# Miniball/IDS Autofill Hardware Guide

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## Contents

# 1 Overview

This document describes the hardware for the Miniball autofill system. The ISOLDE Decay Station uses a clone of this system.

The autofill system has two main parts to it, one mounted on the frame of the instrument, the other in electronics rack (for Miniball it is in rack 5).

Note that in 2015, we threw out the old ISA-based system, so only the USB version is now in use. The old rack-mounted PC was replaced by a desktop lying on its side on a shelf; the ISA-based PT100 is gone and the USB-based one is used instead.

## 1.1 The part at the frame

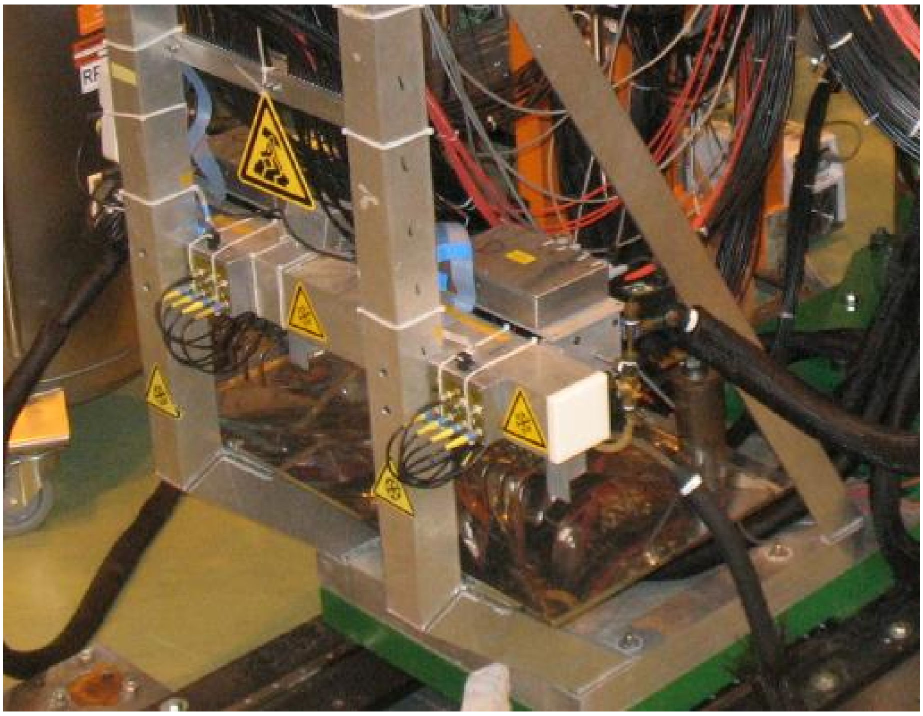


Figure 1: The part of the filling system at the frame.

There are four manifolds A, B, C and D which are fully independent of each other. Each manifold has 8 tubes, of which two are blanked off and the rest have electrovalves[1]. The electrovalves are 220 V AC, so no transformer is needed.

Of the six tubes with valves, one serves as an inlet and is connected directly to the liquid nitrogen tank. Another serves as a purge and goes to the outside world via a LN2 sensor. When we perform a filling cycle, the first thing we do

[1]IDS has only one manifold, but none of the outlets are blanked off.

is open the inlet and purge valves, so that nitrogen flows from the tank to the outside. Initially, only gaseous nitrogen flows, but when the LN2 sensor detects that it is liquid, we close the purge valve and open one or more of the other four valves which go to the detectors.

Note that there must be a pressure release valve on the manifold to prevent pressure build up when the LN2, which is trapped there after the filling cycle has ended and all the electrovalves have been closed, expands.

There are always two pipes between the manifold and the Ge detector, one connecting the outlet of the manifold to the inlet of the detector and the other going from the detector to the outside world via a LN2 sensor, so that we know when the detector is full.

The manifold has two electrical connections, one for 220 V AC mains power and the other is a wide flat cable for the control signals. The 220 V power comes from two power sockets mounted on the frame which are perfectly normal German mains sockets except that the cable supplying them is in a metal sleeve where it trails on the floor, in order to protect it. The wide flat cable goes to the electronics racks.

There are eight LN2 sensors, but we only use five of them. The first four are for the detectors and correspond to the four detector outlets. The last one is for the purge. BNC cables go from the sensors to a convertor box, which connects the signals to a narrow flat cable which goes to the electronics racks.

Furthermore each Ge detector has a PT100 signal which is connected via a twin-core BNC cable to the electronics racks.

## 1.2 The part at the electronics racks

In rack 5 of the electronics racks (for IDS it will be somewhere else), we have the rack-mounted filling computer, the PT100 readout box (for all four manifolds) and four manifold control boxes (one for each manifold).

The PT100 readout box has sixteen D-sub connectors, each of which can be connected to one PT100. We use special long cables with BNC on one end (connected to the detector) and D-sub on the other (connected to the readout box). The software assumes that the first (leftmost) four connectors are for manifold A, the next four for B and so on. Since we normally use mainfolds A and C, this means that the first four are connected, then the next four are unused and then the following four are connected with the last four unused. It uses multiplexed ADCs to measure the resistance of the PT100.

Each of the four manifold control boxes is connected with a wide flat cable to the manifold (controls the electrovalves) and with a narrow flat cable to the LN2 sensors (via the flat cable to BNC convertor box).

