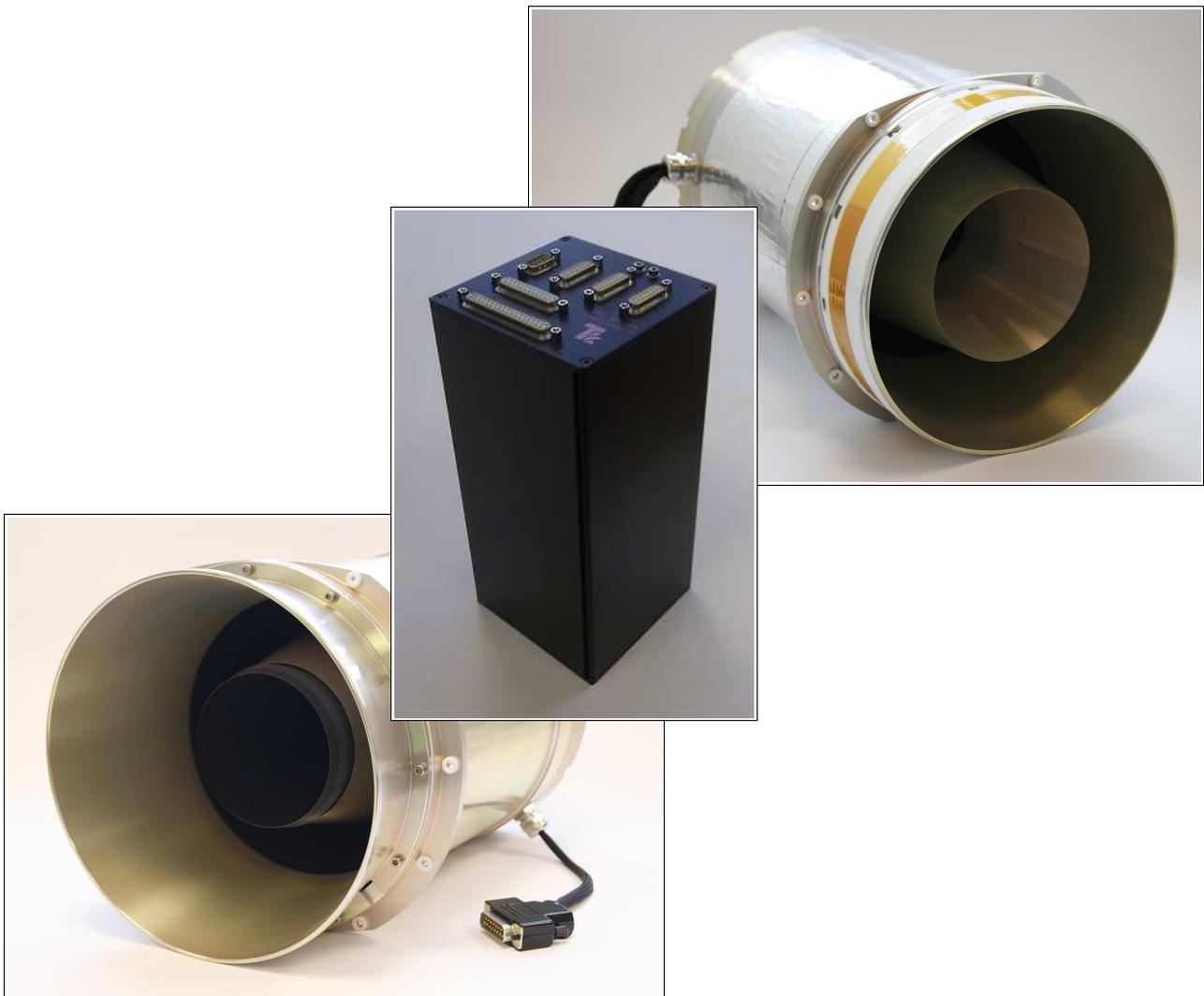




# Hot and Ambient Calibration Loads

## *Installation and Operating Manual*



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Thomas Keating Limited  
Station Mills, Daux Road  
Billingshurst, West Sussex  
RH14 9SH, England

Phone +44 (0)1403 782045

Fax +44 (0)1403 785464

<http://www.terahertz.co.uk/>

## Reference Documents

- [RD1] FEND-40.06.00.00-009-C-SPE, Calibration Device Technical Specifications
- [RD2] FEND-40.06.04.00-017-B-DSN, ALMA Calibration Loads Design Report
- [RD3] FEND-40.06.04.00-016-D-REP, ALMA Calibration Loads Test Report
- [RD4] P. Yagoubov, et al., “Calibration Loads for ALMA,” *International Conference on Infrared, Millimeter, and Terahertz Waves*, 2011
- [RD5] A. Murk, et al., “Development of Conical Calibration Targets for ALMA,” *21st International Symposium on Space Terahertz Technology*, 2010

## Abbreviations

ACL	Ambient Calibration Load
ALMA	Atacama Large Millimeter Array
AT	Ambient Temperature
CAN	Controller Area Network
EEPROM	Electrically Erasable Programmable Read-Only Memory
ESO	European Southern Observatory
HLC	Hot (and Ambient) Load Controller
HCL	Hot Calibration Load
MA	Main Absorber (cone)
MR	Main Reflector
NA	Not Applicable
SA	Secondary Absorber (cylinder)
SF	Solar Filter
SR	Secondary Reflector (front-most part around aperture)

# 1 Introduction

The hot and ambient load controller is a complicated device, designed to integrate into the ALMA telescopes and deal with the solar filter and ambient temperature sensors as well as handling the calibration loads. Due to the low numbers produced, the controller units manufactured are direct copies of the ALMA controllers, still including the circuitry for the solar filter and ambient temperature sensors.

## 1.1 The System

The system is comprised of the following components:

- Hot calibration load.
  - Equipped with 4 heater circuits, 3 control sensors and 5 read-out sensors.
- Ambient calibration load.
  - Equipped with 3 temperature sensors.
- Hot and ambient load controller.
- USB-to-CAN compact interface.
  - IXXAT part number 1.01.0087.10100.
- Power and CAN cable.
  - As shown in Figure 14 on page 25.
- Dummy connectors for the solar filter and ambient temperature sensors.
  - As shown in Figure 15 on page 25.

## 1.2 Acknowledgement

The product contains ALMA load technology, developed by ESO. Thomas Keating Ltd is a licensee of the ESO ALMA load technology developed and transferred by ESO (<http://www.eso.org/>). Technology partially protected by patent application, ESO, 11 007 146.1.

The terms of Thomas Keating Ltd's license from ESO precludes use in any military application. We therefore expect customers to comply with this limitation and not to sell, transfer or otherwise commercialize the product to any entity under United Nations or European Union embargo.

## 2 The Calibration Loads

### 2.1 Origin

The ALMA project has a challenging goal of absolute flux calibration better than 5%, and in order to meet this goal, has adopted a two-load calibration scheme. Very stringent performance specifications were placed on the calibration loads, but there was also a constrained volume available for each load: 290 mm in length, and 200 mm in diameter.

The original prototype used a traditional pyramidal array design, mounted at the base of a cylindrical shroud. However it was found that the performance (temperature uniformity and backscatter at low frequency bands) of these prototypes was insufficient, so that a conical load design would be required. The need to fit such a design into a limited length lead to the development of the current “folded cone” structure. As shown in Figure 1, this features a central absorber cone, surrounded by a conical reflector. The space between this reflector and a secondary absorber forms a second absorbing cavity. Finally a secondary reflector is mounted at the aperture to direct the beam into the calibration load, and to provide thermal isolation from the environment.

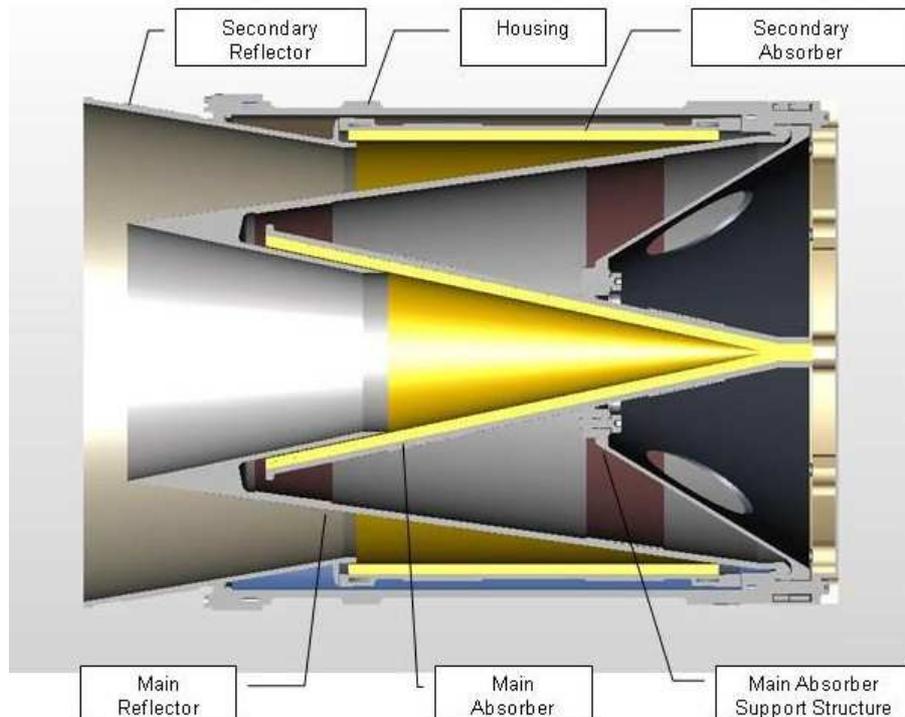


Figure 1: Cross-section view of the hot calibration load, from [RD4].

