Operator's Handbook

ITC503

Temperature controller

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OXFORD INSTRUMENTS

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Warnings

Before you attempt to install or operate this equipment for the first time, please make sure that you are aware of the precautions that you must take to ensure your own safety.

Caution If you change set-up data and want it to be retained after power down, the data must be deliberately STORED as described in section 5.6.

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1 Safety

The following general safety precautions must be observed during the operation, service and repair of this instrument.

1.1 Protective Ground

To minimise shock hazard the instrument must be connected to an electrical ground. The ground wire (green/yellow) in the instrument power cable must be connected to the installation electrical ground system. Do not use extension cords without a protective earth conductor. Do not disconnect the protective ground inside or outside the instrument. Do not have external circuits connected to the instrument when its protective ground is disconnected.

1.2 Repair and Adjustment

Ensure that the instrument is disconnected from the AC power supply (switching off the front panel POWER switch is not sufficient) before the covers are removed or fuses are replaced, otherwise dangerous voltages are accessible. Capacitors inside the instrument and power connector filter, if fitted, may remain charged after removal of AC power. These should be discharged before starting work.

For fault finding and calibration, the AC Power supply may require reconnection. This work may only be carried out by skilled personnel who are aware of the hazard involved.

2 Introduction

2.1 Use of this Manual

This manual provides operating and service information for the Oxford Instruments Intelligent Temperature Controller model ITC503.

Sections 1-4 provide essential information and should be read before operating the instrument for the first time.

The remainder of the manual provides more detail on specific aspects and may be referred to as required. Section 16 attempts to identify some of the more common operating pitfalls and may be useful if problems are encountered.

Users already familiar with the ITC4 or ITC502 Temperature Controller, should refer to Section 17, which lists the differences between these controllers and the ITC503.

Two other short documents are provided and you may find them useful to help you to run the ITC503:

a) Quick start - ITC502 and ITC503 temperature controllers.

b) Setting up sensors on an ITC5 - How to change the set-up.

2.2 Description of ITC503

ITC503 is a high performance laboratory temperature controller, with a number of features specifically intended for use in cryogenic applications. In its most common application ITC503 will be used to control the temperature of some "sample", the properties of which are being investigated as a function of temperature. The sample will have a sensor monitoring its temperature, and a heater and/or some means of cooling, whereby its temperature may be varied. The whole will normally be surrounded by some form of thermal insulation to isolate the sample from its environment. In this manual the term "sample" will be used to refer to any object being controlled and the term "system" will be used to refer to the complete assembly.

ITC503 is a microprocessor based instrument and is controlled by an operating program contained in a programmable memory chip (EPROM). This program is referred to as the ITC503 **firmware**. The firmware is coded with a two part number (for example 1.01) where the first digit indicates a major version of the firmware and the second two digits cover minor revisions.

The basic ITC503 includes a single input channel for one sensor. A further two independent input channels may be added for systems with more than one sensor.

For use in cryogenic applications ITC503 can accept a wide range of different temperature sensors and can provide up to 80W of heating power. In addition it contains internal logic to drive a motorised valve as a means of controlling sample cooling in a continuous flow cryostat. ITC503 displays the sample temperature on a four and one half digit display, covering a range of up to -19999 to +19999 for Centigrade ranges.

For cryogenic ranges, temperatures are displayed in Kelvin and the display is able to auto-range, to display low temperatures to greater precision. With an appropriate sensor ITC503 can provide a display resolution of 1mK for temperatures below 20K.

Manual operation of the controller is by means of front panel push buttons and associated status lamps.

Remote computer control and monitoring is possible by means of built-in RS232 (Serial) or GPIB (IEEE-488) Interfaces, both fitted as standard to ITC503.

The controller incorporates a number of safety features to prevent damage to the system if a fault should occur in the sensor or the controller itself. Where three sensors are fitted, all are continuously monitored for over-temperature, irrespective of which sensor(s) are selected for control and display.

Sensor calibration data and many of the controller operating parameters are held in a non-volatile memory, which is retained when the controller is switched off.

ITC503 offers automatic selection of appropriate control parameters (PID values) for operation throughout its working range. These parameters may themselves be "learnt" for a particular system, by use of ITC503 operating in conjunction with the Oxford Instruments Object-Bench software, supplied with the instrument.

3 Installation

3.1 Supply Connections

Before applying power to the instrument, ensure that the voltage selector on the rear panel is correctly set for the intended supply voltage.

If necessary, open the voltage selector panel using the slot provided, withdraw the voltage selector and replace it in the correct orientation for the intended voltage. Check that the correct fuses are fitted, then close the voltage selector panel.

Fuse ratings are:

100-120v1.6A Type T (Slow Blow)
200-240v0.8A Type T (Slow Blow)

3.2 Heater and Sensor Connections

Connections to the heater and sensor are by means of a 9 way D-socket on the rear panel. Where more than one input channel is fitted, separate connectors are used for each channel. The pin connections are the same for each channel and the heater connections are brought out in parallel on each channel.

Pin connections are:

1 Input High
2 Input Low for Normal Applications
3 Input GND (Linked to pin 2, isolated from supply GND)
4 Current Source +ve
5 Current Source -ve
6 Heater Output +ve
7 Heater Output -ve
8 Input Low for Thermocouples with RT Ref. Junction
9 Chassis Ground

Connections between this socket and the actual sensor will vary with the type of sensor in use, as shown in the table below.

	Thermo-couple	**Metal Resistor**	**Ge/Carbon Resistor**	**Si/GaAs Diode**
Input High	V+	V+	V-	V-
Input Low	V-	V-	V+	V+
Current +ve	n/c	I+	I+	I+
Current -ve	n/c	I-	I-	I-

Note that the polarity of the voltage input connections is reversed for semiconductor resistors and diodes. For these sensors, the sensor resistance or sensor voltage falls with increasing temperature.

For some thermocouple ranges a room temperature reference junction may be used. (Not recommended for cryogenic applications). It is important to note that the room temperature compensating sensor is mounted at the rear panel of ITC503. To get accurate compensation it is essential that the thermocouple reference junction is at the same temperature. This in turn means that the cable linking the sensor to ITC503 must use thermocouple compensating cable. If the rear panel in the region of the connector is likely to be exposed to temperature fluctuations, it will be an advantage if a draught shield is placed around the plug, and the Room Temperature sensor, positioned immediately to its right.

The Input connections are electrically isolated from the controller ground and the chassis ground. The Heater Output connections are electrically isolated from the input ground, the controller ground and the chassis ground. All these connections are capacitatively coupled to chassis ground with capacitors rated at 50V so should not be taken more than 50V from earth potential.

Where more than one input channel is fitted there is also electrical isolation between separate input channels.

3.3 RS232 Serial Data Line Connections

The bi-directional serial data link from the computer is connected via a 25 way D-socket on the rear panel. ITC503 is configured as a DCE with the standard pin outs given below. The majority of computer RS232 interfaces are configured as a DTE and are fitted with a 25 way D plug. For this type of connector, a simple lead connecting pin 1 to pin 1, pin 2 to pin 2 and so on is all that is required. For computers fitted with a 9 way D plug for RS232, (AT style COM port), a standard "AT lead" fitted with a 9 way socket and a 25 way plug is required.

Pin connections at the ITC503 RS232 socket are:

Pin	Signal Name	Notes
1	FG	Linked to Chassis Ground in ITC503
2	TD	Data from Computer to ITC503
3	RD	Data from ITC503 to Computer
4	RTS	Linked to Pin 5 in ITC503
5	CTS	Linked to Pin 4 in ITC503
6	DSR	Linked to +5V when ITC503 is powered
7	SG	Linked to Digital Ground in ITC503
8	DCD	Linked to +5V when ITC503 is powered

All other pins are open circuit.

ITC503 does not require signals to be present on any of the "modem control" lines, RTS or DTR (pin 20). RTS is looped back as CTS and logic high levels are returned on DSR and DCD to ensure maximum compatibility with any requirement of the computer.

Voltage levels for the transmitted and received data are:

Tx Data High	> +5.5V
Tx Data Low	<-5.5V
Rx Data High Threshold	< +2.6V
Rx Data Low Threshold	> +1.4V
Max Rx Input Voltage	+/-30V

Data protocols are:

Baud Rate	9600
Tx Start Bits	1
Tx Data Bits	8
Tx Stop Bits	2
Rx Start Bits	1
Rx Data Bits	8
Rx Stop Bits	1 or 2
Parity	None

3.4 The Oxford Instruments ISOBUS

A unique feature of ITC503 and other Oxford Instruments products, is the ability to connect a number of instruments simultaneously, to a single RS232 port on a computer and to control each one independently. This is done by means of an ISOBUS cable which carries a single MASTER connector (25-way D socket) and up to eight, daisy-chained SLAVE connectors (25-way D plugs). Each slave connector incorporates full optical isolation so that the slaves are all isolated from the master and from each other. The slaves connectors draw their power from the individual instruments, via the DCD signal on pin 8. The master connector may draw its power from either DTR or RTS signals from the computer.

To use ISOBUS, a special communication protocol is required, which is part of the command structure of Oxford Instruments' products and is described in section 8.5.

3.5 GPIB (IEEE-488)

Connections to the GPIB are made via a standard 24 way GPIB connector. Assignment of the connector pins conforms to the standard IEEE-488.1. Connections should be made using a standard GPIB cable.
GPIB connections should never be made or broken whilst the controller or any of the instruments connected to the Bus are powered up. Failure to observe this precaution can result in damage to one or more instruments.

The GPIB interface complies fully with IEEE-488.1-1987 as a talker/listener, able to generate service requests and respond to serial poll and device clear commands. It does not support parallel polling and has no trigger function. Open collector drivers are used on the bus lines so it does not prevent parallel polling of other devices on the bus. Its complete GPIB capability is specified by the Capability Identification Codes:-

SH1 AH1 T6 L4 SR1 RL0 PP0 DC1 DT0 C0 E1

Two lamps are fitted to the rear panel immediately below the GPIB connector, to assist in diagnosing any GPIB communication problems. The RED lamp lights whenever the ITC503 is addressed to TALK and the GREEN lamp lights whenever it is addressed to listen. The behaviour of the lamps is very dependent on the GPIB controller in use. Some controllers un-address an instrument at the end of any transaction, in which case the lamps will just blink on for each transaction. Others leave instruments addressed between transactions in which case one or other lamp may remain lit depending on whether ITC503 was last addressed to talk or to listen.

Before any communication can occur, ITC503 must be given a unique GPIB address. By default, ITC503 is supplied with its address set to 24. If this address is already in use by another instrument on the bus, it can be changed from the front panel via the Test Mode. This is described in section 7.5.

3.6 The GPIB to ISOBUS Gateway

An ITC503 fitted with a GPIB interface has the ability to act as a GATEWAY to an ISOBUS cable, allowing other instruments to be linked to the GPIB without themselves requiring GPIB interfaces. This can enable other Oxford Instruments' products, for which an internal GPIB interface is not available, to be linked. It offers the additional advantage of optical isolation between these instruments and the GPIB.

To use the gateway, all that is required is GATEWAY MASTER ADAPTOR. This allows the 25 way ISOBUS MASTER socket to be linked to the 25 way RS232 socket on the ITC502 The adaptor is a symmetrical 25-way plug to 25-way plug link, with pin connections as shown below.

N.B. Beware of using 25-way plug to 25-way plug adaptors, sold as "DCE-linkers" by some suppliers. A variety of different conventions exist for these, not all of which will work as a Gateway Master Adaptor. The correct adaptor may be obtained from Oxford Instruments.

25 WAY PLUG	25 WAY PLUG
1	1
2	3
3	2
7	7
6	4
4	6

The necessary protocols for use as a Gateway Master are included as standard in ITC503 and are described in section 8.6.5.

3.7 Auxiliary Port Connections

The auxiliary port serves five separate functions.

a) It provides a stepper motor drive and sense input for use with an automatic gas flow control accessory (AutoGFS). Alternatively it provides a compressor enable signal for use with a cryocooler system

b) It provides an over-ride input to disable the heater output. This is intended for use with a separate over -temperature cut-out switch and displays the message "Hot 0".

c) It provides a pseudo-analogue temperature output for use with a chart recorder. (Should be used in conjunction with the Oxford Instruments Chart Recorder output lead, which incorporates the necessary pull-up resistor and passive filter). A second pseudo-analogue output mimics the setting of the Gas Control output to control a variable speed cryohead for use with a cryocooler system.

d) It provides drive signals to one or more external heater select relays for systems with more than one heater.

e) It provides control signals for the high power output unit OP3KW MkII, if fitted.

Connections to the port are by means of a 15-way D-socket on the rear panel.

The outputs are open-collector transistors (Specification as for ULN2803A) and can sink up to 500mA from a supply of up to 25 volts maximum. When driving an inductive load, it is recommended that a diode is connected across the load to absorb the stored energy.

For low power loads, current may be drawn directly from pin 15, which is connected via a diode and fuse, to the internal unregulated 11 volt line. A maximum total current of 500mA may be drawn from this source.

Heater-2 select relay is energised when controlling on Sensor 2. Heater-3 select relay is energised when controlling on Sensor 3. Neither relay is energised when controlling on Sensor 1.

The input lines on the auxiliary socket are suitable for either TTL level inputs or contact closures to +5v. The input device is a 74HC244 and 100K ohm pull-down resistors to 0v are fitted.

The AutoGFS sense input on K5, should be linked to +5v when an AutoGFS is connected.

If a thermal shut down device is connected to socket K7, it should be connected such that an overtemperature will pull the pin above 2.5 volts. The internal 100K resistor may be shunted by an external resistor, if required to match a sensor characteristic.

Pin connections at the Auxiliary socket are:

1	Output Bit 0(Stepper Motor) / Compressor Disable
9	Output Bit 1(Stepper Motor)
2	Output Bit 2(Stepper Motor)
10	Output Bit 3(Stepper Motor)
3	Output Bit 4(Heater-2 Select Relay)
11	Output Bit 5(Heater-3 Select Relay)
4	Output Bit 6(Pseudo-Analogue Gas Control o/p)
12	Output Bit 7(Pseudo-Analogue Temperature o/p)
5	Input K4(Auto GFS Sense)
13	Input K5(Spare)
6	Input K6(Spare)
14	Input K7("Hot 0" Shutdown)
7	+5v
15	Driver Protection / +11v unregulated.
8	0v

3.8 Analogue Output

The pseudo-analogue output on pin 12 of the auxiliary port is intended to drive a chart recorder for trend monitoring. The pin is alternately pulled to 0v and released with a time dependent waveform, the mean value of which represents the analogue output. To use the output, a pull-up resistor should be fitted to a suitable reference voltage (not greater than 25V). A passive filter with a cut-off frequency of about 1Hz should be connected between this pin and the chart recorder input. A Recorder Output Lead, including a pull-up to +5V and a 2 stage passive filter, is available as an optional accessory if required.

The analogue output always indicates the temperature for the current display channel. Thus the DISPLAY SENSOR button may be used to select any sensor for trend monitoring. The output is always scaled to cover the full working range of the instrument (0 to 1677.7K)

A second similar output on pin 4 monitors the current position of the gas control valve. This allows for the use of a variable speed cryohead motor, controlled by the analogue voltage when ITC503 is used in conjunction with a cryocooler.

3.9 ITC heater control board

The standard ITC, with or without the extra sensor channel interface board (SCI), has a single heater output. Hence only one heater can be connected and it is not possible to control a heater change from a computer.

The heater control board allows up to three separate heaters to be connected and these can be switched, as the sensor is switched, under computer or manual control.

By adding links on the control board, heater outputs can be associated with different sensor inputs, or with pairs of inputs. For the case where one output is associated with the three inputs, the heater control board is not required.

The heater control board plugs into the rear of the ITC without any modification.

- it can be retrofitted easily
- it operates via computer or manual control
- up to three different heater outputs can be controlled with the three sensor inputs to the ITC
- the ITC requires the SCI interface

3.10 Room Temperature Thermocouple

Reference All thermocouples have at least two active junctions. The MEASURING junction is exposed to the temperature to be measured, whilst the REFERENCE junction is held at a known reference temperature. For some applications it is convenient to allow the reference junction to be at Room Temperature (RT Reference). A separate sensor then monitors room temperature close to the reference junction and compensates for the effect of room temperature fluctuations. (RT Compensation).

For the highest precision work a fixed reference junction temperature is always preferable. However in many applications the convenience of an RT reference outweighs the slight loss of accuracy. In general, RT compensation is suitable for high temperature applications but **not recommended for cryogenic work**. There are three reasons for this:

a) Thermocouple sensitivity tends to fall at low temperatures so a small RT error will cause a larger low temperature error.

b) A given temperature error (in degrees) is more likely to be significant at low temperature than at high temperature.

c) The actual thermocouple wires must be taken all the way from the cryostat to the controller, since no compensating cable (see below) is available for common cryogenic thermocouples.

3.11 Use of RT Reference with Channel 1

The essence of accurate RT compensation is to keep the reference junction and the compensating sensor at the same temperature. ITC503 incorporates an RT sensor on the rear panel close to the SENSOR 1 connector. Thus the reference junction is assumed to be made at the connector. This is achieved by bringing the actual thermocouple wires back to the connector. Alternatively, a suitable thermocouple COMPENSATING CABLE may be used. This is cable having a thermal EMF which matches the thermal EMF of the actual thermocouple over a limited temperature range around room temperature. Its advantages are that it is less fragile than the thermocouple wire and unlike many thermocouples, need not be made from precious metals.

The ITC503 RT sensor is normally set to provide a 39 μV/degree compensation, which is correct for Chromel/Alumel and Copper/Constantan thermocouples. Other values of compensation may be obtained by changing the value of R156 on the input PCB. (Value in Ohms equals μV/degree).

For use with RT compensation the sensor connections are made to pins 1 and 8, as given in section 3.2. For best results, the connector and the RT sensor should be enclosed within a draught shield.

When RT compensation is in use, the switch settings for SW1 and SW2 on the input card, will differ from settings for the same thermocouple with a fixed reference junction temperature. Section 11.2 lists the settings for a number of common configurations.

3.12 Use of RT Reference with Channels 2 & 3

ITC503 does not have a separate RT sensor for channels 2 & 3 (where fitted). Where RT compensation is required on only one channel of a multi channel instrument, Channel 1 should be employed for this purpose.

Where RT compensation is required on more than one channel, the Channel 1 RT sensor is employed for all channels. This is achieved by linking pin 2 on the SENSOR 1 connector to pin 2 on the SENSOR connector for any other channels requiring compensation. The -ve connections for **all** thermocouples are then linked to pin 8 of the SENSOR 1 connector, whilst the +ve connections are taken to pin 1 of the individual SENSOR connectors as usual. For best results all three connectors and the RT sensor should be within a single draught shield.

Different Switch settings for SW1 and SW2 as described above, will apply on all channels where RT compensation is used.

4 Local Operation

4.1 Front Panel Controls

The front panel controls are grouped together in logically related blocks.

POWER

The main ON/OFF switch. A green lamp illuminates whenever the instrument is switched on.

ADJUST

The red RAISE and LOWER buttons provide the main means of adjusting any parameter. They have no effect on their own but are always used in conjunction with one of the other buttons. Whenever a parameter is being adjusted, its current value is shown on the main display. Setting a value involves pressing RAISE and/or LOWER until the required value is shown.

Operation of the RAISE and LOWER controls has been designed to allow large changes to be made relatively quickly whilst at the same time enabling any value to be set exactly. Pressing RAISE or LOWER briefly will cause the value to change by one unit. If the button is held in, the last figure will start to change at about 5 units per second. After 2 seconds, an approximately 10-fold increase in rate will occur, followed after further 2 second intervals by two more rate increases. Altogether there are 4 different rates. Whenever RAISE or LOWER is released, the next lower speed will be selected. This allows the user to "home-in" on the required value most ergonomically.

The position of the decimal point in the display will automatically change when the display auto-ranges.

A secondary use of RAISE and LOWER is in conjunction with LOC/REM, to enter the TEST & CONFIGURATION mode, as described below.

CONTROL

Control of the instrument may either be LOCAL from the front panel, or REMOTE via the RS232 interface. The LOC/REM button may be used to switch between LOCAL and REMOTE.

When LOCK is lit, the instrument is locked into either local or remote control and the LOC/REM button has no effect. At power up, ITC503is locked in LOCAL, since at that time the instrument has no way of "knowing" if there is a computer connected to the RS232 interface.

When ITC503 is in REMOTE, many of the front panel controls are disabled. Those controls which only affect the display, will still work but those which could change the operation of the instrument will not. If LOCK is lit whilst in REMOTE, all the front panel controls are inoperative.

The LOC/REM control button has a number of secondary SELECT functions which are obtained by pressing this button whilst one or more other buttons are held depressed. If LOC/REM is pressed whilst both RAISE and LOWER are held in, ITC503 enters the TEST mode (described elsewhere). If LOC/REM is pressed whilst the LIMIT button is held in, current calibration and configuration data is STORED in the non volatile memory and so is retained at power-up.

PID

When ITC502 is controlling a system, the Proportional, Integral and Derivative settings may either be set manually or selected automatically from the learnt characteristics of a particular system by means of the AUTO button. The AUTO lamp illuminates when auto PID settings are in use. Learning the characteristics of the system is one of the facilities provided by the Object-Bench program supplied with ITC503. It is not possible to select auto PID if no learnt data has been loaded.

HEATER

The normal way in which ITC503 effects its control, is by applying power to a heater. In MANUAL control the heater voltage may be varied by RAISE and LOWER. In AUTOMATIC control the heater voltage is varied in response to the difference between a measured temperature and a set-point.

Where more than one sensor is fitted, the SENSOR button may be used to select which sensor is to be used for control. To avoid an inadvertent change of sensor whilst ITC503 is controlling, the SENSOR button will only operate whilst the heater is in MANUAL and in LOCAL control.

In general, sensors mounted on different parts of an apparatus are likely to be at different temperatures. Hence when switching between control sensors, a change in set point will be required. ITC503 performs this change automatically. Where control has been established on one sensor, the optimum set point for the new sensor is the prevailing temperature for that sensor at the point of switch over. This is the set point that ITC503 selects.

Pressing AUTO or MAN switches between the MANUAL and AUTOMATIC states. In either case, whilst the button is pressed the main display gives an approximate indication of the output voltage. (N.B. This is not a calibrated parameter. If a particular requirement needs an accurate value for the heater voltage, a meter should be connected to the heater leads). When ITC503 is in REMOTE control, switching between AUTO and MANUAL is disabled, but it is still possible to use the buttons to display the output voltage, unless ITC503 is in LOCK & REMOTE.

A 10 segment bar-graph is provided to give a continuous indication of heater operation.

When the maximum heater voltage has been limited (see section 5), the main display will indicate the actual output voltage whilst AUTO or MAN are pressed. The bar-graph display will automatically be scaled so that an output on the limit will light all 10 bars.

GAS FLOW

A single button, with an associated lamp, allows AUTOMATIC or MANUAL control of gas flow to be selected. This is provided for use with an automatic gas flow controller accessory (AutoGFS). It may be used to vary the flow of refrigerant in the same way that the heater controls are used to vary the heating power. If an AutoGFS accessory is fitted, the GAS lamp will flash for a time after switch-on, whilst the controller establishes a reference position for the needle valve. During this time the Gas Flow Button will be disabled.

An alternative use of the GAS FLOW control is in conjunction with a cryocooler. Here the GAS FLOW control is automatically used to vary the speed of the cold head motor, to provide sufficient cooling for the desired temperature, whilst maximising the life of the cold head. In this application if GAS FLOW is set to MANUAL, at a setting of zero, the cryocooler compressor is automatically shut down.

SWEEP

The ITC503 incorporates a programmable sweep facility. This is controlled by a single RUN/PROGRAM button with three lamps. It is described in detail in section 6.

DISPLAY

The main display normally indicates the measured temperature. Two different display formats are in use for cryogenic and non-cryogenic applications.

For cryogenic ranges the temperature is displayed in Kelvin as a number in the range 0 to 1677.7K (The full working range of the instrument). No + or - sign is displayed and where an appropriate sensor is in use, the display auto-ranges as the temperature falls to give an ultimate resolution of 0.001K at temperatures below 20K. With certain sensor types, the measurement stability may be insufficient to allow resolution to 0.001K and auto-ranging will either not be available at all or will be limited to 0.01K resolution.

For non-cryogenic ranges, temperature is displayed in Celsius as a signed number in the range -273.1 to +1404.6C with either a + or a - sign displayed. Resolution is always to 0.1C and no auto-ranging occurs.

Where more than one input channel is fitted, the SENSOR button may be used to switch between input sensors. This affects only the displayed temperature, and so remains operational even in REMOTE control. Whilst the button is pressed, the display indicates the range code for the sensor being selected. This serves as a reminder of which sensor has been associated with which channel.