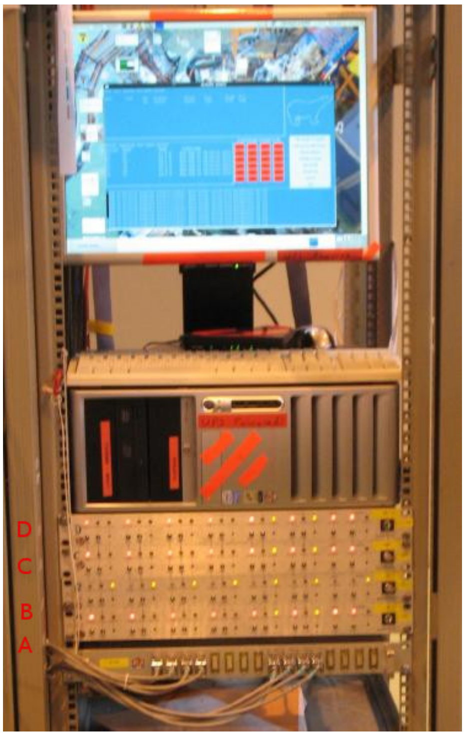



Figure 2: The filling system electronics in rack 5 of the electronics racks. The autofill PC is lying on its side, with the monitor and keyboard on top. Below it are the four manifold controllers (D on top) and at the bottom, the PT100 readout.

## 2 The USB upgrade

Due to worries that an ISA-based system would become increasingly difficult to maintain and support in the future and the problems of obtaining spares, it was decided to develop a new computer interface for the filling system, with new software. The first thought was to use PCI, but it soon became apparent, that USB was starting to dominate the commercial market and was likely to be a better option.

A USB module was found (the USB-DIO96H/50, also known as USB-1096HFS/50) which is pin-to-pin compatible with the ISA card and uses the same sockets as that ISA card, making it possible to simply plug the manifold controllers into either the ISA card or the USB module. The software is different, but the differences are confined to two files, one for ISA and one for USB, which provide the same functions. Executables can then be built for both systems.

For the PT100 readout, there was nothing suitable, which was directly compatible, either as PCI or as USB. Instead, a USB temperature readout card was chosen, which gives a direct temperature reading, without the PT100 readout box.

It is intended for it to be possible for both systems to coexist on the computer and to select which one is called via symbolic links to the main programs. i.e. the program *fill* is a link to either *fill_isa* or *fill_usb*. In principle, it would be possible to have the ISA card controlling the valves and reading the sensors and USB module for the temperatures or vice versa. In this way, the USB system serves as an alternative to the ISA system, rather than a replacement. However, the old ISA hardware was finally thrown out in 2015. So now only the USB version is relevant.

# 3 Inventory

This is a list of the items sent to CERN in 2004 (updated in 2007 because of some new items) as part of the filling system.

- Three long blue wide flat cables for manifold control (the fourth is broken).
- Three long grey narrow flat cables for LN2 sensors (the fourth is broken).
- Eight long cables with D-sub on one end and twin-core BNC on the other (PT100 readout)
- Four adaptor cables (about 20 cm long) with twin-core BNC on one end and single-core BNC on the other.
- 19" rack mounted AF computer
- Monitor for AF computer.
- Four 19" rack mounted manifold control box.
- Four small keys for manifold box key controls.
- Two short flat cable to connect pairs of manifold control boxes.
- Four manifolds with valves and overpressure release valve and LN2 sensors.
- Four BNC to narrow flat cable conversion boxes for PT100 sensors.
- Four power cords for the manifolds.
- Twenty short BNC cables to connect conversion box to PT100 sensors.
- Two double socket outlets with armoured cables for manifold power.
- Tube from LN2 vessel to manifold A/B.
- Tube from LN2 vessel to manifold C/D.
- Tube from manifold B to A.
- Tube from manifold C to D.
- Heat gun for thawing LN2 lines.
- Mauve hair-dryer for thawing LN2 lines.

- Eight LN2 filling wands of the new type.
- Twenty-one LN2 filling wands of the old type.
- Packet of spare O-rings for the old type of filling wand.
- Packet of loops to fix LN2 lines to wands.
- Four LN2 lines with red labels.
- Four LN2 lines with yellow labels.
- Spare LN2 lines.
- Miscellaneous bits of plumbing (connectors etc.)
- Two spare electrovalves.
- Two spare 0.5 Amp fuses for manifold controllers.
- Two Wessington 300 litre LN2 vessels
- Two Apollo 300 litre LN2 vessels
- One USB-DIO96H/50 USB digital input/output module.
- Power supply for USB-DIO96H/50
- One PT100 readout box containing two USB-TEMP USB temperature readout modules.
- One three-port USB hub.
- One blue serial cable to connect to UPS.
- One ethernet switch to provide private network to HV system.

From 2007, we have new twin-core BNC cables for the PT100s. These have the same D-sub connectors at the end which connects to the PT100 readout box, but have twin-core BNC connectors at the other end. All of the Miniball detectors have been modified to use these connectors. For the others, there are four short (about 20 cm) cables to connect between the new cables and the old connectors.

From 2008, we have new USB-DIO96H/50 and USB-TEMP modules, for a new USB-based interface, rather than the old ISA one.

# 4 Cabling

## 4.1 Manifold controller boxes

There are two wide flat cables coming out of the back of the autofill computer (which cannot be detached) that each connects to a manifold controller at the back of the manifold control boxes. Then there are two separate very short flat cables to connect the remaining two controllers to the ones which are connected to the computer. Each has an input and an output and the controller boxes are paired up, so that one cable comes from the computer to the input, then

