QMC Instruments Ltd

Cooled InSb Bolometer System

Operating Manual

Model QFI/2B

QMC Instruments Ltd

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QMC Instruments Ltd

First - A Word of Warning

Lifting and Handling the Cryostat

Please take care when moving and lifting the system. It is 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 photograph above shows part of a badly damaged system. We do not want this kind of thing 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 QFI/2B

This is a QMC Instruments Ltd. detector system type QFI/2B which incorporates an Indium Antimonide (InSb) hot electron bolometer with magnetically enhanced response. The detector is mounted in an optical integrating cavity behind a condensing cone optic and low-pass blocking filters. These components are mounted in a type TK1813 liquid helium cryostat built to our specification by our sister company, Thomas Keating Ltd.

• The Indium Antimonide Hot Electron Bolometer

This is a QMC Instruments Ltd. Type QFI/XB InSb hot-electron bolometer with homogeneous magnetic field tuning. The InSb detector element sits in a magnetic field applied by permanent magnets to either side of its mount. The field geometry is designed to give optimised absorption at 2THz. The detector is designed for operation at 4.2K. Theory of operation is described in Appendix A.

The detector is mounted in an optical cavity behind a condensing cone optic and is restricted in bandwidth using appropriate multi-mesh low-pass filters.

• Filter Performance

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 aperture of the cone. The filter 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 Preamplifier

The system incorporates a ULN95 preamplifier. This is mounted to the side of the body of the cryostat to reduce signal interference. The preamplifier runs 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
QFI/2B detector system	xxxx
QFI/XB detector	xxxx
ULN95 preamplifier	xxxx
TK1813 cryostat	xxxxx-x

QMC Instruments Ltd

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 QFI/2B

- Thomas Keating Ltd. cryostat, type TK1813, containing:
    - Detector type QFI/XB
    - Cold condensing cone optic
    - Low-pass type QMMF filters mounted at both 4.2K and 77K
- 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
- 1-off ULN95 preamplifier, with power supply lead and rechargeable NiCd battery pack
- Outer vacuum case base plate with O-ring
- 77K radiation shield base plate
- Liquid nitrogen blow-out tube
- Spares kit which includes:
    - O-rings
    - Set of screws
    - ULN95 preamplifier power supply lead
    - M3 and M4 Allen keys
- Operating manual

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 affects 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 and other small items that are required to prepare the system can be found in the spares kit.

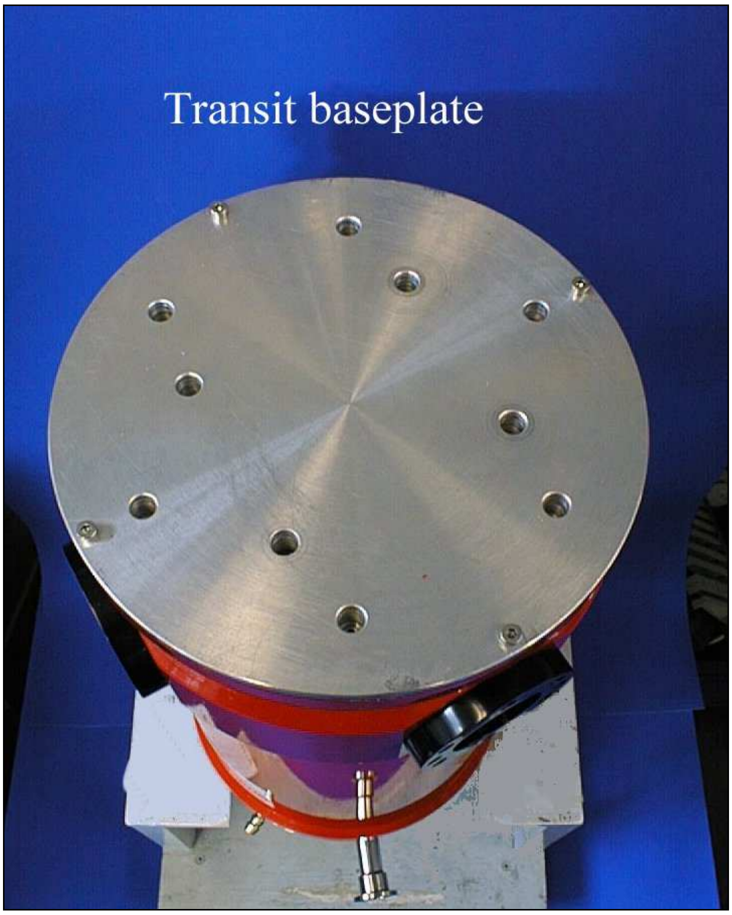


Photo 1.1. Transit base-plate

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 Photos 1.2(a, b)

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 cone attached to it. There are two filters, one of which can be found mounted onto the end of the 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.