Pressing the SET button switches the display to indicate the set temperature. Provided the controller is in LOCAL, the RAISE and LOWER buttons may be used to adjust the set point.

Similarly, pressing the PROP, INT and DERIV buttons allows the value of the corresponding control terms to be displayed and modified.

The display block includes two additional buttons LIMIT and CAL. These are rarely used controls and are recessed behind the front panel to prevent inadvertent operation. They may be operated using a pointed object, such as the point of a pencil. Their operation is described in sections 5 and 7 respectively.

4.2 First Time Operation

Switch on the instrument by means of the POWER switch. Check that the green POWER lamp lights.

After about one second the display will show "G" followed by a number, which indicates the instrument's GPIB address (see below). Alternatively if the GPIB interface has been disabled (by setting the GPIB address to 0), the display will show "S" followed by a number, indicating the instrument's ISOBUS address. In either case, this will be followed by the word "PASS". This indicates that the ITC503 has completed its self test and initialisation.

After a further pause the internal SAFETY RELAY will close. This links the heater to the controller output. At the same time, the display will show the measured temperature for Channel 1.

If an AutoGFS accessory is fitted, the GAS FLOW lamp may continue to flash for several minutes whilst the needle valve is reset. During this period, Gas Flow control is disabled, but all other functions operate normally.

The ITC502 will now be under LOCAL control from the front panel, with the HEATER and GAS FLOW in MANUAL and the heater voltage at zero.

4.3 Sensor Selection

Pressing the DISPLAY SENSOR button will cycle the display round the three possible input sensors. (If only one channel is fitted the display will still switch between channels but will not give a meaningful reading for sensors 2 and 3). Similarly the HEATER SENSOR button may be used to select which of the three sensors is to be used for automatic control. This button is disabled unless ITC503 is in LOCAL and the heater is set to MANUAL. When changing control sensors ITC503 will automatically reset the SET temperature as described in section 4.1 under HEATER. If a Heater Select relay accessory is fitted, the appropriate heater will be selected as the control sensor is changed

4.4 Setting a Desired Temperature

Press the SET button to display the desired temperature. Whilst holding SET pressed, RAISE and LOWER may be used to change the set point.

When in REMOTE control, provided LOCK is not lit, the SET button may still be used to display the set point, but this cannot be adjusted by means of RAISE and LOWER.

4.5 Manual Heater Control

Press the Heater MAN button to select manual heater control. Whilst the button is pressed the display will indicate the approximate output voltage. (Note that this is an uncalibrated parameter and will vary to some extent with the heater loading).

Whilst MAN is pressed, the output voltage may be varied by means of RAISE and LOWER.

If the controller is in REMOTE it will not be possible to switch from AUTO to MANUAL from the front panel. However if the controller is already in MANUAL and is not in LOCK, pressing MAN will allow the output voltage to be displayed, though RAISE and LOWER will have no effect.

ITC503 incorporates "bumpless" AUTO to MANUAL and MANUAL to AUTO transitions. This means that if the controller is operating in AUTO and is switched to MANUAL the heater voltage is held constant at its existing value. Similarly if the controller is operating in MANUAL with the measured temperature equal to the set point and is switched to AUTO, the heater voltage will remain unchanged. (If the measured temperature is not at the set point, the heater voltage will of course change when switched to AUTO as the controller attempts to bring the temperature to the set point).

4.6 Automatic Heater Control

Press the Heater AUTO button to select automatic heater control. As for manual control, whilst the button is pressed the display will indicate the approximate output voltage. The heater output will be varied by the controller such that the measured temperature is brought towards the set point.

When in REMOTE, switching from MANUAL to AUTO is prevented, but pressing AUTO whilst the controller is in AUTO will allow the output voltage to be displayed, provided LOCK is not lit.

4.7 Manual Setting of P, I and D Control Terms

The PROPORTIONAL, INTEGRAL and DERIVATIVE control terms may be displayed and set by means of the PROP, INT and DERIV buttons. (Refer to section 14 for a definition of the three control terms).

PROP indicates the PROPORTIONAL BAND in Kelvin to a resolution of 0.001K (Note this marks a change from ITC4 and ITC502 where the proportional band is expressed as a percentage of the control sensor range in use. The extended precision of ITC503 arithmetic allows the proportional band to be expressed directly in temperature units avoiding any possibility of discontinuities when switching from one control sensor to another).

INT indicates the INTEGRAL ACTION TIME in minutes, covering a range of 0 to 140 minutes in steps of 0.1 minute.

DERIV indicates the DERIVATIVE ACTION TIME in minutes, covering a range of 0 to 273 minutes (Though values beyond 70 minutes are unlikely to be required in practice.).

RAISE and LOWER may be used to vary the control terms whilst in LOCAL control. Once a set of values has been chosen, they may be retained in the ITC503's non-volatile memory and will not need resetting at switch on, provided a STORE operation is performed (section 5.6).

The P, I and D terms cover a large range of values to cover systems ranging from a small laboratory cryostat to a large furnace. For most laboratory applications a PROPORTIONAL BAND of 5 to 50K will be appropriate, with an INTEGRAL TIME of 1 to 10 minutes.

The main purpose of DERIVATIVE action is to reduce overshoot, when approaching a new set temperature. For many small systems derivative action will not be required and may be left at zero. (Hold LOWER pressed for a second after 000.0 is displayed to ensure that there is not a small residual setting of less than 0.05 mins which will show as zero).

The PROP and INT controls should not normally be set to zero, since this would correspond to ON/OFF control (See section 14).

Section 14 covers the theory behind P,I,D control. However the following procedure gives a good rule-of-thumb for setting the controls to a value that is close to optimum.

a) Set INT for a time much longer than the expected response time of the system.

b) Set DERIV to zero.

c) Select AUTO and reduce PROP until the temperature starts to oscillate above and below some mean value (not necessarily the set point).

d) Time the period of oscillation (in minutes). This is a measure of the response time of the system.

e) Set INT to a value approximately equal to the response time. Then increase the PROP setting to a point where oscillation just ceases. Note the value of PROP at this point, then set it to approximately double this value. This gives a good starting point for THE PROP and INT control terms.

f) Test how the system responds to step changes in the SET point and modify the PROP and INT settings for a reasonably fast response without excessive overshoot.

g) If overshoot remains a problem following a large step change in SET, try the effect of adding some DERIVATIVE action. A good initial setting is half to one third of the system response time measured above. This will probably require PROP to be re-optimised for best results.

h) When optimising P, I and D the aim should be to achieve the lowest values of all three terms, consistent with no oscillation and an acceptably small amount of overshoot. This will give the fastest response for the system.

When adjusting the control terms remember that reducing the PROPORTIONAL BAND increases the controller gain. This can cause some confusion when the concept of PID control is first encountered.

Unlike the ITC502 there is no facility for associating PID values with each step. On the ITC503 this is acheived more simply by use of the Auto PID feature, as decribed in the following section.

4.8 Automatic Setting of P, I & D Control Terms

At cryogenic temperatures, the thermal behaviour of systems can vary widely as the temperature is varied, due to changes in specific heats and gas viscosity and density. It is therefore not surprising that changes in the values of P, I and D will be required for control at different temperatures. ITC503 allows these values to be selected automatically for different SET temperatures. The required values are held in an AUTO-PID look-up table within the instrument. This table can hold up to 32 sets of PID values. Selecting the PID AUTO function allows the values from this table to be used.

The values held in the table will be a function of the specific cryogenic system in use. ITC503 allows these values to be determined automatically by use of the AUTO TUNE algorithm, which forms part of the Object Bench software supplied with the instrument. Alternatively values in the AUTO-PID table may be entered or modified from the front panel by means of test mode 5 (See section 7.4).

4.9 Gas Flow Control

ITC503 is able to control a motorised needle valve, regulating the flow of cryogen used to cool a sample. The needle valve may either be fitted to the main cryostat, controlling the flow between the cryogen reservoir and a Variable Temperature insert, or it may be incorporated in an automated Gas Flow Syphon, linking the cryostat with a separate cryogen storage vessel. The flow dynamics of the two systems are rather different. The former will be referred to here as an Automatic Needle Valve (AutoNV) and the latter as an Automatic Gas Flow Syphon (AutoGFS).

In either case, with a motorised valve connected, the GAS FLOW lamp will flash following switch-on and the controller will drive the valve towards its closed position for a distance equal to the full travel of the valve. This ensures that the valve is fully closed (A slipping clutch operates when the closed position is reached.) During this period the HEATER controls may be operated normally, but GAS FLOW control will be inhibited.

Once the closed position has been established, GAS FLOW control may be used to control the valve. Pressing Gas Flow AUTO will toggle between automatic control of the valve (GAS AUTO lamp lit) and manual control of the valve (GAS AUTO lamp unlit). Whilst the Gas Flow AUTO button is pressed, the display will show the current position of the valve, as a percentage of fully open. If RAISE or LOWER is pressed at the same time, manual gas flow control will automatically be selected (the AUTO lamp will go out if it was previously lit) and any required valve position may be set. Note that since the new value can be set faster than the valve can follow, the valve will continue to drive after the Gas Flow button is released, until the selected position is achieved. If the button is pressed again during this process, the display will show the position the valve has currently reached. If further manual movement is required, RAISE or LOWER should again be used to specify a new target setting.

Automatic Gas flow may be used either on its own at a fixed heater setting, or more usually in conjunction with automatic heater control. (Since the control response to the gas flow regulator is much slower than that to the heater, it is normally possible to achieve a more stable control with the heater and gas flow both under automatic control).

The values of the PROP, INT and DERIV settings required for best control will not necessarily be the same for automatic gas control as for automatic heater control. Having decided upon the control mode required, the PID values should be optimised as described above. Although not normally necessary, it is possible to separately tune the gas flow control. This is described below in section 7.3.

When automatic gas control is used on its own, ITC503 attempts to control at the desired set temperature in the usual way. When automatic gas flow is used in conjunction with automatic heater control, the latter takes over responsibility of achieving the desired temperature, whilst the gas flow control attempts to maintain a specific target heater power. This target heater power is determined by the set temperature, and has been chosen to give the best balance between control stability and cryogen usage. The relationship between target heater voltage and set point temperature is determined by a **Target Table** and a **Gas Flow Scaling** parameter. When ITC503 is initially set up, a Gas Flow Configuration Parameter must be set to specify a particular Target Table and certain other parameters for Gas Flow Control. This is described in section 7.3.

4.10 Cryocooler Control

An alternative use of the Gas Flow controller is in conjunction with a Closed Cycle Cryocooler. Operation is as described above for use with an AutoGFS. Where a needle valve setting is varied for the AutoGFS, the speed of the Cold Head motor is varied on a Cryocooler. Alternatively the Cryocooler may be shut down completely by setting a value of Zero, using LOWER whilst holding the Gas Flow button pressed. This automatically turns off the Cryocooler Compressor Motor. In Cryocooler mode, there is no flashing lamp at power up, since there is no need to initialise a gas valve position.

Selecting between Cryocooler and AutoGFS modes is by means of the **Gas Flow Configuration Parameter**, described in section 7.3.

4.11 Use with OP3KW MkII

Where ITC503 is being used with a furnace for high temperature work, output powers greater than 80W may be required. The OP3KW MkII is an accessory which allows powers up to 3KW on 230V mains, or 1.5KW on 115V mains. It provides a directly switched mains output rated at 15 amps. The output is cycled on and off with a varying duty cycle, by means of a solid state switch. The switch only operates at the zero crossing points of the mains waveform, to minimise transisents and will have a minimum on or off period of 1 second. It is connected to the ITC503 via the Auxilary port. It cannot be used in conjunction with either a Cryocooler or an AutoGFS.

Selecting OP3KW mode is by means of the **Gas Flow Configuration Parameter**, described in section 7.3.

4.12 Test Mode

The operations described so far are all part of the ITC503 normal **operating mode**. An additional **test mode** is available. This provides facilities to assist in testing the ITC503 and to configure it for use with specific sensors, to configure it for Gas Flow or Cryocooler operation and to set the GPIB address for use with the GPIB interface.

Test mode is entered from the front panel by holding the two red buttons RAISE and LOWER pressed, whilst pressing and releasing the LOC/REM button. ITC503 will display the message:

tESt

to indicate that it is entering test mode. After a second this will change to;

t 00

indicating that Test 0 may now be performed. (Test 0 in fact provides the exit from test mode and restarts ITC502 for normal operation). RAISE and LOWER may be used at this point to step through the 8 possible test functions, Test 0 to Test 7. When the chosen "t" number is displayed, LOC/REM may be pressed to access the function. The following table lists the available functions.

Test 0	Restart Normal Operation
Test 1	Test Front Panel Display and Lamps
Test 2	Test Front Panel Buttons
Test 3	Set GPIB Address
Test 4	Set Front Panel Display Variable
Test 5	Display / Adjust Auto-PID Table
Test 6	Configure Gas Flow / Cryocooler
Test 7	Configure Sensor Range

Tests 1, 2 and 4 are intended to assist in fault finding and are described in detail in section4.12. Test 3 allows the GPIB address to be set and is described in section 7.5. Test 5 allows the Auto-PID table to be edited and is described in section 7.4. Test 6 is concerned with Gas Flow Configuration and is described in section 7.3. Test 7 allows sensor configuration to be selected and is described in section 11.5.

5 Limits

Limits may be placed on a number of the controller parameters, either as a means of improving control performance, or to ensure the safety of the system being controlled.

5.1 Limiting Maximum Heater Output

The normal full output of the controller is 40V which is capable of delivering up to 80W into a 20 ohm load. When controlling, it is generally desirable to achieve an approximate balance between heating and cooling such that the rate at which the temperature rises with the heater full-on is approximately the same as the rate at which it falls with the heater off. At low temperatures this can be achieved by means of a limit on the heater voltage. Once set, the limit cannot be exceeded in either AUTO or MAN.

To set a heater power limit, first ensure that the controller is in LOCAL and is switched to MAN, preferably with the heater volts set to zero. Press the recessed LIMIT button and hold it pressed. Now press the heater MAN button and release it. The display will switch to show the heater limit in volts (approximate value). RAISE and LOWER may then be used to adjust this, whilst LIMIT remains pressed.

5.2 Limiting Sensor Temperatures

A limiting value may be placed on the measured temperature. Where more than one sensor is in use, separate limits may be placed on each. All the sensors will be continuously checked against their respective limits, irrespective of which sensor is used for display or control.

The limits are set in the same way as that for output power described above. First use the DISPLAY SENSOR button to select the sensor whose limit is to be set. Press LIMIT and hold it pressed, then briefly press and release the DISPLAY SENSOR button, to indicate that a display sensor is to be adjusted. The current limiting value will be displayed and RAISE and LOWER may be used as usual to modify it. The same sequence may be repeated for each of the other sensors.

The limits should normally be set a little above the maximum operating temperature for the system.

If a limit is set to 1677.7K, it will be disabled, since it is impossible to get a measured temperature greater than this.

Warning: **An ITC503 which has not been supplied as part of a complete system, will normally be shipped with the limits disabled in this way. If your cryostat can be damaged by over-temperature, you should set appropriate limits before operating the system.**

If any limit is exceeded the ITC503 will immediately display one of the messages:

Hot 1, Hot 2, Hot 3

indicating which sensor has detected the over-temperature. At the same time the heater output voltage will be set to zero. If this causes the temperature to fall below the limit, the message will clear and normal operation will resume. If the heater is in AUTO, heater voltage will be reapplied as necessary to achieve the SET temperature. (In MAN, the heater voltage will remain at zero until a new value is selected).

If after 10 seconds the temperature is still above the limit, ITC503 will assume that a fault may have occurred in the heater circuit. It will therefore open its output safety relay, completely isolating the heater from the controller output. If this occurs the display will remain latched in the "Hot n" state, even after the system has cooled. To restore normal operation, it will be necessary to switch ITC503 off and on again.

By setting a wrong limit, it is possible to end up in a situation where the "Hot n" message is displayed from switch-on. If this occurs, refer to section 16.

5.3 Limiting Set Temperature

The Set Temperature is automatically limited to the Sensor Limit described above, for the control sensor in use. It is possible to place an additional limit (below the sensor limit) on the set temperature.

To set this limit, the SET button is pressed briefly, whilst holding LIMIT. Then RAISE and LOWER are used as above.

5.4 System Over-Temperature

Shutdown An external over-temperature limit may be connected to the AUXILIARY socket, as described in section . If this device detects an over-temperature the message:

Hot 0

will be displayed. The same protocol applies. If the condition disappears within 10 seconds, normal operation will resume. If it does not, the safety relay will open and the instrument will remain latched in the "Hot 0" state.3.4.

5.5 Limiting Display Resolution

As the temperature falls the display resolution normally increases automatically (for Kelvin ranges only). The ultimate display resolution is determined by the sensor type in use. For most ranges this will be 0.001K. For some (for example thermocouples) only 0.01K is available. In many systems the full resolution will not be necessary and it may be less distracting to limit the display resolution to less than the ultimate available for the sensor. This may be achieved using the LIMIT button as follows.

Press and **hold** the DISPLAY SENSOR button, such that the required SENSOR lamp is lit. Now press and release, the LIMIT button. The display will show:-

o.ooo

or something similar. RAISE and LOWER may be used to move the position of the decimal point within this display, which indicates how many decimal places will be be displayed at the lowest temperature. In the example shown the display will give 3 decimal places, and hence 0.001K resolution. This may be reduced to 2, 1 or even 0 decimal places if required. Where a sensor is only able to provide 2 decimal places, it will not be possible to position the decimal point to show a third place.

5.6 Storing Limits and other Power-Up Defaults

Whenever any data has been changed, which is intended to be retained after power down, this must be deliberately STORED. This write operation is achieved by holding LIMIT pressed in, whilst pressing and releasing LOC/REM. The display will briefly show "Stor" indicating that the data has been correctly stored. (It is not necessary to hold LOC/REM pressed, the complete RAM contents will always be written to the EEPROM).

If instead of showing "Stor", the display shows "Prot", this indicates that the memory is protected by the hardware WRITE-ENABLE switch being in the OFF position. This is a small 2 way Dual-in-Line switch SW2 on the motherboard. Set it to the "ON" position and try again. Only Switch No.1 of this switch has any effect but it will generally be easiest to move both parts of the switch together.

The switch need only be returned to the OFF position if it is desired to prevent any possibility of the data being changed by someone tampering with the front panel.

Any changes that are to be retained after power down must be stored in this way. This includes changes to range data, span and zero calibration, sweep values, hot limits and so on.

5.7 Temporarily Disabling Sensor Temperature Limits

(Only applies to firmware version 1.07 and later.)

There may be occasions when you wish to temporarily disable one or more of the temperature limit on one or more sensors. For example the sensor for that channel may have been disconnected or the limit may have been set to too low a value. This can be done by pressing the HEATER SENSOR SELECT button until the sensor lamp is lit for the channel you wish to disable. Whilst holding this button pressed, if you simultaneously press and release the RAISE and LOWER buttons, the limit will be disabled. If the channel was already displaying its **hot** message, this will be cleared. Note that if the output safety relay has already opened, cancelling the limit will not close the relay. If you really wish to close the relay after disabling one or more hot limits, enter the test mode by pressing RAISE, LOWER and LOC/REM, then exit again through t=0. This will restart the controller and close the relay, leaving the limits disabled.

Disabling the limits in this way will not be preserved after power off, even if you have performed a STORE operation. This is done deliberately to prevent limits being disabled permenantly by mistake.

6 Sweep

6.1 Purpose of Sweep

The sweep facility allows the set point to be programmed to follow a fixed temperature/time profile. The profile consists of a series of constant temperature steps joined by linear ramps.

A program may consist of up to 16 ramps and 16 steps. Each ramp and step may last for a period programmable from 0.1 minute to 24 hours. Once programmed, the same sequence may be repeated as often as required and if desired, may be retained in non-volatile memory when ITC503 is switched off.

The Auto-PID facility may be used in conjunction with the sweep facility to provide optimum control over a wide temperature range. (To avoid the risk of discontinuities during a sweep, it may be helpful to ensure that the start and end temperatures for the sweep ramps coincide with the Auto-PID segments).

The sweep is controlled from the front panel by a single RUN/PROGRAM button, operable only in LOCAL control.

6.2 Starting a Sweep

Press the RUN/PROGRAM button and release. The display will show

run

whilst the button is pressed and providing a program is present, the SWEEP lamp will light when the button is released. The set point will start to ramp towards the value selected for the first program step. When the first sweep time is complete, the temperature will have reached its programmed set point. The SWEEP lamp will go out and the HOLD lamp will light. This sequence will be repeated for each of the programmed steps. After the 16th step has been completed, both lights will go out and the controller will be left with the set point equal to that of the 16th step. Any steps with sweep and hold times set to zero will be bypassed. (If neither SWEEP nor HOLD lamp lights when RUN/PROGRAM is released, it means that all 16 steps have zero for both sweep time and hold time.)

Remember that the sweep facility programs the ITC503 set point. The measured temperature will tend to lag behind the set point by an amount dependant upon the response time of the system. Remember also that ITC503 must be set to AUTO if the actual temperature is to be varied!

6.3 Monitoring the Progress of a Sweep

At any time during a sweep, the HOLD and SWEEP lamps will indicate whether the set point is being ramped or held.

The SET button may be pressed at any time to indicate the current value of the set point.

If RUN/PROGRAM is pressed briefly, whilst the sweep is running, the display will indicate:

P nn

where nn is the current program step number in the range 1 to 16.

* WARNING *

Do not hold RUN/PROGRAM too long, or the sweep will be terminated, see below.

6.4 Stopping a Sweep

If left uninterrupted, a sweep program will continue till all steps have been completed. If required it can be terminated before it is complete by pressing RUN/PROGRAM, and holding it until the display changes to:

End

The sweep program will be aborted and the set point will be left at the value it had reached when the sweep was terminated.

6.5 Programming the Sweep

A Sweep Program may be entered from the front panel, starting with the controller in LOCAL. The method is as follows:

Press RUN/PROGRAM and hold it in.

Wait till the display changes from "run" to "Pro", then release the button. ITC503 is now in the program mode and the display will indicate

P 01

showing that the first program step is to be examined. (If you wait too long with the "P 01" display, ITC503 will automatically leave the program mode and resume normal operation.)

Press and hold RUN/PROGRAM and the PROGRAM lamp will light and the programmed set point for the first step will be displayed. It may be adjusted if required, in the usual way, by means of RAISE and LOWER.

Release RUN/PROGRAM and press it again. SWEEP will now light, and the sweep time taken by the controller to reach this programmed set point, will be displayed. The time is displayed in minutes with a resolution of 0.1 minute (6 seconds). RAISE and LOWER allow this to be adjusted between zero and 1339.9 minutes (24 hours).

Note that for the first step, this will be the time taken to sweep to the first set point from the set temperature when the program run commences. Thus the actual sweep rate will be recomputed for each run.

Releasing RUN/PROGRAM and pressing it again will cause HOLD to light and will display the hold time at the first temperature, again in minutes. After this has been set, RUN/PROGRAM may be released and the display will again show "P 01". If any of the settings require further modification, the sequence can be repeated as often as desired.

When all parameters associated with step 1 of the sweep have been programmed, RAISE should be pressed on its own, whilst "P 01" is displayed. The display will change to "P 02". The same sequence may then be followed to set the programmed temperature and sweep and hold times and PID values for this step.

All 16 steps may be programmed in the same way. It is not necessary to examine or program the steps in any order. Once the "P nn" display is shown, RAISE and LOWER may be used to select any step. The display rolls round from 16 to 1, so that pressing LOWER when "P 01" is displayed is a quick way of getting to "P 16".

Where a program of less than the full 16 steps is required, the SWEEP and HOLD times for all the unused steps should be set to zero. When the program is run, ITC503 will automatically bypass these steps. The programmed temperature of step "P 16" has a special significance. This is the temperature at which the set point will remain when the sweep is completed and should be set accordingly.

To escape from the sweep programming mode, simply leave the controller with no buttons pressed and "P nn" displayed. After about 5 seconds, ITC503 will switch back to a normal operating mode and display the measured temperature.

6.6 Storing a Sweep Program

If the sweep program is to be retained when the instrument is turned off, it must be stored in the EEPROM memory. This is done using the LIMIT and LOC/REM buttons as described in section 5.6.

7 Calibration and Configuration

7.1 Sensor Calibration

To match ITC503 to the exact characteristics of a specific sensor, a calibration must be carried out at the two ends of the working range. This is achieved by means of the recessed CAL button.

Use DISPLAY SENSOR to select the sensor to be calibrated.

Cool the sensor to a known temperature near to the bottom of the range, or apply an equivalent input from a calibrator. Allow the display reading to stabilise.

Press CAL. The display will initially show:

Lo

showing that the lower calibration point is to be adjusted and will then display its current value. Whilst holding CAL pressed, use RAISE and LOWER to set the correct temperature reading. ITC503will update the "ZERO" value stored in its memory.

