QMC Instruments Ltd

Cooled Dual Channel Detector System

Channel 1: InSb Hot Electron Bolometer. Type QFI/XBI

Channel 2: NTD Germanium Bolometer. Type QGeB/X(4.2)

Operating Manual

Model QGeB/3(2+XBI)

QMC Instruments Ltd

CONTENTS

First - A Word of Warning

Lifting and Handling the Cryostat

Please take care when moving and lifting the system. The cryostat is designed to offer the best possible environment for your detectors and at the same time give great cryogenic performance for your convenience. It is, as a consequence, rather heavy.

Using Cryogens

Cryogenic liquids are potentially dangerous. If you are not already familiar with the standard procedures appropriate for the use of liquid nitrogen and liquid helium, please seek advice before proceeding.

Operating this equipment involves the use of vacuum and cryogenic liquids. Please read this manual carefully before you operate the system – although this is not a safety instruction manual, the text describes our own procedures and this may help to avoid accidents.

The photo below shows part of a damaged system. We do not want this to happen to you. Please ensure that all personnel involved in the use of the detector system are fully accustomed with the techniques involved.

Introduction

• The detector system. Type QGeB(2+XBI)/3

This is a QMC Instruments Ltd. detector system type QGeB/3(2+XBI) which incorporates a composite structure thermal bolometer with a Germanium thermistor, and an Indium Antimonide (InSb) hot electron bolometer with magnetically enhanced response. The detectors are mounted in optical integrating cavities behind Winston Cone optics and low-pass blocking filters. These components are mounted in a type TK1840 liquid helium cryostat built to our specification by our sister company Thomas Keating Ltd.

• Channel 1. The indium antimonide hot electron bolometer. Type QFI/XBI

This detector is an indium antimonide (InSb) hot electron bolometer with dimensions of approximately 5mm square. The InSb is magnetically tuned to provide the broadest possible frequency coverage with optimised sensitivity. The detector falls to 50% of its maximum sensitivity at approximately 1.5THz. The detector is mounted on a quartz substrate for electrical isolation from the integrating cavity and to allow thermal contact with the detector mounting block.

• Channel 2. The germanium bolometer. Type QGeB/X(4.2)

This detector is a germanium thermistor mounted on a thin SiN substrate on which is deposited a metallic absorbing layer with a diameter of 3mm. Incident power is absorbed by the metal film which then heats up. The thermistor is in good thermal contact with the layer, and it heats up and cools, its electrical resistance changes. This change in resistance is sensed by a change in voltage at the input of a low-noise preamplifier.

• The Filters

Unrivalled cryogenic efficiency and broad-band transmission efficiency is achieved using our unique multi-mesh filters (product code QMMF) which are mounted on both the liquid nitrogen radiation shield of the cryostat, and on the entrance apertures of the Winston Cones. The filters mounted at 77K greatly reduces the radiative heat load incident on the liquid helium cooled stage from room temperature objects by cutting off sharply at the upper limit of the observing band and then reflecting all higher unwanted frequencies. The measured transmission spectrum of the filters is presented in **Appendix C.**

• The Preamplifiers

The system incorporates ULN95 preamplifiers. These are mounted to the side of the body of the cryostat to reduce signal interference. The preamplifiers run either from internal rechargeable NiCd batteries or from an external supply. The circuit includes a bias potentiometer and a number of test/monitoring facilities for ease of operation.

- **Serial numbers**

Item	Serial Number
QGeB(2+XBI)/3 detector system	xxxx
QFI/XBI detector	xxxx
QGeB/X(4.2) detector	xxxx
ULN95 preamplifier (InSb channel)	xxxx
ULN95 preamplifier (Ge channel)	xxxx
TK1840 cryostat	xxxxx-x
QTT/F flexible helium transfer tube	xxxx

Packing List

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

Detector System Type QGeB/3

- Thomas Keating Ltd. cryostat, type TK1840, containing:
  - Detector type QGeB/X(4.2)
  - Cold condensing optics for the Ge channel. f/3.5 Winston Cone with 15mm diameter entrance aperture
  - Detector type QFI/XBI
  - Cold condensing optics for the InSb channel. f/2 Winston Cone with 25mm diameter entrance aperture
  - Two 10-pin electrical connections into the cryostat
  - Low-pass type QMMF filters mounted on the Winston Cones at 4.2K and on the 77K stage apertures. 77K shield aperture diameter is 25mm for channel 1, the InSb hot electron bolometer. 77K shield aperture diameter is 18mm for channel 2, the Ge bolometer
- Cryostat fitted with:
  - Transit protection fixtures
  - Over-pressure relief valve fitted to the cryostat top plate
  - Non-return valve
  - Two-off preamplifier mounting screws
- Cryostat central neck safety baffle which includes:
  - Over-pressure relief valve
- Two ULN95 preamplifiers with:
  - Power supply lead
  - Rechargeable NiCd battery pack
- Outer vacuum case base plate with O-ring
- 77K and 40K radiation shield base plates
- Liquid nitrogen blow-out tube
- Spares kit which includes:
  - O-rings
  - Set of screws
  - ULN95 preamplifier spare 500mA fuses
  - 3 spacers to separate the 40K and 77K shields
  - M3 and M4 Allen keys
- Operating manual

Liquid Helium Transfer Tube

- Type QTT/F flexible liquid helium transfer tube
- 2-off screw-on 500mm extensions for the transfer tube

1. Unpacking and Preparing the System for Operation

The system is not supplied in a condition that renders it ready for immediate use. A temporary base-plate has been installed to protect the system from damage during its journey. The following procedure must be carried out to prepare the detector system for operation. To prepare the system for transportation the following procedure should be followed in reverse.

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

Initial inspection

Please inspect the flight case in which the goods were shipped, and the contents, for any obvious sign that damage has occurred in transit. If you think that the package has been damaged in some way, please contact us before proceeding further. Your equipment is guaranteed for two years against failure resulting from effects beyond your control, and we will be happy to make any repairs at no cost to you during this time.

The O-rings, bolts, screws etc, which are required to prepare the system, can be found in the spares kit.

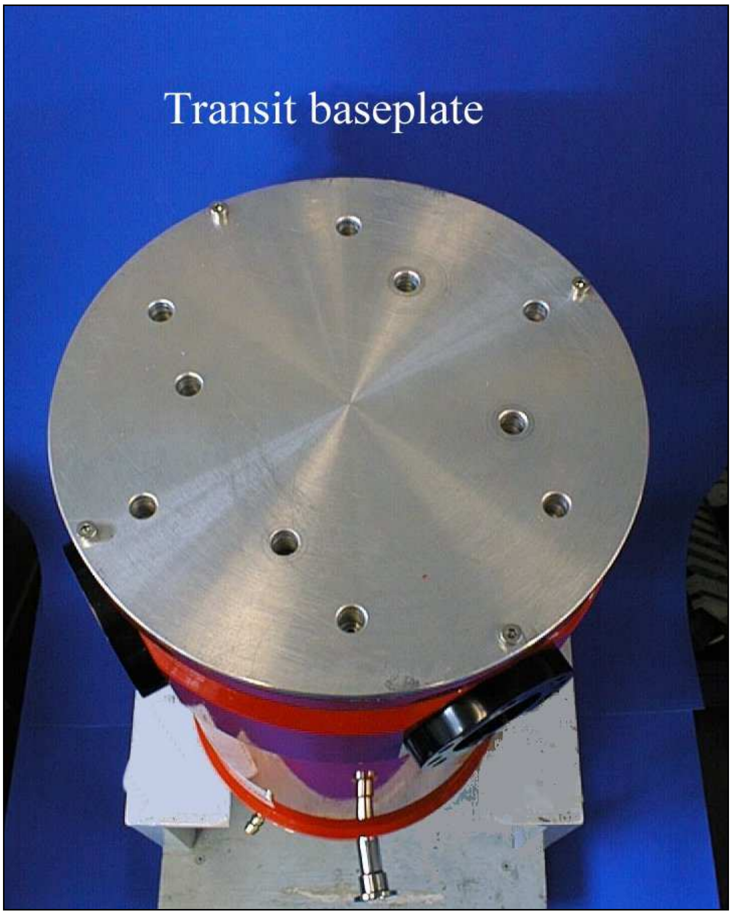

Photo 1.1. Transit base-plate

Removing the Transit Plate

Refer to Photo 1.1

To allow access to the bottom-plate invert the cryostat so that it rests on the stainless lifting ring. To avoid marking the ring, stand the system on something to protect it such as soft tissue, cloth or bubble wrap.

The aluminium transit base-plate should be removed by unscrewing all the socket head screws holding it in place and carefully lifting it from the cryostat.

Cryostat visual inspection

Refer to Photo 1.2

Taking care not to disturb the wires that run along the work surface, remove the four support pillars.

The detector block is bolted onto the cold-plate with the Winston Cone attached to it. There are two filters, one of which can be found mounted onto the end of the Winston Cone and held in place by the filter cap; the other is located in the optical aperture of the liquid nitrogen shield. It is important for good detector performance that the detector / cone assembly is in good thermal contact with the work surface. You should confirm that the detector block is firmly screwed in position and that the filters have not worked loose in transit. It is possible that vacuum grease that is used to ensure good thermal contact of the detector block with the cold-plate, and small flakes of hardened GE varnish, which is a yellow substance used to glue the wires to the cold-plate, may be found in the cryostat. This is quite normal and will not give rise to operating difficulties.

Photo 1.2. The four support pillars and the detector optics

Fitting the cryostat base-plates

Refer to Photo 1.3 and 1.4

The TK1840 cryostat has a gas cooled 40K radiation shield base-plate, liquid nitrogen cooled 77K radiation shield base-plate, and a room temperature outer vacuum casing base-plate. The 40K and 77K shields are located using the set of M3 screws provided. Remember to install the small black spacers between the 40K and 77K shields. The black OVC base-plate is located using the M4 socket-headed screws provided. It is important to check that the O-ring is in place, that it is clean, well greased and that its seating is free of marks and scratches. The screws locating the OVC base-plate should not be over-tightened, as this can distort the O-ring and may cause vacuum leaks. If the screws are equally tightened, it is normal for a small gap to show between the lip of the OVC base-plate and the bottom of the cryostat casing.

