BROOKHAVEN NATIONAL LABORATORY

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Liquid Argon Front End Crate

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Abstract

This document specifies and describes the components used in the Front End Crate of the Liquid Argon Calorimeter. The document is divided in five major sections (chapters) that describes the hardware. The assembly chapter can be used as a guide on how to assemble the crate on the cryostat ends.

Warning : This document is a working document. It contains ideas which are under evaluation and study. Always download the latest document for the updated document. Document is dated automaticaly when processed.

Preliminary Version - Work in Progress

1. Introduction

The Liquid Argon (LAr) Front End Crate (FEC) houses the electronics boards servicing the Liquid Argon Calorimeter readout. These card are signal amplification and digitization, calibration, trigger primitives, and monitoring boards.

Crates are mounted on the rim of the cryostat ends, either in the barrel or in the end cap. In the barrel, crates are mounted in the gap between the tile calorimeter barrel and end cap. In the end cap they are assembled at the back of the end cap cryostat. This arrangement restricts the access of the crates for long periods of time and imposes the first design constraint - poor accessibility. The second role of the crate system is to provide adequate EMI shielding for the electronics installed. Any electrical current which reaches the surface of the crate should be diverted to the cryostat.

The following is a list of requirements:

1. Front end crate will be mounted on the rims of the cryostat for the barrel and for the end cap. Crates should be designed to service all the liquid argon calorimeters electronic channels.
2. The access to the crate should take place at the rate of one per year during the operation of the ATLAS experiment.
3. Crate should shield the electronics from RF noise (EMI). It should be designed as a Faraday Cage for the electronics boards.
4. Cooling of electronics within should be performed by liquid cooling given the space constraints.
5. Crates will be mounted in all directions. Therefore proper dimensioning is needed to hold the load in all directions.
6. Backplane should not be used to transport power to the boards.
7. Crate will be located in regions where the integrated radiation dose is of about 100kRad over the lifetime of the experiment.
8. Aluminum alloys should be used where possible due to the low atomic number.

2. The Front End Crate Design

The restricted access of the crate, environmental and mechanical constraints, forces the design of custom front end crates and front end boards format. Figure 1 illustrates the space constraints for a crate located in the *crack* between the barrel and end cap in operating conditions. Two distinct situations are shown. One for the normal situation and the second for the case near the barrel support structures. In Figure 1 it is also indicated the routing for access cables for signal and power.

The conceptual design of the FEC is shown in Figure 2. Crates are mounted on top of mechanical structures called pedestals, transition pieces between the cryostat cylindrical walls

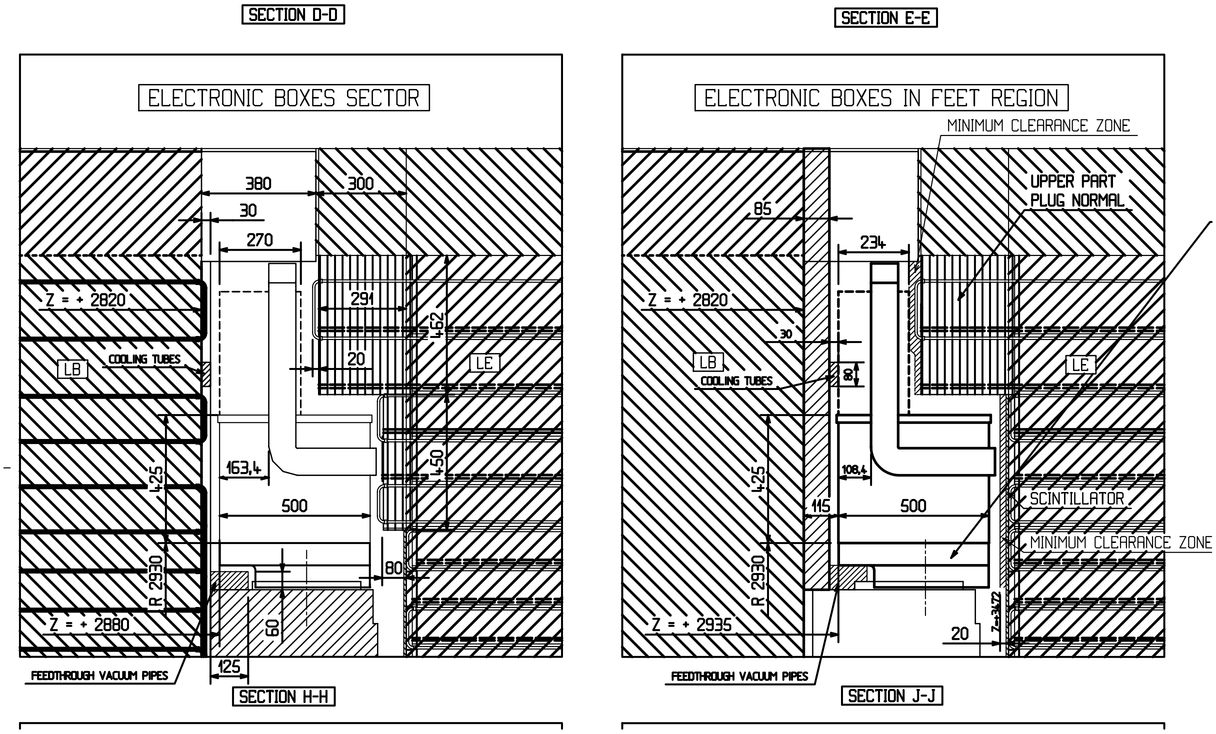

Figure 1: View of the crate in the gap

and the flat crate bottom. Inside the pedestal signals are routed to the baseplane from the feedthroughs via strip line cables (warm cables). Baseplanes play a role of a backplane with the exception that only analog signals will be routed on the lines and no large current flow is to be present. Therefore the power distribution will be done in the front part of the crate via a dedicated power bus.

Cards will be inserted in the crate from the top (in the figure). Each card will be equipped with two cooling plates. The cooling plates are heat exchangers. Liquid circulating in the cooling plates removes the heat from components. To prevent leaks liquid will be kept under atmospheric pressure.

Crates will be mounted all around the perimeter of the circumference as the calorimeter has a ϕ-modularity. This is illustrated in Figure 3 for the Gap C for the top half of the cryostat. The mechanical integrity of the crate and pedestal structure need to be properly dimensioned to hold the electronics weight at different angles. In the Figure 3 the spaces between crates are shown as empty. These areas will be used for the routing of cables to the inner detectors.

Crates will provide RF shielding for the Front End Electronics.

2.1 The Electronics Card Format

The format of the printed circuit card used by ATLAS Larg is custom. The external dimensions of the cards are: $490 \times 409.5 mm^2$. The board thickness is limited to a maximum