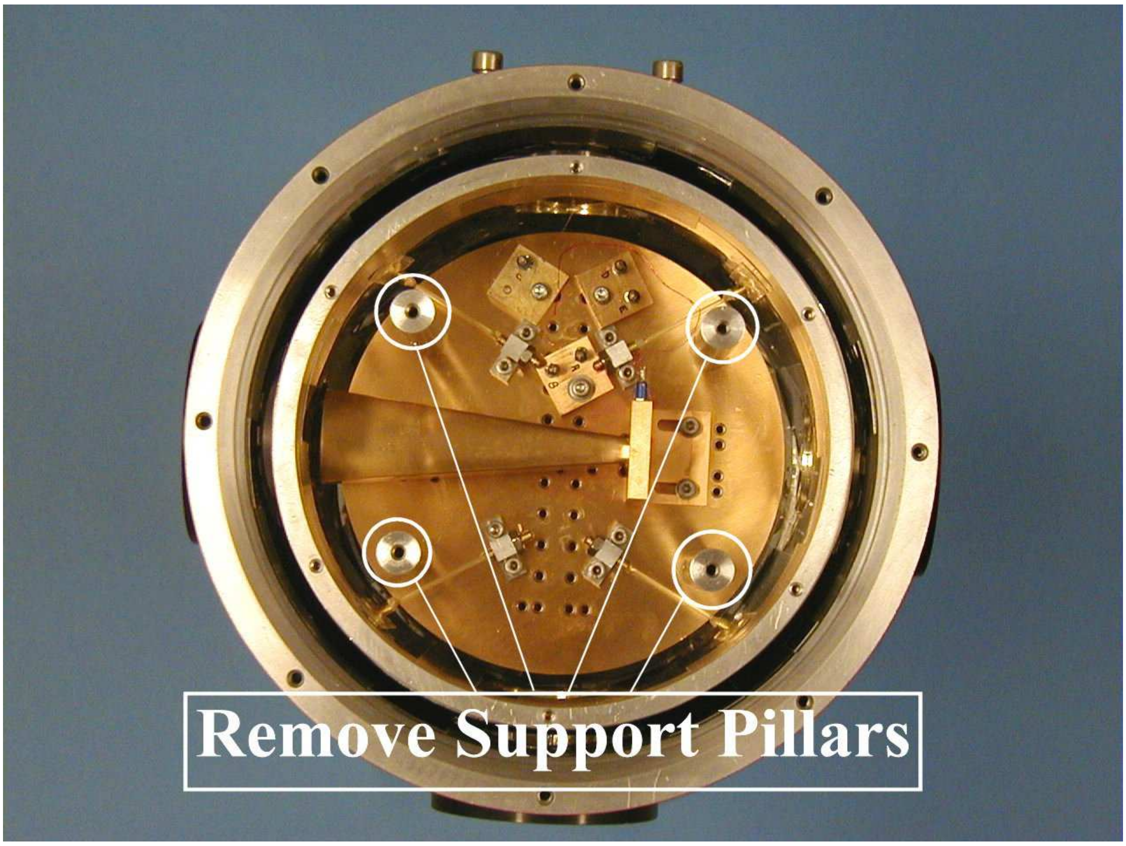


Photo 1.2a. The four support pillars and the detector optics

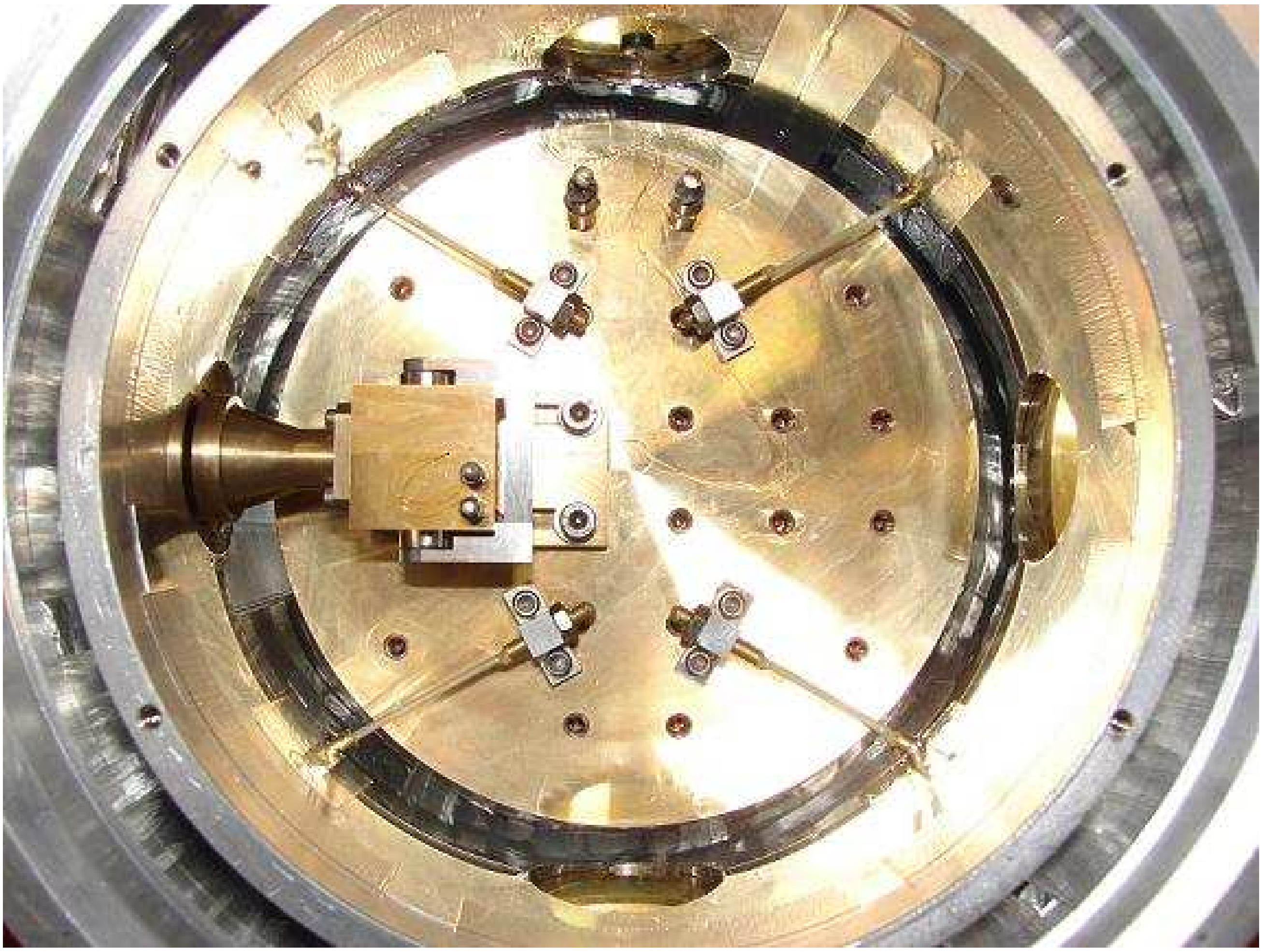


Photo 1.2b. The inside view of the tuned InSb detector system

Fitting the cryostat base-plates

Refer to Photos 1.3 and 1.4, and Figure 1.1

The TK1813 cryostat has a liquid nitrogen cooled 77K radiation shield base-plate, and a room temperature outer vacuum casing (OVC) base-plate. The 77K shield is located using the set of M3 screws provided. 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 because 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 **Fig. 1.1.**

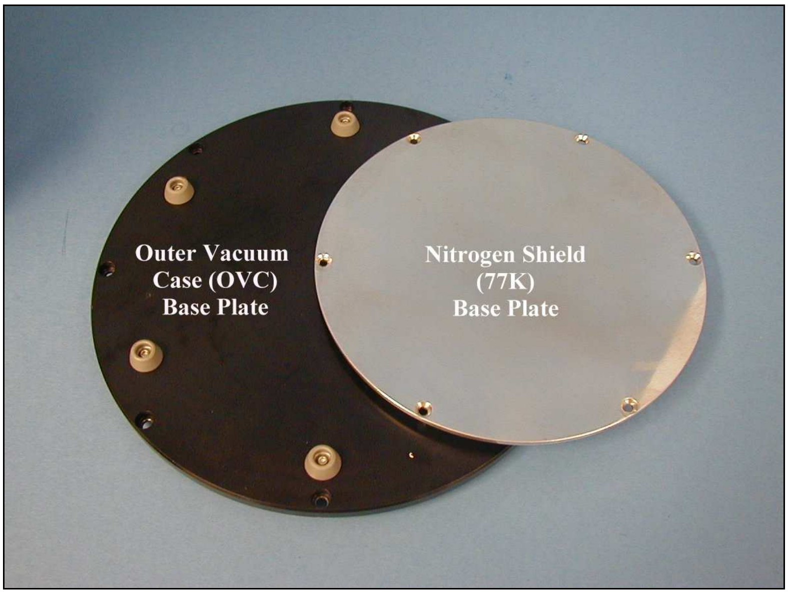


Photo 1.3. Cryostat base-plates

Photo 1.4. Liquid nitrogen base-plate in position

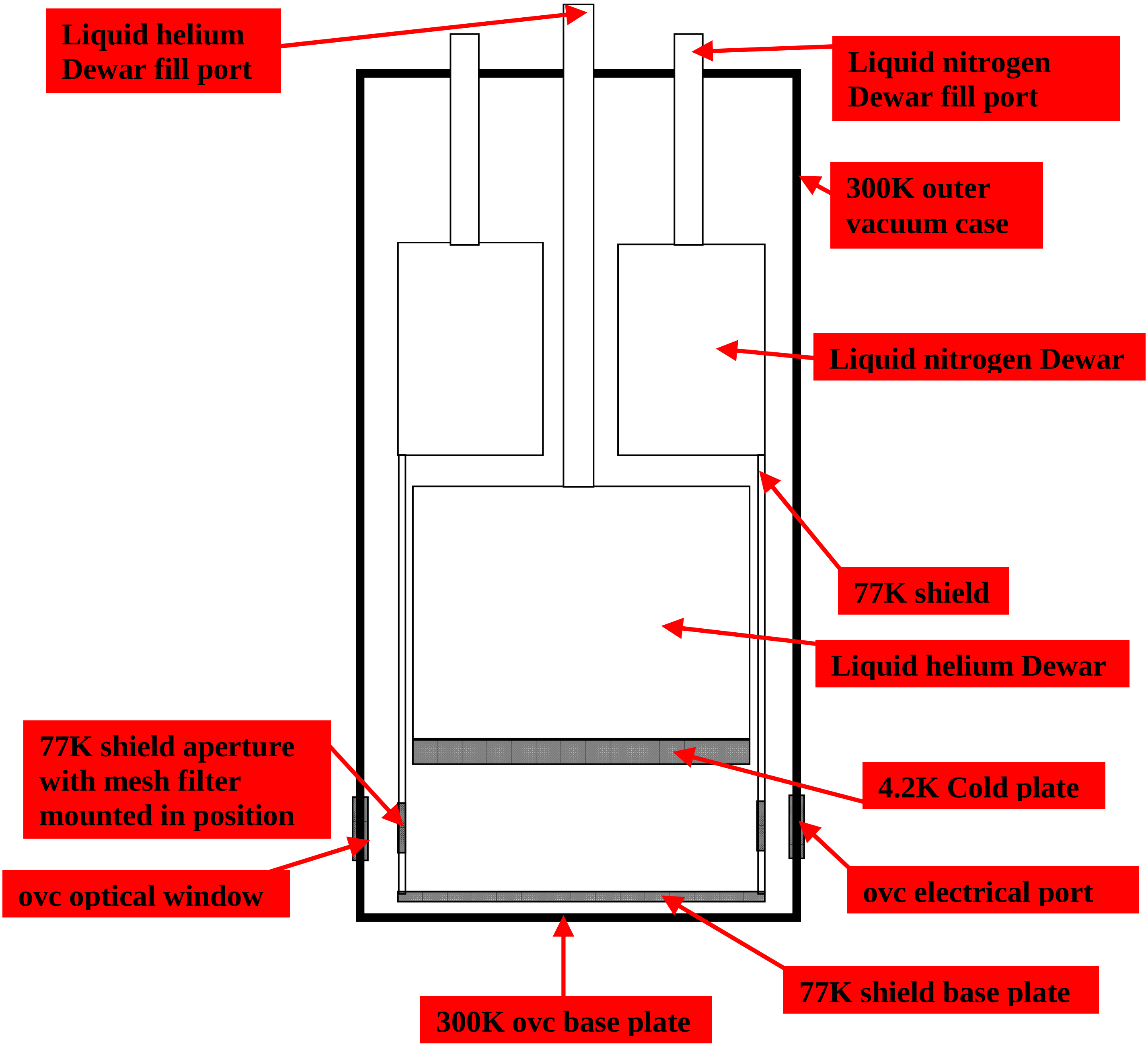


Figure 1.1. Cryostat schematic showing the main features of the cryostat. Not to scale

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.