A schematic of the cryostat is shown in **Figure 1.1.**

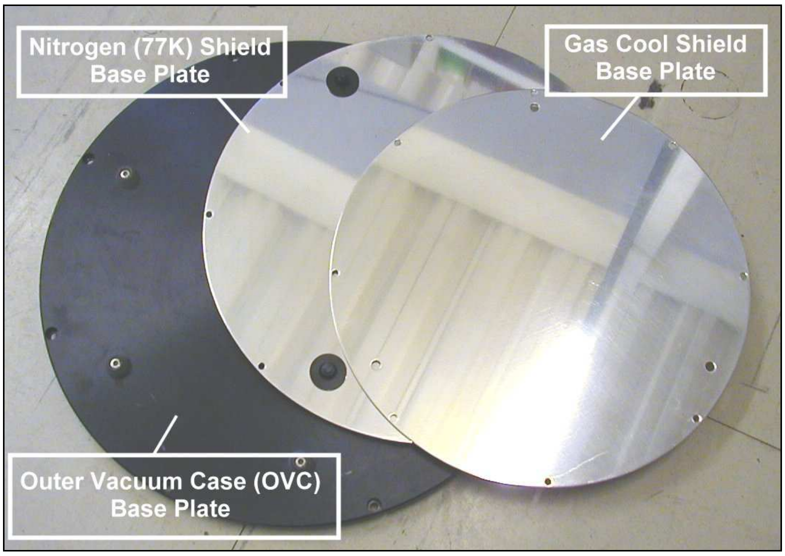

Photo 1.3. Cryostat base-plates

Photo 1.4. Liquid nitrogen base-plate in position

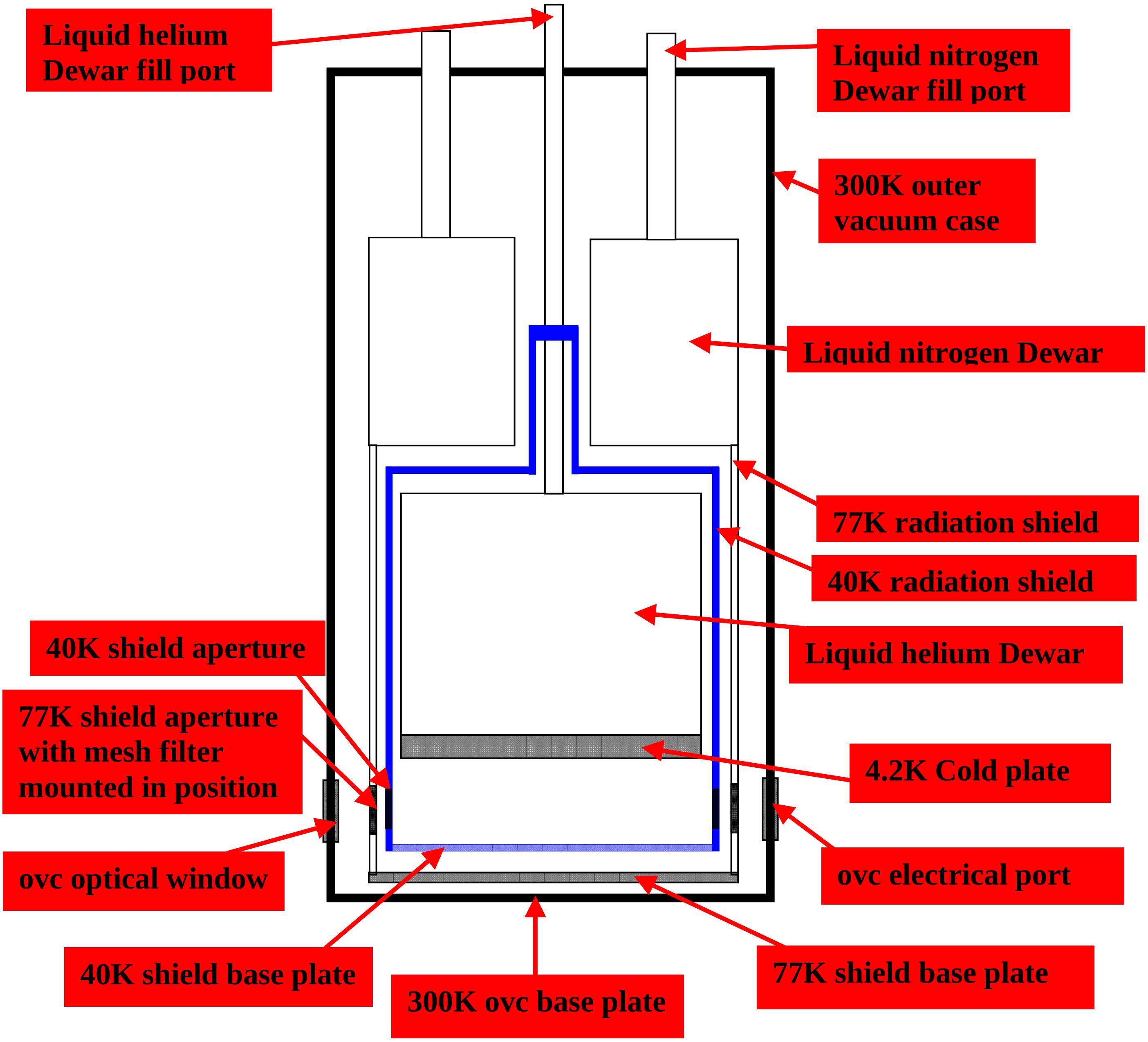

Figure 1.1. Cryostat schematic showing the main features of the cryostat. Not to scale

2. Evacuating the Cryostat

Please refer to **photo 2.1.** Before cooling the cryostat, the vacuum chamber must be evacuated by connecting a suitable pump to the evacuation port located on the top-plate. The pump should be capable of reducing the pressure in the cryostat to below 10^{-1}mbar. This can with time be achieved by using a rotary pump only, but for optimum cryogenic performance of the cryostat it is better to use a diffusion or turbo-molecular pump to reduce the pressure still further.

The pumping system should ideally have a pressure gauge measuring the pressure as close to the cryostat as possible. The spare NW16/KF16 port located on the top-plate of the cryostat can be used to attach a pressure gauge to monitor the pressure in the cryostat directly.

Always check the quality of the pump system and pumping line prior to opening the cryostat valve.

The vacuum valve should be opened very slowly when the pressure in the cryostat is at or close to atmospheric pressure. This prevents rapid pressure changes that risk damage to the delicate components inside the cryostat.

Typically, the system could be ready for pre-cooling (refer to Section 3) after pumping for thirty minutes using a two stage pumping station.

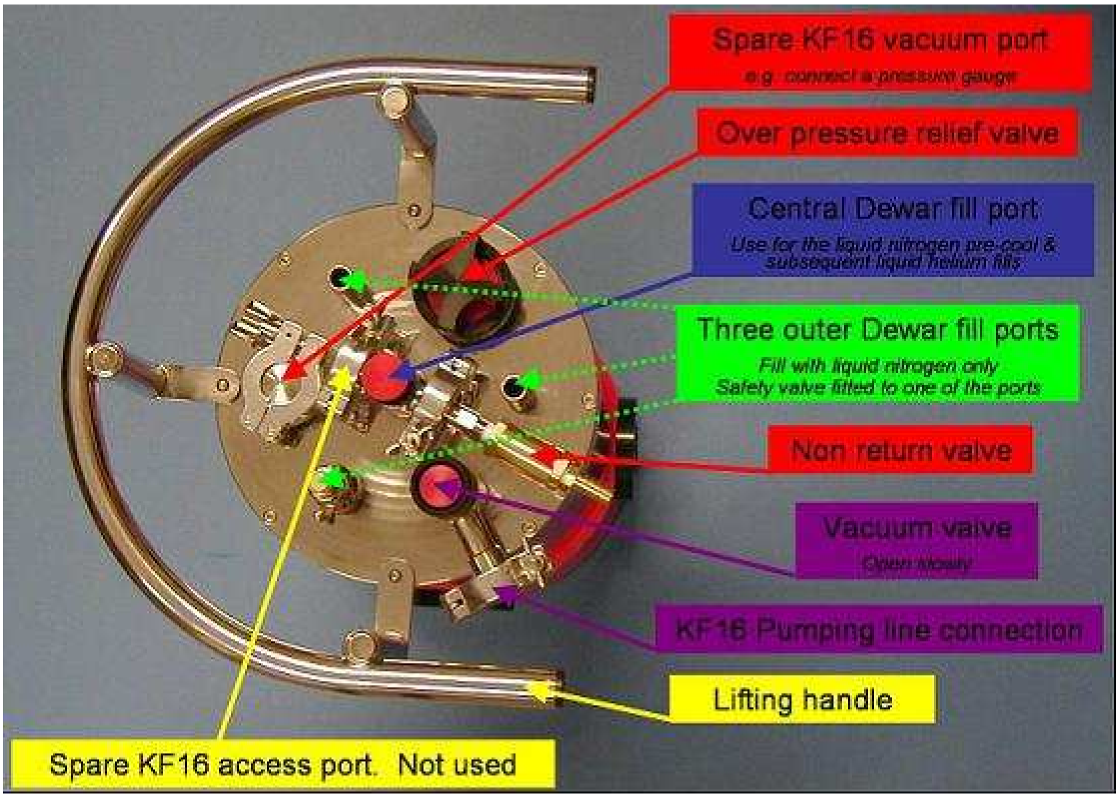

Photo 2.1. Cryostat top-plate fittings

3. Liquid Nitrogen Pre-cool

IMPORTANT: Refer to the warning at the front of the manual before proceeding with cryogenic cooling of this system.

A word about your vacuum pump

The pressure in the cryostat should drop rapidly when filling with liquid nitrogen because some of the gas, mainly oxygen, begins to cryopump (condense onto the cold surfaces). The system can remain attached to the pump during the pre-cool period if the pump you are using is an oil diffusion or turbomolecular type pump with a base pressure lower than 10^{-6}mbar. If you are only using a rotary pump, then the pressure in the cryostat will be lower during the pre-cool period than the pump is capable of generating, and the pump must therefore be detached immediately prior to cooling.

The need to pre-cool the central reservoir with liquid nitrogen

When a satisfactory pressure has been reached in the cryostat vacuum chamber, it is necessary to pre-cool the cryostat with liquid nitrogen before cooling with liquid helium. This will reduce the amount of liquid helium used.

Fill both liquid nitrogen and liquid helium reservoirs with liquid nitrogen using the appropriate ports, **photo 2.1**. Liquid nitrogen need only be poured in through one of the three liquid nitrogen ports. The neck baffle assembly should be unscrewed and removed from the central liquid helium port to enable the liquid nitrogen cryogen to be poured into the liquid helium reservoir.

For preference, transfer the liquid nitrogen directly from a pressurized liquid nitrogen storage Dewar which should take around 15 minutes to complete. Alternatively, pour the liquid nitrogen using a bucket and a funnel, as shown in **photo 3.1**, which may take in excess of an hour to complete. In this case, the funnel must be attached to a pipe which extends down into the neck and well into the reservoir itself. For a TK1840 cryostat a length of at least 200mm is needed. The pipe diameter should be about 6mm (1/4 inch) to allow both reasonable throughput and space outside of the pipe for boiling nitrogen gas to escape.

Safety valves

The top-plate fittings are shown in **photo 2.1**. The helium reservoir access port should always be fitted with the non-return valve to stop the condensation of moisture within the neck. This moisture could freeze and block the neck of the cryostat which in turn could lead to failure and damage.

The cryostat neck baffle is shown in **photo 3.2**. The baffle incorporates an overpressure release valve. Should an ice blockage form in the central neck of the cryostat, gas will be unable to escape through the non-return valve. Such an event will cause the overpressure relief valve, located at the top of the baffle, to open thereby releasing pressure from the inner reservoir.

The pre-cool period

The length of pre-cool period will determine the initial efficiency of use of liquid helium. For a TK1813 we recommend a minimum pre-cool of four hours, but it is often convenient to leave a cryostat overnight if, for example, it has been attached to a pump throughout the day. Larger cryostats (TK1840, TK1865 and TK1875) require a longer minimum pre-cool period because the additional gas cooled radiation shield is only weakly linked to the other temperature stages and therefore cools slowly. For these larger cryostats, a twelve hour minimum pre-cool period is recommended.

Photo 3.1. Using a funnel to fill the cryostat with liquid nitrogen

Photo 3.2. Cryostat neck baffle

Removing the liquid nitrogen from the central reservoir

When the pre-cool period is complete the liquid nitrogen in the helium reservoir should be removed. This is best done using a supply of compressed dry nitrogen gas and the blow out tube supplied. The O-ring and tightening ring from the central reservoir access port, and brass washer from the spares kit, should be arranged on the blow out tube as shown in **photo 3.3**. The non-return valve should be replaced with the adaptor nozzle. The liquid nitrogen can now be removed from the central reservoir by applying (through the adaptor nozzle) a small overpressure within the reservoir as shown in **photo 3.4.** The liquid nitrogen is directed into a safe container, and can be used to replenish the outer reservoir.

It is important that all of the liquid nitrogen is removed from the central reservoir before the liquid helium transfer is started. Any liquid nitrogen remaining in the central reservoir will be frozen by the liquid helium. Nitrogen ice forms an effective insulating layer which will prevent the detector reaching its intended operating temperature. A large amount of expensive liquid helium will also be wasted in creating a small amount of very cold nitrogen ice!

The supply of dry nitrogen gas can be continued until the stream of ejected liquid nitrogen ceases. Ensure that the blow out tube does not block, that it is properly located and it reaches the bottom of the helium reservoir.

