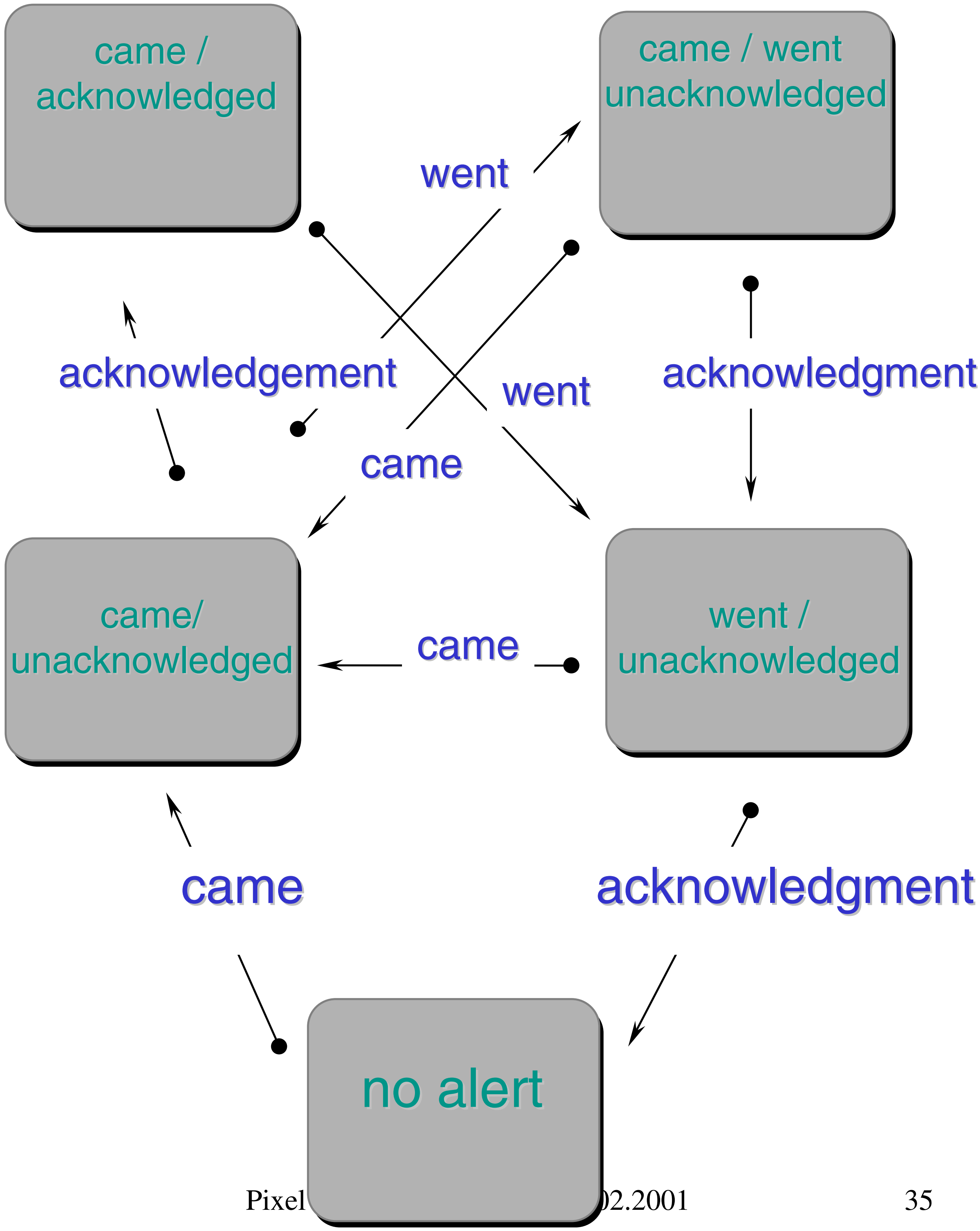
```
workCB (string dp, int x, int y)
{
  int z;

  z = x + y;
  dpSet(dp, z); /* writes the value
  of “z“ to the data-point “dp“ */
}
```

Definitions



PVSS II „Came“ and „Went Alarms Require and Log Acknowledgements



DCS DAQ Electronics Status

- First pre-production E-LMBs delivered
  - (In pixels, CERN, Wuppertal have taken delivery)
- Small E-LMB test system running with PVSS II SCADA software in cooling lab
- Requested 25 E-LMBs (delivery Spring '01) for Evaporative Cooling Demonstrator and Cooling System at SCT assembly site #1 (Oxford, late '01)
- Scalable PVSS2 with E-LMB system to be developed for Evaporative Cooling Demonstrator (2 students, end Feb + V. Filimonov for 2 months)
- Need to speed Add-On DAC development for E-LMB SPI Bus (Wuppertal/ NIKHEF) Convergence to common ATLAS spec has started
- Experience has shown Cooling Developments are best motor for controls/ DCS DAQ development:
- PVSS2+E-LMBs at Local Site when pixel cooling tests shift from CERN?? (Much to do…)

SOME FAULT RESPONSE ACTIONS

FROM SAFETY ANALYSIS REPORT JUNE 2000, CONTACT: G. BENINCASA

(1) Global LVDC power failure

Need to protect structures from excessive cold at 0 power.

➔ ➔ Taken care of within a few seconds by analog flow regulation scheme on the basis of sensed exhaust temperature. (See later in talk)

(2) Isolation of a Cooling Circuit

Prevent excessive pressure building up in inactive circuit containing C_3F_8 liquid valves/regulators.

➔ ➔ First close C_3F_8 liquid supply regulator
(Analog compressed air signal #1 via I➔P to Saturated Liquid Pressure or below)

NOTE: Exhaust back-pressure regulator NOT a shut-off device:
➔ ➔ will regulate C_3F_8 boiling pressure to its dome load pressure
(analog compressed air signal #2 via I➔P)

(3) Turn-on to correct boiling pressure.

Compressor Aspiration Tank pre-filled to preferred pressur (P$_{tank}$ > P$_{evap}$) with superheated C_3F_8 vapor (via flash evaporation from liquid delivery), for start of pressure ramp dow

➔ ➔ then reduced at required speed
(analog air signal #2 to back-pressure regulator)

(4) DACs, I➔P Regulators MUST be on Cascaded Redundant UPS.