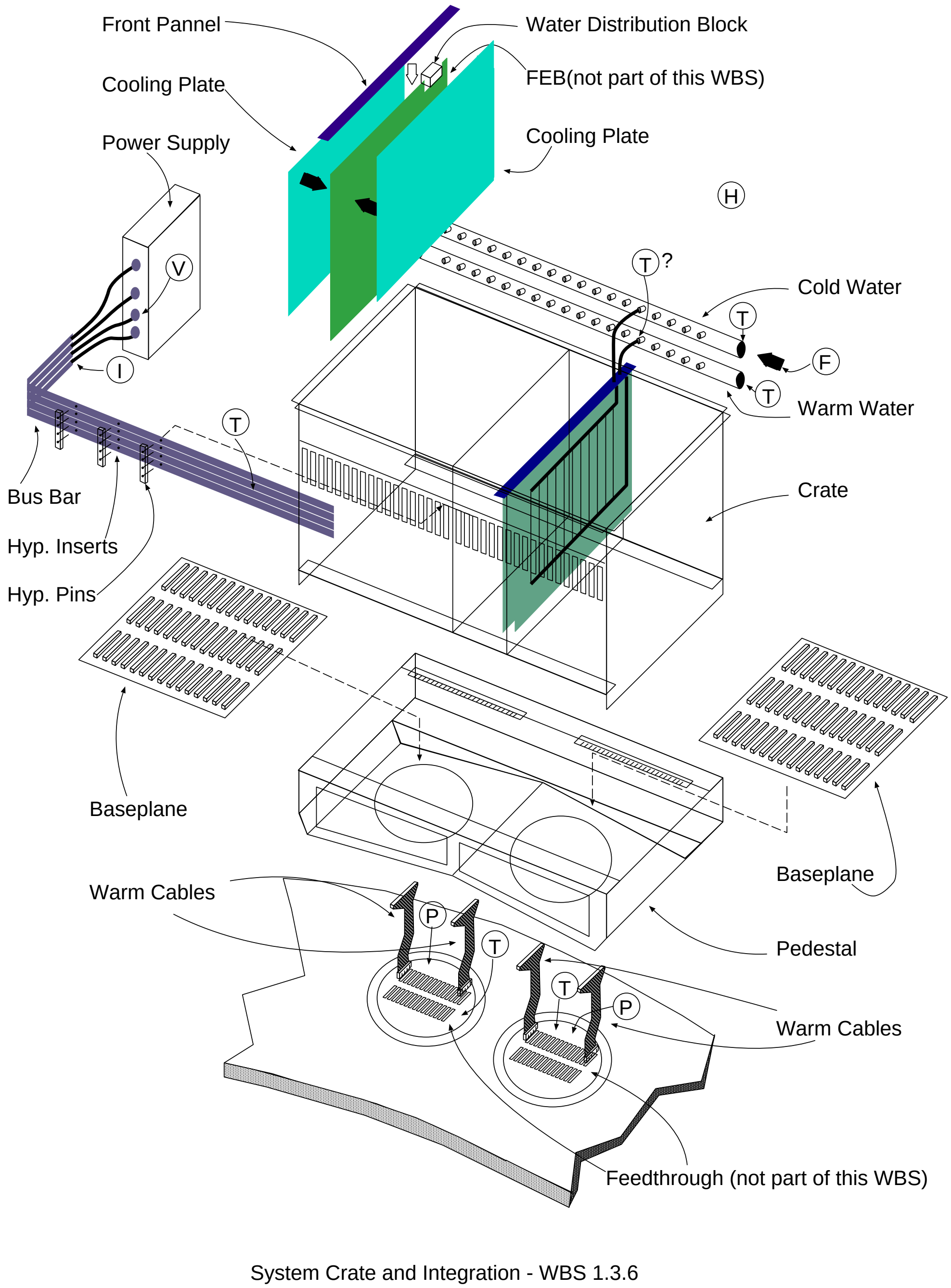

Figure 2: Conceptual Drawing of Crate

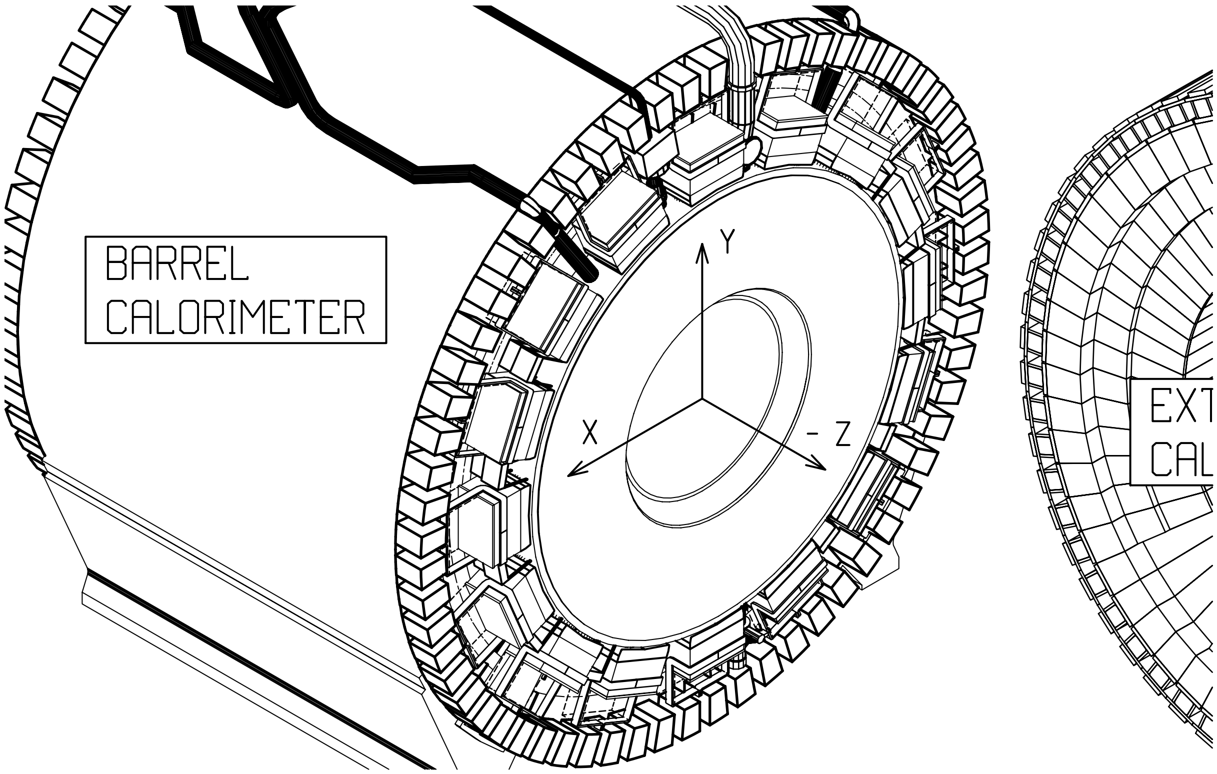

Figure 3: Front End Crates mounted on the end of the Barrel Cryostat

of 0.100"(2.54 mm). Figures 4-6 illustrates the card dimensions, and all the connectors and their locations. Cards will be located in the crate at a pitch of 0.800"(20.3 mm). However all cards are mounted on the center relative to the front panel as indicated by Figures 4-6. This is a fundamental difference to VME style mounts.

The connectors in the card are chosen in function of space considerations. The basic rule for the choice of connectors is that their height should not exceed 8mm. This is to avoid any problems during insertion and extraction of boards.

Board weight is 10.0 lb (5 kg) approximately, when assembled with cooling plates and all the necessary assembly parts. This weight was determined for the Front End Board. Other boards are expected to be lighter.
Note 1 - for insertion purposes the sides of the board should be clear of components for 5 mm.

2.2 Power connection to the Boards

The power connection scheme is different than any previously used for electronics crate design. This is to obey the requirements. Since low level signals are located at the bottom of the crate (baseplane) the power distribution will take place at the top front of the crate. A detail of the connection scheme is shown in Figure AA.

A power bus is installed with hypertronics contact inserts. These inserts are pass through connections. Cards will be inserted first into the crate. After this operation a set of pins

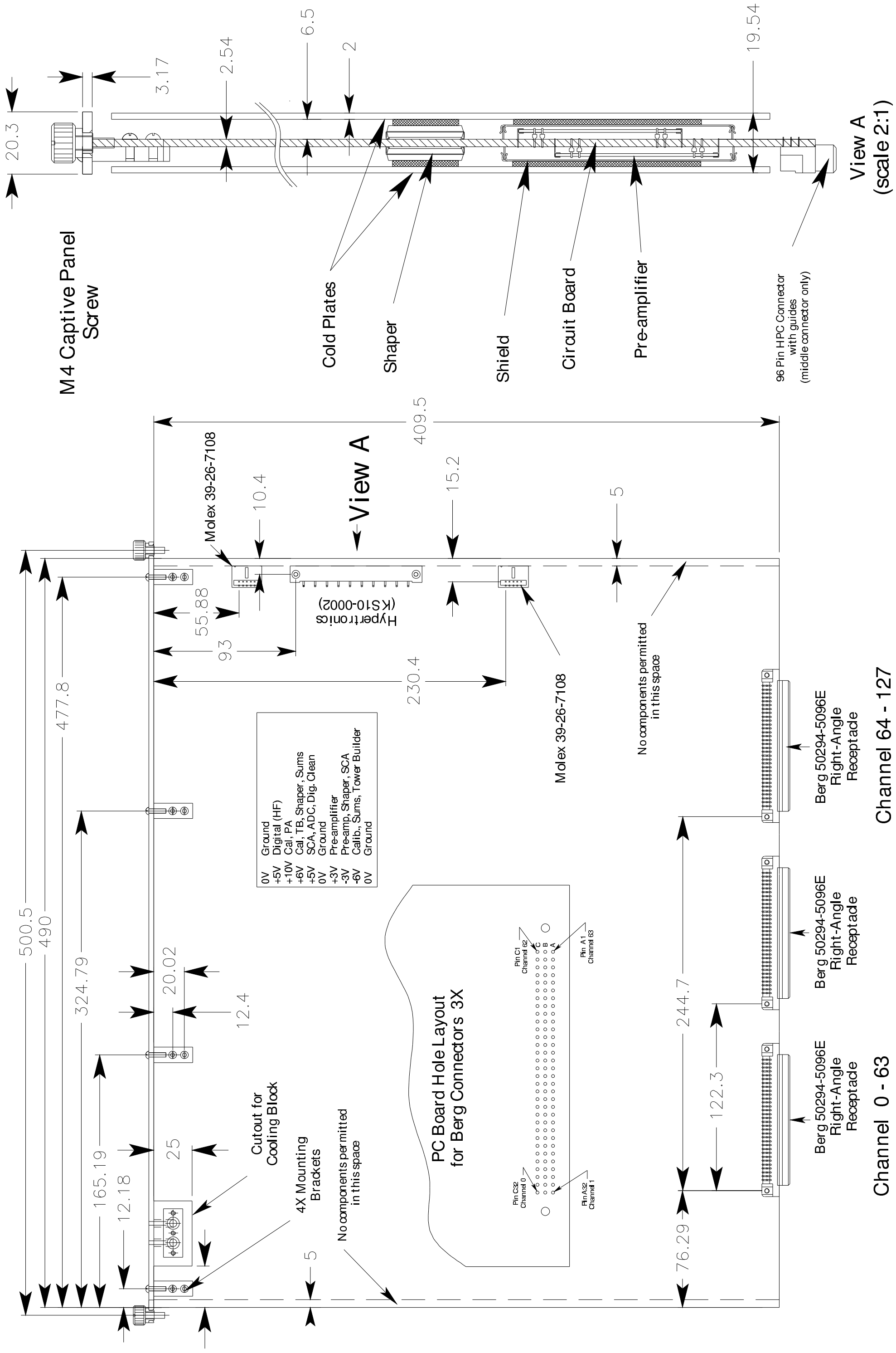

Figure 4: FEB dimensions. A cutout view is also shown.