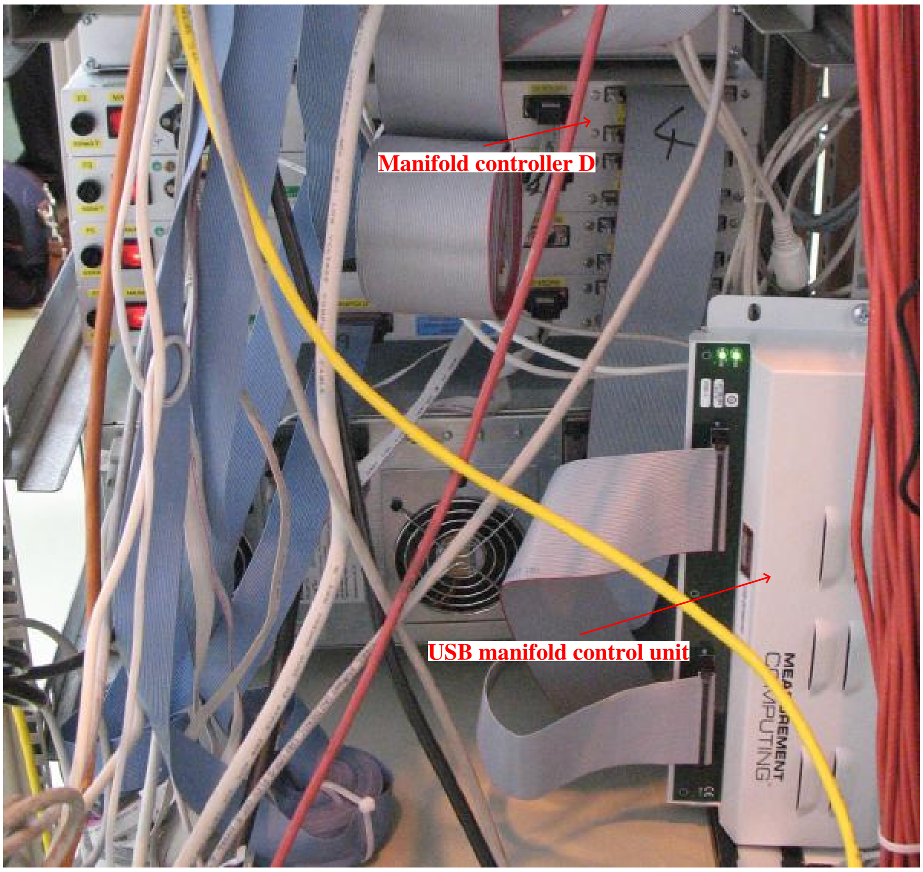



Figure 3: The USB digital I/O unit used to control the manifolds. It has two flat cables, each of which controls two manifolds. These are connected directly to manifolds B and D and indirectly to A and C.

a short cable from that controller's output to the next controller's input. The order of these connections determines which box controls which manifold. As the cables which connect between manifolds are very short, it is only possible to put controller A below B and D below C, so rather than having B, A, D, C, I chose to have D, C, B, A as the order from top to bottom. The two cables go to the inputs of B and D. The outputs from those manifolds go via the short cable to the inputs of A and C, respectively and the outputs of A and C are unused.

Each manifold controller has one wide one long wide light-blue flat cable going down to its manifold and one narrow grey flat cable going down to the LN2 sensors for that manifold.

Each manifold controller needs a 220 V power supply via a standard cord (like the ones for crates and PCs).

Note that we do not use the bias shutdown feature, because the Miniball clusters are not equipped with bias-shutdown cables.

Figure 3 shows the back of the autofill rack with the manifold controler unit and the flat cables which go from it to two of the manifolds (B and D). The connection to manifolds A and C is a short flat cable going from one manifold controller box to the other (hidden by the cable labelled "4").

### 4.2 Ethernet

There are now two ethernet controllers in the autofill computer. One is for the connection to the outside world, while the upper one is for a private network via a crossed cable to the high voltage mainframe.

### 4.3 PT100 readout box

The old ISA system had a special conversion box for the PT100 readout. With the new USB system, a 19" rack-mounted box was made with D-sub connectors on the front and two USB-TEMP modules on the inside. Each has a USB connector going to the PC. They receive their power via USB. See figure 5.

### 4.4 Manifolds

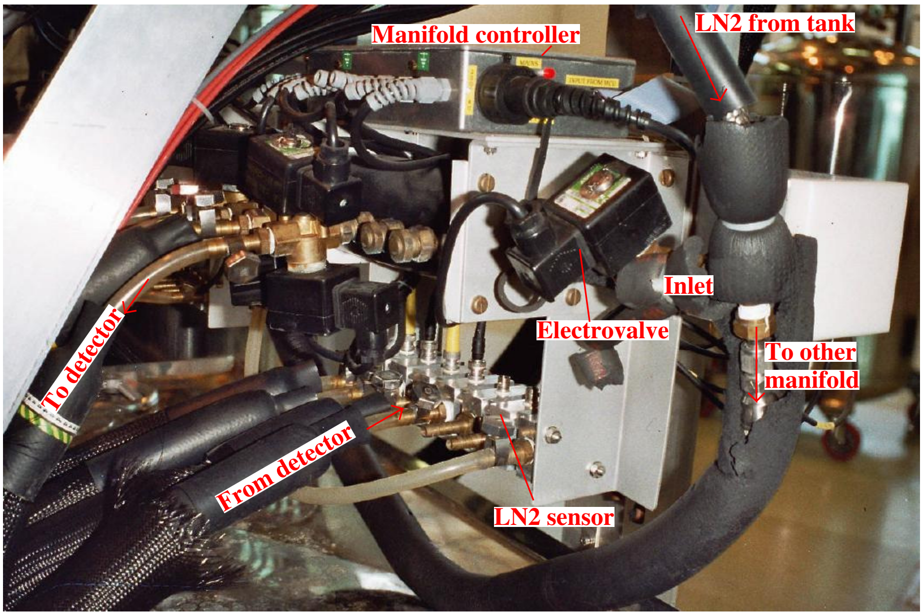



Figure 4: A manifold: There is a T-piece at the entrance to the manifold, which is connected to the LN2 tank on one side and to the next manifold on the other. There is an electrovalve on the inlet and one more for each output. Four outputs go to detectors, one is for purge, two are blanked off. The return hose goes to the LN2 sensor, which is connected by a BNC cable to a convertor box, from where it goes by flat cable to the computer.