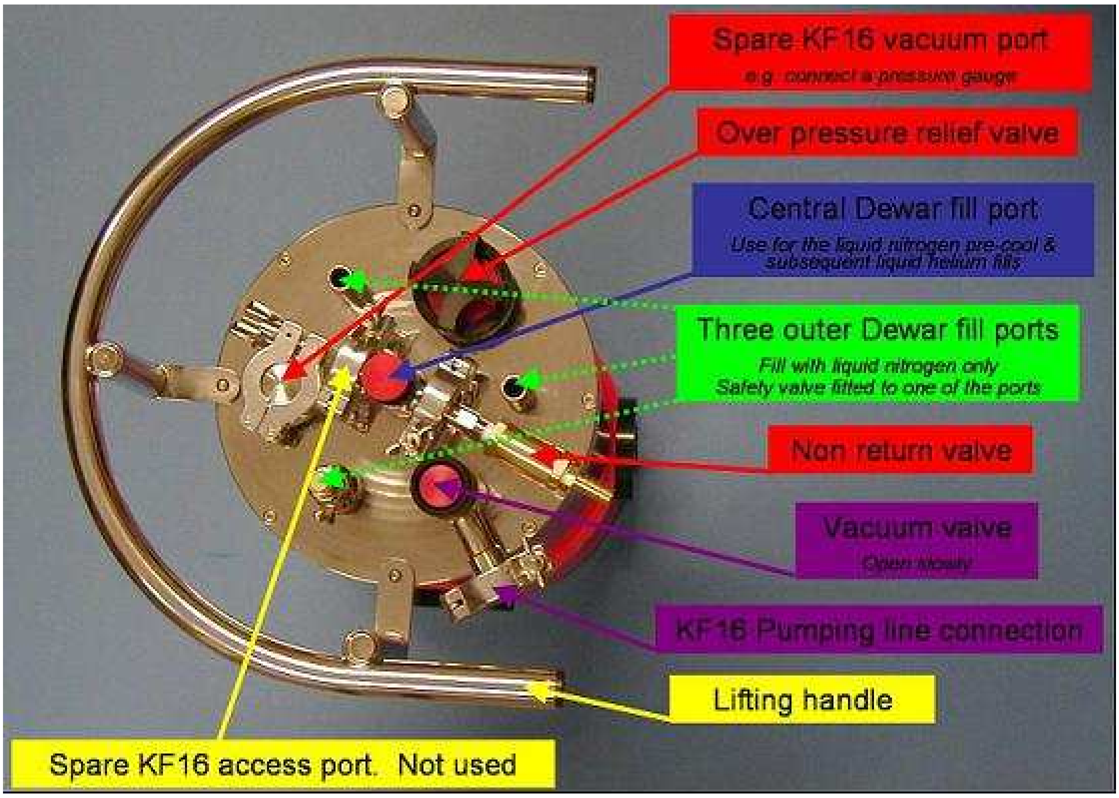


Photo 2.1. TK1813 cryostat top-plate fittings

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 TK1813 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. In the case of an Indium Antimonide detector, the detector impedance should be monitored to check that the temperature is above 77K.

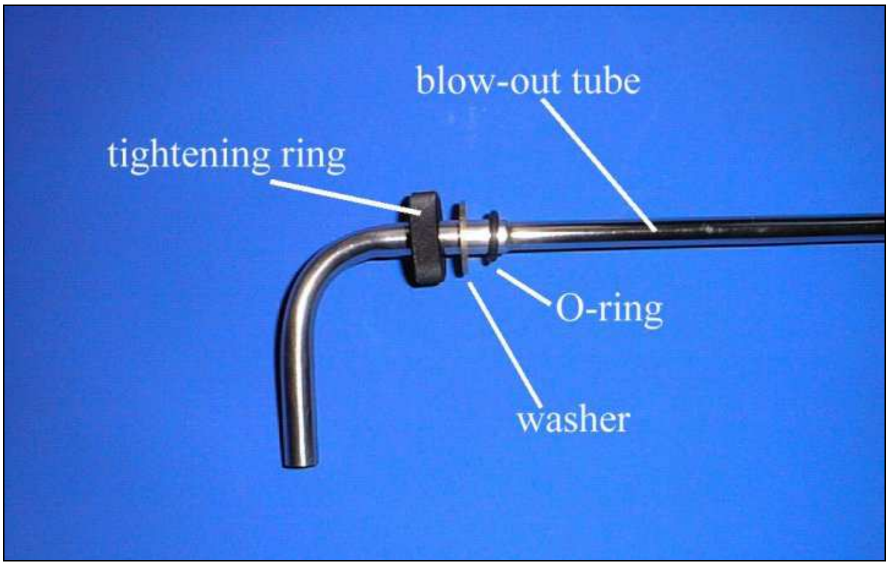


Photo 3.3. The blow out tube

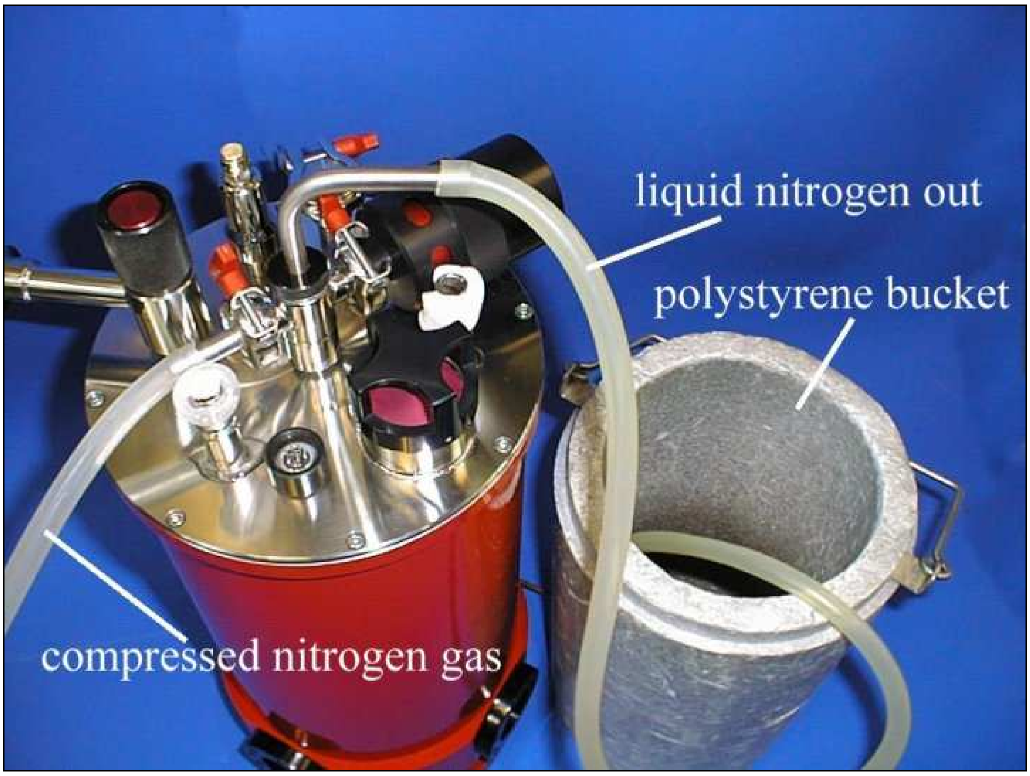


Photo 3.4. Arrangement to blow the liquid nitrogen out of the liquid helium reservoir

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 leaving adequate venting for helium gas during transfer.

QMC Instruments Ltd. offers both rigid and flexible liquid helium transfer tubes which are designed for the TK range of cryostats. Please contact us if you require assistance.

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 TK1813 cryostat to cool down from 77K to 4.2K and to fill with liquid helium; and the whole process should consume about four 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. This kind of 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 D and E of the preamplifier input connector as shown in **photo. 4.4.**

Photo 4.1. Liquid helium transfer

Photo 4.2. Helium gas exhaust during fill

Photo 4.3. Helium plume when complete

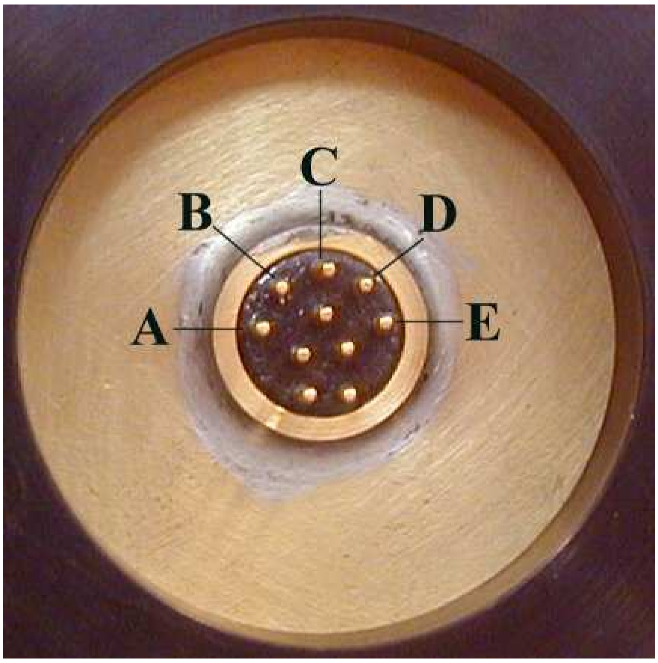


Photo 4.4. Electrical port pin assignments. InSb detector attached to pins D-E

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 Preamplifier

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 $Hz^{-1/2}$ rms > 1kHz**
		(input shorted)	**≈ 3nV $Hz^{-1/2}$ rms at 10Hz**

Table 5.1. ULN95 Technical specification

Mounting the preamplifier

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 preamplifier should be mounted onto the black anodised vacuum window surrounding the 10-pin electrical feedthrough which is located on the side of the cryostat. The two mounting bolts can be found screwed into this. 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 preamplifier

The ULN95 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 preamplifier from external power. A power lead is 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.

