

QMC Instruments Ltd

Temperature Controller Operating Manual



Model TC04/1
Serial Number: xxxx

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Warnings

Electric shock risk

Removal of the Temperature Controller's outer casing must be carried out by authorised personnel only. There are no user serviceable parts inside. Unauthorised tampering with this unit will invalidate the guarantee

Electrostatic Sensitive Device

Because of the low voltages that this unit needs to measure accurately, particular care should be paid to the earthing of the users complete experimental system, of which the Temperature Controller is a part. Hence please note the following:

- The cryostat should be earthed before connecting the amplifier unit to it
- Disconnect the amplifier from the Temperature Controller while working on the amplifier
- Wear an earth strap when working on the amplifier

Packing List

The following items are included in this shipment. Please check the contents against this list and contact QMC Instruments if you suspect that any items are damaged or missing.

- *1-off* Temperature Controller to fit a 19-inch rack mount
- *1-off* Amplifier unit
- *2-off* 2m 15-pin male to 15-pin female D socket cable for the RTDs. These are a special construction so do not extend these by adding another cable. Please contact QMC Instruments if longer cables are needed
- *2-off* 2m 25-pin male to 25-pin female D socket cables for the diodes and heaters
- *1-off* 2m red CAT5e RJ45 to RJ45 ethernet cable
- *1-off* 2m 9-pin male to 9-pin female serial cable
- *4-off* 4-pin pre-wired RTD connectors (Red, Green, Blue and Yellow wires). These are needed to connect up the RTDs
- *4-off* RTD connectors with 1k Ω test resistors mounted in place in the RTD inputs in the amplifier. These should remain connected when the RTD channel is not used
- *1-off* 2m UK mains power cable

Introduction

Model TC04/1 Temperature Controller

The QMC Instruments Ltd Temperature Controller provides accurate temperature measurement and control in the range -273.10°C to approximately $+300^{\circ}\text{C}$, as determined by the diode used, though the principal design requirement is for a cryogenic temperature controller. This unit provides:

- 6 heater supplies, each rated to 25V, 100mA maximum
- 8 diode readouts
- 4 resistance temperature detector (RTD) channels
- An ethernet (network) interface
- 19" rack mount
- Front panel display showing the heater and diode voltages, and RTD operating information

This unit was specifically designed to satisfy the low temperature research requirements of the Astronomy Instrumentation Group at Cardiff where multiple heating and temperature readout points are required. There were shortcomings in the technology available that led to its conception and subsequent development. It provides temperature monitoring and control from 50mK to 573K through the use of up to six heaters, eight diode channels and four RTDs.

Temperature control and / or monitoring using the unit may be carried out at the front panel, or via a web interface through a PC. Data / performance monitoring can be carried out using any supported web-enabled device, including a mobile phone.

A detailed specification can be found in **Appendix A**.

Amplifier Unit

The Amplifier unit is housed in an EMI shielded box which is designed to interface the temperature controller to the system sensors, **Fig. 1**. It is specifically designed for any low temperature (sub 1K) work where highly accurate temperature measurement and control is required; hence low bias current is used. It has very low noise characteristics so as not to interfere with the signal.

The six heater, eight diode and four RTD signal channels route through the amplifier unit using filtered connectors.

The amplifier will need to be opened by the user and the shielded box adapted to fit it to their system.

Diode and resistance thermometer detector (RTD) calibration data

Any diode or RTD can be used. The system has been successfully tried and tested using BC859 silicon transistors mounted in copper housing blocks for the diode thermometers, and a Lakeshore GRT for the RTD.