Whilst CAL is being held, the measured input value will be frozen, to prevent any input noise confusing the adjustment. If the input is changing during the calibration process, the displayed value will change when CAL is released. In this case simply repeat the process to calibrate for the latest measured value.

Change to a temperature or calibrator input near the top of the range and repeat the process. This time ITC503 will display:

Hi

and update its stored "SPAN" value.

ITC503 will then attempt to recalculate both ZERO and SPAN values such that both calibration points remain correct, so there is no interaction between the Lo and Hi calibration. The display will blink briefly as this occurs. Any subsequent recalibration of the Lo point will preserve the most recent Hi point, and vice versa. (Only applies to firmware 1.07 and later.)

ITC503 automatically decides whether to calibrate ZERO or SPAN depending on whether the input is in the lower or upper part of its range. If the input value (mV, Ohms, Siemens and so on) is less than 25% of the full input span, the ZERO will be adjusted. If it is above this point, the SPAN will be adjusted. (The 25% point has been chosen, to allow users with a 300K range, to calibrate ZERO at 4.2K and SPAN at 77K, if this part of the range is of particular interest). Occasionally it may be helpful to over-ride this automatic detection. For example you may wish to calibrate at 77K and Room Temperature. If you hold LOWER pressed when you first press CAL, you will force calibration of the Lo point. Similarly holding RAISE pressed when pressing CAL will force calibration of a Hi point. (Only applies to firmware 1.07 and later.) You should use this technique with some caution. Having the two caibration points close together will make for a very inaccurate calibration at the ends of the range.

7.2 Storing the Calibration

Normally after a change has been made to the calibration, it is desirable that the new calibration is retained when the instrument is switched off. Thus the calibration data must be stored, using the LIMIT and LOC/REM buttons as described in section 5.6.

7.3 Gas Flow and Cryocooler

Configuration Before the Gas Flow control algorithm can be used, it must be configured for a particular combination of hardware. A number of parameters must be set:

The Valve Gearing parameter specifies the number of steps required to move the valve from its fully closed to its fully open position.

The **Target Table and Features Configuration** parameter specifies which target table is to be used, and whether certain specific features of the algorithm are to be active.

The **Gas Flow Scaling** acts as a scaling parameter on the value obtained from the target heater voltage table. Thus adjusting this parameter allows the heater voltage (and hence cryogen usage) to be adjusted for the whole temperature range.

Gas flow control is based on both the temperature error and the heater error. The sensitivity of the algorithm to each of these errors may be separately adjusted by two parameters. The **Temperature Error Sensitivity** varies the sensitivity of the cooling algorithm to temperature errors between the measured and set temperatures. The **Heater Voltage Error Sensitivity** varies the sensitivity of the algorithm to errors between the actual Heater Voltage and the Target Value for the chosen set point temperature.

In some applications it is desirable to prevent the gas flow valve closing fully, during AUTO gas flow control. A **Minimum Gas Valve in Auto** parameter allows this to be done. It specifies the minimum percentage the valve will close to during automatic operation. The valve will still close fully following power up, in order to establish the fully closed position, and it may still be closed fully in manual operation. During automatic operation it will cease to close when this setting is reached. If the valve is already fully closed when control is switched from GAS MAN to GAS AUTO, the valve will immediately open to this setting. (This feature was only introduced at firmware version 1.09 and is not present in earlier versions than this).

Adjustment of all these parameters is carried out from Test Mode 6. Test mode is entered by pressing LOC/REM in conjunction with RAISE and LOWER as described in section 4.12. When test 6 is selected, the display will briefly show:

Conf

then enter a sub-menu of configuration options, designated C0 to C7.

The table below shows the full list and these are described in detail in the following sections.

C 0	Exit (Resumes normal operation)
C 1	Valve Gearing
C 2	Target Table & Features Configuration
C 3	Gas Flow Scaling
C 4	Temperature Error Sensitivity
C 5	Heater Voltage Error Sensitivity
C 6	Minimum Gas Valve in Auto
C 7	(Unused)

7.3.1 Adjusting the Valve Gearing

The parameter can have values in the range 0 to 7 representing a binary scale of numbers of steps between fully open and fully closed. A default value of 2 will be set for an instrument which has never been specifically configured.

VALUE	VALVE STEPS
0	65536
1	32768
2	16384
3	8192
4	4096
5	2048
6	1024
7	512

7.3.2 Adjusting the Gas Flow Parameter

The parameter is a number in the range 0 to 255. It may be regarded as an 8-bit binary number with the bits having the following significance.

BIT	VALUE	SIGNIFICANCE
0	1	Fast Cooldown Enable
1	2	Cooldown Termination Enable
2	4	Slow Valve on Setpoint Increase Enable
3	8	(Unused)
4	16	(Unused)
32		(Unused)
6	64	) Target Table and AUX. PORT mode
7	128	) (See Below)

Target Table and Mode:

BIT6	BIT7	VALUE	MODE	TARGET TABLE
0	0	0	Cryocooler	Cryocooler
1	0	64	Gas Flow	Static CF (Normal Setting)
0	1	128	Gas Flow	Dynamic CF / VT
1	1	192	Gas Flow	Custom Downloaded

7.3.3 Adjusting the Error Sensitivities

Allowable values for the Temperature and Heater Error Sensitivities are in the range 0 to 31. C=4 adjusts the Temperature Error Sensitivity and C=5 adjusts the Heater Error Sensitivity. Larger numbers give lower sensitivity.

7.3.4 Adjusting the Minimum Gas Valve in Auto

The minimum valve position is displayed as a percentage and may be adjusted in the range 0.0% to 99.9%. The default value is 0% for a stand alone ITC503. Where the ITC503 has been supplied as part of a complete system, this parameter will have been set to an optimum value during system testing at the factory. (Note that this parameter is not present for firmware earlier than 1.09)

7.4 Auto-PID Configuration

The Auto-PID data table is normally set up automatically via the computer interface using data learned by the auto-tune algorithm supplied with ITC503, as part of Object Bench. However it may be examined and modified from Test Mode, by selecting Test 5.

When T 5 is selected, the display initially shows L 01 corresponding to the first entry in the table. With L 01 displayed, the P, I, D and SET controls may be used in conjunction with RAISE and LOWER to set PID values that will apply from 0K up to the temperature supplied with the SET parameter. This temperature defines the point at which the second entry in the table will take over. When the required values have been set for the first entry, pressing RAISE will change the display to L 02. The parameters for the second entry may then be set in the same way. The SET parameters for successive entries in the table must be in ascending sequence. Any entry for which the SET parameter is zero will mark the top of the table, indicating that no further entries will be used. If auto-PID operation is attempted above the SET parameter value for the last entry in use, the PID values used will be those of the last entry. If the SET parameter for the first entry in the table is zero, auto-PID operation is not possible. If the PID AUTO button is pressed, nothing will happen.

7.5 Setting the GPIB Address

The GPIB interface is normally supplied set to a GPIB address of 24. This may be changed using Test 3 (see section 4.12 for entry to Test Mode). On accessing Test 3, the display will now show G nn where nn is the current GPIB address. Use RAISE and LOWER to display the desired new address, then press LOC/REM to select it. The instrument will revert to the t=0 state. Pressing LOC/REM again will restart the instrument, with the new address in operation. Any address in the range 1 to 30 may be selected. (Although 31 may be selected, it is not a valid GPIB address since it is reserved for the UNTALK, UNLISTEN functions). Setting the GPIB address to 0 has a special significance. It DISABLES the GPIB interface ensuring that only RS232 operation is possible. To ENABLE it again it is only necessary to return to the t=3 mode and select a new non-zero address.

After the address has been changed, if the new address is to be retained on power down, it must be copied into the Non-Volatile memory by means of the STORE operation (See section 5.6).

8 Remote Operation

8.1 Introduction

ITC503 may be remotely operated by means of its RS232 or GPIB interface. This allows a computer to interrogate the instrument and if required, to take control of it.

When in control, the computer has the option of locking out the front panel controls, or of allowing the front panel LOC/REM control to remain active, so that an operator may restore LOCAL operation if required.

8.2 Communication Protocols

ITC503 is always fitted with both Serial (RS232) and GPIB (IEEE-488) interfaces. Details of the hardware communication protocols for the two interfaces are given in sections 3.3 and 3.5 respectively.

The same command protocols are used for the Serial and GPIB interfaces.

All commands consist of a string of printing ASCII characters, terminated by a Carriage Return character. A Line Feed character may optionally be sent after the Carriage Return but is ignored by ITC503.

Unless the command starts with a "$" (dollar) character, all commands will evoke a response from ITC503. The response will consist of a string of one or more printing ASCII characters and will be terminated by a Carriage Return Character. This may optionally be followed by a Line Feed character.

The response will normally be sent immediately following the command. If a front panel button is pressed when the command is received, the response may be delayed until the button is released. With the Serial Interface in use, the response will be transmitted automatically as soon as it is available. With the GPIB interface the response will be sent when the instrument is next addressed to talk.

If the first character of a command is a "$", the command will be obeyed but no response will be sent. (See section 8.5).

ITC503 will accept a command string at all times. If a computer linked by the serial (RS232) port, is unable to accept data from ITC503 at the full rate of the 9600 baud interface, the "W" command may be used to instruct ITC503 to send more slowly.

8.3 Commands and Responses

Commands to ITC503 all consist of a single letter, optionally followed by a numeric parameter, the whole being terminated by a Carriage Return. All common operational commands are based on Upper Case letters with mnemonic significance. Lower Case letters are used for some of the more specialised commands. The response sent by ITC503 varies depending on the command. Usually it consists of the Command letter received, followed by the value of any data requested. Where a command instructs ITC503 to carry out an action rather than to send data, the command letter alone will be returned.

If a command is not recognised, has an illegal parameter or cannot be obeyed for any reason, an error response will be sent. This consists of a "?" (question mark), followed by all or part of the command string in question. To simplify error handling in the computer, the "?" will always be the first character returned.

The most common reason for a command error is attempting to execute a control command whilst ITC503 is in LOCAL control. If in doubt, the "X" command may be used to determine the current status.

8.4 Numeric Parameters

All numeric parameters are treated as signed decimal numbers and are sent as a string of decimal digits with an appropriately placed decimal point. Note that this **is not the same convention used by** ITC4 **and** ITC502 where all numbers were treated as signed integers. The change has been introduced to accommodate auto- ranging where the number of decimal places available may vary throughout a range. For consistency, the decimal format is used for **all** numbers sent and received by ITC503. Essentially the format of all numbers matches that displayed on the front panel.

8.5 Use with Oxford Instruments ISOBUS

The Oxford Instruments ISOBUS allows a number of instruments to be driven in parallel from a single RS232 port on a computer, using a special cable assembly.

To allow separate instruments to be distinguished, each is allocated a unique address in the range 0 to 9, held in non-volatile memory. By default, an ITC503 is supplied with the an Isobus address of 1.

When operating on ISOBUS an instrument must be able to recognise and respond to commands addressed to it, whilst ignoring commands addressed to other instruments. This is achieved by starting all commands with a special ISOBUS control character.

When more than one powered-up instrument is connected on ISOBUS, no command should be issued which does not have an ISOBUS control character as its first character. Issuing such a command would result in an unintelligible response, as all instruments would reply together. (N.B. This will only result in lost data. No hardware damage will be caused).

Following the control character and its parameter (where required), the rest of the command follows the form described above. The response of the instrument depends on the initial control character in the following manner:

@n (At) addresses the command to instrument number n, where n is a digit in the range 0 to 9. This instrument obeys the command and returns its usual response. All other instruments ignore the command and send no reply.

$ (Dollar) instructs all instruments to send no reply. This is normally used to precede a command being sent to all instruments simultaneously, and prevents a conflict as they all echo the command together.

It may also be used in non-ISOBUS applications if the computer does not wish to receive a response.

It should be used with caution however, since all responses are suppressed, including the "?" error response. Thus the computer has no way of knowing if a command has been received or even if the instrument is connected.

If a command is to be addressed to a specific instrument, but no reply is required, it is permissible to use "$" and "@n" together. The "$" should always come first.

& (Ampersand) instructs an instrument to ignore any following ISOBUS control characters. It is included in the ISOBUS protocol to allow instruments whose command repertoire includes "@", "$", "&" or "!" to be used on ISOBUS. ITC503 does not require the use of this command.

!n (Exclamation) instructs the instrument that from now on its address is to be n. This command is included here since it is relevant to ISOBUS operation. However for obvious reasons, it should not be sent when more than one instrument is powered up and connected to ISOBUS. (It would result in all instruments having the same address!). The command is intended for initial setting up of instruments, one at a time. To avoid inadvertently changing addresses, the "!" command will only be obeyed following a "U" command with a non-zero password. (See section 9). Note that the address set this way is the ISOBUS address, not the GPIB address. The latter cannot be set via the interface, since until an address is defined, GPIB communication is not possible.

8.6 The GPIB Interface

The GPIB Interface allows the ITC503 to be computer controlled by means of the General Purpose Interface Bus (GPIB), also known as HPIB and IEEE-488 interface.

It supplements rather than replaces the RS232 Serial Interface. It allows an instrument to be controlled either by GPIB or RS232 (not both simultaneously). In addition when operating under GPIB control, the RS232 interface may be used as a GATEWAY to further OI instruments, not themselves fitted with a GPIB interface.

The instructions which follow assume some basic familiarity with the concepts of the GPIB. This will typically be provided as part of the documentation supporting a GPIB controller card for a computer and so on.

Even with the GPIB interface fitted it is still possible to communicate with the instrument via the RS232 interface in the standard way. This is the default condition after power up a restart from test mode, and ISOBUS addressing may be used if desired.

Provided the GPIB interface has not been deliberately DISABLED by setting its address to 0 (see section 7.5), it may be switched to the GPIB IN-USE state at any time. This occurs automatically when a GPIB Controller asserts the REN line and addresses the interface either to talk or listen at the GPIB address selected. Once it has been put into the GPIB IN-USE state, it remains in that state until power down or until a t=0 re-start.

8.6.1 Sending Commands via the GPIB

Commands sent via the GPIB follow exactly the same syntax as for the RS232 interface. Commands must be terminated by a Carriage Return <CR> character, (ASCII 13). A Line Feed <LF> may be sent if desired but is not needed and will have no effect. (Your GPIB controller may send <CRLF> by default). Provided it is operating (as opposed to being in TEST mode) the ITC503 will accept commands at all times. Where commands produce a response message, this should be read before a further command is issued.

8.6.2 Accepting Responses via the GPIB

Messages returned via the GPIB consist by default, of an ASCII character string, terminated by a <CR>. If your controller expects <LF> as a terminating character, this may be achieved by sending an initial "Q2" command after power up. Note that the "Q2" command itself produces no response message but that all subsequent messages are terminated by the <CRLF> pair. The interface never asserts the EOI line at the end of a message, instead allowing either <CR> or <LF> to be used as the End-of-String (EOS) character.

8.6.3 The Status Byte, Use of a Serial Poll

One of the problems with a GPIB interface is knowing when a message is available to be read. If a device is addressed to TALK but has no data available, it will wait indefinitely, unless the controller includes a TIMEOUT facility (see section 8.6.10). There are a number of ways by which the controller can determine when data is available. The simplest but least reliable, is to "know" from which command has been sent, whether a reply will be produced. This is fine until something unexpected happens. A better alternative is to read a STATUS BYTE from the instrument by conducting a SERIAL POLL of it. The ITC503 interface will always respond to a serial poll and will return a status byte. Three bits in this byte have significance for ITC503 as follows.

Bit 6 (Value 64 decimal)	RQS (Requesting Service)
Bit 4 (Value 16 decimal)	MAV (Message Available)
Bit 1 (Value 2 decimal)	BAV (Byte Available)

The bit positions for the SRQ and MAV bits are as specified in IEEE-488.1 and IEEE-488.2 respectively. (Note the convention here is that the Least Significant Bit is Bit 0. This is sometimes referred to as data line D1. Thus lines D1 to D8 correspond to Bits 0 to 7). The BAV bit is set as soon as at least one byte is available to be read. The MAV bit is set when a complete message up to and including the <CR> or <LF> character is available to be read. The RQS bit indicates that the instrument has requested service by asserting the GPIB SRQ line true (see section 8.6.4).

The Status byte may be read as many times as the controller wishes. The MAV and BAV bits will reflect the current status of the interface at the time the byte is read (but see below). Hence once set, they will remain set until the message has been read. The SRQ bit behaves differently (in accordance with IEEE-488.1). The first time the status byte is read after the interface has requested service, it will be set. The act of reading the status byte clears the service request bit and at the same time allows the interface to release the SRQ line. It will not be asserted again unless a further service request is issued.

ITC503 updates the status byte every millisecond. Thus if the Status Byte is read within 1mS of reading data from the interface, The MAV and BAV bits may not yet have been cleared, even though all available data has been read. If these bits are found to be unexpectedly set immediately after a data read, a second read of the Status byte at least 1mS later will confirm whether there really is data remaining.

8.6.4 Use of the Service Request Line

The interface will issue a service request (by pulling the SRQ line), at the point a complete message becomes available to be read, (that is at the point at which MAV is first set), unless the interface is already addressed to TALK at that point. In the latter case no service request is required since the controller is already waiting to read the data or in process of doing so.

Hence use of the SRQ line allows a suitably equipped controller to handle all data from the interface on an interrupt basis. If the controller is not equipped to do this, it may simply ignore the SRQ line and poll the status byte on a regular basis until the MAV bit indicates data is available.

8.6.5 Use of the Device Clear Function

When the GPIB interface receives a device clear message from the controller, it responds by clearing all the communication buffers to their empty, power-up state. It does not reset any of the temperature control functions to the power-up state. Device Clear may thus be safely used to empty the buffers if these have been filled with a number of unread messages. Device Clear may be sent by either the GPIB DCL message (which clears all connected devices), or by means of the SDC message addressed specifically to its address.

Note that if an ISOBUS GATEWAY is in use, only the buffers in the MASTER instrument are cleared. If data is currently being transmitted from a SLAVE instrument to the MASTER, this will be read into the buffer after it has been cleared.

8.6.6 Use of the Interface Clear (IFC) Function

Receipt of the single line IFC message clears the GPIB interface functions as specified by IEEE-488.1. It does not clear any pending data in the buffers. Nor does it have any effect on operation of the temperature control function.

8.6.7 Non-Implemented Features of the GPIB

The GPIB Remote Enable (REN) line is used only to alert the interface to the presence of an active controller. It is not used for LOCAL/REMOTE switching which is carried out by the simpler "C" command, for compatibility with RS232 operation. Similarly the GPIB LOCAL LOCKOUT command and GOTO LOCAL commands have no effect. This functionality too is a part of the "C" command.

The interface does not respond to a Parallel Poll request. By virtue of its use of open collector data buffers, it can however co-exist on the GPIB with other instruments which do have a Parallel Poll facility.

8.6.8 Compatibility with IEEE-488.2

Compatibility with certain aspects of this extension to the original standard has already been mentioned in a number of places (for example the format of the Status Byte). However details of the command sequences and formats within messages, error handling and status reporting all follow the existing **ITC** syntax and protocols used on RS232. This precludes complete compliance with the rather more complex IEEE-488.2 syntax. In particular there is no attempt to support the "Standard Commands for Programmable Instruments" (SCPI).

8.6.9 Use of the GPIB Interface as a GATEWAY to ISOBUS

When the interface is operating in the GPIB IN-USE state, all characters received via the GPIB are echoed back out on the RS232 line. Similarly any characters received on the RS232 are made available to be read by the GPIB controller (with MAV, BAV and SRQ being set appropriately as above). This allows one or more other instruments to be connected to the first instrument using the Oxford Instruments ISOBUS. These may share the benefits of being controlled by the GPIB controller, whilst at the same time enjoying the advantages of optical isolation provided by ISOBUS. To use this GATEWAY, requires only a GATEWAY MASTER ADAPTOR, as described in section 3.6.

No special command protocols are required to access the GATEWAY. All OI instruments fitted with RS232 can be accessed in this way. The command strings sent to individual instruments when used in this way are simply prefaced by their ISOBUS ADDRESSES as described above. Note the distinction between the GPIB address which is common to all the instruments on the GATEWAY and their individual ISOBUS addresses which form a part of the message string, preceded by the "@" character. The ISOBUS GATEWAY MASTER (that is the instrument actually fitted with the GPIB interface) always has the ISOBUS address "@0". This must be used when addressing this instrument, since a command sent with no "@" prefix would be seen by all instruments (just as for a simple ISOBUS system).

8.6.10 Writing a "Rugged" GPIB Control Program

A lot of effort has been put into making the design of the GPIB interface as tolerant as possible. However in any computer interface designed to operate unattended for periods of time, it is essential to assume that data corruption may occur at any time. Usually this is due to static, power line surges, operator error and so on. Any controller program should be designed to cope with this. In particular all attempts to write data to or read data from any instrument should have a TIMEOUT facility built in. The GPIB handshake sequence makes it all to easy for lost data to result in the bus hanging indefinitely. When a timeout occurs the controller should attempt to assess what is happening. In the case of the ITC GPIB interface this is best done by means of a serial poll. If this too times out, the next recourse should be to reset the interface by means of the Interface Clear (IFC) line. If a serial poll is still unable to get a response, the controller must assume that the instrument has been switched off, failed or a connector has fallen out. As a last resort it should attempt to alert an operator and/or if possible continue operating the remaining instruments.

9 Command List

A brief summary of the available commands is given below. Fuller details are given in the following section.

Commands fall into 4 categories:

MONITOR COMMANDS which are always recognised.

CONTROL COMMANDS which are only recognised when in REMOTE control.

SYSTEM COMMANDS which are only recognised after receipt of the correct"UNLOCK KEY".

SPECIALIST COMMANDS which are primarily for use in conjunction with OI supplied high level system software. They provide a means to preload certain advanced control features associated with the GAS FLOW algorithm and to read diagnostic information from the ITC503 to assist with control algorithm development.

In the list which follows, "n" represents a decimal digit 0-9.

MONITOR COMMANDS (always recognised)

Cn	SET CONTROL LOCAL/REMOTE/LOCK
Qn	DEFINE COMMUNICATION PROTOCOL
Rn	READ PARAMETER n
Unnnnn	UNLOCK FOR "!" AND SYSTEM COMMANDS
V	READ VERSION
Wnnnn	SET WAIT INTERVAL BETWEEN OUTPUT CHARACTERS
X	EXAMINE STATUS

CONTROL COMMANDS (recognised only in REMOTE)

An	SET AUTO/MAN FOR HEATER & GAS
Dnnnn	SET DERIVATIVE ACTION TIME
Fn	SET FRONT PANEL TO DISPLAY PARAMETER n
Gnnn	SET GAS FLOW (in MANUAL only)
Hn	SET SENSOR FOR HEATER CONTROL
Innnn	SET INTEGRAL ACTION TIME
Ln	SET AUTO-PID (Learned PID's)
Mnnn	SET MAXIMUM HEATER VOLTS LIMIT
Onnn	SET OUTPUT VOLTS (in MANUAL only)
Pnnnn	SET PROPORTIONAL BAND
Sn	START/STOP SWEEP
Tnnnnn	SET DESIRED TEMPERATURE

SYSTEM COMMANDS (recognised only after correct Unnnnn command)

Y	LOAD ENTIRE RAM CONTENTS
Z	DUMP ENTIRE RAM CONTENTS
~	STORE RAM CONTENT TO EEPROM
!	SET ISOBUS ADDRESS (See section 8.5)

SPECIALIST COMMANDS (all lower-case letters)

xnnn	SET TABLE POINTER x to nnn
ynnn	SET TABLE POINTER y to nnn
snnnnn	PROGRAM SWEEP TABLE
r	READ SWEEP TABLE
w	WIPE SWEEP TABLE
pnnn	PROGRAM AUTO PID TABLE PID
q	READ AUTO PID TABLE PID
vnnn	PROGRAM CUSTOM TARGET VOLTAGE TABLE
t	READ VALUE FROM TARGET VOLTAGE TABLE
cnnn	SET GAS FLOW CONFIGURATION PARAMETER
d	READ GAS FLOW CONFIGURATION PARAMETER
m	READ GAS FLOW CONTROL STATUS
n	READ TARGET VOLTS
o	READ VALVE SCALING

10 Command Syntax

10.1 User Commands

Cn COMMAND

The control command sets ITC503 into LOCAL or REMOTE and determines whether the LOC/REM button is LOCKED or active. At power up ITC503 defaults to the C0 state. Allowed values are:

C0	LOCAL & LOCKED (Default State)
C1	REMOTE & LOCKED (Front Panel Disabled)
C2	LOCAL & UNLOCKED
C3	REMOTE & UNLOCKED (Front Panel Active)

In the C3 state buttons such as SET, PROP etc, can be used to examine values on the display, but RAISE and LOWER cannot be used to change these values. However the LOC/REM is active and so can be used to switch to the C2 state in order to change values. While any buttons are held pressed in the C3 state, the instrument will not respond to any remote commands. Instead these are held pending and acted upon when the button is released. Computer programs should either be written to tolerate this delay or should put the instrument into the C1 state to completely disable the front panel controls.