In the case of the ambient load, which must operate over the whole ALMA frequency range, the main absorber cone finishes at a sharp edge which obscures the tip of the main reflector. Meanwhile for the hot load, which is not required in the lowest 2 bands, the secondary reflector itself has a sharp edge and folds back inside the cone to provide additional thermal isolation.

## 2.2 Performance

The performance of the calibration loads is discussed in detail in the technical specification [RD1], and the design [RD2] and test [RD3] reports. The key parameters are summarized in Table 1, and the measured backscatter performance is shown in Figures 4–6. Improved performance was found at the nominal tilt angle of 2.5° rather than the loads being viewed directly head on.

Specification		Ambient Calibration Load	Hot Calibration Load
Design frequency range		31 – 950 GHz (ALMA bands 1–10)	84 – 950 GHz (ALMA bands 3–10)
Radiometric accuracy design goal		±0.3K	±1K (at 70°C)
Backscatter design goal		-60 dB	-56 dB
Measured backscatter (S11)	Band 1 (31 – 45 GHz)	Average -55 dB (at nominal 2.5° tilt)	-30 to -45 dB †
	Band 2 (67 – 84 GHz)	Below -55 dB	-50 dB †
	95 – 150 GHz	Mostly below -60 dB	Mostly below -60 dB
	150 – 720 GHz	Mostly below -60 dB ‡	Mostly below -60 dB ‡
Maximum set temperature		NA	90°C *
Typical mass		5.4 kg	5.6 kg

† Performance not specified for this load and frequency.

‡ Results from prototype calibration loads.

\* Read-out temperature may settle a few degrees below this.

Table 1: Summary of the design goals and measured performance of the calibration loads.

## 2.3 Radiometer beam sizes

The performance of a load is a function not only of the load itself but – in a time reversed view – the radiometer’s probing beam. To give accurate results, such beams must obviously be smaller than the active area of the load. Figure 2 gives the size of the AMLA beams (at the 1/e amplitude level) arriving at the loads, and Figure 3 gives these sizes against the probing beam sizes in the following S11 measurements in Figures 4–6.

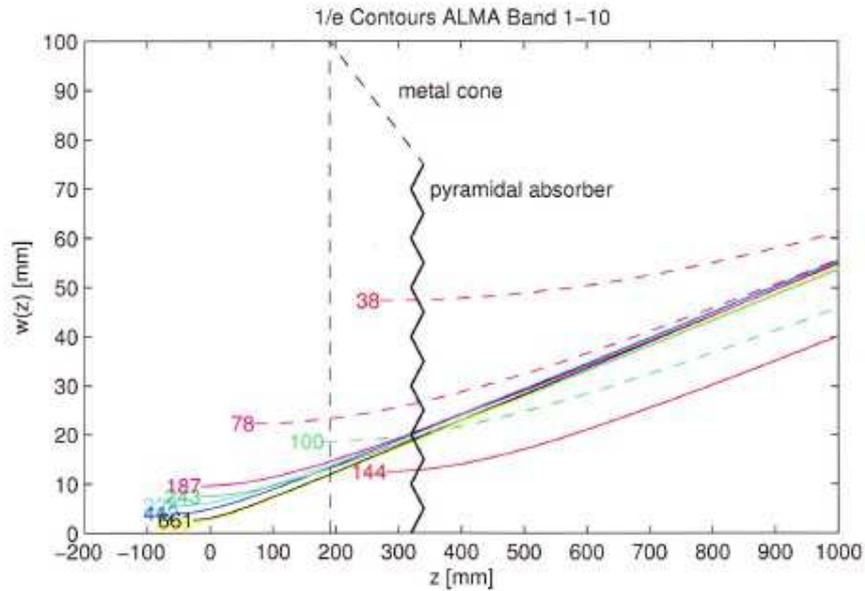


Figure 2: – ALMA beam sizes as a function of frequency

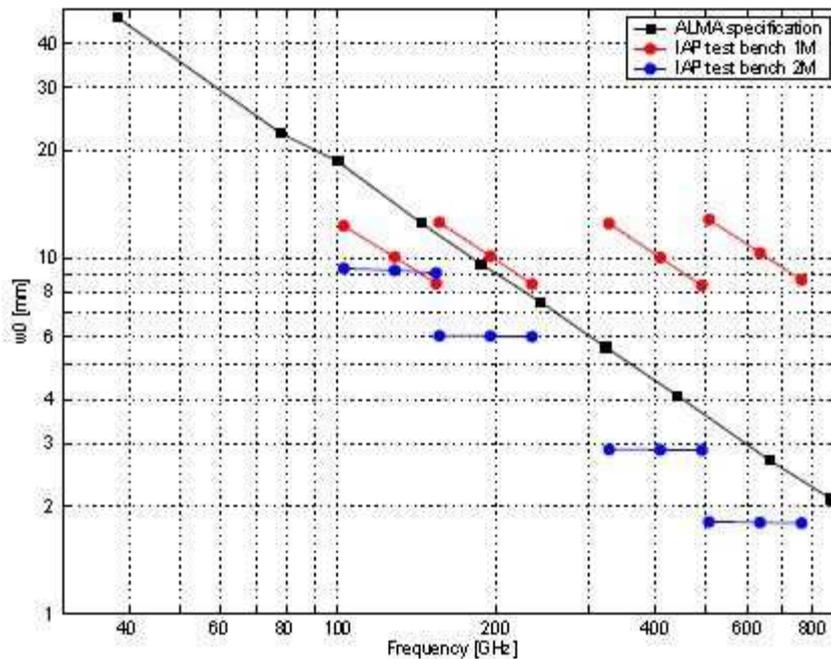
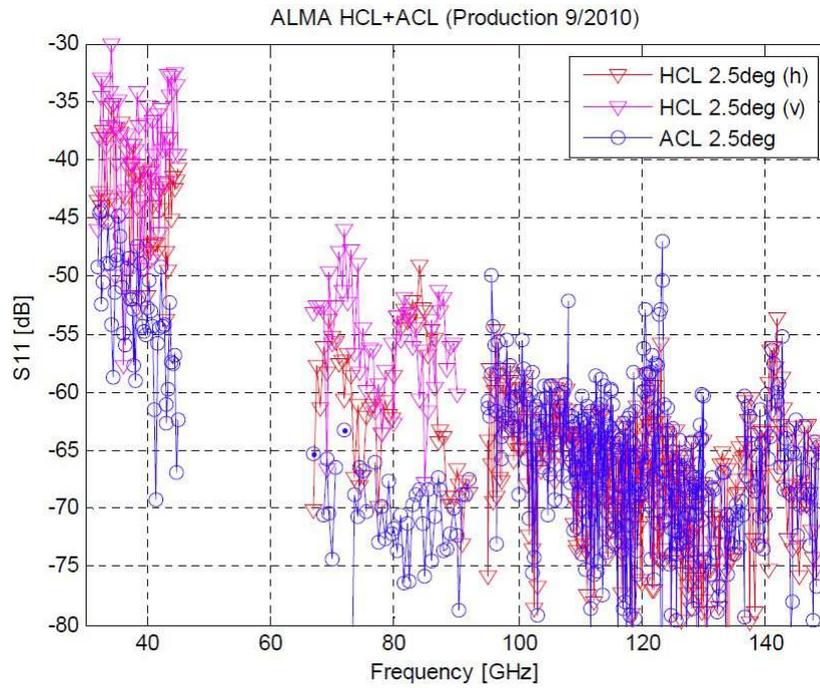


Figure 1 : Comparison of the specified ALMA beam waist radius at the center frequencies of Band 1 to 10 (black squares) with the accessible beam waists of the IAP setup using one (red) or two (blue) focusing reflectors. Measurements below 100 GHz were made with the original ALMA feed horns and lens antennas. In the overlap region at 100 GHz measurements were made with the ALMA and the IAP optics, which resulted in consistent results.

Figure 3: Beam sizes used to probe the performance of the ALMA loads



*Figure 4: S11 performance of production calibration loads, from [RD3]. Spikes at 120 and 140 GHz are test artefacts due to reduced VNA sensitivity at these frequencies.*

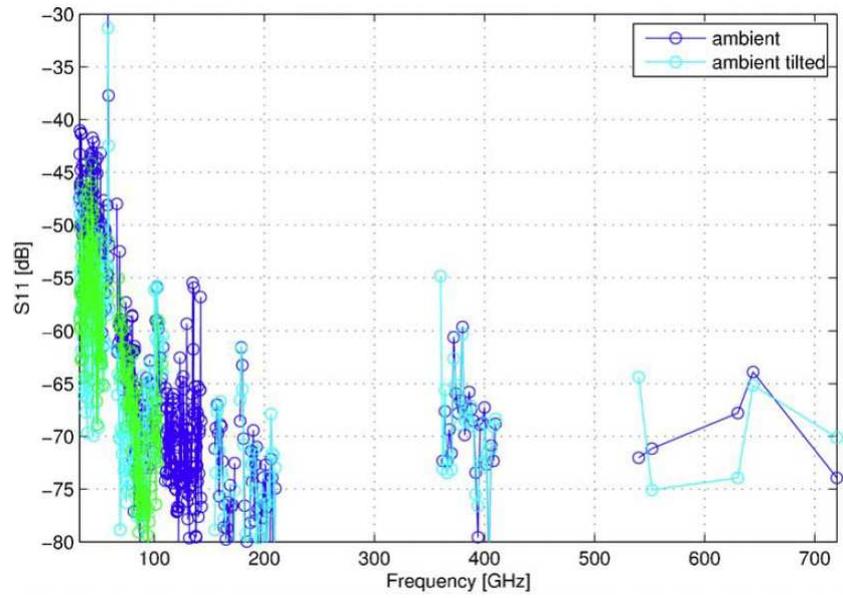


Figure 5:  $S_{11}$  performance of prototype ambient calibration load, from [RD3] / [RD4].