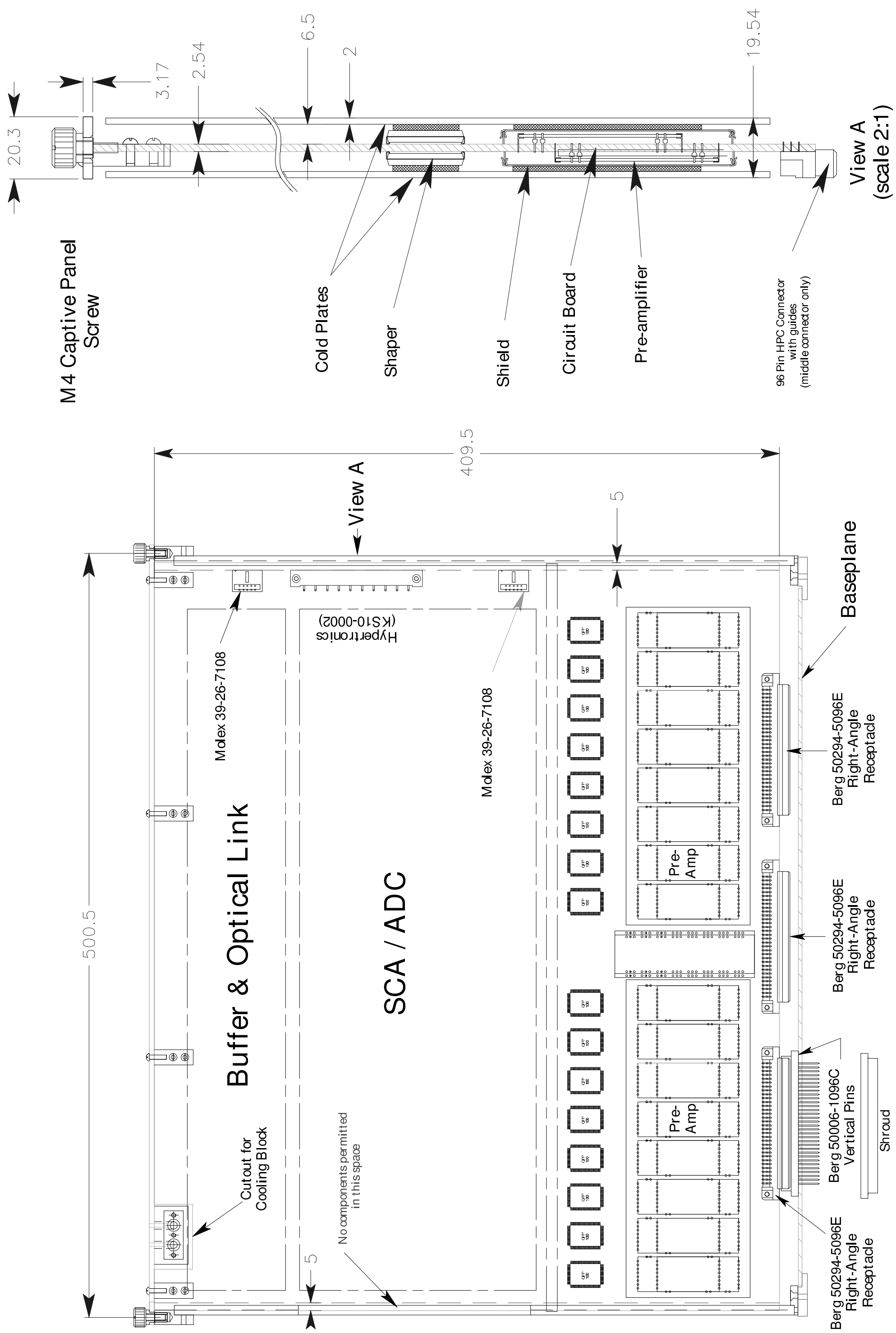

Figure 5: FEB dimensions. Division of the board

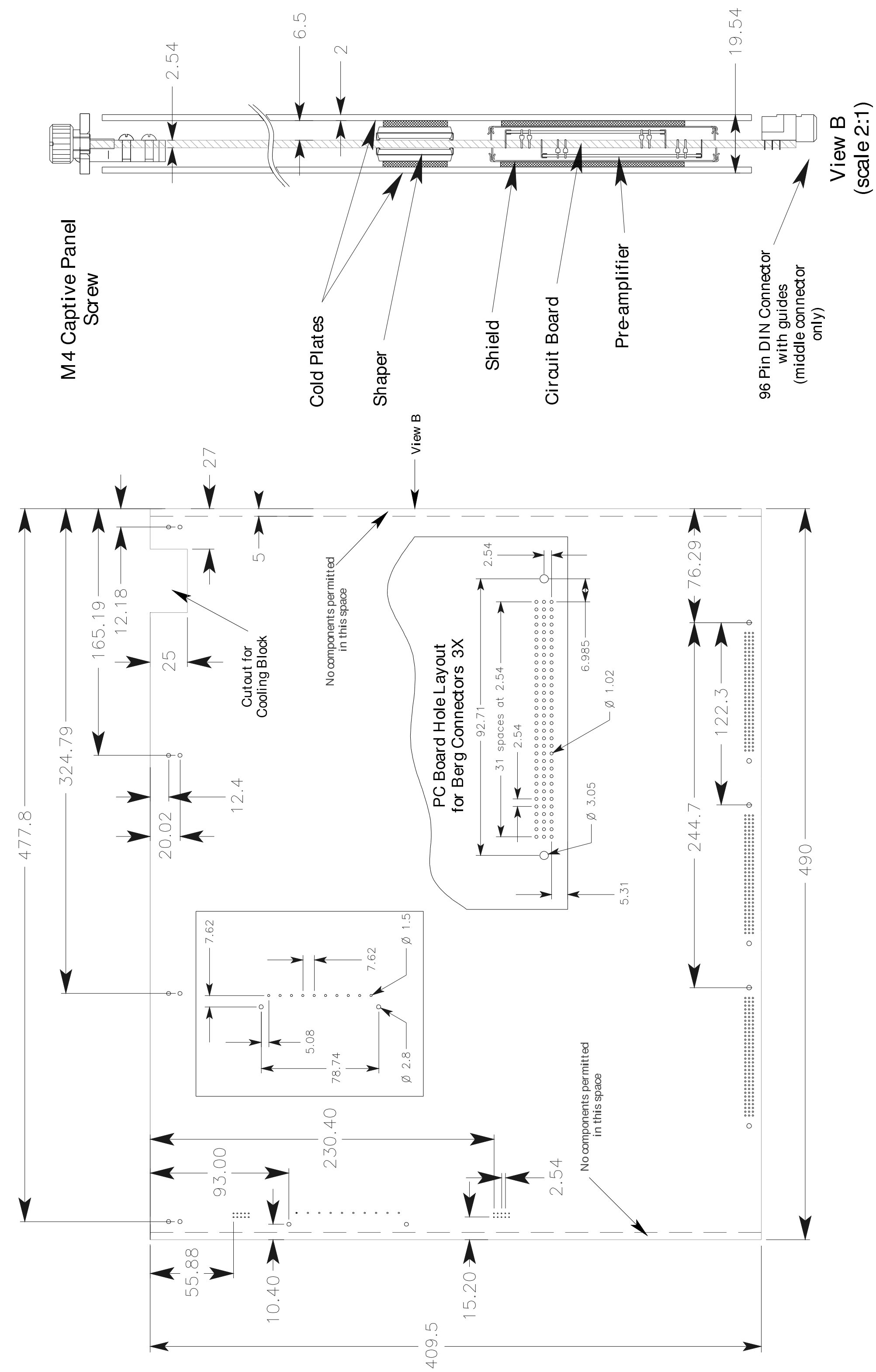

Figure 6: FEB dimensions. Hole pattern.

(comb) is inserted through the power bus and makes the contact with the electronics card.

The contacts are rated to 10 A at the voltages we intend to operate. Hypertonics contacts temperature vs current indicates a temperature raise of approximately 10^{o}C at the maximum current. These contacts have a nominal resitance of $2.5m\Omega$.

2.3 Card Mating Conditions

Two connections are critical for the board operation. These are the connectors located at the baseplane and power connections. They are located on different board edges and a require a tight control over the mechanical tolerances is needed. Mating conditions for the HPC and power connectors are as follows:

- HPC. HPC connectors being used in the design requires a minimum mating engagement of 4.56mm. Since the pin headers we are using are 5.60 mm long a maximum mismatch of 1.00 mm is allowed.
- Power Connectors. Power connectors allow for a maximum mismatch of 0.5 mm.

With this in mind we adopted the following rules for the design.

- **Rule 1** Front Panel should be in full contact with the body of the crate in the insertion position.
- **Rule 2** Front Panel is to be mounted flush against the front side of the board and all connectors on the board is to be referenced from this end.

2.4 Metal Finish and plating

Metal finish for aluminum parts should follow MIL-C-5541E, Class 3 specification. The specification is for surface conversion of aluminum using alodine or chem-film finish. The specification is used and followed by most aluminum panel finish used either in NIM, CAMAC, or VME standards for individual module construction or crate specification.

Crate and Pedestal can also be Tin Plated.

For the plating of contacts a hard finish is preferred. The options are hard gold plating or palladium-nickel with gold flash. For further reading consult Refs [2]-[5].

Note 1 - Alodine, Chromicoat, Iridite, Oakite are trademarks for the same surface chemical conversion. MIL-C-5541E applies for all the above chemicals.

2.5 Front Panel

The front panel will be an adaptation of a front panel adopted in the industry wide standard IEEE 1101.10. This type of front panel is used in VME64 and Compact PCI. The main feature of the panel is that it provides a good RF shielding at the front of the crate. This is achieved by rf gaskets installed at the edges of the panel making proper contact between two modules.

The front panel is only an adaptation since we don't make use of the ejection system neither the ESD (electrostatic discharge) grounding pin. The ejection and retaining will be made by two captive screws the same used in IEEE-585 (CAMAC) standard. For reference, see Southco part number 47-80-326-10. The ejection force is adequate for the number of contacts used and should be adequate for at least 4 DIN style connectors. Screws are also chosen for retaining of the module and would not allow for movement of the module when the crates are mounted upside down.

Grounding of the front panel for individual connection should be considered. In this case front panels should be equipped with pins.

Water inlet and outlet are mounted on the front panel.

Note 1 - Crate should always have the whole front covered at all times with blank front panels for operation.

2.6 Connectors

The following is a provisional list of connector that will be used in the Front End Cards.

- Signal Connectors **BERG 50294-5096E Right Angle Receptacle** or equivalent [1].
- SPAC interface **Molex 39-26-7108**
- TTC interface **Molex 39-26-7108**
- Power Connector **Hypertronics KS10-0002**

Note 1 - Any other connector to be used in the design should be mounted in the space indicated in Figure 1. If a connector is to be soldered on one side of the board it should not exceed a height of **8.5 mm** measured from the surface of the board.

2.7 Faraday Cage

Attachment II describes the rules to be used for grounding of signal cables and services to the front end crate.

3. Electronics Channels Serviced

Table 1 summarizes the needs for crates to service the Barrel, End Cap EM, Hadronic End Cap and Forward calorimeters. This is a summary extracted from Attachment I, Mapping of the LAr Calorimeters.

For the barrel calorimeter crates located near to the support structures will need special pedestals. There are four instances that this will be necessary.

Table 2 summarizes the type of boards in each crate for the different subsystems. The Front End Boards are subdivided into two types according to the type of preamplifiers used. The Hadronic EndCap will use a different style Front End Board since preamplifiers are located in the interior of the cryostat.

The Hadronic EndCap will require cards to transfer low voltage signals to the preamplifiers. The required gauge for the currents will be defined.

	Barrel EM	End Cap EM	Endcap Sp.	FCAL
Crates	32	16	8	2
Pedestals	32	16	8	2
Baseplanes	64	32	16	2
Warm Cables	2304	1152	608	72
Cooling Plates	2304	1152	608	72
Power Bus	32	16	8	2

Table 1: Number of Crates, Pedestals, Baseplanes, Warm Cables, Cooling Plates, and Power Buses needed for the Liquid Argon Calorimeters.

	Barrel EM	EndCap EM	Endcap Sp.	FCAL
Front End Board	28	26	17	14
HEC Front End Board			6	
Calibration Board	2	2	3	1
Monitoring Board	2	4	2	1
Controller	2	2	2	1
Tower Builder	2	2	3	1
Low Voltage ByPass			3	
HEC Tower Driver			2	
Total in Crate	36	36	38	18

Table 2: Type of electronics cards for each liquid argon subsystem

4. Pedestal and Crate

4.1 Space Considerations

In designing the System Crate we have considered the space available for crates in the crack between the barrel and endcap. This sets the tightest requirements as far as dimensions are concerned since it has to share space with other services in the area.

The available volume defines the external envelope of crate and pedestal. The pedestal dimensions are also limited by services at the back near to the interface with the Barrel Tile Calorimeter.

4.2 Finite Element Analysis

Dimensioning of the crate and pedestal has been done with the aid of finite element analysis (FEA). The total weight of the electronics installed in the crate is estimated to be approximately 380 lb (190 kg). Crates mounted at 90^o present the largest problem. At this position and with crates mounted from its base stresses may induce deformation of the crate which may difficult insertion and extraction of electronics cards. Stresses at high values may also induce rupture at weld joints if not properly dimensioned. Attachment III is the FEA of an early design for the crate and pedestal system. Results of the study revealed weak points in the design. Calculations were performed assuming a uniform load of 400 lb (200 kg). Deformations were found to be minimum. However stresses at the pedestal base were unacceptable and very near to aluminum yield values.

The results of the analysis were then used to modify the design of the crate and pedestal. Stresses in the pedestal were solved by eliminating as much as possible weld joints at the mounting points near to the feed through. The new design is shown in figure YY.

4.3 Feed through Services

We have considered the fact that services to the feed through will be mounted in the pedestal. The available volume has been increased at the maximum. The space at the back of the pedestal where services will be present cannot be used. Penetrations to the pedestal will be made from the back wall.

4.4 Shielding and Gasketing

Special attention will be paid to the issue of RF shielding. The goal is to shield the electronics as much as possible. To achieve this goal we note the following weak points:

1. The contact point between the pedestal and cryostat wall. This contact is one of the most difficult to be addressed because of the difficulties of surface finish of the cryostat wall. This surface should be treated by hand painting alodine with a brush. Procedure should comply to Mil Spec 5514-E. To guarantee contact it is recommended to use a RF gasket.

2. The contact between the crate and pedestal. This contact point will be made by the use of RF gasket. Alternatively the an RF painted gasket can be used.

3. Front Panel. Front panel should be installed at all times to prevent EMI. Front panel when installed should be equipped with RF Gasketing to better the contact between modules.

4. Baseplane to Pedestal. This area will be gasketed with Be-Cu gasket to insure a good contact between the baseplane ground plane and the structure of the pedestal.

5. Fractures. No fractures should be present at the sides of crates.

6. Weak Points. The crate is not completely shielded since there are a number of openings to be used for signal and power connections. They are minimized by the use of windows.

4.5 Construction

The pedestal is built as a 3 piece welded aluminum construction. These parts are the body, front, and back sections. It also has three other parts which are added later - the cover door, and two support bars for the baseplane.