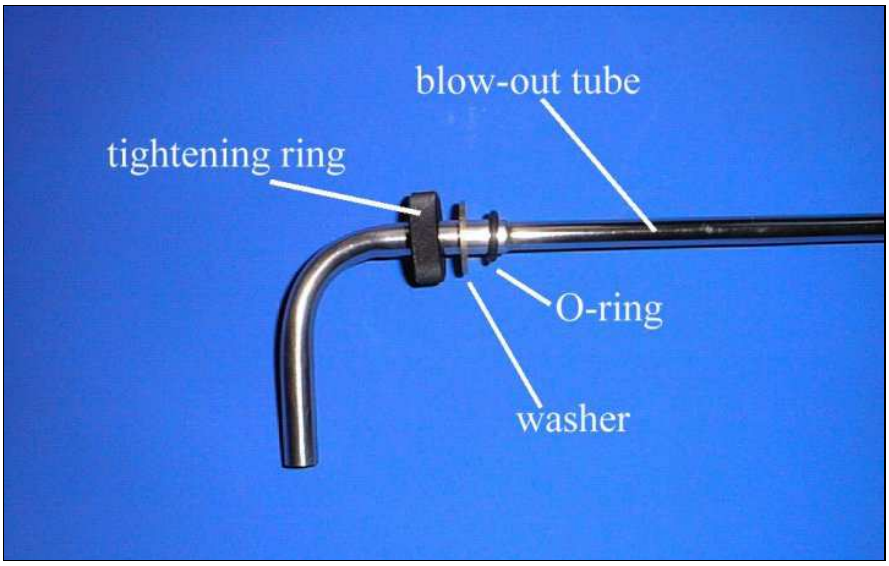

Photo 3.3. The blow out tube

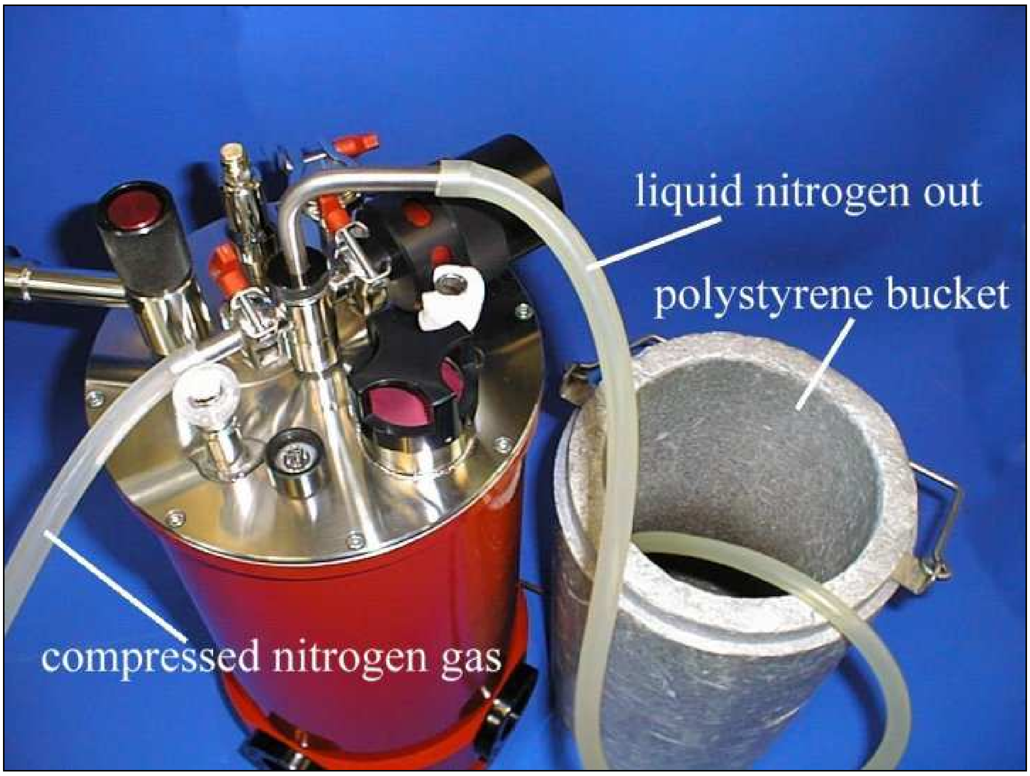

Photo 3.4. Arrangement to blow the liquid nitrogen out of the liquid helium reservoir

4. Liquid Helium Transfer

When you are certain that all liquid nitrogen has been removed from the central reservoir the cryostat can be filled with liquid helium. The blow-out tube should be removed from the central neck and the cryostat should be arranged such that the transfer tube reaches the bottom of the cryostat and the storage Dewar simultaneously.

It is wasteful to transfer liquid helium too quickly. A rubber bladder can be used to control the pressure driving the transfer, and the rate of filling can be judged from the size of the plume of exhaust helium gas rising from the cryostat.

The liquid helium transfer tube

It is important that the liquid helium transfer tube used is designed to suit both the detector cryostat and the liquid helium storage Dewar. The delivery end of the transfer tube should have a fully evacuated section with diameter approximately 6mm (¼ inch) and length at least 200mm. It should therefore permit liquid helium to be delivered efficiently into the central reservoir while at the same time leave space for spent helium gas to escape without a build-up of pressure within the cryostat.

The QMC Instruments Ltd flexible liquid helium transfer tube, product code QTT/F, that you have ordered has a reach in excess of 1000mm and two 500mm extension pieces.

Photo 4.1 depicts a liquid helium transfer in progress. **Photo 4.2** shows a typical boil-off plume in the phase when the cryostat is cooling between 77K and 4.2K. **Photo 4.3** shows the larger, cloudier and more erratic plume, which results when the liquid helium reservoir is full. At this stage the transfer should be terminated. It should take about thirty to forty minutes for a TK1840 cryostat to cool down from 77K to 4.2K and to fill with liquid helium; and the whole process should consume about six litres of liquid helium.

Helium gas recovery

Here in Cardiff we have no facilities for recovering spent helium gas, hence all the liquid helium transfers undertaken in our laboratories are “open” in the manner shown in the photos. However some installations offer recovery facilities whereby a helium return line is attached to the exhaust port of the cryostat. Use the black anodized aluminium tightening ring and O-ring from the central neck fitting to make a seal around the liquid helium transfer tube. Under such circumstances, a coarse flow meter could be inserted in the return line to indicate flow rate from the transfer. Usually a steady flow-rate is indicated during the cool and fill phases of the transfer. When the reservoir is full however, the flow rate becomes erratic, and the transfer should be terminated.

When the transfer is complete the transfer tube should be removed carefully but swiftly and the safety valves fitted without delay.

The InSb detector exhibits a rapid increase in resistance as it approaches liquid helium temperature and this can be used as a check on the final stages of the transfer. The InSb bolometer resistance can be measured using a multimeter across pins C and F of the room temperature channel one 10-pin electrical connector as shown in **photo. 4.4.**

The Ge bolometer is connected across pins D and E of the opposite channel two 10-pin electrical connector. The 330kΩ cold bias resistor is connected across pins B and D. Note that the detector resistance will not rise until its temperature is below about 10K, so no change will be observed until your helium transfer is almost complete.

Photo 4.1. Liquid helium transfer

Photo 4.2. Helium gas exhaust during fill

Photo 4.3. Helium plume when complete

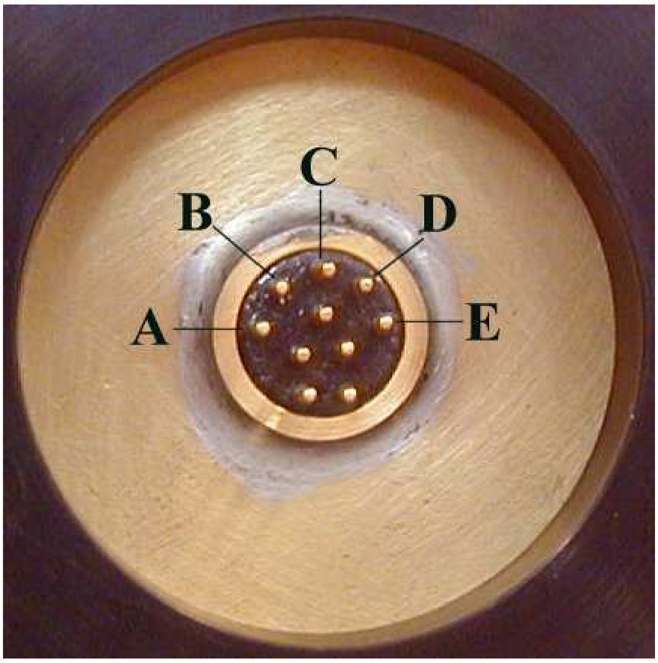

Photo 4.4. Electrical port pin assignments. Pin F is the centre pin

Keeping the cryostat cold

It is important to keep all the neck fittings and safety valves in place whenever the cryostat is cold. If these are removed for liquid helium transfer, they should be removed only at the last moment when all other preparations have been made. They should be replaced as soon as the transfer tube is removed.

The cryostat can be kept continuously cold by repeatedly replenishing the cryogens. Hold times for both the liquid helium in the central reservoir and liquid nitrogen in the outer reservoir are shown in **Table 6.1** in **Section 6.**

Note that the liquid nitrogen in the outer reservoir will require topping up more often than the liquid helium, and that the first fill liquid helium hold time may be shorter. This is because the initial liquid helium boil-off rate may be high if significant further cooling takes place when the transfer is complete.

When transferring liquid helium into a cryostat that already contains liquid helium, the transfer tube should be fully cooled before it is inserted into the cryostat neck. This prevents the warm transfer tube and warm helium gas from boiling away excessive amounts of the liquid helium already in the cryostat. In this case the transfer tube is inserted into the storage Dewar and the pressure control bladder inflated slightly to pass gas through the tube to cool it. When the transfer tube has cooled, thick milky helium gas emerges from the delivery end, **photo 4.5**, and the transfer tube can then be manoeuvred carefully to the cryostat and lowered into the central neck. The refill can then proceed in the way described above.

Detector system operation

The detector system is ready for use as soon as the liquid helium fill is complete. The performance may improve very slightly during the first hour or so after the first fill liquid helium transfer while the detector and filters cool to their final operating temperature.

Remember that the resistance of the detector is a function of current once it is at operating temperature.

Photo 4.5. Liquid helium emerging from a cold tube

5. The ULN95 Preamplifiers

Background

The ULN95 (Ultra Low Noise) preamplifier is a voltage mode low noise preamplifier designed for use with cooled detectors. It can be powered either from internal rechargeable batteries or from an external ±15V DC supply. Switchable gain options, a potentiometer bias supply control and full detector status monitoring are provided. Output is 50Ω bnc as standard, and the circuit is housed in an RF shielded enclosure designed to mount directly to the detector cryostat to reduce interference and provide a common ground.

The input impedance is high, so the preamplifier can be used with a range of cooled detectors, including InSb hot electron bolometers (types QFI/X, QFI/XB and QFI/XBI) and composite Silicon and Germanium bolometers (types QSIB/X and QGEB/X).

The technical specification of the ULN95 is given in **Table 5.1** below.

Output impedance **50Ω bnc**	Bias Supply: **0-10V multi-turn potentiometer**
Input impedance **>10GΩ**	Voltage Gain: **x100, x1000 switchable**
Bandwidth **0.5Hz to 1MHz**	Output Noise: **≈ 1nV $\text{Hz}^{-1/2}$ rms > 1kHz**
	(input shorted) **≈ 3nV $\text{Hz}^{-1/2}$ rms at 10Hz**

Table 5.1. ULN95 Technical specification

Preparing the preamplifiers

The preamplifier batteries have been disconnected for transit. Open the front of the ULN95 by unbolting the four bolts that hold the lid in place. The battery pack should be fixed in position as shown in **Photo 5.1a,** using the four nylon fixing screws.

The battery connecting lead, **Photo 5.1b,** which can only be fitted one way, should be connected to the 4-pin connector at the top of the left hand circuit board as viewed with the battery pack uppermost in the box. The preamplifiers should then be mounted onto the black anodised vacuum window surrounding the 10-pin electrical feedthrough which is located on the side of the cryostat taking care to connect the correct preamplifier to the correct electrical port. The two mounting bolts can be found screwed into the black anodised vacuum window. Once mounted, the preamplifier 10-pin electrical input lead should be connected to the cryostat 10-pin electrical feedthrough through the hole in the lower section of the preamplifier housing, **Photo 5.1a.**

Powering the preamplifiers

The ULN95s can be operated from the internal batteries or from an external power supply. External power is supplied via the 4-pin socket located at the top of the preamplifier control panel. The three isolated pins are used while the earth tag is not used. A twin channel power supply, an example of which is pictured in **Photo 5.2**, will be needed to run the preamplifiers from external power. Power leads are supplied for this purpose. The internal NiCd batteries, which may not necessarily be charged before despatch, are recharged from the external power supply via the same socket. Please note that the NiCd rechargeable batteries will not be able to be recharged and used indefinitely. Through normal and proper use they will need replacing after about 200 charge/discharge cycles.

