Controls and Instrumentation for the Hall-A charge calorimeter

13th May 2004

1. Temperature monitoring
2. Heater controls and power monitoring
3. Position controls
4. FSD interlocks
5. Current readout using the calorimeter as a Faraday Cup
6. Cooling water control

Requirements

- The amount of charge deposited in the calorimeter, Q, is related to the temperature rise:

  $$Q = \Delta T \bullet C_{heat} \bullet m \bullet e / E_{beam},$$

  where ΔT, is the temperature rise, C_{heat} is the specific heat of the slug, e, is the electron charge and E_{beam} is the energy of the beam.
- $C_{heat} \bullet m$ is measured by using a resistive heater embedded into the calorimeter.

  $$C_{heat} \bullet m = P_{\Omega} \bullet \Delta t / \Delta T_{\Omega},$$

  where ΔT_{Ω} is the measured temperature change due to the resistive heater, P_{Ω}, is the power ($V_{\Omega} \bullet I_{\Omega}$) of the heater and Δt is the amount of time the heater is on.
- Replacing $C_{heat} \bullet m$ in the equation for Q, yields:

  $$Q = \Delta T \bullet e \bullet P_{\Omega} \bullet \Delta t / (E_{beam} \bullet \Delta T_{\Omega}),$$

  note that Q depends on the ratio of the two measured temperature changes.

Requirements(cont)

The goal is to make a precision 0.5% device. Simulations have shown that losses due to escaping energetic particles will be at this level, so the instrumentation error should be significantly below 0.5%. The Table below shows the error allocation:

Quantity	Precision	Accuracy	Relative Error Contribution to Q
ΔT	0.025$°C$		0.2%
I_Ω		13.5mA	0.1%
V_Ω		6mV	0.01%
Total			0.22%

Thermometry

Resistive Temperature Device [RTD] The device of choice for robust, stable temperature monitoring are platinum RTDs. These devices consist of wound platinum wire of a known resistance versus temperature curve. The resistance varies as a function of temperature and the dependence is a known standard. The fact that the temperature range needed for the measurements ranges from to 10$^\circ C$ to 60$^\circ C$ also aids in meeting the linearity requirements. Platinum RTDs can be fabricated that have 0.01$^\circ C$ [or better] repeatability with a wider temperature range than required. For a 30$^\circ C$ temperature change such repeatability will result in a 0.05% error.

Thermistors Highly non-linear response, fast response time. Not particularly stable, requires frequent calibration.

Thermocouple Voltage generated at a bimetallic junction is proportional to the temperature.

device	precision	stability	comment
thermistor	high	poor	fast, highly non-linear
thermocouple	low	good	not a precision device
RTD	high	excellent	slow response but repeatible

RTD

- RTDs respond and stabilize rather slowly to temperature [over periods of minutes].
- The calorimeter will take of order tens of minutes to reach equilibrium, so this is not an issue.
- We plan on continuously monitoring the temperature at the maximum rate allowed so that the time versus temperature function can be monitored, and the time and temperature at the peak can be extracted.
- four wire hook up to eliminate lead-loss errors
- six RTDs attached to the slug.
  - Locations of the RTDs will be determined by the thermal model.
  - insert the RTDs into small diameter holes in the slug.

RTD Readout

There are several models of RTD readout electronics to choose from. We are looking at two choices:

Sensoray S518 The Sensoray 518 smart A/D board (Sensoray 518 `http://www.sensoray.com/html/s518data.htm`) is a relatively inexpensive 8-channel 16bit PC104 daughter card. It has pre-loaded coefficients for 100Ω RTDs and supports four wire hook up. Note that with 16bits of data, the bit precision is 0.0125$^{\circ}C$ which matches nicely the precision of the RTDs. We are presently playing with this device to see if it meets these specifications. In addition to the eight channels per board, each board has its own temperature sensor, so one can correct for drifts due to the temperature of the electronics.

With all eight channels configured the S518 board can read out all eight channels at a 5Hz rate, which is sufficiently faster than the response time of the calorimeter and the RTDs.