The body and back are made of aluminum 5052, which is softer than 6061 but allows for pre-forming before welding. The front part is a aluminum L-profile cut and machined to size. The folding of different parts are made with the use of a computer aided bending machine. Pieces are then welded either by a MIL qualified welder or in production by a robotic welding

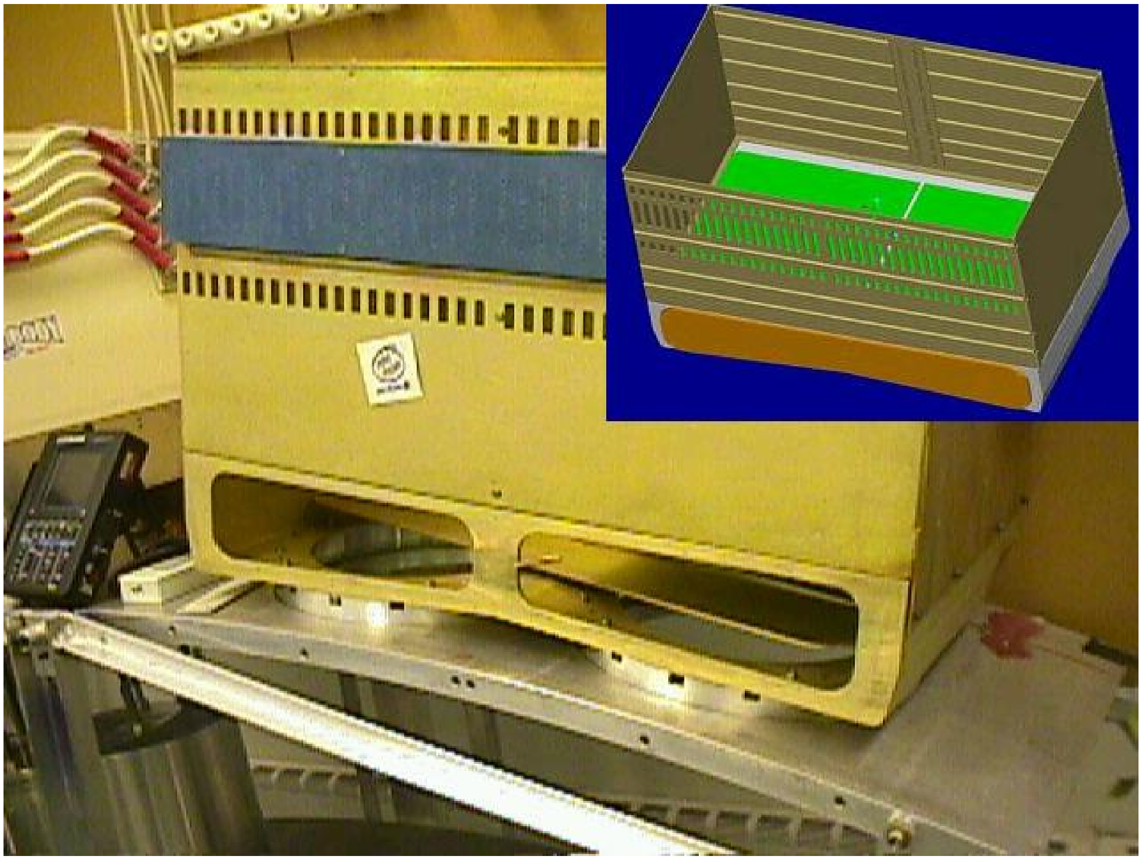

Figure 7: Sheet metal Crate

machine. This step is critical to distribute heat and minimize distortion during the welding process.

The last step is to machine all the necessary parts, and in particular finish the mating surface to the crate. In this section grooves for RF shielding are used. The whole pedestal is then submitted to surface finish as per MIL-C-5541E, Class 3.

The crate is built using sheet-metal technology. The crate is constructed as two parts. First is the construction of an outer shell. This part provides the necessary rigidity. It will be built as two L shaped interlocking parts. Rigidity is built in to the system by appropriately creating creases on the surface of the sheet metal. Every piece is designed with aid of parametric CAD tools prior to manufacturing. This allows to achieve good mechanical tolerances in manufacturing. As a second step an inner layer with card guides is spot welded from the inside. Too keep the shape and dimensions at correct values we will use dummy steel cards during assembly.

The crate mates with the pedestal at its bottom. Due to the bulkiness and weight it is designed to be assembled by two persons. The relative alignment is made by a set of dowel pins on the pedestal. On the crate sides two mini-skirts are used to first secure the crate to the pedestal. After this step is completed all the screws at the bottom of the crate and on the inside are inserted. The mini-skirts will provide good electrical contact to the pedestal from the sides and avoid any cracks for EM radiation leakage. The bottom contact is guaranteed by having M3 screws at 10mm spacing.

To improve the contact between crate and pedestal an oven cured RF gasket material will be applied at the bottom of the crate.

4.6 Quality Assurance

Crate will be checked for dimensions using steel reference cards before and after any welding operation. This is to guarantee the mechanical integrity of the crate.

To be defined are questions related to insuring proper RF shielding.

5. Warm Cables

Warm Cables are used to connect signals from the feed through to the baseplane. Each warm cable is an assembly of two strip line cables with custom termination at the ends. On one end the termination is a HPC connector to mate to the baseplane connector. The other side of the connector is an custom designed connector to mate with the feed through.

5.1 Requirements

1. Environmental
   - Temperature of operation. During Test Cycles in the laboratory between 15^oC to 27^oC. Relative Humidity not to exceed 60
   - Operations Under operational conditions cables will be at 30^oC maximum, except for accidents.
   - Radiation Levels Dose expected for 10 years of operation is 100kRad
   - Vibration Not expected other than during transport.
   - Shock Not expected other than during handling, i.e. drops.
2. Physical Properties
   - Length The total cable length (from connector end to connector end) should be a minimum of 13" long.
3. Flex Circuit
   - Flex Circuit shall be manufactured to ANSI/IPC-A 600 Revision E (Acceptability of Printed Circuit Board Specifications Class 2), and ANDI/IPC-FC-250 Rev A (Specifications for Single and Double Sided Flexible Printed Wiring).
   - The line impedance shall be 33 Ohms +- 10%.
   - Signal traces shall have a finished width of .008" (0.2032mm) with 10width of 0.016" (0.4064mm) with a tolerance of 10%.

- Signal line length shall be equal between signal lines to provide a maximum of 50 ps delay spread between lines.
- Dielectric Material between signal and ground layers shall be Dupont Electronics Materials type AP9121 adhesive less kapton or an equivalent material. Approval of vendor selected material other then that specified is required.
- Thermo set Adhesive when used to bond printed circuit board to a stiffener should have a peel strength of 3 lbs per square inch minimum when tested in accordance to IPC-FC-250A.
- Pressure Sensitive Adhesives are not Permitted.
- A Polyimide cover layer with a total thickness (including adhesive) of 0.003" (0.076mm) is required. Signal traces must be exposed for soldering.
- A bright tin finish is required on all exposed copper traces. Tin plating shall be in accordance with MIL-T-10727, type 1.
- A complete Automated Optical Inspection of the flex layer is required.
- The flex circuit shall be tested for opens and shorts. Signal and ground traces shall have no mouse bites that exceed 5
- All exposed copper shall be solder coated per IPC-250.
- Copper Thickness shall be 1 oz (38 microns)
- Insulation resistance between two adjacent lines shall be a minimum of 500 Megohms

4. Assembly Specifications

   - The cross talk between any two adjacent lines should be less than 1% for sinusoidal waveforms of 40 MHz. Cross talk to distant neighbors shall be less than 0.02%.
   - The allowable maximum resistance of each signal line shall be 1 Ohm, with a uniformity of 15%.
   - Custom connector is to mate the pin carrier on attachment 1.
   - Custom connector should be inserted manually at least for 2 mm prior to assisted insertion by the jack screws.
   - Connectors can be partly ejected by the jack screws.
   - Custom assembly can be over molded. If molding option is used PVC 90 shall be used.
   - Plastic parts are allowed in the assembly of the body but materials to be used should not be in the excluded table list attached. In case of doubt the manufacturer should consult with BNL or present certification that materials will withstand an integrated radiation dose of 100 krad (ionizing) and a neutron flux of 10^{13}.

5. Ground connection

   - In mating position should have a resistance less than 5 mili-Ohm per side.

- Should preserve the above value, with deterioration accepted to 9 mili-Ohm, during the operation time of the detector. Hence plating and spring constant should be dimensioned adequately.

5.2 Prototypes

Prototype cables are build to evaluate mating conditions, manufacturability, and labor quality. Prototypes permit the detection of possible potential problems which may cause unreliable connections and quality assurance nightmares.

Two prototype cables were built. The first cable is designed in house and the second designed by FCI Berg Electronic. The cables differ in the manufacturing process and assembly.

The in house prototype uses two rigid-flex circuits. Receptacles are crimped and soldered to the flex part of the circuit. Receptacles used are AMP part number 487406-1, with key removed. Receptacles are then securely inserted into the plastic housing. The next step is to solder the ground shields which is done on the rigid part of the circuit. The rigid part of the circuit is a transition piece which brings the ground to the exterior part of the cable. The ground shield are made of Cu-Be thermally treated and manufactured by Instrument Specialties. The two independent sides of cables are then joined at one end by a custom housing and riveted. The other side which is not custom is terminated by a HPC connector which is soldered.

The commercial prototype is manufactured in somewhat different manner. The two circuits are only flex circuits and no crimping is used. All connections are soldered. On the custom connector side receptacles (BERG part number BUS-12-067) specially made for the assembly are soldered. Shields are also soldered directly to the flex circuit. The shields are similar to the ones used in the in house prototypes but proper for soldering. Receptacles are inserted into plastic housing and a custom housing glued (in the prototype). The Berg HPC connector is soldered on the other extremity.

Test results on the prototypes are available. Data for the in house prototypes are available from experiences in the test beam and laboratory tests. These indicate parameters compliant with the specifications. (Need to enclose test results). Commercial prototypes are less tests since full prototypes are recently available.

Prototypes indicate few particularities of the warm cable.

- **Jack Screws** Jack screws should primarily used to fasten the custom connector to the pin carrier. They should also aid in the insertion and ejection of the connector but in limited fashion. There is a need to understand the best design. We treat the jack screws slightly different for the warm cables since there is a potential of multiple insertions for these cables.

- **Tearing of Kapton** Kapton is a material which can be teared with ease. Standard design techniques to protect ordinary tearing should be adopted. Tearing could be a result of access to the pedestal volume.

- **Ohmic Resistance** The requirements on the Ohmic resistance of the warm cable is not as severe as for the vacuum cable. There is no heat loss because of the copper line cross sections.

5.3 Production Issues

For the production of cables a number of issues are open:

1. Approval of design. A final design should satisfy all the mechanical and electrical performance.
2. Radiation Damage. Cable material should be scrutinized and tested for radiation damage.
3. Production time. Cables should be produced in a span of maximum 18 months.
4. Testing. Flexible cables should be tested prior to assembly
5. Assembly Testing. Assembly should be fully tested for conductivity and shorts. Lot test should be performed to monitor quality.

5.4 Quality Assurance

Quality assurance for cable production will be made in three stages

1. Design. At the design stage we will address the proper selection of materials, plating, suppliers. Proper design practices will already guarantee a number of problems. Parameters such as cross talk, impedance, resistance should be addressed at this level.
2. Flex Circuit Test. This is an intermediate step where the flex circuit will be visually inspected and tested for continuity
3. Assembly Test. Assembly tests will address the quality of the assembly.
4. Full Test. Full test should be required only for a certain percentage of the cables. These tests includes full TDR (time domain reflectrometry), cross talk measurements, delay spread, dielectric material integrity, ground connection resistance, and others...
5. Full Destructive Test. This test will be used to cut the cable in sections and examine under microscope solder quality, etc...

6. Baseplane

Baseplanes will be used as a two purpose element. First it will be the interface between the warm cables and Front End Boards. Second it will route trigger sum signals from the individual front end boards to the tower builder cards.

Each crate uses two baseplanes. Figure 8 shows the baseplane for the barrel crate. In the picture one test board is inserted.

6.1 Connectors

The connectors used in the baseplane are from the BERG HPC connector family. Each baseplane is built as three row and 19 columns, in a total of 57 connectors. The columns are defined as per document describing the mapping.