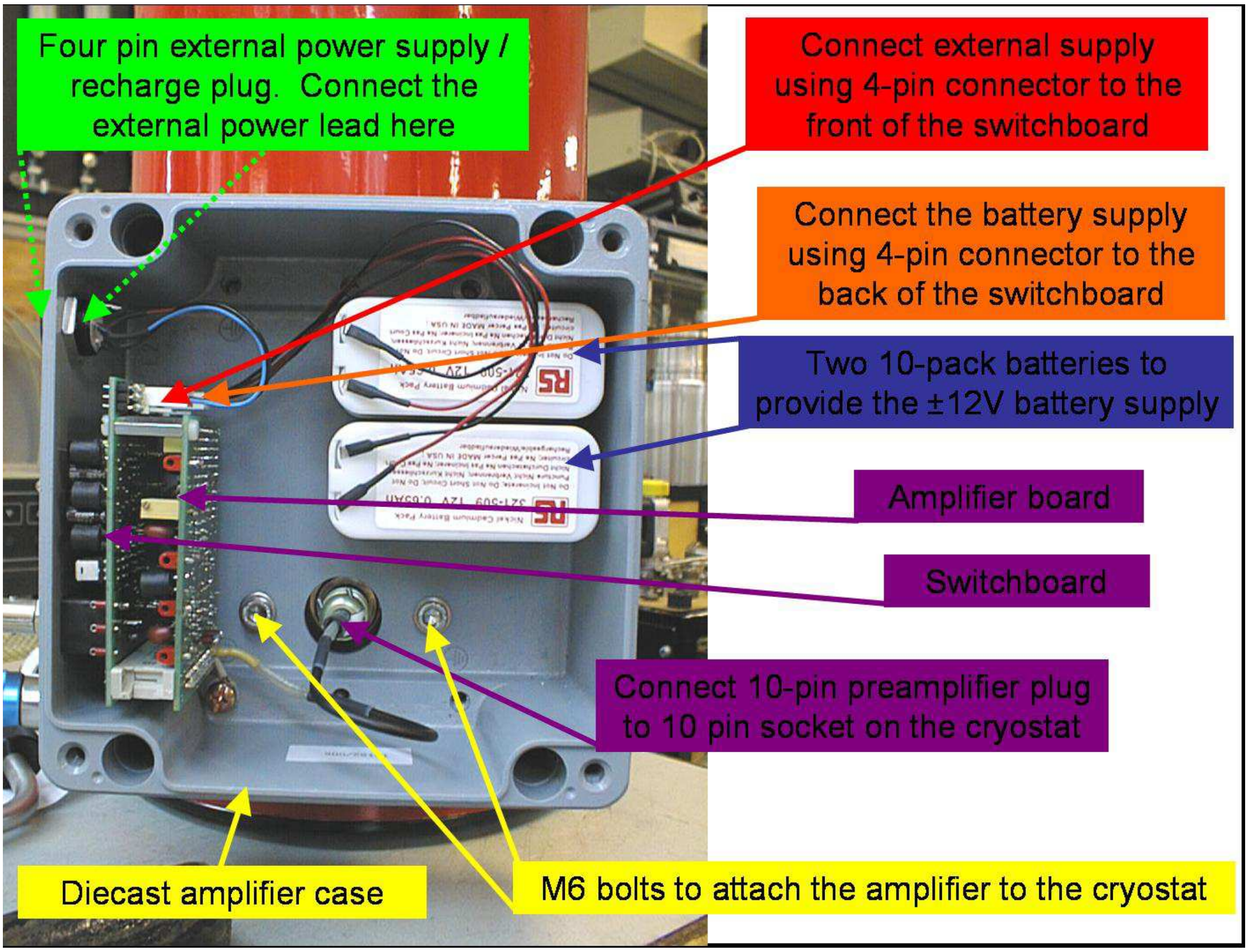


Photo 5.1a. Preamplifier layout

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. It is a Farnell Instruments Ltd, stabilised power supply 2 x 0-30V, 1A. The photo 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.

A current of approximately 90mA will be drawn when using a ±16.5V external power supply to both power the amplifier and recharge the amplifier batteries.

Approx 35mA will be drawn when using a ±16.5V external power supply to power the amplifier.

When connecting a discharged preamplifier (off for at least 10 seconds) to an external power supply there is a surge to about 130mA for the initial charging of the circuits / components.

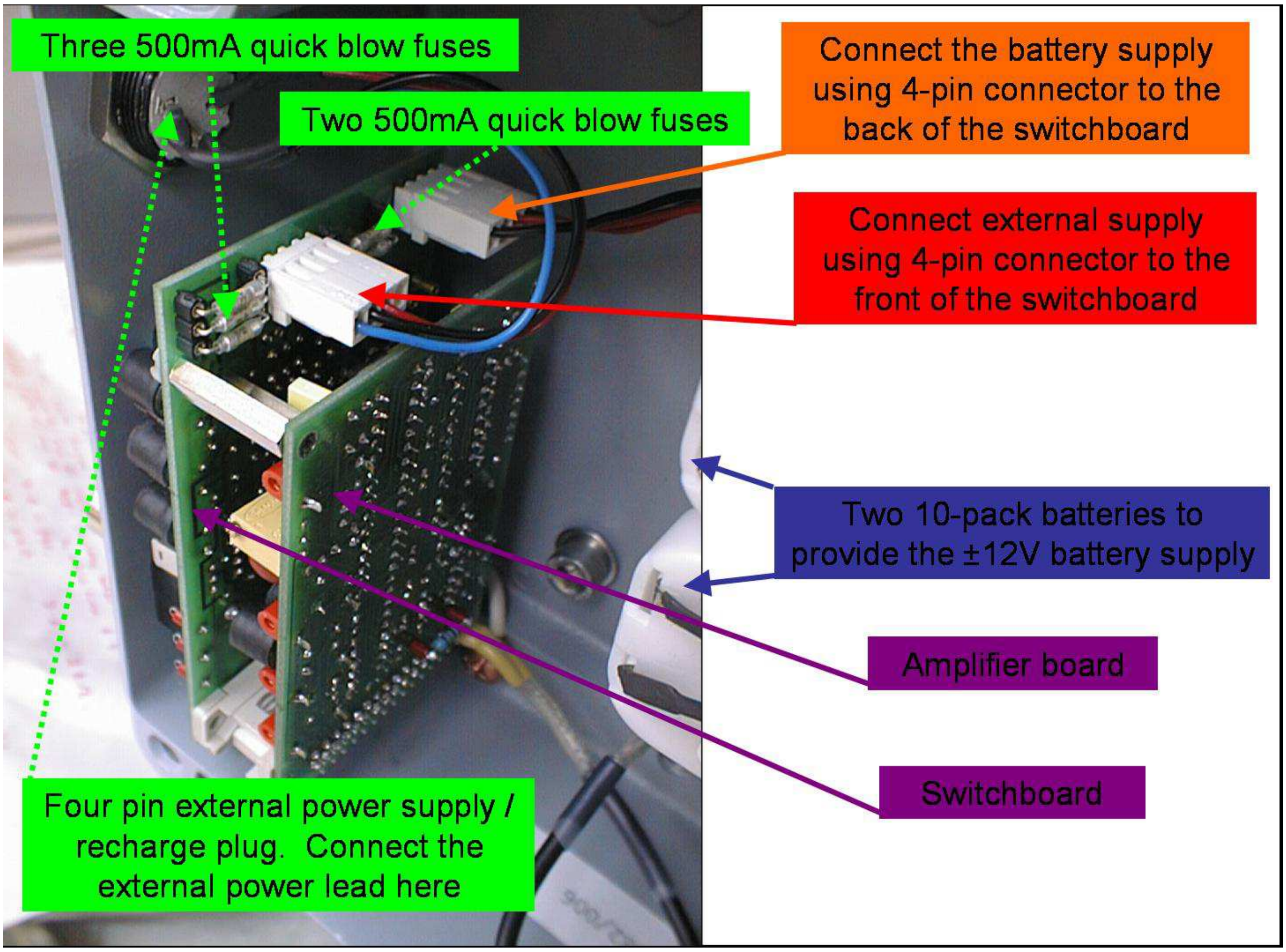


Photo 5.1b. The preamplifier boards

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** of the preamplifier
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.

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.

Photo 5.2. Power supply connections

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.

