System Overview for Pixel Opto-heater System

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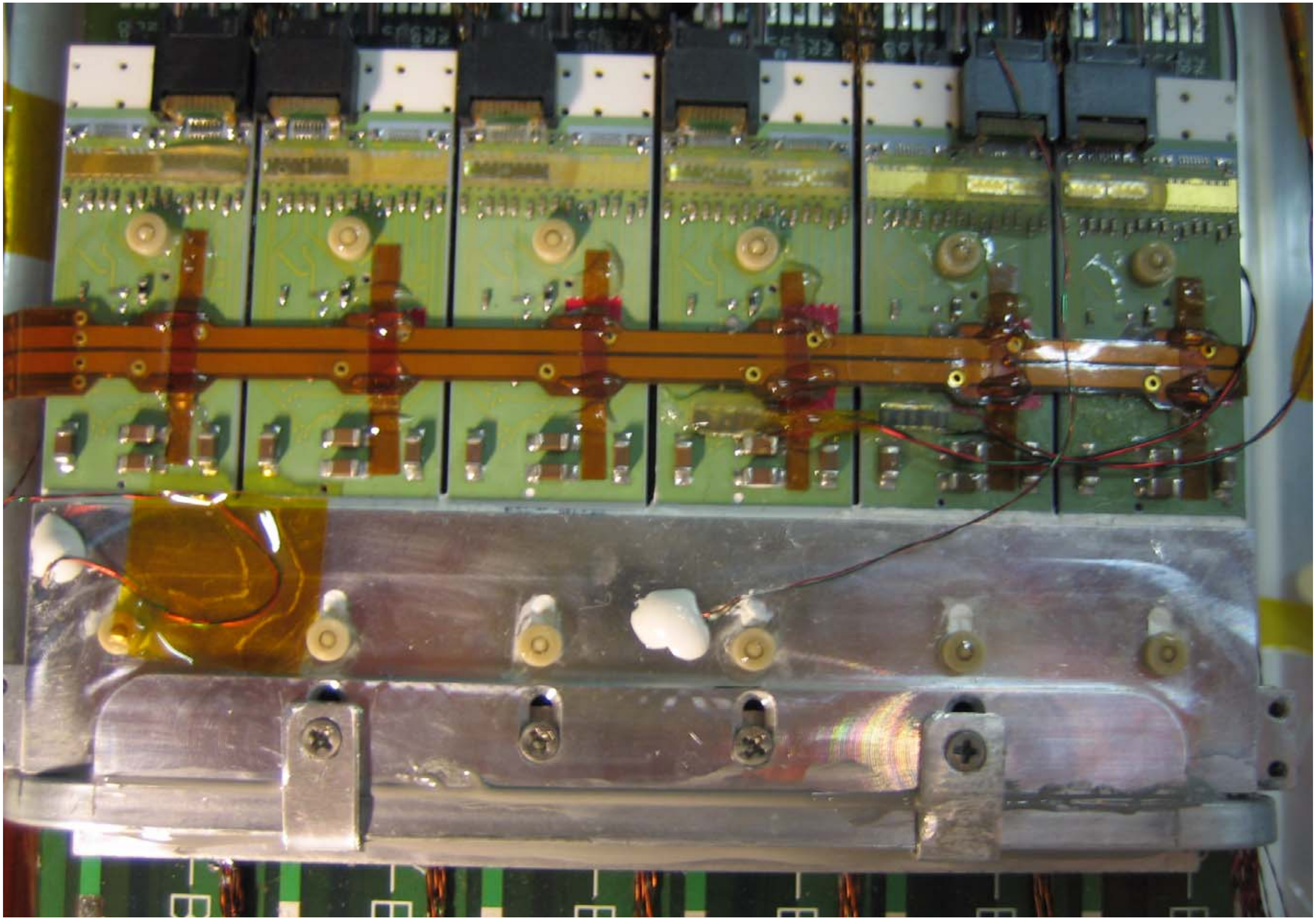
Inside the Pixel Package

Opto-heater strips:

- Implement resistive heating elements which will be thermally coupled to each opto-board. Target is to be able to deliver up to 3W per opto-board (the natural power dissipation is about 0.7W per D-board and 1.0W per B-board).
- A group of six opto-boards is treated as one circuit, so there are three circuits per octant: ISP, bottom OSP, and top OSP. This gives 24 circuits per detector end.
- Each heater element is made up of 600Ω 0.5W rated 1210 package thick-film SMD resistors. A group of 4 are connected in parallel to make a 600Ω 2W equivalent resistor as the basic heating element for one opto-board.
- Based on manufacturers data sheet, we believe it is safe to operate these resistors at 1.5 x (nominal power), particular as they will be tightly thermally coupled to the opto-boards, which will act as an efficient heatsink.
- The string of 6 heaters for one circuit will be connected in parallel to form an effective 100Ω 18W heater distributed over the 6 opto-boards.
- The heater switchcard system developed for thermal barrier heater pads in the ID is capable of providing up to 48VDC with a programmable duty-cycle.
- The proposed services chain would imply a roughly 5Ω round-trip resistance in a given circuit, leading to a DC current of about 0.45A in a circuit at full input voltage. This corresponds to 20W maximum power dissipation in one circuit.