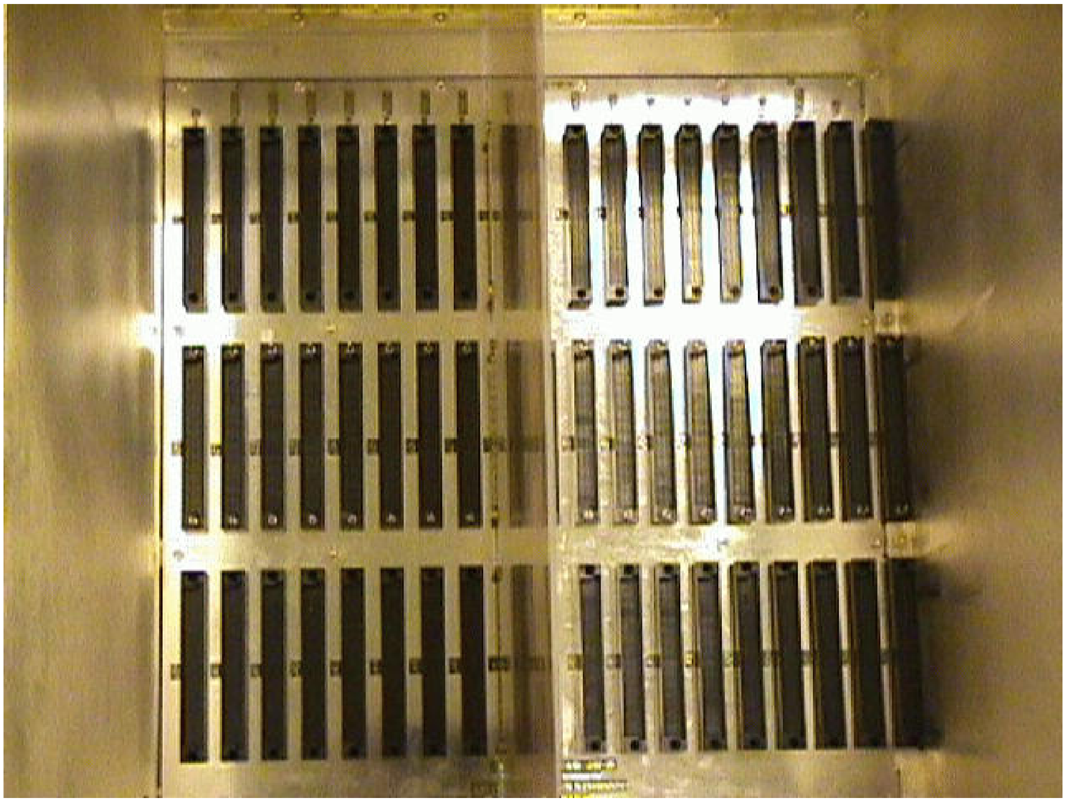

Figure 8: Picture of the Barrel Baseplane

6.2 RF and Grounding Issues

The baseplane is grounded to the body of the pedestal. The baseplane ground layers, specially those at the outside layers, makes contact with the body of the crate. Electrical currents from the Front End Boards should flow on these layers to the body of the crate.

This can be achieved by good electrical connection between the baseplane and boards. One approach that is being adopted is to use shields....

6.3 Types of Baseplane

To accommodate the routing of trigger sums for different detectors different baseplanes will be manufactured. The different types are for the Barrel EM, EndCap EM, EndCap Special, Hadronic EndCap, and Forward Calorimeter.

The Barrel EM baseplane is the same for all the 32 crates. These baseplanes are all equal. The Endcap needs two types of baseplanes since the mapping changes from the outer to the inner wheel. The Hadronic EndCap requires its own routing. The Forward Calorimeter will require the routing of calibration signals as well.

7. Power Bus

The power bus distributes the power to the electronics cards in the crate. The connection scheme is custom and illustrated in Fig XX. Power requirements vary from system to system, and they are tabulated below. The highest required currents are for the +5V lines.

7.1 Power Bus Design

The power bus is installed on the front of the crate. The power transfer is achieved as illustrated in Figure VI. In each copper bar an double open end contacts are inserted. These contacts are engineering for a maximum current of 10A each and the contact is a spring loaded contact. After the electronics card is inserted in the crate a set of pins are inserted through the contacts and mates with connectors on the front end board. The alignment of the power connectors with the bus bar is critical. This is achieved by having as a reference the top of the crate.

The power requirements for the crates are presented in Table 3 and Table YU for the barrel and endcap crates. A quick examine of the table show that We require a minimum of 140A to 150A in few lines. These are very high currents to be transported in enclosed spaces and proper precaution and dimensioning is required. Bars are dimensioned to carry a total of 200A.

The copper cross section is calculated using the following relation which is applied for laminar bus bars.

$$Area(mils^2) = 300 \times I(A) \times (1 + 0.075 \times (N - 1))$$

where N is the number of conductors, I is the current in amperes, and the cross section is given in square mills.

For $I = 200A$, the equation yields $A = 64.8mm^2$. Since the equation applies for laminated bus bar heat dissipation conditions are better. For our situation the conductors have a smaller heat dissipation area. Therefore a larger cross section is desired. The closest copper bars really available from stock are $12.7.4mm^2$ or a cross section of $81.3mm^2$ (25% larger then calculated). Therefore these are selected for the construction of the copper bars.

7.2 Parts List

The following is a list of Parts used for power connection.

1. ϕ**1.5 knurled socket** - Hypertronics YSK015-098
2. **10 position male pin carrier** - Hypertronics KS10-0003
3. **10 position female right angle** - Hypertronics KS10-0002
4. **Bus Bar termination** - ODU - 181.617.000.301.000
5. **Bus Bar cable termination** - ODU - 171.617.100.201.000

Line	Nominal (V)	FEB (A)	Control (A)	Calib (A)	Monitor (A)	Tower Builder (A)	Total (A)
1	Ground						
2	6.0	106.4	0.	5.5	0.	0.	111.9
3	11.0	14.0	0.	0.5	0.	0.	14.5
4	7.0	0.	0.	7.7	0.	7.8	15.5
5	6.0	56.0	0.	0.2	0.	0.	56.2
6	Ground						
7	4.0	131.6	0.	0.	0.	0.	131.6
8	-4.0	137.2	0.	0.5	0.	0.	137.2
9	-7.0	5.6	2.1	0.	0.	2.4	10.1
10	Ground						

Table 3: Voltages for Barrel

7.3 High Power Contacts

Three companies that manufacture high power contacts were considered. All three use similar principles to achieve high performance in contacts that need high current. The companies are:

- Hypertronics [8] - Hypertronics connectors are based on the principle of hyperbolic contacts. The insertion force is minimum and contact reliable. The contact resistance is somewhat higher due to the small contact area.
- ODU [7] - Odu connectors use two different contacts - springtac and lamella. One characteristic is the low contact resistance.
- Radsok [6] - These contacts are hyperbolic in nature such as the hypertronics. However they are made from sheetmetal. They are low cost contacts and low resistance. The drawback is the existance only for a minimum of 6mm diameter connections.

7.4 Manufacturing

The bus bar design is shown in figure YY. Each color on the bus bar represents a different voltage. Manufacturing of power bus is realized following these steps.

1. Copper bars are cut to size and bends made. The copper used is 110 alloy, $12.7.4\ mm^2$ cross section.
2. Copper bars are terminated with connectors.
3. The copper bars are then bonded together with epoxy using a gluing fixture. The front and back of the bus bar are covered with a thin G10 plates that also serves as a safety guard. Aluminum mounting bars are also glued in the process.
4. After the curing process takes place the bus bar is mounted on a NC milling machine for drilling. This guarantees good relative accuracy for the positioning of the holes. Note

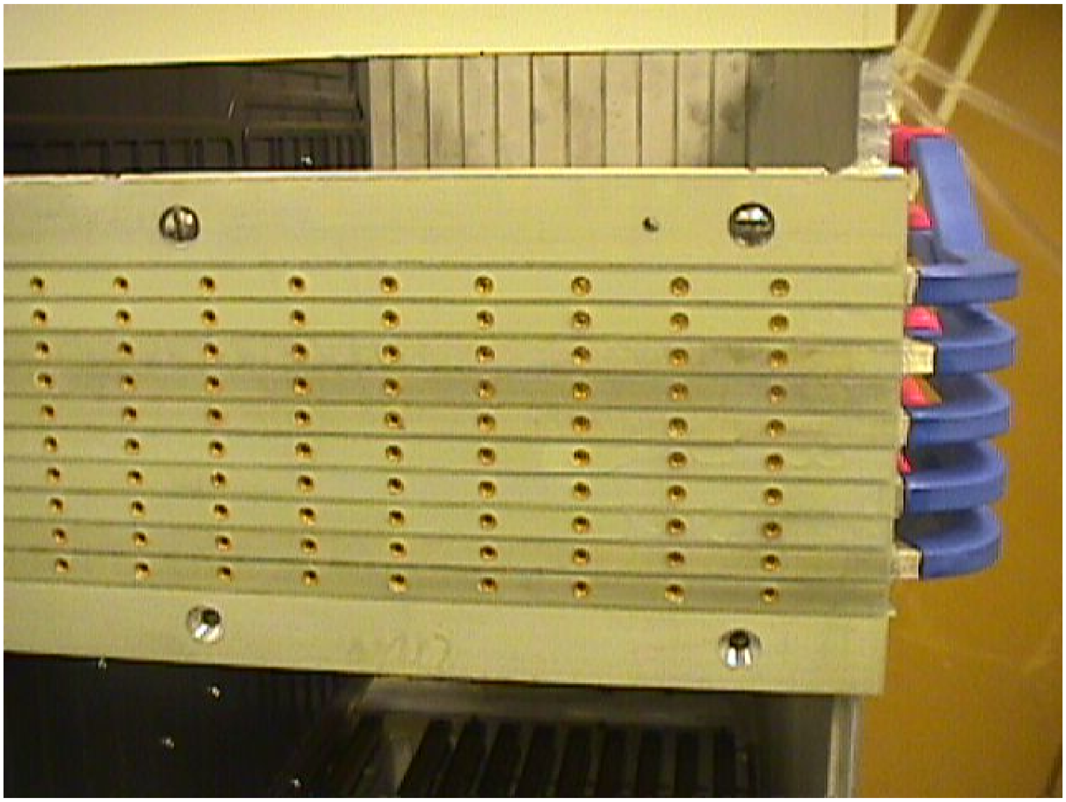

Figure 9: Power Bus prototype. The bus bar is built starting by gluing 10 copper lines (1/4 x 0.400) and two aluminum mounting bars. After the curing time of the epoxy, the bus bar is mounted on a NC machine for precision drilling. Inserts are then press fitted and bus bars terminated.

this also guarantees a good relative positioning of the contact holes with bus mounting holes.

5. Next the inserts are put in place using a press.
6. To finalize the manufacturing process the exposed copper parts mostly at the ends receives a epoxy coating for safety.

7.5 Termination of Bus bar

Bus bars will be terminated by high power connectors. The suggested power bar termination is manufactured by ODU and belongs to the Springtac family.

7.6 Quality Assurance and Testing

There are several places that requires checking:

- Visual checking of the inserts. Contacts should be good.

- Ends should be visually checked for contact. Ends should also be tinned, prior to any crimping or soldering.
- Insulation between bars when not connected to power supply should be measured at 1kV when leakage current should be less than $1\mu A$.
- Bus bars should be tested at full load for 168 hours before installation
- Relative distance between inserts and mounting holes should be found to within 0.2mm.

7.7 Cooling Issues

The operation of high current usually implies in heat build up on the power lines. Proper cooling may be necessary. There are two distinct heat sources in the busbar design. First is the Ohmic resistance of the copper bar. This is measured to be of the order of $15m\ \Omega$. The second source of heat arises from the contact resistance in the inserts. For example, hypetronics inserts at 6A can warm up by 10^oC above room temperature. This is according to the manufacturer under normal circunstances.