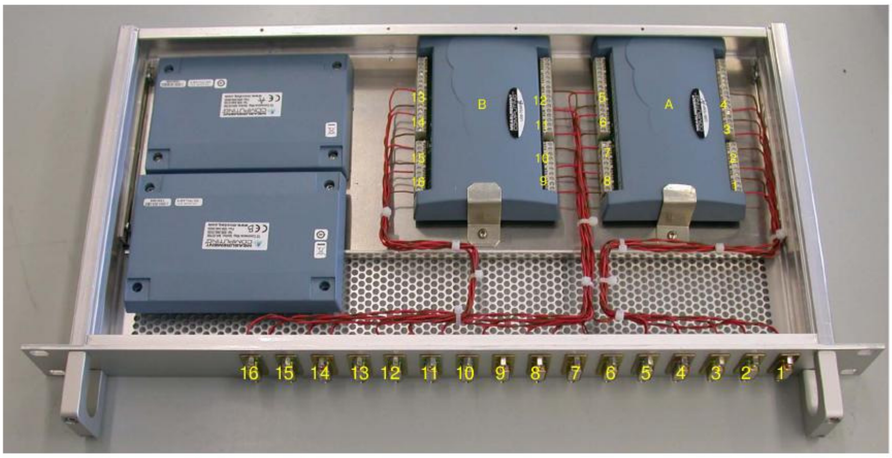
The manifolds need 220 V power and have special cables with German plugs on one end and the correct connector for the manifold on the other. The other end of the long wide light-blue flat cable coming down from the manifold controller box goes here too.

Note that the 220 V power comes from two German socket outlets mounted onto the frame which have armoured cables to protect them where they lie on the floor.

## 4.5 LN2 sensors

A BNC cable goes from the LN2 sensor to a box which connects 8 BNC inputs to a flat cable output. The long narrow grey cables coming down from the manifold controller boxes go here.

## 4.6 PT100s




| Nr. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adr. | A | A | A | A | A | A | A | A | B | B | B | B | B | B | B | B |
| | I1+/C0L | IC01/I1- | I2+/C2L | IC23/I2- | I3+/C4L | IC45/I3- | I4+/C6L | IC67/I4- | I1+/C0L | IC01/I1- | I2+/C2L | IC23/I2- | I3+/C4L | IC45/I3- | I4+/C6L | IC67/I4- |

Figure 5: The new PT100 readout unit opened up. On the right are two USB-TEMP modules (their lids are on the left). The software maps channel 16 to A1, 15 to A2 , 12 to B1 etc.

From each detector a long RG-174 cable with a BNC connector on the detector end goes up to the PT100 readout box where it has a D-sub connector. These plug directly into the detectors. Note, however, that they are not essential to the operation of the system.

From 2007, these cables have been replaced with thicker (and more robust to liquid nitrogen) twin-core BNC cables. The D-sub connector remains the same, but the end going into the detector is now twin core rather than single core. All of the clusters have been adapted to this new connector. There are also adapter cables, to make it possible to use the dewar PT100 or a normal BNC connector.

## 5 Power supply

Note that we use three different power supplies for the filling system:

- The filling computer and the network hub are on the UPS, so if the power fails it can still send out a message. The PT100 readout box gets its power from the computer.
- The manifold controllers are on normal mains power with the rest of the electronics.
- The manifolds are on normal mains power at the frame.

## 6 The Electrovalves

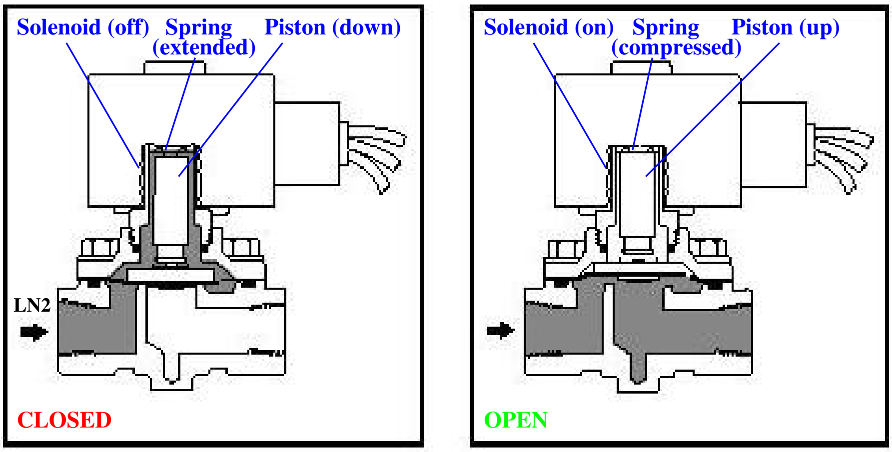



Figure 6: The operation of the ASCO valves. The picture on the left shows the valve in the de-energised (closed) state and the one on the right shows the energised (open) state

We use ASCO solenoid electrovalves. They consist of two parts which can be replaced independently of one another:

- A brass pipe containing the valve itself, which is closed by piston inside. A spring keeps the piston in the closed position normally. However, the piston is magetised, so when a magnetic field is applied via the solenoid, it pulls on the piston, against the force of the spring, opening the valve. If the power to the solenoid fails, the valve closes.
- A black box containing a solenoid which is used to Since the brass part is sealed, it is possible to remove the black box which is just clipped on, without depressurising the LN2 pipes.

Note that the direction of flow is critical to the operation of these valves and they are labelled on the brass part to indicate which is the inlet side and which the outlet.

The only mode of failure I have come across is for the piston not to close properly because the spring has lost its elasticity due to frequent cooling and warming cycles. When there is no pressure in the system, it is possible to dismantle the brass part, take the spring out and stretch it a bit. Then put everything back together and it might work better.

# 7 The Manifold Control Boxes

Each manifold control box has a key on the far right to select between automatic control (i.e. control via the computer) and manual control (control via the front panel switches). There are controls for eight channels. The first four are for detectors, and the last two are for the purge and inlet valves. Miniball does not use channels five and six, but IDS does. Each channel has:

- Switch to open and close valve (down = open, up = closed). This only works when the key is set to manual.
- Detector cool override switch. If this is on, filling is only enabled if the bias shutdown is connected, but since Miniball doesn't have a bias shutdown, we always turn this switch off, except for channels 5 and 6 (which we don't use).
- Bi-colour LED to indicate valve state (red = closed, green = open, off = failure).
- Screw potentiometer to adjust the LN2 detection threshold.
- Orange LED to indicate LN2 detection (on = liquid, off = gas).
- Orange LED for bias shutdown (which we don't use).