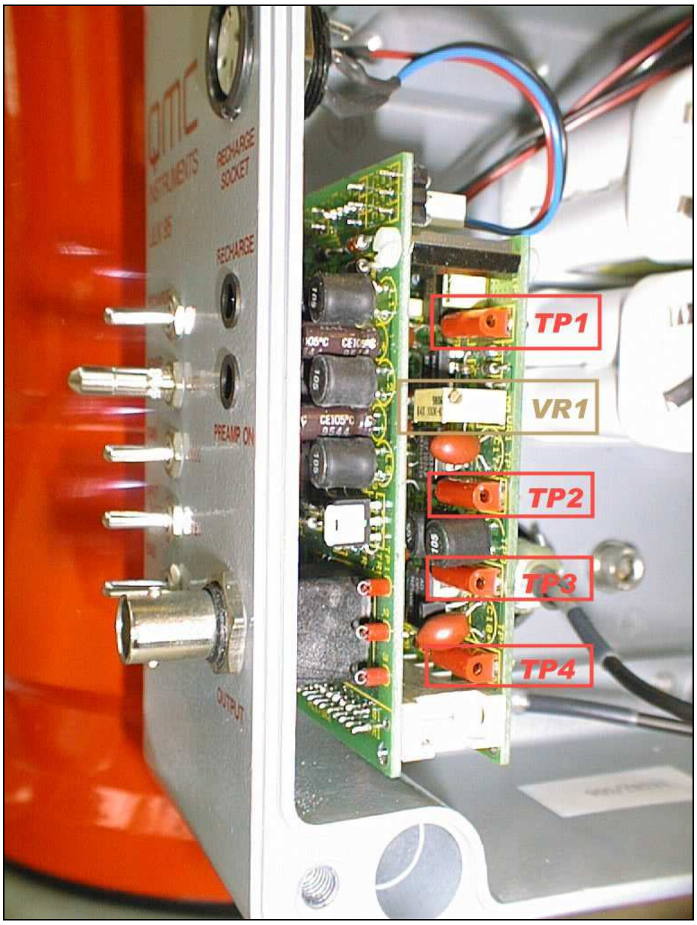


Photo 5.3. View of the switchboard and amplifier circuit board identifying the voltage test points and multi turn potentiometer

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

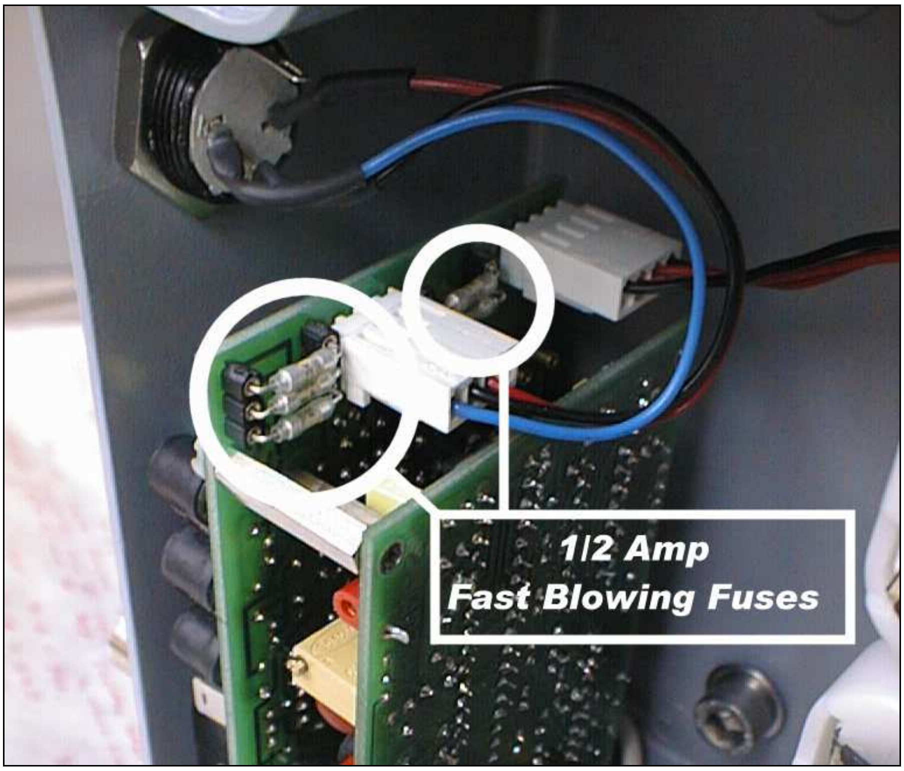


Photo 5.4. View of the switchboard and amplifier board, showing the location of the 500mA fuses

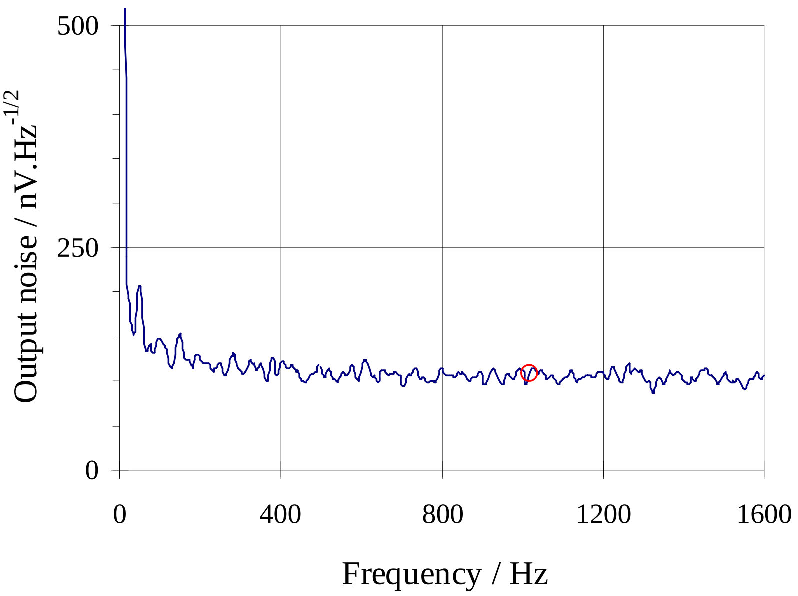


Fig. 5.1a. Typical preamplifier input shorted noise spectra
Amplifier gain = x100. Noise at 1kHz = 1.0nV.Hz$^{-1/2}$

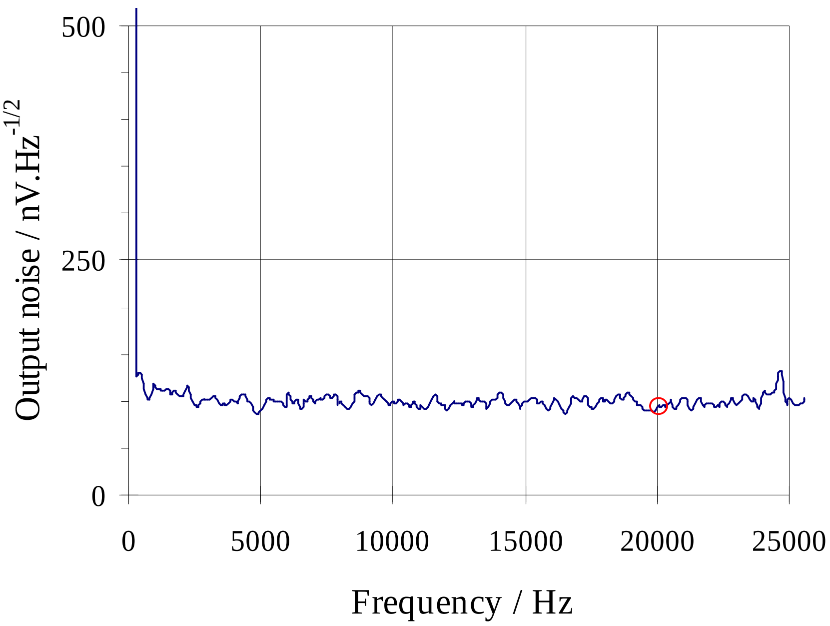


Fig. 5.1b. Typical preamplifier input shorted noise spectra
Amplifier gain = x100. Noise at 20kHz = 1.0nV.Hz$^{-1/2}$

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 indium antimonide hot electron bolometer is calibrated at a standard signal wavelength of 1.1mm (275GHz).

The typical spectral responsivity of an InSb detector with homogeneous magnetic field tuning is shown in **Fig. A1**. 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.