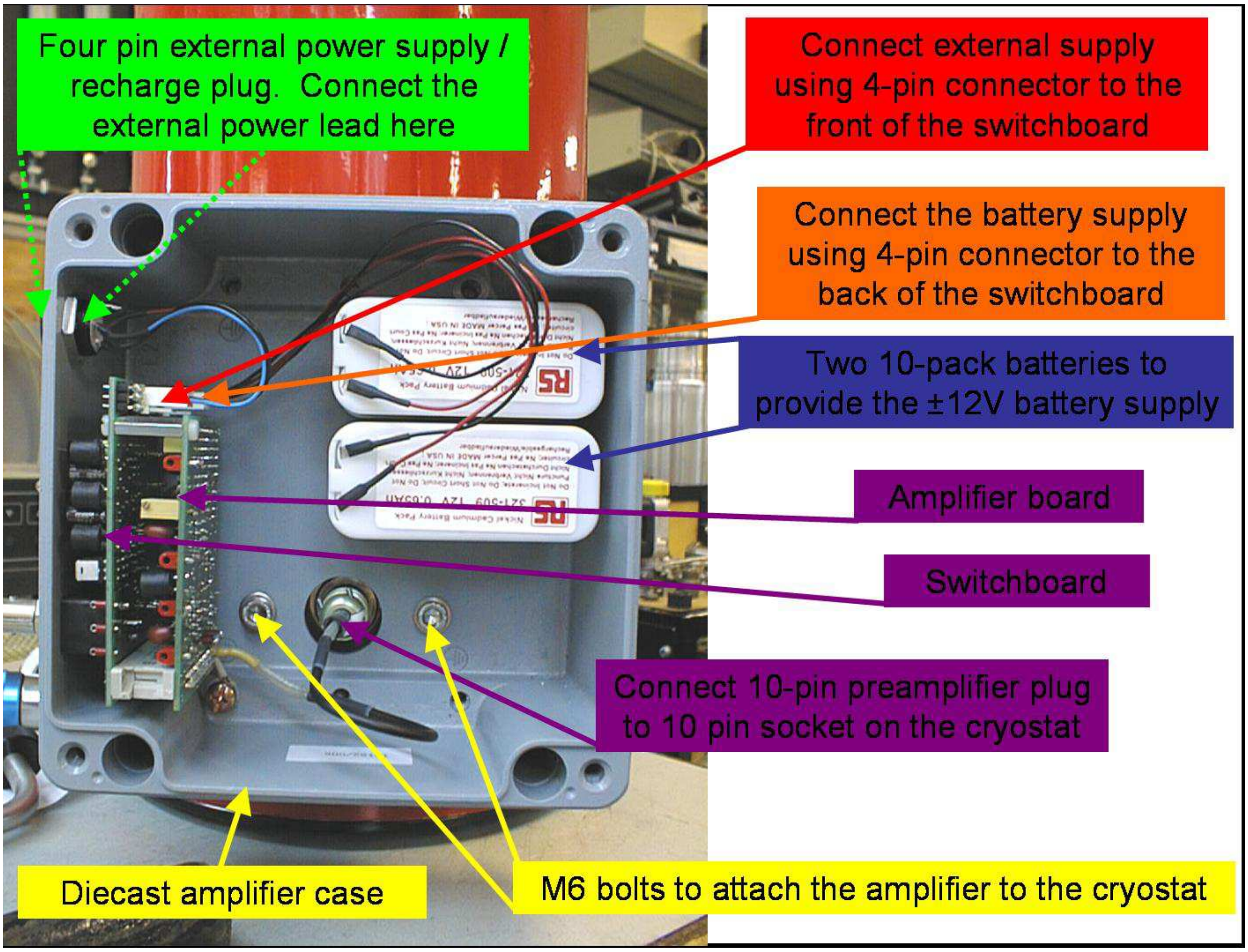

Photo 5.1a. Mounting the preamplifier to the cryostat

Power Option a) Using an external PS

Photo 5.2 shows a typical twin channel laboratory power supply which can supply 30V dc per channel. The photo also shows how the power lead supplied with the detector should be connected to such a supply.

When powering the preamplifier, make sure that the voltage output is at zero before switching on, and then increase the voltage gradually on both power supplies simultaneously to 15V.

If the power supply has a current limiting facility, this should be set to 200mA. The current supplied to the power socket is limited internally but occasionally transients can blow the 500mA protection fuses.

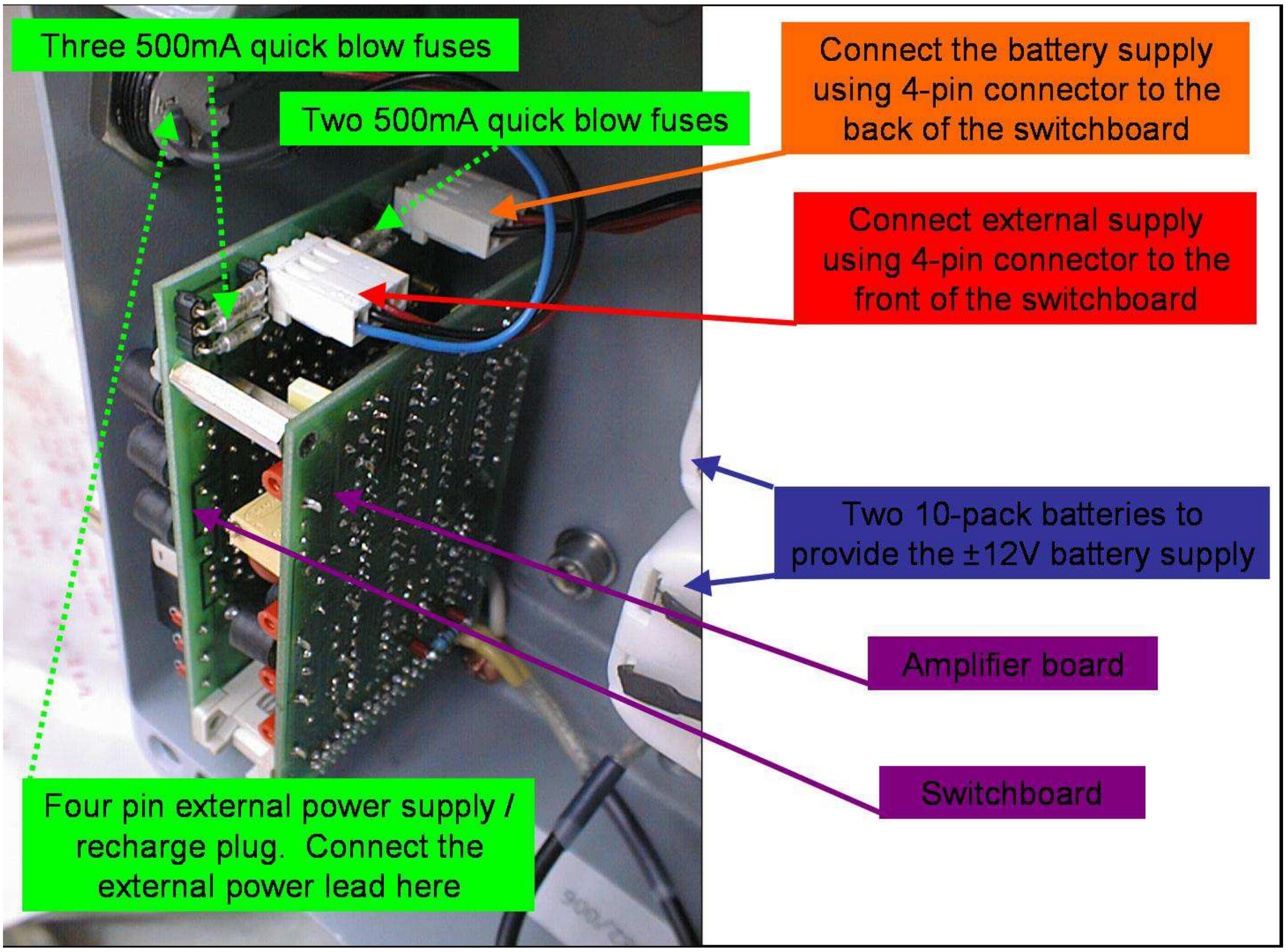

Photo 5.1b. Connecting the batteries

External supply switch-on procedure is as follows from the following initial settings:

RECHARGE = **OFF**; POWER = **EXT**; INPUT = **SHORTED**; BIAS = **OFF**

1. Ensure that the power supply output voltages are set to 0V
2. Connect the power lead as shown in **Photo 5.2**. Plug the other end into the **RECHARGE SOCKET**
3. Increase the two output voltages to 15V gradually. The red **PREAMP ON** light should illuminate
4. Set the INPUT switch to the **OPEN** position
5. Set the BIAS switch to the **ON** position
6. Select the desired GAIN

At this stage, you can "Say Hello" to your detector. A hand waved rapidly in front of the detector window should generate a readily visible response on an oscilloscope.

Photo 5.2. Power supply connections

Power Option b) Using the internal batteries

Battery supply switch-on procedure is as follows from the following initial settings:

RECHARGE = **OFF**; POWER = **EXT**; INPUT = **SHORTED**; BIAS = **OFF**

1. Set the POWER switch to **BATT**. The **PREAMP ON** light should illuminate
2. Set the INPUT switch to the **OPEN** position
3. Set the BIAS switch to the **ON** position
4. Select the desired GAIN

Fully charged batteries will be able to operate the preamplifier for at least 12 hours. However, this does depend to an extent on the level of output used. The power drain on the batteries is higher if the signal level is large.

Recharging the batteries

Battery recharge procedure is as follows from the following initial settings:

RECHARGE = **OFF**; POWER = **EXT**; INPUT = **SHORTED**; BIAS = **OFF**

1. Ensure that the power supply output voltages are set to zero
2. Connect the power lead as shown in **Photo 5.2**. Plug the other end into the **RECHARGE SOCKET**
3. Set the RECHARGE switch to **ON**
4. Increase the voltage to +/-15V as described above. The **PREAMP ON** light should illuminate
5. Increase the voltage gradually to +/-18V. The **RECHARGE ON** light illuminates brightly

Do not exceed a supply voltage of +/-20V. If you proceed according to these instructions it is not possible to overcharge the cells. The batteries will be fully charged when the recharge light goes out, which should take no more than eight hours.

You can operate the amplifier and recharge the batteries simultaneously.

When switching off, remember to switch the power option switch to external supply, otherwise the batteries will drain.

Altering the detector bias

The detector requires a d.c. bias current I_B which is supplied by the preamplifier. I_B is set to the optimum value during testing at the QMC Instruments; hence it should not normally be necessary to alter the bias conditions of the detector. However, I_B will have to be optimised if the temperature of operation is altered, for example by pumping and cooling the helium bath to 1.5K.

Photo 5.3. View of the switchboard and amplifier circuit board identifying the voltage test points and multi turn potentiometer

The bias voltage V_B supplied to the bias load resistor can be measured using the test points within the preamplifier box. On the board closest to the battery pack there are four test points and a variable resistor which are assigned, **photo 5.3**, as follows:

TP1 Zero volt test point
TP2 V_B test point
TP3 I_B test point (1mV/µA)
TP4 Detector voltage test point, V_{Det}
VR1 V_B adjust

To measure V_B connect a voltmeter across TP1 and TP2. To set V_B adjust the multi-turn potentiometer VR1. V_B will have been set at QMC Instruments Ltd during testing but can be altered using the potentiometer VR1 and measured between TP1 and TP2. To measure I_B connect a voltmeter across TP1 and TP3 and convert the measured voltage in mV to I_B/µA using the conversion factor 1mV/µA. V_{Det} is measured by connecting a voltmeter across TP1 and TP4. The operating resistance of the detector can then be calculated from $R_{Op} = V_{Det}/I_B$. Occasional monitoring of this voltage will confirm that the detector temperature and the bias current are correct and stable.

Figs. 5.1(a, b) give typical input shorted noise of the ULN95 amplifier at a gain of x100

Troubleshooting

If after recharging the battery packs performance starts to fall it is likely that the NiCd rechargeable battery packs will need replacing. It is normal for NiCd rechargeable batteries to need replacing periodically when they no longer hold charge. Replacement battery packs can be obtained from RS.