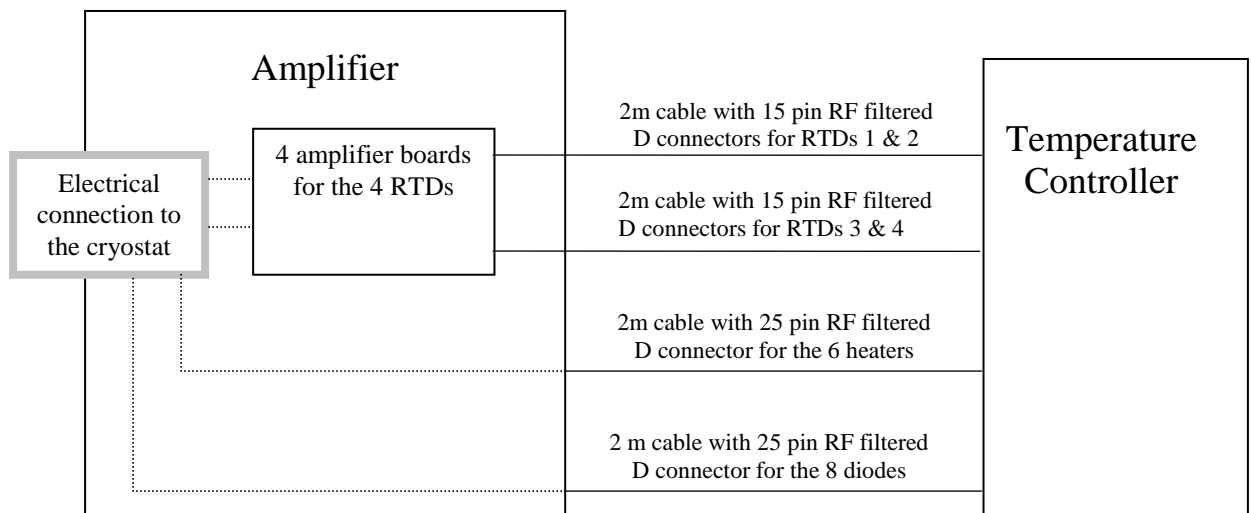


Fig. 1. Schematic of the temperature controller

Grounding

Ensure that the unit and associated equipment is properly grounded at a single point. The amplifier box and cryostat / system must be connected directly together and earthed. Ensure that pin 13 of the heater D-25 connector is always earthed.

Temperature Controller Operation

Unpack the unit and confirm that the items listed in the packing list are present and that there is no evidence of damage to the parts.

Photographs included in this manual are general photos that may not be specific to your particular system.

Fig. 2 shows the rear panel of the unit where the following are identified. From left to right:

- Fan (not shown in photo below)
- The mains power connection located above the fuses
- Two fuse mounts
- Two 15-pin D socket connectors for the four resistance temperature detectors (RTDs). Each connector links to two RTD amplifiers
- 25-pin D plug connector to read the diodes
- 25-pin D socket connectors to power the heaters
- Cooling fins
- 9-pin D serial socket (used to update the software)
- Ethernet connector
- Two unused ports

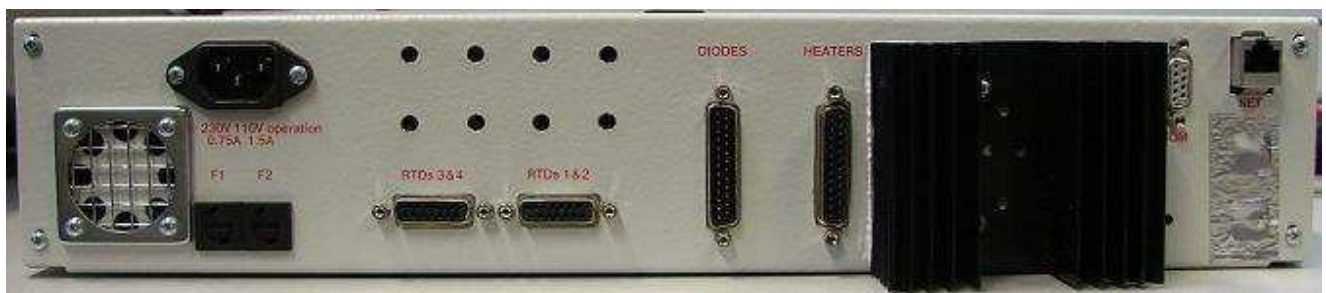


Fig. 2. Temperature Controller rear panel

Note: Remember to make sure that all the RTD connectors are in place and not open circuit before powering up the unit and running the webserver. Use the supplied test connectors for unused connectors.

Operation via the instrument panel (using the front panel controls)

Note: While the instrument can be operated via the front panel console, it is expected that the user will use the web interface for cryogenic monitoring and control.

Switching on

Plug into the mains and switch the unit on at the front panel, **Fig. 3**. The green power LED's should all illuminate to indicate that the power supplies are correct.

Diode readouts

There are eight diode readouts, **Fig. 4**, that are accessed via the eight position switch. A voltage readout is given. Convert this to temperature using the appropriate diode calibration chart.