Omega DP251 This controller from Omega Controls, Omega DP250 `http://www.omega.com/pptst/DP250.html`, is a factor of ten more expensive [for 16 channels] compared to the S518 board, with about the same precision. The cost buys comfort that the device comes pre-calibrated with a NIST traceable RTD.

Calibration and Error Budget

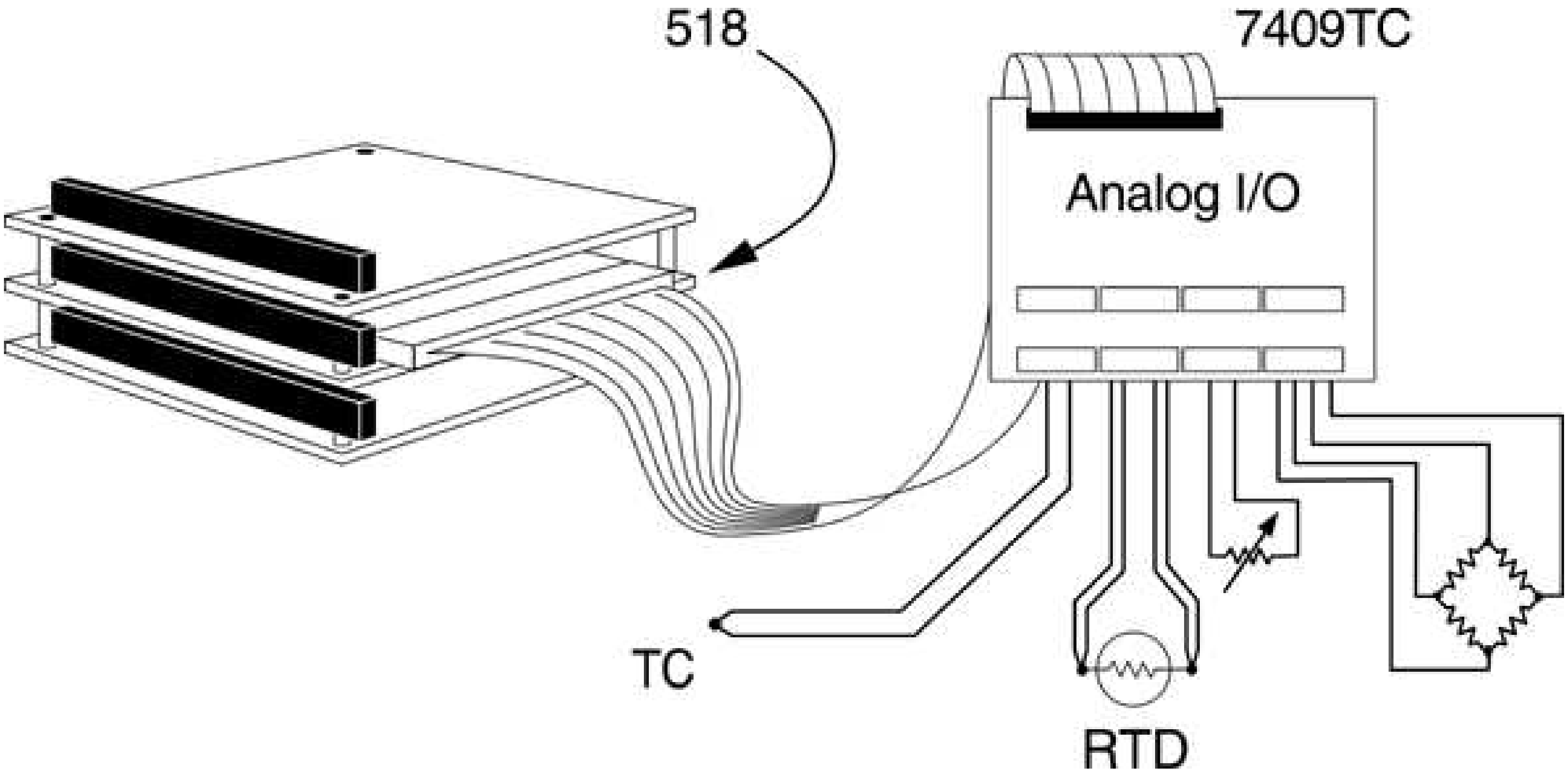
We plan on purchasing both of these systems. We will use the Omega-DP251 to calibrate the Sensoray S518 card and if in the process we find that the S518 is unacceptable, the Omega-DP251 will put in the field with a 16 channel multiplexer. The attractiveness of the Sensoray S518 and the PC104 architecture, is that the electronics will be in a small package, that can easily move from the test location to the hall and can be easily shielded from the radiation [electronic and particle] in the hall.