Note, however, that the purge and inlet valves don't have all these.

The control boxes are mounted so that the control for manifold A is at the bottom and D at the top. This is because of the way the cables to the computer are set up, so that it is not possible to have A at the top and D at the bottom.

# 8 Computer interface (USB version)

The new USB-based system uses the following USB-modules:

- A *Measurement Computing* USB-DIO96H/50 digital input/output module with outputs to control the valves and inputs to read the state of the LN2 sensors and bias shutdown (N.B. Miniball doesn't use the bias shutdown).
- A *Measurement Computing* USB-TEMP temperature measurement module to read the PT100 values.

# 9 Manual operation

The hardware can be operated manually using the switches.

- Switch the key for the manifold to “Manual”. Note that this prevents the software from communicating with the manifold controller, so it will trigger a fill error if the computer tries to fill in this state.
- Using the small switches, open the purge and inlet valves. This should cause nitrogen to flow from the tank out of the purge into the air. At first it will be gaseous nitrogen, but after a while, liquid should flow.
- When you see liquid coming out, or you see the LN2 detector LED come on for the purge, close the purge valve and open the valves to the detectors you want to fill.
- When you see LN2 on each detector outlet, or the LED for the LN2 sensor comes on, close the corresponding valve.
- When you have closed the last valve, close the inlet valve.
- Switch the key back to “Auto” to let the computer have control.

# 10 Setting the LN2 sensor thresholds

You need two people to do this properly, one at the manifold to look and shout when liquid comes out and one at the electronics to adjust the threshold with a small screwdriver. You should do each channel separately, because if you have more than one channel at a time it is hard to see what is happening.

Just follow the procedure for filling and when the person at the frame sees liquid, adjust the LN2 sensor potentiometer so that you the LED just comes on without flickering.

# 11 Test Procedures

## 11.1 Power-on check

This test should be peformed whenever the system is switched back on after turning the power off.

- There is a red light on each manifold at the frame next to where the 220 V power cord connects to it. This should be on. If not, it probably indicates there is no AC power, so check everything is plugged in and the main fuse hasn’t tripped.
- There is a red light on the PT100 readout box in the electronics rack. It should be on. If not, it is probably a power problem.
- Check that at least one LED is lit on each control box. If nothing is lit, it might be the fuse at the back of the control box, which is accesible from outside without dismounting the box from the rack. Or it might be a power problem. Note that there’s a power switch at the back.

- Normally, the LEDs indicating the valve state should be either red (closed) or green (open) but not off. If they are off, it could indicate that there is no power to the manifold, that the cable is not properly connected, or is damaged, or that one of the internal fuses of the control box has failed. One set of cables was damaged in 2003, so one of the manifold controllers will always be in this state. There are two 0.5 Amp fuses inside the manifold control box, which can only be accessed by dismounting the box from the rack and opening it up. They are standard 0.5 Amp fuses.
- The LN2 sensor LEDs should normally be off unless liquid nitrogen is flowing. However, they also go on if the cable is disconnected, or if the threshold is set incorrectly. As Miniball does not use channels 5 and 6 (they are blanked off at the manifold) they are not usually connected, so the LEDS are always on. This is not the case for IDS, where all six channels are connected. For the manifold (manifold B of Miniball) with the broken cables, it is also normal for all seven LEDs to be on, since the cable is not connected. The others should all be off unless liquid is flowing. If not, it indicates either that the threshold is set incorrectly (see section 10), the flat cable is damaged or that the BNC connection from the LN2 sensor to the BNC to flat cable conversion box (at the frame) is unplugged or damaged.
- Make sure all the valve switches are set to closed, the enable/disable switches are disabled except for channels 5 and 6 and the keys to “Auto” except for the unused manifold.

### 11.2 Warm manual test

It is possible to perform a test without LN2 to make sure the valves operate. This test checks the hardware and the various cables.

- Switch the key to “Manual”.
- For each valve in turn, switch the valve to open and then back to closed. You should hear a click when the valve opens, though closing is virtually silent. If you have a second person, that person should be able to feel that the valve vibrates slightly when open.
- Don’t leave the valves on for too many minutes without liquid nitrogen, because they can get quite hot.
- Switch the key to “Auto”.

### 11.3 LN2 sensor test

Normally the LN2 sensor LEDs are off if everything is connected up. For each sensor in turn, unplug the BNC cable at the frame and the LED should come on. Then plug it back in. This indicates that the LN2 sensor cables and that part of the control box is working.

## 11.4 Warm automatic test

This is similar to the warm manual test, except that it is performed via the computer, with a human plugging and unplugging the LN2 sensors to fake the detection of LN2. This test checks the full computer control of the hardware. If this works, the only likely problems are plumbing problems (i.e. leaky pipes and joints, or icing up).

- Make sure the key is set to “Auto”.
- On the filling computer, type “fill XX” where XX is one of the manifold names (A1, A2, A3, A4, B1, B2, B3, B4 etc.) The inlet and purge valves should open. Check that the LEDs on the control box indicate this and check that the valves themselves are vibrating.
- Unplug the LN2 sensor for the purge. This tricks the computer into thinking there is LN2 there. It needs to be “liquid” for a few seconds before the computer accepts it and it should then close the purge valve and open the outlet valve that you selected (you should hear a click when this happens). Plug the LN2 sensor for the purge back in. Check that the valves are vibrating (inlet and outlet but not purge) and that the LEDs on the control box show the same thing.
- Unplug the LN2 sensor for the outlet. Again this tricks the computer into thinking there is LN2. After a while it should close all the valves. Then you can plug the LN2 sensor for the outlet back in. Check that none of the valves are vibrating and that the LEDs on the control box all indicate “closed”.
- Repeat for each outlet.

## 11.5 Cold plumbing test

This test is to see if there are leaks.