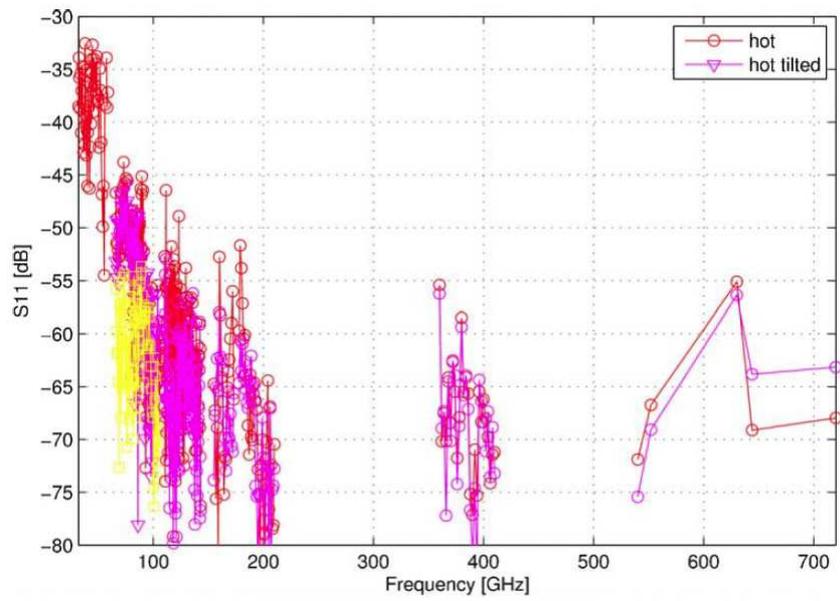


Figure 6:  $S_{11}$  performance of prototype hot calibration load, from [RD3].

## 2.4 Main Components of the Design

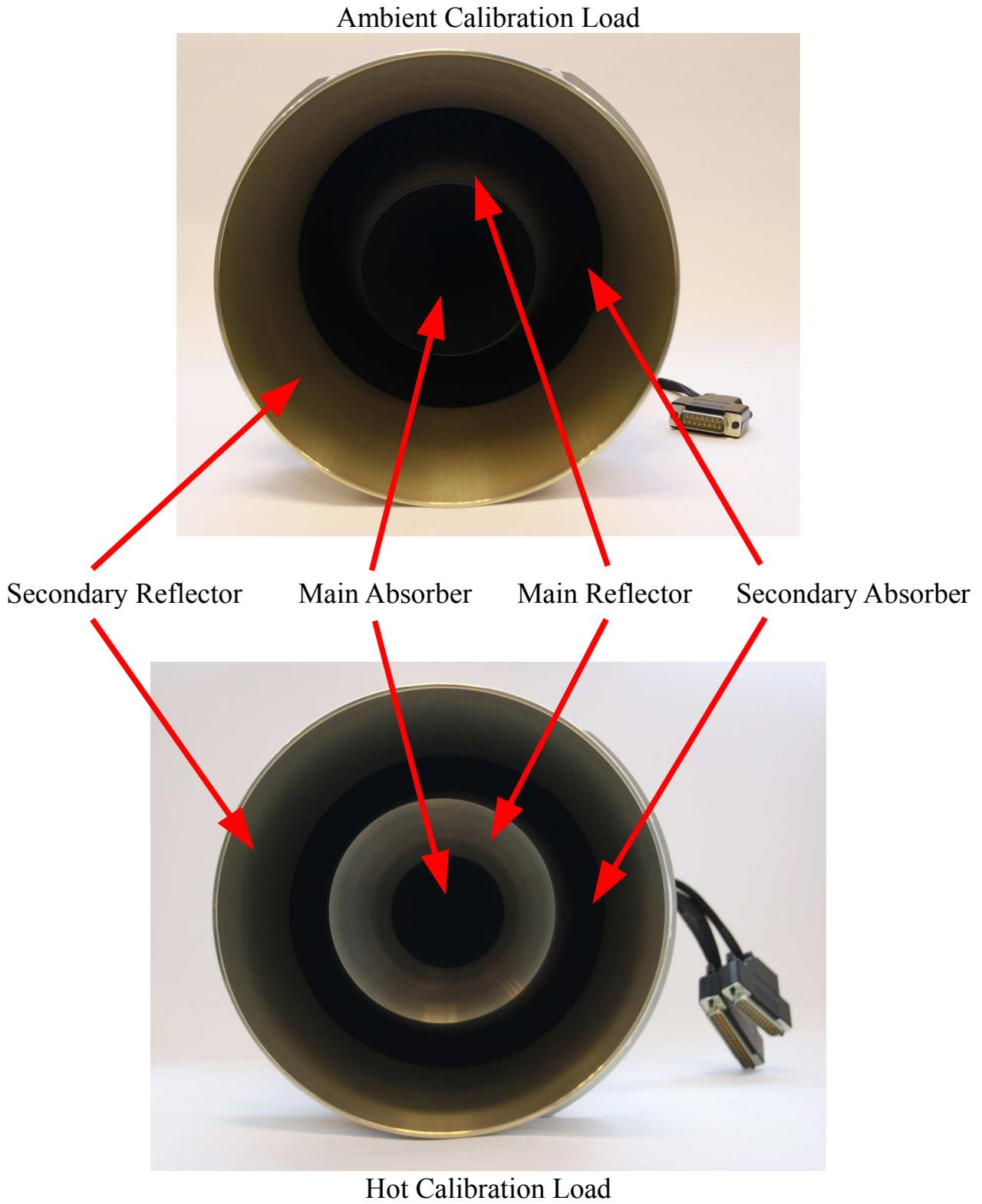


Figure 7: Photographs of the ambient and hot calibration loads with the absorbing and reflecting components labelled.

## 2.5 Temperature Sensor Locations

Figures 8 and 9 show sketches of the absorber parts and the main reflectors of the calibration loads, with the locations of the sensors marked. Note that 4-wire sensors are used for temperature read-out, and 3-wire sensors are used for control.

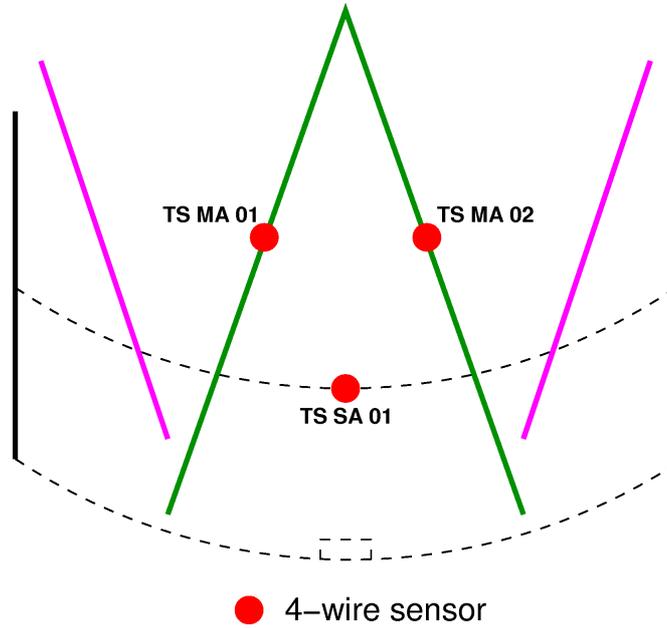


Figure 8: Sketch of the sensor locations in the ambient load.

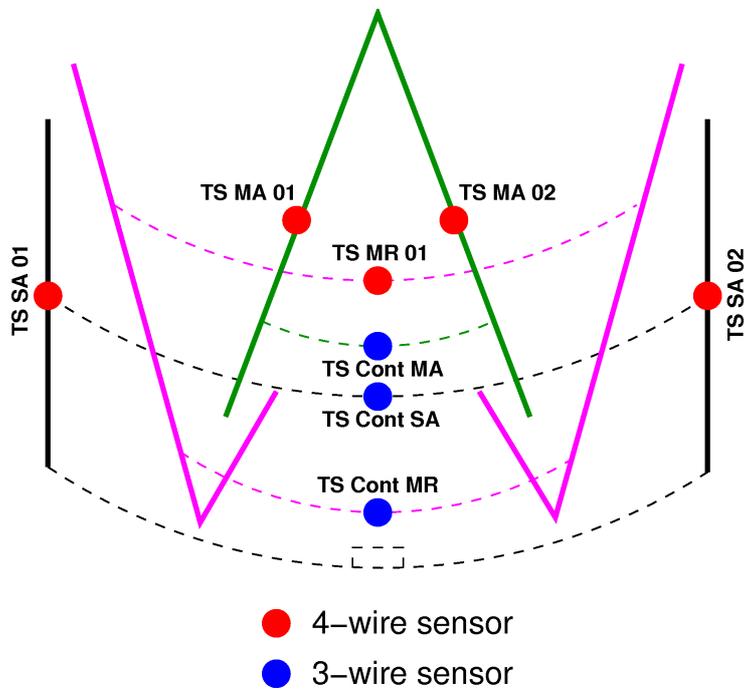


Figure 9: Sketch of the sensor locations in the hot load.

## 2.6 Mechanical Interface

At the ALMA telescopes, the calibration loads are mounted in a calibration wheel which is attached to the end of a robotic arm. The mounting interface of this wheel is shown in Figure 10. It consists of 10 M4 holes on a 209mm PCD, with a pitch suitable for 12 holes. The aperture end of the calibration load is inserted through an aperture in this wheel and secured with the M4 screws which pass through clearance holes in the load housing. The small insulating feet provide some thermal isolation between the calibration loads and the wheel.