Qn COMMAND

Defines the communication protocol.

Currently only 2 values of n are significant:

Q0	"Normal" (Default Value)
Q2	Sends <LF> after each <CR>

Note that unlike all other commands, the Q command does not produce an echoed response to the computer. (Having changed the communication protocol, it automatically clears the communications buffer).

Rn COMMAND

The READ command allows the computer to interrogate any of a number of variables. The returned value is always an integer as defined in section 8.4. Allowed values for n are listed below. (R11 and above are intended as service diagnostics and are unlikely to be of use to the user).

R0	SET TEMPERATURE
R1	SENSOR 1 TEMPERATURE
R2	SENSOR 2 TEMPERATURE
R3	SENSOR 3 TEMPERATURE
R4	TEMPERATURE ERROR (+ve when SET > MEASURED)
R5	HEATER O/P (as % of current limit)
R6	HEATER O/P (as Volts, approx.)
R7	GAS FLOW O/P (arbitrary units)
R8	PROPORTIONAL BAND
R9	INTEGRAL ACTION TIME
R10	DERIVATIVE ACTION TIME
R11	CHANNEL 1 FREQ/4
R12	CHANNEL 2 FREQ/4
R13	CHANNEL 3 FREQ/4

Unnnnn COMMAND

The UNLOCK command allows access to the SYSTEM commands. This set of commands are intended for diagnostic and configuration purposes and have the power to erase or modify the contents of the memory. The U command must be sent with the correct KEY parameter before these commands may be used. The KEY value for these commands is 9999. The whole of section 12 should be read before any attempt is made to use this key!

A lower level of key protection is provided for the "!" command, to avoid accidental errors. Any non-zero value will unlock this command.

Two additional special key values are significant. These are intended specifically to allow a GATEWAY MASTER instrument to be used to load RAM data (via a "Y" command) to a SLAVE instrument, without the data being "obeyed" as commands, by the MASTER. A value of U1234 puts the MASTER to SLEEP, until the specific sequence U4321 is detected. Whilst it is asleep, all data received via the GPIB interface is passed on to the slave but ignored by the master.

Thus the allowed values of U are:

U0	LOCKED (Power-up Default)
U1	"!" COMMAND UNLOCKED
U1234	SLEEP
U4321	WAKE UP
U9999	"L", "Y" & "Z" COMMANDS UNLOCKED

V COMMAND

The VERSION command requires no parameters. It returns a message indicating the instrument type and firmware version number.

Wnnnn COMMAND

The WAIT command sets a delay interval before each character is sent from ITC503 via the computer interface. This allows ITC503 to communicate with a slow computer with no input buffering. The parameter nnnn specifies the delay in milliseconds. It defaults to zero at power-up.

(N.B. the W command does not reduce the rate at which ITC503 can accept data from computer.)

X COMMAND

The EXAMINE command allows the computer to read the current ITC503 STATUS. It requires no parameters and will return a message string of the form:

XnAnCnSnnHnLn

where the digits "n" have the following meaning:

Xn	SYSTEM STATUS	(Always zero currently)
An	AUTO/MAN STATUS	(n as for A COMMAND but see below)
Cn	LOC/REM/LOCK STATUS	(n as for C COMMAND)
Snn	SWEEP STATUS	(nn=0-32 as follows)
	nn=0	SWEEP NOT RUNNING
	nn=2P-1	SWEEPING to step P
	nn=2P	HOLDING at step P
Hn	CONTROL SENSOR	(n as for H COMMAND)
Ln	AUTO-PID STATUS	(n as for L COMMAND)

On systems fitted with AutoGFS, the digit following "A" will be increased by 4, during the initial calibration period whilst the GAS MAN lamp is flashing.

An COMMAND

The AUTO/MANUAL command allows the heater and gas flow control functions to be set to AUTO or MANUAL. Allowed values are:

A0	HEATER MANUAL, GAS MANUAL
A1	HEATER AUTO, GAS MANUAL
A2	HEATER MANUAL, GAS AUTO
A3	HEATER AUTO, GAS AUTO

N.B. "MANUAL" in the context of REMOTE control means that the HEATER or GAS FLOW may be set directly by an "O" or "G" computer command.

"A2" and "A3" commands will not be accepted during the initial AutoGFS calibration phase, whilst GAS MAN is flashing.

Pnnnn, Innnn & Dnnnn COMMANDS

Set PROPORTIONAL, INTEGRAL and DERIVATIVE control terms. The values taken by n correspond to those given in section 4.7.

Fnn COMMAND

The FRONT PANEL DISPLAY command sets the display to show one of the internal parameters rather than the normal measured temperature. Normal display operation may be restored by pressing the SENSOR button. The command is intended chiefly for use during test and fault diagnosis. n may take the same values as for the "R" command above, with the same significance.

Gnnn COMMAND

Sets the GAS FLOW to a defined value nnn (For use with AutoGFS). The value is expressed as a percentage to a resolution of 0.1%. The "G" command will not be accepted during the initial AutoGFS calibration phase, whilst GAS MAN is flashing (and the "X" command returns a value of 4 or greater).

Hn COMMAND

The HEATER SENSOR command defines the sensor to be used for automatic control. n may take the values 1-3 corresponding to the three input channels.

Ln COMMAND

The command enables or disables use of the tabled of (Learnt) Auto-PID values.

L0	DISABLES USE OF AUTO-PID
L1	USES AUTO-PID

When the "L0" command is issued, the P, I and D values will remain at their existing settings. These will remain in force until they are changed by the issue of individual "P", "I" or "D" commands or until an "L1" command is issued.

If Auto-PID table is not in use (that is the "SET" parameter for the first entry has been set to zero), the "L1" command will not be available and will produce a "?L1" error response.

Mnnn COMMAND

The MAXIMUM HEATER command sets the maximum heater voltage that ITC503 may deliver, under automatic control or in response to an "O" command. This performs the same function as the Output Limit described in section 5.1. nnn is specified as a decimal number with a resolution of 0.1 volt, and is approximate.

"M0" may be used to specify a dynamically varying limit as described in section 5.1.

Onnn COMMAND

Sets the required heater output in MANUAL. The parameter nnn is expressed as a percentage of the maximum heater voltage set by the "M" command in units of 0.1%. (Hence the range of nnn is 0 to 99.9).

Sn COMMAND

The SWEEP command may be used to start and stop a sweep remotely.

S0	STOPS SWEEP
S1	STARTS SWEEP

Values of n from 2-32 may also be sent and have the effect of entering the sweep program part way through. The value of n has the same significance as for the S part of the status message (see above). Note however that if n is an odd number other than 1, the set point will immediately change to the programmed temperature for the preceding step and start its sweep from there.

Tnnnnn COMMAND

The TEMPERATURE command sets a set point temperature. The parameter is the required temperature, sent as an signed decimal number in accordance with section 8.4.

Note that if a sweep is running, the temperature set by the T command will be over-ridden by the sweep.

Yn COMMAND

The Y command allows the contents of the RAM memory to be loaded in binary, via the serial interface. It is not intended as a user command. If n is omitted or has the value 2, only the first 2 kilobytes of the memory are loaded. If n has the value 8, the entire 8 kilobytes are loaded. (In general all calibration parameters of interest are held within the first 2 kB). Note that after loading the memory in this way, the new content will be lost at power-down, unless it has been saved by a STORE sequence as described in section 5.6.

Zn COMMAND

The Z command allows the contents of the RAM memory to be dumped in binary, via the serial interface. It is not intended as a user command. Like the Y command, omitting n or setting it to 2 results in a 2kB dump. Setting n to 8 gives a full 8kB dump.

~ COMMAND

The ~ (tilde) command allows the contents of the RAM memory to be stored to the EEPROM memory. Itis not intended as a user command. If The correct Unnnn password is not in force, or if the internal Write Enable switch is set to OFF, the command will be rejected with a ?~ response. If the command is accepted the display will show **Stor** and the ~ response will be sent, when the store operation is complete. (This may take 2 or 3 seconds.) (Only applies to firmware version 1.07 and later.)

10.2 Specialist Commands

In general the commands in this section are not intended for customer use. They have been provided for engineering use during algorithm development and to interface with certain Oxford Instruments application software. The details which follow are provided for interest only. They are correct for version 1.0 firmware but the commands will not necessarily be retained in this form in future versions of the firmware.

Note that if any parameters changed by these commands are to be retained after power down, the STORE procedure must be used as usual.

xnnn & ynnn COMMANDS

The x and y commands set pointers into tables for loading and/or examining data values in the table. The sequence of operations is to load either or both pointers as appropriate, then issue the command to load or examine the data. (See for example the "s" command which follows). nnn are decimal integers in the range 0 to 128. If a command is issued with incorrect values set for x or y, that command will not be obeyed and an error response will be returned.

Since all the tables which use the x and y pointers expect values of 1 or more for x and y, it is good practice to leave x and y set to zero after use. This will ensure that if one of the "table" commands is issued inadvertently, it will always be rejected and produce an error response.

snnnnn COMMAND (Program Sweep Table)

The s command allows programming the individual steps of the sweep table. The x pointer should be preset to the sweep step (1 to 16). The y pointer selects the parameter to program from:

y=1	Set Point Temperature
y=2	Sweep Time to Set Point
y=3	Hold Time at Set Point

To program a sweep, ITC503 must be in REMOTE and a sweep must not be running.

r COMMAND (Read Sweep Table)

The r command allows the individual steps of the sweep table to be read back, using the x and y pointers as above.

w COMMAND (Wipe Sweep Table)

Wipes all the values entered by the s command (or entered manually). This command will not be recognised if ITC503 is in LOCAL or if a Sweep is Running.

pnnnnn COMMAND (Program Auto-PID Table)

The pnnn command allows programming of PID settings for use in Auto-PID mode. 32 entries are allowed in the Auto-PID Table. Each entry contains an Upper Temperature Limit, and values for P, I and D which will apply to set temperatures up to that limit and down to the Upper Temperature Limit of the previous entry. It is therefore apparent that the values for the Upper Temperature Limit must appear in ascending order within the table. A value of 0 for the Upper Temperature Limit of any entry is used to mark the end of the active part of the table. Any higher entries will be ignored. If Auto-PID operation is selected at a set point higher than the Upper Temperature Limit of the highest entry in use, the PID values for the highest entry in use will apply.

The P, I and D values for the first entry in the table apply down to 0K. If the Upper Limit Temperature for the first entry is set to zero (p=0 for x=1, y=1), auto-PID operation will be disabled.

The x pointer defines the entry (1 to 32). The y pointer selects the parameter from:

y=1	Upper Temperature Limit
y=2	Proportional Band
y=3	Integral Action Time
y=4	Derivative Action Time

ITC503 must be in REMOTE to program PID values.

q COMMAND (Read Auto-PID Table)

The q command allows the individual entries in the Auto-PID table to be read back, using the x and y pointers as above.

vnnn COMMAND (Program Custom Target Heater Voltage Table)

Programs values into the custom target heater voltage table, which may be used for automatic Gas Flow Control. The x pointer defines the element in the table to program (1 to 64). The y pointer is not used. In an instrument which has never had the custom table programmed, this will have been preloaded during test with a copy of the normal "Static CF" table. Thus if minor modifications to this table are required, it is only necessary to load those points which are to be changed.

t COMMAND (Read Custom Target Heater Voltage Table)

Reads back the value from the x pointer.

cnnn COMMAND (Set Gas Flow Configuration Parameter)

The c command sets the values of the Gas Flow Configuration parameters (See section 7.3 for details of the parameters). The x pointer is used to define which of the parameters is set.

d COMMAND (Read Gas Flow Configuration Parameters)

The converse of the c command. The x pointer is used to determine which parameter is read.

m COMMAND (Read Flow Control Status)

Return the status of the flow control algorithm. The number returned is an integer in the range 0 to 255. It is valid only when GAS is in AUTO and is intended for algorithm diagnostic purposes. Its bits have the following significance.

BIT	MEANING
7	Not Used
6	Not Used
5	Not Used
4	Heater Error Sign (1 = -ve)
3	Temperature Error Sign
2	Slow Valve Action Occurring
1	Cooldown Termination Occurring
0	Fast Cooldown Occurring

n COMMAND (Read Target Voltage)

Reads the current heater target voltage with which the actual heater voltage is being compared. Value returned is to one place of decimals. It is valid only if in GAS AUTO.

o COMMAND (Read Valve Scaling)

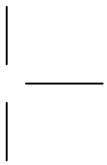
Another diagnostic value, valid only in GAS AUTO.

11 Sensor Range Configuration

11.1 Introduction

Each sensor input channel of ITC503 may be configured to a range suitable for use with a specific sensor. Normally an instrument is supplied with the specified range(s) configured ready for use. However it is possible to reconfigure it for use with different sensors should this be required.

The existing configuration may be determined by the code(s) displayed when the DISPLAY SENSOR button is pressed. Limitations of a 7-segment display, mean that the characters are a rather stylised mixture of upper and lower case. "K" is particularly obscure and is shown as:



ITC503 comes with data for many of the most commonly used ranges included in the program memory. A further 3 ranges may be accommodated as custom calibrations in the non-volatile memory. For some sensors, ranges are available with either a Centigrade or Kelvin display. To identify these, the sensor code for all Centigrade ranges has an extra decimal point following the final digit.

The table in section 11.2 shows range details for the standard ranges included within the program memory of Version 1.0 firmware. (The standard ranges may be changed from time to time in response to variations in sensor popularity). The temperature range listed is the useful working range. On many ranges ITC503 will continue to indicate slightly outside this range. Note that the number of decimal places shown for the ends of the range indicate the display resolution available at these points. On some ranges (for example thermocouples) the display resolution will be limited to 10mK because the sensor sensitivity is too poor to allow useful resolution to 1mK.

The remainder of section 11 shows how to configure the instrument for use on one of these installed ranges. Section 12 takes configuration a stage further and shows how a completely new custom range may be designed and installed. In the following description, abbreviated component references are used. Thus SW1 refers to SW101 on channel 1, SW501 on channel 2 and SW401 on channel 3.

11.2 Range Data

CODE	SENSOR	RANGE	Tref	SW1 (Rear Switch)	SW2 (Front Switch
Lin	Linear Range	0-1677.7		(As required, See Note 2)	
Null	Centre Zero	-838.9- +838.9		(As required, See Note 2)	
Con 1	Conductance	0-20		00001 11110	01001 01010
TG 5	AuFe 0.03/Chr	2-500K	4.2K	11000 11111	00000 11000
TG 5	AuFe 0.03/Chr	2-500K	77K	11000 11100	00000 11000
TG 5	AuFe 0.03/Chr	2-500K	273K	11000 10100	00000 11000
TG 57	AuFe 0.07/Chr	2-500K	(Tref and Switches as for AuFe 0.03)		
CN 3	Cernox Resistor	1.5-300K		01100 11010	01001 01010
TT 5	Copper/Const.	20-500K	77K	10100 11111	00000 11000
TT 5	Copper/Const.	20-500K	RT	10100 11111	00000 10100
TT 4.	Copper/Const.	-250-400C	77K	10001 10111	00000 11000
TT 4.	Copper/Const.	-250-400C	RT	10001 11100	00000 10100
TK 10	Chromel/Alumel	0-1000C	0C	01111 10111	00000 11000
TK 10	Chromel/Alumel	0-1000C	RT	01111 10111	00000 10100
TK 13.	Chromel/Alumel	-200-1370C	0C	01110 10100	00000 11000
TK 13.	Chromel/Alumel	-200-1370C	RT	01110 11111	00000 11000
CR 11	Ruthenium Oxide	0.250-10K		00100 10010	00101 01000
RF 52	RhFe Resistor	1.5-500K		01111 11111	10010 10000
RP 1.	Plat Resistor	-200-+100C		10110 11111	01010 10100
RP 5	Plat Resistor	20-500K	Pure	10010 11111	01010 11000
RP 51	Plat Resistor	50-500K	Ballasted	10010 11111	01010 11000
RL 3	CLTS	2-300K		10111 01111	01010 10100
DS 32	Si Diode (OI)	2-300K		00010 00000	00110 11000
DS 31	Si Diode (LS)	2-300K		00010 00000	00110 11000
CC 35	C-Glass CR500	2-300K	(Typ only)	00001 11011	10001 01010
CA 21	100R Allen Brad	4-250K		00111 11000	01001 01010
CA 22	270R Allen Brad	4-250K		00011 10010	01001 01010
CS 01	470R Speer	0.250-9.999K		00011 11010	00101 01010

Notes:

a) Switch settings in this table are intended as a guide only. In particular the span and zero settings defined by SW1 may change for different sensors. In the case of thermocouples, the zero switch setting will vary with the reference junction temperature. Settings are given above for some of the more common combinations. Others may easily be obtained empirically (see section 12.5).

b) The Lin and Null ranges are general purpose ranges and may be set up for any desired span and zero. Both provide a linear relationship between input and display. One provides a unipolar display, whilst the other is centre zero.

c) Note that whilst it is theoretically possible to use a Room Temperature reference junction with a cryogenic thermocouple such as AuFe/Chromel, this is not recommended. The accuracy and stability obtained are unlikely to be acceptable for cryogenic applications

d) The spread of 27 Ohm Rhodium Iron Sensors is such that two typical curves are included. Curve A should be used for those sensors having a 4.2K resistance of 2 ohms or greater, whilst Curve B should be used for sensors with a 4.2K resistance less than 2 ohms. Use of the appropriate curve should result in linearisation errors of less than 1K over the full temperature range. For a more accurate fit to a specific sensor, a custom calibration should be ordered.

e) Two platinum ranges are provided, one for a pure platinum element, the other for a ballasted element to BS1904/DIN43760. The latter element is more readily available but its performance below 73K is currently unspecified. (The data between 50K and 73K is based on BS1904:1964 rather than BS1904:1984).

11.3 Access to Configuration Controls

Configuring ITC503 involves setting switches on the input board and selecting the appropriate linearisation data table. To carry out this work the top cover of the instrument must be removed. Before attempting this, read the Safety Information in Section 1 of this manual.

To remove the top cover, first remove the 4 screws securing it. The cover may then be slid towards one side, until the opposite side may be lifted clear of the side casing.

Where a second input board is fitted for 2/3 channel use, this will locate over the channel 1 board. The switches on the channel 1 board are placed at the edge of the board such that they remain accessible. On the upper board, the switches are associated with the two channels in a logical manner, such that the channel 3 switches are nearer the left hand side of the instruments. On all boards SW1 is nearer the rear panel. N.B. The full component references used on the PCB for SW1 are SW101, SW501 and SW401 for channels 1-3 respectively. Except when referring to a specific channel, the first digits are omitted here.

11.4 Hardware Configuration

Configuring the input stage hardware involves setting up the correct pattern on the two sets of DIP switches associated with the channel being configured. The preceding table gives the correct pattern for each of the standard ranges. In each case a "1" represents a switch in the "ON" position (nearer the left side of the instrument) SW1 is the set of switches nearest the rear panel.

It is not necessary to know the function of the switches, in order to set them correctly. However a brief indication may prove helpful.

SW1 is split into two sections each of 5 switches. SW1/1 to SW1/5 define the input span, whilst SW1/6 to SW1/10 define the input zero. The pattern on the switches may be regarded as a binary number with the highest numbered switch being the least significant bit. The all "ON" position gives the smallest span and zero whilst the all "OFF" position gives the largest.

SW2/1 to SW2/3 define the magnitude of the sensor energisation current, when required.

SW2/4 selects constant current energisation for metallic resistance thermometers.

SW2/5 selects constant voltage energisation for semiconductor resistance thermometers.

SW2/6 selects normal voltage sense operation. It is set to OFF for semiconductor resistance thermometers.

SW2/7 selects a negative zero offset for suppressed zero ranges.

SW2/8 selects a positive zero offset for elevated zero ranges.

SW2/9 selects a small zero offset for use with semiconductor resistance thermometers.

SW2/10 halves the input sensitivity for use with Gallium Arsenide diodes.

11.5 Linearisation Configuration

To select the correct software data table, proceed as follows.

Switch the instrument on and ensure that the DISPLAY SENSOR lamp is showing the channel which is to be configured. If necessary press SENSOR to change channels.

Now hold the RED RAISE and LOWER buttons pressed, whilst pressing and releasing the LOC/REM button. The message

tESt

will appear followed shortly by:

t 00

Press LOWER and release, to display:

t 07

Then press LOC/REM. The display will show

LOAd

followed shortly by:

Lin

which is the code for the first one of the available standard ranges.

Press RAISE or LOWER to cycle through the available ranges until the code for the required range is displayed. The ranges displayed will include both the standard ranges and any custom ranges that have been installed.

Press LOC/REM and the range will be configured. ITC503 will then leave the test mode and start normal operation with the "PASS" message.

After re-configuring a range, it will be necessary to carry out the calibration described in section 7.

12 Sensor Range Design

12.1 Introduction

The preceding section described how to configure ITC503 to use a range already installed in either the program or non-volatile memories. This section describes how a range may be designed and loaded into one of the non-volatile memory tables. It is not practicable to design and load an ITC503 range "by hand". However the Object Bench software supplied with the instrument includes a Custom Range utility which makes the task relatively easy. If a suitable computer is not available to run Object Bench (Requires Microsoft Windows 3.1 or later), Oxford Instruments is still able to provide a custom range design service.

The information which follows discusses the background to sensor range design.

12.2 Types of Sensor

The first stage in designing a range is to decide what type of sensor is to be used.

The various sensors may be divided into a number of classes on the basis of the input configuration they require.

Thermocouples act as voltage sources and their output voltage is measured. They require a precisely known reference junction temperature. This may either be a fixed temperature or may be room temperature. In the latter case a Room Temperature Compensation sensor in ITC503 will correct for variations in room temperature. (A room temperature compensated reference is not recommended for cryogenic applications). Thermocouples do not have good sensitivity at cryogenic temperatures and auto-ranging should not be allowed to extend below 10mK resolution.

Metallic Resistance Thermometers have a resistance which rises approximately linearly with temperature. ITC503 passes a constant current through the sensor and measures the voltage produced (4-wire resistance measurement). With a suitable resistor and appropriate energisation, resolution to 1mK is possible at low temperatures.

Semiconductor Resistance Thermometers have a resistance which falls very non-linearly with temperature. By measuring the sensor conductance, a function is obtained which rises with increasing temperature and is more nearly linear. ITC503 achieves a 4-wire conductance measurement by controlling the sensor current in such a way that the voltage across the sensor is held constant. The sensor current is then measured to indicate temperature. Apart from providing a more linear measuring function, this method has the added advantage that sensor dissipation is automatically reduced as the temperature falls. Sensitivity at low temperatures is good and resolution to 1mK is possible.

Semiconductor Diodes have a voltage which falls with rising temperature. ITC503 provides a constant current energisation for these, as for metallic resistance thermometers, but the connections to input high and low are reversed, so that input high still receives a voltage which rises with increasing temperature. Diodes too have good resolution at low temperatures and can provide 1mK resolution.

12.3 Selecting Input Configuration

Having decided upon the sensor type the input stage configuration may be determined and the settings for SW2/4 to SW2/9 established. The details which follow are for reference only. The Object Bench Custom Range utility will automatically indicate the correct settings.

SW2/7 and SW2/8 set the polarity of the zero offset. For thermocouples the setting of these is determined by the relation between the bottom end of the range and the thermocouple reference junction temperature. Where the reference junction temperature is above the bottom of the range, SW2/7 should be ON. Where it is substantially below the bottom of the range, SW2/8 should be ON. If the reference junction is at or just below the bottom of the range, no zero offset is required and both SW2/7 and SW2/8 may be set to OFF.

Where a thermocouple range is intended for use with a compensated room temperature reference, SW2/8 should be ON.

For most metal resistance thermometers, SW2/7 should be on. Where the sensor resistance has fallen almost to zero at the bottom of the range, no zero offset is required and both SW2/7 and SW2/8 may be set to OFF.

SW2/10 is set to ON only for Gallium Arsenide Diodes. It has the effect of adding an offset between the input amplifier and the subsequent voltage to frequency convertor, so allowing the large (5V) swing of the GaAs diode to be kept within the working range of the span and zero switches.

12.4 Selecting Sensor Energisation

For resistance thermometers and diodes the preferred sensor energisation may be set by SW2/1 to SW2/3. Again the Object Bench utility will indicate the correct settings.

For Metal Resistors and Diodes, constant current energisation is used and the possible currents are:

	SW2/1	SW2/2	SW2/3
10 μA	OFF	OFF	ON
100 μA	OFF	ON	OFF
1 mA	ON	OFF	OFF

For semiconductor resistors, it is the sensor voltage rather than the current which is held constant. The switch settings from the table above will define the current which passes through the sensor **at the highest temperature of the range.** This will define a sensor voltage given by the product of the current and the sensor resistance at this highest temperature. The current should be selected by means of SW2/1 to SW2/3, such that this voltage is in the range 2mV to 19.9mV. Sensor voltages above 20mV may result in significant errors due to sensor self heating.