- Connect up a tank of LN2 to the system and open up all the hand operated valves. Leave it for a while and look for icing up. If the pipes are leak tight, no LN2 can flow, so it should not get cold. If it does, this indicates there is some problem (probably on the tank side of the inlet valve).
- Switch the key to “Manual”.
- Open the inlet valve, but leave all the others closed. Leave it for five to ten minutes and look for icing up. Again, since the outlet and purge valves are supposedly closed, no LN2 can flow, so it should not get cold.
- Close the inlet valve and switch the key back to “Auto”.

If you have leaks, they are likely to be at joints. Always use teflon tape around the screw thread of the joints. If you have a leak, it is probably a good idea to replace the teflon tape.

### 11.6 PT100 test

A PT100 has 25 Ω resistance at 87 K and 50 Ω resistance at 149 K. So if you connect a 50 Ohm resistor to the cable in place of the detector, the temperature read should be about 149 K and if you put two 50 Ohm resistors in parallel (i.e. with a T-piece), you should get 87 K. Note that there are calibration coefficients in the file */var/lib/autofill/pt100_cal.dat*. These are normally 25.8944 and 2.45849 for all channels, as this is the calibration of the PT100 readout box. Note, however, that you can disable the PT100 readout for a channel by putting a larger number, if you get spurious results on channels that are not connected.

## 12 Troubleshooting

The following modes of failure have occured in the past:

- One of the filling lines to/from the detectors iced up. The result was that first the filling time increased appreciably and then it wouldn't fill at all. The pressure on the outlet during the fill was negligible. The solution was to unplug the pipe from the detector, thaw it out, dry it out and put it back. This is by far the most common mode of failure.
- The 0.5 Amp fuse inside a manifold controller box failed. Some LEDs worked (because the main fuse was OK) but the LEDs indicating valve open/closed status were off. The solution was to replace the fuse.
- Somebody placed a heavy piece of metal on the flat cables going from the manifold controller to the LN2 sensors and the manifold. The result was that the insulation was cut and the metal shorted the LN2 sensors together, so when one detector was full, more than one channel indicated "liquid" even though only one channel was being filled. The solution was to use the spare cable.
- The spring inside a valve lost its elasticity. The result was that LN2 was seen coming out of the detector long after the valve was closed. The short-term solution was to open up the valve and stretch the spring a bit. The long-term solution was to change out the valve. Note that the solenoid part didn't need to be changed.
- The PT100 readout cable was damaged by LN2 burns close to the detector, so it sometimes gave spurious readings. The short-term solution was to repair the cable by cutting the bad part off and putting a new connector on. As a long term solution, we have replaced these thin RG174 cables with more robust twin-core BNC ones.
- Somebody unplugged the manifold power in order to plug in a hair-dryer to dry their hair (the hair dryer is normally used to de-ice filling lines) and forgot to plug it back in. The result was a fill failure. The solution is to only unplug the unused manifold when using the hair dryer for de-icing and always to put it back, and to dry hair elsewhere.
- The LN2 tank ran dry. The result was the pressure dropped and the succeeded for some detectors with very long filling times (because of the reduced pressure) and failed for others. The solution was to get more LN2.

- The main fuse tripped. The main fuse box for Miniball is in the corner behind the racks. There are six fuses, one for each rack plus one spare. If that is OK, look at the "alim depuis" (= powered from) label and find that fuse box and trace it back. **WARNING: this might change and is definitely different for IDS. So make sure you know where the fuse is!**

- No LN2 was delivered by the tanker, although it was ordered. It turned out that the amount we had ordered put the price over some threshold, so it went to central purchasing who delayed the order by a week. The solution is not to order too much on a single order.

# 13 Circuit diagrams for Exogam filling system

The circuits here are for the Exogam filling system which is very similar to the Miniball/IDS one. Both were designed by Bob Hide of York.