Heater supplies operation

There are six heater supplies, **Fig. 5**. With a heater switch in the top position, the voltage can be controlled via the network CPU up to the maximum voltage set. The middle switch position is off. When in the bottom 'max' position, the maximum voltage can be set by adjusting the 'set max' potentiometer i.e. the heater maximum power levels are controlled through the front panel. This hard wired maximum cannot be changed through the web interface; rather a proportion up to this can be set. Each heater supply is disconnected when the demand is less than 100mV.



Fig. 3. Mains power



Fig. 4. Diode selector and readout

Select one of the heaters from the six position switch to read the voltage supplied to that heater channel. When a heater is off, which is indicated by the green 'active' light being off, the display readout (e.g. 0.06) should be ignored.

The maximum heater current is 110mA. The current through the heater can be determined by connecting a floating voltmeter to the heater Output Monitor 'I sense' points and measuring the voltage drop. Convert this voltage to a heater current where $1V \equiv 100mA$. If the heater attempts to draw more than 110mA, the supply will operate at constant current, and the voltage will drop.

The red LED fault lights indicate open circuit detection which occurs when the heater resistance exceeds approximately 10k Ω . These operate only when the voltage exceeds 3V.

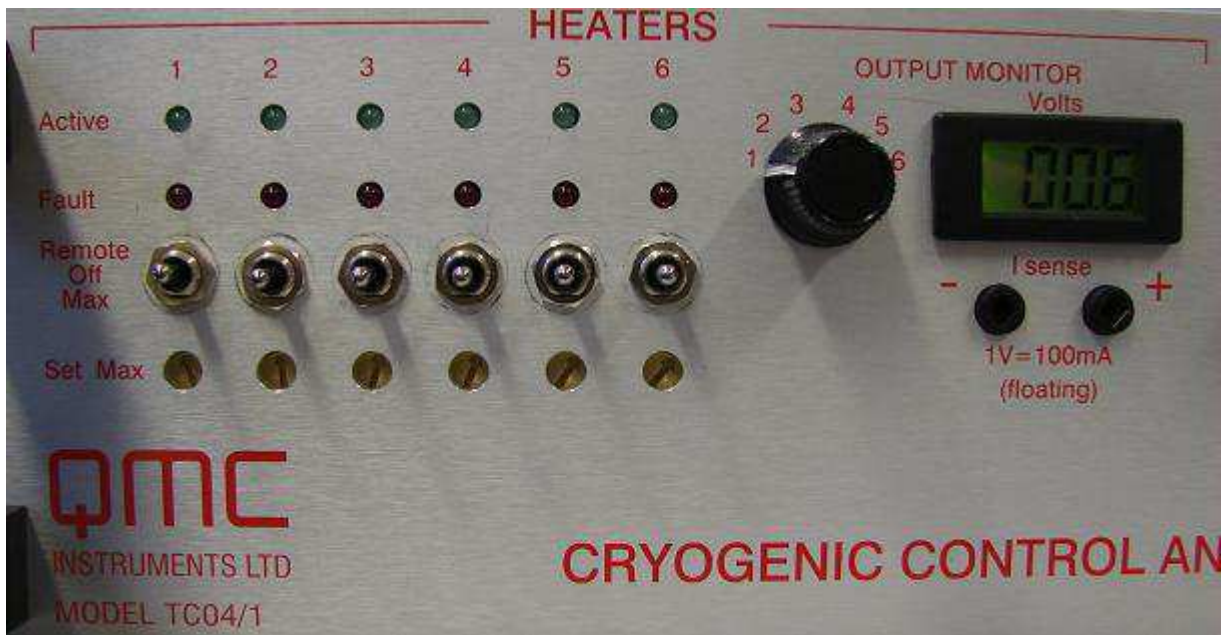


Fig. 5. The six position heater select switch, heater readout and heater controls

RTD control

There are four RTDs that are controlled individually via the red and black push buttons on the front panel, **Fig 6.**

Press the black button to cycle through the menus and the red button to toggle settings. The default menu when the device is switched on is the main menu. The menu hierarchy follows:

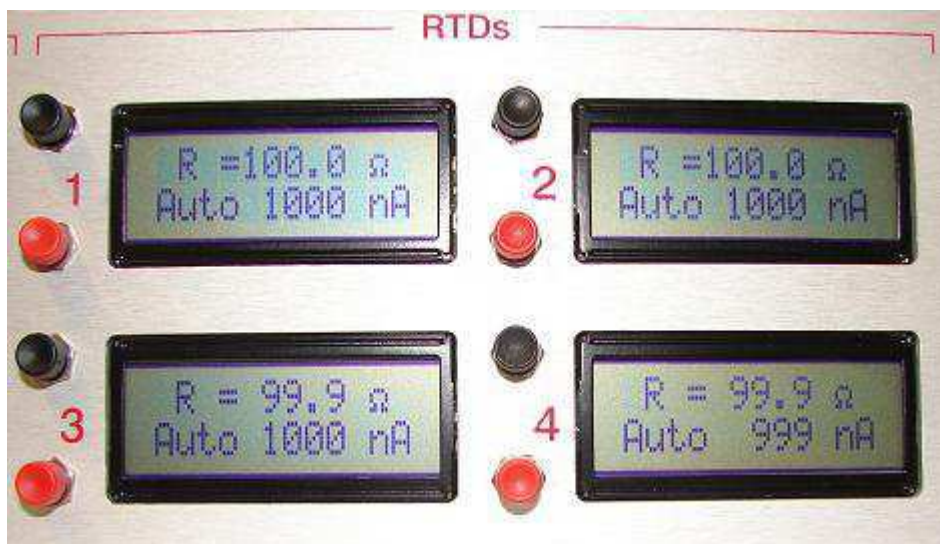


Fig. 6. The four RTD channels and the push button controls

Main menu

The main display on powering up the unit gives the resistance of the four RTD channels. The bias current through the RTD is displayed. Press the red button to swap between the Auto range and User range. On Auto range the current will be set at the highest value that will maintain the RTD voltage

below the set maximum RTD voltage, V_{\max} (see below). For a system working optimally, and using version 2b of the RTD chip, the current values are 1, 10, 100, or 1000nA.

I drive menu

Press the black button once from the main menu to go this menu.

If the main display above was set to Auto the current cannot be manually adjusted, i.e. I-drive cannot be selected. If User mode was selected in the main menu, then the red button can be pressed to decrease the current until it reaches 'minimum'. The current cannot be increased in User mode. To do this return to the main display and select Auto whereby the current will increase to a level limited by V_{\max} . The current should be decreased if V_{\max} is set to 100 μ V and you are worried about heating in the RTD.

RTD maximum voltage, V_{\max} , menu

Press the black button twice from the main menu to access this.

There are two V_{\max} settings available. These are 100 μ V and 1000 μ V. Press the red button to toggle between them. Use 100 μ V if you are worried about heating in the RTD.

Quadrature voltage, V_q , menu

Press the black button three times from the main menu to display this.

This locks-in the voltage across the RTD. I is set through the RTD and the voltage V is read back. If the voltage is not completely in-phase with the drive, a voltage V_q results that is 90° out of phase with the drive. To reduce V_q to a minimum value, which is required for optimum accuracy, it is necessary to re-zero by pressing the red button. $V_q = 1\%$ gives an error less than 0.02% in resistance.

Enter menu prompt

Note that these functions are available through the web interface

Press the black button four times from the main menu again to access an 'Enter Menu' prompt.

Press red to enter this menu and then cycle through the options by pressing the black button. Pressing the black button cycles through the following options. Press the red button to adjust a particular option.

- Increase the 'lock-in' phase. This will change V and V_q . Unscaled V_q is displayed as a difference
- Decrease the 'lock-in' phase. This changes V and V_q . Unscaled V_q is displayed as a difference
- Drive on/off. Setting this to off sets the ac drive to the RTD to zero. Note that if the RTD is open circuit a large dc component can result from the constant current drive.
- Decrease the drive (bias) frequency (arbitrary units, approx Hz*10)
- Increase the drive (bias) frequency (arbitrary units, approx Hz*10)
- Information screen. Displays range (binary), and unscaled V , V_q and I . These are for service use.
- Averaging. Take the mean of several readings. Set the number of readings to average over. Choose from increasing powers of 2 from 1 to 64. This applies to the front panel readings only
- Re-start. Reboot that channel. Contact QMC if it becomes necessary to use this function
- Exit. Return to the main menu

From an operational point, it is usual to leave the RTD settings on Auto, V_{max} on $1000\mu V$ unless temperatures are very low, and occasionally re-zero the quadrature component.

Operation using a PC web interface

An ethernet port on the back of the unit enables it to be connected to a network and, provided that the infrastructure is present, accessed from any point in the world using any supported internet enabled device, such as a PC or mobile phone.