If problems are suspected with the ULN95 preamplifier there are some basic checks that can be carried out. Disconnect the ULN95 from the external supply and then open the box it by undoing the four bolts. Check the following:

- Check the five 500mA fuses to make sure that they have not blown, **photo 5.4**
- The switchboard should be firmly attached to the RF shielded case
- The switchboard and amplifier board should be firmly attached to one another
- The 10-pin plug should be firmly attached to the cryostat 10-pin electrical feedthrough
- Confirm that the battery packs are firmly attached in position to the RF shielded casing, and that they are connected to the switchboard
- Confirm that there are no obvious problems with the switchboards and amplifier board. The boards can be detached and removed from the case for inspection. Check for any loose components or blackened areas

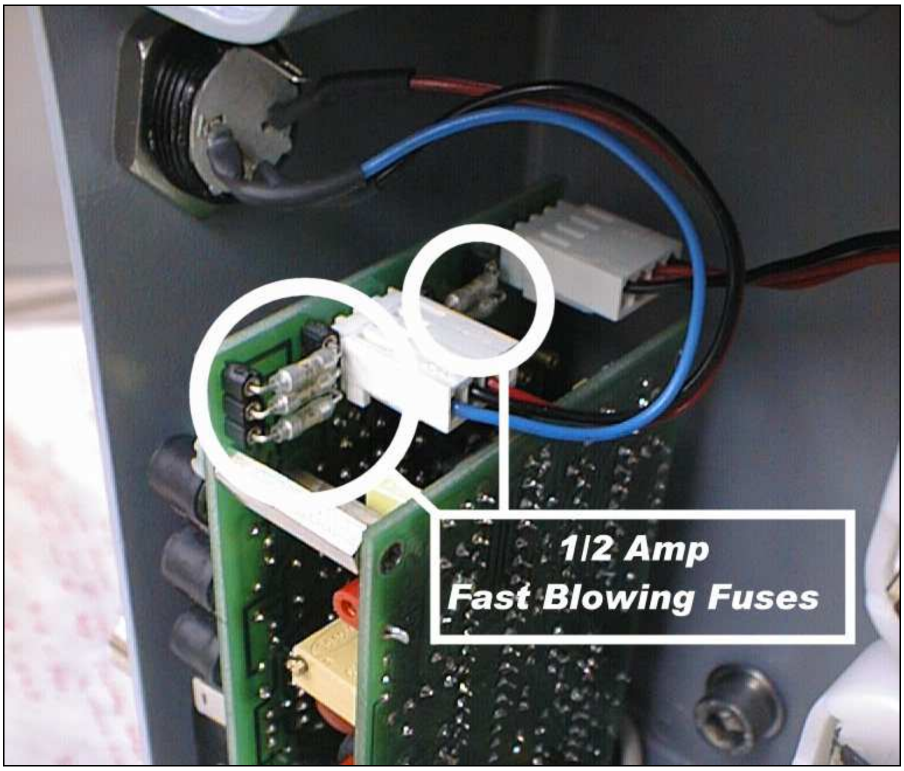

Photo 5.4. View of the switchboard and amplifier board, showing the location of the 500mA fuses

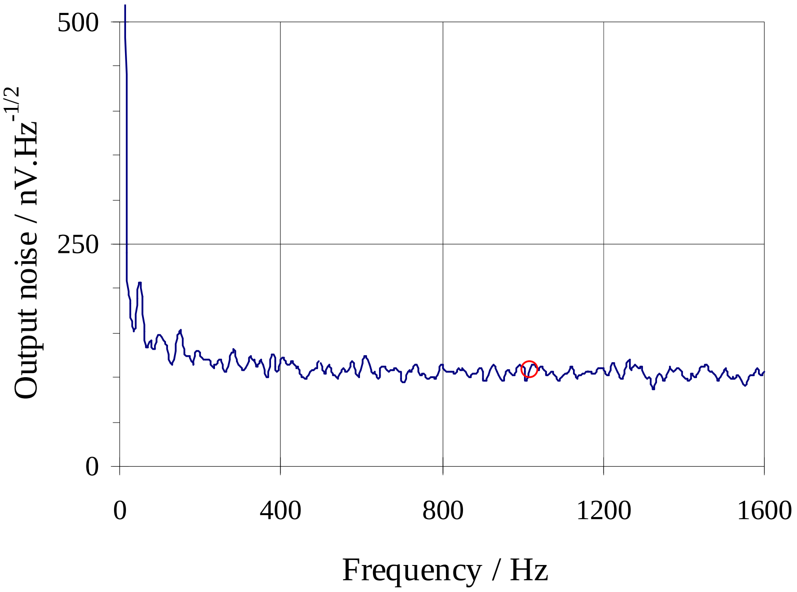

Fig. 5.1a. Typical preamplifier input shorted noise spectra
Amplifier gain = x100. Noise at 1kHz = 1.0nV.Hz$^{-1/2}$

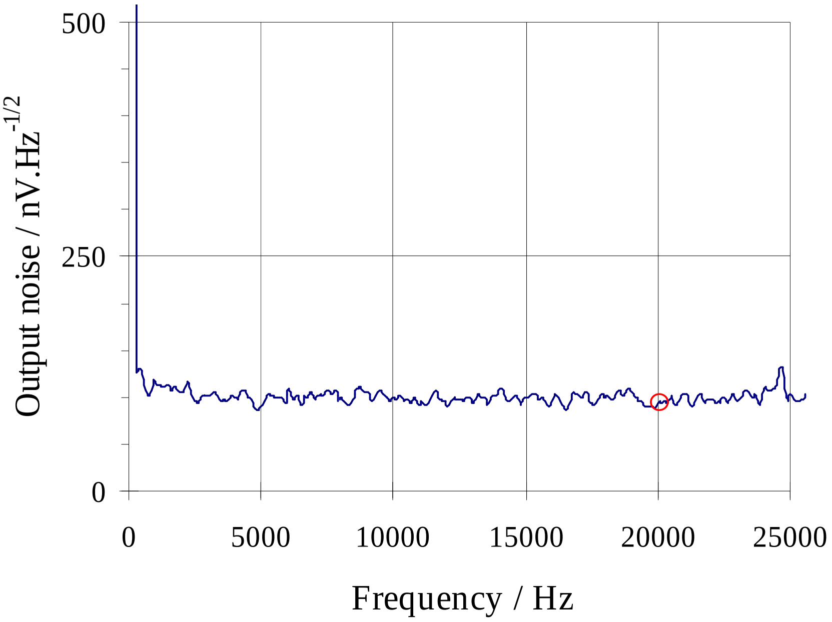

Fig. 5.1b. Typical preamplifier input shorted noise spectra
Amplifier gain = x100. Noise at 20kHz = 1.0nV.Hz$^{-1/2}$

6. System Calibration and Test Results

The detector is calibrated using QMC Instruments unique range of mesh filters to provide an appropriate level of signal within a known wavelength range. A blackbody source is used to provide a broad band signal, which is passed through a combination of filters. This provides a measured amount of incident power on the cryostat window. A lock-in amplifier and / or signal analyser are used to measure the detector output signal. The germanium bolometer and indium antimonide hot electron bolometer is calibrated at a standard signal wavelength of 1.1mm (275GHz). A band-pass filter is used for this which has been used to calibrate all QMC Instruments detector systems and provides a useful cross-calibration.

The typical spectral responsivity of an InSb detector with inhomogeneous magnetic field tuning is shown in **Fig. A2**. in **Appendix. A.** The response function was measured using an FT spectrometer and the response of the InSb detector is ratioed against that of a thermal bolometer coupled with the same window and filters but, for operational reasons, a rather different optical set-up. We do not therefore expect the data in A2 to be accurate to a high degree. It is intended only as a guide to expected performance.

The optical parameters that define the performance of the detector are defined below and the arrangement for the optical tests is shown in **Fig. 6.1**.

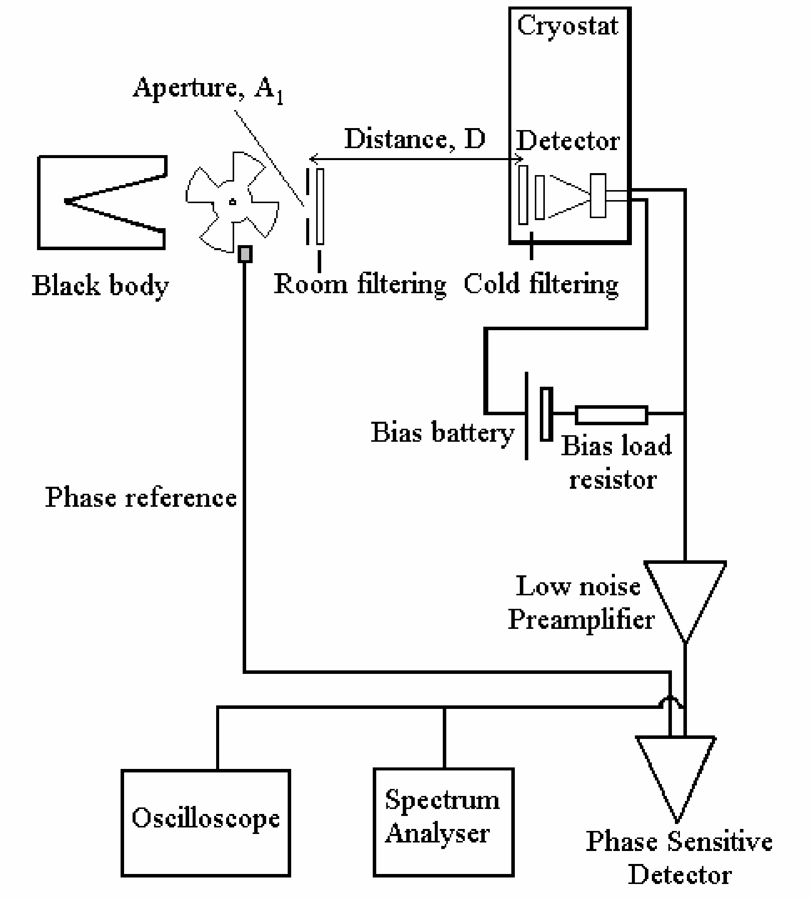

Fig. 6.1. The optical test arrangement

The system optical responsivity, $R_{optical}$, is defined as:

$$R_{optical} = V_{out}/P_{det}$$

where V_{out} is the voltage response at the input of the amplifier (i.e. assuming a preamplifier gain of 1) and P_{det} is the power incident on the window of the cryostat within the field of view determined by the cold optics.

The incident power, P_{det}, is calculated using

$$P_{\mathrm{det}} = \frac{A_1 A_2}{D^2} \frac{2k\beta\Delta T}{3c^2}\left(\nu_2^3 - \nu_1^3\right)$$

where

- A_1 and A_2 are the aperture areas of the black body source and the receiving optics respectively
- D is the distance between these points
- $k = 1.38\mathrm{x}10^{-23}\mathrm{JK}^{-1}$ is Boltzmann's constant
- β is an attenuation factor, which accounts for the room temperature filter transmission losses and the square wave modulation
- $\Delta T = 500\mathrm{K}$ is the temperature difference between the black body source temperature, $T_s = 800\mathrm{K}$, and ambient temperature, $T_b = 300\mathrm{K}$
- $c = 3\mathrm{x}10^8\mathrm{ms}^{-1}$ is the vacuum speed of light
- ν_2 and ν_1 define the upper and lower frequency of the filter passband

The rms noise voltage N_m, generated by the detector system is measured in a 1Hz bandwidth at a spot frequency of 1kHz using a signal analyser. This is also referred to as the input of the amplifier.

The sensitivity of the system is represented by the system optical Noise Equivalent Power (NEP_{opt}). It is this parameter which predicts the signal/noise ratio that will be produced when a certain known signal flux density is incident at the cryostat window within the field of view. NEP_{opt} represents the power incident that will produce a voltage response equal to the noise voltage i.e. a signal to noise ratio of 1.

The System Optical N.E.P. is defined as follows:

$$NEP = N_m/R_{optical}$$

System Cryogenic Performance

The liquid nitrogen and liquid helium hold-times of the system are measured in QMC Instruments Ltd. tests and tabulated in **Table 6.1**. The liquid helium boil-off is measured over a few days to allow the internal components and radiation shields within the cryostat to reach thermal equilibrium. When equilibrium is reached the base boil-off is measured and used to determine the liquid helium hold-time of the cryostat. The hold-time indicated below is the subsequent fill hold-time. Note that a first fill will not last for as long due to the high initial boil-off when the cryostat is cooling from liquid nitrogen temperature.

In order to achieve these figures it is important that the operating instructions laid out in this manual are followed, and that care is taken to ensure that the cryostat is completely full before the liquid helium transfer is terminated.

The system test log sheet is given in **Appendix B.** This shows exactly what steps were taken to run the system and the elapsed time between each action.