If a similar mounting is to be used, the central aperture must be sufficiently large to allow the calibration load to be passed through easily. The diameter of the calibration load housing is 200mm, so the aperture could have a diameter of around 200.5mm, or slightly larger to allow the hot load to be inserted with the secondary reflector insulation in place. The end of the secondary reflector will then protrude by about 65mm beyond the mounting surface..

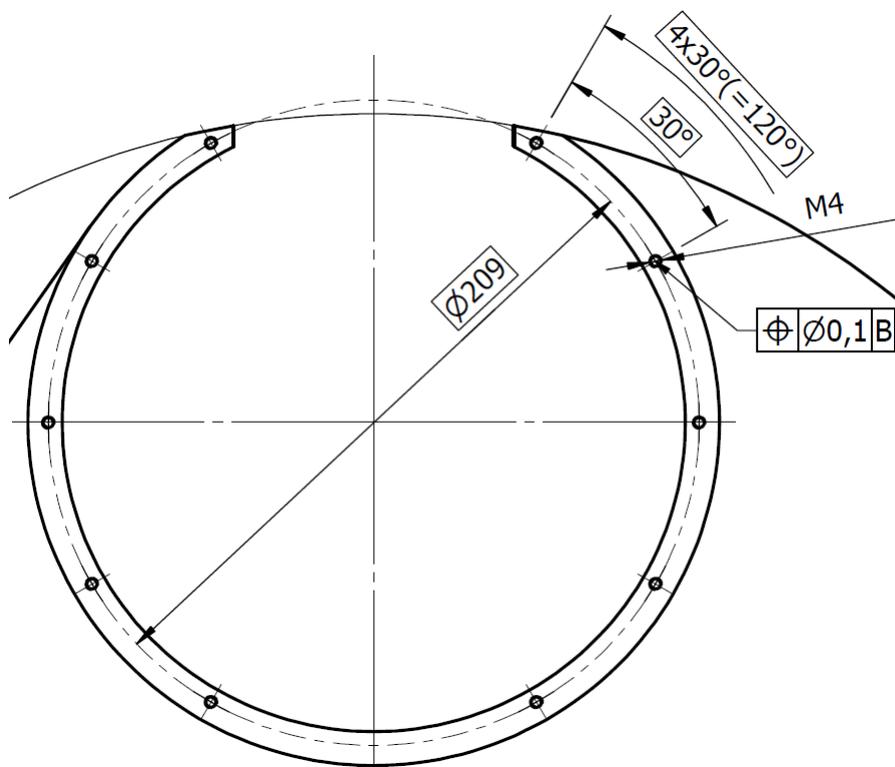


Figure 10: Drawing of the mechanical interface of the calibration wheel where a calibration load is mounted.

The apertures of the two calibration loads are given in Table 2.

<b>Aperture</b>	<b>Ambient Calibration Load</b>	<b>Hot Calibration Load</b>
Main absorber	83.4 mm	57.57 mm †
Main reflector	89 mm ‡	100 mm
Inner edge of secondary reflector	159 mm	
Outer edge of secondary reflector	198 mm	

† *Clear aperture through main reflector.*

‡ *Obscured by main absorber.*

*Table 2: Aperture diameters for the two calibration loads.*

### 3 The Load Controller

The hot and ambient load controller consists of three components mounted on a top-hat DIN rail. From the ‘top’ end where the sockets are located, these components are as follows:

- Phoenix opto-coupler  
*Used as a heater power switch for the Minco box.*
- ‘Minco box’  
*An aluminium box containing the three Minco temperature controllers.*
- Beckhoff bus modules:
  - 1-wire bus connected via serial module  
*Reads the calibration offsets from the EEPROMs located in the sensor cable connectors.*
  - Temperature sensor reading modules
  - A/D and D/A modules
  - Bus controller  
*This runs firmware which implements the logic required to operate the calibration loads.*

Some labelled photographs of these components are given in Appendix A.

## **4 Installation of the System**

### **4.1 Power Supply**

The hot and ambient load controller requires a 24 volt power supply capable of providing a current of up to 10 ampères. (Typically the load controller draws a current of about 7 A when all heater circuits are active.) A bench power supply configured for constant voltage at 24 V would be suitable, provided that the voltage control knobs are locked to prevent them being turned accidentally. The supplied power and CAN cable has banana plugs which must be connected to the power supply with the correct polarity. The 9-pin, 45° D connector (with two wires) should be connected to the controller.

### **4.2 CAN Bus**

The power connection of the hot and ambient load controller also carries the CAN bus. The second 9-pin D connector (with a single wire and a straight shell) on the power cable should therefore be connected to the IXXAT USB-to-CAN compact adaptor, and this device connected to a PC via its USB lead.

### **4.3 Dummy Sensors**

Each of the sensor connectors for the hot and ambient load controller contains a small EEPROM as well as the connections for the PRT 100 sensors. The EEPROM is used to store the temperature calibration offsets for the attached sensors. For the ambient temperature and solar filter connections, which will be unused, dummies are provided. These each contain the required EEPROM and some 110  $\Omega$  resistors simulating PRT 100s at room temperature. These dummies must be connected to the hot and ambient load controller to ensure proper operation.

### **4.4 Calibration Loads**

Finally the hot and ambient calibration loads are connected to the controller. The hot load has two connectors — the smaller of these carrying the heater power with each connection strapped across 3 pins in the plug. The wiring schematics for these connections are given on page 26.

## 5 Software Installation

### 5.1 CAN driver

The IXXAT driver for the USB-to-CAN compact adaptor should be installed. The installation media may offer a choice of versions, in which case version 3 (VCI 3.2) is recommended.

### 5.2 LabVIEW

Either LabVIEW or the LabVIEW runtime (downloadable from the NI website) should be installed on the PC.

### 5.3 Hot and Ambient Load Console

The console application should be unpacked into a suitable location. It includes the following files:

- HLConsole.exe  
*Compiled LabVIEW application.*
- data
  - HotLoadDLL.dll  
*Compiled C++ library which communicates with IXXAT CAN drivers.*  
  
*Provides a higher-level interface for some operations, such as sending temperature and weighting factor settings.*

## 6 Software Operation

### 6.1 Overview

The rôle of the LabVIEW hot and ambient load console is to exchange messages with the firmware running in the hot and ambient load controller. It displays the data received from the controller, and allows control messages to be sent. The firmware inside the hot and ambient load controller is responsible for interpreting the control parameters sent to it, and operating the heater system appropriately. It reports its status by a set of status and alarm bits which the console software then displays as 'LED' indicators, along with numerical information sent by the controller.

### 6.2 Initialization

When the hot and ambient load controller is powered up, it starts executing the firmware programme, which will — after a delay — read the calibration offsets from the EEPROMs and apply them to the measured temperatures. It will then set a default temperature of 85°C for the hot calibration load. At this stage it does not transmit messages on the CAN bus.

The compiled LabVIEW application should start automatically when opened, if this is not the case, the run button in the toolbar should be clicked. To activate the display, click the button labelled “Start communication with load controller”. This sends a series of messages to initialize the communication, so the display should start updating and the “Time since last message received” should stay close to zero — if this value is ever seen to rise, it indicates that the load controller has stopped communicating. The “Stop communication with load controller” button can be used to stop the transmission. Note that the “Controller node ID” should be set to 11 to match the address selected via the switches on the Beckhoff bus controller.

The temperature read-outs from the hot and ambient calibration load stabilize after a period of about two hours. During this time, the temperatures have been observed to drift downwards by about 0.3°C. Therefore the system should be allowed to ‘warm up’ for two hours before calibrations are performed.