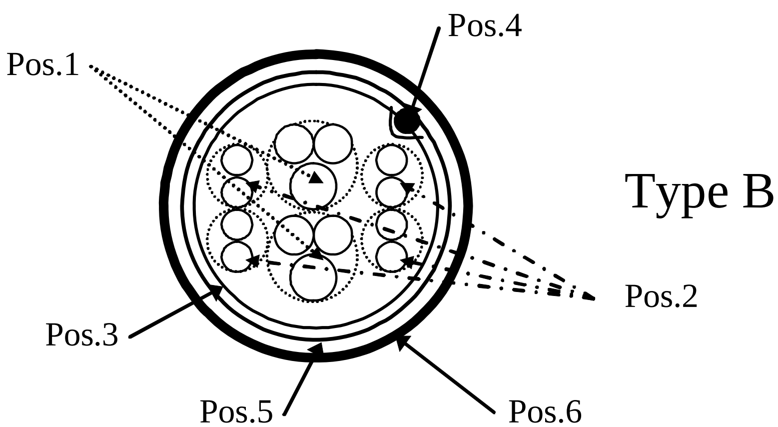
- Example of Heater Circuit integration into production SQP:



- Connection to pigtail, and location of heater NTC, are on leftmost position in photo.

Services chain inside the pixel package:

Type 2 Heater Services (OD of cable is 7mm):



Heater cable consists of two triplets for powering two pairs of heater circuits, and four doublets for the corresponding thermistors.

The triplet consists of two AWG 24 stranded copper conductors and one AWG 22 stranded copper conductor. The insulation is Siltem, just like the pixel Type 2 cables.

The doublet consists of two AWG 28 stranded copper conductor with Siltem insulation.

There is a single Al foil shield around all conductors, with an AWG 23 drain wire.

- Propose to use one cable for the four heater circuits in the OSPs of an SQP, and to use one such cable for the two heater circuits in the ISPs of an SQP. This is not low mass, but allows crimp connection at PP1 and offers internal shielding and bundling of conductors. Could connect shield to detector common at PP1. Cables would follow BPSS longerons to go from PP0 to PP1.

Connectors:

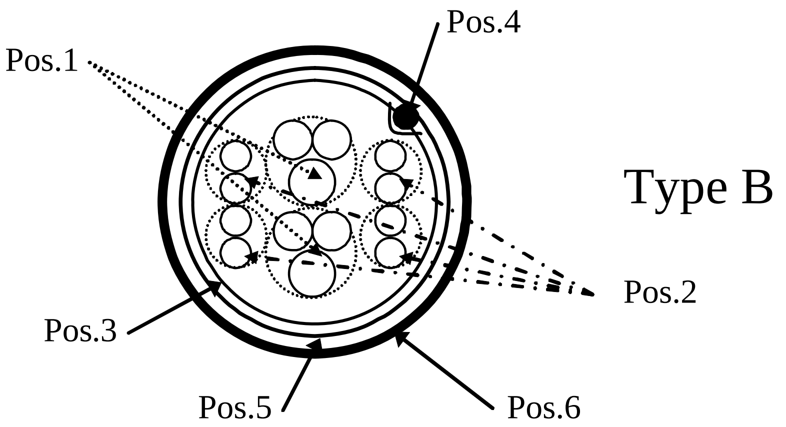
- The switchcard system for the heater circuit powering is based on cards and crates. The basic output connector supports 8 channels, or two heater cables, using a single AMP 34-pin connector. It is assumed in the cabling that heater circuits are paired, with a common return (a “triple” is always used to power a pair of circuits).
- This 8-channel group would correspond to the services from one end of one SQP in the proposed scheme, which uses only 3/4 of the available channels.
- Although it is not efficient, it would be natural to then terminate two heater cables into a single LEMO 5F connector at PP1, and a single 34-pin AMP connector at the US/USA end, requiring a total of 4 additional connectors on PP1 on each end.