12.5 Selecting Zero and Span

The details which follow describe how the span and zero switches may be set empirically. However where Object Bench has been used to design a range, it will provide details of these switch settings too. Note that there are frequently alternative combinations of switch settings either of which are equally acceptable. If the empirical values do not agree with those provided by Object Bench this does not mean that either are wrong. Both may be acceptable.

Remember that SW1/1-5 and 6-10 correspond to binary numbers defining the span and zero respectively, in a logarithmic sequence (Section 11.4). To set these it is necessary to be able to simulate the sensor input conditions whilst monitoring the voltage between TP3 and TP0 on the input board.

First establish a zero switch setting SW1/6-10 by trial and error, such that with an input corresponding to the bottom of the range, the voltage at TP3 is as close to zero as possible, whilst remaining positive. (Typically this will be around 0.5 volts).

Now change to an input for the top of the range, and set SW1/1-5 to achieve a voltage as close to 5 volts as possible, without exceeding 5.25 volts. (Typically 4.5 - 5.0 volts).

There will be some interaction between the two sets of switches and a second iteration may be found to be necessary.

For Semiconductor Resistance Sensors, where conductance is measured rather than resistance, a different procedure is required. The low temperature end of the range is always fixed at a conductance of zero. Then the "zero" switches SW1/6-10 are adjusted at the high temperature end of the range to achieve a voltage as close to 5 volts as possible. The "span" switches SW1/1-5 then define the dynamic response of the system by determining the AC feedback necessary to stabilise the closed loop conductance measurement. A typical value for these is 00011. Larger values will give a faster response, but the loop may become unstable at the low temperature end. Try unplugging the sensor and plugging it back in again with the sensor near its base temperature. If there is any tendency to oscillate about a value, a lower value of the span switch setting should be used. Note that it is normal for the response of the conductance range to be much slower at the high temperature end of the range than at the low end. This is desirable since specific heats are lower at low temperatures, so a faster control response is possible.

Although the "span" switches do not provide DC feedback in the conductance measuring mode, they do have a loading effect of the "zero" switches so some interaction will occur in their settings.

12.6 Calculation and Loading of Linearisation Data

No details of the linearisation calculation process are provided here. To achieve the required accuracy needed for auto ranging at low temperatures, ITC503 employs a more complicated linearisation algorithm than ITC502 with a totally different data structure. The calculations and data transfer should only be attempted with the aid of Object Bench (supplied free with every ITC503).

13 Theory of Calibration and Linearisation

In the interests of long term stability and ease of adjustment, ITC503 contains no conventional calibration presets. Instead the calibration constants are held in the non-volatile memory and "adjusted" to match a particular sensor by means of the front panel controls. This section covers the theory behind this.

13.1 Hardware Calibration

The input signal is amplified to produce a signal within the range 0 to 5 volts at TP3 on the input board.

The role of the span and zero switches SW1 is to ensure that a given input range occupies as much as possible of this 0 to 5 volt range without ever going outside it. The ratio between successive switch positions is never less than 0.7 so it is always possible to fill at least 70% of the 0 to 5 volt range.

The 0 to 5 volt signal is passed to the following voltage to frequency converter, where it is converted into a frequency in the range 0 to 65kHz approx. This is read as a 24 bit number by the microprocessor.

13.2 Input Software Calibration

The raw frequency count has a ZERO value added and is multiplied by a SPAN, to convert it to a number which runs from 0 to 16777215 for the full working range. This serves two purposes. It allows interpolation between the switch steps and it allows variation between individual sensors to be calibrated out. When RAISE and LOWER are operated with the CAL button pressed, it is the values of ZERO and SPAN which are adjusted.

13.3 Linearisation

The lineariser proper takes the 24-bit number from the input calibration and remaps it to a new 24-bit number directly representing temperature in 0.1mK units. This mapping incorporates corrections for sensor non-linearity. The mapping is achieved by approximating the true sensor characteristic by means of a variable number (128 maximum) of straight line segments. These segments may be distributed as required throughout the sensor range. In general the segments will be concentrated towards lower temperatures, where increased resolution is required, and around any sharp discontinuities in the sensor characteristic.

Optimal use of 128 freely distributed segments, provides considerably greater precision than is possible using the 256 equally spaced segments employed in ITC4 and ITC502 for only a modest increase in computation time. Distribution of the segments for optimal performance makes the range design process more complex but this is handled by the Object Bench Custom Range utility and need not concern the user.

14 Theory of Control

14.1 General

The aim of a controller is to maintain the temperature of a system as close as possible to some desired temperature (the SET POINT) and to minimise the effect of changes in heat load on the system. When a steady state is established, the heating provided by the controller will exactly balance the heat lost by the system to its surroundings. A further function of the controller is to follow any changes in the set point as rapidly as possible. Thus the criteria for good control are:

CONTROL ACCURACY	The mean temperature of the system should be as close as possible to the desired temperature.
CONTROL STABILITY	The fluctuations above and below the mean temperature should be small.
CONTROL RESPONSE	The system should follow changes in the set point as rapidly as possible.

In the following sections a number of possible control systems of increasing complexity are described, culminating in 3-TERM or P.I.D. control, as used in ITC503.

14.2 Open Loop Operation

In an open loop system, a fixed heater power is applied and the system is allowed to come to equilibrium. There is no control as such, since the heater power can only be changed by the intervention of a human operator. The system takes a long time to reach equilibrium and any changes in the heat loss from the system, produce corresponding changes in the system temperature. The hot plates on a domestic cooker are an example of this form of "control". This mode of operation can be obtained with ITC503 in its MANUAL mode.

14.3 On-Off Control

In an on-off (or "bang-bang") control system the heater power is either full on (if the temperature is below the set point) or off (if it is above). The control accuracy and response can be very good with this form of control and the system can be made largely immune to changes in heat loss. However the control stability can never be good since the system temperature must always cycle above and below the set point. The magnitude of the temperature fluctuations depends on the thermal properties of the system. For some systems, where temperature fluctuations are not important, this is a perfectly satisfactory and simple system of control. (for example the domestic electric oven).

14.4 Proportional Control

A proportional control system overcomes the problems of temperature cycling by allowing the heater power to be continuously varied. The heater voltage at any instant is proportional to the error between the measured and desired temperatures. Thus a negative error (temperature below the setpoint) will produce an increase in heater voltage in order to correct that error.

If the output voltage were proportional to the error over the whole range of the instrument, a large error would be required in order to generate the necessary output voltage. For example an error swing of +50% of span to -50% of span would be required to swing the output from zero to full power. Thus, although the control stability might be good, the accuracy would be very poor.

By increasing the GAIN of the controller the output can be made proportional to the error over part of the total range of the instrument. Outside this range the output is either fully on or completely off. The range over which the output is proportional to the input is the PROPORTIONAL BAND. In ITC503 this is expressed directly in degrees.

By reducing the proportional band, the accuracy of the controller may be improved since a smaller error will then be necessary to produce a given change in output.

This would seem to imply that, by sufficiently reducing the proportional band, any required accuracy could be obtained. Unfortunately as the proportional band is progressively reduced, there will come a point at which temperature oscillations appear. (In the limit, a controller with a proportional band of 0 is an on-off controller, as described above).

The reduction in proportional band which can be achieved before the onset of oscillations, will depend largely on the design of the system being controlled. In some systems it may be possible to achieve the required control accuracy without oscillations but in most cases this will not be so.

14.5 Integral Action

To overcome this problem, INTEGRAL ACTION is introduced. Consider a system controlled by proportional action as described above, with the proportional band sufficiently large to prevent oscillation. The result will be stable control but with a residual error between the measured and desired temperatures. Suppose this error signal is fed to an integrator, the output of which is added to the existing controller output. The effect of this will be to vary the overall output until control is achieved with no residual error. At this point the input to the integrator will be zero and this will therefore maintain a constant output. Integral action has thus served to remove the residual error. Provided the contribution from the integrator is only allowed to vary slowly, proportional action will prevent the occurrence of oscillations. The response of the integrator is characterised by the INTEGRAL ACTION TIME. This is defined as the time taken for the output to vary from zero to full output, in the presence of a fixed error equal to the proportional band.

To ensure that the integrator itself does not give rise to oscillations, it is usual to employ an Integral Action Time of at least the response time constant of the system.

When a controller is responding to a large change in set point, the integrator will charge whilst the system is approaching the new set point. If left unchecked the integrator is likely to be fully charged by the time the temperature comes within the proportional band. This will inevitably result in a large overshoot. To overcome this it is usual to incorporate an INTEGRAL DESATURATOR whose function is to hold the integrator in its discharged state when the measured temperature is outside the proportional band. This can considerably reduce the amount of overshoot. In ITC503 a more sophisticated DESATURATION ALGORITHM is employed, which rather than discharging the integrator, deliberately pre-charges it in such a way as to further minimise overshoot.

14.6 Derivative Action

The combination of Proportional and Integral Action will suffice to ensure that accurate and stable control can be achieved at a fixed temperature. However when the set point is changed many systems will tend to overshoot the required value. By means of Derivative Action this effect may be reduced or eliminated completely. Derivative Action monitors the rate at which the measured temperature is changing and modifies the control output such as to reduce this rate of change. (Derivative Action is exactly analogous to the use of velocity feedback in servo systems and serves the same function).

Like Integral Action, Derivative Action is characterised by an action time. If the measured temperature is changing at a rate of one proportional band per DERIVATIVE ACTION TIME, Derivative Action will contribute a signal sufficient to reduce a full output to zero or vice versa.

In ITC503, use of the integral desaturation algorithm referred to above, may be sufficient to limit overshoot in many systems. In this case no derivative action will be required.

14.7 North American Terminology

In North America, a different terminology exists for 3-term control.

PROPORTIONAL BAND is replaced by its reciprocal, GAIN.

INTEGRAL ACTION is replaced by RESET. This may either be specified as a time (as for integral action) or as its reciprocal, "REPEATS PER MINUTE".

DERIVATIVE ACTION is replaced by RATE. Again this may be specified as a time or as repeats per minute.

14.8 Theory of Gas Flow Control

ITC503 has the ability to drive a motorised needle valve. In the GAS AUTO mode the position of the needle valve is controlled automatically to provide variable cooling power in conjunction with the heater for temperature control.

The valve position is controlled by an integrator. In other words control operates relative to the current position rather than being an absolute setting. This is necessary as it is not generally practical to calibrate a cryogenic needle valve in absolute terms.

The integrator output is related to the valve position by a **Valve Gearing** parameter, which defines how many steps exist between the valve fully open and fully closed positions. This allows the ITC503 to be matched to a variety of different needle valve and stepper motor combinations. Total numbers of steps between 512 and 65536 can be accommodated, in binary increments. Valve gearing forms part of the Gas Flow Configuration Parameter (section 7.3).

The integrator is driven by two error signals, a **temperature error** (the difference between the set point and the temperature measured by the control sensor) and a **heater voltage error** the difference between the expected heater voltage and the actual heater voltage delivered by the heater control algorithm. The error signals are scaled by the error sensitivities (see section 7.3) and are also compensated for valve non-linearity (decreasing error sensitivity with increasing temperature and lower flows).

The sensitivity to temperature errors is such that the valve will respond to large temperature errors (for example following a change in set point) but will be relatively unaffected by small temperature errors when close to the set point, allowing the fine control of temperature to be dominated by the heater. When control is established at the set point, the temperature error is by definition zero, so control of the valve integrator is dominated by the heater voltage error, such that this too tends to zero as the cooling is adjusted until the heater voltage reaches its expected target value. The expected heater voltage is itself a function of the set temperature. The two are related by a look-up table known as the **Target Heater Voltage Table**. The table contains 64 discrete target heater voltage values, each covering 1/64 of the total working temperature range. The working range of the tables covers 0 to 512K (The Gas Flow cooling algorithm will never be required to operate outside this range). The value from the table is scaled to the Maximum Heater Output Voltage (section 5.1) and multiplied by the **Gas Flow Scaling Factor** (section 7.3) to obtain the final target heater voltage.

Prior to firmware version 1.09, the Target Heater Voltage is set to the nearest step in the table, so can take a series of 64 discrete values. From firmware version 1.09 onwards, i linear interpolation is made between the table steps. This prevents any risk of discontinuities in the gas flow algorithm perturbing the temperature stabilty when carrying out temperature sweeps with automatic gas flow control operating.

Three separate Target Tables are held within the firmware, matched to different applications and there is provision for a forth table to be downloaded via the computer interface for very non-standard applications. In general one of the three standard table coupled with the Gas Flow Scaling factor (see below) is sufficient to cover most applications. The reason for having a number of tables, together with a scaling factor, is that the optimum target voltage represents a compromise between a number of factors.

At the most simplistic level, a target heater voltage of zero under all conditions would provide minimum cryogen usage and hence most economic operation. The disadvantage is that whilst heater power could be delivered to correct for rapid falls in temperature it would not be possible to correct for rapid rises in temperature and the result would be poor control stability.

A next level would be to ensure that the target voltage is sufficient to ensure that the heater voltage never falls to zero when correcting for minor fluctuations during steady state control. This can give good control stability at the sensor and heat exchanger and is a good operating strategy for so called "static" cryostats, where the experimental sample and temperature sensor are in good thermal contact with the heat exchanger.

Many applications do not permit this good thermal contact and the sample must be cooled by contact with the gas stream leaving the heat exchanger. Such cryostats are referred to as "dynamic". Sometimes it is still possible to have a temperature sensor in contact with the sample, so that its actual temperature is known. However often this is not the case and the sample temperature must be inferred from a sensor elsewhere in the gas stream. The gas responsible for thermal contact between heat exchanger, sensor and sample, is of course the cooling gas obtained by evaporation of cryogen. In such a situation it is often necessary to sacrifice efficiency of cryogen use, to achieve a minimal temperature gradient between sensor and sample and hence to operate with a higher target heater voltage than would be appropriate for a static cryostat. However even here it is important not to use too high a value. Not only is this wasteful of cryogen, it can degrade the temperature errors since at very high gas flows, there is insufficient time for good heat exchange within the heat exchanger.

Achieving the correct balance can be a time consuming operation, often involving a series of measurements made under various conditions, with a separate measuring sensor mounted in the position which will finally be occupied by the sample. Fortunately, once measured, the results are predictable between cryostats of a similar type. Thus it is normally possible to achieve good results by setting up the various parameters to a set of OI recommended values for a particular cryostat type.

The algorithm described above yields good results under steady state conditions. However when a system is initially cooled down, or large changes are made to the set temperature, it can be unnecessarily slow to respond. Three additional features are built into the algorithm to avoid this problem. They can all be enabled or disabled by setting bits in the GFS Configuration parameter.

Fast Cooldown when enabled activates when the temperature is well above the set point and is not falling. (Typical conditions at the start of a run). It results in the needle valve opening rapidly until cooling starts.

Cooldown Termination resolves the problem at then end of the cooldown, when the temperature approaches the set point and the heater starts to come on. If the valve is more than 50% open at this point, cooldown termination, causes it to close rapidly until the 50% point is reached, when the normal algorithm takes over.

Slow Valve if enabled reduces the rate at which the valve may close, following an increase in set temperature. This can prevent a problem whereby the needle valve may close altogether following a large set point increase. If this occurs, on an AutoGFS, the syphon starts to warm and can take some time to re-establish stable flow conditions once the set temperature is reached.

15 Servicing

15.1 Circuit Description

The majority of the circuitry involved in ITC503 is conventional and can be readily understood from the circuit diagrams. The notes which follow cover those areas where some additional explanation may be required.

The power supply is totally conventional, providing a high power DC heater supply and a separate 5v supply for the logic. The raw 11 volts from which the 5v is obtained, is used on the main PCB to monitor mains volts. Should this fall below 8 volts, a RESET is performed. (If ITC503 is operated on very low mains volts, it may keep resetting. This may be identified by the "PASS" message reappearing during use.)

The main transformer also generates an 18v AC supply for the input circuits. A separate transformer on the input board splits this into separate isolated supplies for the input amplifier and the current source. Regulated reference supplies of +/-6.2v are generated on the input board.

The input amplifier uses a chopper stabilised amplifier for best stability. This incorporates internal protection against electro-static discharge (ESD) and further protection is provided by the input filter and the fully floating supplies.

The ladder networks associated with SW1 have been designed to give approximately equal ratios of 0.7 between steps.

The sensor current source U103A floats on its own power supply. However it derives its reference supply from the main input stage reference rails, using the three amplifier instrumentation configuration U103 B, C & D, to provide the necessary common mode rejection.

Note when testing the current source, there must be some electrical path between the current source and the input amplifier, to ensure that this remains within the common mode range of the amplifier. In use, this path is provided via the sensor leads. For testing, it is suggested that pins 3 and 5 of the input connector should be linked.

Referencing the current source from the main input reference permits an easy re-configuration for a true 4-wire conductance measurement. This is achieved by opening SW2/6 and SW2/4 and closing SW2/5. The main amplifier now operates open loop and the overall feedback loop is closed via the current source. The normal zero network is used to define an expected sensor voltage and the feedback loop now slaves the sensor current to achieve this. A capacitor across SW2/6 ensures AC stability in this configuration.

The high level signal from the input stage is fed via a filter to a voltage to frequency convertor and thence via a high speed opto-isolator to a counter on the microprocessor board.

The microprocessor circuit is conventional and incorporates CPU, EPROM, RAM, CTC and UART chips. The keyboard and display are mapped directly as i/o ports on the microprocessor bus and the CPU handles all the display decoding and multiplexing in software.

An EEPROM U3, is used to retain data when the instrument is powered down. When a STORE operation is performed, the entire RAM content is written to this chip. Its content is automatically copied back to the RAM at power up. The EEPROM used requires a specific code sequence to be sent before any write operation is permitted. This prevents corruption of the EEPROM data should the normal CPU operation be disturbed by a mains transient or ESD. (Should this IC require replacing, an exact equivalent from the same manufacturer should be used, or advice sought from Oxford Instruments. Not all manufacturer's "equivalent" EEPROMs support this Software Data Protection). Further protection is provided by switch S2 in the write enable line. When switched off, this prevents all EEPROM writes.

The output stage accepts a high frequency time proportioned waveform from the microprocessor via the opto-isolator U201. This is converted to a 27 v p-p waveform at TP203.

A DC level is established from this by filtering and is used in a conventional analogue output stage. R217, R218 and Q203 provide Safe Operating Area protection for the output device Q204.

Q201 and Q202 provide protection to the heater in the event of a failure within the digital circuitry. Should this occur, the drive to the output stage would remain fixed in one or other state. If it is ON, the heater output is zero and no problem arises. If it is OFF, C201 will charge, switching on Q202 and taking the heater output to zero. In normal use the microprocessor ensures that the output drive is always pulsed on briefly, so switching on Q201 and preventing C201 charging.

The protection relay RL1 allows the microprocessor to switch off the heater under circumstances where failure of the output stage is suspected.

The GPIB sub-board employs a dedicated GPIB interface IC type uPD7210. This supports all the GPIB protocol. The bus transceivers are type 75160 and 75161 and are fitted in sockets to allow easy replacement. (GPIB transceivers can be damaged if GPIB connections are made or broken whilst instruments are powered up!).

The sub-board links to the main board via the U5 UART socket. The UART is included on the GPIB board and a PAL on this board maps both the GPIB chip and the UART into the original UART i/o space.

15.2 Test Mode

ITC503 performs a basic self test of the microprocessor and memory at switch on, before displaying the "PASS" message. A more detailed hardware test mode is available for help during fault finding. This has already been described in section 4.12. In that section entering test mode from the front panel was described. This route may not work under certain fault conditions. An alternative method of entering the test mode is by pressing the internal RED button S1 on the main circuit board. Provided the basic CPU and memory are operational, this route will always access the test mode.

Use of the test mode to configure gas flow control, GPIB address and sensor range has been described earlier. See section 4.12 for a list of all test mode functions. Those functions specifically intended to assist with hardware testing are described now.

Test 01 lights each LED or display segment in turn, then pulls each of the auxiliary output lines low in turn. When the test is complete, ITC503 re-enters the test mode.

Test 02 tests the control buttons. When the test is entered, the display will be blank. If the buttons are pressed, one at a time, each should light a single segment in the upper half of the display. Stuck buttons will give a permanently lit segment. If more than one segment lights for a single button, track shorts are indicated. To leave test 2, POWER must be switched off.

Test 04 allows the front panel display to be set to indicate one of the internal parameters rather than the normal measured temperature. This produces the same effect as the "Fn" command described in section 10, without the need to connect a computer. When test 4 is selected, the display will show:

F 00

RAISE and LOWER may be used to select an option in the range 0 to 15 for front panel display. The options are as given in the list for the "R" command in section 10. When the required option has been selected, pressing LOC/REM will implement it. ITC503 will return to normal operation but with the selected parameter on display. To restore a normal display, the display SENSOR button may be used.

16 In Case of Difficulty

This section indicates some of the more common pitfalls and operator errors.

Display always shows "Hot 0"
Cryostat safety sensor faulty or disconnected.

Display always shows "Hot 1", "Hot 2" or "Hot 3"
Sensor not connected, or faulty.

Sensor limit inadvertently set to zero (see section 5.2). In this case it will be necessary to reset the limit. The simplest procedure is to temporarily disable the limit as described in section 5.7. This will restore the display and make it easy to reset the limit to its correct value. If your firmware is earlier than 1.07 this facility is not available. In this case the display will always show the "Hot" message, and the limit must be reset whilst "flying-blind". The procedure shown below should be used. This is the same procedure normally used to change a limit, but the absence of a display can be disconcerting! If more than one limit is wrongly set it may be necessary to reset each in turn.

a) Switch on POWER

b) Use DISPLAY SENSOR to select the sensor shown in the "Hot" message.

c) Press LIMIT and hold in.

d) Press SENSOR and release.

e) Still holding LIMIT, press RAISE and hold for 10 seconds.

f) Release LIMIT, then press it again, and press LOC/REM to store the new settings.

g) Switch off POWER and switch on again. All should now be well, with the LIMIT set to maximum.

h) IT set to maximum.

No Heater Output
The heater limit has been set close to zero. (See section 5.1).

Heater Output Voltage Varies with Set Temperature
This is intentional when the heater limit is set to zero. (See section 5.1).

RAISE and LOWER appear not to work
Controller is set to REMOTE

HEATER SENSOR appears not to change sensor
Controller is in REMOTE or AUTO

ITC503 **appears to control with a large offset**
INT time has been set to a very large value.

ITC503 **only moves very slowly towards set point**
DERIV time has been set to a very large value.

Nothing happens when PID AUTO is pressed
No data is present in the Auto-PID table, or it has been disabled by writing a zero to the upper limit for the first entry in the table.

When SWEEP used, LED's light but the temperature does not change
Not switched to AUTO.

Set Point changes without pressing SET
SWEEP RUN/PROG pressed.

HEATER SENSOR changed (see section 4.3).

"PASS" message appears during operation
Low mains voltage. ITC503 is resetting. It will switch to MAN with output at zero. Check mains voltage setting is correct.

Calibration changes when RAISE/LOWER pressed
CAL button stuck in.

Cannot get SPAN & ZERO calibration correct together
The calibration points chosen are not sufficiently near the ends of the range, so ITC503 is adjusting the same constant, (for example the ZERO) at both points (see section 7.1). (Display will show the same message, either "Hi" or "Lo" at both points).

The span DIP switches (SW1/1 to SW1/5) are wrongly set so that the voltage at TP3 stops a long way short of 5 volts (see section 12.5).

Measured Display will not Reach Full Range
Either the span or zero switches (SW1/1 to SW1/10) are wrongly set so that the voltage at TP3 goes below zero or above 5.75 volts at the extremes of the range (see section 12.5).

Calibration, Limits etc. lost after Power Down
The STORE operation has not been performed after calibrating, setting limits and so on. (see section 5.6).

No Display or Abnormal Display (for example Multiple Decimal Points)
This probably indicates a hardware defect but can occasionally be due to corruption of the non-volatile RAM content. The first action should be to switch ITC503 off and on again. This will reload the RAM from the EEPROM. If this cures the problem and it does not recur the RAM had probably been corrupted by a supply glitch or injudicious use of the "Y" command. If the problem recurs, a hardware fault in the microprocessor or RAM is indicated.

If switching the power off and on does not cure the problem, or if it was initially discovered at switch on, the contents of the EEPROM itself may be corrupt. There are two **reset** procedures which may assist in diagnosing the problem. A two-button reset is carried out by holding the RAISE button pressed, whilst pressing and releasing the internal RED test button S1 on the main PCB (See section 11). This partially resets the RAM content and will always restore a "PASS" message and a normal display if no other faults are present. A **three-button reset** completely resets the entire memory, wiping out all calibration information and any custom linearisation curves which have been installed. It is carried out by holding both RAISE and LOWER pressed whilst pressing and releasing S1 on the main PCB.