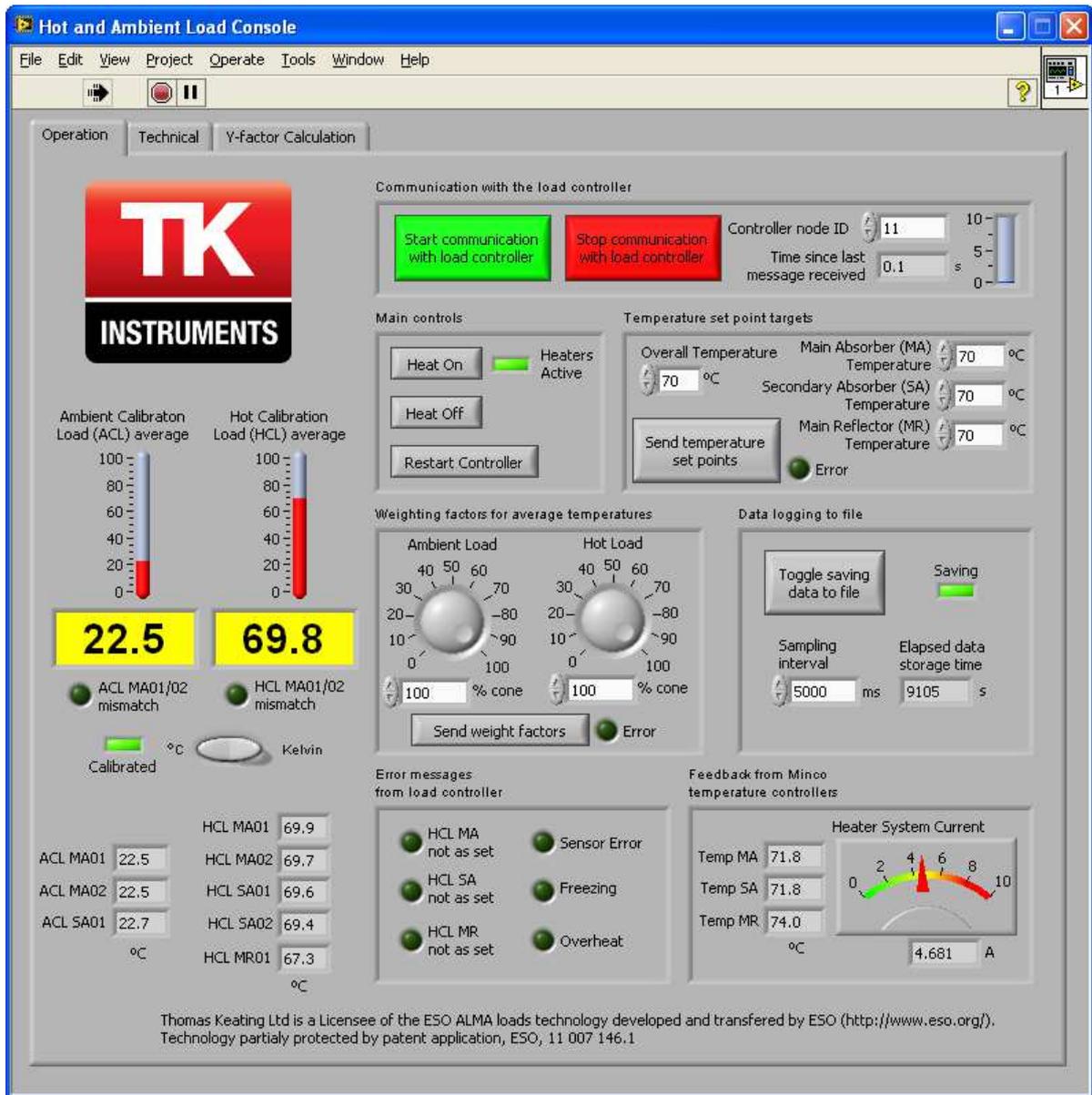


Figure 11: front panel of hot and ambient load console application. Square green ‘LED’ indicators have been used to show correct operation. Round pink ‘LEDs’ indicate errors or warnings, along with the “time since last message received” tank which will fill up if there is a communications problem.

### 6.3 Selecting the Operating Temperature

The hot load has 4 heated components:

- **MA** Main Absorber
  - This is the central cone.
  - It is controlled by heater circuit 3.
  
- **SA** Secondary Absorber
  - This is the absorbing cylinder forming part of the outer folded cone.
  - It is controlled by heater circuit 2.
  
- **MR** Main Reflector
  - The metal reflector forming the second part of the outer folded cone.
  - It is controlled by heater circuit 1.
  
- **SR** Secondary Reflector
  - The reflector shroud around the aperture of the calibration load.
  - *It is heated continuously at full power whenever any of the other heaters are active.*

The console software has 4 input boxes which can be used to control the temperature of the MA, SA and MR. Note that the SR temperature is not controlled. The first of the input boxes — labelled “Overall Temperature” can be used to supply a single temperature for all of the controlled components. Alternatively the individual input setting boxes can be used. The “Send temperature set points” transmits all 4 values to the firmware. The firmware is then supposed to look for values which have changed since the previous transmission. Therefore, if the “Overall Temperature” values has been changed, the controller will set this new temperature for all temperature-controlled components. Alternatively if individual settings have been altered, only the corresponding components will be set to new target temperatures. The corresponding “Error” light indicates a problem with the set point temperatures received by the controller (the allowed range is from 0.5°C above the average ambient temperature to 90°C). Note that sending new set points to the controller has the side-effect of attempting to switch the heaters on.

The “Heat On” and “Heat Off” buttons can be used to switch the heater circuits on or off without altering the temperature set-points stored in the controller. “Restart Controller” can be pressed to instruct the controller to restart, for example to force it to re-load calibration data from the EEPROMs in the sensor connectors. Note that this will of course break communication, and the “Start communication with load controller” button must be pressed again to resume communication once the controller has reset (perhaps a few seconds).

The “HCL MA/SA/MR not as set” indicators will go out when each component is within 5°C of the **individually** set temperature (2°C for the MA cone).

Note that, although the three circuit (MA, SA and MR) temperatures can be set in principle independently, there is a thermal link between them. A better overall accuracy is obtained by setting them all to the same temperature, which can be done by using the “Overall Temperature” input box only.

## 6.4 Temperature Read-Out

The firmware in the load controller reports both an average temperature for each load, and the individual readings for each sensor. The main average values are displayed on the left hand side (yellow boxes and thermometer scales), marked “Hot/Ambient Calibration Load (HCL/ACL) average”. The scale can be changed between Kelvin and °C. The “mismatch” indicators will warn if the two temperatures measured on the MA differ by more than 1°C (2°C for the ambient sensors and solar filter shown on the “Technical” tab.) The “Calibrated” indicator illuminates when the controller has **attempted** to read calibration data from the EEPROMs in the sensor connectors.

The temperatures for the individual sensors are shown at the lower left of the display, always in units of °C.

The “average” temperatures displayed for the hot and ambient loads are a weighted average of the temperatures of the main absorber cone and secondary absorber cylinder for each load

$$T_{\text{ambient load}} = w_a * (T_{\text{MA01}} + T_{\text{MA02}}) / 2 + (1 - w_a) * T_{\text{SA01}}$$

$$T_{\text{hot load}} = w_h * (T_{\text{MA01}} + T_{\text{MA02}}) / 2 + (1 - w_h) * (T_{\text{SA01}} + T_{\text{SA02}}) / 2$$

where the ambient and hot weighting factors,  $w_a$  and  $w_h$ , are applied by the firmware. A high weighting factor (100%) would be used for a very small beam which fits within the central cone — this is the default factor used by the firmware before valid weights are received. The console software can be used to transmit weighting factors to the firmware. The firmware responds by setting a status bit which will be on to indicate an error if **both** weights are invalid. Please note that, since the weights are sent in the same CAN message as the MA and SA temperature set points, the HotLoadDLL file will have to re-transmit the last transmitted temperature values with the weights setting.

At the lower right corner of the display are a set of values read from the Minco temperature controllers. These show a rough (and uncalibrated) measurement of the temperature of each controlled component and the total current drawn by the heaters.

Other error indicators on the display are as follows:

- **Sensor Error**
  - One or more of the read-out PRT100 sensors is faulty or disconnected.
- **Freezing**
  - The ambient temperature is below 10°C. (Not meaningful if a dummy ambient temperature sensor connector is attached.)
- **Overheat**
  - All sensors read over 100°C for any part of the hot load.

## **6.5 Logging the Temperature to a File**

The values received from the load controller can be logged to a data file if required. The “Toggle saving data to file” button can be used to start this process. A file name will be prompted for, and then the software will save data at the specified interval. During this process the “Saving” indicator will be illuminated and “Elapsed data storage time” can be seen to count upwards each time a measurement is written to the file. The saving process is stopped when the “Toggle saving data to file” button is pressed again.

The format of the file is tab-separated text, with a brief header giving the log start time and date and the column headings. Subsequent lines give the time in seconds from the beginning. The columns written to the file are listed in Table 3.

<b>Column Heading</b>	<b>Meaning</b>	
Time(sec)	Time since the beginning of the log file.	
HEAT	Current values of the controls of the console application (not necessarily having been transmitted to the controller).	
HEAT_MR		
HEAT_SA		
HEAT_MA		
Weight_ACL		
Weight_HCL		
AMBIENT_TEMP_AV	(Weighted) average temperature values.	
AMBIENT_LOAD_AV		
HOT_LOAD_AV		
SOLAR_FILTER_AV		
AT_01	Individual temperature values.	
AT_02		
ACL_MA01		
ACL_MA02		
ACL_SA01		
HCL_MA01		
HCL_MA02		
HCL_SA01		
HCL_SA02		
HCL_MR01		
SF_01		
SF_02		
Vtemp_MR		Feedback from Minco temperature controllers.
Vtemp_SA		
Vtemp_MA		
Vcurrent	Current as measured (roughly) on the heater switch.	
Status(hex)	Information bytes.	
Alarm(hex)		
Config(hex)	Firmware version.	
Get_Wt_ACL	Weighting factors as reported by the firmware.	
Get_Wt_HCL		

*Table 3: Columns saved to the data file and their associated meanings.*

## 6.6 Technical Panel

The second tab in the console application provides additional technical information and controls, including:

- “STOP”
  - Stops the console application.
- “Send start communication broadcast” and “Send stop communication broadcast”
  - Similar to the corresponding coloured buttons on the main operation tab, but without setting a specific controller node ID.
  - Note that the HotLoadDLL file will have to assume a node ID of 11 to configure the PDO5 and PDO6 messages.
- Temperature of ambient sensors and solar filters.
  - Should read approximately 25°C with the supplied dummies.
  - Displayed as for the ambient and hot calibration loads.
- Ready and Stable bits, as set by the controller firmware.
- Firmware version.
- Status and alarm bytes (as hex), from which the status bits are extracted to control the various ‘LED’ indicators
- Weighting factors (for calculation of average temperatures)
  - As reported by the controller firmware.
- Facilities for transmitting raw messages and basic temperature commands to the controllers.
- The time since each of the 6 possible messages was received from the controller.
  - These messages will be transmitted as required (by the values to be reported changing).
  - The minimum of these values is displayed on the main operation tab.