The error budget allocates 0.2% for measuring ΔT. If the initial and final temperatures of a 30C change are each measured with two bits of precision (0.025C) then the error on ΔT is $\frac{\sqrt{2}\star 0.025}{30} = 0.12\%$. The temperature difference is measured twice, the beam exposure and the resistive heater, so this error must be multiplied by $\sqrt{2}$, yielding 0.17% error on the charge deposited. This meets the requirement of 0.2%. Averaging and fitting might provide for an improved precision.

S518 and RTD cabling

- 20mA constant current source for measuring the resistance of the RTD.
- pre-configured for 4-wire hook up, minimizes lead-loss errors.

S518 and cabling



Resistive Heater

The power supplied by the resistive heater is an important quantity for the calibration of the slug. By using a quality power supply, measuring the current and the voltage drop **at** the heater the power deposited into the slug will be measured.

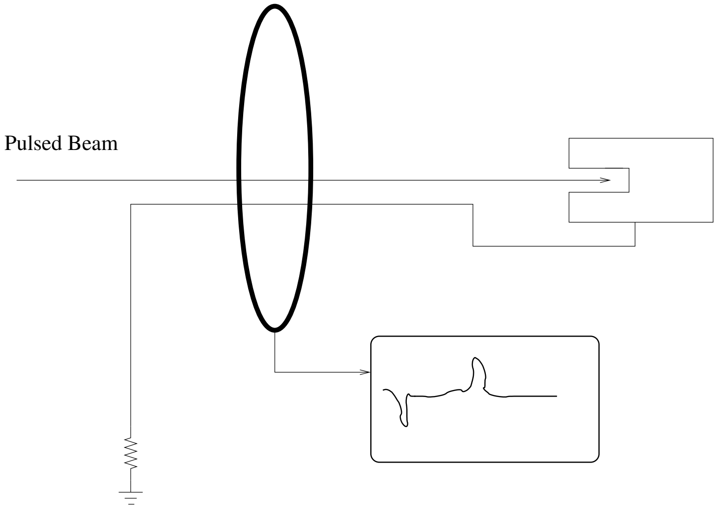
Agilent 6675 The Agilent 6675 series power supplies will provide 2000W of power to a firerod heating element. The power supplies provides a programming accuracy of 13.5mA accuracy on the output current. For 20A of delivered current this corresponds to 0.07% error on the power. The voltage across the heater [which has variable resistance as a function of temperature] will be measured so that the voltage drop in the wires is not used in the power calculation. A simple precision voltage divider at the heater [to get the 100V within the +/-5V of the S518 card] will result in a voltage error of 0.003%, which is below the 0.01% value allocated for this measurement.

Faraday Cup Readout

We plan on instrumenting the charge bleed off wire in a similar fashion as the Hall-B Faraday Cup. The current will be converted to a voltage via a PMT5-R, PMT5-R `http://www.aricorp.com/preamp_tech.htm#pmtpa`, current to voltage amplifier. The voltage will be digitized either by the S518 card [16bits], or the ADC on the PC104 CPU [12bits].

In addition to the I->V amplifier, the circuit will have a large GigaOhm resistor to ground to insure that the charge will bleed off to ground.

Simulations of charge losses are yet to be performed. We are also investigated measuring the charge loss via a transformer coil with the beam and wire simultaneously running through it.



Controls and Readback

The three position actuator will be controlled via the digital I/O on the PC104 CPU card. Position indicator switches will be installed and readback via the digital I/O on the PC104 CPU card.