Provided a STORE operation is not performed, the EEPROM will not be re-written so these resets can be used as safe diagnostics**. (N.B. This is not the case with** ITC4 **or some other OI instruments).** If they cure the problem, it is possible to use STORE to re-write the EEPROM but this should be used as a last resort when the EEPROM is known to be beyond recovery (for example after replacement of the EEPROM chip). After a three-button reset, any custom ranges must be re-installed, the range configuration described in Section 11.5 must be carried out and finally the Zero and Span calibration described in Section 7 must be carried out.

17 Differences Between ITC503 and ITC4

For convenience of users already familiar with ITC4, we list here the most significant differences between this and ITC503.

Memory Technology ITC503 employs a new EEPROM technology for its Non-Volatile memory, in place of the battery-backed RAM technology used by ITC4. This is much less susceptible to memory corruption caused by mains glitches or electrostatic discharge.

Need to STORE Data Any data changes which are to be retained in the Non-Volatile memory after power off, must be actively STORED (see section 5.6). This is a benefit of the new memory technology and avoids the risk of calibrations and so on being lost inadvertently.

Write Protect Switch An internal switch can be used to disable all writes to the EEPROM, allowing calibrations and so on to be made safe from front panel tampering.

Extended Command Set The available commands for computer control have been extended. Section 9 provides details.

Extended Status Reply The response message to the "X" command now includes a report of which sensor is being used forcontrol and the Status of the auto-PID algorithm.

Extended Arithmetic The raw data measurement and internal arithmetic are carried out to 24 bit precision.

Auto Ranging The displayed temperature auto-ranges at lower temperatures to give increased resolution.

Changed Number Format The format used to send and receive numbers via the computer interface has been changed to accommodate auto-ranging. All numbers are now sent in decimal format with a decimal point included where appropriate, exactly mimicing the front panel display.

Auto PID Operation ITC503 can select PID values automatically based on its set temperature. The data used can be learned automatically for a particular system by running ITC503 in conjunction with Object Bench software.

Enhanced Gas Control The Gas Flow Control algorithm has been extensively rewritten and a number of extra features added to give improved control over a wide range of cryostat types (see section 14.8).

Cryocooler Support Support for Cryocooler operation is now included in the standard firmware. On ITC4 a separate version of firmware was required.

GPIB Interface An internal GPIB interface included. This allows for full GPIB control without the need for an external (GPV24) adaptor. In addition the GATEWAY facility allows this to act as an adaptor to older instruments such as ITC4 via ISOBUS.

Self Test Display As part of self test, ITC503 displays its GPIB address or its ISOBUS address, before the "PASS" message.

Improved Input Filtering Additional filtering has been added to the input and current source connections. This can prevent the risk of electrical noise picked up on the sensor wiring contributing to sensor self heating.

18 Specification

INPUT CHANNELS	1 standard, 3 optional
INPUT RANGE	5mV TO 2V FSD
INPUT OFFSET	-2v to +2v
CURRENT SOURCE	10uA, 100uA, 1mA (+/-10%)
SENSOR TYPES	
Voltage Input	5mV to 2V FSD
Resistance Input	4-wire, 5 Ohm to 200 K Ohm FSD
Thermocouple	See List. (RT comp. on Celsius ranges)
Pt, RhFe Resistor	4-wire resistance measurement
Ge, Carbon Resistor	4-wire conductance measurement
Si, GaAs Diode	Volts sense at constant current
HEATER OUTPUT	0-40v DC
HEATER RESISTANCE	20 ohms min
OUTPUT POWER	80W max into 20 ohms
AUXILIARY I/O	For gas controller
CHART RECORDER	o/pTime Prop Signal on AUX Socket. (Requires external passive filter)
DISPLAY TYPE	0.56 inch RED LED
DISPLAY RANGE	0.000K to 1667.7K (Auto-ranging) -273.2C to 1394.7C
CONTROL METHOD	Digital 3-Term (P,I,D)
SAMPLE RATE	4 Hz
INPUT RESOLUTION	24 Bit
OUTPUT RESOLUTION	16 Bit
INTERNAL ARITHMETIC	24 Bit for Error Generation 16 Bit for P & D Terms 32 Bit for I Term
RS232 INTERFACE	Configured as DCE
HANDSHAKE	None Required
BAUD RATE	9600 Baud
IEEE-488 INTERFACE	Internal Interface
CONNECTORS	
POWER IN	IEC 3 pin
SENSOR INPUT	9 way D socket
AUXILIARY I/O	15 way D socket
RS232	25 way D socket
POWER REQUIREMENTS	100-240V 50/60Hz
POWER CONSUMPTION	120VA approx

CASE STYLE	Freestanding Metal Case Optional Rack Mount Ears
DIMENSIONS	
FREESTANDING	446mm x 106mm x 298mm
RACK MOUNT	19 inch x 2U x 298mm
WEIGHT	6.5kg

19 Appendix 1 - Capacitance Sensor Input

19.1 Description of Capacitance Sensor Input Board

19.1.1 Features

- Suitable for any sensor capacitance up to 200nF maximum
- 900 Hz Sine Wave Excitation for best sensor stability
- Low amplitude excitation (35mV RMS) avoids self heating
- Excitation Frequency locked to supply prevents strobe effects
- Automatic Set Point Transfer when sensor selected
- Zero Impedance measuring circuit immune to cable capacitance

19.1.2 General

Capacitance temperature sensors exhibit less magnetic field dependence than most other cryogenic thermometers and can therefore serve as the ideal control sensor for use in the presence of strong magnetic fields. They do however exhibit poor stability with respect to ageing and thermal cycling and so cannot be used as a primary temperature measuring element. The preferred method of operation is to use another sensor with good long term stability (for example a rhodium iron resistor) to establish stable control at the required temperature, in the presence of zero magnetic field. When stability is achieved, control is switched to the capacitance sensor, before energising the magnetic field. This sensor then holds the temperature constant, whilst the indicated temperature from the primary sensor appears to vary due to the presence of the field.

The ITC503 Capacitance Sensor range card is designed to make this operation as simple as possible. It provides a low, constant amplitude, constant frequency sine wave, excitation for the sensor and uses coherent detection (a lock-in amplifier) to detect the recovered signal from the sensor. Zero impedance source and detection circuitry is used to eliminate effects due to variations in cable capacitance. The card is installed in the Channel 1 position in ITC503, leaving Channels 2 and 3 free for the primary sensor and an optional third sensor. When switching control from the primary sensor to the capacitance sensor, ITC503 software automatically adjusts the set point to the correct value for the capacitance sensor, without any special calibration and balancing procedures being required. This set point transfer is carried out to the full internal precision of the ITC503 maths (1 part in 65384), even when the displayed capacitance reading does not achieve this resolution. With a suitable sensor, this allows a single range to cover temperatures to 300K whilst still achieving a Set Point resolution better than 0.1K at 4.2K, despite the non linearity of the sensor.

Excitation is always applied to the capacitance sensor, whichever measuring sensor is in use (capacitance sensors can exhibit a short term aging effect following changes in excitation amplitude or frequency).

There are a number of inherent limitations involved in the use of a capacitance sensor which must be born in mind. Firstly the long term stability of the sensor is not good and variations may be expected from one thermal cycle to the next. It is therefore not appropriate for use as a primary standard. Moreover the shape of the capacitance versus temperature curve may vary between runs and also between cooling and heating. For these reasons, no attempt is made to create a linearised temperature display for the sensor. The value displayed is simply a linear scale related directly to capacitance. This can if necessary be scaled to read actual capacitance in nano-farads, but this offers no operational advantage and may reduce the displayed resolution (though not the control resolution for the reasons discussed above).

The second limitation of the capacitance sensor is the shape of the capacitance versus temperature curve. All capacitance sensors are based on high dielectric constant "ferroelectric" ceramic materials. These all achieve their high dielectric constant by operating close to a lambda point in their phase diagram. At this point the capacitance goes through a maximum. In the low temperature region below the lambda point, capacitance increases with increasing temperature. It is in this region that the sensors are most useful. One family of sensors typified by the Lakeshore model CS-401, exhibit their maximum at around 65K and are usable as control sensors up to about 60K. A second family based on a commercial multilayer ceramic element available from a number of sources, have their maximum at or above 290K and are usable up to at least 270K. The Lakeshore model CS-501 is an example of this family.

In both cases it would be possible to reverse the sense of the control action and allow operation above the capacitance maximum. However there will always be a forbidden region around the maximum where stable control is impractical. In practice there is little point in attempting to operate above the maximum, even in the case of the CS-401 family. Above 60K errors due to magnetic field on the primary sensor are generally small and this itself may be used for control.

As supplied, the Capacitance Sensor Range Card is suitable for use with either family of sensors. However if operation is only required at low temperatures, increased resolution may be obtained by a component value changes to C1, R9, R16 & R17.

19.1.3 Installation

The Capacitance Sensor Range Card is installed in ITC503 in place of the existing Channel 1 Range Card. Before attempting to install the card, ensure that the Safety Information given in the Section 1 has been read and that the instrument is completely disconnected from the supply mains. When retro-fitting the card to an existing instrument, it will normally be found easier to remove the bottom cover and to take out the existing card complete with its mounting spacers, from below. The rear panel should be released and swung clear to allow the card to be withdrawn. The spacers may then be fitted to the new card before it is installed. This method avoids the need to remove the Channel 2,3 card (if fitted).

19.2 Connections

Connections from ITC503 to the sensor should be made in screened cable. Two separately shielded conductors are required, one carrying the sensor excitation, the other carrying the sensed voltage. The use of a pair of conductors within a single shield is not recommended. It can lead to reading fluctuations if the cable is moved. The shield of the voltage sense lead should be bonded to the cryostat. The shield of the excitation lead should be left isolated at the cryostat end. Both shields are grounded at the ITC503 end. Within the cryostat, the two conductors are taken to the two ends of the sensor, using thin copper wire with good heatsinking to the point of measurement. (Standard good cryogenic practice). Separate shielding of the wires is not needed within the cryostat, provided they are mechanically anchored to prevent gross movements relative to each other.

Pin connections are:

PIN	LEAD	CONNECTION AT CRYOSTAT
1	Sense Lead Inner	One end of Sensor
2	Sense Lead Shield	Cryostat Body
3	Excitation Lead Shield	(No Connection)
4	Source Lead Inner	Other end of Sensor
5	(No Connection)	
6	Heater Output +ve	Heater
7	Heater Output -ve	Heater
8	Provision for TC RT Comp.	(See Below)
9	Chassis Ground	

The Capacitance Sensor Range Card mounts in the Channel 1 position within ITC503. Where thermocouples are used with a room temperature compensated reference junction, the compensating sensor for all channels is mounted on the Channel 1 board. In general RT compensation of thermocouples is not appropriate for cryogenic applications so that the need for a capacitance sensor and RT compensated thermocouples are normally mutually exclusive. However there may be occasions when an ITC503 is being configured for two separate tasks, only one of which is a cryogenic application. For this reason, provision is made on the board to include an RT sensor by fitting components U9 and R45. The sensor output is then made available on pin 8 of the connector, which should be used in conjunction with a thermocouple connected to Channel 2 or 3, as described in the main part of this manual.

19.3 Use of the Capacitance Sensor Card

A conventional calibrated sensor (for example a Rhodium Iron resistor) installed in Channel 2 or 3, should be used to establish control at the temperature of interest. Once control is established at the required set point, the DISPLAY SENSOR button may be used to select Channel 1 and confirm that the capacitance sensor is operating and has reached a stable reading. (After a large temperature change, there may be a small initial drift due to short term senor "aging", normally towards a lower value). When the sensor has had time to settle the HEATER CONTROL SENSOR button may be pressed to select the capacitance sensor for control purposes. ITC503 will automatically copy the present reading into the set point so that control continues at the same temperature. (Note that this set point transfer will be carried out to the full precision of the ITC503, which may be greater than the displayed precision for the capacitance sensor). If desired, control stability may be verified by continuing to display the temperature from the primary sensor whilst controlling with the capacitance sensor. If a magnetic field is now applied, its effect on the reading of the primary sensor may be observed, whilst the capacitance sensor keeps the temperature stable.

19.4 Calibration

Since a capacitance sensor is used only as a transfer standard, there is no need to make any specific calibration of the sensor. In many applications it is sufficient to set Channel 1 up for "Lin" following the procedure given in the manual. However it can often be advantageous to install a range which indicates approximate temperature. This can be calculated in the same way as normal ranges, using the typical sensor calibration and taking capacitance as the raw measured variable. This gives the advantage of a similar sensitivity on the capacitance range and the reference sensor range, avoiding any need to change PID terms when switching control between the two sensors.

19.4.1 Calibration when using a "Lin" Range

With no sensor connected, the CAL button may be used to obtain a display at or very close to zero. With the sensor connected, and at its temperature of maximum capacitance (or an equivalent capacitor connected in its place), the CAL button may be used to obtain a display the highest possible reading. This allows the maximum resolution to be obtained for control with the capacitance sensor. Alternatively, the display may be calibrated to read directly in nF by setting 0.0 with the sensor o/c and 100.0 with a calibrated 100nF capacitor connected in place of the sensor.

19.4.2 Calibration when using a "Temperature Display" Range

If a range has been set up to display approximate temperatures, the CAL button may be used in the usual way to get a correct reading of temperature near the bottom and top of the working range. However it is important to remember that the sensor itself may not be reproducible between successive thermal cycles, so the displayed value should never be taken as an indicator of the true temperature.

19.5 Circuit Description

U2A forms a Wien Bridge Oscillator generating a sine wave at 900Hz. Q1 controls the loop gain to allow amplitude stabilisation. Q2 controls the frequency to allow locking to a harmonic of the mains frequency. RV1 provides a coarse frequency adjust. Oscillator output at TP2 is 900Hz approx 5V p-p.

U2C produces a square wave of 9V p-p at the oscillator frequency at TP7. D2,D3 control the square wave amplitude. R33, R34 provide feedback to ensure fast edges. Input network C8, R32 matches the phase shift of the square-wave to that of the phase detectors described below.

U2D is an identical circuit generating a square wave at mains frequency. (50Hz or 60Hz) at TP8. U4 and U5A form a divide by 3 generating 300Hz from the 900Hz square-wave. This resets U5B, which is set again on the next positive going edge at TP8. The waveform at TP9 thus consists of positive going pulses at a repetition rate of 50Hz or 60Hz with a width varying from 0 to 3.3 mS. The network D1, R38, R39, C2 converts this to a DC voltage between -6.2V and 0V at the gate of Q2, such that the oscillator frequency remains locked to either the 15th or 18th harmonic of the mains. (This prevents any strobing effects on the measured capacitance due to supply mains pickup at the sensor).

The sine-wave at TP2 is attenuated to approximately 100mV p-p by R9, R16 to provide sensor excitation via SK102/4. This waveform is then re-amplified to 5V p-p by U1C and fed to the Phase Sensitive Detector U1D, which inverts alternate half cycles giving a 2.5V peak positive going signal at TP5. The mean DC level at this point is given by 2.5*2/PI or approx 1.6V. R26 and R27 provide a 1.6V reference voltage from the +6.2V rail and U2B forms an error amplifier driving the gate of Q1 and closing the amplitude feedback loop. Loop damping is provided by R28, R30 and C7. Controlling the amplitude from the excitation signal at SK102/4 ensures that the source impedance at this point is effectively zero, so that capacitance to ground in the excitation cable does not affect the measurement.

The excitation results in an AC current flowing through the sensor capacitance and into the virtual earth of U1A via SK102/1. U1A amplifies this producing a voltage in the range 0 to 5V p-p at TP1 for a sensor capacitance in the range 0 to 100nF. The feedback component for U1A is the capacitor C1, the value of which may be varied to suit different sensors. Use of a high stability polycarbonate capacitor as the feedback element around U1A ensures that the measurement is temperature and frequency independent and that the waveform at TP1 is in-phase with the drive waveform for a pure capacitance sensor. Since U1A is configured as a virtual earth amplifier, it presents a zero load impedance to the sensor such that cable capacitance on this lead also has no effect. R2 provides DC feedback to stabilise the working point of U1A, but has no effect on the measurement.

The amplified signal from the sensor is detected in U1B to produce a unipolar positive going signal proportional to sensor capacitance at TP3. The maximum value at this point is approximately 5V peak giving a mean value of 3.2V. This is filtered by R40, C10, R41, C11 before being fed to U6 to be converted to a frequency in the range 0 to 60kHz which is fed via the opto-isolator U7 to the ITC503 main PCB.

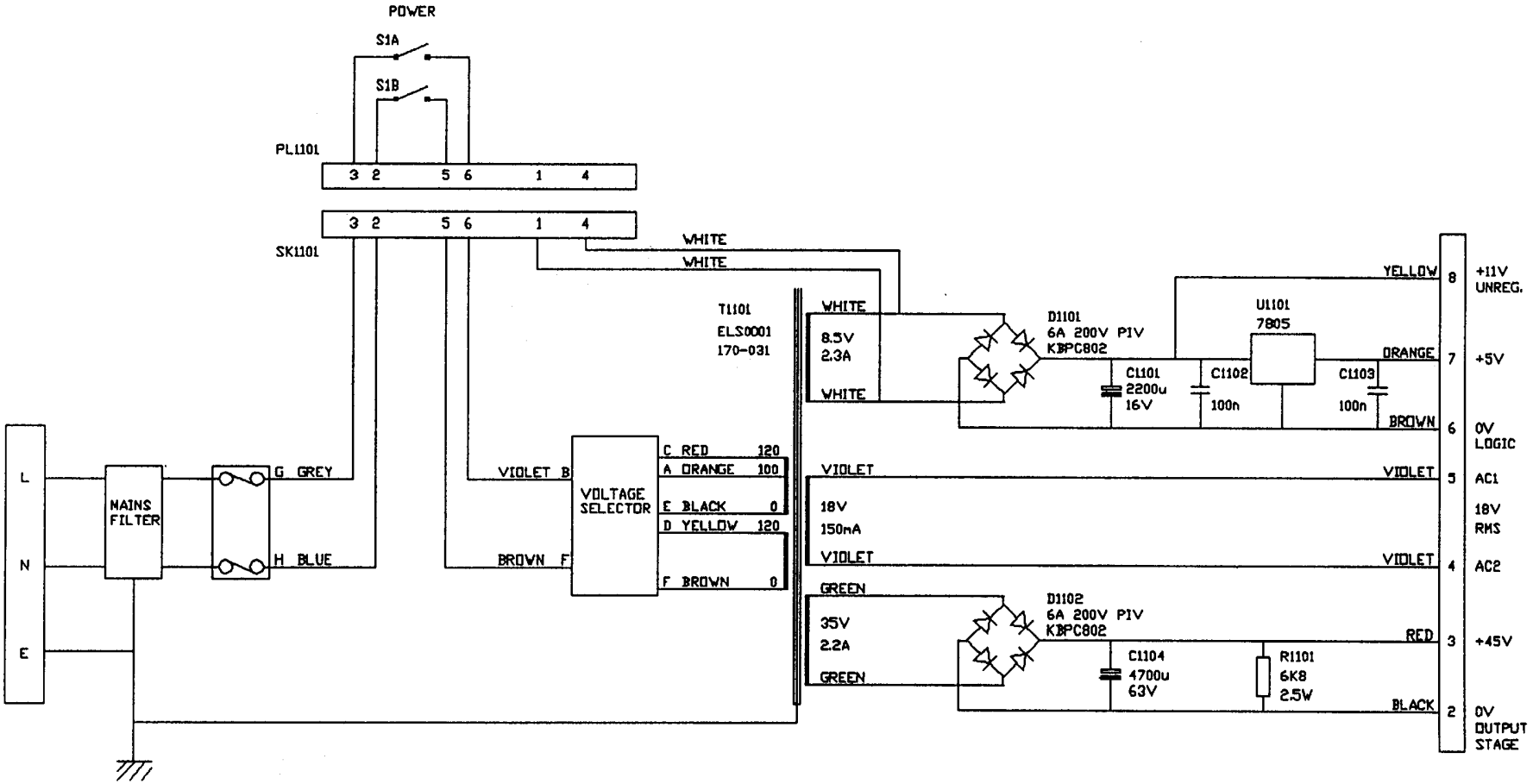
High stability power rails are provided by U8 which derives its reference from diode D6.

A capacitance sensor itself requires no room temperature reference compensation. Moreover since the sensor is for use in cryogenic systems it is not expected that any thermocouple sensors used for channels 2 and 3 will require a room temperature reference junction. However against the remote possibility that one should be required, provision is made on the board for the RT sensing circuit U9, R45. These components are not normally fitted.

20 Circuit Diagrams

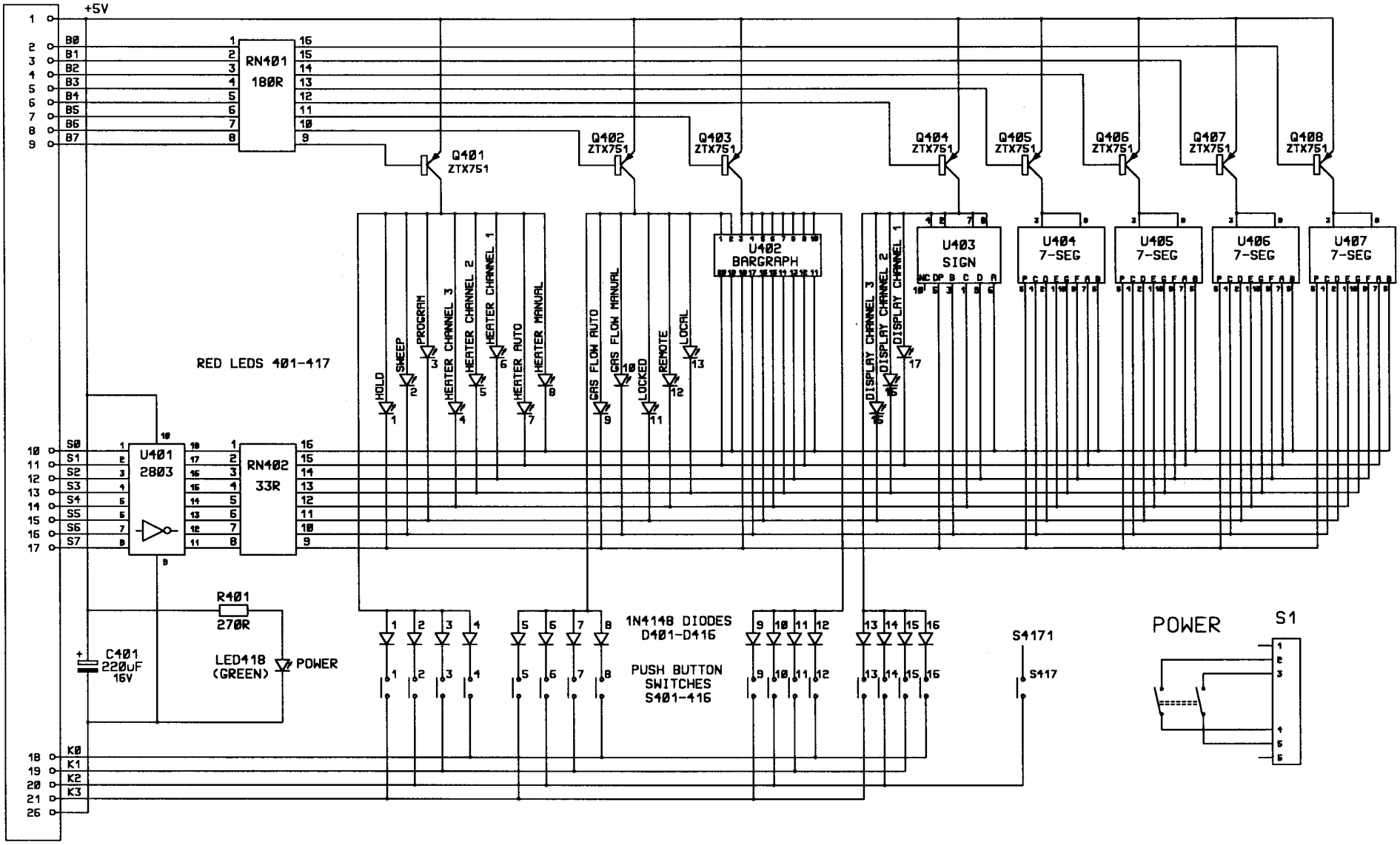
The following circuit diagrams are included, covering ITC503 itself, together with its accessories:

Drawing Number	No. of pages	Description
CQA1102	(1 sheet)	POWER SUPPLY
CQB0102	(1 sheet)	KEY / DISPLAY BOARD
CQB0202	(4 sheets)	CPU / DIGITAL CONTROL BOARD
CQB0302	(2 sheets)	INPUT AMPLIFIER BOARD
CQB0602	(2 sheets)	CAPACITANCE SENSOR INPUT BOARD
CQB1602	(1 sheet)	CHART RECORDER OUTPUT LEAD
CQB1802	(1 sheet)	AUTOMATIC HEATER SELECT RELAY BOARD
CVA0002	(1 sheet)	OXFORD INSTRUMENTS ISOBUS CABLE
CVG0102	(1 sheet)	GPIB INTERFACE



			ITC / VTC POWER SUPPLY
ISSUE 1	16/6/93 AFS	RE-DRAWN	DRAWING NUMBER A4/ CQA1102

OXFORD



REV	DATE	DESCRIPTION
07	7/6/99	C731 U403 CHANGED BACK TO SIGN
06	3/2/98	400 ADDED TO IDENTS, U403 WAS SIGN DISPLAY
05	21/6/93	DRAWING NUMBER CORRECTED (WAS CQC0102 IN ERROR)
04	1/7/91	REDRAWN

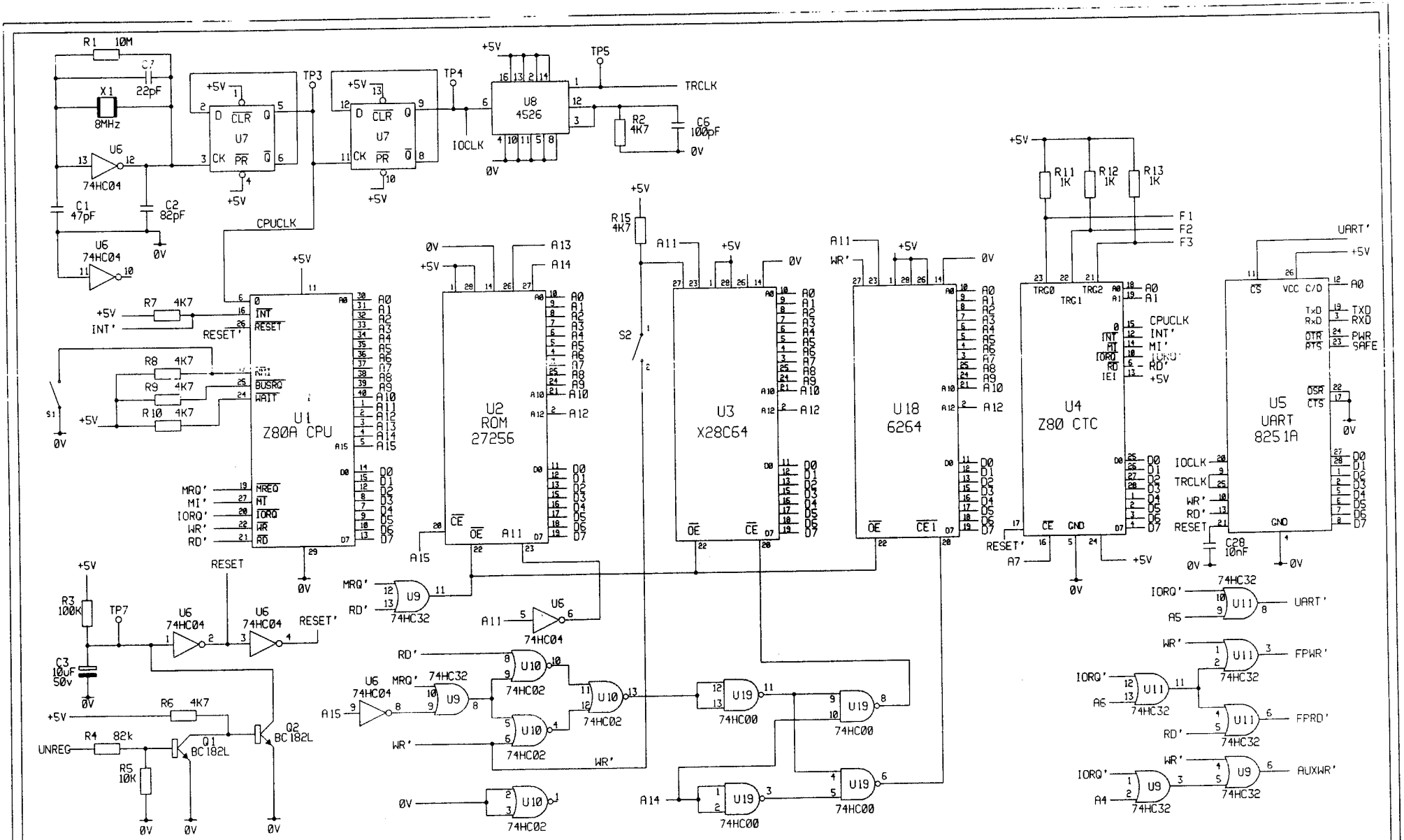
TITLE

ITC KEY/DISPLAY BOARD

OXFORD

DRAWING NUMBER

A4/CQB0102 SHT 1 OF 1



05	6/6/97	C586 R220 ADDED
04	22:11:93	U6 PIN 11 TAKEN TO 0V
03	21:8:93	C28 ADDED
02	16:3:93	PRODUCTION ISSUE
01	29:1:93	ORIGINAL

TITLE

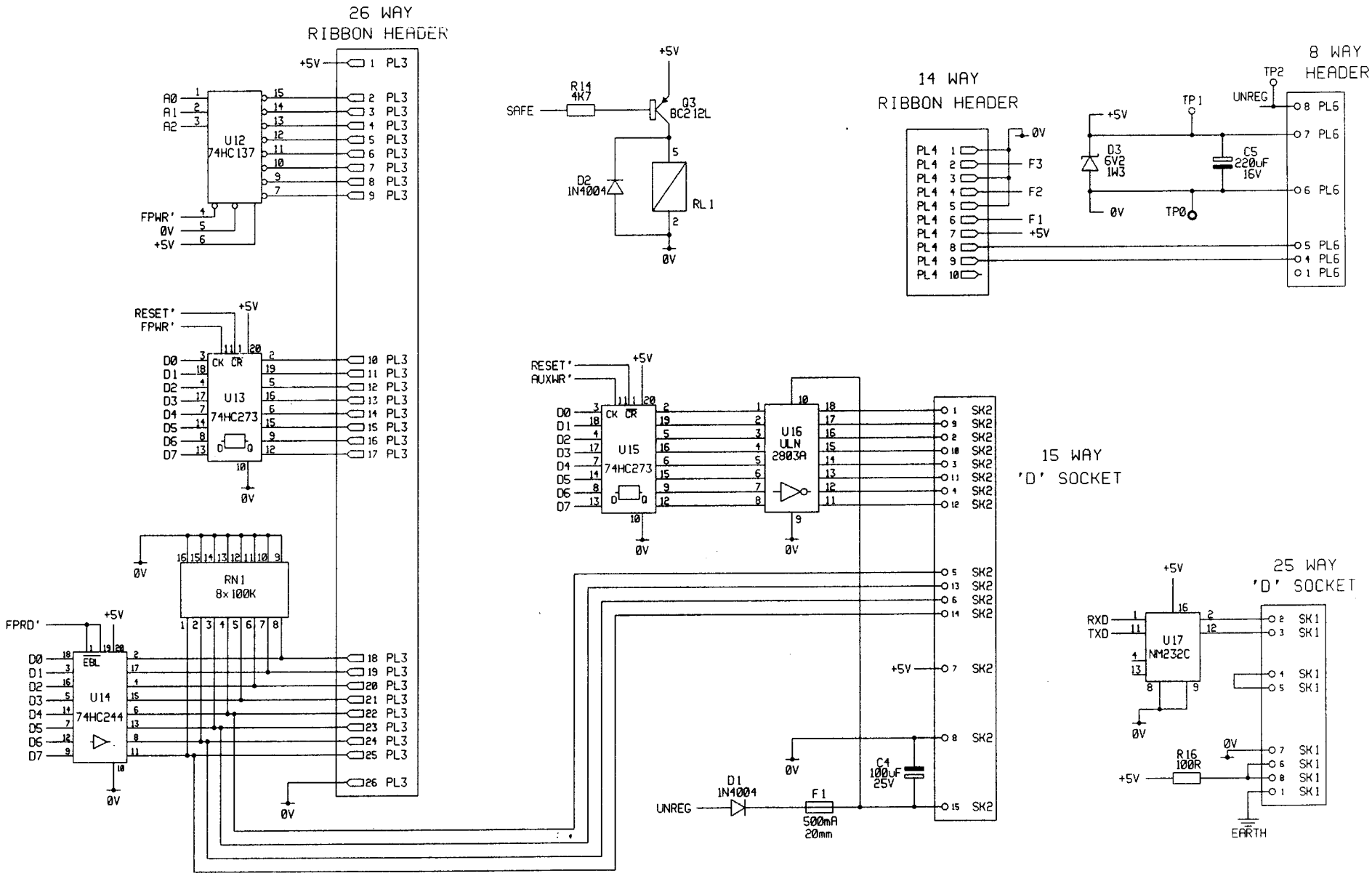
CPU/DIGITAL CONTROL PCB

·MEMORY AND TIMING

OXFORD

DRAWING NUMBER

A4 CQB0202 1 of 4



05	6/6/97	C586 R220 ADDED
04	22:11:93	U6 PIN 11 TAKEN TO 0V
03	21:8:93	C28 ADDED
02	16:3:93	PRODUCTION ISSUE
01	29:1:93	ORIGINAL

TITLE

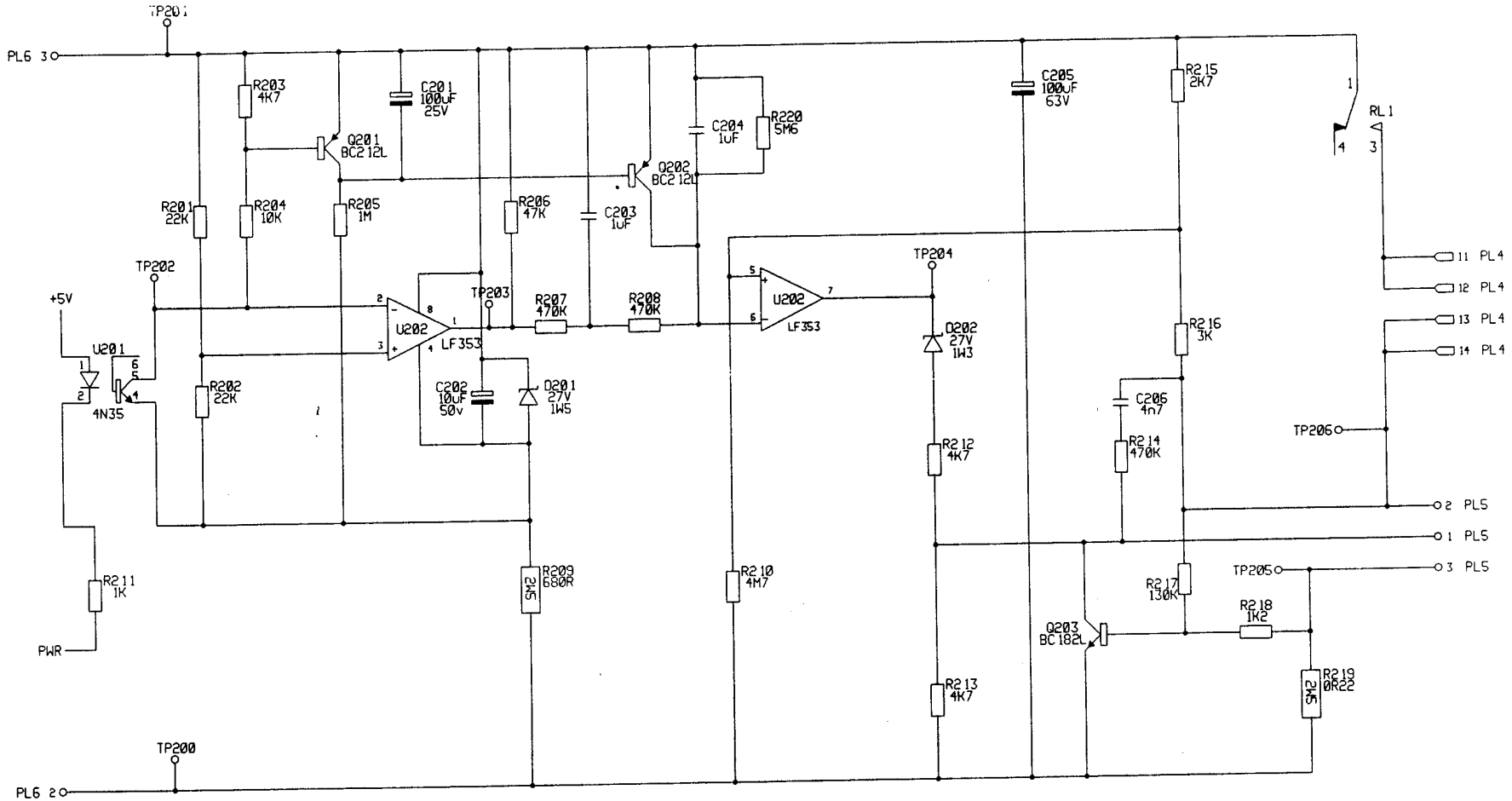
CPU/DIGITAL CONTROL PCB

INPUT & OUTPUT PORTS

OXFORD

DRAWING NUMBER

A4 CQB0202 2 of 4



05	6/6/97	C586 R220 ADDED
04	22:11:93	U6 PIN 11 TAKEN TO 0V
03	21:8:93	C28 ADDED
02	16:3:93	PRODUCTION ISSUE
01	29:1:93	ORIGINAL

TITLE

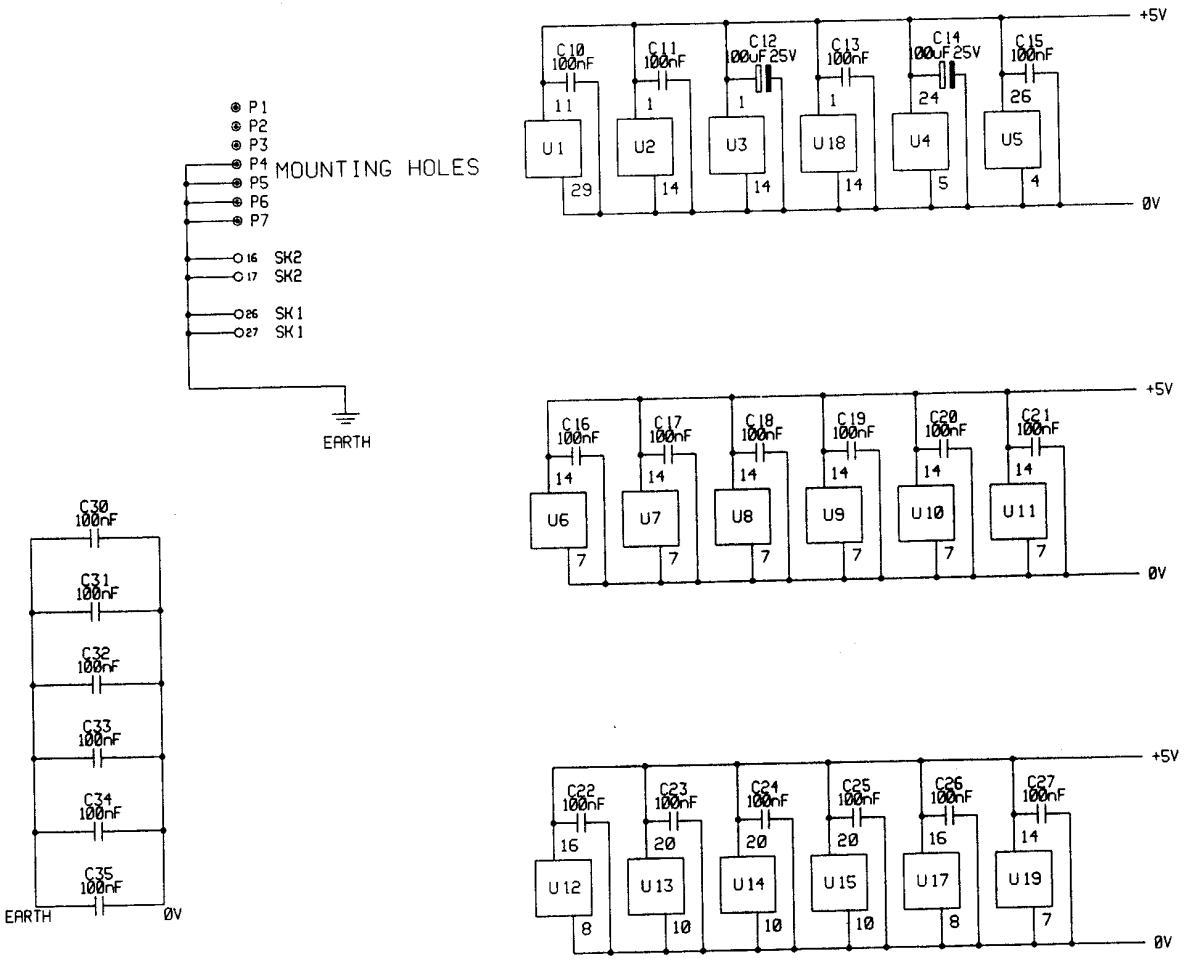
CPU/DIGITAL CONTROL PCB

HEATER OUTPUT

OXFORD

DRAWING NUMBER

A4 CQB0202 3 of 4



DECOUPLING CAPACITORS TO BE CLOSE TO THE RELEVANT COMPONENT.

05	6/6/97	C586 R220 ADDED
04	22:11:93	U6 PIN 11 TAKEN TO 0V
03	21:8:93	C28 ADDED
02	16:3:93	PRODUCTION ISSUE
01	29:1:93	ORIGINAL

TITLE

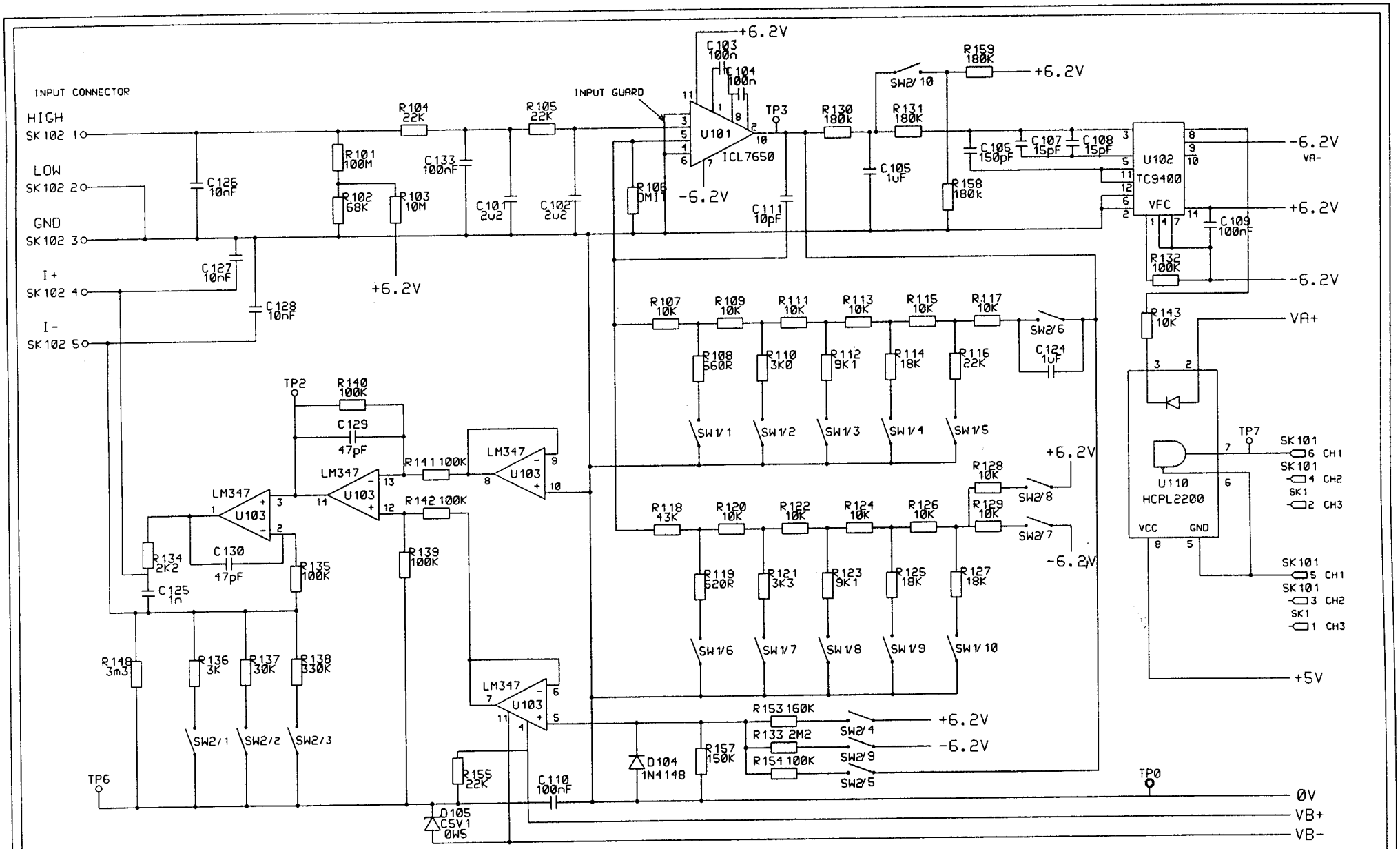
CPU/DIGITAL CONTROL PCB

DECOUPLING CAPACITORS

OXFORD

DRAWING NUMBER

A4 CQB0202 4 of 4



07	22:8:95	C111 10nF ADDED
06	20:9:93	REDRAWN, C26-C30, R58 & 59, S2/10 ADDED

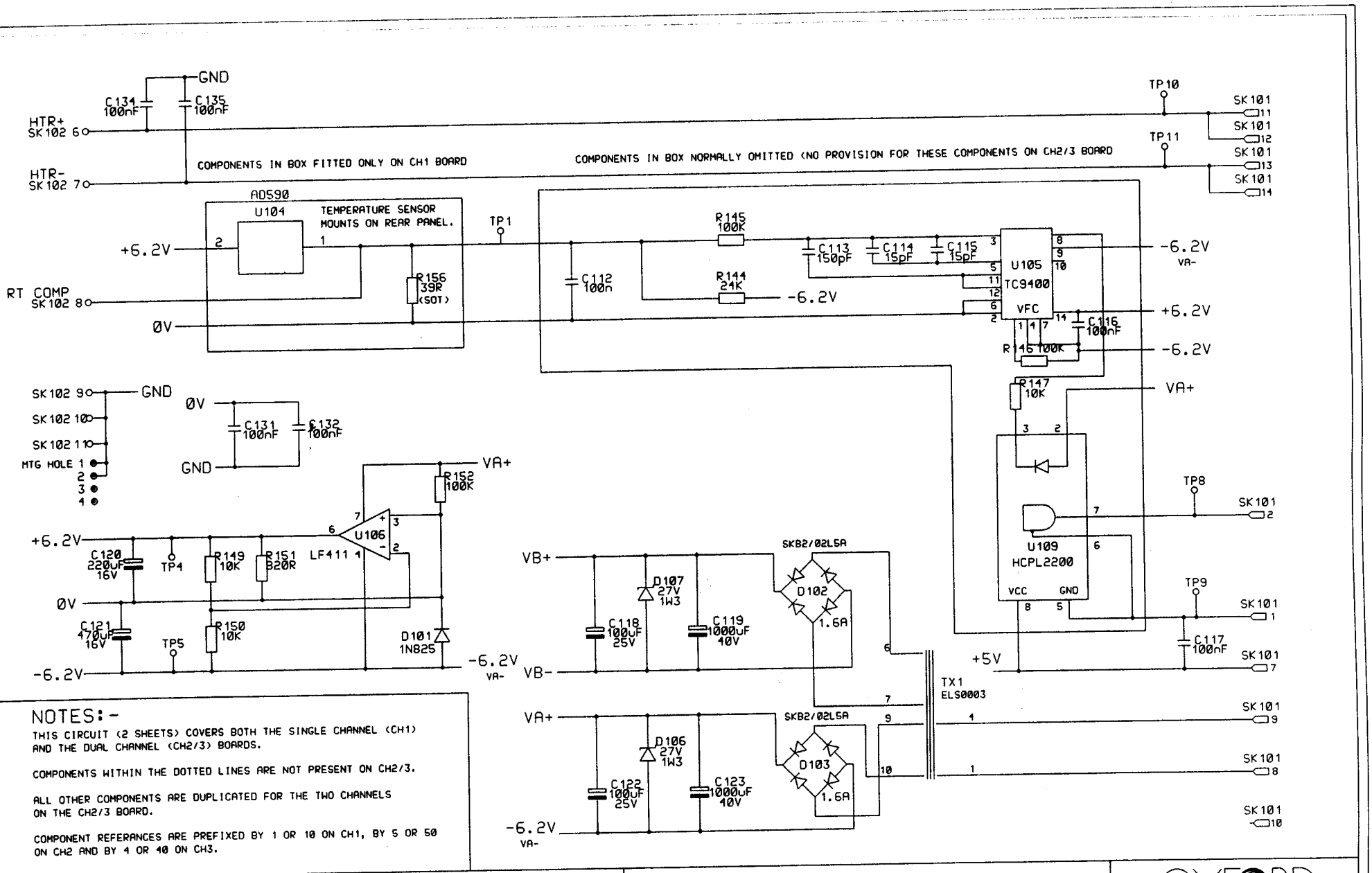
TITLE

ITC INPUT AMPLIFIER PCB CCT DIAGRAM

OXFORD

DRAWING NUMBER

A4 CQB0302 1 of 2



NOTES:-

THIS CIRCUIT (2 SHEETS) COVERS BOTH THE SINGLE CHANNEL (CH1) AND THE DUAL CHANNEL (CH2/3) BOARDS.