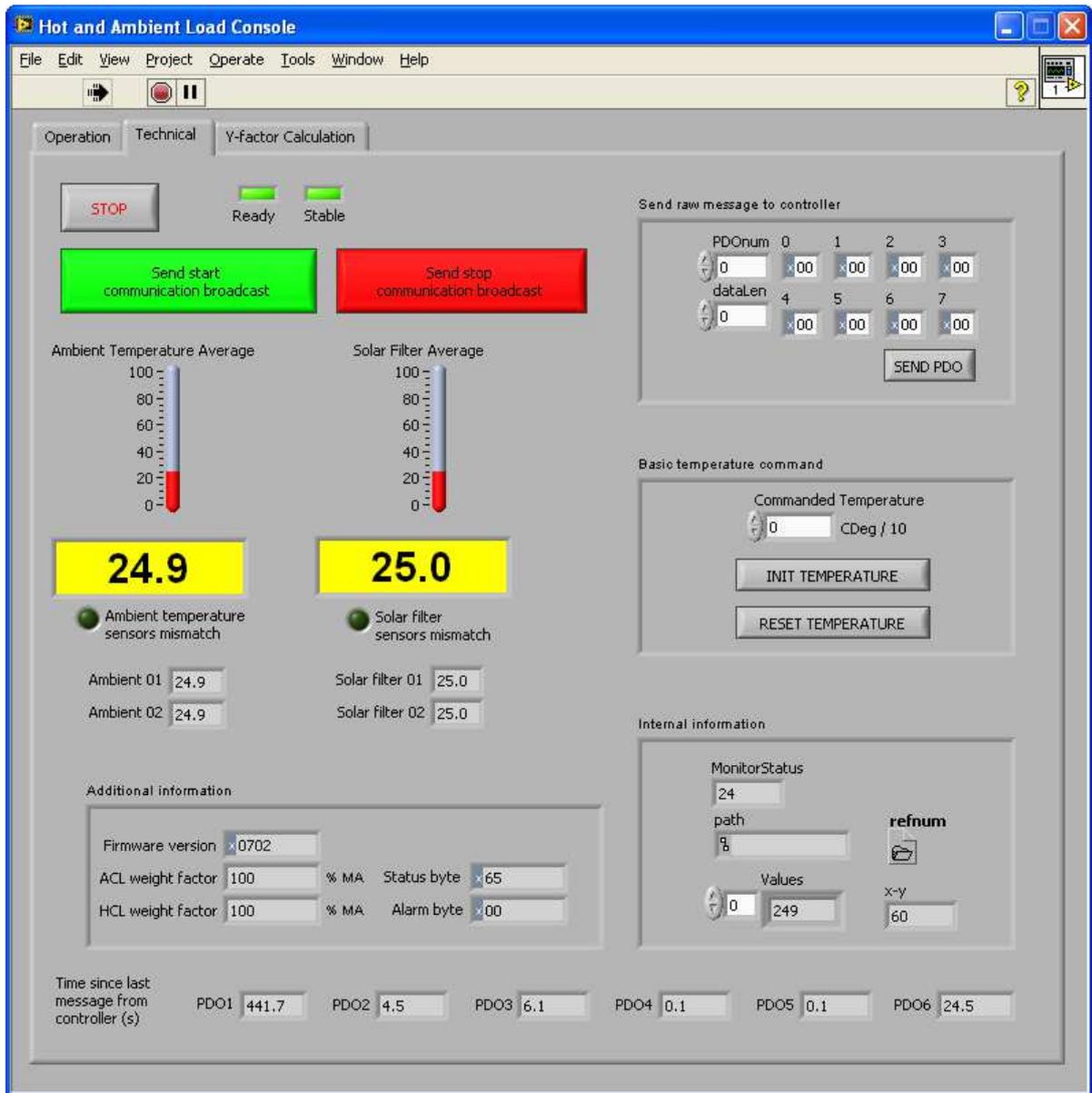


Figure 12: technical panel of hot and ambient load console application.

## 6.7 Y-Factor Calculation

The third tab in the console application provides a quick method to perform a Y-factor calculation to determine a receiver noise temperature based on the temperatures of the hot and ambient loads.

The power measured by a receiver should be recorded when it ‘sees’ the ambient and hot calibration loads. These measurements can then be entered into the two input boxes in either linear units of power (or voltage, counts or any other measurement proportional to power), or in dB, provided that the unit selector is set appropriately. The Y-factor (ratio between the powers on the hot and ambient loads) will then be displayed, and converted to a noise temperature based on the (weighted average) temperatures of the hot and ambient loads.

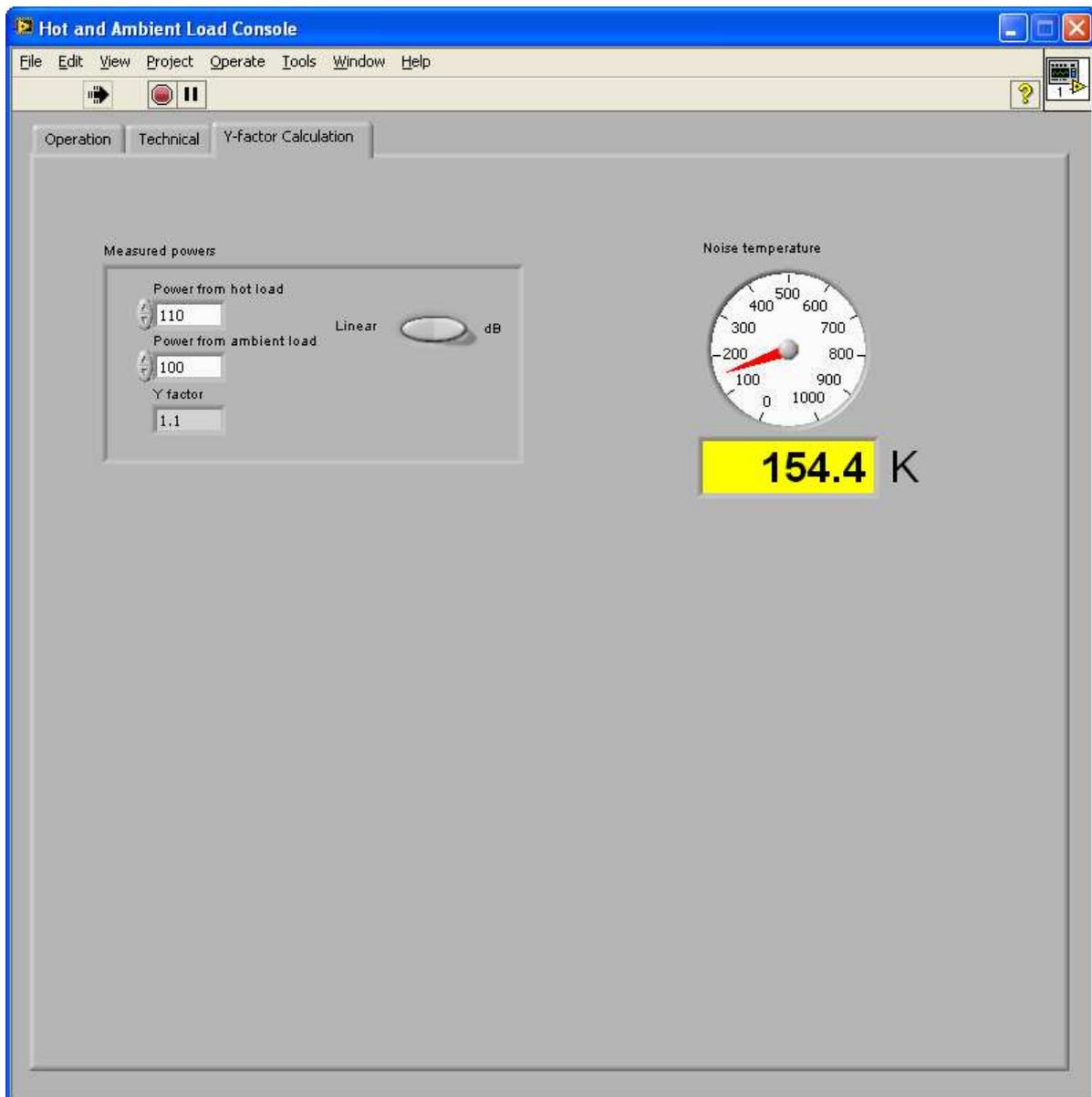


Figure 13: Y-factor calculation panel.

## 7 Wiring Schematics

This section shows the wiring schematics for the connectors of the hot and ambient load controller.

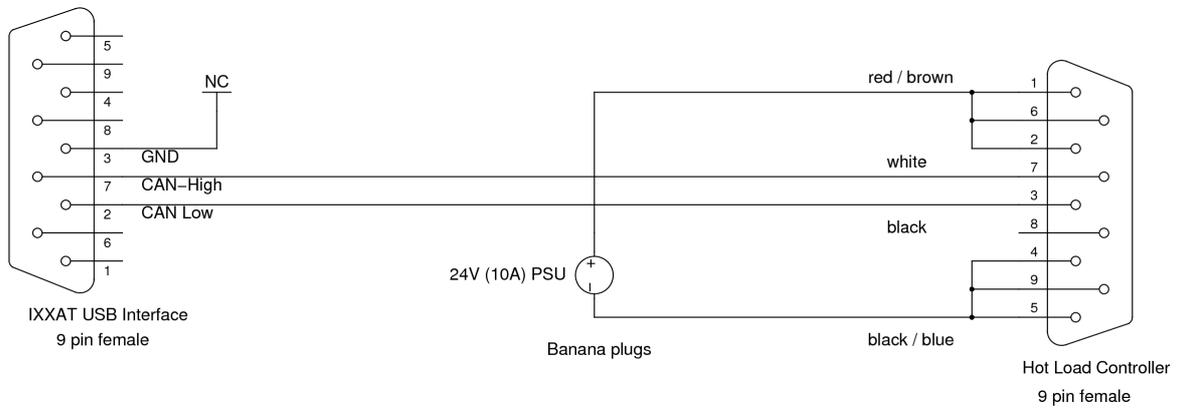


Figure 14: Schematic of power / CAN cable.