Liquid helium reservoir capacity / litres	4.46
Liquid nitrogen reservoir capacity / litres	4.34
Base helium boil-off / litres of gas per min at STP	0.35
Liquid helium subsequent fill hold-time / hours	160 ± 16
Liquid nitrogen hold-time / hours	44 ± 5

Table 6.1. System cryogenic performance

Detector Test Results

T/K	Pins C-F. InSb hot electron bolometer
300	147.5 Ω [†]
77	3.0 kΩ [†]
4.2	39.2 kΩ [†]

Table 6.2a. Measured values of resistance R_{CF}/kΩ across the InSb detector as a function of temperature T/K as the detector is cooled

[†] Measured resistance non-rectifying

T/K	Pins D-E Bolometer	Pins B-D Cold bias resistor
300	103.5 Ω [†]	330.6 kΩ
77	57.9 Ω [†]	324.5 kΩ
4.2	210.7 kΩ [†]	335.5 kΩ

Table 6.2b. Measured values of resistance of the Ge bolometer at the preamplifier input socket as a function of temperature T/K as the detector is cooled

[†] All values should be polarity independent

NOTE: The values tabulated in **Tables 6.2(a, b)** are only intended as a guide. They are dependent on the actual temperature of the detector element and the Ohmmeter's measuring current, particularly when the detector is at 4.2K.

System Optical Arrangement

Liquid nitrogen 77K shield aperture	25mm diameter
Winston Cone field of view	f/2 at 25mm diameter
300K window	1.8mm thick planar HDPE
77K shield filter	100cm^{-1} low-pass QMMF[†]
4.2K Filter	100cm^{-1} low-pass QMMF[†]

Table 6.3a. Optical aperture sizes and filter details for the InSb detector, channel 1
†Refer to **Appendix C** for the transmission profile

Liquid nitrogen 77K shield aperture	18mm diameter
Winston Cone field of view	f/3.5 at 15mm diameter
300K window	1.0mm thick planar HDPE
77K shield filter	600cm^{-1} (20THz) low-pass QMMF[†]
4.2K Filter	600cm^{-1} (20THz) low-pass QMMF[†]

Table 6.3b. Optical aperture sizes and filter details for the Ge bolometer, channel 2
†Refer to **Appendix C** for the transmission profile

System Calibration Results

Bias Resistance	120kΩ
Bias voltage, V_B	3.5V
Bias current, I_B	26μA[‡]
Detector voltage, V_{Det}	750mV
Detector operating resistance R_{Op}	28.8kΩ
System optical responsivity	4.6kV.W^{-1}
System rms output noise at 1kHz	3.5nV.Hz$^{-\frac{1}{2}}$
System optical NEP at 1kHz	0.76pW.Hz$^{-\frac{1}{2}}$
System rms output noise at 10kHz	3.0nV.Hz$^{-\frac{1}{2}}$
System optical NEP at 10kHz	0.65pW.Hz$^{-\frac{1}{2}}$

Table 6.4a. InSb detector test results
‡ Refer to **5. The ULN95 Preamplifier, Altering the detector bias** for a description of the preamplifier test points settings used to take these measurements

The system output noise spectra for the indium antimonide detector are given in **Figs 6.2(a, b).** They were measured using a gain of x100 on the ULN95 preamplifier.

Bias Resistance (4.2K)	330 kΩ
Bias voltage, V_B	9V
Bias current, I_B	20µA ‡
Detector voltage, V_{Det}	2.4 V
Detector operating resistance R_{Op}	120 kΩ
System optical responsivity	18.6kV.W^{-1}
System rms output noise at 80Hz	16nV.Hz$^{-1/2}$
System optical NEP at 80Hz	0.86pW.Hz$^{-1/2}$

Table 6.4b. Ge detector test results

‡ Refer to **5. The ULN95 Preamplifier, Altering the detector bias** for a description of the preamplifier test points settings used to take these measurements

The system output noise spectrum for the germanium bolometer is presented in **Fig 6.3.** The spectrum was measured at zero signal conditions (viewing 300K dc radiative load) at best bias conditions.

Response of System to Different Filter Regimes

The signal power calculated during the calibration of the system at 275GHz was approximately 21pW. The system is therefore calibrated in a low signal-to-noise scenario. The following additional tests are recorded for comparison and use should the detector be exposed to thermal sources. These additional tests assist us in checking that the bolometer is linear when exposed to higher signal loads and that the spectral responsivity of the system is correct.

Filter Scheme	System Response
a) No additional filters (5THz low-pass)	3.2 V
b) 100cm-1 (3THz) low-pass	18 mV
c) 200cm-1 (6THz) low-pass	117 mV
d) 300cm-1 (9THz) low-pass	400 mV

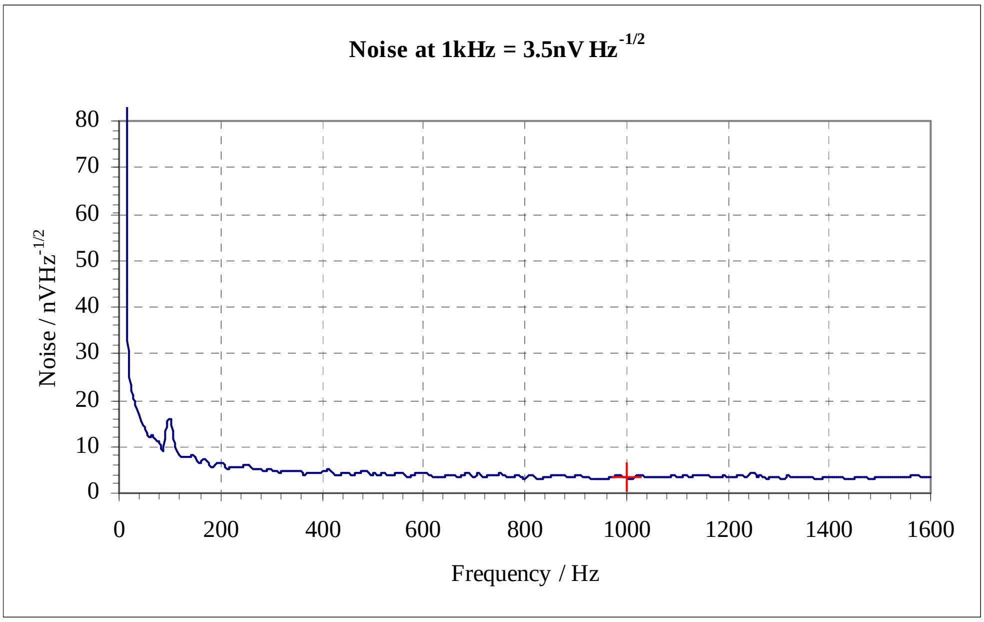

Fig. 6.2a. System output noise spectrum for the InSb detector 0 to 1600Hz

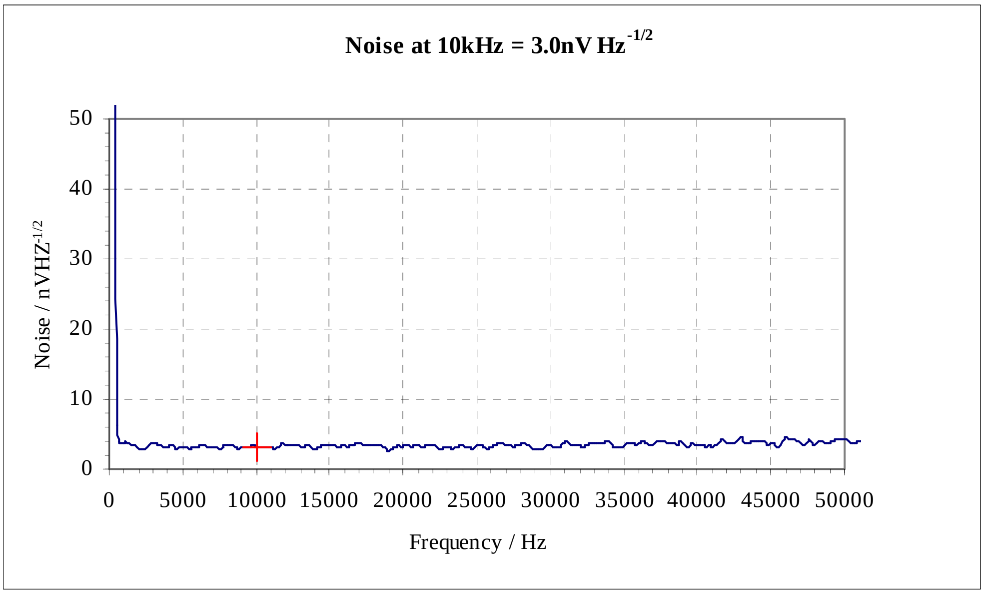

Fig. 6.2b. System output noise spectrum for the InSb detector 0 to 50kHz

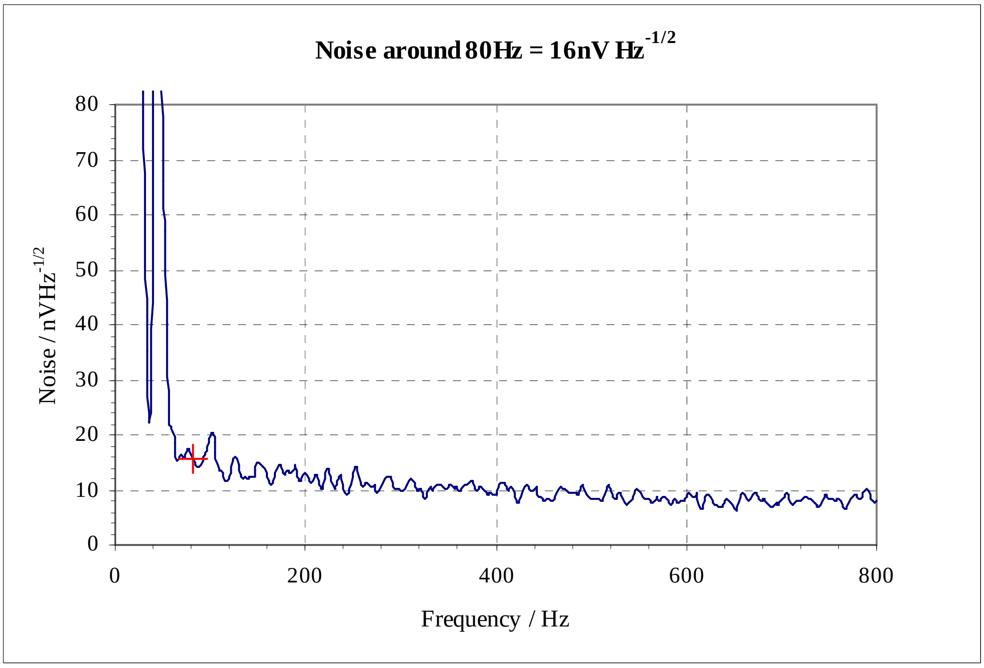

Fig. 6.3. System output noise spectrum for the Ge bolometer. 0 to 800Hz

Appendix A1. Theory of Operation of the InSb Hot Electron Bolometer

The detecting element is a QMC Instruments Ltd. hot electron bolometer type QFI/XBI. The active crystal element is a square of side approximately 5mm. The crystal is thermally anchored to the surface of its mount.

Photo A1.1. InSb detector manufactured as a toaster element mounted on a quartz substrate

Absorption of radiation by free carrier electrons results in a rise in their mean temperature away from and above that of the host InSb crystal lattice. The mobility, μ, of the electrons is a function of temperature and is given by

$$\mu = CT^{3/2}$$

where C is a constant. This change in electron mobility is detectable as a change in the impedance of the crystal. The low effective mass of the carriers provides for a relatively fast detection mechanism. At 4.2K the relaxation timescale is of order 0.3μs, corresponding to a -3dB instantaneous bandwidth of approximately 1MHz. Thus this type of detector offers both sensitive and fast detection in the millimeter and sub-millimeter wavelength range.

This particular type of detector uses high purity undoped n-type InSb and has a geometry which not only gives high electrical impedance, but presents maximum detection area to the incoming signal over a wide range of wavelengths and therefore reduces the problems associated with signal coupling, particularly at long wavelengths.

This detector is usually operated at 4.2K. However, a slight increase in sensitivity is available by reducing the operating temperature by pumping on the main liquid helium bath. At higher operating temperatures, speed of detection increases at the expense of sensitivity.

The optimum bias conditions for the detector will vary as a function of temperature. Clients wishing to operate detectors at temperatures other than 4.2K should contact QMC Instruments technical staff who will be happy to advise.

Magnetically Tuned Detectors

The standard hot electron bolometer without magnetic enhancement of any kind has particularly good sensitivity at frequencies below 600GHz, **Figure A1.1**, where the absorption coefficient is relatively high. Above 600GHz however, the absorptivity falls with the square of the frequency such that sensitivity has fallen by more than one order of magnitude at 1.5THz, and by more than two orders of magnitude at 2.5THz.