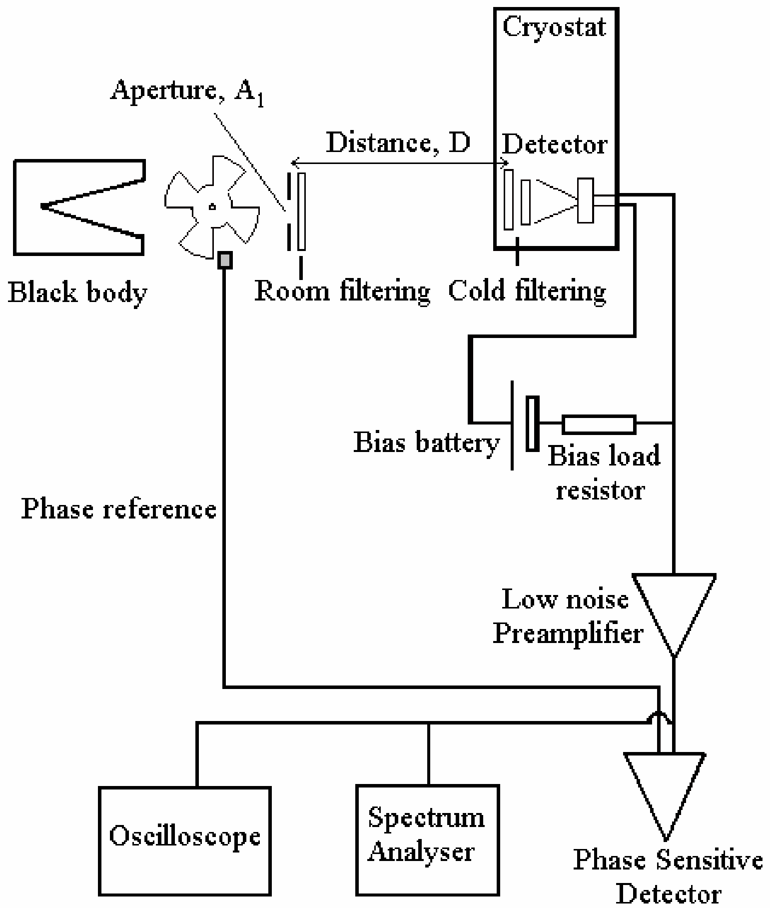


Fig. 6.1. The optical test arrangement

We measured an FTS background spectrum with this system. This data is shown in **Fig 6.4** later in this chapter.

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

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

$$R_{optica}l = V_{out}/P_{det}$$

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

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

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
- $k = 1.38\text{x}10^{-23}\text{JK}^{-1}$ is Boltzmann's constant
- β is an attenuation factor, which accounts for the room temperature filter transmission losses and the square wave modulation
- ΔT = 500K is the temperature difference between the black body source temperature, T_s = 800K, and ambient temperature, T_b = 300K
- $c = 3\text{x}10^8\text{ms}^{-1}$ 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	1.79
Liquid nitrogen reservoir capacity / litres	1.75
Base helium boil-off / litres of gas per min at STP	0.17
Liquid helium subsequent fill hold-time / hours	132 ± 14
Liquid nitrogen hold-time / hours	19 ± 3

Table 6.1. System cryogenic performance

Detector Test Results

This detector was tested at 4.2K in the QMC Instruments Ltd TK1813 cryostat with a ULN95 signal preamplifier supplied as part of this detector system

T/K	R
300	84Ω
77	$2.45k\Omega$
4.2	$63.5k\Omega$

Table 6.2. Measured resistance of the InSb detector as a function of temperature T/K as the detector is cooled. The measured resistance values are non-rectifying

NOTE: The values tabulated in **Table 6.2** are only intended as a guide. They are dependent on the actual temperature of the detector element and the Ohmmeter's measuring current at 4.2K.

System Optical Configuration

Liquid nitrogen 77K shield aperture	25mm diameter
Condensing optic entrance aperture	16mm diameter
300K window	2mm thick planar HDPE
77K shield filter	$100cm^{-1}$ low-pass QMMF†
4.2K Filter	$100cm^{-1}$ low-pass QMMF†

Table 6.3. Optical aperture sizes and filter details
†Refer to **Appendix C** for the transmission profile

Optical Calibration Results

Bias Resistance	150kΩ
Bias voltage, V_B	10.0V
Bias current, I_B	56μA
Detector voltage, V_{Det}	1.68V
Detector operating resistance R_{Op}	30.5kΩ
System rms output noise at 1kHz	$7.3nV.Hz^{-½}$
System rms output noise at 10kHz	$5.4nV.Hz^{-½}$
System optical responsivity	$5.4kV W^{-1}$
System optical NEP at 1kHz	$1.6pW.Hz^{-½}$
System optical NEP at 10kHz	$1.0pW.Hz^{-½}$

Table 6.4. System calibration summary

The system output noise spectrum is given in **Fig. 6.3**

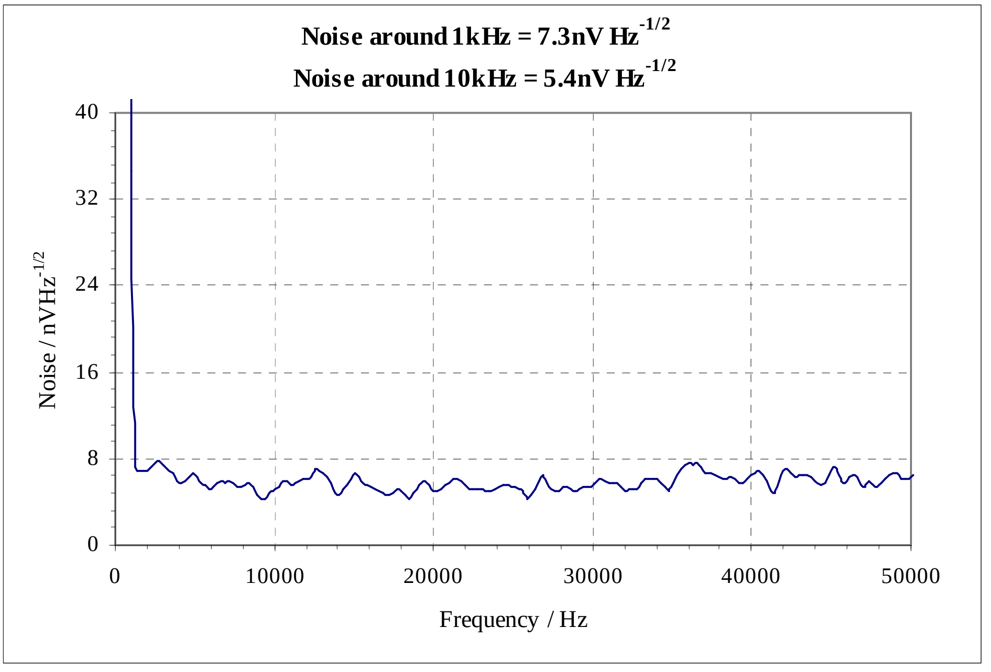


Fig. 6.3. System output noise spectrum for the InSb detector 0 to 50kHz

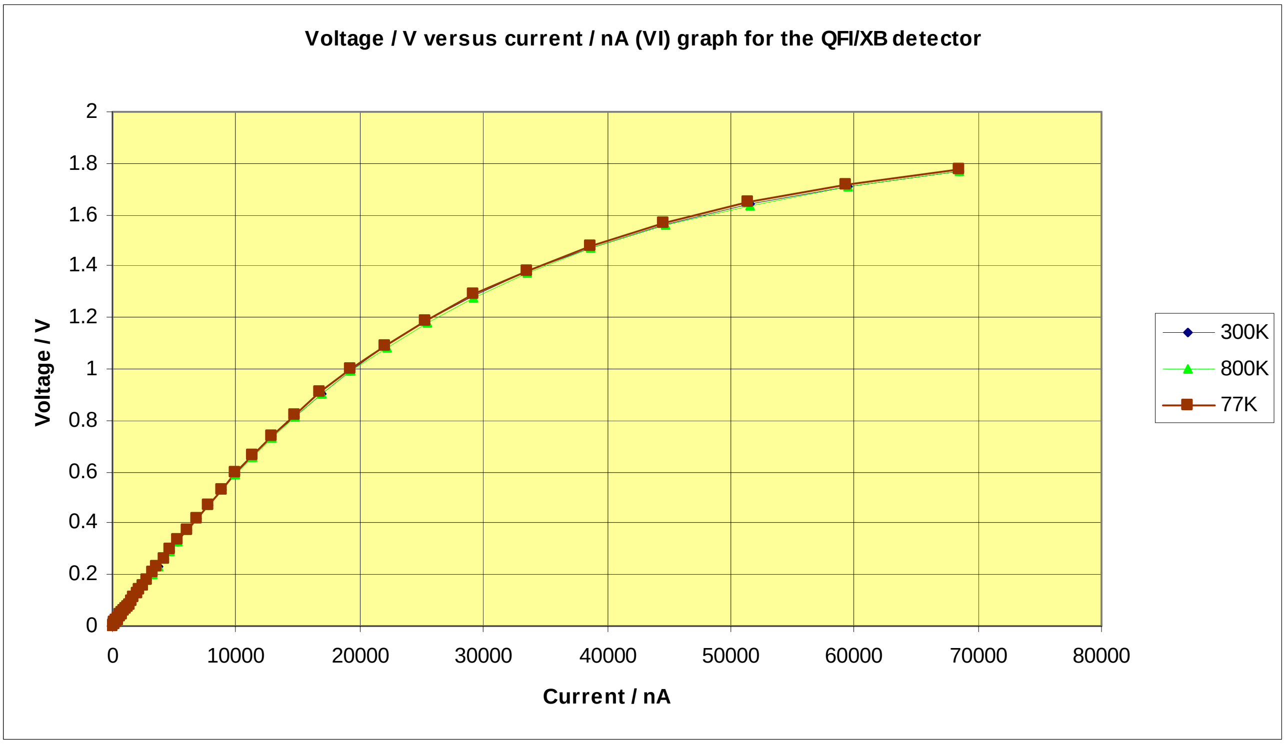


Fig. 6.4. The detector system VI characteristic measured with both a 77K, 300K and a 800K dc load