Outside the Pixel Package

Services chain outside the pixel package:

- The scheme used by the cooling group for heater services uses the Type 2 cable already defined to reach the PP2 region, and a larger Type 3 cable for the outer region. The two cables are spliced together using a special technique developed at CERN.

Type 3 Heater Services (OD of cable is 13mm):



Heater cable consists of two triplets for powering two pairs of heater circuits, and four doublets for the corresponding thermistors.

The triplet consists of three AWG 14 stranded copper conductors with standard insulation.

The doublet consists of two AWG 28 stranded copper conductor with standard insulation.

There is a single Al foil shield around all conductors, with an AWG 20 drain wire.

Proposed installation:

- Extra rack space is available in US15, next to existing heater supply crates, suggesting this is the path of least resistance. Also note that the cable runs to US15 are much shorter than for USA15 (typically 20m less), meaning lower costs and voltage drops. Therefore propose to route services to US15 side.
- The shortest paths are from Sector 1 and Sector 3:

  Sector 1 = O8 and O1, 45m length for Type 3 VDD cable, 10.6m length for Type 2 VDD cable

  Sector 3 = O2, 49m length for Type 3 VDD cable, 11.0m length for Type 2 VDD cable.

  Sector 13 = O7, 70m length for Type 3 VDD, 11.5m length for Type 2 VDD cable.
- Including the 2.5m cable length inside the pixel package, the cable run would be roughly 50m of Type 3 heater cable and 14m of Type 2 heater cable.
- The characteristics of the proposed services would be:

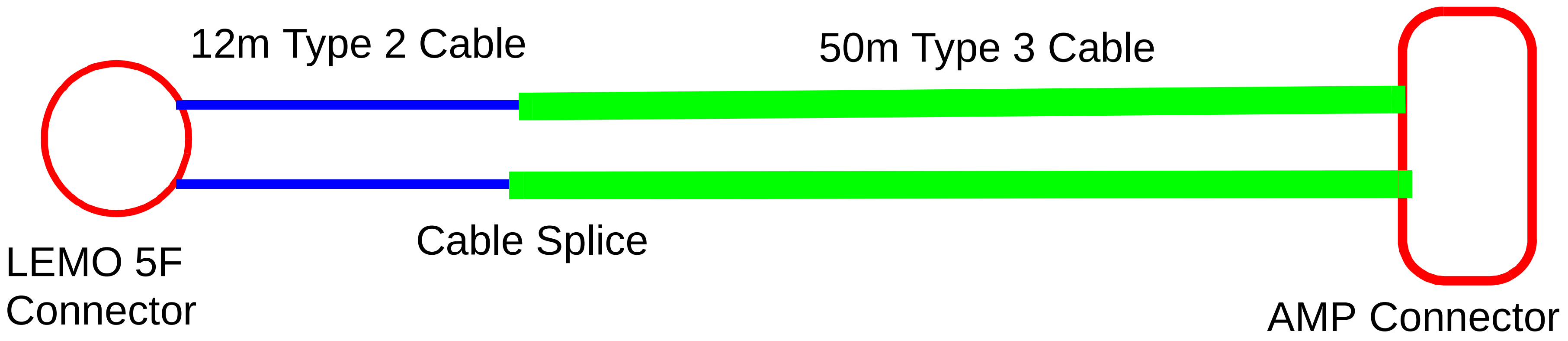
  AWG14 cable is 8.3Ω/km, giving roughly 1Ω round-trip for the proposed cable.

  AWG22 cable is 52.9Ω/km and must carry current from two circuits, while AWG24 cable is 84.2Ω/km, giving about 3Ω round-trip for the proposed cable.
- With our low currents, we could consider using Type 2 cable for the full run, giving a resistance of 10Ω for 50m, or a total of 13Ω. However, as this cable is expensive, and available in small quantity, this is most likely not a practical solution.
- For an output voltage of 48V, the Type 2/3 solution would give 0.46A in each circuit, and a total power of 21W per circuit. A pure Type 2 solution would give 0.42A in each circuit, and a total power of about 18W per circuit.

Services configuration:

- Propose to have LEMO build the harnesses. Propose to build single length, since these multi-cable harnesses will be difficult enough to handle as it is, and this allows all connectors to be terminated in the factory.
- Propose to use 2 cables per LEMO connector, using the heatshrink boot from the 2-cable HV cables. This would result in more cables, but a more managable cable harness, and would allow termination of PP1 with one connector per SQP. There would be only one AMP connector on the other end.
- The splicing of the Type 2/3 cables, and most likely the termination of the AMP connector, could be done at CERN. LEMO would then only be required to attach the LEMO-5F connector. Only 8 cables would be required for the final installation. However, would like 2 cables for the System Test setup in SR1, and perhaps 2 spare cables, so the total would be 12 cables.