7.8 Monitoring and Safety

The operation of bus bar with such high currents introduces risks. This is specially true for two reasons. First is the difficult acessability of the bus. Second any high resistance points may represent fire hazards. Other standards in the past had similar problems, specially FASTBUS.

Therefore monitoring of the power bus itself is an important safety issue. Current plans to monitor the power bus includes two types of measurement:

- Current measurements of the bus bar and power supplies. This will be a first indication if all electronics are performing properly.
- Temperature Monitors. We plan to measure the temperature in bus bars using either RTD's or thermocouples. However it may be possible to use infrared thermocouples to monitor larger areas.

8. Power Supplies

Power supplies have the following constraints.

- Should provide power with 25% excess of required by the boards.
- Should have a maximum ripple of 1 mV. (???)

8.1 Switching vs Linear

There are two choices of power supplies, each one offering pros and cons.

Linear power supplies are know for the low ripple and stability. For a number of year they have been the supply of choice for low noise electronics. However they are bulky and inefficient. They would require space and could only be mounted far away from the crates, thus requiring long cable runs. At the currents required, e.g. 150A, this imply in large ohmic losses and the need for cooling.

Switching power supplies are known for the noise levels and until quite recently not commonly used for low noise electronics. Newer switching power supplies offer low noise. In their favor they are compact and proper to fit in tight spaces. Therefore the need for long cables would be reduced. The negative points for our particular use are magnetic field and radiation.

8.2 Location

The major problem with the power supplies happens in the Endcap region. End caps retract when access to the barrel is required. If power supplies are to be located on the exterior of the detector it would require disconnection of cables each time they are moved. Cables would be required to be very flexible as well since some movement will be made with cables connected. Therefore it would be highly desirable to have switching power supplies located near to the electronics.

8.3 Cooling

In both cases the power supplies will be water cooled.

8.4 Monitoring

Monitoring of the power supply will be required at all times. The parameters to be monitored are the following

- Voltage at the Power supply. This monitors the voltage at the power supply output.
- Voltage at the Bus Bar. Monitor of the voltage at the bus bar
- Current. Monitor the current of each individual power line
- Temperature of the power supply.

9. Cooling

9.1 Overview

The electronics in the front end crate will be refrigerated using a liquid cooling system. The option for this method of cooling was chosen due to absolute lack of space to install air cooling.

In the liquid cooling of electronics heat is removed from the components by conduction. Thus heat exchangers need to be placed in contact with components. This is the opposite of air cooling where forced air circulates on the surface of the components and carry the hot air away from the components. Liquid cooling presents several technical difficulties and some of them apply only for the present case.

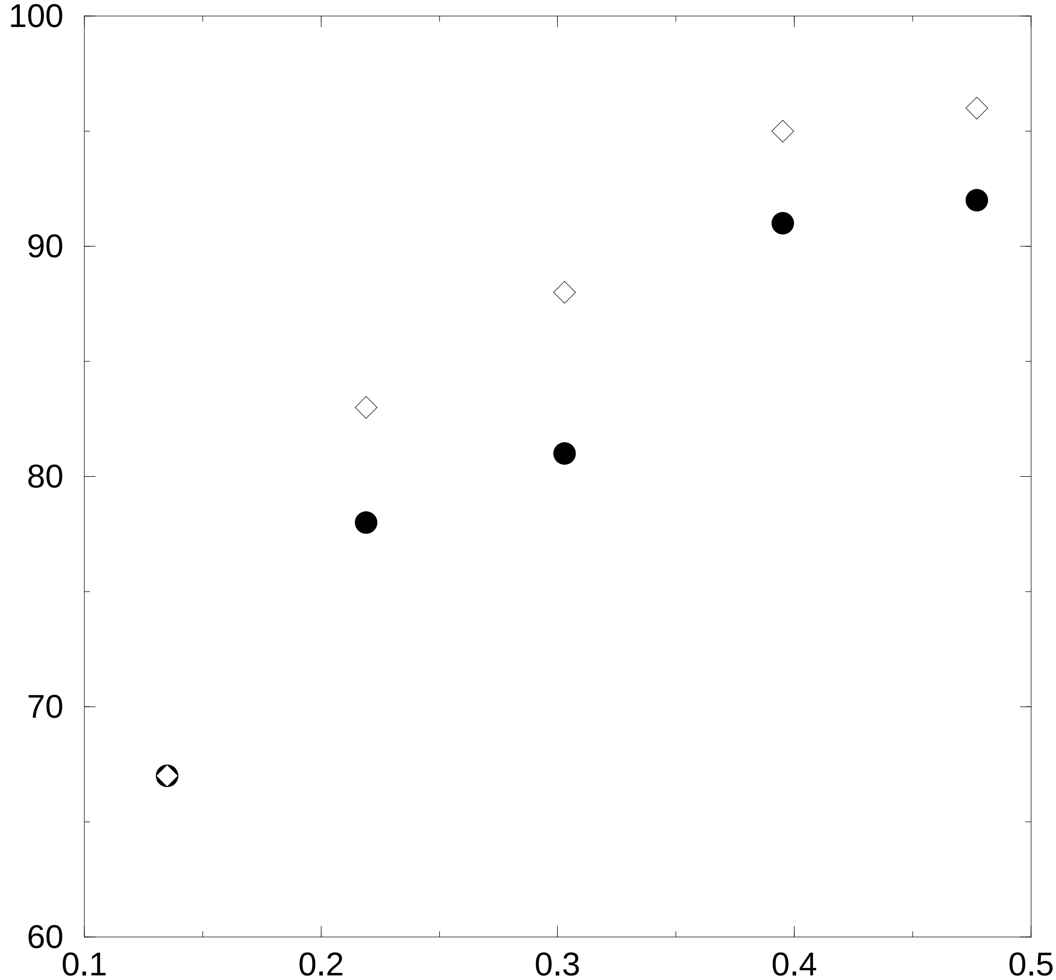

Figure 10: Efficiency of cooling as function of water flow in liters/minute. Open triangles for T=14 and black circles for T=18.

1. Leaks. Quite often liquid cooling systems used pressurized fluid on the heat exchangers. Leaks may represent serious problems given the proximity to electricity.

2. Contact between heat exchanger and components. This is the first problem in the design. Every component to be cooled need to be in close proximity to the heat exchanger.

3. Thin heat exchangers. Thin heat exchangers represent a manufacturing problem and also may represent very large pressure drops and imply in large pumping systems.

4. Materials. For physics purposes the chosen material is aluminum. Aluminum presents a number of problems being the most serious of them quick oxidation when in high humidity environment. It is also a material which is hard to handle during bonding, welding, etc...

We have addressed the items above with the following solutions.

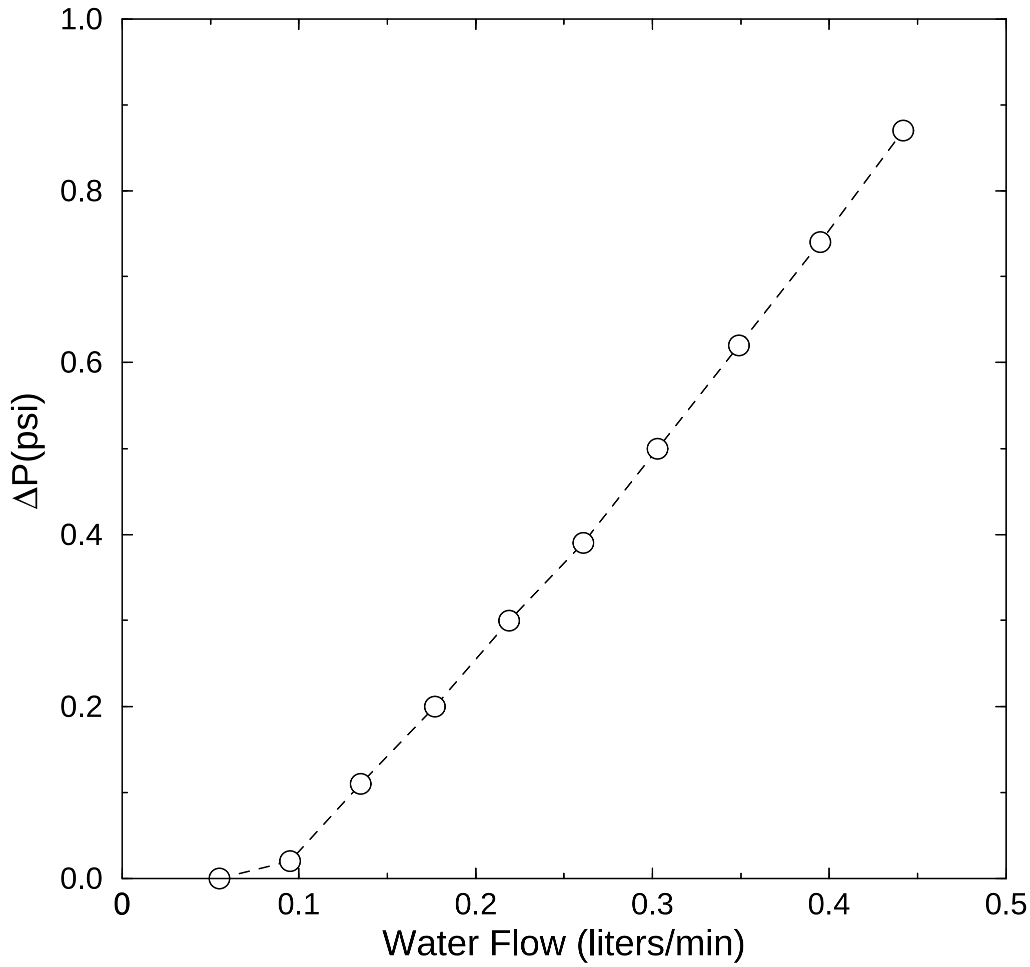

Figure 11: Pressure drop across the cooling plate as function of Water flow

- Cooling fluid will be circulated below atmospheric pressure. Typically 600mb. This takes care of minor leaks. In case of leaks air will migrate into the system.
- To guarantee good contact between the cooling plate and the components a heat conductive elastomer will be used. These are typically silicone rubber impregnated with aluminum oxide or boron nitrate. Large gaps will be filled with aluminum to provide better conductivity
- This heat exchangers are manufactured as described in the next subsection.

Fluid cooling of electronics is not new. It is possible to find in the literature a number of references to projects where water cooling is used. In general in every case where high power devices are used, e.g. large DC current supplies or high power computers, water cooling is used. The solution in these cases is relatively simple due to large availability of space. A metallic piece, such as a copper plate, in thermal contact with the component is refrigerated by water. Heat removal happens in two stages. First heat is conducted from the component to the metallic plate. Second heat is removed from the plate to the fluid. A temperature gradient develops between the component and water since two high thermally resistive points exist. First is the contact between plate and component. This can be minimized by the use of heat conductive grease, foam, or any other agent that at near microscopic level allows for a good contact between the plate and component. It is generally true that pressure of the order of $5\ lb/in^2$ is required for good contact. The second resistance point is between the plate and water. This is formed because of the transition between copper and water.

In the case of the present electronics one of the largest problems is the space constraint. In theory a thicker plate in contact with the component would be desirable since it would spread the heat more uniformly. However with 2 mm of space available this requirement is hard to be satisfied. The water flow channel alone would take this space. Therefore the option that was chosen is to manufacture very thin plates and have many flow channels. This increases the contact points between water and components. However the plate itself is not a good heat spreader.

To eliminate gaps between components and cooling plate silicone impregnated with aluminum oxide is used. This material has a heat conductivity of $0.8 \approx 1.2\ W/m.K$, which is roughly 300 times lower than aluminum. Therefore places with large gaps between components and cooling plates are filled with metallic (aluminum) heat spreaders of proper thickness. Note however that the metallic spreaders themselves are not appropriate to guarantee good thermal contact between cooling plate and components. Mechanical tolerances and surface quality still requires the use of foam, but in reduced thicknesses.