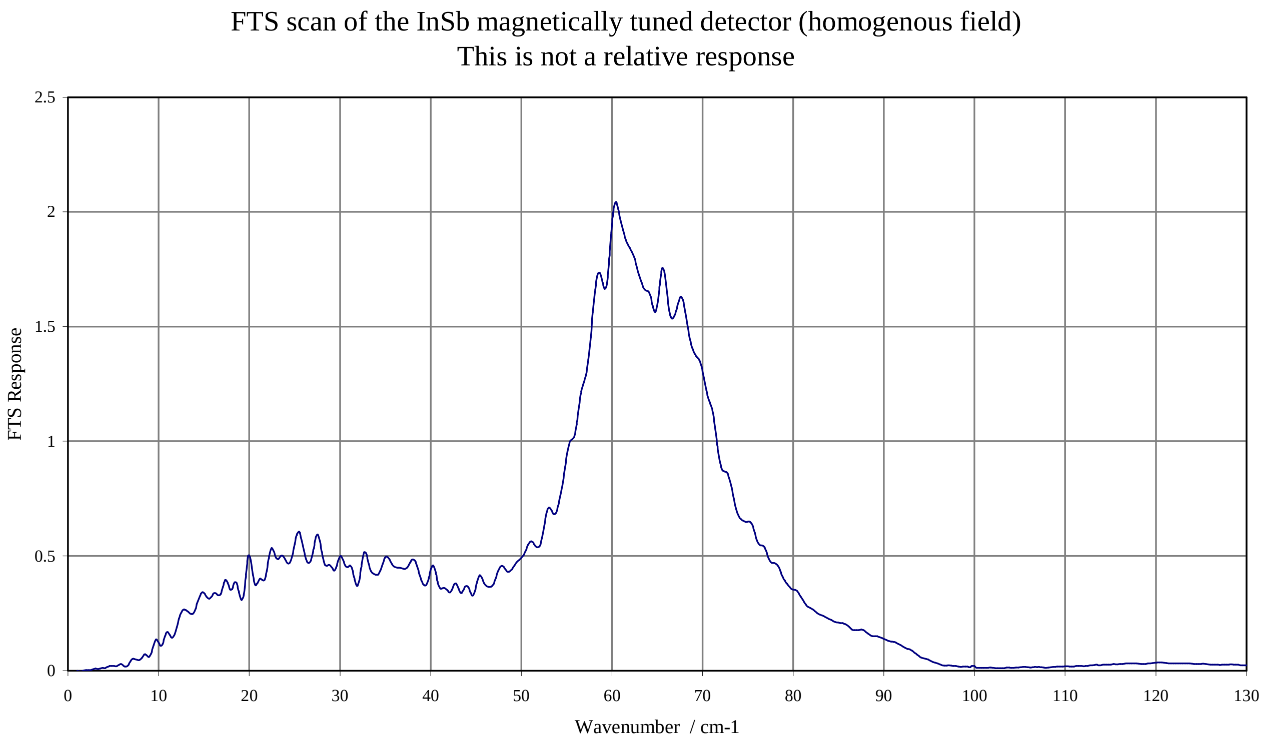


Fig. 6.5. Scan of the response of the tuned indium antimonide detector
in a Fourier Transform Spectrometer showing the cyclotron resonance peak

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

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

Photo A.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 A.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, $m^* = 0.01359m_e$ is the effective carrier mass in InSb. m_e is the electron rest mass = 9.11×10^{-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 A.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.

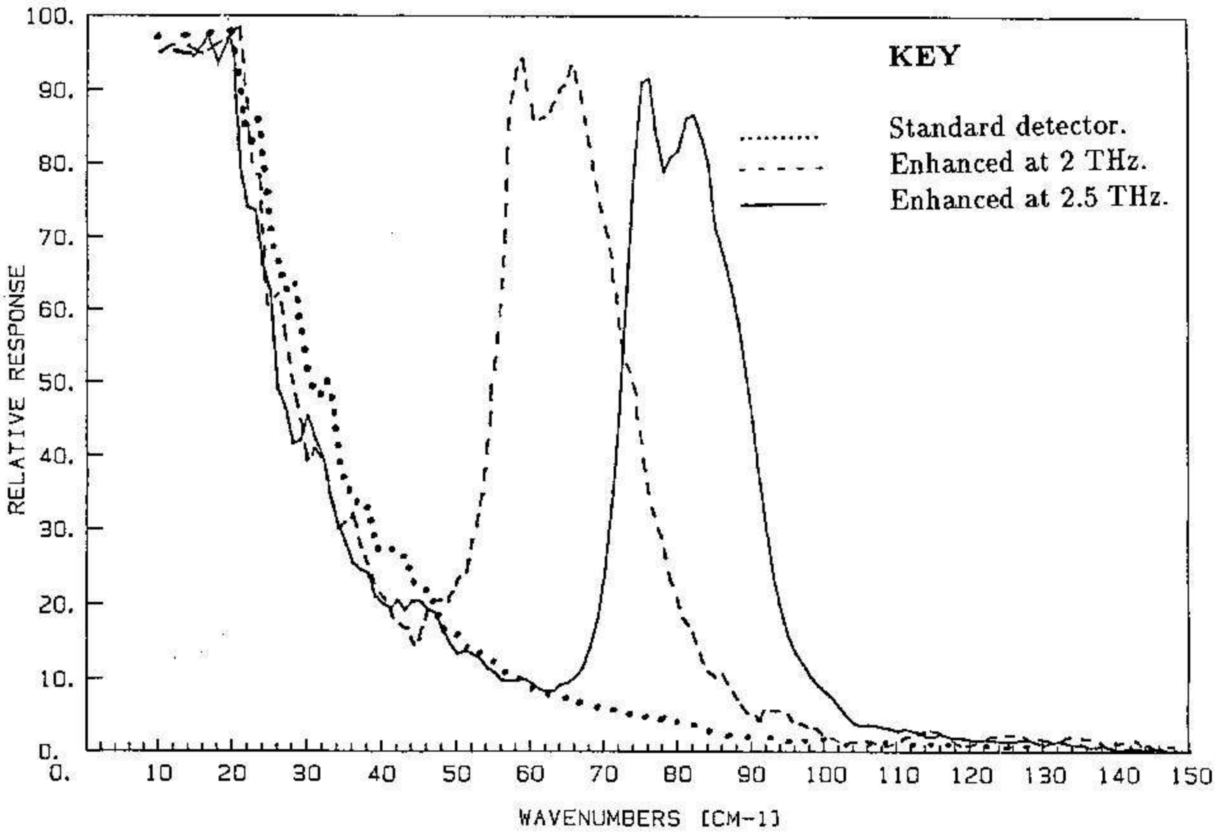


Fig. A.1. Spectral responsivity of a QFI/X detector with no magnetic field applied and two examples of type QFI/XB detectors enhanced at 2THz and 2.5THz