In the presence of an appropriately oriented magnetic field, however, absorption is enhanced at the cyclotron frequency. The central frequency ω of the resonance peak is given by:

$$\omega=eB/m^*$$

where e is the electron charge, B is the magnetic field, $m^* = 00.01359m_e$ is the effective carrier mass in InSb. m_e is the electron rest mass = $9.11\mathrm{x}10^{-31}$kg.

In InSb m^* is small compared to the electron mass, so relatively high cyclotron resonance frequencies are attainable using the smaller field strengths available using permanent magnets.

For detectors subjected to a uniform magnetic field, the resonance peak FWHM is of order 400 - 500 GHz, and such detectors are ideal for FIR laser applications or relatively narrow band spectroscopy. The spectral responsivity of this type of detector is shown in **Figure A.1.** Tuning with a single magnetic field strength cannot cover the full potential spectral range of the detector.

The inhomogeneously tuned InSb detector, first introduced in 1994, lies in an inhomogeneous magnetic field. In such a configuration, the resonance peak is broadened. The result is excellent absorptivity to frequencies below about 1.5THz. The spectral responsivity of this type of detector is shown in **Figure A1.2.** The dips and peaks are genuine and reproducible. They are caused by interference affects resulting from the thickness of the planar InSb detector element, and interference effects from the optical filters used - a planar 120cm^{-1} blocking filter. The measurement is for this reason not a true measurement of the detector response alone.

Considerable magnetoresistance is observed in these magnetic field conditions, and the level of noise measured from the detector is relatively high compared to the Johnson noise associated with the operating impedance of the device. However, as the magnetic field leads to a much more significant increase in responsivity over a broader range of frequencies, the advantages of magnetic tuning far outweigh the disadvantages.

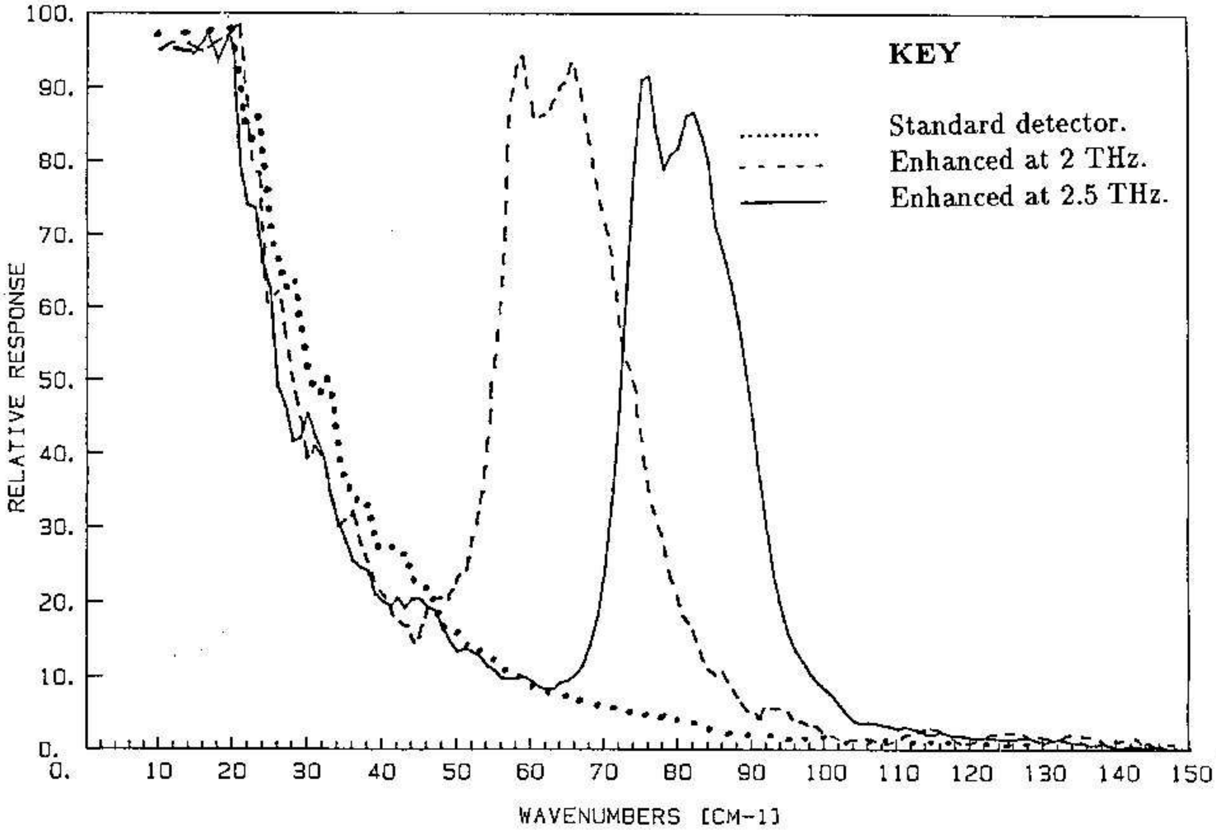

Fig. A1.1. Spectral responsivity of a QFI/X detector with no magnetic field applied and two examples of type QFI/XB detectors enhanced at 2THz and 2.5THz

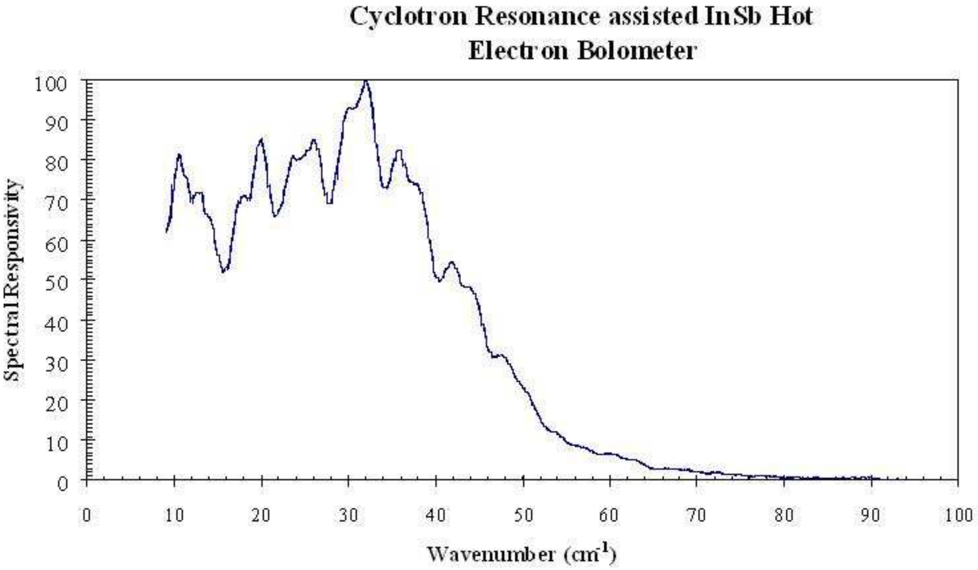

Fig. A1.2. Spectral responsivity of the Type QFI/XBI detector

Temperature Stability

Figure A1.3 below shows the measured temperature, over a period of 100 seconds, of an InSb detector mounted on a 1mm thick quartz substrate in a typical configuration. The measured temperature in this configuration where the detector block is bolted on to the cold stage is 4.2K ± 200µK.

Mounting the detector block on to 75µm of Kapton tape reduces the thermal fluctuations by a factor of about 10; measured temperature is around 4.2K ± 20µK. However, the detecting element takes a few hours to reach thermal equilibrium

Typically the InSb detector is mounted on a quartz substrate, though sapphire and diamond (CVD) are other options.

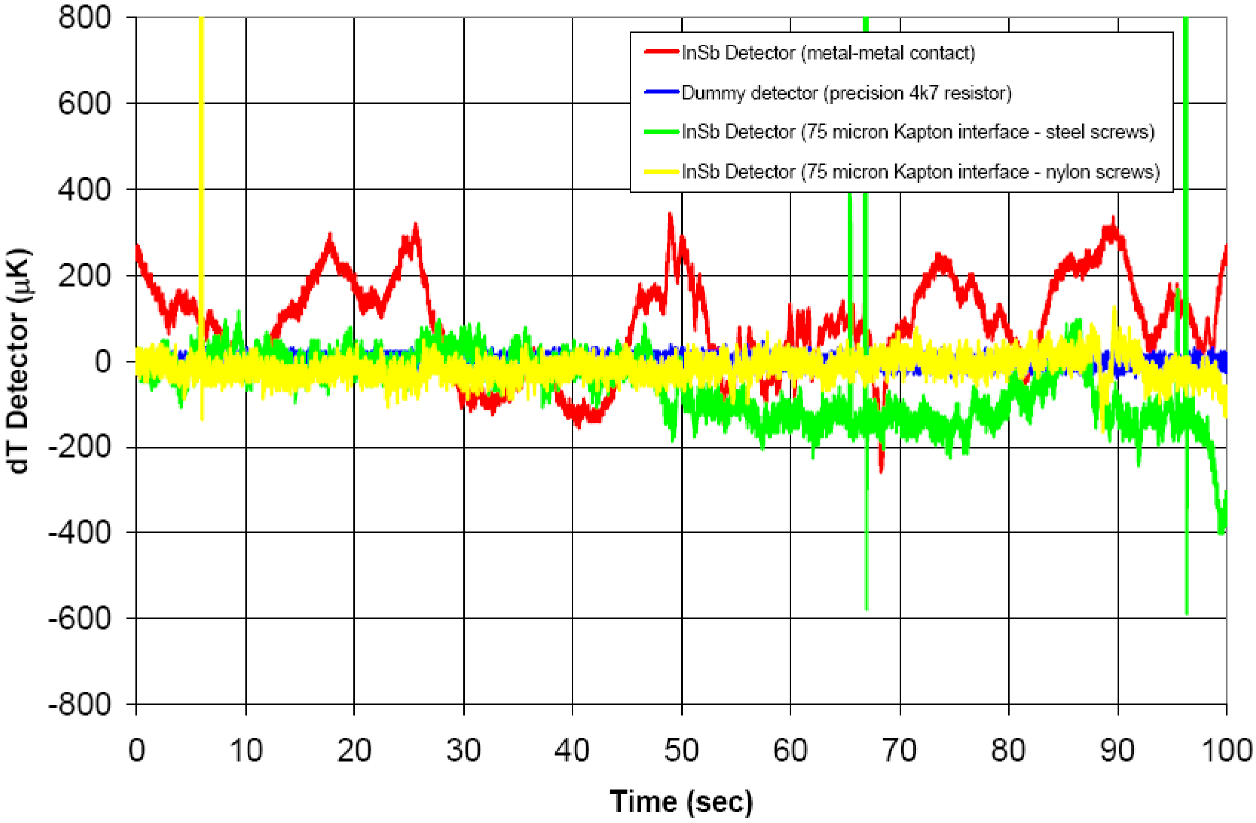

Fig A1.3. InSb detector temperature measurements

Operating Impedance of the Detector Element

The typical operating impedance of an untuned InSb detector is 2kΩ to 5kΩ. A tuned detector has an operating impedance of around 8kΩ to 15kΩ. The operating impedance, when an operating current is passed through the detector, is lower than the actual measured resistance of the InSb. The detector resistance at 4.2K will depend on the physical nature of the InSb wafer from which the detector is prepared, and its treatment at QMC prior to being mounted in the detector block.

An 800K blackbody signal with a HDPE window on the cryostat ovc and low pass filtering on the cryostat will generate a resistance change of about 50mΩ.

Appendix A2. Theory of Operation of the Germanium Bolometer

The detector mounted in this system is a composite structure germanium bolometer designed for operation at 4.2K. The active element (thermistor) is mounted on a thin film metallic absorber with 3mm diameter which is deposited on a SiN substrate to give excellent thermal shielding. This structure is suspended in an integrating cavity behind the Winston cone condensing optic. The absorbing metal film is designed to have an impedance matched to that of free space in order to optimise absorption efficiency over a large range of wavelengths.

The metal film warms as radiation is absorbed. The detector element is in good thermal contact with the absorber, and therefore warms and cools with it. The SiN supporting membrane has very low thermal conductivity, which ensures that absorbed heat is lost almost entirely through the thermistor. It is the change in resistance of the thermistor as the element changes temperature that is sensed as a voltage change at the input of the preamplifier.

The wires connecting the thermistor to its mount are thin and as short as possible in order to reduce thermal capacitance. This permits the detector to have the maximum possible \speed of detection.