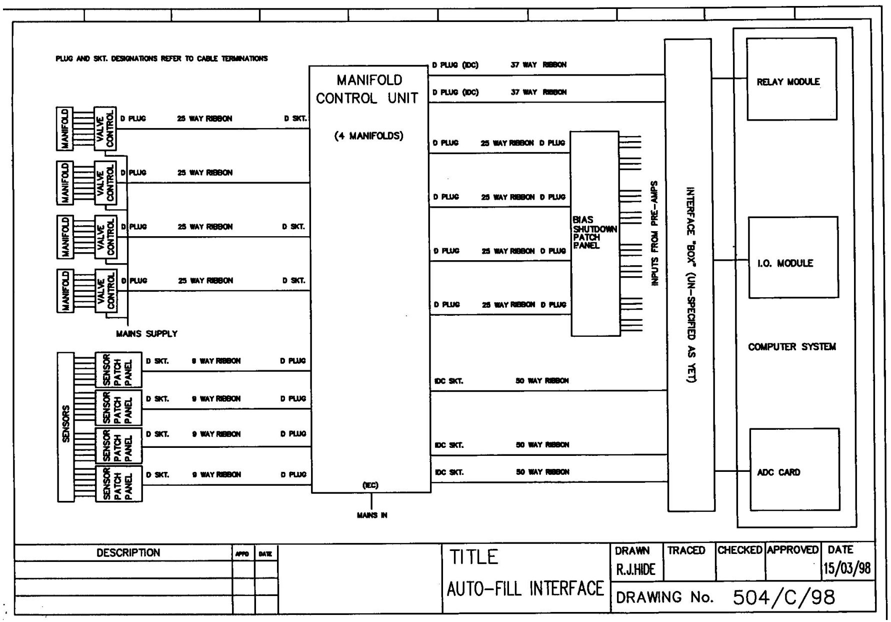



Figure 7: Autofill interface

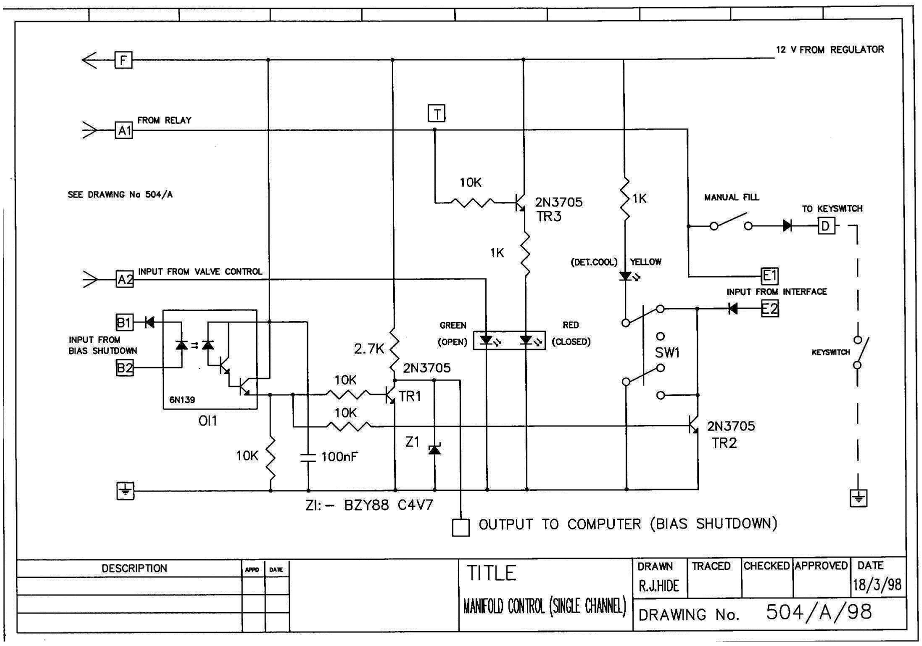



Figure 8: Manifold control (single channel)

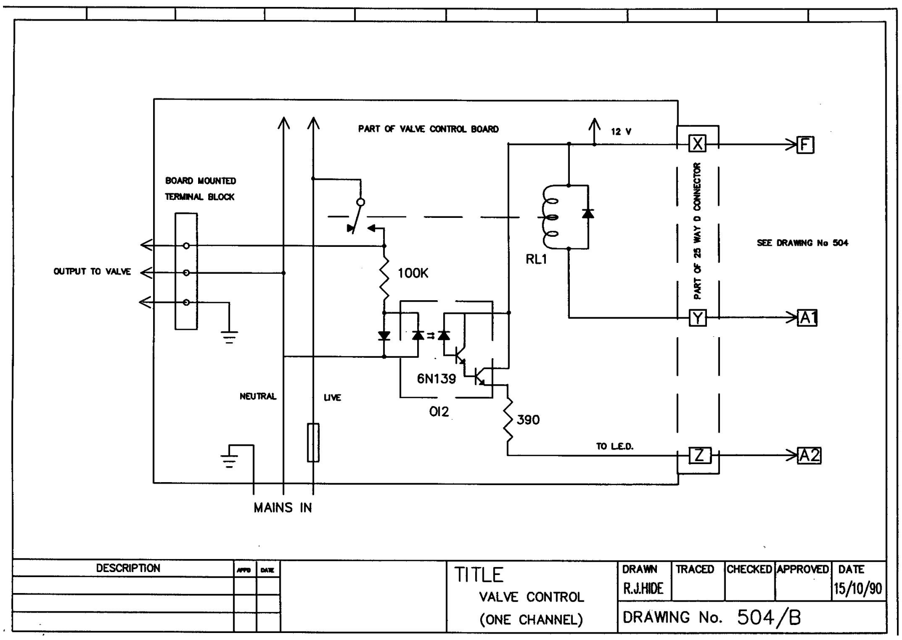



Figure 9: Valve control (one channel)