9.2 Cooling Plates

Thin heat exchangers are fabricated as two bonded plates. In one of the plates a flow pattern is embossed by hydro forming channels against another aluminum mold. This process is slower than traditional stamping. However it is more appropriate to form soft metals.

The next step in the manufacture is to provide surface treatment for the aluminum. Aluminum is known for its corrosion problems. Pure aluminum will oxidize in contact with air in matter of minutes. There are several types of treatment that can be used to prevent corrosion. Widely used by the aircraft and electronics industry is the chemical surface conversion. This is covered in length by MIL-C-5541E. The advantages of this process are: readily available and cost. Tests in the lab with chemically active water (with chlorine) showed that this type of treatment is not adequate for our applications. Microscopic analysis of the aluminum material showed that during hydro forming, micro fissures are introduced in the bends and those cannot be protected by chemical treatment. The surface also becomes too smooth for bonding purposes.

A second method to protect aluminum from corrosion is anodizing. In anodizing process a layer of aluminum oxide is formed on the surface. The film formed by anodizing penetrates in fissures and thus preventing corrosion at these points. The surface is also appropriate for bonding. Therefore we used this process for the surface treatment.

Plates, one flat and one with flow channels, are bonded next with –glue– from DuPont. This bonding agent has a kapton carrier that helps to keep the adhesive in place. Tests with

Figure 12: Cooling plate - the final product. The holes in the plate are for the attachment to the Front End Board. The large number of holes is to allow for a large contact pressure.

other types of adhesive showed not to be appropriate for this application for spreading into the channels during the curing processes. When bonded the important parameter to watch is the peel strength. The chosen adhesive has a peel strength of $8\ lb/in^2$ which is adequate for our purposes. Tests made with water running at $60\ lb/in^2$ for 8 hours showed that bonding can withstand the pressure. Samples cut from the bonding were examined using metallurgical techniques. Analysis show a good adhesive surface. A second exploratory technique was used to examine the bond - X-Ray micro-tomography. This also shows good surface adhesion.

The total thickness of the manufactured plates are 2.2mm, 10% wider than expected.

9.3 Attachment of Cooling Plates

Cooling plates are attached to the water manifolds by Manifold Blocks. These blocks shown in FigDD provide a side entrance and exit of water. Early tests with water injected and extracted from top using tubing show a large impedance due to the thickness of the plate. At this point the plate is sealed by two O-rings.

Plates are attached to the electronics board on aluminum stand-offs **Amatom 19053-A-2545 Female Standoff and Amatom 19931-A-2545 Male/Female Standoff**. The stand-offs are made of aluminum and establishes a distance of 6mm from the board surface to the cooling plate. The space between the cooling plate and components are taken by space occupiers. Screws for the attachment of plates are low head profile screws known as **Wafer**

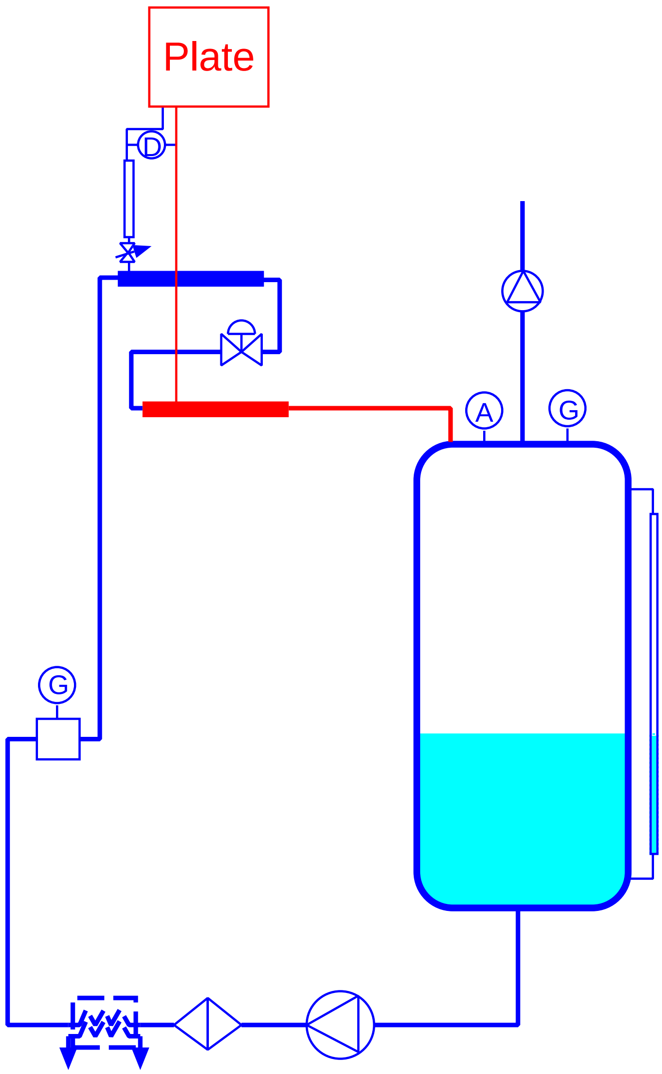

Figure 13: Semi Leak less Water Circulator

Screws and widely used by the portable computer industry. For the purposes of the cooling plates they will be specially ordered from **North East Fasteners Corporation, Terriville, CT 06786-0322**.

Two are the material to be used for space occupier. For large spaces aluminum plates are used. To improve the thermal contact foam is used. The foam requires a pressure of about 5-10lb/in^2.

9.4 Properties

Two are the basic properties of the the cooling plate: pressure drop and heat removal capacity.

Large pressure drops are due to large impedance. With thin plates pressure drops are bound to be large. Measurements of pressure drop at different flow rates is shown in figure for water. The flow regime in the test is mostly laminar, since the calculated Reynolds number is less than 1500 for all the points measured.

Heat removal efficiency can be translated to the water temperature raise. Such measurement is limited by how good the thermal contact is between the components and cooling plate. For safety purposes a heat equivalent board was used. The board is has resistors with equivalent component positioning and power dissipation. Figure AAA show the efficiency as function of water flow. Input power is determined by the current provided to the board by the power supply. A efficiency of 95% can be achieved.

This has been measured for a stand alone board and in a crate cooling performance may improve. The actual temperature that the component will be running depends on the temperature gradient that will develop between the heat source and cooling plate. This obviously depend on the quality of thermal contact.

9.5 Manufacturing and QA

Manufacturing the plates will require many inspection steps. In the bonding process the important parameters are the quality of the surface which should be free of grease and all foreign materials. Thin aluminum will require inspection for punctures.

During hydro forming aluminum should be inspected for tears in corners of the mold. This can be minimized by proper construction of molds.

Anodizing of the aluminum should be made in Mil qualified houses.

After the bonding either with the use of pyralux or other adhesive there remain the question of bubble formation inside the plate. These can be detected by infrared imagery, a technique used in the aluminum bonding of aircraft panels.

9.6 Manifolds

The manifold will be used to feed coolant to the FEB. Manifolds will be equipped with quick disconnect connections.

9.7 Water vs Fluorocarbon

Two are the coolants under consideration.

- **Water** Water is our coolant of choice. Low pressure operation guarantees leak free operation. Water offers a number of advantages over any other coolant with respect to physical properties. With lower density and lower heat capacity it is the ideal liquid for cooling. However it requires constant purification and may induce loss of electronics in case of catastrophic leaks.
- **Fluoroinert** Fluoroinert as the name says is a fluid that does not interact with electronics components. It will not damage electronics in the same manner as water. However it is a denser liquid and higher heat capacity. This would require larger pumps and increase the pressure drop in the cooling plates. It is also known to attack plastic materials.

9.8 Circulators

The coolant circulator will be dimensioned to provide water at around 18^oC below atmospheric pressure. As illustrated in Figure 13 the circulator is a semi-leakless unit. The circulator consists of a water reservoir where the top part is kept below the atmospheric pressure. The pump is locate at the bottom of the reservoir and compresses the water on the way up. With enough negative pressure in the reservoir the pressure at the input of the cooling plates is already negative.

To operate such a unit it is necessary a PLC (Programmable logic controller). Constant monitoring of the vacuum and water flow is required.

9.9 Monitoring and DCS

A liquid cooled electronics require constant monitoring of the performance. Unlike air cooling where in most cases just monitoring of the air flow is needed individual boards may be necessary. However it may be necessary only to monitor the water temperature output.

10. Integration Issues

Integration issues are several. The System Crate interfaces and interferes with a number of neighboring devices.

10.1 Pedestal

The pedestal volume is shared with services to the feed through. These services are vacuum gauges, heaters, temperature probes, and vacuum valves. The concern about having these element in the pedestal is the obvious source for electronics noise. Both vacuum valve and gauge could be mounted outside of the volume, but both heater and temperature sensor will have to be mounted on to the pin carrier. Careful evaluation need to be made.

10.2 Crate

The Main role of the crate is to provide shielding for RF noise. Services for inner detector will be present in between cracks. These services include power cables, signal cables, cooling pipes, sensor cables. It would be highly desirable to measure the effectiveness of shielding.

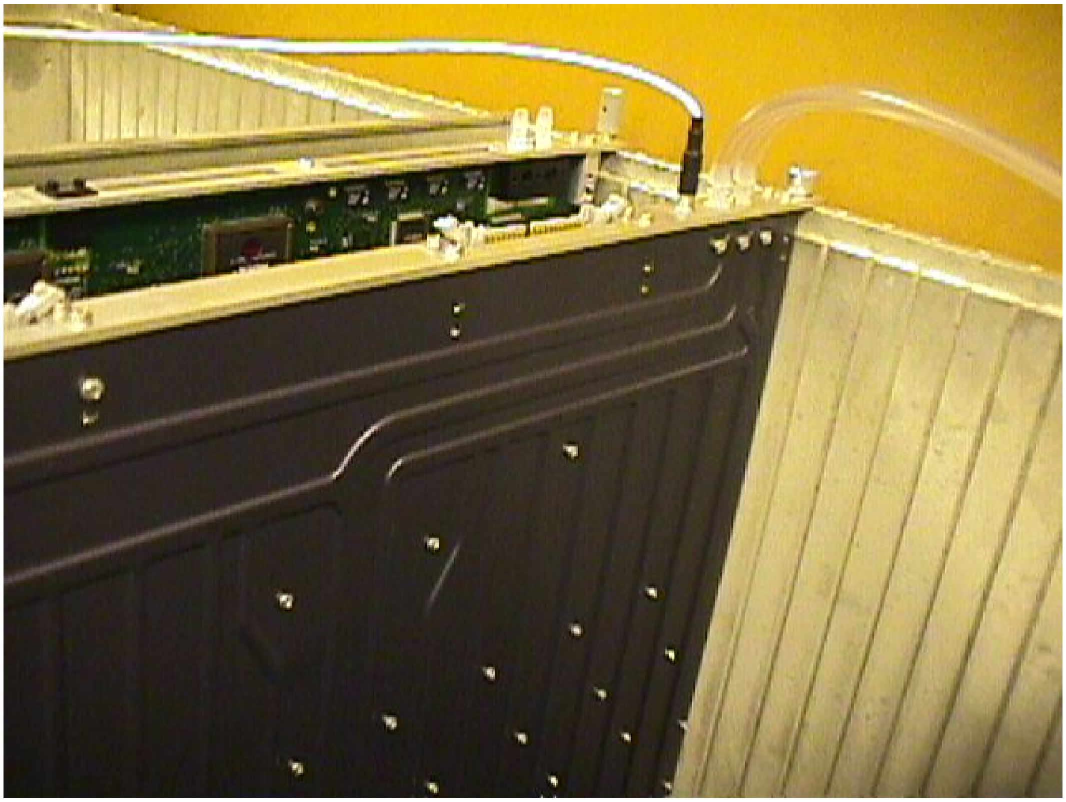

Figure 14: Front End Board and Calibration Board in the Lab installation. The FEB has the cooling plates mounted whereas the Calibration Board is shown without the cooling plates.