The device has the following states:

- **A** Cooling, slug on cooling plate
- **B** Equilibrium position, off the cooling plate, but not in the beam. This is the location of the slug after exposure to beam or resistive heating
- **C** In beam exposure
- **D** Between states **A** & **B**
- **E** Between states **B** & **C**

The following conditions should turn off the beam via a FSD interlock:

1. The exterior temperature of the slug exceeds 100$^\circ C$ and in the **C** state.
2. The slug is in state **E**, between the equilibrium position and the beam position.

FSD #1 will be implemented via a klixon temperature switch, and FSD#2 will be a position indicator switch that opens when in state **E**.

Cooling water control

In order the chill the slug after beam exposure, the base plate will have embedded water loops. The circulating water temperature will be controlled by a commercial water chiller [heater option is also a possibility]. Two models under consideration are from FTS Systems:fts systems `http://www.ftssystems.com/maxicool.htm`, RC100LT or the RS44. The more expensive unit includes a heater, so the base plate can be raised above room temperature if desired.

The water chiller will be controlled by the PC104 card via a RS232 interface.

Channel count for controls

Table 1: Channel Counts for the Hall-A calorimeter

element	number signals	Readout/Control
RTDs on slug	6	ADC
RTD on cooling plate	1	ADC
RTD on vacuum wall	1	ADC
FSD over temp kixon	1	TTL I/O input
power supply	1	RS232
Chiller	1	RS232
Position/state Switches	5	TTL I/O input
Position Actuator	3	TTL I/O output
FCUP current	1	ADC
Heater Voltage	1	ADC