COMPONENTS WITHIN THE DOTTED LINES ARE NOT PRESENT ON CH2/3.

ALL OTHER COMPONENTS ARE DUPLICATED FOR THE TWO CHANNELS ON THE CH2/3 BOARD.

COMPONENT REFERANCES ARE PREFIXED BY 1 OR 10 ON CH1, BY 5 OR 50 ON CH2 AND BY 4 OR 40 ON CH3.

07	22:8:95	C111 10nF ADDED
06	20:9:93	REDRAWN, C26-C30, R58 & 59, S2/10 ADDED

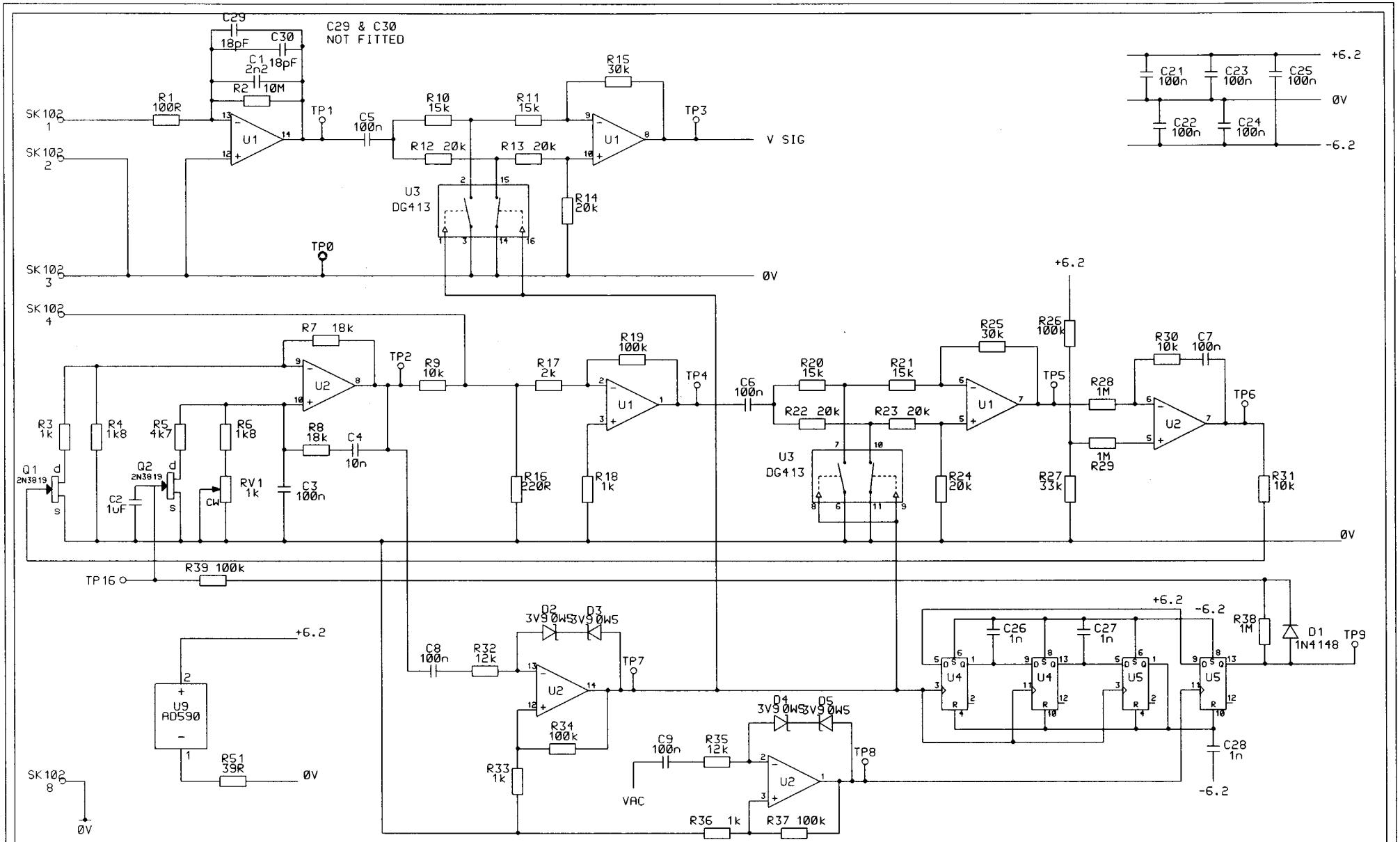
TITLE

ITC INPUT AMPLIFIER PCB CCT DIAGRAM

OXFORD

DRAWING NUMBER

A4 CQB0302 2 of 2

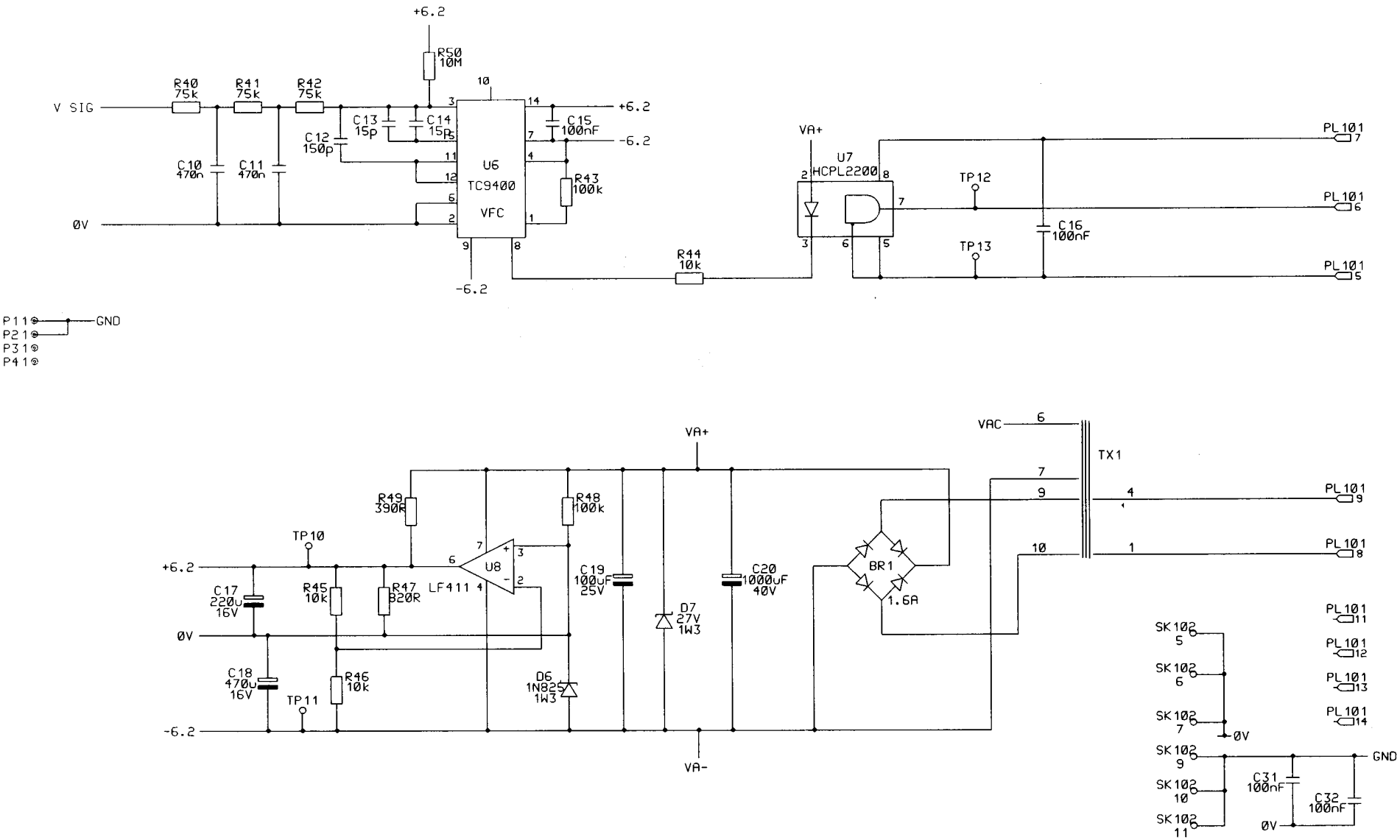


08	18/6/97	C593 TRACKS MODDED, C29 & C30 ADDED

ITC CAPACITANCE PCB
CCT DIAGRAM

OXFORD

DRAWING NUMBER
A4/ CQB0602 sht 1 of 2

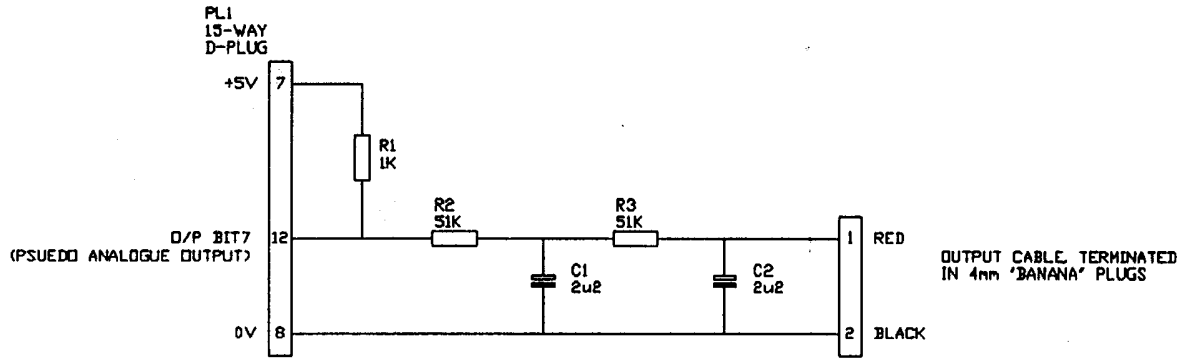


08	18/6/97	C593 TRACKS MODDED, C29 & C30 ADDED

ITC CAPACITANCE PCB
CCT DIAGRAM

OXFORD

DRAWING NUMBER
A4/CQB0602 sht 2 of 2



NOTES

THE RECORDER OUTPUT LEAD CONVERTS THE PSEUDO ANALOGUE OUTPUT VOLTAGE AVAILABLE AT THE AUXILIARY SOCKET, INTO A DC VOLTAGE SUITABLE FOR A CHART RECORDER.

THE OUTPUT VOLTAGE IS RELATED TO THE MINIMUM AND MAXIMUM VLUES OF THE DISPLAY RANGE IN USE.

OUTPUT VOLTAGE AT MINIMUM DISPLAY VALUE = 0.66V TYPICAL
OUTPUT VOLTAGE AT MAXIMUM DISPLAY VALUE = 4.84V TYPICAL

LINEARITY BETWEEN THESE END POINTS IS BETTER THAN 1% OF RANGE.

THE RECORDER OUTPUT LEAD IS INTENDED FOR TREND RECORDING ON A CHART RECORDER, NOT PRECISION DATA LOGGING. THE LATTER SHOULD ALWAYS BE CARRIED OUT DIGITALLY VIA RS232 OR GPIB.

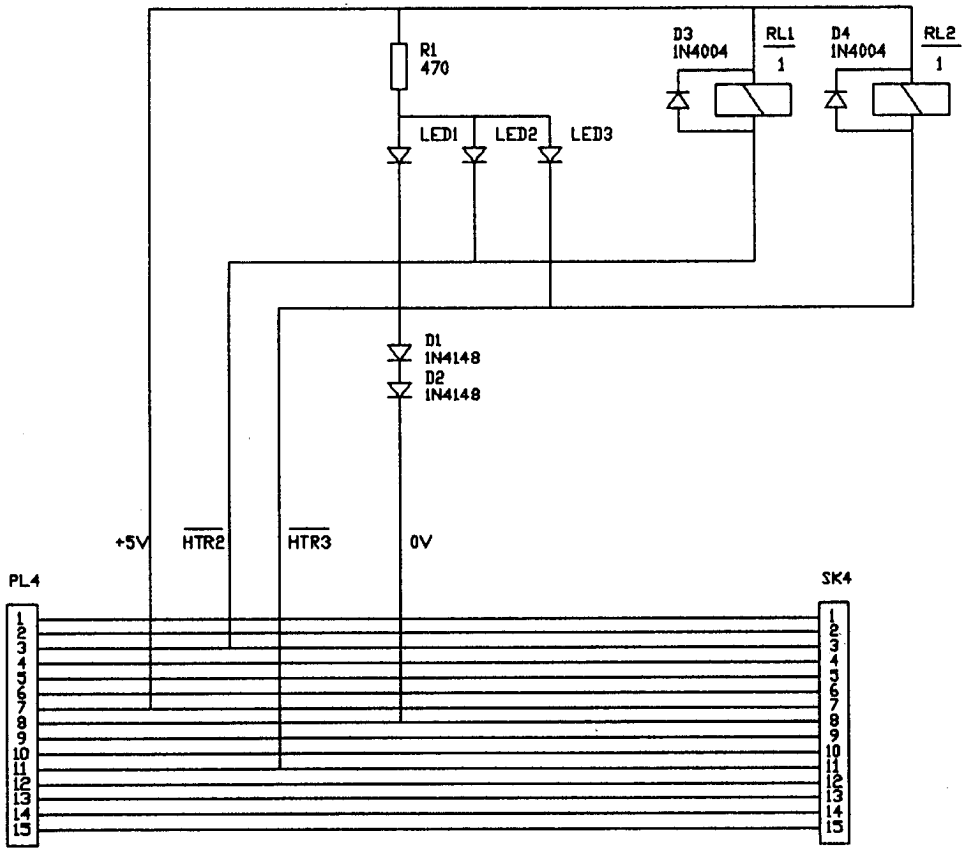
ISSUE 2	21/6/93 AFS	REDRAWN

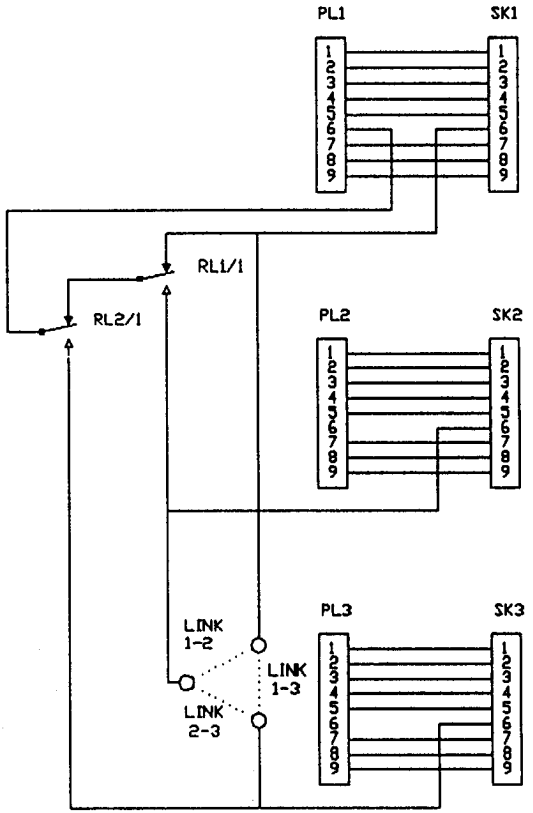
CHART RECORDER OUTPUT LEAD

OXFORD

DRAWING NUMBER

A4/ CQB1602



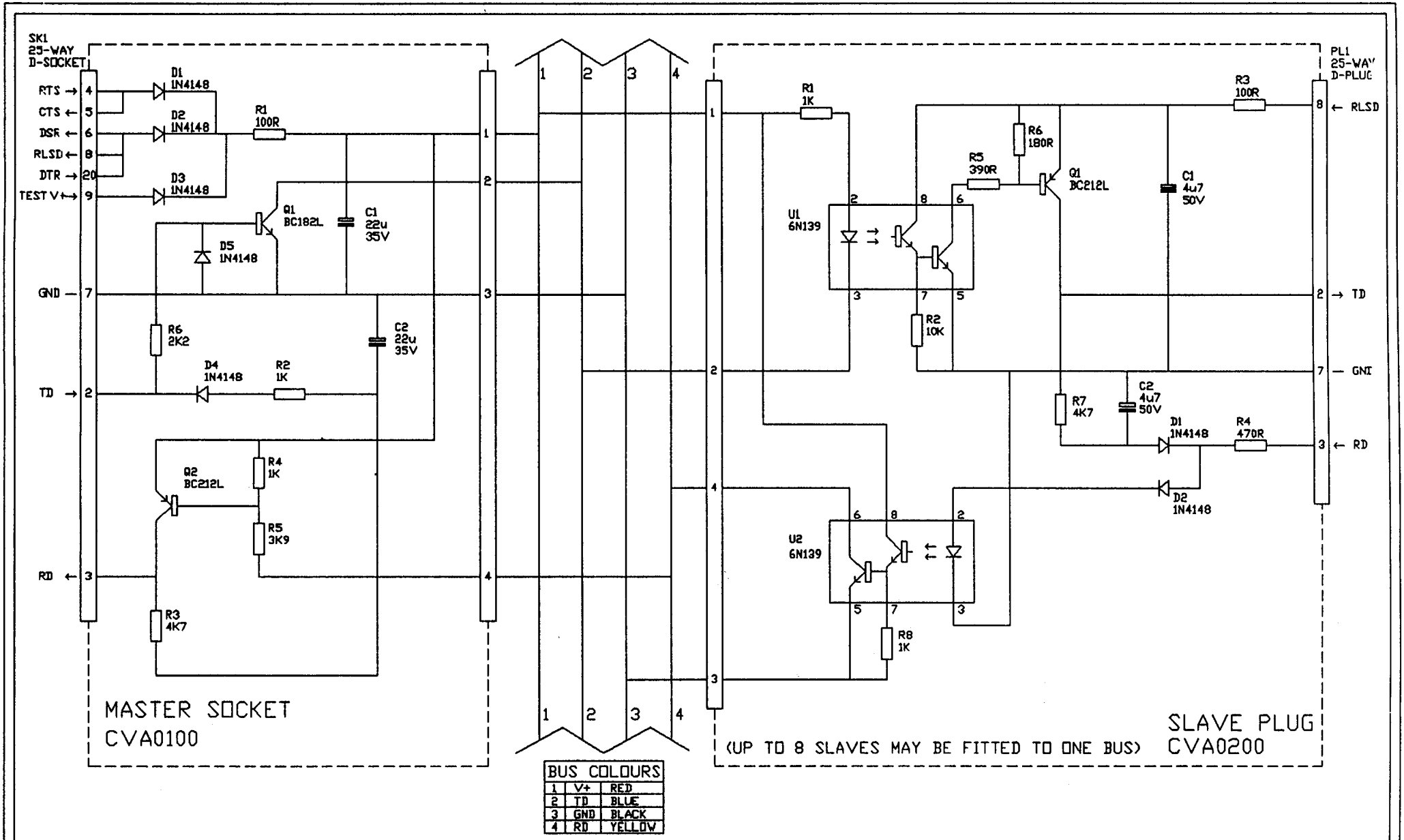


ISSUE 1	18/9/89 AFS	ORIGINAL

AUTOMATIC HEATER SELECT
RELAY BOARD

OXFORD

DRAWING NUMBER
A4/ CQB1802

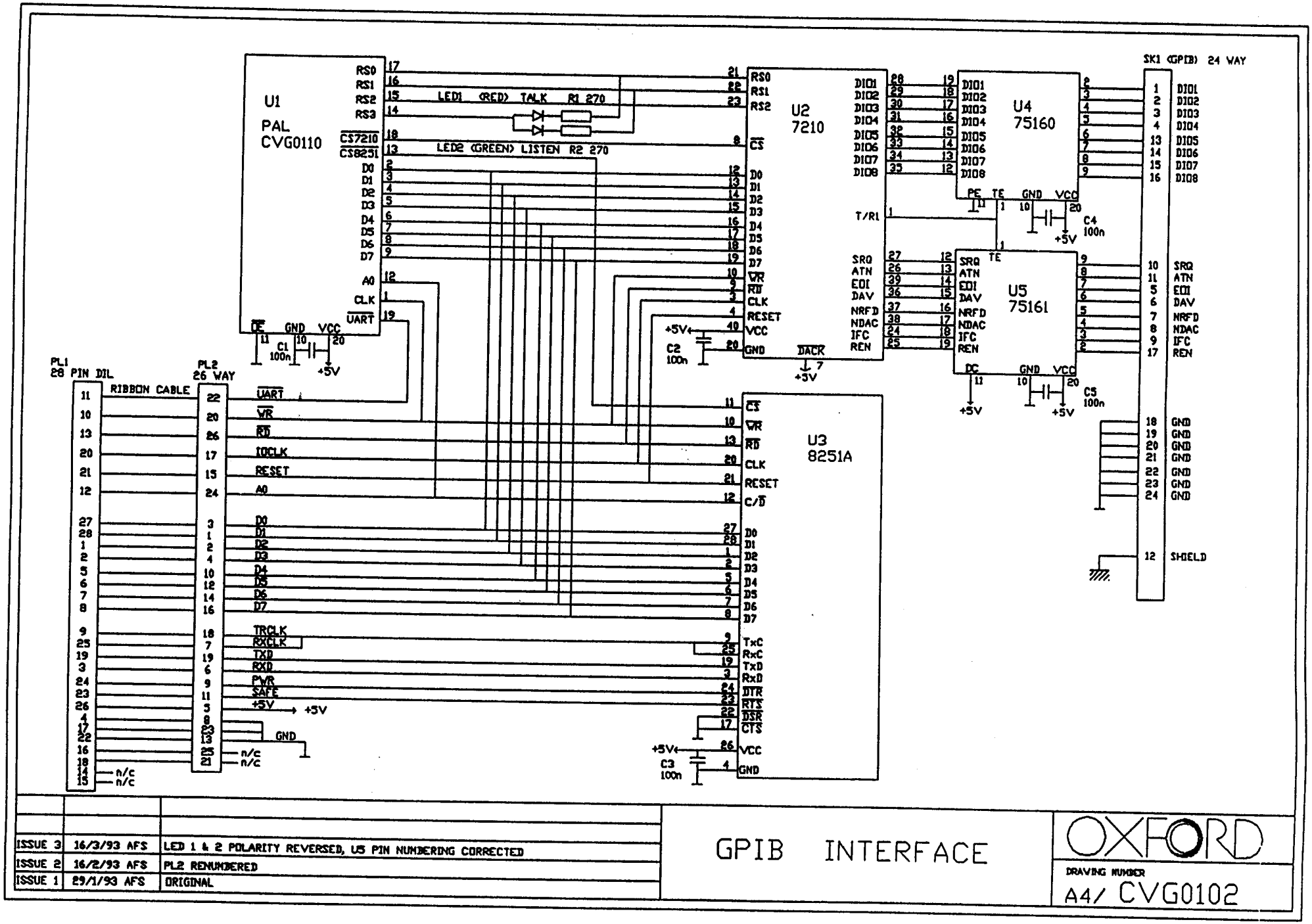


ISSUE 4	26/7/93 AFS	C1 CONNECTIONS CORRECTED. U1, U2 IDENTIFIER ADDED.
ISSUE 3	21/6/93 AFS	REDRAWN

OXFORD ISOBUS CABLE

OXFORD

DRAWING NUMBER
A4/ CVA0002



ISSUE 3	16/3/93 AFS	LED 1 & 2 POLARITY REVERSED, U5 PIN NUMBERING CORRECTED
ISSUE 2	16/2/93 AFS	PL2 RENUMBERED
ISSUE 1	29/1/93 AFS	ORIGINAL

GPIB INTERFACE

OXFORD

DRAWING NUMBER

A4/ CVG0102