Fig. 7 below provides a schematic of the set up:

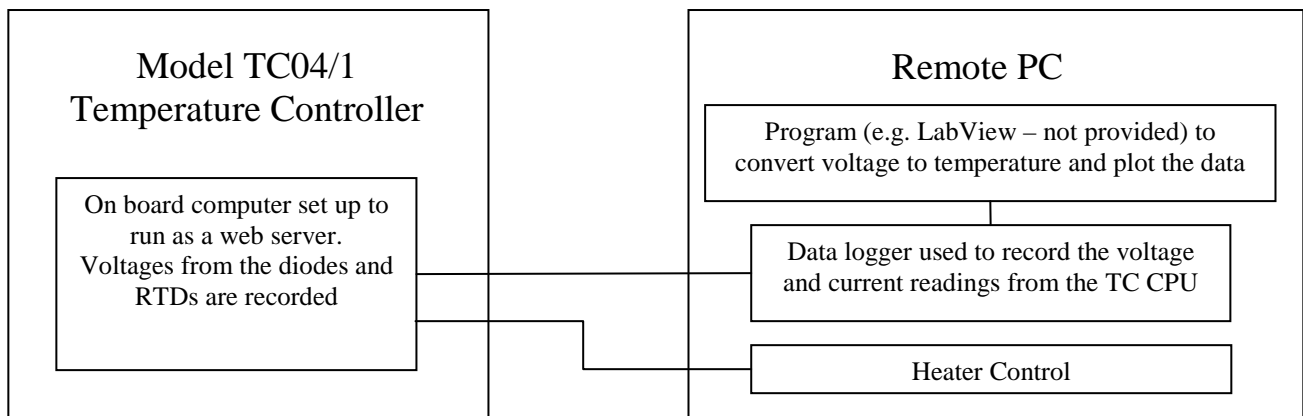


Fig. 7. PC – Temperature controller interface

The temperature controller CPU is a SNAP module from Imsys Technologies. It is set up to run a webserver, and it measures the voltages from the diodes and RTDs. Data is transferred using the I2C bus. A data logging program on the host PC can record the diode and RTD voltage / current values. By using a program on the remote PC, such as LabView (not provided), the output voltages can be converted to temperature and the results plotted. The user will need the diode / RTD calibration curve appropriate to those used in their system for this.

The ethernet cable provided can be used to talk to the SNAP webserver via a switch. To connect directly to the temperature controller from a PC a CAT5e cross-over cable (not supplied) or CAT5e cross over coupler will be needed. The unit will take a couple of minutes after switching on to boot, and for the webserver to run. Once it has booted enter the SNAP IP address into a web browser and the pages served from the SNAP can be browsed.

A local PC can be used to store data and display the results. Note that the protocol currently used is the non-secure http, and not https.

Figs. 8 and 9 show example diode and RTD readouts.

Channels	Ch.1	Ch.2	Ch.3	Ch.4	Ch.5	Ch.6	Ch.7	Ch.8
Diodes A	311.5 K	309.8 K	310.9 K					
RTD 1-4								
Channels	Ch.1 (V)	Ch.2 (V)	Ch.3 (V)	Ch.4 (V)	Ch.5 (V)	Ch.6 (V)	Ch.7 (V)	Ch.8 (V)
Diodes A	0.392	0.389	0.391	0.016	0.007	0.007	0.008	0.008
Channels	V1 (μV)	V1q (μV)	I1 (nA)	R1 (Ω)	V2 (μV)	V2q (μV)	I2 (nA)	R2 (Ω)
RTD 1-2	100.050	3.050	100.125	1000.96	99.975	6.550	99.950	1001.89
Channels	V3 (μV)	V3q (μV)	I3 (nA)	R3 (Ω)	V4 (μV)	V4q (μV)	I4 (nA)	R4 (Ω)
RTD 3-4	99.425	8.650	99.775	998.01	99.375	10.850	99.800	999.66

Fig. 8. Full Dewar readout page showing current diode and RTD values

RTD	I range	Auto I	V max	Binning	Freq.	Drive	Phase	Auto 0	
1	100 nA	<input checked="" type="checkbox"/>	100 μV	1	177	<input checked="" type="checkbox"/>	90		Start Update
2	100 nA	<input checked="" type="checkbox"/>	100 μV	1	147	<input checked="" type="checkbox"/>	90		Start Update
3	100 nA	<input checked="" type="checkbox"/>	100 μV	1	124	<input checked="" type="checkbox"/>	90		Start Update
4	100 nA	<input checked="" type="checkbox"/>	100 μV	1	104	<input checked="" type="checkbox"/>	90		Start Update
All									Start Update

Fig. 9. RTD control page

When the temperature controller is switched on, it boots up a telnet server, web server and ftp server. The web server loads up the:

- Dewar.xml file which contains the operating modes for your system. An example xml file is shown in Appendix B
- Dewar.props file which contains for example the heater channel names

The code is parsed and starts in the default idle state. Data can now be viewed through the web connection and clients on remote PC's can talk to the TC CPU to receive data. Figs. 8 and 9 above are examples of the web pages served.