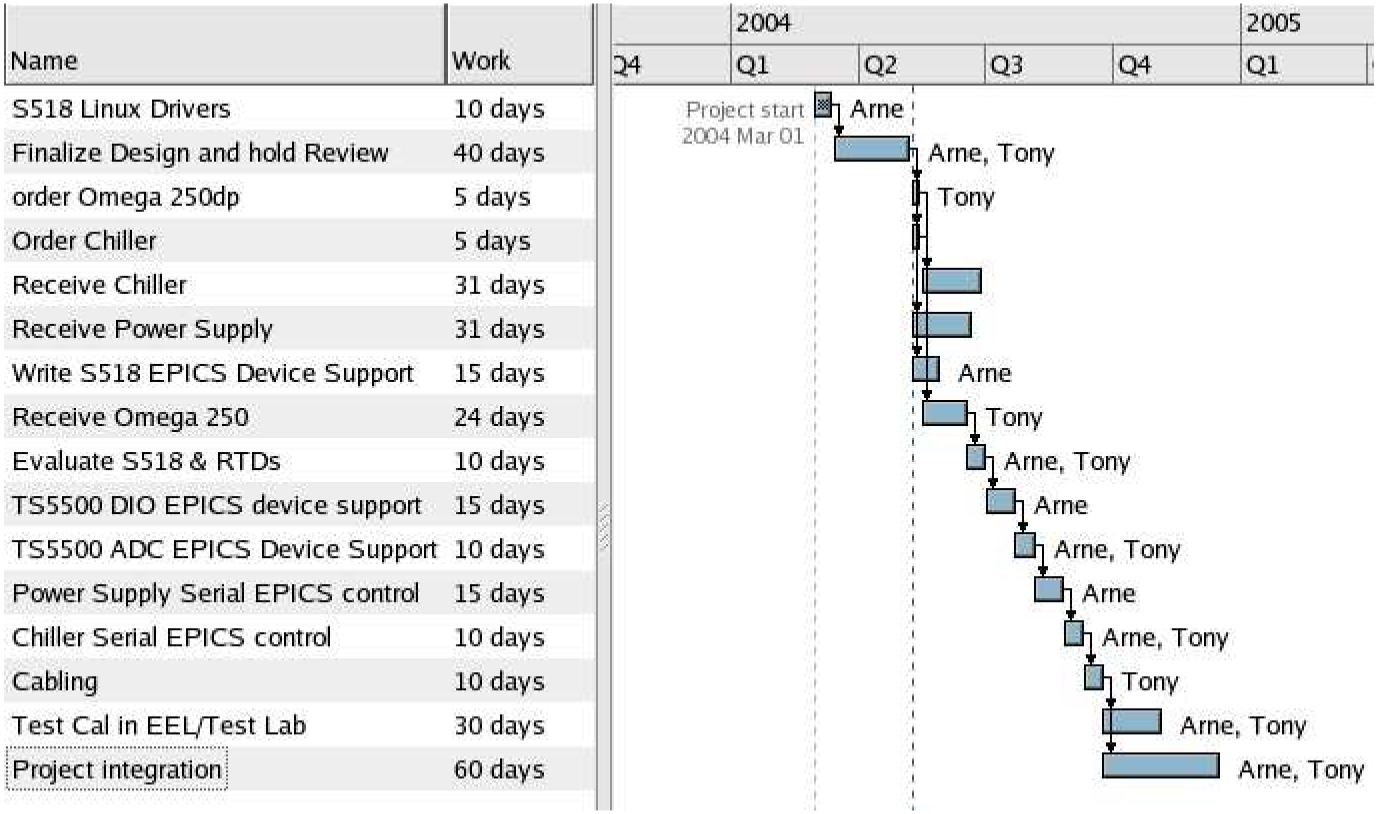
Cost Table for controls

Table 2: Cost Table

what	quantity	cost/ea($k)	cost ($k)
PC104 CPU	2	0.75	1.5
Sensoray 518 with termination	4	0.360	1.44
H2O chiller	1	4 (to 7)	4 (to 7)
RTDs	16	0.1	1.6
Omega DP251-RS2	1	3.375	3.375
Omega-multiplexer (if needed)	1	(3.48)	0 - (3.48)
Omega Traceable RTD [PRP-2]	1	0.52	0.52
Power Supply	1	4.773	4.773
Heater	2		
I->V amplifier	1	1	1
klixon	2	0.010	0.020
FSD Switches	2		
Position Indicator Switches	10		
Total	-	-	17.4-(23.9)

PC104 architecture

- ✔ The controls timeline is dominated by writing EPICS support software.
- ✔ Epics on PC104 cards proven technology:
  - ✔ G0 Yo analog readouts are 8 ADC channels read out at a 5kHz rate,
  - ✔ Hall-B's NMR probe configurator and readout is a functioning serial interface
  - ✔ plus a few others.
- ✔ The platform is quite stable even with EPICS running on it; the Yo PC104 CPU did not need a single reboot during the whole G0 run.
- ✔ Steve Wood has a PC104 card (not running EPICS) in Hall-C that survives in the high radiation environment.
- ✔ With that stated, the scope of the software project is not that large that one person cannot do it all in the 6months. All the low level linux drivers are already written, the EPICS device support and databases need to be coded.
- ✔ The testing outside the endstation can proceed before any of this software is written, as the devices needed [power supply, RTD readout, water chiller] all have front panel interfaces.



Name	Work
S518 Linux Drivers	10 days
Finalize Design and hold Review	40 days
order Omega 250dp	5 days
Order Chiller	5 days
Receive Chiller	31 days
Receive Power Supply	31 days
Write S518 EPICS Device Support	15 days
Receive Omega 250	24 days
Evaluate S518 & RTDs	10 days
TS5500 DIO EPICS device support	15 days
TS5500 ADC EPICS Device Support	10 days
Power Supply Serial EPICS control	15 days
Chiller Serial EPICS control	10 days
Cabling	10 days
Test Cal in EEL/Test Lab	30 days
Project integration	60 days

Figure 1: Controls timeline

Summary

- Thermometry is the largest contributor to the precision
    - 100Ω platinum RTDs meet the specification
    - Electronic noise must be kept to a minimum to achieve best possible precision
    - newly available 500Ω or 1000Ω RTDs will be studied
- Self contained controls system via PC104 card
    - small inexpensive unit
    - easy to move
    - easy to shield, locate closer to the calorimeter
    - self contained helps avoid ground loops with other system