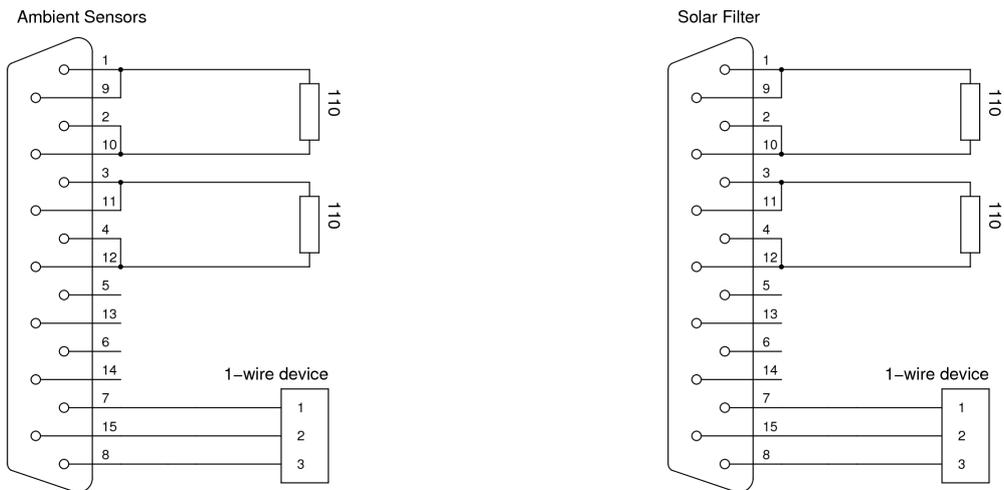


Figure 15: Schematic of dummy connectors. The 110Ω resistors could be replaced with PRT100 sensors to add additional readout channels.

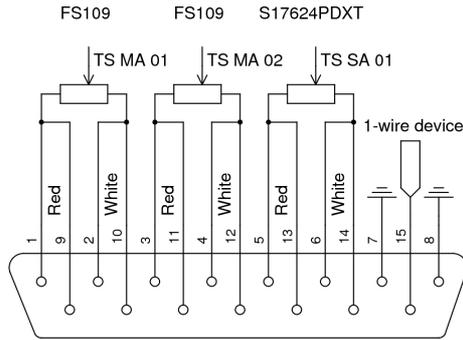


Figure 16: Ambient load sensors connector.

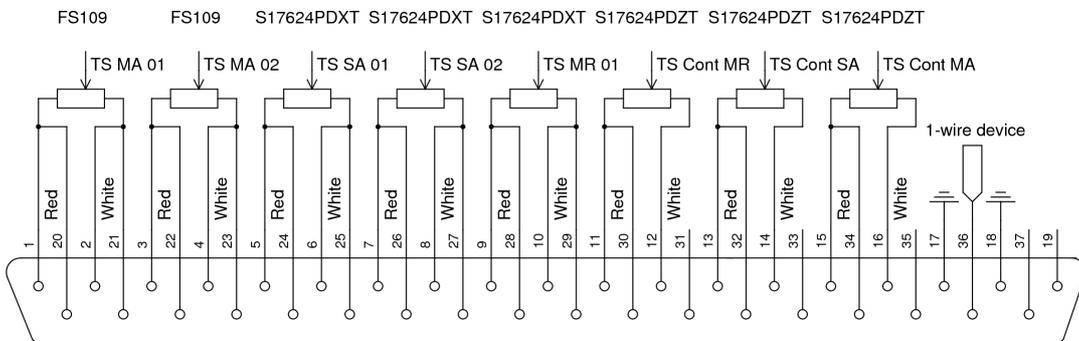


Figure 17: Hot load sensors connector.

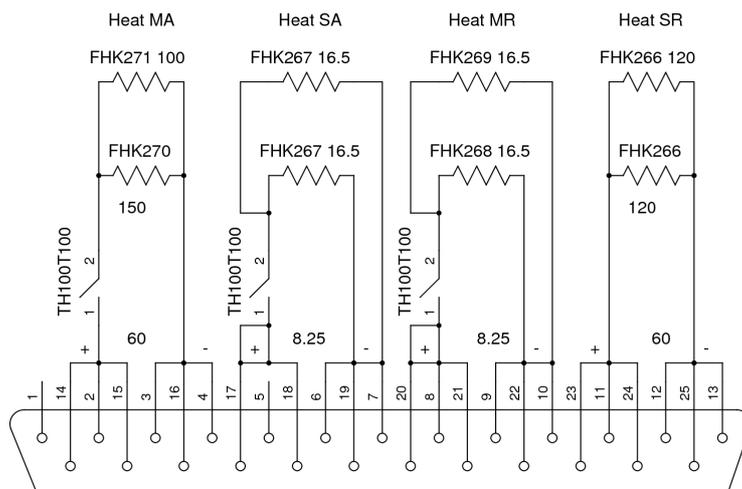
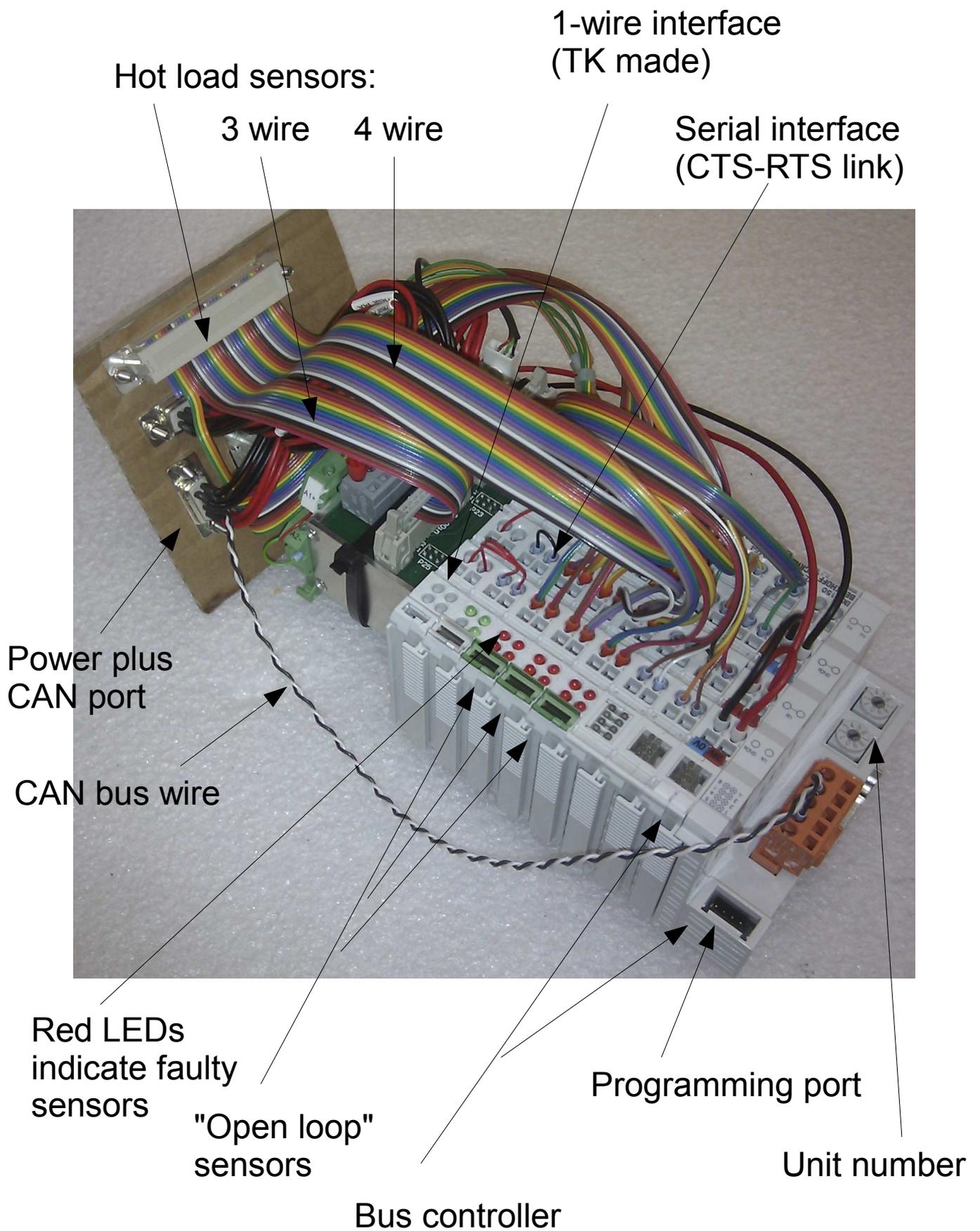
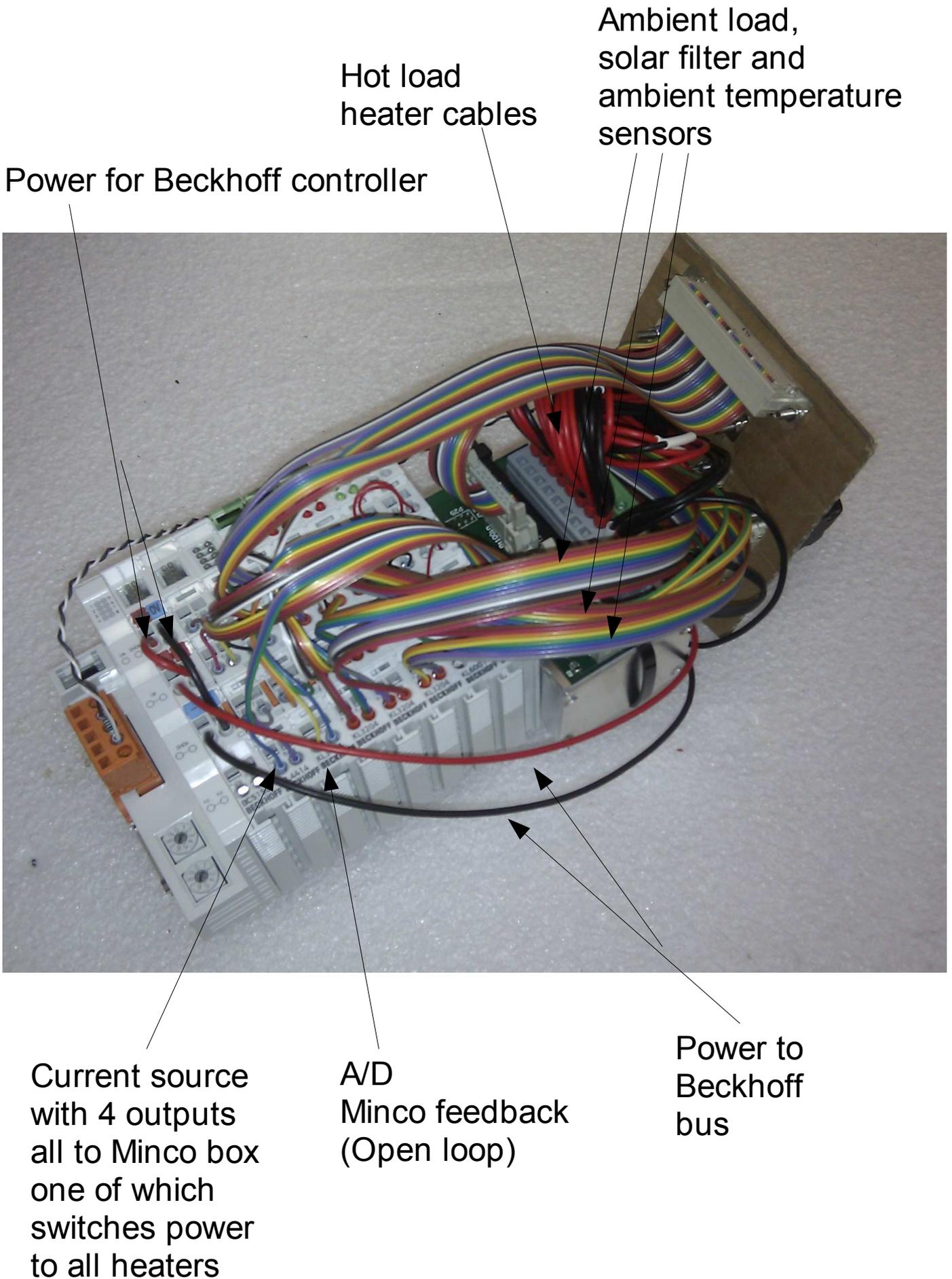