Settings

The IP settings for this SNAP are:

- IP address 141.108.12.126
- Netmask 255.255.255.0
- Gateway 141.108.12.254
- MAC address 00:0b:b9:bc:f8:4b

The user accounts on the SNAP can be accessed via telnet or ftp. The following user accounts are available.

Root user	Root password	Web user	Web password
root	RTDroot	web	RTDweb

The IP settings (IP address, subnet mask, gateway etc) can be altered by the user. A method using the ethernet cable is outlined below.

1. Connect the Temperature Controller up to a local computer using the ethernet cable
2. Assign IP settings to the computer so that it is on the same subnetwork as the Temperature Controller. For the above assigned values a netmask of 255.255.255.0 and an IP address of 141.108.12.x where x is in the range 0 to 255, excluding 126.
3. Open a Telnet connection to the Temperature Controller. Use the IPCONFIG command to assign a new IP address to the Temperature Controller.
4. The Telnet connection to the Temperature Controller from the computer drops when this is assigned because they are no longer on the same subnet. Leave the telnet window open.
5. Assign IP settings to the computer so that it is on the same (new) subnetwork as the Temperature Controller.
6. Return to the Telnet window which now should be able to access the Temperature Controller and assign the new subnet mask / gateway and commit the changes to the SNAP.

Appendix A. Detailed Specification

Heater Supplies

- Six heaters
- Relay isolation when off (the heater negative wire is still connected via 100ohms to cryostat earth)
- Front panel override and monitoring
- Open circuit detection
- Maximum voltage = 25V
- Maximum current approx 100mA

Diode Readouts

- Eight channels
- Drive current = 10 μ A
- Maximum voltage sense = 2V
- Accuracy = 0.2%
- Resolution = 0.5mV via the network interface; 1mV on the front panel
- Block disable to shorts out all diodes (available via Ethernet only)

RTD Readouts

- Four channels. Non multiplexed
- Resistance up to 1M Ω
- Constant sinusoidal current drive, 1nA to 1000nA
- Frequency. Approx 10Hz to 20Hz
- Voltage sense: 100 μ V or 1mV ranges. In-phase and quadrature measurements. This ensures that phase changes due to wiring and circuitry can be accommodated
- Current sense: 1nA to 1000nA ranges (matches drive). In-phase measurement only
- Phase control: +/- 20 deg
- Resolution: As a percentage of the maximum resistance measurable on any decade range, this is 0.025% (network interface) or 0.1% (front panel). For example, at a drive of 1nA and a maximum voltage of 100 μ V the maximum resistance measurable is 100k Ω , giving a network interface resolution of 25 Ω and a front panel resolution of 100 Ω .
- Absolute accuracy of resistance measurement: 0.4% (<100k Ω) ambient temperature 15C to 25C
- Ground isolated preamp on cryostat for each channel

Interface

- Ethernet. Cat-5e cabling.

Control Computer

- Built-in embedded Java computer
- Provides control functions and thermometer readout
- Heaters may be controlled according to a user script, e.g. for recycling a helium sorption fridge
- RJ45 socket provides direct connexion to the ethernet
- Control and diagnostics are available through a web interface
- Serves readout data to clients across the network
- Client for Windows, provide tabular data and logging
- Open source client libraries for Windows and Linux supplied for application extension