<u>Basic Cable Concept:</u>

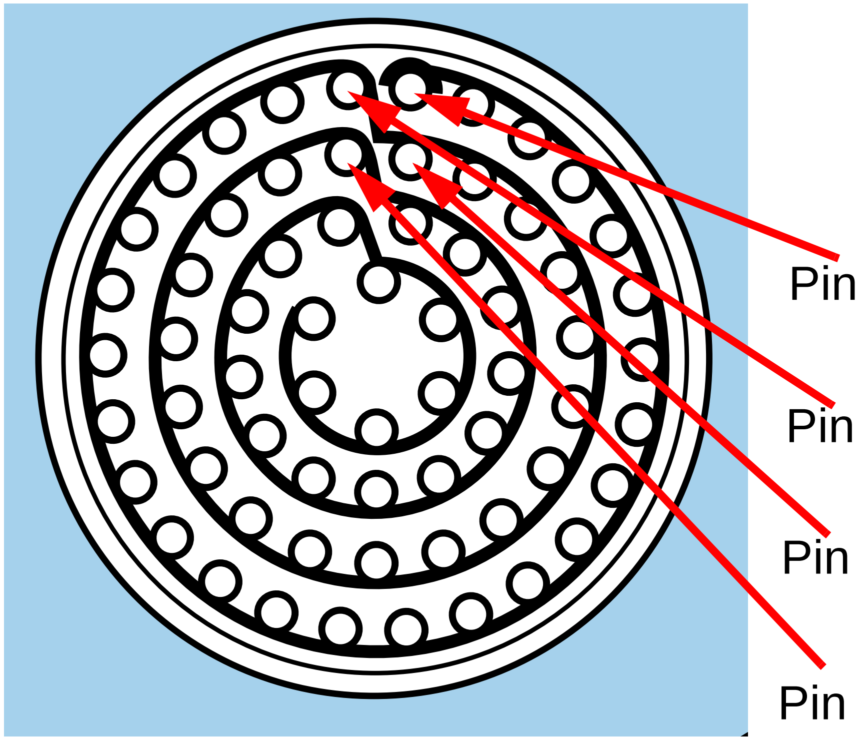


Type 2/3 Cable Definitions:

Name	Type 2 Color	Type 2 Size	Type 3 Color	Type 3 Size	
Drain	Bare Wire	AWG 23	Bare Wire	AWG 20	
NTC1P	Purple	AWG28	Purple	AWG28	Pair
NTC1N	White	AWG28	White	AWG28	
NTC2P	Brown	AWG28	Brown	AWG28	Pair
NTC2N	White	AWG28	White	AWG28	
NTC3P	Green	AWG28	Green	AWG28	Pair
NTC3N	White	AWG28	White	AWG28	
NTC4P	Orange	AWG28	Orange	AWG28	Pair
NTC4N	White	AWG28	White	AWG28	
Heater1	Pink	AWG24	Pink	AWG14	Triplet
Heater2	Gray	AWG24	Gray	AWG14	
Return12	Black	AWG22	Black	AWG14	
Heater3	Green	AWG24	Green	AWG14	Triplet
Heater4	Yellow	AWG24	Yellow	AWG14	
Return34	Red	AWG22	Red	AWG14	

Connector Pinout for LEMO-5F:

- Use FGW.5F.364.XLC, just like for LV cables. Use 2-cable boot from HV cables.
- Pin definitions (Note: two shield foils are connected to connector shell):



Cable Number 1:

Pin 1 = Drain_1

Pin 2/3 = NTC1P_1 / NTC1N_1

Pin 4/5 = NTC2P_1 / NTC2N_1

Pin 6/7 = NTC3P_1 / NTC3N_1

Pin 8/9 = NTC4P_1 / NTC4N_1

Pin 27/28/29 = Heater1_1, Heater2_1, Return12_1

Pin 30/31/32 = Heater3_1, Heater4_1, Return34_1

Cable Number 2:

Pin 14 = Drain_2

Pin 15/16 = NTC1P_2/NTC1N_2

Pin 17/18 = NTC2P_2/NTC2N_2

Pin 19/20 = NTC3P_2/NTC3N_2

Pin 21/22 = NTC4P_2/NTC4N_2

Pin 37/38/39 = Heater1_2, Heater2_2, Return12_2

Pin 40/41/42 = Heater3_2, Heater4_2, Return34_2

Connector Pinout for LEMO-5F:

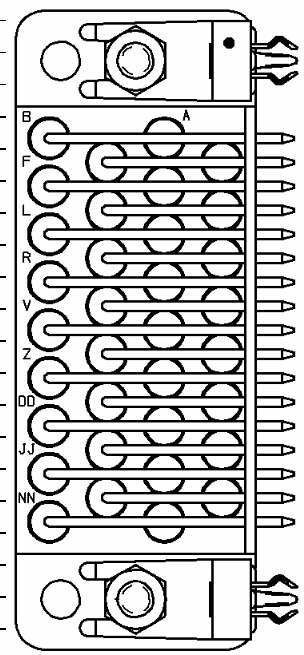
Name	Type 2 Color	Type 2 Size	Cable 1 Pin Assignment	Cable 2 Pin Assignment
Drain	Bare Wire	AWG 23	pin 1	pin 14
NTC1P	Purple	AWG28	pin 2	pin 15
NTC1N	White	AWG28	pin 3	pin 16
NTC2P	Brown	AWG28	pin 4	pin 17
NTC2N	White	AWG28	pin 5	pin 18
NTC3P	Green	AWG28	pin 6	pin 19
NTC3N	White	AWG28	pin 7	pin 20
NTC4P	Orange	AWG28	pin 8	pin 21
NTC4N	White	AWG28	pin 9	pin 22
Heater1	Pink	AWG24	pin 27	pin 37
Heater2	Gray	AWG24	pin 28	pin 38
Return12	Black	AWG22	pin 29	pin 39
Heater3	Green	AWG24	pin 30	pin 40
Heater4	Yellow	AWG24	pin 31	pin 41
Return34	Red	AWG22	pin 32	pin 42

Connector Pin-out for AMP 34-pin (part 213574-2):

- Two cables are merged into one AMP connector as follows:

Pin allocation:

Pin number	*Function*
A	CABLE_SCREEN
B	CABLE_SCREEN
C	THERMAL_SENSEP_01
D	Not connected
E	THERMAL_SENSEN_01
F	THERMAL_SENSEN_03
H	THERMAL_SENSEP_02
J	THERMAL_SENSEP_03
K	THERMAL_SENSEN_02
L	THERMAL_SENSEN_04
M	HEATER_01+
N	THERMAL_SENSEP_04
P	C1_48V_POWER-
R	HEATER_03+
S	HEATER_02+
T	C1_48V_POWER-
U	Not connected
V	HEATER_04+
W	HEATER_05+
X	Not connected
Y	C1_48V_POWER-
Z	HEATER_07+
AA	HEATER_08+
BB	C1_48V_POWER-
CC	THERMAL_SENSEN_05
DD	HEATER_08+
EE	THERMAL_SENSEP_05
FF	THERMAL_SENSEP_07
HH	THERMAL_SENSEN_06
JJ	THERMAL_SENSEN_07
KK	THERMAL_SENSEP_06
LL	THERMAL_SENSEP_08
MM	CABLE_SCREEN
NN	THERMAL_SENSEN_08



Cable Number 1:

Pin A = Drain1

Pin C/E = NTC1P/NTC1N

Pin H/K = NTC2P/NTC2N

Pin J/F = NTC3P/NTC3N

Pin N/L = NTC4P/NTC4N

Pin M/S/P = Heater1, Heater2, Return12

Pin R/V/T = Heater3, Heater4, Return34

Cable Number 2:

Pin MM = Drain2

Pin EE/CC = NTC5P/NTC5N

Pin KK/HH = NTC6P/NTC6N

Pin FF/JJ = NTC7P/NTC7N

Pin LL/NN = NTC8P/NTC8N

Pin W/AA/Y = Heater5, Heater6, Return56

Pin Z/DD/BB = Heater7, Heater8, Return78

Connector Pin-out for AMP 34-pin (part 213574-2):