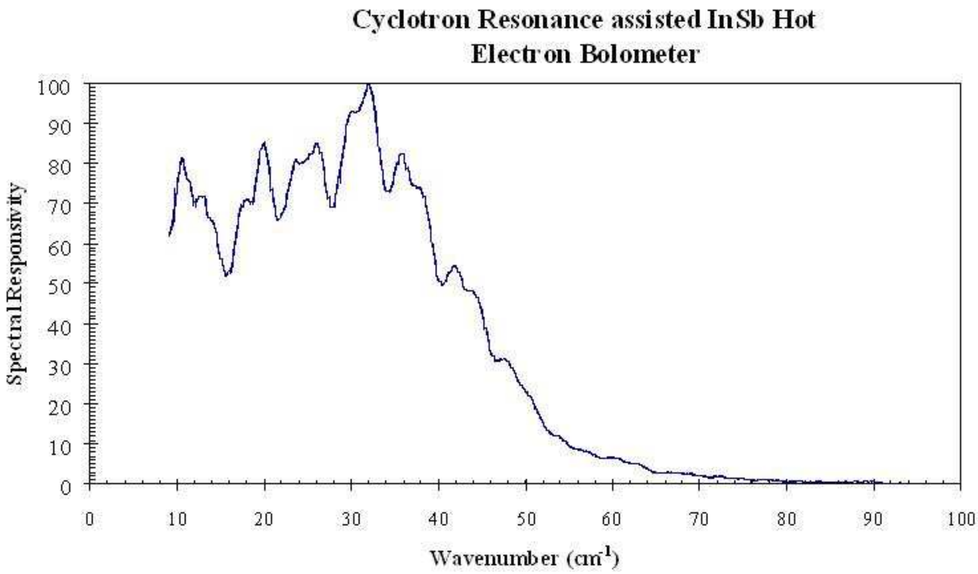


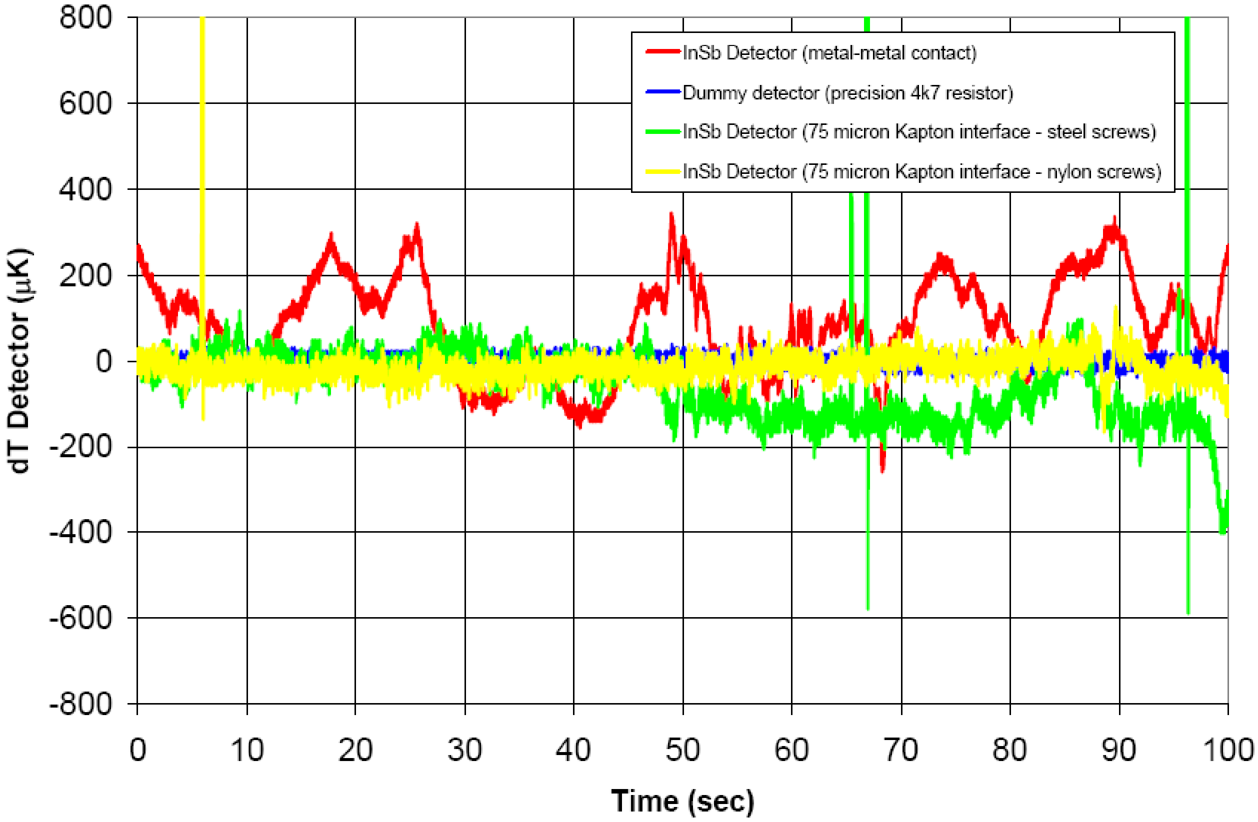
Fig. A.2. Spectral responsivity of the Type QFI/XBI detector

Temperature Stability

Figure A.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.



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 C. Filter Transmission

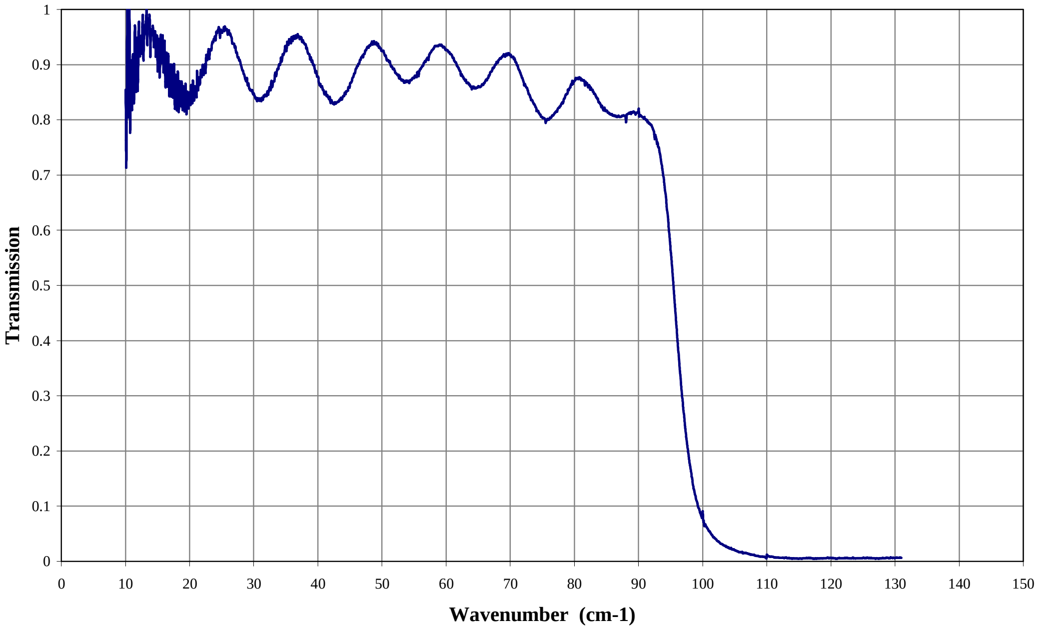


Fig. C1. Transmission spectrum for the type QMMF 100cm^{-1} low pass filter

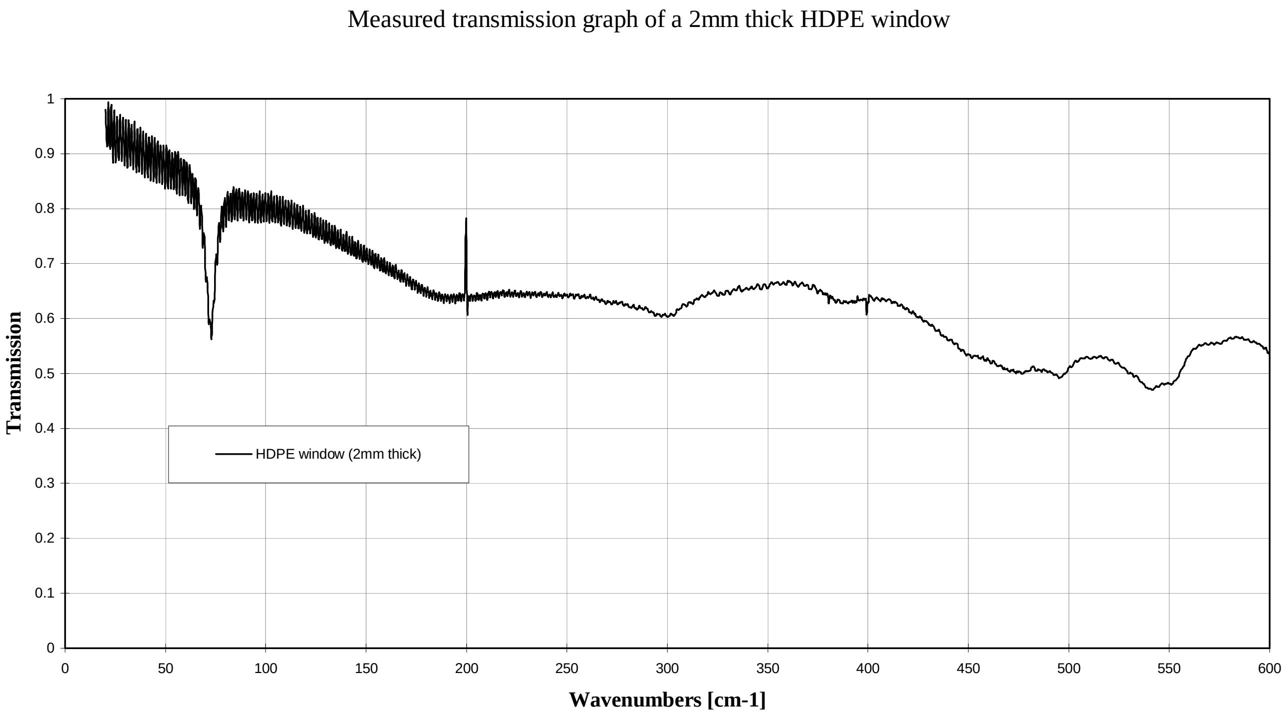


Fig. C.2. Measured transmission of a 2mm thick HDPE window from 20cm^{-1} to 600cm^{-1}. The polyethylene characteristic absorption increase is clearly seen around 73cm^{-1}

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.

DLR 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 equipment, 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 the equipment 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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