Appendix B. Example xml file showing fridge control cycles

```

<?xml version="1.1"?>

<!-- Trial Dewar definition - Simon Melhuish -->
<!-- Changes 15/11/04 (Gareth): -->
<!-- Modified for 2 stage in VeriCold system-->
<!-- Changed precool conditions to allow for poorer PT
performance-->
<!-- Changes 19/01/05 (Gareth): -->
<!-- Allow 4He to condense longer (10mins) -->
<!-- Added auto recycle state -->
<!-- Changes 19/07/05 (Gareth): -->
<!-- Changed precool condition to that for Diode BC32 -->

<dewar>
<defaultstate>idle</defaultstate>
<state name="idle">
<actions>
<message>Idle</message>
</actions>
<!-- This is the idle state. Do nothing. Wait for nothing. -->
</state>

<state name="precool">
<actions>
<message> System is pre-cooling</message>
<heater chan="1" V="3.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="0.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
<if goto="start">
<and>
<diode chan="2" greaterthan="1.75892"/><!-- 3.4 K -->
<grt chan="1" greaterthan="123"/><!-- < 3.5 K -->
</and>
</if>
</tests>
</state>

<state name="start">
<!-- This is where we start recycling. Turn off everything -->
<actions>
<message>Start fridge cycle</message>
<heater chan="1" V="3.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="0.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
<if goto="heat4He">
<!-- Allow 2 mins for heat switches to go off -->
<timeout time="10" since="start"/>
</if>
</tests>
</state>

<state name="faststart">
<!-- This is where we start recycling. Turn off everything -->
<actions>
<message>Execute a fast start from "cold"</message>
<heater chan="1" V="15.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="0.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
</tests>
</state>

<state name="heat4He">
<!-- Wait in case 4He not hot enough yet -->
<actions>
<message>Started condense 4He</message>
<heater chan="1" V="5.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="0.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
<if goto="condense4">
<diode chan="3" lessthan="1.103"/>
<!-- wait for > 30 K -->
</if>
</tests>
</state>

<state name="condense4">
<!-- Wait for 4He to condense - heater already hot -->
<actions>
<message>Waiting for 4He condensation</message>
<heater chan="1" V="3.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="0.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
<if goto="pump4">
<!-- Wait 10min for He to condense -->
<timeout time="600" since="condense4"/>
</if>
</tests>
</state>

<state name="pump4">
<!-- Start to pump 4He, by turning off H4 and turning on HS4
-->
<actions>
<message>Started pump 4He</message>
<heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
<heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
<heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
<heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
</tests>
</state>

```

```

    <!-- Normally we will wait a set time to start condensing
3He -->
    <timeout time="300" since="pump4"/>
    </if>
</tests>
</state>

<state name="heat3He">
<!-- Start to condense 3He, by turning up the heater -->
<actions>
    <message>Started condense 3He</message>
    <!-- Heater 4 is 3He -->
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="10.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="condense3">
    <!-- Wait 1000s for T to rise, and He to start condensing --
>
    <timeout time="1000" since="heat3He"/>
    <diode chan="4" lessthan="1.07"/>
    <!-- wait for > 50 K -->
    </if>
</tests>
</state>

<state name="condense3">
<!-- Set normal condensation voltage -->
<actions>
    <message>Waiting for 3He condensation</message>
    <!-- Heater 4 is 3He -->
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="Wait4He">
    <!-- Wait 2min to settle -->
    <timeout time="120" since="condense3"/>
    </if>
</tests>
</state>

<state name="Wait4He">
<actions>
    <message>Waiting for 4He to cool</message>
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="Wait4HeEx">
    <or>
        <grtdot chan="1" lessthan="0" samples="300"/>
        <!-- wait for temp to flatten out -->
        <grt chan="1" greaterthan="875"/>
        <!-- wait for < 0.95K -->
    </or>
    </if>
</tests>

```

```

</state>

<state name="Wait4HeEx">
<actions>
    <message>Waiting for 4He exhaustion</message>
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="5.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="0.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="pump3">
        <grtdot chan="1" lessthan="-0.042" samples="300"/>
        <!-- wait sharp temperature rise -->
    </if>
</tests>
</state>

<state name="pump3">
<!-- Start to pump 3He, by turning off H3 and turning on HS3
-->
<actions>
    <message>Started pump 3He</message>
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="0.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="3.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="running">
        <grt chan="1" greaterthan="23000"/> <!-- 0.351 K -->
    </if>
</tests>
</state>

<state name="running">
<actions>
    <message>Fridge cold!</message>
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="0.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="3.0"/> <!-- HS3 - 3He switch -->
</actions>
</state>

<state name="AutoRecycle">
<!-- Put into this state when running, to automatically recycle
fridge -->
<actions>
    <message>Ready to auto recycle</message>
    <heater chan="1" V="0.0"/> <!-- H4 - 4He pump -->
    <heater chan="2" V="0.0"/> <!-- H3 - 3He pump -->
    <heater chan="3" V="3.0"/> <!-- HS4 - 4He switch -->
    <heater chan="4" V="3.0"/> <!-- HS3 - 3He switch -->
</actions>
<tests>
    <if goto="faststart">
        <grt chan="1" lessthan="800"/> <!-- about 1 K -->
    </if>
</tests>
</state>

</dewar>