Figure 18: Hot load heaters connector.

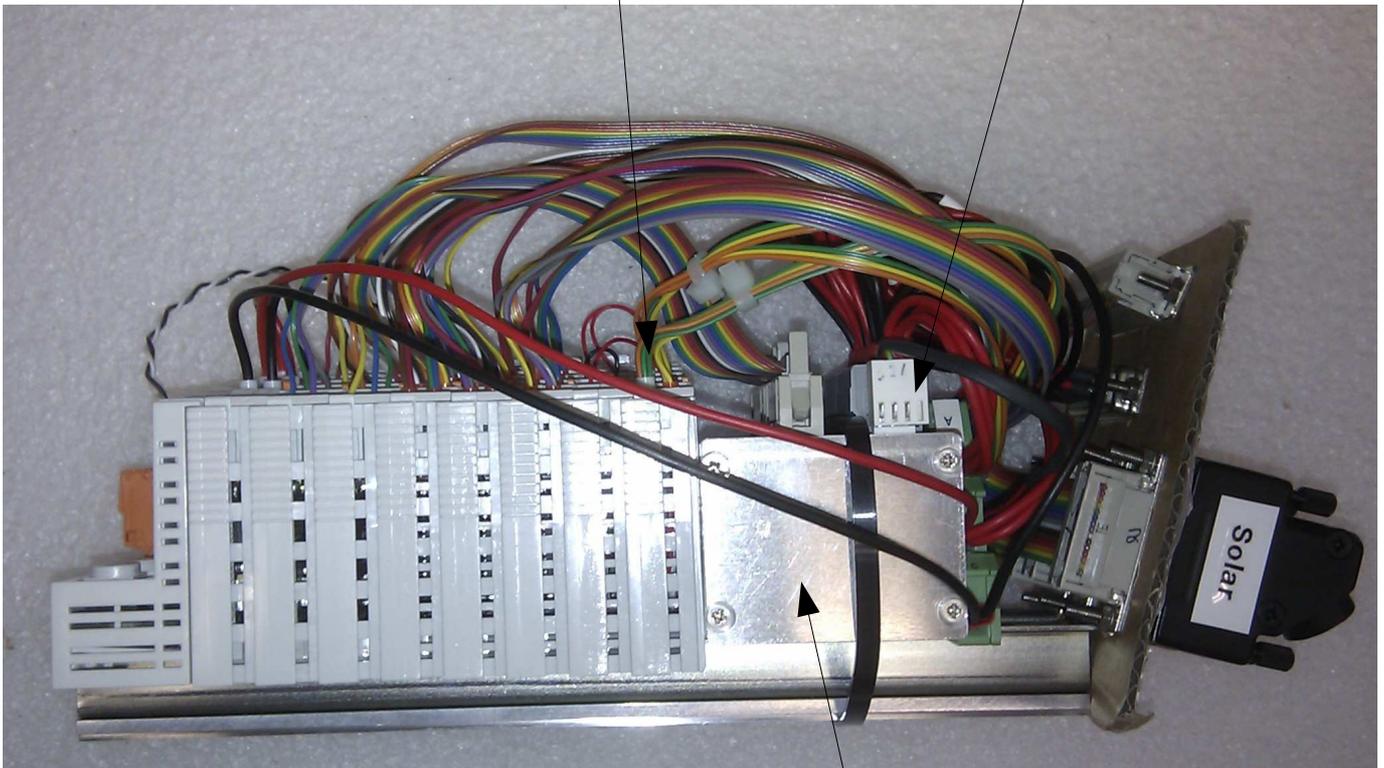
# Appendix A: Photographs of Internal Components





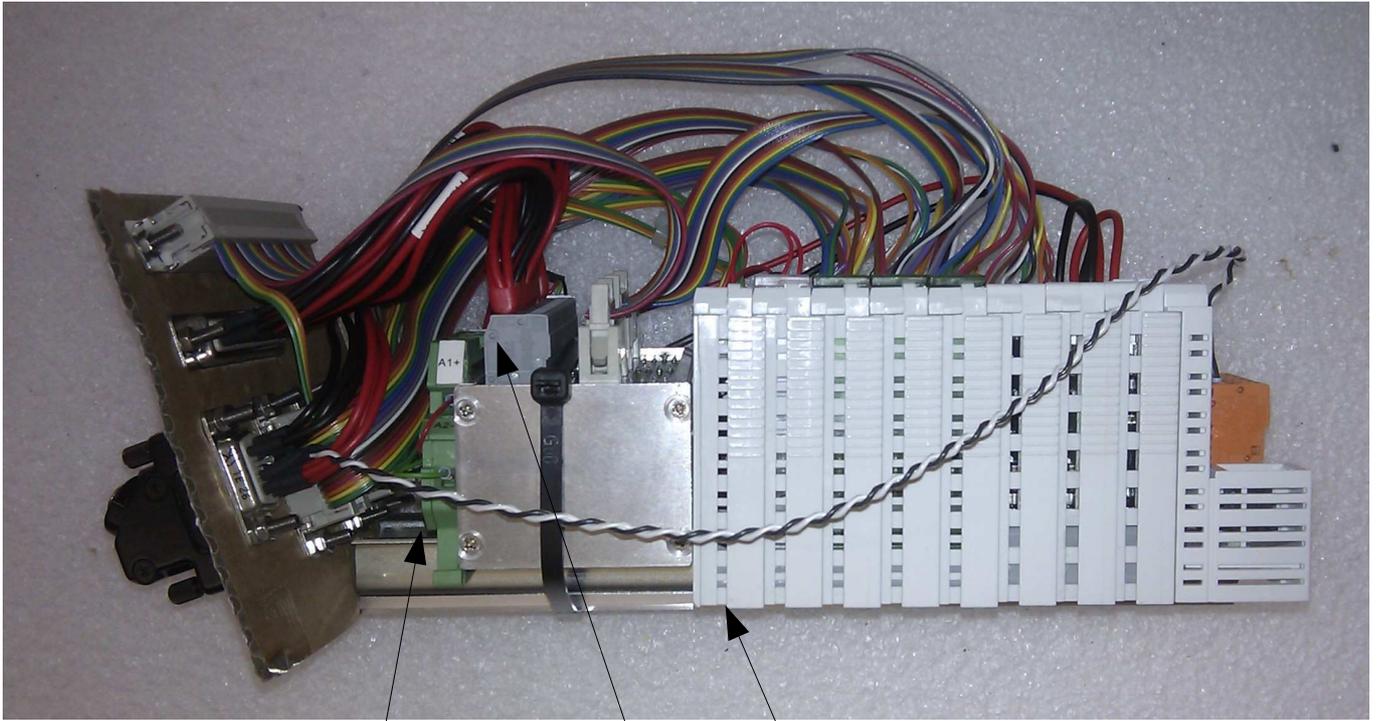
1-wire interface cables  
going to calibration offset  
EEPROMs in connectors

3 pin connection  
to power switch:  
ground,  
current source,  
and feedback  
to A/D



2 TK PCBs  
to take Minco  
heater controllers

3 control  
1 heater on all the time (secondary reflector)  
(software switch)



Heater switch

1-wire interface

Contacts removed from spares of these connectors to make the 1-wire interface