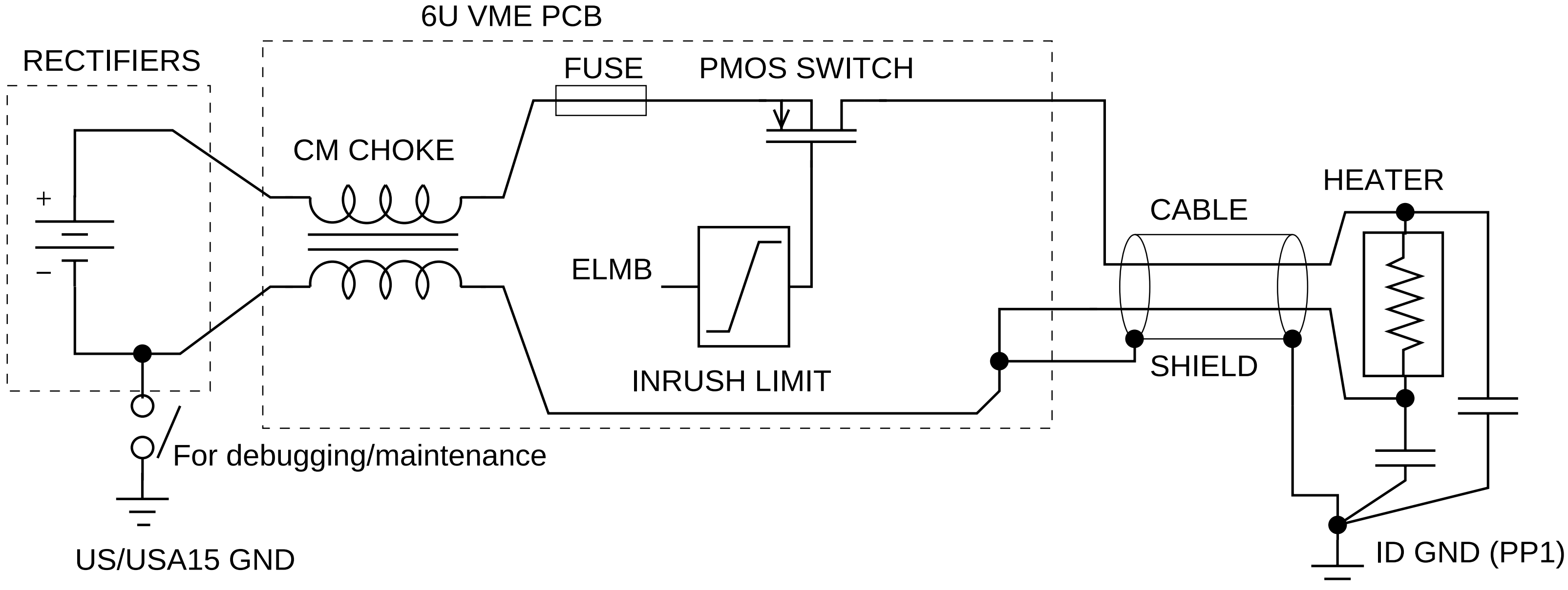
Name	Type 3 Color	Type 3 Size	Cable 1 Pin Assignment	Cable 2 Pin Assignment
Drain	Bare Wire	AWG 20	pin A	pin MM
NTC1P	Purple	AWG28	pin C	pin EE
NTC1N	White	AWG28	pin E	pin CC
NTC2P	Brown	AWG28	pin H	pin KK
NTC2N	White	AWG28	pin K	pin HH
NTC3P	Green	AWG28	pin J	pin FF
NTC3N	White	AWG28	pin F	pin JJ
NTC4P	Orange	AWG28	pin N	pin LL
NTC4N	White	AWG28	pin L	pin NN
Heater1	Pink	AWG14	pin M	pin W
Heater2	Gray	AWG14	pin S	pin AA
Return12	Black	AWG14	pin P	pin Y
Heater3	Green	AWG14	pin R	pin Z
Heater4	Yellow	AWG14	pin V	pin DD
Return34	Red	AWG14	pin T	pin BB

Heater switchcard system:

- Crate based system, using one 48V input supply per switchcard. Each card in a crate supports 24 channels, at up to 1.6A per channel (a total of 40A per card).
- A Controller Card provides ELMB power (analog and digital), only CANBus power is provided from the external CANBus. A single crate supports a controller and up to six switchcards (plus up to two additional daisy-chained crates). The controller distributes the DSS signals and the CANbus to individual switchcards.
- All control functions (thermistor monitoring, current sensing, and switching control of individual outputs) are under the control of an ELMB mounted on the switchcard.
- Channels are grouped into 3 groups of 8, with each group corresponding to one AMP output connector, which is in turn connected to two heater cables. Each group of 8 is “isolated” by a large common-mode choke and a CLC pi filter.
- The proposed Type 2/3 cable scheme would then require 2 cards (with only 4/6 of the available outputs used) for each end of the detector. Note in total, we foresee needing only about 10A for each end of the detector (1KW total heater power).
- Each channel consists of a heater output circuit with the switching circuitry and a high-side current monitor, plus a thermistor input for temperature regulation and/or interlock functions.
- The switching circuit is opto-coupled to the ELMB driver circuits (which use the ELMB digital supply). The current monitor uses a high-side instrumentation amp allowing inputs between 0V and 60V, and uses the ELMB analog supply.