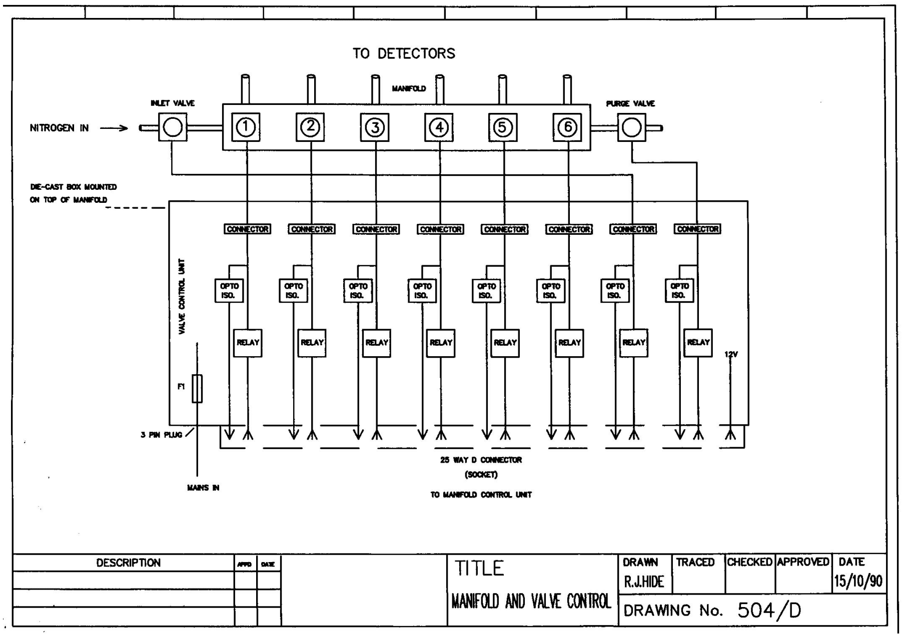



Figure 10: Manifold and valve control

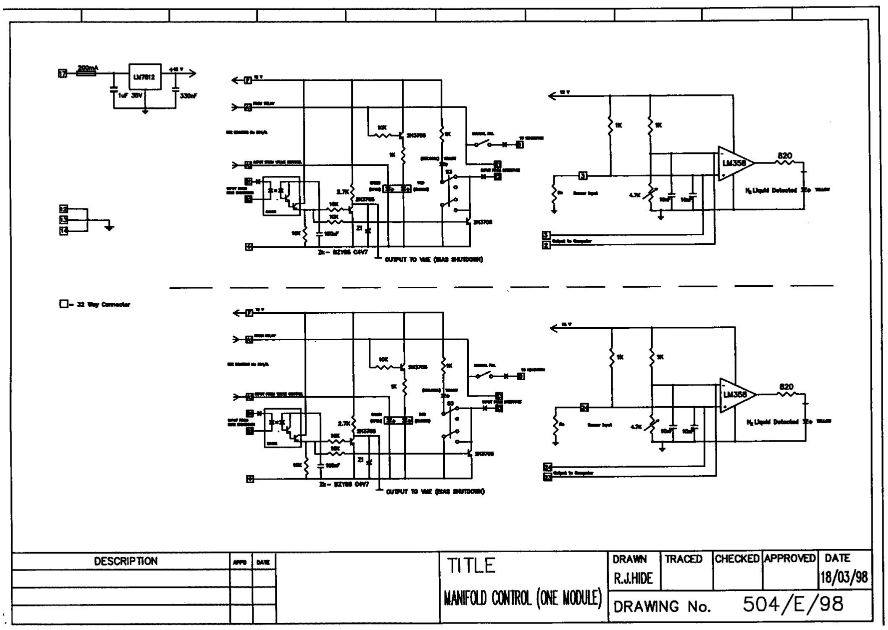



Figure 11: Manifold control (one module)

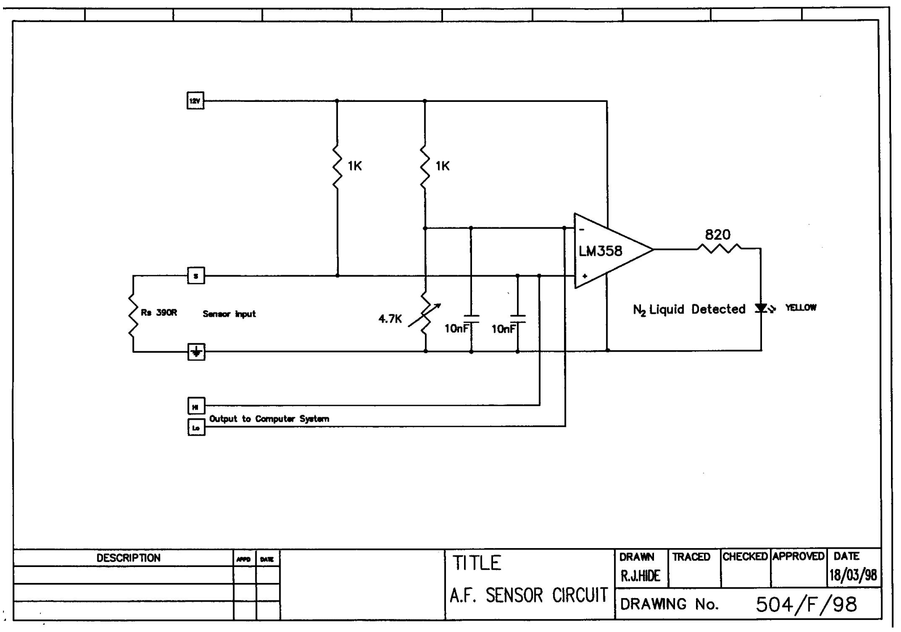



Figure 12: LN2 sensor

# 14 PT100 cable connection

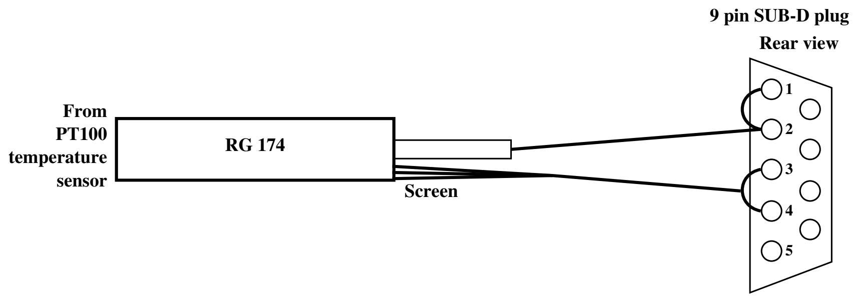



Figure 13: The old PT100 cable connection design

The old design used the wire and the shield of an RG174 cable. This had two disadvantages. Firstly, the connector at the detector end had to be insulated from ground, because the signal was using the shield. Secondly, the RG174 cables are very thin and easily damaged by LN2.

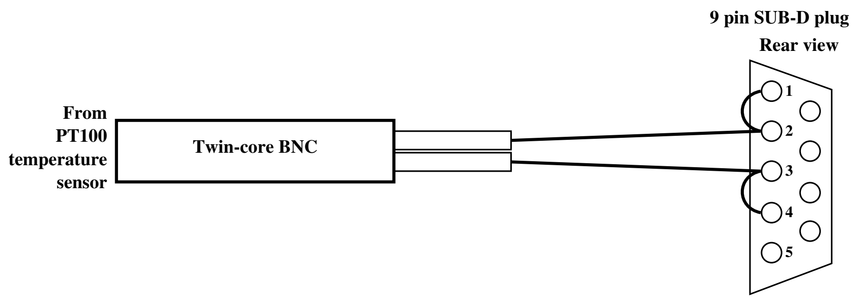



Figure 14: The new design for the the PT100 cable connection

The new design has pins 1 and 2 connected to one wire of a twin-core BNC cable and pins 3 and 4 to the other. The screen is then grounded at the detector end but not at the PT100 box end.

Four of the Miniball clusters have been modified to use the twin BNC connectors directly. For the other four, adaptor cables have been made, which connect the single BNC connectors on those detectors to the twin BNC cable. This still has the disadvantage that the screen must be kept insulated from ground, but the adaptors are made with RG58 cable which is more robust, so at least the cables are more resistant to LN2 splashes.