```


Appendix C. Connection Diagram

TEMPERATURE CONTROLLER REAR PANEL CONNECTIONS						
Diodes 25 way D-plug		Heaters 25 way D-socket		RTDs (2 connectors) 15 way D-sockets ‡		
Pin	Allocation	Pin	Allocation	Pin	Allocation	
1	D1 anode	1	Heater 1 positive	1	Drive	
2	D2 anode	2	Heater 1 return †	2	Isense	1 or 3
3	D3 anode	3	Heater 2 positive	3	Vsense	
4	D4 anode	4	Heater 2 return †	4	-15V	
5	D5 anode	5	Heater 3 positive	5	+15V	
6	D6 anode	6	Heater 3 return †	6	Vsense	
7	D7 anode	7	Heater 4 positive	7	Isense	2 or 4
8	D8 anode	8	Heater 4 return †	8	Drive	
9	<i>Not connected</i>	9	Heater 5 positive	9	D&I return	1 or 3
10	<i>Not connected</i>	10	Heater 5 return †	10	V return	
11	<i>Not connected</i>	11	Heater 6 positive	11	-15V (<i>Not connected</i>)	
12	<i>Not connected</i>	12	Heater 6 return †	12	Rack earth	
13	<i>Not connected</i>	13	Cryostat 0V	13	+15V (<i>Not connected</i>)	
14	D1 cathode	14	<i>Not connected</i>	14	<i>connected</i>	
15	D2 cathode	15	<i>Not connected</i>	15	V return	2 or 4
16	D3 cathode	16	<i>Not connected</i>		D&I return	
17	D4 cathode	17	<i>Not connected</i>			
18	D5 cathode	18	<i>Not connected</i>			
19	D6 cathode	19	<i>Not connected</i>			
20	D7 cathode	20	<i>Not connected</i>			
21	D8 cathode	21	<i>Not connected</i>			
22	<i>Not connected</i>	22	<i>Not connected</i>			
23	<i>Not connected</i>	23	<i>Not connected</i>			
24	<i>Not connected</i>	24	<i>Not connected</i>			
25	<i>Not connected</i>	25	<i>Not connected</i>			

Table C.1. Pin Connection Diagram on the rear panel of the Temperature Controller

† Each return connected via 10Ω to Cryostat Earth

‡ These cables are 4 cable pairs individually screened with overall screen

AMPLIFIER BOX CONNECTIONS TO THE SYSTEM				
Diodes 25 way D-plug	Heaters 25 way D-socket	RTDs (2 connectors) 15 way D-sockets †		
As in Table C.1	As in Table C.1	Pin	Allocation	Wire
		1	Drive +	Red
		2	Drive -	Green
		3	Sense -	Blue
		4	Sense +	Yellow

Table C.2. Pin Connections

Contract details and guarantee

This equipment is guaranteed for a period of two years from the date of delivery against failure caused by defective materials or workmanship. Defective parts will be repaired or replaced on return to the final supplier at no cost, provided that failure is not due to misuse or mishandling after delivery. QMC Instruments Limited will assume no liability for loss of life or damage to property arising from the use or misuse of its products.

Purchase Order N^o
Purchase Order Date
QMCIL Reference
Temperature Controller Serial N^o

On receipt of your shipment

Please check that your equipment has arrived safely. Please advise QMC Instruments if you suspect any damage has been incurred during transport and delivery, or if any of the items are missing.

This operating manual contains instructions for operation of the temperature controller and amplifier. The user is advised to read this document carefully prior to operation of the temperature controller and amplifier and is reminded that our guarantee will be invalidated if the equipment is damaged through misuse.

Signed.....
Ken Wood, Director, QMC Instruments Ltd.

Date.....

QMC Instruments technical staff will be happy to advise you if you have any questions or difficulties. The contact details are:

Ken Wood (Sales and Marketing Director)
QMC Instruments Ltd
Cardiff University
School of Physics and Astronomy
Queens Buildings
The Parade
Cardiff
CF24 3AA
UK

T. +44 (0) 29 2045 1071
F. +44 (0) 29 2045 1271
E. k.wood@terahertz.co.uk
www.terahertz.co.uk