- The 48V heater supply and its ground are coupled to the ELMB analog ground by a 1KΩ safety resistor, but are otherwise independent. The supply is therefore “floating” as far as the switchcards are concerned.
- It is not clear what the grounding scheme of the input DC supplies is. The supply used is a Cherokee DPS2000L2 40A 48VDC module. The datasheet does not discuss maximum voltage differences between chassis ground and the 48VDC return. However, it is a high-efficiency DC-DC converter supply, and so I would expect no DC coupling to chassis ground, but most likely a large capacitive coupling (similar to the Wiener LV supplies we use).
- There is one DSS input coming from the controller, which will turn off all channels on a switchcard, independent of the ELMB state for that switchcard.
- Each group of 8 channels can be turned on and off as a unit under ELMB control
- Each individual channel has a programmable “warning” and “error” state for min/max temperature and min/max output current. The “error” status causes the ELMB to shut down the channel in question, providing a firmware interlock.

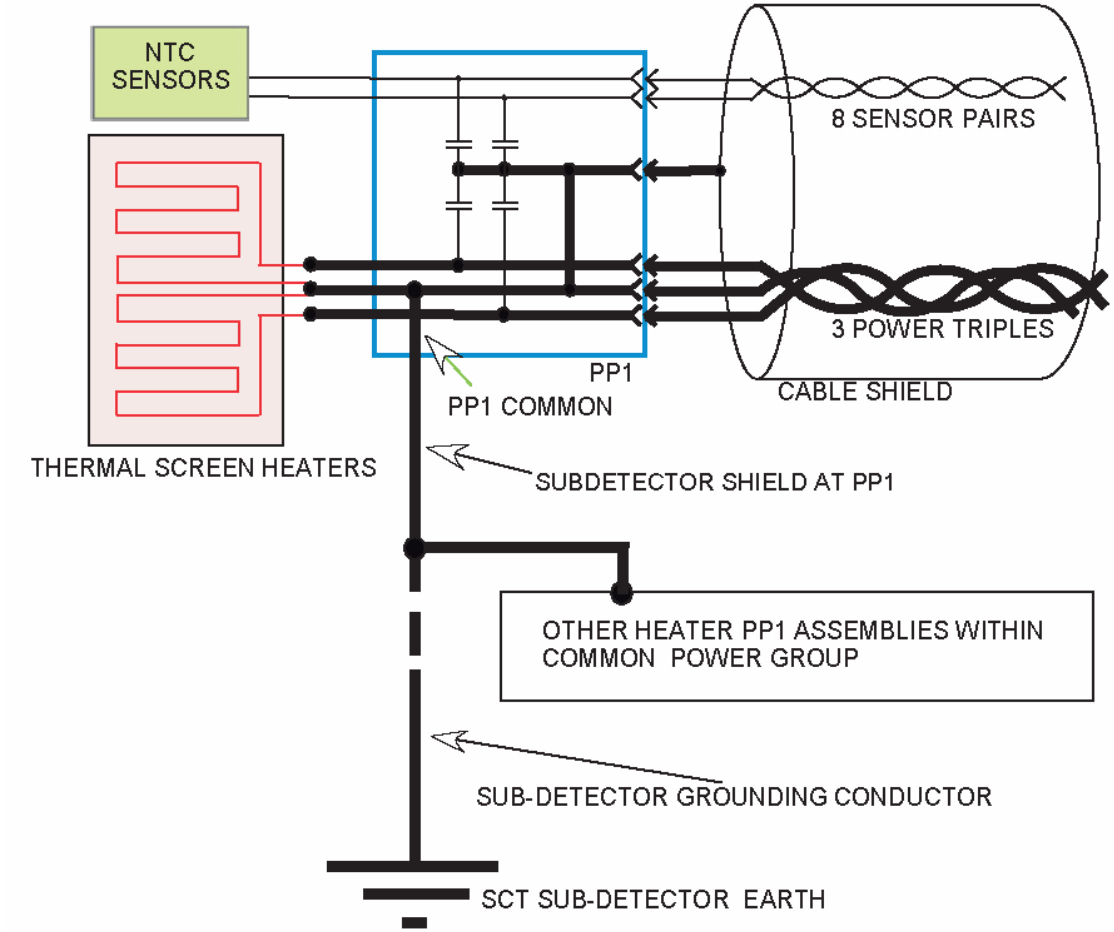
- There are five different operation modes, selectable separately for each channel. These include “off”, “timed” in which the duty cycle is programmed for a given period, “auto” in which the NTC input is used by the ELMB to regulate the heater output current, “follow” in which the channel in question is slaved off a neighboring channel, and “on”.
- The switching is performed with a roughly 1ms switching time constant to minimize EMI effects. If this is too noisy, could even imagine regulating the temperature in the “on” mode by controlling the input DC voltage (no switching at all).
- Block diagram of channel (or channel group):



- Note block diagram uses non-standard grounding scheme. Each card connects to a 40A 48V Cherokee supply. Internally, the three groups of eight channels are “decoupled” by CM chokes. The cable shield is DC-connected to the heater return.