Based on the V-I characteristic measured at 4.2K (see Figure A1 below), we define the detector Electrical Responsivity, measured in Volts per Watt (VW^{-1}) as:

$$Resp_{elec} = -\left(\frac{I_0}{2}\right)\left(\frac{Z_0 - R_0}{R_0}\right)$$

where the detector impedance $R_0 = V_0 / I_0$

- V_0 is the voltage across detector at operating point
- I_0 is the bias current at operating point
- Z_0 is the slope of V-I at the operating point

The electrical responsivity represents the volts per watt response of the detector under ideal conditions in which all incident photons are absorbed. This is an idealised maximum and does not represent the true sensitivity of the actual detector.

Total intrinsic detector noise is dominated by Johnson noise V_J and phonon noise V_{Ph}:

$$V_J = \sqrt{4kT_{\text{det}} R_0 f}$$

$$V_{Ph} = \sqrt{4kT_{\text{det}} G}$$

$$V_T{}^2 = (V_{Ph}{}^2 + V_J{}^2)$$

where

- $k = 1.38\text{x}10^{-23} JK^{-1}$ is Boltzmann's constant
- T_{det} is the detector temperature
- f is the measurement bandwidth
- G is the detector thermal conductance (WK^{-1})

For an optimised bolometer the total intrinsic noise voltage is twice the phonon contribution:

$$V_T{}^2 = 1.5V_J{}^2$$

hence

$$V_T = 1.2V_J$$

In practice the measured detector noise will be greater than the theoretical minimum described above. Detectors of this kind are susceptible to microphonic noise. At 4K for example, the bolometer will “see” liquid helium boiling noise. The limiting NEP, which represents the ideal NEP of the detector, corresponding to ideal photon absorption in conjunction with ideal noise performance, is defined thus:

$$NEP_{\lim} = V_T / Resp_{elec}$$

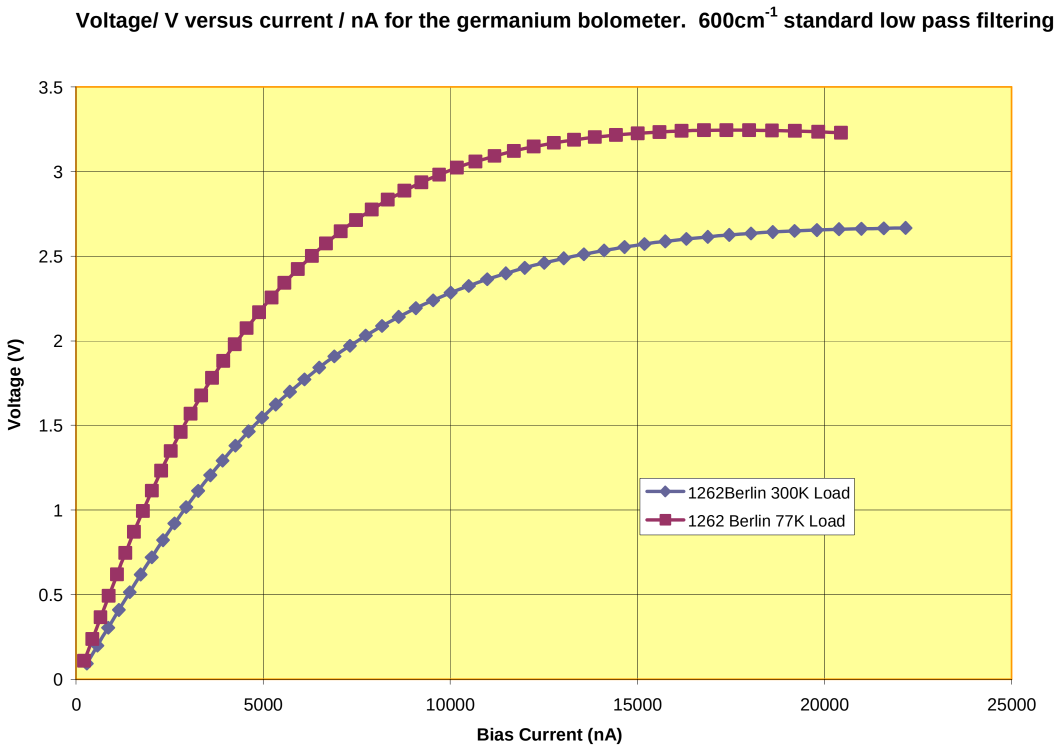

Figure A2.1. The detector VI characteristic measured through 600cm^{-1} low-pass filtering with both a 300K and a 77K dc load.

Appendix C. Filter and Window Transmission

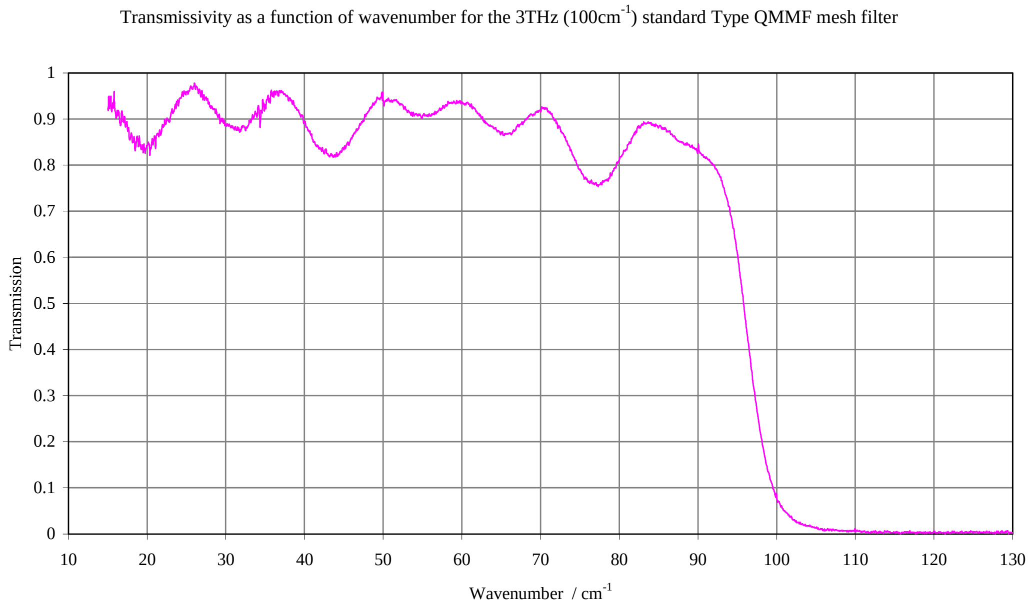

Fig. C1. Transmission spectrum for the type QMMF 100cm^{-1} low pass filter

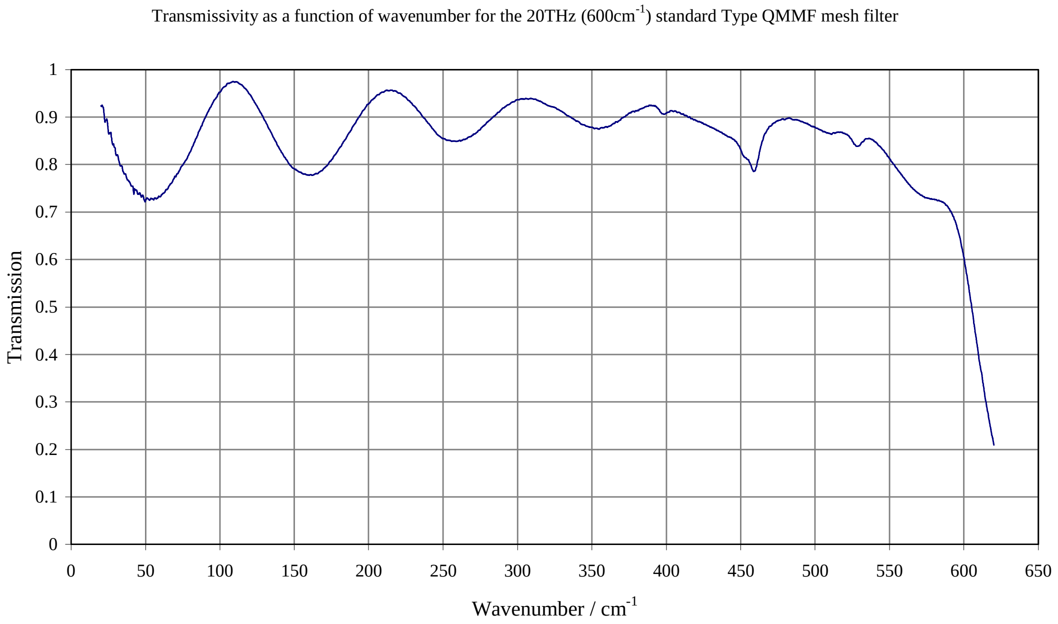

Fig. C2. Transmission spectrum for the type QMMF 600cm^{-1} low pass filter

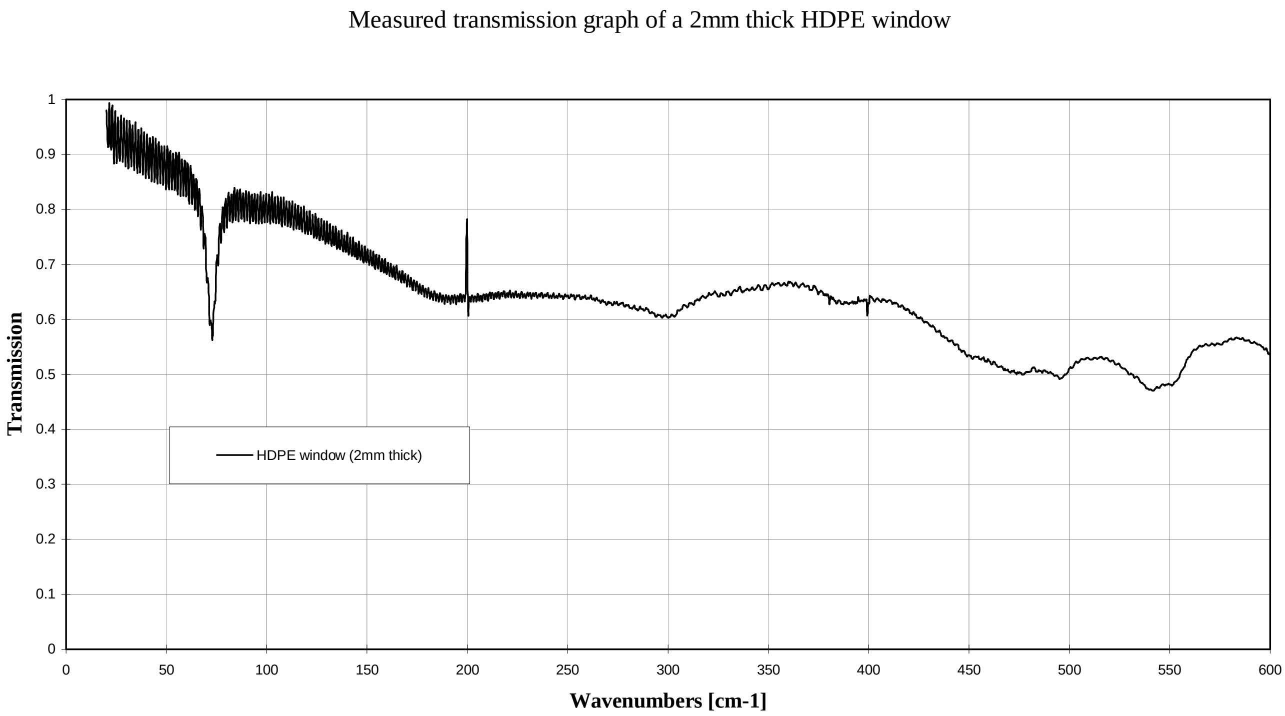

Fig. C.3. Measured transmission of a 2mm thick HDPE window from $20cm^{-1}$ to $600cm^{-1}$. The polyethylene characteristic absorption increase is clearly seen around $73cm^{-1}$

QMC Instruments Ltd

Contract details and guarantee

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

Purchase Order Number
Purchase Order Date
QMCIL Reference
System Serial Number

On receipt of your shipment

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

This operating manual contains instructions for operation of the detector system, together with QMC Instruments Ltd. test performance data, against which our guarantee is given as stated above. The user is advised to read this document carefully prior to operation of the detector system and is reminded that our guarantee will be invalidated if it is damaged through misuse.

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

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

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