Crate should also provide shielding of digital activities to the other detectors.

The body of the crate will be used to divert any currents that reaches its surface to the cryostat. It is assumed that the cryostat will be the reference ground for the system.

Both requirements implies in a good conductive system between the crate and the feed through. Therefore care should be taken to use galvanic compatible metals, RF gaskets where needed, proper surface finish, and establish good electrical contact between crate and cards.

10.3 Baseplane

Undesirable currents on FEB should be diverted from the cards to the crate body, and from there to the cryostat. This can only be achieved effectively by providing a very low impedance connection between boards and baseplane grounds. In the present design the HPC shields on the FEB receive a shield mounted on them. On the baseplane shield clips are mounted and make contact with the FEB shield when cards are inserted.

10.4 Power Bus

Power bus represents a safety issue. With the available high current any points of high resistance may be a source of fire. this has been observed in other similar high current

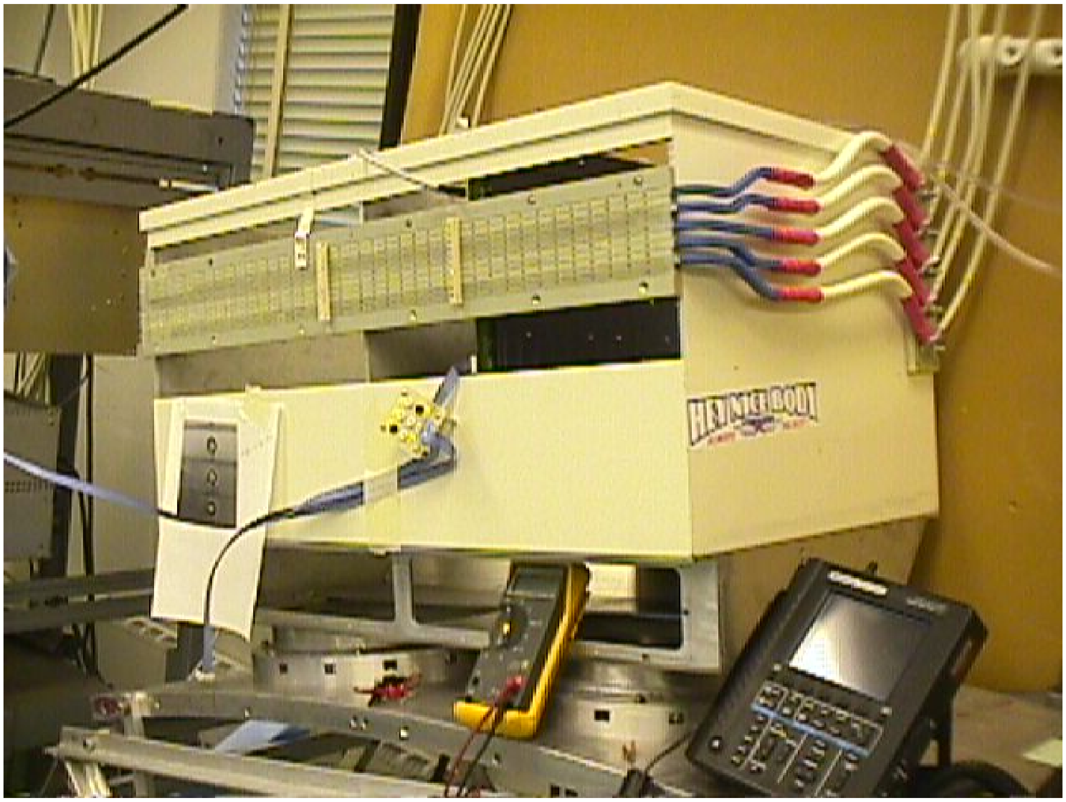

Figure 15: Assembly shows an early prototype for crate an bus bar.

systems such as FASTBUS. Most fires were observed on the card side with poor contact to power supplies. Connections between the power bus and cables is another point of danger. Appropriate cooling and monitoring is needed.

10.5 Cooling

Fluid cooling of electronics is always used when large amount of power is to be removed. This is the case for high power CPUs. However in the present situation it is used for lack of space. The problem with the cooling in the present environment is to establish a good contact between components and cooling plate. This may not be as simple as it seems since all the hot spots need to be taken care off.

10.6 Card Insertion and Extraction

Inserting and extracting cards from the top as shown in Fig 2 is not the equivalent as in normal crates. When of insertion happens from the top of the crate any misalignments with the direction of insertion will result in having the electronics board stuck against the guides. Guides have little effect in helping insertion.

10.7 Operation of Front End Crate

The limited access to the crates, water cooling, and high power required by the electronics, requires constant monitoring of the crates during normal operation. The monitoring will be made by the aid of a computerized system and part of the DCS (detector control system).

It will be necessary to interlock the power supply for a number of reasons. High currents needed to operate the front end cards represent high risk of fire. In similar situations, i.e. high current operations, FASTBUS crates suffered from fire hazard potential. The fire is caused by overheating of connections, which is cause by its turn by poor ohmic contact. (*Note that poor Ohmic contact in general also implies in large thermal resistance*). In normal circumstances the thermal contact resistance for the power connection is $2.0\ m\Omega$ and manufacture data suggests that at 6A current the contact temperature could be 10-15 ^oC above room temperature. In the bus bar the heat will be dissipated to the copper bars, however, in the card end heat build up near to the solder joint can be observed. Voltage and Current on the bus bar need to be monitored. However it is possible that very localized hot spots not been seen in the overall current used by the electronics.

Water flow to the crate should also be monitored at all times. Loss of coolant flow to the crates will overheat the electronics. With zero air circulation in the crate it is very likely that heat build up will induce at a minimum the loss of all the electronics. It is possible to monitor each individual board in the crate as well for temperature by monitoring the water outlet temperature. Under normal operating conditions, i.e. with constant water flow at a nominal rate, coolant temperature is well predictable. In case of malfunction of the electronics and depending on the severity of the problem the water temperature will vary accordingly.

Detailed implementation of a monitoring and control schemes will be made with close cooperation with the ATLAS DCS group. The first attempt for the installation will be made during the test beam phase.

10.8 Mockup

To evaluate the integration issues in a laboratory environment a mockup simulating the crate installation has been built. In the mockup it is possible to simulate diverse operating conditions. The mockup is shown in Fig 16

The first use of the mockup is to allow for the understanding of cable and other services routing in the crate area. It will be useful for the location of sensors.

One of the crates will be used with electronics which will be used to understand the level of noise because of different sources. It will be used as a test bed for new implementations.

The second crate will be used to test system issues such as the performance of bus bars, and cooling system. Heat equivalent boards will be used instead of real Front End Boards.

The mockup will be used to study the interference between the services for inner trackers and liquid argon electronics. This work will be done in collaboration with other groups in ATLAS.

11. Installation

Figure 16: Laboratory mockup of two crates. A water cooling system is shown at the back. The curved surface simulates the ends of the cryostat. One 'open' feed through is also seen.

The schedule for the installation of the front end crates follows the installation of the cryostat. After all the feedthroughs are installed, e.g., in the Barrel Cryostat in the West Area, the installation of the pedestal, warm cables, and baseplanes will began. These parts will be installed before the cryostat is lowered to the pit.

According to the Technical Coordination TDR [9] the Barrel cryostat will be delivered to CERN on the 2nd Quarter of year 2001. The feed through installation and tests should follow the delivery. The Integration of detector and solenoid should take place in the first quarter of year 2002 and should last for 6 months. Thus by the 2nd quarter of 2001 crate assemblies should be delivered to CERN.

Each assembly is composed of Crate, Pedestal, Bus Bar, Baseplanes, and Warm Cables. The whole assembly will be mounted once at the surface for testing of cabling. Crates will be disassembled and re mounted when the cryostat is lowered. Pedestals, baseplanes, and warm cables will remain installed and lowered with the cryostat. Protective covers will be installed on the crates to minimize the risk of damage to baseplanes.

Once in the experimental zone the crates and bus bars will be reinstalled. At this stage it is conceivable that a retest of the cabling may be done to examine any damages during the process of lowering the cryostat into the pit. Water cooling manifolds will be installed.

Similar installation scenarios will be followed for the the EndCap A and EndCap C.

12. Appendix A

Dictionary of commonly used abbreviations

- **LAr** - Liquid Argon
- **FEC** - Front End Crate
- **FEB** - Front End Board. Refers to readout board.
- **EMI** - Electro Magnetic Interference
- **QA** - Quality Assurance
- **Mil Spec** - Military Specification
- **DCS** - Detector Control System

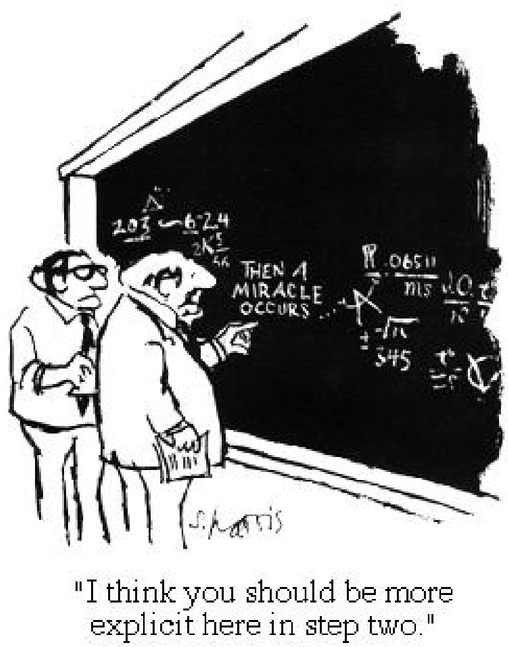

Figure 17: ...and a miracle occurs

13. Appendix B

Attachments to this document

- Mapping of the LAr calorimeter, J. Colas, et al.
- Grounding Rules for Calorimeter, V. Radeka.
- Finite Element Analysis of Atlas Front End Crate, Memo from Chien Pai, BNL.
- MIL-C-5541E specification of 2/20/91.

14. *References

[1] HPC System Components, Berg Electronics, (1994), http://www.bergelect.com.

[2] Palladium and Palladium Alloy Plating for the 90's, E.J.Kudrak, J.A. Abys, H.K. Straschil, I. Kadija, and J.J. Maisano, Proceedings of the Connectors 93 meeting, East Midlands Airport Hilton National Hotel, England

[3] Wear Reliability of Gold Flashed Palladium vs Hard Gold on a High-Speed Digital Connector System, E.J. Kudrak, J.A. Abys, I. Kadija and J.J. Maisano., Plating and Surface Finishing, March 1991

[4] Palladium-Cobalt, J.A. Abys, The Connector Specifier, February, 1999

[5] Palladium-Nickel Alloy Plating System, BERG electronics, july 1998, publication - 950507-001. http://www.bergelect.com.

[6] Radsok, KonneKtech, Division of K&K Stamping Company, 34230 Riviera Drive, Fraser, MI 48026

[7] ODU-USA, Inc. 451 Constitution Ave, Camarillo, CA 93012

[8] Hypertronics Corporation, 16 Brent Drive, Hudson, MA 01749

[9] ATLAS Technical co-ordination Technical Design Report