Grounding scheme:

- Heaters are electrically isolated from opto-boards and their grounds.
- Issue is how to treat the overall grounding of the system:



- Recommended scheme from the switchcard designer involves connecting the heater cable shield to the heater power return, and connecting both to the PP1 commoning point of the detector. This is identical to module grounding scheme.

- In addition, dedicated filtering capacitors are added between all lines and the PP1 commoning point. For heaters, this is done using a small “patch panel PCB”.

This does not appear to be the best approach for our opto-heaters:

- The noise performance of the 48 VDC supplies is decent (max 250mV p-p ripple), and there is extensive filtering on the switchcard. The heater voltages then travel on a long cable (capacitive filtering) which uses shielded twisted pair. There is little opportunity for significant noise injection from the cables themselves.
- There are large currents flowing in the heater system, albeit with very low frequencies, and there is no strong argument to mix them into the detector ground.
- In addition, one could worry about the impact of possible ground faults in the switchcard, which could lead to driving the detector ground to potentially large voltages (or effectively, to driving large ground-fault currents into the overall ATLAS ground).
- The alternative would be to leave the heaters isolated (floating) from the detector, and just apply some kind of “safety ground” (large resistor, order 1KΩ ?), preferably off-detector. Note that there is already a safety resistor like this in each switchcard, between the Heater Return and the local ELMB grounds.
- Propose to connect shields of heater cables to LEMO-5F shell, which will connect to PP1b and the Pixel Detector commoning point. This will result in a DC shield path from the detector to the 48 VDC supply return. However, this is OK, since the supply should be floating. Can AC-couple the shield to the supply if necessary.

Proposed system configuration:

- Need to decide whether to use a common crate/supply for heater switchcards for both ends of the detector, or whether grounding considerations would prefer more than one crate.
- Overhead of a second crate is large and seems un-necessary, because the grounding of a given switchcard is largely determined by the connections to the 48VDC power supply. There is little or no additional isolation achieved by using two crates.
- Also need to understand whether we can share cables from the two ends of the detector in one switchcard, or whether separate switchcards are preferred.
- Since one switchcard is necessarily powered by one 48 VDC supply, and therefore will share a common ground, would prefer not to make un-necessary loops by sharing one switchcard between detector ends. The preferred solution is therefore to use 4 cards.
- Could still economise by sharing 48V supply between 2 cards for one detector end, as the supply provides 40A and we only need 10A per detector end.

Proposed system:

- One crate with four switchcards and two 48 VDC supplies.

System issues:

- Concern about whether, even with 1ms risetime, switching of 48V can cause pickup or noise problems in opto-link system. Heaters themselves are located over LVDS traces, whose 350mV signals can be susceptible to pickup. Expect that slow rise (48mV/µs) should eliminate any problems.
- Need to investigate range of input voltages over which the system will operate. This can provide a backup to switched operation if there are indications of pickup in full system operation. Also, is the switching of different channels coherent ?
- Some concern about the time constants of the switchcard (typically order of seconds, limited by ELMB performance in scanning 24 temperature and current sense channels and controlling switches. The thermal mass of the opto-boards is small, and there may be a tendency to track the variations in heater power. Lab measurements now indicate that this is not a real concern (time constants are much longer, and opto-boards are relatively strongly coupled to larger mass heat spreader plates).
- The expert who has programmed the ELMB that is at the heart of this system is Francesco Bellina, who is now working with pixels, so in principle, we could imagine implementing modified or improved algorithms if necessary...

Next Steps:

- Propose to have LEMO build 12 cables of the type described here. A total of 8 cables would be required for the final installation, and 2 cables would be used for the System Test setup in SR1 (allowing operation of one quadrant of the detector, or two SQPs).
- Have requested parts from Heater group (cable is available, need components, tooling, and procedure for splicing Type 2/3 cable, and need components, tooling, and procedure for termination of AMP 34-pin connectors).
- Propose to begin assembling hardware for the SR1 setup to allow for operation within about one month. This setup would include a single crate and a single switchcard.
- Begin assembling hardware for the US15 setup to allow for operation by the beginning of May.